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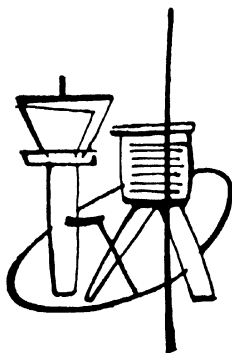
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N. KOLOBKOV



# OUR ATMOSPHERIC OCEAN



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## INTRODUCTION

The importance of the atmosphere in the life of our planet cannot be overestimated. The earth is surrounded on all sides by air, with the surface like the floor of an enormous ocean of gas.

The atmosphere is like a mantle preserving the heat that comes from the sun. It is like the glass of a hot-house, for it lets in the solar rays but prevents the heat from dissipating into space. That is why the alternation of day and night on our planet does not give rise to sharp contrasts of heat and cold. The atmosphere is the planet's invisible shield. It protects all living beings on earth from the scorching rays of the sun. It gives birth to the clouds, to the winds, and to the rains. It scatters the sunshine and makes gradual the change from light to darkness; it brings light to hidden parts of the globe; and it is a medium for the propagation of sound. Through the air, liners fly to all parts of the world. And through the air, man's first interplanetary ships will hurtle.

This is why we must study the atmosphere, its composition, its properties, and its structure. The history of atmospheric studies is the story of how man learned about the clouds and beyond, of how he made light, sound, and radio serve as his scouts into this ocean of air. It is the history of numerous inventions, bold surmises, and wonderful discoveries. The achievements of investigators of the atmosphere are added proof of the prowess of science disclosing the innermost secrets of nature.

At the dawn of history, primitive man tried to fathom the awe-inspiring phenomena of nature. The endless cycle of atmospheric processes, the absence of any apparent sequence, sudden and profound changes in the weather puzzled even civilized man. Meteorological phenomena long defied attempts to study them. But observations of the sky and of the behaviour of animals and plants on the eve of changes in the weather had been conducted since remote antiquity (for instance, in ancient Babylonia, over 6,000 years ago).

The first meteorological observations made in Greece and Egypt date back to 200-300 B.C. Specially engraved tablets, called *parapegmata*, preserve the drawings of an instrument very much like today's wind vane for measuring the direction and velocity of the wind. The amount of rainfall was also measured. Rather detailed records of the weather were kept in ancient Rome, too. In those days, problems of the weather were in the hands of priests and astrologers.

In the centuries that followed, non-instrumental routine observations of the weather were conducted in nearly all countries. They contain the first written records of thunderstorms, rainstorms, hurricanes, droughts, and so forth. True, these records contain more superstition than meteorology, yet from the point of view of secular periodicity of the weather such documents still have scientific value. In old Russia, weather records have been found in chronicles that date back to the thirteenth century.

Instrumental observations began in the sixteenth century (from the time of the invention of the thermometer), and in more detail, in the seventeenth century with the invention of the barometer. Astronomers were the first to engage in studies of the state of the atmosphere. Accustomed to working with precise apparatus, they made stringent demands on meteorological instruments, so that beginning with the end of the seventeenth century their observations may be compared with modern work.

The first attempt at a scientific explanation of atmospheric phenomena was made by Mikhail Lomonosov in his *Discourse*



on *Atmospheric Phenomena Originating from the Electrical Force*. The great Russian scientist established that the winds from the sea, in St. Petersburg and Arkhangelsk, "... tame the severity of winter cold by bringing rainy weather ... the sea imparts to the air more warmth than the vast snow-covered land ..." (1763). Lomonosov, with his peculiar ability to foresee, was the first in European science to write of the usefulness of predicting the weather. He considered meteorology "the better part of natural science," a knowledge of which "is most valuable to the human race," and weather forecasts he regarded as "human society's great acquisition." In his *Discourse on the Great Accuracy of Sea Routes* (1759), Lomonosov, with a profound knowledge of the matter, posed the problem of "... establishing self-recording meteorological observatories, in which I have new suggestions for the arrangement and introduction of various new instruments. ..."

The first detailed day-by-day records of the weather were begun in 1722 on the personal order of Peter the First. In St. Petersburg, the Russian Academy of Sciences carried out a series of observations between 1726 and 1800. When in 1730 the Great Northern Expedition set out under the leadership of Bering, it was given instructions to "conduct meteorological observations everywhere possible." Such was the beginning of the first permanent network of weather stations in the world.

In 1810, the founder of Kharkov University, V. N. Karazin,\* submitted to the Russian government a project for the establishment of a large network of meteorological stations "from Kola to Tiflis and from Lepaya to Nizhne-Kolymsk," and pointed out the usefulness of weather observations both for science and for practical purposes. He suggested collecting the observational materials in a special Meteorological Committee. Karazin's

\* V. N. Karazin (1773-1842) was buried in the town of Nikolayev. His gravestone bears an interesting inscription: "... on April 2, 1842, he decreed his serfs henceforth free human beings ... he was a student of nature who first advanced the idea of converting meteorology into an exact and useful science, he was honorary member of two Universities-Moscow and Kharkov-and member of various learned societies, both Russian and foreign. . . ."

project was put on a realistic basis only in 1849, when a Chief Physical Observatory was opened in St. Petersburg "for a physical study of Russia." This observatory was linked with scores of weather stations. The meteorological network began to function on the basis of a unified set of instructions, and with unified periods of observation.

The weather stations were particularly active in the sixties of last century. The range of work expanded at the stations of Kazan University, the Moscow Geodetic Institute, in Odessa, Yekaterinburg (now Sverdlovsk), and elsewhere.

The Geographic Society, which was organized in 1845, exerted a considerable influence on the development of meteorology in Russia. The Society set up a Meteorological Committee, which in 1870 was reorganized into a Meteorological Commission. At the head of this Commission, between 1883 and 1916, was the outstanding Russian meteorologist A. I. Voeikov. The Meteorological Commission organized large-scale observations of the weather, and attracted numerous lovers of nature who volunteered their services as observers.

The great Russian chemist Dmitri Mendeleev also devoted much attention to meteorology. One of his ideas was to send aloft special instruments attached to captive balloons and to release hydrogen-filled sounding balloons. Mendeleev was again first to advance the idea of building pressurized gondolas in stratostats for studying the upper atmosphere.

Beginning with 1872, the number of weather stations increased with particular rapidity, for practical activities were demanding regular and timely predictions of the weather, or, as we now know them, weather forecasts. In that year, the Chief Physical Observatory established a "Weather Service" and put M. A. Rykachev in charge of it.

The Weather Service started out by predicting storms in the Baltic Sea. Tall masts were put up in the ports; warning signals in the form of combinations of cones and cylinders were hung out by day, and lanterns by night. Ships did not leave port when there was a storm brewing. Despite occasional mistakes due to imperfect forecasting methods and the small number of weather

stations, this service was recognized generally, and in 1880 storm warnings were sent out to shipping in the White, Caspian, and Black seas. Soon afterwards, branches of the Weather Service sprang up in Yekaterinburg, Vladivostok, and at the Tiflis Observatory.

The activities of Russian meteorologists became widely known. Particularly outstanding are the studies of M. A. Rykachev on cyclones in Europe, A. I. Voeikov on climatology and meteorology, A. V. Klossovsky on thunderstorms, P. I. Brounov on anticyclones, B. I. Sreznevsky on storms and cold waves, G. A. Lyuboslavsky on agricultural meteorology, and many others. These investigations have made Russian meteorology world famous.

Still, the Weather Service was slow to develop. Numerous projects for its expansion were shelved because the tsarist government refused to give money for new weather stations. It was only the Great October Socialist Revolution that opened up broad new vistas to the Weather Service.

On June 21, 1921, the Council of People's Commissars headed by Lenin issued a decree on the organization of a meteorological service in the Soviet Union. Eight years later, in 1929, the underlying ideas of the decree led to the establishment of a unified hydrometeorological service. Also set up was a Weather Service at the head of which was the Central Weather Bureau in Moscow (now called the Central Institute of Weather Forecasting). The range of weather stations grew, with new stations appearing in the Arctic and sparsely inhabited areas of Siberia. The number of high-altitude stations increased, dozens of local weather bureaus appeared, and the aviation weather service grew into an independent branch. The rapidly expanding system of radio communications increased the possibilities of meteorology, and exchange of weather reports took on an international character, becoming simple, efficient, and cheap.

Since 1930, weather forecasts have been made up on the basis of a profound study of air masses, their properties and movements. A new methodology for forecasting weather con-

ditions has been developed by meteorologists A. I. Asknazy, S. P. Khromov, and A. F. Dyubyuk. Valuable contributions have also been made to the science of weather by the Norwegian scientists V. Bjerknes and T. Bergeron, the English meteorologist Shaw, the German physicist R. Scherhag, and others.

In connection with the observed warming up of the Arctic Basin, Professor V. Y. Vize, well-known Arctic explorer, meteorologist and climatologist, has posed a new, "Sun-Earth," problem that has undergone considerable development in recent years and is widely recognized by leading scientific circles. Weather workers are being helped by astronomers. Several astronomical observatories have set up their own Solar Service. The Pulkovo Observatory has a solar physics division, and new branches of physics have emerged—heliophysics and heliogeophysics. Prominent workers in these fields are M. S. Eigenson, A. B. Severny, M. N. Gnevyshev, A. I. Ol, B. M. Rubashev, and many others.

Academician B. P. Multanovsky has worked out a new method of long-range forecasting. Corresponding members of the U.S.S.R. Academy of Sciences Kibel and Blinova have worked out mathematical procedures for forecasting the principal weather elements—pressure, temperature, and wind. With respect to long-range forecasting, very important among the most recent meteorological investigations is the work of the Arctic Research Institute devoted to studies of the general circulation of the atmosphere. Particularly important are the observations of the meteorological stations "North Pole" 1, 2 and 3 (NP-1, NP-2, NP-3). These were multi-purpose observations conducted in the remotest areas of the Arctic. They were continued by North Pole Stations 4, 5, 6, 7 and 8. At the South Pole, the Soviet Antarctic Expedition carried out important investigations in accordance with the programme of the International Geophysical Year.

High-altitude meteorological stations study the physical state of the upper layers of the atmosphere, carry out observations of glaciers, etc. The highest stations are situated on Mt. Elbrus

(4,250 m), the Fedchenko Glacier (4,200 m), and Mt. Kazbegi (3,600 m). To study still higher layers of the atmosphere, hundreds of aerological stations every day send aloft radiosondes that reach altitudes of 25-30 kilometres and more. At many airports of the Civil Air Fleet, so-called "flying laboratories" take off daily. Since 1945, automatic radiometeorological stations have been operating in highly inaccessible regions. In recent years, atmospheric studies are being conducted with rockets. During the Third International Geophysical Year (1957-1958), the Soviet Union, and later the United States, launched artificial earth satellites, which have added much to our knowledge of the ionosphere.

Science is now confronted by a broad range of problems reaching far into the depths of our atmospheric ocean. That they will be resolved is evident from technological achievements and the enormous energy of men of science.

The tremendous progress made by science in the past points to new discoveries in the upper layers of the atmosphere that may be expected in the very nearest future.



*PART ONE*  
**THE ATMOSPHERE**





*CHAPTER ONE*

**THE ATMOSPHERIC OCEAN  
AND METHODS OF STUDYING IT**

The atmosphere of the earth stretches hundreds of miles upwards. It weighs over 5,000,000,000,000,000 tons, which is equal to the weight of 5,000,000 cubic kilometres of water. And yet this is but one millionth of the entire mass of our planet.

The terrestrial atmosphere, or, simply, the air, is in a state of constant motion. The moving air exerts a constant pressure on objects on the ground. This pressure has long been utilized by man—to drive windmills, sailing ships, etc. But it was only in the seventeenth century that air was found to have weight. This was proved by Torricelli, a pupil of Galilei. On the basis of his discovery, he invented, in 1643, the barometer, an instrument for measuring atmospheric pressure. This pressure is equal to the weight of a vertical column of air over a horizontal unit of area. The air pressure decreases with altitude, and at great heights the air is extremely rarefied.

The normal atmospheric pressure at sea level is 1,033 grammes per square centimetre. This will support a column of mercury (in a barometer) 760 millimetres high, or just over 1,000 millibars (a bar is a unit of pressure; one millibar =  $\frac{1}{1000}$  bar; 1013.2 millibars = 760 millimetres).

The air density is highest at the earth's surface: one cubic metre of air here weighs about 1,290 grammes; at a height of 20 kilometres a cubic metre of air weighs only 90 grammes, and

at 40 kilometres a mere 4 grammes. The bulk of the air is concentrated in the lowest, relatively thin, layer of the atmosphere. It has been calculated that the first five kilometres contain half of the entire mass of air, while the first 15 kilometres make up  $\frac{9}{10}$  of the total mass. To get some idea of the relative thickness of this layer, take an ordinary class-room globe and paste a sheet of writing paper on it. The thickness of the paper is our 15-kilometre layer of air.

For a long time no method could be found for studying the upper atmosphere. But with the advent of aeronautics the problem was solved.

We know from history that people had long dreamed of flying. At first, attempts were made to imitate the flight of birds by using wings. In 1731, a scrivener in Ryazan by the name of Kryakutnoi rose into the air a slight distance in a balloon filled with hot smoke. But such experimentation was slow to develop because the "air fliers" were persecuted by the tsarist government and the church. A tsarist ukaze read: "Man is not a bird, for he is wingless. This is not an act of God but of the devil." Even as late as 1784, Catherine II issued an edict forbidding anyone to fly in balloons and engage in "aeromania."

In Russia, the first scientific balloon flight was organized by the Academy of Sciences in June 1804, in St. Petersburg, with the participation of Academician Zakharov. The balloon reached a height of 2,480 metres.

In the thirties of last century, the noted Russian physicist Karazin, working in Kharkov, launched a large number of balloons that carried devices for collecting atmospheric electricity.

A whole series of scientific balloon flights was carried out by Academician Rykachev in 1868-1873 and, somewhat later, by Pomortsev. All the observations and analyses of the data obtained were performed with great accuracy.

These flights were the beginning of a systematic study of the atmosphere. From then on, the principal meteorological elements, such as air pressure, temperature, humidity, wind velocity, etc., have been studied according to a definite programme.

Today, a variety of methods are utilized in atmospheric studies. One of these is the balloon flights that we have just discussed.

However, high-altitude ascents in balloons involve a number of difficulties and frequently endanger the lives of the aeronauts. Many intrepid explorers have perished in attempts to reach high altitudes. And so scientists have sought for other, safer and cheaper, methods of exploration. Firstly, these were unmanned balloons controlled by cable. But their ceiling was rather low—not over 4 to 5 kilometres.

At the end of last century a different method was suggested. This was a modification of an idea that Lomonosov had proposed—atmospheric exploration by means of *sounding balloons*. In this method, a self-recording instrument called a *meteorograph*, which “sounds” the atmosphere, is attached to a hydrogen-filled\* balloon several cubic metres in volume.

At first the balloons were made of cloth or paper. They reached altitudes of 15 kilometres. With the advent of highly elastic rubber that can stretch to the thinness of cigarette paper, sounding balloons attained 30 kilometres and more. Such heights became feasible because the air pressure outside decreases with altitude, the rubber balloon expands and rises higher without losing its buoyancy until the balloon bursts. It then acts as a parachute softening the landing of the meteorograph.

A considerable disadvantage of this method, however, is that during the ascent the meteorograph is usually carried far away by air currents (there have been cases when balloons sent aloft in Leningrad have landed in the south of the Ukraine). This has slowed up analysis of instrument readings. Sounding balloons have landed in sparsely populated areas and disappeared altogether or have been found after such a long time that the instrument readings were no longer usable.

\* At 0° Centigrade and 760 millimetres mercury pressure, one cubic metre of chemically pure hydrogen weighs 90 grammes, which is 14.3 times lighter than air. Hydrogen is a combustible gas. When mixed with air it combines with the oxygen to produce detonating gas.

This situation was remedied by attaching a second balloon filled with hydrogen to one-half or one-third the volume of the first one. When the main balloon bursts, the second serves as a reliable parachute. When the instrument lands, the second balloon remains aloft as a signal. In addition, these sounding balloons may be used for automatic air sampling at high altitudes.

Nowadays, *radiosondes*, in which the tape and drum are replaced by a short-wave radio-transmitting set, are used to get instantaneous data on the state of the atmosphere. The transmitter automatically transmits to earth signals on the pressure, temperature, and humidity at high altitude. Furthermore, the flight of the radiosonde may be tracked by radar, thus making it possible to determine the wind force at various altitudes. The first radiosonde in the Soviet Union (designed by Professor Molchanov) was sent aloft in 1930 near Leningrad.

Wind direction and velocity can be observed in clear weather or when there is a small cloud cover by sending up a small hydrogen-filled rubber balloon. A theodolite is used to track the balloon. Since a pilot balloon has a constant ascension rate and, for this reason, its height can be computed exactly at any instant, it is possible to determine the direction and velocity of the wind from the angles given by the theodolite. Pilot balloons have been known to reach altitudes of 38 kilometres.

Another method of probing the atmosphere is by sending aloft self-recording instruments in aircraft. Though the development of aviation has required a thorough study of our atmospheric ocean, it in turn provides opportunities for such studies.

Big airports send up "flying-laboratory" aircraft every day. These flights are cancelled only in extremely adverse weather. Some "flying laboratories" make air soundings twice daily.

A meteorograph, thermometer, and icing dummy ( a model aeroplane) are attached to the wing of the aircraft. In addition, all kinds of observations are carried out with respect to cloud structure and air turbulence by means of an accelerometer and other instruments.

Here is how T. Yudin describes the flight of a "flying laboratory" that took off from the Vnukovo airfield on January 5, 1956.

"The aircraft on the ramp is an ordinary passenger plane with the number L-4909 written large across the fuselage. From the outside it is no different from other craft of this kind, though its mission is quite unusual.

"The aerologist takes his place at one of the desks in the spacious saloon of the 'flying laboratory'. He adjusts his microscope for studies of cloud elements and readies other devices for aerial observations. Across from him, at a second desk, is the second aerologist. On a panel in front, he has an altimeter, an aerial compass, horizontal- and vertical-speed indicators, and other instruments. These instruments will help to draw up a picture of the meteorological situation along the entire flight route.

"Preparations for this routine flight come to an end, the crew take up their places, and the airport dispatcher radioes clearance for take-off. The plane taxis out to the runway, and in another minute is above the white airfield with its varicoloured lights. Right from the start the plane goes into a steep climb.

"The scientific staff get down to work immediately. A searchlight flashes on outside the window of the cabin—the aeroplane is approaching the lower fringe of the clouds, and, so as not to pass it by accidentally, the aerologist switches on a powerful light. The plane is now in the clouds. With a special instrument the aerologist takes his first air sample, and then puts it under the microscope where he carefully examines the cloud particles he has caught.

"The ground temperature just before take-off was 4° C. below zero, now the thermometer reads 10 below.

"The ground lights have disappeared, covered by a thick blanket of cloud. For fifteen minutes the plane pushes through the overcast, and all this time the aerologists are watching their instruments, especially the icing dummy. But the clouds do not prove dangerous—the ice-up is only 3 to 4 millimetres.

“‘But a few days ago,’ the aerologist recalls, ‘we struck an area in which we actually watched the plane cover over with a thick crust of ice, and it was no easy job getting out either.’

“But now there is no trouble. Above the clouds the night sky is studded with countless stars, and the moon is shedding a cold bluish light on our plane. At 3,000 metres the thermometer reads 26° below zero. When the altimeter needle passes the 4,000 mark, we all don our oxygen masks. 5,000 metres, temperature—minus 34° Centigrade.

“One hour and 20 minutes from take-off we reach our ceiling—6,400 metres above sea-level. It is now 41° below zero outside.

“‘Could be worse,’ remarks the aerologist. ‘Once last month it was 56 below at this height.’

“But now the altimeter needle is falling back. The aeroplane passes down through a milky-white film of cloud and all of a sudden finds itself in a snowstorm. Big snowflakes, falling fast, close from view the landing field below. But the pilot has our craft on course. A sharp bell rings in the cabin. That is a signal from the instruments that the plane is making a good landing. Minutes later the aeroplane hits the ground.

“In two hours we covered some 500 kilometres. The ‘flying laboratory’ staff have studied the weather at various altitudes and over a large area. The weather scouts have brought in their observational materials. All routes leading out of the capital to the far ends of the country are now open to traffic. The crews of planes taking off today on routine flights will have an accurate weather forecast.”

But aeroplanes cannot reach the heights that stratosphere balloons (stratostats) do. For example, in 1934 the *Osoaviakhim* balloon reached an altitude of 22 kilometres. In 1935, the American stratostat *Explorer* climbed 22 kilometres 50 metres. A stratostat is a huge balloon which lifts a hermetically sealed gondola with a crew of several men. On the outside are instruments, some of them self-recording.

Flights in stratosphere balloons have yielded much valuable material in upper-atmosphere studies. The dream of the great

Lomonosov, "...to build a tiny machine that would carry aloft thermometers and other small meteorological instruments," has come true. Lomonosov's idea was a precursor of today's method of vertical sounding of the atmosphere.

All the foregoing methods of investigation are limited by a "ceiling" of twenty to thirty kilometres. How is one to find out what is happening in the higher layers of the atmosphere? Later on I shall describe the use of rockets and artificial earth satellites in the study of atmospheric phenomena. Now I should like to discuss some methods developed by Soviet scientists for observing, from the ground, events in the atmosphere that occur several hundreds of kilometres up. In contrast to the above-described "direct" methods, these will be called "indirect" methods of studying the upper atmosphere.

The composition of the very highest layers of the atmosphere is studied by means of Academician Fesenkov's twilight method. While the sun is above the horizon we receive its direct rays and, in addition, the light scattered by the atmosphere. This is daylight. When the sun sinks below the horizon at sunset, the solar rays continue to illuminate a part of our atmosphere above the horizon. As the sun sinks lower the scattered light gradually grows fainter. This is twilight.

The evening sky exhibits three twilight arches. Each of them has its specific colour, since the different layers of air scatter the sun's rays differently. The first arch goes below the horizon when the sun is already  $8^{\circ}$  below. This is when the brightest stars come out. The scattering layer that produces the first twilight arch is at a height of 10 to 11 kilometres.

The second arch disappears when the sun is  $18^{\circ}$  below the horizon. This is when darkness sets in. The height of the scattering layer is now 70 to 75 kilometres. Instrumental observations have shown a third arch to disappear. In this case, the scattering layer is 200 kilometres high.

Twilight observations thus suggest that the atmosphere has a stratified structure with boundaries between the layers at 10-11, 70-75, and 200 kilometres.

Yuri Gagarin, the Soviet cosmonaut, made vastly interesting observations during his space flight, the first in the world, on April 12, 1961. The altitude of the flight ranged between 175 and 300 kilometres. Gagarin said that from that altitude the day side of the earth can very well be seen. One can clearly discern the continental coastlines, islands, large rivers, and water reservoirs, and accidents of the ground. "During the space flight I saw the spherical form of the earth for the first time with my own eyes. It appears like a sphere when you look at the horizon. It should be noted that the horizon presents a very unique and unusually beautiful picture. One can observe an uncommonly colourful transition from the light surface of the earth to the perfectly black sky with stars shining in it. This transition is very fine, it is like a film surrounding the earth. The film is a delicate blue, and the transition from blue to black is unusually smooth and beautiful. It is quite difficult to describe. But when I emerged from the earth's shadow the horizon had changed. It had a bright orange strip which changed to blue and then to deep black again."

There are still other indirect methods for studying the upper layers of the atmosphere.

In the northern part of Europe, between 55° and 65° north latitude, one can often observe light clouds with a characteristically wide range of bright colours. These are mother-of-pearl clouds. Measurements show that they soar between 25 and 30 kilometres from the earth. Optical phenomena in these clouds (for example, lunar halos) suggest that they consist of droplets of supercooled water or ice crystals. They are most frequently seen in Norway. The waves in western air currents that flow over the Norwegian mountains possess considerable amplitudes and reach heights of twenty and thirty kilometres without much damping. Ascending currents develop on the crests of the air waves and carry water vapour into the upper layers, where it condenses to form the mother-of-pearl clouds. The delicate structure of these clouds indicates a low density, but there can be no question that water vapour reaches these extreme altitudes. In 1950, mother-of-pearl clouds were ob-



served at 24 kilometres above Alaska. They formed on the leeward side of a 6.5-kilometre mountain range with a strong north wind blowing at 50 metres a second. Mother-of-pearl clouds have velocities that vary from a couple of kilometres per hour to 350 an hour.

On a clear, moonless night one can observe dozens—sometimes even hundreds—of “shooting stars.” These are minute fragments of heavenly bodies, oftentimes as small as a grain of sand, composed of basalt rock and meteoric iron. Such particles, called *meteors*, plunge into the earth’s atmosphere at speeds from 10 to 70 kilometres a second, and burn up at great heights. Large-size meteors (some weigh several tons) do not have time to disintegrate in flight and reach the ground only fused at the surface. These are known as *meteorites*. The famous Siberian meteorite which fell near the Podkamennaya Tunguska River in June 1908 weighed over a million tons.

On entering the atmosphere, meteors collide with the molecules of the air. In the top, tenuous layers, such collisions are rare, but lower down, in the dense atmosphere, they become more frequent. As the meteor rushes in, a “cushion” of highly compressed air—which, therefore, becomes very hot, up to 20,000° C.—builds up and begins to glow, while the meteoric material disintegrates and also contributes to the light. This is the main source of heat—air friction here plays an insignificant part. The highest point at which meteors begin to glow (red incandescence) is at 150 kilometres. They become brighter at 100 kilometres, and sometimes at lower altitudes, depending on their velocity.

Meteors die out at various heights but mostly between 80 and 45 kilometres from the surface, with a maximum at about 60 kilometres. All this is added proof of the existence of an atmosphere at great altitudes, and of its stratified structure.

Observations of meteor flights and the rate at which they decay give us information about the density of the atmosphere and the temperature. Meteors sometimes leave in their wake a glowing streak, or train, which enables us to calculate the wind force at high elevations.

During recent years Soviet scientists have used searchlights in studies of the upper atmosphere. The beam of a powerful searchlight reaches tens of kilometres into the sky. In clear weather, it cuts through layers of the atmosphere heavily laden with dust, through layers with large quantities of water vapour, and through cloud formations that escape visual detection, depicting them as peculiar spots and blinks.

To conclude our survey of methods of studying the atmosphere, a few words are in place about the *cosmic rays*, which are extremely important in studies of the structure of atomic nuclei and the electrical state of the upper atmosphere.

Starting out from the mysterious depths of the universe and moving at speeds close to light—roughly 300,000 kilometres per second—cosmic rays traverse enormous distances before they reach the earth. They form an incessant stream of atomic nuclei possessing colossal energies—of the order of thousands and tens of thousands of millions of electron-volts. Yet some of these particles have still greater energies. So truly tremendous are they that if a ball of matter weighing one gramme plunged into the Black Sea with the speed of a cosmic-ray particle the water would begin to boil. Fortunately, we may be sure that nothing of the kind will happen, because these particles have such immeasurably small masses that a single one falling to earth goes quite unnoticed.

Scientists are interested in these rays from outer space because when they collide—at nearly the speed of light—with the nuclei of various elements they give rise to new physical phenomena. Cosmic-ray studies have, for one thing, been instrumental in disclosing the nature of nuclear forces, those forces that keep the atomic nucleus stable binding together its component parts.

The particles of cosmic radiation possess a tremendous penetrating power. In their passage through great thicknesses of air, water and rock they slow down, yet they have been detected scores of metres underground.

The question is often asked: Is there any way of obtaining such particles artificially?

Modern science and technology are moving towards a so-

lution to this problem. True, the energies of our machine-accelerated particles are still far from cosmic energies. For instance, the U.S.S.R. Academy of Sciences has a synchrocyclotron that speeds protons to an energy of 680 million electron-volts; it also has an atom-smashing machine called a proton synchrotron that hurls protons to energies of 10,000 million electron-volts. And in the making are still more powerful machines calculated to accelerate particles to energies of 50,000 million and more electron-volts. Which means that our man-made energies are slowly but surely approaching those of the cosmic rays from the depths of the universe.

Some scientists (the American physicist John Simpson for one) think that cosmic radiation originates in our sun and in the millions upon millions of other suns in the Galaxy. Cosmic radiation is thought to be associated with thermonuclear processes.

One way in which cosmic radiation manifests itself is in the formation of *free ions* in the atmospheric air. Ions are charged atoms and molecules of the atmospheric gases. The term ion (from the Greek "to go") means a particle of matter capable of moving under the action of electric forces.

Cosmic-ray observations include determining the number of ions produced by these rays per second in one cubic centimetre of air inside a closed vessel. For this purpose, complex instruments are carried aloft to various altitudes. It has been found that all layers of the atmosphere contain such charged particles. In the lower layers, there are relatively few ions (several hundred per cubic centimetre), and the number fluctuates considerably, especially during thunderstorms. From 3 kilometres upwards, the ion number increases gradually, and, as the measurements made by A. V. Verigo during the stratostat flight in 1935 show, this growth continues up to 15 kilometres. This increase in number of ions is, undoubtedly, connected with the effects of cosmic radiation, the intensity of which increases with altitude.

The ion abundance is greatest at about 80 kilometres height. Upwards of this limit extends the ionosphere, where each cubic centimetre contains millions of ions produced by the ultraviolet

rays of the sun. The existence of the ionosphere and its structure were established in observations of the propagation of radio waves. It has been proved that a radio wave sent almost vertically upwards returns to earth after refraction in the upper layers of the atmosphere. These layers should be good conductors of electricity, and this is possible only if there are large quantities of free ions. Special apparatus is used to record the return wave, and from the time lapse it is possible to get an idea of the height of the reflecting layer. When we vary the wave-length the waves are observed to return from layers in the atmosphere at different altitudes.

The reflecting layer is sometimes recorded at 2,000 kilometres height, which indicates that there is some gas present there too.

### Composition of the Atmosphere

The air at the earth's surface and at low levels consists of a mechanical mixture of gases, mainly nitrogen and oxygen. The air likewise contains a bit of carbon dioxide and traces of some of the rare gases. By volume, dry atmospheric air contains 78 per cent nitrogen, 21 per cent oxygen, and 0.9 per cent argon. The quantity of carbon dioxide varies, with an average of only about 0.03 per cent, though in big cities this goes up to 0.05 per cent and even more. In addition, the atmosphere always contains variable quantities of water vapour (from 0.1 to 4 per cent). There is much more water vapour in hot muggy weather than during severe frosts. The presence of water vapour alters the percentage content of the gases, and for this reason the composition of dry and humid air differs.

Oxygen is a gas that supports combustion and is vital to breathing. Nitrogen, on the contrary, does not contribute to the vital processes and hardly at all combines with other substances. Argon, like the relatively recently discovered neon, belongs to the rare-gas group and finds application in luminous gas lamps and tubes used for signalization and lighting. Hydrogen and helium are very light gases, and so make up an insignificant portion of the atmosphere. These gases emerge

from the earth and, despite the constant mixing of the air, rapidly rise to the very highest layers of the atmosphere, and then go on out into interplanetary space.

Why is the earth surrounded by nitrogen and oxygen? Generations of scientists have been looking for an answer. Here is one given by the Soviet scientist K. K. Korovin. For years he has been studying the relationships of elements in nature and their transformations and has found that some are principal elements and others are companion elements. The latter easily convert one into another and retain their quantitative equilibrium. The main companion elements of the earth are nitrogen and oxygen. This is due to the fact that the atmosphere is always in contact with the land and water surface of the earth; as a result there is a constant interaction between the air molecules and those of the soil and water.

Thus, the constant composition of the earth's atmosphere and the quantitative equilibrium of its component elements (chiefly nitrogen and oxygen) are due to a continuous mutual transformation occurring under the action of the sun's rays, lightning discharges, cosmic radiation, and other physical factors. It is noteworthy that the processes which establish this equilibrium are directly related to the land and water areas.

The seas, oceans and large lakes occupy 71 per cent of the surface of the globe; small lakes, rivers and other bodies of water make up 7 per cent. Which means that 78 per cent of the surface is water and 22 per cent land. This is why the terrestrial atmosphere contains 78 per cent nitrogen, 21 per cent oxygen, and less than 1 per cent of the inert gases.

In addition to these gases, there is a fine dust floating about in the atmosphere. Part of it is of cosmic and volcanic origin, some comes from weathering of the rocks, and a portion is made up of minute particles of the soil, the products of incomplete combustion found in smoke, the products of animal and vegetable origin, and so forth.

In the upper layers, the dust is of cosmic origin (the remains of disintegrated meteors, for instance). There are relatively small quantities of this material, but, as investigations have

shown, this dust gets heated by the sun's rays and becomes a source of vertical air movements at high altitudes.

Years of observations of the intensity of solar radiation have disclosed a noticeable fall in the transparency of the atmosphere in August when the amount of incoming solar heat diminishes by 4-5 per cent. This is accounted for by the fact that in its orbital motion about the sun, the earth in August passes through a swarm of cosmic dust and meteors—the debris of a comet that broke up in 1862. During this period, whole showers of meteors appear emanating from the constellation Perseus, whence the name Perseids. The Perseids put on their best display about August 12. The stars of the constellation Perseus indicate that part of space containing the accumulation of cosmic debris which the earth crosses in its orbital motion.

From time to time, great volcanic eruptions eject far up into the atmosphere (up to 50 kilometres) enormous quantities of fine dust that envelops the whole globe causing the sky to darken. This dust settles down very gradually and may remain in the upper atmosphere for years. In June 1912, after a big eruption of the Katmai Volcano in Alaska, for several months nearly the entire Northern Hemisphere registered a fall in solar radiation by approximately 50 per cent. Even after the atmosphere had cleared up to some extent and the layer of haze disappeared entirely, solar radiation was still about 20 per cent below normal. Only in 1915 did the atmosphere rid itself completely of the dust, and then the sunshine returned to normal.

The question naturally arises: Did such a reduction in the influx of sunlight bring about a fall in temperature at the earth's surface? Observations failed to show any departures from normal. In this connection, scientists advanced the view of a "regulating" action on the part of water vapour in the atmosphere.

Indeed, an increase in solar radiation should involve an increase in evaporation from the oceans and enhanced cloud formation. But as a result there is an increase, firstly, of reflected sunlight from the cloud surface, and, secondly, of the

absorption of solar heat in the atmosphere; and that portion of the solar energy that heats the land and the seas diminishes. For this reason, an increase in temperature near the surface will be much less than would correspond to the observed increase in solar radiation. And conversely, a decrease in solar radiation will cause a reduction in the amount of water vapour in the atmosphere, and, hence, the latter will act to retard the fall in temperature. Water vapour thus plays the role of a regulator of air temperature both at the surface and in the free atmosphere.

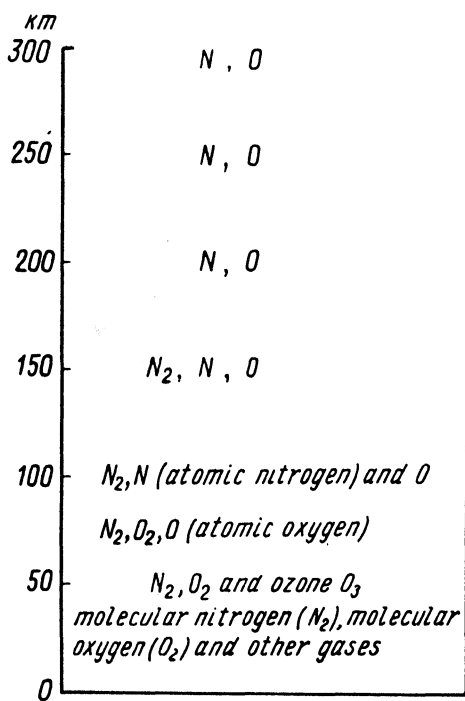
The chief source of atmospheric dust are the minute products of rock erosion and soil particles that are caught up by the wind and thermal convection (transport of heat by moving air). A good deal of smoke, that is, the products of incomplete combustion, also accumulate in the atmosphere polluting the air of cities and industrial centres. Forest fires, burning peat bogs and steppe regions contribute large amounts of smoke, too. The surf on the shore and storms at sea send water into the air where it evaporates leaving particles of salt that are then carried about by the winds. Nuclear test explosions eject into the air enormous quantities of radioactive dust. The gradual fallout of this dust constitutes a grave danger to the health of human beings everywhere.

And, lastly, the atmosphere also contains minute particles of the remains of vegetable and animal organisms, bacteria, the spores of plants, and so on. Long rains can clean out the lower strata of the atmosphere, but do not affect the upper layers.

Thus, the terrestrial atmosphere contains more than just gaseous substances. In addition to dust, there are always products of the condensation of water vapour in the air—drops of water and ice crystals. These water droplets that are too small for the eye to see produce a mist which from afar appears like a bluish haze. The larger droplets form fogs and clouds. All this is enveloped by a thin gas layer that differs from the surrounding air by its humidity and other physical properties.

Does the composition of the air vary with altitude? For a long time scientists could give no definite answer because they could not get specimens of air from extreme altitudes. It was

thought that the predominating gas in the lower layers was oxygen, and higher up, nitrogen, while the very highest were made up of hydrogen and helium. However, this idea had to be discarded when the first samples of air were obtained at 15 to 30 kilometres up. Good samples were obtained during the flight of the *U.S.S.R.* stratosphere balloon in 1933. The air composition at 18 kilometres height was found to be the same as at the surface. It was established that the atmosphere is constantly being mixed by vertical air currents. Later, air



Composition of the air at various levels

samples were obtained from 30 kilometres by means of pilot balloons carrying automatic flasks for trapping gas. Again, the composition was practically the same as at ground level. There was just a bit less oxygen and only a little water vapour, which is due to the very low temperature at extreme altitudes.

What is the composition of the air at still greater heights and how are samples to be got?

Scientists have made use of the indirect methods of investigation that we have already mentioned. They have found out for sure that the upper atmosphere

does not contain either hydrogen or helium, and that both nitrogen and oxygen are present. But the oxygen differs from that at the surface. Down below we encounter molecular oxygen, where each molecule consists of two atoms. Chemists symbolize it as  $O_2$ . In the upper atmosphere, the oxygen is



split by the sun's ultraviolet rays into atoms producing what is known as atomic oxygen, O. Its complete decomposition into atoms occurs from 100 kilometres on upwards. At 200 kilometres height nitrogen breaks up into atoms (the figure on p. 30 shows the air composition at various heights).

Astronomers have long noticed that the night sky possesses a faint glow, which, nevertheless, is much stronger than the luminosity of the stars. This light was found to result from the decomposition of oxygen molecules under the action of the sun's ultraviolet radiation. The energy consumed during the day goes to produce a glow at night in a layer of air from 100 to 1,000 and more kilometres thick.

When aerologists studied the spectrum of the night skylight they detected a yellow line. In 1936, V. I. Chernayev proved that this line belongs to the metal sodium. Its atoms produce an emission at 80 kilometres above the earth. It is still a mystery how sodium got to that altitude. During recent years, scientists have discovered other metals, too, in the atmosphere. At 130-150 kilometres, calcium, magnesium, and iron have been found. True, the quantities are absolutely negligible—just a few atoms among large numbers of molecules and atoms of the gas of the extremely tenuous atmosphere.

Finally, atmospheric air has been found to contain ozone, which, it appears, plays a very important part in the life of our planet. The point is that ozone consists of the same atoms as oxygen, the only difference being that a molecule of oxygen contains two atoms, while one of ozone has three—O<sub>3</sub>. In the atmosphere, ozone is formed out of oxygen under the action of ultraviolet radiation and electric discharges, as will be recalled from the familiar odour after a violent thunderstorm when the air is rich in ozone.

It is now known that the greater part of the ozone is not at the earth's surface but in the upper levels of the atmosphere—between 15 and 50 kilometres. And the total amount is small. If all the ozone could be collected into a single layer at normal pressure (760 millimetres of mercury) it would be only 3-5 centimetres thick.

Yet, despite the small amount of ozone in the air, it is enough to screen out a great deal of the sun's ultraviolet radiation.

Ultraviolet rays are known to be very important to human life: they promote metabolism, kill harmful bacteria, and so forth. But if they reached the earth in full force they would destroy all living organisms.

### The Structure of the Atmosphere

The atmosphere is divided into several layers: the troposphere (the lowest), the stratosphere and, lastly, the ionosphere.

The best studied layer is, naturally, the *troposphere*. In middle latitudes, it reaches thicknesses of 10 to 12 kilometres, thinning out towards the poles to 9 kilometres and expanding towards the equator to 18. The troposphere contains the bulk of the atmospheric mass, and for this reason exhibits the most diverse forms of weather.

First of all, there is a continuous fall in temperature with increasing altitude—an average of  $6^{\circ}$  each 1,000 metres. This is due to the fact that the air freely transmits the sunlight but does not itself heat up. Like the glass in a hothouse, it holds in the heat radiated by the earth.

The sun's rays heat up the earth's surface and the adjoining lower levels of air very considerably. The heat rising from the earth is absorbed by water vapour, carbon dioxide, and dust particles in the lower layer of the atmosphere. Higher up the air is thinner, there is less water vapour, and the heat radiated from below has already been absorbed by the lower-lying layers. That is why the air is cooler, and it accounts for the fall in temperature with altitude.

During the winter the surface of the earth cools off. The snow cover makes its contribution to this process by reflecting the greater part of the sunlight and by radiating the heat into the upper air. This very often makes the air at the surface cooler than higher up. Within certain limits the temperature increases with the altitude. This is the so-called winter *inversion* of temperature.

When there is no influx of heat to the earth's surface, temperature inversions may occur at other seasons and at various altitudes. This is why the temperature fall with altitude is seen only in mean figures. Exceptions are frequent.

During the summer time the solar radiation heats up the earth intensely and unevenly. Those portions that are hotter send up currents of air and eddies. The air from cooler areas flows in and, in turn, is replaced by air coming downwards. Convection sets in causing a vertical mixing of the atmosphere. Convection dissipates fog and reduces the amount of dust in the lower levels.

The upflowing air enters the more tenuous layers, expands and gradually cools off at the rate of  $1^{\circ}$  per 100 metres of ascent. This comes from the work done in expanding the air. We should, therefore, not confuse the regular fall in temperature with altitude that is always present with the cooling of air as it ascends.

For a given temperature, the air can hold only a definite quantity of water vapour.

At a certain height, the temperature becomes so low that there is excess water vapour—supersaturation. Condensation begins, tiny water droplets form to produce a cloud. Water vapour condenses particularly well on particles of dust and smoke floating in the air. In the cold seasons, the excess water vapour is converted into ice crystals and snow-flakes, and then ice clouds soar aloft. The same clouds are also formed in the summer time at high altitudes where the air temperature is quite a bit below zero. Clouds can likewise form in a collision of two air masses—warm and cold. In this case, the warm mass, being the lighter of the two, slides upwards on top of the cold mass. Thus appear large clouds that lie above the long and broad interface of the two masses of air. Precipitation from these clouds is in the form of continuous rain and snow.

In summer the air temperature is very high leading to considerable evaporation of moisture. As a result, a good deal of water vapour collects in the air, and the clouds are mostly of the heavy cumulus kind. If sufficiently developed, these

clouds precipitate heavy rains. During the winter there is little water vapour in the air and the clouds are usually flat and stratified. This is why there is far less precipitation in winter.

Thus, vertical currents in the troposphere effect a continual mixing of the air that makes for constant composition at all levels. The troposphere is the seat of the continual formation of clouds, precipitation and all the stormy phenomena of nature. This is why it has come to be known as the "laboratory of the weather."

Moving upwards, the troposphere passes into a relatively thin (500 to 1,000 metres) layer called the *tropopause*, and then into the second atmospheric level—the *stratosphere*, which was discovered comparatively recently (it was still unknown at the end of last century). For some time after its discovery, the stratosphere was considered to be absolutely lacking in vertical air currents, and with only weak horizontal winds. It was thought that the gases here were in layers, according to weight and density, with different percentage contents of the separate gases. Hence the name stratosphere (from the Latin *stratus* meaning "a spreading out").

However, subsequent studies showed that this was far from being the case. It was found that the stratosphere is in continuous turmoil due to air currents reaching up to great elevations, though these movements are not so violent as those in the troposphere. For this reason, stratospheric air differs but slightly from tropospheric air in composition. There is no quiescence there, and from time to time hurricane winds develop.

At this level, the temperature fall with altitude stops. Sometimes, even an irregular increase in temperature is observed. At times, the gradually declining temperature gives way to a slight increase. The stratosphere is believed to extend up to 80 kilometres. Observations have shown that the lower part of the stratosphere over the Arctic is warmer than over the equator. The mean temperature of the stratosphere over the Arctic is minus 45° C., over the middle latitudes, minus 55°, and over the equator, minus 80°.

In certain cases, the temperature in the stratosphere may deviate considerably from these figures. Over low pressure areas (cyclones), the stratospheric temperature exhibits a marked increase, while over high pressure areas (anticyclones) there is a pronounced decrease.

In the stratosphere, fall in temperature with altitude is a rare occurrence. The temperature is usually constant or even rises somewhat. Direct observations have been taken up to 36 kilometres—the altitude reached by a radiosonde released in 1946 at the Central Aerological Observatory in Moscow. The gradual rise in temperature that sets in at about 18 kilometres changes, at 30 kilometres, to a sharp increase, reaching some 40 to 50° above zero at 40 to 50 kilometres.

This warming up process at high levels is, it appears, due to the presence of ozone. Ozone absorbs the ultraviolet rays of the sun and heats up. The highest layers of ozone absorb the greatest amounts of heat because they are the first to intercept the solar radiation.

Observations of meteor glow suggest that at 80 kilometres up the temperature again falls sharply, probably to minus 40 and 50° Centigrade.

The stratosphere thus has three layers: a constant-temperature layer between 10 and 30 kilometres; a warm layer between 35 and 50 kilometres; and a cold layer from 60 to 80 kilometres.

The rarefied air of the stratosphere makes the sky look nearly black. The weather here is always good. The sky is cloudless, with the exception of rare mother-of-pearl clouds that appear at 25 to 30 kilometres, and an occasional noctilucent cloud at 80 kilometres height. But the density is very low in both types.

The third atmospheric layer—the *ionosphere*—begins at about 80 kilometres. We have already mentioned the fact that the formation of ions here is due to ultraviolet radiation from the sun. These rays knock electrons out of the atoms of gas, making the remainder of the atom a positive ion; the ejected electrons are negative ions. An important part here is played by cosmic rays, which have already been discussed.

At certain elevations, ionization increases considerably forming something in the nature of concentrated layers of ions. Two such layers stand out: *E* at 80 to 100 kilometres, and *F* at about 200 kilometres heights. The *F* layer may split, in which case its lower part ranges between 180 and 200 kilometres, and its upper region, between 250 and 350 kilometres. These layers exert a great influence on the propagation of radio waves. Certain wave-lengths do not bend round the earth along the surface but are reflected from these layers to earth, and then back again, thus bouncing back and forth as they move forward. This gives rise to alternating zones of silence and good reception, which makes radio transmission uncertain. But looked at from another angle, this phenomenon makes possible the reception of radio signals at great distances from very low-power transmitters. For instance, a Soviet radio amateur working with low-power equipment maintained two-way communication for quite some time with Byrd's Antarctic expedition 20,000 kilometres away. Ionospheric studies have made communication via ultra-short waves possible on a mass scale even with low-power transmitters.

On the other hand, reception is sometimes interrupted, due to the silence zone, even at short distances. The diesel-electric ship *Ob* off the Antarctic shores was in free two-way contact with Spitzbergen in the Arctic, while an aircraft that took off into the interior of Antarctica soon lost touch with the base of the Soviet Antarctic Expedition at Mirny. Radio operators at Mirny sent out signals on different wave-lengths, but there was no response from the aeroplane. Everyone was anxious. It was only on the return lap at a distance of 750 kilometres that the plane was contacted. It appeared later that the interruption was due to the radio waves not being able to get through.

The ionosphere extends up to very high elevations, possibly to 800-900 kilometres.

During recent years the atmospheric layers beyond 800 kilometres have been called the *sphere of dissipation*, because dissipation of the gas particles is a characteristic peculiarity of these levels. From below, the particles are scattered into the

upper regions, and from the sphere of dissipation they escape into outer space. In this sphere, the gas is very tenuous—of the order of an artificial vacuum created in the laboratory.

In a rarefied medium, collisions of gas atoms are very infrequent. A gas particle will cover a considerable distance before encountering another particle. At the earth's surface the free path length of an air molecule (i.e., the distance between encounters) is about one one-hundred thousandth of a centimetre, at 100 kilometres height it is nearly one centimetre, and in the dissipation sphere, hundreds of metres. It is obvious then that with such rare encounters uncharged particles of gas can easily fly away into outer space.

Where is the upper boundary of the atmosphere?

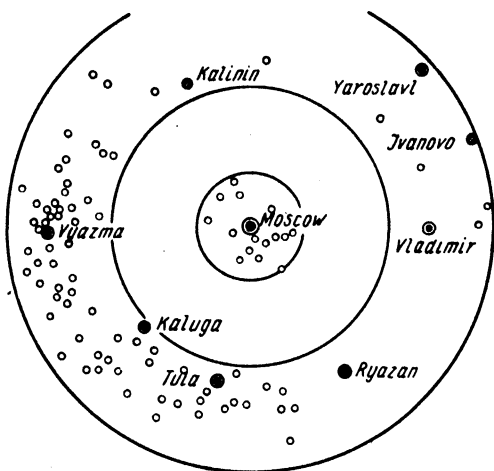
The answer is that the atmosphere has no boundary; it becomes more and more rarefied, finally passing into interplanetary space.

### **The Latest Methods in Upper-Atmosphere Investigation**

*Sound phenomena.* Observations of artillery fire, volcanic eruptions, and explosions have long since shown that, near the earth's surface, the force of sound does not diminish in continuous fashion as one recedes from the point of origin. Around the zone of audibility is a belt from 100 to 150 kilometres in width in which sound is not heard at all. This is followed by a new zone of audibility that gradually diminishes to zero. At times it has been possible to discern two more such belts; and in some cases there has been observed only a small section in which the sound was audible.

On May 9, 1920, some artillery warehouses exploded near Moscow. Shock waves destroyed villages around the focal point of the explosion, thousands of window panes in the city itself were broken, and in some houses the window frames, too, were knocked out. The frames and glass were broken outwards and not inwards for the following reason: the first to approach was the zone of rarefaction of the shock wave, this was followed by a zone of compression. On the baro-

grams\* the blasts of the air waves were recorded as sharp and almost instantaneous oscillations of pressure, the amplitude (the swing of the oscillations) of which was directly proportional to the force of the explosion. The needle of the big



Zones of audibility during the explosion of May 9, 1920, in the environs of Moscow (open circles denote points that reported audibility)

microbarograph of the University Observatory at Krasnaya Presnya was knocked beyond the recording scale several times. Enormous smoke rings, like the eddy rings that come out of the stack of a steam locomotive, raced skywards to clouds floating at 1,400 metres. The eddy rings pierced the clouds upsetting the structure at the lower fringe. This was clearly visible in binoculars and even

with the naked eye. However, no compression nor dissipation of the cloud cover, nor any increase in wind force was evident—even such a tremendous energy release was not enough to disrupt the equilibrium of the atmosphere.

Professor V. I. Vitkevich carried out a detailed investigation of the audibility of sound in these explosions. In the accompanying diagram, the zones of audibility and silence are very clear-cut. A remarkable fact is that 60 to 70 kilometres from Moscow the explosion was not heard, whereas it was reported at places like Ryazan (180 km), Vyazma (220 km), Ivanovo (250 km). The zones of audibility and silence were arranged quite regularly in belts, which is directly connected

\* A barogram is a curve recorded on the ribbon of the barograph which automatically records the air pressure.



with the low wind velocities of that day. During the day the wind was from the north-east at 20 to 25 kilometres an hour, and so most of the reports were received from the south-western sector, since sound is propagated better with the wind than against it. In the case of strong winds, the zones of audibility become elongated into irregular ellipses in the direction of motion of the air currents.

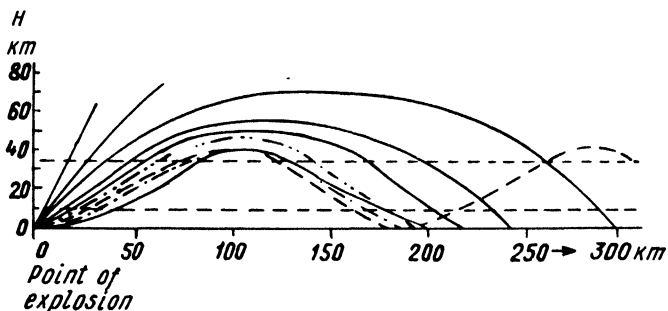
The reason for the abnormal audibility of sound is the reflection of sound waves moving upwards into the upper atmosphere. The sound velocity in these layers is higher than at the earth's surface.

The accompanying diagram shows the paths of sound waves that originated in the explosion of May 9, 1920. We know that the velocity of sound varies with the temperature, decreasing with falling temperature. Accordingly, a shock wave which at the point of explosion has the shape of a sphere gradually pulls out horizontally as it recedes from the seat of the explosion. This is because the sound velocity inevitably diminishes with falling temperature. The sound wave is more and more deviated upwards until, finally, it leaves the surface. A zone of silence results at the point where the sound wave detaches itself from the ground. However, if the air temperature diminished with altitude continuously, a sound wave would never return once it had escaped. Actually, however, the sound again becomes audible at some distance. This means that the wave was bent earthwards in the upper atmosphere. It is due to the sharp rise in temperature at considerable heights. It has been found that at about 40 kilometres the temperature again begins to increase gradually. The table below gives the sound velocities and the presumed temperatures at high altitudes.

**Sound Velocity and Temperature Versus Height**

|                                    |     |     |     |     |     |     |     |
|------------------------------------|-----|-----|-----|-----|-----|-----|-----|
| Height, km. . . . .                | 0   | 5   | 15  | 30  | 40  | 50  | 60  |
| Temperature, °C. . . . .           | 15  | -10 | -55 | -55 | -5  | 16  | 30  |
| Velocity of sound, m./sec. . . . . | 345 | 325 | 299 | 299 | 328 | 345 | 388 |

At altitudes over 40 kilometres there is a region where the temperature is very high and so the sound wave is bent back



Pathways of sound waves in the May 9, 1920, explosion

earthwards. The figure shows how the zone of silence is formed when the wave leaves the surface, and how it breaks off at points again returning to earth. The dashed line shows the possible formation of a second, third, etc., zone of silence.

Thus, sound waves are a good means for studying the upper layers of the atmosphere. Before World War II, regular investigations were carried out both in this country and abroad in the propagation of audibility of artificial explosions. At various points the sound was registered by sound-recording instruments sensitive to the very slightest sound vibrations. In order to avoid errors it was usual to fire off two explosions with a small interval between. During the Second International Polar Year (1932), several explosions were made on Novaya Zemlya, and the audibility was recorded at our polar stations.

The measurements of sound audibility during the polar night showed that the warm layer here was at a height of 32 to 35 kilometres.

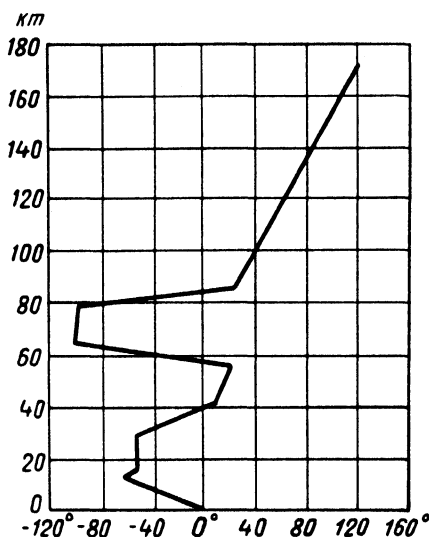
The figure on page 41 shows the distribution of temperature in the atmosphere computed on the basis of observations of a shock wave produced by a big explosion on Helgoland Island on April 18, 1947. Again, as in other experiments of this type, a warm layer of air (temperature, plus 20° C.) was detected at 40 to 50 kilometres altitude. Above this level, the temperature again decreased and was minus 95° C. at

70-80 kilometres. It then began once more to rise, and at between 86 and 172 kilometres it reached plus 125° C.

Observations of the behaviour of sound from explosions are expanding, they are being conducted not only in moderate latitudes, but in the tropics, at the equator, in the Arctic, and in the Antarctic. Recently, the velocity of the sound of exploding hand-grenades slung under rockets was determined. The sound method of upper-atmosphere investigations will continue to be used.

But speaking of temperature in the very high layers of the atmosphere, where the air medium is tenuous in the extreme, we must decide just what and how we are measuring.

When measuring the temperature of water in the laboratory we immerse a thermometer in the vessel and mix the water so that the temperature will everywhere be the same; only then do we take the reading. Clearly, it is possible to measure the temperature only inside a limited space in which there exists thermal equilibrium. When we measure the temperature in the lower layers of the atmosphere, where the air is not in thermal equilibrium, we place the thermometer in a box that protects it from the direct sunlight, from the radiation of surrounding objects, from atmospheric radiation, etc. Very often in such cases a psychrometer is used (the Greek *psychros* meaning "cold"). This gives the thermometer artificial ventilation. But in the upper atmosphere such apparatus is too crude.



Distribution curve of atmospheric temperatures computed from observations of a wave of the great explosion on Helgoland Island on April 18, 1947

At altitudes exceeding 50 kilometres the notion of temperature in the sense of physiologically perceptible heat or cold no longer holds. This is because by air temperature we mean the motion and collisions of gas molecules. At high altitudes the air is very tenuous, the free path length of the molecules is greatly increased, and the number of encounters diminishes. This means that the sphere of a thermometer in this medium will experience very infrequent impacts of the air molecules. But in the sunlight it will absorb the solar rays directly, while in the shade it will radiate into cold, interplanetary space. For this reason, the thermometer will heat up in the daytime and cool off at night. This, in scientific parlance, is called being in radiant equilibrium. But it is not the temperature of the air.

Cases of intense heating have been observed at much lower altitudes during stratosphere balloon flights. The temperature, at 18 kilometres height, in the gondola of the *U.S.S.R.-1* stratostat was plus  $14^{\circ}\text{C}$ .; in the gondola of the *Osoaviakhim* stratostat it was plus  $15^{\circ}$  at 22 kilometres. In Piccard's flight, the turning mechanism of the gondola failed, and its black side was all the time turned towards the sun; inside, the temperature was very high (plus  $38^{\circ}\text{C}$ .). In all these cases, the outside temperature remained  $40^{\circ}$  below zero.

All this makes scientists seek other methods, even indirect, for determining temperatures at high altitudes. For instance, a determination is made of the air density and the variation of this density; that is, they determine the number of particles per unit volume and then compute the temperature.

In passing, it may also be noted that despite the tremendous wind velocities at these altitudes, the air currents cannot be measured with ground instruments (anemometers) because of the extreme tenuousness of the gases.

*"Twilight method."* This is a technique of atmospheric studies worked out by V. G. Fesekov, N. M. Shtaupe, T. G. Megrelshvili, and others.

Both the daylight sky and the twilight sky get their colour from the scattering of light by the molecules of the air. How-

ever, there is an essential difference between these two related phenomena. When the sun is high in the sky the brightness of the day sky is caused mainly by the lower, dense, layers of air. The brightness of the twilight sky is due to the scattering of light in the upper layers of the atmosphere, with the height increasing as the sun goes below the horizon. We know that the brightness of scattered light is proportional to the density of the air. Through observations of twilight intensity by means of special instruments (photometers) one may gauge the density of the air at various heights, and thus calculate the temperature\* at these levels.

This method has remarkably confirmed the fact of a sharp temperature change at the upper fringe of the stratosphere (about 80 kilometres height). Above this boundary, the temperature rises to plus 300° C. at 250 kilometres.



Meteorological rocket on launching rack

*Rocket observations.* During recent years atmospheric studies have been conducted with rockets. The father of rocket theory and of liquid-fuel rocket engines is the Russian scientist K. E. Tsiolkovsky.

The first Soviet liquid-fuel rocket proposed by Tsiolkovsky was launched in 1933. Watching its precarious ascent, no one would have ventured to say that some twenty years later rockets would reach heights of hundreds of kilometres, and would even go all the way to the moon.

Beginning with 1949, the launching of rockets equipped with scientific instrumentation gradually became one of the methods of height-atmosphere studies in the U.S.S.R.

In May 1949, the first vertical rocket flight to 110 kilometres was accomplished. The first rockets carried instrumentation weighing 120-130 kilogrammes.

With each new firing the programme of scientific investigation expanded, new instruments were added, and the overall payload became heavier and heavier.

A new step forward in upper-atmospheric studies was the rocket flight of May 1957 (with experimental apparatus weighing 2,200 kilogrammes) that reached a height of 212 kilometres. The instrumentation and experimental animals were safely returned to the earth. This flight was followed by a whole series of more involved undertakings.

Carrying out the programme of the International Geophysical Year, scientists, on February 21, 1958, at 11 hr. 42 min. Moscow Time launched a single-stage geophysical rocket from the European part of the Soviet Union (middle latitudes) to a record height of 473 km. The rocket carried geophysical instruments for multipurpose investigations of the upper atmosphere. Its 1,520-kilogramme payload included radio-telemetric gear, power supplies, and auxiliary systems together with the container.

The rocket carried the following geophysical instruments: an ultra-short-wave dispersion radiointerferometer for measuring the free-electron density in the ionosphere; an instrument for measuring the ionic composition of the atmosphere;

apparatus for studying the density of positive ions in the atmosphere; an instrument for measuring the electron temperature; ionization and magnetic pressure gauges for air-pressure measurements; instruments for recording micrometeor impacts; and a solar spectrograph for registering the ultra-violet region of the spectrum.

The rocket was stabilized throughout the flight, including the period of free coasting, by means of special devices which precluded rotation about the longitudinal and transverse axes. This circumstance greatly increased the accuracy and value of the scientific investigations.

The rocket was launched at a slight angle to the vertical in a pre-set direction, and, on return to earth, impacted in exactly the specified area.

Analysis of the materials showed that the instrumentation functioned very satisfactorily during the flight.

The ascent established a world record for rockets of this class.

Rocket velocities have increased to 8-11 kilometres per second, and the "ceiling" is now at 473 kilometres for a one-stage rocket. But very high-speed flight causes the rocket to heat up, thus interfering greatly with measurements of temperature and pressure of the air. In the extremely tenuous air, parachutes are of no use, since they encounter hardly any air resistance and fall almost like in a vacuum. This has made it necessary to reconsider and reconstruct the entire measuring technique. Since direct temperature measurements during rocket flight do not yield precise results, microbarometers are used to measure the pressure of the air. And then the temperature is computed from the pressure decrease with altitude.

For control another method is employed. A comparison is made of the impact pressure of the air at an opening in the front part of the rocket and the undistorted pressure in the rear part. With a known rocket velocity, this information makes it possible to determine the speed of sound in a given layer, and, hence, the temperature.

What contributions to science have meteorological measurements by means of rockets made?

Sounding balloons have ascended to 30-35 kilometres. This stratum of air has been probed thoroughly and at many points on the globe. Data on the higher layers of the atmosphere have been obtained by indirect methods of research. The rocket plays the decisive role in verifying this information, making it possible to decipher the structure of the upper atmosphere.

Following a smooth and steady decline in temperature up to 30 kilometres, where the warm breath of the earth is no longer felt and the temperature is, on an average, close to minus 55-60° C., we enter a warm layer of the stratosphere with its region of ozone that is formed and heated by the sun. The indirect methods of investigation have proved that there is a warm stratum with a temperature of 20-30° C. It disappears at 50 kilometres, and up to the top fringes of the stratosphere (80 km) the temperature falls rapidly to 50-60° and even 95° below zero. Here float the very highest noctilucent clouds. Higher still, the temperature again rises above the boiling point of water.

Confirmation has also been obtained with respect to indirect measurements of air pressure in the upper levels. Microbarometers show diminishing pressure with increasing altitude: 50 kilometres, about 1 millibar, 75 km, about 0.05 mb., 90 km, 0.005 mb.

We know that the greater part of the ultraviolet radiation is absorbed by the ozonosphere; for this reason it is very important to obtain a photograph of the ultraviolet spectrum above the ozone layer. This has been done by automatic rocket equipment. Photographs have been obtained at various heights up to 300 kilometres. It appears that at the earth's surface the spectrum is short, but that the higher one goes the longer the ultraviolet band becomes. Aloft, the solar radiation is undiluted in strength. Also, rockets have helped to establish the fact that the sun emits X-rays generated in the solar chromosphere and corona. It is thus clear that solar radiation pro-



duces an ionizing effect on the upper layers of the terrestrial atmosphere.

We already know a great deal about cosmic rays. But, like the sun's rays, they undergo various transformations in transit through the atmosphere. To obtain information about cosmic radiation from first-hand sources one must send his instruments a hundred and more kilometres high. Counters of cosmic-ray particles have been rocketed up to heights where the density of the air is a thousand million times less than at ground level.

Up to 100 kilometres, the composition of the air was determined by sending aloft special cylinders for taking air samples. There are many reasons why it is difficult to collect an air sample sufficient for analysis, and so other methods have to be invoked.

Between 100 and 220 kilometres we gauge the composition of the air from the spectrum of positive ions which is analysed by means of a mass spectrometer carried in the container of the rocket. Experiments have shown that the predominant ions at these altitudes are those with mass number 30 (ions of nitrogen oxide) and mass number 16 (ions of atomic oxygen).

Studies of micrometeors entering the atmosphere from interplanetary space are of great interest both to geophysics and as regards the safety factor in rocket and satellite flights.

Most important here is a determination of the density of meteoric particles and their energies.

In the experiment carried out on February 21, 1958, special apparatus was installed at four points around the perimeter of the nose part of the rocket. Micrometeor movements were reliably established out to 300 kilometres. Between 125 and 250 kilometres, 44 micrometeor impacts were recorded per square metre, while there were only 9 impacts up to 300 kilometres.

The electron density of the ionosphere (measured by the number of free electrons per cubic centimetre) affects the rate and direction of propagation of radio waves. Ionospheric studies from the ground have played a tremendous role in the

establishment of long-range radio communications. But to maintain radio communications with vehicles moving in outer space, one has to know the properties of the ionosphere as a whole. Rockets carrying scientific instruments have substantially changed our views on the structure of the ionosphere.

We now know that there is no pronounced ionospheric *E* layer. Actually, above the maximum of electron density in the region of 100-120 kilometres there is an area in which the ionization varies but slightly, and makes a gradual transition to an increase in the next layer. It was earlier thought that the electron density falls off rapidly over the maximum of the *F* layer, diminishing almost to zero at about 380 kilometres. In reality, even at 470 kilometres the measured electron density has been found equal to a million electrons per cubic centimetre. This means that the electron density falls off very slowly above the maximum in the *F* layer. There is, apparently, an intense diffusion of charged particles from the denser lower-lying regions of the ionosphere. This is of great interest for an understanding of the physics of phenomena in the outer ionosphere.

To carry out biological investigations in the upper atmosphere, Soviet scientists have sent aloft, by rocket, experimental animals (dogs) to heights of 100 and 210 kilometres. It has been found possible to maintain (in hermetically sealed cabins) the necessary barometric pressure, temperature, and normal composition of the air during a three-hour flight with two animals in the cabin. To study animals in flight, special instruments were designed to register blood pressure, pulse, heart currents, behaviour, temperature, and pressure of the air in the cabin, the effects of acceleration, etc.

The animals were recovered by separating the pressurized cabin from the rocket and parachuting it to earth.

The materials obtained permit drawing the conclusion that the accelerations during take-off of the rocket and re-entry of the separated cabin into the dense layers of the atmosphere during descent, and also the state of weightlessness over a time

of 3.5 to 6 minutes were quite tolerable. Some of the dogs made the flight a second time. There is one, called Plucky, that has done it five times. The state of their health is checked up immediately after the flights and then there is a long-term follow-up afterwards, but no changes whatsoever have been detected.

In the second stage of the research, the instruments and animals were catapulted from the rocket and then parachuted to earth. This time special high-altitude capsules were used. The catapult equipment functioned safely at 110 kilometres altitude and at a speed of about 1.2 kilometres per second.

The parachute gear went into action at 85-75 kilometres, and the dogs spent over an hour returning to earth. No deleterious effects to the health of the animals during these flights were detected.\*

To summarize, then, we have investigated the physiological effects of various factors peculiar to flight in the upper reaches of the atmosphere, we have worked out means of ensuring normal conditions for animals, and have also developed methods for saving them in case of emergency.

Rockets will yield much valuable material in the way of photographs of solar flares. These flares produce a direct effect on the state of our atmosphere, giving rise to a violent play of the forces of nature in different latitudes of the globe.

The rocket method of sounding the atmosphere has thus become the most reliable and powerful technique of exploring the upper air.

*Investigating the atmosphere with radio waves.* As in the case of the propagation of sound waves, radio transmissions frequently exhibit zones of anomalous audibility. We already know that the upper layers of the atmosphere are capable of

\* On August 19, 1960, the Soviet Union launched a spaceship-satellite with two dogs—Belka and Strelka—and the next day brought them back to earth safe and sound.

reflecting radio waves and returning them to earth. Under favourable conditions, a receiving station has to do with two systems of waves: those that are propagated in a straight line, and others that make detours by reflections from the upper levels of the atmosphere. This reflection is due to the fact that the propagation velocity of radio waves in the upper atmosphere is greater than at the earth's surface. The enhanced rate of propagation of radio waves in the ionosphere is due to the high ionization of the upper levels. Besides, as a consequence of the low pressure there, free electrons can stay in that state for a long time, while in the dense air near the surface they quickly settle onto particles suspended in the air (dust, condensation nuclei, etc.).

In June 1951, newspapers in the Netherlands came out with the sensational report that Dutch and Belgian radio fans had received television broadcasts from the Soviet Union (over a distance of 2,000 kilometres). On some days the field intensity of the Soviet television centres was so high that local broadcasts were, so to say, "pushed off" the television screens. Photographs were received from the Netherlands showing the Soviet announcer, the programmes, and so forth.

During the summer of 1955, many radio amateurs in the Soviet Union were regularly receiving super-long-distance television broadcasts from Italian, German, French, Czech and Swedish television centres. There have been many such cases, though the normal television radius does not exceed 100 to 180 kilometres at the present time.

The propagation of radio waves about a metre in length over distances of several hundreds of kilometres may be suitably explained by specific transient conditions in the troposphere, but the propagation of these same waves over thousands of kilometres can be accounted for only by the influence of the ionosphere, as witness the many cases already mentioned above of radio communications maintained between stations separated by 20,000 kilometres. This is why ionospheric studies now go beyond the limits of purely meteorological problems and are of importance to radio engineering as well.

Several methods are employed to determine the height of an ionized or conducting layer. The most common is the pulse method and the method of "critical frequency."\* Short-wave energy in the form of pulses is directed upwards by means of special reflectors, and is reflected from the ionized layer to the earth, where it is recorded by a receiving station. The second method is based on the fact that the critical frequency of a wave depends on the degree of ionization in the atmosphere and increases with this ionization. If the wave frequency for a given ionized layer is greater than critical, reflection will not take place, and the wave will continue upwards until it encounters a layer with higher ionization. Now if we gradually increase the frequency, the reflected signals will be received at larger and larger intervals, showing that the reflection is from a higher layer. Thus, from the time lag we can compute the height of the conducting layer, and from the critical frequency, the degree of ionization.

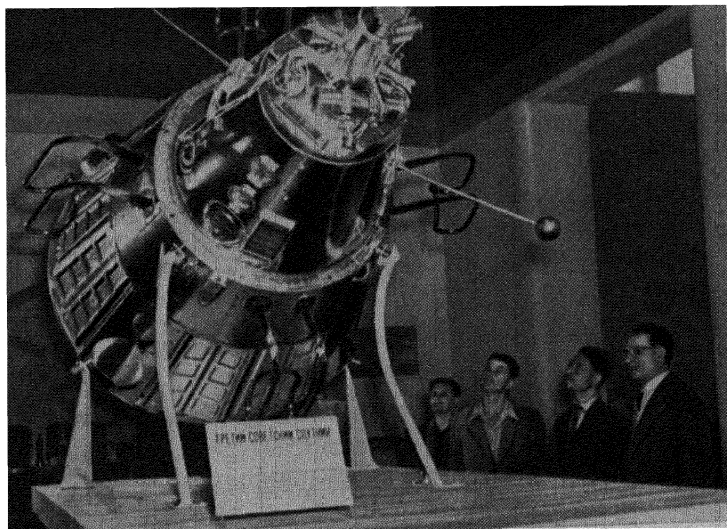
As regards super-long-distance broadcasts, investigations carried out by Professor A. Kazantsev have shown that they are to be explained by reflection from sporadic strata in the ionosphere. A sporadic layer is a rather stable accumulation of ionized clouds, which, as it were, stud the normal layers of the ionosphere. The sites of ionized clouds always coincide with the region of meteor glow and, obviously, are due to the meteors leaving in their wake highly ionized "trails." But ionized clouds are quickly dissipated and therefore do not produce any effect exceeding just a few minutes.

*Artificial earth satellites.* October 4, 1957, will go down in history as the date of an extraordinary scientific experiment—the launching of the first artificial earth satellite. The labour and creative genius of Soviet people made possible the first artificial cosmic body.

The successful launching of the first artificial earth satellites signified the beginning of man's penetration into outer space.

\* The critical frequency of electromagnetic waves is that limiting frequency at which the waves, at vertical incidence, are reflected from an ionized layer.

These man-made bodies opened up broad vistas for many very important scientific studies. Of great scientific and practical interest are studies of the ionosphere and the mechanism of its formation, the action of solar radiations and cosmic rays on the terrestrial atmosphere, studies of density, temperature, magnetic and electrostatic fields at high altitudes, etc.



Model of Sputnik III at Moscow's Exhibition of Economic Achievement

Although the importance of artificial satellites for scientific exploration has been common knowledge for a long time, the actual launching of a satellite had, until recently, been an unsolvable problem. It was only after the Soviet Union had built an intercontinental ballistic missile that it became possible to launch a satellite. The superlative design qualities of this rocket have enabled us to put into orbit satellites with considerable payloads of scientific instrumentation.

What have artificial earth satellites given us in the way of information about the atmosphere? In the chapter on rockets we considered the state of the atmosphere up to 460 kilometres.

Satellites have risen much higher. The upper atmosphere has been found to have a very high temperature (of the order of 2,000° C.) and the density of the air is greater than had been thought. But this does not mean that a body at this height will melt. Since the air is extremely tenuous, collisions of atoms are very rare, and the temperature has a purely physical significance. It has also been found that the atmosphere pulsates in a 24-hour period. In the daytime the density of the upper layers is several times that at night, and it is greater in summer than in winter. This is, apparently, due to solar radiation.

It was noted that strong magnetic storms associated with corpuscular streams produced a simultaneous increase in temperature and density of the atmosphere. This was suggested by the increased drag on the satellite. Apparently, corpuscles are also responsible for the fact that the density of the upper layers in polar regions is roughly five times that at the equator.

The shape of the air envelope of the earth is not spherical, but elongated towards the night side of the planet in the form of a tail. This gaseous tail extends out to 100,000 kilometres. Judging by the nature of its glow, it consists of nitrogen and oxygen like the atmosphere proper. If the origin of this tail were atmospheric dissipation, the gases would be scattered in all directions. It seems that the tail is shaped by the pressure of the sun's rays on the upper layers of the atmosphere.

Scientists have found that the earth is enveloped in an electron halo of a complex multistorey structure. The lower layer of this halo was detected by instruments of Sputnik III. Scientists are very much undecided as to the nature of the radiations and densities of the charged particles about the planet. But one thing is certain: this discovery has put on a firm foundation our notions about many processes in the ionosphere, and will permit of a truer approach to the problems of space flight and protection against radiations. Outer space, which had seemed empty, has turned out to be the playground of intricate processes.

## Solar Energy

The radiant energy of the sun is the source of life on earth in all its multiplicity. Said the great Timiryazev: "Man can consider himself the son of the sun. Solar radiation is the chief source of heat on this planet."

The total quantity of this energy is enormous. Every second the earth receives energy equivalent to that produced in burning three million tons of petrol.

All other sources of heat are absolutely negligible when compared with this immense store. Thus, measurements with a very sensitive thermometer show that the thermal radiation of the moon raises the temperature here on earth by only one six-thousandth of a degree.

The heat in the earth's interior likewise produces but an infinitesimal effect on the surface temperature. The temperature in the interior is undoubtedly very high, but since the earth's crust is a poor conductor of heat, this has little effect. This heat is capable of raising the surface temperature by only  $0.1^{\circ}$ . For the watery part of the surface the value of this heat is still less, because the bottom of the ocean is at about  $0^{\circ}\text{C}$ .

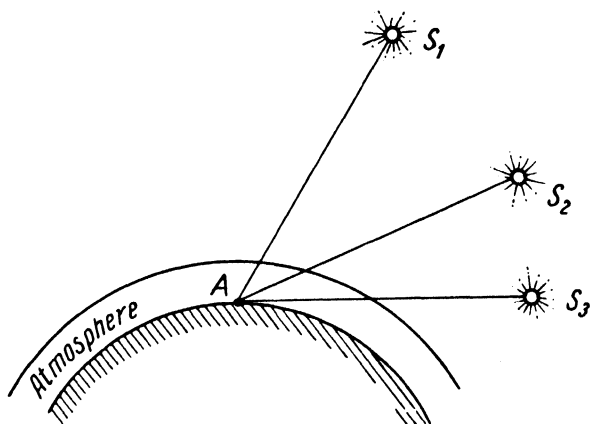
Volcanic eruptions and forest fires can add to the temperature over restricted areas, but this is only temporary and does not play a noticeable part in the heat budget of the earth.

The sun's energy generates the winds and the sea currents, maintains the cycle of water in the atmosphere, and heats the earth's surface; this heat gradually penetrates into the earth, creating that supply of energy which is needed for organic life. The visible part of solar radiation creates the daylight and all the diversity of optical phenomena (the blue colour of the sky, rainbows, and the like). Solar energy accumulated in the form of coal enables modern man to develop industry, build coal-burning power stations, factories, blast furnaces. Rivers and waterfalls, which are likewise accumulated energy ("white coal"), provide man with another important source of power to satisfy his needs. Air currents turn windmills ("blue coal"). And, finally, solar devices powered by the sun's energy concen-



trated by means of mirrors ("yellow coal") are being constructed. Naturally, the study of solar radiation forms a cornerstone of modern physics.

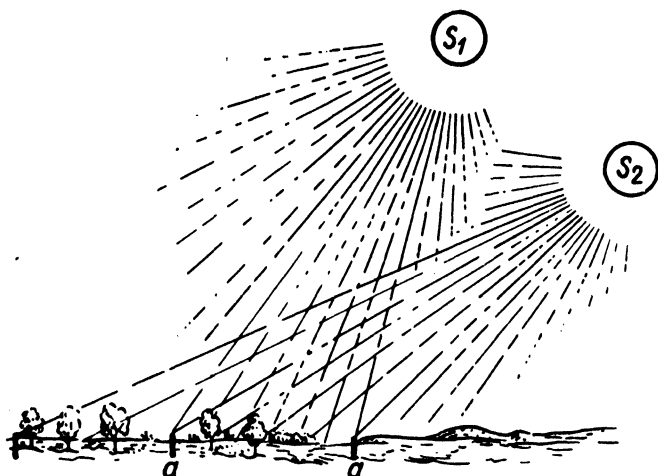
The sun's rays transverse the terrestrial atmosphere at various angles of incidence and, consequently, pass through various thicknesses of air. As the sun sinks to the horizon the



Absorption of solar rays by the atmosphere: A—point of observation,  $S_1$ ,  $S_2$ ,  $S_3$  denote various heights of the sun above the horizon

path of a ray in the atmosphere becomes longer, with the result that absorption increases and its energy diminishes. For this reason, the greatest amount of heat is delivered at noon. At the fringes of the atmosphere, every square centimetre of surface normal to the incident rays of the sun receives 1.88 calories in one minute; at the surface of the earth each square centimetre gets an average of 1.2 calories. And yet, in 24 hours, the earth acquires more heat than that produced by all the fuel humanity burns in a hundred years. Irrespective of absorption of sunlight by the atmosphere, the same surface area receives more light when the sun is high in the sky and least just before sunset. This explains the diurnal and annual march of temperature.

Such is the influx of thermal energy. But the surface of the earth expends heat at the same time. This expenditure proceeds in various ways: part of the energy received from the sun is passed on to the air, and part is radiated into the atmosphere. A certain portion of this radiation is lost out into space. Then



Sunshine heats the earth's surface. When the sun is high in the sky, the *aa* area receives more sunshine than when the sun is low in the sky

the atmosphere itself radiates heat energy both in the direction of the earth's surface and out into space.

During the day, the heat loss is more than covered by the influx of solar radiation, but during the night, loss is the predominant process. Night radiation is strongest in clear, dry, and calm weather; it decreases with increasing quantities of water vapour in the atmosphere. Here, water vapour plays the part of regulator: on the one hand, it absorbs part of the sunshine, thus lessening the heat received by the surface, on the other, it reduces the night cooling. This is why the nights are cold in deserts where the air is dry. To take an example, in the Sahara the temperature at night falls below freezing, while by day the heat goes up to 40° C. in the shade.

The cloud cover is something in the nature of a blanket that protects the earth from radiation loss, particularly if the clouds are low and dense. On a clear night the ground may cool off to 6 and 8° below the air temperature. A clean snow surface is an especially strong radiator—the temperature difference between the snow and the air may even reach 15° C.

In the spring and, especially, the autumn, after a warm clear day, the night radiation sometimes leads to frosts. The temperature falls to 3-5° below zero, and is harmful to plants.

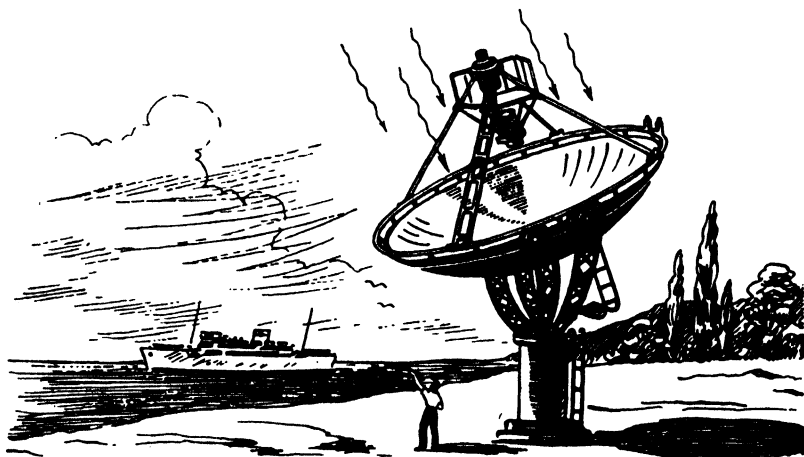
In the daytime the heat is conveyed from the surface to the lower layers of the atmosphere by radiation and convection. But this transfer process requires a certain time, so the maximum temperature in the ground air layer sets in not at noon but at 2 or 3 in the afternoon. In summer, in clear weather, the ground heats up to such an extent that the temperature may be 35 to 40° above that of the air. The ground heats the lower stratum of air, and strong convection currents develop that convey the heat to heights of 1,000-1,500 metres.

At night the ground cools off due to radiation losses into outer space. This cooling is conveyed to the strata of air in direct contact with the ground. But the cooling process is slow and occurs in a thin layer because air is a poor conductor of heat. Besides, at night there are fewer eddy currents in the atmosphere to mix the air. For this reason, the fall in temperature is only gradually conveyed upwards and rapidly diminishes with height. The minimum night temperature at ground level and on the surface of the soil sets in almost at the same time.

The soil-surface temperature also affects the annual march of temperature of the air. In the middle latitudes of the Northern Hemisphere, the warmest month is July, and the coldest, January. Thus, the thermal state of the lower atmospheric layer reflects—with a certain lag, it is true—all the changes that the earth's surface undergoes.

The enormous quantities of solar energy that reach the earth's surface have not as yet been utilized technically to any extent, although the problem is an old one. Two thousand

years ago, Roman priests used solar energy to demonstrate “miracles” to the people. One was the kindling of the sacred fire on the altar of the goddess Vesta. The priests set up a metal mirror in the temple and in its focus put a piece of dry wood that burst into flame under the concentrated rays of the sun.



A solar machine

In 1837, the well-known astronomer Herschel built a “solar box” called a hot-box, blackened on the inside and covered with two glass sheets separated by a layer of air. The temperature in this box rose to  $120^{\circ}\text{C}$ .—enough to boil water. This, essentially, was the origin of the idea of a “solar boiler,” first built by a Frenchman, Mouchot, in 1874. The boiler was heated by means of a conic reflector that changed its position with the sun. At the end of last century, K. D. Tserassky, in Moscow, used a parabolic mirror that concentrated the sun’s rays to melt metal. The focus temperature reached  $3,500^{\circ}\text{C}$ .

The reserves of solar energy are inexhaustible. Suffice it to say that if we could put to use only 1 per cent of the solar energy falling on the Sahara desert, man would have at his disposal ten times the power requirements of the population of the whole world.

Solar energy is difficult to harness because it has to be concentrated from a large area, since the energy incident on a square centimetre is rather small. For this reason, solar devices are of necessity unwieldy. What is more, they demand clear, cloudless days, of which there are not so many in moderate latitudes. This is why direct utilization of solar energy on a large scale is, practically speaking, possible only in countries that have many sunny days, for example, Central Asia. Uzbekistan has over 280 clear days a year, and Turkmenia even more.

More and more attempts are now being made to utilize solar energy directly. The solar observatory at Mount Wilson, California, has built a "solar kitchen" that prepares hot meals for the observatory staff. The underlying principle is a box with double glass cover. In the United States again, a radio set has been designed with storage batteries charged by the sunlight. Several hours of charging is sufficient for the battery to power the radio in the dark for 500 hours. A 100-horsepower solar steam engine is in operation near Cairo, Egypt.

Working in Tashkent, a Soviet physicist, K. G. Trofimov, used a solar energy accumulator with eight sheets of glass and obtained a temperature of  $225^{\circ}\text{C}$ . on a clear summer day and up to  $100^{\circ}$  on a cloudy day (from diffuse radiation). Tashkent also has in operation a solar bathhouse and several laundries.

The members of the solar group at the U.S.S.R. Academy of Sciences Power Institute are working on the problem of utilizing solar power for the country's economy. The Tashkent Cannery has built a solar boiler that operates at 10 atmospheres and produces up to 100 kilogrammes of steam per hour. The sun's rays are concentrated by a paraboloidal mirror 10 metres in diameter. The temperature at the focus reaches  $1,500^{\circ}\text{C}$ . In 1955 the solar team made tests of other devices designed for industrial and home use. Solar heaters for showers functioned without a hitch. Other devices that performed satisfactorily were solar kitchens, a solar fruit and vegetable drier, and so forth.

Of greatest interest is a high-temperature solar device in which a paraboloidal reflector (two metres in diameter) produces at the focus a temperature of from 3,500 to 4,000° C. Using this device, scientists melted with ease various metals, including tungsten. Only seconds were needed to melt a steel rod.

The Sun and Wind Laboratory of the Power Institute has developed models of solar water heaters for bathhouses, laundries, and shower-baths. They can be set up wherever the weather provides an average of 100 to 120 sunny days a year. Under these conditions, they pay for themselves in four-five years. But in the southern districts of the country, water heaters can do this in one and a half to two seasons. It has been calculated that heating water with solar heaters in the southern parts of the U.S.S.R. amounts to an annual saving of 9 million tons of fuel.

A solar water heater is a box frame with pipes inside connected to a storage tank. The pipes and box are painted black and covered with glass. Under the sun's rays, the water in the pipes circulates and heats up automatically and continuously. A typical water-heating unit daily produces 500 to 700 litres of water heated to 50-60° C. These devices are now in serial production, and dozens of them are being sent to state farms.

The Sun and Wind Laboratory is now engaged in designing solar boilers that will be far more powerful than the Tashkent device. One of these projects is the first solar power plant in the country. Experimentation is also in progress here on applying solar energy for the mass production of artificial ice.

A hundred and twenty years ago, the French scientist Peltier detected a strange phenomenon. He soldered together three dissimilar conductors, passed a current through them, and found that one end of the circuit heated up while the other end cooled off. A hundred years later Soviet scientists discovered the amazing ability of semiconductors to convert heat into cold and cold into heat. Semiconductors are capable of producing a temperature difference of as much as 60°. This means that if one end of a circuit made up of semiconductors

is heated to  $40^{\circ}\text{C}$ ., the other end will be  $20^{\circ}$  below zero. That is the principle of the semiconductor refrigerator: the internal circuit is cooled by heating the part that is outside.

Scientists are taking the next step. They ask: What if the area of the experiment is increased to that of a whole house, and the circuit is switched around with the cold end outdoors? Then the exterior cold will heat up the semiconductor inside the house. The rooms will then be heated by the outdoor frost!

However, great though these achievements are, one cannot but remark that the solar power plants are cumbersome and their efficiency in the conversion of solar energy, low—not above 8 to 10 per cent. This is due to the fact that the radiant energy must first be converted into heat, and then to mechanical energy. In each stage of conversion, energy is lost, particularly during the transformation of thermal power into mechanical.

This confronted scientists with the question: Is it not possible to convert the sun's radiant energy into electric power directly?

Academician A. Yoffe said that physical laboratories already had the facilities for solving this problem of obtaining electric energy from the sun at far higher efficiencies. These are semiconductor thermoelements and photocells.

The most common photocells are selenium cells. They are very simple in design: a layer of crystalline selenium is deposited on an iron plate and then coated over with a very thin layer of gold. Current flows when the photocell is illuminated. The more light incident on the cell, the stronger the current. Now if large numbers of photocells were placed out under the sunshine, a hectare area covered with them would generate a thousand kilowatts of electricity. Fruitless deserts and rooftops will become sources of enormous quantities of energy if cheap, weather-resistant photocells are developed.

By concentrating solar rays with cheap mirrors made of plain tin or polished aluminium and using semiconductor thermoelements, it is possible to obtain the same amount of elec-

tricity with fewer semiconductors, but with larger areas covered with mirrors to gather the sun's rays.

A thermoelement of this kind is a plate made of two different semiconductors soldered together called a thermocouple. If one is heated to 200-300 degrees and the other cooled, current will begin to flow. It is generated by the potential difference caused by the temperature gradient at the junctions of the thermocouples. The electrons in the hot layer move much faster than those in the cold part, creating a flow of electrons from the hot to the cold which is greater than that in the opposite direction. This is what creates current.

A solution of this problem on a grand scale in our day borders on the fantastic because it would be very expensive to manufacture so many photocells. But on a small basis, this idea can become practical. It is quite feasible to construct a metal or glass mirror of 3 square metres to produce from 500 to 1,000 watts, or build a roof that will supply all household electricity needs of the tenants. There is a big future for such facilities in the middle latitudes, particularly in the sunny republics of Central Asia.

## **The Atmospheric Cycle of Water**

Studies of the cycle of water in the atmosphere are becoming exceedingly important in connection with the titanic nature-transformation undertakings now in progress in the U.S.S.R. Scientific investigations into the water circulation in the atmosphere are especially important for proper solutions to the problem of water storage in artificial lakes and reservoirs. No less important is its subsequent distribution through irrigation systems and passage through the turbines of powerful hydro-power stations.

New enormous reservoirs are being built in the Soviet Union. Following the Kuibyshev and Stalingrad "seas" on the Volga, big artificial lakes will make their appearance at Cheboksary, Gorky, and Saratov. The Dnieper has given birth to the Kakhovka reservoir, to be followed by two more at Kremen-



chug and Dnieprodzerzhinsk. In Central Asia, not far from Leninabad on the Syr-Darya River, an enormous 600-kilometre-long storage reservoir is under construction. It will hold 4,000 million cubic metres of water and will irrigate and supply with water hundreds of thousands of hectares of new land. In Siberia, new reservoirs will appear on the Angara and Yenisei rivers near the Bratsk and Krasnoyarsk hydro-electric stations now under construction. The dam at the Irkutsk hydrostation has raised the water level of Lake Baikal and increased considerably the surface area of the lake. The time is not far off when the inland "seas" on the Kama, Ob and many other rivers will come to life.

In no way less vast are the tasks confronting irrigation development. The Hungry Steppe in Central Asia will receive water and be irrigated, a Crimean canal is to be built, and the irrigation systems in the Transcaucasus and in the republics of Central Asia completely reconstructed. This is only a part. All these structures—both existing and future—will inevitably be subjected to the laws of the circulation of water.

Water participates in nearly every process occurring on the earth. It supports the life of the vegetation cover, upon which depends the very existence of human life. Together with the sun's energy it creates climatic belts and zones. Water is found everywhere—in the atmosphere and in the soil. Even the human organism is about 70 per cent by weight composed of water. Hence the interest in studies of the circulation of water.

In nature, water circulates due to the action of the sun's thermal rays. It evaporates from the surfaces of the seas and oceans, is carried by air currents to all points of the globe, where it is precipitated to the ground. If the precipitation is again into the sea, one speaks of the *small cycle of water*.

When precipitation occurs over the land, a part of it is returned to the sea via rivers and streams and, to some extent, along with the ground waters, while another part again enters the atmosphere through evaporation of water by plants. This is the *big cycle of water*.

Scientific studies of the circulation of water in the atmosphere are exceedingly important for a proper solution to problems of water accumulation in artificial lakes and reservoirs and its subsequent distribution through irrigation systems.

We have already noted that the watery part of the globe comprises 71 per cent of the surface area. Sources of evaporation are thus more than sufficient. Water vapour is constantly entering the atmosphere, and at first glance it appears strange that the earth has vast expanses of waterless desert where rain hardly ever falls and very little at that when it does.

The point is that water vapour is the most mobile and unstable component of the atmosphere. It is constantly in the formative stage (evaporation) or in the precipitation stage (condensation). The atmosphere gets its supply of water vapour mainly via evaporation from the surface areas of oceans and seas. Secondary sources of evaporation are lakes, rivers, rain-wetted soil, and also forests and meadows.

The quantity of evaporated and precipitated water is always in equilibrium. The inflow and outflow of water in nature is called the *water budget*. Scientists have come to the conclusion that the earth's water reserve is constant. It could hardly be otherwise, for in the absence of a water balance there would be a continual accumulation of water at some one place, which does not occur.

The loss of water vapour into outer space from the fringes of the atmosphere, and the influx of water from the earth's interior in the form of juvenile waters are, practically, of no consequence.

Snow that falls in the mountains in part melts in summer and, in part, at high elevations, is compacted and later slides down in the form of glaciers that melt at lower levels. True, in the region of eternal frost (in Greenland and on the Antarctic continent) there have accumulated enormous quantities of compacted snow that has, with time, converted into *névé* ice and, later, glacial ice.

In bygone ages, these land areas received great amounts of precipitation that has resulted in a thousand-metre-thick layer

of ice. About 11 per cent of the entire surface of the earth is covered with eternal ice. The Antarctic continent is nearly completely covered with an ice cap. In addition, the continental ice has reached out into the sea in the form of tongues as big as 140 kilometres long and 40 kilometres wide.

In the Northern Hemisphere, uninterrupted ice-fields cover many Arctic islands, such as Victoria, Bely, Schmidt Island, Ushakov Island, and others. Nine tenths of Greenland and Franz-Joseph Land are covered with continental glacial ice. The same goes for nearly half of Severnaya Zemlya and one third of Novaya Zemlya.

On these islands, glaciers make up a good portion of the coastline, in places breaking seaward in sheer 10-12 metre drops. The glaciers here frequently break up, giving rise to huge icebergs that float out to sea.

Icebergs of exceptional size are sometimes met with. They can be nearly 150 metres high and a kilometre long. In the Antarctic they are still more majestic. One is on record 28 kilometres long and 20 wide. At the end of February 1956, Soviet sailors and scientists studying meteorological and other problems in the Antarctic aboard the diesel-electric ship *Ob* encountered a floating island of ice 18 kilometres long. An iceberg of such size is truly amazing.

If all the ice that has accumulated on the globe over millennia were to melt, the level of the world ocean would rise 10 to 15 metres, and a considerable part of the land area would be inundated. But in so far as the air temperature of the world remains practically constant, despite the slight warming up of the Arctic, this will not occur in our age.

The circulation of water involves hundreds of thousands of cubic kilometres of water—roughly one four-thousandths of the total amount contained in our seas and oceans. About one fifth of all the solar energy that reaches the earth's surface goes to evaporate this enormous quantity of water.

The water evaporated during the year again falls out as precipitation, and if distributed over the globe in an even layer, it would be about a metre in thickness. In reality, this does

not occur, for the precipitation is uneven. In the coastal desert area of South Africa, at Luderiz-Buchte, annual precipitation amounts to only 2 centimetres. Along the coasts of Chile and Peru (South America) numerous cases have been recorded when not a single drop of rain had fallen in five years running. There are little children here that don't even know what rain is. In the Atakama desert in South America, corpses of the first gold-prospectors have been found as dried up mummies that have been preserved to this day, though the men died over 400 years ago. This is added proof of the absence of precipitation and of unusually dry air.

Now contrast this with the rainiest spot on the globe, the town of Cherrapundje on the bank of the Brahmaputra River in India with its annual precipitation of 12 to 15 metres. There have been cases when a metre of rain has fallen in 24 hours—a two-year norm for Moscow.

Rain soaks into the soil in different ways, depending, firstly, on the soil composition, and, secondly, on the quality of cultivation of the land. If there is a lot of rain, even the sands of the deserts come to life and the locality will cover over with luxuriant vegetation. When there is little precipitation, cultivation of the soil must be improved so as to reduce evaporation. In such cases, cultivation techniques are extremely important, for a properly tilled field will very reluctantly return the moisture it has. Likewise important is the method of planting. For example, the checkrow pocket technique of planting potatoes, maize and other agricultural crops helps the plants to retain moisture.

How does this turnover of moisture in the atmosphere take place?

This question is answered by the latest studies of Soviet scientists—Drozdov, Kashin, Sapozhnikova, Kalinin, and others. They are of the opinion that forest shelter belts and reservoirs cannot change the climate over large areas. Investigations have shown that one can speak only of altering the local climate, that is, the microclimate. These researches yield

a clear picture of the turnover of moisture and all the facts that are necessary for hydraulic calculations.

The point is that the bulk of the moisture carried by the winds is contained in a 5-kilometre-thick layer of the atmosphere. Since we know where the air masses usually move during the year and what their average velocity is, we can compute the amount of moisture, in the form of water vapour, that passes over the territory of the Soviet Union.

This is a truly colossal quantity. For example, 8,500 cubic kilometres of moisture is carried over the European part of the U.S.S.R., which is equivalent to that of four huge bodies of water the size of Lake Ladoga. The direction is Atlantic Ocean—Europe—Siberia. Just over a third, or 3,120 cubic kilometres, falls to earth as precipitation. Of this quantity, 930 cubic kilometres passes to the oceans and seas by way of rivers, and 2,190 cubic kilometres is re-evaporated into the air. Hence, 90 per cent of the moisture moving across the European part of the Soviet Union passes all the way into Siberia.

Some are of the opinion that the ocean moisture that reaches the continent goes through several cycles over it: precipitation, evaporation, precipitation, etc. In actuality, however, we have seen that only a third of the moisture is precipitated from the air moving over a given territory. Besides, it has been found that the moisture that evaporates into the air does not, as a rule, fall in the same place, but is carried far away.

What effect do forest shelter belts have on the quantity of precipitation?

Research answers this query as follows. The amount increases, but over a very limited area. The mechanism of this phenomenon is involved. It appears that forest belts are a sort of unevenness in the earth's surface, which acts to retard the horizontal air motions (wind), making the air currents overflow the obstacles and causing the air masses to rise. Vertical air currents increase in strength and this, in turn, accelerates the condensation of water vapour, which results in more precipitation.

Consequently, the increase in precipitation brought about by forest areas is due not to enhanced evaporation in the forests, but to the mechanical action on the air stream. From this standpoint, separate belts produce a greater increase in precipitation than does a solid forest. Forest belts produce a noticeable effect on precipitation from the clouds of local convection. To some extent, they will likewise affect frontal precipitation.\*

The U.S.S.R. has planted quite some number of forest shelter belts. They help to retain snow and thus increase the supply of soil moisture. The reduction in water runoff into rivers leads to its retention in the ground and to enhanced moisture in the soil. This results in more evaporation and a slight fall in air temperature. All this leads to an increase in the relative humidity and to a marked improvement in the microclimate of the steppe regions.

What effect on the microclimate do reservoirs and artificial lakes have?

In winter, after freezing over, the water surface will in no way differ from the land surface, particularly if there is a snow cover on top. The only thing that is noticeable is a slightly stronger wind on the even surface of the ice.

In summer, the open surface of the reservoir will affect the state of the meteorological elements mainly along the coastline and adjoining areas. The bigger the water surface the farther inland will the effects be felt.

In summer time, the water is cooler than the air, and so convection above its surface diminishes and there will be a less intense formation of cumulus clouds over the reservoir than over the land. In autumn, when the water is warmer than the air, there will be more foggy days along the coast of the reservoir. If the wind is weak or moderate, the fogs move inland with the wind.

Reservoirs likewise affect the air temperature of the littoral regions. During the warm time of the year, large reservoirs give rise to local winds—breezes. In the daytime, the breezes blow

\* See Part II, Chapter I, on the formation of frontal precipitation.

landwards, and at night, offshore. The cool day breeze keeps the temperature down, and it is therefore lower in the coastline region than in adjacent areas.

At night the temperature over the water basin is higher than over the land. But it does not become warmer in the coastal areas because the breeze is from the land. Naturally, in the case of strong constant winds the breeze action is nullified.

When winds pass over a reservoir on the leeward side the temperature is higher or lower than that in adjoining regions, depending on how much the water temperature is higher or lower than that of the incoming air.

Thus, the effect of large reservoirs is not felt in the climate of a large territory, but only on a coastal scale (with adjoining areas), that is, within the range of the microclimate. For medium-size reservoirs, this effect will be confined only to the coastal belt. Small ponds and reservoirs are, of course, unable to affect even the microclimate. These basins of water store up the spring floods and the rainfall of summer thunder-showers and help in local irrigation or in watering of cattle.

## **Exploring the Arctic and Antarctic**

Scientists have been wont to say that the "keys to the weather lie in the Arctic." This is indeed true. The Arctic Basin is a seat of cold air. From time to time the Arctic air makes incursions into moderate and, sometimes, southern latitudes, and due to its density becomes "boss" of the weather. Hence the obvious interest meteorologists have in the state of the atmosphere in the Arctic. At present, a broad network of aerometeorological stations has been established with round-the-year observations and investigations of the Arctic Basin.

Man has made his way very slowly into the higher latitudes of the Arctic. We still do not know when he first crossed the Arctic Circle. Even the ancients knew of the existence of countries in which the sun, for months at a time, shines down on bleak deserts of ice, and then again for months does not even come up over the horizon.

The Norwegian Vikings discovered Greenland, North America and Iceland. At the end of the ninth century, the Norwegian Ohthere first penetrated into the Barents Sea and White Sea. It is believed that the Russians reached the shores of the White Sea at the beginning of the twelfth century. They gradually settled in the northern regions, and at the beginning of the thirteenth century, they founded the colony of Kola on the Kola Peninsula near Murmansk. The sea route from the White Sea to Western Europe was opened by the Russians in the fifteenth century.

The Russians made their way into the Pechora region before they came to the White Sea area. This is mentioned, among other things, in the Nestor chronicle that dates from 1096. Explorations beyond the Urals, in the lower reaches of the Ob River, were made in the latter half of the twelfth century. By the middle of the sixteenth century, Russian walrus hunters and fishermen were quite familiar with the sea route to the mouth of the Ob, and visited the shores of Novaya Zemlya and Spitsbergen, which they called Grumant.

With first-hand information about the Far North obtained from the Russian *pomors*, fishing vessels from Norway, Holland, and England began to ply the northern seas. As far back as 1570, Simon van Salingen (Holland) conducted the first hydrographical studies in the Barents Sea, and Brunel, also from Holland but in the service of the Russians, reached the mouth of the Ob in a Russian vessel in 1580. At about the same time, Russian sailors had already reached the mouth of the Yenisei.

In 1594, Willem Barents reached the northern tip of Novaya Zemlya, which the Russian manufacturers had earlier christened "Spory Navolok." The Barents expedition collected valuable cartographic data and information about the nature of islands in the Arctic Ocean. Barents was one of the first outstanding explorers of the Arctic. His weather investigations on Novaya Zemlya are "the first meteorological observations . . . in the Arctic. . . . They are of scientific value to this



day.”\* After Barents, the well-known English navigator Henry Hudson was first, in 1608, to carry out observations of the behaviour of a magnetic needle in the Arctic (Novaya Zemlya).

At the beginning of the seventeenth century, the Russians crossed the Kara Sea, entered the Laptev Sea through the Vilkitsk Straits and then rounded the northernmost tip of Eurasia—Chelyuskin Cape. In 1648, Fedot Popov and the Cossack Semyon Dezhnev reached the cape Chukotsky Nos (now Cape Dezhnev) by sea, thus proving that Asia is not connected to America, but is separated by a straits. An expedition organized by the Russian government and under the leadership of Vitus Bering (the prominent Russian sailor Aleksei Chirikov also participated) confirmed, in 1728, that the Asian and American continents are really separated by a straits. Since then this waterway has been called Bering Straits.

1733 saw the appearance of the Great Northern Expedition, the participants of which were a whole galaxy of explorers—S. G. Malygin, D. L. Ovtsyn, Semyon Chelyuskin, Pronchishchev, Khariton and Dmitry Laptevs, and many others who have glorified Russian science. In addition to a description of the shores, the Great Northern Expedition amassed considerable data on magnetic declination and tidal phenomena. Extremely interesting material was collected on meteorology, and the animal and plant life of the southern part of the Arctic Basin.

The fur-dealer Savva Loshkin was the first to round Novaya Zemlya from the north. Scientific exploration of Novaya Zemlya, however, was continued (after Barents and Hudson) in 1768-69 by an expedition under F. Rozmyslov. He made cartographical studies and conducted regular observations of the weather, collecting meteorological information about the nature of this severe area. The next explorer of Novaya Zemlya was the well-known F. P. Litke, active in this region between 1821 and 1824. The work begun by Litke was continued by

\* V. Y. Vize, *The Seas of the Soviet Arctic*, Russ. ed., Glavsevmorput, Moscow-Leningrad, 1948, p. 31.

P. K. Pakhtusov, who concentrated on meteorological observations which he carried out every two hours with the strictest regularity. Pakhtusov played such a prominent role in disclosing the mysteries of the Arctic that a monument was put up in his honour at Kronstadt in 1886.

All these expeditions, and subsequent ones too, established the fact of extreme variations in the quantity of ice in the Barents and Kara seas that wash Novaya Zemlya on the west and east. This is very important for weather forecasting in the European part of the Soviet Union.

Still greater progress in Arctic exploration is connected with the name of V. A. Rusanov who perished there. For several years he studied this severe area of the globe. It was he who came to the conclusion that the glaciers on Novaya Zemlya are generally retreating.

An important stage in Arctic exploration was the setting up of meteorological stations on Novaya Zemlya. The first station here was opened in 1896. However, only in the Soviet period was a ramified network of weather stations established on Novaya Zemlya. Now, meteorological observations are supplemented by aerological, hydrological, magnetic, and actinometric observations, which, to one degree or another, help in the study of world-wide atmospheric phenomena.

A few words are in order concerning studies of the Barents Sea due to the fact that the North Cape Stream (a tributary of the Atlantic, or Gulf Stream) passes from the west to the very shores of Novaya Zemlya. The huge stream of warm Atlantic waters produces a very strong effect not only on the life and climate of the Barents Sea, but also on the climate of the whole north of Europe. N. M. Knipovich, working here from 1908 onwards, played an important part in this study. He supervised the compilation of the first bathymetric map (map of sea depths) and a map of the currents in the Barents Sea. Knipovich's studies likewise demonstrated that the annual temperature fluctuations caused by the North Cape Stream produce a direct effect on atmospheric conditions far beyond this part of the globe.

In 1926, the *Sedov* ice-breaker expedition established, with the help of deep-water hydrological stations, that the North Cape Stream reaches the northern shores of Franz Josef Land, true, only as a bottom layer.

Franz Josef Land and Spitsbergen form the northern boundary of the Barents Sea. At the same time, Franz Josef Land juts into the Arctic Ocean as the northernmost land area and is therefore of prime interest. Before its discovery, the noted geographer and revolutionist P. A. Kropotkin, on the basis of observations of ice movements in the Barents Sea, arrived at the conclusion that there should be land between Spitsbergen and Novaya Zemlya and that it should extend northwards even farther than Spitsbergen. And true enough, an Austrian expedition under the command of J. Payer discovered, in 1873, an archipelago consisting of a large number of islands, the northernmost of which is Rudolf Island. In brief, the subsequent study of Franz Josef Land is as follows. First there was a British expedition under Jackson (1894-1897), then an Italian expedition under the Duke of the Abruzzi (1899-1900), and then Fridtjof Nansen who wintered over there after an unsuccessful attempt to reach the North Pole. The conditions during this winter were extremely difficult. Nansen and his companion built a hut of stones, caulked the cracks with moss, and made a roof of walrus skin. To break away the frozen stones they used the runners of their sledges; the shoulder-bone of a walrus did for a shovel, and a walrus tusk took the place of a pick. Their food was the meat of polar bears, for fuel they used walrus fat, which likewise served for purposes of lighting, and Nansen called the cracklings made of this fat, "sweets."

During this winter Nansen carried on regular meteorological observations that are especially valuable because they were made in the very heart of the Arctic.

In 1912-14, G. Y. Sedov made an attempt to reach the North Pole from Franz Josef Land. This expedition ended in the tragic death of Sedov. One of the members, V. Y. Vize, made some interesting observations of glacial movements.

In 1929, a weather station that has been extremely important in the weather service of the U.S.S.R. was set up on Franz Josef Land, in Tikhaya Bay—this is where Sedov's ship, the *St. Foka*, wintered over. Here too, in 1931, was established the northernmost magnetic station in the world. This was the first polar station to begin aerological observations by means of radiosondes. The northernmost weather station in the world was opened in 1932 on Rudolf Island, one of the islands of this archipelago. In 1932-33, an expedition under I. D. Papanin wintered over, studying radio waves and atmospheric electricity, and conducting aerological observations and geomagnetic investigations.

Here, again, in 1933, the first Soviet automatic meteorological station designed by Professor Molchanov was set up. The readings of the instruments were transmitted to the mainland at regular intervals on short waves without man's participation. In 1938, aircraft were used to probe the upper layers of the atmosphere over Tikhaya Bay.

Soviet scientific studies indicate that during the past 20-25 years there has been observed (under the influence of an enhanced influx of water from the Atlantic Ocean) a slight rise in water temperature in the Barents Sea. This, undoubtedly, affects the climatic conditions over an appreciable part of Northern Europe. In addition, Soviet workers "have established that the temperature rise has occurred not only in the region of the Barents Sea, but throughout the Arctic, including its central portion."\* The warming up of the Arctic is connected with a general enhanced circulation of the atmosphere over the entire globe, while the increased influx of water from the Atlantic Ocean is only a consequence of the intensification of atmospheric circulation.

The warming up of the Arctic has naturally reduced the total quantity of Arctic ice. It is enough to say that now the ice area in August is one half what it was in 1925. Besides,

\* V. Y. Vize, *The Seas of the Soviet Arctic*, Russ. ed., Glavsevmorput, Moscow-Leningrad, 1948, p. 129.

along the coastline the sea freezes over later and breaks up earlier than in the first quarter of the century. The significance this has for meteorology is best summed up in the words of Professor Vize, who claims that "the warming up of the Arctic climate represents the biggest fluctuation in the global climate recorded by meteorological chronicles since the discovery of the thermometer."\*

A separate problem is the study of currents in the Arctic Basin. In 1879-81, an American expedition under George de Long made an attempt to drift through the central part of the Arctic Basin on the ship *Jeannette*. The *Jeannette* was crushed in the ice and sank northeast of the Novosibirsk Islands at 77°00'15" north latitude and 154°59' east longitude. De Long himself perished in the delta of the Lena when trying to reach shore across the drifting ice.

The expedition found that from the Novosibirsk Islands the ice drifts through the Polar Basin in the direction of the passage between Spitsbergen and Greenland and is carried out into the Atlantic Ocean by the East Greenland Current. This led Nansen to the idea of utilizing the drift of polar ice to reach the North Pole. Nansen's *Fram* drifted for three years, from 1894 to 1896, and passed the Pole at a distance of 700 kilometres. This drift once again defined the main direction of currents in the Arctic Basin.

Another attempt to reach the North Pole in drifting ice was made in 1922-25. This was done in Amundsen's ship *Maud*. Amundsen himself did not take part. The ship was under the command of H. Sverdrup and the scientific work was conducted by O. Wisting and F. Malmgren. Again the ice drift failed to reach the pole, but the scientific results were considerable. Interesting materials were obtained in meteorology, aerology, and terrestrial magnetism. The observations of drifting ice put the name of the young Norwegian scientist Malmgren among the most prominent explorers of the Arctic.

The last drift of a vessel through the Central Arctic Basin was accomplished in 1937-40 by the ice-breaker *Sedov* which

\* *Ibid.*

was caught in the ice of the Laptev Sea. The captain of the *Sedov* during this forced drift was K. S. Badigin, while the scientific work was in the charge of a young Soviet scientist, V. K. Buinitsky. In many respects, the *Sedov* repeated the drift of the *Fram* but went farther north reaching a record point at 86°39'55" north latitude. The drift came to an end in the Sea of Greenland at 80°30' north latitude and 1°50' west longitude.

Arctic exploration took a new turn with the ice-breaker. Full credit in this matter goes to Admiral S. O. Makarov who was the first, in polar exploration, to use ice-breakers which at present are so widely employed both for science and transportation in the polar seas. Makarov was the first to sail actively in polar waters among heavy ice floes, thus blazing the trail for Arctic navigation by means of the latest in engineering. Just recently the atomic ice-breaker *Lenin* set out on its maiden voyage into Arctic waters.

Leading polar explorers, at the beginning of the century, time and again looked on aircraft as the ideal transport facility for Arctic exploration. The experience of Soviet polar explorers has shown that only close collaboration between scientists and aviators can make possible a penetration into the higher latitudes and multipurpose studies of these parts of the globe. Prior to the use of aircraft, a vast area of the lifeless ice desert remained almost totally unexplored, hydrometeorologically speaking, which makes it clear why air flights over the Arctic Basin are of such great importance for studies of these regions.

The first flights into the Arctic were made in 1914 by the Russian pilot I. I. Nagursky. He made five sorties from Krestovaya Inlet on Novaya Zemlya in search of the *Sedov* expedition. "Nagursky had already expressed the view that aviation would become the chief means for conquering and harnessing the Arctic."\*

In 1924, B. I. Chukhnovsky flew over the Arctic ice, and in May of 1925, Roald Amundsen flew as far as 87° north lati-

\* E. I. Vyazov, *Roald Amundsen*, Russ. ed., Geografiz, 1955, p. 30.

tude. Again in 1925, Arctic missions were flown by the Soviet aviator O. S. Kalvits, and in 1926, by M. S. Babushkin. In that same year, the American flier Richard Byrd flew over the North Pole.

In 1929, Soviet aircraft began regular flights over the Kara Sea. In 1932, a plane piloted by A. D. Alekseyev reached Severnaya Zemlya. The same year saw a tragic accident that once again demonstrated the force of vertical air currents. An aeroplane piloted by A. M. Pertsel in the area of Matochkin Shar was caught in an air current and dashed from a height of one thousand metres straight into the water. The crew perished.

From 1935, Soviet pilots began to fly routine missions over the Laptev Sea.

In 1937, a large number of airborne trips were made northwards to land Papanin's group in the vicinity of the North Pole.

By 1938, flights at any time of the year, even during the polar night, had become commonplace. Scientific research flights to the higher latitudes of the Arctic began in 1939. Pilot I. I. Cherevichny and navigator V. I. Akkuratov reached 82° north latitude near the so-called "Pole of Inaccessibility." In 1940, Cherevichny made a long winter flight in the dark of night, with only the unsteady light of the moon and occasional flashes of the aurora borealis to accompany him, visiting a number of polar meteorological stations scattered about the Soviet Arctic.

In 1945, polar aviator M. A. Titlov and navigator Akkuratov flew over the North Pole just when the polar night was setting in; meteorologically speaking, this is one of the most difficult times of the year.

However, one must not for a moment think that Arctic flying is a simple undertaking. The frost, snowstorms and polar night are still there. To these we must add heavy icing of aircraft, magnetic anomalies that make it hard for the navigator to keep on course, frequent blocking of radio waves, and an exceedingly fast-changing weather pattern. What is more, landing on the ice is quite some feat, requiring of the pilot

mathematical precision and distance judgment. An added difficulty in bringing a plane, especially one on wheels, down on to the ice is that the ice floes are usually snow-covered, making it no easy job to determine the floe thickness or to locate crevasses.

All these difficulties are progressively being overcome. Technically, polar aviation is improving, and so also is the skill of the fliers, navigators, mechanics, and radio operators. And the pilots are getting better service from radio stations, airfields, and weather forecasters.

Regular Arctic studies on the basis of a multipurpose programme began with the establishment of the "North Pole" 1 station—a weather station under Papanin that operated for nine months. The North Pole was first reached by dog-sledge in 1909 by the American explorer Peary. In 1926 the Pole was crossed by Richard Byrd in an aeroplane and by R. Amundsen in the dirigible *Norge*. In 1928, the Italian Umberto Nobile flew over the Pole a second time in the dirigible *Italia*, but the flight ended tragically—the dirigible crashed. All these flights were essentially displays of sportsmanship and gave science very little. It was only during the flight of the *Italia* that occasional observations in meteorology, terrestrial magnetism, atmospheric electricity, and radioactivity were made. The Soviet "North Pole" 1 station was operated along quite different lines. A regular and profound study was made of the drifting ice in the region of the Pole, of the temperature distribution, the salinity, density and chemical composition of the water in the Polar Basin; likewise, complete meteorological observations were conducted.

Fridtjof Nansen spent three whole years in the high Arctic latitudes during the drift of the *Fram* and arrived at the conclusion that there is no life at the North Pole. This was on the grounds that in the latitudes of the Arctic Ocean signs of life diminish with each degree northwards towards the Central Polar Basin. Nansen believed that in the polar regions, where the ocean is eternally covered with thick heavy ice, the sunlight is unable to penetrate the surface layers of water in



amounts sufficient for the development of vegetative plankton, which is the main food for lower crustaceans and other minute animals, which in turn serve as food for fish and other inhabitants of the ocean. Nansen's erroneous views continued in science for forty years.

The first day at the Pole our courageous four (the Papanin expedition of 1937) heard a soft chirruping. In astonishment they glanced round and saw a tiny snow-bunting perched on the wing of the plane. This was so unexpected that, at first, suspicion arose that the bird might have been brought in on the plane from Rudolf Island. But no, this couldn't be. So the snow-bunting had flown to the Pole by itself. This first manifestation of life at the Pole was followed by many others, all of which completely overturned the prevailing scientific view of the lifelessness of the North Pole.

Papanin soon wrote in his diary that they had seen a family of polar bears: a mother with two small cubs. "This means that the mother bear gave birth to her cubs here in the centre of the Arctic Ocean. They had to be fed, and this is added proof to upset the 'facts' about the Polar Basin being without life."

Valuable materials were also obtained by the crew of the *Georgy Sedov*, a steam-powered ice-breaker, during its 1937-40 drift in Arctic ice, and during the flights and ice landings in 1941 by I. I. Cherevichny together with polar explorer M. E. Ostrekin at the "Pole of Inaccessibility."

During the post-war years, special high-latitude airborne expeditions and groups of scientists of the Arctic Institute of Glavsevmorput (Chief Northern Sea Route Administration) were equipped for Arctic exploration. Scientists were dropped on to drifting ice floes at specified points to carry out all kinds of investigations. In 1950, "North Pole" 2 station was set up in the area of the "Pole of Inaccessibility" under the leadership of M. M. Somov, Doctor of Geographical Sciences. This station was in operation until the spring of 1951.

The Soviet Government passed a decision to expand the earlier begun scientific exploration in the Arctic, and in the spring of 1954 the U.S.S.R. Academy of Sciences together with

the Chief Northern Sea Route Administration organized a high-latitude airborne expedition.

The aim of the expedition was to establish two permanent scientific stations on drifting ice floes in the Central Polar Basin, carry out scientific research in understudied regions of the Central Arctic, and organize systematic weather studies.

Unlike the previous expeditions, the high-latitude expedition of 1954 made a three-prong attack on the Arctic. It began in the east from the shores of the Chukotsk Peninsula. In early spring, aircraft flew missions over the Arctic ice to select sites in advance for the scientific drifting stations and for temporary intermediate depots on the ice that would be necessary for building up stocks of goods and equipment for the stations. At the same time, an aircraft detachment was sent to the North Pole from the islands of Severnaya Zemlya. A third group made numerous landings on the ice near the Pole and a detailed study of the slopes of the Lomonosov Submarine Ridge, which divides the Arctic Ocean into two parts.

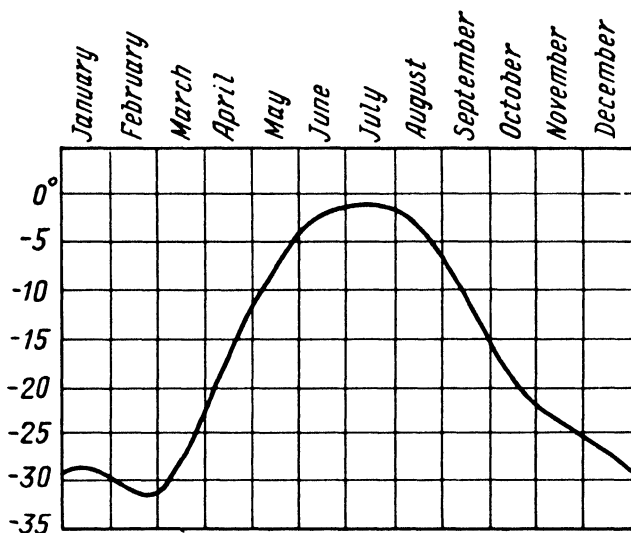
In selecting the site of the "North-Pole" 3 scientific station, previous knowledge about drifting ice floes was taken into consideration. The point is that enormous ice formations, whole islands of ice, are afloat in the eastern sector of the Soviet Arctic. These drifting floes pursue a complicated circular clockwise course. Scientists call this ice motion anticyclonic by analogy with the movement of winds in high-pressure areas. In the western part of the Arctic, the ice moves in a counterclockwise sense, giving rise to the name of cyclonic drift.\*

The "ice islands" start off in the region of the Canadian Arctic Archipelago and drift into the Arctic Ocean passing from 500 to 600 kilometres north of Wrangel Island. Having reached the region of the North Geographical Pole, the "ice islands" return to the Canadian Arctic Archipelago. Some of them repeat this cycle for years at a time. It was this drift that was reckoned on when the "North Pole" 3 station was estab-

\* An anticyclone is a system of winds in a high-pressure area. A cyclone is a wind system of low pressure. For more detail see Chapter 3, Part II, of this book.

lished. The scientific staff of the station was put on the ice at a point  $86^{\circ}$  north latitude and  $176^{\circ}$  west longitude in April 1954. The station was headed by Candidate of Geographical Sciences A. F. Treshnikov.

During the first few months, the floe with the scientific camp drifted as the scientists had expected. In August it was near



The annual march of air temperature in the Central Arctic

the North Pole. But then the ice pack around the station did not go clockwise. After a long drift from the Pole it all of a sudden began to move towards Greenland, following the route of the "North Pole" 1 station. Apparently, the hydrological and atmospheric forces that govern ice movements were such as to sweep the ice out more strongly than in previous years through the straits between Greenland and Spitsbergen. Then the floe with the "North Pole" 3 station got on to the line of the Lomonosov Ridge. Under strong winds it crossed this boundary, entered the zone of cyclonic drift, and headed for the Atlantic Ocean. The route that it was now to follow had already been studied by Soviet workers. Besides, the ice around

the station was continually hummocking and breaking up, and so the station was closed down.

Almost at the same time, the "North Pole" 4 scientific station, with Candidate of Geographical Sciences Y. I. Tolstikov in command, began to function. This station was put on to the ice somewhat to the south, in the vicinity of 76° north latitude and 175° west longitude.

From the very start, both scientific stations strictly adhered to their research programme. Synoptic maps of the Soviet Union were enriched with valuable data on the weather about the Pole and in the eastern part of the Arctic Ocean. The stations carried out a wide coverage of meteorological observations; including studies of the surface air layer, of high atmospheric levels, and the direction and velocity of the wind. Aerologists using radiosondes studied the stratosphere. Eight times a day the results of meteorological and aerological observations were radioed to the mainland.

Besides landing scientific stations on drifting ice floes, the high-latitude expedition made an extensive study of the circumpolar area. Mobile groups of airmen and scientists made frequent landings on drifting ice-fields. An airborne observatory under Candidate of Geographical Sciences Dolgin was actively engaged in weather scouting over the northern part of the Arctic Ocean and made an extensive survey-study of the ice cover.

In March 1955, Glavsevmorput sent up to the Arctic a fresh high-latitude expedition. Big tasks confronted the polar airmen and scientists, who broke up into three groups. The first was charged with taking the scientific team of the "North Pole" 3 station off the ice. The second was to set up a new station, "North Pole" 5, and relieve the wintering-over party at "North Pole" 4. The third group intended to continue studies of the Lomonosov Submarine Ridge.

The first group encountered great difficulties, since the ice situation near the "North Pole" 3 station was disquieting. The floe on which it was situated, had diminished in size drastically during the past year. It had broken up into several pieces and

was lashed with crevasses. The first landing strip was found nearby the station, but it had to be abandoned urgently due to the sudden appearance of crevasses on the surface of the floe. This was followed by high-ridged hummocks crashing down in a roar on to the edges. The aeroplane just had time to take off from the floe when the latter broke up into a multitude of fragments.

A new landing site was found only at a distance of 30 kilometres from the camp. Helicopters and light planes moved the people to the new site. The courageous polar men got into the spacious flagship of the expedition. But the Arctic was reluctant to part from them. A deep cyclone was building up to block their way to the mainland; however, the experienced pilots completed their mission successfully.

It was likewise no easy job to find a floe for the scientific camp of station "North Pole" 5. The state of the ice was particularly unfavourable, precisely where the new drifting station was to be set up. The ice broke everywhere sending cracks in all directions, and clearings were steaming all around. Fresh hummocks piling up into huge conglomerations stretched to the very horizon. But here was the very place that the scientists had to be in order to explore this part of the Arctic.

Finally, after numerous flights and scouting missions a suitable floe some 500 kilometres to the west of "North Pole" 4 station was found. Work immediately began on the scientific station. The crew of the airborne observatory had to overcome no small number of difficulties, for they could not look for something convenient and safe to land on—the research points had been mapped out by scientists back in Moscow.

In April 1956, some of the men were taken off the "North Pole" 5 station, drifting in the direction of the Greenland Sea, and taken back to Leningrad and Moscow. At the same time, work got underway on a new station, "North Pole" 6, which soon began to radio regular weather reports and other scientific data to the mainland. These stations were followed by "North Pole" 7 in 1957 and "North Pole" 8 in 1959.



Weather section of drifting station "North Pole" 6

These high-latitude airborne expeditions fully coped with the task of setting up scientific stations and ensuring their uninterrupted operation; they carried out a multiprong study of areas of the Central Arctic that had never been visited by polar explorers.

The camps of these scientific stations are equipped with radio transmitters, laboratories for studying hydrology, aerometeorology, and geophysics, and other research facilities. The station staffs live in prefabricated houses and extra-warm tents heated by gas or with coal stoves of special design. Lorries and tractors are available for work inside the camp. And the stations also have helicopters. Nearby emergency sites with food and mobile radio stations are kept in case of sudden movements and break-up of the ice.

It is hard to work in the Arctic with its raging hurricane winds, fierce frosts and polar snowstorms, and an interminably long polar night. The spring and brief polar summer flit past almost unnoticed. Though it may seem strange, the wintering

parties consider summer the most unpleasant time on a drifting floe. In summer, the sun's rays melt the snow cover, and the water literally floods the camp. Then high rubber boots are the only means of getting about on an ice floe and this has to be done with extreme caution, otherwise you can fall into a thawing hole in the ice and go under.

What new facts have these multiple-purpose investigations of the Central Arctic given science?

Let us first consider the results of aerometeorological studies. For several decades, the prevailing scientific view was that there existed in the central part of the Arctic Ocean a constant "cap" of high pressure consisting of masses of cold Arctic air. In other words, there was believed to be a constant anticyclone, the existence of which was supposedly maintained by the low Arctic temperatures. The "cap" could migrate to one side or another of a certain sector of the Arctic. If it moved into the American sector, waves of cold swept over the United States; if towards the Soviet sector, cold masses overflowed into the European part of the U.S.S.R. and Siberia.



Soviet scientists refuted this view and proved that no such high-pressure "cap" existed and that deep cyclones are often observed in the Central Arctic. The transient anticyclones that form there are small and the cold masses do not extend far upwards, staying mainly in the lower layer of the atmosphere. From time to time, the North Pole region is hit by warm air masses, bringing about sudden warm spells. In a single day forty-degree frosts are pushed out by more or less moderate frosts.

New data have been obtained also about the penetration into high latitudes of warm air masses from the Pacific Ocean through the Bering Sea and the Sea of Okhotsk. These masses move out over a cold 200-metre surface layer and extend throughout the troposphere up to 7-9 kilometres. Warm air enters along the western periphery of a high anticyclone, the centre of which is located over Alaska.

In such a synoptic situation, a stationary, slowly filling cyclone settles over the circumpolar region, while cold masses of Arctic air overflow the western periphery into the European part of the Soviet Union and Western Siberia.

The most severe frosts in the Arctic reach 40 to 45° C., rarely approaching 50°, and falling short of the Greenland frosts (65°) and those of Siberia (Verkhoyansk and Oimekon, minus 70° C.). This is due to the warming effects of the Arctic Ocean and the lively circulation of air masses. On summer days the temperature of the air can rise above 0° C.

Active cyclonic developments, the struggle of cold Arctic air and warm air masses arriving from the Atlantic and Pacific oceans, sharp fluctuations of the meteorological elements, and a peculiar process of transformation of air masses during the polar day and polar night—such are the new facts extracted by scientists working on the spot. All these factors are extremely important in the Weather Service and for normal navigation over the Northern Sea Route.

Newly obtained hydrological data confirmed the suspected complexity of the bottom contour of the Arctic Ocean. We may now consider the bed of this enormous water basin to be



constructed along the lines of the Mediterranean Sea. It was cut out of the land mass by subsidences and elevations along fractures in the earth's crust. Also fixed is the position of the Lomonosov Submarine Ridge that extends from the North Pole region towards Greenland and Ellesmere Island. This ridge has been found to have sheer slopes with deep troughs adjoining them. Besides the Lomonosov Ridge, other elevations on the bottom have been discovered that divide the Arctic Ocean into a number of deep-water troughs. And it has been definitely established that the main Lomonosov Ridge divides the Arctic Ocean into two isolated water basins.

Determinations of the elements of terrestrial magnetism and registration of their variations have yielded new information on the nature of the magnetic anomaly in the circumpolar region and on a certain connection of this phenomenon with the position of the Lomonosov Submarine Ridge.

Also disclosed is the picture of ice drifts over a vast expanse of the Arctic Ocean. Observations have confirmed the dependence of ice drifts upon atmospheric and hydrological phenomena, the bottom contour, and certain other natural phenomena. Once again, it has been confirmed that a goodly portion of the ice floes in the western part of the ocean is carried out into the Greenland and Barents seas, though this process is far from being regular. The main schemes of ice drifts and data on their thicknesses permit of drawing practical conclusions concerning the formation of the Aion and Taimyr masses that lie directly along the Northern Sea Route.

Likewise corroborated is the slight mobility of the many-year ice pack in the eastern part of the ocean, along the Canadian Archipelago, the Beaufort Sea, and, partly, the Chuckchee Sea. In these regions the ice is old, very thick, and is rarely carried out of the eastern part of the ocean.

Observations of icebergs have made it possible to point out more precisely where they form and the routes they take in the Arctic Ocean.

One of the interesting conclusions of the expeditions is that the ice every year is "rejuvenated" through melting of the

surface during the journey southwards and a build-up underneath on its northbound leg.

Observations of the animal world carried out by drifting stations have shown that flocks of birds fly out over the ice thousands of kilometres from land. And beneath the ice there is life—fish, medusas, and other aquatic organisms. Such, in brief outline, are the scientific winnings gained by drifting stations and high-latitude airborne expeditions.

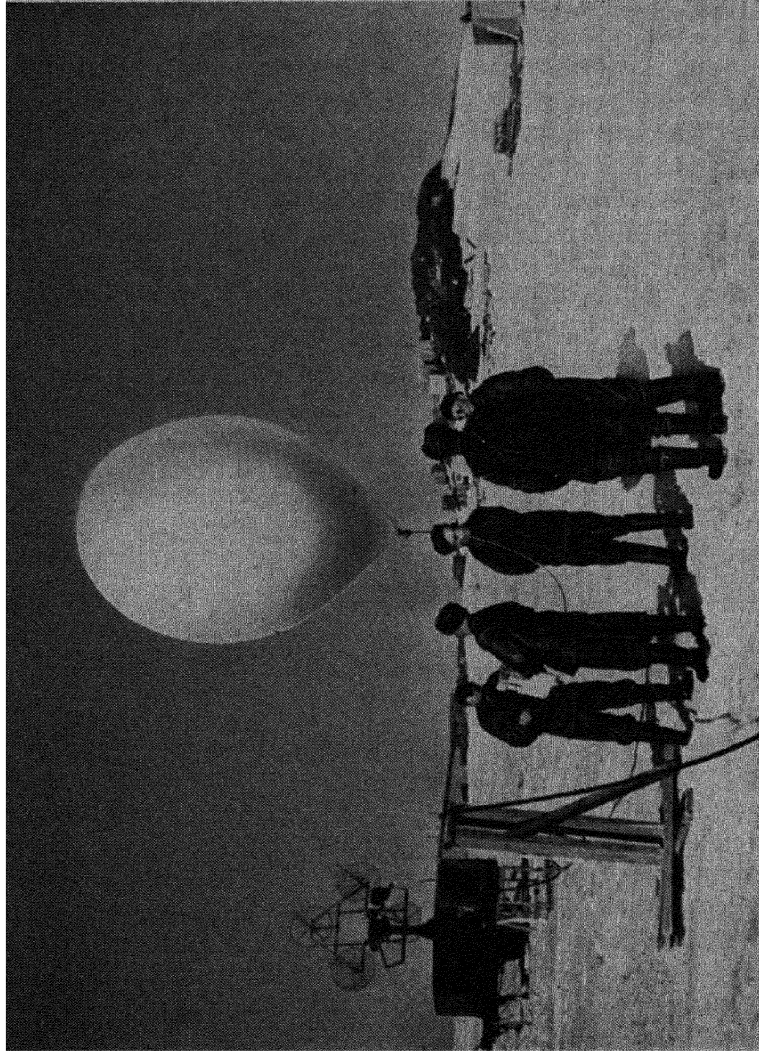
\* \* \*

To the extreme south of the globe lies a vast continent—Antarctica. Nearly seven times the size of Greenland, it has a territory covering 14 million square kilometres. It is almost entirely covered with a layer of ice hundreds of metres thick. In places the ice sheet reaches a height of two kilometres. Antarctica is the highest continent of the globe. This elevated plateau is ringed by chains of mountains. On the average, the continent is 2 to 3 kilometres above sea level, while isolated rocky peaks tower to 6 and 7 kilometres.

The ice of the Antarctic is in slow movement oceanwards, forming gigantic tongues that extend out tens of kilometres. These are icebergs in the making. This shield of ice oftentimes drops sheer to the water, making approach to the land difficult. No wonder, then, that there are still many spots here where human beings have never trodden.

The eternal ice and great elevation above sea level make the climate of Antarctica unusually rigorous. It is much colder than the climate of the northernmost latitudes of the Arctic. Even in summer the temperature rarely rises above zero, while winter temperatures drop to 60° and more (a record low of minus 88.3 degrees Centigrade was registered in 1960 at the Soviet station Vostok). Antarctica is also the most windy place in the world. Snow hurricanes that last for days on end are common. This is a desert of ice where even birds do not fly.

One hundred and forty years have passed since the Russian ships *Vostok* and *Mirny* under the command of Bellingshausen



At Mirny aerologists of Soviet Antarctic expedition about to release radiosondes

and Lazarev discovered Antarctica in 1820, but to this day we know very little about the nature of the sixth continent of the world. Since then many expeditions have visited these distant and bleak shores, among them Shackleton, Amundsen who reached the South Pole in 1911, and Robert Scott who died on his return from the Pole in 1912. However, all these expeditions, with the sole exception of Shackleton's, were essentially sporting events. Only subsequent expeditions made some additions to our knowledge about the nature of this far-away land. The British, who have made a more or less regular study of the Antarctic, now have seven stations there. Argentina has about the same number of scientific stations. In 1953, Australian scientists opened up a research station in Mawson Bay. France has organized a station at the windiest spot on the continent—Adélie Land.

But very little of Antarctica has been studied. Less than half the coastline has been explored and mapped. The outlines of this sixth part of the world are today hardly more reliable than those on the quaint maps of America used in the sixteenth century. About the central parts of Antarctica we know only as much as has been given us by the few trips inland by dog team and tractor and by rare air flights. For this reason, the inland areas of the Antarctic still remain blind spots on the map. We still don't know whether Antarctica is a continent or a group of large islands joined by a single "cap" of ice. Little exploration has been done in such bodies of water as Weddell Sea, Bellingshausen Sea, Amundsen Sea, Ross Sea, and Davis Sea, which cut deep into the south-polar continent.

It is very important to know the meteorological processes in Antarctica. Without such knowledge it is impossible to make correct weather forecasts for all of the Southern Hemisphere. Undoubtedly, such knowledge will be of great help in our long-term forecasting, too. For this reason, Antarctica is a wide-open field for all manner of scientific investigations. This vast natural laboratory was given over to a wide range of scientific research during the Third International Geophysical Year.

## International Geophysical Year (IGY)

On July 1, 1957, the scientists of 67 states began observations of an extremely broad range of geophysical phenomena simultaneously and over the entire surface of the earth in accordance with the unified programme of the IGY.

The period selected for the IGY was not accidental, for it coincided with the maximum of solar activity, which periodically recurs every few years. And for this reason, all geophysical phenomena associated with solar activity would be particularly intense. To co-ordinate the efforts of all countries, a special international committee charged with conducting the IGY was established, and it worked out a programme of scientific research and supervised all the work.

The programme of the IGY encompassed ten broad divisions of scientific investigation unparalleled in scope and range. In the field of meteorology, attention was focussed mainly on the general circulation of the atmosphere. A study was made of the cloud cover, winds at various altitudes, visibility, air pressure, temperature, precipitation, humidity, solar radiation, the ozone content in the atmosphere, and so forth.

Some 100 scientific institutions in the U.S.S.R. conducted investigations according to the unified IGY plan. Observations were carried out at 572 stations scattered throughout the country and beyond its borders, including the Antarctic and the Arctic. Four stations—Mirny, Pionerskaya, Vostok, and Lazarev—functioned in the Antarctic, while the Arctic had four “North Pole” stations—NP-5, NP-6, NP-7, and NP-8. Besides meteorological investigations, studies were made of the earth’s magnetic field, solar activity and various processes in the upper atmosphere, the structure of the earth’s interior and terrestrial seismicity, glaciers and the oceans.

To organize the collection, storage and processing of enormous quantities of extremely important materials obtained on a planet-wide scale, world centres were established and supported by a series of regional centres, each collecting data on one of the ten divisions of the programme. The IGY

committee established two such World Centres, one in the U.S.S.R. and the other in the U.S.A. Each of these centres collected a full set of all the materials and investigations over the period of the IGY, and stored not only the originals but also copies of observational records and catalogues of all the data obtained.

Some idea of the amount of work the centres handled can be gained from the following example: the materials of worldwide meteorological observations during the IGY will amount to 1,800 volumes of 500 sheets each.

The World Data Centres are equipped with the very latest machines and devices for mass-scale duplication of data, including microfilming. It has been estimated that one hundred kilometres of film will be needed just to record the data.

New apparatus and instruments, some specially designed for the IGY, contributed in no small degree to the successful prosecution of the observational programme.

In this respect, there can be no doubt that the biggest achievement was the launching by the U.S.S.R. of its artificial earth satellites, space rockets, and spaceships.

Very extensive and multi-faceted were IGY investigations into atmospheric and hydrological processes. Instruments were designed and refined for actinometric observations and for studying atmospheric electricity.

One of the most interesting of geophysical phenomena—the aurorae—was studied by means of an S-180 camera designed by Professor Lebedinsky. These cameras were in use at 34 stations situated in high geomagnetic latitudes, in the Antarctic and the Arctic. A prominent place in IGY investigations was taken by studies of nocturnal glow. Ten stations with automatic and continuous-recording apparatus conducted these observations in the U.S.S.R.

The U.S.S.R. has a ramified network of Sun Service stations which were expanded and modernized for the IGY. Instruments at many observatories were unified. Solar flares produce a particularly strong effect on the terrestrial atmosphere. To

keep track of all such phenomena, a solar-flare patrol was set up; each station had specified hours of observation.

Marine studies were conducted by Soviet scientists on 12 ships, including such large and well-equipped research vessels as the *Vityaz*, *Ob*, *Lomonosov*, and others.

Very interesting investigations into terrestrial magnetism were carried out by the only non-magnetic vessel in the world, *Zarya*.

In the study of sea currents, use was made of automatic, anchored and drifting buoy stations. These stations were equipped with modern automatic instruments.

A great contribution was made to the IGY storehouse by the scientists of other countries. In Antarctica much was done by expeditions of the U.S.A. and Great Britain. The United States established seven stations in the Antarctic, of which the most important are those deep in the interior of the continent. One is at the South Pole, and another at Mary Byrd Land. The British workers accomplished one of the most important undertakings in this area—the crossing of the Antarctic by land. The expedition made the 3,500-kilometre trek on four Sno-Cat tractors.

Preliminary IGY data already give indications of what a success the undertaking was.

On August 25, 1958, the Soviet Vostok station, located 3,300 metres above sea level on the Antarctic continent, registered a temperature of minus 87.4°C. (in August 1960 a record temperature of minus 88.3°C. was recorded). Such temperatures have never been recorded anywhere on the earth at any time. The cold pole at Verkoyansk and Oimekon (minus 69°C., minus 72°C.) has given up first place to the Antarctic station of Vostok. It is interesting to note that the theoretical limit for low temperatures calculated on the basis of the radiation-heat budget of Antarctica allowed for frosts down to minus 80°C. So you see, nature makes its own correction to theory.

In such fierce cold, station staff members were not allowed outside for more than 15 minutes a shift even though they wore special clothes.

The ice sheet over Antarctica had been thought to have a maximum thickness of 2,000 metres, whereas in reality it has turned out to be 3,000 metres. In places the ice cap overlies rock that is 100 to 200 metres below the level of the ocean. This is a suspicious fact. Is Antarctica really a solid continent? Maybe it is an archipelago! It may be that the colossal pressure of the ice sheet has pressed parts of the continent below sea level.

The unusually high solar activity during the IGY gave rise to radical changes in the atmosphere of the earth. The entire globe was enveloped in meteorological catastrophes that once again showed how intimately related are solar and atmospheric processes.

The IGY was to end on December 31, 1958, but was extended for another year due to the extreme importance of the data obtained.

The results of the IGY investigations carried out by scientists from many countries banded together in a single effort will be of enormous value to science and the whole of humanity.



## CHAPTER TWO

### ATMOSPHERIC ELECTRICITY

The process of condensation of water vapour in the atmosphere accompanied by lightning and thunder, that is, visible and audible electric discharges, is known as a thunderstorm. Thunder and lightning are always associated with clouds and, as a rule, with rain, hail, or snow.

Thunderstorms have always fired the imagination of man. They terrified our ancestors who were poorly protected from the elements. Fires and death strewn by bolts of lightning produced a deep impression on them. Not knowing how to explain the origin and causes of thunderstorms and not being able to fight them, people thought they were an act of the gods that were punishing mortals for their "sins." The ancient Slavs worshipped the god Peroun, creator of lightning, and the ancient Greeks, Zeus the Thunderer.

Today, these legends belong only to the past, for the thunderstorm is now explainable in natural terms. People have not only learned to foresee where and when it would strike, but they have also learned to render lightning harmless.

The impression is particularly striking when the thunderstorm is right overhead, when one clap of thunder follows another, when the wind is raging and the rain is coming down in torrents out of dark clouds. It is only in cities, in large stone houses that we no longer feel the true might of the raging elements.

Despite the fear of lightning, scientists have long made careful observations of this terrible phenomenon of the atmosphere and have tried to study and understand it.

It has been known that certain substances, for example, amber and sulphur, possess the property to attract light things if rubbed against cloth. It had also been noticed that bluish sparks are seen and a soft crackling is heard when clean dry hair is combed. In both cases the active force is that of electricity.

The first electric machine was constructed in the eighteenth century. It was like a grinding lathe, where in place of the grinding stone was a spinning glass ball in contact with cloth. If you brought your hand close to the rotating ball, a weak spark would jump from the ball to your hand. In more refined machines of the same type, electric charges were "removed" with a metal chain and transferred to a copper sphere (conductor). These machines produced intermittent sparks up to 3 and 4 centimetres long.

In the middle of the eighteenth century these "electric experiments" became rather common. Those not interested in science regarded them as amusing entertainment. Some made money in putting on trick shows with electricity. But all this time scientists were experimenting very seriously, penetrating into the mystery of electrical phenomena. They were attempting to get to the root of lightning and find ways of fighting it. However, laboratory-made electric sparks and the crackling that accompanied them were too weak for any connection to be established between lightning and thunder. Suppositions concerning the electrical nature of lightning remained unproved.

The first scholar in Russia to make a serious study of atmospheric electricity was M. V. Lomonosov. In the middle of the eighteenth century, he built a "thunder machine" together with his friend Professor Richmann. On the roof of his house Lomonosov erected a tall "iron arrow," the lower end of which went down inside the building. An iron ruler and a silk thread was attached to the lower end of the arrow (making it something like a modern electroscope). A similar "machine" was set up in

Richmann's flat. When a thunderstorm passed nearby, the metal rod and ruler became so charged with electricity that one could extract from the ruler sparks like those produced by electric machines (this was first done and observed on July 15, 1752). Lomonosov thus proved experimentally the identity of the nature of lightning and the electric spark of the laboratory.

However, experiments of this kind were very dangerous. Tall metallic rods were real "lightning attracting things" that threatened to kill the investigators. This is what actually happened. In 1753 Richmann was killed by lightning "pulled into" his room by this device when observing atmospheric electricity during a thunderstorm.

It was only by accident that Lomonosov escaped the same fate. During this thunderstorm, Lomonosov, who lived a short distance from Richmann, was also busy with the same experiments. Here is how he describes the events of this day: "I inspected my thunder machine but did not see the least sign of electricity. However, when the food was being put on the table I at last saw electric sparks appearing from the wire, and by that time I was joined by my wife and others. Like me they all kept touching the wire and the rod attached to it. . . . The loudest peal of thunder crashed suddenly at the moment I had my hand near the iron rod and the sparks crackled. Everybody ran away from me. . . ." In a few minutes, Richmann's servant came running up to Lomonosov with the report that "the professor has been struck by thunder."\*

Lomonosov was fearless when it concerned experiments with atmospheric electricity, but he was afraid that "this case might be so twisted as to do harm to the growth of the sciences," and with good reason.

Not only in the serf state of Russia but in other countries as well, churchmen began a campaign against investigations of atmospheric electricity. Many of these obscurantists greeted the

\* B. B. Kudryavtsev, *The Life and Work of M. V. Lomonosov*, Foreign Languages Publishing House, Moscow, 1954, p. 65.

death of Richmann with malicious glee, explaining it as "the punishing hand of God" for the "impertinence" of the scientist.

Quite different was the reception of leading thinkers round the world. Richmann's death did not discourage them, but made them more persistent in their investigations. The fight with lightning continued. It was, at the same time, a struggle of scientific thought against religious superstitions.

On November 25, 1753, Lomonosov expounded to a meeting of the Academy of Sciences his theory, which gave an essentially correct explanation of why and how atmospheric electricity accumulates.\* He saw the causes in the ascending and descending currents of unequally heated air. Due to the movements of large masses of air, friction is generated among the particles of water vapour, which thus become charged with electricity. Lightning is the result of an electric discharge between a cloud and the earth, or between two clouds charged with unlike electricity.

In his numerous experiments with the "thunder machine," Lomonosov was moved not by academic considerations but by urgent practical demands. Writing to I. I. Shuvalov, he said: "I see that Professor Richmann was killed by thunder under the very same circumstances that I myself was in at the time. On July 26th, a bit after noon a thundercloud appeared from the north. The thunder was particularly strong, but there was not a drop of rain . . . the electrical thunder force may be diverted, however, to a rod of iron that should stand in an open place, and into which the thunder could strike as often as it liked."

After constructing this scheme of the formation of thunder, which corresponds in broad outline to modern views, Lomonosov pointed out that electrical forces are present in the atmosphere not only in stormclouds but in clear weather, too. He thus established the existence of electricity in the atmosphere.

Abroad, experiments with atmospheric electricity were carried out in 1752 by the outstanding American scientist

\* B. B. Kudryavtsev, *The Life and Work of M. V. Lomonosov*, Foreign Languages Publishing House, Moscow, 1954, p. 65.

Benjamin Franklin. He noticed that pointed rods are capable of extracting electrical energy from an electrically charged medium. To prove it he did the following experiment. Just before a thunderstorm, Franklin sent a large kite with a silk string up into the stormclouds. The kite had a metal wire attached to it. The rain wet the string and turned it into a conductor of electric current. When touched, the string emitted a spark, and a sharp pricking was felt in the fingers. Franklin then touched the string with a metal key. A big spark jumped from the string and a crackling sound was heard. The electricity of a thundercloud had run down the conductor and was drawn off by means of a key that served as discharger. By this experiment Franklin proved the existence of atmospheric electricity and found a way to obtain it using a pointed metallic object.

The accumulation of experimental material on electric fields in the atmosphere and the big theoretical studies carried out by scientists both in Russia and abroad made it possible, by the start of this century, to draw a picture of the distribution of electric charges in the atmosphere and those disturbances in the electric field that lead to the formation of lightning. Textbooks on meteorology now devote whole chapters to problems of atmospheric electricity.\*

In 1901, physicist G. O. Yegorov drew some important conclusions from a series of electric-field observations in the Pavlov Magnetic-Meteorological Observatory and raised the question of the necessity of setting up a network of observation posts to study atmospheric electricity in accordance with a unified programme.

However, it was only after the Great October Socialist Revolution that this project could be put into effect.

Extensive research into atmospheric electricity has been carried out by the Chief Geophysical Observatory named after A. I. Voeikov, in particular by professors V. N. Obolensky,

\* For instance, in an excellent book by the noted Russian scientist A. I. Voeikov entitled *Meteorology in Four Parts*, 1903.

P. N. Tverskoi, and Y. I. Frenkel. All these studies, coupled with the work of other scientists, have made it possible to investigate the territory of the Soviet Union with respect to the character and peculiarities of electrical processes in the atmosphere.

The Power Institute of the U.S.S.R. Academy of Sciences is engaged in a broad research programme of lightning studies. The publications of the Institute have become widely recognized in many countries.

### **Modern Views on the Nature of Electrical Phenomena in the Atmosphere**

The material that makes up the surface layer of the earth's crust has a higher electric conductivity than the lower layer of the atmosphere. Sea water is a very good conductor, moist soil is a good conductor, while the conductivity of air is very low. But the conductivity of the air increases with height due to enhanced ionization of the atmosphere, first slowly, then faster, and at a level of roughly 80 kilometres, it reaches a value approximately equal to the conductivity of fresh water. This is why scientists regard the upper layers of the atmosphere as a sort of conducting shell, and the globe together with the atmospheric envelope, a gigantic spherical condenser in which the inner shell is the land and sea surface, and the outer, the conducting envelope of air. It is in between these two layers that electric charges arise.

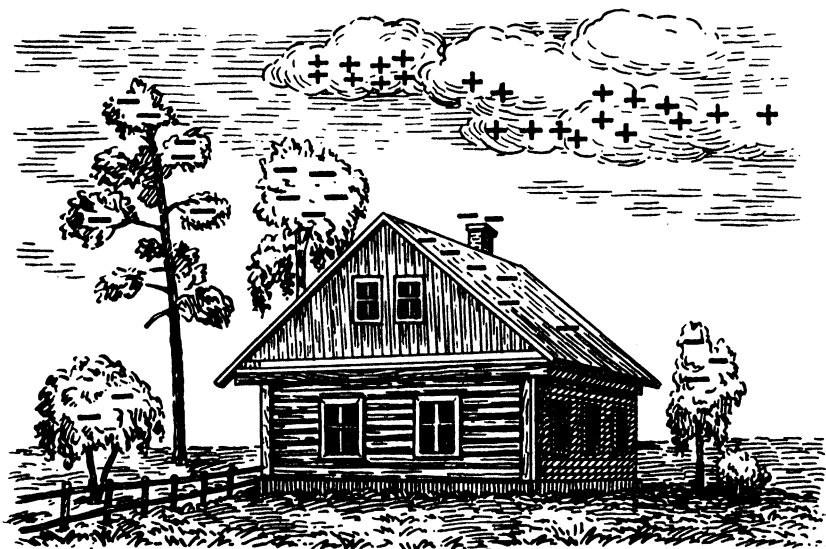
Even in good weather there is a constant electric tension between the atmosphere and the earth. In most cases, the air is positively charged, and the earth negatively.

How do stormclouds get charged with electricity?

We have already noted that as far back as two hundred years ago, Lomonosov anticipated the modern theories of atmospheric electricity, stating correctly that the electrical state of the atmosphere is produced and maintained by ascending and descending currents, that is to say, actually by the work of the wind. Lomonosov considered the size of the charge to

be dependent on the "friction of particles of water vapour." Consequently, the more vapour in the atmosphere, the stronger the electric field. And true enough, the more humid the air, the heavier the stormclouds and the more intensely the atmospheric electricity manifests itself.

In *Atmospheric Electricity* (1902), N. A. Gezekhus regards electrical phenomena in the atmosphere in relation to the wind



Distribution of electricity in a thundercloud and on the earth's surface

and to snowstorms. Dust or snow, wind-blown from the earth's surface, change the charge of atmospheric electricity through mutual friction of the particles and friction with the surface over which they move. Gezekhus devoted much time to a study of the nature of electrification of dust particles during dust storms. At times, "dry" thunderstorms have been observed, in which rather heavy stormclouds have only a few drops of rain but are accompanied by strong squalls that swirl whole clouds of dust up from the ground. In such cases, there are usually only a few lightning discharges or none at all, but the air becomes greatly electrified.

Gezekhus has given a description of some unusual electrical phenomena during a dust storm in Egypt. The top of the pyramid of Cheops was enveloped in a fog of dust. There was a strange noise and whistling in the air. When one held his finger above his head, there was a sharp clap accompanied by a pricking sensation. By wrapping with wet paper an empty bottle banded about the neck with a strip of metal foil, a Leiden jar was obtained that charged up to a high degree when held high above one's head. Sparks nearly a centimetre long were drawn out of it with a big crackling noise.

Volcanic eruptions are ordinarily accompanied by strong electric phenomena, too. This is because the dust, ashes, and small volcanic fragments become charged with negative electricity. The air is then so strongly charged that this in itself makes it dangerous to stand even at the foot of the volcano. This was observed, for example, on the Kamchatka Peninsula during the eruption of the Bezymyannaya Volcano, which belongs to the famous Klyuchevsky group of volcanoes thought to be long since extinct. All of a sudden, on October 22, 1955, it again broke out and is still simmering. From the mouth of the crater, thick clouds of gas and ash rise several kilometres into the air and are lighted up by flashes of lightning. The earth shudders from the explosive bursts. Clouds of ash fill the sky and sometimes even darken the daylight. In the vicinity of the volcano the air is extremely electrified, thus again corroborating the correctness of Gezekhus' conclusions made as long ago as last century.

Gezekhus' most remarkable discovery (made jointly with Aganin) had to do with his investigations into the electrification of water droplets, which laid the foundation for a proper understanding of the electrification of clouds and precipitation. In the air near waterfalls, these workers found free negative electricity caused by the spray of the water getting a negative charge. When a stream hits the surface of the water before having had time to break up into droplets, there is no electrification. Electrification is observed only when the stream of water striking the surface has already broken up into separate,



tiny droplets. Here, the electric charges do not originate from impacts and fusion of the drops, but only in the sliding or separation of a layer of spray from the surface.

Developing the ideas of Gezekhus and Aganin, Lenard and his pupils investigated the conditions of electrification in the splashing of raindrops. If a raindrop receives a sharp impact, tiny negatively charged droplets are torn from its surface as if by an explosion (the Gezekhus effect). This occurs when the raindrops strike the ground.

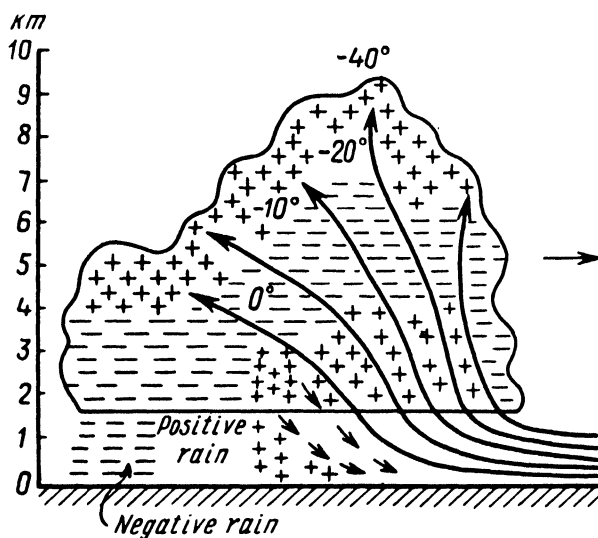
The Gezekhus effect is also observed in the case of raindrops suspended in the air when an ascending current carrying droplets of water is sufficiently gusty.

Large drops in an air current are not stable and remain intact only for a few seconds. The process that develops in a single droplet is as follows. At first a gust of air blows a raindrop up into a hat-like affair, the top of which, for an instant, turns into a thin film that is soon broken by the updraught. The air rushes through this annular water residue, entraining upwards a large number of minute negatively charged droplets, while the large positively charged parts are thrown sideways. If these charged particles are once again scattered the effect naturally increases, and the charges too. The Gezekhus effect accounts for the origin of thunderstorm electricity. A prerequisite to its manifestation in raindrops is the presence, in an incipient thunderstorm, of an ascending current of air with velocities from 3 to 8 metres per second or more (these create eddies). This is all due to the work of the wind. The stronger the ascending currents the sooner and more completely is the cloud charged.

However, one must take into account that there may be other reasons for the accumulation of electric charges in a stormcloud. Airborne experiments in thunderstorm clouds carried out in 1954 by the Chief Geophysical Observatory showed that a cloud becomes highly charged with electricity when ice crystals appear. Outwardly, this is apparent from the appearance at the top of the stormcloud of a shield of cirrus clouds.

Studies by Y. I. Frenkel have shown that the water droplets in a cloud become charged due to the absorption of ions present in the air. Ions, it will be recalled, are tiny particles charged with positive or negative electricity. Such particles are molecules of air and water vapour, and also the larger particles of dust, smoke and droplets of fog. An atom of air, if one of its electrons has been knocked out, is likewise an ion. This occurs when the atom is split into two parts, one (the bigger) consisting of the nucleus and the remaining cloud of electrons. It is positively charged and is called an ion, while the other particle is the knocked-out and, now, free electron.

Professor Frenkel believes that during the initial formative stage, with ions of both signs in equal quantities in the air, the drop will absorb mainly negative ions. This is because a falling drop ordinarily has a negative charge on top and a positive charge underneath. If the rate of fall of the drop is greater than the rate of motion of the ions, it will move in a counter direction and will entrain negative ions from the counter air flow and thus acquire a negative charge. A series of experi-



The electrical state of a stormcloud

ments has proved the possibility of such a preferential capture of ions of a single sign.

As the drops merge they increase in size and charge. The charge increases in proportion to the volume. If the drops in a cloud grow fast enough, considerable electric voltages will arise that are sufficient to produce lightning.

On page 104 is a diagram of a typical distribution of electric charges in a stormcloud. The solid lines denote the currents; the more closely spaced they are the stronger the current. It is here that we encounter extremely strong convections that give rise to the Gezekhus effect. Here, too, is the region of positive charges. In the rear, where the convection becomes weaker, positively charged rain falls. With the exception of this area, the lower edge and middle of the stormcloud is negatively charged.

Ice crystals form in the upper part of the cloud. Colliding, they break up. Tiny fragments acquire a positive charge and are carried upwards to fill the dome of the cloud. The larger negative crystals descend into the middle and lower portions of the cloud.

Opposite charges attract, as we know. But air is a poor conductor and prevents this process. The result is a gradual accumulation of electric charge in the stormcloud. This goes on until so much builds up that an electric spark jumps across (breakdown)—this is an electric discharge in the form of lightning.

CHAPTER THREE  
LIGHTNING AND THUNDER

Types of Lightning

If the intensity of an electric field in the air exceeds a certain limit, the ions acquire velocities sufficient to disrupt, by collision, the air molecules that they encounter. The result is an independent glowing discharge.

The shape of the discharge is largely dependent on the intensity of the influx of electricity. Atmospheric discharges are ordinarily divided into the so-called *St. Elmo's fire* and lightning (sheet, forked, beaded, rocket, and ball).

The name *St. Elmo's fire* comes from *St. Elmo's church* on the spire of which such glows had frequently been observed as far back as the mid-sixteenth century. This light is seen most often in the mountains, and sometimes on the masts of ships at sea. If a sufficiently strong electric field is produced by a thunderstorm or snowstorm, *St. Elmo's fire* can even appear on flat land.

When the field intensity in the atmosphere increases substantially near objects protruding above the earth's surface (blades of grass, poles, ship masts, wires, etc.), the potential gradient can easily reach 30 kV/m. Glow discharges, or discharges in the form of a luminous ring, then form about such projections. In the case of big currents, the discharges have the shape of separate brushes.

An interesting case of this kind was recently observed by a group of Soviet mountain climbers in the Tien Shan Mountains. When there was just a little distance left to the summit of the mountain the climbers were ascending, the clouds suddenly thickened up, closing out the sun, and a wind arose. Lightning was flashing all around and thunderclaps rocked the mountains.

"Your hair's on fire," cried one of the group to his mate.

And it was! Sparks were jumping off his hair. At that instant the heads of the other climbers were surrounded by a bright glow, and sparks were coming out of their hair. Then there were little flashes sparkling off their finger-tips. They also coiled round the pickaxes, cameras, metal buttons, buckles. The rocks all around them were buzzing and the air smelled of ozone. Lightning was constantly lashing the sky.

Then the storm stopped just as suddenly as it had begun. The clouds dispersed and the wind died down. The climbers calmly continued the ascent.

A similar case was observed by a group of Frunze mountaineers on July 6, 1950, in the Kirghiz Ala-Tau. The group had reached 3,800 metres when they noticed that the weather was changing. Leaden clouds were climbing up over the mountain peaks. The distant horizon darkened.

Master of Sport, alpinist V. I. Ratsek, who was in the lead, detected the slight, barely perceptible odour of "broken rock"—the typical pre-thunderstorm sign at these heights.

It grew dark, and a sparse soft hail began to fall. But the ascent continued. And all the climbers noticed an unusual thing: the peaks appeared to be vibrating and emitting a monotonous drone. The same sound was coming from the ropes and pickaxes, too. The buzzing was punctuated by a slight crackling sound. Finally, a mountain thunderstorm broke loose. The pickaxes and all metal things were left behind as being extremely dangerous companions in a thunderstorm. The mountaineers found hiding places under jutting rocks.

At this moment Ratsek reached the top. The rocks at the summit were glowing, and to his companions Ratsek appeared to be surrounded by a glowing halo. Shafts of light radiated

upwards from his outstretched, gloved hand. There was a stronger and stronger smell of broken stone, the rocks buzzed and crackled. The hair on the heads of the climbers stood on end in a literal sense. The skin on their heads hurt—it felt as if they were being scalped. All this lasted about 15 minutes. Then the group began to descend. The situation was getting worse; the quaking air had let loose snow avalanches and rock falls, but the descent passed without a mishap.

The nameless peak where this happened was christened Peak Electro.

The foregoing is an excellent picture of what we call St. Elmo's fire.

St. Elmo's fire is also observed near high-voltage power lines (the so-called corona).

*Lightning* is a gigantic electric spark oftentimes kilometres in length. A thunderstorm discharge possesses enormous force. During the discharge, energy accumulates at voltages from 10 to 100 and more million volts, whereas the duration of the discharge is but thousandths of a second. This voltage is many times greater than that produced in the very largest electric devices ever built. This is why such a relatively brief electric discharge is so dangerous.

A stormcloud is constantly generating electricity with a power output estimated at several millions of kilowatts. This is enough to supply with light and power a city of 10,000,000 inhabitants for as long as the thunderstorm is in action. The prime mover of this colossal energy is the wind, for it is precisely the ascending currents of air that support a cloud containing hundreds of thousands of tons of water.

The number of thunderstorms occurring all over the world is very great—roughly 16 million a year, or 44,000 daily. In other words, there are about 2,000 thunderstorms every hour of the day. Though the number fluctuates, this is very close to actuality.

To determine the total electric power output of thunderstorms, we must also take into consideration that about 100 flashes of lightning occur every second on the globe and, in

addition, that there still remains a tremendous supply of reserve electricity. Observations show that in places which record 45 to 50 thunderstorms a year every square kilometre of the earth's surface records one stroke of lightning. Naturally, there is more lightning where there are more thunderstorms. Computing the overall total sum of energy, we arrive at a stupendous figure which is one thousandth of the total energy intercepted by the earth from the sun in the form of light and heat. What role these figures play in the electric and heat budget of the globe is as yet not known.

*Sheet lightning* is an electric flash on a cloud surface. It may simply be the reflection of spark lightning hidden behind the clouds, but it may also be a special type of discharge in the form of brushing or blinking light that appears in the upper parts of clouds. This type of lightning is due to the fact that although the electric field in the cloud is strong enough for a discharge the influx of new electricity is slow. Here, the supply of electricity is exhausted before the flickering discharge passes into a spark (forked) discharge.

Thunderstorms with sheet lightning belong in the category of weak ones. In middle latitudes they occur only in early spring and late autumn.

Ordinary *forked lightning* is a gigantic tortuous electric spark with many branches. It is never zigzagged as is so often pictured in drawings. Photographs of lightning flashes have never revealed this unnatural shape.

The main bolt of the forked lightning shown in the accompanying photograph strikes water. It has a large number of branches and looks like a river with its tributaries. Forked lightning is distinguished by its very high currents (up to 200,000 amperes). It is frequently the cause of fire when it strikes buildings. This lightning can break big trees and is a killer. Forked lightning is sometimes called "incendiary lightning." It is usually 2 to 3 kilometres in length, but lightning flashes up to 10 kilometres long have been observed.

Despite the fact that photographs of forked lightning were made as early as last century, its structure was deciphered only

just recently. This is because snapshots made on a stationary plate, without a breakdown of the phenomenon into separate brief intervals, do not give a full picture of the discharge. Only the use of special cameras and techniques has made it possible to disclose the structure and the process of development of lightning.

According to studies made by I. S. Stekolnikov, forked lightning consists of a discharge channel that carries current. The discharge channel is preceded by what is known as a "leader" that represents the initial stage and marks out a path for the lightning in the air. The channel is what is seen directly by the eye and what is photographed by a still camera as lightning.

The process of appearance and development of lightning as traced by special photographs gives the following picture: electrons ever present in the atmosphere begin to move from a cloud groundwards. This flow of electrons is due to the electric pressure created by charges in the cloud. At first the electrons flow in small quantities in a narrow channel like a stream. High-speed electrons accumulate in that part of the cloud that initiates the channel. These electrons collide with the atoms of the air and break them up into positive ions and electrons.

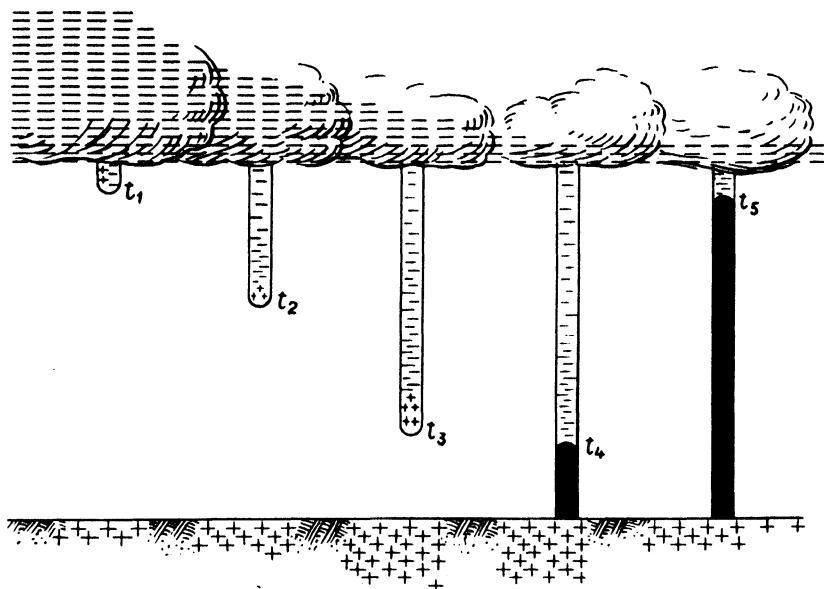
The electrons thus released stream earthwards, again colliding with and breaking up air atoms. Like a mountain avalanche, the electron flood reaches out to ever greater masses of air splitting up the atoms in its path. The air heats up, conductivity improves, and what was once an insulator becomes a conductor.

The electricity now begins to surge from the cloud through this conducting channel in the air, and in a hundredth fraction of a second the electron avalanche has reached the earth. This concludes the preparatory stage of the lightning stroke—it has blasted its way to earth.

Now begins the tempestuous flow of electricity through the channel. Negative and positive electricity combine. The main process develops from earth to cloud. This is the electric dis-



charge between earth and cloud, which is actually an electric current of enormous strength. The channel of lightning is greatly heated and glows brightly. All this takes place in almost no time.



The development of forked lightning

If our eye were capable of registering phenomena like special cameras do, we would first see a small tongue of light reaching earthwards some fifteen metres out of the cloud. In 0.001 second the light disappears, and then flashes on again, but this time, some thirty metres long. The process is repeated until it reaches the earth. As it moves earthwards, branches of lightning flash out and down from the main stroke, which is called the leader of the discharge. The instant the leader reaches the ground, the second and main stage of the stroke sets in—the discharge. A monstrous flame extends from earth to cloud, covering the path traversed by the leader. Rising upwards, it also branches out in the same paths made by the leader.

Due to pauses, the first leader takes a relatively long time (in many cases, up to 0.01 second) to reach the earth. The main stroke moves much faster covering the same distance in about 0.0001 second.

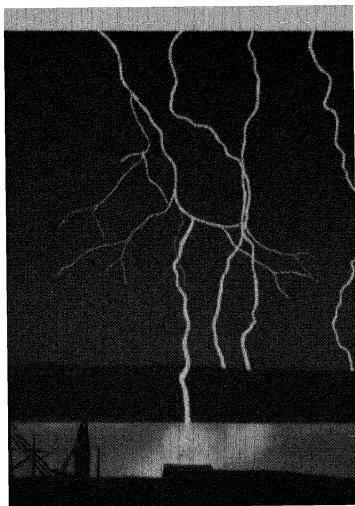
In the case of a second and subsequent lightning bolts, the process differs. This time the leaders do not have any pauses and they gradually move earthwards along the same path traversed by the leader of the first stroke of the series. As soon as the leader has taken shape, a fresh spark—a new flash of lightning—passes along this route. Within a short interval of time, the process can repeat, and go on repeating itself until the entire supply of electric energy is exhausted.

The accompanying photograph gives a vivid picture of five successive discharges (over a single channel) that remain parallel even in the snapshot.

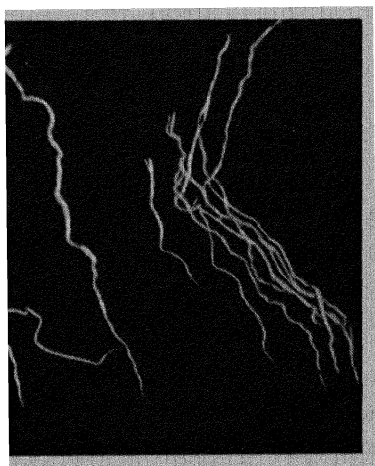
The camera is so designed as to permit one to compute the time between the separate parts of the lightning stroke. The lightning discharge turned out to be aperiodic, and not periodic as had been thought earlier. The human eye is not capable of perceiving separately more than seven flashes a second. Anything faster merges into a single whole. But if the interval between discharges is longer than one seventh of a second, these fluctuations are noticeable even without a camera—a thing that is not so infrequent (blinking discharge).

The photograph we have just discussed is that of an extremely powerful lightning bolt of a very large stormcloud with simultaneous strokes to different points on the earth. The quantity of electricity was distributed in it very unevenly, and not at all like a good conductor would have given. This led to the appearance of discharge points. The points of impact of the air channel are spaced a kilometre and more apart from each other.

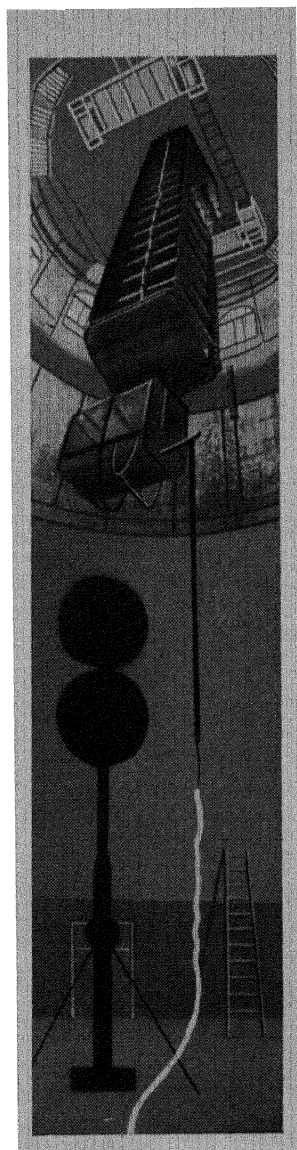
Lightning falling from cloud to earth has a duration of a minute fraction of a second (from 0.001 to 0.02). Between clouds, lightning takes a longer time, sometimes as much as 1.5 seconds. This is seen in the photographs and also because the light emitted by such a stroke is enough for one to notice the branches of trees swaying in the wind or the motion of a train.



Forked lightning



Photograph of lightning made  
with moving camera



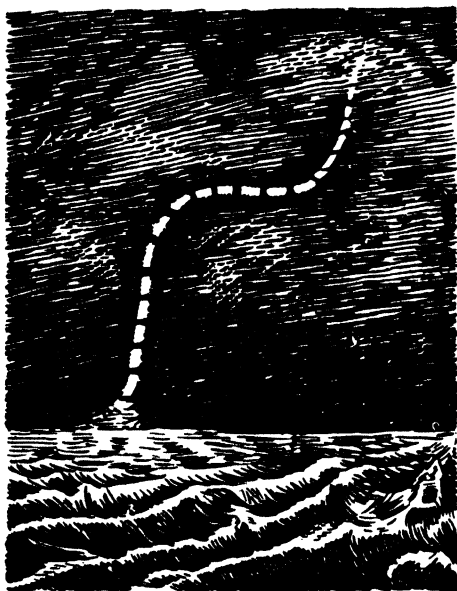
A stroke of artificial  
lightning in the labora-  
tory

Such lightning comes from very slow discharges, while the other kind is a momentary phenomenon.

The discharge channel can have a width up to 40 and 50 centimetres. However, most of the current undoubtedly passes down a route only a few centimetres in width.

The temperature in a lightning stroke (in the channel) exceeds  $18,000^{\circ}\text{C}$ .

*Beaded lightning* on a cloud background appears like a glowing dashed line. This is an exceedingly rare form. It is apparently a transition type between forked lightning and ball lightning.



Beaded lightning

A. P. Cherkesov, who has been watching thunderstorms in Rostov-on-Don for 17 years, reports only one case of beaded lightning. During a strong thunderstorm on June 8, 1953, at about 10 P.M., a dazzling lightning bolt flashed, and a stroke of beaded lightning went down the same path. The whole thing consisted of two stages: forked lightning, followed (with no time interval at all) by a stroke of beaded lightning that took the same path.

*Rocket lightning*, in contrast to other types, develops very slowly. It can be followed with the unaided eye. The discharge lasts about 1 to 1.5 seconds. This is quite enough to light up moving vehicles and swaying branches of trees.

The most remarkable, rare, and mysterious type of lightning is *ball lightning*—a spherical glowing mass the size of a fist or even one's head. Ball lightning is moderately fast and so very

easy to follow. It sometimes disappears without a trace, and sometimes explodes with a terrific bang.

Ball lightning strokes pursue tortuous paths and often follow the direction of the wind.

Repeated attempts have been made to picture ball lightning as an optical illusion. But we now have many authentic obser-



Photograph of ball lightning and the path it took

vations of this rare phenomenon. What is more, scientists have recorded ball lightning when photographing ordinary lightning.

Ball lightning usually makes its appearance directly after the forked type. Hence the obvious conclusion that forked lightning is a prerequisite of ball lightning. And true enough, the cameraman who captured this type relates that, following the forked discharge, there appeared a shapeless, slowly descending luminous mass. Five shots were taken in three minutes, and the ball strokes (there were several altogether) were re-

corded at different stages in their development. Some of the balls were over 10 metres in diameter, which is much bigger than what some of the earlier estimates made them out. This is obviously due to the fact that the distance of the lightning from the observer was not taken into consideration.

Ball lightning is usually accompanied by a whistling or buzzing sound, and leaves behind it a sharp-smelling haze. A stroke can last from a second to several minutes.

Ball lightning moves with air currents, but there have been cases when it acts independently. For a time the ball can stand still, "boiling" and shooting out sparks.

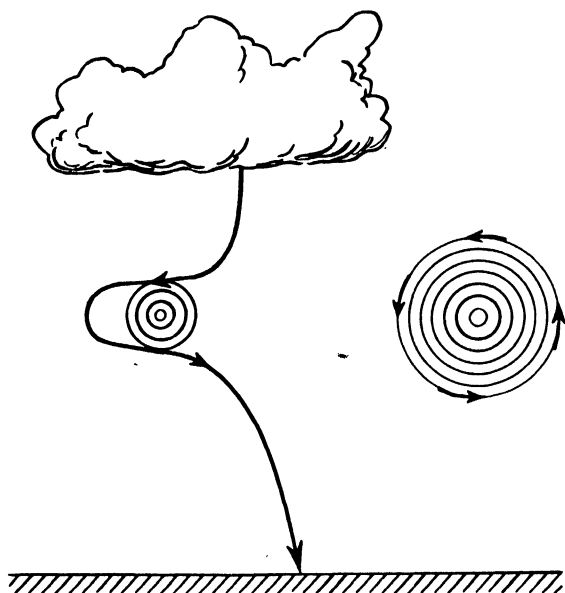
Bolts of ball lightning are attracted to buildings and may be drawn in through open doors, windows, and at times even through cracks. They roll along wires, heating them. To touch such a wire is to invite death.

No full account has yet been given of ball lightning. Most scientists consider ball lightning to be an eddy formation that appears in a sharp bend of the path the stroke has taken, just like eddies are produced by the interaction of two counter currents of air. Ball lightning is a blob of incandescent gas, something like a spinning top, that gets its stability from a balance between the forces of external pressure and the centrifugal force of rapid rotation produced during the discharge. But this stability is short-lived. Ball lightning disintegrates (sometimes with an explosion) as soon as the equilibrium of these forces is upset and air penetrates to the centre.

This point of view has been corroborated under the following circumstances: Forked lightning was observed to strike a lightning-rod on a meteorological tower. When the lightning struck, a glowing ball about the size of a child's head formed at a point where the rod bent round a projection on the tower in the form of a letter C, and at about 6 metres from the tower it went into the ground.

Gezekhus made a very interesting experiment and obtained artificial ball lightning. He took a transformer that generated a 10,000-volt alternating current, put one end of the wire in water and connected the other to a horizontal copper plate

some 2-4 centimetres above the water. The result was a discharge under the plate in the form of a luminescent globular body. Only the slightest breath of air was needed to move the spheroid in any direction. When the spheroid was covered with a glass bell, brownish vapour of the products of nitrogen oxidation appeared. This suggested that ball lightning consists of nitrogen oxides that burn under the influence of strong oscillatory discharges. It is also believed that ball lightning is a mass of highly electrified detonating gas formed when forked lightning decomposes water into oxygen and hydrogen.



The origin of ball lightning

Studies carried out by P. N. Chirvinsky have shown that not only detonating gas but also ozone and certain nitrogen oxides that form during electric discharges are capable of exploding.

Chirvinsky believes that ball lightning is a mass of a highly electrified mixture of gases, mainly nitrogen, oxygen, hydrogen, and also small quantities of ozone and nitrogen oxides. This

mixture is in a state of unstable equilibrium under varying pressure, and can explode for various reasons, some of which are very insignificant. On touching a conductor it can calmly discharge. The quiet outflow of electricity from the surface of ball lightning sometimes gives rise to a characteristic crackling sound.

Ball lightning is still a mystery. Its extraordinary explosive power, when a ball less than a gramme in weight can demolish a huge smoke-stack blasting the brick to bits, finds no explanation even if we take into account the high temperature produced in the explosion of a detonating mixture of gases.

### Lightning Strokes

A single thunderstorm can exhibit different types of lightning. Some arise high in the clouds and do not reach the ground, while others strike between cloud and earth.

Present-day statistics on thunderstorms or the number of storm days are not applicable for an estimate of discharge activity in the atmosphere in different parts of the globe. A short thunderstorm with one or several lightning strokes is considered equivalent to a storm that lasts hours and releases numberless powerful bolts. All the thunderstorms of Iceland, Spitsbergen and Northern Europe together cannot produce as many strokes as a single storm in the Alps or the Caucasus.

During a thunderstorm in the Alps, one observer counted 1,000 strokes of lightning in 14 minutes. In another one, there were 3,600 in 1 hour and 45 minutes. A still greater number was recorded in a big storm in Africa—7,000 in one hour. And, finally, in the most thundery region—the equatorial belt—thunderstorms have frequently produced over 10,000 lightning strokes in one hour.

These facts show that the number of thunderstorms over a period of time cannot serve as a reliable criterion in solving the problem of the number of lightning strokes to the earth. There is no direct relationship between the number of storms and lightning strokes. In this connection, of particular interest are



maps compiled by L. A. Kuzmin for the European part of the U.S.S.R. that show the number of direct lightning strokes.

When lightning strikes human beings, structures, trees, and so forth, it behaves differently, and sometimes in a most freakish manner. In one case, lightning kills a man without even touching his clothes, in another, it strips him naked without hurting him at all. And then there is the case when it stripped the gilt from a chandelier and deposited it on the wall plaster. But there can be no doubt that the actions of lightning only appear freakish. In reality they obey definite physical laws, which are now, for the most part, known.

Here are a few of the freak doings of lightning.

During a very intense thunderstorm, a pedestrian was bruised, knocked unconscious and undressed by lightning. The only thing left from his clothes was a piece of boot with the nails in it and a sleeve of his shirt. He came to in ten minutes highly surprised to find himself completely bare, and began to complain of the cold. He escaped with only wounds.

Sometimes, people killed by lightning are not hurt externally, but a post-mortem examination reveals paralysis of the brain.

It frequently happens that people killed or only stunned by lightning lose all of their hair. The hair disappears when the person is struck, or falls out a few days later.

In the majority of cases, those struck by lightning fall instantaneously, without any cramps at all. They lose consciousness at once, without having seen, heard or felt anything. When they regain their senses, they don't remember anything and can't understand why they are lying on the ground.

Lightning sometimes prints, on the bodies of those killed, the impressions of objects close by. Once three children hid under a tree during a thunderstorm. Lightning hit the tree but the children were not killed. When they came to their senses, they noticed that on the body of one was an exact image of twigs with the leaves printed out in all detail.

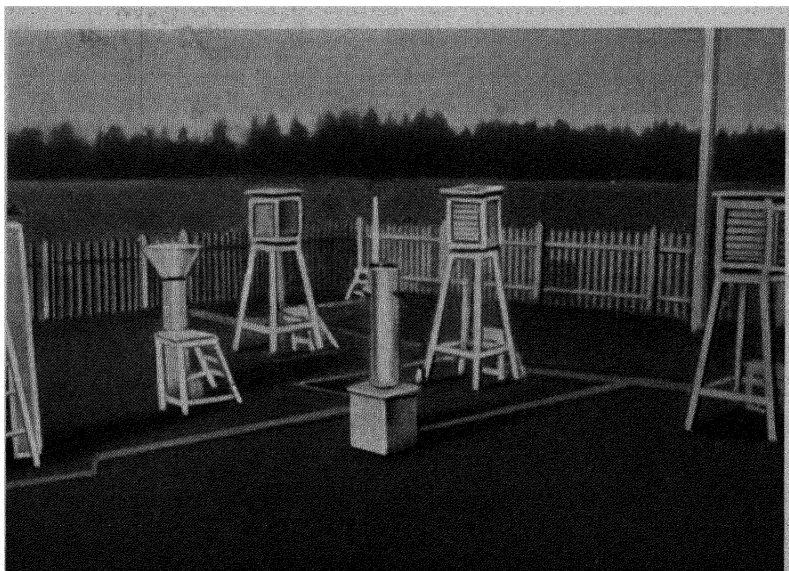
Lightning very often strikes trees. Most susceptible in this respect are oak-trees that have a ramified and deep-lying root system and, consequently, offer a relatively smaller resistance.

Oaks are followed by other deciduous species, then fir and pine. Least to suffer from lightning is beech.

Lightning turns trees into chips, because the high temperature of the spark boils the sap of the tree instantaneously; the steam blasts the wood to pieces which fly tens of metres in all directions, sometimes carrying whole pieces of trees such a distance.

In a medium discharge, the trunk is deeply gouged; through the charred channel, the discharge passes into the ground. Hundred-year-old oaks standing by themselves out in the open often carry traces of "healed wounds" from lightning strokes. Once in a while, dry trunks are completely turned into bast and destroyed. This is apparently due to the dry wood being transformed into gas under the exceedingly high temperature in the lightning channel.

Telegraph wire during a thunderstorm is highly charged with atmospheric electricity, and at times station apparatus is spoiled or even blown completely to bits. Iron poles and lattice-work

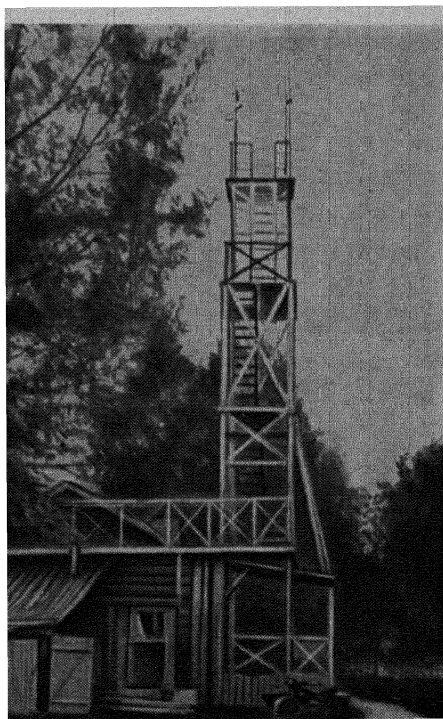


Yard of weather station

are good conductors of electricity and, therefore, charge up during a thunderstorm, making it dangerous to approach them. Draughty winds and metals are all good conductors preferred by lightning.

When lightning encounters resistance it can melt thick metal rods, electric wiring, and vaporize aerials. Even lightning-rods exhibit burnt tips when lightning discharges have been frequent. Lightning is so powerful that it can break through large porcelain insulators.

The destructive action of lightning is especially great when tall brick stacks without lightning-rods are hit. In one case, a stroke of lightning completely demolished about 30 metres at the top of a smoke-stack, split in two the next 15 metres, and caused a large crack in the lower part. Falling bricks broke through the roof of a building next to it. Small pieces of brick



Weather station

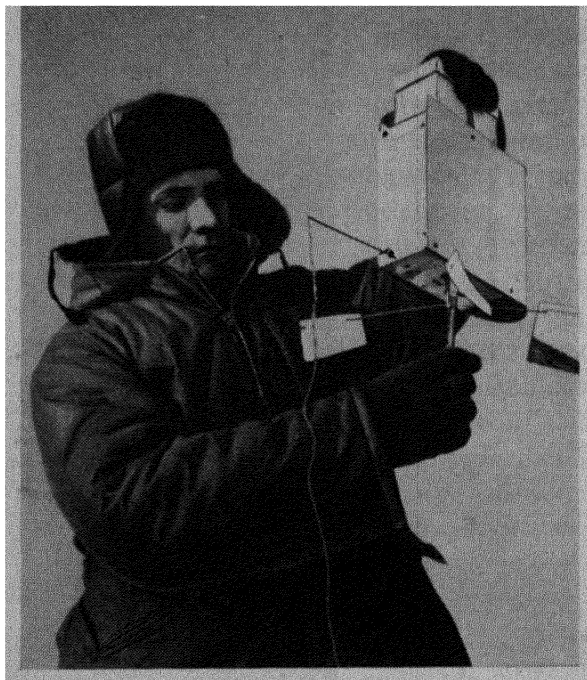
were thrown to as far as 300 metres. In another case, a stroke moved a 25-ton brick wall nearly 7 metres.

In mountainous regions lightning frequently breaks into pieces huge rocks, which are vitrified in the most intense thunderstorms. This happened in the Caucasus at 4,000 metres elevation.

Lightning strokes into sandy soil fuse the sand, giving rise to so-called fulgurites ("devil's fingers"). These autographs of

lightning are often seen in clayey and hard rocks. Fulgurites a metre and more long have been found.

The physiological action of lightning is frequently fatal. Despite the very short time of action, the current paralyses the brain cells, causes paralysis of the heart, and, in a favour-



Releasing a radiosonde

able case, produces severe burns. First aid (artificial respiration, special injections, etc.) can frequently help to bring back to life those struck by lightning.

Lightning can often do great damage to railway transport. An item in *Pravda* of July 3, 1937, reads: "The thunderstorm that broke out over Moscow lasted late into the night. It raged over the capital and then swept into the suburban areas. In Mytishchi, at a little after six in the evening, a stroke of lightning burned up the wires of the electric railway. Traffic

stopped all along the line. By seven-thirty the line was in operation after repairs.

"A few minutes later a second powerful stroke hit Losinostrovskaya, breaking wires and tearing out track."

To conclude these descriptions let us take a few cases from the annals of ball lightning.

Once, during a violent thunderstorm a ball of lightning came down an open chimney in a workmen's barracks and rolled out on to the floor. It looked like a kitten curled up into a ball and rolling about with no paws. The lightning bounded up to the feet of one of the workmen as if wanting to play with him. In a terrible fright, the man pulled away his feet. The lightning then rose up to his face, and the man drew back. The ball went on up to the ceiling and then headed for a hole that had been made for an iron stove, burnt a piece of paper, and made a quiet retreat through a brick chimney. On reaching the roof level the ball exploded with such force that it broke in the roof, and threw pieces of brick all over the yard.

An intense thunderstorm broke out in Leningrad on the night of June 11, 1928, with violent lightning strokes and heavy thunder.

In the words of an eyewitness: "The window in our third-floor flat was left open for the night. At about three in the morning, just before one of a series of lightning strokes, a draught arose because of a window carelessly left open at the other end of the flat. At 2:50 A.M. a ball of lightning suddenly entered the room through the window, lighted up everything and quickly moved into the next room emitting a dry crackling noise. Following the draught, the lightning reached a small round table and exploded about a metre from an electric outlet. The people sitting at the table were stunned and thrown to the side. The explosion was accompanied by a flash like that of ordinary lightning. A lightning-like zigzag bounced to the outlet and burnt it out. The whole flat was filled with a suffocating gassy odour with a peculiar smell of sulphur."\*

\* N. V. Kolobkov, *Thunderstorms and Squalls*, Russ. ed., Gidrometizdat, 1939, p. 22.

Fire statistics on lightning strokes in tsarist Russia showed that lightning took a toll of over 3,000 farmsteads a year. In the Soviet Union protective measures have reduced this figure by a factor of three (according to the data of Stekolnikov, there were 1,037 fires in 1939), and it continues to diminish.

Lightning strokes are sometimes accompanied by real natural calamities. On June 20, 1940, in Tokyo, at 10 P.M. a hurricane broke loose with heavy showers accompanied by a violent thunderstorm. Lightning striking in the centre of the city started a large fire, the flames of which showed all over the city. Other strokes started fires in ten other parts of the city.

### **Laboratory Studies of Lightning**

The damage caused by lightning has made it necessary to combat it somehow. Both the U.S.S.R. and other countries have thunderstorm laboratories in natural conditions, mostly in mountainous regions where the storms are more intense and more frequent than in flat country. In addition, experiments have been made to obtain artificial lightning—of course, on a rather miniature scale.

A great deal of research work is being conducted in the U.S.S.R. on lightning studies. Here, the leading role is being played by the Academy of Sciences Power Institute, the Leningrad Polytechnic Institute, and the All-Union Electrotechnical Institute.

The Power Institute has constructed thunderstorm laboratories in the Caucasus under the supervision of Professor Stekolnikov. Attached to the "lightning-catcher" tower are several aerials from 100 to 1,000 metres long. Aerials of this length are used to increase the chances of a direct discharge into the lightning-catcher (receiver).

A stroke of lightning that hits the aerial enters the laboratory, passes through a series of devices that automatically register its structure, and then goes into the earth. All the apparatus here is carefully protected by means of special attachments in order to make it safe for the workers and to

eliminate the effects of electrostatic and rapidly varying electromagnetic fields.

The laboratories have obtained large numbers of records of the parameters of lightning in the case of direct hits to current receivers, thus making it possible to get a picture of the development of an electric discharge.

Professor Stekolnikov has developed an improved type of camera. It is circular in shape and supplied with a number of lenses. This enables pictures to be taken of minute details in the developing parts of lightning. Film inside the camera is in fast rotation, helping to fathom the mysteries of the streaking pace of lightning.

Every flash of lightning leaves its trace on the film in the form of a series of tortuous lines. One is barely noticeable, another one is brighter, and the third still brighter, all following the same channel. Quite different, indeed, from what we see with the naked eye. To measure the voltage and current of the lightning after it strikes the receiver, it is fed to a special oscillograph or klydonograph, and only then goes into the ground.

An oscillograph can show us what happens in a millionth part of a second. It records electron beams. From the oscillogram we find the duration, voltage, and current intensity of the lightning.

Simpler but no less accurate is the klydonograph, an instrument designed by Stekolnikov and Kalinin. The lightning enters the instrument and moves out to a point in front of which is a moving photographic film. Under the film is a metal plate. The flash produces a reddish glow on the tip of the point. This is recorded on film, which displays the entire course of the discharge.

Hydrogen-filled sounding balloons are used in studies of the electric fields of thunderstorm clouds. A free flying sounding balloon is equipped with aërials and automatic devices that measure the charge in the given part of the cloud. Hundreds of such balloons have pierced stormclouds from base to top, giving a picture of their electrical state.

However, in studying the behaviour of natural lightning one has to wait for direct strokes and discharges into the lightning receiver, and these are not so very frequent even in thundry regions. Hence the idea of making artificial lightning in the laboratory. In the U.S.S.R., this was first accomplished in the Kharkov Institute of Electrical Engineering. A mobile "lightning generator" was designed to generate tremendous voltages for exceedingly short periods of time (millionths of a second).

One of these lightning generators produces a peak voltage of 3,000,000 volts. During a ten-millionths-of-a-second discharge it has a power output of 5,000,000 kilowatts.

A still more powerful device for obtaining artificial lightning was built at the Power Institute in Moscow. This laboratory has produced momentary voltages far in excess of 5,000,000 volts. Lightning strokes 15 and more metres long have been obtained.

Here is a description of these experiments by I. Donskaya and S. Ikonnikova: "The little door clicks to, and the light, latticed cabin starts a smooth upward glide. A steel cable winding round a drum raises it higher and closer to the metal spheres and plates above. Under the dome of the building they hang like some freak structure. By comparison, the cabin looks small and fragile. At the bottom row of plates it stops. The scientist and his apparatus, which looks like a big camera, find it a close fit inside the cabin. Through the netting you can see him disconnect the wire to ground.

"A solemn command of 'Attention' is pronounced. The technician reaches for the switch and—a dazzling arrow of fire pierces the air with a horrific crash. Surging downwards, it seems to strike the cabin and, cutting through the air, plunges into the floor.

"Stunned and blinded, we stand stock-still fearing for the man in the cabin who is studying the lightning, for this lightning generator has built up a charge of millions of volts. A stupendous voltage! But neither the tension nor the current need be feared if only one obligatory condition is observed—you can hold on with bare hands to the wire, live with its colossal



tension, but you must be hanging in the air. The least contact with the earth or even a close approach spells inevitable death."

Artificial lightning may be directed at any models and structures to test high-voltage electric discharges. Laboratory lightning has, for instance, been sent into an automobile made completely of metal. The car was not damaged in the least, while the lightning went through the body and, from the rim of one of the wheels, right into the earth. Experiments have shown that ordinary high-voltage insulation is not good enough for lightning, which goes right through a string of twenty porcelain insulators, so great is the voltage of the electric spark.

Great numbers of such experiments have been conducted, and it has become quite clear why lightning does not in the least sow its strokes haphazardly. Why does lightning spare a dry tree on a hillside, and strike the river bank at the base of the hill? Why does lightning strike moist sand and leave behind its "devil's fingers"? Of two masts of the same height one metal and one wooden, it hits the metal one. Lightning strikes by selection. Experiments have determined what lightning "prefers."

Once an experiment like this was tried. Right under the lightning generator a tall mound of sand was built, with a low mound of clay soil next to it. One would think that the lightning should strike the high hill, taking the shortest route in its difficult traverse through the air. But the silverish serpent leapt down into the clayey pyramid. As it seeks out the most passable layers in the air, so, on approach to the ground, it plunges into soil that best conducts electricity.

On the basis of numerous experiments carried out under the most diverse conditions, Stekolnikov built a theory of the selectivity of lightning strokes. Until recently, the choice of lightning-rods and their siting did not rest on any really scientific findings. It was laboratory research of lightning and experiments with the strokes of artificial sparks into mock-ups of structures that made it possible to work out a methodology for proper lightning protection.

This methodology has made safe the upper stories of tall buildings, thousands of kilometres of high-voltage transmission

lines, fuel depots, and the like. The electric networks of such giant power stations as Kuibyshev, Stalingrad, Kakhovka, Bratsk, and others are now absolutely invulnerable.

At present, Soviet scientists are making a deep study of lightning, of problems concerned with the accumulation of atmospheric electricity and the distribution of charges in thunderstorm clouds. Ball lightning, too, is expected to give up its secret, even though it resists laboratory investigation.

### Protective Measures against Lightning

The knowledge we have amassed about the nature of lightning permits us to solve a highly important practical problem—that of finding protective measures against electric discharges in the atmosphere. This problem had engaged the attention of Lomonosov, for, in his words, “knowing the rules sought out by glass, we shall turn thunder away from our homes.”

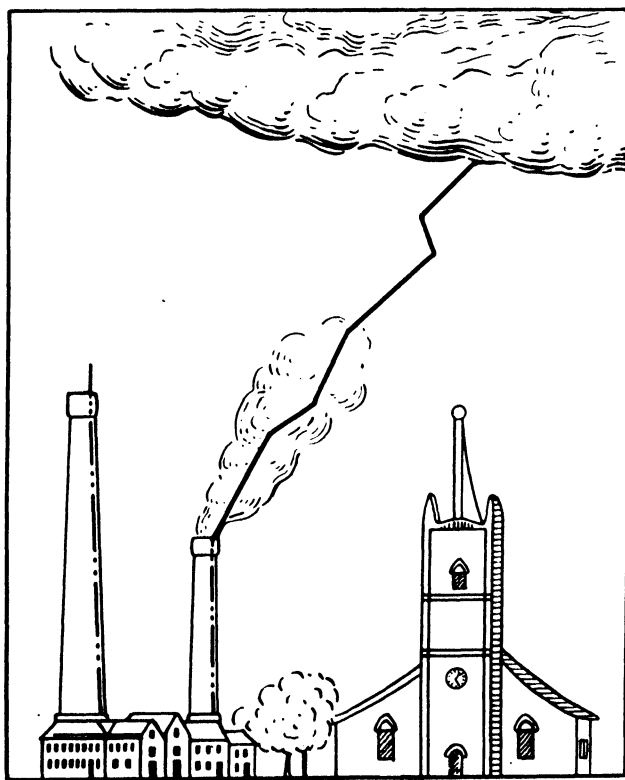
We already know that the path lightning takes is not straight, but abounds in numerous fanciful twists and turns that lengthen the route many times over. Closely connected with this is the problem of selectivity in lightning strokes to the earth's surface.

Lightning takes the path of least resistance, following accumulations of better-conducting particles where lower breakdown voltages are needed.

The effect of a large accumulation of conducting particles on the path that lightning takes near the ground is evident from the following case. Lightning once struck a small smoking chimney although it was within the zone of a well-earthed lightning-rod on a higher chimney nearby. This may be accounted for by the fact that the smoke rising up out of the smaller stack served as a highly conductive layer causing the stroke to deviate from its usual pathway (to the lightning-rod).

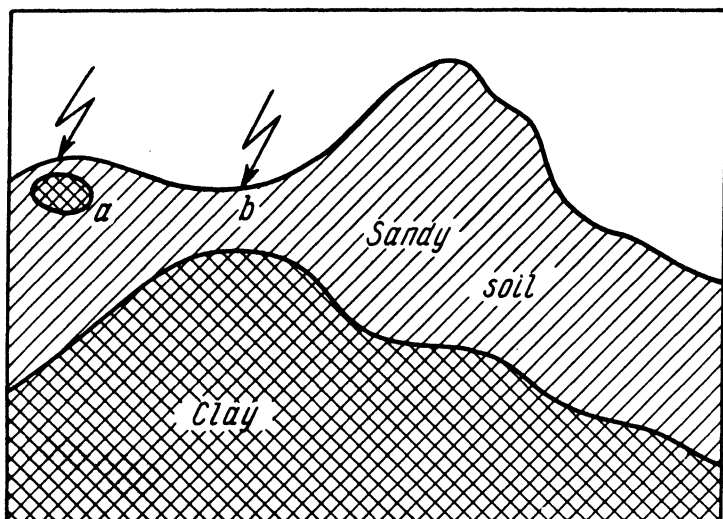
A similar effect is seen in a column of exhaust gases. There are cases when aircraft emitting a cone of exhaust gases right near a stormcloud are struck.

The increased number of lightning strokes to confined areas of the earth's surface (selectivity of lightning) depends on the conductivity of the soil layers at the surface and in depth. The figure on page 130 shows a cross section of the earth's surface. Let a portion of the stormcloud, from which a discharge is about to originate, be located right over the hill. The lightning will choose the path of least resistance. Since the conductivity of clay is greater than that of sand, the development of the discharge will be determined not by the upper terrain but by the contour of the upper layer of clay. The lightning will strike points *a* and *b*.



Lightning strikes a smoke-stack

Near the town of Zvenigorod, Moscow Oblast, is a patch of woods where lightning strikes the trees of a very limited area every single year. This selectivity was particularly prominent in the summer of 1934 when the author counted seven split trees in the single month of July. Soil studies here revealed



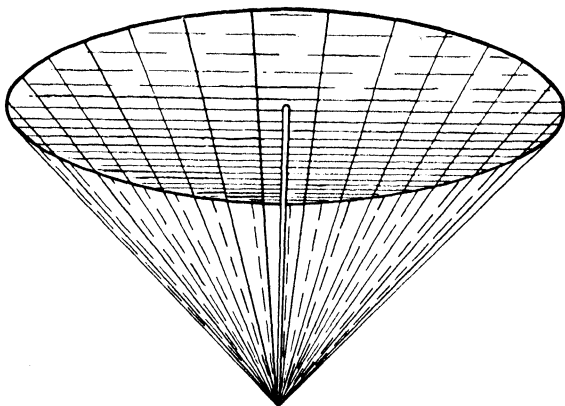
Selectivity of lightning (after Stekolnikov)

pseudo ground water and running ground. Soil of this composition readily attracts lightning.

Stekolnikov's experiments, repeated later in other countries, have completely confirmed his theory on the selectivity of lightning strokes and upset the earlier and erroneous conceptions which held that the path of lightning at the surface is determined by the presence, over certain areas, of highly electrified columns of air.

To protect buildings and other structures against destruction and fire by lightning, use is made of what was once called in Russia a "thunder-rod" but is now more properly called a "lightning-rod"—a metal rod connected with a properly earthed conductor.

The idea of using pointed rods for protection against lightning was suggested by Franklin. As far back as 1750 he wrote: "Would not these pointed rods probably draw the electrical fire silently out of a cloud before it came high enough to strike, and thereby secure us from that most sudden and terrible mischief?"



Area protected by a lightning-rod

In October 1752, Franklin carried out his famous kite experiment to draw "fire from the clouds."

However, the very first observations with pointed rods demonstrated that these devices did not in the least discharge the thunderstorm clouds. The rods not only failed to prevent the formation of lightning, but were frequently struck. At that time, not enough attention was paid to earthing, and the earthing itself was very primitive. The result was that lightning bolts that hit the rod were frequently very destructive leading to fires and casualties. All this led people to distrust the lightning-rod, and Franklin was flooded with complaints about the rods not being able to prevent the storm discharges.

Lomonosov, who, independently of Franklin, proposed this method of protection against lightning, was absolutely right in considering that the lightning-rod deflected lightning, which had already developed, away from the structure it was pro-

tecting by taking the discharge on itself and directing it into the ground where it dissipated. He wrote: "I view it as a useful thing to put these arrows in places quite some distance away from human activities, so that the striking lightning should spend itself more on them than on the heads of humans and their dwellings."\*

Franklin, de Roma, and other scientists abroad erroneously held that the lightning-rod was capable of dissipating thunderstorm electricity and thus preventing the formation of lightning. However, Lomonosov in 1752 proved that this task was beyond the capabilities of a dozen lightning-rods and that their role as calm equalizers of atmospheric electricity was negligibly small. The principal task of a lightning-rod is to deflect the spark discharge into the ground and prevent the formation, by induction, of dangerous charges in conductors.

It was only thirty years later that lightning-rods appeared in Europe. In the first place, the clergy were strongly against them. Even some of the conservative representatives of the scientific community came out against this "impertinent contrivance." They said that it was senseless and dangerous to put up lightning-rods, because the lightning would pass into the ground through the rod and—cause an explosion of the subsoil water! What is more, an earthquake might arise that would destroy the building "on which the lightning-rod is erected." Despite this resistance, 1782 saw the first lightning-rods set up in Russia and in Western Europe, at first on government buildings, and later on private structures. True, they were erected only when the building had already been struck by lightning and people had been killed and fires started. In Russia, the first lightning-rod was put up on the tower of the St. Peter and Paul Cathedral only after a lightning bolt had hit it.

In the community at large, lightning-rods are not so common despite the fact that they are definitely useful and even necessary. They are usually erected only on big structures like fac-

\* I. S. Stekolnikov, *Lightning and Thunder*, Russ. ed., Gostekhizdat, 1946, p. 32.

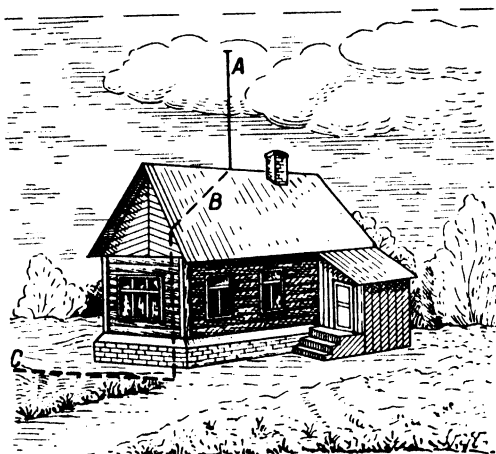
tories and huge smoke-stacks. The reason is that they are relatively expensive, difficult to install, and the ordinary run of people are not familiar enough with their design. The point is that mistakes made in erecting them can lead to very regrettable results, far worse than if they hadn't been there in the first place.

The lightning-rod gives equal protection on all sides, creating about it a protected area in the form of a cone or tent.

Lightning protection of a small dwelling house with metal roofing is shown in the accompanying figure.\*

The most suitable protection is a rod-type lightning protector A, which in this case is erected on the building itself, in the middle of the ridge of the roof. The house has the following approximate dimensions: length, 15-20 metres, width, 7-8 metres, and height up to ridge, 7 metres. Given these dimensions, the lightning-rod should be 5 metres above the ridge. This is enough for all parts of the house to be within the protective zone.

The lightning-rod is attached to a wooden pole fixed to the timbers of the roof. Any 8-9-millimetre-diameter wire passed down the pole can serve as the current-carrying conductor. The wire may be either circular or rectangular, but it must have a cross-section of at least 50 square millimetres. On the pole, the wire should be held in place by iron clamps and extend at least one metre over the top of the pole. Current lead B



Protection against lightning for a house with metal roof

\* I. S. Stekolnikov, *Thunderstorms and Lightning Protection*, Russ. ed. "Pravda" Publishing House, Moscow, 1951, p. 26.

should follow the roof and then go down the wall of the house into the earth (into a metre-deep ditch, at the bottom of which is the earthing device in the form of a cable or sheet, C). The length of the ditch can vary, depending on the character of the soil: in clay it should be 8 metres, in loamy soil, 5 metres, in chernozem (black earth), 10 metres, and in sandy clay, from 15 to 25 metres. The lower the conductivity of the soil, the longer the underground conductor should be.

In sandy soils, the earthing system of a lightning-rod should have two or three branches pointing in different directions. And each one some 10 to 16 metres long.

If the roofing is made of combustible material, the lightning-rod should be separate from the house, for instance, on a tree near the structure, and attached with brace wires. It is then sufficient to pass the wire down the trunk of the tree or a pole.

A single lightning-rod can protect two houses at one time if their outlines do not extend beyond the protective cone of the lightning-rod.

The thing to bear in mind during a thunderstorm is to keep as far as possible away from the lightning-rod and the earthing.

To protect high-voltage transmission lines against lightning, one or two wires are strung over the steel towers and are directly connected to them. Most of the direct lightning strokes hit these earthed wires, or what might be called horizontal lightning-rods, and go down into the earth through the steel tower. The current-carrying wires are carefully insulated from the towers. In small lower-power electrical networks that usually use wooden poles, only one protective wire is used, and from it, at regular intervals, a reliable earthing wire is passed down the poles. This protection is quite sufficient in the case of direct strokes of lightning, but is not a complete guarantee against excessive voltages in the circuit due to induction from nearby electric discharges.

A special type of lightning-rod is connected into the circuit to preclude such accidents. Under normal operating conditions of the network, the lightning-rod plays the part of an insu-



lator. But when overvoltages occur due to induction from lightning, the lightning-rod instantaneously turns into a conductor, serving as a sort of valve, which, on opening, drains to earth the surplus voltage. As soon as the voltage returns to normal, the discharger immediately becomes an insulator again. This automatic action is so fast that the transient increase in voltage is not felt at all by the consumer.

Studies of numerous cases of lightning strokes to buildings, human beings, and so forth, show that they can frequently be avoided if certain precautions are taken. These precautions are rather well known, but are ordinarily neglected, particularly in big cities. Statistics show that big cities, too, have their toll of fires and casualties due to lightning.

A direct stroke is not the only way lightning can affect living beings. Let us suppose lightning has struck some distance away from a person. The electric current that went into the ground spreads out passing under the feet of the person close to the site of the stroke. The electricity then passes into one foot, up through the body, and down the other foot into the ground again.

The wetter the shoes are the greater the amount of electricity that gets into the body, and the more chance there is of a fatality. But even if the result is not fatal, the electric current can do irreparable damage to the human organism. The bigger the lightning current and the drier the soil at the point of impact, the wider the danger range to human beings and animals.

Naturally, a lightning stroke loses strength with increasing distance from the place hit, and at 5 to 10 metres away one



Man hit as lightning strikes nearby tree (after Stekolnikov)

can consider himself safe from a lightning stroke acting through the ground. For this reason, during a thunderstorm one should stay as far away as possible from the lightning-rod, tall trees, and other objects that lightning prefers.

A few words are in order concerning other simple and easily carried-out rules of caution.

Just before a thunderstorm, close all windows to prevent draughts through the rooms. At least, keep the windows open only on one side. Close up all chimneys because ball lightning is known to choose precisely such paths even when the air is just barely in motion. During an intense thunderstorm, it is best to stay as far away from windows and stoves as possible. Lightning often hits the chimney and demolishes the stove. When it hits the house it goes along the walls and corners that are close to gutters. This naturally applies to one-storey houses and the upper stories of large buildings. During a thunderstorm, it is best to stay away from wires and large pieces of metal, such as iron poles. It is not wise to use the telephone, especially during a violent storm. In such cases, rural telephone stations usually disengage connections. Close discharges can induce such big currents that electric lamps light up and fuses blow.

Radio aerials during a thunderstorm should be earthed. The outside aerial, being a thin wire, will of course not withstand such a strong discharge as lightning and will be burned out instantly; but when the aerial is earthed, the radio set will be saved, and even if the wire is destroyed there won't be any fire, which would undoubtedly occur otherwise. We know of hardly any cases when an earthed aerial was hit, and the extremely rare recorded cases only ended in the lead-in wire melting. The building itself was not damaged.

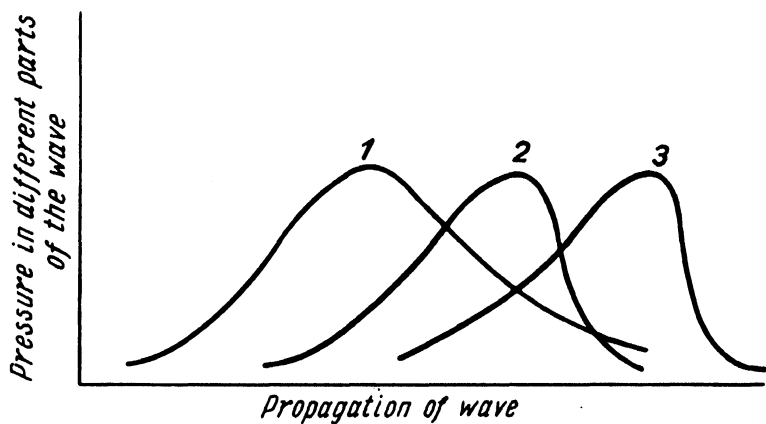
Do not under any circumstances look for shelter from the rain under trees during a thunderstorm. We have already said that lightning very often hits single large trees, especially oak-trees. And do not hide in wattled or poorly log-covered sheds or in hay-stacks.

As regards ball lightning, so far we know of no reliable methods of protection, nor even the principles of such protection. Lightning-rods offer no protection against ball lightning; quite the reverse, there have been frequent cases of objects being hit that were completely protected from ordinary lightning. The only thing that we know is that ball lightning very rarely pierces window glass, which makes a closed window good protection.

## Thunder

Like any electric spark, lightning is accompanied by noise. Very strong lightning strokes are attended by considerable sound. Thunder arises due to a sudden and exceedingly great heating and subsequent rapid cooling of the air in the lightning channel. Special sound-measuring studies of thunder corroborate this. It turns out that during the first fraction of a second the sound wave behaves like a shock wave, being propagated at 15 to 20 times the normal speed of sound in the air (340 metres per second). In this case we hear a sharp crackle. In 0.1 to 0.3 second the shock wave of thunder gradually turns into an ordinary sound wave.

At the point of explosion, due to the rapid formation of a large quantity of gases, a high pressure develops reaching



Disintegration of a shock wave

several thousand atmospheres. The pressure of the gases instantaneously pushes out the adjoining layer of air and thus produces a wave, which is rapidly propagated in all directions from the point of explosion.

On the front of this wave is a compression of air, which is followed by a rarefaction.

Although the rate of propagation of the wave is far greater than that of sound, it rapidly diminishes with distance, and the wave itself disintegrates and changes. First of all, the width of the compression front increases and the maximum compression quickly moves to the very front part of the wave.

Those parts of the wave in which the compression is greater overtake each other and, thus, the wave form becomes steep in the front part and sloping in the rear. The number of forward-moving particles falls off, and the number of backward-moving particles increases. This accounts for the apparently strange fact that at a certain distance from the site of the explosion, window glass is blown out in the direction of the seat of the explosion.

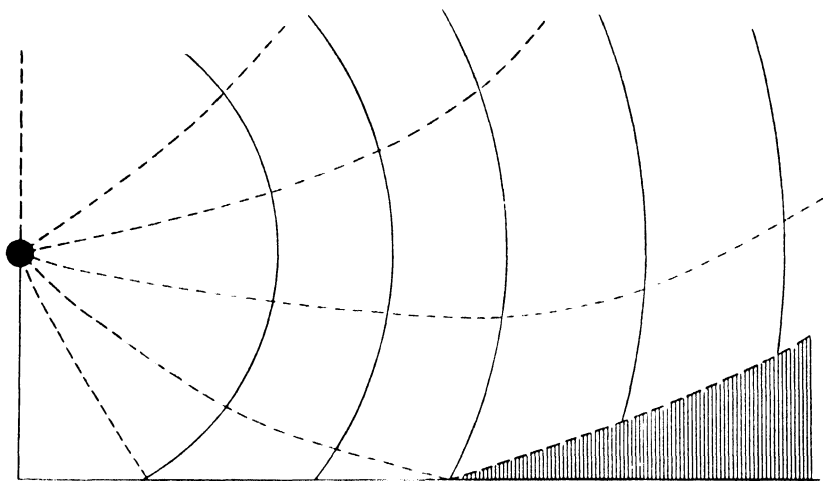
The shock wave breaks up into a number of sound waves. They move over the surface becoming reinforced and superimposed on one another. Thus, the observer hears a succession of various parts of the "interwoven" sound wave that are perceived as alternating reinforcement and attenuation of sound—the roll of thunder.

We know that lightning consists not of a single spark but of many discharges that shoot along the same route. Each of these discharges emits a shock wave, so that in reality we have several shock waves being propagated with various peculiarities typical of each one. And the different fronts of these waves reach the observer.

In some textbooks, rolls of thunder are explained mainly as the reflection of sound waves from various inhomogeneous layers of air and from objects on the ground. But this is only secondary to the chief reasons given above.

Close and strong bolts of thunder that one hears right after the flash of lightning originate in the shock wave that has not

yet had time to disintegrate. At this stage, the vibrations of the air are perceived by our ear as a crackling sound. The rolling of thunder indicates that the sound source is at a distance.



Trajectories of sound waves during thunder

If one takes into consideration the first phase in the development of thunder (the shock wave), then, when reckoning the distance to the thunderstorm from the interval between the lightning flash and the thunder, one should add a slight correction of about 300 to 500 metres. The restricted audibility area of thunder is due to the fact that the main energy of the thunder consists of long waves not received by the ear, while the short waves are comparatively weaker and quickly absorbed by the air.

Lightning strokes that hit the earth usually create a roar like that of cannon, which is followed by continued rolling that always ends in a dull and heavy crack. This is enough to judge of the nature of the discharge and to distinguish it easily from the rumbling of a lightning stroke between clouds. The rolling of thunder is due not only to the nature of the shock wave, but also to the gradual approach of the sound from different

parts of the stroke of lightning, which is several kilometres long.

On an average, the thunder from a single flash of lightning lasts about 30 to 40 seconds, in individual cases, up to a minute. The audibility range is 18 to 20 kilometres, though sometimes it reaches 30 kilometres.

The writer once observed a distant and very intense thunderstorm under exceptionally good conditions, and reckoned the interval between lightning and thunder at 150 seconds, which corresponds to 50 kilometres. Intervals of 3 minutes (60 kilometres) have been claimed, but anything beyond that should be considered an exaggeration or simply a mistake.

It is known that sound waves passing from upper air levels to lower and denser levels are deflected upwards and refracted (see figure on page 139). The last point of audible thunder will be where the sound wave touches the earth's surface; this is then followed by a zone of silence.

Sound waves that originate in rarefied air have very little energy and are rapidly damped. This is why lightnings in the clouds, that is, at 1,000 to 1,500 metres and higher do not produce such loud thunder as when the lightning strikes the earth.

As with any sound, the range of audibility is greater to windward than to leeward.

*PART TWO*  
**STORMS**





*CHAPTER ONE*  
**THUNDERSTORMS**

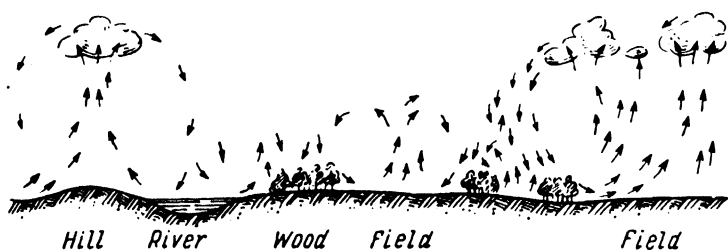
**The Formation of Thunderstorm Clouds**

In the summer time, almost every day one can observe the formation of whitish, cotton-like clouds. These go by the name of cumulus clouds. They usually make their appearance in the morning when the sun has already had time to heat up the ground, and the lighter, warm currents of air begin to rise shimmering in the distance. On a hot, windless day, all objects seen at a distance, on the horizon, appear to be quivering. This comes from little jets of warm air continually rising from the ground that has been heated by the sun. The soil gives up to the heated air a part of its moisture, and, hidden from the eye, this water vapour rises into the upper air.

The summer sun gets hotter and hotter; more and more heated air jets push their way upwards, higher and higher; the separate little jets flow together like tributaries building up a huge current. As it works up into the higher rarefied layers, the heated air begins to expand and, hence, to cool. At a certain height, depending on the temperature and humidity on the ground, the air cools to such an extent that part of the water vapour condenses. This results in myriads of minute visible droplets of water—a cloud.

This comes about because the quantity of water vapour in the air cannot increase indefinitely. For every temperature there comes a time when the air is saturated with water vapour.

The less the air is heated, the smaller the quantity of water vapour in it. At plus  $20^{\circ}\text{C}$ ., every cubic metre of air can have up to 17 grammes of water in the form of water vapour. If the air cools to  $10^{\circ}$ , the quantity of vapour will fall to 9.5 grammes. All the excess moisture in this case turns into tiny water



Cloud formation on a calm summer day

droplets, that is to say, it condenses. As the air ascends into higher levels it cools, giving rise to clouds.

The first to appear in the sky is a small white patch. But fresh currents of warm air rushing in from below and containing water vapour build up the mass into a dome-shaped structure that soon becomes a real cumulus cloud.

The accompanying drawing illustrates the simplest case of the formation of such clouds on a clear summer day. The air above hills and fields heats up more than that over rivers or woodland, producing uprushing currents over the heated areas that are compensated for by descending currents which develop over the cooler areas. In other words, cooler air will be coming down over rivers and wooded districts. Rising, the warm air cools off, and the water vapour condenses and turns into large cumulus clouds.

As soon as the ground stops heating up, the cumulus clouds melt away and by evening disappear altogether. These clouds are known as "fair-weather cumulus" because they do not develop beyond a definite limit and do not upset the weather.

The evaporation of moisture from any surface requires a great deal of heat, which is again returned to the atmosphere when the vapour rises turning into minute water droplets. This is called releasing the latent heat of evaporation.

The latent heat of condensation plays a major role in the development of cumulus clouds and their transformation, under specific conditions, into thunderstorm clouds. No less important is the fall in temperature with elevation. If the air in the lower levels is very warm, even hot, and the lapse rate (fall of temperature with elevation) is steeper than usual, the ascending current will lead to the formation of a heavy cloud, since the uprushing warm air will remain warmer than the surrounding air. The upward currents will be moving at a high rate and bringing in great amounts of water vapour.

Ordinarily the ascending current that cools as it rises becomes heavier than the surrounding air, and it stops its ascent; the cloud ceases to grow and remains a small cumulus. This is usually the case in good, moderately warm weather. The picture is quite different, however, during a hot spell when the air is very humid, or "muggy" as it is often described. In this case, a broad stream of moist, ascending air rises to 1,500-2,000 metres and forms a heavy cumulus cloud. Condensation of the water vapour in the cloud releases the latent heat, thus keeping the upward current warmer than its surroundings; the cloud will continue to grow and finally turn into an enormous thundercloud.

Some idea of the force of the uprushing currents in a heavy cumulus cloud may be gained from the following unusual case that involved three parachute jumpers of the Minsk Flying Club on August 1, 1950, near the town of Borisov.

"Of the three parachutists that cleared the plane almost simultaneously, only one succeeded in making a normal descent and landing safely in 2 minutes and 15 seconds after bailing out. The other two were caught in a strong ascending current that carried them quite a distance up until they were lost in the cloud. One of them landed only 40 minutes later some 8 kilometres to the south of the start, while the other spent two hours in the cloud and then touched down 14 kilometres east of the starting point.

"The jump was made at 17 hours 30 minutes at 800 metres. After the parachutes opened both men were very quickly

dragged into the cloud at 1,500 metres. Here the temperature fell to 8°C. The first parachutist was held up in the cloud for half an hour in a solid fog before he could get loose. The second man was lifted to 3,000-3,500 metres, where it was getting colder all the time. The parachute began to ice over, and his clothes were covered with hoarfrost. But the sportsman did not lose his head. He shook the shroud lines at intervals to get rid of the pieces of sleet and ice. As evening approached, the upward current grew weaker, and the parachutist at last began to descend. Soon the ground came into view and he made a safe landing after a two hours' stay in the air."

A thundercloud is several kilometres in thickness (up to 10) and from afar resembles mountain peaks covered with snow. The top of the cloud is such a good reflector of sunlight that it appears brilliantly white. But not a single ray of light is able to get through so much cloud. This makes the thunderstorm cloud appear blue from below if the sun is shining on it from the side, and almost black and gloomy if it shuts out the sun.

The formation of very heavy thunderstorm clouds that frequently encompass the entire first layer of the atmosphere (troposphere) requires special conditions, a sufficient readiness, one might say, for such powerful and violent processes. However, heating the lower layers of air is not enough for the development of strong convection\* currents (in which case, the process stops with the formation of cumulus clouds only). This state of "readiness" requires, firstly, that the state of the atmosphere be unstable up to 3-4 kilometres, secondly, that, up above, the lapse rate should be very high, and, finally, that down below the weather should be hot with a great deal of water vapour. These conditions are needed so that the rising particles of air should all the time be warmer than the ambient medium. Then the warm air will sort of float up.

A thundercloud cannot grow indefinitely. The minute water droplets in the lower part and the ice crystals in the upper part,

\* In meteorology, by convection is meant vertical air movements due to uneven horizontal distribution of temperature.

where it is cold, combine into bigger particles. There finally comes a point when the ascending current feeding the cloud is no longer able to hold the particles up, and the droplets fall coalescing with others into big drops of rain.

First a big drop falls to the ground, then another, which is followed by a sparse fall of large drops that soon grows into a downpour. A flash of lightning rips through the cloud, then a second, a third—the thunderstorm is in full play!

Beautiful descriptions of thunderstorms have been given by Tolstoi, Chekhov, Turgenev, Gorky.

In his trilogy, *Childhood, Boyhood, Youth*, Lev Tolstoi writes: "The sun declined towards the west and burned my neck and cheeks intolerably with its hot, slanting rays. It was impossible to touch the scorching sides of the britchka. A thick dust rose over the road and filled the air. There was not the slightest breeze to carry it away. All my attention was focussed on the clouds, which had before been scattered over the sky, and were now gathering into one dark menacing mass. From time to time distant thunder rumbled.

"It was still ten versts to the nearest village, but the great, dark-purple cloud, which had arisen from I knew not where, for there was not the slightest breeze, was moving swiftly upon us. The sun, not yet hidden by the clouds, brightly lit up its sombre mass and the grey streaks which stretched from it to the very horizon. Lightning flashed from time to time in the distance and a low rumble was heard which gradually became louder as it approached and merged into broken peals embracing the heavens. . . . An uncanny feeling came over me. I was conscious of the blood pounding in my veins. Presently the first clouds veiled the sun; for the last time it peeped forth, cast a last gleam of light over the glowering horizon, and vanished. The entire landscape suddenly changed and assumed a gloomy aspect. The aspen coppice quivered; the leaves took on a greyish tint, and clearly stood out against the purple cloud—and rustled and fluttered; the tops of the tall birches rocked, and tufts of dry grass whirled across the road. . . .

"The lightning seemed to flash in the britchka itself, blinding

us. . . . At the same moment a majestic peal boomed directly above our heads, and seemed to rise ever higher and higher and to spread ever wider and wider, in a vast spiral, gradually swelling, until it burst in a deafening crash, which sent a shudder through us and forced us to hold our breath. . . . A blinding flash of lightning filled the whole ravine for a moment with its fiery glare; it was accompanied, without the slightest interval, by such a deafening clap of thunder that it seemed as though the whole vault of heaven were crumbling down upon us. The wind became still stronger. . . . A large drop of rain fell heavily upon the leathery hood of the britchka, then a second, a third, a fourth; and all at once it beat upon us like a drum, and the whole landscape resounded with the regular patter of falling rain.

"The slanting rain, driven by the fierce wind, was pouring down in torrents. . . . The dust, which at first had been beaten into pellets, was now liquid mud, through which the wheels splashed; the jolts became fewer, and turbid brooks flowed in the ruts. The lightning flashes grew broader and paler; the thunder-claps were no longer so startling above the pitter-patter of the rain.

"The rain no longer fell so heavily; the thundercloud began to disperse; light appeared where the sun must be, and a rift of clear azure was almost visible through the greyish-white edges of the cloud. Yet a moment, and a timid ray of sunlight gleamed in the pools on the road, in the fine, straight streaks of rain which fell as if through a sieve, and upon the shining, newly-washed green of the wayside grass. The black thundercloud stretching over the opposite portion of the sky was no less sinister. . . ."

If the atmosphere is sufficiently prepared, the development of a thunderstorm cloud proceeds very quickly; sometimes in less than 30 to 40 minutes mountainous thunderclouds build up out of a clear blue sky.

\* Lev Tolstoi, *Childhood, Boyhood, Youth*, Foreign Languages Publishing House, Moscow, pp. 138-142.

In the initial stage of development of a thunderstorm, we see a cumulus cloud that differs from the "fair-weather cumulus" in its great vertical growth and tendency towards a turret-like structure. It soon turns into a typical heavy cumulus cloud with a well developed snowy-white dome and dark base. Above is a light, vapourish haze, which is quickly pierced by the upward-growing dome. This is the cloud cap which indicates that the summit is growing rapidly. It is due to the strong ascending current in the main body of the cloud. The uprushing current lifts the overlying layers of air, and the water vapour condenses. The cap is pierced by the summit of the cumulus cloud and remains below with the appearance of a belt around the cloud. There may be several of these caps at different levels in a growing cloud. But watch the top; eddies in the upward current swirl about as if everything were boiling—a thunderstorm is inevitable.

This state doesn't last long. The summit soon begins to ice over. Isolated projections, "clouds of steam," begin to smooth out and light up; the dome loses its sharp outlines and becomes covered with a "shield" of icy clouds. These are frozen drops of water, the supercooled state of which has come to an end. Below, a sheet of rain appears lashed with flashes of lightning. The thunderstorm is upon you.

### **Thunderclouds During Volcanic Eruptions and Big Fires**

In volcanic eruptions, enormous quantities of water vapour that are ejected together with incandescent lava, belch forth with hurricane force. In minutes, a column of steam and ash is carried to great heights; here the steam condenses to form cloud structures mixed with ash. These clouds are frequently the source of violent downpours accompanied by the continual flashing of lightning. This was the case during eruptions of Vesuvius.

Even in northern latitudes volcanic eruptions are attended by thunderstorms. In Iceland thunderstorms are ordinarily a rare event and not violent. But during eruptions, heavy storm-

clouds appear with flashing lightning and rolling thunder all the time. The same picture was observed on Kamchatka during an eruption of Bezmyannaya Volcano on March 30, 1956.

Fires have also given rise to cumulus clouds as a consequence of artificial convection. They usually resemble the cumuli of fine weather, but in very big fires they can turn into thunderclouds.

Thunderclouds of this kind appeared over the Tokyo conflagration that continued 40 hours in the wake of a destructive earthquake on September 1, 1923. The huge clouds over Tokyo and Yokohama were visible 40 kilometres away. They were very sharply outlined with beautiful spherical projections. In the sunshine, the clouds were silverish and appeared much brighter than ordinary stormclouds. Photographic observations showed that the domes of the clouds reached to six kilometres and, in places, even to eight.

Notwithstanding the destruction, Japanese meteorologists continued their observations. At the Tokyo Meteorological Observatory, which was quite some distance from the site of the fire, the temperature reached 45°C. The heat started an air current that attained gale force (up to 22 metres a second). Calculations showed that air currents ascending directly over the fire reached 70 metres a second—a vertical hurricane—and not less than 15 metres per second over a vast area. The lower edge of the clouds was 2 kilometres up.

It is interesting to note that heavy cumulonimbus clouds with peaks over 20 kilometres high were observed during the explosion of the Tunguska Meteorite of June 30, 1908, and during the American atomic-bomb burst at Hiroshima in 1945. In both cases, the cumulus rainclouds were cauliflower- or mushroom-like and were accompanied by thunder and torrential rains. It is thought that the downpour of June 30, 1908, was so intense as to put out the taiga fire that had started.

An exceptional case of rising temperature from big forest fires occurred at the beginning of August 1934 not far from the mouth of the Kolyma River, at Cape Medvezhy. The mercury suddenly rose to plus 16°C. Everything was a haze,



through which the sun cast a feeble light and shone like a copper-red disk. There was a strong burning odour in the air. This unusual polar-sea spectacle was caused by enormous forest fires in the north-east of Siberia. The burning smell and "dry fog" were also reported by a radio station on Bolshoi Lya-khovsky Island.

### Classification of Thunderstorms and the Movements of Stormclouds

When thunderclouds form inside a very warm and homogeneous air mass, they are attended by thunderstorms called *air-mass thunderstorms*.

The existence of stormclouds forming inside a homogeneous mass of air frequently depends on such local conditions as terrain, temperature, humidity. Such a uniform mass of air can occupy a large territory, often hundreds of thousands of square kilometres. For this reason, air-mass thunderstorms break out over large areas, but retain the individual structure of the clouds that originate simultaneously in different places. Each cloud moves and develops independently of the others. Each thunderstorm embraces a small region and quickly dies out. Nearby, another thunderstorm breaks loose and, after covering a small distance, dissipates, and so on. Storms like these are accompanied by heavy downpours, frequently with hail and numberless lightning strokes. But the rainfall is very unevenly distributed—spotty—with a dry zone lying alongside an area of abundant precipitation.

In the middle latitudes, the most common are the *frontal* thunderstorms due to the interaction of two air masses, warm and cold.

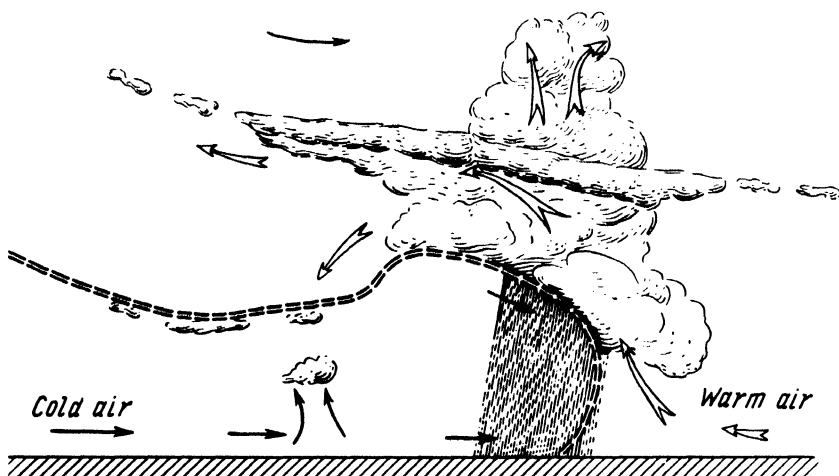
Under what conditions do they form?

People travelling on long journeys often notice that there is no change in the weather throughout the trip. But it happens sometimes that in a space of 30-40 kilometres the weather changes sharply. This is first of all apparent in the jump in temperature. If we were to look at a map of the weather

during the days of our journey, we would see that in the first case our route lay inside a homogeneous air mass, and in the second case, we moved from one mass of air into another. The sharp change in the weather occurred precisely on the boundary between the two masses, in the transition zone which is known as an *atmospheric front*; such weather is called *frontal* weather in contrast to phenomena inside air masses.

When a cold mass sweeps into a warm zone and, being denser and heavier, underflows it, the warm mass is made to move violently upwards. A strong upcurrent of warm air in summer leads to the formation of thunderclouds. In this case, the meeting ground of the cold and warm masses is termed a *cold front*. The front can extend hundreds of kilometres and everywhere be accompanied by thunderstorms, which are then called frontal thunderstorms. They move in an uninterrupted chain, pass over quickly, but embrace very large areas due to the long front.

The drawing below shows a vertical cross-section of a front when a mass of cold air is moving into a warm region. The incursion in the lower levels is in the form of a “head” which forces the warmer air in front to rise rapidly. This shape



Vertical cross-section of cold front with thunderstorms

develops due to the cold air having different velocities in its various layers. The lowest layer experiences friction against the earth's surface and is thus slowed up, while the higher layers advance. The motion of air particles in the "head" is similar to that of the caterpillar treads of a tank: the first cold air is encountered at an elevation and then later at ground level. Huge conglomerations of clouds form on the "head" and resemble mountains or turrets. They weave along over the earth for long distances carrying with them thunderstorms, heavy showers, and violent squally winds.

Clouds of a cold front can rise to great heights but are not very wide. Since a cold front usually moves fast, the stormy weather does not last long. The stronger air currents in the upper layers carry out of the cloud system of the cold front separate altocumulus clouds that are sometimes flat and sometimes rounded—the familiar "whitecaps." They precede the front giving warning of its approach, though in hot weather they may not be present.

Since stormclouds form only when the weather is sufficiently warm and there is a considerable supply of moisture in the air, both frontal and air-mass thunderstorms are observed in the warm half of the year. Under favourable conditions they may arise in early spring and late autumn. In the southern part of the Soviet Union such thunderstorms occur even in winter.

In the interior of the continent, the daily march of thunderstorms is everywhere the same: most of them occur in the afternoon soon after the diurnal maximum of temperature is reached. The fewest storms occur on the continent between midnight and 9 A.M., with the minimum between 6 and 7 A.M.

With the exception of purely local thunderstorms that form in mountainous areas and dissipate there by evening, most thunderstorms exhibit a translational motion, which is the reason for their long continuance; this is due to the fact that when they are in motion they sweep up fresh masses of warm air. Their rate of progression is extremely varied. There are thunderstorms that crawl along at 5 to 10 kilometres an hour, and then there are those that race along at a clip of over 100.

Thunderstorms usually follow the prevailing upper air current, which originates from differences in atmospheric pressure at this level. In the middle latitudes, the prevailing current is between 3 and 5 kilometres up. This is very important to bear in mind, for thunderstorms can move in a direction opposite to that of the ground wind. In middle latitudes, thunderstorms move from west and south-west. This holds for all of Europe and conforms to the general circulation of the atmosphere.

In a homogeneous air mass, thunderstorms move more slowly than do the frontal type. Sometimes they burst out in almost one place. In July 1940, for instance, a nocturnal thunderstorm raged for four hours and more over Mozhaïsk, while the surrounding countryside was absolutely clear. Flashes of heat lightning observed on the horizon pointed straight to Mozhaïsk. Thanks to the fair moonless weather the lightning of this exceedingly stationary thunderstorm was observed up to distances of 300 kilometres. The flashes were seen in Smolensk, Kalinin, Tula, and other towns.

On July 15, 1944, Zvenigorod experienced a violent thunderstorm for over three hours. It originated, developed, and died out in one spot.

Other thunderstorms move at a terrifying rate, some, for example, at 100 to 110 kilometres an hour, as happened in the central regions of the U.S.S.R. on the night of September 14-15, 1941.

A thunderstorm speed record was made on August 25, 1890, over Northern Italy—170 kilometres per hour.

### Geographical Distribution of Thunderstorms

A thunderstorm is considered close if the interval between the lightning and the thunder does not exceed 10 seconds (3 kilometres distance). If this interval is greater, the storm is considered distant. Far-off lightning without thunder is known as heat lightning.

When reckoning the frequency of occurrence of thunderstorms and compiling maps of the distribution of thunderstorm

action, account is taken not of the total number of storms (which may recur two or three times a day) but of the number of days (in a month or year) that thunderstorms were recorded at the point of observation. Heat lightning is discounted.

Let us first consider the distribution of thunderstorms on a global scale. It must be pointed out that, as a rule, the frequency diminishes from the equator to the polar regions. This is natural, for we know that thunderstorms require high temperatures and humidity of the air, both of which fall off from the equator to the poles. Thunderstorms are a very rare occurrence near the Arctic Circle. But in lower latitudes, too, there are areas in which they are infrequent or totally absent, as, for instance, the Sahara, Arabian, Kara-Kum deserts or along the western coast of South Africa where the air is extremely dry.

In the Southern Hemisphere, thunderstorms disappear at a considerable distance from the Antarctic Circle. Here the thunderstorm boundary lies between 50 and 55° south latitude. Yet individual thunderstorms have been observed right down to Antarctica.

In the Northern Hemisphere, thunderstorms occur once in a while in the Barents and Kara seas. They have been recorded on Novaya Zemlya and even on Spitsbergen, at 78° N. This great northward advance is due to the effects of the warm North Cape current (a branch of the Gulf Stream).

In the equatorial belt, Beitsorg on the Island of Java, has an annual average of 167 thunderstorm days, Jakarta has 138, Bismarcksborg (Western Africa, 8° N.), 168, Mexico, 137, Gondar (Southern Ethiopia), 230 days a year. The prominent Russian scientist A. I. Voyeikov noted that in the equatorial parts of South America one could hear the rumbling of thunder round the year; flashes of heat lightning start up at dusk and last till morning.

Towards the moderate latitudes, the number of thunderstorms falls off, but by no means regularly. On an average, we may consider that the equator has 100 to 150 storm days, the tropical latitudes, from 75 to 100, the middle latitudes, from

30 to 50 days, and near the polar circles and beyond, only a few days a year.

The general rule is that there are more thunderstorms in warm and humid areas than in cold and dry, and more over land than at sea.

On mountain slopes, where upward air currents are strengthened by the terrain, there are far more thunderstorms than over flat country. Mountainous regions have 25 to 30 thundery days, while plains in the same latitudes have only about 10.

At mid-sea, thunderstorms are rare, but still come to three to five a year. This number increases closer to land and at lower latitudes.

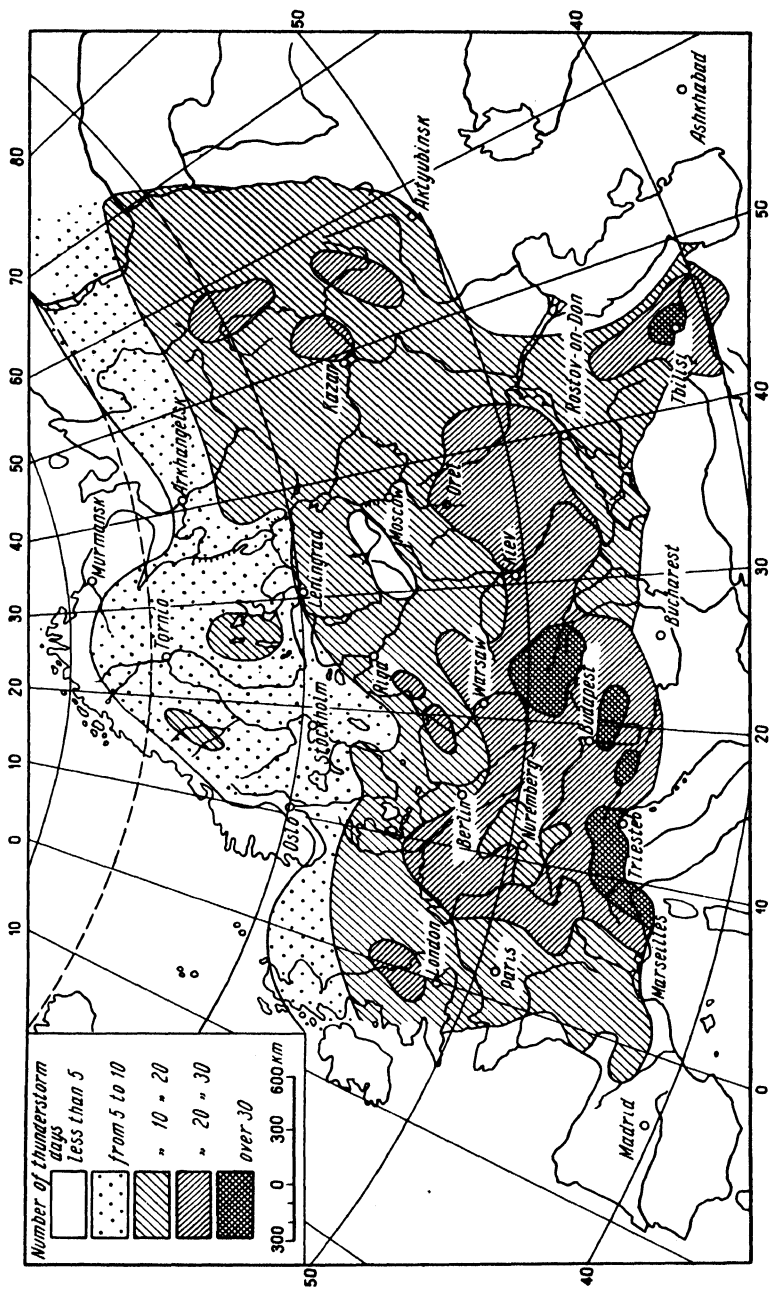
In the tropical zone, thunderstorms coincide with the rainy period. Here the season of rain actually begins with such storms. There are fewer storms towards the middle of the rainy period, then they increase towards the end, when there are more fair days. Usually, more thunderstorms mean approaching end of the rainy season. The equatorial zone during the rainy period is likewise conspicuous for its daily noon-time thunderstorms and, in places, nocturnal thunderstorms, which recur with uncanny regularity.

How many thunderstorm days does Europe have? (See accompanying map.)

The largest number is observed in mountainous regions (Alps, 40, Carpathians, 35), and a much smaller number in flat country. Western Europe has 20-25 days, Central Europe, 25 to 30 days. The number diminishes northwards: Norway having 6 to 8 days, beyond the Arctic Circle, 2. There are more in Sweden (7-10).

In Western Europe, the thunderstorm maximum comes in summer (generally June and July), the minimum, in winter. The North Sea coastline has from 3 to 7 a decade. In the southern half of Western Europe, the peak is frequently shifted to the mid-season periods.

The Norwegian coastline has a belated thunderstorm maximum in August, and, in addition, a second peak in January. The January storms are connected with violent winter cyclones.



Distribution of thunderstorms in Europe (after Tverskoi)

In the European part of the Soviet Union, thunderstorms are distributed as follows. The northern districts, including Karelia, have few stormy days (the extreme northern areas have already been mentioned). Moving southwards, the number increases. In the central areas, there are from 18 to 25 thunderstorms, with some places that report as many as 25 and more. It is interesting to note that in these same latitudes we encounter a zone with less than 20 storm days (for example, Smolensk), which corresponds, so to speak, to a shift of this locality 500 kilometres northwards.

The total number of thunderstorm days increases very sharply in a south-westerly direction, but not beyond the latitude of Kharkov, where it again falls off towards the Black Sea. The shores of the Caspian Sea have very few thunderstorms.

The mountainous regions of the Soviet Union are rich in thunderstorms: the Southern Urals every year sees some 25 to 30 storm days. The thunderstorms here are very severe and frequently attended by violent squalls and hailstorms. The North Caucasus is the most thundery region in the U.S.S.R.

Beyond the Urals, over the vast lowlands of Siberia, the number of storm days falls to 10-12 a year, and even to 6 on the shores of Lake Baikal. Towards the Far East coastline, thunderstorm action increases, especially in places where the terrain holds up the southeastern summer flow of maritime air from the Pacific Ocean. A goodly portion of the thunderstorms in these areas is connected with typhoons, which will be described later on.

Summer thunderstorms predominate over the territory of the Soviet Union, with the exception of regions where there is little rainfall in summer, such as the eastern part of the Transcaucasus and Central Asia. Thunderstorms are most frequent here in spring and autumn, because the temperature is low in winter in these parts of the country, while the summer is excessively dry.

On the Black Sea coast, too, thunderstorms are most frequent in the spring and autumn. Along the Soviet Baltic coast



there are few in April and May and more in August and September.

Winter thunderstorms in the middle latitudes are an extremely rare occurrence. Statistics say that there is only one thunderstorm in ten years. The warm and humid Black Sea coast of the Caucasus alone produces 20 per cent of the winter crop of thunderstorms.

### Local Indications of an Approaching Thunderstorm

Lenin wrote: "A miraculous prophecy is a fairy-tale. But scientific prophecy is fact."

Scientific prophecy (prediction) of the weather, both short-term and long-term, is the task of the Weather Service of the U.S.S.R. It is headed by the Central Institute of Weather Forecasting in Moscow. Several times a day the Central Institute and the weather bureaus of the republics and the *oblasts* (regions) broadcast reports of the weather and give forecasts for the next 24 hours, for the month, and sometimes for longer periods.

But, as we have already seen, thunderstorms are frequently local in character. For this reason, no forecasting office, at the present level of science, can make a forecast sufficiently detailed to indicate at what points a thunderstorm is expected to pass. The weather bureau is only able to state a large area and the degree of probability of the storm appearing within it.

However, any careful observer with a general knowledge of the mechanism of thunderstorm phenomena and the conditions under which they originate can predict one a few hours before it arrives if he makes use of local indications that presage changes in the weather.

Local indications, or scientific weather lore, reflect phenomena that have been known to occur in the atmosphere. In this respect, it is very helpful to watch the state of cloud, temperature and humidity, the wind and other elements of the weather. Very useful likewise are air-pressure observations,

even with a simple aneroid barometer. But many valuable conclusions may be drawn without any instruments at all. How familiar is the ability of old-timers to foresee the weather, for theirs is the accumulated experience of daily observations.

Let us consider a few local signs that enable us to predict a thunderstorm, at times within 6 to 8 hours of its onset.

To start with, never forecast a thunderstorm on the basis of a single sign. Several are needed for comparison, and the more that coincide the more accurate will the forecast be. You can really be sure of the coming weather if the signs all point in one direction.

It is more difficult to foresee a thunderstorm if the various signs are different or (all the more so) contradictory. In this case, select the most prominent ones and see what conclusion can be drawn from the largest number of mutually corroborative signs.

One of the most reliable and true signs of an approaching thunderstorm are turret-like altocumulus clouds. They are not only indicative of thunderstorm weather but also serve to predict the actual storm. These clouds usually make their appearance in the early morning hours, at times, on an absolutely clear sky, about 12 to 20 hours before the storm. They look like fleecy plates that grow little protuberances, which later take on the form of tiny turrets. The whole process sometimes takes only 5 to 10 minutes, with some of the growths appearing and others disappearing. Experience shows that the smaller these altocumulus turret clouds are and the higher they get, the later the thunderstorm will strike (sometimes a whole day later). Large clouds, on the other hand, suggest that the storm will break out in only some two or three hours after they appear.

The high turreted clouds, called altocumulus castellatus, that usually make their appearance at 4 kilometres altitude indicate that the temperature at these heights falls very rapidly and that the unstable state of the atmosphere here is already accompanied by convection. If low cumulus clouds begin to develop and, with their summits, penetrate to the level of the "castle

clouds" the subsequent growth of these lower ones will be violent and will soon lead to a thunderstorm.

The humidity of the air is one of the most significant signs of an approaching thunderstorm and also of the degree of its intensity. If the amount of water vapour in the air increases appreciably, you may expect a thunderstorm. It is well to repeat that much of value can be obtained from observations of the clouds. Every experienced weatherman "reads" the clouds freely and deciphers from them the atmospheric processes.

The following are some signs that help to predict thunderstorms.

Almost every summer day, during fair weather, one can see cumulus clouds appearing at about 10 in the morning. They build up during the daytime but by evening usually disperse. The weather does not change. But then there comes a day when the cumulus clouds show up in early morning, grow rapidly, and by noon attain mountainous proportions several kilometres high. The sun is more and more often hidden by them. And in a few hours the heavy clouds build up into a thundercloud, hiding the sun completely. Peals of thunder are heard in the distance. A thunderstorm is inevitable.

A careful glance at the approaching cloud sometimes reveals a shield of cirrus (feathery) clouds just above the summit, the so-called anvil. We already know that this is an indication of ice forming in the upper parts of the cloud and that hailstones are present. If the air temperature is not very high, the hailstones will be small and will melt on the way down, reaching the ground as big raindrops. But if the weather is sultry and hot, the anvil builds up to great size very quickly. This means that the cloud has many large hailstones that will definitely reach the ground.

A cloud with falling hail is ashy in colour with conspicuous white streaks on the leading edge (these are falling pieces of ice). As the clouds approach, a continual rolling of thunder is heard that turns into a crashing and banging. Another very typical thing is the far-off noise of hail hitting the earth. In this case, the flashes of lightning are seen only between clouds.

Strokes to the earth are not in evidence, though science is not yet able to account for it in any way. Observant people seeing a cloud like this accurately predict hail.

When a stormcloud approaches with very low base and ragged edges, while the summit extends way up, the thing to expect is a squall.



In Northern France the Oise River flooded  
the streets of the town of Guise



Squall cloud

In middle latitudes, thunderstorms are sometimes known to occur at night. Nocturnal thunderstorms can likewise be spotted by the type of cloud. Usually, on the eve of a nocturnal thunderstorm following a fair day, the sky, by evening, is covered with a veil of cirrus or thin altostratus clouds. At this time, low stratus clouds glide past the setting sun. Although the air is unusually warm, the wind does not die down by evening, there is no dew, and the grass and trees remain dry. The barometer gradually falls.

It is possible to forecast a night thunderstorm from other signs too. For instance, if altocumulus ("sheepback") clouds are seen in the morning, and towards evening there appear stratocumulus clouds with falling pressure, one may expect a noc-



Alto cumulus turret-like clouds



Heavy cumulus clouds before a thunderstorm      a      Stratocumulus clouds before a thunderstorm

turnal thunderstorm. It may likewise be expected when cumuli-form clouds do not dissolve by evening, but, instead, continue to develop.

A particularly true indication of impending thunderstorm during the summer months are opposite currents of air that may be detected by the cloud movements. For example, cumulus clouds move from the east, while altocumulus come in from the west. One must be careful, however, not to make the mistake of regarding clouds of different levels as moving in opposite directions when the lower-level clouds (closer to the observer) appear to be overtaking the upper ones, although in reality the upper clouds are moving much faster.

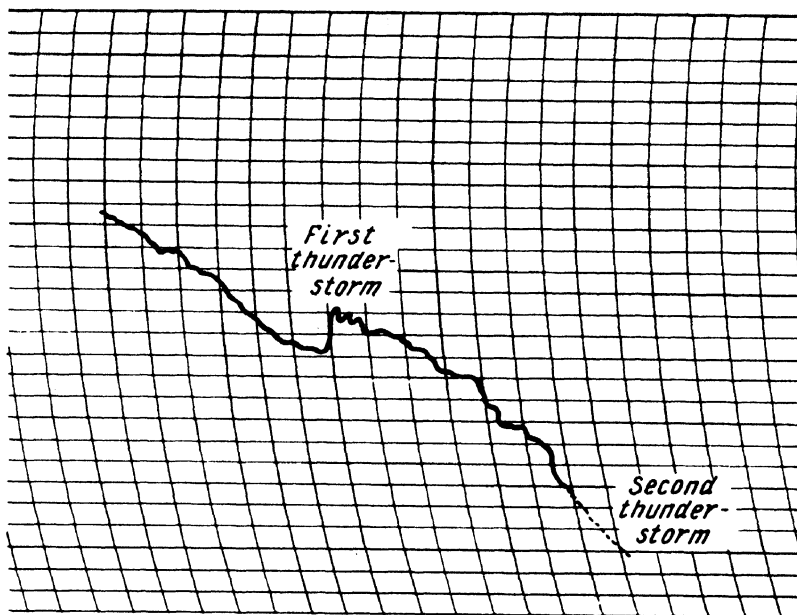
If after a thunderstorm has passed, the ground wind begins to blow in the same direction as prior to the storm, and the pressure again begins to fall rapidly (see figure), one should expect another thunderstorm.

When a cold front is approaching the point of observation, the stormclouds move in line formation. Their low base covers a good portion of the horizon and, in virtue of perspective, they appear as a huge arc with a sheet of falling rain (which is lighter than the remainder of the cloud).

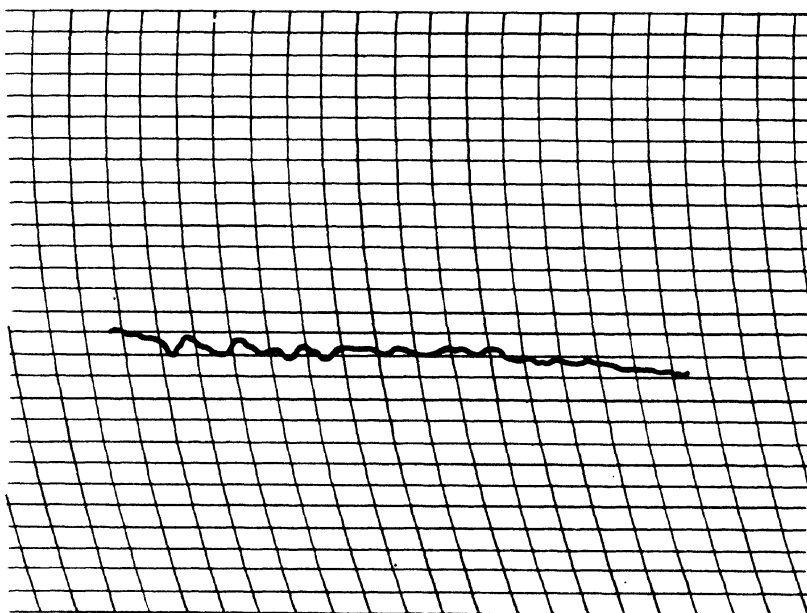
The air pressure preceding a thunderstorm falls but slightly in the case of local (or heat) thunderstorms and more strongly, in jerky steps, in the case of frontal storms. The wavy nature of the barogram indicates a storm approaching or passing nearby, frequently in the field of view.

A thunderstorm is frequently preceded by a pre-storm haze. The sun becomes dim, appearing as a yellow disk that is easy to look at. Radio listeners hear more interference. There are also indications that foretell fair weather. For instance, abundant dew is usually seen to fall on the eve of a fair spell. If at night a fog descends on to a river, pond or lowland, and dissipates early in the morning before sunrise, the day will be clear. A cool night after a hot summer day is a true sign that the clear dry weather will continue for a long time.

It is also possible to determine the weather from the behaviour of animals and plants. Swallows usually fly high in



Barometric pressure in repeated thunderstorms



Barogram showing the approach of an air-mass thunderstorm

advance of fair weather and low, along the ground, before a rain. Sparrows take dust baths before rain.

Before a spell of warm fair weather, ants are particularly active, and spiders race about their webs in among the bushes; cocks crow right up to midnight, and the evening air is filled with swarming clouds of mosquitoes. But if the bees stop gathering honey from the flowers, and hide away in their hives with loud buzzing, you should expect rain.

Flowers are living barometers too.

The leaves of the red meadow clover fold up at night and on overcast days before a rain. If the water lilies suddenly close the petals of their pretty flowers, expect rain any minute even if the sun is shining brightly. If the corolla of celandine and the caps of lady's-smock droop, rain is coming. Nearly all meadow and garden flowers, lilac, and jasmin are most fragrant just before a rain. Thus, not only indications of the weather, that is, observations of the life of our ocean of air, of the wind, the cloud movements, the stars, the temperature and humidity of the air, but also observations of the plants and animals help lovers of nature to foresee the weather.



## CHAPTER TWO

### RAINSTORMS

The products of the condensation of water vapour that fall to earth in solid or liquid form (snow, rain, hail, and so forth) are known as precipitation.

The quantity of rainfall is not the total volume of water, but the height (in millimetres) of the layer that would form if the water did not flow off, soak into the ground, or evaporate.

A small rain produces a very thin layer of water, as will readily be seen on a flat asphalted area with no run-off. But if we begin to reckon the amount of water that has fallen over a big area, the figure will be enormous. A rainfall that yields a one-millimetre layer of water, pours 10 cubic metres (over 900 buckets) of water on every hectare of land (1 hectare = 2.471 acres). A light rainfall will produce 2 to 3 millimetres of precipitation, a moderate rain, from 5 to 10 millimetres—which shows how lavishly nature waters the earth.

A heavy rain (thunder-shower or cloud-burst) is one that yields 1 millimetre of precipitation in one minute. This quantity is determined by a special instrument called a self-recording rain-gauge.

In the middle belt of the Soviet Union, a heavy rain can yield up to 1.5 millimetres of precipitation in one minute, which is 1,350 buckets of water per hectare. Measurements after thunder-showers have often shown from 30 to 40 millimetres and more of rainfall. This means that over 30,000 buckets of water were dumped on every hectare of land.

Downpours like this occur every year.

In July 1882, a heavy thunder-shower broke loose over Kukuyevskaya Station on the Kursk Railway. The rain came down in a constant torrent for several hours running. Freshets coursed through the lowlands like a spring flood. This rain-storm unloosed 140,000 buckets (158 millimetres) of water per hectare, and may be recorded as exceptional.

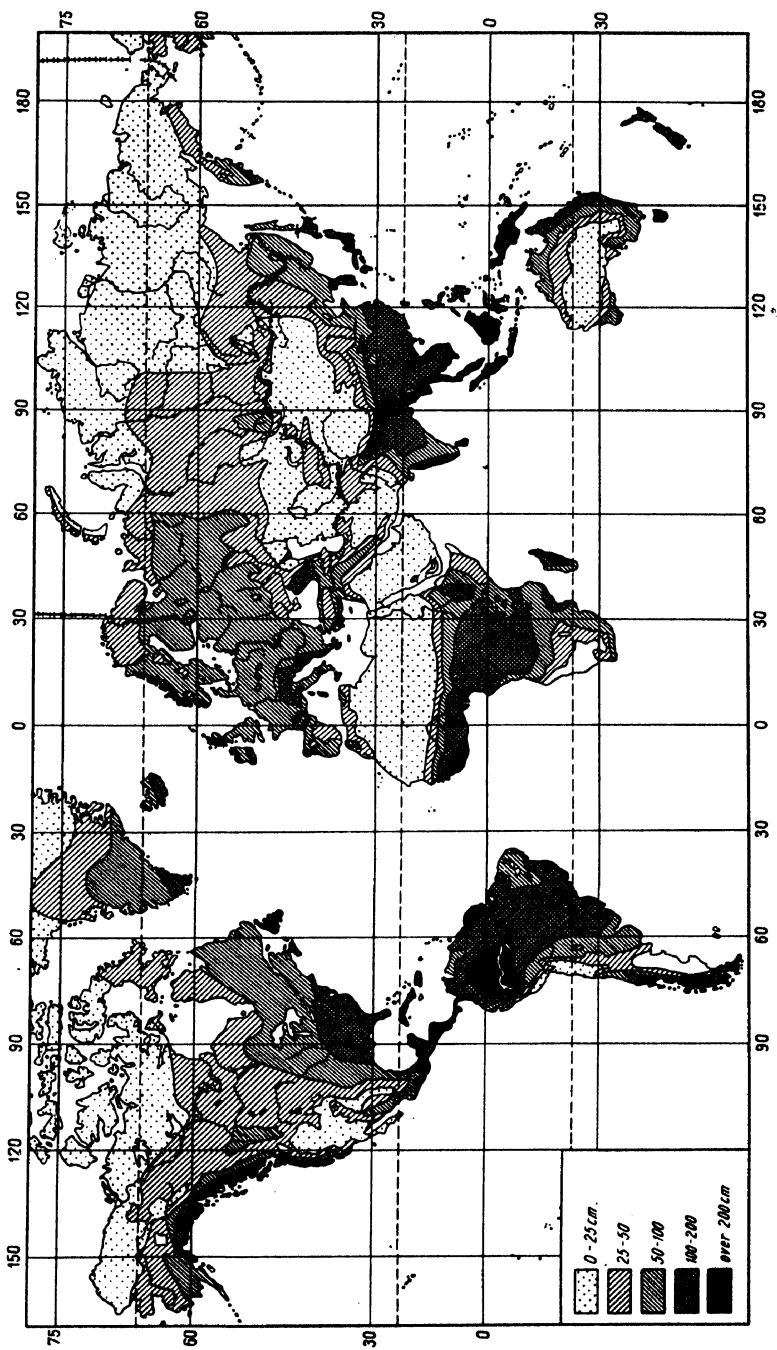
Thunder-showers are stronger in southern latitudes. In the Crimea, for instance, showers can yield 3 millimetres, while the Caucasus mountains do up to 5 and 6 in one minute.

Still more intense are the tropical downpours. During a storm in Kauai (Hawaiian Islands), 86 millimetres of rain fell in 4 minutes, which is 21.5 millimetres a minute. The tropics have witnessed torrential rains a metre deep in 24 hours. Which is just about twice as much as Moscow gets in a whole year!

The "Precipitation Map" on the opposite page shows how conspicuously these areas cluster about the equator.

In the Soviet Union, the area about Batumi has the highest rainfall—an average of 2.5 metres annually. On the whole, however, the intensity of rainstorms and the quantity of precipitation increase in the direction from north-east to south-west. Northern weather stations have recorded a maximum of 70 millimetres, those in middle latitudes, 100 to 120 millimetres, and the south-western stations, 140 to 160 millimetres. An exceptional downpour in August of 1889 near Kishinev resulted in 208 millimetres, in Sochi it was 246; and in August 1949, Kishinev had 260 millimetres of rainfall. This is the peak daily maximum for over half a century.

Mountainous terrain has a marked effect on the intensity of rainstorms. To windward, the mountains serve as a barrier for air currents, and favourable conditions are created for great uprushing of the air. This builds up the velocity of the vertical air current, which leads to a particular development of shower clouds and, hence, to veritable cloud-bursts. For this reason, though we have generally diminishing rainfall to the east, there are places in the Urals with maxima of 120-130 millimetres in



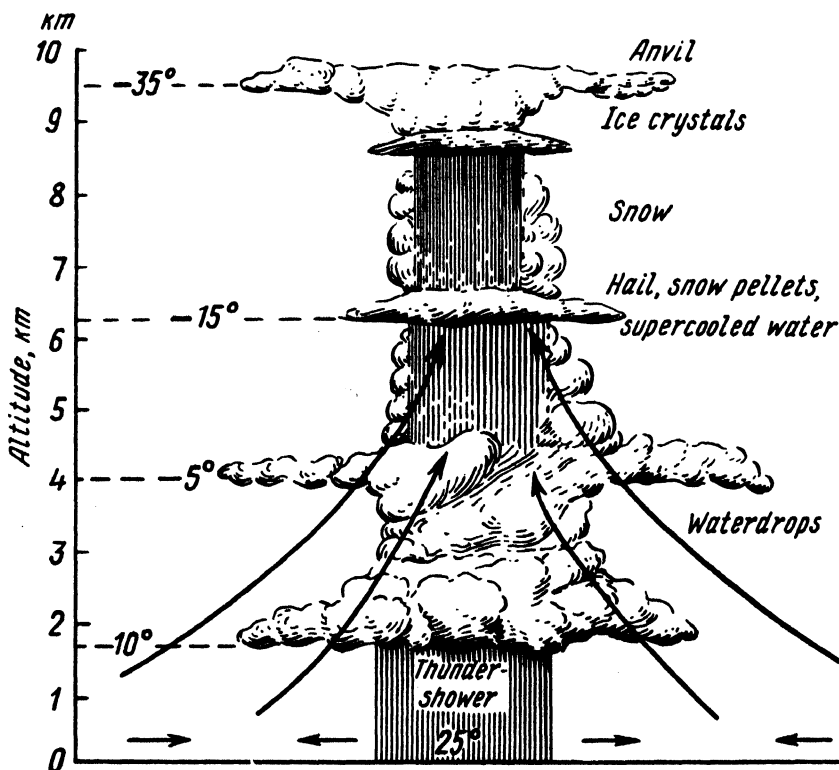
Distribution of precipitation

24 hours; the Caucasus has had 180 to 200 millimetres in 24 hours.

The 24-hour maximum falls off perceptibly towards the south-east, with Uralsk, for instance, having 88 millimetres and Orenburg only 71.

How frequently do torrential rains occur in the Soviet Union?

Statistics show that heavy rains yielding over 150 millimetres are an extreme rarity—once in a hundred years. Rains with less precipitation, say from 40 to 60 millimetres, occur in the south-west of the U.S.S.R. about six times in 10 years, in the central districts of the European part of the country, four times, and twice in 10 years in the north. Naturally, the less intense the rainstorm the more frequently it is known to occur.



Vertical cross-section of raincloud

Where does the atmosphere get such large quantities of water? How do rainstorms originate?

We already know how thunderclouds form and what conditions are necessary for their growth.

With the development of aviation and its higher ceilings, more attention was turned to a study of clouds, especially the cumulonimbus type. Special flights were organized into rainclouds with recording instruments. Glider pilots, too, have flown in rainclouds in bold raids and have done much both for aviation and meteorology. Thanks to this we are well acquainted with the structure of rainclouds.

Let us see what happens inside a raincloud. The drawing on p. 170 gives a cross-section of such a cloud at the peak of a cloud-burst. The vertical scale is in kilometres. The base is about 1,500 metres up, while the summit rises to 9 kilometres.

This mountainous cloud is the scene of the most intense atmospheric turbulence, and its structure is so complicated that it is rightly called the "factory of the weather." An interesting thing is the vertical temperature distribution. When it is 25°C. on the ground, the temperature at the base of the cloud has fallen to 10°, and at 4 kilometres height, to minus 5°. Above that are severe frosts, reaching 30° below at an altitude of 8 kilometres. Due to this temperature distribution, the first third of the cloud consists of water drops, the second, of a mixture of super-cooled water,\* hail and snow pellets, and the last third, of snow. This snow plunges earthwards in a solid sheet of large flakes into the lower levels and is observed from below as white streaks and bands fringing the cloud. Yet, watching a thunder-shower, it is hard to imagine a real winter snowstorm in play aloft. Only the falling hailstones tell us that up in the cloud it is below zero.

From the very summit of the cloud, where it is still colder, there emerge cirrus, filament-like clouds (*cirrus fillosus*) consisting of tiny needles of ice, like the bristles of a brush.

\* In the pure state, water can cool to below zero, at times even to minus 15 or 20 degrees C., and more and not freeze. But it is enough for a snow-flake or ice crystal to get into such supercooled water and it will freeze instantly.

Inside, the cloud is seething and raging and writhing. Up-rushing currents carry fresh moist air from the earth's surface that feed into the raincloud in an endless flow. New droplets form and begin to fall; coalescing with others, they build up into heavy raindrops and plunge earthwards in a torrent.

Though there are hundreds of thousands of tons of water suspended in the air (in the form of raindrops, and sometimes hail), the supply would not be enough for a prolonged rain if it weren't for the influx of ascending currents. Nearby areas supply fresh portions of moist air to take the place of those that have gone up into the cloud. The new air rises gradually, cools, and the water vapour condenses into fresh droplets that grow larger and at last fall down, and so on, again and again.

This influx of water vapour and its condensation continues until, for some reason, the air currents weaken. As soon as this occurs, the cloud loses its cumulus form and spreads out, having exhausted its supplies of water. The stronger the upward currents and the greater the height they attain, the thicker the raincloud, the larger the raindrops, and the more rainfall there is per unit area.

### **The Destructive Force of Rainstorms**

Only rains of average force are useful to agriculture. Showers are often even harmful. During a heavy downpour, the water is not absorbed into the earth and runs off over the surface. It carries off the most valuable nutrient particles and in this way destroys the soil structure forming deep gullies and ravines. Heavy rains sand up rivers, break down their banks, and produce floods. They destroy roads and railway slopes, and cause landslides.

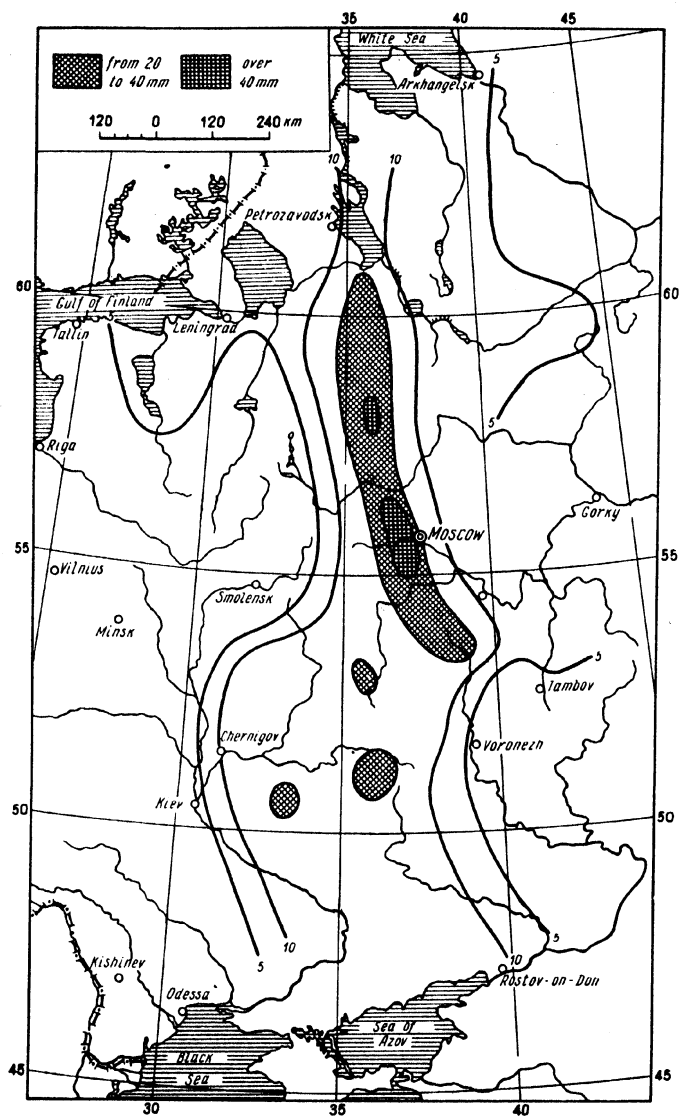
On June 23, 1927, over 100 millimetres of rainfall were recorded in 24 hours between Beliye Stolby and Leninskaya not far from Moscow on the Moscow-Donbas Railway Line. The Shebantsevo Weather Station registered 162 mm. The downpour lasted for several hours, washing out whole fields and cultivated plots. The entire harvest was lost and the hay ruined.

A few hours after the rain, the writer passed through this area. On both sides of the railway were veritable lakes of water that stretched on and on. Turbid whirling streams raced along where hardly a creek had ever existed. Isohyet lines on the map on page 174 indicate points with the same amount of precipitation registered during this rainstorm. The region of 20 millimetres or more rainfall forms an elongated belt from Ryazan Oblast (Region) through the entire Moscow Oblast and farther north. Inside this belt are two nuclei with maximum precipitation, where the weather stations recorded from 41 to 81 millimetres.

Showers always have a sharp boundary line: next to an area that has experienced only a few drops of rain is another one that is flooded. This phenomenon is readily accounted for if one recalls the structure of the raincloud—an isolated mountain of cloud with sides that fall sheer groundwards.

On June 29, 1924, the central part of Moscow received 95 millimetres of rain in an hour and a half, while Zamoskvorechye and the suburbs didn't get a drop. The damage done by the storm was considerable, particularly in the vicinity of the Gruzinsky streets. This comparatively low part of the city was virtually under water. The drainage pipes were not able to cope with the swirling streams and the water swept into basements and warehouses. In places it was a metre deep stopping all traffic. Herzen Street, which slopes down towards Manezh Square was a turbulent river of water that had picked up a newspaper stand and was whirling it along. In the Zoological Gardens, the ponds had overflowed their banks and were streaming into the currents coursing down the nearby streets. The Neglinka River, which had been put underground into a pipe, overflowed, sending a fountain spurting a metre and a half out of one of the manholes.

In the European part of the Soviet Union, the summer of 1933 gave a rich display of thunder-showers. They covered such a large territory and were so intense as to give rise to terrible floods on the rivers. In July the level of the Moscow River rose 7 metres. Pontoon bridges were swept away, and



Isohyets during the rainstorm of June 23, 1927



in places it was no longer possible to cross. The river was afloat with logs, boards and pieces of wood carried out of flooded areas. This mass of timber accumulated near ferry stations tearing the boats from their anchors, breaking steel cables, and inflicting all manner of damage.

The heavy rains raised the level of the Oka River and the Volga, and steamships navigated freely where once had been sand-bars. A large number of storage reservoirs, to say nothing of small ponds, overflowed, breaking through dams and rolled over the countryside. The rain damaged the railway bed, caused the ground to settle and twisted the tracks; landslides occurred on high embankments. Property loss from the rains went into the tens of millions of rubles.

A catastrophic flood was caused by downpours in France in January of 1955. The Marne and the Seine rose high above their normal levels. In many places the water swept away dams and dykes. The inundated area extended a hundred kilometres embracing about three hundred populated centres. Two hundred industrial plants had to be closed; a hundred thousand workers lost employment. Hundreds of roads were flooded, and traffic was held up on many railway lines.

In Paris itself, the water poured into a number of stations of the underground and whole blocks were flooded in a number of districts of the city.

During recent years, heavy floods have resulted from rainstorms in Canada, the United States, Italy, and Southern Korea. One occurred in May of 1950 when the Red River in the southern part of Manitoba Province (Canada) overflowed its banks. Large numbers of cattle and poultry were lost. Over a hundred thousand persons were left homeless. A sixth of the town of Winnipeg was under water, and an enormous lake 600 square miles in area extended from the city down to the state boundary with the United States. Dozens of small towns were flooded completely. Losses due to the floods reached hundreds of millions of dollars.

A terrible flood that lasted several months occurred in Italy in November 1951. The rains had been coming down for over

a week without letup—more than ordinarily comes in three months—and caused a big rise in the level of the Po River. The levees along the river failed in two spots. The water swept through the 800-metre wide gap with violent force and plunged onwards into the Po valley over the fields and gardens leaving complete ruin in its wake. In the village of Occhiobello, 100 persons lost their lives on the very first day of the flood. The streams of water carried off whole houses, uprooted trees and spread out over the valley. In just a short time, the cities of Rovigo, Adria, Cavarzere, and hundreds of villages were under water.

The Adige River flowing to the north of the Po, merged with the latter to form a huge lake. Over 6,000 square kilometres were inundated with the loss of fine fertile land that had been yielding two harvests a year. Casualties rose into huge figures. Hundreds of thousands of people were left homeless and propertyless.

At the beginning of July 1954, heavy rains and thunderstorms raged without letup for two weeks in Central Europe, starting an unprecedented series of floods. All of Germany, Austria, Hungary and Czechoslovakia was struck by this calamity, and the Danube and Elbe rivers overflowed their banks.

Floods in Bavaria (German Federal Republic) deprived 50,000 of their homes. The water covered over 165,000 hectares of land. Property losses amounted to roughly 500 million marks. Wrote the Hamburg newspaper *Die Welt*: "This great destruction could in large measure have been averted if the dams and levees had been kept in a proper state."

In the German Democratic Republic, the Elbe River raged with unusual force. A threatening situation arose in the area between Dessau and Magdeburg. But thanks to the energetic and combined efforts of state bodies, units of the German People's Police, and numerous volunteers from the working population, and also due to help rendered by the Soviet Army, the extent of the damage was not so great.

Soviet troops likewise greatly helped the population that had suffered from floods in various parts of Austria. In many

places, above all in Pöchlarn, Ybbs, Orling and Ponsee, they helped in evacuation and supplying the population with food.

A still bigger flood resulted from heavy rains along the Mississippi and Missouri rivers in mid-April 1952. Copious rainfall melted the snow rapidly in the headwaters of rivers overflowing the catchment basin of the Missouri-Mississippi system. As a result, nearly a third of the United States was under water.

The first rivers to rise over their banks were those in Montana and North and South Dakota. The flood then spread to Minnesota, Wisconsin, Nebraska, Iowa, Kansas, Missouri, and particularly along the Missouri River and the upper reaches of the Mississippi. Some idea of the property damage in the first week of the flood can be gained from the fact that in the town of Blenko, Iowa, that was inundated and abandoned, over half a million bushels of corn (maize) in the storehouses were lost.

As in earlier years, the main seat of the flood was the valley of the Missouri. The water level here went up several metres, and the avalanche of water plunged into the valley sweeping up everything before it. According to official reports, 1,250,000 acres of land, 50 towns, a large number of hamlets and farmsteads, and also considerable sections of railway lines and highways were flooded, and 114,000 persons were homeless. In the single town of Council Bluffs, Iowa, over 40,000 people fled from the raging elements. Property losses due to the flood came to hundreds of millions of dollars.

Pouring rains and storms at the end of December 1955 caused another flood on the western seaboard of the United States, affecting three states: California, Oregon, and Nevada. The water of ten big rivers burst their banks and flooded the towns of Santa Cruz and Klamath in California, Reno in Nevada and others in these states. The flood claimed many lives and caused enormous property damage in 23 counties.

In mid-September 1952, Southern Korea experienced the most severe flood in the past thirty years. The western coastline was flooded over a vast area due to intense downpours that had

been continuous since the end of August, and also a typhoon that swept in from the Yellow Sea. The Kimgan, Yensangan, Chomchingan, and Sangan rivers burst their banks, inundating many towns and whole counties. Tens of thousands of hectares of rice and sorghum fields, and orchards and gardens went under water. Mountain streams coming down the slopes of volcanoes turned into impetuous rivers that swept before them absolutely everything.

The Northern Chola Province suffered most, in particular districts along the Kimgan River. Here the water level rose 7-8 and in places even 10 metres. In this province alone, twenty thousand peasant families and the families of many office and factory workers in the towns suffered. Several thousand people were drowned in Kimchzhe County, and some two thousand sought refuge for many long days and nights on hills and volcanoes surrounded by water. Nearly the entire population of the county was left without shelter, food or any means of existence. During the one week between September 12 and 18 the water carried away over three thousand peasant houses along the western coast of South Korea.

Such is the picture of rain floods and their terrible consequences in the moderate latitudes.

Rivers in the tropical zone overflow during the rainy period, when thunder-showers are enacted every day. They are so intense that a single rain precipitates far more water than a whole rainy month in Moscow. All the tropical rivers swell up and burst their banks. Such big rivers as the Amazon and the Orinoco raise their level tens of metres. A flood area turns into boundless expanses of water that freshen up the littoral waters of the ocean for hundreds of miles out.

Since heavy rains in the hot countries come only at a definite season, the floods occur with remarkable regularity. For instance, the Nile overflows every year on July 5 or only a few days earlier or later. At this time, the fields come to life as if by the stroke of a magic wand. Before the flood, the water level in the lower reaches of the river falls to a minimum, and even the smallest ships are unable to navigate it. Numberless

sand islands stick out and big, black-slime areas of the river bed open up. Then at the beginning of July, without any apparent reason, the water in the river begins to rise, until by August it overflows the banks, rushing out into the adjoining fields. Actually, the reason for this flooding of the Nile is extremely simple: heavy rains fall at the headwaters of the river in Ethiopia, and enormous masses of water move downstream.

In January of 1952, Java experienced 4 metres of rainfall in three days, which is the usual seven months' supply. The result was the biggest flood in the last 20 years. The raging waters inundated the plantations destroying the crops. Traffic on the railways and highways was interrupted. A large number of people perished.

In the middle of February 1955, torrential rains in Indonesia caused another flood that struck the largest islands of the country—Sumatra, Java, and Borneo. This flood was a veritable national calamity. In the central part of Java the water washed away or damaged over 11,000 houses, inundating hundreds of hectares of rice fields. In this district alone, the losses were reckoned at 10,000,000 rupees.

The Island of Sumatra was most heavily stricken. Roads connecting the cities of Palembang, Buikittingi and Djambi were destroyed. The Djambi district got it worse with 350,000 out of 400,000 inhabitants suffering from the flood.

The overflowing of Australian rivers is particularly disastrous. On the whole, the Australian continent suffers from a lack of water; nowhere on earth are there so few rivers as in Australia. But everywhere one finds winding creeks, meandering gulches, and the dried-up beds of rain streams. Every down-pour sends turbid rushing freshets through them. Any road, or trail will turn into a threatening flow of water which will inundate whole towns. Boats become the only vehicles. The water demolishes bridges, fences and houses. People are drowned in lakes of grimy water. Rivers which days before had been mere trickles now overflow their banks inundating the countryside for miles around.

One of these floods occurred at the end of February 1955 when the Hunter River overflowed. There were six fatalities, 13 missing, and about 10,000 persons left homeless. The flood hit 50 communities in the valley of the Hunter. A large number of towns were cut off from the outer world, and telephone communications were disrupted.

On February 11, 1956, Radio Melbourne reported that pouring rains in New South Wales had caused one of the worst floods in Australian history. In the Sydney area (second city of Australia) hundreds of families had to leave their homes. Many tried to save themselves on the roofs of buildings. The suburbs were cut off from Sydney and the main roads were washed out. The army was in charge of rescue work in the flooded areas.

The great Chinese rivers Hwang Ho and Hwai Ho literally rage after heavy rainstorms. Up until recently, these rivers were the cause of the greatest natural calamities in the provinces of Henan, Anhoi and Tsyansu. The Hwai Ho valley has experienced some 1,000 floods in the past 2,000 years—one every other year. They have originated in the summer rains due to the monsoons that blow from the Indian Ocean. The Hwai Ho and its tributaries swell up from incessant rains. During this period the middle reaches of the river have a discharge rate of 13,000 cubic metres a second, whereas the discharge capacity of the river on this section does not exceed 6-7 thousand cubic metres. Inundations of the Hwai Ho River spread at times to 30 kilometres.

One of the most terrible floods occurred in November 1887. Nearly a sixth part of the vast territory of the Honan Province, called the "Garden of China," was inundated and converted into an enormous lake the size of Holland. That this was once a city could be seen only from the few pointed roofs of pagodas or the spires of towers. A huge dam on the Hwang Ho River near the town of Kaifeng was broken along a stretch of several kilometres. Everything aboveground was swept before surging waters. Not less than 3,000 large villages were wiped out in the first few hours, and almost the entire population perished.

The Chinese have fought floods for ages, but the struggle was without system. It frequently happened that the saving of one place resulted in the loss of another. The floods became particularly catastrophic after 1938, when the Kuomintang destroyed the dam on the Hwang Ho which flows north of the Hwai Ho. This was done purposely to hold up the Japanese troops in Northern China and direct them against the communist areas of the country. The waters of the Hwang Ho rushed southwards breaking into the basin of the Hwai Ho River, demolishing the bank reinforcement, and filling up the river bed with sediments. This flood took a toll of 500,000 lives and left 3,000,000 persons homeless.

Since that time, the Hwai Ho River overtopped its banks every year. And although in 1947 the river was again turned into its old channel, floods did not diminish, since by this time the river channels had become filled with sediment.

It was only with the establishment of the Chinese People's Republic that the situation changed radically. Solicitous of the needs of the working people, the government of the new democratic China launched a plan for the construction of new irrigation structures, the repair of levees, the draining of lands swamped up due to flooding, the building of irrigation canals and dams, the dredging of river channels, and the like. All these measures have already saved millions of hectares of arable land from inundation. To illustrate, a big irrigation job was completed on the Hwai Ho River in 1953. Many hundreds of thousands of peasants, who took part in this nation-wide construction job, completed, in the headwaters of the river, spillway dams and locks at the Chentsuwan storage reservoir, dug a diversion channel in the lower courses of the Hwai Ho River, created a ramified network of irrigation canals, and deepened the channels of the tributaries of the Hwang Ho—the Chung Ho, Pung Ho, and others. The Nawan, Poshan and Fotszuming storage reservoirs have been completed. And the locks on the San Ho River are ready. The labour enthusiasm of the peasant brigades and the industrial workers that arrived to

help them has made it possible to put new irrigation structures into operation ahead of schedule.

Another calamity is the flooding and silting up of the lower reaches of the Hwang Ho. Not a single river in the world has as much silt as is carried by the waters of this stream. The sediment raises the level of the river 10 centimetres every year.

In July 1955, the All-Chinese Assembly of People's Representatives, in session in Peking, unanimously adopted a tremendous plan of construction on the Hwang Ho River. The plan to tame this "most unruly river in the world" provides for converting it into something like a "water ladder," the steps of which will be 46 dams. As a result, the flood menace will be overcome, the water will become pure, and the channel constant. Add to this the annual generation of 110,000 million kilowatt-hours of cheap electricity by new power stations. This is ten times the power resources of the whole of China in 1954.

The construction of dams on the Hwang Ho River will increase the irrigated area at least seven times over, bringing it up to 7.7 million hectares. The yearly grain crop from the irrigated lands alone will increase by about 7 million tons, and the cotton crop, by 600,000 tons. Lastly, the dams will make the river navigable all the way up to Lienchou. This will result in a considerable extension of the water-ways throughout the basin. The day is not far off when floods on the Hwang Ho—and in other parts of China, too—will become an impossibility.

The first serious test of a system of protection that has not yet been completed occurred at the beginning of August of 1954 when rainstorms of unprecedented duration and force hit extensive areas in Central-Southern and Eastern China. In some places, the rainfall in two to three days was as much as occurs during the most rainy month of the year. The level of the Yangtse and Hwai Ho rivers jumped way up. Over 800,000 people came out in a heroic struggle against this natural calamity working on the building up of levees to protect the Hwai Ho channel. The whole country was tense as it watched the duel between raging nature and the courageous inhabitants of Hankow. Day by day the water in the river



rose, and day by day the hundred-kilometre long levee protecting the city also rose. Fishermen and boat owners anchored a five-kilometre line of rafts along the embankment so as to protect the dam from waves raised on the Yangtse by a hurricane wind. All along the levees one could see piles of bamboo mats, stones, and sacks of earth prepared in the event of a break-through. Emergency groups were on round-the-clock duty along the levees.

Several tens of thousands were on the look-out day and night to see that nothing happened to the dam of the Tsingkiang storage reservoir that was built during the years of people's China. Rains in the upper reaches of the Yangtse and in the region of Lake Tungting brought the level of the water so far up that in order to save the dam it was necessary to flood not only the reservoir but also some of the adjoining territory.

This natural calamity put the population of several provinces of China to the test but did not break the will or spirit of the working people. In these trying days, the people, at times risking their lives in the struggle with the raging elements, were thinking not only of their own homes but also of the fate of all the people. And the forces of nature retreated before the selfless and combined efforts of the people.

During that period India also experienced an unprecedented flood that covered a territory of 4,500 square miles between Purnea (State of Bihar) to Kutch Bihar (West Bengal). The flood affected 300,000 persons in the northern part of Bengal, 7 million in the district of Tirhut, and 600,000 around Darbhanga. In the districts of Singhla, Jalley, Janjarpur and Bahar the water wiped out 100 villages. Four hundred thousand suffered in Nirmali, Pratapgange, Bhimnagar, Supaul, Kshinapur, Sahars, Bangaon, Madhipur, Singeswar, Asthan and Sourbazar. Floods also occurred in some regions of Nepal and in East Bengal.

In the State of Bihar, 8,000 villages suffered from the flood; the railway bed was damaged over a distance of 460 miles. According to estimates of the Bihar government, property losses due to the flood were reckoned at 100,000,000 rupees.

The Brahmaputra River overflowed its banks and flooded the State of Assam.

After heavy rains, every river destroys its banks and builds up new islands, spits, and bars from the eroded material. It meanders, leaving behind old channels (ox-bow lakes) that gradually grow over and then dry up altogether.

Farm lands too suffer from heavy rains. It has been computed that a single downpour can wash off 40 to 50 tons of the upper plant-feeding soil layer from one hectare of cultivated steppe land inclined at only 2 degrees.

Gully formation is another negative aspect of heavy rainfall. It is amazing how fast gullies develop in downpours.

There are particularly many gullies in the steppe regions of the southern and middle belts of the European part of the Soviet Union. For the most part, the soil of this vast territory is the rich chernozem underlain by sandy clay with a substantial admixture of lime. Such clay is very easily scoured by rain-wash. Tiny rivulets are often sufficient to start a gully. A crack that appears in the ground during a dry period, or a rut in a road can serve to originate pathways for the rushing water.

In summer thunderstorms, swirling streams scour the soil forming multitudes of waterfalls and cutting deep into the sandy soil. A channel with steep sides and narrow bottom is very quickly formed. This is the future gully. With every rain it scours deeper and digs forward. Collecting from a vast area, the turbid waters plunge into the channel, excavating ditches and holes along the bottom, and erode the earth and soil, carrying them downstream and depositing them in a thick layer on the fields and meadows. The greatest erosion is at the top of the gully. Here, branch gullies soon develop resembling the clawy paws of a monster as they split up and reach out in all directions. A crazy patchwork of channels slash through an immense area.

The gullies grow with astonishing rapidity. In 1870, surveying was done near Kharkov for construction of a railway line. In 15 years the site was seen to have developed enormous

gullies, one of which was 120 metres in length, and 28 metres deep, another 220 metres long and 6 metres deep.

What raging waters can do in gullies after a downpour is described by A. P. Nechayev when on a visit to the outskirts of Saratov. "Numerous gullies branched off in all directions like dark serpents writhing over the countryside. The very next day after my arrival I went on an excursion. Turning off the road into the first gully I was amazed by the picture that confronted me. I suddenly found myself in a wild, dark, and wet ravine. The sun's rays did not reach the bottom of it. And the farther I went the higher rose the walls. Above me there remained only a narrow strip of blue sky. All at once came a far-off roll of thunder, then another, then a third. A thunderstorm was approaching. Several large drops struck me in the face, and a whirlwind passed overhead, where the dust was in a turmoil. It had now got dark down here; I realized that rain was approaching and that the water would come rushing down the ravine. I was in a trap. To climb straight up these steep crumbly bluffs was impossible. But I had to get out. And so I ran stumbling over the stones that cluttered the bottom of the ravine. The rumbling thunder was coming closer and closer. I ran as fast as I could. All of a sudden from a distance came a muffled noise. There was no doubt that this was water coursing down the ravine in a tempestuous stream. I ran faster still as the noise drew nearer. And just as I reached the road a muddy flow of water plunged into the gully. I climbed up the steep bank of the newly formed river and, seeing it now in full play, I realized the danger that I had been in. Below was a seething, foaming mass. Rushing over the rocks and tearing off huge hunks of earth from the banks, it plunged forward in a fury, all the while rising higher and higher. There had obviously been a cloud-burst in the upper part of the ravine. . . .

"As I approached our house, I saw a whole crowd of people bunched around the garden behind. It was unbelievable. The garden was gone and in its place was raging water that had spread out into a whole lake. From all the gullies around, the water had rushed into the river, broken through the dam at the

mill, and, in a furious stream, had swept away structures on the bank. The water had us hemmed in. It had merged with our pond and was coming up to the house itself. . . ."

The roads in localities cut by gullies are so tortuous and skirted by such steep slopes that one can drive only in the daytime and then only with the greatest caution. New gullies appear every year, making wide detours or new bridges necessary.

Gullies are detrimental to agriculture in that they dry up the countryside. Cutting deep into the land, a gully intercepts the ground water which before had reached the surface as springs. And so in localities replete with gullies the streams, wells, and ponds gradually dry up and vanish from the face of the earth leaving behind only dry depressions—mute witness to their former existence.

Though the northern half of the European part of the U.S.S.R. experiences rainstorms, there are hardly any gullies. Why is it that the sands and clays that underlie the topsoil layer here are not scoured out?

The answer lies in the fact that the north is wooded while the south is steppe land. Forest vegetation anchors the soil with its roots, thus protecting it from erosion. Gullies cannot form until the vegetative cover is damaged.

Rainstorms in mountainous areas are often disastrous. The mad rushing of mountain rivers, especially after thunder-showers and during the summer melting of the snows, is a common experience. Enormous rocks thunder down the mountainsides into the valleys below, sweeping away whole communities and covering up the fertile valleys. Cloud-bursts in the mountains give rise to roaring streams that race at breakneck speed into the dry valleys below. In mountain valleys one is often impressed by piles of gravel with smoothed and polished fragments. Could it be that these stones rolled down here by themselves? And why so many of them? These glacier-polished boulders are brought down by torrential rainstorms.

Particularly extensive is the damage when a stream plunges down into a big valley and dams up the river channel. In a

short time the river overflows its banks, inundating the fields around, carrying away dwellings and domestic animals, and killing people. There have been cases when masses of gravel and rock have stopped up a river, giving rise to a new and permanent lake. More often, however, the stream breaks through the dam. It is one thing if this takes place slowly. But quite frequently the water breaks down the dam and plunges into the valley below sweeping away everything before it.

In mountainous areas of the U.S.S.R., such torrential floods are common. They often lead to great destruction and loss of life in the Tien Shans, Zaili Alatau, and other mountainous areas. Floods of this kind in the Caucasus just recently (1953) did a great deal of damage.

Up till now we have been speaking of showers of rain. What about showers of snow?

In the winter time there is much less vapour in the air than in other seasons, due to low temperatures. In winter, the amount of heat delivered to the surface (snow) by sunshine is negligible; for this reason, convection is weak, condensation of water vapour is diminished, and clouds are spread out and stratified. This is why the very strongest snow-fall in winter is a far cry from summer precipitation. If in such storms the snow-flakes melted in the air, only minute water droplets (a fine drizzle), would reach the ground. And true enough, the density of freshly fallen dry snow is from 10 to 15 times less than that of water. You can prove it to yourself by cutting out a chunk of compacted snow and melting it. The only exception is wet snow that falls at temperatures close to zero degrees Centigrade in large flakes. But then it is not made up of single flakes but hundreds held together by drops of water.

This is why the very heaviest snow-falls cannot give the amount of precipitation observed during summer rainstorms. Still, meteorology uses the term "snow shower." This is an intense fall of snow (usually attended by a squally wind) that begins suddenly, continues for only a short time, and just as suddenly ends. Sailors and wintering-over parties in the Arctic are familiar with such short-lived snowstorms.

In the southern part of the Soviet Union, shower snow sometimes lets loose together with a thunderstorm.

Winter precipitation, on the other hand, can last a long time—all day and all night and more. In such cases the volume of snow is tremendous. And transportation is extremely difficult if the snow-fall is accompanied by a strong wind (blizzard), by frosts, and if it takes place in open country.

On March 8, 1932, Moscow experienced a snow-fall of 30 centimetres in 12 hours. In volume, this is equivalent to several millions of cubic metres. Traffic was at a standstill, and the city looked like a big snowed-under village. Thousands of people and hundreds of machines worked to clear it away.

The winter of 1929 was very severe in the Crimea. Big flakes of snow began to fall in Yalta on the evening of February 6th, and by morning it was 75 centimetres deep. With brief intervals, the snow continued to come down until the 10th, and by that time the layer of snow had reached one metre. Interurban traffic stopped altogether as the Crimea experienced the heaviest snowfall in 50 years.

First to be affected were the birds. In these areas, many migratory birds remain for the winter and usually cope with the Yalta weather very well. When the storm was over, the birds fluttered about in fright not being able to find shelter or food because all was covered over by a thick layer of snow. Sapped of their strength they fell into the water and drowned. Many perished right on the snow. Wild ducks, herded into Yalta Bay by the raging elements, trustingly came to man for protection.

### **Protective Measures Against Rainstorms**

Woods and meadows are the best regulators of water movement on the earth's surface. Wooded areas retain precipitation, diminish evaporation, and promote a gradual and even run-off into rivers. This in turn reduces the number of newly forming gullies and large rain channels, lowers the water level during floods, and protects the rivers from shallowing, silting-up and the deposition of sand.

Mass-scale destruction of forests in river basins, is deleterious to river regimes. Where wooded areas have been destroyed, spring-flood waters run rampant, the inundated area is great, and the rise in water level is high. Rainstorms here can bring summer and autumn floods.

Large-scale cutting of timber has long since been recognized as harmful. But in many countries, measures taken to conserve the forest cover prove to be late. The forests have already been cut and calamities are a frequent occurrence.

In mountainous areas it is now necessary to construct complex structures to protect communities and fields from the devastating action of mountain torrents.

A recent development is the building of stone dams in the upper parts of valleys and in all the branch valleys. A whole series of so-called "live barriers," are placed between the dams. Throughout the width of the valley are interwoven barriers of branches which in time send down shoots forming dense, live walls. Tree planting on mountain slopes continues right up to the level where torrents originate.

In order to combat gullying, it is best to refrain from ploughing up the steep slopes of overgrown ravines; but if this is absolutely necessary, one should plough the slope crosswise taking care to protect the ravine from rain-wash. Another deleterious practice is the pasturing of cattle on ravine slopes and the destroying of the forest cover. In this way it is possible to prevent the development of gullies. But if a gully has already developed, one should take steps to protect adjoining lands from scour, and gradually strengthen the rain channel. The first task is to reduce the force of the water draining off the gully. To do this, obstacles are placed in its way. The simplest method is to place underbrush along the bottom and walls. Streams of water pushing through the underbrush are checked; they lose their force and deposit the silt and sand they are carrying. Covered with sediment, the flooring soon grows over with grass and bushes. True, the flooring sometimes has to be redone two or three times.

A second method of reinforcement consists in setting up

barriers or weirs. The effect is achieved sooner by combining this with underbrush flooring of the gully. The weir can be either "live" or "dead." In the first case, the building material is willow stakes or fascine work, i.e., "live brushwood" tied in bundles up to a metre in thickness. The willow stakes are driven into the ground and are interwoven with willow rods right to the top. The fascine mattress is laid horizontally in several rows one on top of the other and is anchored by stakes driven into the ground. "Dead" weirs are made of dry stakes interwoven with brushwood and of layers of sod reinforced with wattling, or of wood and stone.

All weirs function in the same way, so that use may be made of any material that happens to be at hand.

In addition to strengthening the bed of the gully, an attempt should be made to eliminate cave-ins and landslides on the slopes. For this purpose, a crumbling slope is lined with sod straight or in checkered fashion, and sometimes grass and trees are planted. All these methods stop gully development; neighbouring fields are no longer threatened by sand and clay being deposited as before, and rainstorms can no longer do harm.

In agriculture, an active organized struggle is waged against the destructive effects of water and wind. An essential element here are forest shelter belts and bushes that protect the fields from rain run-off and the wind.

Very important also are advanced agricultural techniques and the use of fertilizers. In this case, the plants develop earlier and better, and they are more resistant to the action of water and wind.

To summarize, then, the best way to combat rainstorms is forestation and the building of forest-conservancy zones near rivers, particularly in their upper reaches.

## Hail

Hail is made up of tiny pieces of ice, mostly irregular in shape, that fall with rain or without it (dry hail).

Hail is most common in the warm season of the year. On



hot days it can become very large—the size of a pigeon's or even a hen's egg. In some rare instances hailstones have been known to weigh almost a kilogramme. Hail is precipitated by very heavy cumulonimbus clouds with low base and high summit. It is usually accompanied by a thunderstorm but may occur without one.

Violent hailstorms have been known since ancient times. The annals of history show that not only individual areas but even whole countries, such as Egypt, France and Italy, have experienced hailstorms. And today, too, reports come in from time to time of similar storms.

To find out how hail forms in the atmosphere let us go back to the structure of the thundercloud, which can at the same time serve as a source of hail. The prevailing temperatures high aloft in summer are between 20 and 30° C. Developing in height, a towering cumulus makes its way into these cold layers and the supercooled raindrops quickly freeze up. This is how hail originates. The higher the temperature of the lower air layer and the more water vapour it has and the more violent the turbulence in the forming hail cloud, the bigger the separate hailstones get.

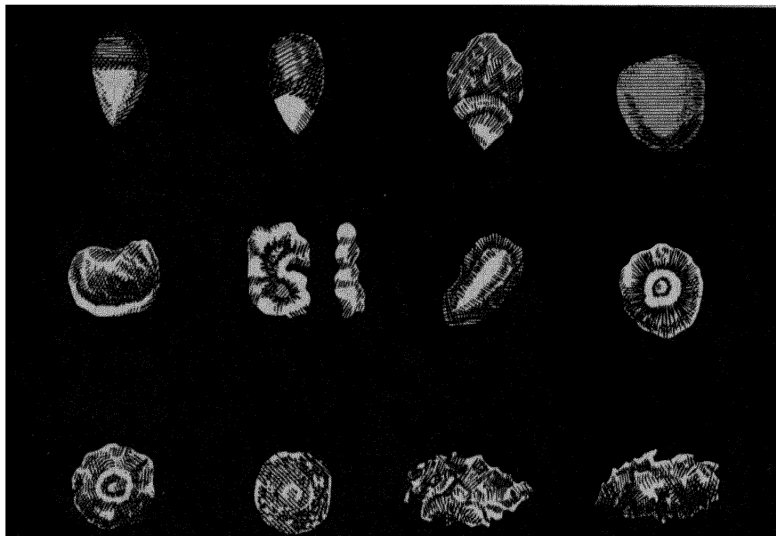
The structure of a stone will give you some idea of the history of its development. A large hailstone cut in half reveals a layer-like structure, something like an onion bulb. In the centre is a dull white nucleus; its lack of transparency is due to the presence of a large number of tiny air bubbles.

On June 29, 1904, a hurricane struck Moscow with large hailstones, some of which were the size of one's fist (weighing over 400 grammes) and covered with many "thorns" and projections.

Inside the hailstone was an opaque snow core covered by more or less regular ice-clear and snow-cloudy layers. Layer thicknesses varied from 2 millimetres to tenths of a millimetre. The biggest hailstones numbered only two or three per 5 square metres, which accounts for the insignificant damage done. Besides, it fell sheer down so that glass windows were not affected. Only greenhouses and glass roofs suffered. Some of the panes of glass were shot through as if by bullets, leaving

smooth edges and no cracks—so great was the force with which they struck.

The accompanying photograph shows hailstones of different shapes. Some stones clearly exhibit the white cloudy nucleus, which resembles snow pellets that fall in winter. The outer shell, however, nearly always consists of transparent ice.



Photograph of hailstones

The layered structure of hailstones is due to water freezing around the nucleus. The degree of transparency of these layers depends on the freezing rate: the faster the freezing, the cloudier the ice will be. This is exactly what happens in the autumn when puddles freeze over. If there is a sudden severe frost the puddles of water freeze to the bottom with a whitish cloudy ice, if the cooling is gradual, a light crust of transparent ice is formed.

The freezing rate also depends on the temperature of the water. It is generally considered that pure water begins to freeze at  $0^{\circ}\text{C}.$ , but in the free atmosphere this does not always

hold; it is more correct to say that zero degree is the melting point of ice.

In the atmosphere, raindrops and the smaller liquid-drop particles of a cloud may remain in the supercooled state down to a very low temperature of minus 25 to 30°C. Supercooled drops of water in the mid-section of the cloud are caught up by strong currents and carried aloft. In the upper parts of the cloud they encounter ice needles and solidify rapidly.

The subsequent growth of the hailstones proceeds under quite different conditions. When the upward current spends itself, the stones begin to fall, and since they are colder than the surrounding air, which is saturated with droplets of water, new layers of ice freeze on in transit.

Also, water vapour may settle onto the hailstones in the form of hoarfrost covering it with a whitish film. This process is aided by the low temperature of the stones falling from great heights. Even in hot countries, hailstones reach the ground with temperatures of minus 5 to 8°C. Naturally, their temperature aloft is lower still.

A fresh vertical current of air, and the hailstones will again be carried into the upper parts of the cloud, where they will cool off, encounter supercooled water, and expand through the freezing-on of droplets. Here, the hailstones can acquire "thorns"—tiny pieces of ice that freeze on to them.

Thus, in order that big hail may form, a thunderstorm cloud must have a strong ascending current extending far aloft.

To support 10-millimetre-thick hailstones in the air, the vertical current must have a velocity of 10 metres per second; for 100-millimetre stones, 30 metres a second. Consequently, if the up-current increases in strength, the hailstones are carried upwards, if it decreases, they fall.

There can be no doubt that a whirlwind has the strength to raise aloft enormous masses of water and hail and support them there for some time. Pilots in aircraft and gliders have recorded vertical currents up to 16-20 metres per second in ordinary thunderstorm clouds. Bigger clouds have higher speeds. Photography and cinematography, used to observe the development

of the domes of violently expanding hail clouds (the shots were made at definite intervals of time), have shown that maximum current speeds exceed 50 metres a second. This is a veritable vertical hurricane capable of raising kilogramme hailstones.

An ascending current does not remain constant in speed, but, like the winds below, varies, getting stronger, then weaker, then stronger again. Hail falls during a calm, and rushes upwards in the next gust. By covering this route up and down a few times the hailstone can build up to quite some size. When it becomes so heavy that the uprushing current is no longer able to support it, or when the falling hailstone finds a place where the up-current is weak, it falls to the earth. The reader may have witnessed the fall of "dry" hail (without rain) on the edge of a raincloud. It was here that the hail "found" weak currents and fell to earth.

Hailstones have been known to attain colossal sizes. A hailstorm in India on May 11, 1929, produced kilogramme hailstones 130 millimetres in diameter. This is the biggest hail ever encountered in meteorology. On the ground, the stones can freeze together and form larger pieces; this accounts for stories of hailstones the size of a horse's head and even bigger. But that is something quite different.

Large hail is, of course, a rare occurrence. More frequently we encounter rains with small hailstones of pea size.

Hailstones come in the most diverse shapes. Of particular interest is the pear-shaped type. In this case, the apex of the pear consists of cloudy white ice, and the base of clear ice. The formation of such hail begins with the cone-shaped nucleus. This nucleus falls base-down. The apex of the cone directs the fall like the tail of an air bomb. The ice accretes on the base of the cone.

Another, very rare, shape is that of a flat disk with a thick rim. These disks strive to maintain a horizontal attitude during fall, and so drop along a zigzag line; under the influence of air streaming past them the hailstones grow rapidly about the perimeter.

Since it is difficult to obtain data on the mechanism of hailstone formation in natural conditions by direct observation, Soviet scientists (V. I. Akkuratov and Y. P. Puzanov) have carried out special laboratory experiments in an attempt to obtain artificial hailstones.

Using a pipette, they carefully deposited different size water drops into a vessel with kerosene that had first been cooled to minus 5-15° C. The drops did not lose their spherical shapes and quietly settled to the bottom gradually freezing. If the temperature of the kerosene was very low, the drops burst with a noise without having had time to freeze all the way through. The reason for the rupture of the ice shell is perfectly clear. When water freezes it increases in volume and creates such a strong pressure from within that the outer shell of the artificial hailstone breaks. However, if the drops froze at a higher temperature they froze solid, straight through. In this case, the transparent drop took on a whitish colour with a cloudy-white core. The sphericity was always distorted and the hailstone became pear-shaped. Microscope studies revealed the presence of bubbles of air at the centre of the stone, which made the nucleus translucent. The impression is that of a snowflake surrounded by a crust of ice. However, there does not always need to be a large flake at the centre. These experiments have shown that the analogy in the structure of both natural and artificial hailstones is complete.

Hail clouds are always very heavy. Even in moderate latitudes a case was observed of a hail cloud 10 kilometres in thickness. When the summit of the cloud rises into the higher layers of the atmosphere it begins to form ice. This is evident from below from the darkening of the summits, the disappearance of boiling projections, and from the wisps of cirriform clouds emanating from the summit. At times, these wisps form, at the summit of the cloud, a shield somewhat like a fan, which indicates that there is an enormous cloud ready to let loose a hailstorm.

Studies of hail clouds have shown that every big cumulonimbus always carries with it currents of hail, and if the

hail does not reach the ground it is because it has melted on the way down. In summer, hail is usually preceded by a very cold rain with large separate drops that splash on the ground leaving "craters" a few centimetres across. This is melted hail.

Mountains 2,000 to 3,000 metres in height do not impede the motion of hail clouds. There have been cases when the speed and straight-line motion of such clouds were maintained even when passing over very high mountain ranges, which is perfectly natural when we recall the elevation at which hail originates.

A hail cloud is sometimes noisy as it approaches due to the falling stones. It is distinctive in that its base is grey with an ashy hue, it is broken up into patches, and the top is like a mountain of cloud with yellowish irregular hilly projections. From above, the cloud mountains appear to be covered with sheets of rough cirrus clouds.

The hail zone in a cloud never occupies much space. Carried by the wind, it sows its hail along a narrow strip which rarely exceeds 15 kilometres in width. It is hardly ever broader than one kilometre. But hail strips have been known to reach 400 kilometres and more in length.

A hailstorm does not usually last long, but in a short time it can destroy crops completely.

Meteorological history gives the case of a hailstorm that covered all of France. This was on July 18, 1788. The hail cut two swaths from south-west to north-east at a speed of about 70 kilometres an hour. The first was 730 kilometres long and, on an average, about 15 wide. The second, paralleling the first a little eastwards, was 840 kilometres long and about 8 wide. Between these two was an interval of about 20 kilometres that did not experience any hail but was hit by a heavy rain. Losses due to the hailstorm were computed at tens of millions of francs. In places, hailstones reached 250 grammes. Trees were stripped bare, crops were crushed to the ground completely, small livestock was killed off and large stock injured. Wild fowl disappeared from the forests for a long time.

Rough computations put the total volume of ice in the hailstorm at over 4 million cubic metres.

Violent hailstorms have been observed in the U.S.S.R., too.

On June 9, 1926, after a long spell of good weather, a downpour hit Odessa with hail that inflicted great damage. Tons of ice plunged down onto the city. A news item even ran "Odessa Iced Under."

The thunderstorm broke in the morning and lasted one and a half hours but the hail stopped in 40 minutes. The clouds came in from the sea in the direction of the wind blowing in the upper levels and counter to the surface wind from the north. The hail did not fall everywhere at the same time. At the docks it began at 5:50 P.M., on Maly Fontan Street, at 6:20 P.M. The average hailstones weighed 30 grammes, but they increased in size and weight reaching 300 grammes. The earth was covered with a mantle of ice as much as 20 centimetres deep in depressions. This ice cover stayed on the ground for many hours. Most of the cellars and basements and warehouses were flooded. On many streets the pavement was swept away. In places, the ground gave way forming deep depressions, tram tracks were washed away.

This hailstorm wrought terrible devastation. Everywhere, window panes were broken, sashes damaged, and tile and even iron roofs wrecked. Considerable damage was done to some of Odessa's best buildings constructed on the "lantern" principle (huge roofs covered with Bohemian glass), these included the Post Office, the Arcades, and the Opera House. The glass roofs of the customs buildings were completely ruined. Heaps of broken glass covered the pavements. Rain poured through holes in the roofs spoiling property. A quarter of all the telephones were put out of order. Telegraph communications were interrupted.

Despite its force the track of the storm was not very wide, and the hail cut a narrow swath that writhed freakishly, leaving damaged buildings with all windows broken and roofs punctured right next to houses completely intact and untouched by the hail. In some districts the downpour was torrential, while in others there was only a light summer rain.

On the outskirts of the city, the crops and many orchards perished from the hail. A number of persons were injured. Ships at sea could not enter the port because of the storm.

The hail- and rainstorm did not confine itself to Odessa, but passed northwards in a narrow path. In Konstantinovka the water overflowed a railway embankment and inundated a glass works. In two places the road bed was scoured and a railway bridge wrecked. Stone abutments weighing a ton each were carried a distance of 100 to 200 metres by the flood. Seven persons lost their lives and much livestock perished.

Dense clouds that give birth to hail are always very highly charged with electricity, part of which is used up in discharges between clouds. Isolated claps of thunder accompanied by lightning give way to a continual rumbling with no lightning visible or only with frequent and small serpent-like flashes jumping between cloud layers. Sometimes there are no violent and sharp claps of thunder at all.

This fact is noted by many observers, but has not yet been explained.

Hail is a common companion of thunderstorms. And so its diurnal march is similar to that of thunderstorms—mostly coming in the hot afternoon hours.

Hail at night is an extremely rare occurrence. An account of one has been given by V. I. Solovyov at the hamlet of Targyn in Eastern Kazakhstan. "At 1 A.M. on July 13, 1948, this hamlet (700-800 metres above sea level) experienced a violent thunderstorm with hail. On an average, the hailstones weighed from 30 to 50 grammes but sometimes attained 250 to 300 grammes. To windward, the windows in houses were blown out, plaster was knocked off, and trees stripped of their branches. Garden crops were destroyed completely. Three different types of hailstones were distinguishable: egg-shaped, semi-spherical, and flat. The egg-shaped type reached a length of 7-8 centimetres and a diameter of 2.5-3 centimetres, with one end rounded, as if fused, and the other pointed. The rounded end began with clear bluish ice, followed by rings of



dullish white ice. The pointed end consisted of tiny pieces of ice fused together."

Hail is most common at the beginning of summer when the lower air is thoroughly heated, and the top air retains its low temperature. At this time of year there is a steep fall of temperature with elevation, thus favouring the formation of hail.

Statistics of hail damage, and property loss therefrom, point to places and whole areas that are particularly often and violently affected by hailstorms. Studies by Voyerikov in the U.S.S.R. indicate that such places are found in the Caucasus, for example, around Kislovodsk. These are warm and moist areas with lush vegetation, frequently the lower leeward slopes of mountains.

Flat land also has areas that every year experience hailstorms, though not so strong as those in the Caucasus. These include places west of Kiev and also near Tambov and Penza. Hailstorms are especially rare in the far north of the European part of the U.S.S.R., the shores of the Baltic Sea, and the dry Aral-Caspian steppe lands.

Man has long been in search of ways to dissipate hail clouds, but no practical results have yet been forthcoming.

Science today is still confronted by this problem of fighting hailstorms. Scientific thinking should seek in nature itself for a means of dispersing clouds. Meanwhile the only thing we can do is to clear up, as fast as possible, the wreckage left in the wake of the storm.

## CHAPTER THREE

# WINDSTORMS

### Gales and Hurricanes

A harmless breeze that cools a hot summer's day sometimes freshens up to gale force and can even develop into a hurricane. Then the wind becomes dangerous. A storm on land uproots trees and tears off roofs. At sea, it builds up waves, making navigation difficult and dangerous, at times even to huge ocean liners.

A gale is a continuous strong wind blowing at a speed in excess of 15 metres per second (on the Beaufort Wind Scale it is Force 8 and above). On land, the wind ordinarily becomes gusty in the ground layer due to friction against the earth's surface. It becomes uneven both in speed and direction, and develops small eddies and separate currents. The higher the speed of the wind the more gusty it becomes. Gusts of wind in a storm will exceed the average velocity by  $1\frac{1}{2}$  and 2 times. It is quite obvious that, all other things being equal, wind on the land cannot attain the force it does in the open sea. Here the winds are far stronger.

The internationally recognized scale of wind force (Beaufort's scale) contains 12 types. Force 9 wind is called a strong gale (see table), Force 10 is a whole gale, and Force 11 is a storm. When the wind force exceeds 30 metres per second (Force 12) it is called a hurricane. These names describe the force of the wind, though they all designate the same thing—a storm.

A serious study of storms was begun about one hundred years ago. The inducement was the famous Balaklava Storm (or Crimean Storm) that hit the Crimean shores in 1854.

On November 14, 1854, the English and French fleets that were laying siege to Sevastopol began preparations for a landing in the area of the Balaklava Bay. All of a sudden a gale struck and later developed into a hurricane. The unprepared fleet of the English and French proved helpless against the raging elements and was almost completely destroyed.

International Scale of Wind

| Beaufort wind force | Descriptive term | Wind velocity, metres/sec. | Wind action                                                     |
|---------------------|------------------|----------------------------|-----------------------------------------------------------------|
| 0                   | Calm             | 0-0.5                      | Smoke rises vertically.                                         |
| 1                   | Light air        | 0.6-1.7                    | Smoke drifts from stacks.                                       |
| 2                   | Light breeze     | 1.8-3.3                    | Leaves rustle; wind felt on face.                               |
| 3                   | Gentle breeze    | 3.4-5.2                    | Small twigs in motion.                                          |
| 4                   | Moderate breeze  | 5.3-7.4                    | Wind raises dust.                                               |
| 5                   | Fresh breeze     | 7.5-9.6                    | Small trees sway; crested wavelets form on water.               |
| 6                   | Strong breeze    | 9.7-12.4                   | Large branches in motion; whistling heard in telegraph wires.   |
| 7                   | Moderate gale    | 12.5-15.2                  | Tops of trees in motion.                                        |
| 8                   | Fresh gale       | 15.3-18.2                  | Wind breaks twigs and dry branches; generally impedes progress. |
| 9                   | Strong gale      | 18.3-21.5                  | Wind removes tiles and bricks of chimneys.                      |
| 10                  | Whole gale       | 21.6-25.1                  | Trees bent and uprooted.                                        |
| 11                  | Storm            | 25.2-29                    | Widespread damage (rarely experienced).                         |
| 12                  | Hurricane        | 30 and over                |                                                                 |

Some of the ships sank near the shore, some out at sea, and only a few vessels succeeded in escaping by heading for the Turkish shores.

It was learned later that the storm had begun three days before in the south of France, had then moved into the Balkans, and on November 14 had reached the Crimean shores.

It was in the nature of a whirlwind—what is now called a cyclone—moving from west to east.

Subsequent storm studies are associated mainly with the works of Russian scientists, Academician M. A. Rykachev, P. I. Brounov, B. I. Sreznevsky, and others. It has now been established that in many cases it is possible to foresee the direction of the winds and to give timely warning to threatened areas. In his investigations, Professor Sreznevsky demonstrated that storms are associated not only with cyclones but can appear also on the perimeter of anticyclones, that is to say, in areas of relative calm. The establishment of this fact has proved to be a very important circumstance in forecasting storms. Warning signals of oncoming storms have played a particularly significant role in navigation, saving thousands of human lives, and much shipping and cargo.

How do storm winds originate and what are their movements?

It is common knowledge that the primary cause of the wind is the different heating of the air, which gives rise to density differences. This in turn creates a pressure differential at adjoining sections of the earth's surface. Above heated sections of the surface, the warmed-up air expands, becomes lighter and rises, being displaced by inflowing cold air from adjacent, less heated areas. This is how the wind is born, and if the difference in pressure is very great it blows at a terrific speed.

It must be pointed out that the foregoing explanation is only a brief outline of the origin of the wind. Actually, the origin and development of the wind is a far more complex affair. In some cases the wind may blow from cold areas into heated, while in others, on the contrary, from warm to cold. In addition, the earth's rotation affects the direction of the wind—in the Northern Hemisphere it is noticeably deflected to the right.

Storm winds are in most cases associated with enormous atmospheric whirlwinds called cyclones.

A *cyclone* is a circular system of winds moving at an angle to the centre of the whirl in a counter-clockwise sense. The lowest air pressure is at the centre of the cyclone and it increases

outwards. The pressure in the deep storm cyclones of winter time can fall to 950 millibars and lower. These cyclones are characterized by strong pressure gradients that give rise to storms.

What is a pressure gradient?

If we compare the readings of pressure-measuring instruments (barometers) spaced at, say, 100 kilometres, we will see that they differ: higher in one place and lower in another. Since air pressure diminishes with altitude it may appear that the difference is dependent only on the elevation of the instruments above sea level. However, when we introduce an appropriate correction and reduce all readings to sea level, the difference remains. A pictorial representation may be obtained by comparing the instrument readings taken at the same time over a considerable portion of the earth's surface and plotting them on a map. It will then be clear that the pressure changes from place to place. Now connect up the points of identical pressure and you get *isobars*, and the map will exhibit areas of *low* and *high* pressure.

If near each point of barometer reading we indicate the direction of the wind with an arrow and give its velocity, we will see that the wind blows from places of high pressure to points of low pressure. And the wind velocity is always greater where the pressure changes sharply.

The difference in air pressure per unit distance is called the *pressure gradient*. The unit of distance is taken to be the length of one degree of latitude (111 kilometres) and the pressure is measured in millimetres or millibars. On the isobar map, the pressure gradient is measured by placing a ruler at right angles to the isobars.

The bigger the pressure gradients the higher the wind velocity. Weak winds have gradients of 1 to 2 millibars per 111 kilometres distance, fresh winds, 2-3 millibars every 111 kilometres, and in storms pressure gradients reach 5 to 6 and more millibars.

The wind force in a cyclone is usually proportional to its depth. The depth of a cyclone is measured by the pressure in its centre. Indeed, if the pressure at the centre of the cyclone

has fallen to 950 millibars, the pressure at the perimeter is close to normal, or 1,000-1,010 millibars. From this it follows that the pressure differential between centre and perimeter can attain 50 to 60 millibars. This enormous difference, even in the case of a comparatively large cyclone diameter, leads to very steep pressure gradients that give rise to storm winds. Like a river where the current is faster in places of steeper sloping bed, so here too, the wind is stronger where the isobars are more closely spaced. The winds converging from all directions at the cyclone centre cause the air to rise.

In middle latitudes, deep storm cyclones are a rare occurrence. But even here cyclones with Force 12 winds (hurricanes) make their appearance once a decade. Such cyclones were recorded over the European part of the Soviet Union in January 1923 and in September 1942 (see accompanying weather map with storm cyclone in January 1923).

The solid lines on the map are isobars. The figures on the isobars denote the amount of pressure. In the centre of the cyclone it was below 945 millibars. The circles designate the weather stations of the central areas of the European part of the Soviet Union and describe the weather. The cloud cover is indicated by the amount of shading in each circle. An open circle denotes clear sky, a shaded circle, overcast. Two dots to the left of the circle indicate rain, a star, snow. The arrows attached to the circles indicate the wind direction, while the dashes in the tail denote the velocity of the wind in Beaufort numbers (each force number is approximately equal to 2-3 metres per second). A short dash is one force number, a long one, two. The figures to the right of the circle give the temperature of the air in degrees Centigrade.

The isobars on the map are very closely spaced (steep gradients). This indicates that there are places where the winds are of Force 12. This deep cyclone is an extremely rare occurrence in these latitudes. The daily weather maps usually show much weaker cyclones, accompanied by fresh winds and long-time overcast weather with precipitation, and they sometimes follow one after the other.



Cyclones ordinarily move at a speed of 30 to 40 kilometres an hour. However, there are cases when they seem to remain in one place, though wind velocities remain high. On the other hand, there are cyclones with velocities exceeding 80 kilometres an hour. For instance, the January 28, 1923, cyclone covered 2,400 kilometres in 24 hours, which is 100 kilometres an hour.

Cyclones attended by storms in the European part of the U.S.S.R. and in Europe in general are ordinarily observed in the winter time. It is then that they attain their greatest depth. They are less frequent in autumn and spring. Summer cyclones of such force are an exception.

The seat of cyclone formation is a zone where warm and cold air currents come together. These air currents are observed to meet in all latitudes of the moderate belt, which means that cyclones can originate in any place of moderate latitude.

Cyclones most often appear in the vicinity of Iceland. This is due to the fact that here the cold air currents sweeping down from the perpetual ice of Greenland come into collision with the warm air currents progressing over the warm Gulf Stream. This is a "cyclone centre" in the true sense of the word. From here they push out eastwards and south-eastwards towards Europe.

Another "cyclone centre" is situated on the seaboard of North America, whence the cyclones again move east crossing the Atlantic Ocean and reaching the coast of Europe. Some cyclones originate over the Mediterranean Sea and move to the north and north-east.

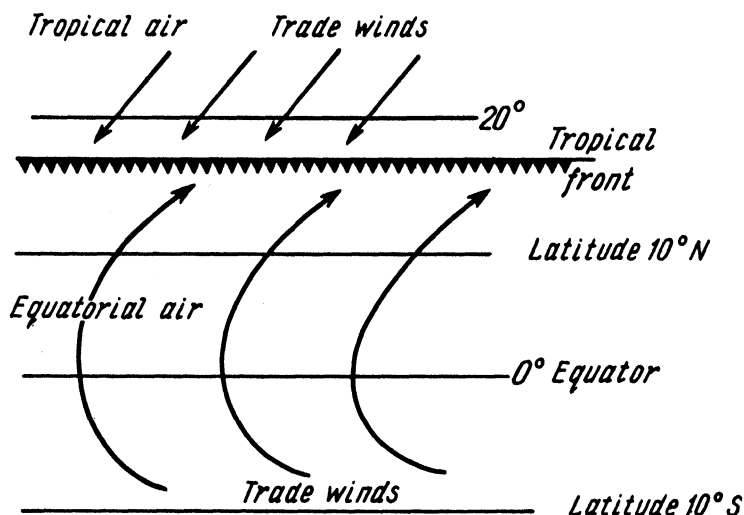
If cyclone "paths" are plotted on a map for a period of years, it will be seen that the greatest number of cyclones over Soviet territory move from west to east.

Like the cyclones of moderate latitudes, tropical cyclones are whirlwinds with forward motion, but still they are different from those of moderate latitudes. They have smaller diameters that do not exceed 200 to 500 kilometres. On the other hand, their pressure gradients are very high, reaching at times 20 millibars. This is why the wind velocities often attain hurricane force. The pressure in a tropical cyclone falls to 940 millibars and lower. An example is a typhoon that ripped



across the East China Sea on August 18, 1927. The pressure at the centre fell to 887 millibars.

Such a fall in a tropical cyclone is connected with a tempestuous uprush of enormous masses of humid air. This process is attended by an extraordinary condensation of water vapour



Tropical cyclone in the making (after Kunits)

and the release of the latent heat of condensation. Since water vapour occupies a volume 800 times that of raindrops, it is quite natural that the rapid rise of air masses causes a deepening of the cyclone, which in turn enhances the suction action of the whirlwind, leading to an influx of new moist air masses, to renewed condensation, and, thus, to a fresh deepening of the cyclone. This continues until the increasing friction, due to higher wind velocities, and the diminishing influx of moist air leads to equilibrium, that is, to the final phase in the life of a cyclone. At times, this phase lasts over a week.

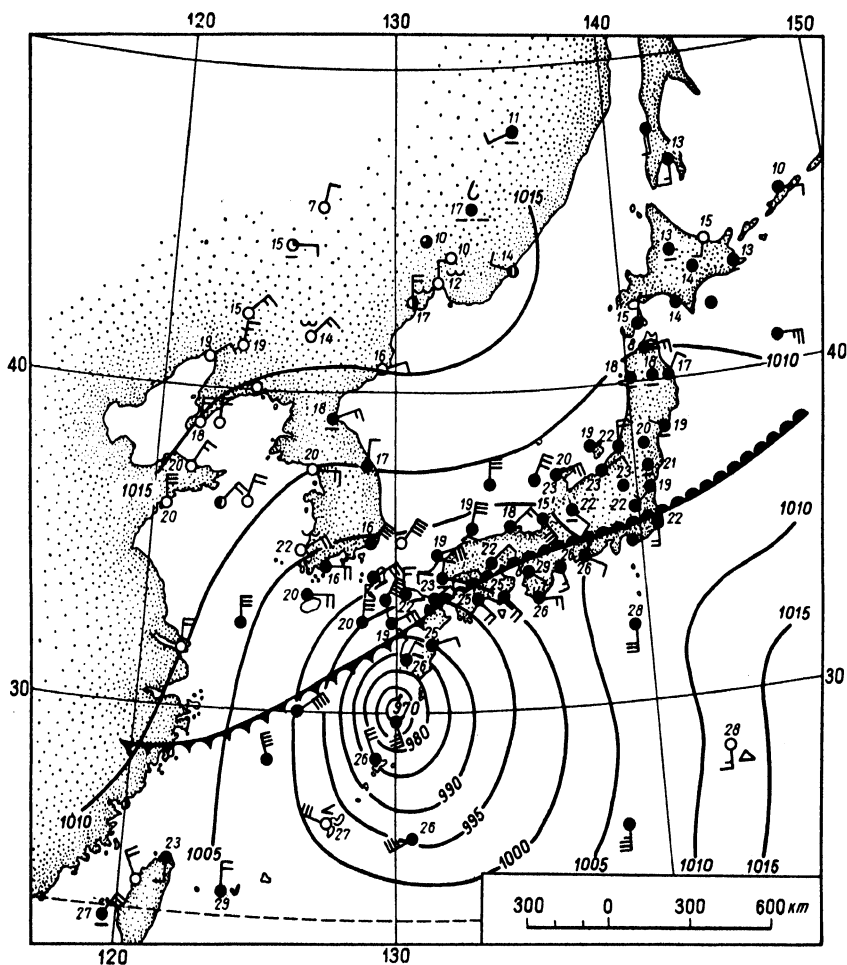
Unlike the cyclones of moderate latitudes (with the exception of Asia), the tropical cyclones form mostly in the summer and autumn. They are comparatively rare, appearing from 3 to 10 times a year.

Tropical cyclones usually originate between 6 and 20° north and south latitude. They cannot form near the equator (see figure). Cyclones build up most often in the following areas.

In the Caribbean Sea (near the Antilles) and in the Mexico Gulf. These are known as West Indies or Antilles hurricanes.

In the Bay of Bengal and the Arabian Sea.

In the East-Asian seas near the Philippines, in the South and East China seas and the Sea of Japan. These are called typhoons.

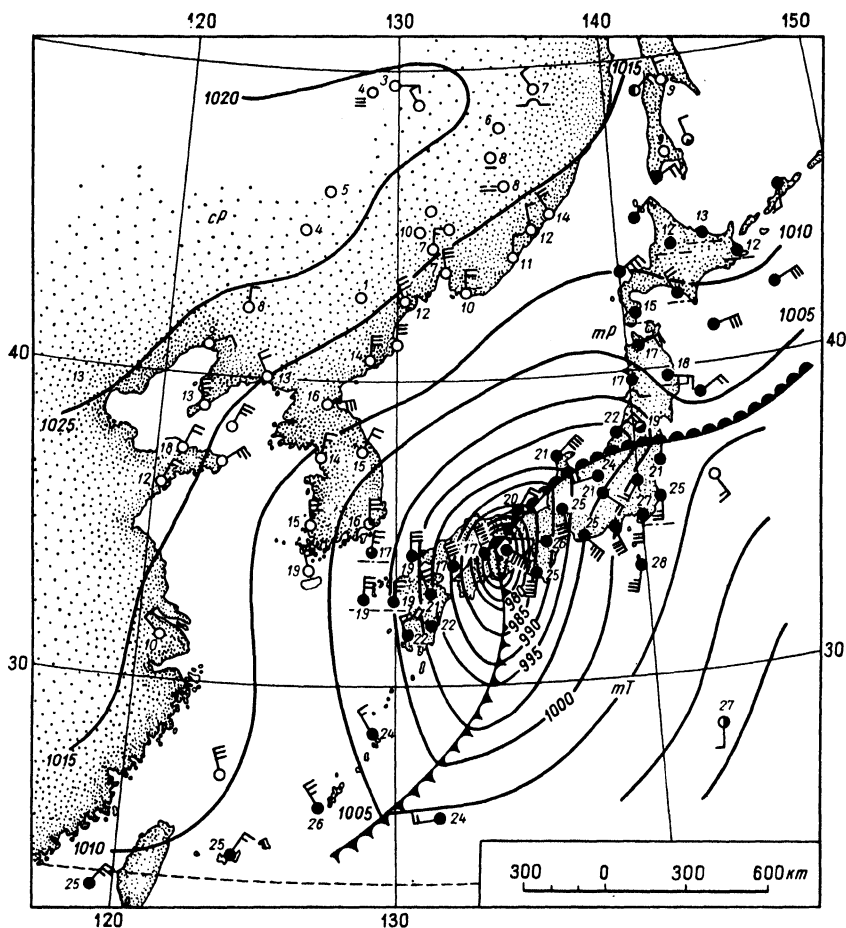


The typhoon of September 20, 1934 (after Khromov)

In the Indian Ocean near the Island of Mauritius.

In the Pacific Ocean, in the vicinity of the Hebrides and the Samoa Islands.

In the Northern Hemisphere, tropical cyclones first move north-westwards at a low speed, about 15 kilometres an hour. Reaching 25-30° north latitude the cyclone slows down. Then it begins to move towards the north-east at a progressively increasing speed.



The typhoon of September 21, 1934 (after Khromov)

The *typhoons* of the East-Asian seas sometimes reach the Soviet Far East. These cyclones originate during June-September in the area between the Mariana, Caroline and Philippine islands. They first move north-westwards to Taiwan or the Riukiu Island, then turn to the north and north-east. Typhoons move at a speed of 10 to 15 kilometres an hour from the point of origin. After they change direction, the velocity increases all the time reaching 60 to 90 kilometres an hour on occasion.

The accompanying maps show the weather during a most violent typhoon that streaked across Japan on September 20-21, 1934. At the centre of the typhoon the pressure fell to 970 millibars on September 20th and to 965 millibars on the 21st. The unusual close spacing of the isobars accounts for the wind force of 12.

Deep cyclones with high wind speeds inflict great damage.

The storm that struck the central districts of the European part of the U.S.S.R. on September 23, 1942, upturned thousands of trees and telephone poles, breaking wires, tearing off roofs and blowing down fences. In places the wind speed reached 30 metres a second.

Violent storm winds hit France in July of 1950. The wind reached Force 12, or hurricane violence. The destruction they wrought was disastrous.

The hurricanes were accompanied by waterspouts and hail. In depressions the layer of hail reached half a metre with some hailstones the size of an egg. The rainfall raised the levels of rivers 2 and 3 metres causing floods. In many districts of the country, all the grapes, wheat and other crops were destroyed.

In November 1950, a roaring storm crossed the Atlantic seaboard of the U.S.A. In the Great Lakes area and Pennsylvania, the wind was accompanied by a terrific snow-fall. In some states the gale wind brought heavy rains. Press reports tell of tremendous losses caused by the storm. Factories were closed, electricity cut off, telephone communications interrupted, traffic stopped. The storm took a toll of over one hundred lives, with several thousand persons injured.

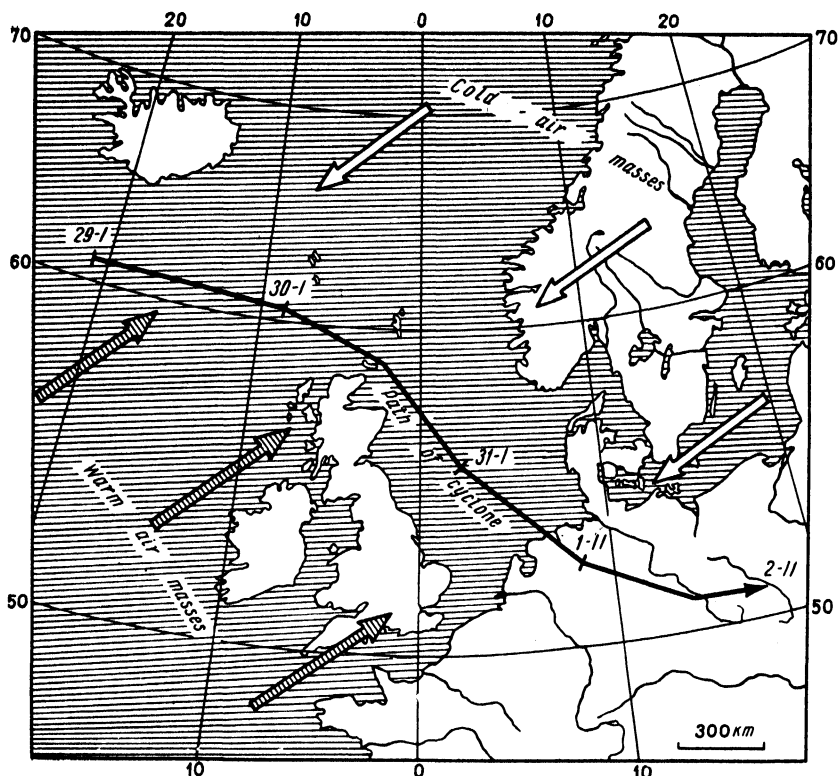
On August 31, 1952, a hurricane struck the coastline of South Carolina (U.S.A.) devastating a 100-mile-wide belt. In Charleston, electric transmission towers were blown down, trees uprooted, windows broken, and roofs torn off. The city was left without electricity and the streets were flooded.

One of the most violent hurricanes in recent years swept across the North Sea from the morning of January 31 till the evening of February 1, 1953. Cyclones were raging round the world, and the peak of this atmospheric activity was the North Sea hurricane.

With tremendously destructive force, it swept over the eastern shores of the British Isles, into the Netherlands and Belgium. The Western press considered this one of the most terrible catastrophes to visit Europe in the last hundred years. Strong winds pulled along the surface waters of the North Sea driving enormous masses of sea water into the narrow southwestern part—round the coast of Belgium, the Netherlands, and South-East England. This sent up the water level in the mouths of rivers and broke dykes and other protecting structures along the seacoast, serving as the starting point of terrible floods. But weather history likewise knows that a quarter of a century earlier, January 6-7, 1928, the east coast of England, including London, was likewise hit by a disastrous flood. It was then that meteorologists were instructed to investigate the causes of this flood and to find out ways of forecasting them.

The investigations were carried out and weather men warned of a possible repetition of such floods. But during all these 25 years, nothing essential had been done on the east coast to reinforce the antiquated dykes and dams.

The flood started under the following circumstances. A deep cyclone appeared over the North Atlantic, to the south of Iceland, on January 29, 1953. Building up, it headed for the south-east, towards Europe (see figure on page 212) and reached the North Sea on January 31. The cyclone was then at peak strength and at its deepest. Diminishing in strength, the cyclone entered Germany on February 2nd and filled up. Tremendous



Path of cyclone from January 29 to February 5, 1953 (after Kolobkov)

pressure gradients caused gale winds that became hurricanes in places. A maximum wind speed of 35 metres a second was reached over the North Sea.

Mountainous waves swept down onto the north-western seacoast of Europe and the eastern shores of Britain where not a single community escaped, some being wiped completely off the face of the earth.

In the Netherlands, dykes and dams protecting the polders (tracts of fertile land below sea level) were broken in several places. The water rushed through these gaps in a stream up to 9 metres deep and penetrated 65 kilometres inland. Protective structures on a number of islands likewise gave way and the

land was inundated completely. Many large ports, like Rotterdam, were destroyed or heavily damaged.

In Belgium, a 60-kilometre-long section between Ostend and the border with the Netherlands was particularly hard hit by the hurricane and floods. The dams and sea front were wrecked and houses went under water. The resorts of Ostend, Blankenberghe, Heyst and Knocke were destroyed.

About 3,000 persons lost their lives or were missing as a result of the incursion of the sea into the coast lands of North-Western Europe. Hundreds of thousands were rendered homeless. Property losses were incalculable. In the Netherlands this was still worse because fertile lands became salty from the sea water.

While Western Europe was fighting the hurricane, the eastern areas experienced an unprecedented snowstorm. The snow cover, in places two and four metres thick, paralyzed all railways, highway and urban traffic. The roads were dammed up with huge snow-drifts. Heavy falls of snow were recorded in Germany and Poland.



Snow in Rome is a rare occurrence. Italian school children play snow-balls

The tragedy left in the wake of the hurricane and floods in Western Europe attracted the attention of the foreign press. Newspapers demanded investigations to determine whether or not these sacrifices were inevitable.

Of course they were not. Dams and dykes were in disrepair.

The losses would not have been so great if the hurricane warnings of the weather service had reached the population at large in the threatened areas. In the Soviet Union, in such cases, all means of communication and information are mobilized. Aircraft are widely used and the most energetic measures are taken.

To illustrate the care for the population in the struggle with hurricanes and floods, let us review the latest flood in Poland. Heavy snow-fall connected with the passage of a cyclone in mid-February of 1953 caused a high rise in the water level of the Vistula River, especially in its mouth. But due to a properly functioning system of protective levees, the river could not inflict any damage when it overflowed its banks. The system of massive structures along the shores of the Baltic Sea protected from inundation the territory of Gdansk Zulawy, which is below sea level.

Gdansk Zulawy is a vast low stretch of country with 200,000 hectares of fertile farm lands. The whole place was flooded by the Hitlerites in their retreat. Western experts believed it would take at least a hundred years to reclaim it. But the Polish people bent every effort and completed the immense job in only six years. The newly built system of dykes at Zulawy now withstands the most violent storms and floods. The dykes protect the fertile Zulawy lands from floods and assure the farmers of this seacoast area that they can till in peace.

During the first 10 days of January 1954, a series of cyclones passed along the same path but dipped into more southern latitudes.

The press reported that the storm which raged over nearly the whole of Sweden was the most fierce in many years, with wind speeds reaching 35 metres a second at times. Highway



and railway traffic was interrupted, telegraph and telephone communications cut off, and electricity facilities damaged, leaving whole districts without light. In the vicinity of Stockholm alone, up to a million trees were lying prostrate.

The storm struck Denmark too. Several dams were destroyed on Fyn Island and the swirling waters inundated the fields. In Nyborg, part of the sea-front and many residences were flooded. Warehouses in the port of Odense suffered.

A storm raged on the North Sea, and the tremendous pressure of the water again broke through the dykes at many places along the Belgian coast. In the towns of Ostend and Knocke the water poured into the streets along the shore.

The cyclone struck Italy as well. The central and northern districts of the country experienced an unheard-of fall of snow. In the town of Piacenza a 70-centimetre layer of snow covered the ground. Traffic came to a standstill, work stopped, food supplies were intermittent.

In the province of Alessandria the snow lay 1.5 metres thick in the Curone valley. Forty centimetres of snow fell on the streets of Alessandria itself, and half a metre was recorded at Turin, Verona, Brescia, Trento, Spoleto. The Alto Adige district got a truly unusual experience—twenty degrees below zero Centigrade. By January 8th, exceedingly low temperatures, heavy snow-fall and snowstorms had visited the entire peninsula. A hurricane ripped through Trieste at over 100 kilometres an hour causing a large number of casualties.

In Switzerland and Yugoslavia, snow-drifts held up traffic on many railway lines. In France, below-zero weather set in, with some places—Mèze and Nancy—at minus 20° Centigrade.

One of the cyclones that originated in Iceland crossed the Mediterranean and hit North Africa. Snow fell even in Algeria.

In mid-January 1954, storms swept into Northern Germany, with wind speeds reaching 130 kilometres an hour. In Hamburg, Bremen, Kiel, Cologne and other towns, roofs were torn off and trees uprooted. Storms also raged in England and the Netherlands.

The frosts and blizzards that had whipped Western Europe at the beginning of 1954 struck again with renewed force in the first half of March.

A particularly violent snowstorm swept over Albania. Mountains of dry prickly snow were dumped on the northern parts of the country. Supplies of food, clothing, medicine and fuel for the population were cut off. In places the snow was four and five metres deep.

This blizzard was connected with a deep cyclone that had stayed on along the northern shores of the Mediterranean. The cyclone raged several days and brought about an influx of cold air from the U.S.S.R.

In Bulgaria it sent the temperature down below zero; the Black Sea near Burgas was covered over with ice 6 to 7 miles from the shore-line. Ships were held up for 20 days. Passage to the open sea was closed until the Soviet steamship *Nogin* broke through the ice.

This was a winter of severe frosts and abundant snow for Rumania too. Snow was still on the ground in the southern part of the country near Bucharest at the end of March. Blizzards had built up snow-drifts in many parts of the country, some reaching six metres in height.

A new and violent cyclone ripped across Western Europe at the end of December 1954. For three days strong gales and storms raged. Shipping suffered in the North Sea near England, Belgium, the Netherlands, and North Germany, with loss of life at 115 persons and 23 ships either damaged or sunk. Once again the southern part of Rotterdam was flooded. Floods were reported in Denmark and Belgium as well.

The cyclone brought snow for two days running to the Swiss and Italian Alps, and Austria too, where the mountain roads were snowed under.

Europe experienced an unusually cold winter in 1956 that left misery in its wake. Severe frosts and snowstorms disrupted transport and communications and took a toll of human life. Eight hundred persons lost their lives in Western Europe due to the cold during the first twenty days of February.

Already at the beginning of December 1955, the drifting stations "North Pole" 4 and 5 reported unusually low temperatures (minus 45-48°C.) for this time of year. It was obvious that masses of cold air were accumulating in the Arctic and that they would sooner or later spill over southwards. And, true enough, all of December was replete with cold waves. Severe frosts were recorded in the European part of the Soviet Union and in Siberia. In January the frosts abated somewhat, but on the other hand the snow-falls were more frequent and more abundant.

A new wave of cold struck the European part of the U.S.S.R. on January 25, 1956. Forty-degree frosts were observed not only in the north but in the central areas and, in places, in the Ukraine. The Baltic republics reported frosts exceeding 30 degrees. The coldest day was January 31st. In Moscow, where the city air moderates the winter climate, frosts reached 35 and 37°C., while the environs registered 42-45° below. Outside the city, mercury thermometers froze; those who didn't have alcohol thermometers lost track of the temperature.

In Denmark, navigation between islands was brought to a complete standstill. The same thing occurred on the rivers of Germany. The Rhine was ice-bound. In the Netherlands the thermometer showed 20° below zero.

A record low was noted in Sweden, with 53° below zero Centigrade on the Nordland plateau.

By the beginning of February 1956, the cold wave had swept far to the south and south-west, covering the whole of Western Europe, Asia Minor, and even North Africa. The frosts in these localities were a real catastrophe.

France was gripped by a long spell of below-zero weather. A very low temperature of minus 30°C. was recorded on the 2nd of February in Saint Laurent (Jura Department). In Paris the temperature dropped to minus 20°C. Hundreds of people living in dilapidated houses or totally homeless sought refuge in police commissariats. The port of Nantes was closed because the ice was a metre thick. Snowstorms raged in the south-west of France. In Bordeaux, pedestrians moved about on skis. The

damage that the frost did to French agriculture is measured in tens of thousands of millions of francs. Heavy snow-falls were reported in Spain. In the environs of Saragossa the temperature fell to  $20^{\circ}$  below zero, in the Pyrenees to  $32^{\circ}$  below.

The Arctic air reached Italy as well. Nearly the whole country, including Naples, was snowed under. In Rome, snow fell for the first time in 10 years. In a number of provinces snow-drifts cut off hundreds of communities from the outer world. In places the snow cover reached four metres! The unusual cold lasted all of February and half of March.

In Greece, the usual spring weather was replaced by winter frosts reaching to 15 and  $20^{\circ}$ . The snow lay 3 to 4 metres deep in places; barracks that had been built after an earthquake in Volos were crushed by the weight of the snow. The district of Arcadia was in a state of emergency, for the population was left without food. This was the worst weather Greece had experienced in 30 years.

In the Lebanon, a snowstorm raged for three days. Telephone communications between Beirut and some other cities were interrupted on February 9th. Due to snow-drifts the highway between Beirut and Damascus was closed for a long time.

Such persistent colds with an extraordinarily deep penetration of Arctic air into southern latitudes are a rare occurrence. It is due to the fact that, in the system of general circulation of the atmosphere, the ordinary transfer of air masses from west to east gives way to a meridional transfer. On certain parts of the globe, the air masses move from north to south, while on others, frequently adjoining, from south to north. This is what happened in the winter of 1956. There was a very lively exchange of air masses and on a very large scale—from the subtropics to the Arctic. During the severe frosts in Europe, warm air masses penetrated into the Arctic latitudes from the south through the Bering Sea. The "North Pole" 5 station recorded a temperature of  $0^{\circ}\text{C}$ . in the very heart of the polar night!

But usually the most violent hurricanes are met in the tropics (tropical cyclones). Wind velocities of 60 and 70 metres a

second are not rare. A wind like this uproots big trees and drags them along the ground, reverses the flow of river water, and destroys the grass cover. And this is something to be expected if one considers that a wind blowing at 50 metres a second produces a pressure of approximately 200 kilogrammes on every square metre.

On islands, the damage due to winds is increased by huge ocean waves that not only destroy separate structures on the shore but wipe out completely whole communities and even cities. Hurricanes have thrown mammoth ocean liners ashore.

In June 1949, a typhoon streaked across the Japanese Islands. Over a thousand fishing vessels perished at sea. A steam ferry-boat was caught off the Kiushu Island and sank. Only two persons out of 130 were saved. A still more violent typhoon struck Japan on October 14, 1951.

A typhoon that hit the Island of Luzon in the Philippines on October 21, 1952, took the lives of 444 persons, with 27 injured and 460 missing. Half a million were left homeless. The hurricane completely destroyed the town of Legaspi with its population of 80 thousand and the port of Tabaco. In the single province of Albai, property losses from the typhoon reached tens of millions of dollars. The province of Sorsogon was left without water and food.

True, hurricanes of such force do not occur every year and they affect small areas. But less destructive storms break out in the tropical oceans every year.

The approach of a tropical cyclone is felt in nature long before it actually arrives. The first signs are seen in the sky. On the eve, at sunrise and sunset, the sky is streaked with very bright red hues. Then it becomes a copper red, and a dark band appears on the horizon. Usually a day in advance, an extreme calm sets in, and the air is hot and oppressive. Nature seems to be collecting its forces for a fierce blow. Seeking refuge from inevitable death, the birds of the sea strike deep inland in huge flocks. Beasts go underground.

From afar is heard a dull noise that gradually changes into a distant groaning of the wind. These are the sounds of the

approaching storm. Even before this, special apparatus records the infrasonic waves that our ear cannot perceive. This phenomenon was investigated by Academician V. V. Shuleikin and called the "voice of the sea." Shuleikin noticed that small crustacea dwelling on the beach are sensitive to such sound waves. Long before the storm they dig into the grass to escape death under the pebble "grindstones" of the beach. Jelly-fish, too, seem to be warned in advance, when the barometer does not yet show any change whatsoever. They seek to escape the storm by moving out into the sea away from the shores.

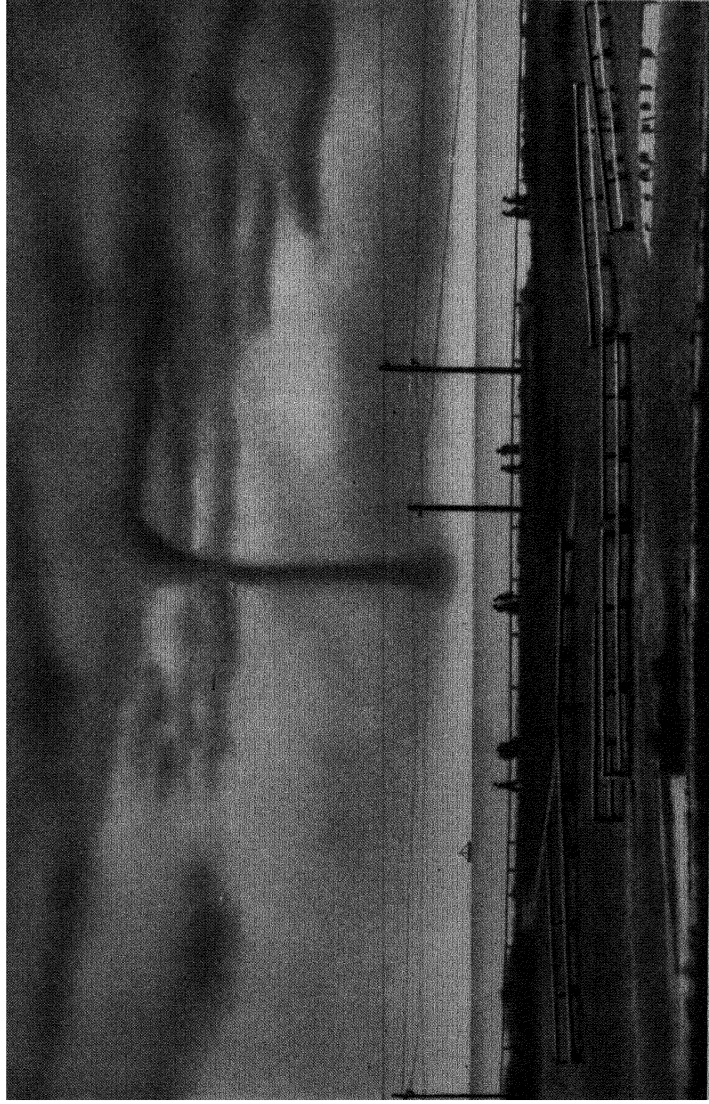
The air pressure begins to fall 24 hours (sometimes even 48 hours) before the arrival of the hurricane. The faster the fall of the barometer, the sooner and stronger will be the wind. The pressure drop ceases only when the centre of the cyclone passes nearby. But there in the distance is a black cloud, its ragged edges scudding across the sky. Squalls are coming constantly in gusts. The downpour shuts out the horizon. Thunder rumbles without letup as lightning strokes slash the darkness.

The centre of a tropical cyclone always has a spot of calm. Here the sky clears for a moment, the sun's rays pierce the sombre surroundings and the wind abates, but the ocean is still raging. Seamen call this the "eye of the storm." A little while later, the barometer takes one more jump upwards, and from the opposite side of the horizon another hurricane is seen approaching. The centre of the cyclone has passed.

Tropical cyclones are fiercest in the open sea and on the coastlines of islands or continents. Here they play freely not encountering the slightest obstacle. But still, vessels at sea are in less danger than in poorly protected harbours where high waves can throw the ship ashore. This is why ships always try to put out to sea, away from the shores, before a cyclone strikes.

Such is the nature of storms and hurricanes. We are not yet able to stop them or direct them into other channels. But we can give warning of a storm, we can broadcast by radio to ships in mid-ocean and in ports, to airfields and to aircraft

Waterspout





Tornado



Thundercloud before tornado (after Kolobkov)

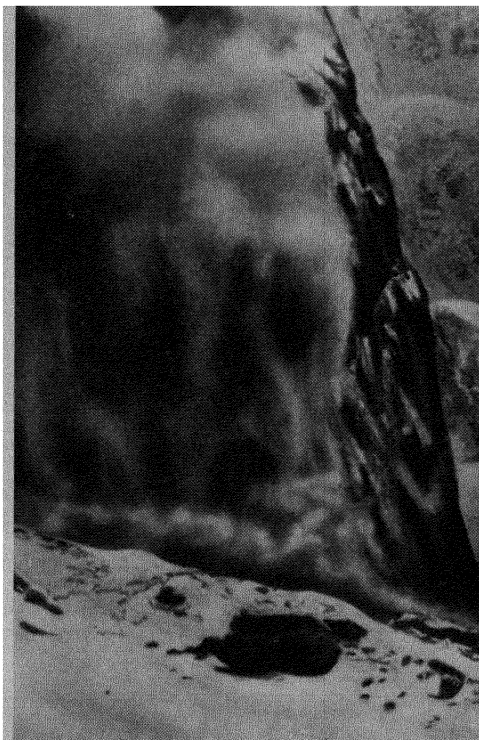


aloft, to various organizations and to the population. This is being done at present by the Weather Service of the U.S.S.R., at the head of which stands the Central Institute of Weather Forecasting.

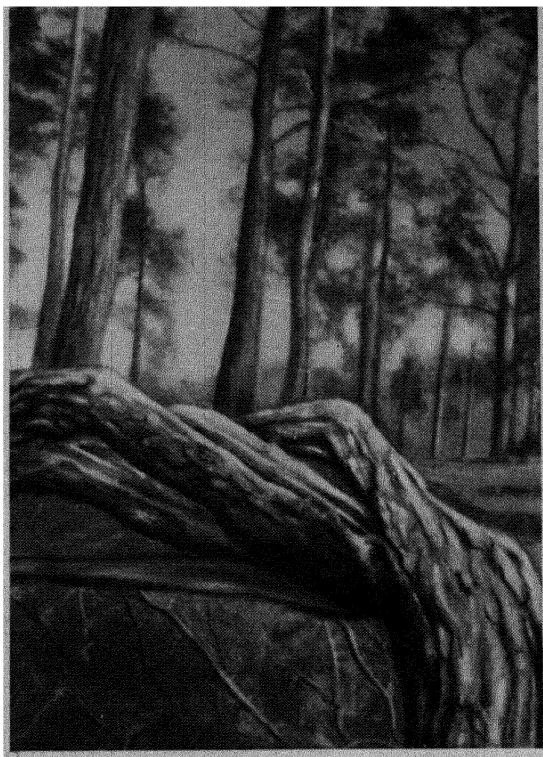
This institute concentrates all information about the weather. Every day it receives tens of thousands of telegrams and radio-grams from all parts of the Soviet Union and from other countries. These materials receive top priority. On the basis of the information obtained, weather maps are compiled for Europe and Asia and the whole Northern Hemisphere.

Forecasters keep constant watch over storm areas using weather maps, and issue storm warnings to areas that are threatened by gales and hurricanes. In turn, local weather services better acquainted with the conditions of development and movement of storms in their areas issue detailed warnings that specify the onset of the storm and also report by telegraph and radio. This is the task of the forecasting offices of the krajs (territories) and oblasts (regions).

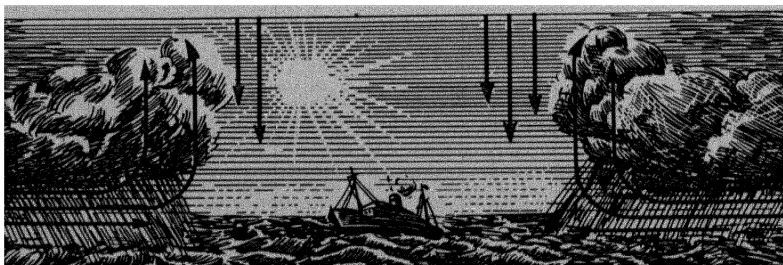
To illustrate, on February 3, 1952, the Forecasting Institute issued a warning of a south-west storm to be expected on



First phase of enormous land-slide on Inylchek glacier (Tien Shans) in August 1952 (photograph by V. Ratsek)



Tornado-twisted tree



"The Eye of the Storm" in the centre of a tropical cyclone where downdrafts of air clear away clouds

February 4th in the Baltic Sea with a wind force of 8. How should the forecasters of the local Weather Service react?

With this wind direction it is obvious that the storm would be felt mostly on the eastern coastline of the Baltic Sea, from Kaliningrad to Tallinn, for here the waves would be coming in from the open sea. In the Riga Bay, it would not be so strong and would be felt mostly in its north-eastern part. The waves would be still smaller in the Gulf of Finland. The storm would attain its greatest force in the open sea.

Taking these circumstances into account, the local Weather Service issued differentiated forecasts for the separate areas. For some, a wind force of 8 was forecast, for others Force 7, and for still others, only a fresh wind of Force 6. This forecast was relayed to all ports on the Baltic Sea and to all vessels at sea.

The forecast was correct in every respect. Many other storm warnings in the Baltic, Black and other seas have been just as accurate.

In the Caspian Sea, fishing goes on round the year. In the winter time, thousands are engaged in under-ice fishing. A winter storm can break up the ice and carry whole floes out to sea. The aim of the Weather Service is to give timely warning to fishing teams of impending storms, their strength, and of the danger of the ice breaking up. The fishermen of the Caspian can work in peace, for they know that they will be given timely warning of any danger.

*Meteorological apparatus.* The Soviet Weather Service is equipped with the latest devices for solving the problems that confront it. Thousands of instruments at scattered points throughout the Soviet Union record direction and velocity of the wind. Among them are the inventions of Soviet scientists, engineers and designers: Goltsman's hurricane gauge, Neusypin's anemometer, an automatic radio-meteorological station (ARMS) designed by Gorileichenko, Surazhsky and Maltsev, a mercury barograph designed by Kolobkov, an automatic cloud measuring device, and many others.

Every day, information about the weather and the co-ordinates of drifting automatic radio-meteorological stations (DARMS) are plotted on weather maps.

Since 1956, every year the Arctic has had in operation DARMS situated in different areas right up to the North Pole. They transmit information about the temperature, air pressure, and direction and velocity of the wind.

Outwardly, the automatic weather station is a duraluminium tower 12 metres high. It is set up on a tripod that is anchored to the ice. On the ice, right under the tower, is the radio transmitter and a metal holder with the measuring instruments.

Some parts of the DARMS are located in the water under the ice to protect them from low temperatures. This is possible because even in severe frosts the temperature of the water falls to only a little below 1°C. Under the ice, in a hermetically sealed cylindrical case, are the primary batteries and the clock-work that switches on the station.

When in operation, the station automatically converts the readings of the meteorological unit into Morse-code signals and broadcasts them once every 24 hours. Shore and island polar stations take fixes of the signals and for this reason the DARMS yield information not only about the weather in near-inaccessible areas of the Arctic but also about the movement of ice in the Polar Basin.

DARMS can function continuously for one year. Together with its radio tower it weighs 220 kilogrammes.

The setting up of a DARMS on drifting ice-floes is no easy task. In some cases, airborne expeditions had to cut paths through hummocked ice, and drag heavy sledges with the equipment over long distances.

Every day, at a strictly definite time, the DARMS—these true helpers of the polar men in their important and difficult job—are on the air.

High-speed electronic computing machines have found wide application in the weather forecasting service. They have made it possible to apply hydrodynamic methods of forecasting that

require enormous volumes of computation within a very short period of time. For example, the time spent in making a daily weather forecast must not exceed one hour. In this case, the computers do, with the greatest of ease, a job that would take a human computer a month or more.

Thanks to the fruitful work of our meteorologists, aerologists, hydrologists, and forecasters, the Soviet Weather Service is successfully coping with the problems that confront it at the present stage of weather knowledge.

## Squalls

A squall is a sudden freshening of the wind with sharp shifts in direction. The temperature in a squall falls the more (as much as 10-15° at times) the stronger it is. The air pressure increases sharply when a squall passes (this is called a squall jump). A squally wind is like a crashing blow—so great is the damage that it can inflict in just a few minutes.

Unlike ordinary storms that last quite some time, squalls sweep in suddenly and disappear just as suddenly. But in force, the squall wind is no less violent than hurricane winds, sometimes even stronger.

Particular attention was devoted to squall studies at the end of last century, after the British sailing warship, the frigate *Eurydice*, perished right near the shore. This was in March of 1878. The frigate was returning from a distant voyage. A cold penetrating wind was blowing and the rain was interspersed with sleet. The harbour was already in sight and the sailors could see the people awaiting the ship. All of a sudden a squall swept in knocking the stunned people on the wharf off their feet, so strong was the wind.

A shroud of snow covered the horizon turning day into night. The sea seethed with mountainous rollers. And all this lasted but five minutes. The hurricane wind subsided instantly and the sky cleared. But there was not the slightest trace of the frigate. In vain did the people peer seawards, the water was

blank. The *Eurydice* had been overturned by a gust of wind and sank instantaneously with all hands. It was only several days later that the ship was found by deep-sea divers on the bottom of the sea at the entrance to the harbour.



Scheme of a squall cloud. The ragged edges in the lower part are eddies; in the middle part is a strip of cloud in a zone pierced by inversion; in the upper portion are cirriform fragments of the dome of the cloud

When information about the storm began to come in from various localities it appeared that the squall had travelled at a fantastic speed—90 kilometres an hour—cutting a narrow (1.5-3 kilometres) swath over 700 kilometres long. This was why it came on so suddenly and lasted only about five minutes.

We now know the causes of such hurricane winds.

Squalls are usually associated with thunderstorms but often originate outside them. On weather maps, a squall zone is from 200 to 800 kilometres long and very narrow (0.5 to 6 kilometres). Feeble winds usually blow ahead of the squall front. On the front itself the wind shifts sharply, even to the reverse direction, and becomes very strong.

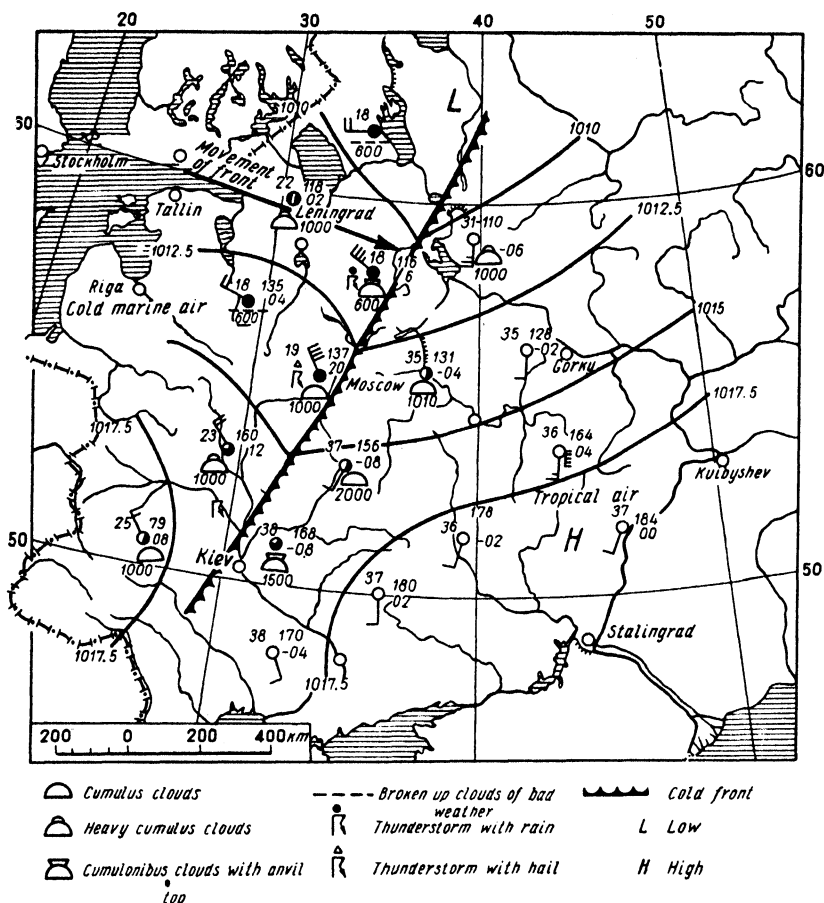
The squall is observed throughout the front but its force varies at different sections. The entire energy is concentrated in separate places and here the squall is destructive. Elsewhere, the wind freshens only slightly. The reason for this is to be sought in the "preparedness" of the atmosphere for such stormy processes. The important thing is the temperature of the air before the squall, its humidity, the degree of instability of the atmosphere, and topographic peculiarities.

Squalls are usually attended by thunderstorm clouds with very low base and very high summit. The more developed they are, the stronger the squall. In front of the main mass of cloud is a "swirling roll" consisting of low ragged patches.

As a rule, a squall is accompanied by a brief strong rain. But it sometimes happens that there is no precipitation due to insufficient moisture in the air. Squalls extend upwards to 2,000-3,000 metres, but turbulence of the air is particularly developed and dangerous in the lower layers.

A squall develops when cold air rushes into warm air. As the two currents collide, a tempestuous squall builds up if there is a considerable temperature difference between the cold and warm air masses. The bigger the difference the stronger the squall. The intensity also increases with the quantity of water vapour in the ground layer of air.

We have already spoken of the fact that cold air masses penetrate into a warm zone not like a wedge but in the form of a battering ram. The maximum wind speed is in the central part of the "ram's head," diminishing somewhat downwards, and falling off noticeably in the front part. The shape of the "head" accounts for the ferocity of the phenomenon in the front



Weather map with squall front (after Kolobkov)

part of the squall, the concentration of energy in a small sector and the pressure differential at the ground. The rising air in front of and above the incoming "head" leads to the formation of squall clouds, because rising air quickly cools making the water vapour condense. Moscow experienced a violent squall on May 28, 1937. It reached hurricane force with a wind velocity of over 30 metres a second.

The squall was accompanied by thunder, rain and hail. The



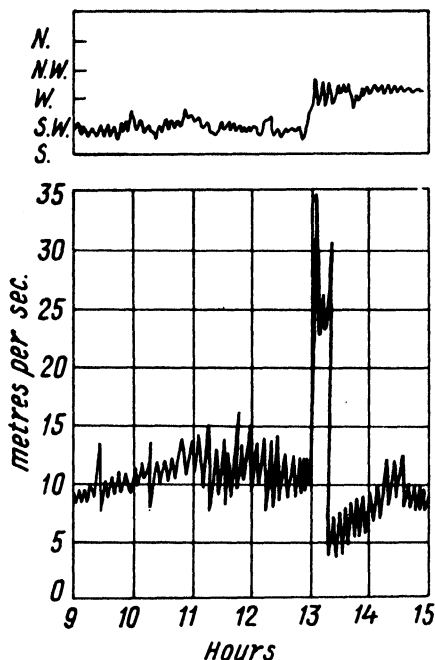
raindrops were torn to pieces by the wind, forming a solid wall that streamed over obstacles and caused eddies. The day darkened to a gloom. The whistling and shrieking wind completely drowned out the rumbling thunder, though brilliant flashes of lightning continually whipped the sky.

The chart on this page is the record of an automatic instrument called an anemograph. At first the wind speed built up in jumps. At 1:12 P.M. the velocity of the wind spurted from 10 to 26 metres per second. Continuing upwards at a rapid pace, it reached 35 metres a second at 1:14, but this hardly lasted two minutes.

By 1:19 it had abated to 20 metres a second, but then at 1:20 it jumped again to 30, and then fell to 5 metres a second.

In Moscow, the wind force was so great that it pressed out window panes together with the frames. In Orlikov Street the hurricane broke a thick shop window. Enormous trees were uprooted in Stromynka Street. At the "Dynamo" recreation park, an outdoor stage was torn to pieces. In many streets, high-voltage lines were broken and a number of people were killed by electricity.

At several points along the Kazan Railway electric wires were broken. Traffic stopped near Ramenskoye. In the town itself, a severe gust overturned a many-ton hoisting crane. Luckily there were no casualties.



Squall jump in direction and velocity of wind in Moscow on May 28, 1937

The wind force was greatest in Petrovsky Park where the hurricane ripped across the open Khodynskoye Field. Here, roofs of buildings were torn off, fences overturned, trees uprooted, and scaffolding ripped to shreds. The wind carried pieces of iron, tarpaper and wood into the centre of the city. On the Leningrad Highway, trolleybus wires were torn and telephone poles lay prostrate.

Is it possible to predict squalls? The answer is an unequivocal yes. This requires following, by means of daily weather maps, the movements of cold fronts and the development of thunderstorms. By determining the movement of such fronts it is possible to warn threatened areas in time. Squall warnings constitute one of the tasks of meteorologists.

### Tornadoes

It is a sultry summer afternoon. Suddenly the sun goes behind an enormous black cloud. The thunderstorm is still far off, but the rumbling can already be heard. Nature is absolutely still—the stillness before the storm.

The sound of thunder is louder, the black cloud grows before our eyes. All of a sudden a whirling roll of cloud emerges from behind the curtain of rain, reaches the edge of the thundercloud, and, writhing, dips earthwards. Up from the ground rushes a twisting tower of dust. All this merges into a single column, like the trunk of a gigantic elephant. Inside the trunk or funnel, the air is whirling at a terrific speed, spiralling upwards at the same time. One can see how the vortex sucks up dust, branches, boards, and even whole timbers. It twists them and whirls them. It tears off roofs, knocks down fences, uproots trees and twists them all about. All this lasts but a minute or two, then the whirlwind vanishes leaving in its wake a terrible downpour and thunderstorm.

This unusual phenomenon of nature is known as a *tornado*. The vortex with vertical axis is accompanied by a wind driving at a colossal speed. Inside the tornado, the wind speed reaches 100 and more metres a second, which is many times

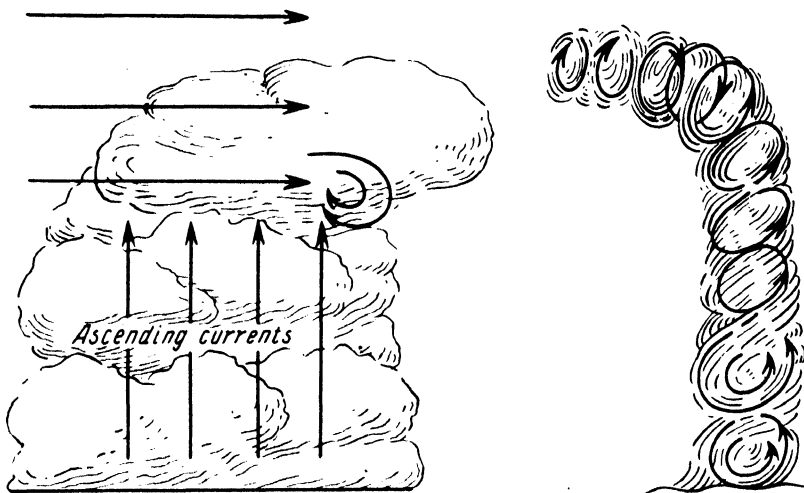
the most violent hurricanes. At sea, these twisters are water-spouts with diameters from 25 to 100 metres. On land, they are called tornadoes and are bigger still—100 to 1,000 metres, at times even growing to 1.5 and 2 kilometres. The funnel reaches to apparent heights of 800-1,500 metres.

The tornado goes by different names. In Russia it is called *smerch*, in France, *trombe*, in the United States, *tornado*.

The air movement in the tornado is vortical like the cyclone. But here the similarity ends. While cyclones are whirlwinds of enormous proportions, covering whole countries, the tornado is a purely local phenomenon.

Tornadoes are very common in the United States. In rural areas people build special storm cellars as refuges from this terrifying thing of nature. In the U.S.S.R. tornadoes are a rare occurrence. Though the tiny whirlwinds called dust devils that are often seen in spring on country roads resemble tornadoes—a sort of toy twister—their origin is quite different.

It must be emphasized that when a tornado passes through, the wind retains the same speed it had before, even at a close



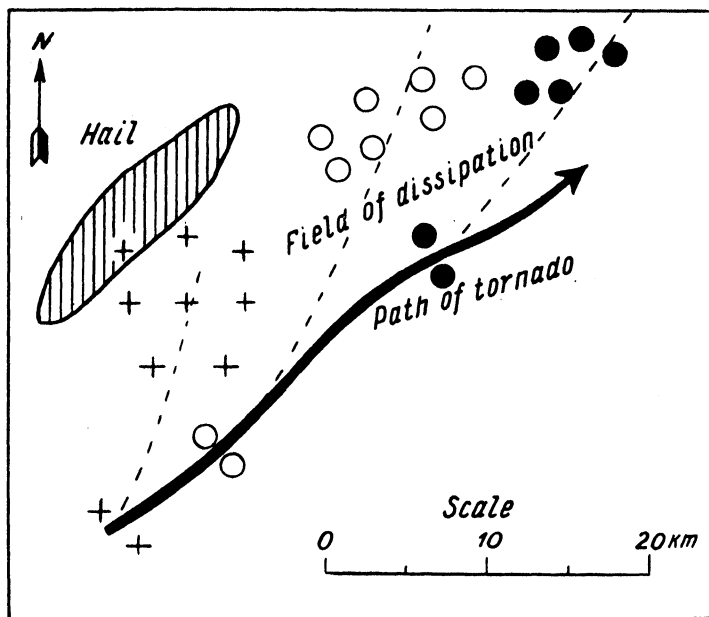
Build-up of tornado in cloud

distance. At times there is complete calm just a few dozen metres from the tornado path. The tremendous whirling speeds inside the vortex develop centrifugal forces that throw the air from the centre to the periphery, producing a big drop in pressure on the inside. This is evident from the fact that a waterspout can pull up a whole column of water as high as 6 metres. Recalling that the pressure of the atmosphere is capable of raising water only 10 metres (suction pumps), it will be clear that the vacuum inside a tornado or waterspout is very great. Buildings that have weathered a tornado, frequently have all their windows pushed out.

The extreme rarefaction inside the tornado causes a considerable drop in temperature, which results in condensation of the water vapour in the air. This is what gives the tornado its vortex cloud (trunk or funnel). The suction action of a tornado is also due to the reduced pressure.

Tornadoes were for a long time a real mystery of nature, for there were very few good observations and photographs of them. It is no easy matter to observe a tornado. Imagine the state of a person when everything about him is crumbling in clouds of dust. What is more, tornadoes have the habit of making sudden appearances. Nevertheless, we have now amassed sufficient material to account for this phenomenon.

The tornado originates in the central part of a powerful stormcloud, where there are very strong vertical air currents with sharp irregularities both in direction and force of the wind. Scientists believe this to be the "axis" of the vertical currents. If this axis is hit by a strong horizontal current, the uprushing flow is "overturned" producing a vortex with horizontal axis that rolls forward, as it were, and gradually emerges from the cloud. The laws of mechanics state that such a whirlwind cannot decay in the cloud, but must bend into a vortical ring. In doing so, the whirlwind bends earthwards in the form of tiny vortexes, moving down until it comes in contact with the ground on both sides of the cloud.



Outer field of dissipation of tornado. Crosses and circles denote places where objects were picked up and deposited

The truth of such reasoning is corroborated by the fact that one often sees bilateral tornadoes dipping their funnels earthwards to the left and the right of the cloud at the same time. The same laws of physics state that the air a very short distance from the vortex may remain calm. This accounts for the weak winds that adjoin tornadoes.

If two tornadoes (corresponding to the two respective ends of the vortical ring) appear at once, the direction of rotation in them must be in opposite senses. In a tornado that is dropping on the right side of the cloud (if we look in the direction of motion), the rotation must be counter-clockwise. When emerging from the cloud the vortex has a horizontal axis of rotation, but as it drops earthwards the tornado bends the axis of rotation into the vertical. The horizontal part of the vortex is usually seen only when it comes out of the cloud, because its continuation is masked by clouds. But sometimes one sees a

vortex with a horizontal axis. Proof of the existence of a horizontal axis in a vortex concealed by cloud lies in the fact that the tornado invariably descends from the cloud. If the vortex loses contact with the earth, its funnel is pulled back into the cloud, though not completely. The funnel then again dips earthwards, retreats, and so on.

Observations show that a tornado is always located to one side of the path of hail or heaviest rain. This, apparently, is the supply source of the twisting storm, though it is occasionally masked by other cloud layers.

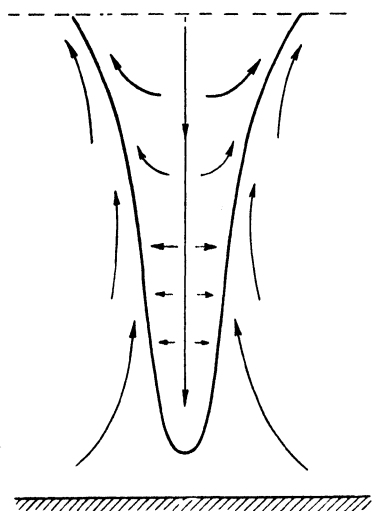
The so-called outer field of dissipation is the most cogent proof that a tornado has a horizontal part. Objects caught up by a tornado fall back to earth not only close to its base, but also on the other side of the hail belt at distances over 10 kilometres. They pass through the horizontal arm of the tornado

and are then thrown leftwards and ahead because the storm is always in motion.

Apparently, a tornado originates in the cloud some 3 to 4 kilometres up. This is supposed to be so because objects lifted from the ground have frequently been observed to be iced over when they fall in the outer field of dissipation. It will be recalled that in summer the zero-temperature zone begins at just this level.

Occasionally, there appear several tornadoes on the same side of the stormcloud. This is more frequent in waterspouts.

The formation of such "companion" vortexes is due to the fact that at this point the tornado detaches itself from the cloud. The first vortex has not had time to decay when there is already a second, a third, etc.



Internal structure of tornado

A tornado consists of a descending funnel-shaped vortex or nucleus and an outer envelop that begins at the surface and tapers gradually upwards. The nucleus need not descend to the ground. The whirling motion is conveyed to the envelope due to internal friction of the air (see figure).

Inside the nucleus, the current is downwards, while in the envelope and peripheral parts of the nucleus the motion is ascending.

The velocity of the upward-moving currents of air is unusually great, frequently exceeding 50 metres a second. This is actually a vertical hurricane. There have been cases when tornadoes have picked up small animals and even human beings and carried them quite some distance before putting them down again.

When a parachute jumper makes a delayed jump, his speed of fall at first increases. But then there comes a time when the air drag builds up to such a point that it balances the acceleration, and then the parachutist falls at a uniform rate that does not exceed 55 metres per second. If there is an upcurrent of more than 55 metres a second, the parachute jumper will begin to move upwards instead. Hence the conclusion that people are lifted up into the air because the ascending currents in tornadoes have speeds in excess of 55 metres a second.

The suction action of tornadoes and waterspouts is so great that the vortex has been known to suck up fish, frogs and medusas with the water and drop them down far inshore, whence the "raining of fish" that has been the cause of so much superstitious fear.

In June 1927, a waterspout appeared over a small lake near Serpukhov, sucked up into its enormous trunk a lot of fish, and moved towards the town. On the outskirts, it fell to pieces raining the fish earthwards.

An unusual rain of marine jelly-fish was recorded in the Far East (Kavalerovo Village) in the summer of 1933. The fish fell out during a heavy rainstorm. Since the village is some 50 kilometres from the seacoast, only a tornado could have brought them such a distance.

Tornadoes can also account for the mysterious "bloody" rains that frightened superstitious people in the old days. It was not blood, of course, but raindrops of a reddish colour. A tornado could have sucked up into its funnel the red pollen of plants, fine-grained reddish sand, or maybe it was the "rusty" water of swamps mixed with raindrops that produced these sanguine rains.

In Spain, once, the inhabitants of a hamlet were astonished to see grains of wheat falling from a stormcloud. It turned out that a tornado had wrecked some storehouses of grain and carried off the harvest, dropping it over the hamlet.

On another occasion, over Germany, branches and limbs of trees began falling from the clouds in perfectly still weather. There were so many that they formed whole piles of brushwood. At this time, one could see a murky cloud on the horizon with a pendant protuberance something like the column of smoke from a distant conflagration. A tornado had apparently passed over a wooded area, broken the tree, carried off the "products of its labour" through the horizontal arm, and deposited them in this village.

A miraculous "rain" was recorded on June 17, 1940, in the Village of Meshchery, Pavlov Rayon (District), Gorky Oblast (Region), when the raindrops of a thunderstorm were accompanied by silver coins! After the rain, school children and local farmers collected about one thousand silver kopeks of the latter sixteenth century. This extraordinary occurrence can be attributed to a tornado. Somewhere, the heavy rain had scoured away the soil and laid bare an old treasure of coins that were picked up by the tornado.

But not always do tornadoes confine themselves to such harmless freaks. They are often the cause of great damage. Wooden structures are pulled completely to pieces, age-old trees are uprooted, and those left standing, twisted into corkscrews. Tornadoes sometimes even damage stone structures.

Fortunately, these twisting storms do not recur more than once or twice a century in any one place. But the territory of the Soviet Union is so vast that every year brings reports from



different places of the passage of a tornado. Still some of them escape notice when they pass over sparsely settled places or large wooded areas. For instance, hunters in the untracked Siberian taiga have come across places where swaths have been cut 200-300 metres wide and 15 to 20 kilometres long with the trees lying prostrate. This is obviously the work of a tornado.

A destructive tornado ripped over Moscow on June 29, 1904. This day marked a series of violent thunderstorms in the gubernias of Moscow, Kaluga, Tula, and Yaroslavl. The thunderstorms were accompanied by heavy falls of hail. The most terrible destruction was inflicted by a tornado that originated to the south-east of Moscow and passed through the eastern part of the city. The tornado path was about 40 kilometres long, and varied in width from 100 to 700 metres.

The tornado wiped off the face of the earth a number of suburban Moscow villages, decimated thousands of hectares of wooded land, and wrecked buildings in the eastern part of Moscow. The number of casualties was great. In Moscow the whirlwind destroyed Annenhof Grove (at Lefortovo) that had trees up to a metre across. Eyewitnesses reported that the trees fell "as if by command," and many of them were charred. The tornado passed over with a terrifying roar, doing damage for 30 seconds to a minute or two. The snapping of falling trees was drowned out in the raging wind.

The tornado struck at about five in the afternoon. The weather in Moscow just before had been cloudy, warm and very oppressive ("sticky"), with slight easterly winds. On the horizon to the south, against the general background of a shapeless mass of cloud there began to form a very high and unusually massive thundercloud with large tufts of a delicate white colour. On top, the clouds dispersed and were surrounded by a thick cirriform veil.

Soon afterwards the city was hit by heavy hail, and the tornado itself was detected in the form of a column. Wide below, it gradually tapered cone-like, and then expanded again in the clouds. In other places, the tornado was like a black

column of smoke rising into the sky. So much water was sucked up as it crossed the Moscow River that the bed was momentarily exposed.

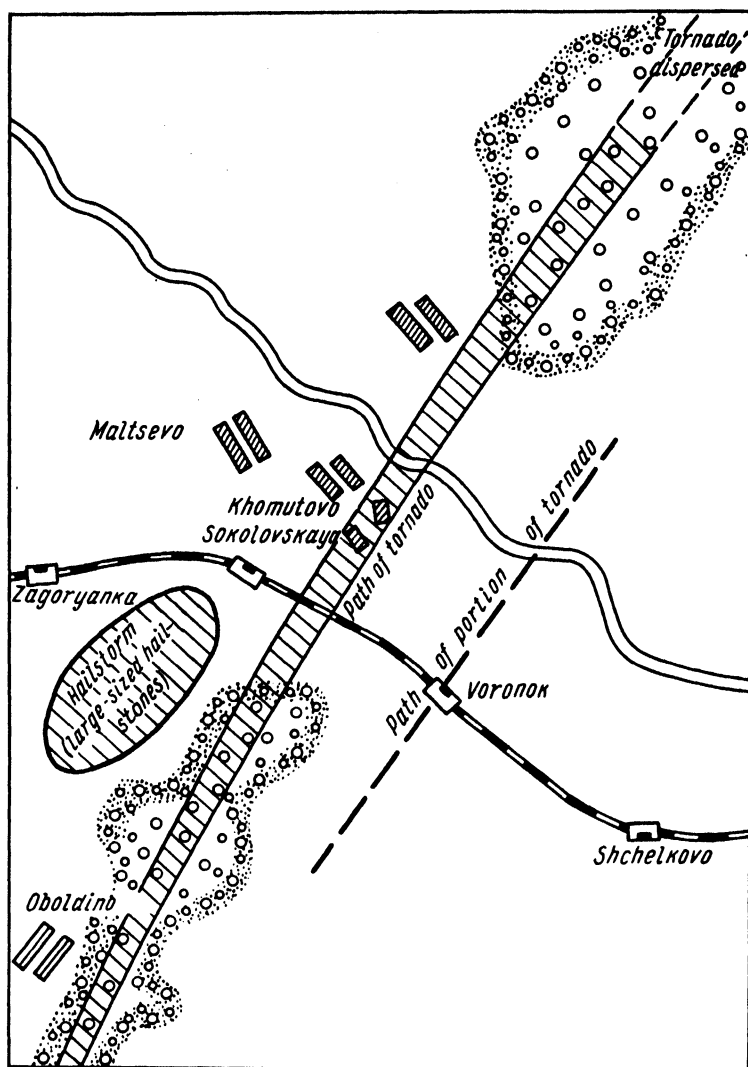
On September 2, 1945, Moscow suburbs were again struck by a devastating tornado.

It originated to the south of Valentinovskaya Station on the North Railway, and swept down upon the village, then passed through another village, Oboldino. Crossing the railway it tore down the electric wires, a companion tornado wrecking part of a building at Voronok Station. From there it passed the village of Khomutovo, ripped out into the open field and vanished in a grove some five kilometres away. The entire storm path was strewn with wreckage of buildings and knocked-down trees and telephone poles.

At the site of the catastrophe considerable material was collected in the form of photographs, reports of eyewitnesses, and the like. Particularly valuable was an examination of fallen trees—concrete evidence of the direction of rotation and the speed of the wind in this tornado.

Eyewitnesses describe its approach as follows. A stormcloud with a very low base elongated horizontally in the form of a shaft appeared on the southern horizon. The eastern and western parts of the cloud produced a pendant funnel, the right (eastern) part of which reached the ground. Not far from the tornado, the stormcloud broke off sharply and steeply, exhibiting tremendous vertical development. Outside the cloud and the path of the tornado, the ground wind speed hardly changed at all.

The tornado proved to be a huge greyish mass moving from the south-west and rotating counter-clockwise. Inside the tornado one could see boards, pieces of iron and the like. It ripped across the railway at 4:20 P.M. On the ground, the tornado was approximately 50 metres in diameter. Before vanishing it increased to 300 metres across. The damage was greatest farther from the centre of the vortex. Particularly great was the damage along the right side where the rotary motion of the whirl coincided with its translatory motion.



Tornado path on September 2, 1945

Heavy hail—some stones reaching the size of pigeon and chicken eggs—fell on the left side of the storm path. Some of the hailstones consisted of several pieces of ice of a dirty greyish colour and injured a few of the local inhabitants.

A very interesting report comes from aviator Loginov, who encountered the tornado aloft and escaped it by veering out of its path. He relates that at 4:30 P. M. and 160° "we approached the stormcloud from the north-east at 300 metres altitude and at a distance of 250-300 metres from its right flank.



Tornado as seen from aircraft (drawing by Loginov)

Here the sky was clear. An enormous whirl of black cloud was seen at about 350 metres altitude right in the centre of the stormcloud. The whirling motion was in the direction of the forward-moving cloud and appeared to be rolling. Its apparent diameter reached 100 to 150 metres. While skirting the cloud on a level with the centre of rotation of the vortex, our plane was thrown upwards from 300 to 450 metres. I put the craft in a big angle of glide, but it still went upwards, and even when we were far to the rear of the storm, we were tossed up and down violently for three or four minutes."

An analysis of available material showed that the tornado had dipped to the ground on the right-hand side (relative to the

direction of motion) of the stormcloud and was moving from south-south-west to north-north-east at about 60 kilometres an hour. It was accompanied by sometimes one, sometimes two companion twisters. It had apparently originated at an altitude of 3,000-4,000 metres in the central part of the thundercloud. And, as is usually the case, the storm travelled to the right of the path of hail, and both were moving in the same direction.

The rotation of the wind in the tornado was cyclonic (counter-clockwise). This was authentically established not only by eyewitnesses but also by the character of the destruction and the direction of fallen trees. On the right side of the whirl, trees were knocked down from the east and south-east; on the left, from the north and west.

On some portions of the tornado path, the vortex lifted from the ground—"tired," as it were, of wrecking—and tried to pull back into the cloud, but a fresh influx of energy from the stormcloud sent it down to the earth again. This is indicated by photographs of trees sheared off in the middle and even upper parts of their trunks. In places of greatest damage, the twister slowed down due to the tremendous friction. This is supported by many eyewitnesses who estimate the time of destruction at 3-4 minutes, whereas in open spaces the tornado "laboured" for only 1-1.5 minutes.

The maximum wind speed can be gauged only from the destruction. In our case, the estimates range from 70 to 80 metres a second, which is hardly the maximum.

There was no damage done outside the vortex and its companion twisters. Quite the contrary, the winds were moderate or totally absent (a calm). And when the thunderstorm and rain came later, the wind speed did not exceed 10 to 12 metres a second.

The reports of eyewitnesses suggest the formation of a second tornado end on the left side of the cloud (a twisting, cone-shaped, pendant cloud on the left-hand side of the stormcloud). However, this part of the cloud vortex did not develop further.

The least damage was noted in the centre of the vortex, which points to an uneven structure and the existence of two shells in the tornado: the inner and calmer one, where the currents collide, and the outer one with maximum wind velocity. At any rate there was no whirling motion in the central part because here the trees fell in all directions.

The ascending currents in the vortex were tremendous: eye-witnesses were astounded by the timbers, boards, broken roofs, thick branches, and other things that were flying about.

Many have seen the horizontal part of a tornado. The "twisting roll" of cloud was, obviously, this horizontal portion of the vortex emerging from the cloud.

The outer field of dissipation was to the west of the vortex, for stacks of hay picked up by the twister in Khomutovo were deposited in a neat collection some 3 to 4 kilometres west of the village. Other objects thrown down by the tornado were also found at the same distance to the west of the vortex and a little forwards.

The companion twister that demolished half of the Voronok station building was to the right of the main vortex. It moved parallel to the latter and at the same speed. In diameter, it was roughly 50 metres and had the same cyclonic wind rotation.

The tornado passed some 50 to 100 metres to the east of a weather station. An analysis of the record of a self-recording barograph indicates pressure changes, with something of a vacuum inside the tornado itself. This pressure fluctuation continued 7 or 8 minutes, while the destructive action of the tornado near the weather station lasted only 1-1.5 minutes. The impression is that the main tornado together with its companions was in a funnel of perturbation of very large diameter—of the order of 7 to 8 kilometres. The surprising thing, however, is that such fluctuations in pressure were attended by wind velocity increases only up to 10 metres a second.

Another distinguishing feature of this tornado was the late season—September. In these latitudes, thunderstorms usually abate or disappear entirely at this time of year, for tornadoes

are always associated with the intense formation of thunderclouds. This is the first observed case so late in the season.

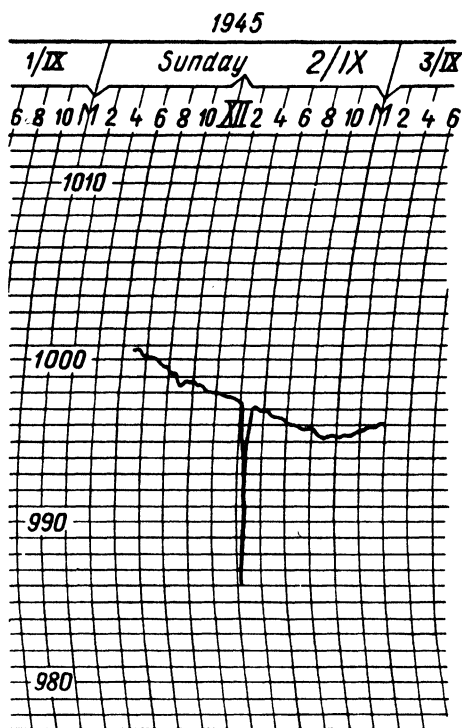
An unusually violent tornado swept down on Khimki Rayon of Moscow Oblast on the afternoon of August 17, 1951, and went into a tantrum of rage over the town of Skhodnya.

The tornado originated near the village of Golikovo and moved from south to north about 10 kilometres to the Klyazma River where it disintegrated. The width of the tornado path varied from 200 metres at the beginning up to 1,000 metres in the latter half of the journey.

The storm was preceded by hot weather with an afternoon temperature of 29° C.

At 4:30 P. M., a towering, menacing thundercloud made its appearance to the south. Every now and then lightning flashes cut through it. On the right-hand side (in the direction of motion), elongated bulges pushed earthwards from the cloud, then retreated, continuing to pulsate. One of them dipped down to the ground turning into a tornado funnel. The sky darkened almost to night.

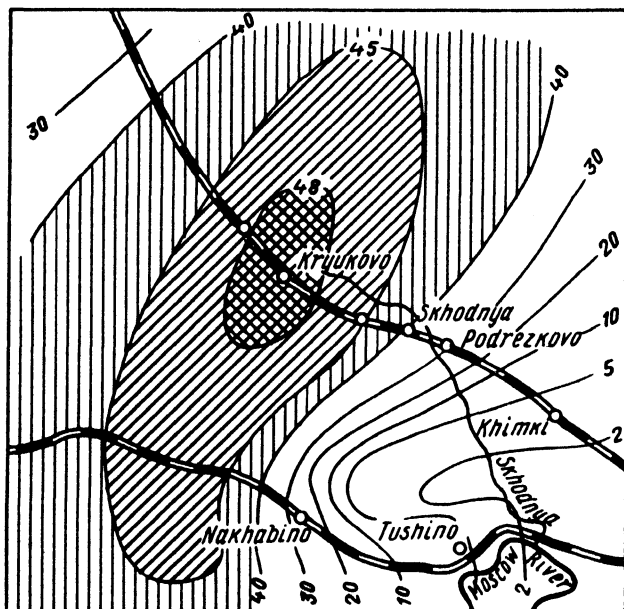
One could hear the approaching whirl, the snapping and cracking of trees. Along with it came a downpour with 40 to 55 millimetres of rainfall. In places, hail like walnuts came thundering down. Separate hailstones reached the size of goose eggs.



Barogram in neighbourhood of tornado

Hundred-year-old pines and birches 60 to 70 centimetres thick were blown down. Some of the trees were carried a hundred metres from the fringe of the wood. A large number of buildings were demolished.

Waterspouts on the Black Sea are a frequent occurrence. Sometimes, several spouts form at once. But these sea twisters



Isohyets of rainstorm accompanied by tornado, August 17, 1951, in Khimki Rayon, Moscow Oblast (after Remizov)

are not so powerful. There is not a single authenticated case of one sinking a ship.

An observer at the coastal weather station Cholpan-ata has given a description of a waterspout on Lake Issyk-Kul. It made its appearance on the lake at 11 A.M. on October 14, 1928, during a heavy rain and hail. The funnel descended on the left-hand side (in the direction of motion) of the stormcloud. In cross-section, the enormous column of water looked like a double-concave lens. In about 20 minutes the spout covered a distance over the lake of roughly 12 to 15 kilometres. Twice



it disappeared for a short time, but came to life again. The waterspout gradually grew pale, the column broke in the middle, the upper part vanishing into the heavy stormcloud and the lower falling into the lake. Then it reappeared—not out of the lake, but falling out of the cloud. Twice, little branch spouts grew up near the mother spout, but they disappeared very quickly. At the top of the column where it connected with the cloud, water spray formed a smooth horizontal pipe-like affair some one and a half times the size of the waterspout itself. This enormous water-filled pipe was clearly distinguishable because it was very bright against the general black background of the clouds. The waterspout was in a constant wiggling motion, all the while retaining its vertical position; the writhing of the water-pipe in the clouds was like the convulsions of a mammoth snake.

When the spout vanished completely, it left behind a turmoil like a boiling cauldron. Quite some time passed before the lake calmed down.

We are still far from being able to predict tornadoes and waterspouts. If one consults the weather map when a tornado makes its appearance, the synoptic situation will appear to differ but slightly from the ordinary thunderstorm. Hot, sultry weather, a very high humidity, and violent thunderstorm activity are the necessary signs of a possible tornado. But these are not enough. Not always do they give rise to tornadoes.

Nevertheless, Soviet weather men, compiling detailed weather maps (micromaps) for tornado areas and studying the conditions under which they arise, have noted characteristic peculiarities that attend the birth of a tornado. This is important in establishing forecasting techniques not only for tornadoes but for squalls, which ordinarily appear under tornado conditions.

Guns were formerly used to fight waterspouts at sea. The cannon balls broke the spout into two pieces: the lower part, which collapsed into the sea, and the upper part, which pulled back into the clouds. But the diameter of a waterspout is measured only in tens of metres, while that of the tornado reaches hundreds of metres. This method, therefore, holds little

hope for combating twisters. We still have to study the nature of tornadoes and waterspouts, and investigate theoretically to find ways of forecasting these dangerous whirlwinds. Predicting phenomena is another way of fighting them.

### Local Storms

The topography of mountainous countries, particularly near the coastline, creates a favourable situation for local storms, which sometimes attain hurricane force.

When masses of air rush out of a broad and deep valley and plunge into a mountain gorge, the resulting storm is something in the nature of a huge "draught." If the wind is blowing from a mountain plateau that falls sheer to the sea, the storm is like an "airfall."

Novorossiisk frequently experiences storms of this nature. Here, a violent north-east wind blows from the Markhotsk Pass (about 400 metres above sea level). This Novorossiisk wind is called *bora*, from the Greek, meaning a cold north wind.

How does it originate?

The Caucasian Range separates the expansive North Caucasian Plateau from the warm Black Sea which never freezes over. The mountain ridge along the Novorossiisk coast is relatively low (500-600 metres). In the winter time, the extremely cold air of Arctic anticyclones coming down from the north accumulates on this plateau. Not having a natural outlet to the sea, the cold air begins to overflow the ridge of mountains. With fierce violence it breaks into the Markhotsk Pass, which is below the surrounding mountains, and plunges seawards where the pressure is then usually low.

A north-easterly wind develops in the form of an "airfall" that rushes down into the bay and town of Novorossiisk. If at this time the Black Sea is experiencing a cyclone, the north-eastern draught is still greater, and the *bora* attains hurricane force. At times the temperature falls to below minus 20°C. aggravating the already catastrophic action of the wind.

The wind velocity of a *bora* is very great. There have been

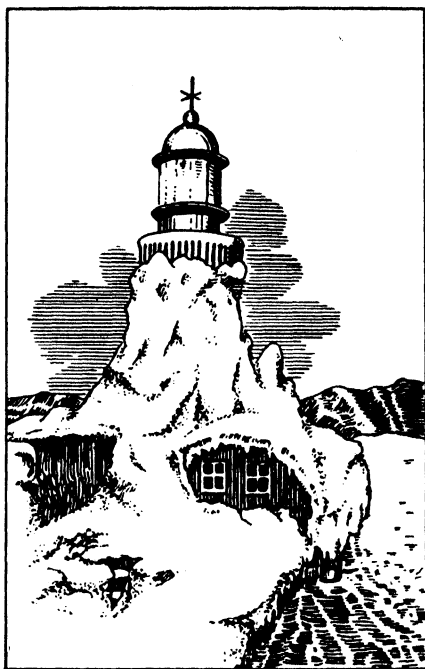
instances of 40 metres a second and more. Gusts even reach 50 and 60 metres a second. In 1928, a Goltsman hurricane gauge registered gusts up to 80 metres a second.

In a *bora* the spray from waves becomes supercooled and covers the embankment with a crust of ice. Ice thicknesses of 3 and 4 metres have been reached. Buildings along the shore are likewise iced over. There have been cases when the ice stops up the doors and windows and even chimneys. Often, the glazed frost is increased by cold rain.

During a particularly strong *bora* on January 12, 1848, four vessels of the Black Sea Squadron perished

under the weight of a crust of ice. Here is a description of how one of these vessels—the cutter *Struya (Jet)*—succumbed.

“A crust of ice began to build up on the bow, and got so thick that little by little the ship dipped forward.... The frozen crew made every effort to cut off the ice and keep the cutter from sinking. Axes were heated in the galley, crowbars were brought into action, and boiling water was tried in a vain effort to stop the growing crust of ice. By nightfall the *bora* was raging still more fiercely... the ice dust cut into the skin, actually tearing it off the hands and faces of the men, so much so that the sailors who died were indistinguishable. Under these impossible conditions the Russian sailors did not lose heart and even succeeded in dragging all the guns astern, although they had frozen to the deck together with their mountings, forming



Beacon iced over in *bora*

a solid whole. Slowly and persistently the ice thickened. The general exhaustion passed all bounds. Many of the men were so tired and cold that they fell asleep and froze to death on the instant. The cold, ice and water gripped the heroes with a pitiless, merciless gradualness. . . .”

There have been many cases when the enormous force of the wind tore ships in the Novorossiisk Bay from their anchors and threw them onto the shore. The only salvation from a *bora* is the open sea, because the field of action of this wind is confined to a narrow strip along the coast.

When the gusts are particularly strong the *bora* can demolish buildings, pull out telephone poles, overturn loaded railway cars.

The pressure in Novorossiisk during a *bora* “airfall” is from 8 to 10 millibars higher than at neighbouring stations. A released pilot balloon will not rise. It is rapidly carried out to sea along the surface, and only at some distance from the shore does it begin to gain altitude.

Due to the *bora*, the mean annual wind velocity on the Markhotsk Pass is about 10 metres a second, which is the record for the whole Soviet Union. This is something in the nature of a “pole of winds.” Since the origin of the *bora* is known, the Weather Service issues warnings on its development as soon as a cold anticyclone begins to descend from the Scandinavian countries or the north of the European part of the Soviet Union.

The local inhabitants recognize the approach of a *bora* from the appearance of ragged clouds on the summit of the ridge.

A relative of the *bora*, the *Baku norther*, is a violent northerly wind which sometimes attains storm strength (Force 11). At times it blows for several days running, causing a sharp fall in temperature.

A *bora*-type wind occurs on Novaya Zemlya, too. Here it is usually accompanied by a snowstorm.

Also similar to the *bora* is a Baikal wind called *sarma*. This wind is especially strong in the winter half of the year.

Mountainous and valley winds of storm force are likewise observed in many places of the Pamir, Tien Shan, and Caucasus mountains.

The *mistral* that blows in Provence, France, and along the French coast of the Mediterranean, and also the *gallego* of Spain form in the same way as the *bora*.

The Antarctic has areas in which the wind attains exceptional force. One of these is Adélie Land just under the South Polar Circle (130° east longitude). There the mean annual wind velocity is twice that at the Markhotsk Pass. Storms rage nearly every day at Adélie Land, making it the southern "pole of winds."

The Australian scientist Douglas Mawson, who wintered over in the vicinity of Adélie Land at the beginning of this century gave a description of the "Home of the Blizzard" in a book by this name.

The cold air constantly flowing down from the glacial heights of the Antarctic continent carries with it snow dust which acquires a terrific force of impact. In Mawson's words: "The abrasion-effects produced by the impact of the snow particles were astonishing. Pillars of ice were cut through in a few days, rope was frayed, wood etched and metal polished. Some rusty dog-chains were exposed to it, and, in a few days, they had a definite sheen. A deal box, facing the wind, lost all its painted bands and in a fortnight was handsomely marked; the hard, knotty fibres being only slightly attacked, whilst the softer, pithy laminae were corroded to a depth of one eighth of an inch."

A blizzard is sometimes attended by tornadoes of snow. The force of this swirling column of snow may be gauged from what happened to the top of the box on Mawson's aero-sleigh. Though weighing over one hundred and fifty kilogrammes, it was picked up bodily and carried 50 metres away. An hour later a raging twister caught it up again and dashed it to pieces against the rocks.

### Dust Storms, Dry Winds, Droughts

In hot, dry weather, strong winds caused by a passing cyclone or squall raise clouds of dust. There is so much dust in the air that the sky darkens and the sun is seen as a faint red disk. This is a dust storm.

Storms brought about by cyclones are of long duration and are deadly to crops. They are likewise detrimental to the health, for the dust gets into our lungs.

In squalls, there is not much harm done, because these storms are short-lived even though they are violent. The dust they raise is usually washed out by the very next rain.

Dust storms are particularly severe in sand deserts where they are frequently accompanied by still more terrible occurrences—sand tornadoes. Whole caravans have been known to be sanded under by such storms.

Central Asia has a very dry and hot wind of extreme violence that goes by the name of *afganets*. The name comes from the south-westerly direction from which it blows. It is a local wind and is in no way connected with Afghanistan. The local name is *kara-buran* which means black storm.

The playground of the *afganets* is mainly the valley of the Amu-Darya, but it frequently occurs in other places of Central Asia. The *afganets* is caused by cold fronts under conditions of extreme heat ( $40^{\circ}\text{C}$ . and more), scorching sand, and the complete absence of rainfall. The energy of the cold front, which in ordinary circumstances is expended in the production of thunder- and rainstorms, is here manifested in the form of sand storms in which the dust particles suspended in the air are greatly heated by the sun. The dust rises several kilometres and remains suspended in the air spreading over vast areas and impairing visibility.

In the Sahara, Arabian and other deserts, dust storms attain great violence. Here they are called *simoom* and *khamsin*. The *simoom* comes from an Arabic word meaning poisonous. These winds are, of course, not poisonous, but are intensely hot ( $40$  to  $50^{\circ}\text{C}$ .), and, carrying clouds of sand at terrific speeds, they actually do great harm to all living things.

The harbinger of the *simoom* is an expanding black cloud on the horizon. This is the approaching mass of dust. The cloud grows rapidly, throwing a haze over the sky; soon the clouds of sand screen out the sun altogether. The air becomes hot, and it is hard to breathe. Camels dig their heads into the sand,

travellers cover themselves with clothing, yet the sand finds its way into every cranny. The heat becomes so unbearable that many lose consciousness. Animals flee in panic.

The khamsin (which means "fifty" in Arabic) is a murderous dry wind that blows in Egypt twenty-five days before the vernal equinox and the same number after it. It differs from the simoom in being of longer duration but of less intensity.

The interior of Africa gives rise to a dusty, dry wind called the *harmattan*. In the winter months, it blows from the interior of the continent to the Atlantic Ocean. This tempestuous easterly wind is felt even hundreds of kilometres from the western shores of Africa. At times the harmattan carries so much dust into the ocean that ships from Cape Verde arrive at the Canary Islands all covered over with a thick layer as if they had been carrying lime or cement.

We know the origin of the harmattan. In winter, the air over the African continent is colder than the waters of the Atlantic Ocean. Despite the fact that the prevalent pressure in these latitudes is generally high, it gets still higher over the continent; the pressure gradient moves oceanwards, and here easterly winds are blowing. Dust "fogs" penetrate hundreds of kilometres into the Atlantic Ocean. The annals of marine navigation relate of the "sea of gloom" in the eastern part of the Atlantic. This is the result of violent harmattans.

At times the African dust is carried far into Europe. In the spring of 1901, extremely violent dust storms in the Sahara raised enormous quantities of sand and, on the wings of a cyclone, swept into Italy the next day, and then on into Hungary and Germany. Three days later, very fine dust particles reached Russia. Weather stations noted an orange film on the snow cover even in the Urals and in Western Siberia.

When cyclones moving across the western part of the Mediterranean from Africa break into Southern Europe, their system of circulation sweeps up the overheated air of the Sahara. The *sirocco* is an intensely hot wind that blows in Italy and the adjoining islands. There is very little water vapour in the air

when the sirocco blows; it is dry and withering. Even at night the temperature does not drop below 30°C.

Much harm is done by the hot and dry easterly winds called *sukhovei* (dry winds) that blow in the south-eastern and southern parts of the European section of the Soviet Union. Despite the fact that there is frequently sufficient moisture, evaporation during these winds is so great that the moisture does not have time to reach the above-ground portions of the plants. The plants perish, and do not simply wither but are what is known as "gripped." Besides, these dry winds desiccate the soil giving rise to deep cracks on the surface. During dust storms the dry particles of soil are easily carried away by the wind. The scorching wind bears along masses of minute dust particles that penetrate everywhere. When the *sukhoveis* blow, all steppe vegetation dries up, even the leaves on the trees. Grain crops mature earlier than usual, yielding lean and almost empty ears; the grains do not ripen and likewise dry up.

But these dry winds should not be confused with droughts. What is the origin of droughts?

The principal suppliers of moisture are known to be the vast expanses of water in the oceans and seas. We know that the sea and the land do not heat up evenly. Water heats up slowly and just as slowly releases its warmth to the ambient air. The land gets warmer more quickly and just as quickly cools off.

Evaporation of the water is likewise uneven, increasing with rising temperatures. In the hot summer time the surface of the sea heats up and gives to the air large quantities of water vapour. The winds carry this moisture to the land masses.

The Atlantic Ocean is the chief supply agent of moisture for the European part of the Soviet Union. The wind carries the moisture to the continent, but it gradually loses a good deal en route. This is why the southern, and particularly the south-eastern, parts of the European Soviet Union do not always receive sufficient moisture. True, winds from the Black Sea carry additional quantities of moisture to our southern areas. But when these moist winds are for a long time supplanted by winds from the Aral-Caspian steppe lands, a drought sets in.



And if, in addition, precipitation during the winter has been meagre, the drought will be very severe.

In summer the sun is high above the horizon. The nights are short. During the day the sun heats the ground so intensely that it does not have time to cool off during the night. Every day the ground is heated more and more, and evaporation of the moisture keeps apace. Its reserves dwindle and finally vanish completely. Rivers and lakes grow shallow, and small bodies of water dry up entirely. Plants suffer from the lack of moisture and begin to wither.

At the beginning, vegetation receives small quantities of moisture from morning dew. Dew forms in the night on account of condensation of water vapour in the cooled air. But since the temperature goes up every day, the air becomes drier and the dew diminishes. In the evening it settles out later and later, and in the morning it evaporates earlier and earlier, until it disappears entirely. The plants are then cut off from even this small source of moisture.

If clouds appeared they would shield the earth from the burning rays of the sun, but the dry air and the sun-scorched soil do not give up enough moisture for clouds to form. The cloudless sky aids in a merciless heating of the soil and the ground layer of air. True, the nightly fall in temperature brings the plants a rest from the exhausting sultriness, but it is short-lived. The sun rises and in a short time the ground layer of air is warmed up again, and stifling heat sets in. The plants die.

The calamity is capped by strong winds that swirl up whole clouds of dust which consists of the fertile upper layer of soil that is carried great distances by the wind. The wind disperses it in the air.

In 1955, the inhabitants of the oblasts of Tambov, Penza, Balashov and Stalingrad observed a strange thing. From the 18th to the 20th of April, strong southerly and southeasterly winds blew a whitish dust into a thin layer that covered the ground, the trees and all structures.

Many eyewitnesses have described this picture. On the 19th and 20th of April Balashov Oblast experienced a white fog

that was so dense that the sun could hardly penetrate through the haze. As it settled to the ground, the fog covered everything with a white coating like that of fine flour. Half an hour in the streets was enough to make anyone look like a miller. The dust crept into one's mouth giving the taste of saltiness and a tickling sensation in the throat, and a cough. In Tambov Oblast the sediment was reminiscent of lime dust. The window panes were covered over with a white layer and became "frosted." In places there was a freezing whitish mist. Metal quickly rusted under this coating. Stalingrad Oblast reported a peculiar haze which settled to form a coating like hoarfrost.

Weather maps answered the query of where this dust came from. They showed clearly the direction the air mass was moving in, its speed and the seat at which it originated. The dust fog moved from the south-east to the north-west. It was first noted in Stalingrad Oblast and then in Balashov, Tambov, and Penza oblasts; the latest reports on the dust came from Ryazan Oblast. The weather maps revealed completely the travel pattern of the air mass. They showed that the air mass from the Aral-Caspian steppes had passed through Kara-Bogaz-Gol, the Caspian Sea, and Stalingrad Oblast towards Moscow. The mass was swept on by easterly and south-easterly storm winds at a rate of 20 metres per second along the ground. At higher levels the wind speed was still greater.

What is the nature of this dust?

The answer is given by a chemical analysis of the coating sampled in places where it settled out. It was found to be loess dust with an admixture of chlorous salts. Hence the salty taste noted by many of the eyewitnesses. This foggy mist was made up of the dust of Central Asia plus salt particles from Kara-Bogaz-Gol. When the rain subsided or the wind abated, the dust settled to the ground.

A storm on the Great Plains of the United States that broke out on May 9 and lasted till May 11, 1934, sent dust up to a height of 7 kilometres. During the dry year of 1933, dust storms swept the whole country from Arizona to New England. In the spring of 1936, some states experienced up to 22 dust-

storm days a month. During recent years, dry winds in the United States have ruined at least 20 million hectares of fertile land. Intense drought and dust storms were observed in the spring of 1955 in the region of the Great Plains in the states of Kansas, Oklahoma, Texas, Nebraska, New Mexico, Colorado and Wyoming. Land suffered over an area of 2.8 million hectares, sown mainly to wheat; and there were threats of erosion to another 8 million hectares.

Drought strikes not only at plants, its adverse effects are likewise felt by animals, fowl, and fish. The high temperature and dryness of the air make the animals thirsty, they cease to eat and seek refuge from the stifling heat. Dairy cattle lose weight, milk yields fall, and by winter the animals are weak, exhausted, and frail.

The shallow rivers, lakes, ponds and dried-up creeks force the beasts and birds and fish to change their habits. The animals leave their habitats in search of water and frequently approach human dwellings. Even the cautious elk seeks water in wells and tanks of water for domestic animals. Due to a lack of grass vegetation, forest mice attack shoots and young trees.

The birds have a hard time too. Drying-up ponds and reservoirs force wild duck to aggregate at the only bodies of water that are left, and they cease to fear human beings. Food becomes more and more scarce. Hunger compels the forest fowl to make forays into farm crops. Large fish move into deeper water.

Prolonged weather observations indicate that droughts affect very large areas and extend over two- and three-year periods. However, droughts are more frequently limited to a single year. During 60 years prior to the 1917 Revolution, the Volga experienced 7 crop-killing droughts, the eastern part of the Ukraine over 15, the south of the Ukraine, 10. The two-year droughts of 1863-64, 1895-96, 1920-21, and 1945-46 were the most devastating. During the past 100 years, there have been only two three-year droughts: in 1890-92 and 1905-07.

The tiny private farms of pre-revolutionary Russia were not able to fight the drought, and hunger carried off many thousands of lives.

*CHAPTER FOUR*  
**THE EFFECTS OF LARGE CITIES  
ON THE MICROCLIMATE**

The inquisitive reader has probably often asked himself whether a city can have any effect on the climate.

In February of 1955, the author made a trip to Zvenigorod, some 50 kilometres to the west of Moscow. The morning was clear and frosty, the Moscow thermometer was 15° below, Centigrade. The day was a perfect calm. But in Zvenigorod it was 32 degrees of frost. The absolute silence was broken by the snapping of trees; sounds were distorted—a thing that occurs only at very low temperatures. And all this was only a few tens of kilometres from Moscow. Could it be that the “breath” of Moscow heated up the air?

The investigations of meteorologists give an affirmative answer. Though this is a rare case, indeed, a difference of 5 to 10 degrees in winter temperature between a town and its environs is a common occurrence that is almost daily recorded in weather reports during calm weather.

Moscow covers a large territory. Hundreds of thousands of buildings, asphalted streets, factories produce a marked change in the climate. This is why Moscow has its own peculiar microclimate. Not only temperature, but other weather elements as well—wind, cloudiness, precipitation, sunshine, transparency of the air—differ sharply from the suburban areas. Only a continual strong wind gives the city a good ventilating and smooths out the contrasts. But in this case, too, the meteorolog-

ical conditions on the windward side of a large city differ from those to leeward.

The problem of the microclimate of Moscow is not an idle one, for millions of people reside in the capital. And the dust- and smoke-polluted air exerts a direct effect on the health of the city dwellers. For this reason, weather men devote considerable attention to studies of the microclimate of Moscow. This also holds true for other large cities like Leningrad, Kiev, Kharkov, Sverdlovsk, Kuibyshev, and others.

When an aircraft approaches Moscow in clear weather, one sees an enormous grey cloud hanging over the city long before the silhouettes of the tall buildings come into view. When there is a wind, the cloud is elongated in the form of a cone. This is the dust, smoke, and soot raised by updraughts of air to heights of 500 and 1,000 metres. This grey cone is sometimes visible from as far as Mozhaisk or Serpukhov, over a hundred kilometres off. When an aeroplane comes in to land at a Moscow airport it sinks down into a yellowish haze that reduces the sunshine, and the air is filled with a multitude of odours. This is how the breathing of the city creates, as it were, its own atmosphere.

Now let us see how Moscow affects the weather elements. It is surrounded by meteorological stations, and there are quite a few in the city itself. In addition, numerous measurements have been made with mobile weather stations.

Start with the temperature of the air. It is influenced even by the numerous furnaces in the city that create a smoke screen out of the products of incomplete combustion. The result is a sort of cloud which in winter tends to keep the warmth in. Moscow rarely experiences what are known as "brilliant" frosts with crystal-clear air. The city is always overhung by a haze. In the severe winter of 1940, the temperature at a Moscow airfield on January 17 was  $47^{\circ}$  below, Centigrade, while the centre of the city registered only  $40^{\circ}$ . Farther out, the temperature was still lower—Zvenigorod, minus  $49^{\circ}$ , Klin, even minus  $51^{\circ}$ . These were record lows for nearly a century.

In the winter of 1955-56, the absolute minimum of temperature was recorded on January 31. That day, the centre of the city was at 32° below zero, the Leningrad Highway at 36°, Zvenigorod and Klin at 42°. Let us recall at this point that mercury freezes at minus 38.9 degrees C., so that in severe frosts it is necessary to use alcohol thermometers. But the mercury thermometers are not taken indoors because mercury does not expand upon freezing. So the talk about thermometers bursting in forty-degree frosts is a complete misunderstanding.

In summer, the mass of minute particles suspended in the air over the city are heated up by the sun's rays; later they release their heat to the ambient air. To this we can add the heating up of pavements, streets, and brick buildings. Asphalt can even become soft from the heat, so soft that one's footprints are left in it on a hot day. Hot summer days in the city are accompanied by thick dry fogs. The heated air is stifling. On a day like this in July 1954, the temperature in the centre of the city went up to 41° C., whereas outside the city it was only 35°.

The warming effect of the city tells on the mean annual temperature too; it is one whole degree higher than outside the city. At first glance this difference doesn't seem to be very big, but one should not lose sight of the fact that such an increase in the mean annual temperature is equivalent to moving Moscow 300 kilometres to the south. This is precisely why late spring and early autumn frosts are almost harmless in the city.

Moscow and Leningrad also increase the number of foggy days. They are two and a half times more frequent than in the suburban areas. Why is this so? Fogs form when moist air cools, when excess moisture appears as minute droplets, which are what produces the fog. This is why fogs are most frequent over swamps, lakes and rivers. It would seem that such a favourable situation is absent in a city, yet there are more fogs here than elsewhere. One has only to drive out of the city on a foggy day to find clear weather again just a few kilometres away.

The fact of the matter is that cooling of the air is not enough to condense water vapour into water droplets. So-called condensation nuclei must be afloat in the air. These nuclei are so small as to be invisible to the naked eye. They are minute particles of dust, smoke and the like, onto which the water vapour condenses. There are more than enough of such nuclei hovering over a city, and with suitable temperature conditions and sufficient humidity, everything is ready for the formation of fog. This is why cities have more fogs and bigger fogs.

We have all heard of the famous London fogs, which the Londoners have christened "pea-soup" due to their dirty-yellow colour. The London fogs are a true bane to urban transport, and the city dwellers lose over half the hours of sunshine because the sun is shut out by a thick curtain of fog. Writes V. Mayevsky in his *British Isles* (Molodaya Gvardia, 1955, p. 9): "... there are days when the streets of London are absolutely empty. The city is enveloped in a yellow devil called smog. Smog is a neologism in the English language and comes from a combination of two words 'smoke' and 'fog.' This, in short, is the notorious impenetrable London fog mixed with the smoke of thousands of city smoke-stacks. This is not just a fog, it is a natural calamity. In December of 1952, six thousand persons in England succumbed to one in a single week. Is this to be wondered at when five and a half thousand tons of soot and dirt settled to the ground. The portion that reached heart sufferers and lung patients was, for many, fatal."

Russian fogs cannot be compared with the London fogs, but still their number is very great. For this reason, the fight against smoke and dust in the big cities of the Soviet Union must be waged unremittingly. In this respect, a big part is played by rationalization of the fuel system. Such measures as the switching of separate furnaces to district central heating, the transition to gas heating both in industry and in the home, and, finally, the replacement of coal by electricity should definitely improve the climatic conditions of large cities. Of no small importance in air purification is the use of smoke-catchers and

ultrasonic filters. And we all know how important is the planting of trees and shrubs in a city. All these measures will undoubtedly play their positive role in improving a city's microclimate.

Tall buildings serve as protection from the wind, and so the wind in a city never attains the force it does outside. What is more, the wind direction depends in large measure on the directions of the streets. Buildings artificially create unevenness in the earth's surface, which distorts the wind flow, sending it hundreds of metres upwards. Therefore, an air mass moving over Moscow is, as it were, compressed in its lower levels and is accompanied by gusts and violent eddies, and only at 200 to 300 metres altitude is the flow free. This leads to an increase in the wind speed because the air masses compressed below strive to carry the required volumes of air over the buildings. Even on a quiet night, the winds on the outskirts of Moscow blow from the fields towards the centre of the city where it is warmer.

Then again the summer heating of the city streets creates ascending currents of air. This added contribution to upward moving currents leads to increased cloudiness, in turn resulting in more summer rains. Muscovites are quite right in saying that not a single raincloud passes them by. And true enough, in 60 years of observations, the annual mean of precipitation in Moscow is 620 millimetres, while the Mikhelson Weather Station (of the Timiryazev Agricultural Academy) on the north-western outskirts of the city recorded only 533 millimetres. The maximum intensity of rainfall, that is, the quantity of rain falling in one minute, is 2.1 millimetres in Moscow, while it is only 1.45 millimetres at the Academy. These figures are added proof of the effects of a city on its microclimate.

The air humidity in Moscow is usually less than outside the city at the same time, for there are few sources of evaporation here. But watering of the streets creates a temporary increase in the moisture. This is why miniature cumulus clouds often appear over the city in the forenoon. In actuality, they are artificially created clouds.



We have reviewed the difference in the distribution of weather elements in the city and its environs. This same difference exists in the city itself but on a smaller scale.

A curious thing is the microclimate of tall buildings. In cloudy weather, skyscrapers reach right up into the clouds. This has often happened to the Moscow University building which stands highest above the city. Looking out of a top storey one sees only a sea of fog, while down below the visibility is good.

On calm summer days the air temperature up above is a few degrees lower than on the first floor level. At night, it is just the opposite—warmer on the top storeys. This is known as temperature inversion, which is particularly evident in the winter time in clear calm weather. The temperature up above can then be 8 to 10 degrees higher than at the ground.

Tall buildings have reliable lightning-rods that completely protect them. But in thunderstorms the electric discharges choose precisely these high objects, so that from the top storeys it seems that the lightning is constantly striking the spire of the building. The crashing is unimaginable. As the weather men of such a top station put it, the impression one gets during a thunderstorm is like that of one of Mark Twain's characters who put on the roof of his house a dozen lightning-rods that attracted all the lightning strokes.

## Controlling the Weather

A hot sultry day, oppressive and sticky. Work is in full swing in enormous fruit orchards and berry fields. All of a sudden the duty weather man of the giant state farm receives a warning from the Weather Service that a thunderstorm with heavy rain and hail is expected in the area any hour. The man on duty contacts the nearest airfield, and aircraft attack the thunderclouds.

In the afternoon, the horizon darkens and in the haze one sees the outlines of heavy towering clouds. Nature is silent. Then the rumbling of motors cuts in. These are squadrons of aircraft taking up the struggle with the elements. Looking

through binoculars one can see the advanced aerial guard dive into the stormcloud and let loose a foggy cone of smoke. The planes pass above the cloud, too, leaving in their wake a long trail. The cloud is "seeded" with chemical substances. In 10 to 15 minutes the towering clouds become shapeless and the proud summits aloft lose their lustre. The mass of cloud changes before our eyes, losing its former strength. The clouds become loose and take on a peaceful appearance. The aircraft return after their victory over the clouds, which now float over the farm letting out a warm abundant fall of rain. There is no storm, no hail, no destructive cloud-burst. The plants avidly absorb the moisture. The harvest is saved.

This imaginary picture that we have drawn is not something of the far future. Small-scale control of the weather, first attacking the simpler forms, and later the more complex, is a realistic possibility.

People have long posed the problem of controlling the weather. It is very important to be able to predict the weather, but far more important is it to be able to alter it in the interests of society, or to fight deleterious phenomena in the atmosphere. It would be very good, indeed, if, under the conditions of a planned socialist economy, one could bring about rain during a drought, or, just the reverse, stop torrential rains and render harmless a hail cloud threatening the farm lands.

We know that powerful forces are at work in the atmospheric processes. The sun sends radiant energy to the earth. But the land and the sea, the equatorial and polar areas heat up differently. The resulting difference in temperature is the basic cause of air-mass movements. The direction and speed of their travel are likewise dependent on the rotation of the earth and on the local terrain. If we wanted to change the motion of air currents for only a few days, we would have to apply an energy measured in thousands of millions of kilowatt-hours.

These are astronomical figures, says Corresponding Member of the Soviet Academy of Sciences Y. K. Fyodorov in one of his works. A run-of-the-mill local thunderstorm spends energy equivalent to ten or fifteen hydrogen-bomb explosions. Or take

a medium storm at sea. To maintain it would require the energy of hundreds of atomic bursts. This is why man is not yet able to make a frontal attack on the elements and bring about, artificially, changes in the movements of air masses or create cyclones and anticyclones or fight thunderstorms and rains.

Yet even now we are in possession of mighty weapons for influencing the climate. Firstly, we can change the surface configuration over which the air masses travel and thus alter the physical state of the atmosphere. Man has long since learned to protect himself from the harmful effects of adverse weather: he builds dwellings, air-conditions them, grows tropical plants in hothouses, irrigates arid lands, drains swamps, and plants trees in steppe and desert areas. We beautify the cities with trees and shrubbery, and plant orchards and parks, utilize the energy of the wind and the moving water of rivers. In his constant struggle with the elemental forces of nature, man has mobilized all his ingenuity and organizing ability to produce virtual miracles. Yet, despite all the attainments of present-day science, the natural forces often inflict great damage: droughts, devastating floods, destructive hurricanes, hailstorms and the like. It is quite clear, then, that it is not out of idle curiosity that people ask the question: Isn't there some way of fighting these terrible storms of the atmosphere?

Attempts to influence the weather were made back in antiquity. But they were of a primitive nature, in keeping with the low level of culture of the times. And the methods used stemmed from the most preposterous superstitions and religious prejudices. In China, for example, during a drought spell the image of a dragon, which personified the evil forces of nature, was beaten with appropriate ceremony. To stop rain, some peoples had the custom of putting red-hot stones on the ground, while in Siam (now Thailand) roofs were removed from temples so that the gods could stop the rain sooner, otherwise they themselves would get wet. Many still remember the church services devoted to "prayers for rain." Some of the ministers of the church very prudently bought barometers and came to service only after consulting them and finding that

they were indicating "rain." They thought—and rightly so—that it would be "safer" that way.

People in the Middle Ages firmly believed that noise could disperse hail clouds, and so they rang the bells when a thunderstorm was approaching. To this day some of the bells still bear such fanciful inscriptions as: "I call upon the living, I mourn the dead, and I break lightning." The noise, of course, did not disperse the storm, but many were the bell-ringers who lost their lives in the high towers when lightning struck.

Even in this century some held that the firing of guns could cause a shaking of the air sufficient to produce rain. The Battle of Borodino was cited as an example. But the investigations of meteorologists have shown that the weather during battles and after them is exactly as it should be by virtue of the general atmospheric conditions. The effect of explosions during shelling is negligible; the heat effect, as compared with the solar energy, is exceedingly small; and the chemical action, if compared with the combustion products of fuel burnt in a large industrial city, is again decidedly insignificant.

Last century, attempts were made to fire guns into clouds to prevent hail. Experiments were conducted in many countries, including Russia, and were widely publicized. Special "mortars" were built in the form of enormous cones with the bases towards the clouds. A powder charge was placed in the lower part of the mortar, and the explosion ejected a whirling smoke ring like that which comes out of a steam locomotive. It was thought that the eddy turbulence in this ring would prevent the formation of hail in the stormcloud. Now we know that to prevent hail with such mortars is almost the same as to try to stop a train by firing buckshot into it.

Another method was tried. Enormous kites carrying explosives were sent aloft towards the hail cloud in the hope that the explosion would break up the hailstones into tiny harmless pieces. These cloud detonations were stopped only after special commissions of scientists proved them to be useless.

During the Second World War some believed that the big increase in ordnance, the growth in power and number of

explosions increased precipitation at the front. Investigations, however, have refuted this point of view. During the fierce fighting at Berlin in April 1945, when a tremendous amount of artillery was concentrated on a narrow section of the front, no rain resulted, and through the smoke one could always see the sun.

After the unsuccessful experiments with shooting guns, scientists and inventors took another line utilizing the scientific attainments of physics and meteorology. It is known that a protracted rain requires the ascent of enormous masses of humid air to heights of several kilometres. Consequently, if one built a gigantic stack and drove air upwards with ventilators, clouds would inevitably form and rain would result. But, economically speaking, this method does not justify the expense. Computations show that one would need to burn many thousands of tons of coal in order to obtain a 10-millimetre rain, which is just enough for a liberal watering of one square kilometre. As a result, rain is got at an exorbitant price and does not justify the outlay.

In the 1920's, attempts were made to obtain rain by cooling the air. To do this, liquid oxygen and dust-like solid carbon dioxide (dry ice) were carried aloft in balloons and jettisoned into the clouds. The experiments had a limited success. A great deal of money was spent on the cooling mixture, but the rainfall was insignificant.

Somewhat later, Professor V. I. Vitkevich supervised a joint undertaking of the Geophysical Institute and the Central Aeronavigation Station in Moscow, where experiments were carried out in the precipitation of clouds and the dispersion of fogs by means of electrically charged sand. It was assumed that the decisive role in the formation of rain is played by electric charges of the drops. It was reasoned that if the drops could be recharged by electrified sand this would cause rain. The laboratory experiments were a success, and it was proved that electric charges facilitate the condensation of water vapour and disperse fog. But when the experiments were taken outside the laboratory and the charged sand was dropped from aircraft

onto cumulus clouds, they actually dispersed somewhat, but no rain fell.

In 1931, at the All-Union Conference for Fighting Drought, Professor M. A. Aganin read a paper on the possibility of artificial rain formation. In a number of laboratory experiments, he disclosed the mechanism of the fusion of drops of water and demonstrated the process of the origin of rain. This began a series of confident steps in the organisation of investigations and experiments both in the laboratory and in the free atmosphere. The studies were conducted in Moscow in the Central Institute of Experimental Meteorology under the leadership of Professor S. L. Bastamov and in the Leningrad Institute of Experimental Meteorology under the supervision of Professor V. N. Obolensky.

In 1934, experiments in artificial rain-making were conducted in the environs of Ashkhabad (Central Asia) by a group of scientists under engineer V. A. Fedoseyev. The clouds were "seeded" with calcium chloride, which promoted the fusion and enlargement of water droplets in the cloud. The calcium chloride powder was dispersed from an aircraft flying above the cloud or inside it. In several instances, the cloud "seeded" with calcium chloride produced a small rain despite the summer dryness of the air that is so common in Ashkhabad. The first raindrops contained calcium chloride, but later on there wasn't a trace left. Thus, Fedoseyev demonstrated that, like an avalanche of snow which builds up out of a single snowball, the fusion process of the first drops spreads throughout the cloud. In other words, it is sufficient to give the natural forces an impulse to alter the physical state of the moisture in some part of a cloud, and the change will spread of itself to all other parts.

In the summer of 1936, experiments in artificial rain-making were carried out in a cloud that covered the top of Mt. Dzyncha in the vicinity of Gagra on the Black Sea coast. A powerful aircraft engine was set up on the top of the mountain in the midst of cloud; the propeller dispersed calcium chloride powder. In as little as 6 to 7 minutes, a 400-metre-diameter hole was

formed in the thickness of the cloud. The most interesting thing was that this hole had even edges as if they had been cut with a plumb line—something that never occurs under natural conditions. This was followed by rainfall that lasted until the whole cloud had disintegrated.

Scientific investigations have demonstrated that under natural conditions the principal reason for rainfall from a highly unstable cloud is the difference in the size of the drops. In a stable cloud, on the contrary, all drops are of the same size and at equal distances from one another. To have the rain fall, one must make the drops fuse and enlarge in at least one part of the cloud. This is what is achieved by the action of calcium chloride.

Experiments in other countries began later than in the U.S.S.R., but they have also been conducted, especially in the United States, on a large scale.

What is the situation at present as regards weather control?

In the U.S.S.R., everything is being done to influence the local climate and the weather. Storage reservoirs and canals are built, forest shelter belts planted, etc.

In the summer time the water is colder than the air. For this reason, ascending currents over large storage reservoirs lose their strength and there are fewer cumulus clouds than over land areas. And the number of clear days increases. On the contrary, in the autumn when the water is warmer than the air, there are more foggy days on the shores of reservoirs and adjoining areas. This warms up the microclimate and shifts the onset of autumn frosts to a later date.

At the same time, it is incorrect to think that the considerable changes in the weather that have been observed during recent years are due to the building of storage reservoirs, canals, shelter belts, and the like. We have already stated that no hydraulic structure can affect the climate over a considerable area.

Sometimes, frosts are fought with smoke screens, burning oil and special smokeboxes, and steam-mains are used to heat the air. These are effective but costly.

In 1954, Soviet scientists carried out successful experiments in obtaining an artificial fog by means of spraying superheated water under high pressure. Carried out in vineyards near Odessa, the experiments showed that man-made fogs are very stable. They roll low over the land and provide excellent protection against frosts.

In addition to changing the climate, there is yet another method of weather control. It is based on the fact that meteorological processes are in large measure a struggle of contradictory phenomena. This frequently upsets the stability of the atmosphere, and a relatively slight intervention in the weather process is sufficient to change the nature of its development. Such effects include accelerating or retarding rainfall, retarding the development of hail or thunderstorms, the dispersing of clouds. Experiments in cloud control are developing along three lines: attacking already existing clouds, the building of artificial clouds to obtain rainfall, and the dispersing of clouds and fogs.

The solution of these problems has required numerous investigations that have to do with cloud structure and the process of forming precipitation. Special chambers have been built in which it is possible to produce artificial fog, to produce a cloud made of ice crystals, to enlarge water drops, and to trace the effects of electrical forces on the formation of rain. In addition, outside the laboratory, weather men continue to study clouds in the free atmosphere in aircraft and by balloon.

The problem of obtaining man-made rain has been solved only on a small scale, in clouds covering small areas. The point is that each cloud is only one of many links in a complex process of the formation of precipitation. It does not simply expend the accumulated reserve of water, but is a kind of "generator of moisture" that converts water vapour to water drops or ice crystals. An enormous mass of moisture passes through every cloud; and so to affect large cloud masses requires such tremendous quantities of energy as are at present beyond the practical reach of man.



The production of artificial rain is tantamount to effecting the process by which nature makes rain every day. Let it be recalled that in a small rain the entire cloud consists only of



*a*

- a) roll of cloud without ice crystals prior to seeding with dry ice;  
b) five minutes after seeding. Sheet of rain is seen falling

tiny water droplets. In heavy rains, the cloud carries in its lower part drops of water, in the middle portion, drops of supercooled water, and higher still, ice crystals.

We already know that when supercooled water comes into contact with ice crystals it freezes instantaneously and forms hailstones. As a hailstone cools, new layers freeze on, it grows larger and heavier and falls into the lower warm levels of the atmosphere. Here it melts and then falls to earth as a large drop of rain. This is the process that myriads of drops pass through. For this reason, icing at the summit of the cloud is necessary for a heavy rain. In nature this occurs when there are strong upcurrents that carry the cloud masses into high levels where the temperature is below zero the year round.

But it is also possible to cool a cloud and create a large number of ice nuclei artificially. To do this, rainless clouds scudding endlessly across the skies are "seeded" by aircraft with dry ice at minus  $80^{\circ}\text{C}$ . The particles of solid carbon dioxide bring about the formation of ice crystals which lead to icing at the top of the cloud. And this, as we know, is the necessary condition for a good fall of rain. The more cooling substance used in seeding, the heavier the rain. But such experiments are very expensive. To make them cheaper, scientists seek to cool the entire cloud by a chain reaction, which is possible only when the atmosphere is in an unstable state.

Let us now consider a series of experiments in the seeding of clouds with dry ice (solidified carbon dioxide) that were carried out in the Hawaiian Islands in November 1947.

Radiosondes were released in the morning and evening at Honolulu airdrome 100 kilometres from the test site. They showed that the temperature diminished with altitude by  $6^{\circ}\text{C}$ . per 1,000 metres. The  $0^{\circ}$  isotherm was located at 4,500 metres, and slight south-western winds were blowing.

In the morning, three cumulus clouds hung over the Island of Molokai with their base lying at 750 metres. The tops of the two bigger clouds towered to a height of over 2,000 metres. In a little while these clouds joined into a circular-like formation

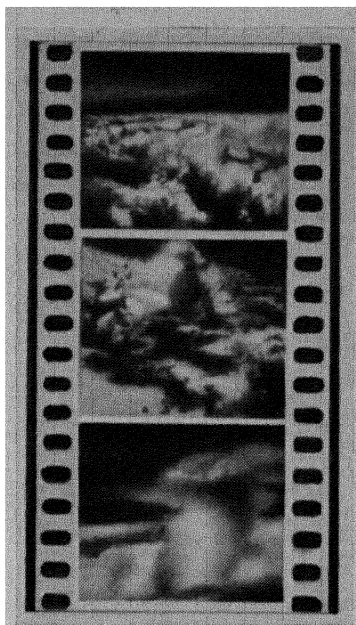
about 15 kilometres in diameter. A flight over the newly formed cloud showed that it had two turreted tops.

The first turret of cloud was seeded with 22 kilogrammes of finely divided dry ice. The aircraft was then at an altitude of 2,600 metres directly above the top. The top of the second turret was seeded at nearly the same time. Nine minutes after the seeding, rain fell in the area immediately under the top of the first turret. Under the second turret, sheets of rain appeared 15 minutes after seeding, but the rain did not reach the earth.

An hour passed, and rain was still coming down under the first turret. The rainy area continued to expand until it had covered up to 90 square kilometres.

Then a second flight was made. It showed that both cloud tops had merged into one, reaching a height of 4,700 metres. The second seeding with 45 kilogrammes of dry ice very soon produced a shower that lasted 35 minutes. During this time, 32 mm of rainfall were recorded. That day there was no rain at all from other clouds that were just as large as the seeded one.

It was, therefore, clear that the rain had been brought on artificially. After the first seeding it spread out rather slowly, although the cloud increased in thickness vertically at a high rate and to a very considerable extent. The second seeding caused a sudden increase in the intensity and area of the rainfall.



Cloud seeding with granular carbon dioxide in Australia, February 5, 1950

- a) clouds before seeding; b) clouds 13 minutes after seeding; c) clouds 20 minutes after seeding. Anvil has formed

In experiments carried out in Australia, as many as eight clouds were seeded with granular carbon dioxide. The aircraft were equipped with radar to determine the position of the rainfall zone. The radar beam reflected from the mass of falling raindrops or hailstones producing an echo signal that was recorded. It was then a simple job to compute the distance to the rainfall area and its approximate size.

Radar observations showed that rainfall was actually recorded from six of the clouds, while in four cases the rain was heavy.

One of the most effective experiments was conducted on February 5, 1950, in the interior of New South Wales. On this day, the sky was two thirds covered with cumulus clouds, while over the coastal plain and the Pacific Ocean it was absolutely cloudless. One of the cumulus clouds was seeded with 68 kilogrammes of granular carbon dioxide. Within five minutes the aircraft radar recorded rain echo-signals. After the second portion (the same as the first) of dry ice was released the intensity of the echoes increased. Twenty minutes later there was a heavy rain that covered an area of at least 50 square kilometres. Later, farmers likewise confirmed that there had been a heavy rainfall. Yet neighbouring areas within a radius up to 160 kilometres from the aircraft did not experience any rain at all that day. These experiments were undoubtedly very successful, but it must be stressed that they were conducted under very favourable atmospheric conditions that required but the slightest interference for rain to start falling at the command of man.

In some of the experiments, dry ice was replaced by silver iodide, the crystals of which have a lattice similar to the crystal lattice of ice. It was found that real ice crystals build up on silver iodide at a temperature of minus  $5-7^{\circ}\text{C}.$ , and readily give rise to snow-flakes. Similar experiments have been carried out in many countries, including the U.S.S.R.

All these experiments have proved the fundamental possibility of actively altering the cloud cover. However, it is by

far not always possible to do this. Seeding has often resulted in the clouds merely melting away without yielding a drop of rain. In other cases, a chain process could not be achieved, and, despite intensive cloud seeding, there was very little rainfall. All this suggests that the process of weather control is exceedingly complex.

Aside from experimenting with existing clouds, attempts are made to produce artificial clouds. To do this, cooling agents are injected into upward currents on a clear day. Sometimes this interference produces clouds and sometimes it doesn't. Yet such a cloud barrier would be highly appreciated, say, in Central Asia where for months on end the scorching sun mercilessly beats down out of a clear sky. Here, a little "shading" of the sun after an artificial watering could do much to increase the yield.

The foregoing experiments show us how slow and hard is the attack on the atmosphere. We still require many laboratory experiments and investigations in the free atmosphere to arrive, at last, at practically valuable results. But that which science has achieved in the past 25 years indicates that we are on the right path. Man-made rain and artificial scattering of clouds and fogs has come out of the realm of fantasy and is gradually becoming reality. The science waiting list contains still vaster problems—the fight against hurricanes, thunderstorms, rainstorms, and droughts. These demand energy in quantities that man does not yet possess. The offensive against the formidable elements will continue on many fronts, and the decisive word will doubtlessly be spoken by nuclear energy.

## Solar Activity and the Weather

All atmospheric processes on earth are dependent on our prime source of energy—the sun. Before fluctuations in solar radiation were discovered it was thought that at the fringe of

the atmosphere each square centimetre of surface perpendicular to the sun's rays receives 1.88 calories of energy. This quantity was called the "solar constant." But subsequent research has shown that solar radiation experiences fluctuations which are particularly strong in the ultra-violet region of the spectrum.

The sun is known to have spots that appear and disappear. Systematic observations have been in progress since the seventeenth century and they show that sun-spots pass from minimum to maximum in an average of 11 years (more precisely from 9 to 14 years). The last sun-spot maximum was observed in 1958, while in 1954 there wasn't a single spot on the sun for eight months running. In each cycle they originate on both sides of the solar equator in about latitude  $30^{\circ}$ . As the number of sun-spots increases, they come closer and closer to the equator; astronomers have never seen any sun-spots near the poles. The sun-spot maximum is ordinarily accompanied by enhanced activity yielding faculae, prominences, and corpuscular streams that plunge into our atmosphere. Taken together all these phenomena represent *solar activity*.

It is believed that changes in solar activity exert a perceptible influence on the state of the planets that have atmospheres and thus, naturally, on the terrestrial atmosphere.

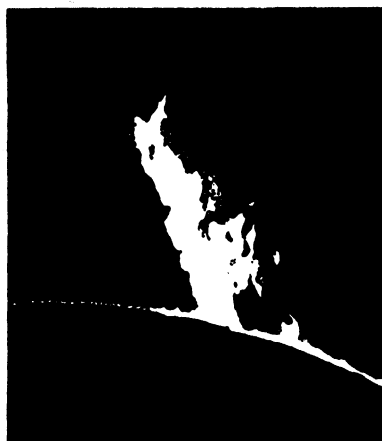
What are sun-spots? They are enormous vortexes that appear on the surface of the incandescent sun and are attended by huge clouds (known as flocculi) of hot hydrogen and calcium. The vortexes are accompanied by transient but bright eruptions (faculae) of particularly hot gases that are ejected from the solar interior. These eruptions are sometimes in the nature of stupendous explosions. Incandescent gases are thrown out at velocities of 200 and 300 kilometres a second to distances up to a million kilometres. These are prominences. The gases stream upwards spreading out into vast cloud-like formations that gradually settle back to the surface. Judging by the fact that sun-spots are powerful whirlwinds of incandescent gases, they resemble the terrestrial cyclones, only on a far vaster scale.

To take an example, between March 8 and 17, 1947, there was observed a composite sun-spot 215,000 kilometres in length, which is 17 times the earth's diameter. The spot soon vanished from view due to the sun's rotation on its axis, but since the sun completes one rotation in 25 to 30 days, the spot re-appeared some two weeks later on the other side of the solar disk.

Sun-spots usually appear in groups, and are constantly undergoing change: new spots appearing, old ones breaking up and disappearing. Sun-spots have lifetimes ranging from a few days to several months. On the background of the brilliant sun, the spots appear dark due to the lower temperature of the solar gases in these areas. Astronomers reckon the sun-spot temperature at  $4,500^{\circ}\text{C}.$ , while the radiating surface of the sun is put at  $6,000^{\circ}$ .

All these stormy processes on the sun give rise to electromagnetic disturbances on the earth. Compass needles oscillate, telegraph and radio communications are disrupted, and the number of aurorae increases. Magnetic disturbances are particularly strong when the sun-spots pass near the centre of the visible disk of the sun. This is because the strong radiations of the central regions of the sun are least absorbed by the solar atmosphere and, due to their direction, have more chance of encountering the earth. This is a time of enhanced ultra-violet radiation, on which depends the state of the ionosphere and, especially, the  $F_2$  layer, which is particularly important in radio-wave propagation.

During solar eruptions, the surface has sites of enhanced corpuscular radiation. These sites need not necessarily be associated with sun-spots, and then they do not differ very much



Gas eruptions on the sun  
(prominences)

from other portions of the solar surface. Corpuscular radiation exerts a pronounced effect on the state of the terrestrial atmosphere, whence the name "geoactive." Geoactive corpuscular streams ejected by the sun consist of the same number of particles with charges of opposite sign. The speed of these particles is determined from the time of transit between sun and earth. This is done by taking the difference between the time of ejection of the corpuscular stream (the onset of a large flare) and the time it arrives on earth (the commencement of a magnetic storm).

Numerous calculations indicate enormous particle velocities, up to 1,500 kilometres per second. They therefore require slightly over 24 hours to cover the sun-earth distance. However, there are indications of corpuscles with lower speeds.

During recent years it has been noted that the sun exhibits transient flares, of particularly hot gases, that ordinarily occur in the neighbourhood of sun-spots. These, apparently, are the principal cause of fast disturbances in the earth's atmosphere.

The sun-earth problem is now the object of study of a whole galaxy of Soviet workers including such figures as M. N. Gnevyshev, L. A. Vitels, B. M. Rubashev, S. A. Govorov, P. P. Predtechensky, A. B. Severny, M. S. Eigensohn and others. These scientists have noticed that during years of enhanced solar activity the circulation of air masses throughout the terrestrial atmosphere increases. And this, in turn, leads to an increase in storm phenomena on the earth. They are most intense and dangerous during this period.

Why does enhanced circulation in the atmosphere lead to an aggravation of processes operating in our ocean of air?

There are areas on the earth with a constantly hot climate—the equator and parts of the tropics; then there are the vast refrigerators like the Arctic and Antarctic. On the equator and in the tropics the sun is high above the horizon and radiates a great deal of heat to the earth's surface. In the Arctic and Antarctic, nearly half the year is cold polar night, while in the summer (the polar day) the ice surface receives the slanting rays of the sun that seem to glide over the surface. Yet, if we



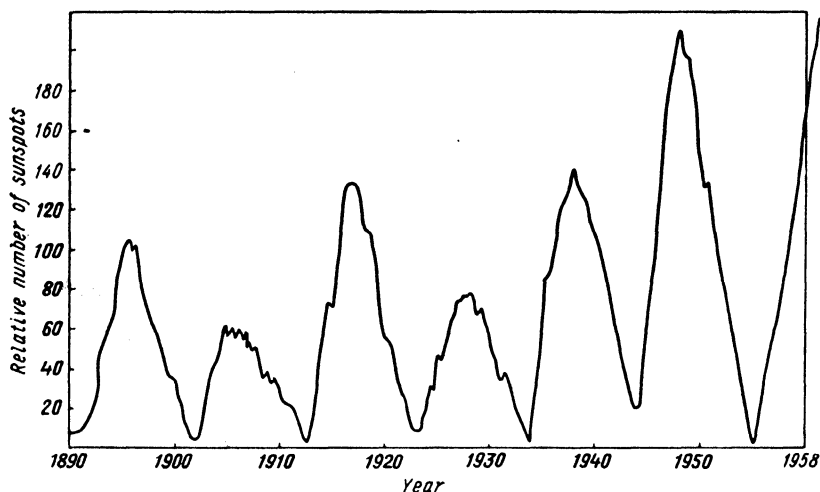
dismiss atmospheric effects, theoretical calculations show that in summer the Arctic regions receive one and a half times more heat than the equator all because of the protracted and constant half-year day. But the greater part of this heat is absorbed by the air and is expended in melting the age-long masses of ice. This why the air temperature rarely climbs over  $0^{\circ}$  C.

This temperature difference brings enormous volumes of air into motion. A constant struggle develops between the warm and cold currents that strive to equalize this difference in temperature between the north and the south. The struggle continues with alternating success. At times the warm air gets the upper hand and punches a "warm tongue" far northwards to Greenland and Franz Joseph Land. At other times, masses of Arctic air move southwards in a gigantic "drop," sweeping down to the Black and Mediterranean seas, and reaching out to Central Asia and Egypt. The boundary lines between the fighting air masses are the most restless regions of our atmosphere. It is here that the numerous cyclones get their start.

During years of enhanced circulation of air masses, which is brought about by solar activity, there are more collisions of warm and cold currents. This is when truly vast volumes of air participate. Contrasts between the moving masses sharpen, and powerful cyclones and anticyclones arise where they collide. One has only to look over barograms for a number of years to see that there are great fluctuations of pressure during years of sun-spot maxima. Pressure gradients always rise during these periods. And cyclones, in turn, give rise to frequent thunderstorms, hurricanes, rainstorms, and windstorms. It is clear, therefore, that the atmosphere at this period is in a more tense state than in years of sun-spot minima.

The eleven-year sun-spot cycle recurs invariably. In 4 to 5 years, the number of spots increases to a maximum, and then in the next 6 to 7 years diminishes to a minimum. Then everything recurs as before. We all know how easy it is to determine the age of a felled tree from its annual rings. A care-

ful inspection will show that the rings are not all of the same thickness: some years they are very thin, in others noticeably thicker. What this indicates is the effect of various climatic conditions, and rainfall above all. And it appears that the thickness of the rings varies in an eleven-year cycle that coin-



Graph illustrating 11-year periodicity of solar activity since 1890

cides with the development of the sun-spot cycle. Studies of the rings of pine and fir-trees up to 600 years old, of oaks up to 1,000 years, and cypresses and American sequoias up to 3,000 years have demonstrated that the older the tree the more marked is the 11-year cycle of recurrence in the development of tree rings. If to these we add sections made from the trunks of morainic oaks found in river channels and from tree remains found in peat bogs, it is possible to trace the climate 8 to 10 thousand years back.

That the 11-year cycle has been in existence for a long time, we know from studies of bottom deposits in lakes, seas, and oceans. The principle of this method is very simple: if fluctuations in solar activity affect the march of the weather, increasing or diminishing the amount of precipitation or

moving it from one part of the globe to another, then we can judge of these changes from silt deposits. Numerous silt samples have shown that, firstly, the silt is deposited in strata, and, secondly, that the thickness of the layers varies. Deposits in seas and oceans reveal the very same thing, which here is due to variations in the intensity of tropical rain and the melting of icebergs and ice floes moving out of the Arctic into warmer latitudes. Irrespective of the water basin from which they are taken, these samples exhibit periodicity over the course of hundreds of thousands of years with an average cycle of 5.7 and 10.9 years.

Soviet scientists have also established a double 11-year cycle, or a 22-year cycle. In addition, a secular cycle of rise and fall in sun-spots has been discovered with a period of 80 to 90 years. Meteorology and climatology are particularly indebted to this cycle, for it undoubtedly affects the number of sun-spots at the time of the 11-year maximum. For instance, the sun-spot maximum of 1948 proved to be very high because the usual 11-year maximum coincided with the secular maximum. And what is more, the spots reached sizes that made them visible to the naked eye.

In recent years, M. S. Eigenson has found a 5-6-year cycle of solar activity that throws new light on the nature of many geophysical phenomena that exhibit two maxima (two peaks) in the 11-year cycle. This accounts for the sizes of silt deposits having periods of 5.7 and 10.9 years. Analyses of many years of precipitation observations at weather stations have revealed a similar rhythm. The amount of precipitation varies in periods of 5.7 and 11.05 years on the average.

The connection between terrestrial atmospheric processes and solar activity naturally raises the question of utilizing this relationship for long-term weather forecasting.

The answer requires some explanation. Magnetic storms and the aurorae had for a long time seemed to be due only to solar radiation with the same periodicity as the sun-spots. Consequently, if it is possible to determine the onset of sun-spot maxima, it should be possible to forecast the frequency and

strength of magnetic storms and aurorae. However, the investigations of M. S. Babushnikov and M. S. Eigenson have shown that the relationship of these phenomena is very involved. It is conditioned not only by sun-spots but also by the corpuscular radiation of the sun. In addition, the frequency of magnetic storms is dependent on the 5-6-year cycle of solar activity. For this reason, one can map out only the general course of coming events. On the other hand, if we follow flares and reckon the corpuscular velocities, only short-range forecasts are possible.

The weather is still more complicated. Not always do storms, hurricanes and heavy rains on the earth correlate with the sun-spot maximum. This relationship is so many-sided and so involved by intermediate links that it does not always manifest itself even within the limits of a whole year. And what is more, the enhanced circulation of the atmosphere affects in different ways the various regions of the globe. For example, there was abundant rainfall in the north in 1946 when an extremely severe drought struck the southern half of the European part of the U.S.S.R. Stormy weather during the winter of 1952-53 in the Atlantic Ocean was contrasted with stable calm weather in Siberia. Therefore, only general regularities may be established.

One thing is certain, during years of sun-spot maxima the terrestrial atmosphere rages, and some part of the globe will definitely suffer natural calamities. In 1945 and 1946, severe droughts struck vast areas in India, while in 1948, all of India and Pakistan was literally flooded by torrential rains.

The connection with solar activity is most evident in the weather of the tropics and the equatorial belt where the climate is distinguished by greater constancy than in moderate latitudes. For example, monsoons\* sharply increase at sun-spot

\* The monsoons are periodic winds that blow seawards half the year and landwards the other half. Winter cooling on the continents produces high pressure, and the winds blow out to sea from the land. In the summer half-year, on the contrary, high pressure prevails over the oceans and seas, and the winds blow on-shore.

maxima. And rain periods in tropical countries are connected with the monsoons. The torrential rains in India in 1948 coincided in time with the maximum of solar activity.

A similar convincing relationship has been demonstrated by N. S. Shcherbinovsky in the case of the locust. He established a periodicity in its reproduction that coincides with the 11-year cycle of sun-spots. It was found that the desert locust (*Schistocerca gregaria*) multiplies very rapidly after abundant monsoon rains in India, Arabia and Africa. This is due to the fact that the monsoons bring to life the deserts, which cover over with grass supplying abundant food for the locust. From here the locust moves northwards in vast swarms, at times getting as far as Central Asia and the Transcaucasus.

This relationship was particularly evident following the strong monsoon of 1948. A contributory factor was the unusually snowy and severe winter of 1948-49 associated with deep incursions of Arctic air masses that had rolled south to the tropics. That winter the frosts gripped Turkey and Iran. In February of 1949, the streets of Jerusalem were covered with an 80-centimetre layer of snow. The Syrian desert was likewise snowed under and communications between Mesopotamia and the Mediterranean coast ceased altogether. Such was the intensity of air-mass circulation that year.

On the basis of data on solar activity, Professor Shcherbinovsky compiled a long-term (15 years) forecast of locust development, and, in the main areas, it has proved very correct right up until lately. B. S. Gurevich has shown that droughts embracing large territories are likewise connected with the sun-spot cycle. Droughts brought in from outside areas develop in phase with enhanced solar activity (for instance, the drought of 1946). Steady-type droughts, which embrace smaller territories, are especially intense during the phase of depressed solar activity. Consequently, droughts are always the result of causes of an astronomical character.

The violent solar activity of recent years—the highest during the past 200 years—has given rise to a large number

of extremely severe atmospheric phenomena that we have considered in various chapters of this book.

Thunderstorm statistics for the Soviet Union likewise point to a definite interrelationship between solar activity and the number of thunderstorms. The thunderstorm curve follows the curve of solar activity, but the relationship with the 11-year cycle is complicated by secondary maxima which apparently are associated with 5-6-year cycles of activity.

According to the latest investigations of S. P. Khromov and M. S. Eigenson, there are, in the general circulation of the atmosphere, certain specific "sun-sensitive" zones associated with the principal atmospheric fronts. The first front—Arctic or Antarctic—separates the polar air from the air masses of moderate latitudes and passes approximately near the 65th parallel. The second front separates the air of the moderate latitudes from the tropical air masses and lies below the 40th parallel. The third front—or tropical—separates the tropical air from the equatorial and lies close to the 10th parallel. It is mainly on these fronts that the weather-making cyclones and anticyclones are formed. Weather maps always show the main fronts clearly.

In the upper part of the troposphere and the lower part of the stratosphere over the first two fronts, there are zones with sharply contrasting weather elements. These zones lie along parallels of latitude that girdle the whole planet. Here are the air jets—narrow currents of air, in which westerly winds blow at 150-200 kilometres an hour in the winter time. The areas of the main fronts are points of particular sensitivity to solar activity. Whence the clear-cut relationship, of which we have already spoken, between cyclonic events and solar activity.

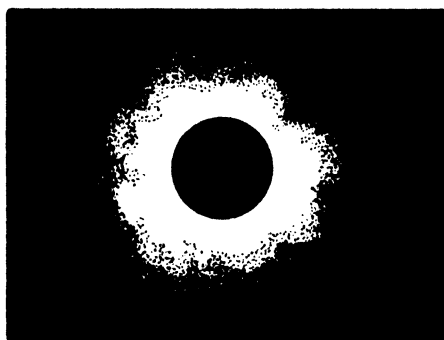
High-altitude radiosondes have been known to register transient (24-48 hours), but sharp, increases of temperature at high elevations. Such warm spells have invariably set in after the appearance of solar faculae which are the biggest

emitters of corpuscular radiation. To take an example, in February 1952, high-altitude radiosondes in Germany registered a warming up at 24-30 kilometres height following a solar flare. In just over 24 hours the temperature rose 40°. Several days later the heat diminished and, in attenuated form, settled down into a layer between 12 and 25 kilometres. This is again suggestive of the effect solar activity has on the terrestrial atmosphere.

In March 1955, L. R. Rakipova noticed a solar-activity relationship between phenomena in the troposphere and the stratosphere. These include the appearance of mother-of-pearl clouds, differences in concentration of ozone and ions, and sharp changes in direction and velocity of the wind at high altitudes. All this is due to disturbances arising in the stratosphere. And the source of these disturbances is again solar activity, because flares cause a heating up of the top layers of the stratosphere. These layers expand, giving rise to a high-altitude cyclone with air currents from the centre to the periphery. This outflow of air from the heated zone causes a fall in pressure that extends right to the earth's surface. If at this time a cyclone is in progress in the troposphere, it will be reinforced (deepened); and if there is an anticyclone, it will be weakened. Thus, this downwards (from stratosphere to troposphere) action has its effect on the state of those weather-makers the cyclones and anticyclones. It had long since been known that the stratosphere exerts effects on the troposphere, but up till now it could not be accounted for.

When dealing with the sun-earth problem it should be borne in mind that solar activity affects the entire atmosphere or at least its sun-sensitive zones. This results in the disturbance of enormous volumes of air over vast expanses, even whole continents. For this reason, particular events, for instance, individual thunderstorms, rainstorms, or local squalls cannot be explained on the basis of solar activity, no matter how violent they are.

In June and July 1955 the southern part of the Ukraine experienced extremely heavy rainstorms. According to the



Solar corona during sun-spot minimum (top)  
and maximum (bottom)

observations of A. S. Govorov, Nikolayev had 190 millimetres of rainfall on June 30 in two hours and 50 minutes. The rain caused a flood in the city. The rainfall was greater than at any time in the past 150 years even during a whole month. On August 7th the rainstorm repeated, yielding 127 millimetres in 24 hours.

A study of these storms showed that local events were not the cause. Abundant rains with up to 100 millimetres and more were also recorded in the adjoining oblasts of Kherson, Odessa and a few others, embracing a large area. A. S. Govorov relates their origin with

the corpuscular radiation of the sun. It is interesting to note that there were very few sun-spots at the time.

Eigenson has given a still more brilliant example of corpuscular activity of the sun during a sun-spot minimum.

The winter, spring, and summer of 1954 in moderate and subtropical latitudes were very far from normal. The winter was very severe, the spring cold and drawn-out, and the summer very arid in some places, and very wet in others. In the winter of 1954, cold air masses penetrated to southern latitudes right down to Northern Africa. Rumania and Albania were snowed under (see Part II, Chapter 3). The summer saw disastrous rainstorms and floods in Western Europe, China, and India (see Part II, Chapter 2). At the same time, the air



temperature in the northern part of Europe in the winter of 1954 was much above normal.

The general circulation of the atmosphere in 1954 was greatly enhanced, and for this reason, during the winter and spring, cold masses of Arctic air pushed southwards at a high speed and brought a cool spell to the southern latitudes. At the same time, warm tropical air flowed under into the Arctic producing extremely warm weather in the north.

The reason for this unusual meteorological situation was enhanced corpuscular radiation from the sun. It proved to be particularly high because it had developed on the background of a close maximum of secular periodicity in solar activity. Added proof of the activity of corpuscular radiation comes from the very large number of magnetic storms and aurorae observed in the same year of 1954.

The natural question is: Were such cases observed in earlier years? The answer is yes. A. P. Moiseyev noted an aurora borealis in Moscow on March 24, 1923, that is, in a year of minimum apparent solar activity. Yet at these latitudes, aurorae are extremely rare, usually putting on a display only in years of extremely high solar activity. The summer of 1923 was marked by heavy rains in almost all of Europe, with a severe drought in Siberia. As in 1954, the atmospheric circulation was very intense. A similar picture was observed in 1933.

Advances in astronomy have yielded another curious, at first glance, fact. Our planet has been found to exhibit accelerations and retardations in its rotation. The earth does not rotate in exactly 24 hours as we are accustomed to thinking. True, the difference is reckoned only in fractions of a second, but to astronomers this has meaning, too. And the most interesting thing is that the reason for this irregularity in the earth's rotation is the solar activity. It appears that the movement of water and air masses on the globe, and the fluctuations in the intensity of the circulation of the atmosphere and water are fully sufficient to bring about an irregularity in the earth's rotation. A deep snow cover over a vast

area, or copious summer rains covering extensive territory immediately affect the rotation of the globe.

We have analyzed the most important aspects of the sun-earth problem. We have demonstrated the complex dependence of atmospheric processes on solar activity, and also the evidence of many intermediate mechanisms that attenuate and mask the manifestations of this activity. We have also determined the dependence of the weather on fluctuations of radiant energy from the sun. Now, astronomers, meteorologists, hydrologists, geophysicists, weather forecasters, and other specialists are jointly engaged in solving the problem of long-range forecasting of many phenomena in the ionosphere, stratosphere, and in that laboratory of the weather, the troposphere. For this purpose special apparatus has been constructed and erected at the astronomical observatories at Pulkovo, Kislovodsk, Lvov, Tashkent, and in the Crimea.

Progress is also being made in the forecasting of solar phenomena, for one thing, sun-spot activities. And this, as we know, affects the forecasting of happenings that will occur in the atmosphere. Here is a forecast on the current cycle of solar activity made by astronomer P. P. Predtechensky: "The new cycle will begin in February 1956. It is believed that the ascending lap will take 2.9 years and will be short and very stormy; the decay period will last 6.1 years with a maximum in January of 1959, and the cycle will end in February 1965. It will thus have a duration of only 9 years.\*

Observations of solar activity indicate that despite a certain shift in periodicity, this activity develops violently.

On February 23, 1956, a tremendous explosion occurred on the sun—the biggest since 1942—equal in force to the detonation of a million hydrogen bombs. On the earth, this explosion initiated a larger number of magnetic storms and sharply stepped up the atmospheric circulation, which in turn gave rise to

\* P. P. Predtechensky, *Forecasting Solar Activity for the End of the 18th Cycle and the 19th Cycle*, "Izvestia Glavnoi Geofizicheskoi Observatorii imeni A. I. Voeikova," 1950.

meteorological catastrophes in various portions of the globe. This shows that there undoubtedly exists a relationship between the weather and solar activity. Naturally, further studies in this field will lead to more valuable results in long-term weather forecasting. However, let us repeat that only the most general weather regularities on the globe can be established on the basis of processes occurring on the sun. Much has yet to be done before it is possible to pinpoint the place and time of weather events as a function of the 5-6-year cycle of sun-spot development, with an appropriate account of corpuscular radiations, to determine phenomena in the terrestrial atmosphere according to season as dependent on solar activity, and so on.

Scientists have much to do before weather forecasting based on solar activity can be put on a truly practical basis. The Sun Service and Weather Service materials of the IGY will undoubtedly clarify much in the sun-earth problem.

Preliminary information indicates that although the solar radiation outside the earth remains constant on the whole, there is observed a redistribution of energy that finds expression in fluctuations of ultra-violet radiation and enhanced ejection of fast particles (corpuscles). Strong disturbances on the sun increase tremendously its ultra-violet radiation and ejection of corpuscles. The active radiation of the sun is doubtlessly absorbed (totally or partially) by the upper layers of the atmosphere, which affects their heat-circulation regime and gives rise to disturbances. The movement of such disturbances into lower-lying levels requires a mixing of these layers, which, apparently, is what occurs, as may be judged by the degree of retardation of artificial earth satellites.

### **Fighting Storms**

We have seen how many human lives are lost in natural calamities engendered by stormy phenomena in the atmosphere, and what enormous damage is done. It is for this reason that scientists are conducting such an active struggle against the great forces of nature.

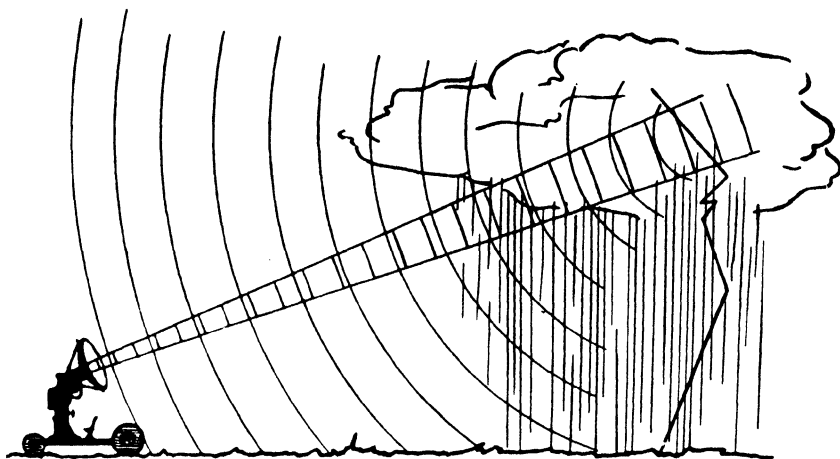
Present-day knowledge of menacing atmospheric phenomena not only enables us to explain them but also to foresee them and, thus, to some extent, to render them harmless by the means at our disposal.

Now, weather men armed with the latest techniques of investigating the atmosphere, warn of the approach of thunderstorms, rainstorms, gales, and hurricanes. Short-range forecasts of one or two days have already become part and parcel of our life and are given in timely radio broadcasts. At the same time, much is being done on long-range forecasting. The system of long-range forecasting of the school of Academician B. P. Miltanovsky is now being expanded by recent studies in the sun-earth problem.

Radio has opened up entirely new vistas for determining the seats of thunderstorms and their movements. For example, we know that every flash of lightning is reflected in radio reception by a characteristic crackling (atmospheric interference). The first instrument to record lightning discharges (this was done on a revolving drum) was A. S. Popov's storm indicator. Unfortunately, it did not have directional reception. Recording all lightning flashes, it could not indicate the point on the horizon of a given lightning stroke. Still, this instrument was widely used in meteorological observatories at the beginning of the century.

About 30 years ago, detector (crystal) receivers were used to locate thunderstorms in the vicinity of a weather station. Ordinary radio broadcasts were used for proper tuning. The distance to the thunderstorm was gauged roughly by the intensity of the radio interference (a "crackling" noise). It was found that a crystal receiver did not react to lightning flashes more than 100 kilometres distant from the point of observation. This suggested that whenever there was no atmospheric interference, there were no thunderstorms within a radius of 100 kilometres from the station. Increasing interference would mean that a thunderstorm wave was approaching, though local signs did not yet indicate one.

Refinements in radio apparatus have put into the hands of weather men more complicated recorders of atmospheric interference and its intensity. It has been established that such interference can be propagated in various directions for thousands of kilometres. Subsequent studies of interference



Radar detects distant stormcloud

have shown it to be highly important not only in radio communications but also for the Weather Service. Instruments designed to determine the location of the seat of a thunderstorm have been built. Proper spacing of the apparatus at two or three points has made it possible to give a graphical determination of the velocity and direction of a thunderstorm wave. Through the use of such apparatus, aircraft, power, and agricultural organizations are given timely warnings of an approaching thunderstorm.

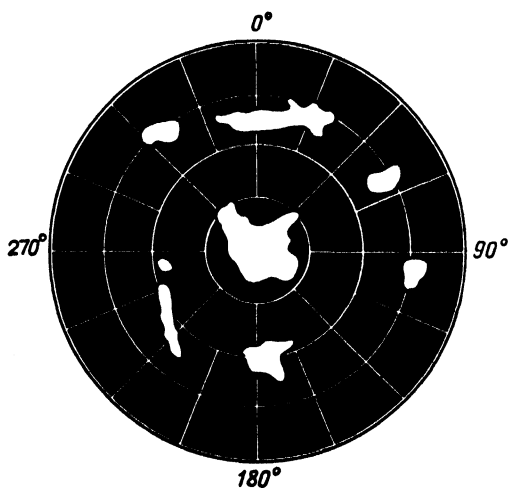
Of late, radar has found applications in meteorology. Radar can track radiosondes in flight and determine the direction and velocity of the wind beyond the clouds and at night. Radar is also capable of tracking rockets. The radar beam is reflected from clouds (radio echo) consisting of water drops and crystals. The heavier the sheet of rain the stronger the radio echo.

This is how we determine the distance to the front of a thunderstorm, rainstorm, or squall and, hence, their expected time of arrival. Right now, Moscow's Central Institute of Weather Forecasting has apparatus that helps the forecaster to "see" the clouds up to 200-300 kilometres around the capital.

The employment of electronics in meteorology has likewise greatly extended the limits of its practical application and has given birth to a new branch called radio meteorology.

Radar is used to follow the flights of meteors, and, by recording the trail of ionized gases (the "train" of the meteor), to determine the direction and velocity of the wind in the ionosphere. This is how it was found out that the rarefied air masses in the ionosphere are racing along at a tremendous speed of up to 200 kilometres an hour. Radar can also detect a tropical cyclone when it is still far out at sea, and follow its movements.

These new radio and radar techniques have greatly enriched meteorology and have made many a weather man's dream come true. Meteorologists now are so swamped with facts that only computing machines can process them. Although mathe-



Thunderclouds displayed on circular-view radar screen

mathematical analysis has always been a powerful weapon that can lay bare the laws of nature, meteorologists have frequently had to resort to extreme simplifications in resolving important practical problems due to the involved computations. These limitations have now been removed by electronic computers.

The Soviet school of Fridman, Kochin, and Kibel has found a way of making scientific predictions of the weather on the basis of a mathematical analysis of the movements of air masses and their temperatures at high altitudes. A forecast of this nature requires enormous computation in addition to a dense network of weather stations recording high-level phenomena. The new electronic machines carry out the most involved computations in just no time.

The findings of numerous stations are plotted on a modern weather map. These maps cover all of Europe, Asia, part of the Atlantic Ocean, Africa, the Arctic and are compiled eight times a day (24 hours). Twice a day, a weather map of the Northern Hemisphere is made, and once a day, a map of the whole world. Up until just recently, data plotters were overloaded with work. Now, automatic machines are going to take over this arduous work and speed up the whole process immeasurably.

Correct and timely weather prediction is very important to all branches of the economy. But still more intriguing is control of the weather. However, until this problem is solved and extricated from the field of experimentation, we have to adjust our activities to fit the weather. In the field of agriculture this is the task of agricultural physics. The Institute of Agricultural Physics has worked out methods of improving the thermal conditions for germination of potatoes, maize, and other plants, has found ways to anchor the shifting sands of deserts and to afforest them, to supply arid regions with food and water for vegetable growing. The Institute grows vegetables the year round in greenhouses. The plants are more easily protected from spring frosts by replacing glass with organic films. Studies of the requirements of individual agricultural crops as regards light, heat, moisture, and carbon dioxide permit of a proper approach to the problem of adapting the soil and the micro-

climate to the plant, and, conversely, of adapting the plant to the soil and climate.

In the fight against droughts, particular attention is given to land improvement. Under construction are new irrigational systems in Central Asia and the Transcaucasus, on the Volga and in other parts of the country. Hundreds of thousands of hectares of arid land are being irrigated and receiving water on the basis of the Volga-Don Shipping Canal and the Tsimlyansk storage reservoir.

The concern of the Party and Government for the economic development of the republics of Central Asia and the Transcaucasus, as well as other parts of the country has found expression in a broad programme of irrigation construction. The Akhunbabayev Canal is nearing completion in the Uzbek S.S.R. A new irrigation system is extending out into the fields of Andizhan Oblast. The Farkhad dam and the hydroelectric station on the Syr-Darya ensure gravity irrigation to over 400,000 hectares of new land in the Hungry Steppe. To improve water supplies to areas in the valleys of the Zeravshan and Kashka-Darya rivers, the Katta-Kurgan storage reservoir has been built. The Kuyu-Mazarsk reservoir is also nearing completion. Here the work was done by voluntary participation of the local inhabitants. Large-scale irrigation developments are in progress in Kirghizia, where the Bolshoi Chuisky Canal and the Orto-Tokoisk storage reservoir are almost completed.

In the Turkmenian S.S.R., construction work is in progress on the Kara-Kum Canal. Near the Murghab delta the canal is nearly finished and will take water from the Amu-Darya to one of the most ancient oases in the world—the Merv Oasis. The completion of the first stage of this construction job will make it possible to irrigate over 100,000 hectares of virgin soil. Irrigated areas in Mari Oblast, where the most valuable fine-fibre cottons are grown, will be doubled. Within the canal area, there will be large numbers of vineyards and orchards, with 5,000,000 hectares of pasture land watered, thus permitting a big increase in karakul-sheep breeding. The canal will pass near Ashkhabad and will abundantly supply the capital of the repub-



lic with water. When the whole canal is completed, the area of irrigated land will reach 450,000 hectares.

In January 1954, the turbines of the Mingechaur hydropower station went into operation. This power development near the gateway to the Boz-dag supplies cheap electricity and at the same time irrigates hundreds of thousands of hectares of farm land. In the Kura-Araks low country the new lands are given over to cotton, grain, tobacco, and to new orchards, vineyards, and pasture.

In Armenia, irrigation is developing on the basis of the water resources of high-altitude Lake Sevan and the Zanga, Araks, and Akhuryan rivers.

Irrigation work has begun in the Volga-Akhtuba flood plain. Levees protect thousands of hectares of land which was formerly inundated every year during flood. New orchards and berry gardens have been laid out, and vegetables and potatoes are grown on the flood-protected land.

Take a look at a map of the Soviet Union. The Volga and its tributaries stand out like a mighty tree. But the outlines of the great Russian river have already changed. For a quarter of a century, the "Moscow Sea" with its some 300 square kilometres of surface has dominated the headwaters of the Volga. It feeds the Moscow Canal and has converted the capital into a port of five seas; it supplements the city's demand for water and has raised the level of the Moscow River.

Near the old town of Uglich a second development has raised the level of the Volga 12 metres. And there is a third hydro development near the town of Rybinsk. The "Rybinsk Sea" here covers over 4,600 square kilometres—fifteen times the size of the Moscow Sea. It is so big in fact that there are places where you can't see the shores on any side. The waves are high in stormy weather, and river boats hasten to refuge in bays, shelters and ports.

A fourth development has been completed near Gorodets, with its dam raising the Volga 18 metres. This has produced the storage reservoir called "Gorodets Sea" which is hundreds of kilometres long and 20 wide. A big hydro development has been

completed on the Kama, giving rise to the 250-kilometre-long "Kama Sea," which is ten times the size of the Moscow Sea.

The biggest hydroelectric power station in the world was completed some time ago near the city of Kuibyshev on the Volga River. The dam of the Volga power station impounds a vast "Kuibyshev Sea." Its 5,000 odd square kilometres make it the largest artificial reservoir in the world. It extends for 600 kilometres up the Volga and for 300 up the Kama. The rise in water level reaches the town of Cheboksary. In places the sea is over 30 kilometres wide.

Nearing completion at Stalingrad is a second giant power development with the "Stalingrad Sea," 600 kilometres in length and up to 30 in width, covering an area of 3,500 square kilometres.

The Volga storage reservoirs are redoing the nature of this territory. Many of the tributaries are now navigable. Millions upon millions of cubic metres of water will flow from these reservoirs through irrigation canals transforming the Volga steppe lands into flourishing fields and orchards.

New storage reservoirs are appearing on other rivers as well. The Ust-Kamenogorsk hydro development has given birth to the 80-kilometre-long "Irtysh Sea." Other developments include the Novosibirsk and Irkutsk power stations. The Angara River has been tamed and will now freeze over together with Lake Baikal, relieving Irkutsk of frequent and unusually dense fogs that roll in over the city in winter. Under construction at Bratsk on the Angara is the world's most powerful hydroelectric station—equivalent to the Kuibyshev and Stalingrad stations put together. A bigger one still is going up on the Yenisei River not far from Krasnoyarsk.

This is how the Soviet people are remaking nature, obtaining cheap electricity and fighting droughts.

The U.S.S.R. still has many arid steppe lands, semi-deserts and desert lands that need moisture. No less extensive are the areas of swampy land, where cultivated crops suffer from an excess of water. Reclamation work is conducted on a grand scale here. Drainage work is linked up with clearing, deepen-

ing and straightening the rivers, and the construction of storage reservoirs on them to retain the spring flood waters.

What progress have we made in the fight against the raging elements? And what is the outlook?

There are fields in which we have achieved complete victory. For instance, we fully protect all buildings and structures from lightning and we do it so neatly that the lightning-rods do not yield the slightest spark. One can easily imagine what just such a tiny spark would do near petrol storage tanks and warehouses of explosives.

Rainstorm protection is likewise progressing. City drainage systems have been improved and expanded. In the countryside, the soil is anchored, drainage systems built, and trees and shrubs planted. An energetic struggle is being waged against gully formation. Railway beds are reinforced with broken stone on top to break up thunderstorm streams. In mountainous regions, success has been achieved in fighting torrents. Yet there is still a lot to be studied as regards rainstorms—their intensity, recurrence, and prediction.

Storms can be fought only by timely forecasting. We have said that prediction is one of the methods of combating them. The weather men are confronted by the task of improving storm forecasts to make them absolutely reliable.

Soviet power engineers and inventors are helping to harness the limitless energy of the wind. Wind power stations are spreading.

On the agenda is the fight against hailstorms. Studies conducted by the Institute of Experimental Meteorology, now merged with the Chief Geophysical Observatory named after A. I. Voeikov, point to the fundamental feasibility of preventing hailstorms.

We can now say boldly that the time is not far distant when the fruitful co-operation of scientists and inventors will permit us not only to foresee the onset of storms, but to actively combat them.



*PART THREE*

**EXTRAORDINARY PHENOMENA  
IN THE EARTH'S ATMOSPHERE**



CHAPTER ONE  
PHENOMENA IN THE UPPER LAYERS  
OF THE ATMOSPHERE

Noctilucent Clouds

During observations of the sky at the Moscow Observatory on June 13, 1885, Professor V. K. Tserassky noticed some strange clouds of a bluish-steel colour. They seemed very dense, but in reality were so transparent as to let through the full brilliance of the stars. These clouds resembled cirrus clouds and disappeared as soon as the sunshine from below the horizon ceased to illuminate them. The ordinary cirriform clouds had long since become dark, while these were still brightly shining. They received the name of noctilucent.

*Noctilucent clouds* are observed in the summer time between 50 and 65° of latitude in both hemispheres. They are most frequently seen in the northern half of the horizon. Accurate photographs have shown that the noctilucent clouds float at a height of 80 to 85 kilometres. It is interesting to note that this altitude remains constant. We know that the boundary of the twilight arc is located here and that this is the beginning of the ionosphere. Besides, this layer is the lower boundary of the aurorae.

Despite the fact that many years have passed since the discovery of noctilucent clouds, the question of their origin has not yet been resolved completely. This is because they are quite a rarity.

Soviet scientists, basing themselves on modern data of the physical nature of the upper atmosphere, give a most probable explanation of the formation of noctilucent clouds. They believe these clouds to appear when water vapour condenses. But where can water vapour come from at such great heights? Water vapour is fed into the atmosphere from the earth's surface.

If water vapour reaches such altitudes from the troposphere, this means that all layers of the stratosphere undergo a thorough mixing. Consequently, the stratosphere has vertical air currents as well as horizontal. The air pressure at the level at which noctilucent clouds originate does not exceed hundredths of a millimetre, the temperature is very low, and the water-vapour pressure is negligible. This is the reason why noctilucent clouds are exceedingly transparent and cannot blot out the stars despite their great thickness. The appearance of noctilucent clouds is invariably associated with enhanced solar activity. Whence we may conclude that they consist of water molecules that do not necessarily need to come from below.

During the eruptions of gases in solar prominences, which are particularly intense at periods of enhanced solar activity, the sun ejects corpuscular streams that enter the upper layers of the atmosphere. There is also an influx of hydrogen together with the corpuscles. And since there is atomic oxygen at 80-85 kilometres height, it combines with the hydrogen to form molecules of water. This is where the material comes to make up these mysterious noctilucent clouds, which from time to time light up the dark twilight sky with their illusive beams.

Of late, noctilucent clouds appeared in 1950, very many times in 1951 and less frequently in 1952.

A particularly interesting noctilucent display was observed on the night of July 6-7, 1951. Due to the great height at which these clouds soared, they were seen simultaneously in Moscow, Zvenigorod, Rybinsk, and at many other places.

The night air was exceptionally transparent. The noctilucent clouds were detected at 11:30 P. M. in the northern half of

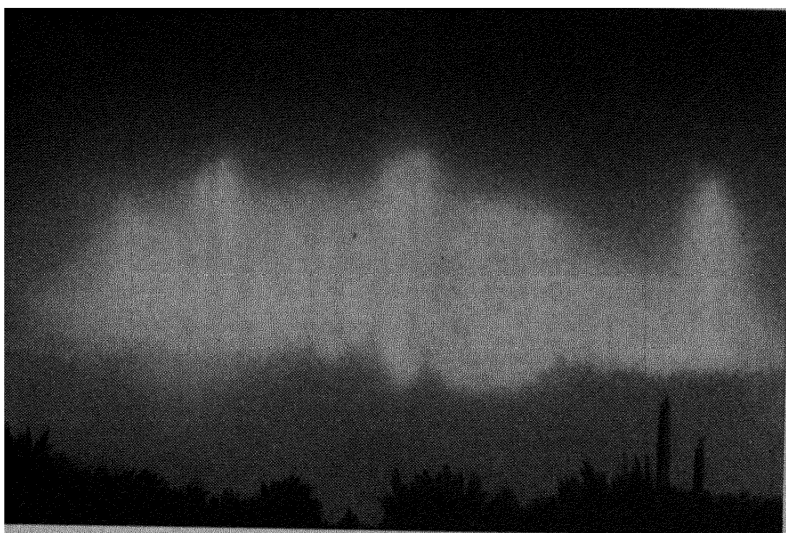


the sky. Especially attractive that night was the complex system of jets and streaks, their unusual brilliance, the emergence of separate rays and of tiny dark cells, and other structural peculiarities of the noctilucent clouds. Many of the details and eddies were seen to be exceedingly mobile and changeable. After midnight, the noctilucent cloud area increased. By two o'clock its upper fringe had nearly reached the zenith. At dawn the clouds seemed to melt away in the bright morning sky.

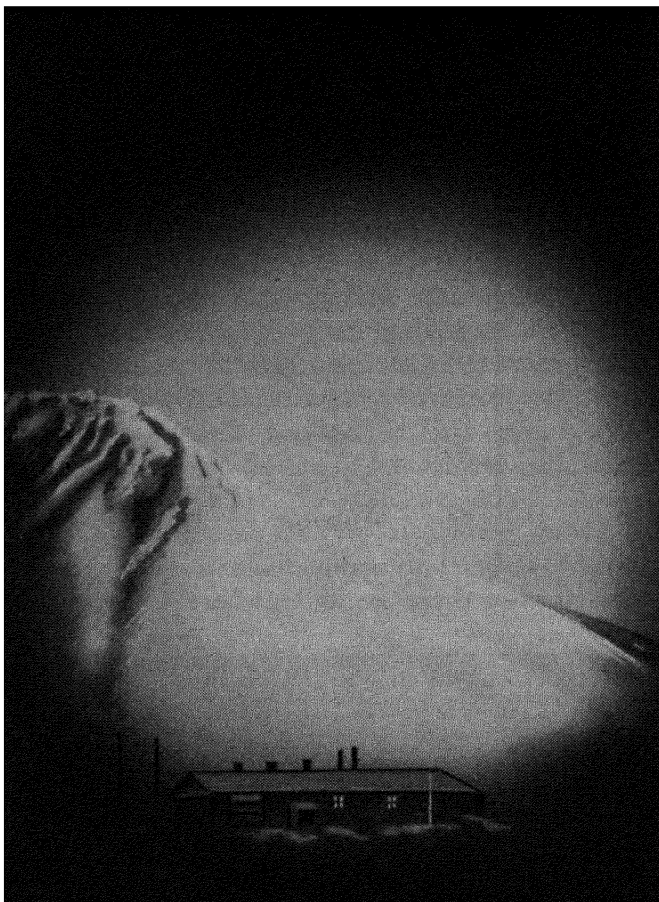
Noctilucent clouds are known to move very quickly, with speeds sometimes attaining many hundreds of kilometres an hour. Their direction is mainly from the east and north-east. But due to the extreme tenuousness of the upper air, this terrible hurricane can hardly be measured with existing meteorological instruments.

### Aurorae

The *aurora polaris*, sometimes incorrectly thought to be confined to the northern regions (where it is called aurora



Aurora (draperies)



Aurora (pulsating)

borealis or the northern lights), is met with in both hemispheres of the globe and is doubtlessly one of the most magnificent and awe-inspiring phenomena of nature. The impression is unforgettable to anyone who has once seen an aurora. It is for this reason that aurorae have always excited the liveliest interest of investigators.

The aurora usually puts in a sudden appearance. Sometimes it disappears in just a few minutes, but often continues the display for hours changing its brightness, its place in the sky and its general pattern. Against the dark background of the night sky, the aurorae appear dazzlingly bright, while in actuality their brightness is not very great. Only the very strongest make it possible to read by their light.

Auroral observations began hundreds of years ago. Lomonosov devoted much attention to them. Although in those days only pencil drawings of the aurorae were made, important information was obtained on their geographical location. In 1900 photography began to be used in studying auroral displays.

Despite the multifarious forms that aurorae take, the following seem to be basic:

1. Stationary forms:

- a) general night glow without sharp boundaries;
- b) pulsating glow with brightness changes in 20 to 30 seconds;
- c) stationary arcs or vertical pulsating bands.

2. Non-stationary forms:

- a) draperies with moving bands with ray structure. The draperies flutter as if moved by wind;
- b) drapery arcs with well-defined ray structure cutting across the arc;
- c) single rays or in bunches. These are usually very much elongated upwards.

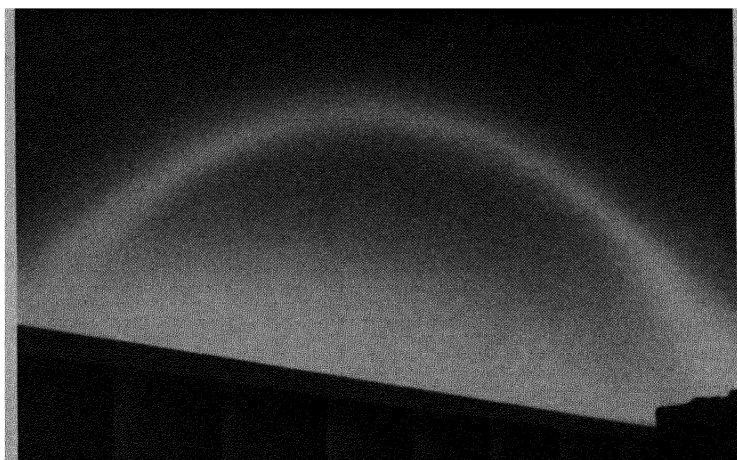
Such are the general shapes of auroral displays. However, the most intricate combinations are possible, with one type merging into another.

The usual colour of aurorae is greenish-yellow, but the drapery rays can also be of a violet or reddish hue.

The geographical distribution of auroral displays indicates some connection with terrestrial magnetism. In the Northern Hemisphere, aurorae become more frequent as one moves northwards. Hence the name northern lights (*aurora borealis*). They are rare in middle latitudes and exceedingly rare near the



Noctilucent clouds observed July 6-7, 1951



"Ring around the sun"

equator. This also goes for the Southern Hemisphere: the farther south the more frequent they are.

If points with the same number of aurorae per year are connected with lines, they will form roughly concentric circles with a centre that does not coincide with the geo-

graphical pole. The central circle with an average number of aurorae slightly over 100 a year embraces nearly the entire Arctic. They are most frequent in a belt at a distance of 2,200 to 2,800 kilometres from the magnetic pole. The number diminishes southwards. At Moscow latitude, the northern lights are seen once in ten to fifteen years.

The heights of auroral displays vary in the extreme, but, as a rule, they never descend below 100 to 80 kilometres. This means that all auroral glows are in the ionosphere. Nowadays, with photography, cinematography, and telephone communications, altitude measurements of aurorae have attained a high degree of accuracy. It turns out that the lower boundary is at 100-110 kilometres and the upper boundary, at 300 to 350 kilometres. In rare cases it reaches 400-600 kilometres, and in very rare instances has been known to be at 700 and more.

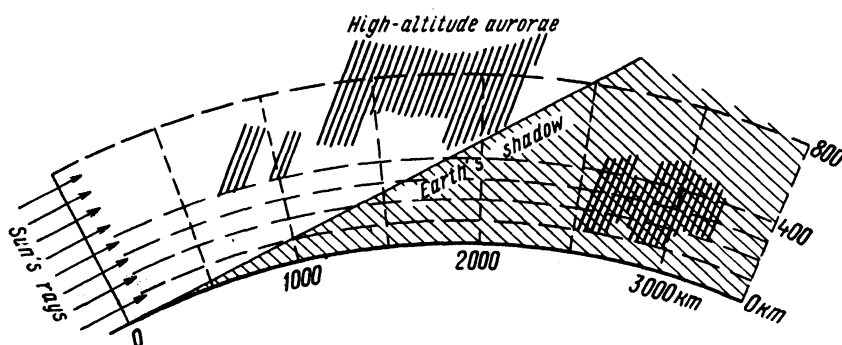
Of late it has been found that there is a special form of aurora that makes its appearance at very great heights, the top boundary being at 1,000 and 1,200 kilometres. These glows arise only during twilight. Determinations of the positions of these high-altitude glows in space and comparisons with the position of the globe indicate that they are always located in a sun-illuminated portion of the atmosphere. The glows have a ray structure. The figure on page 308 shows the sphere of auroral displays.

The high aurorae differ from the ordinary type in colour as well: they are a greyish-violet while the usual glows are greenish-yellow. These glows indicate that at 1,000-1,200 kilometres height there is still a certain amount of air, though it is in a highly tenuous state.

Despite the low brightness of the aurorae, they may be studied spectroscopically. Auroral spectra yield very valuable information about the structure of the upper atmosphere.

If a beam of sunlight is allowed to pass through a three-sided glass prism, it will be dispersed into several colours. This dispersed light is the so-called spectrum. The spectrum recognizes seven basic colours from violet to red (as in a

rainbow). Light is known to be propagated in waves. Different wave-lengths produce the impression of different colours. The prism refracts the component parts of light differently: the violet rays (short waves) undergo the greatest refraction and are deflected to the base of the prism more than are the red rays. All the other colours arrange themselves between these two extremes. The atoms and molecules of any incandescent substance produce a spectrum and emit rays of a definite wave-length that is characteristic of the given substance. For instance,



Rays of very high and of ordinary aurorae

incandescent sodium vapour yields a yellow light. Thus, from the spectrum of a substance, one can determine its composition and in some cases even more accurately than by means of a chemical analysis.

If you take the solar spectrum you will notice a large number of dark bands. These are absorption bands that are due to the fact that the rays of light coming from the sun are absorbed by atoms in the terrestrial atmosphere. The atoms of each gas absorb waves of a strictly definite length, of the very same length as the waves that these substances themselves emit under other conditions. Therefore, studies of lines of absorption enable us to determine the composition of a substance through which light has passed.

In aurorae there is a glowing of the upper atmosphere, and, for this reason, auroral spectra indicate which atoms are glowing and what their physical state is; that is to say, we obtain the composition of the air at great heights. Scientists are sometimes encountered by unexpected phenomena and problems.

Thus, at the end of last century a mysterious green line was detected in the auroral spectrum. It could not be identified with a single spectral line of any known terrestrial element. A similar line had earlier been found in the spectrum of the solar corona and had been attributed to an unknown gas called "coronium." The scientists then decided that the upper atmosphere that puts on the auroral displays is filled with a similar light gas, which was christened "geocoronium." However, Soviet workers have demonstrated that neither coronium nor geocoronium exists. The mysterious green line in the spectrum belongs to oxygen that has been dissociated into atoms.

What is the nature of the polar lights?

The aurora polaris originates under the bombardment of the upper atmosphere by charged particles (corpuscles) emitted from the sun. The impacts of corpuscles give rise to the self-glow of the tenuous gases of the atmosphere at great altitudes. This phenomenon is periodic and depends on solar activity. The streams of charged particles pushed out of the sun are attracted by the earth's magnetic field, and, therefore, the bulk concentrates in the areas of the magnetic poles. This accounts for the high recurrence of aurorae in the Arctic and Antarctic.

Since the auroral glow is associated with solar activity, it, like magnetic phenomena, exhibits a coincidence with the 11-year sun-spot cycle.

The aurorae are likewise closely related to magnetic storms. It has long been known that a compass needle sometimes fluctuates erratically. It deviates to one side several degrees and even a few tens of degrees. This is a magnetic storm. During magnetic storms, which last for hours and even days, a compass is useless to navigation. Magnetic storms are more

frequent and powerful in polar areas than in moderate latitudes. This is precisely the time that brilliant aurorae put on their displays. During very great magnetic storms, aurorae flash on in such unusual places as England or the middle belt of the U.S.S.R.

The author, for example, saw the northern lights in Moscow (latitude 55°) on October 17, 1930. At about 6:00 P. M., in the northern half of the horizon, there began to appear bright streaks, arcs, and spots that alternately flared up and decayed. Somewhat later, bright cloudlets appeared in the zenith as well. On the eastern side, the spots were in rapid westward movement. Columns of light were variously arranged and scintillated differently—at times becoming as light as moonshine. At 7 P. M., to the north, a segment of light became particularly prominent, moved quickly to the west and died out.

It is interesting to note that Germany also experienced an auroral display on that day. It was observed at about 8:00 P. M., that is, two hours after the onset at Moscow. The impression was that the discharge process had moved from east to west at the speed of rotation of the earth.

On February 21, 1950, Moscow's night sky put on a brighter auroral display that lasted some hours. It was also observed at Maloyaroslavets, Lipetsk, and over Bashkiria.

This display was exceptionally bright and remarkable for its play of light. At about 9 P. M. two crimson spots appeared in the sky. They spread out wide changing their shapes into draperies. At 11:30, two blue arcs lighted up in the northern part of the sky. In a short time, these were replaced by two spots that rapidly turned into a number of long dark-red rays, which began from the horizon and reached nearly to the zenith. The brilliance and colour of the rays were constantly changing. Claret colour gave way to light blue, and this, in turn, to green. Gradually the play of rays abated, and by 3 A. M. the glow had become a feeble whitish luminescence in the northern part of the sky.

That same evening, the observatory noted a great magnetic storm, strong disturbance in the earth's electric currents, and



considerable changes in the electric state of the ionosphere, which resulted in impaired propagation of radio waves. All these happenings were connected with a large group of sun-spots that appeared in the central part of the visible solar disk.

During the latest sun-spot maximum (1958), an aurora was observed even down to the latitude of Alma-Ata.

The common cause relating all these phenomena are electric currents (the motion of ions or electrons) in the upper layers of the atmosphere. This had been foreseen by Lomonosov (see his *Discourse on Phenomena of the Air that Originate from the Electrical Force*).

From this point of view, aurorae are similar to the luminescence of a rarefied gas in an electric discharge tube (Geissler tubes). Electric discharges in the upper atmosphere cause disturbances in the magnetic field of the earth known as magnetic storms.

To summarize, then, all the foregoing phenomena indicate a relationship between, and a sequence of, the sun, aurorae—magnetic storms, and the ionosphere.

## CHAPTER TWO

# OPTICAL PHENOMENA IN THE ATMOSPHERE

### The Green Flash

From the depths of the ages there has come down to us a folk belief, based on religion, that on the days of certain church holidays the sun “plays” at sunrise and sunset. This play consists in changes of colour and brightness. The sun shimmers as it were emitting bright green and red rays.

Science has established that this belief is connected with a rather rare, but extremely interesting, optical phenomenon that goes by the name of the *green flash*.

This optical phenomenon consists in the fact that the sun produces a brilliant green flash just before it vanishes from view below the horizon at sunset. At sunrise, the green ray flashes on the instant the sun appears above the horizon.

This phenomenon was first explained by Corresponding Member of the U.S.S.R. Academy of Sciences G. A. Tikhov.

The terrestrial atmosphere may be regarded as a glass prism which disperses the sunlight into its component colours. This is called dispersion of light. It stretches the solar disk downwards on the horizon, dispersing it into a number of vari-coloured images. The atmospheric dispersion at the horizon elongates the sun by  $1/64$ th of its diameter. At this time, the alternation of colours—violet, blue, green, etc.—is apparent only at the upper and lower limbs.

Atmospheric dispersion acts to divide, as it were, the sun into three disks that overlap, making the edges project accordingly. Therefore, when the sun sets and there is only a very narrow upper band, its colour rapidly passes from white through light blue to dark blue. The "blue flash" is an exceedingly rare occurrence and is observed only under conditions of supreme transparency of the atmosphere.

The thickness of the air greatly attenuates the short-wave rays—violet and blue. This is why at sunset the violet, blue, and green rays do not reach the observer, leaving only yellow and red; the sun gets red at sunset and stays that way.

However, under favourable conditions, when the air on the horizon is very transparent, the green rays persist. In this case, the colour of the outer rim of the setting solar disk changes from yellow to pure green.

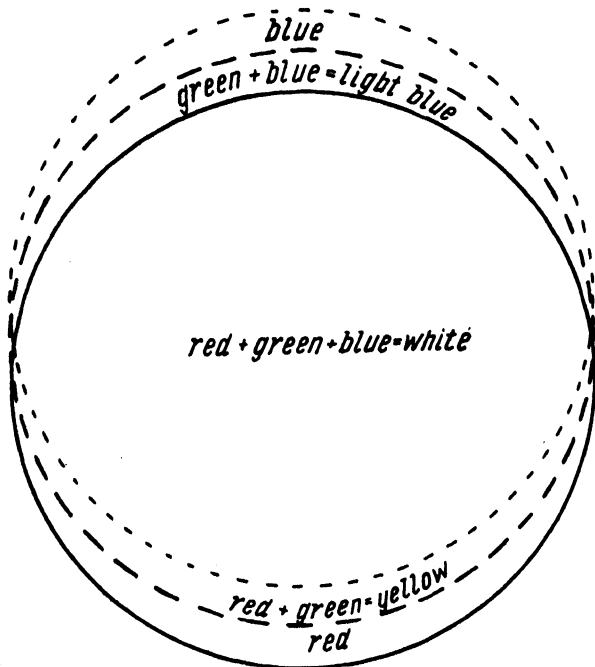
The green flash does not last over 1 to 3 seconds and depends on the latitude of the locality in which it is observed and the time of year. But, due to the inertia of the retina of our eye, the green flash appears to persist for a longer time. It vanishes quickest at the vernal and autumnal equinoxes when the sun is on the celestial equator. And it is longest at the summer and winter solstices when the sun comes up over the horizon in a very sloping path.

Observations of the green flash help to determine the state of the atmosphere, its transparency, its relation to air masses, and so forth. However, it may be seen only when there is very little water vapour in the air. If at sunset the sun is red and easy to look at with the naked eye, one may be sure that there will be no green flash. On the contrary, if there is little change in the whitish-yellow colour and the sun sets bright, one may expect the appearance of the green flash.

The green flash is best seen where the horizon is even (at sea, in a steppe region). At times, strips of cloud on the horizon smooth out its surface and the green flashes on like at sea. When looking for the green flash it is best to look at the horizon and not directly at the sun so as to escape the blinding effect of the sunlight. And only when half of the sun has sunk

below the horizon should one keep his eye on the sun all the time.

The green flash foretells good, dry weather. And if the blue flash puts in an appearance as well, you may expect exceptionally clear weather.



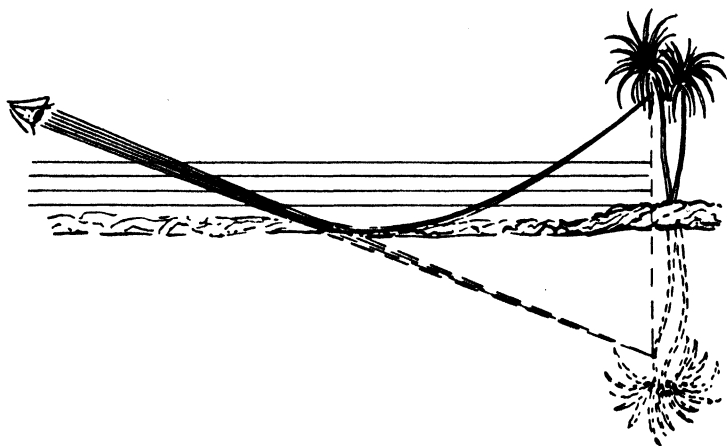
The green flash explained

Systematic observations of the green flash have never been made anywhere, and so amateur observations can be very valuable scientifically as an indirect method of studying the transparency of the atmosphere.

### Mirage

Deserts in Africa and Asia sometimes give a picture of rippling water surface on the background of the scorching sand. The rocks and bushes and individual trees appear to be

reflected in it as inverted images. Wearied by the heat, the travellers move towards the water, which all the time moves farther and farther away. This is the *inferior mirage*. Last century it brought death to many caravans that lost their way following this will-o'-the-wisp.



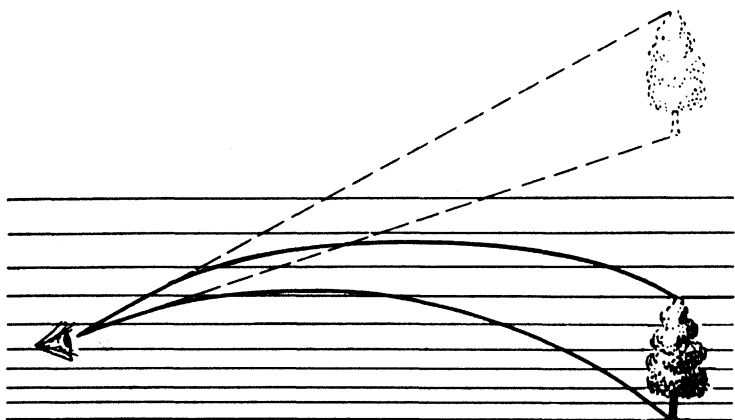
Inferior mirage

Before a ray of light reaches our eye, it traverses layers of air of different density and is deflected from its original direction. Passing from less heated layers to more heated, that is, from the denser to the less dense, the ray of light is more and more deflected from its straight path. A time can come when it makes a right angle with the latter. This angle is known as the *limit* angle, because further deflection of the ray will cause it to be reflected from the layer of air, and the observed object will be inverted.

In deserts, the extreme heating of the sand in an inferior mirage creates enormous vertical temperature gradients (temperature fall with altitude); for this reason, the density of the air grows rapidly in the lower layer. In this case, the curved ray of light produces an inverted image of the sky. Projected downwards, it creates the impression of a brilliant surface of water due to its homogeneity.

In some cases, the inferior mirage is known to appear in moderate latitudes. Motoring over a sun-beaten asphalt highway, one is suddenly confronted by a surface of water—astonishing, how come water? But it is always there, just a bit ahead, and constantly retreating. Then it vanishes just as suddenly.

The inferior mirage results when the ground layers of air are heated more than the upper levels, when light rays fall on these heated layers at a very acute angle, and, finally, when



Superior mirage

the observer is on flat country and at a big distance from the object.

The inferior mirage is mostly observed in the forenoon. The lower layers of air are then overheated, and the heat has not yet reached the higher layers.

Given air layers of different density, and also different angles of refraction and reflection of light rays in the atmosphere, the mirage sometimes produces fictitious images that appear to be real. Such, for example, are the mirages of non-existing islands that have often taken ships off their courses. There have been cases when sailors have long sought for islands that appear on the horizon and vanish when approached. And on land, images of towns have appeared and then disappeared.

A traveller in Algeria relates the following. "One hot July day, a friend of mine and myself were riding on horseback between Bône and Ghelma. Within about eight kilometres from Bône at one in the afternoon, we stopped stock-still at a turn in our path from surprise at a picture that could never have been expected. To the east of Bône, on an expanse of sand where we had been only two days before, lay a whole city with domes and bell towers all clearly outlined in the air sloping in steps down to a sea. The illusion was so complete that only reason refused to permit the reality of this vision which we watched for half an hour. Where had this reflection of a fantastic city come from? There was nothing in it like Bône, La Calle, or Ghelma, the last two of which were a 100 kilometres distant. We had to think that this was the reflection of some large town on the coast of Sicily. Yet this seemed absolutely incredible. . . ."

The opposite of the above is known as a *superior mirage*. In this case, the image of an object on the horizon appears above it in highly distorted form.

Once there appeared, in the air, the inverted image of a ship which at the time was beyond the horizon. Through a telescope one could see the various parts of the ship, which was 50 kilometres distant.

In the case of superior mirage the density of the air rapidly diminishes with height. This often occurs in clear weather and at high pressure. The superior mirage is most frequently observed early in the morning, when the ground air layer is still cold from contact with the night-chilled earth, while the upper layers of air are warm. The superior mirage is particularly frequent in polar countries, where the low-lying layers of air cool off due to contact with the ice cover.

Mirages form under one condition only—the absence of a strong wind. Wind mixes the upper and lower (ground) layers of the atmosphere, the air becomes homogeneous, and a mirage cannot develop. A slight breeze generates oscillations of the images, making the picture still more fantastic.

Sometimes a mirage distorts the shape of the solar disk at sunrise and sunset. It occasionally happens that a second sun suddenly appears, slightly separated from the first. This is usually observed in an absolutely clear, cloudless sky.

Superior and inferior mirages are readily reproduced in the laboratory. To obtain a superior mirage, take a glass fishbowl and fill it with water. Add table salt so that a saturated solution forms at the bottom. The density of the liquid will gradually diminish from bottom to top. If a beam of light is sent slightly upwards in the dark, one can trace the trajectory with its vertex and two branches and obtain a double image of a small illuminated object, for instance a hole in the side of the bowl.

To obtain an inferior mirage, take a long metal plate and heat it. Look along the heated surface at small, appropriately arranged objects and you will see their inverted images just below the objects themselves.

The unusual, vertical distribution of density of the ground layers of air can bring about a rising and expansion of the horizon. In this case, very distant objects come into view. From Hastings (England) it is occasionally possible to see a French port across the English Channel that ordinarily cannot be seen in the best telescopes. And the naked eye even takes in the separate elevations along the shore.

An interesting case was recorded in the Japanese Sea on the eastern coast of Korea. A mountain range appeared on the pure disk of the rising sun and then vanished the instant the sun detached itself from the horizon. There were obviously mountains on the line between the sun and the observer. Judging by the map, this was a mountain on the island of Honshu over 900 kilometres away. Cases have been known when the mountain ranges of Turkey, 400 kilometres away, have been seen from the Crimean coast.

Occasionally just the reverse happens, a depression of the horizon. Thus, the mountains of Corsica which are ordinarily visible from Genoa and Provence, appear to be submerged in the sea.



Rather often an unusual vertical distribution of temperature of the air creates an apparent increase in the size of objects. Cook's expedition in the polar sea once noticed an enormous island of ice with high mountain peaks. When they came up closer to the island they saw only a few tiny ice floes floating in the water.

The atmosphere is sometimes exceptionally favourable for the appearance of mirages. The horizon displays palaces, cities, and trees lying beyond it. These images are usually very distorted, move about from place to place, and create a fascinating impression. Such phenomena are especially frequent near Reggio in the Strait of Messina. They are called *fata morgana*.

An interesting mirage is often seen in the mountains. This is observed mostly in Germany on the Brocken Mountain, whence its name—The Brocken Spectre—which reflects the feeling it evokes in those who see it.

Brocken is the highest mountain in the Harz Range. It rises to 1,150 metres above sea level, and from its summit the horizon stretches off a good hundred kilometres.

Here is a description of the Brocken Spectre: "The sun rose at four o'clock in the morning. A strong wind was driving the clouds. Fifteen minutes later, the shadow of a huge human figure appeared in the west, and when the wind knocked Hane's hat off he raised his hand to his head and the shadow repeated this gesture exactly, and then began to repeat all the movements of the traveller. Hane called his companion and repeated the experiment, and the shadows again followed the gestures of both observers."\*

These mirages are observed in the Alps, the Caucasus, and the Pamirs. A necessary condition for their appearance is a background of cloud in the opposite part of the sky from the sun. The time should be just a few minutes after sunrise or before sunset.

\* Flammarion, *L'atmosphère*, Paris 1888, p. 223.

## Rainbow

This beautiful display has attracted attention since remote antiquity.

The rainbow is a large coloured arc that appears on the background of a rain cloud when the sun is shining on the opposite side of the sky. The centre of the rainbow is ordinarily under the horizon at the point of intersection of the celestial sphere with a straight line passing through the centre of the sun and the observer's eye, that is, at a point opposite the sun. This is why the semicircle of the rainbow is visible only when the sun is near the horizon. The full rainbow circle has been seen from mountains or aircraft when the sun is high above the horizon.

There have been cases when two rainbows appear—one under the other. The bottom bow is called the primary, and the upper one, the secondary. Both bows have their red edges facing each other. The red edge of the primary bow is convex, while that of the secondary is concave. A series of coloured arcs arranged like a spectrum adhere to the red arc. Though it is common to speak of "all the colours of the rainbow," we actually see only three (the conspicuous ones being red, yellow, and green) or a maximum of five colours. As a rule, the latter two—blue and violet—are very feeble. Usually the bow has no blue at all, and sometimes even pure red is absent, being replaced by a light orange colour.

The width of the rainbow and of the separate coloured arcs is not always the same. Arc radii can likewise differ. On the average, the angular radius of the primary bow is  $42^{\circ}$ , and of the secondary, about  $50^{\circ}$ .

If there are no objects behind the rainbow, it appears at some distance. But if there are objects there, the bow appears very close—some hundreds of metres.

So-called secondary arcs may appear inside the primary rainbow. Such arcs are far less frequent on the outside of the primary bow.

It is commonly believed that there will be no rain after a

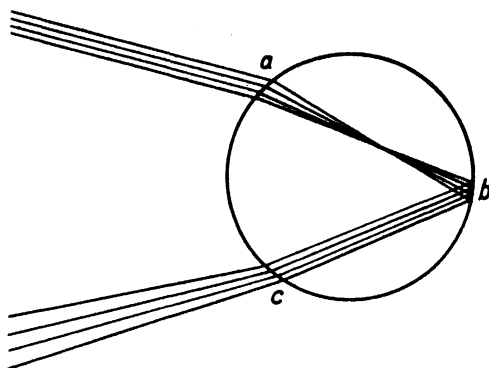
rainbow. This is not true because the rainbow is a purely optical phenomenon. There is far more to be learned from the colour of the bow. For instance, a very bright rainbow with predominant red is suggestive of the presence of large raindrops and, in general, of large quantities of water vapour in the air. This is a sign of rainy weather. If the rainbow exhibits a conspicuous green, this means the raindrops are small and there is little water vapour in the air. The bad weather will not last long.

The moonlight occasionally gives rise to a fog-bow, which appears white due to the enfeebled night colours. A real fog-bow is observed during a fog, especially in the mountains and on the seacoast. It appears as a broad and brilliant white bow slightly coloured both on the inside and outside.

Rainbows occur not only in rainy weather, but also when large numbers of water drops are dispersed in the air, for instance, near waterfalls. This is why it is so easy to reproduce a rainbow in the laboratory. A still easier way to make a rainbow is to fill your mouth with water and spray it in the sunlight.

Rainbows originate from light refraction in water drops. They get their colours from the fact that the indexes of refraction for waves of a light beam of different length are not the same, and also because the droplets are of a spherical shape and the light is refracted twice when passing through them.

Imagine a drop of water in the form of a circle (see the figure on page 322). The ray of sunlight enters the drop at  $a$ , is refracted, reaches  $b$ , and is reflected; it impinges on  $c$ , where it is again refracted, and then reaches the eye of the observer. This refraction, which differs for the various colours of the spectrum, disperses the sunlight into its component colours. The red rays are but slightly deflected from their original direction, orange are bent more, and so on until we get to ultra-violet that suffer the greatest deflection. This means that if red has reached the eye of the observer, the other rays in this drop will not be present. But an orange ray may arrive from a lower-lying drop,



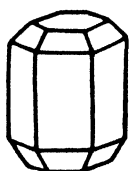
Origin of rainbow

a yellow ray from a lower one still, etc. The result is that the observer will have before him a series of coloured dots, with red at the top and violet at the bottom.

Let us imagine a cone, the axis of which passes through the eye of the observer, and the base is on the sheet of raindrops; each drop on the surface of such a cone will then be in a similar position with respect to both the sun and the observer. Now suppose that these drops send the eye red rays, then all red points produced by them will merge into a single red bow.

Following the same line, but a little below, will be the orange dots, then the yellow dots, etc. This is an arc spectrum which is called a rainbow.

Observations of the distribution of colours in rainbows, of



Ice crystals

their brightness, and the widths of the individual coloured bands help determine the size of the raindrops. The value of this method is that sizes of drops can be reckoned at a distance without coming into contact and spoiling them, as is the case

with ground methods. Rainbow observations likewise make it possible to measure drops in the free atmosphere.

## Solar and Lunar Coronas

These are what coloured rings around heavenly bodies are called. They make their appearance when the sun or moon is covered over with a thin layer of cloud, which is sometimes so delicate that at night it is not even visible. Lunar coronas can be seen with the naked eye, solar coronas through tinted glasses or by reflection of the sun in calm water.

Coronas sometimes appear about planets and bright stars.

In colour, they are bluish inside and reddish outside. Diameters range from 1 to 10 degrees (the sun and moon diameters are about 0.5 degree).

Coronas are due to diffraction of light, in other words, they result from the deflection of a ray of light from its rectilinear path. This occurs when a light ray passes through openings the sizes of which are close to the wavelengths of the light. In thin clouds, the light rays pass through intervals between the water drops or ice crystals. Corona formation requires that the size of the water drops or ice particles should be approximately the same, otherwise coronas of different sizes will overlap, giving the impression of a smeared-out spot encircling the moon. This is why the corona is not always visible when clouds cover the luminary.

If a cloud consists of water droplets, only an aureole is ordinarily seen. But in the case of cirrus clouds that consist of ice crystals, the coronas appear very distinctly, have beautiful colouring, and are sometimes accompanied by additional coronas. The bigger the particles comprising the cloud, the smaller the diameter of the corona. If the particles are very large, the corona is so close to the disk that it is no longer distinguishable. But at the same time coronas are visible around the planets and stars. From this we may conclude that when exceedingly small coronas appear, very many large particles are afloat in the air and, therefore, precipitation is to be expected.

Systematic observations of coronas have made it possible to solve certain problems connected with the physics of clouds.

These include problems of the size of cloud drops and crystals, the structure of clouds that have formed under various climatic conditions and at different times of the year, etc. A knowledge of the size of cloud particles can open up to us many new facts about the structure and life of clouds. For instance, coronas do not always have a strictly regular shape, but are often elongated in some direction. This indicates that the cloud has drops or crystals of different sizes which are not mixed up but arranged in separate groups.

Systematic studies of coronas yield additional material for gauging possible changes in the weather.

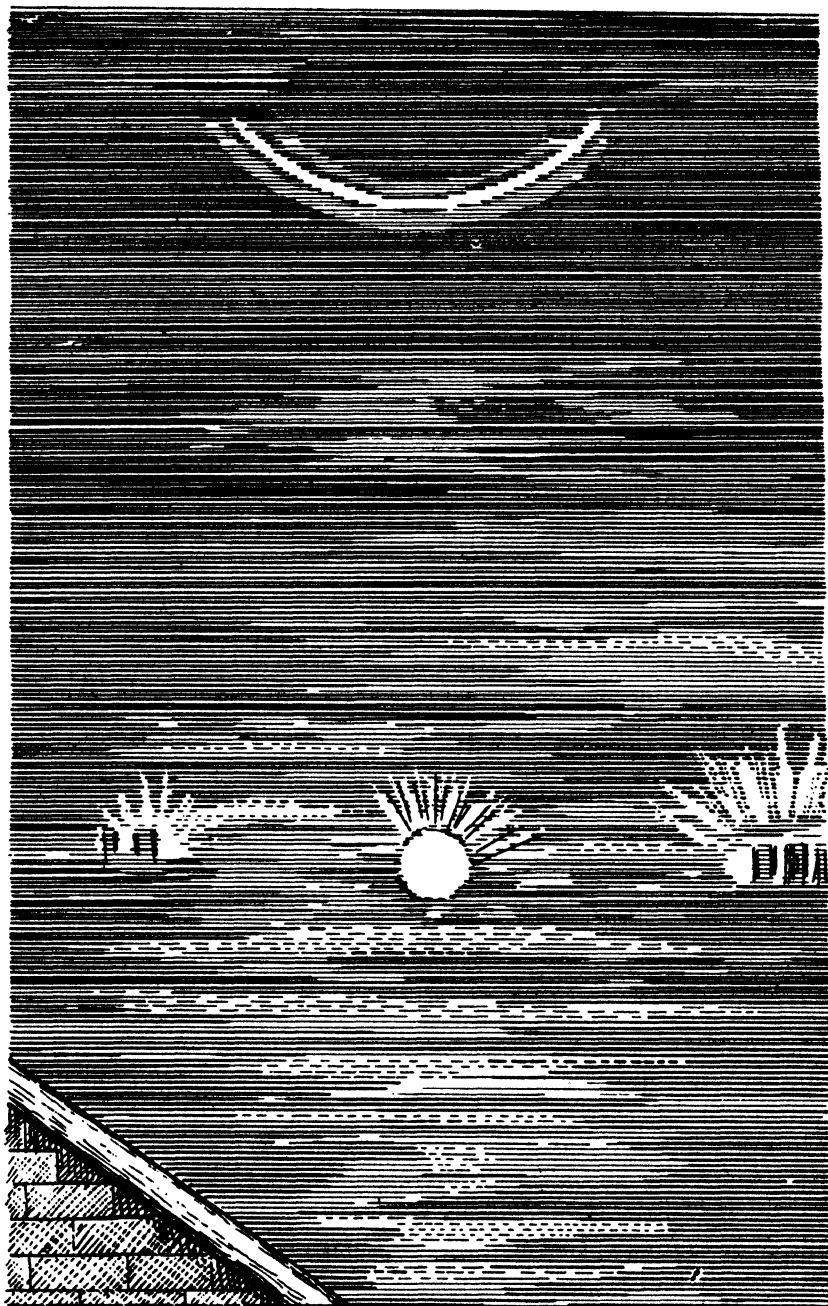
## Halo

When the sun (or moon) is covered by cirrus clouds (ice clouds), optical phenomena called haloes (rings round the sun, mock suns, sun pillars) occur as a result of refraction of light in ice crystals and reflections of light from crystal faces. The diverse manifestations of haloes are due, on the one hand, to the variety of crystal forms in the clouds, and, on the other hand, to their orientation when they fall to earth.

Most frequently it is a ring of radius  $22.5^\circ$  with the centre in the sun or moon. The inner part of the ring is of a reddish colour, the outer, bluish. The sky inside the ring is darker, but outside the illumination is far better. The formation of such a ring is due to the fact that the air is afloat with ice crystals, the axes of which are randomly oriented. And refraction occurs in prisms the refraction angle of which is equal to  $60^\circ$ . Not always is the whole ring visible, but only separate parts, especially the upper part.

Since cirrus clouds precede a cyclone, the appearance of iridescent rings usually foretells a turn for bad weather. This local indication is particularly trustworthy if the cloud density increases directly after the rings appear.

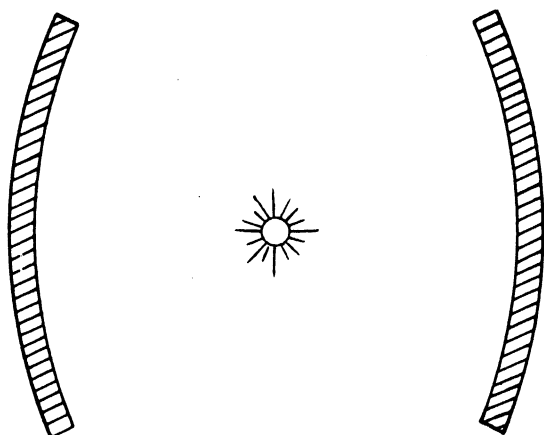
In many years of observations, A. P. Moiseyev of Moscow Oblast has found that haloes are seen about heavenly bodies on an average of 110 times a year. The halo frequency has a



Mock suns

pronounced annual march with a maximum during the summer months and a minimum in November and December.

A ring around the sun or moon at  $46^{\circ}$  is a rare occurrence. It is due to refraction of light rays in ice crystals whose refraction angle  $90^{\circ}$ . The crystals have highly diversified



Sun pillars

orientations. The colour arrangement is the same as in the  $22.5^{\circ}$ -degree ring. Ordinarily only the upper part of the ring, and not the whole is visible.

A mock sun is a clear-cut and brilliant spot that is so bright as to create the impression of a second sun. It is at the same height as the real sun and lags  $22.5^{\circ}$  behind. Mock suns are richly coloured: red, on the side towards the sun, and violet on the outside. A mock sun tapers off in a horizontal tail in a direction opposite to the sun and at times up to  $20^{\circ}$  in length.

Mock suns may be regarded as special cases of the  $22.5^{\circ}$ -degree ring, when the axes of all crystals suspended in the air are oriented vertically. Mock suns usually put in an appearance when there are separate cirrus cloudlets, which are often absolutely invisible.

Above the sun there sometimes appears a bright vertical pillar some  $5$  to  $40^{\circ}$  in length, tapering towards the top.



The pillar is usually seen when the sun and moon are on the horizon or even just under it. The formation of such pillars is due to reflection of rays from the bases of ice crystals floating in the air or slowly descending earthwards.

In severe frosts, one may witness two pillars, on either side of the sun. Needles of ice scintillating in the sunshine ("diamond dust") are then seen to be afloat low in the air. These pillars are a special case of the 22.5-degree halo that has not developed to full form due to insufficient vertical extent of the crystals (they are mostly close to the ground). That they are related to haloes is indicated by the arc-like shape of the pillars and the similar colouring.

V. Volovich, member of the wintering-over party of the drifting station "North Pole" 3, gives the following interesting description of such pillars: "Today we cannot say that we got up with the first rays of light. The sun did not dip below the horizon and has been wandering about the ice floe. Two rainbow-like pillars on either side—mock suns—are in a play of pale colour."

The halo phenomena occasionally combine to build up exceedingly complex shapes.

In conclusion it may be noted that all optical phenomena depend on the position of the sun or moon with respect to the eye of the observer. Therefore, each observer sees his own rainbow, halo, corona, and so forth.

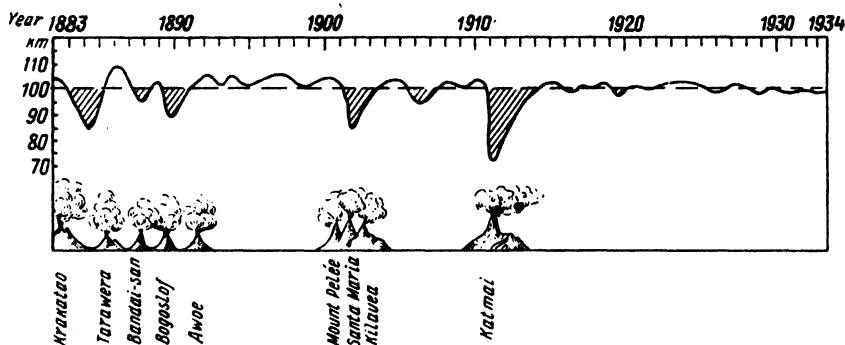
## Dust in the Atmosphere

All optical phenomena that occur in the atmosphere may be explained in terms of refraction, reflection, absorption, and scattering of light. The incomplete transparency of the atmosphere gives rise to the blue colour of the sky, the coloration of dawn, twilight, and other phenomena.

Dust in the air reduces the transparency considerably. We have already noted that the dust of the atmosphere is of different origin. In the upper levels is dust of cosmic origin—the product of disintegrated meteors that plunge into the

terrestrial atmosphere every day in large numbers. At times the earth itself runs into a cloud of cosmic dust in its travel through space.

From time to time the atmosphere also receives huge quantities of minute volcanic dust produced by powerful eruptions of volcanoes. This dust is thrown up several tens of kilometres and then wafted round the globe by high-altitude winds. It



The effects of volcanic eruptions on the transparency of the atmosphere (after Kalitin)

stays in the air in a suspended state for a very long time, even years on end.

One of the greatest eruptions of the Krakatau Volcano in Sunda Strait occurred in August 1883. Nearly the whole island was thrown into the air. The dust ejected by this eruption soon shrouded the entire globe initiating a series of optical phenomena, which included enormous coronas about the sun in the form of brownish-red rings. One such ring had an outer radius of about 20 degrees and a width of close to 10 degrees. The inner space between the ring and the sun was white with a bluish hue. Such rings were also observed after the eruption of the volcanoes of Mont Pelé (Martinique Island) and Katmai (Alaska).

The above chart compares volcanic eruptions and observed optical deviations. The curve shows a deviation of the magnitude of insolation intensity from the mean (in per cent).

The volcanoes are depicted at the bottom with the years in which they erupted. As may be seen from the figure, each decrease in transparency of the terrestrial atmosphere is associated with an influx of volcanic dust into the air. These data cover the period from 1883 to 1934.

The greatest pollution of the atmosphere with volcanic dust occurred on June 6, 1912, when Katmai erupted. The eruption was so violent that the sea around the volcano was covered with a solid layer of pumice, while volcanic dust settled in a 30-centimetre layer out to a distance of 160 kilometres.

Obviously, the eruption of the Bezymyannaya Volcano on Kamchatka Peninsula has added to the dust content of the atmosphere. Observations now in progress there will undoubtedly contribute new findings to this little-studied problem. The study of atmospheric transparency during eruptions is of interest not only from the point of view of dust pollution of the air, but also because it is possible to determine from the dust content the speeds of air currents at altitudes that are hard to reach by other methods.

\* \* \*

In this book we have spoken of the structure of the atmosphere, of stormy and unusual phenomena, of their origin and development, and of ways of combating them.

Scientists armed with the latest weapons of atmospheric research can give warning of approaching thunderstorms, rainstorms, and windstorms. They are developing effective ways of fighting natural calamities. Research institutes are carrying their experiments out of laboratories into nature itself—the atmosphere. The new laboratories are the plains, the mountains, the seas. The Voeikov Geophysical Observatory has specially equipped aircraft for flights in thunderclouds. “Flying laboratories” are also at the disposal of Glavsevmorput in its explorations of the Arctic and Antarctic. Wide use is being made of radar. The upper atmosphere is being attacked by rockets, ultra-short radio waves, and by artificial earth satellites. The

time is not far off when Soviet researchers will have new means of fighting the elements. We are already conducting experiments with cloud seeding (or the converse, artificial cloud formation) with the use of chemical substances and electrically charged particles. Man-made rain has repeatedly been brought to arid places on the globe through the latest weapons that science has created. Atomic energy harnessed to control the raging elements will open up to mankind still broader vistas. When tamed, the destructive forces of nature will work to the good of man.

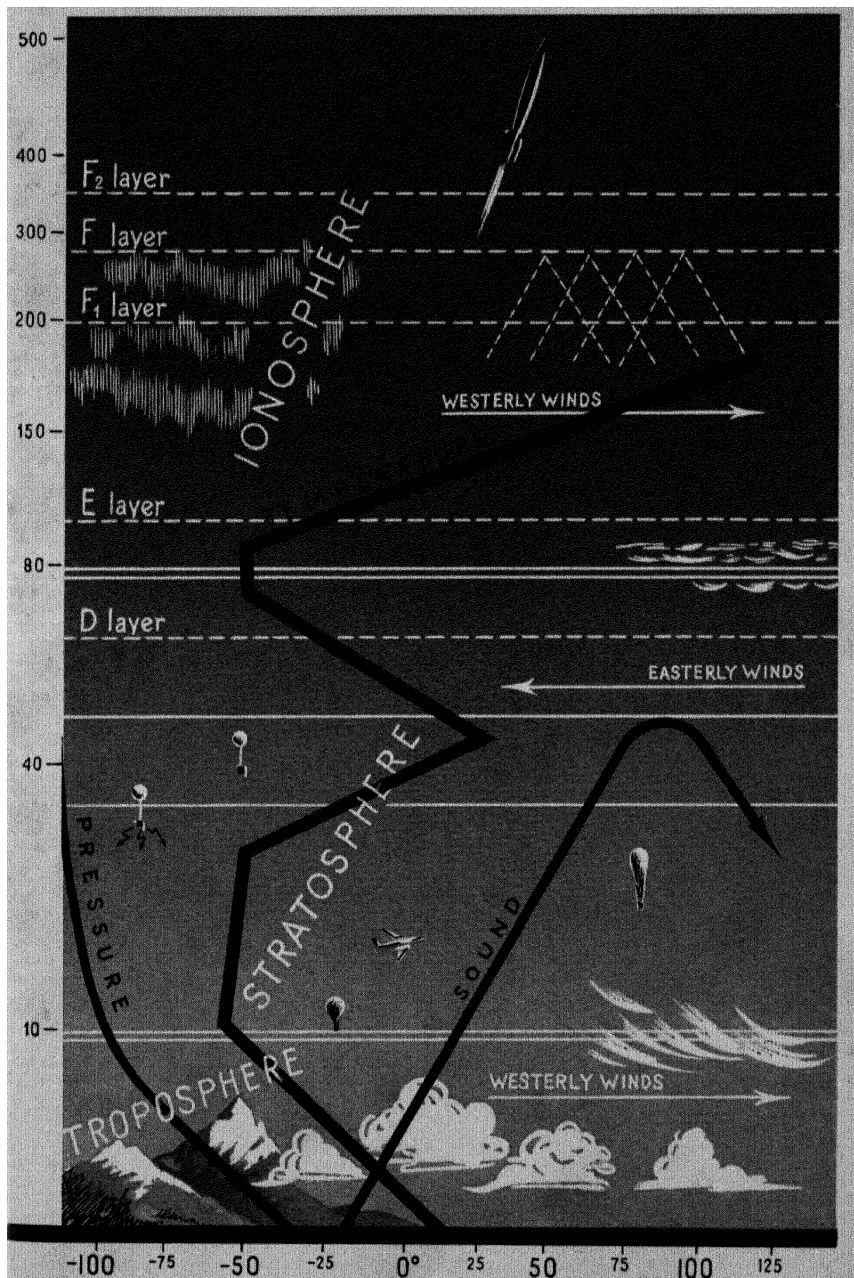
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**Н. В. КОЛОБКОВ**

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