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COMPOSITION AND PROPERTIES OF THE STRATOSPHERE AND IONOSPHERE

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The history of the study of the higher strata of the earth's atmosphere is rich in remarkable discoveries and daring hypotheses which were later confirmed, but for a great many years seemed very remote from practical affairs. It was thought, for example, that stratospheric processes were not important to weather service. But some time ago, geophysicists were called upon to answer many questions on the composition of the upper strata of the atmosphere which proved important both for meteorology and for weather bureau purposes.

Soviet geophysics was not taken by surprise by this "sudden" demand. Even 15 years ago an energetic movement had started in this branch of Soviet science, and soon our scientists occupied a prominent place among the well-known stratosphere explorers. Soviet scientists have invented and applied the radiosonde, which is now an important means of stratosphere study used in all countries. In 1933, the "USSR" stratosphere balloon established a world record for stratosphere flight (19 kilometers); during the flight valuable experiments were made. In 1934, the Commission for Stratosphere Study, Academy of Sciences USSR, under direction of Academician S. I. Vavilov, laid the groundwork for training highly qualified stratosphere experts and for systematic development of scientific research. At present Soviet geophysics has achieved important results on fundamental physical problems of the stratosphere and ionosphere which are often ahead of the achievements of foreign science.

Stratosphere

The existence of the stratosphere long remained a mystery which outstanding scientists endeavored to explain. And, even though now much of the theory on the origin of the stratosphere appears indisputable, the problem as a whole is still a long way from being solved.

The invention of radiosonde made it possible to measure the air's temperature at altitudes of 25-30 kilometers. It appeared that the temperature of the atmosphere even rises a little with increasing altitude, although very slightly.

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The tropopause (sometimes called the substratosphere) was also discovered. This intermediate zone between the troposphere and the stratosphere, extends 1-3 kilometers, and has such distinctive temperature conditions as temperature inversion. The altitude of the tropopause (and therefore, the beginning of the stratosphere) depends on the geographic latitude. Near the equator it rises up to 16-18 kilometers, near the poles it is as low as 3-6 kilometers, and in the middle latitudes it extends to 9-11 kilometers. Above the equator the stratosphere is much colder (-70 to -80 degrees) than in the middle latitudes (-45 to -55 degrees), and above the polar regions the stratosphere is warmest. The altitude of the tropopause shows regular seasonal changes. It is lowest in spring and highest in autumn.

To explain temperature conditions in the stratosphere, certain factors were studied which influence air temperature at high and low altitudes. A study was made of atmospheric absorption of ultraviolet, visible, and infrared rays of the sun. Laboratories studied the absorption spectra for nitrogen, oxygen, carbon dioxide, water vapor, ozone, and other gases in the air. Since these spectra are often related in a very complicated way to the gas pressure and temperature, they acquire a different aspect at different atmospheric levels. Theorists have developed the mathematical theory of radiation equilibrium and other thermal atmospheric processes. This intensive scientific work continued steadily for 40 years with a variety of results, some of them very important, and a systematic theory of the stratosphere has been developed. However, as we shall see later, this theory requires a great deal of improvement.

Stratosphere Theory

Briefly, the present theory describes the troposphere as the region where the temperature is regulated mainly by turbulent movements of air, and the stratosphere as the region where an exchange of the heat of radiation (radiation equilibrium) regulates temperature conditions.

The main source of the heat entering the atmosphere is always the sun, but sometimes this heat enters the atmosphere indirectly. The radiation of the sun, the surface temperature of which is around 6,000 degrees, contains the maximum amount of energy in the visible part of the spectrum; the curve of energy distribution according to the spectrum reaches a maximum in the green, and in the ultraviolet and infrared regions the curve descends abruptly. But since the earth's atmosphere is transparent for rays of the visible spectrum, the rays reach the earth's surface almost without attenuation. The greater part of these rays is absorbed by the earth's surface, or by the ocean, respectively. Only a small portion of the rays is reflected (the sea reflects about 10 percent of the falling light, the land from 3 to 25 percent, and the snow 50 to 70 percent); all the rest is absorbed. The sun's rays give almost no heat to the air; they give nearly all their heat to the earth. The main source of heat in the air is the earth's surface which has been warmed by the sun's rays.

The earth, like any other heated object, radiates; but due to the earth's low temperature, its reradiation consists only of infrared rays. This radiation is actively absorbed by the air, which has strong absorption zones in the infrared region. Since the earth's surface in relation to the atmosphere may be compared to a hot stove, the temperature of the air decreases with the increase of altitude near the earth's surface, in the troposphere.

The temperature gradient caused by the absorption of reradiation from the earth is so considerable that it creates powerful vertical movements, equalizing the temperature, due to the rising of warm air from below to the colder upper strata. The cooling-off process of the air with simultaneous expansion in moving upward causes the temperature gradient of 6 degrees per kilometer, which is characteristic, on the average, for the troposphere.

The vertical air action occurs in the form of turbulent movements. Great progress in the study of atmospheric turbulence has been made through the work

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of Academician A. N. Kolmogorov and his pupil, Professor A. M. Obukhov. Their research work, concentrated in the Geophysical Institute of the Academy of Sciences USSR, is far ahead of that of foreign authors and opens up new perspectives on other fundamental problems of geophysics (the theory of precipitation, etc.)

In the stratosphere, as we know, the temperature does not fall with a gain in altitude, and therefore, there are no vertical movements of air comparable in force to those in the troposphere. In the stratosphere the air temperature does not depend on its inter-mixing, but is determined by radiation equilibrium. Any volume of air of a certain temperature, radiates in all directions, the quantity of the radiation increasing the higher the temperature. At the same time, the air absorbs part of the radiated energy, passing through it in the form of reradiation from the earth's surface and radiation from all its surrounding volumes of atmospheric air. If the radiated energy is greater than the absorbed energy, the given volume of air, constantly losing part of the inner energy, cools off; if the procedure is reversed, it is heated. A stable temperature in a state of equilibrium is one at which the loss of energy through radiation will equal the intake of energy through absorption. In the development of this theory of radiation equilibrium, the mathematical works of Professor E. S. Kuznetsov in the Geophysical Institute of the Academy of Sciences USSR have been of great importance. The methods of solving equations for transfer of radiated energy in a diffusion and absorption medium, worked out by the well-known Soviet astrophysicist, V. A. Ambartsumyan, president of the Academy of Sciences Armenian SSR, have been very successful. His work has been awarded the Stalin prize. The participation of astrophysicists in developing similar geophysical problems is not accidental. The power and light conditions in stellar atmospheres are being investigated with the aid of a similar theory of radiation equilibrium.

Therefore, in the troposphere the turbulent vertical movement of the air acts as temperature regulator, whereas in the stratosphere the temperature is regulated by radiation equilibrium.

But why does a change in the temperature-regulating mechanism occur at a certain altitude - in the tropopause? Is it possible to explain by the theory of radiation equilibrium the increase of air temperature with altitude in the stratosphere, the decrease in altitude of the tropopause when approaching the poles and its higher altitude near the equator? Why is the stratosphere coldest above the equator? As we shall see later, these questions force us to seek radical improvements in the existing theory.

Water Vapor in the Stratosphere

The absorption of radiated energy by the different gases of which the air is composed reveals one interesting features: the smaller the quantity of a certain gas in the atmosphere, the greater and more important is the absorption process. Let us consider the approximate content by volume of five gases which are always present in the air: nitrogen (7[illegible]), oxygen (20%), water vapor (2%), carbon dioxide (0.02%), and ozone (0.000[illegible]%). Nitrogen, the volume of which is four times greater than the total of the remaining gases, does not absorb (either in the infrared, the visible, or the ultraviolet zones), and has no influence on energy processes in the atmosphere. Oxygen absorbs radiation, but not excessively. Absorption of radiated energy by water vapor and CO_2 is very strong, and by ozone is exceedingly high.

Ozone is a remarkable gas and we shall have to pay particular attention to its importance in stratospheric processes. But the properties of ozone have been investigated only recently, and all through the development of the stratosphere theory the principal significance has been ascribed to water vapor. One became accustomed to the role of water vapor; it was treated as a fetish. Although this attitude must be overcome soon by geophysicists, there is no doubt that the importance of water vapor is very great.

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Water vapor, which has strong absorption zones in the infrared region of the spectrum, obtains the greatest quantity of absorbed energy through reradiation from the earth. This determines its great influence on the heat balance of the troposphere. The founders of the theory of radiation equilibrium in the stratosphere proceeded from the assumption that the function of water vapor is just as important and that it represents the main absorbing element in the stratosphere. It now appears that this is not quite correct, that the importance of water vapor was overestimated and the importance of other gases underestimated.

The determination of the quantity of water vapor in the upper layers of the troposphere and in the stratosphere was so difficult that up to 1946 it was not possible to obtain reliable data. The difficulties were due to two reasons. At low temperatures of the stratosphere the quantity of water vapor is very insignificant, even in air which is saturated by vapors (fractions of a milligram per cubic meter of air), and the vapor itself assumes complex properties at such low temperatures, which makes it very difficult to measure its quantity. It was assumed that in the upper layers of the troposphere water vapor approaches saturation. In the absence of definite data and for the sake of agreement in temperature calculations for the stratosphere, theorists assumed that there is so much water vapor in the stratosphere that it approaches saturation.

Only in 1945-1946 was it possible to use sufficiently reliable methods for measuring water vapor in the stratosphere. It appeared that there is considerably less water vapor in the stratosphere than had been assumed, and that the transition from troposphere to stratosphere is characterized by an abrupt decrease of the water vapor content. The quantity of water vapor in the stratosphere is entirely insufficient to maintain, by its absorption of radiated energy, the temperature we observe in that region.

Does this mean that the theory of radiation equilibrium as a temperature regulator in the stratosphere is incorrect? No, that is not so. But the particular importance of water vapor must, apparently, be transferred to another element of the air - ozone.

Ozone in the Stratosphere

It has long been observed that the spectrum of the sun and of any star breaks off in the ultraviolet end at a certain point near the wave length 0.3 μ. At the same time there seemed no doubt that the spectra of the sun and the stars must extend a great deal farther in the direction of short wave lengths. Everything pointed to the fact that the earth's atmosphere is not transparent for such rays. However, the problem was complicated by the fact that not one of the known atmospheric gases absorbes the rays in question and the atmosphere must be transparent for them.

Further laboratory experiments disclosed that ozone has a strong absorption quality, beginning at the wave length 0.3 μ. But in measuring the content of ozone it appeared that the air near the earth's surface contains only a minimal quantity of ozone (0.000001 percent), so that the absorption of light by atmospheric ozone cannot completely cut off the sun's spectrum near the above-mentioned wave length.

But is there, perhaps, a much greater quantity of ozone in the upper layers of the atmosphere?

The study of the upper atmospheric strata by indirect methods is an outstanding achievement of contemporary geophysics. Academician V. G. Fesenkov, pioneer in this field, published a scientific work in 1915 showing that it was impossible, by measuring the luminosity of the sky at twilight, to study the distribution of density in the air up to a considerable altitude, 100-200 kilometers. In 1923, V. G. Fesenkov published the mathematical theory of the twilight method. During the past years the twilight method, which we shall describe further, has been widely used in the USSR and in foreign countries. But soon after the twilight method, other optical methods for studying the upper strata of the atmosphere were developed, in connection with observation of meteors, luminosity of the sky by night, etc.

It appeared that ozone was contained, principally, in the upper layers of the stratosphere. The greatest ozone content is at an altitude of 22-25 kilometers; above and below that level the quantity of ozone decreases.

During every flight of a balloon into the stratosphere, careful measurements were made to verify the distribution of ozone at high altitudes. All indirect measurements in the stratosphere, the last of which was made in 1947, have fully confirmed the above results.

It has been shown that the ultraviolet radiation of the sun, with a wave length of 0.18μ and shorter, aids the process of ozone formation. Here we encounter an important modern scientific problem, the "earth - sun" problem. The effects of the sun on terrestrial phenomena are varied. This is one of the great problems of geophysics and astrophysics, which is now the subject of extensive study.

It has recently been proved that ozone has such a strong absorption band in the infrared region of the spectrum, near the wave-length 10μ, that in spite of the fact that the total quantity of ozone in the atmosphere is one fifty-thousandth of the quantity of water vapor, the energy absorbed by ozone from the reradiation of the earth is only slightly less than the energy absorbed by water vapor. But the differences in the vertical distribution of these two gases also determine their different functions with regard to the temperature of the troposphere and stratosphere. In the troposphere there is a great quantity of vapor, and not much ozone, so the function of ozone as compared to water vapor is insignificant. However, the greater the altitude the less water vapor and the more ozone we find. The tropopause, i.e., the beginning of the stratosphere, must be the critical zone, where quantity changes over into quality. The transition to the stratosphere is accompanied by a sudden decrease in quantity of water vapor and increase in quantity of ozone, so that in the stratosphere the function of principal temperature regulator is taken over by ozone.

There are many reasons to assume that this view will influence further development of the stratosphere theory, but being new, it must be verified and developed. What factors are in favor of this opinion and what aspects of it must be carefully and critically studied?

It is not only a question of a small quantity of water vapor being present in the stratosphere. Since there is a great amount of water vapor in the troposphere, nearly all the earth's radiation of the wave lengths absorbed by water vapor remains in the troposphere, and it reaches the stratospheric water vapor only in a very reduced form. On the other hand, the earth's radiation of waves of the length 10μ, which is absorbed by ozone, passes freely through the troposphere and reaches the stratospheric ozone with almost undiminished force.

It is possible to calculate the balanced temperature which one or the other gas would have if it were the only component of air in the stratosphere. It appears that in the case of water vapor it is -80 to -85 degrees, and for ozone, -35 degrees, that is, 50 degrees higher. Therefore, the higher the proportion of ozone to the quantity of water vapor in the air, the higher will be the temperature of the air. But this proportion in the stratosphere increases with altitude, and therefore the temperature rises also. The theory which did not take into account the function of ozone was unable to explain this basic fact.

It has been determined by optical measurements that the quantity of ozone in the stratosphere depends on the geographic latitude and on the season of the year. Near the equator the quantity of ozone decreases, near the poles it increases. In spring, the quantity of ozone is greatest; in the autumn, least. If we take this into consideration, it will not be difficult to explain, on the basis of the theory of radiation equilibrium, the decrease in temperature of the stratosphere and the increase in altitude of the tropopause from the poles to the equator, as well as the decrease in altitude of the tropopause in spring and its increase in autumn. These basic facts could not be explained by theory until quite recently.

The quantitative side of this new theory has not been sufficiently developed, mainly because of a lack of necessary data on the water vapor and ozone content at different altitudes.

We have already mentioned the difficulty of measuring water vapor content in the stratosphere. Data on ozone are particularly lacking for the most interesting part of the stratosphere, that is, the beginning of that region, in a layer of 10 to 20 kilometers. Existing methods do not enable us to obtain systematic data for separate, sufficiently thin layers, or to measure changes in the content of ozone through the tropopause, but we have seen that this phase is of the greatest importance. In the meantime, outstanding specialists in many countries have worked to improve methods of determining the ozone content. The lack of necessary methods is due to the very complicated nature of the problem, -- a minimal ozone content, and the necessity of measuring it in high, not easily accessible, strata.

To develop the stratosphere theory further, more definite data are necessary on the vertical distribution of water vapor and ozone up to an altitude of 14-18 kilometers.

Temperature of the Upper Strata of the Atmosphere

Measurements with the aid of radiosonde, disclosing a slight increase of temperature in the stratosphere with increasing altitude, were made up to 25-30 kilometers. But during the last decade important results have been obtained by indirect methods, showing that in the higher strata special temperature conditions prevail which may be described briefly by the rule: "the higher, the warmer." Let us first consider the acoustic data.

During World War I it was observed that sometimes heavy artillery fire heard at a great distance was not audible at closer range. Later it was determined by phonometric research methods that during heavy explosions there exist abnormal zones of audibility. Normal audibility disappears at a distance of 30-50 kilometers, then follows a zone of 30-50 kilometers where the explosion is not heard; but beyond this, at a greater distance from the point of explosion, the sound is again heard. It was proved theoretically that a return of sound waves occurs by refraction in the air strata at an altitude of 35-60 kilometers. Such sound refraction with its subsequent return to earth can occur if the air temperature in the refraction layers, on which the diffusion speed of sound waves is dependent, rises with increasing altitude. The phenomena under observation can be explained if we assume that at an altitude of from 25-30 kilometers up to 60 kilometers the air temperature rapidly increases with altitude, reaching around +30 degrees at an altitude of 40 kilometers, around +60 degrees at an altitude of 50 kilometers, and approximately +75 degrees at an altitude of 60 kilometers. It is impossible to penetrate to an altitude above 60 kilometers by means of acoustic sounding, because in the higher strata sound waves are very strongly absorbed.

The continuous temperature rise with altitude in these strata is confirmed by twilight observations. As we mentioned before, Academician V. G. Fesenkov developed a theory, which was improved by N. M. Shtaude, permitting the calculation of air density in different strata at altitudes of 20-30 kilometers up to 150-250 kilometers according to the extent of twilight luminosity of the sky at different stages of the sunset. Knowing the vertical distribution of air density, one may calculate the distribution of temperature and pressure.

The twilight method of exploring the higher strata of the atmosphere has acquired particular importance during the past few years. Following the lead of Soviet geophysicists, it was widely used in Germany, US, England, France and other countries, but Soviet scientists even now occupy a leading position due to the theoretical works of N. M. Shtaude, the research work of the Geophysical Institute

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of the Academy of Sciences USSR, and the fundamental works of the newly founded Abastuman Astrophysical Observatory of the Academy of Sciences Georgian SSR, which has already been publicized.

Interesting results were obtained by observations of meteor luminescence. By photographing meteors from two points simultaneously, we are able to determine the altitude, speed and luminosity of meteors at different points of the path. From these data it was possible to make theoretical calculations of the air density at the points of ignition and extinction of the meteor and the points of greatest luminosity (between 40 and 110 kilometers of altitude).

Finally, during the last 6-8 years it was possible to make a number of experiments determining air density in high strata by observing the reflection of radio waves (see "Ionosphere," below). All these methods are in agreement and enable us to build up a certain picture of upper stratosphere temperatures. Above 60 kilometers the temperature begins to fall, and at an altitude of 80 kilometers the temperature is around -10 degrees, but above 80 kilometers there is another strong increase in temperature (8-10 degrees per kilometer), which reaches +100 degrees at an altitude of 90-95 kilometers. Here we enter a particular region of the atmosphere - the ionosphere.

The Ionosphere

The idea arose about 65 years ago that somewhere, in extremely high layers of the earth's atmosphere, there is a layer of air with high electrical conductivity. This thought was taken up again after the invention of radio and the first transmission of radio signals across the ocean. It had not been possible to explain the bending of radio waves around the globe by the effect of diffraction. The problem of calculating the diffraction of radio waves around the earth is very complicated and only 2 or 3 years ago, after 40 years of efforts by eminent theorists in many countries, this problem was satisfactorily solved by the outstanding research work of Academician V. A. Fok.

In 1902, a hypothesis was stated according to which a reflection of radio waves takes place from a high layer of air possessing great conductivity. In 1926, the existence of reflecting layers (ionosphere) was proved experimentally by the method of radio impulses. Several reflecting layers were found: layer E at an altitude of 100 kilometers, layer F at 250-300 kilometers, which is sometimes divided into two layers, F_1 and F_2. In addition, there is a weakly reflecting layer D at an altitude of 50-60 kilometers, which reflects only the very long (kilometer) radio waves. The existence of conducting layers results in the propagation of radio waves above the earth as in a spherical condenser, i.e., between concentric conducting layers (the surface of the earth or ocean and the ionosphere). As a result, the distance of reception grows.

The conductivity of reflecting layers is determined by the presence of free electrons and ions, i.e., the air in these layers is ionized. The determination of ion and electron concentration at different altitudes in the ionosphere, which greatly influences the long-distance propagation of radio waves, constitutes the fundamental problem of physics of the ionosphere and radiophysics.

However, in determining the concentration of charged particles there is one principal difficulty. Radio methods do not enable us to distinguish free electrons from ions (we are not speaking here of the influence of the earth's magnetic field). The effect of N electrons (the number of particles in one cubic centimeter) on a radio wave is the same as the effect of $N_i = NM$ ions, where M is the proportion of the ion mass to the electron mass. The ion mass of nitrogen or oxygen is approximately 30,000 times greater than the electron mass; therefore, the action of one electron is equivalent to the action of 30,000 ions. This discrepancy is a stumbling block in radiophysics, and enormous efforts have been made to eliminate it. Although now (by indirect criteria) one may consider as sufficiently established that the F layer has an electronic nature, and that in the E layer both electrons and ions influence the propagation of radio waves, the problem has not yet been solved in its entirety and remains the principal problem of modern radio-physics. In particular, it is necessary to obtain accurate data on the concentration of electrons and ions in the E layer. If the conductivity of the E layer had a purely electronic nature, N would be 2×10^5 per cubic centimeter. If the properties of the E layer are, in fact, determined by ions, then $Ni = 6 \times 10^9$. The concentration of electrons in the F layer constitutes around 2.6×10^6 per cubic centimeter.

The ionosphere represents an ionized medium (plasma), consisting of molecules, atoms, ions and electrons. This medium is quasi-neutral, the number of positive particles equaling the negative. Even in the F layer the degree of ionization is very limited. From the data of twilight methods, which are considered most reliable, it is known that the air density at an altitude of 250 kilometers is 10^{-11} grams per cubic centimeter, or 2×10^{11} molecules per cubic centimeter. Therefore, in the F layer there is only one electron per 10^5 molecules. In the E layer the share of electrons is correspondingly less. But such a degree of ionization is sufficient to create the remarkable phenomena which makes possible long-distance radio communication.

Composition of the Air in the Ionosphere and the Problem of Vertical Mixing

Thus, strictly speaking, at an altitude of around 100 kilometers the stratosphere ends. Above that we find the ionosphere.

Nature gives us a wonderful opportunity to determine the chemical composition of layers above 100 kilometers by studying the spectra of aurora borealis and luminosity of the nocturnal sky. By photographing polar lights simultaneously from two points, 10-50 kilometers apart, it is possible to determine the altitude of the lights. It appeared that the lower rim of the lights never goes below 100 kilometers, the upper rim extends up to an altitude of 250-400 kilometers, and on rare occasions even up to 800-1,000 kilometers. A study of the spectra of auroras has made it possible to determine the composition of the air at an altitude of 100 kilometers and higher.

Thirty years ago another interesting phenomenon, luminosity of the night sky, was discovered. The brilliance of the sky on a clear moonless night as shown by calculations and measurements, is two or three times greater than it should be, i.e., greater than could be explained by the light of all the stars. It was proved that the high layers of air, particularly in the layer at 130-180 kilometers, are continuously giving out light. The study of spectra of this light, the nature of which is not entirely clear, enables us to determine the composition of the higher layers of the atmosphere above any part of the world, and not only above the polar regions as in the case of polar lights. Investigations have shown that the air, even in the highest layers, is made up of the same nitrogen-oxygen components as in the lower strata. This result was unexpected, as it had previously been assumed, from the basic conditions of hydrostatics which are the foundation of the barometric formula, that in the higher strata the lighter gases should predominate and the ionosphere should be almost entirely hydrogenous. It has now been proved that there is no hydrogen in the stratosphere and ionosphere, at least not as a constant and noticeable component. Therefore, the atmosphere at all altitudes is "mixed." This result is not trivial, for according to the stratosphere theory there should be no vertical movement in the stratosphere, the region of stable vertical equilibrium.

The problem of mixed atmosphere is important in contemporary geophysics. During the past few years, complicated analyses of air samples have been taken at different levels, up to an altitude of 29 kilometers, in different parts of the world. Principal attention was given to the oxygen content (heavy gas) and helium (light gas). Up to an altitude of 20 kilometers the oxygen content remains strictly unchanged -- 20.9 percent by volume. Above 20 kilometers a slight decrease in oxygen content has been determined, up to 20.4 percent at an altitude of 28.5 kilometers. The helium content near the earth is 0.00052 percent, and at an altitude

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of 25 kilometers is 0.00054 percent. Explaining the mechanism of vertical mixing in the stratosphere and ionosphere is an important task of geophysicists. Of course, the temperature criterion of vertical stability of the stratosphere is incomplete. It is also necessary to consider horizontal air movements, especially because there are constant air currents of great velocity in the stratosphere and ionosphere.

Ionosphere and Sun

The spectra of polar lights and of night-sky luminosity show that in the ionosphere oxygen is completely dissociated. During the past 3-5 years, there have been indications of a partial dissociation of nitrogen, but this question is still under discussion.

What agent maintains the constant dissociation and ionization of air in the ionosphere? The radiation of the sun acts as such an agent. During the periods when large spots pass throught the central meridian of the sun, the ionization of high layers is suddenly increased, accompanied by disturbances to radio communications, magnetic storms, and particularly bright polar lights. But what kind of solar radiation - ultraviolet or corpuscular - causes ionization and dissociation? This is one of the chief problems of contemporary astrophysics and geophysics under study at present. There are arguments for both kinds of radiation.

Since 1932, special observations have been made in connection with the solution of this problem, during solar eclipses, to show not only the optical but also the corpuscular eclipse. Light takes about 9 minutes to travel from the sun to the earth, and the corpuscles projected by the sun take much longer. As a result, the moment of optical eclipse is removed by 24 hours or more from the moment of corpuscular eclipse.

A great number of eclipses were observed with the aid of radio waves to study the change in ionization during optical and corpuscular eclipses. The active influence of ultraviolet radiation on the F layer has been definitely established (decrease of ionization by 10-20 percent at the moment of optical eclipse). The influence of corpuscular radiation is difficult to prove and the results are not certain. However, the observations of Ya. L. Al'pert and B. N. Gorozhankin near Moscow, during the solar eclipse of 9 July 1945, have made it possible to draw a conclusion regarding the influence of corpuscular solar currents, rushing at a speed of 400-600 kilometers per second and more.

It is still necessary to make a number of observations with the aid of new instruments during future solar eclipses to explain all essential circumstances of the dissociating and ionizing action of solar radiation in the ionosphere.

Temperature of Ionosphere

To determine the air temperature in layers located above 100 kilometers, one must use primarily three indirect methods. All of them give certain information regarding the vertical distribution of air density, out of which it is possible to reach conclusions regarding temperature distribution. The basic method is the twilight method described above. The most reliable results, covering a 4-year period of continuous observations (theoretically developed in 1947), were obtained by the Abastuman Astrophysical Observatory of the Academy of Sciences Georgian SSR. They agree with independent determinations of density, made during the last few years by radio methods for four levels: D, E, F_1 and F_2 layers. Finally, in 1946 an interesting work of Garang [Harang?], a Norwegian geophysicist was published, on determination of air density by measuring the brilliance of polar lights at different altitudes.

The results of all three methods approximately agree up to a level of 170-180 kilometers. The temperature rises rapidly with altitude, reaching a value of +700 degrees in the layer at 170-180 kilometers. Above 180 kilometers, according to twilight data, the temperature remains almost constant and even decreases slightly above 240 kilometers. The other two methods show a continued rise of temperature up to +1200 degrees and more at an altitude of 250 kilometers.

We have good reason to assume that the twilight data are closest to reality. The future will show how correct this is.

The more recent and exact theory of Ya. L. Al'pert and V. L. Ginzburg (Physical Institute of the Academy of Sciences USSR), which takes into account the increase in number of collisions as a result of increase in effective cross section of ions, also gives the moderate temperature of +30 degrees for the highest F_2 layer.

In 1947, the American press and radio, in particular the notorious "Voice of America" radio broadcasts, raised a great to-do about the "overwhelming" results of temperature measurements in the upper strata of the air, supposedly obtained during experimental flights to the stratosphere by the V-2 rocket-projectile. However, it appeared that no results had been obtained which would alter the picture of temperature distribution as previously established and described above. The same applies to other questions, such as the vertical distribution of ozone.

Wind in the Stratosphere

The study of air currents in the upper atmospheric strata is a problem of great practical and theoretical importance. The development of the theory of general atmospheric circulation, the principles of a general study of movements in the atmosphere, and theoretical principles of weather forecasts, as well as the demands of long-range artillery, rocket aviation, and sound ranging, require exact information regarding the speed and direction of air movements at different altitude levels and at different global points, depending on the time of the day and the season. The information available to geophysics is not yet sufficient, and it is imperative that more complete data be obtained.

To study the problem of wind in the stratosphere several methods have been used. First, observations of luminous clouds, sometimes visible after sunset and before sunrise, have been made. Simultaneous photographing from two points a sufficient distance apart, together with exact measurement of the sighting angles of the camera, has shown that luminous clouds are found almost invariably at an altitude of 80-83 kilometers (apparently, the constant altitude level is connected with the existence of a constant powerful temperature inversion, beginning at this level; see above). The same kind of measurement shows the existence of fast movements of luminous clouds and makes it possible to measure their speed.

We should further point to the study of meteor trails. A meteor often leaves behind a luminous trail, sometimes visible for a long time. Usually there is a drift of the meteor trails, which are goniometrically photographed from the ends of a determined base to determine the velocity and direction of wind at different altitudes.

Quite recently, results have been obtained by radio observations regarding the movement of "clouds" of high ionic concentration in the ionosphere.

Important information may be obtained from sonometric measurements of zones of abnormal audibility in the case of heavy explosions, a field that has not been sufficiently developed up to the present. An exact theory on this complicated phenomenon has been developed by Soviet geophysicists, including Professor S. V. Chibisov.

Finally, in 1946, a number of observations were made in England on the drift of smoke formed by firing special smoke-projectiles up to an altitude of 30 kilometers.

It has been determined that there are powerful and regular air currents at different atmospheric levels. Here, for example, is one of the typical schemes: The wind velocity in the troposphere increases with altitude, reaching a maximum of 20-25 meters per second below the tropopause, and there is a prevailing wind direction at this altitude. In the stratosphere the wind velocity at first decreases rapidly with increasing altitude, reaching a minimum of 6-8 meters per second at a level of 19-22 kilometers, but in higher strata we observe a very rapid increase of wind, up to 70 meters per second at an altitude of 40 kilometers and 140 meters per second at an altitude of 60 kilometers. A strong temperature inversion, beginning at a level of 80 kilometers (see above), possibly plays the part of a "second tropopause" in some respects. At any rate, the wind velocity here apparently reaches its maximum (up to 160 meters per second), and in all probability, it decreases at higher altitude levels.

The prevailing wind direction in the second tropopause is directly opposed to the direction in the real tropopause. It is possible that these two tropopauses constitute an important element of a closed circulation scheme in the stratosphere, the greater velocities in the upper tropopause being necessary to balance the masses, as the air density decreases with altitude.

Stratosphere and Weather

There have long been attempts to connect the phenomena in the stratosphere with the weather-forming processes in the troposphere. Although certain correlations have been definitely established, we do not yet have a complete picture of the influence of the higher layers of the stratosphere on the weather. But there are many reasons to believe that in developing our knowledge of the stratosphere, the important role of stratospheric processes in the theory of weather forecasts will be more definitely outlined. At any rate, during the past few years important signs have been observed. We shall not go into this extensive subject as a whole, but will only mention a few examples.

Interesting data have been obtained in England and America regarding measurements of ozone content in the stratosphere as an indication of impending change of air masses and the approach of a synoptic front. The great importance of ozone measurements in the study of general atmospheric circulation is now definitely established, but research in this field has not been given sufficient attention by Soviet geophysicists. We should devote ourselves seriously to this question, particularly since we have highly qualified personnel who can conduct this research efficiently if properly organized.

The influence of the stratosphere and ionosphere on tropospheric meteorological processes is becoming more and more evident in connection with the influence of solar ultraviolet and corpuscular radiation on the ionosphere. We are thinking not only of the highly publicized discovery of the Australian scientists who established a distinct parallelism in the changes of degree of ionization in the E layer, on one hand, and the atmospheric pressure at ground level, on the other hand (far-reaching correlations have also been established by Professor E. N. Kessen and his collaborators); but we are thinking especially of the organized and promising research work on the connection between processes on the sun and phenomena in the troposphere. The various and powerful effects of the sun on the ionosphere are, apparently, transmitted through the stratosphere to the troposphere. Interesting correlations have been found between phenomena visible on the surface of the sun and certain meteorological processes. The mechanism of transmission of these influences through the stratosphere is not yet clear. The development of the problem as a whole depends, we believe, mainly on the measure of success in gaining an understanding of this mechanism.

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