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N. Ya. Bugoslavskaya

Solar Activity and the Ionosphere

FOR RADIO COMMUNICATIONS SPECIALISTS

PERGAMON PRESS

SOLAR ACTIVITY AND THE IONOSPHERE

N. Ya. BUGOSLAVSKAYA

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FOR
RADIO COMMUNICATIONS
SPECIALISTS

Translated from the Russian by
G. O. HARDING

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PREFACE

Research on phenomena taking place on the sun and their influences on vital processes on the earth is of great theoretical and practical significance for those working on electrical communications generally, and on radio communications in particular.

The present lecture contains the fundamental facts about the composition of solar radiation, and about the connection between geomagnetic-ionospheric storms, which affect the regular operation of radio communications, and the radiation from active regions of the sun.

A knowledge on the part of radio communications specialists about the nature of these phenomena on the sun, and of the reasons for their influencing the conditions for propagation of radio waves, helps them to solve practical problems connected with securing reliable radio communication.

The material of the lecture is largely a generalization of the experimental work carried out by the Institute for research into the earth's magnetism, the ionosphere and propagation of radio waves (NIZMIR) under the Ministry of Communications of the U.S.S.R., and of the experimental work in this field carried out over many years by the lecturer herself.

Technical department
Ministry of Communications
of the U.S.S.R.

INTRODUCTION

The action of the sun on the life of the earth is extremely varied. However, we are interested in its effect on the propagation of radio waves in short-wave radio communication. Many questions relating to the effect of solar radiation on conditions of short-wave propagation still need to be studied, and formed part of the programme of observations during the International Geophysical Year. Naturally, in the present lecture not every question can be fully treated and sufficiently definite answers provided.

It is well known that short-wave propagation is carried out by reflecting radio waves from the electrically-charged, ionized layers of the earth's atmosphere, that is, from the ionosphere. Hence, we shall survey the effect of solar radiation on just these atmospheric layers, and we ignore the whole of the atmosphere lower than about 60 kilometres.

At the present time, the question of how solar activity influences radio communication cannot be put in a very simplified form. Radiation from the calm undisturbed sun, and radiation from its disturbed (i.e. active) regions, affect the earth's atmosphere, forming ionized layers, which are capable of reflecting radio waves. The state of these layers determines short-wave radio communication conditions, and consequently disturbance of the structure of the ionosphere can lead to interruption of radio communication. The same processes on the sun produce, in different geographical latitudes of the earth, different effects on the ionosphere, and, therefore, on radio communication. For example, during many ionospheric disturbances, communications in the Arctic are interrupted, in central latitudes they are severely impeded, but at the same time, in low latitudes communications remain normal, or even become better than usual. Hence, one cannot claim a direct dependence between disruptions of radio communication and processes on the sun: the more so, because the quality of the radio transmission depends to a great extent on the correct choice of operating frequencies and on other technical operating conditions. It is essential to consider two separate problems. What is the influence of solar activity on the state of the ionosphere, and what radio communication paths are possible during various ionospheric conditions? Neither of these problems is sufficiently solved to satisfy the radio communication expert. The present lecture will serve to acquaint us mainly with the first problem. The lecture can be divided into two parts. In the first part we shall consider the irradiation of the atmosphere, and its dependence on geographical latitude; the energy of the regular (constant) incident solar radiation, and the process in the atmosphere connected with it; and the diurnal, seasonal and periodic changes in state of the ionosphere, together with the corresponding changes in radio propagation conditions. In the second part of the lecture, we shall consider the processes in discrete active regions of the sun; the irregular solar radiation connected with these processes and its disturbing effect on the earth's atmosphere; and, finally, the ionospheric and geomagnetic-ionospheric disturbances, and the related changes in conditions for the propagation of short-waves.

The author assumes that the reader is acquainted with the general structure of the ionosphere, the fundamentals of short-wave radio propagation, and has a

basic knowledge of astronomy. On the other hand, the author considers herself free, for the sake of a full and ordered exposition, to remind the reader of certain elementary matters. The author tries, as far as is possible in the present lecture, to bring the questions considered up to the level of present-day knowledge.

REGULAR SOLAR RADIATION

THE LAWS OF IRRADIATION OF THE EARTH

Composition of Solar Radiation

When observing the state of the ionosphere, its diurnal and seasonal changes, its sometimes stormy condition, and the appearance of its various layers, one should keep in mind the complicated and varied composition of solar radiation impinging on the ionosphere. The whole range of ionospheric conditions and changes result from the complexity of solar radiation.

First of all, one should distinguish in solar radiation electromagnetic (or wave) radiation, and corpuscular radiation.

The electromagnetic radiation of the sun covers a very large range of wavelengths, and only an insignificant part of this range comprises radiation visible to the human eye. The long-wave part of the range can be detected by its thermal effect, and may be studied with thermoelectric devices.

In 1942, radio radiation from the sun was discovered, although its existence was already suspected in the 90's of the last century. Subsequent measurements showed the presence in the solar radio spectrum of wavelengths from millimetres to several metres (our atmosphere does not admit waves longer than 10 to 15 metres).

With regard to short wavelength electromagnetic radiation, i.e. ultra-violet rays, one may observe the solar spectrum by using photographic plates and photo-electric cells. At 290 mμ, the spectrum is interrupted owing to atmospheric absorption. A narrow section of the solar spectrum is still visible at about 220 mμ. However, by sending up spectrographs in rockets, it has been shown that the solar spectrum extends considerably further, but the higher layers of the earth's atmosphere do not admit waves shorter than about 100 mμ. Recently, very short wavelength solar radiation has been discovered; as short as X-rays, and even shorter. In Fig. 1 the solar spectrum is shown and its various parts indicated.

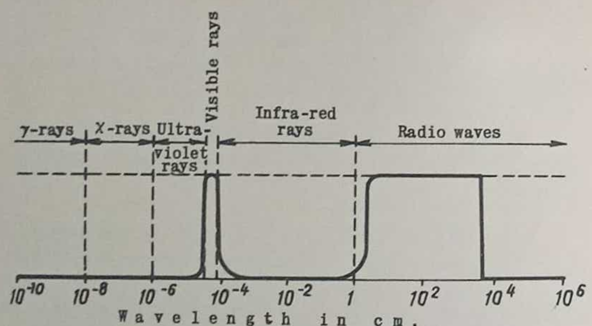


Fig. 1. The spectral composition of solar wave radiation.

Solar radiations possess different energies, depending on their wavelength, and they penetrate, or are absorbed, in the atmosphere to varying degrees.

In considering the physical processes of radiation, it is convenient to characterize waves, not by their length, but by the number of oscillations per second, i.e. by their frequency, ν. The energy of radiation is proportional to its frequency, and is characterized by the so-called quantum energy, which is equal to the product of a certain constant h and the frequency ν.

When considering processes in the atmosphere, produced by solar radiation, one must also take into account the intensity of the radiation as represented by the number of energy quanta.

Laws of the Irradiation of the Earth

Illumination at different geographical latitudes. The sun illuminates simultaneously one half of the earth's surface. At the boundary of the illuminated and dark hemispheres the sun appears at the horizon, i.e. its rays are tangential to the earth's surface. In the middle of the illuminated hemisphere is a point from which the sun is seen at its zenith and its rays fall vertically. This point is called the subsolar point. The further one is from this point, the less the height of the sun above the horizon; the sun's elevation equals 90° minus the angular distance of the observer from this point. At a given geographical position, the sun is at its highest at midday in the summer. Thus the sun's elevation

$$h = 90° - \varphi + \delta$$

where φ is the geographical latitude of the point of observation

δ is the declination of the sun, i.e. its angular distance from the celestial (also terrestial) equatorial plane (Fig. 2) or

$$z = \pm(\varphi - \delta),$$

where z is the zenithal distance of the sun.

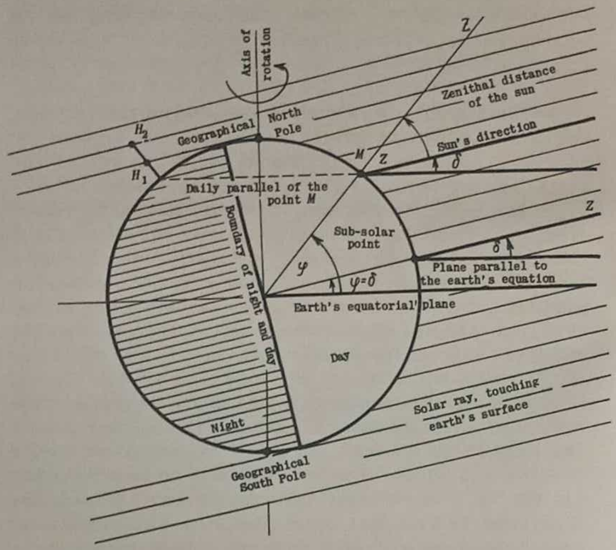


Fig. 2. Geometry of the earth's illumination

The latitude of the sub-solar point is equal to the declination of the sun. In the course of twenty-four hours, this point moves from east to west along a parallel owing to the earth's rotation. In the course of a year, it changes its latitude (as does the declination of the

sun) within the limits $\pm 23^{\circ} 27'$. During the year, the declination changes as follows. On the days of the equinoxes, 21 March and 23 September, it is equal to 0°; on the day of the summer solstice, 22 June, it reaches its most northerly value $+ 23^{\circ}27'$, and on the day of the winter solstice, 22 December, it attains its most southerly value, $- 23^{\circ}27'$. Hence, the sub-solar point moves between the latitudinal limits $\pm 23^{\circ}27'$, i.e. between the tropics.

As the sub-solar point moves, so also do the northern and southern limits of day and night. On 22 June the northern limit moves $23^{\circ}27'$ beyond the North Pole of the earth, and the whole of the polar region remains in daylight for twenty-four hours. Correspondingly, the region around the South Pole remains in darkness for twenty-four hours. Thus the polar circles, lying along the latitudes $\pm 66^{\circ}33'$ are the boundaries of the region of polar day and night. The length of the polar day and night within this region varies from a single day at the polar circle to half a year at the pole itself.

Hence, in all phenomena depending on the sun's illumination, there appear two periodicities - daily, and seasonal, i.e. annual. In the first case, the whole field of illumination moves from east to west with the visible daily movement of the sun. In the second case, the conditions of illumination at each geographical latitude vary from month to month with the change in the sun's declination. The conditions of illumination change most sharply from winter to summer near the poles, and least sharply at the equator.

The quantity of solar energy. The quantity of solar energy falling on unit area of the external surface of the earth's atmosphere depends on the angle at which the solar-rays fall on it, and is equal to

$$\varepsilon = \varepsilon_0 \cos z,$$

where ε_0 is the solar constant, i.e. the quantity of energy falling perpendicularly on one cm^2 of the earth in one minute, this being approximately equal to 2 cal.

z is the zenithal distance of the sun.

By calculating the amount of energy falling at different geographical latitudes in the course of a day, a month and a year, we get an idea of the distribution of solar radiation on the external surface of the atmosphere, or of the so-called "solar climate".

The distribution of solar energy on the earth's surface differs substantially from the distribution of solar wave-radiation on the external surface of the atmosphere. The sun's rays passing through the thickness of the earth's atmosphere, especially its lower layers, suffer absorption depending on their path length in the atmosphere. The lower the elevation of the sun, the greater the absorption. At noon on a summer's day in Moscow, about 50% of the energy falling on the atmosphere reaches the earth's surface, and at noon on a winter's day, in all, only about 7%. On 22 June more solar energy falls on the atmosphere at the North Pole during twenty four hours than at the equator during the same period of time.

In considering daily and seasonal variations in the ionosphere, the solar climate must clearly be taken into account.

The illumination of the atmosphere at different heights. To determine the conditions of illumination of the high layers of the ionosphere, it would not be quite

correct to apply the conditions of the sun's visibility at the earth's surface. The higher above the surface, the greater is the horizon, and the earlier the sun's rays become incident. For any point above the earth's surface the increase in the horizon, or its 'angle of depression', is determined by the angle between the horizontal plane and the tangent to the earth's surface through the given point.

Thus owing to this angle of depression of the horizon, the sun rises earlier in the ionosphere, and sets later. In the ionosphere above Moscow, the sun does not set in summer. However, before arriving at a given point in the ionosphere, the sun's radiation passes through a greater thickness of atmosphere outside terrestial daylight hours, and the ultra-violet rays, which are most active as far as the ionosphere is concerned, are absorbed. Therefore the 'sunrise' in the ionosphere, which increases the density of ionisation, i.e. increases the 'critical frequencies', takes place only slightly earlier, and the 'sunset' only slightly later, than at the earth's surface.

Ionizing Action of Solar Radiation on the Earth's Atmosphere

The existence of the ionosphere, i.e. of electrically charged layers in the earth's atmosphere, which reflect radio waves, is due to the action of ultra-violet solar radiation. The energy of ultra-violet rays is so great that it can ionize an atom, i.e. remove from it an electron, which then moves freely, and is no longer attached to the atom. The electron carries a negative electric charge, while the atom with one electron missing becomes a positive ion. Hence, in the atmosphere there appear charged particles. For a greater intensity of ultra-violet radiation, the number of electrons and ions is increased, the concentration of charge in the atmosphere is higher, and the ionized layer is denser (i.e. the ionization process predominates over the simultaneously occurring recombination process between electrons and ions). When illumination ceases, recombination increases, free electrons become attached again and (neutral) atoms are once more restored.

The density of ionization is considerably lower at night than by day, since the majority of electrons and ions are then recombined. When the sun rises, ionization increases again, becoming greater as the sun rises higher above the horizon. At low geographical latitudes, where the sun's elevation is greater, the ionosphere has a higher density of ionization.

If the intensity of ultra-violet radiation from the sun increases, this will lead to an increase of ionization of the ionosphere in the whole of the hemisphere which is illuminated at a given time, and the effect will be more in evidence where the sun is higher above the horizon.

Ionization of the various gases comprising the earth's atmosphere requires different amounts of energy, since the ionization potentials of the various gases are different. The ionization potential of a gas depends also upon whether it is in a dissociated state, i.e. in the form of separate atoms, or whether it is in molecular form. No matter how great the flow of radiation, if its energy is less than the ionization potential of a given gas, ionization will not take place. All the energy of the incident radiation will be used in heating the gas, and, consequently, in expanding it.

On the other hand, if the energy of a light quantum falling on the atmosphere is equal to or greater than the ionization potential of the gases in the atmosphere, then ionization will occur irrespective of the intensity of the stream; the light quantum will remove an electron. Ionized layers are formed in the ionosphere, the degree of ionization being determined by the intensity of the radiation.

Presence of several Ionized Layers in the Atmosphere

At the earth's surface oxygen and nitrogen, which, with other gases, make up the earth's atmosphere, are present in a molecular state. The pressure of the air falls with increasing height above the earth's surface. At an altitude of 5.5 kilometres it is approximately half the atmospheric pressure at sea level, i.e. the normal pressure. At an altitude of 50 kilometres, the pressure is one-thousandth of the normal pressure. The atmosphere becomes more and more rarefied, and this means that the mean distance between the separate particles of gas is increasing. At the earth's surface, under normal temperature, particles of gas move through free paths of the order of one hundred-thousandth of a centimetre. At an altitude of 50 kilometres the free path of a particle averages thousandths of a centimetre. The longer the free path, the more difficult it is for separate atoms to combine into molecules.

At altitudes above one hundred kilometres, oxygen proves to be completely in the monatomic state. The transition of nitrogen from the molecular to the monatomic state takes place at a different (higher) altitude.

Researches confirm more and more that the chemical composition of the earth's atmosphere is practically the same throughout its thickness, i.e. that the atmosphere is mixed, but that the states of its component gases (molecular and atomic) at different altitudes vary. The ionization potentials of the gases also vary. This leads to the formation, not of one, but of several layers under the action of solar radiation, and the ionosphere is thus stratified. Hence, solar rays of varying energy produce varying effects, and can have no effect at all on certain ionospheric layers.

Influence of the Earth's Magnetic Field on the Distribution of Ionization

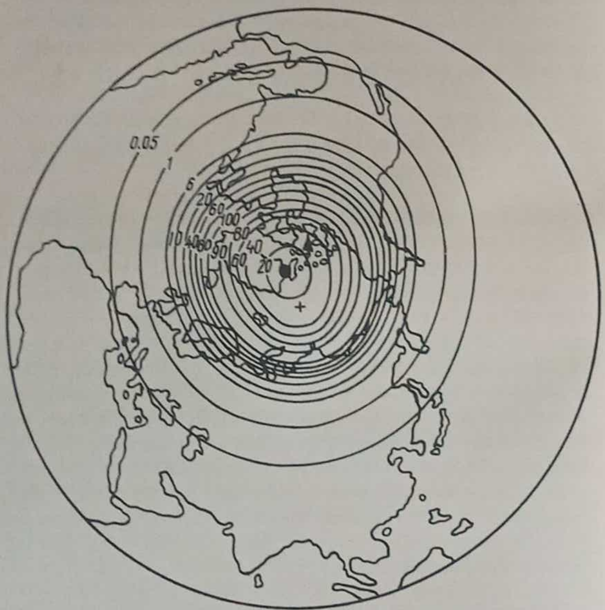
A particle carrying an electric charge, when placed in a magnetic field, will describe a definite path under the influence of the forces of this field. A freely suspended magnetic needle indicates the direction of the force of the earth's magnetic field; the angle of inclination of the direction of this force to the horizon is different at various points of the earth. A magnetic needle, rotating about a vertical axis, indicates the direction of the horizontal component of this force, i.e. the direction of the magnetic meridian. The magnetic and geographical meridians do not coincide, since the magnetic pole does not coincide with the geographical pole. The *magnetic* pole and the *geomagnetic* pole are to be distinguished. At certain places in the earth's crust there are deposits of iron ore, which introduce an additional effect, or distortion, into the general geomagnetic field, as a result of which the position of the earth's magnetic pole differs from that of the geomagnetic pole, i.e. the pole of the general geomagnetic field free from the influence of local disturbances. The influence

of such deposits rapidly weakens with increasing height above the earth's surface, and at the altitude of ionospheric layers it is practically absent. The motion of charged particles at high altitudes, and also the movement of charged particles approaching the earth from the sun, and perhaps from cosmic space, takes place under the influence of the general geomagnetic field, the intensity of which changes regularly and smoothly from the geomagnetic equator to the geomagnetic poles.

The geomagnetic pole in the northern hemisphere of the earth is situated at a point with geographical co-ordinates, longitude 69° W, latitude 78° N.

The distribution of ions and electrons formed under the action of ultra-violet solar radiation, depends on the height of the sun above the horizon. After their production, the particles may move to other regions under the influence of the geomagnetic field. Hence, it turns out that at the same geographical latitude the density of ionization at equal altitudes may be unequal. The geographical distribution of ionization in the ionospheric layer proves to be considerably more complicated than the distribution of solar energy - the solar climate. Thus, the geographical latitude of Yakutsk is 7° higher than that of Moscow, and the geomagnetic latitude is 1° lower than that of Moscow, but the density of ionization in Yakutsk at mid-day proves to be identical with that in Moscow at the same time.

The geomagnetic field substantially influences the direction of movement of charged particles approaching the earth from space. Under the action of the field they are directed towards the poles, and around each magnetic pole there is a circular zone, where charged particles most frequently strike the earth's atmosphere (Fig. 3). This is the zone in which polar aurorae are most frequent, and, as we shall see later, where geomagnetic-ionospheric disturbances are greatest. Charged particles of varying energy (mass, speed and charge) are deflected in different ways by the earth's magnetic field. The lightest are



● geomagnetic pole + geographical pole ▲ magnetic pole

Fig. 3. The zone of the polar aurorae and the zone of arctic absorption.

deflected to a greater extent, and strike the earth's atmosphere closer to the geomagnetic pole. Within the zone of the greatest number of polar aurorae yet another zone is formed of maximum magnetic and ionospheric disturbance close to the geomagnetic pole itself. With increase of geomagnetic latitude (and not geographical) the intensity of corpuscular irradiation of the earth becomes greater, and all phenomena in the ionosphere connected with it are intensified.

RADIATION OF DISTURBED (ACTIVE) REGIONS OF THE SUN, AND IONOSPHERIC DISTURBANCES

General Structure of the Sun

The high temperature of the sun, from approximately 6000° at its surface to millions of degrees in its interior, and its gaseous state, lead to a constant movement of solar matter. This movement is varied, and depends on the depth or level at which it takes place, on the solar latitude, and on whether the region of the sun under consideration is "calm" or "disturbed".

As a reference level, from which we shall measure altitude, we shall take that surface of the sun which we can see as brighly shining and radiating warmth and light; it is called the photosphere. More precisely, the photosphere is a thin layer (about 0.001 of the sun's radius) which is impossible to penetrate with the resources of modern instruments. The photosphere is a layer of convection or vertical intermixing of matter. Streams of solar matter rise up from beneath the photospheric layer and come out to the surface and fall back again to the place from which they rose. The temperatures of ascending and descending streams differ, and so their brightnesses are also different; where the temperature is lower, the brightness is less. When observing the photosphere through a telescope (or on a photograph), we see convective currents in the form of intermittent bright and greyish spots, as though the whole shining surface of the sun were covered by a regular network; this phenomenon is called *granulation*.

The visible brightness of this solar disc is not uniform: in the centre it is greater, but along the edges of the disc a darkening can be observed. This may be explained by the fact that the depth to which a visual ray penetrates in the centre of the disc corresponds to deeper, brighter and hotter layers of the solar surface.

Above the photosphere is the solar atmosphere, consisting of several layers with different physical compositions and with different movements of solar matter. The lower layers of the solar atmosphere are called the chromosphere.

During total solar eclipses the chromosphere is visible as a serrated red border standing out from the edge of the lunar disc. The kinetic energy of photospheric convection is transferred to the layer above – the chromosphere. Every prominence of the chromosphere is a whirlwind, rising above the photosphere. The chromosphere, indeed, consists of such whirlwinds, and is in an unstable turbulent condition. The height of the chromosphere averages about 8000 kilometres, but some prominences rise higher.

During a total eclipse of the sun, the external layers of the solar atmosphere – the solar corona – are visible.

The corona has a radiant fibrous structure. Above the calm surface of the sun, its rays are thin and weak, and distinguishable only on very good photographs. Normally, they mingle together and look like a compact aurora which rapidly weakens the further from the edge of the solar disc.

Researches have shown that for every such coronal ray, there is a corresponding prominence in the chromosphere. One can assume that the energy of turbulent motion in the chromosphere leads to a certain amount of solar matter being thrown off into cosmic space, and the rays of the solar corona are indeed streams of particles moving away from the sun.

As a result of the high temperature on the sun, chemical elements exist in monatomic state, and only in certain discrete regions where the temperature is lower (for example in the nuclei of sun spots, the temperature is about 4700^{o}) are chemical compounds to be found. Atoms of solar matter are in constant random movement; at a temperature of 6000^{o} the speed of this thermal movement reaches many kilometres per second. This results in frequent collisions of atoms, and leads to the atoms being ionized during such collisions, losing one or several of their electrons. Solar matter is largely ionized, and consequently charged. The ionization of solar matter is not identical at all levels of the solar atmosphere; it reaches its greatest value in the distant regions of the solar corona, where atoms may be deprived of a dozen of their electrons, and the free electrons – the 'electron gas' – are an essential component part of it.

The movement of ionized matter brings about the existence of magnetic fields in different regions of the sun, these fields being especially powerful where such movement has a whirlwind or vortex character (in the regions of sunspots). Such magnetic fields have in their turn a directional influence on the movement of ionized solar matter.

The large content of negative hydrogen ions (i.e. hydrogen atoms with electrons attached) in solar matter renders it opaque. Although at the level of the photosphere the total gas density approximately equals the density of the earth's atmosphere at the surface of the earth, rays visible to our eyes cannot penetrate into the depths of the photosphere. Consequently, even in a greatly magnified image, the sun always appears sharply defined.

We have now completed our general survey of the sun's structure and its outer layers as they appear to us under quiet conditions. The radiation of quiet regions of the sun, i.e. its regular radiation – ultra-violet and corpuscular, constantly affects the earth's atmosphere, creating in it charged layers – the ionosphere, and governs all those phenomena in the ionosphere mentioned above. But the sun is rarely quiet. At isolated points of its surface, structural disruptions appear, clouds of gases ascend, whirlwind movements begin, matter from the internal parts of the sun is thrown off into cosmic space, and so on. These regions of the sun are disturbed, or active regions, and the radiation emitted from them is irregular radiation. As this solar radiation strikes the earth's atmosphere, it causes irregular phenomena in in the latter, i.e. disturbances. We are interested in ionospheric disturbances, and especially those which are detrimental to short-wave radio communication.

Active Regions of the Sun

Studies of the sun have shown that various phenomena

FIG. 4. ACTIVE FORMATIONS OF THE SUN

(a) Faculae

Solar photograph, taken on 20 May 1951, 8.42 U.T., showing well-developed faculae (surrounding the sunspots near to the Sun's limb). North is at the top, East to the left.

(Royal Greenwich Observatory at Herstmonceux)

(b) Group of Sunspots

A large group, photographed on 18 May 1951, 8.28 U.T. North is at the top, East on the left.

(Royal Greenwich Observatory at Herstmonceux)

(c) Flare

A brilliant flare can be seen on this specially prepared monochromatic photograph ("H-alpha picture"), obtained on 7 November 1956, 12.10 U.T. North is at the top, East on the left.

(Royal Greenwich Observatory at Herstmonceux)

(d) Prominence—Types

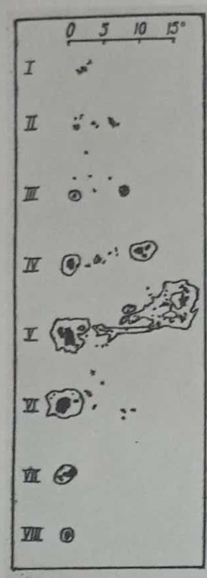
A typical prominence; on its right, near the Sun's limb, one can see the transition of a dark marking, lying above the solar surface, into another prominence. Photographed on 16 April 1957, 12.32 U.T.; North is at the top, East on the left.

(Royal Greenwich Observatory at Herstmonceux)

(e) Prominence—Details

A beautiful large prominence, photographed on 11 September 1956, at 13.49 U.T. A sequence of photographs taken within one hour showed impressively a growth of the loop-structure, which appeared to be one of continuous replacement rather than one of the particular loop expanding. On the scale of this enlargement, 9/16 inch corresponds to ca. 0.5 minutes of arc.

(Photograph: Dr. R. B. Dunn, Sacramento Peak Observatory, New Mexico, U.S.A.)



(f) Classification of the Activity and Lifetimes of Groups

in the active regions of the sun are physically interconnected, being separate phases of a single process of disturbance, which begins, develops, reaches a certain level of development, declines and finally subsides. It has been found that not all solar latitudes are equally subject to disturbances; the zones of greatest disturbance are situated on both sides of the solar equator, extending approximately to latitudes of $\pm 45^{\circ}$; the equator itself is, as it were, a calm belt, subject to little disturbance. In the zones of most disturbance, the active regions are continually being created and destroyed. However, certain solar processes take place in polar regions also.

Let us trace the development of an active region. Somewhere in the depths of the sun below the photospheric level, conditions of equilibrium are upset. What this disturbance is, and the reasons for it, are still unknown. It is clear only that it proceeds with the liberation of atomic or nuclear energy. On the visible surface of the sun above the seat of the disturbance, the uniform granulation of the photosphere is destroyed. Bright spots of irregular shape (faculae) appear. The faculae grow, and the area occupied by them increases. Faculae normally do not fully occupy a solid area, but stretch out in the form of bright fibres or points (Fig. 4a). Their outlines change. In this form the faculae can exist from several days to several months. Physically, these faculae appear as clouds of gases above the photosphere itself; their temperature is a little higher (by about 200°) than the temperature of the photosphere. If, during a total solar eclipse, a facula is situated on the edge of the solar disc, at this point of the solar corona a narrow pencil of rays will be seen. This pencil of straight coronal rays is brighter than the general background, and extends far from the sun. The fields of the faculae give rise to the long straight coronal rays, producing streams of charged particles of solar matter. If the process is weak, the faculae die away and disappear, and the surface of the sun becomes calm once more, whilst the corona regains its former undisturbed structure.

If the process is a powerful one, dark spots (vortices) appear in the field of the facula, at first in the form of tiny dark points (pores), and then their areas increase and become confused. Around each dark point, the nucleus of the spot, a grey border, or penumbra, forms. The spots usually appear in groups; in a large complicated group there are a hundred or so spots. Each spot represents a vortex with its base deep below the photosphere, and its top rising above it. In the centre of this vortex, there is a rising current of solar gases, which are expanding, and whose temperature proves to be lower on the whole than the temperature of the photosphere. The centre of the vortex is seen as the centre or nucleus of the spot. The ascending matter spreads and forms the penumbra of the spot; above this a second vortex develops, moving in the opposite direction. A group of spots is a region of the sun occupied by complex vortex movement (Fig. 4a). The dimensions of separate spots, and of whole groups, vary widely. The length of a large group may exceed the diameter of the earth by a factor of ten, and consequently have a surface area considerably greater than the surface of the whole earth. In a group, two large basic spots stand out, one at the front part of the group, and one in the tail. In the development of a group one can trace a definite regularity, a definite sequence in the changing of its form, and this is reflected in the present accepted classification (Fig. 4e). If the process is especially powerful, the group goes through the complete development, but if it is weak, the group fades before achieving its full possible development. A group can exist several days, and sometimes several months, undergoing continuous changes.

Magnetic fields of great strength are associated with sunspots, and are evidently caused by the movement of ionized solar matter. The nucleus of a spot is a magnetic pole. In groups of spots, which have two basic ones, these spots are the poles of the magnetic field of the group. In a group with one basic spot, the second magnetic pole is often hidden in a nearby region of bright faculae. In certain groups, the intensity of the magnetic field reaches hundreds or thousands of Gauss (up to 4500); (the intensity of the earth's magnetic field is 0.6 Gauss).

The magnetic field of a group of sunspots alters the spatial direction of corpuscular streams, i.e. distorts the coronal rays originating in neighbouring facula fields. If the magnetic field of a group is strong, the corpuscular streams may not leave the sun at all, but return, forming above the group, as it were, closed shells of coronal matter.

So-called eruptions (flares) are associated with regions of sunspot groups, and sometimes even with separate facula fields. An eruption is a complicated phenomenon, beginning with an outburst of ultra-violet radiation. Under the influence of the liberated ultra-violet radiation, the region of the facula at the point of eruption becomes many times brighter than normal, as if the temperature of the facula were $20,000^{\circ}$ (Fig. 4c).

A flare develops rapidly, and may last from several minutes to tens of minutes, and very occasionally up to two or three hours. The ultra-violet radiation ceases, and the brightness of the facula returns to its former strength. In an active group, flares may occur one after the other. At the same time as the outburst of ultra-violet short-wave radiation from the region of the eruption, a powerful corpuscular stream of solar matter is thrown outwards. It moves away from the sun at a speed of the order of 1500 to 2000 kilometres per second. Eruptions in a group of sunspots do not always occur; the more active the group, and the faculae associated with it, the more likely the occurrence of eruptions.

The ejection of solar matter above the surface need not be accompanied by outbursts of ultra-violet radiation; for example, the case of prominences (Figs. 4d and 4e). In structure and composition, the majority of prominences resemble the various projections in the quiet chromosphere, but have considerably larger dimensions. During total solar eclipses, prominences stand out from the dark edge of the moon like 'tongues of fire', and sometimes rise to a height of hundreds of thousands of kilometres above the sun's surface. The speed of matter in prominences may be as much as 500 km/s. The ascending matter falls back to the surface, but part of it may leave the sun. The movement of matter in prominences often indicates the presence of magnetic fields, and the matter seems to move along lines of force from one pole to another. The large quantity of hydrogen and calcium in prominences allows us to observe them on the sun's disc by spectral methods using the lines of these elements. They are represented by dark filaments, stretching sometimes for many tens of thousands of kilometres in the direction of the sun's rotation. In their form, dimension, activity and duration, prominences are very varied. Large dark filaments may exist several months. Active prominences, and short, rapidly moving filaments, sometimes appear and soon disappear again. Active prominences rise also in the region of groups of sunspots, their movement and orientation being in accordance with the magnetic field and movement of the matter in the group.

Above each prominence (filament) in the solar corona, there appear long, wide rays extending far away from the sun. Apparently, part of the matter of the prominence

itself goes towards the formation of this ray, as is indicated by the inner shells over the prominence; the further the shell of coronal matter is from the prominence, the more extended it becomes. Finally, these shells are stretched out to become coronal rays. These rays are also corpuscular streams of solar matter, but in their external form, composition and physical characteristics, they differ from the corpuscular streams which develop above the fields of faculae.

The activity of the sun is apparent also in its radio radiation. Thus, at decimetre - wavelengths one may observe irregular flares, lasting several minutes, or tens of minutes, flares recurring every twenty-seven days (some of these are associated with chromospheric flares), and slowly changing components (these are associated with sunspots). At metre-wavelengths, 'noise storms' are to be observed, which continue from several hours to several days (these too are connected with sunspots).

Radiation of Active Solar Regions and Disturbances in the Ionosphere

General observations. The variety of the physical processes taking place in the active regions of the sun, leads to radiations which differ in wavelength, intensity, energy, and in the charge of the particles emitted. This radiation may be divided into two sorts – wave and corpuscular. The laws governing the propagation of radiation from the sun, and the illumination of the earth, are the same as the laws of radiation when the surface of the sun is undisturbed. Different types of radiation have varying effects on the layers of the ionosphere, and disturb in various ways the normal (quiet) condition of the layers, consequently creating different types of disturbance. The dependence of the state of the ionosphere on the incident solar radiation is important for radio communication, because transmission of short radio-waves depends on the state of the ionosphere. Unfortunately this matter remains, in many respects, unsolved; but one may safely assume that a detailed study of the complex observations obtained during the International Geophysical Year will lead to solutions to the many problems still unexplored.

Every deviation of the ionosphere from its normal state, which is created by regular or undisturbed solar radiation, may be termed a 'disturbance'. In radio communication, however, slight deviations may not be felt, the more so because in the ionosphere itself we observe continual fluctuations of all its parameters. We shall consider the effect of radiation from the disturbed regions of the sun on the ionosphere from the point of view of short-wave radio communication, and we shall note the disturbances which have one or another influence on it.

Ultra-violet disturbances. Disturbances caused by ultra-violet solar radiation take place during daylight. They embrace large areas of the earth's illuminated hemisphere, and are dependent on the height of the sun above the horizon. These disturbances are not accompanied by magnetic disturbances, or if they are, then only by weak ones. The intensification of ultra-violet radiation leads to an increase in ionization of the corresponding ionospheric layer, and to a rise in its critical frequency. However, the increase in the degree of ionization of the layer may be accompanied by a redistribution of ionization within the layer itself, by a division of the layer, or by some other change in the distribution of the density of ionization with altitude. Hence, it may happen that, with an *increase* of ultra-violet radiation, at the maximum of the layer, the density of part of the layer will *decrease*, resulting in a fall in its critical frequency.

During eruptions on the sun, periods of complete absorption of radio-waves are caused by outbursts of ultra-violet radiation of 1-15 Å (the Dellinger-Mögel effect). These outbursts quickly increase, by many times, the ionization in the D layer of the ionosphere. Such an increase of ionization in the D layer leads to the absorption of the whole range of short radio-waves, and radio communication is interrupted. Anomalous absorption ceases when the eruption ceases. Observations have shown that eruptions in the centre of the solar disc are especially effective in this way. On the edge of the disc only violent eruptions are effective. Weak eruptions may give only an increased, but not complete, absorption. When the sun is low above the horizon, and its rays fall obliquely, an ultra-violet outburst also may not give complete absorption. At high altitudes the Dellinger effect is almost absent.

Increased absorption in the lower layers in the daytime differs from the Dellinger effect in its duration, and it is also stronger where the sun is higher. The solar processes which cause this are, as yet, unknown.

The rise in the critical frequency, i.e. the increase in ionization density, of the F_2 layer is of varying duration, including short increases of several hours (flares) and prolonged increases continuing over several days. The prolonged increases resemble in character an increase in the critical frequency during maximum solar activity. This may be observed especially in summer months at middle latitudes. For a period of several days, the general level of the F_2 layer critical frequency rises higher than on neighbouring days. Obviously the radiation of the solar corona plays an important part in the formation of the F_2 layer; it is possible that an increase in its ultra-violet radiation occurs, and produces this phenomenon. The reasons for the short outbursts have not yet been established.

Towards April, in middle latitudes, the ionosphere switches from the typical winter daily behaviour with one maximum, to the summer type of variation with a small minimum about noon (and conversely in autumn). At this time the ionosphere is very sensitive to quantitative changes in the solar radiation. There is reason to suppose that the alternation of summer and winter conditions is caused not only by the increase of the height of the sun at midday, but also by the variations of its ultraviolet radiation, the increase of which also leads to a redistribution of ionization with altitude.

Corpuscular, or geomagnetic-ionospheric, disturbances. Disturbances of the ionosphere caused by corpuscular streams from the sun are more violent than ultraviolet disturbances, and are accompanied by disturbances of the earth's magnetic field. The earth is constantly subject to this corpuscular radiation, both on calm and disturbed days; in the first case, corpuscular streams are emitted from the calm undisturbed surface of the sun, and in the second, they originate in its active regions. The energy of the particles of these two streams is substantially different; they are emitted during different solar processes, and have different physical properties. Hence, it would seem to be possible to classify corpuscular disturbances. However, this has not been achieved, since these disturbances have not yet been fully clarified.

Under the influence of the earth's magnetic field, the charged particles of corpuscular streams concentrate around the geomagnetic poles and form two zones of maximum irradiation. The inner zone surrounds the geomagnetic pole at a distance of the order of 10°; the second zone, the zone of maximum polar aurorae, extends along the

northern edges of the European and Asian continents. Both these zones undoubtedly owe their existence to particles of varying kinetic energy and charge. Within these zones, geomagnetic-ionospheric disturbances are most violent. Outside these zones, disturbances may be observed, but they are not as intense. Geomagnetic-ionospheric disturbances have a sharply defined latitudinal limit. South of Ashkhabad they rarely occur, and, when they do, they do not affect radio communication.

Very severe geomagnetic-ionospheric storms may be observed far beyond the limits of these two zones. They encompass the central and southern latitudes. During these storms, aurorae may be seen in southern regions of the Soviet Union, in southern Europe, and even in North Africa. These storms possibly have a different nature from the more common storms, and may be associated with corpuscular emissions during chromospheric flares or eruptions.

These disturbances give rise to a decrease in the critical frequency of the F_2 layer, and sometimes may even completely destroy the layer. But there are disturbances of the ionosphere, also accompanied by weak magnetic disturbances, which occur with a *rise* in the critical frequency of the F_2 layer. There are fewer of these disturbances than of the former kind, and they are not detrimental to radio communication. They have been little studied, and we shall not dwell on them here.

The more common kind of geomagnetic-ionospheric disturbances, which are accompanied by a reduction of the critical frequency of the F_2 layer, are strongest and most frequent in the zone of maximum polar aurorae. In this zone magnetic and ionospheric disturbances begin practically simultaneously. Further south the ionospheric disturbance lags behind the magnetic disturbance. At the latitude of Moscow, this lag is of several hours. In the southerly latitudes of the Soviet Union these disturbances are rarely observed, and cause almost no interruption in radio communications; quite frequently at these times the critical frequency of the F_2 layer in southern latitudes is increased.

Disturbances in the ionosphere commence with a reduction in the critical frequency of the F_2 layer, and with the development of marked diffusion, and are followed by the appearance of a sporadic E layer, which at high latitudes may completely shield all layers above it. In the zone of greatest corpuscular irradiation, after a little time, complete polar absorption develops at the level of the D layer. This is the most intense phase of a disturbance. Outside this zone complete absorption appears only during very severe disturbances, and at the latitude of Moscow the absorption is very rarely complete. In middle latitudes, the critical frequency of the F_2 layer falls by 50-60% and even more. In daylight hours ionospheric disturbance diminishes somewhat, and absorption, the sporadic E layer, and diffusion decrease. The duration of geomagnetic-ionospheric disturbances is normally rather greater than twenty-four hours, sometimes forty-eight hours, but rarely more.

The Soviet Union may be divided into three zones according to the intensity and character of geomagnetic-ionospheric disturbances occurring in its territory: an arctic zone, or zone of greatest disturbance, whose southern boundary is approximately coincident with a geomagnetic parallel passing slightly north of Leningrad; a central zone, whose southern boundary passes between Rostov-on-Don and Ashkhabad; and a southern zone, which stretches beyond the borders of Soviet territory.

Eleven-Year Cycle of Solar Phenomena

All phenomena on the sun undergo an eleven year cycle, changing from almost complete calm to very high activity. For the quantitative representation of the intensity of solar activity in its various manifestations, a number of different indices are used. In considering the eleven year cycle in various solar phenomena, we shall be concerned with these indices. It is customary to take the number of groups and spots as a measure of the intensity of solar activity, this number being the most easily observable solar phenomenon, and to relate all other phenomena to a maximum or minimum of sunspots. The "relative number of sunspots R", or Wolf's number W, is taken as an index of the sunspot forming activity of the sun.

$$W = R = K(10q + f),$$

where q is the number of groups observed, i.e. of active centres,

f is the total number of spots in all groups under observation,

and K is a coefficient, depending on the instrument and the observer, which serves to make the numerical values of R (or W) obtained in different observatories under various conditions conform to a single scale.

The number R is obtained for each day of observation, and also the number R' (or W') for the central portion of the sun's disc, bounded by 0.5 of its visible radius. The values of R depend critically on the day-today number of groups and number of spots. To represent the general behaviour of the spot-forming activity of the sun, monthly and annual averages of R are calculated, using various methods for averaging and smoothing. In years of maximum solar activity, spots are forming on the sun's surface every day. In years of calm or minimum activity, not a single spot may appear, nor a vortex occur, on the surface of the sun for many days, weeks, or even for several months. But in years of maximum activity, the number of groups of spots may be as high as ten or twelve, and the number of spots in separate groups may exceed one hundred, whilst the values of relative numbers of spots R may reach two hundred or more (Fig. 5).

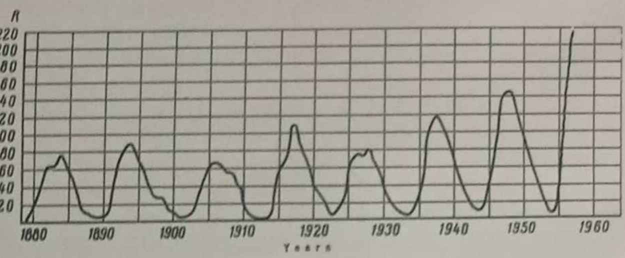


Fig. 5. The eleven-year cycle of solar activity.

As the number of spots increases, their dimensions increase; thus the total area of spots S, or the sum of the areas of spots in the central portion of the disc S', may serve as an index of spot-forming activity.

At the beginning of the eleven-year cycle sunspots appear in the high latitudes of the active zone $\pm$ (30 to 40°). As the maximum of the cycle approaches, the number of spots in central latitudes decreases, and their groups move closer to the equator. At the maximum, spots can be observed chiefly about $\pm$ (16 to 14°). With the

decline of activity after the maximum, the number of spots in central latitudes continues to decrease, and, towards the subsequent minimum, groups occupy an equatorial zone $\pm$ (5 to 10°). The succeeding cycle normally commences before the previous cycle has subsided, and thus groups of two cycles can be observed simultaneously, the old group near the equator, and the new one at high latitudes. During the eleven-year cycle faculae may also be observed. Their behaviour is exactly the same as that of groups of spots, but their active zone is wider. It stretches from the equator to high latitudes of approximately $\pm$ 60°. Moreover, there are 'high latitude' faculae which develop in polar regions. The behaviour of the intensity and frequency of occurrence of flares or eruptions coincides very closely with the behaviour of the relative number of sunspots. In a period of minimum activity, powerful eruptions rarely occur.

The eleven-year cycle of prominences is rather different. Prominences can be divided into low and high latitude types. The former are connected with the zone of spot formation, and the boundaries of their occurrence are $\pm$ 60°. The long dark filaments of these prominences stretch, normally at a slight angle to the equator, along the outside edge of the zone occupied by spots. The average latitude of the location of these prominences is higher than the average latitude of the spots; but in the eleven-year cycle, they change also. The maximum number of prominences lags in time behind the maximum in the curve of the relative number of sunspots. Prominences of the second group are situated in polar regions. Their average latitude during the cycle also alters, in antiphase. In their intensity and other physical characteristics, high latitude prominences are the same as low latitude ones.

The appearance of the solar corona (Fig. 6), and the spatial direction of long coronal rays (corpuscular streams of emitted solar matter), are determined by three factors - by the latitudinal location of the faculae and prominences, which give rise to these rays, by the general magnetic field of the sun, which apparently changes during the cycle, and by the local magnetic fields of groups of sunspots and other formations. During the period of the minimum number of sunspots, long coronal rays from the equator right up to the latitudes $\pm 45^{o}$ deviate from the radial direction, and run parallel to the plane of the solar equator. The polar regions are characterized by the short rays of the undisturbed surface of the sun. With the growth of spot formation i.e, with the appearance of faculae and spots of the new cycle, the corona takes on, as it were, an intermediate aspect at latitudes about $\pm 40^{o}$, and long waves of radial direction appear. At the period of the maximum number of spots, rays from all over the corona point in radial directions, and the general shape of the corona becomes spherical. Then, only those rays which originate near the equator itself are parallel to the equatorial plane (Fig. 7).

The same eleven-year cycle exists in all terrestrial phenomena connected with solar processes. It is clearly demonstrated in the ionosphere. Solar radiation falling on the ionosphere changes during the cycle both in quantity and in composition.

As was mentioned above, ionization of the earth's atmosphere, and the formation of ionospheric layers, take place mainly under the influence of the ionizing ultraviolet solar radiation. In years of maximum solar activity, the general intensity of this radiation proves to be considerably greater (for wavelengths 1-100 Å, by several times) than in years of minimum activity. Hence, the ionization of all layers of the ionosphere is greater in years of maximum solar activity. The daily curve of

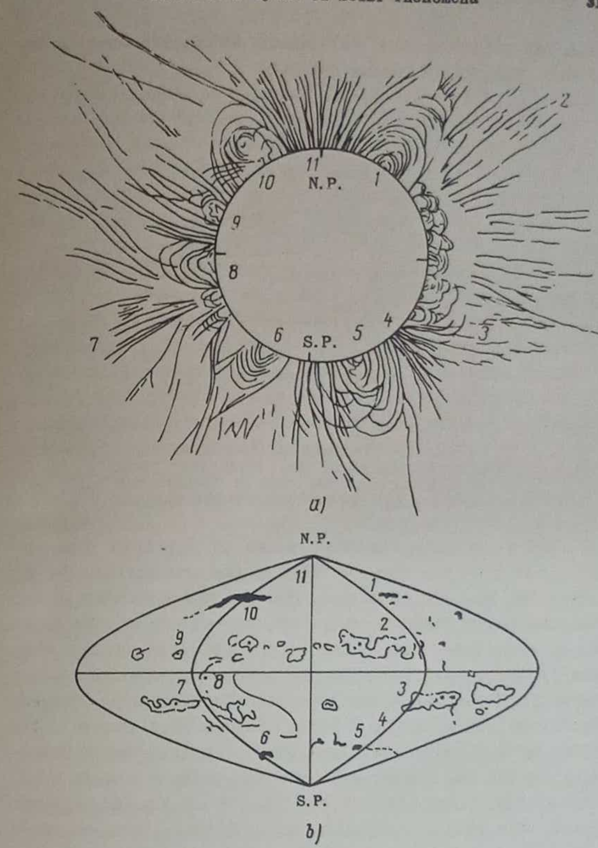


Fig. 6. The relation between features of the solar corona and processes on the surface of the sun.

a) The solar corona, 19th June, 1936.

b) Diagrammatic map of the sun on the same date.

critical frequencies of all layers during the maximum is higher, especially during daytime.

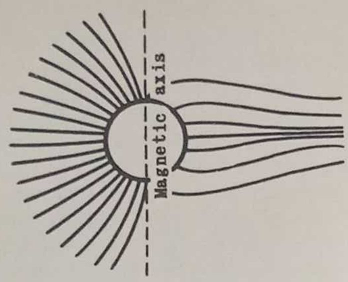


Fig. 7. The form of the corona at different phases of the eleven-year cycle:
On the left: at the time of the maximum
On the right: at the time of the minimum

If we compare the noon values of critical frequencies, or the maximum density of ionization of the F_2 layer, at periods of maximum and minimum solar activity, the changes of ionizing radiation prove to be of the order of five to ten times. But it is difficult to say what really occurs, since, with the change of the ionization density of the layer, its vertical structure also changes. Radiation ionizing the E layer changes by a factor of the order of 1.5 to 2. The behaviour of ultra-violet radiation during the eleven-year cycle is evidently very similar to the behaviour of the number of sunspots, and, hence, the cyclic change in the critical frequencies is close to the behaviour of the relative number of sunspots, R. When making a long-term forecast of radio conditions, we must consider the phase of solar activity and its level in terms of the relative number of sunspots in order to draw curves of the daily behaviour of critical frequencies.

The change in the number and intensity of corpuscular storms during the eleven-year cycle is different from the change in ultra-violet radiation. The number of radio storms caused by powerful and comparatively wide corpuscular streams from eruptions is at its maximum when there is a maximum number of sunspots. But disturbances caused by narrow corpuscular streams are conditioned by the earth's entering a corpuscular stream. The probability of such an entry is greater when the number of these streams is greater, i.e. when there are more solar processes occurring which give rise to them, and when the spatial direction of these streams is closer to the orbital plane of the earth. Taking into consideration both these factors, we get a certain delay of the maximum of these disturbances compared with the maximum in R.

At the period of minimum solar activity the majority of disturbances are caused by the straight corpuscular streams from faculae. Faculae can exist for several rotations of the sun (several months), and this brings about an easily observed, and well defined, 27-day repetition of disturbances during minimum solar activity. As regards severe ionospheric storms, caused by streams from eruptions, they seldom occur during the minimum, and they do not mask the 27-day recurrence tendency.

Corpuscular ionospheric disturbances are accompanied by magnetic disturbances. A time plot of these disturbances gives some idea of the behaviour of all types of corpuscular ionospheric disturbances in the eleven-year cycle.

State of the Ionosphere and Conditions of Short-Wave Radio Communication

Under the influence of solar radiation, the ionosphere may be in a calm or disturbed state. In the majority of cases, with a knowledge of the state of the ionosphere, one may select those operating frequencies, which under given conditions will ensure short-wave radio communication. Identical ionospheric conditions may occur under the influence of various solar factors. For example, strong, or even complete, absorption of the whole of the short-wave range in the lower layers of the ionosphere may be caused by a flare of ultra-violet radiation on the sun. But it may occur also during periods of geomagnetic-ionospheric disturbance. In both cases, operating frequencies are affected in the same way, and it is sometimes necessary temporarily to close down radio communications. The consideration of this second problem is not within the range of the present lecture, and we shall touch on these matters only briefly at this point. Ionospheric conditions from the point of view of radio communications are characterized by several parameters, which determine the ranges of operating frequencies for a given radio path, and also the quality of communication at frequencies in this range. If, at any time, radio signals on certain frequencies begin to fade, then the changes in the operating frequencies which are necessary to maintain radio communication may be deduced from the prevailing and expected ionospheric conditions.

Let us consider the basic characteristics of the ionosphere.

1. The critical frequency of the F_2 layer is the highest frequency reflected from the ionosphere over short distances, and is the quantity necessary for estimating the maximum usable frequency over long distance radio circuits.

2. The height and structure of the reflecting F_2 layer determine the maximum usable frequency (MUF) for a given radio circuit, i.e. when the waves are incident obliquely on the reflecting F_2 layer. For the same critical frequency, but for different heights of the layer, or different vertical ionization distributions, the MUF will be different.

$$\text{MUF } (3000) = f_{cr} \cdot M\ (3000),$$

where $M(3000)$ is a coefficient, by which f_{cr} must be multiplied for the case of oblique incidence, and which is determined specifically for the distance 3000 km. Other estimates are made for other distances.

During geomagnetic-ionospheric disturbances which are accompanied by a reduction of the critical frequency of the F_2 layer, the values of MUF are lowered, and the range of operating frequencies is then more restricted.

In summer during the daytime, it may turn out that the MUF for the F_2 layer is lower than the MUF for the E layer, as a result of the large value of the M coefficient of the latter, and, in consequence, the upper limit of the range of operating frequencies is determined by the E layer. During periods when the critical frequency of the F_2 layer falls, the upper limit of the range of operating frequencies may again be determined by the MUF for the E layer, which remains undisturbed.

3. The limiting frequency for reflection, and the character of the sporadic E layer. Often, when there is a sporadic E layer with a high limiting frequency for reflection, radio communication may be effected at frequencies appreciably higher than the MUF of the F_2 layer;

then the sporadic E layer assists communication. However, the sporadic E layer may be semi-transparent, in which case part of the energy of the waves will be reflected from it, while part will penetrate and be reflected by the F layer; thus the radio path is complicated, same of the energy is scattered, and reception will be weakened.

4. Absorption in the lower layers of the ionosphere. The lower limit of possible operating frequencies is determined by the state of the lower layers of the ionosphere, which absorb radio waves – chiefly the D layer. The lower limit depends on the power of the transmitter, and on the length of the radio path. With increase of absorbtion, the lower limit of possible working frequencies is increased, and the range of frequencies is reduced from its lower end. Ionospheric absorption is detrimental to good radio communication; and, depending on whether ultra-violet radiation from the sun, or corpuscular streams, cause the absorption, it spreads over the globe, and becomes greater towards the sub-solar point, or towards the zone of maximum magnetic disturbance.

5. The diffuseness of the F_2 layer points to a cloudy structure with perhaps more than one layer. The diffuseness is apparent during geomagnetic-ionospheric disturbances in middle and high latitudes, and also, typically, during calm periods on winter nights. In southern latitudes, the layer sometimes becomes diffuse during day-time hours. A radio wave, incident on this diffuse layer, is partially scattered, its energy is dissipated, and radio reception is weakened. To improve radio communication, it is advantageous to change to as low a frequency as possible, in order that the radio wave should not penetrate the layer deeply.

Conclusion

From what has been said, it is obvious that radio communication conditions are determined by the state of the ionosphere. Hence, in order to choose operating frequencies correctly, or to know the reason for a break in reception, it is necessary to know the state of the ionosphere. The ionospheric situation for radio communication is described completely by the critical frequency of the F_2 layer, by its M(3000)-coefficient for oblique incidence, by the character and limiting frequency of the sporadic E layer, by the absorption in the lower layers of the ionosphere, and by the diffuseness of the F_2 layer. These data enable one to choose the best carrier-frequency for a given radio circuit, or to discover the reasons for a failure in reception.

In order to know what the prospects are for satisfactory radio-wave propagation at a given future time, it is necessary to predict ionospheric conditions; and these are dictated by the solar radiation. Thus, it is necessary to consider the processes currently taking place on the sun and those expected, to establish what kinds of radiation are associated with them, and to use the appropriate laws of the earth's irradiation. It is then possible to say, with a greater or lesser degree of certainty, the kind of ionospheric conditions to be expected in different regions of the earth at a given time, and to forecast, on this basis, the propagation of radio waves for the radio paths of interest.

THE SUN SERVICE

A systematic observation "Sun Service", of the state and activity of the sun is being carried out in the U.S.S.R. and on an international scale.

The programme of "Sun Service" includes:

1. Daily derivation of indices of solar activity for the number and area of spots, for the area and intensity of faculae and flocculi, for the number of prominences and dark filaments (spicules) and for their dimensions, and for the intensity of the inner parts of the solar corona. (Modern instruments make it possible to observe the brightest parts of the corona, which are close to the sun, without an eclipse).

2. The observation of brief active phenomena (flares and eruptions) as far as possible for twenty-four hours every day.

3. The construction of a diagrammatic map of the sun for each revolution.

On the basis of such observations, it is possible to make short and long-range forecasts of solar activity and its influence on radio communications.

A considerable number of astronomical observatories in the U.S.S.R. are taking part in "Sun Service". During

the period of the International Geophysical Year and of the International Geophysical Co-operation 1959, the programme of solar observations is being widened, and observatories are being provided with new equipment. The hours for observing brief phenomena are shared among the observatories.