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WORLDWIDE news about the recent activity on the sun provoked considerable interest in these phenomena and their effects on the earth. Scientists in Tokyo, at Kodaikanal, India, in the United States, in Great Britain, to mention only a few places, reported their observations of the events of February twenty-third. Since the Manila Observatory *ionospheric station at* Baguio was favorably located for observing the effects in the upper atmosphere, a few brief comments about our records may help to explain what was happening.

On February twenty-third, 1956, an outbreak on the sun occurred. Such an outburst of white light associated with dark spots on the sun is known as a solar flare. The time of occurrence of this particular flare, from an astronomical and geophysical viewpoint, was extremely advantageous to observers in the Philippines. The Baguio records show that the flare disturbed the ionosphere shortly after eleven thirty and before eleven forty five in the morning. It is well to recall that this time corresponds to about three thirty five in the morning or before sunrise in England and to about ten thirty five of the previous night or after sunset on the East coast of the United States. Observers in these and similar regions were on the dark side of the earth. Whatever such observers noticed would indicate the extent of the flare effects as they curved around the earth to those locations. Direct observations were obstructed by the earth itself. The Philippines was scientifically better located. Our part of the earth was nearly directly under the sun for the flare came on nearly at local noon when the sun crosses our meridian.

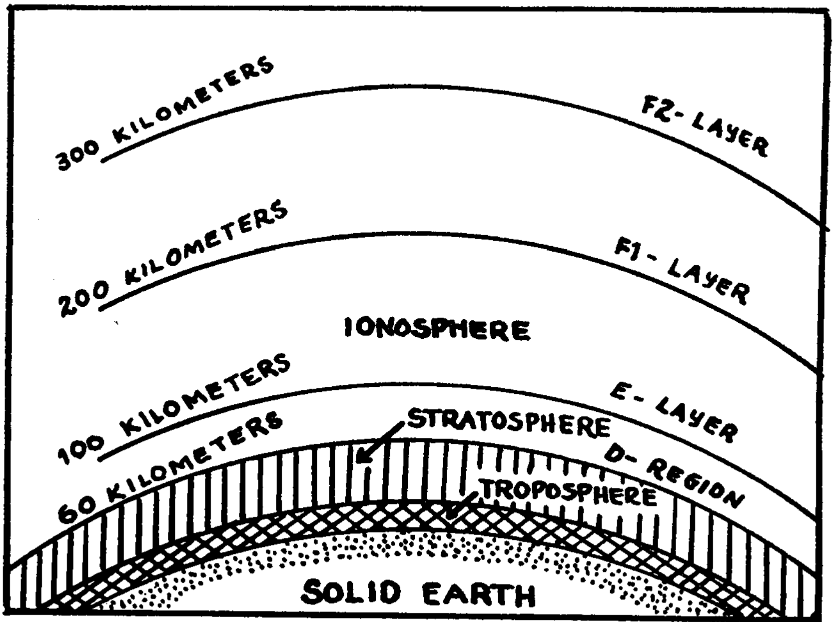
THE IONOSPHERE

To appreciate the ionospheric effects of the February twenty-third solar flare, a brief summary of the usual structure of the ionosphere may prove helpful.[1] In the earth's upper atmosphere beginning at about sixty kilometers (thirty-six miles) and going upward there exist various regions and layers of ionized or charged particles. (Figure 1) Electrons and ions formed from the elements of the atmosphere such as oxygen and nitrogen atoms and molecules constitute these electrified particles. Appropriate names have been given to the layers or regions according to their distinguishing characteristics. The D-region is located at approximately sixty kilometers; the E-region centers around one hundred kilometers and the F1- and F2-regions are found in the daylight hours at heights of about 200 and 300 kilometers respectively.

The agency which is chiefly responsible for the formation of these layers is the ultra-violet light from the sun. This radiation is not visible as are the radiations in the spectral colors of the rainbow. An eclipse of the sun such as the one we had on June 20th, 1955 leaves no doubt about the solar control of the density of ionization in our atmosphere. The Baguio records of that eclipse are a splendid example.[2] Besides the ultra-violet light some other agencies, for example, meteors and cosmic rays, contribute to the ionization or to the number of electrically charged particles in a cubic centimeter of the upper atmosphere.

ITS USE

Do these ionized layers at such great heights above the solid earth have any importance or use for our modern world? A singularly important use is made of the ionosphere in long distance radio communication. Radio waves similar to light waves tend to travel in straight lines. Since our earth is prac-



NORMAL DAYTIME ATMOSPHERE Fig.1

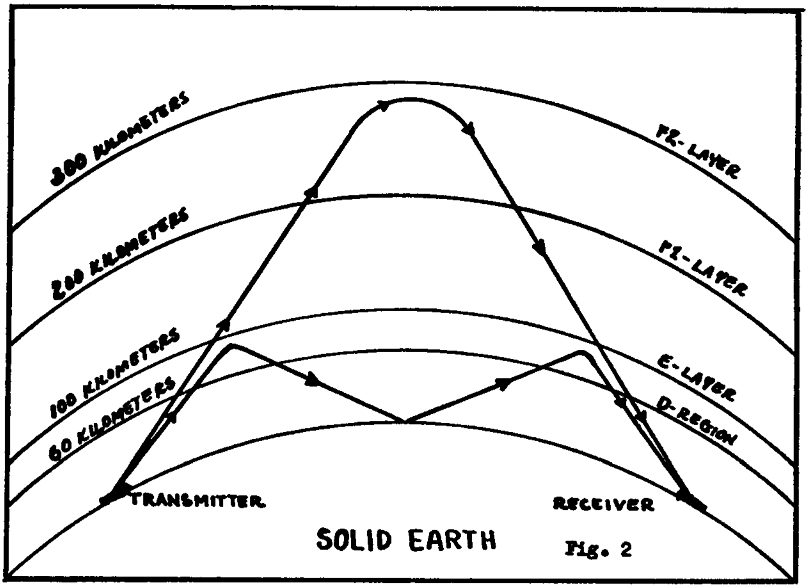


Fig. 2

NORMAL TRANSMISSION
BETWEEN NEARBY STATIONS
SINGLE HOP BY F2-LAYER — DOUBLE HOP BY E-LAYER

tically a sphere, to communicate by radio from one distant point to another it is necessary that radio waves in some way bend around the earth. They cannot be transmitted through the solid earth but they can travel through the earth's atmosphere. In so travelling outward, they soon encounter the ionized layers. (Figure 2) The latter behave somewhat like a mirror for the waves and reflect them back to the earth. Reflections from the ionosphere to earth, and so back and forth many times, take place in the course of a transmission between, say, Moscow and Manila. The usual layers of the ionosphere which serve as the mirror are the E-, the F1- and the F2-layers. The F2-layer being more dense in ionization usually dominates the transmission. It is further clear from the figure that high-frequency radio transmission may be by different modes: either by single or multiple hop. As long as the concentration of ions in these layers is dense enough radio-frequency waves which reach these layers are bent back to the earth and transmission of information is possible.

Apart from relatively infrequent disturbed conditions, the ionosphere shows definite patterns of regularity depending on the hour of the day, the season of the year, the geographical position of the earth and the phase of the sunspot cycle. By neglecting the usual irregularities, it is possible to predict with high accuracy the condition of the ionosphere several months in advance.

IONOSPHERIC DISTURBANCES

The major departures from regularity are of two kinds: a) ionospheric storms and b) sudden ionospheric disturbances. In the tropics everyone is familiar with a meteorological storm such as a typhoon. In Philippine latitudes these are now known by female names, for example, Ruby which visited us on November 8, 1954 and Kate on September 23, 1955. That a typhoon shows marked departure from "quiet" weather conditions is evident to all who have experienced a typhoon. A storm in the ionosphere is so-called, not because it is accompanied by rain or clouds or winds apparent to all, but because there is erratic variance from the average conditions which are normally found in the upper atmosphere. When Ruby and Kate were ushering in destruction the ionosphere was quiet and peaceful. On the other hand, the sun can be shining serenely through a cloudless sky when the ionosphere is having stormy weather. Yet a typhoon and an ionospheric storm can be designated by the common term "storm" because both indicate widely erratic disturbances away from normal conditions. Thus an ionospheric storm represents a marked departure from the average conditions in such characteristics as layer heights, electron and ion densities, and regularity of stratification. These abnormal conditions may last for a period of several days to the detriment of radio communication.

It is the second kind of disturbance which is of present interest to us. It is called by various names: a sudden ionospheric disturbance (abbreviated to SID), the Dellinger effect[3] or a sudden radio fade-out. A SID comes on very rapidly but does not last as long as the usual ionospheric storm. Still it is usually more severe and prevents, at least in its intense early stages, any high-frequency radio use of the ionosphere.

A description of the records taken at the Jesuit Observatory at Mirador will indicate the various phases of a SID. Most of the indicated features are typical but a few are peculiar to the recent fade-out. It is significant to recall that this year represents the first time a SID has been clearly reported at Baguio throughout the four years of our records. One reason for the lack of previous disturbances is our location near the geomagnetic equator. In the Philippines, the geomagnetic equator passes through Leyte and so is north of the geographic equator. There is a technique in long distance radio communication which will bring out the importance of this location. Ionospheric disturbances are much more frequent in the latitudes more remote from the equator. Radio communication between North America and Europe can be ruined by a disturbance over the usual northern great circle path. There is an expedient resorted to under these circumstances. By directive antennas radio traffic is channeled through the tropical regions and this remains quite dependable when mild disturbances trouble the ionosphere over the northern latitudes. However, for about an hour last February twenty-third, even this expedient through our latitudes would have been of no avail. A disturbance of such intensity occurred that radio frequency radiation could not penetrate to the reflecting layers of the ionosphere.

THE BAGUIO RECORDS

Records are being continuously taken at the Baguio ionosphere station by means of a special type of recorder called an ionosonde. The ionosonde operates on a principle similar to that of radar. A transmitter sends vertically upward pulsed energy. The pulses are produced in this fashion. The transmitter is on for a few millionths of a second and then is off until the next pulse starts. There are sixty of these pulses in a second. Besides, in the short interval of fifteen seconds, the transmitter changes its frequency continuously from one to twenty-five megacycles a second. This energy is partially reflected from the encountered layers of the ionosphere. The reflections by analogy with sound waves are referred to as echoes. These echoes, really the returned high-frequency radio radiation, are detected by a special type of radio receiver which presents them on an oscilloscope for visual and photographic observation. One observes on the oscilloscope a graph of the radio frequencies plotted against the heights. In observing the various graphs or patterns, one can examine the echoes from the E-, F1-, and F2-layers for a variety of characteristics with numerical values.

What do the Manila Observatory records show for that one particular day? Up to eleven thirty in the morning of that day, the ionospheric characteristics followed the normal trend in values. At eleven thirty, the echo from the F2-layer showed an ionization density and a virtual height for that layer very close to the monthly average values for these factors. The F1-layer and the normal E-layer had the expected values for these same characteristics at this time of day. After fifteen minutes, that is, at eleven forty-five, the next ionogram or photographic record was taken. *No echoes from any layer of the ionosphere were in evidence.* This means that radio frequency waves were not being reflected from the ionosphere. Radio communications would be in a state of complete fade-out under these conditions. (It is understood that the foregoing remark applies to those frequencies which depend on the ionosphere for their propagation.)

Because a SID comes on without warning—though there are indications which create some expectancy—no records were taken within the fifteen minute interval following eleven thirty. The time of the onset of the fade-out can only be estimated as at about eleven thirty-five or eleven forty. The full brunt of the SID was being felt at eleven forty-five. The records at twelve and twelve-one o'clock also lack any indication of an echo.

At twelve fifteen, a faint echo began to appear. Only the higher frequencies were being reflected from the F2-region. The 12:30 and 12:45 ionograms show a better echo beginning at lower frequencies than those of the preceding one and going to a slightly higher frequency. The ionosphere was recovering slowly after the rapid onset of the disturbance. At one o'clock the F1-layer put in its appearance and there are indications but no certainty that the critical frequency was higher that usual. At this time no echoes were received below six megacycles a second in frequency.

Beginning at one fifteen and lasting for about two more hours, our records were taken every five minutes in order to observe the restoration of the ionosphere to normalcy. When the critical frequency of the F2-layer clearly appeared, it showed that the density of the ionization in the F2-region was very high. From one twenty on the number of electrons and ions in a cubic centimeter of the atmosphere at this height was greatly in excess of the number found at the same time of the day during the previous days of this month. Thus, at three o'clock on the disturbed day, the ionization density of the F2-layer was twenty-three per cent higher than it was at the same time on the twenty-second; twenty-eight per cent higher than on the twenty-fifth, and sixty per cent higher than the median value of the month. The virtual heights of the F2-layer on the disturbed day were not clear but indications on the records would suggest virtual heights in the vicinity of three hundred and ninety kilometers or four hundred kilometers. This value is about eighty or ninety kilometers greater than the median value of this characteristic for the month.

The F1-layer during the SID was not clearly separated from the F2-layer. Hence, no positive, certain affirmation can be made. However, indications of very high values for the density of ionization in this layer are found in the records. It was not until two forty when the E-region presented an echo and this was of the sporadic type. At three fifteen, the normal E-layer began to appear. This would mark the end of the disturbance. It is interesting to note that the sporadic E-layer from three five until three fifteen showed the appearances of a spread echo indicative of the turbulence in this region.

By four thirty, the ionosphere was well restored to its normal conditions though the dense ionization persisted. The critical frequencies were higher than the average. From seven until eleven in the night a turbulent state existed in the F-region. This cleared up around midnight but became pronounced again from about midnight until seven fifteen on the following morning. This spread echo turbulence was unusual for the month and shows some connection with the SID.

It is interesting to note that the highest densities of ionization for the entire month occurred just about seventy-two hours or three days after this big disturbance.

To summarize the above abbreviated description of the events in the ionosphere during the SID, we may point out the following. The SID started abruptly at about eleven thirty-five leaving the ionosphere violently disturbed. The clearing was gradual until three fifteen in the afternoon. Where echoes appeared, the density of ionization was unusually high and even the virtual heights seemed higher than the average. It was not until three fifteen that the lower end of the frequency range was reflected from the usual layers. During the night, pronounced turbulence was observed. The effect appearing seventy-two hours after the SID seemed to have some relation to it.

SOLAR FLARES

Having looked at the effects in the ionosphere we can now consider the agency which was responsible for them. The cause of SID's is fairly well understood. In all cases where adequate solar data are available, a solar flare has been observed to take place simultaneously with the onset of the SID. SID's are the only events in the ionosphere which are known to have a correspondence with particular events on the sun.

The very notable changes in the ionospheric characteristics for this year 1956 at Baguio do show correspondence with spot activity on the sun but this relationship is statistical rather than singular. A word of explanation may clarify the difference in the two kinds of relationships. When a radio fade-out of the SID type comes, a particular flare on the sun is the operative agency. The flare is observed to begin and the SID starts at practically the same time. A particular definite flare is associated with a single SID. In the statistical relationship, one singular event in the ionosphere is not so related to a solar phenomenon. The density of ionization in the F2-layer for February 1956 exceeds vastly and remarkably the ionization for the same month in each year: 1953, 1954, 1955. Similiarly, sunspot activity for February 1956 vastly exceeds that for February of the same three years. But these are average values over a period of time, namely throughout the month. If a very large increase in sunspot number is reported on a particular day, the ionosphere need not increase its ionization density simultaneously, but rather, over an interval of time, the increase will be observed. Average characteristics of both phenomena show the correspondence but not necessarily single events.

A solar flare then is responsible for a SID. As it affects the ionosphere in a SID, a flare is a burst of bright light from the chromosphere arising out of a sunspot or a group of sunspots. Hence, it is to be expected that more flares will be detected when sunspots are more numerous. Flares are seldom observed and examined to advantage in white light. That is why elaborate instruments which separate out or filter out various components or colors of the light are used to study them directly. When a spectroscope is available, one of the best colors for observing flares is the color technically referred to as the alpha line of hydrogen.

Why is a flare referred to as a burst of *light* rather than as an explosion or an eruption of *particles* from the sun? From the simultaneity of the observation of the flare and the effect of the flare in the ionosphere, the solar emanation must travel with the speed of light. This is the greatest speed with which a signal can be transmitted in the physical world. The bursts of radiation are not corpuscular, in the sense of being made up of streams of electrons or atoms, say, of hydrogen or helium. Such streams, it seems, could not reach the earth with the above mentioned speed. The sun is about ninety-three million miles away and so the light from the sun travels about eight minutes before reaching our outer atmosphere. The brighter flares send forth, besides the light which can be detected by the eye, great amounts of light of shorter wave length as ultra-violet light and X-rays. As soon as a flare is detected on the earth either visually or photographically, effects in the ionosphere may be noticed. The arrival of the agency producing the changed ionization and the arrival of the light by which the flare is detected are simultaneous.

The study of flares shows that they rise rapidly to peak intensity, remain for a brief period at the peak, and then return to the pre-flare brightness. During the highest intensity of brightness, solar emanation or radiant light flashes into our upper atmosphere at a rapid rate. This flash of radiation explains why the radio black-out is so sudden. Unusual amounts of radiation pour into the ionosphere. Here it is absorbed by the atoms and molecules of the gases in the atmosphere. This results in the dissolution of the atoms and molecules by the separation of one or more electrons from the parent atom or molecule. This separation of the electrically charged units establishes a densely electrified condition or a state of high ionization. The ionized state comes quickly, somewhat like the lighting of a flourescent lamp when proper striking voltage is applied.

THE USUAL SID

During the past twenty-five years, the solar-SID relationship has been widely studied. Many cases have been examined. The conclusion is now regularly given that in a SID only the D-region of the ionosphere is affected. The solar radiation is so penetrating and of such intensity that it passes through the upper layers of the ionosphere without absorption there. The upper layers are not further ionized in the presence of the activity which is responsible for the SID. The peculiar solar radiation descends to the D-region producing there the aforementioned dense cloud of ionization.

While our main concern in this paper is with the SID of February twenty-third, it will help for an understanding of that exceptional event to compare it with another one which followed shortly after. On March 10, 1956, sixteen days later, (the proximity is significant from the solar viewpoint) another solar flare produced a SID. The time of day scientifically for Baguio was again excellent. According to our records, at about 12:45, just after noon, the radio blackout began. Four of our ionograms taken at one P.M., at one-one, at one-fifteen, and at one-twenty show that the D-region was made so absorbing that none of our signals could penetrate to the upper regions. After nearly forty minutes, that is, at about one twenty-five, the ionic density of the D-region began to lessen. Faint traces of the higher F2-region began to appear on our ionograms. For the next hour and a half approximately, the D-region remained partially disturbed, clearing with the passage of time. Without making a detailed report on the analysis of this SID, it may be said that it was similar to those that are usually reported. All of the enhancement of the ionization was found in the D-region. The upper layers were not augmented by the profusion of solar radiation through them. In this respect, the March tenth event is entirely typical.

Apart from the chemical composition of the atmosphere below the E-region and into the D-region, the production of the ionization is usually attributed to the greater concentration of particles there. In the gaseous atmosphere, the atomic and molecular particles (most of these are not ions) move about because of their kinetic energy. At the height of the F-region these particles can move great distances without colliding with other particles. But in the D-region this mean free path, i.e., the average distance without collision, is much reduced and collisions are proportionately increased. This comes about because there are so many more moving particles, in a given volume, at this D-level than there are at the F2-level. For every particle in a cubic centimeter at the F-region there are

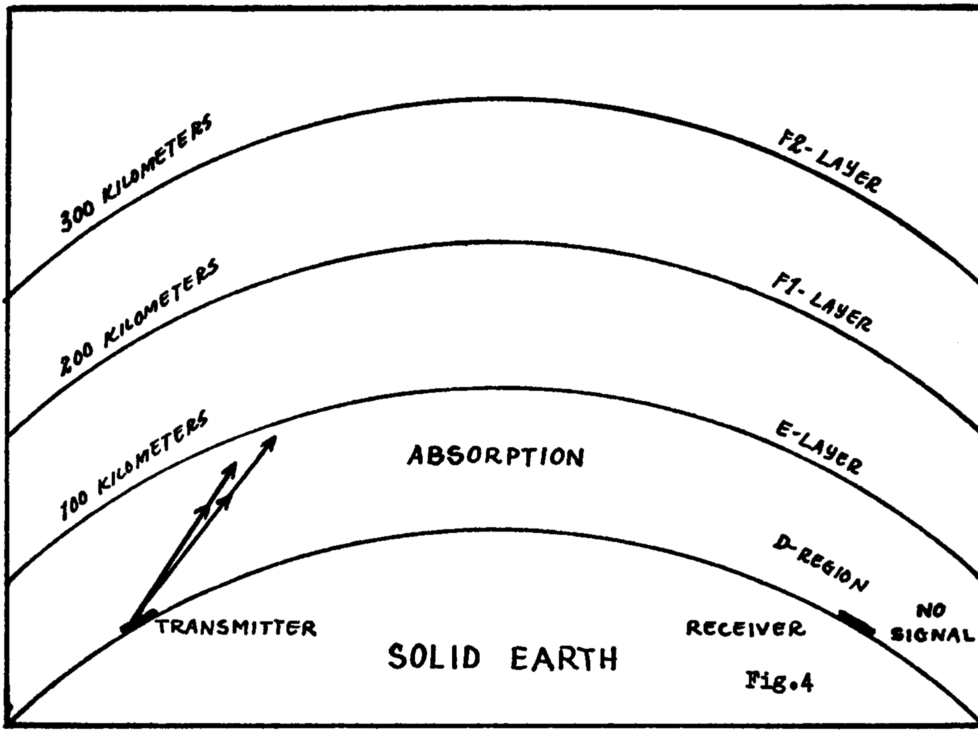
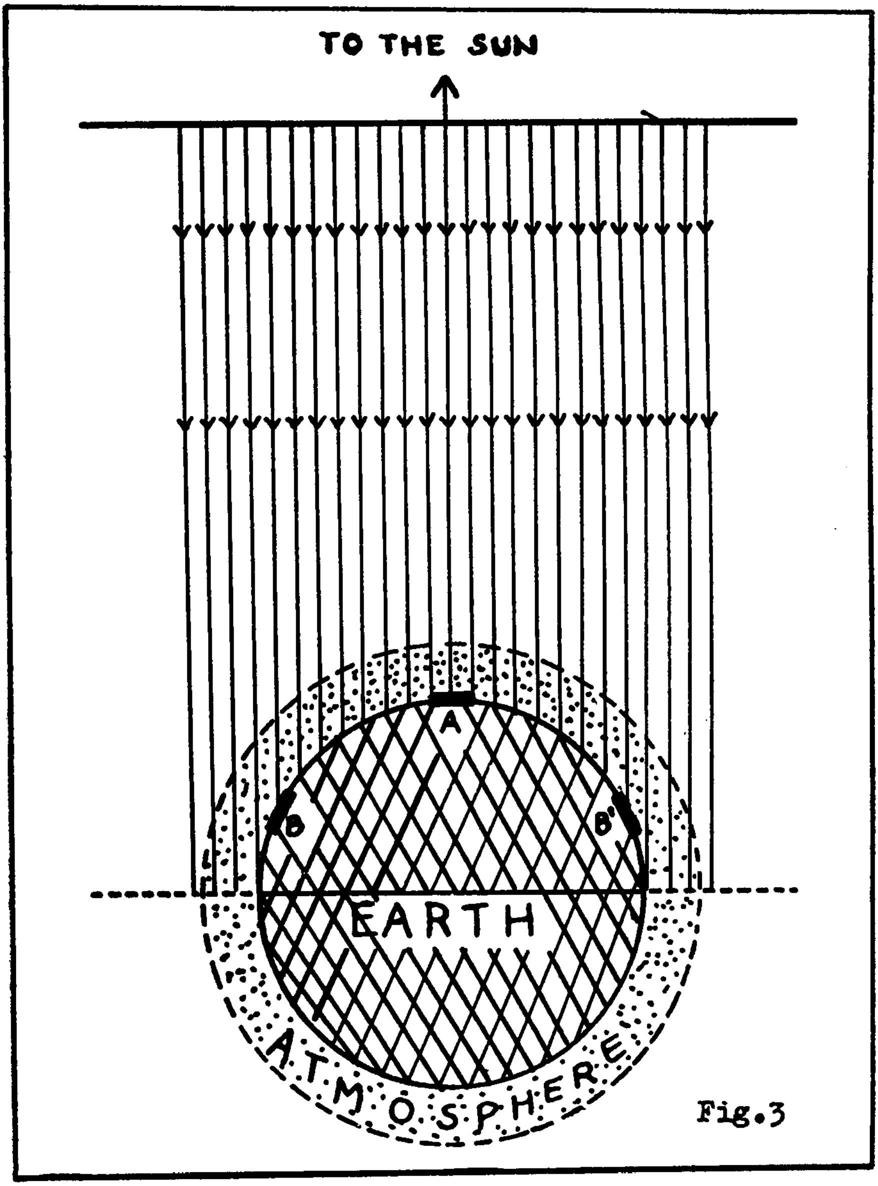


Fig.4

DISTURBANCE IN IONOSPHERE
ENERGY ABSORBED BEFORE
IT CAN BE REFLECTED



Greater effect of flare in vertical direction.

more than a million particles in the same volume at the D-region.

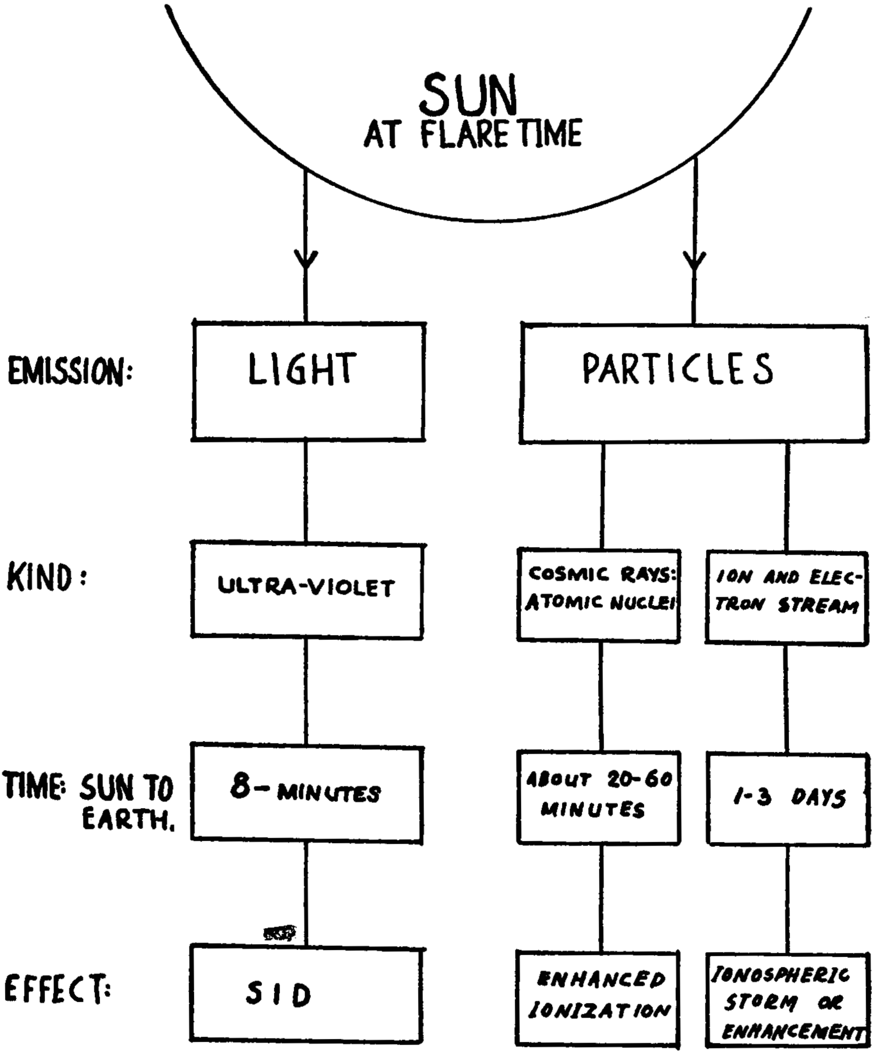
From the flare, a concentrated cloud of electrical charges at the D-layer level is produced over the entire sunlit hemisphere of the earth but the effect is more pronounced in a vertical or nearly vertical direction. See Figure 3. At noontime a point on the earth is vertically under the sun but before sunset and after sunrise, the angle is quite oblique and approaches the horizontal. The intensity of light to such a latter place is much diminished. This is due not only to the much longer path through the atmosphere but especially to the obliqueness at which the radiant light strikes the surface. Let us compare two extreme points on the earth by assigning position and local time to them. *Point A* is near the earth's equator and the time is local noon. For this point, the sun is almost overhead. *Point B* is in the polar regions and the local time is near sunset. From the above considerations, it is clear that point B will receive some radiation from the sun but the amount will be vastly less than that received at point A. It is to be expected then that a SID-producing flare will pour much more radiation into the D-region above point A then into the same region above point B. This qualitative description may be an oversimplification of the case. Let it suffice to illustrate the importance of position and local time.

We have been following the radiation as it comes from the sun and penetrates through the upper spaces of the atmosphere and finally is absorbed in the D-region. Let us now start again from the solid earth and try to carry on long distance radio communication. After the commencement of the SID communications cease. What is the reason for this blackout? It is found in the peculiarity of the D-region. If the higher layers of the ionosphere have their ionization enhanced their ability to reflect radio-frequency waves is similarly augmented. But the D-region is not normally a reflecting layer for radio waves but an absorber of the energy. As the radio waves leave the surface of the earth their first encounter with the ionosphere is at the D-region. Here in a disturbance they are blocked or absorbed. See Figure 4. They do not penetrate to the E- and F-regions and so the ionosphere cannot behave as a mirror for those waves. Radio men in these straits will report fadeouts since their signals do not reach the remote receiver sites. However, the SID condition does not last long. As the D-region is a good absorber because of the density of particles, so for the same reason the ions soon lose their charged condition. The positive and negative ions more readily collide with one another. When an electron collides with a positive ion, the negative and positive charges attract one another. No longer are there two ions, one positive and the other negative, but now there is one neutral particle. The frequency of collision is very high because there are many moving particles in a small space. The average distance between particles is minute. As the ionized condition starts to disappear by recombination of the ions, the radio waves can penetrate and the upper layers of the ionosphere can be reached. They then gradually but not suddenly return to their normal way of acting. What happens is expected—the return of echoes after a SID starts with the higher frequencies and gradually works down to the lower ones.

Insistence has been made on the fact that a flare is a bright light rather than a gaseous stream. This is not to deny that corpuscular emission may take place along with the solar phenomenon known as a flare. In fact, the strong effects noticed in the ionosphere over Baguio about seventy-two hours after the flare would indicate that particles travelling with a speed of about 550 kilometers a second were emitted from the sun. (Figure 5)

AN EXPLANATION

A careful reading of the foregoing account of the changes observed on February twenty-third will show that we have not offered any explanation for some of them. Our Baguio records definitely show unprecedented changes in the upper layers of the ionosphere. These are not explained by the ordinary and usual occurrences of a SID. In fact, they go counter to what is usually expected. Unfortunately at this time of writing, we have not seen any data from other ionospheric stations which may be able to confirm our results. But our records are so



AN INTENSE FLARE AND THE IONOSPHERE

Fig. 5

clear and so incontrovertible that some explanation must be given. We venture a tentative explanation.

The solar flare of February 23, 1956 was unusual in many respects. The effect that was most noticed in the hemisphere on the dark side of the earth was the large increase of cosmic-ray intensity.[4] According to the report, this was the largest increase in cosmic-ray intensity yet recorded at Cheltenham, U.S.A. This cosmic-ray activity was world wide. For reasons previously given, the increase in the intensity of the cosmic rays associated with the flare might be expected to be greater more directly under the sun. While the usual ionizing agency during a SID is ultra-violet light, this type of radiation in itself would not explain the augmented ionization in the upper regions. In the ordinary SID, ultra-violet light is abundant but the ionization in the upper reflecting layers of the ionosphere is not enhanced. Some other agency is needed to explain this. The reports of the cosmic ray activity place the start of that activity within a half hour of the detection of the flare. This is a tribute to the energy of the particles which make up the primary cosmic rays from the sun. This energy still dwarfs any coming from the great man-made nuclear devices. The cosmic ray particles then leave the sun with speeds of the order of one third the speed of light. Possessing this kinetic energy, they would in their encounter with the gaseous matter of the upper atmosphere produce intensified ionization. This would come about in both of these two ways: first, by the direct impact of the primary particles with the atoms and molecules of the atmosphere and secondly, by the production through nuclear bombardment of other very energetic fragments. In other words, the increase in ionization in the F-region could be both a primary and a secondary effect of the cosmic rays. There is no need to limit the paths of the secondary cosmic-rays to the lines of gravitational force of the earth. Enough of these rays could proceed even counter to the attraction of gravity by reason of their energy of motion. Our records do not show what was happening in the upper ionosphere from after eleven thirty until twelve fifteen. This is a sufficient time interval for the cosmic rays to have produced their effects in those sections of the atmosphere. (Figure 5)

ANY CAUSE FOR ALARM

A question arises now about the flares. We have noted that the more intense flares are associated with sunspot activity. At present, April 1956, we are quite far removed from the predicted maximum of sunspot activity. The maximum is expected in the midyear of 1958 though there are present indications that it will come earlier. If flare activity increases, is human living endangered by the bursts from the sun?

The answer to this question can be given under two aspects.

Under God's Providence, this earth of ours has experienced in its history many sunspot maxima without any woeful effects on the human population. It is only in recent human history that we have known about the existence of SID's and so of the peculiar solar radiation responsible for them. Before the beginning of the twentieth century there was no long distance radio communication to be bothered by radio fade-outs. The very existence of the ionosphere was physically established only about 30 years ago in 1924. Solar effects on the earth's magnetic field have been known for a little longer time. Further, the recorded history of solar flares is all too brief. Even though knowledge of all these phenomena is recent and limited, no one can prudently doubt that solar flares and SID's were going on for centuries before we became aware of their existence. Our present knowledge of existing events is not likely to cause those phenomena to turn suddenly into catastrophes.

Apart from these historical considerations the physical factors involved illustrate more definitely the Providence of God in protecting His human race from disasters not in the least suspected. Our atmosphere according to the physical laws is so arranged that we get the benefit of the radiations without the evils of destructive rays. A SID illustrates this. Radiation that might be harmful passes through the upper ionosphere—a nearly perfect vacuum on laboratory standards—with relatively small amounts absorbed. Yet in these rarified F-and E-regions some selective absorption does take place. At the level of the D-region, sixty kilometers up, the atoms and molecules are more abundant and more absorbent of energy. Since much of the intense radiation is stopped at these relatively rarified regions of the atmosphere, penetrating radiation to be lethal or harmful to life on earth would need to be of intensity of an entirely different order. If all the atmosphere in a vertical column above 220 kilometers were compressed to the density of air at sea level the total height of that column would be a microscopic fraction (.0002) of a centimeter. Under similar conditions all the atmosphere above one hundred kilometers would be compressed to only 2 centimeters (less than an inch); above sixty kilometers the atmosphere would be equivalent to 220 centimeters. To penetrate from sixty down to fifty kilometers, radiation would pass through about four times as much air as it passed through in the whole course of its journey through the rest of the upper atmosphere. Besides this rapid increase in atmospheric density as one descends in the atmosphere there is the well known Ozone layer centering around twenty five kilometers above sea level. If, finally, the radiation penetrated to the five kilometer height, it would still have to pass through, in the last five kilometers, about as much atmosphere as in the whole course of its previous passage. The above discussion indicates the protection we receive from favorable densities alone. When the nature of the atoms and molecules is considered, we know that we are securely protected from destructive solar radiation. We can look forward to the coming International Geophysical Year for an enlarging of our knowledge of the earth and the sun without being perturbed about dire destruction from solar flares.

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[2] A report in press at London

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