Philippine Studies: Historical and Ethnographic Viewpoints

Volume 3 | Number 2 Article 4

6-28-1955

Ionosphere Research at the Manila Observatory

James J. Hennessey

Recommended Citation

Hennessey, James J. (1955) "Ionosphere Research at the Manila Observatory," *Philippine Studies: Historical and Ethnographic Viewpoints*: Vol. 3: No. 2, Article 4.
Available at: https://archium.ateneo.edu/phstudies/vol3/iss2/4

philippine studies

Ateneo de Manila University • Loyola Heights, Quezon City • 1108 Philippines

Ionosphere Research at the Manila Observatory

James J. Hennessey

Philippine Studies vol. 3, no. 2 (1955): 164–186

Ionosphere Research at the Manila Observatory

JAMES J. HENNESSEY

The history of the Manila Observatory—its modest beginnings in 1865 in a garret of the Ateneo de Manila in Intramuros, its transfer to commodious and well-equipped quarters on Padre Faura Street, its total demolition during the Battle of Manila in 1945, and its recent resurrection on Mirador Hill in Baguio—has been outlined by Father Charles Deppermann, S.J. in a recent article.[1] Those who read that article will remember that the Jesuit Fathers assigned to the Manila Observatory in Baguio are at present engaged in two types of research: seismological and ionospheric. They will soon embark on a third: researches in the spectrum of the sun. In this paper I wish to explain the type of work we are doing in ionosphere research.

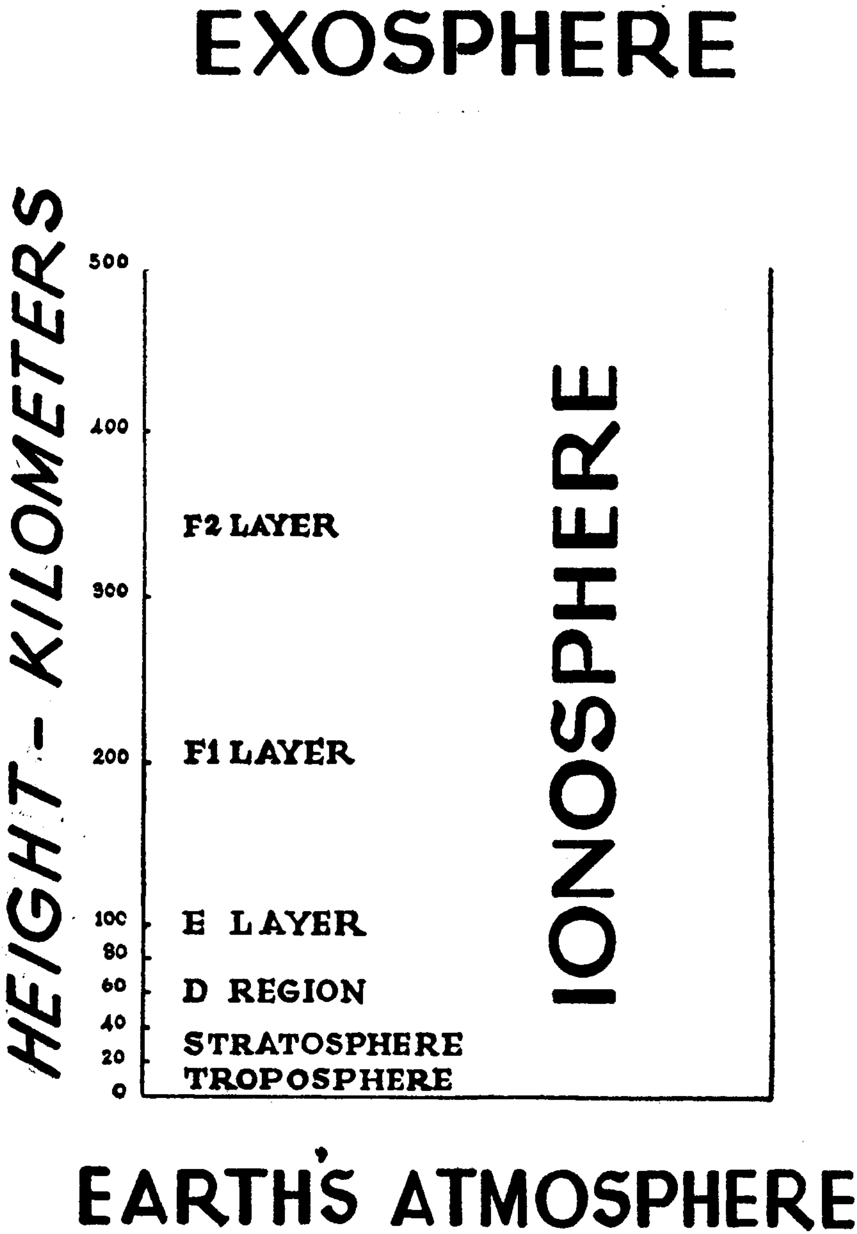
From its inception in 1865 to its total demolition in 1945, the Observatory was engaged in seismic and astronomical, but chiefly in meteorological work—the study of the earth's *troposphere* (i.e. the lowest part of the atmosphere, nearest the earth's surface). This meteorological work was particularly necessary since the Manila Observatory was also serving the Philippines (under the Spanish, the American, and the Commonwealth regimes) as the Government Weather Bureau. Since the war, with the Manila Observatory no longer serving as a Government Weather Bureau, the Jesuit scientists have shifted their field of investigation from the troposhere to the *ionosphere*—the highest portion of the earth's atmosphere.

THE ATMOSPHERE

A brief approximate description of the atmosphere, beginning at the solid earth (or lithosphere) and advancing upward to the limits of the earth, will indicate the nature of the principal regions of the terrestrial atmosphere. (Fig. 1) Dwelling on the nearly spherical, firm earth, man lives in the densest region of the atmosphere known as the *troposphere.* In this region, extending to about twelve kilometers above sea level, the constantly changing weather conditions develop and clouds are formed. Here in this relatively thin shell around the earth are found over three fourths of the bulk of the atmosphere. It is not surprising that this region of the weather—of storms, of rains and snows, of warm and cold fronts, of air masses and general convective activity—has long been a subject of investigation and discussion.

Above the troposphere, the next major region is the *stratosphere,* extending vertically from twelve to sixty kilometers. *Strata* are *layers* and when the name was given at the beginning of this century to this "layered region," it was thought that an orderly series of wind layers existed in great calm with little or no mixing of atmospheric masses. It was also considered to be an isothermal region, that is, a region where constant temperatures are maintained. While the stratosphere is still generally described by these features, investigation has modified these ideas. It is now known that there is turbulence and mixing of air masses there. Temperature variations with variations in height are clearly revealed by the instruments that go on rocket flights. However since the region is generally free of water vapor, clouds do not form to give us the changes we associate with "weather."

Above the stratosphere the *ionosphere* extends through the remainder of the atmosphere until it blends with interplanetary space. This blending or fringe region on the periphery of the earth is known as the *exosphere.* Rarely does the investigation of the ionosphere go beyond a thousand


EXOSPHERE
HEIGHT - KILOMETERS
500
400
300
200
100
80
60
40
20
0
F2 LAYER
F1 LAYER
E LAYER
D REGION
STRATOSPHERE
TROPOSPHERE
IONOSPHERE
EARTH'S ATMOSPHERE

(FIG. 1)

kilometers, even though the atmosphere may theoretically extend twenty times that distance. The ionosphere, then, (in this triple division of the atmosphere into troposphere, stratosphere and ionosphere) is the uppermost region of the atmosphere.

But this division neglects the consideration of the nature of the region as suggested by its name. That derives from the fact that in this upper area there are concentrations of electrons and positively-charged and negatively-charged particles. These particles are usually atoms or molecules which have an excess or a deficit of one or more electrons. Such charged or electrified particles are known as ions. The word is familiar, after Faraday, from electrolysis where, for example, water is broken up into oxygen and hydrogen. Each hydrogen atom carries a positive charge (or more properly has lost its valence electron) and so is a positive ion, and the oxygen atom with a net excess of two electrons similarly is a negative ion. Though each ion (*go-er*) carries a small charge, yet the ions are so numerous (for example, in an auto storage battery) that they constitute large currents of electricity. Strictly, a free electron is distinguished from an ion; but in ionosphere work where no ambiguity arises it is customary to lump electrons with ions. Each electron, due to its small mass, is nearly two thousand times as effective in certain processes as a singly charged ion of hydrogen, the ion with smallest mass. Because of this greater influence of electrons one might be inclined to call the region under discussion the electronosphere, but the present name is in possession and, besides, it takes into consideration the presence of the ions.

As far as the concentration of matter (which here is in the gaseous state) is concerned, the ionosphere is extremely tenuous. As the height increases, the density or the mass of the particles in a unit volume decreases. If the density of air at sea level is 1220 grams per cubic meter, at ninety kilometers above sea level the density is about four one thousandths of a gram per cubic meter. This is a reduction of some three hundred thousand times and corresponds to the density, in order of magnitude, that is found in the "vacuum" of the ordinary electric light bulb. At two hundred kilometers above sea level the density and pressure correspond to the best vacua that can be produced in the laboratory with high quality vacuum pumps. The ionosphere, then, is really a low pressure laboratory without restriction on the volume of the vacuum so that the experimenter has vacuum conditions without being harrassed by walls enclosing the vacuum. In this region, if one can devise a means of observing, one can study those phenomena that require high vacua. Some such investigations might be bombardments of gases by charged and uncharged particles; magnetic double refraction; electric discharge phenomena; ionization by collision; photochemical reactions; and recombination of ions and electrons.

BRIEF HISTORICAL SURVEY

Before this present century, knowledge of the ionosphere was exceedingly limited and more theoretical than real. Mathematicians and magneticians formed postulates about the upper atmosphere. Gauss in his mathematical researches over a century ago gave indication of the possibility of such a region. Balfour Stewart in 1882 suggested that there was an electron current at about the upper cloud level. Schuster in 1889 extended the work of Stewart. But the efforts of these men were not widely known and were more suggestive than complete.

In December 1901 Marconi succeeded in transmitting radio waves from Cornwall, England, across the Atlantic to Newfoundland. This remarkable transmission created a problem which provoked the interest of the world's great theoretical physicists. Radio waves, partaking of the nature of light waves, travel in a straight line in a homogeneous medium. Since the earth is approximately spherical, how did the waves in Marconi's experiment change from their straight line path to reach a distant point on the earth's surface? Radio waves, unlike seismic waves, do not travel through the solid earth. The curvature of the earth should therefore have interfered with the progress of the waves to distant places.

A theory that would require the curving of the waves around the obstacle (in this case, the earth)—a diffraction theory—was investigated by distinguished mathematicians of world renown. A partial list of these would include Lord Rayleigh, Poincaré, MacDonald, Sommerfield, March, von Rybczynski, Love, Van der Pol, Larmor and others. Yet the conclusions of these scholars were entirely divergent, for they were trying to explain the results of the transmission on a principle that did not apply. Apparently diffraction was not sufficient to explain the propagation.

In 1902 Professor Kennelly of Harvard and O. Heaviside of England, quite independently, suggested that an electrically conducting region or layer must exist in the upper atmosphere. This layer, they suggested, refracts the waves, preventing them from escaping totally from the earth's atmosphere, and bends their path back to the earth. But the existence of this layer was not immediately established.

The first direct proof by experimental means for the existence of the ionosphere came in 1925 with the experiments of Appleton and Barnett in England and Breit and Tuve in the United States. The method of the Breit-Tuve experiment was one which is widely used today in the study of the variations of the ionosphere. Pulses of electromagnetic energy are shot vertically upward, to be reflected back to a receiver where the echoes are observed and recorded.

The above brief history indicates how recent is the investigation of the ionosphere. The research is young but active and growing. Its growth has been accelerated by the blossoming of the science of electronics. A more detailed description of the structure in this region is now available.

STRUCTURE OF THE IONOSPHERE

The ionized region or layer which was responsible for the refraction of the Marconi radio waves back to the earth has been known as the "Kennelly-Heaviside layer" because of their contribution just mentioned. It is now common practice to refer to the total region as the ionosphere. Within the ionosphere, various layers are identified and classified according to the concentration of free electrons and ions. At the suggestion of Appleton these layers, arranged by height, are designated by letters of the alphabet. The principal layers are the E and the F, though there are others which at times play a dominant role in radio transmission. Starting the classification with the letter E allows for possible discovery of layers lower than this layer and also of indefinite layers above it. A general, not detailed, discussion of each of the significant layers as they are known and appear on records will show the various properties of the ionosphere itself.

In talking about the ionosphere we must distinguish carefully the density of the *atmosphere* which exists at a certain altitude, from the density of *ionization*. The total number of particles or their total mass in a given volume may be rather slight aloft in comparison with sea level standards, but at that same height the density of the ionization may be relatively high. Density of ionization depends not on the number of particles, but on the number and intensity of the *ions* present. The density of ionization at a particular height is said to be a maximum if immediately above and below that height the number of electrified or charged particles is definitely fewer. The presence of layers, then, in the ionosphere corresponds to various *maxima* of ion concentration distributed at different heights. The words *region* and *layer* in regard to the ionosphere have been distinguished. The accepted meaning of these two terms is as follows:

A *region* of the ionosphere is a portion of the atmosphere in which there is a tendency for the formation of definite ionized layers.

A *layer* of the ionosphere is a regularly stratified distribution of ionization which is formed in a region of the ionosphere and is capable of reflecting radio waves back to earth.

When radio waves are sent upward from a transmitter, they pass through the lower regions of the atmosphere. What happens to this radio energy as it encounters the ionosphere gives information about the structure of the ionosphere itself. The first encounter is with the lowest region of the ionosphere, known as the D region. It seems better to refer to this as a region rather than as a layer, for its presence is chiefly known by its absorption of medium-frequency radio waves. An ionization maximum in the region is not clearly defined. Some slight indications of reflection of radio waves at oblique incidence from heights of about sixty kilometers confirm the existence of ionization in this region. Because our equipment at Baguio sends out radiation at vertical incidence our records do not show an echo corresponding to this height range of fifty to ninety kilometers. However, absorption at the lower-frequency end of our records is evident. This absorption, indicative of electron density changes in the D region, varies seasonally and daily with the altitude of the sun. Irregular solar activity also affects this region. From the knowledge of the radio frequencies which are absorbed, one can assign a value to the ionization density. The mathematical and physical theory for this has been carefully worked out. Since, at these lower heights, the number of particles present is much greater than at the heights of the other layers, recombination of the positive and negative ions to form neutral particles takes place quite rapidly. Since the unlike-charged particles attract one another, when they come close together they will combine. And since moreover the chances for close approach are greatly increased with greater concentration of the ions, in the D region, once the ionizing processes cease to act, the positive and negative ions combine in a matter of a few seconds.

Above the D region the E region is formed and is considered to extend from eighty to 140 kilometers. It is to be expected that height ranges overlap in the ionosphere since the layers vary so much in height. In this E region the atmosphere shows a change in composition from molecular oxygen to atomic oxygen. Changes in height and, more significantly, successive values in the ionization density are observed according to the time of the day, the season of the year, the latitude and longitude of the position, and the sunspot epoch—to indicate a few of the concomitant variants.

In this region, depending on the degree of refinement one desires to use, distinction is made of various kinds of E layer. It is sufficient to indicate the normal E layer and the sporadic E layer. The normal E layer is regular in following the solar altitude quite closely. The layer appears on our records only after the sun rises. As the sun moves toward the zenith, the concentration of ions in this layer increases. At the highest altitude of the sun (around noon or shortly thereafter) the ion concentration in the layer is a maximum. In the afternoon the ion density decreases with the setting sun. Before sunset this normal layer vanishes from the records and does not reappear until after sunrise on the morrow. This variation in ionization with the altitude of the sun indicates the control the sun has upon the ionosphere, especially noticeable in this layer. The ultraviolet rays from the sun impart additional energy to the electrons in the oxygen molecules and atoms. An electron is liberated from the oxygen, thus producing a free negative electron and a positive ion. This process is called photo-ionization of oxygen.

Besides the normal E layer, in this same region the records show another layer which is very irregular in occurrence and ion density. It may be present at any time of the day or night. Over Baguio its trace is more often found on our records than not. Occasionally this layer reflects frequencies in excess of the upper limit of our equipment, that is, above twenty-five megacycles a second. Under such circumstances this layer is very densely ionized. This sporadic ionization may pass in a few minutes or it may endure for hours with changes in its ion density. Sometimes this layer is itself stratified (as occasionally are other layers also), in which case there are maxima of ion concentrations at more than one level within the region. Above the E region, and centering around one hundred and fifty kilometers above sea level there is another distribution of ionization which shows up as a layer. Not regularly in evidence, its characteristics are not well known. Because it appears below the usual heights of the F1 layer and seems to be dissimilar to that layer, it is known as the E2. The physical process of photo-ionization is probably responsible for this layer.

The region which exerts most control over long-distance radio communication by means of the ionosphere is undoubtedly the F region. Other layers, at times, such as a dense sporadic E or the normal E under peculiar circumstances, may afford better conditions for the electromagnetic radio waves but more frequently the F region gives the optimum traffic frequency.

The F region during the daytime manifests a dual structure so that two layers, F1 and F2, must be considered. The behaviour of the F1 layer is quite similar to that of the normal E layer. However, it is more densely ionized and appears at greater heights, roughly from 160 to 240 kilometers. The lowest heights are usually around midday. Like the E layer, the F1 layer shows a correspondence in ion density to the altitude of the sun. Still, as a layer distinct from the F2 layer, it appears later in the morning and ceases earlier in the afternoon than the normal E layer. Ultraviolet light from the sun appears as the ionizing agency of this layer. The separation of the highest frequency reflected from the F1 layer is not sharply defined at all times from the lower frequency reflected from the F2 layer.

Because the F2 layer has peculiarities that are not found in the lower layers it has been given extensive study. In the daytime the F2 exists as a layer distinguishable from the F1, but toward sunset the two layers coalesce. The one remaining is also referred to as the F2 layer. No simple variation with the solar altitude, even in a broad sense, is indicated for this layer.

Some of its peculiarities may be indicated in a general way: In the northern hemisphere during the winter months, such as December and January, the altitude of the sun at noon is much lower than during July and August. Yet the maximum electron density of the F2 layer is found in winter rather than in summer. In the winter months the F1 trace is with difficulty distinguished from F2. In summer the separation is more marked. The maximum ion density for the F2 usually occurs, not at noon, but from an hour to several hours after noon. At times due to a slight maximum before noon, a "minimum" value of ion density, that is to say, a drop followed by a rise, is indicated for noon itself. Our Baguio records show instances of a definite increase in ionization after midnight. These few peculiarities indicate that no simple law of solar altitude dependence applies to the F2 region.

All the characteristics of the F2 layer show greater variations than do the corresponding ones of the E and F1 layers. In attempting to explain the F2 layer various other factors are proposed, e.g. the influence of the earth's magnetism, the use of geomagnetic rather than geographic co-ordinates, consideration of the total electron content in the entire F2 region rather than electron concentration, or even a consideration of the total electron content in the combined F1 and F2 regions. In spite of the lack of a complete and adequate theory for this layer, statistical knowledge of its behavior does allow for accuracy in short-time predictions of its characteristics.

Are any layers above the F layer known? It seems very probable to us at Baguio that there is a G layer. Though located at a greater height above the ground level than the F layer, it usually does not appear on the ionograms because it is blanketed by the more dense F layer. At times when the ion density of the F layer is low, the G layer does appear. Perhaps, that indicates that the G layer is in existence all the time. The infrequent appearance of this trace casts some doubt on its real, enduring, daytime existence except at rare times. In any case, if this layer is normally present, it seldom has an ion density in excess of that of the F2 layer. The height of the maximum ion concentration for the G layer is centered around 450 kilometers.

We have considered these various layers of the ionosphere because all radio research indicates that such concentrations of ions exist. The sharpness in the maxima of these layers may be stressed excessively, as the results of recent exploration of the ionosphere with Viking Rockets indicate. The rocket exploration up to two hundred kilometers showed that the daytime ionosphere *remained* dense in ionization throughout the E region and up to the F1 region. There were only minor peaks in density. However, the distribution of ionization, as obtained from the rocket exploration, agreed very closely with the ionograms that were taken while the rocket flight was in progress.

Our information about the ionosphere, as indicated in the foregoing discussion, has been learned principally from research technics quite similar to those used in the original experiment of Breit and Tuve. The equipment which is used at Baguio, after nearly thirty years of elaboration in electronics throughout the world, is now capable of doing automatically in fifteen seconds, and in a more complete manner, what required more or less an hour of painstaking operation in the earlier days. A general description of the instruments and their use will help to explain the nature of the ionospheric program at Baguio.

THE INSTRUMENTS

Let us begin with an illustration familiar from elementary physics. It is a commonplace problem to have a man with a stopwatch set off some kind of a sound disturbance, v.g., a pistol shot, in order to determine the distance to a remote cliff. The sound travels out to the cliff and is reflected back. Having started his stopwatch at the firing of the pistol, the observer stops it when he hears the sound echo. He makes suitable assumptions about the speed of the sound in air at the prevailing temperature. Knowing the speed of sound, and having read the time of travel out to the cliff and back, he can easily compute the distance to the cliff. The distance from the observer to the cliff is the product of the speed of sound and one half the total travel time. Thus, if the stop watch reads ten seconds, the cliff is a little over a mile away under usual conditions.

For this experiment, at least three things are needed: 1) a source of disturbance that is not continuous, v.g., a single pistol shot; 2) the detector, i.e., the observer's ears listening for the echo; and 3) a timing device, i.e., the stop watch. Modern radar, an outgrowth of the original radio-echo technic first developed by Breit and Tuve, uses a similar principle for determining the distance of aircraft and other objects.

The modern instrument used in ionosphere stations is called an ionosonde. As its name suggests, it is employed to "sound" the ionosphere, and so to make ionospheric measurements. The Baguio ionosonde is the type C-2 automatic recorder developed by, and on loan from, the National Bureau of Standards of Washington, D. C. Since in this instrument sound waves are not used, but rather radio waves, the travel times are of a much different order. Sound waves cannot be used to give us the required information for they do not interact with the ionized regions as do electromagnetic or radio waves.

First, then, as in the analogy of the sound echo, the ionosonde must possess a device for producing a non-continuous signal disturbance. If the signal were continuous it would confuse the reception of the echo. Essentially this requirement means a radio-frequency transmitter sending out a pulsed signal. It is assumed that the radio energy travels with the speed of light in a vacuum, which is the greatest possible signal speed in the physical universe, according to current theory. This speed is approximately 186,000 miles a second. Thus a distance of one hundred kilometers gives a round-trip time of 666 microseconds. (A microsecond is one one-millionth of a second.) It is clear, then, that where distances of the order of the dimensions of the earth's atmosphere are concerned, the corresponding time measurements for radio waves will be more suitably expressed in microseconds rather than in seconds. Our transmitter sends out pulses which are fifty microseconds long. This means that for fifty microseconds the transmitter is giving out a burst of radio frequency energy and then it shuts off until the next pulse. Sixty of these pulses are transmitted each second. Thus, in every second or one million microseconds, energy goes out for only three thousand microseconds and the remaining 997,000 microseconds the transmitter is shut down. The "silent" intervals give the pulses of energy time to travel upward to the ionosphere and to return before the next pulse is sent out. It is plain that such a switching arrangement can only be carried out electronically since no mechanical device would respond quickly enough. Strictly, one could operate an ionosonde at a single frequency, say, at six megacycles a second or some such value. In that case, the transmitter would send out vibrations at the rate of six million cycles a second and in pulses as before. However, the information about the ionosphere, being limited to this one frequency, would be quite meager. Our practice with the C-2 ionosonde is to have the transmitter put out radiation that ranges from one to twenty-five megacycles a second in a period of fifteen seconds. In that manner we can see how the ionosphere behaves towards a variety of frequencies. The transmitter must develop considerable power to do its work well. The peak power of our installation is ten kilowatts. The transmitting antenna is designed, as far as is conveniently possible, to direct the energy vertically upward. Since it has to handle such a wide range of frequencies, it is a broad-banded antenna. It has the shape of a delta or a half rhombic. The broad-banded output-amplifier stages operate at one thousand, four thousand and eight thousand volts. The transmitter, then, with its accompanying circuits and the antenna, serves in an excellent manner the function of the pistol for the sound echo.

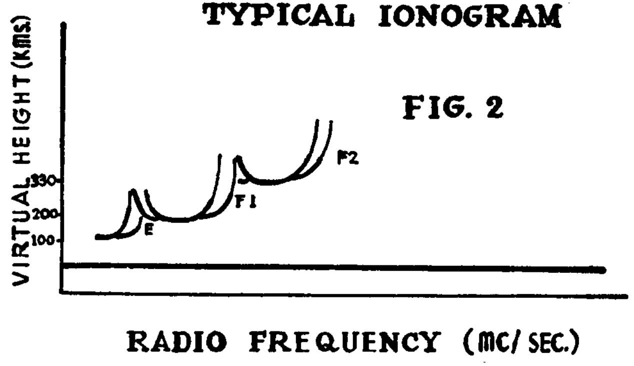
The second element required is the detector. In the ionosonde this consists of various units all working harmoniously and synchronously. Let us trace the course of the electromagnetic energy as it leaves the transmitting antenna. Travelling with the speed of light the energy reaches the ionized regions. As it enters, its velocity is decreased because that medium has an index of refraction for the waves, quite different from that of free space. The electrons of the ionosphere take up the energy of the radio waves and then, when dense enough, reradiate it away again. The process is not simple but effectively the ray of energy is reflected from the ionosphere, due to the encounter with the dense bank of electrons. The energy returns with the speed of light to be picked up by the receiving antenna. This reflected energy which reaches the antenna is an extremely minute fraction of the transmitted energy. Hence, as in the case of conventional radio receivers, the signal is amplified many times. The amplifier is broad-banded and it doubly converts the received signal into a frequency that is then rectified and electronically prepared for presentation to two cathode-ray oscilloscope circuits. These are similar to television circuits. One of the oscilloscopes is used for visual presentation on a screen and the other for permanent recording. By observing the pattern on the monitor-scope, or screen, the operator can detect any malfunctioning of the equipment or observe unusual events in the ionosphere. Meanwhile, a thirty-five millimeter movie camera takes a record of the presentation on the recording oscilloscope.

The third element (which corresponds to the stop watch) is an electronic circuit which allows for the simultaneous presentation of height markers and frequency markers along with the ionospheric echo. The height markers which occur on the oscilloscope face are really measures of time intervals. The heights are not actual heights of the ionospheric layers but rather the virtual heights i.e. the heights which correspond to a time interval multiplied by the speed of the radio waves (assumed to be that of light in free space). The oscilloscope presents a pattern or graph with virtual heights plotted along the vertical axis and frequencies along the horizontal axis. In our usual recordings, the heights are marked from ground level to 1000 kilometers with a reference line drawn at each hundred kilometer distance. The frequencies go from one to twenty-five megacycles a second. These photographic records, known as *ionograms*, are taken every fifteen minutes throughout the day and the night. Our information about the ionosphere comes chiefly from the analysis of such records.

We repeat the important units that enter into the proper functioning of the ionosonde. A pulsed transmitter sends out radio frequency energy, varying from one to twenty-five megacycles a second, in a time interval of fifteen seconds. This intense energy is directed by the transmitting antenna vertically to enter the upper atmosphere. Here it is influenced by the dense layers of electrons and is "reflected" back partially to a receiving antenna. This feeds the received signal into an amplifier which multiplies its effectiveness. The two oscilloscopes respond to this enhanced signal along with the traces from the marker units. The camera records by photograph the configuration presented on the screen.

IONOGRAM DETAILS

To one who has examined ionograms for even a short time certain characteristic phenomena are noticeable. It might be of interest to point out some of these which are of frequent occurrence and are fairly well explained. Many other significant variations found on the records, can, for present purposes, be left to the speculations and discussion of the proficient. (Fig. 2)



TYPICAL IONOGRAM

FIG. 2

Normally the echoes present a sharp trace corresponding to each of the layers that are present at the time. At the horizontal part of the trace the minimum height for the layer can be read off by comparison with the height markers. As one follows with the eye the echo trace of a particular layer from the leveling-off point in the direction of the higher frequencies, he observes that the apparent height increases and the curve rises until it shoots vertically upward. The reason for this rise in apparent height with the higher frequency may be delay or retardation of the energy that passes up and down through the lower part of the ionized layer. The higher frequencies penetrate further and further into the layer until a certain frequency is reached such that the layer will no longer reflect that frequency or any higher frequency. The frequency corresponding to this complete penetration is called the critical frequency for that layer. At that point the trace is vertical.

But surprisingly one notices that in the vicinity of this penetration or critical frequency the trace becomes twofold for this layer, that is, there appear two traces separated, at Baguio, by about one half a megacycle. Why does the layer show this doubling of the trace or better, a pair of traces? The reason is to be found in the earth's magnetic field. The electromagnetic energy used for probing the ionosphere becomes polarized in the presence of the magnetic field. This polarization phenomenon is similar to the effect that is had when light passes through a Nicol prism or through certain crystals such as tourmaline. Due to the crystal a single spot appears as doubled because the ray of light has separated into two kinds of light taking different paths. These double rays of light are referred to as the ordinary and the extraordinary rays. By analogy the two traces on the ionogram are called the ordinary and the extraordinary traces. The influence of the earth's magnetic field is an instance of the complicating factors found in the actual physical record.

Another noticeable feature on the ionograms is the presence of multiple echoes. If a strong trace is observed to be horizontal, say, at 300 kilometers virtual height, another trace may be found at 600 kilometers and perhaps a third weaker trace at 900 kilometers. Let us consider the trace at 600 kilometers in comparison with the one at 300 kilometers. These traces are similar but the one at 600 kilometers has a slope twice that of the one at 300 kilometers. The higher trace is often helpful for checking our evaluation of the lower trace. We know that the trace at 300 kilometers is formed due to energy which has gone from the transmitter up to the layer and then has been returned to the receiver. This makes one round trip for the energy of the radio waves. The higher trace is due not to the existence of a real layer at just twice the height of the first one, but rather to the fact that the transmitted energy has traveled in this fashion: from the transmitter up to the layer, back to the earth where it is reflected upward again to the layer and then back to the receiver, that is, it makes two round trips to the layer. It is evident from this that the trace at 900 kilometers is due to three round trips from the ground to the same layer and back. This explains the use of the term *multiple echo.* As many as 18 round trips have been observed and reported in the literature. When a tenth or twelfth or higher multiple echo shows up on the records, it has little resemblance to the first echo, since the steepness of its slope increases for each reflection.

Other variations of these multiple echoes can be noticed. We consider the M and N reflections as simple cases. The reason for the letters as designation will be clear if one traces the path for an echo which starts in a slightly oblique direction towards the ionosphere and terminates at a receiver at some distance from the transmitter. (Fig. 3 & 4) Suppose there is an E layer at 100 kilometers and an F layer at 300 kilometers. If the energy reaches the F layer and is reflected back down to the top of the E layer and thence up to the F layer again and finally down to the receiver, we see that it has travelled up three hundred, then down two hundred, then up another two hundred and finally down three hundred kilometers. This M trace should appear then at half the total path length or at five hundred kilometers. To illustrate the so-called N reflection (the N is not a perfect N) for the same two layers, the energy rises to the F layer, three hundred kilometers, then comes back to the earth, three hundred kilometers more, then goes up to the E layer, one hundred kilometers, and finally goes down one hundred kilometers to the receiver. Such an N trace willl appear at one half the total path or at four hundred kilometers. These multiple echoes serve a useful purpose and inform us about certain things in the ionosphere as well as about the performance of the equipment. The detection of multiple echoes is fairly simple but interpretation of the condition of the ionosphere from them may be complexedly involved.

From around midnight and during the early morning hours, at times, a condition characterized as *spread echo* is observed. The trace is exceedingly diffuse and lacking in sharpness. Now and then the condition is so bad that even

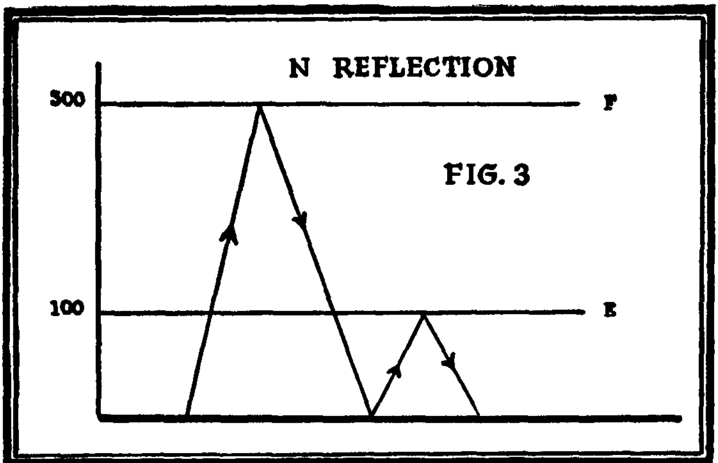

N REFLECTION

FIG. 3

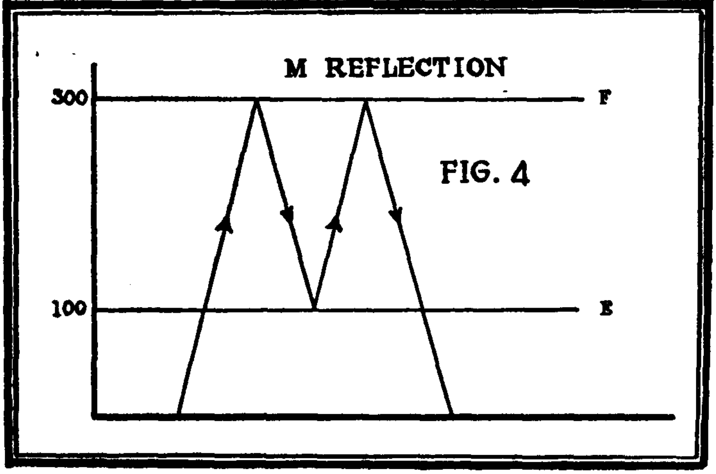

M REFLECTION

FIG. 4

probable values of the characteristics cannot be given. Such a trace indicates some turbulence or unusual stratification in the ionospheric layer. In contrast to the auroral regions, Baguio in the tropics is fairly free from the occurrences of this condition.

If successive ionograms are studied, the pre-dawn dip in the critical frequency of the F region is in evidence almost daily. This means that strong recombination of the ions in this region takes place an hour or so before the sun shines on the ionosphere. After ground-level sunrise the normal E layer puts in its appearance, and a little later the bifurcation of the F layer into the F1 and F2 commences. These changes build up toward noon and then reverse as the sun gets lower. Once in a while, at no fixed time of day or night, the sporadic E layer will assert itself and blanket all higher layers. That condition indicates that the radio energy could not pass through the sporadic E layer in one or both directions as it would need to do to manifest the higher layers. It also means that the sporadic E layer is remarkedly dense in ionization.

All of the foregoing illustrations of variation in the ionograms are elements that would come to light by a superficial study of the records. The more technical and fruitful analysis requires careful scrutiny and checking. But there is still a great absence of knowledge about many of the basic ionospheric properties. Much can still be gleaned from the comparative study of the records in correlation with other physical processes. Some of these are sunspots, solar disturbances, auroral displays, magnetic storms, rotation of the earth, thunderstorms, thermal changes, barometric effect, meteors and countless other physical phenomena. The facts about ionospheric storms and winds in the ionosphere are still in an active state of inquiry. Much is known but more remains to be investigated and learned. But it is an attractive witness to God's Providence for us men that even when we were unaware of the existence of the ionosphere, it did exist as a shield to absorb solar and cosmic radiation harmful to the life of the human race.

WHY THIS RESEARCH

Under the present method of performance at Baguio the ionosonde takes about one hundred and twenty ionograms a day; for besides the quarter-hourly sweep, an additional record is taken one minute after the hour. In the course of three years of operation a vast number of pictures, about one hundred thousand, have been accumulated. Yet it is doubtful whether any two pictures are exactly alike in all thirteen characteristics that are daily scaled and recorded. To be sure, a search for two identical ionograms would not be very useful; but the impression that we have indicates the variety in the records and the changeableness of the ionosphere. It also shows the need of many observations if predictions are to have a firm statistical basis. But what is the nature of these predictions? Why should there be interest in the ionosphere?

The first evident reply is given from the utilitarian standpoint. In the modern world long-distance communication is a necessity. The quickest way to carry on that exchange of intelligence is by means of radio transmission. To do this in a practical way, those radio wave lengths or frequencies must be used which are reflected from the ionosphere. (Fig. 5) Otherwise, due to the curvature of the earth, the waves will not arrive at a distant receiver. It is desirable to operate a transmitter at the greatest frequency, the so-called maximum usable frequency, for if the frequency of operation is notably lower, the energy is attenuated by the path in the ionized layers. Excessive power with unduly large corresponding transmitter installations would be required for intelligible reception. If the frequency, on the other hand, is so high that the waves penetrate the ionosphere, the energy goes out into space without reflection to a distant reception point on the earth. Since the height and density of the ionospheric layers are so changeable, to be assured of constant transmission, the broadcasting station must be aware of these changes to provide for proper contacts. For accuracy in predictions of radio paths over the surface of

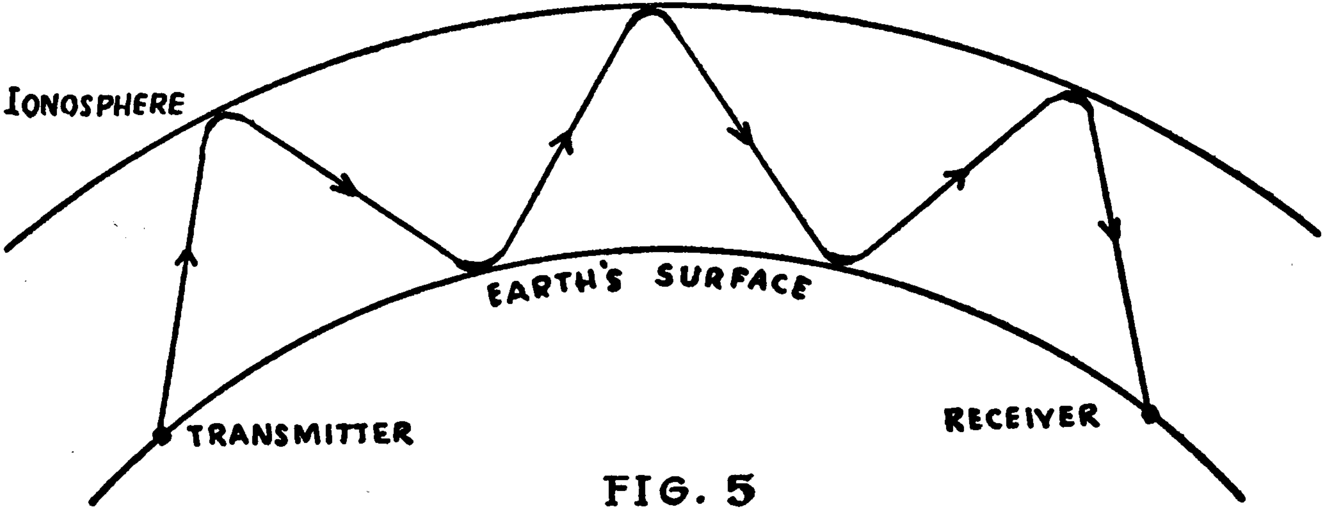


FIG. 5

DISTANT RADIO TRANSMISSION

the earth, it is necessary to have observations from well-distributed ionospheric stations. Any particular station can give only characteristics in the latitude and longitude of that station. To assist the National Bureau of Standards in making these predictions, the Manila Observatory (conducting the only station in the Philippines) sends numerical summaries of its records to the Central Radio Propagation Laboratory now located in Boulder, Colorado.

The second aspect of interest in the ionosphere is vastly more significant. A research organization, such as the Manila Observatory, is always interested in basic problems of its special science. It aims at furthering fundamental knowledge. It is content to leave the practical uses, normally, to others, provided it can open up, even in a slight way, new vistas. Such may be done by a new generalization or unification or by the discovery of a hitherto unsuspected relationship. In the Manila Observatory this type of work has always been more highly esteemed than even such beneficial and more spectacular work as actual warnings about typhoons and other disasters. The reasonableness of this is simply that the more universal knowledge does not oppose, but rather raises, the other particularized type of work to a superior plane. Certainly, in the case of ionospheric studies, there are many unsolved problems that need elucidation. If, for example, one knew the adequate and complete causes of the sporadic E layer, he would learn directly from those causes the changes that take place there. The usual laborious technic of prediction would surely be facilitated. To discover such relationships is usually a plodding task and only occasionally a stroke of genius; but because scientists have the firm conviction that natural processes are intelligible, they will go on searching and researching. And all the time more and vaster problems are being disclosed to make the quest inviting.

* * *

---

[1] "The Manila Observatory Rises Again," PHILIPPINE STUDIES, I (June, 1953), 31-41.