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THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATION TOPSIDE SOUNDER PROGRAM

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SUMMARY

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The NASA Topside Sounder Program is reviewed with particular emphasis upon the fixed-frequency topside sounder satellite which is scheduled for 1963. A rocket test conducted on June 24, 1961, as part of this project established the feasibility of the topside sounding technique and revealed many of the unique phenomena associated with it. A comparison of the design of the *fixed*-frequency topside sounder with that of the Alouette (1962 $\beta\alpha$), the recent Canadian *swept*-frequency topside sounder, reveals the complementary features of their scientific objectives and the basic differences in the technologies employed. Although the common goal of the two experiments is to improve our knowledge of the detailed structure of the upper ionosphere, the differences in approach have resulted in the development of separate data analysis techniques.

AUTHOR

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INTRODUCTION

A topside sounder is a satellite version of instrumentation used extensively on the ground for routine observations of the ionosphere. The conventional equipment used for such ground-based soundings of the ionosphere is basically a low-frequency radar. If a radar is operated with a carrier frequency of a few megacycles, echoes are received from the ionosphere; the electron density at the reflection level is determined from the carrier frequency, and the altitude at which reflection takes place is indicated by the signal's round trip propagation time. Changing the radar carrier frequency results in reflections occurring at different density levels, and a complete altitude profile of electron density can be derived up to the altitude of *maximum* electron density. This altitude can vary from about 250 km to 400 km or more, depending upon the latitude and upon the sun-spot number (Reference 1). The level of maximum electron density separates the "bottomside" and the "topside" of the ionosphere.

The vertical radio sounding technique has been used for about 30 years and until the advent of space research it was the main tool for ionospheric investigations. Ground-based observations have revealed the broad features of the structure and behavior of the bottomside ionosphere, e. g., the daily and seasonal variations and the strong controlling effect of the 11-year sunspot cycle, the differences between the polar, temperate, and equatorial regions of the ionosphere, and the influence of the geomagnetic field. Many other ionospheric peculiarities such as sporadic E, spread-F, and the seasonal and equatorial anomalies were also discovered from these ground-based studies. Although these phenomena are quite well documented, their detailed mechanisms are far from being completely understood. Nevertheless these early ground-based observations have stimulated considerable theoretical study of the fundamental phenomena occurring in the ionosphere; and the resulting body of knowledge has provided an excellent starting point for ionospheric investigations utilizing space technology.

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*Based on a talk presented at the American Astronautical Society/American Association for the Advancement of Science meeting at Philadelphia, Pennsylvania, December 27, 1962.

INVESTIGATIONS OF THE TOPSIDE IONOSPHERE

Before 1958 little was known about the upper or topside ionosphere, except that it was relatively heavily ionized. Radar signals reflected from the moon (References 2 and 3) had shown that the total electron content in the topside was about three times that in the bottomside. Direct exploration of the upper ionosphere began in 1958 when *high altitude space vehicles* became available. It should be noted, however, that the development of a ground-based method for topside studies also began in 1958. This method, known as the incoherent backscatter technique (Reference 4), is now used systematically for observations over a few geographic locations (References 5 and 6). The NASA space science program, organized during the latter part of 1958 and the beginning of 1959, emphasized the investigation of the topside ionosphere by providing for four different groups of experiments. The four basic approaches are illustrated in Figure 1.

Direct measurements provide a detailed picture of the ionosphere in the immediate vicinity of the spacecraft. Typical parameters which can be obtained are electron and ion densities N_e and N_i, electron and ion temperatures T_e and T_i, and ionic composition. Explorer VIII (1960 ξ1) and Ariel I (1962 σ1) were both direct measurement satellites. Explorer VIII was one of two space projects credited with the experimental discovery of an ionized helium belt which, during the daytime, envelops the earth at altitudes ranging from 1000 to 2500 km (Reference 7). Sputnik III (1958 δ2) and Explorer VIII together showed that atomic oxygen was the major ionic constituent of the topside ionosphere below 1000 km. Electron temperatures measured by Explorer VIII were found to vary

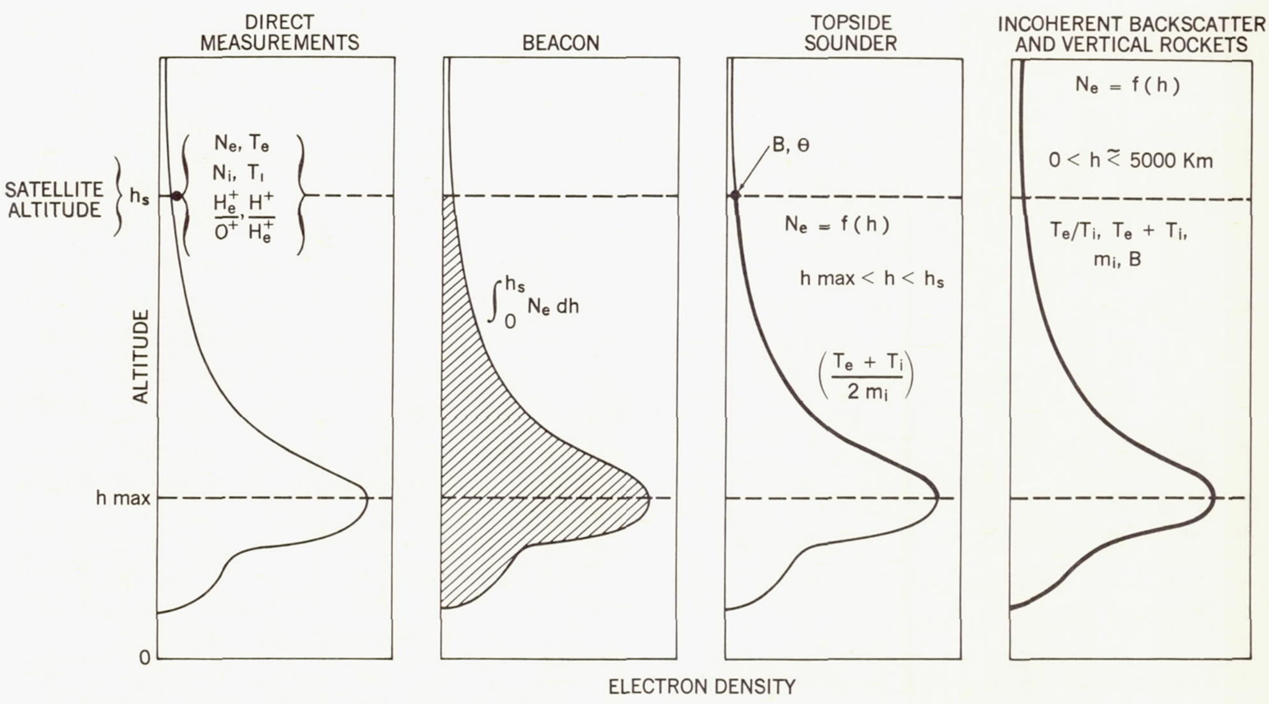

Figure 1—Four types of ionospheric experiment.

between 1000°K at night and 1800°K in the daytime. These results were subsequently confirmed and extended by Ariel I, which contained improved versions of the Explorer VIII experiments (Reference 8).

The *beacon* satellite provides transmissions of radio signals at frequencies high enough to penetrate the ionosphere, but low enough to be influenced by the ionosphere (Reference 9). Beacon observations yield the total electron content $\int_0^{h_s} N_e dh$ below the satellite and provide some information about irregularities. This type of satellite is ideal for international participation, since independent observers all over the world can obtain information about the ionosphere, with relatively simple radio receivers.

It will be sufficient to note at this point that with the *topside sounder* technique it is possible to obtain a complete topside profile up to the satellite, and also to obtain additional local parameters such as the intensity B and the direction θ of the earth's magnetic field.

High-altitude *vertical rocket soundings* have been primarily useful for obtaining typical topside electron density profiles. One of the most accurate topside profiles ever obtained is shown in Figure 2. The smoothness of this curve and the exponential decay of the density with altitude suggest that for the particular location and time of the measurement, the ion-electron gas in the topside ionosphere behaved very much like a neutral gas (Reference 10). In other words, the density distribution seemed to be controlled by gravity, temperature, and mass. In the case of an ion-electron gas, the temperature is the average of the electron and ion temperature. Similarly the effective mass is the mean electron-ion mass, which is essentially half of the ion mass. The electron density profile shown in Figure 3 reveals a change in ion composition at an altitude of about 1000 km, and it provides supporting evidence that the transition was one from O^+ to He^+ as shown by the solid curve rather than O^+ to H^+ as shown by the dashed curve (Reference 11).

From these experimental data the model of the quiet topside ionosphere at middle latitudes shown in Figure 4 was derived, which indicates

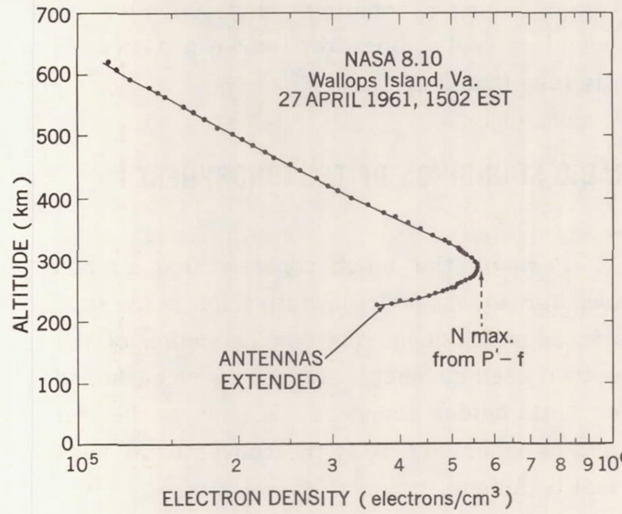

Figure 2—Vertical rocket electron-density profile obtained by a vertical rocket.

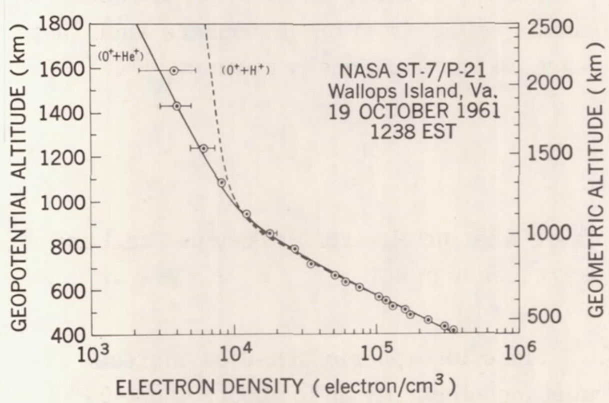

Figure 3—Experimental electron-density profile indicating a change in ionic composition at about 1000 kilometers.

the three regions where O^+, He^+, and H^+ are respectively predominant (Reference 12). Experimental observations (References 11, 13, and 7), as well as theoretical considerations (Reference 14) show that the altitude distribution of the three major ionic constituents is controlled by the topside temperature in the manner illustrated by Figure 5. The 3-to-1 range of temperatures shown in Figure 5 illustrates the range of values which might be expected during a complete sunspot cycle. A typical diurnal temperature variation is generally less than 2-to-1.

RADIO SOUNDINGS OF THE IONOSPHERE

Perhaps the most sophisticated method used for ionospheric investigation is the topside sounding technique, an extension of the method used so successfully in ground-based (or bottomside) sounders. It may be helpful first to describe briefly the conventional vertical technique.

The sounding equipment used is basically a low-frequency radar system in which the carrier frequency is swept periodically from about 1 Mc to about 20 Mc. The transmitted signals reflect from the ionosphere when they reach an electron density given by

$$N = \frac{f^2}{80.6} , \qquad (1)$$

where N is the electron density per cm^3 and f is frequency in kc.

Since ionospheric densities increase almost monotonically up to about 300 or 400 km, echoes are obtained from increasingly higher altitudes as the frequency is increased from 1 to 20 Mc. Actually, it is only under very

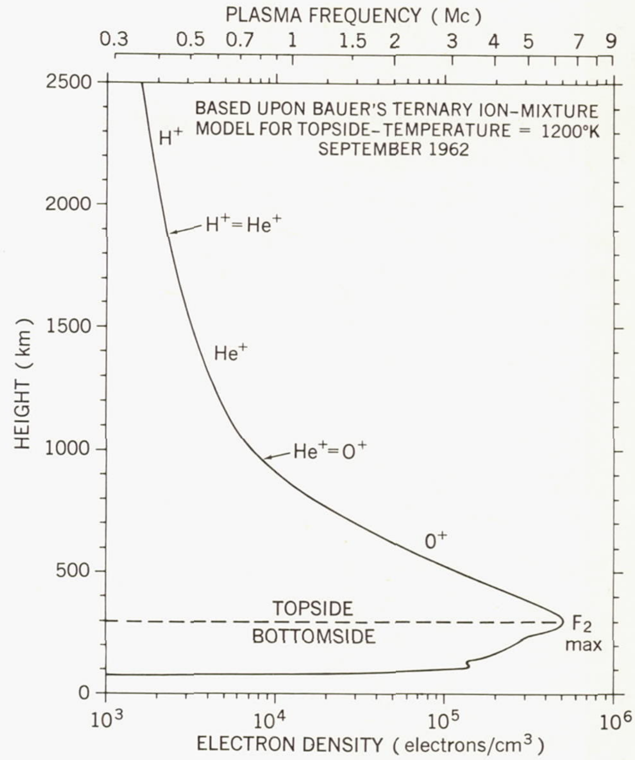

Figure 4—Theoretical average daytime ionosphere.

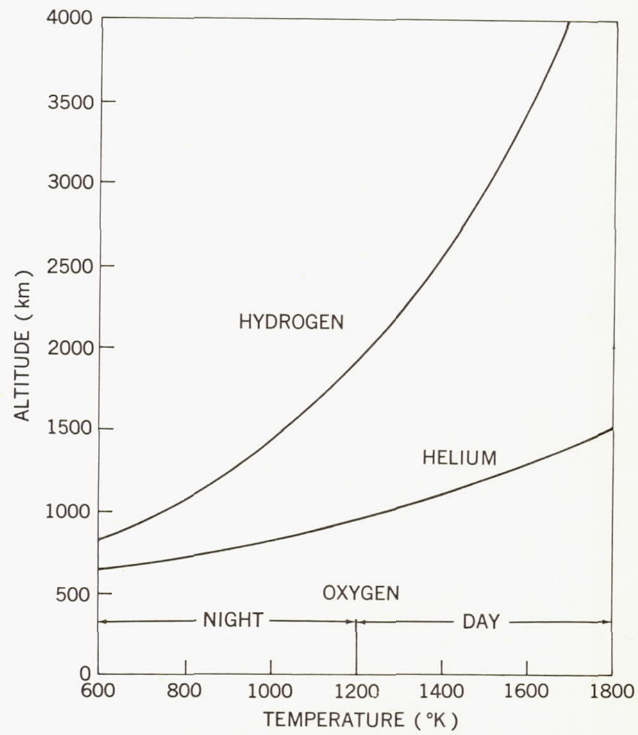

Figure 5—Principal ionic constituents as a function of altitude and temperature.

rare conditions that the maximum electron density is large enough to reflect 20 Mc; and in practice there is a maximum frequency (less than 20 Mc) for which a reflection can be obtained.

The instrumentation measures the round-trip time for the pulsed signal and plots this quantity as a function of the sounding frequency. The result is a record such as the one shown in Figure 6. The time scale is actually calibrated in terms of altitude, i. e., the travel time is converted to an equivalent distance based upon the free-space propagation velocity. Since the velocities in an ionized medium are less than free-space velocities, the altitudes so obtained are greater by a factor which is a function of the electron-density profile, the frequency used, and, to a lesser extent, the magnetic field of the earth. In view of the distortion in the height scale, this presentation is called a P′-f (or h′-f) record, i. e., a record of *apparent path lengths*, or *virtual heights*, versus *frequency*. A subsequent analysis, which takes these effects into consideration, can be performed to convert the P′-f record to electron density versus altitude.

Multiple echoes can also be seen in Figure 6 corresponding to two round trips between the ground and the ionosphere. Additional features which can be noted in Figure 7 (a redrawn version of Figure 6) include the presence of two traces, corresponding to the ordinary and extraordinary modes of propagation which are due to the presence of the earth's magnetic field. These two modes have different propagation and reflection properties.

The frequency at which reflection occurs for the ordinary mode is

$$f_0 = 10^{-3} \sqrt{81 N_e} \text{ Mc} , \qquad (2)$$

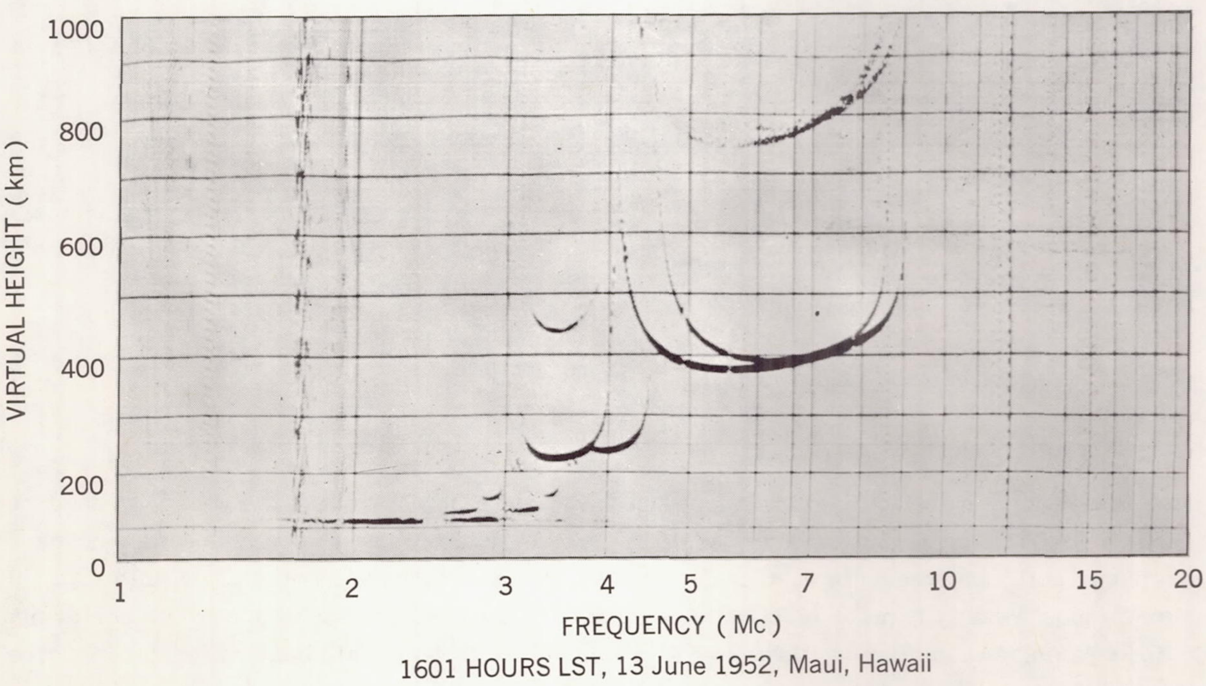

Figure 6—Typical bottomside sounding.

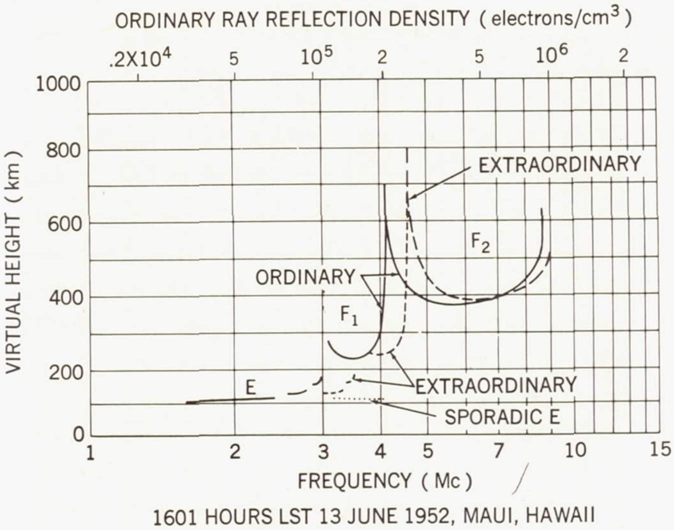

Figure 7—Typical virtual height record (traced from ionogram).

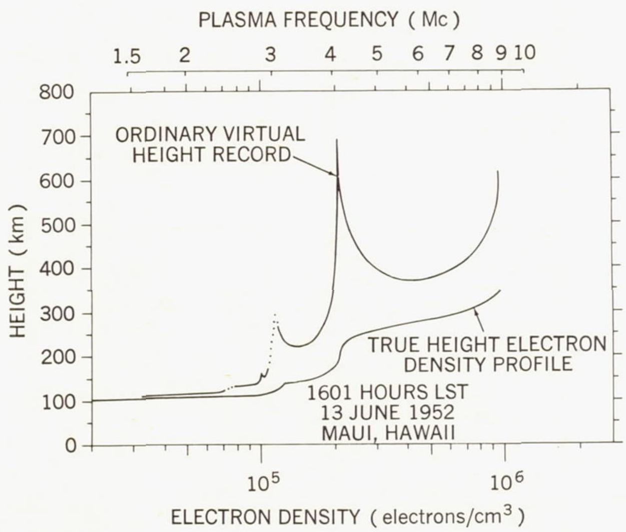

Figure 8—Reduced true height electron density profile from bottomside sounding.

where N_e is the electron density in electrons/cm^3. For the extraordinary mode, the reflection condition is

$$f_X = \frac{f_H + \sqrt{4f_0^2 + f_H^2}}{2} \text{ Mc}, \qquad (3)$$

where $f_H = 2.8H$ Mc and H is the earth's magnetic field in gauss. There is also the Z mode, usually seen only at high latitudes and not apparent in Figures 6 and 7; for this mode, the reflection condition is

$$f_Z = \frac{-f_H + \sqrt{4f_0^2 + f_H^2}}{2} \text{ Mc}. \qquad (4)$$

If $f_0 >> f_H$, the approximations

$$f_X \approx f_0 + \frac{f_H}{2},$$

$$f_Z \approx f_0 - \frac{f_H}{2}$$

may be used.

The formula relating the virtual height h′ and the actual height h at which reflection occurs is

$$h' = \int_0^h \left(\mu + f\frac{\partial\mu}{\partial f}\right) dh, \qquad (5)$$

where μ, the phase refractive index, is a function of the electron density N_e, the sounding frequency f, the geomagnetic field H, the magnetic dip angle θ_H, and, only in the lowest portion of the ionosphere, the electronic collision frequency ν. The data analysis which involves the solution of this integral equation is most readily done by electronic computers. The result of such an analysis performed on the ionogram shown earlier is illustrated in Figure 8. It is seen that apparent heights and true heights differ quite substantially.

NASA TOPSIDE SOUNDER PROGRAM

Early in 1958, consideration of satellite-borne topside sounding experiments began simultaneously in several United States, Canadian, and European groups. A proposal from the Canadian Defence Research Telecommunication Establishment (DRTE) came to NASA at the end of 1958. NASA was pleased to accept DRTE's cooperation on the Topside Sounder Program, and it was agreed that this scientific undertaking would be a joint Canadian - United States effort with the Canadians responsible for designing and manufacturing the complete satellite and NASA for launching and overall program direction. This topside sounder effort, began in Canada early in 1959. Since its successful launching the spacecraft has been known as the ALOUETTE (1962 $\beta\alpha$).

Concurrently, NASA had requested that the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards conduct feasibility studies and recommend immediate and long-range approaches for this area of research. (CRPL had also proposed a topside sounding experiment in mid 1958.) In June 1959, a CRPL study report recommended the fixed-frequency system as a first-generation experiment and suggested that DRTE be encouraged to develop its swept-frequency system as a second-generation experiment. The latter of these recommendations was, in fact, a concurrence by CRPL with the decision already reached between NASA and DRTE. Then, NASA and CRPL discussed the development of the fixed-frequency system as a parallel effort, in view of its complementary features. The design of a United States fixed-frequency topside sounder experiment began at the Airborne Instruments Laboratory (AIL) in May 1960 under the scientific supervision of CRPL. The swept- and fixed-frequency sounder projects were conducted as a single program under NASA technical direction. Figure 9 is a chart of the responsibility and data distribution for the program.

The telemetry stations for both the swept-frequency and fixed-frequency sounders are shown in Figure 10. The area bounded by the dotted line is the region within which both satellites will be higher than 15 degrees above the horizon for one or more telemetry stations. The entire unshaded area indicates the horizon-to-horizon coverage provided by these stations. It is seen that *each* station can provide data over an area comparable to that of the United States.

Although the two experiments are similar in objective and techniques, the emphasis and instrumentation used in the two experiments are quite different. The Canadian experiment was intended primarily to investigate the polar, arctic, and auroral effects which produce very complex ionospheric conditions over Canada. For that purpose DRTE has established telemetry stations at Resolute Bay, Northwest Territories; Prince Albert, Saskatchewan; and

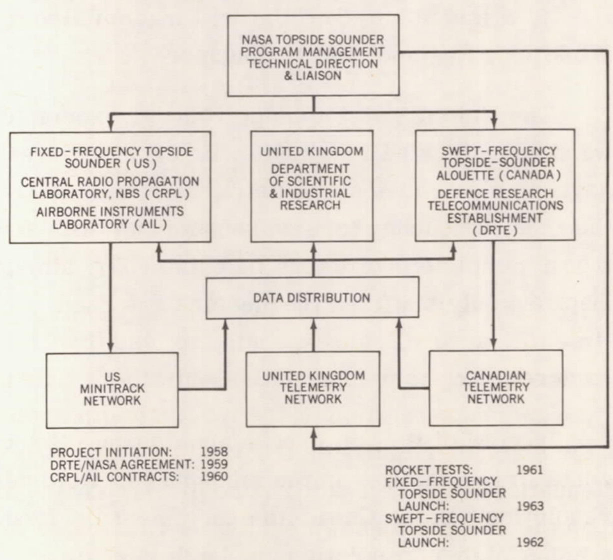

Figure 9—The NASA Topside Sounder Program.

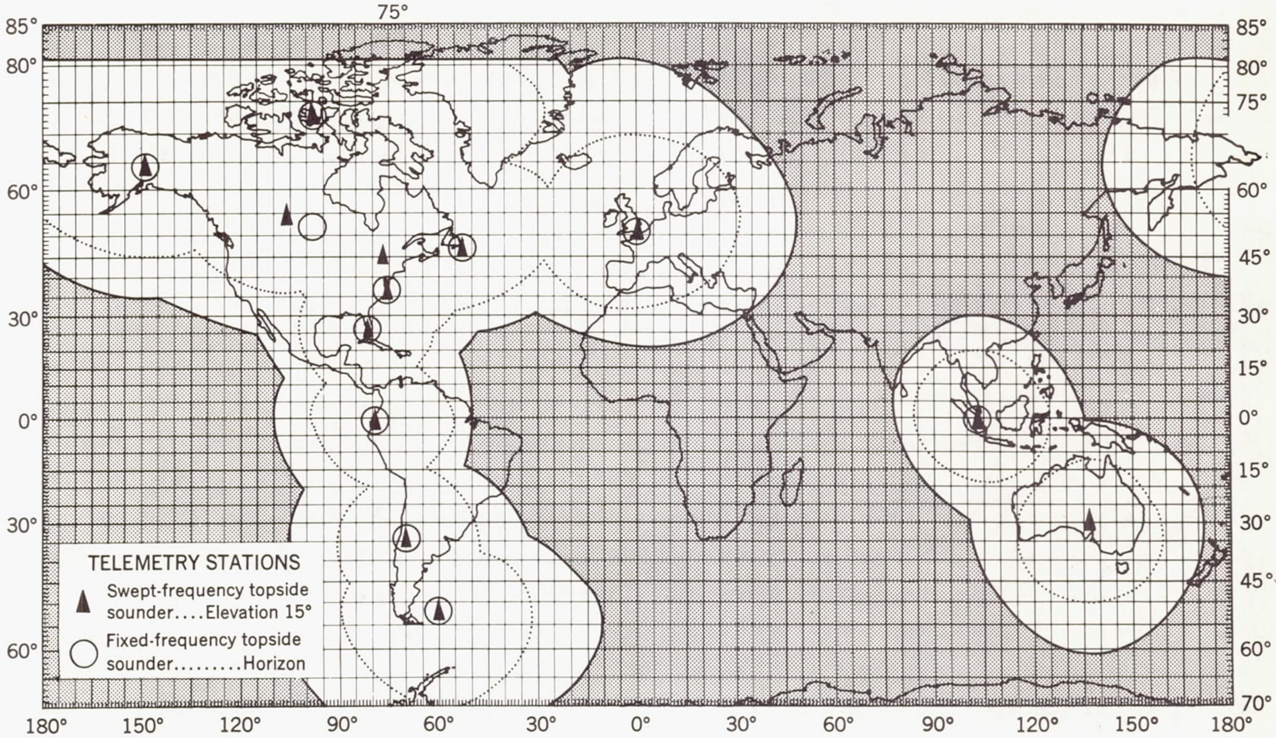

Figure 10—Telemetry coverage for the Topside Sounder Program based on a 1000-km, 80-degree inclination orbit.

Ottawa, Ontario. The United States experimenters, however, will emphasize the study of meridional cross-sections through the ionosphere, using United States and Canadian telemetry stations along the 75°W meridian. The United Kingdom also operates telemetry stations in the South Atlantic; at Winkfield, England; and at Singapore.

The United States topside sounder experiment is illustrated in Figure 11, which shows that downward soundings will be made with six fixed-frequencies ($f_1, \cdots, f_6$). Reflection points for a typical daytime electron density distribution are indicated on the figure, as they would be obtained both from the fixed-frequency topside sounder satellite and from a ground-based sounding station. It is seen that a complete profile can be obtained by simultaneous use of bottomside and topside soundings. Because only six fixed frequencies are used, a complete sounding can be performed in a very short time (0.1 second) corresponding to less than 1 kilometer of horizontal motion of the satellite. Thus, each sounding is performed essentially at a fixed location.

In view of its fast profile acquisition rate, this system is very well suited for determining horizontal irregularities in the ionosphere. However, it provides the vertical structure with only limited resolution. In the Canadian experiment the frequency is swept continuously from 0.5 to 11.5 Mc and a much higher resolution in depth is achieved; but a complete sweep requires about 12 seconds, during which the satellite travels nearly 90 km horizontally. Thus, the swept-frequency soundings provide very accurate profiles where the ionosphere is horizontally stratified; but they are subject to errors due to horizontal gradients in the ionospheric structure.

ROCKET TESTS CONDUCTED IN THE FIXED-FREQUENCY TOPSIDE SOUNDER PROGRAM

Since previous rocket experimentation provides no precedent for the Topside Sounder Program, an important part of the CRPL-AIL effort has been the rocket testing of a simplified topside sounder. The original plan called for only a single daytime firing to a height of about 1000 km during undisturbed ionospheric conditions. But in June 1960, it was decided that it would be scientifically inadvisable to adjust the parameters of the satellite topside sounders on that basis alone: A nighttime firing under disturbed conditions was deemed highly desirable. The final plan, therefore, included a second rocket test to study topside reflection characteristics at a time when spread-F echoes, indicative of disturbed ionospheric conditions, were being observed on bottomside soundings. In the planning of the Canadian experiment the prevalence of spread-F echoes in polar and arctic regions gave considerable importance to knowing the degree to which topside echoes will be degraded during this condition. Since spread-F is regularly observed in the equatorial region, the results of the tests were also useful in planning the United States experiment.

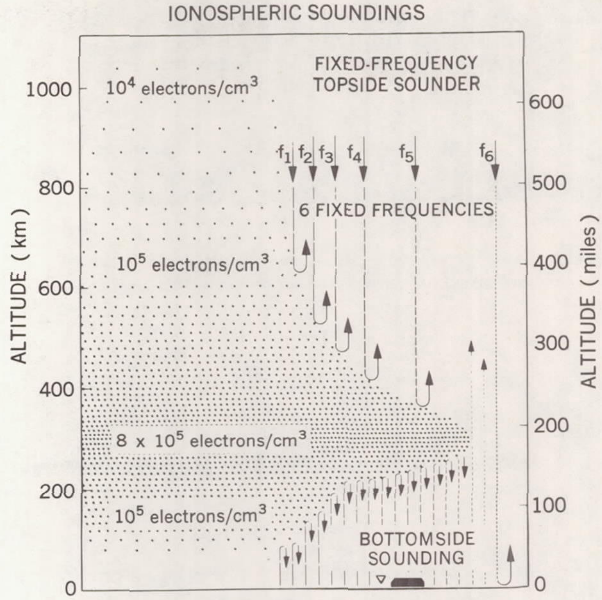

Figure 11—The United States topside sounder experiment.

The daytime test (Reference 15) and the nighttime test (Reference 16) were both conducted successfully and the results were presented at the Eighth Annual National Meeting of the American Astronautical Society in January 1962 (Reference 17). The success of these two experiments was most important to the program, since they demonstrated the feasibility of the topside sounder technique. In both flights the maximum altitude was about 1000 km, which corresponded to the planned altitude for both satellites. Figure 12, a portion of the record taken near the apogee of the daytime flight, shows strong echoes at 4.07 Mc and 5.97 Mc, the two frequencies chosen for that test. This result showed that the power level planned for the sounding transmitter was adequate and that proper design parameters had been used for the instrumentation. The night test subsequently revealed, however, that under spread-F conditions the strength of the received echoes could be enhanced by as much as two orders of magnitude. This required modification of the satellite receiver design to protect against saturation. A most important discovery resulting from these rocket tests was the fact that unusual effects occur when the sounder frequency is the same as one of the local plasma resonances. These effects, which are shown in Figure 13 for daytime tests, occured as the sounder passed through the three reflection levels—the ordinary, extraordinary, and z levels—for each of

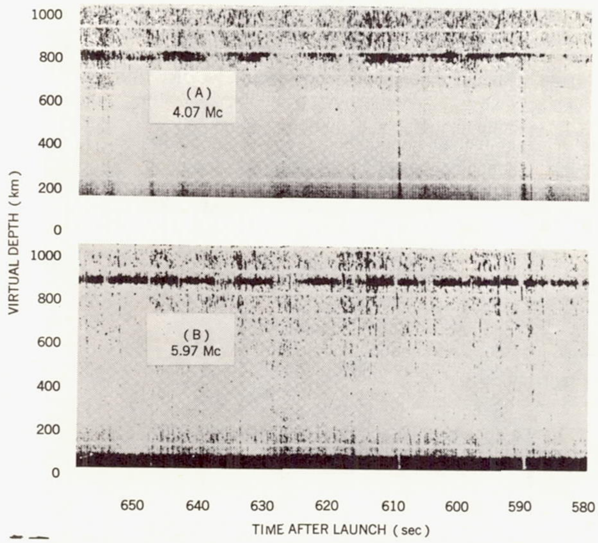

Figure 12—Expanded record of the apogee portion of the daytime rocket test.

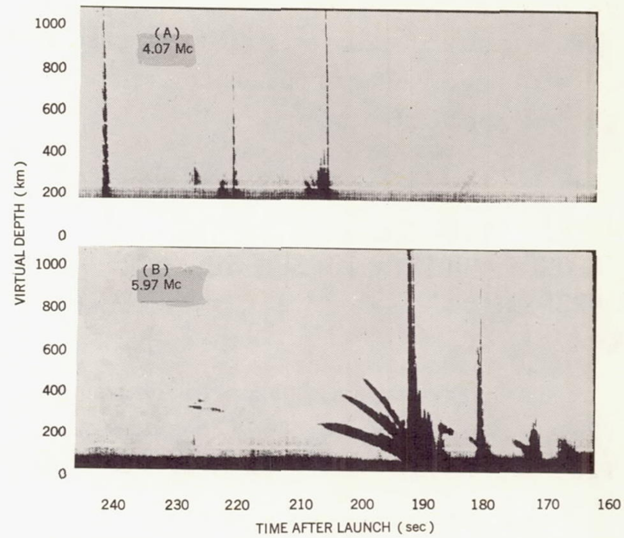

Figure 13—Plasma resonances observed on the daytime rocket tests.

the two frequencies. When one of these conditions is encountered, the sounder provides not only the local electron density, but also the local geomagnetic field. These phenomena have since been observed regularly on the swept-frequency topside sounder ionograms.

ENGINEERING DESIGNS OF THE CANADIAN AND UNITED STATES TOPSIDE SOUNDERS

Both topside sounder satellites consist basically of a pulsed transmitter and a receiver tuned to the transmitter wave frequency to obtain the echo returns from the ionosphere. The receiver's output is telemetered to the ground via a 2-watt transmitter operating in the 136 Mc band. Both satellites operate only when commanded from a telemetry station. They then obtain and telemeter data for a 10-minute period and turn off automatically after this interval to avoid discharging the storage batteries. Solar cells charging nickel-cadmium storage batteries provide the power for both spacecraft: No active temperature controls are used on either.

The two spacecraft employ different techniques of obtaining ionospheric data: The wave frequency of the swept-frequency transmitter is continuously varied from 0.5 Mc to 11.5 Mc at a rate of about 1 Mc/sec. The fixed-frequency sounder transmits at six fixed frequencies: 2.85, 3.72, 4.60, 5.47, 6.82, and 8.57 Mc.* The pulse repetition rates for both sounders is 66 pulses/sec; therefore, both spacecraft acquire data points at the same rate. The telemetry video format has been designed so

*These frequencies were changed to 1.5, 2.0, 2.85, 3.72, 5.47, and 7.22 Mc subsequent to the presentation of this paper.

that the telemetry acquisition and data processing equipment are nearly identical for both spacecraft. Completely transistorized electronics were used in both satellites, and both were designed to have useful lifetimes of about 1 year.

The choice of sounding frequencies is limited by two important quantities. Since any frequency greater than the critical frequency f_0F_2 of the F region of the ionosphere will penetrate through to the ground, the expected maximum value of f_0F_2 sets the upper frequency limit. The lower frequency limit is set by the efficiency of the sounding antenna, which decreases rapidly for an antenna that is small compared to a wavelength. However, for the fixed-frequency topside sounder, it was also convenient to choose frequencies which could be grouped into pairs with equal differences, so that each pair can use the same receiver intermediate frequency. This led initially to the following three pairs of nominal frequencies: 3 and 5 Mc; 4 and 6 Mc; and 8 and 10 Mc; the two frequencies in each pair differing by 2 Mc, the receiver intermediate frequency. Actually, because the launching was postponed to a later date in the solar cycle, the frequencies were revised downward to 2.85 and 3.72 Mc; 4.60 and 5.47 Mc; and 6.82 and 8.57 Mc.* Figures 14 and 15 illustrate the latitude ranges over which the critical frequencies of the F region are expected to exceed the fixed sounding frequencies at noon and midnight for March, April, and May 1963. Although predictions for the later months of 1963 are not yet available, the usefulness of the fixed-frequency topside sounder satellite for profile determination will probably decrease somewhat during the summer and increase again during the following winter.

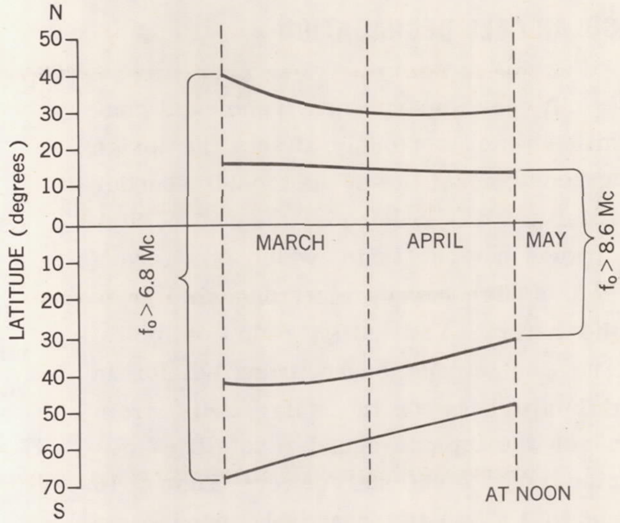

Figure 14—Predicted latitudes at which the critical frequency at noon will exceed 6.8 and 8.6 Mc for the period of March to May 1963.

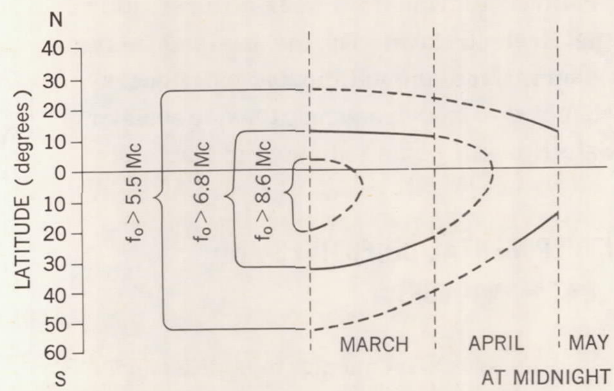

Figure 15—Predicted latitudes at which the critical frequency at midnight will exceed 5.5, 6.8, and 8.6 Mc for the period of March to May 1963.

The important mechanical and electrical characteristics of both spacecraft are summarized in Table 1.

*These frequencies were changed to 1.5, 2.0, 2.85, 3.72, 5.47, and 7.22 Mc subsequent to the presentation of this paper.

SOLAR CELL DEGRADATION

A very important environmental condition which seriously affects the design and operational life of the topside sounder satellites was created by the recent high altitude nuclear tests, which produced a belt of high energy electrons similar to the natural Van Allen radiation belts. These electrons cause a degradation in the efficiency of the solar cells from which the topside sounder satellites derive their electrical power: Figure 16 shows the predicted and observed solar cell degradation for the swept-frequency topside sounder satellite. It is of interest to note that most of the degradation in the performance of an experiment with an operational lifetime of 1 year occurs within the first 40 days. On the basis of these observations, the anticipated daily operation of the fixed-frequency topside sounder satellite will be as indicated in Table 2.

EXPERIMENTAL OBJECTIVES AND DATA ANALYSIS

The swept-frequency topside sounder satellite is unquestionably more sophisticated than the fixed-frequency version of the topside sounder. This has resulted in a much larger and heavier spacecraft requiring a bigger and more expensive launch vehicle. The fixed-frequency topside sounder approach might therefore be more suitable for space applications where size and weight are at a premium, e. g., the initial exploration of the planetary ionospheres. However, there are considerations other than those involving weight, size, and relative complexity. A more important difference is the fact that

Table 1

Characteristics of the Swept-Frequency and Fixed-Frequency Topside Sounder Satellites.

Characteristic	Swept-Frequency Topside Sounder	Fixed-Frequency Topside Sounder
Mechanical:		
Shape	oblate spheroid	truncated cone
Diameter	42 inches	20 inches
Height	34 inches	32-1/2 inches
Weight	319 pounds	95 pounds
Sounding antenna type	2 crossed dipoles 150 feet tip-to-tip 75 feet tip-to-tip	3 crossed dipoles 62 feet tip-to-tip
Telemetry antenna type	turnstile	turnstile
Number of solar cells	6480	2400
Storage battery type	nickel-cadmium	nickel-cadmium
Electrical:		
Sounding frequency	0.45 to 11.5 Mc	2.85, 3.72, 4.60, 5.47, 6.82, and 8.57 Mc
Pulse width	100 μsec	100 μsec
Pulse repetition rate	67/sec	67/sec
2-watt telemetry transmitter frequency	136.089 Mc	136.350 Mc
Orbit:	80° inclination, 1000 km circular	80° inclination, 1000 km circular
Launch Vehicle:	Thor-Agena B	Scout

Table 2

Predicted Daily Operation of the Fixed-Frequency Topside Sounder Satellite Based Upon Anticipated Solar Cell Degradation.

Months After Launch	Hours of Sounding per Day (including 1 hour at night)	Percent of Orbit in Sunlight
0	5.3	100-65
1	3.5	65
2	4.5	100
3	4.4	100
4 to 12	1.8 to 3.2*	65-100**

*Minimum and maximum range of sunlight.

**Minimum and maximum range of percent of orbit in sunlight.

the swept-frequency topside sounder ionograms are better for studying one group of ionospheric problems, fixed-frequency topside sounder ionograms for studying another group.

The swept-frequency topside sounder sweeps at a rate of 1 Mc/sec. The time interval over which reflections are received is about 5 to 10 seconds, depending upon the value of the maximum electron density; and the sweep is repeated every 18 seconds. This means that one sounding is made while the satellite moves 35 to 70 km horizontally, and that there is a distance between successive soundings of 130 km. Since a continous virtual-depth curve is obtained by the swept-frequency technique, this method is best suited for deriving accurate and complete true height profiles, provided that the vertical distribution remains unchanged over the horizontal distance corresponding to a complete sweep. This condition is generally satisfied at middle latitudes under quiet ionospheric conditions. From these profiles, electron-ion temperatures and ionic constituents may be obtained.

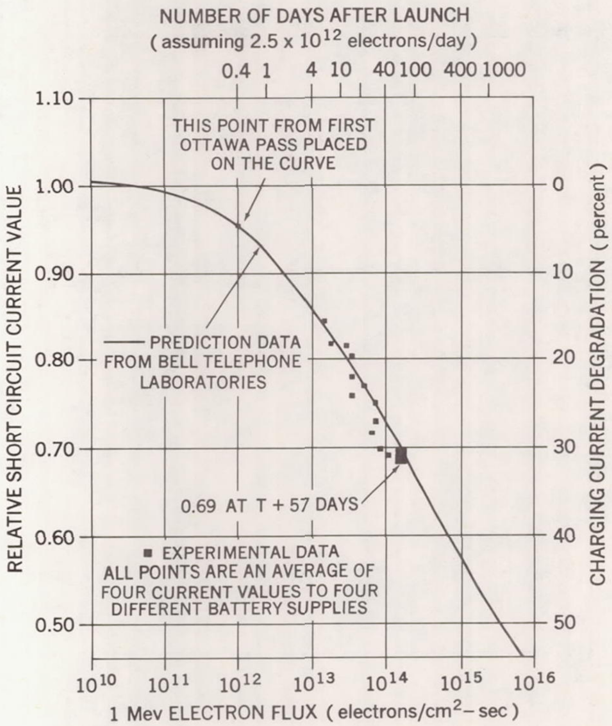

Figure 16—Solar charging current degradation for the swept-frequency topside sounder satellite.

On the other hand, the fixed-frequency topside sounder makes a sounding in depth in 1/10 second, during which time the satellite moves less than 1 km along its orbit. Thus, the fixed-frequency topside sounder ionograms correspond more nearly to the instantaneous vertical electron density distribution beneath the satellite. Since there will be no more than 12 data points (6 ordinary and 6 extraordinary echoes) on each fixed-frequency topside sounder ionogram, the resolution in depth will be limited. However, such resolution is not the primary purpose of the fixed-frequency experiment: it is designed to study the structure of horizontal electron-density gradients and localized irregularities 100 km or less in horizontal extent.

To facilitate these studies, the fixed-frequency topside sounder data are displayed as virtual-depth contours for each sounding frequency, which is related to the electron density at the reflection point by the reflection conditions (Equations 2 through 4). Figure 17 illustrates the virtual depth as a function of frequency, obtained from two consecutive swept-frequency topside sounder ionograms (solid curves) and possible virtual-depth contours for the fixed-frequency topside sounder sounding frequencies (dotted contours). This picture illustrates the difference in the data point distributions. It should be pointed out that these two types of data presentations are identical to those used to study the ionosphere from the ground: pulsed soundings at fixed frequencies (h'-t) and soundings at swept

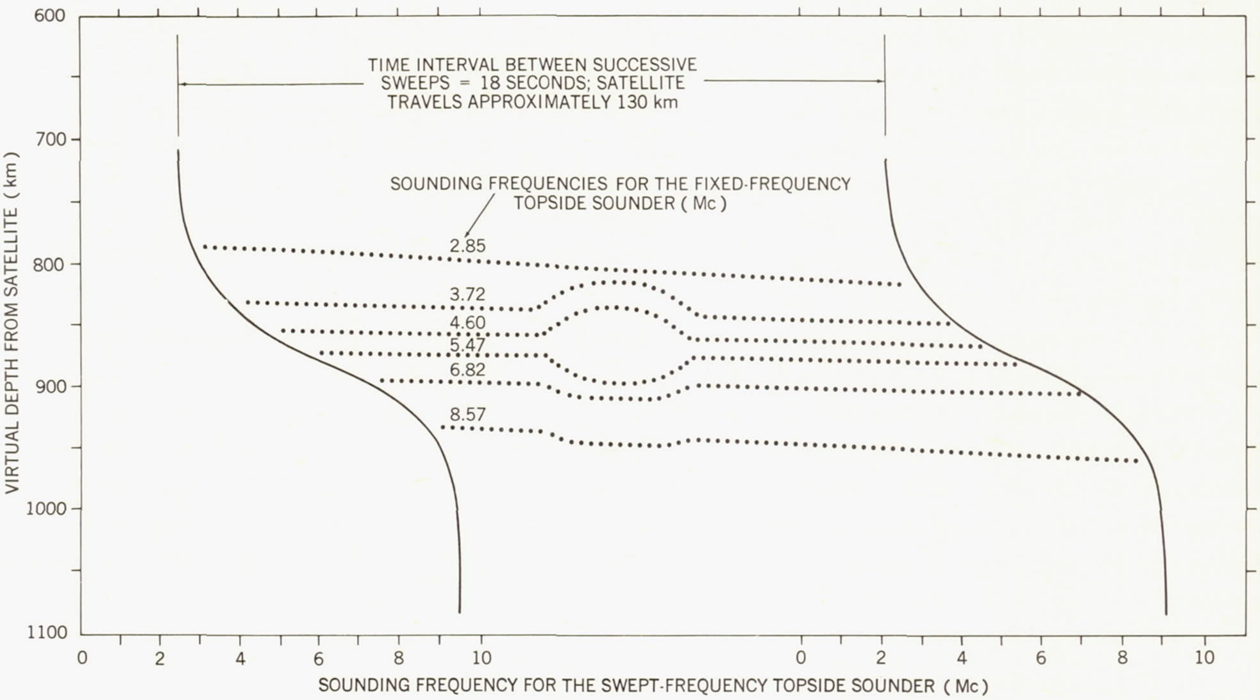

Figure 17—Swept-frequency topside sounder ionograms and simulated fixed-frequency topside sounder data. (Simulated topside sounder data showing successive swept-frequency topside sounder ionograms (solid curves) complemented by fixed-frequency topside sounder virtual-height contours of constant electron density (dotted curves). The number of dots per curve represents 1/3 of the number of data points. The bulge in the dotted curves indicates presence of localized region of enhanced electron density.)

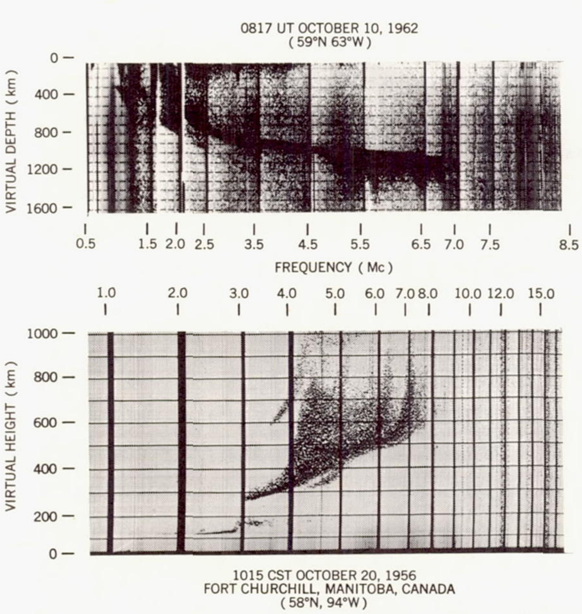

Figure 18—Arctic spread-F.

frequencies (h'-f). The advantage of the fixed-frequency technique is that it can resolve small scale gradients in electron density. For example, Figure 17 shows a localized region of enhanced density; and it is possible to ascertain the altitude, size, and density of this small irregularity. Another type of irregularity known to exist in the ionosphere is a geomagnetic field-aligned irregularity that is most likely associated with the spread F phenomenon. An example of arctic spread-F is shown in the two ionograms of Figure 18: one of these shows spread-F as seen in a swept-frequency topside sounder ionogram; the other shows spread-F in a conventional bottomside sounding.

There may be two quite different kinds of field-aligned irregularities in the F region, which give rise to two different kinds of spread-F.

This theory is based on inferences from bottomside soundings, rocket tests of the fixed-frequency topside sounder, and swept-frequency topside sounder ionograms. The first kind of irregularity consists of columns of *excess* ionization $(+\Delta N_e)$, and spread-F from these is due to scattering of radio waves which impinge normally to the axis of the columns. The second kind consists of columns *deficient* in ionization $(-\Delta N_e)$, and spread-F in this case is due to ducting of radio waves with in the columns (Reference 18). The two types of irregularities occur at both high and low latitudes. Much of the complication of spread-F may be due to the varying intensity and geometrical arrangement of these two types of irregularities.

Because the diameter of these irregularities can be as small as a kilometer or less, swept-frequency soundings do not resolve individual irregularities. The fixed-frequency method, on the other hand, should help clarify the nature of these irregularities, particularly the ducting types, since it will resolve their size, spacing, length, and relation to the latitude and degree of magnetic disturbance, etc. Also, an indication of the magnitude of $\Delta N_e/N_e$ can be obtained from the relative efficiency of ducting on the several fixed frequencies. The need for resolving such horizontal gradients can be seen from Figure 19 (Reference 19) which illustrates the equatorial

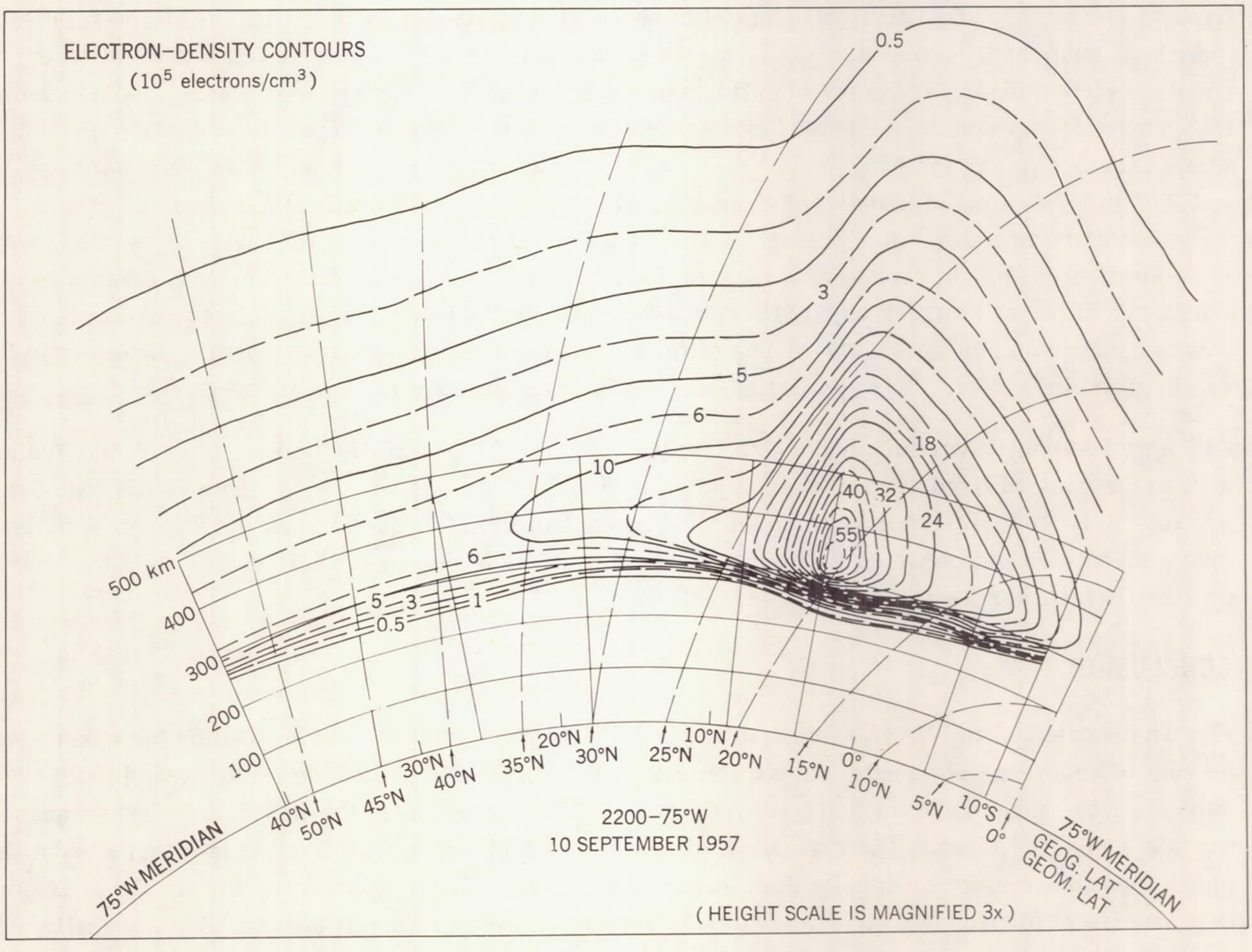

Figure 19—The equatorial anomaly.

anomaly: contours of constant electron density along the 75th West meridian reveal very pronounced horizontal gradients in the equatorial regions.

TRUE HEIGHT ANALYSIS

The virtual depth measured at a particular sounding frequency is proportional to the total round-trip time of the transmitted signal. If the virtual depths are known as a function of frequency, it is possible to derive the true heights of reflections. The heart of any program of analysis lies in the integral of Equation 5 which must be inverted and solved for the true height h. One important difference between the existing methods of data reduction is the number of data points required for the analysis. This difference poses no problem in reducing the continuous swept-frequency topside sounder ionograms, and most methods may be applied with proper modifications. However, some are not well suited for analyzing the fixed-frequency topside sounder data, since there will be a maximum of 12 data points for each ionogram. Even though a maximum of only 12 points can be determined on a true height profile, these points should be enough to define some important ionospheric parameters such as scale height and the latitudinal distribution of ionization. The analysis of the fixed-frequency sounding data will be facilitated by what is already known from the swept-frequency topside sounder data. Fixed-frequency sounding data are being simulated at GSFC and CRPL by choosing virtual depths at the six planned sounding frequencies from swept-frequency topside sounder ionograms, and various methods of analysis are being tested. For example, a lamination method which assumed linear (or exponential) distribution of ionization between data points has been applied at GSFC to these simulated data and compared with the results of a complete analysis of swept-frequency topside sounder ionograms. With this assumption the integral (Equation 5) can be inverted to obtain the true height profile by a method due to Jackson (Reference 20). The true heights so obtained can differ by as much as 50 km from a true height analysis of the swept-frequency topside sounder ionogram. However, the slopes of the profiles and hence the corresponding scale heights are in good agreement. This approach is currently being pursued further at GSFC.

A more sophisticated method under investigation at CRPL and GSFC that lends itself particularly well to the planned fixed-frequency data point distribution is a method which assumes the true height profile can be represented by a polynomial. Upon subsitution into the integral it is possible to derive a matrix set of coefficients which, when multiplied by observed virtual depths, yield the true heights (References 21 and 22).

CONCLUSION

The success of the NASA program of topside ionosphere studies is evidenced by the considerable amount of knowledge obtained from Explorer VIII, Ariel I, and high altitude rocket soundings. Perhaps the most spectacular of these accomplishments to date has been the Canadian swept-frequency topside sounder, Alouette, (References 22 through 36) which will probably yield more data about the upper ionosphere electron density distribution than all the other programs combined. Other important aspects of ionospheric structure hitherto relatively unexplored will be studied synoptically with the launching of the United States fixed-frequency topside sounder satellite in 1963.

What remains to be obtained is a better understanding of the solar control of the earth's upper ionosphere. These sun-earth relationships should be investigated over a period extending from the minimum to the maximum of solar activity. To accomplish this objective it is planned to combine the best features of the various ionospheric satellite experiments in a single ionospheric monitoring satellite.

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