would write examinations that emphasize interpreting data, applying tests to hypotheses, and drawing valid conclusions instead of merely memorizing and regurgitating facts. On the other hand, in many universities the upper positions are still filled by men to whom biology means classification rather than experimentation, morphology rather than biochemistry, organ physiology rather than cell biology. We cannot afford to discard taxonomy, morphology, or gross physiology—they are important parts of biology and will remain so. But they do not comprise all of biology—they are only a diminishing proportion of it. In Japan, as in the United States, the examination system must become more flexible. It must change with the development of science itself, must encourage scientific attitudes and cease defeating the introduction of new disciplines, new outlooks, new subject matter. The universities and the examining boards in some educational systems indeed exhibit a rigor mortis.

On balance, the science education centers in Japan may well represent the most significant educational experiment of our time. Their vitality, which springs from their local relationship to the prefectural schools and their permanent staffs, far exceeds in my own estimation that of most of the summer science institutes held in the United States, which lack that close relation to the local schools and which by their impermanency countenance ill-planned and ill-taught programs that are often little different from the usual summer school sessions. The best summer institutes in the United States are indeed very good, but far too few of them reach a passable standard. That is because, for the most part, their staffs are recruited quickly, teach their favorite subjects without much consideration of their appropriateness or suitability for improving science education in the lower schools, and depart without much contact with other members of the staff. What is needed is serious, continuous, prolonged, hard work devoted to the development of the right sorts of courses for renewing the training of science teachers. The Japanese seem to be achieving just that. We would do well, with our vast resources for the improvement of education, to emulate them. As they have profited by employing and improving upon our NSF-supported programs in science education, we may likewise profit through the establishment of science education centers modeled on theirs.

Ionospheric Topside Sounding

Satellite observations of radio echoes are providing a picture of structure in the upper ionosphere.

W. Calvert

Above an altitude of 300 kilometers, the density of the earth's atmosphere (less than 10^{-10} that at sea level) corresponds to a good laboratory vacuum. Nonetheless, the region still exhibits important physical properties, particularly for the propagation of radio waves.

Solar ultraviolet radiation and particle bombardment ionize the constituents of the upper atmosphere and produce the *ionosphere* (*1*). Extending upward from around 70 kilometers, the ionosphere is usually described in terms of the density of free electrons (Fig. 1). The electron density increases in a series of regular layers (D, E or E_s, F_1, and F_2) up to a peak in the vicinity of 300 kilometers. Above the peak, in the *topside* of the ionosphere, the electron density continuously decreases to very great heights. The fraction of the particles which are ionized is minute at the base of the ionosphere, but increases with height and reaches the order of 10 percent at 1000 kilometers.

Because it is ionized, the ionosphere exhibits the properties of a plasma and profoundly affects the propagation of radio waves (*2*). At times it can reflect back to the earth frequencies as high as 60 Mcy/sec, thus making possible shortwave radio communications over long distances. This practical application enhances the importance of understanding the ionosphere.

The neutral atmosphere, held to the earth by gravity, tends toward an equilibrium distribution in which the density decreases exponentially with height. The scale of the variation (that is, the change in height for an e-fold change in density) is called the *scale-height*. It is proportional to the absolute temperature divided by the mean molecular mass. At the earth's surface the scale-height is about 8 kilometers. Above the peak of the ionosphere, where the mean molecular mass is less and the temperature greater, the scale-height may be tens or hundreds of kilometers.

Except for two factors, similar considerations apply to the ionized components of the topside ionosphere. First, the ions and electrons are bound together by strong electrical forces which prevent their gravitational separation. The two act as a composite gas with a scale-height about twice that of the ions alone. Second, the equilibrium situation pictured above is not always encountered. Dynamic processes (such as the production of ion-electron pairs competing with the loss by recombination or the diffusion of the ionized component through the neutral gas) can control the situation. Nonetheless, in the topside of the ionosphere the electron-density distribution is still essentially exponential, with the scale-height reflecting the temperature and mean ionic mass (*3*).

Furthermore, thermodynamic equilibrium does not always apply. The temperature of the ions and the temperature of the electrons may differ not only from one another, but also from the temperature of the neutral gas. During the day the ions at the peak of the ionosphere may be somewhat hotter than the neutrals, and the electrons may be twice as hot as either the ions or the neutral particles. Toward greater heights in the topside the neutral temperature and the electron temperature

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are each essentially constant but different, whereas the ion temperature increases with height to meet the electron temperature (*4*).

The state of the ionosphere depends on a wide variety of factors. The density of electrons, the ion composition, the temperatures, and even the relative importance of different physical processes are strong functions of time and position. Among other factors, they change with local time, season, solar sunspot activity, and geographic position on the earth.

The ISIS program (International Satellites for Ionospheric Studies) is devoted to the study of the topside of the ionosphere with satellite-borne radio sounders (*5*). Participants in the program include NASA and ESSA (Environmental Science Services Administration) in the United States, the Defence Research Telecommunications Establishment in Canada, and the Radio and Space Research Station in England, in addition to institutions and individuals in a number of other countries.

The purpose of this article is to describe some of the highlights of the ISIS program. I will begin with the topside sounding technique and experiments, and then proceed to the major conclusions in the following areas: the ambient ionosphere and the equatorial anomaly, irregularities in the distribution of electron density, the structure of the high-latitude ionosphere, and finally, various studies of plasma physics.

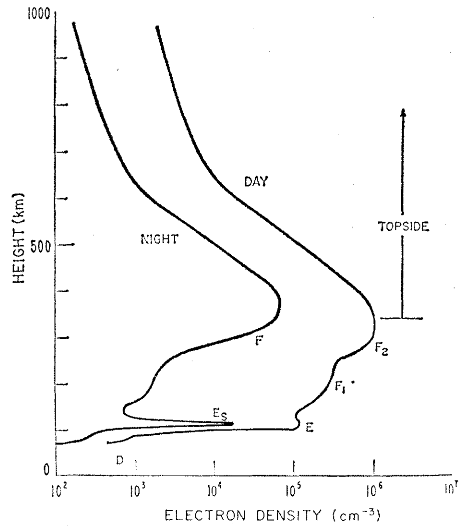

Fig. 1. Vertical profiles of the electron density in the typical *ionosphere*. The topside sounders measure the ionospheric properties above the altitude of maximum density (that is, in the "topside").

Topside Sounding Technique

Free electrons in the ionosphere are responsible for its influence on radio propagation. The electron current induced by the radio wave retards the propagation of energy. If the density of electrons is great enough, the wave may be totally reflected. The critical value of electron density necessary for reflection increases with the square of the frequency: $N = 0.0124\ f^2$ electrons per cubic meter, where f is in cycles per second. The wave can pass vertically through into space if the maximum electron density at the peak of the ionosphere is not this great. The earth's magnetic field modifies the picture in that it makes the ionosphere birefringent. The additional "extraordinary" wave is retarded more and is reflected by a somewhat lesser electron density.

Vertical reflection of pulsed radio waves has been the principal technique of ionospheric exploration for about 40 years (*6*). In this technique radio-wave pulses are transmitted upward into the ionosphere and the delays of the echoes are recorded as a function of frequency. After correction for the slower group velocity within the ionosphere, these delays give the height of reflection, just as radar delays give the range of an aircraft. Since the electron density required for reflection is known, this technique yields the vertical profile of electron density up to the peak of the ionosphere. Approximately 100 vertical-sounding instruments (called ionosondes) are currently being operated at various locations throughout the world.

Pulsed radio ionosondes can measure the electron density only up to the peak of the ionosphere. Radio waves at frequencies high enough to penetrate to greater altitudes are lost into space and produce no echoes. For this reason, the topside of the ionosphere was virtually unexplored before the development of satellites. In recent years topside sounder satellites have been used to complete the observations of ionospheric electron density above the peak.

The topside sounder technique is essentially that of the ground-based pulsed ionosondes, but instrumented for an orbiting satellite. The satellite, placed high in the ionosphere, transmits radio pulses and receives echoes from the underlying ionosphere. The received echoes are then relayed to the ground on a very-high-frequency channel. The purpose, of course, is to measure the vertical electron-density profile downward from the satellite to the peak of the ionosphere, where it should meet the ground-based observations.

The pulsed radio sounders have proved to be versatile. In both the ground-based and satellite situations phenomena more subtle than the simple ionospheric reflection have been identified. For example, both instruments have been used to study irregularities in the density of electrons (meters to kilometers in size) which scatter radio energy back to the sounder over paths oblique to the vertical. The analysis in such a case is indirect. The propagation path and the echo mechanism in the ionosphere must be treated simultaneously to arrive at a consistent interpretation of the echoes. Another example of versatility, peculiar to the satellite sounders, is the discovery of plasma resonances by the Alouette I satellite. The pulsed transmitter, immersed in the ionospheric plasma, was found to excite local oscillations at certain characteristic frequencies which are related to the density of electrons, the density of various ions, and the strength of the magnetic field. Irregularities and resonances will be discussed further below.

The topside sounder experiments have been extraordinarily successful. Two rockets and three satellites have been successfully launched and each has provided unique observations. Details of the satellite experiments are collected in Table 1. Since preliminary rocket observations (*7*) have been surpassed by the satellite observations, the rocket experiments will not be discussed.

Alouette I was constructed by the Canadian Defence Research Telecommunications Establishment and launched by NASA (*8*). Now in its third year of operation, it has provided more than 4000 hours of observations. Alouette I and its younger Canadian companion, Alouette II (*9*), sweep in frequency to permit calculation of electron-density profiles (see Fig. 2). Auxiliary experiments, measuring very-low-frequency radio waves and energetic particles, were included in Alouette I for correlative observations. This was carried a step further when Alouette II and a direct measurements satellite were launched by the same rocket to compare the two kinds of observations while both satellites were close in orbit. Because the data analysis had just begun, the new Alouette II results are not covered in this article.

Table 1. Topside sounder satellites.

Description	Alouette I	Explorer XX	Alouette II*
Launch date	Sept. 1962	Aug. 1964	Nov. 1965
Altitude	960 to 1030 km	870 to 1010 km	500 to 3000 km
Inclination	80°	80°	80°
Frequency (Mcy/sec)	Swept 0.5 to 12	1.50, 2.00, 2.85, 3.72, 5.47, 7.22	Swept 0.2 to 14
Power	100 watts	8 to 45 watts	100 to 300 watts
Pulse	100 μsec	100 μsec	100 μsec
Other experiments	VLF† receiver; particles	Ion probe	VLF† receiver; particles; Langmuir probe

* Launched with Direct Measurement Explorer A, which performs local measurements of composition, ion and electron temperatures, and so forth. † VLF, very low frequency.

Explorer XX, the second of the three satellites to be launched, was constructed by Airborne Instruments Laboratory, launched by NASA, and operated by ESSA. It sounded on six fixed frequencies in rapid sequence to provide a finer spatial resolution than the Alouettes (*10*). Completing its sounding cycle in a tenth of a second, rather than 10 or 20 seconds, it could distinguish details as close as 1 kilometer along its orbit. However, the necessary limitation to only six frequencies precludes the reliable calculation of electron-density profiles. Explorer XX terminated operation as this article was being written. In 16 months it had obtained 1000 hours of topside observations.

It is planned to continue the topside sounder observations for the remainder of a solar sunspot cycle. The subsequent satellites will increase in sophistication and will benefit from the experience with their predecessors. ISIS-A, scheduled for 1967, will combine fixed-frequency and swept-frequency sounding and will include a number of direct measurements on the same spacecraft.

It would be incorrect to imply that topside sounder satellites are alone responsible for advancing our understanding of the topside of the ionosphere over the past few years. Among other techniques, incoherent scatter observations and satellite direct measurements have also proved invaluable.

Incoherent scatter relies on the very weak signal scattered back by electrons at radio frequencies high enough to freely penetrate the ionosphere (*11*). Extremely large antennas and high transmitter powers are required to observe this weak signal. The technique, implemented at four locations from the equator to the auroral zone, yields not only the electron density but also the electron temperature, the ion temperature, and the ion composition.

Direct satellite measurements involve diverse and specialized instruments to measure the characteristics of the medium surrounding the satellite (*12*). The densities and temperatures of electrons, ions, and neutrals, the total density, the ion composition, and the local magnetic field are among the quantities sought. In spite of the difficulties of implementation and calibration (common to their laboratory counterparts) such measurements are providing a great deal of valuable data. However, they do not make measurements over a large height range as do the topside sounders and the incoherent scatter devices.

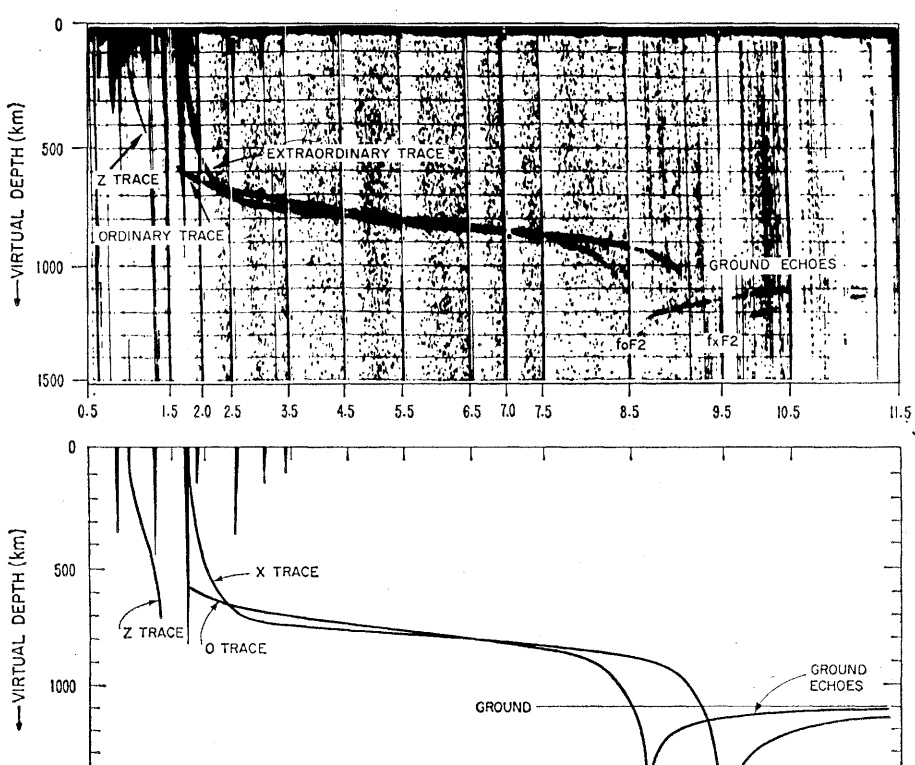

Fig. 2. Alouette I satellite observations of radio echoes from the topside of the ionosphere. The echo delays increase downward, and the frequency increases toward the right. All three traces predicted by propagation theory are observed, as are reflections from the ground at high frequencies.

The Ambient Ionosphere

The Alouettes are more than adequately fulfilling their purpose in providing vertical electron-density profiles. Over one million swept-frequency records have already been recorded. A portion of them have been routinely analyzed and the results are published (*13*); others are analyzed as the need arises.

The calculation of electron-density profiles is a straightforward integration based on the known variation of refractive index with frequency, magnetic field, and so forth. Therefore it was surprising that the topside profiles did not always match with those obtained from the ground. There remains a small discrepancy, a few times the observational error, in some of the computed topside profiles (*14*). Figure 3 is a typical case where the Alouette profile disagrees with both incoherent scatter and conventional ionosonde measurements near the ionosphere peak. Off-vertical propagation (into large-scale ripples in the ionosphere) is a possible explanation of the discrepancy, but the matter is still an open question. The discrepancy limits the precision of Alouette I electron-density measurements to within 10 percent at the peak of the ionosphere.

The vertical uniformity of the ionosphere over quite a few kilometers near the satellite permits the accurate measurement of local electron density by upward extrapolation of echo traces like those in Fig. 2. The local density thus measured from the frequencies where the echoes cut off is felt to be accurate to 2 percent and independent of any perturbation caused by the satellite. The accuracy of the electron-density measurement therefore varies with height from about 10 percent at the ionosphere peak to about 2 percent at the satellite.

An immediate application of the top side electron-density profiles is the determination of temperature and composition from the scale-height or, better, from the overall shape of the profile (*15*). For this analysis hydrostatic equilibrium is assumed. Although such an assumption is sometimes questionable, this approach has been fruitful at low and middle latitudes. It has been found that the temperature (an average for electrons and ions) is in the range 800° to 2000°K, and increases with latitude. At a given height, a greater fraction of heavier ions is found at higher latitudes.

A further use of the profile has been in the study of the equatorial anomaly. In this anomaly the electron density at the peak of the ionosphere has a characteristic maximum on either side of the magnetic dip equator. It is an anomaly to the simple theory of formation of the ionosphere by production and loss, because that theory would predict only a single maximum where the sun is directly overhead.

The topside sounders have revealed a clear picture of the equatorial anomaly (*16*). At the 1000-km altitude of Alouette I or Explorer XX the maximum electron density occurs at the magnetic dip equator. The contours of electron density in a vertical north-south plane, an example of which is Fig. 4, form a dome centered on the magnetic equator. In the afternoon, when the anomaly is strongest, a ledge forms within which the electron-density contours are often surprisingly horizontal. This ledge lies along the magnetic field lines which connect the enhanced densities toward the north and south.

The dome and ledge structures are important clues to the explanation of the equatorial anomaly. While the explanation is not complete, certain conclusions have proved interesting (*17*). For example, it appears that hydrostatic equilibrium exists along magnetic field lines. The question then becomes one of the division of electron density among the various field lines. Whether or not electric fields within the ionosphere are responsible for a redistribution of density (and thus responsible for the anomaly) is not yet clear.

Irregularities

Ionospheric irregularities are variations in electron density, of up to a few percent, and of a size which depends on the method of observation. Because of the large mobility of ions along the magnetic field, relative to that across, the irregularities are usually greatly elongated along the field.

As with ground-based ionosondes, the topside-sounder observations of irregularities involve the interpretation of the additional echoes they produce. Most of the successful echo interpretations have relied heavily on the field-aligned geometry. For frequencies around 1 Mcy/sec, the echoes fall into two categories (see Fig. 5). Irregularities thinner than the wavelength (width < ½ km) produce echoes essentially perpendicular to their long dimension by coherent scattering. The directional property comes from the requirement that echo wavelets from different parts of the irregularity must add in phase to produce a strong echo. Irregularities thicker than wavelength (width > ½ km) can produce ducted echoes by guiding radio energy along the magnetic field. When the ducted waves are launched from a satellite while it is within an irregularity, extremely strong echoes are obtained. Weaker ducted echoes may be obtained when the satellite is above the irregularity for propagation paths which couple to the irregularity at lower heights.

The topside sounders have yielded many observations of irregularities, by both ducting and scattering (*18*). At low and middle latitudes irregularities occur primarily at night; at high latitudes they occur at all times. As with the previous ground-based observations, an intense band of irregularities was found in the nighttime equatorial region.

The topside sounders have proved that the duct irregularities can be continuous along the magnetic field between the northern and southern hemispheres. Such irregularities were first observed near the magnetic equator with Alouette I (*19*). Later they were observed up to 40° north and south of the magnetic equator with Explorer XX (*20*). These continuous irregularities, called conjugate ducts, are as long as 30,000 km between reflection points and are only a few kilometers wide. Furthermore, strong conjugate echoes were obtained with transmitter pulses as weak as 8 watts, indicating that propagation along the conjugate ducts must be extremely efficient. Conjugate ducts are most common in the morning between 0200 and 1000 hours local

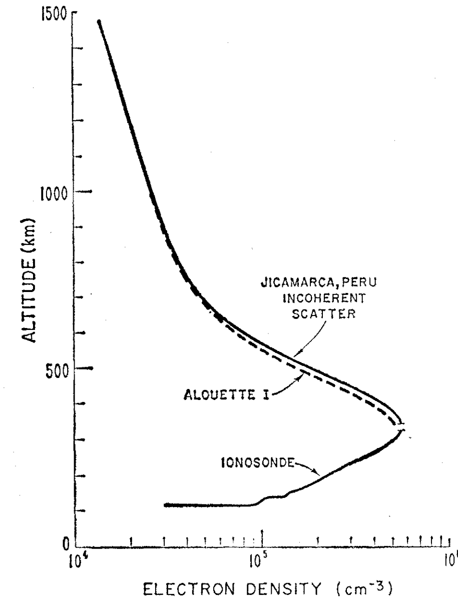

Fig. 3. Simultaneous Alouette I and ground-based measurements of electron density over South America, about 2015 U.T., 28 May 1964. The agreement is good, except for a small discrepancy near the peak of the ionosphere.

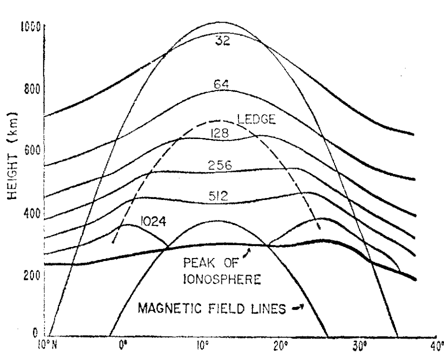

Fig. 4. A topside-sounder observation of the equatorial anomaly over South America, 1550 local time, 17 February 1963. The distribution of electron density in the anomaly is controlled by the earth's magnetic field. (Unit of electron density: 10^3 cm^{-3}.)

Table 2. Electron plasma-wave resonances. Definitions: N, density of electrons; e, electronic charge; m_e, electronic mass; B, magnetic field strength; ϵ_o, permittivity of free space.

Resonance	Frequency
Plasma	$\omega_N = (Ne^2/\epsilon_0 m_e)^{\frac{1}{2}}$
Electron cyclotron	$\omega_H = eB/m_e$
Electron cyclotron harmonics	$n\omega_H, n = 2, 3, \ldots$
Electron hybrid	$\omega_T = (\omega^2_N + \omega^2_H)^{\frac{1}{2}}$
Electron hybrid harmonic	$2\omega_T$

time. The relationship between these conjugate ducts, observed at 1 to 4 Mcy/sec, and the whistler ducts (*21*), observed at 2 to 30 kcy/sec and at higher latitudes, is not yet clear.

High Latitudes

The topside sounders have proved especially valuable at high latitudes, where the horizontal electron-density structure is too small to be resolved by any reasonable network of ground-based ionosondes. Figure 6 is an example of the Alouette I observations of such structure. Around 50° to 60° geomagnetic latitude, an east-west trough of greatly depressed electron density is observed at night (*22*). The trough appears to be a major feature of the night-time ionosphere which lasts from about 1800 to 0600, magnetic time. Its width is characteristically 500 to 1000 km. Inside the trough the electron density is drastically reduced, by as much as a factor of two, at 1000 km altitude, and by as much as an order of magnitude at the peak of the ionosphere. Other satellite measurements indicate that the temperature (at least the electron temperature) is much greater within the trough (*23*).

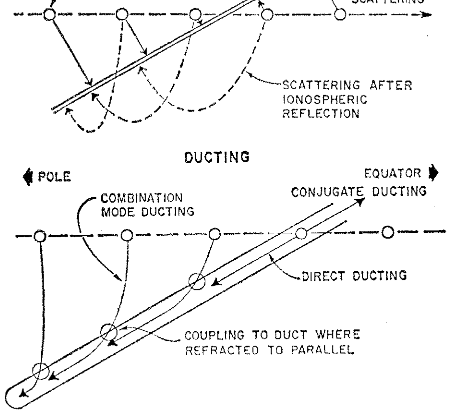

Fig. 5. The geometry of echoes from electron-density irregularities observed by the topside satellites. Thin irregularities *scatter* the radio energy. Thick irregularities *duct* the radio energy along the magnetic field—even to the conjugate reflection point in the opposite hemisphere.

At latitudes just poleward of the trough, the ionosphere places even more serious demands on the resolution of measuring instruments. It has been found that the electron density can vary by a factor of two within a few kilometers, and occasionally within a few hundred meters, across the magnetic field. The electron density is usually as high as that observed equatorward of the trough. It is attractive to relate these large, irregular densities to the precipitation of auroral particles (*24*).

At latitudes above the auroral zone, the polar cap electron density remains relatively high. It is usually much smoother than that either in the trough or in the auroral zone itself.

Plasma Studies

In addition to the ionospheric measurements, the topside sounders have proved very useful in the observation of plasma wave phenomena. This, and a parallel situation with orbiting very-low-frequency receivers, has focused attention on the use of the ionosphere for plasma wave studies.

The ionosphere is an attractive plasma because a number of convenient approximations actually pertain to the topside region. Except for the surface of the satellite itself, the ionospheric plasma is virtually infinite and is not disturbed by boundaries. It is often essentially uniform for many kilometers. The characteristic frequencies of the plasma are convenient: megacycles per second for electron phenomena; hundreds of cycles to kilocycles per second for ion phenomena. Above 1000 km the frequencies of particle collisions (which impede coherent plasma interactions) are orders of magnitude less than these characteristic frequencies. It is truly an unbounded, uniform, collisionless plasma. In addition, it is a plasma for which the electron density and magnetic field can easily be measured to an accuracy of 2 percent.

The confirmation of the cold-plasma dispersion relations by the topside sounder experiments is usually taken for granted. The pattern of echoes observed by the Alouettes (Fig. 2), for each of the "o," "x," and "z" modes, is consistent with the theory. Furthermore, true-height calculations based on different modes always give consistent results. Not only is there internal consistency between the three modes, but there is also agreement with the incoherent-scatter measurements (such as that in Fig. 3 from the satellite altitude downward for a few hundred kilometers).

In addition to the well-understood electromagnetic echoes, the topside sounders have revealed that the ionospheric plasma is resonant at certain characteristic frequencies (*25*). These frequencies, listed in Table 2, are related to the electron plasma frequency ω_N (proportional to the square root of the electron density) and the electron cyclotron frequency ω_H (proportional to the magnetic field strength). On the Alouette records, such as Fig. 2, they appear as "spikes" extending downward from the transmitter pulse. On the Explorer XX records the spikes are greatly expanded and a fringe pattern is revealed (Fig. 7) (*26*). The fringe patterns are not yet fully understood. It is felt that they must be beats between different components of the oscillations near the satellite (either in frequency or in wave number) which are excited simultaneously.

Although the theoretical explanation (*27*) of the resonances is incomplete, it appears clear that the resonances are caused by plasma waves with group velocities so small that the oscillations in the nearby plasma can travel with the satellite. For the resonances at the plasma frequency and at the upper hybrid frequency the waves are essentially electrostatic, in which the restoring force of the oscillation comes from electrostatic forces of charge separation. The cyclotron resonances are similar, but with the additional subtlety of phase-bunching of the electrons in their gyration about the magnetic field.

The very-low-frequency receivers on the Alouette satellites, as well as those on a few other satellites, have also revealed interesting plasma-wave phenomena involving various ion waves (*28*). These phenomena, the lower-hybrid resonance band and the ion whistlers, have already proved their usefulness in the measurement of ion composition and temperature.

The lower-hybrid resonance band is very-low-frequency noise excited in the vicinity of the satellite by naturally occurring fractional-hop whistlers. The frequency spectrum of the noise forms a band with a low-frequency limit at the local lower-hybrid resonance frequency. Most of the noise bands decrease in frequency toward the poles. This indicates the change in composition to heavier ions at higher latitudes. With the additional measurement of local electron-density by the Alouette sounder, quantitative limits on the ion composition have been established from the lower-hybrid resonance observations (*29*).

The ion whistlers received in a satellite are separate branches of the whistler signal caused by the influence of ions on the wave dispersion relations. The main (electron) whistlers are received as descending tones. The ion whistlers branch away from the main whistlers at a "crossover" frequency and ascend in tone toward the ion cyclotron frequency. Ion whistlers have been observed for both hydrogen and helium (*30*). Since the crossover condition depends on the relative concentration of different ions, the crossover frequencies provide a measure of the local composition. It is likely that the observation of ion whistler phenomena will develop into a powerful measurement technique.

These plasma wave studies have opened a new avenue for plasma research, that is, the performance of primarily plasma physics experiments, rather than geophysical experiments, in the ionosphere. It is surprising that the topside sounder and very-low-frequency experiments have been so fruitful in this respect, in view of the fact that the instruments were designed for other purposes.

Summary

Over the past few years, the satellite topside sounders have significantly contributed to the understanding of the upper ionosphere. A great quantity of radio echo data has been accumulated, from which the ionospheric electron-density distribution can be determined.

The topside measurements of electron density essentially agree with similar measurements from the ground, except for an occasional 10-percent discrepancy near the peak of the ionosphere. While horizontal non-uniformity is a likely cause, this discrepancy has not yet been adequately explained.

The electron-density scale heights measured at a constant altitude indicate both a higher temperature and a heav-

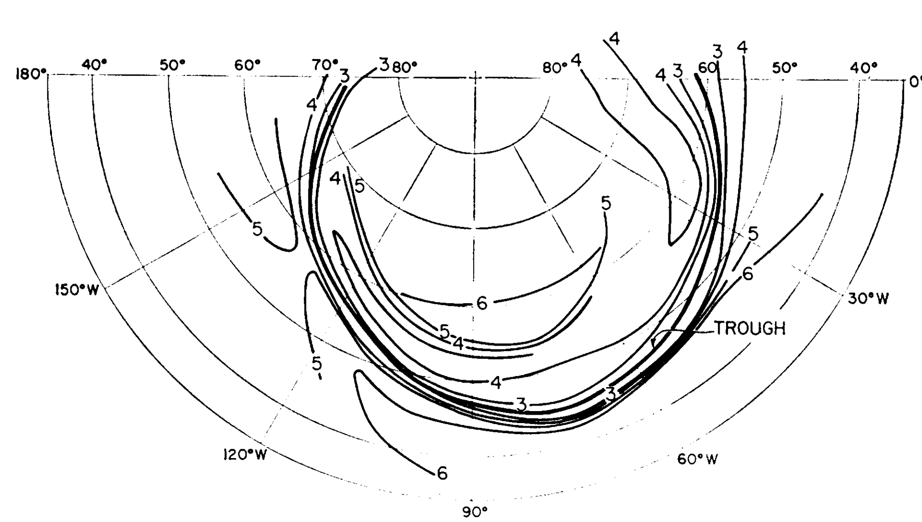

Fig. 6. A contour map, drawn from Alouette I observations on successive orbits, which shows a deep electron-density *trough* at high latitudes. The extraordinary penetration frequencies (in megacycles per second) shown here indicate nearly an order-of-magnitude density decrease at the peak of the ionosphere. [Adapted from the work of D. B. Muldrew (*22*)]

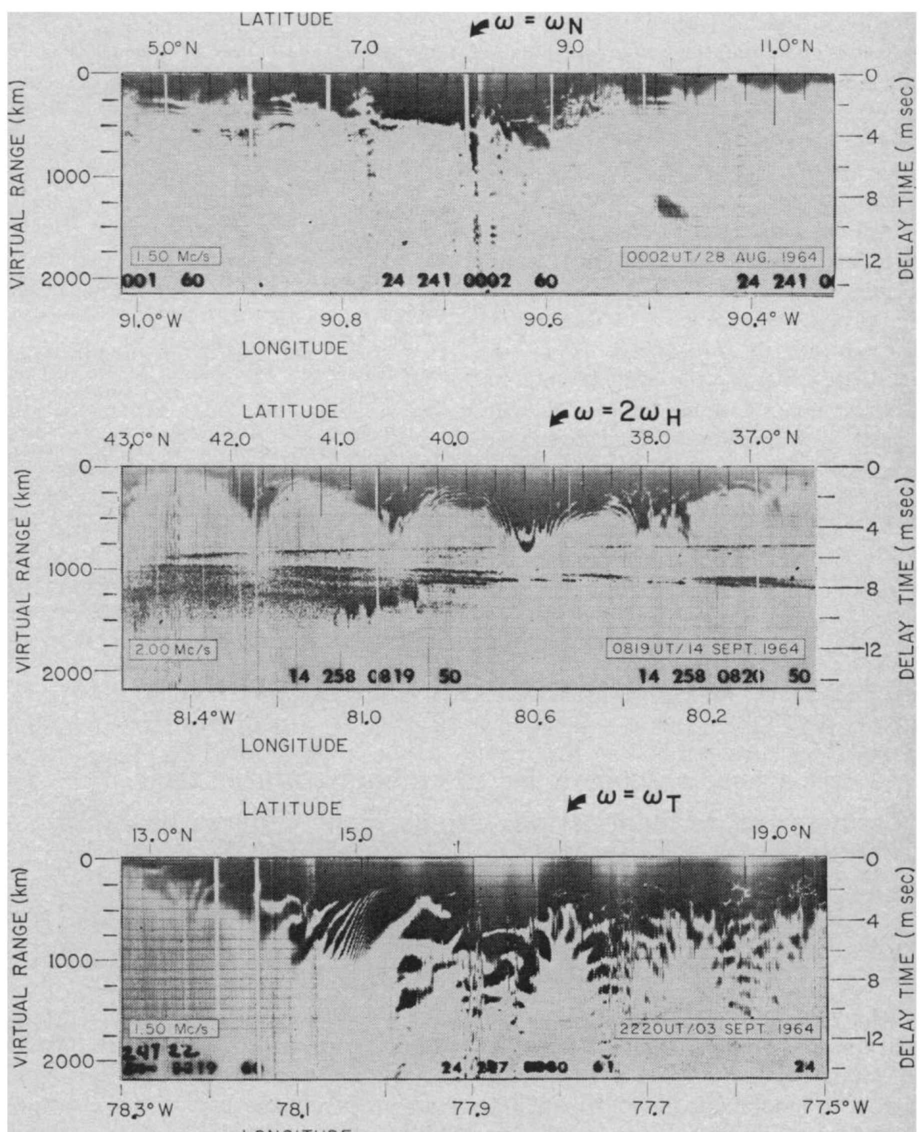

Fig. 7. Fringe patterns of the *plasma resonances* observed by Explorer XX. These resonances, which appear as downward spikes in Fig. 2, are attributed to electrostatic plasma oscillations in the vicinity of the satellite.

ier mean ion mass at high latitudes. At low latitudes the topside measurements have shown the detailed latitudinal structure of the equatorial anomaly, demonstrating control by the geomagnetic field.

A variety of electron-density irregularities have been studied. Most are greatly elongated along the magnetic field, and produce echoes either by lateral scattering, if they are thin, or by longitudinal ducting, if they are thick. Some of the thick irregularities are continuous between the hemispheres and support conjugate echo propagation.

The topside sounders have revealed the complex structure of the ionosphere near the auroral zone and at higher latitudes. At night an east-west trough of greatly reduced electron density occurs equatorward of the auroral zone. At the auroral zone itself the electron density is high and quite variable, both in space and time. The electron density at the polar cap within the auroral zone is often uniform and smooth. Ionospheric irregularities are common in the area of the trough and the auroral zone.

Among other satellites, the topside sounders have been used in various plasma studies involving the excitation and propagation of waves. These studies suggest that the ionosphere is an appropriate region for future plasma physics investigations, especially with rocket and satellite payloads designed specifically for that purpose.

References

1. J. A. Ratcliffe, *Physics of the Upper Atmosphere* (Academic Press, New York, 1960); K. Davies, *Natl. Bur. Std. U.S. Monograph 80*, "Ionospheric Radio Propagation" (1965); C. O. Hines, I. Paghis, T. R. Hartz, J. A. Fejer, *Physics of the Earth's Upper Atmosphere* (Prentice-Hall, Englewood Cliffs, N.J., 1965); R. E. Bourdeau, *Science* **148**, 585 (1965).
2. J. A. Ratcliffe, *The Magnetoionic Theory* (University Press, Cambridge, England, 1962); K. G. Budden, *Radio Waves in the Ionosphere* (University Press, Cambridge, England, 1961).
3. G. L. Nelms, *Can. J. Phys.* **41**, 202 (1963); P. R. Arendt, *Nature* **208**, 443 (1965); A. C. Aikin and S. J. Bauer, in *Introduction to Space Science*, W. N. Hess, Ed. (Gordon and Breach, New York, 1965), p. 133.
4. W. B. Hanson, in *Space Research*, W. Priester, Ed. (North-Holland, Amsterdam, 1963), vol. 3, p. 282.
5. J. E. Jackson, in *Electron Density Distribution in the Ionosphere and Exosphere*, E. Thrane, Ed. (North-Holland, Amsterdam, 1964), p. 325; J. H. Chapman, in *Progress in Radio Science*, G. M. Brown, Ed. (Elsevier, Amsterdam, 1965), vol. 3, p. 264.
6. S. C. Gladden, *Natl. Bur. Std. U.S. Tech. Note 28* (1959).
7. R. W. Knecht, T. E. VanZandt, S. Russell, *J. Geophys. Res.* **66**, 3078 (1961); R. W. Knecht and S. Russell, *ibid.* **67**, 1178 (1962); W. Calvert, T. E. VanZandt, R. W. Knecht, G. B. Goe, in *Proceedings of the International Conference on the Ionosphere*, A. C. Stickland, Ed. (Inst. of Physics and the Physical Soc., London, 1963), p. 324.
8. E. S. Warren, *Can. J. Phys.* **40**, 1692 (1962); J. H. Chapman, *J. Spacecraft Rockets* **1**, 684 (1964).
9. G. L. Nelms, R. E. Barrington, J. S. Belrose, T. R. Hartz, I. B. McDiarmid, L. H. Brace, *Can. J. Phys.*, in press.
10 W. Calvert, R. W. Knecht, T. E. VanZandt, *Science* **146**, 391 (1964).
11. K. L. Bowles, *ibid.* **139**, 389 (1963).
12. The three books in reference (*1*) describe a wide variety of direct measurements and discuss their results, as does *Introduction to Space Science*, W. N. Hess, Ed. (Gordon and Breach, New York, 1965).
13. The Defence Research Telecommunications Establishment (Shirley Bay, Ottawa, Ontario, Canada) currently publishes Alouette I processed data in two forms: *ALOSYN* contains directly scaled local and peak quantities, *N(h)* contains complete vertical electron-density profiles. The NASA Ames Research Center (Palo Alto, Calif.) will be publishing vertical electron-density profiles.
14. R. Cohen and T. E. VanZandt, in preparation.
15. R. W. Knecht and T. E. VanZandt, *Nature* **197**, 641 (1963); W. Calvert, H. Rishbeth, T. E. VanZandt, *IG Bull. 83*, reprinted in *Trans. Am. Geophys. Union* **45**, 398 (1964); J. O. Thomas, M. J. Rycroft, L. Colin, K. L. Chan, in *Electron Density Profiles in the Ionosphere and Exosphere*, J. Frihagen, Ed. (North-Holland, Amsterdam, 1966), p. 322.
16. G. E. K. Lockwood and G. L. Nelms, *J. Atmospheric Terrest. Phys.* **26**, 569 (1964); J. W. King, P. A. Smith, D. Eccles, G. F. Fooks, H. Helm, *Proc. Roy. Soc. London Ser. A* **281**, 464 (1964).
17. T. E. VanZandt, R. B. Norton, H. Rishbeth, private communication; R. J. Moffett and W. B. Hanson, *Nature* **206**, 705 (1965); E. N. Bramley and M. Peart, *J. Atmospheric Terrest. Phys.* **27**, 1201 (1965).
18. L. E. Petrie, *Can. J. Phys.* **41**, 194 (1963); G. E. K. Lockwood and L. E. Petrie, *Planetary Space Sci.* **11**, 327 (1963); W. Calvert and C. W. Schmid, *J. Geophys. Res.* **69**, 1839 (1964).
19. D. B. Muldrew, *J. Geophys. Res.* **68**, 5355 (1963).
20. B. T. Loftus, T. E. VanZandt, W. Calvert, *Ann. Geophys.*, in press.
21. R. A. Helliwell, *Whistlers and Related Ionospheric Phenomena* (Stanford Univ. Press, Stanford, Calif., 1965).
22. D. B. Muldrew, *J. Geophys. Res.* **70**, 2635 (1965).
23. L. H. Brace and B. M. Reddy, *ibid.*, p. 5783.
24. D. S. Lund, W. Calvert, T. E. VanZandt, in preparation.
25. G. E. K. Lockwood, *Can. J. Phys.* **41**, 190 (1963); **43**, 291 (1965); W. Calvert and G. B. Goe, *J. Geophys. Res.* **68**, 6113 (1963).
26. W. Calvert, in *Electron Density Profiles in the Ionosphere and Exosphere*, J. Frihagen, Ed. (North-Holland, Amsterdam, 1966), p. 281; W. Calvert and T. E. VanZandt, *J. Geophys. Res.* **71**, 1799 (1966).
27. J. A. Fejer and W. Calvert, *ibid.* **69**, 5049 (1964); J. P. Dougherty and J. J. Monaghan, *Proc. Roy. Soc. London Ser. A* **289**, 214 (1965); W. D. Deering and J. A. Fejer, *Phys. Fluids* **8**, 2066 (1965); P. A. Sturrock, *ibid.* p. 88; J. Nuttall, *J. Geophys. Res.* **70**, 1119 (1965); ———, *Phys. Fluids* **8**, 281 (1965).
28. J. S. Belrose and R. E. Barrington, *Radio Sci.* **69D**, 69 (1965); D. A. Gurnett *et al.*, *J. Geophys. Res.* **70**, 1665 (1965).
29. R. E. Barrington, J. S. Belrose, G. L. Nelms, *J. Geophys. Res.* **70**, 1647 (1965).
30. R. E. Barrington, J. S. Belrose, W. E. Mather, *Nature*, in press.

Internal Clocks and Insect Diapause

Insects use photoperiodic information to bring their growth and dormant periods into harmony with season.

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Many insects have internal "clocks" that measure with utmost precision the duration of light and dark in each day. This photoperiodic information is used by the insects to perceive changes in season. The clock is especially important to phytophagous insects living in temperate zones, for they must adapt to seasonal change or perish. Their growth and reproductive phases must be synchronized with favorable seasons of climate and with the availability of host plants, and unfavorable seasons must be bridged by a dormant condition called diapause if the population is to survive. Furthermore, the insects must make preparations for the unfavorable season well in advance of its occurrence. Changes in the lengths of the days provide the information they need in order to make such adjustments.

Seasonal Synchronization

Since Garner and Allard (*1*), Marcovitch (*2*), and Rowan (*3*) discovered that the photoperiod plays an important role in enabling many plants and animals to synchronize their activities with the seasons, many examples of this phenomenon in insects have been reported (*4–6*). Withrow computed that organisms must have a clock that measures day length with a precision of 1 to 3 percent if they are to measure

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