Meetings

Ionospheric Sporadic E: Cause and Structure

The second seminar on the Cause and Structure of Temperate Latitude Sporadic E was held at Vail, Colorado, 19–22 June 1968. (The first seminar was held in Estes Park, Colorado, in 1965.) The seminar was again hosted by the Environmental Science Services Administration and the National Center for Atmospheric Research, and was additionally supported by the Voice of America.

Participation in the seminar was by invitation; approxmately 40 scientists from Australia, Canada, Germany, Japan, and the United States attended.

Topics and reviewers of the major sessions were as follows: Prediction and Morphology (K. Rawer, Ionosphären Institut, Breisach, F. R. Germany); Structure: Radio Measurements (J. D. Whitehead, University of Queensland, Brisbane, Australia); Structure: Rocket Observations (L. G. Smith, GCA Corporation, Bedford, Massachusetts); Composition and the Role of Metallic Ions: Rocket Observations (C. Y. Johnson, Naval Research Laboratory, Washington, D.C.); Composition and the Role of Metallic Ions: Laboratory Measurements (E. E. Ferguson, ESSA, Research Laboratories, Boulder, Colorado); Wind and Sporadic E (N. W. Rosenberg, AFCRL, Bedford, Massachusetts); and Theory of the Cause (W. I. Axford, University of California, La Jolla).

The final session was devoted to an assessment of the field and the formulation of future plans. Whitehead, Rawer, and D. R. Layzer (Harvard) led this session.

In an effort to describe the behavior of the most striking cases of sporadic E, "intense sporadic E" (foEs greater than 10 or 15 Mhz, where foEs is the ordinary ray critical frequency of Es) has been examined in terms of its seasonal, diurnal, and geographic variations; geomagnetic correlation; and year-to-year variability. Various mechanisms that have been proposed as causes of sporadic E are then rated in terms of their ability to explain the observed statistics. It appears probable that a series of boundary conditions need to be fulfilled to produce intense sporadic E.

To make a significant contribution to the understanding of the formation of Es layers or blobs, the choice of fbEs (the blanketing frequency of Es) was also emphasized, and various morphological features of blanketing Es have been analyzed. First, diurnal, seasonal, latitudinal, and longitudinal variations on a global scale have been obtained, and then significant solar-cycle effects on blanketing Es have been established. Geomagnetic storm effects on blanketing Es and geomagnetic variations associated with blanketing Es formation have also been examined.

The viewpoint that the Es phenomenon depends on ambient ionization and wind shear has been adopted, and "synthetic" wind shears have been computed from the fbEs data. A correlation between these wind shears and the sunspot number is then found. One of the most interesting findings is a certain relation with the electric field produced by the magnetic Sq and L variations.

World numerical maps of lower decile, median, and upper decile values of the monthly distributions of foEs have been prepared for all 12 months of both a solar-cycle-maximum and a solar-cycle-minimum year for use in estimating the effects of Es on propagation. The fbEs maps used in conjunction with the foEs maps provide a system for calculating frequencies which may be propagated by reflection from the sporadic-E layer. Sample contour maps of both foEs and fbEs are shown, as well as sample calculations of Es MUF (maximum usable frequency). Comparisons have been made with the charts of percentage of occurrence of foEs and fbEs developed by the U.S.S.R. Academy of Sciences.

The most obvious comment is that the radio measurements imply, according to theory, considerable irregularity of horizontal structure in sporadic E whereas the rocket measurements, which at most make two passes through the sporadic-E cloud, indicate little horizontal irregularity. A possible model for sporadic E consists of a collection of ionized clouds, the whole collection extending for several hundred kilometers, but with the individual clouds being perhaps only tens of kilometers in horizontal extent. However, the radio measurements show that the structure varies greatly from time to time, so that the model is variable.

Radio techniques now being developed should assist in determining the more detailed structure, including the thickness of sporadic-E layers. Also, it is possible to measure both horizontal and vertical movements by radio techniques. The question as to whether partial reflection occurs from small over-dense clouds or irregular vertical under-dense structure will remain open, at least until a full wave solution is calculated for the under-dense structure, or until a rocket passes through a small over-dense cloud (the chances may be only 1 percent of any rocket doing this).

Rocket-borne probes give a profile of electron or positive ion density along the trajectory of the vehicle. In practice, then, the profiles of sporadic E are nearly vertical in one dimension. A large number of vertical profiles of sporadic-E layers have now been accumulated, and many are available in the literature. These range from the nearly triangular shape of small daytime and most nighttime layers to the rectangular shape of intense daytime layers. Few cases of the latter have been observed and it would be desirable to have more examples.

In order to overcome the limitation relative to horizontal variation that can be obtained from a single probe, launching several probes on slightly different trajectories from a single rocket has been suggested. These probes would pass through the layer simultaneously but with horizontal separations determined by the ejection mechanism. Separations of 1 km on the downleg of the trajectory could be easily accomplished. However, the principal difficulty that can be expected is that of determining the relative positions of the probes with sufficient accuracy.

The relation between the rocket observations and the various radio techniques is not yet clear. The physical property of the sporadic-E layers which gives rise to the nonblanketing echo on the ionosonde is probably the most important unresolved problem.

Data from the planar ion trap and the

radio-frequency ion mass spectrometer after two Aerobee rocket flights that traversed sporadic-E layers above White Sands, New Mexico, were presented. On the ascent during the first flight a minimum in the ion distribution, a factor of 5 below the ambient density in the region, was observed between two secondary maxima. Ion mass spectra taken when the rocket was within the Es layers showed it to be composed of atomic metallic ions of Na, Mg, Si, Ca, and Fe. Magnesium was the dominant ion detected in the mass spectra. Neither nitric oxide nor molecular oxygen ions were observed within the Es layer. The second flight recorded a weak Es layer. As before, Mg, Ca, and Fe ions were observed within the Es layer. Iron and magnesium ions were observed in and below but not above this layer. Nitric oxide ions were detected in the peak density region of this weak layer.

Metallic ions in the D and E regions were also detected by cryogenically pumped, quadrupole ion mass spectrometers aboard six rockets; they were launched during and after the 1965 Leonid meteor shower, at sunrise and sunset from Eglin AFB, and during the 1966 solar eclipse in Brazil. Every rocket flight that observed Es events detected metallic ions within the Es layer and, depending on the strength of the layer, observed a decrease in the molecular ion density. However, the converse is not true that the presence of metallic ions does not necessarily indicate an Es layer. Based on these rocket observations, the roles of charge transfer between the molecular ions and metallic atoms and of vertical neutral wind convergence in the formation and maintenance of metallic ion layers were discussed, but the group did not arrive at a definitive conclusion.

Atomic recombination processes which can liberate free metal atoms from solid surfaces of certain metallic compounds may play a role in liberating metallic atoms from dust layers in the ionosphere. Experiments involving the bombardment of solid films of Na_2SO_4 and other sodium salt by-products from a nitrogen discharge suggest that atomic or molecular excited species in the atmosphere may fulfill this role.

Recently available reaction rate measurements on atmospheric metal ion and metal oxide ion reactions indicate that chemical ion (and therefore electron) loss is not significant for the metallic ion sporadic-E layers in the

100-km region and above. It was also pointed out that some early theoretical treatments of meteor trail deionization which invoked electron attachment are now obsolete due to the subsequent experimental discovery and rate constant measurements of associative detachment processes, particularly for $O_2^- + O \rightarrow O_3 + e$. The associative detachment at 80 km is several orders of magnitude faster than the electron attachment. Three-body metal ion association, followed by electron recombination might, however, be important in meteor trail deionization in the ~ 80-km region.

Data from a new meteor-wind observation system in France, which provides returns from several hundred meteors per hour, with data at 2-km altitude spacing between 80- and 110-km altitude from each meteor, have been processed by power spectral analysis to assess prevailing and tidal components, and to anaylze the residual nontidal contributions. The major component is semidiurnal, with vertical wavelength greater than 100 km and an amplitude of 10 to 70 m/s. A downward phase velocity of the order of 10 km/hour is largely due to the semidiurnal component.

A statistical analysis of 70 midlatitude vapor trails between 90 and 150 km showed not only a consistent zonal flow to the east below 100-km altitude, but also mean values of total velocity of 50 to 70 m/s and mean shears of 0.02 to 0.004 m/s/m, varying with altitude. The altitude variation of velocity and shear can be explained by energy injection from below and viscous dissipation within the region of a simple helical profile, rotating in 12 hours and increasing in wavelength from 20 km at 90-km altitude to 100 km at 150-km altitude.

Simultaneous rocket observations of sporadic-E electron-ion density and wind profiles were successful in relating sporadic-E layering above 105 km to wind-shear structure. Below this height, the terminal deposition zone predicted by the "corkscrew" mechanism complicates the simple association of ion layers with shears.

Those areas of wind measurements in which adequate data are not available at this time include vertical winds, daytime winds above 110 km (the upper limits of the meteor-wind technique), and horizontally spaced winds to permit convergence estimates. Incoherent backscatter studies and drift reflections from ground sites may eventually largely displace rocket studies for statistically large sample collections.

On the whole, there is substantial agreement about the processes which lead to the production of temperate-zone sporadic E—that is, the layers are produced by the wind-shear mechanism and are composed mostly of long-lived metallic ions except possibly at higher altitudes when molecular ions can be involved. Most of the discussion therefore was concerned with refinements of the wind-shear theory and with the special problems associated with the production and loss of metallic ions.

Calculations of the loss rate of metallic ions into the D region due to the "corkscrew" mechanism showed that difficulties arise unless the sweeping effect is inhibited by the presence of standing waves. The main problem is that the density of metallic atoms present in the E region must be sufficient to allow ions to be produced at a rate comparable to the loss due to the "corkscrew" mechanism, and also be highly variable in order to account for the nighttime variations of fbEs.

The "corkscrew" mechanism shows that Es layers formed of long-lived ions can be expected to follow nodes in the effective neutral wind profile down to altitudes less than about 100 km. At lower altitudes the process fails quite suddenly at the point where the vertical ionization drift velocity and the descending phase velocity of the neutral wind profile become comparable.

It must be remembered that molecular ions can also play a role at higher altitudes ($\geq$ 120 km) where the vertical drift speeds of the ions can be quite large. Numerical solutions for the formation (by the wind-shear mechanism) of Es layers comprised of molecular ions showed that a uniform electric polarization field affects the rate of growth, movement, equilibrium, position, and maximum density. Particular attention was paid to the effects that might be produced by abrupt changes in the neutral gas, that is, gravity "shocks," and by electric polarization fields. Kinks in the ionization drift-velocity profile could lead to the flat-topped Es layers sometimes observed. The characteristic variations of Es occurrence according to season, time of day, and geomagnetic activity might somehow be accounted for by variations in the electric polarization field.

Concerning the effects of gravity waves, the vertical motion and the associated variations in density and temperature of the neutral gas can produce weak Es layers due to the resulting changes in the ionization production and loss rates, as well as by the redistribution processes usually considered in the wind-shear theory. The electron temperature in the E region and in Es layers can be noticeably affected by variations of the neutral temperature associated with gravity waves.

Papers on the formation of small-scale irregularities of ionization by the so-called "crossed-field" instability produced considerable argument, mainly concerning the appropriate boundary conditions and the shape of the initial perturbation to be used in the analysis. One linearized treatment of the problem appeared to show that the configuration adopted was quite stable, whereas a non-linear treatment using different initial conditions showed the explosive development of plasma turbulence after some tens of seconds. A considerable amount of further study of this problem is obviously required.

Metallic ions seem to play an important role in Es at heights lower than about 110 km, but molecular ions are important for Es at higher levels. Since the electric polarization fields play an important role in the rate of Es growth, position, and maximum density, a future investigation of this field together with a detailed theoretical attack on the field's effect on Es is very desirable. Rocket observations should be conducted simultaneously at close horizontal spacing with more accurate height resolution. In addition to measurements of ionization density and composition, it is necessary to measure other parameters such as ion temperature, neutral density, and magnetic field in the vicinity of Es blobs. Upper atmosphere wind observations during the daytime and measurements of the vertical wind are required. The character of tidal oscillations should also be examined.

In summary, the very complex phenomenon of Es needs to be attacked with a combination of all possible methods in a well-organized form, particularly with better coordination of rocket and ground-based experiments and with cooperation between different groups and disciplines.

The proceedings of the seminar were distributed in October 1968. Those who wish to obtain a copy are advised to contact Mrs. Mary Landers, ESSA, R60, Boulder, Colorado 80302.

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