Review of USA Activity in the Fields of Interest of URSI Commission 3 During the Triennium 1957 Through 1959

Because of the IGY, there has been an unprecedented emphasis on the geophysical aspects of the ionosphere. Rockets, satellites, moon echoes, VLF propagation in the "whistler" mode, and, most recently, incoherent scatter by the ionospheric electrons have enabled the observable ionosphere to be extended far beyond the former limit set by the maximum electron density at 300 to 500 kilometers.

During the IGY there was a considerable shift in emphasis in ionospheric investigations toward the polar regions, both arctic and antarctic. In the antarctic conventional observing techniques were used; in the north, however, extensive programs of rocket and balloon observations were brought to bear on the special effects of the auroral zone. Ground-launched rockets were fired at Ft. Churchill, Canada, and balloon-launched rockets (rockoons) were fired at various places. Balloon-borne radiation counters were also flown at various places in and near the auroral zone.

In the URSI, Commission 4 currently has the responsibility for ionospheric propagation at VLF and LF, for whistlers and whistler mode propagation, for hydromagnetic waves in the ionosphere and the extra low frequency oscillations (micropulsations) of the geomagnetic field which are thought to be associated with them, and for certain aspects of the exosphere. The reader is therefore referred to the report of USA Commission 4 for reviews of activity in these topics.

This review is confined to work published between January 1957 and December 1959. Also rather than cover the same ground in detail, reference is made to reviews of Upper Atmosphere Studies (under Meteorology and Atmospheric Physics), and work in Geomagnetism and Geoelectricity, Solar-Terrestrial Relationships, Ionosphere, Aurora, Airglow, Chemistry of the Outer Atmosphere, and Radiation Belts (under Geomagnetism and Aeronomy), in the Triennial Report of the American Geophysical Union to the UGGI (International Union of Geodesy and Geophysics) [AGU, 1960]. Another important review paper [JTAC, 1960] on radio transmission by ionospheric scatter was prepared by the Joint Technical Advisory Committee of the Institute of Radio Engineers and of the Radio and Television Manufacturers Association.

1. Structure of the Upper Atmosphere

Model atmospheres based on rocket and satellite data were derived by Champion and Minzner [1959], Kallmann [1959] and Harris and Jastrow [1959]. Studies of atmospheric density based on satellite orbits only were made by Schilling and Sterne [1959], Schilling and Whitney [1959], and Siry [1959]. Warwick [1959] used spin decay deduced from the radio signals of Sputnik I to derive a density at 220 km. All agree that densities above about 200 km are substantially higher than was previously thought, but there is still some disagreement in the interpretation of the rocket data for the lower altitudes (e.g., 90 km). Whipple [1959] reexamined the electron temperature derived from Russian measurements with Sputnik III and concluded it should be about 8,000 °K instead of 15,000 °K. Sterne [1958], discussing the reliabilities of rocket and satellite measurements, indicated that there was substantial disagreement between measurements at the same altitudes. He concluded that the satellite measurements were more reliable. LaGow and Horowitz [1958] pointed out that there was no disagreement when allowance was made for latitudinal variations.

LaGow, Horowitz, and Ainsworth [1959] discussed the arctic atmospheric structure based on rocket measurements at 59° N latitude. Summer densities between 30- and 70-km altitude were 5 to 10 percent higher than the Rocket Panel values for 33° N;* winter densities between 25 and 40 km were 10 to 20 percent lower than the summer values (i.e., 5 to 10 percent lower than the Rocket Panel values for 33° N); daytime density at 200 km, both in summer and in winter, was higher than the summer value at 33° N. Horowitz, LaGow, and Giuliani [1959] reported measurements of fall-day atmospheric structure at 59° N. Holmes and Johnson [1959] reported measurements of relative concentrations of atomic and molecular ions in the arctic ionosphere. The positive ions of O_2, NO, N_2, H_2O, O, and N were identified. O_2^+, NO^+, and O^+ were by far the most abundant. NO^+ dominated in the region below 200 km at night, and below 180 km in daylight. O_2^+ was only a minor constituent of the lower E region at night. O^+ appeared above 130 km and was most abundant above 200 km day and night. O_2^+ increased above 100 km to a maximum relative concentration between 150 and 200 km day and night, but decreased rapidly above 200 km. It was the most abundant between 85 and 90 km during a daylight polar blackout.

Stroud et al. [1959] reported extremely low arctic summer temperatures at 80-km altitude in striking contrast to relatively high temperatures at this altitude in winter. Indications of atmospheric tides

*Average of all values obtained at White Sands, New Mexico, before 1952.

in satellite motions were discussed by Parkyn and Groves [1959]. Dessler [1959] proposed that upper atmosphere density variations due to hydromagnetic heating could account for irregular orbital accelerations of satellites, as well as the sudden disappearance of trapped radiation from the Argus nuclear explosion. The theory of disturbances induced in the ionospheric plasma by satellites was discussed by Kraus and Watson [1958]. Kellogg [1959] reviewed the results of rocket and satellite measurements presented at the 1958 meeting of the CSAGI in Moscow.

2. Ionizing Radiations

Considerable progress was made in the investigation and understanding of the fluxes of radiations (photons and corpuscles) which produce the ionospheric layers and cause the associated phenomena of geomagnetic and ionospheric storms, aurora, radio wave absorption, and so forth. Both rockets and balloons were used to detect soft X-rays and low-energy protons in the auroral regions, and the flux and spectrum of solar ultraviolet radiation. Peterson and Winckler [1959] reported a solar gamma-ray burst detected during a balloon flight. The gamma-ray burst was coincident with a solar flare and associated radio noise bursts, SID, earth-current disturbance, and magnetic crochet. References to other papers are given in the AGU Triennial Report [1960], together with discussion of the implications and interrelations of these phenomena.

3. Electron Densities

Kelso [1957] developed a method for converting vertical incidence records of virtual pulse-echo height versus frequency (h′-f records, also called ionograms) into profiles of electron density versus height, which is a compromise between the original method of Kelso coefficients and the later method due to Budden. Kay [1959] discussed the relationship of the precision of virtual height measurement to the pulse length and gave a precise experimental definition of group time delay. Wright [1959] gave the results of a true-height analysis of ionograms from stations along the 75th meridian in the form of contours of electron density representing a vertical cross-section of the ionosphere for this meridian.

Jackson and Seddon [1959] reported rocket measurements through an aurora. Severe electron density gradients were encountered. There was evidence of electron densities greater than $10^6/cm^3$ in the region 90 to 130 km, and indications of "filaments" with densities greater than $10^7/cm^3$. Jackson and Kane [1959] indicated a new method of measuring local electron density using an rf probe technique. Haycock, Swigart, and Baker [1959] gave a detailed development of the theory involved in the determination of electron densities from the group retardation of 6 Mc/s pulses transmitted from rocket to ground, and discussed the results of 3 rockets fired at White Sands to a height of 137 km.

Bauer and Daniels [1959] measured the total electron content in a vertical column of the ionosphere by means of the Faraday rotation of radio waves reflected from the moon. They found that the ratio of the number of electrons above the level of maximum density to the number below was 4 to 5 during three nights in June before sunrise, dropping to about 3 after sunrise. On two days in November the ratio was about 3 both before and after sunrise. Prenatt [1959] reported that Faraday rotation measurements by rocket to 235 km agreed with measurements by an older technique on the same rocket flight.

Gordon [1958] predicted that incoherent scattering by ionospheric electrons could be detected and would enable electron densities to be measured throughout the ionosphere. Bowles [1958] obtained the first echoes, using a high power pulse transmitter at 41 Mc/s and a special high gain antenna beamed vertically.

4. Satellite Beacon Studies

Bowhill [1958] discussed the theory of the rate of Faraday rotation of the plane of polarization for a satellite signal. Daniels and Bauer [1959] developed the theory of the rotation more generally and discussed the application of its measurement to ionospheric studies using either moon echoes or satellite beacons. Arendt [1959] reported some observations of the rotation of satellite signals and discussed their interpretation on the assumption that the ionosphere had no appreciable horizontal variations in electron density. Parthasarathy and Reid [1959] reported values of the integrated electron density for four passes of Sputnik III near 600 km over College, Alaska, based on the rate of Faraday rotation. With spaced antennas receiving Sputnik III, Parthasarathy, Balser, and DeWitt [1959] used the times of abrupt weakening of the signal to deduce the height (104 km) of a discrete absorbing region during an auroral display.

Hutchinson [1959] discussed ionospheric effects on the measurement of the slant range at nearest approach. Arendt and Hutchinson [1959] discussed the problem of disentangling spin and Faraday rotation. Wells [1958] and Garriott and Villard [1958] reported signal enhancements when the satellite was near the antipode, and Dewan [1959] discussed some unusual effects in the propagation of satellite signals.

5. Ionospheric Processes

Mitra [1959] gave a theoretical discussion of the electron loss coefficient in the daytime processes in the ionosphere from 60 to 600 km at intermediate latitudes. Dalgarno [1958] pointed out the dilemma posed by rocket measurements of neutral particle density in the *F*2 region, which would indicate too rapid diffusion if the usual values of the diffusion coefficient are taken, and offers some evidence that the value of the diffusion coefficient may be about ¼ the value usually assumed. Farley (1959] discussed theory of the effects of electrostatic fields in an ionosphere with a vertical magnetic field with a view toward elucidating the phenomena of spread F and radio star scintillation. Hoffman [1959] called attention to a possible mechanism for radiation and reflection from ionized gas clouds.

6. Ionospheric Disturbances

A study of the storm-time variations of the $F2$ layer critical frequency was carried out for 38 stations between 60° N and 60° S geomagnetic latitude by Matsushita [1959]. Tandberg-Hanssen [1958] found that in general the height of the E layer remained unchanged during magnetic storms, while the $F1$ layer tended to rise. Warwick and Hansen [1959] found a definite tendency for geomagnetic disturbance to follow the largest solar flares near sunspot maximum, but not near sunspot minimum. Their results indicated that the area of the flare was a more reliable index than its "importance". Maxwell, Thompson, and Garmire [1959] found that slow-drift type II solar radio bursts were 45 percent associated with subsequent aurora and magnetic storms. The mean delay was 33 hr, in good agreement with the speed of 1,000 km/sec deduced from the radio data. The geomagnetic effects were enhanced if the bursts occurred near an equinox and were accompanied by a flare of importance 2 or 3, or by continuous (type IV) radiation.

Bauer [1957, 1958a] described an apparent correlation between the variations of the critical frequency and virtual height of the $F2$ layer with frontal passages in the troposphere, and Bauer [1958b], and Mook [1958] discussed an apparent ionospheric response to the passage of hurricanes.

7. Sporadic E and Spread F

Smith [1957] published a survey of the geographic and temporal occurrence of sporadic E. Thomas and Smith [1959] brought Smith's survey up-to-date. Matsushita [1958] studied the association of the occurrence of blanketing Es and slant Es with magnetic bays. Penndorf and Coroniti [1958] analyzed the occurrence of sporadic E in the polar regions and proposed designation of two types: the Thule type which occurs primarily over the polar cap, and the auroral type. Davis, Smith, and Ellyett [1959] analyzed the occurrence of sporadic E as observed at 28 and 50 Mc/s over a 1,243-km path. Gerson [1959] used reports of 50 Mc/s contacts by radio amateurs to determine the annual distribution of sporadic E in North America. Knecht [1959] reported a lunar influence on the time of first appearance of equatorial sporadic E in the morning at Huancayo.

Renau [1959] proposed a theory of spread F based upon specular reflection from magnetic field-alined irregularities near the level of reflection in the $F2$ layer. Reber [1958] discussed the behavior of spread F over Hawaii since the last sunspot minimum.

8. Studies of the Lower Ionosphere

Warwick and Zirin [1957] measured the diurnal variation of the absorption of cosmic noise at 18 Mc/s, and used the results in a theoretical discussion of the distribution of electron density, and the related processes in the D-region of the ionosphere. Houston [1958] derived an electron distribution for the D and E regions of the ionosphere based on recent theories and information concerning the atmospheric constituents, ionizing radiations, and the reactions. The results compared favorably with experimental measurements. Seddon [1958] reported a rocket measurement of the difference in the absorption of the ordinary and extraordinary wave components at 7.75 Mc/s as a function of altitude to 96 km at White Sands, N. Mex., at noon on a summer day. The absorption was inappreciable below 88 km, small from 88 to 94 km, but increased rapidly beyond 94 km.

Phelps and Pack [1959] made laboratory measurements of the collision frequency of thermal electrons in nitrogen. Under the assumption that the cross section for collision with a molecule of oxygen is no greater, the result agrees with Kane's [1959] determination of the collision frequency in the lower ionosphere. Chapman and Davies [1958] suggested that the approximate daytime constancy of the absorption of VLF radio waves would be accounted for if electrons were liberated by photodetachment from negative ions. Bourdeau, Whipple, and Clark [1959] studied the conductivity of the atmosphere between the stratosphere and the ionosphere, and Rumi [1957] found evidence of radar echoes from this region.

Gibbons and Rao [1957] developed formulas for the calculation of group refractive indices and group heights for frequencies less than the gyrofrequency, taking account of electron collisions. Watts [1958] called attention to a peculiarity of the group refractive index at frequencies below the gyrofrequency which results in retardation of the extraordinary wave at the critical frequencies of the ordinary wave, thus giving additional information about the electron density distribution. Bowhill [1957] applied diffraction theory to the analysis of the fading of low frequency waves reflected at vertical incidence from the ionosphere to deduce properties of its irregularities.

Waynick [1957], and Gibbons and Waynick [1959] reviewed the state of knowledge of the lower ionosphere. Ellyett and Watts [1959] reviewed the evidence for stratification in the lower ionosphere.

9. Radar Studies of Auroral Ionization

Echoes from irregularities in the auroral ionosphere were obtained at frequencies from HF (ionosonde frequencies) to UHF (780 Mc/s). Such echoes have a strong tendency to be aspect sensitive relative to the earth's magnetic field, indicating that the irregularities are field-alined. At the higher frequencies, the echo heights are confined to about 90 to 130 km (Fricker et al., 1957; Leadabrand, Dolphin and Peterson, 1959; Presnell et al., 1959). At the lowest frequencies, however, Bates [1959] showed that the heights may extend above 400 km. Stein [1958b] proposed that long-range echoes observed at HF, such as those described by Leadabrand and Peterson [1958], could be explained in terms of echoes at *E*-region heights resulting from propagation via a tilted *F* layer; but observations at 106 Mc/s by Schlobohm et al. [1959] from a geomagnetic latitude of 43° indicate that the long-range echoes at the lower frequencies may indeed have come from *F*-region heights.

Doppler shifts in echoes obtained with 400 Mc/s radar by Leadabrand, Presnell, Berg, and Dyce [1959] indicated that irregularities tended to drift from the east toward the west with a velocity of about 500 m/s, and that there was no appreciable variation with time of day or with respect to magnetic midnight. The relationship of the irregularities observed with radar techniques to magnetic disturbances was discussed by Nichols [1959].

10. Refraction in the Ionosphere

Marcou, Pfister, and Ulwick [1958] described a ray-tracing technique, taking full account of the earth's magnetic field, suitable for use with high-speed computers. Millman [1958] and Weisbrod and Anderson [1959] discussed refractive effects on radio waves traversing the troposphere and the ionosphere, and Weisbrod and Colin [1959] called attention to the fact that ionospheric bending has a maximum a few degrees above the horizon. Toman [1959] showed the effects of the spherical geometry on the absorption as well as the bending of a wave as a function of the elevation angle near the horizon. Brysk [1958a] discussed the effect of the ionosphere on signals scattered from the surface of the moon.

11. Ionospheric Propagation Studies—General

Villard, Stein, and Yeh [1957] reported observations of exceptionally long-delayed echoes with a HF backscatter sounder beamed across the equator which they interpreted as ground backscatter propagated by two or more successive reflections from the *F*-region of the ionosphere without intermediate ground reflection, caused by tilts of the reflecting layer. It is shown that tilt-supported propagation can take place at frequencies considerably above the MUF predicted in the usual way. Stein [1958a] gave a more general discussion of the effects of tilts.

Silberstein [1958a], comparing backscatter echoes with point-to-point pulse transmission over a 2,370-km path and ionograms taken at the midpoint of the path, concluded that with suitable care the sweep-frequency backscatter technique can provide accurate information about the MUF. Silberstein [1958b] also reported the results of measuring relative pulse time delays over a 7,647-km path at 20.1 Mc/s. Greatly differing modes of propagation were observed from one day to the next indicating that the long path is very sensitive to ionospheric conditions. Agy and Davies [1959] summarized the present state of oblique incidence investigations of the ionosphere, using the sweep-frequency pulse technique, with special reference to the work of the CRPL.

12. Ionospheric Scatter Transmission

This subject was treated in detail in a recent review [JTAC, 1960]. Some additional references are Wheelon [1957a, 1957b], Leighton [1957], Bolgiano [1957a, 1957b], and Heritage et al. [1959].

13. Radio Reflection from Meteor Ionization

Increasing attention has been given to studies of meteor ionization, both as a propagation medium and as a means for observing ionospheric motions. A review paper was given by Manning and Eshleman [1959]. The work can be grouped into several categories.

13.1. The Reflection Properties of Individual Trails

The length of the ionized column produced by a meteor was computed by Eshleman [1957a] as a function of the characteristics of the meteor; this result was then extended to determine the distributions of trail lengths to be expected for shower and sporadic meteors. The length distribution for shower meteors was compared with experimental results and good agreement as found. The theory of trail formation was extended by Manning [1958] to include the effects of the high initial velocity of the particles in the trail. In a typical case, it was found that the trail would expand to a radius of about 14 mean-free-paths in about ⅓ msec and from then on diffuse in the normal manner. Further considerations of the effects of normal diffusion by Flood [1957] and by Hawkins and Winter [1957] indicated that at UHF the effective scattering length of a trail may be greatly reduced and consequently the aspect sensitivity common at VHF will not be present. The analysis of oblique scattering from under-dense trails was extended by Brysk [1958b] to include the effects of the rapid initial diffusion of the trail, and the ray solution for oblique scattering from over-dense trails was obtained by Manning [1959a].

13.2. Computation and Measurement of the Gross Propagation Characteristics of Ensembles of Trails

The discovery that meteor ionization could provide a transmission medium for point-to-point communications at VHF stimulated a number of studies of the characteristics of meteor-burst propagation. These include general experimental studies by Vincent et al. [1957a], by Casey and Holladay [1957], and by Wirth and Keary [1958], analyses of the directional properties of this propagation by Meeks and James [1957, 1959] and Eshleman and Mlodnosky [1957], and examinations of its wavelength dependence by Eshleman [1957b] and by Meeks and James [1958]. The relations between meteor-burst propagation characteristics and the design of communication systems were discussed by Vincent et al. [1957b, c], Montgomery and Sugar [1957], Bliss et al. [1959], and Carpenter and Ochs [1959].

13.3. The Study of Ionospheric Motions Through the Use of Meteor Trails as Indicators

The earlier proposal, by Booker and Cohen, that small-scale turbulence in the lower ionosphere accounted for the observed decays of long-enduring meteor trails received considerable attention by Manning and Eshleman [1957, 1958] and by Booker [1958]. An alternative proposal that large-scale turbulence plays a dominant role in the decay of long-enduring trails was advanced by Manning [1959b] and substantiated by experimental results. This theory was also applied by Manning [1959c] to determine the detailed wind structure at meteoric heights. The general problems of motions in the lower ionosphere, as deduced from meteor observations, were a major topic of an International Symposium on Fluid Mechanics in the Ionosphere and are discussed in the published transactions [Bolgiano, 1959].

14. Ionospheric Propagation Research with Communication Systems Applications

Ionospheric research specifically directed towards more efficient utilization of ionospheric propagation for communications continued during the Triennium. Papers were published which reflect progress in understanding the mechanism, or at least the characteristics of signal distortion imposed by the medium.

14.1. Multipath Effects

Bailey [1958] analyzed the effect of echo on the operation of HF communication circuits. Two distinct kinds of echo are recognized. One kind of echo is observed when the great-circle path coincides with the twilight zone encircling the earth; the second kind, common only on fairly long communication paths, is most severe when the short path is intensely illuminated. While little can be done to obviate echo of the first kind, proper choice of operating frequency and mode of operation can minimize the echo interference of the second kind. In another paper [1959] Bailey considered the relationship of multipath delay times to the path length and the ratio of the operating frequency to the MUF. The term "multipath reduction factor" (MRF) is introduced to specify operating frequencies for given multipath protection, path lengths, and ionospheric conditions. Investigation of multipath occurring within a millisecond pulse was carried out by Lutz et al. [1959] with specific attention to phase changes due to multipath occurring within separated 1-msec pulses.

Hulst [1959], suggested the use of a linear network, called an "inverse ionosphere," which would be automatically adjusted, under the control of a "probe pulse", to provide a delay function for message signals inverse to that imposed by the ionosphere. A new communication technique designed to take advantage of multipath propagation was described by Price and Green [1958]. This rather complicated system performs a continuous detailed measurement of the multipath characteristics, and then adds the various multipath components of the message signals algebraically after appropriate time delays are inserted.

14.2. Fading

Using pulses to separate the modes, Hedlund and Edwards [1958] measured the correlation of fading of horizontally and vertically polarized components of a received wave. As negative correlation was obtained most of the time, the fading was attributed to interference between the oppositely rotating magneto-ionic components. Yeh and Villard [1958], reporting on the occurrence of a HF component (near 20 c/s) of fading superimposed on the normal slow fading, surmised that the signal arrived by two entirely different modes, with the Doppler shift of one mode being much greater than that of the other. One mode was thought to be a normal two-hop transmission, and the second a long one-hop ionosphere-tilt-supported mode. Koch [1959] described a study of the fading of signals from pairs of transmitters, locked in phase, with antennas separated by 1,540 ft for one set of tests, and by 65 miles for another set of tests. In both cases the received carrier envelope fading was approximately Rayleigh distributed, and fading speed was not significantly different for the diversity transmissions. No "diversity gain" was apparent from these tests. Price and Green [1957] reported on some short-term phase perturbation observations of fading waves. Brennan et al. [1958], in a study of the effects of selective fading and signal-to-noise ratios on the performance of phase-keying (Kineplex) and FSK communication systems found that the advantage of the phase-keying system with respect to the FSK system under low signal-to-noise conditions is reduced when selective fading is rather severe.

14.3. Arctic Propagation

Coroniti and Penndorf [1959] and Penndorf and Coroniti [1959] analyzed a large number of ionospheric records to determine the geographic distribution and diurnal variations of auroral effects and sporadic *E* occurrence. The inference is made that, by proper choice of operating paths for a particular time of day, reliability of Arctic communications can be improved. Leadabrand and Yabroff [1958] gave methods for calculating the probability of communication by means of reflections from ionized auroral columns.

14.4. General

Silberstein [1957] conducted tests to determine the effective horizontal radiation pattern of an antenna at a great distance (3,650 km) for ionosphere-propagated signals. The long distance pattern agreed very closely with that obtained by local measurements. K. Davies [1959] pointed out the error involved in the application of standard transmission curves, which neglect the earth's magnetic field, to ionograms in which the virtual height is increased by the presence of the field. The effect is to underestimate the MUF. Millman [1959] gave a method for calculating the angle of the magnetic field with the direction of propagation for any location and for transmission directed at any azimuth and elevation. Pucillo [1957] described a condensed nomographic procedure for determination of high-frequency sky-wave absorption.

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