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IONOSPHERIC EFFECTS DURING THE PARTIAL SOLAR ECLIPSE OF 10 JULY 1972

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A space-based radio navigation system could provide military and civilian users with precise three-dimensional position and velocity data. To determine his position and velocity, the user cross-correlates the coded time signal received from a very-high-altitude satellite with the same coded time signal generated in his receiver. The relative phase, or equivalently the time displacement between the user's receiver and the incoming code, determines the range to the satellite. Simultaneous measurement of such relative phases from four different satellites permits the user to determine his range and his clock bias with respect to the satellite's position and clock, respectively.

The range from user to the various satellites thus obtained is, of course, not the correct geometric range. A propagating navigation signal is slowed down by the ionosphere by an amount proportional to the total electron content along its path. The electron content may be measured in real time, provided the user has dual-frequency capabilities. However, substantial reduction in the cost of user equipment can be realized if the navigation system uses only one frequency. In such a case, the ionospheric time delay will have to be determined through empirical modelling techniques which take into account its spatial and temporal variations. Such models are based on existing and future global electron content data. The information will be transmitted to the user for correction via the navigating signal.

The uncertainties in the excess time delay of transionospheric navigational signals due to the presence of ionospheric electron

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content pose a major problem in the attainment of the expected precision of such systems. Solar control of the ionospheric electron content is a major thrust area in the investigation of content variations and will become an input parameter in future prediction schemes. A solar eclipse offers a unique opportunity to study the effects of the rapid disappearance and reappearance of solar thermal and ionization radiations on the ionospheric production, loss, and transport processes which affect the total ionospheric number density.

Polarization measurements performed at Fort Monmouth, N. J., U.S.A. (40.25° N, 74.025° W), utilizing beacon emissions of the ATS-3 (137.35 MHz), were supplemented with bottomside ionospheric observations made near the subionospheric point (below 350 km along the path to ATS-3) during the partial eclipse of 10 July 1972. The ATS-3 was located at 69.8° W; the subionospheric point was at 37.1° N, 73.6° W which was slightly southeast of the Wallops Island sounding station at 37.9° N, 75.5° W. The maximum obscuration at 300 km above Wallops Island was 77.8 per cent and occurred at 15:48:59.2 EST. First contact was at 14:38:25.9 EST while last contact was at 16:52:14.3 EST.

Figure 1 depicts the time variation of the total electron content from 11:00 to 17:30 EST during the eclipse day and during the two days prior to and the three days following it. From the figure it is clear that on all the control days the total ionization was either increasing or being maintained throughout the time period which the eclipse occurred on 10 July. The electron content decrease on the eclipse day commenced with first contact, reached a relative minimum some 12 minutes prior to last contact, and resumed a sustained increase some 16 minutes after last contact. The overall decrease in electron content was 21 per cent.

Figure 2 shows a comparison of polarization changes during the eclipse day obtained at Fort Monmouth and at Sagamore Hill Radio Observatory, Hamilton, Mass. (42.6° N, 70.8° W). While the general behavior of the polarization variation was similar, the decrease commencing at first contact and the sustained recovery were sharper at the more northern observation station. This may have been due, in part, to the earlier commencement and to greater obscuration of the solar disc at that location.

Equivalent slab thickness, which is equal to $\int Ndh/N_{max}$, is defined as the equivalent thickness of a rectangular unit-area slab having a constant density--that of the peak F_2-region. The physical significance of the slab thickness lies in the fact that it is proportional to the plasma scale height provided we assume that the scale height does not vary significantly with altitude. The plasma scale height, in turn, is proportional to the ratio of the plasma temperature and the mean ionic mass. If it is further assumed that the mean ionic mass in the region of interest is that of oxygen, i.e. 16 amu, the variations of slab thickness are proportional to the plasma temperature. The slab thickness variation arrived at by dividing the total electron content measured at Fort Monmouth by the peak density at the subionospheric point (i.e. at Wallops Island) is shown in Fig. 3. A sustained decrease in slab thickness, and hence in plasma temperature, started ∿26 minutes after first contact, while a sustained increase in slab thickness occurred ∿8 minutes before last contact. The total temperature decrease was ∿21.5 per cent which is about the same total decrease as that of the total electron content, although the time period between the maximum and minimum of the two parameters differed. During the same period of the slab thickness decrease, f_oF_2 remained largely unchanged, varying by ∿1-2 per cent. The picture that emerges is the following: obscuration of the solar disc causes a decline in plasma temperature due to cooling, and a decrease in the total electron content due to recombinations. The decrease in temperature causes a corresponding fall in scale height and the ionization diffuses toward the F_2 peak in order to reattain diffusive equilibrium so that N_{max} (which is proportional to $(f_oF_2)^2$) remains largely unchanged. Further, it may be concluded that in the vicinity of the F_2 peak the loss process rate is of the order of the diffusion process rate in its reaction to the gradual disappearance and reappearance of the solar ionizing radiation. Evans (1), (2) has shown that sometimes N_{max} may increase during an eclipse. He states that two conditions are necessary (but possibly not sufficient) for causing an N_{max} increase: (1) the eclipse must be total, or nearly so, at ionospheric heights and (2) the magnetic dip angle must be >60°. The first condition insures a substantial cooling of plasma temperature and thus a marked decrease in scale height, while the second insures fast vertical diffusion along the magnetic lines of force. While the second condition is satisfied at our observation stations, the first is not. However, our observations show that N_{max} is almost sustained by diffusion, its percentage change being much smaller in comparison to the total electron content percentage changes.

The behavior of the bottomside ionosphere above the subionospheric point is shown in Fig. 4 where the true height variation of fixed plasma frequencies (and hence of electron densities) is shown as a function of time. The following conclusions may be drawn from the figure:

1. The reaction of lower bottomside layers to the eclipse was much more pronounced than that of the higher layers (note the ~200 km change in layer height at 4 MHz vs the ~25 km change at 5.75 MHz).
2. The percentage loss of ionization at lower height layers was much larger than at the higher layers.
3. The altitude variation was fairly symmetric about the time of maximum obscuration. The fact that after the eclipse, layer heights did not return to their pre-eclipse altitude was due to the change of solar incidence angles before and after the eclipse. After last contact the layer heights increased as sunset was approached.
4. Significant oscillation of the density distribution at all altitudes may have been due to internal gravity waves generated by the supersonic movement of the moon's shadow (3), (4).

In sum, the partial eclipse was characterized by a decrease in total content and by a decrease in plasma temperatures and corresponding diffusive fluxes into heights of maximum ionization from the topside and bottomside ionospheres. The diffusion rate to heights of maximum ionization was comparable to recombination rates at those altitudes.

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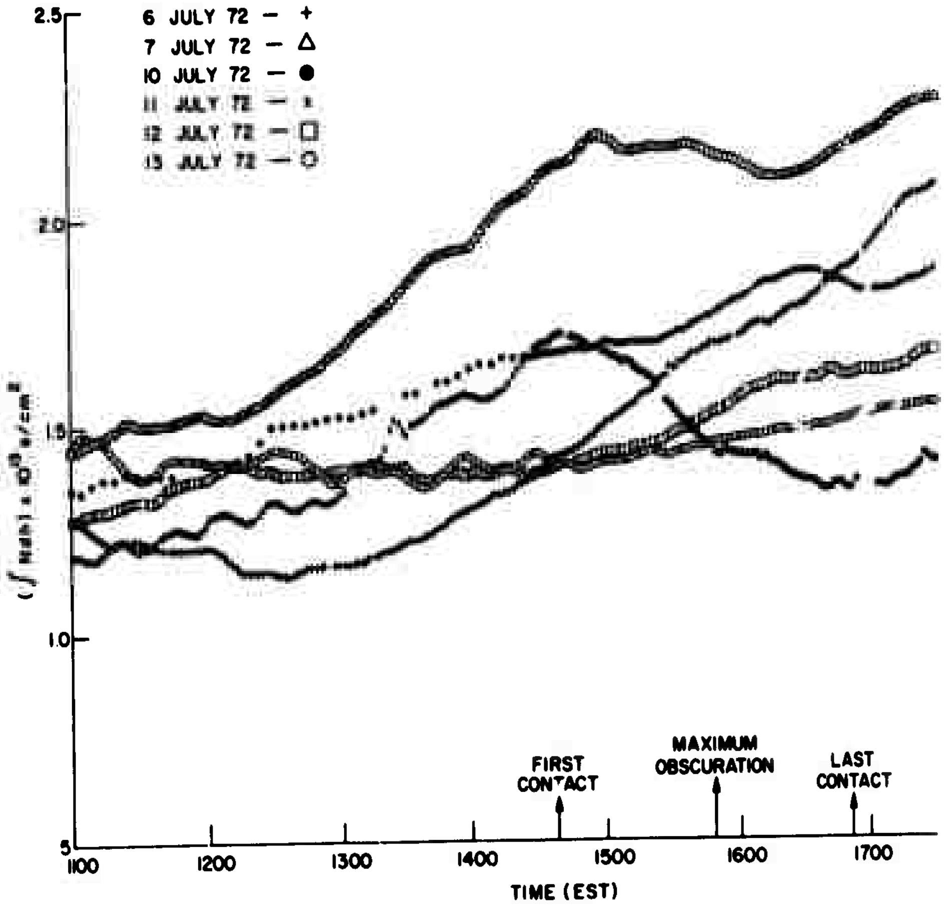

Fig. 1. Total Electron Content Obtained from ATS-3 Polarization Data Taken at Fort Monmouth, N. J., During the Eclipse Day (10 July 1972) and Control Days.

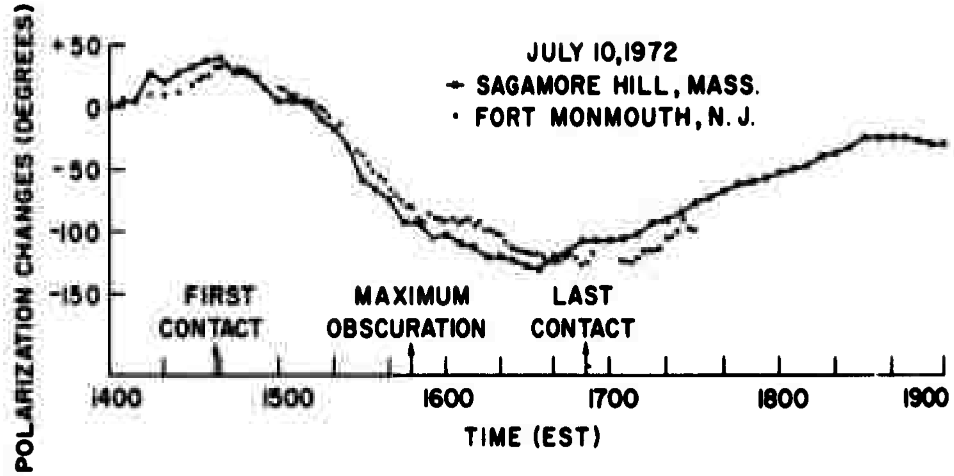

Fig. 2. Relative Polarization Changes at Sagamore Hill, Massachusetts and Fort Monmouth, N. J.

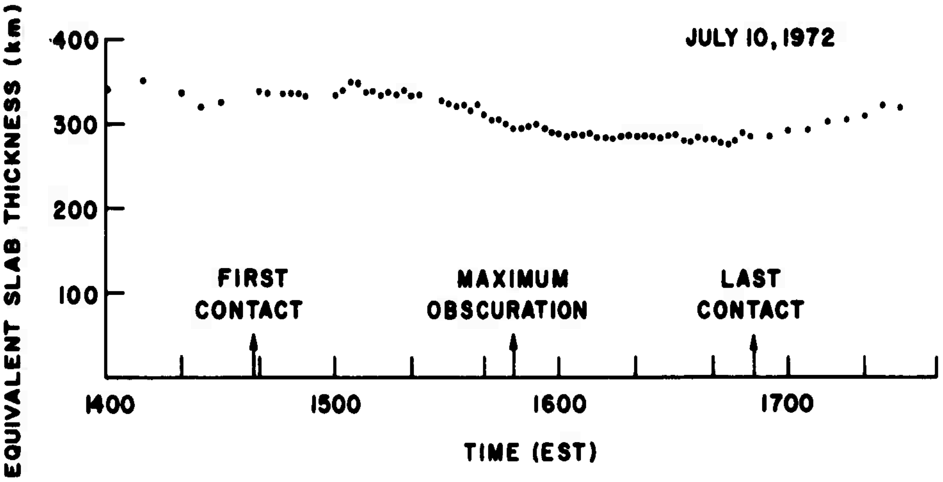

Fig. 3. Equivalent Slab Thickness Variations with Time at Fort Monmouth, New Jersey.

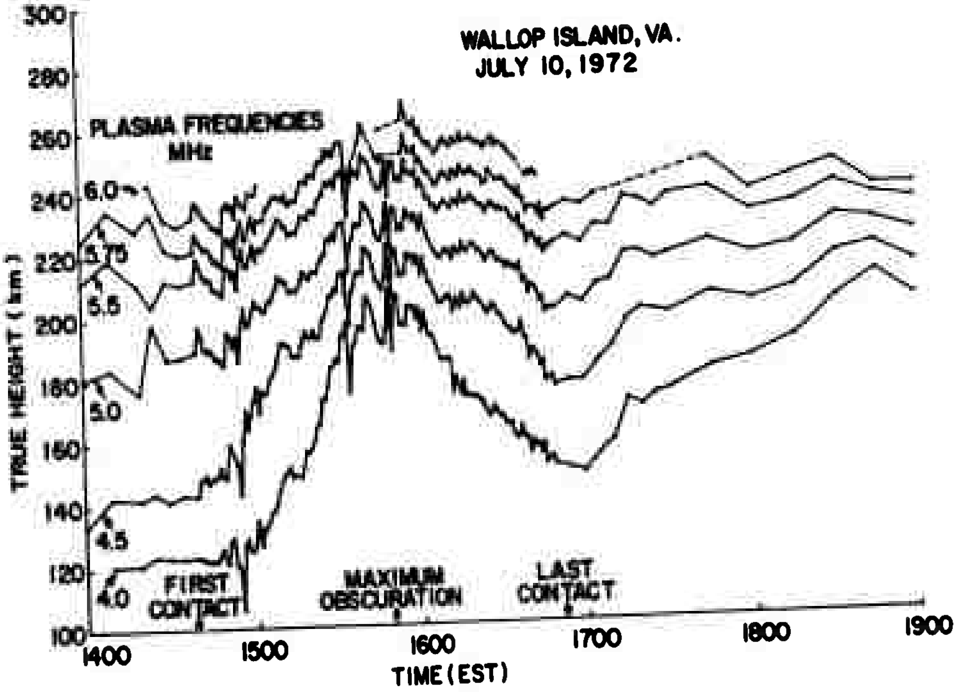

Fig. 4. True Height Variations of 4-6 MHz Fixed Plasma Frequencies as Functions of Time.