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LONGITUDINAL VARIATIONS OF PLASMAPAUSE RADIUS AND THE PROPAGATION OF VLF NOISE WITHIN SMALL ($\Delta L \sim 0.5$) EXTENSIONS OF THE PLASMASPHERE

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Abstract. Simultaneous broadband whistler recordings made during the International Magnetospheric Study (IMS) at the two Antarctic stations Halley and Siple have been used to study longitudinal variations in the radius of the plasmapause observed during local afternoon. In both of the two periods studied thus far, whistler-derived equatorial electron density profiles imply an increase in plasmapause radius between the longitudes of Siple and Halley ($\Delta\phi \sim 30°$) of $\Delta L \sim 0.5$. Intense VLF noise (~2.5 kHz) was observed at Halley but not at Siple, and by echo analysis its propagation path was identified with that of a whistler component travelling close to the plasmapause within the region of larger radius. This leads to the conclusion that the noise was generated by a gyroresonance instability when energetic electrons (typically 10 keV), drifting eastwards in the plasmatrough, encountered enhanced plasma density in the small extension of the plasmasphere.

Introduction

There is evidence from previous research of variations in plasmapause radius with longitude of order 0.5 L within $\Delta\phi \sim 30°$ [e.g., Angerami and Carpenter, 1966; Carpenter, 1978]. These were found to occur at various local times, and are not apparently associated with the evening bulge of the plasmasphere, at which ΔL is typically 1-2 [Carpenter, 1966] . Such structure is poorly documented however, and it was an object of spaced longitude broadband VLF measurements during the IMS to search for evidence of plasmapause structure. In the course of this work, carried out during several years of the IMS, direction-finding techniques were also employed so as to refine the available information on the location of propagation paths within the magnetosphere.

Extensions of the plasmasphere, such as the well-known evening bulge, are important for a number of reasons; one being the destabilizing effects on energetic electrons drifting in longitude in the low density plasmatrough when they encounter a region of larger plasmapause radius and higher density [Kennel and Petschek, 1966; Kaiser and Bullough, 1975]. Plasmapause structure is also an integral measure of preceding convection activity and provides signatures of the manner in which the plasmasphere shape is modulated by the effects of magnetospheric convection [e.g., Kaiser, 1972, Grebowsky and Chen, 1976].

The purpose of the present paper is to report comparisons of data from two IMS VLF stations, Halley and Siple Stations, Antarctica. These comparisons provide evidence of a variation in plasmapause radius of the order 0.5 L, within ~30° of longitude, and also show that the region of extended plasmapause radius may be a center of intense VLF noise activity.

Experimental Data

The data were acquired during 1977 at Halley (75.5S, 26.9W) and at Siple Station (75.9S, 84.3W), Antarctica. The special coordinated campaign during which the data were taken was entitled IPPDYP, or International Plasmapause-Plasmasphere Dynamics Programme, arranged through cooperative discussions among the members of the URSI/IAGA Working Group on Passive Electromagnetic Probing of the Magnetosphere. The campaign involved enhanced recording schedules in the australwinter, with characteristic modes of operation a 1-min-in-5 broadband recording throughout the 24 hours, augmented by continuous recordings at certain time periods. At Halley a goniometer was operated [Bullough and Sagredo, 1973] while at Siple conventional broadband recordings were made using a single-loop antenna.

Case studies have been made of two periods that were selected because well-defined whistlers, including some defining the plasmapause radius, were observed at both stations. In both cases a larger plasmapause radius was observed at Halley, and within the bulgelike extension of the plasmapause intense VLF emissions in the 2-4 kHz range were observed. Figure 1 shows a sketch of the interpretation of the data, illustrating the occurrence of an irregular feature as observed in the afternoon sector. An equatorial cross-section of the magnetosphere is shown with a sketch of the plasmapause as a function of longitude near the two observing stations, which are spaced roughly

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2 hours apart in magnetic local time.

The presence of an irregular feature of the plasmapause such as the one illustrated in Figure 1 is suggested by the equatorial electron densities that may be deduced from whistlers recorded simultaneously at Siple and Halley. Figures 2a and 2b show respectively profiles measured at 2000-2020 UT on 24 June 1977 and at 2025-2035 UT on 12 July 1977. Open circles represent Halley data, while crosses show results from Siple. The dashed curves represent estimates of the gross features of the Siple and Halley profiles, based both on the displayed data and on whistlers recorded in nearby periods. In Figure 2a within the plasmasphere and inside L = 4.3 both stations record densities at comparable levels. However, beyond L = 4.3 the observed densities at Siple are in the plasmatrough while at Halley there is clear evidence of an extension of plasmasphere levels to about L = 4.8. From that point on, the trough densities are comparable to those observed at Siple. A similar pattern was observed on 12 July 1977, as indicated in Figure 2b.

It is not possible to interpret the profile data from a given station as representing a single meridian through the station. However there are sources of information that suggest that to a first approximation the profiles shown in Figure 2 do indeed represent the distribution of densities near to the meridians of the respective stations. For example, in the case of the Halley data of Figure 2a, goniometer measurements of the arrival bearings of the whistler components indicate that the bulk of the whistler traces contributing to the profile were observed at relatively nearby longitudes. Another source of evidence is the fact that intense VLF noise, associated with the extension of the plasmapause observed at Halley, was received only at Halley and not at Siple in the two cases.

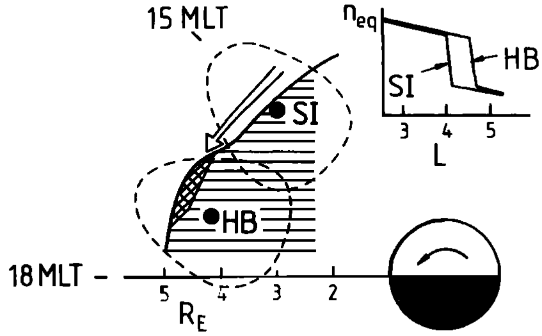

Fig. 1. A sketch of the plasmapause cross-section in the equatorial plane (viewed from the north), as deduced from whistler observation at Halley (HB) and Siple (SI) stations, Antarctica, at about 2000 UT on 24 June 1977. The plasmasphere is shown shaded. The dashed curves indicate the approximate 'viewing windows' of the two stations. The plasmasphere extension near the Halley longitude is inferred from plasma density profiles shown schematically by the inset. The cross-hatched area is a region of intense VLF noise observed at Halley but not at Siple and attributed to gyroresonance instability as eastward drifting energetic particles encounter the region of extended radius.

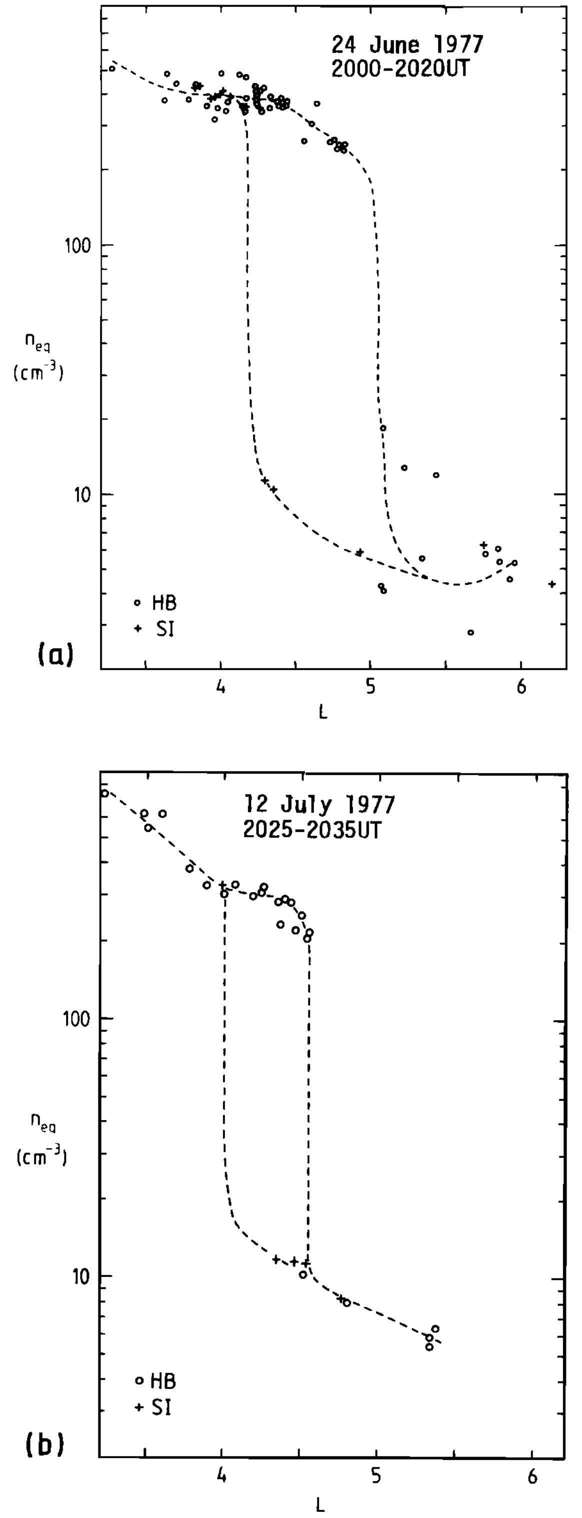

Fig. 2. (a) Equatorial electron density profiles from whistlers observed at Halley (circles) and Siple (crosses), 2000-2020 UT 24 June 1977. Each point represents a single whistler component. (b) Similar to 2a, but for 2025-2035 UT on 12 June 1977. Siple whistlers inside L = 4 were not scaled, but exhibited dispersion properties similar to those at Halley. In the density analysis, Park's [1972] formulae, involving assumption of a diffusive equilibrium (DE) model of the field-line distribution of electrons within the plasmasphere and an R^{-4} distribution outside, were used.

Spectrographic records showing comparisons of the whistlers recorded at Halley and Siple, and of VLF noise during the periods illustrated in Figure 2, are shown in Figures 3 and 4. Figure 3a shows a 30s record of VLF noise recorded at Halley for the 24 June 1977 case, while Figures 3b and 3c show whistlers, predominantly from paths within the plasmasphere, recorded simultaneously at the two stations. The evidence of the larger plasmasphere radius at Halley appears in the form of discrete whistler traces with nose frequencies below the ~4.5 kHz limit of the lowest nose observed on the Siple record. A particularly well-defined whistler component appears at Halley at a nose travel time of ~3.1s, with a nose frequency of ~3 kHz, corresponding to a propagation path with L ≃ 4.8. This component was found to exhibit whistler-mode echoing. Furthermore, the VLF noise forms present on the record were found to have a periodicity similar or identical to that of this particular component, and therefore are assumed to have propagated on the same path near the outer limits of the plasmapause as seen from Halley. This is shown in Figure 3a, a record extending over 30s near the time of the records of Figures 3b and 3c. The frequency scale is expanded to show some of the fine structure while the compressed time scale illustrates the periodicity of many of the elements. The 2-hop whistler-mode period, as determined from the echoing outer plasmasphere whistler marked W, is about 7.1s at 1.5 kHz; a representative element of the emissions, marked E, has the same 2-hop period.

The noise event here has conspicuous line structuring around 2.5 kHz. Matthews and Yearby [1981] recently discussed this case, reporting that line radiation events of this type are not usually observed simultaneously at Siple and Halley, and that they occur at Halley on fewer days and in shorter intervals than at Siple.

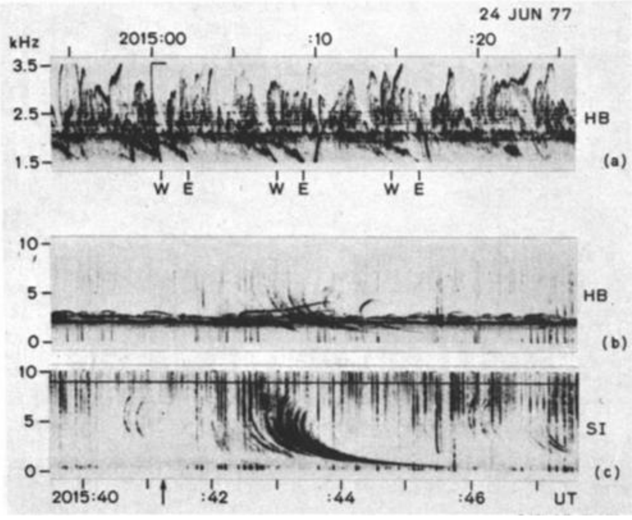

Fig. 3. (a) Expanded frequency scale spectrogram of the 2-3 kHz noise recorded near the time of Figure 3b. Typical two-hop periods are marked for an echoing whistler (W) and emission (E). (b), (c) Spectrograms of typical simultaneous multicomponent whistlers observed at Halley and Siple on 24 June 1977. See text for explanation. The time of the causative sferic, determined from echo periods, is marked by an arrow.

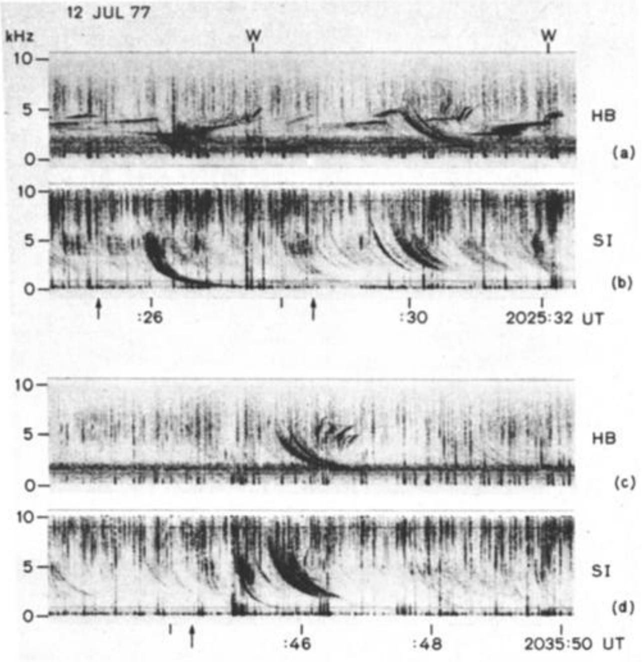

Fig. 4. (a), (b) Simultaneous whistlers at Halley and Siple on 12 July 1977. First-hop and third-hop traces of an echoing whistler component at Halley are marked by W. (c), (d) Another example from 12 July 1977.

Figure 4 shows a similar comparison for 12 July 1977, in this case showing whistlers at 2025 and 2035 UT. In Figures 4a and 4b, two separate whistler events (at 2025:26 and 2025:30) are observed at both stations; most of the components in the first event propagated outside the plasmapause, while the second shows propagation within the plasmasphere. In the first event the traces with the highest nose frequency propagating at lowest L appear at Siple, while traces propagating at higher latitudes are defined at Halley, which also shows a faint indication of the lower part of the Siple components. In the second whistler event, there are similarities in some traces that do not exhibit a direct nose. Again, as in Figure 3, Halley shows components (here the upper parts of nose traces) at travel times longer than those observed at Siple and at lower nose frequency, indicating a larger extension of the plasmasphere. The first-hop and third-hop elements of one of these components, as they appeared in the first whistler event, are marked by the letter W. These appear to be associated with the propagation of periodic VLF emissions that are also present on the record near 3-4 kHz. As in the case of June 24th, we again infer that the VLF emission activity was associated with the region of larger plasmapause radius.

Figures 4c and 4d show another example of simultaneous whistlers at Halley and Siple. In this case emission activity is not present but the difference in the whistler structure is better defined. There is propagation on both sides of the plasmapause in the case of the Siple whistler ('outside' traces near 2035:45, 'inside' ones near 2035:46) while the Halley whistler shows plasmasphere traces only, with a number of components observed below the lowest (plasmaspheric) nose frequency identified on the Siple record.

Direction-finding analysis (Sagredo and Bullough, 1973; Lester and Smith, 1980) has been applied to the periodic noise in the two cases. This analysis confirms that the propagation took place near the meridian of Halley. The identification of the propagation path with that of an echoing whistler component made by echo analysis as described above, is confirmed by the measurement of the same arrival azimuth for the noise as for the whistler.

Discussion and Interpretation

This is only the first of an expected series of reports on Halley-Siple comparisons from the IMS. It illustrates some of the potential value of such comparisons in providing new evidence of irregular structure of the plasmapause and also showing that a small, $\Delta L \sim 0.5$, extension of the plasmasphere may be the site of intense VLF emission activity.

The localized occurrence of VLF emissions in the extended region near Halley may be the result of the drift of energetic electrons eastward from a low to a high density region. If we take the profiles of Figure 2 and the L value of the propagation, say, on 24 June 1977 ($L = 4.8$) then we can infer [e.g., Rycroft, 1976] that the (parallel) energy range of particles resonant with the 2-3 kHz waves near the magnetic equator would have changed from 20-60 keV in the low density region in the vicinity of Siple to 0.5-1.5 keV within the denser region near Halley. Geographically localized zones of VLF emissions have been reported by Lefeuvre and Bullough [1973] from Ariel 3 satellite observations. The fact that fewer line radiation events were observed at Halley than at Siple suggests that their occurrence at Halley may require rather special magnetospheric conditions, such as the presence of a plasmaspheric irregularity of the type described here.

The data points in Figure 2 were deduced from individual whistler components received within about 15 minutes of the times represented in Figures 3 and 4. In these particular cases it was not possible, because of the complexity of the whistlers, to determine unambiguously the extent to which some of the traces were common to the two stations and to what extent each observed a different set of whistlers. A few traces were probably common to both, but these tended to occur within the inner part of the plasmasphere where the density level was fairly similar over the longitude range of the observations and thus do not appear to affect the interpretation of the data.

In both of the present case studies, most of the multicomponent whistlers observed simultaneously at Siple and Halley were excited by a common lightning flash, although there was usually little correspondence in the detailed component structure at the two stations. This normally seems to be the case, and implies that the effective area of illumination by a lightning source in the northern conjugate region is large compared with the viewing areas of the individual receivers, and with their separation.

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