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FIRST RESULTS FROM A COMPARISON OF GROUND-BASED IONOSPHERIC MEASUREMENTS IN THE SOUTHERN HEMISPHERE AND THE USU GLOBAL IONOSPHERIC MODEL

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Abstract: The *F*-layer parameters N_mF_2 and h_mF_2 have been derived from measurements made at two Antarctic stations for quiet days during the austral summer and winter of 1982. Siple (76°S, 84°W) and Halley (76°S, 27°W) are both sited near $L\approx4.2$ and use essentially identical digital HF sounding radars. Even under quiet conditions, systematic differences in N_mF_2 and h_mF_2 can be observed at the two sites. Insight into the source of these differences can be obtained from a comparison of the ionospheric data with theoretical data derived from the USU global ionospheric model. Under austral winter conditions, a relatively good model-observational comparison is obtained. However, for austral summer conditions this agreement is poorer, apparently due to the simplicity of the neutral wind incorporated into the ionospheric model.

1. Introduction

As a result of the large displacement between the magnetic and geographic poles in the Southern Hemisphere, there are subtle differences in the behavior of the high latitude ionosphere in the two hemispheres. Using ionosonde data acquired during the IGY, Duncan (1962) found that the peak critical frequency of the *F*-region (f_oF_2) occurred at 06 UT at several Antarctic stations. A later study by King *et al.* (1968) attributed the 06 UT peak in f_oF_2 to atmospheric winds. This work was extended by Eccles *et al.* (1971) who invoked a simple model of neutral winds to predict the variation of f_oF_2 at a number of locations in both hemispheres. Within the past several years, computer models of the global ionosphere have been developed. Recently, these models have become increasingly sophisticated and can accurately reproduce many ionospheric features. Although our knowledge of the global mechanisms which control ionospheric processes has increased dramatically, model and observational comparisons from the Southern Hemisphere have been sparse, in part due to the lack of detailed ionospheric measurements. Recently, two identical NOAA HF sounding radars were installed in the Antarctic, one at Siple Station (by Utah State University) and the other at Halley (by the British Antarctic Survey). Fortuitously, Siple and Halley Stations have essentially the same latitude in both the geographic and invariant coordinate systems.

This paper will present an analysis of two quiet intervals, one during the austral summer and the second during the austral winter, for which theoretical ionospheric modelling has been carried out. The results from a comparison of the observational and modelling data are discussed.

2. The USU Global Ionospheric Model

The Utah State University global ionospheric model was initially developed as a mid-latitude, multi-ion (NO^+, O_2^+, N_2^+ and O^+) model by SCHUNK and WALKER (1973). The time-dependent ion continuity and momentum equations were solved as a function of altitude for a corotating plasma flux tube, including diurnal variations and all relevant E and F-region processes. This model was extended by SCHUNK *et al.* (1975, 1976) to include high latitude effects due to convection electric fields and particle precipitation. A simplified ion energy equation was also added, based on the assumption that local heating and cooling processing dominate, an assumption which is valid at heights below 500 km. A further extension of the model to include the minor ions N^+ and He^+, an updated photochemical scheme, and the MSIS atmospheric model is described in SCHUNK and RAITT (1980).

The addition of plasma convection and particle precipitation models has been described by SOJKA *et al.* (1981a, b). More recently, ion thermal conduction and diffusion-thermal heat flow has been included in the model, so that the ion temperature is now rigorously calculated at all altitudes between 120–1000 km (SCHUNK and SOJKA, 1982). The ion energy equation and conductivities incorporated in the model are those given by CONRAD and SCHUNK (1979).

3. Observational Results

The experimental data used in this study were acquired at Siple (75.94°S, 84.25°W) and Halley (75.52°S, 26.62°W) Stations in Antarctica. This station pair is characterized by several unique attributes, in addition to almost identical geographic latitude coordinates. As indicated in Fig. 1, both stations are situated near $L \approx 4.2$; the separation in magnetic time is approximately two hours whereas the local time separation is slightly less than four hours. The digital ionospheric sounding systems (GRUBB, 1979) used at both stations were identical in all respects except for the transmitting and receiving antenna configurations. Ionograms were recorded at regular intervals at both sites.

The sounding radar system measures received echoes on two receiver channels, each of which is connected to a separate dipole antenna. Since the phase is one of the measured parameters, echo angle-of-arrival can be derived from the measurements. Using an elevation angle filtering technique (BERKEY and JARVIS, 1985), ionograms which represent only the overhead ionosphere were obtained. Application of this technique was particularly important in interpreting those ionograms which exhibited range or frequency spreading. Having obtained a 'clean' ionogram, the measured virtual range and frequency values were used as input to the true height analysis program developed by TITHERIDGE (1985). This analysis yielded an electron density profile from which the frequency (f_oF_2) and height (h_mF_2) of the peak electron density in the F-region were derived. This procedure is shown schematically in Fig. 2.

As a starting point for the comparison between the observational data and the

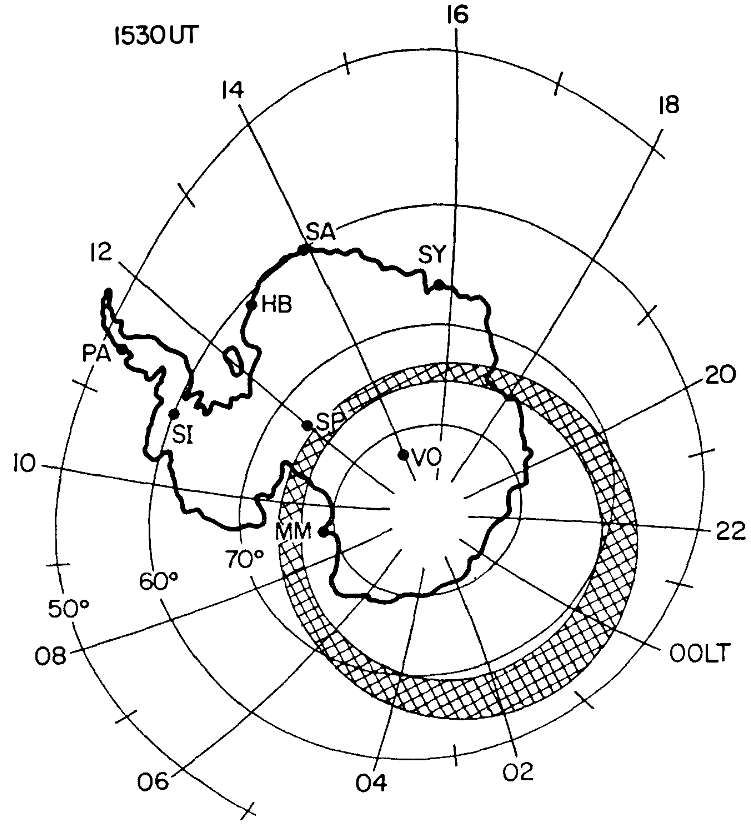

Fig. 1. A map of Antarctica upon which invariant latitude and time coordinates have been superimposed. The location of the auroral oval at 1530 UT is shown as the hatched region. The stations referenced on the map are: Siple (SI), Halley (HB), SANAE (SA), Syowa (SY), Palmer (PA), South Pole (SP), McMurdo (MM) and Vostok (VO). (Figure courtesy of C. G. MacClennan).

global ionospheric model, two of the magnetospherically quietest intervals during 1982 were chosen. One of the selected intervals was during the austral winter (15 August 1982) while the second was an austral summer period (7 November 1982). The model computations traced an ionospheric flux tube appropriate to the latitude of Siple and Halley for a period of 30 h. Note that for quiet conditions, such flux tubes will virtually corotate with the ground station.

An ionogram typical of the data used in this analysis is shown in Fig. 3. This ionogram was recorded at 0800:52 UT on 15 August 1982 at Siple Station, Antarctica. The overhead echoes are those reflected from the mid-latitude ionospheric trough and extend from 1.0 to 1.4 MHz in frequency and 400 to 750 km in range. The large distribution of spread echoes are reflected from a region poleward of the station, which has a larger density ($f_oF_2 \approx 8$ MHz). The results of true-height analysis, using the Titheridge method, are shown in Fig. 4. The lefthand panel of this figure shows the input data, while the righthand panel depicts the electron density profile. For these data, the overhead plasma density was 2.5×10^4 electrons/cm^{-3} while the peak of the layer occurred at 376.3 km with a probable error of 16.3 km.

The time history of h_mF_2 (lefthand panel) and f_oF_2 (righthand panel) for the quiet winter interval (15 August 1982) is illustrated in Figs. 5 and 6 for Siple and Halley,

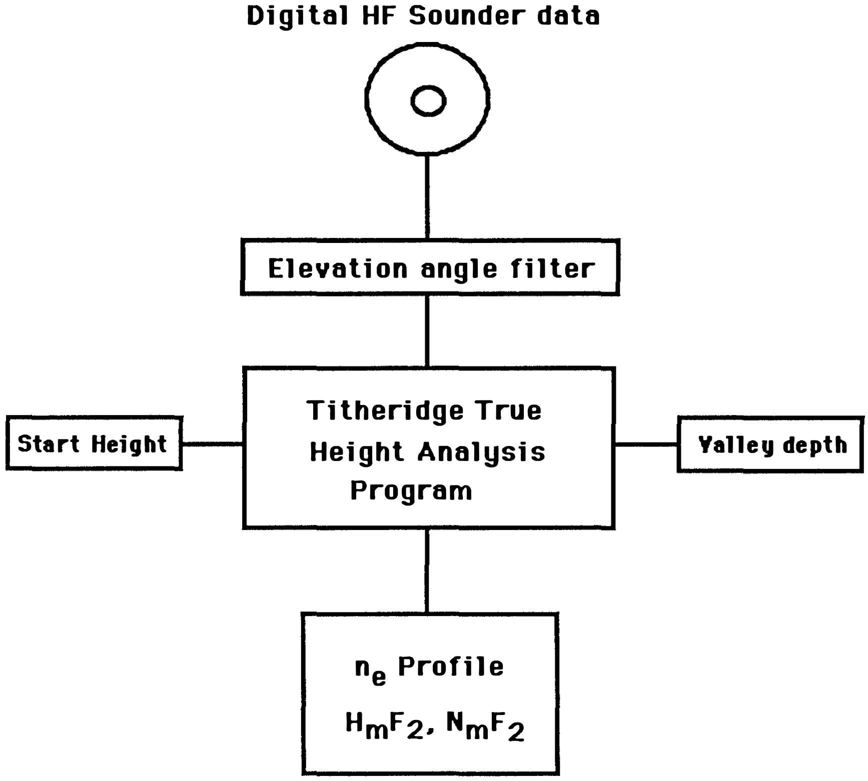

Fig. 2. *A schematic diagram illustrating the methods by which the observational data have been analyzed.*

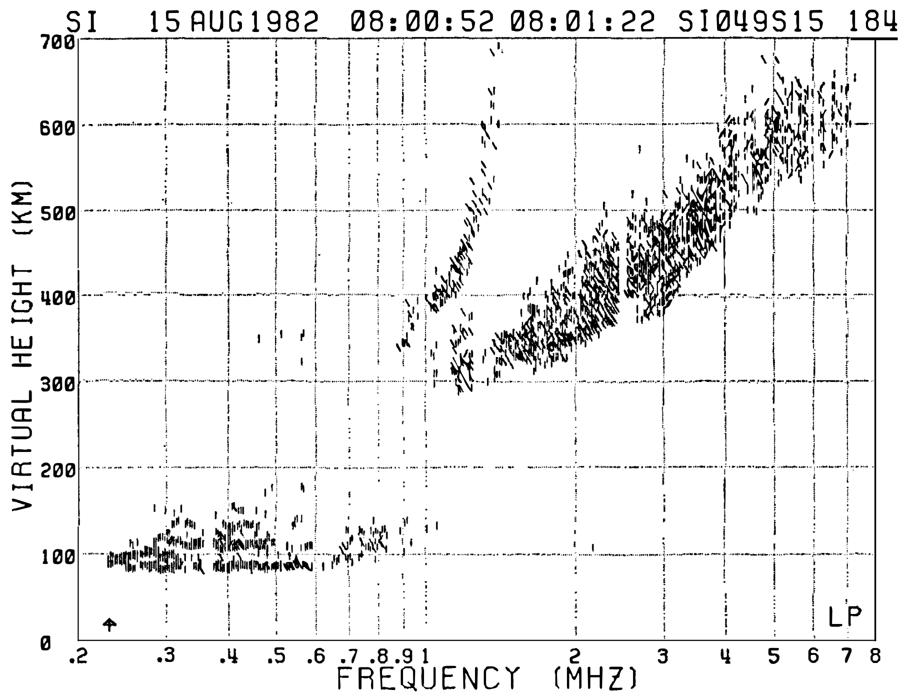

Fig. 3. *An ionogram recorded at Siple Station, Antarctica on August 15, 1982 at 0800:52 UT. Echoes from the ionospheric trough occur between 1.0 and 1.4 MHz. Echo polarization is denoted by the orientation of the graphics symbol.*

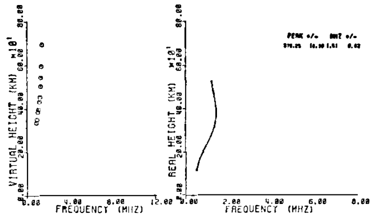

Fig. 4. Results of true height analysis of the ionogram shown in Fig. 3. Only those echoes from the overhead ionosphere have been subjected to analysis. In this case, the mid-latitude ionospheric trough was overhead of the station. The input data are reproduced in the lefthand panel and the resulting electron density profile is shown in the righthand panel.

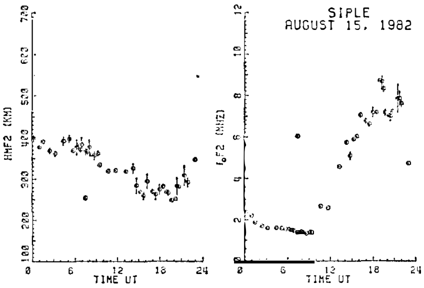

Fig. 5.

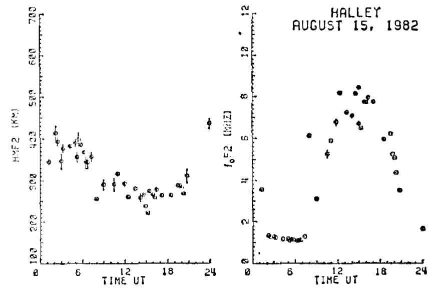

Fig. 6.

Fig. 5, 6. The Universal Time variation of the height of the F-region peak (h_mF_2) and the plasma frequency (f_oF_2) at the peak for August 15, 1982 at Siple (Fig. 5) and Halley (Fig. 6), Stations, Antarctica. The vertical lines drawn through each symbol indicate the probable error in determining either h_mF_2 or f_oF_2 according to the method of TITHERIDGE (1985).

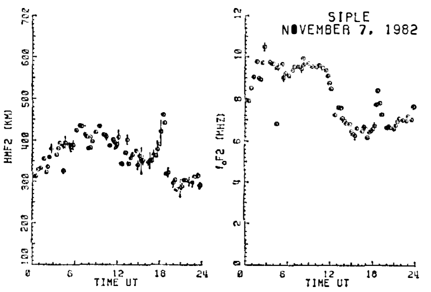

Fig. 7. Same as Fig. 5 for a quiet summer day (November 7, 1982) at Siple Station, Antarctica.

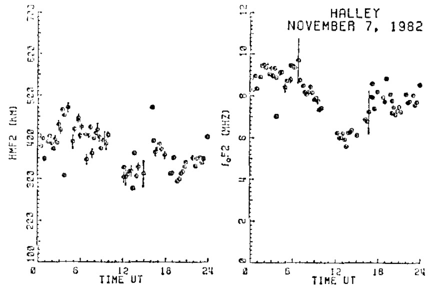

Fig. 8. Same as Fig. 7 for Halley Station, Antarctica.

respectively. The heights attained by the $F2$ region peak are very similar at both stations, whereas the density within the trough region is noticeably smaller at Halley. Peak plasma frequencies near 9 MHz ($\approx 1 \times 10^6$ electrons/cm^{-3}) are reached at both stations.

The same data are shown in Figs. 7 and 8 for a quiet austral summer interval (7 November 1982). In these data, the mid-latitude ionospheric trough is not evident and the peak plasma frequencies are large throughout the day, ranging between 6 and 9 MHz. Again, the heights of the F-layer peak are very consistent at both Siple and Halley during this interval.

4. Model Results

The USU ionospheric model was initialized using the following conditions; the year and season as appropriate for the observational period; no auroral precipitation (since both sites are equatorward of the auroral oval under quiet conditions); because of the low geomagnetic activity level, the plasma flux tubes almost corotate with the stations; and a neutral wind as described in SOJKA *et al.* (1981b). The role of the neutral wind in the mid-latitude trough region is quite important. For this study the reference wind pattern has a small poleward speed in sunlight (<50 m/s) and an equatorward nighttime speed of ≈200 m/s.

The model results for these two intervals are presented in Figs. 9–12, wherein the same parameters used in Figs. 5–8 have been derived. Since the model is sensitive to the magnitude of the neutral wind assumed, three cases are illustrated. Those cases specify (a) no neutral wind, (b) a reference neutral wind value, and (c) twice the value assumed in (b). During the day, the neutral wind induces a vertically downward plasma drift causing h_mF_2 to decrease, a consequence of which is an increased plasma recombination rate, which in turn leads to lower plasma densities. At night the neutral wind induces an upward drift which increases N_mF_2 and maintains the layer height (h_mF_2). Such effects caused by the neutral wind are evident in the model results shown in Figs. 9 and 10. As illustrated by the experimental data, the night-time values of N_mF_2 at Siple and Halley exhibit significant changes as the neutral wind increases. Within the mid-latitude trough, the plasma densities vary by more than a factor of 8 for the three neutral wind cases chosen. In modelling the austral summer data (*cf.* Figs. 11 and 12), only the reference neutral wind has been incorporated. Note that the ionosphere at both stations is sunlit continuously on November 7.

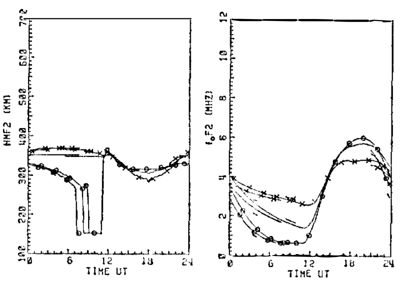

Fig. 9.

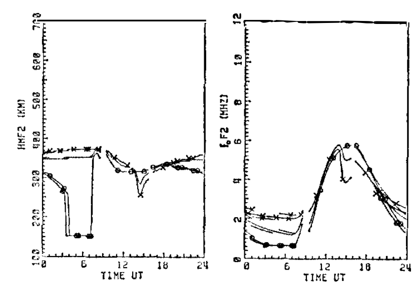

Fig. 10.

Fig. 9, 10. Ionospheric modelling results which show the temporal (UT) variation of h_mF_2 and f_0F_2 for a flux tube started at the latitude of Siple (Fig. 9) and Halley (Fig. 10), Stations, Antarctica. The open circles denote computation without a neutral wind; the unmarked variations are those derived using a reference neutral wind and the curves marked with an X have been derived for twice the reference wind velocity. These data were derived for geophysical conditions appropriate to August 15, 1982.

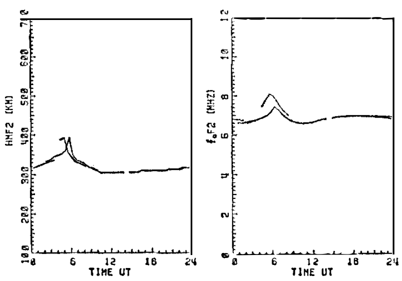

Fig. 11. Same as Fig. 9 for November 7, 1982.

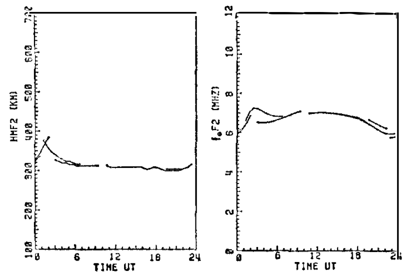

Fig. 12. Same as Fig. 11 for Halley Station, Antarctica.

5. Model-Observation Comparison

Here, the noon and midnight sectors will be used as reference points for the comparison between the model and observational results. First, examining the austral winter results for Siple (Figs. 5 and 9) and Halley (Figs. 6 and 10) in the midnight trough region, the observed and modelled values of N_mF_2 are quite consistent for the case in which a reference model wind value was assumed (unmarked trace). Similarly, there is reasonably good agreement between the modelled and observed values of h_mF_2. In the noon sector, the model results are less consistent, producing smaller values of N_mF_2 and larger layer heights. In order to lower the F-region maximum, a larger (*i.e.* stronger) dayside wind would have to be invoked. This, however, would tend to further reduce the modelled densities leading to even further discrepancy with the observations. A tentative conclusion from this result is that the neutral atmosphere and euv values assumed by the model are not appropriate.

At Halley, the plasma density in the mid-latitude trough is smaller than that observed at Siple. This result is consistent with the modelling results and is most likely a consequence of the UT variation in the extent and form of the mid-latitude trough as determined computationally (for the Northern Hemisphere) by SOJKA *et al.* (1981a). These computations show that the trough is deepest and has the least longitudinal extent when the geomagnetic pole points toward the Sun with respect to the geographic pole. When the opposite configuration exists, the trough is shallower and almost circumvents the pole.

During austral summer conditions, the diurnal variation of N_mF_2 is less marked than in winter due to the fact that the ionosphere is sunlit continuously throughout a 24 h period. The data from Halley and Siple Stations shown in Figs. 7 and 8 illustrate the small variations of N_mF_2 and show that h_mF_2 varies between 300 and 450 km. In the noon sector, where neutral winds induce a downward drift, h_mF_2 attains a value of about 300 km, whereas at night it rises to near 400 km as a result of upward induced winds. N_mF_2 also responds to the raising and lowering of the ionosphere in that within regions of raised h_mF_2, the density (N_mF_2) increases. Comparing the trends in the observational data with the model results (Figs. 11 and 12), reveals a reasonable agreement in the noon sector in both h_mF_2 and N_mF_2, whereas in the night sector the model results are lower in height and smaller in density than are the observations. The model produces only a small region in local time over which h_mF_2 is elevated and N_mF_2 increased. Such a restricted local time enhancement appears to be of the correct magnitude when compared with the observations. However, the wind induced upward drift is not maintained for a long enough time. The model neutral wind again is too simple and its shortcomings are clearly demonstrated by these data sets.

6. Conclusions

The high resolution F-region observations made at Halley and Siple Stations have enabled a unique Southern Hemisphere comparison with the USU high latitude ionospheric model. By carrying out a sophisticated data reduction procedure, these two sets of observations have yielded simultaneous h_mF_2 and N_mF_2 values for quiet austral summer and winter conditions. Resulting from the high resolution, a systematic longitudinal difference is present in these data sets. The ionospheric modelling computer code was run to produce similar data sets for these conditions and the following comparisons were found.

(1) During austral winter conditions on the dayside, reasonably good data-model comparisons in both h_mF_2 and N_mF_2 were obtained.

(2) During night condition (austral winter) N_mF_2 at Halley was systematically $\approx$20% lower than the corresponding values at Siple. The model reproduces this longitudinal variation. Furthermore, this dependence and indeed the h_mF_2 and N_mF_2 values are strongly dependent upon the adopted neutral wind model.

(3) At Halley and Siple, the ionosphere is continuously sunlit throughout the day during the austral summer. Although the h_mF_2 and N_mF_2 variations are less marked, they do show the effect of the neutral wind lowering h_mF_2 on the dayside and raising it at night. This then leads to higher nightside N_mF_2 values. The model yields reasonable values for the dayside h_mF_2 and N_mF_2 but at night has too short a local time period of increased values of h_mF_2 and N_mF_2.

The most apparent problem in trying to model both the austral summer and winter data is the lack of knowledge about the neutral wind pattern. Previous Northern Hemisphere studies using the USU ionospheric model have not suffered from this problem because the data resolution has been insufficient to reveal this problem, especially under aurorally disturbed conditions.

Acknowledgments

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