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Measurements of Trans-Ionospheric Propagation Parameters in the Polar Cap Ionosphere

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Measurements of absolute TEC were made for the first time from the polar cap station located at Thule, Greenland in early 1984 using dual-frequency group delay measurements from high orbit satellites. Measurements of L-band amplitude scintillation and dual-frequency differential carrier phase scintillation were also made. The variability of the TEC was extremely large, with increases above the background values of more than 100 percent observed frequently. Quasi-periodic TEC enhancements with periods as short as 10 min and with amplitudes exceeding 10**17 el/m**2 column were seen over several time intervals of more than two hours. The absolute values of TEC observed in the dark polar cap ionosphere at times exceeded the diurnal maximum values from the mid-latitude ionosphere during this initial period of observations.

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1. INTRODUCTION

Measurements of total electron content (TEC) have been obtained for the first time from the polar cap station at Thule, Greenland, (76.5 degrees North geographic latitude, 86 degrees invariant latitude). The only TEC measurements previously reported from Thule were obtained from Faraday rotation from a geostationary satellite (Klobuchar et al[1]) viewed at an approximate five-degree elevation angle to the south where the ionospheric intersection of the ray path to the satellite was over the auroral zone rather than the polar cap.

It is particularly important to measure the behavior of the TEC in the winter polar cap ionosphere when solar EUV is minimal and the F region can be dominated by transport, rather than by local production. TEC measurements are also important because of ionospheric time delay effects on satellite positioning systems located at high latitudes.

TEC, amplitude and phase scintillation data were obtained from radio waves transmitted from a number of 12-hr, high inclination, sidereal synchronous satellites, each giving approximately two to three hours of data over Thule. The dual

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(Received for publication 30 March 1987)

1. Klobuchar, J.A. et al (1973) Low-elevation angle measurements of total electron content taken from Thule, Greenland, Chapter: Total Electron Content Studies of the Ionosphere, AFCRL-TR-73-0098, AD 762481.

frequency nature of the satellite L-band signals allowed unambiguous measurements of differential group delay, differential carrier phase, and amplitudes on both frequencies.

Figure 1 illustrates the north polar cap region along with the locus of ionospheric intersections of the ray paths to the satellites at a mean height of 400 km.

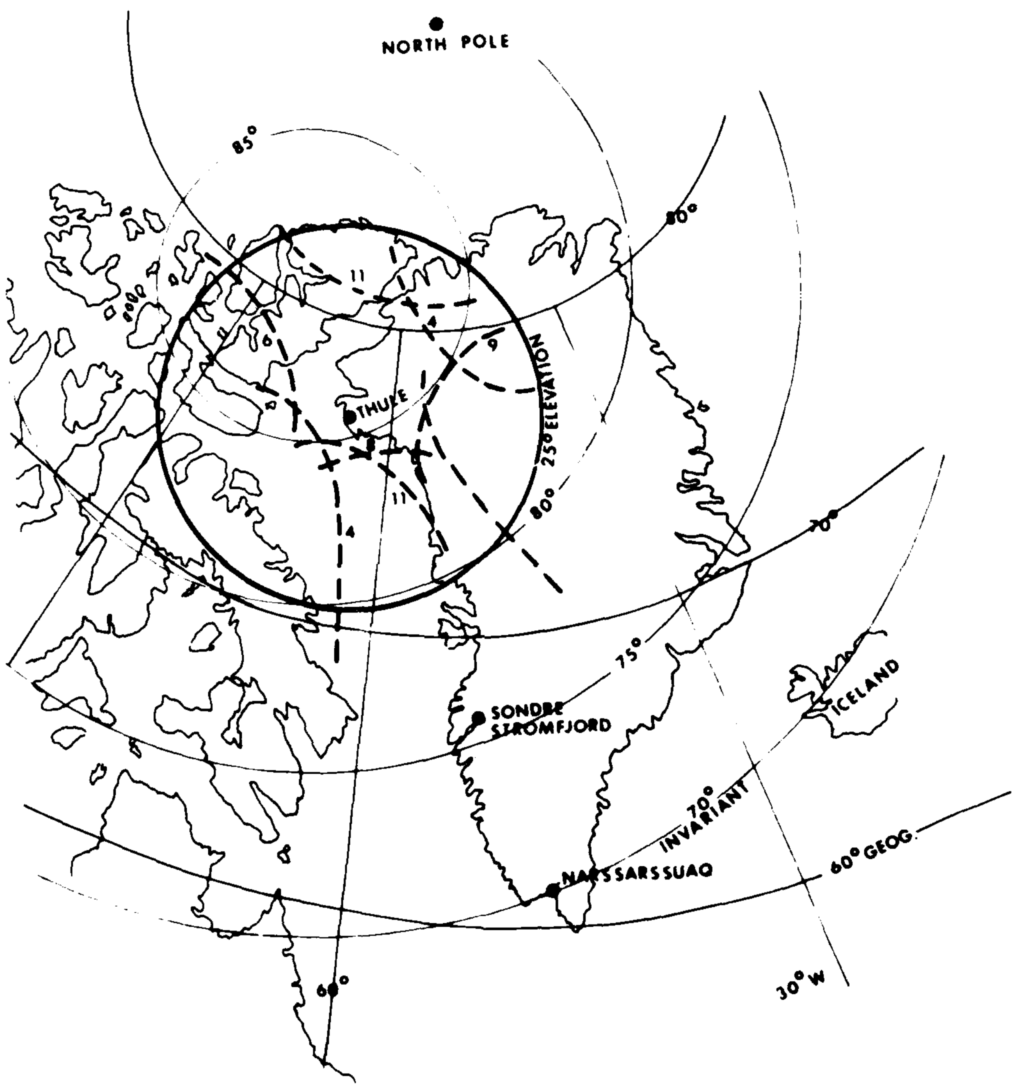

Figure 1. Locus of 400-km Height Intersection of Ray Path to Various Satellites Used to Measure Trans-ionospheric Propagation Parameters. Invariant latitudes are indicated also

Note that most of the projected ray paths from the various satellites were located above 80 degrees invariant latitude. Thus, the measurements were taken in the true polar cap, well northward of the polar cusp and auroral regions. As indicated in Figure 1, most of the data were obtained above 25 degrees elevation with the exception that, when no satellite was visible above 25 degrees elevation, signals from the highest elevation satellite were monitored until the satellite was no longer visible from Thule. The TEC was converted to equivalent vertical values using a mean ionospheric height of 400 km.

2. TEC RESULTS

The TEC results were first plotted in diurnal overplot form as illustrated in Figure 2. Several unusual features of the polar cap TEC, that are not commonly seen in mid- or low-latitude TEC diurnal overplot data, are immediately apparent from Figure 2. The large day-to-day variability is obvious, as is the remarkable variability within the day, or even within a few minutes of time. Generally, when the diurnal TEC differs greatly from monthly mean values in the mid- or low-latitudes, it tends to stay on the same side of the mean curve throughout much of the daytime period. An important exception is, of course, the mid-latitude behavior of TEC during the first day of a magnetic storm in which the TEC can rise to very large values during the afternoon period and then rapidly fall to much lower average values during the dusk period.

At Thule, however, the TEC data illustrated in Figure 2 shows large departures in both directions from an average curve throughout the day. In fact, the entire concept of a mean or median curve for the data set illustrated in Figure 2 is not very useful.

A more useful way to look at the Thule TEC data is to look at individual days, particularly the times of day when the variability is greatest. For this purpose we have chosen the period of day from 19 to 24 hours UT shown in Figure 3. Note that, of the three days illustrated, 1 February 1984 was a quiet day, while 2 and 3 February were magnetically disturbed periods. The extremely high variability of the TEC found on both 2 and 3 February are unmatched in our extensive experience in looking at mid- and low-latitude TEC. The period near 23 hours UT on 2 February 1984 was particularly remarkable since there was a periodic component to the TEC changes having a magnitude in excess of 10 * 10 **16 el/m**2 column, that was significantly greater than the TEC during the quiet day of 1 February. We conclude that the "quiet day" of 1 February likely represents the mean polar cap winter TEC, and that, during disturbed days, the TEC is enhanced above these quiet day values.

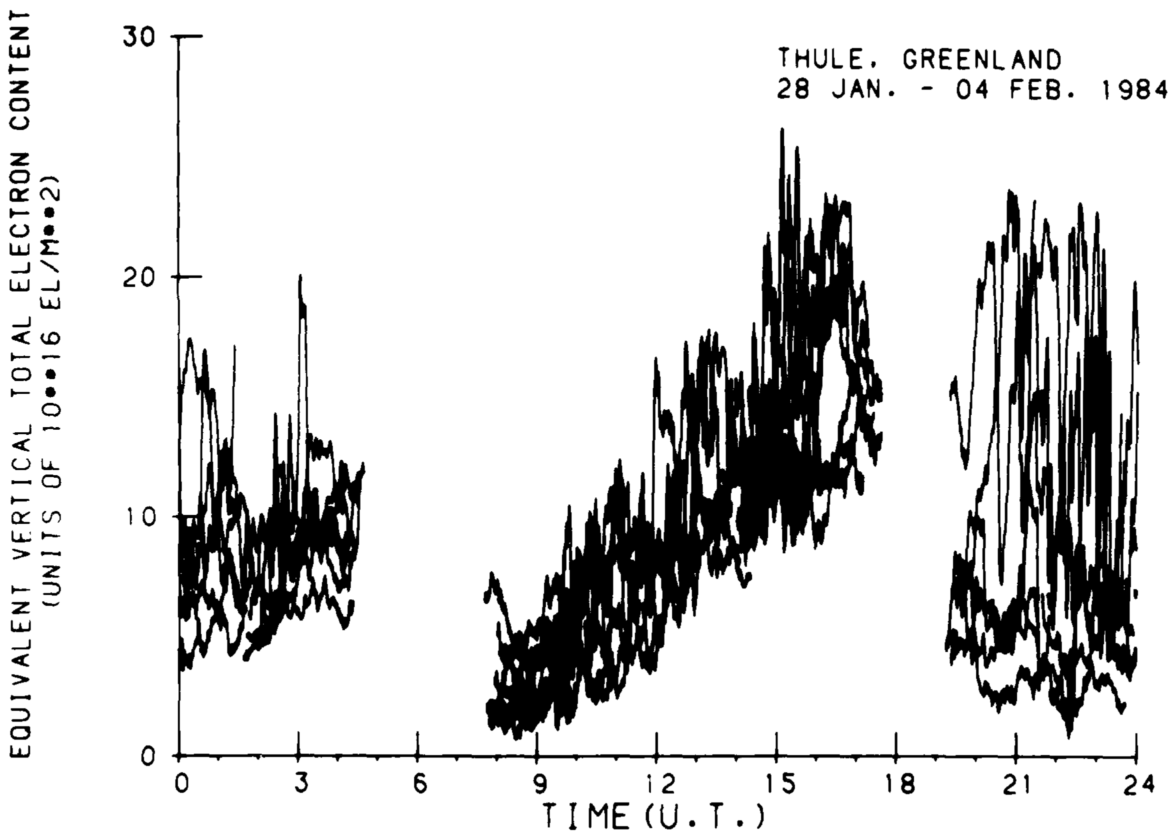

Figure 2. Diurnal Behavior of Equivalent Vertical TEC vs UT for the Period 28 January to 4 February 1984

This is shown more clearly by comparison with a theoretical model in which the solar EUV, the average polar rain precipitation, and the earth's co-rotation are included in the model that is integrated to yield the TEC. These modeled values, for a quiet day condition in the polar cap ionosphere, are shown in Figure 3 for 1 February, as indicated by the open circles. Note the excellent comparison in absolute values of observed quiet day TEC with those of the theoretical model.

The correlation of the TEC enhancements seen on 2 and 3 February with occurrences of amplitude scintillation at 1.2 GHz has been reported in Klobuchar et al.[2] The important point to notice about the TEC enhancements in Figure 3 is that they are extremely large, not only on a percentage basis, but also on an absolute TEC basis.

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2. Klobuchar, J.A., Bishop, G.H., and Doherty, P.H. (1985) Total electron content and L-band amplitude and phase scintillation measurements in the polar cap ionosphere, presented at AGARD Symposium on Propagation Effects on Military Systems in the High Latitude Region, Fairbanks, Alasks, 3-7 June 1985.

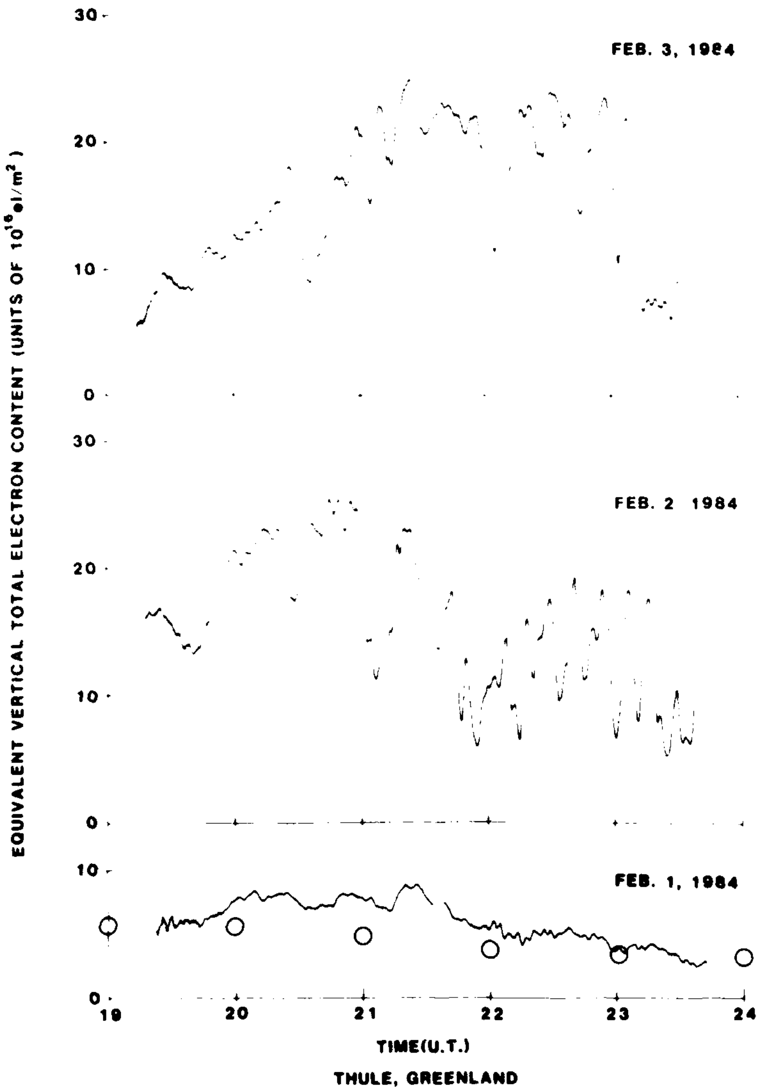

Figure 3. Variation of TEC for the Time Period 19 to 24 Hours UT for 1 to 3 February 1984. The open circles shown in the 1 February plot are the results obtained from a theoretical model including production from solar EUV, polar rain precipitation and co-rotation

3. COMPARISONS WITH TEC FROM OTHER STATIONS

It is instructive to compare the Thule TEC values with TEC data taken from Goose Bay, Labrador, an auroral station, and with Hamilton, Massachusetts, a mid-latitude station. All three stations are located within approximately ten degrees of geographic longitude of each other. Unfortunately, only hourly values of TEC from Goose Bay were available from the same period, while 15-min scaled values of TEC data from Hamilton, Massachusetts were available for most of the same observation period as the Thule data.

Figure 4 shows the diurnal overplots of the Hamilton and Goose Bay TEC data for the same period as the Thule data. The Thule diurnal overplots are again plotted in Figure 4 for comparison purposes with those from the two lower latitude stations.

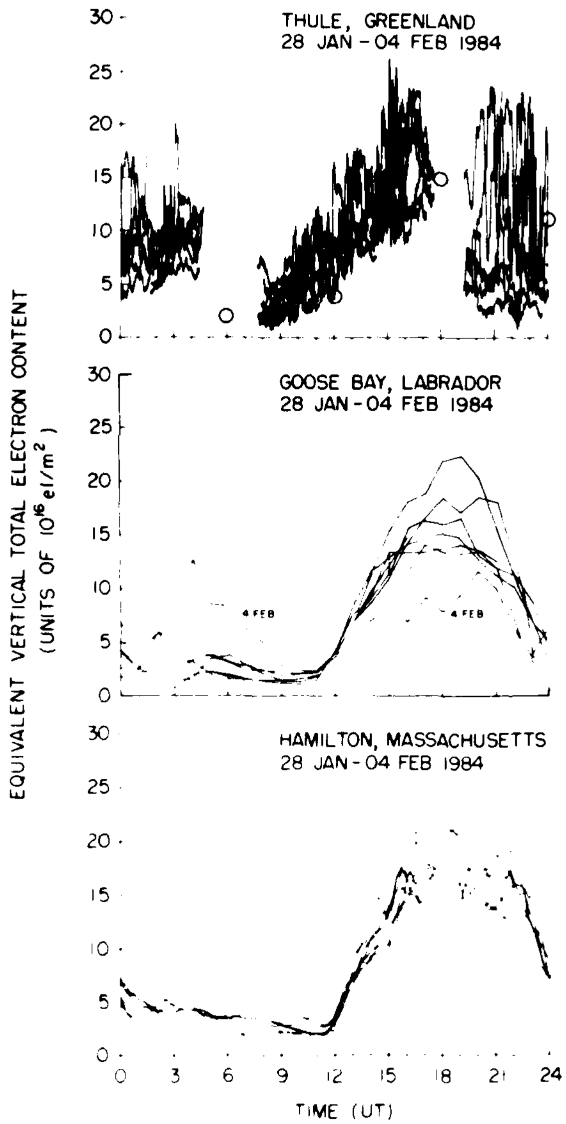

Figure 4. Diurnal Overplots of TEC From: (a) Thule, (b) Goose Bay, and (c) Hamilton, Massachusetts for the 28 January to 4 February 1984 Period. The open circles in (a) are the results obtained from a theoretical model, including production, polar rain precipitation, co-rotation and transport by high latitude electric fields

Note that the maximum TEC values reached from Thule exceeded those from either Hamilton or Goose Bay. Also, while the short-time scale variability of TEC cannot be seen in the Goose Bay data, due to the availability of only the hourly values, even at that sampling rate it would still be obvious if Goose Bay had any evidence of the large, rapid variability seen in the Thule data. Similarly, in the 15-min plots of TEC values from Hamilton, no evidence is seen of the large variability of TEC seen at Thule. Thus, not only are the absolute TEC values higher in the dark Thule ionosphere than in the sunlit mid-latitudes, but the variability is much higher.

4. COMPARISON WITH MODELED TEC DATA

Buchau et al[3] have suggested that plasma is convected over the polar cap, by means of the large-scale electric field structure in the high latitude ionosphere, from the mid-latitude afternoon sector where the plasma was originally generated by solar EUV. Since that suggestion was made by Buchau et al, a theoretical model of high latitude F region electron density developed by Anderson,[4] that includes the effects of the solar EUV, particle precipitation and earth's co-rotation discussed above, was recently modified to include the contribution of plasma convected into the polar cap ionosphere from the afternoon cusp region. The TEC values obtained from this model are represented by the open circles in Figure 4a and can be seen to fairly well approximate the actual TEC observations during the magnetically disturbed days of this observation period. Due to the model complexity and the necessity to follow ionization produced elsewhere that is then convected over the polar cap, the model has been run for only a few representative hours for comparison with Thule TEC data. However, the theoretical results do confirm that the inclusion of lower latitude ionization, convected over the polar cap, can produce a significant increase above the quiet day TEC in the polar cap and can yield values comparable with those high TEC values actually observed from Thule.

5. DISCUSSION

The large, highly variable behavior of TEC at Thule is obviously not due to local solar production. Buchau et al[3] have proposed that plasma is convected over the polar cap, by means of electric fields, from the mid-latitude afternoon

3. Buchau, J., Weber, E.J., Anderson, D.N., Carlson, H.C., Jr., Moore, J.G., Reinisch, B.W., and Livingston, R.C. (1985) Ionospheric structures in the polar cap: their origin and relation to 250-MHz scintillation, Radio Sci., V. 20(No. 3):325-338.

4. Anderson, D.N. (1986) Calculated and Observed Wintertime Nmax (F2) Values at Thule, presented at U.S. URSI Meeting, Boulder, Colorado.

sub-cusp region, where the plasma was originally generated by solar EUV. The enhancements of TEC as seen at Thule are nevertheless the same or higher than the actual diurnal maximum TEC values observed in the mid-latitudes, at least in the American longitude sector. Thus, either some other mechanism must be partially responsible for the Thule TEC values, which are larger than those in the sub-cusp region, or else the mid-latitude region from which they are convected is not represented by the TEC from the Goose Bay and Hamilton stations. Another possibility is that while the ionization may indeed be convected from sub-cusp latitudes to the polar cap, while enroute the low-energy particle precipitation, that occurs predominately in the auroral zone, may add additional ionization and may, in some manner, result in the "patchy" characteristics of the TEC seen over the polar cap and that are not confirmed by the theoretical model.

Additional TEC data from Thule are being processed to determine other aspects of the large, highly variable TEC enhancements, and their associations with scintillations.

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1. Klobuchar, J. A. et al (1973) Low-elevation angle measurements of total electron content taken from Thule, Greenland, Chapter: Total Electron Content Studies of the Ionosphere, AFCRL-TR-73-0098, AD 762481.

2. Klobuchar, J. A., Bishop, G. H., and Doherty, P. H. (1985) Total electron content and L-band amplitude and phase scintillation measurements in the polar cap ionosphere, presented at AGARD Symposium on Propagation Effects on Military Systems in the High Latitude Region, Fairbanks, Alaska, 3-7 June 1985.

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