High Latitude Ionospheric Structures

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ABSTRACT

The high latitude ionosphere has much more structuring than at lower latitudes. The digital ionosonde is a very suitable instrument for studying these structures. Examples of digital ionosonde observations for 3 types of structures are shown. These are Polar Patches, polar auroras, and Poleward Moving Auroral Forms. The properties and mechanisms involved in much of this structuring is unknown.

1.0 INTRODUCTION

This paper presents data on some of the ionospheric structures observed at high latitudes. These observations are by means of digital ionosondes so there is emphasis on the types of different structures that revel themselves to ionosonde observations. The observations reported here use the Canadian Advanced Digital Ionosonde (CADI). The usual observations by CADI are a mixture of ionograms and ‘fixed’ frequency. The fixed frequency is chosen so as to get continuous ionospheric echoes throughout the day. For polar cap observations the usual fixed frequencies are ~3 and ~4 MHz. Fixed frequency observations are done as frequently as every 30 seconds because of the very dynamic ionospheric behaviour at high latitudes. Ionograms (interleaved with the fixed frequency observations) are at less frequent intervals, typically each minute. In general it is easier to identify structures on the fixed frequency recordings. Ionograms are mainly useful when electron densities are needed for some sort of analysis. This emphasis on fixed frequency data versus ionograms is opposite to the traditional role of ionosondes to measure electron densities for propagation work. Here the ionosonde is being used as an imaging tool to show ‘pictures’ of ionospheric structural features.

The remainder of this paper will be divided into subsections each describing one type of ionospheric structure.

2.1 Polar Patches

The polar cap region (poleward of the auroral zone) is always somewhat structured. Most of the structures would normally be referred to as polar patches since even relatively weak structures meet the requirements to be an ‘official’ polar patch (doubling of background electron density and > 100 km size [1]). Figure 1 (top panel) shows fof2 data for a typical day at 2 stations: Eureka and Resolute Bay. Eureka is at ~89^{o} magnetic latitude, and Resolute is 622 km south of Eureka. This day had consistent antisunward convection although the convection speed varied between 100 and 600 m/s during the day. At ~0800 UT the antisunward convection direction is from Resolute to Eureka and at ~2000 UT it is in the opposite direction. It can be seen

MacDougall, J. (2006) High Latitude Ionospheric Structures. In *Characterising the Ionosphere* (pp. 14-1 – 14-10). Meeting Proceedings RTO-MP-IST-056, Paper 14. Neuilly-sur-Seine, France: RTO. Available from: http://www.rto.nato.int/abstracts.asp.

in Figure 1 (top panel) that most of the structures –the polar patches- can be seen at both stations, and if you look closely you can detect the timeshift between the two stations. Note also that the patches are extremely random in appearance, there being structures having a wide variety of periods.

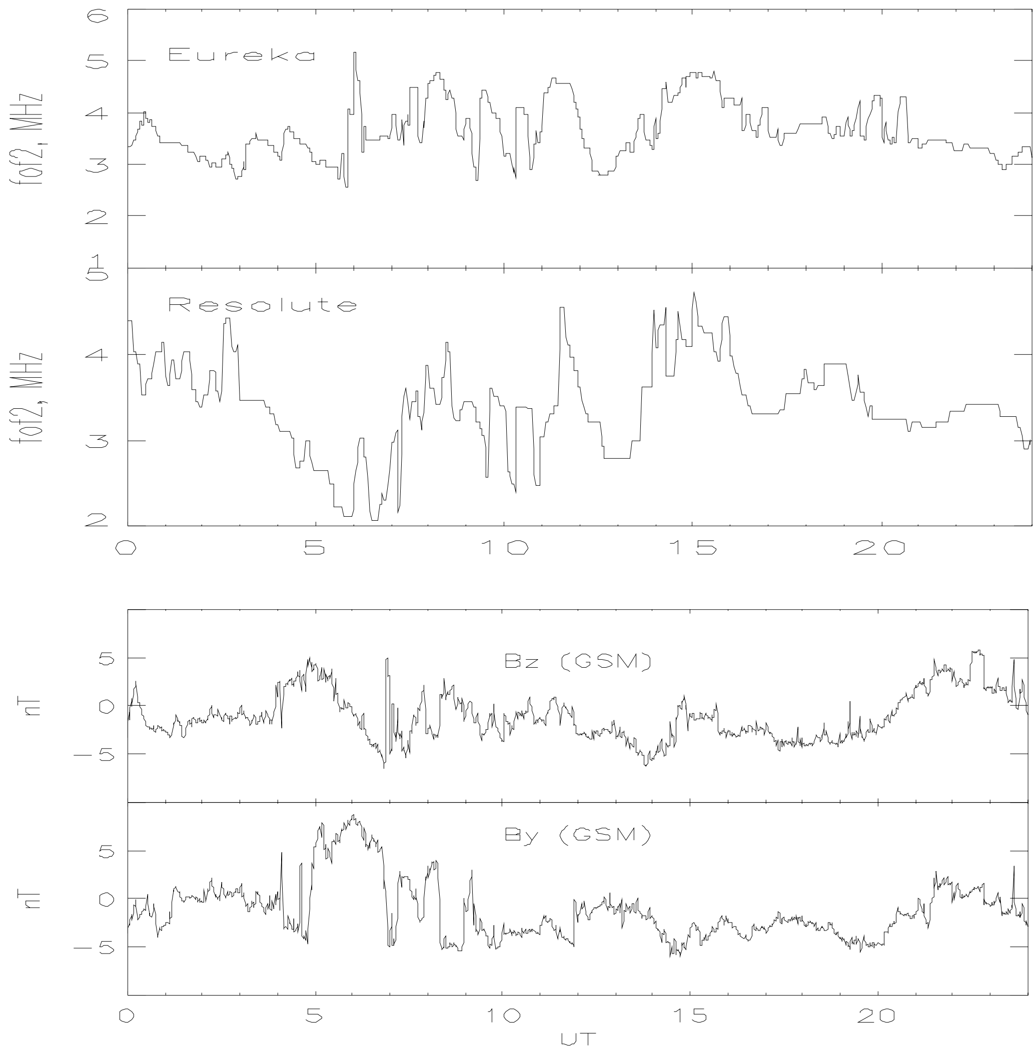

Figure 1: Data for 1996 March 3. The top panel shows fof2 at Eureka and Resolute Bay. The bottom panel shows IMF data.

Since many of the suggested mechanisms for polar patches involve solar wind magnetic fields it is of interest to compare the patches on this day with the IMF and in the bottom panel of Figure 1 the IMF Bz and By measured by the WIND satellite are shown. The times in this panel have not been adjusted for the ~1 hour travel time from WIND to earth. Some of the fof2 structures seem to be related to these IMF variations. Cross correlations between IMF magnetic fields and the fof2 at Eureka and Resolute for this day does not show a clear pattern. The correlation of fof2 with IMF Bz does show weak correlation with the southward IMF Bz, but only ~0.4 maximum correlation.

It is of interest to look at the power spectrum of the patches to see if there is evidence of any periodic behaviour. Figure 2 shows the two power spectra for the data shown in the top panel of Figure 1. Both spectra show a fall-off that seems to indicate a quasi random process, without any obvious dominant spectral peaks. The spectral slope is ~-1.7 or -5/3. For this day the IMF spectral slopes of the solar wind IMF were also very close to -1.7 for both IMF Bz and IMF By. Of course having a similar power spectral behaviour does not identify the two phenomena as being related. However, it does tell us something about the processes that are involved. For instance high latitude scintillations [2] have spectral slopes of ~-2.4 so the processes producing patches must be different from the processes producing scintillations.

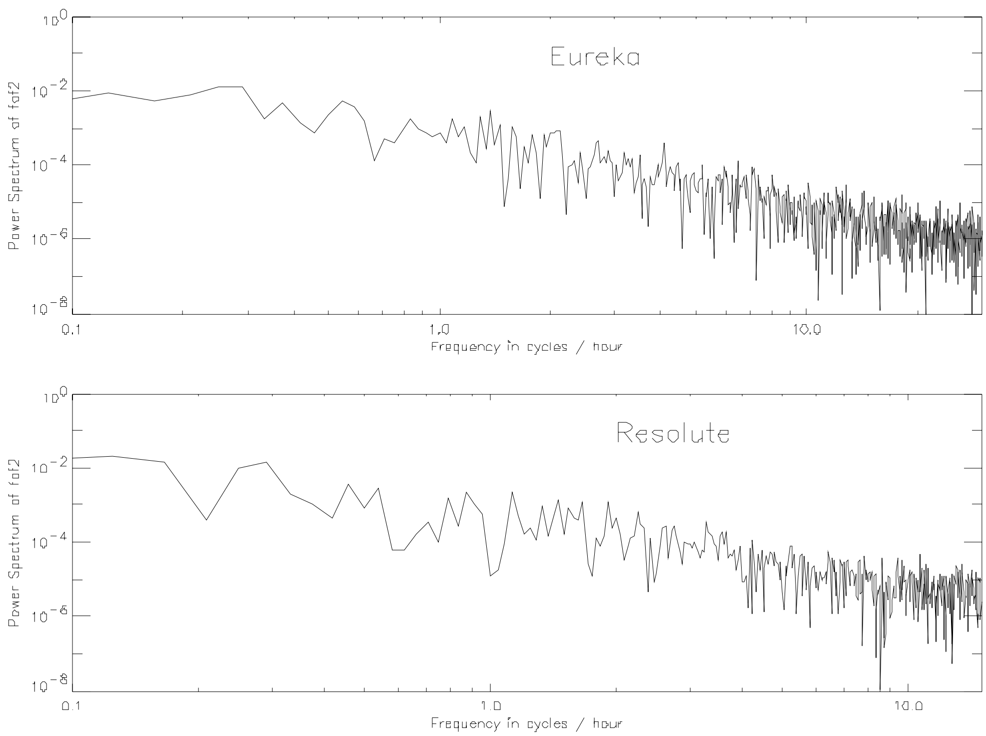

Figure 2: Power spectrum of the patches for 1996 March 3.

2.2 Polar cap auroras

During northward IMF auroras are often seen in the polar cap. Most are referred to as 'sun-aligned-arcs'. An extreme form of these auroras is the 'Theta Aurora' which stretches completely across the central polar cap, and can persist for long intervals. An example of a polar cap aurora observed using the CADI fixed frequency mode is seen in Figure 3. The aurora is the downward sweeping E-region feature.

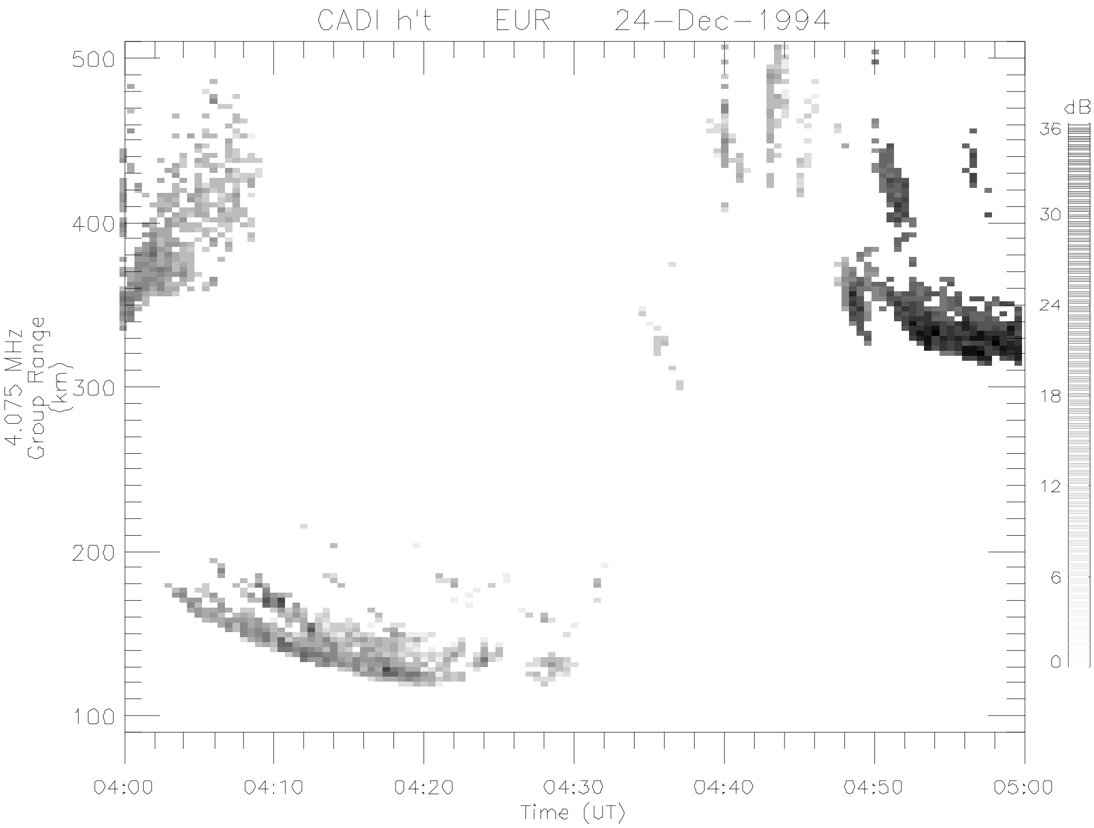

Figure 3: A polar cap aurora seen 1994 December 24 at Eureka.
This shows the height-time at 4 MHz frequency.

This aurora appeared when the IMF turned strongly northward for a relatively short time interval which is marked by the arrow in Figure 4.

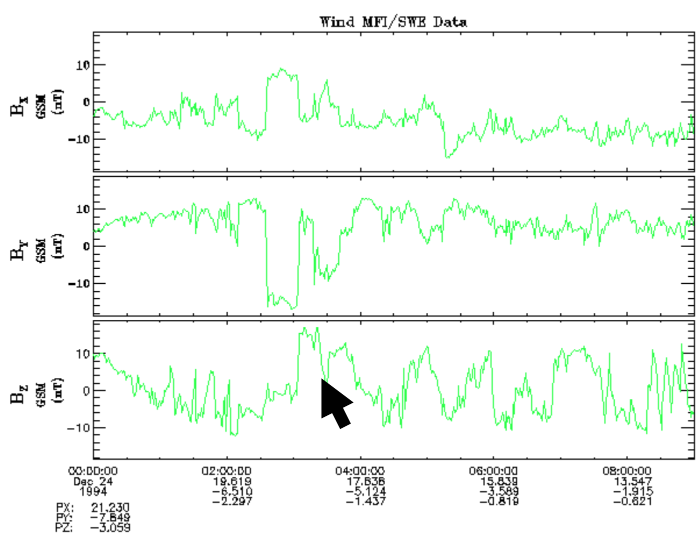

Figure 4: IMF during the Figure 3 event.

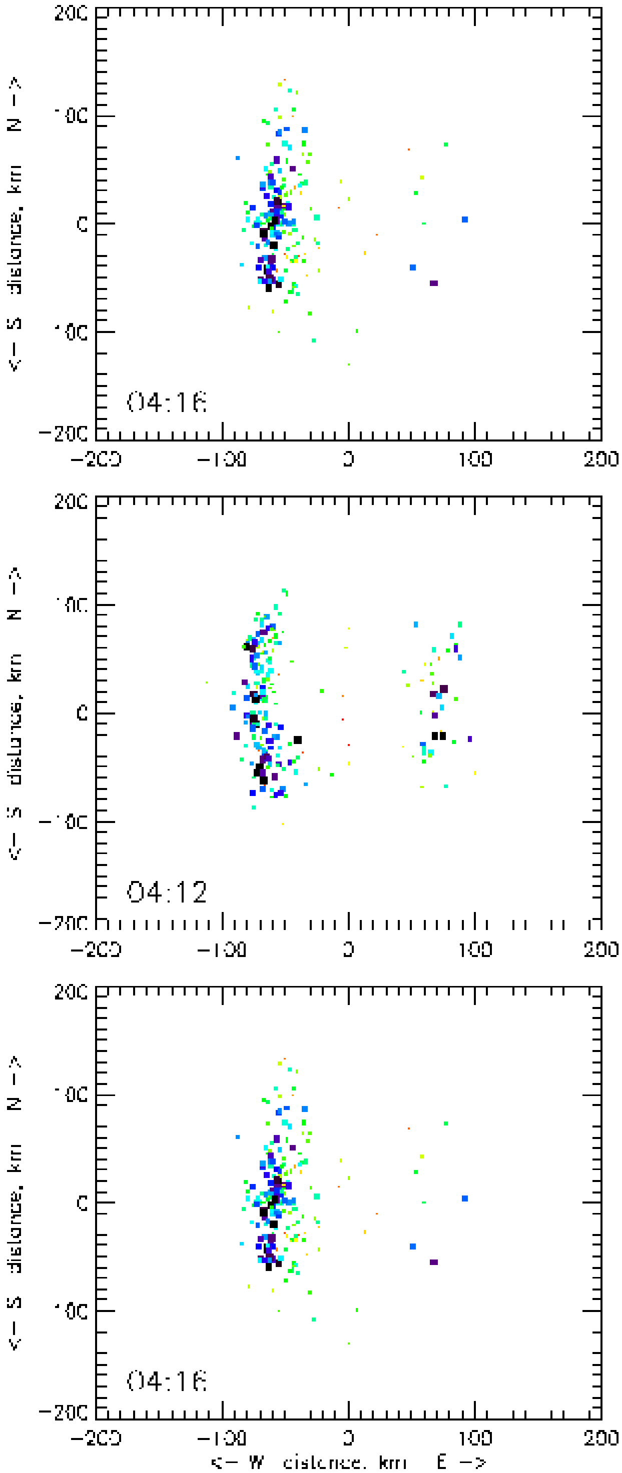

Figure 5: Skymaps of the auroral patch at 3 times.

The location of the arcs can be seen more clearly in Figure 5. This shows the ‘skymap’ location of the echoes seen on all the ionogram frequencies at 3 times marked on each of the panels. There were two parallel north- south aligned arcs to east and to west of zenith. The arcs moved slowly eastward at about 36 m/s. The eastward arc disappeared from view at about 0417 (it has almost disappeared in the bottom panel of Figure 5). North-south is not quite the expected alignment direction of sun-aligned arcs at this UT time at Eureka. However we can examine the convection direction at the time of the arc since (see Figure 3) there were still F region echoes that could be used for convection measurements. The convection direction at this time was very close to southward so the arc is actually aligned with the convection direction. Note that although the IMF had turned strongly northward, the convection was still essentially antisunward.

The lowest height of the arcs as seen in Figure 3 is only ~120 km which would imply low energy precipitation. However, the 120 km is the range and when it is corrected for horizontal distance the lowest height is close to 110 km implying that the electron precipitation energy was a few keV for this event.

Although auroral arcs are usually more clearly seen when they are approaching the overhead point (as was true for the arcs in Figure 3: the reason for this is not known), sometimes the E region arc features are visible both when the arc is approaching and when it is receding from the station’s overhead point. An example of this is shown in Figure 6. The distinctive V-shaped feature is commonly seen for moving features. In this case there was very fast southward motion of the aurora. The convection direction was southward at this time so this feature moved in the same direction as the convection, a rather different behaviour from the feature shown in Figure 3.

The digital ionosonde technique can therefore give us quite a bit of information about auroral features. In general we have only used the CADI observations to tell when there were auroras and have not fully exploited all the information.

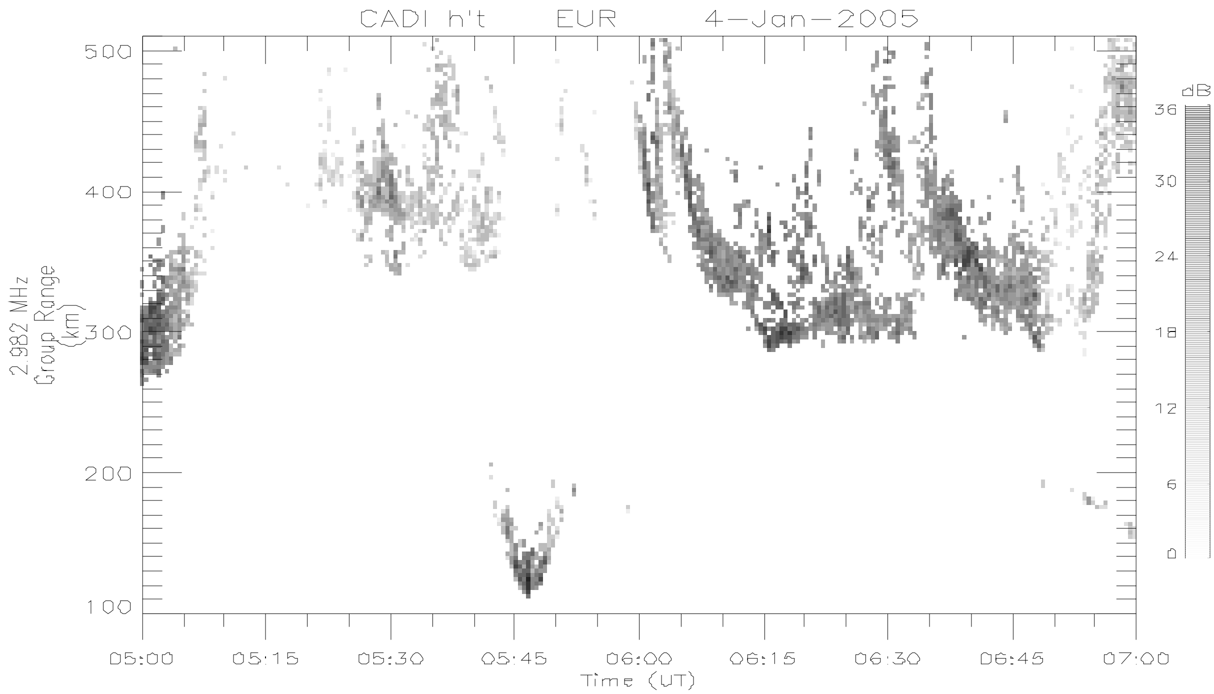

Figure 6: Distinctive V-shaped features due to rapidly moving auroras.

2.3 Poleward Moving Auroral Forms

One particular auroral phenomena that can be observed using digital ionosondes is "Poleward Moving Auroral Forms" (PMAF). These have usually been studied using optical methods [3,4,5]. These PMAF occur for IMF Bz > 0 and IMF By >= 0 during local morning hours, but are a comparatively rare phenomena. An example of one of the events studied in [5] is shown in Figure 7. The E-region auroral structures seems to show the V-shapes discussed above, but the individual auroras are somewhat indistinct. The motion of these auroral patches could be measured by the CADI and showed northward motion at very high effective speeds (~1.5 km/s). The speed from the optical measurements [5] was about ½ the speed measured by the CADI. The reason for the difference in the speeds measured by the two techniques is not known.

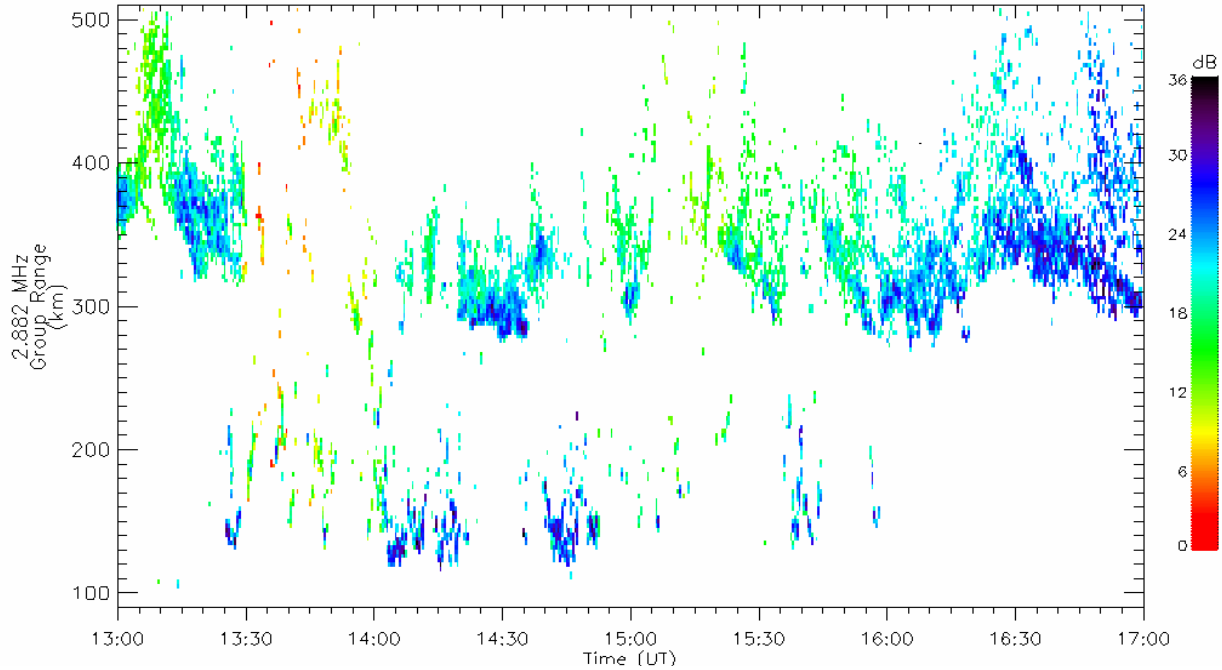

Figure 7: Example of poleward moving auroral forms for 1994 December 13 at Resolute Bay.

A phenomena that is probably related is shown in Figure 8. Here there is very weak E-region features at about 1200-1300 which might be the PMAFs described above. However, the dominant features are in the F region at this time and there one can see V-shaped traces that have shapes similar to the V-traces associated with E-region auroras.

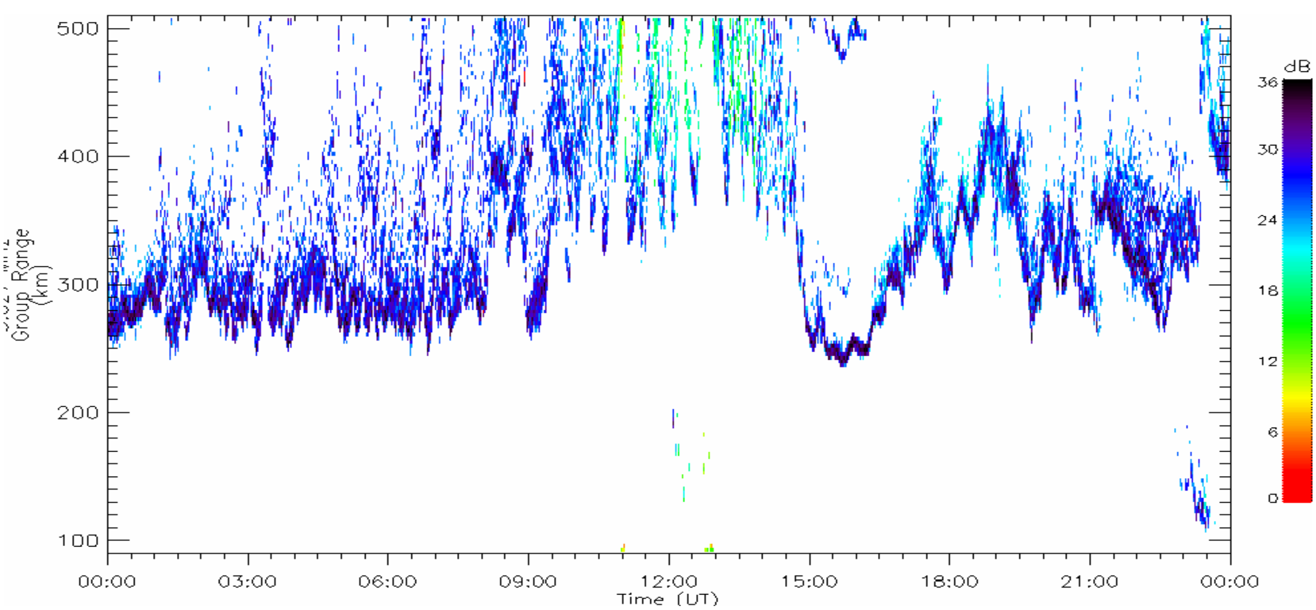

Figure 8: Height-time plot for 2000 November 6 on 3.027 MHz for Resolute Bay

In Figure 9 the horizontal position versus time for the east-west position (top) and the north-south position (bottom) is shown. The east-west positions clearly show westward motion. The north-south motion is less obvious. The apparent velocity from the east-west position was ~800 m/s. We can compare the patch position measurements of ~800 m/s westward with the convection measurements at this time. The measured convection was ~600 m/s towards 300^{o} azimuth (~westward). Thus there is reasonable agreement between the two velocity measurements. This velocity is antisunward. There were unusual solar wind conditions at this time. The solar wind pressure was quite high, and there were large fluctuations in IMF Bz.. Figure 10 shows the IMF magnetic field measured at WIND. The large IMF Bz fluctuations seem to have features that can be related to the individual patches shown in Figure 9. How the IMF Bz fluctuation produce the patches is not at all obvious. The convection stayed antisunward throughout this interval so the patches do not seem to be associated with changes in convection. Note the sideways shift in east-west position shown in Figure 9 as the patches pass overhead. This is due to the patch width since the reflection is from one side of the approaching patch, and from the other side when the patch recedes. From the width of the lateral shift at the overhead position one can estimate the width of the patch. For instance the patch at 1115 shows a lateral shift of ~8 minutes as it passes over Resolute Bay. At 800 m/s the width would therefore be ~384 km. These are therefore not narrow features.

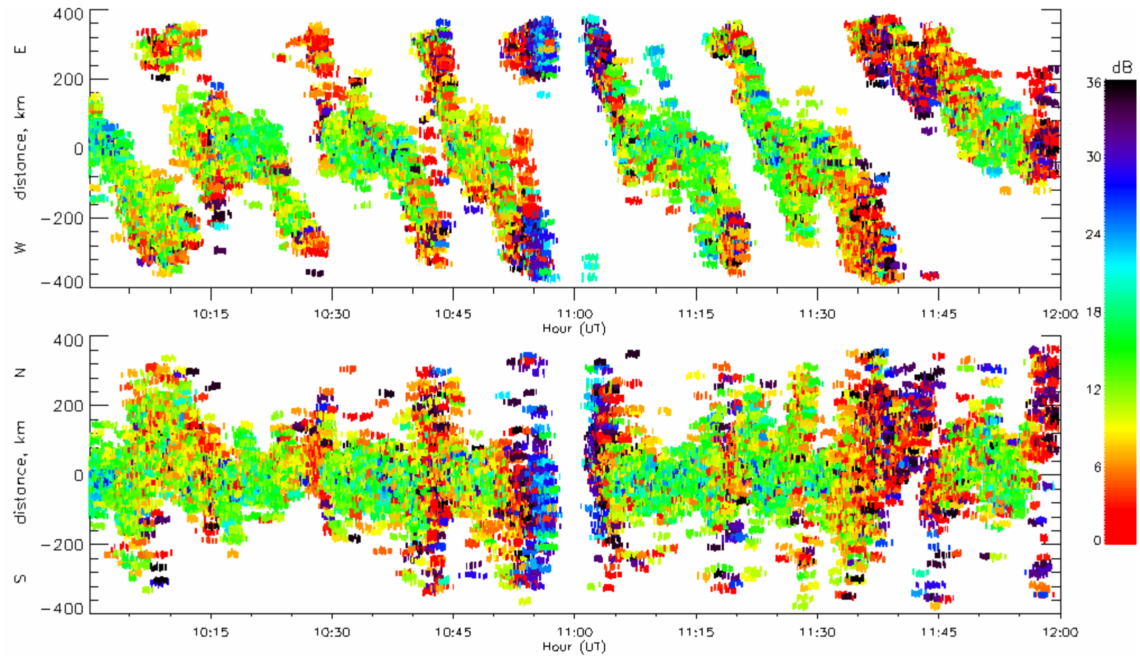

Figure 9: Horizontal location of echoes for the patches shown in Figure 8.

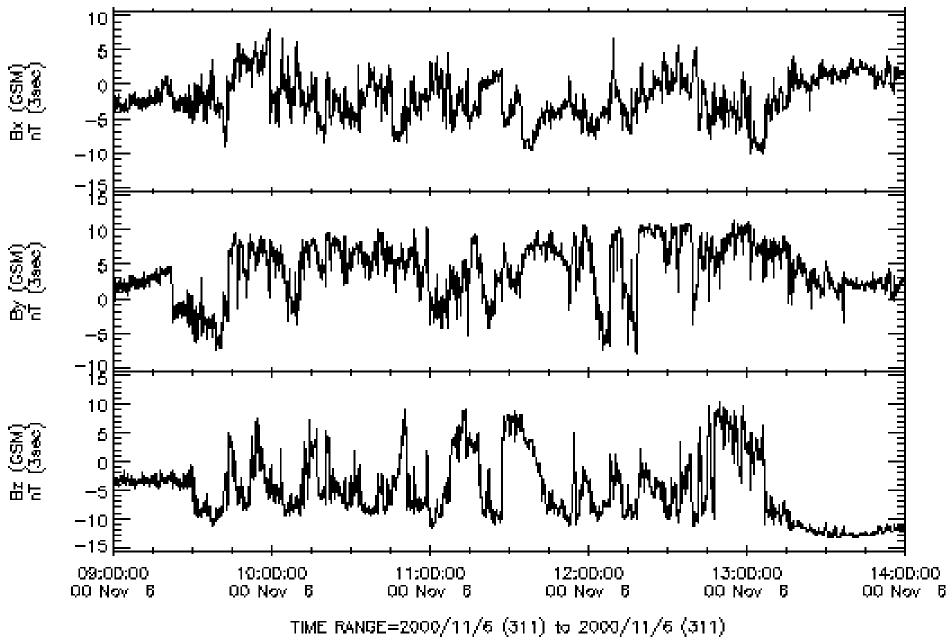

Figure 10: IMF data for the time interval in Figure 9.
(Data from CDAWeb courtesy R. Lepping, NASA/GSFC)

Are these features polar cap patches or are they low energy auroral features? Obviously there are properties of both auroras and polar patches in these events. Note in Figure 8 that there are other V-shaped F region features that may have had a similar origin.

3.0 CONCLUSIONS

Three types of ionospheric structures that are frequently observed in the polar cap region have been described. There are other less frequent ionospheric structures that can be occasionally found. One such structure is troughs in ionospheric density that are produced by enhanced recombination when there is very high convection speeds [6]. We only have one good example of a trough from Resolute Bay and Eureka so, in the central polar cap, structures associated with troughs are quite rare.

Another type of structure that we have searched for without success is the "tongue-of-ionization", a tongue of higher density ionization extending from the cusp region into the central cap region. Unless the trough is very wide the separation of Resolute Bay and Eureka (622 km) should reveal a trough via a difference in ionospheric density when the alignment of the two stations is in the dawn-dusk direction. Such an ionospheric density difference is not at all obvious so troughs in the northern polar cap are not a very distinctive feature.

In this paper Sporadic-E (Es) has not been described or discussed. The appearance of the polar cap Es is not notably different from Es at other latitudes. The mechanisms involved are quite different and have been described in our previous studies [7,8].

The structures described in this paper together with Es and troughs may not be all the different types of ionospheric structures that can be identified in the polar cap region. The height-time fixed frequency plots for different days often look very different, and it is not obvious if the difference is just variations in, for instance, the period or intensity of patches, or whether there are actually a number of other different types of ionospheric structures that have not yet been identified. The polar cap regions probably will continue to be a fruitful region for ionospheric studies and new tools such as AMISR should soon start producing exciting new discoveries.

4.0 REFERENCES

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