POLAR PATCHES

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INTRODUCTION

The first detailed studies of Polar patches were in 1984 [1, 2]. Some degree of patchiness seems to be characteristic of the polar cap ionosphere. Patches have been observed from the ground using radio and optical methods, and by satellites. A major review of patch observations was done in 1996 [3], and since then there seems to have been few new patch studies. There have been a number of suggested mechanisms for patch formation from the ionization entering the polar cap near noon:-

a) Sudden or intermittent expansion of the polar cap to lower latitudes changes the density of the stream of plasma entering the cap [4]. The change in cap size will be in response to changes in the Interplanetary Magnetic Field (IMF).
b) IMF changes, particularly By changes, vary the polar cap convection pattern so that the incoming plasma can vary in density if it comes from locations that are, or are not, sunlit. [5].
c) Various precipitations in the cleft region could enhance the plasma density entering the polar cap [6].
d) High speed plasma flow could enhance recombination (by heating) and produce density depletions [6,7].
e) Processes at lower latitudes could modulate the density of plasma moving toward the polar cap [8].

Some of these processes (a, e) would produce patches that enter the polar cap with a delay with respect to the causative mechanism, whereas other processes (b, c, d) would enter the polar cap immediately they are formed. In general there are no published patch studies that confirm that any one of these mechanisms was the causative mechanism for formation of the observed patches.
In this study we will examine patches on a number of days and attempt to show whether they have properties that agree with one or more of the proposed creation mechanisms.

OBSERVATIONS

There is always a certain amount of "patchiness" in the polar cap ionosphere. To be an "official" patch the following are the requirements [3]: electron density > 2× background density, and size > 100 km. As will be seen, polar cap structures that meet the official patch requirements are relatively common. Since the requirement for an official patch is a doubling of the electron density, in terms of foF_2, which will be shown in this paper, an official patch would be a 41% increase of foF_2.
All of the possible patch creation mechanisms produce the patches before they enter into the polar cap, and it is assumed that after entry the patches are simply conveyed across the cap by convection. In their passage across the cap it is generally assumed that the patches will retain their basic properties although there may be some slight redistribution of ionization by gradient-drift instability mechanisms operating on the patch to produce kilometer scale irregularities. This constancy of patch characteristics during passage across the cap is because convection motion can only cause very slight changes in patch density. This is shown by the following theoretical analysis: The change in electron density due to convection = $dN_e/dt = \nabla\cdot(N_e \boldsymbol{V})$ (1) where N_e is the electron density and $\boldsymbol{V}$ is the convection velocity, $\boldsymbol{V} = \boldsymbol{E}\times\boldsymbol{B}/B^2$ (2). $\boldsymbol{E}$ is the electric field and $\boldsymbol{B}$ is the magnetic field. Combining (1) and (2) we have, for an observer moving with the patch, $dN_e/dt = N_e \nabla\cdot(\boldsymbol{E}\times\boldsymbol{B})/B^2$ (3). Expanding (3) and using typical magnitude values for the various quantities one finds that the possible variation of N_e is << 1%.
Our first example of polar patches, Fig. 1, shows a whole day when the patches behaved in the expected way in that they essentially retained their basic properties as they convected across the polar cap. We call this retention of patch properties 'well-behaved'. Fig. 1 shows the foF_2 observed at 3 polar cap stations which are approximately collinear: Alert (~487 km north of Eureka), Eureka, and Resolute Bay (~ 622 km south of Eureka). The time delays as the patches convected along the line of stations can be seen

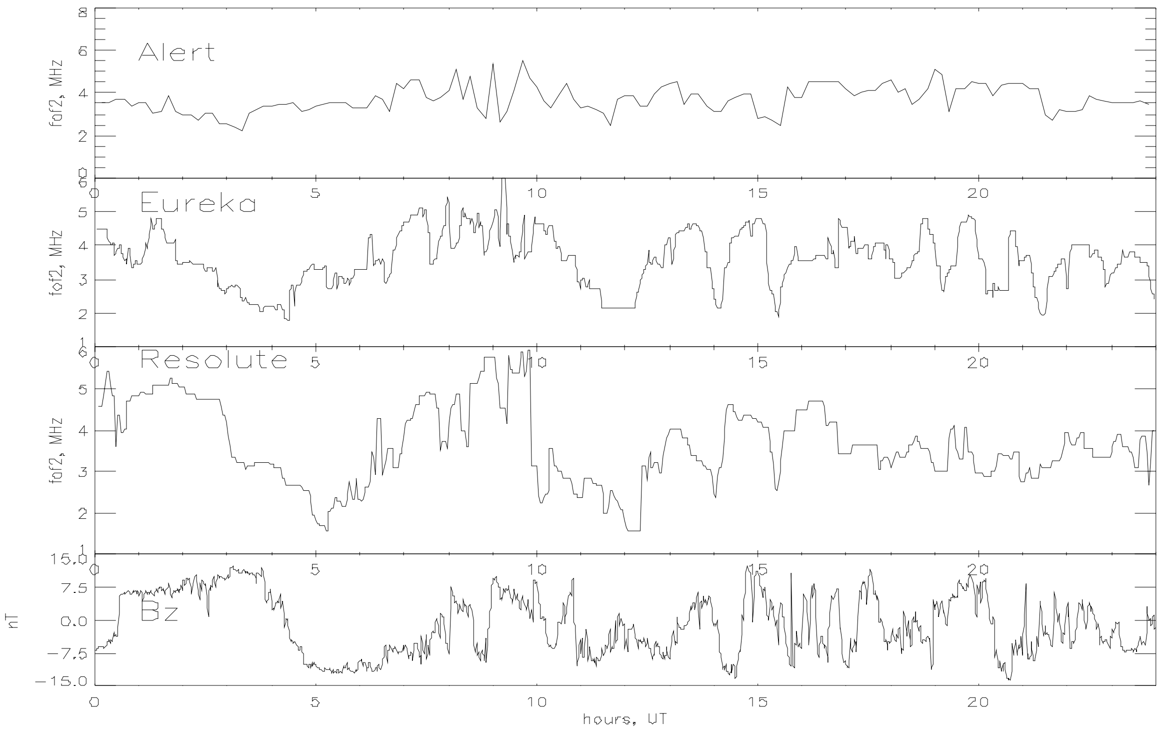

Fig. 1. Example of a 'well-behaved' day. The same patches are clearly seen at 3 polar cap stations. The IMF Bz on this day is shown in the bottom panel. The sampling interval was 5 minutes at Alert, 30s at Eureka, and 1 min at Resolute.

by close inspection of Fig. 1: Around 7 UT the antisunward convective motion is Alert⇒Eureka⇒ Resolute, and around 19UT it is the oppose direction. For this set of data the foF_2 at pairs of stations shows good correlation (not shown) of the order of 0.8 and peaking at the expected time delay for the patch convective motion.

The bottom panel of Fig 1 shows the B_z component of the IMF observed by the WIND satellite. The timescale has not been adjusted to allow for transit time from the satellite (~1 hr) to the magnetosphere. It can be seen that the patches show visual correlation with the IMF Bz. (The IMF B_y component on this day had mostly short period fluctuations and was not correlated with the patches.) It should be pointed out that the IMF Bz variations on this day are unusually strong and well defined. Most days did not show such large clear IMF Bz variations.

To further show the relationship between IMF Bz and the patches we correlated foF_2 at Eureka with IMF Bz. The peak correlation was -0.5 (correlation maximum is with southward IMF Bz) at a delay of 105 minutes which is about the expected time delay from satellite to magnetosphere, plus the convection time from cusp to Eureka. We also correlated the foF_2 with polar cap convection velocity. The peak correlation was also 0.5 and the peak was delayed by ~40 min which is the approximate convection travel time from cusp to Eureka. Since previous studies have shown that the convection speed is well correlated with IMF – Bz it is not clear from these correlations whether the important parameter is the IMF or the convection speed in creating the patches. Other days showed a similar ambiguity in whether the best correlation was with the IMF Bz or with the convection speed.

Our second example, Fig. 2 shows much different behaviour from the first example, and we will refer to this day as 'ill-behaved'. As can be seen for the 2 stations, Eureka and Resolute Bay, the foF_2 variations are not obviously similar. In fact cross correlation of the foF_2 for the 2 stations in 3 hour intervals throughout the day showed very poor correlation (max correlations of the order of 0.2), and at the time when one expects maximum correlations from the measured convection the correlation was almost random (sometimes even negative). Of course the lack of correlation could be because the patches are so small that they are not seen by both stations, but then there should be correlation for times when the convective motion was close to the relative orientation of the 2 stations. The correlation was not obviously better for these times.

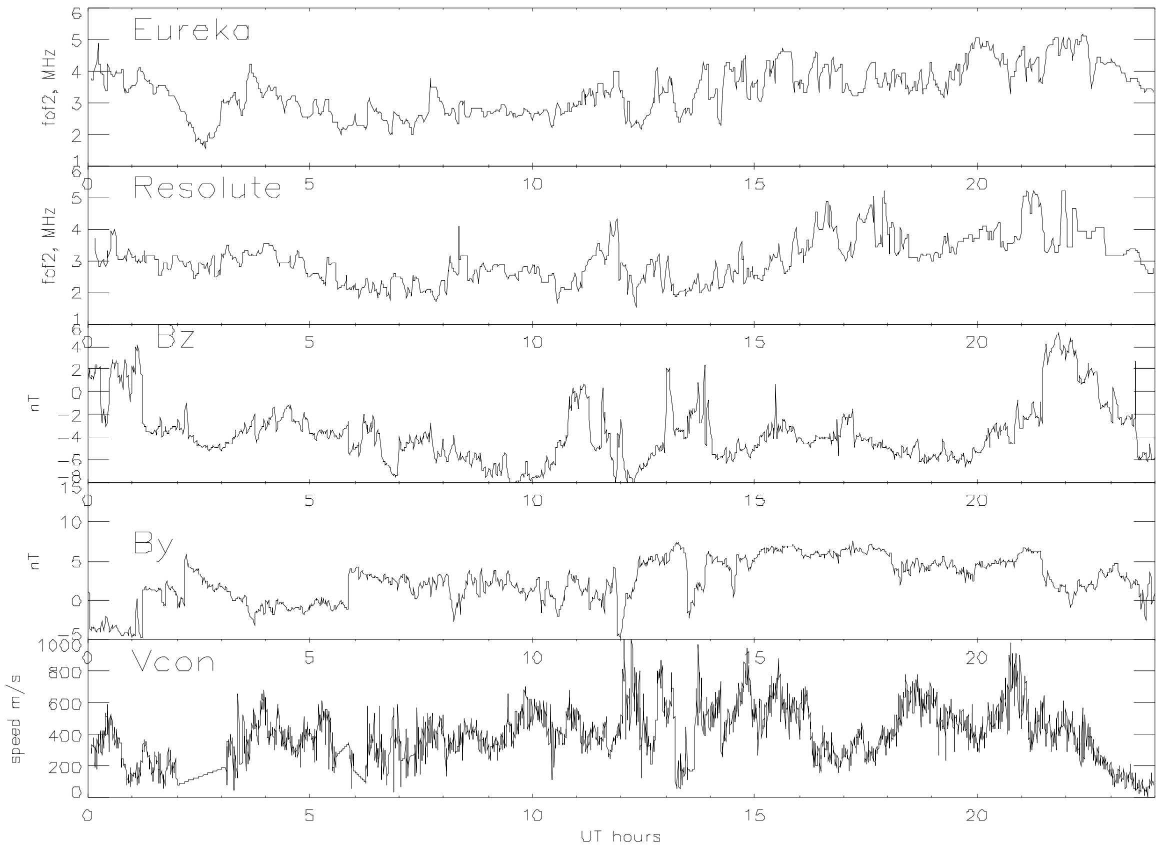

Fig. 2. Data for 1995 Jan. 16. The top 2 panes show the foF_2 variations at Eureka and Resolute Bay. The next 2 panels show the IMF Bz and By components, and the bottom panel shows the sunward convection velocity.

We calculated the same correlations with IMF and convection velocity as for the well-behaved day shown in Fig. 1. For this ill-behaved day the maximum correlation with IMF Bz was -0.2 at a lag of ~130 minutes. There was a relatively better correlation with IMF By (shown in Fig. 2) which was +0.6 at ~125 minutes lag. Thus for this day the foF_2 shows reasonably good correlation with positive IMF By. The correlation of foF_2 and convection velocity was maximum 0.4 at lag ~65 minutes. Therefore this ill-behaved day shows ambiguous correlation results in that there seems to be some correlation of foF_2 and the IMF By, and some correlation of foF_2 with convection velocity, but the foF_2 patches themselves, observed at station pairs, are very poorly correlated.

Our interpretation of the results for this, and other days that are similarly ill-behaved is that there are processes producing weak patches, but as these move across the polar cap they are restructured, probably by gradient-drift type processes. We should emphasis here that there were relatively few days that were well-behaved: most days had ill-behaved patches.

It is of interest to look at the timing of the patches relative to solar wind changes. We will show this for the well-behaved day shown in Fig. 1. The relative timing is shown by Fig. 3. From our correlations, the IMF changes occurred at WIND ~105 minutes before the patch was at Eureka. From the solar wind properties on this day the travel time from the WIND to magnetosphere was ~50 minutes. From the average convection speed on this day, and assuming that the patch has already formed when it is convected into the polar cap, the travel time from cusp to Eureka would have been ~54 minutes. Therefore we can conclude that the patch must have quickly formed in the vicinity of the cusp (see Fig. 3) since there would have been insufficient time for it to have convected from a more distant formation location. This effectively eliminates some of the patch formation mechanisms (a, e see introduction) that have non cusp patch formation locations.

There are other properties of patches that may give us some information that would support one of the formation mechanisms. One property is whether the patches are an enhancement or depletion of ionization. This would tell whether mechanism c or d might be operating. We did two different analyses to examine

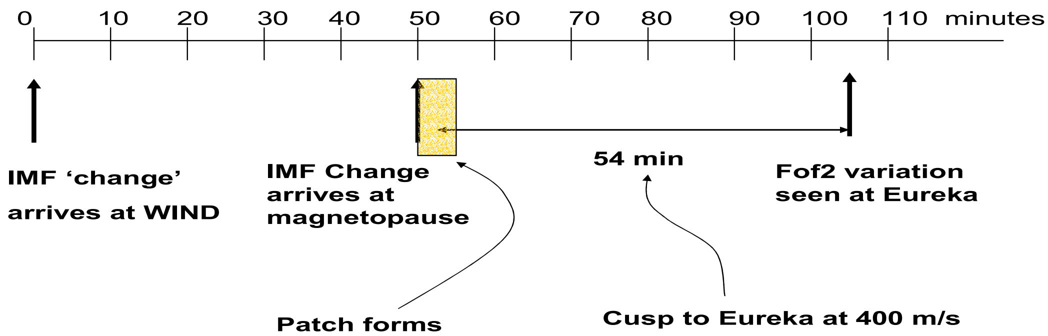

Fig. 3 Timing of patches

the question regarding enhancement/depletion. Firstly we looked at the foF_2 from a station south of the polar cap region to get values for the daytime foF_2. We used Rabbit Lake (mag. lat. 68^o) and for the winter period of 1995 and found that the typical daytime foF_2 was ~6 MHz (also there was no sign of patches at Rabbit Lake). We next compared this value of foF_2 with observed average foF_2 at the polar cap stations. Resolute daytime foF_2 was ~0.5 MHz lower, and Eureka was slightly lower than Resolute (as might be expected for gradual recombination of the F region ionization). The average foF_2 at Resolute and Eureka also showed a clear diurnal variation being ~ 1 MHz lower at nighttime when ionization would be entering the polar cap from a sector less exposed to sunlight. Comparing these average foF_2 values with the foF_2 of patches showed that the patches are could be either enhancements or depletions of ionization. Thus, if only one mechanism is operating, it would need to be one that could produce either depletions or enhancements.

CONCLUSIONS

Polar patches have the following properties which a successful theory for their creation would need to accommodate:-

- Usually poorly correlated between pairs of stations a few hundred kilometers apart.
- Show correlation of maximum density with IMF Bz and with convection speed.
- Sometimes also show correlation with IMF +By
- Time of formation close to when the ionization enters the polar cap.
- Can be either enhancement or depletion of ionization.

The poor correlation between patches observed at pairs of stations is probably local restructuring by gradient-drift processes.

References

[1] Weber, E. J., J. Buchau, J. G. Moore, J. R. Sharber, R. C. Livingston, J. D. Winningham, and B. W. Reinisch, "F-layer ionization patches in the polar cap", *J. Geophys. Res*., vol. 89, pp. 1683-1694, 1984.

[2] Buchau, J., E. J. Weber, D. N. Anderson, H. C. Carlson, and J. G. Moore, "Ionospheric structures in the polar cap: their origin and relationship to 250 MHz scintillation", *Radio Sci*., vol. 20, pp. 325-338, 1985.

[3] Crowley, G., "Critical review of ionospheric patches and blobs", *Review of Radio Science 1993-1996*, ed. W. R. Stone, URSI, 1996.

[4] Anderson, D. N., J. Buchau, and R. A. Heelis, "Origin of density enhancements in the winter polar cap ionosphere", *Radio Sci*., vol. 23, pp. 513-519, 1988.

[5] Sojka, J. J., M. D. Bowline, R. W. Schunk, D. T. Decker, C. E. Valadares, R. Sheehan, D. N. Anderson, and R. A. Heelis, "Modeling polar cap F-region patches using time-varying convection", *Geophys. Res. Lett*., vol. 20, pp. 1783-1786, 1993.

[6] Rodger, A. S., M. Pinnock, J. R. Dudeney, K. B. Baker, and R. A. Greenwald, "A new mechanism for polar patch formation", *J. Geophys. Res*., vol. 99, pp. 6425-6436, 1994.

[7] Valadares, C. E., S. Basu, J. Buchau, and E. Friis-Christensen, "Experimental evidence for the formation and entry of patches into the polar cap", *Radio Sci.*, vol. 29, pp. 167-194, 1994.

[8] Foster, J. C. "Plasma transport through the dayside cleft: a source of ionization patches in the polar cap", *Electromagmnetic Coupling in the Polar Clefts and Caps,* eds. P. E. Sandholt and A. Egeland, D. Reidel, Boston, pp. 343-354, 1989.