Long-Period Oscillation Activity in the Morning Sector during Northward IMF

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Abstract

During extended periods of northward IMF when the magnetosphere is expected to be very quiet, radar and magnetometer measurements have revealed ionospheric disturbances with a period in the range of about 40 - 55 minutes, at latitudes from 70 - 80 degrees. Two examples will be discussed. In the first, on Dec.08/97, the high-latitude magnetometer oscillations were followed by lower-latitude gravity wave oscillations of the same period. In the second, on Nov. 11/98, the long-period pulsations were seen most clearly in the Iceland West range-time velocity plots, and the large-scale convection pattern in the post-midnight/dawn sector showed the periodic changes. The oscillations will be discussed in terms of recent MHD models of the closed magnetosphere during such extended Bz+ conditions.

INTRODUCTION

The magnetosphere during prolonged periods of northward IMF can exhibit a distinctly active behaviour, though not as dynamic as during substorms. During extended northward IMF conditions, the magnetosphere can show oscillations with longer periods than the shorter period oscillations, e.g. the Pc5 range and Ps6 pulsations, seen during Bz- conditions. We shall present two distinctly different morning datasets that illustrate these long-period oscillations, one set being dayside data, the other nightside data. The first set consists of high-latitude magnetometer predominantly prenoon magnetic deflections that correlate well with subsequently-observed SuperDARN gravity wave signatures at lower latitudes; the second set consists of periodic SuperDARN postmidnight convection pattern reconfigurations.

GRAVITY WAVES AND HIGH-LATITUDE MAGNETIC DISTURBANCES WITH 40 MIN PERIODS ON DEC. 08, 1997

Using a thermospheric model, G. H. Millward (Annales Geophys., 12, 94, 1994) showed that if the auroral E-region of the ionosphere is subjected a periodically varying electric fields with periods in the range from about 10 minutes to over an hour, each electric field burst would generate a gravity wave response consisting of a stronger initial wave and a highly damped second wave. The process was quasi-resonant, in that the strength of the gravity waves was greatest when the period of the electric field oscillations was about 50 minutes (40 - 60 minutes). The gravity waves so generated would then propagate away from the auroral zone, and travel to lower (or higher) latitudes where in principle they could be detected. The SuperDARN radar system is known to be quite sensitive to medium-scale gravity waves (e.g. Samson et al., JGR, 95, 7693, 1990; Huang, Andre and Sofko, JGR, 103, 23347, 1998), so the radars should be capable of monitoring electric fields that occurred earlier at higher latitudes by measuring the subsequently-occurring gravity waves at lower latitudes.

What was somewhat unexpected was that one very good example of the above behaviour was seen during northward IMF conditions. Such an example was observed on December 8, 1997, for which the IMF conditions are shown in Figure 1 (note that the figure is incorrectly date-labelled as the ADec. 12/97 Bz+ event@). Figure 1 shows that from about 0940 UT until 1540 UT, the Bz component was positive and varied little, except perhaps for a few variations in the last 40 minutes of the interval.

Figure 2 shows the Goose Bay SuperDARN radar range-time intensity plot during the interval 12 - 20 UT. It is clear that a series of gravity wave signatures appeared from about 13 - 19 UT. The gravity wave phase fronts seen in the ground-scattered power were very nearly parallel throughout the interval, implying that each was a separately generated gravity wave event coming from roughly the same high-latitude source region. The time between successive gravity wave phase fronts was about 40 minutes, within the range of Aresonance periods@ 40 - 60 minutes proposed by Millward (loc. cit.).

The magnetometer records from the MACCS stations at Igloolik, Repulse Bay and Coral Harbour were checked to determine whether there was auroral zone activity prior to the SuperDARN gravity wave observations. Figure 3 shows the magnetometer results. There was an obvious correlation between 40 minute fluctuations seen on the magnetometers and the 40-min gravity wave phase fronts seen later at lower latitudes. In fact, the correlation between the two phenomena was greatest for a lag time of 110 minutes. Assuming that the gravity waves were indeed generated near Repulse Bay at the magnetic latitude of 77 degrees, where the magnetometer deflections have the greatest amplitude, the speed of the gravity wave propagation from that source region to the SuperDARN observations to the south is estimated to be about 180 m/s.

Figure 4 shows a plot of the Fourier transform of the IMF Bx, By and Bz components in the top half, and of the MACCS magnetometer X-component data in the bottom half. The bottom half shows that there is a period of 0.4 mHz (2500 s or ~42 min) seen in the MACCS data, but that there is no such period in the IMF data, especially when the short-lived perturbation in the IMF Bx component from about 1300-1330 UT is removed (see dashed line in Figure 1). Figure 4 does indeed show that the 0.4 mHz peak is most clearly seen on the Repulse Bay magnetometer.

To determine whether there was any latitudinal or longitudinal propagation of the high-latitude source fluctuations, magnetometer records at the MACCS station Igloolik and the CANOPUS station Taloyoak were compared. These stations have virtually identical magnetic latitude, but are separated in longitude by about 900 km. Figure 5 (top half) shows the results for the Z-components; no obvious time lag can be detected. Similarly, the Igloolik results were compared with the Coral Harbour data (bottom half of Fig. 5), and even though these stations were about 5 degrees in MLAT apart (over 500 km), there was again no apparent time shift between the records. The CH Z-trace was inverted because the center of the electrojet was near Repulse Bay at 76.9 MLAT; thus the Z-traces at the higher latitude station IG and the lower latitude station CH had opposite signs. The results appear to show that the electric field perturbations and resulting magnetic field deflections were excited simultaneously over a large region extending from 323.6 to 351.4 degrees in MLON, and from 74.8 to 79.4 degrees in MLAT. These perturbations appear to have been generated within the magnetosphere during the quiet IMF Bz+ conditions, and the implication is that the magnetosphere may have a natural resonant period in the 40-min range after extended northward IMF intervals.

QUASI-PERIODIC CONVECTION RECONFIGURATIONS OF PERIOD ~54 MIN ON NOV. 11, 1998

On Nov. 11, 1998, the Iceland West radar range-time line-of-sight (LOS) Doppler velocity plots showed a series of oscillations that occurred in the interval from about 0330 to 1000 UT, which is after magnetic midnight (01 to 08 MLT). The results are illustrated in Figure 6, for IW radar beam 9. The convection oscillations occur roughly in the magnetic latitude range 70 - 80 MLAT. What is remarkable about this event is that the IMF had turned northward some 14 hours earlier, and remained northward throughout the period shown in Figure 6. The IMF data for the period 00 - 12 UT are shown in Figure 7, with vertical dotted lines showing the time interval of the Figure 6 velocity results.

To illustrate the periodicity of the LOS velocities, Figure 8 shows in red and blue dots the velocities on beams 8 and 9, respectively, in the range cells at range 1665 km. Superimposed is a cosine oscillation with a 54 minute period. It is clear that the LOS velocity fluctuations closely follow the cosine wave.

Figures 9, 10, 11 and 12 illustrate the large-scale convection pattern associated with the IW radar LOS fluctuations. The large-scale pattern behaves in a periodic fashion, but the nature of that periodicity is somewhat unexpected. For about the first 30 minutes, the pattern consists of a cell with a focus near 02 MLT and magnetic latitude 70 degrees. The pattern gradually deforms during that time, changing from roughly circular to more elongated along the L-shells. The pattern then moves eastward for about 20 minutes, until it assumes a final position centered at about magnetic dawn (06 MLT) at 77 MLAT. This behaviour is repeated 7 times, covering a span of over 6 hours.

The SuperDARN convection oscillations were accompanied by GOES-8 oscillations of about the same period, in the Hn (radial) component. This is shown in Figure 13. As shown in the left half, the position of GOES-8 03-10 UT was predominantly in the postmidnight sector, roughly conjugate to the ionospheric location of the SuperDARN results. Figure 14 shows the bandpass filtered Hn results, and the LOS velocities at range 1665 from the beams 8 and 9 of the IW radar. Clearly there is very good agreement between the satellite magnetic and the SuperDARN LOS velocity fluctuations.

Finally, it should be noted that two magnetometer chains have been used to look for the pulsations. The first (not shown) was a CANOPUS/MACCS chain as follows, from highest to lowest magnetic latitude: Gjoa Haven (78), Baker Lake (74), Eskimo Point (72), Fort Churchill (70), Gillam (67) and Island Lake (65). The pulsations are quite clear above 70 MLAT, but below 70, there is little evidence of the pulsations. The second, shown in Figure 14, was a Greenland chain, with stations as follows: Umanaq (77), Attu (75), Sondre Stromfjord (73), Godthab (71), Frederikshab (68) and Narssarssuaq (66). The results are not quite as good as for the CANOPUS/MACCS chain, but again there is clear evidence of the 50-minute period oscillations at latitudes above 70 MLAT. Of course, since the observations were made in November, the height-integrated conductivity at high latitudes is small and the resulting magnetic deflections at the ground are only about 10 nT, so the records do appear to be somewhat noisy.

DISCUSSION

In the first set of observations, individual gravity wave phase fronts with 40 min periodicity at low latitudes were traced back to 40 min period oscillations of the high-latitude current system, as detected by magnetometers. Thus, even during extended Bz+ conditions, there were apparently long-period Joule heating and current bursts, likely associated with electric field oscillations. No phase velocity of these magnetic perturbations could be found in either the latitudinal or longitudinal directions, over about 500 km latitude and 900 km longitude. The result would be consistent with a global magnetospheric oscillation of about 40 min period.

The long-period convection oscillations on Nov. 11/98 also appear to be some type of natural resonance frequency of the Aclosed@ magnetosphere after long periods of Bz+ IMF. The results of the MHD model of Bargatze et al. (JGR, 104, 14583, 1999), illustrated for 3 Bz+ values in Figure 15, show that the size of the magnetosphere is strongly determined by the magnitude of Bz. At seen in the top and middle boxes, the tail position shrinks from X = -85 R_E to X = -40 R_E when Bz changes from +2.5 to +5.0 nT. Thus, a change of only 2.5 nT in Bz results in a 45 R_E displacement of the far tail boundary.

During the convection oscillation period, the Bz value was about 3.5 nT, so to a first approximation the tail is at about 75 R_E. Small increases in Bz would cause the tail to compress a reasonably large amount, which could in turn lead to the generation of compressional MHD waves at a speed of about

$$v_c^2 = \sqrt{C_s^2 + v_A^2} \quad ; \quad C_s = \sqrt{\frac{\gamma\, k_B (T_p + T_i)}{m_p + m_e}} \quad ; \quad V_A = \frac{B}{\sqrt{\mu_0\, \rho}} ,$$

where v_A is the Alfven velocity and C_S is the ion-sound velocity. If we adopt the values of the Bargatze et al. (loc. cit.) model, with B = 6 nT, $T_e = T_i$ = 200 eV, plasma pressure of 3 x 10^{-11} Pa, ion density 0.5 cm^{-3}, and $\gamma = 1$ (isothermal plasma), the Alfven and ion-sound speeds are almost identical at ~ 190 km/s, so the compression MHD wave speed is about 270 km/s. If we then assume that the compressional wave will be reflected from a near-earth boundary at about X = - 10 R_E where there is a sharp pressure increase, then the return time from the tail boundary to the pressure increase and back would be 51 minutes, very near the observed pulsation period. Thus, if there were a global scale standing wave set up due to the propagation of the compressional wave in the Atail cavity@, the period would match that of the convection oscillations.

As opposed to a standing wave, the convection pattern motion in space and time indicates a propagating-wave type of behaviour. It is interesting to note that, in their MHD model for Bz- conditions at the time of substorm onset, Birn and Hesse (JGR, 101, 345, 1996) found that, although the reconnection site was at about X = -23R_E down the tail, the resulting plasma flow led to large shears near X = -13 R_E; thus the FACs observed in the ionosphere were displaced both in magnetic longitude and latitude (significantly equatorward) from the original reconnection activation center. One might assume that, for the northward IMF case, the same sort of behaviour could occur; the ionospheric convection oscillations and associated FACs that are seen in the postmidnight morning sector at lower magnetic latitudes to the earth thus would be the ultimate result of the original Aactivation@ center out near the distant magnetotail boundary.