GEOPHYSICAL RESEARCH LETTERS, VOL. 27, NO. 12, PAGES 1795-1798, JUNE 15, 2000

Quasi-periodic ionospheric disturbances with a 40-min period during prolonged northward interplanetary magnetic field

Chao-Song Huang, G. J. Sofko, A. V. Kustov, J. W. MacDougall[1], and D. A. Andre
Institute of Space and Atmospheric Studies, University of Saskatchewan, Saskatoon, Saskatchewan, Canada

W. J. Hughes
Center for Space Physics, Boston University, Boston, Massachusetts

V. O. Papitashvili
Space Physics Research Laboratory, University of Michigan, Ann Arbor, Michigan

Abstract. It has been observed that quasi-periodic oscillations in the solar wind and interplanetary magnetic field (IMF) can result in the generation of auroral electrojet bursts and gravity waves with a similar period. In this paper, we present radar and magnetometer observations of quasi-periodic ionospheric disturbances during stable, northward IMF. Magnetic deviations of ~10 nT with a 40-min periodicity were registered with ground magnetometers between magnetic latitudes 75° and 80° over an extended region along the longitudinal direction in the morning sector. A sequence of gravity waves were observed by HF radars at lower latitudes and appeared to be closely related to the high-latitude 40-min current disturbances. There were no obvious source perturbations in the upstream solar wind for the ionospheric disturbances. We suggest that field line resonances could be excited in a closed magnetosphere during prolonged northward IMF and result in the generation of the ionospheric current disturbances and gravity waves.

Introduction

High-latitude ionospheric perturbations may have their source from the solar wind and magnetosphere. Energy input from the solar wind and/or magnetosphere to the high-latitude ionosphere can result in the generation of auroral electrojet and atmospheric gravity waves. *Huang et al.* [1998] reported an event which showed a clear cause and effect relationship between the interplanetary magnetic field (IMF), auroral electrojet, and gravity waves. In that event, quasi-periodic southward turnings of the IMF B_z component resulted in quasi-periodic bursts of auroral electrojet, and each burst of auroral electrojet appeared to generate a single gravity wave pulse. The recurrence periods of the IMF southward turnings, the auroral electrojet bursts, and the gravity waves were ~40 min.

Magnetospheric ultra-low-frequency (ULF) waves can also result in perturbations of ionospheric currents and geomagnetic field (for a review, see *Hughes* [1994]). Quasi-sinusoidal magnetic disturbances in the ULF frequency range from 1 Hz to 1 mHz are termed Pc 1-5 pulsations. Conventionally, the Pc-5 period is taken to be 150-600 s. Longer-period (~30 min) pulsations were observed and could be related to the Kelvin-Helmholtz waves excited in the magnetospheric low-latitude boundary layer (LLBL) during strong IMF B_y [*Clauer and Ridley,* 1995]. The magnetic pulsations are generally not accompanied by gravity wave activity.

In this paper, we present observations of high-latitude ionospheric disturbances and lower-latitude gravity waves with a period of ~40 min during stable, northward IMF. These ionospheric disturbances appear to have originated in the magnetosphere.

Observations

We shall concentrate upon an event that occurred on December 8, 1997. Figure 1 shows the solar wind velocity, solar wind density, and IMF components observed with the WIND spacecraft at about $X = 205\ R_E$ during the period of interest. All the parameters were relatively stable. Initially, B_z was small for ~14 hours before 0230 UT, changed to weakly negative (~ -1 nT) during 0230 - 0530 UT, and became positive after 0530 UT. The 3-hour K_p index for this day was 0 during 0000-0300 UT, 0+

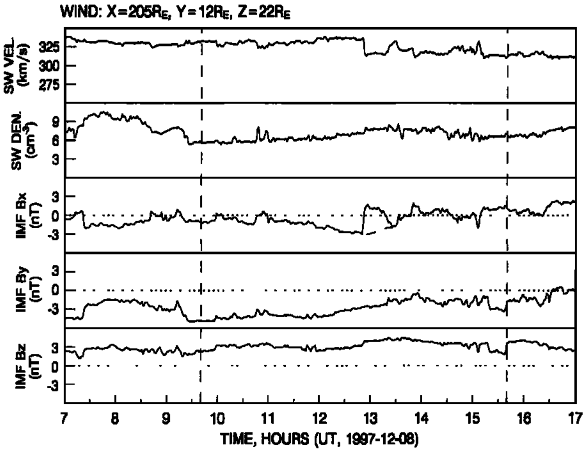

Figure 1. Solar wind and interplanetary magnetic field data observed by the WIND spacecraft during 0700-1700 UT on December 8, 1997.

---

[1] On sabbatical leave from Department of Electrical Engineering, University of Western Ontario, London, Ontario, Canada.

Paper number 1999GL003731.
0094-8276/00/1999GL003731$05.00

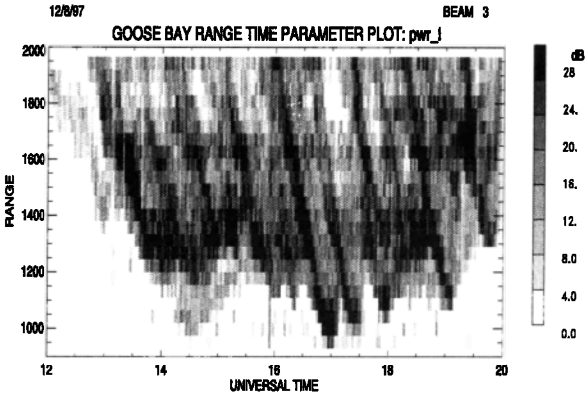

Figure 2. Power of ground backscattered echoes along the Goose Bay HF radar beam 3 between 1200-2000 UT on December 8, 1997. The radar data are plotted as a function of range (in kilometers) along the rays and universal time.

during 0300-1200 UT, and 0 again during 1200-2400 UT. We are interested in the interval 0940-1540 UT, as indicated by the vertical dashed lines in Figure 1. The solar wind would take ~70 min to propagate from the WIND position to the magnetopause. The ionosphere would take an additional ~10 min to respond. An uncertainty of ±10 min in the time delay will not significantly affect our analysis because the IMF is stable and because an interval of six hours is considered.

The Goose Bay HF radar (53.3° N, 60.5° W, geographic) recorded strong echoes on this day. Figure 2 shows a range-time plot of the power of the ground backscattered echoes from radar beam 3. As is typical of ground backscattered echoes, the Doppler velocities are nearly zero, so no velocity plot is shown. The enhancements in the power of the ground echoes arise from ray focusing due to the ionospheric undulations induced by gravity waves and are identified as a signature of gravity waves. There is no Doppler shift at the stationary ground, and only a small Doppler shift at the reflection point due to the small vertical motion there. Readers interested in the use of the HF radars for gravity wave identification are referred to the paper by *Samson et al.* [1990]. The gravity waves in Figure 2 propagate along the beam direction with a phase speed of ~180 m/s. It is important to note that the power enhancements have slopes that are almost parallel to each other, and cannot be traced back to a common source occurring during a short time interval at higher latitudes. This implies that the gravity waves are successive wave pulses generated over many hours, rather than a continuous wave chain of many cycles; each wave pulse is associated with a single activation of the source. The separation between successive wave pulses is ~40 min, implying that the source activity has a similar period.

Figure 3 presents the X component of magnetic deviations observed with MACCS magnetometers located at Igloolik (IG), Repulse Bay (RB), and Coral Harbour (CH). With the estimated 80-min delay, the solar wind/IMF at WIND during 0940-1540 UT will influence the ionosphere from 1100 to 1700 UT. The magnetic local noon at these magnetometer stations is around 1800 UT. The interval indicated by the vertical dashed lines in Figure 3 corresponds approximately to the prenoon interval 0500-1100 MLT. The mean level of the magnetic variations decreases by ~20 nT during 0900-1030 UT. After 1100 UT, the magnetic deviations appear to be periodic, with an amplitude ~10 nT. These magnetic deviations occur mainly in the magnetic latitudinal interval 75-80°, show a periodicity of ~40 min, and become very small below magnetic latitude 74°.

Shown in the bottom panel of Figure 3 is the power of the radar ground echoes taken from beam 3 at range 1575 km. Beam 3 is about 10° east of beam 0, which points directly toward Igloolik (IG); beam 0 recorded a wave pattern similar to beam 3, but with weaker echoes. If the gravity waves are generated in the latitudinal interval 75-80° over which the largest magnetic deviations are observed, the waves will take ~110 min to propagate equatorward from the source to the place where they are observed by the radar. In Figure 3, the radar data are shifted by 110 min to match the wave propagation delay. The shifted gravity wave disturbances are similar to the magnetic disturbances at higher latitudes.

We have performed Fast Fourier Transform analysis of the data. The top part of Figure 4 presents the spectral power of the IMF components during 0940-1540 UT. The B_y and B_z components do not show any observable peaks. The spectrum of B_x appears to have peaks at 0.23 and 0.37 mHz. However, these peaks are caused by the sudden change in B_x between 1250 and 1320 UT. In order to justify this argument, we eliminate the sudden change by a smooth curve to connect the B_x values between 1250 and 1320 UT, as shown by the dashed line in Figure 1. Other parts of the B_x time series remain unchanged. The spectrum of the modified B_x does not have the peaks at 0.23 and 0.37 mHz. The spectra of the solar wind velocity and density do not have any peaks and hence are not shown.

The bottom part of Figure 4 shows the spectra of the magnetic disturbances and the radar echo power. The interval for spectral analysis is 1100-1700 UT for IG and CH, and 1100-1600 UT for RB (there is a problem with the RB data after 1600 UT). The radar echo spectrum is evaluated for the interval 1300-1900 UT, allowing for the gravity wave propagation delay. All the spectra have a dominant peak around 0.4 mHz, corresponding to a period of ~40 min. The 0.4-mHz spectral peak at RB is stronger than that at IG and CH; this is because the RB disturbance has larger amplitude, as shown in Figure 3.

The top part of Figure 5 shows the X component of the magnetic deviations measured at IG and Cambridge Bay (CB). These two stations are located almost at the same magnetic

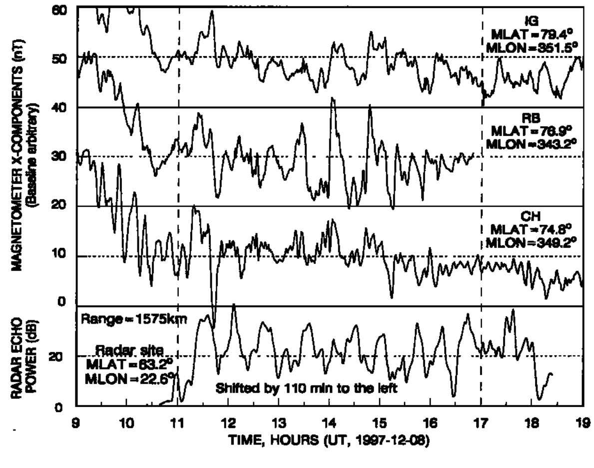

Figure 3. Magnetic deviations recorded by magnetometers during 0900-1900 on December 8, 1997. Geomagnetic coordinates are given in the figure. Shown in the bottom panel are the radar ground echo data which have been shifted by 110 min to the left.

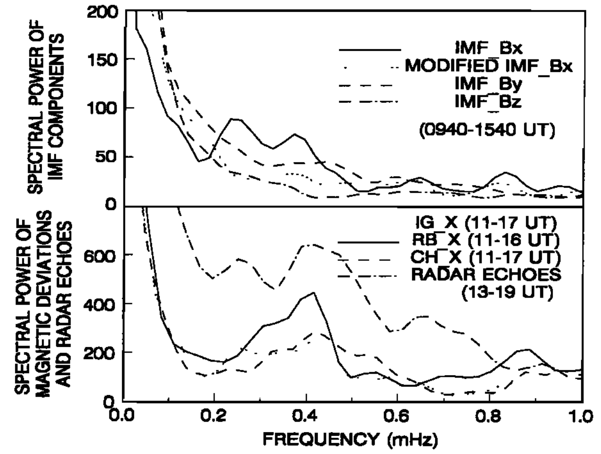

Figure 4. Spectral power of the IMF components (top part) and the magnetic deviations and radar ground echo intensity (bottom part).

latitude but are separated by ~900 km in longitude. Although the peak around 1400 UT appears to have a time shift between the two stations, a stronger peak around 1500 UT is registered almost simultaneously at the two stations. The bottom part presents the *Z* component at IG and CH, which are located at nearly the same magnetic longitude but are separated by ~500 km in latitude. Note that the *Z* component at CH is inverted. Since the magnetic deviations are caused primarily by *E*-region current, the *Z* component of the magnetic deviation has opposite sense on different sides of the center of the current. The similarity between the *Z* component at IG and the inverted *Z* component at CH implies that the current is roughly centered between the two stations. This is consistent with Figure 3 which shows the strongest disturbance in the *X* component at RB.

We checked measurements from CANOPUS magnetometer stations Taloyoak (TALO) and Rankin Inlet (RANK) that are located between IG and CB. The *X* component at TALO is similar to that at CB; the *X* component at RANK is similar to that at CH. We also checked observations from the Kapuskasing HF radar (49.4° N, 82.3° W, geographic). During the same period, the westernmost beam (beam 0) of the Kapuskasing radar recorded strong gravity wave signatures, similar to that recorded by the Goose Bay radar beam 3 (Figure 2). The longitudinal separation between these two beams of the two radars is ~40° at the ionospheric reflection positions of the gravity waves. Other beams of the radars registered similar wave patterns. It is reasonable to conclude that the magnetic deviations and gravity waves were generated over a longitudinally extended region.

Discussion

As discussed in the previous section, the gravity waves shown in Figure 2 are not a continuous wave chain, but are successive single wave pulses arising from successive source activity. The source of the gravity waves could be located at magnetic latitudes 75-80°, where the quasi-periodic current disturbances were centered. One current burst could have generated one gravity wave pulse. The numerical modeling of *Millward* [1994] showed that a sequence of electric field bursts with a repetition period of 40-50 min produced a gravity wave sequence with the same period as the electric field. Our observations are consistent with the modeling.

We now discuss possible mechanisms responsible for the generation of the ionospheric disturbances. Oscillating IMF can cause similar ionospheric disturbances and gravity waves [*Huang et al.*, 1998]. However, the solar wind and IMF are quite steady in the present case, as shown in Figure 1. After removing the positive excursion in the IMF B_x between 1250 and 1320 UT, the spectrum of the modified B_x does not have a clear peak at 0.4 mHz, as shown in the top part of Figure 4. The magnetic disturbances do not show noticeable propagation delay at different longitudes and latitudes, so they are inconsistent with Kelvin-Helmholtz waves at the LLBL [*Clauer and Ridley,* 1995] and with a radially oscillating magnetopause [*Sckopke et al.*, 1981]. Furthermore, the magnetic deviations are not caused by the gravity waves, since ionospheric disturbances induced by equatorward propagating gravity waves would show a large time delay over a latitudinal interval of 500 km. However, such a delay was not observed.

Long-period fluctuations have been observed in the ionosphere and magnetosphere. *Papitashvili et al.* [1996] found that ground magnetic disturbances near magnetic latitude 80° showed evidence of both a primary period of ~15 min and a secondary period of ~60 min. *Chen and Kivelson* [1991] found fluctuations of magnetic field with a period of ~35 min in the magnetotail lobes. They suggested that the 35-min fluctuations could be one of the eigenmode periods of magnetotail fluctuations but indicated that more cases are needed to draw a conclusion. *Rinnert* [1996] presented observations of periodic enhancements of electron density with periods of 40-60 min in the auroral *E* region; the majority of the enhancements occurred in the morning sector. They suggested that the periodic density enhancements were caused by periodic particle precipitation controlled by oscillations in the magnetotail. *Lessard et al.* [1999] found that the magnetic pulsations with periods 1-2 min in the magnetosphere were modulated with a 45-min periodicity. However, it is unclear whether the long-period magnetospheric fluctuations in these studies were caused by fluctuations in the solar wind and/or IMF.

In our case, the ionospheric disturbances do not appear to be caused by IMF fluctuations or by Kelvin-Helmholtz waves in the

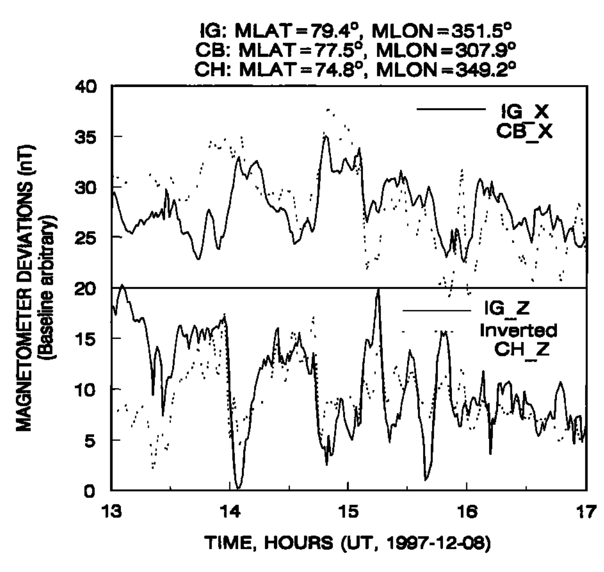

Figure 5. Comparison of magnetic deviations at different longitudes and latitudes. Geomagnetic coordinates are given on the top of the figure.

LLBL. It seems reasonable to conclude that the ionospheric disturbances with a 40-min period originate from within the magnetosphere. This implies that the magnetosphere has a natural period of ~40 min. *Samson et al.* [1992] proposed a cavity model of field line resonances in which resonances occur at periods shorter than 13 min. They mentioned that the outer boundary of the cavity would be greater than 30 R_E if longer periods (20-27 min) were associated with field line resonances. The simulation of *Usadi et al.* [1993] shows that the magnetosphere becomes closed when a northward IMF is present for ~90 min; the deformation of the magnetosphere from a tail shape to a dipolar shape results in large perturbations in the closed magnetosphere. The simulation of *Song et al.* [1999] also shows a closed magnetosphere for northward IMF, with a tail length of ~55 R_E. We propose the following scenario for the generation of the 40-min perturbations. Resonances occur on the nightside dipolar field lines in the closed magnetosphere, similar to those in the cavity model. Since the nightside boundary of the closed magnetosphere is quite large (~55 R_E), the field line resonances may have periods of 40-60 min. The perturbations caused by the deformation of the magnetosphere can excite the resonances. These resonant disturbances are transmitted to the morning sector along the boundary.

We recognize that it is uncertain whether the ionospheric disturbances had a limited phase speed from the present observations. It is difficult to measure the propagation delay because of the small disturbance amplitude and because of the waveform deformation. It is also unclear whether the gravity waves were excited by the weak current perturbations. Further research is required to solve these problems. The purpose of this paper is to show the existence of such long-period disturbances in the ionosphere and magnetosphere. We note that this event is not an isolated one. We have found more events that show ionospheric disturbances with periods 40-60 min during stable, northward IMF. A more detailed study of other events will be the subject of a future paper.

Summary

We have observed quasi-periodic ionospheric disturbances during stable, northward IMF. Magnetic deviations of ~10 nT with a 40-min period were observed between magnetic latitudes 75° and 80° over an extended region along the longitudinal direction in the morning sector. At lower latitudes, gravity waves with similar periods were observed by HF radars. These gravity waves were also observed over an extended longitudinal interval of ~40°. There were no obvious source perturbations in the upstream solar wind for the ionospheric disturbances. We suggest that field line resonances could be excited in the largely closed magnetosphere during prolonged northward IMF. The long period of the resonances was determined by the extended lengths of the outer closed nightside field lines. The magnetospheric resonant perturbations could be the source mechanism for the generation of the ionospheric current disturbances and gravity waves.

Acknowledgments. We acknowledge the CDAWeb for access to the WIND data. The MACCS project is supported by the NSF under grant ATM-9704766 to Boston University and grant ATM-9610072 to Augsburg College. The Goose Bay HF radar is supported by the NSF under grant ATM-9812078. V. O. P. acknowledges partial support from the NSF awards ATM-9614189, ATM-9628706, and OPP-9876473.

References

Chen, S. H., and M. G. Kivelson, On ultralow frequency waves in the lobes of the Earth's magnetotail, *J. Geophys. Res.*, *96*, 15,711, 1991.

Clauer, C. R., and A. J. Ridley, Ionospheric observations of magnetospheric low-latitude boundary layer waves on August 4, 1991, *J. Geophys. Res.*, *100*, 21,873, 1995.

Huang, C. S., D. A. Andre, and G. J. Sofko, Observations of solar wind directly driven auroral electrojets and gravity waves, *J. Geophys. Res.*, *103*, 23,347, 1998.

Hughes, W. J., Magnetospheric ULF waves: A tutorial with a historical perspective, in *Solar Wind Source of Magnetospheric Ultra-Low-Frequency Waves, Geophys. Monogr. Ser.* vol. 81, edited by M. J. Engebretson, K. Takahashi, and M. Scholer, pp. 1-11, AGU, Washington, DC, 1994.

Lessard, M. R., M. K. Hudson, B. J. Anderson, R. L. Arnoldy, H. Luhr, G. D. Reeves, N. Sate, and A. T. Weatherwax, Evidence for a global disturbance with monochromatic pulsations and energetic electron bunching, *J. Geophys. Res.*, *104*, 7011, 1999.

Millward, G. H., A resonance effect in AGWs created by periodic recurrent bursts in the auroral electric field, *Ann. Geophys.*, *12*, 94, 1994.

Papitashvili, V. O., C. R. Clauer, S. B. Musko, B. A. Belov, O. A. Troshichev, and M. G. Gudkov, Low-magnitude, long-period magnetic pulsations observed deep in the southern polar cap, *Antarctic J. of the U. S.*, *31*, 257, 1996.

Rinnert, K., Quasi-periodic precipitation with periods between 40 and 60 minutes, *Ann. Geophys.*, *14*, 707, 1996.

Samson, J. C., R. A. Greenwald, J. M. Ruohoniemi, A. Frey, and K. B. Baker, Goose Bay radar observations of Earth-reflected atmospheric gravity waves in the high-latitude ionosphere, *J. Geophys. Res.*, *95*, 7693, 1990.

Samson, J. C., B. G. Harrold, J. M. Ruohoniemi, R. A. Greenwald, and A. D. M. Walker, Field line resonances associated with MHD waveguides in the magnetosphere, *Geophys. Res. Lett.*, *19*, 441, 1992.

Sckopke, N., G. Paschmann, G. Haerendel, B. U. O. Sonnerup, S. J. Bame, T. G. Forbes, E. W. Hones, Jr., and C. T. Russell, Structure of the low-latitude boundary layer, *J. Geophys. Res.*, *86*, 2099, 1981.

Song, P., D. L. DeZeeuw, T. I. Gombosi, C. P. T. Groth, and K. G. Powell, A numerical study of solar wind-magnetospheric interaction for northward interplanetary magnetic field, *J. Geophys. Res.*, *104*, 28,361, 1999.

Usadi, A., A. Kageyama, K. Watanabe, and T. Sato, A global simulation of the magnetosphere with a long tail: Southward and northward interplanetary magnetic field, *J. Geophys. Res.*, *98*, 7503, 1993.

C. S. Huang, G. J. Sofko, A. V. Kustov, and D. A. Andre, Institute of Space and Atmospheric Studies, University of Saskatchewan, 116 Science Place, Saskatoon, SK S7N 5E2, Canada. (cshuang@dansas.usask.ca)

J. W. MacDougall, Department of Electric Engineering, University of Western Ontario, London, ON. N6A 5B9, Canada.

W. J. Hughes, Center for Space Physics, Boston University, 725 Commonwealth Avenue, Boston, MA 02215.

V. O. Papitashvili, Space Physics Research Laboratory, University of Michigan, Ann Arbor, MI 48019.

(Received: December 14, 1999; revised: March 14, 2000;
Accepted: April 18, 2000)