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Research note

A comparison between vertical winds in the lower thermosphere and magnetic field perturbations on the ground

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Abstract: Vertical winds in the lower thermosphere are estimated from OI 557.7-nm Doppler shifts obtained with a Fabry-Perot interferometer at the Poker Flat Research Range (65.12 N, 147.43 W in geographic coordinate), Alaska. The temporal variation of vertical winds was compared with the horizontal component of the magnetic field obtained at Poker Flat and two other sites, Gakona (62.12 N, 145.14 W) and Fort Yukon (66.36 N, 145.22 W). Two nights of observations were examined and the results were shown here. The results showed that temporal variations of vertical winds were similar to that of magnetic field variation during each substorm. In some cases the results of cross correlation between these two parameters showed that the magnetic field perturbation leads vertical winds in the earlier period of the substorm. The difference increased gradually and reached a maximum at around the center of the recovery phase. From there, the differences decreased. The mechanism for the relation between the two parameters is still unclear, but this result suggests an intimate relation between ionospheric currents and vertical wind in the thermosphere.

key words: thermosphere, neutral winds, ionospheric currents, *E*-region

1. Introduction

The work presented in this report is the first step in a study that is being undertaken to find ways of distinguishing the vertical winds generated by Joule heating from other types of vertical wind. In this first step, vertical winds as deduced from Fabry-Perot interferometer observations were compared with the ΔH-component of magnetic field on the ground. Similar studies could be found in previous publications. For example, Rees *et al.* (1984) showed some examples of the relation between the vertical winds in the *F*-region and magnetic perturbation, *e.g.*, westward traveling surge and positive bay. The results showed that very large upward vertical winds (50–200 m/s) appeared in the sub-storm expansion phase or westward traveling surge. Their duration time was generally short (10–30 min) and they were often temporally and spatially surrounded by weak downward flow sector. Peteherych *et al.* (1983) also showed the comparison between the vertical winds in the *E*-region and magnetic perturbations. Their results showed that the upward winds were associated with westward overhead currents, and with low altitude aurora (~110 km) as determined by the auroral temperature, while a high altitude aurora (~135 km) and eastward currents were associated with the downward wind.

In this study, vertical winds measured with the Communications Research Laboratory's Fabry-Perot Interferometers (CRLFPI) OI 557.7 nm at Poker Flat Research Range, Alaska were compared with the ΔH-component of the magnetic field obtained at 3 magnetometer sites in Alaska. An advantage of our study is that the relationships can be seen more clearly with the high temporal resolution of our FPI observations (2 min) and continuous measurements of zenith direction. In most cases vertical winds are considered very small magnitude (~several ten m/s) which is comparable with FPI's nominal error (~10 m/s, *e.g.*, Price *et al.*, 1995). The cross-correlation is calculated using the least square fitting to determine regression line ($y=ax+b$), If there is a constant offset on the vertical wind, the constant "b" will be influenced significantly but the constant "a" and the correlation coefficient does not change. Therefore this nominal error does not make fatal influence in the analysis. In order to use our results more precisely, we compared CRLFPI results with another instrument, Geophysical Institute-Scanning Doppler Imager (GI-SDI; Conde and Smith, 1998). These two instruments were installed at the same place. The GI-SDI mainly observes horizontal distribution of neutral winds with vertical winds on the zenith direction. We judged the vertical wind true when two instruments observed similar feature of winds simultaneously. In addition to qualitative comparisons, cross correlation was also calculated for more detailed investigation.

The peak altitude of 557.7 nm emission layer is about 110–140 km, and it significantly depends on the precipitating electron energy. It makes very difficult to use 557.7 nm emissions to estimate horizontal wind, because there are very large wind sheer around these heights and the uncertainty of the altitude of emission layer brings a fatal problem. On the other hand, the effect of horizontal wind sheer becomes very small for deducing vertical winds. In some previous studies (*e.g.*, Peteherych *et al.*, 1985; Price and Jacka, 1991; Price *et al.*, 1995) discuss vertical winds using 557.7 nm observations.

2. Instrumentation and observations

The CRLFPI project operates two types of FPIs, one with a narrow field of view and the other with a wide field of view (details of these instrument was described in Ishii *et al.*, 1997). The narrow field-of-view FPI (scanning FPI) was installed at Poker Flat, Alaska throughout September 1998.

A one-night average of vertical wind measurement is used to determine the zero Doppler shift, keeping in mind the possibility of a constant offset in wind velocity. When the observed aurora was too bright, the recorded fringes saturate; this can lead to overestimation of temperature and large errors in velocity. The maximum number of counts in two minutes is 1.206×10^6 so we do not use fringe images with peaks greater than 1.10×10^6 counts in deducing the temperature and velocity.

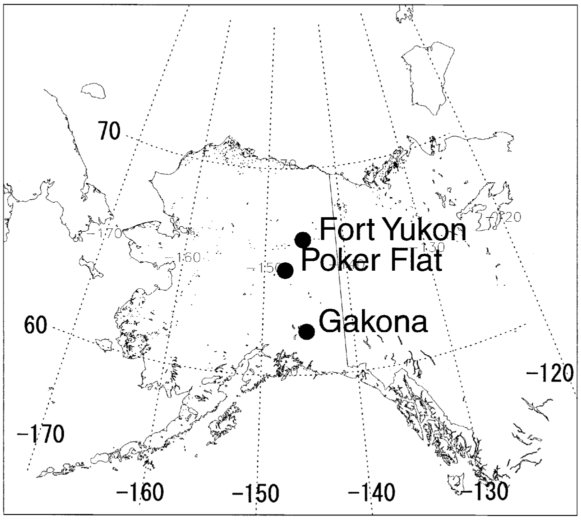

Fig. 1. Locations of the observatories. The CRLFPI was operated at Poker Flat Research Range. The magnetic field was measured at Fort Yukon, Gakona and Poker Flat. This map is plotted with geographic coordinates.

The magnetometer used here (The Geophysical Institute Magnetometer Array) is a basic fluxgate design using a triaxial set of cores (Narod ring-core magnetometer, Narod Geophysics Lt., Canada). Figure 1 shows the location of the three observatories at which the geomagnetic field was recorded; Poker Flat (65.12 N, 147.43 W), Gakona (62.12 W, 145.14 W) and Fort Yukon (66.56 N, 145.22 W). The magnetometer electronics are controlled by an S-100 computer that uses internal calibrations to produce digital output in units of nano Tesla. The nominal data rate is 8 samples per second and 1 sec-average data were provided for this study. The long-term drift is less than 10 pT/day. The noise level is 7 pT/$\sqrt{\ }$Hz at 1 Hz. The error in orthogonality is less than 0.1 degree. For a reference of aurora location, the Meridian scanning Photometer (MSP) observations at OI 557.7 nm are also shown.

3. Results

Two nights of observation (Nov. 25, 1998 and Feb. 11, 1999) were selected for analysis from a total dataset of observation during 83 nights. The criteria for selection were, (1) magnetometer data at PFRR were available, (2) clear sky (All-sky camera image and data from the Meridional Scanning Photometer (MSP) were used to check the weather condition) and (3) the GI-SDI (Geophysical Institute Scanning Doppler Imager) instrument described in Conde and Smith (1998)), was operated simultaneously with CRLFPI. The reason was described in the introduction session. Both the GI-SDI and CRLFPI observes OI 630.0 nm Doppler shift on zenith and the observational quality of both could be evaluated by comparison of these results. It should be noted that the results obtained in this study are for specific events and that a larger dataset than we used will be required to demonstrate any general tendencies.

Some detailed analysis of the vertical wind on the basis of the same dataset was carried out by Ishii *et al.* (2001).

Cross correlations were also calculated as a supplement to qualitative comparisons between the OI 557.7-nm vertical wind and the ΔH-component of the geomagnetic field data. The correlation was calculated in a 2-hour window, which is a typical time scale for magnetic substorms, and the phase lag was also calculated ± 100 min). Each data set was binned in 3 min intervals for calculating the correlations.

Figure 2 shows the results for the first case, observed on November 25, 1998. The upper panel shows vertical winds obtained with OI 557.7 nm (upward positive). The lack of a plot for 1220–1230 UT and 1315–1330 UT is due to fringe saturation that was associated with auroral expansion. The second panel shows the magnetic perturbations. In this case magnetometer data from two sites, Poker Flat (red) and Gakona (blue), were available. The third panel shows MSP results. The last panel shows the cross correlation between the vertical winds and magnetic perturbations with time delay taken into consideration. The vertical axis shows the time lag and the color code shows the correlation coefficients.

Significant downward flows can be seen during 1100–1150 UT. It turned upward in short period and downward flow was seen again from 1230 to 1430 UT. The amplitude of the magnetic perturbations was greater at Poker Flat than at Gakona, which indicates that Poker Flat was closer to the center of ionospheric current than Gakona. The ΔH-component at Poker Flat began to decrease from 1030 UT. It recovered on 1200 UT, but auroral on-set came soon after. This perturbation recovered by 1330 UT. The overall pattern of magnetic variation is qualitatively similar to that of vertical wind. but a notable difference is that the downward flow maintains its magnitude during the recovery phase (1330 UT) and its recovery to zero level is delayed from that of the magnetic field by about 1 hour. The MSP results showed a bright auroral arc appeared at around 1100 UT. It moved southward until 1230 UT. This movement of the auroral arc corresponded to an upward flow in the vertical wind data and temporal recovery of the magnetic field at around 1200 UT. After the expansion at 1230 UT, a bright and broad aurora moved northward.

With a time-lag of zero, the correlation was fairly strong from 0830 to 1100 UT, which is the growth phase of the substorm. In the recovery phase however, the wind-ΔH relation is rather anti-correlated. A significant feature of the correlation diagram is the "V-shaped" structure that bottoms-out at around 1300 UT. This means that this was the period of greatest time lag of vertical wind relative to the magnetic field, *i.e.*, that this is the end of the recovery phase.

Figure 3 shows the results for a second case (February 11, 1999). The format for the figure is same as was used for Fig. 2. Magnetic field data from the Poker Flat and Fort Yukon observatories were available.

There were three significant features over this period. The first one can be seen between 0600 and 0700 UT. Over that period, the vertical wind and magnetic perturbation clearly showed anti-correlated variation; acceleration of the vertical wind is downward and the velocity changes from 20 m/s to -20 m/s, whereas the ΔH-component increased ~200 nT over this period. During the same period, the aurora was located poleward of Poker Flat. Between 0700 to 0800 UT, sudden downward

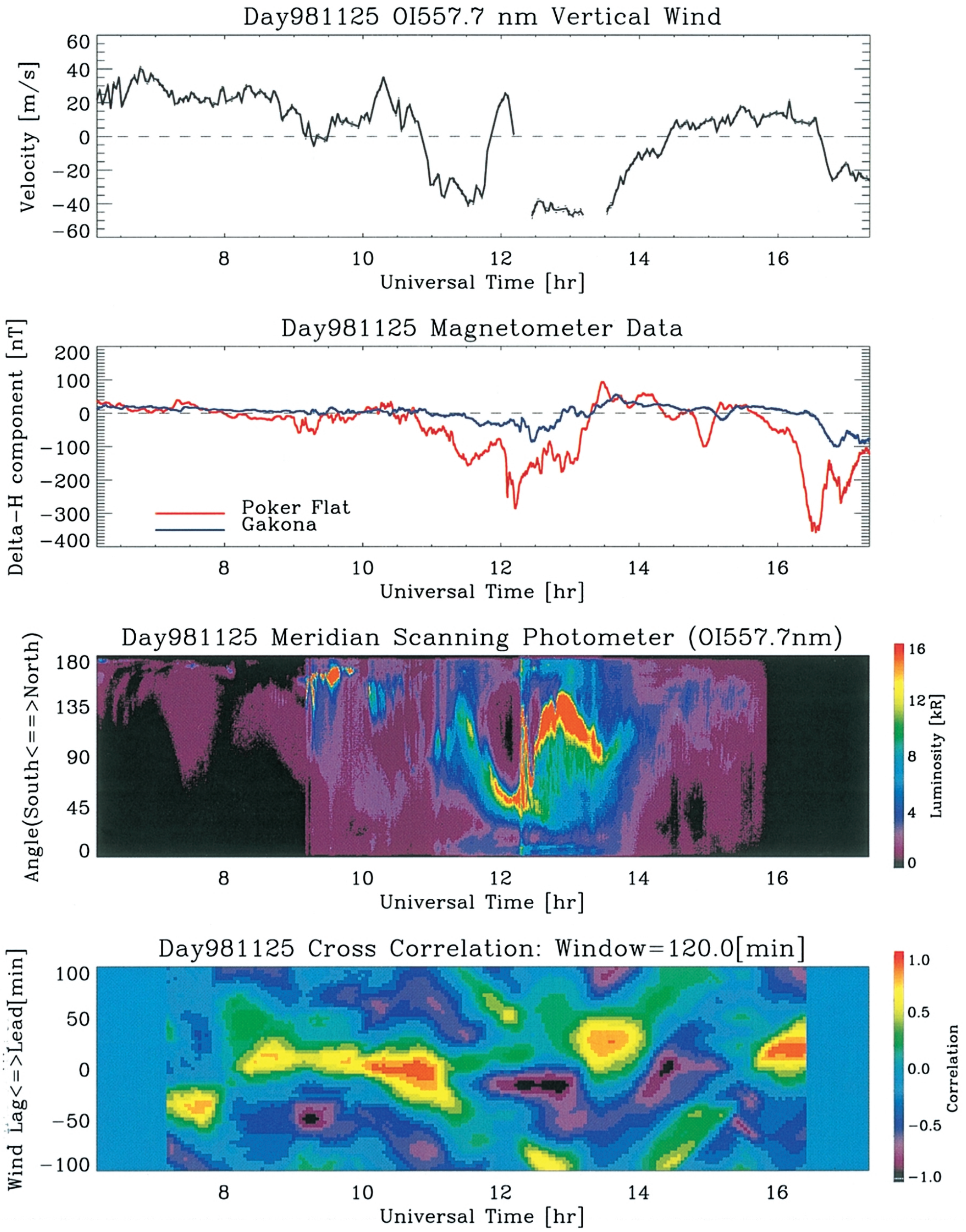

Fig. 2. Case 1: November 25, 1998. A comparison of the vertical wind as deduced from the Doppler shift of OI557.7 nm with the CRLFPI (top panel), ΔH-component of the magnetic field (second panel) and the temporal variation of OI557.7 nm auroral location as obtained with the Meridian Scanning Photometer (third panel). The bottom panel shows the correlation between the vertical wind and magnetic variation as obtained at Poker Flat. The vertical axis indicates the time difference (positive value: wind leading), and the degree of correlation is presented as the color code.

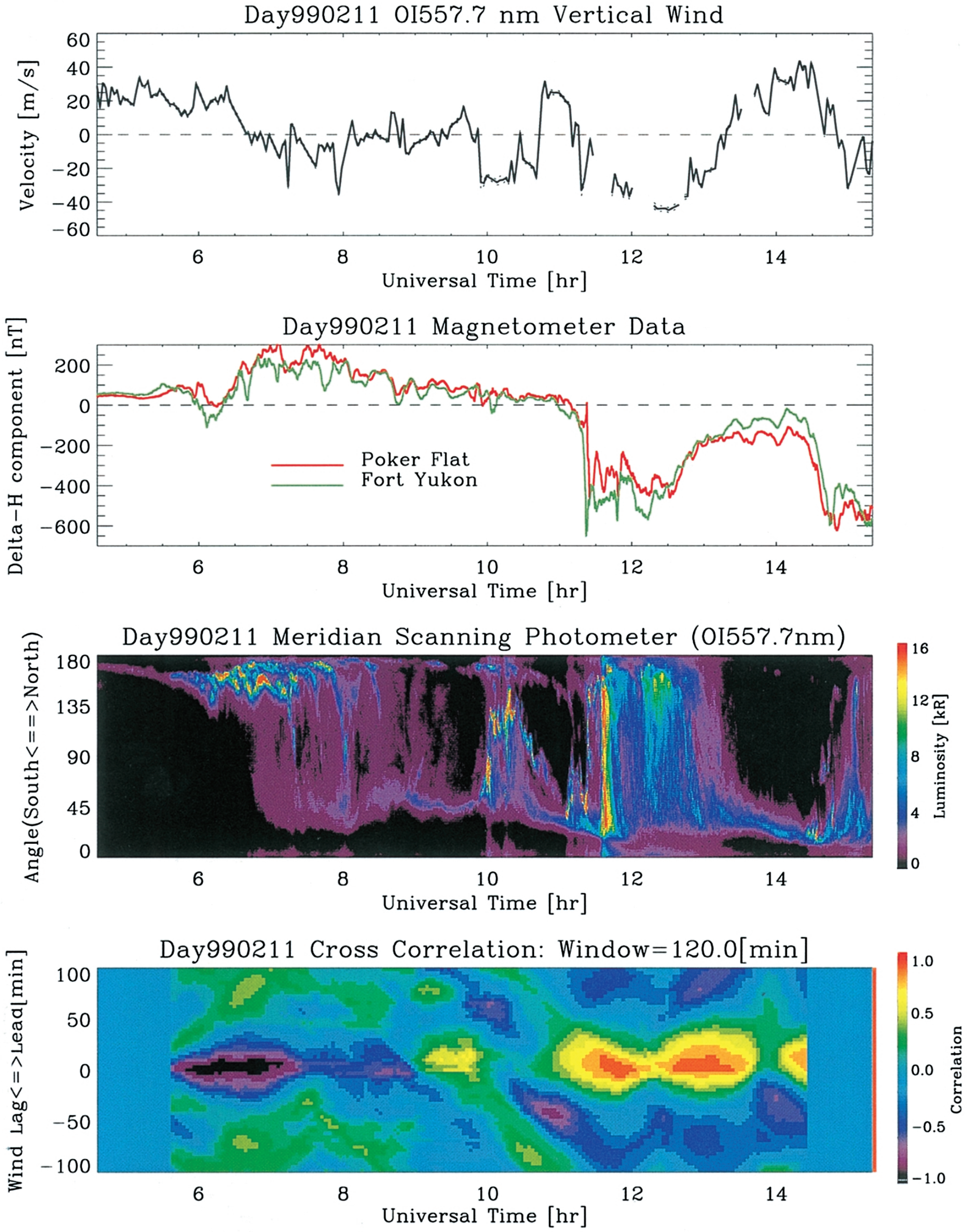

Fig. 3. Case 2: February 11, 1999. Format is same as Fig. 2.

flows occurred twice (~ −20 m/s) but there was no clearly corresponding variation in the magnetic field. The second significant feature is visible between 1000 and 1045 UT. The downward acceleration of the vertical wind in this period is clearly visible, but the level of magnetic perturbation was quite low (~50 nT). The MSP results showed that there was a narrow but bright aurora arc above the observatory.

The third significant event is the substorm that appeared at about 1120 UT. Variations in the vertical wind and magnetic perturbation were similar during this period. When the decrease in magnetic perturbation is at around ~400 nT, the downward vertical wind is around -40 m/s. The phase difference between the two features varies over time and a similar (but less well-defined) 'V-shaped' structure to that seen in case 1 appears in the correlation contour. The maximum phase difference is at around 1200 UT, with ~10 min of wind lag.

We used 83-night dataset and found 43 events of vertical wind which is large enough to distinguish from observational errors in 16 nights (26 events of upward and 17 of downward wind). Seven of the 16 nights have a similar tendency in the relation between the vertical wind and the H-component of magnetic field on the ground. Although there are not quantitatively high correlations, four of the other nine nights have some variations in the vertical wind velocity when the magnetic field fluctuated. Other four nights have no correlation between them.

4. Discussions

In some cases vertical wind variations appear highly correlated with magnetic field perturbations. In particular they behaved in a similar way during substorms (Case 1: 1100–1400 UT; Case 2: 1130–1400 UT), though the relation between the two was not always linear. In a quantitative analysis, the phase difference between the vertical winds and magnetic field increases during the growth phase and reaches maximum during onset and the recovery phase. After that the time difference gradually decreases. It is an attractive idea that these vertical winds are generated by Joule heating associated with ionospheric currents, and that these currents lead to the magnetic perturbations, too. However, there are some difficulties with this idea: in the first place, while vertical winds in the thermosphere are thought to be relatively local in many cases, whereas a magnetic perturbation is the result of ionospheric currents in a large region (~100 km $\times$ 100 km). Secondly, Joule heating is mostly caused by the Pedersen current, whereas the magnetic perturbations on the ground are generated by Hall currents. Furthermore, the mechanism for the induction of downward acceleration by heating is not yet clear. If Joule heating were the main source of the vertical winds examined here, the magnitude of the wind should have corresponded to the absolute values of the magnetic perturbations, because the rate of Joule heating must not be dependent on the directions of ionospheric current *i.e.*, the signatures of magnetic perturbations).

In relation to the first issue, Price *et al.* (1995) estimate that the horizontal area of vertical wind is less than 160 km at the height of the OI 557.7 nm emission layer. The geomagnetic field is thought to be influenced by the ionospheric current across an area with a radius of several-hundred kilometers of radius, because the nearest current is ~100-km distant *i.e.*, the current flowing above the observatory). This is considerably larger than the vertical wind area shown in Price *et al.* (1995), which means that some Joule-heating events with horizontally small scales can generate vertical winds without having an effect in terms of geomagnetic perturbations. The event shown 1000–1045 UT of case 2 may be an example of this process. During this period, some bright but relatively small auroral arcs were located around the zenith of the observatory.

Another idea, which seems more plausible, is that the variation in the auroral arc's location creates both the vertical winds and magnetic perturbations. Crickmore *et al.* (1991) indicated that downward winds are often observed equatorward of the auroral oval, and some other studies (Price *et al*., 1995; Innis *et al*., 1996, 1997) have mentioned that upward flows are often found poleward of the poleward edge of auroral oval. If the vertical wind distributions are fixed on the auroral oval, the high degree of correlation between the vertical wind and magnetic perturbation should be observable from a single observatory with the motion of the auroral arc.

These results suggest that there is an intimate relation between ionospheric currents and neutral dynamics in the lower-thermosphere, although the details of this relation have yet to be revealed. The cases we examined have shown that the proportionality coefficient is not nearly constant with time, even if the variation is similar. As the next step, we need to determine if there is any quantitative relation between the two phenomena.

Another approach would be to deduce the locations of ionospheric currents by using geomagnetic field datasets observed at multiple sites. Luhr *et al.* (1994) estimated the dominant ionospheric current from magnetic observations obtained at Scandinavian magnetometer chain. By applying the same method, we hope to obtain information on the locations of ionospheric currents as well as the locations of aurora as obtained by using MSP.

5. Concluding remarks

We deduced vertical winds in the lower thermosphere from OI 557.7 nm Doppler shifts as measured with a Fabry-Perot interferometer at the Poker Flat Research Range, Alaska. The deduced vertical winds were compared with the ΔH-component of geomagnetic field in the vicinity of the observatory and at Gakona and Fort Yukon. Four nights of observation were examined in this study and two nights of results have been discussed. Temporal variations in the vertical wind (positive upward) were often similar to variations in the magnetic field during substorms. The phase differences between two parameters also varied over time: In growth phase, the magnetic-field variation gradually and increasingly led the changes in the vertical wind and this difference reached a maximum at around the center of the recovery phase. After that, the difference gradually decreased. On the other hand, a clear anti-correlation between the two parameters was seen in one period (case 2; 0600–0700 UT) and a large vertical wind event that did not correspond to magnetic-field variations was seen in another (case 2; 1000–1100 UT). The mechanism of the relation between the two phenomena is still unclear, but this result suggests that there is some intimate relation between ionospheric currents and thermospheric vertical winds.

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