STATISTICAL STUDY OF RELATIONSHIPS BETWEEN DAYSIDE HIGH-ALTITUDE/-LATITUDE O\textsuperscript{+} OUTFLOWS, SOLAR WINDS, AND GEOMAGNETIC ACTIVITY

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ABSTRACT

The terrestrial origin O\textsuperscript{+} outflow, which is persistently observed by the Cluster CIS/CODIF instrument, was studied statistically in succession in the dayside high-altitude (from 5 up to 11 \(R_E\)) and high-latitude (from 75 to 90 degrees invariant latitude, deg ILAT) region. We extended the previous study (Arvelius et al., 2005a), investigating correlations between the properties (namely, maximum or ‘dominant’ differential particle flux, \(MDPF\), and its energy, \(PE\)) of dayside high-altitude polar outflowing O\textsuperscript{+}, solar winds (solar wind moments and the interplanetary magnetic field, IMF, conditions), and local mid-/low-latitude geomagnetic activity (measured by \(ASY/SYM\) indices). In this study, we found firstly that energization and/or acceleration of dayside high-altitude polar outflowing O\textsuperscript{+} is(are) controlled by both strong southward IMF (defined by intensity, \(B_t\), and clock angle, \(\theta\), in this case, \(|\theta| > 135^\circ\)) and solar wind moments (except solar wind electric field), but it(they) occur(s) at two different places: one is the poleward cusp and/or the mantle region controlled by the IMF, the other is the entire polar cap controlled by the solar wind moments. Secondarily outflowing O\textsuperscript{+} flux enhancement and O\textsuperscript{+} keV energization/acceleration process(es) are different in terms of occurrence time scale and location, even tough both are controlled by solar winds and the IMF. Thirdly both energization/acceleration and flux enhancement of dayside high-altitude and high-latitude outflowing O\textsuperscript{+} correlate to local mid-/low-latitude geomagnetic activity (as measured by \(ASY/SYM\) indices), i.e. higher energy of outflowing O\textsuperscript{+} appears at higher altitudes and more equatorward (a similar trend to that of the \(K_p\) index (Arvelius et al., 2005a)), and flux enhancement of outflowing O\textsuperscript{+} appears at lower altitudes and more poleward. However the correlation is not as clear as the case of the IMF conditions / the solar wind parameters.

Key words: Solar wind-magnetosphere interactions; Magnetosphere-ionosphere coupling; O\textsuperscript{+} energization/acceleration; O\textsuperscript{+} outflow.

1. INTRODUCTION

The previous study (Arvelius et al., 2005a) is extended in this study in terms of correlations between the properties of dayside high-altitude and high-latitude outflowing O\textsuperscript{+}, solar winds (IMF conditions and moments), and local mid-/low-latitude geomagnetic activity. The correlations are investigated particularly with a “time-shifted” comparison at the time scale of from tens of minutes to an hour.

The data set of dayside high-altitude and high-latitude outflowing O\textsuperscript{+} is provided by the Cluster CIS/CODIF instrument. We selected 129 Cluster traversals in the dayside polar region (year of 2001-2003, from January to May), and the observation points are counted to more than 80,000. The previous data utilized in this study is the same as that in the previous study (Arvelius et al., 2005a). A sample data is shown in Figure 1.

1.1. Previous results

The results from the previous study (Arvelius et al., 2005a) are shown in Figure 2 and Figure 3. We concluded that (1) the latitudinal distribution of outflowing O\textsuperscript{+} in
terms of peak energy, i.e. $PE$, is consistent with velocity filter dispersion at 6-8 $R_E$ geocentric distance (or below 8 $R_E$ geocentric distance), while that of above 8 $R_E$ geocentric distance cannot be explained by velocity filter effect only, and that (2) a tendency to observe outflowing keV O$^+$ is obvious for $K_p \geq 5$ than $K_p \leq 3$ at higher altitudes.

Concerning above (1), we suggest additional energization and/or acceleration mechanism(s) of outflowing O$^+$ in the dayside high-altitude and high-latitude region. Two candidates examined in the previous paper are (a) centrifugal force and (b) ponderomotive force, and both of them might contribute to energy gain of outflowing keV O$^+$ partially, but not be major process.

On the other hand, the result (2) above indicates that higher $K_p$ is in general related to strong magnetospheric convection, however, as shown in the result (1) above, latitudinal distribution of outflowing keV O$^+$ ions cannot be explained by velocity filter effect, which is caused by the anti-sunward magnetospheric convection only. Therefore we aim to examine correlations between the properties of dayside high-altitude and high-latitude outflowing O$^+$ and the solar winds as well as geomagnetic activity as measured by ASY/SYM indices with high time resolution (1 minutes). In Figure 4 the definition of IMF $B_x$ (anti-)parallel to the geomagnetic field and the legend of gray-scaled bar are shown.
2. RESULTS

2.1. Solar wind dependences on PE

The spatial (both altitudinal and latitudinal) PE distribution of dayside high-latitude and high-latitude outflowing O\(^+\) are examined in response to the IMF conditions / the solar wind moments at different time lags (60, 30, 20, and 10 minutes). The “time lag” means that the solar winds which are estimated to reach the subsolar point precede observing outflowing O\(^+\) events by 60, 30, 20, and 10 minutes.

The optimum time lag for the best correlation is 10 minutes and the clearest correlation can be seen at the altitude interval of 10–12 \(R_E\) geocentric distance. The positive correlations can be seen for (a) strong southward IMF (lock angle, \(\theta\) is defined as \(|\theta|>135^\circ\)) and (b) solar wind velocity x-component, \(V_x\), while the negative correlations can be seen for (c) solar wind proton density, \(N_p\) and (d) solar wind dynamic pressure, \(P_{sw}\). There is no correlation seen for the solar wind electric field (\(E_4\)).

The latitudinal distributions of PE occurrence rates in response to (1) strong southward IMF, \(B_z\) (\(|\theta|>135^\circ\)), (2) IMF \(B_z\) parallel to the geomagnetic field \((B_{z,||})\), and the solar wind moments (3–6) are shown in Figure 5. As shown in Figure 5, the energization and/or acceleration of dayside high-altitude and high-latitude outflowing O\(^+\) is controlled by the solar wind moments \((N_p, V_x\) and \(P_{sw}\)) and the IMF conditions \((B_z (|\theta|>135^\circ))\), however at two different places. One is the poleward cusp and/or the mantle region (below 80 deg ILAT) at higher latitude (i.e. 10–12 \(R_E\) geocentric distance) where the strong southward IMF influences. The other is the entire entire polar cap, in particular 80–85 deg ILAT, at vertically broader altitude intervals (i.e. above 8 \(R_E\) geocentric distance) where the solar wind moments influence dominantly.

2.2. Solar wind dependences on MDPF

The spatial distributions of MDPF occurrence rates are also examined in response to the IMF conditions / the solar wind moments at different time lags (60, 30, 20, and 10 minutes). The optimum time lag for the best correlations is chiefly 60 minutes and the best correlations can be seen at the altitude interval of 6–8 \(R_E\) geocentric distance.

The positive correlations can be seen for (a) strong southward IMF, (b) IMF \(B_{z,||}\) but at the time lag of 10 minutes, (c) solar wind proton density, (d) solar wind dynamics pressure, and (e) solar wind electric field. The negative correlation can be seen only for the solar wind electric field at the time lag of 10 minutes.

The latitudinal distribution of MDPF occurrence rates in response to (1) strong southward IMF, \(B_z\) (\(|\theta|>135^\circ\)) at the altitude interval of 8–10 \(R_E\) geocentric distance, (2) \(P_{sw}\) (also representative for \(N_p\)), (3) \(E_4\), and (4) \(B_{z,||}\) at the time lag of 10 minutes are shown in Figure 6, respectively. The altitude interval chosen for (1) is due to a better statistics. As shown in Figure 6, flux enhancement of
outflowing \( O^+ \) is also controlled by both the solar wind moments \( (N_p, P_{sw}, \text{and } E_A) \) and the strong southward IMF \( (B_z, |\theta|>135^\circ) \), however the optimum time lag and location for the best correlations are different from those in the case of outflowing keV \( O^+ \) energization and/or acceleration process(es). The optimum time lag is in principle 60 minutes. The location for the best correlations is at the altitude interval of 6–8 \( R_E \) geocentric distance and more poleward (i.e. 85–90 deg ILAT). Furthermore, this result indicates also that flux enhancement of outflowing \( O^+ \) is influenced by dynamics of the ionosphere.

2.3. Geomagnetic activity dependences

Both \( PE \) and \( MDPF \) occurrence rates at different time lags (60, 40, and 20 minutes) in response to \( SYM-H \) and \( ASY-D \) indices are also examined. The best correlations can be seen at different places for either \( PE \) or \( MDPF \) occurrence rates of outflowing \( O^+ \): at the altitude interval of 10–12 \( R_E \) geocentric distance for \( PE \), and at the altitude interval of 6–8 \( R_E \) geocentric distance for \( MDPF \). These trends are similar to the cases for the solar winds, while independent of character of geomagnetic activity (i.e. large negative value of \( SYM-H \) index, e.g. less than -50 nT, indicates a ring current enhancement associated with geomagnetic storms, whereas large positive value of \( ASY-D \) index, e.g. more than 20–30 nT, indicates east-west auroral electrojet intensification at the nightside associated with substorm onsets). Only the optimum time lag for the best correlations is different for \( SYM-H \) and \( ASY-D \) indices. The spatial (both altitudinal and latitudinal) distributions of \( PE \) and \( MDPF \) occurrence rates in response to \( ASY-D \) index at the time lag of 20 minutes are shown in Figure 7 and Figure 8. As shown in these figures, both energization/acceleration and flux enhancement of dayside high-altitude and high-latitude outflowing \( O^+ \) correlate to \( ASY-D \) index, i.e. higher energy of outflowing \( O^+ \) appears at higher altitudes and more equatorward, while flux enhancement of outflowing \( O^+ \) appears at lower altitudes and more poleward. The former trend is similar to the case for \( K_p \) index (Arvelius et al., 2005a). However these correlations are not as clear as those for the solar winds.

3. SUMMARY

We summarize this investigation and conclude as follows:

1. The energization and/or acceleration of dayside outflowing \( O^+ \) at high altitudes and high latitudes is directly (i.e. nearly immediately in time scale) controlled by solar winds. The processes occur at two places: one is at the high-altitude poleward and/or the mantle region controlled by the IMF, the other at the entire polar cap above 8 \( R_E \) geocentric distance controlled by the solar wind moments \( (N_p, V_z \text{ and } P_{sw}) \), but not by \( E_A \).

2. The keV \( O^+ \) has a positive correlation to strong southward IMF and \( V_z \), but a negative correlation to \( N_p \) and \( P_{sw} \). There is no correlation between keV \( O^+ \) and the solar wind electric field \( (E_A) \).
3. The energization and/or acceleration process(es) of dayside outflowing O$^+$ in which the energy level achieves more than 1 keV occurs locally at high altitudes. On the other hand, the flux enhancement of dayside outflowing O$^+$ occurs in the entire polar cap region and is strongly related to the dynamics of the ionosphere. These differences are confirmed by the investigation of optimum time lags for the best correlation to the solar wind moments / the IMF conditions.

4. The peak flux of dayside outflowing O$^+$ has a positive correlation to strong southward IMF, $P_{sw}$, and $E_4$, which is fully consistent with other previous studies.

5. Both keV energization/acceleration and flux enhancement of dayside outflowing O$^+$ correlate to geomagnetic activity, i.e. higher energy outflowing O$^+$ appears at higher altitudes and more equatorward, and flux enhancement of outflowing O$^+$ appears at lower altitudes and more poleward. However these correlations to geomagnetic activity are not as clear as those to the solar winds.

The contents of this paper are excerpted from Arvelius et al. (2005b). The investigation of relationships between 3-hour-averaged solar wind parameters (including the IMF conditions) and $K_p$ index has also been done and the results are described in Arvelius et al. (2005c).

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REFERENCES

