Unexpected short-lived ion temperature enhancements of a few 100 K, or "Ti spikes," were observed with the Poker Flat Incoherent Scatter Radar during the International Polar Year. The spikes were found near the F region dusk plasmapause, that is, near the dusk boundary of the high latitude convection region. The spikes were invariably accompanied by sharp plasma density drops. The spike events were often the largest ion temperature values recorded throughout the day. Even though the magnetic conditions at the time of these events were never very disturbed (no magnetic storms), the AL index would always go through a minimum of the order of -100 to -300 nT around the time of the spikes. Given the altitude of the observations, ion frictional heating, that is, large relative drifts between ions and neutrals, had to be at the origin of the spikes. With this in mind, a plausible explanation for the spikes was that the negative AL excursions were associated not just with temporary intensifications in the electric field but also with an equatorward expansion of the convection pattern, leading to ions suddenly moving sunward in a region where the neutrals were still moving anti-sunward. This explanation is supported by the sharp decrease in plasma density seen near the ion temperature spikes, in that they had to be associated with field lines that were corotating prior to occurrence of the substorms. A second possibility is that the electric fields were stronger near the plasmapause, and therefore SAID-like, even though the events were only connected to weak substorms. The two hypotheses are being tested through modeling, larger magnetic and radar data sets, and specialized PINOT campaign experiments.

Throughout the 2007 international polar year, the Poker Flat Incoherent Scatter Radar (PFISR) near Fairbanks, Alaska took long pulse measurements (480/s) along the magnetic field line. It integrated over 15 minute intervals every 35 km between altitudes of 99 km and 663 km, rendering measurements for electron number density ($n_e$), ion velocity ($V_i$), and both ion and electron temperature ($T_i$ and $T_e$, respectively). Throughout the available data, 15 to 45 minutes $T_i$ enhancements of 300 K ($T_i$ spikes) were seen during evenings (18 MLT being roughly 5 UT and 0 MLT being roughly 11 UT) with moderately quiet geomagnetic activity. At roughly the same time (within 1.5 h) there would be a steep $n_e$ depletion and a AL minimum below -100 nT (seen in Figure 1). Epoch studies that took data from all 25 $T_i$ spikes seen throughout 2007 showed that there was an average AL depletion of -220 nT (these depletions ranged from roughly -100 to -300 nT) roughly 15 minutes before the spike, as well as an average $n_e$ depletion of 1 x 10^11 m^-3 beginning 30 minutes before the spike (seen in Figure 2), with time zero being the $T_i$ spike time.

SuperDARN convection plots show that at the time of the $T_i$ enhancements PFISR was in the evening sector just northward of the equatorward edge of the ion convection pattern, near the dusk plasmapause (Figure 3 for example). These maps put PFISR in a region where low density plasma is coming from the night-side, possibly explaining the $n_e$ depletion seen near the $T_i$ spike.

The general ion energy equation can be written as (St.-Maurice & Hanson, JGR, 87(A9):7580, 1982):

$$\frac{3}{2} \left( \frac{D}{Dt} + \nabla \cdot V_i \right) + \nabla \cdot q_i + P_i : \nabla V_i = \sum_n \frac{n_i m_i V_i^2}{m_n} \left[ 3k_B (T_n - T_i) \psi_n + m_n (V_i - V_n)^2 \psi_n \right] + n_i m_i 3k_B (T_n - T_i) + n_i m_n c_e (V_i - V_n)^2$$

(1)

On the left-hand side of equation 1 is the rate of change of internal energy, adiabatic heating/cooling, ion heat flow, and viscous heating. The right side contains heat exchange between neutrals and ions, fractional heating through the relative drift of ions and neutrals, heat exchange between electrons and ions, and fractional heating through a relative drift between ions and electrons. To first order, and for F region applications, this equation can be written as (St.-Maurice, J.-P., & W. Hanson, JGR, 89(A2):987, 1984):

$$T_i \approx \left( \frac{m_i}{3k_B} (V_i - V_n)^2 + T_n \frac{m_i + m_n}{m_n} c_e T_i \right) \left( 1 + \frac{m_i + m_n}{m_n} \frac{v_n}{V_i} \right)^{-1}$$

(2)

From this only a few factors affect the $F$ region $T_i$, namely, $T_n$, the neutral temperature ($T_n$), the mean neutral mass ($m_n$), and the relative drift between ions and neutrals (ion-neutral fractional heating). Since PFISR was not in a region of local $T_i$ or $m_n$ enhancement, and $T_i$ is small in this formula, the $T_i$ spike source must be the relative drift.

Two possible relationships between the AL minima and the $T_i$ spikes (the increased ion-neutral frictional heating) are:

- An equatorward expansion of the convection pattern could lead to ions moving sunward in a region where neutrals are flowing anti-sunward.
- Weak substorms could increase electric fields at the dusk plasmapause boundary, locally enhancing ion frictional heating.

Regarding the $n_e$ depletion, Richards et al. (to be submitted) are showing that when a substorm expands the size of the convection pattern in summer, field tubes that were originally corotating in darkness are brought back towards the sun after having suffered a loss of plasma.

Using four extremely quiet conditions around dusk (AL between 0 and -50 nT), an average quiet dusk density pattern was obtained (Figure 4). This produced a density benchmark for sustained extremely low AL activity. When compared to a day with a $T_i$ spike we find (Figure 5):

- A negative AL excursion translates into a $T_i$ spike when PFISR is in the dusk sector (only one of the two strong 27/June/2007 excursions create a large $T_i$ enhancement).
- There is a strict dusk $n_e" trough" at the time of a strong AL excursion.

Further work:

- Dust PFISR campaigns during substorms are looking into combined neutral wind and $T_i$ observations to investigate possible frictional heating mechanisms.
- More detailed datasets are being studied to examine the dependence of the summer $T_i$ spikes and $n_e" troughs on the magnitude of the substorms and their onset time.
- A detailed presentation of the $n_e" trough is being submitted by Richards et al.
- While $B_s$ is involved on average, the origin of at least some of the weak substorms requires investigation.

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