Proton and electron fluxes in the plasma sheet transition region and their dependence on solar wind parameters

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Outline

- Plasma sheet transition region (PSTR); 6 - 15 Re
  - The region between dipolar and tail like magnetic field configuration.
  - Initial particle population for radiation belts and ring current
  - Particle precipitation into the auroral ionosphere
- High energy tail in proton/electron spectra (>~95/31 keV)
  - Convection enhancements, wave-particle acceleration, burst bulk flows (BBF)
- Which solar wind parameters influence high energy ion/electron fluxes in PSTR the most?
- How it depends on region??
- Which time delays are involved? For different regions? species/energy?

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Data (5m averages)

OMNI 2007-2019
- $V_i, B, Ni, Ti, PD$
- $EKL = -V^*B_{yz} \cdot \sin^2(\theta/2) \cdot 10^{-3}$
- $VBn = -V^*B_{yz} \cdot \cos^2(\theta/2) \cdot 10^{-3}$

Themis A, D, E 2007-2019:
- Spectra GMOM
- $(i/e: 5/6 \text{ eV} - 4\text{MeV}/700 \text{keV})$
- Proton/electron temperature $(T_{i/e})$
- Proton fluxes at 95 and 140 keV $(i_{95}, i_{140})$
- Electron fluxes at 31 and 93 keV $(e_{31}, e_{93})$
- $r, \varphi \text{ SM, dZns}$

Plasma sheet condition
$(R \leq 8Re \cap dZns < 1Re \cap B_{xy} < B_z) \cup (R > 8 \cap (\beta > 1 \cup B_{xy} < B_z))$
$\sim 2.3 \times 10^5$ data points
Regression analysis

Regression equation: \( O^* = \text{const} + \sum_{i=0}^{n} a_i I_i^* \)

\( VIF = \frac{1}{1-R^2} \)

VIF detects multicollinearity in the set of predictors:
- \( VIF = 1 \): predictor does not correlate with other predictors;
- \( VIF > 5 \): predictor correlates with other predictors;

Correction of the predictors set

To minimize multicollinearity in the predictors matrix we calculate VIF for each parameter and then exclude the parameter with maximum VIF. We repeat this process for resulting predictors set until only SM coordinates are left.
- Full set of the parameters, highest CC, PE, vif up to 82.
- Optimal set, CC, PE unchanged, vif < 2.46
- No sw parameters, CC, PE strongly decrease

We will use the optimal set in further analysis.
Electrons: largest impact correspond to \( V_{sw} \) and EKL (at ~2 hrs delay for 31 keV and 8 hrs delay for 93 keV). 
\( CC = 0.73(\text{Te}), 0.83(31\text{keV}), 0.89(93\text{keV}) \)

Protons: largest impact correspond to \( V_{sw} \), and \( Pd \) with 2 hrs delay. EKL is less important 
\( CC = 0.53(\text{Ti}), 0.79(95\text{keV}), 0.85(140\text{keV}) \)

Long IMF Bn (NBL) decreases fluxes of high energy electrons and protons
EKL influence on the plasma sheet parameters

Each point on the plot shows the color-coded correlation coefficient, between plasma sheet parameters ($T_e$, $e_{31}$, $e_{93}$) at time $T_0$ and solar wind EKL parameter averaged for the time period between $T_0 - T$ and $T_0 - (T + \Delta T)$. Both the delay of time window ($T$) and its width ($\Delta T$) are varied to identify their optimal values. Different plots correspond to different plasma sheet regions (see the scheme below).

RESULTS

- The max correlation is observed within 2 hrs delay for $T_e$, and at larger delays for the 31 keV and 93 keV fluxes.
- Largest time delay corresponds to the near Earth region.
LBN influence on the plasma sheet parameters

- Highest negative correlation for the electron 31 keV fluxes are at the R5 and R6 region, correspond to delays 1-2 hours
- Highest negative correlation for the proton 95 keV fluxes are at the R4 region, correspond to delays 1-10 hours.

Each point on the plot shows the color-coded correlation coefficient, between plasma sheet parameters (e31, i95) at time T0 and solar wind EKL parameter averaged for the time period between T0 - T and T0 - (T + △T). Both the delay of time window (T) and its width (△T) are varied to identify their optimal values. Different plots correspond to different plasma sheet regions (see the scheme below).
Vsw influence on plasma sheet parameters

To illustrate the character of SW velocity impact we plot proton/electron fluxes against SM longitude separately for different radial distances for low/high Vsw intervals (EKL was the same in both groups).

- e fluxes (p-fluxes) increase toward dawn (dusk) as expected in the dawn-dusk E-field.
- The strongest Vsw related effects correspond to the most distant range ($11 < r < 14$), being $\sim 1$ order for electrons and 2 orders of magnitude for protons. This shows that Vsw-related flux changes are, to a large extent, formed in the plasma sheet and, then, influence the inner magnetosphere.
- The weakest enhancements are near Earth ($6 < r < 8$) (6 times for electrons and protons).

Median values of 31/93 keV electron fluxes and 95/140 keV proton fluxes at different longitude for two solar wind speed range and same ekl range.
Weight of each predictor (a*rms) for the models of plasma sheet parameters in the different sectors (see the scheme above)

- Vsw impact is stronger on the dawnside for electrons, and on the dusk side for protons; The strongest impact for e31/93 & i95/140 is observed near the midnight;
- EKL impact includes a longer delay for the electrons closer to the earth;
- BNL effect remains in the binned model;
Conclusions

1. Solar wind drivers influence protons and electrons differently. Electrons are influenced similarly by solar wind speed and EKL, while protons mostly by solar wind speed and dynamic pressure, with smaller EKL impact.

2. Vsw-related flux changes are, to a large extent, formed in the plasma sheet and, then, influence the inner magnetosphere.

3. EKL affect different parts of plasma sheet spectra with different time delay up to 24 hours for the fluxes in the high energy tail. The effect includes higher delay in the regions closer to Earth.

4. Timescales of the loss processes, during period of long Bn, can be estimated with NBL parameter. Protons stay longer in the magnetosphere (up to 24 hours) than electrons (2-4 hours) during absence of an energisation mechanism. Proton loss mostly take place at 6-8 Re. Electron loss mostly take place at 8-15 Re.

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