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Solar Wind Driven Empirical Model of Electron Plasma Sheet Densities and Temperatures beyond Geostationary Orbit During Storm Times

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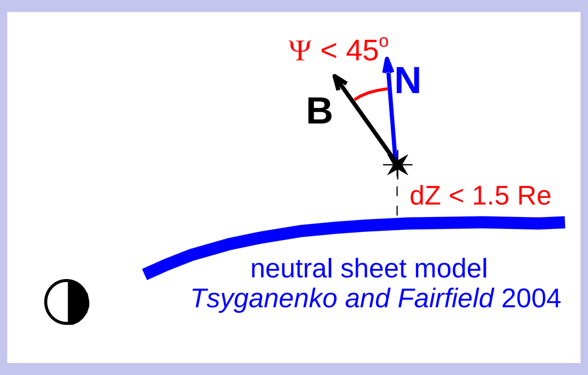
MOTIVATION

Numerical simulations of the inner magnetosphere usually place the outer boundary condition between r=6.6 and 10 R_E. Unfortunately there are few empirical relations between the plasma sheet and solar wind parameters which could play this role in this region. In addition, the characteristics of the electron plasma sheet in this region are of special interest since it is a source of the electrons which end up in the radiation belts, accelerated up to several MeV. We use the excellent particle data from THEMIS mission to construct the empirical relations between the electron plasma parameters and upstream solar wind conditions during geomagnetic storm periods.

Data selection:

- THEMIS A, D, E probes
- The probes are in the central part of the plasma sheet
- Storm-time intervals



Storm-time intervals 2007-2013

Plasma moments:

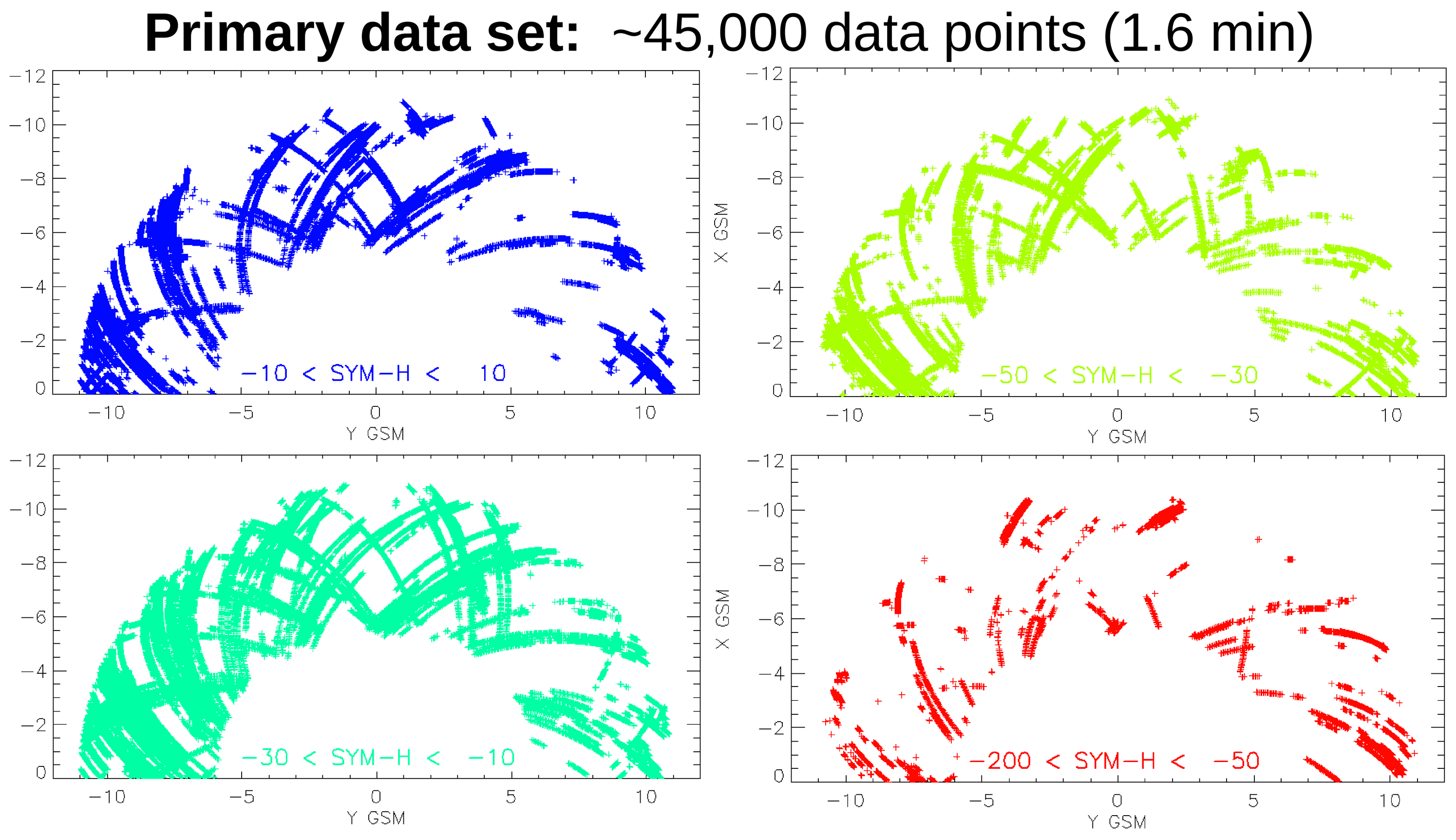
ESA electrons: 30eV - 30 keV; ions: 30eV - 25 keV

SST ions and electrons ~25 keV - 300 keV

Ni = Ne test: $N_i/1.5 < N_e < 1.5N_i$

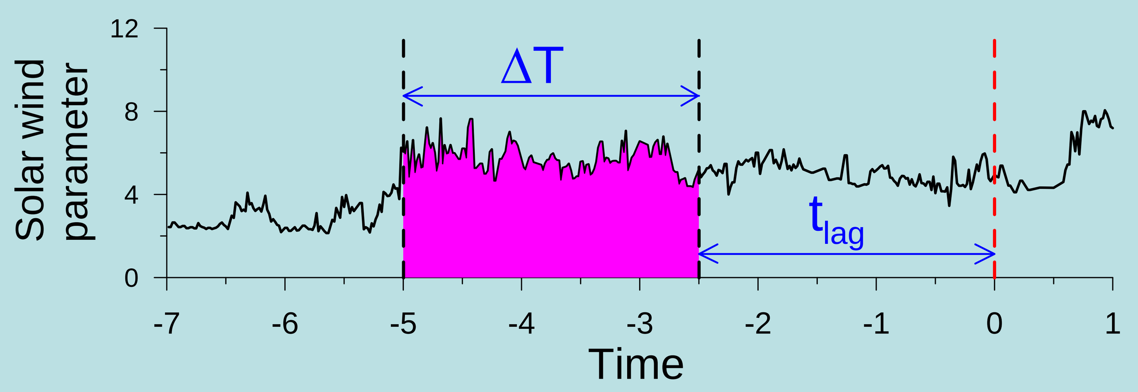
~1/3 of data was excluded by this criterion!

Primary data set: ~45,000 data points (1.6 min)

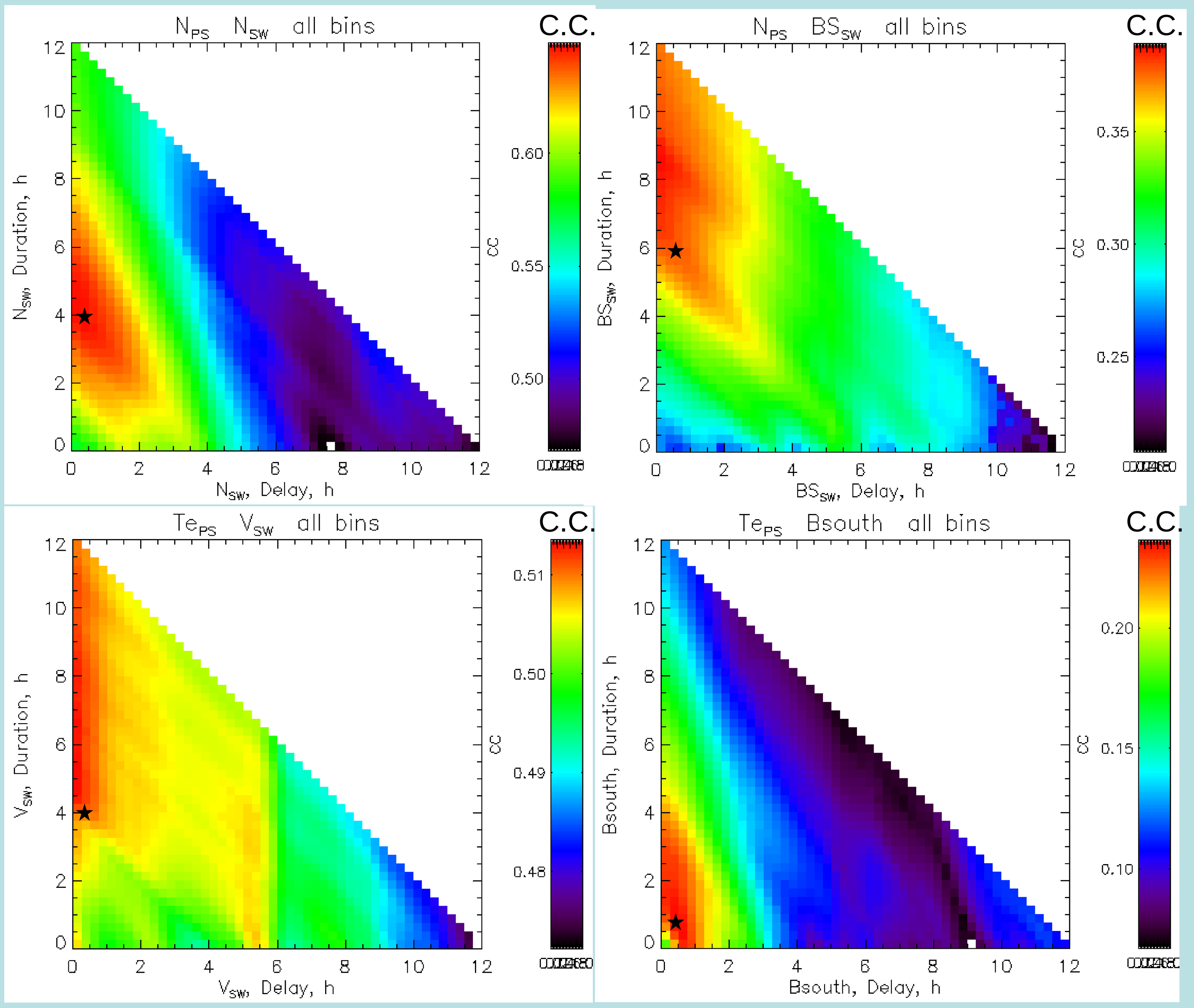


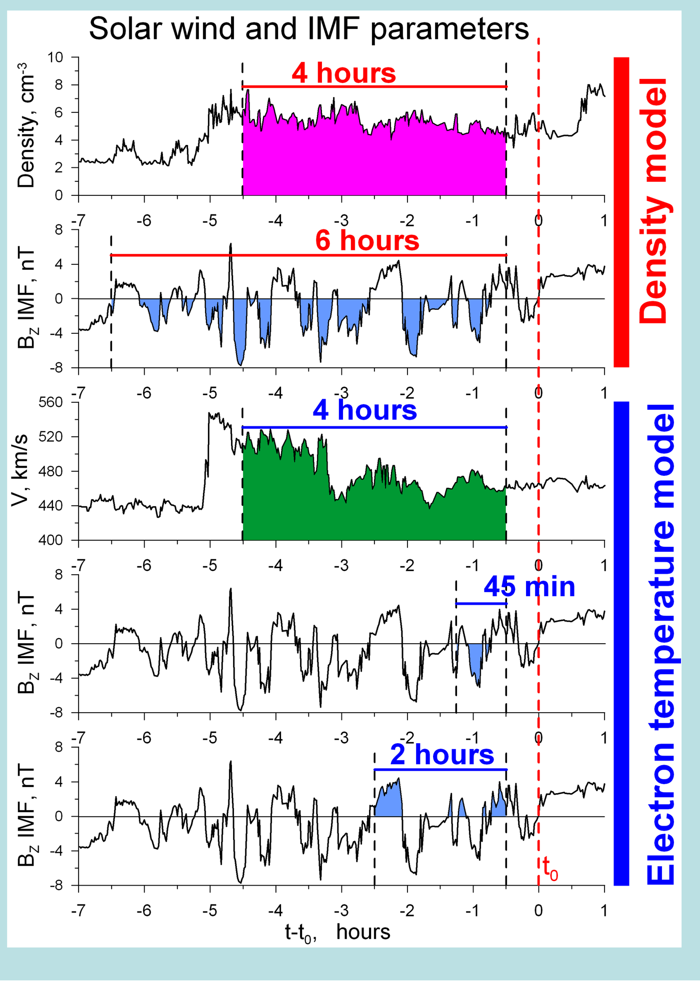
Model input parameters:

Computed as time-integrals over [t_0 - ΔT- t_{lag} ; t_0 - t_{lag}]



ΔT and t_{lag} are determined from analysis of correlations between plasma sheet N_e or T_e and corresponding solar wind parameter:





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Model input parameters

Density model: 2 input parameters
(1) Solar wind proton density
(2) IMF southward component

Temperature model: 3 input parameters
(1) Solar wind velocity
(2) IMF southward component
(3) IMF northward component

Normalization

$$N_{SW} = \langle N_{SW} \rangle / 10cm^{-3}$$
$$V_{SW} = \langle V_{SW} \rangle / 400km/s$$
$$B_S = \langle B_S^{IMF} \rangle / 2nT$$
$$B_N = \langle B_N^{IMF} \rangle / 2nT$$

Spatial dependence

$$r = \sqrt{x^2+y^2+z^2} \qquad \phi = \arctan(-y/x)$$
$$r = R/10\,\mathrm{Re}$$
$$\phi = \arctan(-Y/X)/90°$$

Final model equations

Electron density model: 7 coefficients

$$N_e = 1.23 - 1.01\cdot r + 0.874\cdot r\phi^2 - 0.82\cdot\phi^2 + 0.392\cdot N_{SW} + (0.521 - 0.474\cdot r)\cdot B_S$$

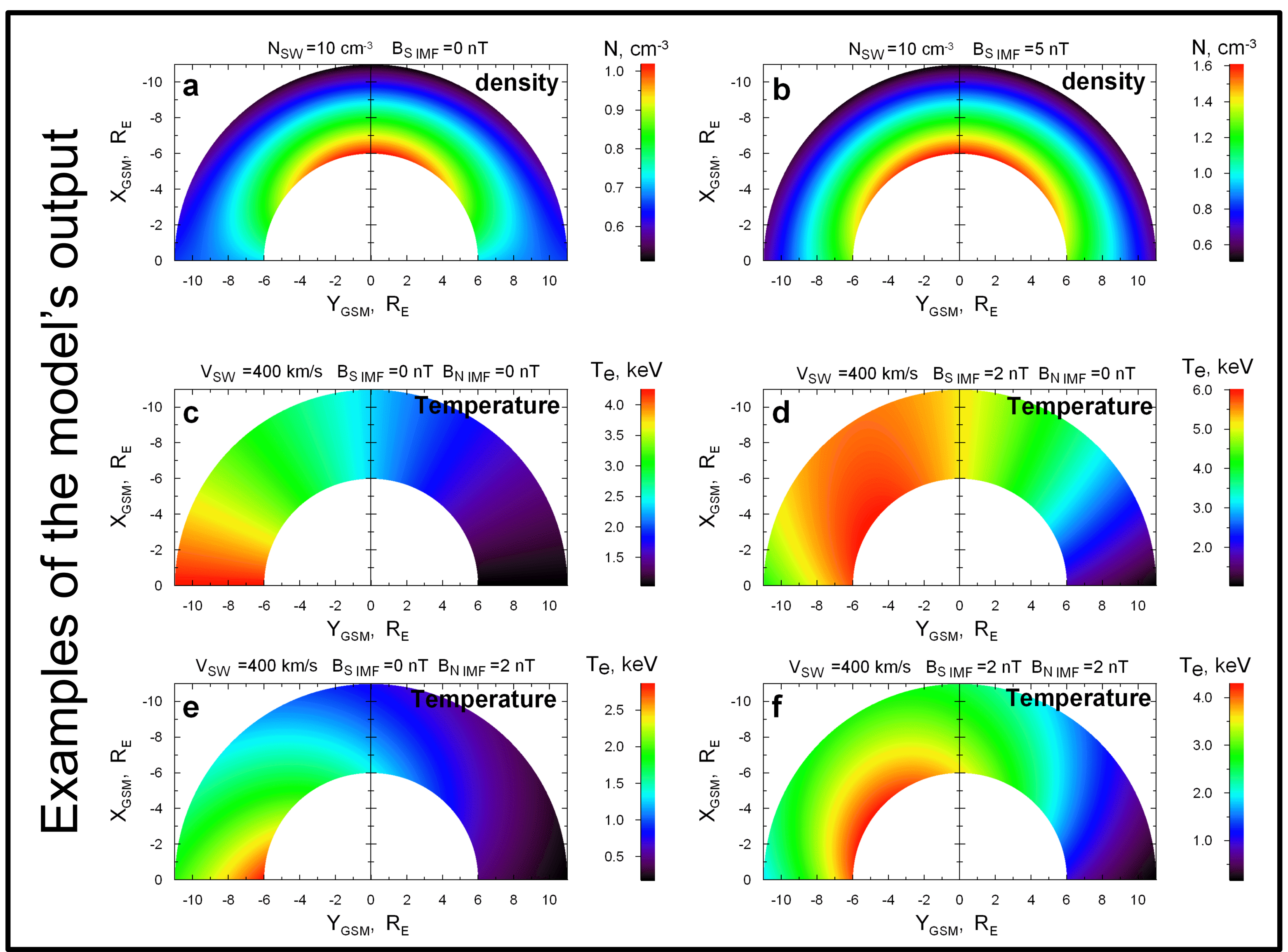
(positive)

Electron temperature model: 9 coefficients

$$T_e = [-0.0215 - 0.426\cdot\phi + 0.874\cdot V_{SW} + (0.587 - 0.538\cdot r\phi^2)\cdot B_S^{0.32} - 0.489\cdot r\cdot B_N^{0.36}]^{2.31}$$

(positive, positive, negative)

Examples of the model's output

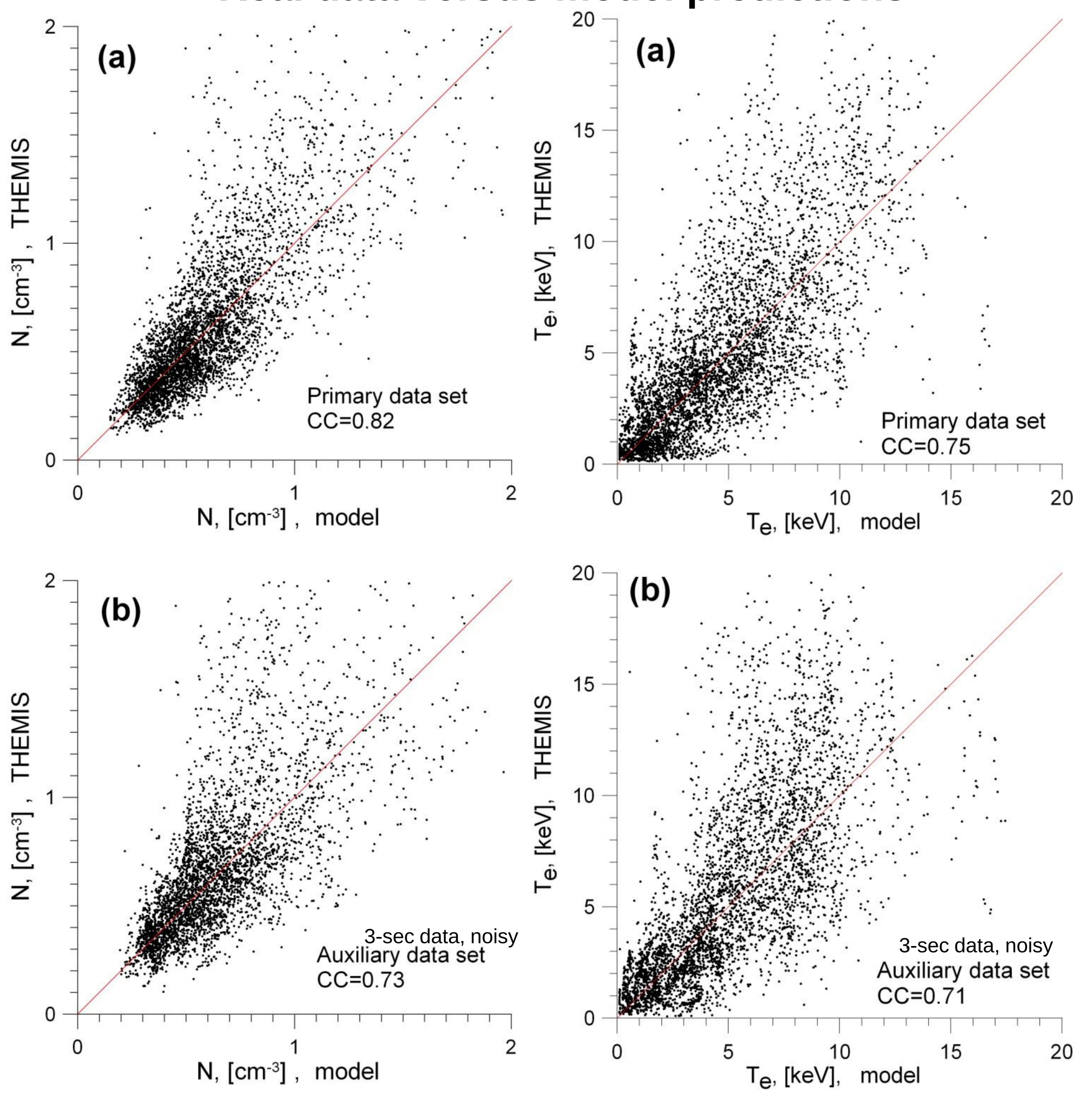


Real data versus model predictions

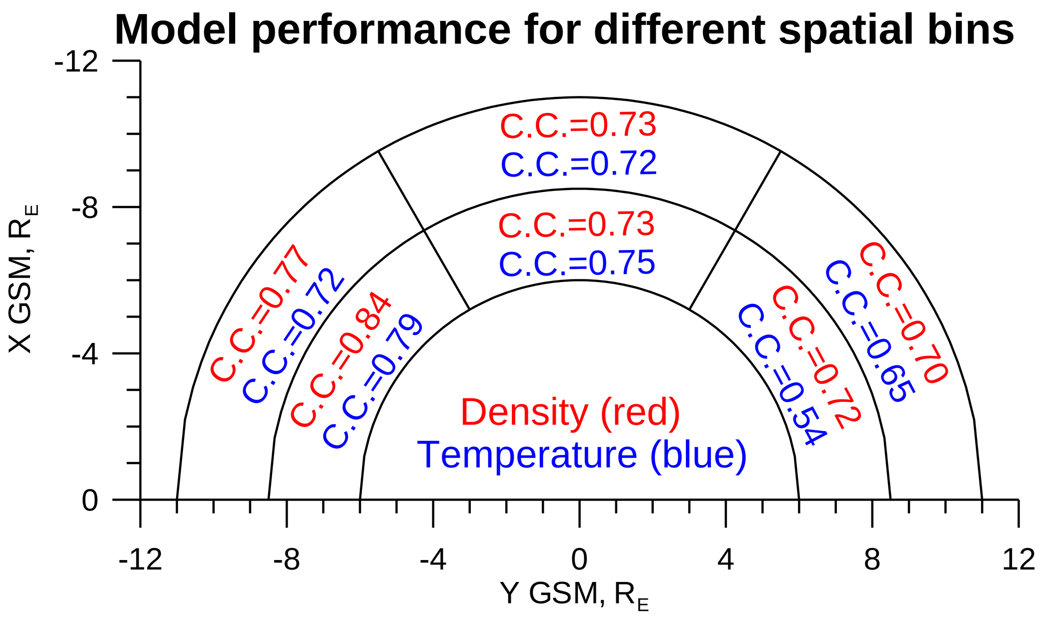
Primary data set:
3 sec resolution, averaged over 1.6 min, ~45,000 data points

Auxiliary data set:
3 sec resolution, transmitted at 1.6 min resolution, ~12,000 data points

Only 26% of the auxiliary data have "neighbors" from primary data set within ±30 min.



Model performance for different spatial bins



Results

- The density distribution is symmetric with respect to the midnight meridian, while electron temperature reveals strong azimuthal asymmetry with a maximum in post-midnight MLT sector.
- The electron density dependence on the external driving is parameterized by the solar wind proton density averaged over 4 h and IMF B_S averaged over 6 h. The solar wind proton density is the main controlling parameter, but the IMF B_S becomes of almost the same importance in the near-Earth region.
- The electron temperature model is parameterized by solar wind velocity (averaged over 4 h), IMF B_S (averaged over 45 min), and IMF B_N (averaged over 2 h). The solar wind velocity is a major controlling parameter, and IMF B_S and B_N are comparable in importance. The effect of B_N manifests mostly in the outer part of the modeled region (r >8 R_E). The influence of the IMF B_S is maximal in the midnight to post-midnight MLT sector.
- Both models show very good performance

Density: C.C.=0.82; RMS = 0.23 cm⁻³
Temperature: C.C.=0.75; RMS = 2.6 keV

For the full model description see *Dubyagin et al.*, JGR, 2016. The model code and subroutines for the input parameters computation are available in supplemental materials of the paper.