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Solar Wind Control of Plasma Sheet Thermal Electrons at r = 6-11Re: Empirical Model

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Solar Wind Control of Plasma Sheet Thermal Electrons at r = 6-11Re: Empirical Model

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Motivation

Multiple simulations of the inner magnetosphere require the boundary condition set between GEO and R ~10 Re [*Chen et al., 1994, Jordanova et al., 1996, Fok et al, 2001, Ebihara et al., 2005, Liemohn et al., 2006, Ganushkina at el., 2005, Wolf et al., 1991, Sazykin 2000, Toffoletto et al., 2003*]

Multiple authors addressed the topic of the plasma parameters dependence on the solar wind conditions [*Terasawa et al., 1997, Borovsky et al., 1998, Wing and Newell 2002, Wang et al., 2006, 2007, 2010*]. One the other hand, there are few analytical equations which could be used as a boundary conditions [*Tsyganenko and Mukai 2003, Sergeev et al., 2015]*

We present the empirical model of the electron density and temperature in the near-Earth plasma sheet. The work is done using THEMIS plasma and magnetic field measurements

Data: THEMIS A, D, E probes

Plasma measurements:

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

SST > 25 keV - 300 keV

SST low energy limit increases with mission lifetime

Plasma moments are computed from
combined distribution functions E = 30 eV - 300 keV (ESA + SST)
ESA - SST Energy gap is interpolated

Magnetic field measurements:

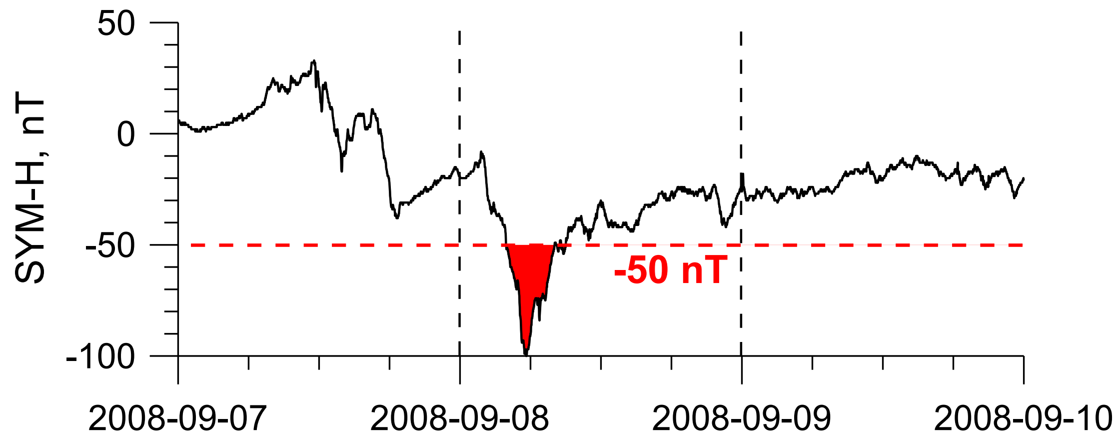
Flux Gate Magnetometer

Solar wind plasma parameters and IMF:

OMNI database, 1-min res.

Activity selection

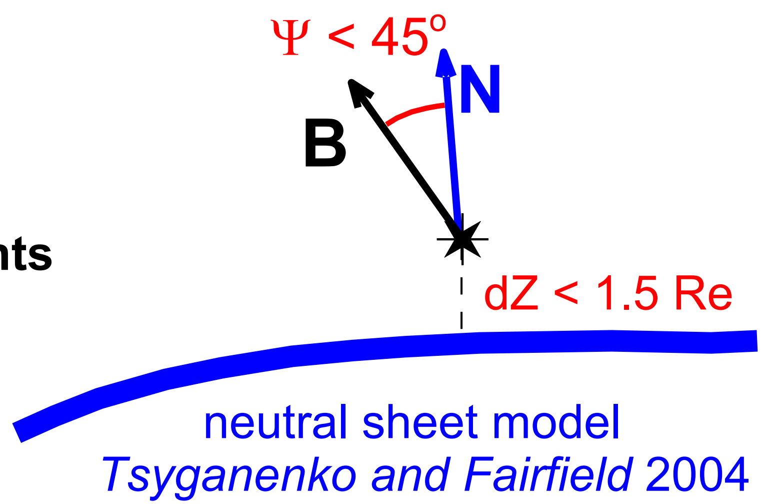
Storm-time intervals 2007-2013



Spatial selection

- **R = 6-11 Re, nightside**
- **The near-neutral sheet measurements**

Caution! This criterion tends to select thick current sheet events!



Depending on detectors modes the data are available:

~1.6 min resolution (accumulated during one spin period, 3 sec) **Auxiliary data set**

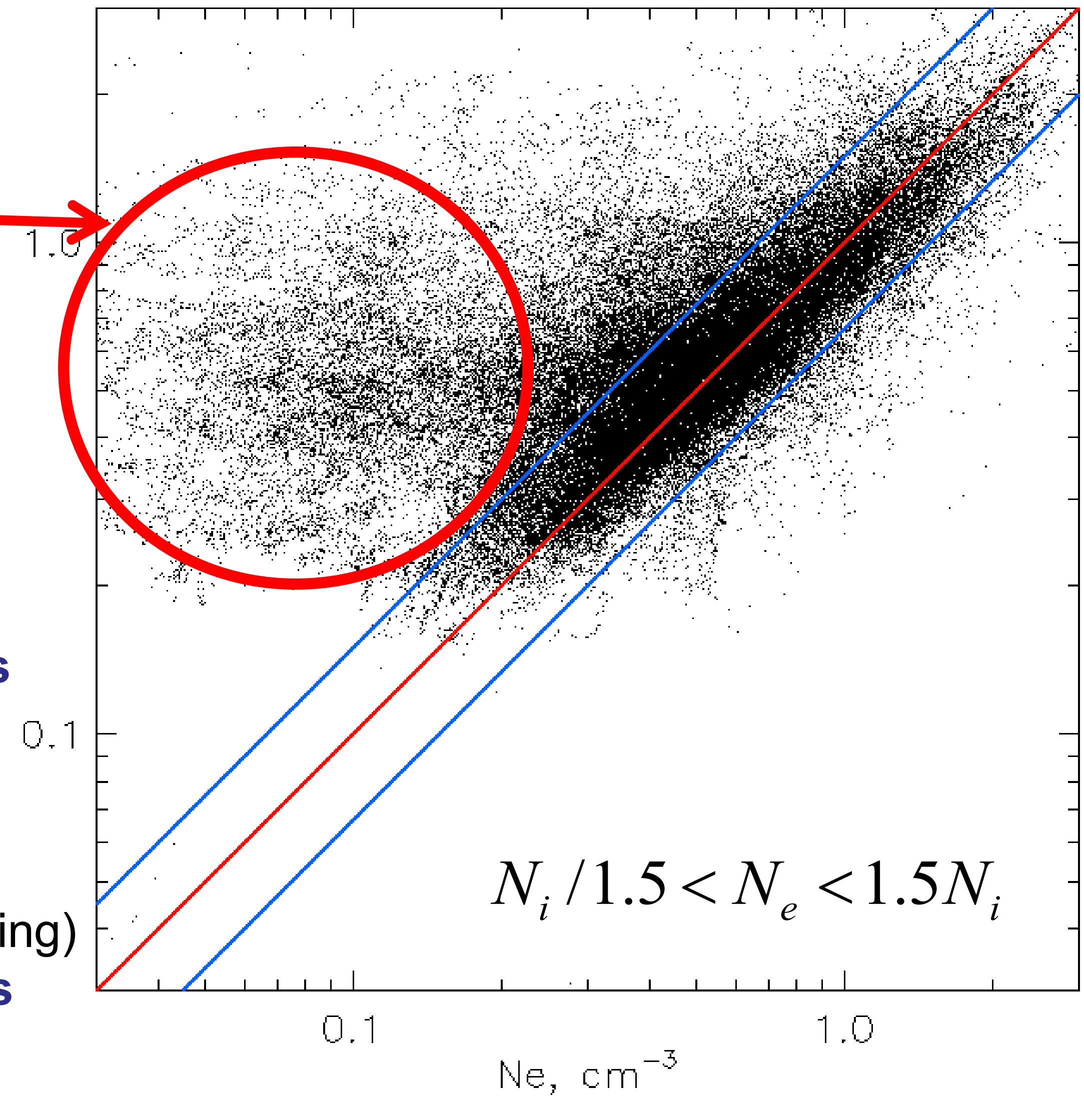
Spin resolution (3 sec), averaged over 1.6 min ; **Primary data set:**

Ni=Ne test

Primary data set
~63,000 records (1.6 min)
After removal of bad points
~45,000 **1264 1h intervals**

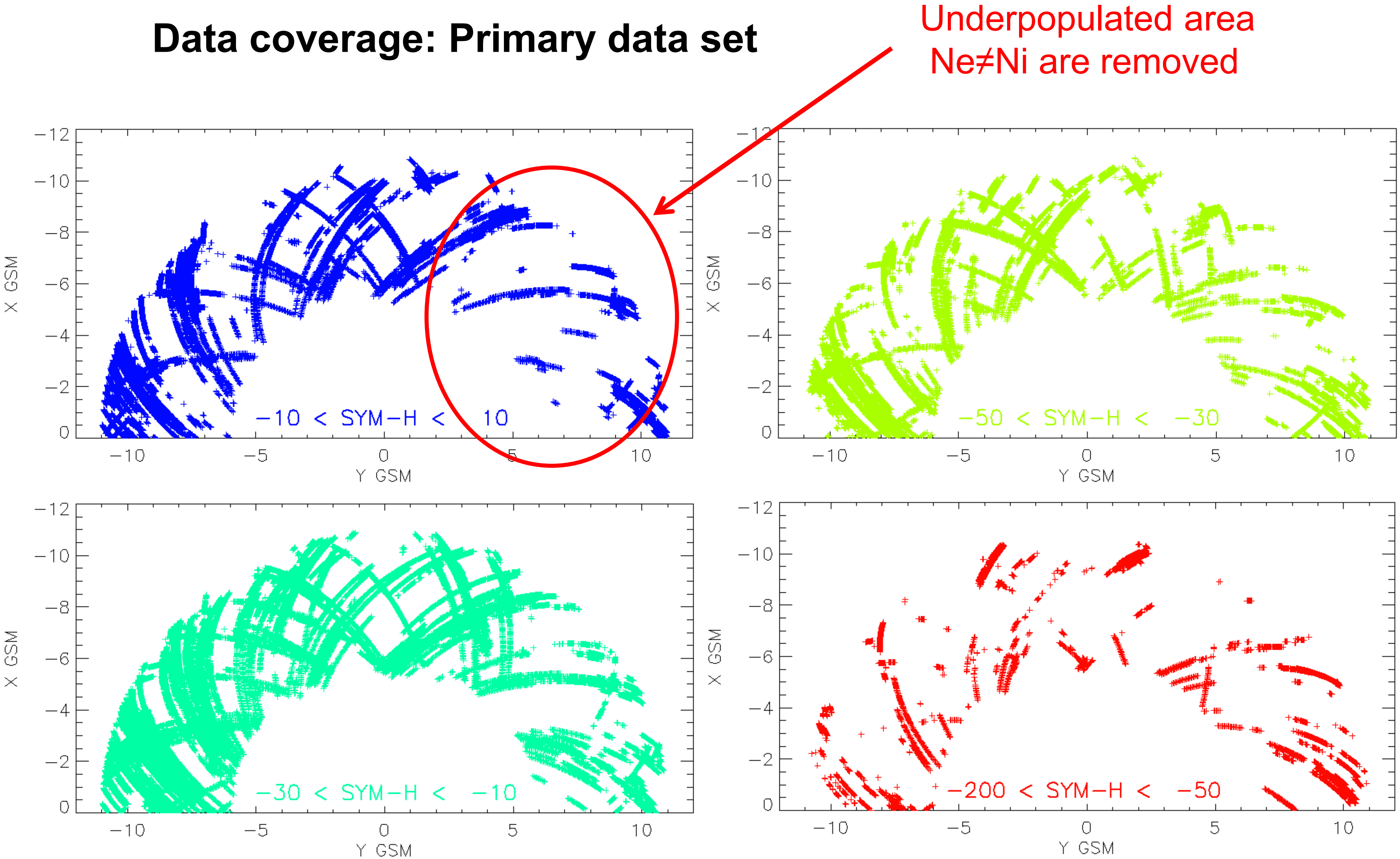
~1/3 of data was excluded!

Auxiliary data set (after cleaning)
~12,000 **1371 1h intervals**



years	2007	2008	2009	2010	2011	2012	2013
# Primary	0	0	0	7,475	11,347	12,693	13,486
# Auxiliary	1,992	583	38	1,688	2,033	2,520	3,317

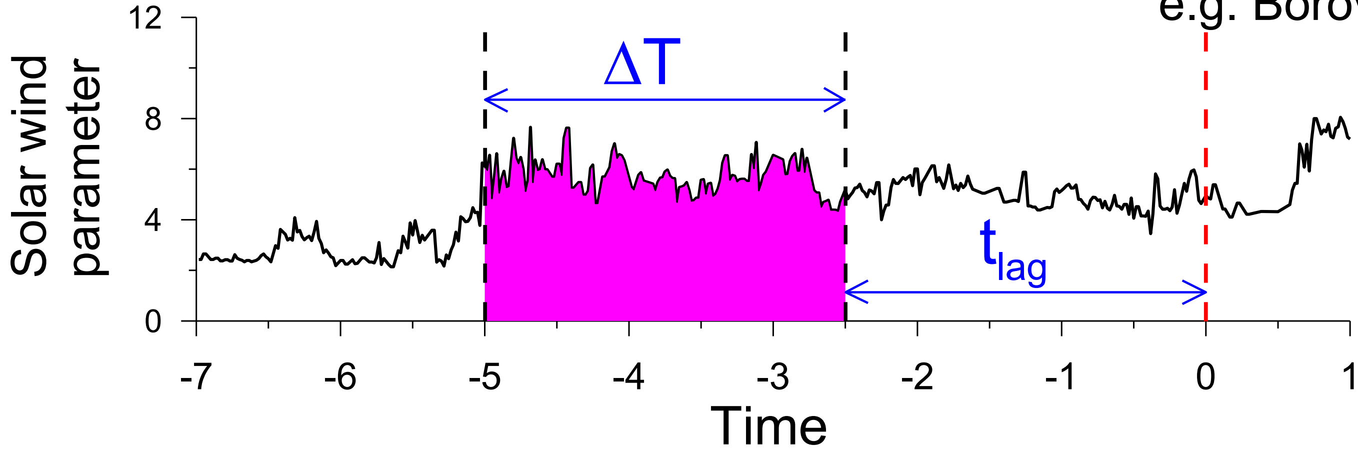
Data coverage: Primary data set



Parameterization of Te, Ne dependence on solar wind parameters

Plasma sheet can respond to the solar wind changes with a delay of few hours

e.g. Borovsky et al., 1998



Density model

(1) N_{SW}, solar wind proton density

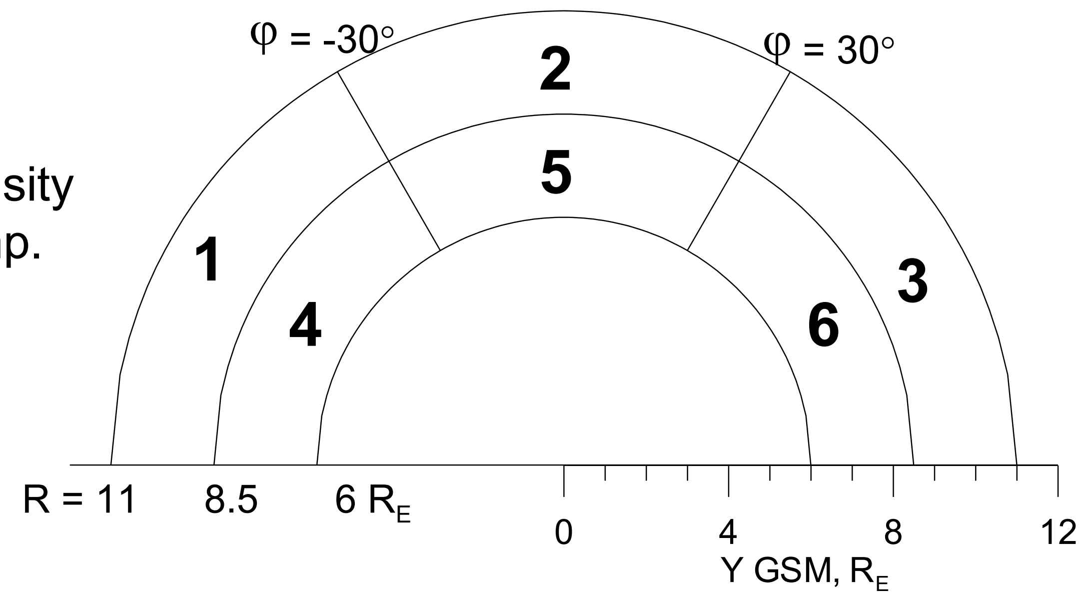
(2) IMF B_S, IMF southward comp.

Temperature model

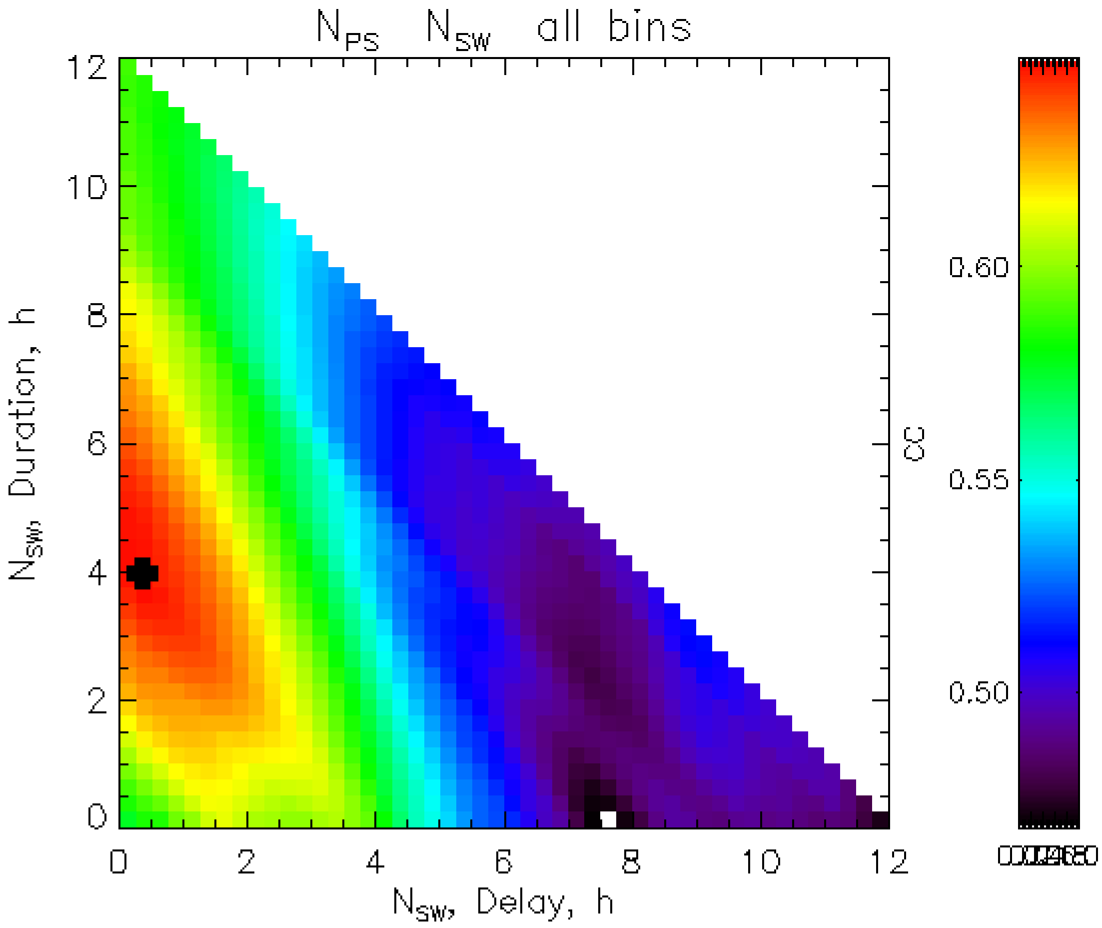
(1) V_{SW}, solar wind velocity

(2) IMF B_S, IMF southward comp.

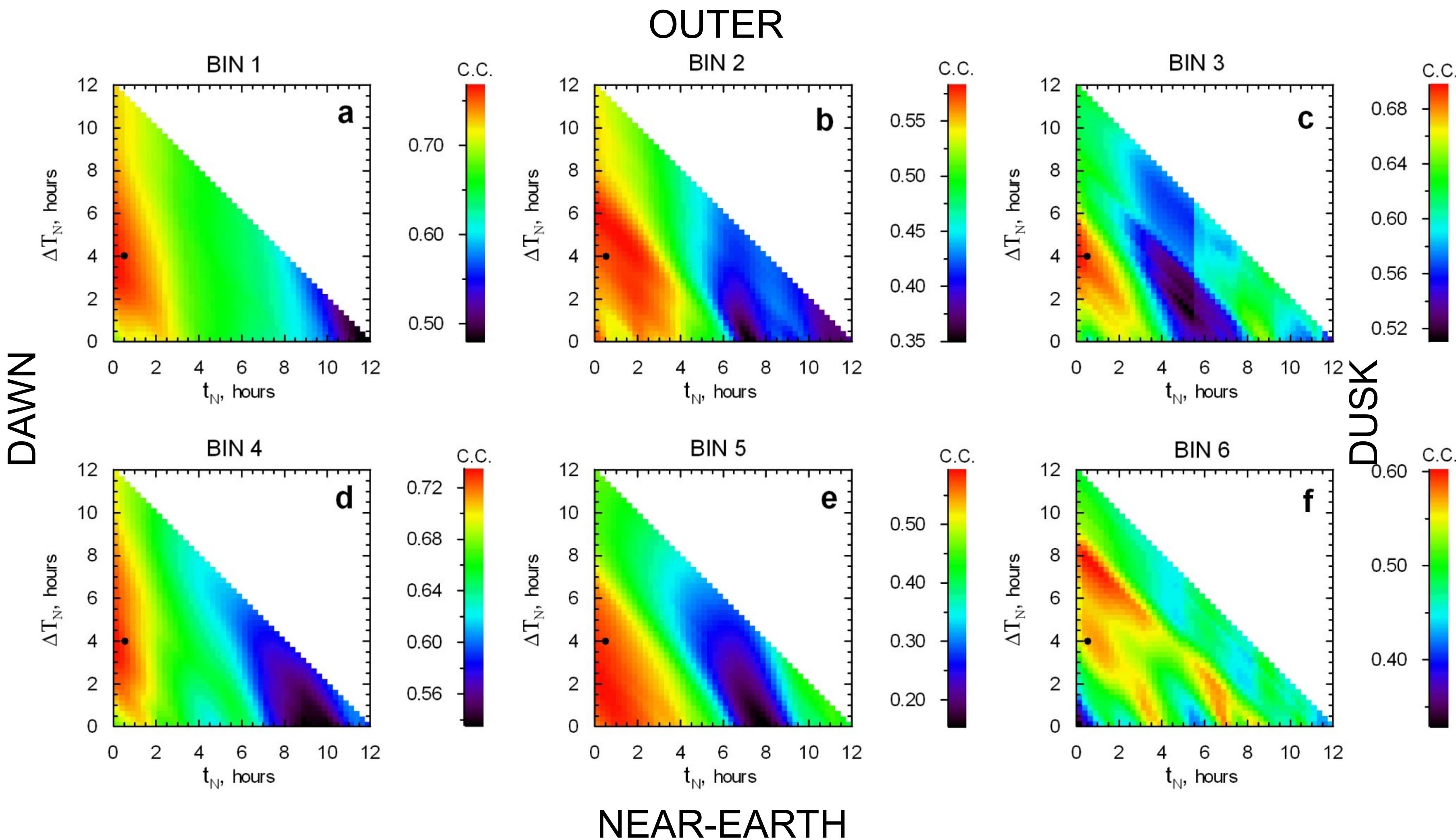
(3) IMF B_N, IMF northward comp.



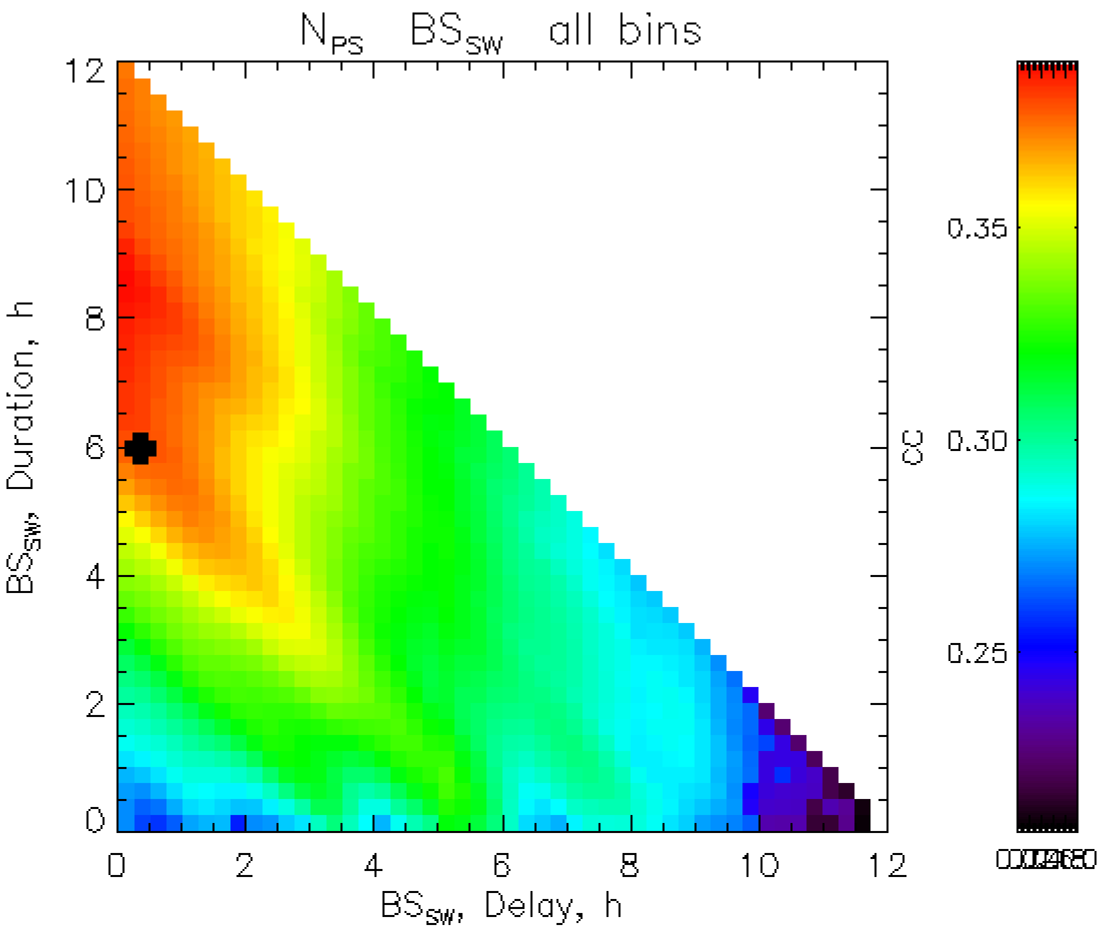
Correlation between plasma sheet **density** and **solar wind proton density**



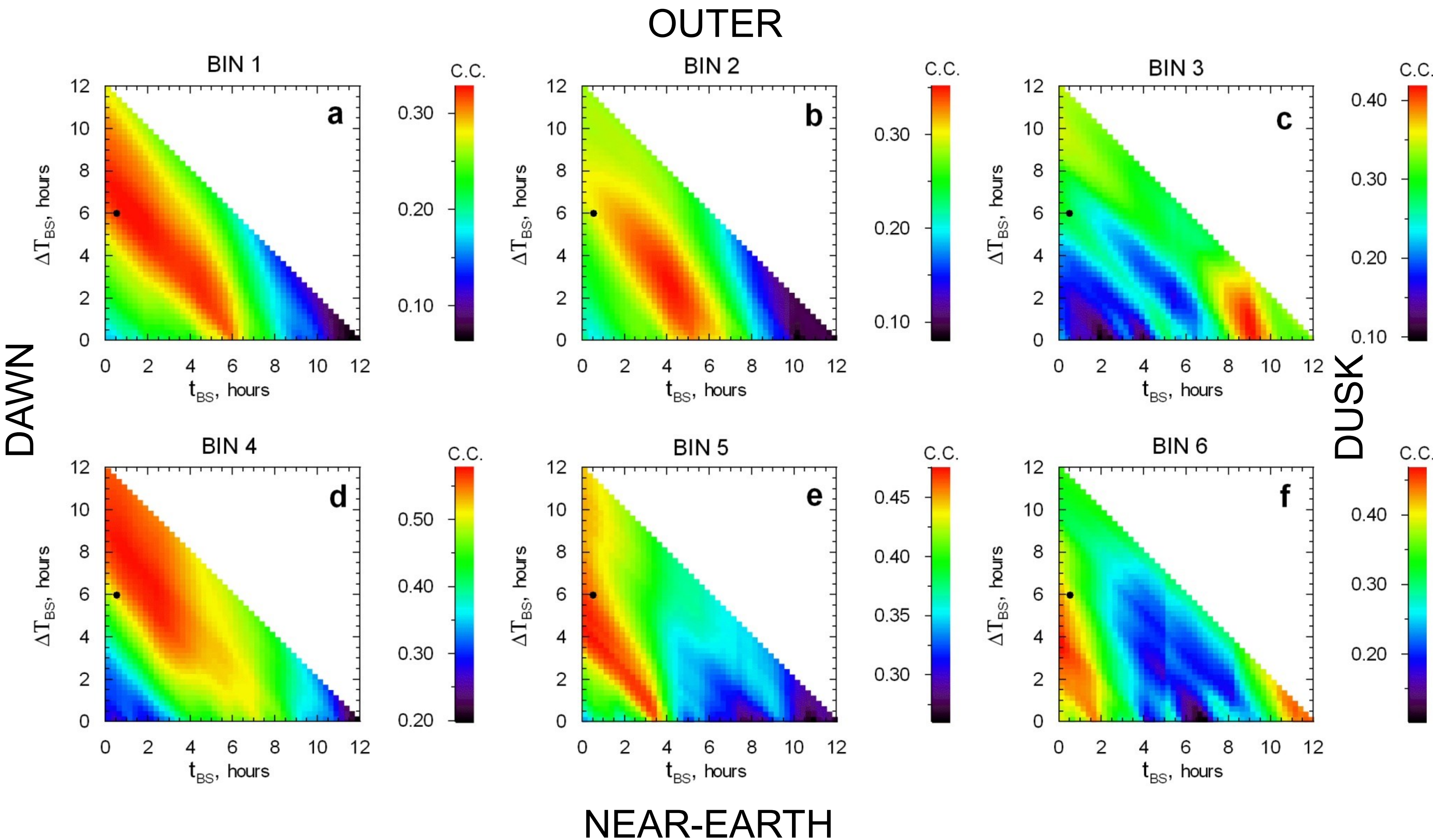
Correlation between plasma sheet **density** and **solar wind proton density**



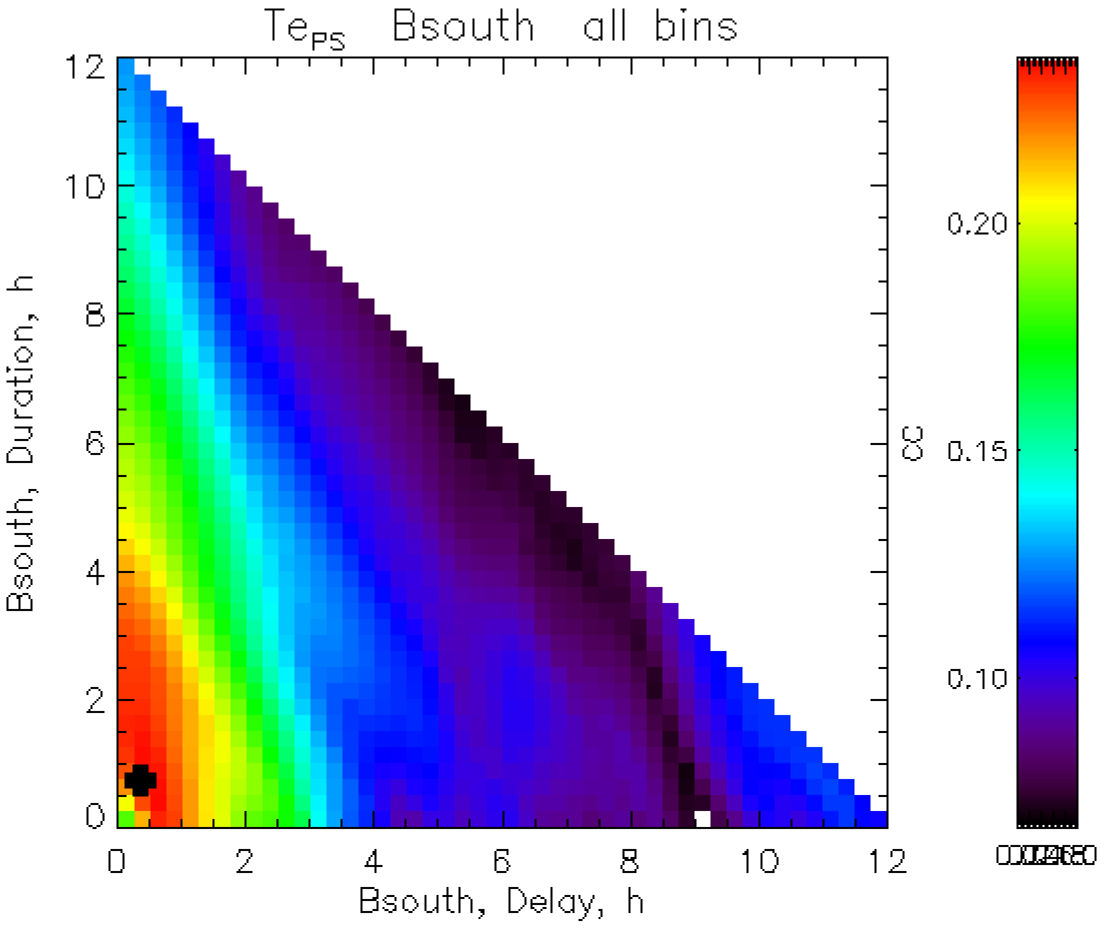
Correlation between plasma sheet **density** and **IMF southward component**



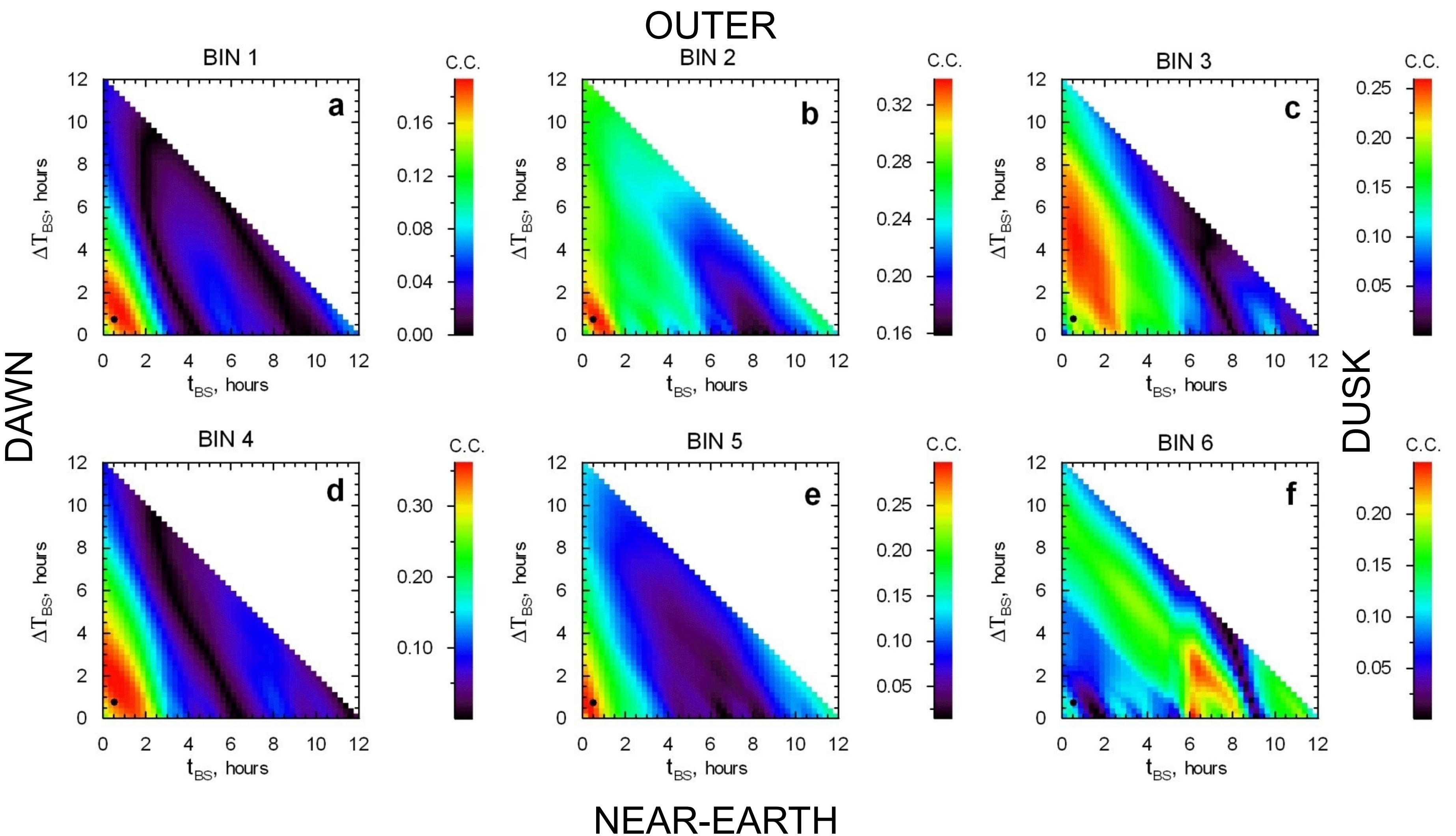
Correlation between plasma sheet **density** and **IMF southward component**



Correlation between plasma sheet **electron temperature** and **IMF southward component**



Correlation between plasma sheet **electron temperature** and **IMF southward component**



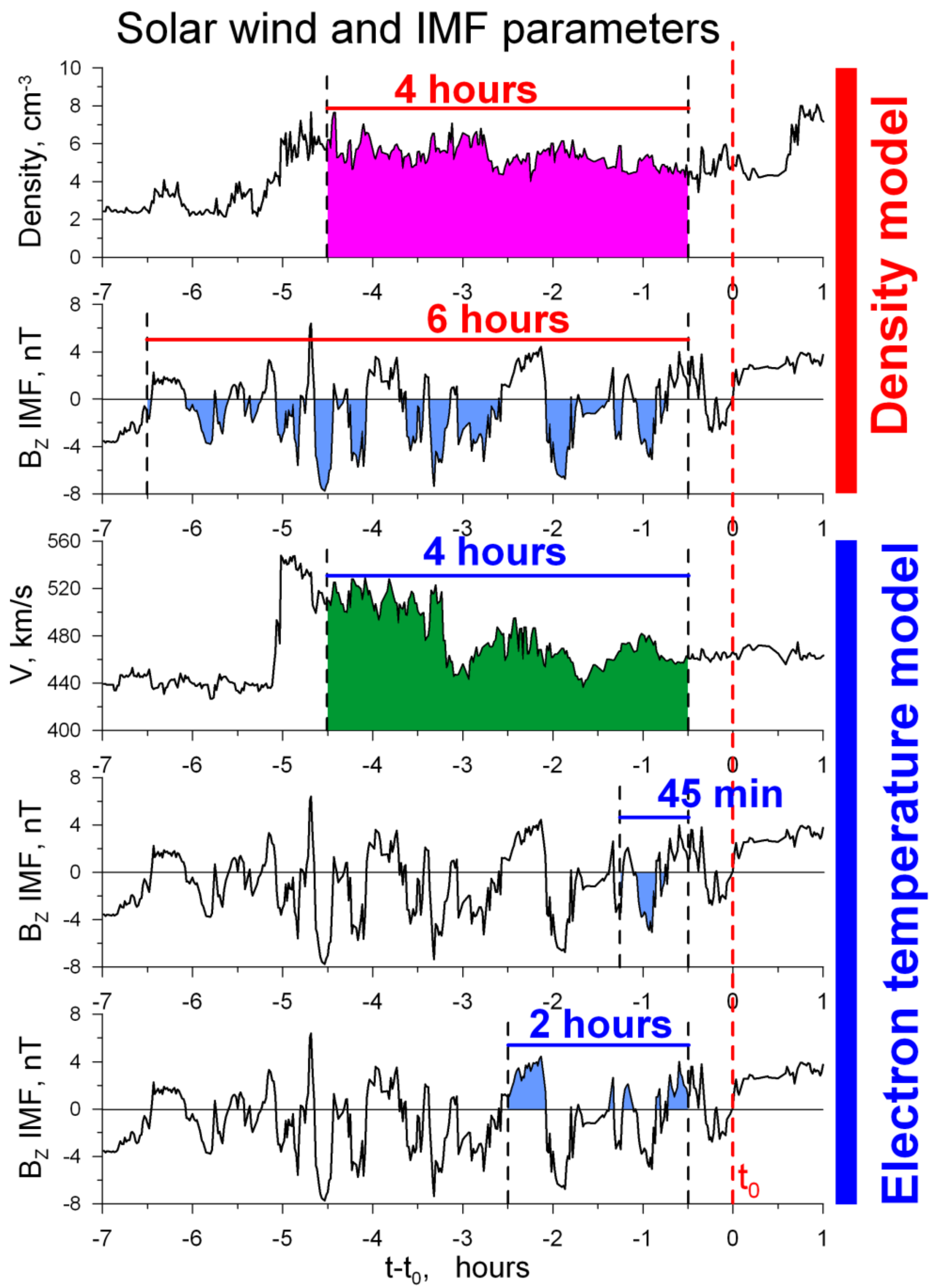
C.C.= 0.64

C.C.= 0.38

C.C.= 0.51

C.C.= 0.24

C.C.= 0.33



Analytical models:

$$P^{PS} = G_0(r,\phi) + \sum_j G_j(r,\phi) \cdot P_j^{SW}$$

$$G(r,\phi) = c_1 + c_2 r + c_3 \phi + c_4 \phi^2 + c_5 r\phi + c_6 r\phi^2$$

18 coefficients for N_e model, 24 coefficients for T_e model

Correlation coefficients between the data and model predictions

Density model: **0.83**

Temperature model: **0.73** **Reference coefficients**

Simplification

We seek for a minimal set of terms which still provide good model quality

After this set is found, we introduce non-linear dependence

Resulting correlation coefficients are:

Density model: **0.82** 7 coefficients

Temperature model: **0.75** 9 coefficients

Final model equations

Electron density model: 7 coefficients

$$N_e = 1.23 - 1.01 \cdot r + 0.874 \cdot r\phi^2 - 0.82 \cdot \phi^2$$

positive → $$+0.392 \cdot N_{SW}$$

positive → $$+(0.521 - 0.474 \cdot r) \cdot B_S$$

Electron temperature model: 9 coefficients

$$T_e = [-0.0215 - 0.426 \cdot \phi$$

positive → $$+0.874 \cdot V_{SW}$$

positive → $$+(0.587 - 0.538 \cdot r\phi^2) \cdot B_S^{0.32}$$

negative → $$-0.489 \cdot r \cdot B_N^{0.36}]^{2.31}$$

$$r = R / 10\,\mathrm{Re}$$

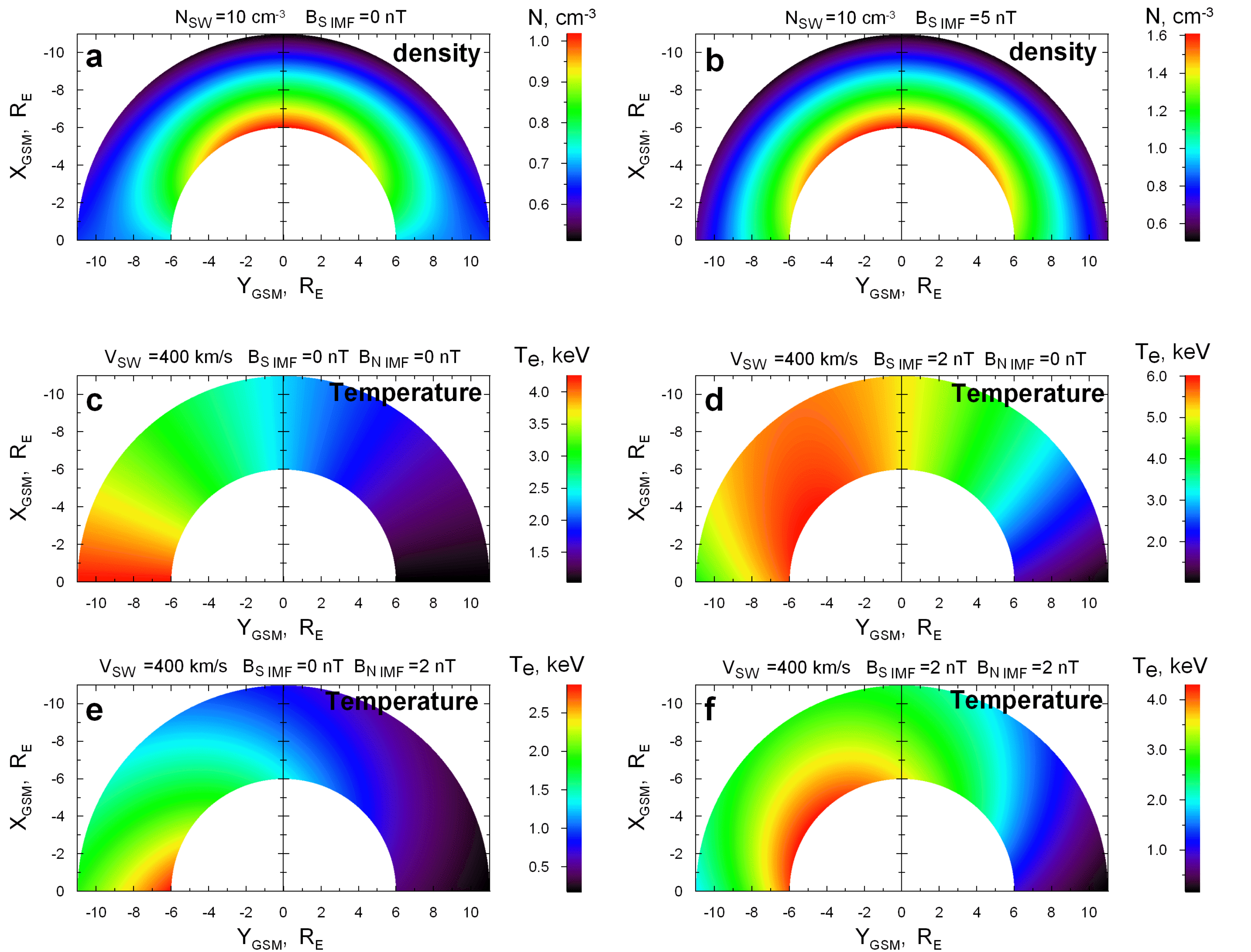
$$\phi = \arctan(-Y / X) / 90°$$

$$N_{SW} = \langle N_{SW} \rangle / 10cm^{-3}$$

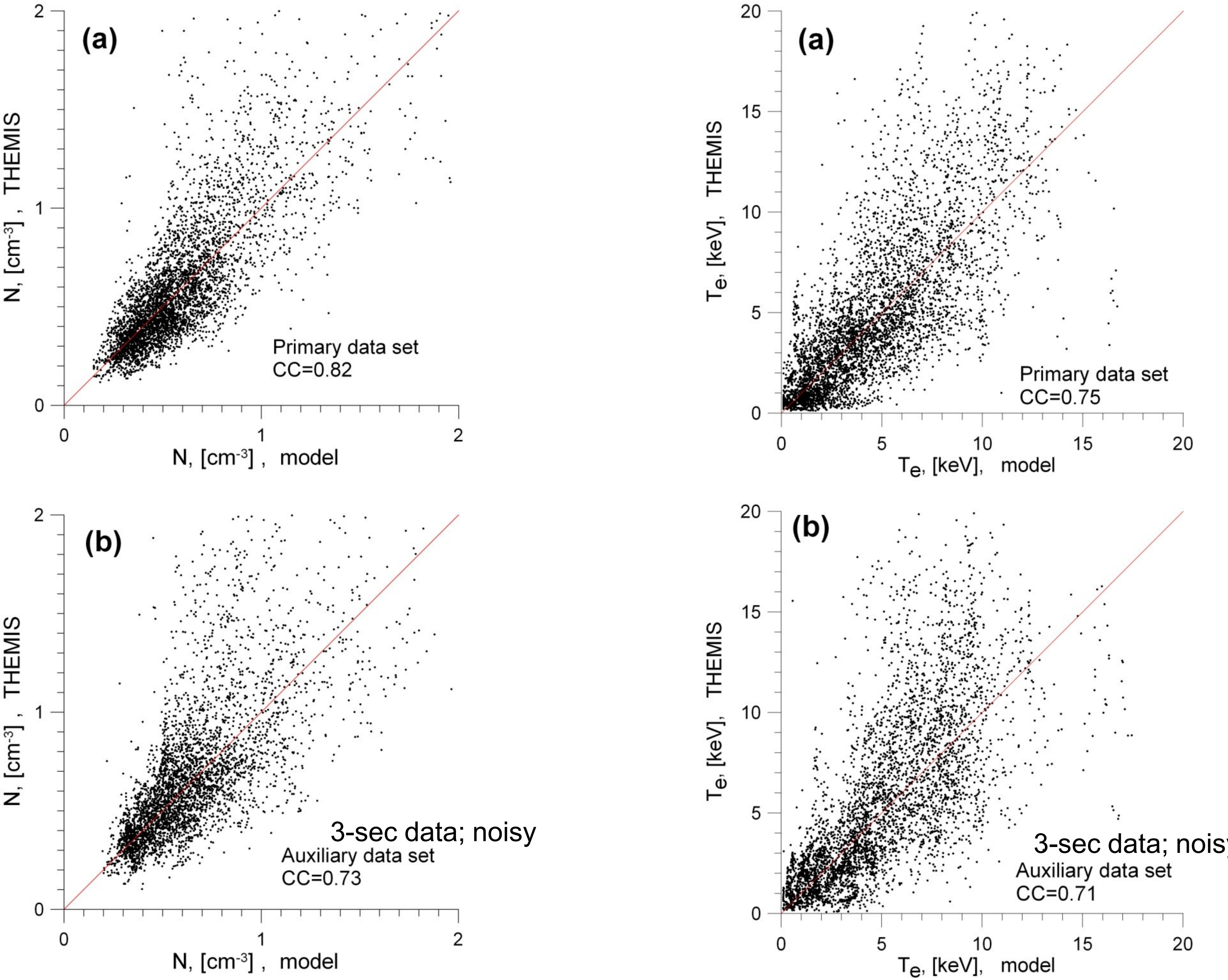
$$V_{SW} = \langle V_{SW} \rangle / 400km/s$$

$$B_S = \langle B_S^{IMF} \rangle / 2nT$$

$$B_N = \langle B_N^{IMF} \rangle / 2nT$$



a
N_{SW} =10 cm^{-3} $B_{S\,IMF}$ =0 nT
density
N, cm^{-3}
b
N_{SW} =10 cm^{-3} $B_{S\,IMF}$ =5 nT
density
N, cm^{-3}
c
V_{SW} =400 km/s $B_{S\,IMF}$ =0 nT $B_{N\,IMF}$ =0 nT
Temperature
T_e, keV
d
V_{SW} =400 km/s $B_{S\,IMF}$ =2 nT $B_{N\,IMF}$ =0 nT
Temperature
T_e, keV
e
V_{SW} =400 km/s $B_{S\,IMF}$ =0 nT $B_{N\,IMF}$ =2 nT
Temperature
T_e, keV
f
V_{SW} =400 km/s $B_{S\,IMF}$ =2 nT $B_{N\,IMF}$ =2 nT
Temperature
T_e, keV
X_{GSM}, R_E
Y_{GSM}, R_E


(a)
N, [cm-3] , THEMIS
N, [cm-3] , model
Primary data set
CC=0.82
(a)
Te, [keV], THEMIS
Te, [keV], model
Primary data set
CC=0.75
(b)
N, [cm-3] , THEMIS
N, [cm-3] , model
3-sec data; noisy
Auxiliary data set
CC=0.73
(b)
Te, [keV], THEMIS
Te, [keV], model
3-sec data; noisy
Auxiliary data set
CC=0.71

Conclusions

- The empirical models of the plasma sheet T_e and N_e at r=6-11Re have been constructed.

- The models are based on ~ 400 hours of THEMIS measurements during geomagnetic storms

- For given location in the equatorial plane, the models output the plasma sheet T_e and N_e as a function of time-integrated solar wind and IMF parameters.

- The 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 model description see *Dubyagin et al.*, JGR, 2016
The model codes and subroutines for the input parameter computation are given in supplemental materials.