MODELING THE MAGNETOSPHERE USING RADIAL BASIS FUNCTIONS

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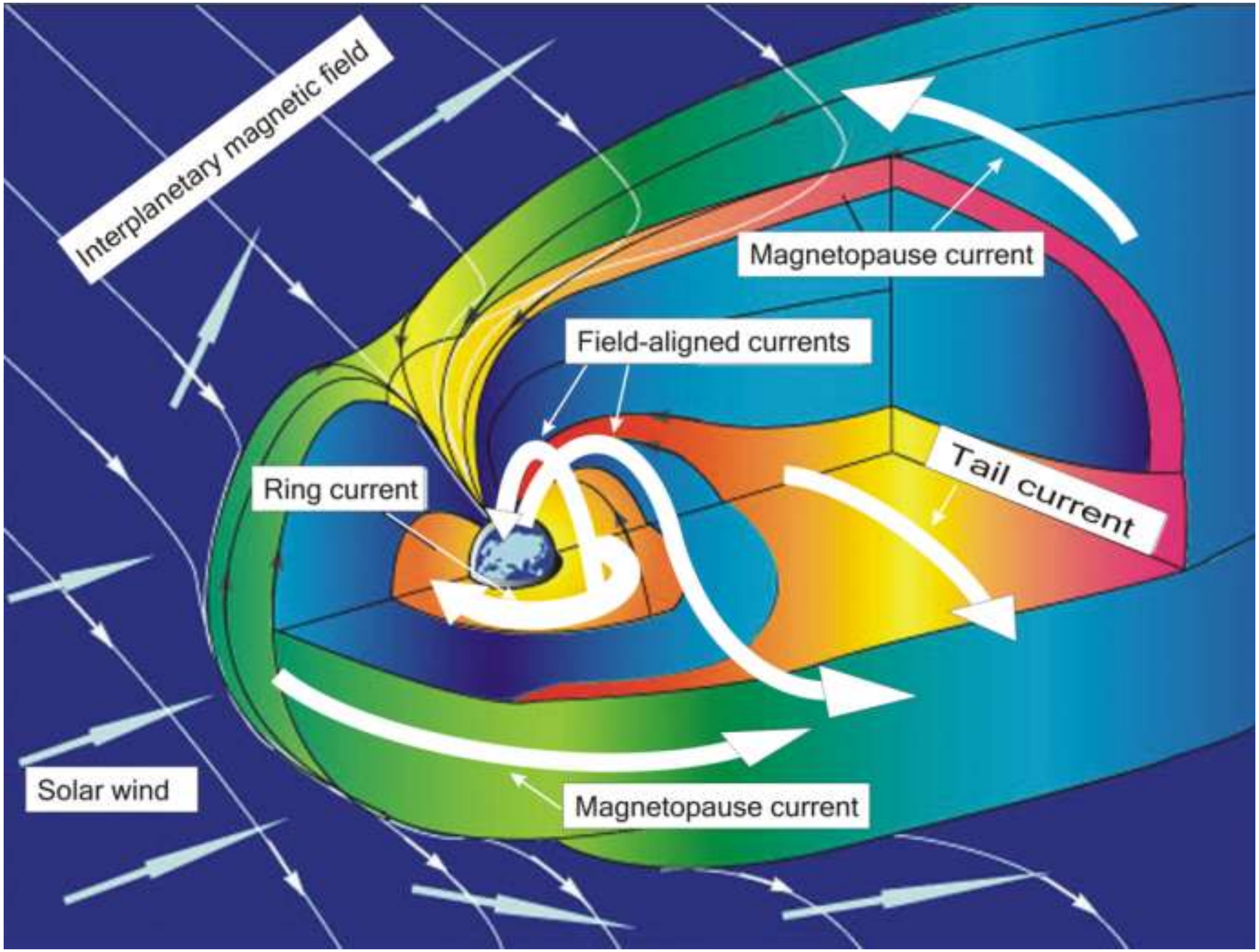
October 17-16 2016, Thailand

Introduction



Earth's magnetosphere

Introduction

Traditional empirical models:

- **Lack of spacecraft data => a few "custom-made" modules representing the principal field sources**

- **Tsyganenko and Sitnov [2007]: 2D Fourier expansion of equatorial currents**

Goal of this work:

Develop a completely new modeling method,
free of any *ad hoc* assumptions on the field source geometry

Method description

- Represent the magnetic field as the sum of toroidal and poloidal components:

$$\mathrm{B}(\mathbf{r}) = \nabla\Psi_1 \times \mathbf{r} + \nabla \times (\nabla\Psi_2 \times \mathbf{r})$$

Ψ_1, Ψ_2 – scalar generating functions

- Radial Basis Function (RBF) expansions:

$$\Psi_{1,2}(\mathbf{r}) = \sum_{i=1}^{N} a_{i_{1,2}} \chi_i(|\mathbf{r} - \mathbf{R_i}|)$$

where $\chi_i = \sqrt{|\mathbf{r} - \mathbf{R_i}|^2 + D^2}$ – radial basis functions (RBF)

$\mathrm{R_i}$ – set of RBF nodes covering the modeling domain

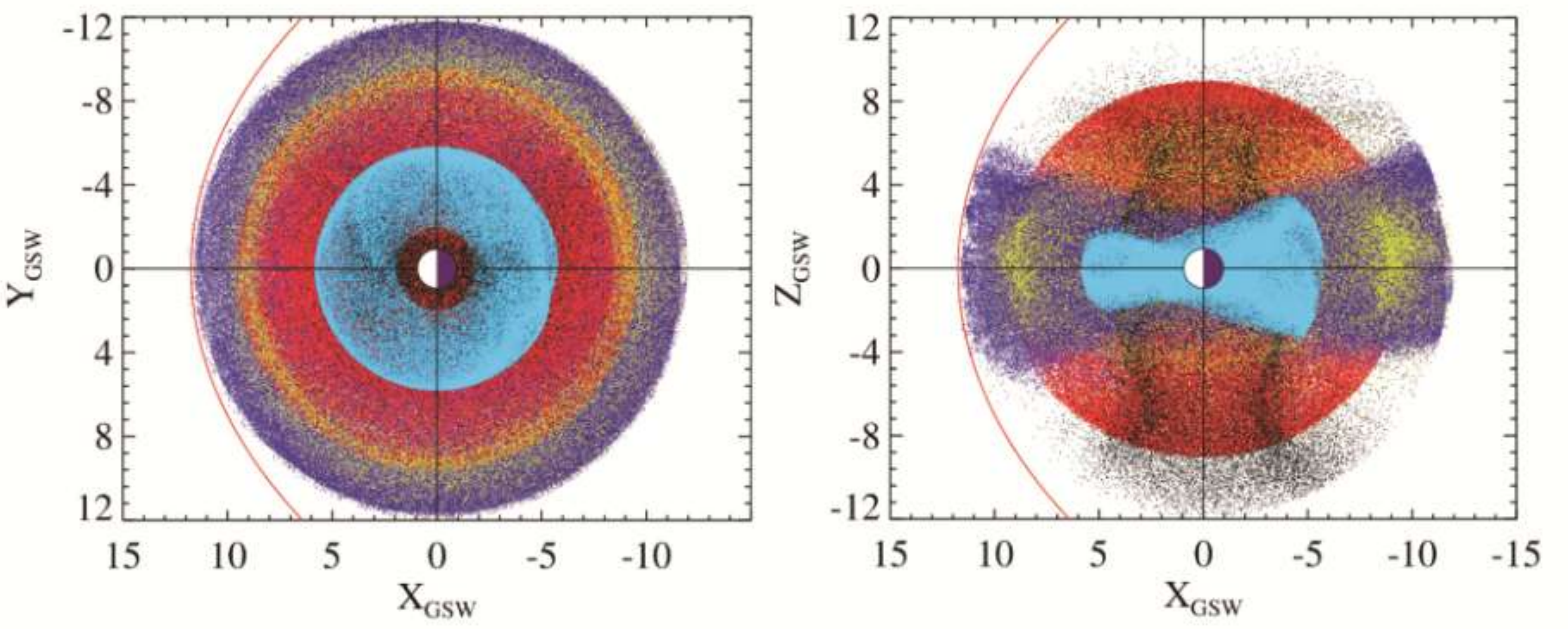
Method description

Advantages of the approach:

- **Possibility to reconstruct the magnetic field in any specific region with a desired resolution**
- **Minimum of a priori assumptions about field sources geometry => maximum new information from data**

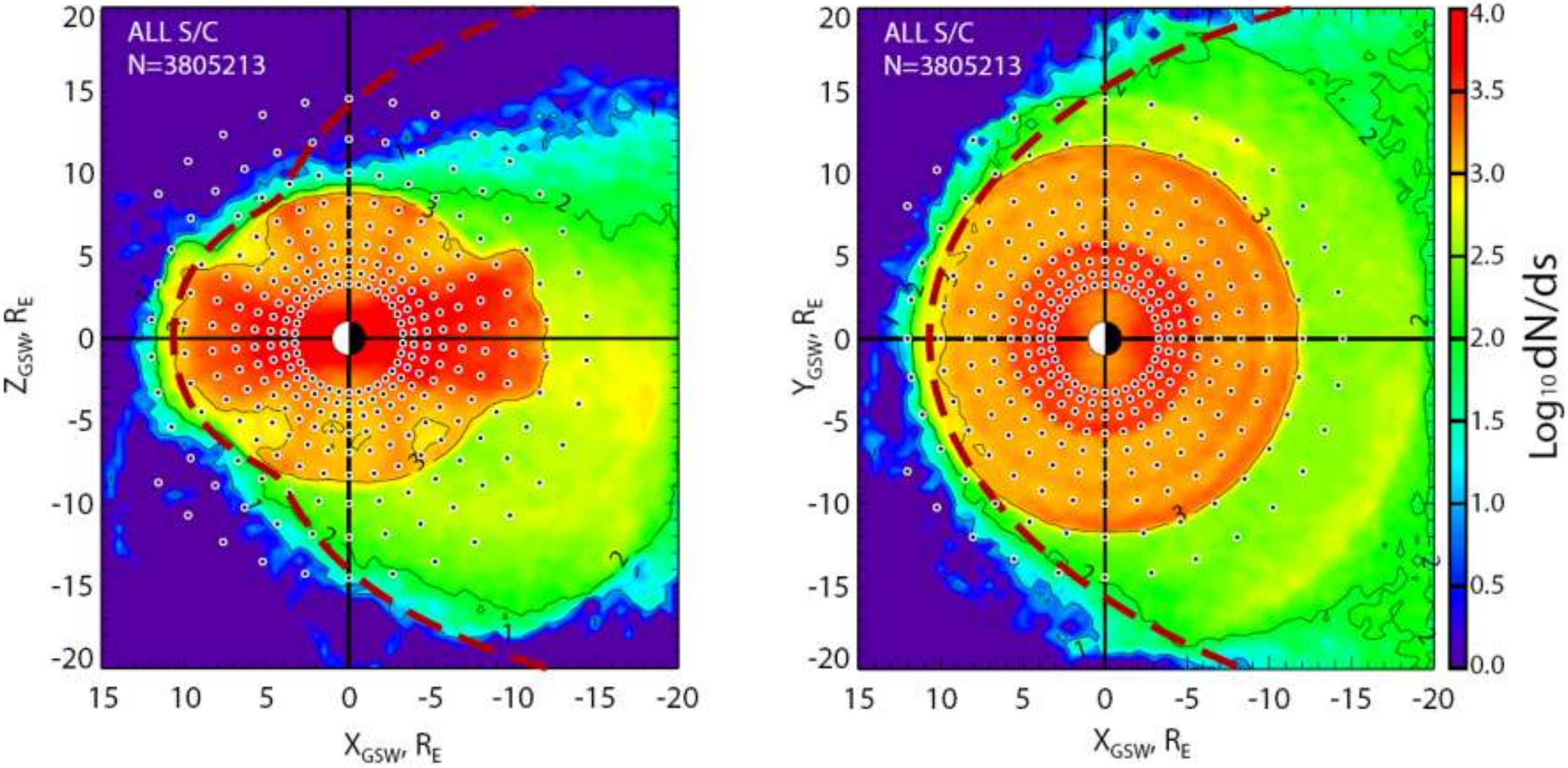
Data

- **Geotail, Polar, Cluster, THEMIS, Van Allen Space Probes (RBSP), OMNI (1995-2015)**



Equatorial (left) and meridional (right) projections of spacecraft data distribution

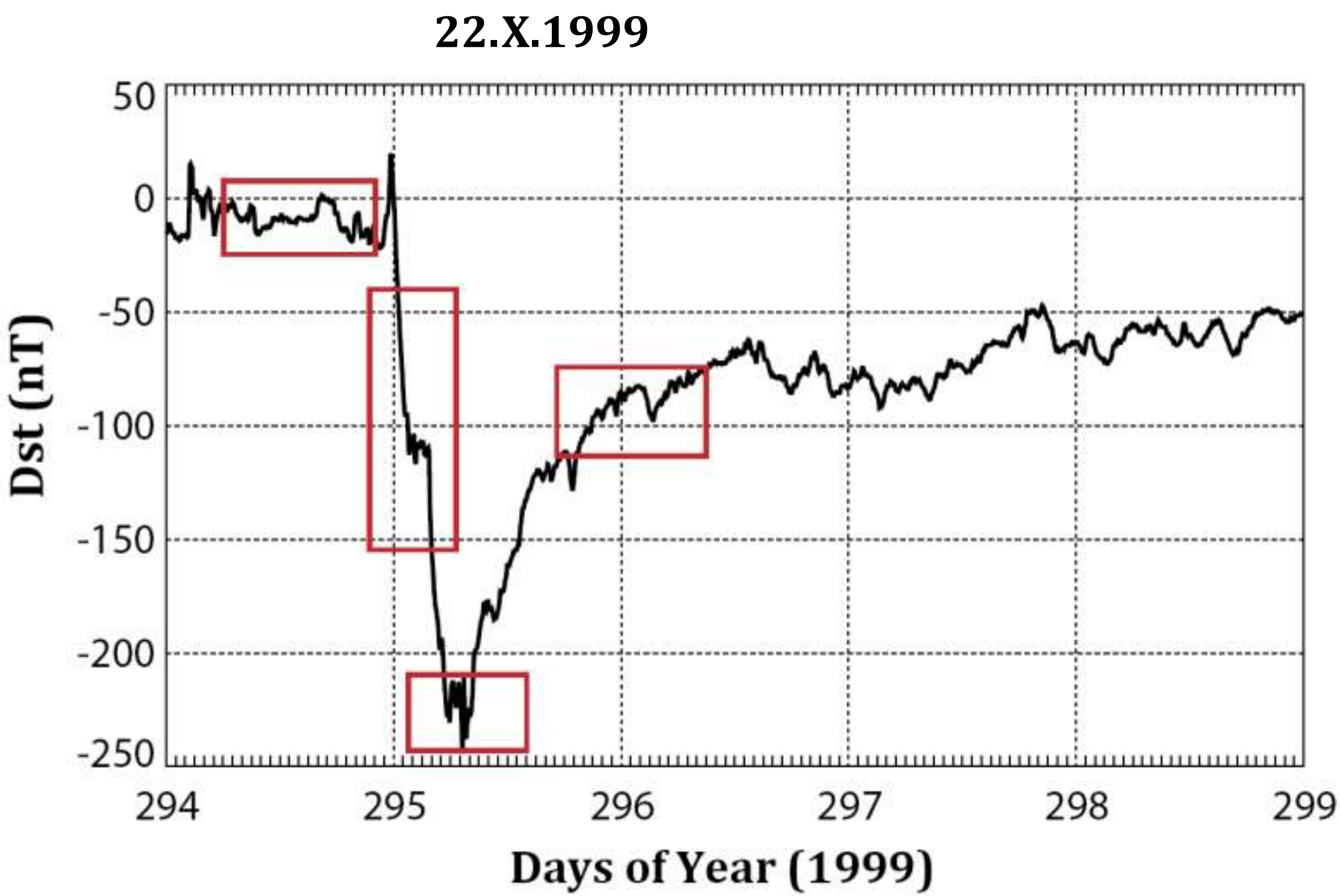
Data and placement scheme



Data coverage in projection on GSW meridian (left) and equatorial (right) planes;
distribution of RBF nodes lying in corresponding planes.

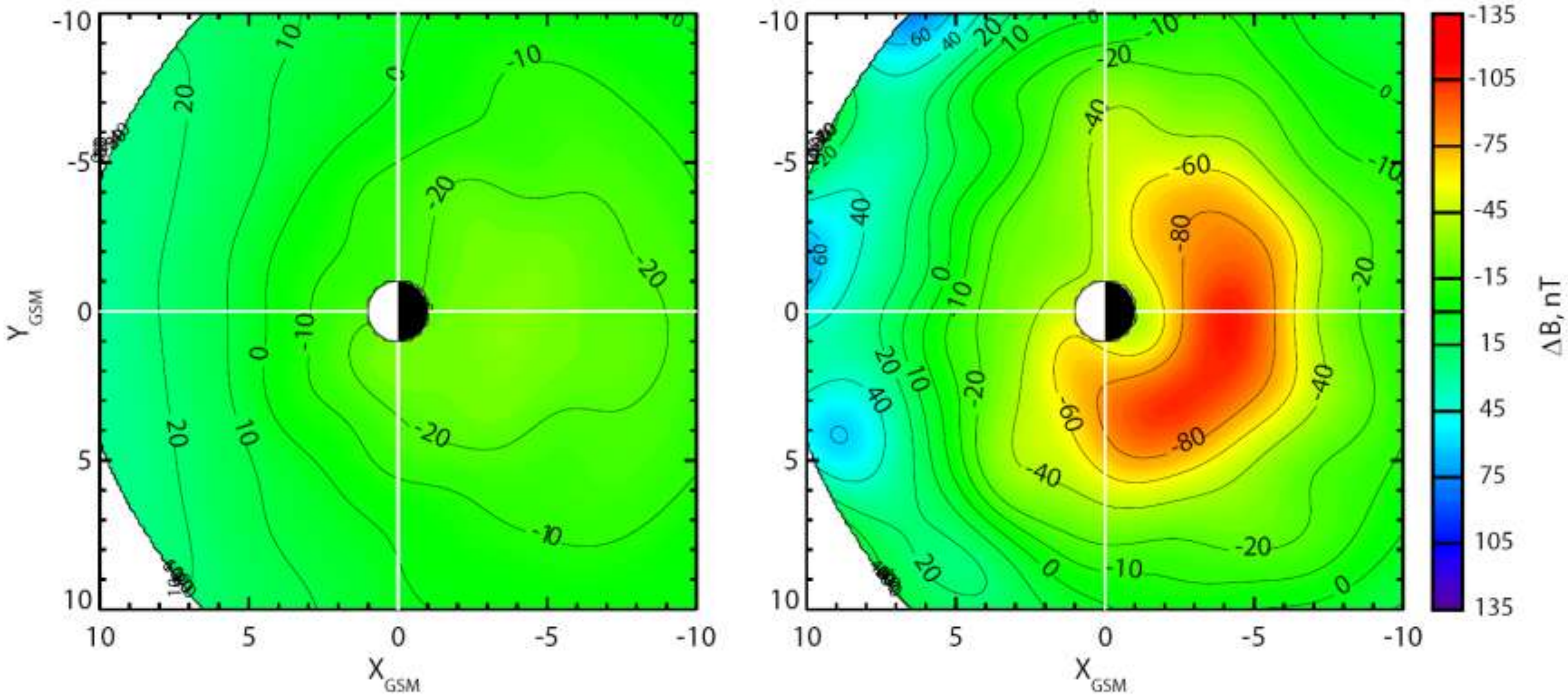
Data: first experiment with RBF

- **Subsets for four different phases of a geomagnetic storm**



Results: distribution of $\Delta B = |\mathbf{B}_{\mathrm{total}}| - |\mathbf{B}_{\mathrm{dipole}}|$

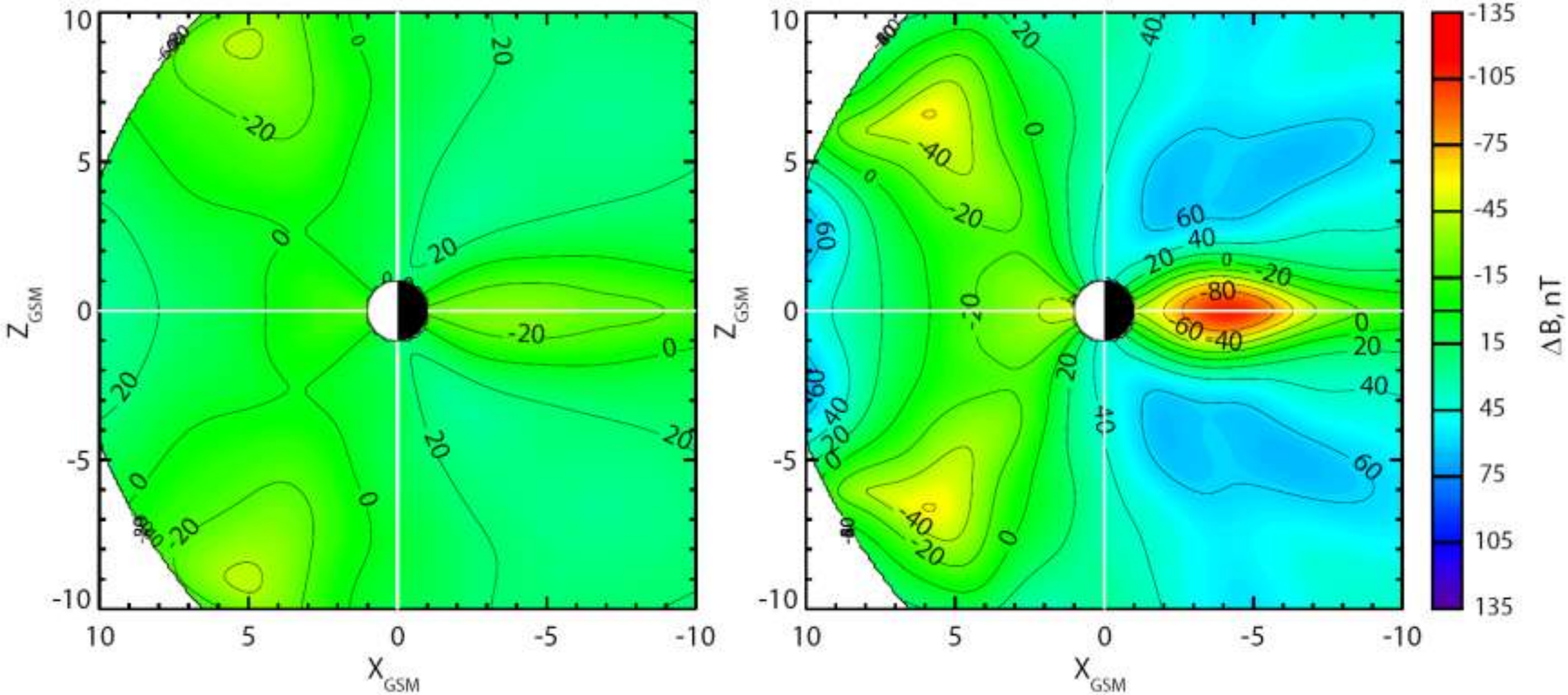
Quite-time conditions **Storm deepening**



Equatorial projection

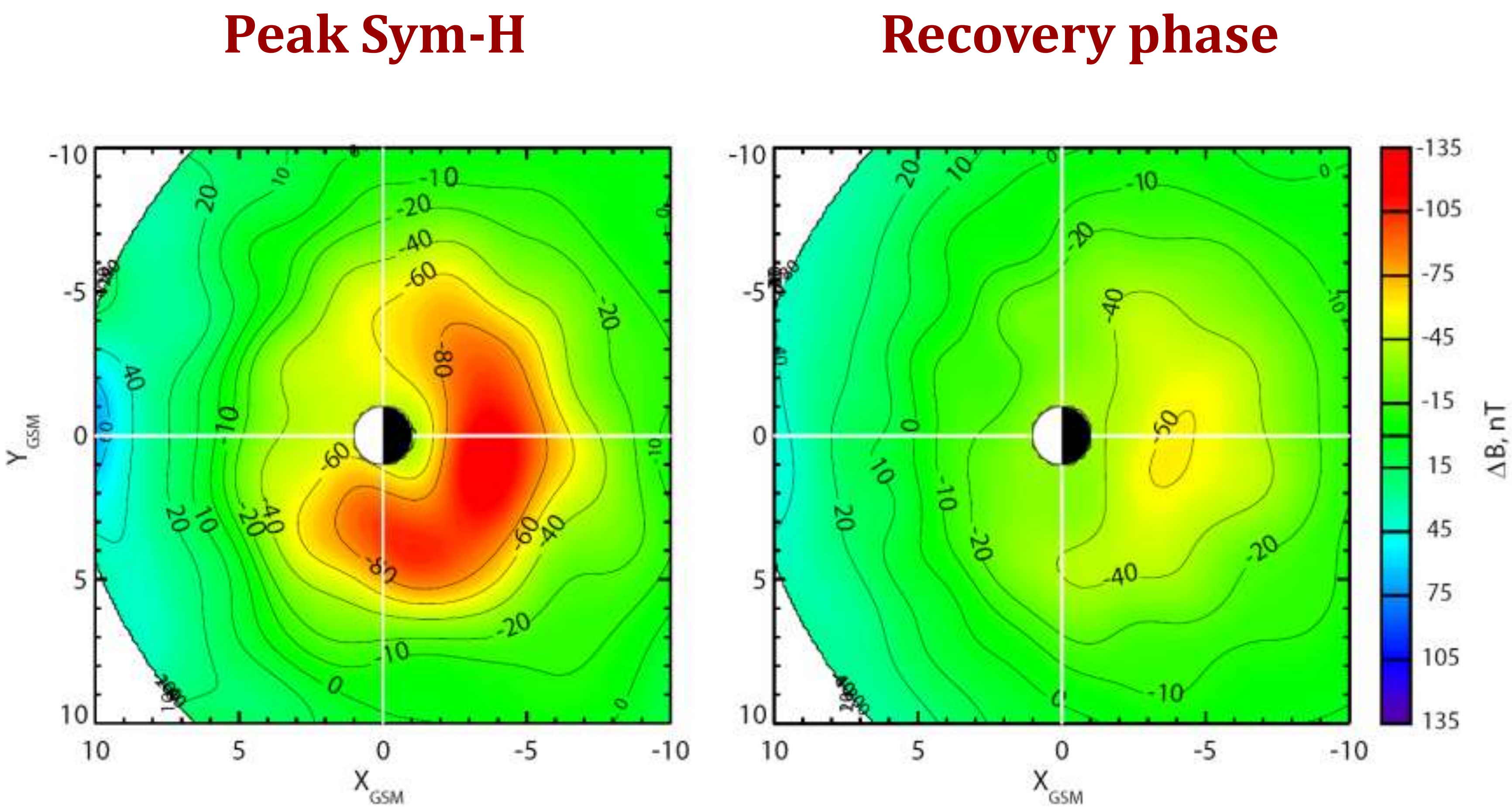
Results: distribution of $\Delta B = |\mathbf{B}_{\text{total}}| - |\mathbf{B}_{\text{dipole}}|$

Quite-time conditions | **Storm deepening**



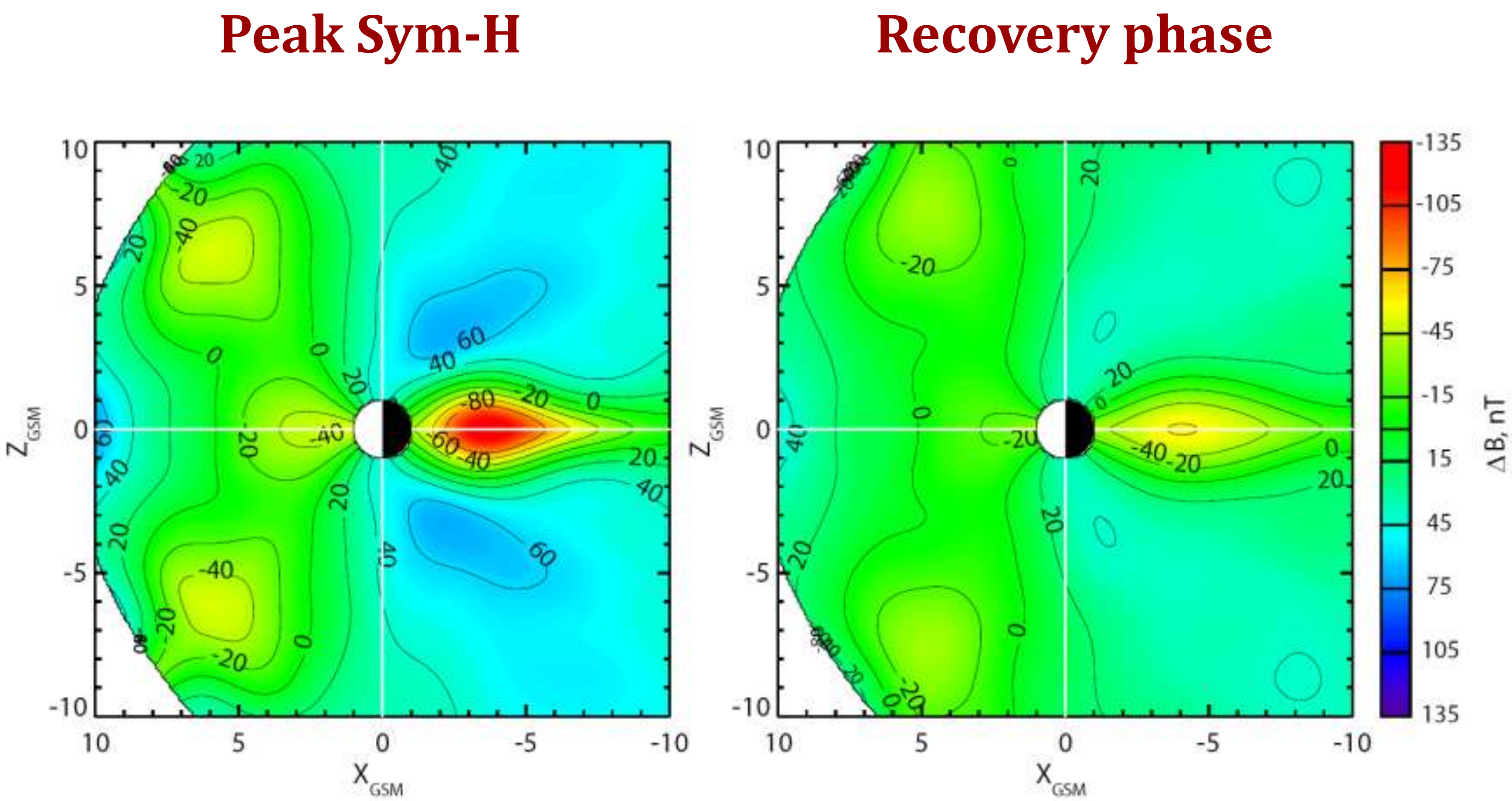
Meridional projection

Results: distribution of $\Delta B = |\mathbf{B}_{\text{total}}| - |\mathbf{B}_{\text{dipole}}|$



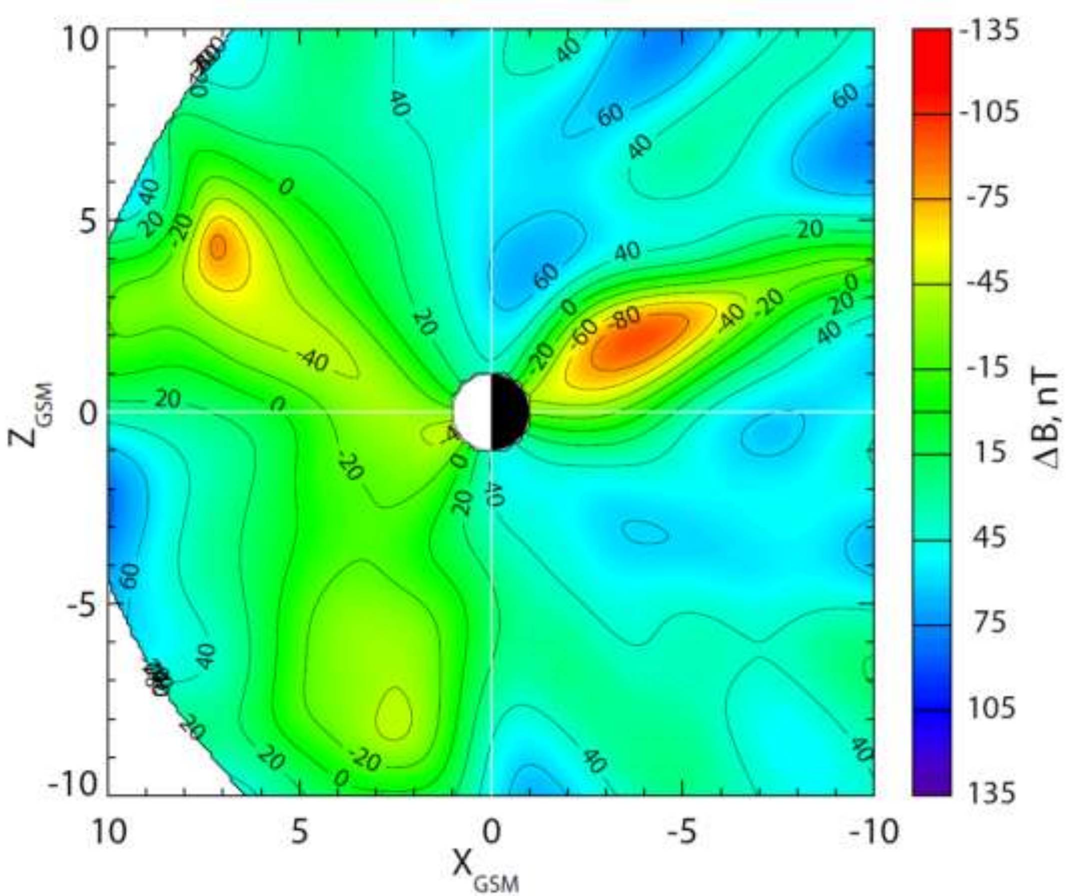
Equatorial projection

Results: distribution of $\Delta B = |\mathbf{B}_{\mathrm{total}}| - |\mathbf{B}_{\mathrm{dipole}}|$



Meridional projection

Results: effects of the Earth’s dipole tilt



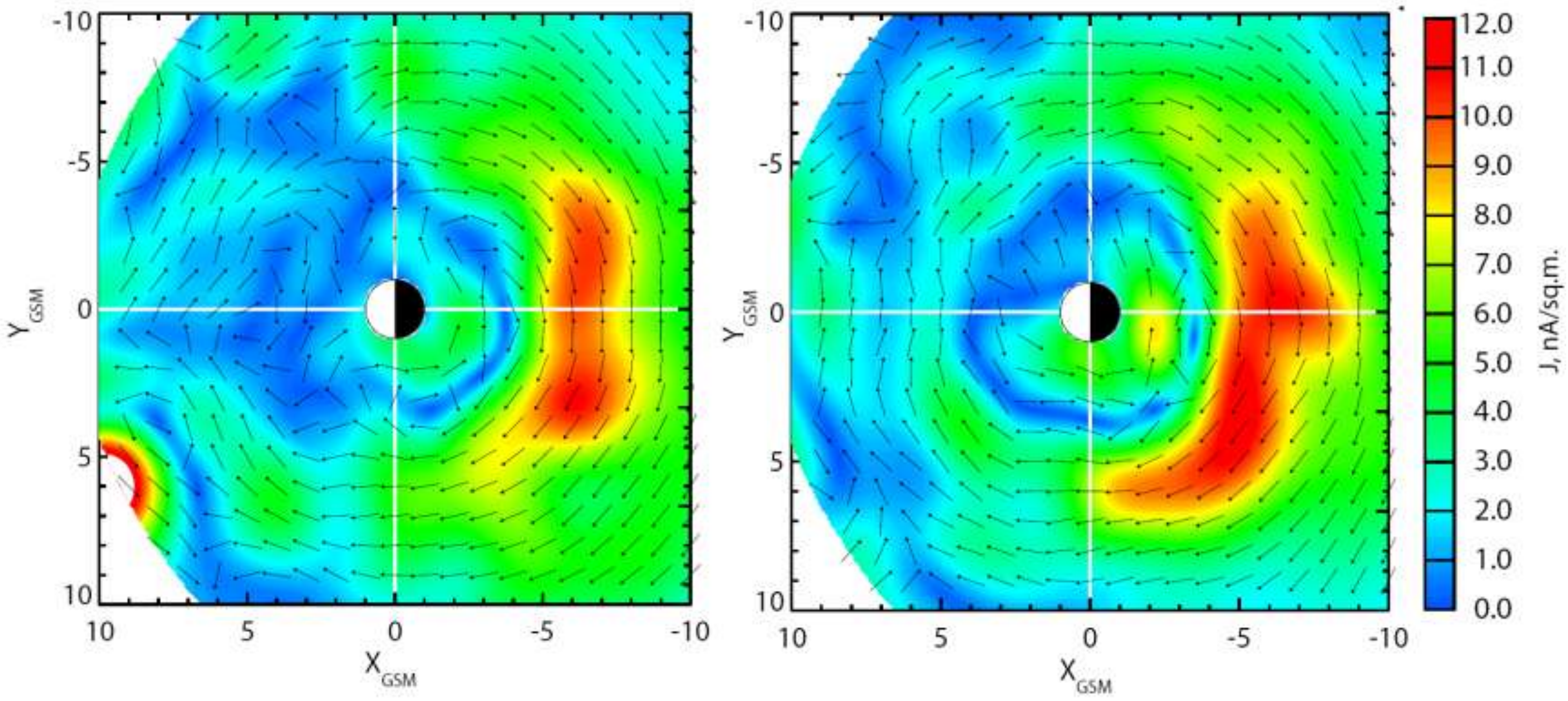
Meridional projection

Large dipole tilt angles => dramatic asymmetry of MF depression between the southern and northern cusps

Results: distribution of current density J

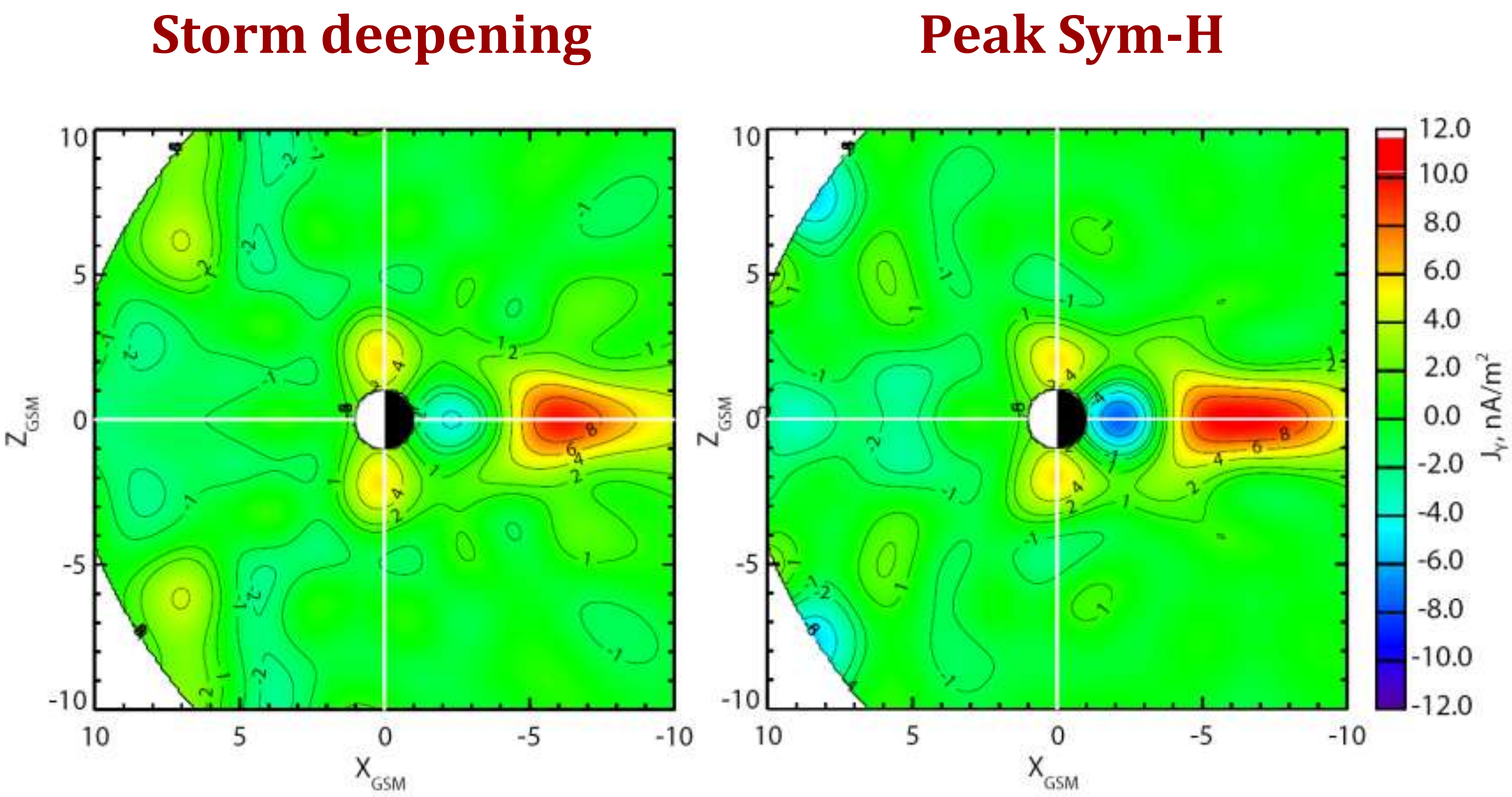
Storm deepening

Peak Sym-H



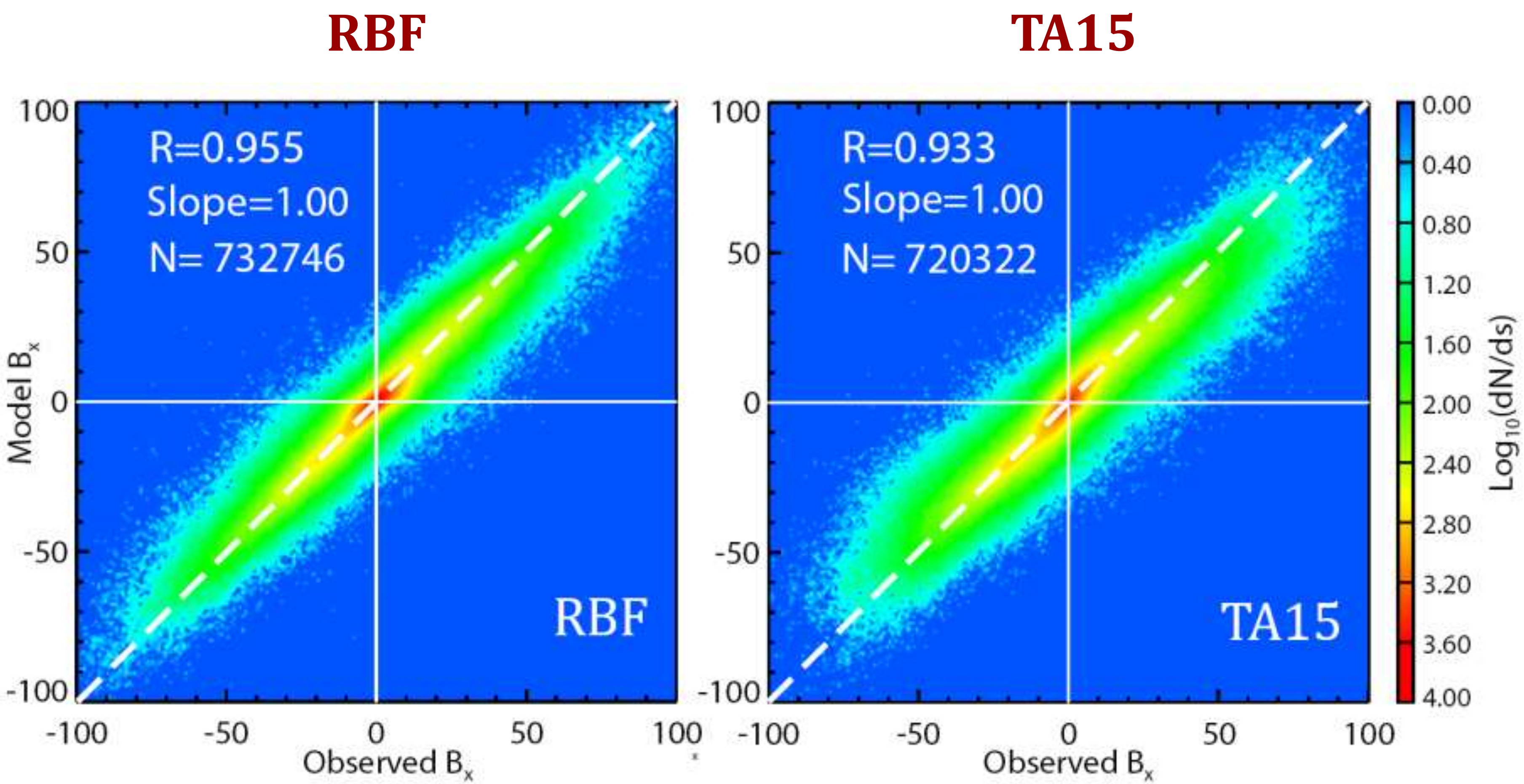
Equatorial projection

Results: distribution of current density J_y



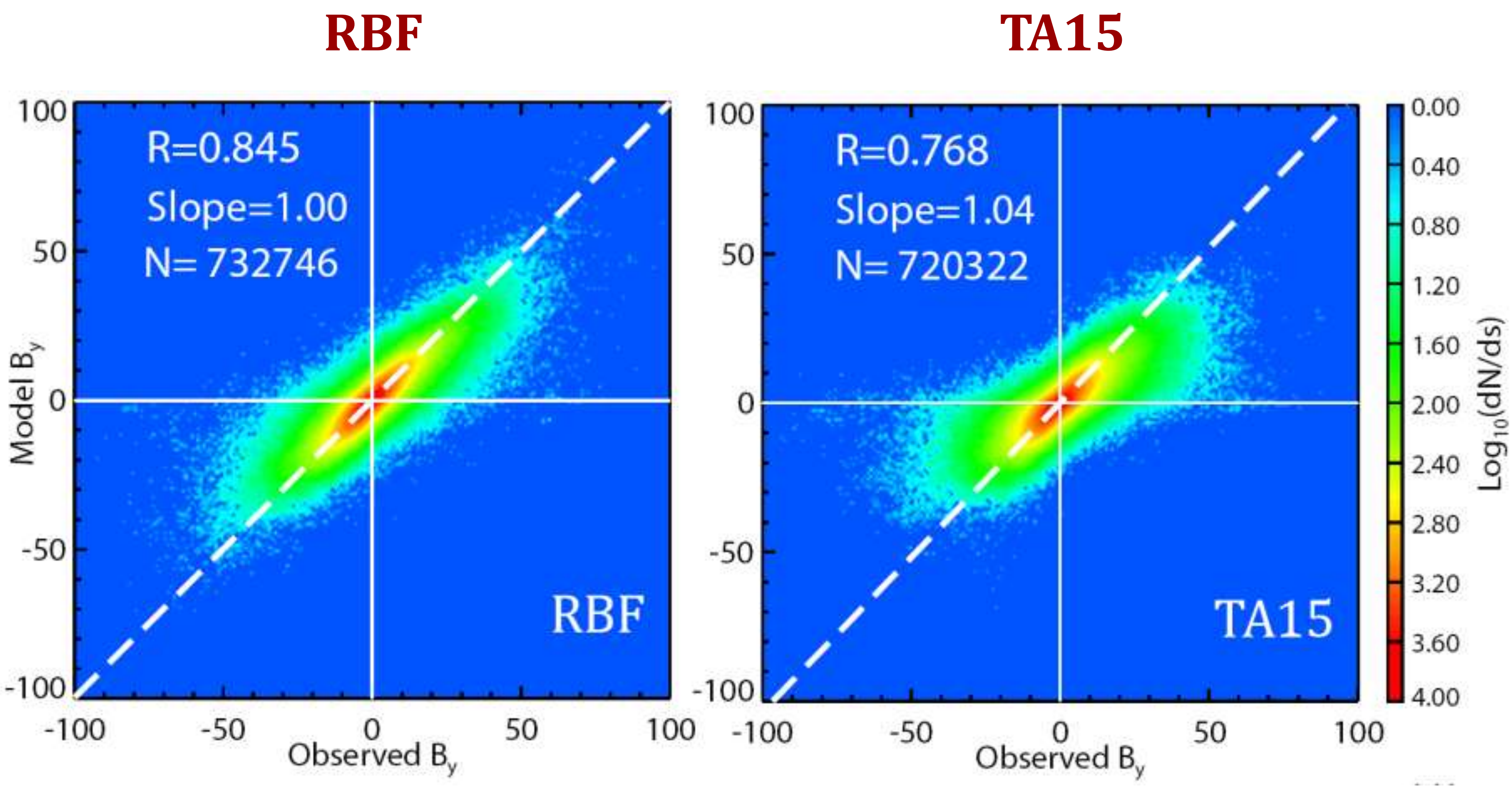
Meridional projection

RBF model vs traditional TA15 model



Scatterplots of the model vs observed MF GSW components

RBF model vs traditional TA15 model



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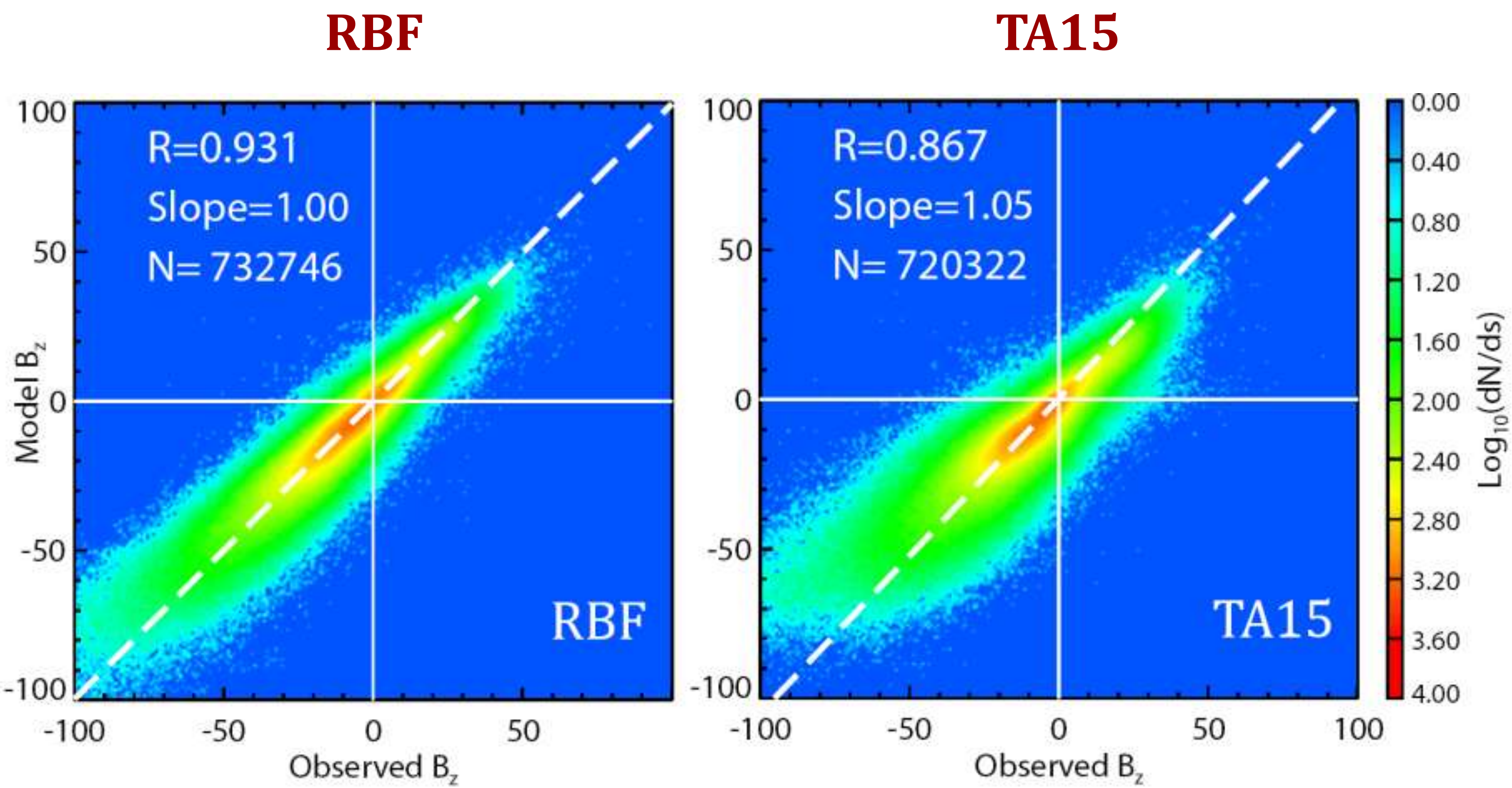


Scatterplots of the model vs observed MF GSW components

Conclusions

- **We developed a new method to reconstruct from data the magnetospheric magnetic field without a priory assumptions about its source geometry**

- **All current systems are reproduced: westward and eastward ring currents, tail current, diamagnetic currents in the cusps, field-aligned currents**

- **A full-fledged RBF model just devised, providing the best ever figure of merit & correlation with data**

Conclusions: future prospects

- **The method can be used as a tool to study the magnetospheric currents in selected areas by focusing the RBF grid on a local region of interest**

- **The method is perfectly suited to consolidate the flow of simultaneous data from constellation-type multispacecraft future missions**

Thank you for attention!

More details:

V. A. Andreeva, N. A. Tsyganenko, (2016),
J. Geophys. Res., v.121, 2249-2263.

and

http://geo.phys.spbu.ru/~tsyganenko/
modeling.html

Test of the RBF-model

- **Target configuration – TA15 model (Tsyganenko and Andreeva, 2015)**
- **2 tests: uniform and real data distribution in respect to RBF nodes**
- **Storm-time conditions:**

$$N = 1.5$$

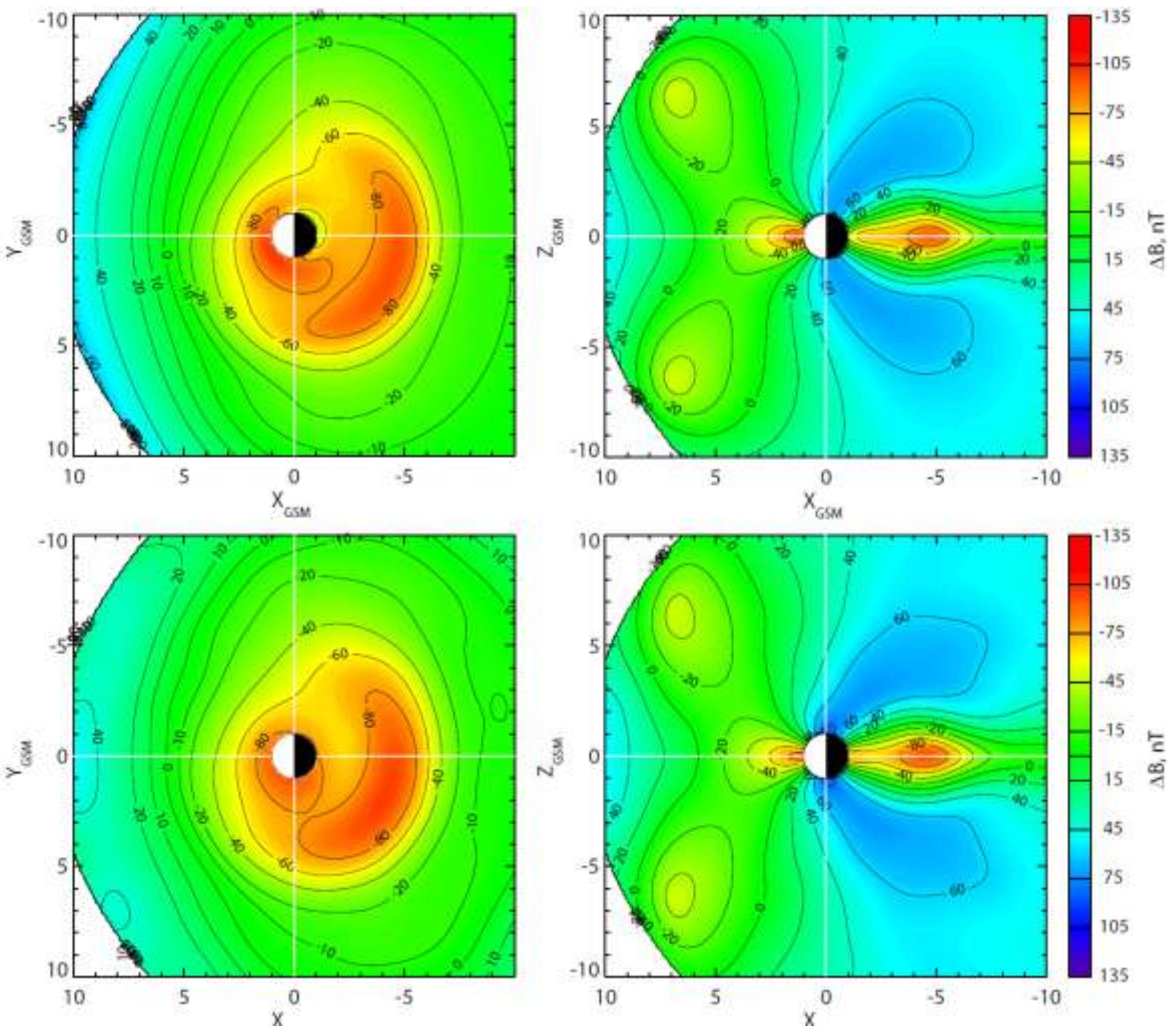
$$\mathrm{IMF}\ B_z = -5\ \mathrm{nT}$$

$$P_{dyn} = 2.5\ \mathrm{nP}$$

Test of the RBF-model

TA15

RBF



Distribution of $\Delta B = |\mathrm{B}_{\mathrm{total}}| - |\mathrm{B}_{\mathrm{dipole}}|$

Data: selection into subsets

6 hour centered average Sym-H index and its time derivative:

$$\langle \mathrm{SymH} \rangle (t) = \frac{1}{73} \sum_{k=-36}^{36} \left[\mathrm{SymH}(t_k) \cos \frac{\pi k}{144} \right]$$

$$\frac{D\langle \mathrm{SymH} \rangle}{Dt}(t) = \frac{1}{73} \sum_{k=-36}^{36} \left[\mathrm{SymH}(t_k) \sin \frac{\pi k}{72} \right]$$

State	N	$\langle$Sym-H$\rangle$ (nT)	$D\langle$Sym-H$\rangle/Dt$ (nT/hour)	$\langle B \rangle$ (nT)	$Q/\langle B \rangle$ (%)
Pre-storm Quiet-Time (QT)	41,611	[-20.0, -5.0]	[-0.5, 0.5]	20.8	42
Storm Deepening (SD)	37,031	[-100.0, -40.0]	[-5.0, -2.0]	56.9	34
Main Phase Peak (MP)	35,439	[-100.0, -50.0]	[-1.0, 1.0]	57.5	32
Recovery Phase (RP)	40,187	[-40.0, -20.0]	[2.5, 3.5]	32.7	34