Event-oriented type of magnetospheric magnetic field modeling

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Special thanks to Marina Kubyshkina (University of St.- Petersburg, St.-Petersburg, Russia)

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GEM 2014 Summer Workshop, June 15 – 20, 2014, Portsmouth, VA

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Modeling Earth's magnetosphere using spacecraft magnetometer data

Why do we need the Earth's magnetic field models?

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

Modeling of the global geomagnetic field has a unique place in the Sun-Earth connection studies, since that field **underlies all processes in the near-Earth space environment:**

- it links the interplanetary medium with the upper atmosphere and ionosphere,
- guides energetic charged particles,
- channels low-frequency electromagnetic waves,
- confines the radiation belts and controls the auroral plasma,
- Reflects the structure of electric currents,
- stores huge amounts of energy, dissipated in the course of magnetospheric substorms.

Understanding the properties of the geospace plasma requires knowing the **structure of the geomagnetic field and its dynamics and relation to the state of the solar wind.**

Magnetospheric magnetic field modelling approaches: Global and event-oriented (1)

Global magnetospheric magnetic field models

- Most widely used (*Tsyganenko [1989, 1995])* , Kp amd IMF/SW dependent
    - good representation of **average** magnetospheric configuration,
    - **fine structure** of magnetic field during substorms and **large magnetic field changes** during storms were **not accounted for**.
- Suitable for storm-time models (*Alexeev et al. [1996, 2001], Tsyganenko [2002]*
    - includes 1 hour time history of the interplanetary medium (T01),
    - model parameters for current systems **fitted to entire data set**,
    - model magnetic field defined by **assumed dependence** on input parameters,
    - no substorm variations.
- Specifically developed for storm-times (*Tsyganenko and Sitnov [2005])*
    - each source has its own relaxation timescale and a driving function, based on an individual best fit combination of the SW and IMF parameters,
    - does not include substorm variations of the magnetic field,
    - different modules can occupy the same space (thin tail current piercing thick ring current region).

Dynamical data-based storm-time modeling with enhanced spatial resolution (TS07)

- field is presented in the form of the expansion (*Tsyganenko and Sitnov,, 2007*)
- binning data using the nearest-neighbor approach (*Sitnov et al., 2008*)

Magnetospheric magnetic field modelling approaches: Global and event-oriented (2)

Event-oriented magnetospheric magnetic field models

- Modifications of existing models with introduction of new parameters (Pulkkinen et al., 1991; *Kubyshkina et al., 1999; Ganushkina et al., 2002; Ganushkina et al., 2004; Kalegaev et al., 2005;Ganushkina et al., 2010)*
    - An accurate representation of magnetospheric configuration for **a specific event,**
    - Suitable for past events analysis
    - Study the **evolution of different current systems** during different storms and their relative contribution to Dst

Adaptive modeling for magnetospheric magnetic field (*Kubyshkina et al., 2008, 2009*)

- To automate the adaptive modeling, **instead of varying the internal parameters**:
    - formally treat the **external input parameters** of the model **as "blind" variables**
    - their values have no relation to the actual solar wind or geomagnetic activity parameters,
    - parameters are determined by fitting the model to the data at each time step.

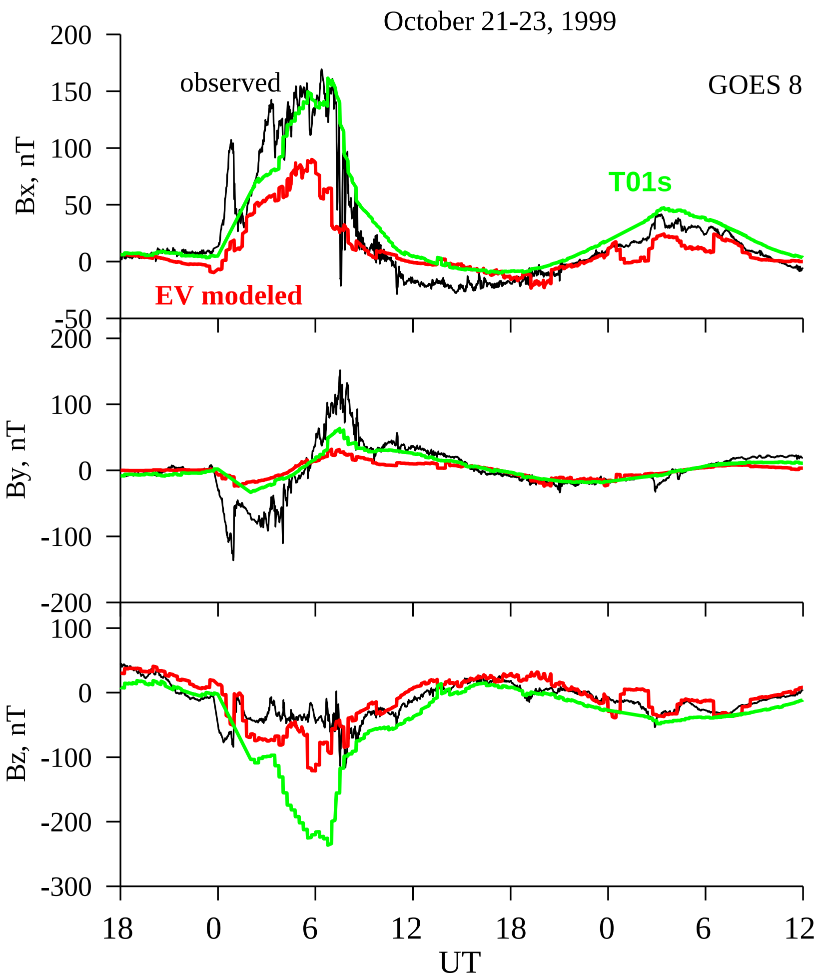
Adaptive modeling for magnetospheric magnetic field (adjusted models) (courtesy of M. Kubyshkina)

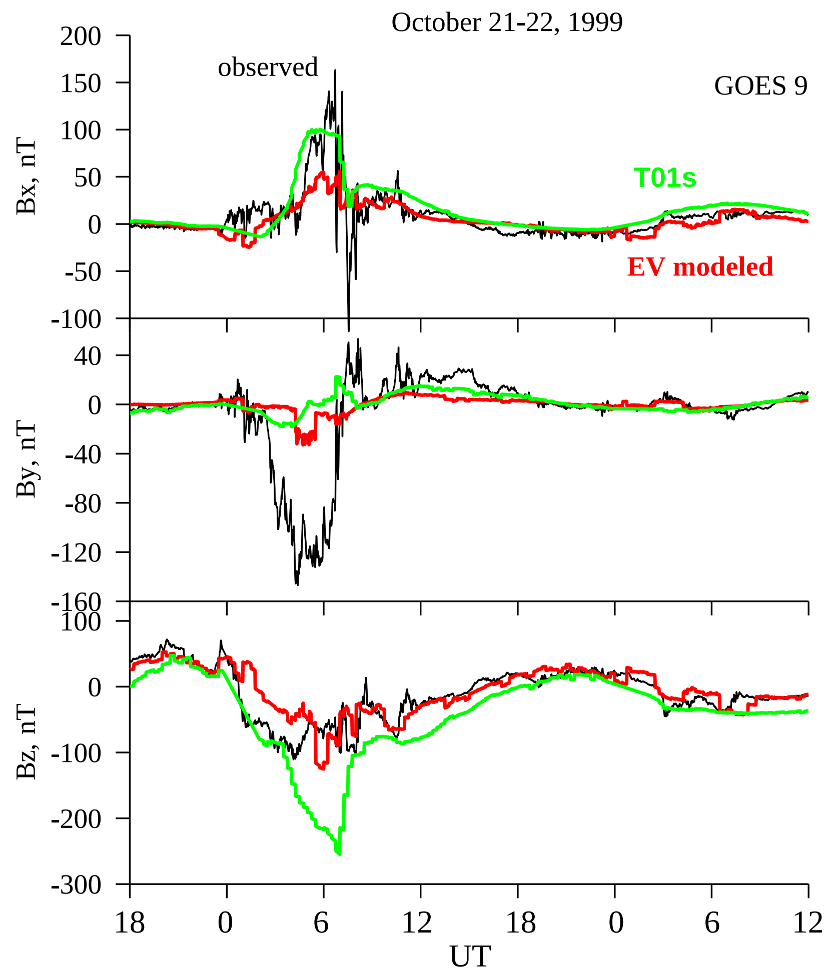
Version	Observations to fit	Parameters varied	Known problems
AM-01	**B field observations at Themis P1..P5**	**T96 parmod(1:4)**	Overestimation of total tail current
AM-02	**level 01 input data + + B field from other SC (Goes etc) in nearby MLT sector + plasma pressure at Themis P1&P2 (→lobe pressure)**	**T96 parmod (1,2,4) + neutral sheet tilt in XZ plane *(due to non-radial SW, flapping etc)***	Underestimation of total tail current (problems to separate between additional tilting and current enhancement)
AM_03	**level 02 input data+ plasma pressure at P1..P5 if available and well determined (pmod obtained from $\nabla P \sim j \times B$)**	**intensities of ring and tail currents + NS tilt in XZ plane + additional tail current with variable thickness Uses parmod (1:4) from AM02**	Too many parameters, hard to avoid local minimums, pressure data often unavailable or bad.

Event-oriented magnetic field modeling

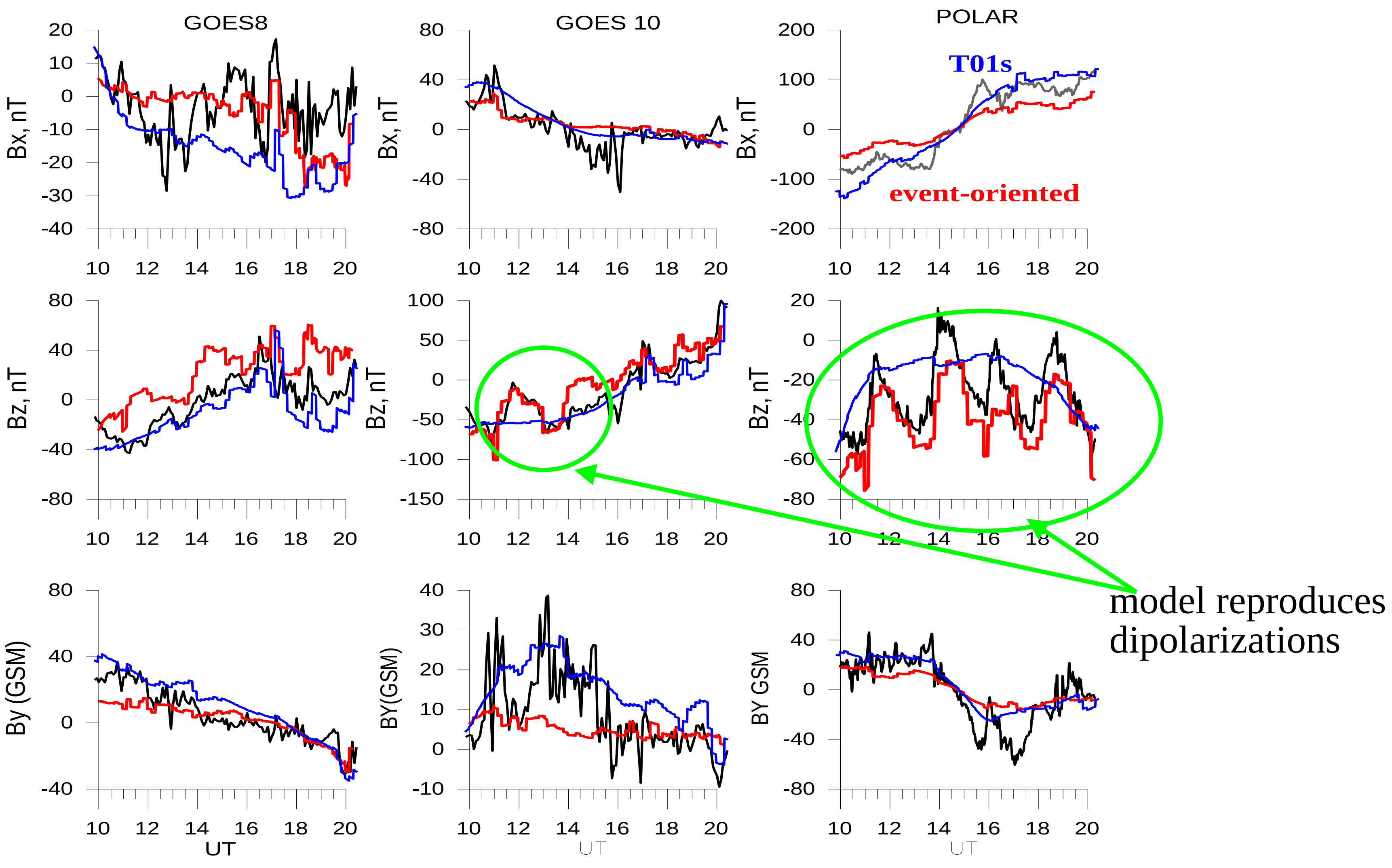
- **Choice of existing magnetospheric magnetic field model to modify:**
  Any model easy to modify, simplest solution: Tsyganenko T89, Kp =4 (for storms)
- **Modifications**
  - Replacing of T89 ring current with asymmetric bean-shaped ring current
  - Varying the global intensity of T89 tail current
  - Addition of thin current sheet
  - Scaling of magnetopause currents
- **Determining free parameters for each current system**
- **Collecting input data**:
  - All available magnetic field measurements in the inner magnetosphere
  - SYM-H measurements on the ground
  - SW and IMF data
- **Varying free parameters**, we find the set of parameters that gives the best fit between model and all available in-situ field observations
- **Difficulties when constructing the event-oriented model**
  - Only **several data points** available;
  - Best model input and output, if satellites are at **different locations;**
  - Point measurements can be represented by **different ways in models.**
- **Additional measurements for fitting model parameters or testing the configuration**
  - Isotropic boundaries;
  - B-direction measured by LANL;
  - Pressure value measured at magnetospheric spacecraft.

Modeling results for October 21- 23, 1999: Comparison with T01S



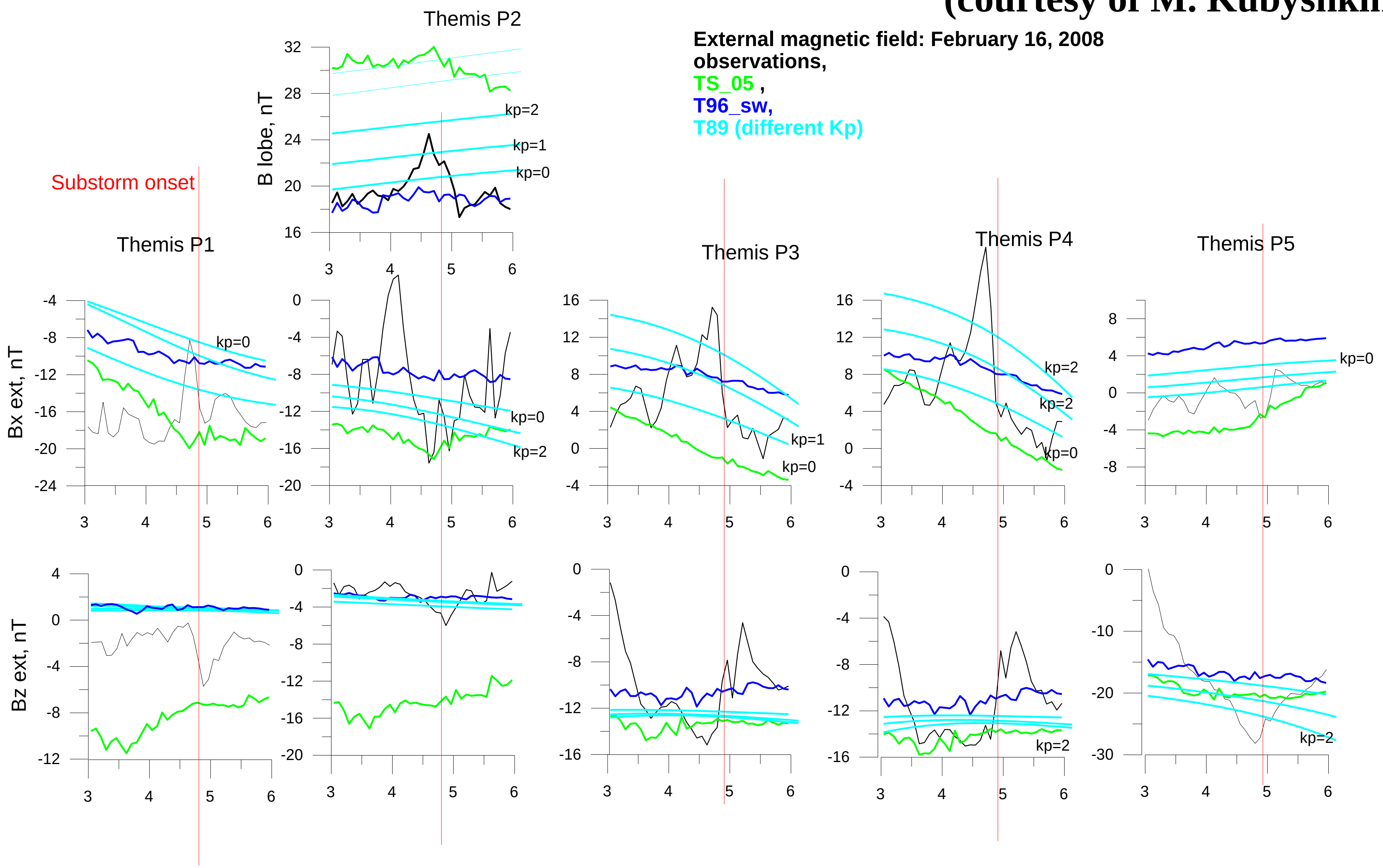


Model results: Sawtooth event on Oct 22, 2001



Example of field representation on board THEMIS with standard models:

(courtesy of M. Kubyshkina)

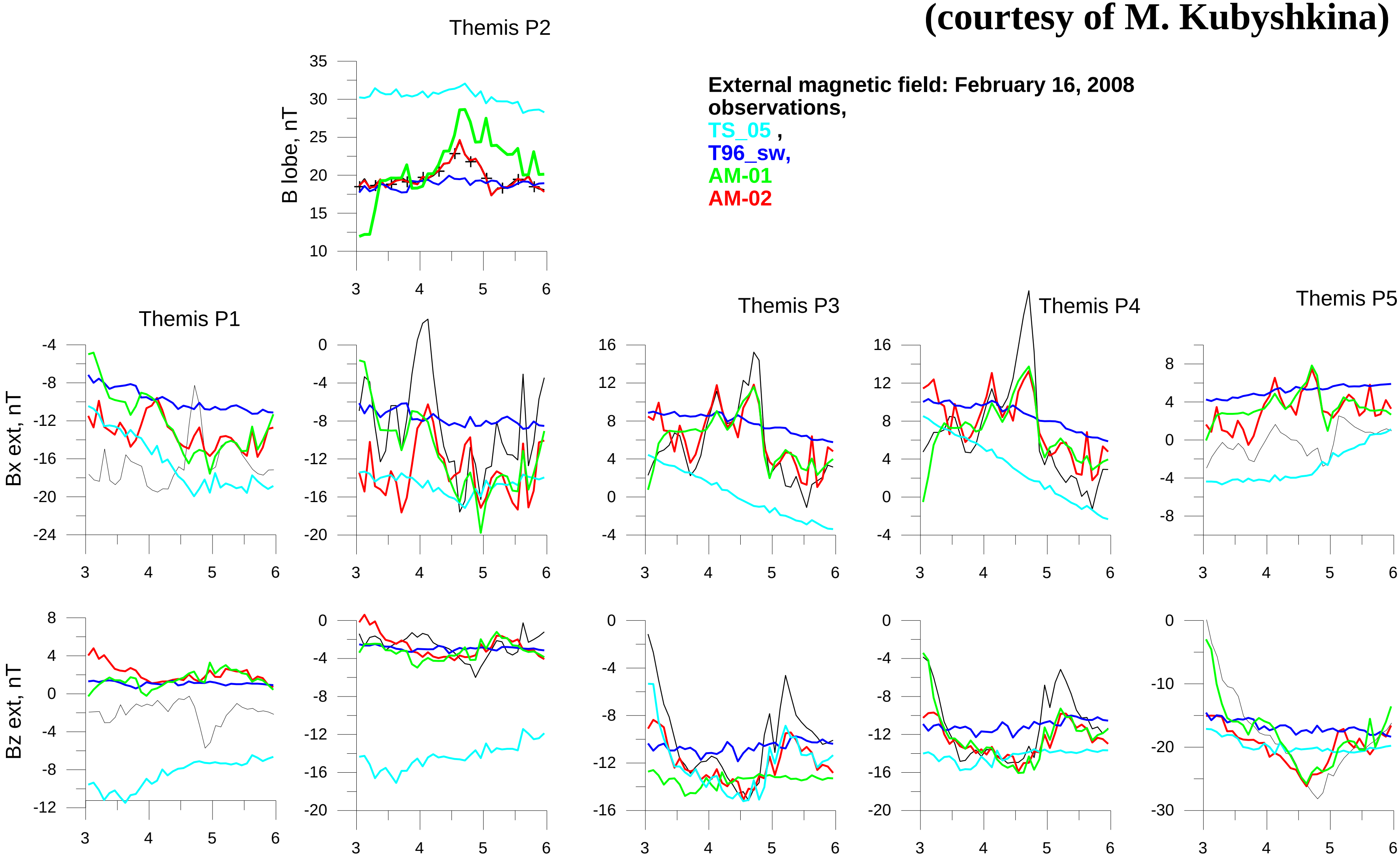


NO adequate substorm variations in any standard model

Field representation by AM-01,02 on board THEMIS

- time variations present and substorm changes reproduced,
- much better field representation on all probes

(courtesy of M. Kubyshkina)



Event-oriented magnetospheric magnetic field modelling: Advantages and disadvantages

+ Allows to play easily with current systems, their location and parameters, to get better agreement with data
+ Good representation of smaller scale variations in magnetic field: substorm-associated, sawtooth events
+ Good representation of local magnetic field variations (observations at a specific satellite)

To get detailed magnetic field variations for **a specific event**, time period, magnetospheric region $\Rightarrow$ **use event-oriented model**

- Only for specific events, when magnetic field data are available at least at 3 satellites in different magnetospheric regions
- Requires some work for determination of model parameters
- the model works best in the MLT sector, where major observations are taken from and may overestimate (or underestimate) magnetic field in other MLT sectors

To get magnetic field quickly, for several storms, over a large region in magnetosphere, good **in average** $\Rightarrow$ **use Tsyganenko models**

Event-oriented magnetospheric magnetic field modelling

Current system	Parameter	Status
Eastward RC	Roeast	2 Re
	Joeast	1.5 nA/m^2
Westward RC	Rowest	2.5 – 4.5 Re
	Jowest	1.5 – 15 nA/m^2
Partial RC	Ropart	5 – 6.5 Re
	Jopart	0.5 - 7 nA/m^2
	C	1
	σ	From Dst
Tail current	ATS	-0.5 – 2
	Antc	0.1 – 2.4
	X1ntc	- 2 Re
	X2ntc	- 10 Re
	Do	0.2 Re
Magnetopause currents	AMP	From SW
	RT	From SW & IMF

Baseline model: Tsyganenko T89 Kp=4

$$\left.\begin{array}{l} \\ \\ \\ \\ \end{array}\right\} \quad \sigma = 0.8, \quad A = 1$$

$$\delta = \frac{\pi}{2}\tanh\frac{|Dst|}{Dst_0}, \qquad Dst_0 = 40\ \mathrm{nT}$$

$$AMP = \left(P_{SW} / \langle P_{SW} \rangle\right)^k, k \approx 1/6.$$

$$R_T = 30 R_E \frac{Z_{T,Shue}}{Z_{T,T89}},$$

Varying free parameters, we find the set of parameters that gives the best fit between model and in-situ magnetic field observations by **Dst** (SYM-index) measurements.

Models magnetic field error:

$\Delta B = |Bobs| - |Bmod|$