

Interhemispheric Magnetic Conjugacy

N. Yu. Ganushkina (1, 2), M. Kubyshkina (3),
N. Partamies (2), E. Tanskanen (2)

(1) University of Michigan, Ann Arbor MI, USA

(2) Finnish Meteorological Institute, Helsinki, Finland

(3) University of St.-Petersburg, St.-Petersburg, Russia

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Magnetic conjugacy

- Understanding of the magnetic mapping in different conditions and between different regions of the near-Earth space has become an increasingly important topic.
- This is particularly important now during the era of clustered satellite missions (e.g. Cluster, THEMIS), which aim at studying **ionospheric signatures** of processes at the distances of 10-20 Re down in the **magnetotail**, or when studying **conjugate signatures of the aurora** with ground-based instruments in both hemispheres.
- We investigate the effect of the **dipole tilt angle** and different **solar wind and IMF** parameters on the magnetic mapping between the hemispheres.
- We use **magnetic field modeling** to provide an unlimited range and combination of the tilt angle and solar wind parameters, but also we analyze the previously reported conjugate events in more detail.

Modelling approach

To investigate the question of magnetic conjugacy:

we follow the magnetic field lines from northern to southern hemisphere using T02 Tsyganenko magnetospheric magnetic field model.

Model parameters: geodipole tilt angle, IMF B_y and B_z , solar wind dynamic pressure, and Dst index, two functions, G1 and G2, that depend on the IMF B_z and solar wind velocity and their time history.

T02 compared to T96 model:

- (1) the model contains the partial ring current and thus dawn-dusk asymmetry of the inner magnetosphere magnetic field;
- (2) the model has better representation of interconnection of IMF B_y with the magnetospheric magnetic field.
- (3) simple dependencies on clear solar wind and IMF parameters as G1 and G2.

TS05 compared to T02:

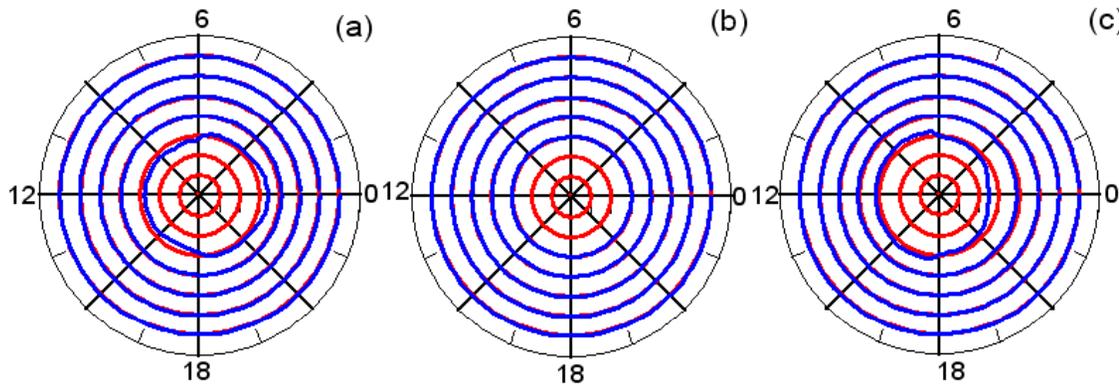
- (1) has a similar mathematical structure but the data used were only for 37 storms with $Dst < -65$ nT
- (2) More complex variables W_i , $i=1,6$, magnitude coefficients for the magnetic fields from each source.

Dipole tilt angle = -33° , winter

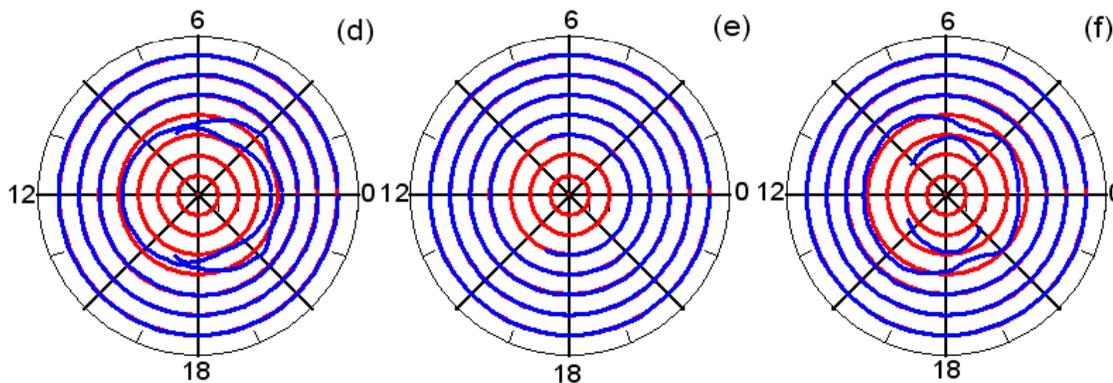
Dipole tilt angle $\sim 0^\circ$, equinox

Dipole tilt angle = $+33^\circ$, summer

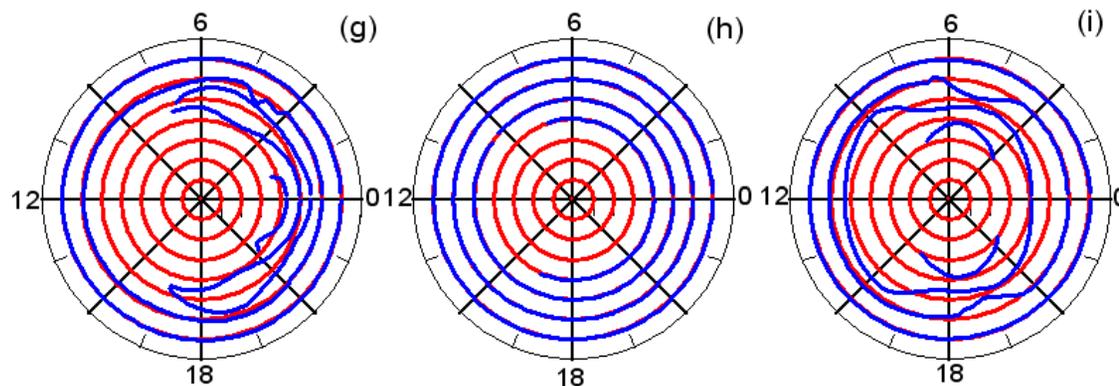
Quiet period: $P_{sw} = 2 \text{ nPa}$, $D_{st} = 10 \text{ nT}$, $IMF B_y = 0 \text{ nT}$, $IMF B_z = 10 \text{ nT}$



Moderately disturbed period: $P_{sw} = 2 \text{ nPa}$, $D_{st} = -20 \text{ nT}$, $IMF B_y = 0 \text{ nT}$, $IMF B_z = -5 \text{ nT}$



Disturbed period: $P_{sw} = 8 \text{ nPa}$, $D_{st} = -100 \text{ nT}$, $IMF B_y = 0 \text{ nT}$, $IMF B_z = -20 \text{ nT}$



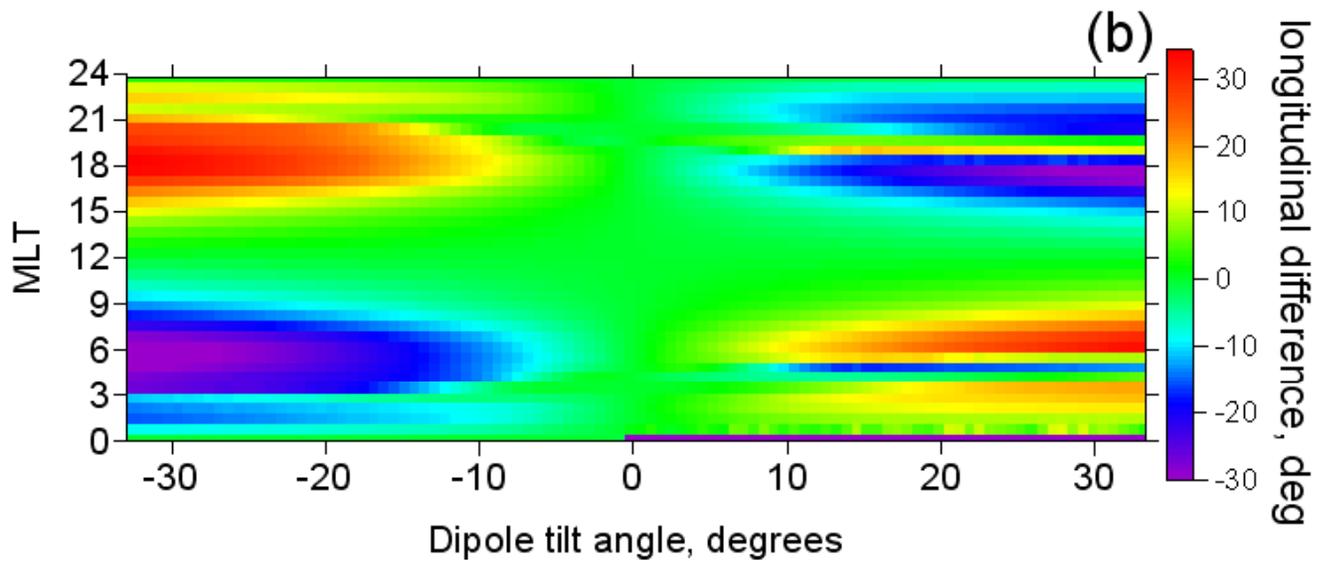
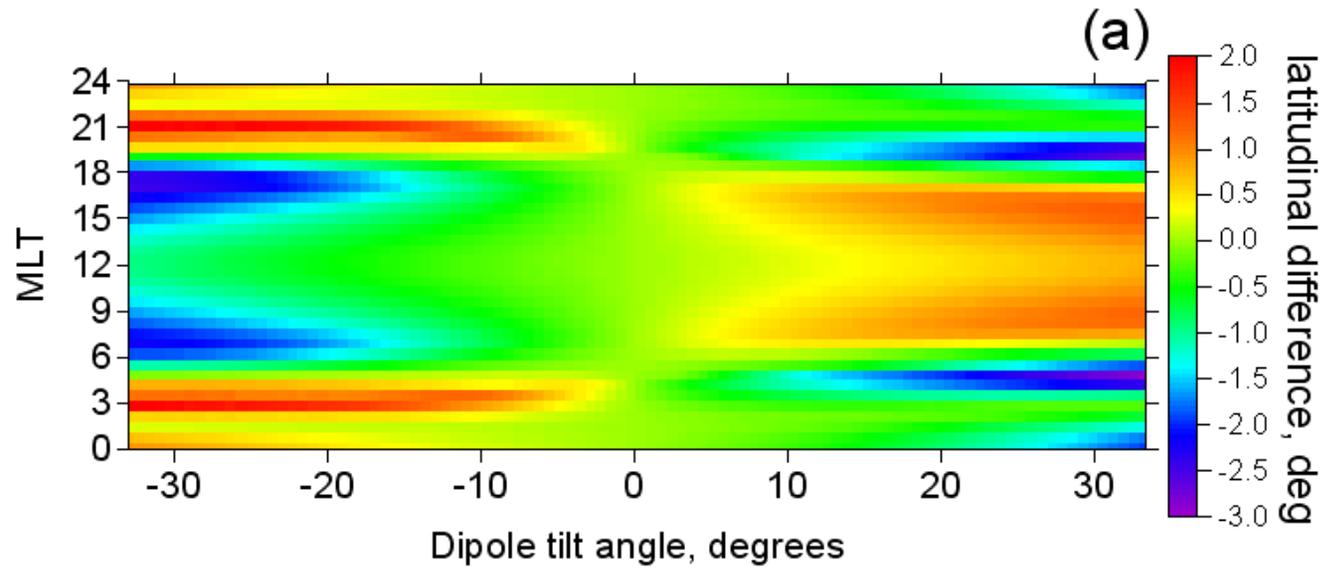
Differences in latitudinal conjugacy in the northern and southern hemispheres

- start from the circles of latitudes from 55° to 75° with 5° step at all MLTs with 15 minutes step in the northern hemisphere.
- trace magnetic field lines from these points in the northern hemisphere to the corresponding points in the southern hemisphere using T02 model.
- use corrected geomagnetic coordinate system to remove the nondipolar effects from the internal magnetic field.

Dependence on dipole tilt angle

Starting at 70 deg latitude, all MLTs, in northern hemisphere

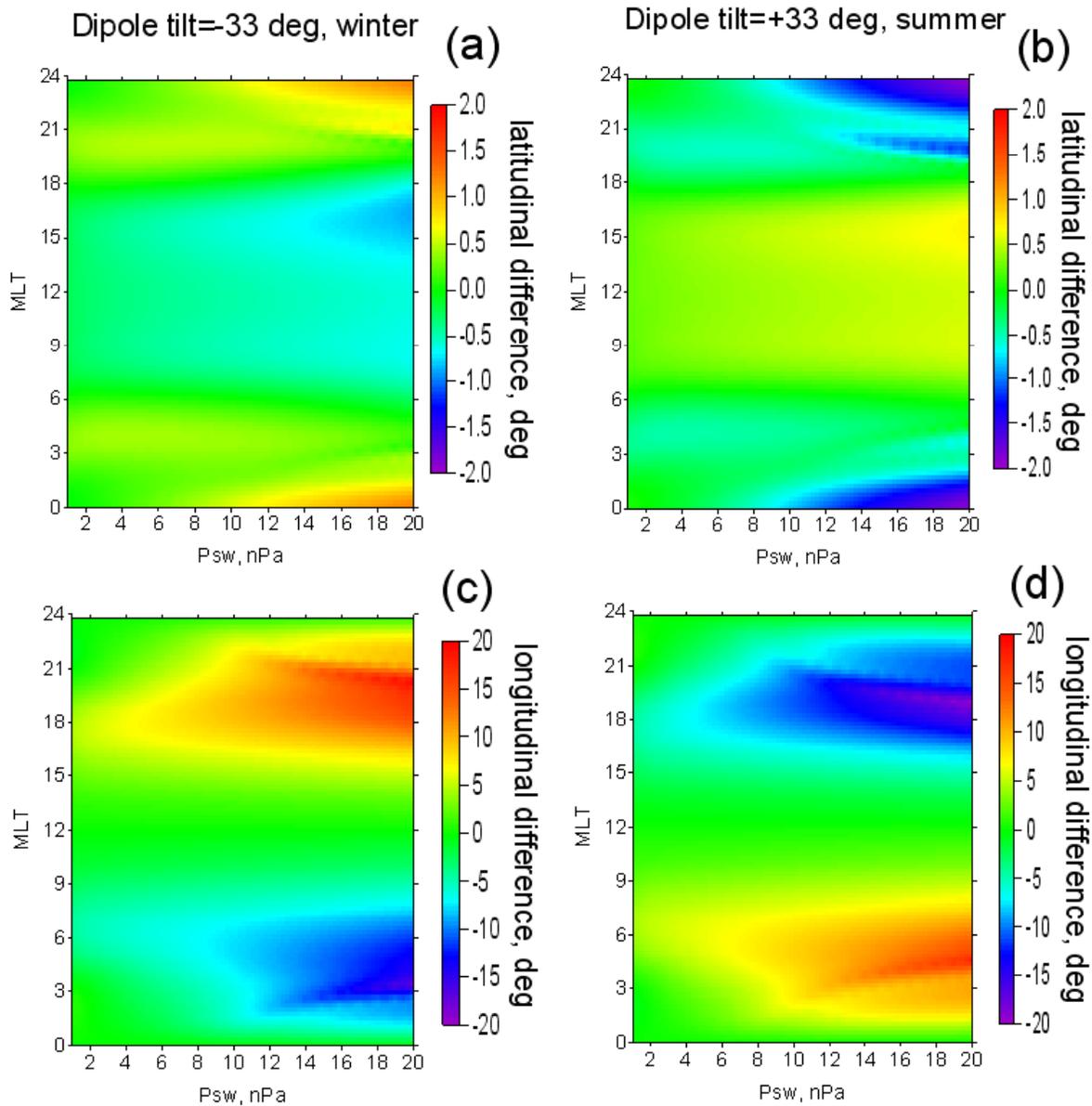
Moderately disturbed period: $P_{sw} = 2$ nPa, $Dst = -20$ nT,
 $IMF B_y = 0$ nT, $IMF B_z = -5$ nT



Dependence on solar wind dynamic pressure P_{sw}

Starting at 70 deg latitude, all MLTs, in northern hemisphere

Moderately disturbed period: Dst = -20 nT, IMF B_y = 0 nT, IMF B_z = -5 nT

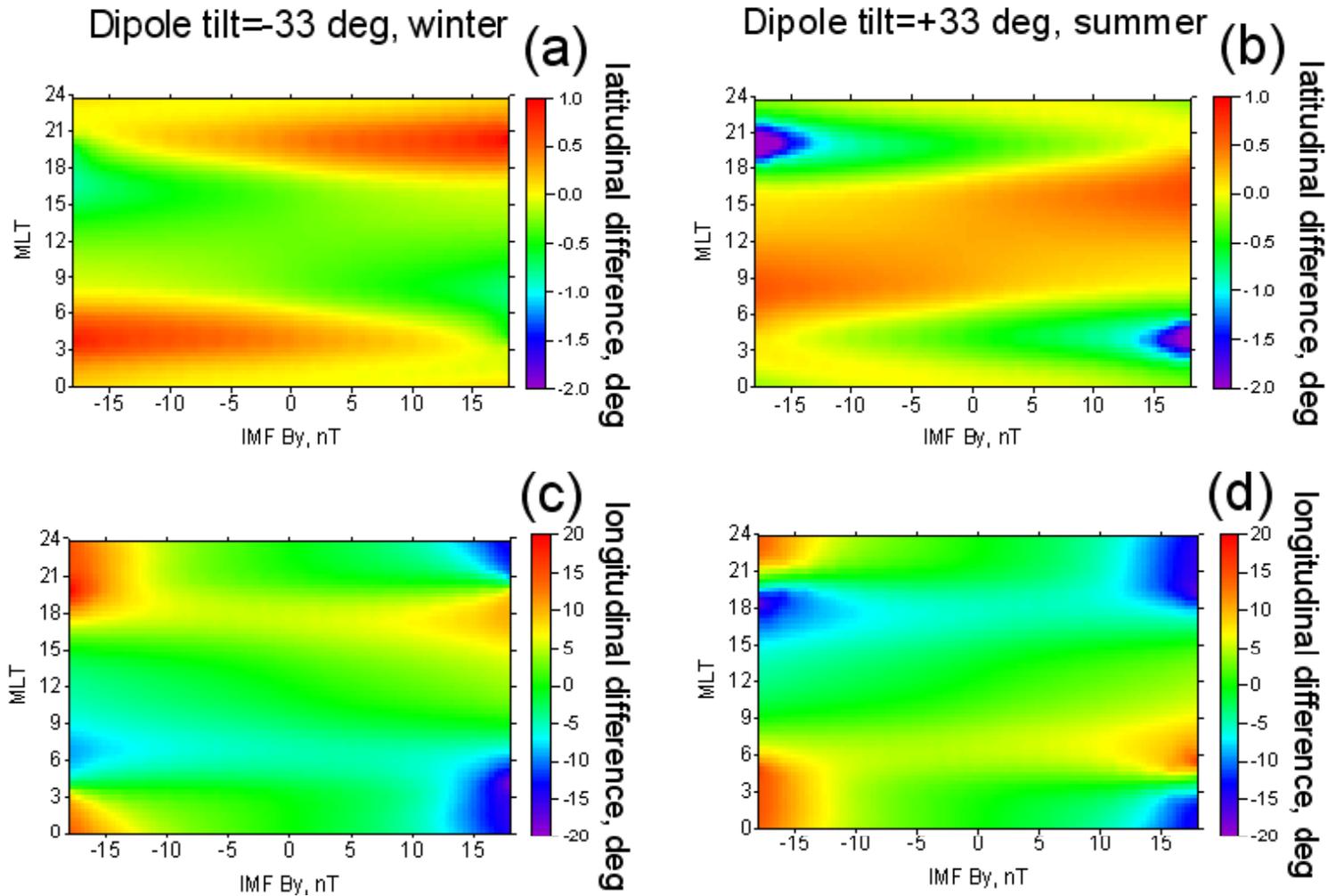


Nightside magnetosphere is much more affected by large P_{sw}

Dependence on IMF By

Starting at 70 deg latitude, all MLTs, in northern hemisphere

Moderately disturbed period: $P_{sw} = 2$ nPa, $Dst = -20$ nT, $IMF B_z = -5$ nT



Asymmetry is present for nonzero IMF By but no dependence on IMF By magnitude

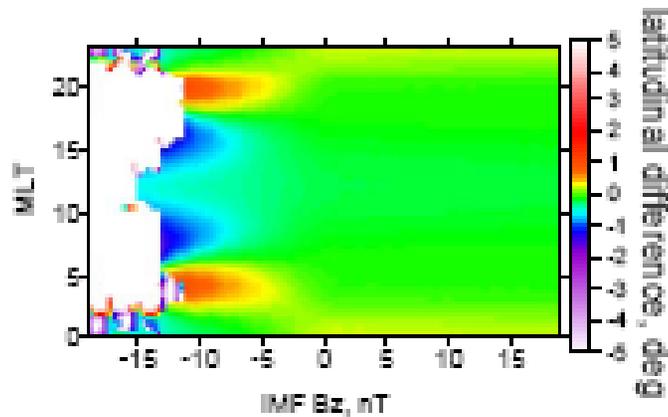
Dependence on IMF Bz

Starting at 70 deg latitude, all MLTs, in northern hemisphere

Moderately disturbed period: $P_{sw} = 2$ nPa, $Dst = -20$ nT, $IMF B_y = 0$ nT

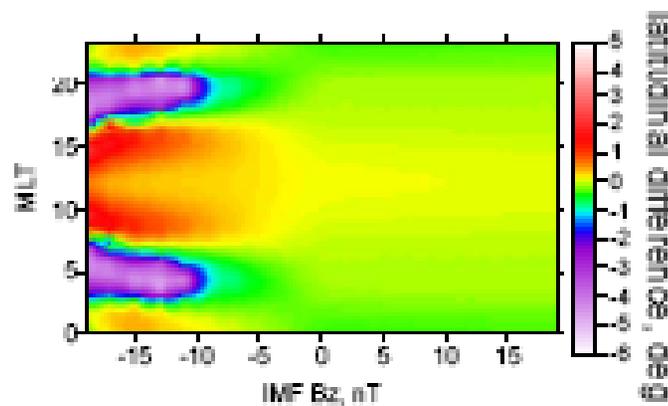
Dipole tilt = -33 deg, winter

(a)

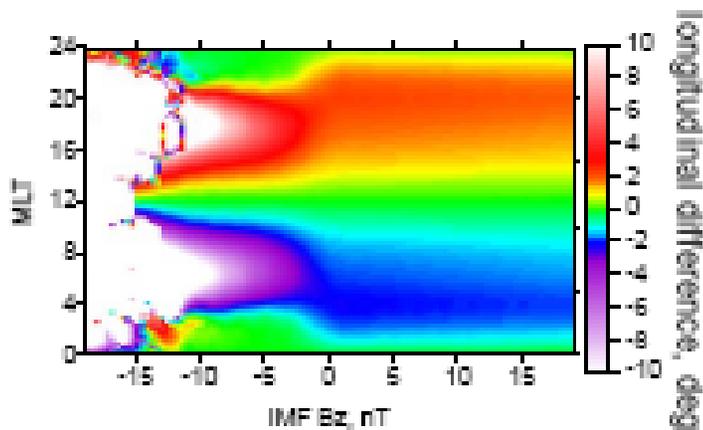


Dipole tilt = +33 deg, summer

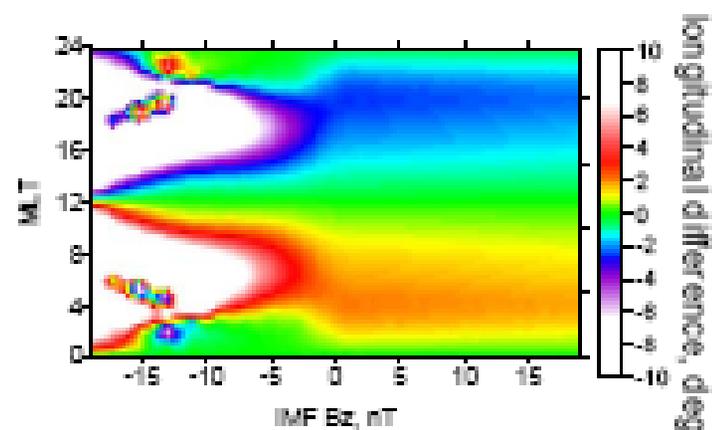
(b)



(c)



(d)



Lat. difference of 3-4 degrees for negative IMF Bz

Modelling approach: Rotation of tail current sheet

Addition to T02 model:

possibility to incorporate changes in the model magnetic field due to **rotation of a tail current sheet from the Sun-Earth line.**

In reality, the tail current sheet can be not aligned along the X_{gsm} line, the non-radial flow of the solar wind can cause the rotation of the tail current sheet. When any of V_y and V_z are not close to zero, even small deviations of the tail location relative to the Sun-Earth line, can cause notable variations in the magnetic field.

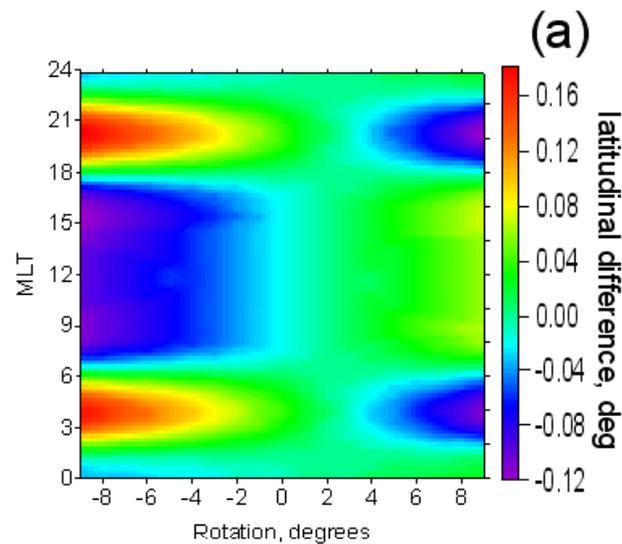
To take into account the rotation:

- consider only V_z component;
- simply rotate the original GSM coordinate system in XZ_{gsm} -plane for a specific **angle $\tan(\alpha) = V_z/V_x$** , the angle at which **solar wind flows to X_{gsm} axis**;
- compute the external magnetic field from T02 model in this coordinate system, where the tail current sheet is directed along “new” (rotated) X_{gsm} axis;
- rotation will result in a change of an **effective "tilt angle"**, which is defined as an angle between Z_{gsm} axis direction and dipole axis direction.;
- changes coming from taking into account the real direction of the solar wind flow depending on the direction of solar wind may increase or decrease the "efficient tilt".

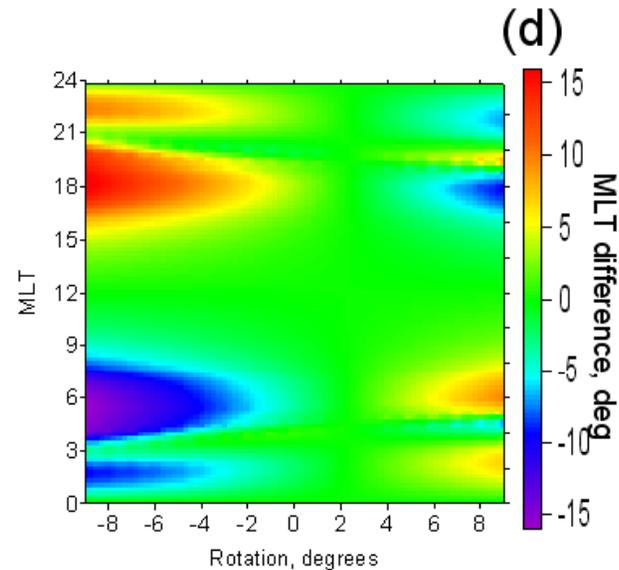
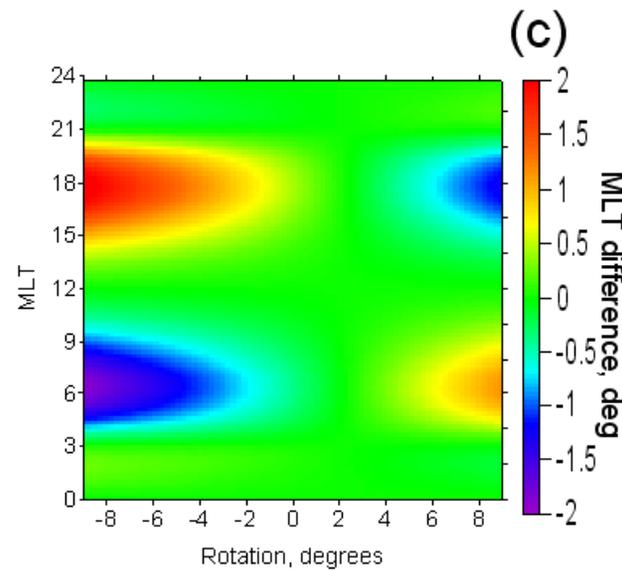
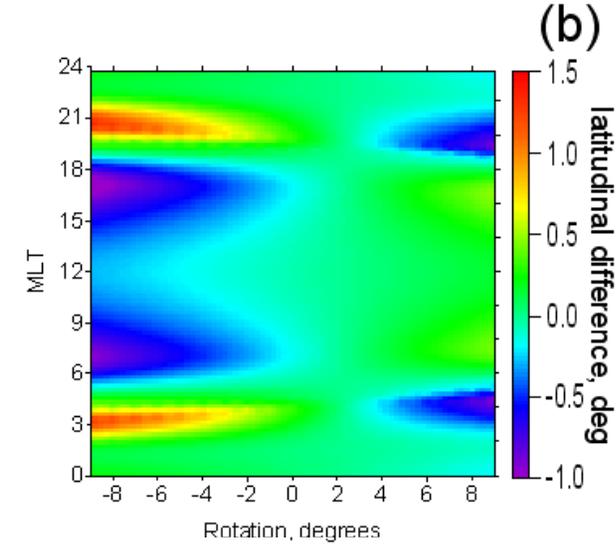
Dependence on rotation of neutral sheet from Sun-Earth line

Moderately disturbed period: $P_{sw} = 2$ nPa, $Dst = -20$ nT,
IMF $B_y = 0$ nT, IMF $B_z = -5$ nT. Dipole tilt angle about 2 degrees

Starting at 65 deg latitude,
all MLTs, in northern hemisphere



Starting at 70 deg latitude,
all MLTs, in northern hemisphere



Conjugate points in the northern and southern hemispheres: Observed

Simultaneous observation made in the northern and southern hemispheres:

Sato et al., 2005:

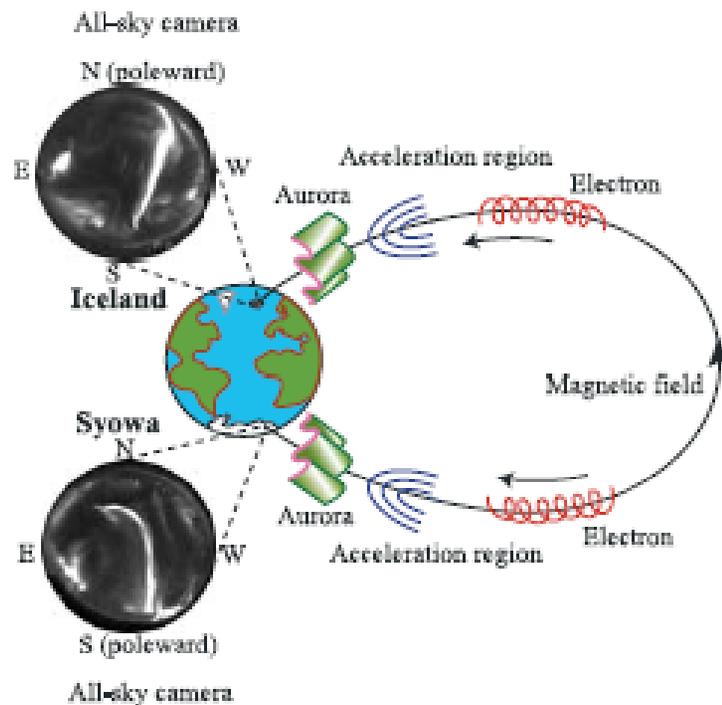
similar auroras were simultaneously acquired with all-sky TV cameras at **Tjornes (Iceland) and Syowa (Antarctica)** magnetically conjugate observatories on magnetic pre-midnight at 2230-2400 UT on September 26, 2003..

One of the results of this study:

the existence of both **latitudinal (poleward -50 km) and longitudinal (westward -200 km) displacement** of the conjugate point in southern hemisphere after one hour of observations.

None of the T96 and T02 Tsyganenko models

could reproduce the observed displacement with the observed solar wind and IMF parameters even taking into account the possible displacement due to IMF B_y and the time delay.



Tracing geomagnetic conjugate points using exceptionally similar synchronous auroras

Natsuo Sato,^{1,2} Akira Kadokura,¹ Yusuke Ebihara,¹ Hiroki Deguchi,² and Thorsteinn Saemundsson³

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Figure 1. Schematic drawing of conjugate auroral observation at Syowa Station in Antarctica and stations in Iceland. Discrete auroras occur in both polar regions at an altitude of 100–120 km on average. The auroral electrons, which are guided along the geomagnetic field lines, are accelerated Earthward via a field-aligned electric field at a typical altitude of ~6000–12,000 km. The auroras as seen from the conjugate ground observatories form mirror images.

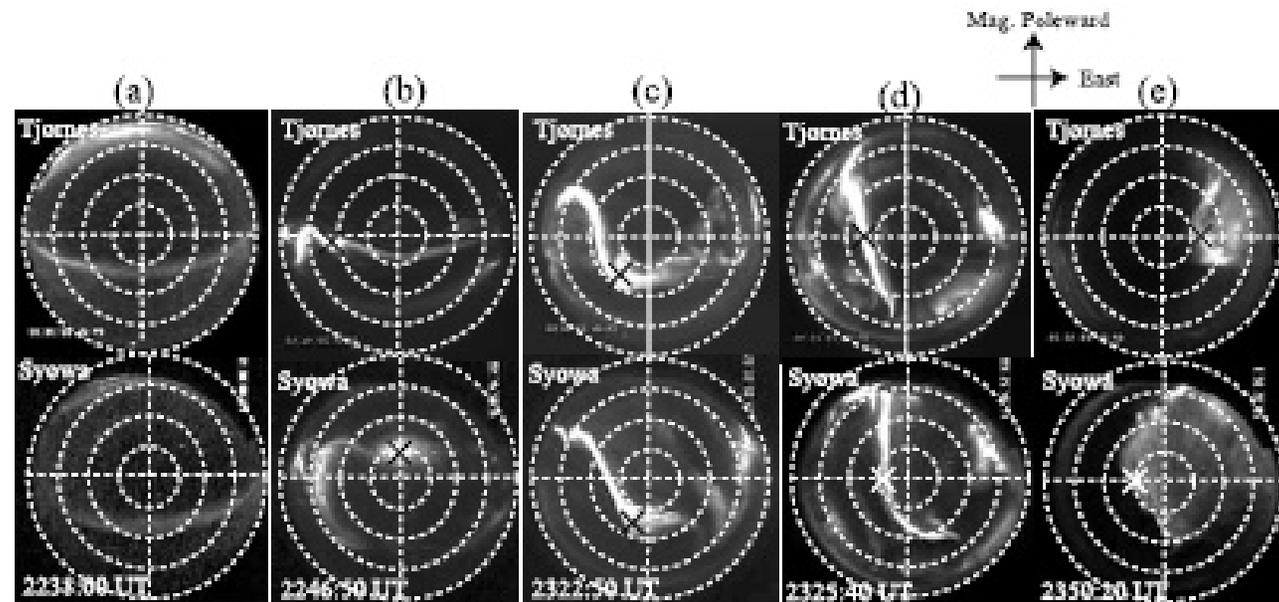
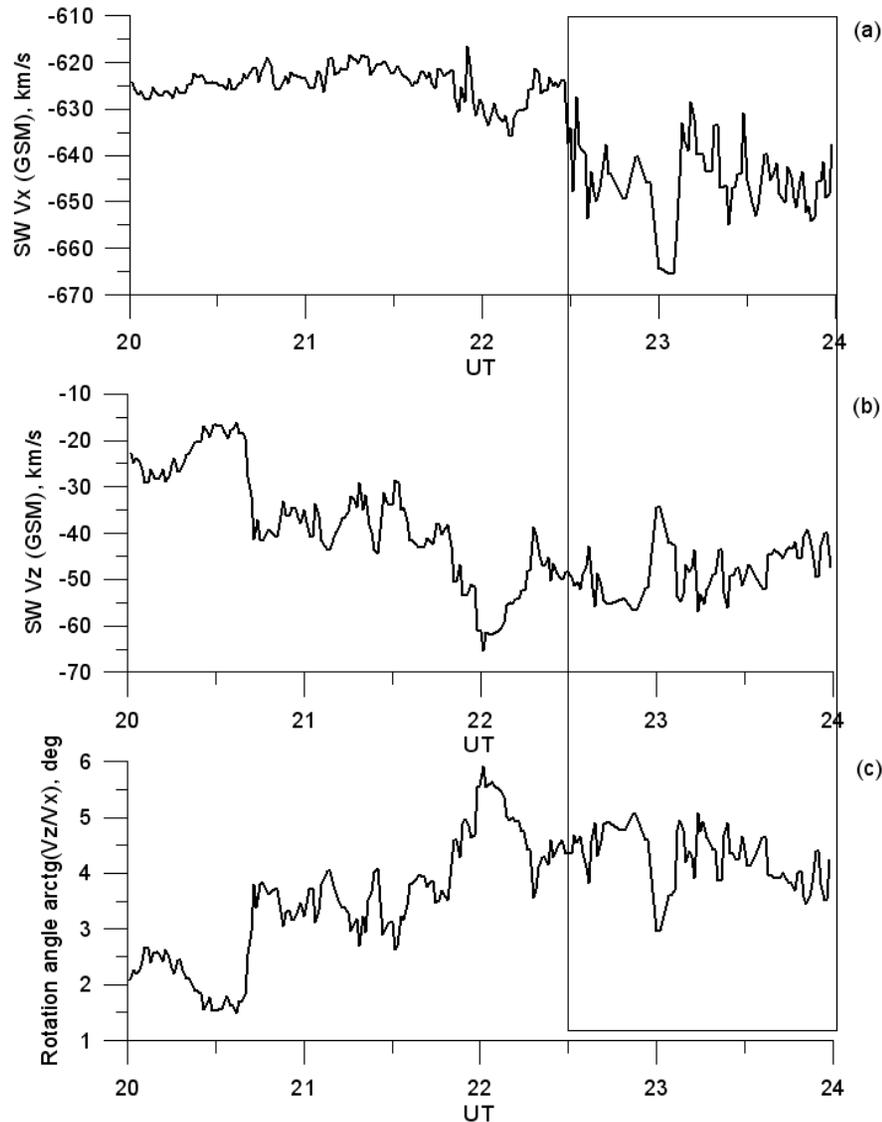


Figure 3. Snapshot auroral images at different times when auroral forms are extremely similar at both observatories.

Conjugate points in the northern and southern hemispheres: Observed and modeled (1)

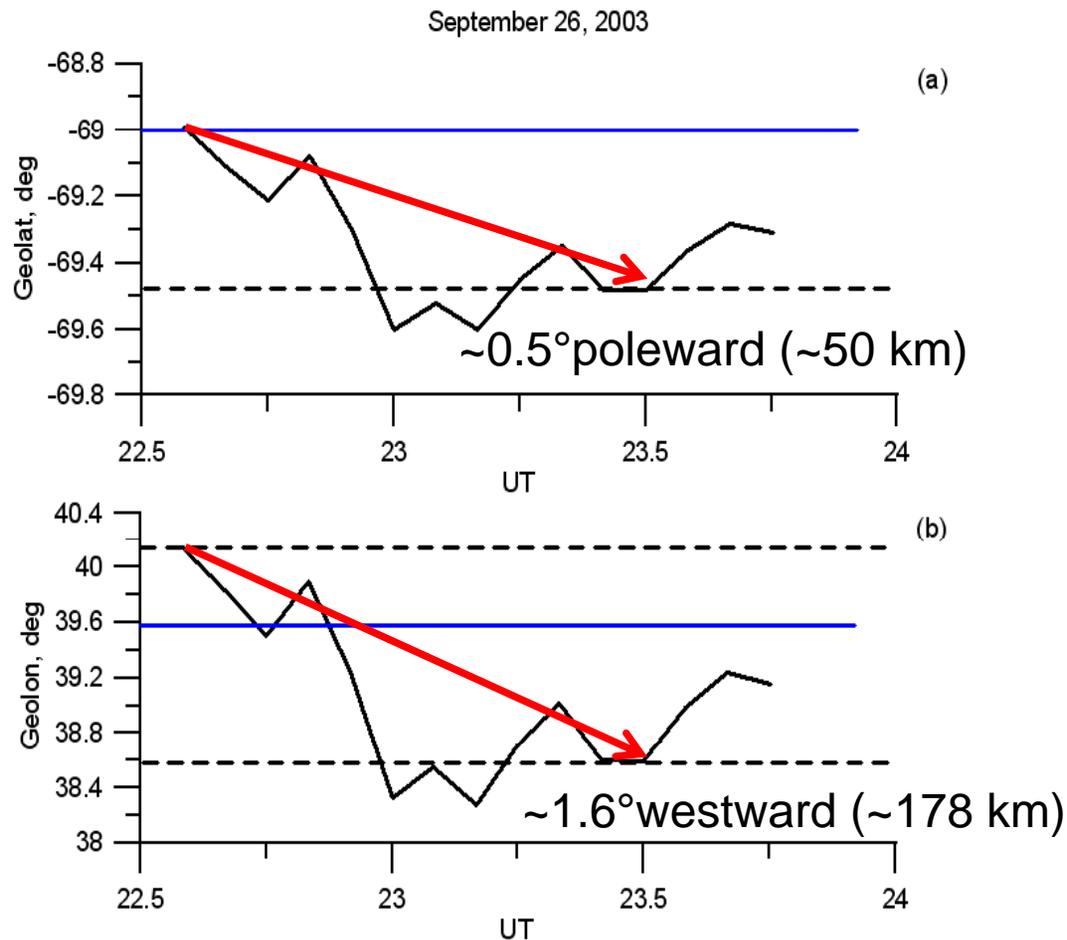
September 26, 2003



Significant deviation of the solar wind from radial (Sun-Earth) direction.

V_z was as large as 55 km/s in absolute values, and the rotation angle can be as large as 3-5\deg.

Conjugate points in the northern and southern hemispheres: Observed and modeled (2)



Footpoints of Tjornes station in the southern hemisphere

Black lines:

latitude and longitude of Tjornes station given by T02 model with rotation angle procedure

Blue lines

latitude and longitude of Tjornes station given by T02 model.

Red arrows

Indicate displacement of initial latitude and longitude at 2230 UT during one hour of observations.

Meridional displacement is 0.5° poleward (50 km) and azimuthal shift is by 1.6° westward (178 km). These values of the modeled displacements are close to the observed ones.

Summary (1)

1. The concept of the interhemispheric magnetic conjugacy was investigated by comparing the conjugate points in the northern and southern hemispheres, using Tsyganenko T02 magnetic field model to follow the magnetic field lines.
2. We studied the influence of the dipole tilt angle, solar wind (solar wind dynamics pressure and flow direction) and IMF parameters (IMF B_y and B_z) on the latitudinal and longitudinal differences between the points in both hemispheres.
3. It was found that the magnetic field lines starting at latitudes of 75° for moderately disturbed and at 60° for disturbed conditions in the northern hemisphere do not come at all to the southern hemisphere for any tilt angles on the dayside.
4. The dominant difference is longitudinal, which reaches up to 30° , while latitudinal differences is about 2° .

Summary (2)

5. The largest differences are observed at dawn and dusk MLTs for large dipole tilt angles during high solar wind dynamic pressure (16-20 nPa) and large IMF B_y values (-15 and 15 nT).

Nightside magnetosphere is much more affected by large Psw.

Asymmetry does not depend on the IMF B_y magnitude.

6. The influence of IMF B_z on the interhemispheric conjugacy depends on the sign of B_z . Lat. Difference can be as large as 3-4 degrees for negative IMF B_z .

7. The influence of the rotation of the tail current sheet from the Sun-Earth line was also studied, which represents the influence of non-radial solar wind flow on the magnetic field configuration. The rotation by several degrees resulted in latitudinal differences of 1° and longitudinal differences of 15° at dawn and dusk MLTs for equinox.

8. Analysis of the magnetic conjugacy of Tjornes (Iceland) and Syowa (Antarctica) observatories, which detected similar auroras simultaneously with all-sky TV cameras, confirmed the importance of taking into account the solar wind flow direction, when it deviates from radial by more than $1-2^\circ$.