RAS Specialist Discussion,

Achievements in Characterising Ionospheric and Magnetospheric Fields

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Motivation and outline

The separation between internal and external field distributions is still the largest obstacle for improving the main field models and in particular for quantifying the secular variation properly.

High-accuracy magnetic field measurements in near-Earth space provide an important constraint for interpreting properly the ionospheric and magnetospheric current systems.
In the past too much faith has been put in indices like Dst.

- Ionospheric current systems on the night side
- Characteristics of magnetospheric currents

Introduction

Ionospheric and magnetospheric fields are caused by electric currents.

Ionosphere

$$\vec{j} = \sigma \left(\vec{E} + \vec{u} \times \vec{B}\right) + \left[n m_i \vec{g} \times \vec{B} - k \nabla \left\{\left(T_i + T_e\right) n\right\} \times \vec{B}\right] \cdot \frac{1}{B^2}$$

drivers:

E-field wind gravity pressure gradient

Magnetosphere

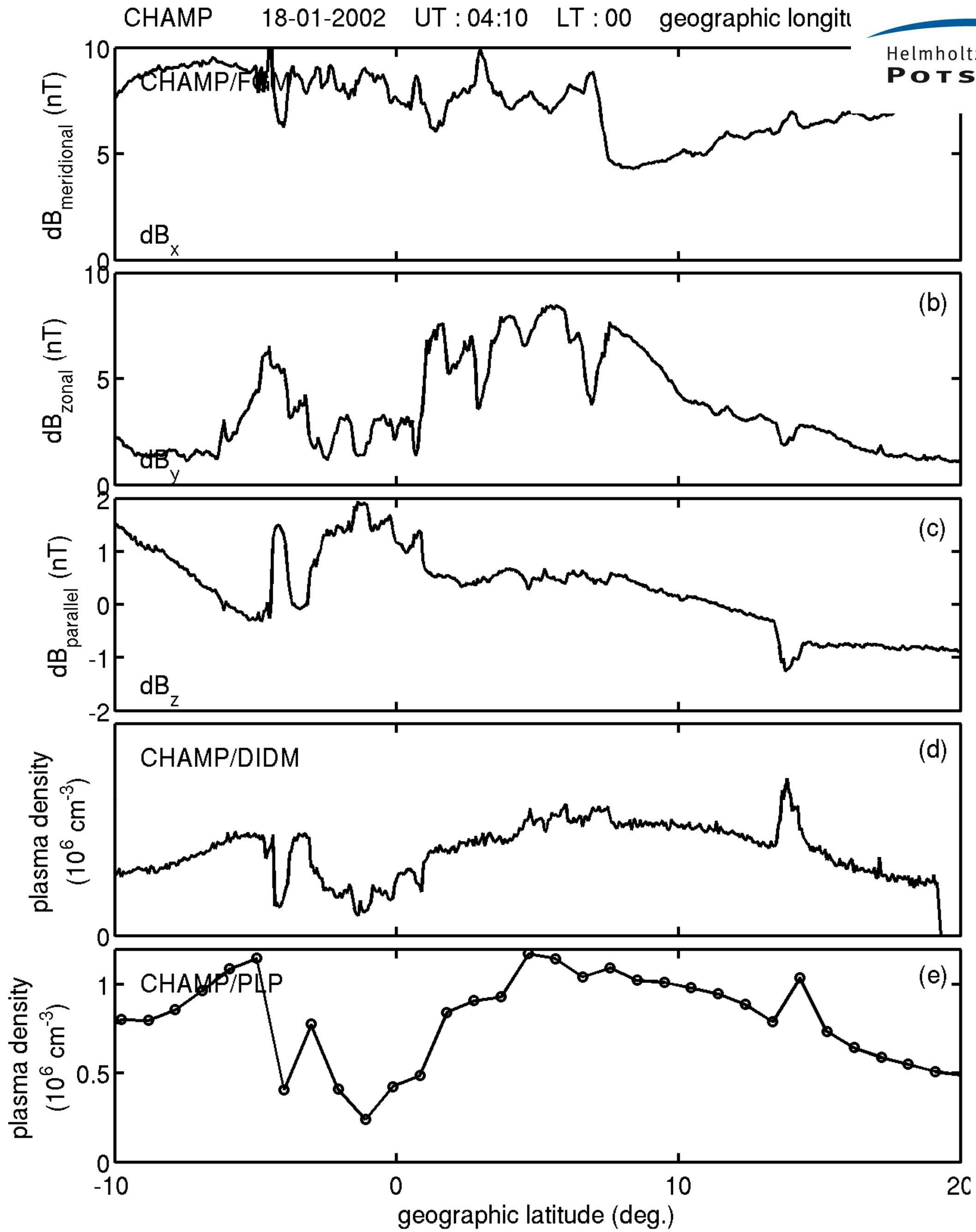
$$\vec{j}_\perp = \left[n m_i v_{\|i}^2 \frac{\hat{r}}{r} \times \vec{B} - n\left(T_i + T_e\right) \frac{k}{\vec{B}} \nabla B \times \vec{B} - k \nabla \left\{\left(T_i + T_e\right) n\right\} \times \vec{B}\right] \cdot \frac{1}{B^2}$$

drivers:

field curvature field gradient pressure gradient

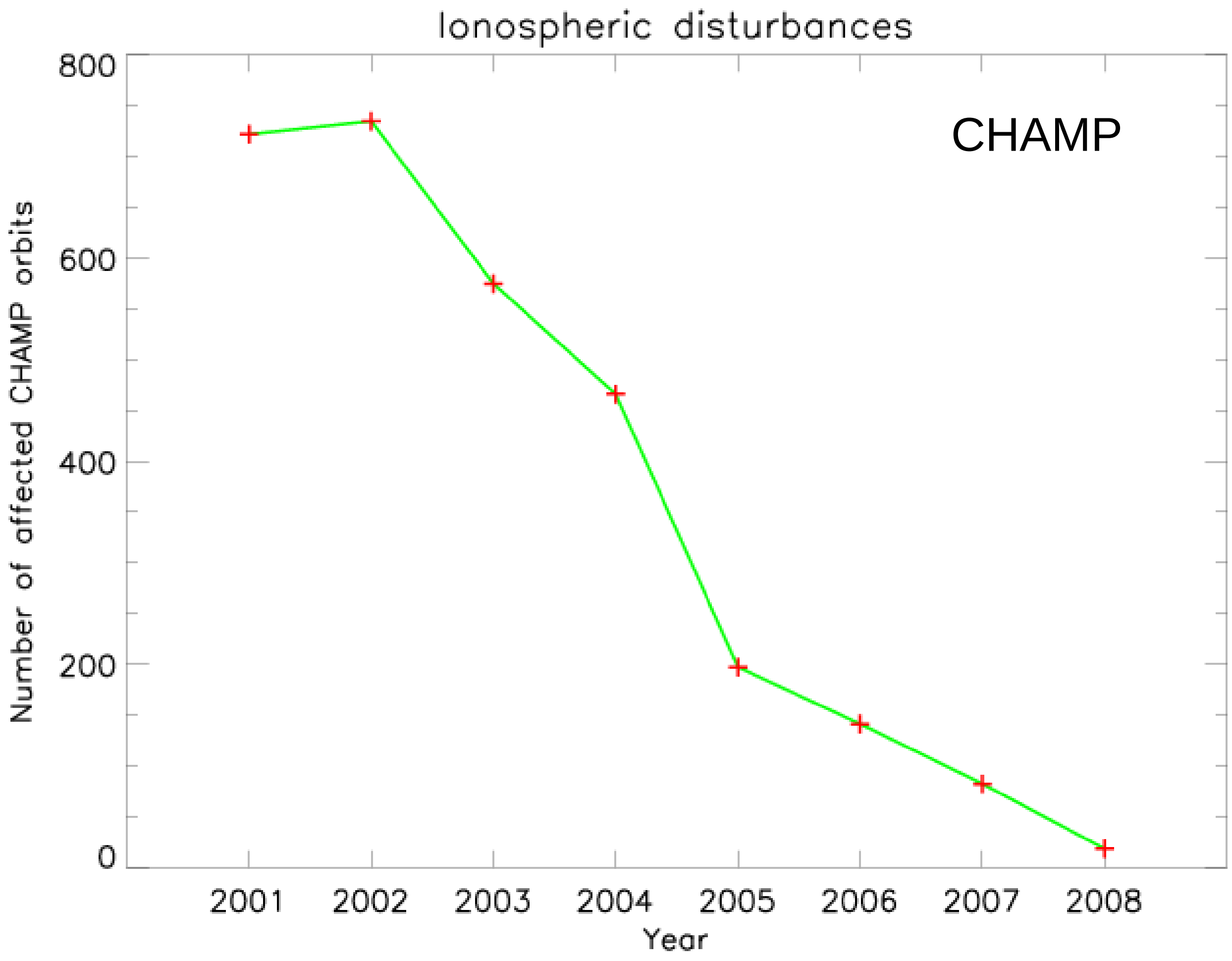
Example of magnetic disturbances caused by plasma irregularities in the night-time ionosphere. Deflections show up in the total field and in the transverse components.

The field strength variations are anti-correlated with the plasma density changes, keeping the total pressure constant.



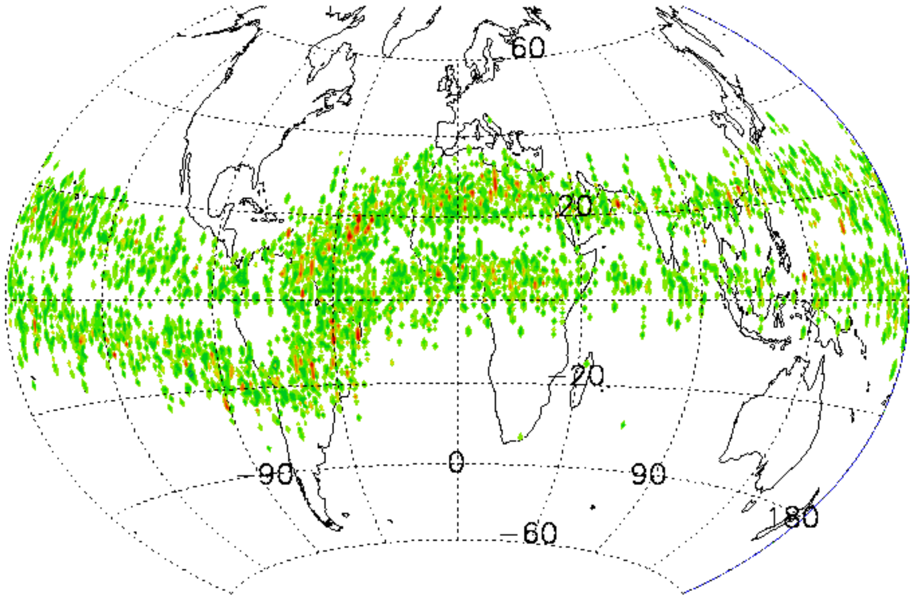
Ionospheric bubble index (Swarm L-2 product)

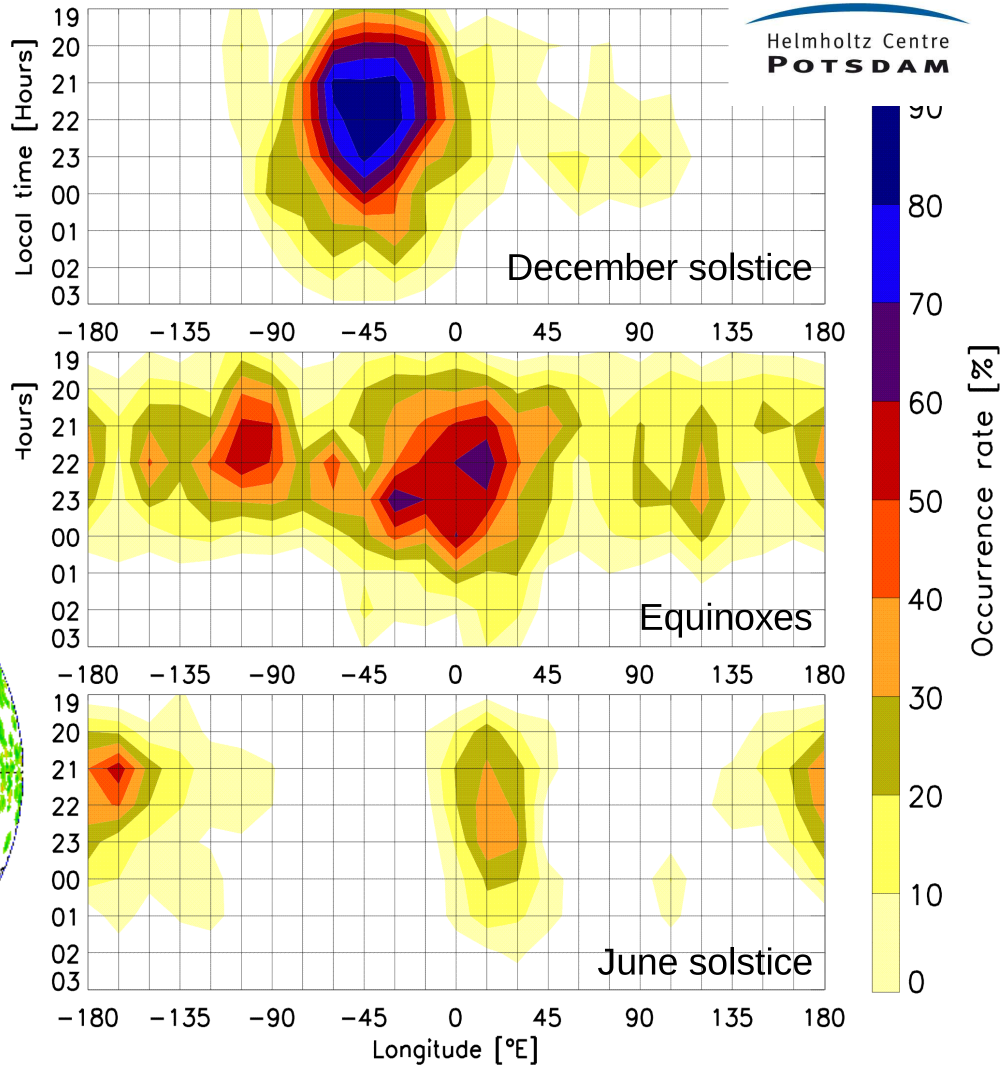
- The occurrence of bubbles is especially high during solar maximum years.



Spatial and temporal distribution of plasma irregularities.

Both show systematic patterns.



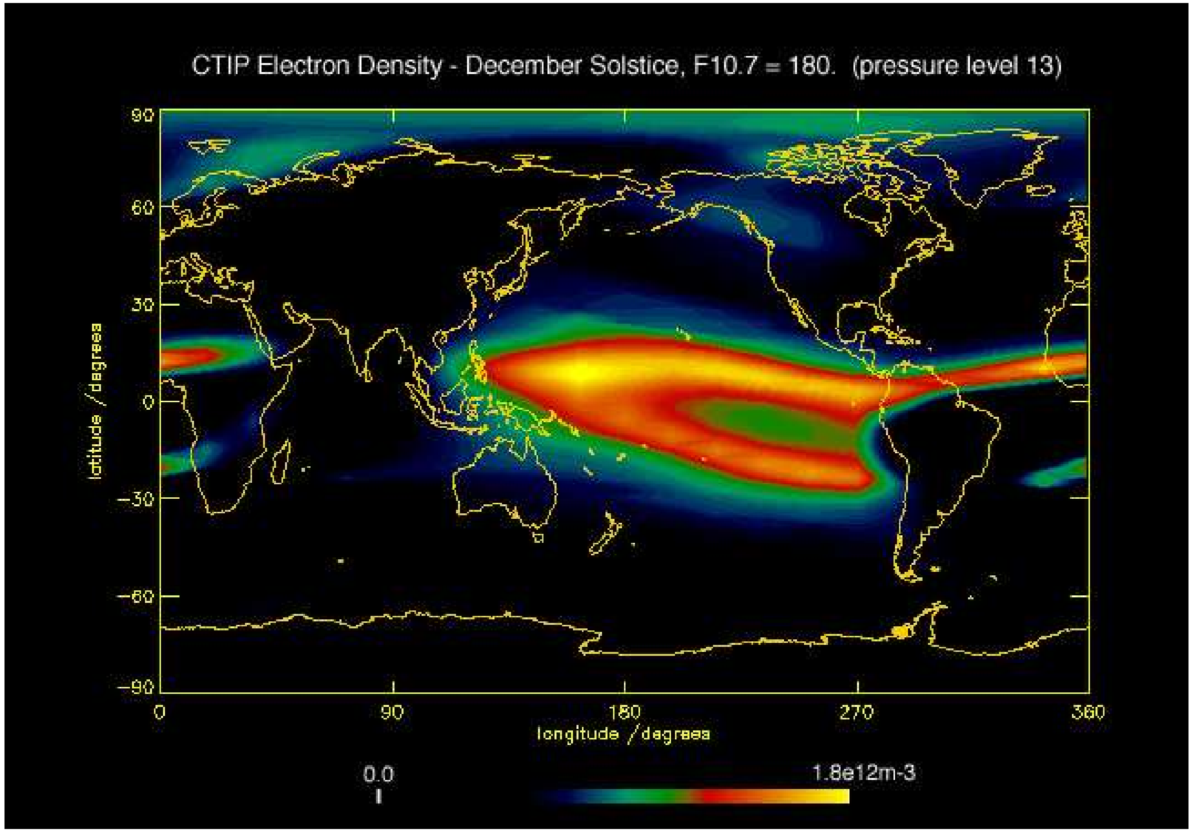


(Stolle et al., 2004, 2008)

Simulating the low-latitude ionosphere

Coupled Thermosphere, Ionosphere and Plasmasphere (CTIP)

- Physical first principle model
  developed at University College London
- Self-consistent model with coupled thermosphere and ionosphere



Noon time at centre of figure

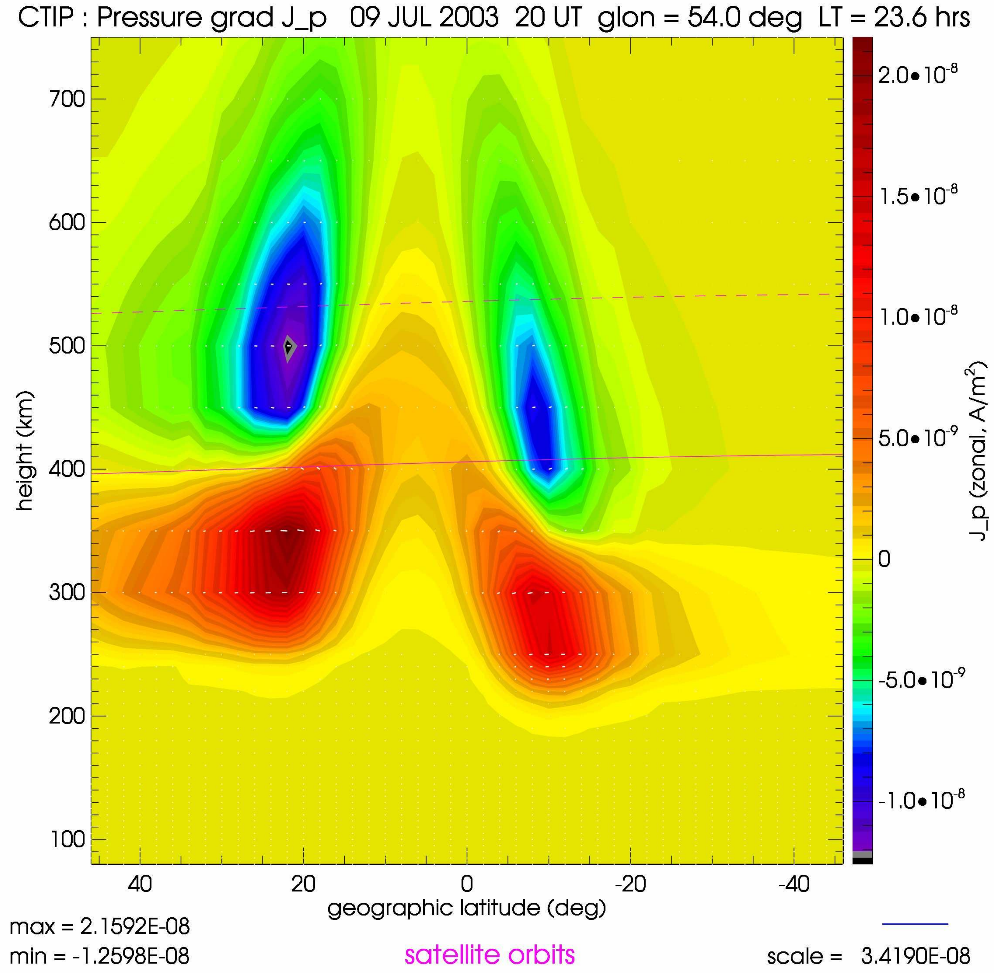
Altitude: ~450 km

ESA supported study for investigating the ionospheric dynamics

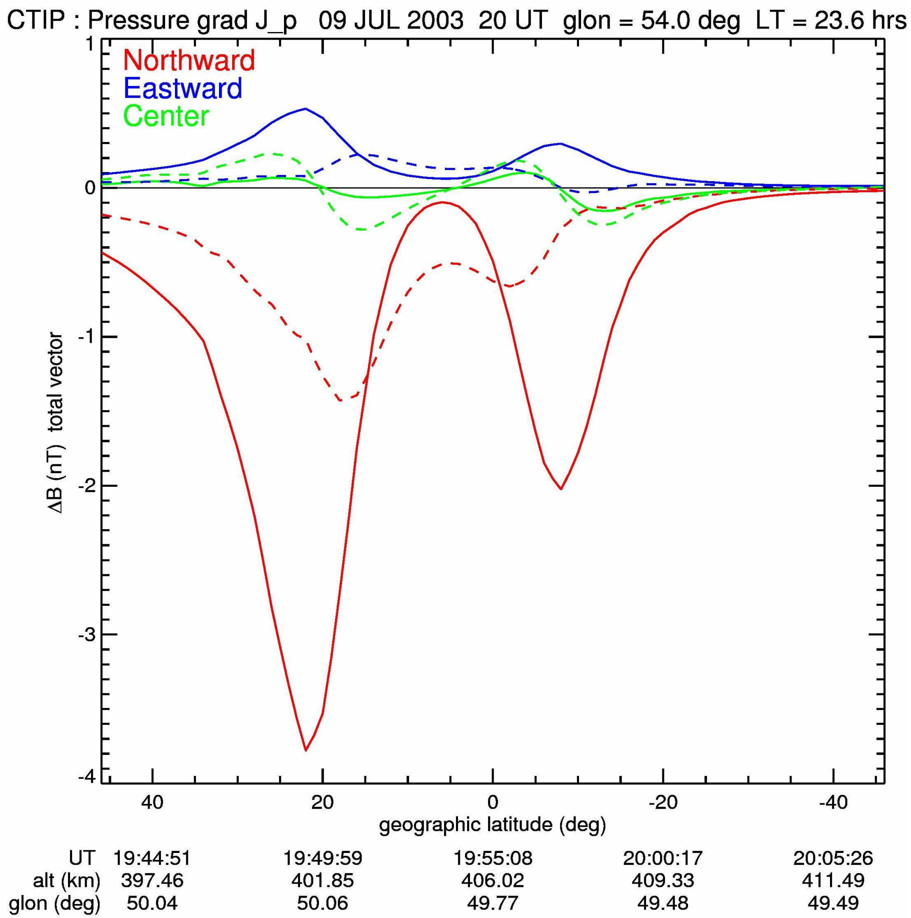
- For selected days the ionospheric conditions were simulated with the help of the CTIP model.
- Simulated ionospheric and thermospheric parameters were compared with observations (CHAMP and radar)
- Swarm satellites on realistic orbits ‘sampled’ the simulated quantities.
- These are discussed in the context of the mission objectives.

Pressure gradient currents, CTIP

Zonal currents in opposite directions



B-fields along orbits
(dashed at 530km)



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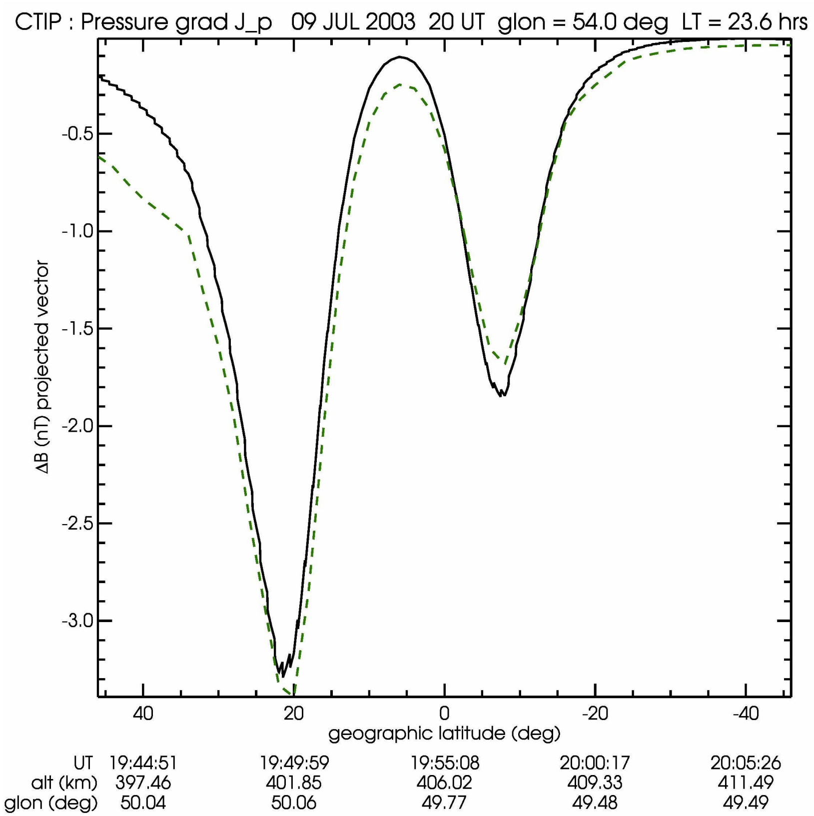
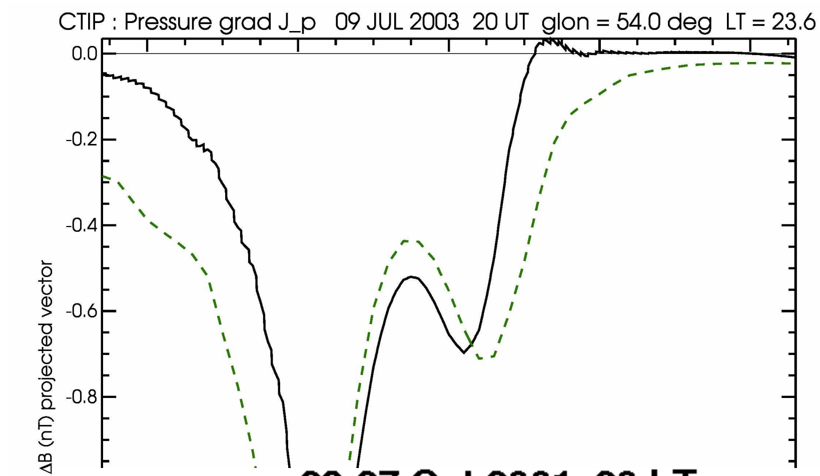
Predicted and derived magnetic perturbations

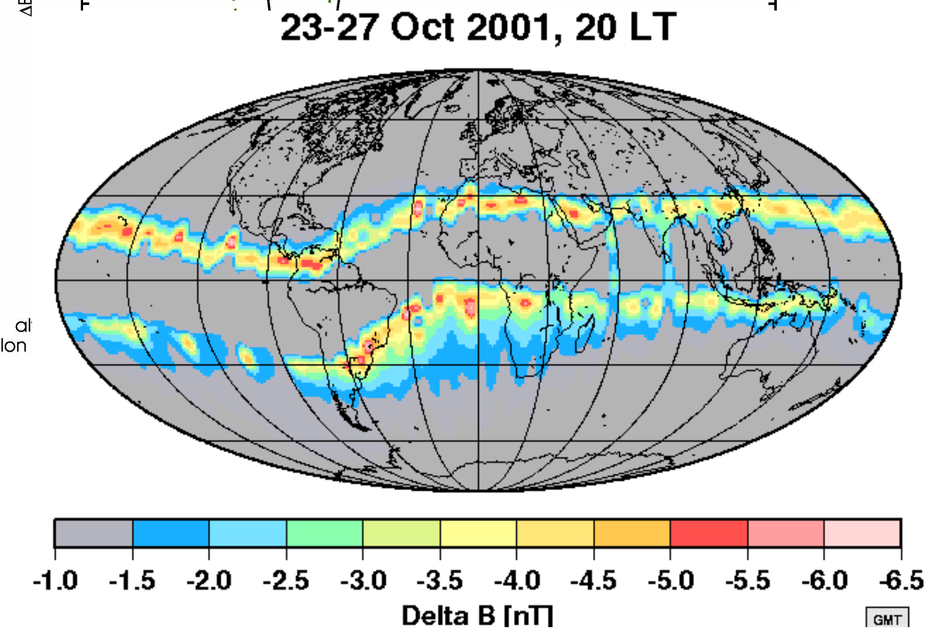
Comparison of B-field deflection as obtained by CTIP from currents (full line) and from diamagnetic effect (dashed)

$$b = n(T_i + T_e)\frac{k\mu_0}{B}$$

(Lühr et al., 2003, GRL)







Results pressure gradient currents

- The CTIP model confirms the existence of significant **pressure gradient** currents on the night side. The magnetic effect of these currents is largest around 400 km altitude and decays rapidly with altitude. (At Ørsted altitudes no signature of field depression can be detected)

- The magnetic effect of pressure gradient currents can be predicted reliably from locally observed plasma parameters (assumption of pressure balance).

Gravity-driven currents

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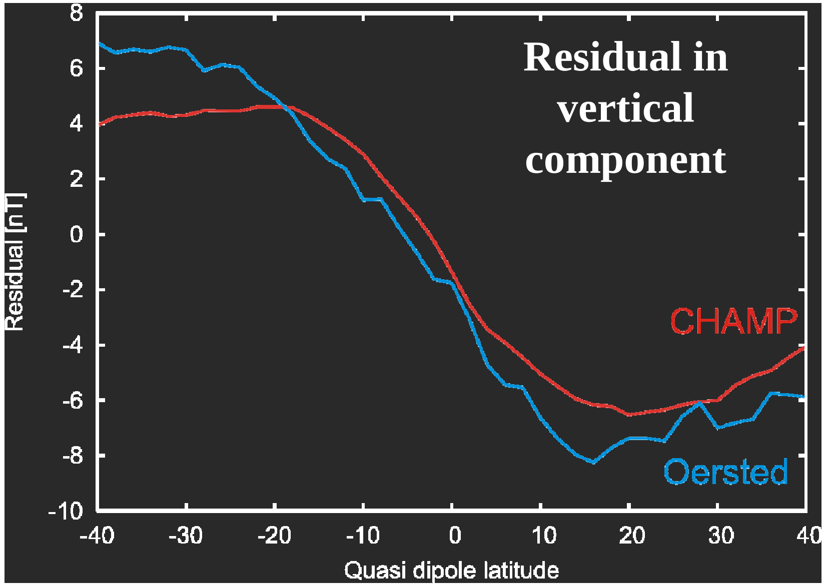
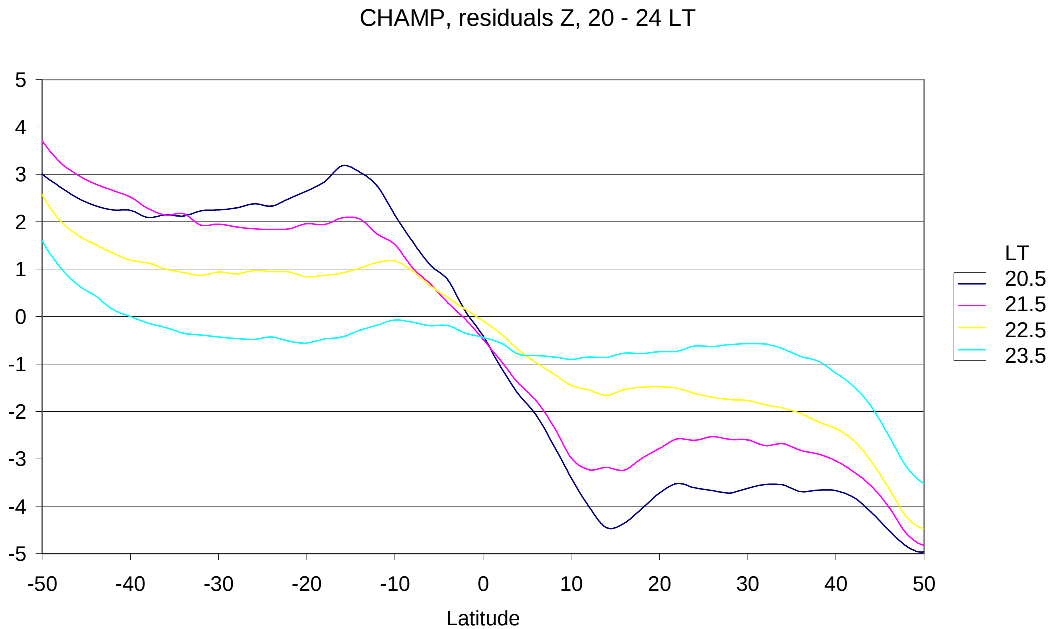


Magnetic field deflection due to gravity currents, 18-20 LT.

$$\vec{j} = \sigma_P \left(\vec{E} + \vec{u} \times \vec{B} \right) + \left[n m_i \vec{g} \times \vec{B} - k \nabla \left\{ \left(T_i + T_e \right) n \right\} \times \vec{B} \right] \cdot \frac{1}{B^2}$$

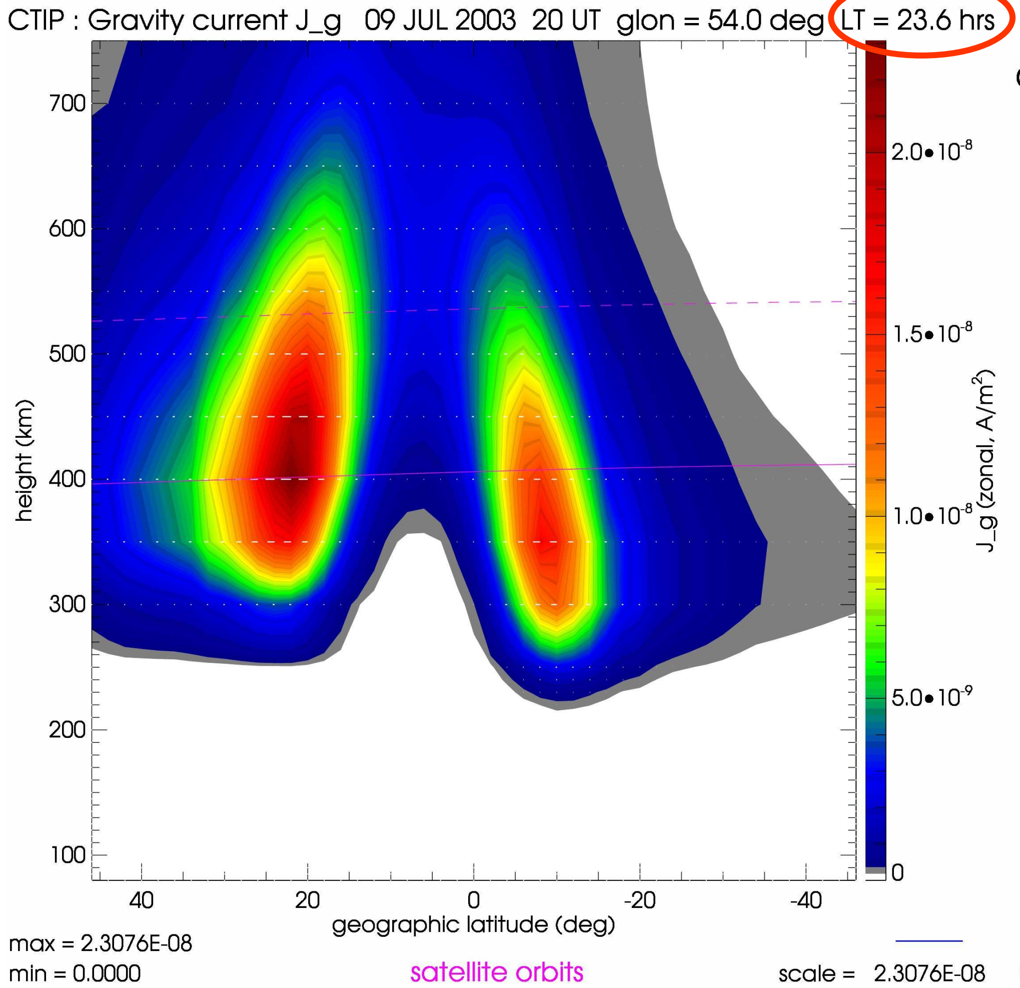
gravity



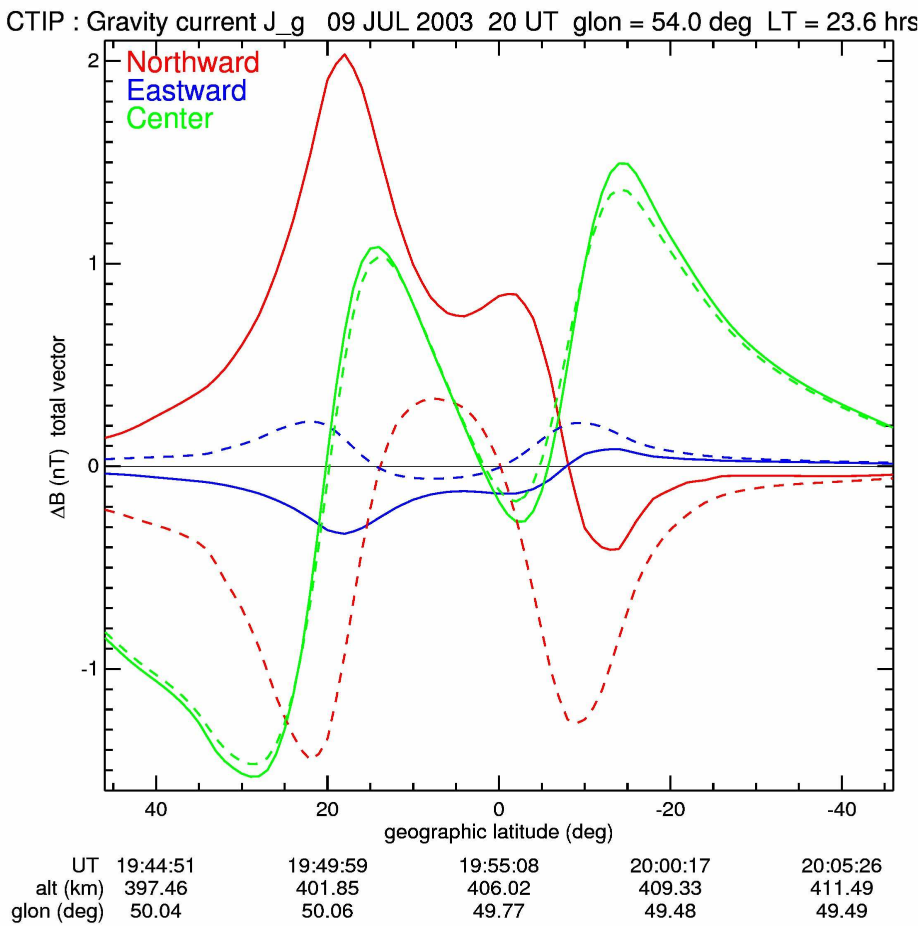
CHAMP, mean deflection, 2001 - 2004

Modelled gravity-driven currents, CTIP

Zonal currents in eastward direction

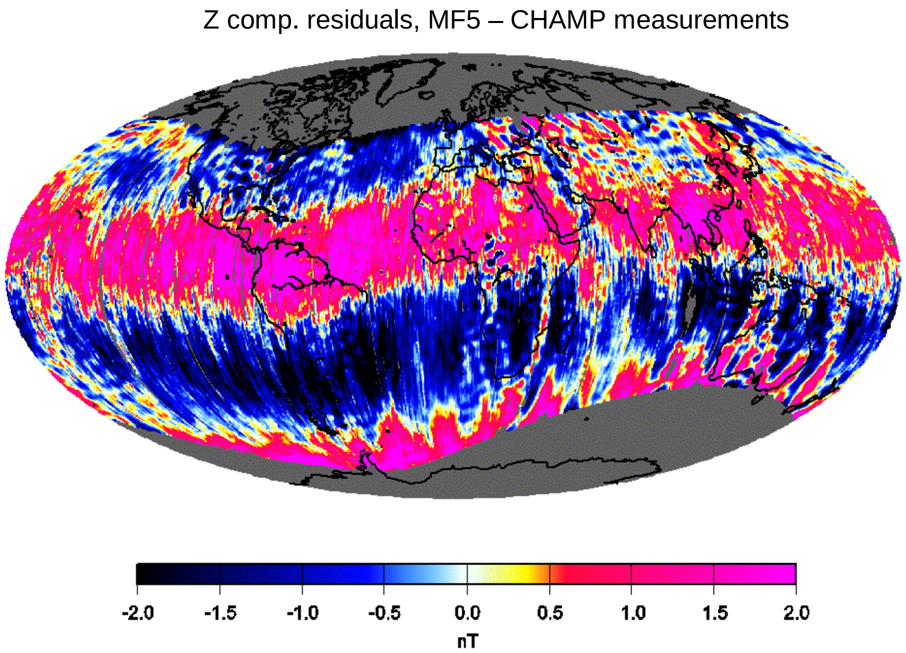


Magnetic field effects at 400 km (full line)
530 km (dashed)



Results gravity-driven currents

- Gravity-driven currents are difficult to model because they set up polarisation E-fields which can drive complex current systems. CTIP was not successful.
- Its magnetic effect (Z comp.) shows little dependence on altitude.
- The correction proposed by Maus and Lühr (2006) caused a clear overcompensation in the vertical comp. of the MF-5 model.



Magnetospheric fields

- Decomposition
- Parameterization

Inner magnetosphere

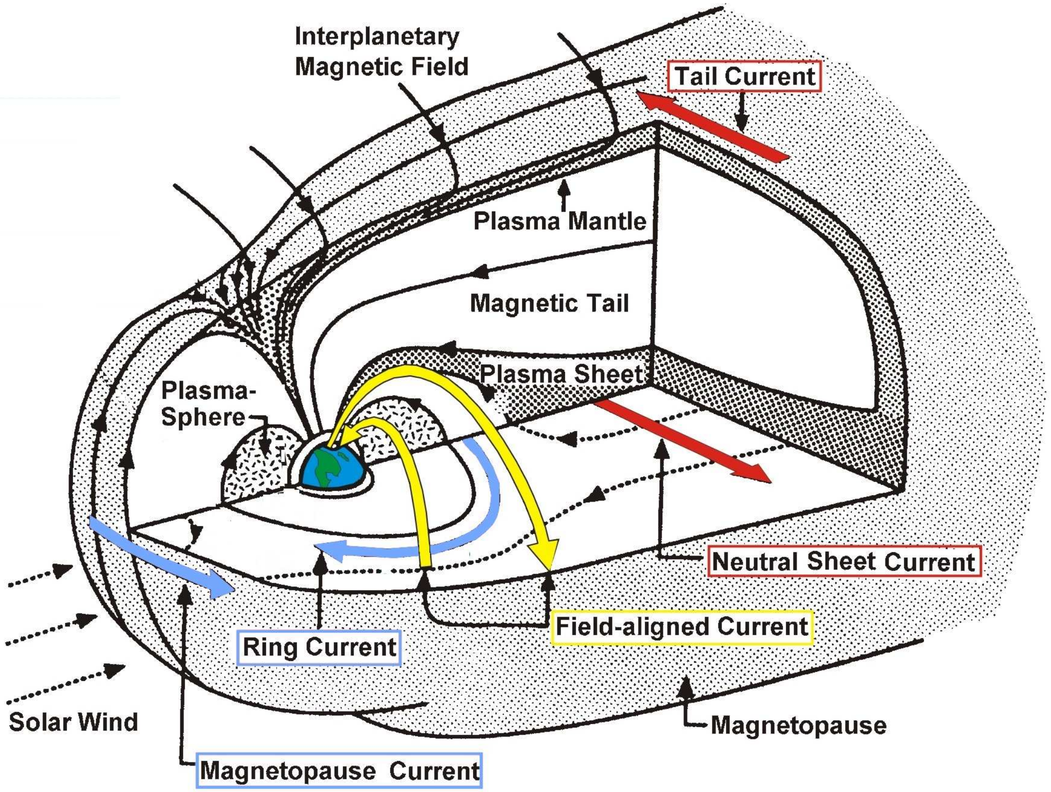
Currents best organized in Solar-Magnetic, SM frame
(Z aligned with dipole axis, X pointing towards Sun, Y to duskside.)
e.g. ring current (blue).

Outer magnetosphere

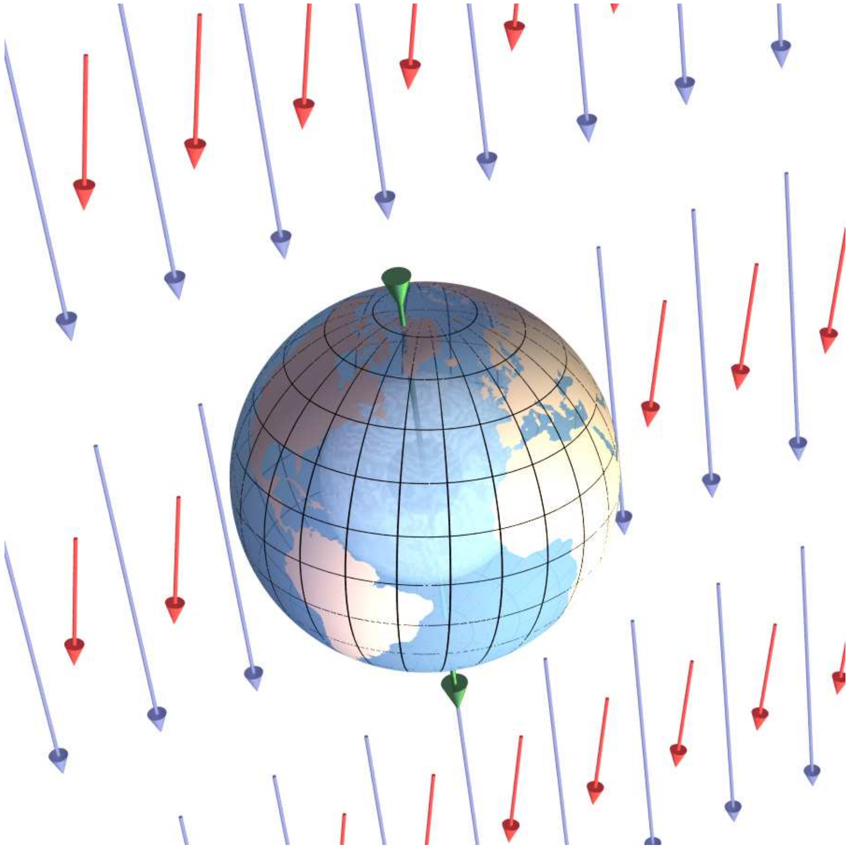
Currents organized in Geocentric-Solar-Magnetospheric, GSM frame
(X pointing from Earth to Sun, Y perpendicular to dipole axis, pointing dawnward, Z completes triad, pointing northward)
e.g. magneto-tail currents (red).

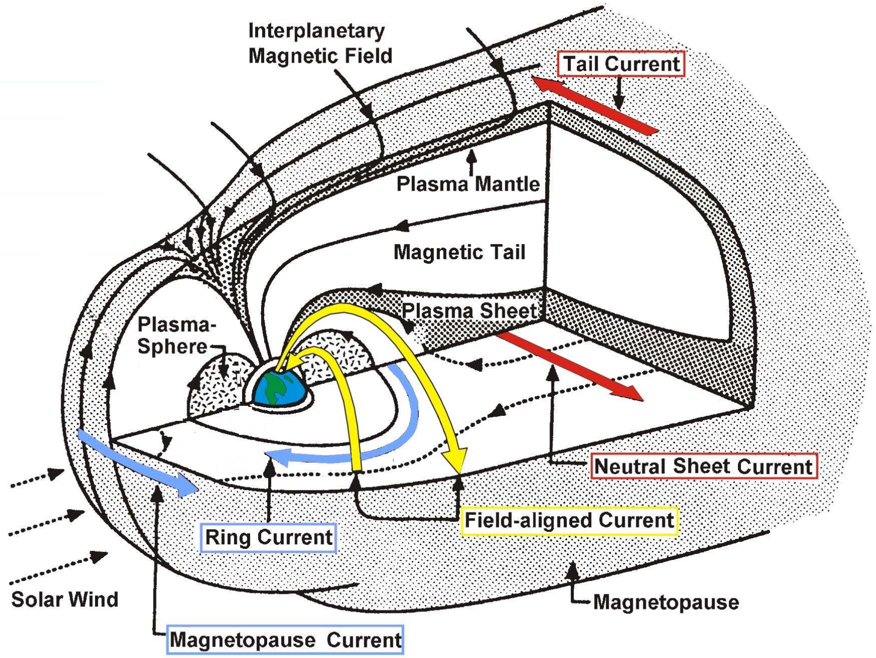
Field-aligned currents

Connecting the magnetospheric regions with the ionosphere (yellow).



Magnetospheric contributions



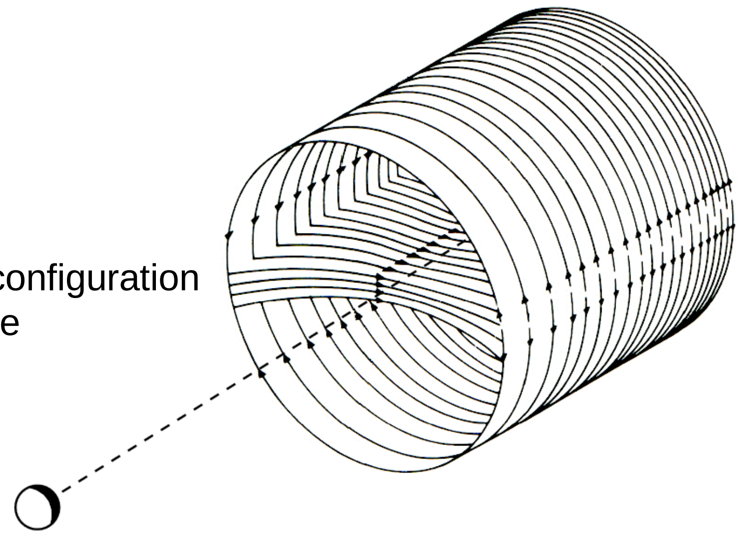


Contributions from

ring current, field aligned with dipole (SM frame)

magneto-tail current, field aligned with GSM-Z comp. (GSM frame)

Tail current configuration in GSM frame



Quantitative properties of external fields

Ring current (in SM frame):

1. The quiet-time field (7.6nT) is only 1/3 of the value reported by Langel and Estes (1985).
2. The magnetic effect at LEO altitude is by 20% smaller than expected from ground (open issue).
   Local time variation of ring current (open issue).

Magneto-tail current (in GSM frame):

1. The magnetic effect of tail currents is aligned with the GSM-Z axis.
2. During quiet times it has a constant strength of 13 nT.
3. Magnetospheric currents/fields are also influenced by the orientation of the interplanetary magnetic field (e.g., Lesur et al., 2005).

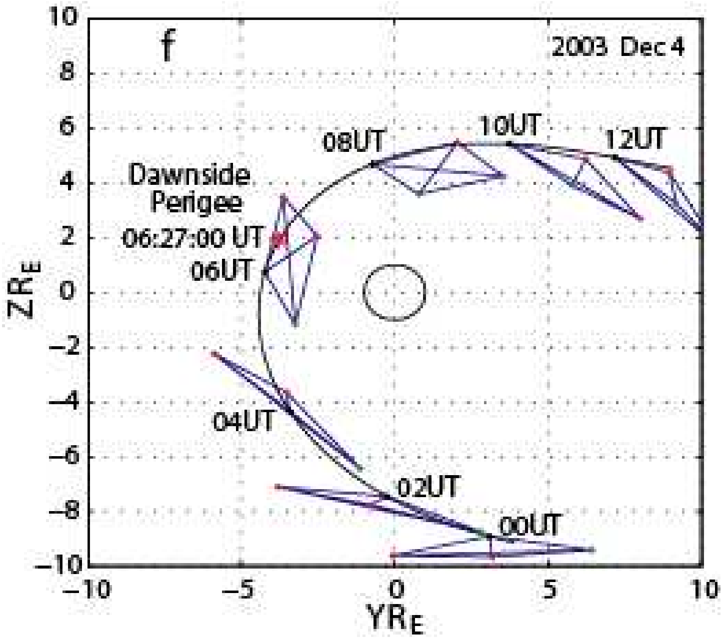
			Order m				
		n	0	1	-1	2	-2
SM	Stable field	1	7.57				
	Stable field	2		0.48	1.74		
	E_{ST}/I_{ST} factor	1	0.79				
GSM	Stable field	1	12.90	0.11	-0.03		
	Stable field	2	0.12	-0.40	-0.07	-0.15	0.15
	IMF correlated:						
	IMF Bx factor	1		-0.10			
	IMF By factor	1			-0.23		

(Maus and Lühr, 2005, GJI)

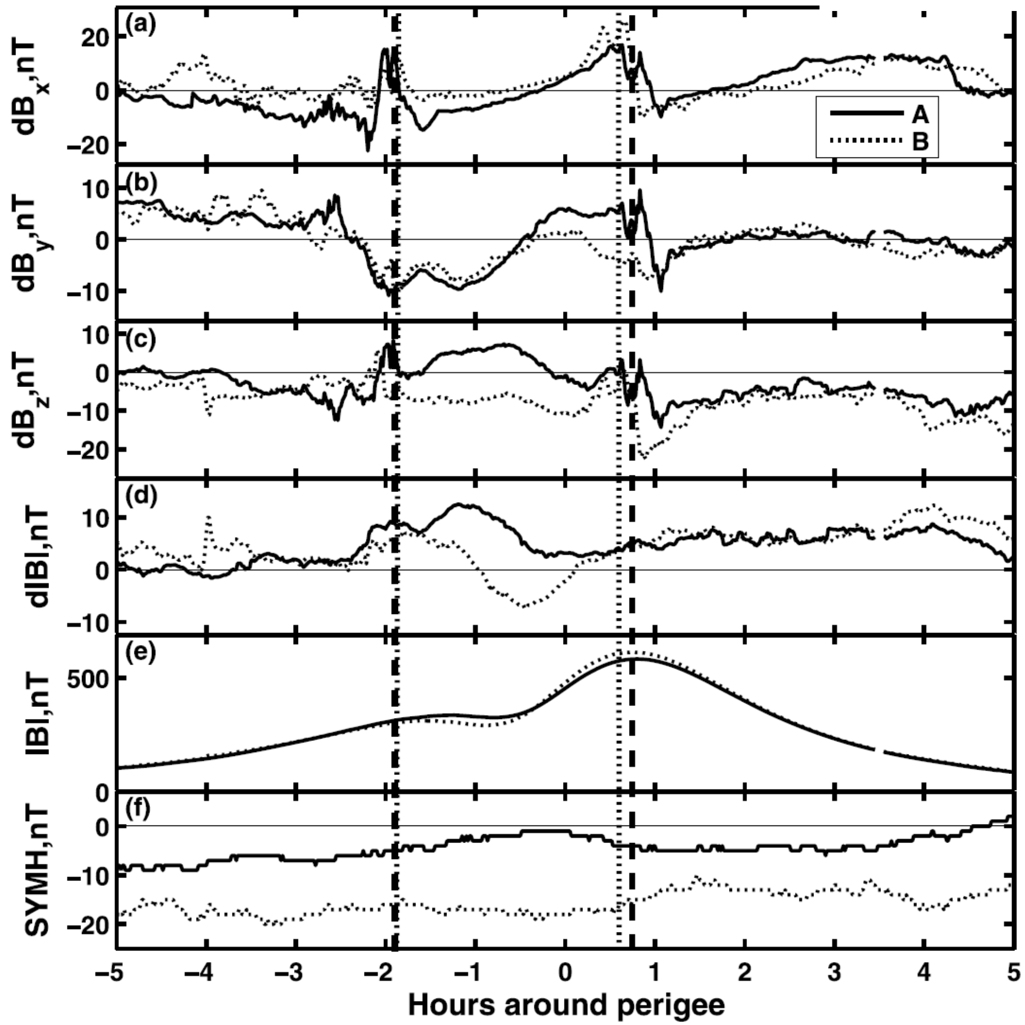
Future aims

- A space-based replacement for the Dst should be developed.
- The decomposition of that index should be physics-based.
- For the validation of the decomposition magnetospheric measurements are indispencable.
- Measurements should be augmented by magnetospheric models in order to make sensible predictions for the near-Earth space.

Cluster passage through ring current



(Woodfield et al., 2007)



A stronger ring current affects primarily the dipole-aligned component Z.

The field strength is reduced inside the RC due to high plasma pressure.

Summary

- ❖ Our knowledge about ionospheric currents on the night side has increased significantly.
- ❖ The proper description of gravity-driven currents is still pending.
- ❖ For the quantification of magnetospheric currents physical properties like the Dessler-Parker-Sckopke relation (Dst is proportional to total particle energy in RC) should be considered.
- ❖ So far little attention has been given to the magnetic effect of large-scale field-aligned currents.

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