Recent achievements in characterising the magnetosphere, ionosphere and thermosphere

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First Swarm International Science Workshop

Nantes, 3-5 May 2006

Pre-CHAMP Assumptions

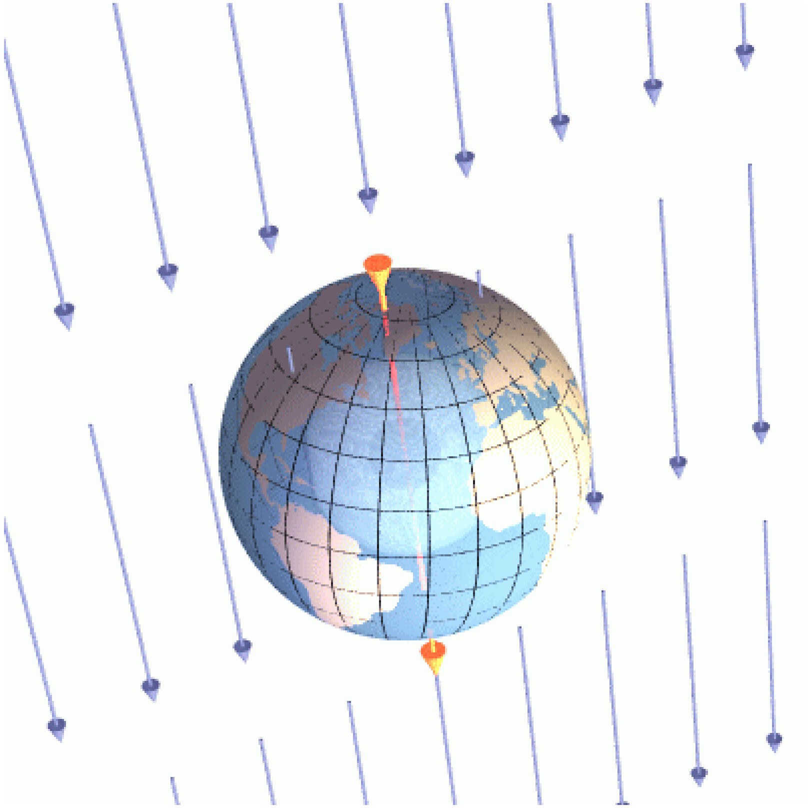
- Magnetospheric field contributions are well ordered in dipole coordinates. The amplitude scales with D_{ST}.

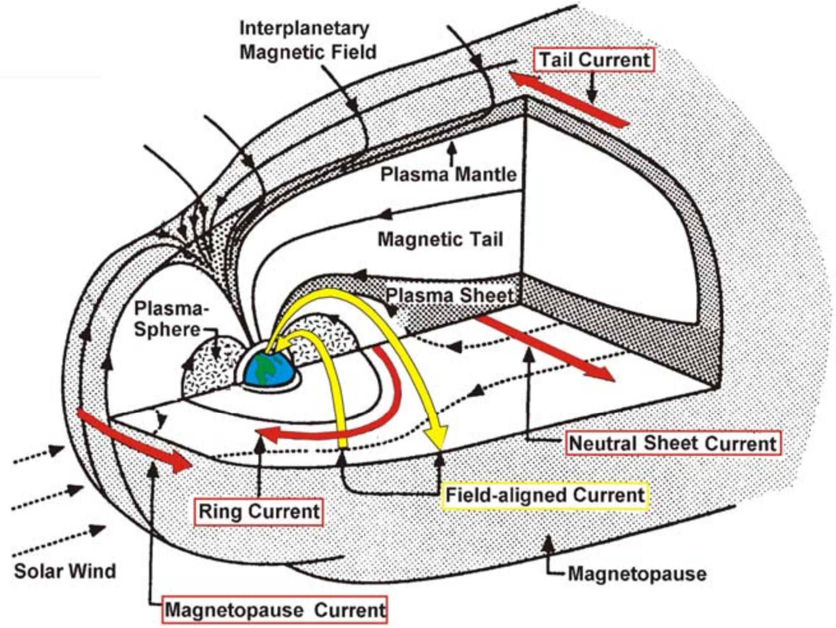
- Ionosphere currents at middle latitudes are negligible at night times.

- All ionospheric currents are confined in the E-layer (100-150 km) except for field-aligned currents.

- The dynamics of the thermosphere (density, winds) is driven by short-wavelength (EUV) solar radiation.

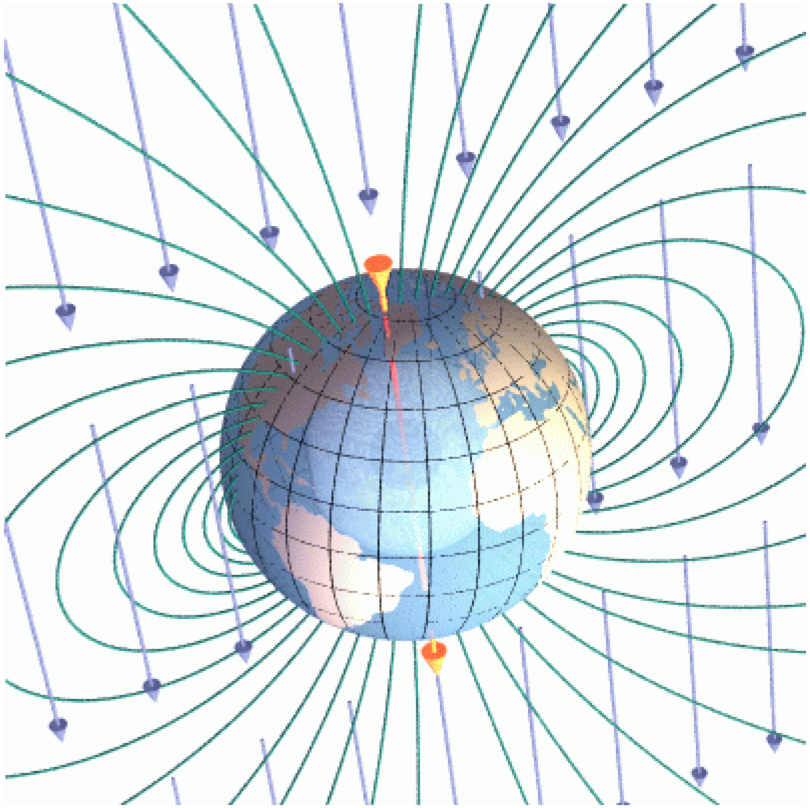
Magnetospheric contributions

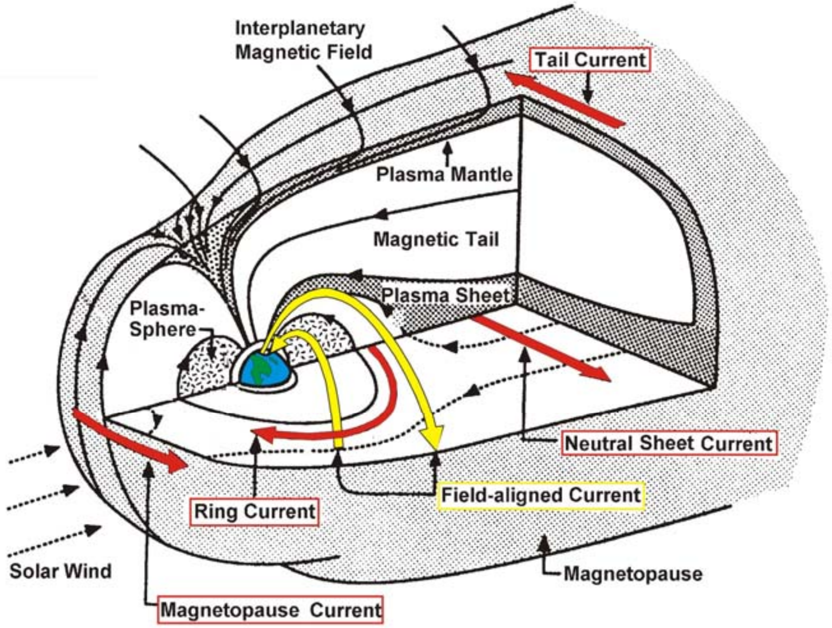




External field from ring current
in dipole coordinates (SM)

Magnetospheric contributions





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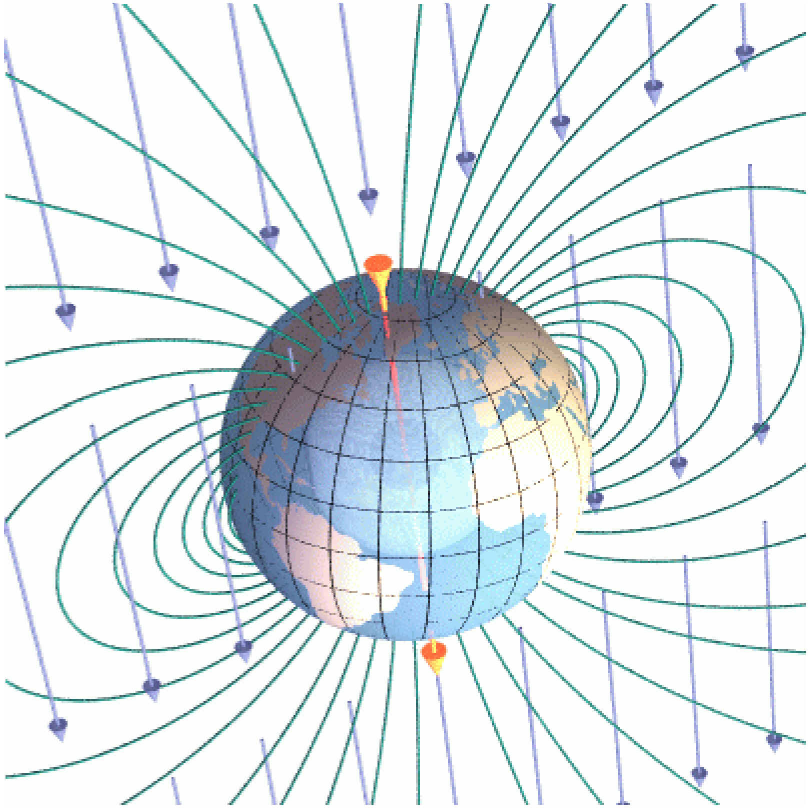

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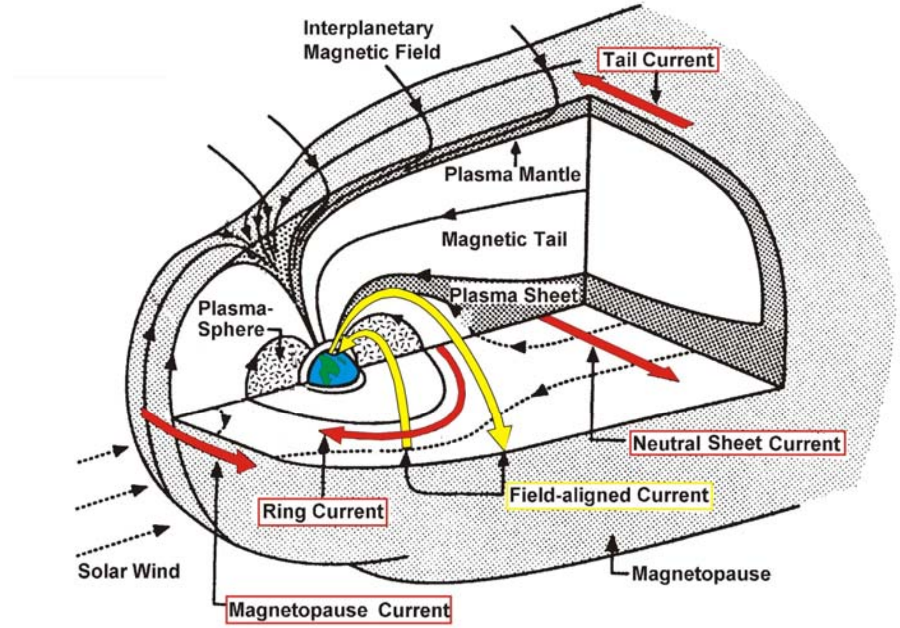
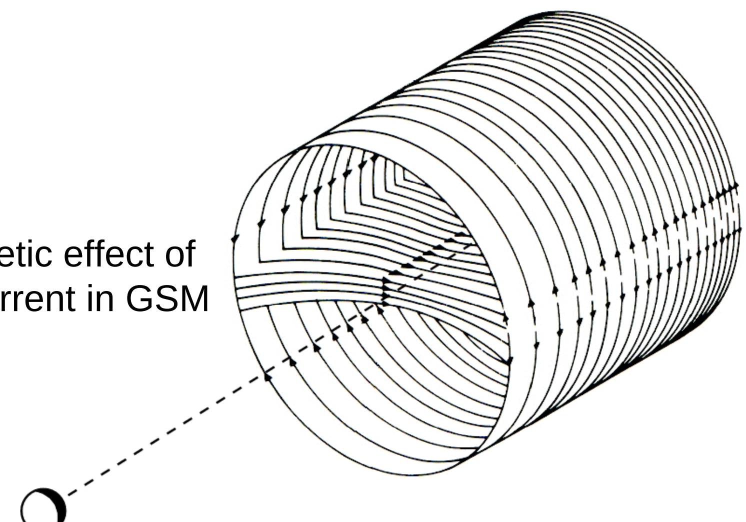
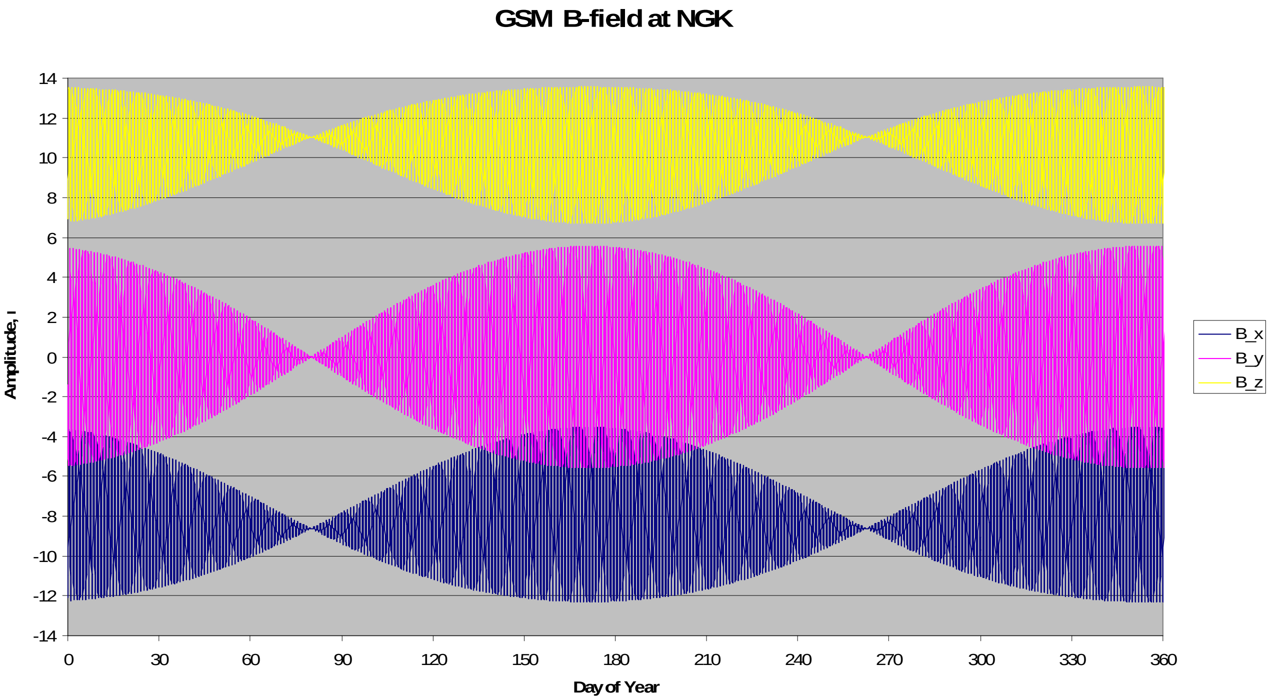


Magnetic effect of
tail current in GSM



Magneto-tail field at NGK



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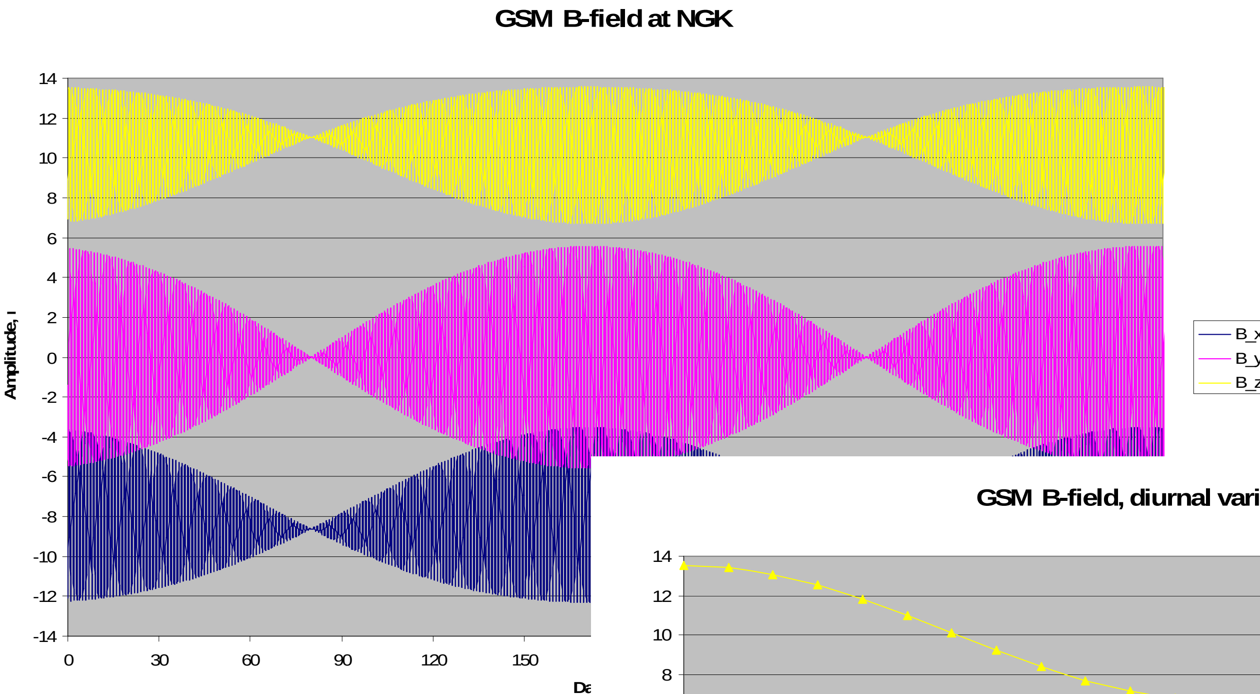
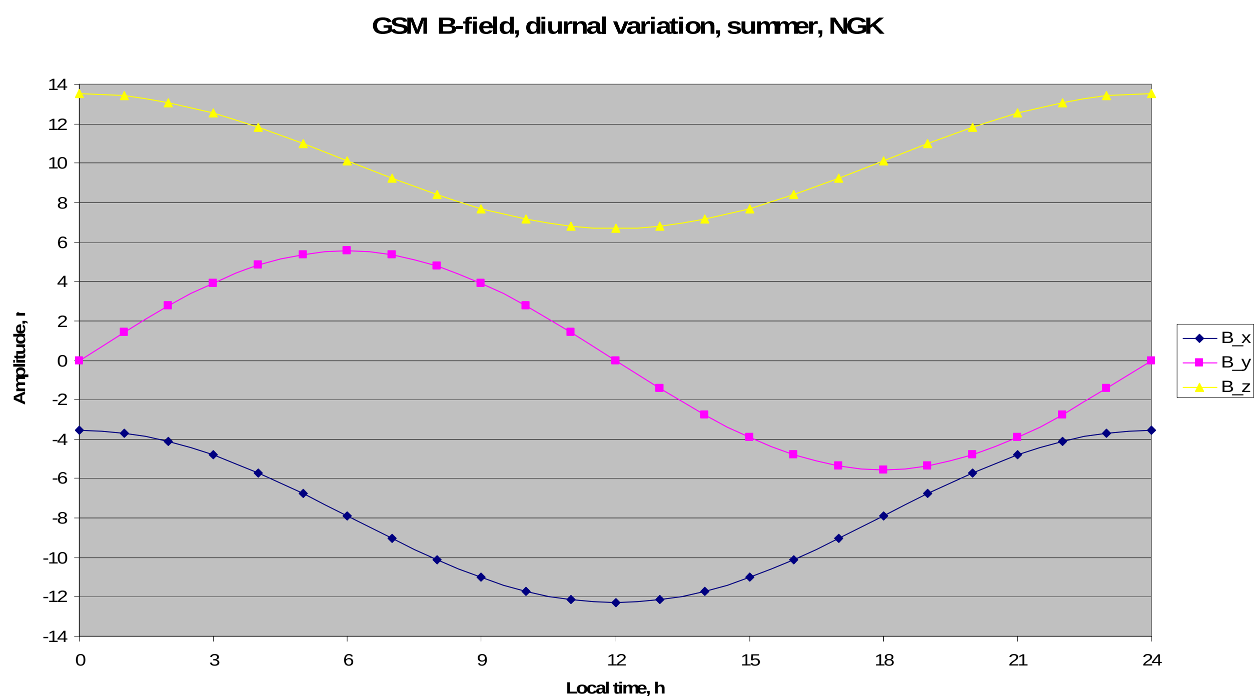
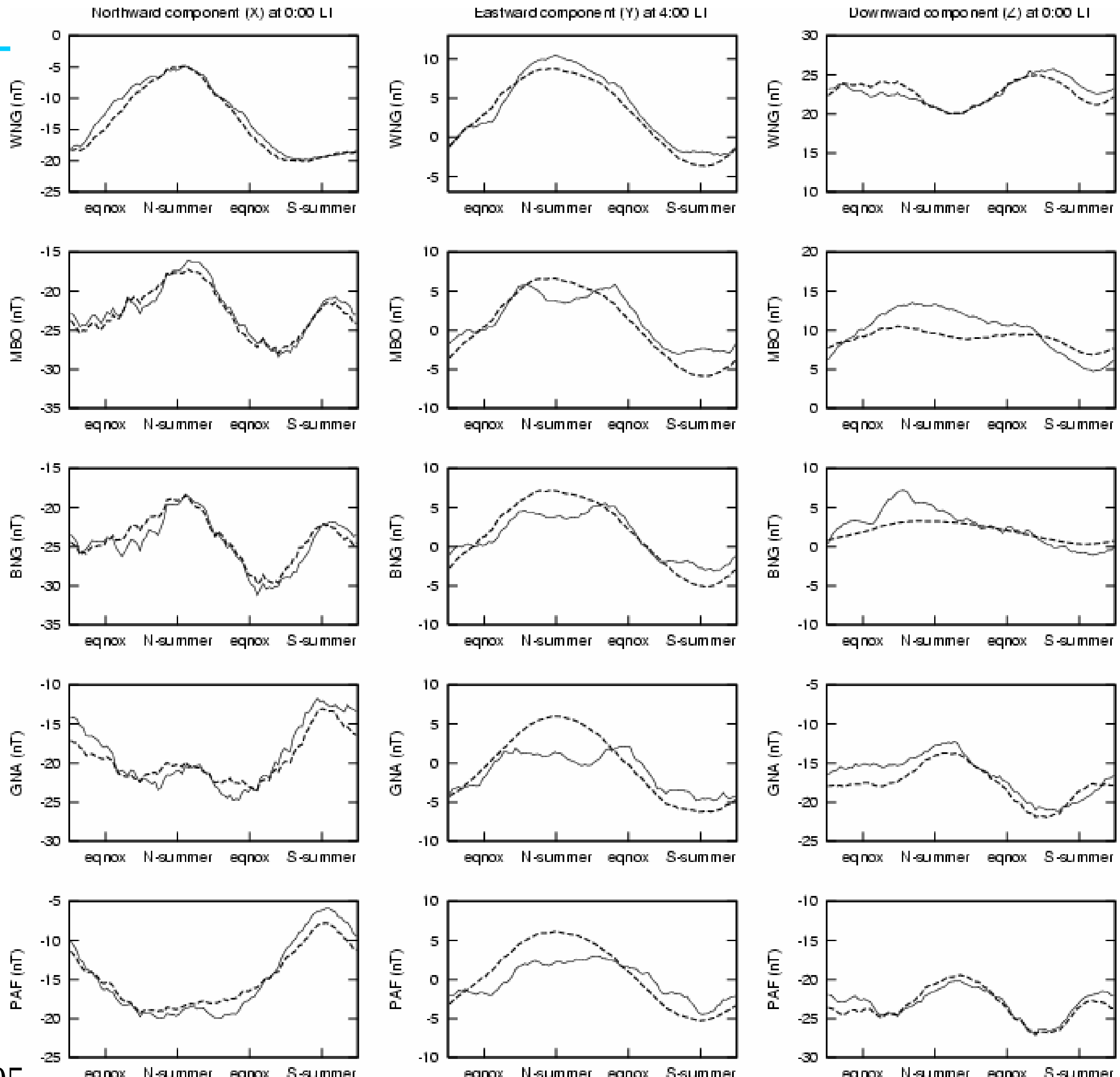




Model – Observatory comparison



54.1°

20.4°

4.4°

-42.4°

-57.2°

mag. lat.

Maus and Lühr, 2005

Structure of Magnetic Fields

- During quiet periods there is no indication of an asymmetric ring current (LT dependence).
- The D_{ST} index has to be decomposed into an internal and external part (I_{ST} and E_{ST}).
- Stable magnetotail currents cause a magnetic field at the Earth of about 13 nT, which exhibits diurnal and annual variations.

Ionospheric currents

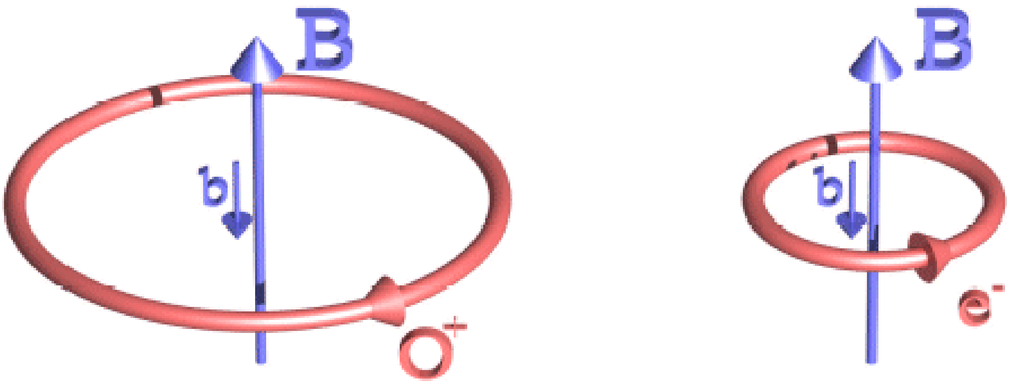
- Spherical harmonic expansions of the magnetic field require measurements in a current-free space.

$$\text{curl } B = \mu_0 \, j = 0$$

- It has been widely assumed that this is true on the night side at satellite altitude.

- CHAMP observations disprove this assumption.

Diamagnetic Effect of Plasma



Magnetic moment of charged particles

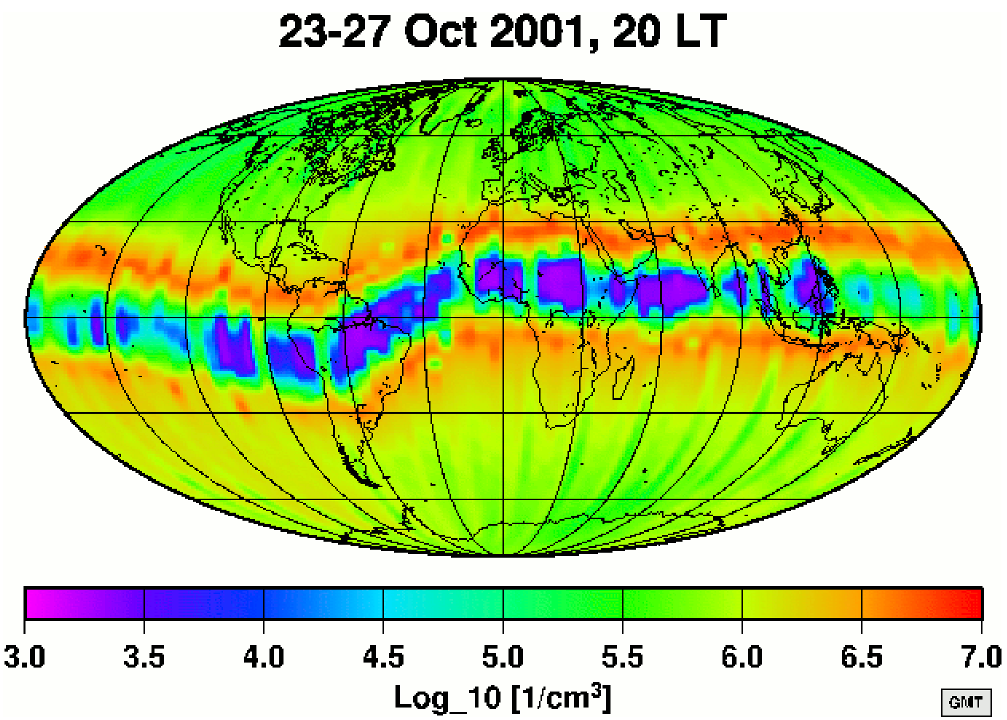
$$M = \pi R_g^2 I$$

$$M = \pi \frac{m^2 v_\perp^2}{e^2 B^2} \frac{e^2 B}{2\pi m}$$

Magnetic moment 1^{st} adiabatic invariant

$$M = \frac{kT}{B}$$

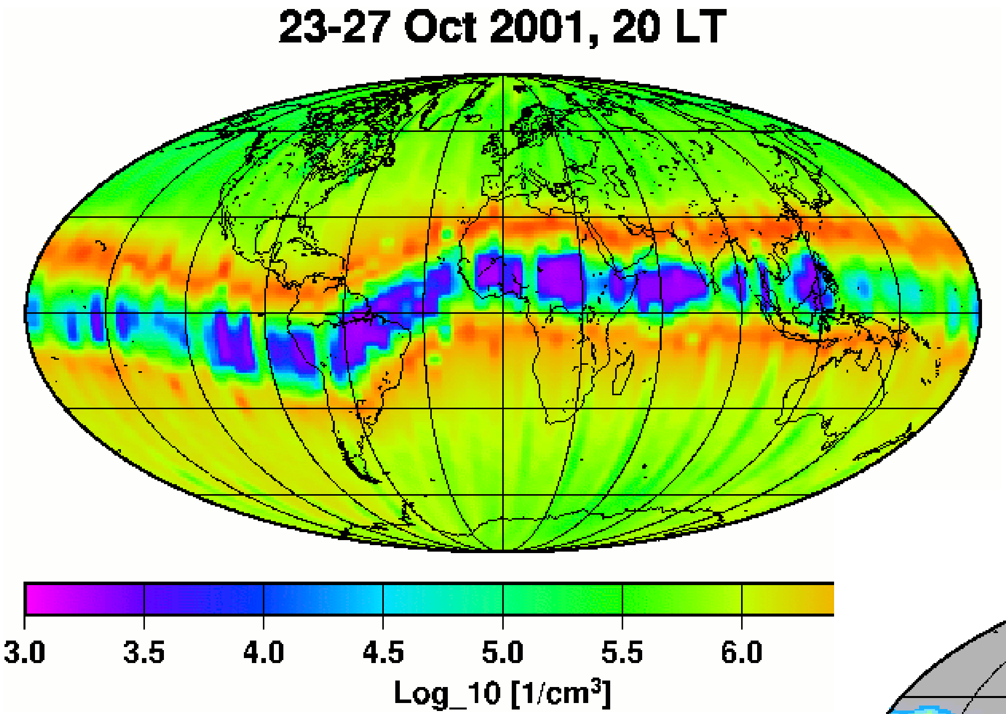
Diamagnetic effect



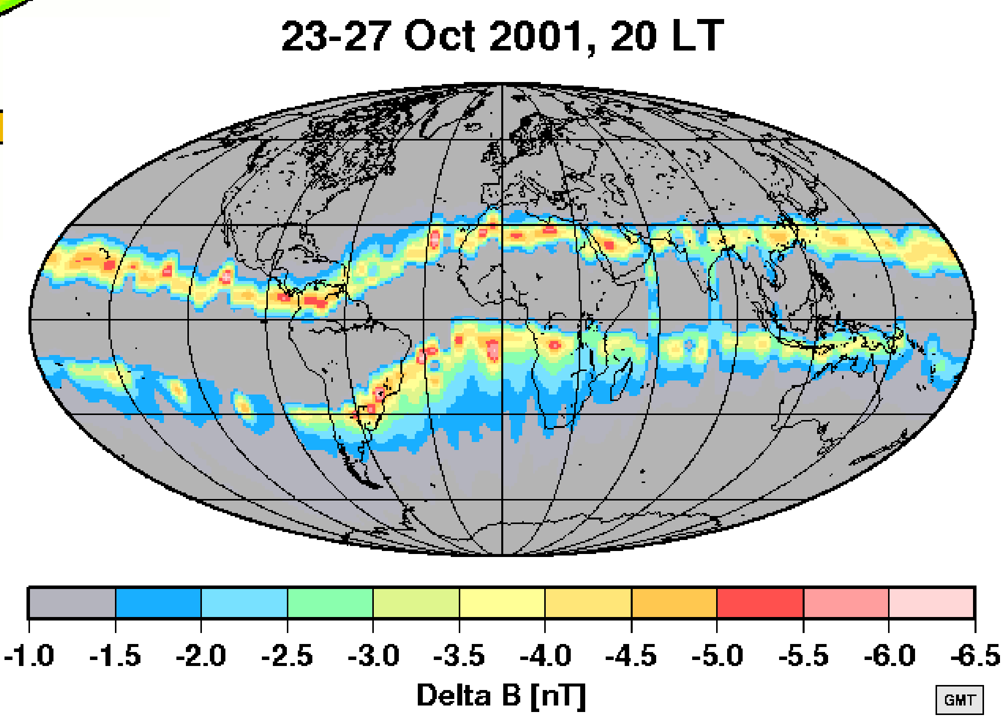
Bands of enhanced plasma density,
Equatorial Ionisation Anomaly

Lühr et al., 2003

Diamagnetic effect



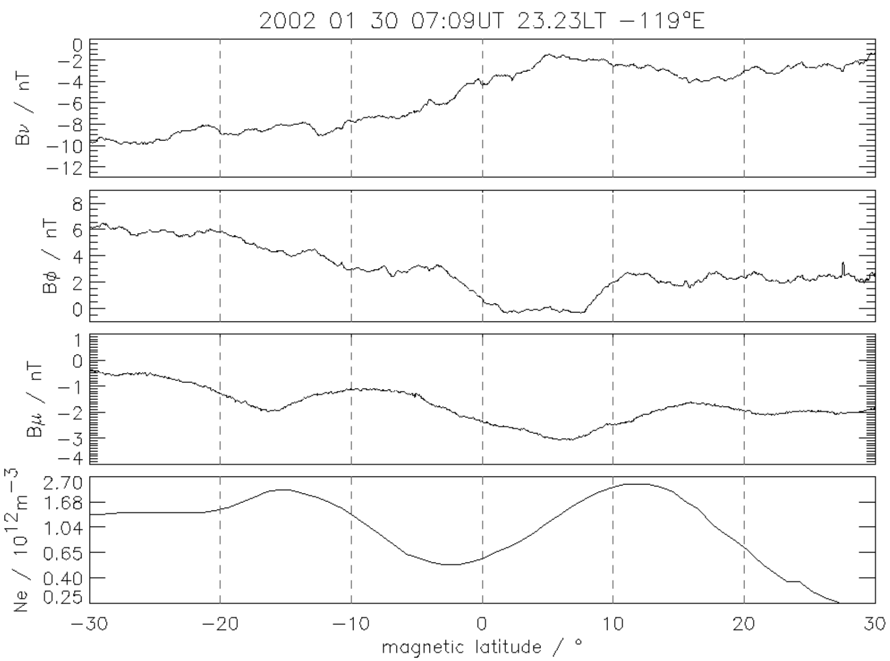
Bands of enhanced plasma density, Equatorial Ionisation Anomaly

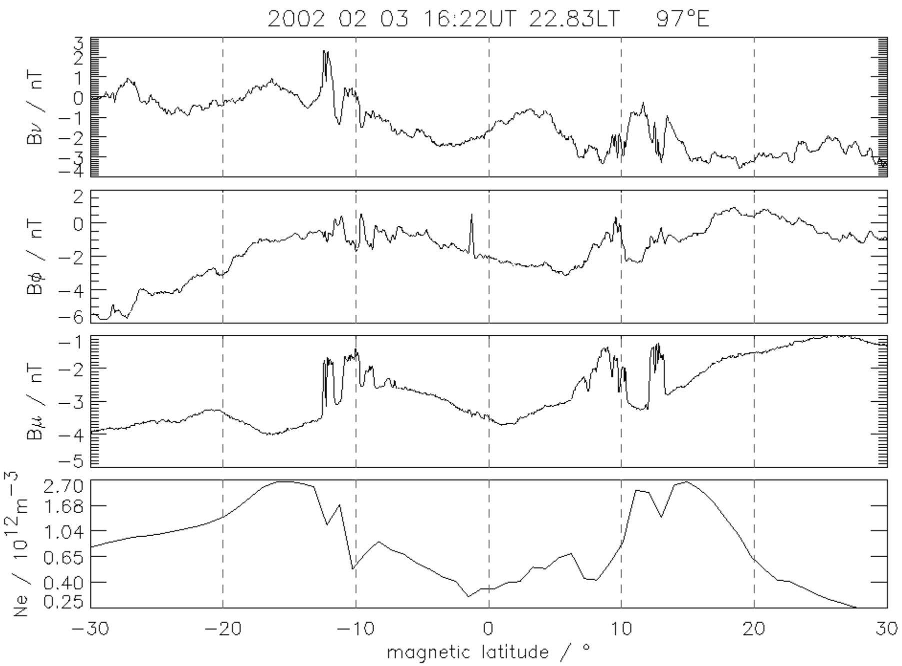


Depressions of the magnetic field of more than 5 nT are observed.

Lühr et al., 2003

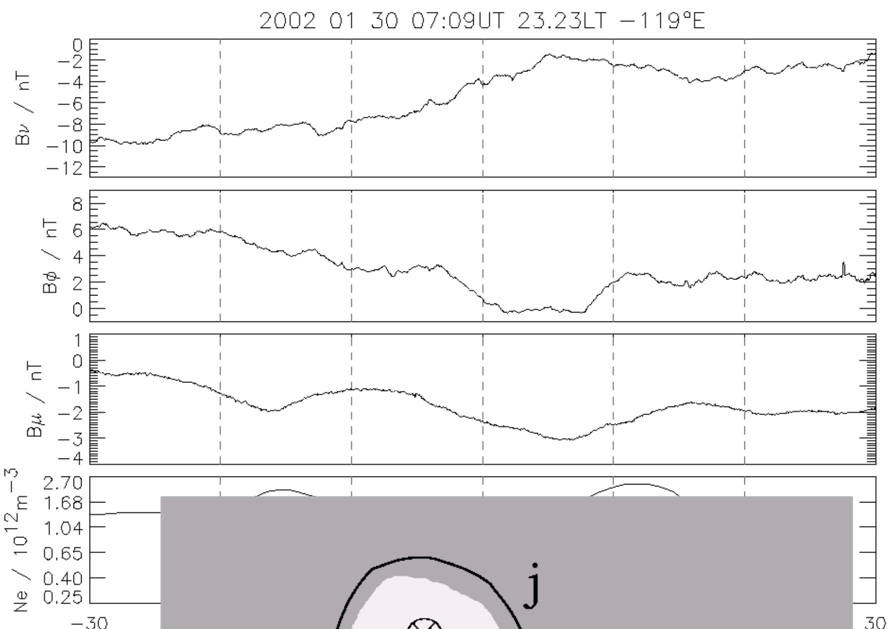
Small-scale density structures

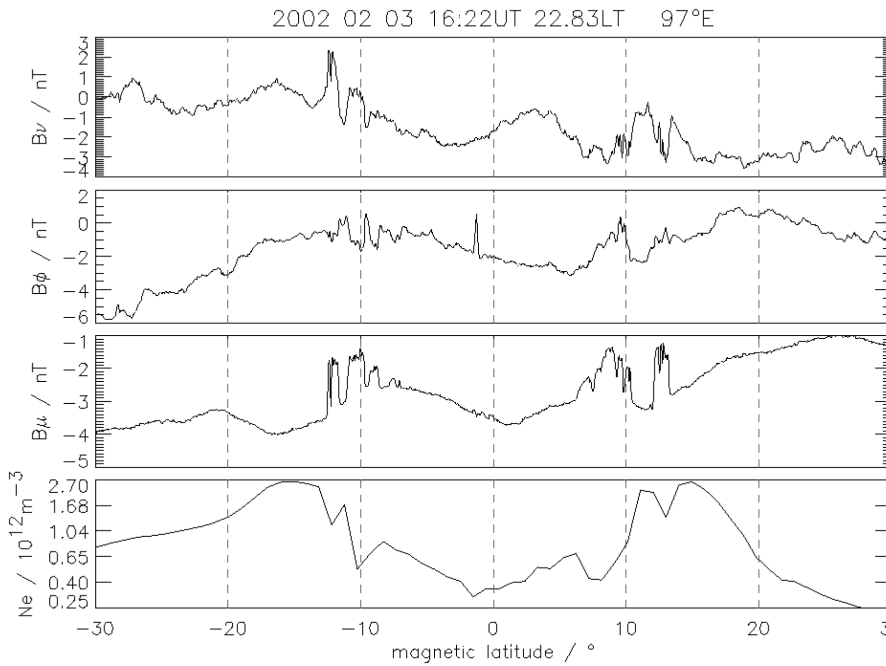




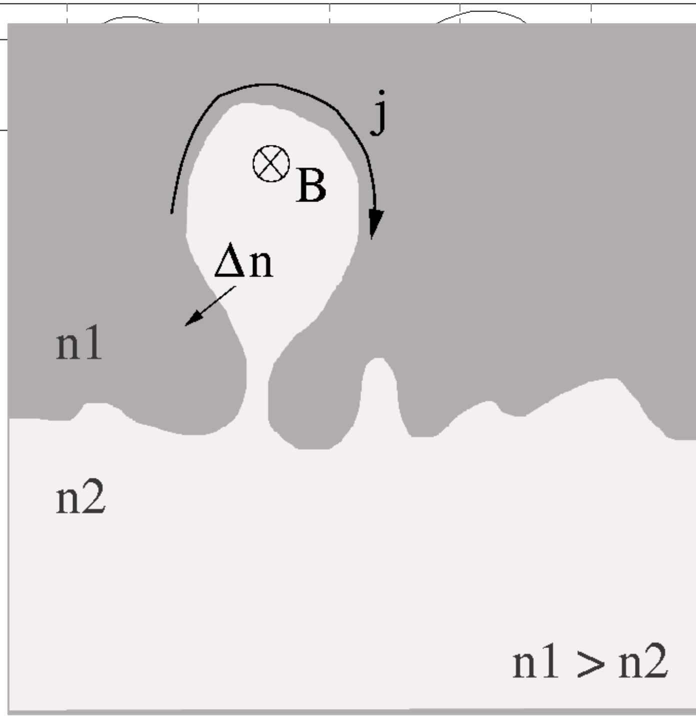
Stolle et al., 2006

Small-scale density structures





West

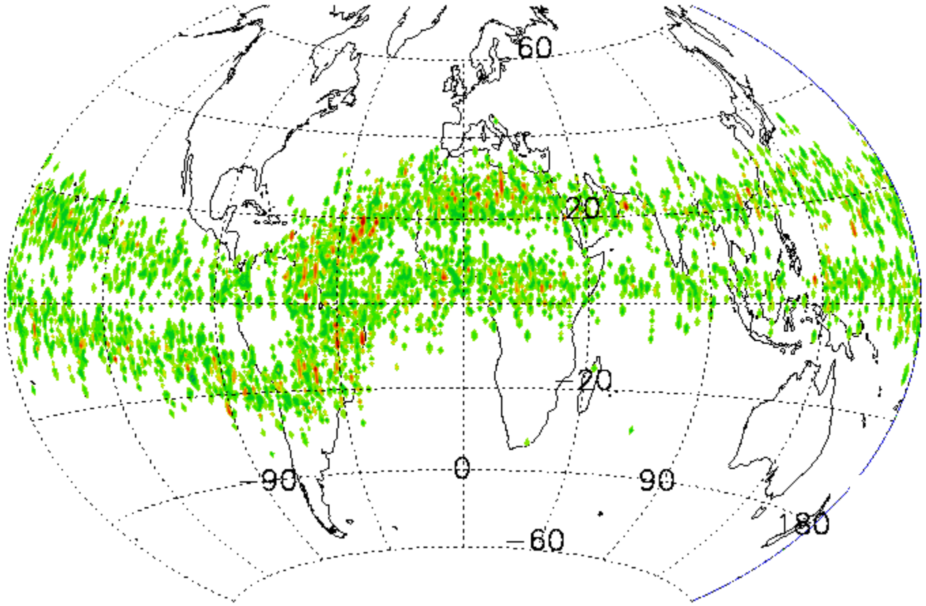


East

Inside depleted plasma regions (bubbles) the magnetic field is enhanced

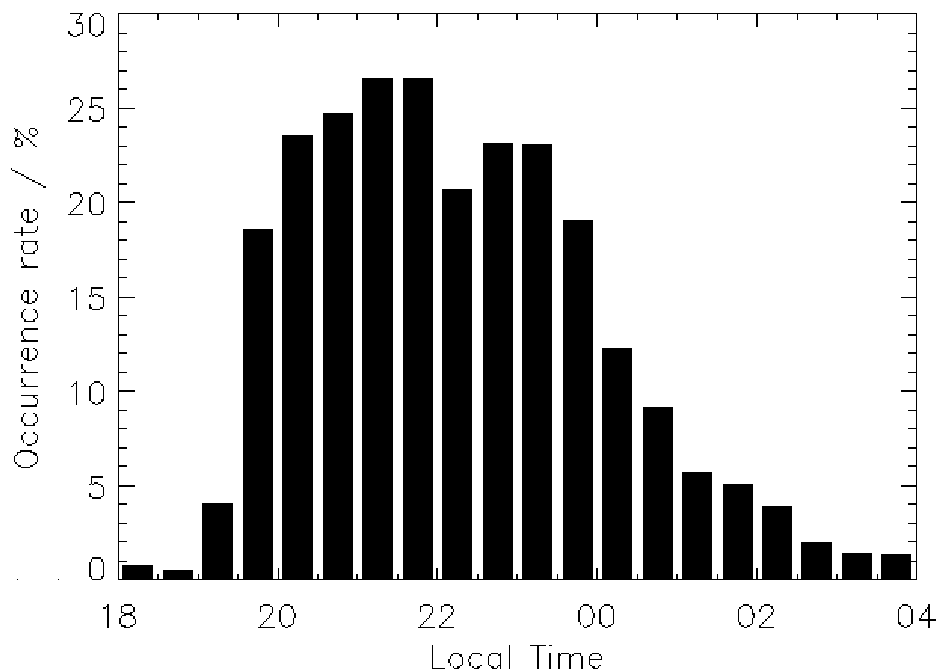
Stolle et al., 2006

Occurrence of plasma bubbles



Bands of affected regions, aligned with the dip-equator

Bubbles are primarily a pre-midnight phenomenon

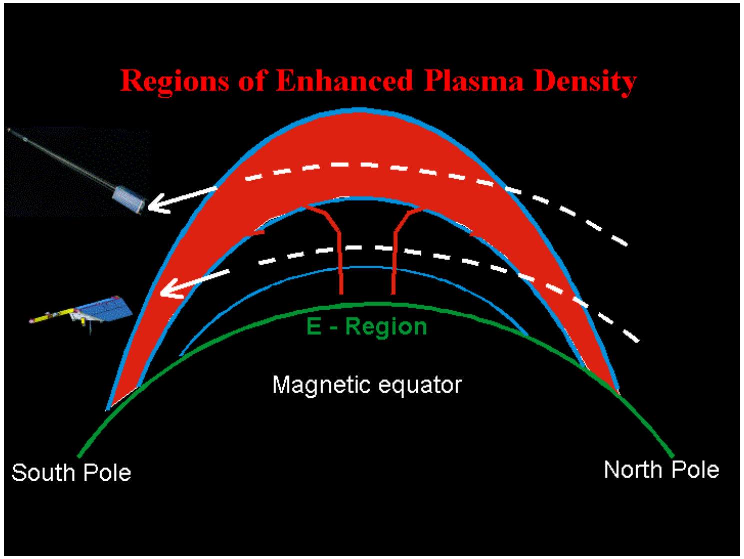


Stolle et al., 2006

Gravity-driven currents

Observations at two altitudes

Ørsted: ~700 km
CHAMP: ~400 km



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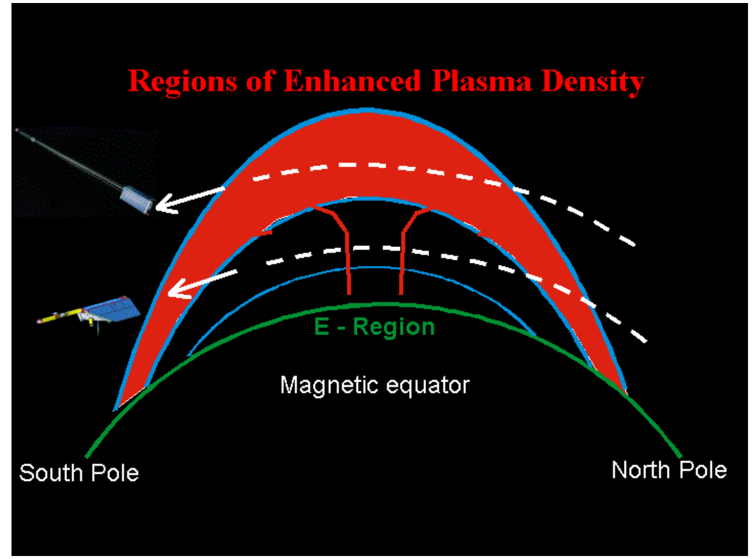

Observations at two altitudes

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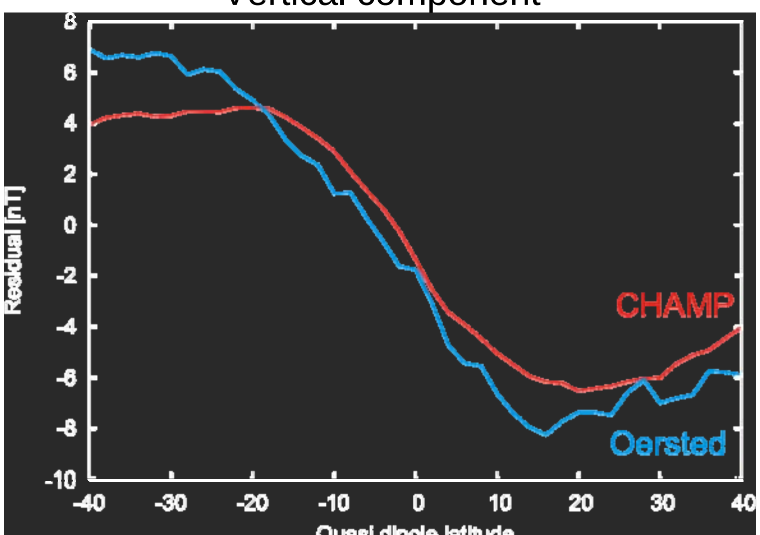
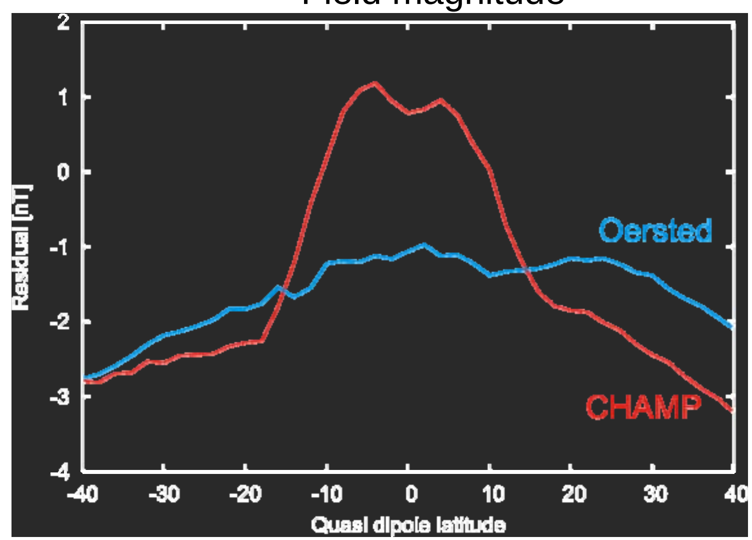
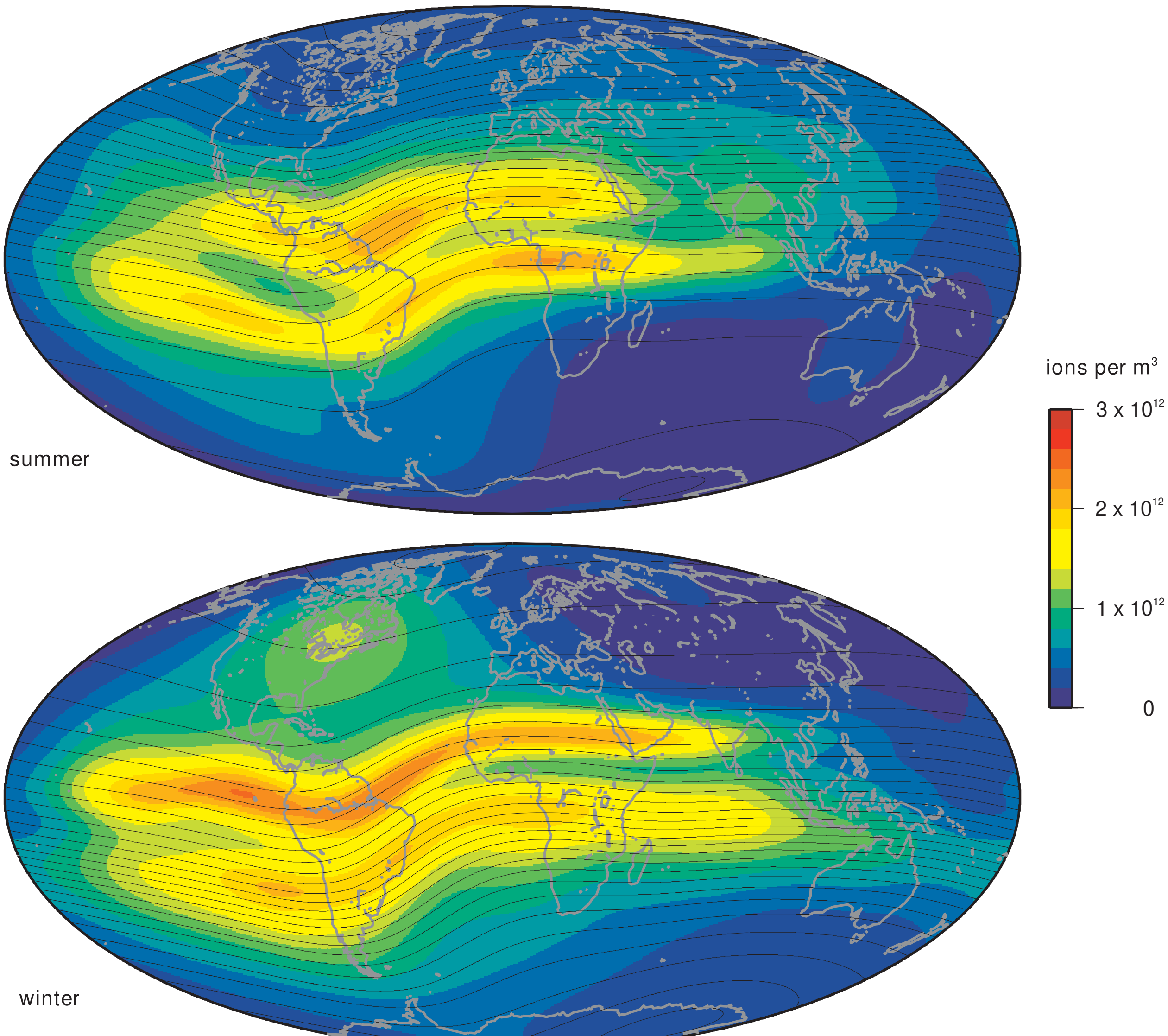
Vertical component



Field magnitude



Ion density and current stream lines at 400 km



Maus and Lühr, 2006

Conclusion 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

- In reality all the different ionospheric currents interact
- For the correction of the net magnetic field effect all the parameters have to be measured or estimated.
- A model-based approach is required to derive the correction values.

Deriving Thermospheric density and wind from the Accelerometer

$$\vec{a} = -\frac{1}{2m} C_d \rho A_{eff} V^2 \vec{v}$$

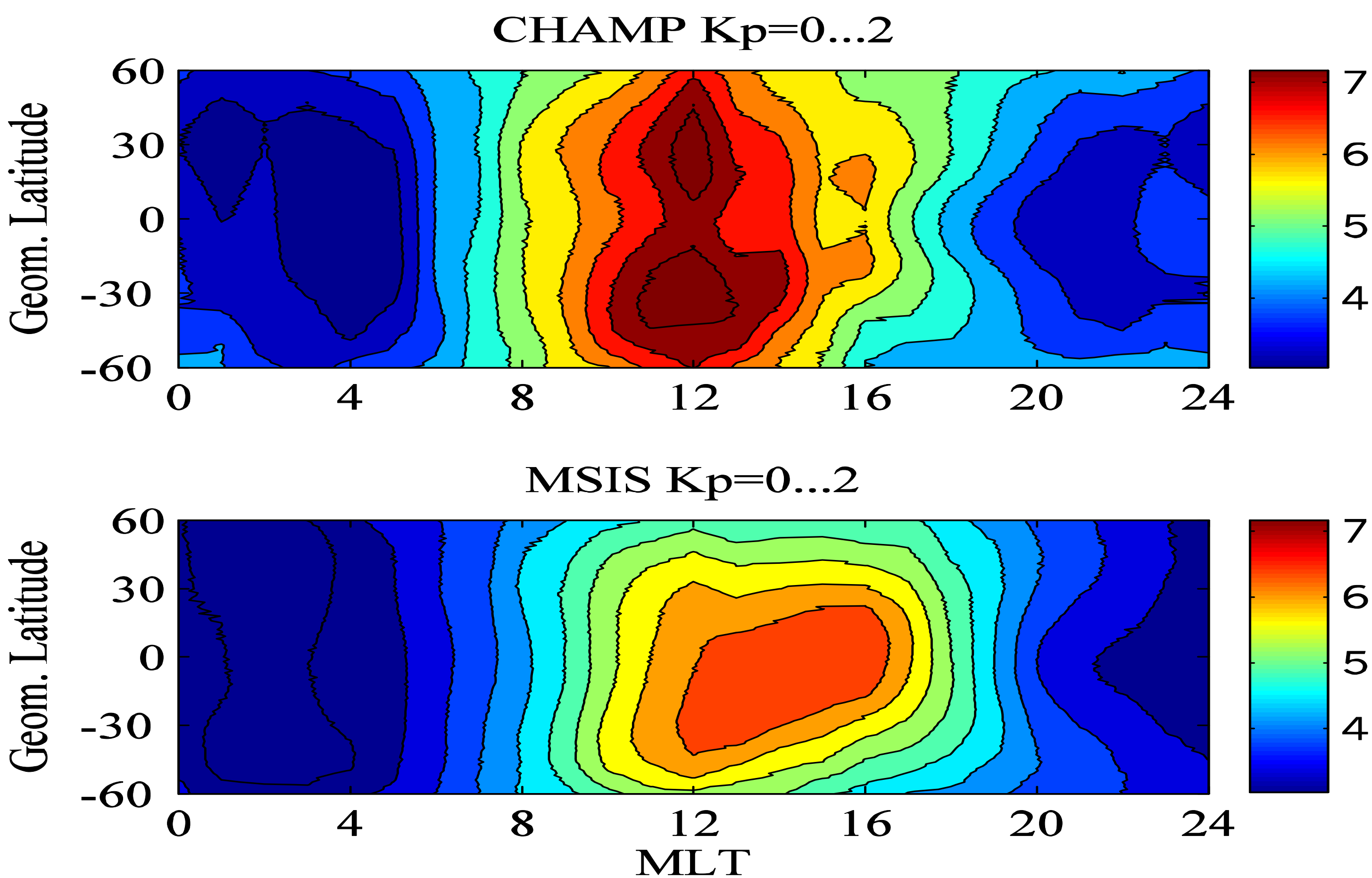
$$A_{eff} = A_x \cos\alpha + A_y \sin\alpha$$

$$\alpha : attitude\ deviation$$

CHAMP: m = 510 kg, C_d = 2.4,

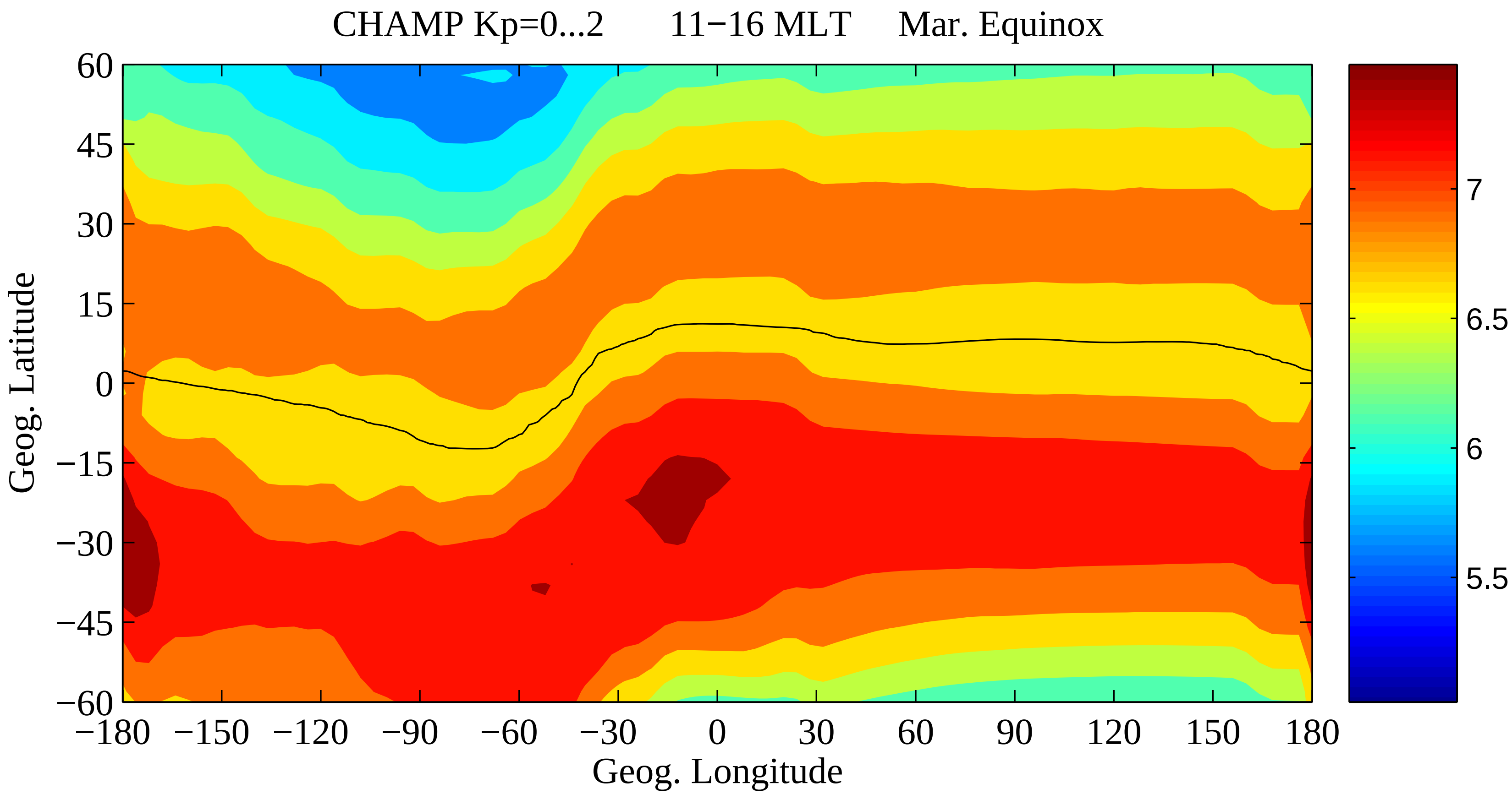
$V^2 = V^2_{orbit} + V^2_{cross}$

Average Thermospheric Density at 400 km

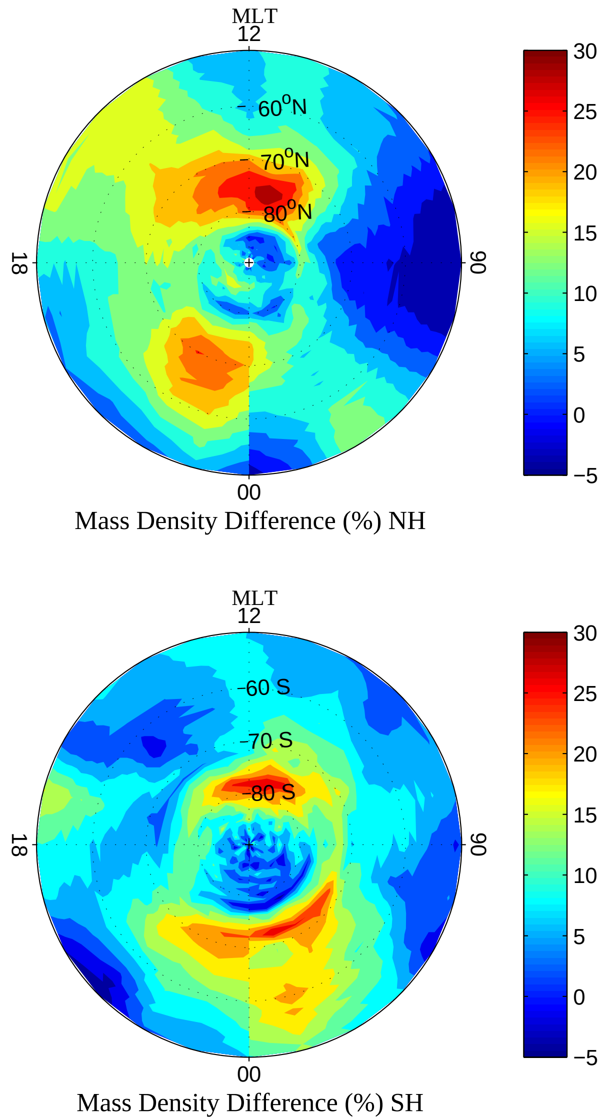


Liu et al., 2005

Mid-latitude density enhancement



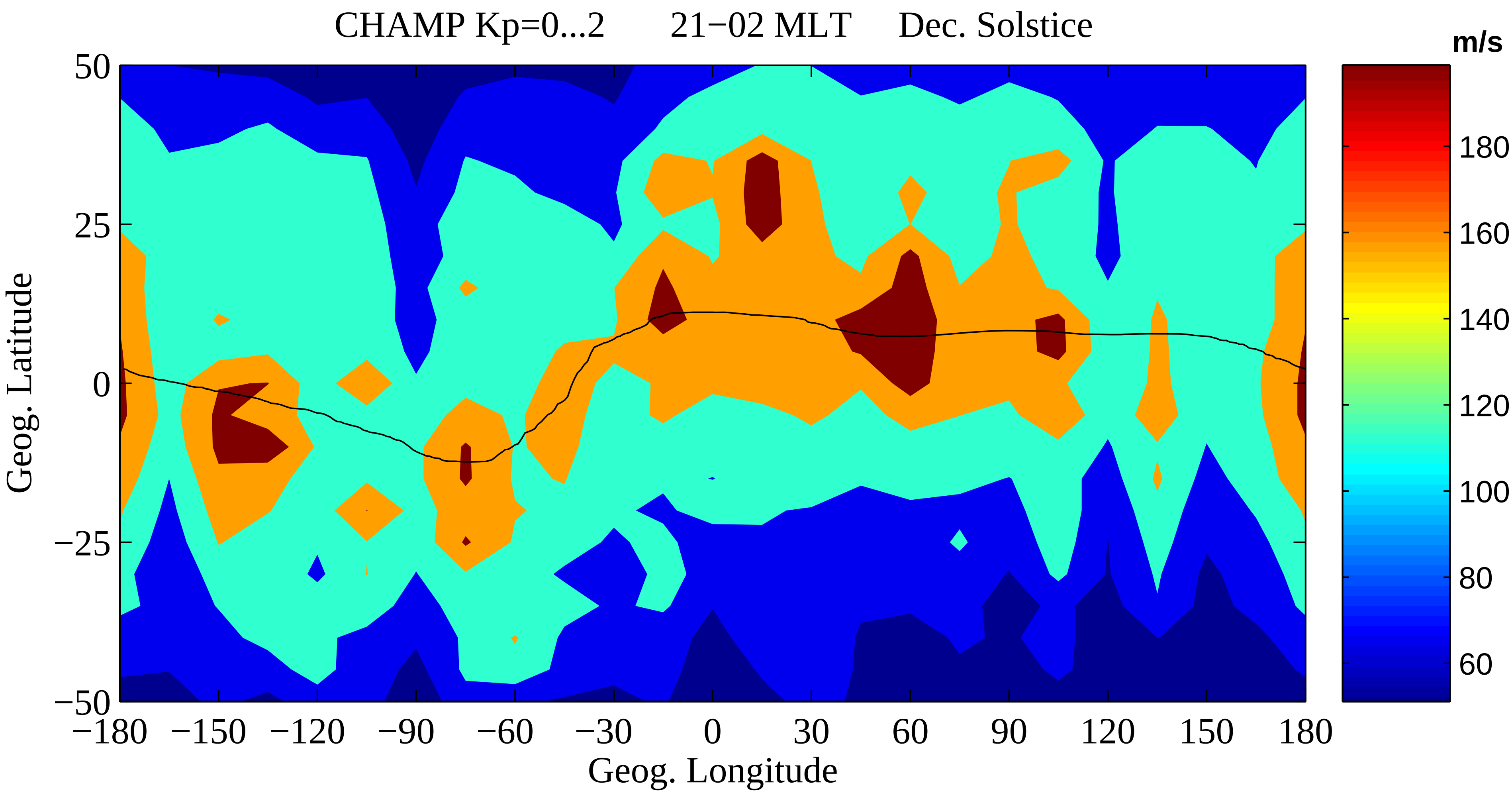
Air density features at high latitudes



Percentage difference in polar regions

Large differences are seen in the cusp and midnight sector, where strong small-scale field-aligned currents occur.

Thermospheric winds at night



Summary

- Modelling magnetospheric contributions in appropriate coordinate systems (SM, GSM) provides a more consistent picture.
- A number of additional ionospheric current systems have been identified. For their characterisation additional instruments are foreseen on *Swarm*.
- The geomagnetic field has been identified as an important driver also for the dynamics of the neutral air in the thermosphere.
- Based on these new findings and its advanced instrumentation we can expect from *Swarm* exciting results in all these fields.