The effects of secular change in the internal magnetic field of the Earth on geomagnetic activity

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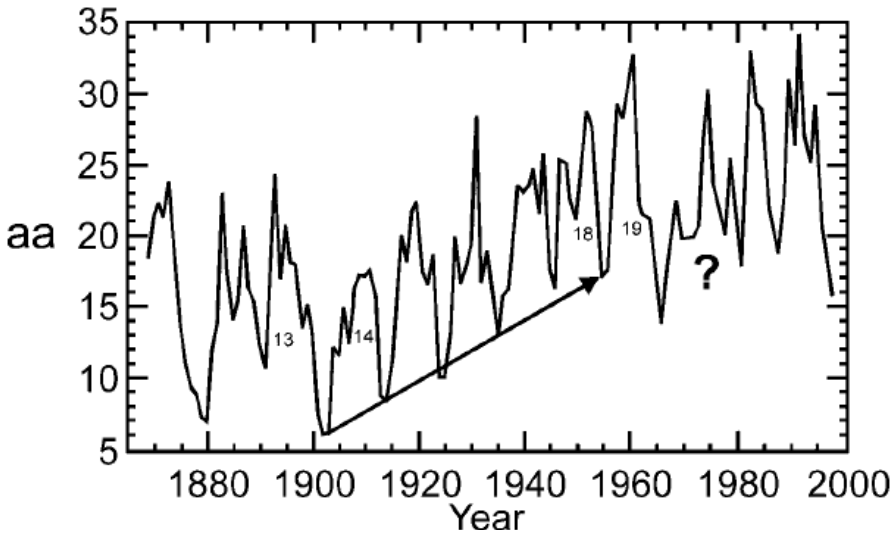
Motivation

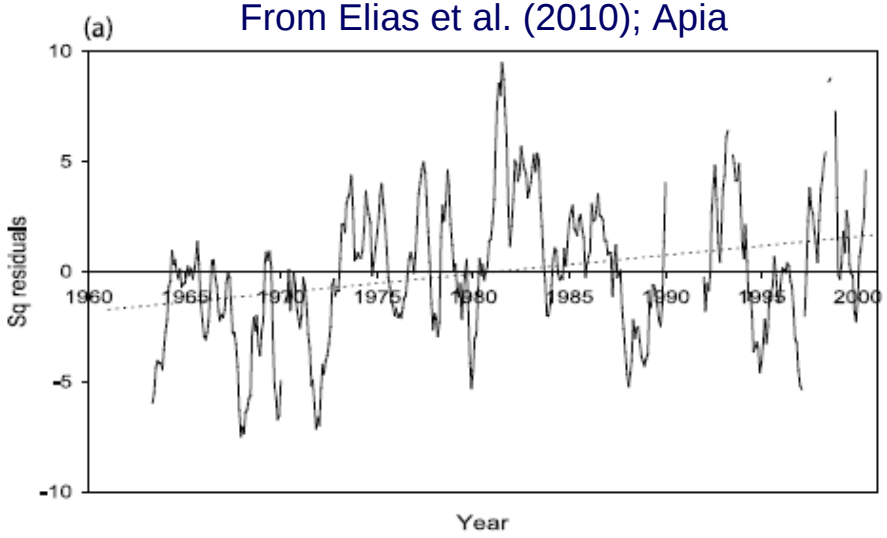
From Cliver and Ling (2002)



- Observed long-term changes in geomagnetic activity, e.g.:
  - Increase in aa index
  - Increase in Sq variation

- Use to gain information about long-term change in the Sun
- But changes in the internal magnetic field may affect geomagnetic activity also
- These effects must be corrected for

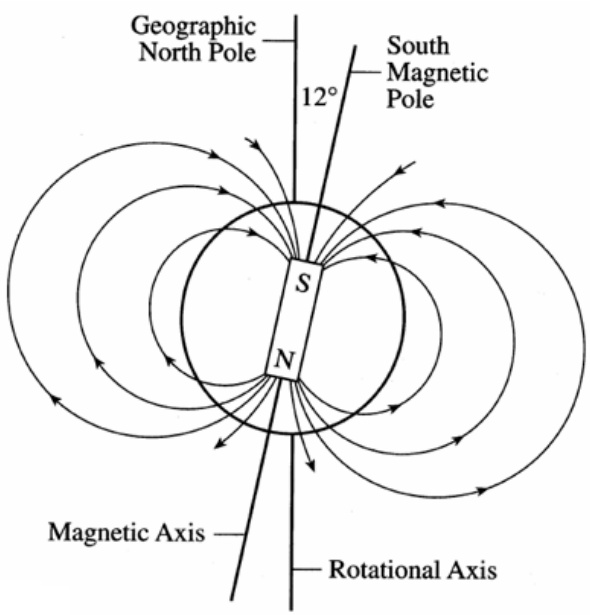
From Elias et al. (2010); Apia



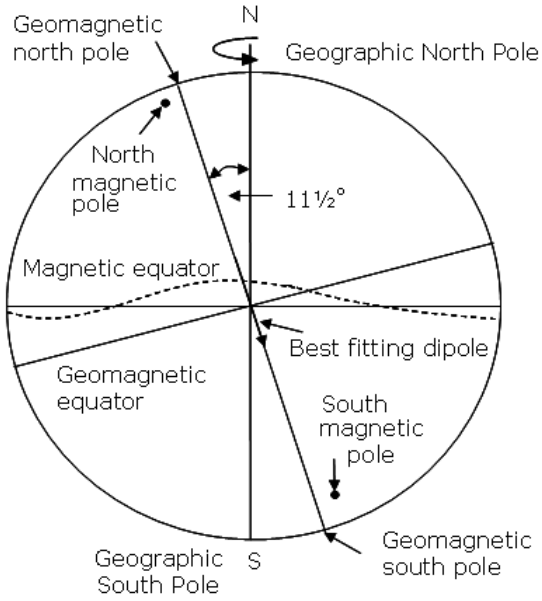
Outline

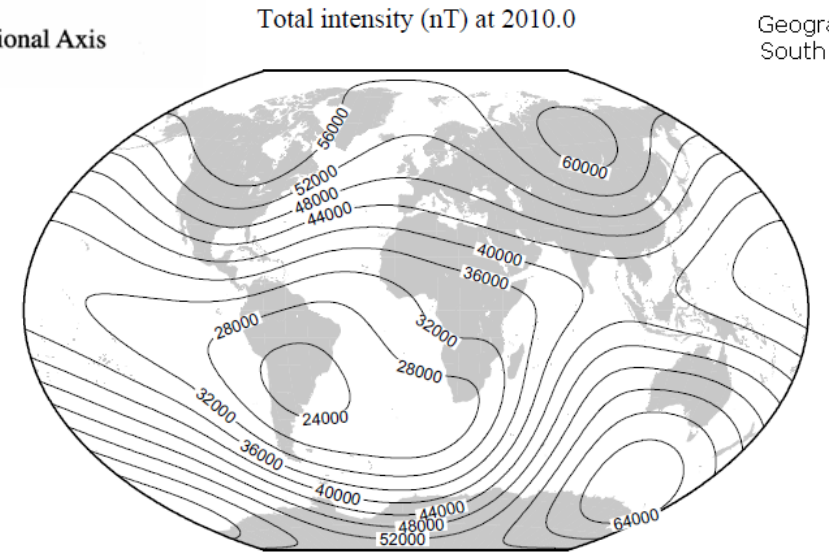
- Background material
  - Changes in the Earth's internal magnetic field
  - Current systems
  - Geomagnetic activity indices
  - Influences of the Earth's magnetic field on geomagnetic activity (theory)
- My work
  - Model description and approach
  - Modelling results
  - Preliminary conclusions

Earth magnetic field structure



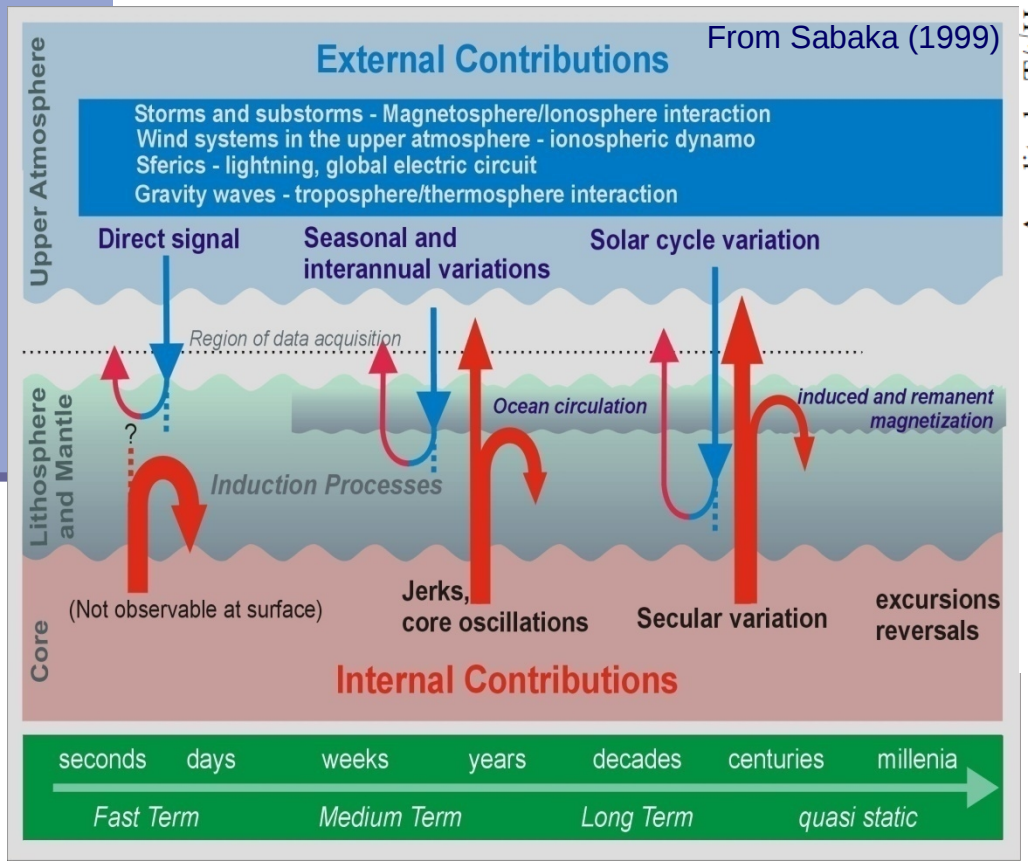
- Main structure dipolar
- But higher order structures are present

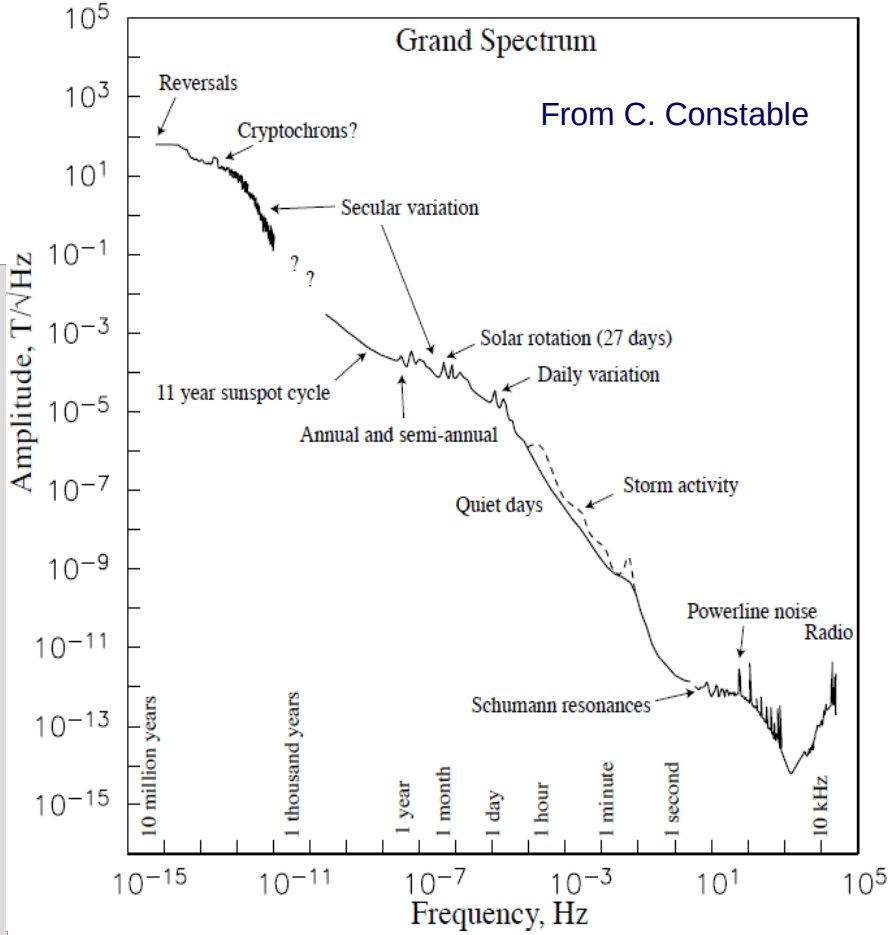




Magnetic field changes from various sources

- Internal source: mainly outer core
- External source: solar wind-magnetosphere-ionosphere interaction

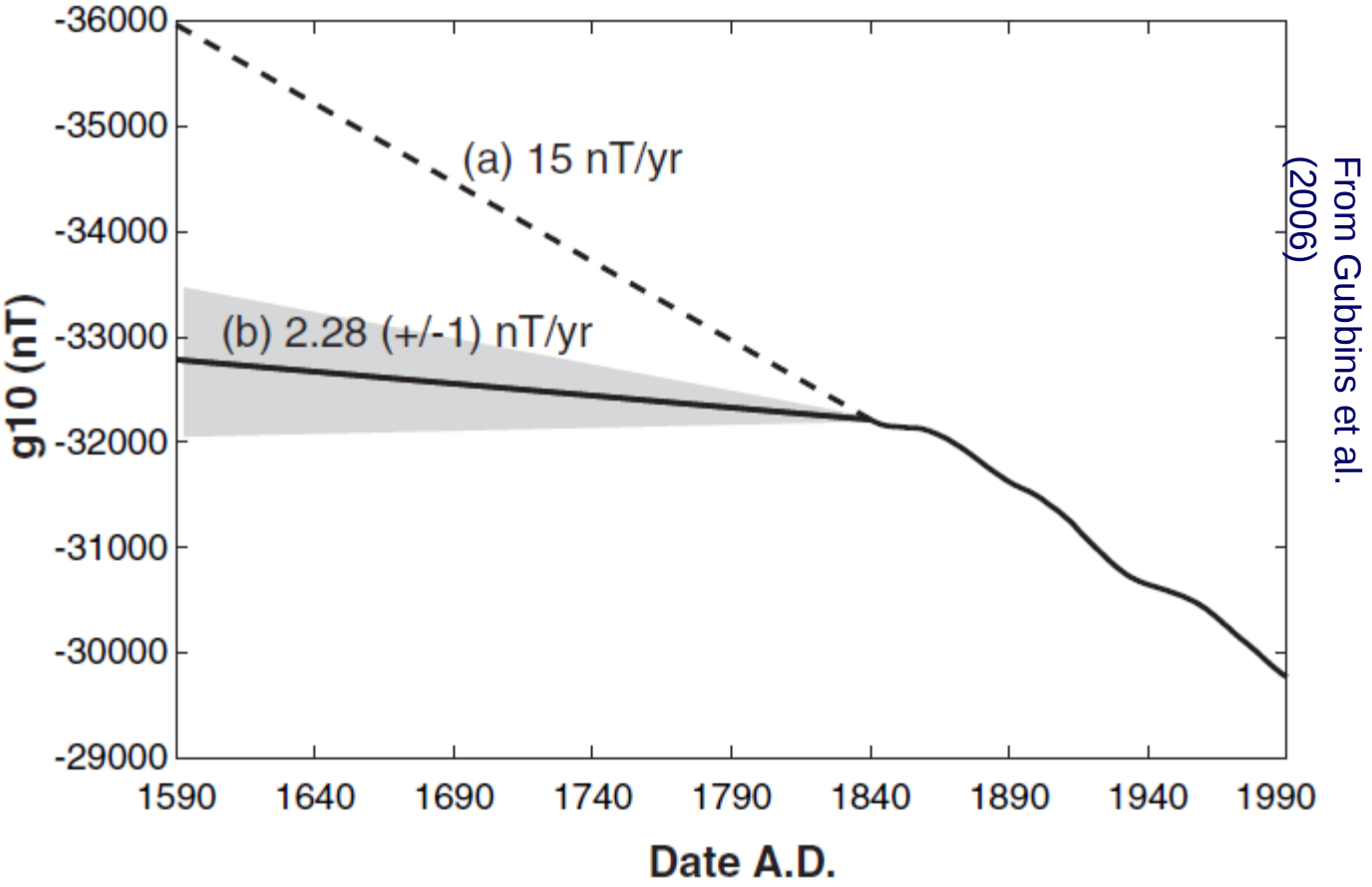




- Timescales and amplitudes different for different sources

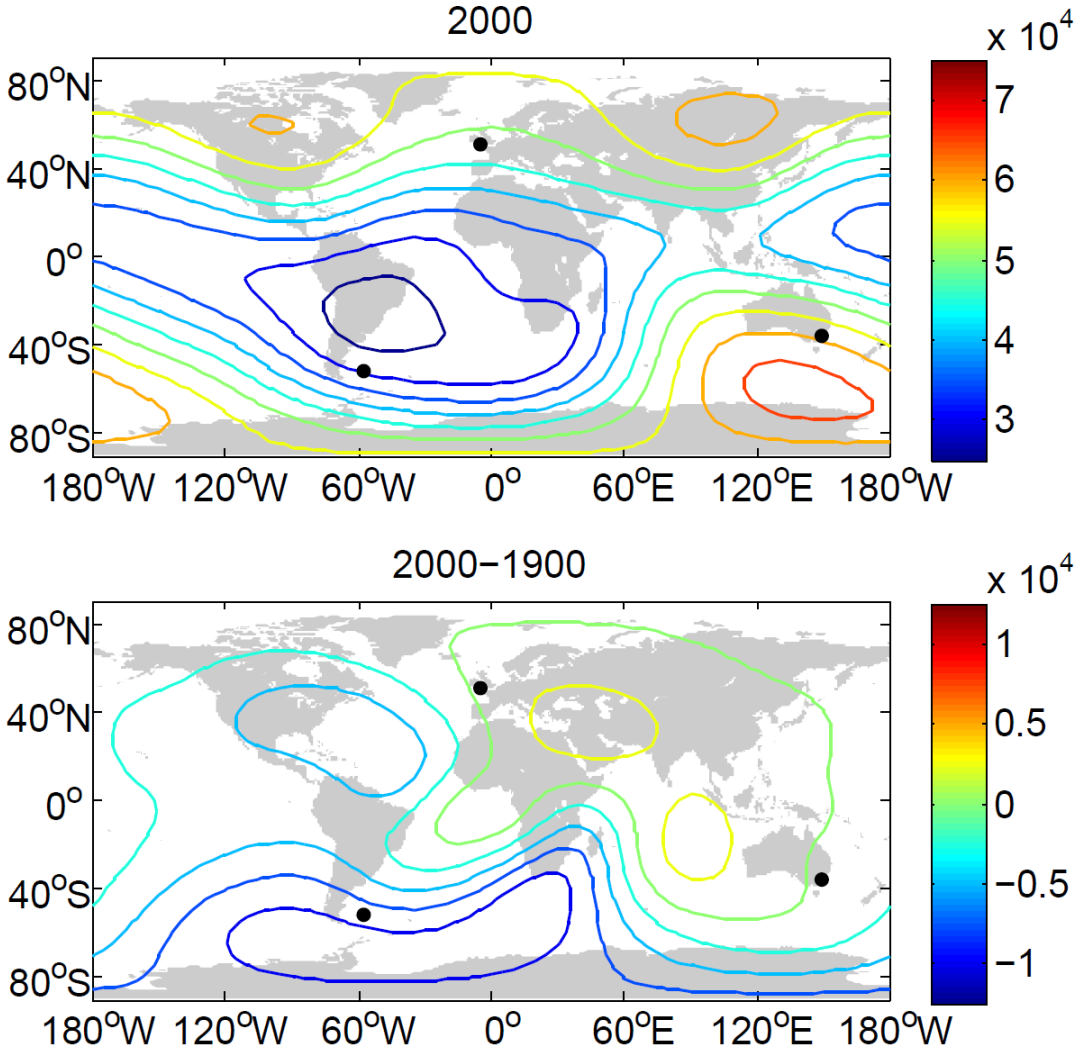
Changes in dipole moment

- The Earth's magnetic field intensity has decreased by 5-7% per century since 1840 (Gubbins et al., 2006; Mandea and Purucker, 2005)



From Gubbins et al. (2006)

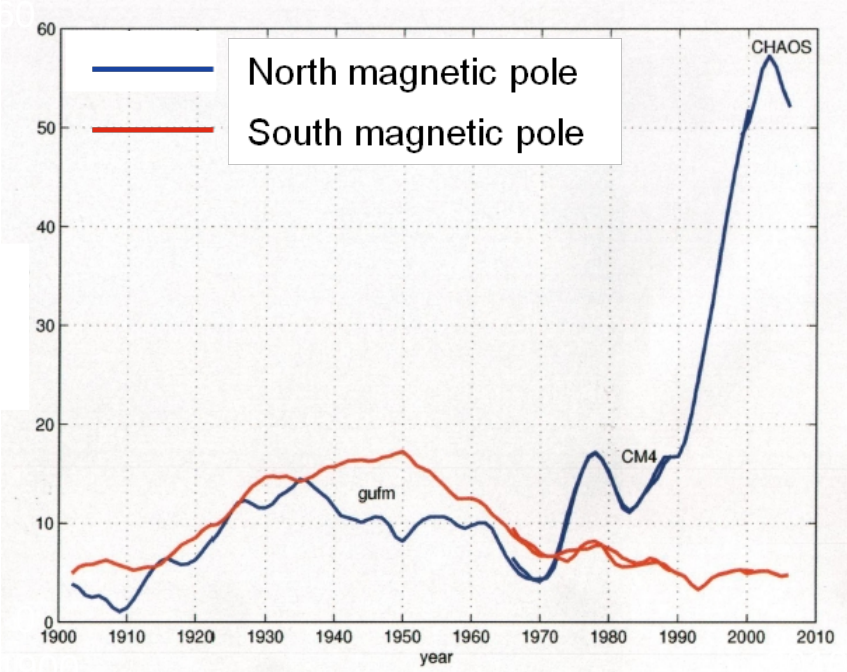
Changes in total field intensity between 1900 and 2000 (IGRF)



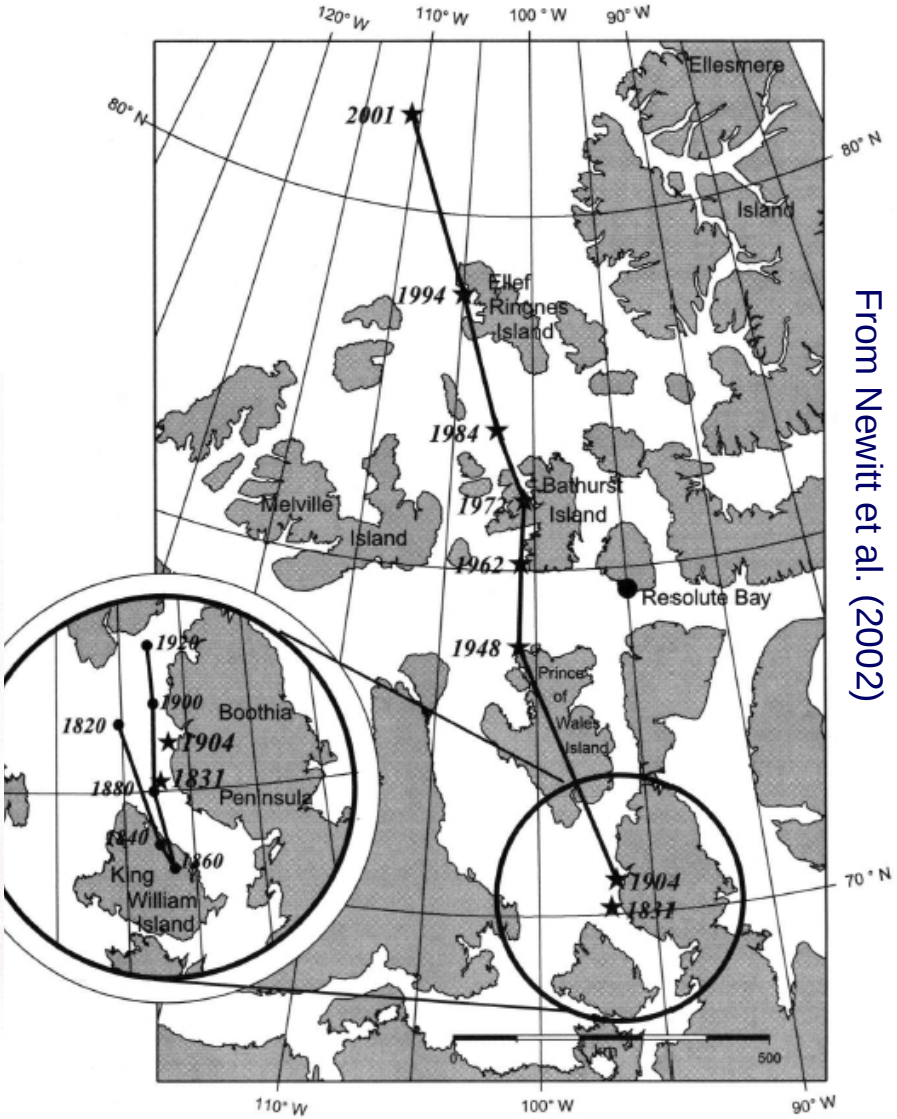
- Change in total field intensity (nT) from 1900 to 2000
- Strongest decrease in southern hemisphere
- Expansion of South Atlantic anomaly

Changes in magnetic pole position

- The location of the North magnetic pole has been changing fast recently
- The location of the South magnetic pole is changing at a slower, and more steady rate

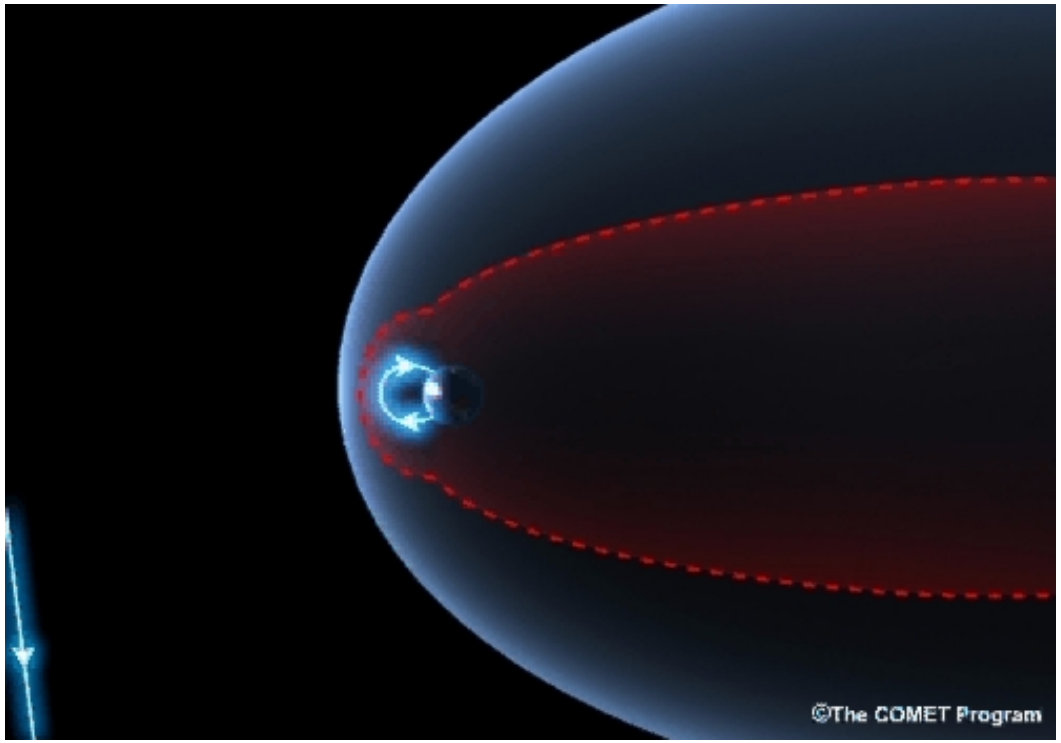


From Olsen and Mandea (2007)



From Newitt et al. (2002)

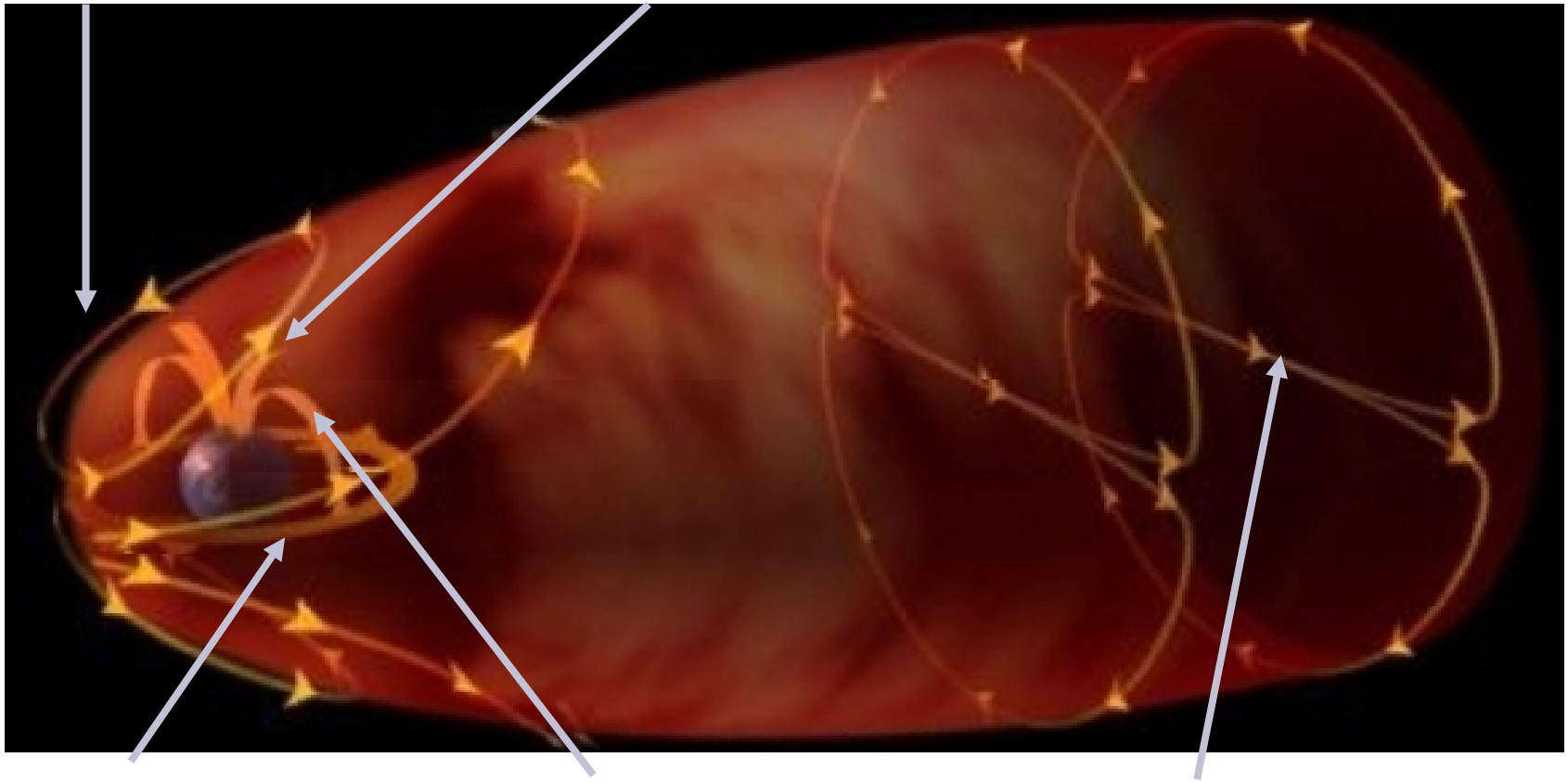
The magnetosphere



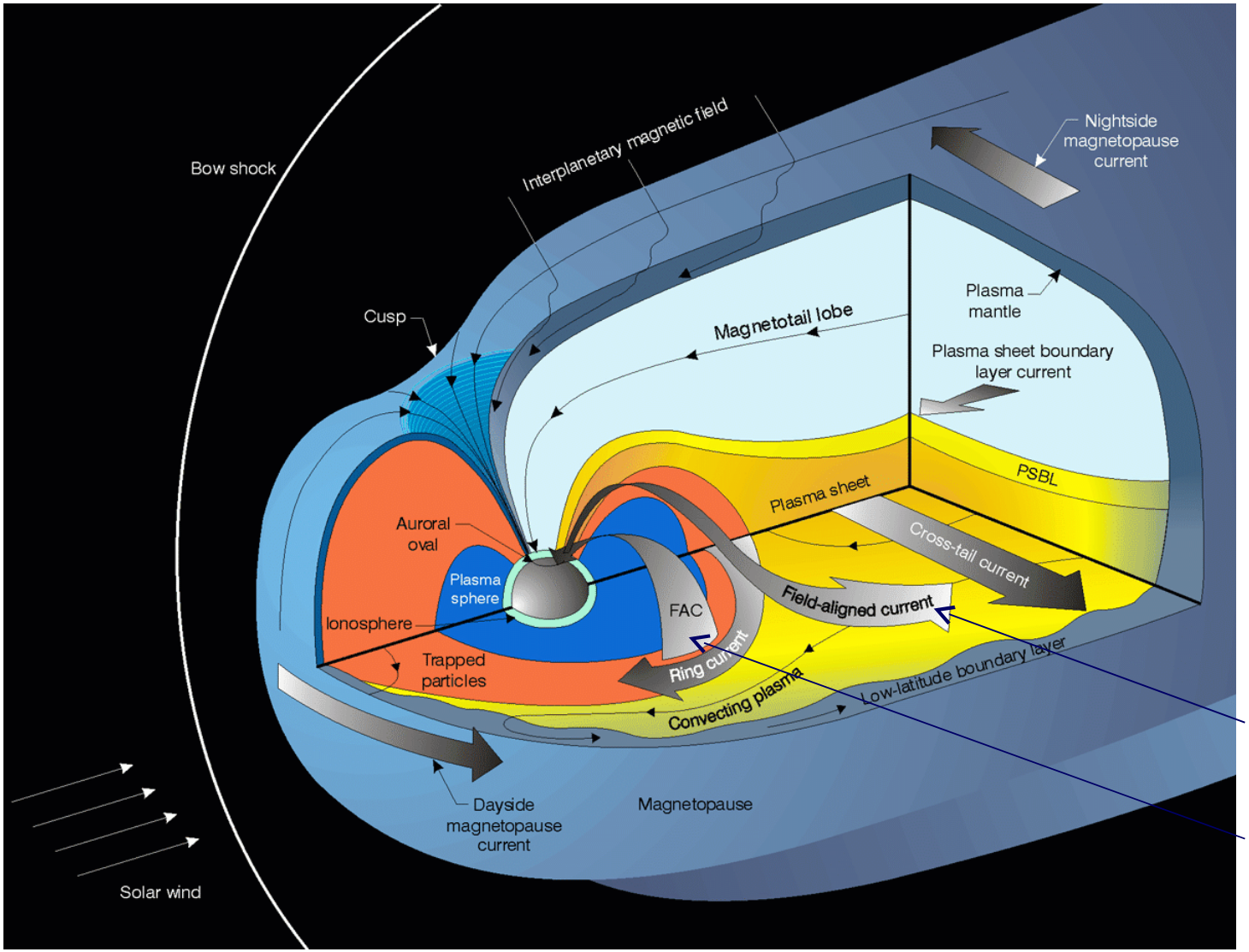
- The magnetosphere is the area of space where the Earth's magnetic field is dominant
- Earth magnetic field lines couple with the IMF carried by the solar wind at the dayside boundary and decouple on the nightside (magnetic merging/ reconnection)

- Disturbances in the solar wind trigger geomagnetic storms
- Pulsed behaviour of the magnetosphere results in substorms
- These give rise to enhanced geomagnetic activity

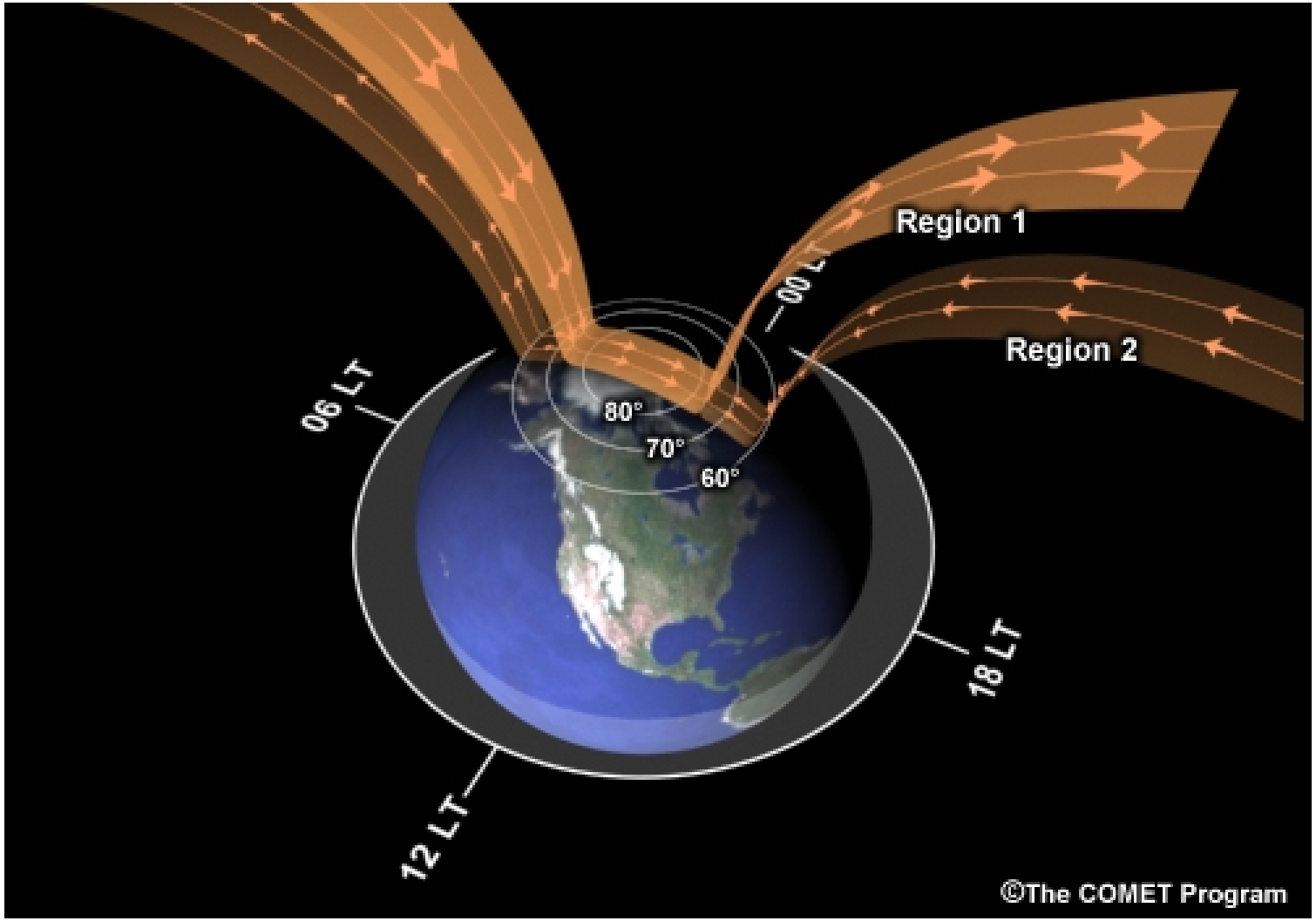
Magnetospheric current systems



Magnetospheric current systems



Ionospheric high-latitude current systems



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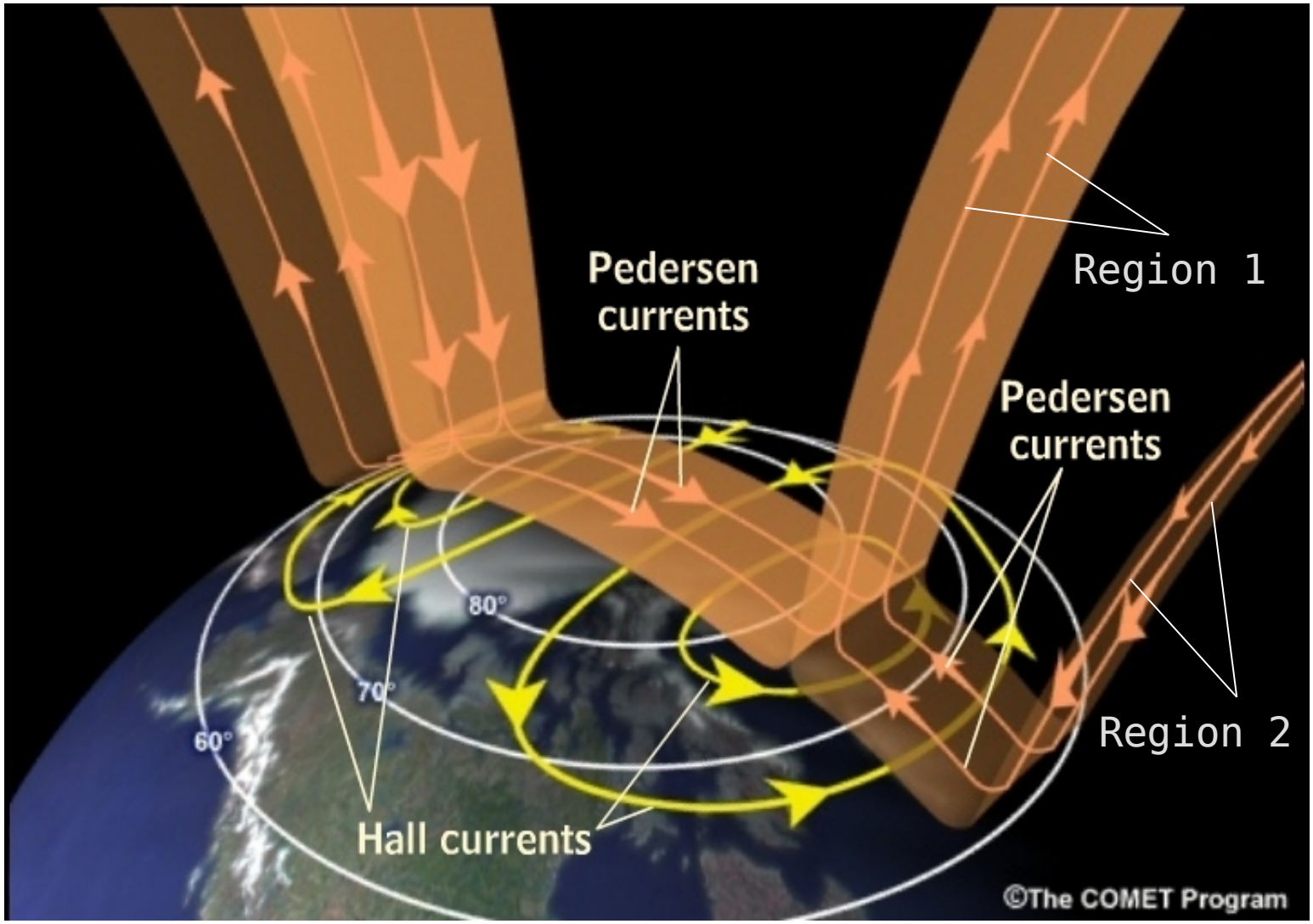

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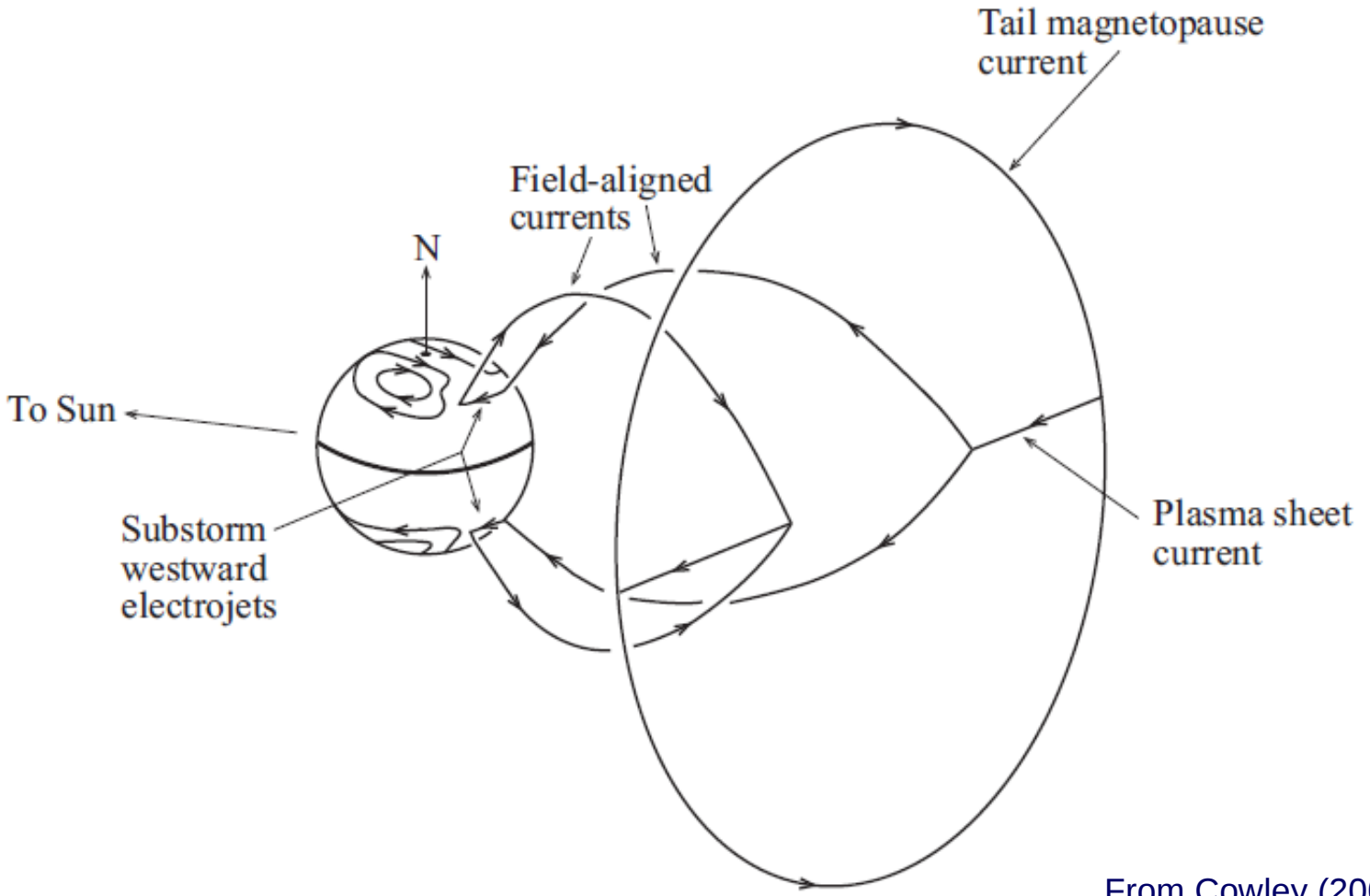
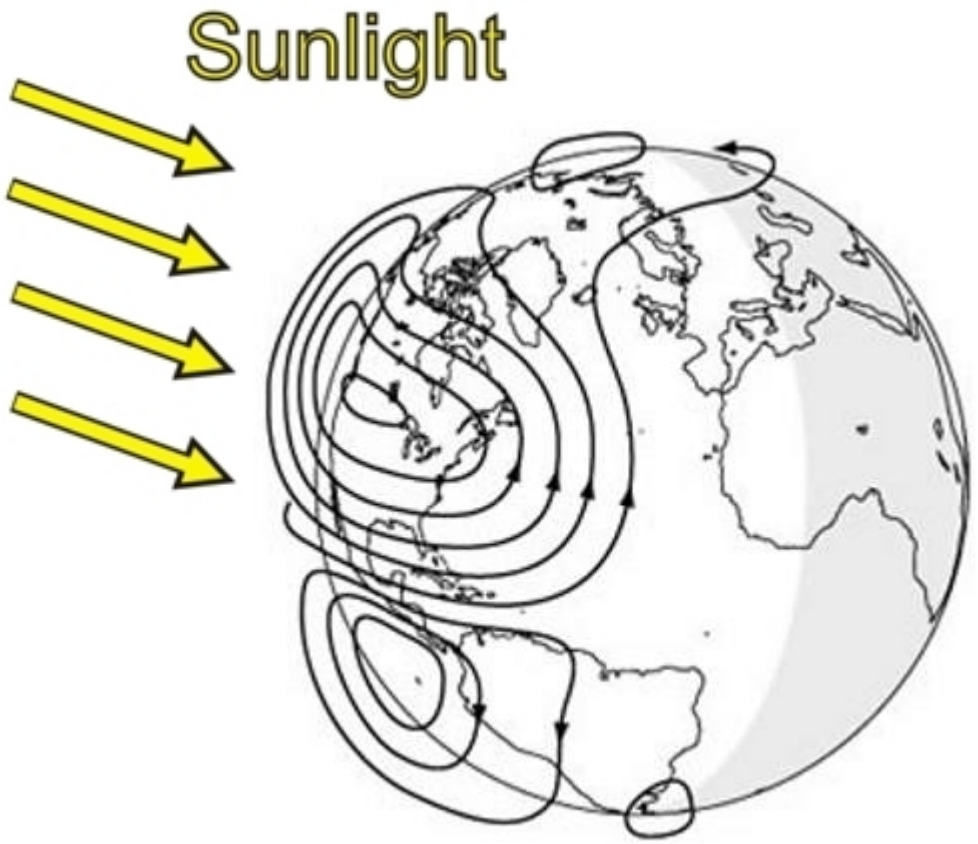


From Cowley (2003)

Ionospheric low and mid-latitude current systems

- Low-middle latitudes
- During quiet times
  - Mostly shielded from the effects of magnetospheric current systems
  - Mainly affected by ionospheric wind dynamo
- Thermospheric neutral winds driven by solar heating
- 90-200 km
- Ionospheric dynamo depends on conductance and therefore on the solar cycle



From www.geomag.bgs.ac.uk
(British Geological Survey)

Magnetic perturbations and geomagnetic activity indices

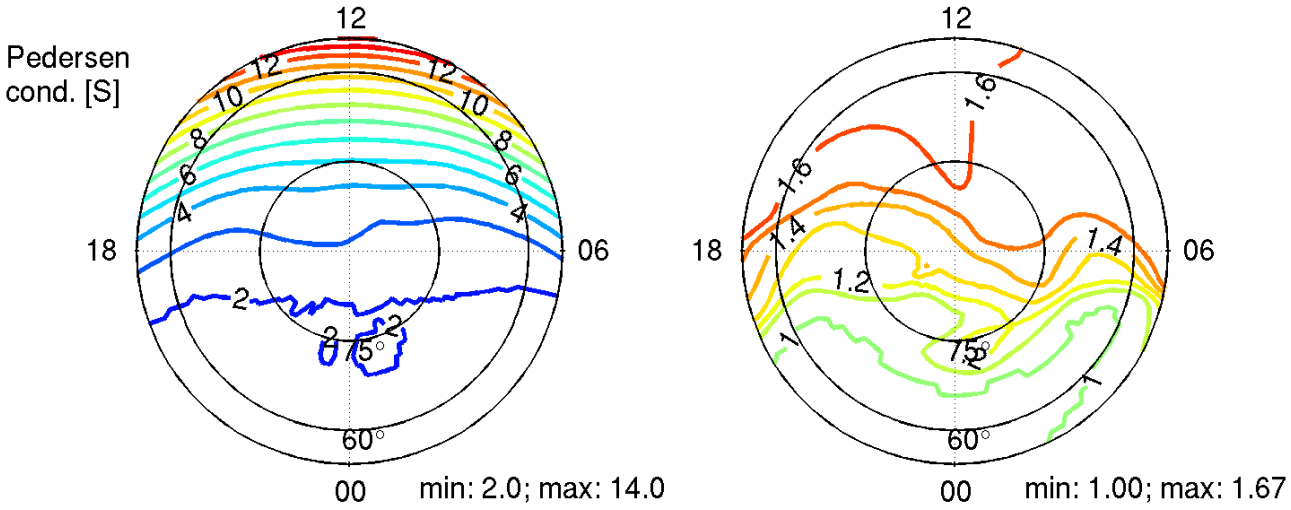
- Ring current
  - Westward current → negative signature of several 10s-100s of nT
  - Measured by D_{st} index
  - Computed from the H-component at 4 near-equatorial stations spread in longitude
- High-latitude ionospheric current systems (auroral electrojets)
  - Perturbations of a few 100s up to ~2000 nT
  - Measured by AU/AL/AE indices
  - Computed from >10 auroral stations from the maximum positive and negative perturbations to the H-component
- Ionospheric wind dynamo
  - S_q variation (solar quiet)
  - Perturbations of a few 10s of nT
  - Smooth variation is subtracted before deriving the K index
- The K index is derived from the maximum range in either of the two horizontal components over a 3-hour interval

How can the magnetic field affect geomagnetic activity?

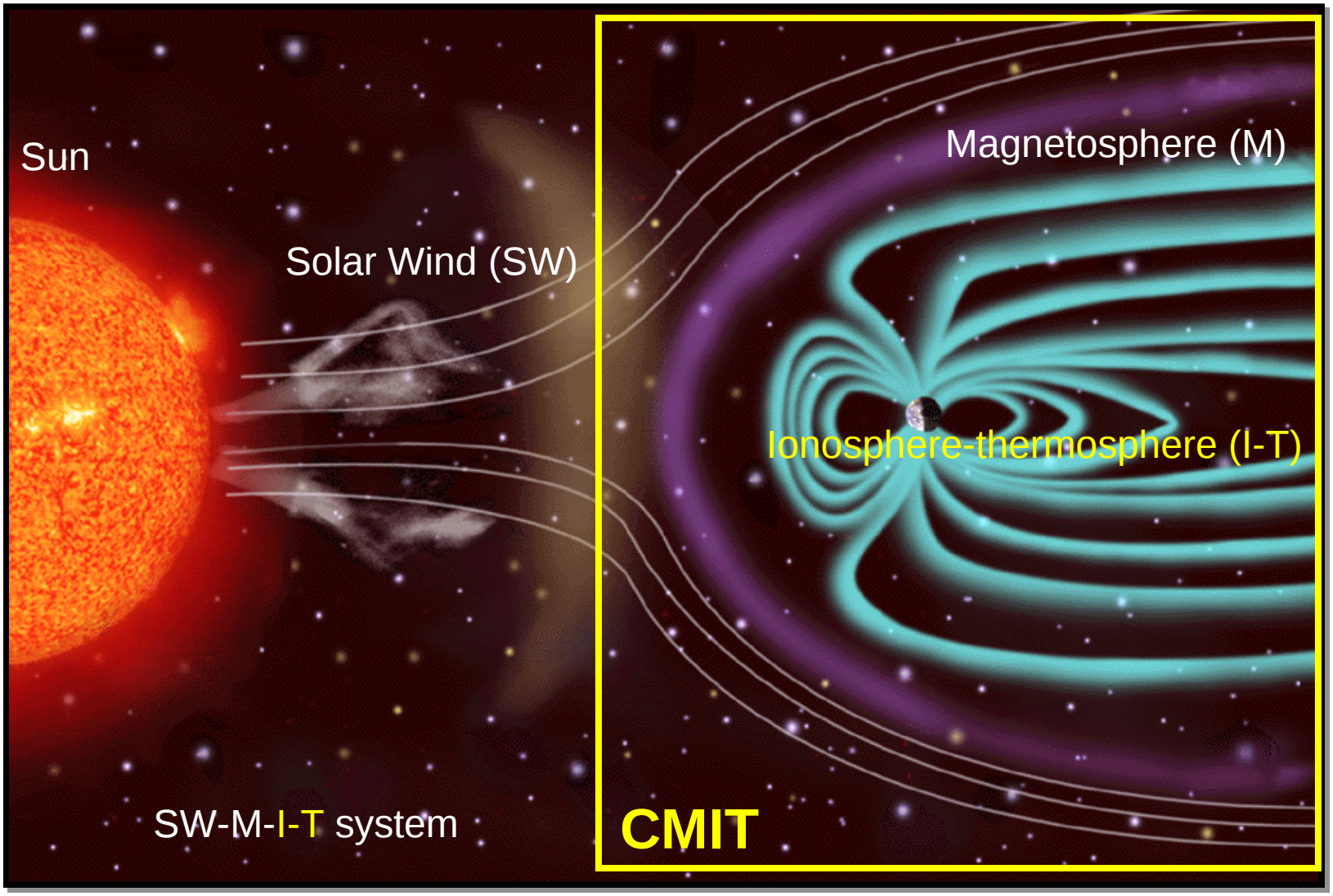
- A reduction in magnetic field strength increases ionospheric conducance
  - Affects the ionospheric wind dynamo
  - Affects high-latitude coupling between the magnetosphere and ionosphere → FACs, Pedersen and Hall currents, response to substorms?
- A reduction in magnetic field strength causes the magnetosphere to shrink
  - Affects the position (w.r.t. the Earth) of magnetospheric current systems
  - Affects the area exposed to the solar wind on the dayside
  - Occurrence frequency / intensity of (sub)storms?
- Changes in the position of the magnetic poles affect the geographic position of high-latitude ionospheric current systems

Previous work on the effect of magnetic field changes on geomagnetic activity

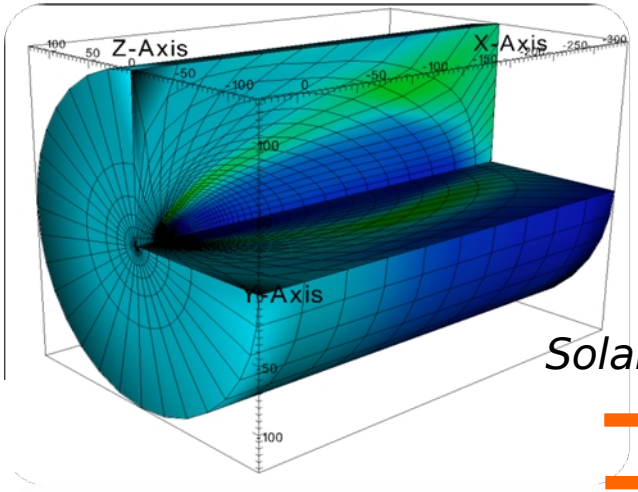
- Clilverd et al. (1998, 2002) estimated that a 10% decrease in *B*
  - Increases the ionospheric conductance by 10%
  - Moves the conductivity profiles up by 10% of a scale height (1 km in the E layer)
- They concluded that the effect on the *aa* index was probably small
- A modelling study by Cnossen et al. (2011) showed that the effect of *B* on ionospheric conductance is larger



The Coupled Magnetosphere-Ionosphere-Thermosphere (CMIT) model

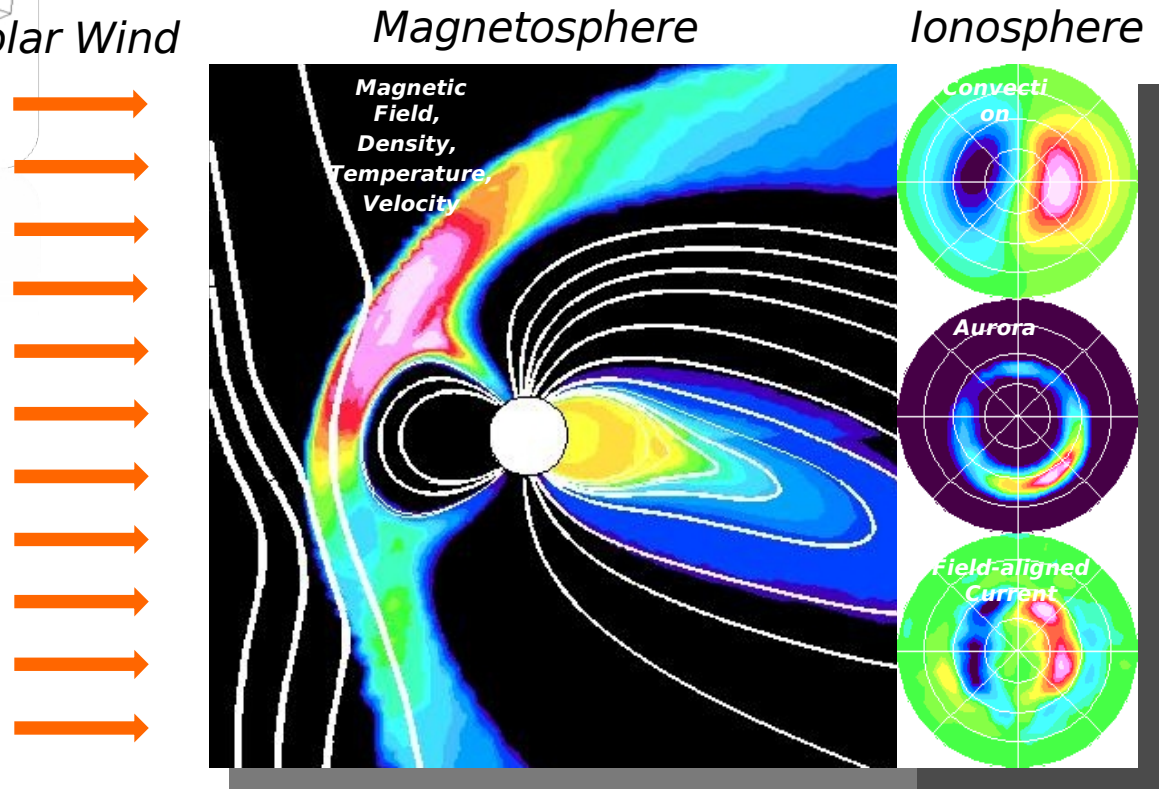


The LFM magnetospheric model



- LFM = Lyon-Fedder-Mobarry MHD code
- 3D Ideal MHD equations
- Upstream solar wind and IMF conditions
- Ionospheric inner boundary conditions

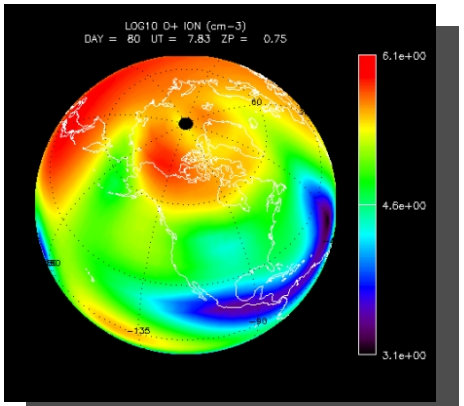
- Distorted spherical grid with azimuthal symmetry
- 30 R_E upwind
- 300 R_E downwind
- 100 R_E out to the sides

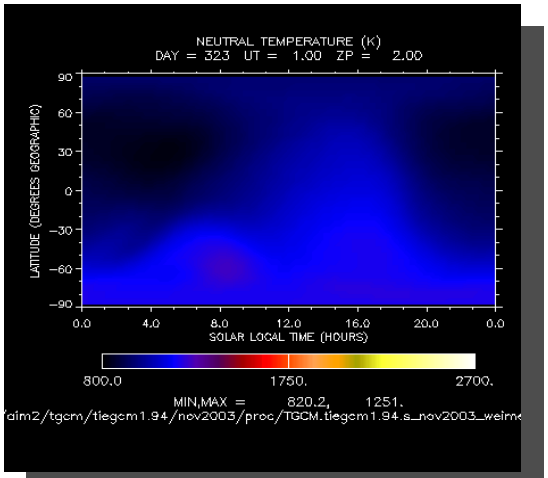


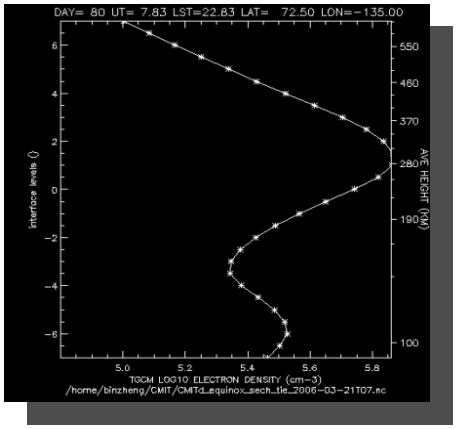
Graphics courtesy of Binzheng Zhang

The TIE-GCM

- TIE-GCM = Thermosphere-Ionosphere-Electrodynamics General Circulation Model
- Solves 3D equations of
  - Momentum
  - Continuity
  - Energy
- 5°x5° global grid
- ~97-500 km
- Includes the low/mid-latitude ionospheric wind dynamo
- Requires
  - Solar radiation flux, parameterized by F10.7
  - Lower boundary forcing (Global Scale Wave Model)
  - High-latitude electric potential
  - Energetic particle precipitation (energy and flux)







Graphics courtesy of Binzheng Zhang

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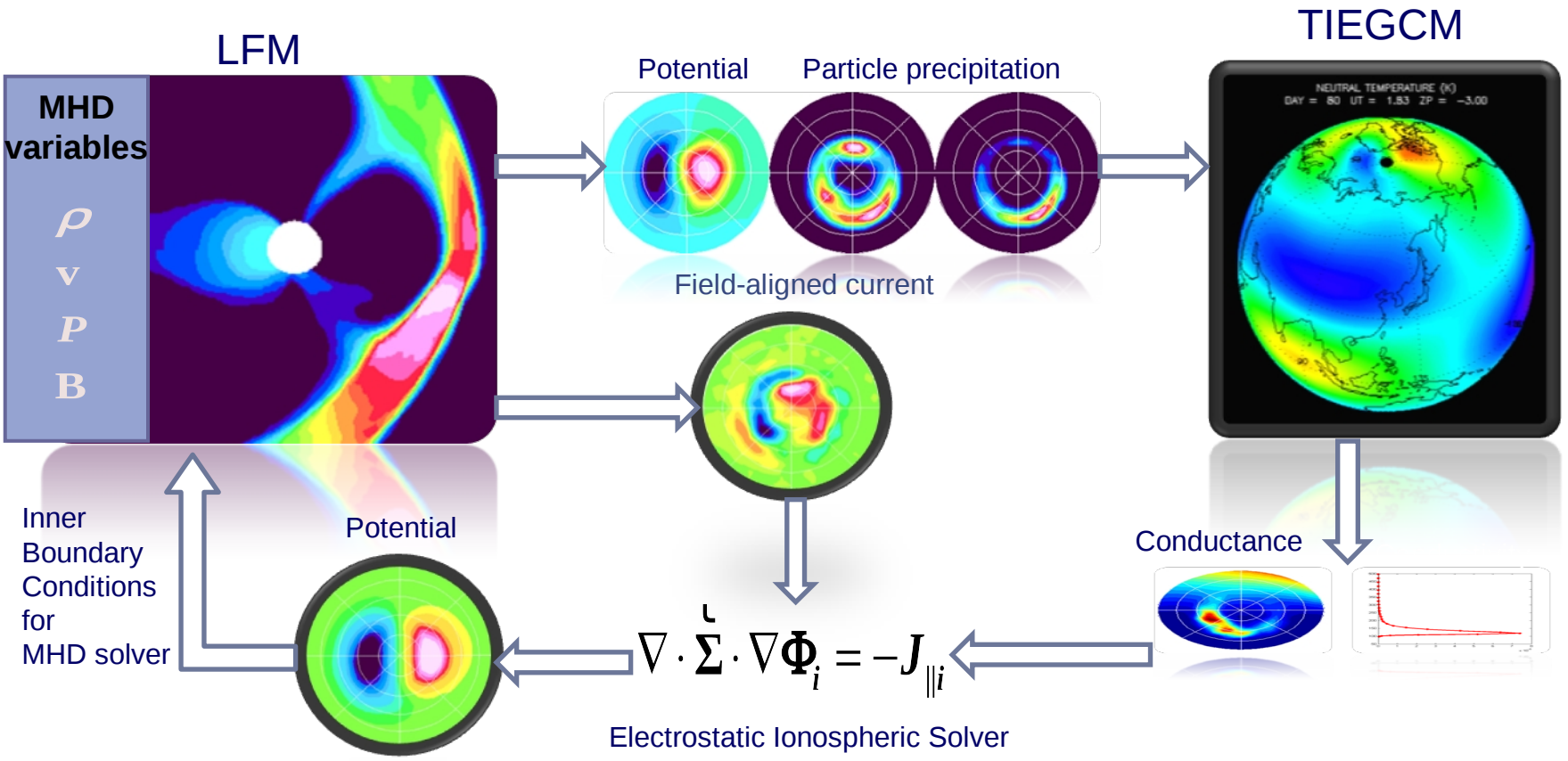


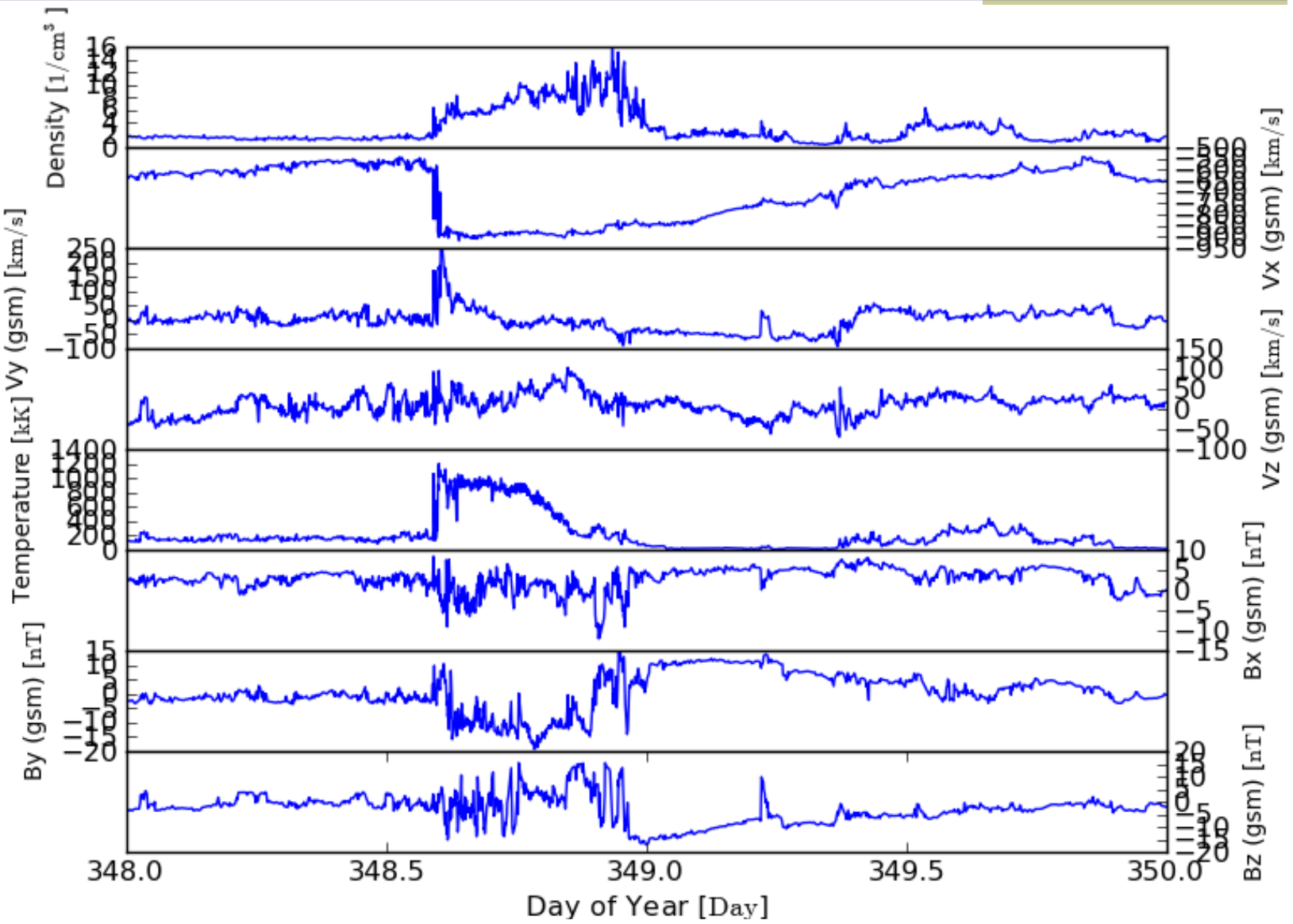
Graphics courtesy of Binzheng Zhang

- LFM = Lyon-Fedder-Mobarry MHD code
- TIEGCM = Thermosphere-Ionosphere-Electrodynamics General Circulation Model

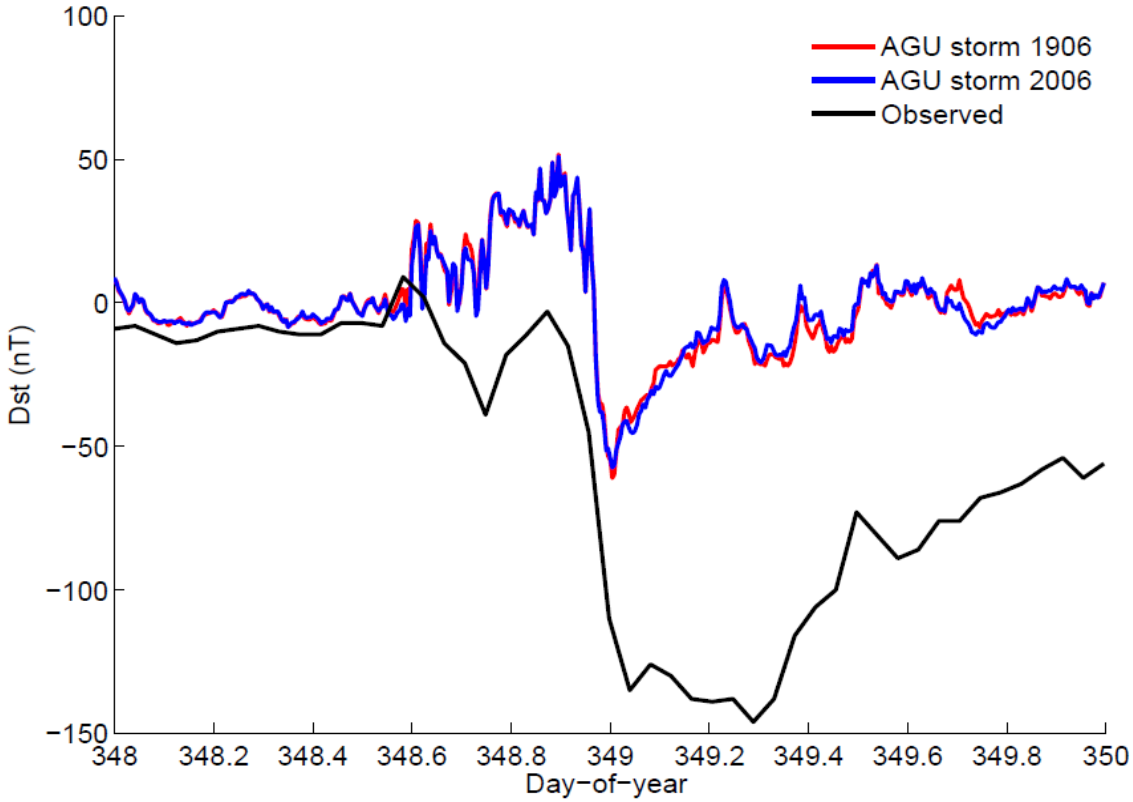
Methodology and limitations

- Simulate the AGU Fall storm with CMIT: 14 and 15 December 2006
  - With the 2006 magnetic field
  - With the 1906 magnetic field
- Compare 2006 results to observations to see how well (or bad) we do
- Calculate D_{st} index
  - Limitation: CMIT does not represent the ring current very well
- Calculate magnetic perturbations on the ground
  - Limitation: only ionospheric current systems are included in the calculation
- Further limitations
  - CMIT experiences trouble with the solar wind conditions on 15 December 2006 --> so far results only for 14 December
  - K-derived indices can only be calculated if the smooth quiet-time variation (S_q) is known
  - Results may be different for other seasons, solar maximum, etc.

Solar wind conditions 14-15 December 2006

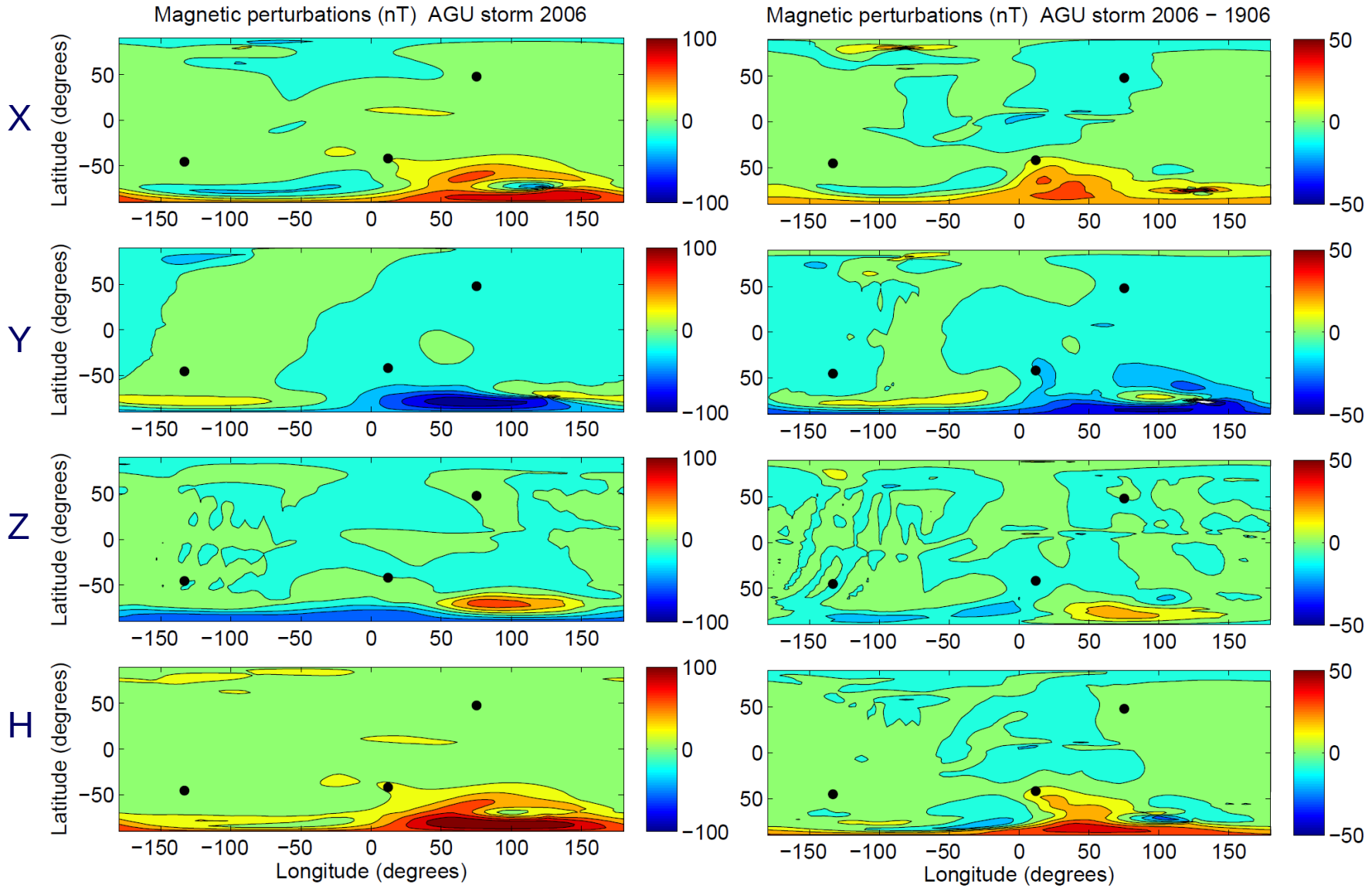


D_{st} index

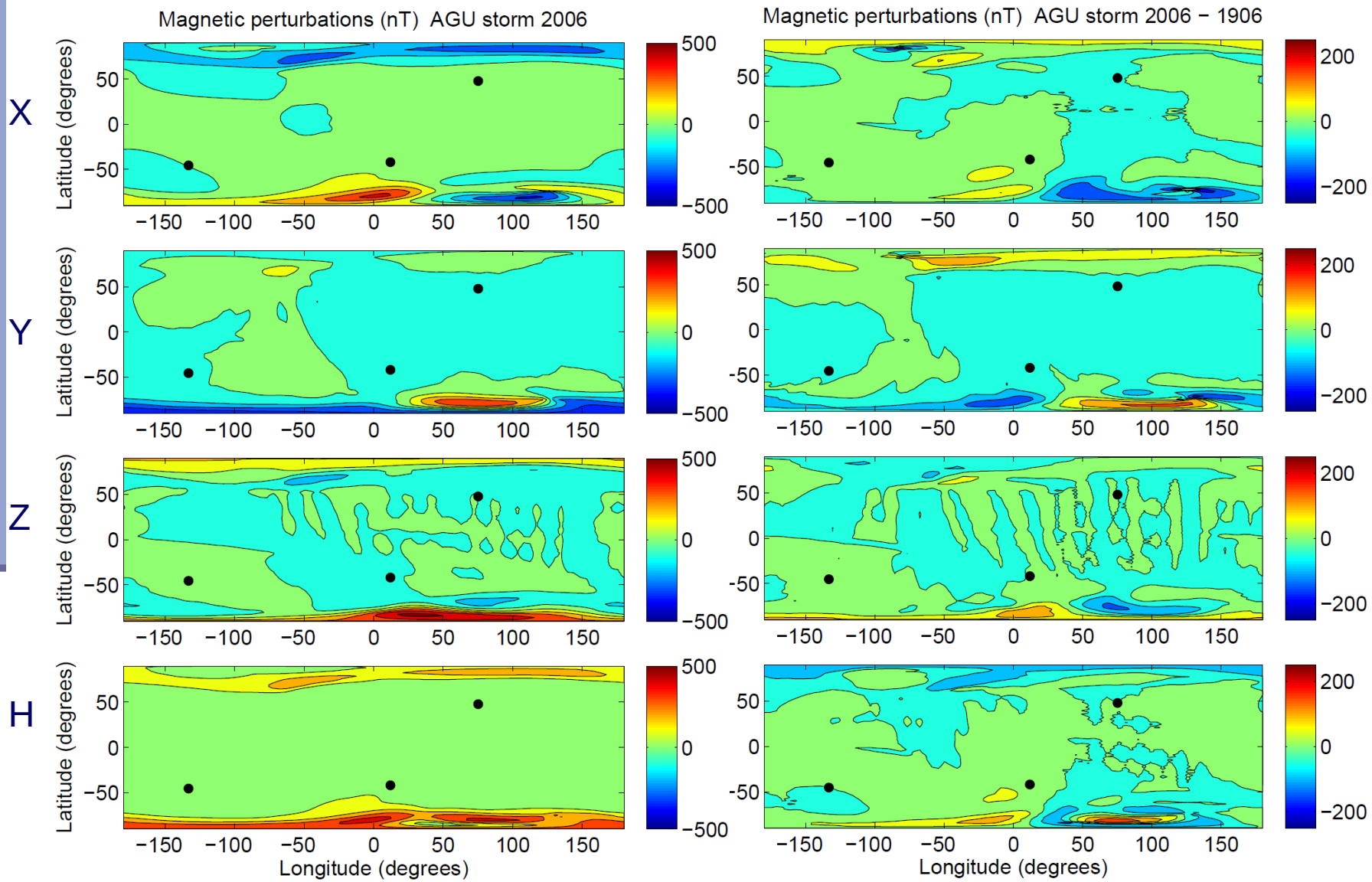


- Modelled D_{st} index does not agree well with observations
- Probably due to poor representation of ring current
- The difference between the 1906 and 2006 simulations is very small

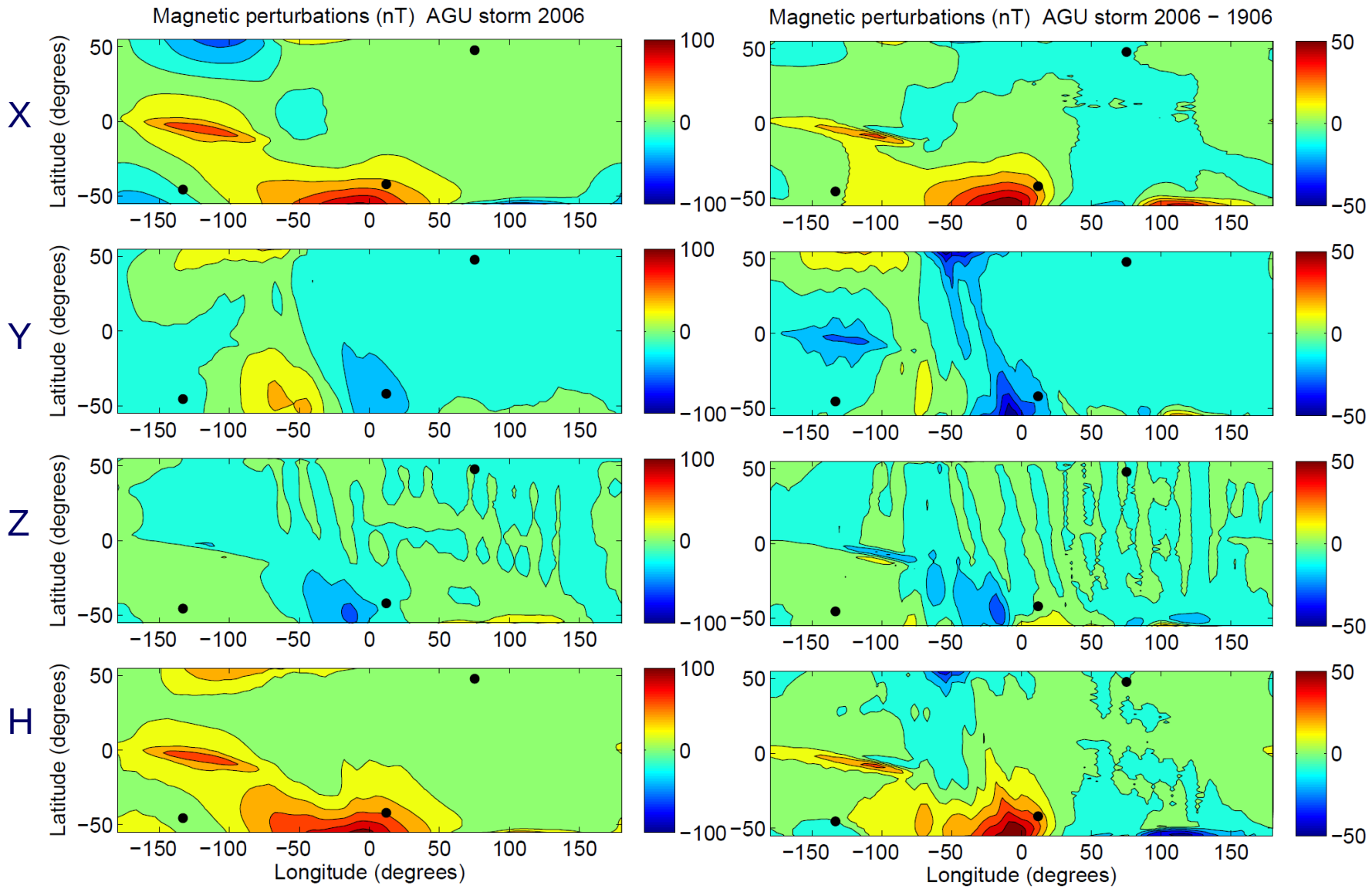
Magnetic perturbation maps: 14 Dec. 10 UT (quiet)



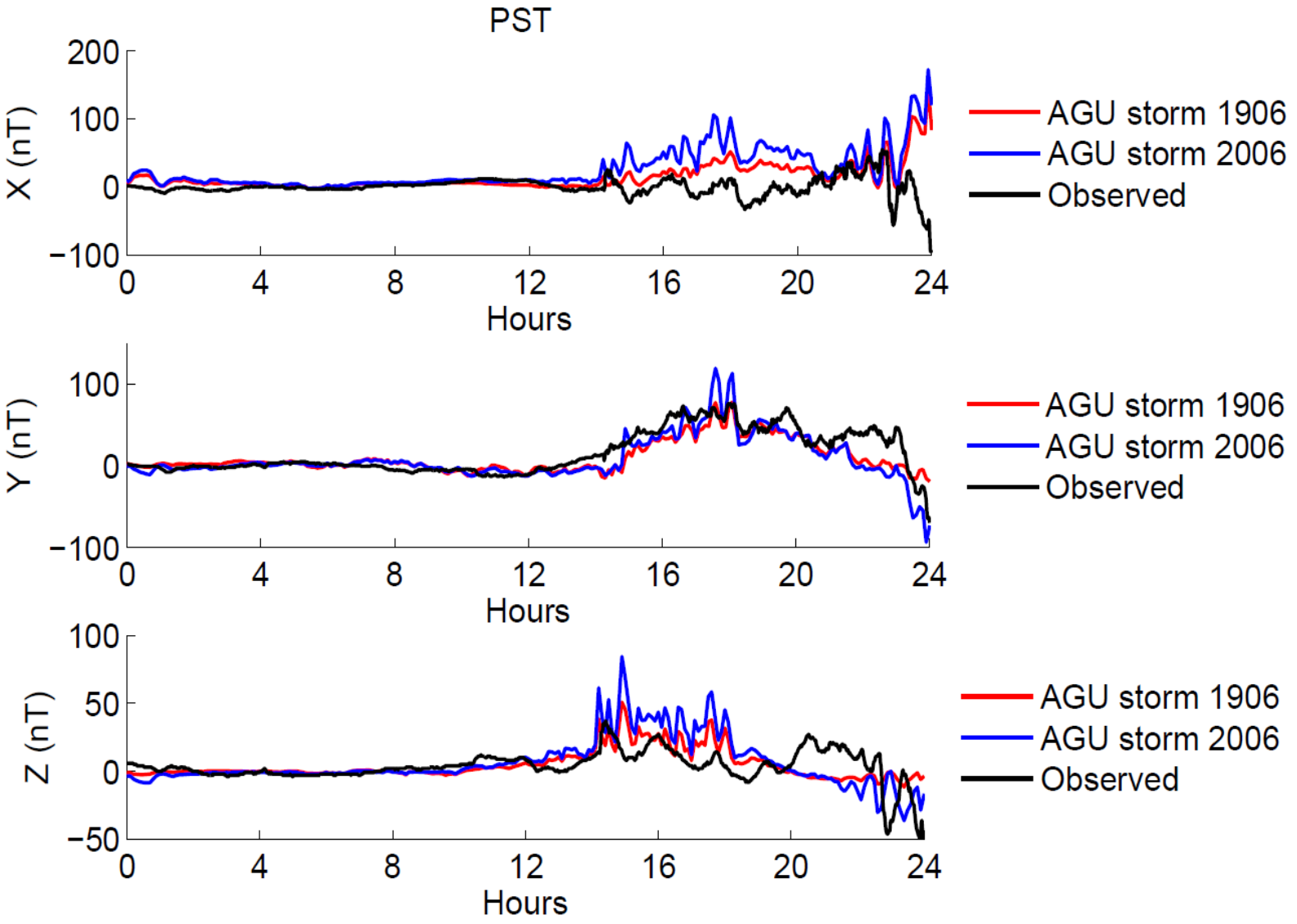
Magnetic perturbation maps: 14 Dec. 20 UT



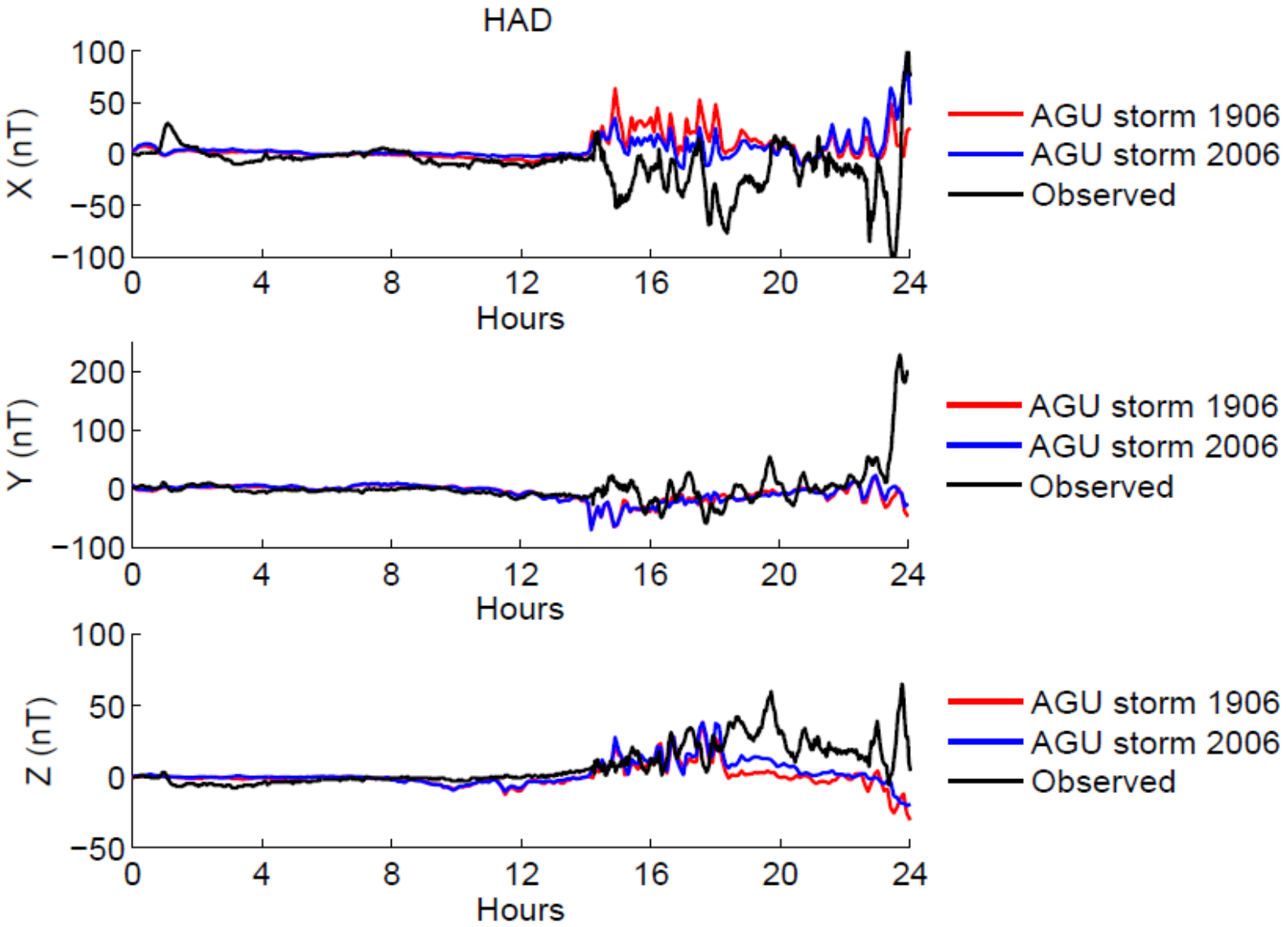
Magnetic perturbation maps: 14 Dec. 20 UT (low/mid-latitude)



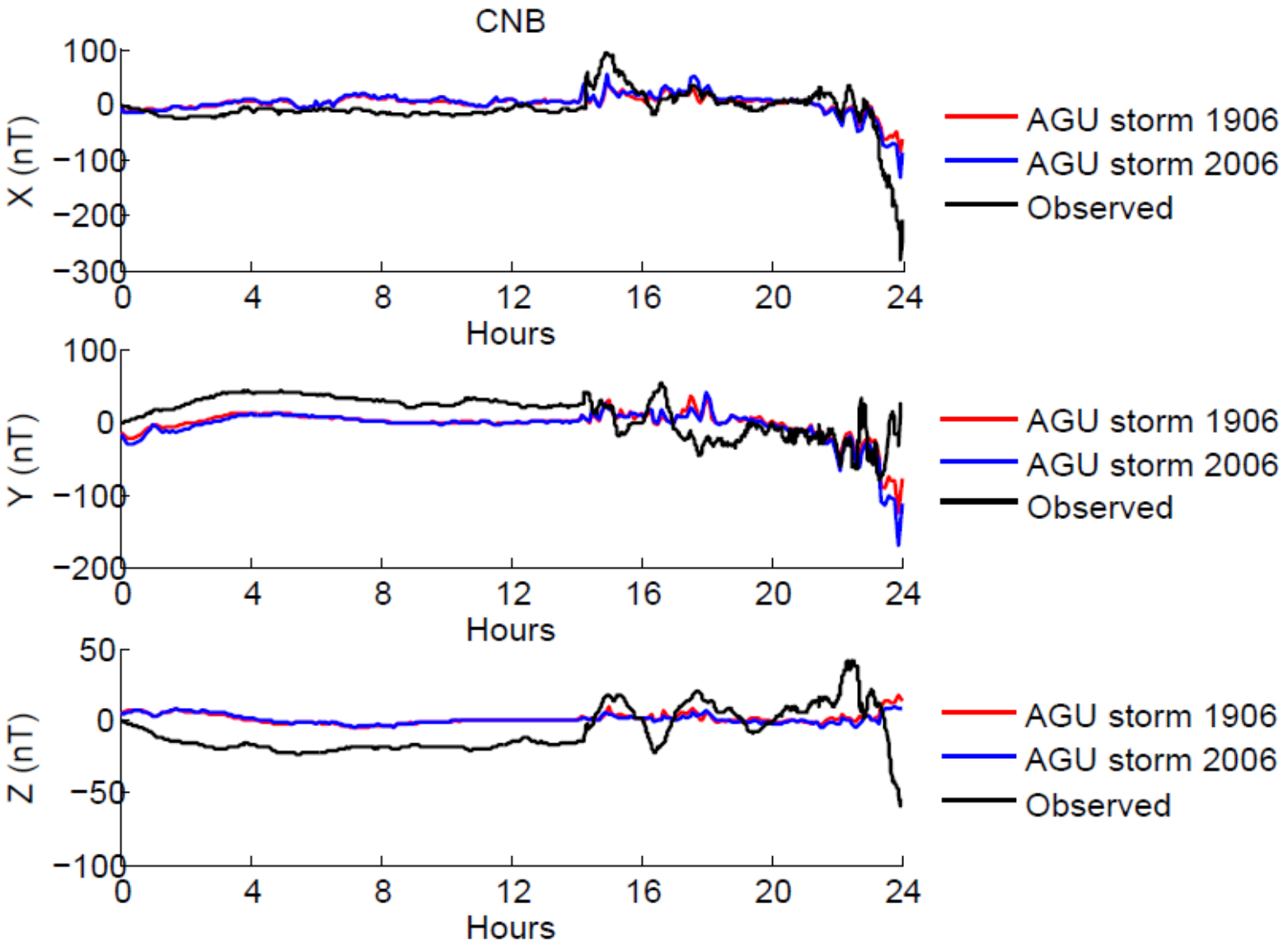
Magnetic perturbations in the South Atlantic anomaly region: Port Stanley



Magnetic perturbations at *aa* index stations: Hartland



Magnetic perturbations at *aa* index stations: Canberra



Summary, conclusions and further work

- The Earth's magnetic field changes in strength and topology over time
- This can cause changes in ionospheric and magnetospheric current systems, and therefore in geomagnetic activity
- Preliminary results from simulations with the Coupled Magnetosphere Thermosphere Ionosphere (CMIT) model indicate that:
  - The effects on geomagnetic depend on location and background conditions
  - The effect on the *aa* index is probably small
- Further work needed, e.g.:
  - Resolve CMIT problem for December 15 2006
  - Influence of solar activity level (F10.7 setting in the model)
  - Other seasons
  - Coupling of CMIT to Rice Convection Model for better ring current
  - Other suggestions?

The end

Thanks for your attention!

Questions?