Update on Empirical Models At CCMC

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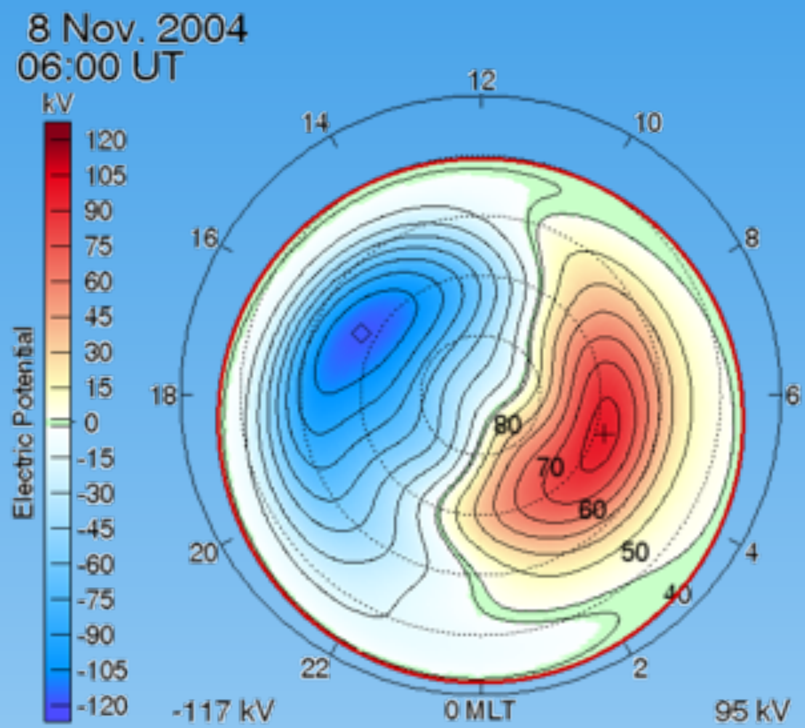
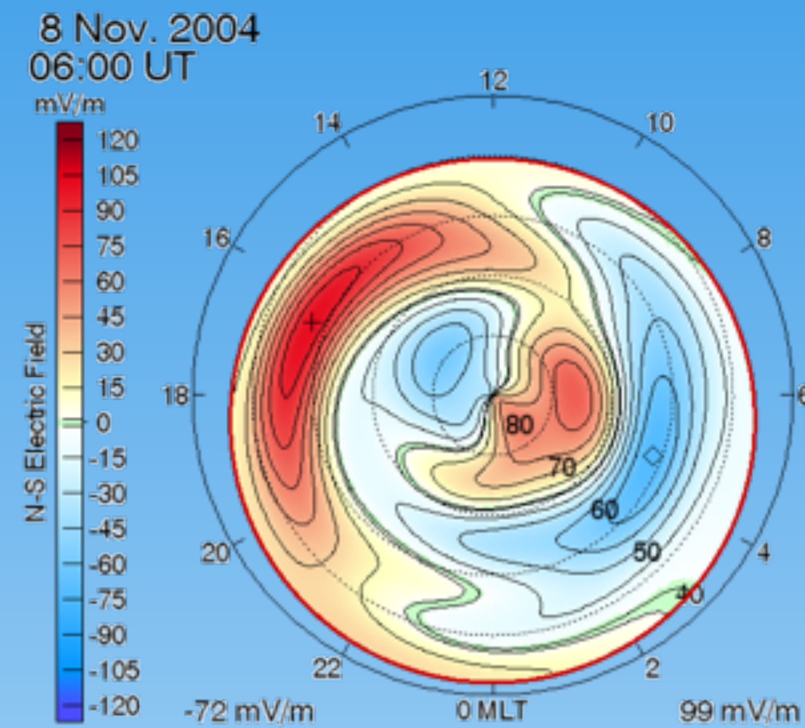
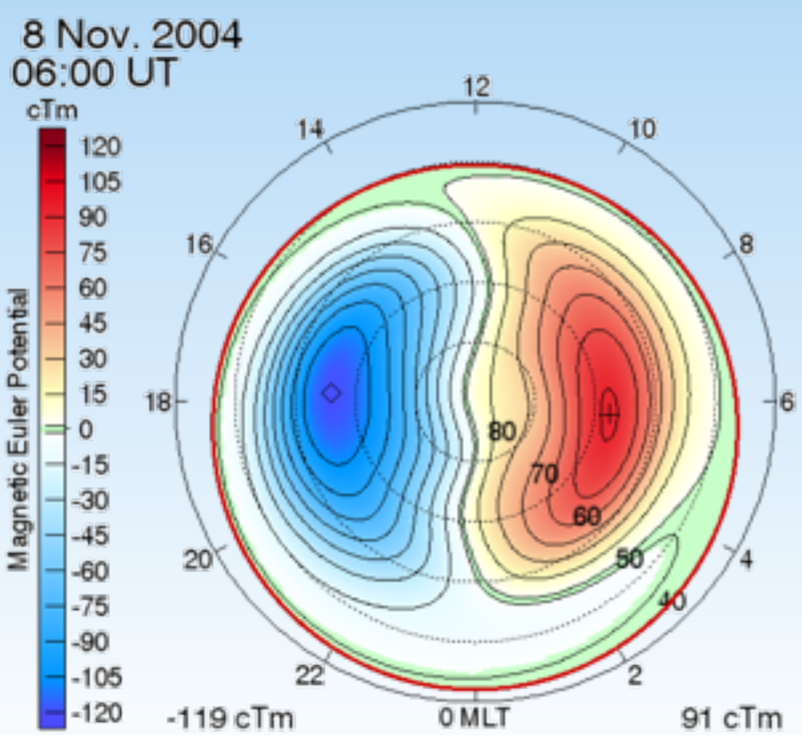
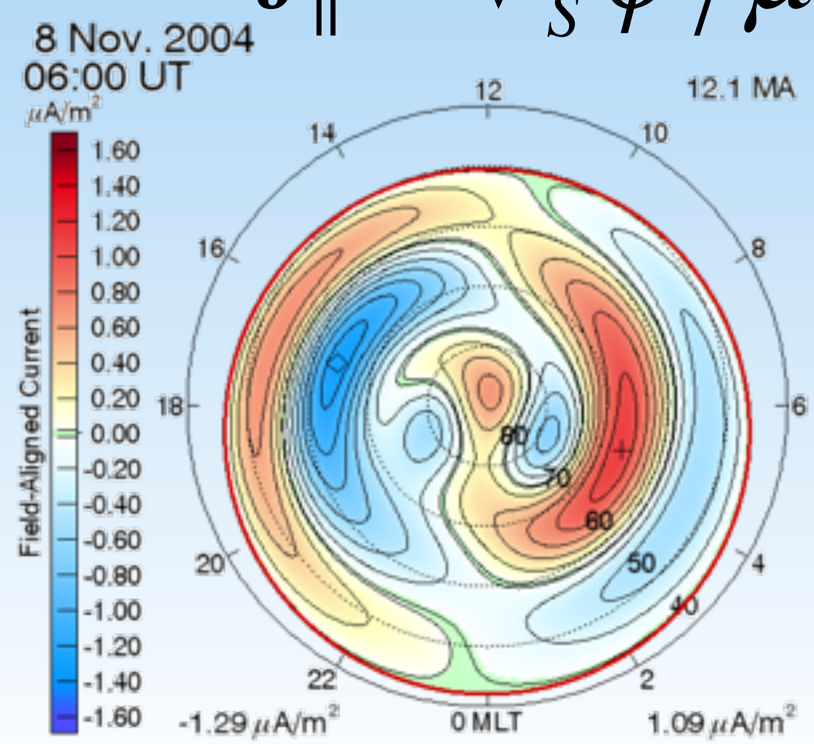




$$\mathbf{E} = -\nabla_S \Phi$$

$$J_{\parallel} = \nabla_S^2 \psi / \mu_o$$



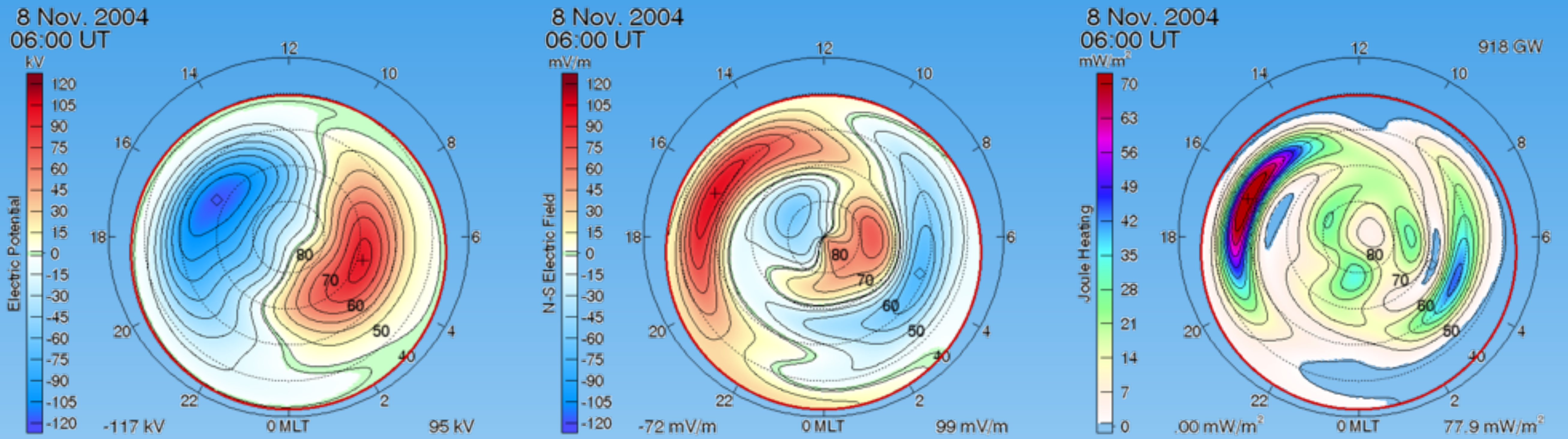


Brief Review:

The 2005 model included both electric potential and magnetic Euler potential.

The magnetic potential model was first created in order to map field-aligned currents, without use of the "infinite current sheet" assumption. Conductivity variations in ionosphere are implicitly included in the magnetometer measurements.

These models use "spherical cap harmonic analysis" (SCHA).



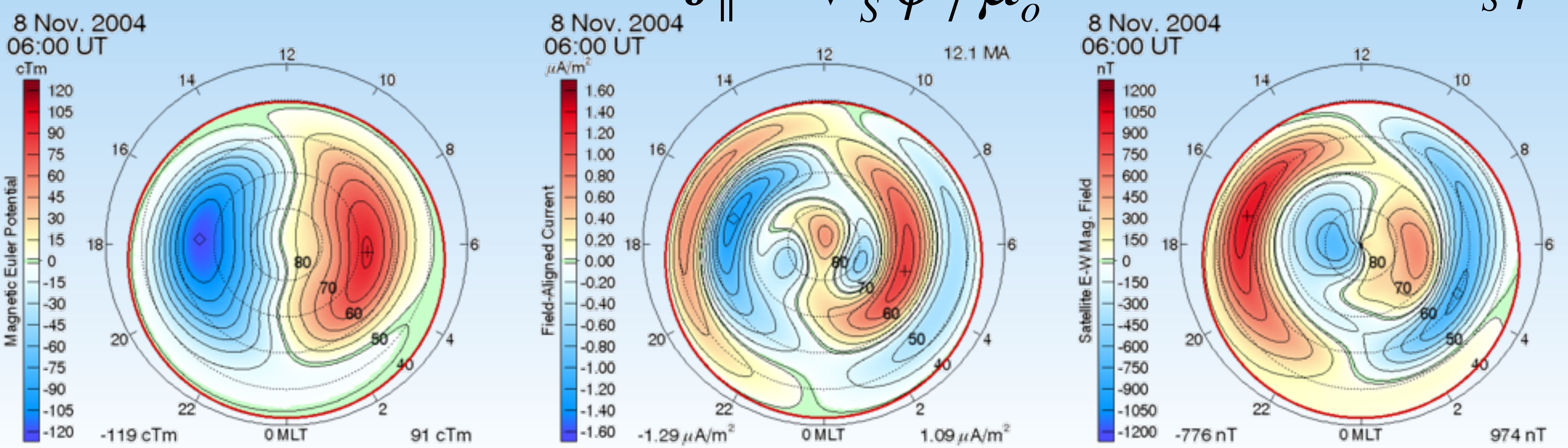
$$\mathbf{E} = -\nabla_S \Phi$$

$$\mathbf{S} = \mathbf{E} \times \Delta\mathbf{B} / \mu_o$$

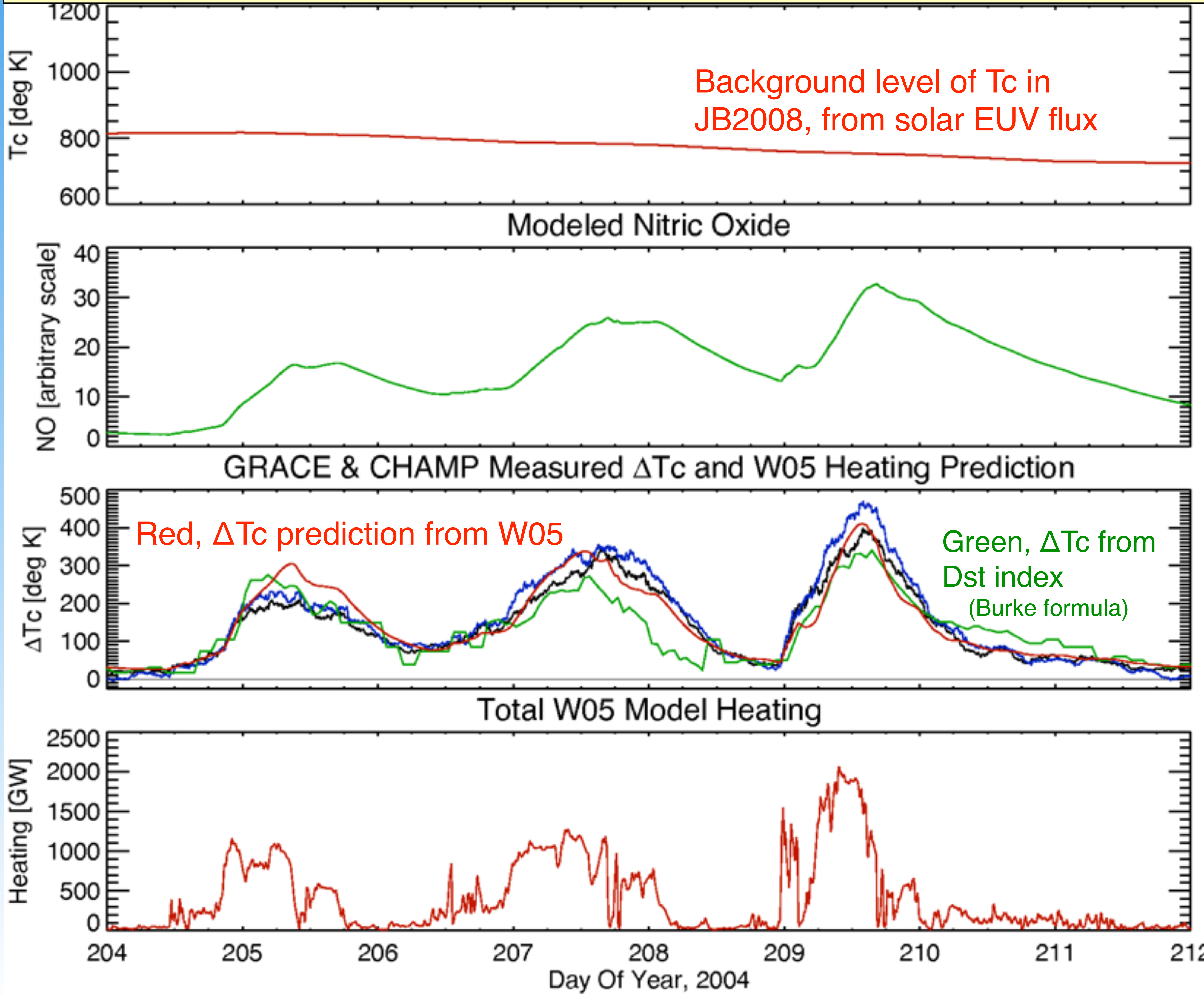
Although developed for a FAC model, the magnetic potentials have been even more useful, in combination with the electric potentials, to obtain the Poynting flux

$$J_{\parallel} = \nabla_S^2 \psi / \mu_o$$

$$\Delta\mathbf{B} = \hat{\mathbf{r}} \times \nabla_S \psi$$



Poynting flux from W05 model compared with change in average exospheric temperature, derived from CHAMP/GRACE densities



The ΔT_C prediction technique:

$$\Delta T_c(t_{n+1}) = \Delta T_c(t_n)(1 - \Delta t / \tau_c) + \beta H_J \Delta t$$

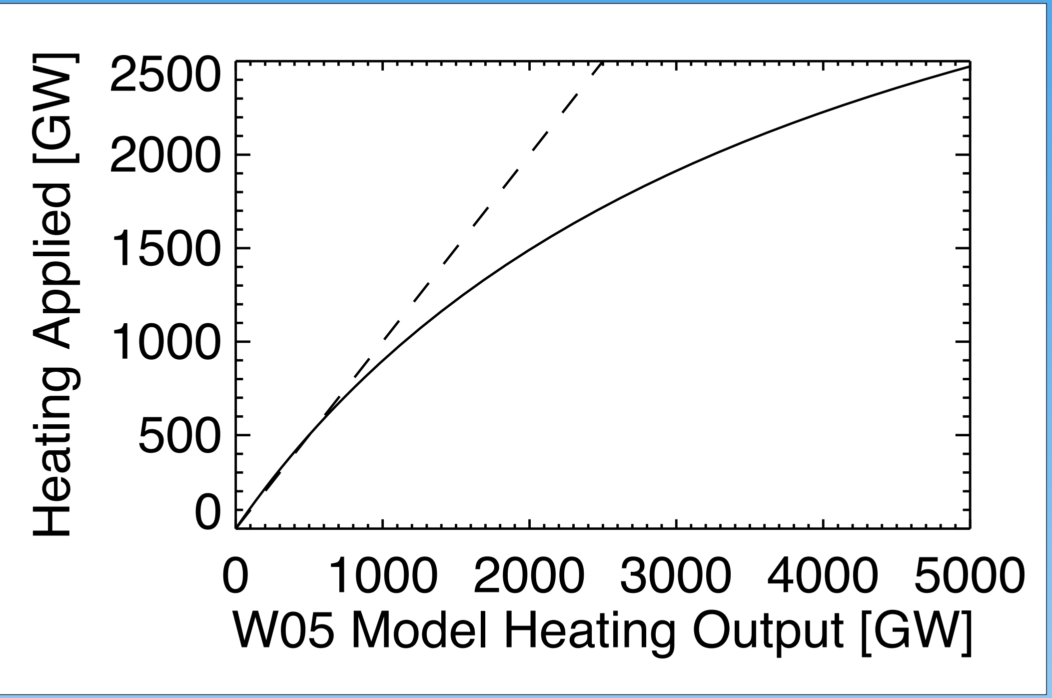
$$\beta = 6.9 \cdot 10^{-4} \ (°\mathrm{K/GW\text{-}min})$$

$$\tau_c = 14.6 \ (\mathrm{hours}) - 0.281 \ NO$$

$$NO(t_{n+1}) = NO(t_n)(1 - \Delta t / \tau_{NO}) + \gamma H_J \Delta t$$

$$\gamma = 2.5 \cdot 10^{-5} \ (\mathrm{units/GW\text{-}min})$$

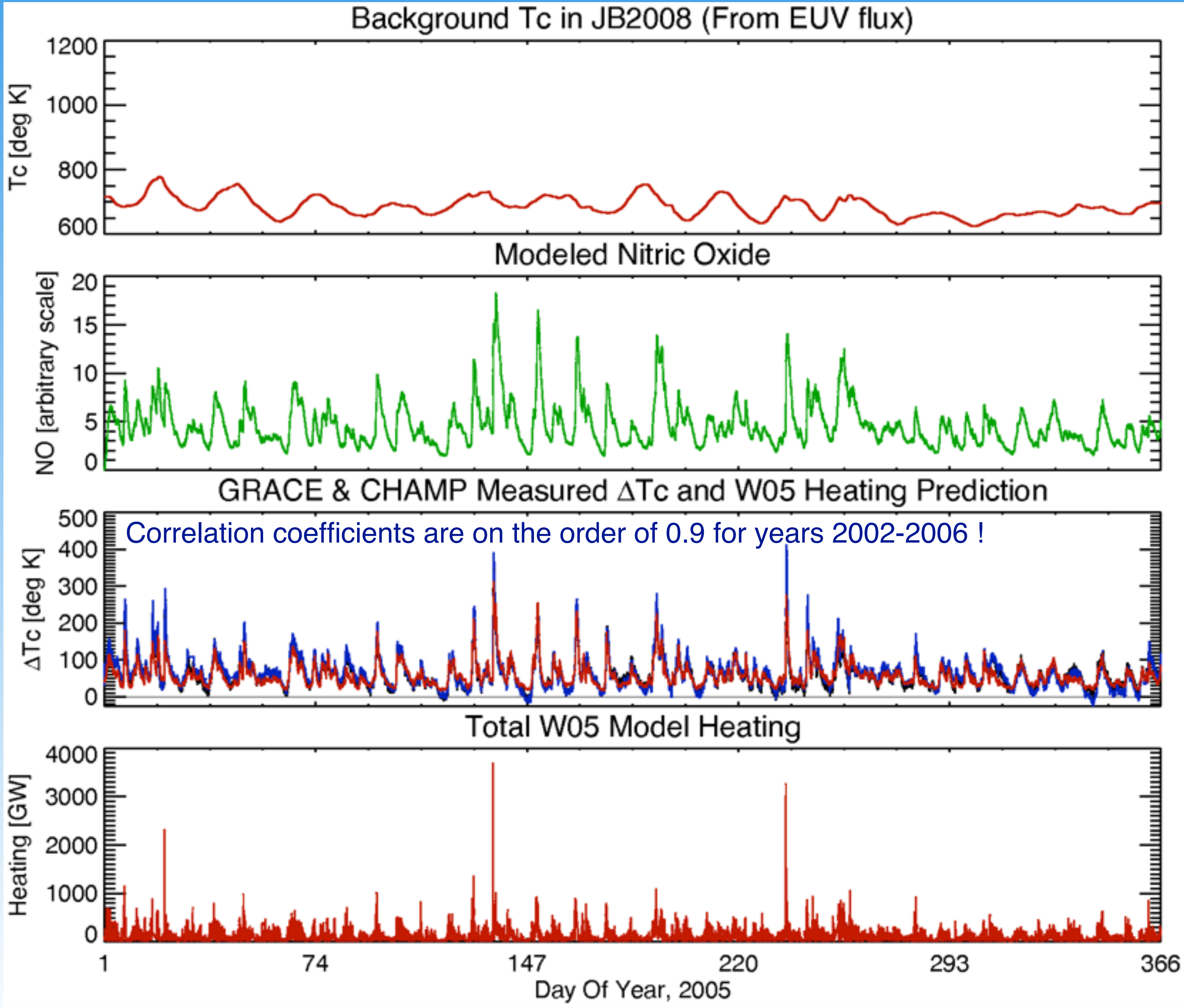
$$\tau_{NO} = 28.0 \ (\mathrm{hours})$$

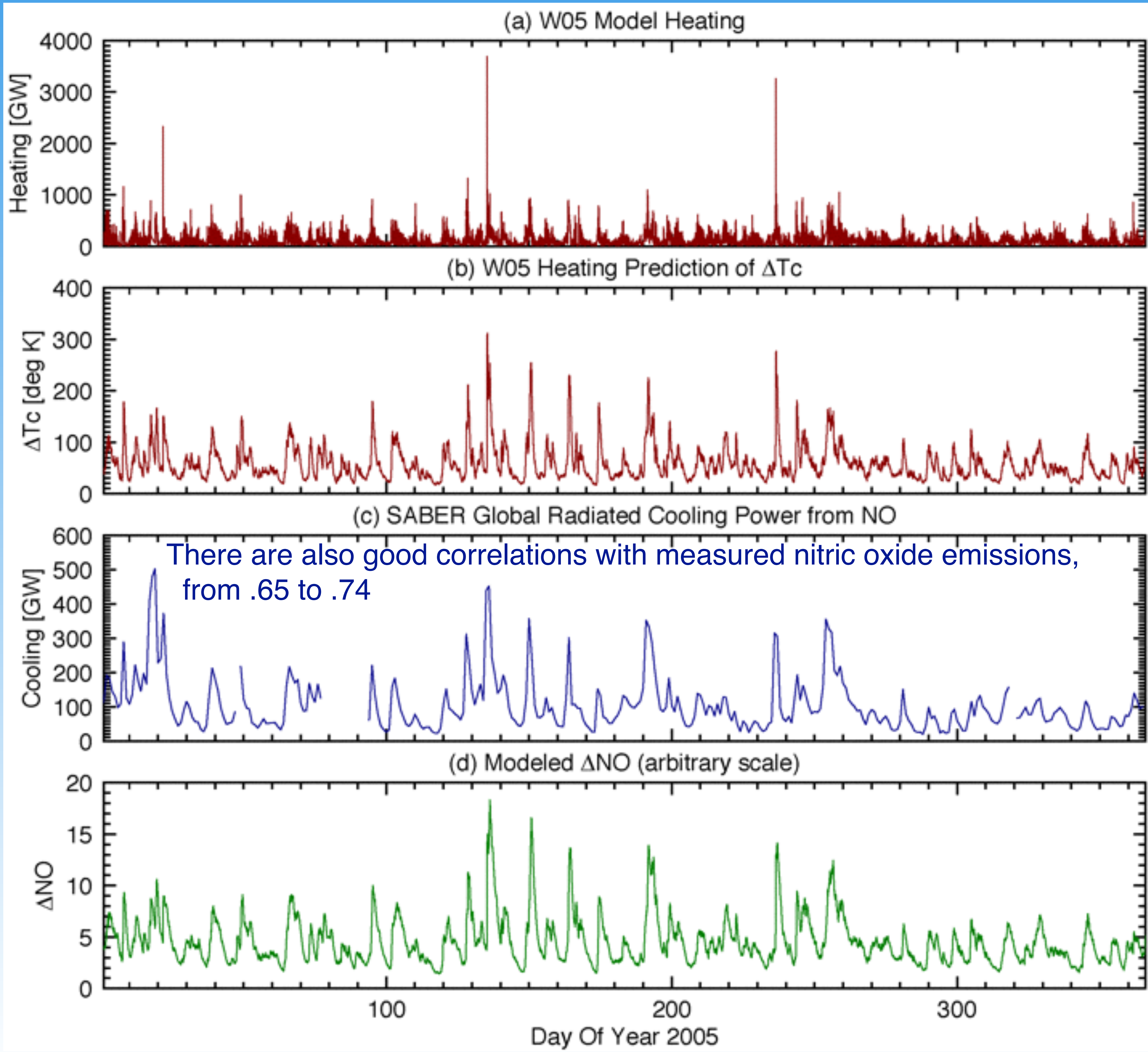


Saturation curve applied to heating

H_J is total Joule heating/Poynting flux from W05 model, with additional saturation applied. All constants (except Υ) obtained by fitting five years of H_J with CHAMP and GRACE measurements of ΔT_C.

A program that does this calculation has been delivered to the CCMC.


Background Tc in JB2008 (From EUV flux)
Tc [deg K]
1200
1000
800
600
Modeled Nitric Oxide
NO [arbitrary scale]
20
15
10
5
0
GRACE & CHAMP Measured ΔTc and W05 Heating Prediction
Correlation coefficients are on the order of 0.9 for years 2002-2006 !
ΔTc [deg K]
500
400
300
200
100
0
Total W05 Model Heating
Heating [GW]
4000
3000
2000
1000
0
1
74
147
220
293
366
Day Of Year, 2005

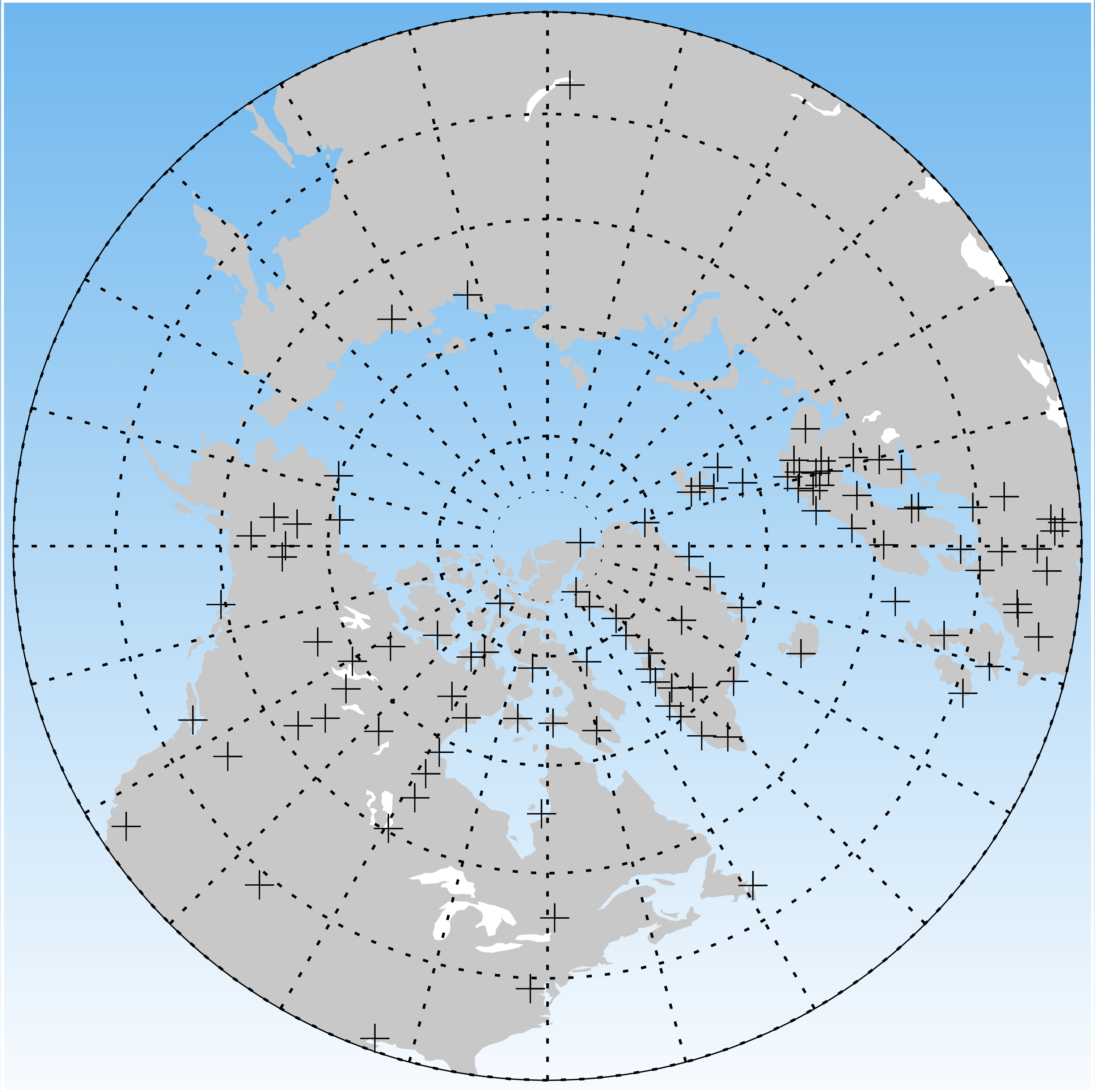

(a) W05 Model Heating
Heating [GW]
(b) W05 Heating Prediction of ΔTc
ΔTc [deg K]
(c) SABER Global Radiated Cooling Power from NO
Cooling [GW]
There are also good correlations with measured nitric oxide emissions, from .65 to .74
(d) Modeled ΔNO (arbitrary scale)
ΔNO
Day Of Year 2005

New model for prediction of geomagnetic perturbations

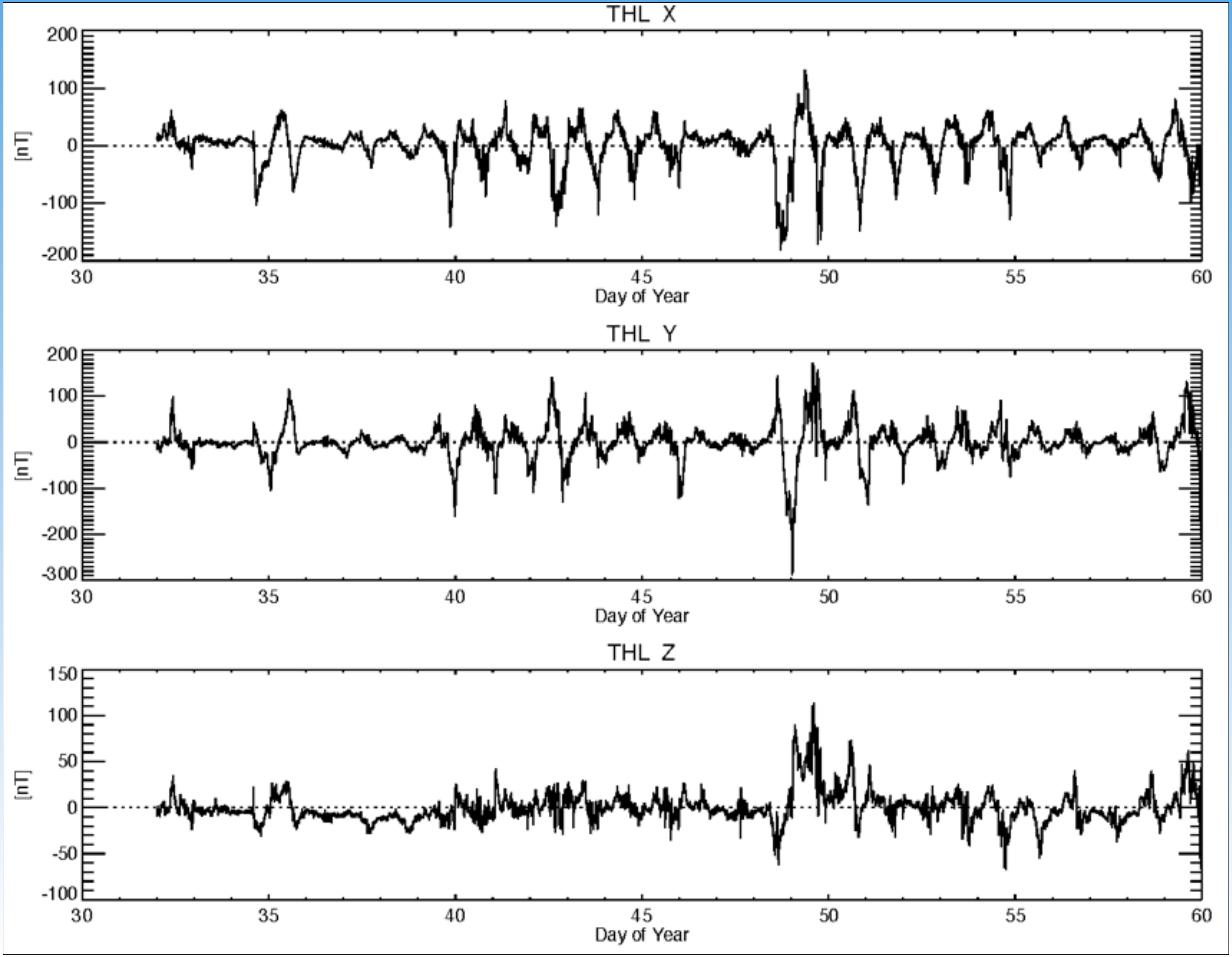
Reference: Weimer, D. R. (2013), An empirical model of ground-level geomagnetic perturbations, *Space Weather*, *11*, 107–120, doi:10.1002/swe.20030

Uses data from >140 magnetometer stations in Northern hemisphere, over an 8-year period (1998-2005), solar wind & IMF, and $F_{10.7}$.

Effects of conductivity variations and induced, underground currents are implicitly included.



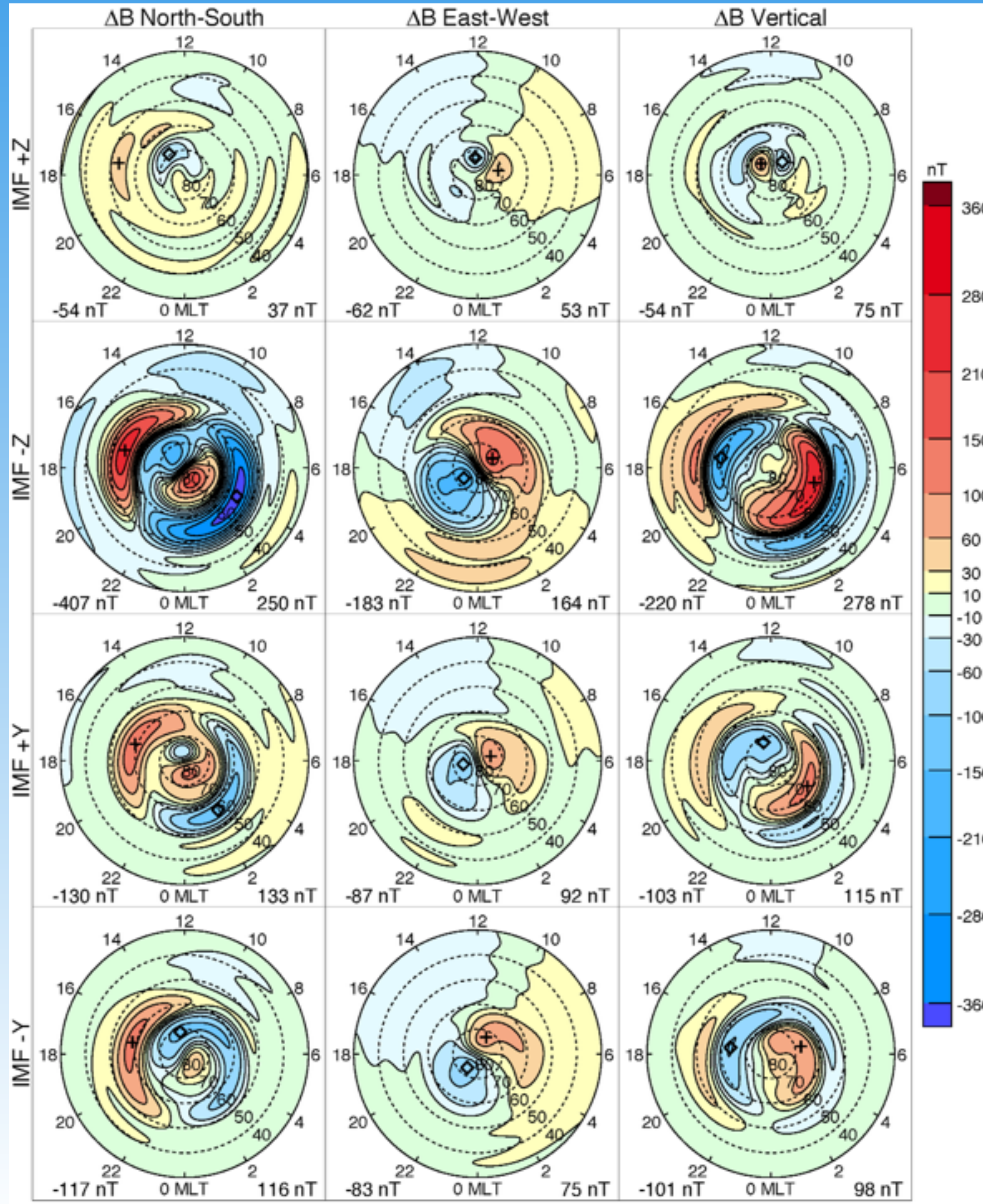
Example of processed data, spanning one month
(≈13,000 of these were examined for quality control)

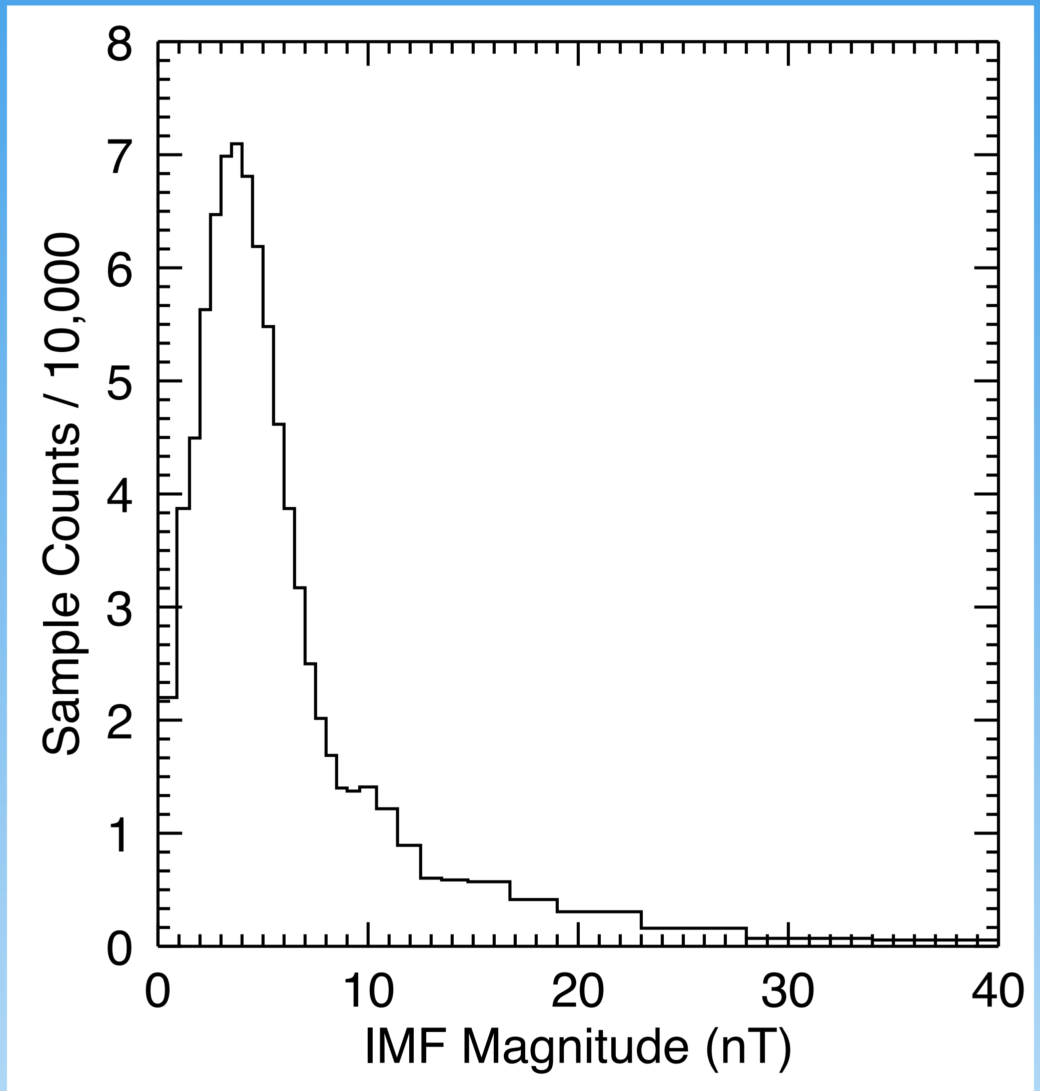


Model results for all three vector components of ΔB, with 8 nT IMF at four clock angle orientations.

Results are consistent with prior models.

Vertical ΔB maps resemble field-aligned current (FAC) maps





The data are divided into 29 bins, sorted according to IMF magnitude. The width of each bin increased above 9 nT, yet there are few samples in the highest bins.

Model coefficients are derived using a least-error fit for each bin, including an over-lap of data from the adjacent bins.

Each vector component is fit separately, using spherical harmonics on a 90º cap, in corrected geomagnetic apex coordinates.

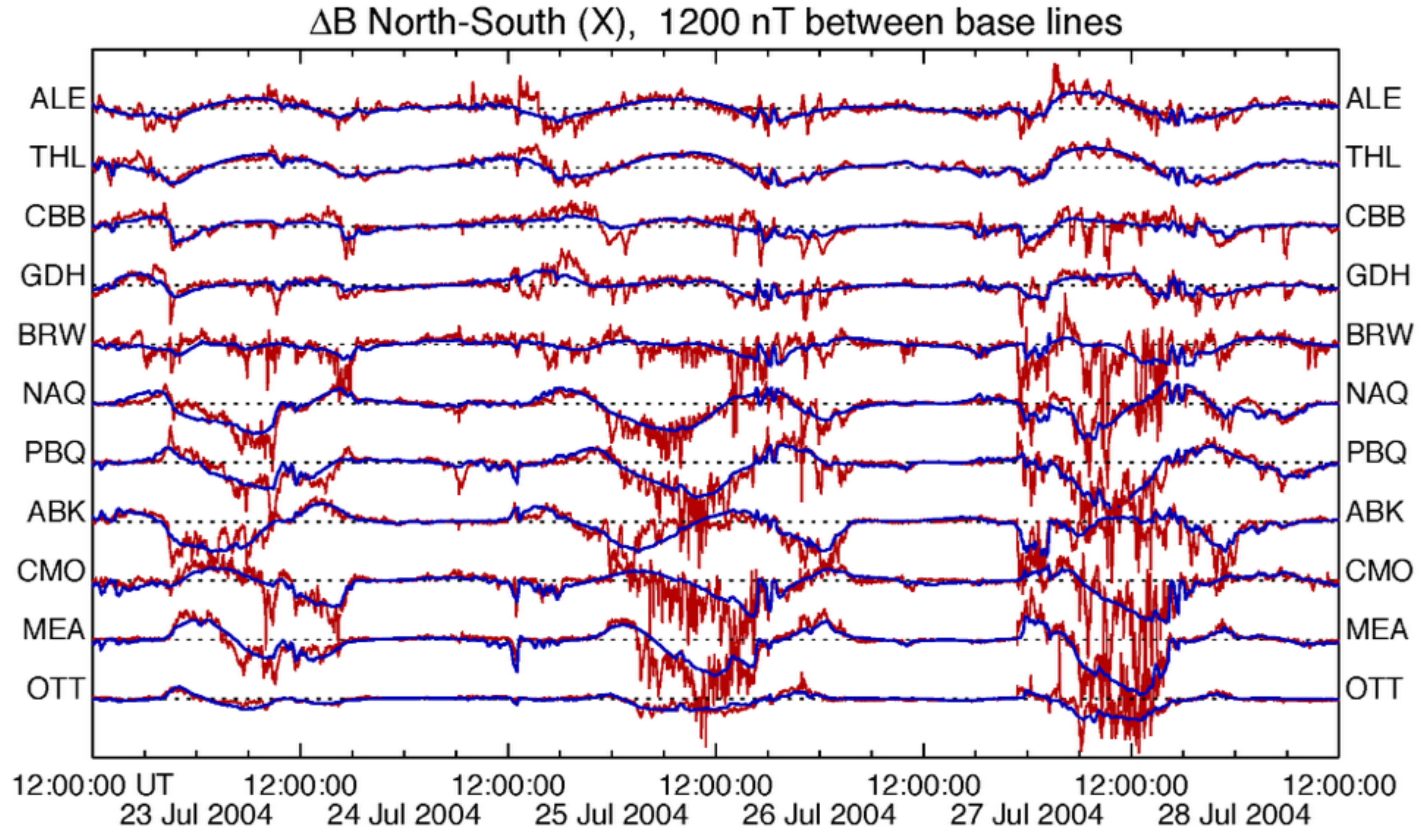
Only even *l-m* combinations of the Legendre polynomials are used.

To obtain a smooth response curve, the C_n coefficients are interpolated, given the IMF magnitude.

$$\Delta B_X(\Lambda,\varphi) = \sum_{l=0}^{31}\sum_{m=0}^{3<l} P_l^m(\cos\Lambda)(g_k^m \cos m\varphi + h_k^m \sin m\varphi)$$

$$\begin{aligned} g_k^m = {} & c_0 + c_1 B_T + c_2 V_{SW} + c_3 t + c_4\sqrt{F_{10.7}} + \\ & c_5 B_T\cos(\theta_c) + c_6 V_{SW}\cos(\theta_c) + c_7 t\cos(\theta_c) + c_8\sqrt{F_{10.7}}\cos(\theta_c) + \\ & c_9 B_T\sin(\theta_c) + c_{10} V_{SW}\sin(\theta_c) + c_{11} t\sin(\theta_c) + c_{12}\sqrt{F_{10.7}}\sin(\theta_c) + \\ & c_{13} B_T\cos(2\theta_c) + c_{14} V_{SW}\cos(2\theta_c) + c_{15} B_T\sin(2\theta_c) + c_{16} V_{SW}\cos(2\theta_c) \end{aligned}$$

The model does very well at prediction of ΔB levels, not so well on the superposed and random, higher frequency variations. Substorms are also not modeled.



Incidental Note About Metrics

Presently used metrics for δB/δt and Regional-K both ignore the sign of ΔB, as well as overall agreement with ΔB level:

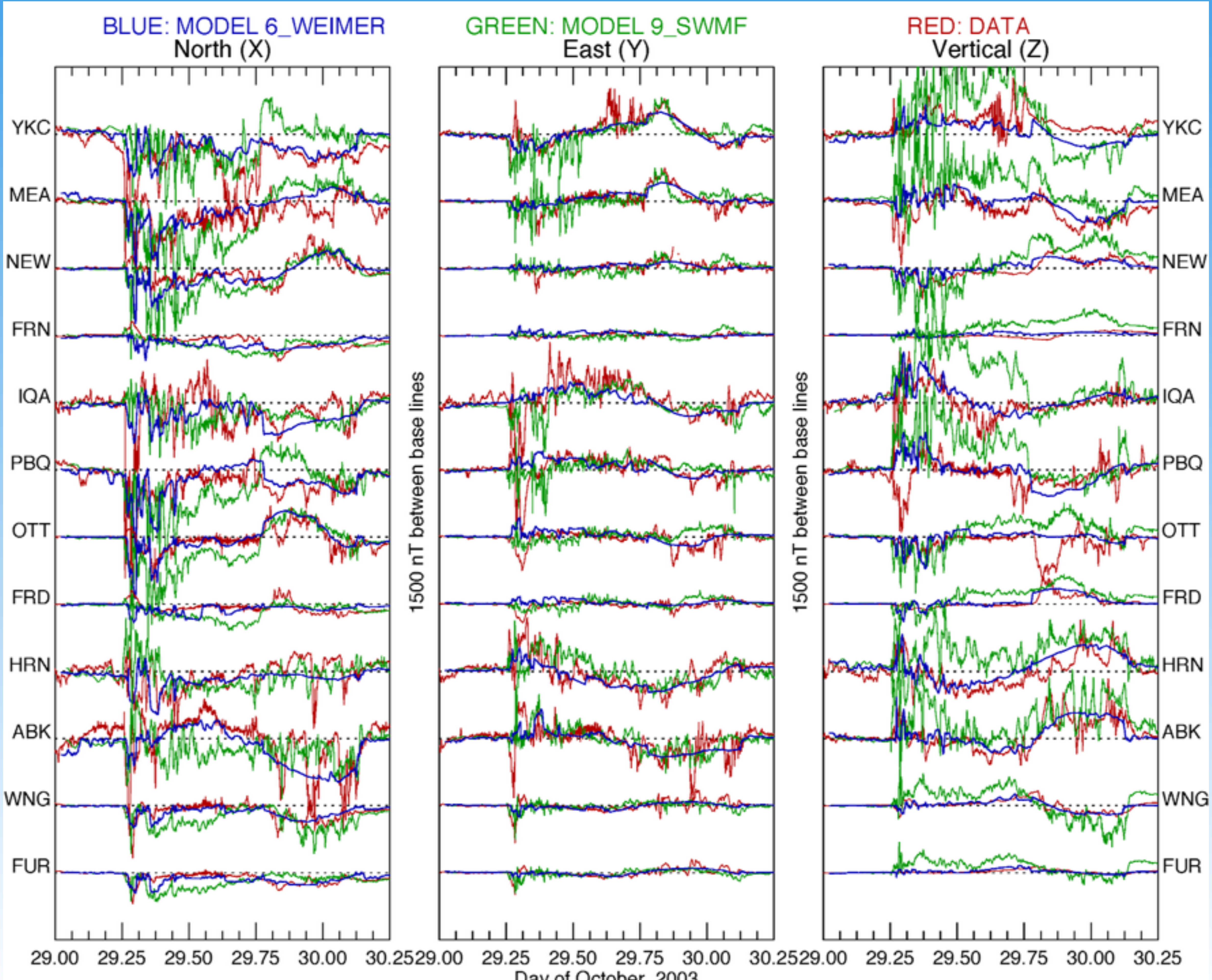
$$dB/dt = \sqrt{\left(dB_x/dt\right)^2 + \left(dB_y/dt\right)^2}$$

K is calculated from the maximum "Range" of ΔB in the two horizontal directions, over three hours =

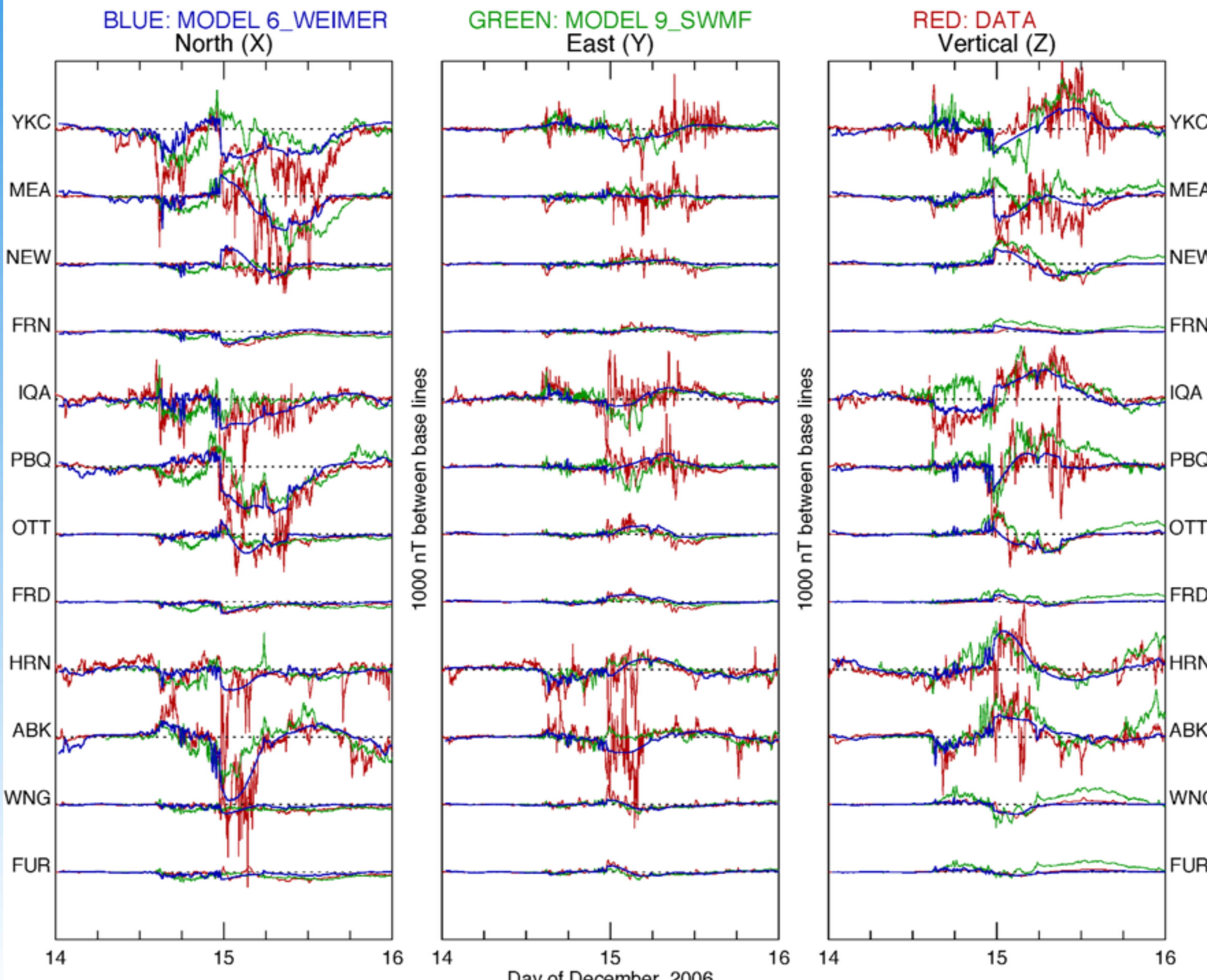
max[(ΔBx,max−ΔBx,min), (ΔBy,max−ΔBy,min)]

As a result, both metrics can result in "good," high scores for predictions of ΔB having signs opposite to the actual ΔB, or very wrong magnitudes, as these metrics only test changes in ΔB during certain time intervals, and not the level.

With the present metrics for δB/δt and Regional-K, it may be possible to do just as well with output from a pseudo-random noise generator, that is added to the more smoothly varying ΔB prediction, scaled to the predicted level.

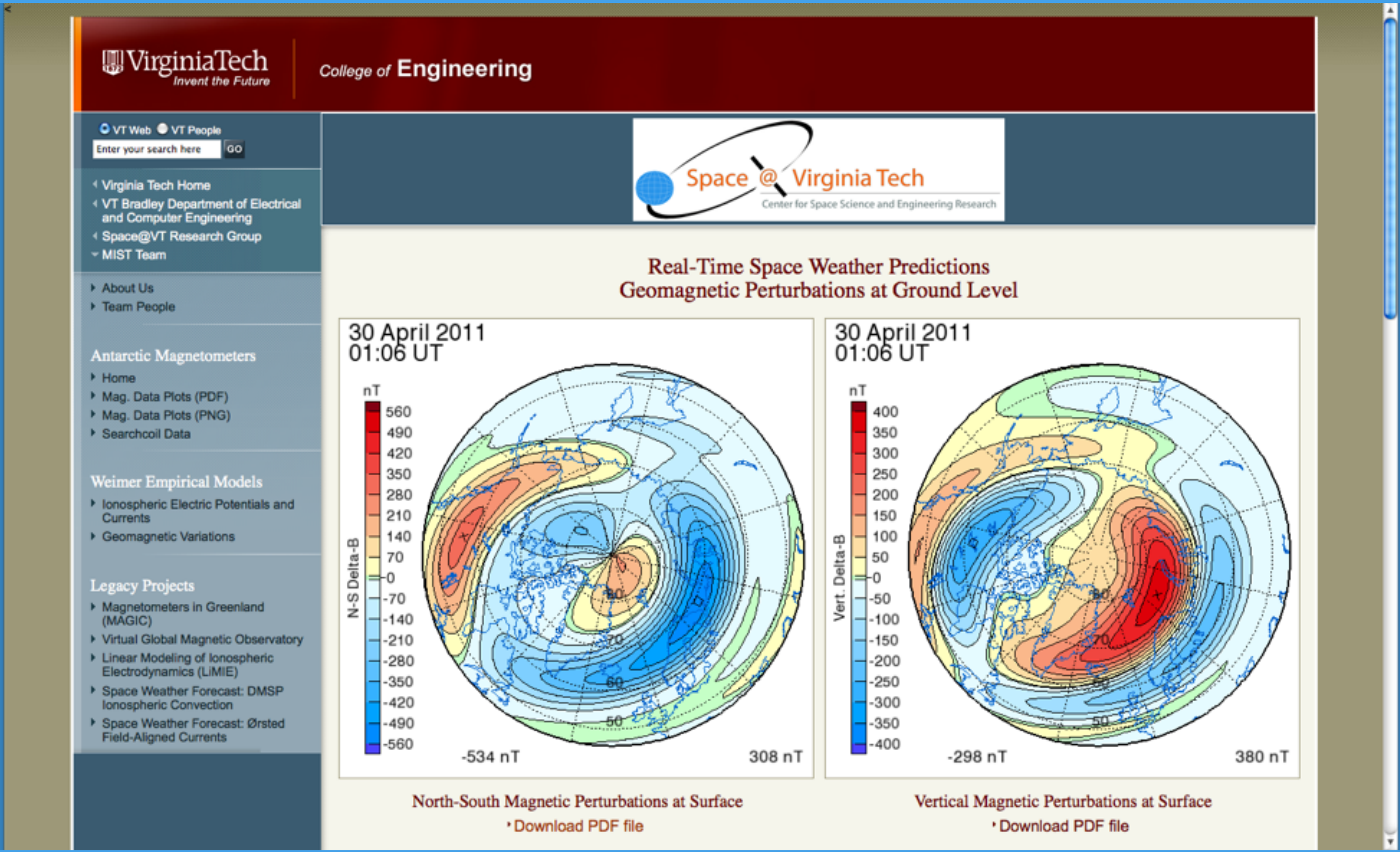


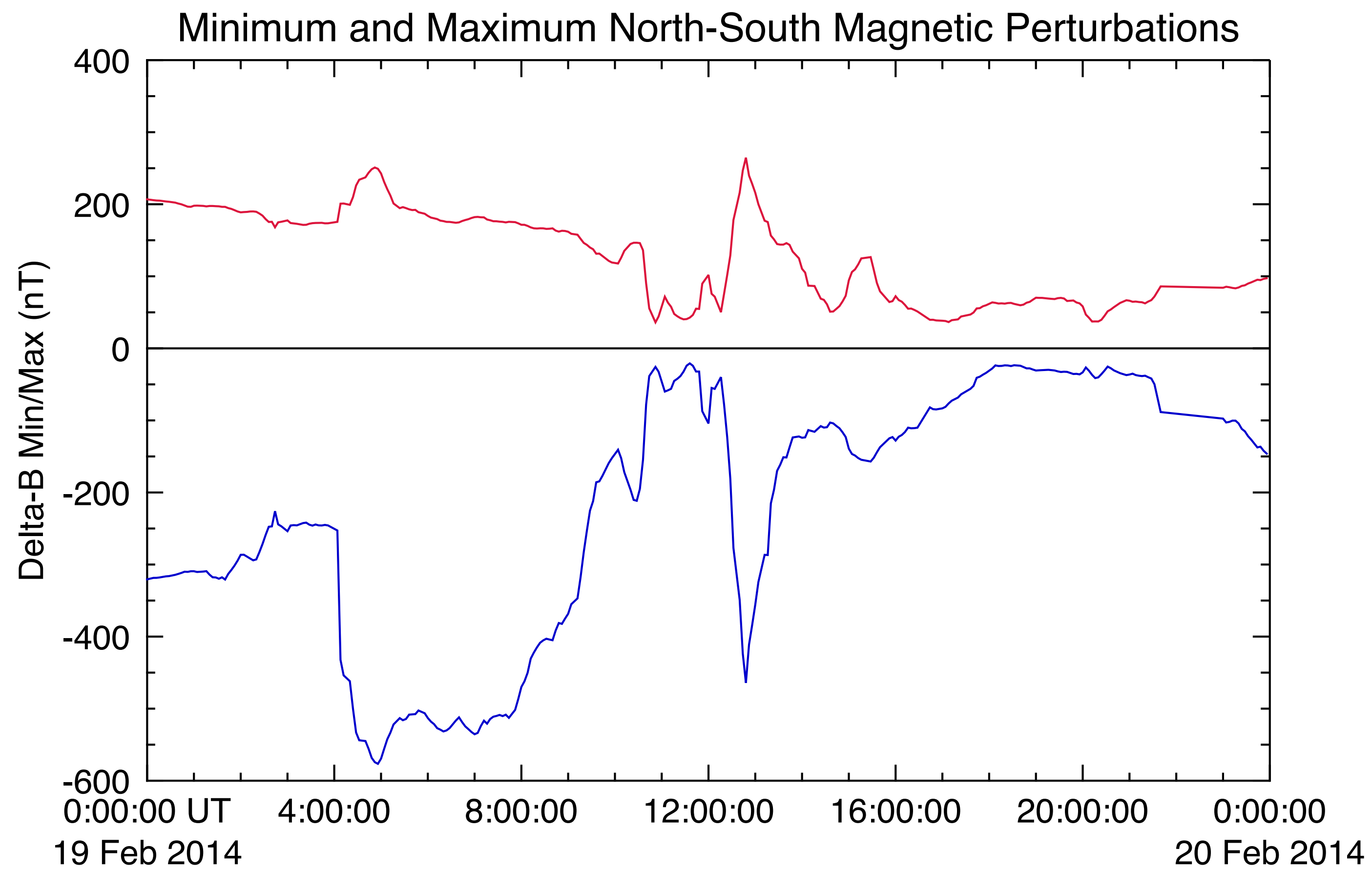
BLUE: MODEL 6_WEIMER
GREEN: MODEL 9_SWMF
RED: DATA
North (X)
East (Y)
Vertical (Z)
YKC
MEA
NEW
FRN
IQA
PBQ
OTT
FRD
HRN
ABK
WNG
FUR
1500 nT between base lines
29.00
29.25
29.50
29.75
30.00
30.25
Day of October, 2003



BLUE: MODEL 6_WEIMER
GREEN: MODEL 9_SWMF
RED: DATA
North (X)
East (Y)
Vertical (Z)
YKC
MEA
NEW
FRN
IQA
PBQ
OTT
FRD
HRN
ABK
WNG
FUR
1000 nT between base lines
14
15
16
Day of December, 2006

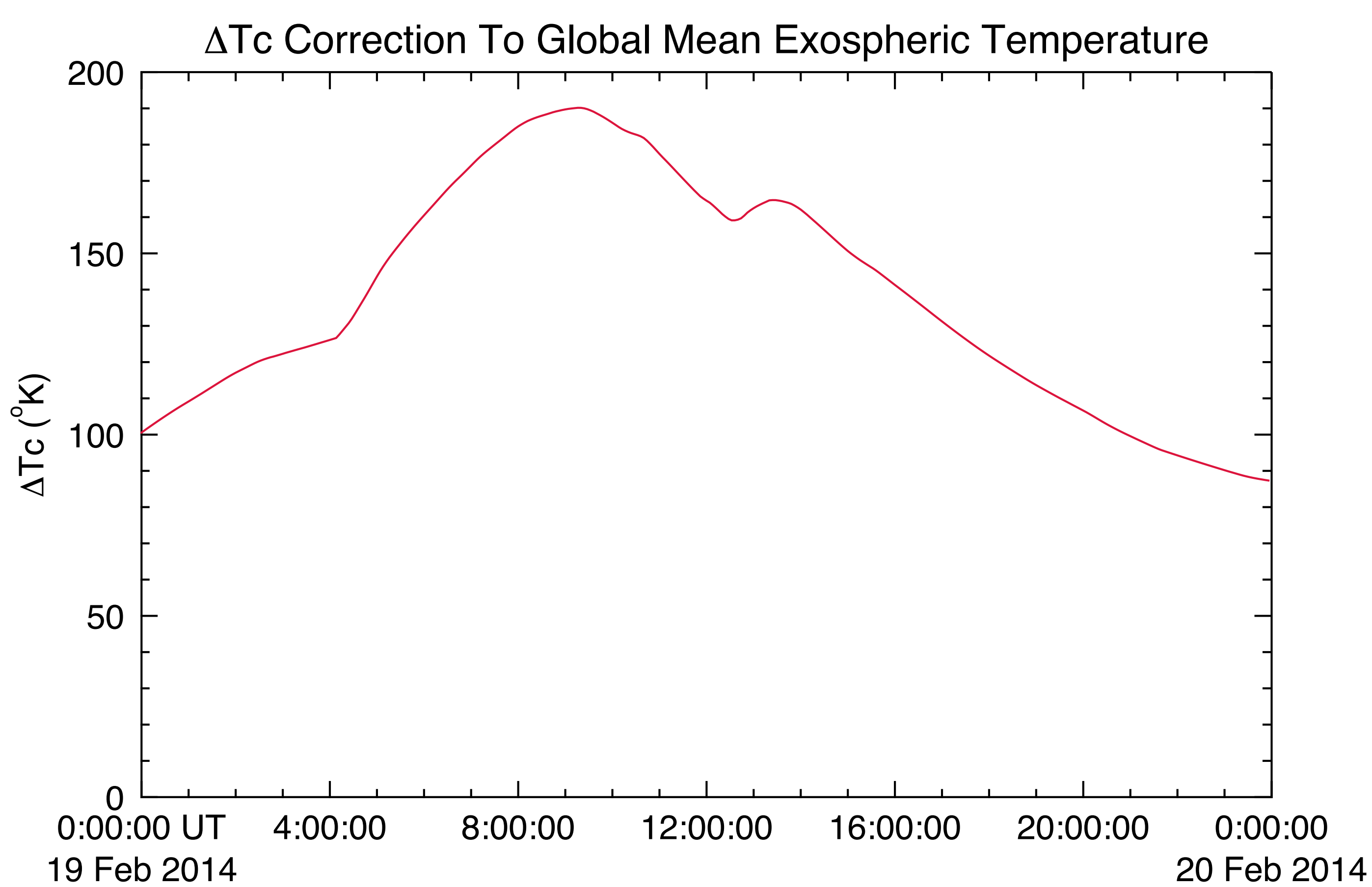
Real-time maps are shown at http://mist.nianet.org/weimerGeomag.html
Operating continuously since 2011; plots archived since Sept. 2012





Recent addition: Daily summary plots, at http://mist.nianet.org/weimerDaily.html

Includes min/max *ΔB-North*, polar cap potential drop, total heating, and real-time exosphere temperature correction, ΔT_C

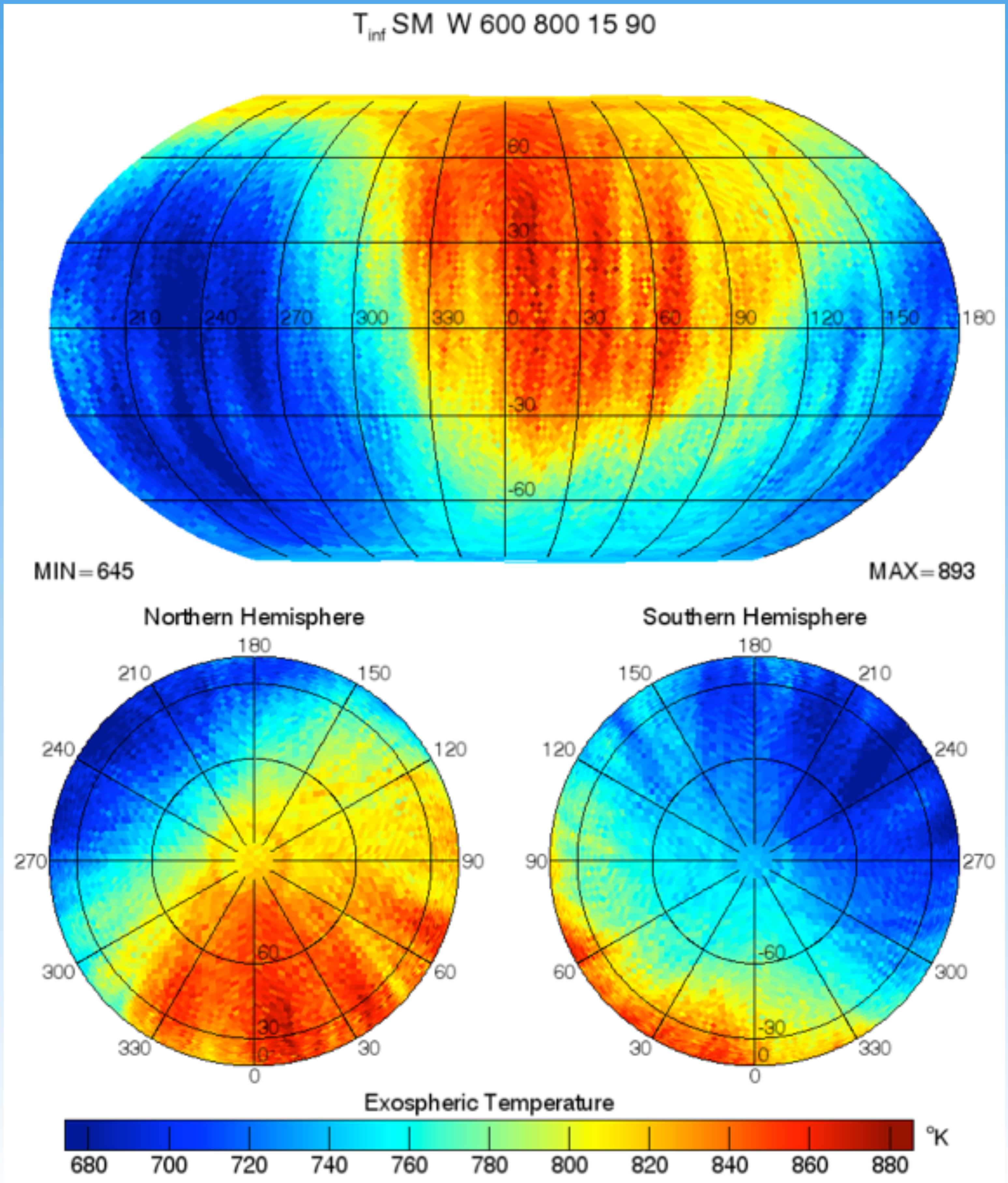


Future models in development:

New FAC model, using data from magnetometers on Oersted, CHAMP, and Swarm.

New thermosphere model

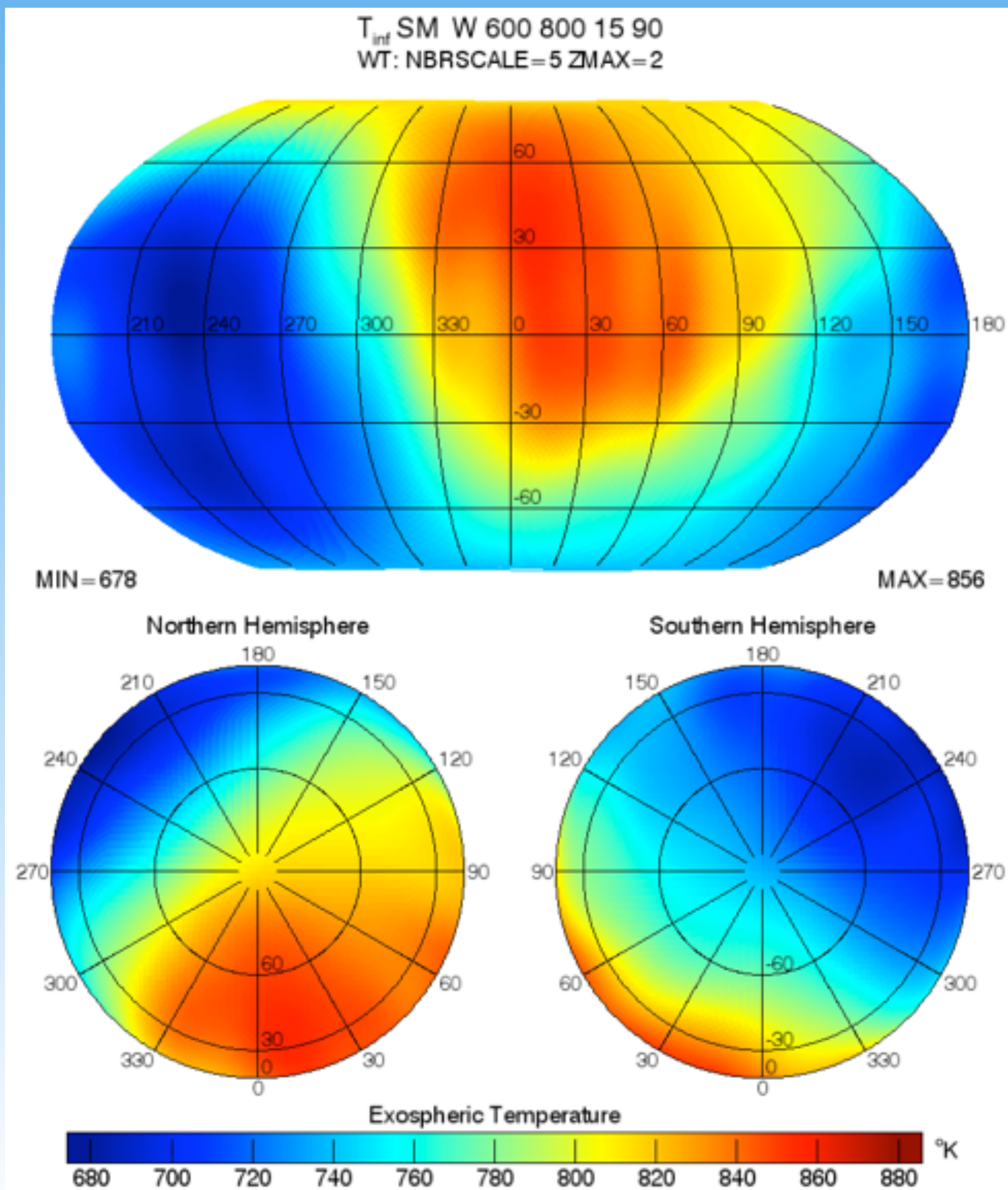
Example of Global Map from CHAMP and GRACE data



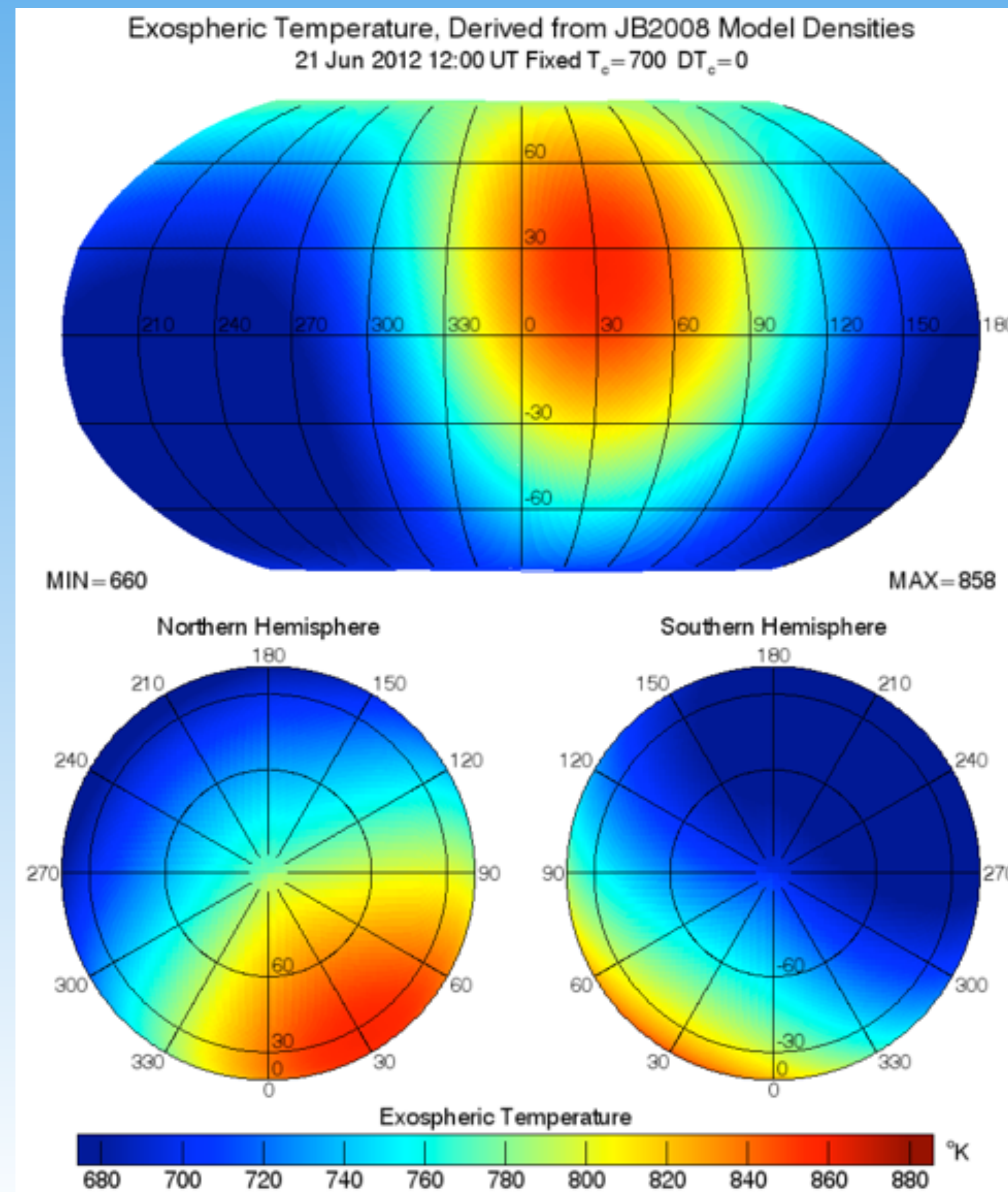
- Years 2002—2006
- "HEALPix" Equal-Area Grid has 12,288 cells
- Means in each cell shown, from times with subsolar lat. > 15°
- JB2008+W05 models predicts that 600 < $T_{\infty min}$ < 800 °K
- Locations in Solar Magnetic coordinates (SM), rather than geographic
- Resolves density/temperature perturbations in auroral ovals
- Meridional bands are side-effect of 27-day period in solar activity, while satellites precess in local time

Wavelet Filtering Applied to Same Data, Compared with JB2008

Smoothing with “Undecimated Wavelet Transform” at 5 scale levels, first two scales set to zero



JB2008 Model at Summer Solstice, and Minimum Temperature T_c Set to 700 °K



Acknowledgments

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The author thanks Eric Sutton for providing calibrated CHAMP and GRACE measurements of neutral density. Bruce Bowman and Kent Tobiska provided the code for the JB2008 model and solar indices. TIMED SABER measurements of nitric oxide emissions were provided by Martin Mlynczak, NASA LaRC.

HEALPix software, from http://healpix.jpl.nasa.gov/, developed by Krzysztof M. Gorski

Spherical wavelet software in "Interactive Sparse Astronomical Data Analysis Packages (iSAP)" , from http://jstarck.free.fr/isap.html, is by J.-L. Starck

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CARISMA, operated by the University of Alberta, funded by the Canadian Space Agency, the member institutes of INTERMAGNET, the Geophysical Institute of the University of Alaska, Augsburg College MACCS Project, the Danish Meteorological Institute, and the IMAGE Magnetometer Array

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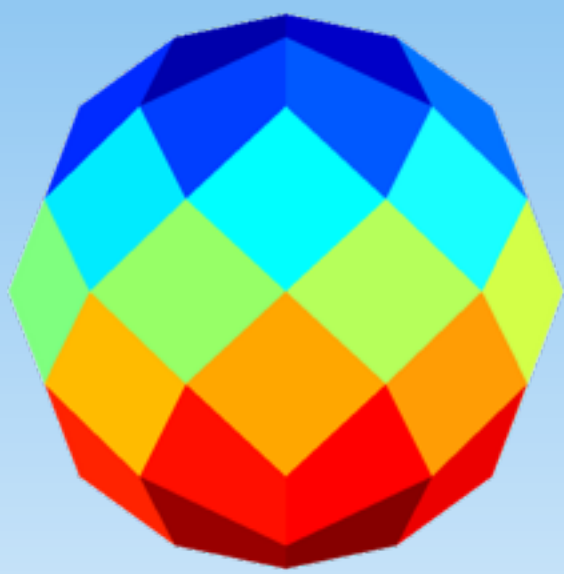
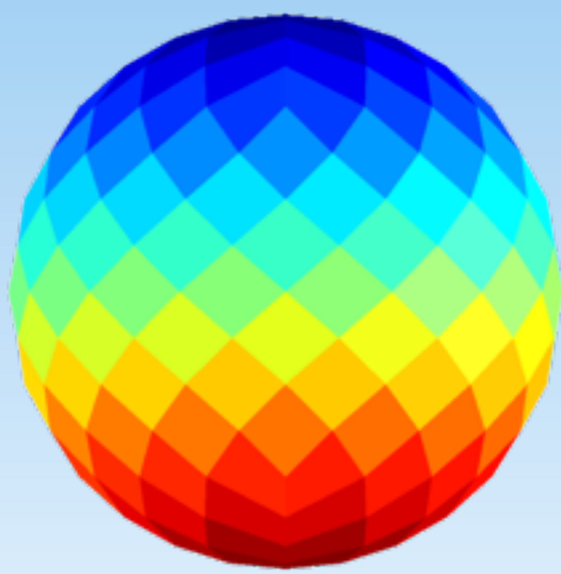
Using the HEALPix Grid for Mapping of Exospheric Temperatures

- HEALPix: Hierarchical Equal Area isoLatitude Pixelization of a sphere.
- Each pixel covers the **same surface area** as every other pixel.
- Pixel centers located on a discrete number of rings of constant latitude.
- Developed within the astrophysics community for all-sky mapping.
- Extensive toolset for analysis, including (spherical) wavelet transforms.

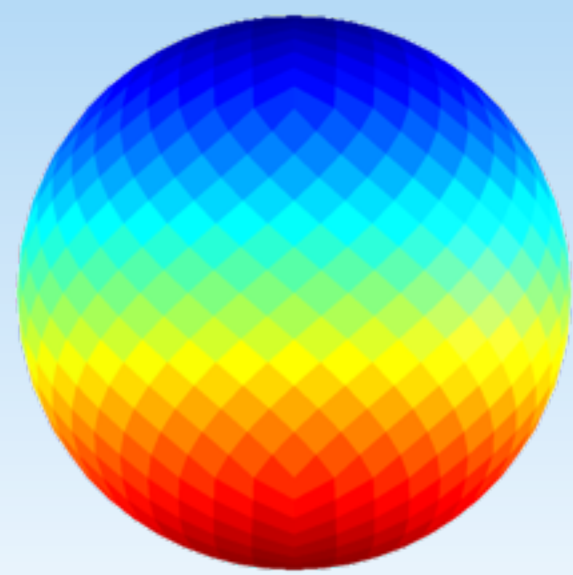


n=2, 48 pixels

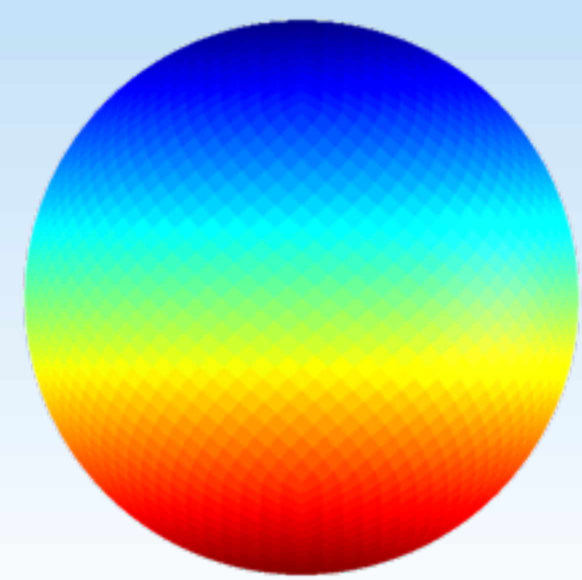


n=4, 192 pixels

n=8, 768 pixels



n=16, 3072 pixels



Progressively higher resolutions

Appendix A: Energy budget of the thermosphere

The total energy content of the thermosphere is proportional to ΔTc. *Burke* [2008] found that a 1°K increase in ΔTc raises the total energy in the thermosphere above 100 km altitude by $1.01 \cdot 10^{14}$ Joules.

$$\Delta T_c(t_{n+1}) = \Delta T_c(t_n)(1 - \Delta t / \tau_c) + \beta H_J \Delta t$$

$$\beta = 6.9 \cdot 10^{-4} \text{ (°K/GW-min)}$$

$$\tau_c = 14.6 \text{ (hours)} - 0.281\, NO$$

$$NO(t_{n+1}) = NO(t_n)(1 - \Delta t / \tau_{NO}) + \gamma H_J \Delta t$$

$$\gamma = 2.5 \cdot 10^{-5} \text{ (units/GW-min)}$$

$$\tau_{NO} = 28.0 \text{ (hours)}$$

With b equal to $6.9 \cdot 10^{-4}$ °K/GW/min, an output of 362 GW from the W05 model over a period of 4 min is needed to raise the Tc temperature by 1°K. A heat input of 362 GW during a 4 min interval amounts to $0.869 \cdot 10^{14}$ J, which is just slightly under the $1.01 \cdot 10^{14}$ Joule figure obtained by *Burke* [2008] for the change in energy. The particle precipitation can account for the other 14%.