Polar Energy Flux, Thermosphere Temperatures, and Nitric Oxide: Tools and Techniques

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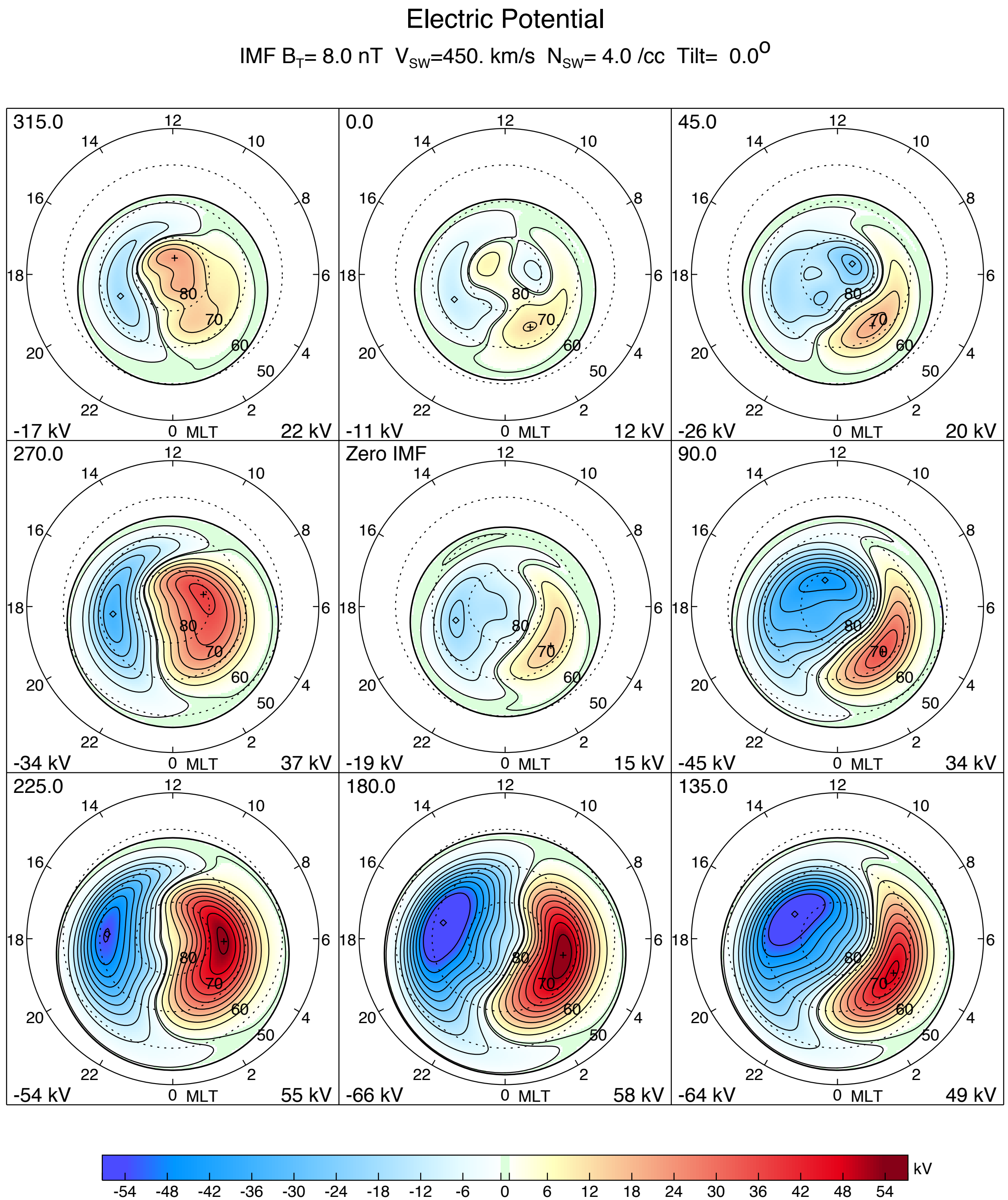
The Poynting flux into the polar ionosphere can be derived from solar wind/IMF measurements.

This is done by combining an empirical model of the electric potentials with an empirical model of the field-aligned current…

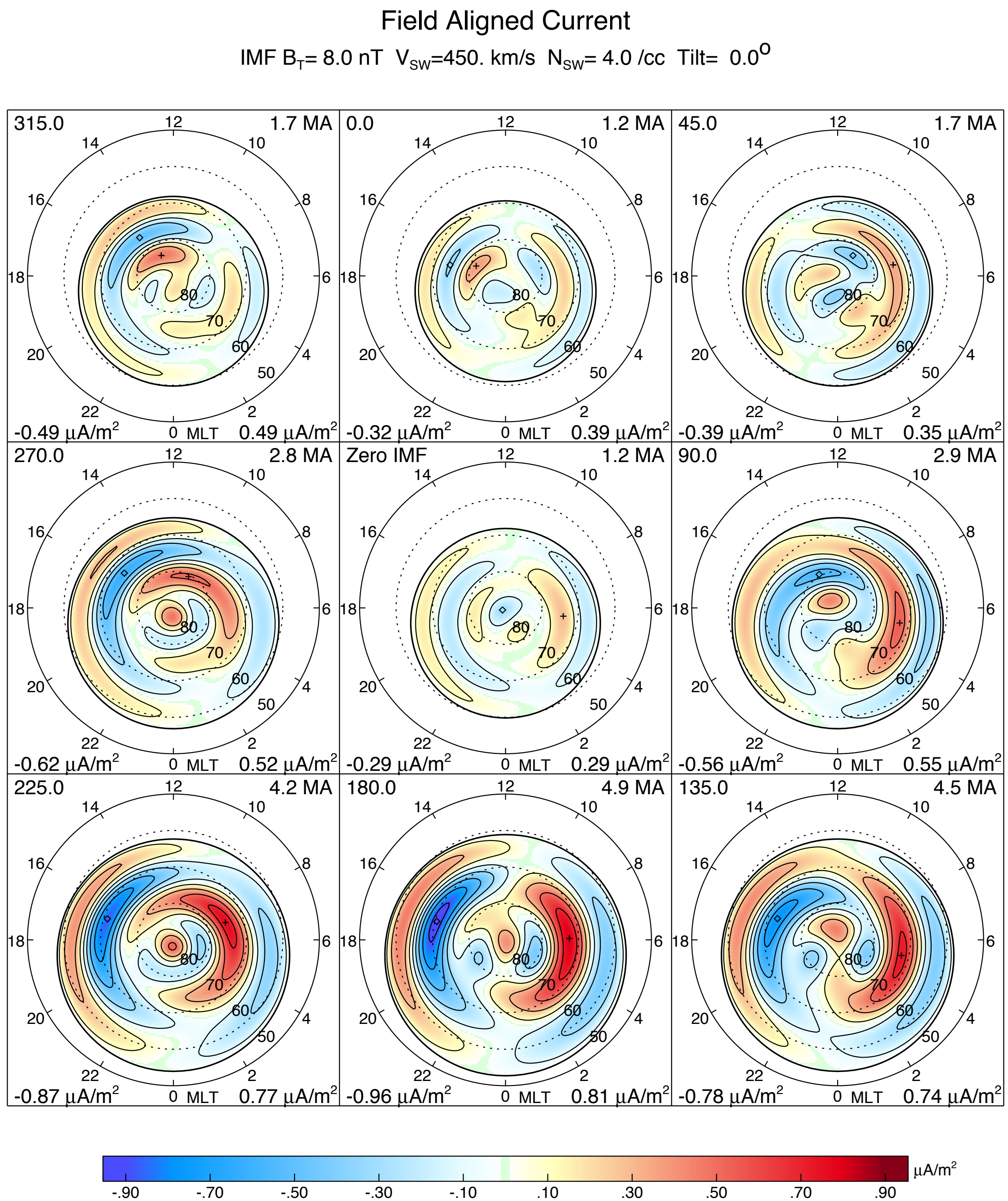


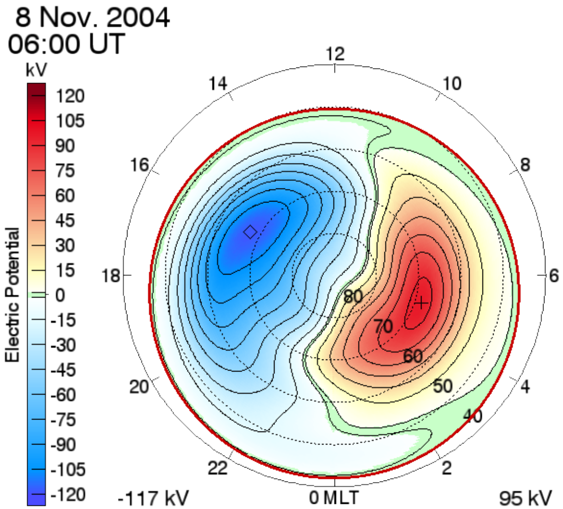
The FAC is obtained from the 2D surface Laplacian operating on the magnetic potential:

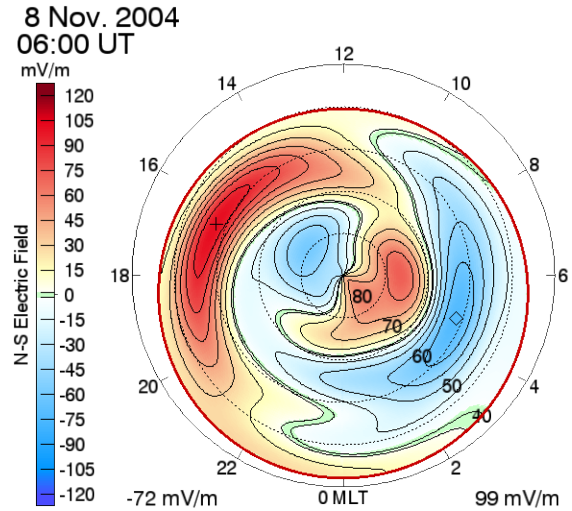
$$\Delta \mathbf{B} = \hat{r} \times \nabla_S \psi$$

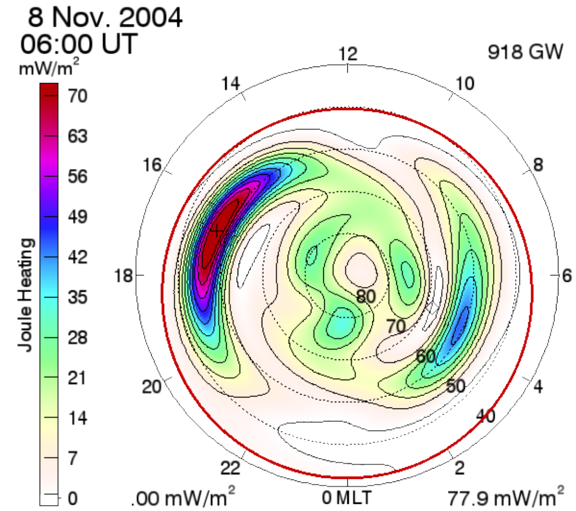
$$J_{\parallel} = \nabla_S^2 \psi / \mu_o$$

The ionospheric conductivity variations are implicitly included in the magnetic field measurements.





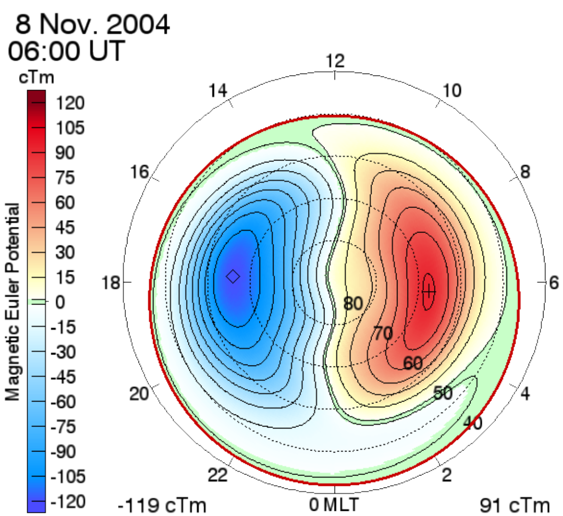


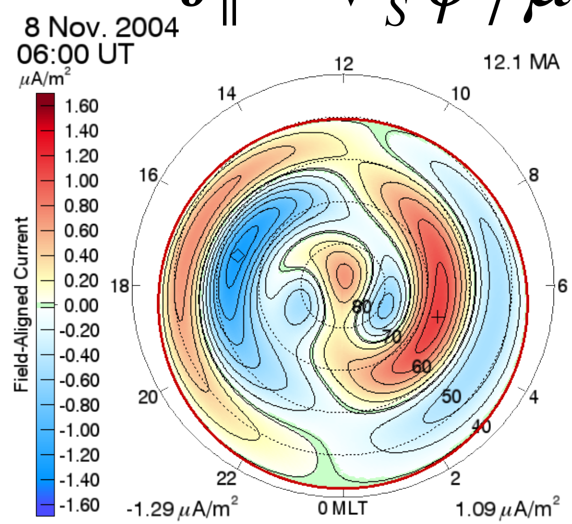


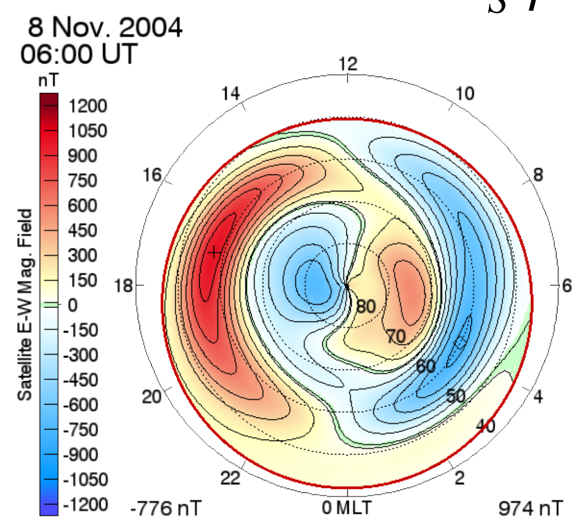
$$\mathbf{E} = -\nabla_S \Phi \qquad \mathbf{S} = \mathbf{E} \times \Delta\mathbf{B}/\mu_o$$

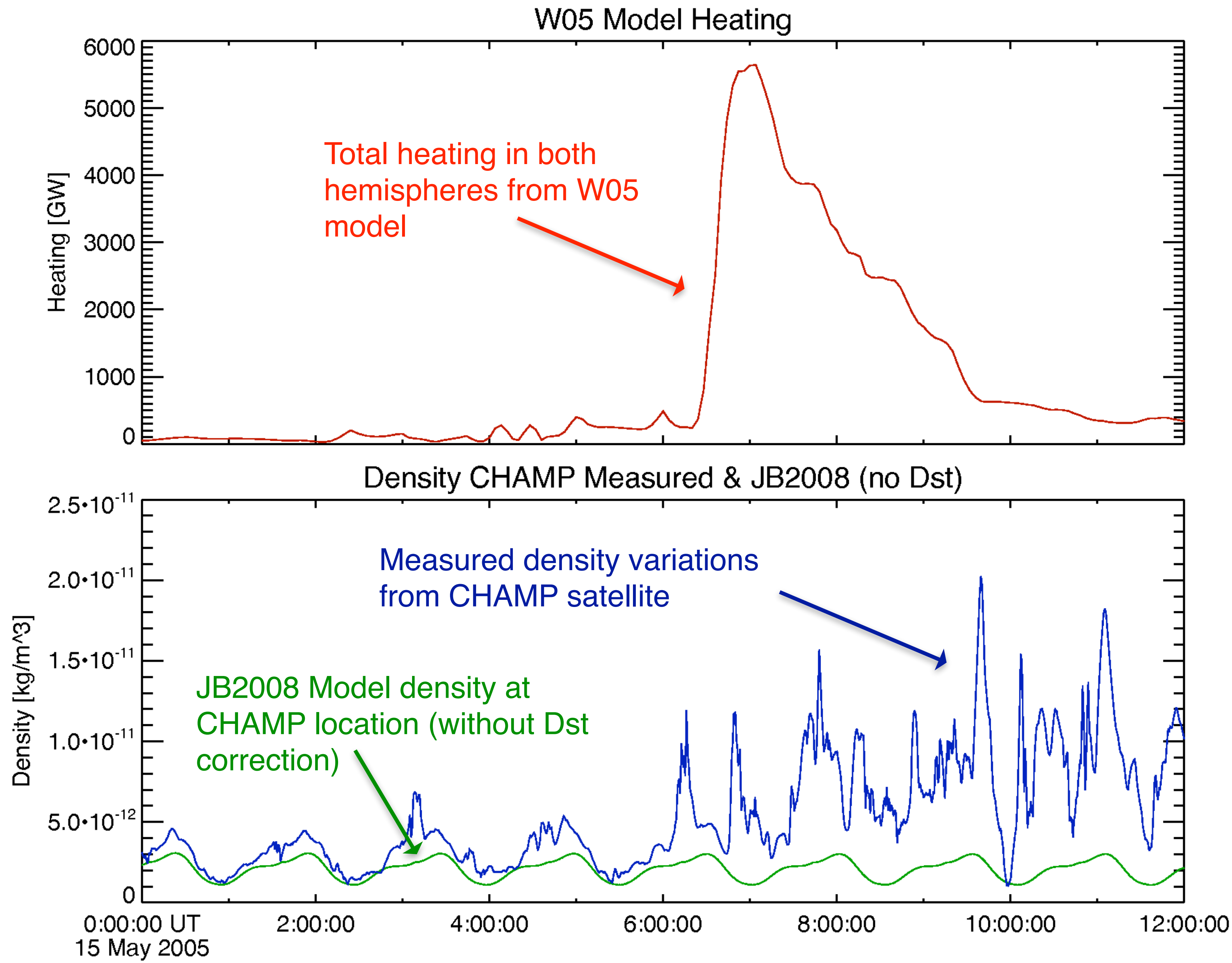
ΔB is obtained from the gradient of the magnetic potential:

$$J_{\parallel} = \nabla_S^2 \psi / \mu_o \qquad \Delta\mathbf{B} = \hat{\mathbf{r}} \times \nabla_S \psi$$

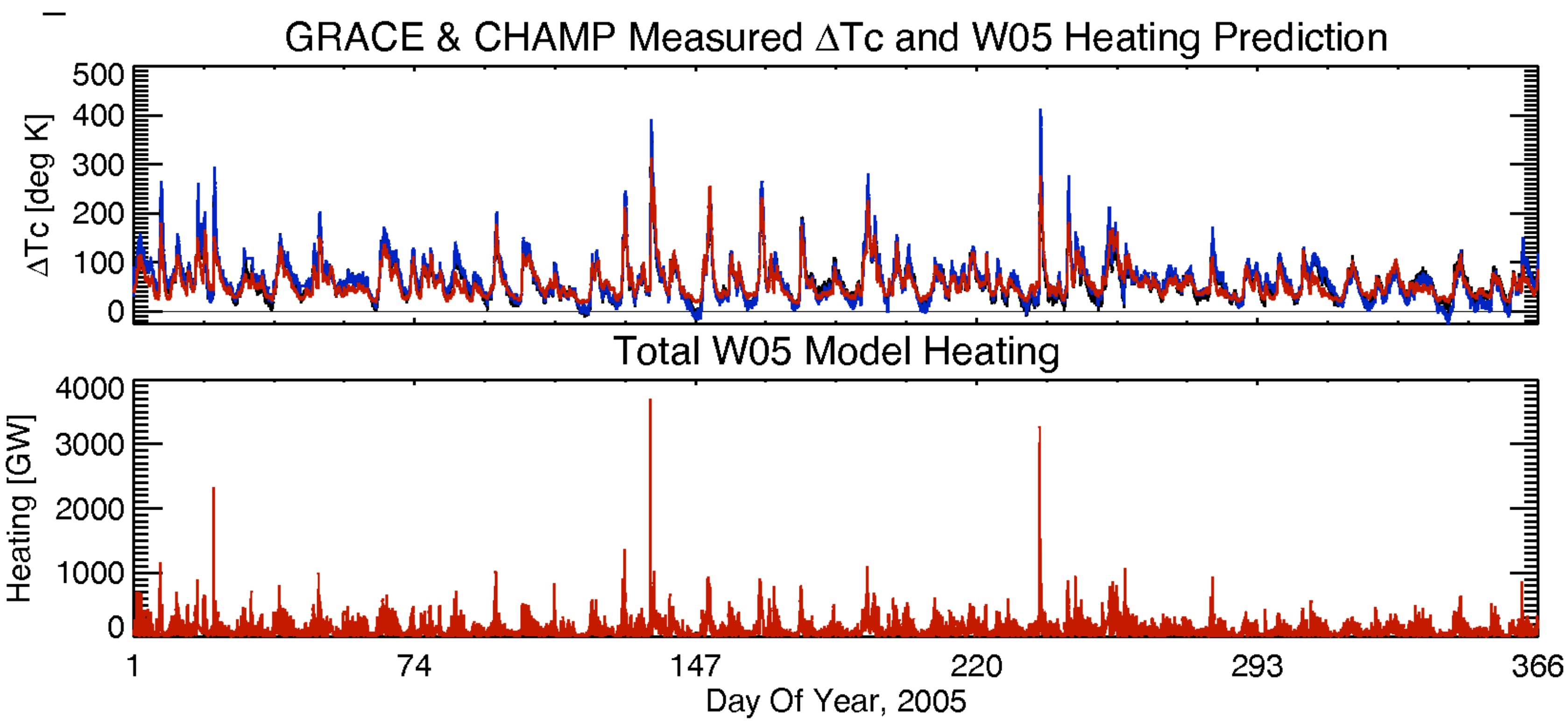







W05 Model Heating
Heating [GW]
6000
5000
4000
3000
2000
1000
0
Total heating in both hemispheres from W05 model
Density CHAMP Measured & JB2008 (no Dst)
Density [kg/m^3]
2.5•10^-11
2.0•10^-11
1.5•10^-11
1.0•10^-11
5.0•10^-12
0
Measured density variations from CHAMP satellite
JB2008 Model density at CHAMP location (without Dst correction)
0:00:00 UT
15 May 2005
2:00:00
4:00:00
6:00:00
8:00:00
10:00:00
12:00:00

In a comparison with the temperature changes in the JB2008 model, derived from CHAMP and GRACE, predicted and measured ΔTc have ≈ 0.9 correlation for 2002 - 2006. Red line is ΔTc prediction from W05, blue and black lines are measured. The W05 model provides more than enough Joule heating.



The ΔT_C prediction used a finite-difference equation. In each time step the temperature increases in proportion to the total heating, and decreases at an exponential rate. It was found that the cooling rate was faster if more heating was applied. An adjustment was added to vary the cooling rate, and it was attributed to extra nitric oxide production. In the first version (2011), these formulas were used:

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

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

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

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

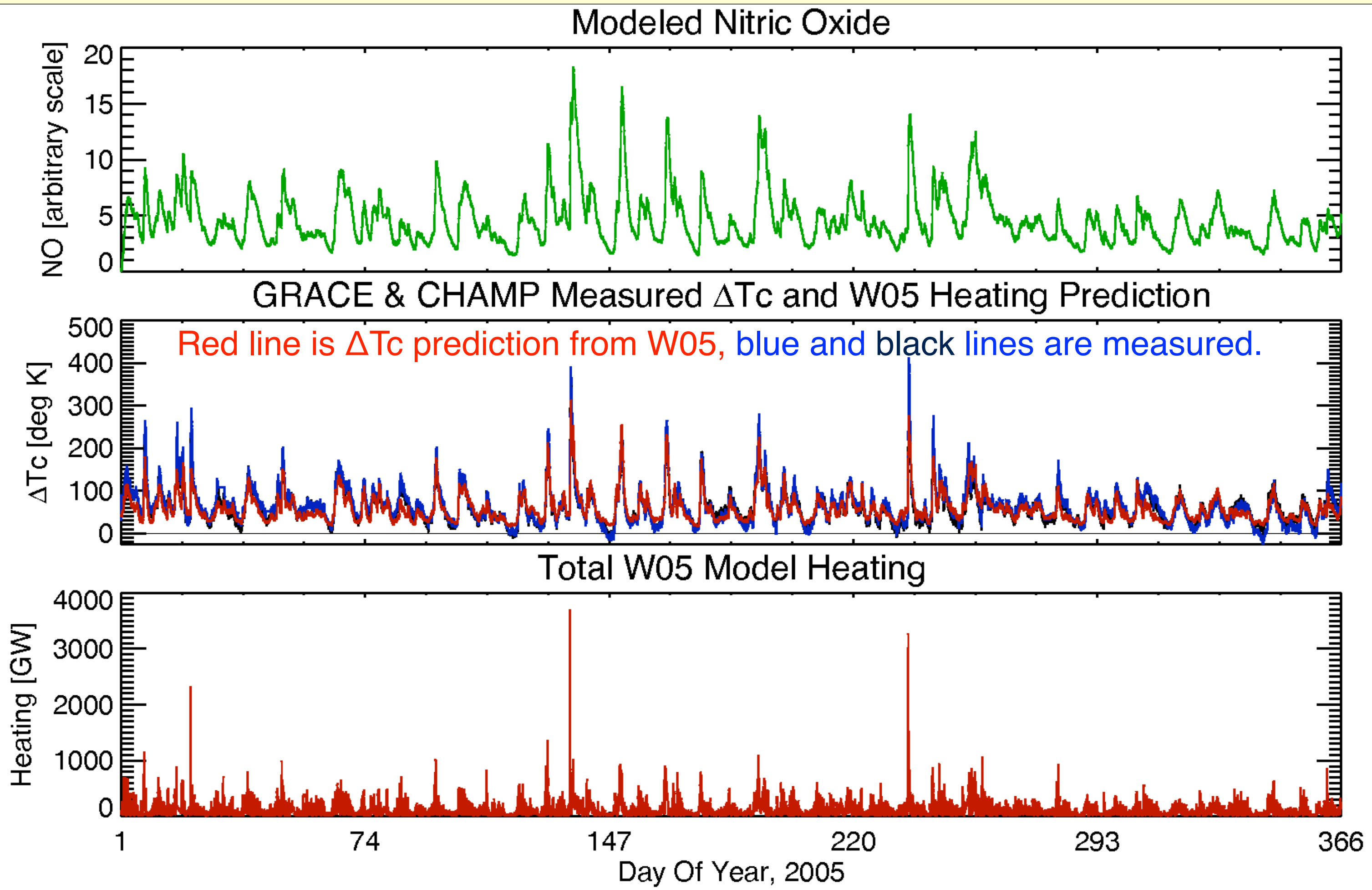
$$NO(t_{n+1}) = NO(t_n)(1 - \Delta t / \tau_{NO}) + bH_P(t_n)\Delta t$$

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

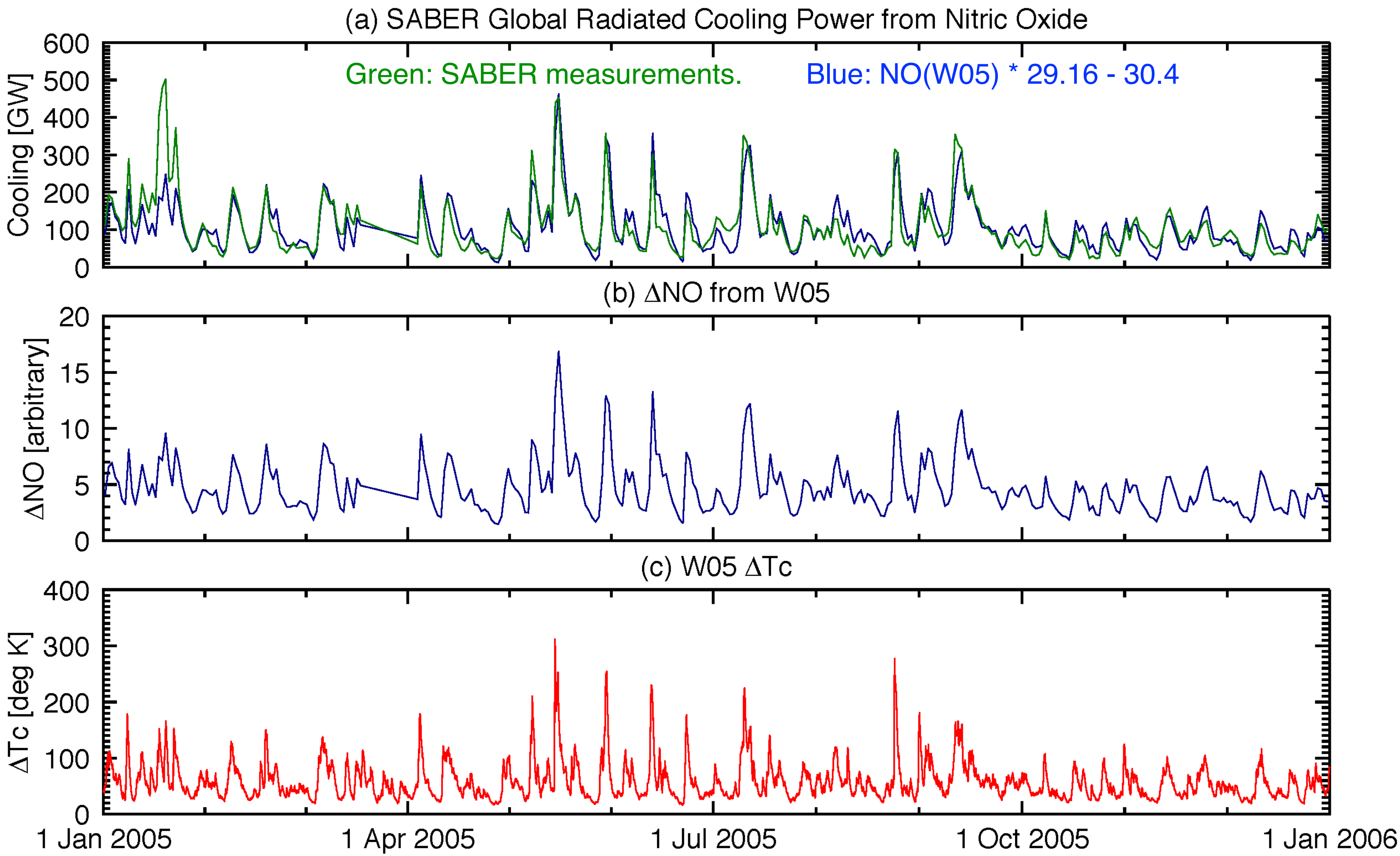
H_P is total Poynting flux from W05 model, with additional "saturation" applied.

All constants (except arbitrary, fixed scale factor *b* for nitric oxide) obtained by fitting five years of H_P with CHAMP and GRACE measurements of ΔT_C.

The differential equations that are used include a quantity for the total amount of nitric oxide in the thermosphere, that causes the exospheric temperatures to decline at a faster rate. All values were determined empirically.



The SABER measurements agree very well with predicted values. Correlation for year 2005 is 0.85, 0.86 in 2003, and 0.91 in 2004.



Revised formulas, used in 2015 paper:

$$\Delta T_c(t_{n+1}) = \Delta T_c(t_n) - \Delta T_c(t_n)(\Delta t/\tau_c) + \alpha H_J(t_n)\,\Delta t - C_{NO}(t_n)\Delta t$$

where C_{NO} is the cooling power due to nitric oxide:

$$C_{NO}(t_n) = \gamma \Delta NO(t_n)(T_{Solar}(t_n) + \Delta T_c(t_n) - \varepsilon)$$

and T_{Solar} is from *Bowman et al.* (2008):

$$T_{Solar} = 392.4 + 3.227\bar{F}_S + 0.298\Delta F_{10} + 2.259\Delta S_{10} + 0.312\Delta M_{10} + 0.178\Delta Y_{10}$$

And the quantity that represents the total nitric oxide is:

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

J_H is the heating in each time step, from J_{W05} model, with additional "saturation" applied*:*

$$J_H = J_{W05}\frac{1 + \frac{500}{1560}}{1. + \frac{J_{W05}}{1560}}$$

$\alpha = 7.08 \cdot 10^{-4}$ K/(GW-min) = $1.2 \cdot 10^{-5}$ K/GJ

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

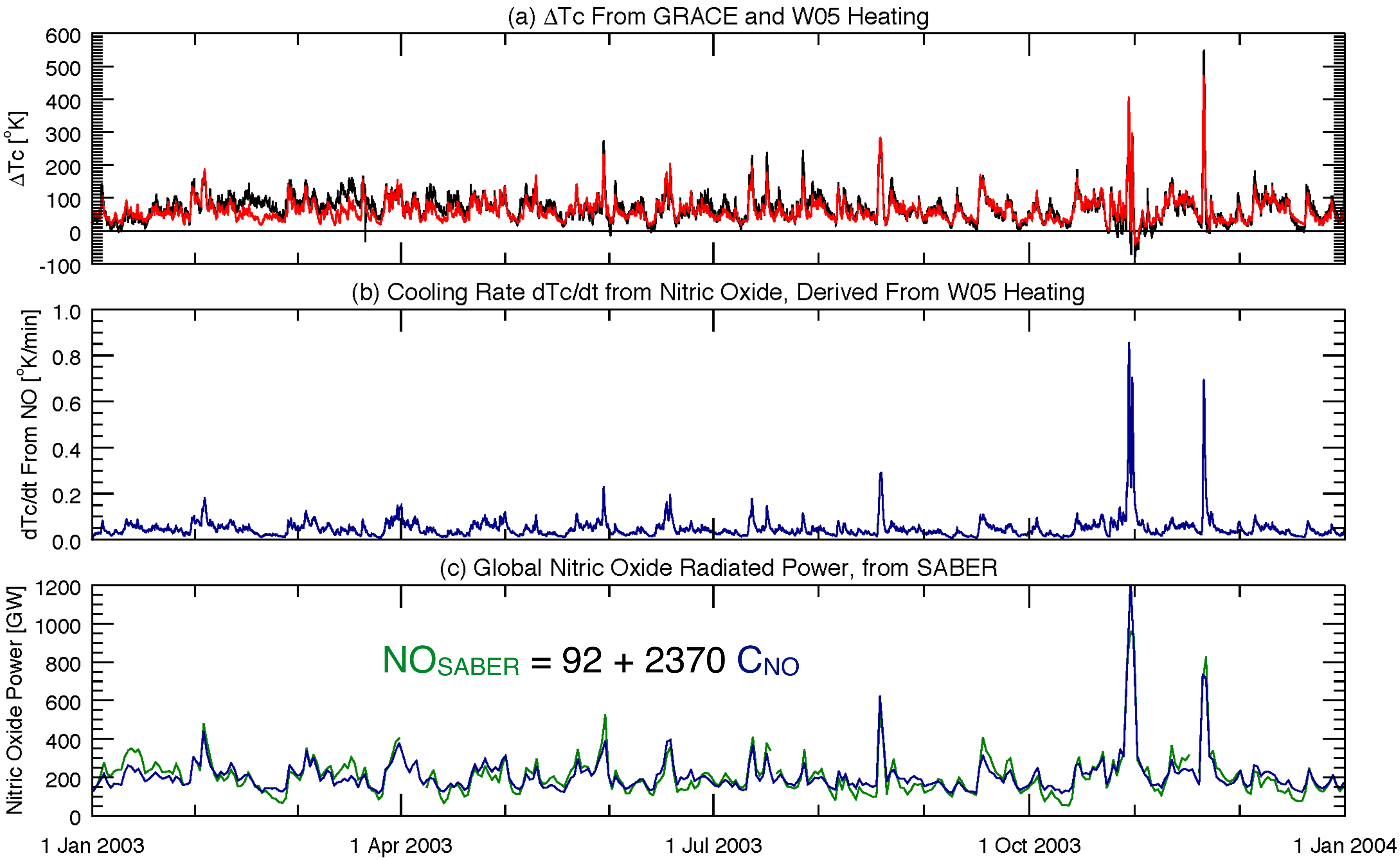
$\gamma = 3.95 \cdot 10^{-5}$/min

τ_c =16.3 hours

τ_{NO} =14.9 hours

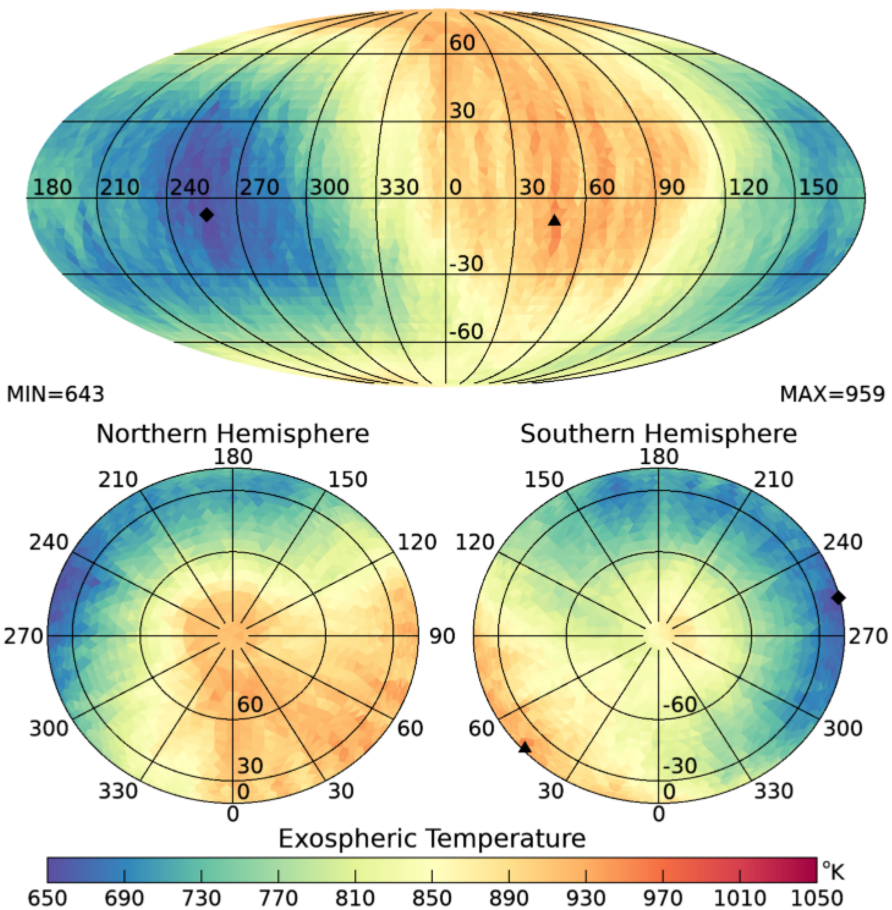
ε = 544°K

The SABER NO emission data agree very well with predicted values. Correlation for 2003 is 0.92, even though no SABER measurements were used in deriving the equations. The fast drop in temperature following the "Halloween Storm" is matched better with these revised (2015) formulas.

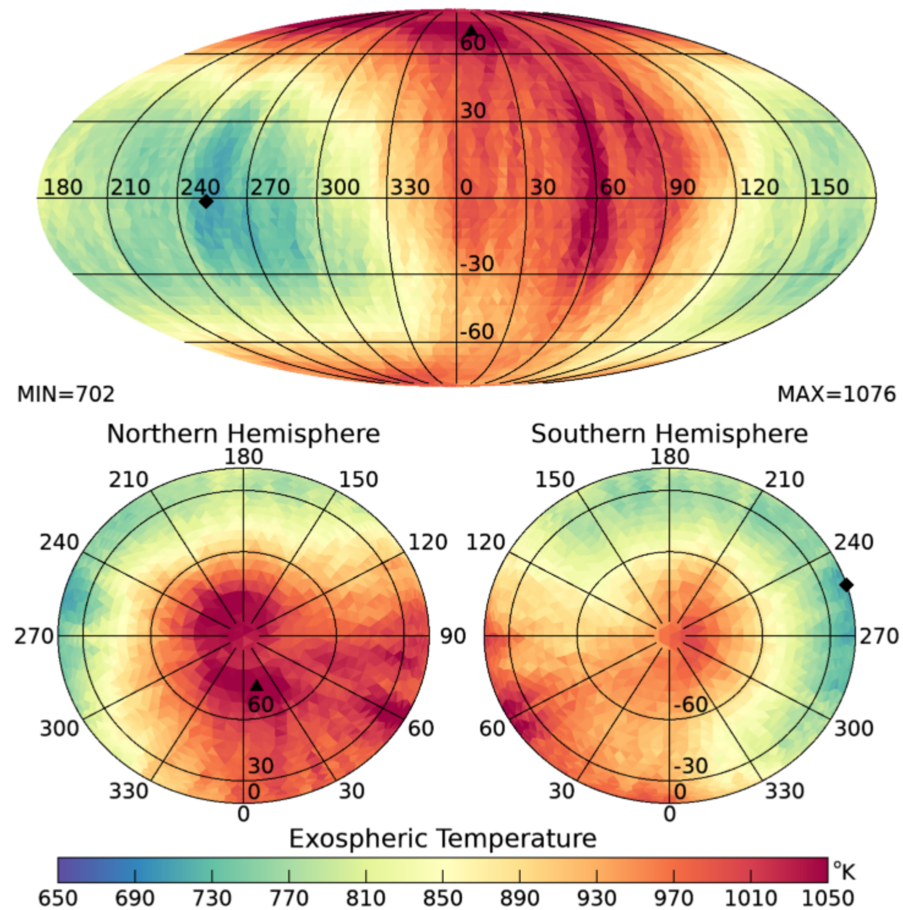


Global maps of exospheric temperatures for low and high levels of auroral Joule heating, in Solar Magnetic coordinates.
In both sets the latitude of subsolar point was above 12 degrees (Northern Summer).

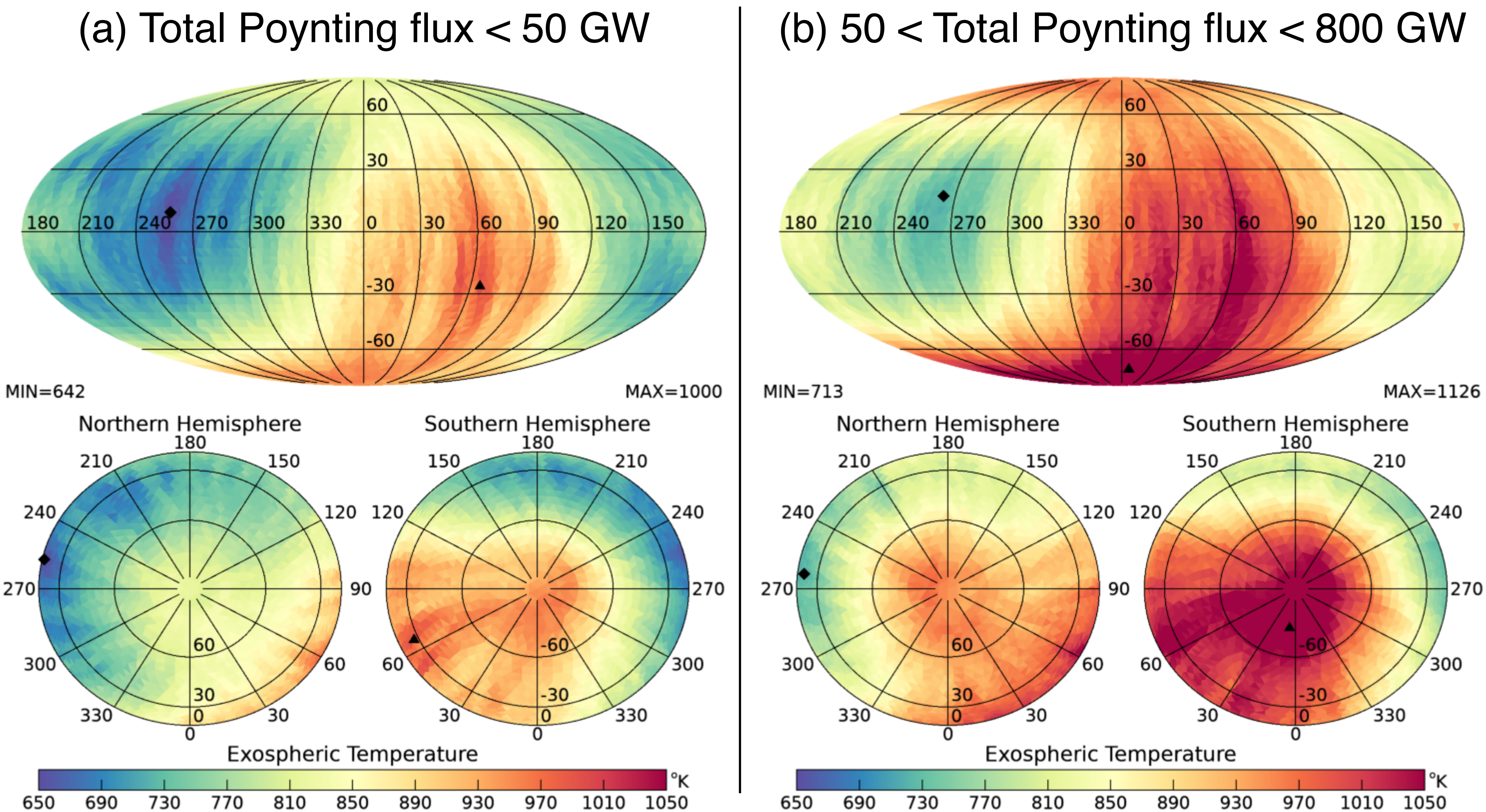
(a) Total Poynting flux < 50 GW



(b) 50 < Total Poynting flux < 800 GW

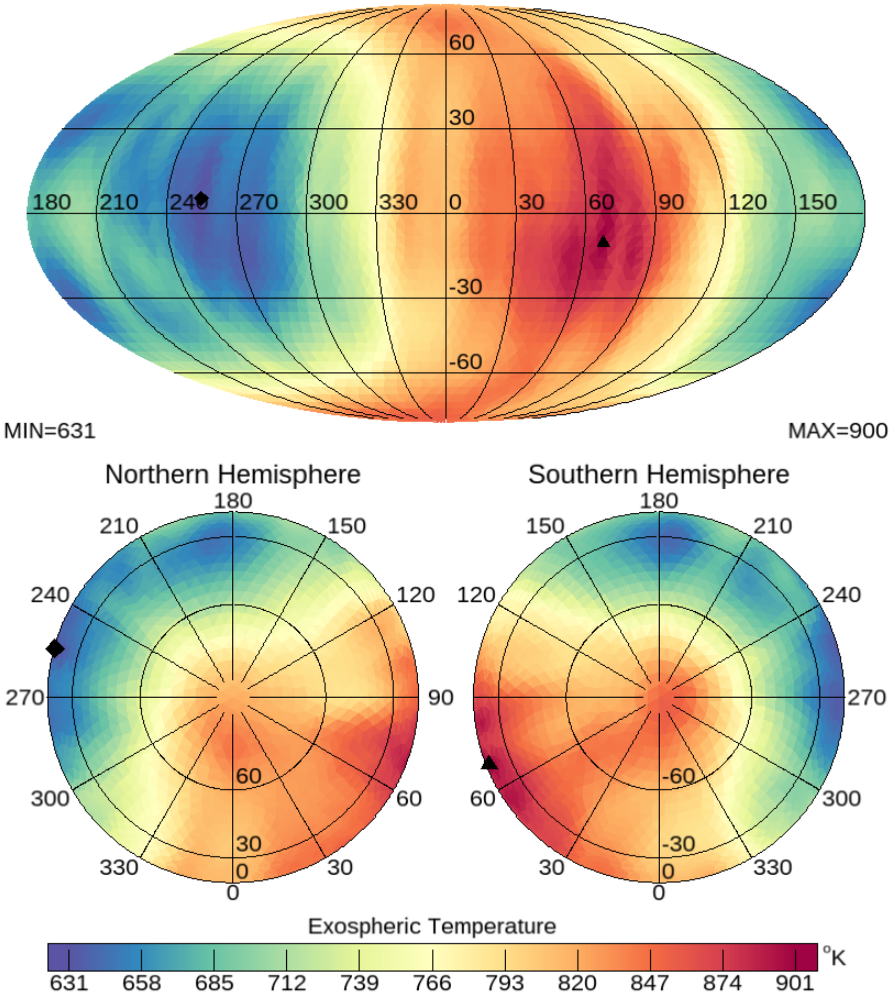


Global maps of exospheric temperatures for low and high levels of auroral Joule heating, in Solar Magnetic coordinates. In both sets the latitude of subsolar point was below -12 degrees (Northern Winter).

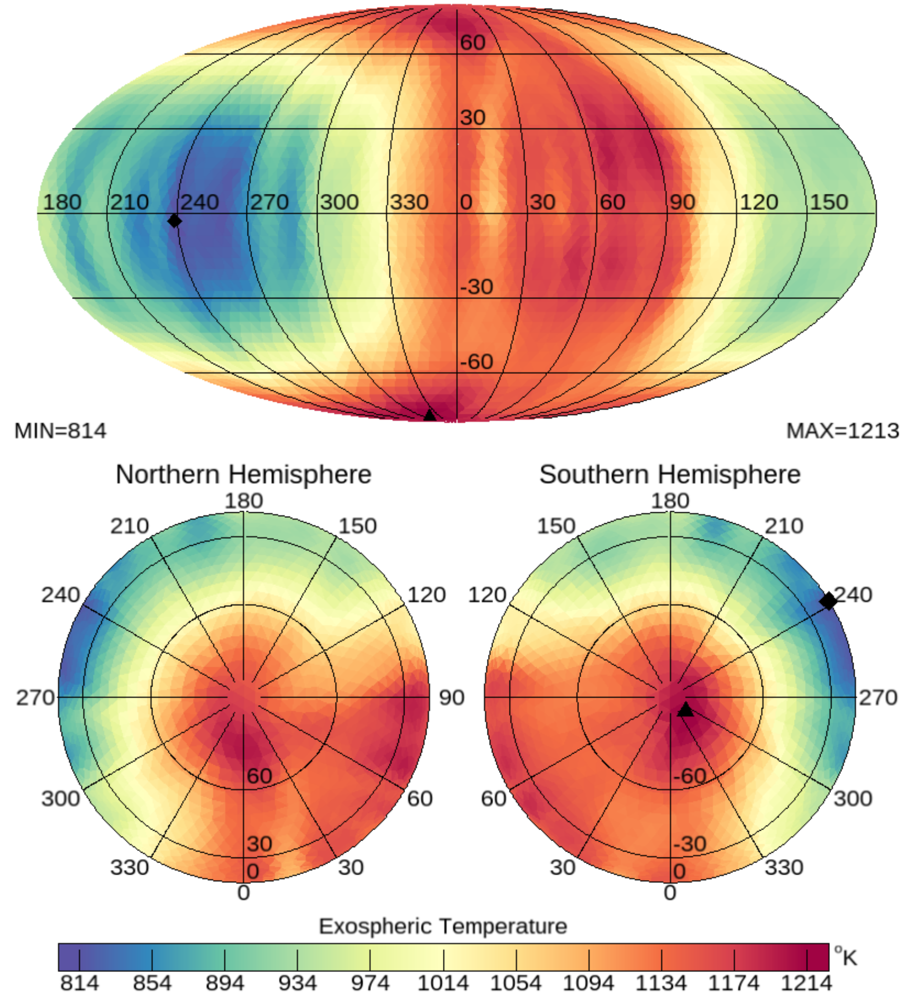


Selecting measurements using only SABER Nitric Oxide emissions. In both sets the latitude of subsolar point was in the range of-12 to +12 degrees latitude (near equinox). Color bars are different.

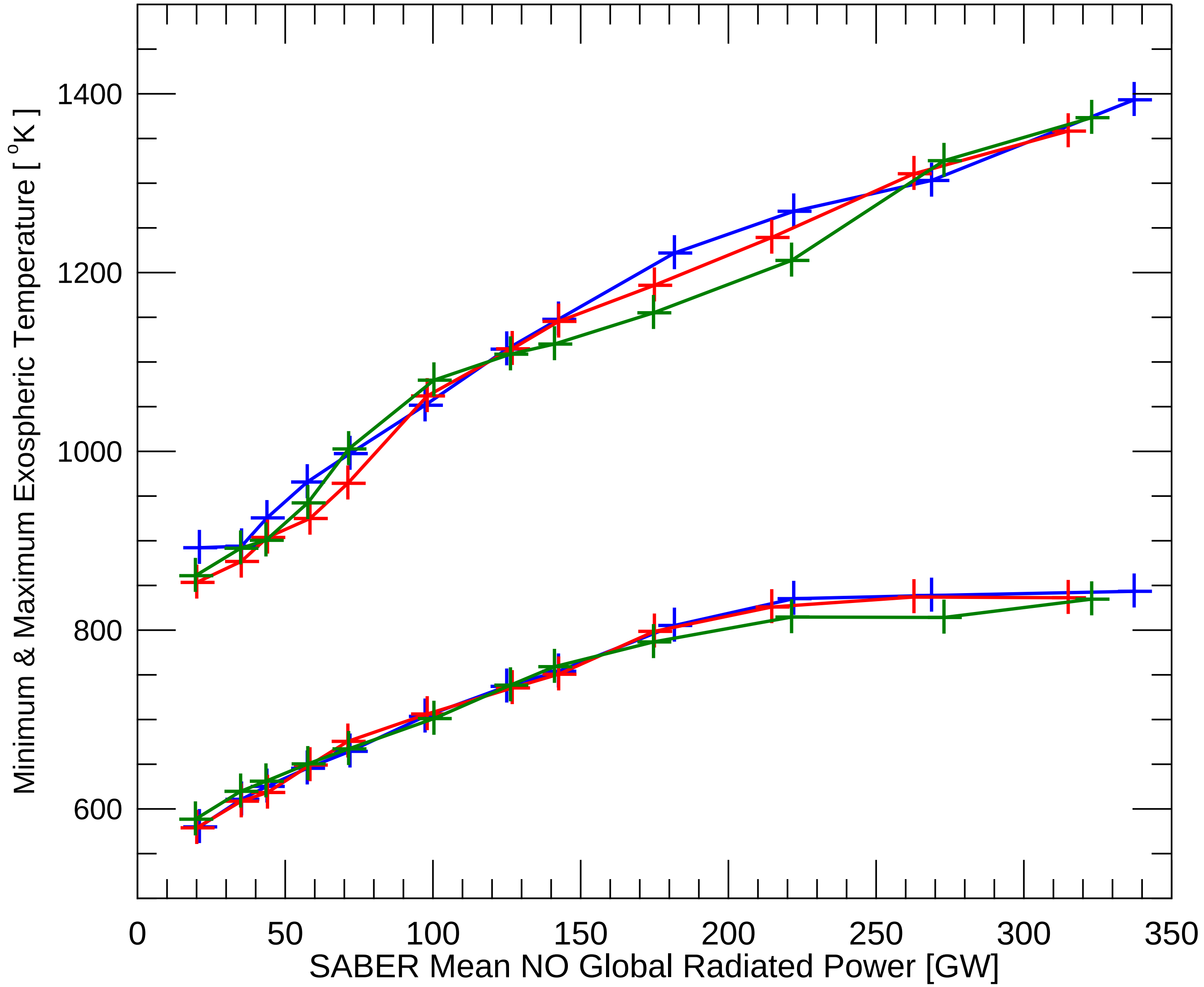
(a) 30 < NO Flux < 60 GW



(b) 160 < NO Flux < 320 GW



From such maps for several ranges of the SABER Nitric Oxide emissions, it is possible to see how the minimum and maximum exospheric temperatures vary with the Nitric Oxide emissions



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