CEDAR-GEMModeling Challenge Session at 2013 GEM Mini-Workshop

Process 1: Quantifying the storm energy input

- Increase in magnetospheric/ionospheric high latitude convection and auroral precipitation
- Enhances conductivity at high latitudes and NO production
- Joule heating increase
- NO cooling IR radiation measured by SABER ($\propto$ NO and T)
- Rate of temperature/density response and recovery

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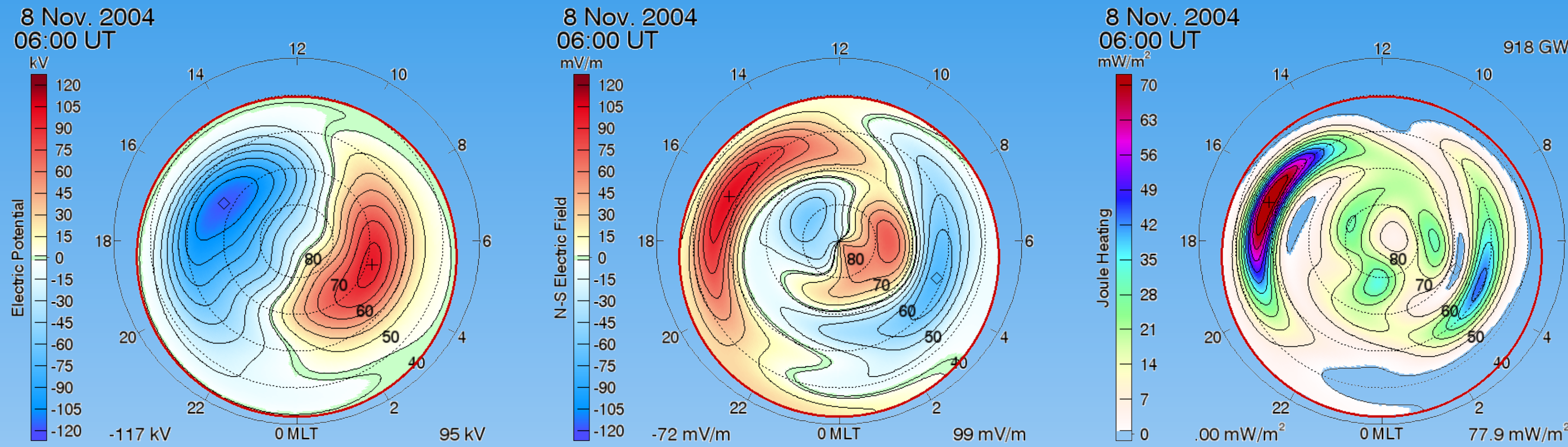
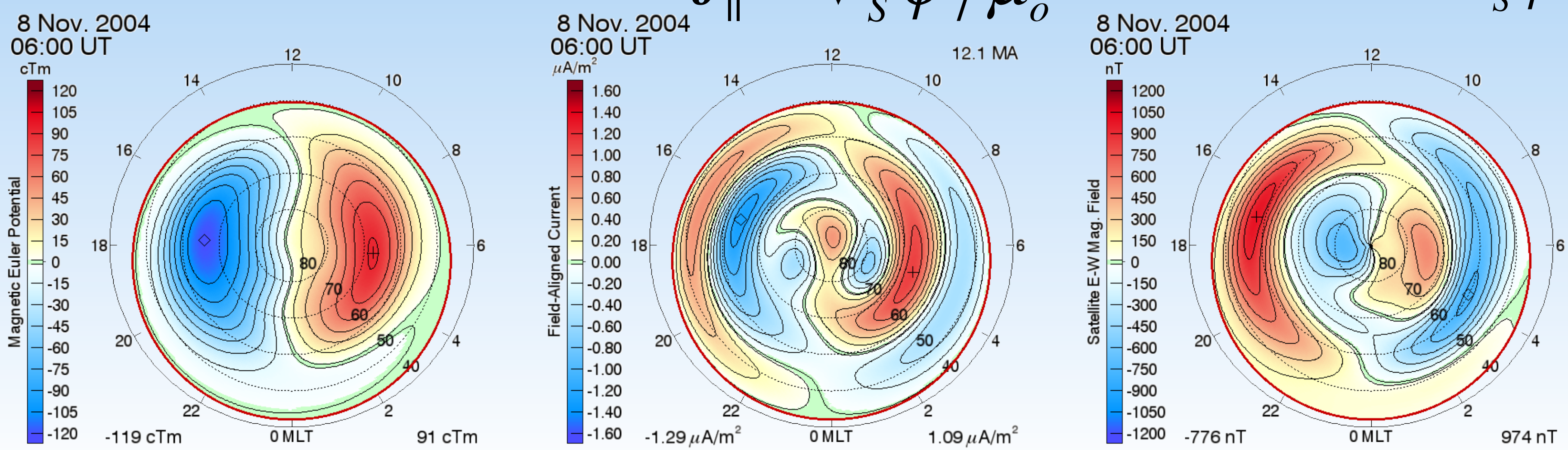
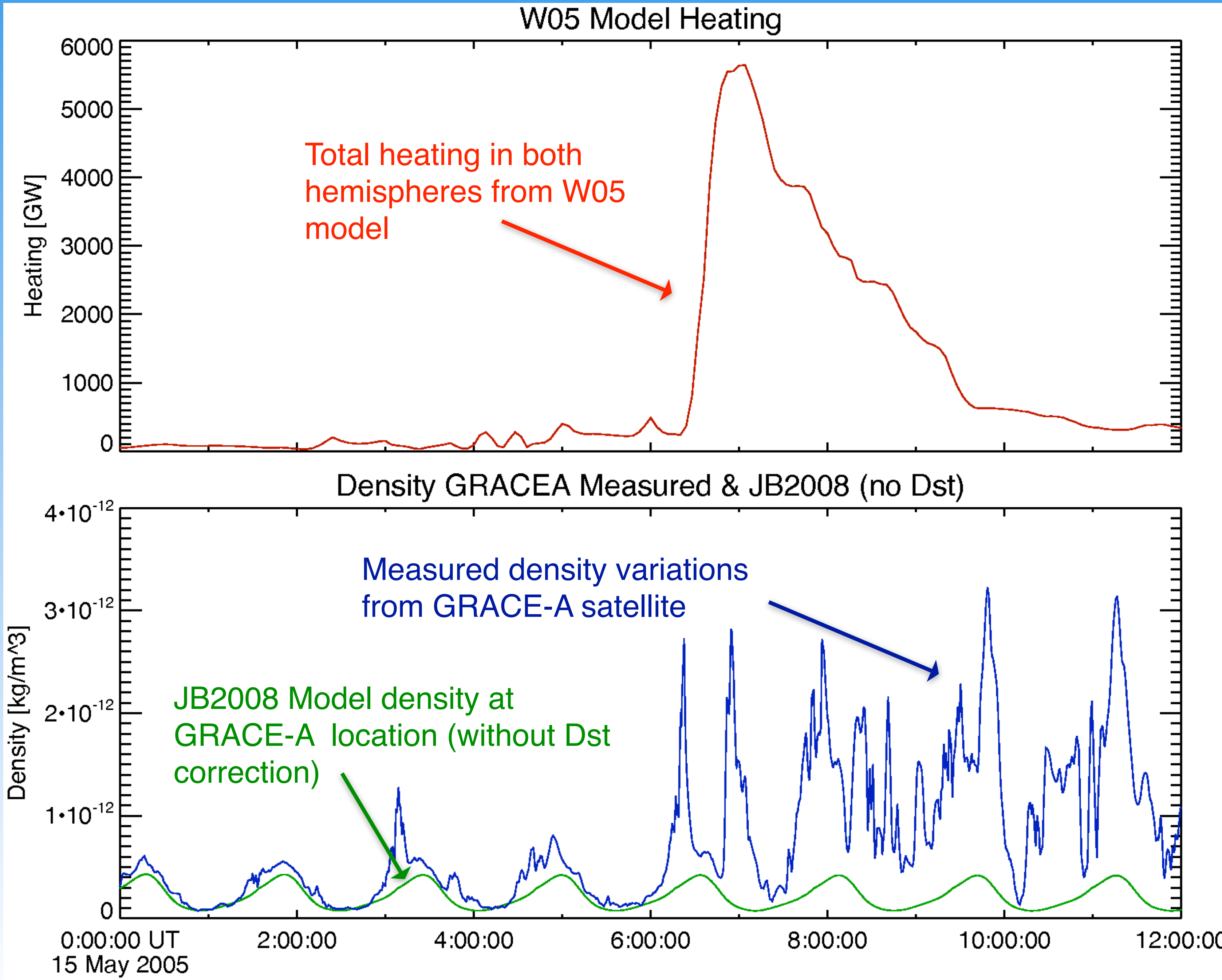


$$\mathbf{E} = -\nabla_S \Phi \qquad \mathbf{S} = \mathbf{E} \times \Delta\mathbf{B}/\mu_o$$

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

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

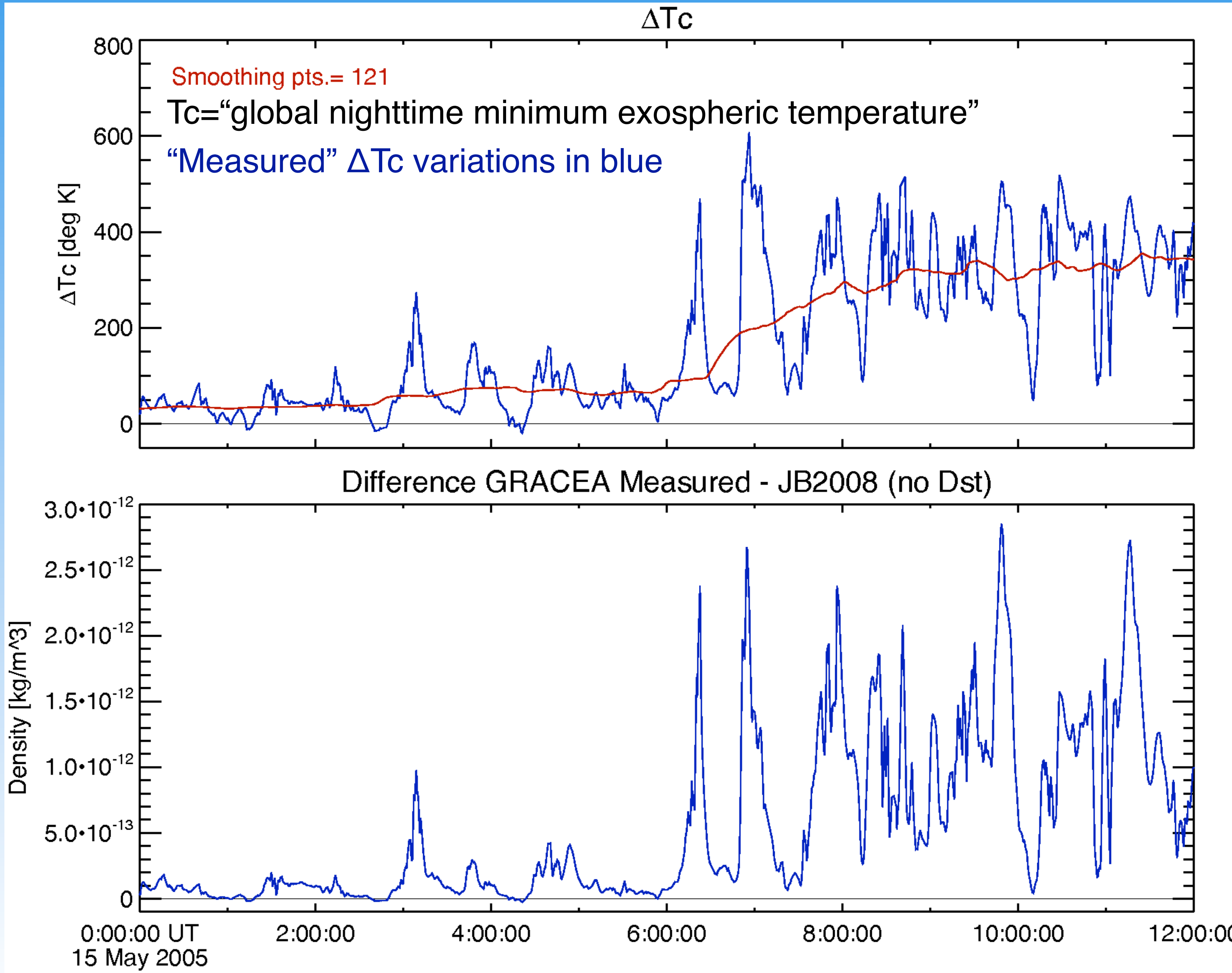




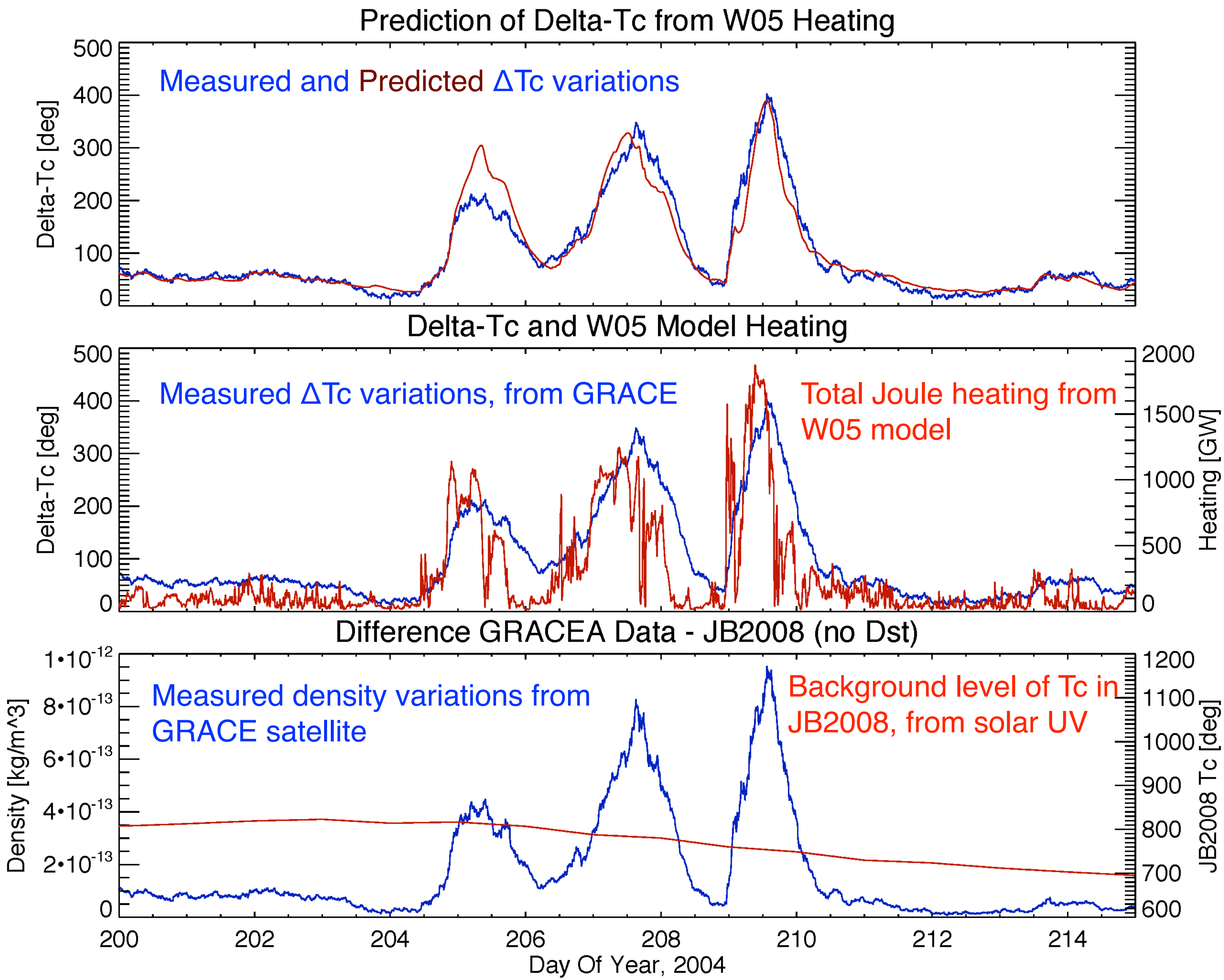
W05 Model Heating
Heating [GW]
6000
5000
4000
3000
2000
1000
0
Total heating in both hemispheres from W05 model
Density GRACEA Measured & JB2008 (no Dst)
Density [kg/m^3]
4•10-12
3•10-12
2•10-12
1•10-12
0
Measured density variations from GRACE-A satellite
JB2008 Model density at GRACE-A location (without 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

- The Jacchia-Bowman 2008 (JB2008)* code uses a parameter named Tc, representing the "global nighttime minimum exospheric temperature." Global values of exospheric temperatures and densities are derived from Tc.
- The slowly varying, "background" level of Tc is calculated from several indices of solar EUV radiation and X-ray flux.
- Faster variations, named ΔTc, are due to the auroral heating in the ionosphere. In the JB2008 model, ΔTc is derived from the Dst geomagnetic index (but Dst is not real-time data).
- ΔTc can be derived by matching densities from JB2008 code with densities measured by CHAMP or GRACE.
- 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.

* Bowman, B. R., W. K. Tobiska, F. A. Marcos, C. Y. Huang, C. S. Lin, and W. J. Burke, A new empirical thermospheric density model JB2008 using new solar and geomagnetic indices, in *AIAA 2008-6438*, AIAA Astrodynamics Conference, Honolulu, HI, 2008.



ΔTc
800
600
400
200
0
ΔTc [deg K]
Smoothing pts.= 121
Tc="global nighttime minimum exospheric temperature"
"Measured" ΔTc variations in blue
Difference GRACEA Measured - JB2008 (no Dst)
3.0•10^-12
2.5•10^-12
2.0•10^-12
1.5•10^-12
1.0•10^-12
5.0•10^-13
0
Density [kg/m^3]
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



Prediction of Delta-Tc from W05 Heating
Measured and Predicted ΔTc variations
Delta-Tc [deg]
500
400
300
200
100
0
Delta-Tc and W05 Model Heating
Measured ΔTc variations, from GRACE
Total Joule heating from
W05 model
Heating [GW]
2000
1500
1000
500
0
Difference GRACEA Data - JB2008 (no Dst)
Measured density variations from
GRACE satellite
Background level of Tc in
JB2008, from solar UV
Density [kg/m^3]
1•10-12
8•10-13
6•10-13
4•10-13
2•10-13
0
JB2008 Tc [deg]
1200
1100
1000
900
800
700
600
200
202
204
206
208
210
212
214
Day Of Year, 2004

The ΔT_C prediction technique:

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

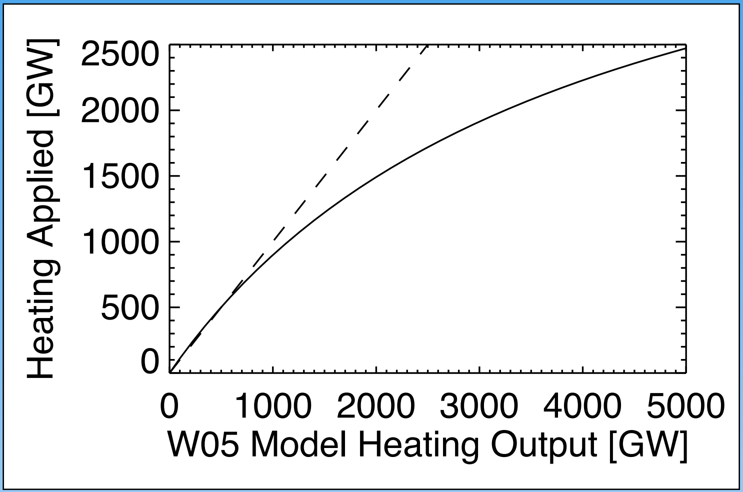
$$\beta = 6.9 \cdot 10^{-4} \ (°\mathrm{K/GW\text{-}min})$$

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

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

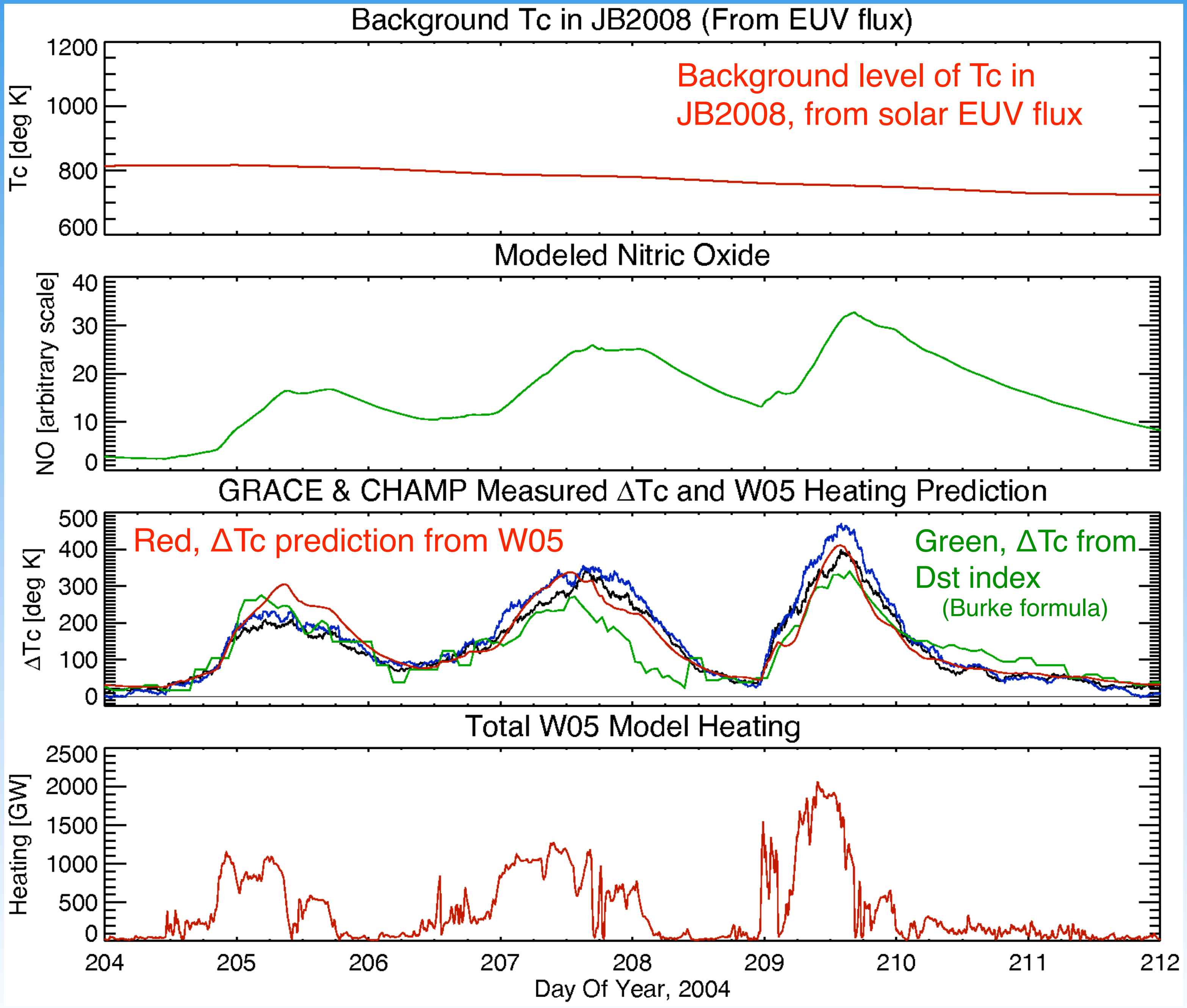
$$\gamma = 2.5 \cdot 10^{-5} \ (\mathrm{units/GW\text{-}min})$$

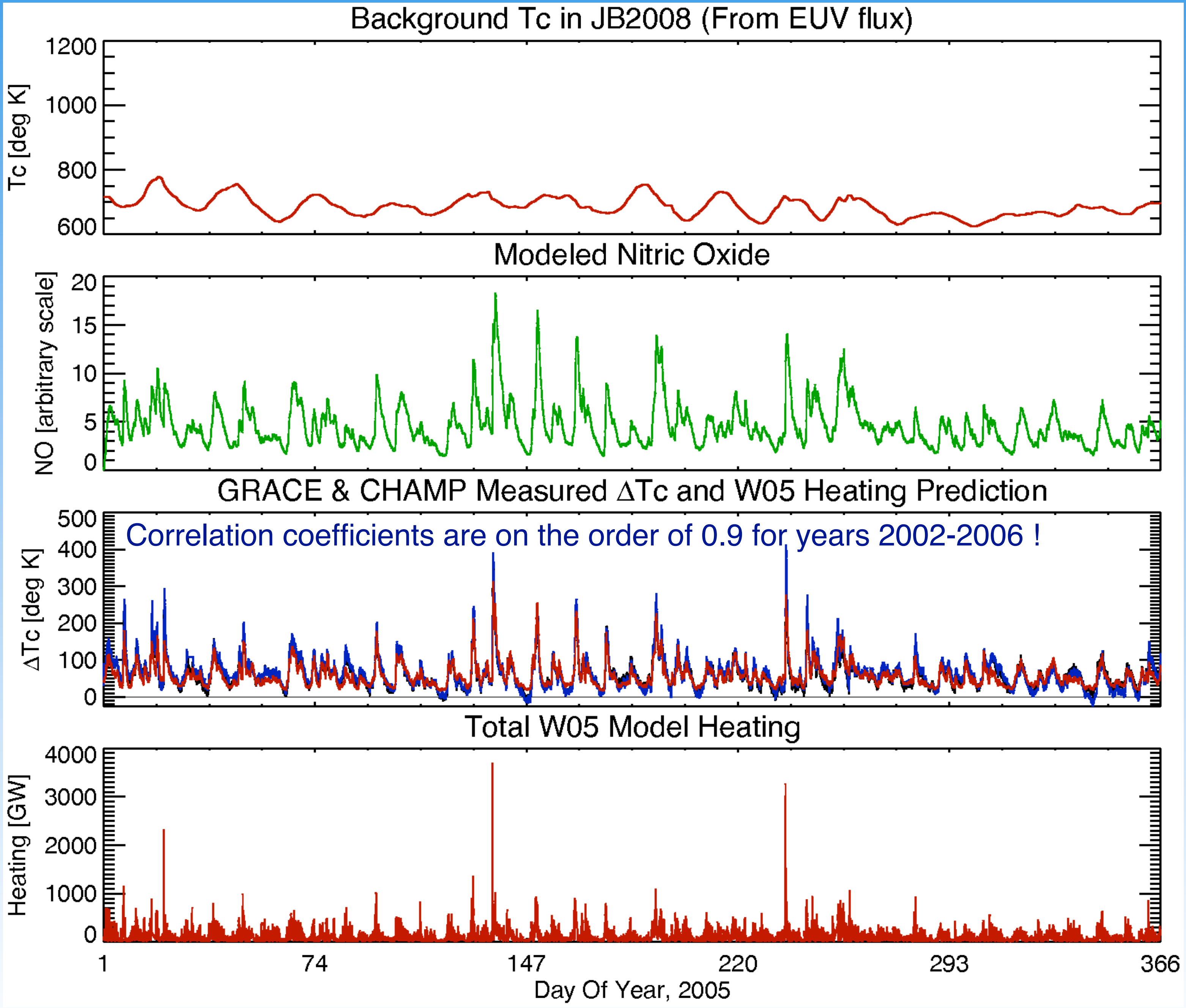
$$\tau_{NO} = 28.0 \ (\mathrm{hours})$$



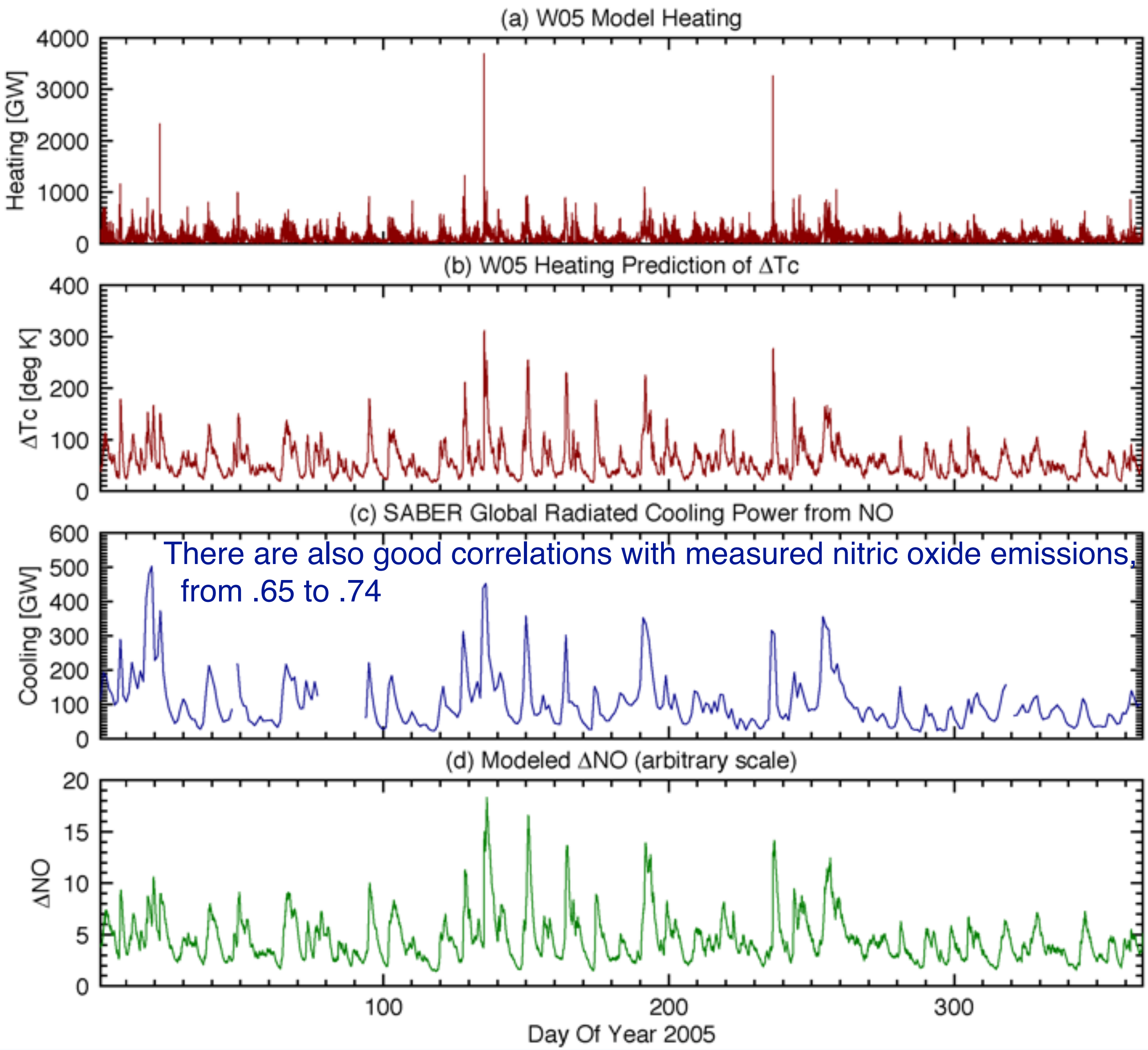
Saturation curve applied to heating

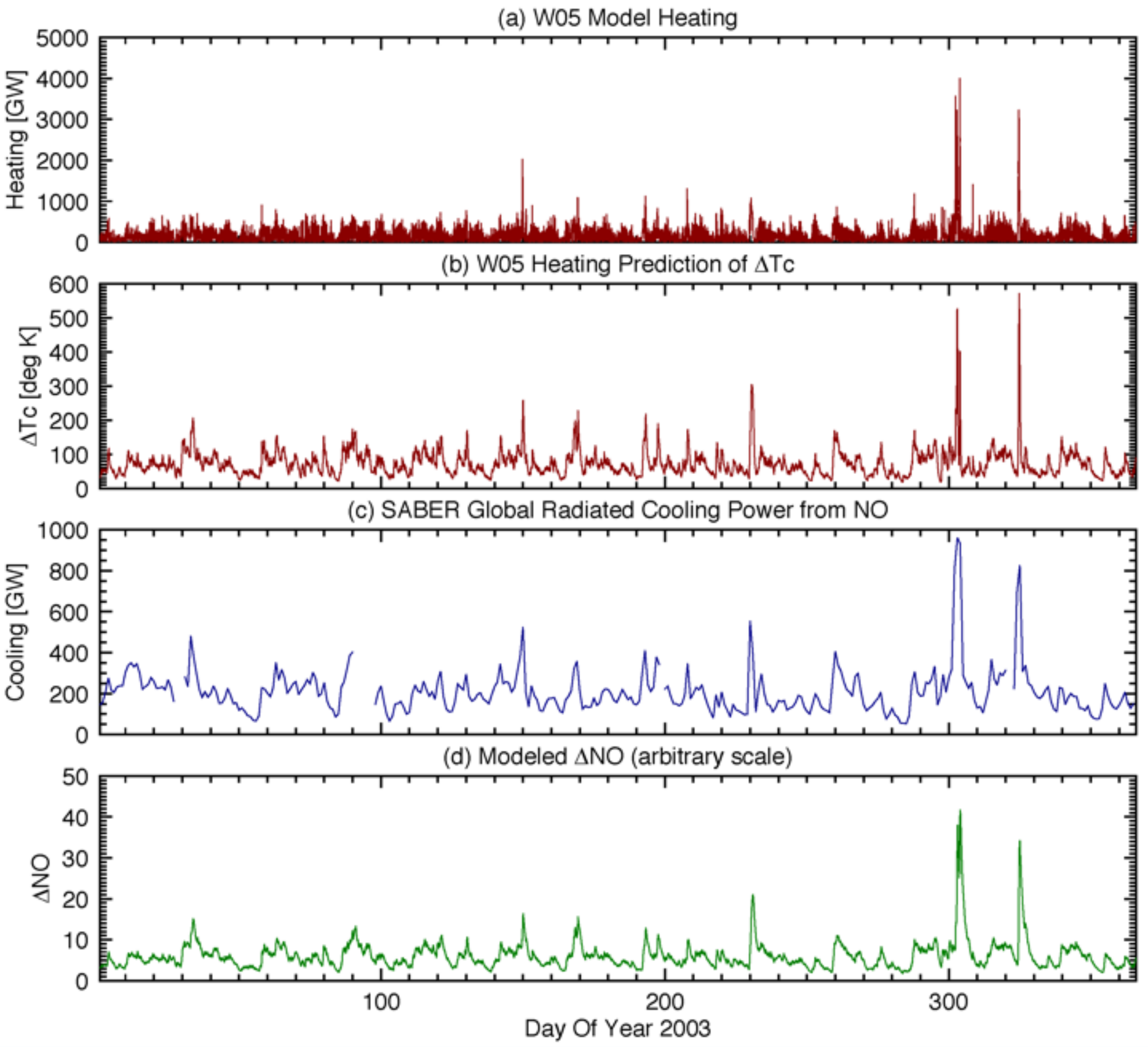
H_J is total Joule heating/Poynting flux from W05 model, with additional saturation applied. All constants (except fixed Υ) obtained by fitting five years of H_J with CHAMP and GRACE measurements of ΔT_C. Details are provided in:
Weimer, D. R., B. R. Bowman, E. K. Sutton, and W. K. Tobiska (2011), Predicting global average thermospheric temperature changes resulting from auroral heating, *J. Geophys. Res., 116*, A01312, doi:10.1029/2010JA015685.


Background Tc in JB2008 (From EUV flux)
Tc [deg K]
1200
1000
800
600
Background level of Tc in
JB2008, from solar EUV flux
Modeled Nitric Oxide
NO [arbitrary scale]
40
30
20
10
0
GRACE & CHAMP Measured ΔTc and W05 Heating Prediction
ΔTc [deg K]
500
400
300
200
100
0
Red, ΔTc prediction from W05
Green, ΔTc from
Dst index
(Burke formula)
Total W05 Model Heating
Heating [GW]
2500
2000
1500
1000
500
0
204
205
206
207
208
209
210
211
212
Day Of Year, 2004



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

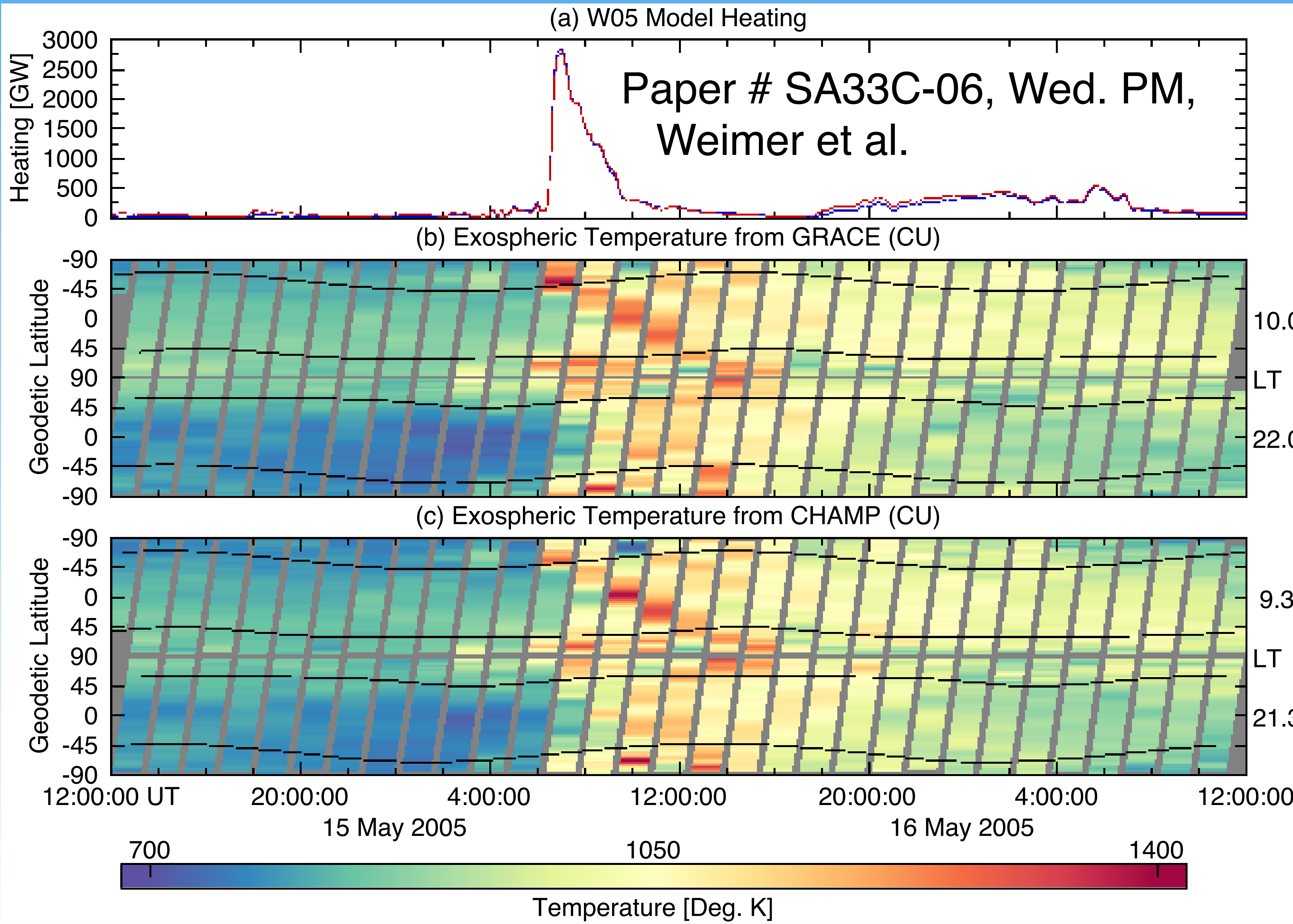

(a) W05 Model Heating
Heating [GW]
4000
3000
2000
1000
0
(b) W05 Heating Prediction of ΔTc
ΔTc [deg K]
400
300
200
100
0
(c) SABER Global Radiated Cooling Power from NO
Cooling [GW]
600
500
400
300
200
100
0
There are also good correlations with measured nitric oxide emissions, from .65 to .74
(d) Modeled ΔNO (arbitrary scale)
ΔNO
20
15
10
5
0
100
200
300
Day Of Year 2005



(a) W05 Model Heating
Heating [GW]
5000
4000
3000
2000
1000
0
(b) W05 Heating Prediction of ΔTc
ΔTc [deg K]
600
500
400
300
200
100
0
(c) SABER Global Radiated Cooling Power from NO
Cooling [GW]
1000
800
600
400
200
0
(d) Modeled ΔNO (arbitrary scale)
ΔNO
50
40
30
20
10
0
100
200
300
Day Of Year 2003

Extreme Heating Event on 15 May 2005

Peak heating at 7 UT, and density spike seen at equator by 9 to 9:45 UT !



Acknowledgments

The author thanks Eric Sutton and Eelco Doornbos 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.

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Appendix A: Energy budget of the thermosphere

The total energy content of the thermosphere is proportional to ΔTc. *Burke* [2008] found that a $1^{o}K$ 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 β 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%.