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

\[ E = -\nabla_S \Phi \]

\[ S = E \times \Delta B / \mu_0 \]

\[ J_\parallel = \nabla_S^2 \psi / \mu_0 \]

\[ \Delta B = \hat{r} \times \nabla_S \psi \]
Measured density variations from GRACE-A satellite

Total heating in both hemispheres from W05 model

JB2008 Model density at GRACE-A location (without Dst correction)
The Jacchia-Bowman 2008 (JB2008)* code uses a parameter named \( T_c \), representing the “global nighttime minimum exospheric temperature.” Global values of exospheric temperatures and densities are derived from \( T_c \).

The slowly varying, “background” level of \( T_c \) is calculated from several indices of solar EUV radiation and X-ray flux.

Faster variations, named \( \Delta T_c \), are due to the auroral heating in the ionosphere. In the JB2008 model, \( \Delta T_c \) is derived from the Dst geomagnetic index (but Dst is not real-time data).

\( \Delta T_c \) 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 \( \Delta T_c \). Burke [2008] found that a 1°K increase in \( \Delta T_c \) raises the total energy in the thermosphere above 100 km altitude by \( 1.01 \times 10^{14} \) Joules.

ΔTc variations in blue

ΔTc = “global nighttime minimum exospheric temperature”

“Measured” ΔTc variations in blue

Difference GRACEA Measured - JB2008 (no Dst)
Measured density variations from GRACE satellite

Measured ΔTc variations, from GRACE

Total Joule heating from W05 model

Background level of Tc in JB2008, from solar UV

Measured and Predicted ΔTc variations
The $\Delta T_C$ prediction technique:

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

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

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

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

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

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

Background level of Tc in JB2008, from solar EUV flux

Modeled Nitric Oxide

GRACE & CHAMP Measured ΔTc and W05 Heating Prediction

Red, ΔTc prediction from W05

Green, ΔTc from Dst index (Burke formula)

Total W05 Model Heating
Correlation coefficients are on the order of 0.9 for years 2002-2006!
There are also good correlations with measured nitric oxide emissions from .65 to .74.
Extreme Heating Event on 15 May 2005
Peak heating at 7 UT, and density spike seen at equator by 9 to 9:45 UT!

(a) W05 Model Heating

(b) Exospheric Temperature from GRACE (CU)

(c) Exospheric Temperature from CHAMP (CU)

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TIMED SABER measurements of nitric oxide emissions were provided by Martin Mlynczak, NASA LaRC.
Appendix A: Energy budget of the thermosphere

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

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

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

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

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

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

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

With $\beta$ equal to $6.9 \cdot 10^{-4} \text{ °K/GW/min}$, an output of 362 GW from the W05 model over a period of 4 min is needed to raise the $T_c$ temperature by $1^\circ$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%.