Neutral Density Variability Driven by Geomagnetic Forcing: Global Joule Heating Index

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Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics Model (CTIPe)

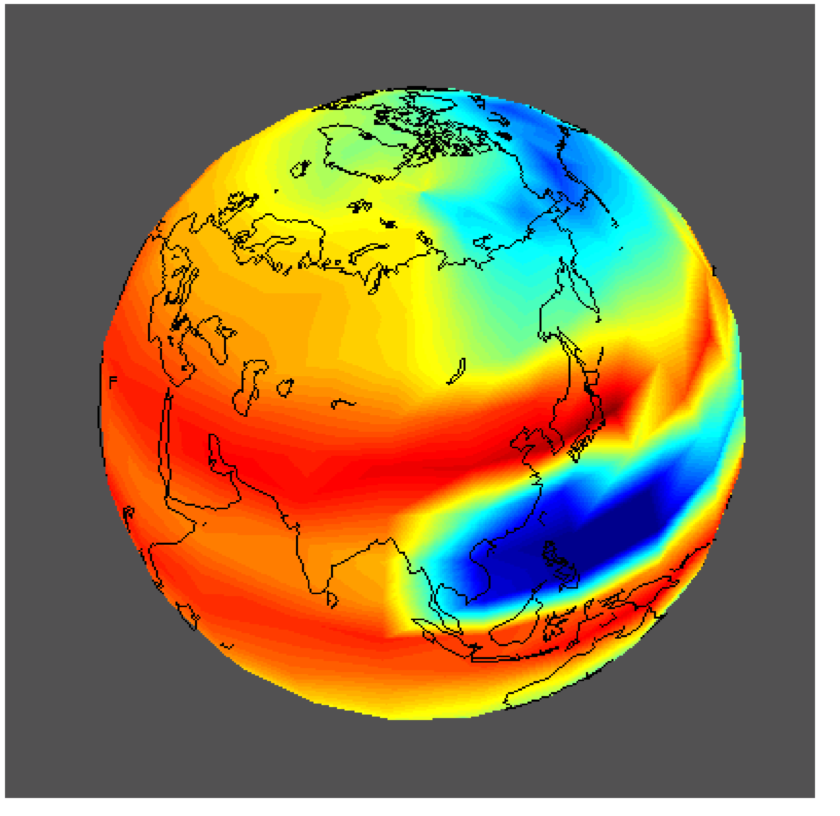
• Global thermosphere 80 - 500 km, solves momentum, energy, composition, etc. Vx, Vy, Vz, Tn, O, O2, N2, … Neutral winds, temperatures and compositions are solved self consistently with the ionosphere (Fuller-Rowell et al., 1996);

• High latitude ionosphere 80 -10,000 km, solves continuity, momentum, energy, etc. O+, H+, O2+, NO+, N2+, N+, Vi, Ti, …. (open flux tubes);

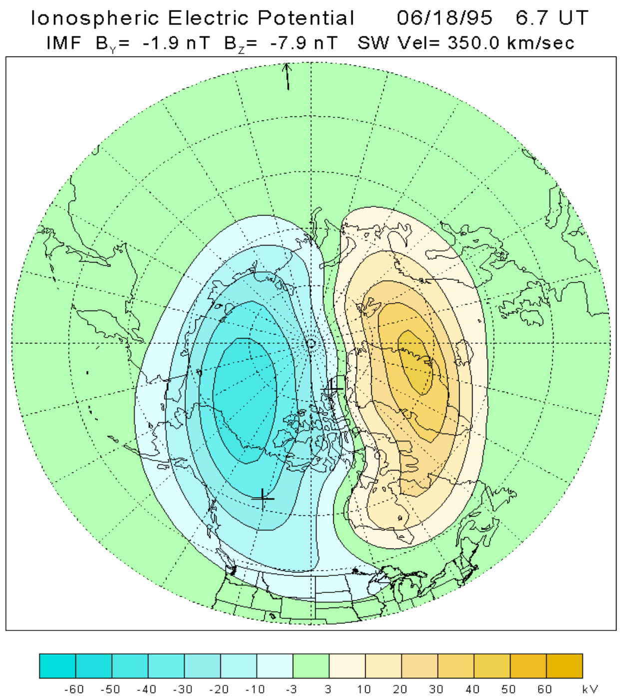
• Plasmasphere, and mid and low latitude ionosphere, closed flux tubes to allow for plasma to be transported between hemispheres (Millward et al., 1996) ;

• Self-consistent electrodynamics (electrodynamics at mid and low latitudes is solved using conductivities from the ionospheric model and neutral winds from the neutral atmosphere code);

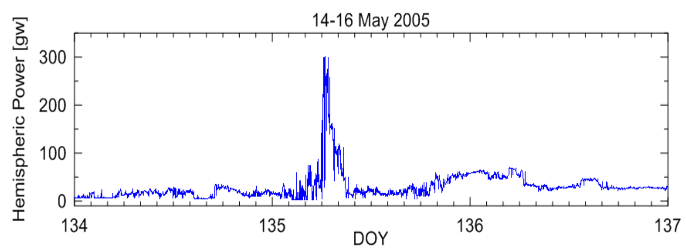
• Forcing: solar UV and EUV, Weimer electric field, TIROS/NOAA auroral precipitation, tidal forcing.

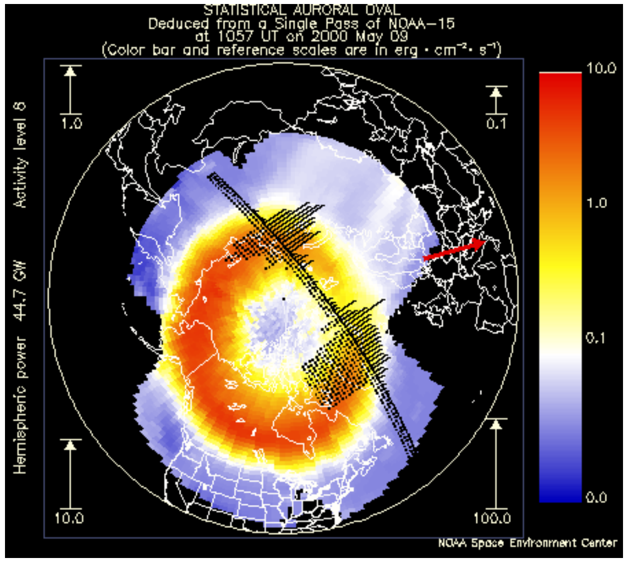


CTIPe Magnetospheric Forcing



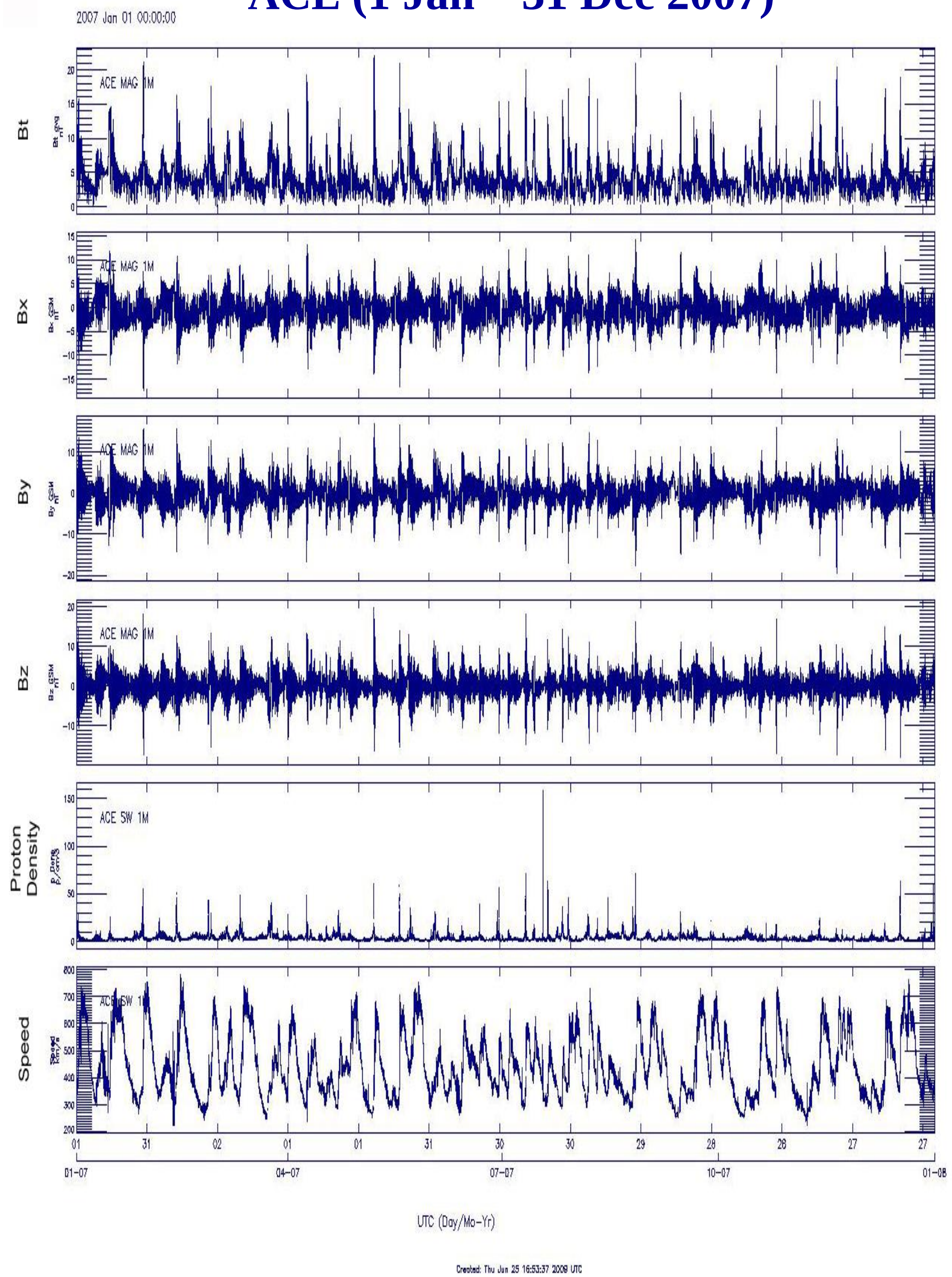
Plasma convection: patterns driven by Weimer 2005 using ACE data (IMF, SW vel., SW den.), 1 min. input (SWPC database).





Particle precipitation: patterns driven either by power index TIROS/NOAA auroral precipitation or derived from ACE solar wind and IMF data.

ACE (1 Jan – 31 Dec 2007)



Challenging Minisatellite Payload (CHAMP)

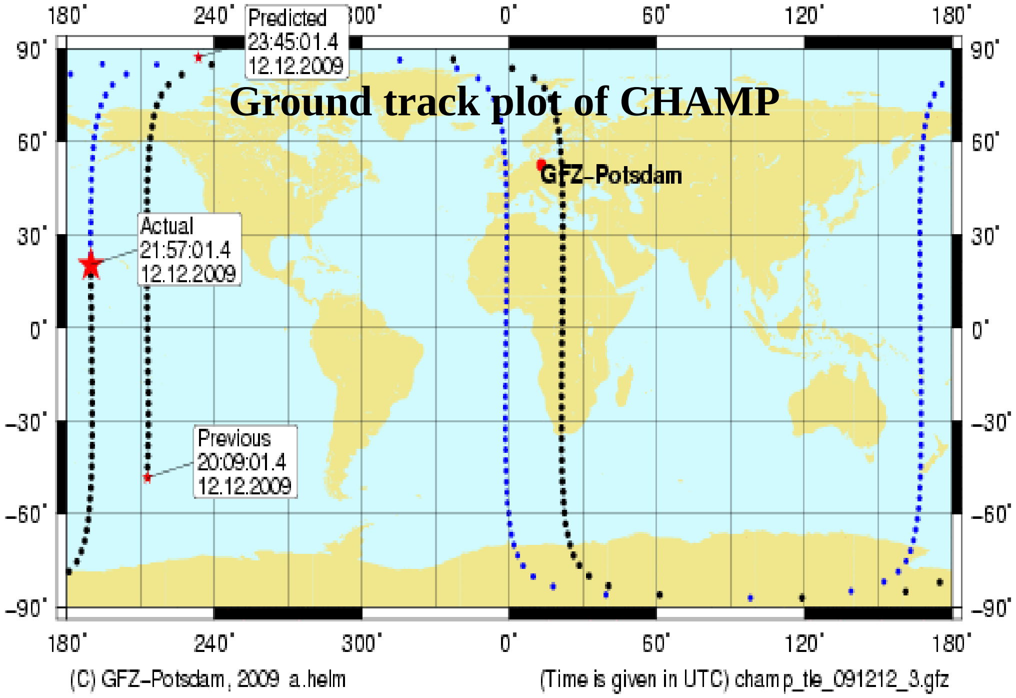
• Launched into a polar orbit at 460 km altitude on July 2000.

• Project plan included a 5-year mission duration to study the gravity and magnetic fields of the Earth, with a secondary goal of studying the upper atmosphere.

• With 87.3° inclination, CHAMP passes the equator almost exactly in the meridional direction. CHAMP drifts in local time, covering all local time sectors in about 130 days.

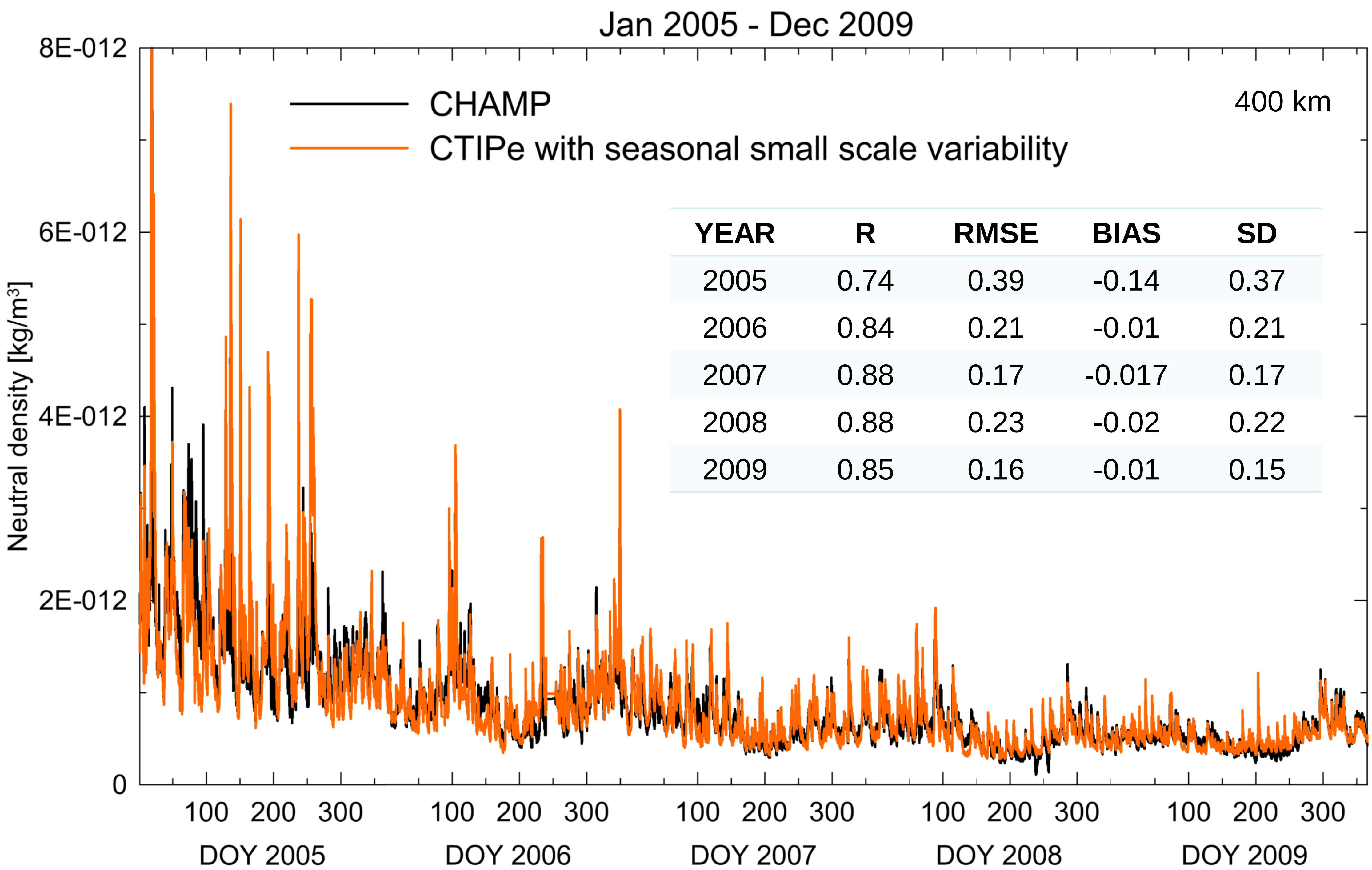
• During the 9-year period after its launch, the orbital altitude has gradually decreased to about 315 km, ending its mission by natural atmospheric re-entry in September 2010.

• One of the instruments on board of CHAMP is a sensitive triaxial accelerometer that is capable of providing estimates of total mass density and cross-track winds.



CHAMP data version 2.3 provided by Eric Sutton

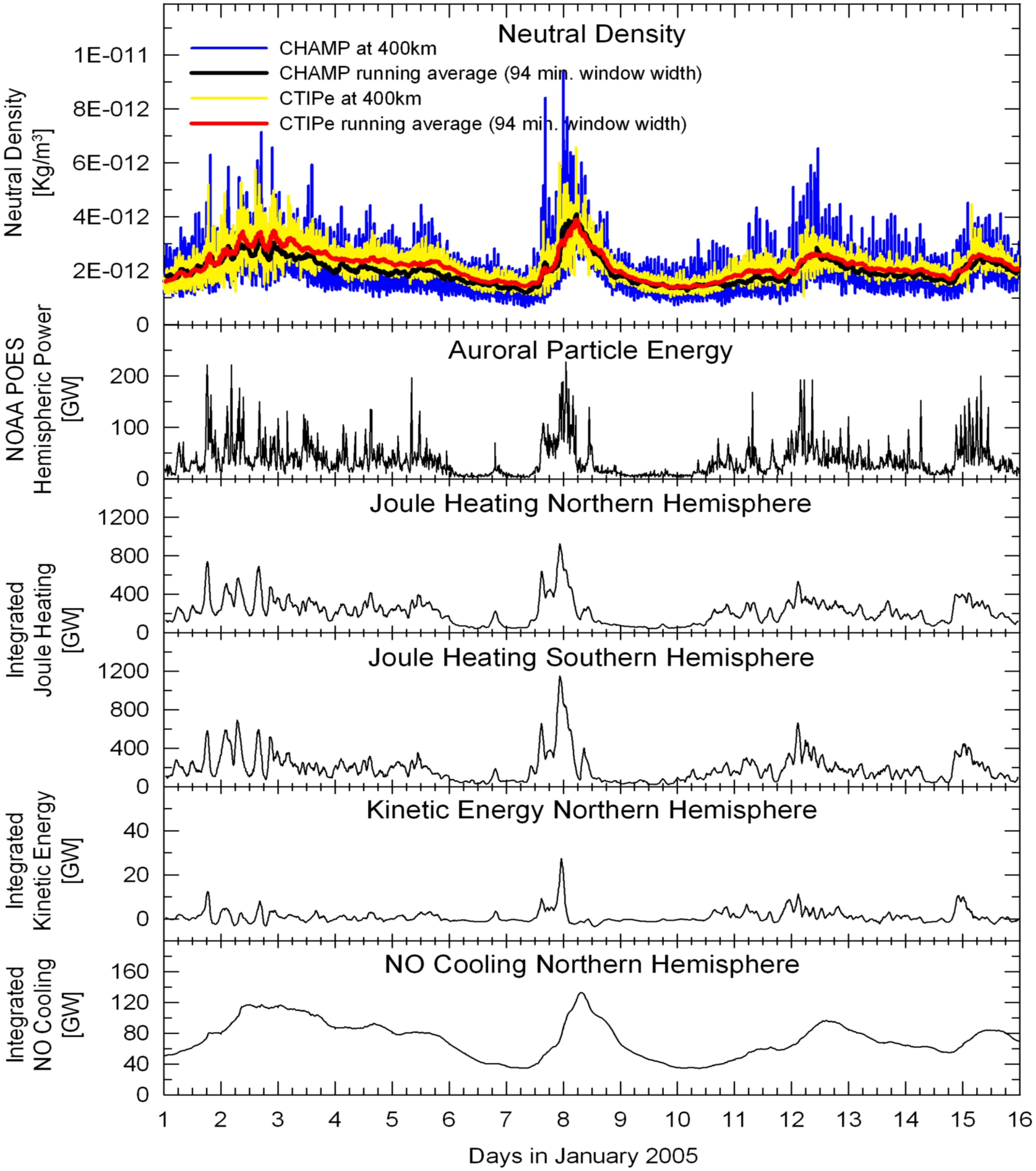
2005-2009 CHAMP/CTIPe Orbit Average Comparisons



YEAR	R	RMSE	BIAS	SD
2005	0.74	0.39	-0.14	0.37
2006	0.84	0.21	-0.01	0.21
2007	0.88	0.17	-0.017	0.17
2008	0.88	0.23	-0.02	0.22
2009	0.85	0.16	-0.01	0.15

CHAMP data version 2.3 provided by Eric Sutton

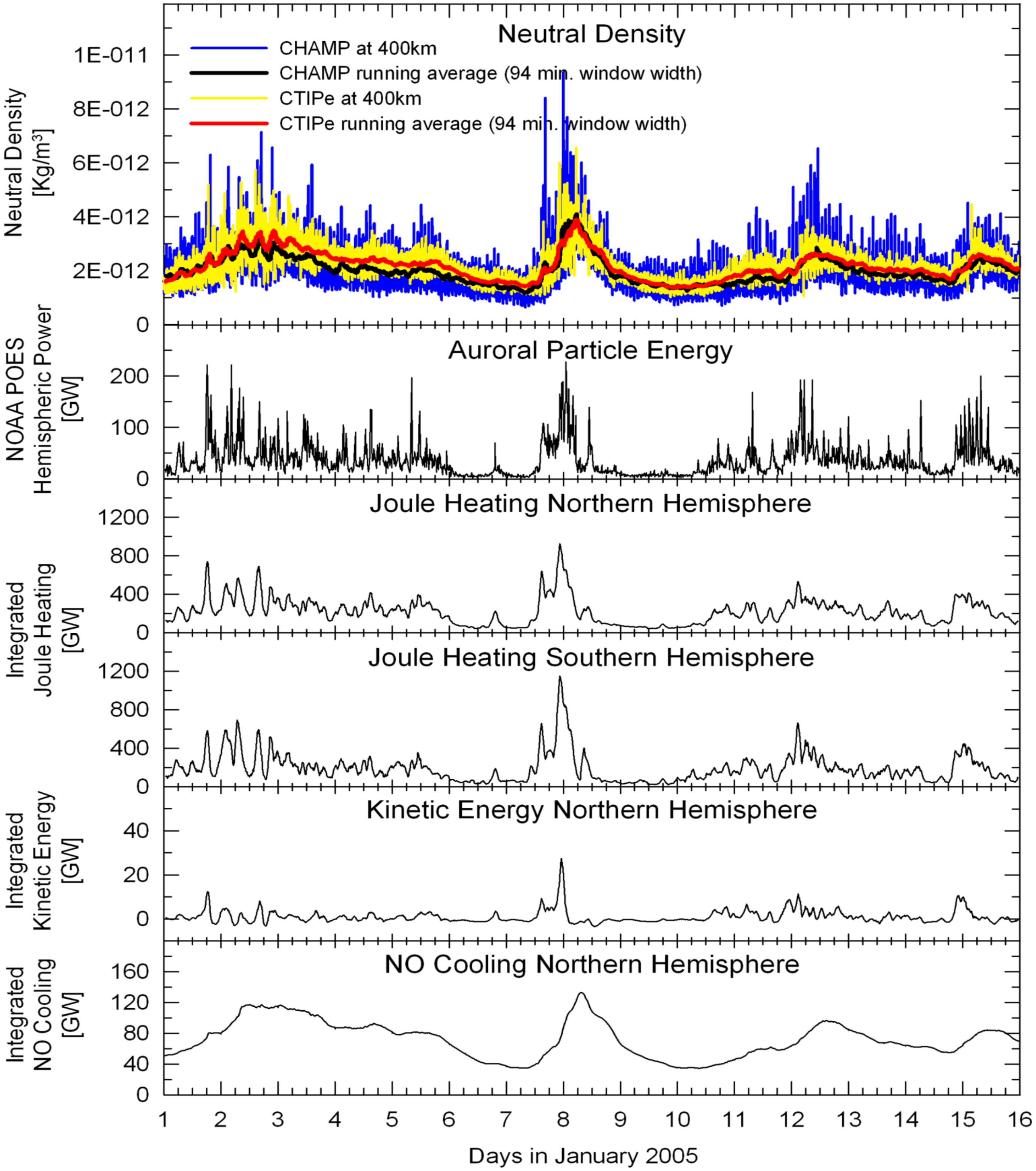
Partitioning of Energy during a Geomagnetic Storm



- Agreement between model and observations suggests that the amount of energy influx from solar radiation and magnetospheric sources deposited into the atmosphere is reasonably accurate, enabling the model to be used to estimate the rate of energy influx from those sources.

- Integrated Joule heating accounts for the majority of energy input into the ionosphere/thermosphere system during geomagnetic storms (e.g., Lu et al., 1995; Knipp et al., 2004; Fuller-Rowell and Solomon, 2010).

Partitioning of Energy during a Geomagnetic Storm (cont'd)

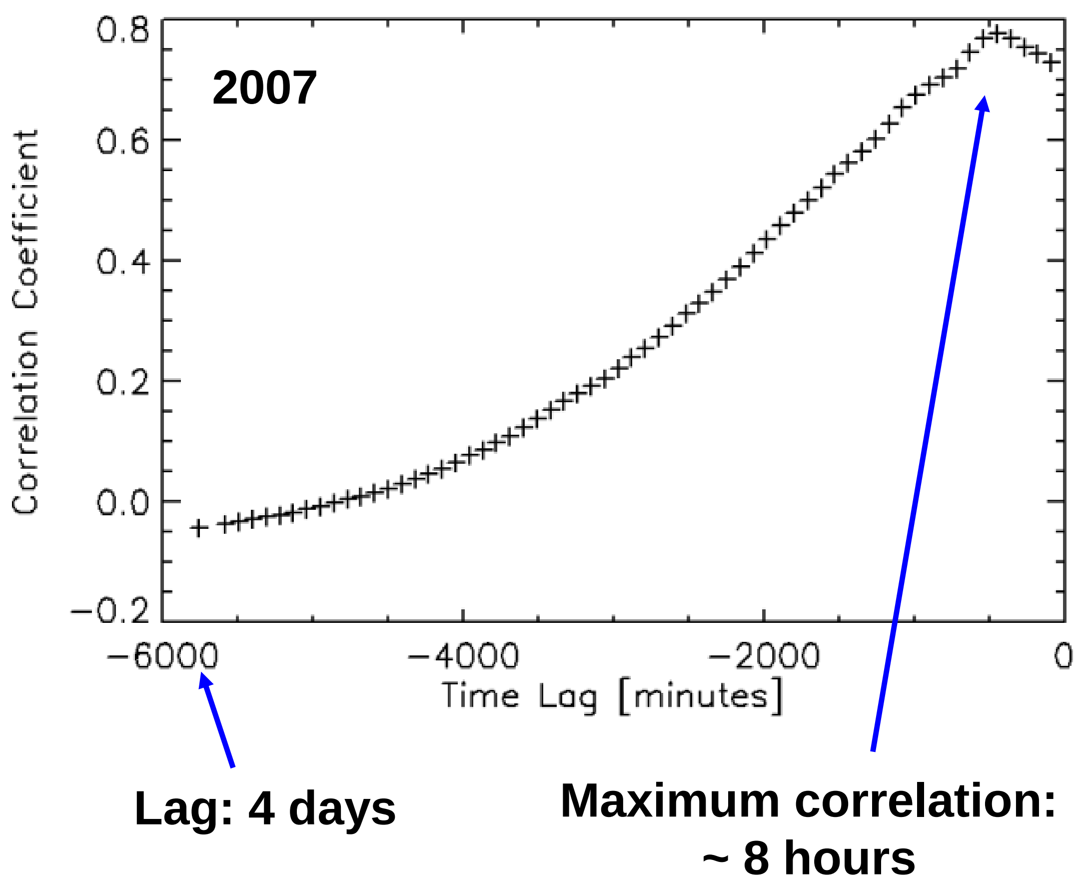


CTIPe is able to follow the CHAMP neutral density response with reasonable fidelity. It is now possible to explore the use the model estimates of Joule heating as an alternative index for the neutral density response. In this study, an index based on CTIPe Joule heating is derived.

Relationship between CTIPe Joule Heating and Neutral Density: Joule Heating Index

• CTIPe Joule heating index is obtained by deriving a relationship between the time series of CTIPe Joule heating and CHAMP neutral density observations.

• Seasonal and solar cycle influences from the CHAMP neutral density observations are removed, so that the residual neutral density variations are primarily due to geomagnetic activity. This is achieved by subtracting the quiet-time density from the satellite density measurements. The quiet-time density is obtained from the empirical model Jacchia-Bowman 2008 (JB2008; Bowman et al., 2008b), assuming no variation from geomagnetic activity, i.e., Ap and Dst are set to zero.

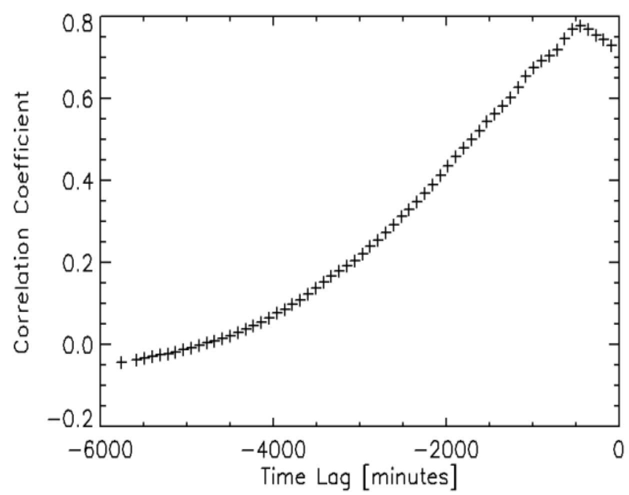


• Cross-correlation between CTIPe Joule heating and residual neutral density as a function of time lag: the maximum of cross-correlation is found at about 8 hours, beyond which the correlation gradually decreases, approaching zero after a lag of about 3 days. This implies that magnetospheric energy sources up to 3 days before are affecting the neutral density at the current time. It also implies the recovery time is about 3 days from NO cooling and downward heat conduction. This correlation analysis provides the filter shape by which to scale the time-series of Joule heating to best match the CHAMP neutral density.

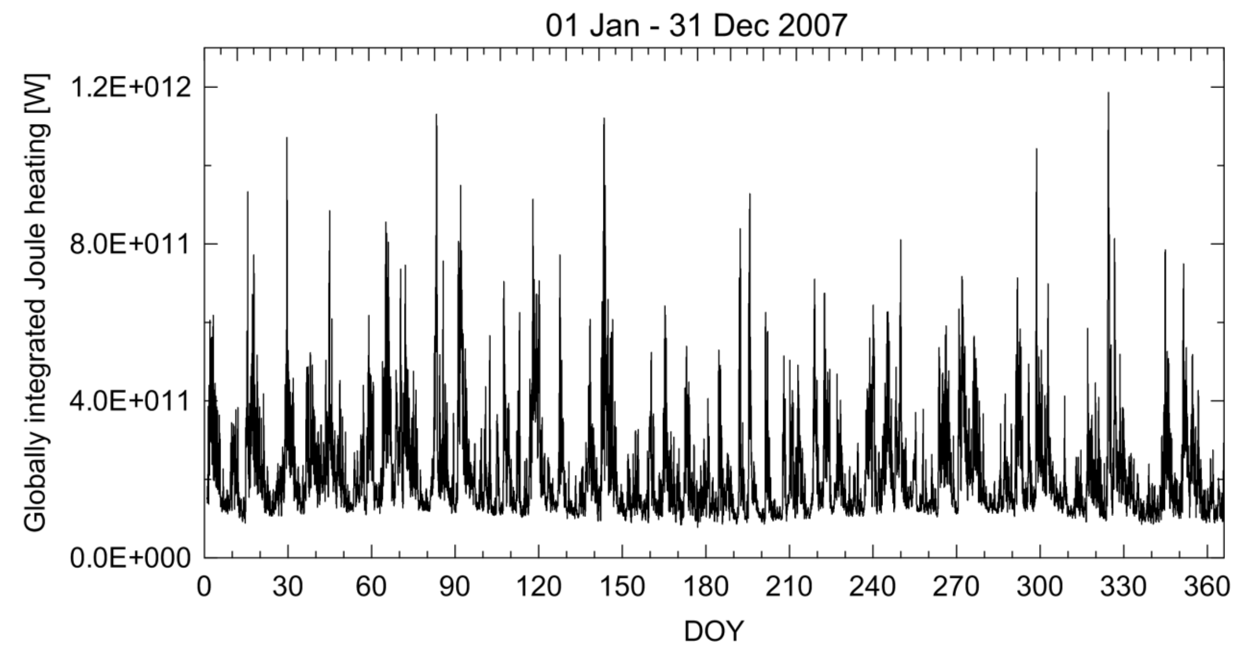
Relationship between CTIPe Joule Heating and Neutral Density: Joule Heating Index (cont'd)

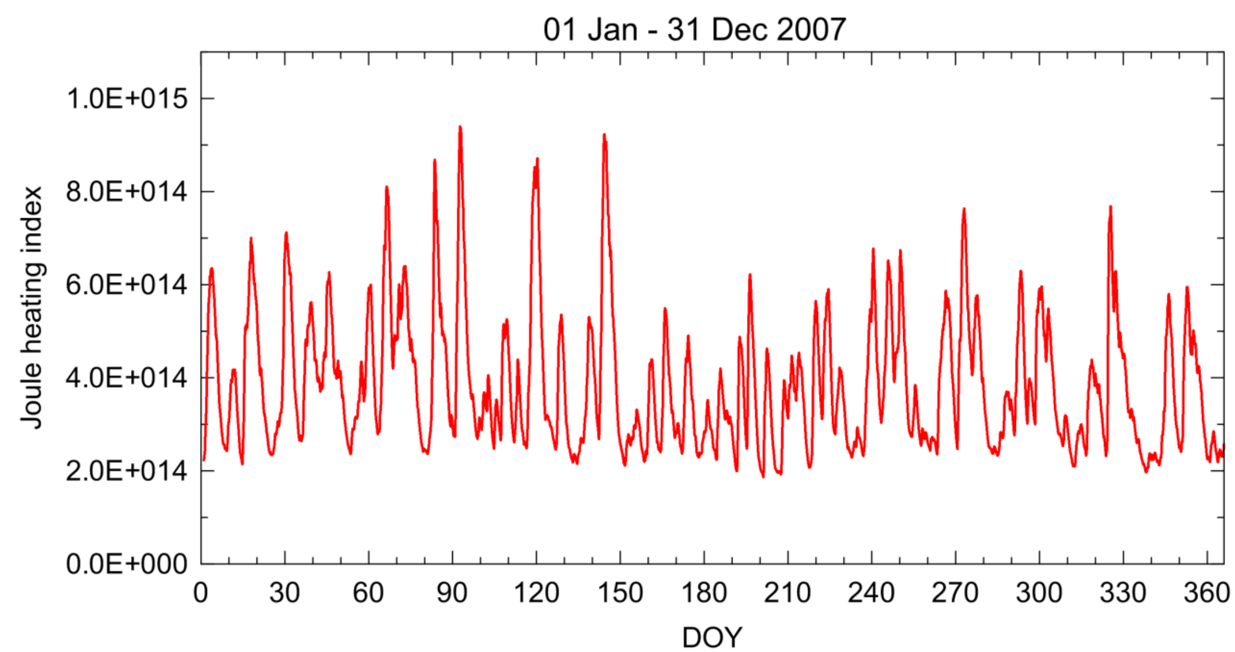
INPUT
(Joule heating)

IMPULSE RESPONSE
(shaping filter)



OUTPUT
(Joule heating index)



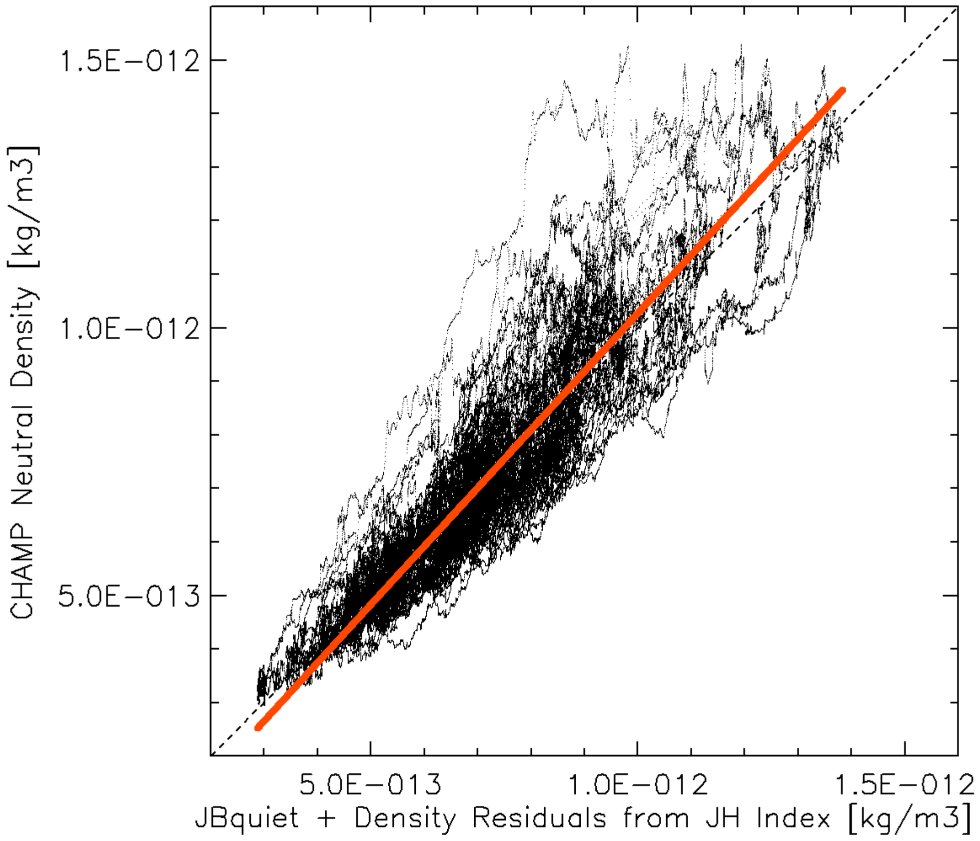


• Convolution of CTIPe Joule heating with the shaping filter results in a new parameter (Joule heating index) representing the integral of the product of the two functions.

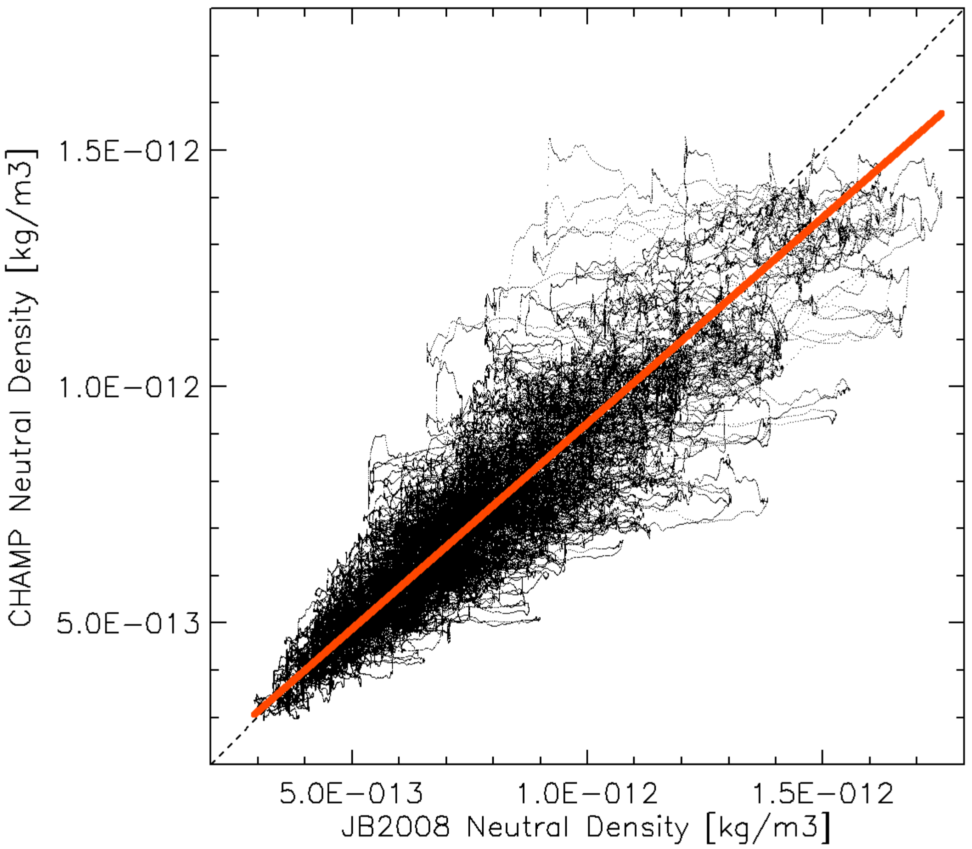
Relationship between CTIPe Joule Heating and Neutral Density: Joule Heating Index (cont'd)

• Linear regression between Joule heating index and the "observed" density residuals (CHAMP minus quiet-time JB2008) is used to produce the new density residuals derived from Joule heating index.

• New absolute values of neutral density are obtained by adding the density residuals derived from Joule heating index to the quiet-time JB2008 neutral density.

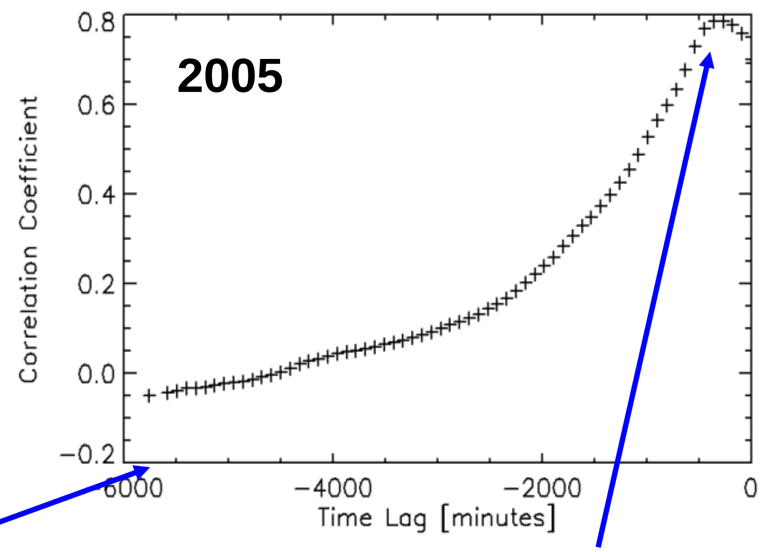


R= 0.92, RMSE= 0.10
BIAS= -0.01, SD= 0.10



R= 0.90, RMSE= 0.16
BIAS= -0.06, SD= 0.14

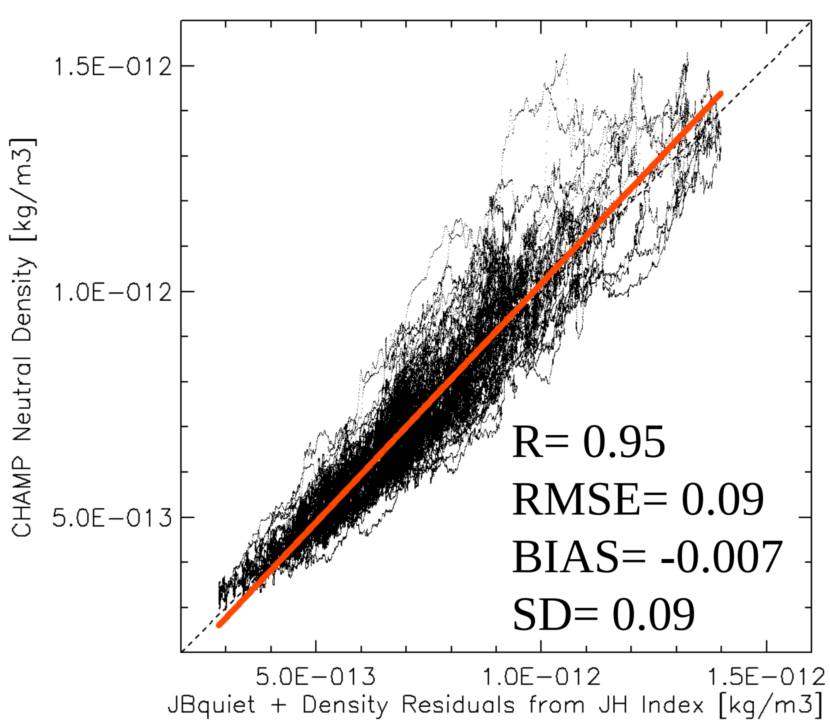
Relationship between CTIPe Joule Heating and Neutral Density: Joule Heating Index (cont'd)

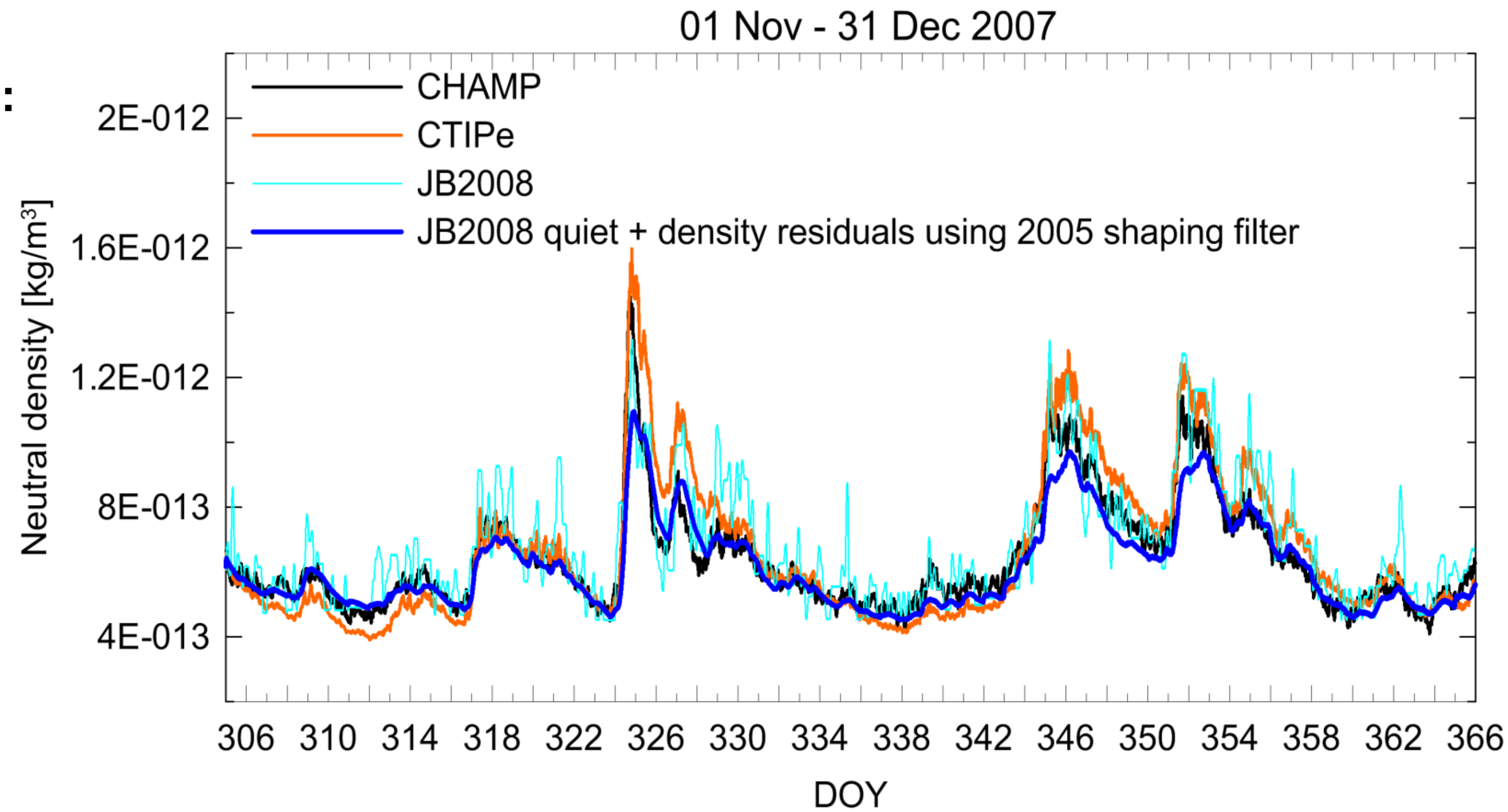


Lag: 4 days

Maximum correlation: ~ 5 hours

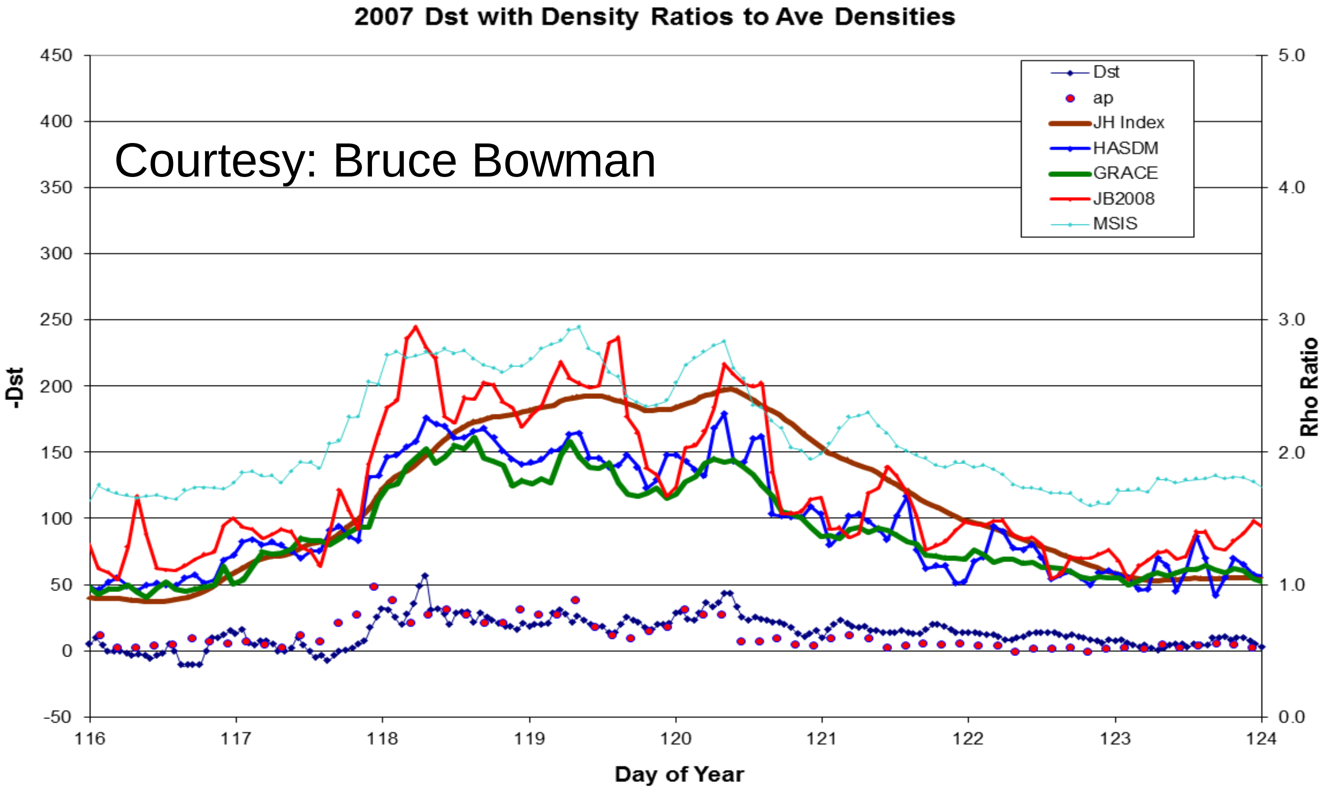
• Convolution of 2007 CTIPe Joule heating with the 2005 shaping filter generates a new set of Joule heating index values. The linear regression is used to obtain the new density residuals derived from Joule heating index, which are added to the 2007 quiet-time JB2008 neutral density to produce the absolute neutral density.

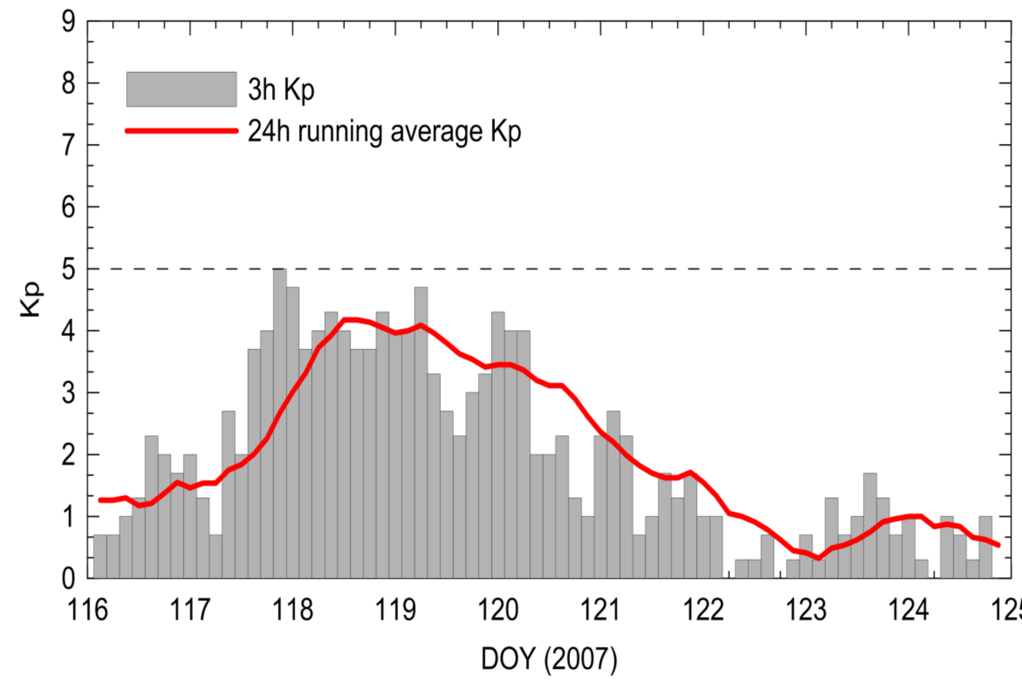




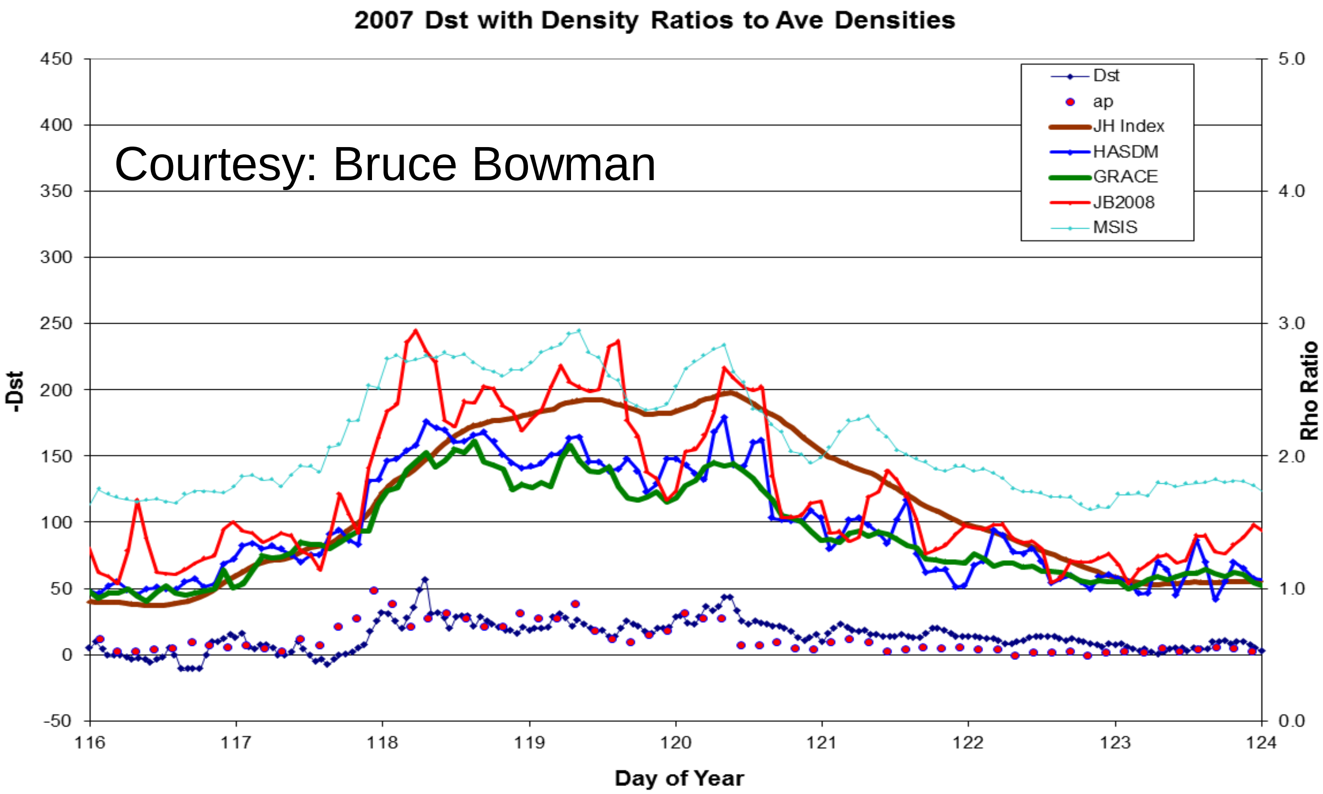
Fedrizzi et al. (Space Weather, 2012)

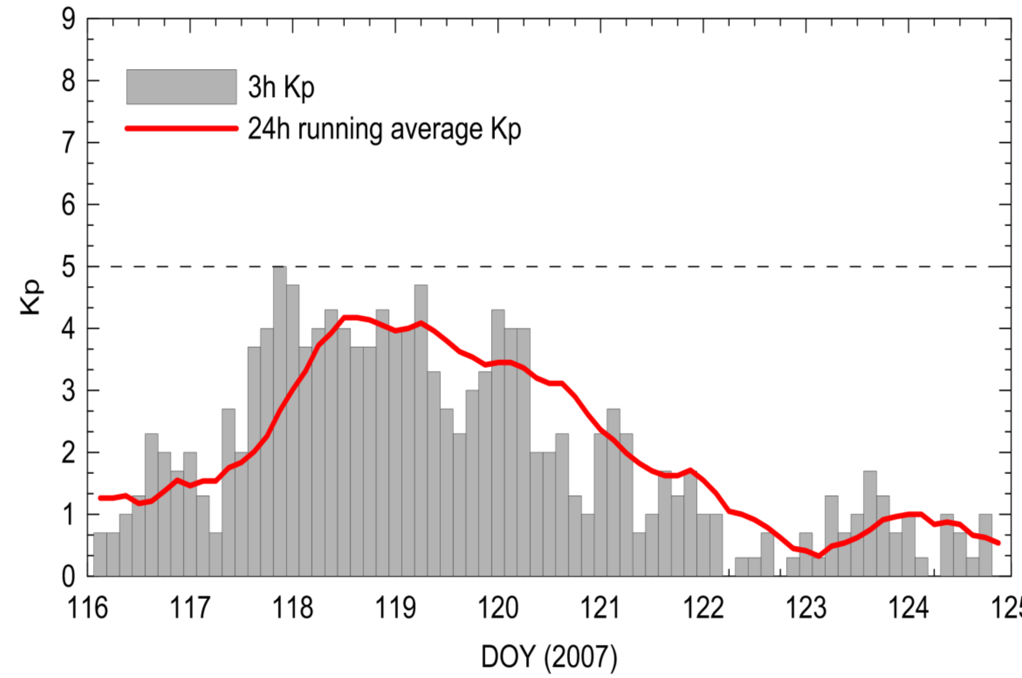
Joule Heating Index Test

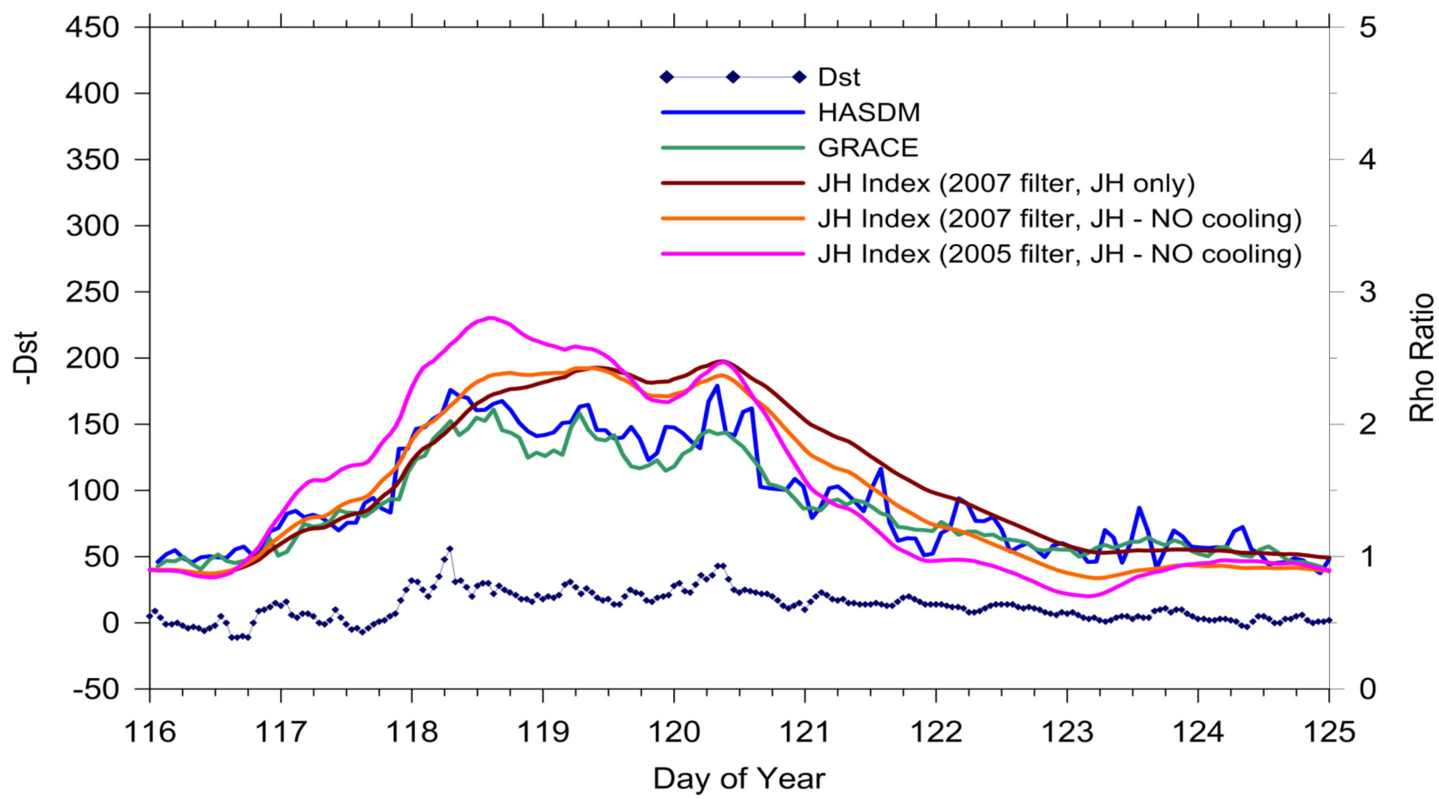




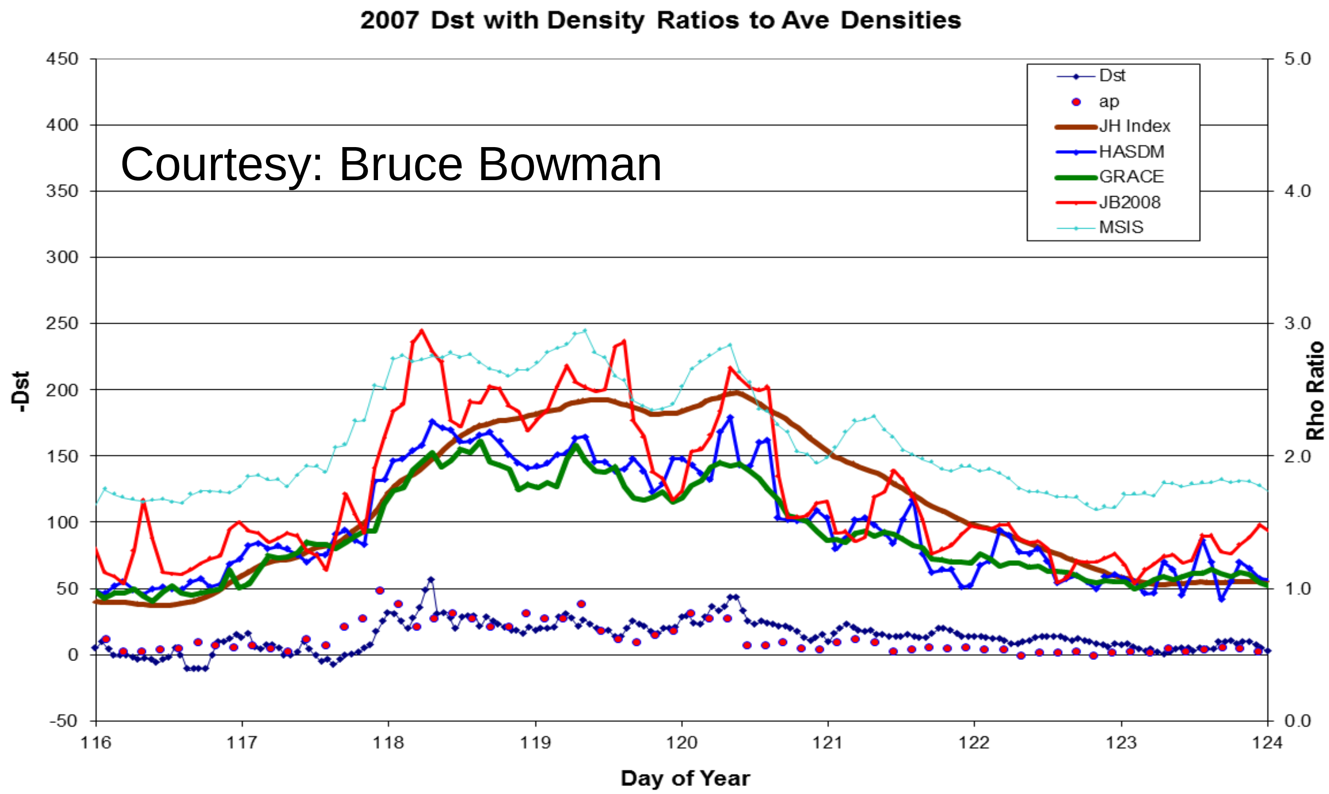
Joule Heating Index Test (cont'd)

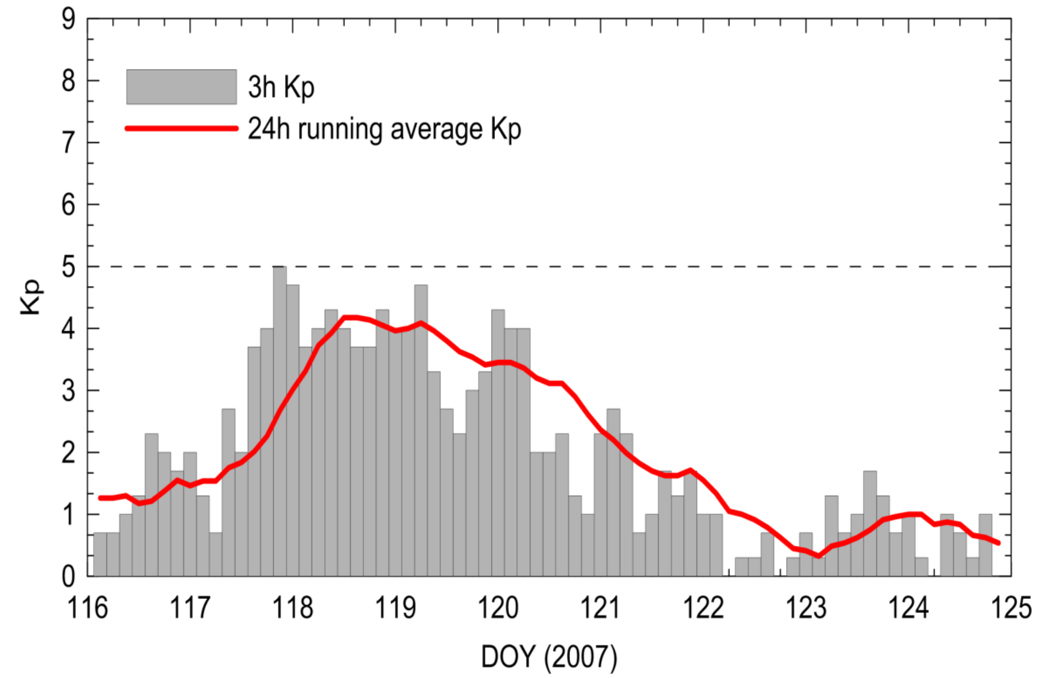


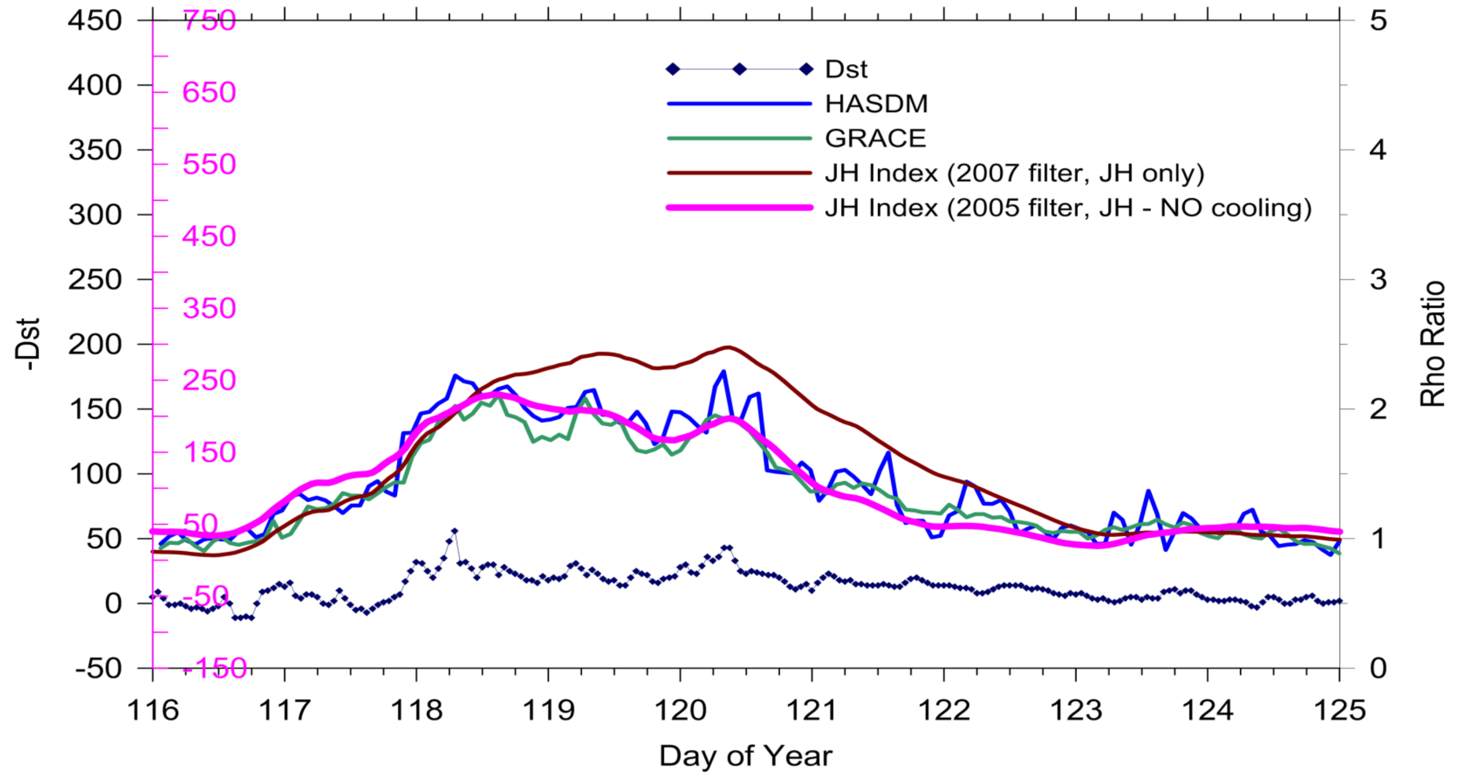




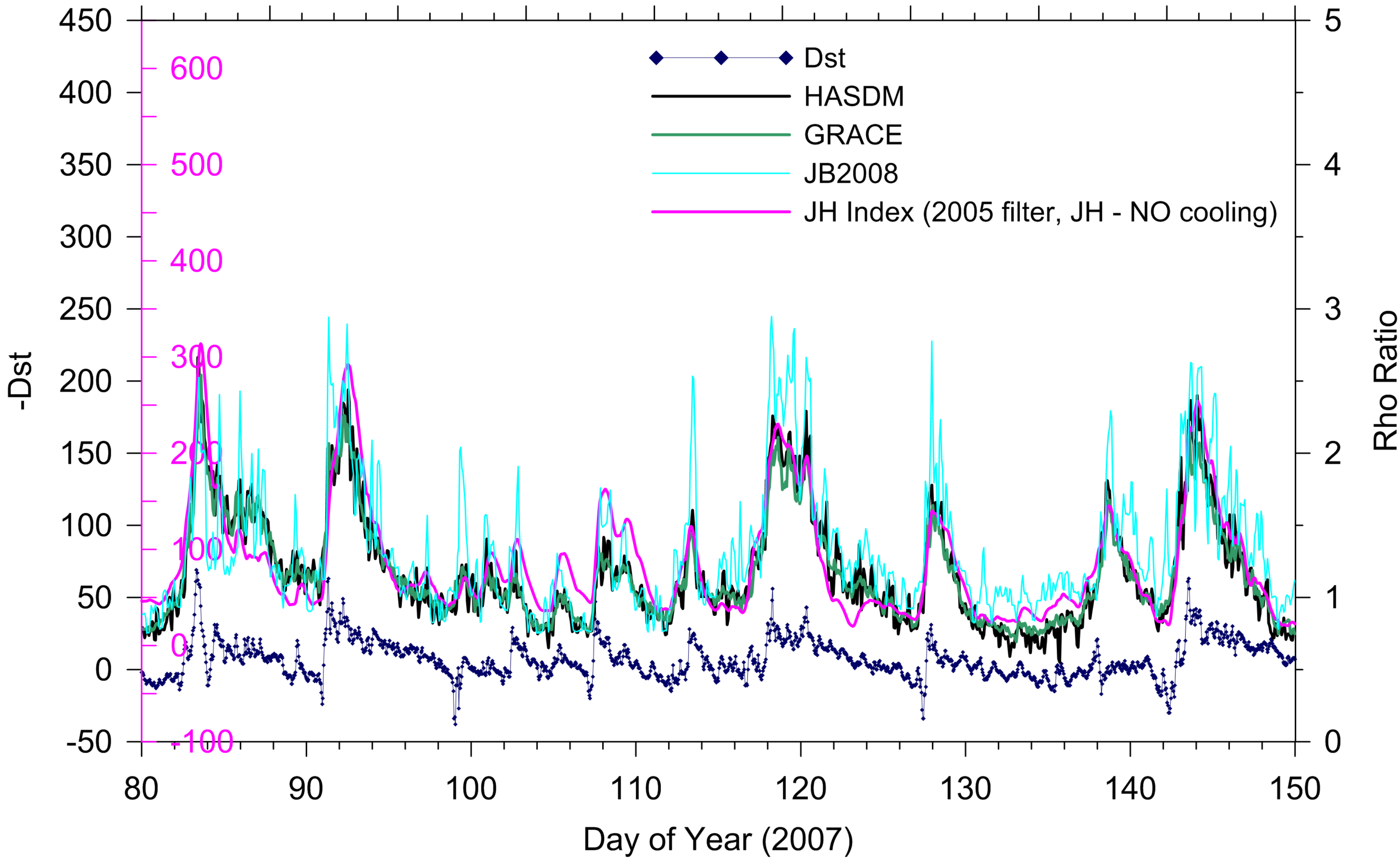
Joule Heating Index Test (cont'd)



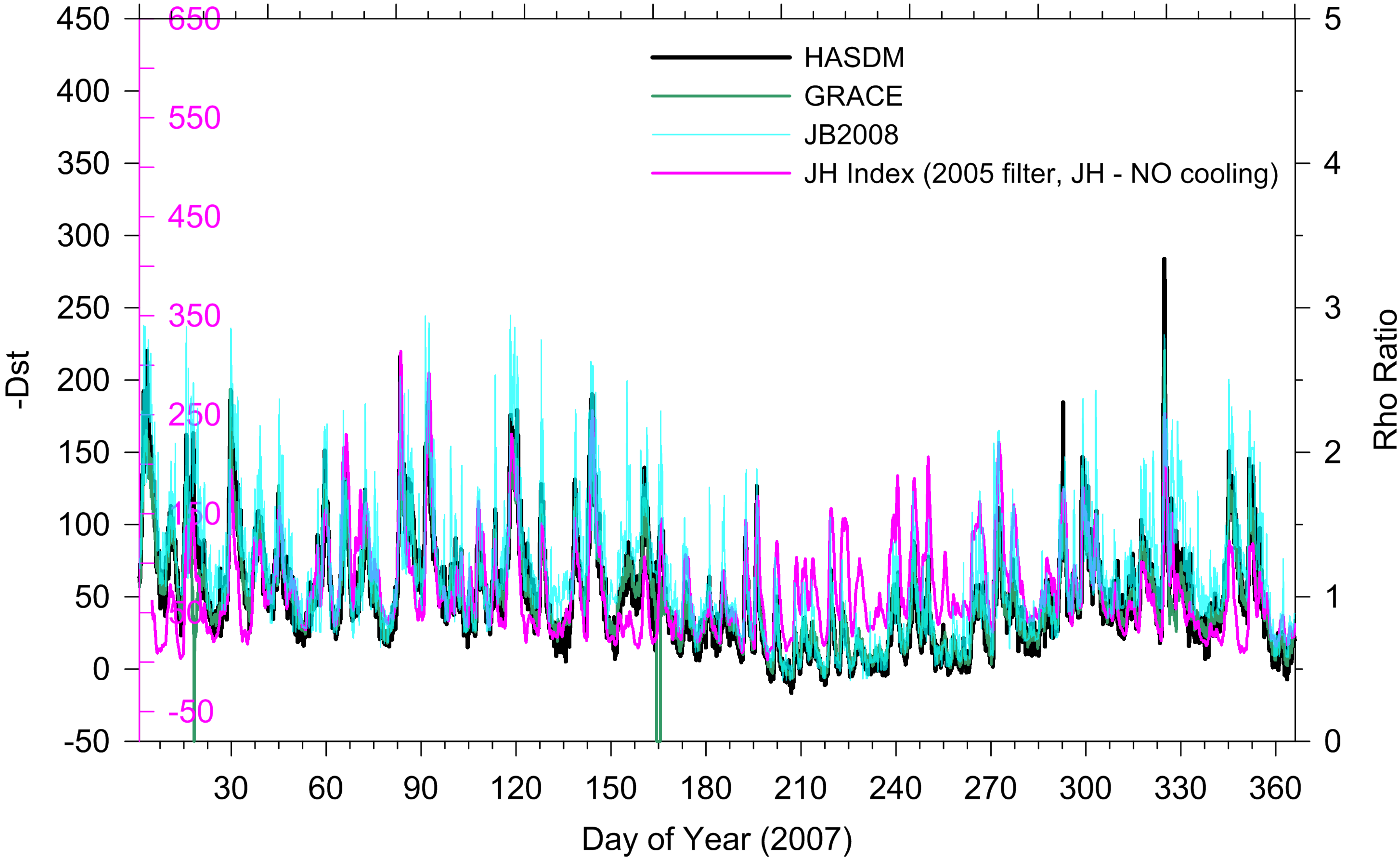




Joule Heating Index Test (cont'd)



Joule Heating Index Test (cont'd)



Summary and Future Work

- Agreement between model and observations suggests that the amount of energy influx from solar radiation and magnetospheric sources deposited into the atmosphere is reasonably accurate, enabling the model to be used to estimate the rate of energy influx from those sources.

- First results on Joule heating index development show improvement in neutral density estimates. Further work is needed, and the analysis will be extended to all years of CHAMP/GRACE/GOCE observations to cover the solar cycle.

- Even though good agreement between CTIPe and CHAMP indicates that Joule heating is reasonably correct, more accurate specification of the Joule heating magnitude and spatial distribution is needed to improve geomagnetic forcing (e.g., MHD models, Weimer and AMIE updated versions).