CTIPe recent developments

Tim Fuller-Rowell, Mariangel Fedrizzi, Mihail Codrescu, Naomi Maruyama, Tomoko Matsuo, Jack Olsen, and Catalin Negrea

CIRES, University of Colorado

Contributions from Dan Weimer, Juan Fontenla, Tom Woods, Bruce Bowman, Larry Paxton

Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics Model (CTIPe)

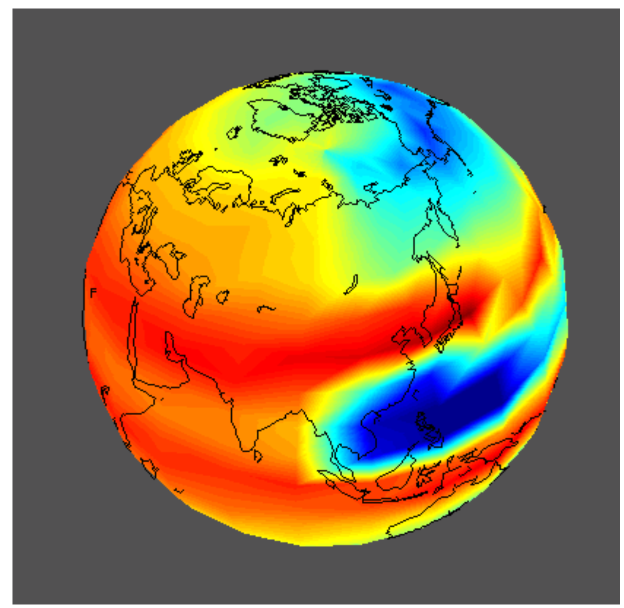
- Global thermosphere 80 - 500 km, solves momentum, energy, composition, etc. Vx, Vy, Vz, Tn, O, O2, N2, … Neutral winds, temperatures and compositions are solved self consistently with the ionosphere (Fuller-Rowell and Rees, 1980);

- High latitude ionosphere 80 -10,000 km, solves continuity, momentum, energy, etc. O^+, H^+, O_2^+, NO^+, N_2^+, N^+, V_i, T_i, …. (open flux tubes) (Quegan et al., 1982;

- 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) (Richmond et al.,);

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

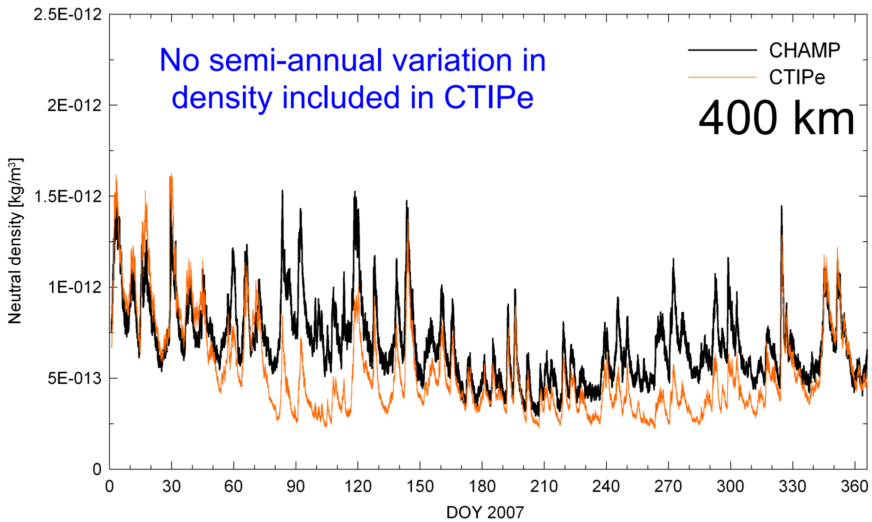


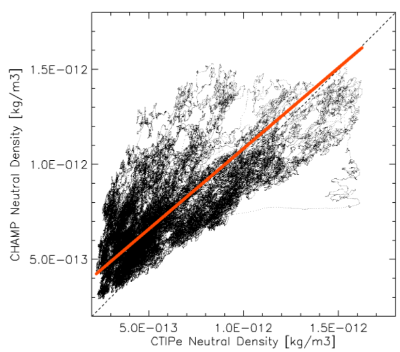
Updates

- On-going validation
- NO cooling
- Lower atmosphere tidal spectrum and eddy diffusion
- Impact of small-scale spectrum of waves
- Robustness – simulation of a Carrington-type event
- Real-time CTIPe and 0.25 scale height version
- New EUV and UV drivers: SRPM (Fontenla) and SDO (Woods)
- Data assimilation
- IPE, RCM

The semi-annual variation challenge

2007 CHAMP/CTIPe Orbit Average Comparisons





R= 0.73
RMSE= 0.31
BIAS= 0.23
SD= 0.21

Possible Mechanisms for Semi-Annual Variation:

- Seasonal variation in eddy diffusivity in the upper mesosphere and lower thermosphere regions due to gravity wave breaking (Qian et al., 2009)
- Thermospheric spoon mechanism associated with the global scale interhemispheric circulation at solstice (Fuller-Rowell, 1998)
- Asymmetry in conductivity distribution at solstice due to inequality of solar radiation between hemispheres (e.g, Lyatsky et al., 2001)
- Semi-annual variation in geomagnetic activity peaking at equinoxes (Russell and McPherron, 1973)
- Conduction mode oscillation of the thermosphere forced by the semi-annually varying Joule heating at high latitudes (Walterscheid,1982)

Some of these mechanisms are not included in the model, and it is possible that a combination of these effects (and various others listed by Qian et al., 2009) could be responsible for the semi-annual variation in density. This is still an open question, and further investigation is required to understand the seasonal processes in the upper atmosphere.

Semi-annual variation using small-scale E-field variability

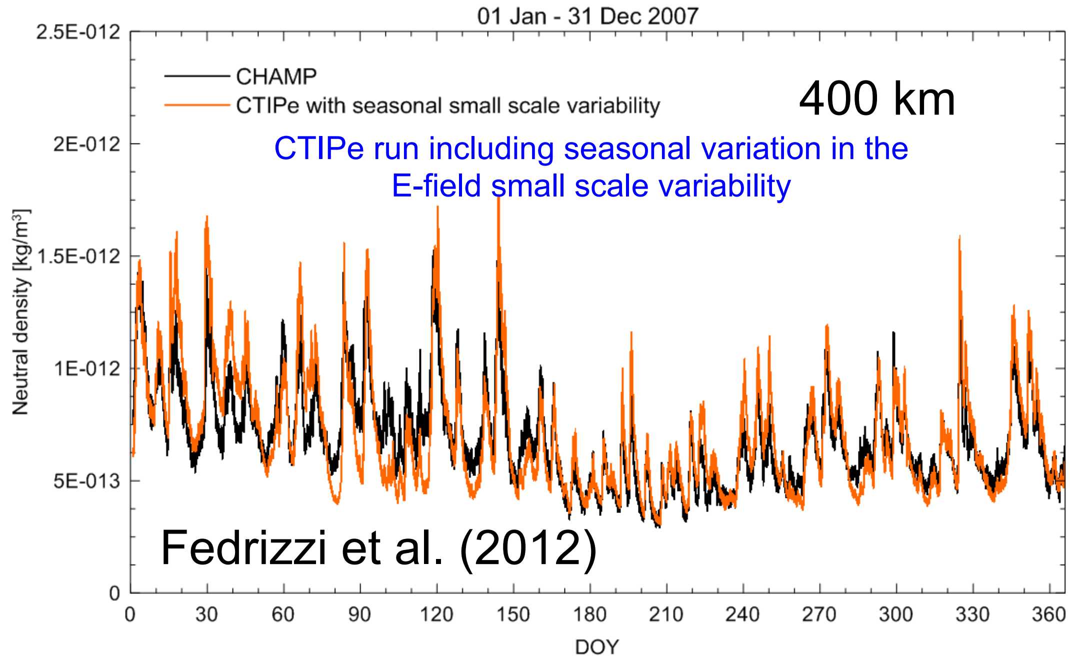
2007 CHAMP/CTIPe Orbit Average Comparisons

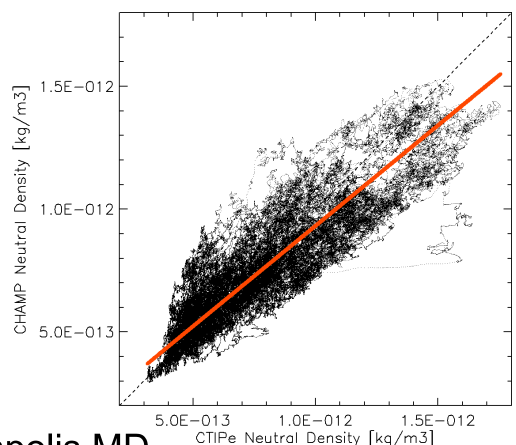
• Main purpose of this study is to simulate the model response to short-period variations in geomagnetic activity during the year.

• To accommodate this goal the semi-annual variation of neutral density in CTIPe has been removed by introducing a semi-annual variation in electric field small-scale variability.

• Electric fields can directly change Joule heating by varying the ion convection at high-latitudes (Deng and Ridley, 2007). An increase in Joule heating raises the neutral temperature, which enhances the neutral density at constant heights.

• Electric field variability changes the distribution of Joule heating significantly, and can introduce interhemispheric asymmetries (Codrescu et al., 1995, 2000).



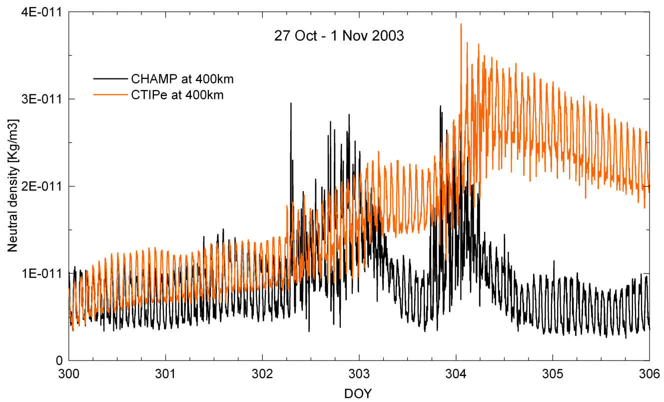


R= 0.88
RMSE= 0.17
BIAS= -0.017
SD= 0.17

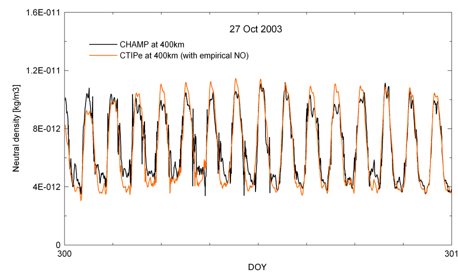
Improved NO cooling at high Kp for recovery time-scale
CHAMP vs CTIPe: 27 Oct – 01 Nov 2003

Halloween Storm (2003)

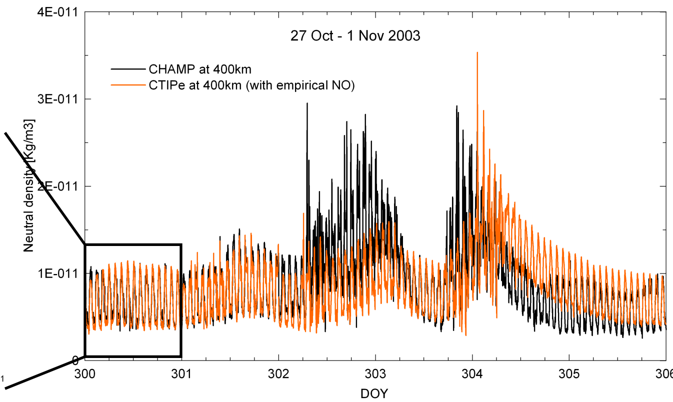
Before empirical NO



CTIPe is sampled along the CHAMP orbit



After empirical NO



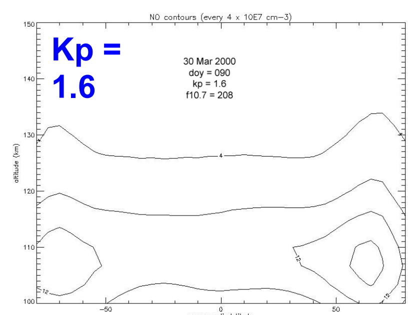
Empircal NO model: Marsh et al. 2004

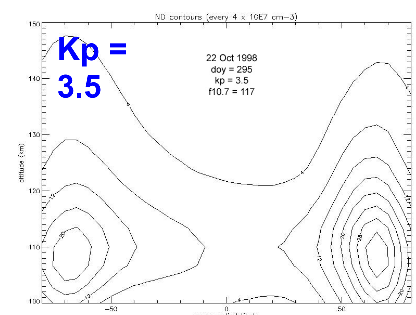
- Based on over 2.5 years of measurements from the Student Nitric Oxide Explorer (SNOE) scientific satellite
- Lower thermosphere (100-150km)
- EOFs
- Dependent on EUV, season, auroral activity, height, and latitude
- Limited to K_p of 5, extrapolated to K_p 9

NO Contours

150 km

100 km



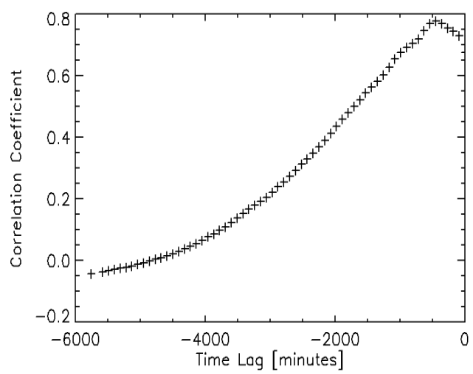


CTIP Joule heating index for satellite drag

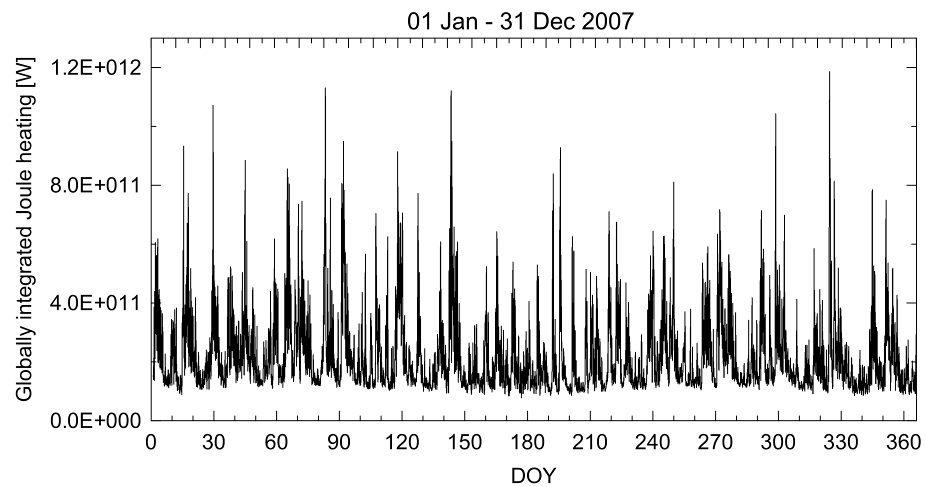
Fedrizzi et al. (Space Weather, 2012)

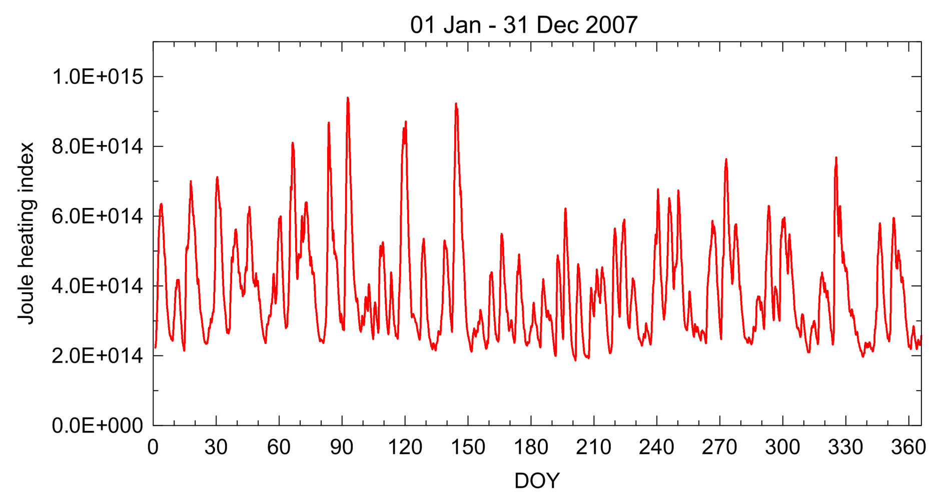
INPUT
(Joule heating)

IMPULSE RESPONSE (shaping filter)



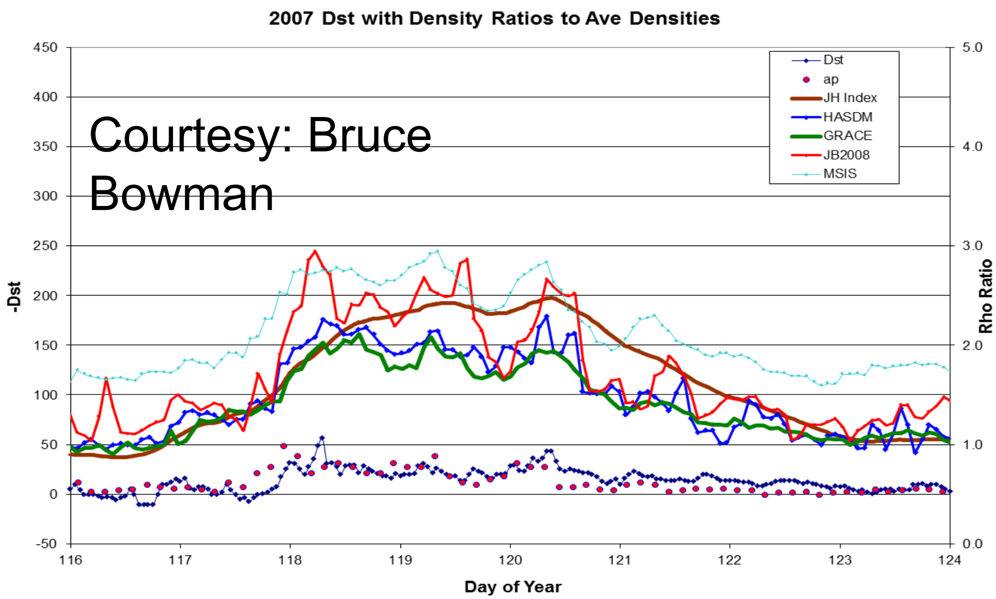
OUTPUT
(Joule heating index)

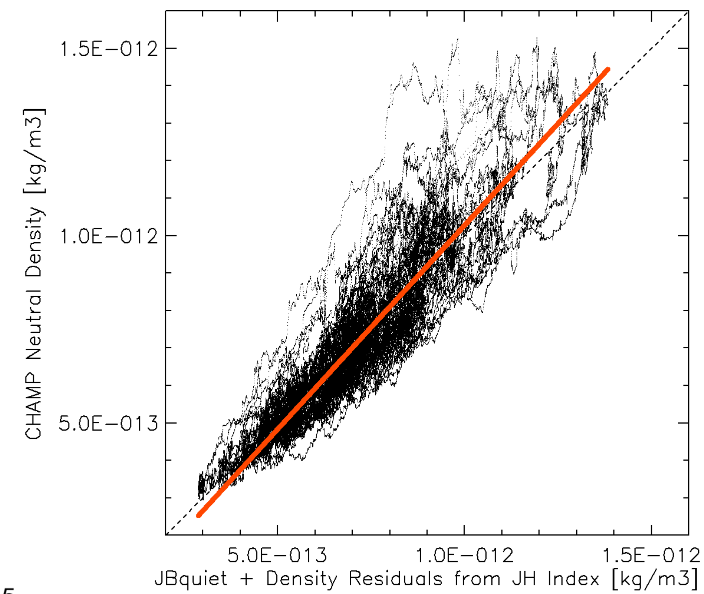


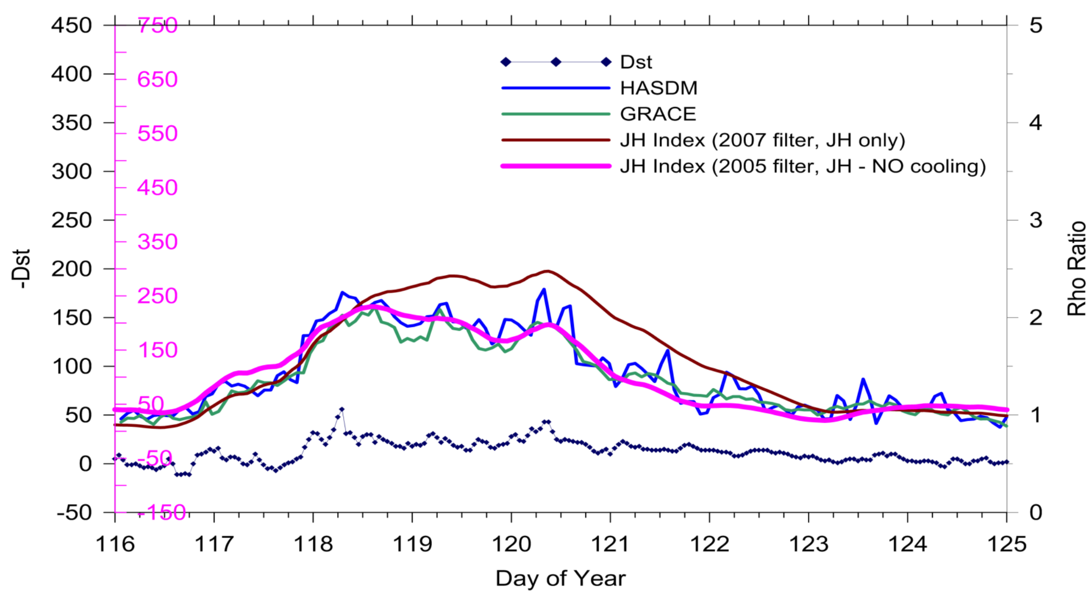


• Convolution of CTIPe Joule heating with the shaping filter results in a new parameter (Joule heating index) representing the integral of the product of the two functions.

CTIPe Joule heating Index Test







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

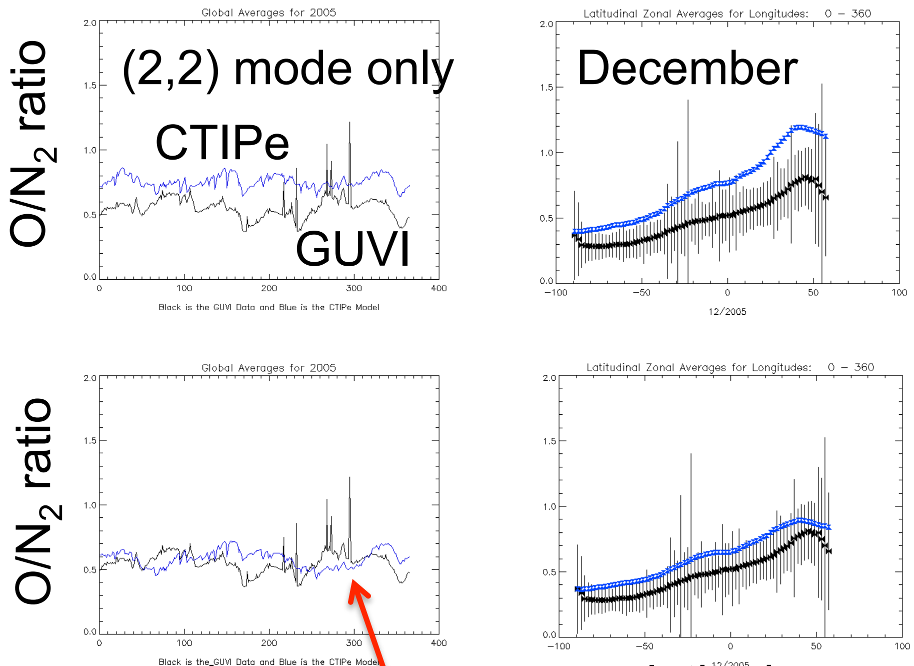
JH Index derived from CTIPe run with NO high K_p scaling factor matches HASDM

Impact of spectrum of tides

Impact of increasing the spectrum of tides in CTIPe on O/N_2 ratio (Olsen et al., 2013)

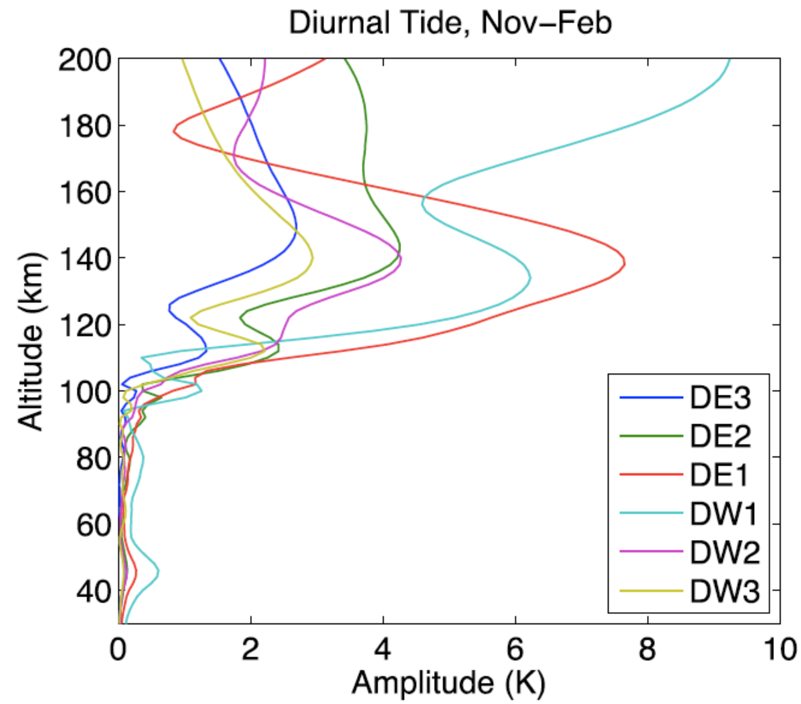
global mean

latitude structure



day no.

latitude

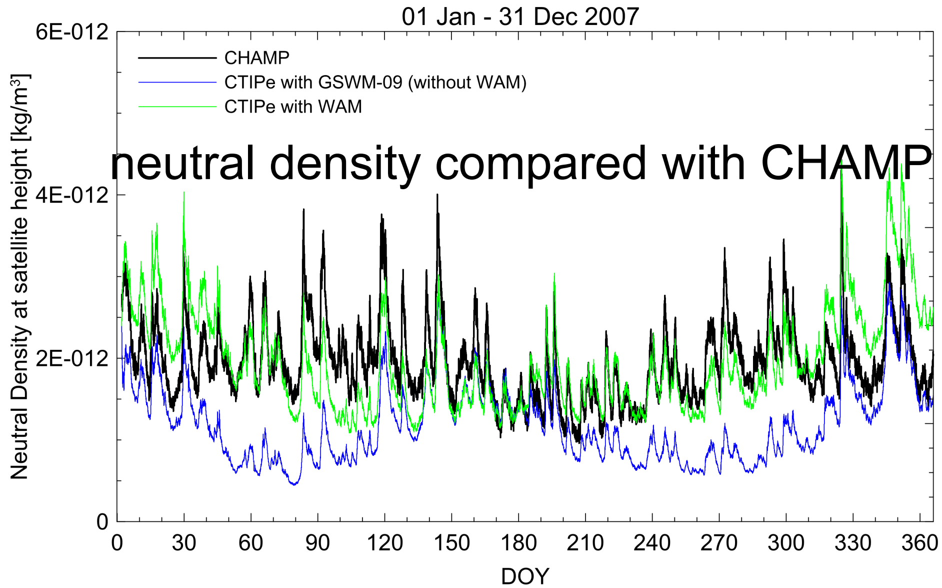


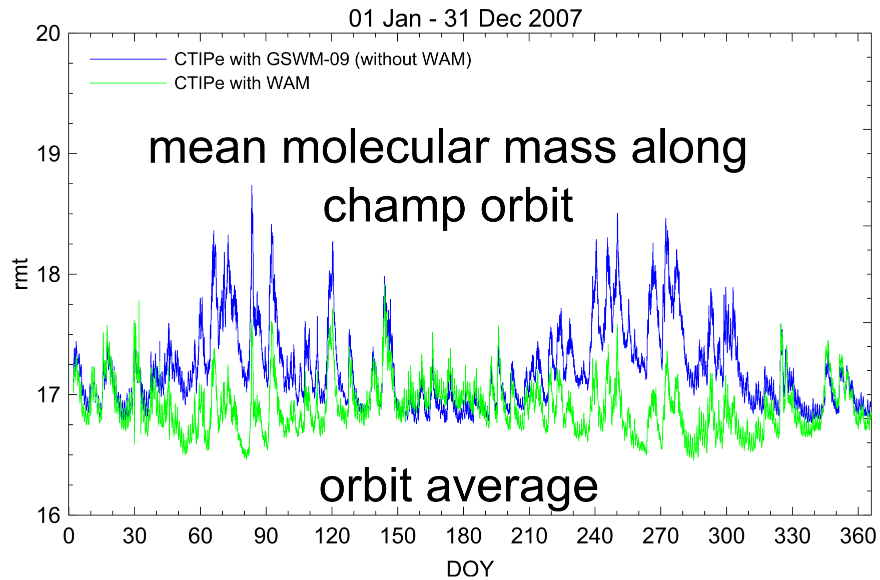
Uses (1,1), (2,2), (2,3), (2,4) and (2,5) modes from Global Scale Wave Model-09 (GSWM-09) Maura Hagan

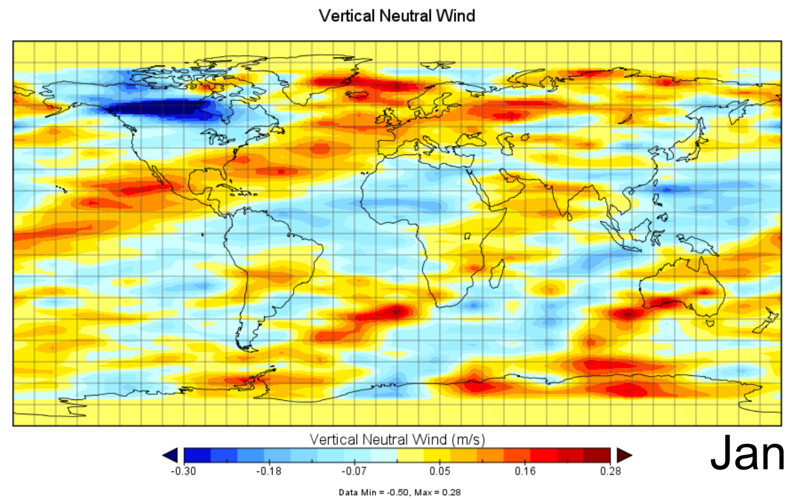
Spectrum is actually much richer in WAM, and many of the tidal modes peak in the lower thermosphere: What is the impact of imposing monthly mean WAM dynamics?

Note: Siskind et al., (2013) showed that you could reduce K_z by a factor of 5 when the NOGAPS spectrum of migrating and non-migrating tides were introduced into TIEGCM

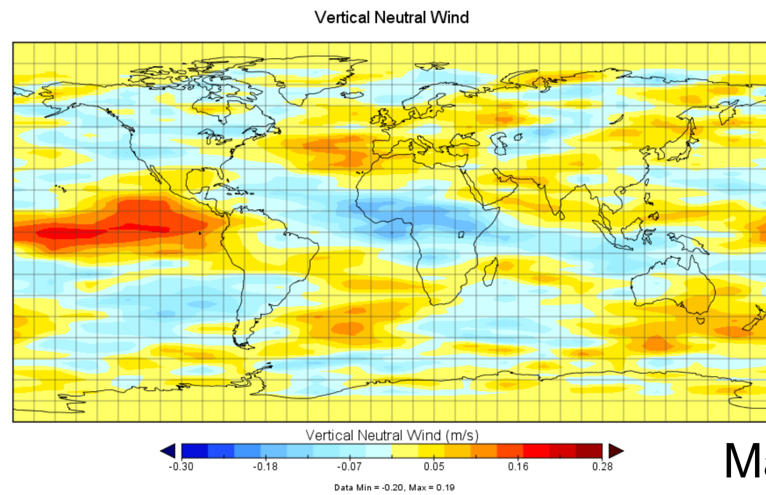
CTIPe driven by WAM
monthly mean spectrum of tides



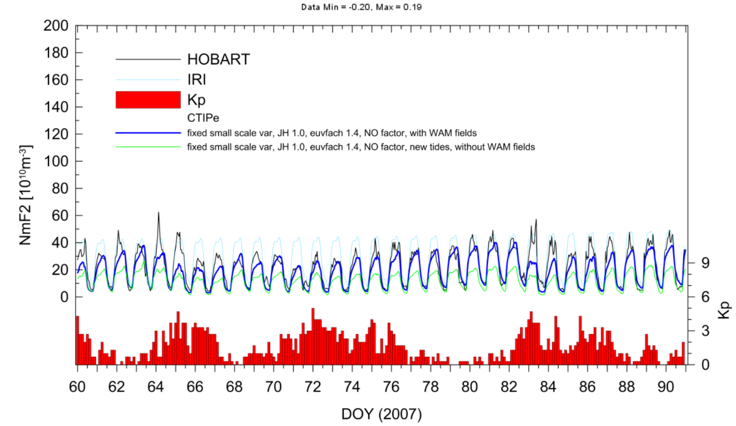




January

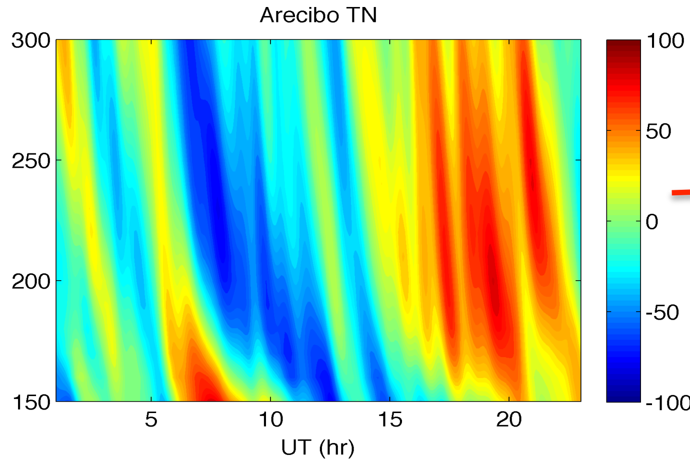


March

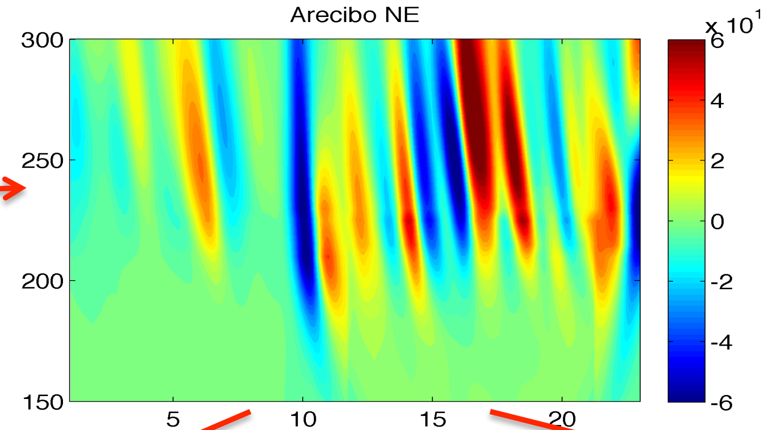


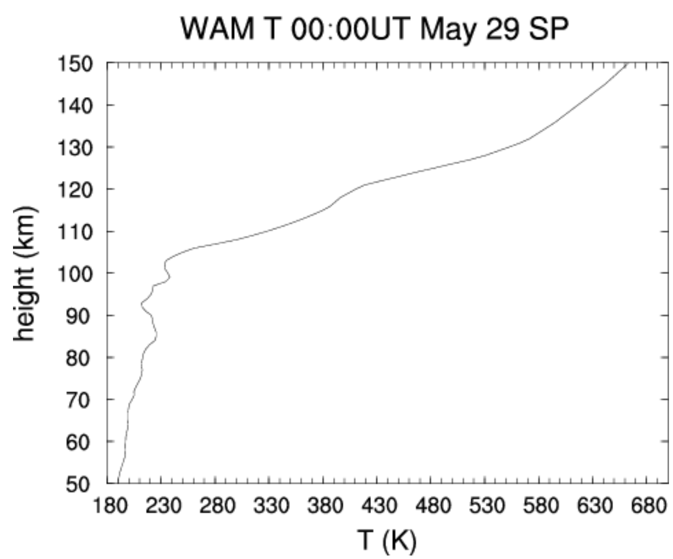
WAM 3-minute temporal resolution driving CTIPe Arecibo plasma density variations

WAM temperature at Arecibo

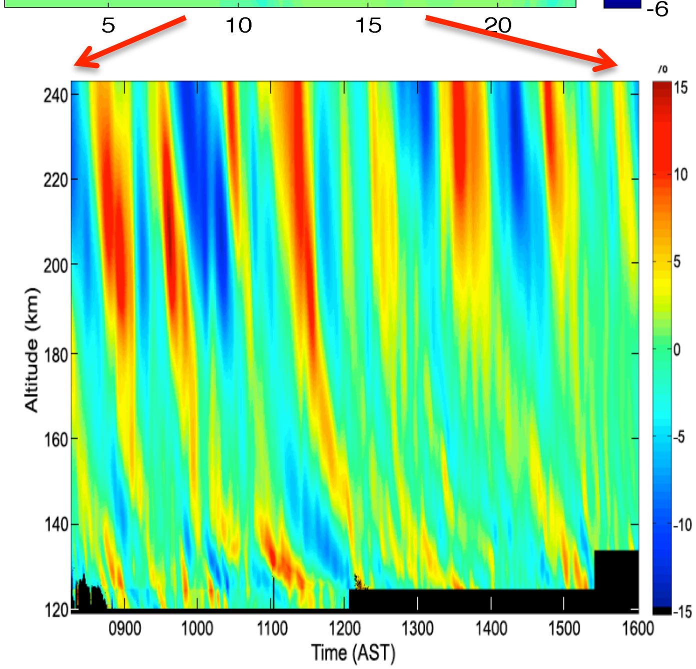


WAM-CTIPe plasma density at Arecibo



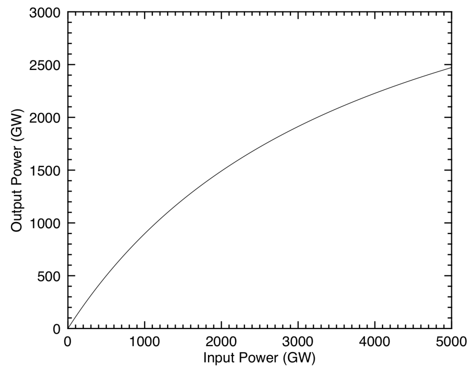


WAM-CTIPe model

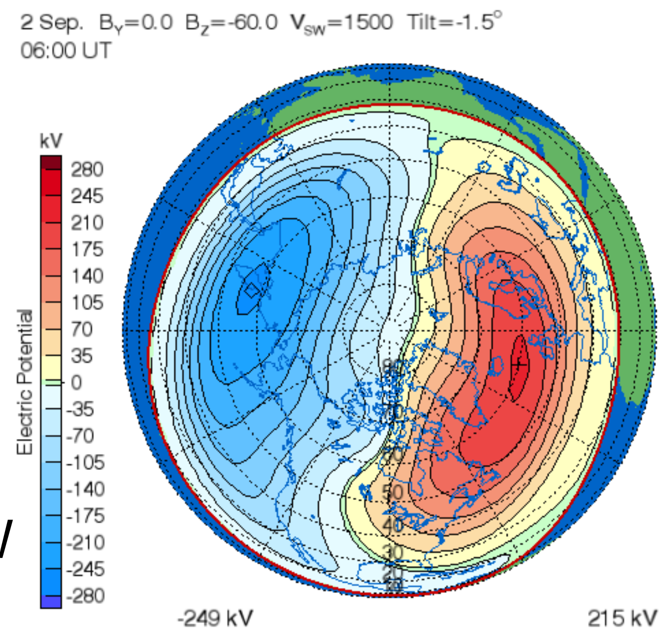


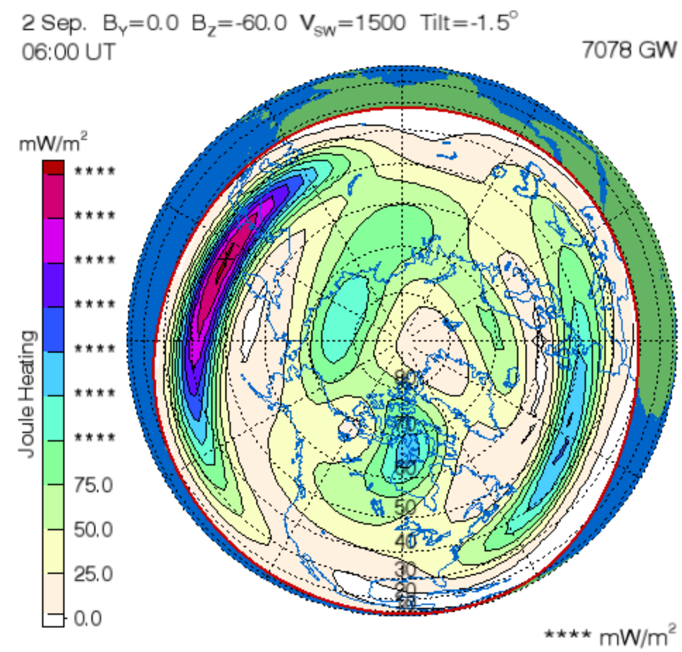
ISR observations of N_e perturbations, Djuth et al.

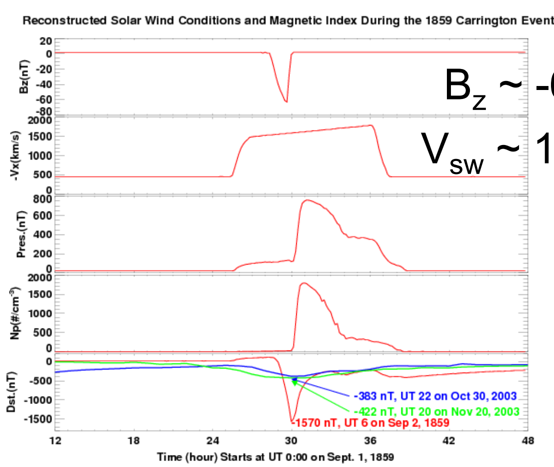
CTIPe Robustness test: simulation of a Carrington-type event
Weimer empirical magnetospheric convection predictions



Power reduced by saturation to 3000 GW







B_z ~ -60 nT

V_{sw} ~ 1800 km/s

Predicts the aurora over Cuba
CPCP ~450kV, Joule heating/Poynting flux estimated to be 7000 GW in each hemisphere, reduced to 3000 GW by magnetospheric saturation

Temerin and Li [2002] & Li et al.[2006]

CTIPe Joule Heating: location of energy injection is consistent with auroral observations

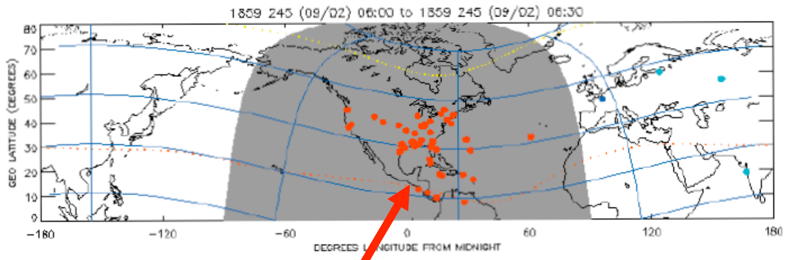
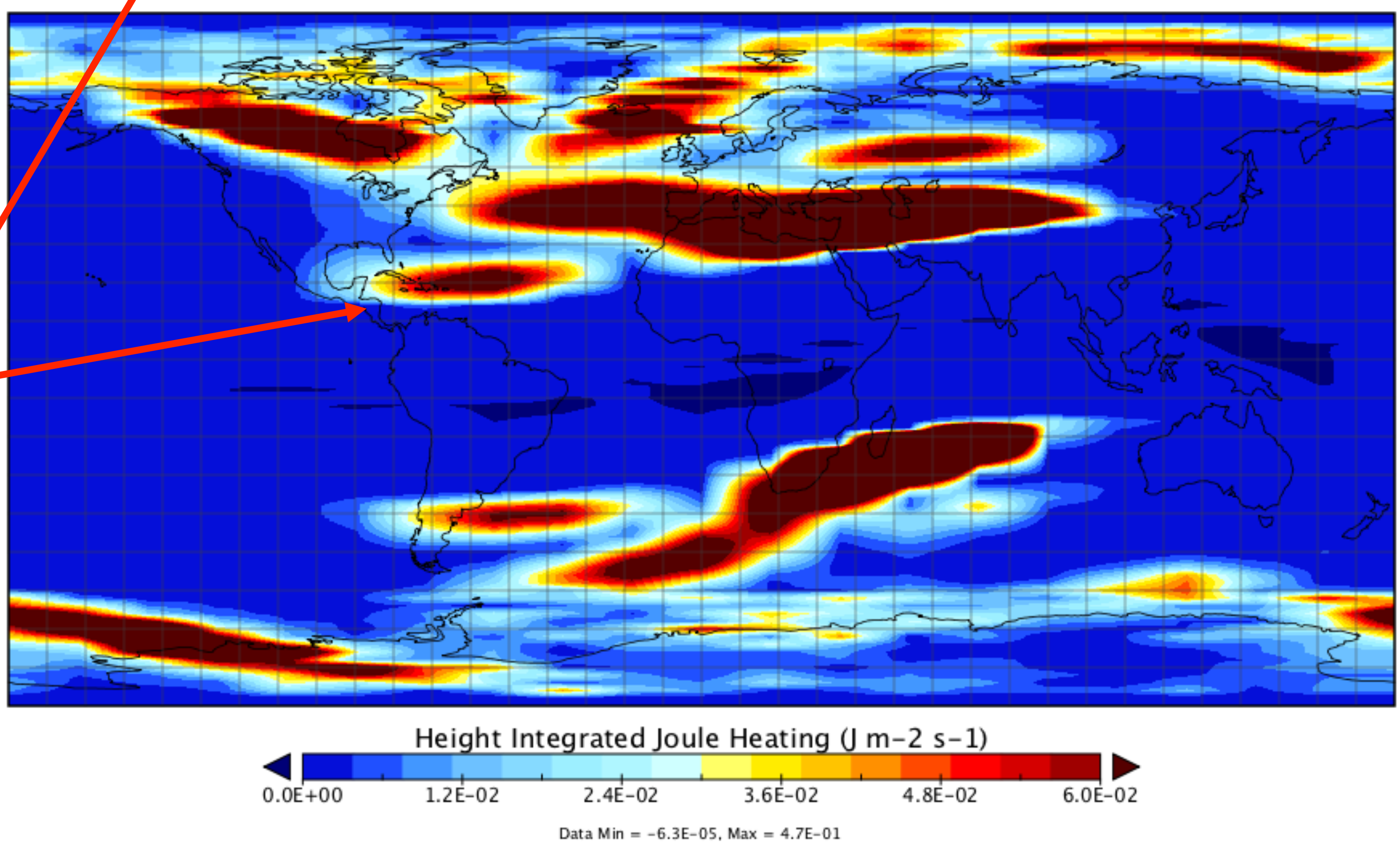
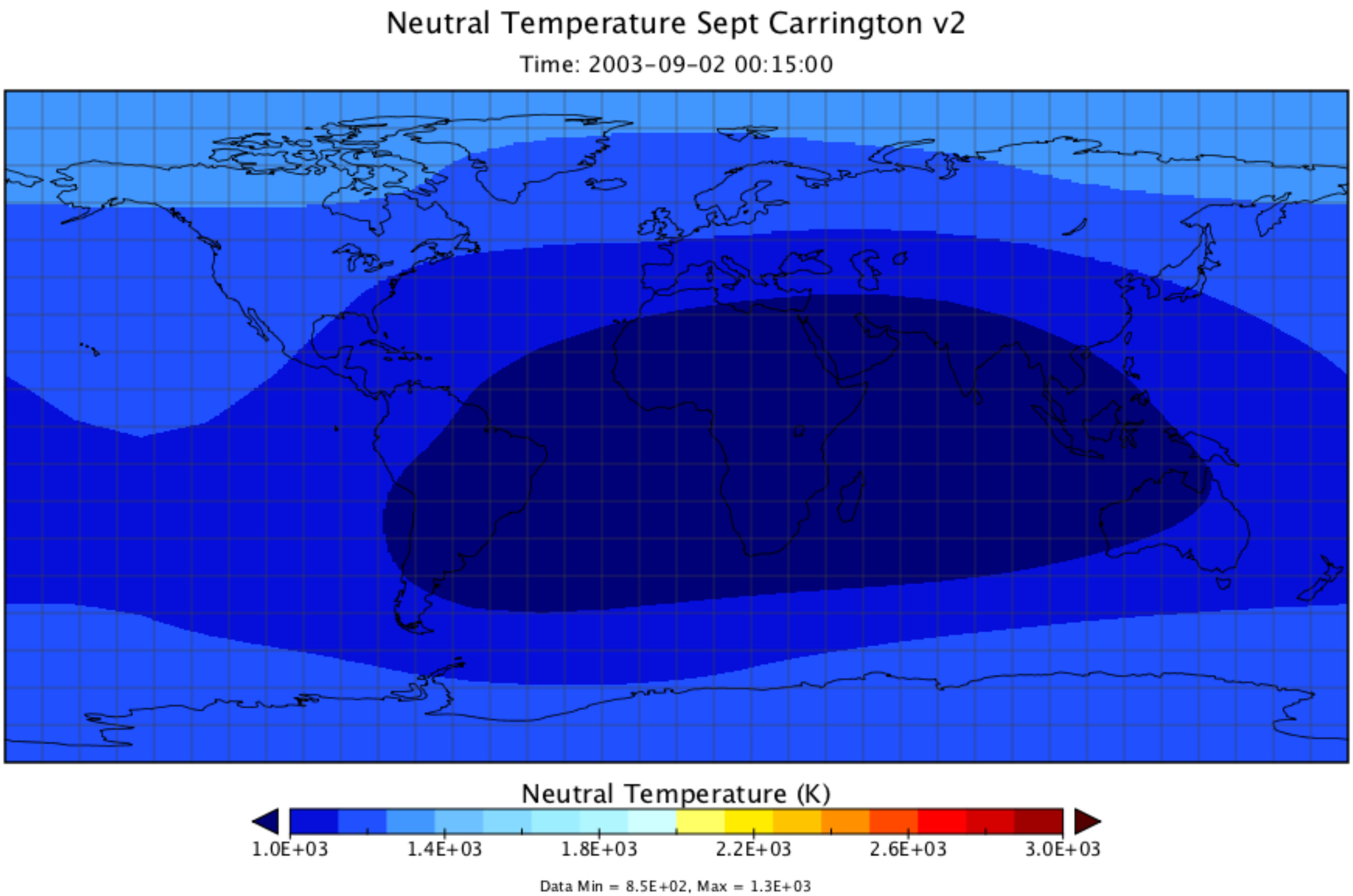


FIGURE 1.2 Locations of reported auroral observations during the first ~1.5 hours of the September 2, 1859, magnetic storm (orange dots). Courtesy J.L. Green, NASA

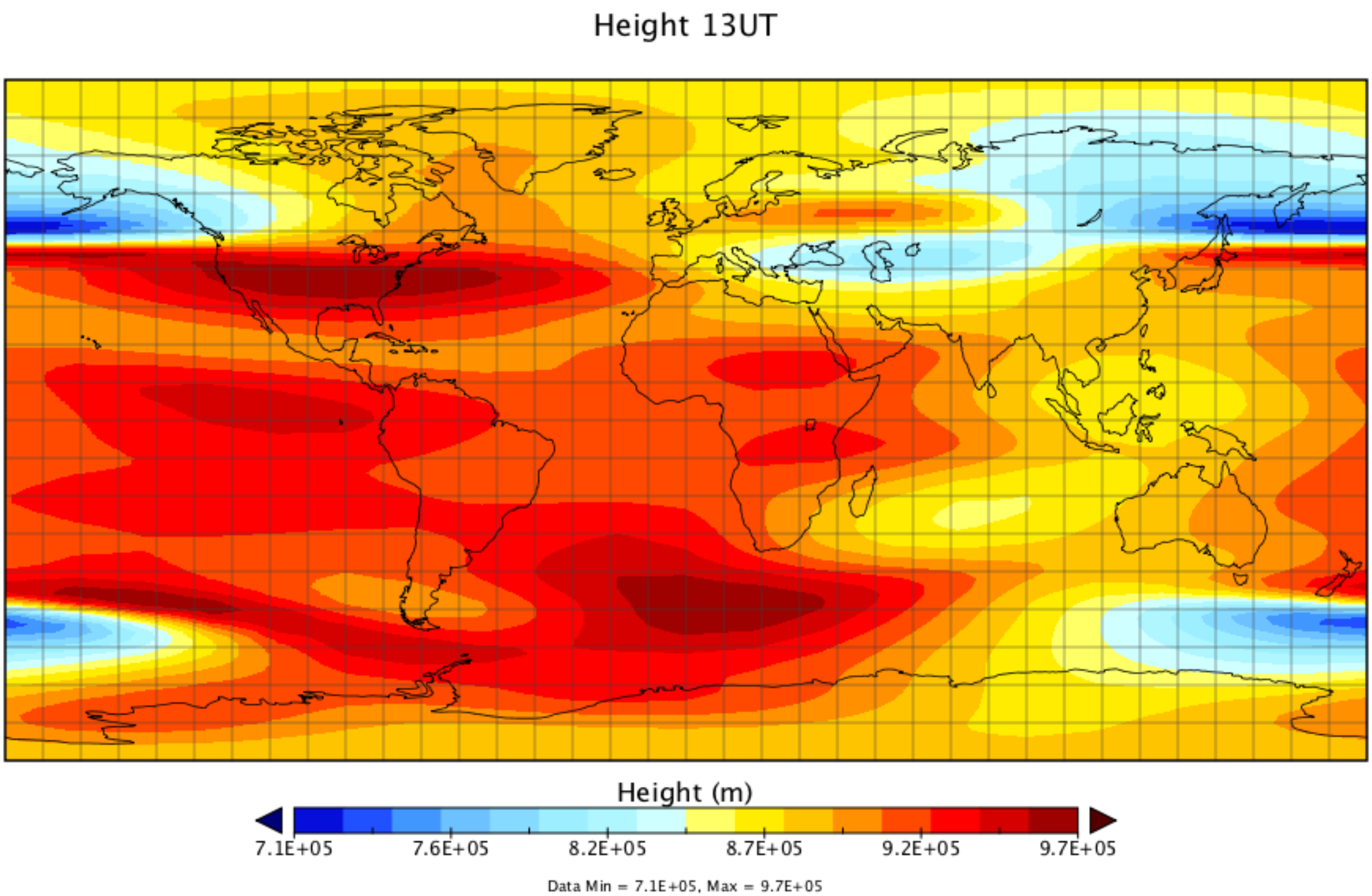
Height Integrated Joule Heating



Neutral temperature can exceed 3000K

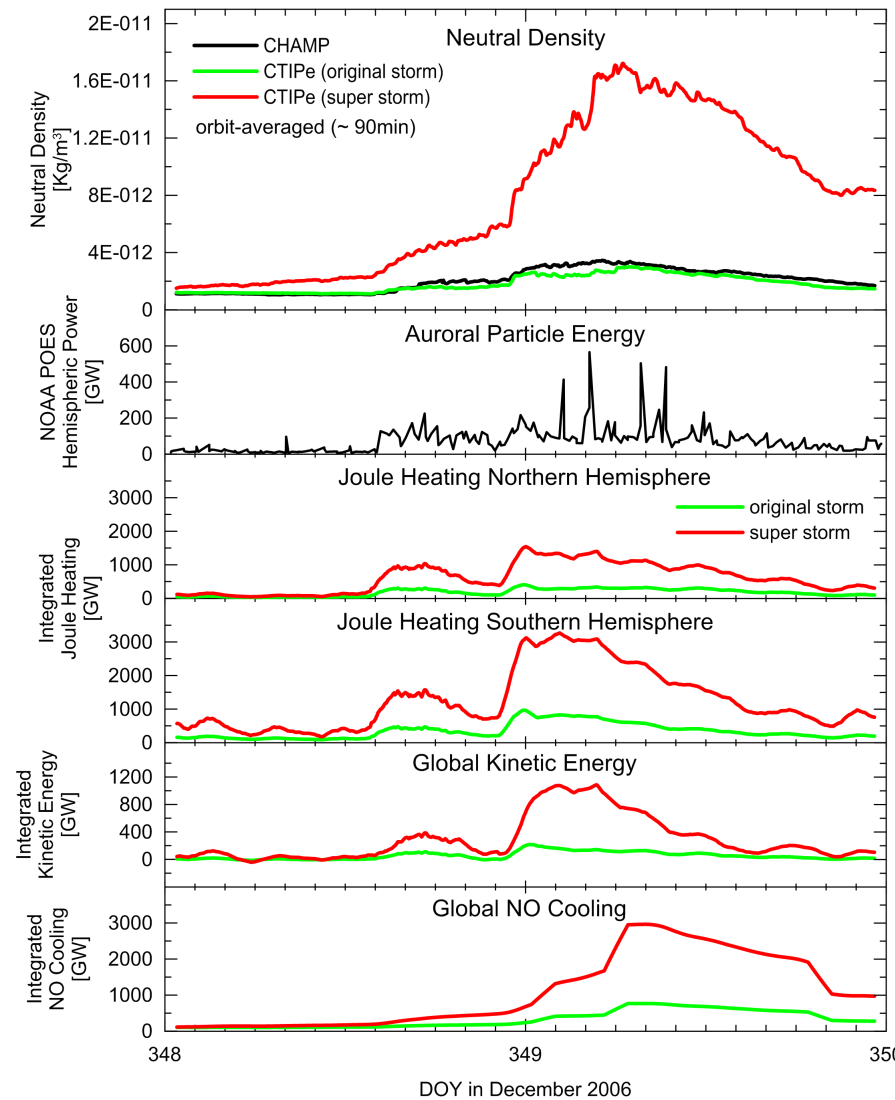


Top of model rises from 500 to ~1000 km



CTIPe Response to a Carrington-type Event

- CTIPe model response to a Carrington-type storm is robust
- Model can withstand large increase in Joule heating (~6000 GW), temperature increases of ~3000 K, peak neutral winds (>1500 m/s), strong vertical winds (+/-150 m/s), and 5 times density response at low Earth orbit

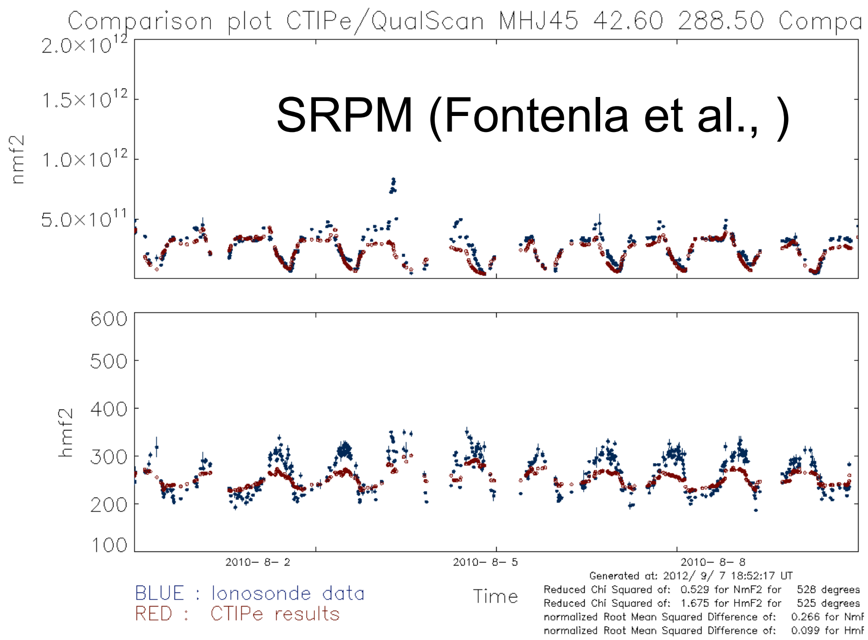


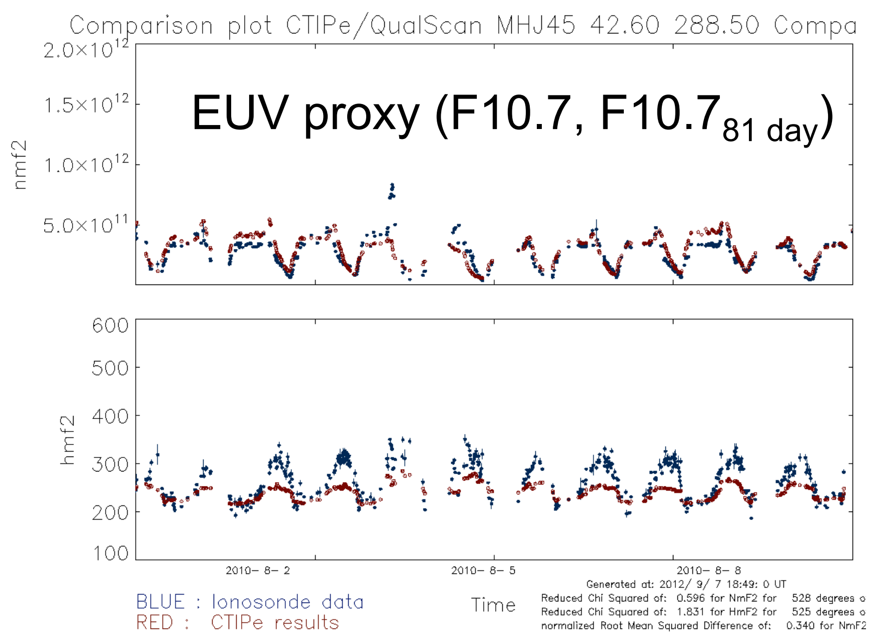
Mihail Codrescu, NOAA-SWPC

Real-time CTIPe

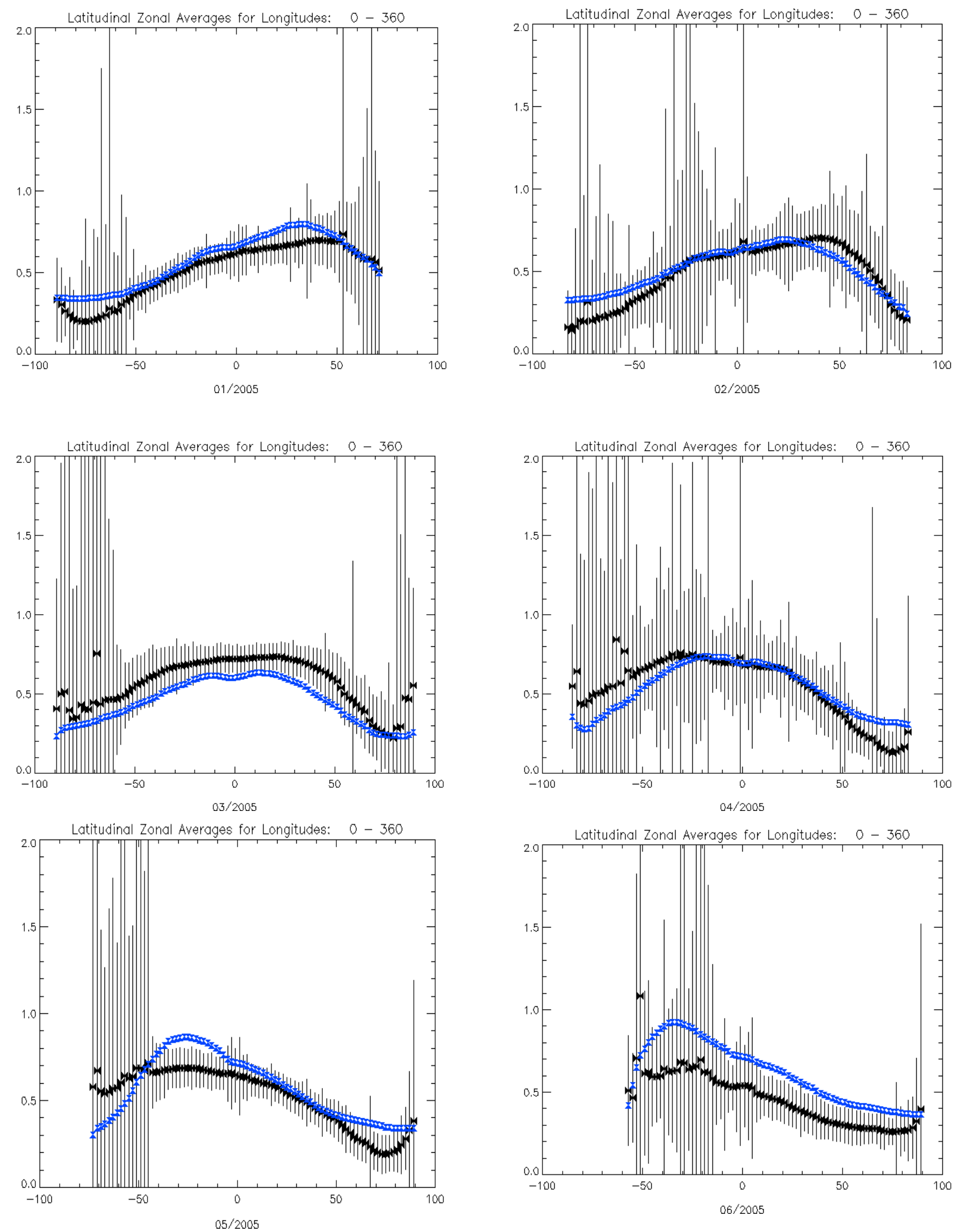
- Implemented in 2010 in test operational mode
- Automated scripts extract solar wind data from operational database
- ACE measurements of IMF, solar wind (SW) velocity and density, and either solar F10.7 or EUV flux to force the global circulation model
- Due to the 30 minute propagation time of SW to the nose of the magnetosphere it provides a 10-20 minute forecast
- Web page shows neutral temperature, electron density, mean molecular mass, nmF2, hmF2, TEC, and model inputs in a quick look format
- Runs 100 times faster than real time (run once, sample 3-D density field)
- Can use SRPM EUV solar radiation forecast and WSA-ENLIL solar wind forecast for prediction
- Automated validation and comparison with GAIM, US-TEC, DLR, etc.
- Can provide Joule heating index for JB2008 in real-time
- http://helios.swpc.noaa.gov/ctipe/CTIP.html
- Mihail testing prototype of ¼ scale height vertical resolution

NmF2 and hmF2 against MH ionosonde





O/N_2 ratio compared with TIMED-GUVI

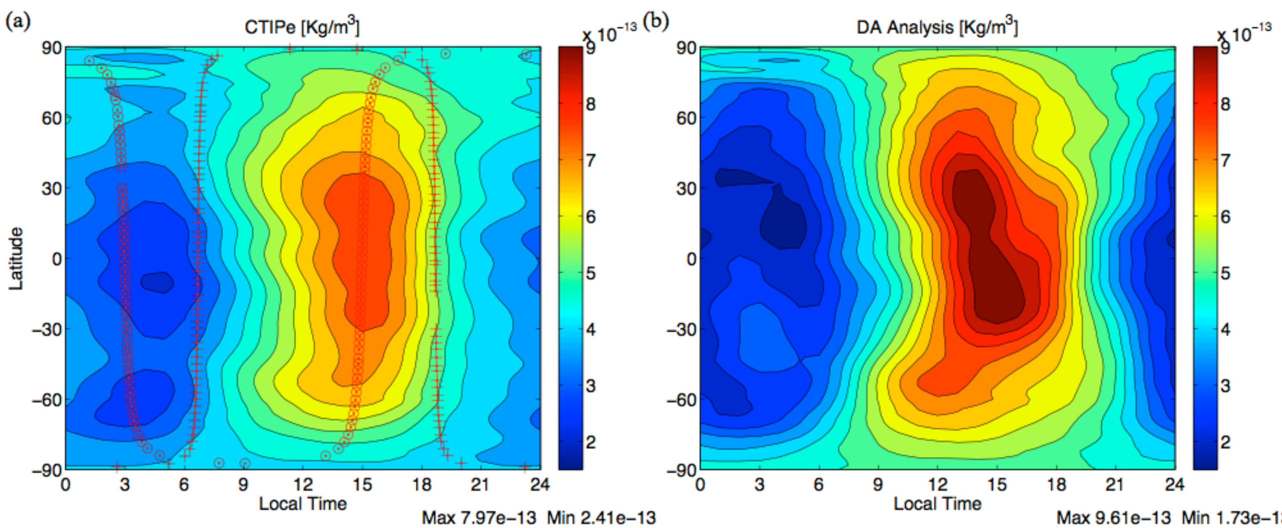


Data Assimilation (Tomoko Matsuo)

Optimal interpolation using CTIPe with maximum-likelihood covariance estimate of the neutral density improves the density specification up to 40-50 % in comparison to CTIPe predictions [Matsuo et al., SW, 2012].

Low-dimensional covariance is built with EOFs to describe large-scale correlation succinctly [Matsuo and Forbes, JGR, 2010; Lei et al., JGR, 2012].

Currently, the analysis is limited to 400km.



Application to real-time CTIPe (STTR)

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- Impact of small-scale spectrum of waves
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- Real-time CTIPe and 0.25 scale height version
- New EUV and UV drivers: SRPM and SDO
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- New ionosphere: IPE; Coupling to RCM (Naomi Maruyama)