How Would the Thermosphere and Ionosphere Respond to an Extreme Space Weather Event and How Would we Validate the Modeled Response

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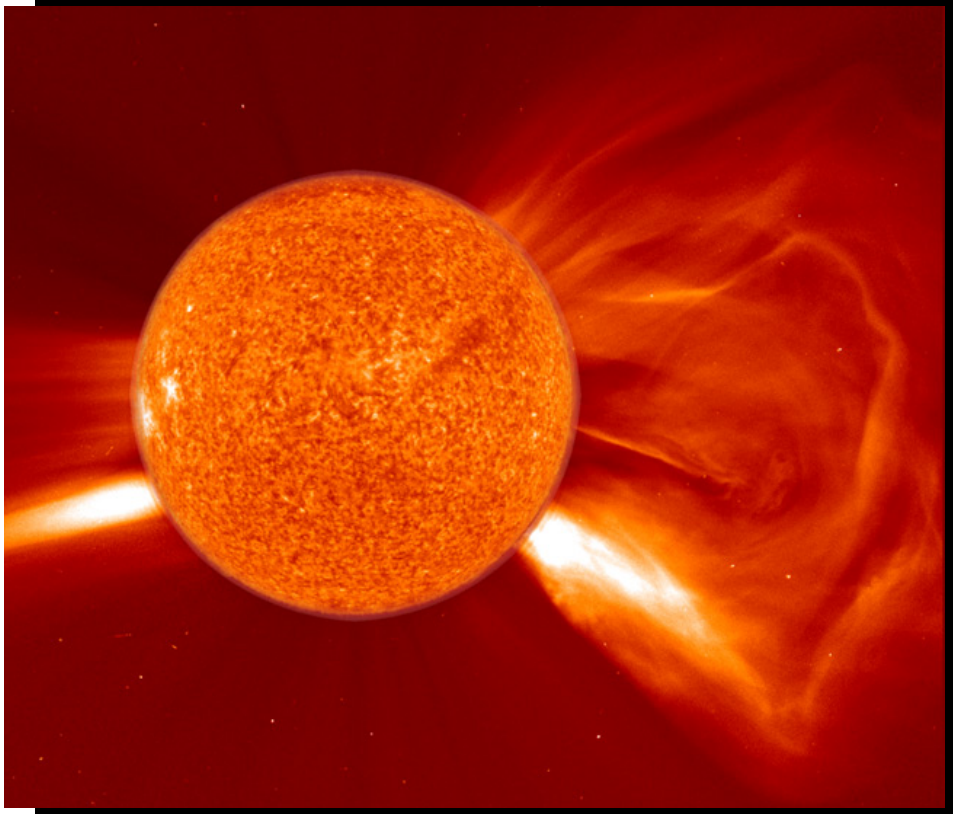
Modeling extreme events



- What would be the impact of a Carrington type event on the geospace system?
- Would our thermosphere-ionosphere-magnetosphere models be about to cope?
- Do the physical processes in the model operate in the same way during an extreme event, do they become more non-linear?
- Are there new physical processes we will need to accommodate and understand?
- How do we validate extreme events?

What is it we care about in thermosphere-ionosphere space weather impacts on operational system?

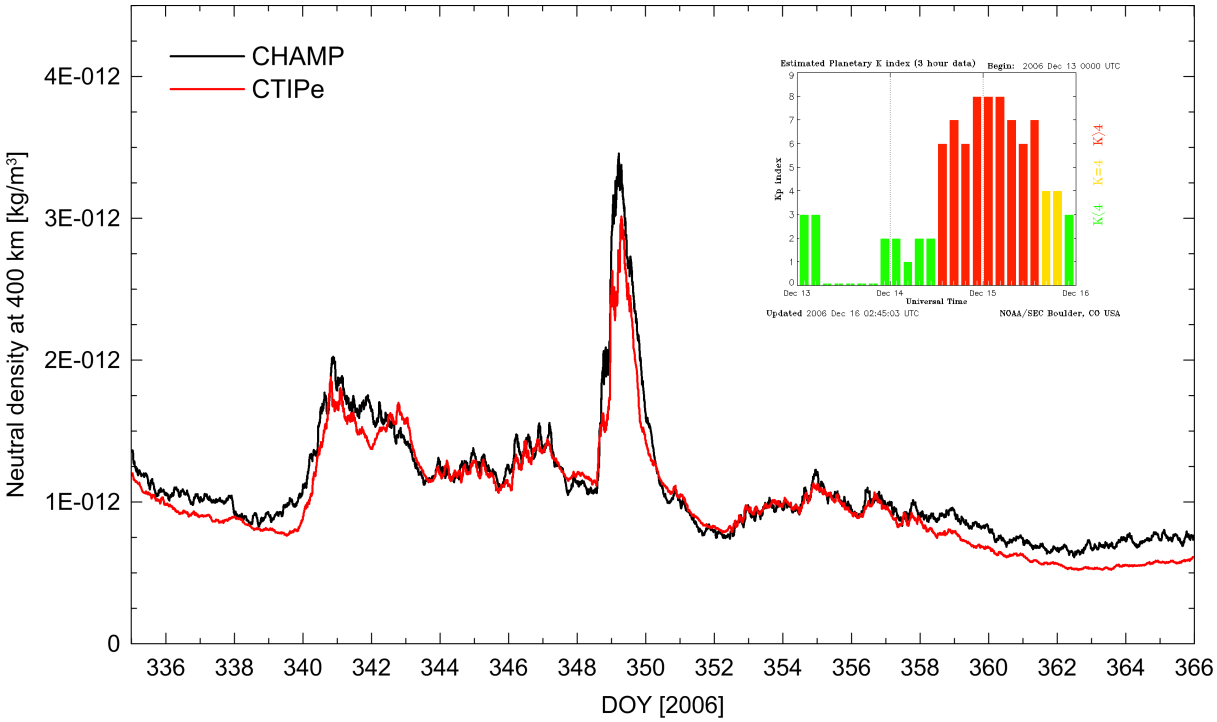
Change in drag on a satellite for orbit prediction, collision avoidance, etc.

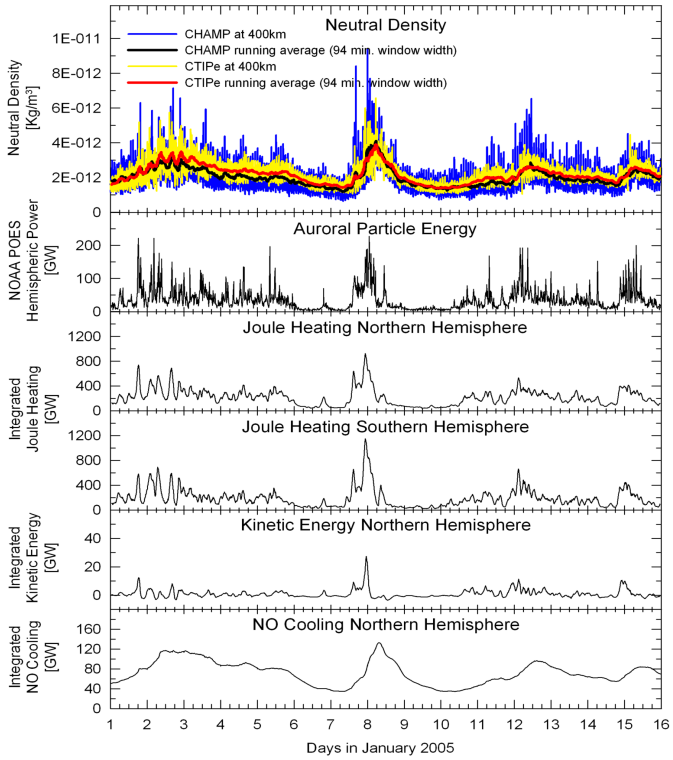
- Driven by neutral atmosphere heating, thermal expansion, in-track winds, neutral composition, NO cooling, wave propagation

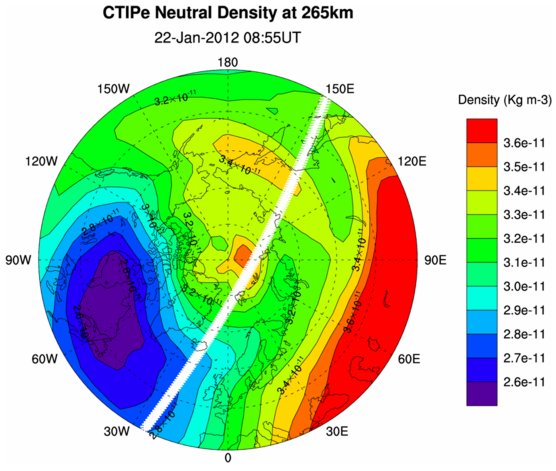
Changes in the ionosphere affect communications, navigation, positioning, which impacts a range of industries: commercial aviation, maritime, surveying, agriculture, etc.

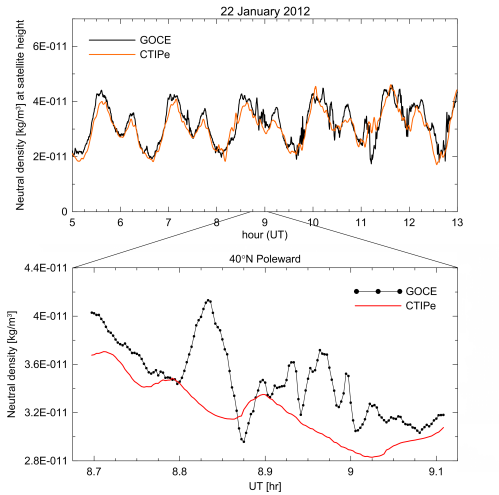
- Driven by expansion of polar cap and magnetospheric convection, plasmasphere erosion, auroral ionization, penetration electric fields to low latitudes, dynamo electric fields, and interaction with the neutral atmosphere winds and composition,

CTIPe vs CHAMP or GOCE







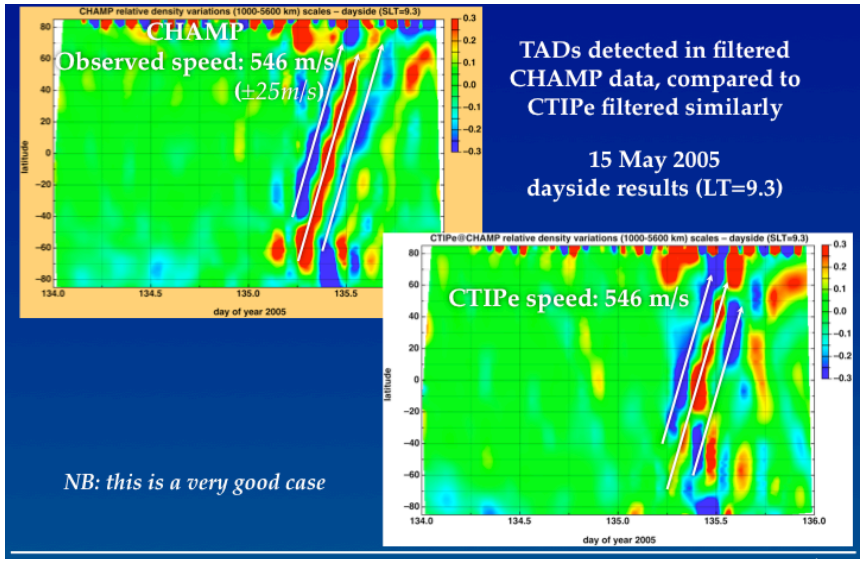


What would this density response look like during a Carrington event?

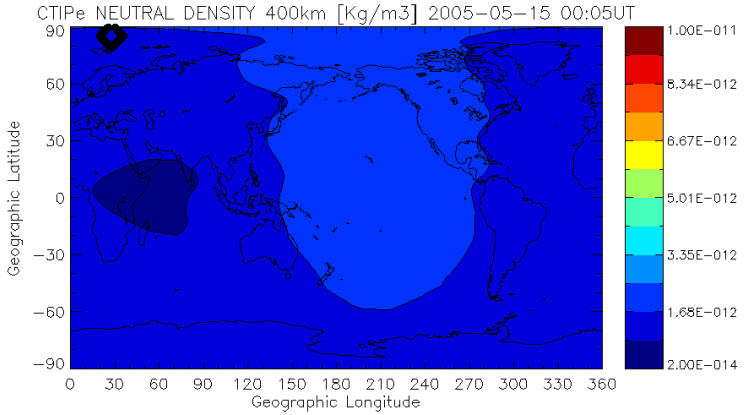
Gravity wave propagation from high to low latitude

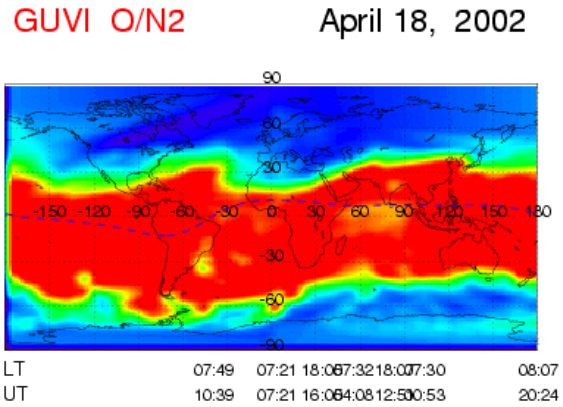
What speed and wave amplitudes of waves can we expect?

e.g., CHAMP density waves.
Can be a complicated superposition.



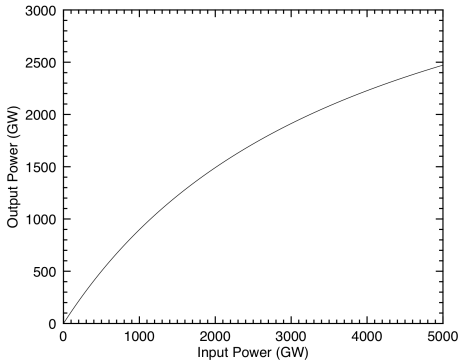
Bruinsma, Fedrizzi, et al.



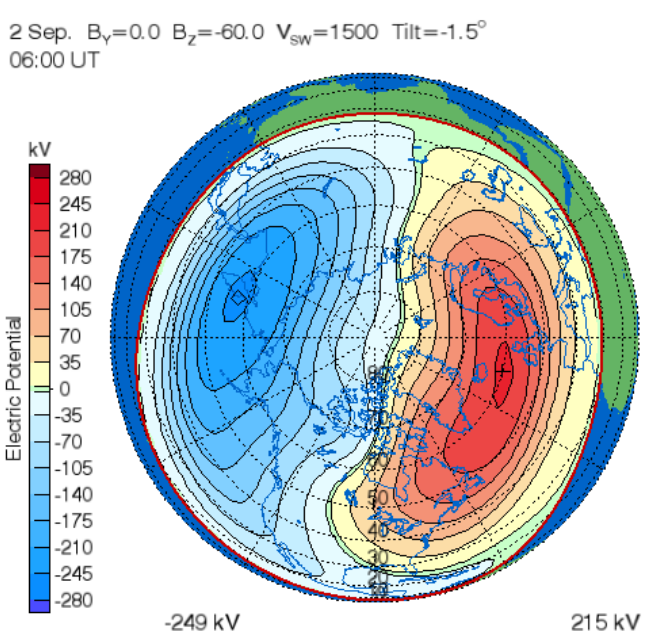


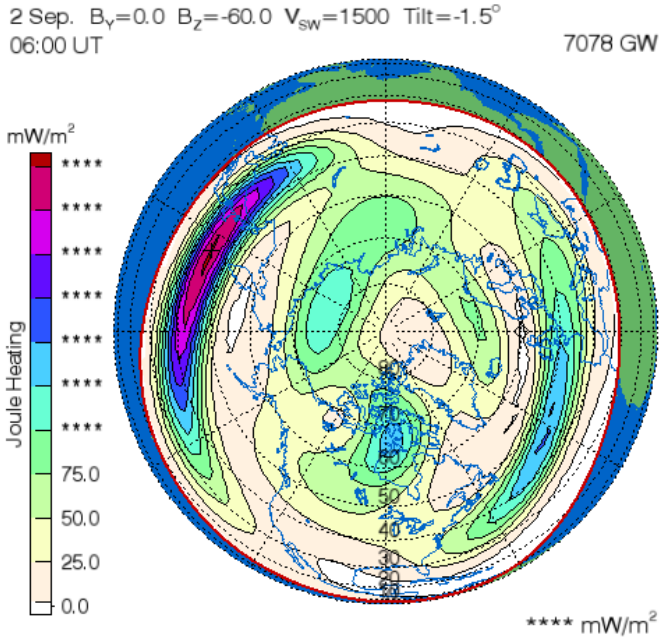
How will the global circulation evolve, neutral composition change, and the ionospheric "negative phase"

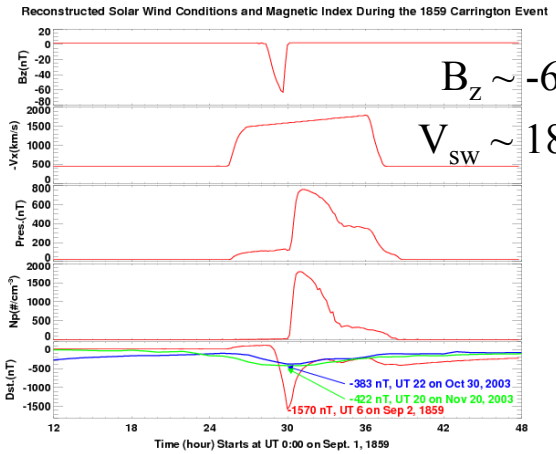
Weimer empirical magnetospheric convection predictions for Carrington event



Power reduced by saturation to 3000 GW







B_z ~ -60 nT

V_{sw} ~ 1800 km/s

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

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

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

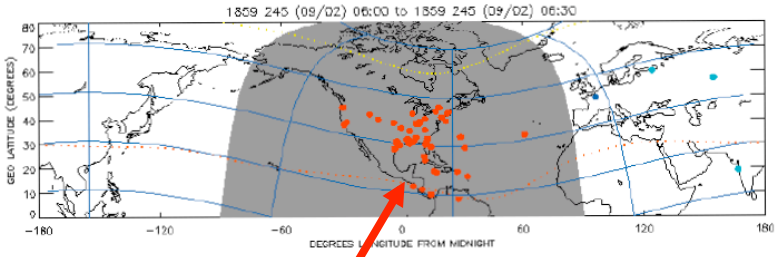
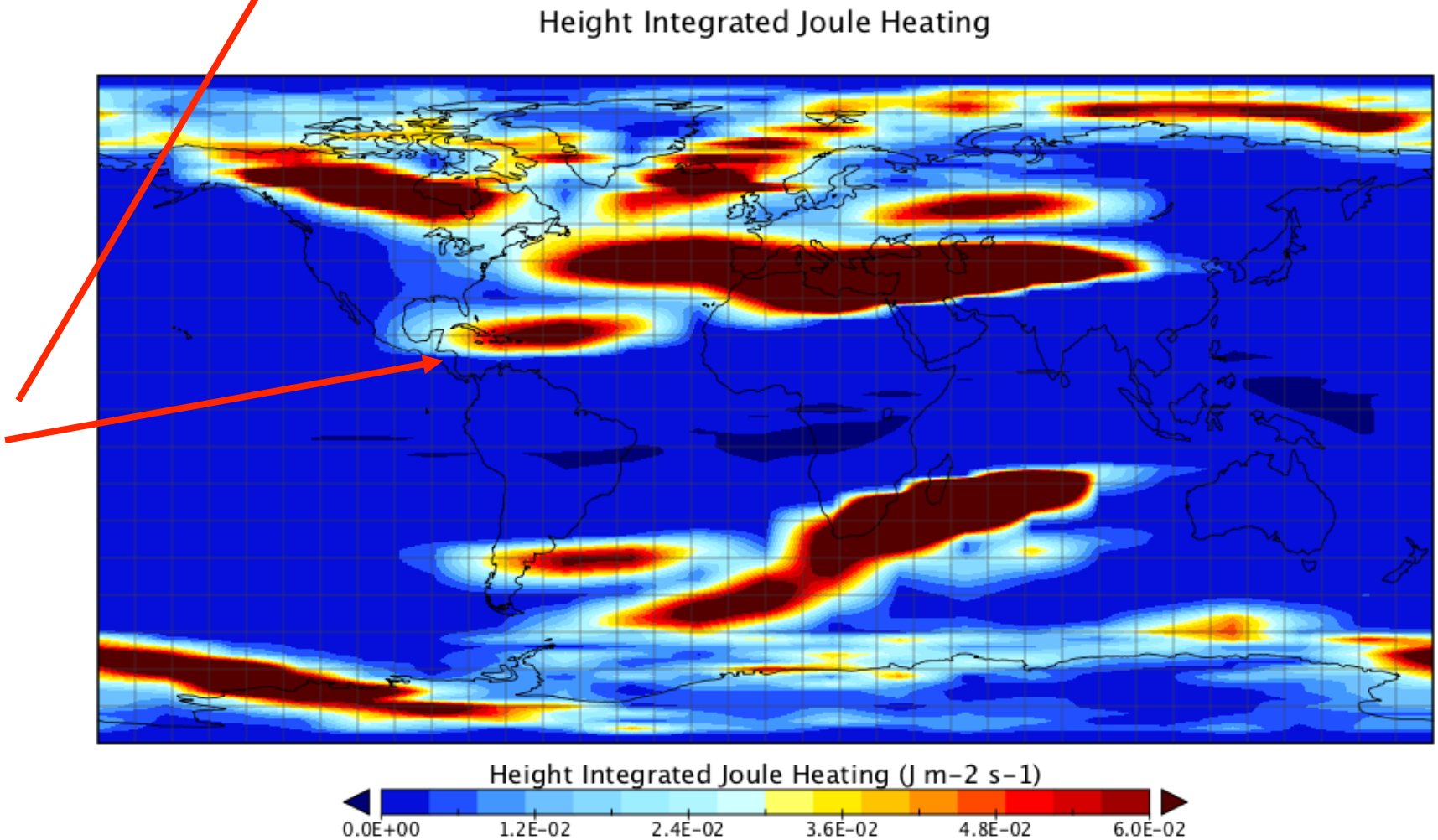


FIGURE 1.2 Locations of reported auroral observations during the first ~1.5 hours of the September 2, 1859, magnetic storm (orange dots). Courtesy J.L. Green, NASA



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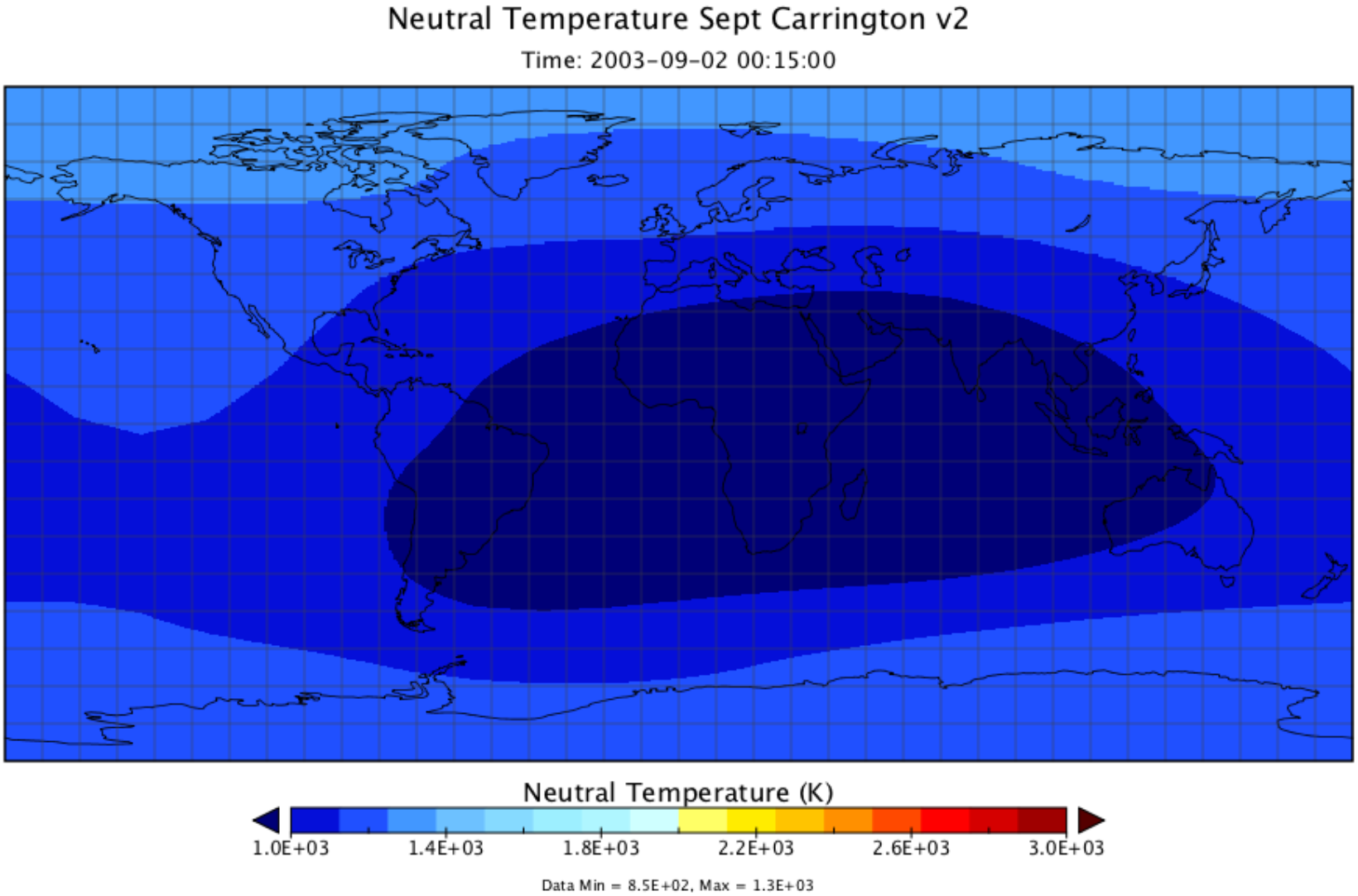
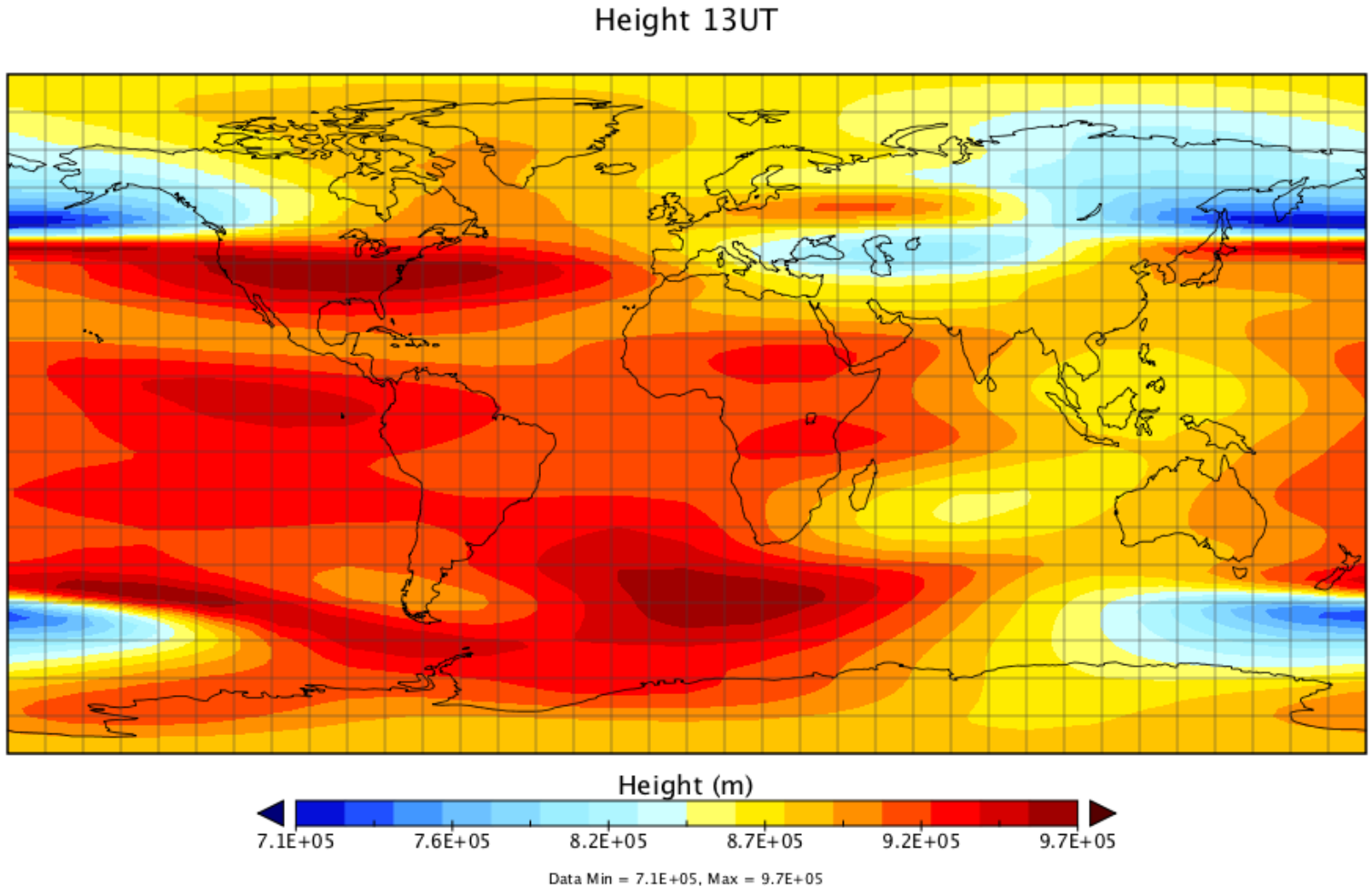
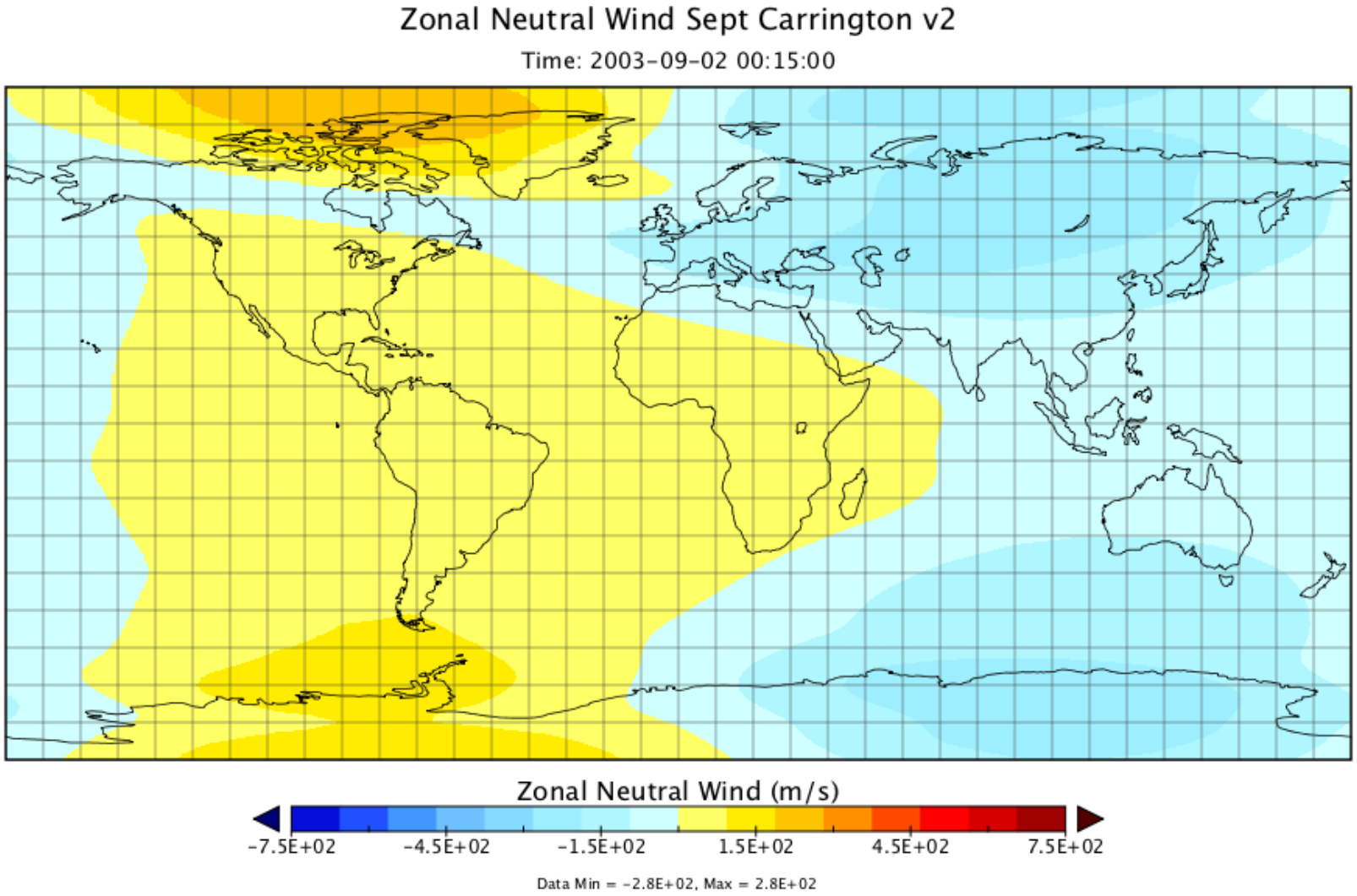
Peak temperature > 3000 K



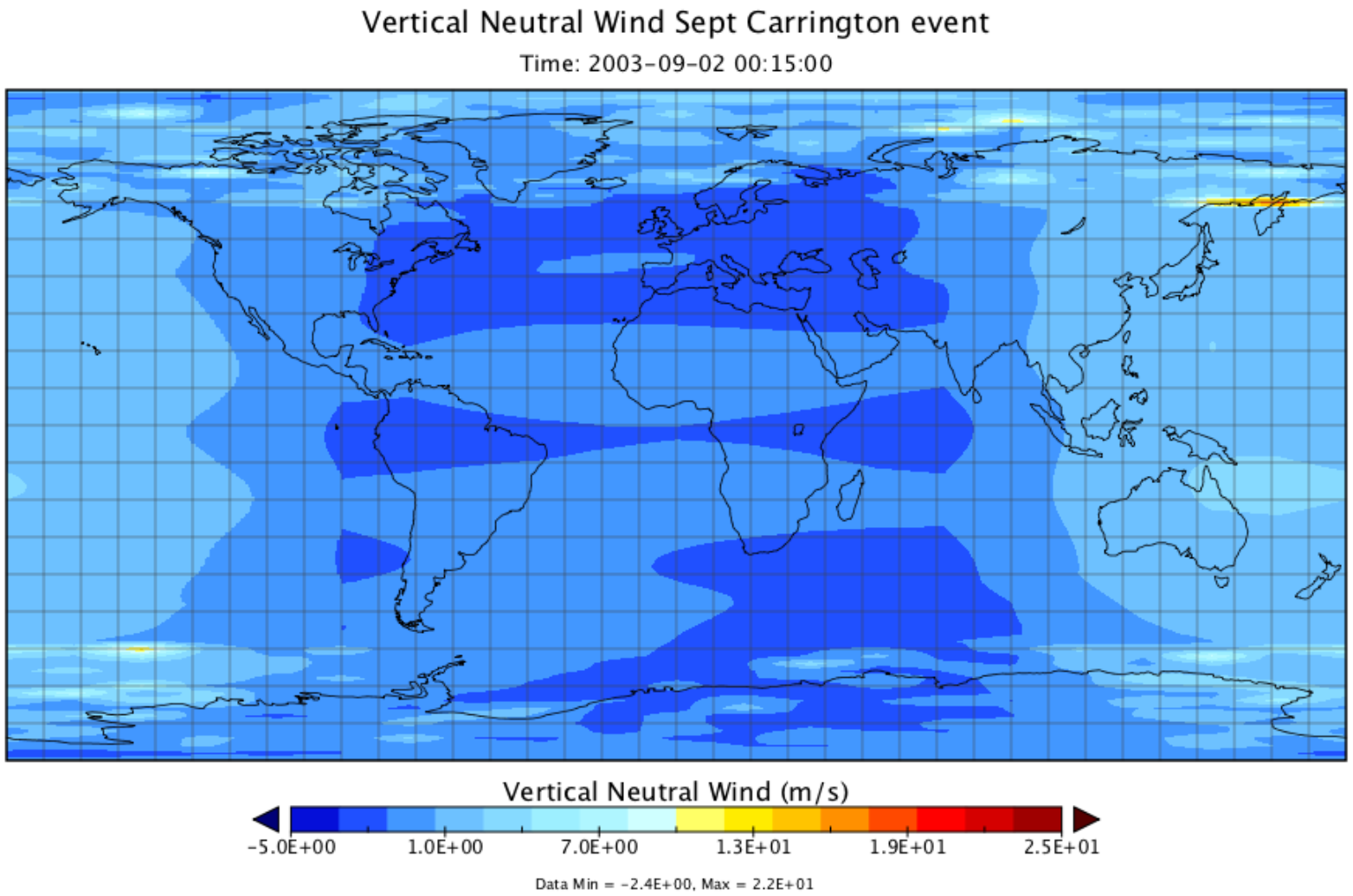
Top of model rises from 500 to ~1000 km



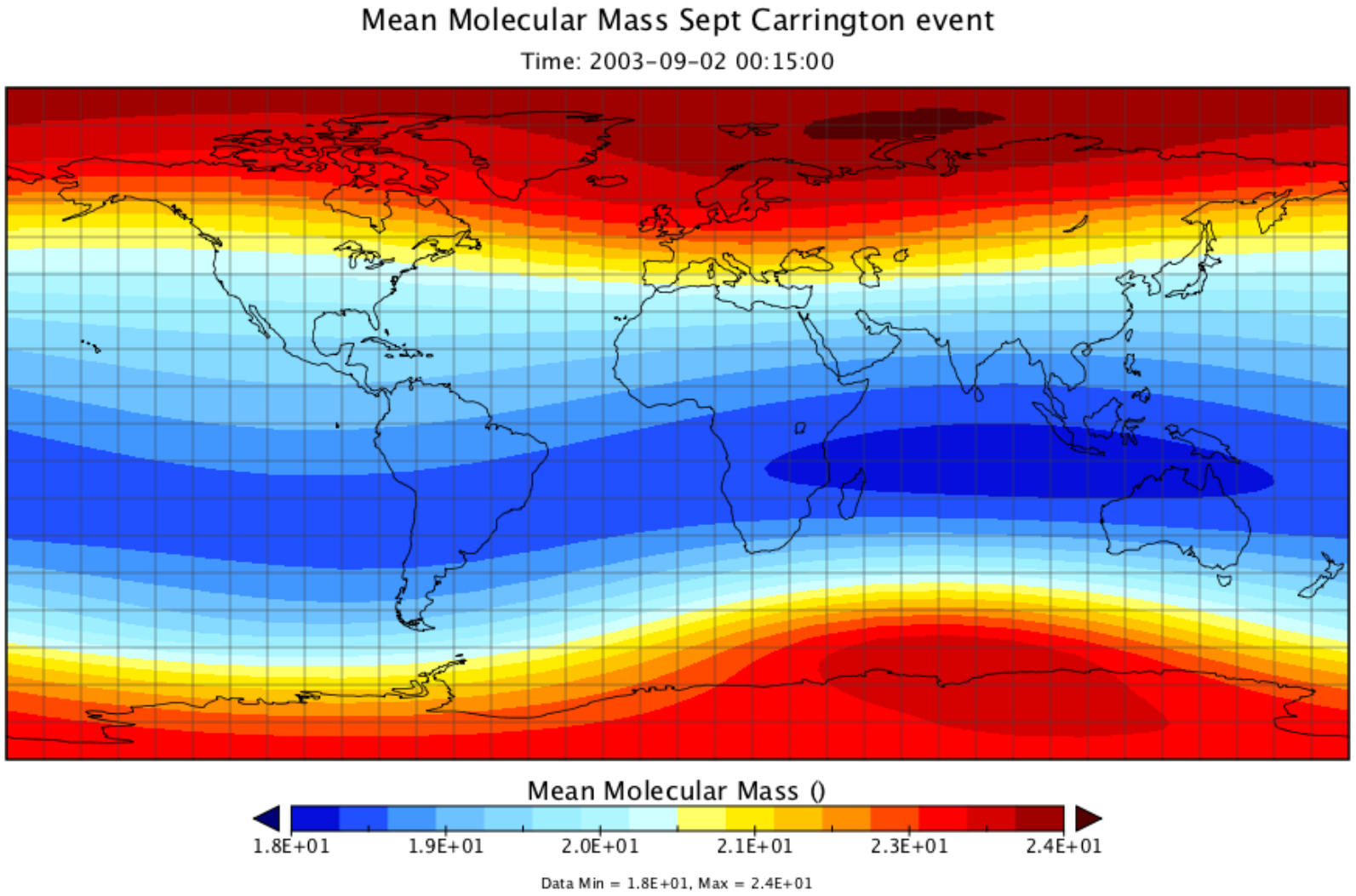
Horizontal winds > 1500 m/s



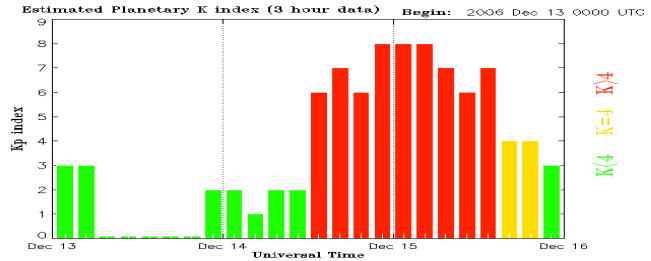
Vertical wind > 150 m/s

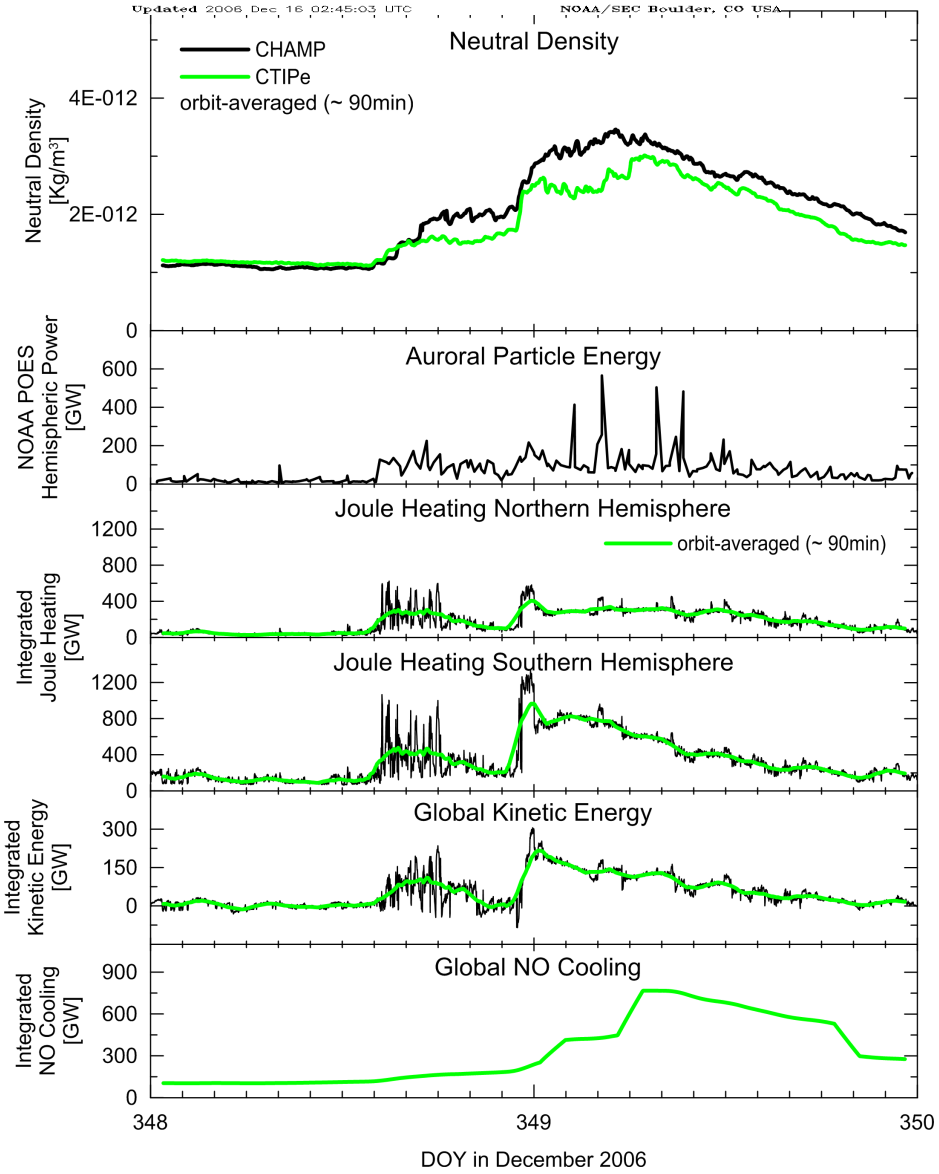


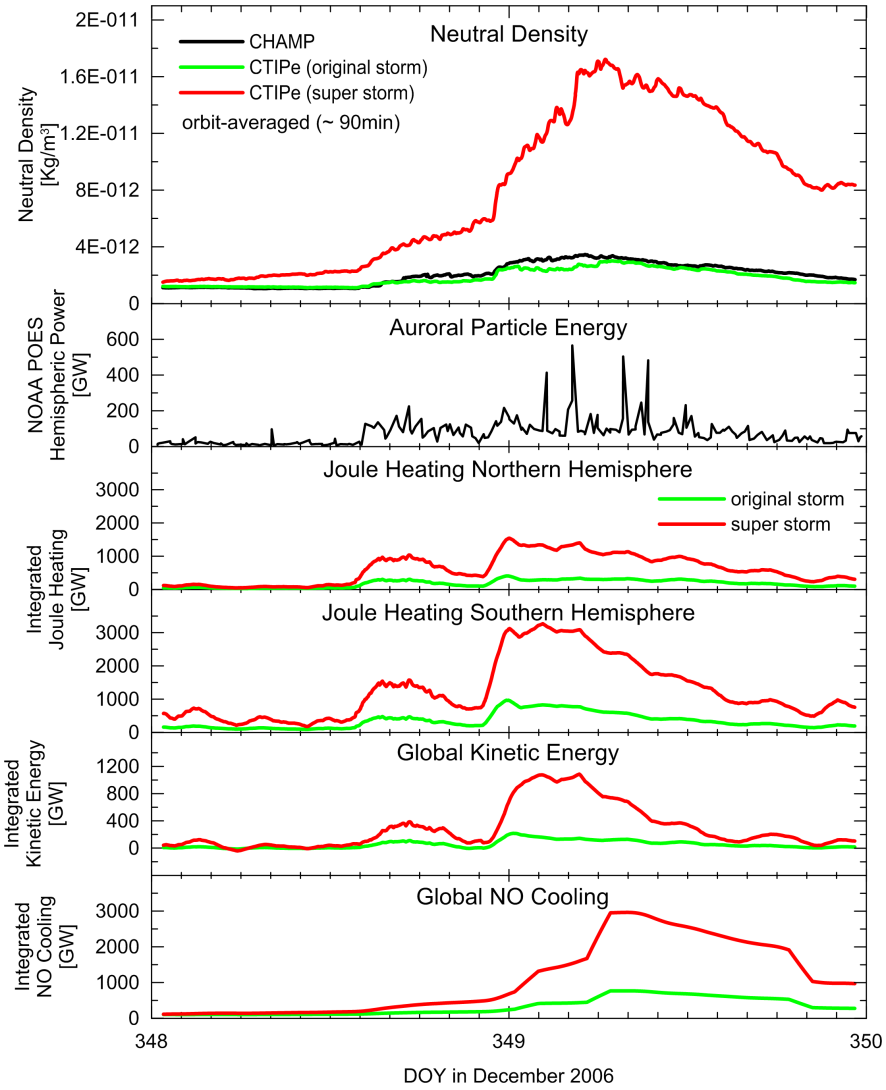
Mean molecular mass



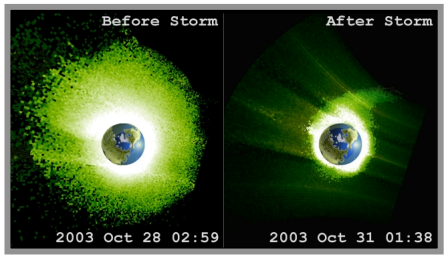
Energy input and density response to realistic time series scaled to peak JH

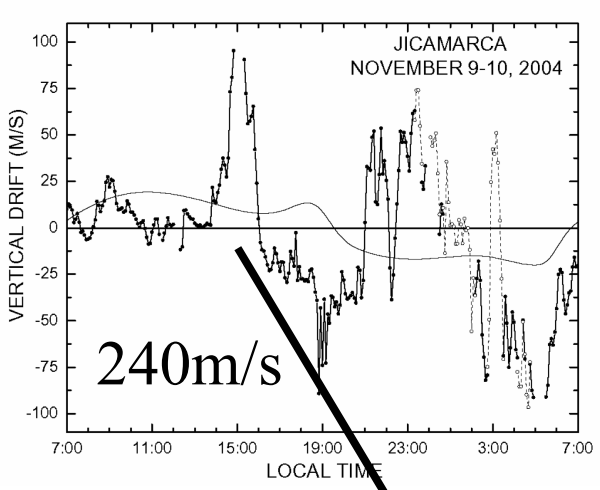


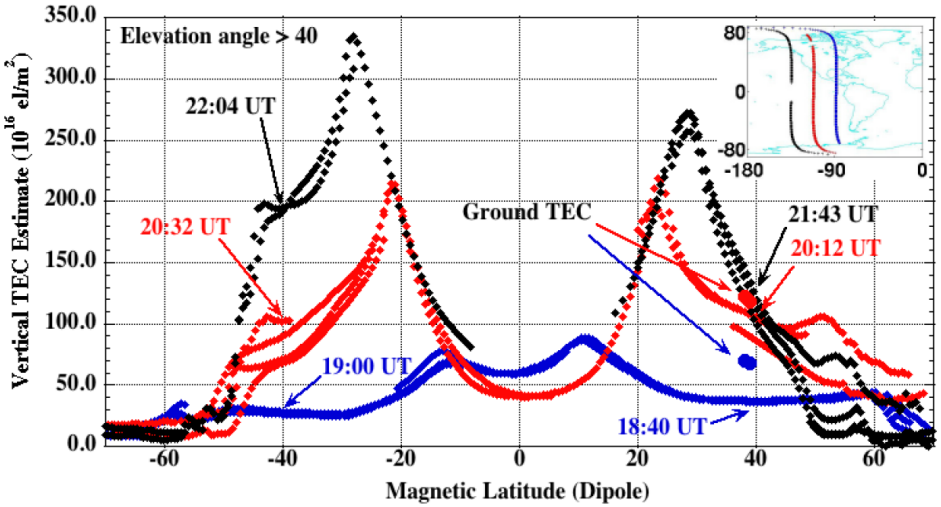




Ionospheric response: expect interaction between poleward movement and plasma increase in EIA due to penetration electric field and build-up of mid-lat plasma by the Heelis effect







Mannucci et al 2005

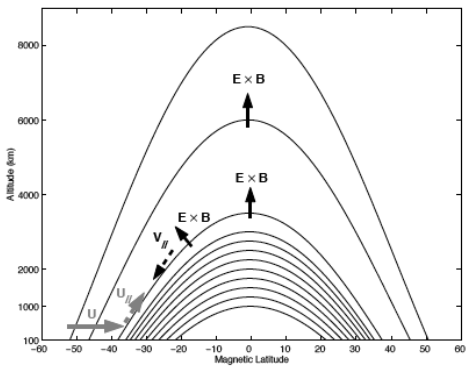


Figure 6. Schematic of the competing effect of the downward field-aligned diffusion and the upward movement of the plasma produced by an equatorward neutral wind at mid latitudes.

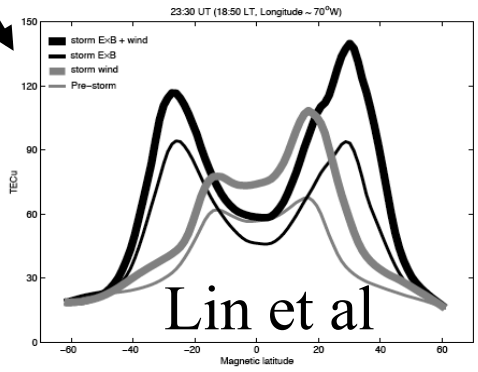
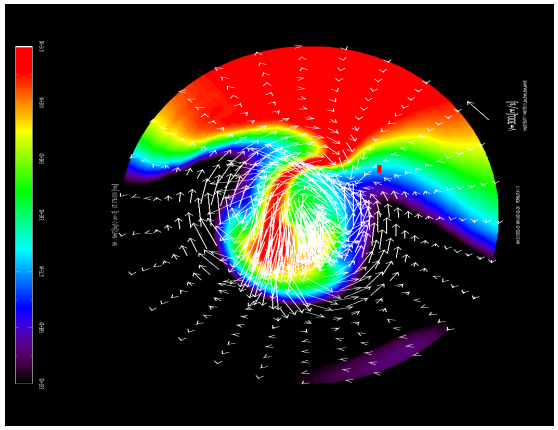


Figure 10. The total electron content (TEC) between altitudes 100 and 2000 km from the SUPIM results at 23:30 UT (18:50 LT) at -70° geographic longitude on the pre-storm day (thin gray line), case 1 (bold gray line), case 2 (thin black line), and the case 3 (bold black line).



Nair estimated vertical plasma drift of 240 m/s

Ionospheric positive storm phases due to convection expansion (Heelis et al.)

Conclusions (1)

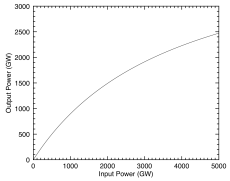
- Response of *neutral atmosphere* to a Carrington type storm appears reasonable and model is robust, and will likely impact the ionosphere appropriately
- Large increase in Joule heating (~6000 GW), temperature (~3000 K) and ion drag winds (1500 m/s), vertical winds (+/-150 m/s) predicted
- Source is now at mid-latitudes
- Neutral density response and impact on drag will likely scale linearly (factor of ~5 increase) with expected rapid decay of orbits, wind response more non-linear (due to transport)
- Gravity wave propagation also responds as expected, wave speed faster due to temperature and sound speed increases, magnitude of waves greatly increased (factor 2 to 5), poleward and equatorward propagation from mid-lat sources, and zonal propagation

Conclusions (2)

- Uncertainty in NO production in this simulation - may make thermosphere colder in aftermath of storm
- Storm circulation no longer pole to equator. Energy input at mid-latitude, energy spreads (fills in) quickly by wind and wave transport globally
- Neutral composition change weaker as a result; clear negative ionospheric phase might not be so apparent, not clear if this is true for more realistic magnetospheric driver with more structure
- CTIPe ionosphere response not yet realistic, requires seamless transport across latitude
- Expect interaction of poleward movement of EIA by penetration electric field (240 m/s vertical plasma drift from Nair model) and build up of plasma at mid latitude by “Heelis” effect
- Need a time dependent and more expanded polar cap boundary for escape of plasma and plasmasphere erosion

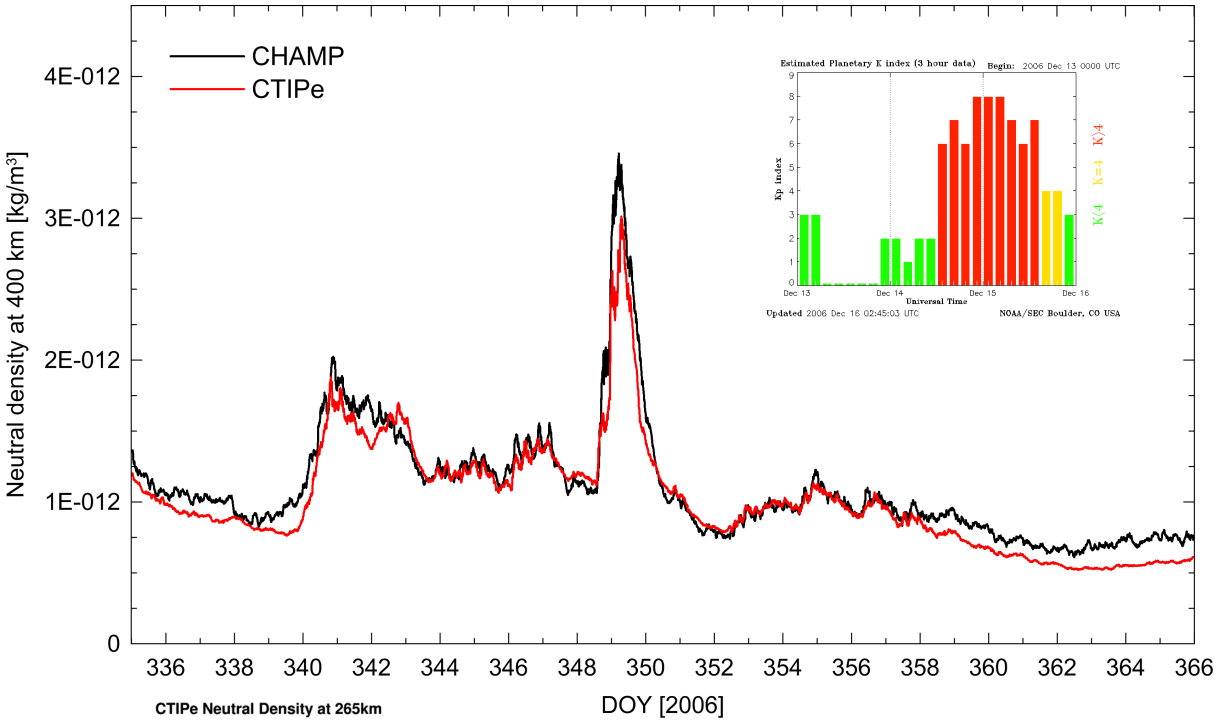
Validation challenges

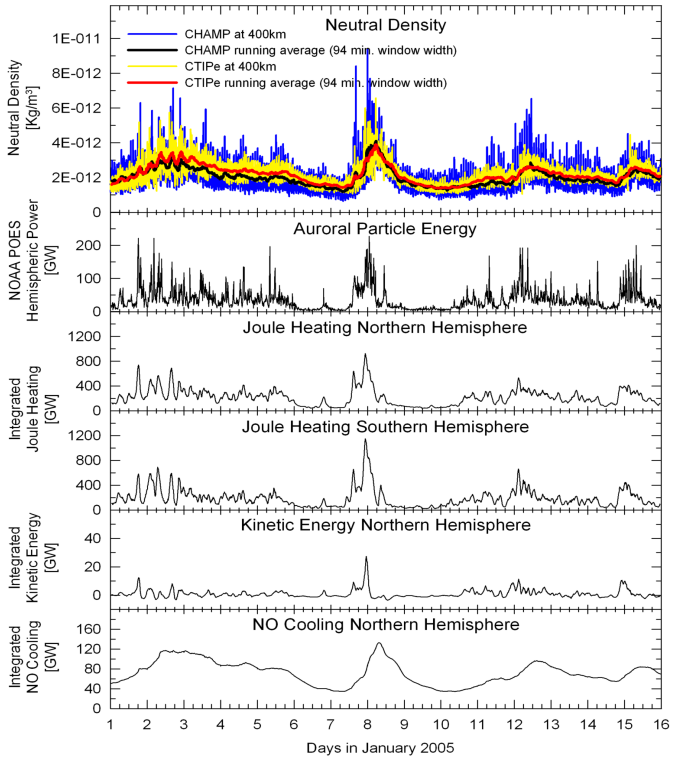
- Make sure at least we can model the biggest events: e.g., Halloween, Bastille, “Parents Day”, March ’89….
- Run MHD codes to check magnetospheric drivers of the system, expansion of convection equatorward, polar cap boundary, penetration electric field, inner magnetosphere shielding, degree of structure, etc.
- Compare OpenGGCM, SWMF, LFM for consistency
- Will the magnetospheric CPCP completely saturate?

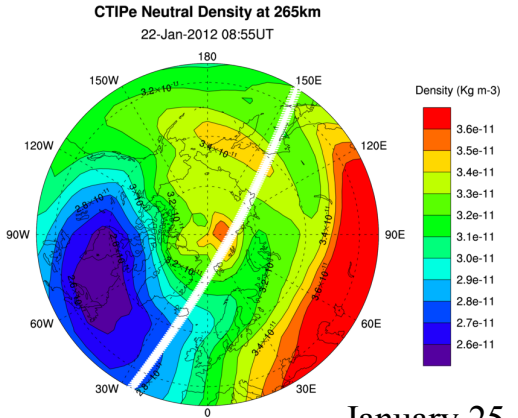


- Need a time dependent and more expanded polar cap boundary for the ionosphere – for escape of plasma, plasmasphere erosion, location of the plasmapause – will we lose most of the ionosphere for a few days?
- Ionospheric response will depend heavily on the magnetospheric drivers
- Thermosphere-ionosphere response will have to rely on understanding the physical processes – does it make sense? (interaction of EIA and SED, penetration electric field and neutral wind dynamo)

CTIPe vs CHAMP Dec 2006
Mariangel Fedrizzi





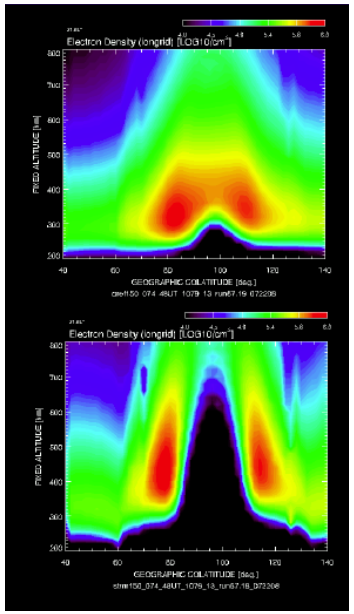


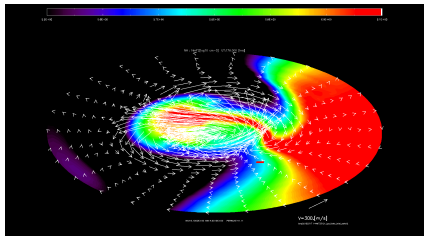
What would this density response look like during a Carrington event?

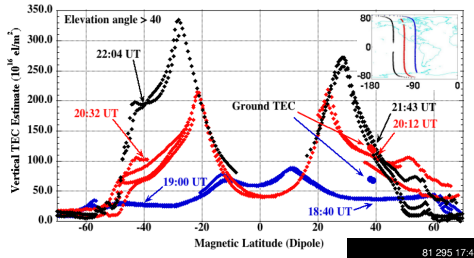
What is the magnitude of the Joule heating rates?

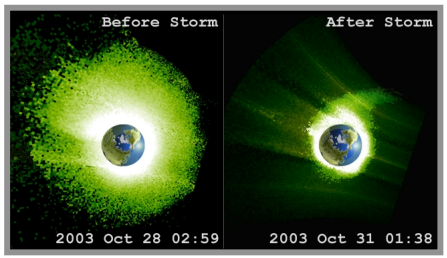
Ionospheric Storm vs Geomagnetic Storm

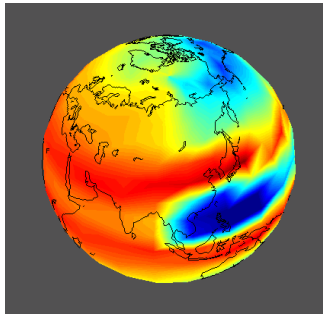
- An “ionospheric storm” are the ionospheric consequences of a “geomagnetic storm”
- Traditionally couched as “positive” and “negative” phases
- Now use terms like “storm enhanced density” and “plasma erosion”

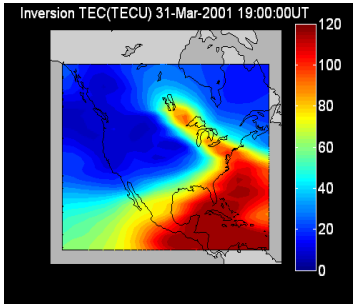


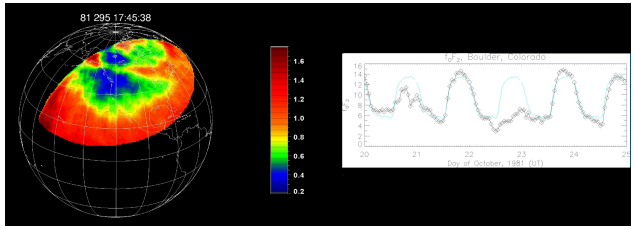


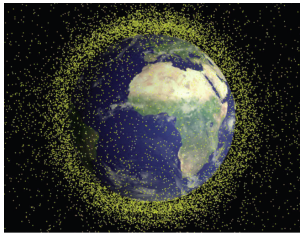




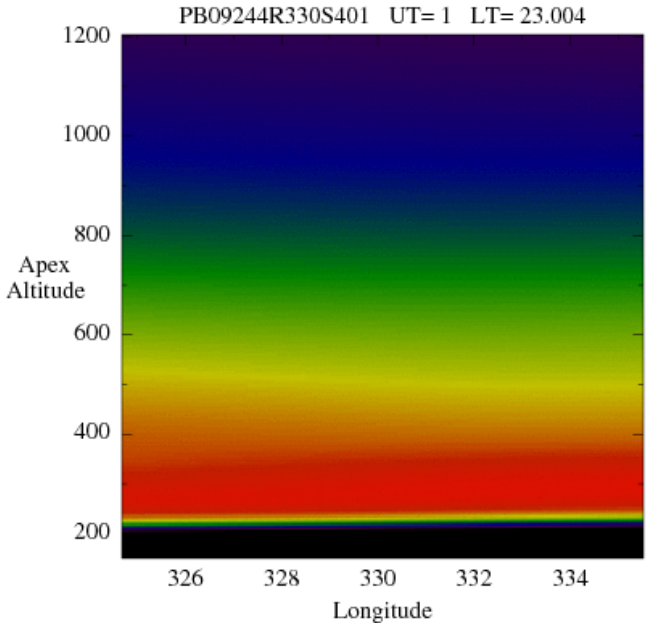


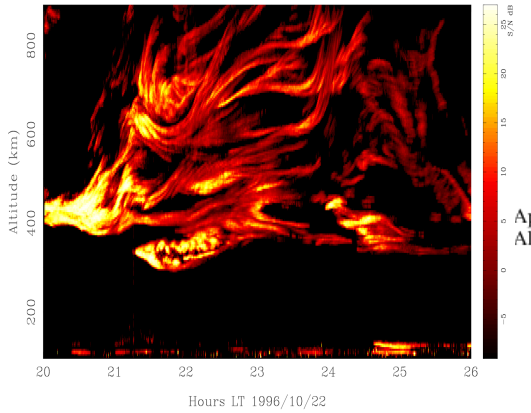


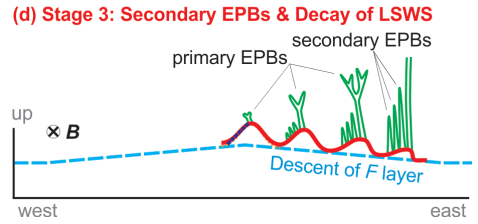


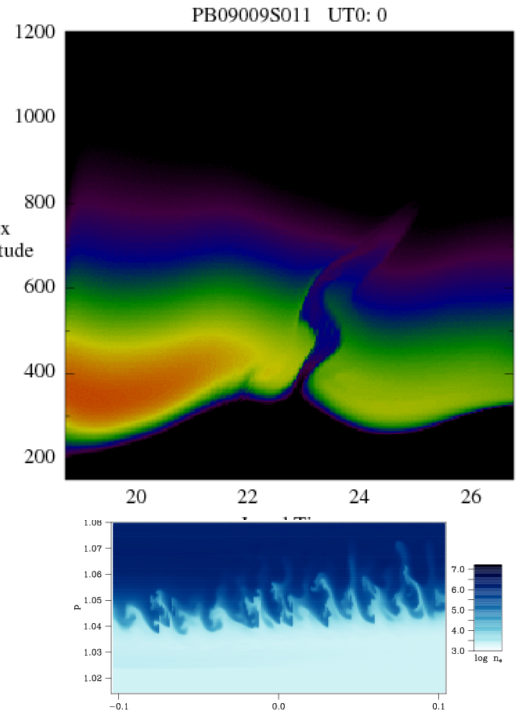


Another space weather hazard: plasma “bubbles” or ionospheric irregularities at low latitudes









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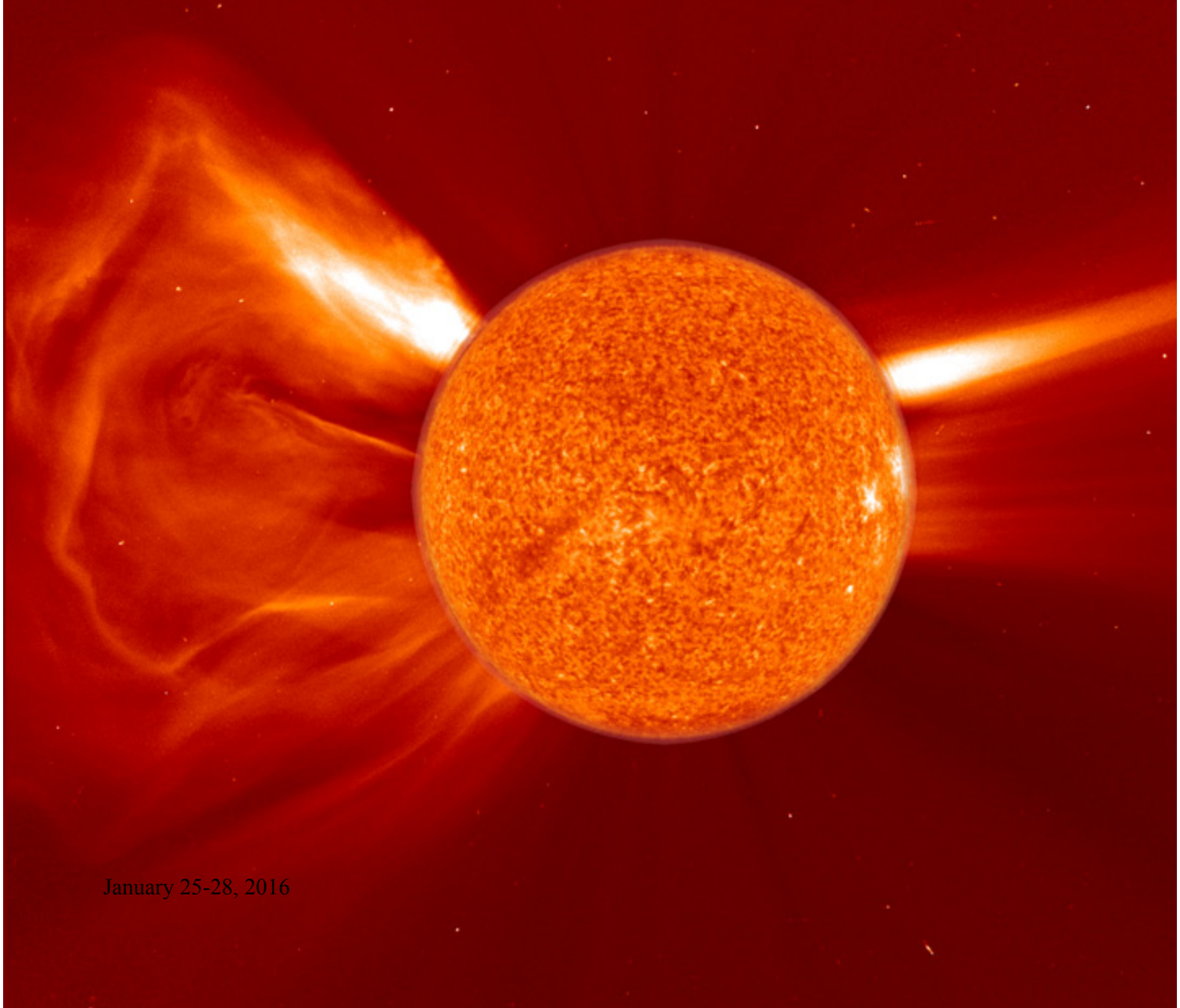

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