Energy transport and partitioning in CIR-HSS events: modeling and observations

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Outline

- External driving (coupling of the solar wind and IT system) and energy partitioning in IT system during CIR-HSS events
- How well does modeling capture energy transport?
- How well do we understand energy transport?

- Uncertainties in input parameters and intrinsic model uncertainties
- Lower boundary driving
- Challenges in developing a general forecasting approach for IT system

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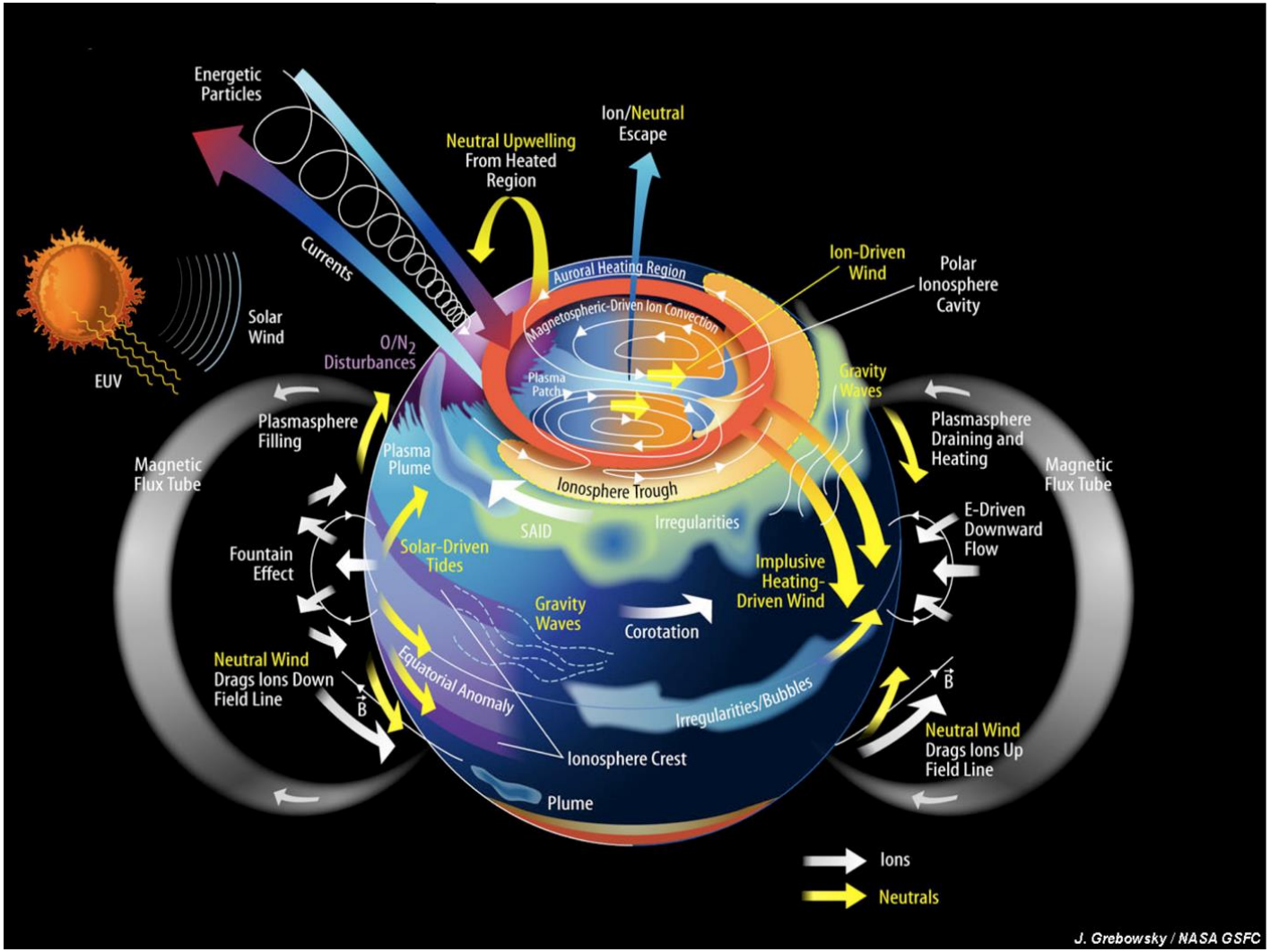
Magnetosphere-Ionosphere-Thermosphere System



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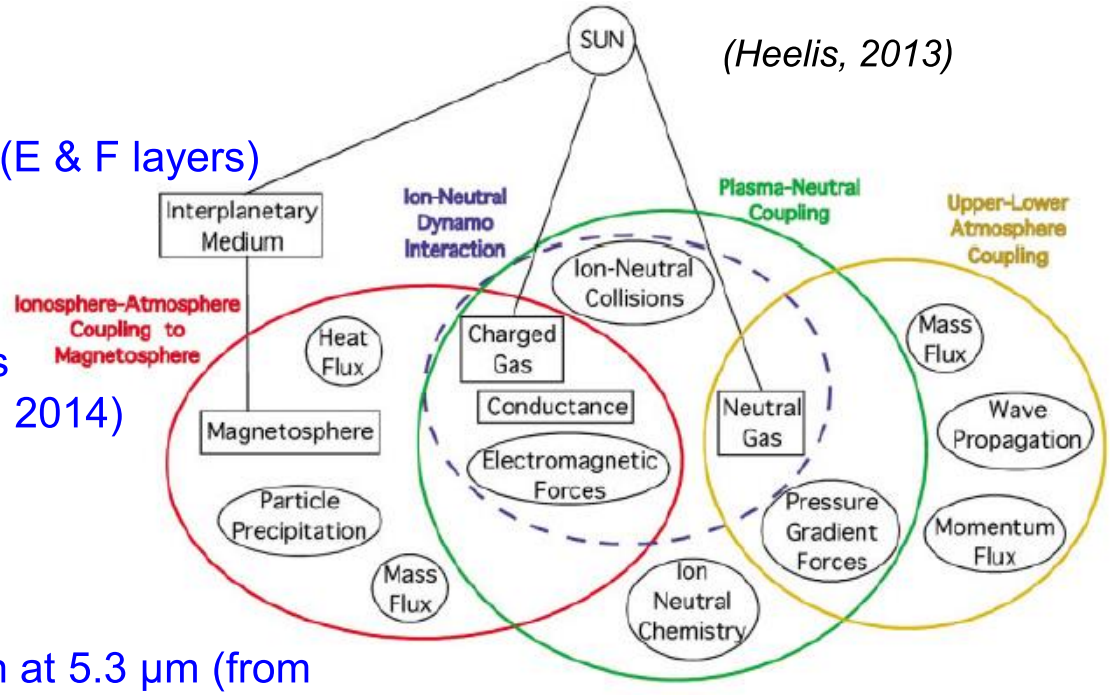
Energy Transport in IT System

Main Energy Inputs into IT:

- Solar EUV
- PC potential -> Joule heating
- High-latitude particle precipitation (E & F layers)
  -> auroral heating,
  ionization -> conductivity
- PPEF (Solomon et al., 2012)
- Entry through high-latitude regions
  (Knipp et al., 2011; Huang et al., 2014)
- Chemical heating
- Driving from below (tides)



(Heelis, 2013)

Energy Sinks in IT:

- Nitric oxide (NO) cooling radiation at 5.3 μm (from 100 to 250 km) -> 80% of JH (Lu et al., 2010)
- Carbon dioxide (CO2) cooling radiation at 15 μm (from 100 to 140 km)
- Neutral winds -> JH (Thayer, 1998)

- Composition (O/N2) changes
- Chemical reactions

Different impact depends on latitude, altitude, LT, longitude, solar activity, geomagnetic storm type, strength and phase

Can a general forecasting approach be developed?

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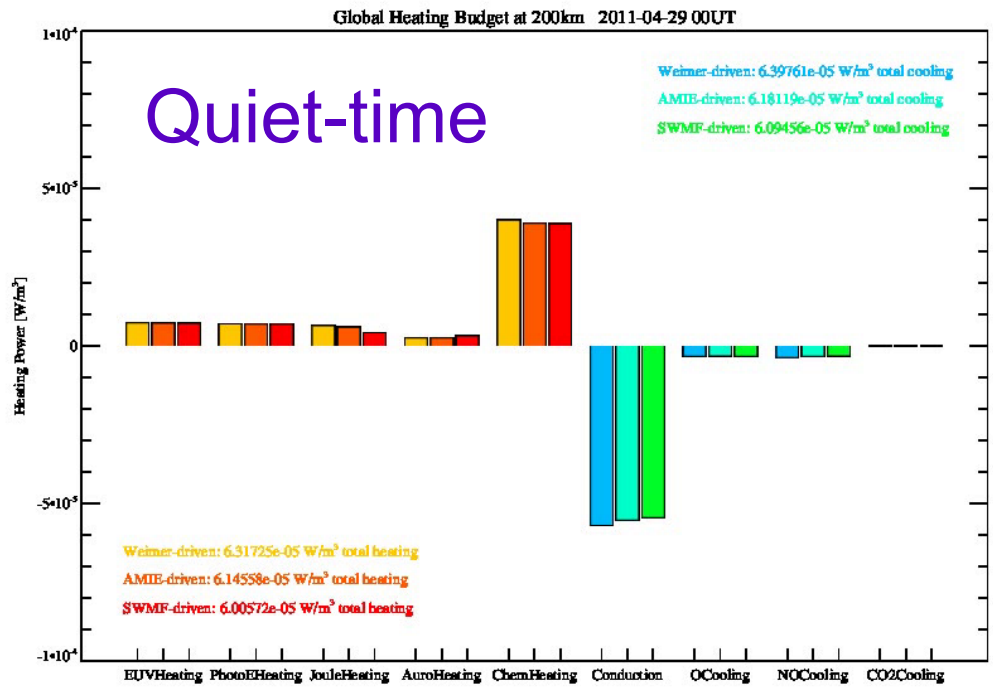
Energy coupling and partitioning in GITM model

- EUV heating (from solar EUV spectra & photo-absorption for 5 major species)
- Photoelectron heating (from photoionization)
- Joule heating
- Auroral heating (based on NOAA HP)
- Chemical heating (solar radiation driven)
- Conduction (due to eddy diffusion)
- NO cooling
- O cooling
- CO2 cooling



$$\mathcal{Q} = Q_{\mathrm{EUV}} + Q_{\mathrm{NO}} + Q_{\mathrm{O}} + \frac{\partial}{\partial r}\left((\kappa_{\mathrm{c}} + \kappa_{\mathrm{eddy}})\frac{\partial T}{\partial r}\right) + N_e \frac{\overline{m}_{\mathrm{i}}\overline{m}_{\mathrm{n}}}{\overline{m}_{\mathrm{i}} + \overline{m}_{\mathrm{n}}} \nu_{\mathrm{in}} (\mathbf{v} - \mathbf{u})^2,$$

(Ridley et al., 2006)

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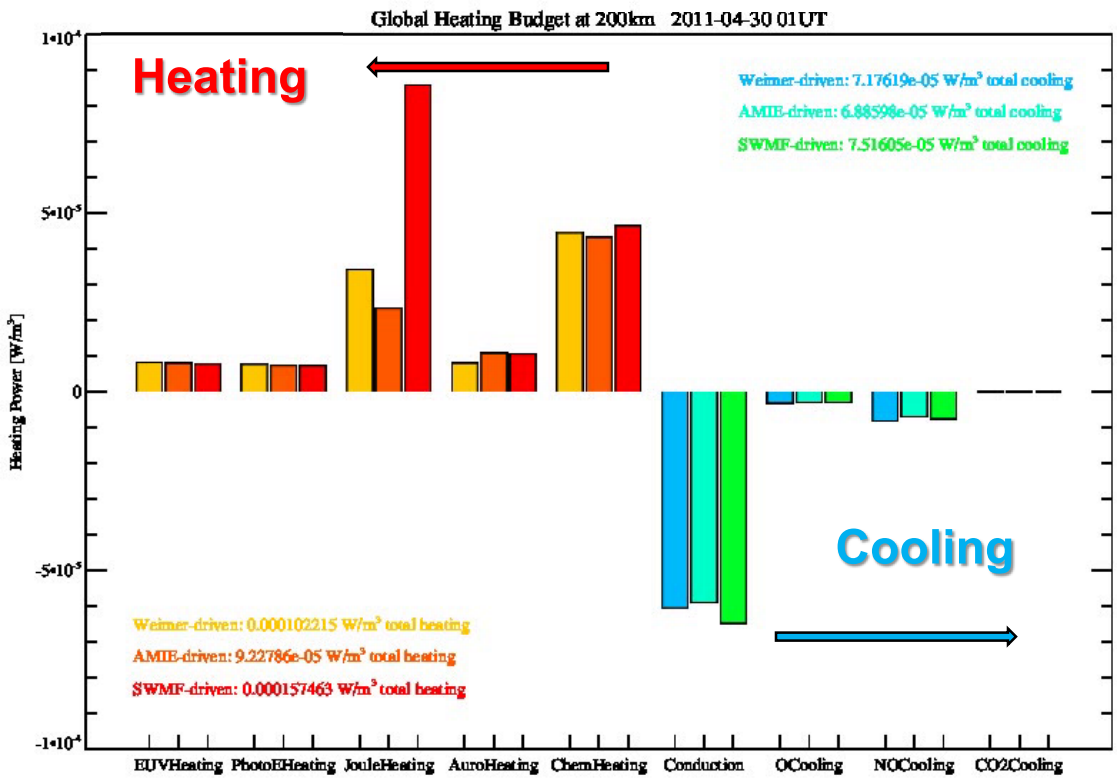
Energy coupling and partitioning at 200km altitude: GITM Modeling

Show movie



- Major QT heating source: chemical heating;
- Storm-time: JH (AMIE- & SWMF-driven)

- Cooling is mostly due <u>to conduction term</u>
- Under-estimation of energetics of mesosphere and lower thermosphere (NO cooling)
- Under-estimation of auroral heating (particle precipitation)?

- Is IT system driven (externally) strongly enough?

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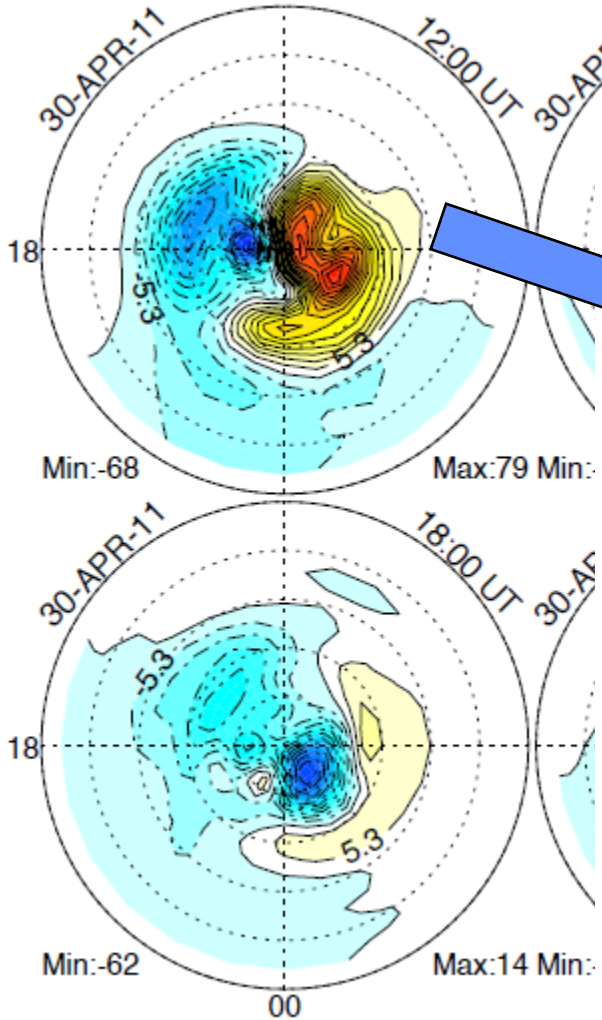
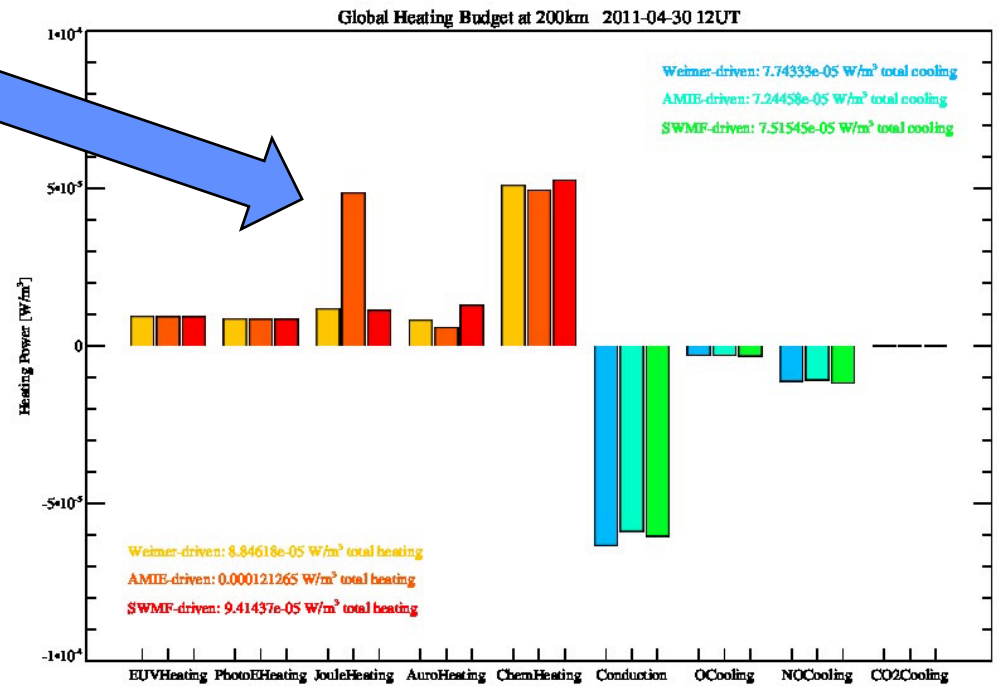
AMIE-driven Potentials





- Different timing in JH peaks if driven by different inputs;

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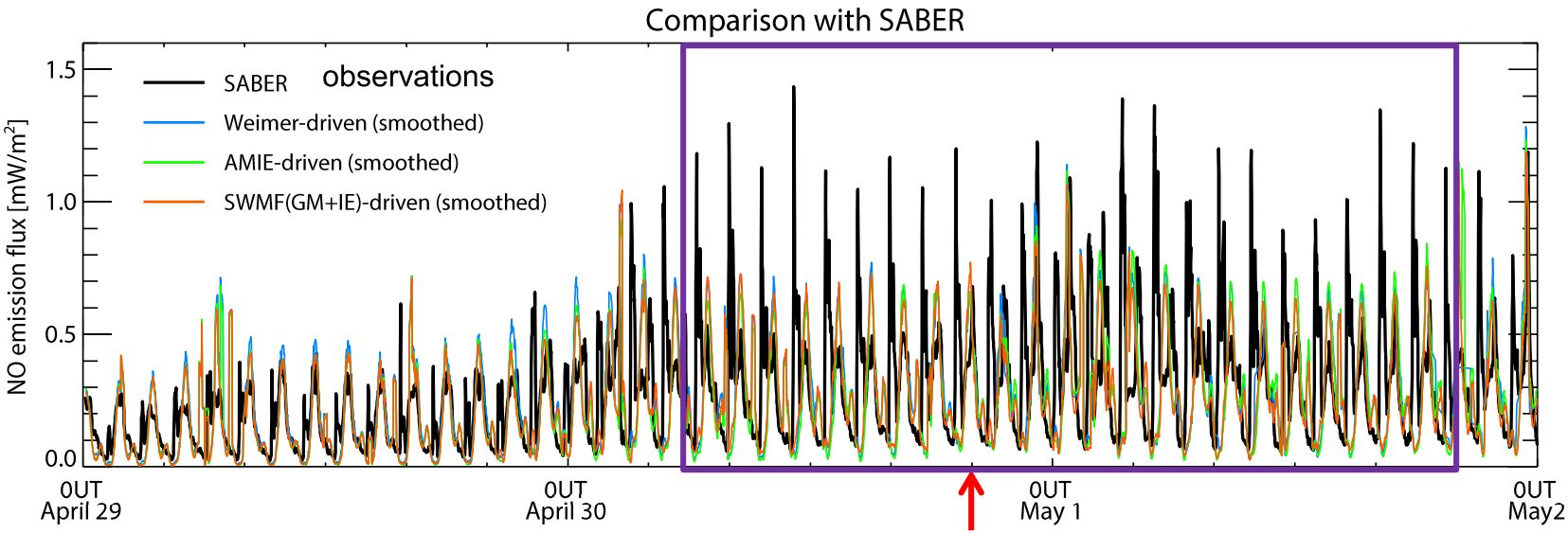
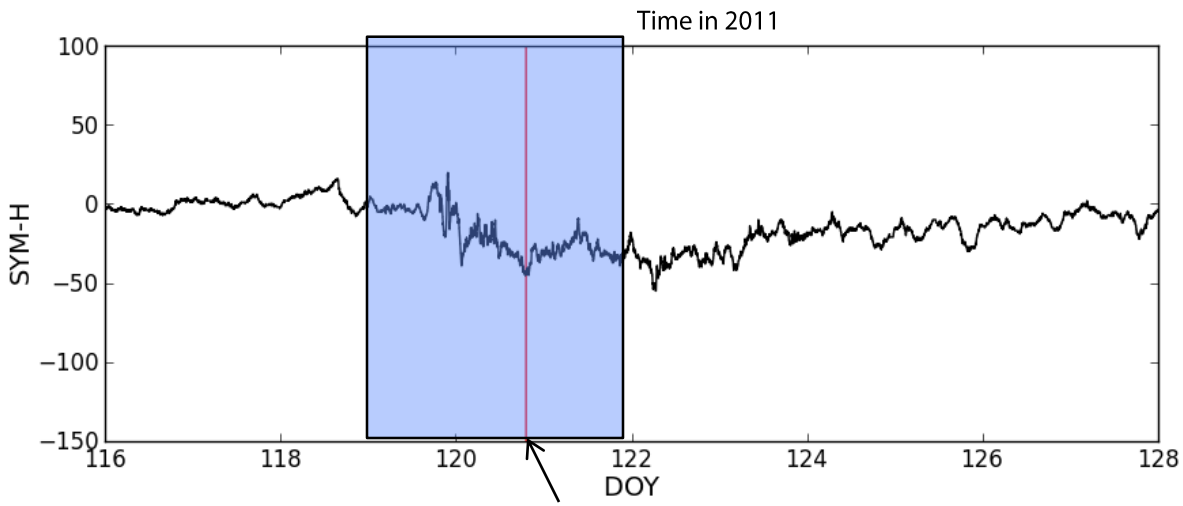
Energy coupling and partitioning: SABER Observations





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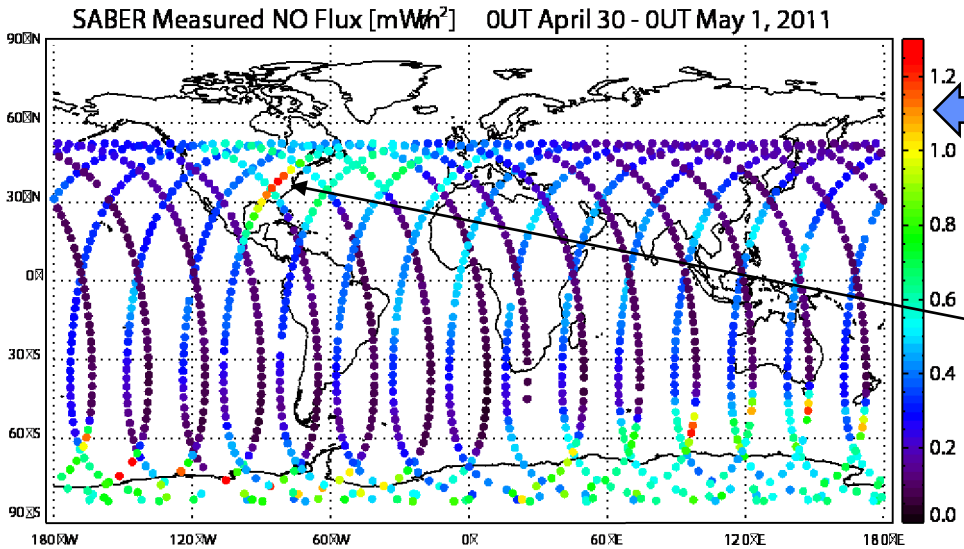
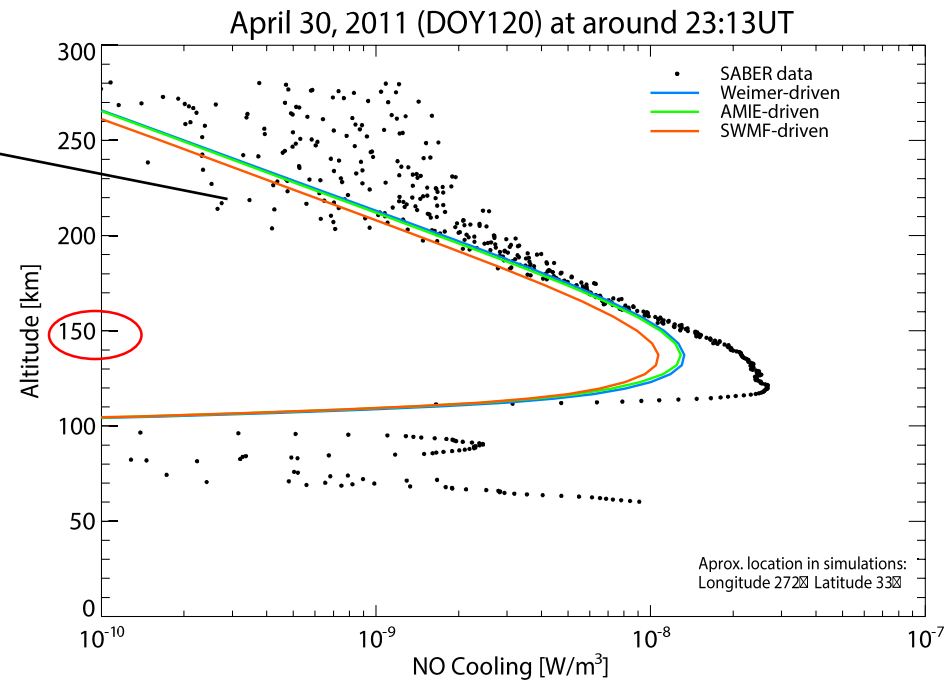
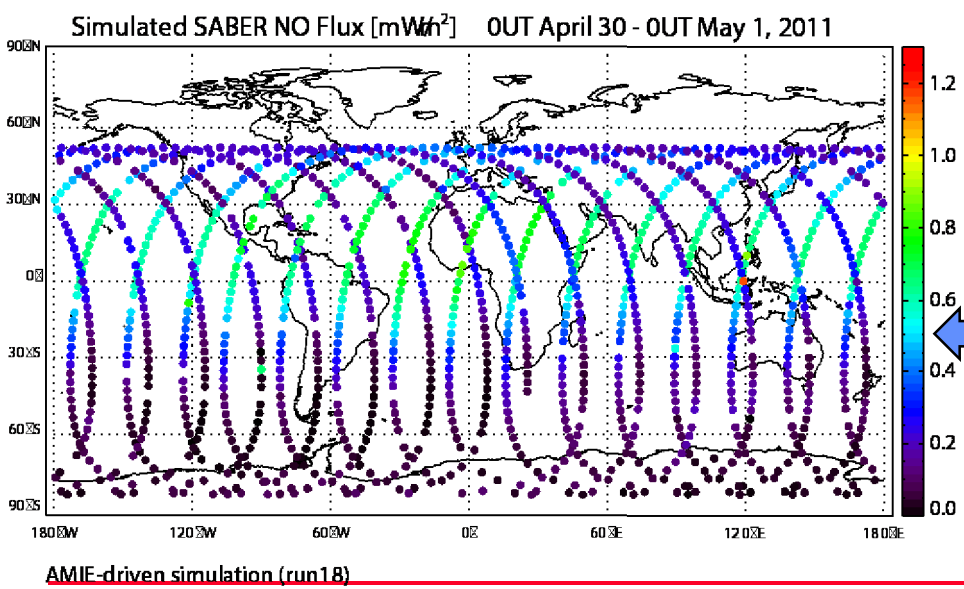
NO Cooling: SABER/TIMED Observations and GITM Modeling



Observations





Modeling

- Under-driving in high-latitudes
- Over-driving in lower- to middle- latitudes;

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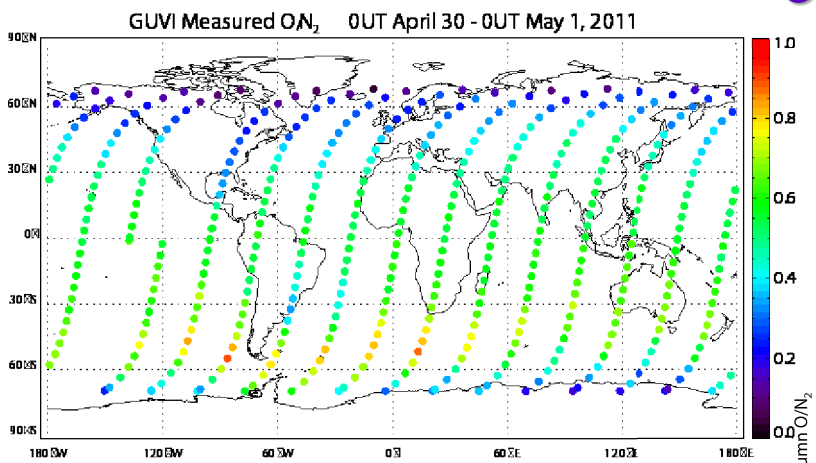
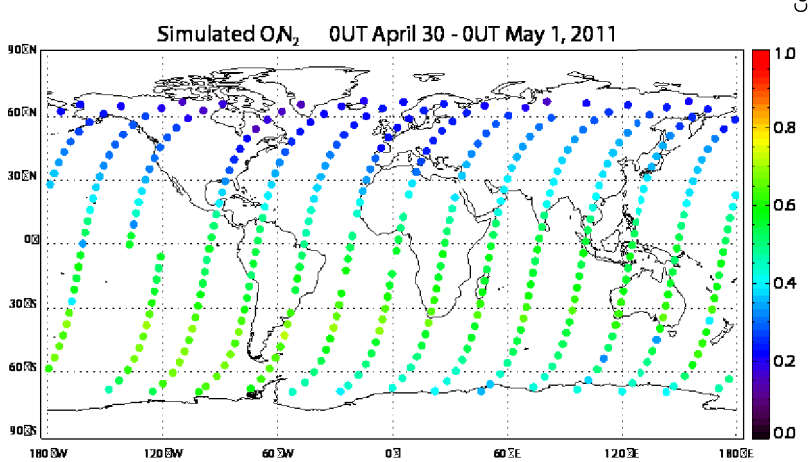
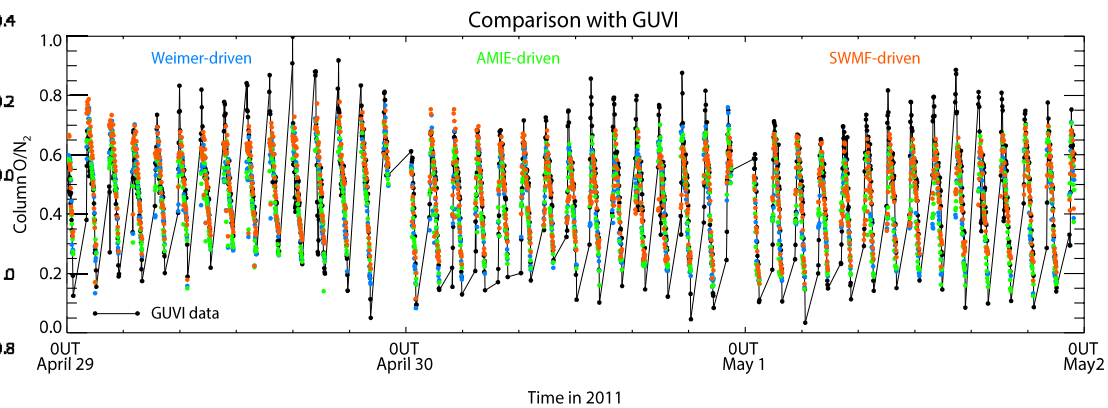
Composition Changes: GUVI/TIMED Observations and GITM Modeling

Observations





AMIE-driven simulation (run18)



Modeling

- Reasonable agreement between observations and modeling
- Under-estimation of composition response in high- to sub-auroral latitudes

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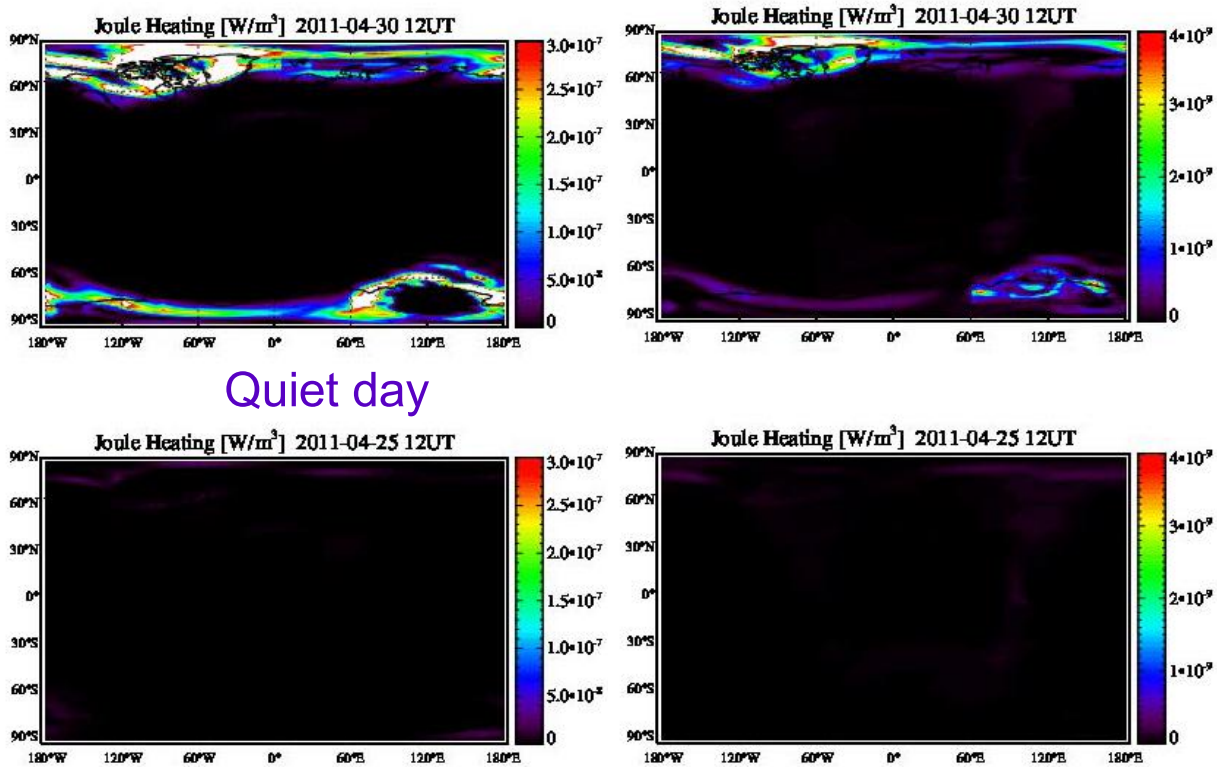
Joule Heating, AMIE-driven run

- (Y. Huang, 2012; Deng, 2011) -> altitude dependence of Joule heating with Joule heating deposited at high altitudes being more efficient in affecting the upper thermosphere than that at low altitudes;
- (Sheng et al., 2014) -> model underestimation of Joule heating in F-layer (>150 km);
- Importance of soft particle precipitation & ionization in neutral density enhancement at ~ 400 km;

Joule Heating,
AMIE-driven model

@ 120 km $3\ 10^{-7}$ @ 300 km $4\ 10^{-9}$



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Auroral Heating, AMIE-driven run

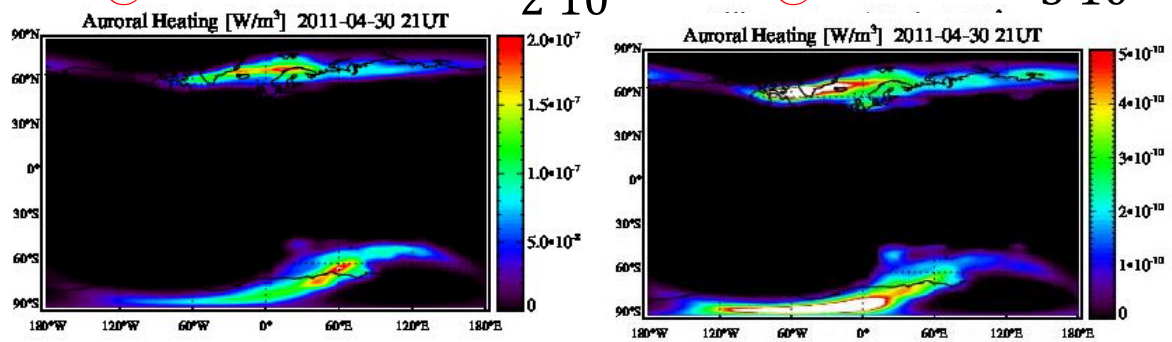
Penetration depth of electrons:

- ~ 100s eV: F-layer (>150 km), soft particles, precipitate in cusp;
- ~1-10 keV: E-layer (100-150 km), discrete aurora;
- ~10 -100 keV: D & E layer (80-100 km), diffuse aurora;

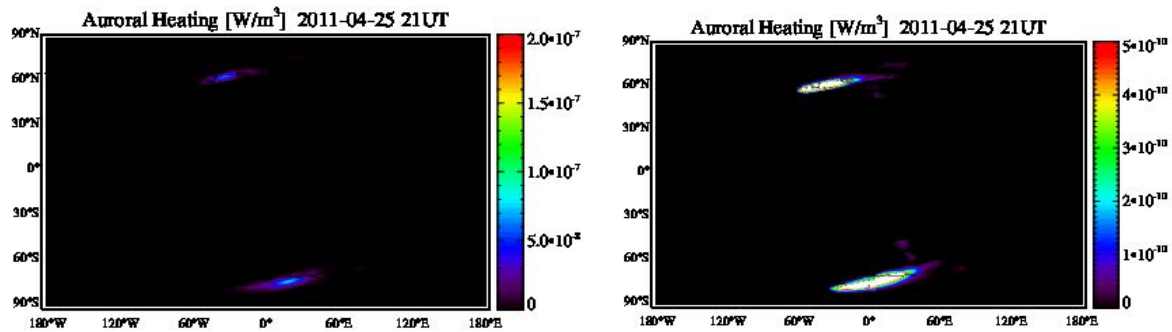
Cut-off latitude > 55° ;

Auroral Heating,
AMIE-driven model

@ 120 km $2\ 10^{-7}$ @ 300 km $5\ 10^{-10}$



Quiet day



During HSS intervals and HILDCAA events there are series of substorms and also convection events that lead to precipitation in the entire auroral zone (including the dayside) as well as the polar cap. HILDCAA auroras can last from several days to weeks (Guarnieri et al., 2006). Precipitating electrons can cause high-latitude D-layer ionization enhancements, e.g., (Rodger et al., 2012), and provide additional ionization in the E-layer (at ~ 100 km).

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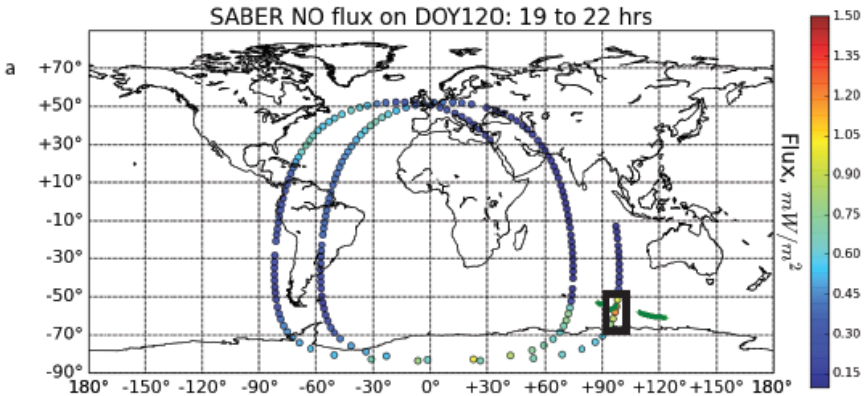
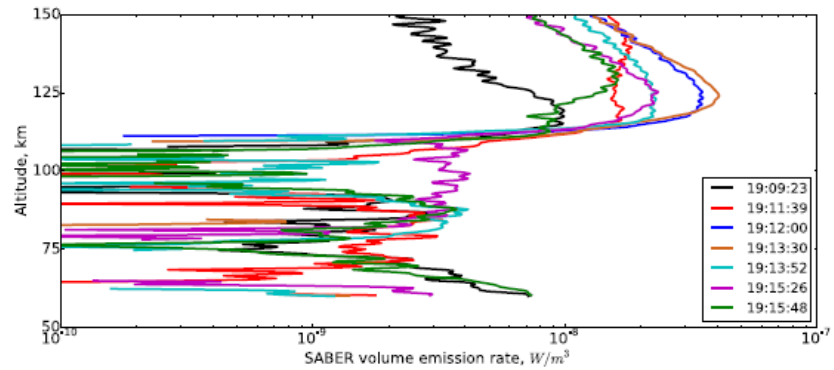
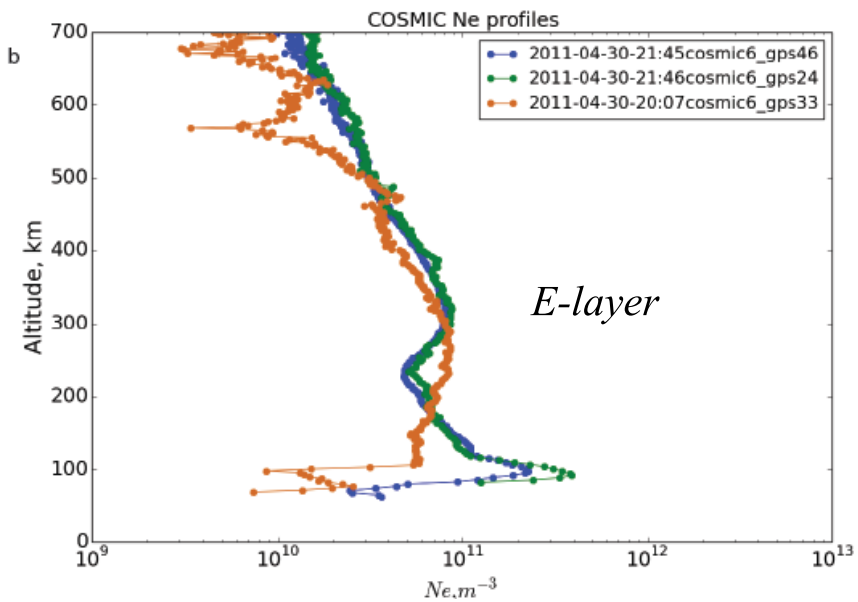
Particle Precipitation and High-Latitude Ionization Events

Colocated COSMIC and SABER measurements







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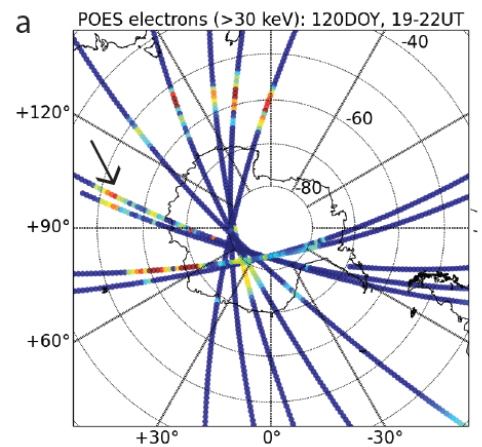

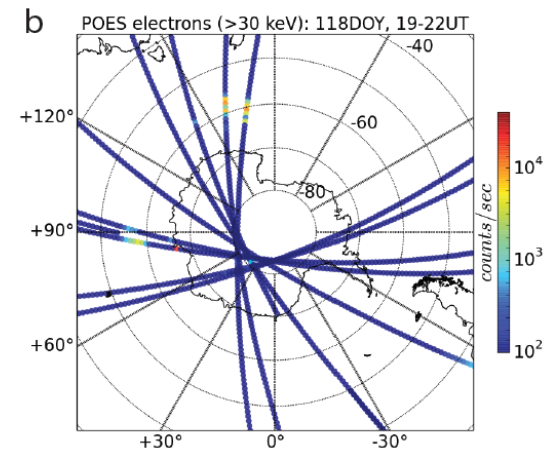

Verkhoglyadova et al., submitted JGR, 2014

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Winds in GITM

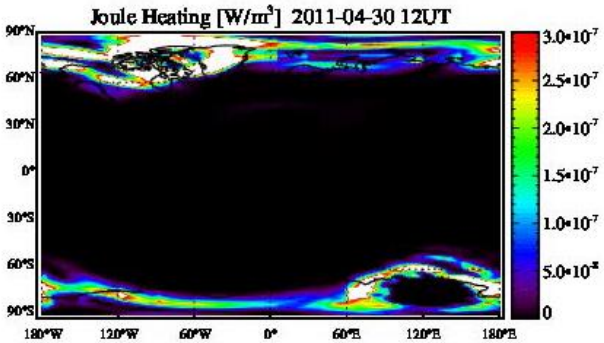
Neutral Wind @ 120 km,
AMIE-driven model

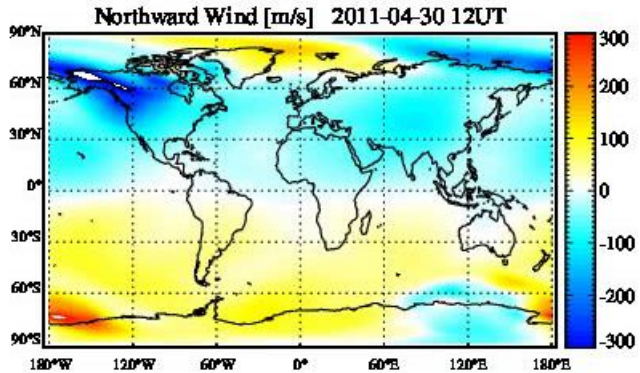
- Disturbance dynamo

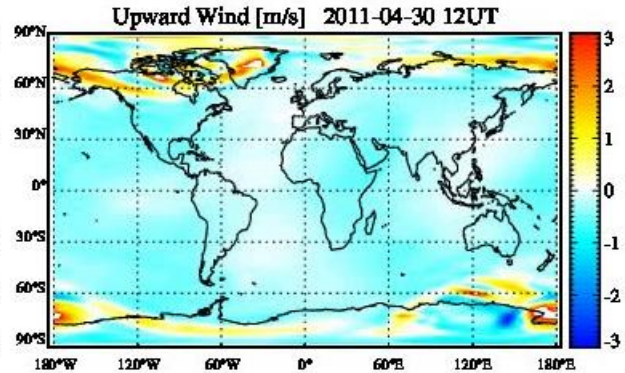
JH -> equator-ward wind

JH -> upward wind

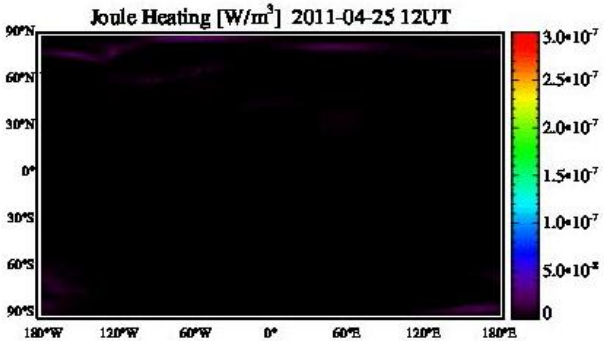
@ 120 km

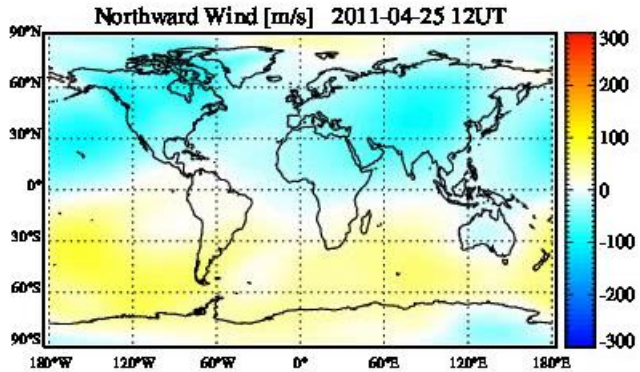


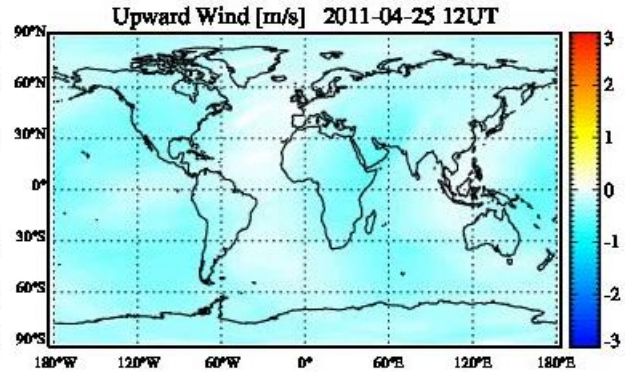




Quiet day







- *Need to compare with TIEGCM winds*

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CONCLUSIONS:

- We capture the main physics reasonably well;
- Shifted timeline in JH for different SW inputs;
- Under-driving (external) of model in high latitudes: JH & particle precipitation in wide energy range (including soft electrons to increase the altitude of energy input);
- Do we account for soft electrons (~ 100s eV) precipitation in models?
- Precipitation in lower E-layer (>10 keV) and local NO emission events;
- Issues with HP: inter-calibration between POES and DMSP (Emery et al., 2008; 2011), but
    - ➢ "estimates are very crude, coming from single satellite passes referenced to 10 global activity levels"
    - ➢ Need better climatology reference maps (current are based on several years in 80th);
    - ➢ *How to forecast?*
- Under-estimation of NO cooling in high to sub-auroral latitudes in GITM;
    - ✓ Comparison with TIEGCM

How do these shortcomings affect forecastable quantities? *Xing Meng's talk on TEC metrics*

- Need to include driving from below (tides) to account for the total energy balance in the system ("energy reservoir" and "trigger" conditions?);

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Challenges and Unsolved problems:

- Two distinct forecasting approaches for two storm types (CME and CIR-HSS)?
- Do we under-estimate the role of very high-latitude region (Knipp et al., 2011; Huang, et al., 2014)
- Do we under-estimate PPEF for weak CIR-HSS type storms?
- Role of pre-conditioning:
  - ❑ HS vs PS: "calm before the storm" (Borovsky and Denton, 2013; McGranaghan, 2014) ;
  - ❑ "settled" quiet-time model run;
- Diagnostics aspect: how well do we capture physics (not forecasting "success" measure itself)

Outstanding topics:

- ✓ Model inputs from the solar wind to tidal forcing, and means of forecasting inputs;
- ✓ Scales of temporal and spatial evolution, and predictability, of the global TI.
- ✓ Validation datasets: which observations provide crucial contributions to understanding the physics behind TI forecasting
- ✓ Forecastable quantities in the TI

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