# Whole Atmosphere Community Climate Model with Thermosphere/Ionosphere Extension (WACCM-X v.2): Model Capabilities and Validation

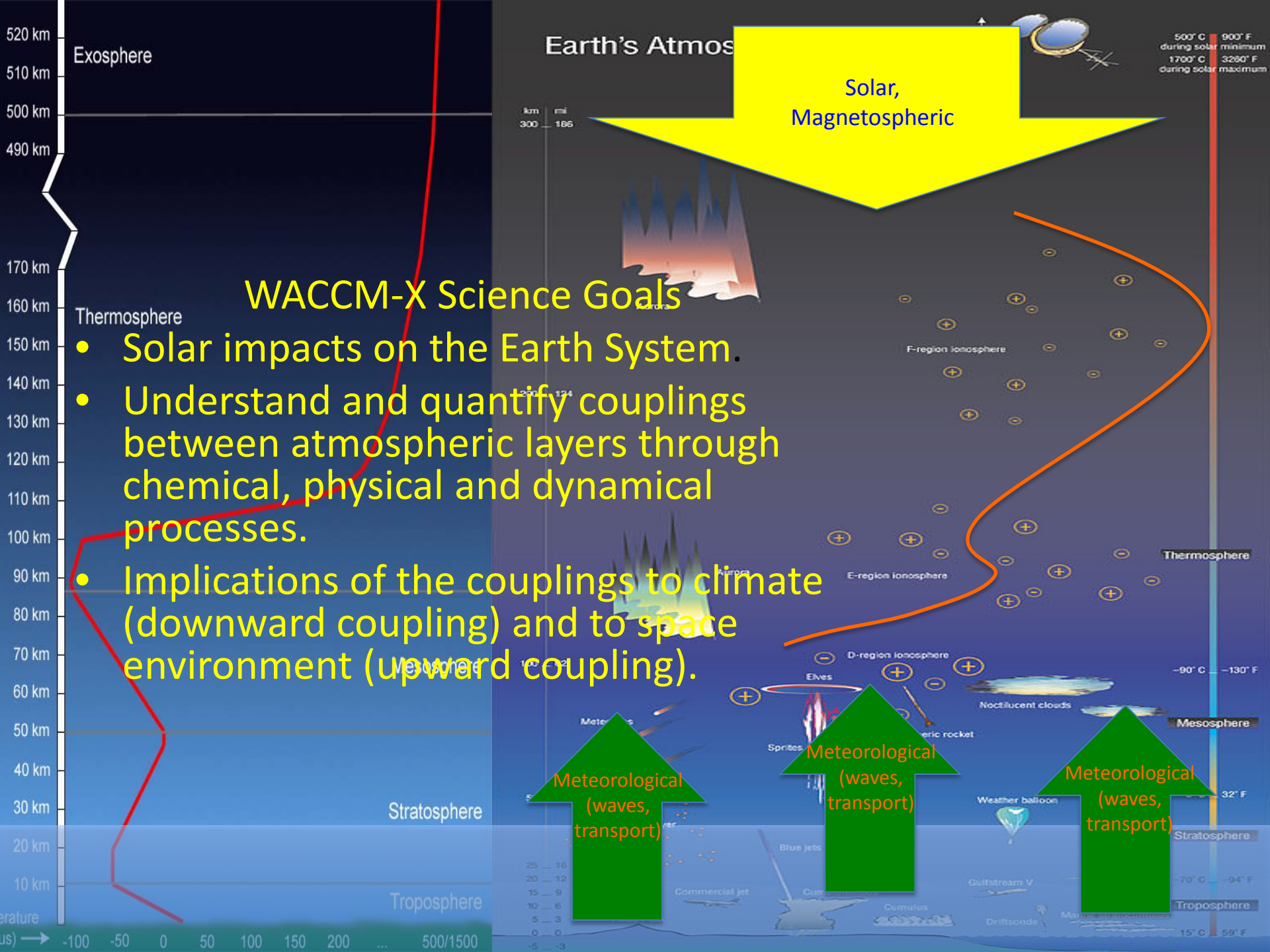
Han-Li Liu and WACCM-X Team

NCAR/HAO: Ben Foster, Jing Liu, Gang Lu, Astrid Maute, Joe McInerney, Nick Pedatella, Liying Qian, Art Richmond, Ray Roble, Stan Solomon, Wenbin Wang

NCAR/ACOM: Chuck Bardeen, Dan Marsh, Francis Vitt

NCAR/CGD: Peter Lauritzen

NCAR/CISL: Jeff Anderson, Kevin Raeder




## WACCM-X Science Goals

- Solar impacts on the Earth System.
- Understand and quantify couplings between atmospheric layers through chemical, physical and dynamical processes.
- Implications of the couplings to climate (downward coupling) and to space environment (upward coupling).

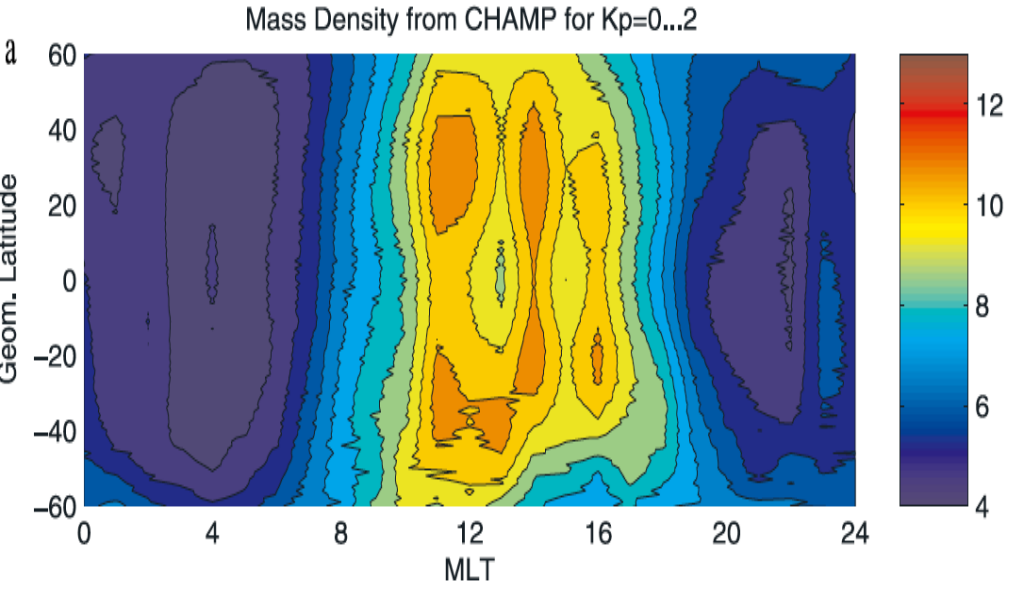
# Major CESM WACCM/WACCM-X Components

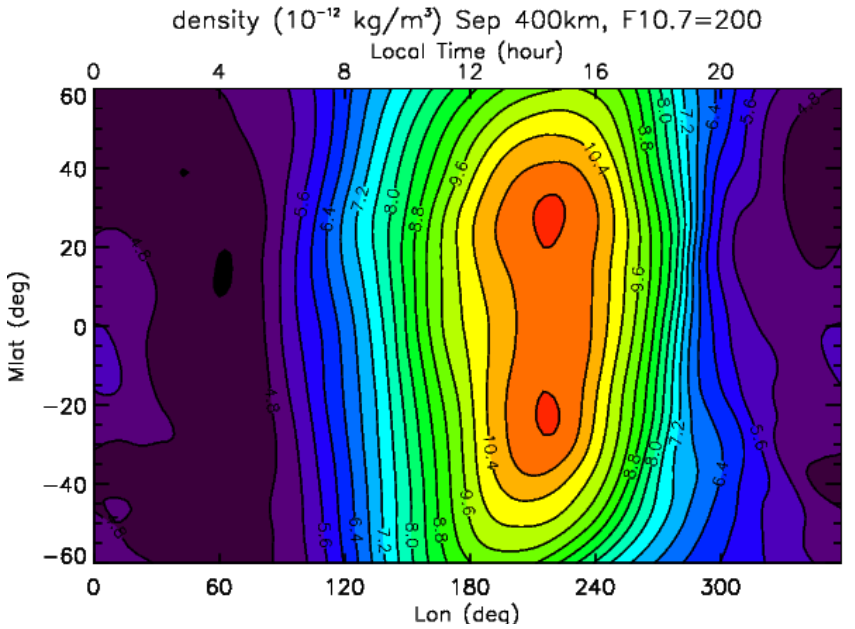
| Model Framework | Chemistry | Neutral Atmos. Physics | Ionospheric Physics | Resolution |
|---|---|---|---|---|
| Atmosphere component of NCAR Community Earth System Model (CESM)<br><br>Extension of the NCAR Community Atmosphere Model (CAM)<br><br>Finite Volume Dynamical Core (modified to consider species dependent Cp, R, m)<br><br>Spectral Element Dynamical Core | MOZART+ Ion Chemistry (~60+ species)<br><br>Fully-interactive with dynamics. | Long wave/short wave/EUV<br><br>RRTMG<br><br>IR cooling (LTE/non-LTE)<br><br>Modal Aerosal/CARMA<br><br>Convection, precip., and cloud param.<br><br>Parameterized GW<br><br>Major/minor species diffusion (+UBC)<br><br>Molecular viscosity and thermal conductivity (+UBC)<br><br>Species dependent Cp, R, m. | Parameterized electric field at high, mid, low latitudes. IGRF geomagnetic field.<br><br>Auroral processes, ion drag and Joule heating<br><br>Ion/electron energy equations<br><br>Ambipolar diffusion<br><br>Ion/electron transport<br><br>Ionospheric dynamo<br><br>Coupling with plasmasphere/magnetosphere | Horizontal:<br>1.9° x 2.5° (lat x lon configurable as needed)<br><br>Vertical:<br>66 levels (0-140km)<br>81/126 levels 0-~600km<br><br>Mesoscale-resolving version:0.25 deg/0.1 scale height. |

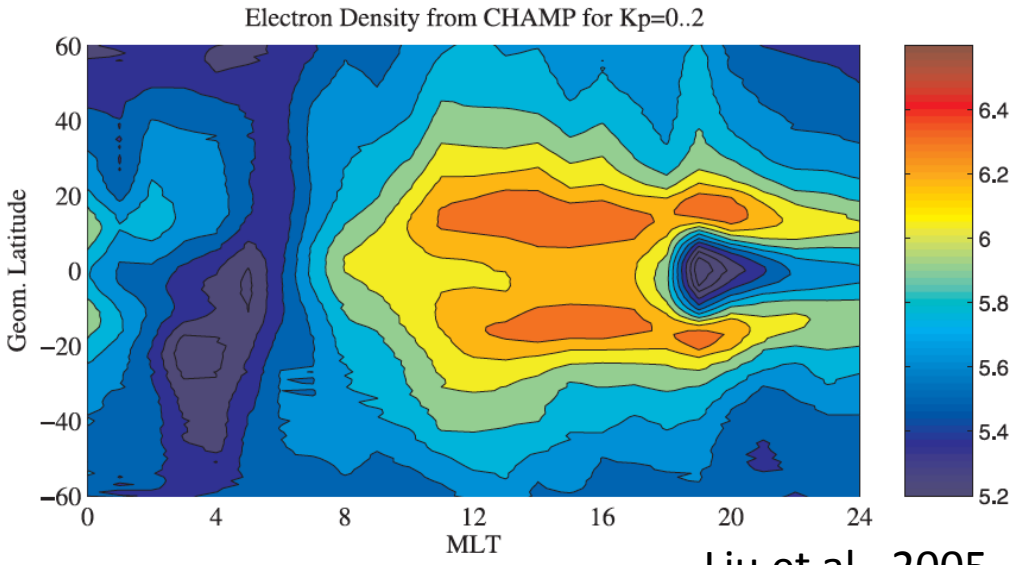
# Key WACCM-X Capabilities

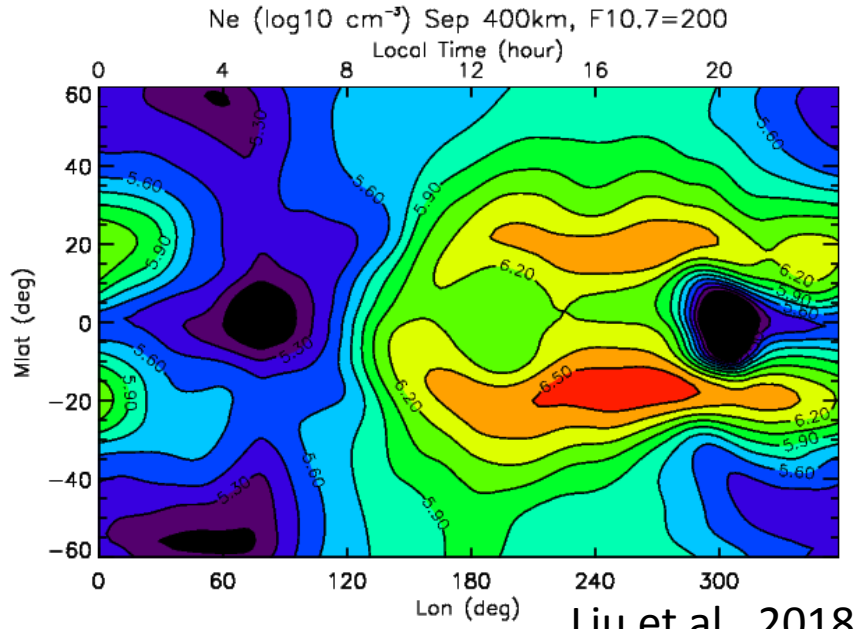
- Physics-based whole atmosphere general circulation model (0-700km)
- Solves dynamics, radiative transfer, photolysis and energetics
- Fully interactive chemistry, including ion chemistry.
- Ionospheric electrodynamics using fully interactive dynamo
- Ion transport in the *F*-region
- Magnetospheric inputs using empirical or specifications, including AMIE
- Coupling with a plasmasphere model (partnership with NRL)
- Whole atmosphere data assimilation for specification and forecast.

# Mass and Electron Density at 400km



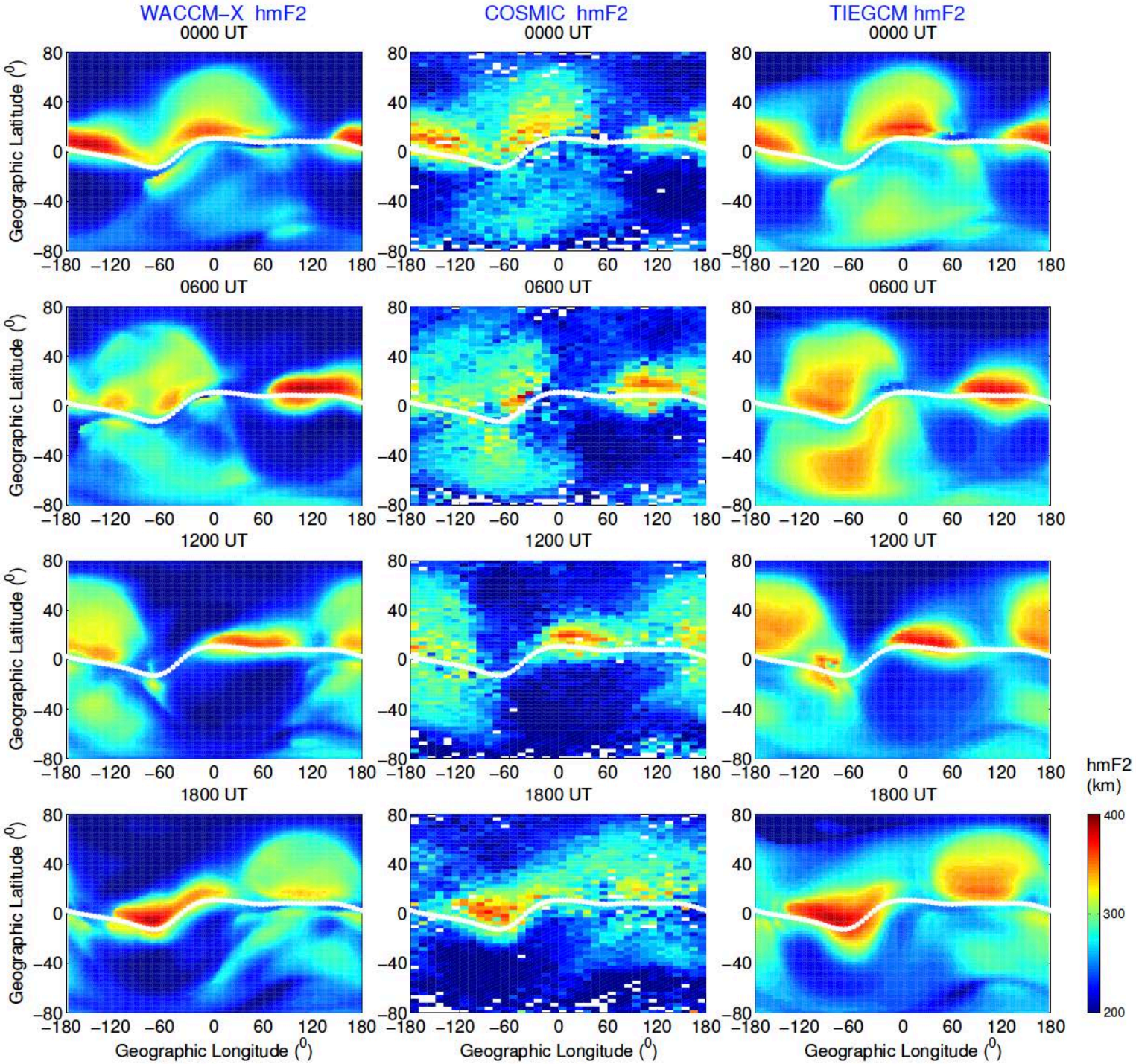




Liu et al., 2005

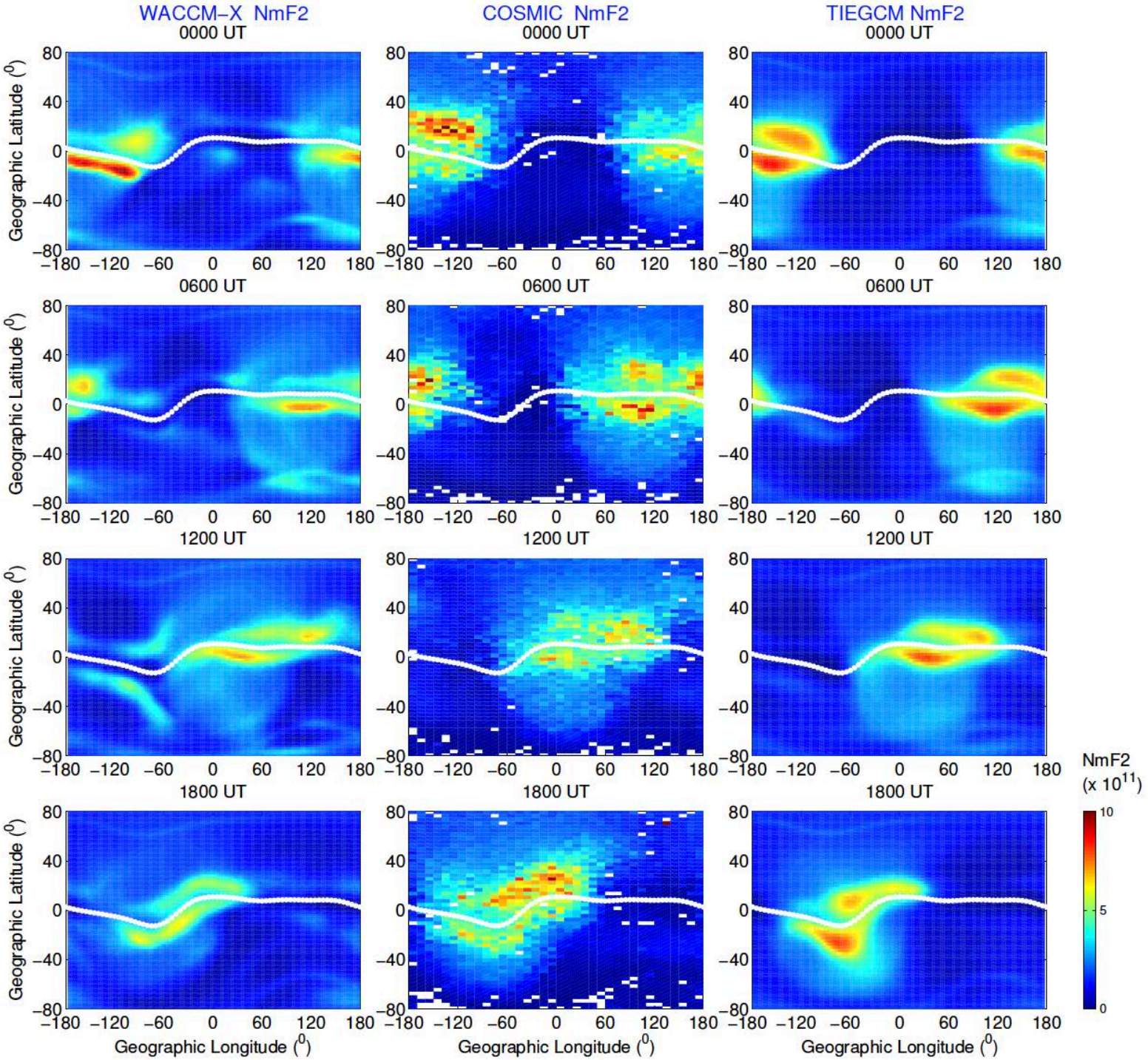
Liu et al., 2018

# Comparison with COSMIC 2008 June



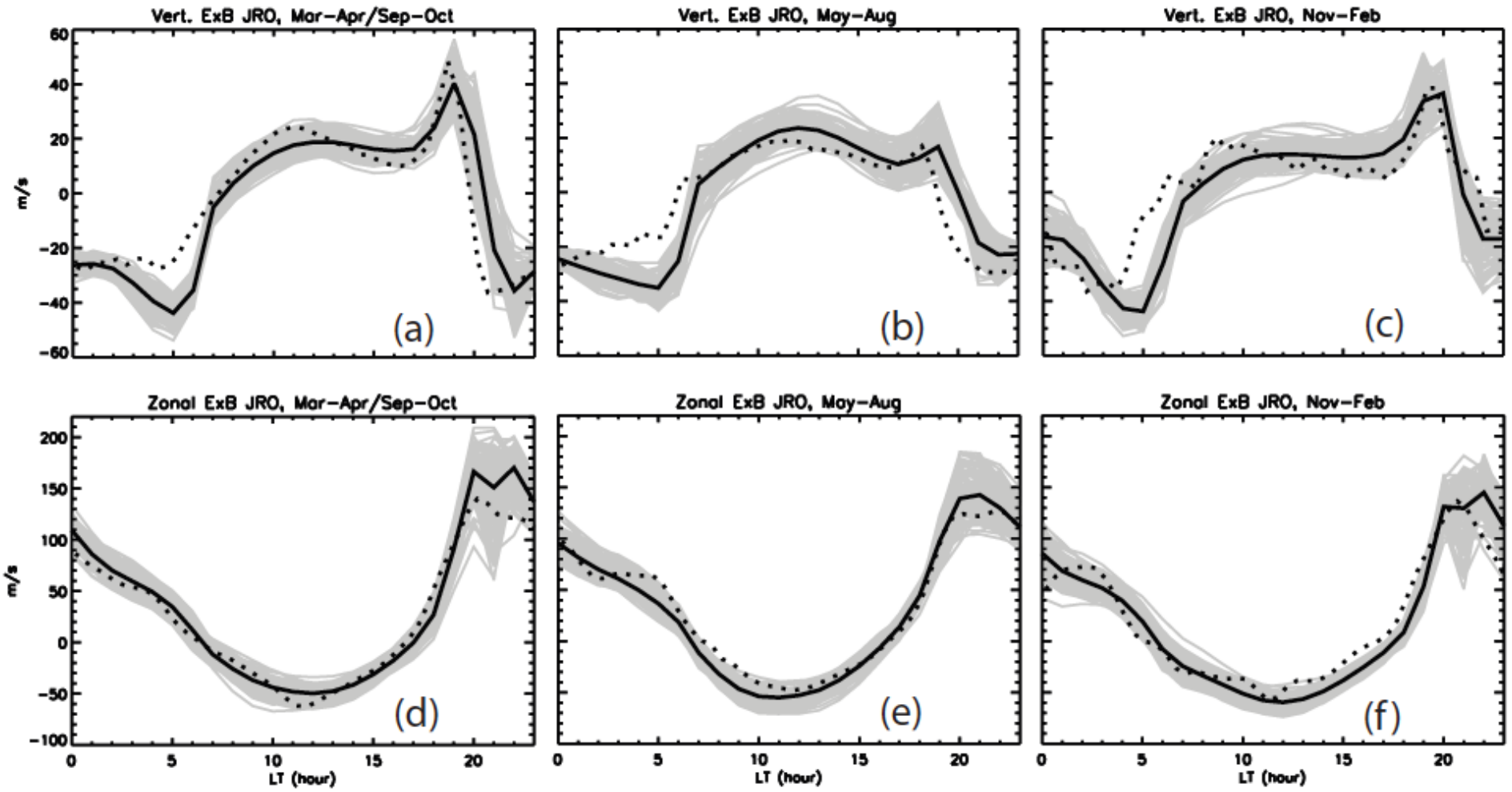

J. Liu et al. 2018

# Comparison with COSMIC 2008 June




J. Liu et al. 2018

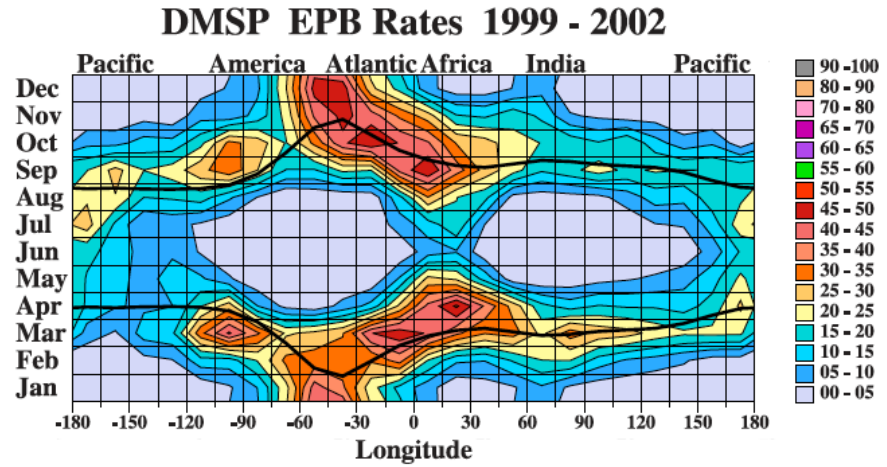
# ExB Drifts: WACCM-X vs Climatology



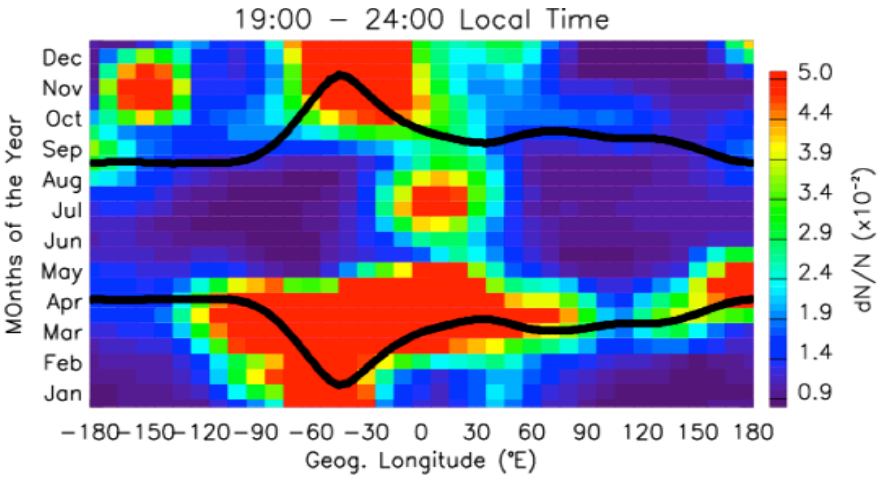

Liu et al., 2018

Dotted line: JRO climatology (Fejer et al., 1991)

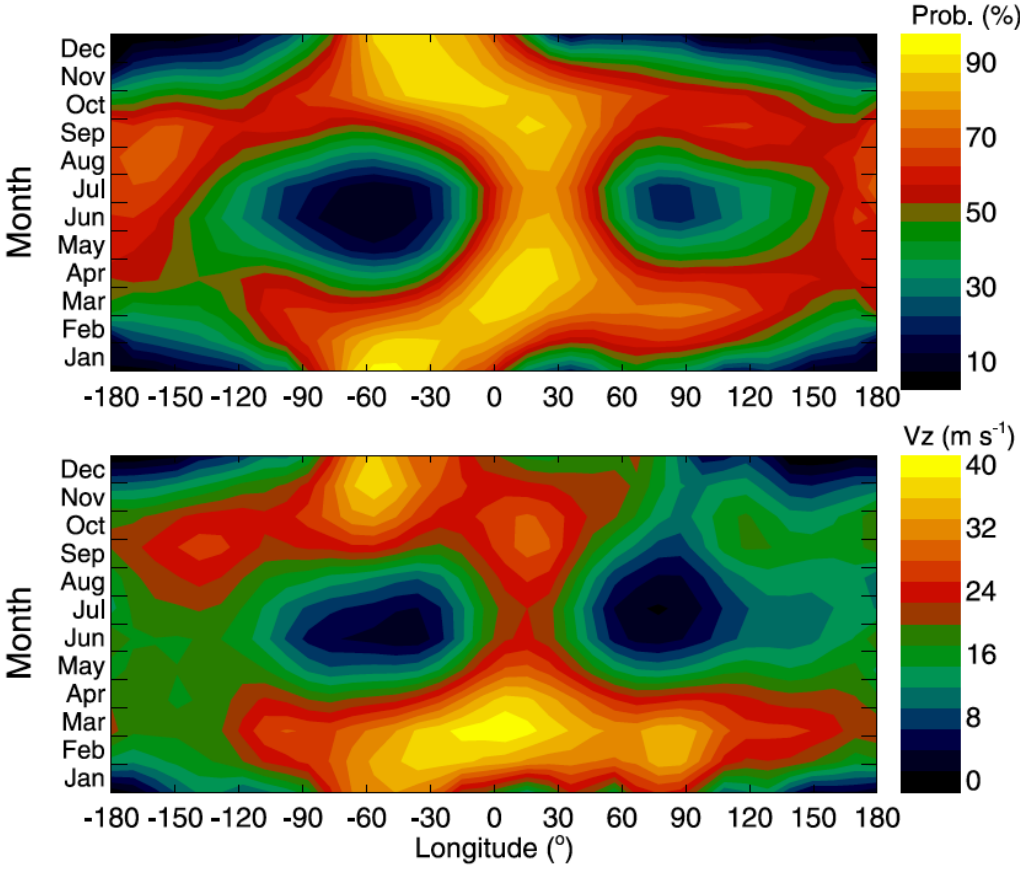
# Variability of PRE and Equatorial Plasma Bubbles (EPB)




Gentile et al., 2006

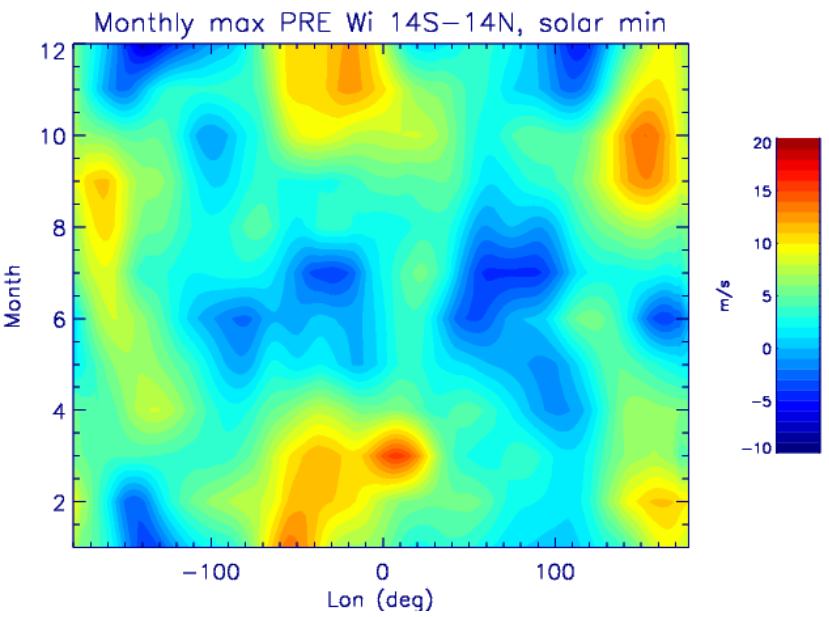


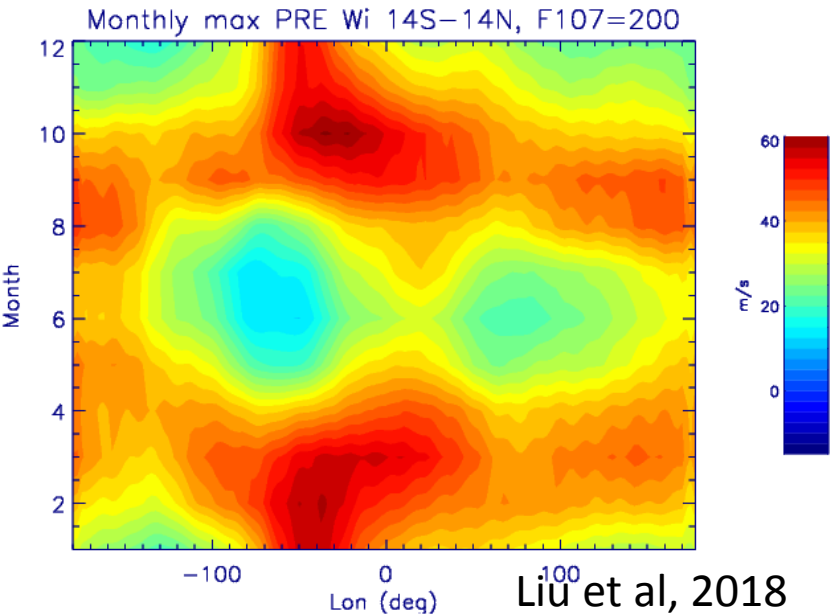

Yizengaw et al., 2014



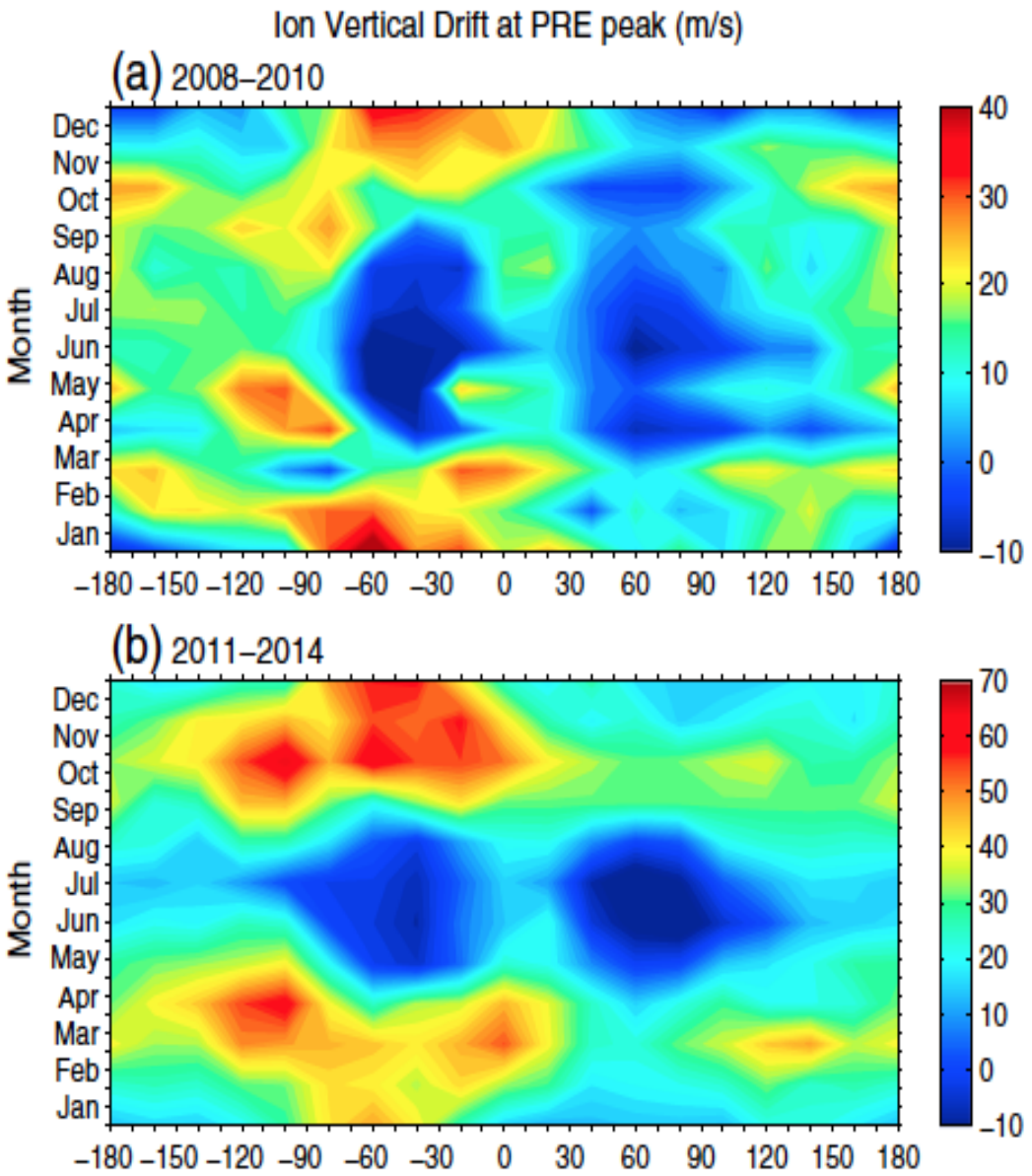

Kil et al., 2009

# Monthly Mean PRE Peak: WACCM-X and Obs.



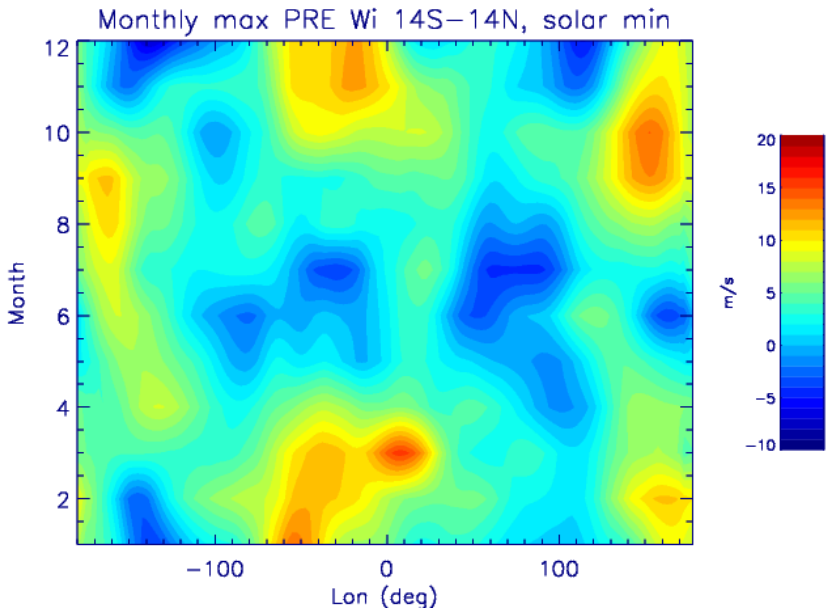



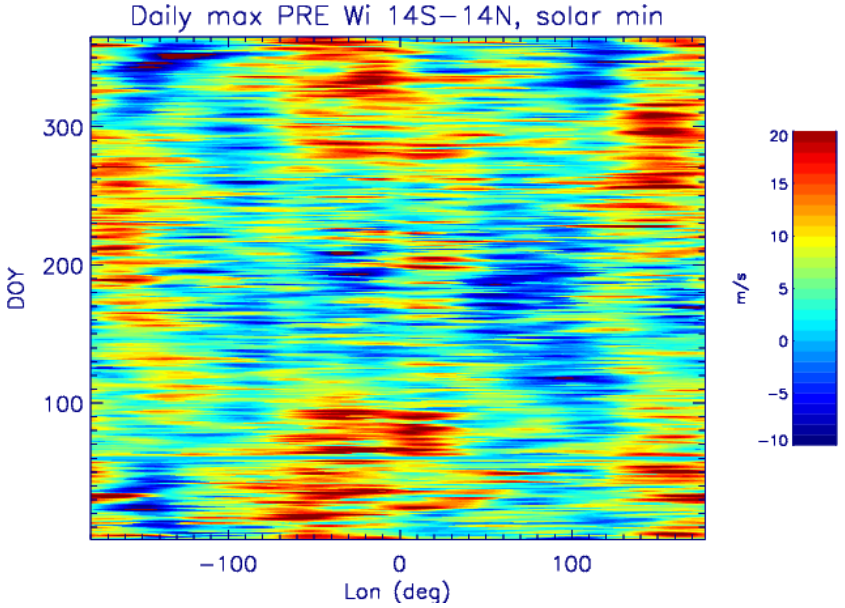

Liu et al, 2018

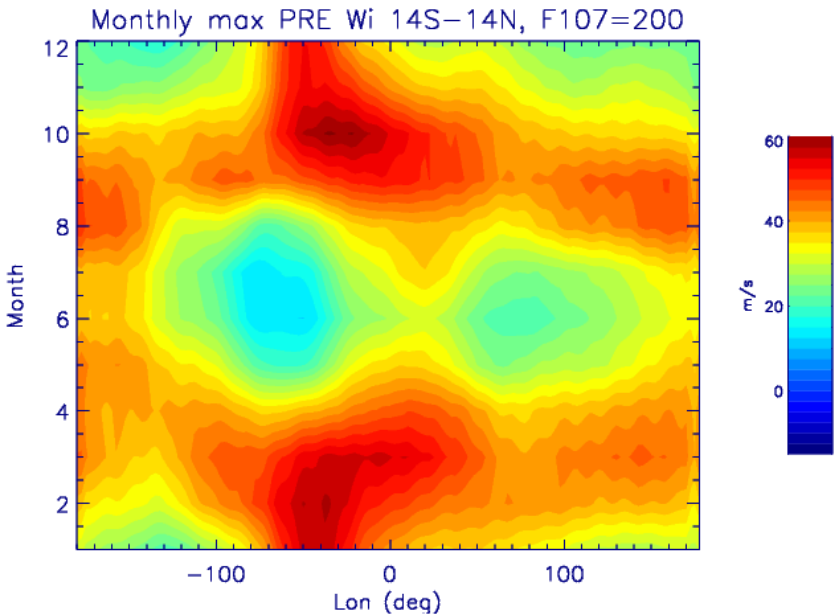


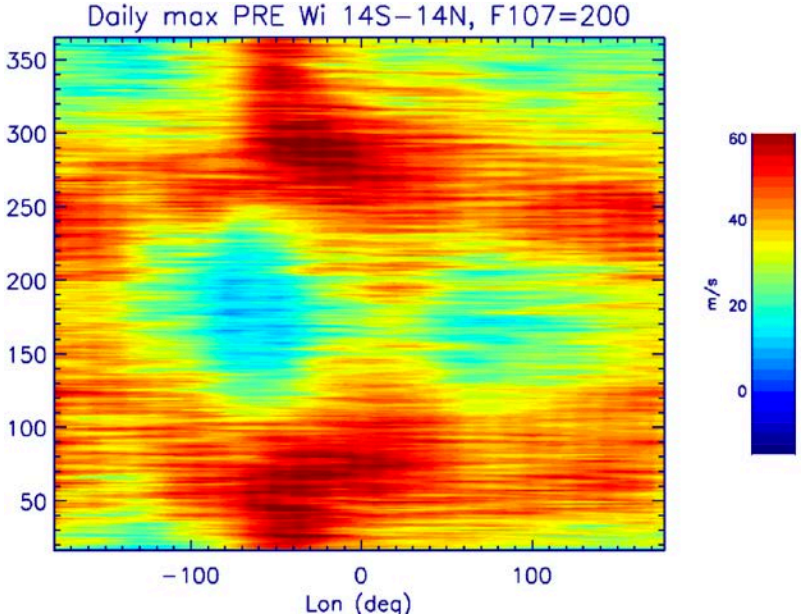

Huang and Hairston, 2015

# Monthly vs Daily Variability

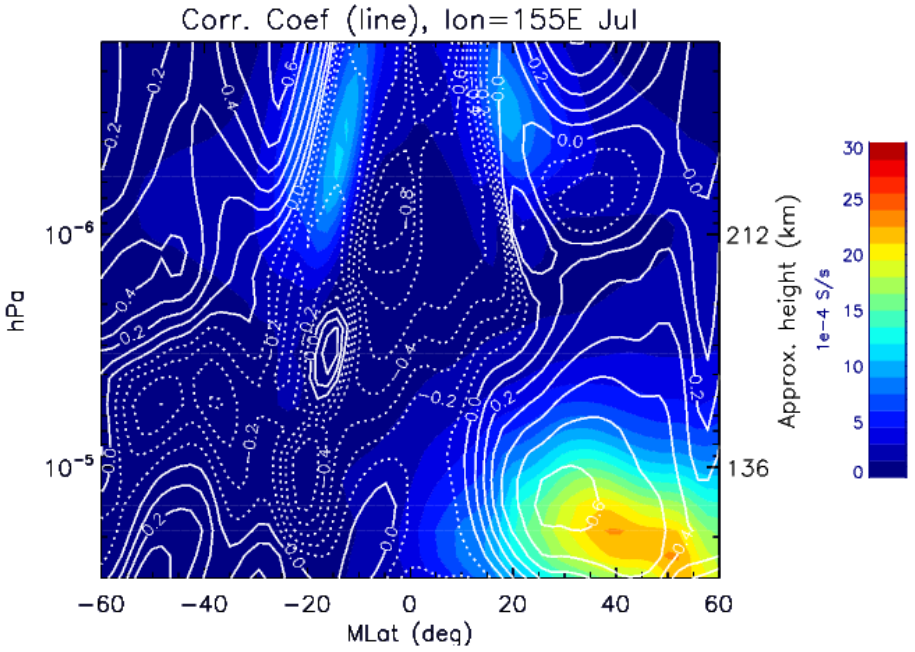


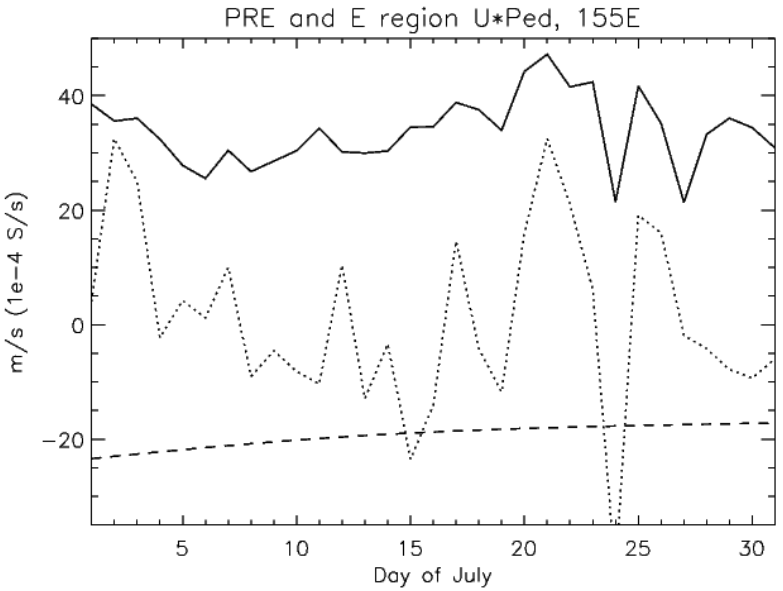



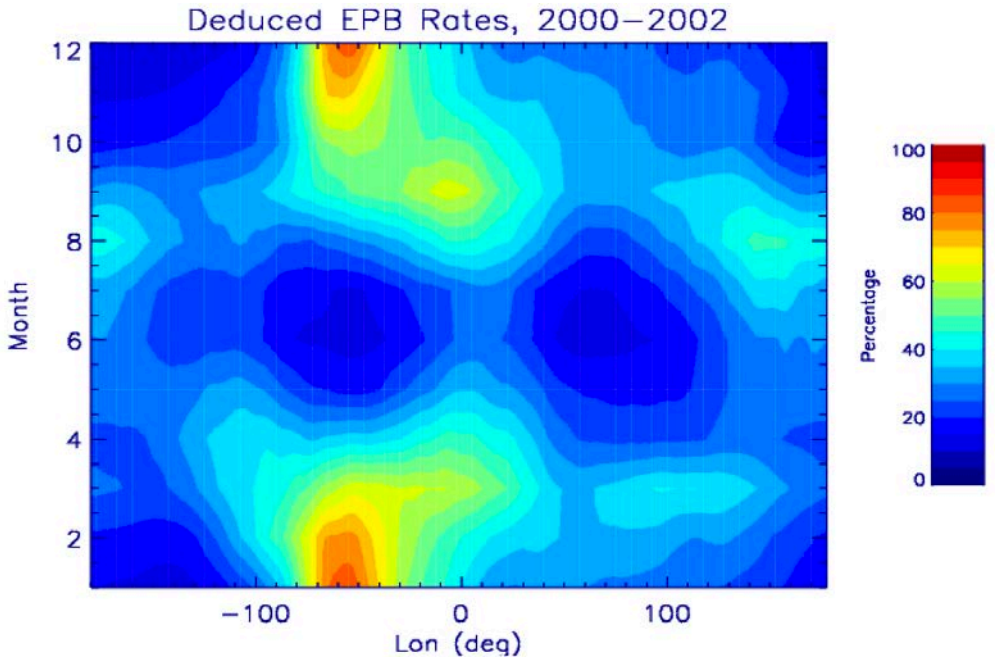
# Variability of PRE and E-region Dynamo

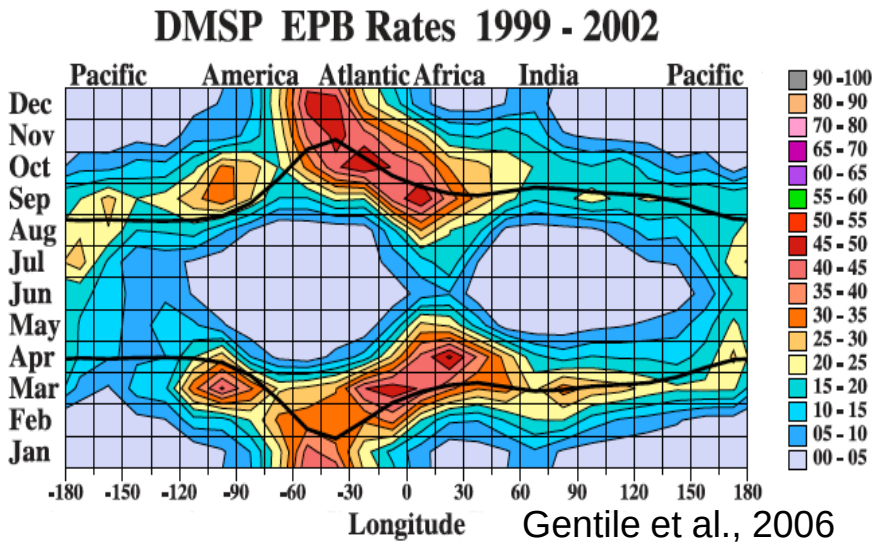


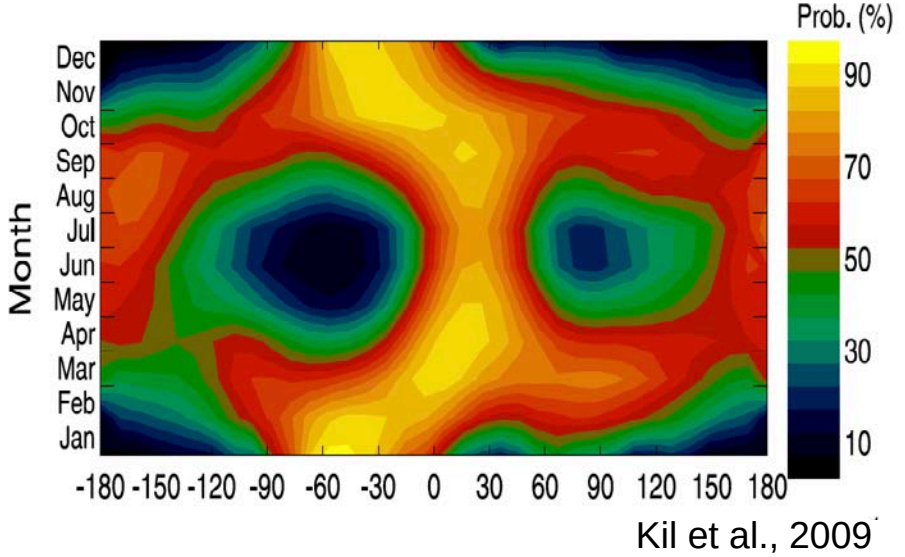

- Summer side E-region neutral wind variability at sunset time strongly affects PRE variability.
- E-region is strongly affected by lower atmospheric waves.

# Occurrence Frequency of Equatorial Plasma Bubbles




Gentile et al., 2006

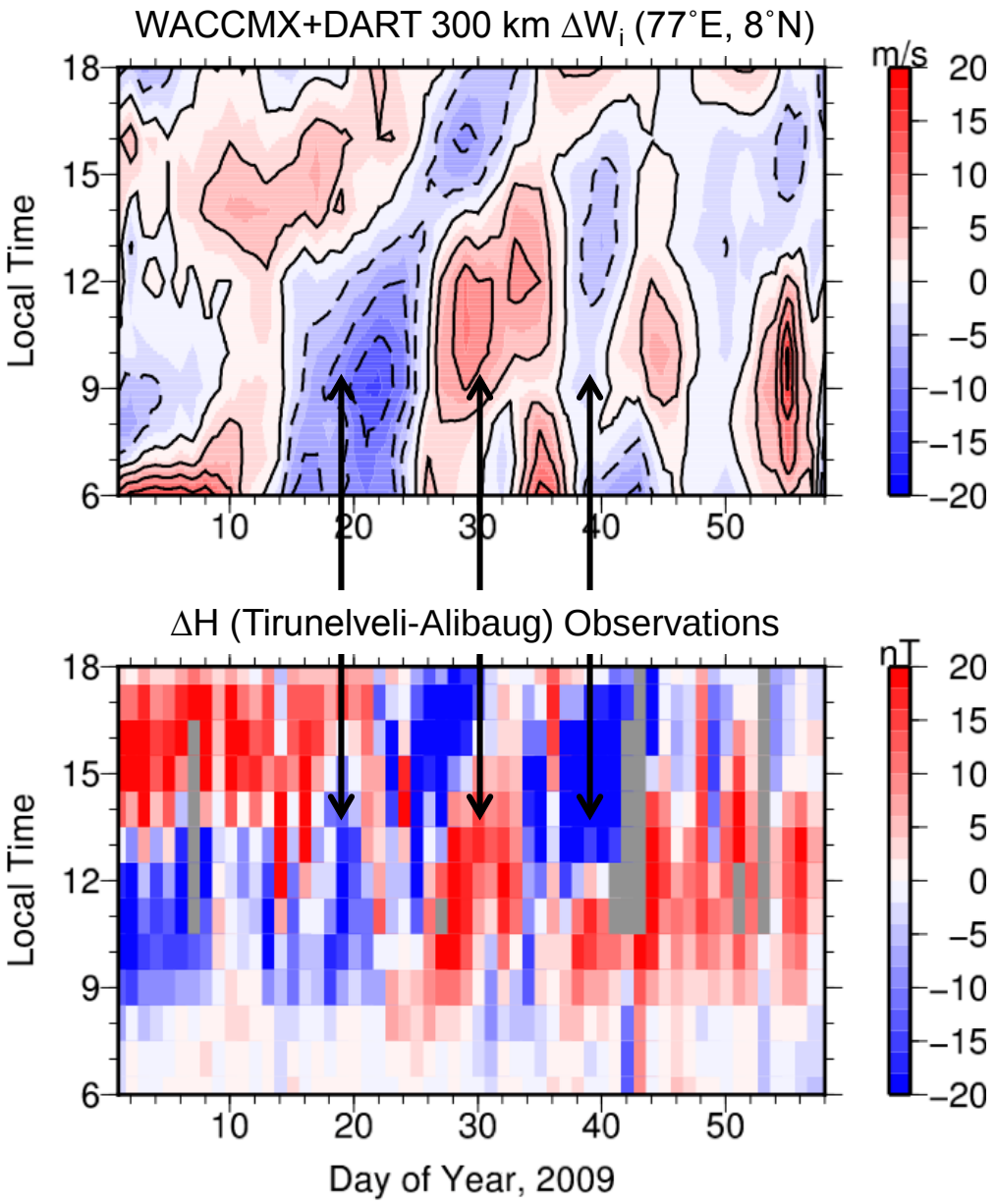



Kil et al., 2009

- The agreement between deduced EPB rates and the observed rates suggest
  - Large-scale dynamics and electrodynamics play a key role in preconditioning EPB
  - Feasibility for probabilistic forecast of EPB—an outlook/warning (analogous to tornado forecast).
- Simulating EPB evoution requires high-resolution capability.

# WACCM-X Data Assimilation: WACCM-X+DART

Ionosphere results based on assimilating data only below 100km (meteorological observations, Aura/MLS, and TIMED/SABER)**: Dominant ionospheric features can be forecast 10-20 days in advance.**




Pedatella et al., 2018

# Summary

- Key WACCM-X capabilities have been developed, and validated against thermospheric and ionospheric observations for both geomagnetically disturbed periods and quiet periods.
- Simulated PRE, an important quantity for the formation of EPB, shows longitudinal and seasonal variation similar to observations.
- Simulated PRE varies significantly from day-to-day. Deduced EPB rate is similar to observations.
  - Large-scale dynamics/electrodynamics important for preconditioning EPB.
  - Feasibility of probabilistic forecast of equatorial space weather events.