Whole Atmosphere Community Climate Model

– X –

Development Status

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High Altitude Observatory

National Center for Atmospheric Research

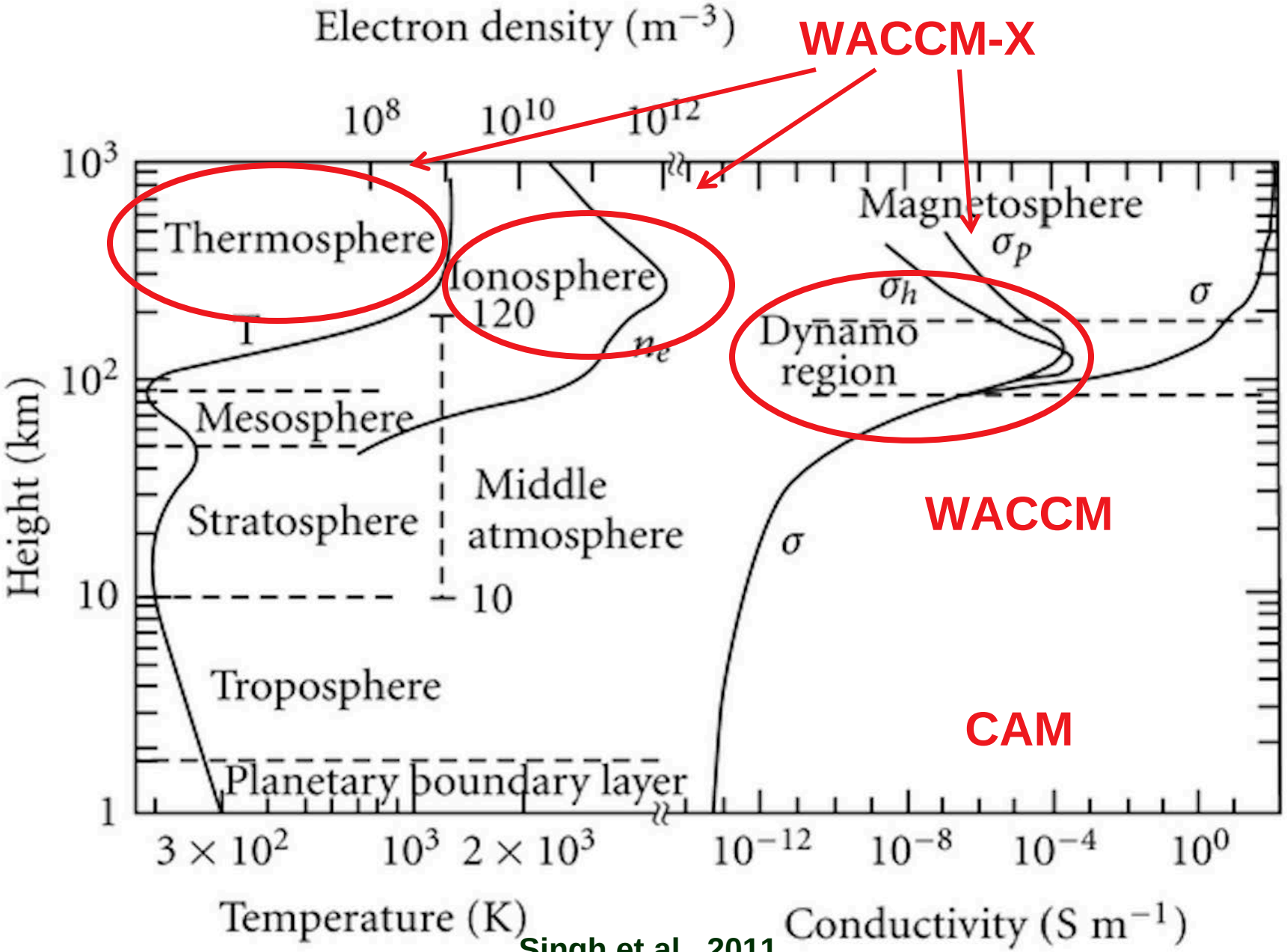
and

NCAR ACOM WACCM Group

Objectives of Whole Atmosphere – Ionosphere Modeling

Advances in whole atmosphere modeling are critical to addressing outstanding fundamental questions in ionosphere-thermosphere research.

- How do solar and geomagnetic influences affect the whole atmosphere?
- What are the relative roles of lower atmosphere and solar/geomagnetic forcing on the ionosphere-thermosphere system?
- How does anthropogenic change affect the thermosphere and ionosphere?
- How do atmospheric waves affect the energy and momentum coupling between the lower atmosphere and the ionosphere-thermosphere?
- What are the connections between small and large scale features in the system, e.g., “plasma bubbles”?
- How does the ionosphere-thermosphere vary over multiple time scales, e.g., “space weather” and “space climate”?

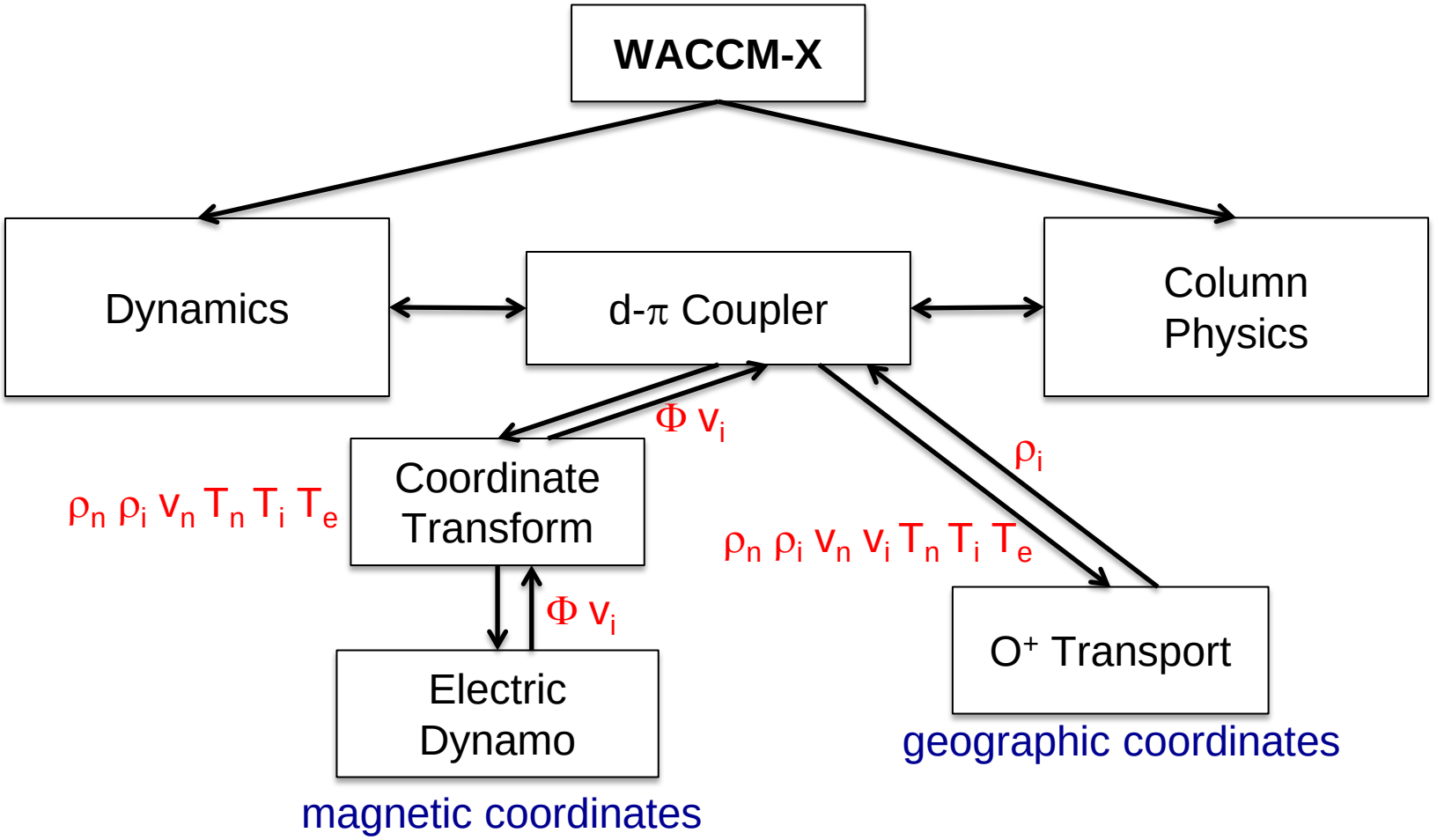


Singh et al., 2011

Major CESM WACCM/WACCM-X Components

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

Ionospheric Dynamics and Electric Dynamo in WACCM-X



d-π Coupler: dynamics-physics-ionosphere-electrodynamics (D-PIE) coupler
Electric Dynamo: calculates global electric potential resulting from wind-driven ions
ρ: density v: velocity T: temperature n: neutral i: ion e: electron Φ: electric potential

Recent Progress on WACCM-X

- Ion and electron energetics implemented
  - Thermal electron heating -> neutral temperature increase
- Improvements in thermosphere
  - Time dependent solar EUV input, O(^{3}P) cooling, H escape flux, helium as a minor species (being tested)
- Parallel equatorial electrodynamo added using geomagnetic coordinates
- Ionospheric dynamics installed
  - Vertical diffusion ("ambipolar diffusion") of O^+
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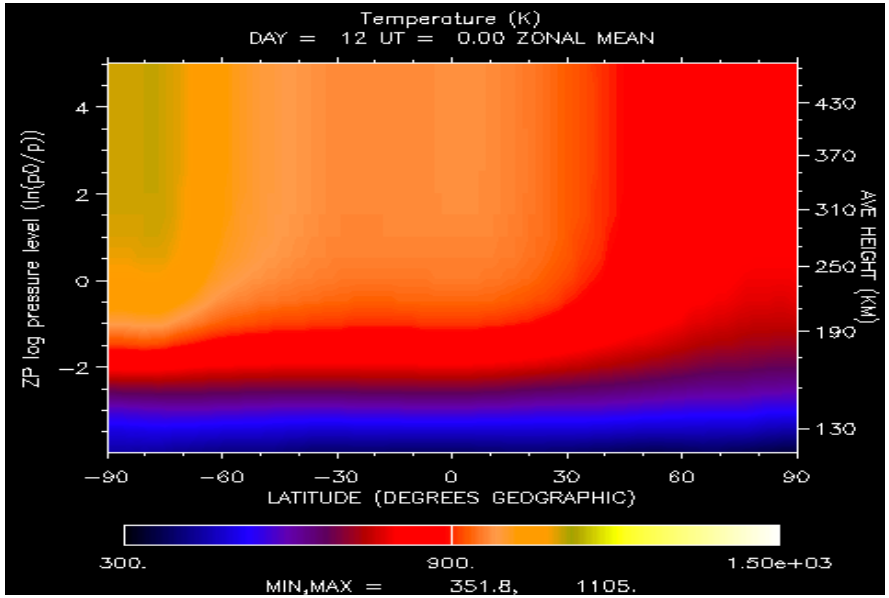
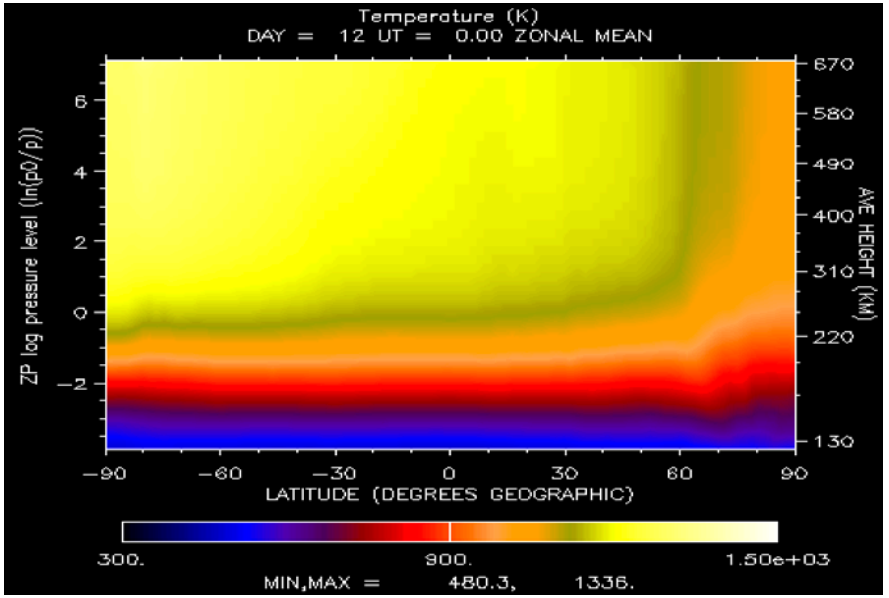
Previous WACCM-X Release



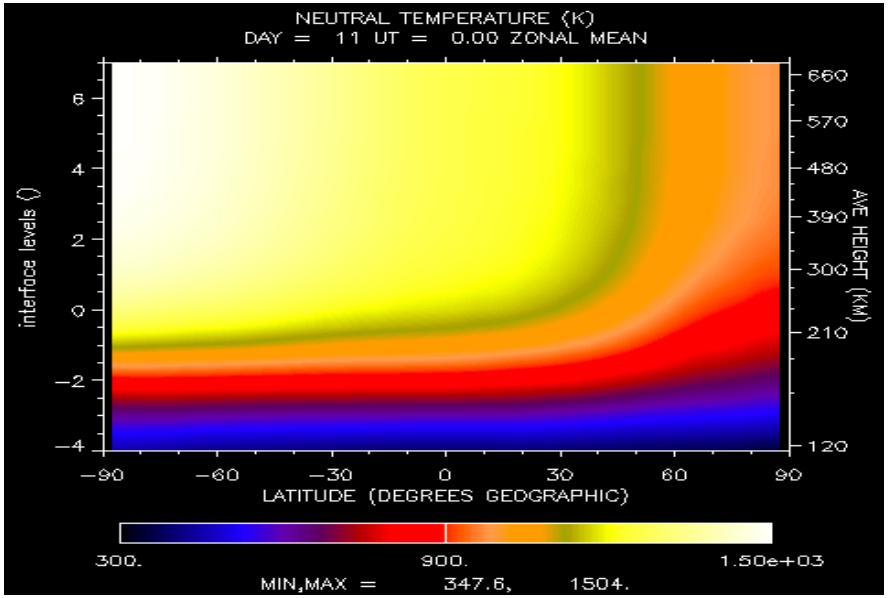
Current WACCM-X



Thermospheric Zonal Mean Temperature (January)

- Ion/electron energetics added
- Thermal electron heating results in higher thermospheric temperature
- Improvement when compared to TIE-GCM

TIE-GCM



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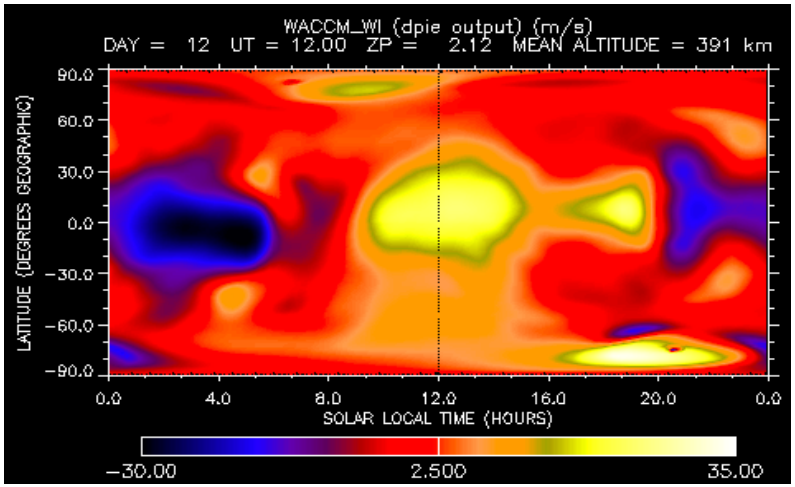
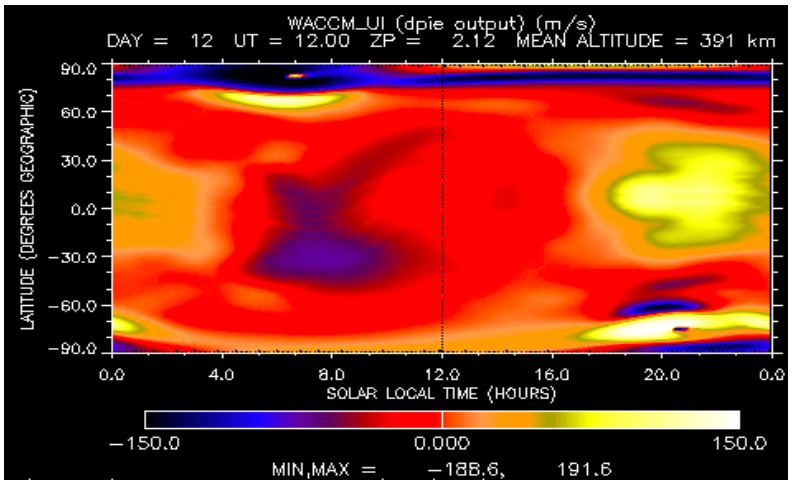
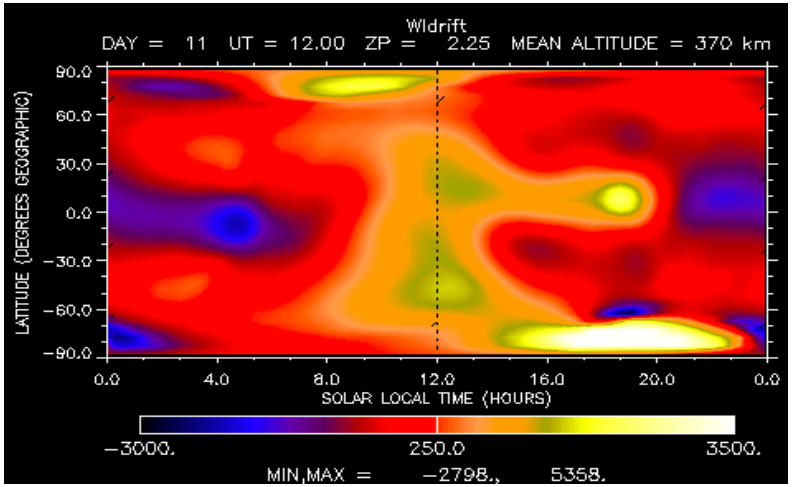
Plasma Drifts

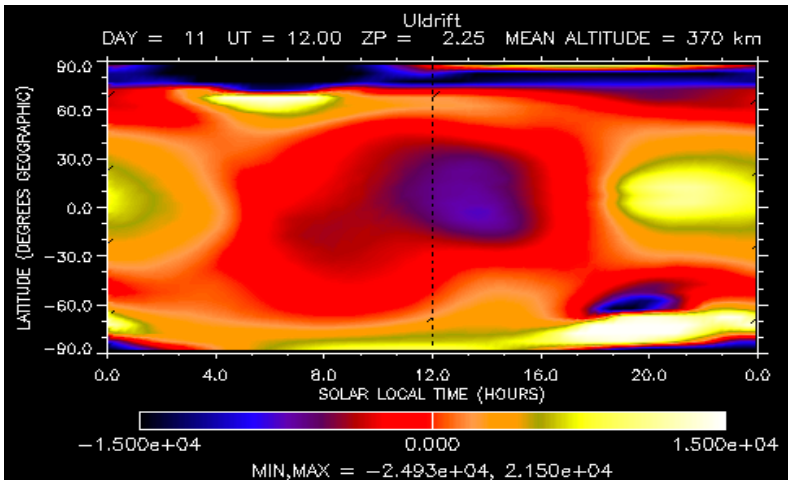
WACCM-X





TIE-GCM



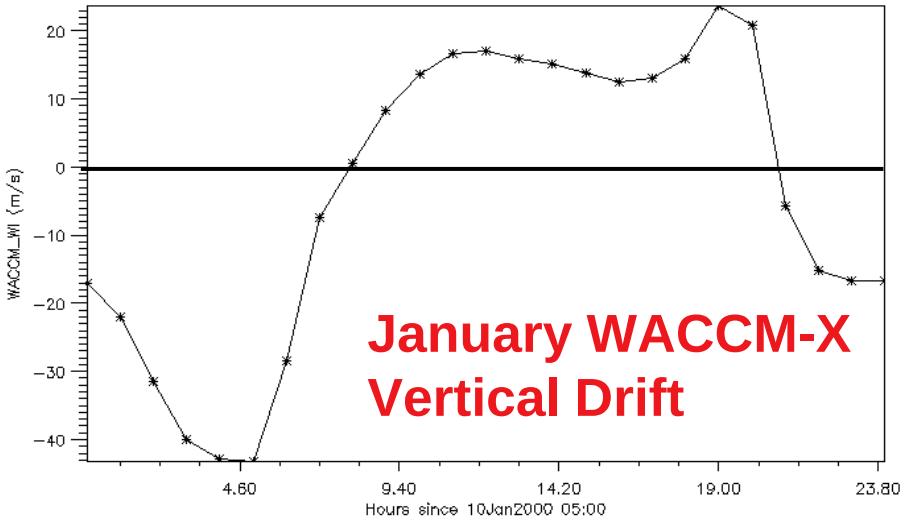


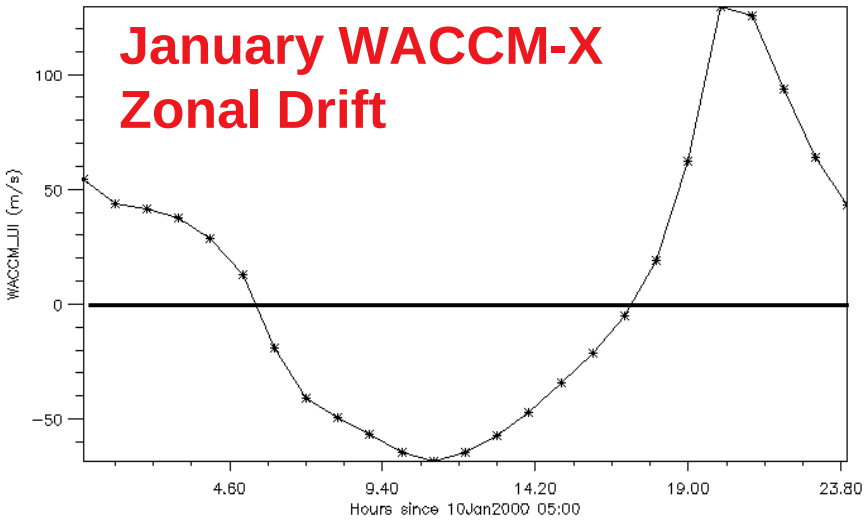
Vertical Drift

Zonal Drift

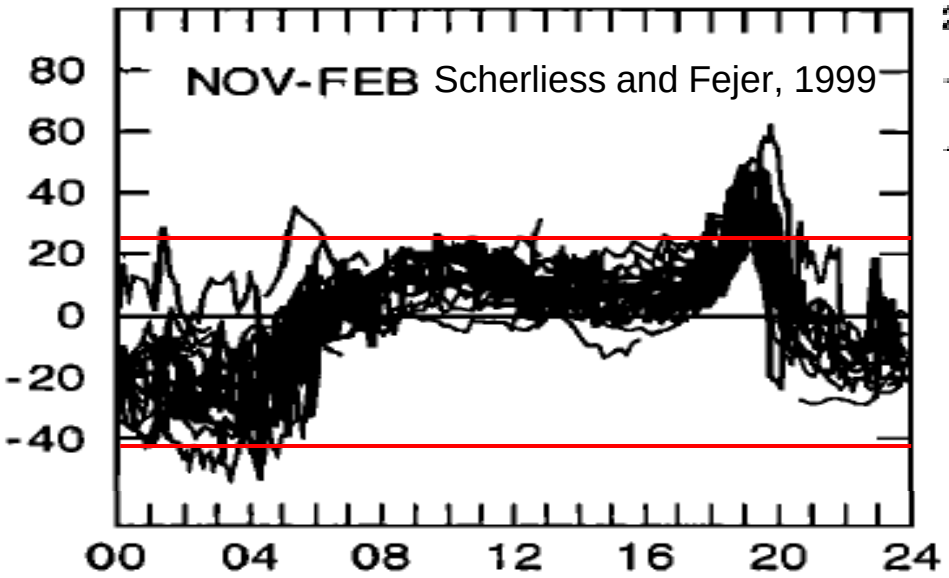
- **Interactive ionospheric electric wind dynamo produces plasma drifts**
- **Vertical and horizontal plasma drifts in good agreement with climatology and TIE-GCM**
- **Vertical drifts upward during day, downward at night, and a clear pre-reversal enhancement**

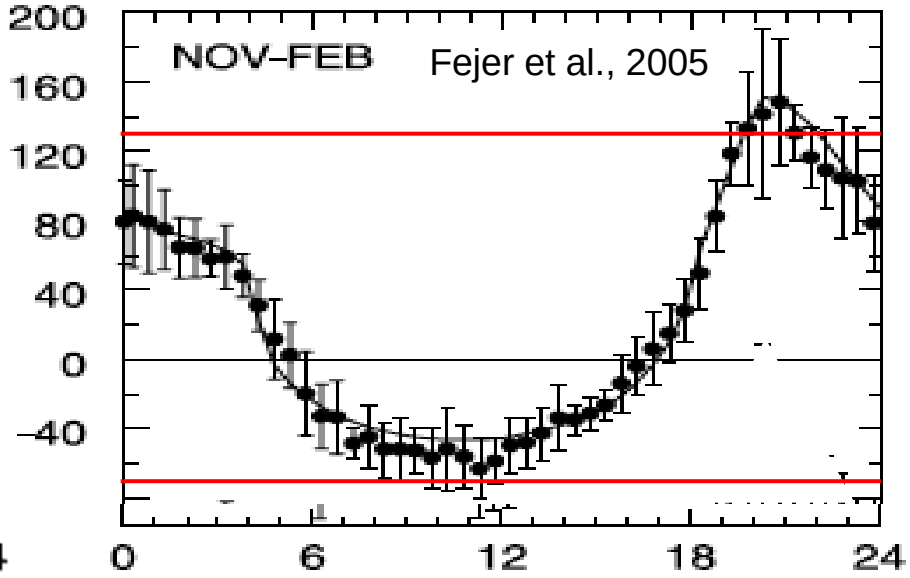
WACCM-X Equatorial ExB Drifts: Model and Radar Observations (Solar Maximum)





ExB Drift





Solar Local Time (Hours)

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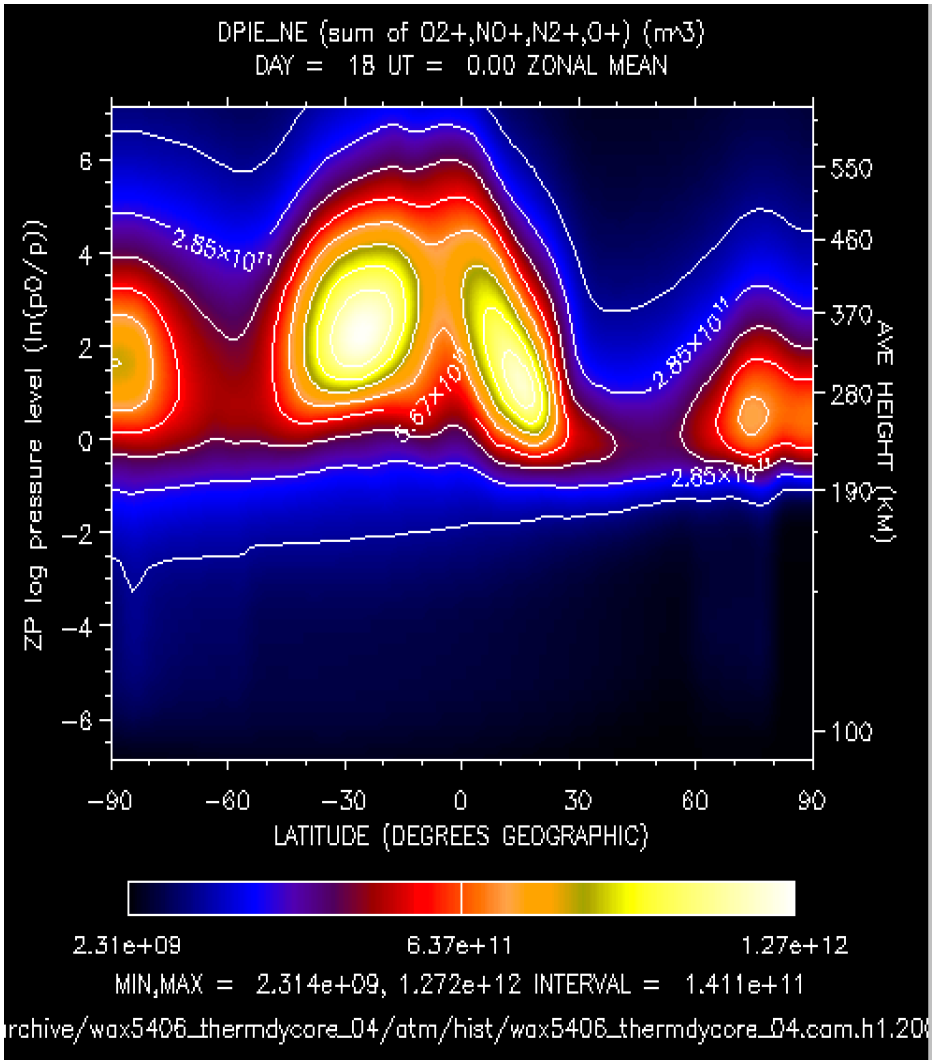
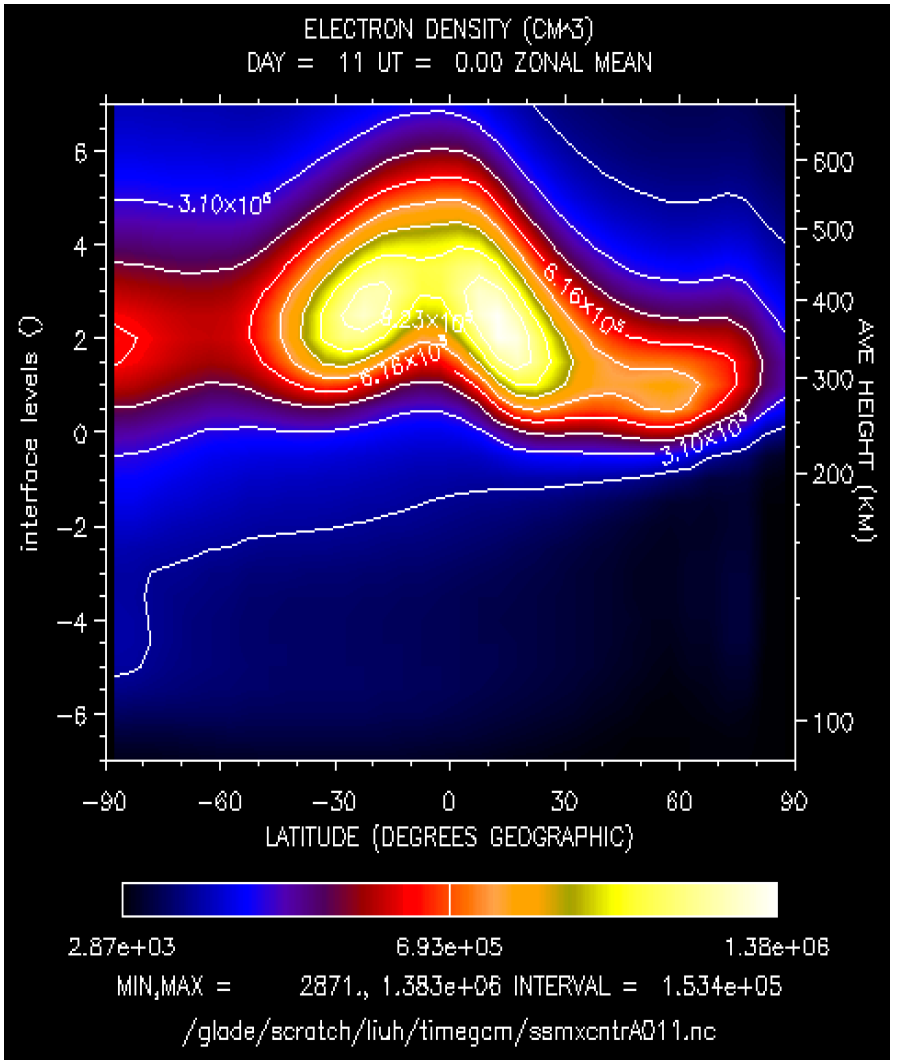
Zonal Mean Electron Number Density

WACCM-X

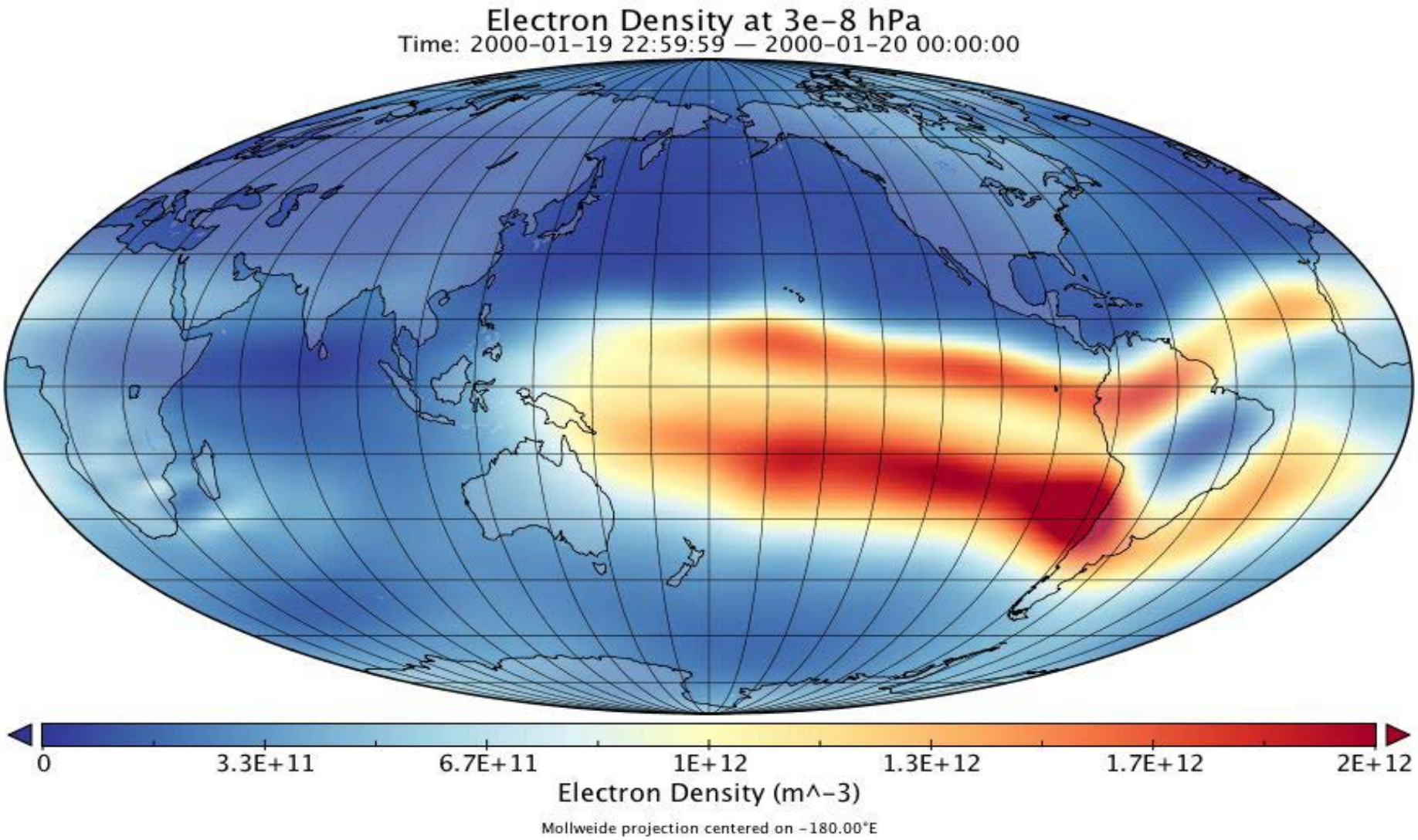


TIE-GCM



- **With ionospheric dynamics, now get equatorial ionospheric anomaly pattern similar to TIE-GCM**

WACCM-X Ionosphere at ~250 km



- **Electrodynamo and Ion transport**
- **Includes ambipolar diffusion, field-aligned transport, and ExB drifts**
- **A well-defined equatorial ionospheric anomaly is produced by the model.**

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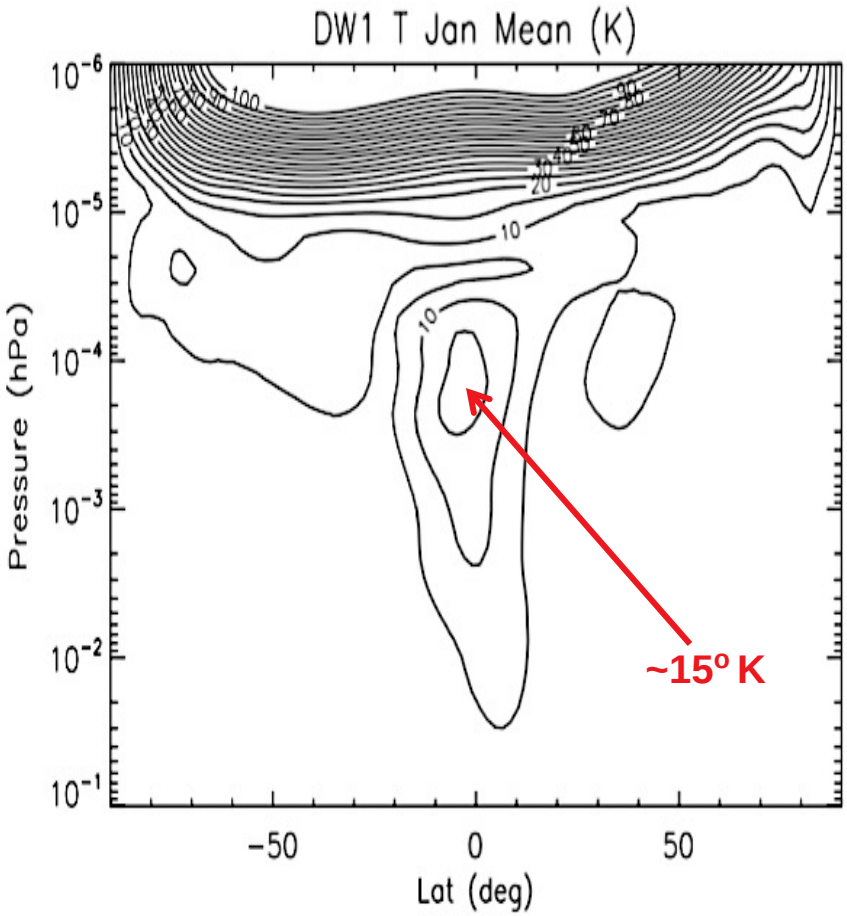
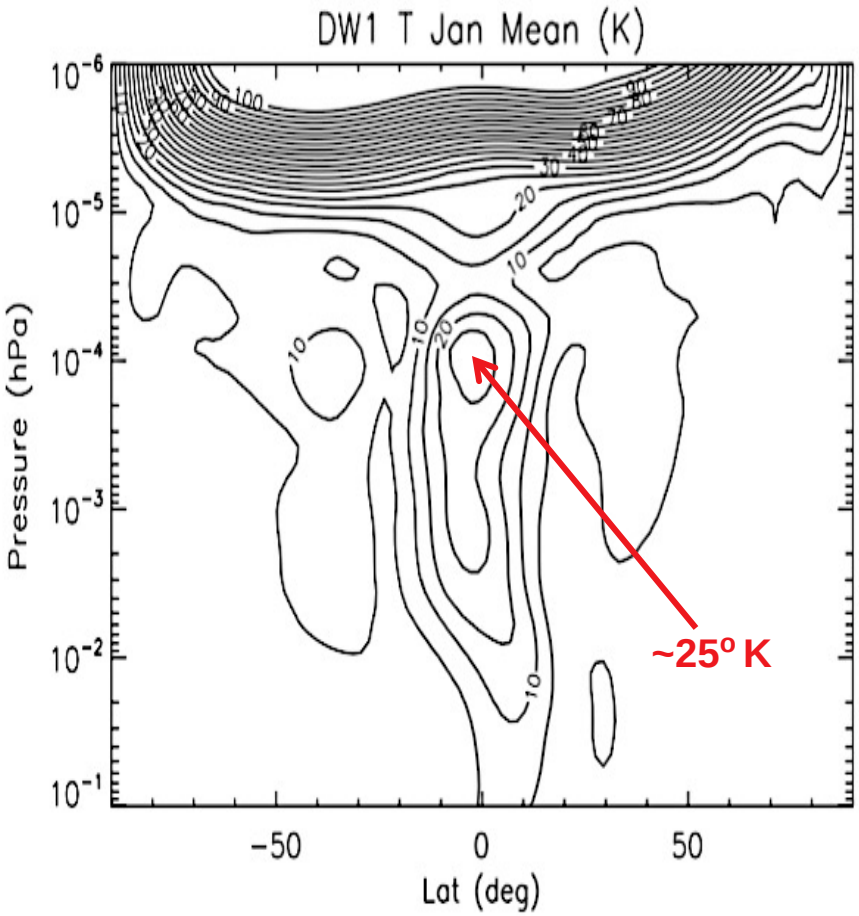
WACCM-X Temperature Tidal Amplitudes (DW1)

Default Divergence Damping



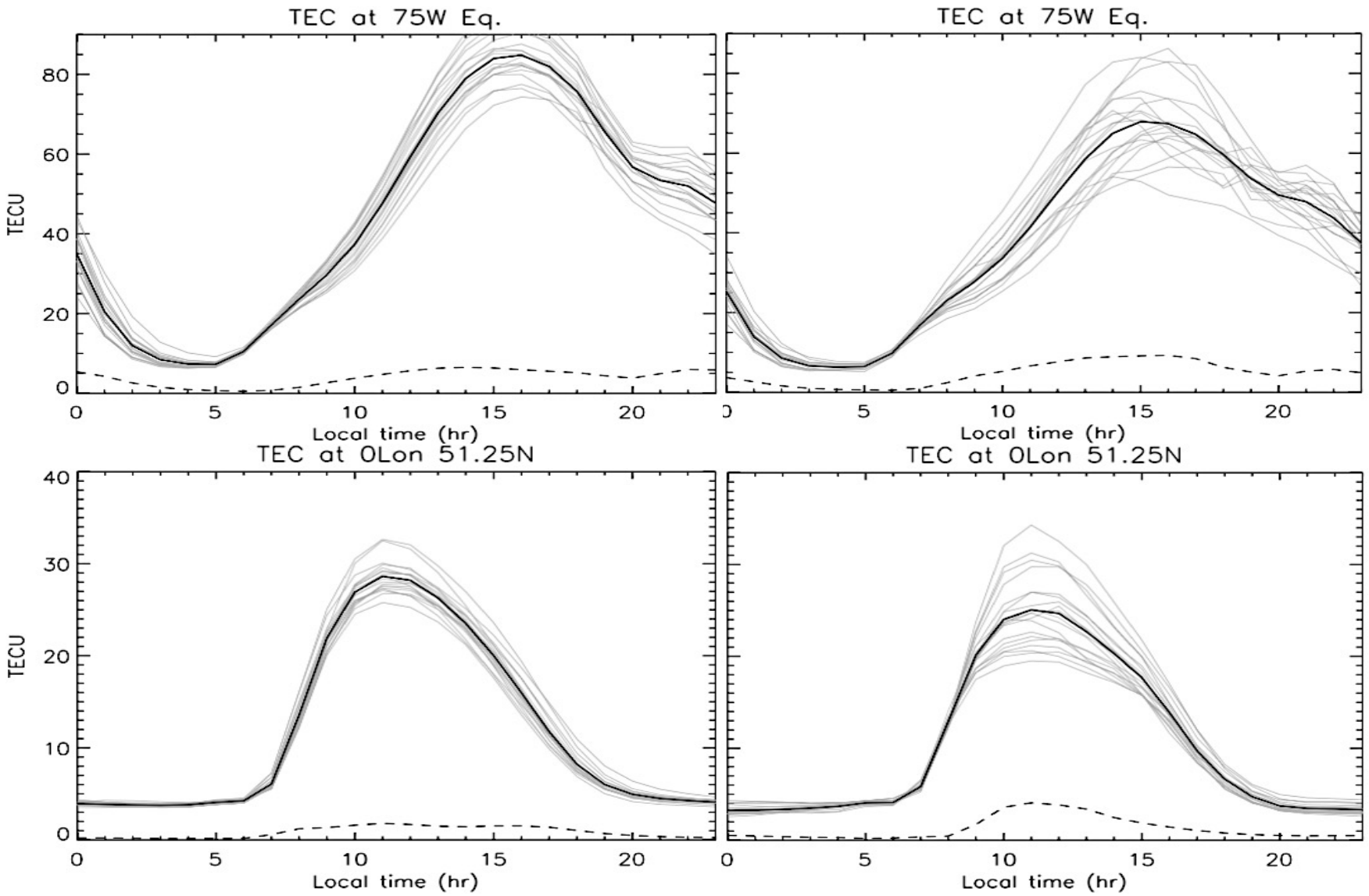
Reduced Divergence Damping



- In CAM, divergence damping set to a default value
- Results in lower amplitude and less variability of diurnal tides propagating through the atmosphere
- In WACCM/WACCM-X this has a significant impact in the mesosphere/thermosphere
- Optimum value for most realistic tides and stability still being investigated

Ionospheric Variability: Total Electron Content (TEC)

Default Divergence Damping **Reduced Divergence Damping**



- **Reduced divergence damping increases TEC variability (dashed)**

Next Step: Implementing an Ionosphere-Plasmasphere Model in WACCM-X

— Geomagnetic coordinate system

— Interhemispheric coupling

— Auroral-equatorial coupling of electrodynamics

— Field-aligned current approach to solving the global electric potential

— Capability for coupling to magnetospheric model

Continuing Development

— Clean up the code to be ready for inclusion in CAM trunk and CESM2

— Testing: helium as minor species, divergence damping, and species dependent specific heat and gas constant in dynamical core

— General verification/validation against observations and empirical models

— Perform SD-WACCM-X runs for targeted time periods with many available thermosphere and ionosphere observations (2009 and/or 2013 SSW periods) for further validation

— WACCM-X+DART for whole atmosphere data assimilation (HAO/DA Postdoctoral Fellow and Nick's talk)