# Whole Atmosphere Community Climate Model

# – X –

# Status, Development, Plans

**AIM Section (& alumni)**

High Altitude Observatory

National Center for Atmospheric Research

HAO

NCAR

# 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 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 anthropogenic change affect the thermosphere and ionosphere?
- How does the ionosphere-thermosphere vary over multiple time scales, e.g., “space weather” and “space climate”?

*There are several possible numerical modeling approaches to addressing these questions; model development that exploits other efforts and advances across NCAR is particularly attractive in a resource-constrained environment.*

# Recent Progress on WACCM-X

- Ion and electron energetics implemented:

    Now calculating $T_i$ and $T_e$ in WACCM-X.

    (Still set $T_i$=$T_e$=$T_n$ in WACCM, which is a good approximation up to ~150 km.)

- Equatorial electrodynamo installed:

    Mostly parallel, with ESMF interpolation from geographic to geomagnetic coords.

- Ionospheric dynamics in progress:

    Vertical diffusion (“ambipolar diffusion”) of $O^+$.

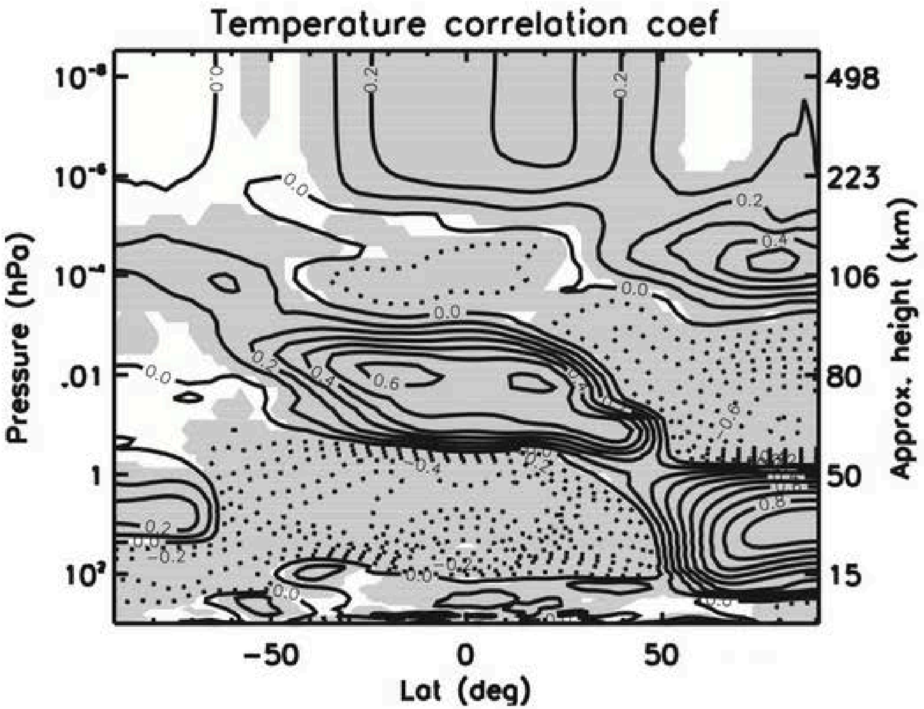
    Horizontal transport of $O^+$ in the upper ionosphere.

# WACCM and WACCM-X Components and Status

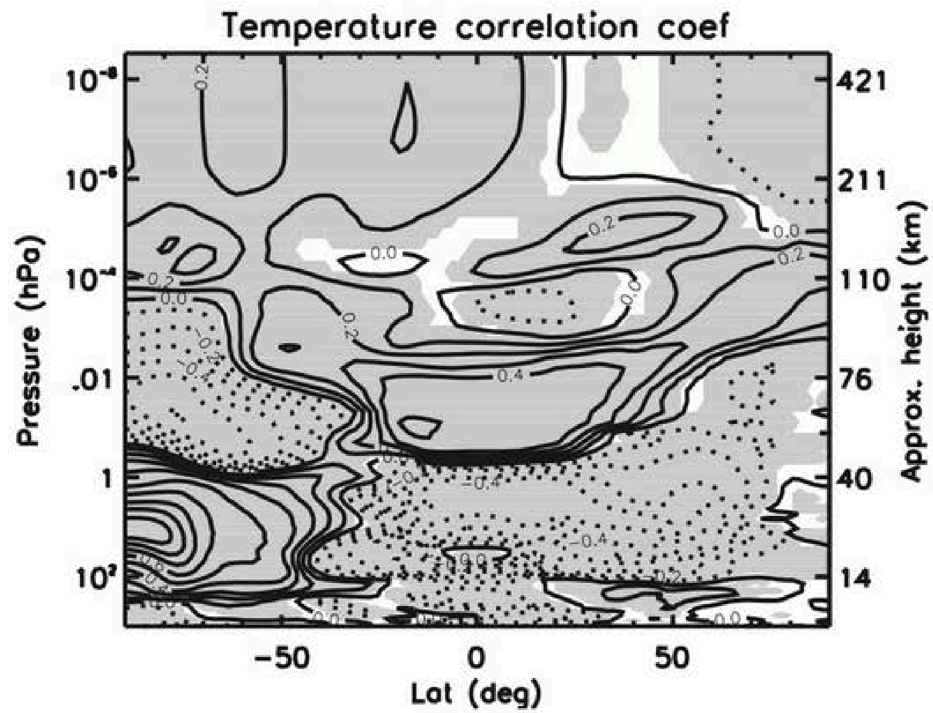
| Model Framework | Chemistry | Physics | Physics-X | Resolution |
|---|---|---|---|---|
| Extension of the NCAR Community Atmosphere Model (CAM)<br><br>Finite Volume Dynamical Core | MOZART+ Ion Chemistry (~60 species)<br><br>Fully-interactive with dynamics. | Long wave/short wave/EUV<br><br>RRTMG<br><br>IR cooling (LTE/non-LTE)<br><br>Modal Aerosol<br><br>CARMA<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>Ionospheric dynamo<br><br>Ion/electron transport<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>81/125 levels 0-~500km<br><br>• < 1.0km in Upper Troposphere/ Lower Stratosphere<br>• 1-2 km in strat.<br>• 0.5 scale height in mesosphere/ thermosphere (0.25 scale height in mesosphere/thermosphere with 125 levels) |

# Highlights — Momentum Coupling and Wave Propagation

**Northern Hemisphere Winter**



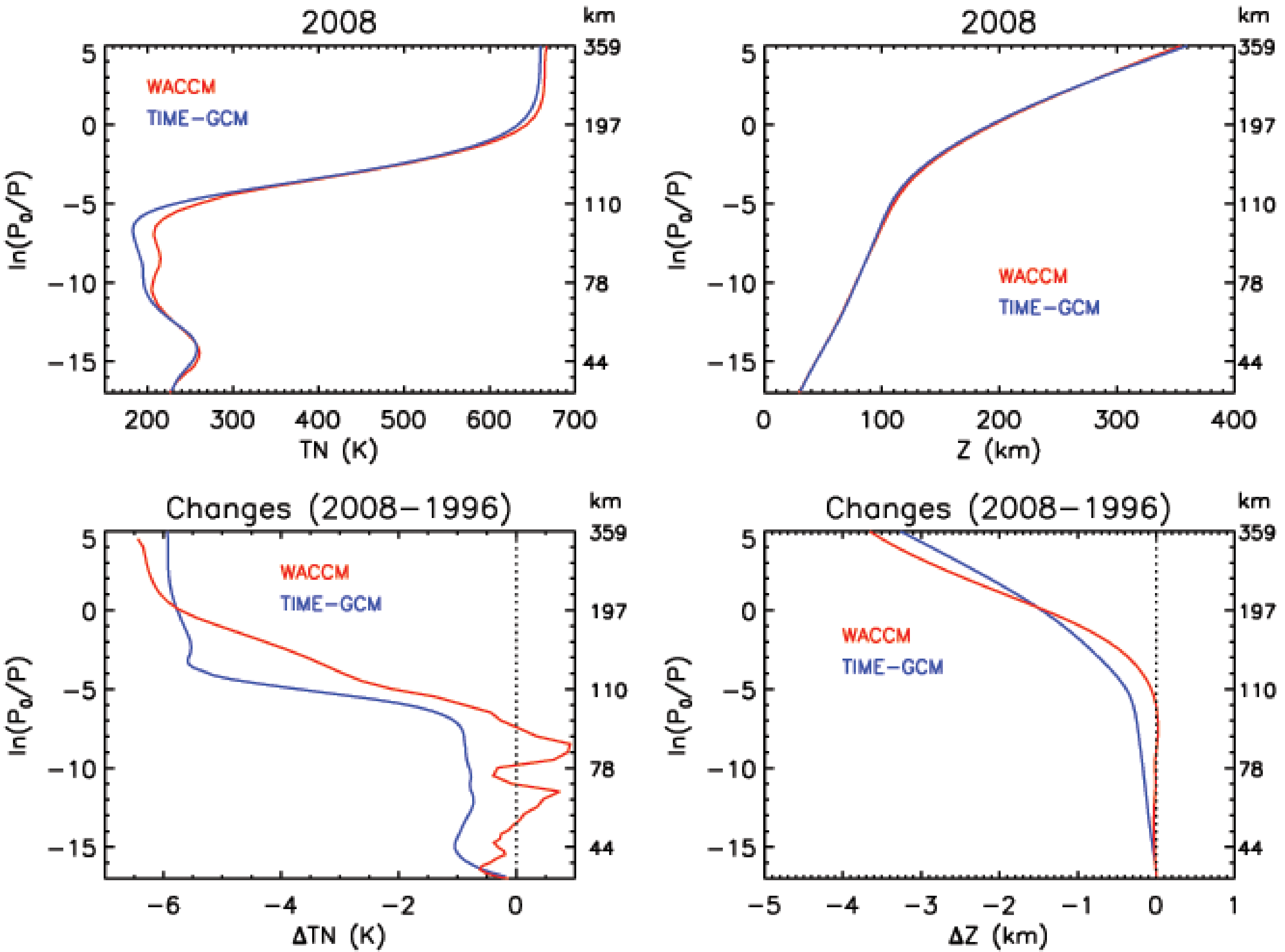

**Southern Hemisphere Winter**



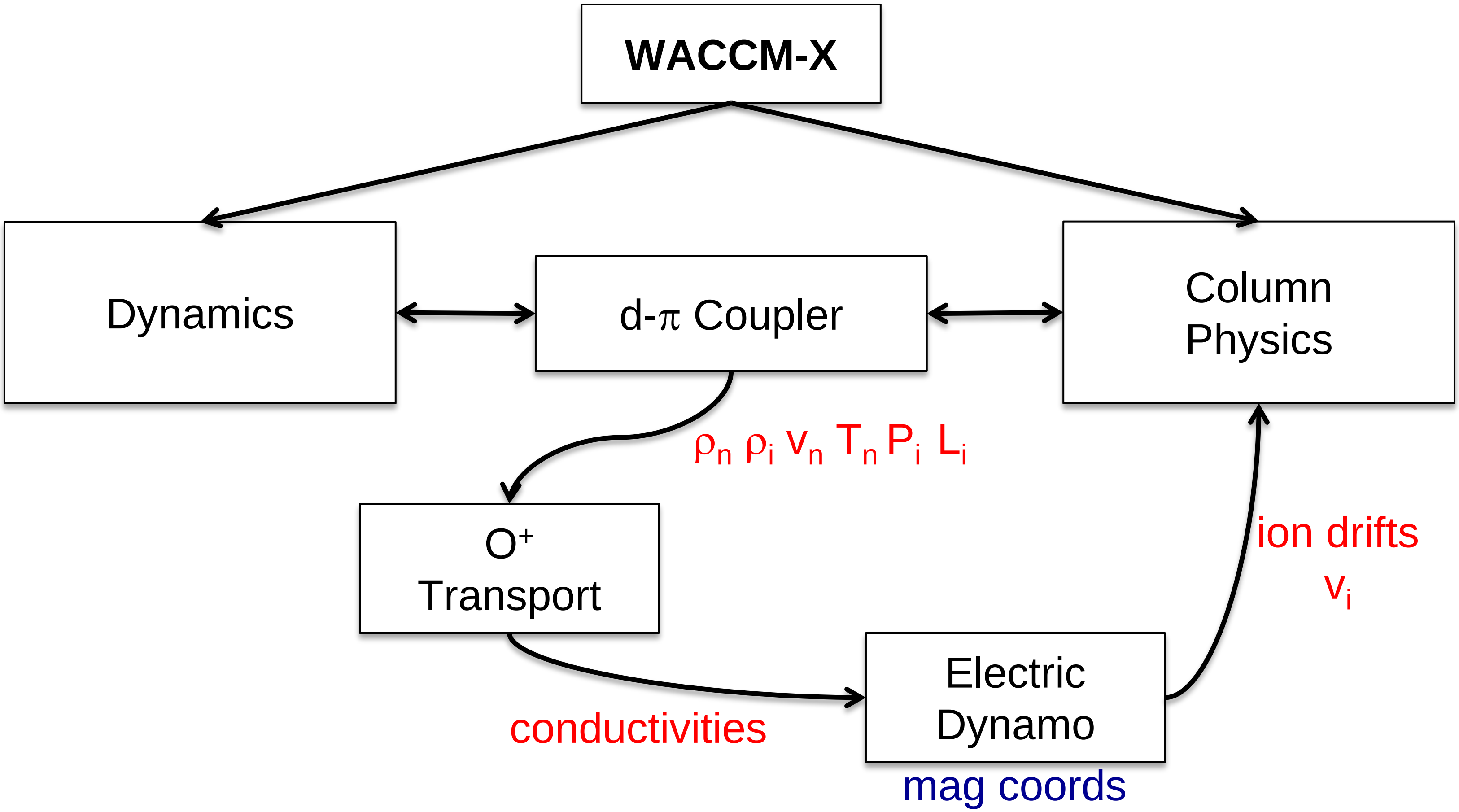

WACCM-X temperature correlation map showing teleconnections between the polar winter stratosphere and the mid-latitude mesosphere-thermosphere

Hanli Liu, *AGU Geophysical Monograph*, *201*, 181, 2014.

# Highlights — Climate Change (preliminary results)



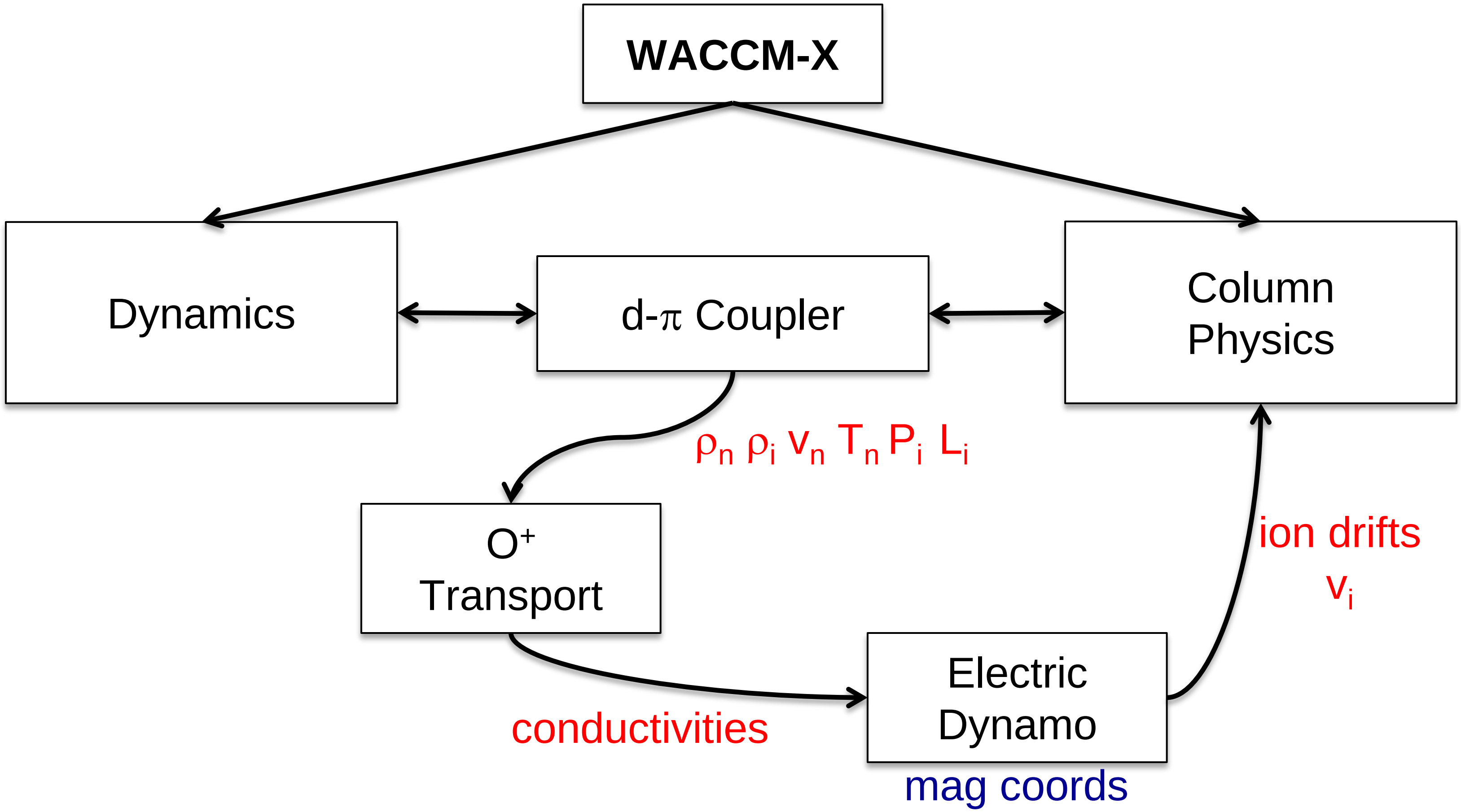
# Integrating Ionospheric Dynamics into WACCM-X




Current concept is to put $O^+$ transport inside the d-$\pi$ Coupler

— Essentially adopting the existing TIME-GCM geographic scheme.

# Integrating Ionospheric Dynamics into WACCM-X

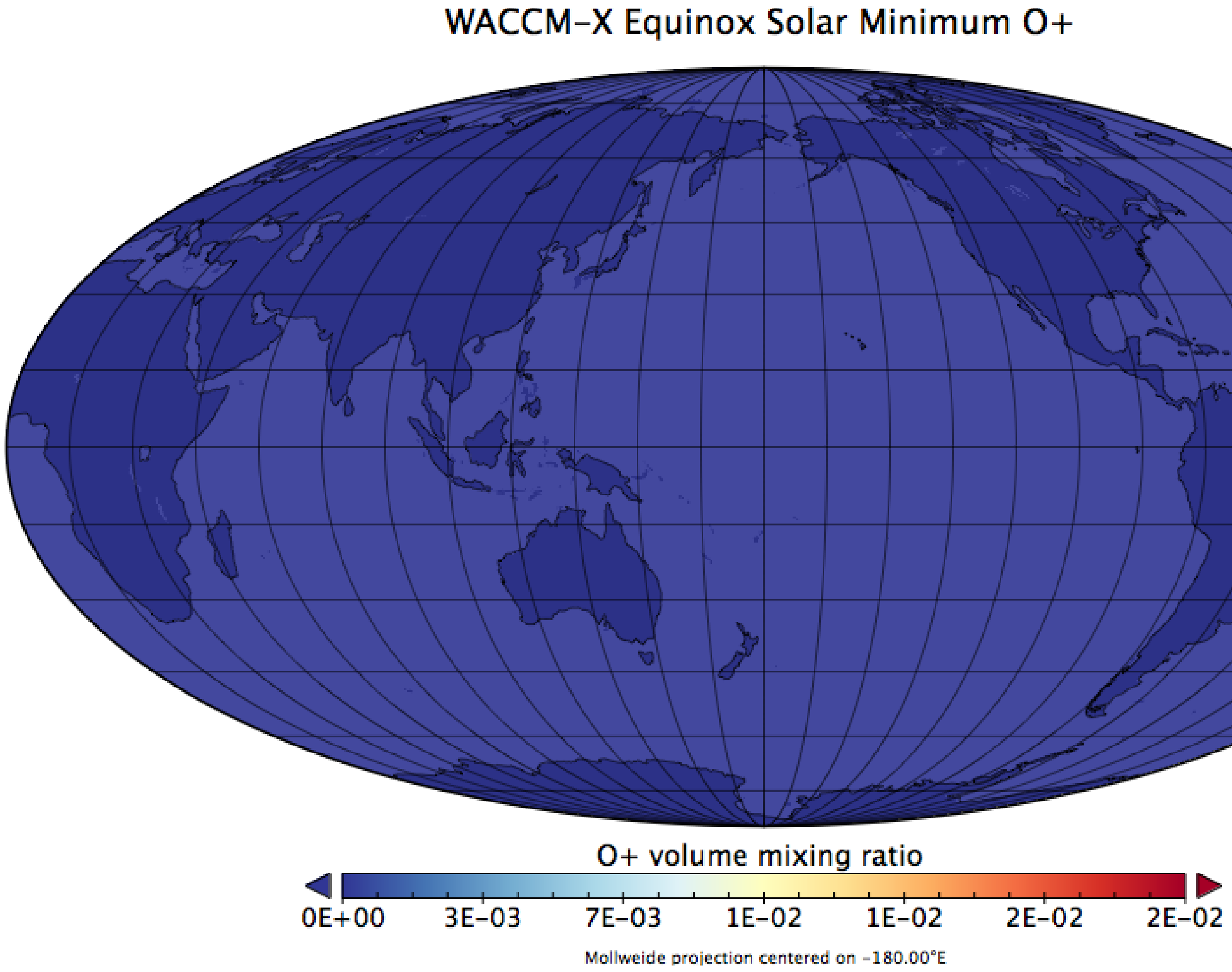



This scheme has some limitations:

- Inherent issues doing $O^+$ transport in geographic coordinates
- May be significant performance bottlenecks with $O^+$ transport inside the d-$\pi$C
- Still requires imposed upper boundary condition for electron and heat flux
- Combining high-latitude potential with the dynamo is not entirely physical

Therefore, it should be considered a short-term solution

# WACCM-X Ionosphere at ~250 km

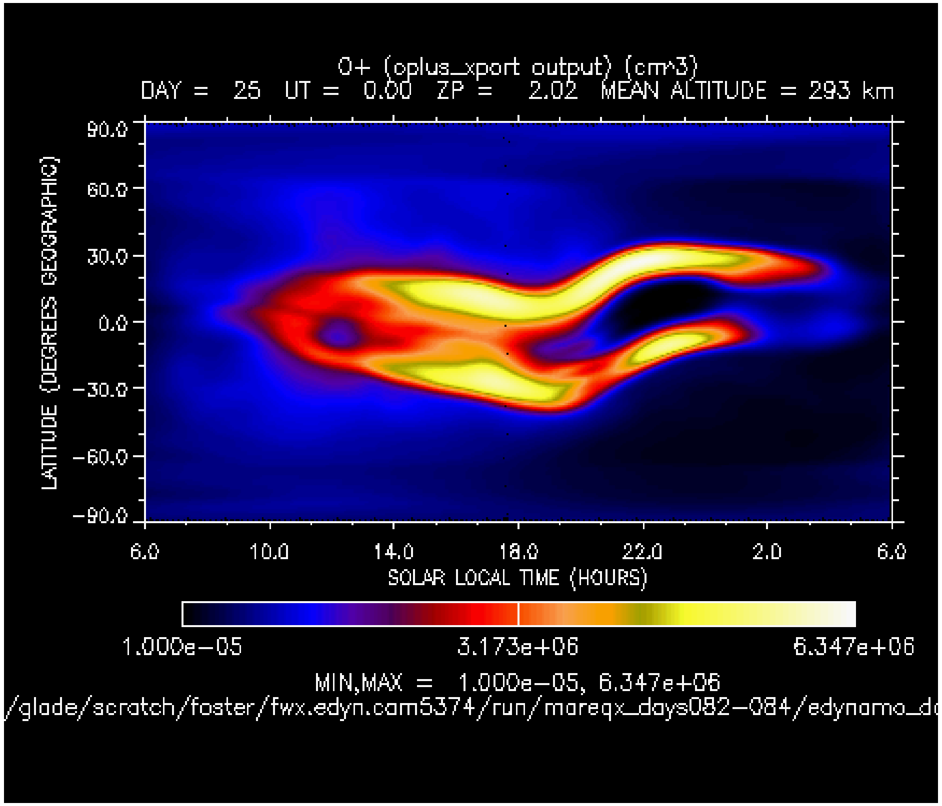



Electrodynamo and Ion transport have been implemented
Includes ambipolar diffusion, field-aligned transport, and ExB drifts

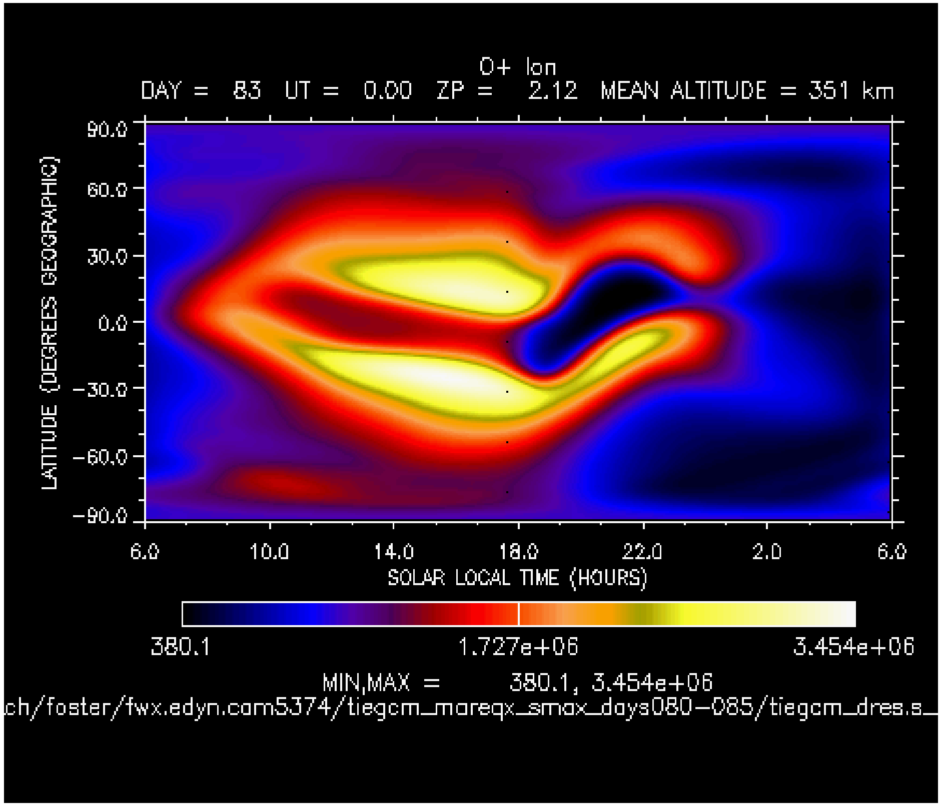
A well-defined equatorial ionospheric anomaly is produced by the model.

# $O^+$ Ions: Equinox, Solar Max
# Local Time vs. Latitude
# F-Region Ionosphere

WACCM-X

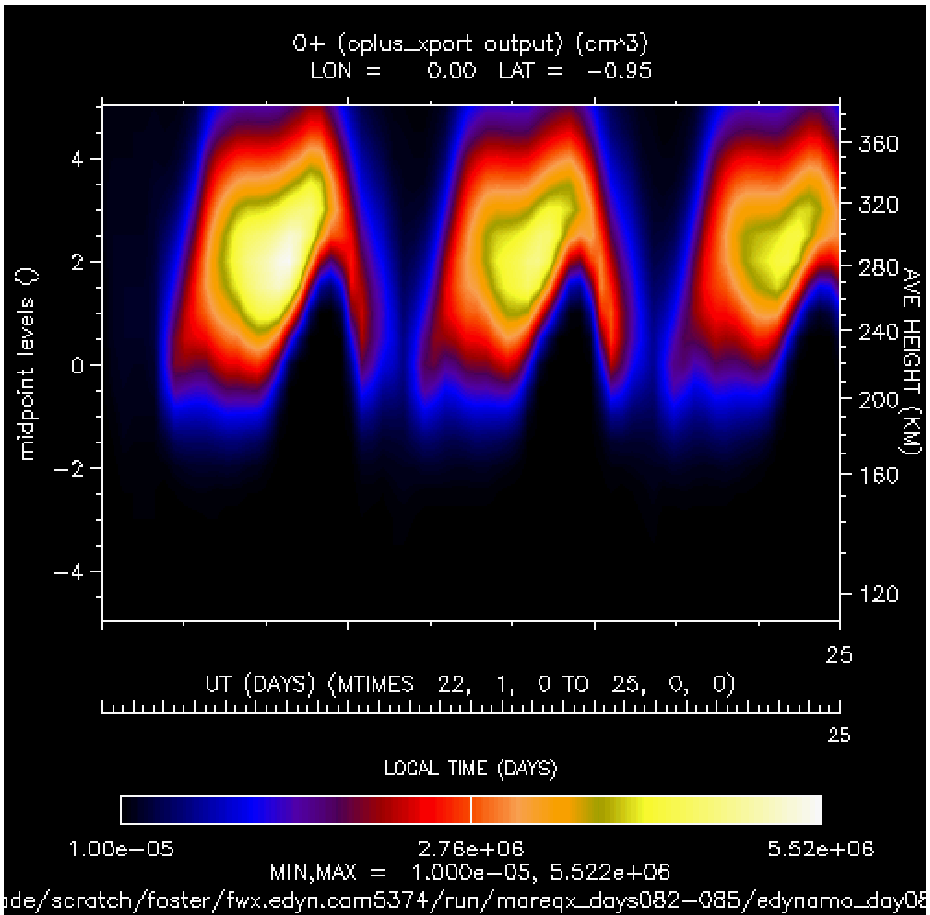



TIE-GCM

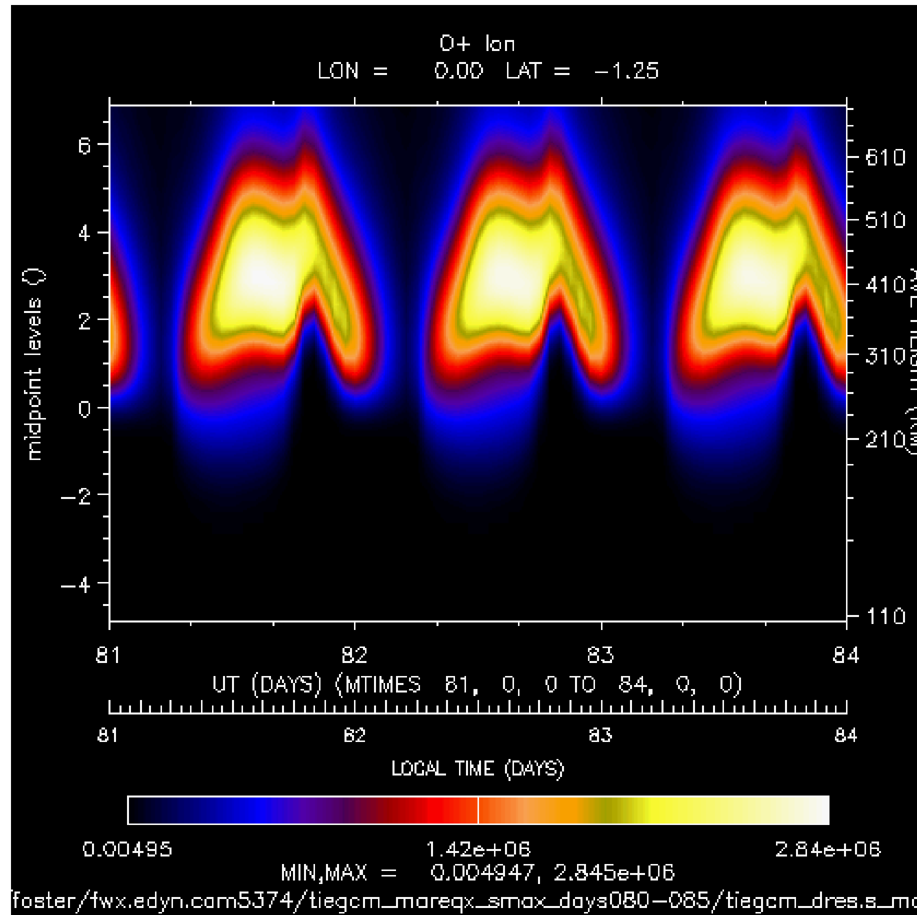


# $O^+$ Ions: Equinox, Solar Max
# UT vs. $\ln(p_0/p)$
# Latitude ~0, Longitude=0

WACCM-X

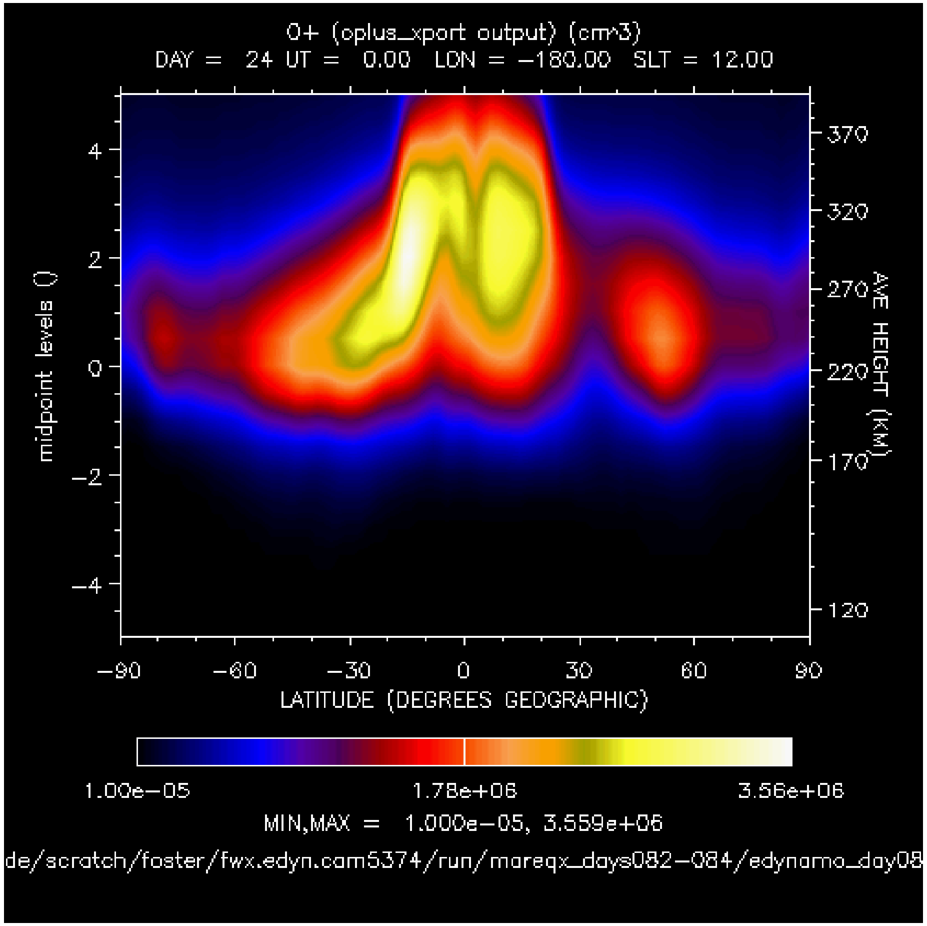



TIE-GCM

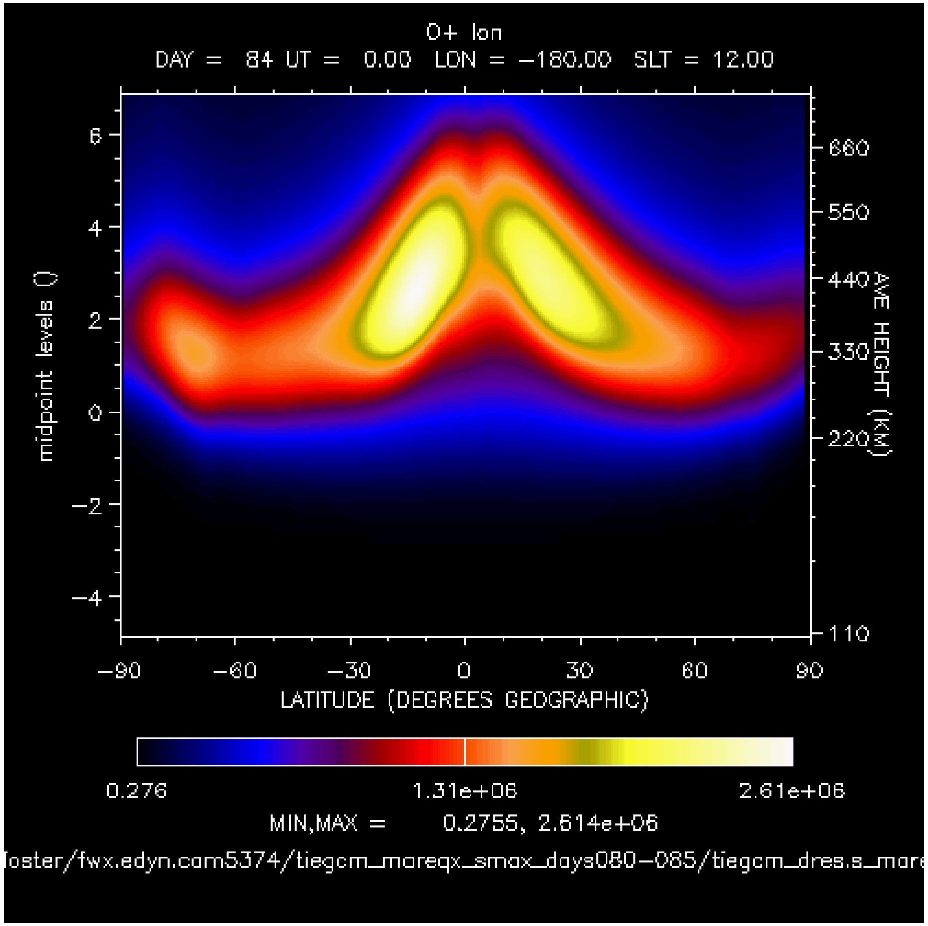


# $O^+$ Ions: Equinox, Solar Max
# Latitude vs. $\ln(p_0/p)$
# Local Time 12

WACCM-X




TIE-GCM



# Do we really need a new ionosphere module?

- **Current approach in TIE-GCM and WACCM:**
  - — Dynamical calculations performed in the geographic coordinate system
    - — Except for electrodynamo, which is calculated in geomagnetic coordinates
  - — Solar rates calculated in geographic coordinates
  - — Aurora calculated in geomagnetic coordinates but applied in geographic
  - — Ion chemistry integrated into neutral chemistry

- **Problems with this approach:**
  - — Upper boundary condition — approximate electron and heat flux
  - — Upper boundary not high enough during big storms
  - — No light ions ($H^+$, $He^+$)
  - — Difficulty porting ion transport methodology to CAM dynamics

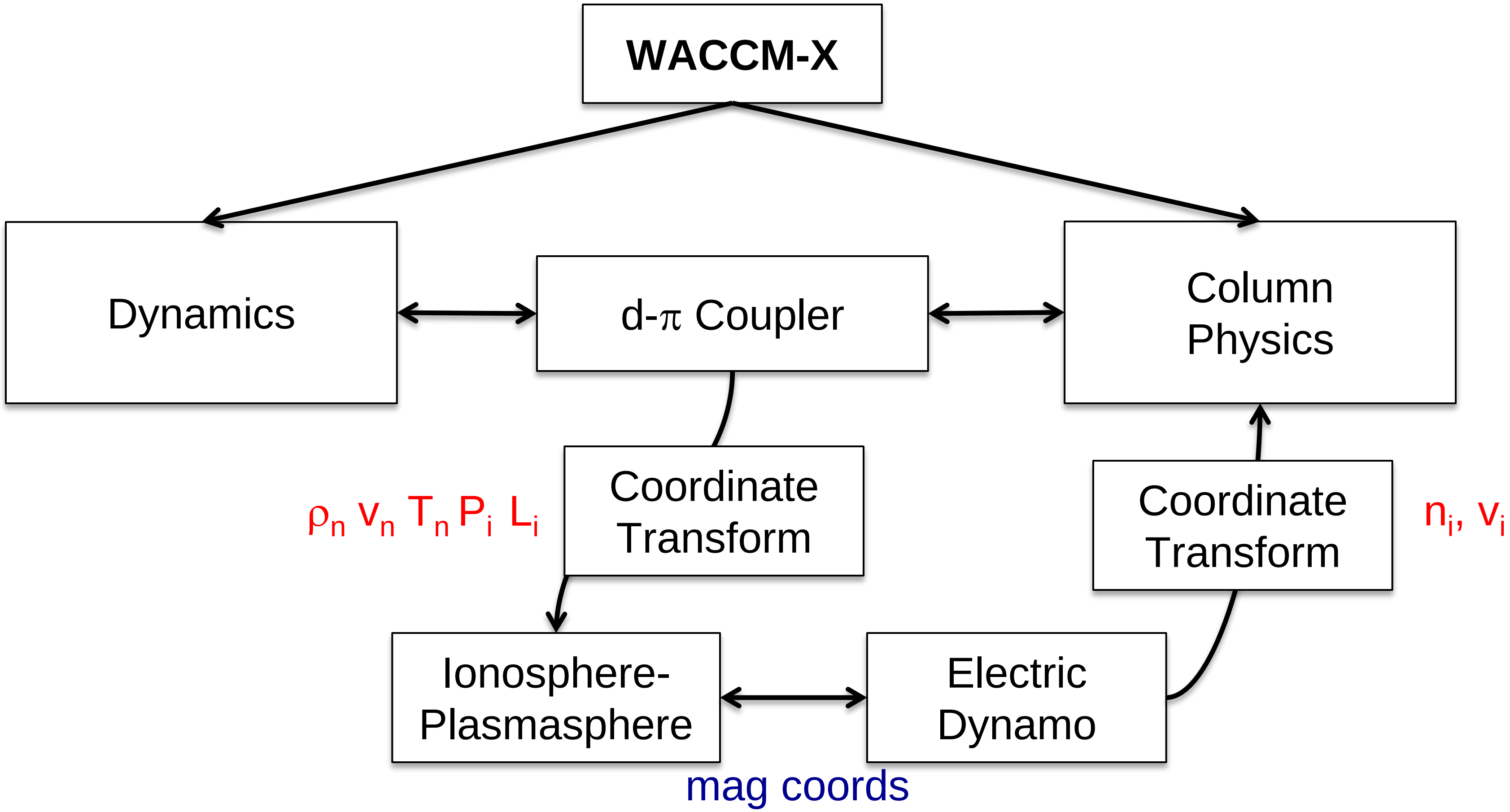
- **Perhaps these can be addressed with incremental development:**
  - — Calculate better upper boundary using other models and measurements
  - — Extend altitude range upward
  - — Add light ion transport
  - — Work with CAM dynamics to solve ion transport issues

- **But we would still be left with some basic issues:**
  - — No self-consistent interhemispheric ionosphere-plasmasphere scheme
  - — Hard to say how we would do light ions in CAM

# Implementing a 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

# Ionospheric Dynamics in WACCM-X — Next Generation




Still some significant decisions:

- Where do ion/electron energetics go ($T_i$ & $T_e$)?
- We really need the aurora in both coordinate systems.
- What is the next-generation ionosphere-plasmasphere model?
  — and what physics does it need to contain?