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WACCM-X Development and Verification and Validation of Model Results

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NSF

Major CESM WACCM/WACCM-X Components

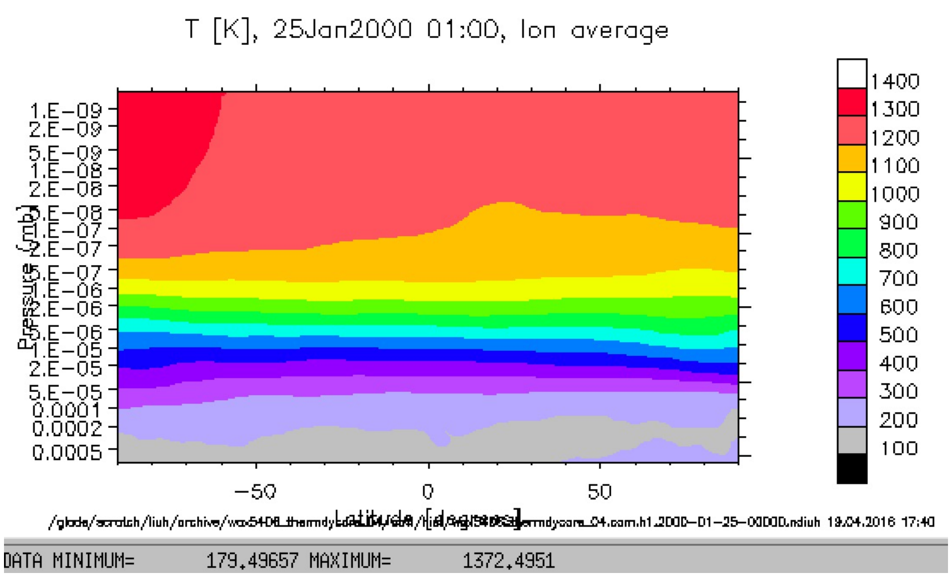
Model Framework	Chemistry	Physics	Physics	Resolution
Atmosphere component of NCAR Community Earth System Model (CESM) Extension of the NCAR Community Atmosphere Model (CAM) Finite Volume Dynamical Core (modified to consider species dependent Cp, R, m) Spectral Element Dynamical Core	MOZART+ Ion Chemistry (~60+ species) Fully-interactive with dynamics.	Long wave/short wave/EUV RRTMG IR cooling (LTE/non-LTE) Modal Aerosal 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.

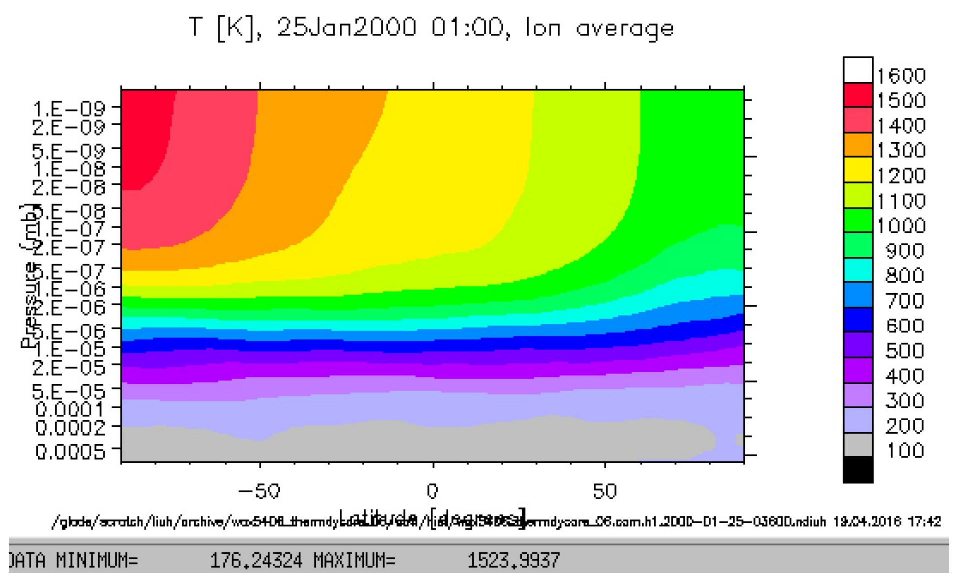
Recent WACCM-X Development

- Interactive Ionosphere Modules
  - Interactive electric wind dynamo.
  - F region O+ transport.
  - Time dependent Te/Ti solver, and thermal electron heating of neutral atmosphere.
  - $O^+(^2P)$ and $O^+(^2D)$ included in ion chemistry and energetics.
  - Bug fix: nighttime E-region ionization rate.
- Thermosphere Modules
  - Ability to take flare time EUV input.
  - $O(^3P)$ cooling.
  - H escape flux parameterization implemented.
  - Helium being added as a minor species.
  - Bug fixes: EUV heating and CO_2 cooling.
- Dynamic core: Species dependent specific heats and gas constant.
- Model domain extended to 4×10^{-10} hPa, with ¼ scale height resolution.
- Reduced divergence damping improves tides.
- WACCM-X with specified dynamics.

Changes to FV Dycore for Variable Species

- The most important change: treatment of pressure gradients in horizontal momentum equations.
  - Standard FV core uses Exner function (p^κ) as the vertical coordinate for the contour integral of the pressure gradient terms.
  - When κ is a variable, Exner function is not a constant on an isobaric surface, so can't be used as a vertical coordinate.
  - Horizontal momentum equations are solved incorrectly (and often become too strong) with the standard formulation. Causes excessively strong upwelling in the summer and downwelling in the winter.
  - Use pressure or log-pressure instead for computing the contour integral (latter has been used in our implementation).
  - Energy (potential temperature) equation is modified to reflect the variable κ.



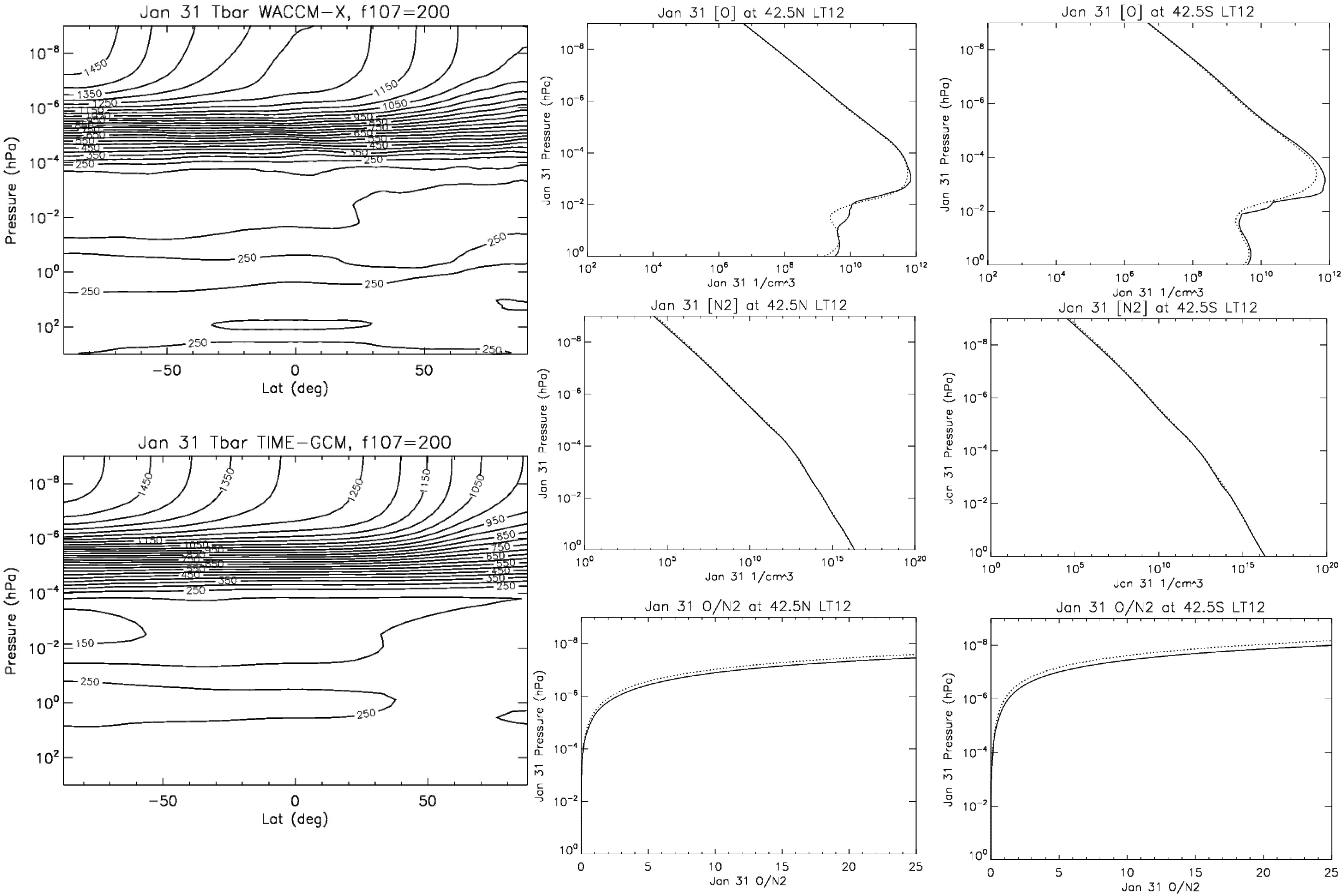


Before dycore changes:

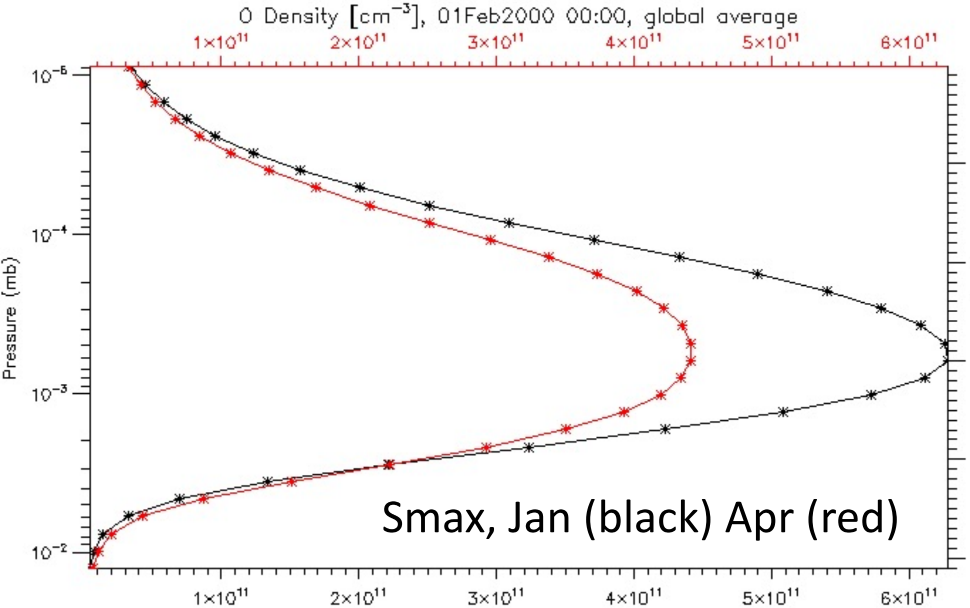
1. Reverse temperature gradient (winter to summer) in the middle thermosphere: $2x10^{-5}$ to $5x10^{-7}$ hPa
2. Small meridional temperature gradient above.
3. Maximum thermosphere temperature lower than TIME-GCM

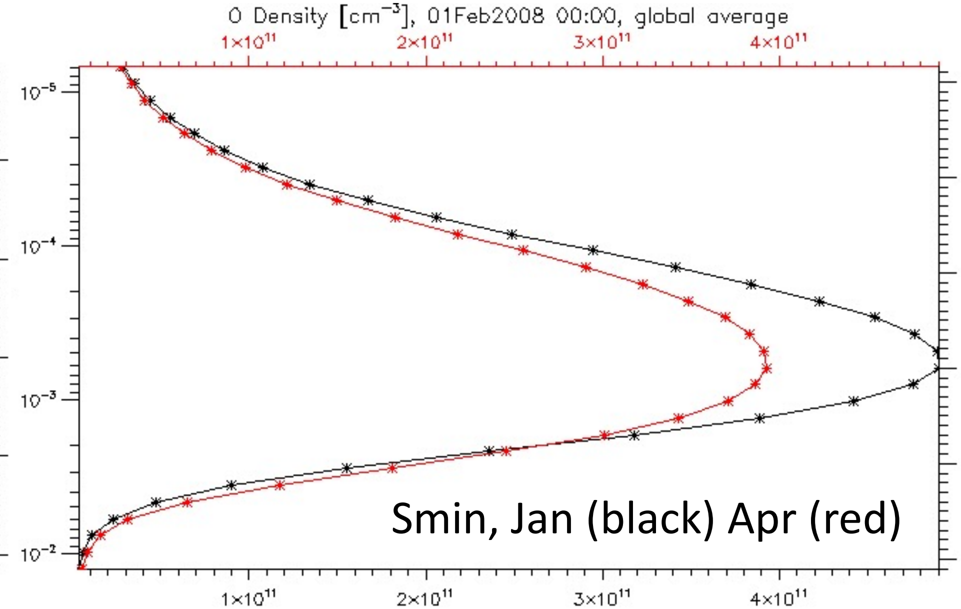
After dycore changes.

T and O, N2 (O/N2): WACCM-X and TIMEG-GCM



O Peak in MLT

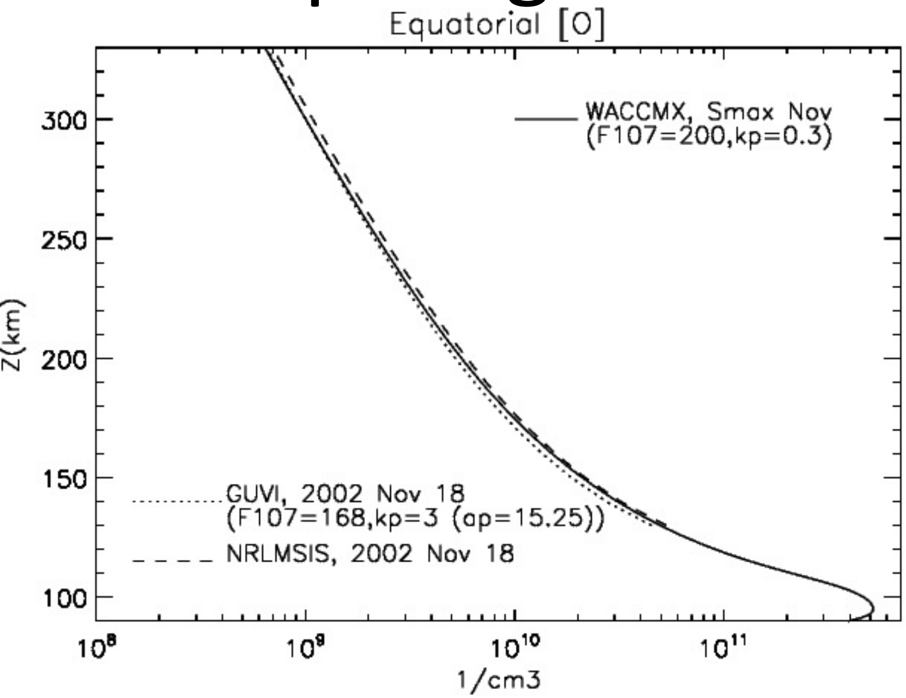


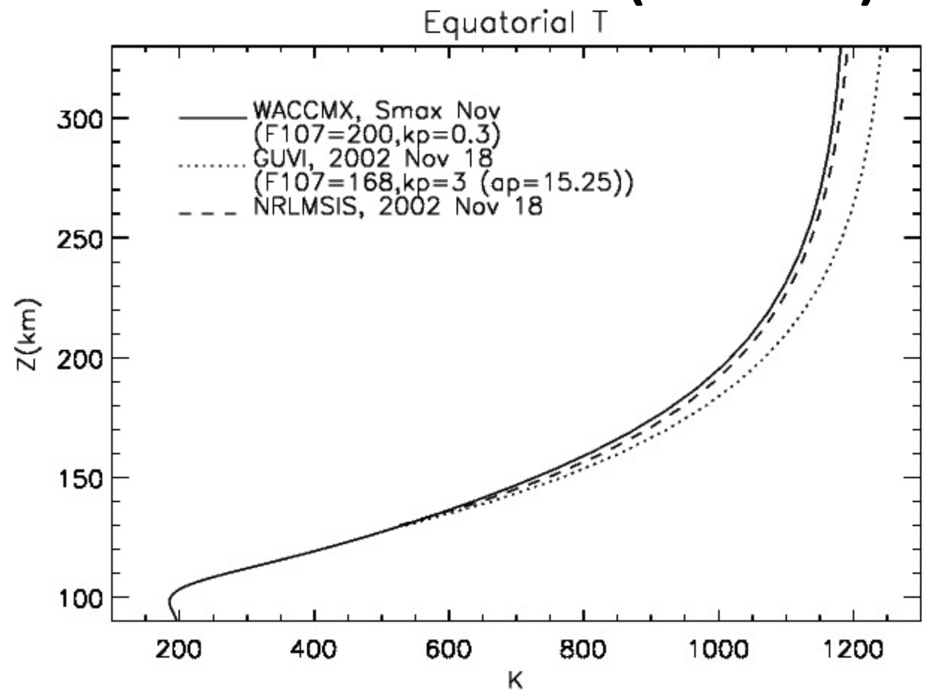


	Pressure			
	0.01 hPa	0.003 hPa	0.001 hPa	0.0004 hPa ~~0.004 hPa~~
Mean altitude (km)	79.2	86.2	92.7	97.9
Day O density (cm^{-3})	1.58 e+10	1.43 e+11	6.22 e+11	7.66 e+11
Night O density (cm^{-3})	5.44 e+09	2.23 e+11	6.56 e+11	5.58 e+11

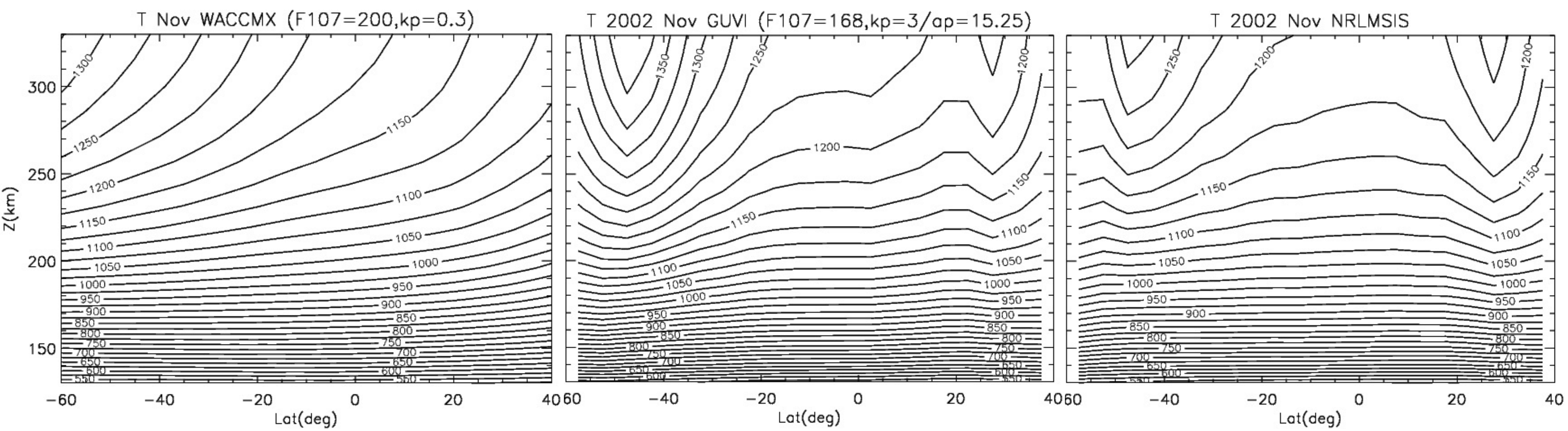
Smith et al., 2010

Comparing with GUVI and NRLMSIS (Smax)

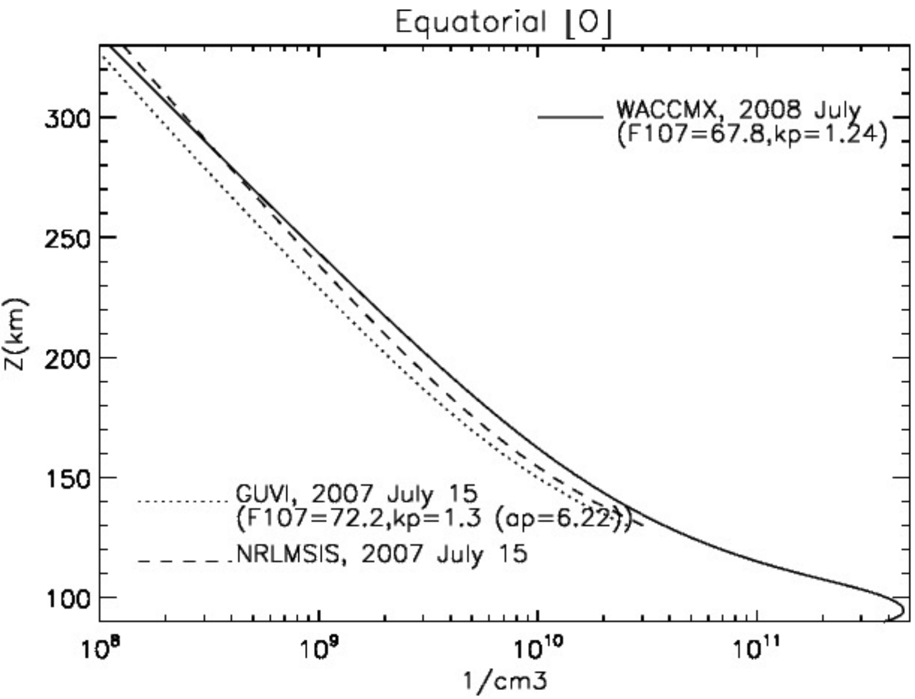


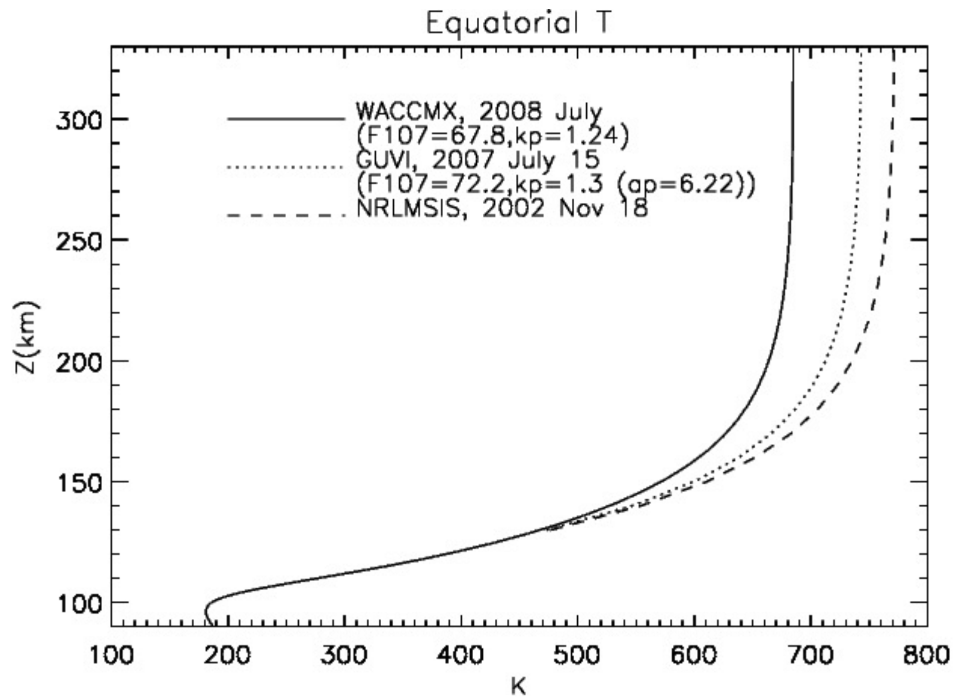


Courtesy of Bob Meier



Comparing with GUVI and NRLMSIS (Smin)





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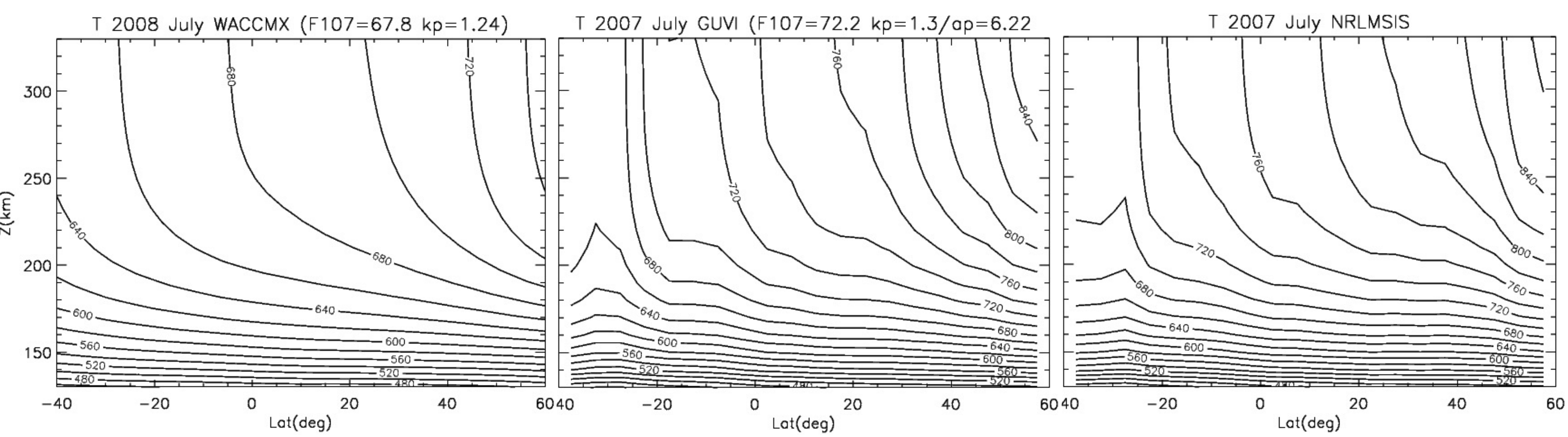
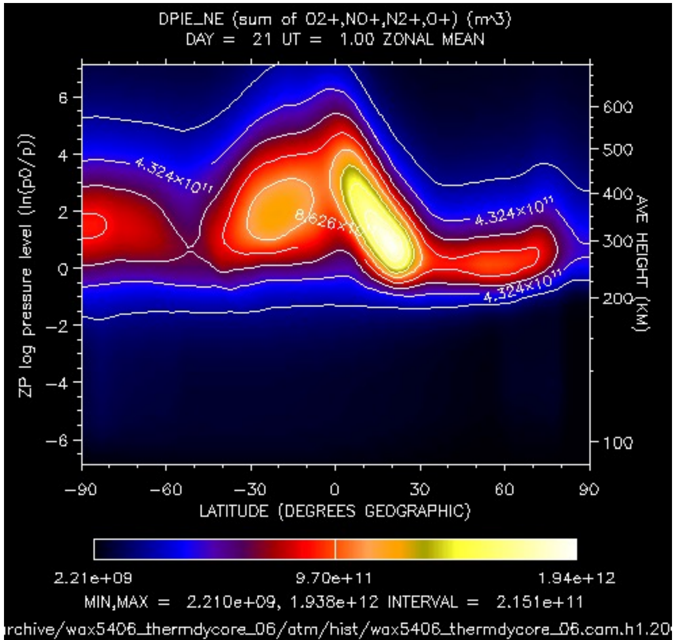
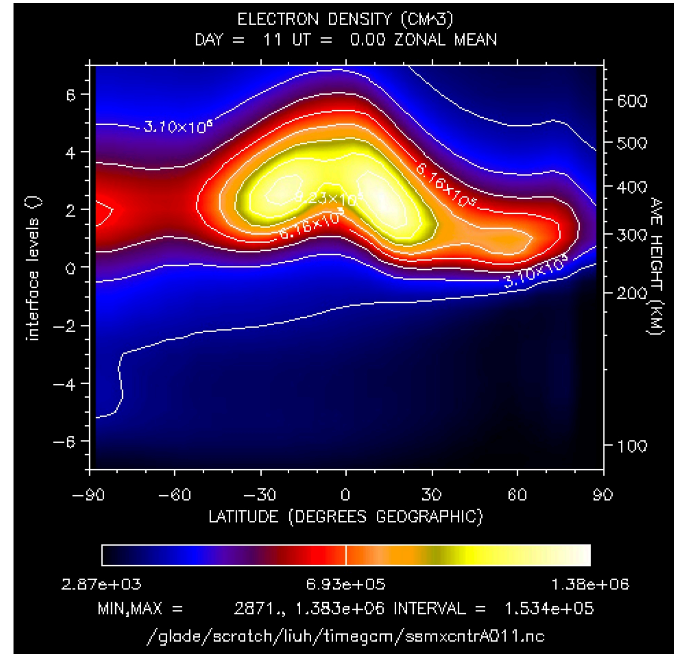


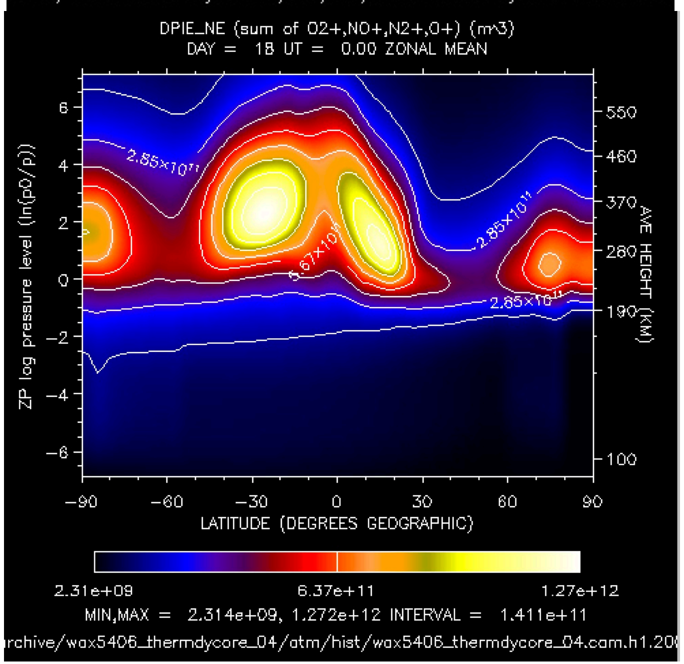
O+ in WACCM-X and TIME-GCM



WACCM-X with new dycore

TIME-GCM

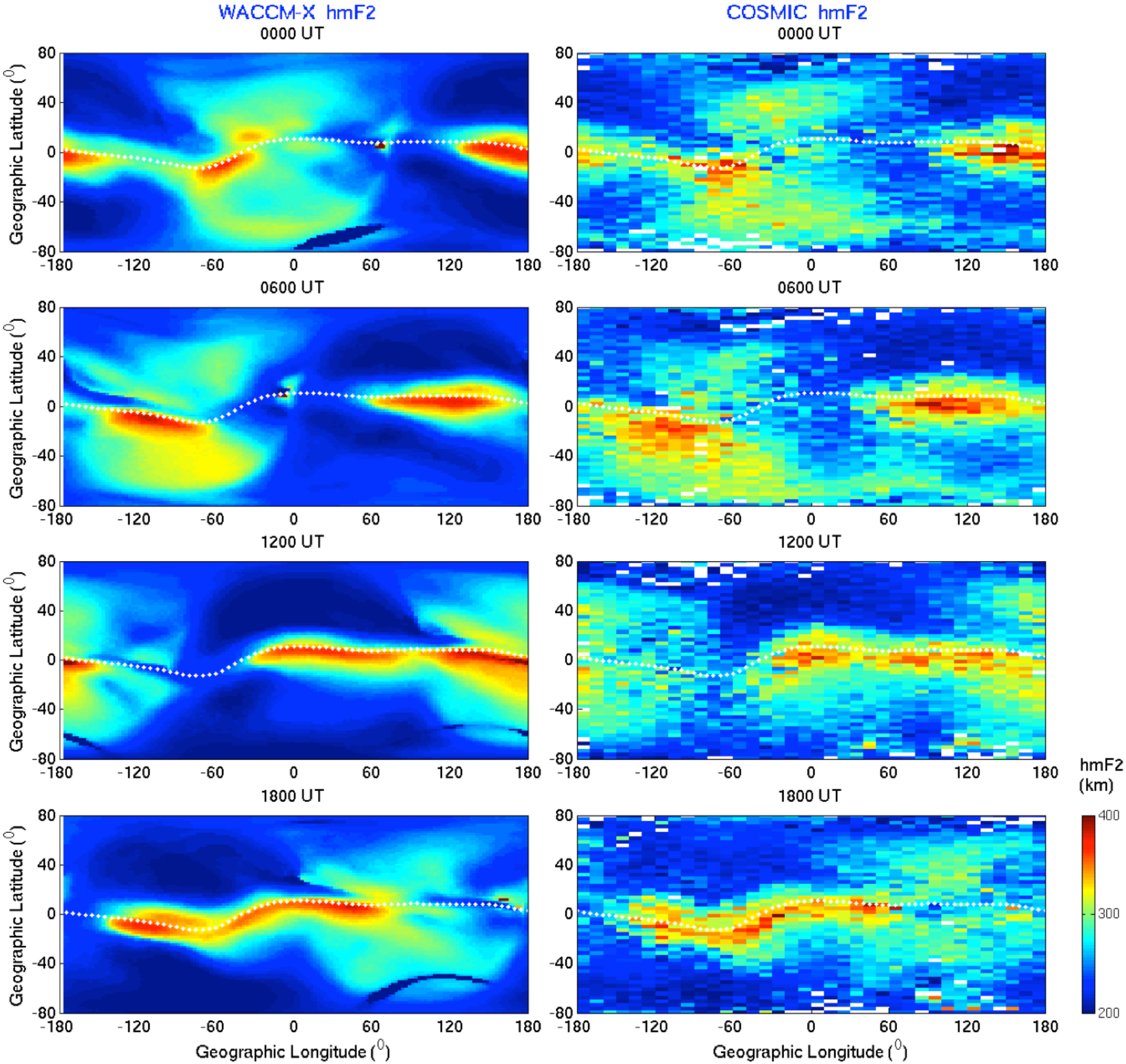




WACCM-X with old dycore

The spurious accumulation of O+ at high laitutdes is gone after the dycore fix.

Comparison with COSMIC 2008 Jan-Feb



Courtesy of Jing Liu

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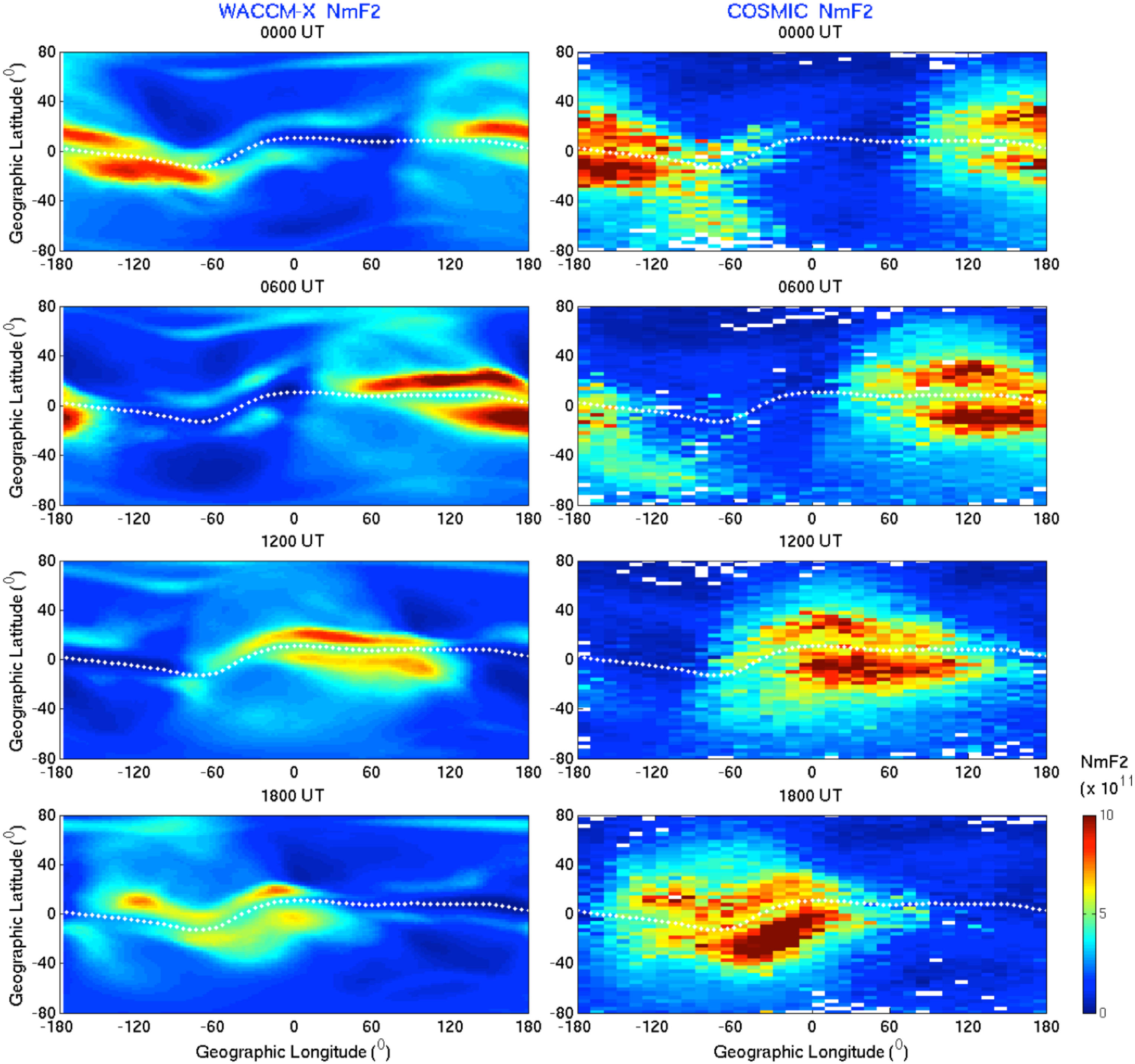
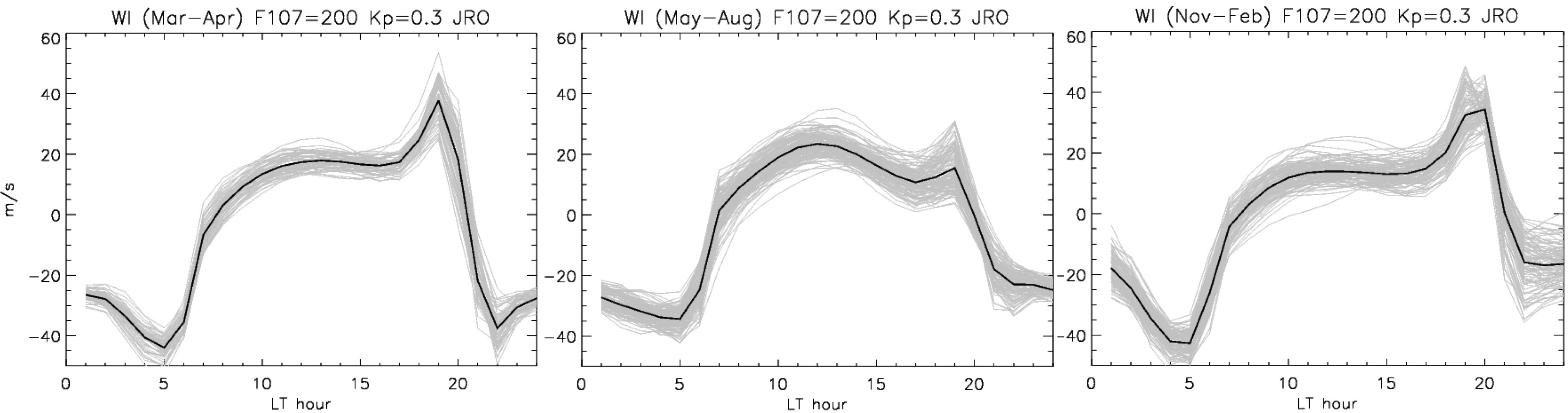
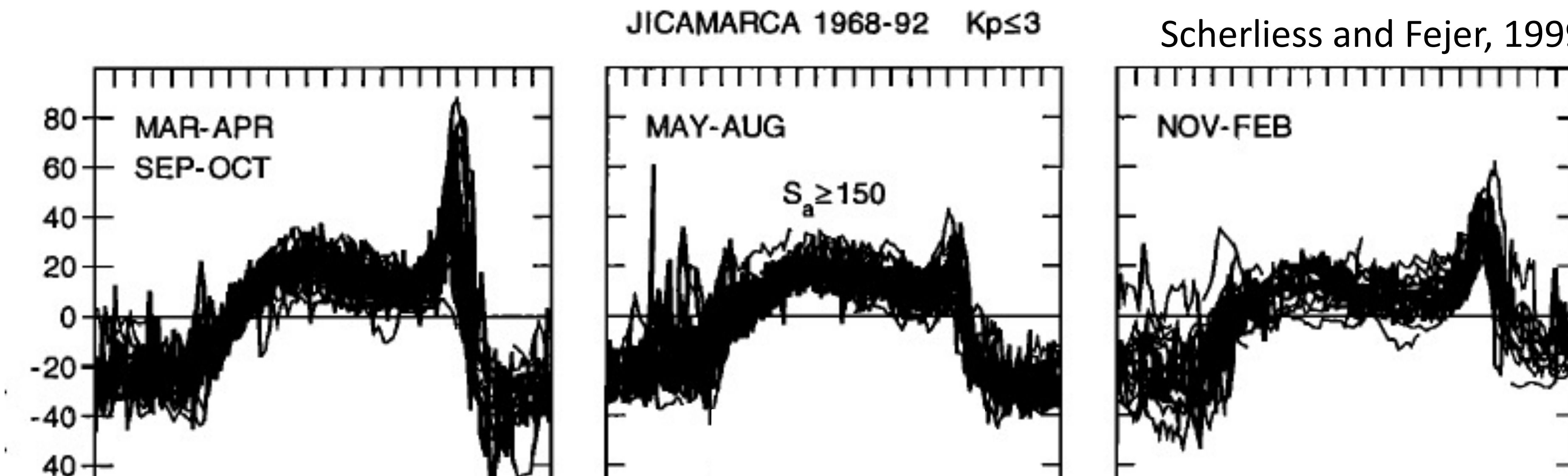


Courtesy of Jing Liu

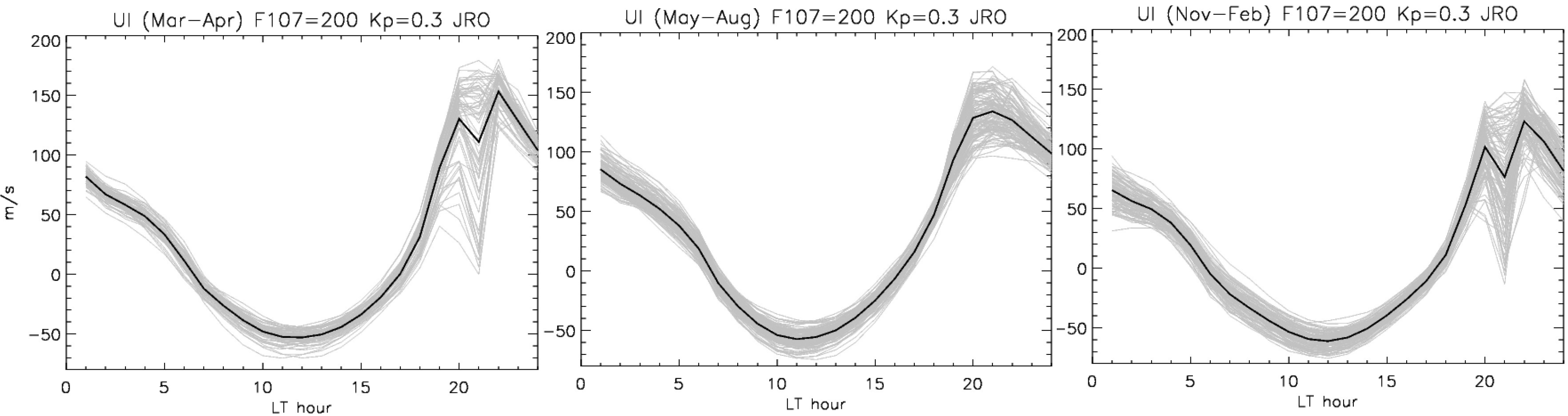
Vertical ExB Drift: Comparison with Smax Climatology



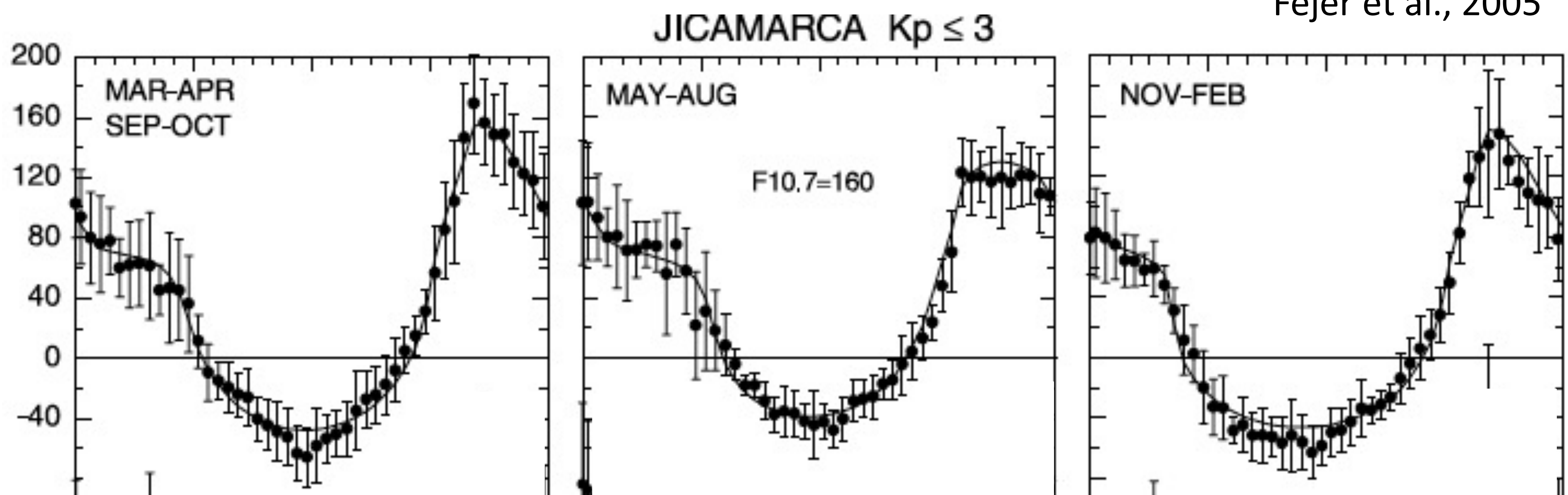
Scherliess and Fejer, 1999



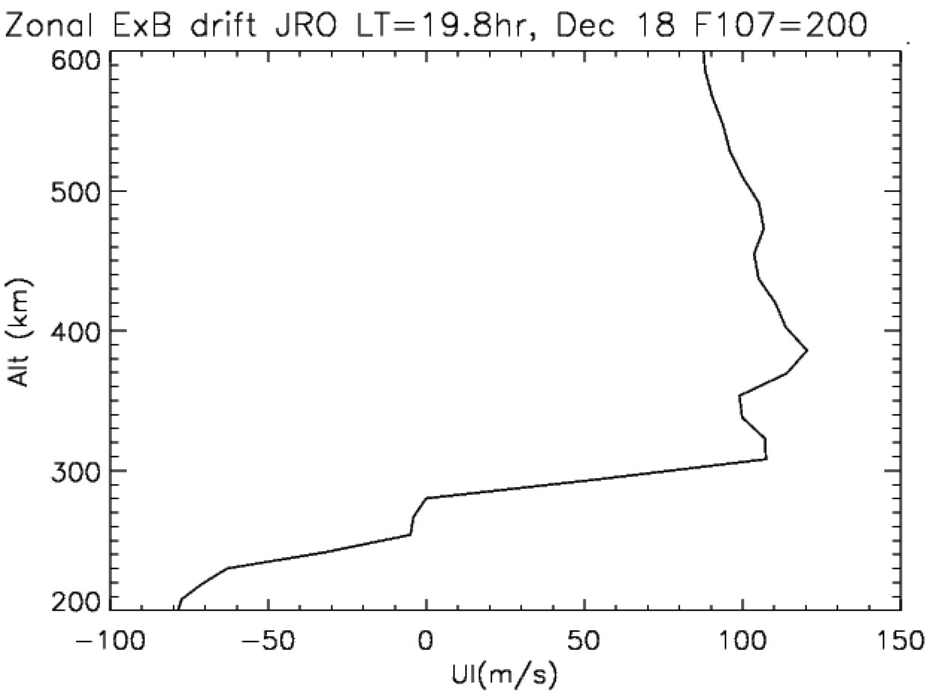
Zonal ExB Drift: Comparison with Smax Climatology

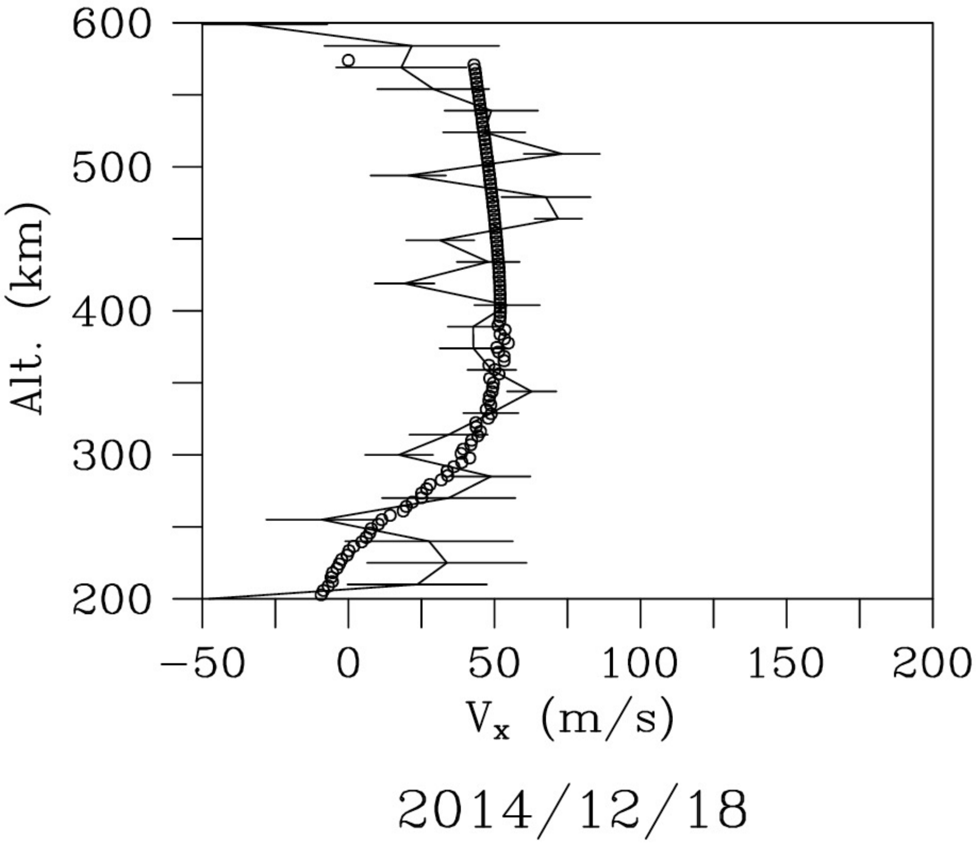


Fejer et al., 2005



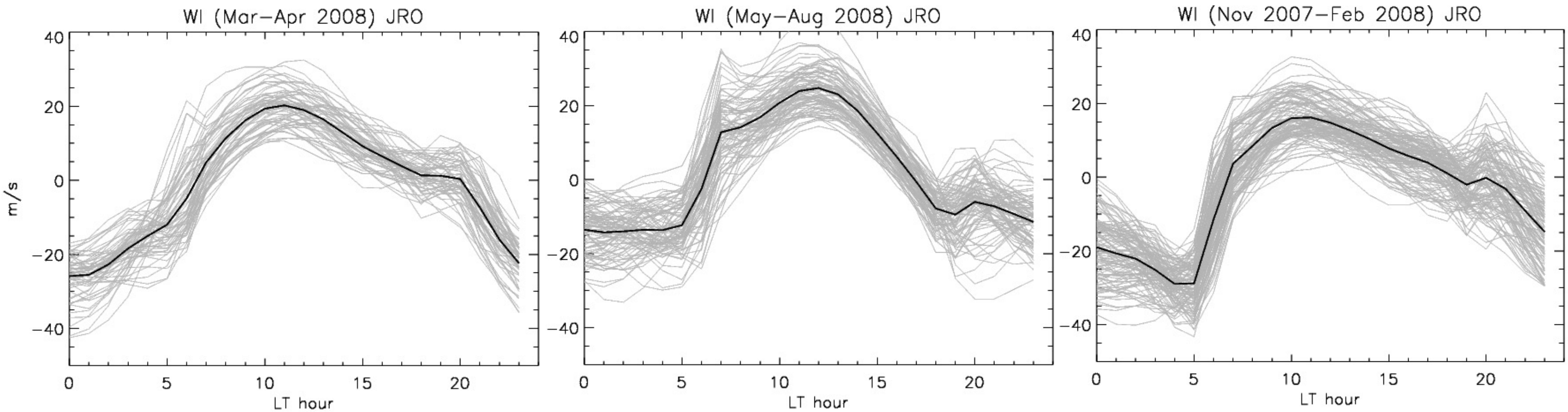
Vertical Profile of Zonal Drift: Smax



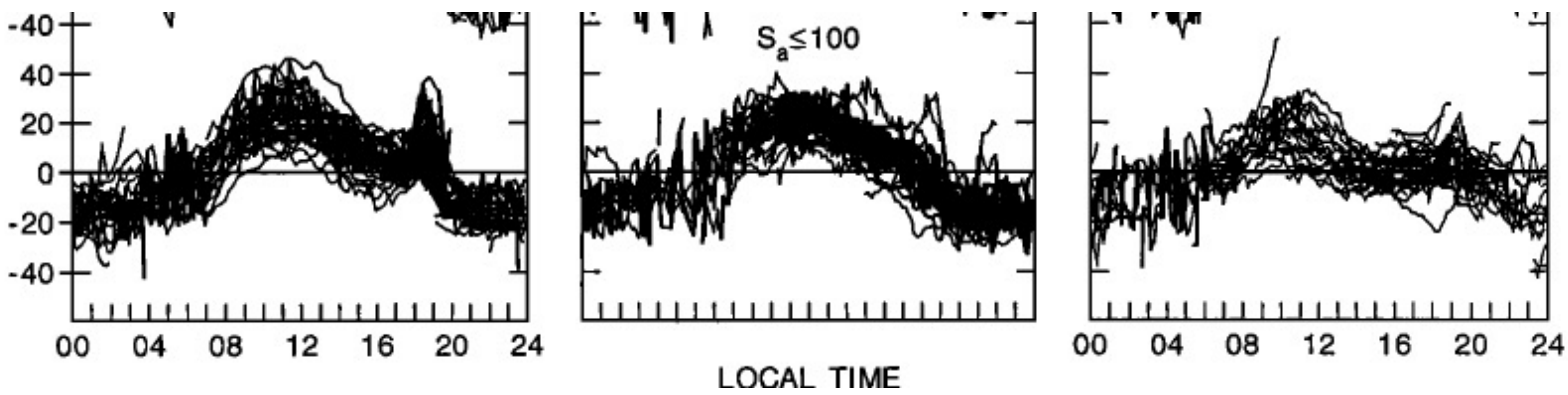


Hysell et al. (2015)

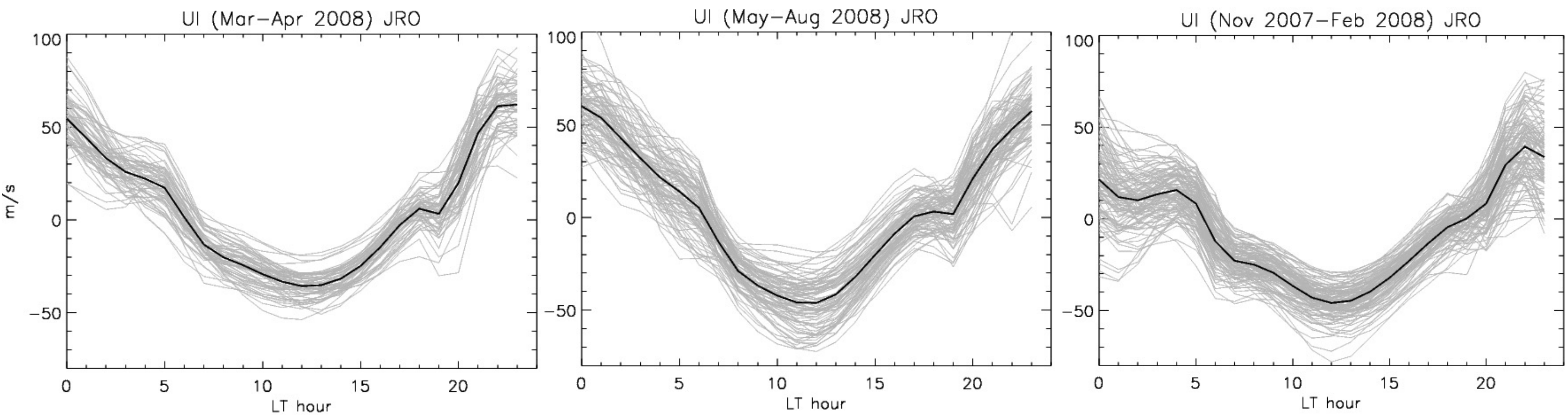
Vertical ExB Drift: Comparison with Smin Climatology



Scherliess and Fejer, 1999



Zonal ExB Drift: Comparison with Smin Climatology



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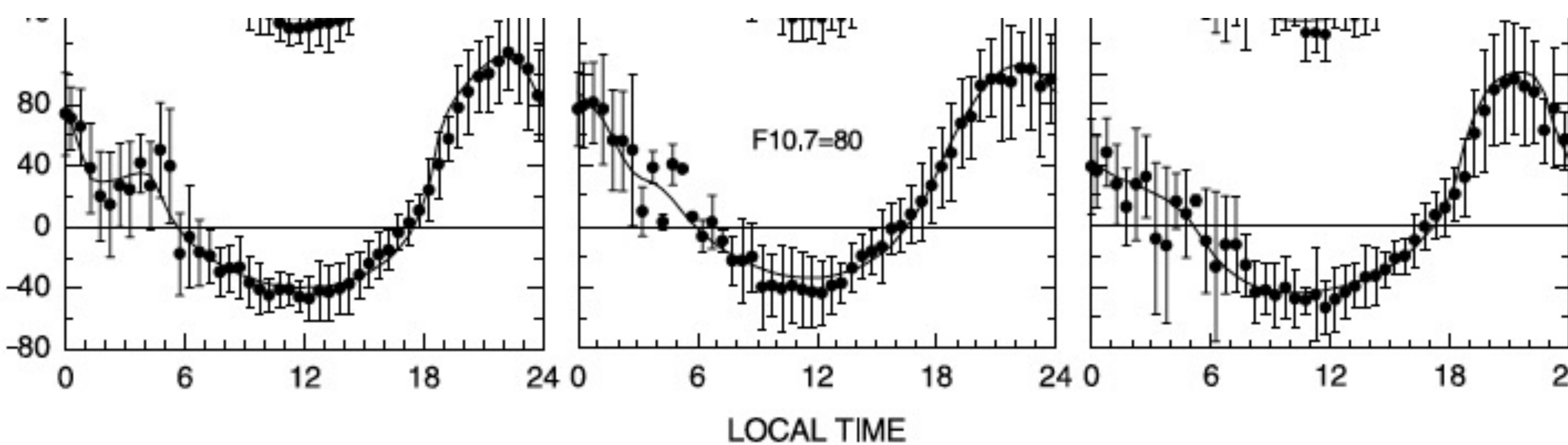
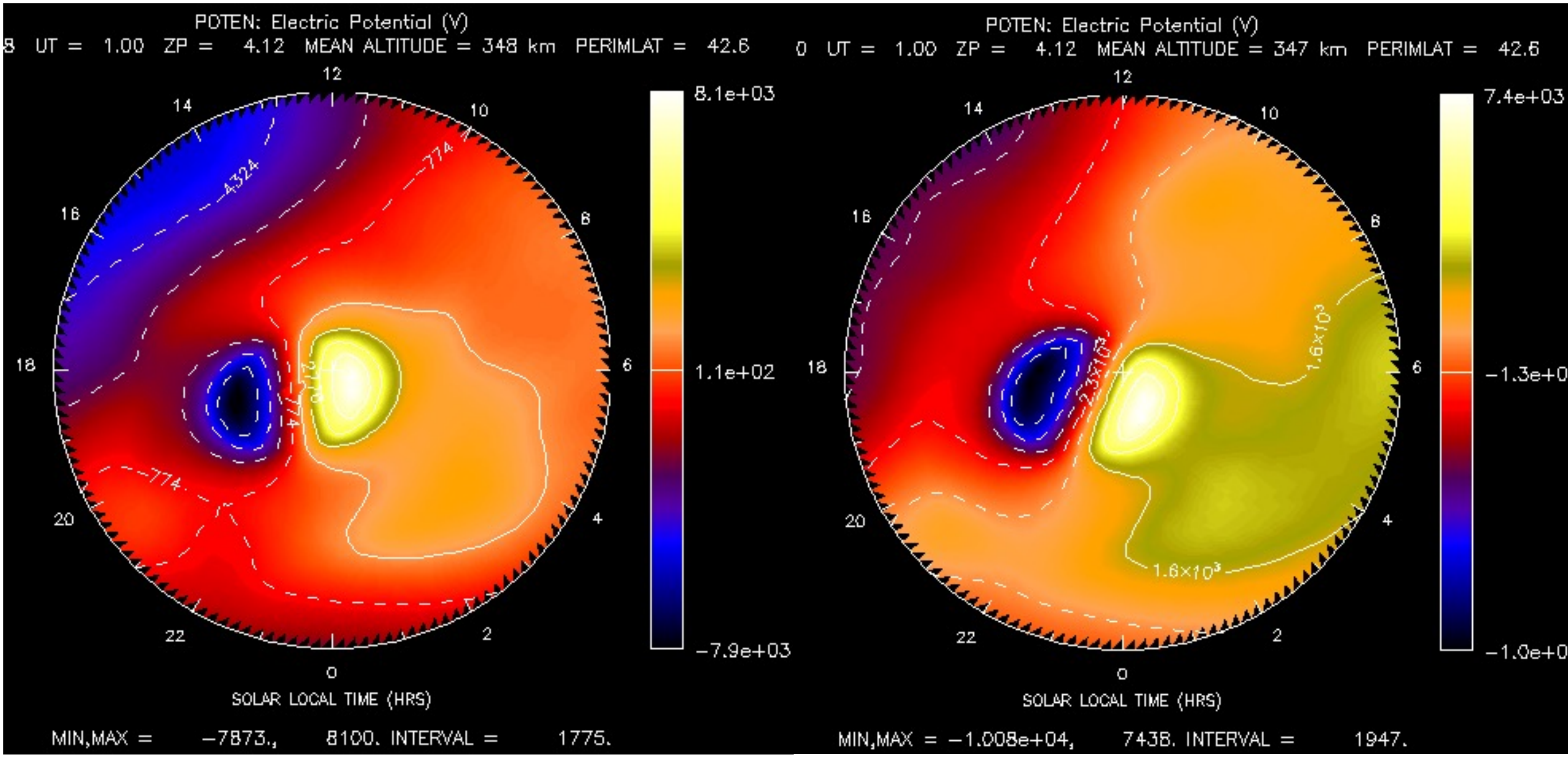
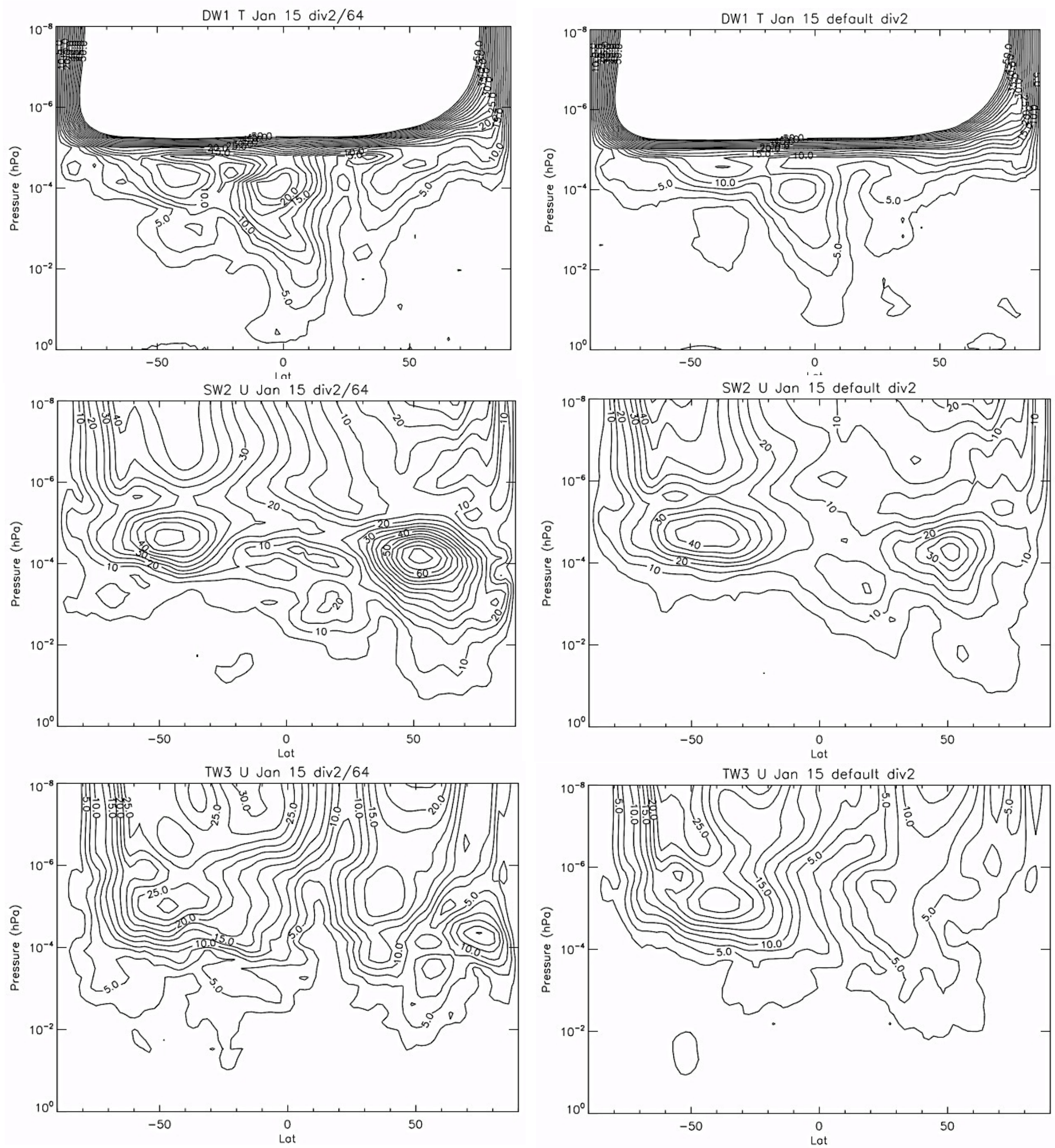


High Latitude Convection Pattern: Heelis



WACCM-X Tides



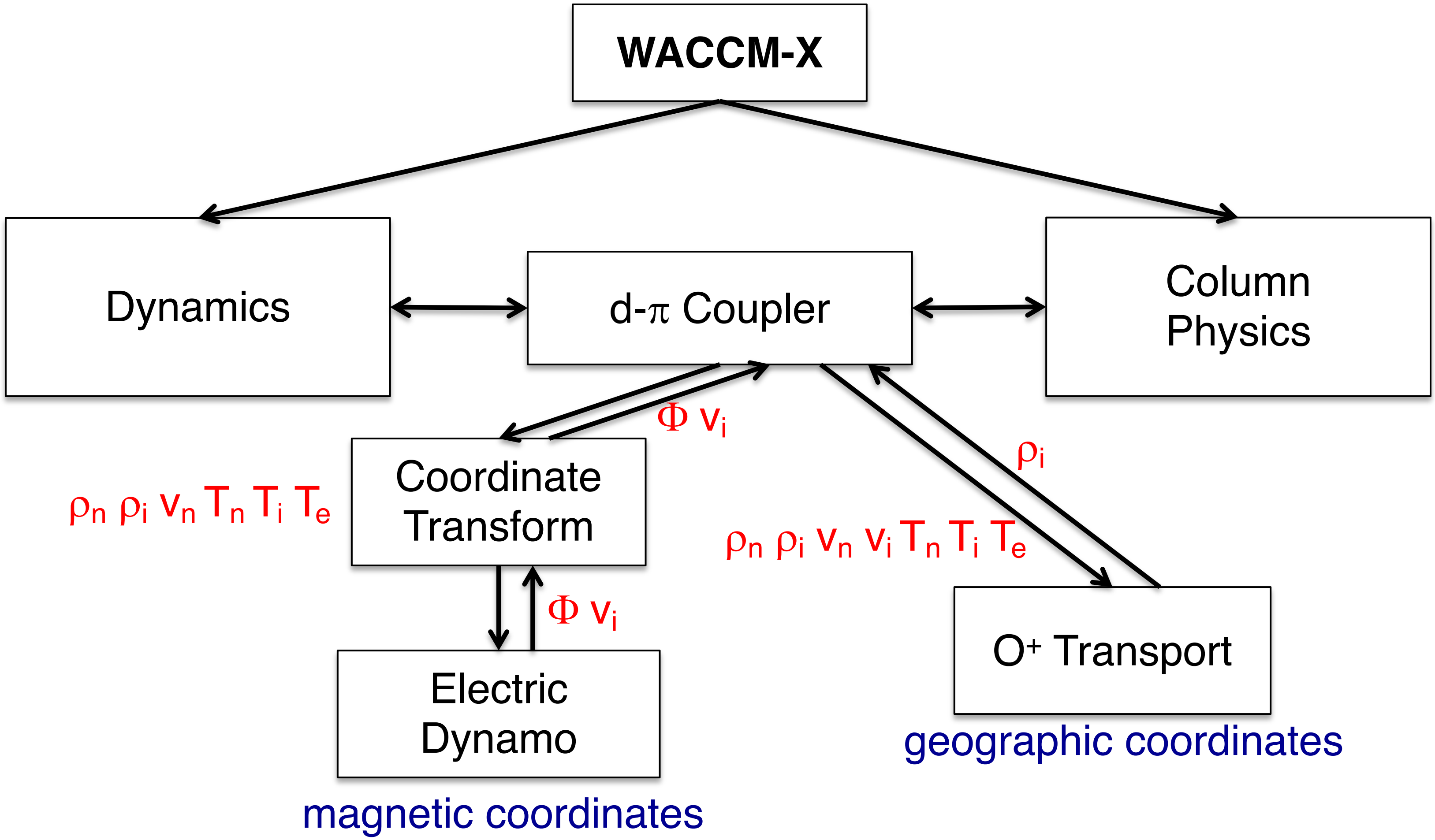
Take Home Message…

- The WACCM-X thermosphere and ionosphere compare well with observations/climatology.
- Try it out when it's released.

Current Development

- Implementation and testing of Helium.
- Prepare for CESM2.0 release (scheduled for December 2016), which will include WACCM-X with the aforementioned features.
- WACCM-X/AMIE.
- WACCM-X Data Assimilation (DART).

High-Level Schematic of Current Configuration

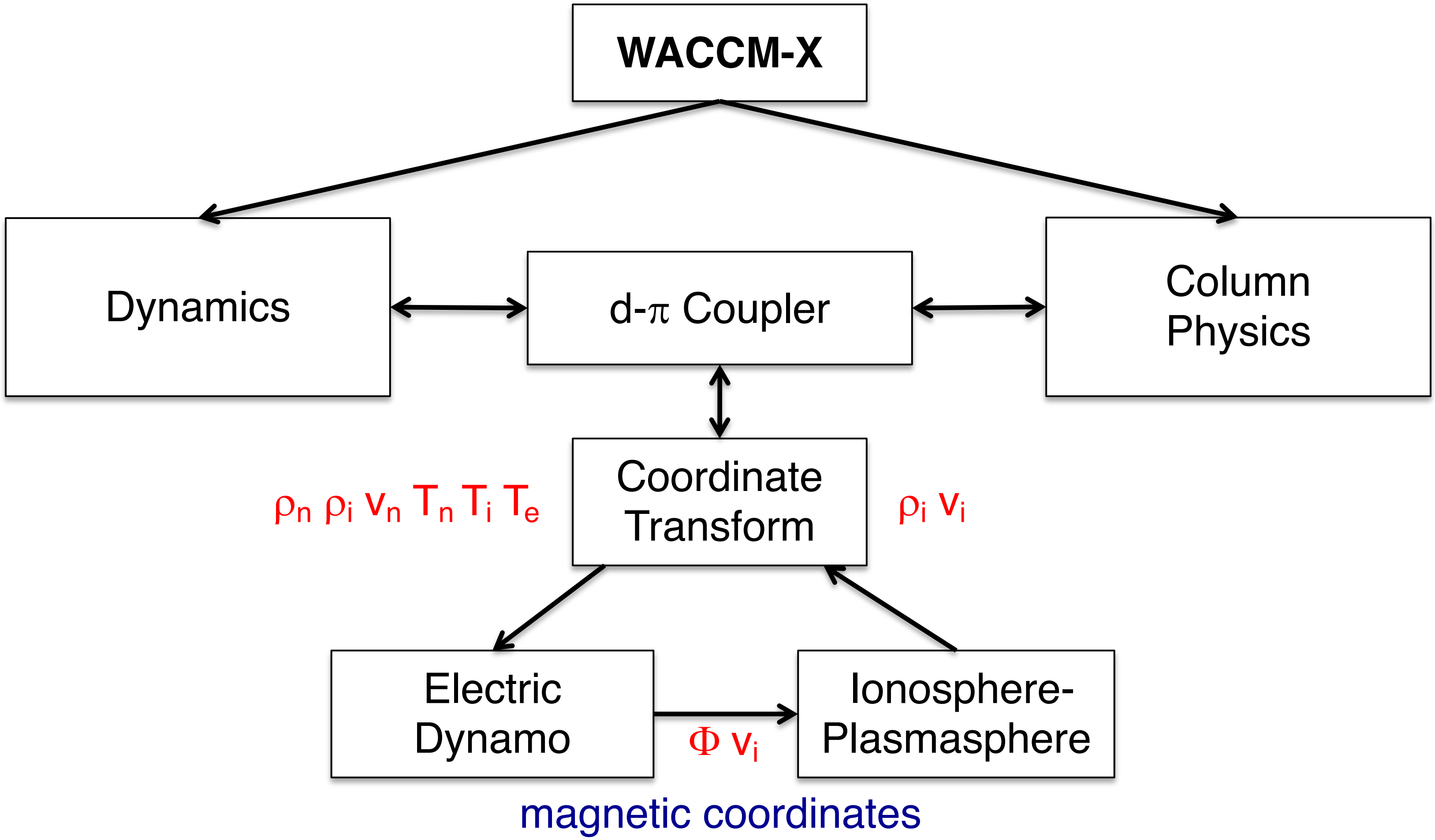


d-π Coupler: dynamics-physics-ionosphere-electrodynamics coupler

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

High-Level Schematic of Proposed Future Development



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