

## Whole Atmosphere Community Climate Model – eXtended (WACCM-X): Development Status

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&

Many others in HAO, ACD, CGD

**Support** from: ONR Seamless Modeling Development, NSF CEDAR Program, NASA LWS Strategic Capability Program, and NSF NCAR-Wyoming Supercomputing Center

# WACCM-X Background

- **NCAR/HAO TIE-GCM/TIME-GCM simulate realistic thermosphere/ionosphere**
- **TGCM transport and physics be included in WACCM**
- **Neutral transport and physics added to WACCM extending the model top from ~145km to ~500km**
- **Vertically extended version of WACCM (WACCM-X) in CESM 1.0.4 release, February 2012**



# Two Recent WACCM-X Tasks

- **A higher resolution WACCM-X for simulations of smaller scales**
  - Started by running a higher resolution version of WACCM (GRL article, Liu et al., 2014)
- **Enhance current WACCM-X ionosphere physics**
  - Electron and ion temperature
  - O<sup>+</sup> transport
  - Include these in CESM/CAM trunk

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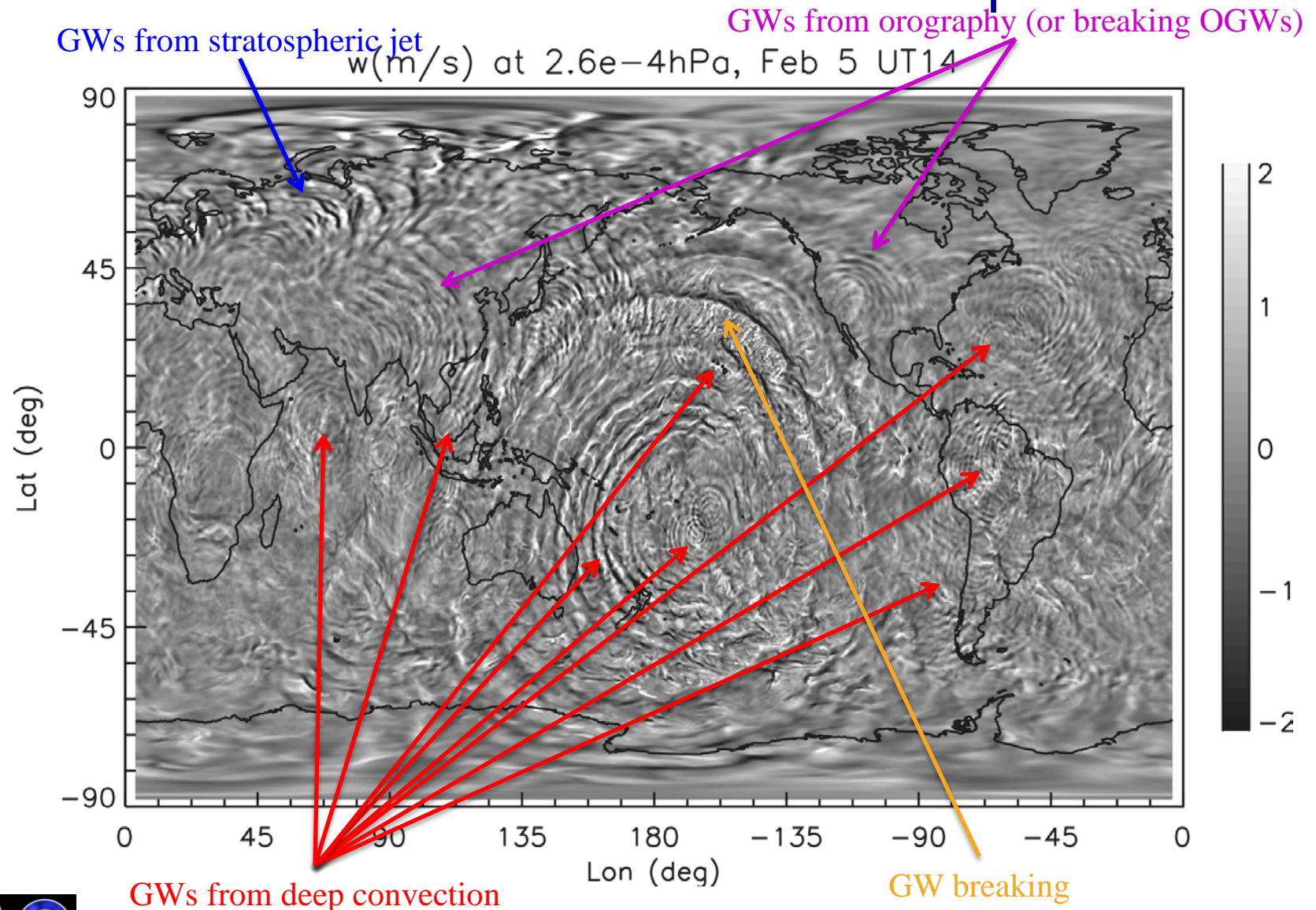
# Motivation

- **Gravity wave forcing dominant in driving MLT circulation/stratosphere circulation (e.g. QBO, polar circulation)**
  - Currently GW parameterization
  - Source of uncertainties/biases
- **Gravity wave perturbations may directly impact ionospheric variability, including ionospheric irregularities**

# WACCM With Spectral Element (SE) Dynamical Core

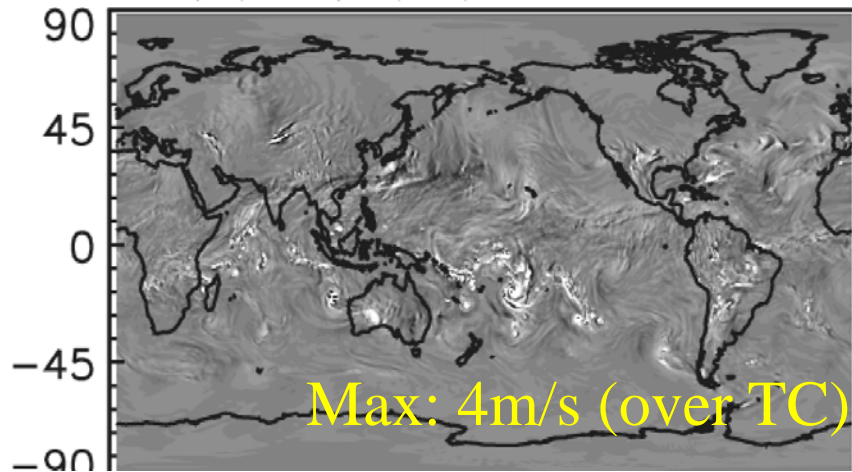
- **WACCM (0-145km) with continuous Galerkin spectral finite element dynamical core**
  - solved on cubed-sphere - no polar singularity
- **Resolution:**
  - ~ 0.25° (25km) horizontal (ne120np4)
  - 0.1 scale height (500-700m) vertical
- **GW parameterization turned off**
- **Deep convection parameterized**
  - Zhang and MacFarlane, 1995
- **Scalable up to 10000+ cores on NSF NWSC/Yellowstone**
- **Completed a one year simulation**

# Gravity Wave Signatures in Vertical Wind in Lower Thermosphere

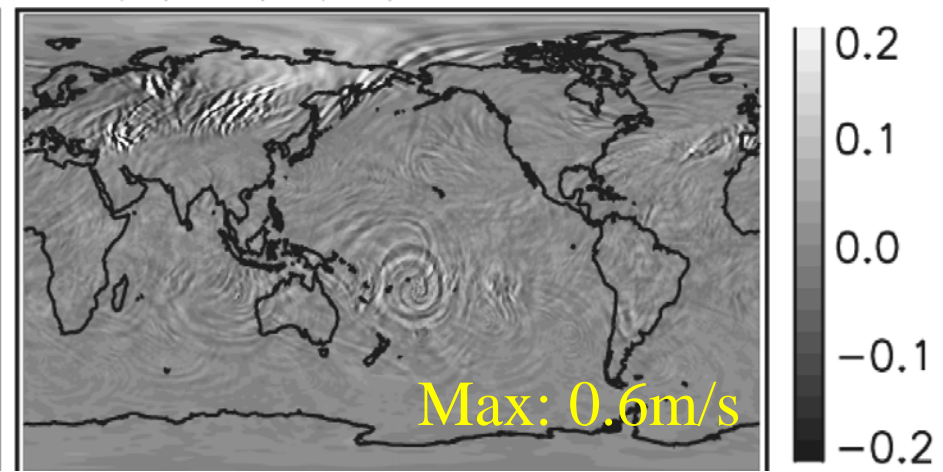


# Vertical Winds: Tropopause to Lower Thermosphere

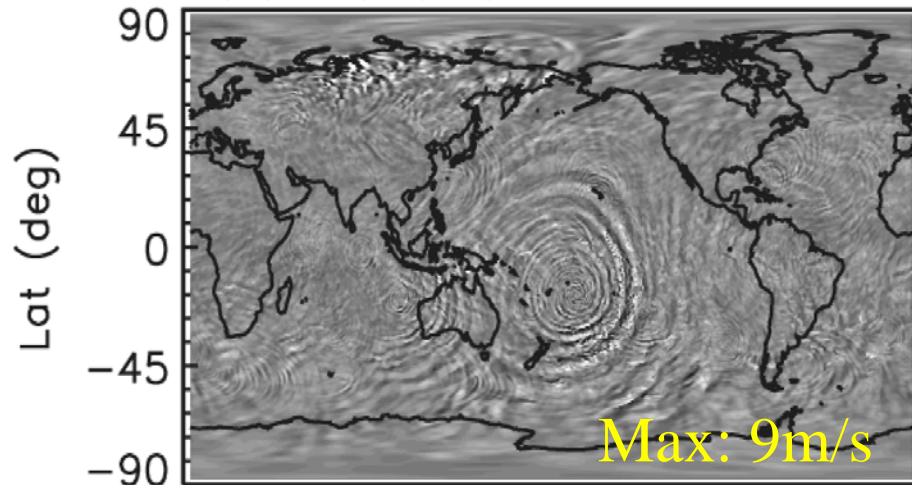
(a)  $w$ (m/s) at 208hPa



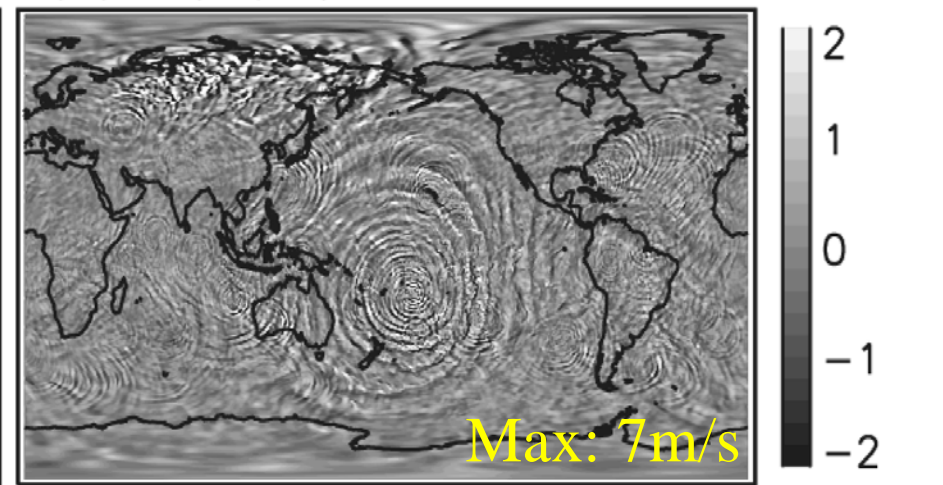
(b)  $w$ (m/s) at 10hPa



(c)  $w$ (m/s) at  $2.4e-3$ hPa



(d)  $w$ (m/s) at  $2.6e-4$ hPa

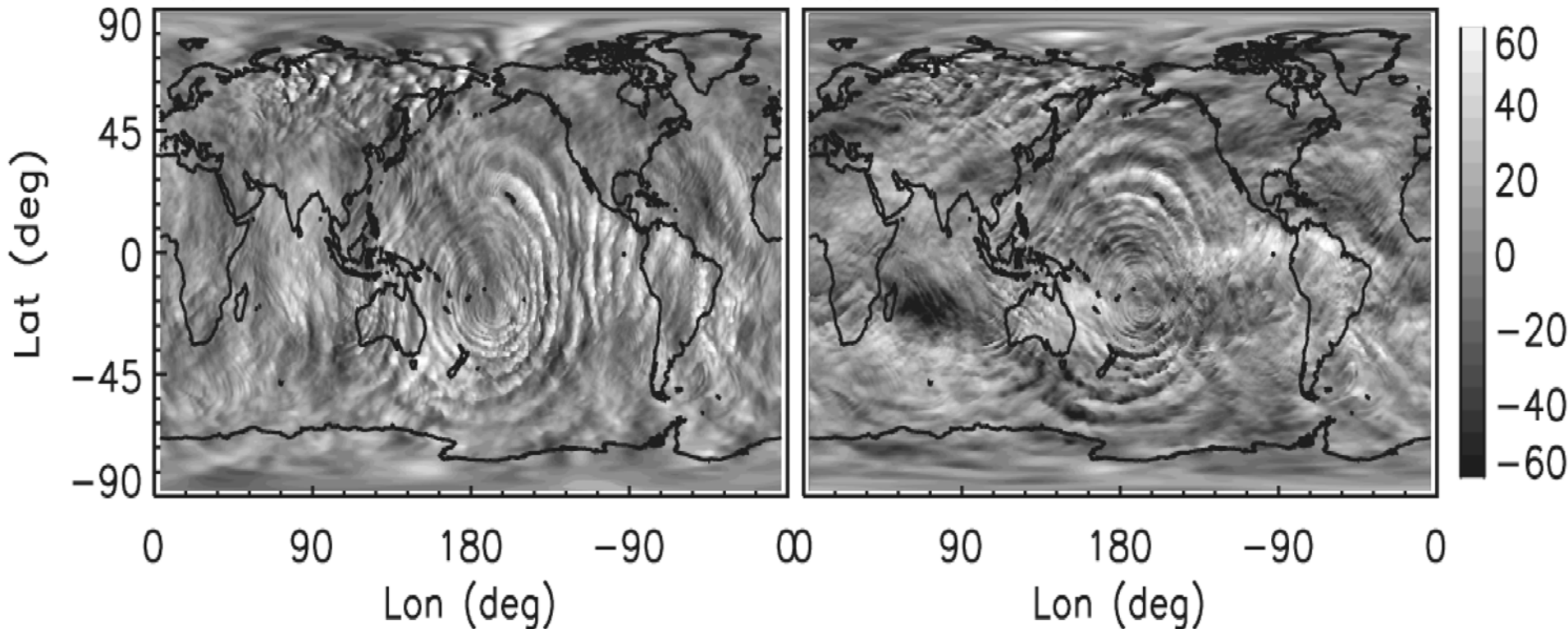




# Horizontal Winds in the Lower Thermosphere

(e)  $u$ (m/s) at  $2.6e-4$ hPa

(f)  $v$ (m/s) at  $2.6e-4$ hPa



Max:  $\sim 160$ m/s

# Altitude Dependence of Temporal/Spatial Scales - Tropopause





# Altitude Dependence of Temporal/Spatial Scales - Lower

Temporal/Spatial Scales

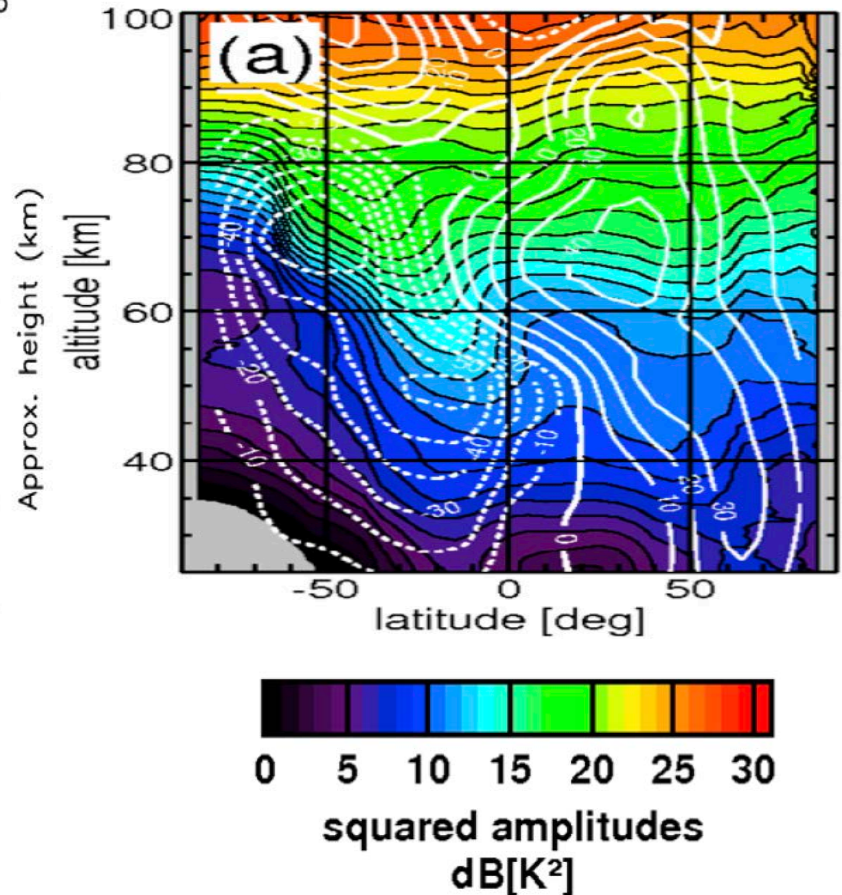
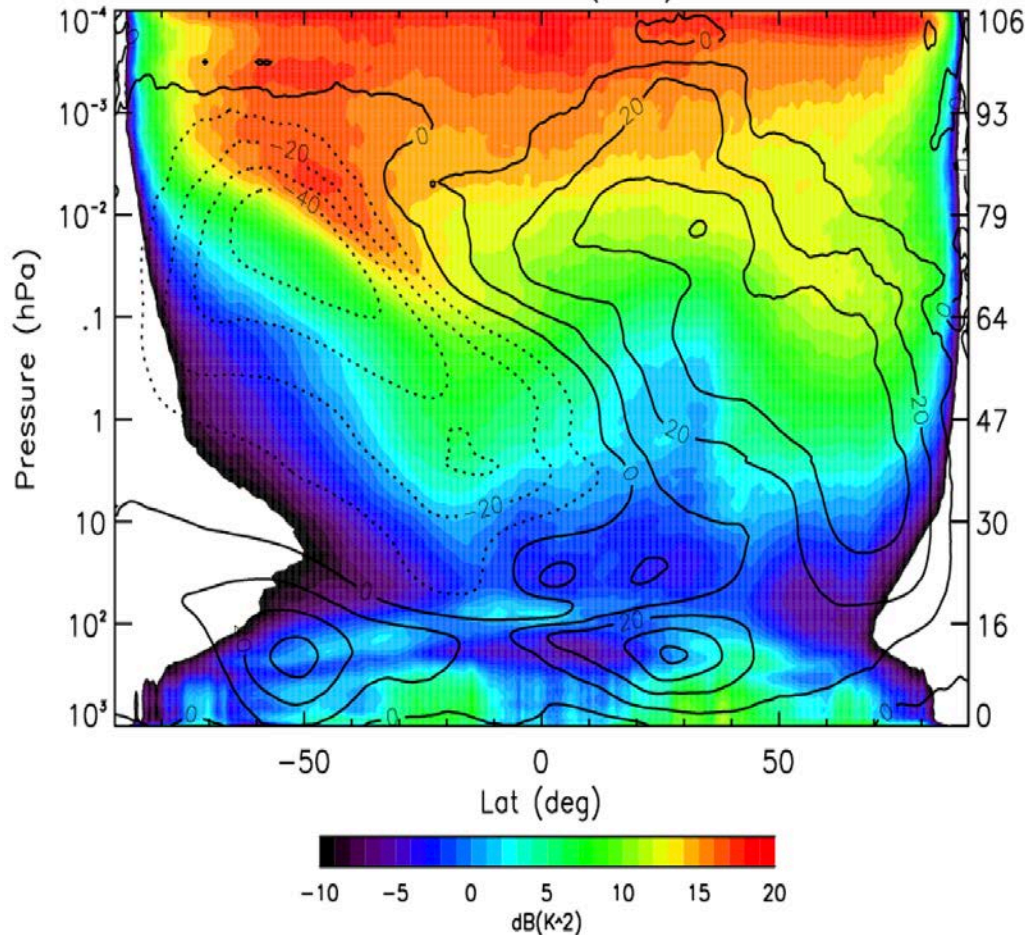


# Wave Amplitude: Comparison with SABER (January)

WACCM-SE NE120NP4

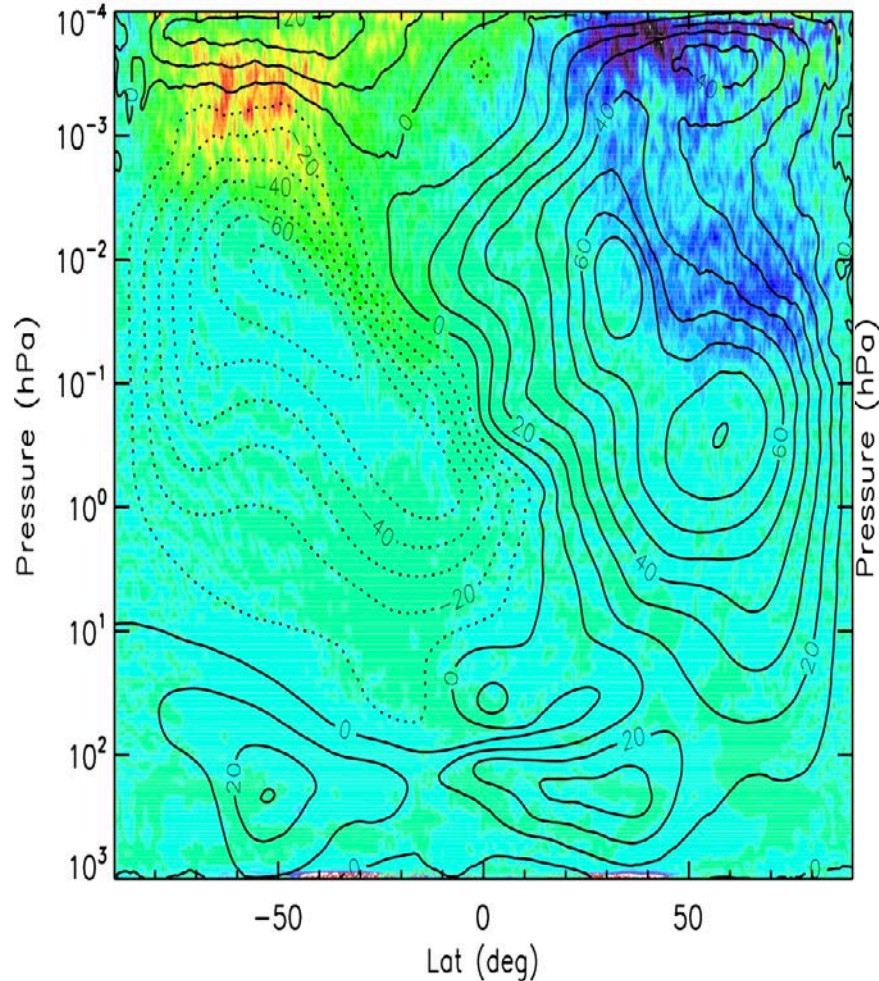
Mean  $dT^2$  ( $s > 6$ )

SABER (Ern et al., 2011)

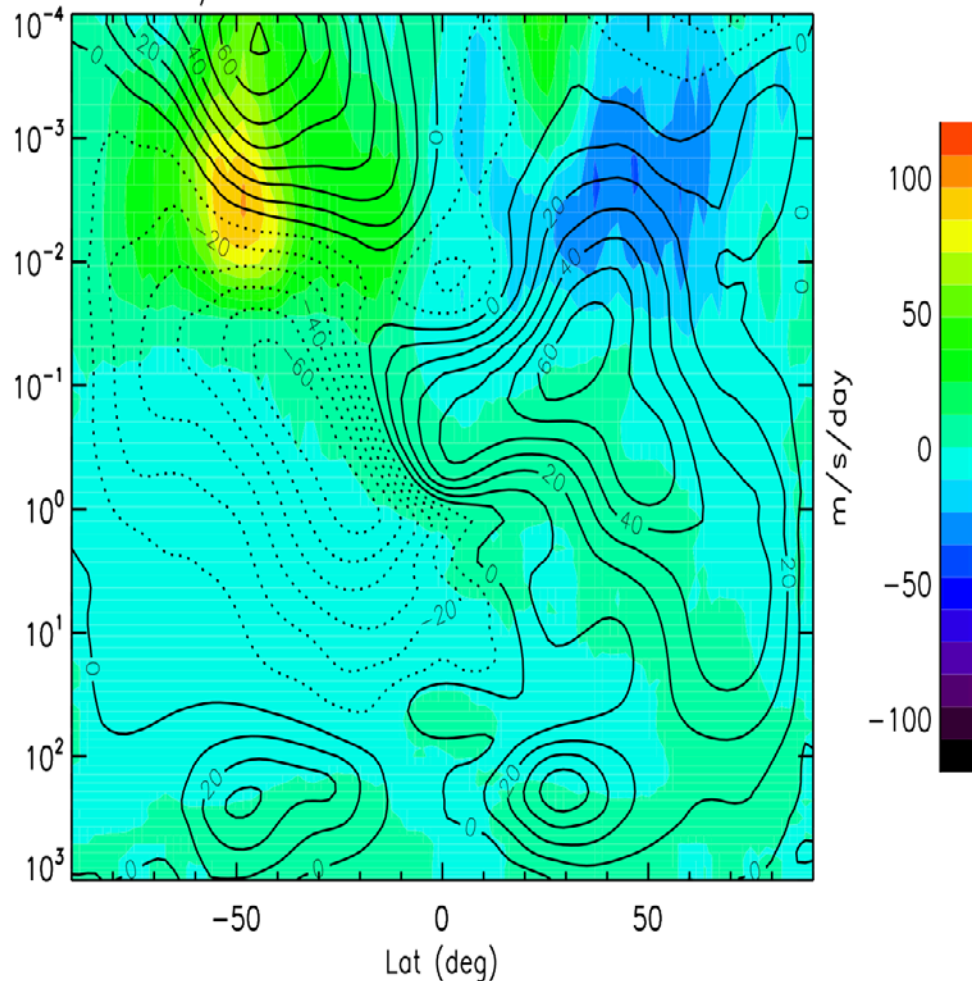


# Zonal Wind and GW Forcing

WACCM-SE NE120 EPDiv



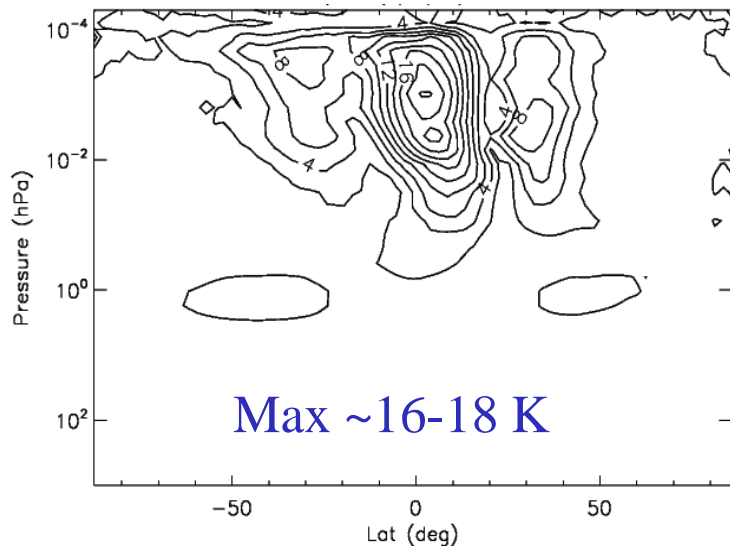
DART/WACCM 1.9x2.5 Parameterized GW





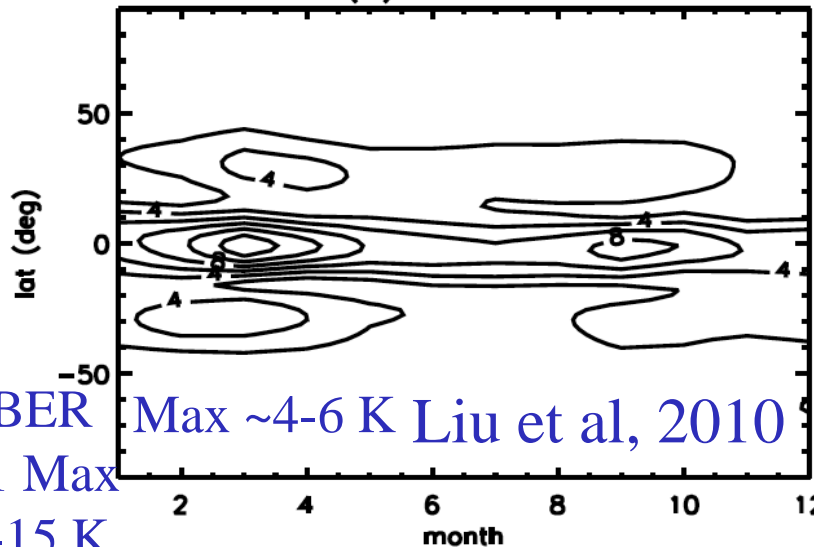
# Migrating Tides

T(DW1)(K) Jan

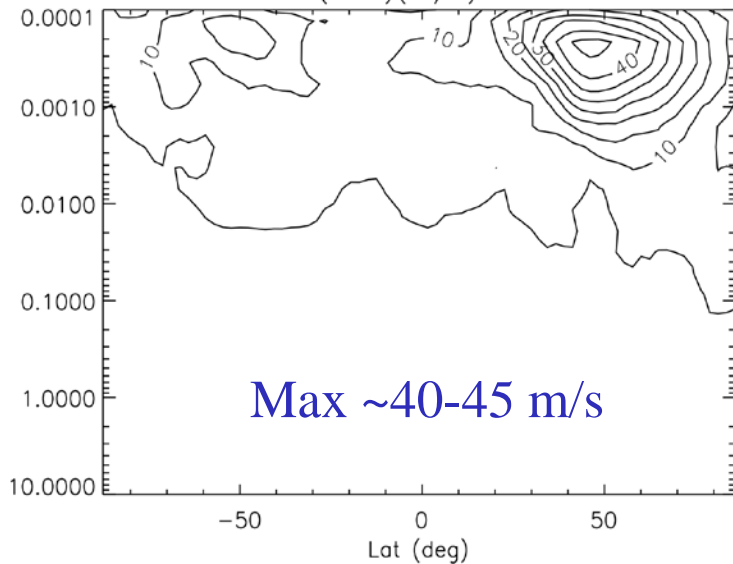


SABER  
DW1 Max  
~12-15 K

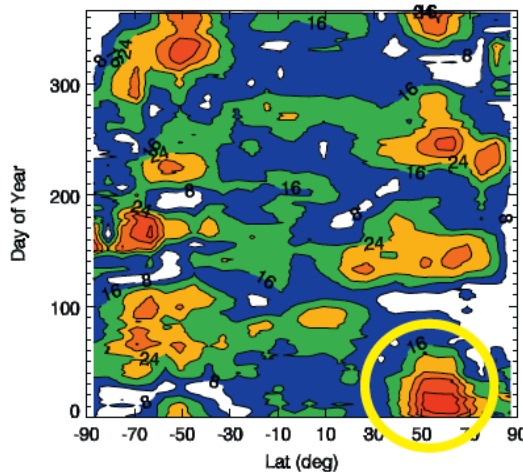
MDT T(K) at 4.0E-03hPa



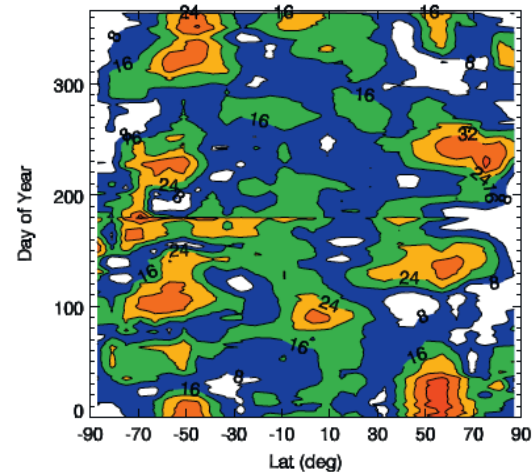
U(SW2)(m/s) Jan



TIDI Zonal Semidiurnal Tide at 95 km W2 2006



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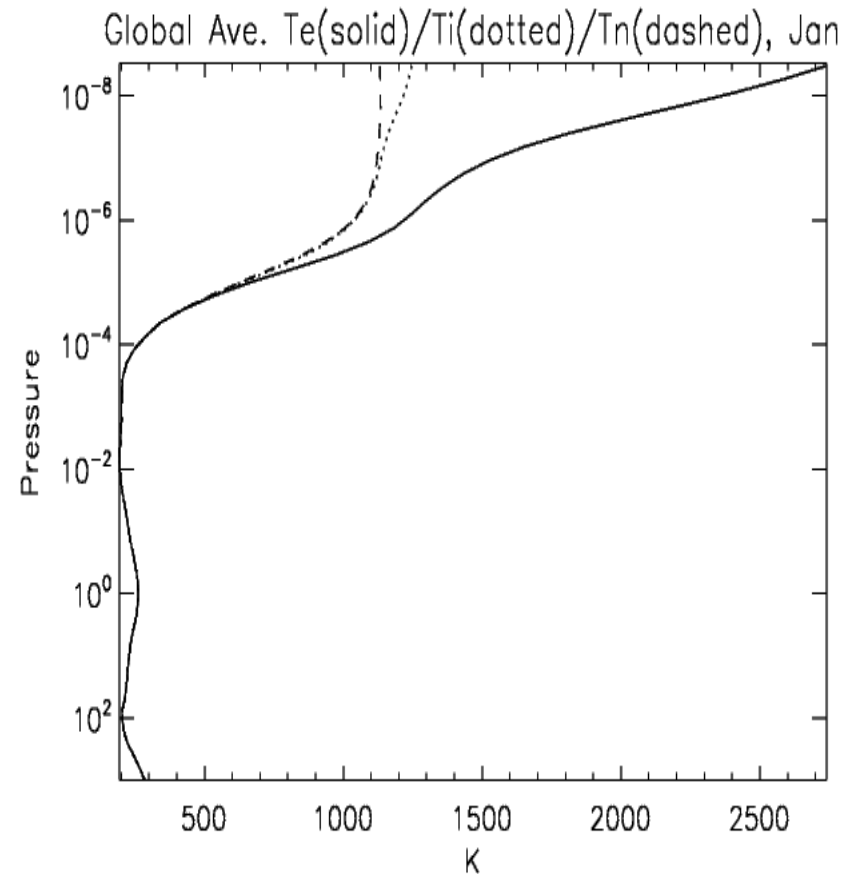
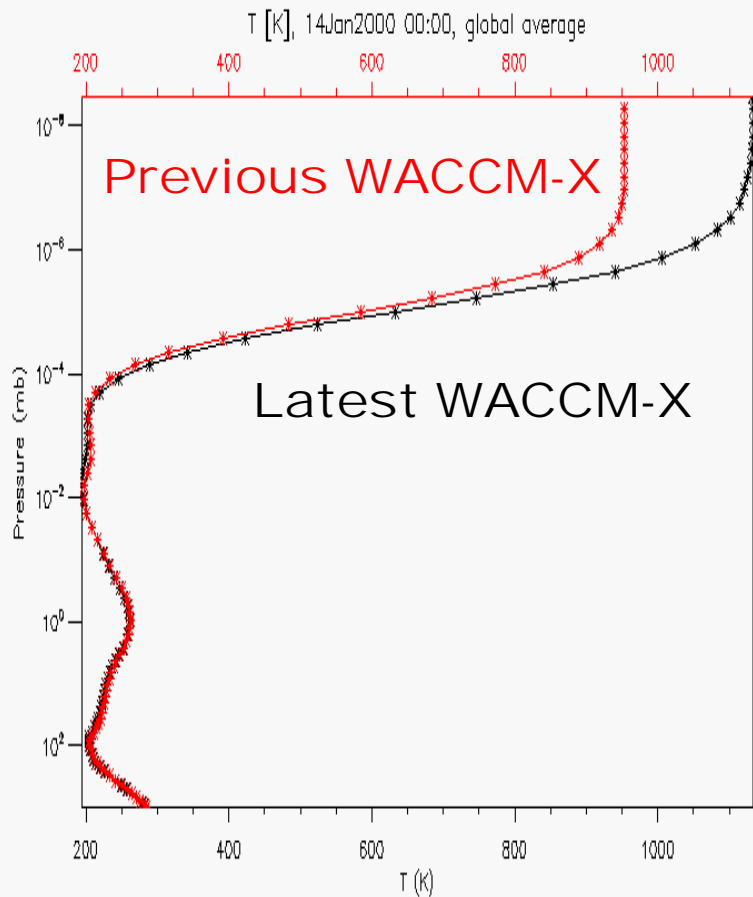
Max ~40-48 m/s Wu et al., 2011

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  - Started by running a higher resolution version of WACCM (GRL article, Liu et al.. 2014)
- **Enhance current WACCM-X ionosphere physics**
  - **Electron and ion temperature**
  - **O+ transport**
  - **Include these in CESM/CAM trunk**

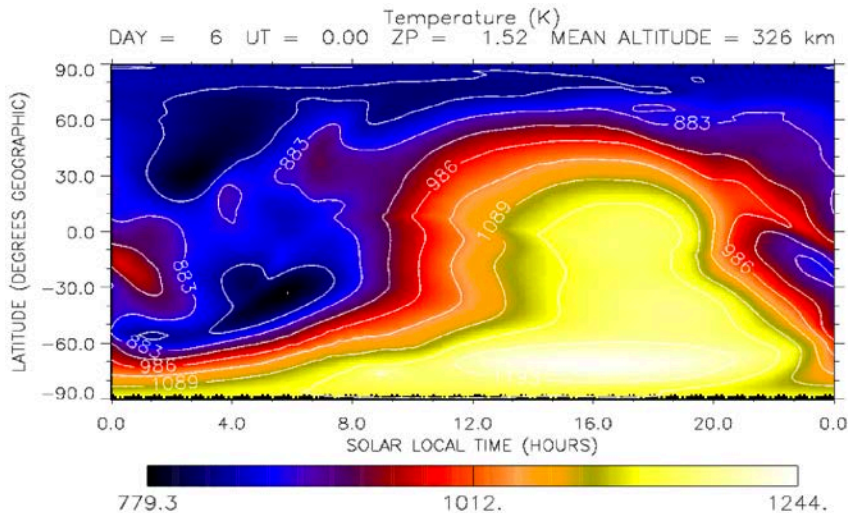
# Electron and Ion Temperature

**WACCM-X FV ~ 2° (100km) horizontal, 0.5 scale height vertical with time-dependent electron and ion temperature solver, as well as neutral heating due to thermal electrons.**

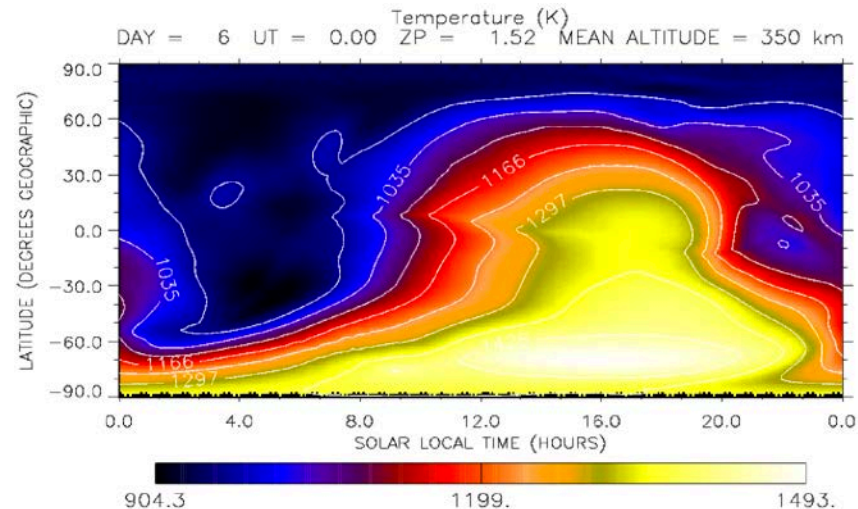


# Electron and Ion Temperature

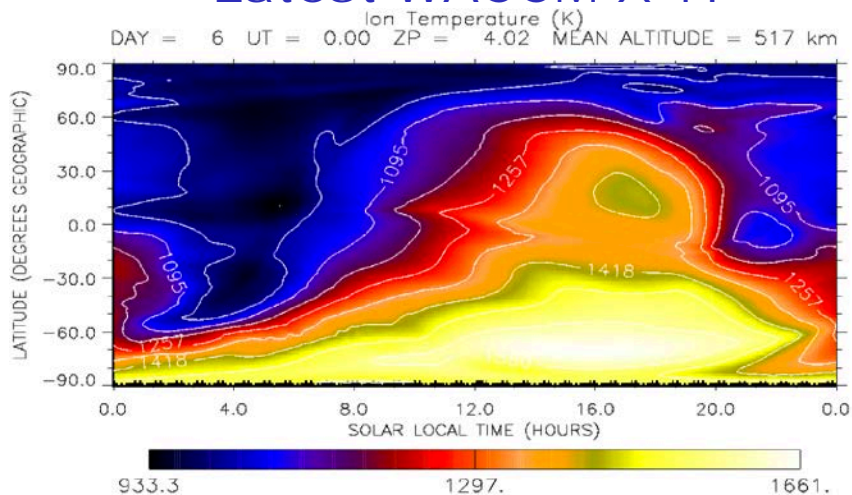
## Previous WACCM-X TN



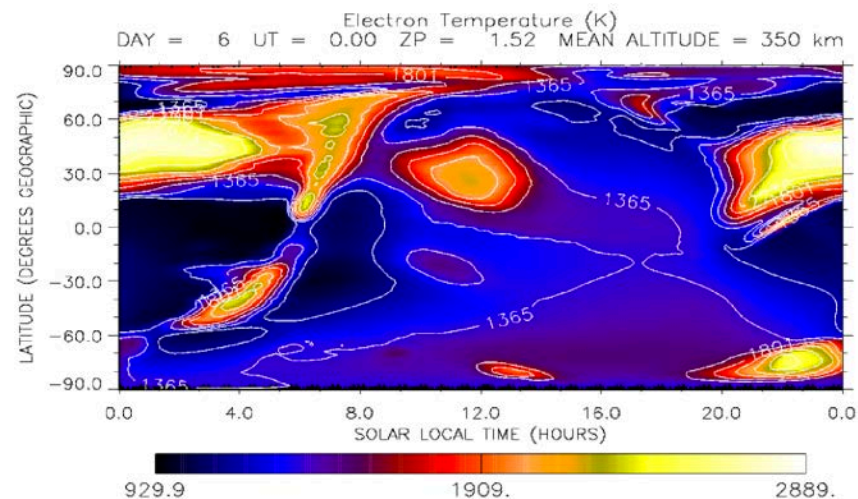
## Latest WACCM-X TN



## Latest WACCM-X TI



## Latest WACCM-X TE





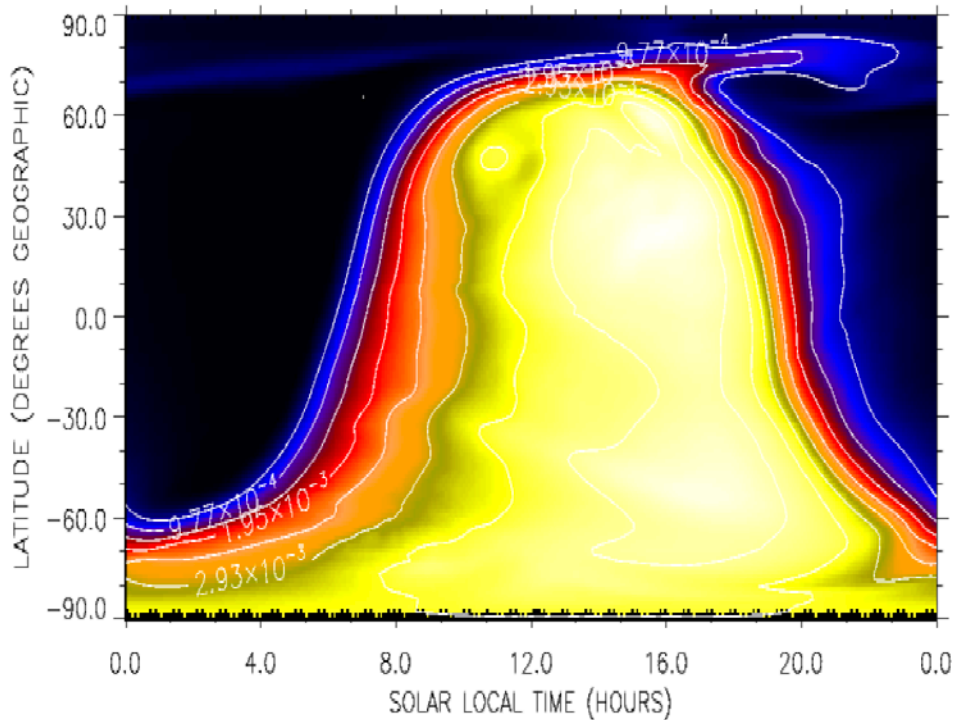
# O+ Transport

Along with TE/TI, added O+ transport due to ambipolar diffusion and ion drift: **Currently only in vertical direction**

Previous WACCM-X

O+ concentration (mol/mol)

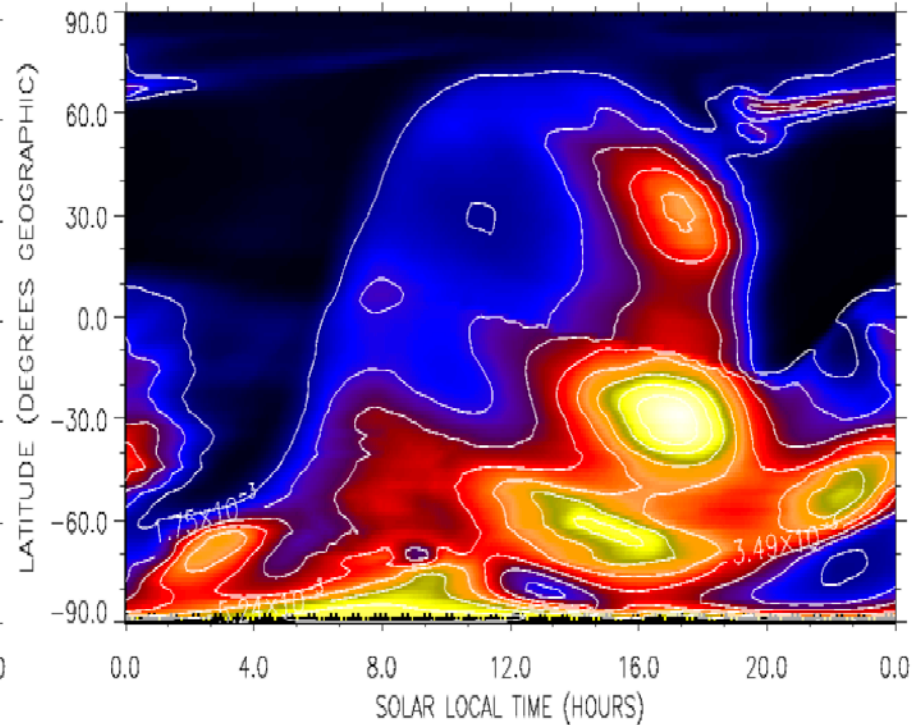
DAY = 6 UT = 0.00 ZP = 1.52 MEAN ALTITUDE = 326 km



Latest WACCM-X

O+ concentration (mol/mol)

DAY = 6 UT = 0.00 ZP = 1.52 MEAN ALTITUDE = 350 km



7.848e-07

0.002197

0.004392

4.590e-06

0.003928

0.007852



# Summary

- **Year long WACCM SE high resolution run including global simulation of gravity waves**
  - **Ultra-high resolution WACCM-SE feasible and valuable to quantify GW distribution and middle/upper atmosphere impacts**
  - **Resolved GWs agree with satellite observations but work to do on jets**
  - **Mesopause temperature at mid-latitudes and winter high latitudes agree better with observations**
  - **Migrating tides stronger and show the correct hemispheric structure in MLT**
- **WACCM-X FV self consistent TE/TI and O<sup>+</sup> vertical ambipolar diffusion now in CESM/CAM trunk**

# Future Work

- **WACCM-X high resolution spectral element (SE) simulation**
  - Recent run of WACCM-X spectral element (SE)  $\sim 1^\circ$  (100km) with interactive chemistry (MAM3)
  - Need to spin up  $\sim 0.25^\circ$  (25km) version
- **WACCM-X ionosphere**
  - Complete  $\sim 12$  year run with latest ionosphere enhancements
  - Transition ionospheric physics to WACCM-X SE
  - Add O+ HORIZONTAL ambipolar diffusion
  - Add TGCM dynamo
  - Turn off dynamical advection for ions/electrons (short-lived)
- **Add TGCM dynamo to WACCM-X and couple plasmasphere model (Ben Foster)**