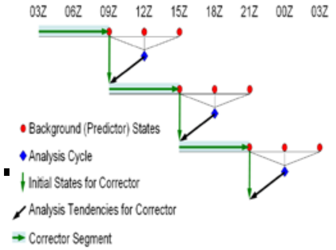
Upper Atmosphere Dynamics of WACCM-X constrained by MERRA and MARS data

V. A. Yudin, H.-L. Liu, A.K. Smith, B. Foster, L.P. Goncharenko, and T. Tsuda

Motivations



- **Constrain the low atmosphere** by 6-hourly modern reanalyses (MERRA) **preserving high-frequency waves (tides and 2-day).**
- **Evaluate model** predictions **by Middle Atmosphere Research Satellite (MARS) and ground-based observations**
- **Perform trial *"on the fly"* assimilation for O_3 and temperature with MARS data** as "specific" extra-chain in WACCM/CAM:

  (Dynamical Cores – Physics – Data assimilation).
- **List potential updates/revisions in CESM formulations** initiated by diagnostics of persistent model-data differences
- **Provide "neutral atmosphere" archives of WACCM-X/MERRA** for studies of the atmosphere-ionosphere coupling during SSW.

Why top lid of WACCM-X is important for vertical coupling by tides ?

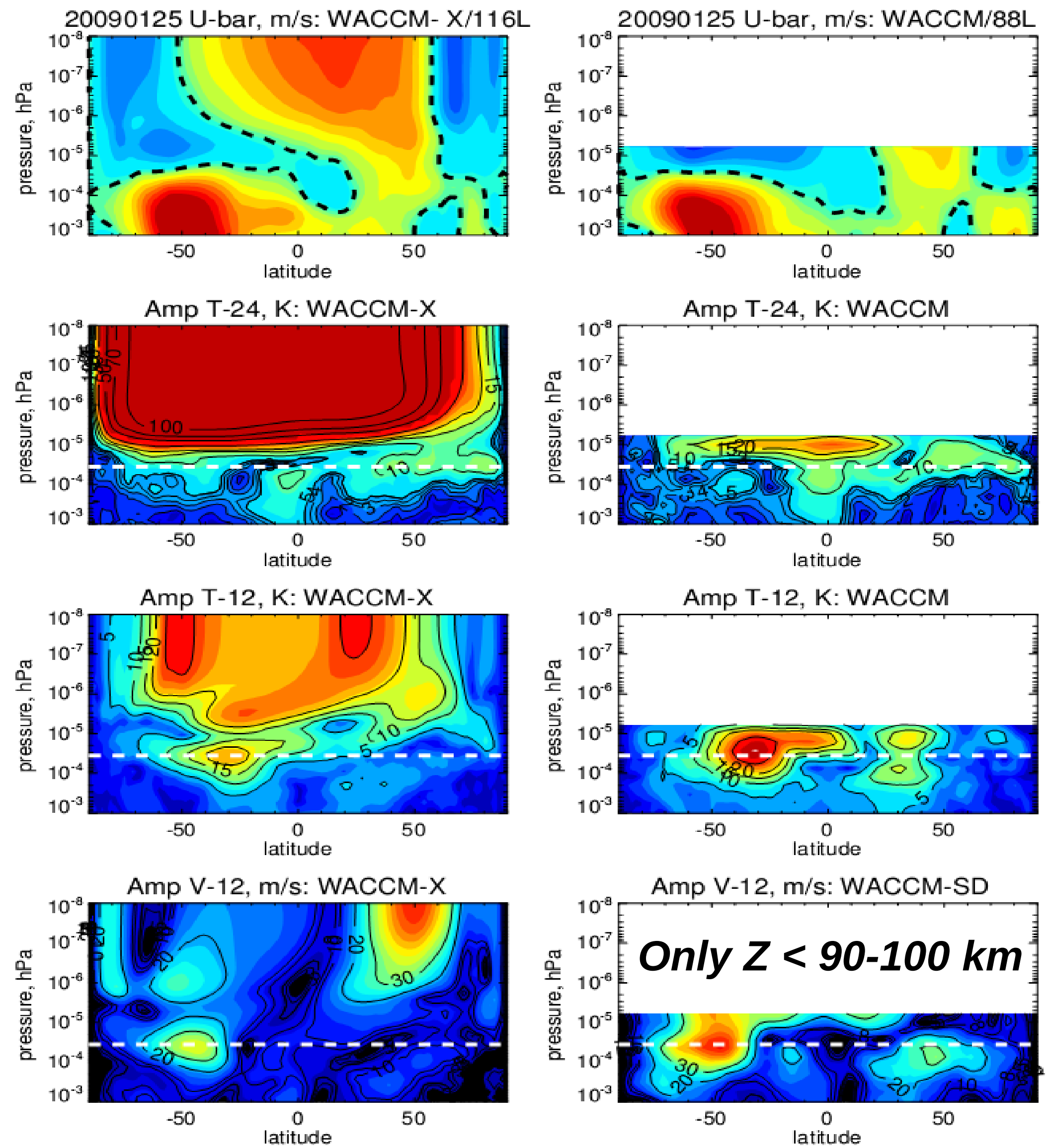
Performing simulations in NCAR Whole Atmosphere Climate Community Models:

WACCM (88-lev top lid at ~ 140 km, right)

WACCM-X (116-lev, top lid at ~500 km, left)

Influence of the top lid position is evident above $10^{(-4)}$ hPa (~100 km, dash-white line) by comparing diurnal and semidiurnal tidal amplitudes.

Numerical reflections of tidal modes with large L_z > 25 km from ~140 km top lid in WACCM-140.



WACCM and WACCM-X with GMAO products, as a forecast and data analysis system for Upper Atmosphere

- **GMAO analysis products:**

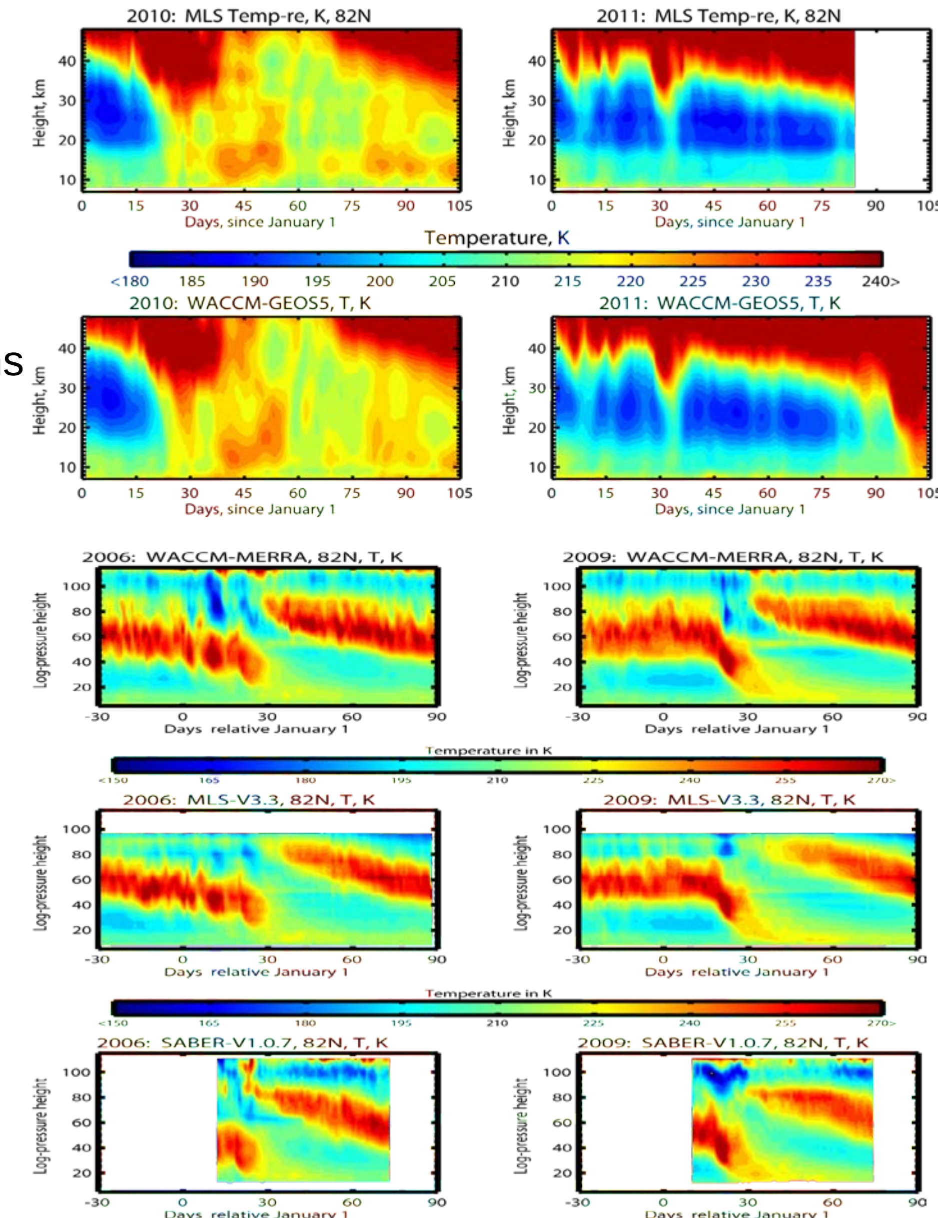
  GEOS-5 is Goddard Earth Observing System with 72-lev (77 km) & HR: 2/3x0.5.

  MERRA (1979-present)– Modern Era Retro analysis for Research and Applications

- **WACCM-GEOS5/MERRA (*Kinnison et al*.)**
  VR of GEOS5 + 16 levels. in 77-140 km;
  HR (2.5^ox1.9^o) is ~ 4 times cruder

- **WACCMX-GEOS5/MERRA** -116 levels from the surface to ~ 500 km (***Yudin et al.)***

- ***Coupling WACCM and GEOS5/MERRA***
  (a) through tendency: for(*X=U, V, T*)
  dX/dt= (Xwac- Xgeos)/Tau
  [surface – ~40 km]
  dX/dt = 0, above 50 km;
  (b) n%-Nudging every time step (1%)

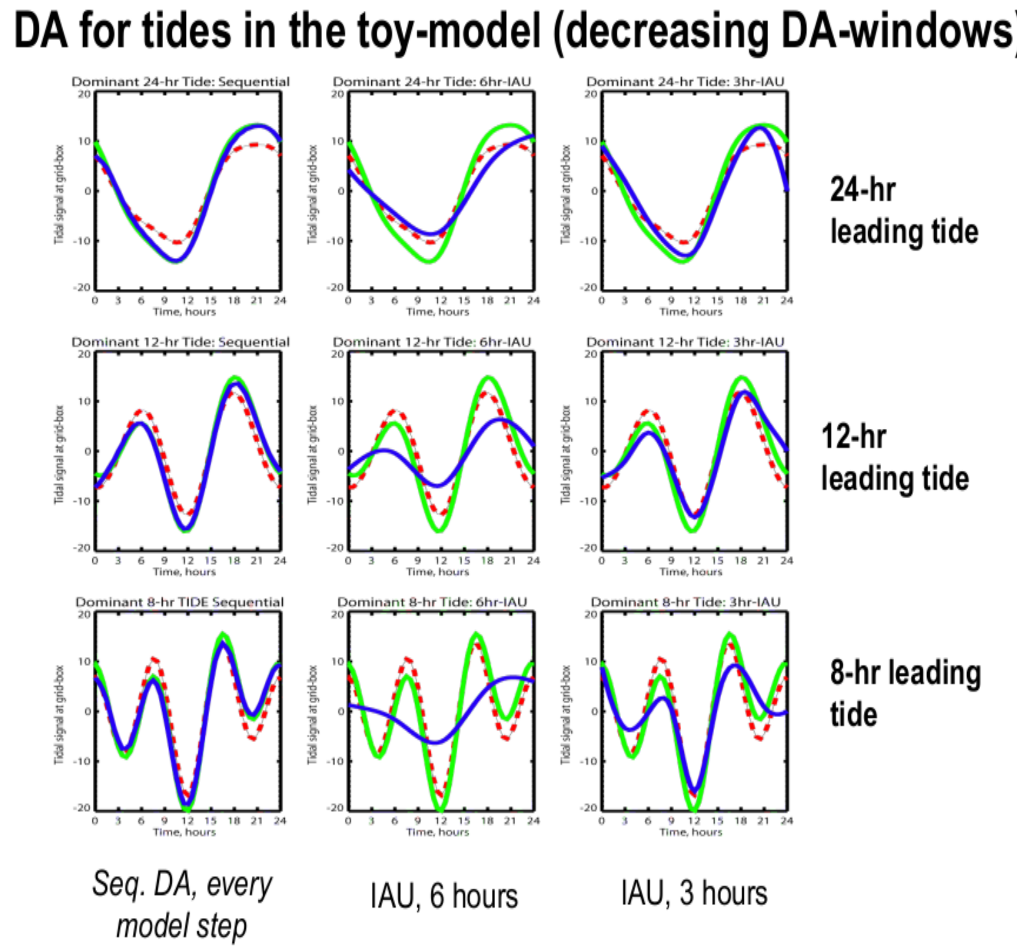


Constraining tides in models by SM and DA

- **Task-1:** Prevent tidal signatures simulated by models during DA. They can be degraded by multi-hour analysis update cycles, or/and nadir data with the restricted vertical resolutions, AMSU-A radiances near the stratopuase).

- **Task-2**: When data contain tidal signals, update the DA algorithms of NWP centers to assimilate properly tidal observations (temporal/vertical resolutions).

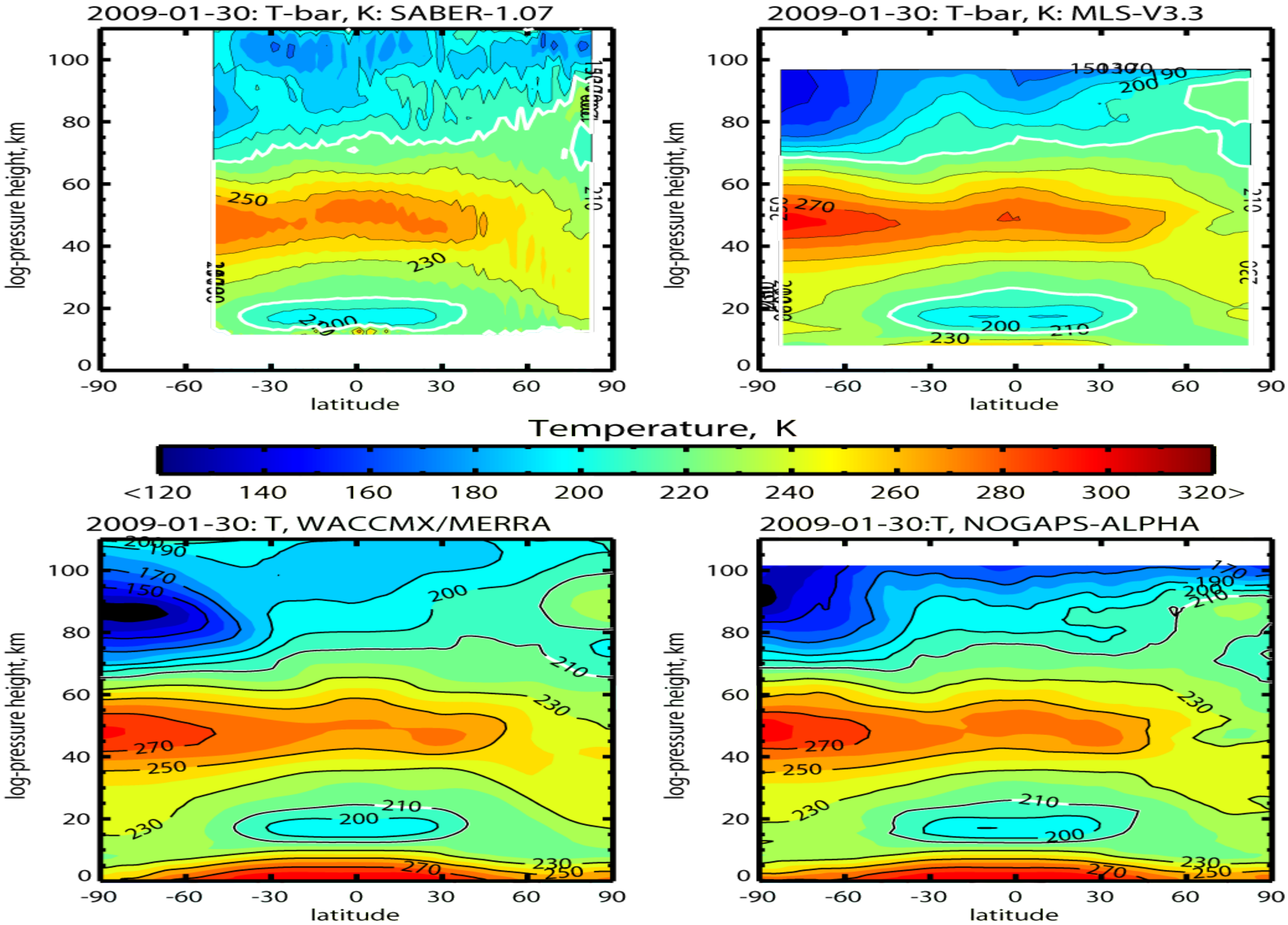
- **Task-3:** Demonstrate using OSSE studies what kind of the temporal and spatial data coverage in the UA-region is needed to advance the Space Weather applications influenced by tidal motions.



On-the-fly | **With model restarts**

Green-true; Blue-DA; Red-Forecast

Model evaluation by data and meteo-analyses



Typical model-data differences

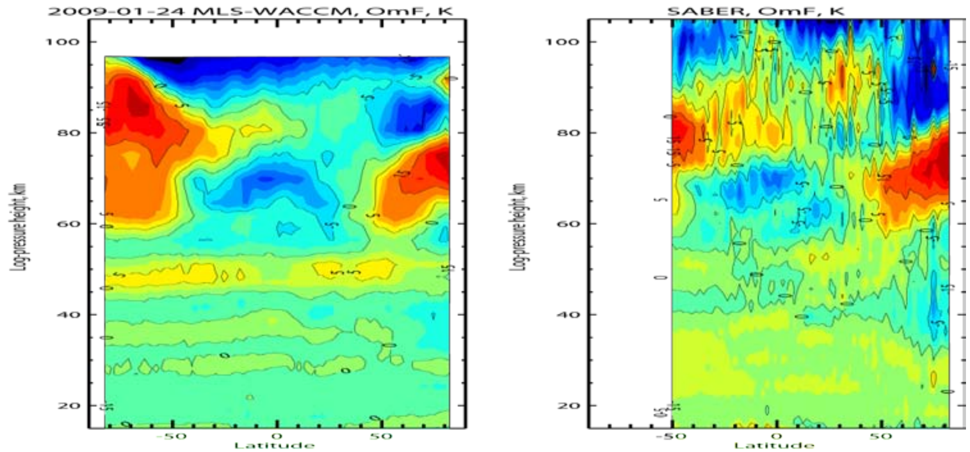
MLS &SABER vs **WACCMX/MERRA T-discrepancies**

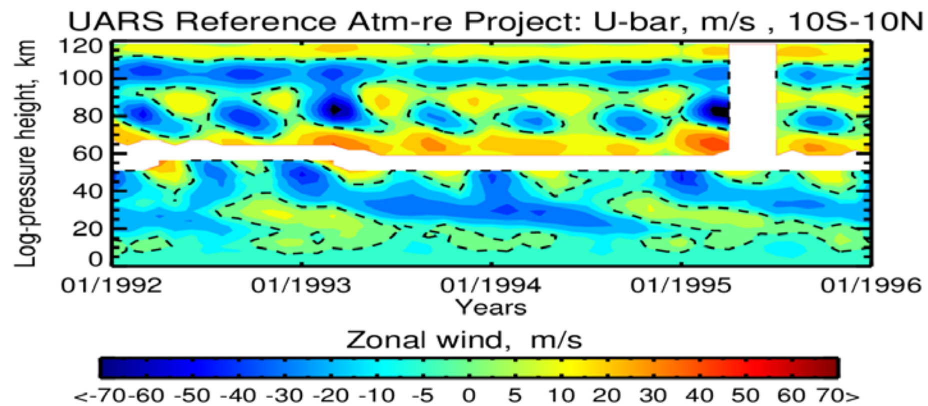
a) polar SH MLT; very cold
b) warmer 90-110 km band;
c) polar night NH above 60km
d) Elevated winter stratopause

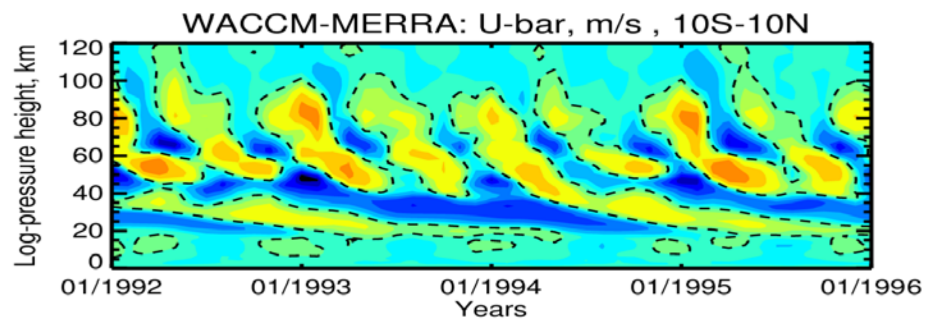
Winds, WACCM vs UARS and radars

a) *strong tropical E-ward winds above 80 km;*
b) *strong wind reversal in extra-tropical MLT*
c) *relatively weak amplitudes of tides, especially in U-winds*.

Tracers: *Strong eddy mixing in coldest regions of MLT*

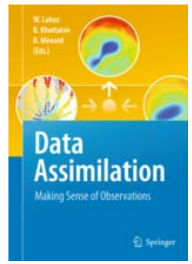






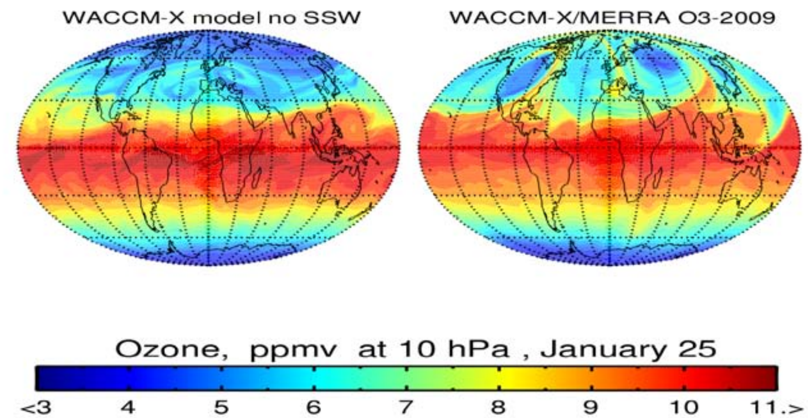
Data Assimilation of Temperature and Ozone: *1. Zonal mean and PWs; 2. Tidal forcing*

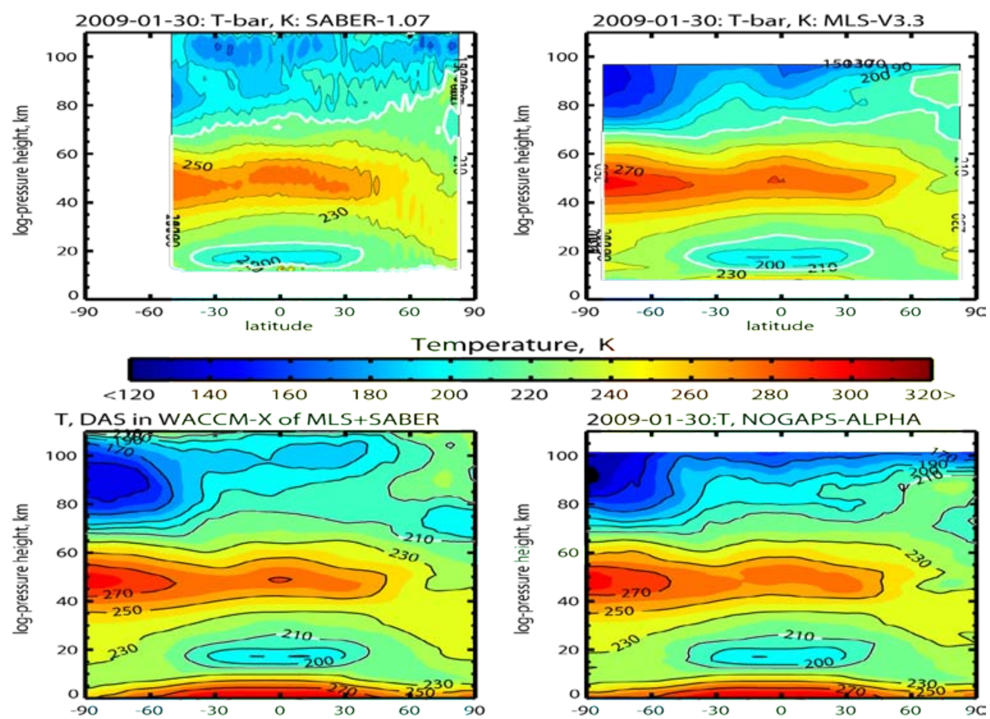
Chemical Data Assimilation, Chapter 4, 2010: *Atmospheric Chemistry and Constituent Transport .Representation and Modelling of Uncertainties in Chemistry and Transport Models, Khattatov and Yudin.*



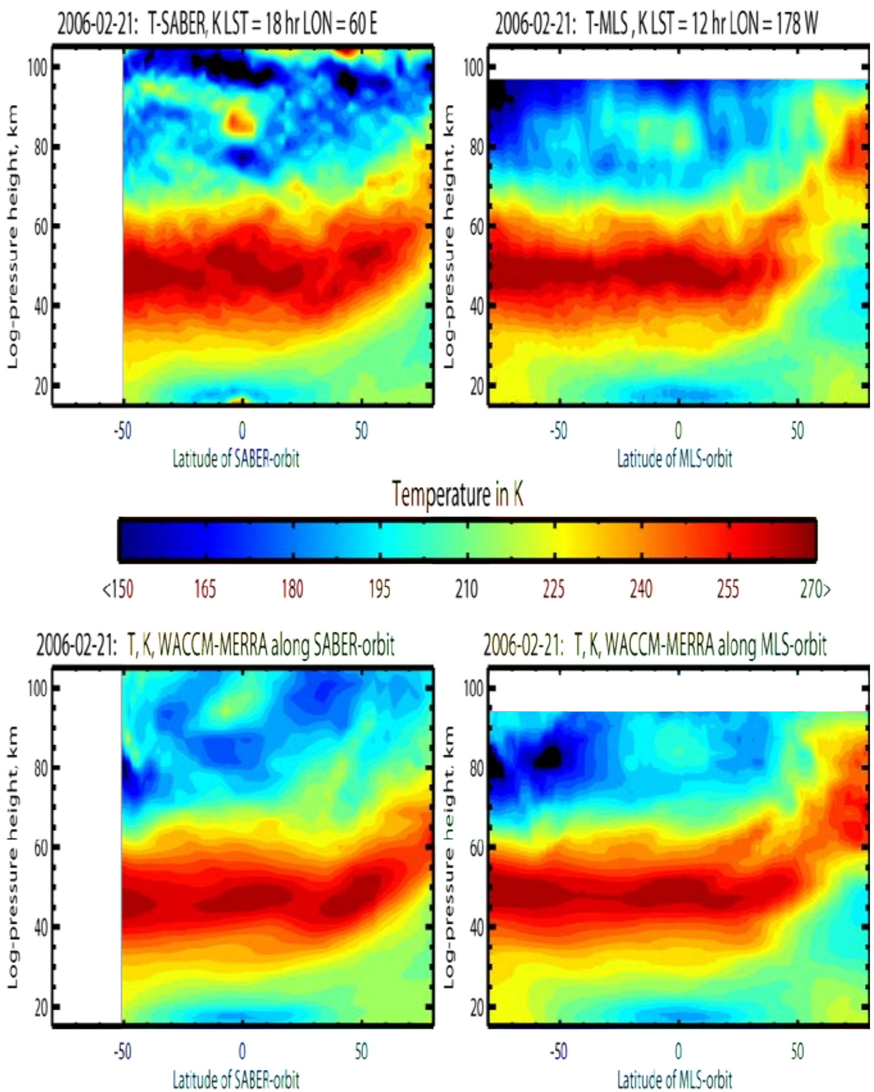
Application of sequential filters on-the-fly in WACCM: *the resolution-sensitive filter-split algorithms for analysis of the space-borne chemical constituents and temperature.*

For assimilation of tides: *frequent and "gentle" data constraining at every time-step*

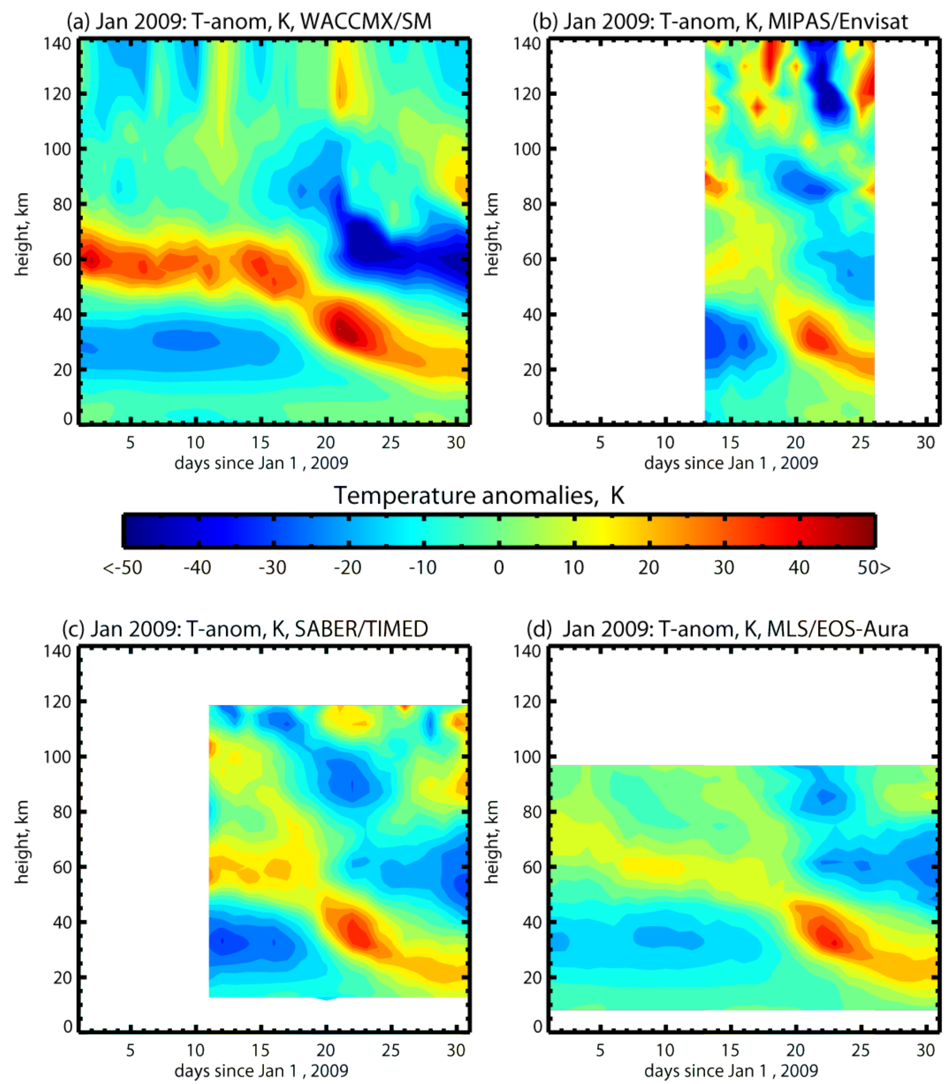




Joint O_3-T analysis in WACCM with MERRA: signatures of vertically-propagated waves and polar coupling



Single orbit T-structures



Zonal averaged 75-85 N T-anomalies

Lessons from constraining model by MERRA and MARS data: list of potential model updates

- Disassemble dry static energy as a model state variable during physics and update eddy diffusion operators.
  (solves in part cold MLT polar T-bias; and eliminate T-dependence of eddy heat conductivity/viscosity/diffusion).

- Consistent mass and energy conservation for physics and dynamical cores *(accurate physics tendencies between parameterizations and d-p coupling)*

- Scale-aware parameterization schemes for GWs with:

  (a) new GW-MF closure;

  (b) dual eddy viscosity (conductivity) and momentum (heat) depositions;

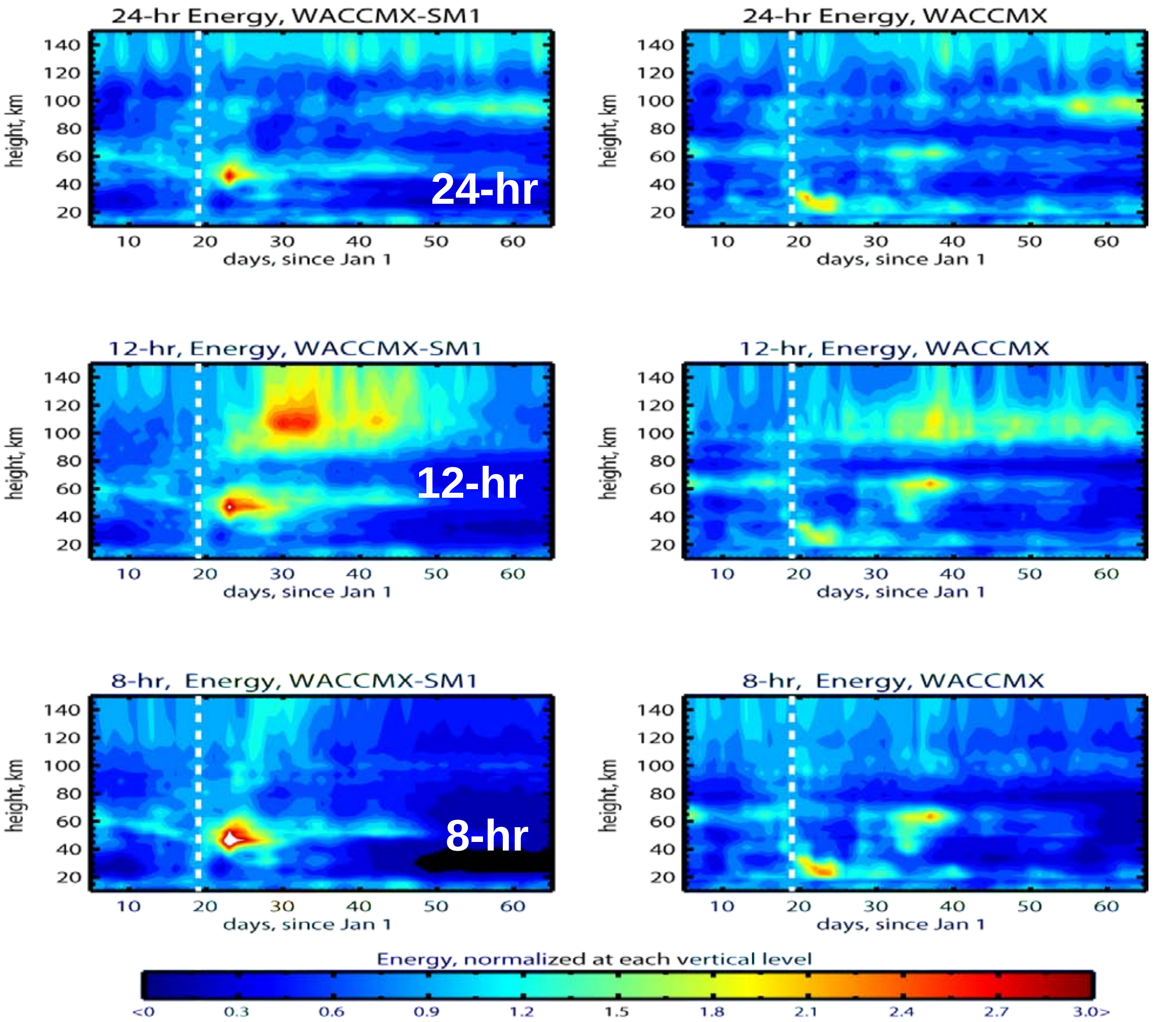
  (c) orchestrating oro-GWs and TMS.

Global Tidal Energies during SSW of 2009

WACCMX-SM1, constraining model by analysis tendencies with tau = 96 hr.

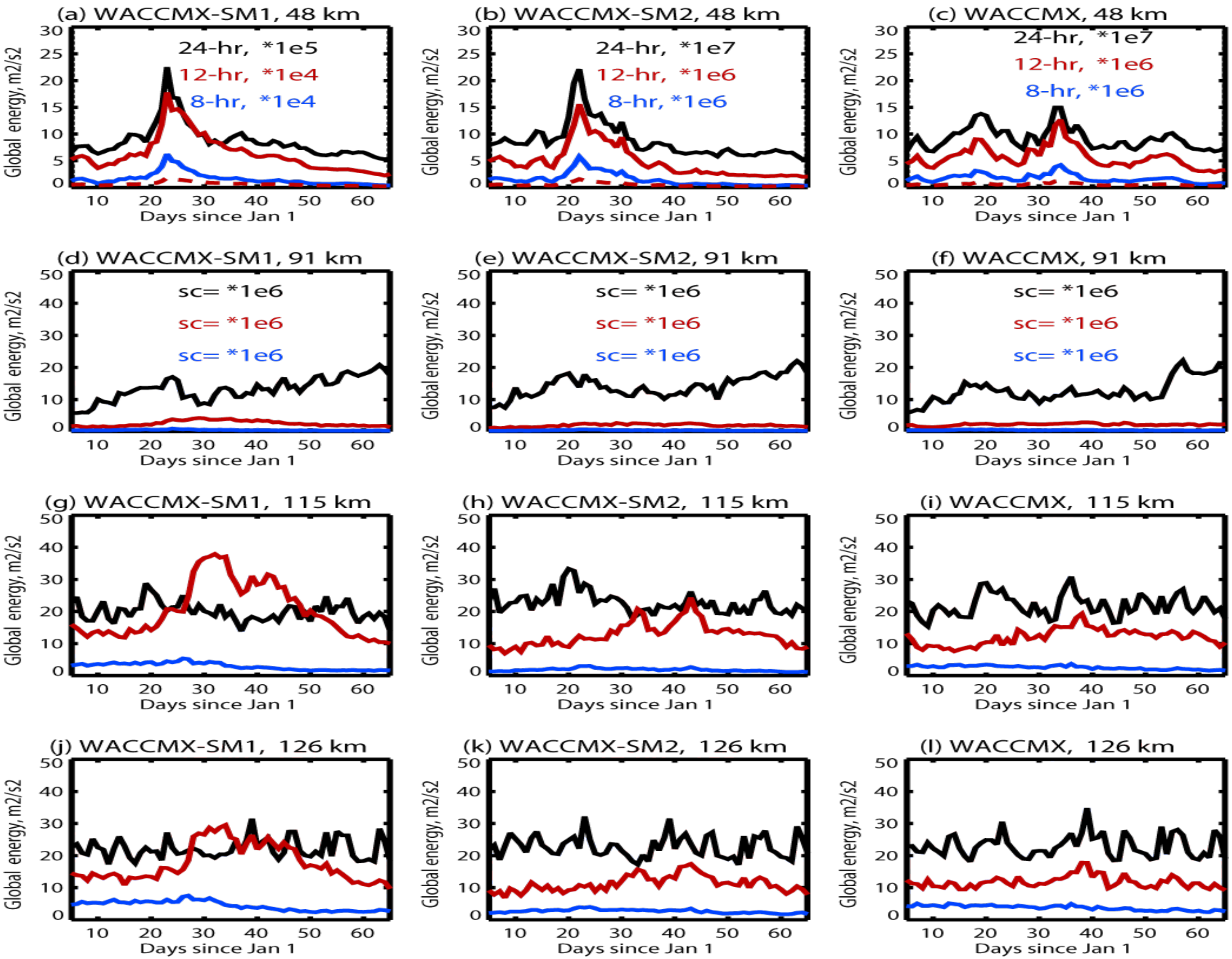
WACCMX-SM2, constraining model by 1%-nudging at every model step.

WACCMX-climate, model no MERRA-meteorology



WACCMX-MERRA-SM1 ***WACCMX***

Tides during Jan-Feb of 2009



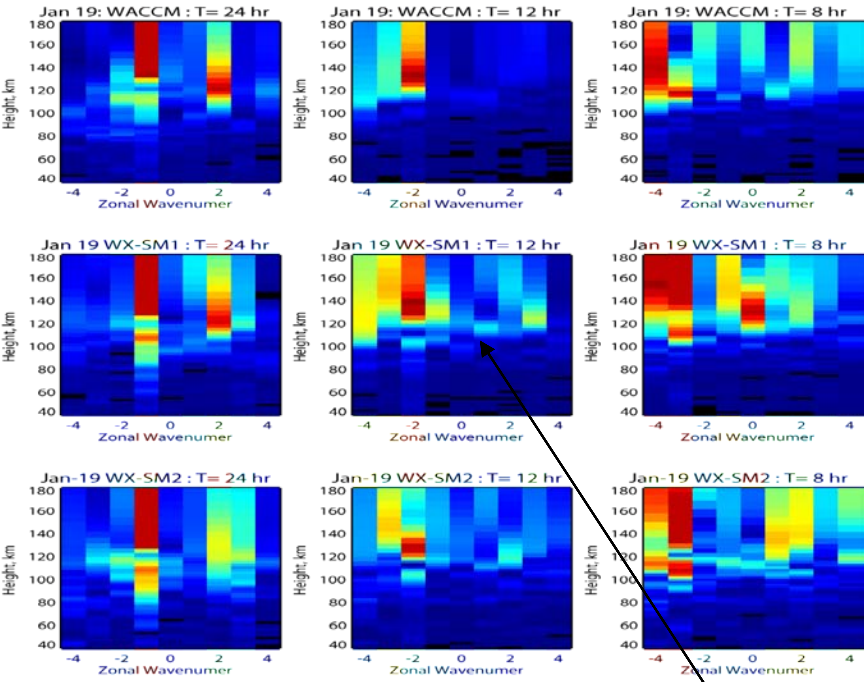
48 km

91 km

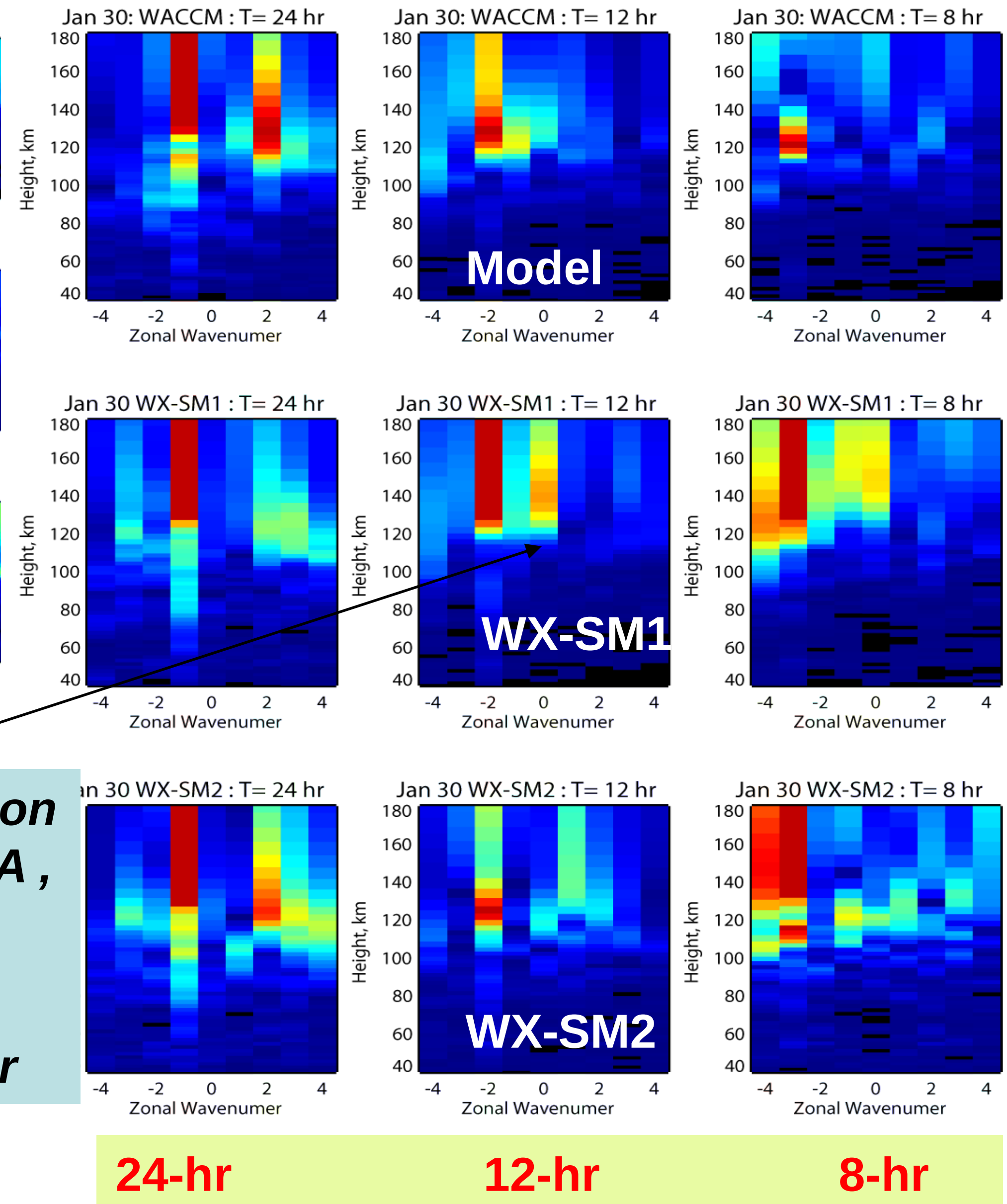
115 km

126 km

Tidal spectra during SSW of 2009 (equator)



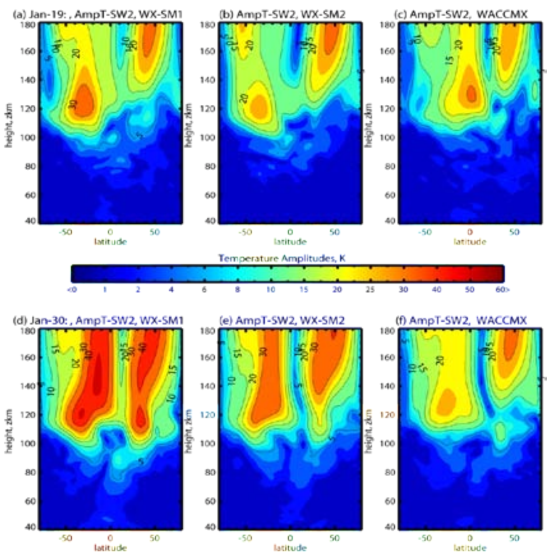
Before SSW

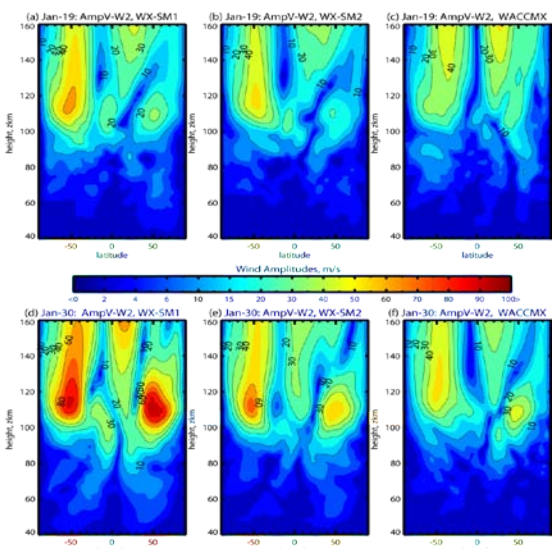


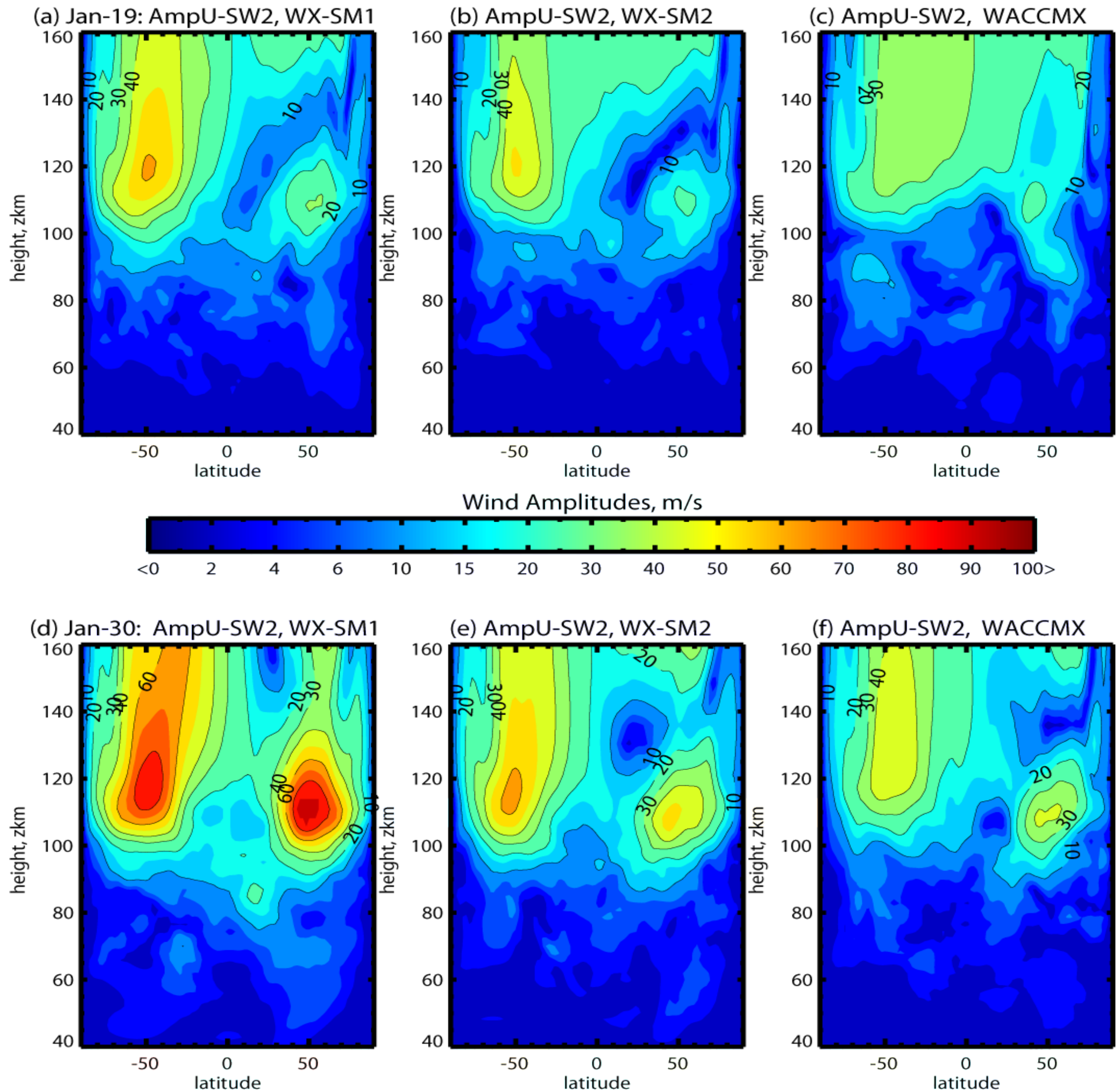
During SSW "resonance" amplification of SW2 and SW0 in WACCM-X/MERRA , less evident with 1%-nudging and no features in WACCM-X/climate.

1) Ozone forcing; 2) SPW2 and S-24hr

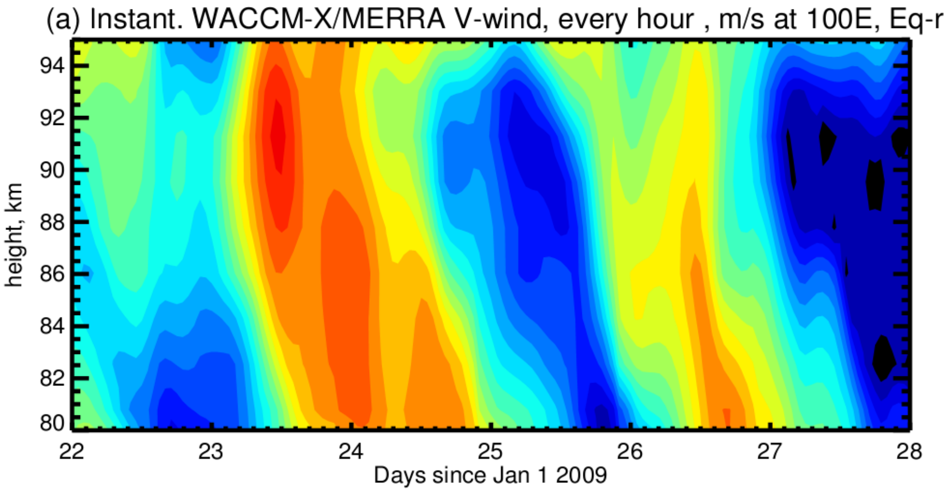
Tidal amplitudes before and during SSW-2009

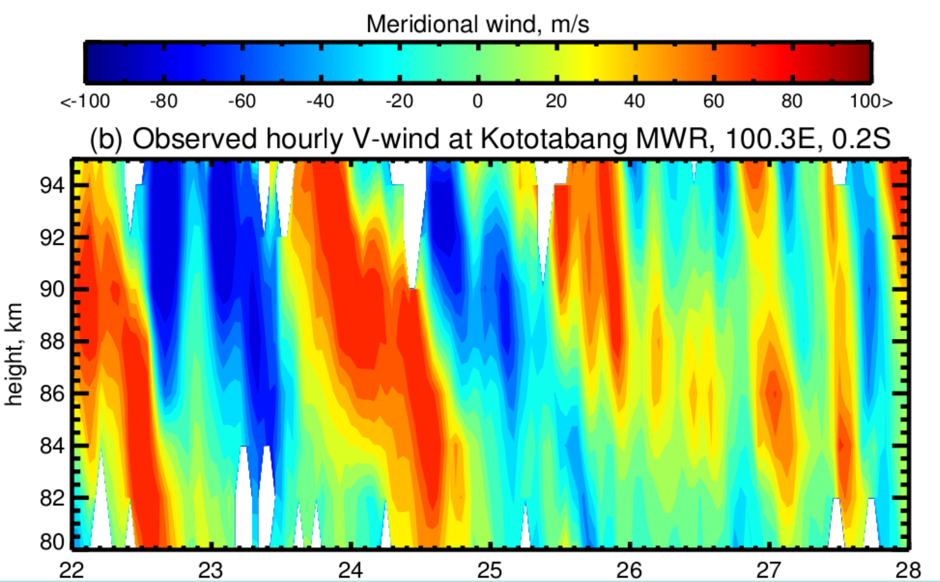


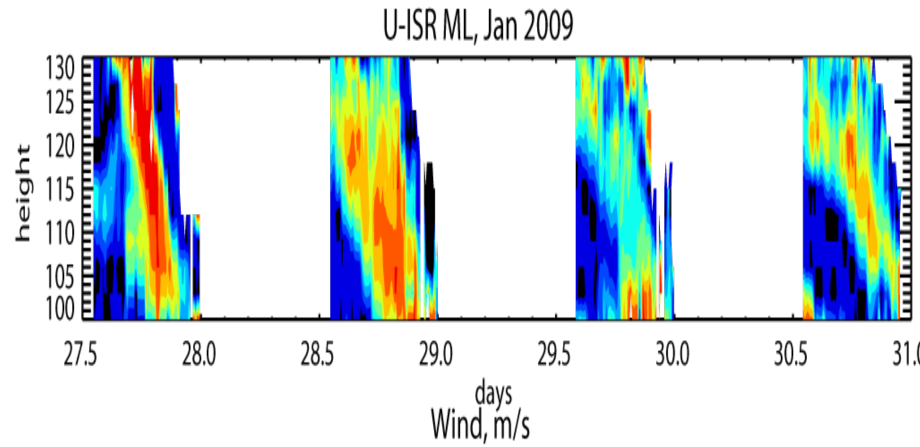


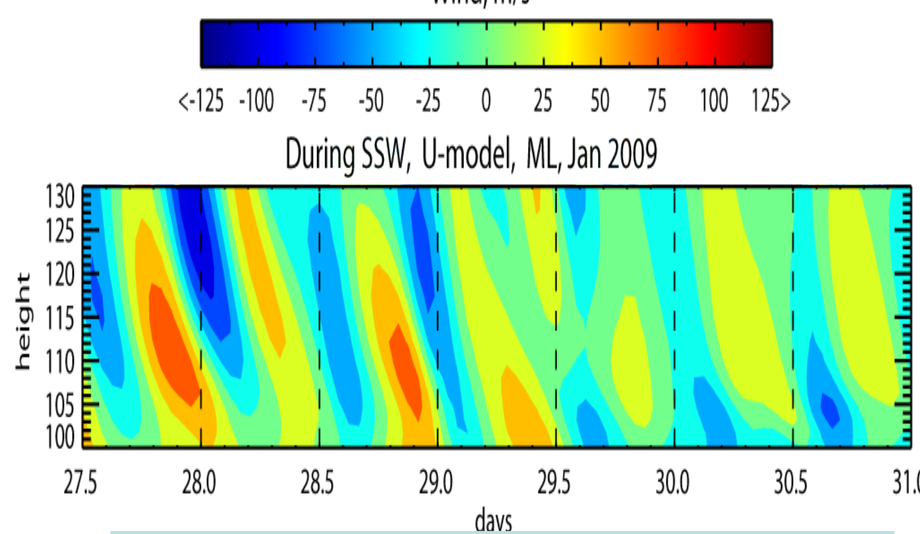


Evaluation of WACCM-X/MERRA (revised GW-scheme) by MWR and ISR radars (2-day wave and 12-hr tide amplifications during SSW)







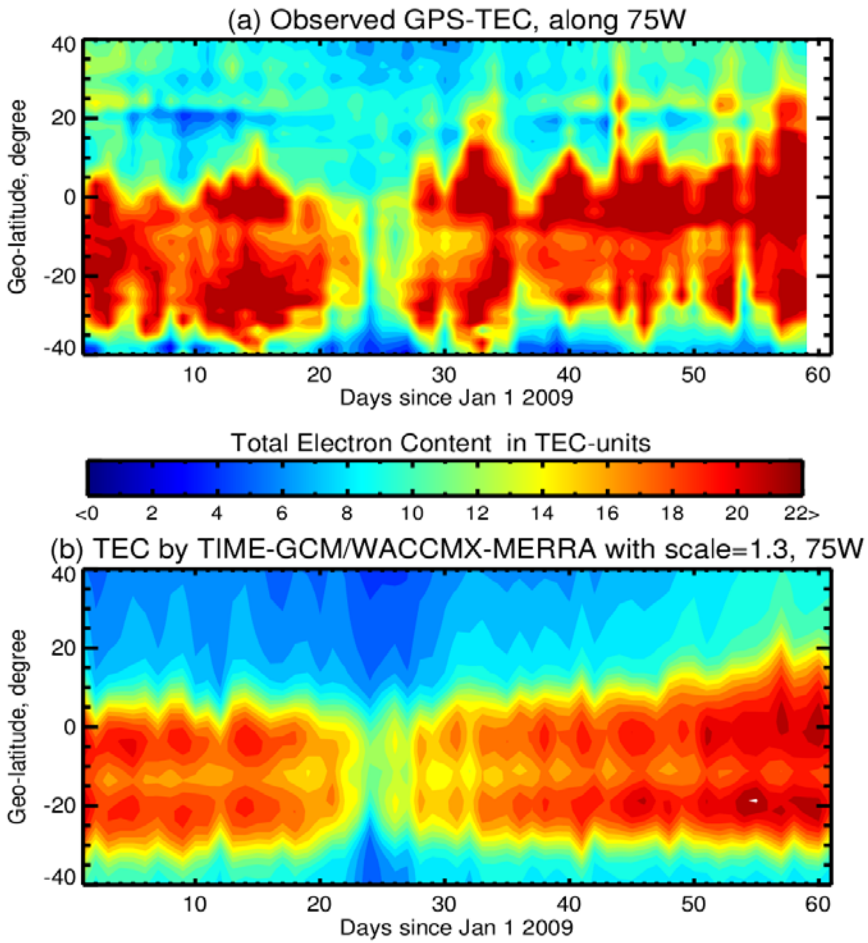


Millstone Hill (MIT), 40°N,75°W,

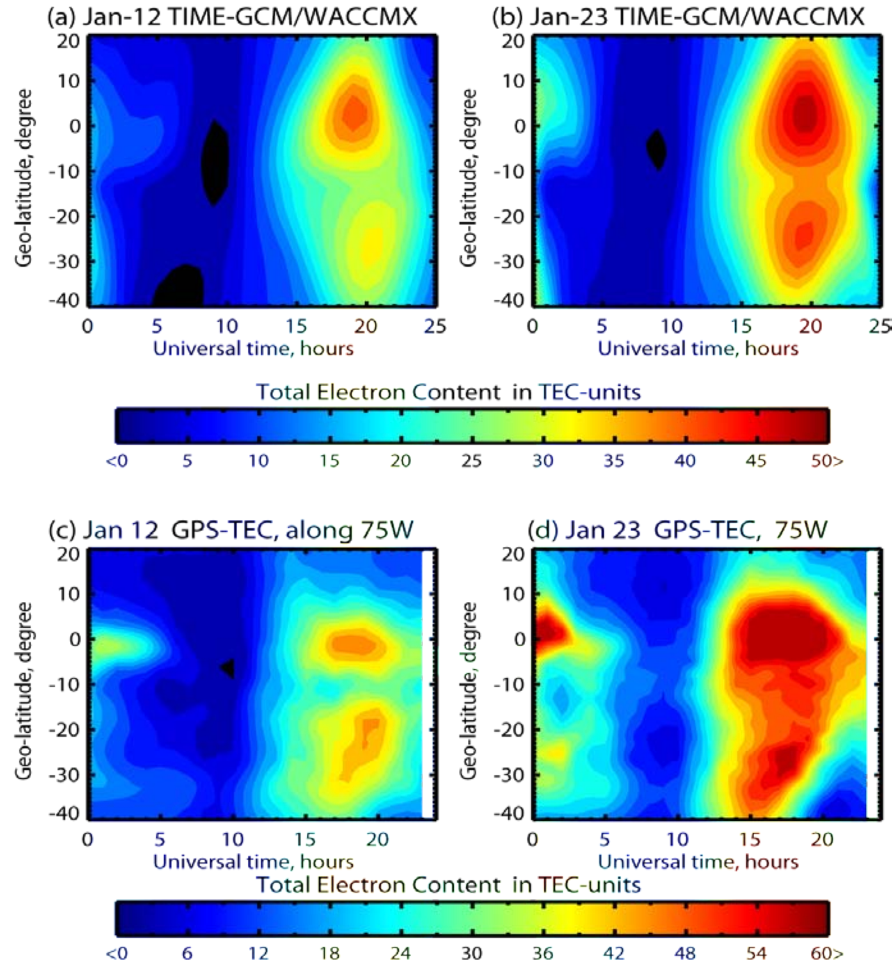
12-hr tide growth during SSW

MWR-data from //database.rish.kyoto-u-ac.jp

Evaluation of TEC variations in TIME-GCM with WACCM-X/MERRA neutral atmosphere below mesopause



SSW Jan 2009, solar-min



SSW Jan 2012:, Before (left) and during SSW and geo-storm (right)

Concluding remarks

Specified Meteorology below 40 km and DA of MARS data 'on-the-fly' in WACCM provide direct 'model-data' comparisons allowing to address the following aspects:

- Case studies of UA dynamics with realistic weather patterns during SSW events.
- New discipline/topic: how to assimilate MARS data and constrain fast-varying waves, tides and resolved IGWs.
- Information on model shortcomings: GW-schemes, diffusion operators, and energy conservation in Physics of WACCM.
- First WACCM-X/TIME-GCM one-way ionosphere-atmosphere coupling during latest warming events.