Variability of Tides in Whole Atmosphere Models Constrained by GEOS Meteorology

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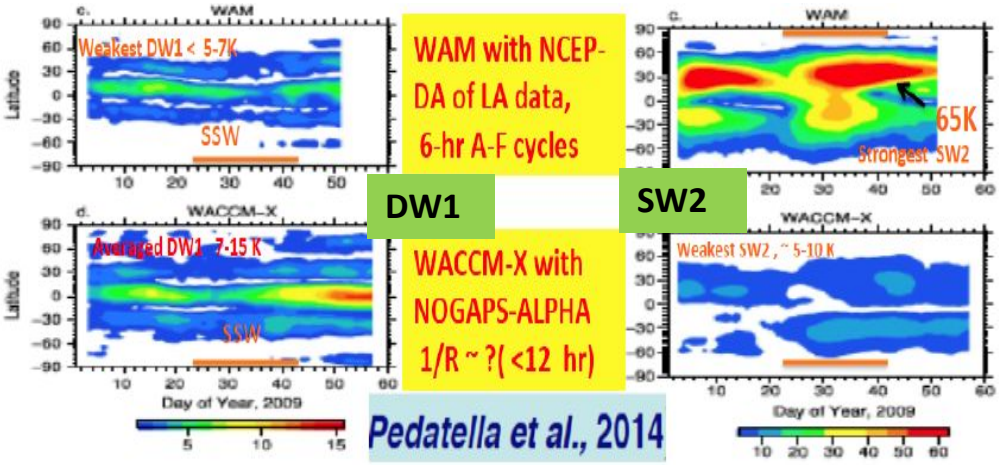
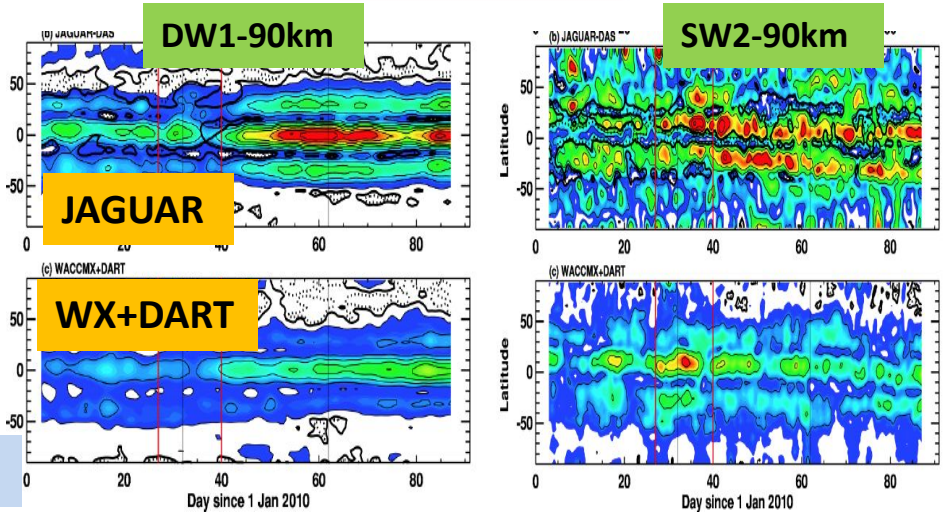
- **Thermal Solar Tides (24-hr and 12-hr) simulated by WA models, WACCM-X an WAM with GEOS products**: MERRA2, GEOS-5/FP (surf -50 km).

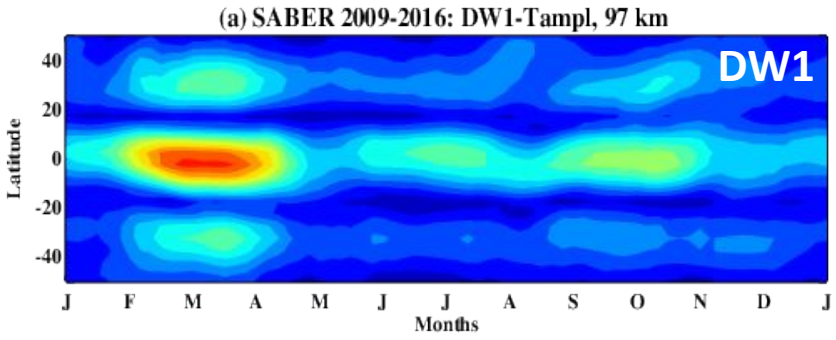
- **Similar diagnostics of tidal modes and daily mean from the WACCM-X-FV/GEOS** – 21-st century (1° /145L, *McInerney, 2022*) and **GSMWAM/GEOS** – 2009-2018 (~2° /150L, *Yudin et al., 2020*).

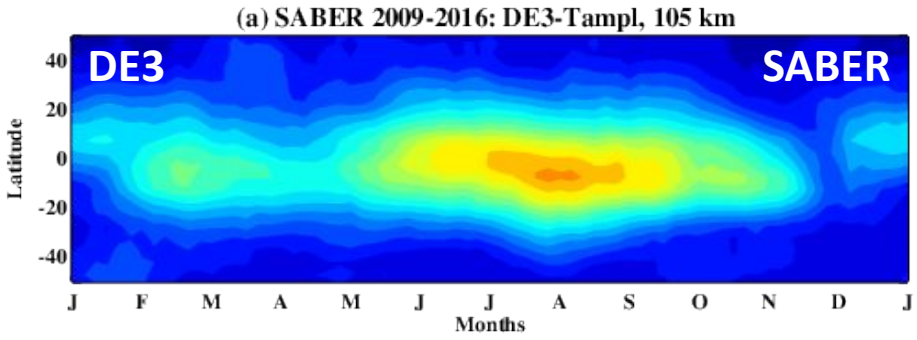
- **Key features of spatio-temporal variability:** vertical and geographical maps; seasonal, inter-annual, event-driven and day-to-day variations.

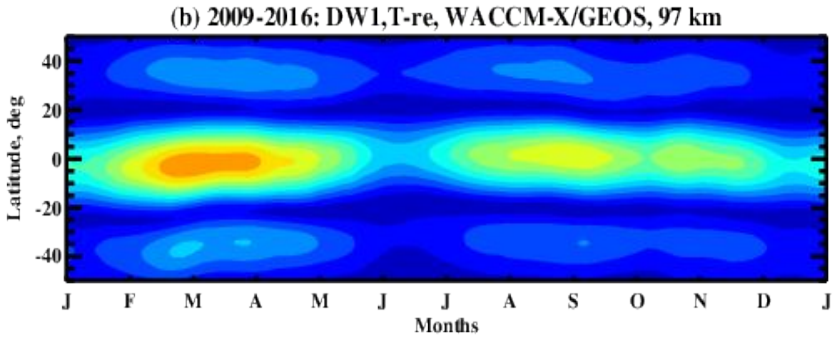


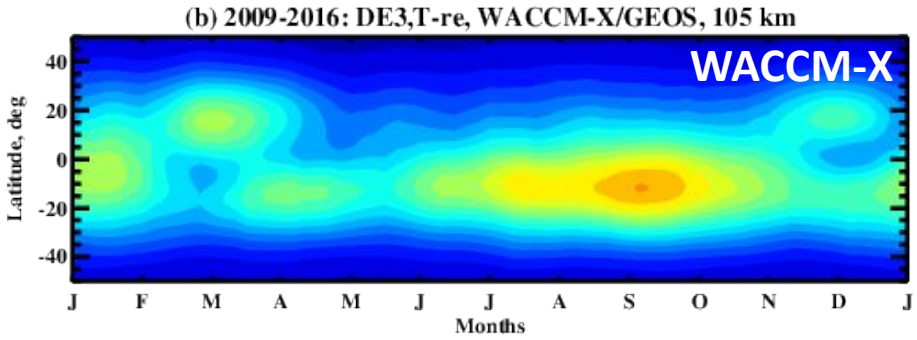


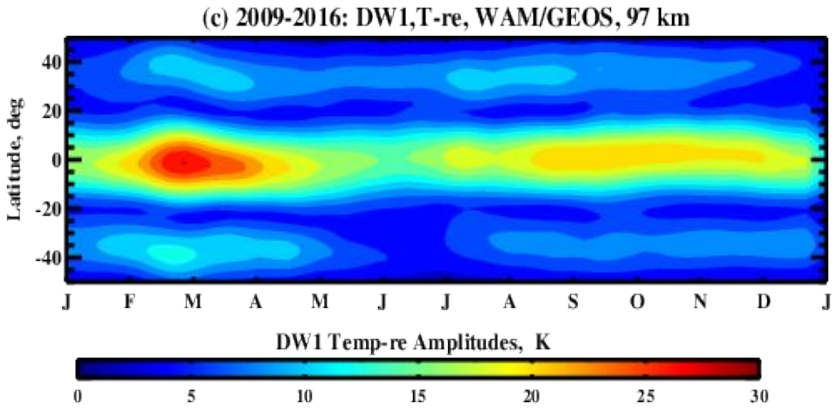
24-hr Tide: Seasonal Variability of DW1 at 97 km and DE3 at 105 km: SABER, WACCM-X/GEOS and WAM/GEOS (2009-2016)

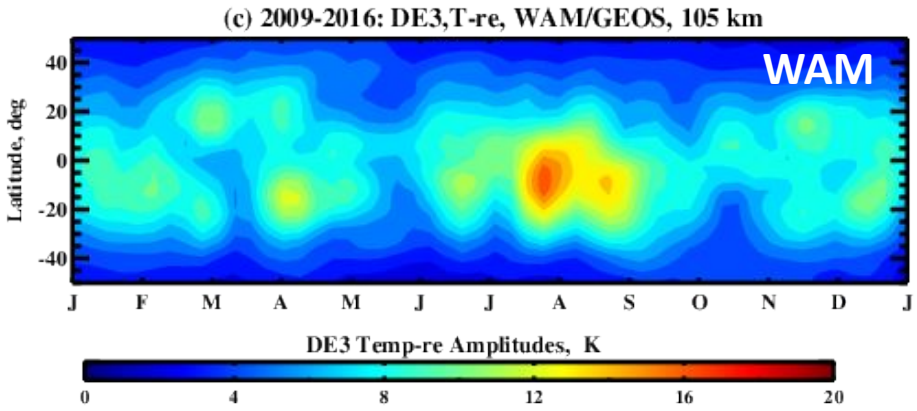




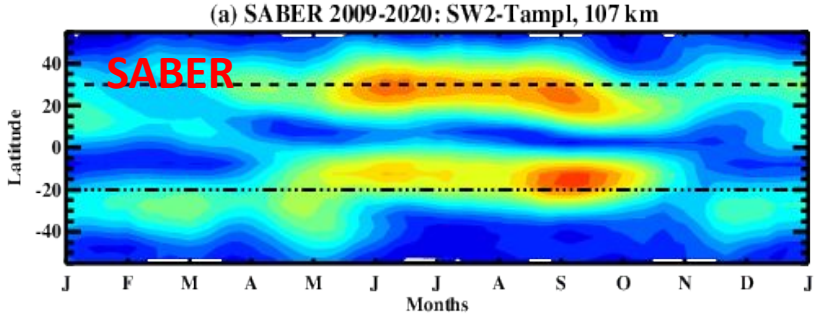


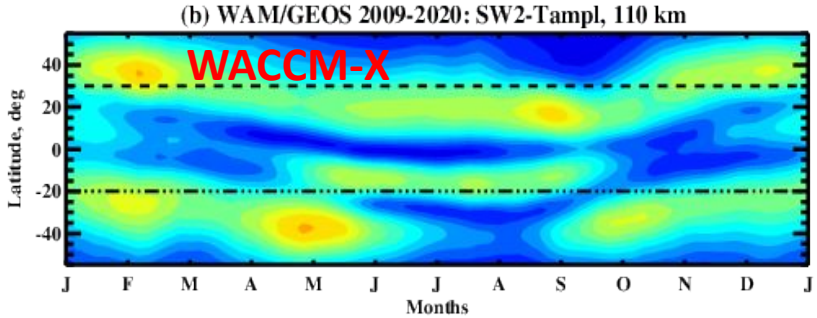


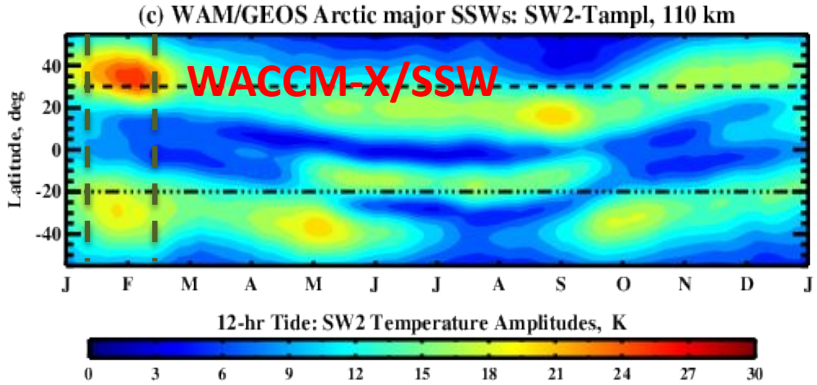


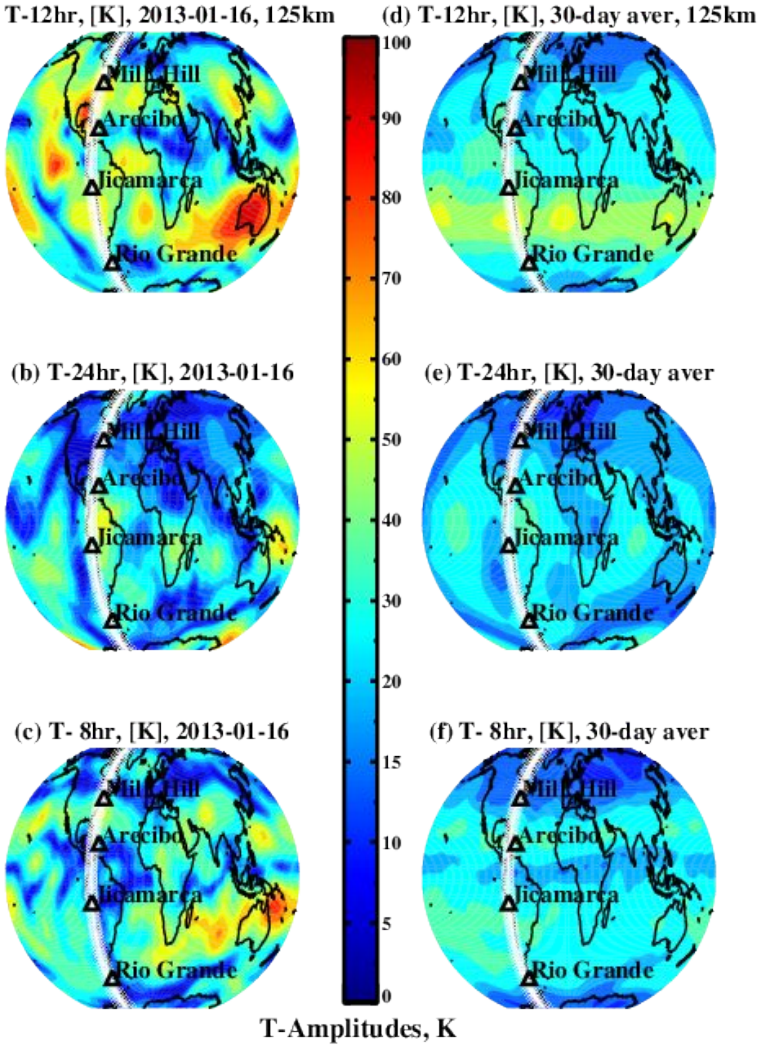


Annual cycles of 12-hr Tide in SABER/TIMED and WACCM-X/GEOS and Impact of SSW events in the MLT (100-120 km)



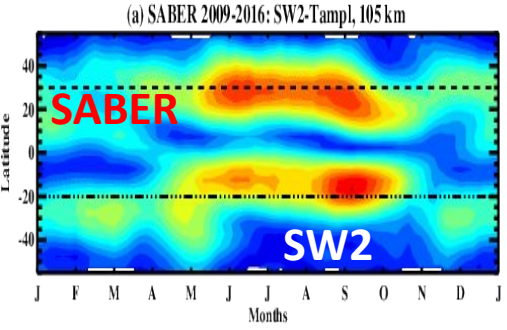


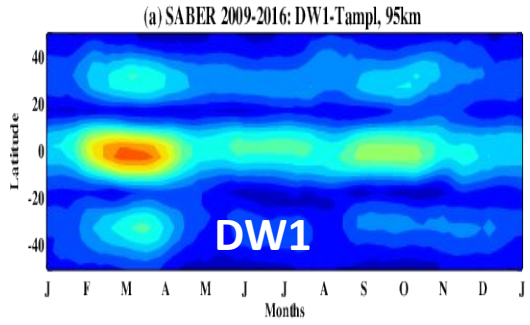


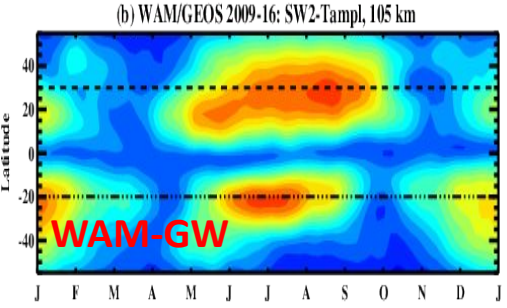


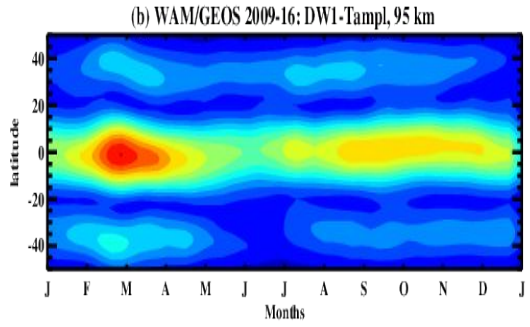
After onset of Arctic SSW events the 12-hr tide represents a dominant mode at 11O-150 km, perturbing diurnal cycles of density, neutral composition and plasma.

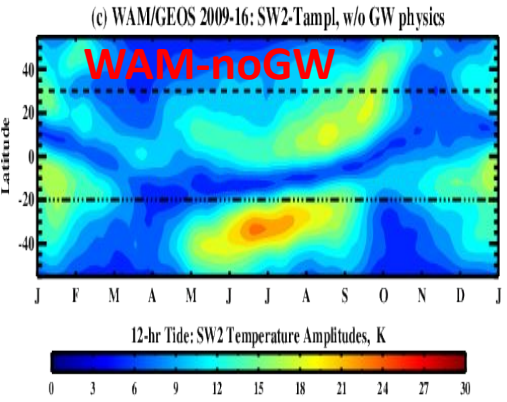
Tidal Variability in the MLT: Annual cycles of SW2 (105 km) and DW1 (95 km) in SABER and WAM/GEOS; role of MF and GWs

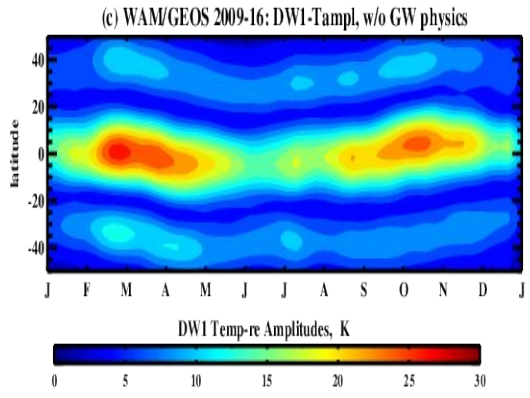


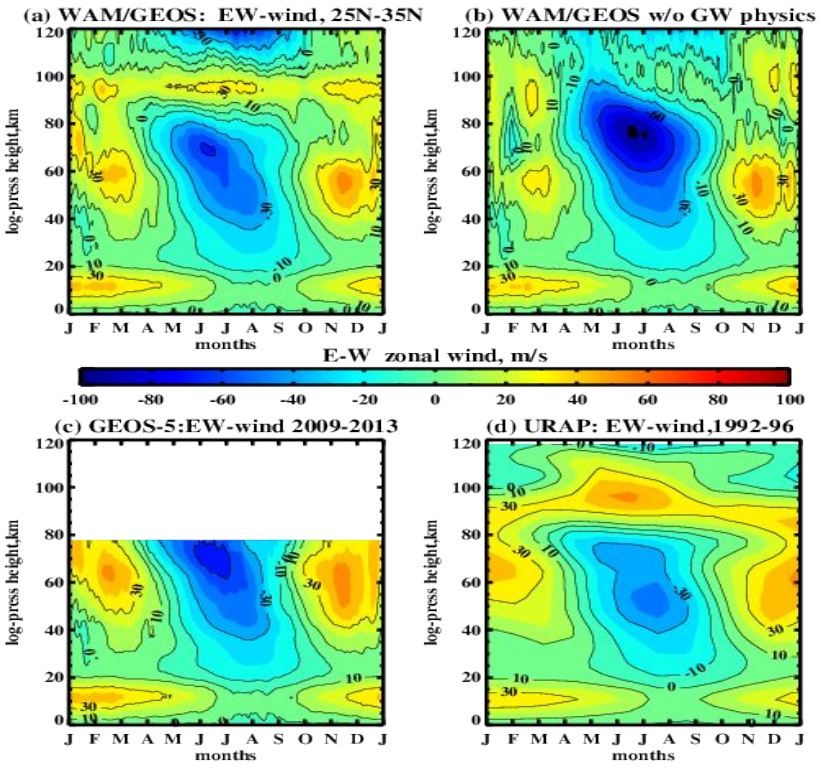






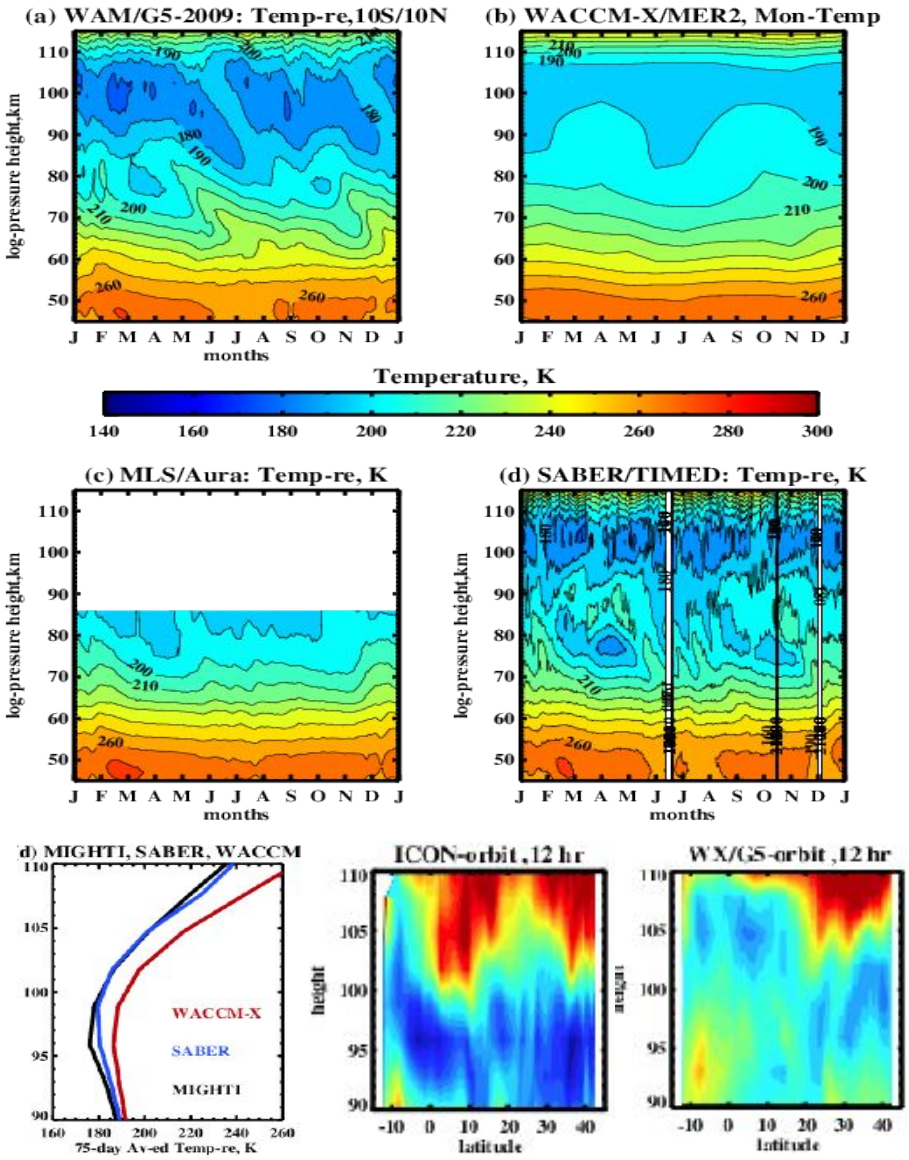


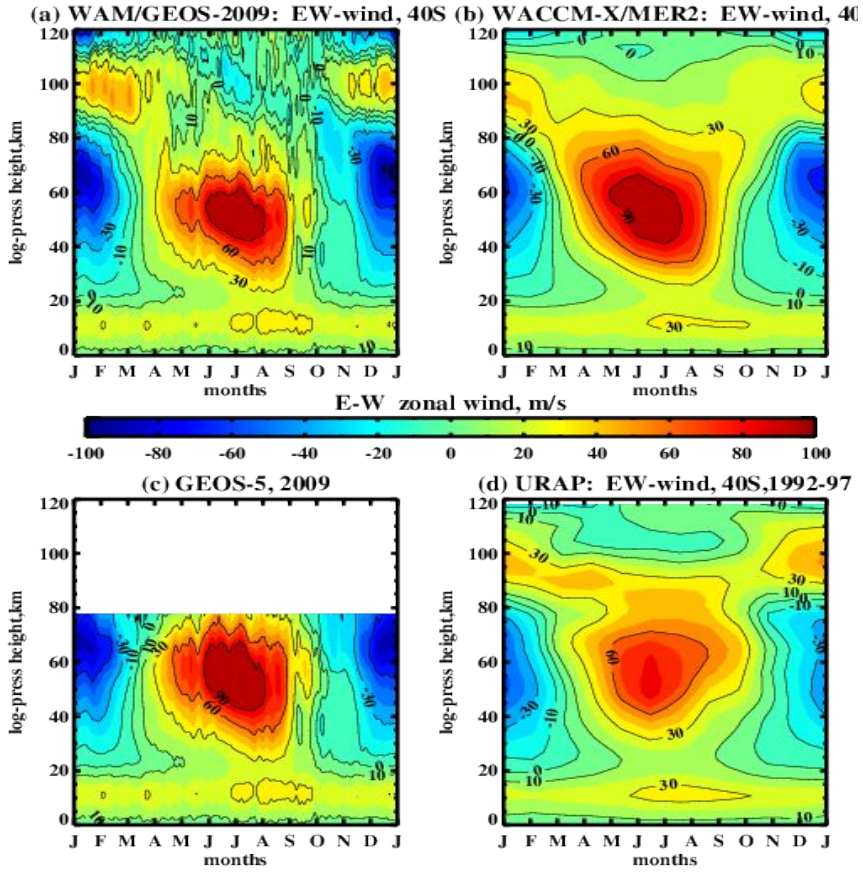




The zonal mean flow, as the background for upward propagating tides represents a key mechanism for seasonal variability of the 12-hr tide (SW2) in the extratropical MLT and 24-hr tide in the tropics; *absence of NGW physics in WAM degrades observed seasonal variations of zonal winds and tides in the MLT.*

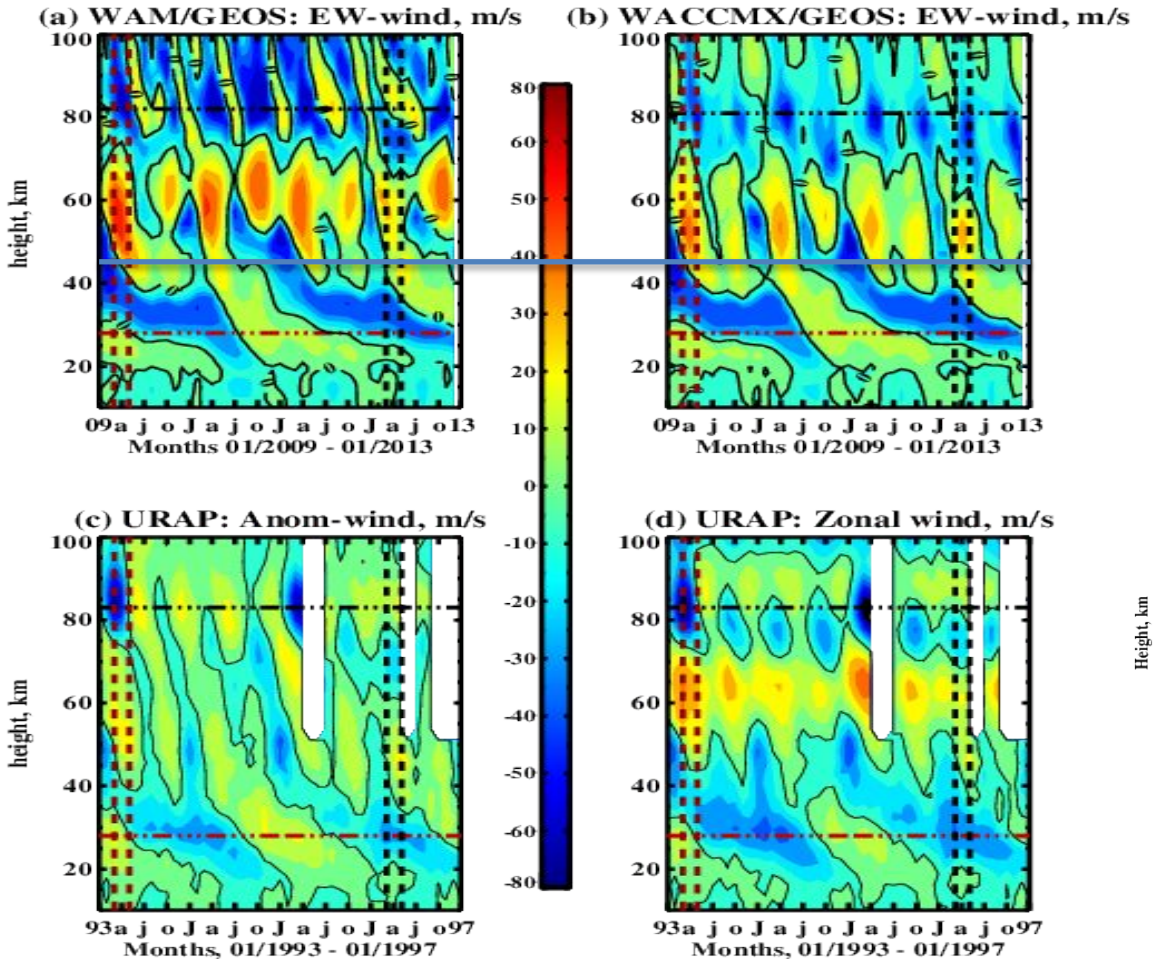
Annual Cycle (2009) of Zonal Mean Temperature (10°N-10°S, WAM, WACCM-X, MLS/EOS-Aura and SABER/TIMED) and Zonal Winds (35°S-45°S, WAM, WACCM-X, GEOS and URAP-climatology)





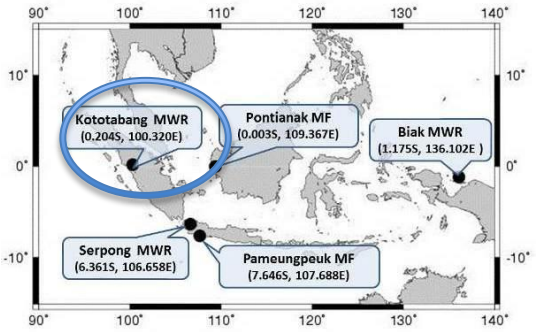
Two schemes of GW physics in WACCM-X and WAM => control seasonal variations of the zonal mean dynamics above SD/SM region in the moderate 1-2 deg resolution runs.

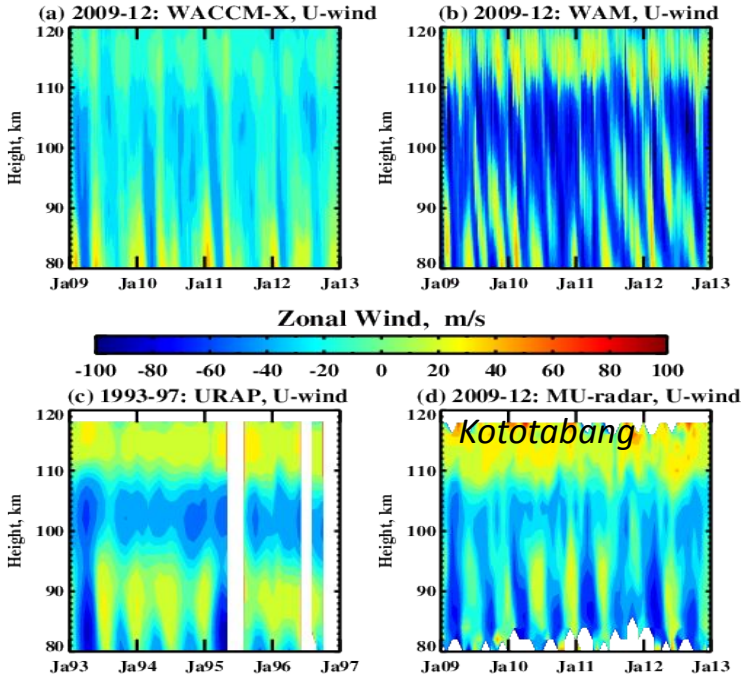
Year-to-Year Variability of the Equatorial (5N-5S) Zonal Mean Flow in (WACCM-X/GEOS, WAM/GEOS, 2009-2013 and URAP, 1993-97)



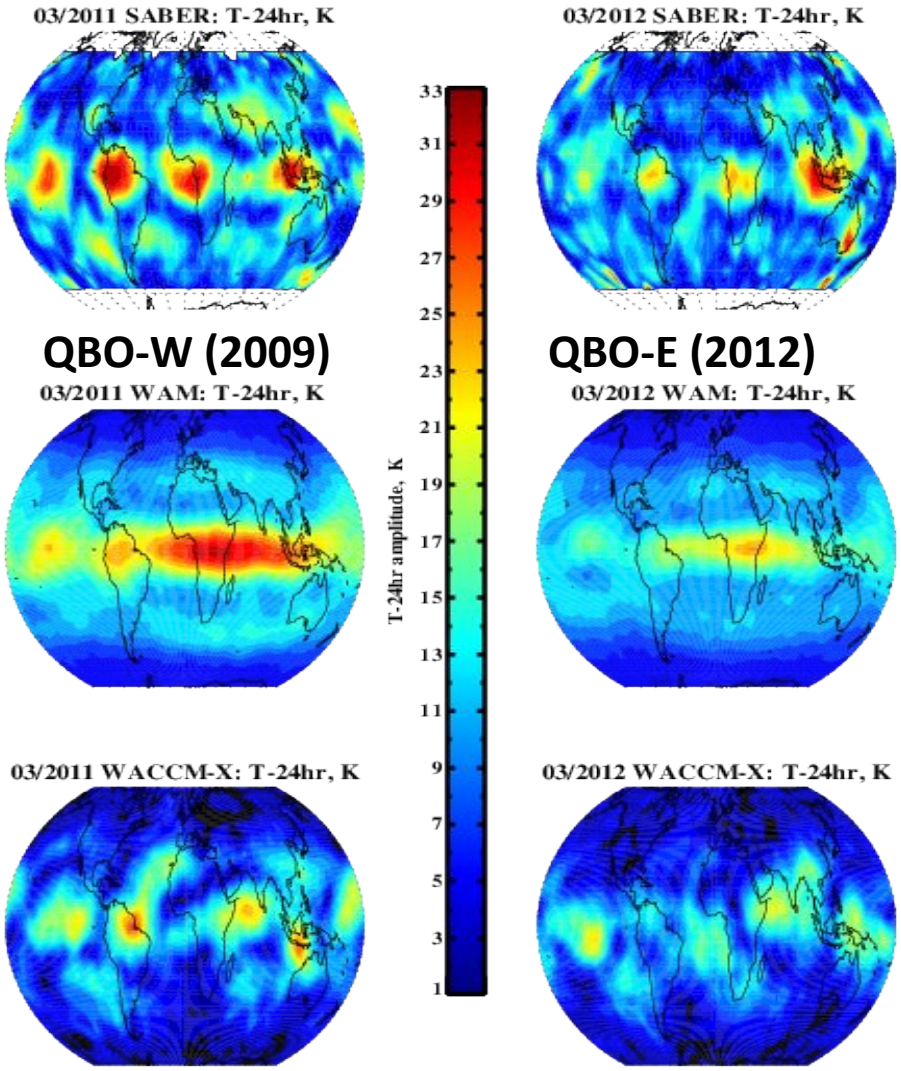
WAM-SM (spectral) and WACCM-X/SD (FV-dycore) simulate the different daily mean MLT flows that define the propagation env-nt for tides and gravity waves.

http://database.rish.kyoto-u.ac.jp/arch/iugonet/



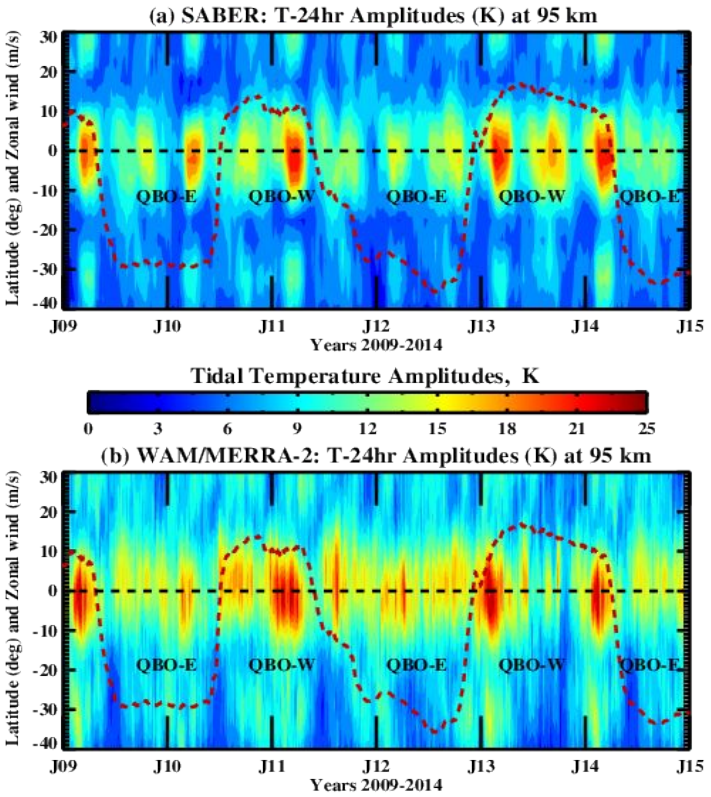


24-hr Tide Longitudinal (03/2009 vs 03/2012) and Year-to-Year Variability at 95 km: SABER, WAM/GEOS and WACCM-X/GEOS



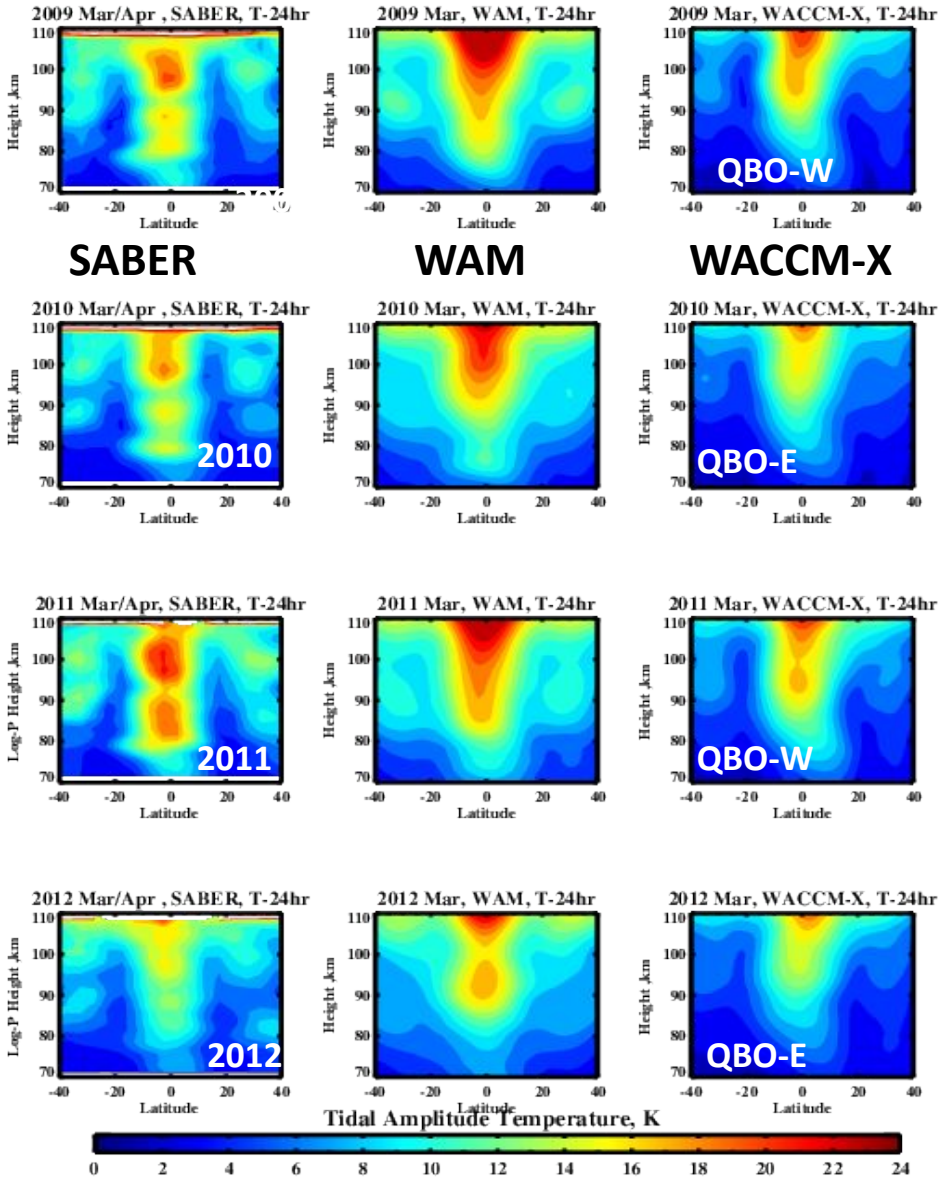
Needs to better constraint the tidal forcing of WA models in the troposphere (DC of latent heat and H_2O)

The Mar-Apr 24-hr QBO-W amplitudes are ~ 1.5/2 times larger than QBO-E tide.



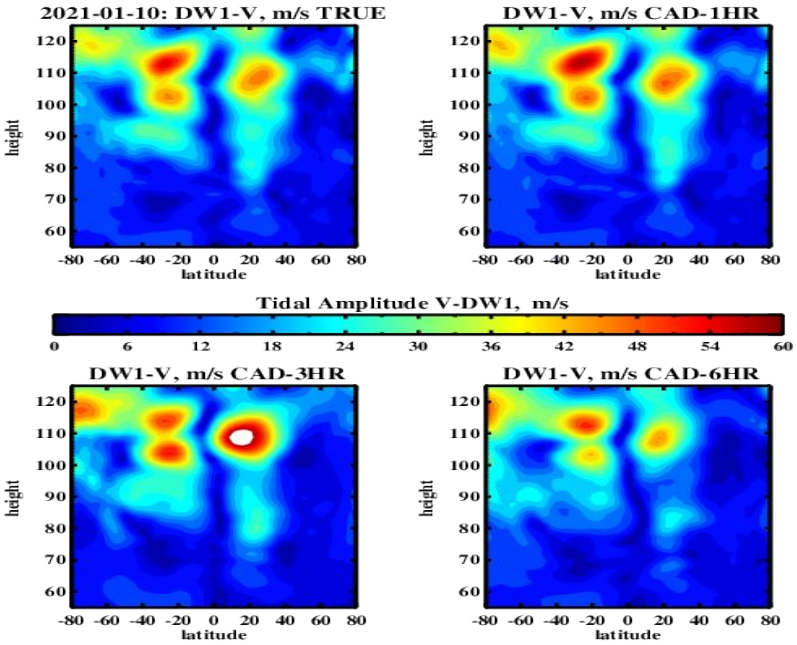
The equatorial diurnal temp-re amplitudes (01/2009-01/2015) deduced from SABER/TIMED data (top) and simulated by WAM/MERRA-2 (bottom); QBO in eq-l zonal wind at 28 km – red-dashed line.

Tidal Variability (2009-2012) of the 24-hr temperature oscillations: SABER/TIMED, WAM/GEOS and WACCM-X/GEOS

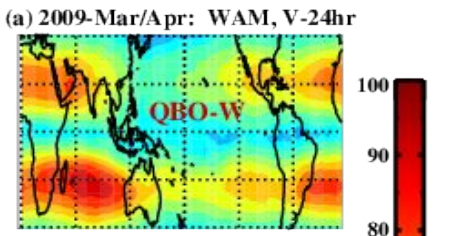


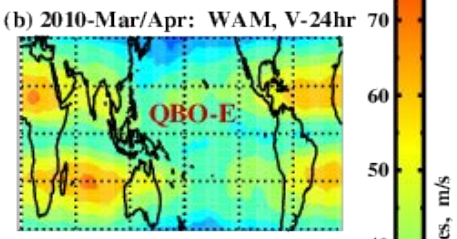
WA simulations constrained by GEOS can reproduce the enhancement of 24-hr tidal amplitudes for QBO-W years (2009 & 2011);

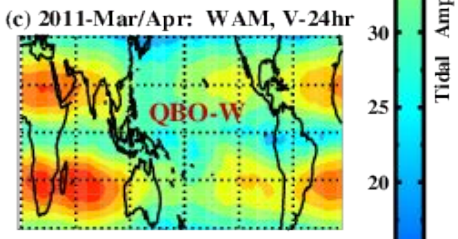
The data-model and model-model differences:
(a) tidal diagnostics from data (60-day SABER) and models (daily);
(b) model physics and dynamics, and
(c) algorithms to ingest the GEOS-meteorology in WAM and WACCM.

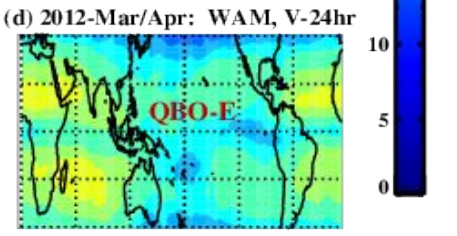


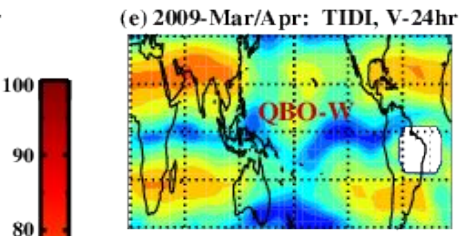
Tidal Variability (2009-2012): QBO of the 24-hr tidal meridional wind oscillations (Equinoxes); 'strong' tide during QBO-W phase

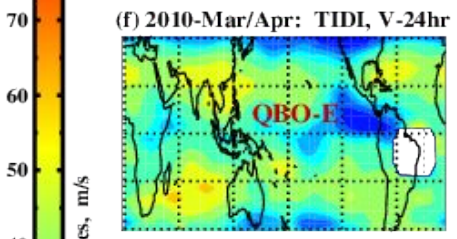


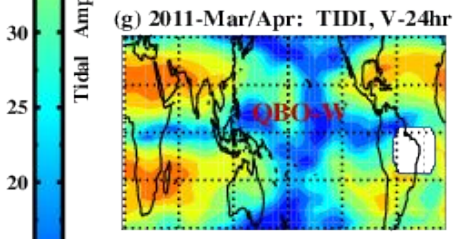


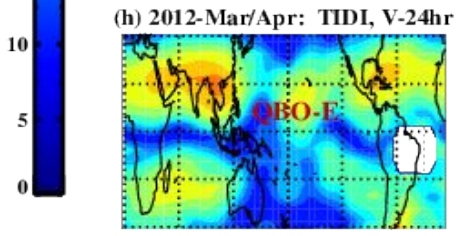


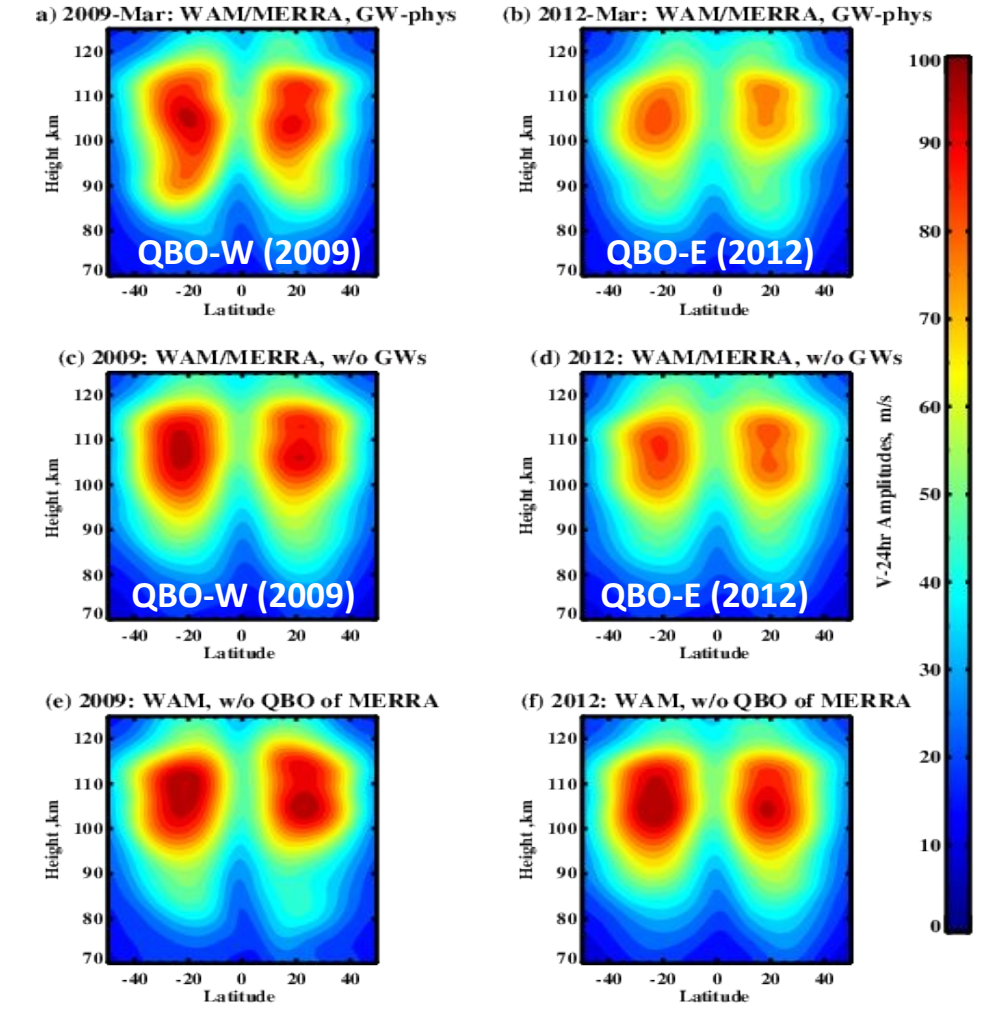








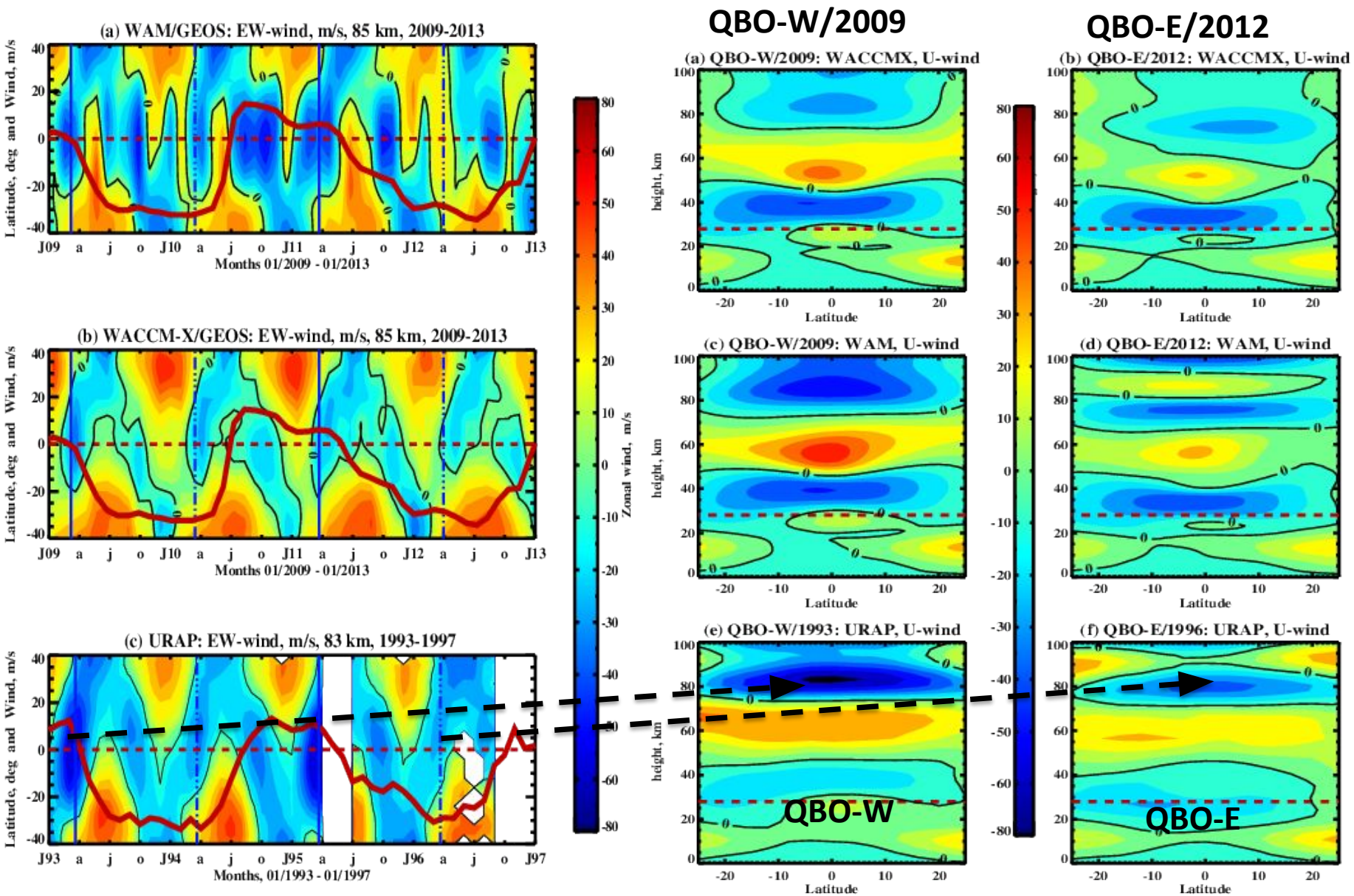




WAM/MERRA-2 **TIDI/TIMED**

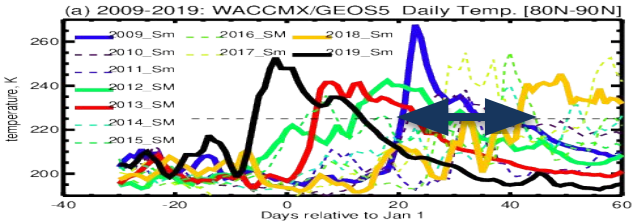
In WAM simulations stratospheric QBO of MERRA-2 produce E/W modulation of the diurnal tide seen im TIDI winds and SABER temperatures (85-105 km).

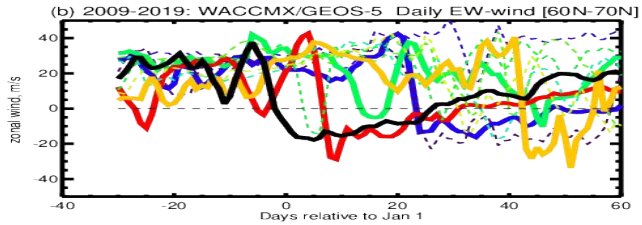
2009-2013: Variability of the Zonal Winds (85 km –left) and during Mar for QBO-W/E (2009/2012, WACCM-X, WAM), and 1993/1996 (URAP)

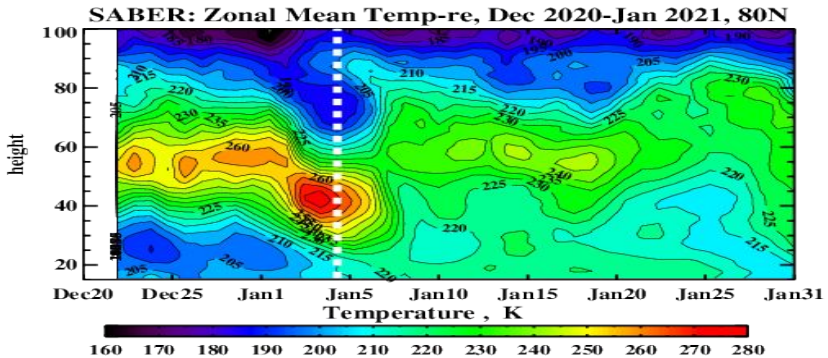


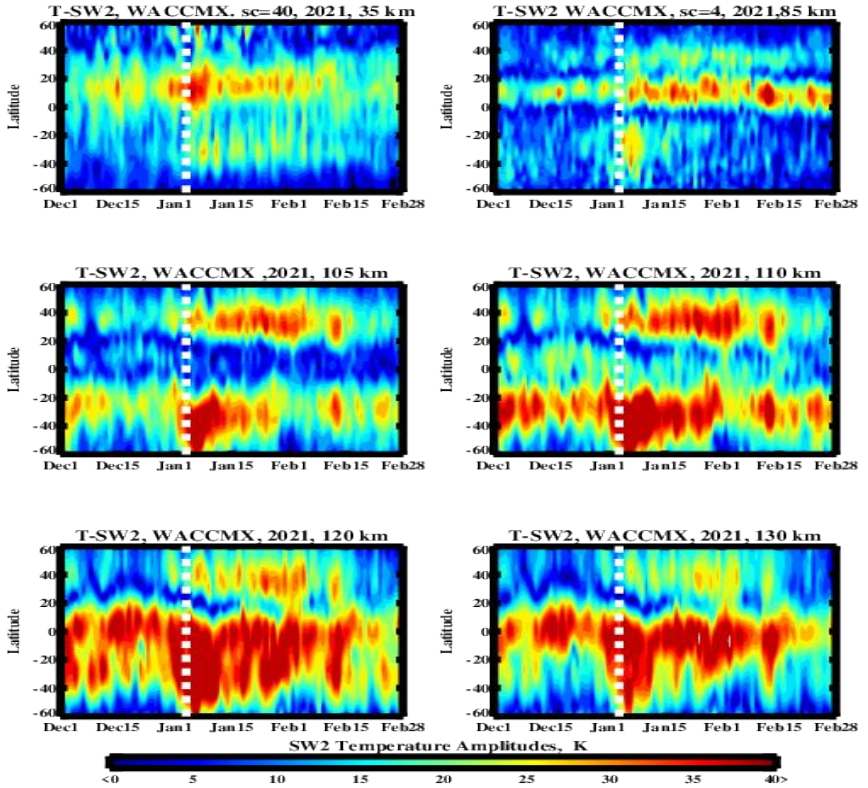
WACCM-X/MERRA-2 during SSW (2009-2021)

1. The WACCM-X with MERRA-2 during all Arctic winters with major and minor SSW events
2. **Nine major and minor midwinter Arctic SSW** events **and minor Antarctic SSW** (2019) => Perturb ITM tidal and PW dynamics that initiate plasma perturbations.
3. ***Recent Arctic Jan 2021***– long lasted SSW as in Jan-Feb of 2009 (**blue lines**).

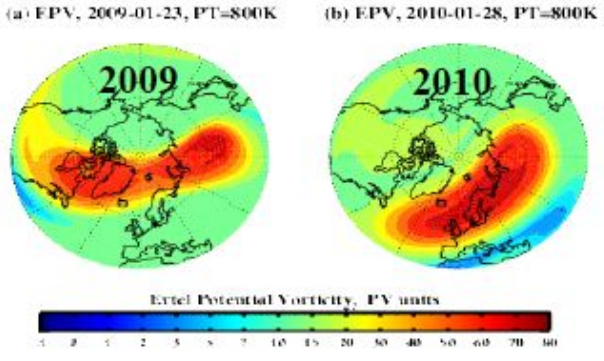


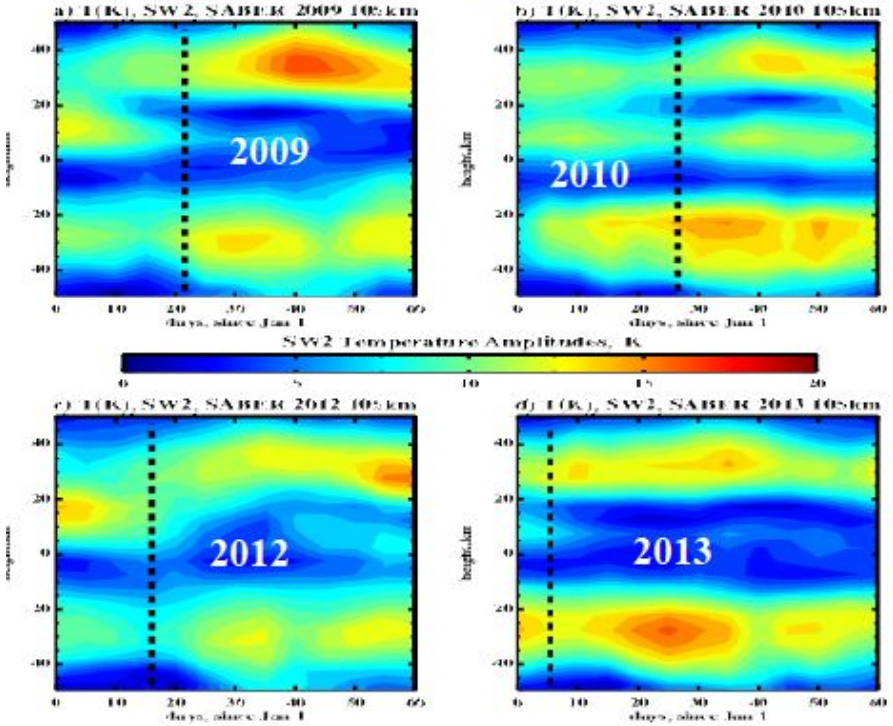


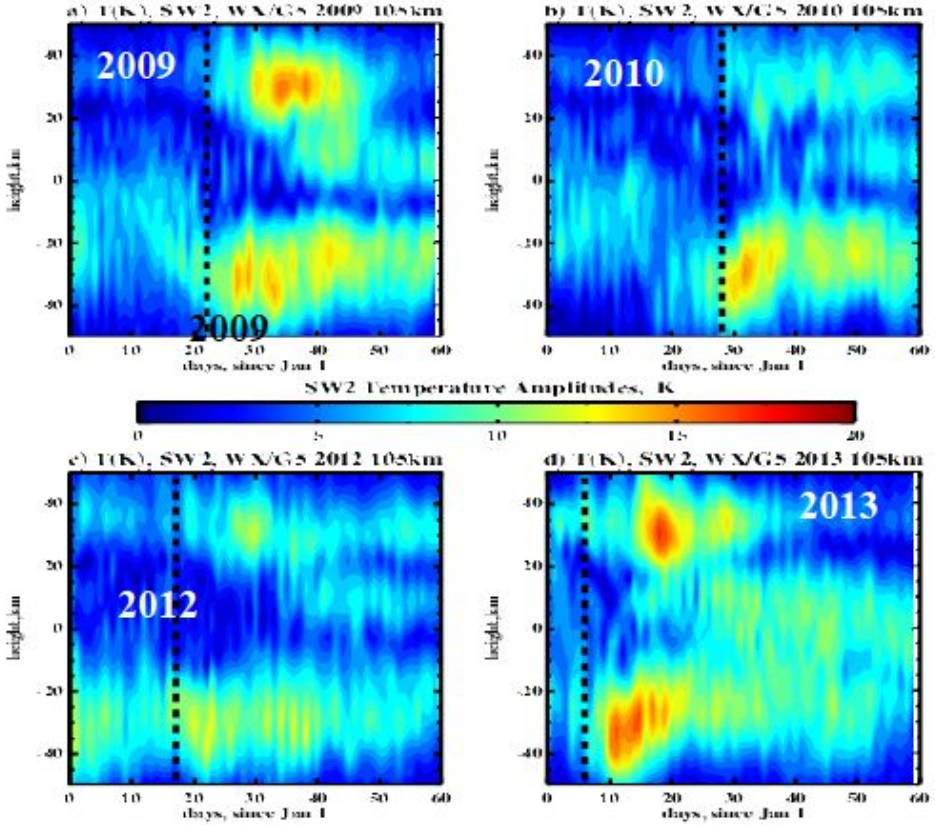




SW2 Temperature Amplitudes at 105 km: SABER and WACCM-X/GEOS-5 (2009, 2010, 2012, 2013)

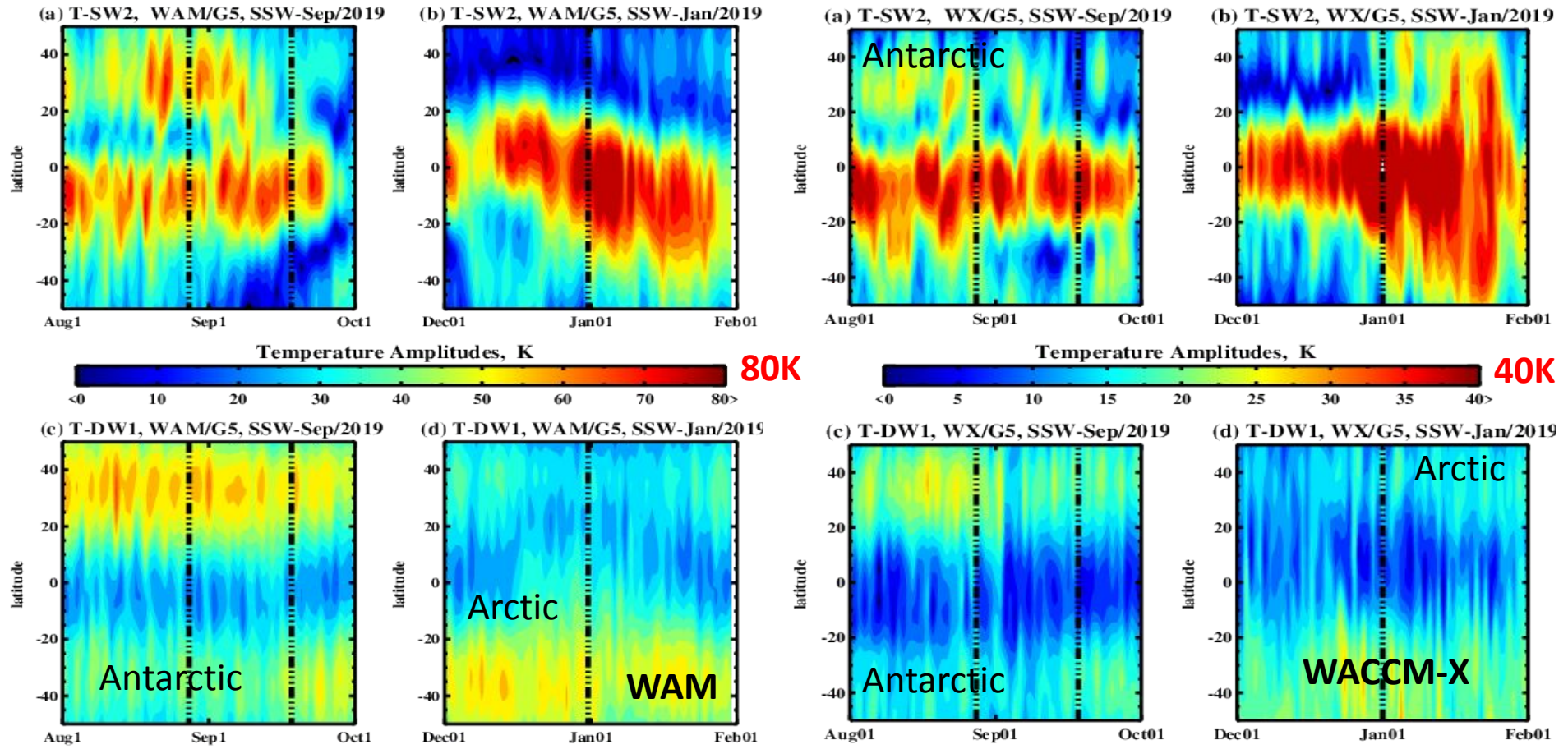






Both, WACCMX/GEOS5 simulations and the 60-day composite SABER temperature tidal analysis dosplay the growth of SW2 amplitudes

GOLD-region (~150 km): Current Predictions of SW2 and for Arcic and Antarctic SSWs of 2019 by WAM (left) and WACCM-X (right)



The large discrepancy between WAM and WACCM-X in the thermosphere (**see limits on colorbars)** highlights needs to use recent NASA's ICON and GOLD instruments exploring the rapid A-F cycles in DA schemes for tidal dynamics and evaluate model-data biases above 120 km.

Concluding Remarks on Variability of Tides

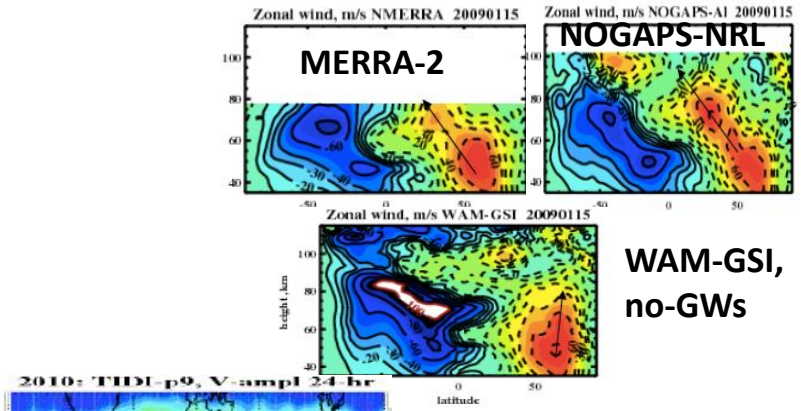
- **Realistic daily mean zonal prevailing flow** as background for tidal modes is a key factor to reproduce variability of tides in the MLT.

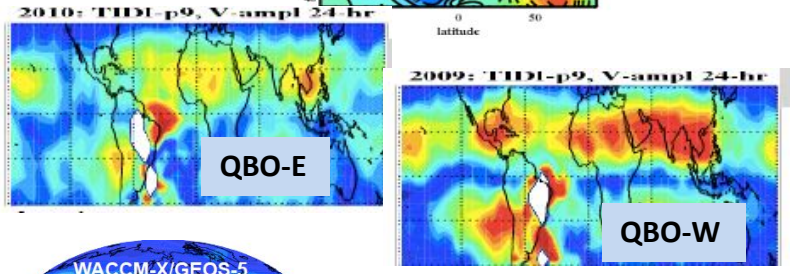
- **SAO & QBO driven variability of 24-hr amplitudes** in the tropical MLT is the key observational metric for WA models.

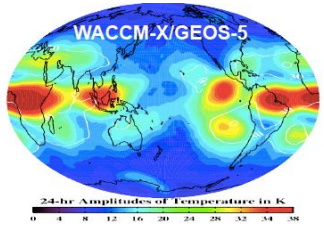
- **"Centers" of tidal activity or longitudinal variability of tides** display regions of strong diurnal cycles related LA sources (**realistic H2O and LHR**).

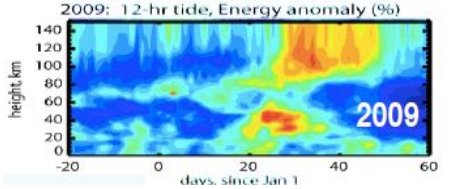
- **Perturbations of tides during mid-winter SSW** in presence and breaking of PWs need further examination.

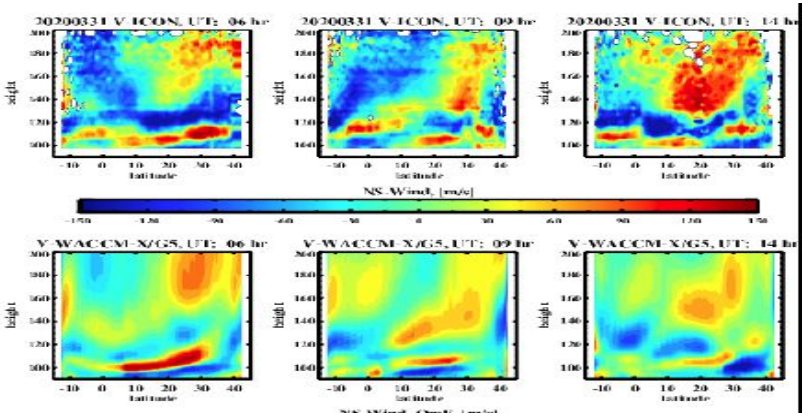
- **"Active" utilization of data in WA models**, novel "nudging" schemes by the 1-hr cadence of reanalyses + "rapid" DA of tidal signals with the model bias corrections (physics & numerics).





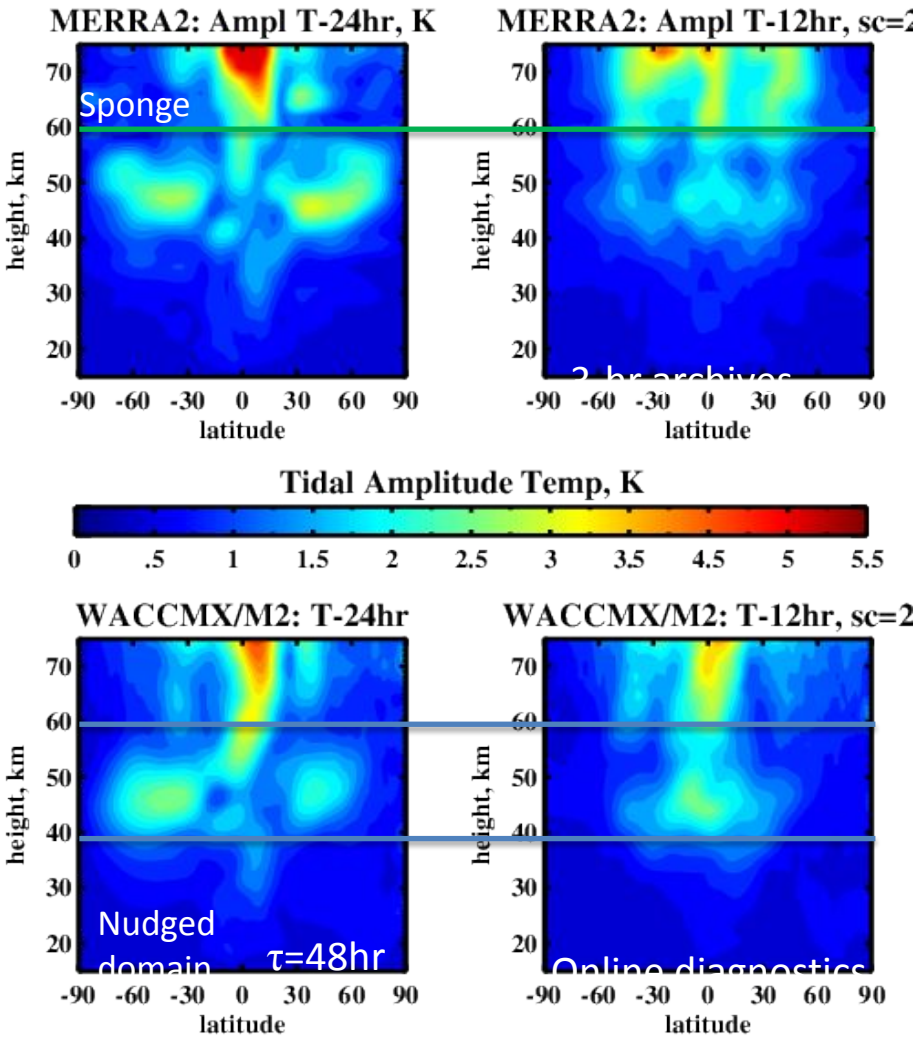


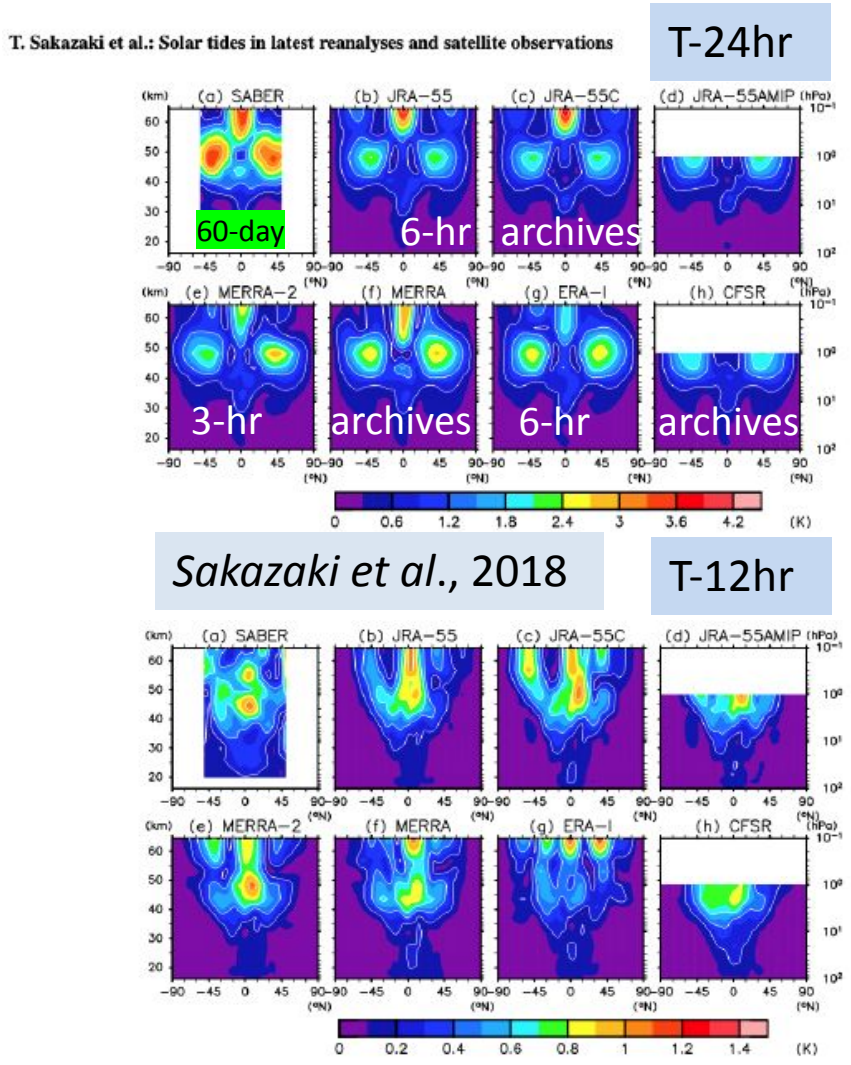




Tides in the Stratosphere and Lower Mesosphere:

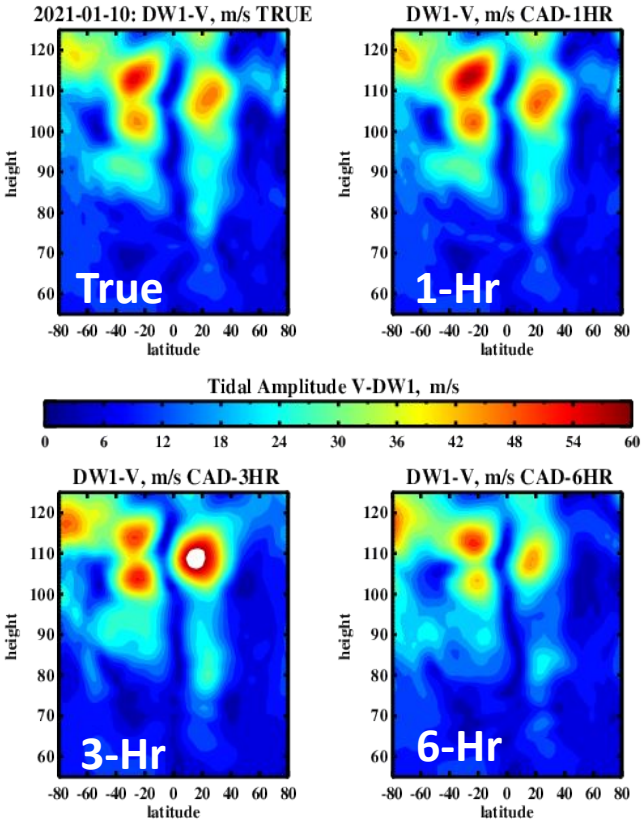
MERRA-2, WACCM-X/MERRA-2, SABER and 7-Reanalyses (3-hr & 6-hr archives)



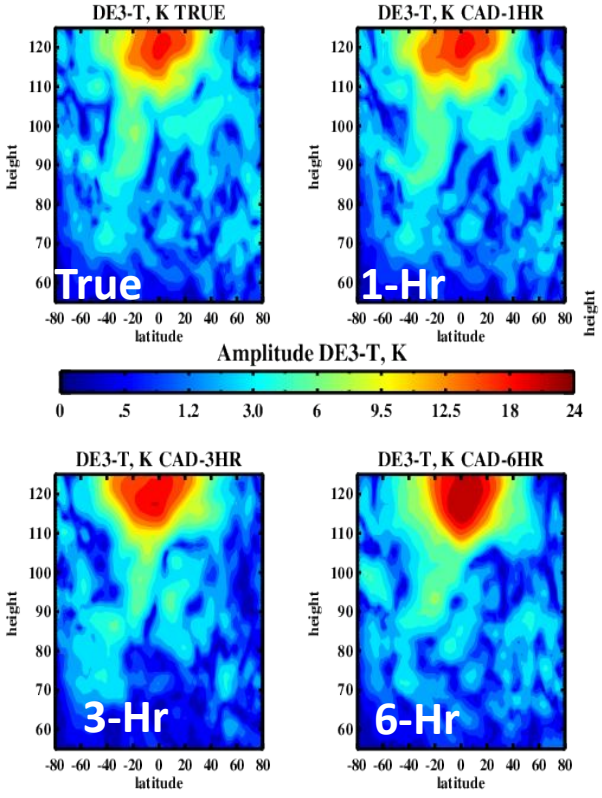


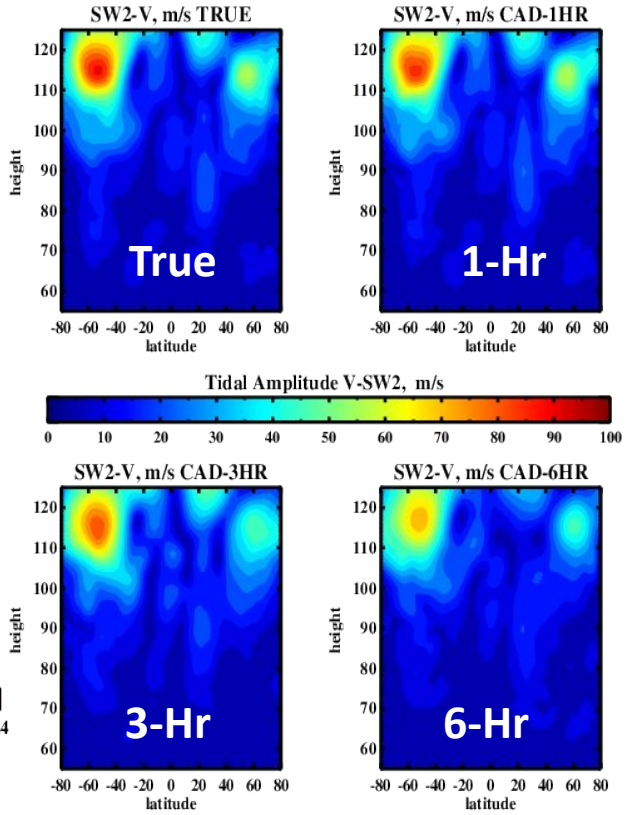
Noticeable discrepancy between tidal diagnostics of models, reanalyses and SABER

Tidal diagnostics of WACCM-X/SD constrained with the 'parent' dynamics: use of the 1-, 3- and 6-Hr archives of WACCM-X (0-45 km)



The 3D WACCM-X/SD simulations constrained by WACCM-X archives below 45 km, 2-day relaxation scale.

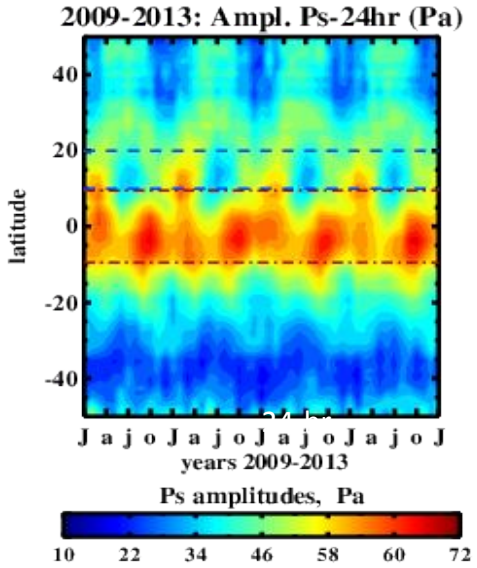


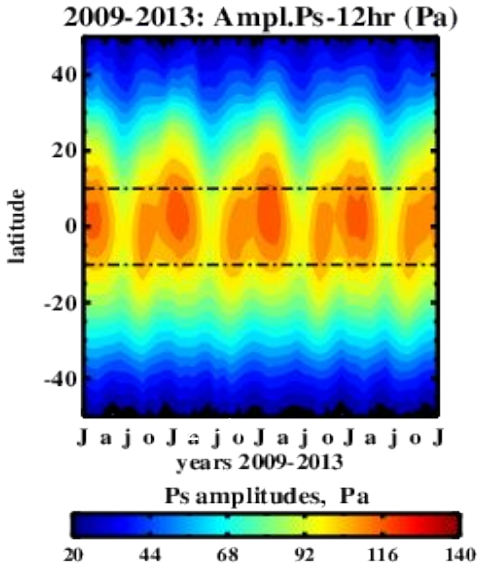


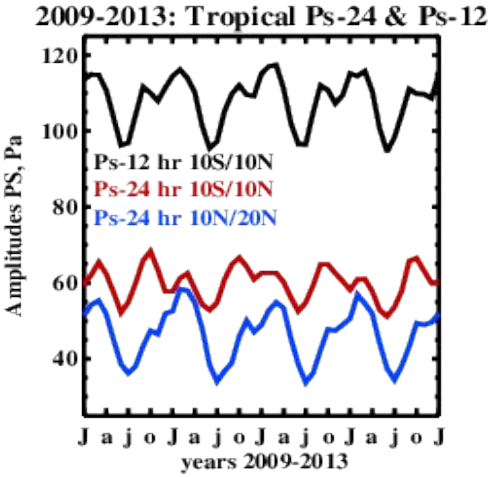
The 6-hr "meteorology" archives cannot accurately constrain the non-migrating (DE3) and migrating (DW1, SW2) tides of WACCM-X

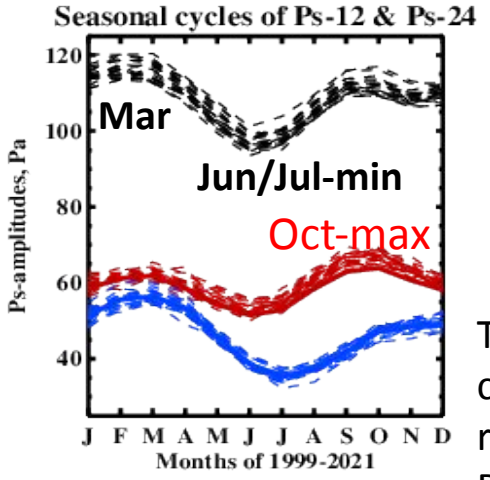
The 1-hr meteorology cadence is a target for archiving NWP analyses to represent diurnal cycles (DC) in WACCM-X/SD; the rapid data analysis in NWP systems is a next goal to constrain accurately DC.

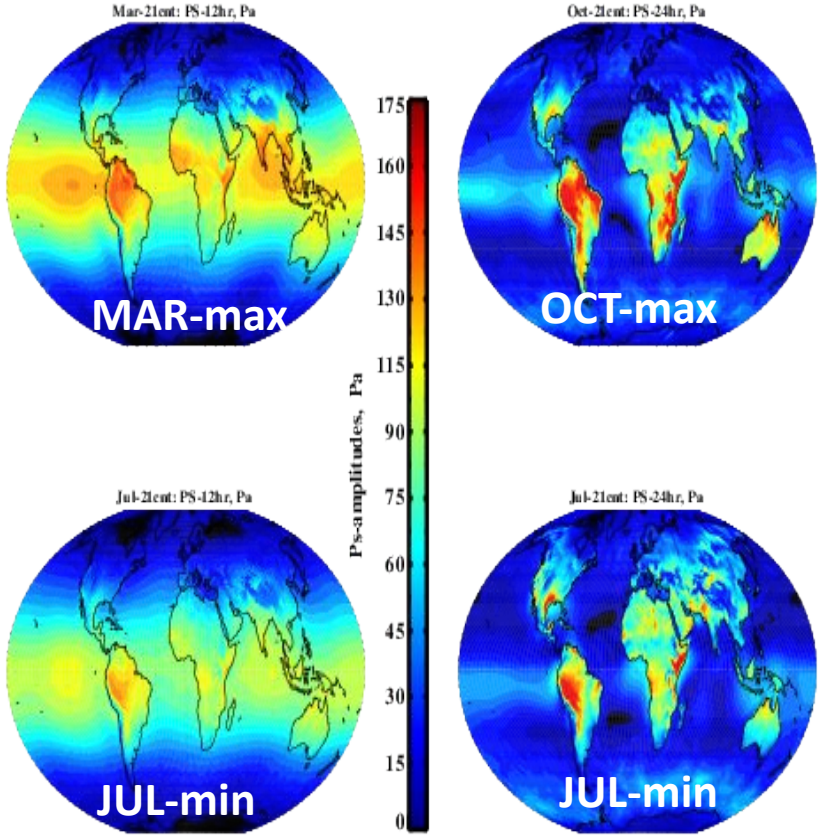
Seasonal Variability and Year-to-Year Variability of 24-hr & 12-hr modes of Surface Pressure (WACCM-X/MERRA-2, 2009-2013)











12-hr Tide **24-hr Tide**

The surface pressure (P_s)of WACCM-X constrained by 3-hr data with τ= 48 hr can reproduce the seasonal and y-2-y variability of P_s of MERRA-2 but the P_s-24 & Ps-12 amplitudes differ from tidal diagnostics of MERRA-2.

Diurnal Variations of the Mass: Annual mean 12-hr & 24-hr tidal modes of Surface Pressure (2000-2020)

MERRA-2 *(from 3-hr cadence of instant P_s-fields)*

WACCM-X/MERRA-2 *(online diagnostics)*