1

Vertically Extended Models of NEMS: Updates in Physics, Long-Term Predictions, and Role of Research Data Analysis

(NEMS/WAM-150L, NEMS/GSM-91L)

Valery A. Yudin[1],
T. J. Fuller-Rowell[1], J. C. Alpert[2] and R. A. Akmaev[3]

[1]Cooperative Institute for Research in Environmental Sciences, University of Colorado,
NWS/SWPC ,
DSRC, Boulder, CO 80027
Valery.Yudin@noaa.gov

3

2017-04-03
NCEP/EMC, College Park

2

Outline

1. **Research Vertically Extended (VE) configurations of NEMS.**

2. **Observations to improve and verify VE models in the Stratosphere and MLT** (mesosphere & lower thermosphere).

3. **Why SWPC & EMC start to extend GSI => 80-110 km**

4. **Upgrades of physics and chemistry in the SMLT to analyze multi-year Research Satellite Data (RSD, SABER & MLS).**

5. **Diagnostics of WAM and GSM-91L "biases" ….and shortcoming of analysis without use of RSD.**

6. **Thoughts on how to "initialize" VE atmosphere models** (in the absence of "analysis" files above 50 km)?

7. **Moving to Unified Dycore-FV3 in VE models:** 1) levels; 2) initialization & regridding; 4) tests for the diurnal cycles & tides.

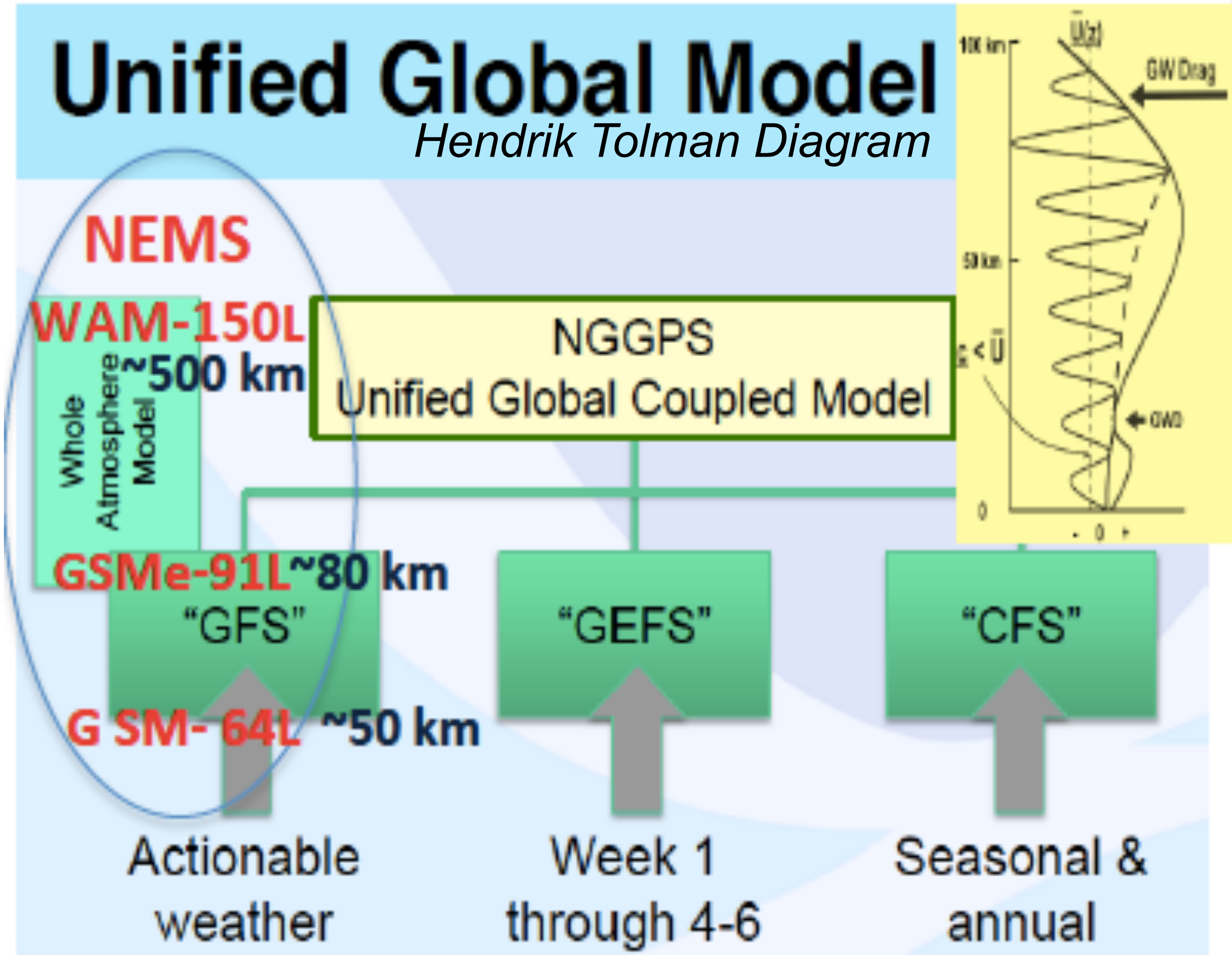
The Vertically Extended Global Atmosphere Models of NOAA Environmental Modeling System (NEMS)

The **NGGPS** transforms & upgrades the **GFS** into the Unified Global Model within **NEMS framework**.

The first vert. extended GFS (from the current 64L to 91L) promises to improve the stratospheric forecasts and the trop-stratosphere coupling.

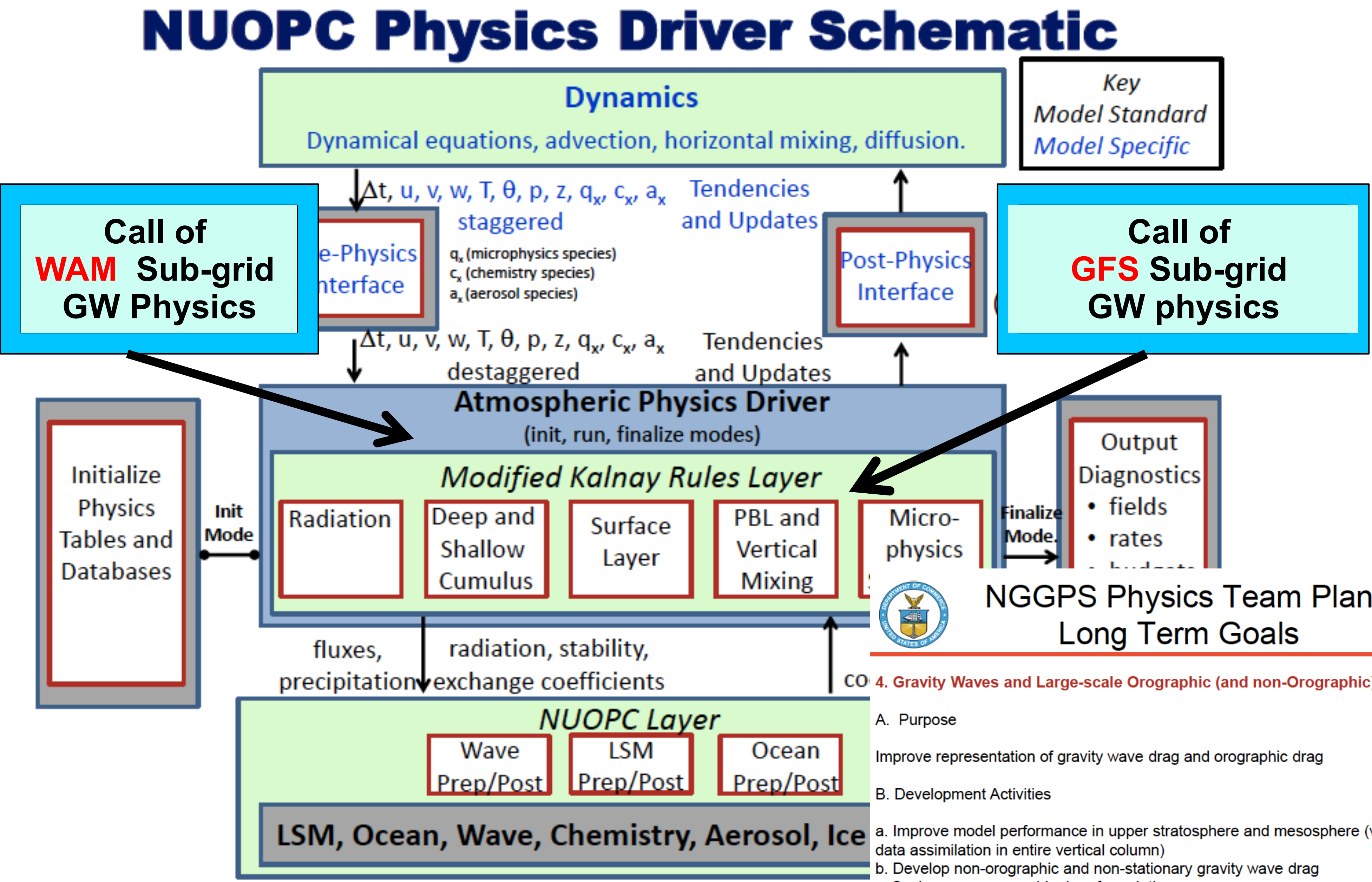
For VE models, our aim is to unify the **GFS-91L** (lid ~80km) and the 150L **Whole Atmosphere Model** (**WAM-150L,** ~500 km) in 2017 **with the identical DYCORE**. ***Time to move towards NEMS-FV3.***

Unification and upgrades of GFS and WAM will streamline the interaction for terrestrial and space weather and climate predictions/ reanalysis under NEMS/NGGPS/



Dynamics and physics of resolved and sub-grid stationary *Orographic GWs* (OGWs) and *Non-stationary GWs* (NGWs) represent the major uncertainties for VE models of NEMS.
R2O/UGW project "unifies" GW physics.

"Placing" non-st. GW schemes in the chain of NEMS (NUOPC) physics of Global Atmosphere Models (WAM & GFS)



NGGPS Physics Team Plan
Long Term Goals

4. Gravity Waves and Large-scale Orographic (and non-Orographic) Drag

A. Purpose

Improve representation of gravity wave drag and orographic drag

B. Development Activities

a. Improve model performance in upper stratosphere and mesosphere (will also improve data assimilation in entire vertical column)
b. Develop non-orographic and non-stationary gravity wave drag
c. Scale-aware orographic drag formulation
d. Gravity wave physics that is adaptable to variable horizontal and vertical resolutions

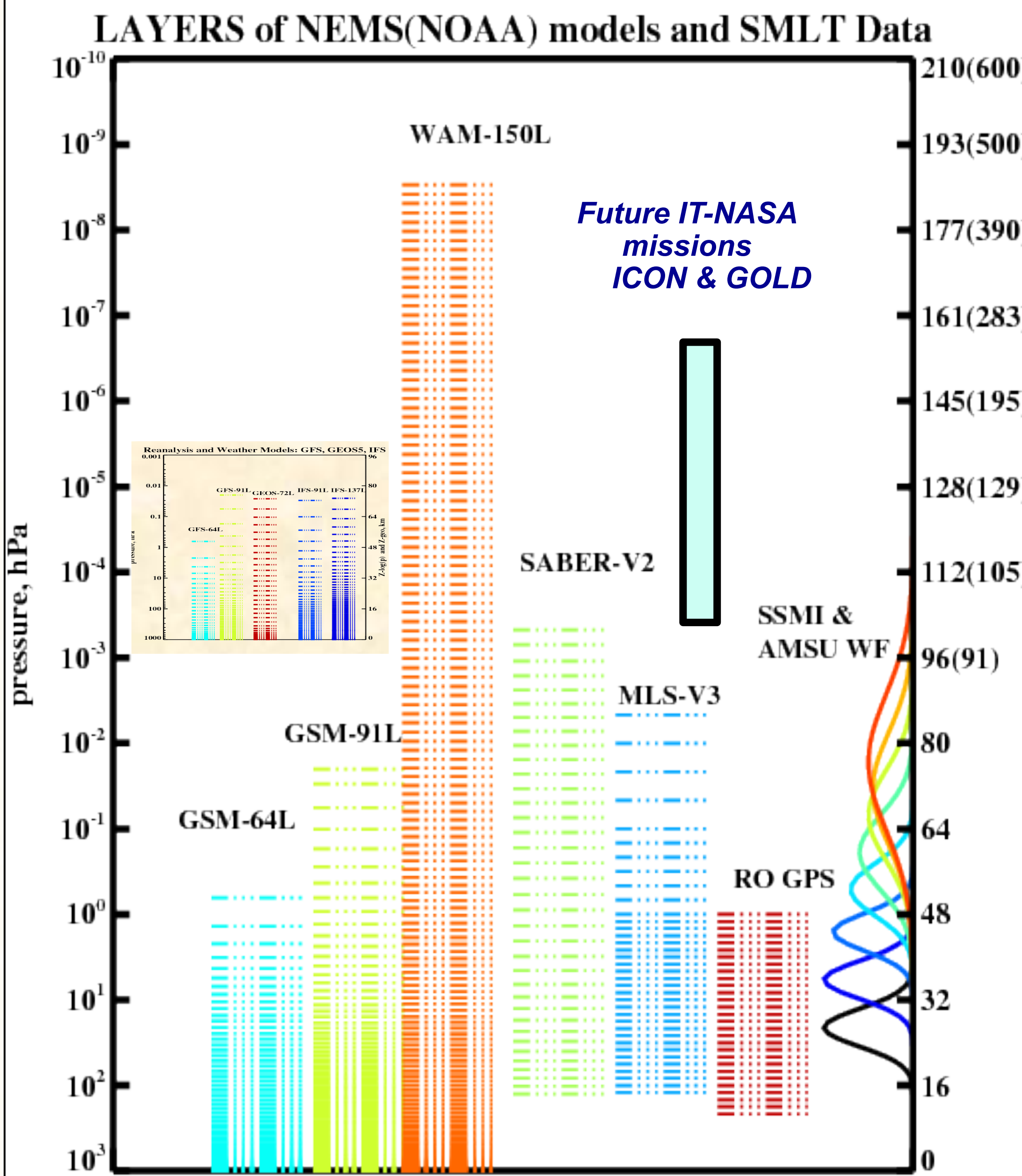
Specifics of Vertically Extended Configuration of NEMS, WAM & GFS/GSM-91L and Suite of Observations

- ❑ **Vertical levels of GSM-91L** follow IFS-91L & GEOS-5 (72L, TL ~80 km); **Decreased** (~3-times) **Rayleigh fric. > ~50 km with inv. scale 15 days.**

- ❑ **Previous** (IFS, NOGAPS, GMAO) **choices for GW intensity at ~ 700 hPa** (or ~500 hPa) *to replicate latid and seasonal GW activity from data.*

- ❑ **GW solvers adapted with dissipation:** (a) Linear saturation; (b) IFS-2000; (c) DSP-Hines-97'; d) Alexander/ Dunkerton 99.
- ❑ **GW physics with (a)-solver** were tested for **T62 ..->..T670 in GSM-91L**

- ❑ **Still In progress**: eddy mixing; adding non-LTE radiation for NEMS91L; tests for oper. res-n (~ 13km); ; **resolution-aware GW-scheme (for … FV3)**



Current and previous analysis of the Research Satellite Data in the Middle Atmosphere:

CMAM (Canada), NOGAPS/NAVGEM (NRL), GEOS-5/MERRA (GMAO), ERA-INTERIM (ECMWF)

:

Middle Atmosphere SSMIS & Limb-viewing Sensors (SABER +MLS) in NRL-NAVGEM

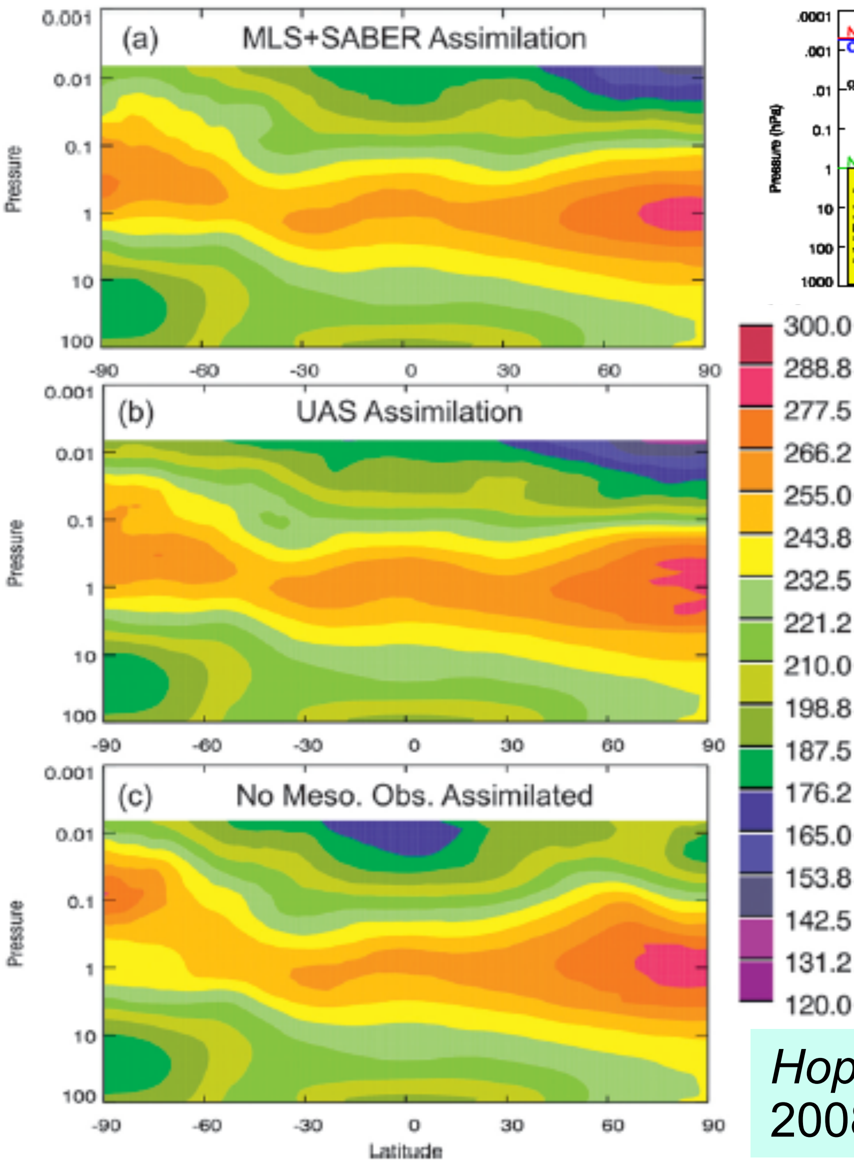
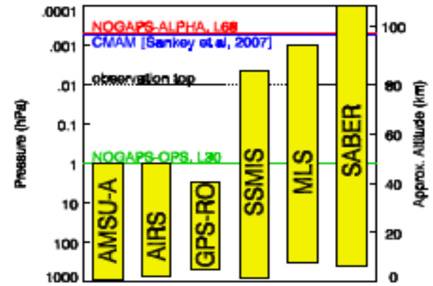
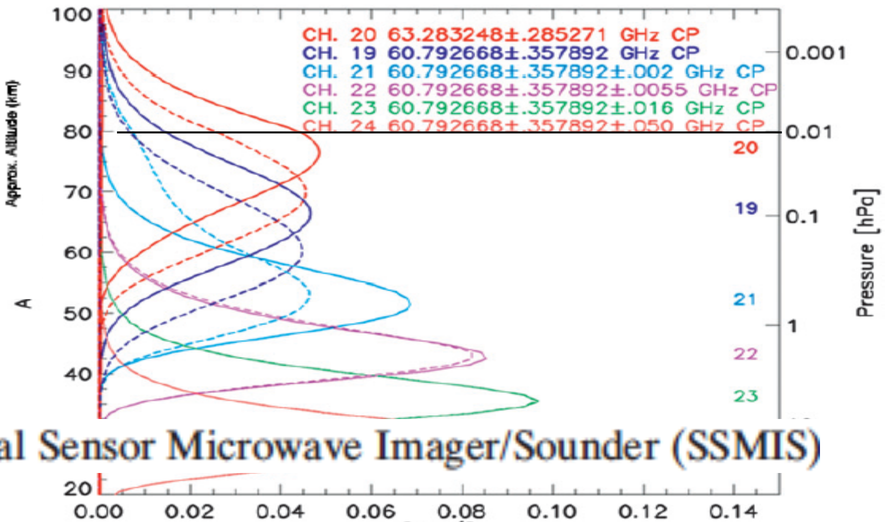
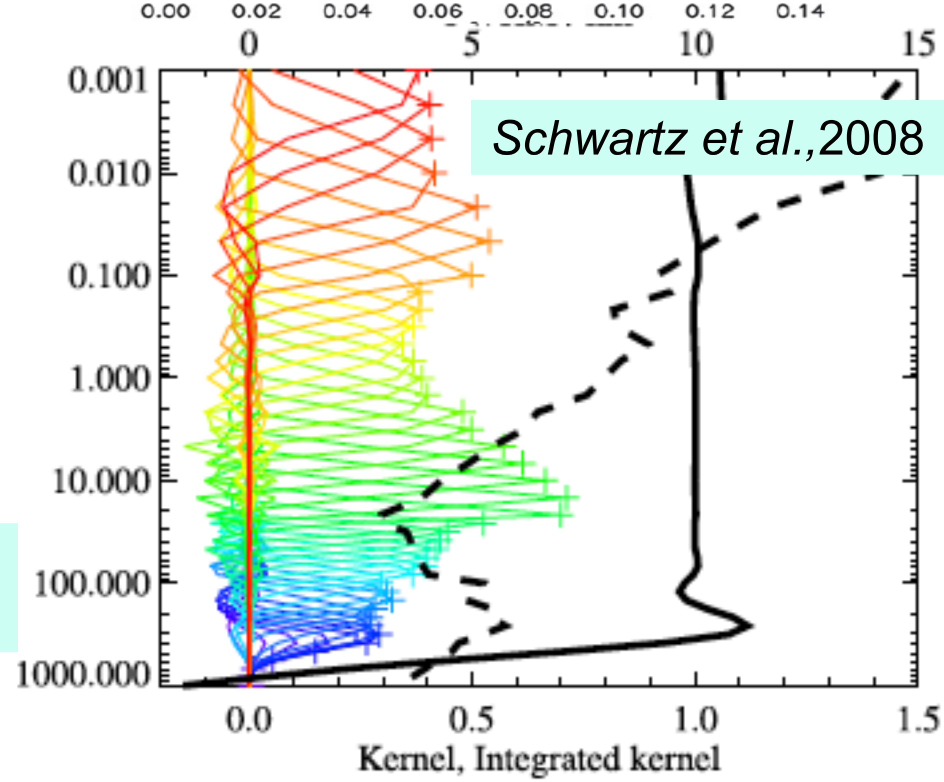


FIG. 6. Zonal mean temperature (see color bar on right for contour levels and units) from





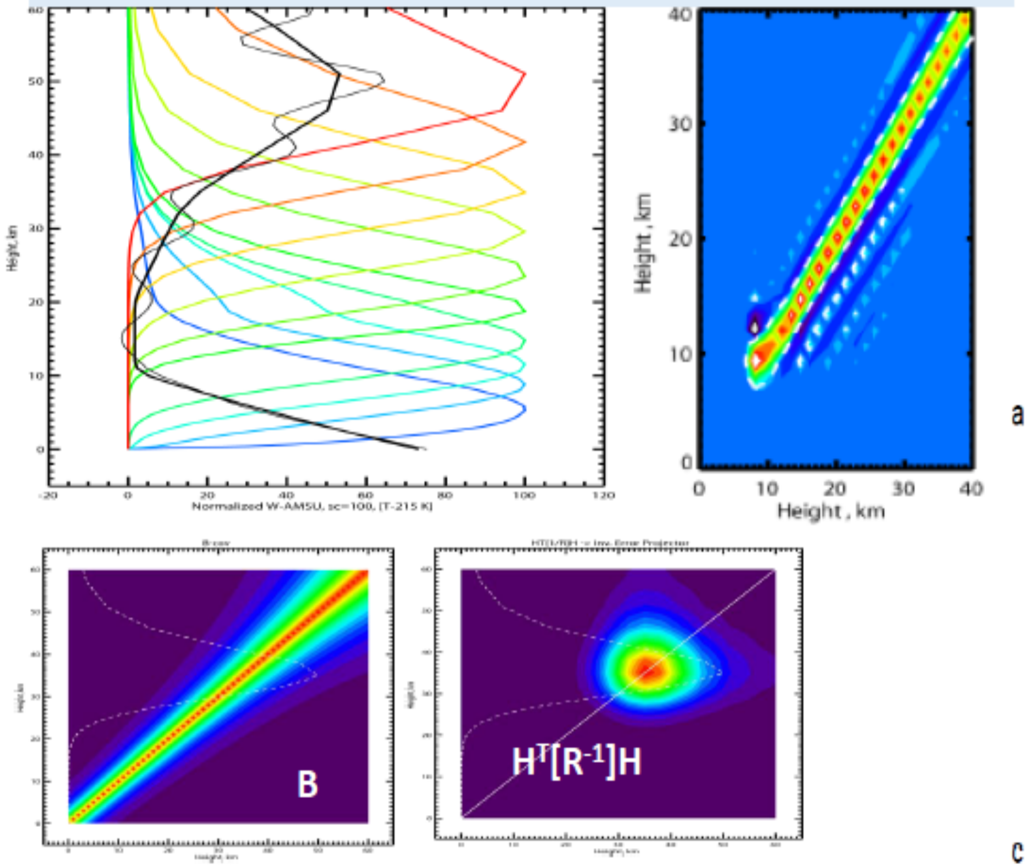


Schwartz et al.,2008

Hoppel et al., 2008, 2013

Example (2): MLS -T and AMSU-A stratospheric temperature channels

AMSU-A Jacobians and Res. Kernels of MLS



$\langle B\rangle^{-1} =/= [B]^{-1} + H^T[R^{-1}]H$

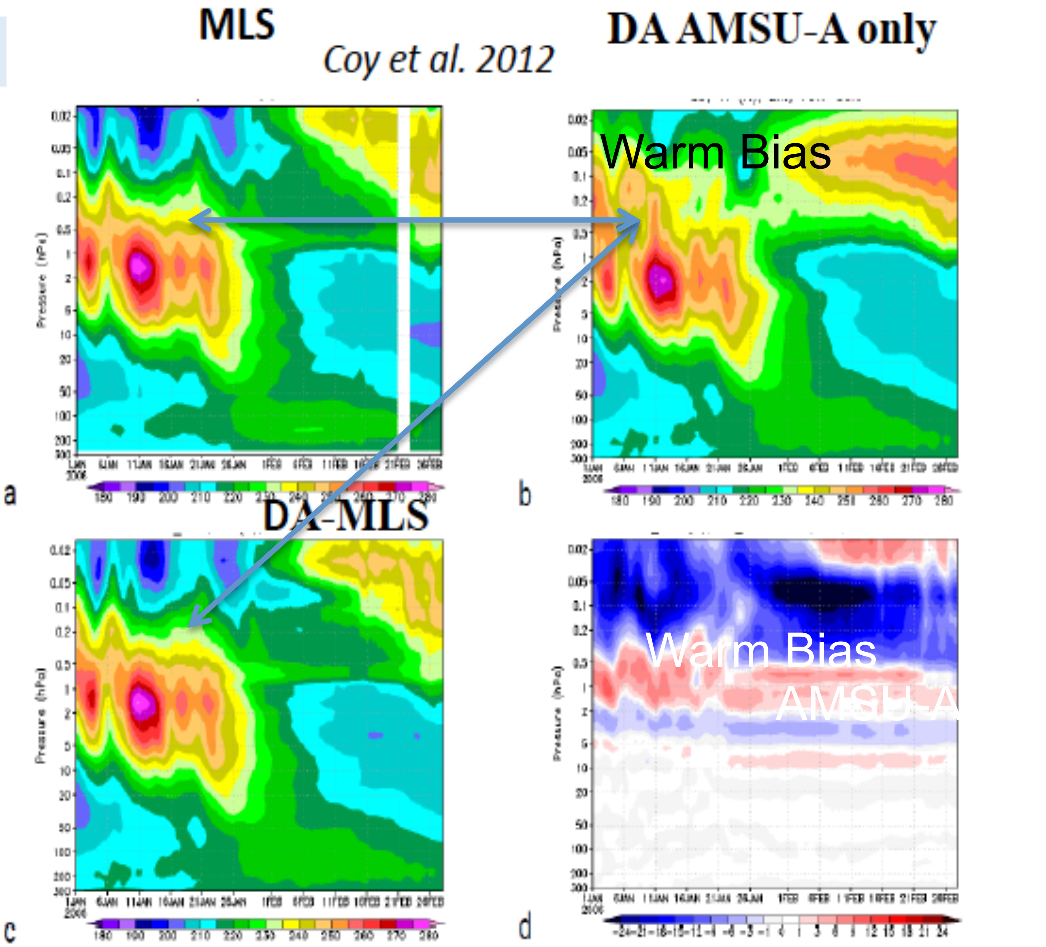


Figure 1. Time series of zonal-averaged temperature between 70°N and 80°N, for Jan. 1 – Feb. 28, 2006. (a) EOS-Aura MLS retrievals; (b) GEOS-5 with AMSU-A radiance observations assimilated; (c) GEOS-5 with AMSU-A radiances and MLS assimilated; (d) difference of GEOS-5 with and without MLS observations.

Vertical Resolution of Limb Data in the stratosphere and mesosphere helps to properly ingest "vertical-temporal" structures of propagated waves (tides and GWs with L_z ~ depth of WF of AMSU)

EOS-Aura MLS (08/2004-present) & TIMED SABER (01/2000-present) Data & Orbits

1. **Data to analyze and use for model verifications:**

(a) Kinetic Temperatures: dz ~2-4km
1700 (SABER) & 3500 profiles (MLS)

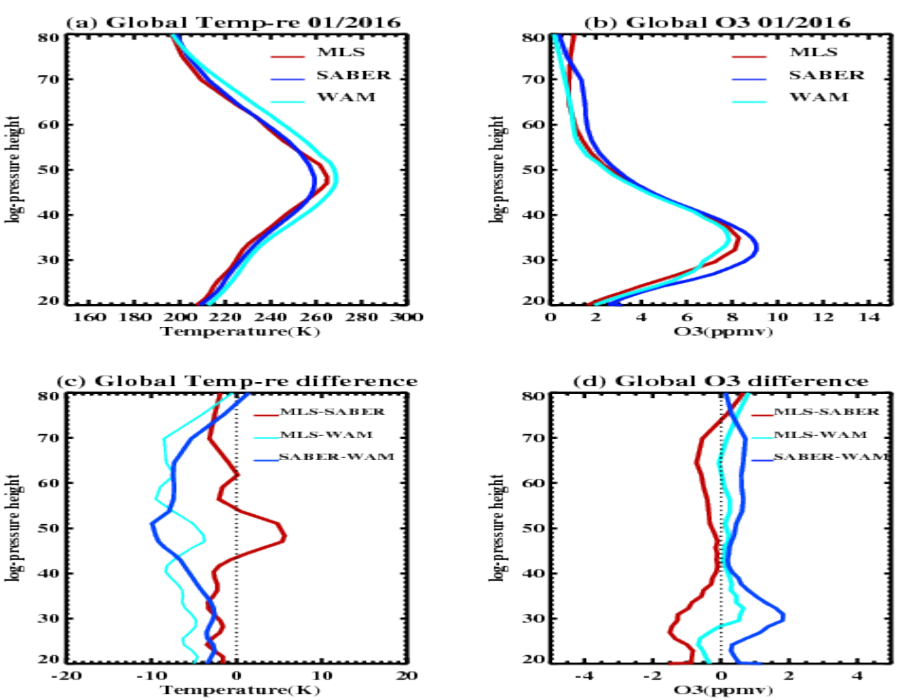
(b) Neutral Composition

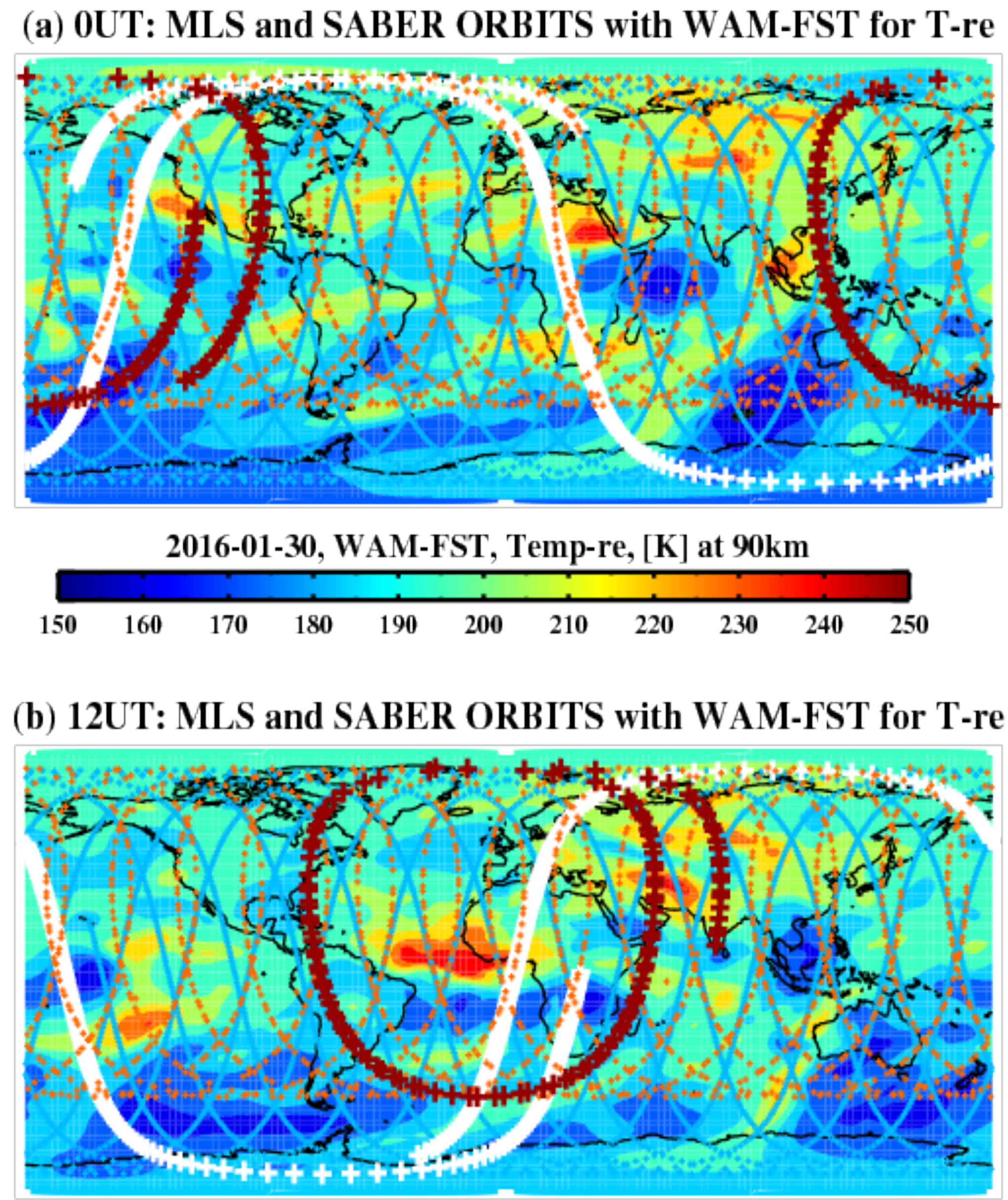
MLS: O_3, H_2O + O_3-*related minor gases*

SABER: O_3, H_2O , *O, H, NO +….*CO_2

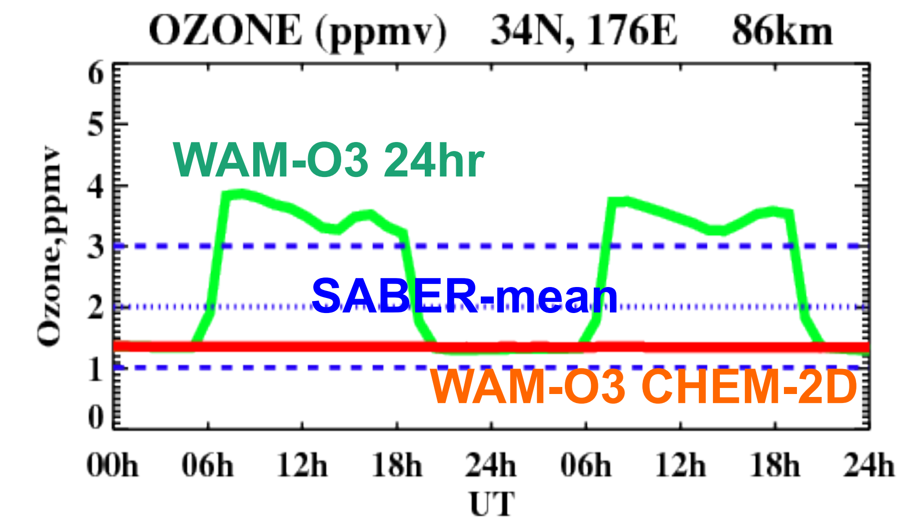
(c) MLS: 12- 85km SABER: 20-105 km

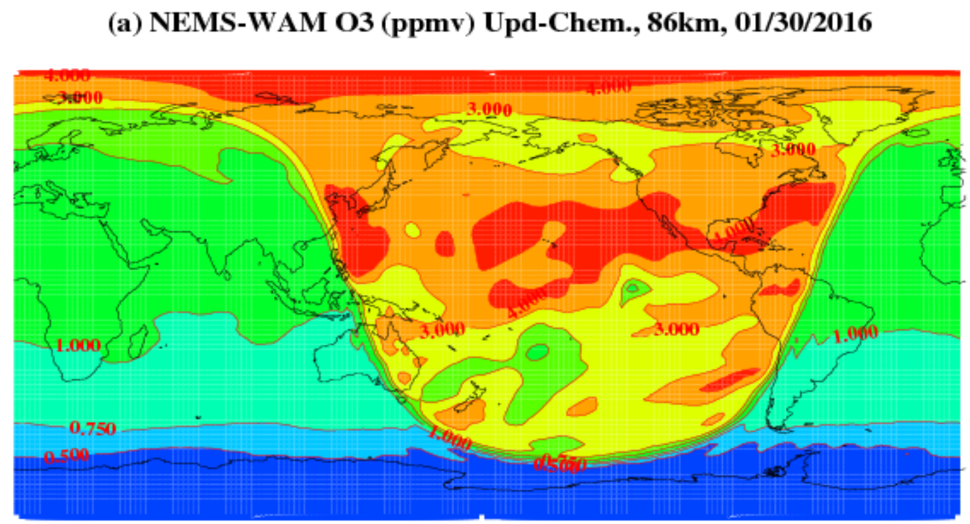
2. Data-Data Consistency (or biases)

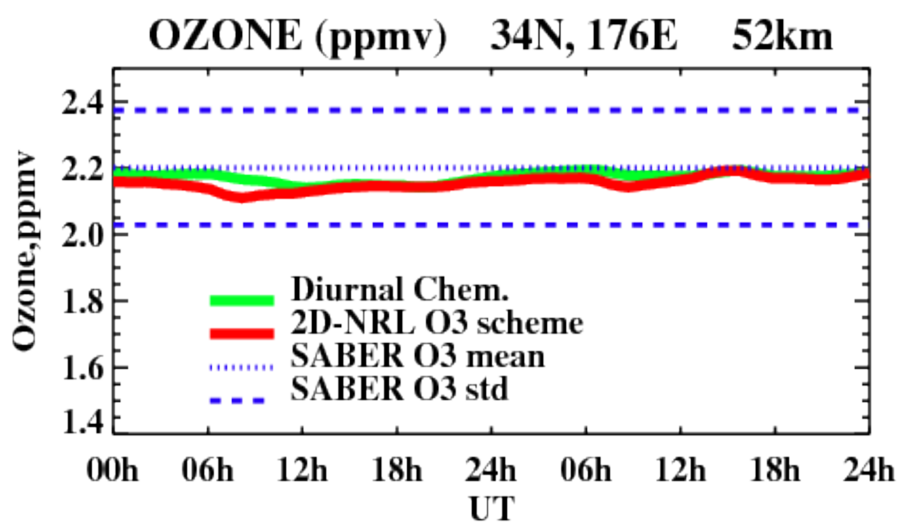


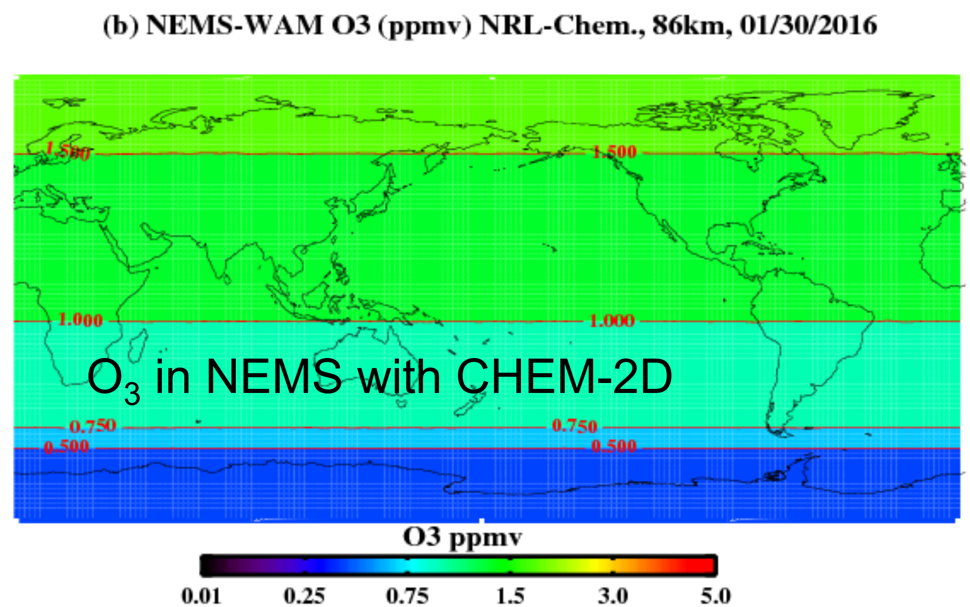


Upgrades of Diurnal Variations of Ozone in WAM (Jan-2016)









NEMS/WAM forecast/analysis vs SABER/MLS

WAM A-F cycles for Jan-Feb 2016

WAM-IAU with the Anal-tendencies of GEOS-5

WAM/GSI-WDAS branch and cycling with EMC wf Q3FY2017 (Kate Howard & Daryl Kleist)

Upgrades of GSI-WDAS:
zero-Jacobians of UA radiance channles above 50 km (issue non-validated domain), still Static Background Errors.

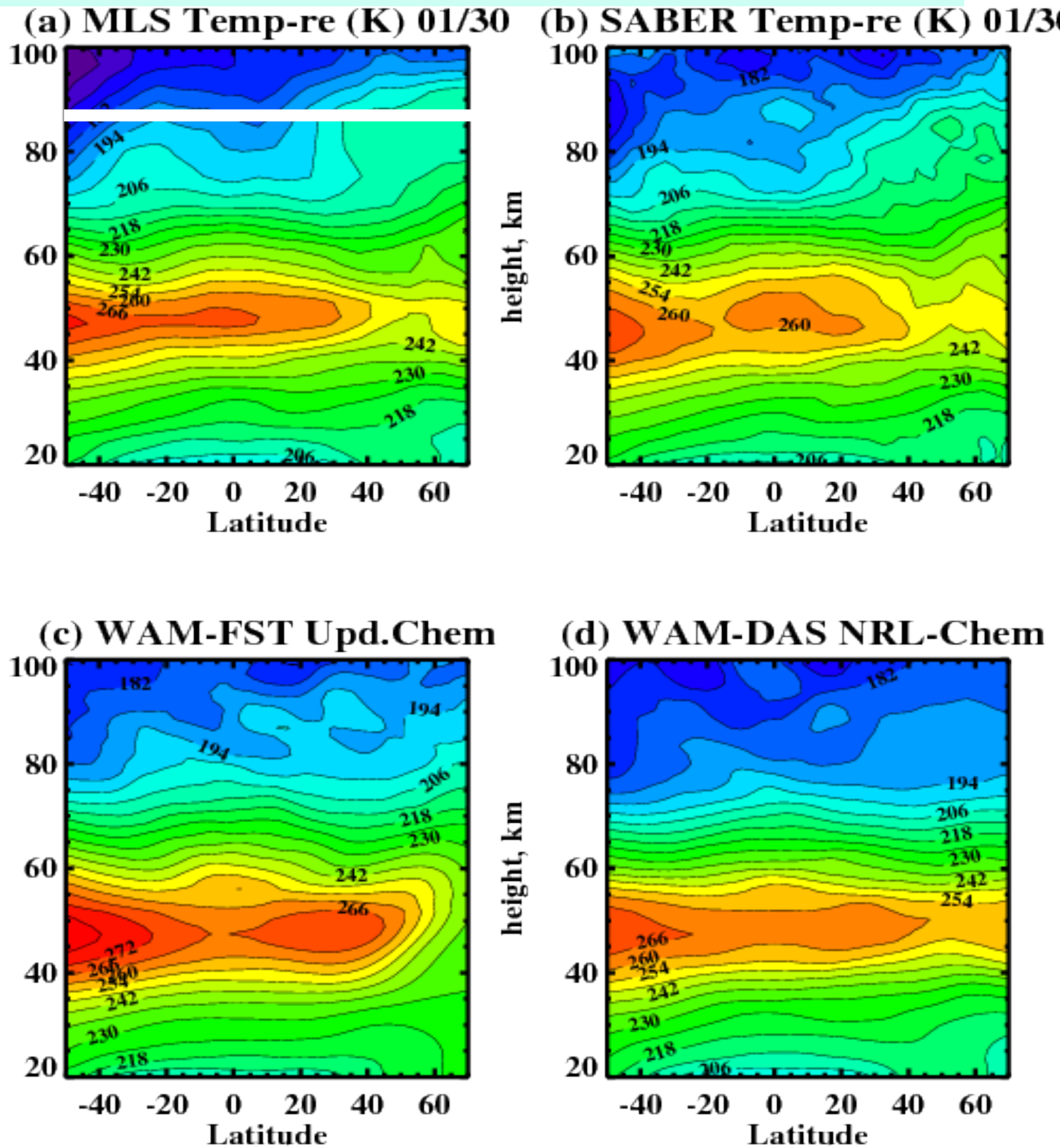
Upgrades of WAM (most in WAM-IPE):

(a) updates of radiation UV/EUV, cooling NO; merge domain "45-55" km

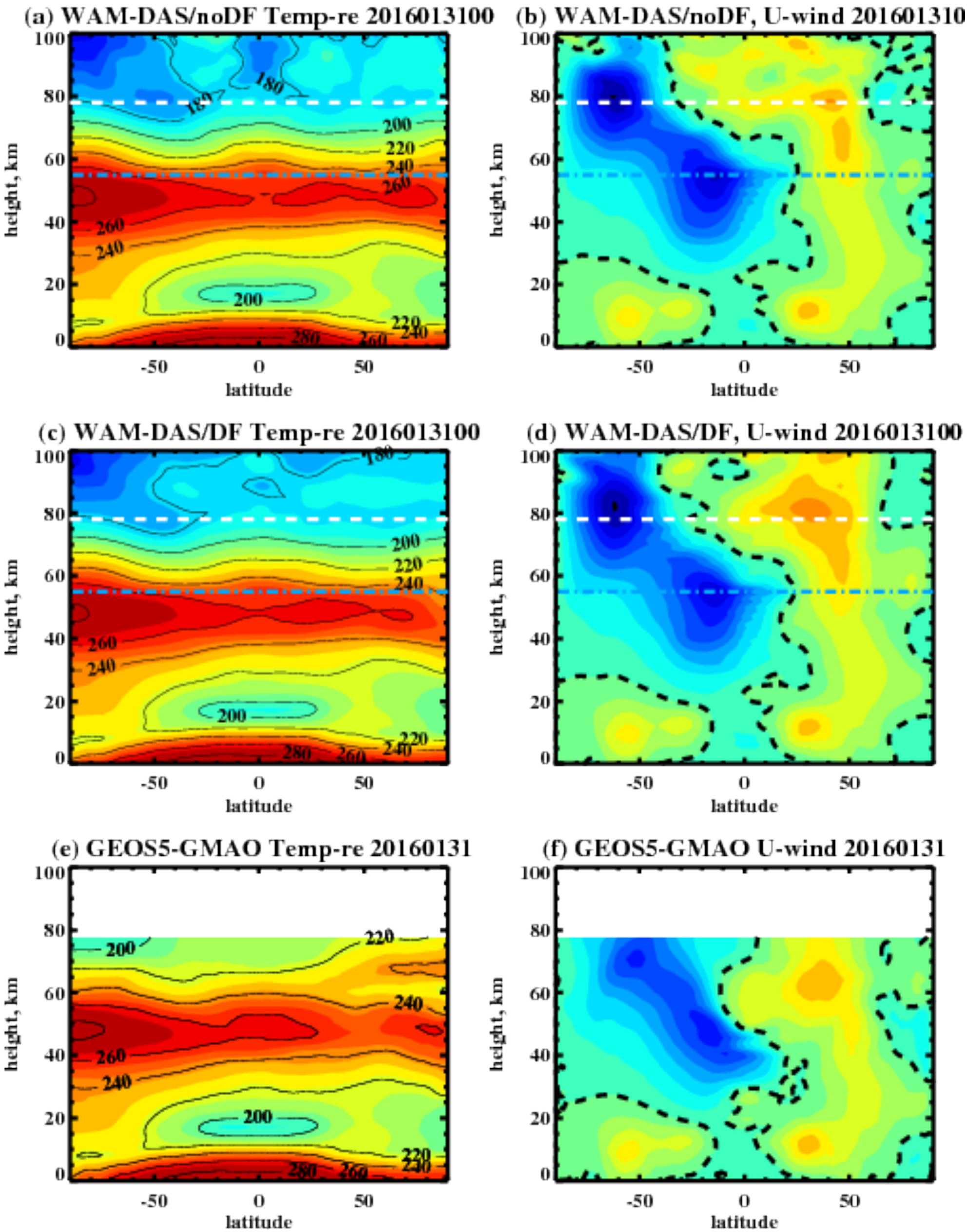
(b) O_3-O_2 photolysis rates

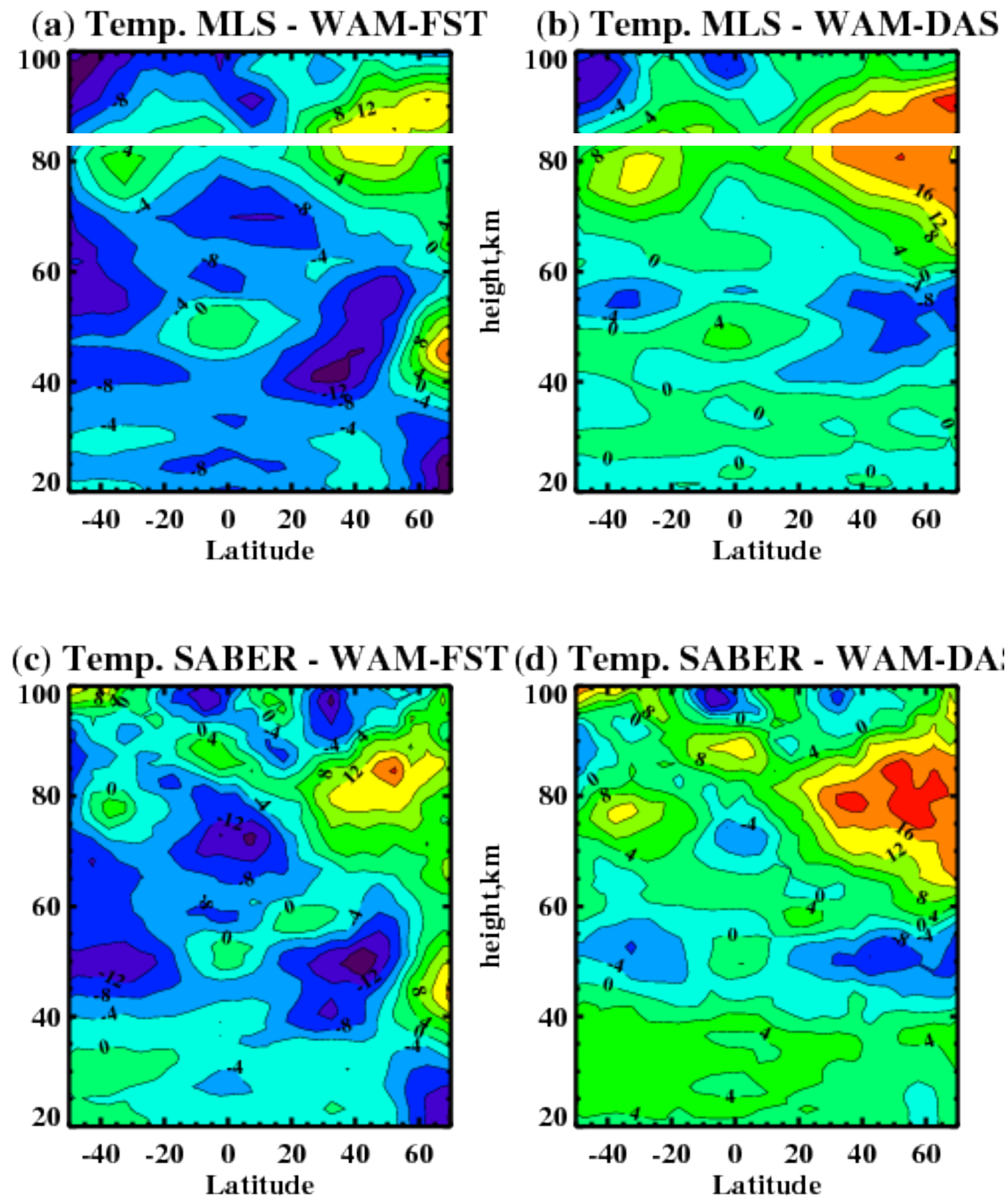
(c) Oxygen chemistry/box solver w/o chemical heating => T-re feedback;

(d) Non-orographic momentum/heat deposition

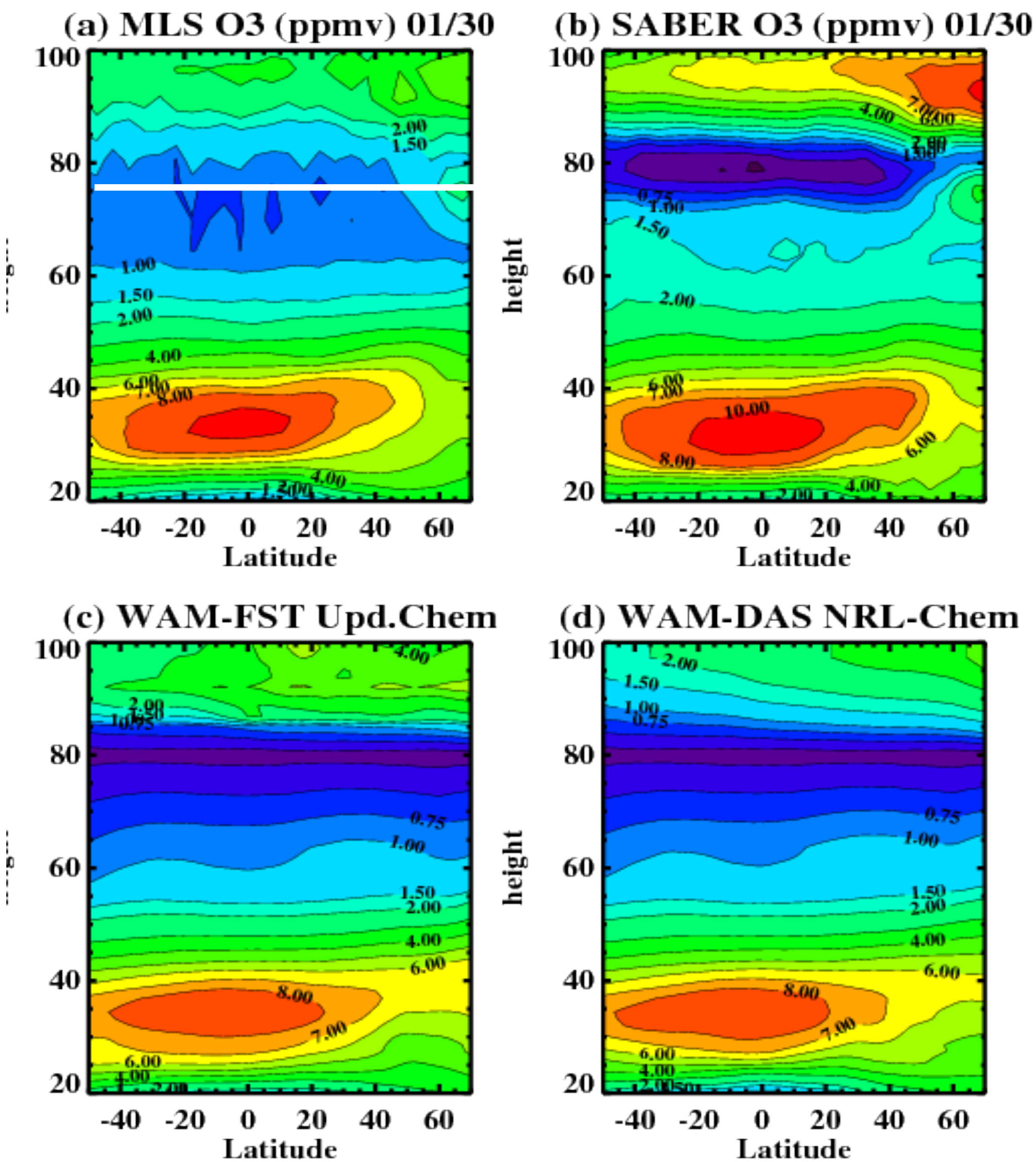


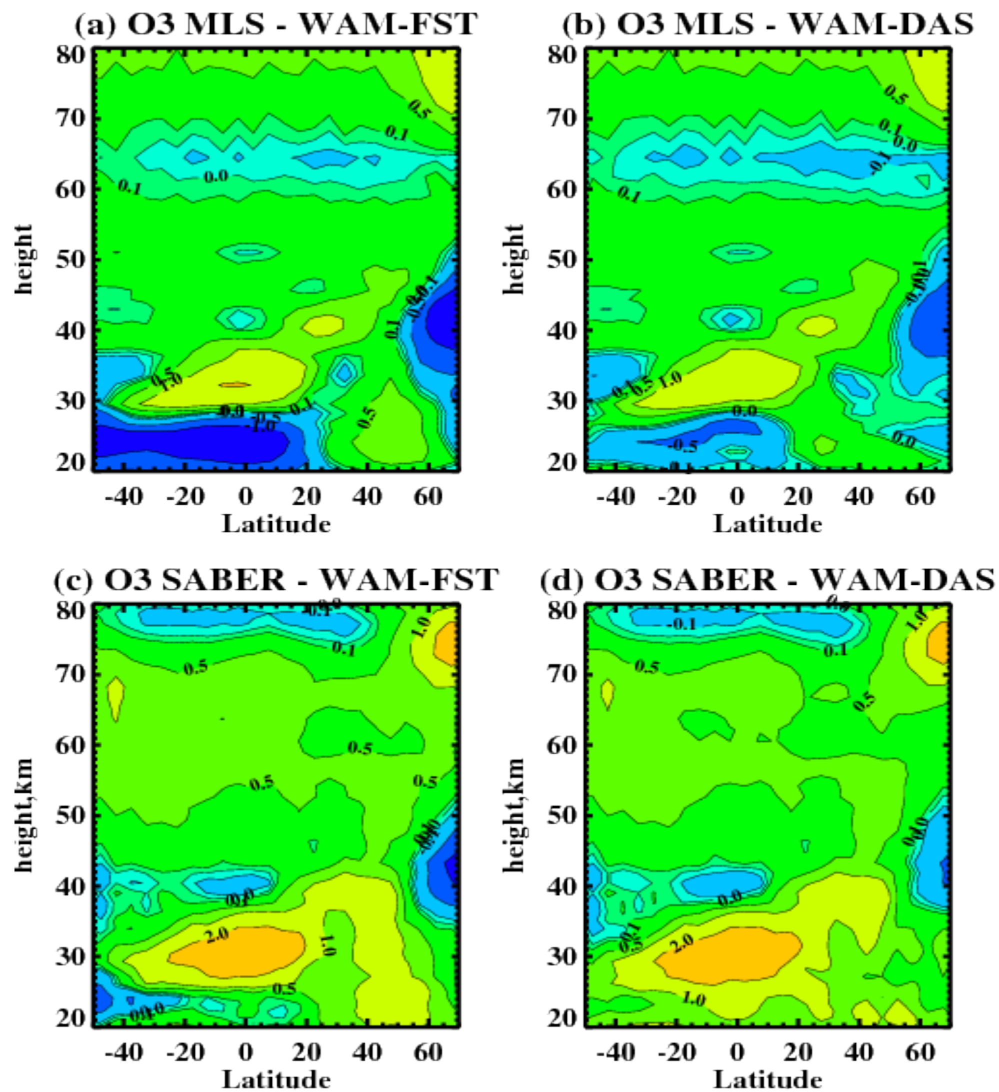
NEMS/WAM (analysis & forecast, Jan 2016) vs GEOS-5, MLS (top) and SABER (bottom)





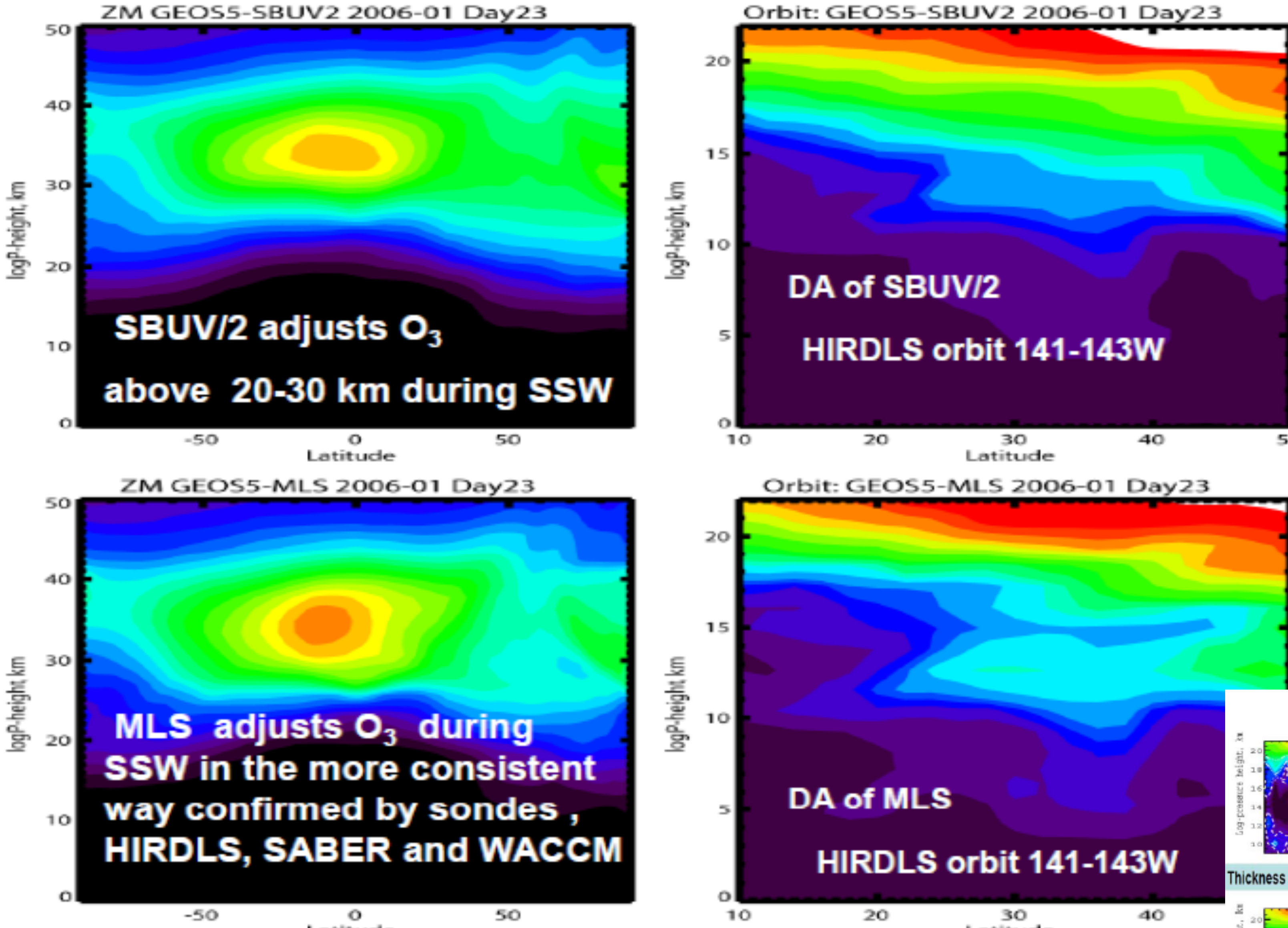
Zonal Mean Ozone: Jan 2016

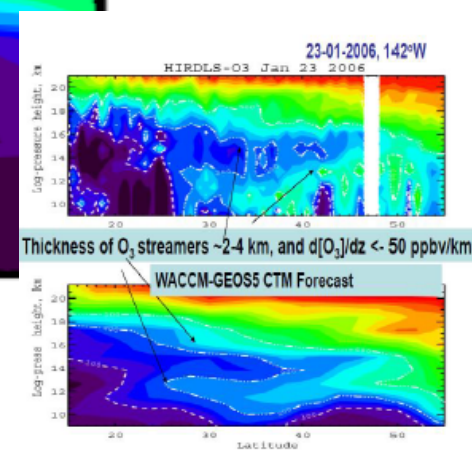




SBUV O3 data cannot remove the systematic “deficit-bias” in the tropical middle stratosphere; needs for MLS-O_3

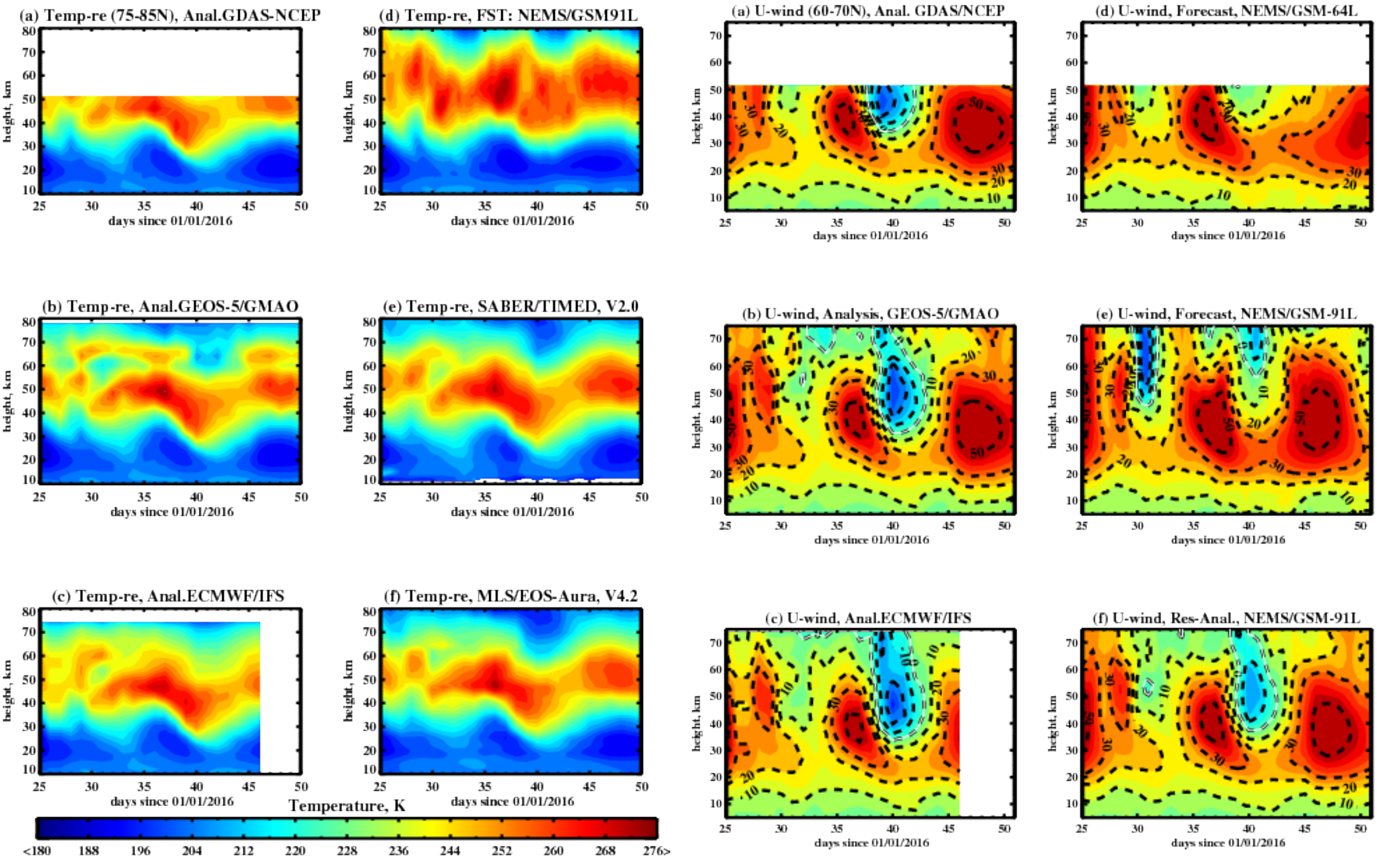
Ozone DA in GEOS-5: Taking out SBUV/2, and addi MLS => restore O_3 laminas, O_3-PV correlations



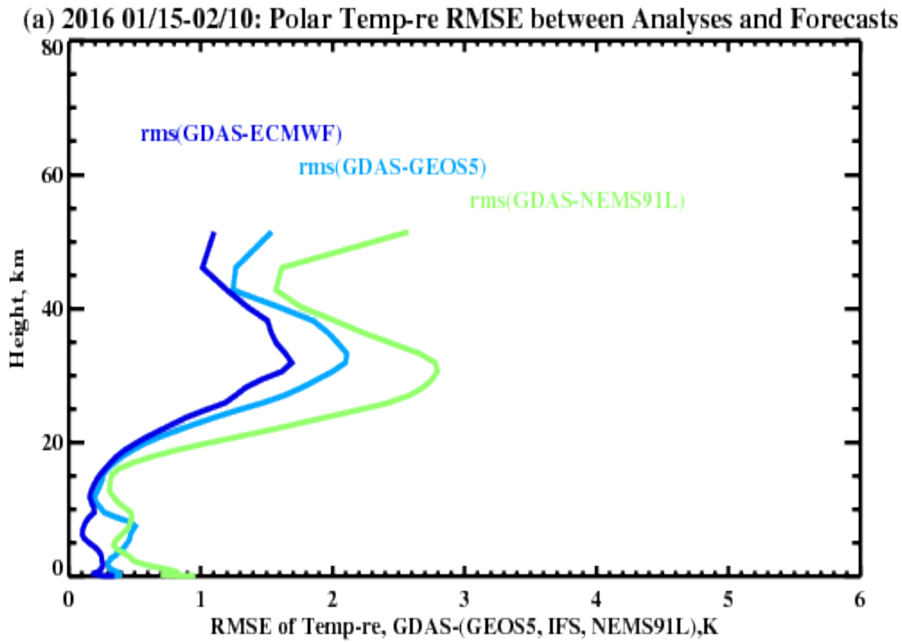


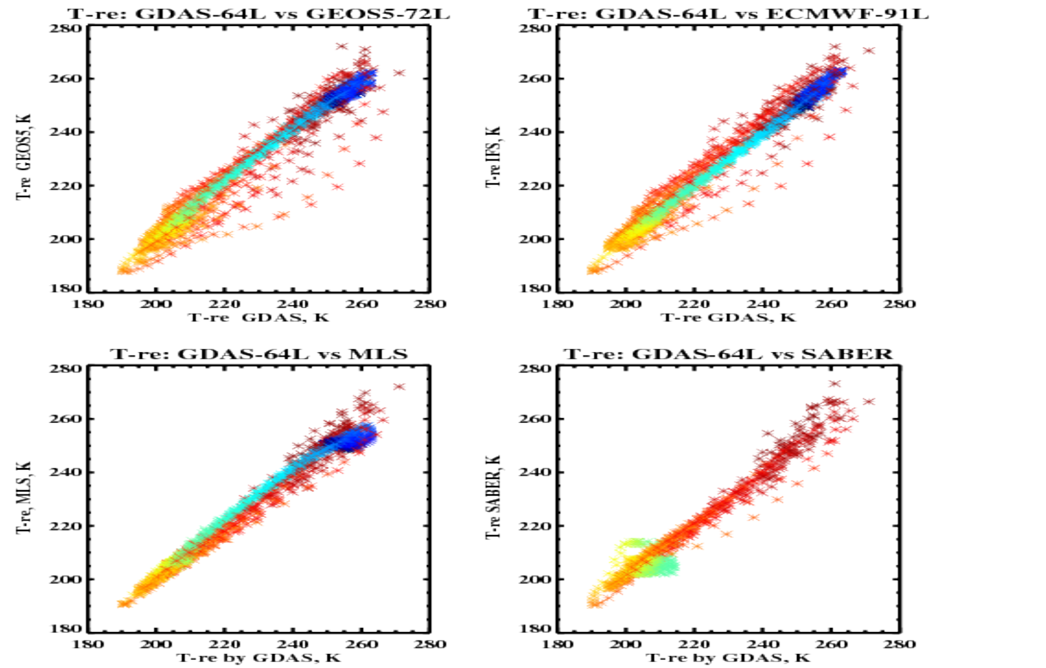
MLS-O3 data analysis will improve Stratospheric Radiation in the tropics & extra-tropics => Assisting Reanalysis to catch QBO in O_3, T, U

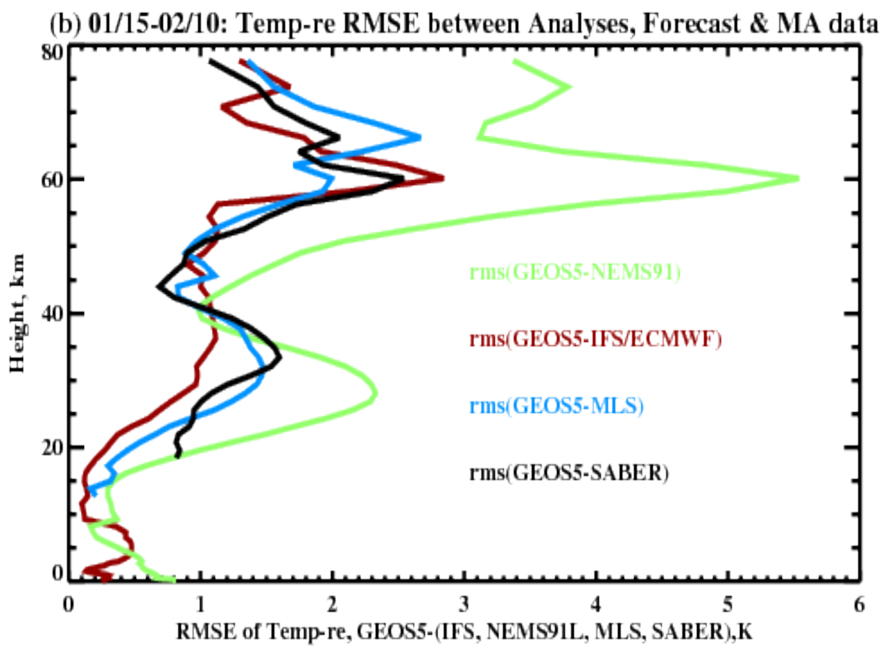
Polar Temperature & Winds: Forecast vs Analyses, Arctic in Jan-Feb 2016 (GSM-91L with NGWs)

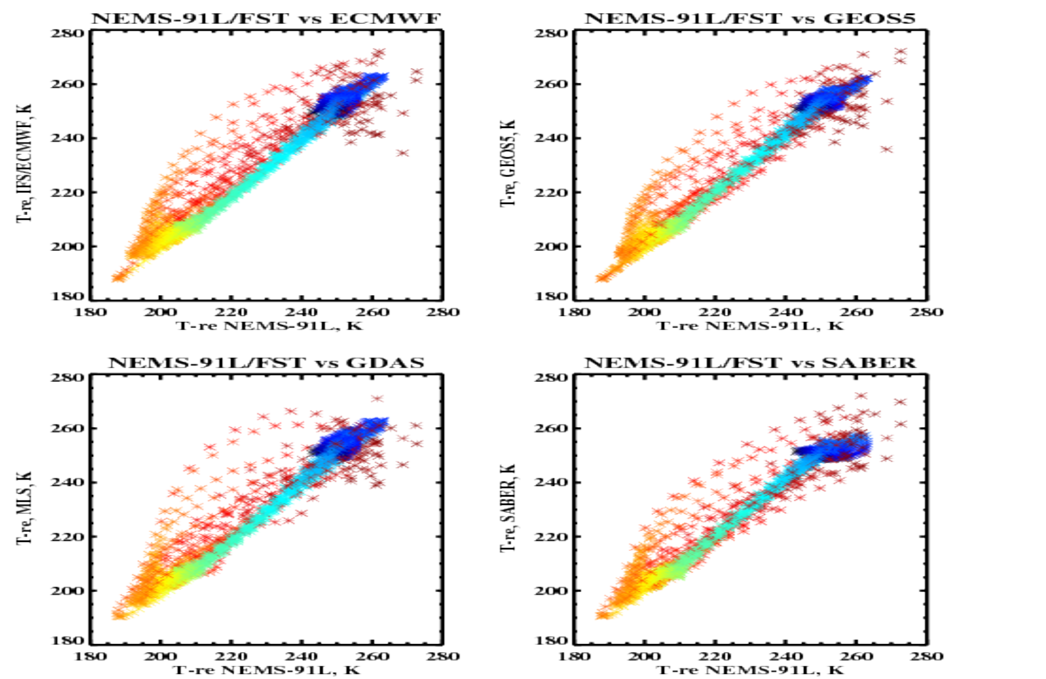


Simple Verifications at VG of GDAS & GEOS-5









June 2014: GFS-forecast in 64L & 91L models with Rayleigh Frictions (RF) and physics of NGWs

Role of RF (wind damping), it attempts to resolve 2 issues:

(1) The top lid model effects, sponge layer to suppress resolved wave reflections; (GFS-64L); extra-heating;

(2) The winter-summer zonal wind drag in the strato-mesosphere.

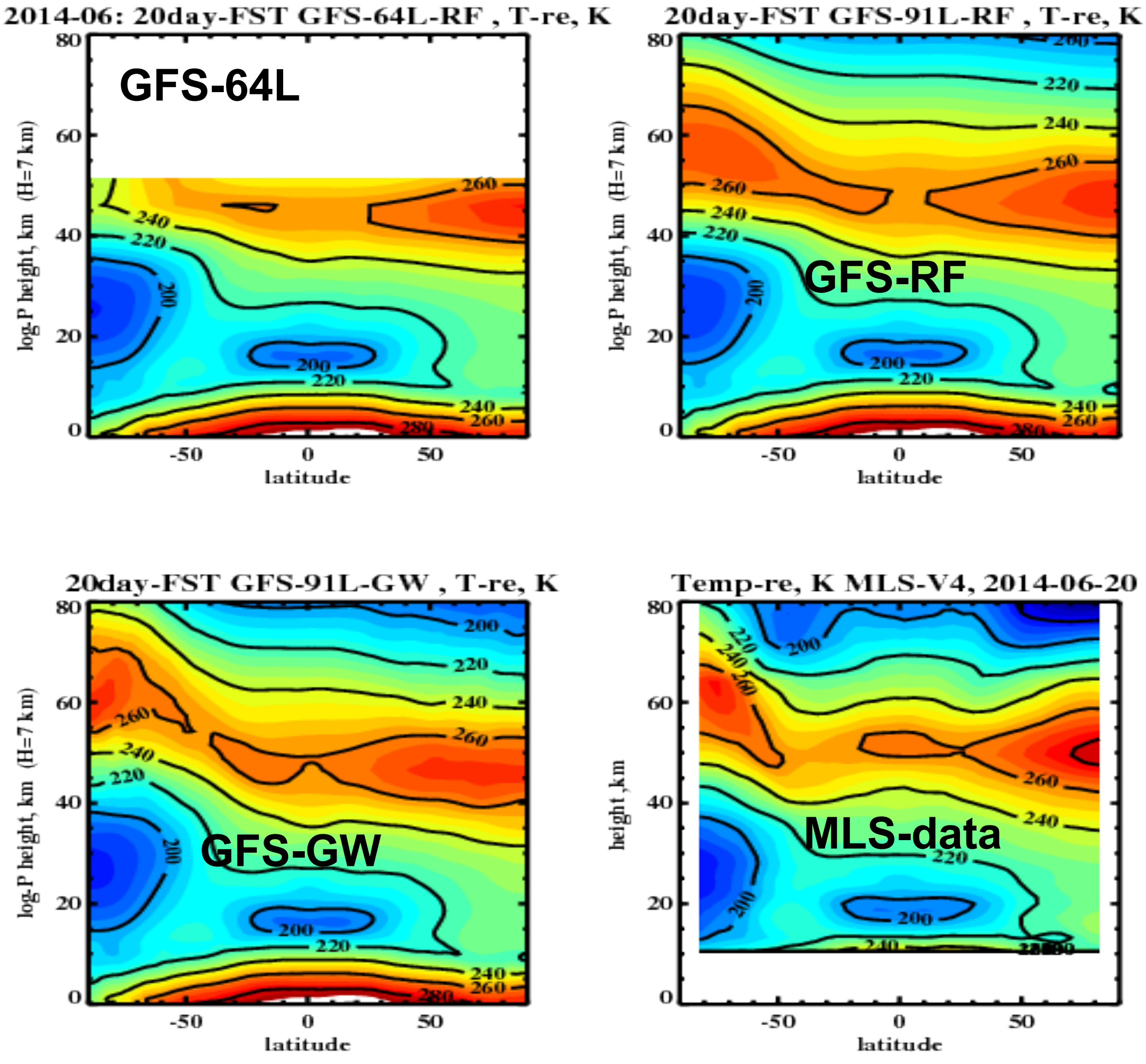
Issues with RF-schemes:

- erroneous reflections of PWs;

-absence of the U-wind reversals above ~70-80 km;

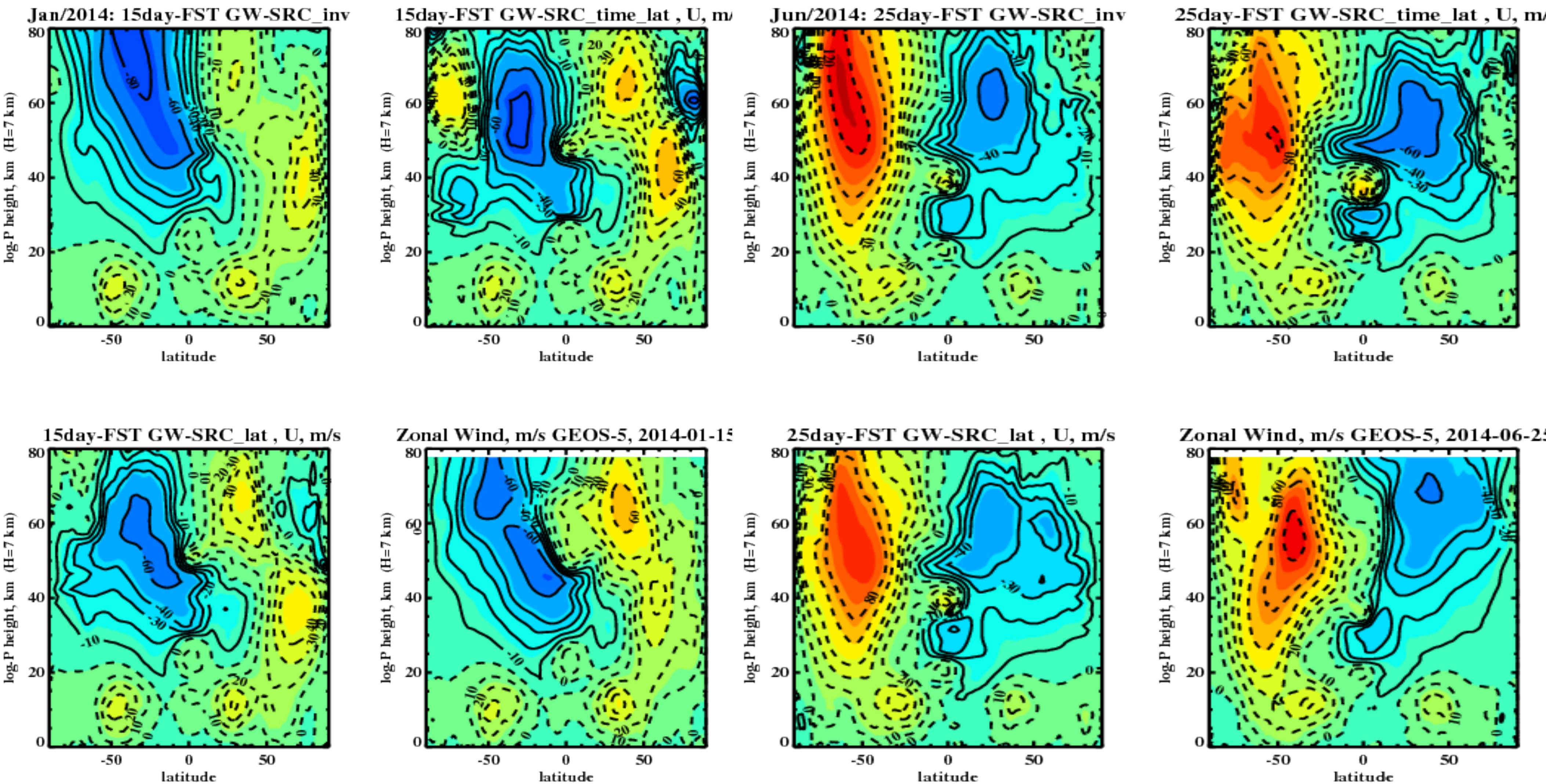
-warm mesosphere relative to EOS-Aura MLS and TIMED-SABER multi-year observations.

Advantage of GW-physics: handle “above-listed” GFS-biases; consistency with the data.



20-day GFS forecasts from June 1 of 2014 vs MLS-Aura 2014-06-30 (mean temperatures)

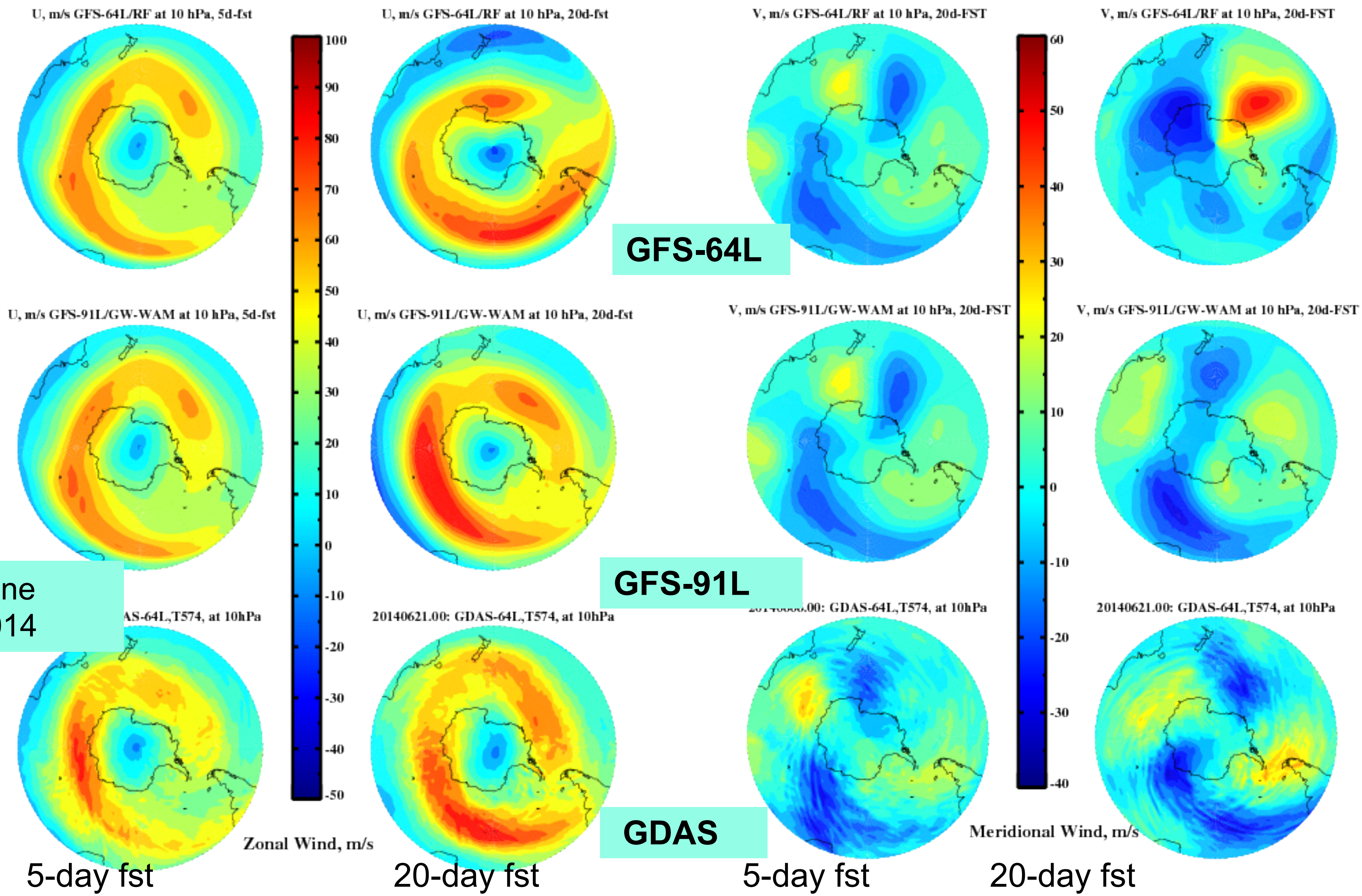
2014 GFS-T574 forecasts in 91L model with GW sources: Jan (15 day, right) and Jun (25 day, left)



GFS-91L with GW physics and GEOS-5 analysis

Sensitivity of GFS-91L runs to specification of GW-sources: *constant, time-lat dependentt & latitude-only dep-nt*

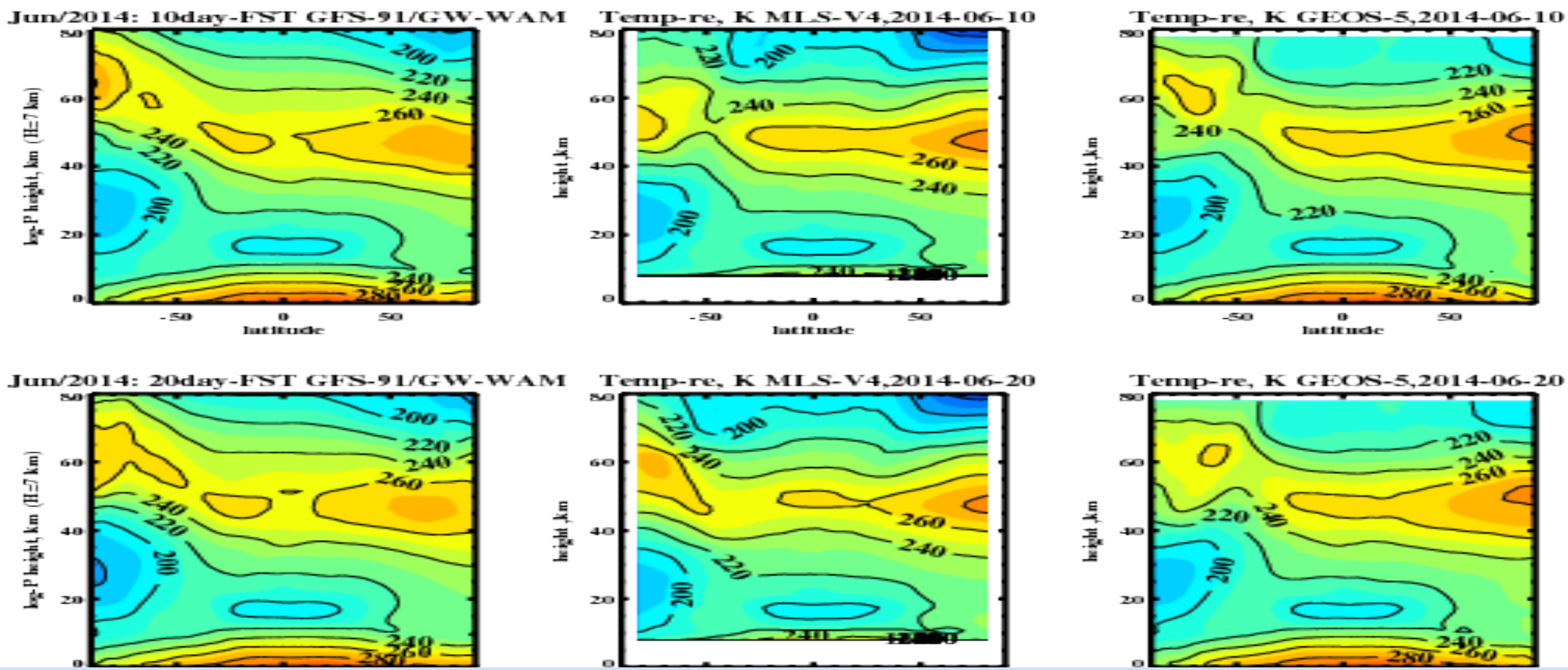
The 10 hPa (~30 km) Forecasts of the South Ocean Winds by GFS-64L, GFS-91L and GDAS-analysis, June 2014



GFS-91L (T670) 10-20-30 day forecasts vs MLS-Aura and GEOS-5

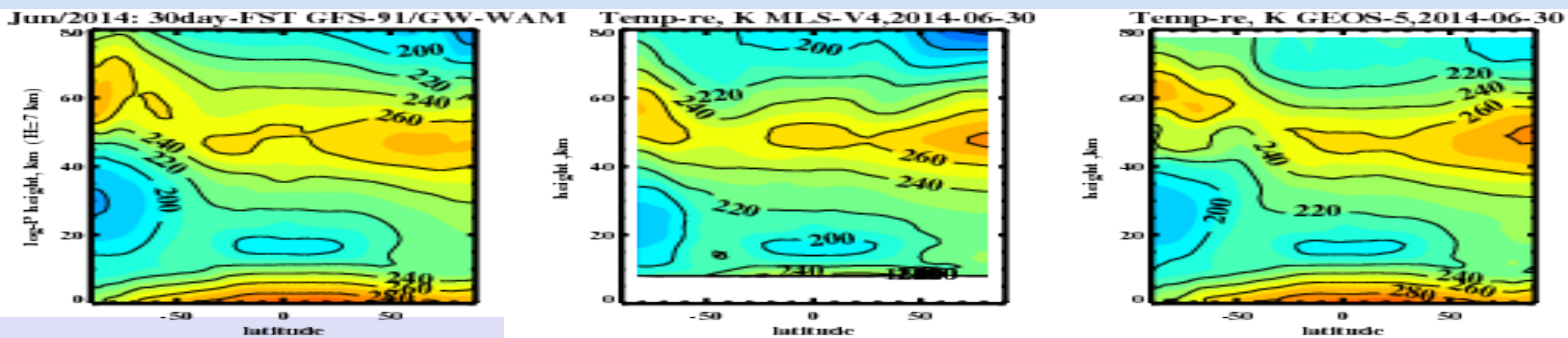
10-day

20-day



GFS-91L forecasts after 30 days continue to match MLS data and GEOS-5 analysis

30-day

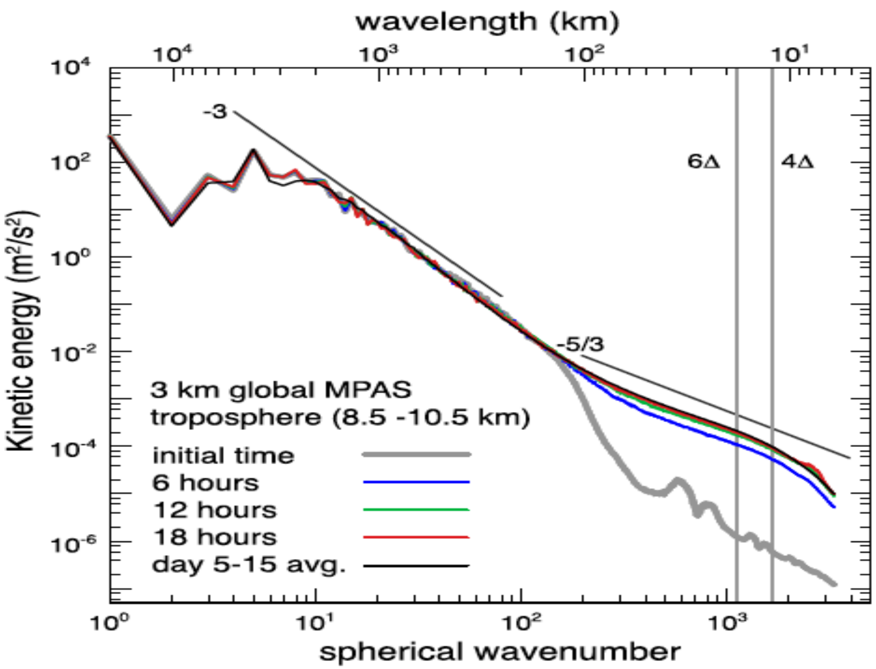


GFS-91L 800-hr forecast
WT: 4 hr 48 min RF
WT: 5 hr 57 min GW-40

EOS-Aura MLS-V4.3
June 2014

GEOS-5 Analysis,
June 2014

Effective horizontal resolution of new/old dycores



L12812 TAKAHASHI ET AL.: GLOBAL SIMUL

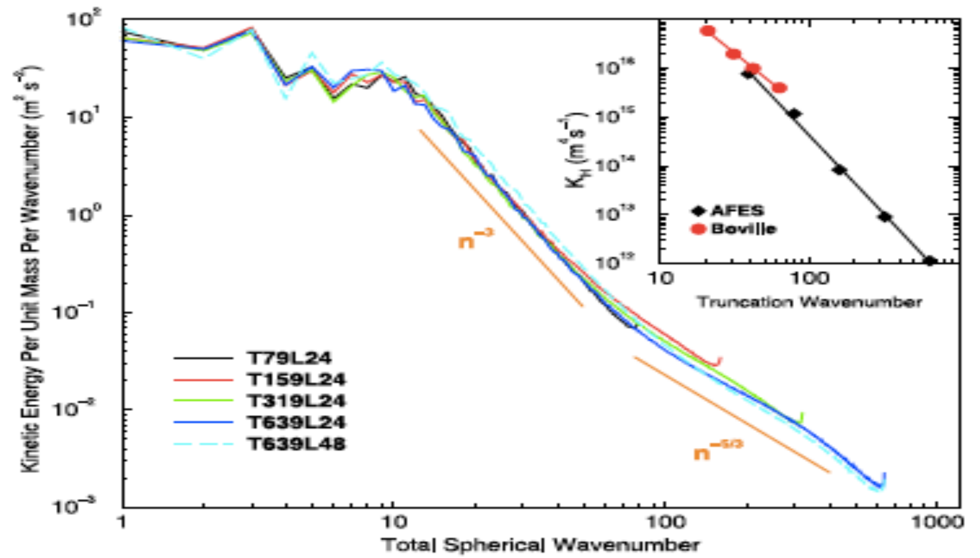
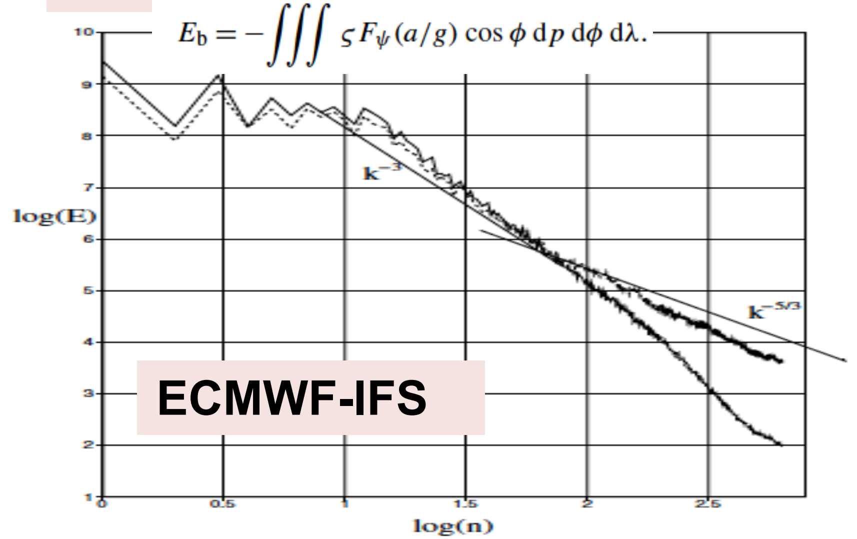
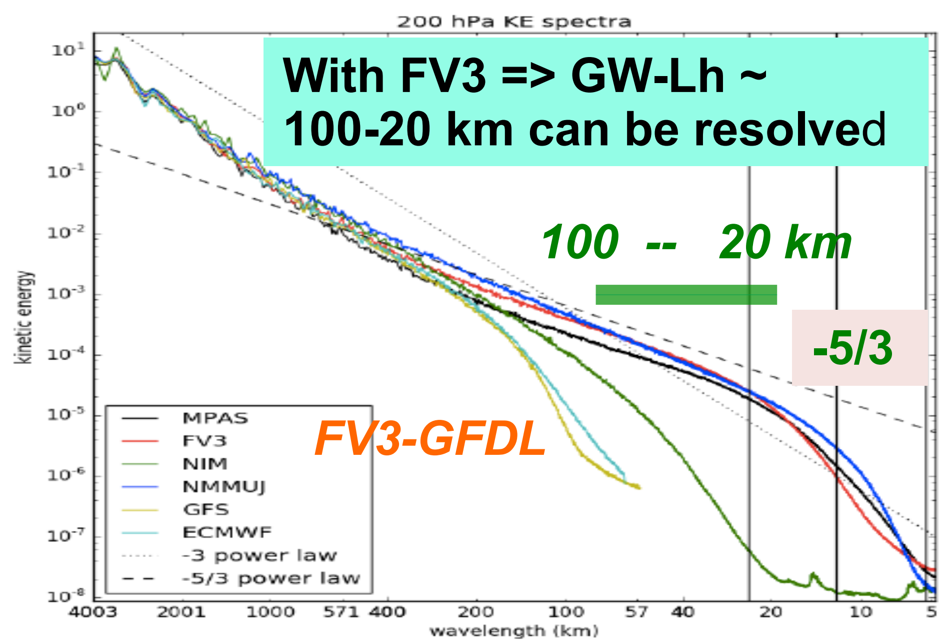


Figure 3. As in Figure 2 but for AFES run with different numerical resolution. Results are shown for the 24 level version truncated at T79, T159, T319 and T639, as well as the T639L48 version. At each horizontal resolution a

SKEB of G. SHUTTS



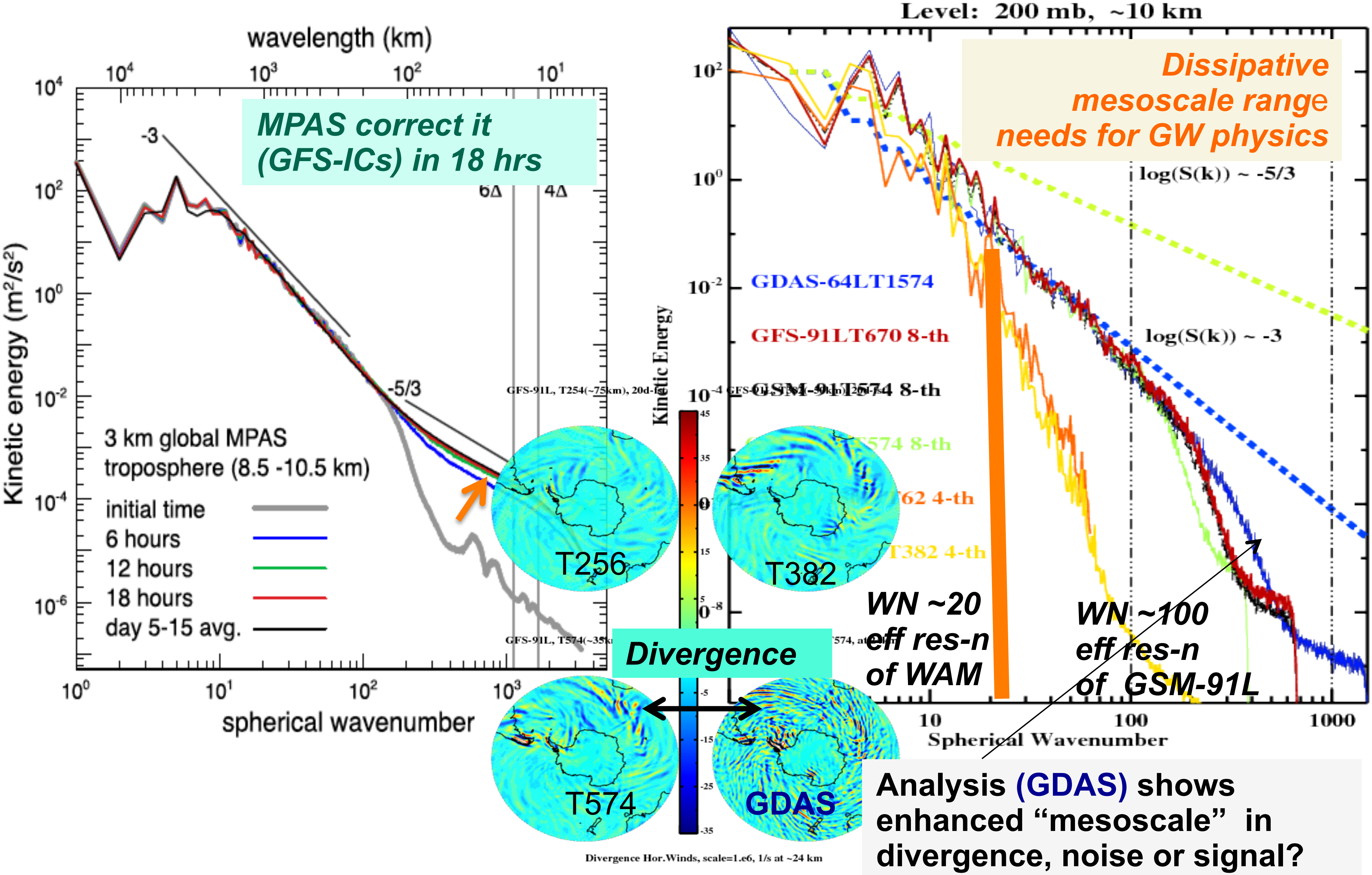
: day 5 in forecasts run at T799 resolution: with backscatte



Resolving "GW-mesoscale" in Kinetic Energy Spectra (KES)

MPAS-dycore with GFS-Ics (Skamarock et al, 2014-left), &

NEMS/WAM (4-th K_h) and NEMS/GSM-91L` (8-th K_h) forecast-analysis



Impacts of Unified GW physics in NEMS/WAM

WAM-trunk, no NGW Physics in the Strato-Mesosphere and Thermosphere, vs NOGAPS, UARS and MERRA

WAM Trunk Run: WAM-NEMS, January (left, top) no NGW physics

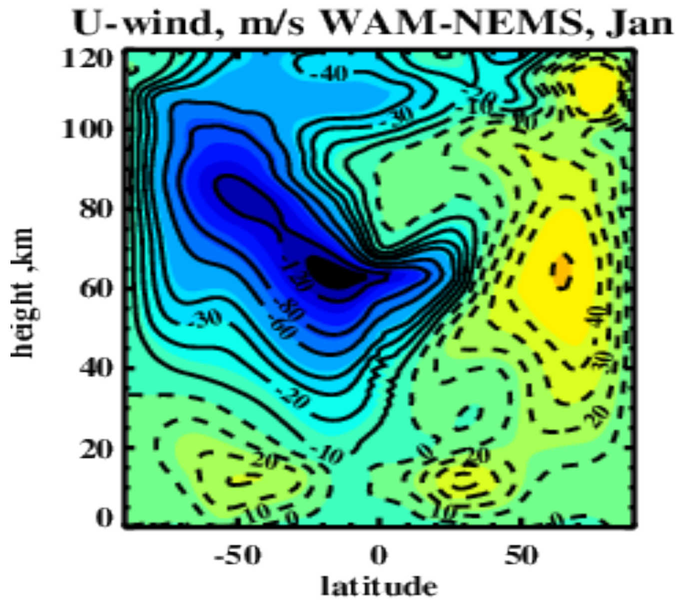
NOGAPS-Alpha, Jan 2009 with DA of SABER and MLS (right, top)

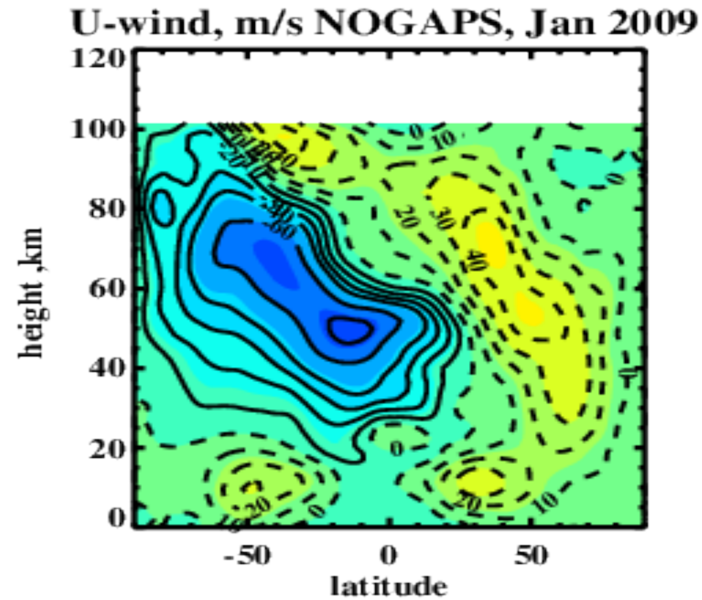
UARS-SPARC wind climatology (1992-97) (HRDI-WINDII) +UKMO

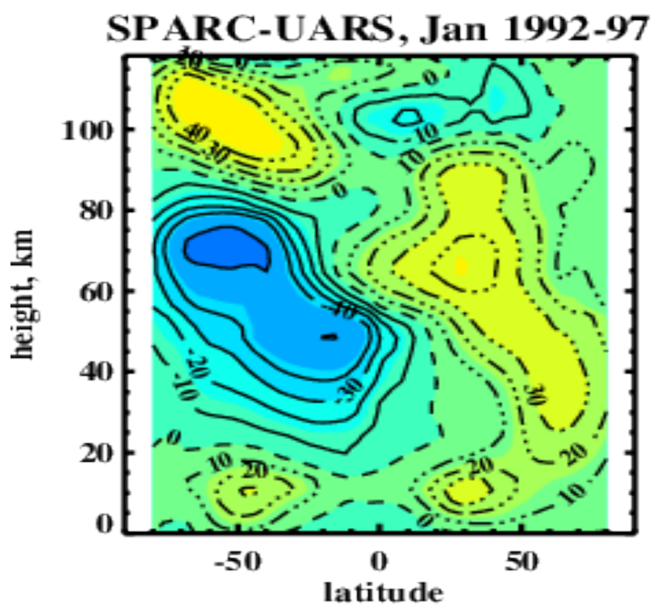
MERRA-V1/GMAO Jan 2009 (right, bottom).

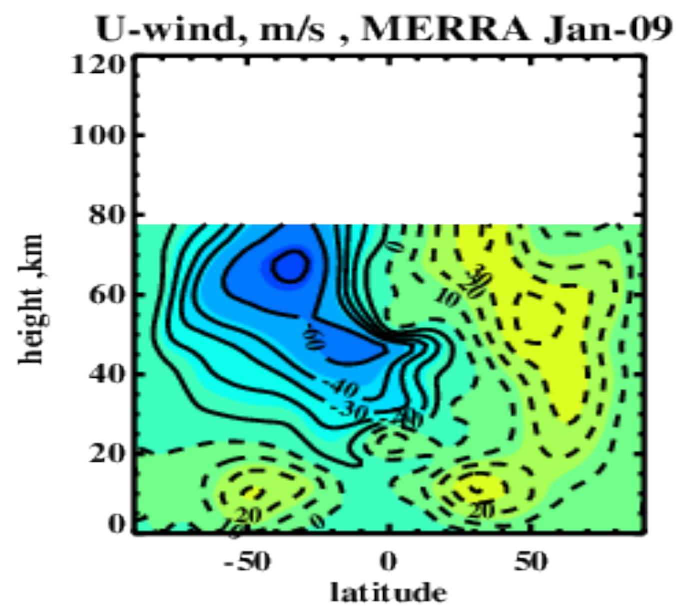
Biases above 40 km:

- *No MLT wind reversals*
- *Cold T-bias at 90-110 km.*
- *Strong strato-meso winds.*
- *Errors in PWs and Tides.*



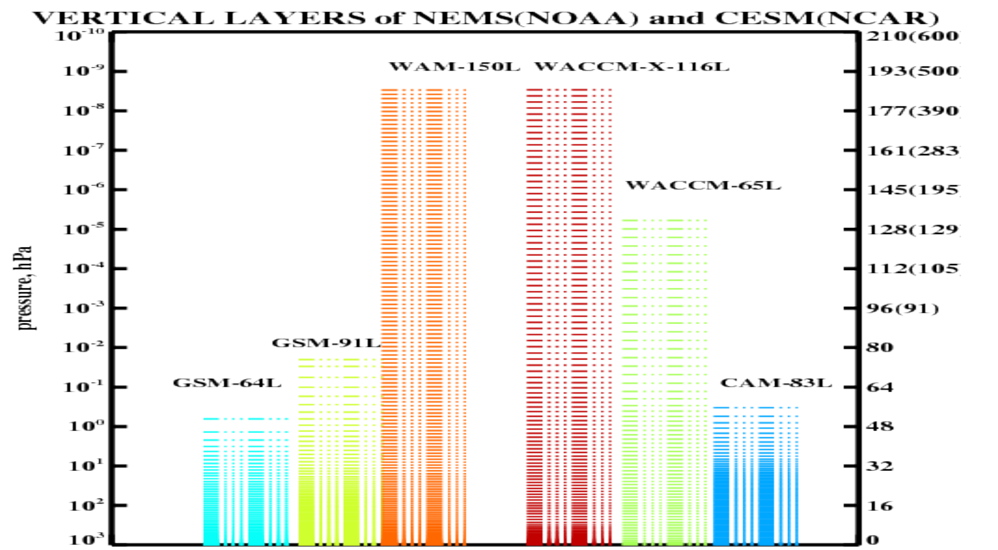


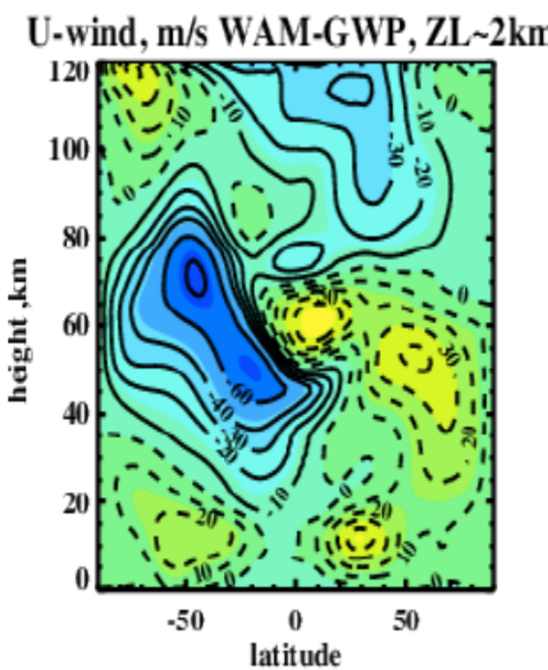


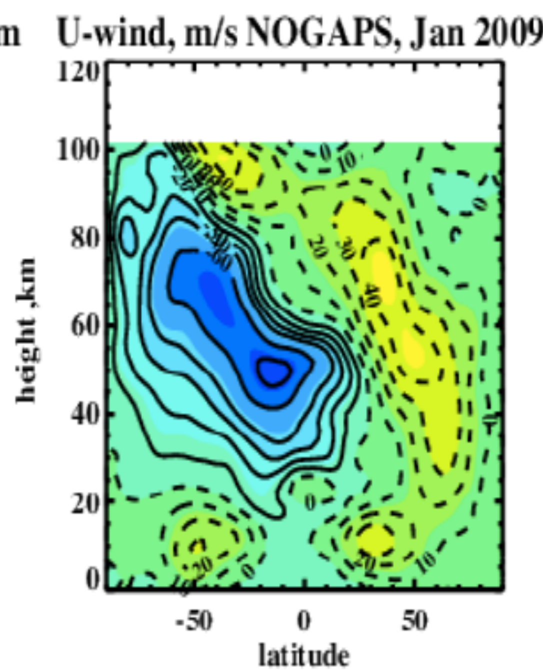


WAM-150L as Vertically Extended Atm-re Model of NEMS: specifics of Physics in the Mesosphere and Thermosphere

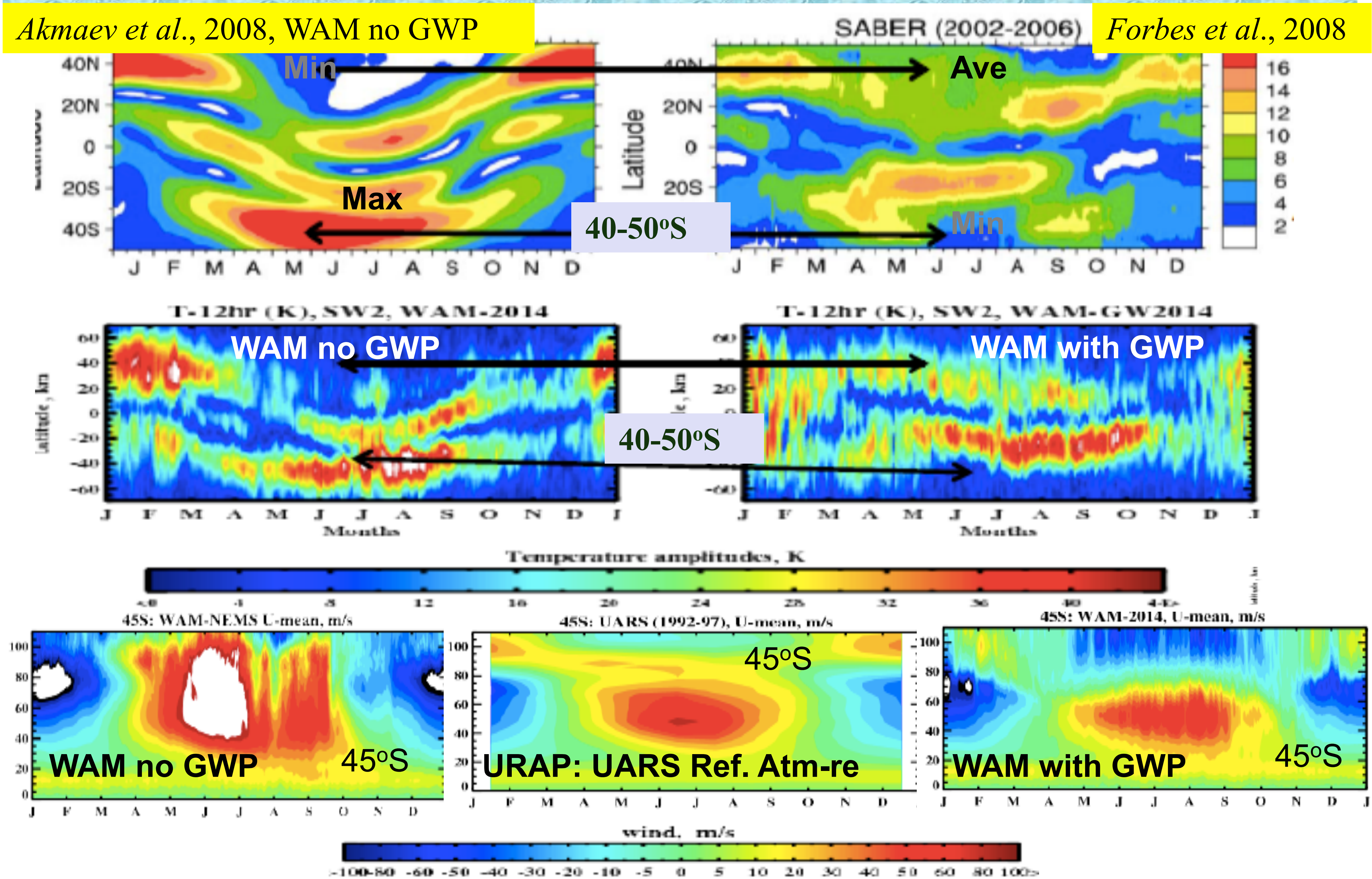
- **WAM, 150 vertical levels with top lid at ~500-600 km; "Zero" Rayleigh damping with molecular visc./cond and 4-th order spectral diffusion.**
- **EUV and non-LTE radiation, ion drag, Joule heating, molecular processes, major tracer (O-O_2N_2) transport-diffusion-chem, & variable "g-C_p-R" (enthalpy).**
- **WAM-T62 as development runs with Eulerian dynamical core enhanced res-ns T254,T382; uniform NGW triggers,~700 hPa.**
- **GW solvers with molecular dis-n: GW drag, heat & mixing**: *4-8 azimuths; stochastic (random draw of single wave) and deterministic spectra (10-20 modes per azimuth) for the linear saturation schemes.*







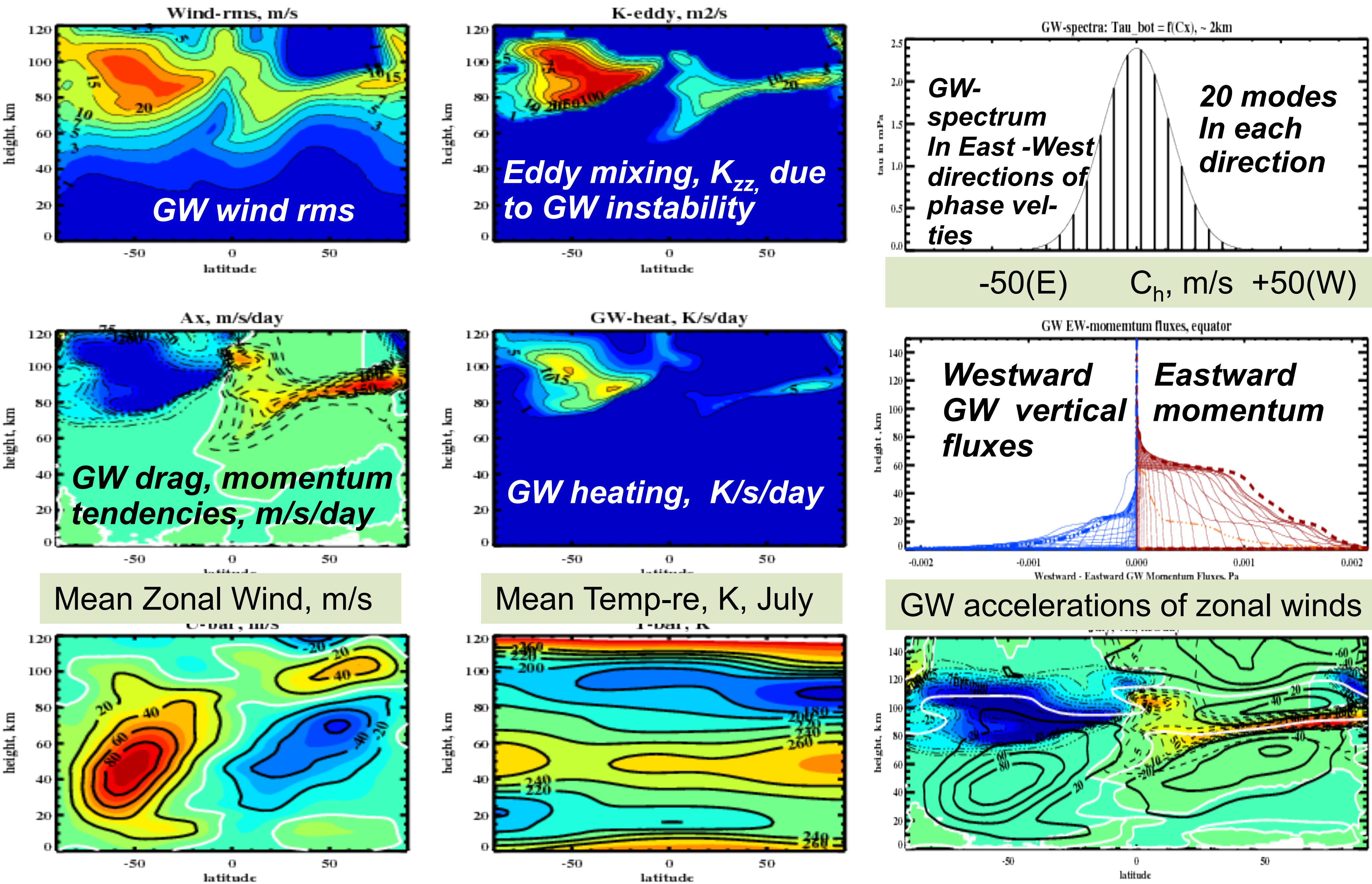
Role of Realistic Zonal Mean Flows in SW2 Tidal Predictions for "JJA" by NEMS-WAM with GW Physics (GWP)



Non-stationary sub-grid Gravity Wave (NGW) Physics in Climate and Weather Models

Model Climate/ Weather	Levels & Top Lid	GW-NST scheme	GW sources	GW-drag	GW-heat	GW-eddy
WACCM & WACCM-X NCAR	68 L (88L) ~140 km (500km)	Lin. Saturation (65 x 2 modes)	Physics-based triggers	Y	Y?	Y
NAVGEM/ NOGAPS-NRL	L70, 0.04 hPa , 70km; (0.001 hPa ~100 km)	Lin. Sat . with stochastic triiggers (~1-4)	Lat-time depend.	Y	Y	Y?
IFS-40R1/ ECMWF	91L (137L), 0.01hPa , 80 km.	Univer. Lin. Sat. (25 x4 modes)	Lat-depend.	Y	Y?	No
GEOS-5/GMAO/ GSFC	72L, 0.01 hPa, ~80 km	NCAR scheme with reduced # of GW modes.	Lat-depend.	Y	Y	No
NEMS-GSM/ GFS91L(128L?)	91L, ~80 km (128L, ~100km?)	Lin. Sat (25 x4 modes)	Lat-depend.	Y	Y	No
NEMS-WAM CU	150L (T62) ~500 km	Lin. Sat (25 x4 modes)	Lat-depend.	Y	Y	Y

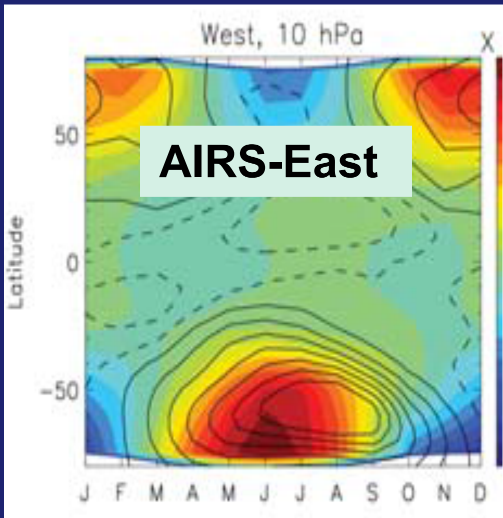
Diagnostics of GW-forcing: non-stationary GWs in July
NOAA-CIRES scheme, implemented in WAM-NEMS

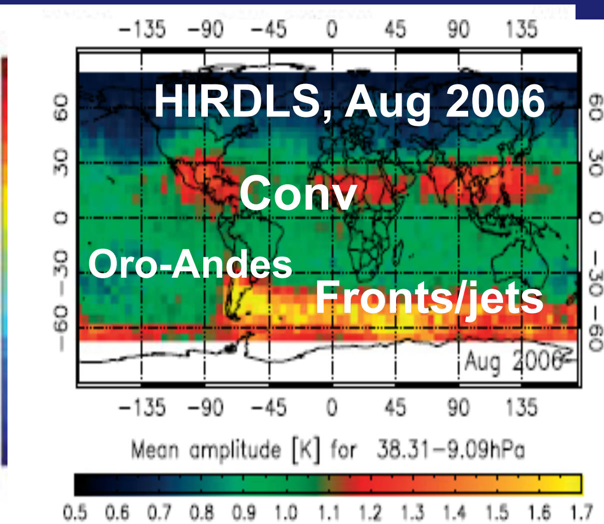


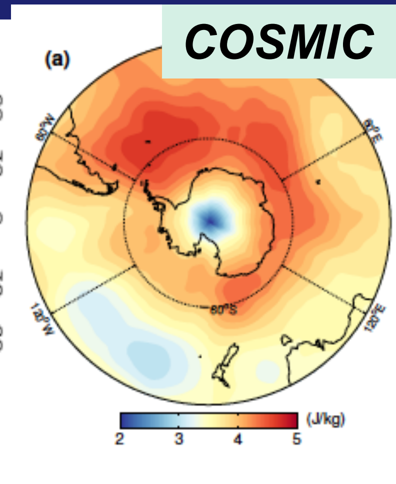
Gravity Wave Hotspots/Sources from Satellites: AIRS, COSMIC, HIRDLS & SABER

Gong et al., 2012

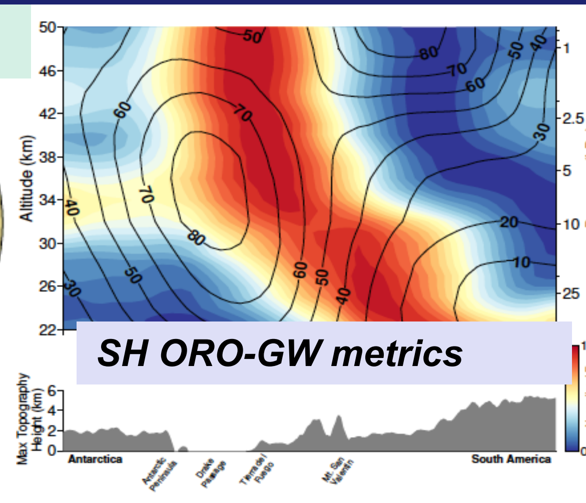
Hindley et al, 2015



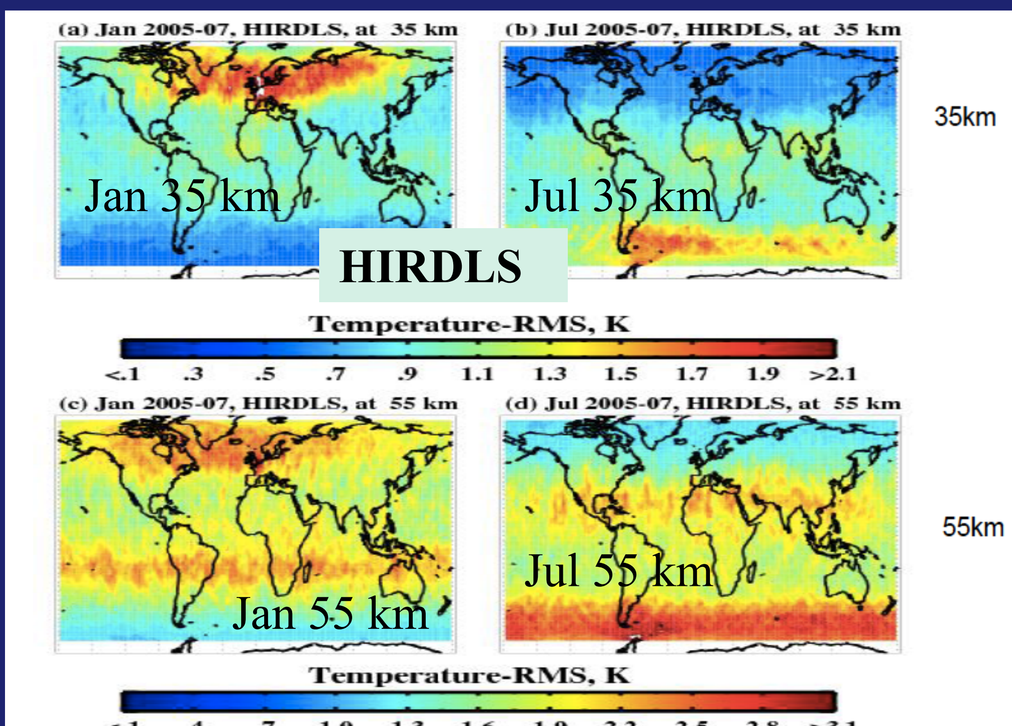


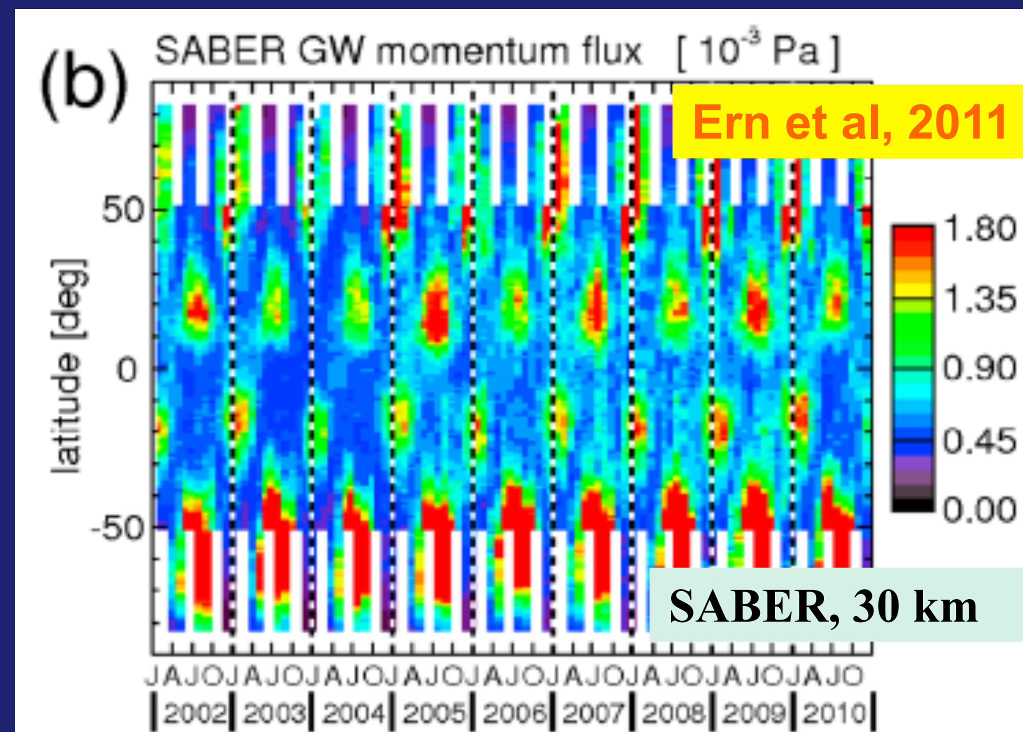


7. Polar stereo projections of E_p at 30 km

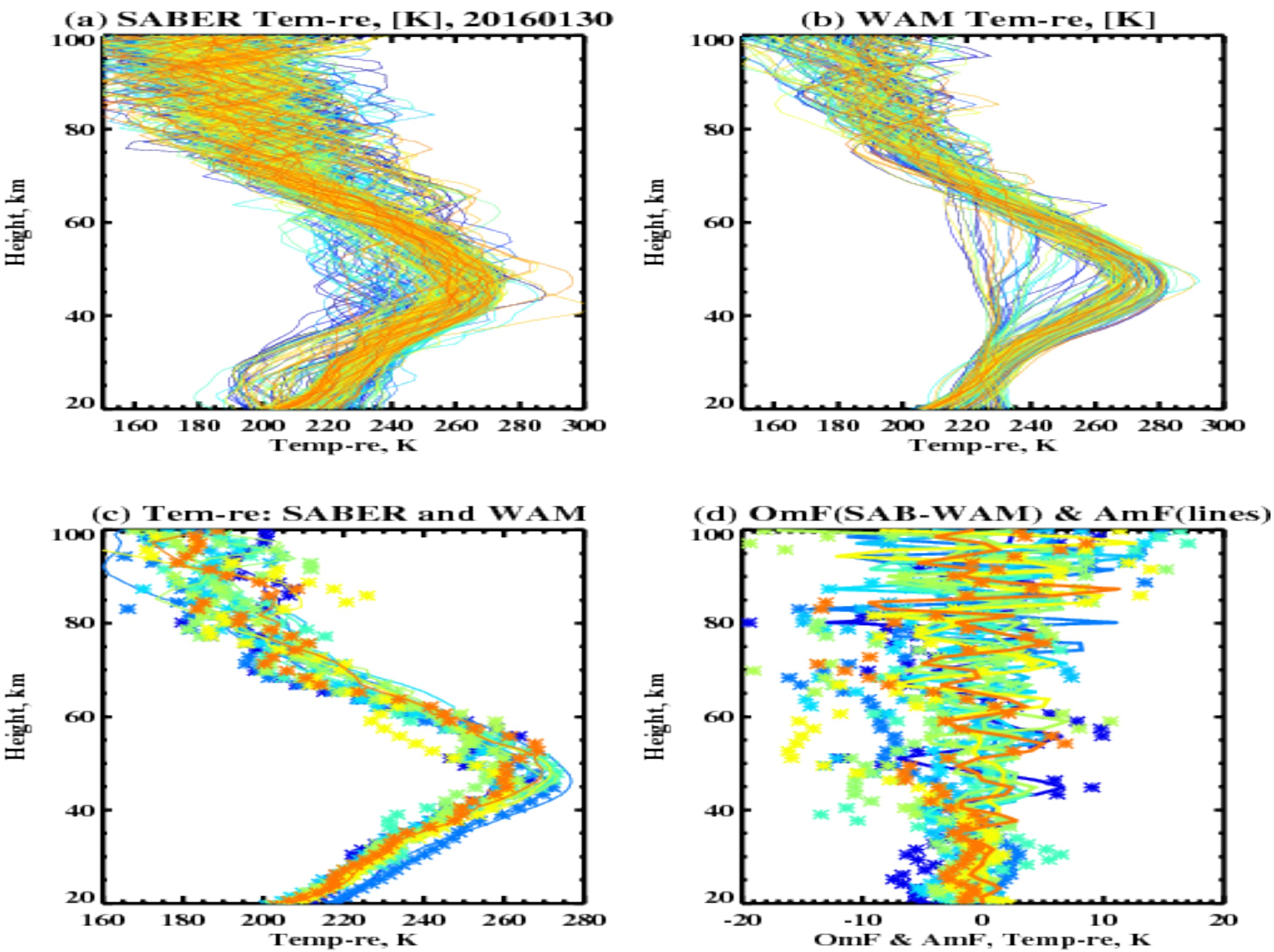


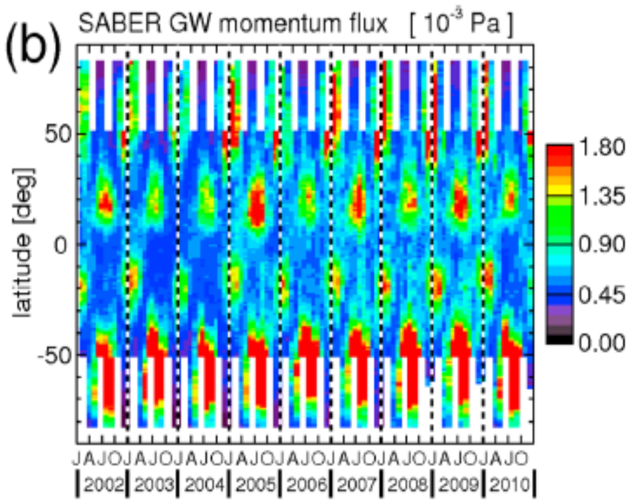
. Normalised monthly-mean meridional cross-section of E_p in August 2010



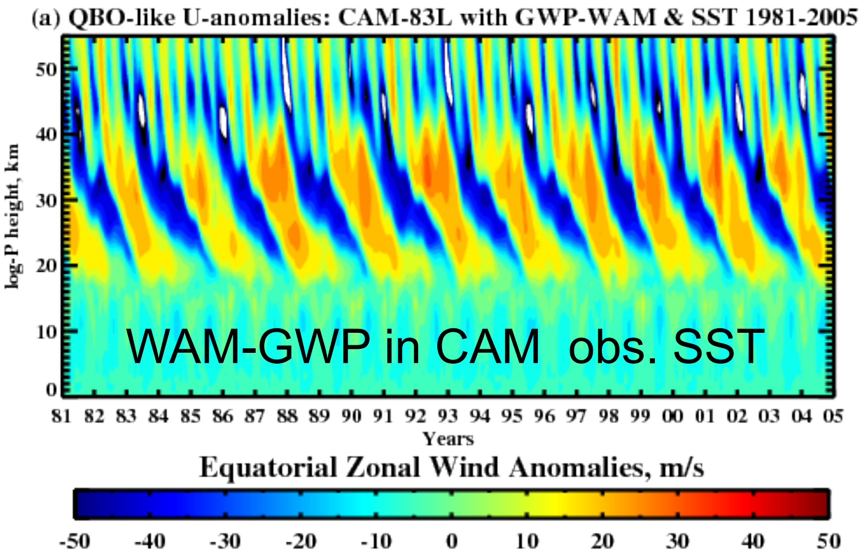


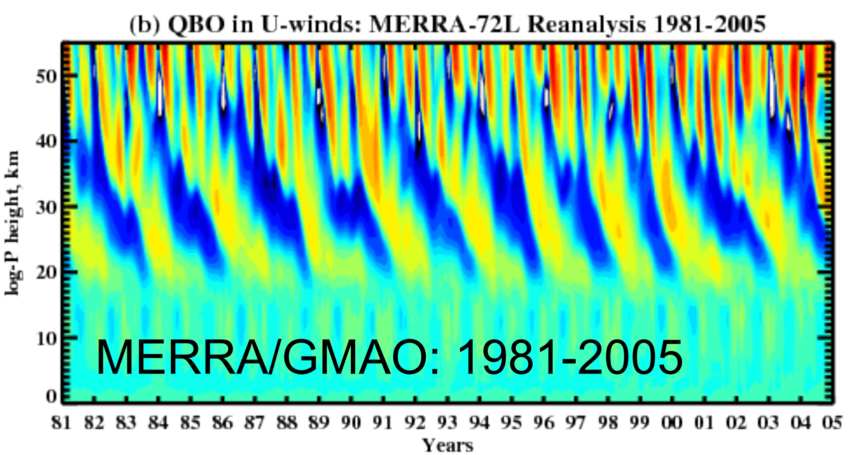
SABER Data Analysis in WAM: GW-activity

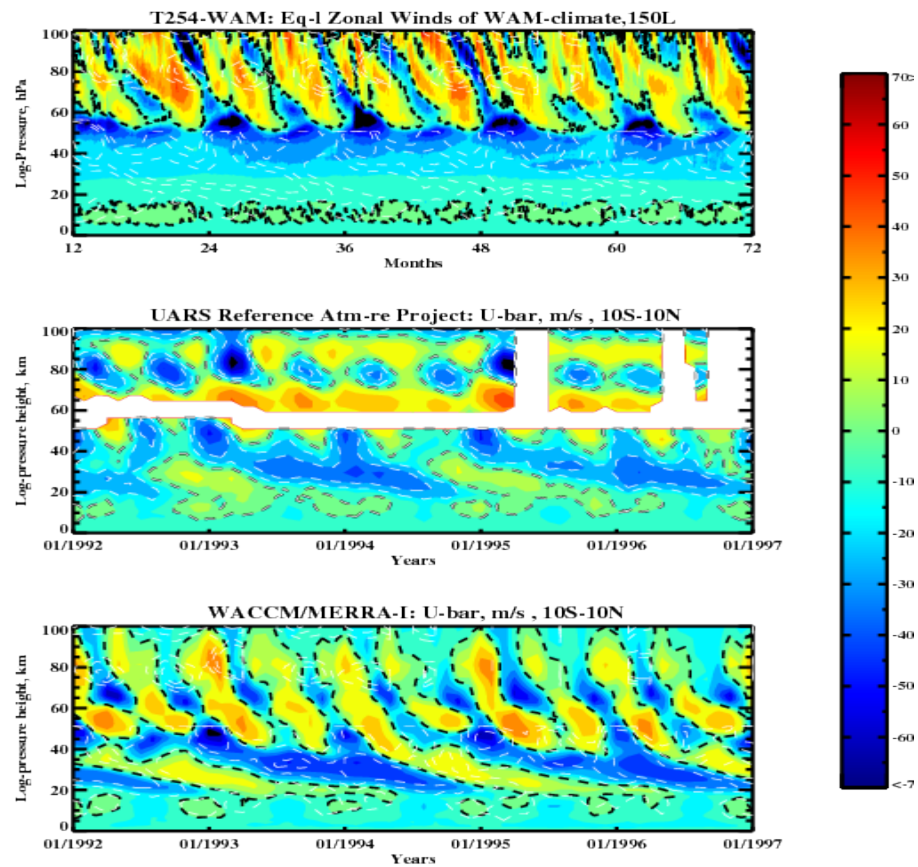


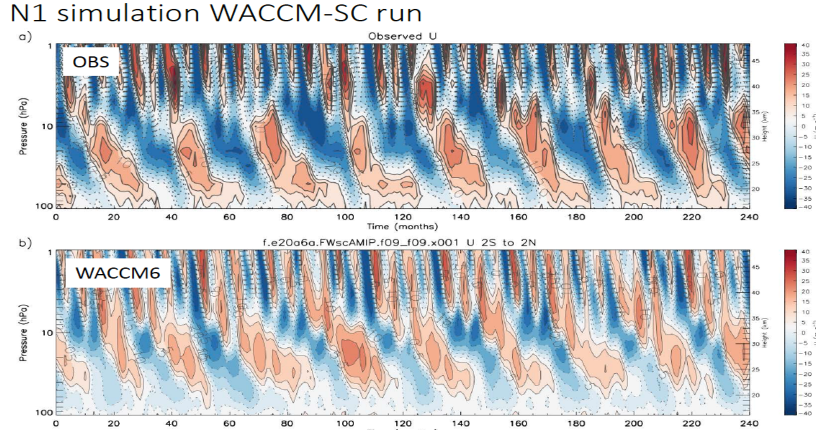


Can we do QBO in NEMS-FV3?



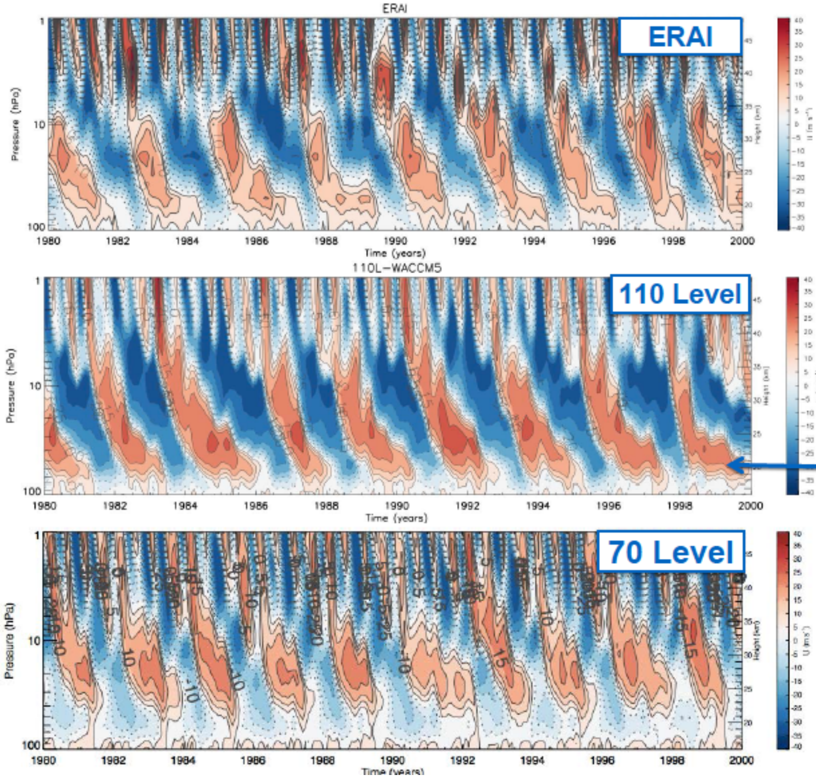






NEMS-WAM GW-physics **in CAM-83L with FV-dycore** "produce" similar tropical wind (QBO-like) oscillations and SAO, compare with recent WACCM6 (01/2017) as presented by Richter et al. (2017)

QBO: 70 vs 110L WACCM



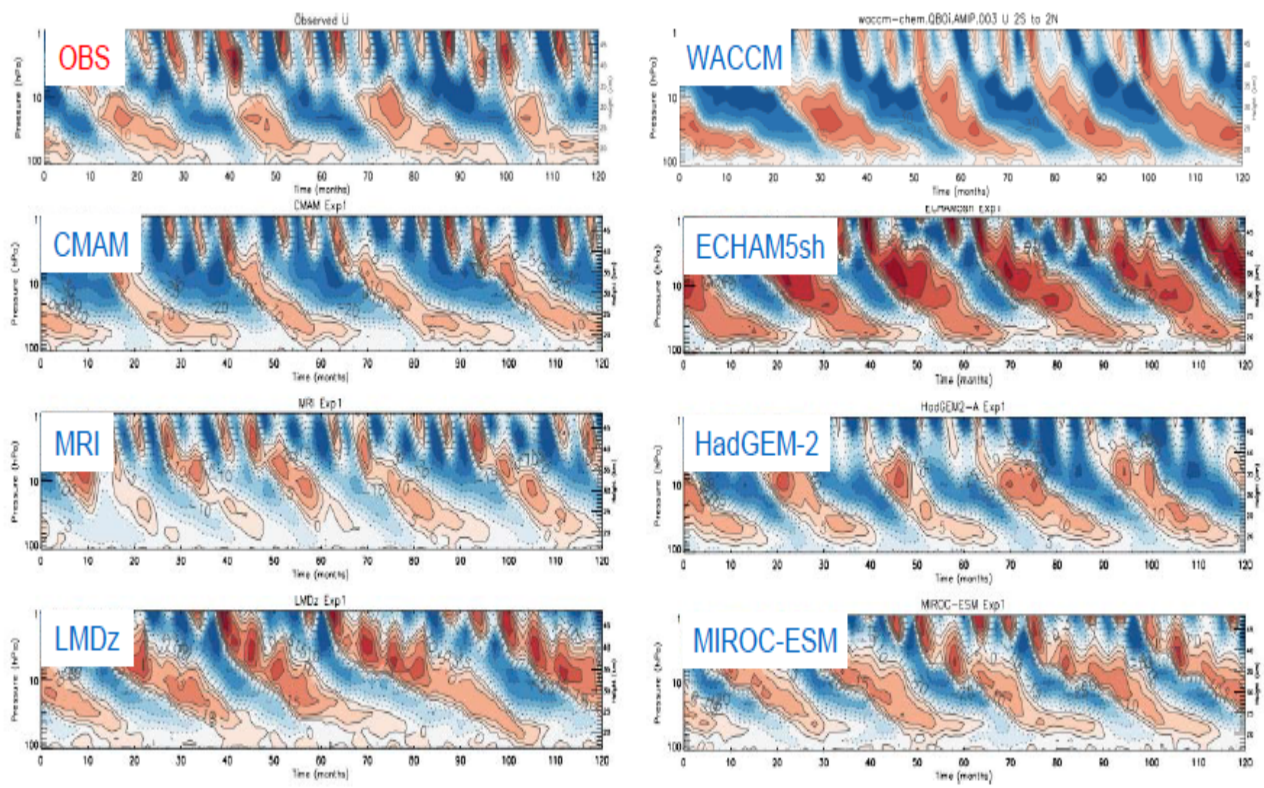
QBO-sensitivity to the Vertical Resolution in WACCM (Richter et al., 2017)

QBO descends to 100 hPa as observed (tropical Kelvin and RG waves are well resolved in the 110L model)

NEMS-FV3 priority in 2017

with UGW physics package

generate QBO-like oscillations



QBO in climate models:
CMAM, WACCM, MRI,
ECHAM, HadGEM, LMDz,
MRI, MIROC
1979-2009 SST
(Fixed+Interactive GW sources)

Towards NEMS/FV3: WAM and FV3-TL90km

Balanced Initialization Technique –BIT

Replace "nudging" algorithms onto the IAU-type drivers by Analysis Tendencies in Model Physics (U, V, T, Ps…) in the GDAS-domain (~surface-35-40 km) and ..

Give opportunity to the model forecast accept during (3-6 days) "analysis state" by the selected "Initial Day"

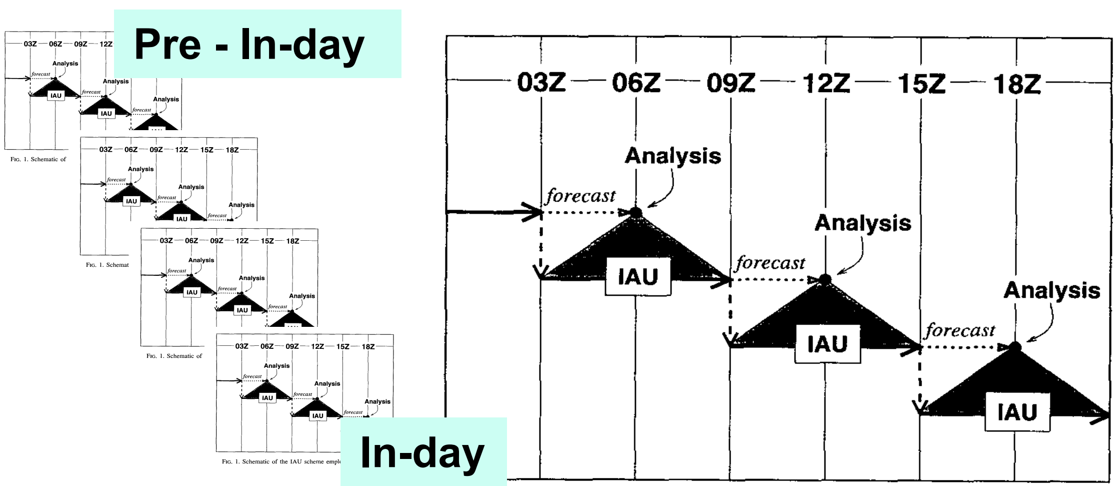
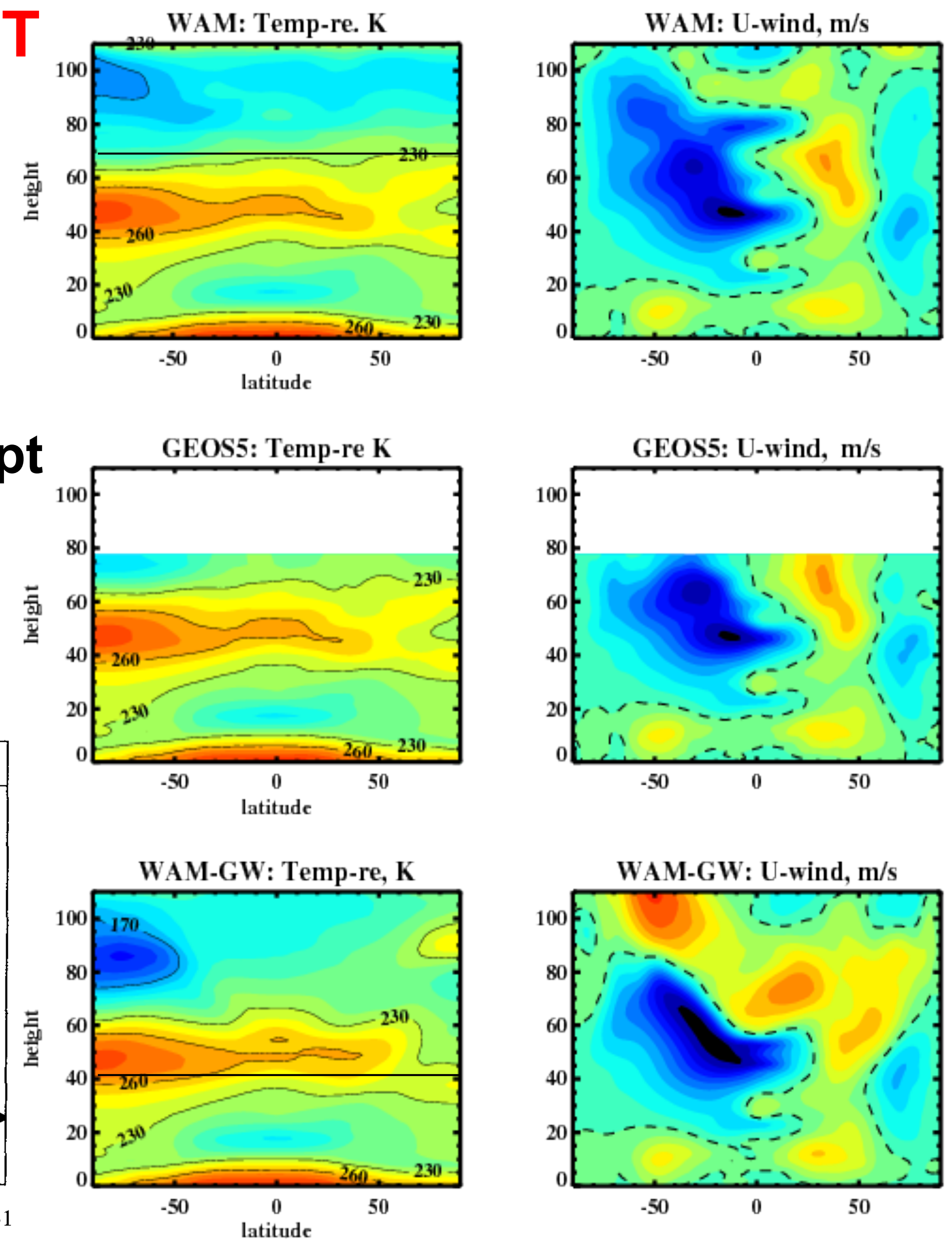


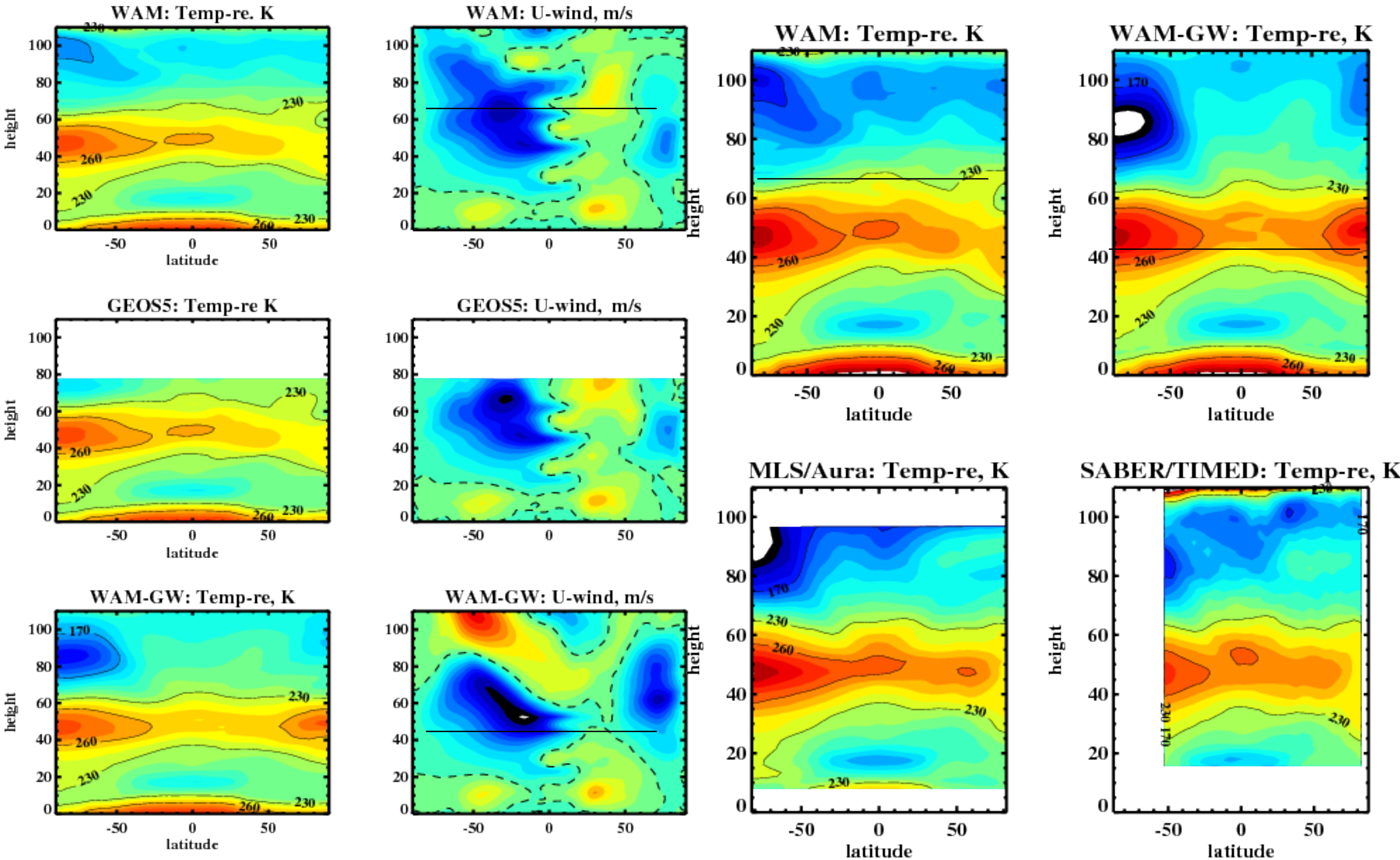
FIG. 1. Schematic of the IAU scheme employed in the GEOS-1

Incremental Analysis Update – IAU, Bloom et al.1996

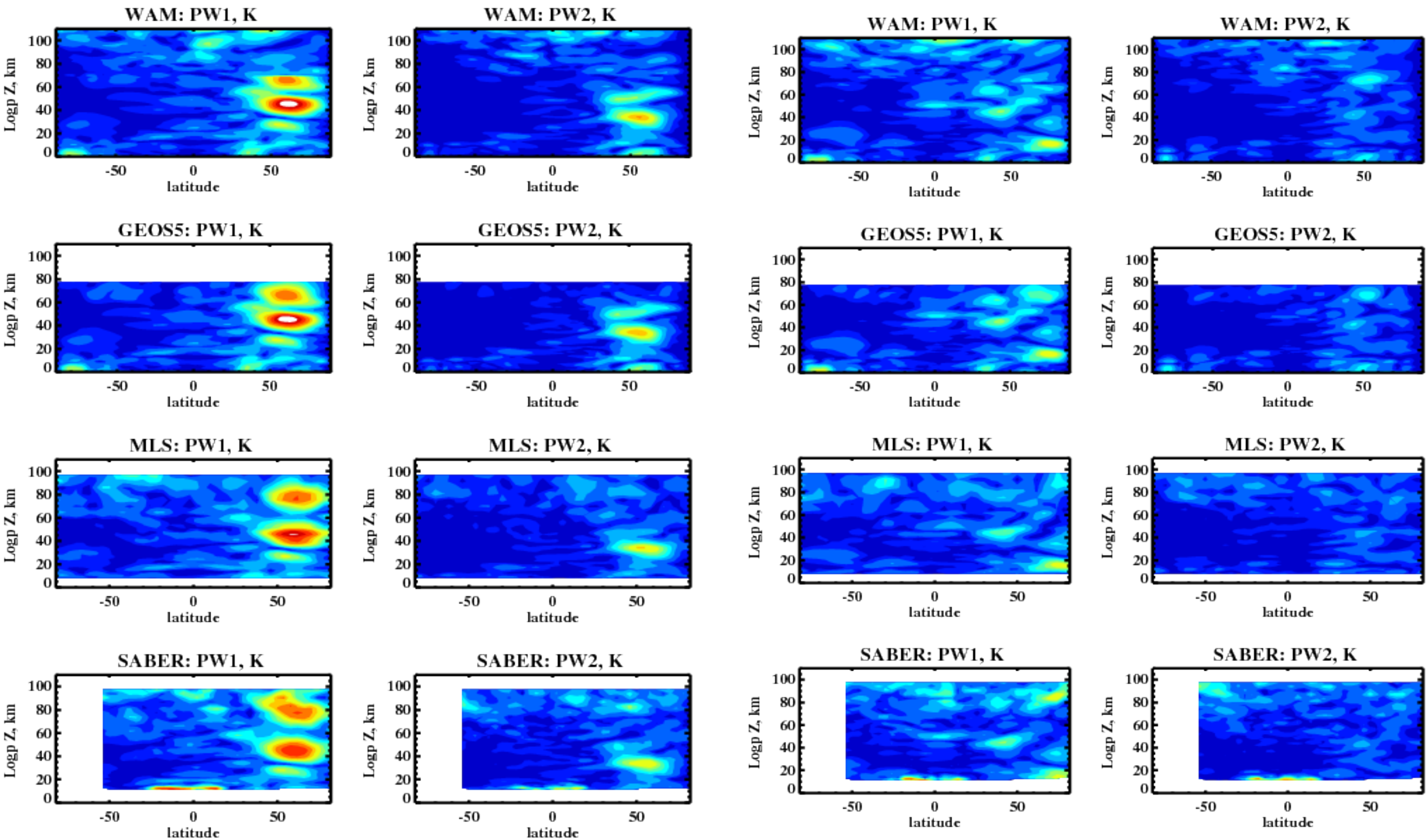


WAM with AT of GEOS-5, 2013/01/28

BIT in WAM with GEOS-5, Jan 2013 (SSW, ZM-state)



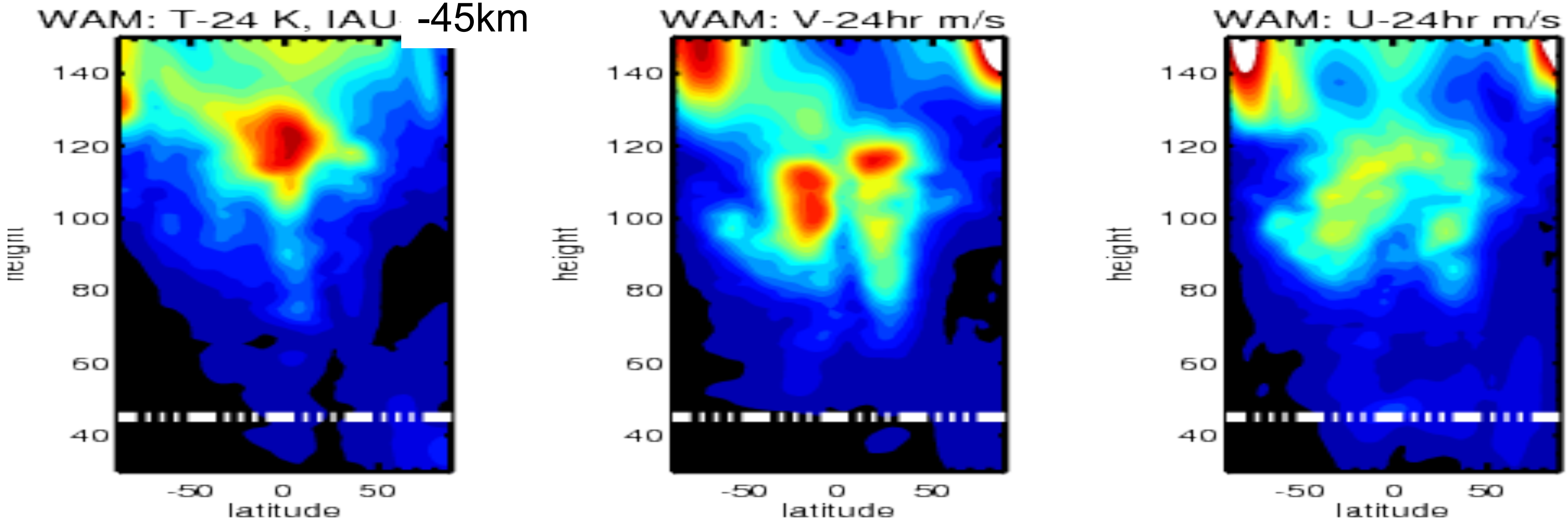
BIT in WAM with GEOS-5, Jan 2013 (SSW, Pl-Waves)



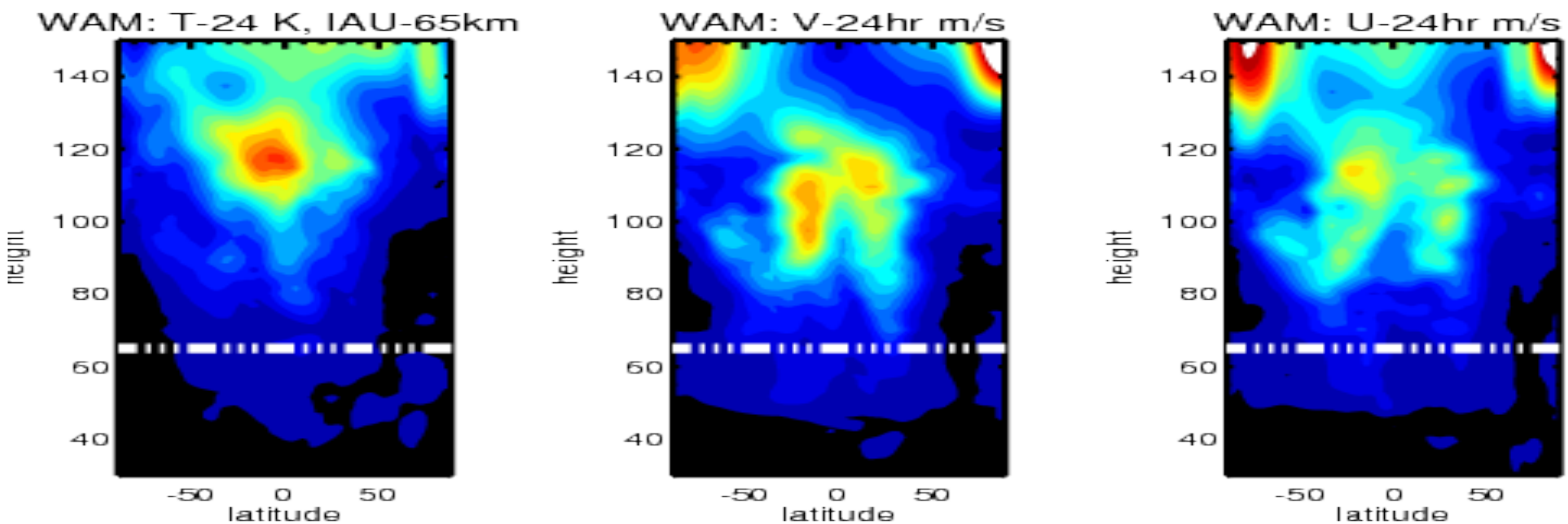
During Warming Onset

After Onset of SSW

BIT + IAU in WAM with GEOS-5, Jan 2013 (SSW, Tides)



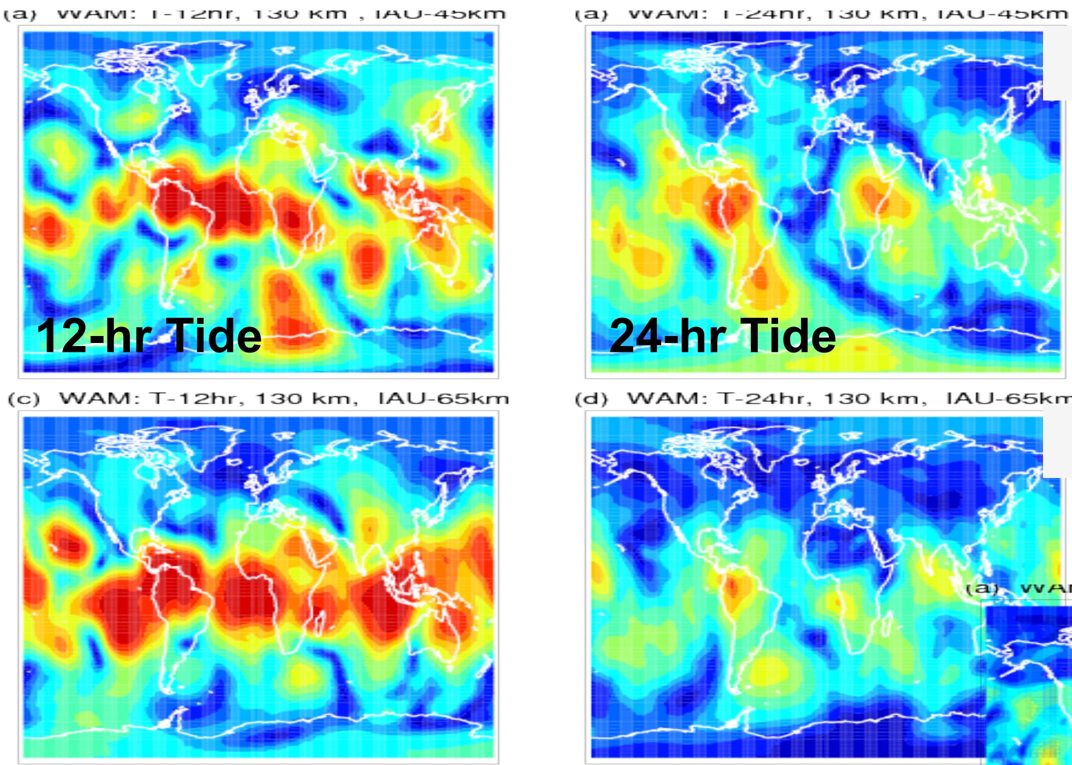
Tides originated at ~45-55 km by diurnal variations of heating, not properly resolved   by “AT”



WAM with GEOS-5(BIT-IAU) : TIDES during SSW-2013

IAU-45 km

IAU-65 km

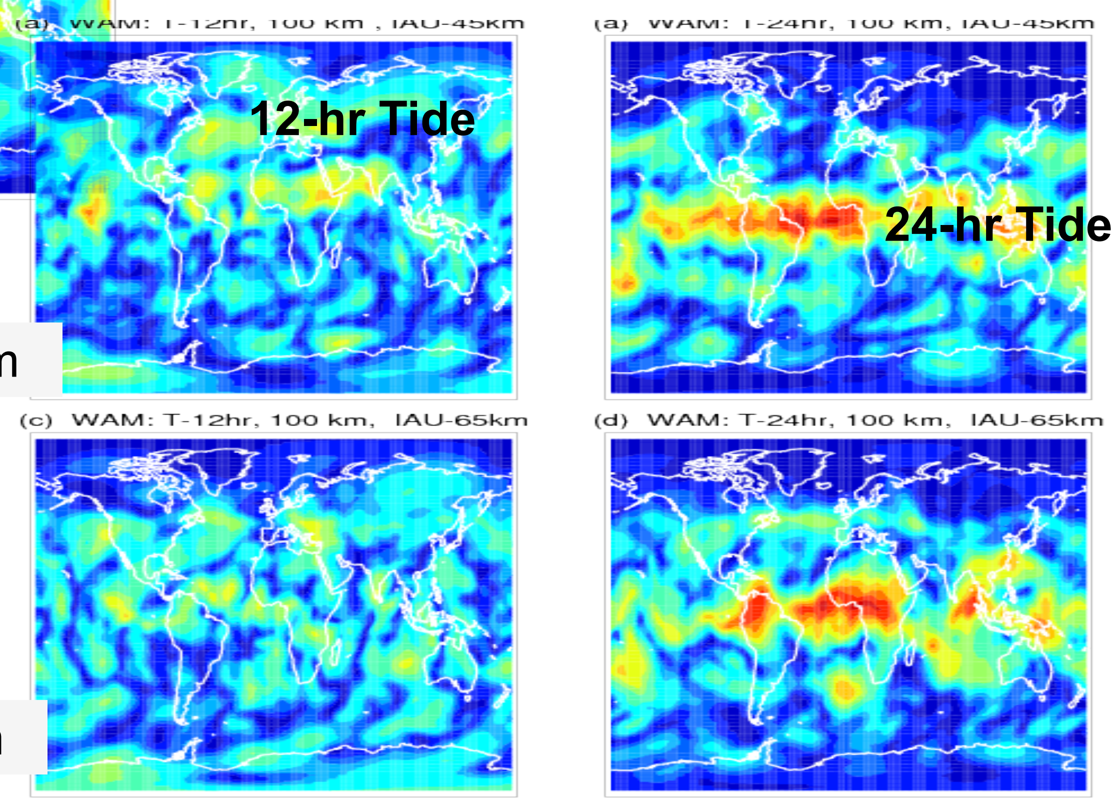


2013/01/18, **130 km**

2013/01/18, **100 km**

IAU-45 km

IAU-65 km



Towards NEMS/FV3: FV3-TL80km and WAM

Selection of Vertical Grid and Top for Operations and Reanalysis with FV3:

TL-80 km: IFS, GEOS-5 and… centers
-100km: NAVGEM-ext, CMAM
-120-140: WACCM

Vertical spacing ~0.5 km :
QBO & SAO (Eq-PWs)

Horizontal Regrid: Conserv. Remapping

Initialization: BIT-IAU type

Metrics: (1) Seasonal cycles
(2) QBO/SAO
(3) MLR-reversal
(4) SSW and Final Warming

WAM – Metrics

1. **Thermodynamics (c_pT, PT & gravity)**
2. **Tidal SAO/QBO for 24-hr in the MLT**
3. **12-hr growth during SSW**
4. **MLT- Zonal wind reversal**
5. **Mesopause Temp-re and Composition**

Summary and what will be next in 2017-18 and… beyond

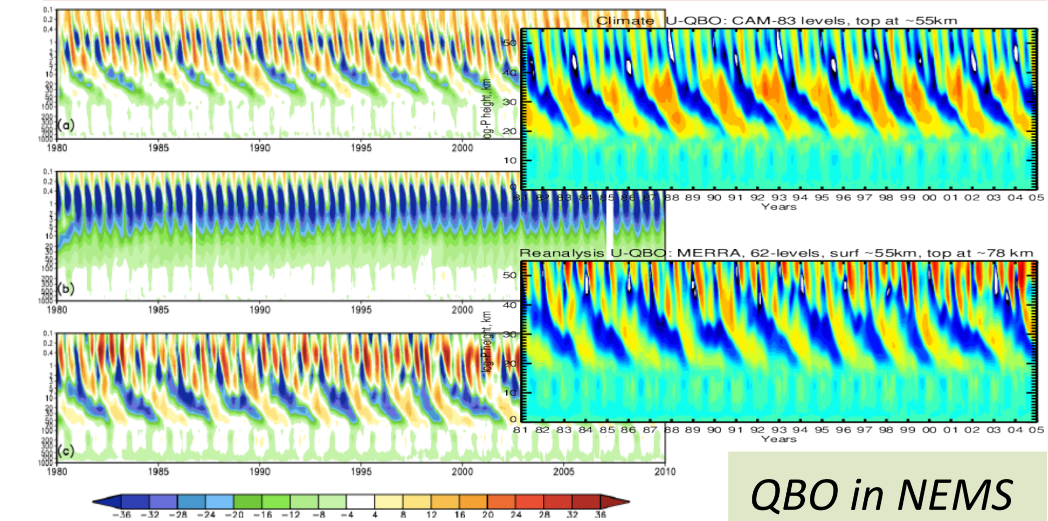
The unified GW physics package (*momentum/drag, energy/heat, and mixing*) for OGW and NGW **was tested**. Its implementations in **GFS/GSM-91L show better skills in the service windows 6-10 days and 2-4 weeks in the stratosphere**. As expected, VE models may improve predictions of SSW, NAO and AO.

For "dissipative" atmosphere four GW solvers are now adapted and we continue their testing in WAM. **WAM-GW simulations display improved dyn-cs > 40 km: *MF, PWs and Tides.***

Next, select "primary" NGW scheme for NEMS/FV3-?L, test it Oct/Nov 2017 along with NEMS/WAM-FV3.

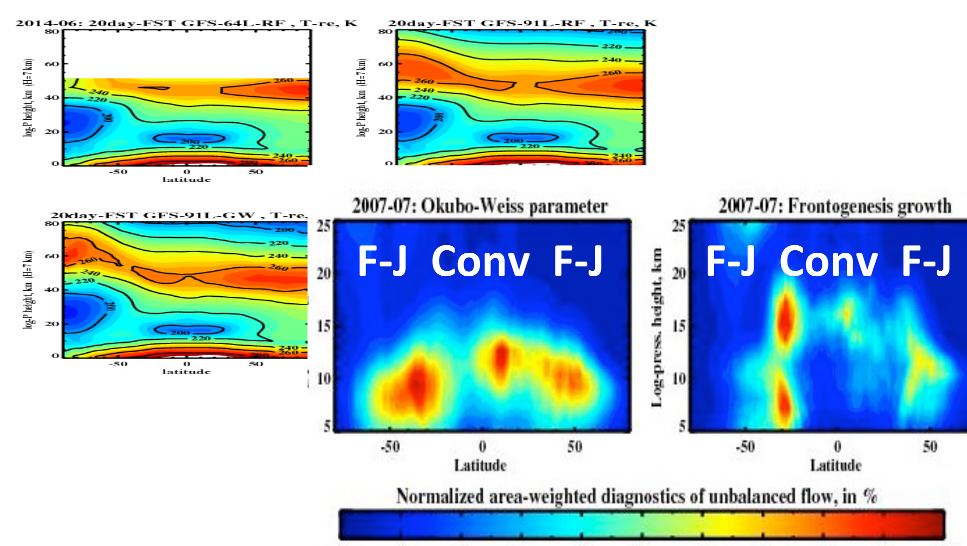
Data Analysis of SABER & MLS data in WAM and extended GFS (model errors).

Long-Term plans for NGGPS GW physics in FV3



Spatial average of zonal wind in m s^{-1} from 10° S to 10° N latitude as a function of pressure level in millibars ;

Stochastic GW physics and wave triggers: role in the ensemble spread & bias corrections in the upper layers for temperature and winds.



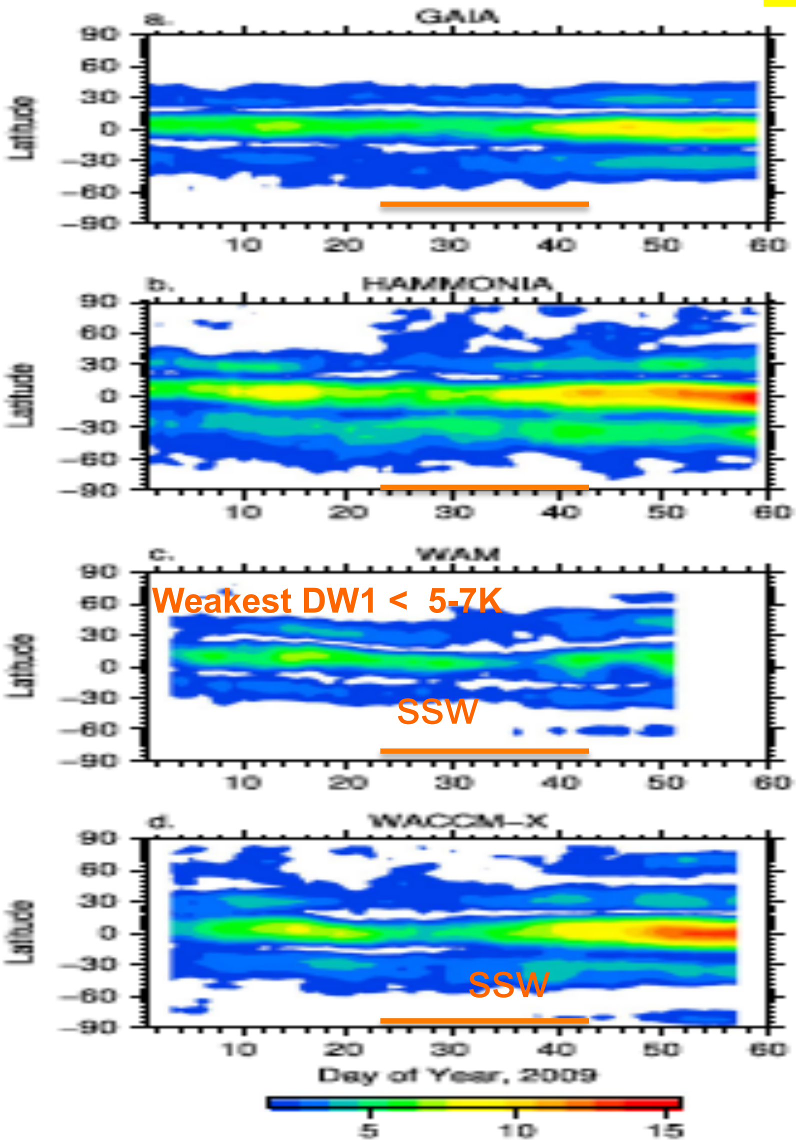
Extra Slides: Tidal Metrics for WAM

The “Multi-model” Spread in D-2-D Tidal Temp-res

DW1, T-amplitudes, 80 km

Jan-Feb of 2009

SW2, T-amplitudes, at 110 km



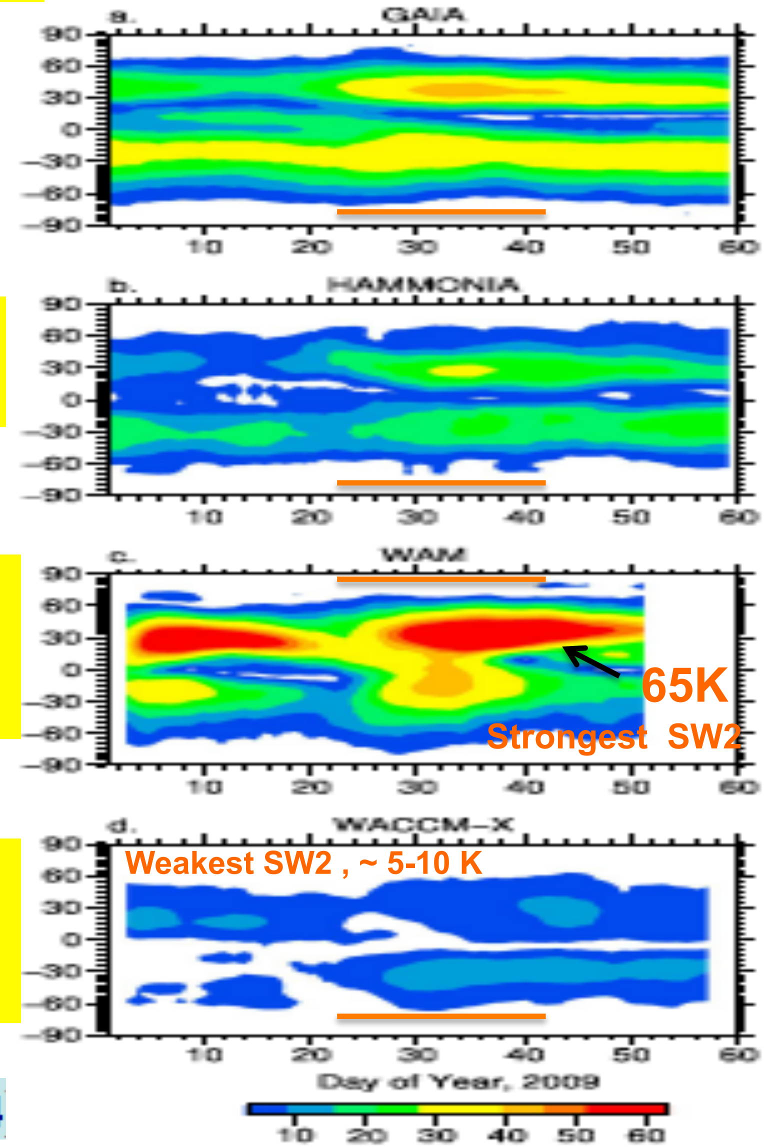
GAIA/ JRA-25, 1/R = 24 hr

HAMMONIA with ERA-Interim

WAM with NCEP-DA of LA data, 6-hr A-F cycles

WACCM-X with NOGAPS-ALPHA 1/R ~ 12 hr

Pedatella et al., 2014

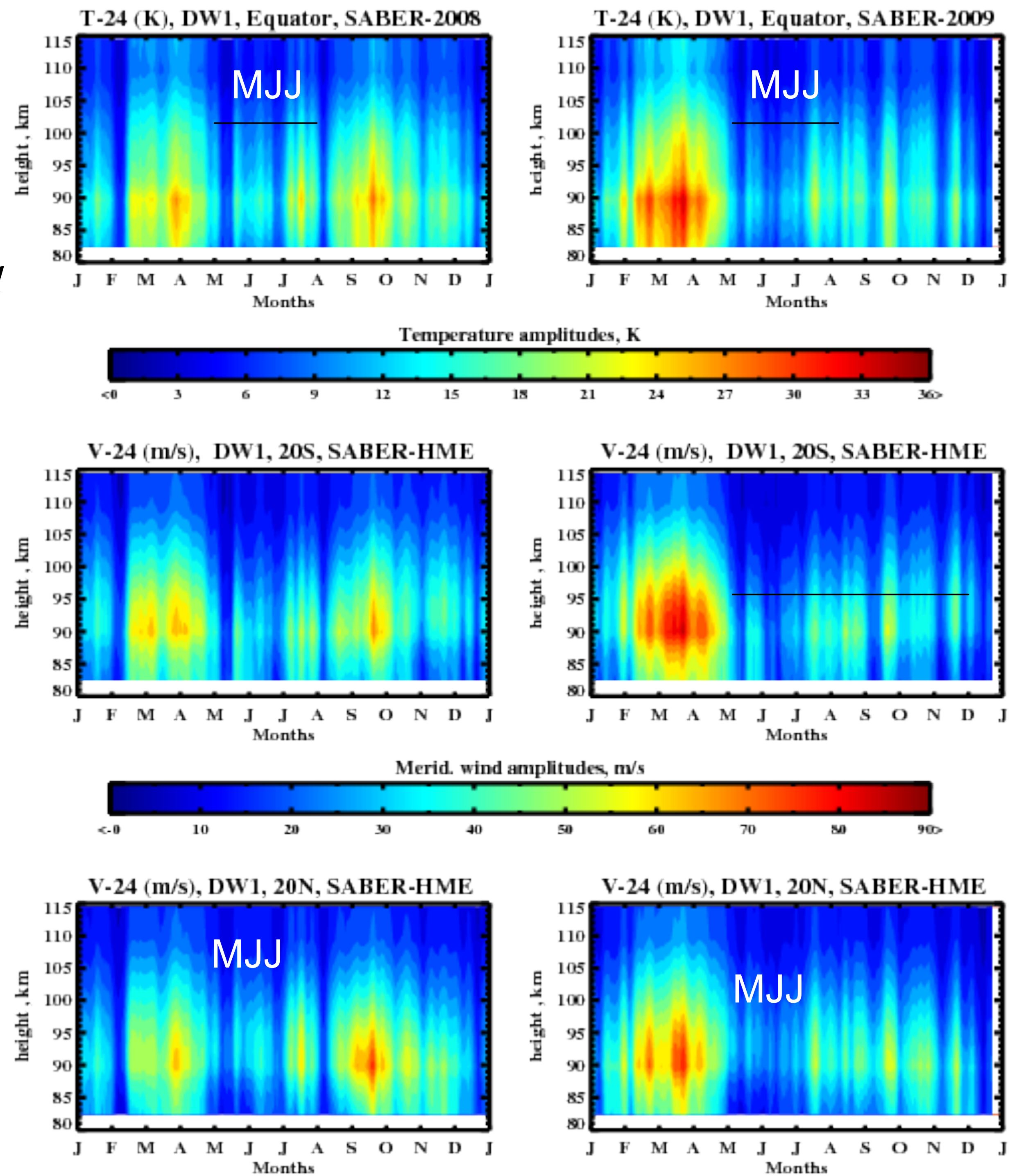


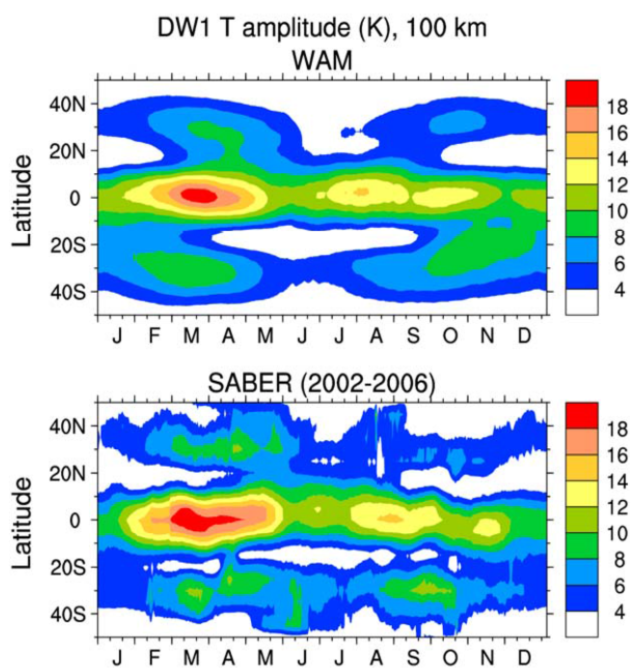
Nudging to Reanalysis = “Simplified” Data Assimilation with selected “Relaxation” to 6-hr separated meteorological data, available at each model cell in nudging domain

SABER day-to-day tidal derivations based on the Dave Ortland [2014] spatial maps (fixed LST) and HME techniques (both T-re & Wind waves) versus ***60-day LSF of Forbes et al.(2008)***

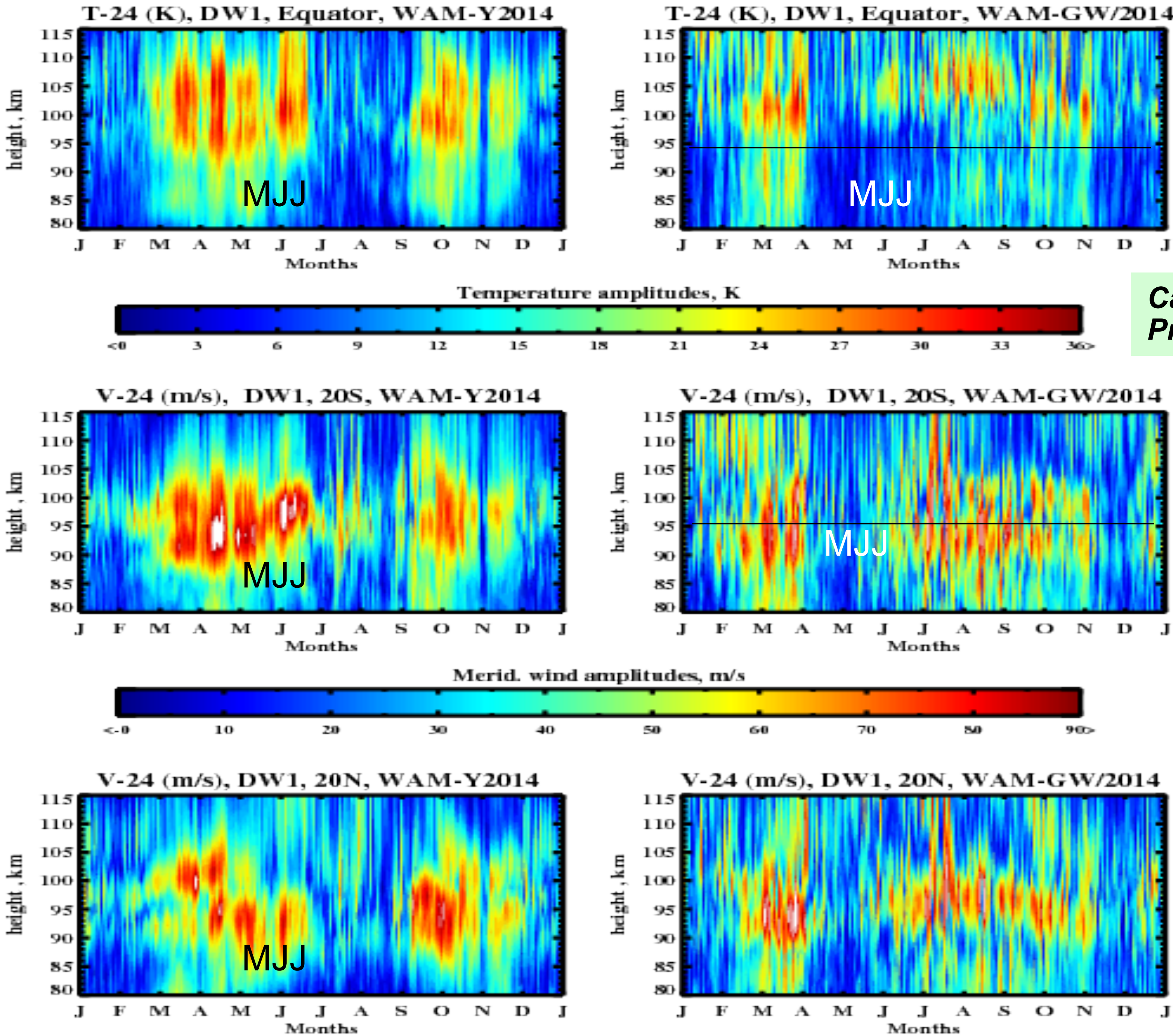
Both techniques reproduce SAO in DW1 (March-Oct) and QBO-DW1 (westerly DW1 ~ 2. easterly DW1 in Mar-Apr, as discussed above).

2008 QBO E-ly Year | **2008 QBO W-ly Year**





Diurnal migrating temperature amplitude near 100 km as a function of



T-eq DW1, [K]

~ 7km higher than SABER estimates

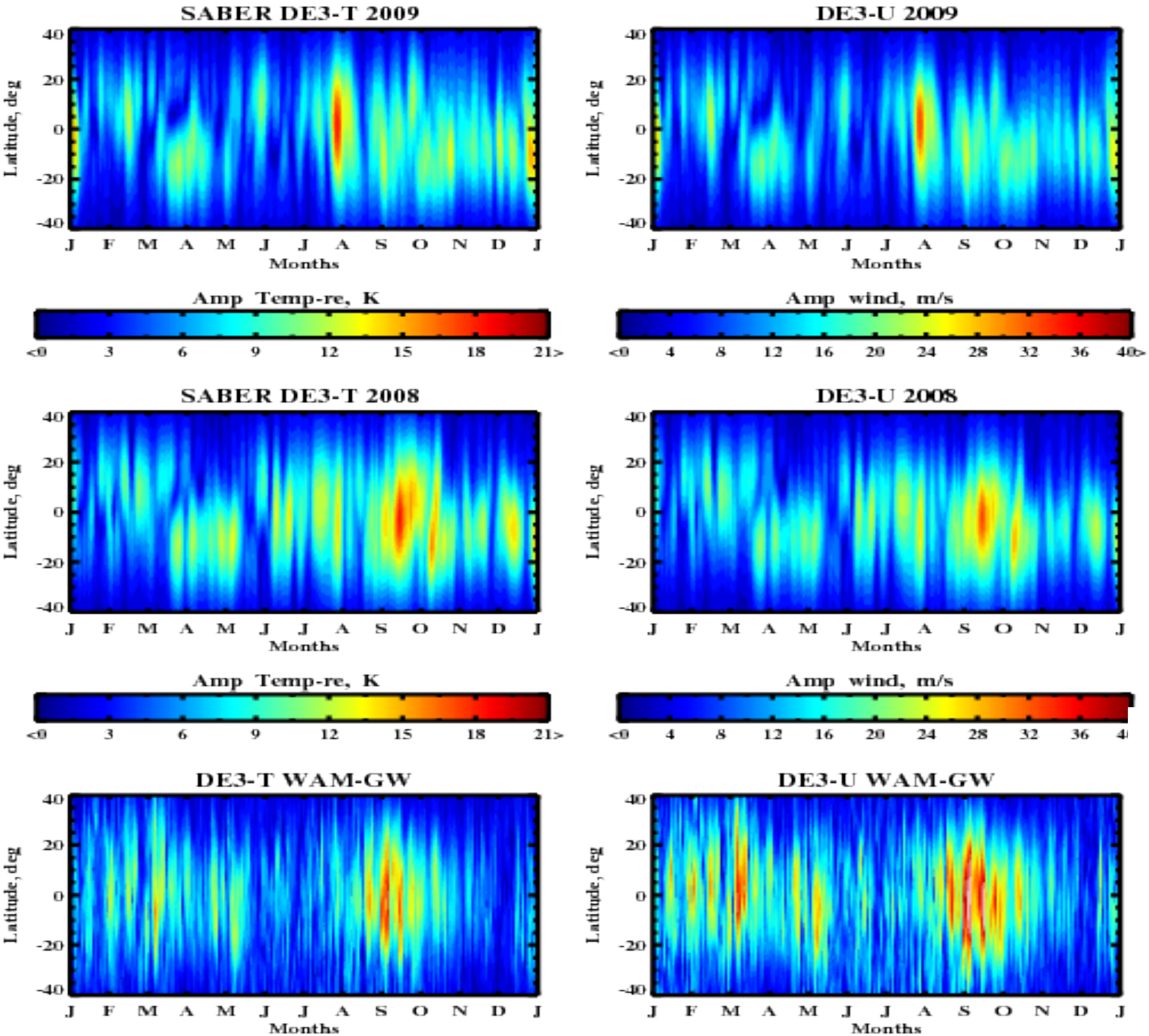
Can be fixed by eddy Pr-number ?

V-20S, m/s

~ 2 km higher than SABER estimates

V-20N, m/s

~ 2 km higher than SABER estimates



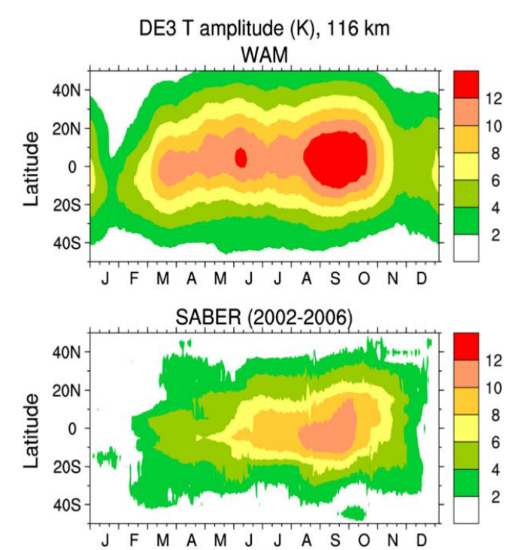
DE3 , Temp, K

DE3 , U-wind, m/s

Y-2-Y & D-2_D variability of DE3- amplitudes at 116 km

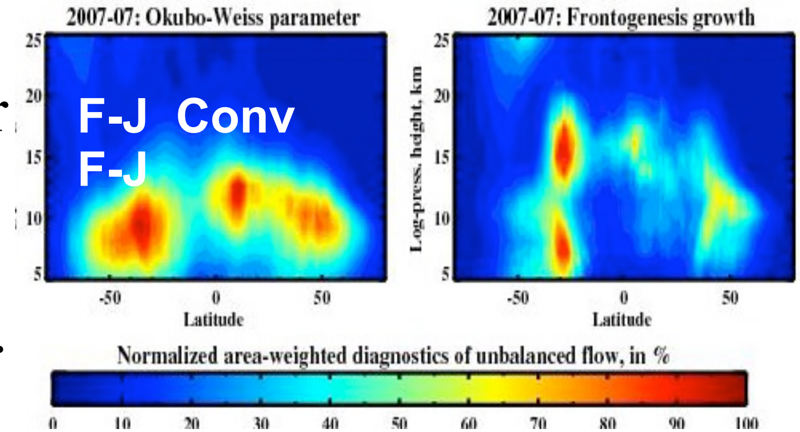
Needs for DA is apparent, mode structure depends on
(1) convective latent heat diurnal variations (source)
(2) Tropical winds

WAM-DE3 is more close to DE3-2008

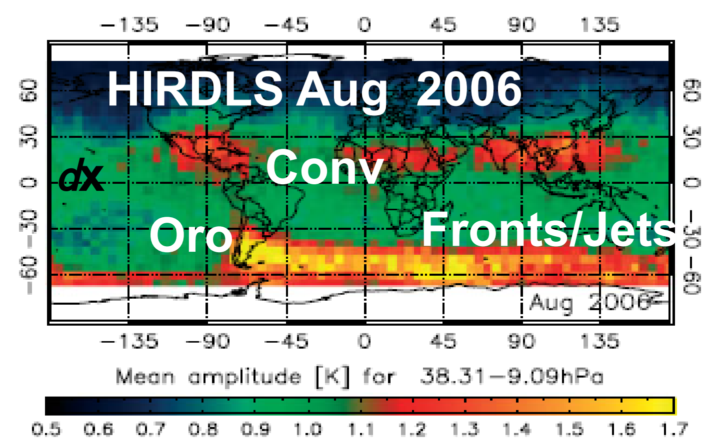


Key future elements of Unified GW physics in the extended atmosphere NOAA models: GFS/GSM-91L and WAM-150L

1. ***GW Sources:*** Stochastic and physics-based mechanisms for GW-excitations in the lower atmosphere, calibrated by the high-res runs analyses, and observations (***3 types of GW sources: orography, convection, fronts/jets***).



2. ***GW Propagation:*** Unified solver for "propagation, dissipation and breaking" of waves excited from all type of GW sources.
3. ***GW Effects:*** Unified representation GW impacts on the 'resolved-scale' flow for all types of GWs (energy-balanced parameterizations of momentum, heat, depositions and eddy mixing).
4. ***Resolution-awareness of sub-grid GW schemes*** in all aspects of wave physics (sources, propagation, dissipation, effects on the resolved-scale flow).



GW Momentum Flux:

$F_{uw} = \langle U'W' \rangle = -L_z \langle U'^2 \rangle / L_x$

$L_x \sim (1\text{-}3)\, dx$

dx – typical size of the H-grid

$F_{uw} \sim 1/dx$, $F_{uw}(T62) < F_{uw}(T670)$

But… $\langle U'^2(T62) \rangle \ll \langle U'^2(T670) \rangle$