NGGPS PHYSICS ACTIVITIES

Jordan Alpert and Stephen Eckermann
Co-Leads
Gravity Waves and Drag
NGGPS Physics Workshop
November 7-9, 2016
NCWCP

Objectives

Development of vertically extended Configurations for Weather and Climate

Under development for Operational prototypes:
NEMS WAM (L150)
NEMS GSM 13km T1534L91
NEMS GSM 13km T1534L128
NEMS GSM 10km T2046L128

Future:
NEMS FV3 (we should recommend funding for this)

- Realistic representations sub-grid scale eddies through parameterizations to represent stationary and non-stationary orographic and non-orographic gravity wave drag,
- Improved representation of momentum fluxes, momentum budget and phenomena such as the QBO, AO and NAO.

Gravity Waves and Drag

Stationary orographic gravity waves and non-stationary non-orographic gravity waves play major role in upper atmosphere
–Momentum deposition in the stratosphere is important for accurate prediction of the Quasi-Biennial Oscillation in the stratosphere
–Implement unified gravity wave physics into NGGPS (collaboration with NCEP Centers, eg., SWPC and Scientific Community, eg., CIRES, NRL that includes turbulent heating and eddy mixing due to wave dissipation and breaking.

Gravity Waves and Drag
EMC; SWPC; NRL
Improve GFS accuracy with improved parameterizations of large-scale surface drag, non-orographic drag and gravity waves

Discussion of physics testing as part of NGGPS plan

Stress tests

- Computational efficiency
- Wide range of model resolutions (scale-aware)
- Process oriented diagnostics
- Selected test cases
- Large-scale tests covering different seasons
- Fully cycled tests
- Decision gates: what qualifies a parameterization to be considered for R2O?

1. Define relevant test cases.
2. Provide initialization and/or forcing for each case.
3. Create benchmarks using operational codes.
4. Compare candidate model runs with benchmarks and observations

And Single Column Model

Integrating Unified Gravity Wave Physics into the Next Generation Global Prediction System

Summary of the 1-year results

GW physics in NEMS-WAM improved zonal mean flows, planetary waves and tides.

GW physics in GFS-91L to bring a realism in the stratospheric dynamics during winters and winter-to-spring transitions comparing to the Rayleigh Friction simulations.

Transition to NOAA operations, climate tests, and future plans

a)Analysis-Forecast Cycling with GFS-91L (~80 km top) with “parallel” operational scripts;

b) NEMS-WAM multi-year climate runs for equatorial oscillations (QBO and SAO).

c) New related projects: Assimilation of middle atmosphere O3, H2O and T-re profiles (MLS & SABER) to properly initialize NGGPS forecasts.

Correction of model bias from sub-grid scale parameterization is an on-going process.

Atmospheric flow is significantly influenced
by orography, creating lift and frictional forces.

The representation of orography and its influence in numerical weather prediction models are necessarily divided into resolvable scales of motion and treated by primitive equations, the remaining sub-grid scales to be treated by parameterization.

Orographic Gravity wave Drag, 1987 (Alpert), 1997 (Alpert & Kim)
Mountain Blocking, 2004 (Alpert)
Upgrade including Vertical Diffusion, 2005 (Alpert, Kistler and EMC)
Convective Gravity Wave Drag, 2014 (Johansson)
Elevation Moments (Collins, Hong, Alpert)

Historically at NCEP

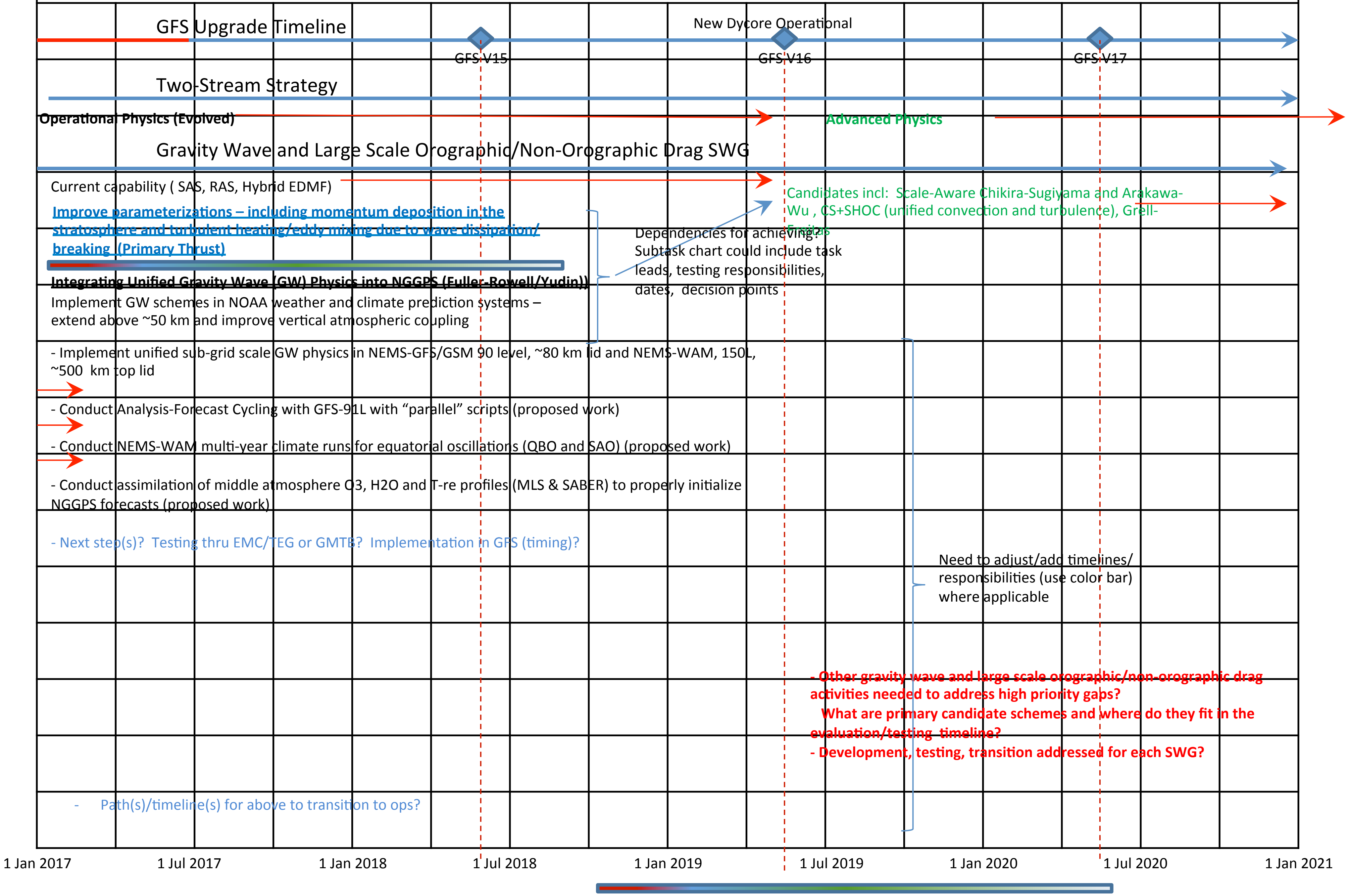
- An augmentation to the gravity wave drag scheme in the NCEP global forecast system (GFS), following the work of Alpert et al., (1988, 1996) and Kim and Arakawa (1995), Mountain Blocking is incorporated from the Lott and Miller (1997) scheme with minor changes and including the dividing streamline.
- Mountain blocking of wind flow around sub-grid scale orography is a process that retards motion at various model vertical levels near or in the boundary layer. See…
- http://www.emc.ncep.noaa.gov/gmb/wd23ja/presentations/nemsgfs_ja_gwd.ppt

… at NCEP

- An augmentation to the gravity wave drag scheme in the NCEP global forecast system (GFS), following the work of Alpert et al., (1988, 1996) and Kim and Arakawa (1995), Mountain Blocking is incorporated from the Lott and Miller (1997) scheme with minor changes and including the dividing streamline.

NGGPS Physics Team Plan

Gravity Wave and Large Scale Orographic/Non-Orographic Drag SWG



GFS Upgrade Timeline

New Dycore Operational

Two-Stream Strategy

Operational Physics (Evolved)

Advanced Physics

Gravity Wave and Large Scale Orographic/Non-Orographic Drag SWG

Current capability (SAS, RAS, Hybrid EDMF)

Candidates incl: Scale-Aware Chikira-Sugiyama and Arakawa-Wu , CS+SHOC (unified convection and turbulence), Grell-Freitas

Improve parameterizations – including momentum deposition in the stratosphere and turbulent heating/eddy mixing due to wave dissipation/ breaking (Primary Thrust)

Dependencies for achieving?
Subtask chart could include task leads, testing responsibilities, dates, decision points

Integrating Unified Gravity Wave (GW) Physics into NGGPS (Fuller-Rowell/Yudin))

Implement GW schemes in NOAA weather and climate prediction systems – extend above ~50 km and improve vertical atmospheric coupling

- Implement unified sub-grid scale GW physics in NEMS-GFS/GSM 90 level, ~80 km lid and NEMS-WAM, 150L, ~500 km top lid

- Conduct Analysis-Forecast Cycling with GFS-91L with “parallel” scripts (proposed work)

- Conduct NEMS-WAM multi-year climate runs for equatorial oscillations (QBO and SAO) (proposed work)

- Conduct assimilation of middle atmosphere O3, H2O and T-re profiles (MLS & SABER) to properly initialize NGGPS forecasts (proposed work)

- Next step(s)? Testing thru EMC/TEG or GMTB? Implementation in GFS (timing)?

Need to adjust/add timelines/ responsibilities (use color bar) where applicable

- Other gravity wave and large scale orographic/non-orographic drag activities needed to address high priority gaps?
What are primary candidate schemes and where do they fit in the evaluation/testing timeline?
- Development, testing, transition addressed for each SWG?

- Path(s)/timeline(s) for above to transition to ops?

Legend: Red text = unfunded; (add colors to indicate funding source?)

Red = Phys Dev; Blue = DTC; Green = EMC

1

Modeling
Gravity Wave Physics
in the NEMS vertically extended GFS

Jordan Alpert

NGGPS Physics Workshop

November 7-9, 2016

NCWCP

20160802 Project:
NOAA-NWS-NWSPO-2015-2004117

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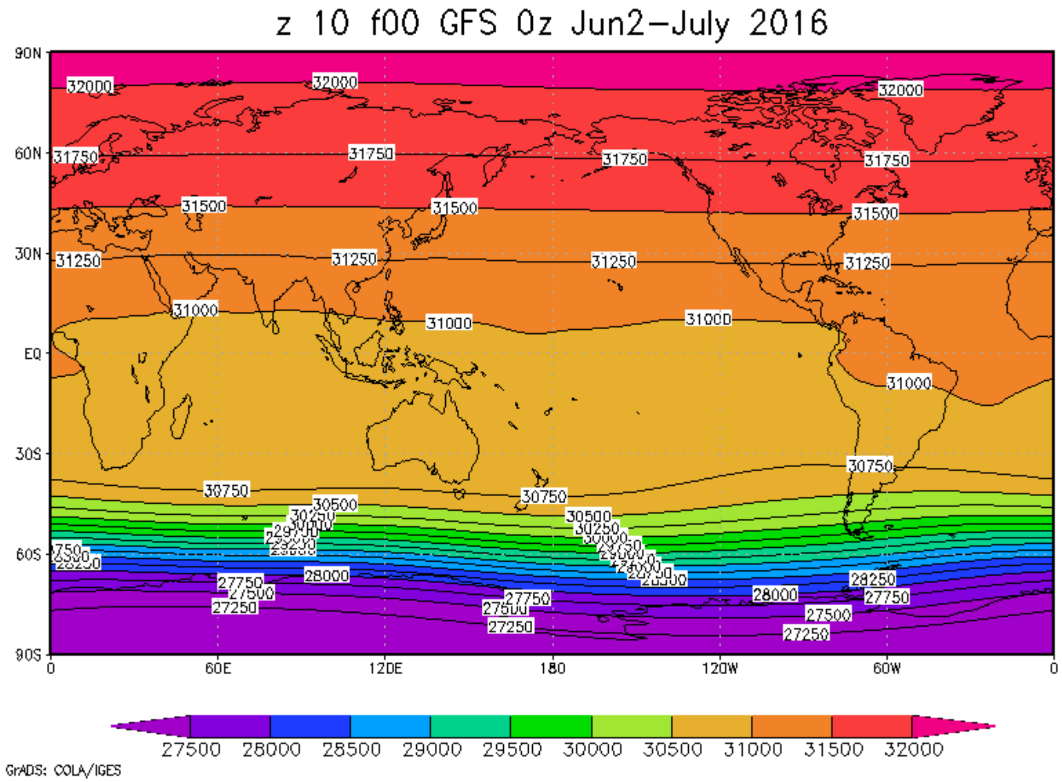
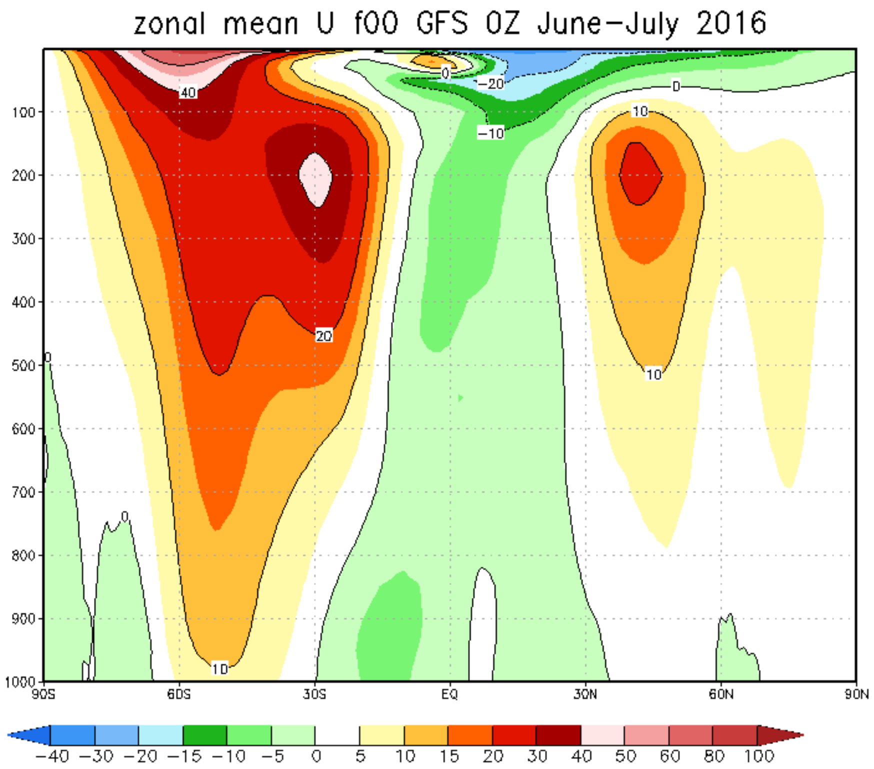
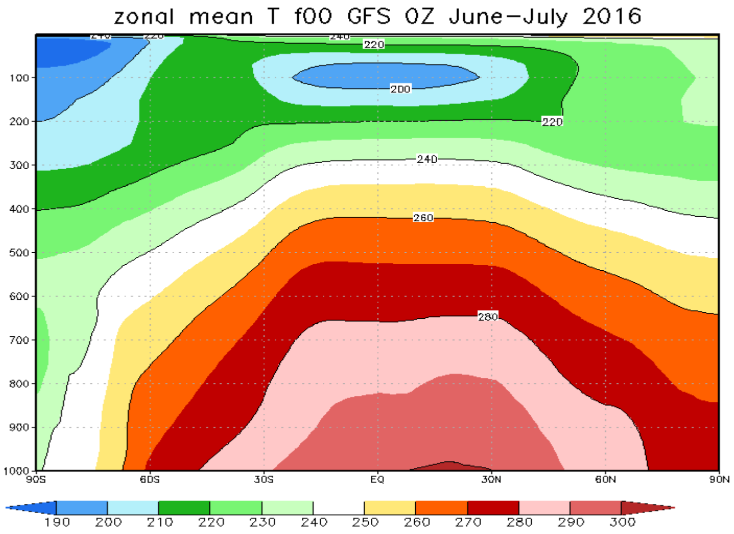




GFS T1534 initial conditions averaged over 2 months (JJ2016), (left) 10 mb Height [m], (right) Zonal mean wind [m/s], and (lower) T (Plots from GW)



The middle atmosphere is dominated by a westerly jet in the winter hemisphere, an easterly jet in the summer hemisphere, and a meridional circulation comprised of upwelling in the tropics and downwelling over the winter pole, referred to as the Brewer–Dobson circulation (Brewer 1949)

Non-orographic gravity waves (nGWD) in the GFS

The middle atmosphere climate is determined by the dominating processes of radiation and wave drag arising from the deposition of momentum from the breaking of small-scale non-orographic gravity waves and large-scale planetary waves.

In the GFS the effect of the nGWD is approximated by Rayleigh friction on the zonal flow.

Underestimation of the poleward circulation between the summer and winter hemispheres and downwelling over the winter pole show that forcing of the mean flow for example, is unrealistically weak if nGWD is neglected.

Weak downwelling is associated with excessively cold winter polar stratospheric temperatures.

GFS Orographic Gravity Wave Drag

Orographic gravity wave drag in its simplest form is for inviscid, linearized, non-rotating flow with the Boussinesq and hydrostatic approximations.

Additional physical processes include the effect of orography anisotropy, vertical wind shear, trapped lee waves, rotation and nonlinearity, frictional and boundary layer effects.

GFS also has a convective GWD based on the work of Chun and Baik 1998, JAS, and Johannson (2008).

Unified Gravity Wave Physics

- **Name and Organization:**

  Tim Fuller-Rowell and Valery Yudin (University of Colorado, CIRES)

  Collaborators: J. Alpert (NCEP/EMC) and R. Akmaev (NWS/SWPC)

- **Project Title:** **Integrating Unified Gravity Wave Physics into the Next Generation Global Prediction System**

- **Objectives:** **Development of the vertically extended configurations of NOAA atmosphere models across the stratopause *with realistic representations of sub-grid scale eddies by unified Gravity Waves (GW) schemes that improve the troposphere-stratosphere coupling, predictors of AO and NAO and propagation of atmospheric tides and planetary waves.***

- **Deliverable(s):** **A unified GW schemes in the vertically extended GFS and future NGGPS global atmosphere model configurations.**

- **Deliverables of Yr-1:** **The GFS-91L with GW physics were delivered to EMC GW group (J. C. Alpert); NEMS/WAM-150L simulations with GWs were used and evaluated by SWPC-WAM researchers (R. Akmaev and T.-W. Fang)**

NWS Operational GFS Model Suite (Compare w/ ECMWF and other models)

- T1534 Semi-Lagrangian (~13 km), 3072x1536 (reduced grid), 64 Layers implemented Jan 15, 2015.
- Time step 450 seconds compared to old operational T574 Eulerian (27 km) 1760x880 (reduced grid) with time step of 200 seconds.
- High resolution through 10 days, 4X/day
- The Computer is an IBM (phase I or II): 35,000 Cores (CPU’s), GFS is required to use <2000/cycle, 4 cycles per day. 8 ½ minutes per model day, or 5% of machine for 5 hours per day with double precision dynamics.
- An Operational 10km, T2046L128 with Gaussian Grid 4096x2048 can be implemented on the CRAY.

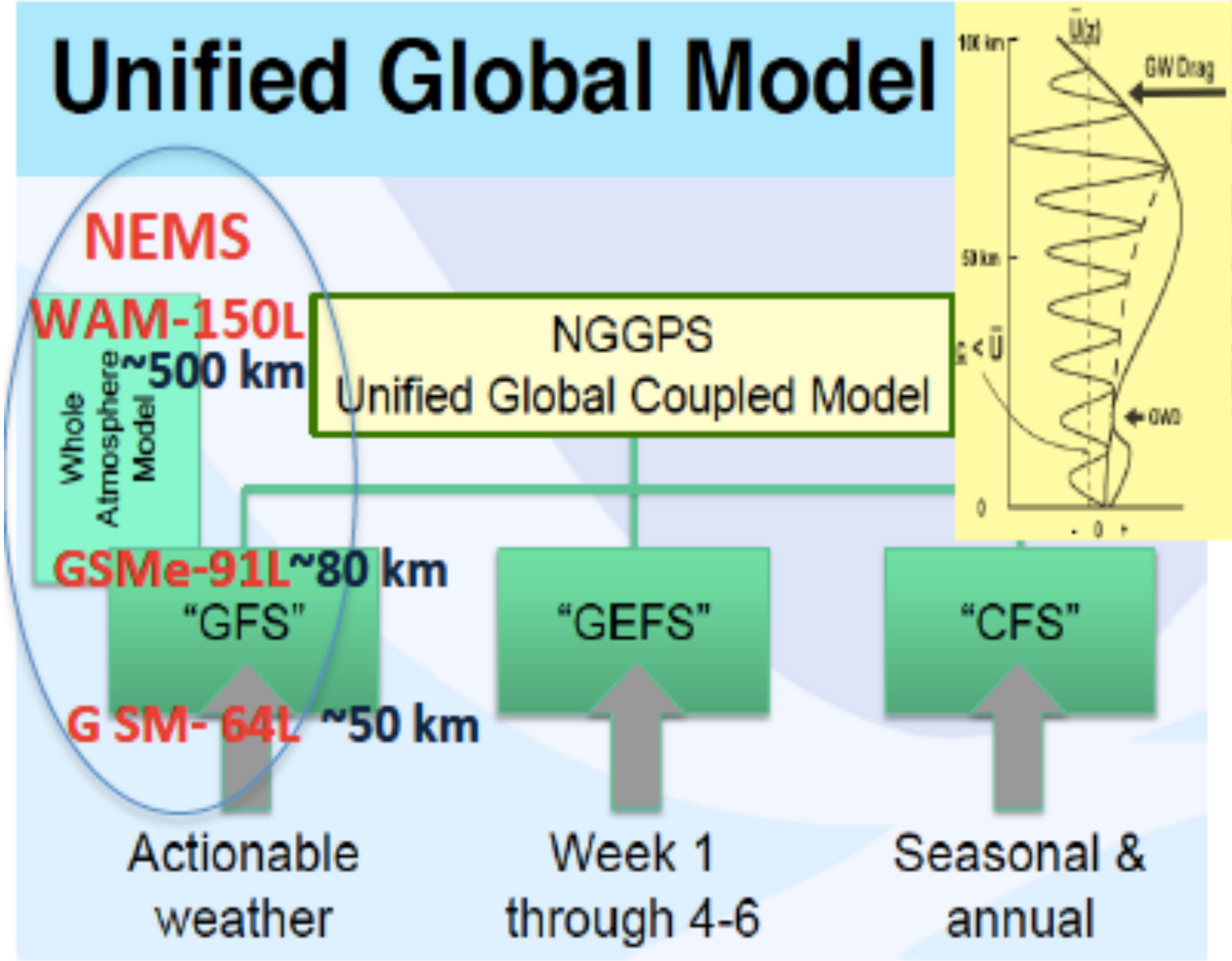
The Vertically Extended Global Atmosphere Models of NOAA Environmental Modeling System (NEMS)

The **R2O/NWS** transforms and upgrades the operational **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 *vertically extended* models, our current aim is to unify the **GFS-91L** (lid ~80km) and the 150L **Whole Atmosphere Model** (**WAM-150L,** ~500 km) under the *Global Spectral Model* (**GSMe**) of NEMS in 2016-17.

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



Unified Global Model

NEMS

WAM-150L ~500 km

Whole Atmosphere Model

GSMe-91L~80 km

G SM- 64L ~50 km

NGGPS
Unified Global Coupled Model

"GFS"

"GEFS"

"CFS"

Actionable weather

Week 1 through 4-6

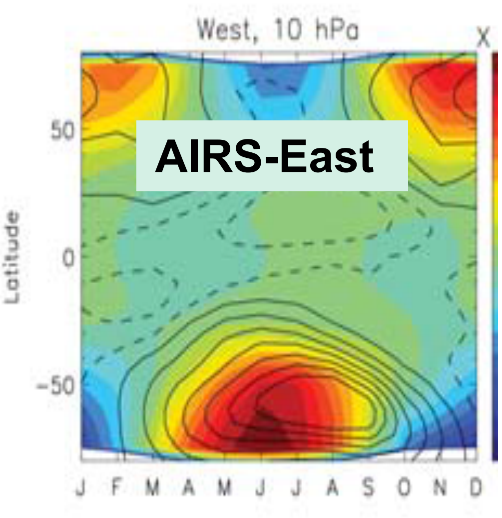
Seasonal & annual

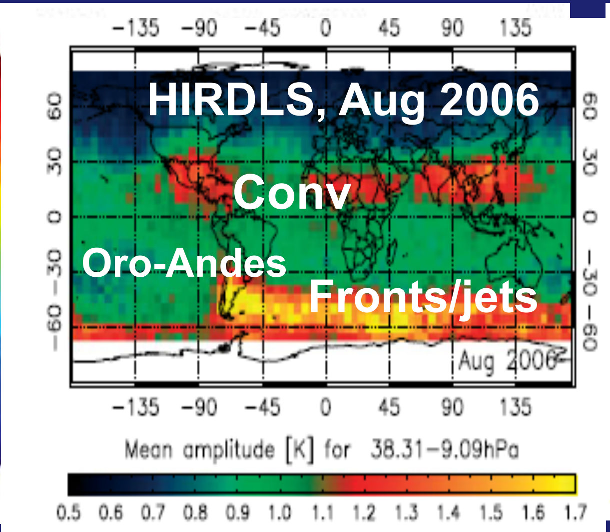
Dynamics and physics of resolved and sub-grid quasi-stationary *Orographic GWs* (OGWs) and *Non-stationary GWs* (NGWs) represent the major uncertainties for extended models of NEMS.
R2O/UGW project "unifies" GW physics.

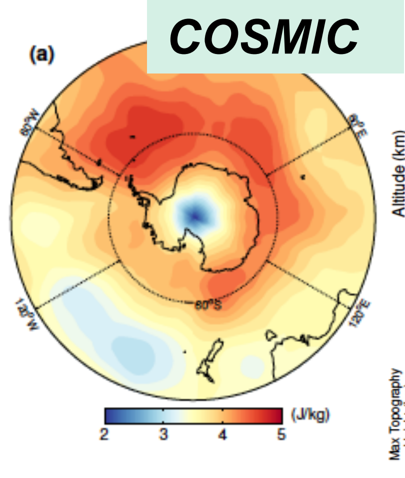
Gravity Wave Hotspots/Sources from Satellites: AIRS, COSMIC, HIRDLS & SABER

Gong et al., 2012

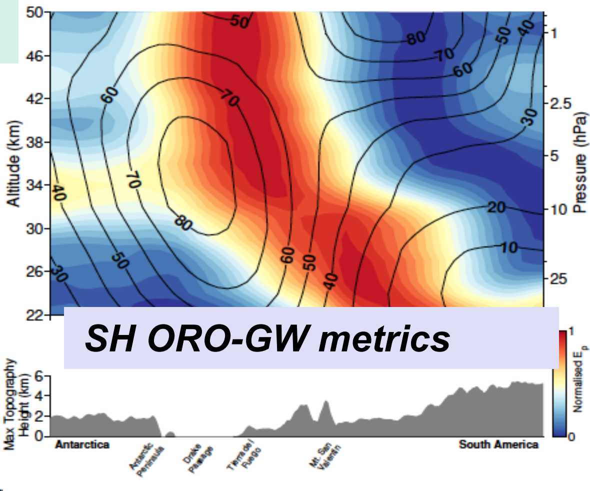
Hindley et al, 2015



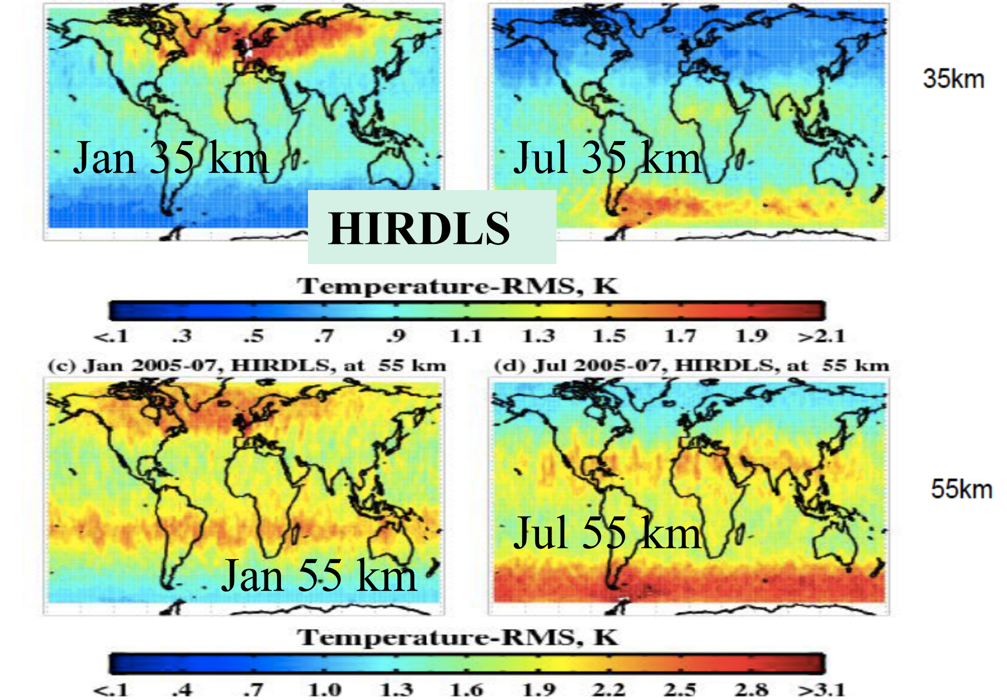


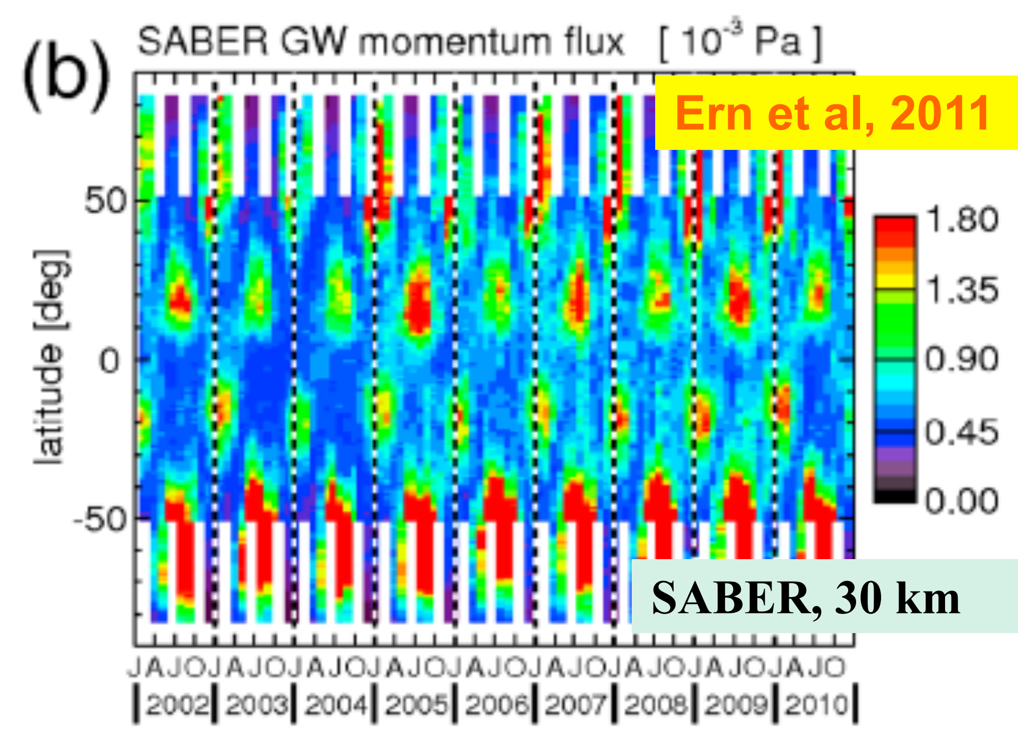


7. Polar stereo projections of E_p at 30 km



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





Unified GW physics in the NCEP models: GFS, NEMS-GSM and NEMS-WAM

Specfic R2O Goals:

(1)Perform "orchestration" of the GW solvers for all types of wave sources (orography, convections, front, jets, and other imbalanced dynamics) ; same breaking criteria and dissipation.

(2)Create portable and adaptable to the type of parameterization "GW-unified" module with 3 stages: **Init - Advance - Diagnose.**

(3)Allow both stochastic and deterministic performance of GW schemes (sources, spectra, and triggers).

(4)Explore novel observational GW metrics/ constraints for "resolved" and sub-grid GWs

(5)Introduce GW effects (drag, heat & eddies) **in the self-consistent, energy-balanced and resolution-aware formulations;** *orchestrate strengths of GW-drag, eddies and Rayleigh friction and "spectral" damping.*

Unified GW Physics Module

INIT: GW_NML, choice of GW sources and solvers

ADVANCE: Drag, Heat, K_{eddy}
every time-step or 1-hr cadence

Data-driven Diagnostics: dominant wavelengths, energy, momentum and heat fluxes.

GW-sources: *NRL, GMAO, ECMWF, NCEP and NCAR;*

GW-solvers : *operational weather and climate schemes with adapts for:*

(a) energy-balanced formulations:

(b) eddy diffusion and mass fluxes and self-cons. heat-drag-K;

(c) resolution-sensitive specifications of parameters.

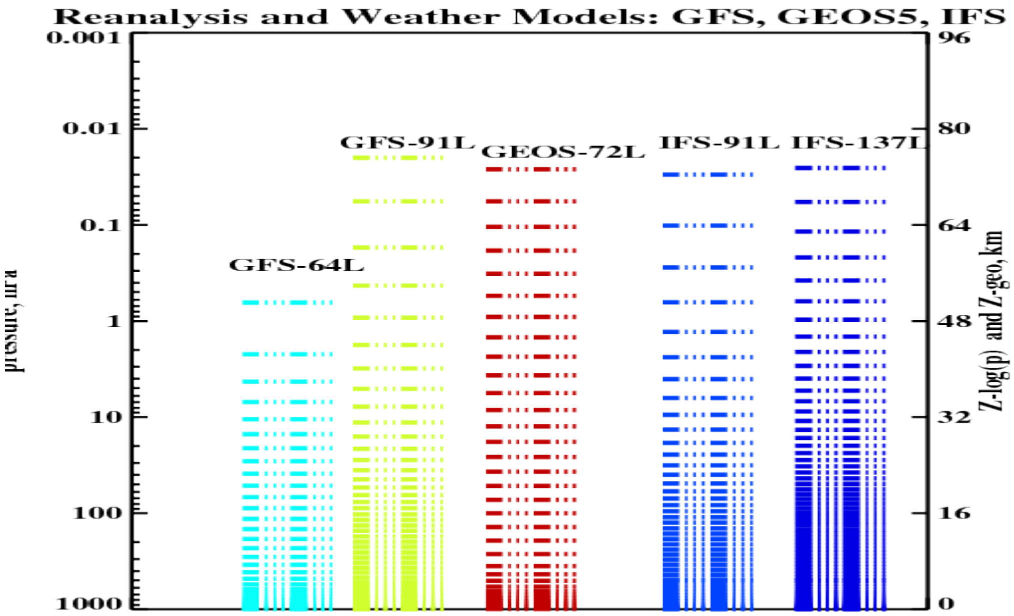
Extending GFS-64L to GFS-91L & First Steps towards "GW-Unified"

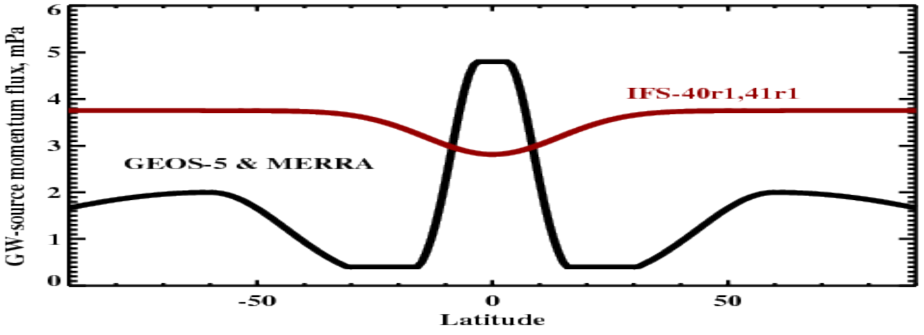
- **Vertical levels and top lid of GFS-91L** follow IFS-91L of ECMWF and resemble GEOS5-72L of GMAO;

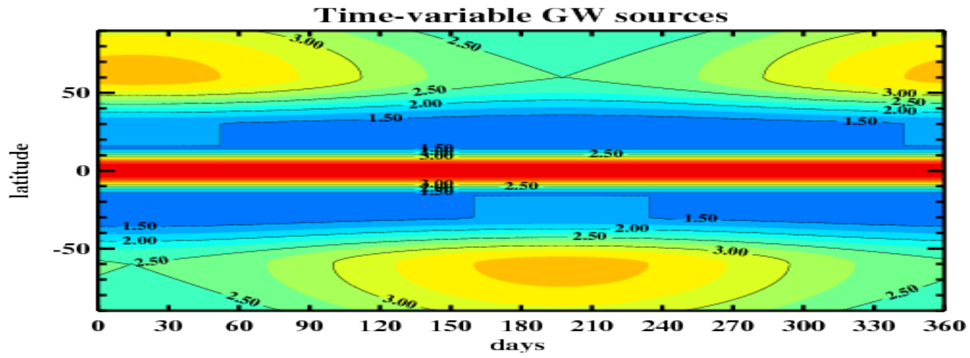
- **Decreased** (3-times, 1/15 days) **Rayleigh damping above ~70 km.**

- **Previous** (IFS, NOGAPS, NCAR) **choices for GW intensity at ~ 700 hPa** (or at ~500 hPa) *to replicate latitudinal and seasonal variations of GW activity in the stratosphere;*
- **GW solvers: (a) Linear saturation of modified Lindzen-81**; (b) Hines'-97 with dissipation and nonlinear saturation;
- **GW physics acts every time-step**: 4 azimuths; 10-25 modes in each azimuth; GFS resolution at T62, T254, T382, T574, & T670 for ~ 1 month.

In progress: online diagnostics and eddy effects; other GW –scheme







Zonal mean flow:
GFS forecasts for Jan and Jun of 2014

GFS-forecast in 64L & 91L models with Rayleigh Frictions and nGW-LS for June 2014

Points: Implementation of RF (wind damping) handles two issues:

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

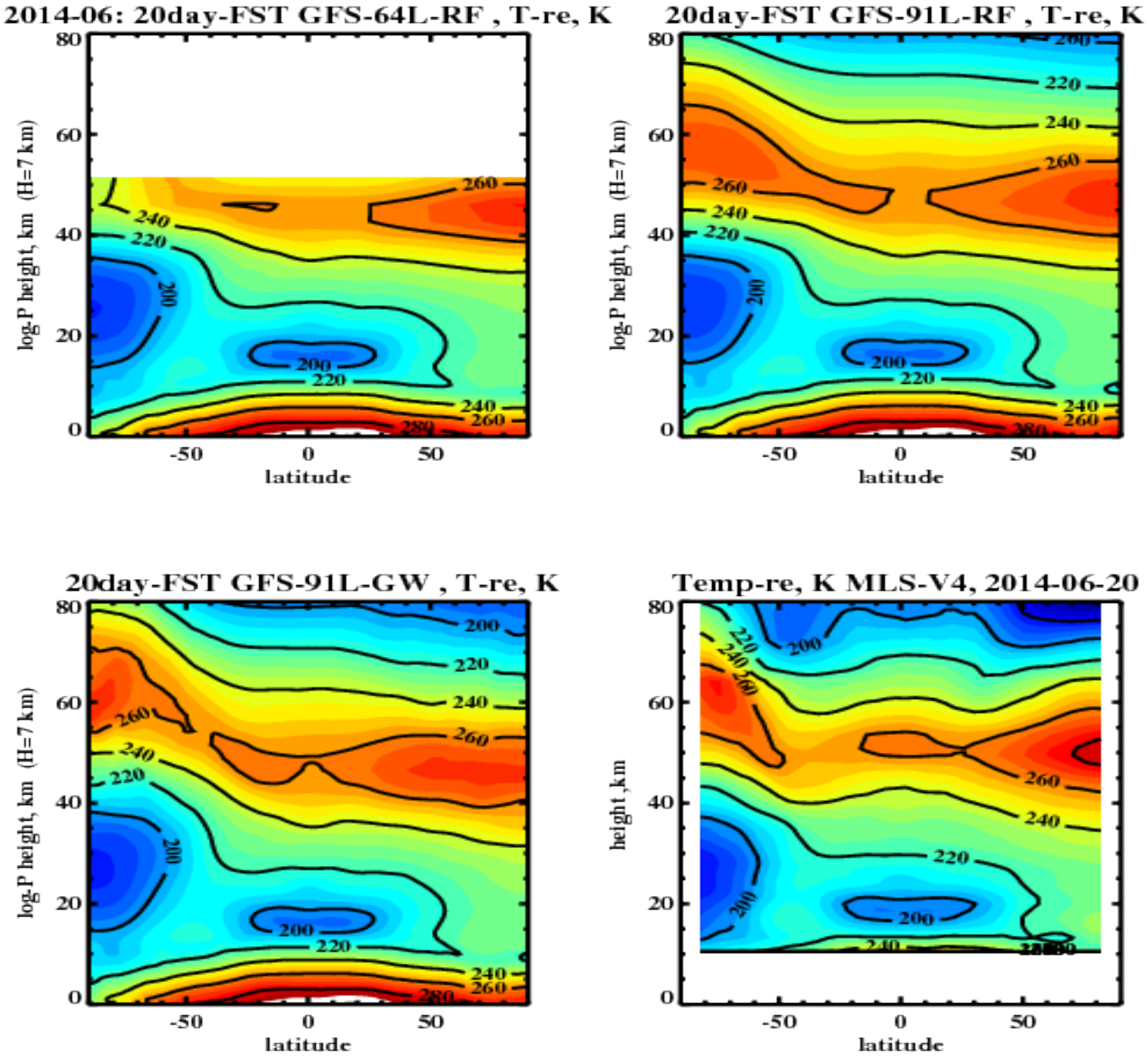
(2) The winter-summer zonal wind drag in the strato-mesosphere.

Issues with RF-schemes:

- Erroneous reflections of PWs;

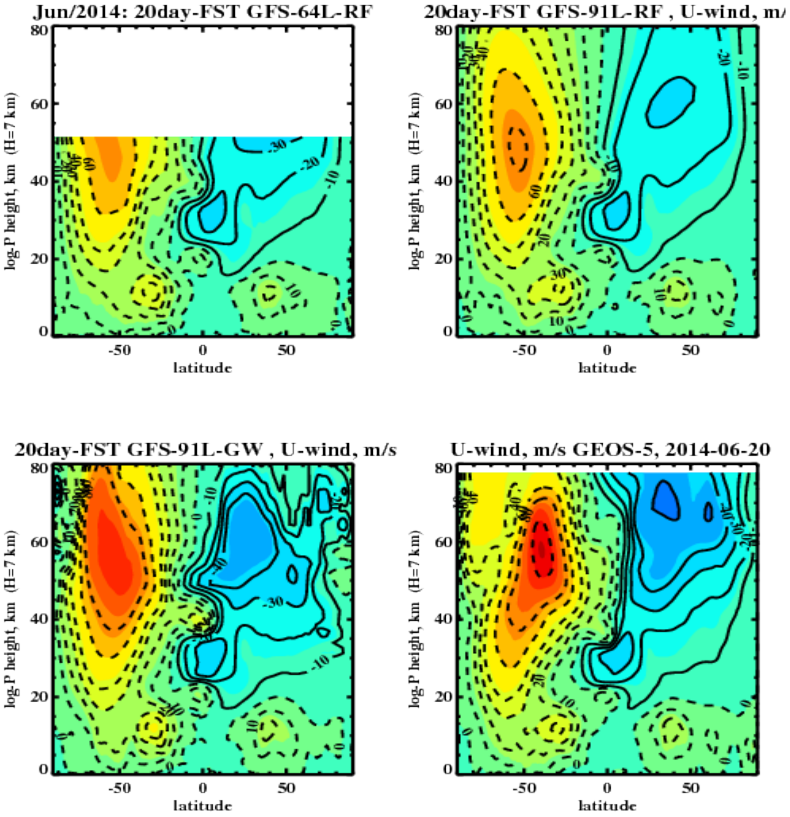
- Absence of the U-wind reversals above ~70-80 km;

- Warm mesosphere relative to EOS-Aura MLS and TIMED-SABER multi-year temperatures



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

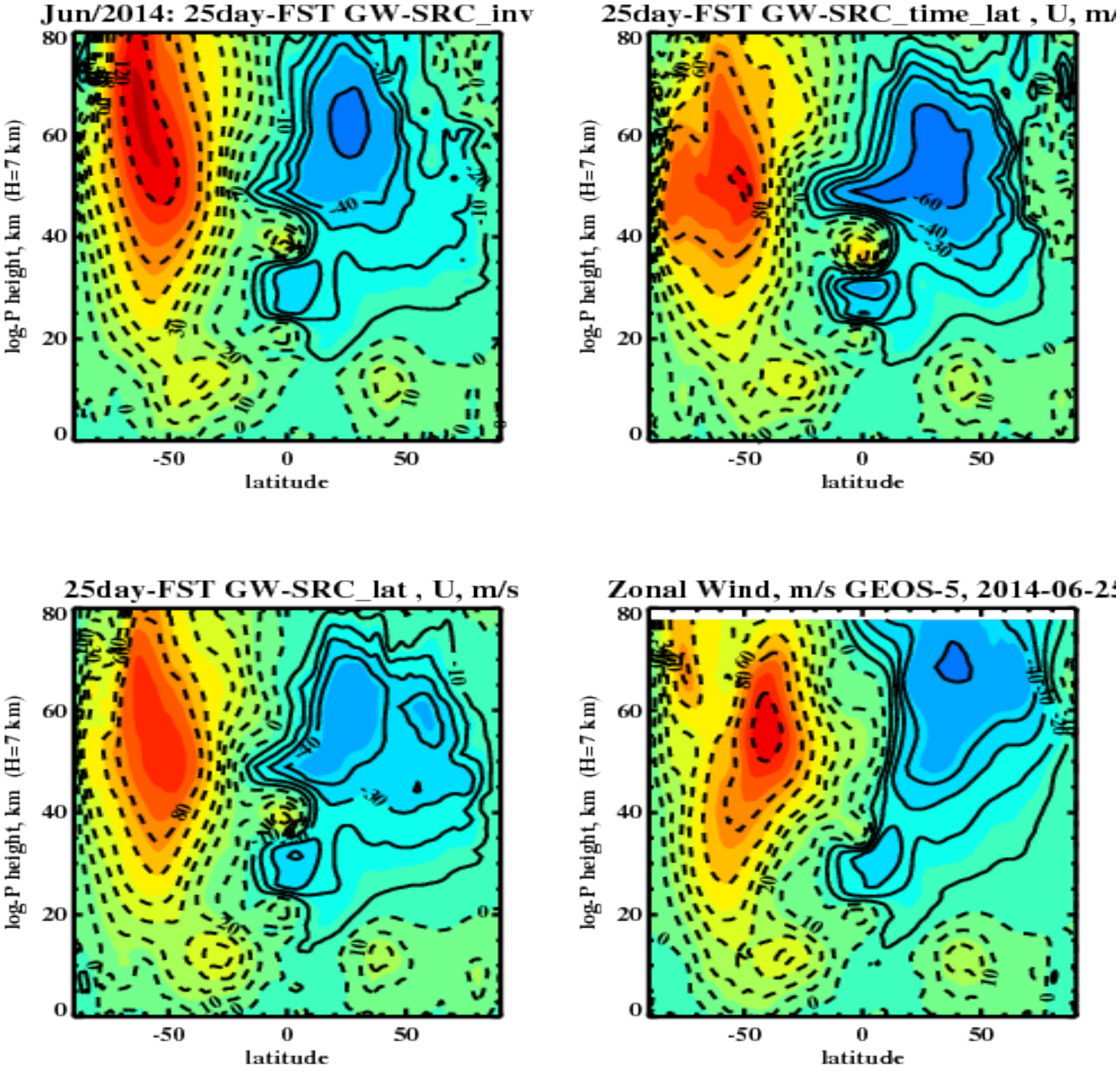
GFS 20-day forecasts in 91L model with different RF and GW sources: June of 2014


Jun/2014: 20day-FST GFS-64L-RF

20day-FST GFS-91L-RF , U-wind, m/

20day-FST GFS-91L-GW , U-wind, m/s

U-wind, m/s GEOS-5, 2014-06-20


Jun/2014: 25day-FST GW-SRC_inv

25day-FST GW-SRC_time_lat , U, m/

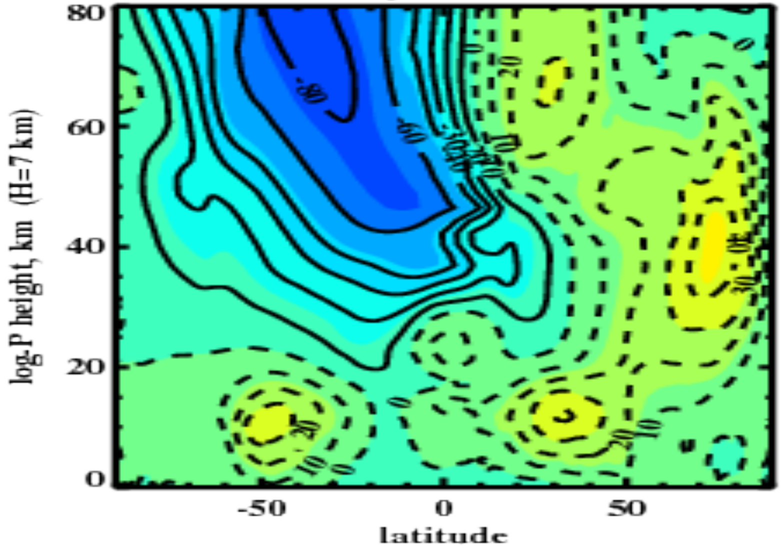
25day-FST GW-SRC_lat , U, m/s

Zonal Wind, m/s GEOS-5, 2014-06-2

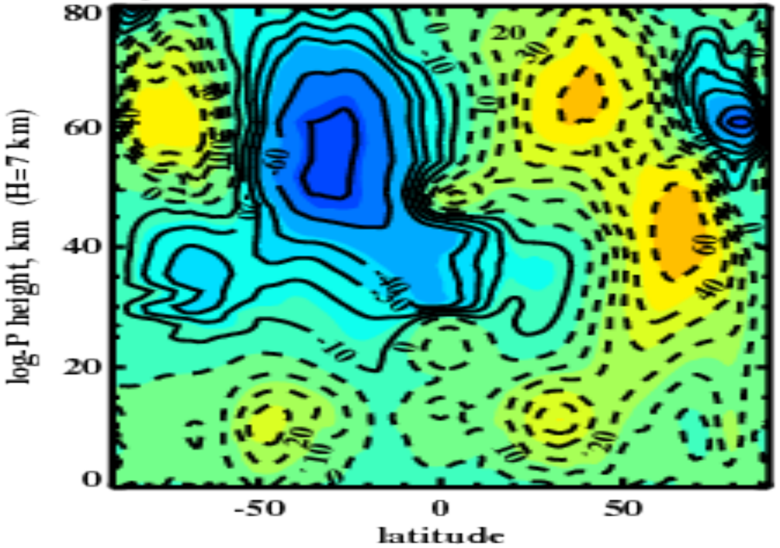
The SH winter-NH summer zonal wind drag in the strato-mesosphere

Jan 2014: Zonal wind and its sensitivity to the choice of the GW-source function

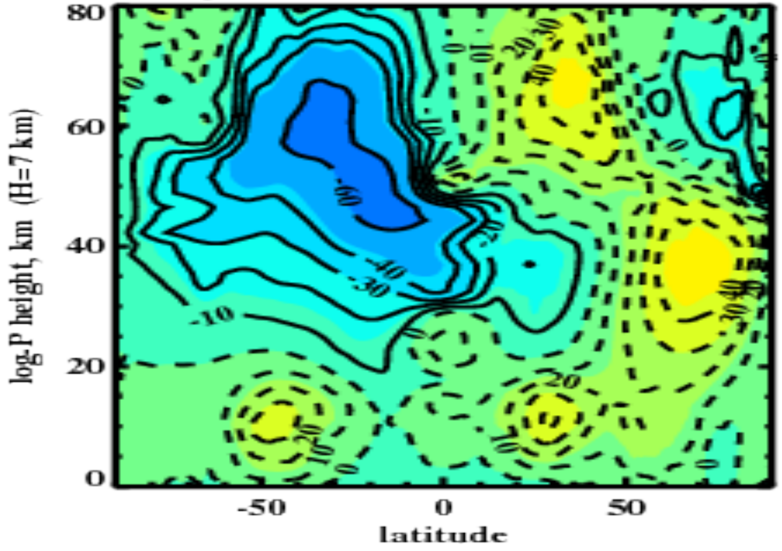
Jan/2014: 15day-FST GW-SRC_inv



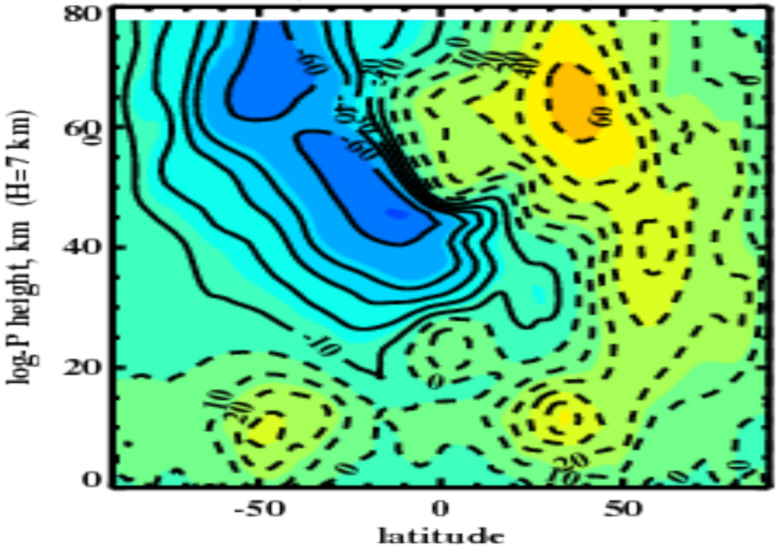
15day-FST GW-SRC_time_lat , U, m



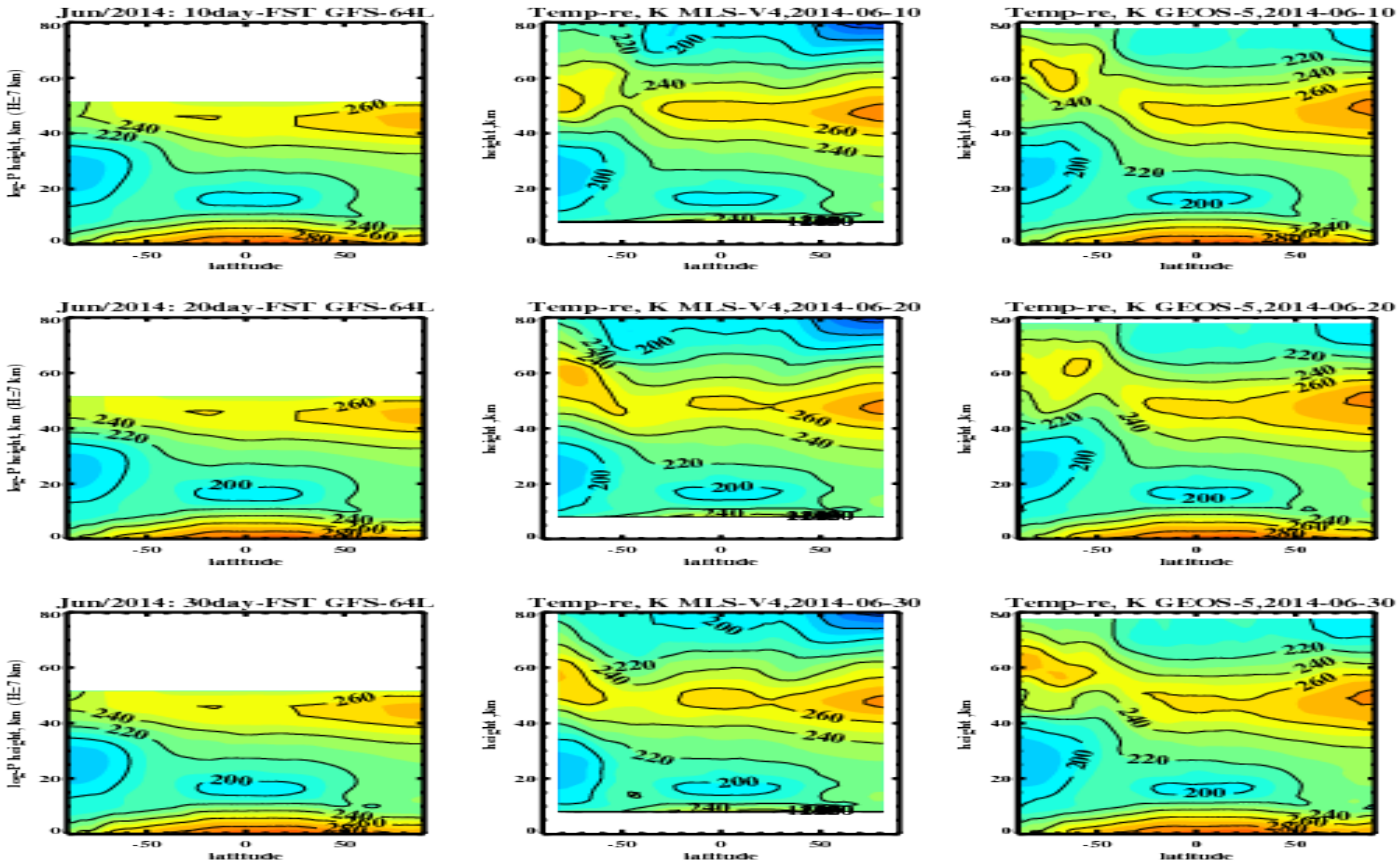
15day-FST GW-SRC_lat , U, m/s



Zonal Wind, m/s GEOS-5, 2014-01-1

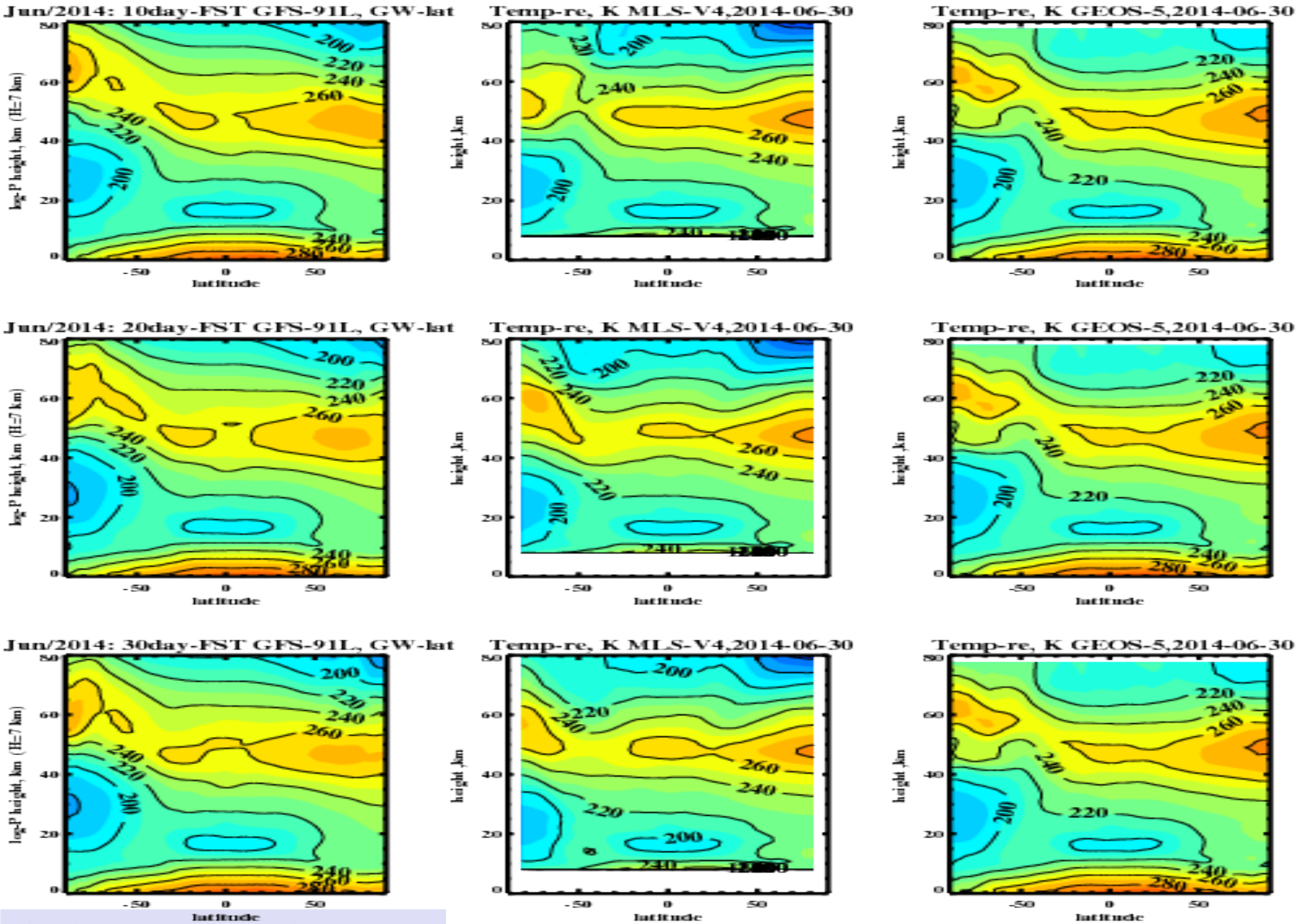


GFS-64L (T670) 10-30 day forecasts vs MLS and GEOS-5



GFS-64 L 800-hr forecast
WT: 3 hr 17 min

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

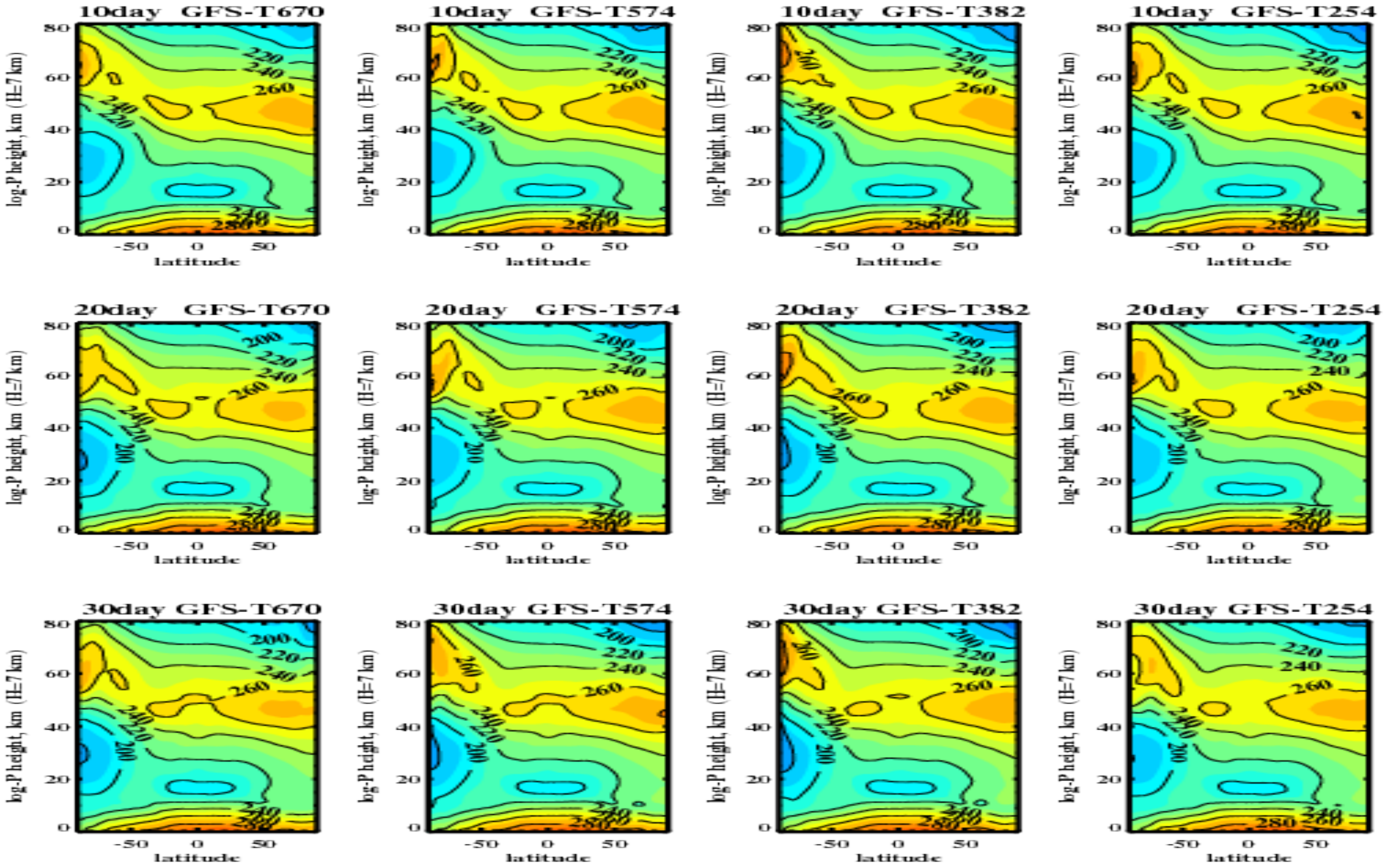


GFS-91L 800-hr forecast
WT: 4 hr 48 min RF
WT: 5 hr 57 min GW-40

EOS-Aura MLS-V4.3
June 2014

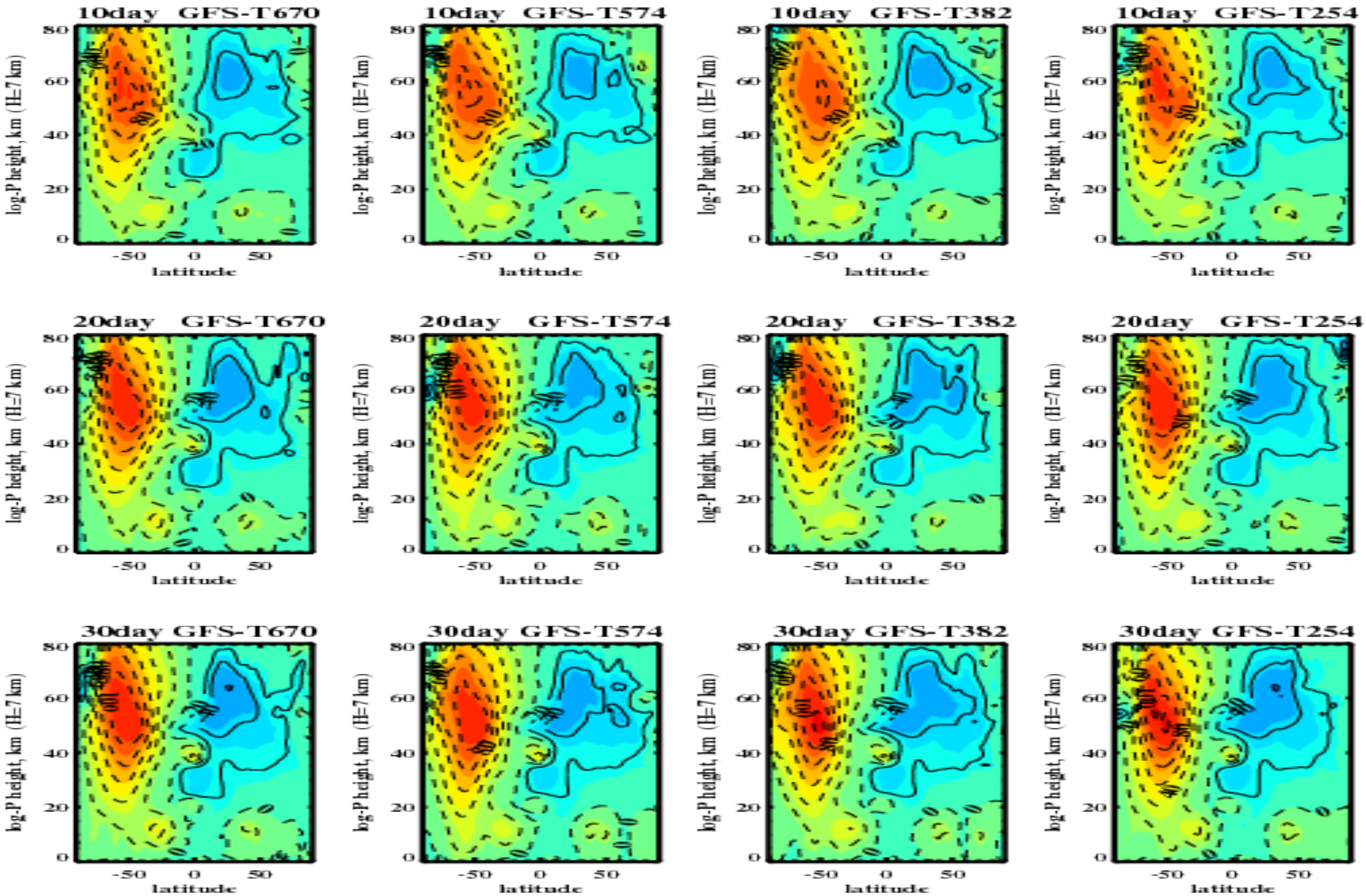
GEOS-5 Analysis,
June 2014

Sensitivity GFS-91GW to horizontal resolutions



T670 (30km) T574 (35km) T382 (50km) T254(75km)

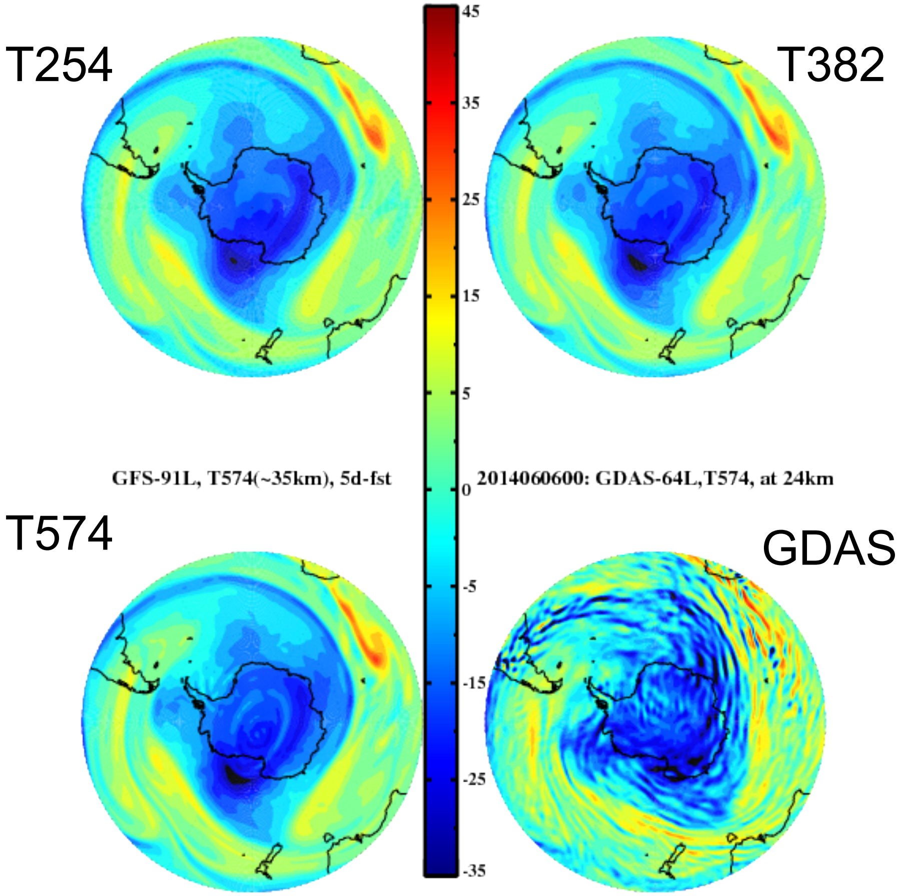
Sensitivity U-winds GFS-91l/GW to horizontal resolutions



T670 (30km) T574 (35km) T382 (50km) T254(75km)

Evaluations at ~ 10hPa (32km): GFS-91L/RF, GFS-64L/RF & GFS-91L/GW by GDAS-T574 (June 2014)

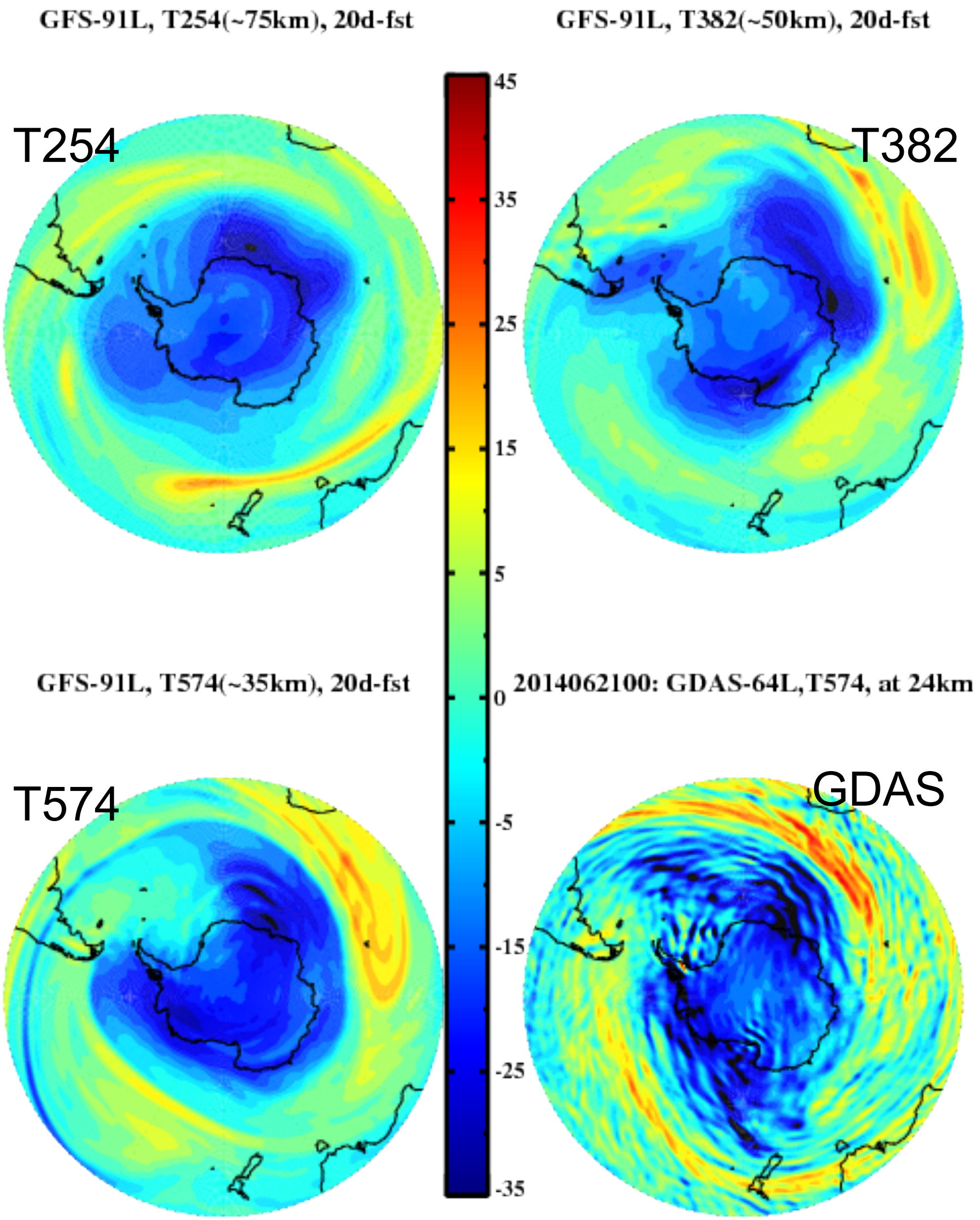
Enhanced resolution of GFS-91L (75 km => 34 km) may better fit GDAS Vorticity and the filament shapes after 20-days over the South Ocean and Antarctica at ~24 km (50 hPa)


GFS-91L, T574(~35km), 5d-fst

2014060600: GDAS-64L,T574, at 24km

Vorticity of Hor.Winds, scale=5.e5, 1/s at ~24 km

5-day FSTs & Analysis


GFS-91L, T254(~75km), 20d-fst

GFS-91L, T382(~50km), 20d-fst

GFS-91L, T574(~35km), 20d-fst

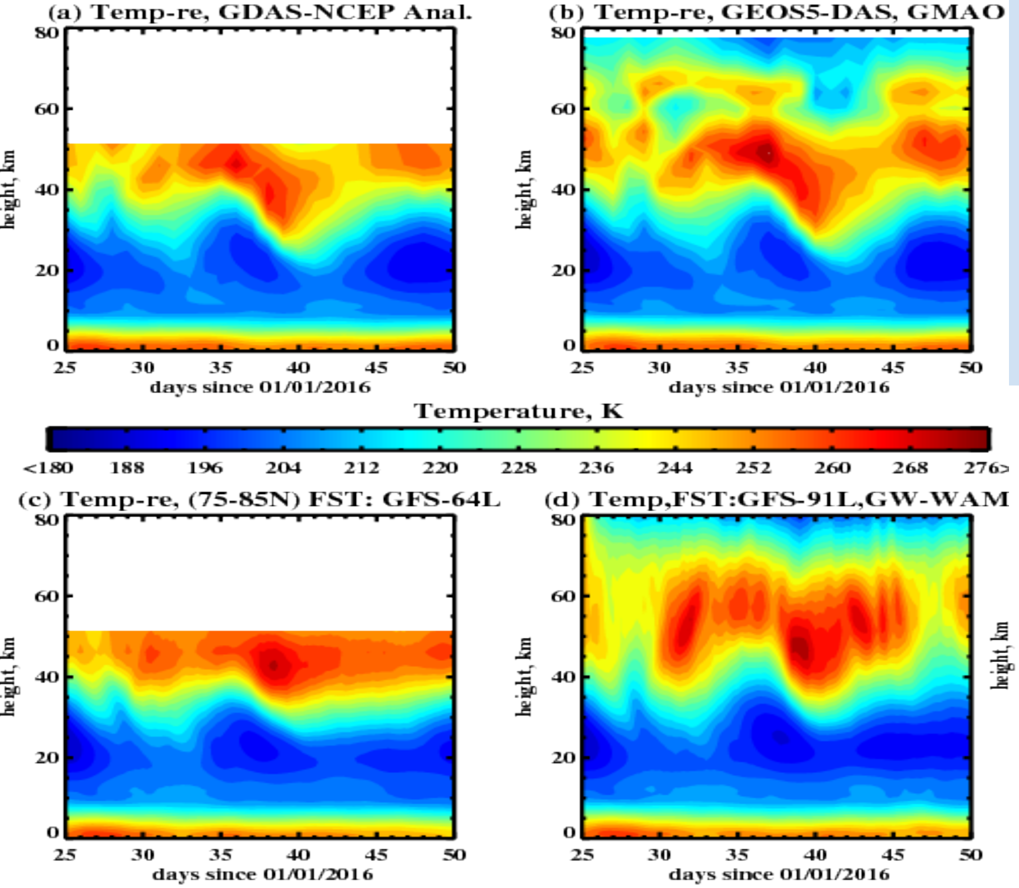
2014062100: GDAS-64L,T574, at 24km

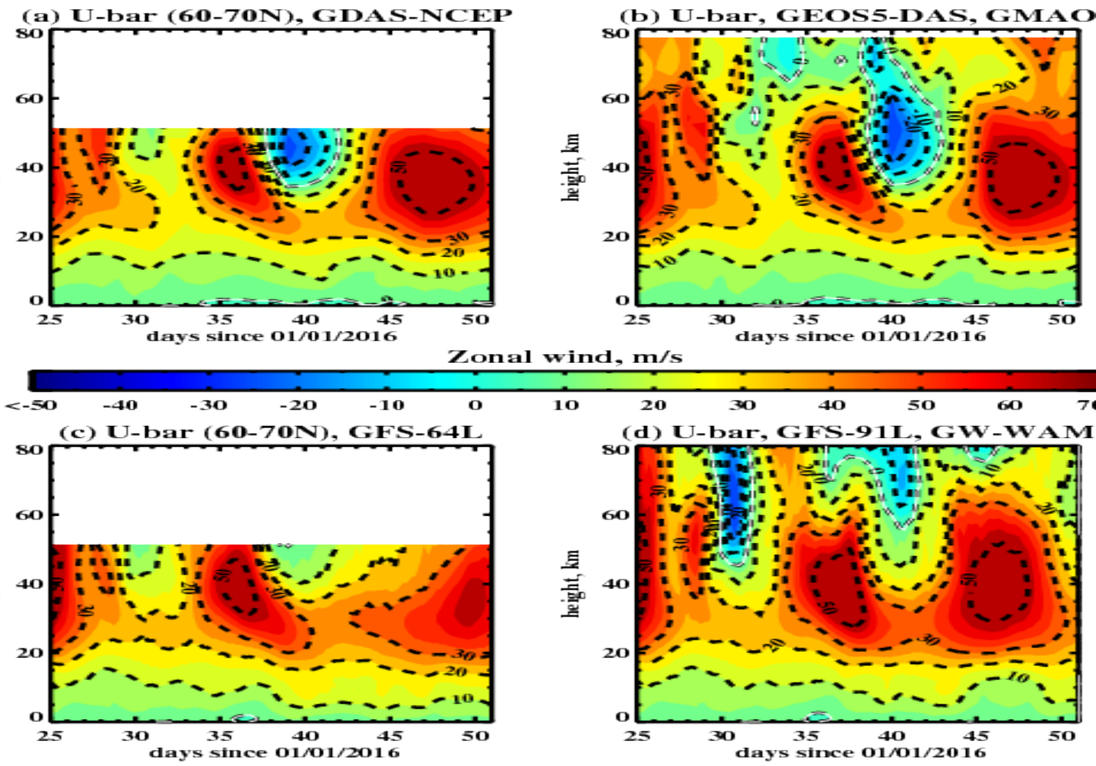
20-day FSTs & Analysis

PV-filaments, desirable feature for forecasts of the ozone transport and polar stratospheric chemistry

NEMS-GSM, 64L & 91L during SSW pulsations of 2016 (01/25 –02/20) vs GDAS-NCEP & GEOS-5/GMAO analyses

The 6-hr separated polar (75-85N) zonal mean temperatures and the high latitude (55-65N) zonal mean winds during the minor Sudden Stratospheric Warming (SSW) pulsations, Feb 2; GFS-91L with GWP tends to predict the wind reversals in upper layers and temperature-wind variations.





The top rows (a-b) display temporal variations deduced from GDAS (64L, T1534) and GEOS-5 (72L, 1/8 deg);
The bottom (c-d): GSM/GFS forecasts at T670 with 64L (c) and 91L (d).

Integrating Unified Gravity Wave Physics into the Next Generation Global Prediction System

- ***Summary of the 1-year results***

GW physics in NEMS-WAM improved zonal mean flows, planetary waves and tides.

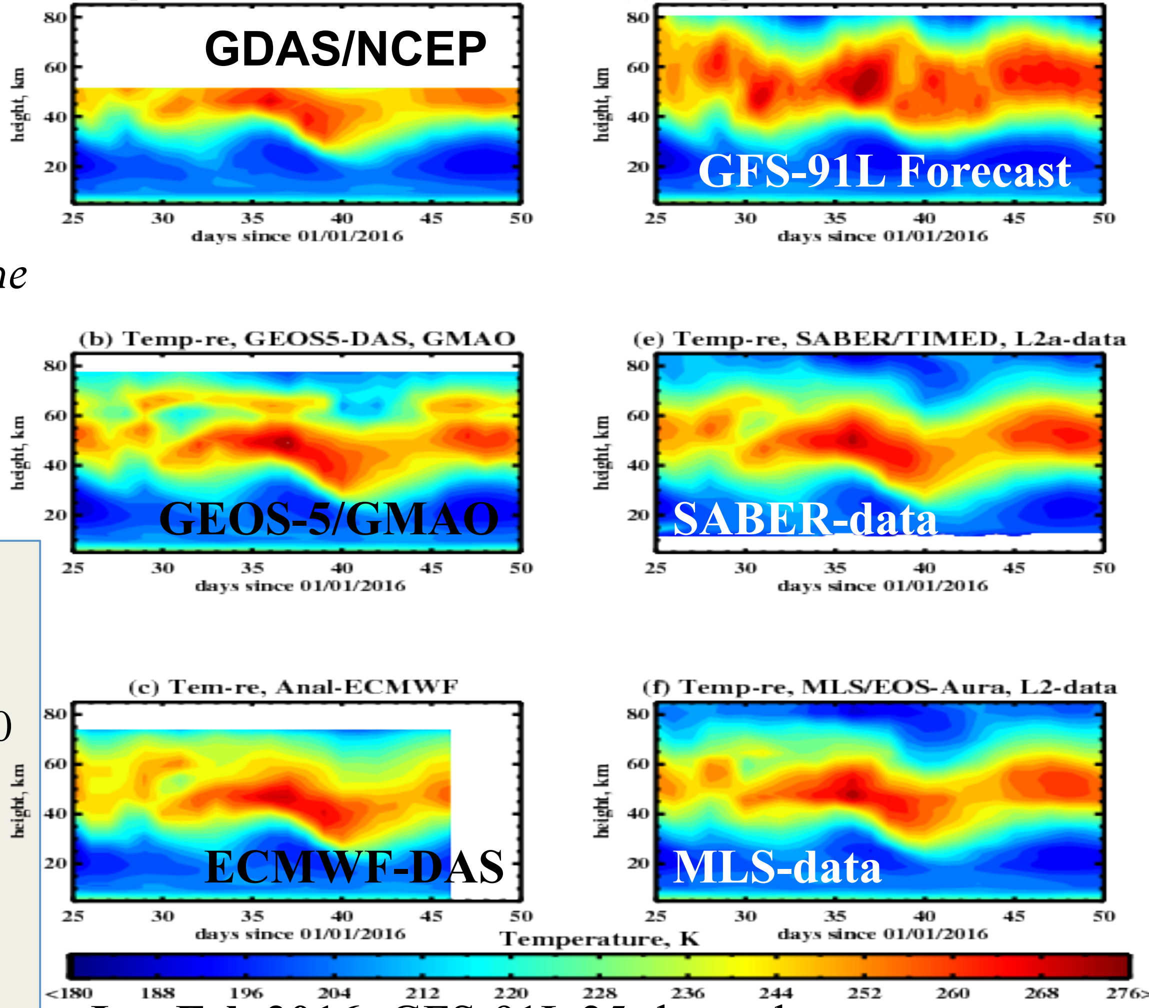
GW physics in GFS-91L brought a realism in the stratospheric dynamics during winters and winter-to-spring transitions comparing to the Rayleigh Friction simulations.

Transition to NOAA operations, climate tests, and future plans

a) ***Analysis-Forecast Cycling with GFS-90L*** (~80 km top) with "parallel" operational scripts; tests during SSW events (2009, 2013, & 2016).

b) ***NEMS-WAM multi-year climate runs*** for self-generated equatorial oscillations (QBO and SAO).

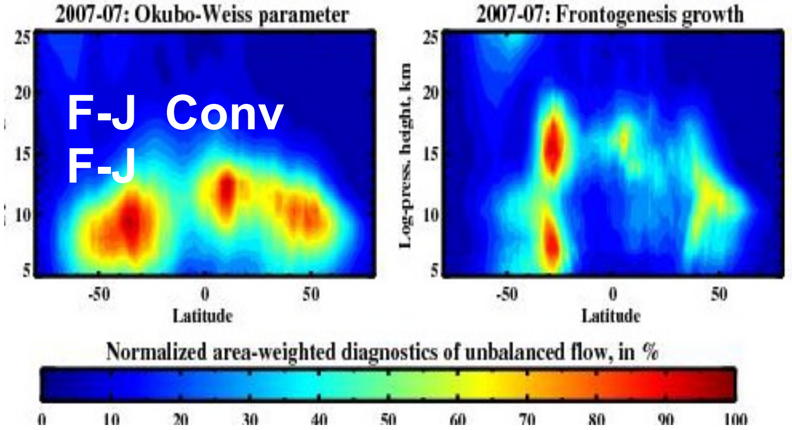
c) ***New related projects: Assimilation of middle atmosphere O_3, H_2O and T-re profiles*** (MLS & SABER) to properly initialize NGGPS forecasts.

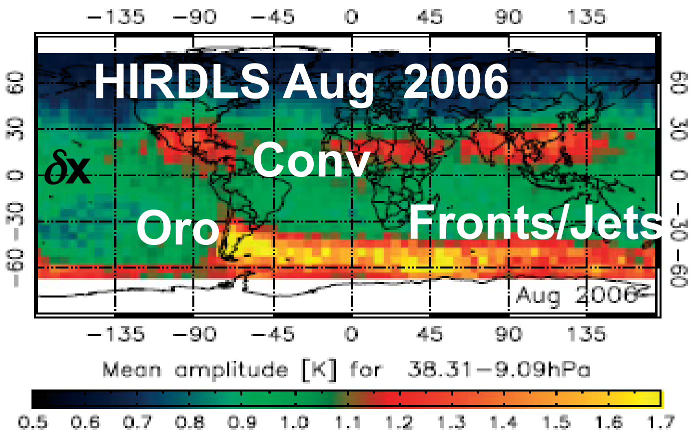


Jan-Feb 2016: GFS-91L 25-day polar temperature forecasts (d), SABER (e) & MLS (f) data (left), and NWP analyses (right column) : GDAS-NCEP (a), GEOS5-GMAO (b) and IFS-ECMWF(c).

Key future elements of nifieUd 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:

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

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

δx – typical size of the H-grid

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

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

Concluding remarks and next steps

1. We present extension of GFS-64L into the mesosphere (~ .01 hPa or ~80 km) with 91-leves that matches configurations of the forecast models of ECMWF (IFS) and GMAO/NASA (GEOS-5)
2. Set of the GFS-91L experiments to incorporate GW physics of non-stationary and orographic GWs were performed
3. Identical GW-scheme has been tested in the multi-year CAM-83L climate simulations forced by observed SST in order to check convective GWs to drive QBO dynamics in CAM-83L.
4. As appears the first implementation of GW physics in GFS-91L provide apparent improvements of the global forecasts beyond 5-days relative to GFS-91RF and GFS-64RF.
5. The resolution-aware formulations of GW-physics and sensitivity forecasts to specifications of GW sources were shown/discussed
6. **Next steps:** (*1) Sensitivity to GW solvers, (2) orchestration of oro-schemes and non-oro GW physics; (3) QBO in GFS; (4) Observational metrics for GW physics and data-based tune-up.*