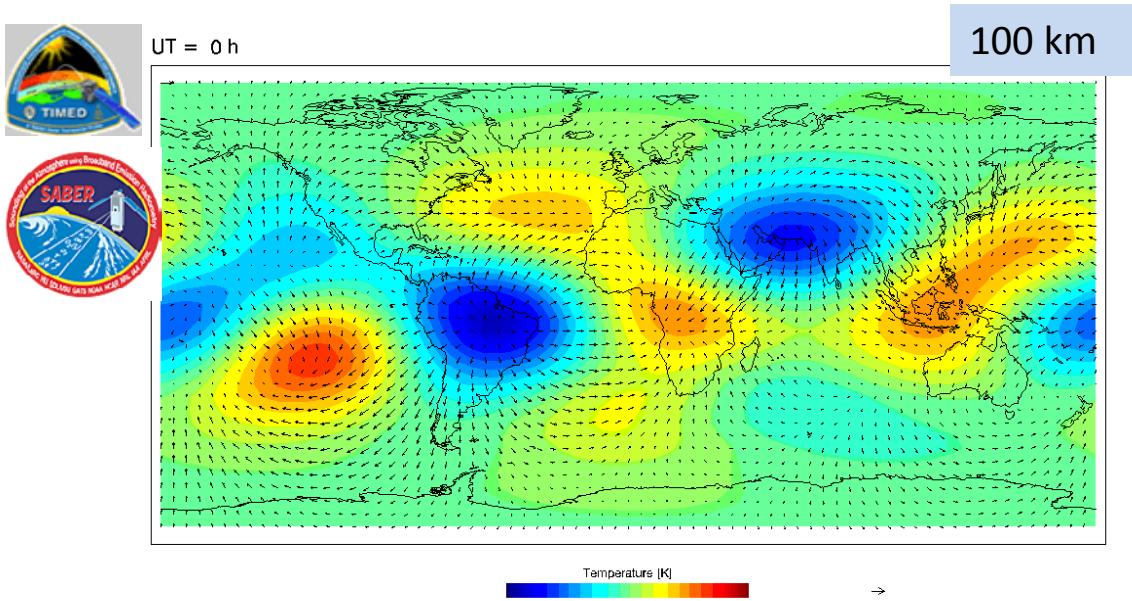
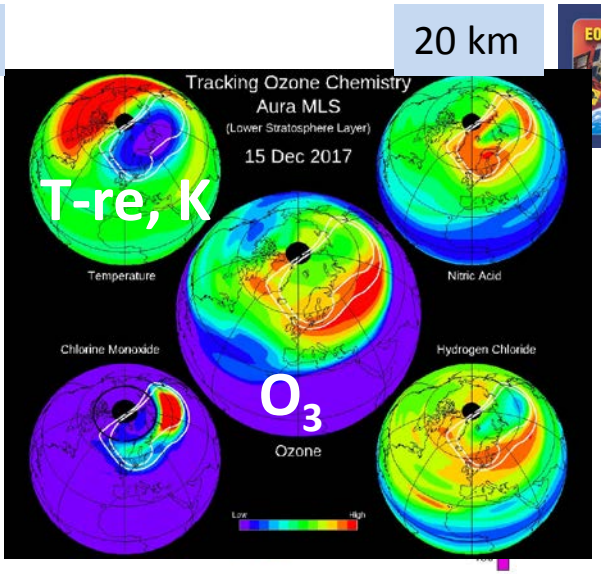
Data Assimilation in the Vertically Extended Global Atmosphere Models of NEMS

Valery Yudin[1], Svetlana Karol[1], Tim Fuller-Rowell[1], Daryl Kleist[2], Kate Friedman[2], and Adam Kubaryk[2]





SABER/TIMED Temperature Diurnal Variations ***------ MLS EOS Aura Ozone, T-re and tracers***

(Sounding Atmosphere by Broadband Emission Radiometry) *(Microwave Limb Sounder)*

[1] – Colorado University, CIRES

[2] – NOAA/NCEP/EMC

NGGPS PI Meeting

August 7 2018, College Park, MD

Background and Purpose

- **Vertically-extended models of the atmosphere have the potential to improve the longer-range tropospheric weather forecasts – the so-called downward control requires removing the artificial lid on weather models**

- **Propagation of waves into the upper atmosphere are important for space weather applications – migrating and non-migrating tides driven in the troposphere (water vapor, latent heat release) and in the stratosphere (ozone) propagate to the ionized lower thermosphere "dynamo" region, and directly into the upper thermosphere**

Methodology and Approach - 1

- ***Extend the NOAA operational Data Assimilation (DA) capability into the mesosphere and thermosphere***

- ***Use the middle atmosphere satellite data (MLS & SABER) to produce realistic retrospective forecast and analysis.***

- ***Develop and test application of the Gridpoint Statistical Interpolation (GSI) DA system in the Vertically Extended (VE) global atmosphere models of NOAA with top lids of 80 km (NEMS/GSM-91L; FV3GFS-128L) and ~600 km (NEMS/WAM-150L and FV3WAM).***

- ***Upgrade model physics of VE models to perform analysis of data (temperature, ozone, oxygen) with strong diurnal cycles***

- ***Upgrade specification background forecast errors in GSI to introduce "errors of the hour" to properly blend the data and forecast performing assimilation of diurnal cycles***

Methodology and Approach - 2

- ***Use the operational GFS workflow V14.0 and upgrade the GSI-observer modules to read MLS temperature and ozone data along with SABER temperature and atomic oxygen to compute appropriate innovations (Observation minus Forecast).***

- ***Introduce and test "intermediate" solutions into the radiance data assimilation scheme of upper satellite sensors to avoid negative impact of their analysis in the mesosphere and lower thermosphere.***

- ***Use the WAM ensemble forecast to develop and test novel background error covariances for temperature, horizontal winds, ozone and atomic oxygen; start testing of the 3DEnVAr GSI scheme with IAU for adequate assimilation of diurnal cycles and tidal signals in the Mesosphere and Lower Thermosphere (MLT)***

- ***Verify analysis of SABER and MLS data in WAM using independent radar and satellite winds and lidar temperature observations in the MLT***

- ***Transfer analysis of MLS and SABER ozone and temperature observations into FV3GFS-128L recently developed extension of FV3GFS above 55 km***

Outline

Vertically extended NOAA/NEMS models:

> with ***Spectral dycore:***
NEMS/GSM-91L & NEMS/WAM-150L

> with ***FV3-based dycore:***
NEMS/FV3GFS-128L & FV3WAM

> Realistic initialization of models for A-F;

> Appropriate updates of model physics.

Vertical extensions for GSI and EnKF:

> extension of background errors > ~55km;

> treatment for extended radiance analysis;

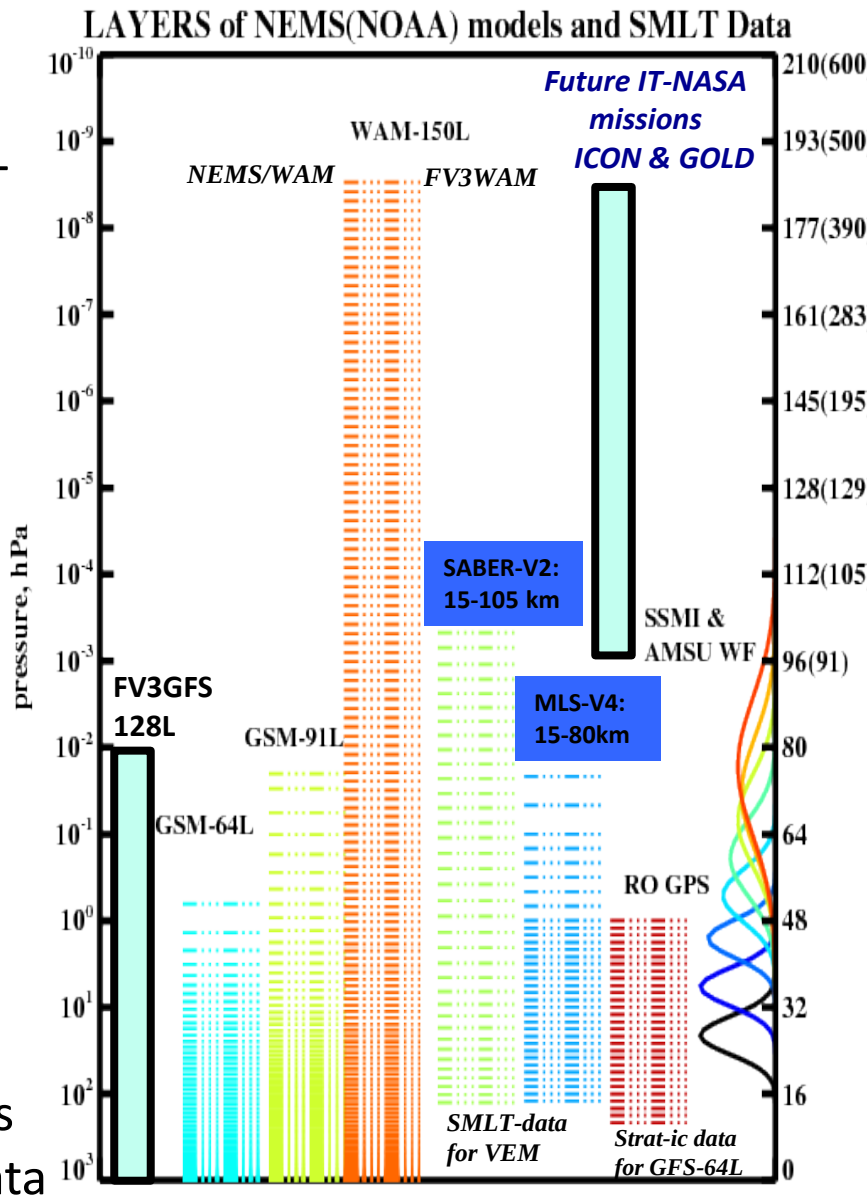
> adjustment of workflow scripts, postprocessing and verifications > ~55km;

SMLT data analysis (T, O_3, O) in NEMS/WAM:

> middle atmosphere analysis: SABER & MLS temperature, ozone & atomic oxygen data;

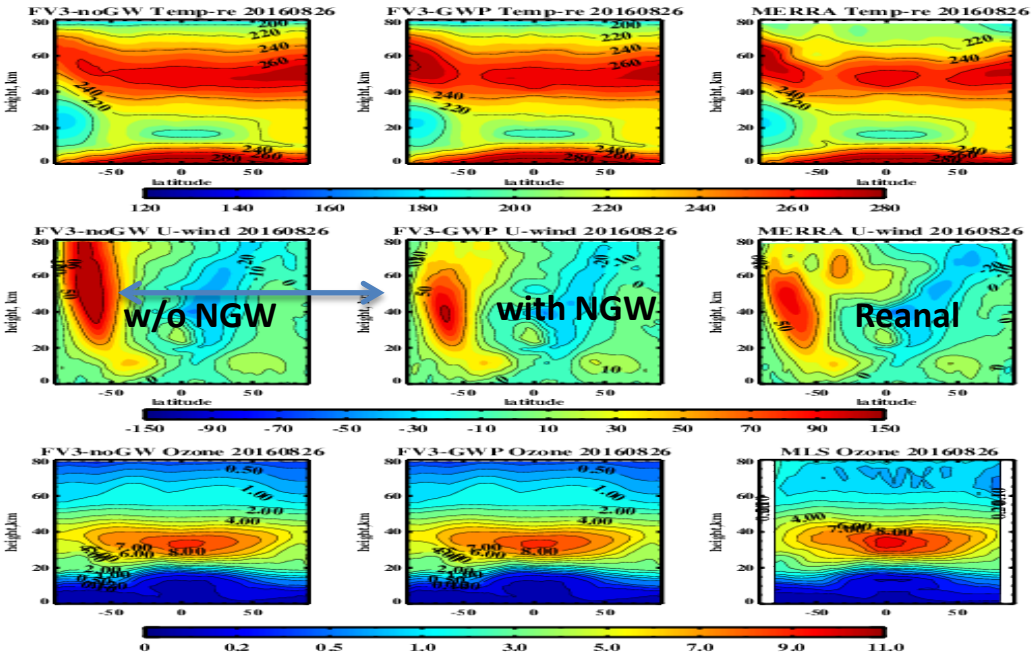
> treatments of data biases and model errors

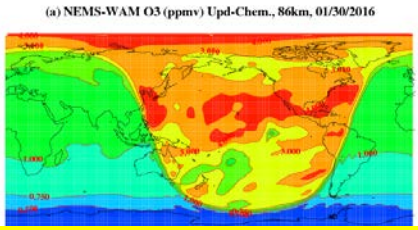
> preparation for analysis of GOLD & ICON data

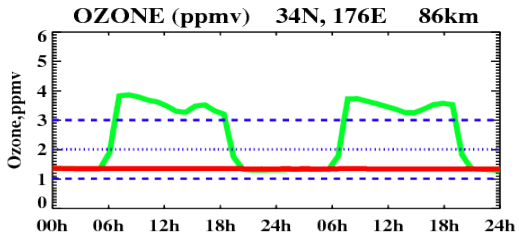


Preparing and tuning VE NOAA model forecasts to analyze MLS and SABER data

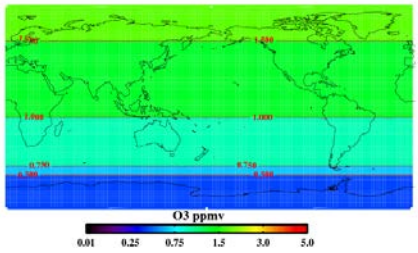
- Nonstationary GW physics to address model biases > ~40 km.
- Additional tune-ups of physics (eddy diffusion, Rayleigh friction, tides) for the realistic analyses in the stratosphere, mesosphere & lower thermosphere (MLT).
- Diurnal variations of O_3 and O in the upper stratosphere and MLT
- Balanced Initialization of of VE models using nudging algorithms below 40 km with available analyses (GDAS, GEOS-5)

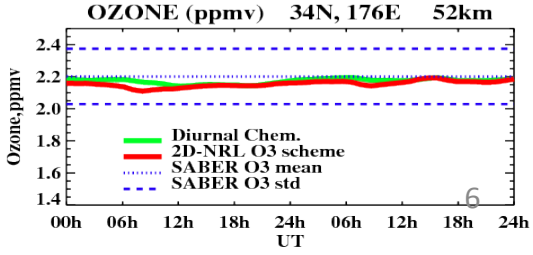




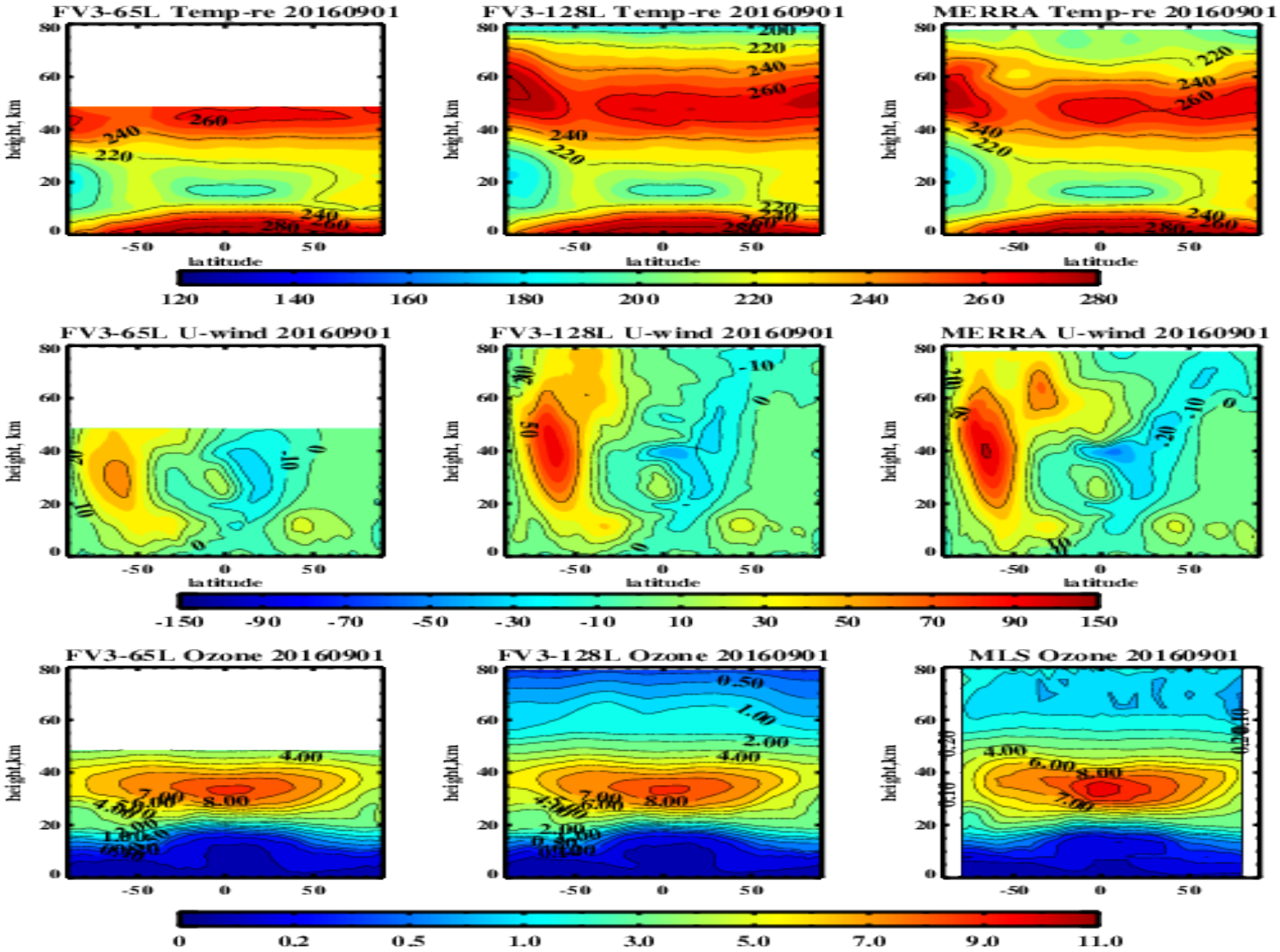


At 96 km O_3- completely depends on diurnal CHEMSITRY





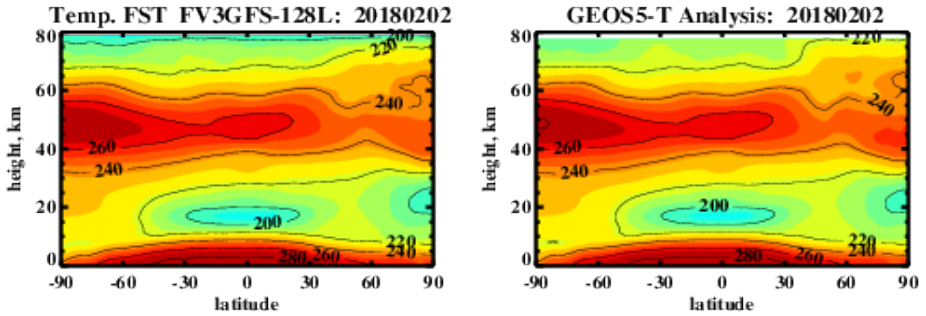
Zonal Mean Temp-re, Wind and O_3 (01-09-2016) after 20-day forecasts by FV3GFS-65L (left), FV3GFS-128L (mid) . MERRA & MLS-O3 (right)

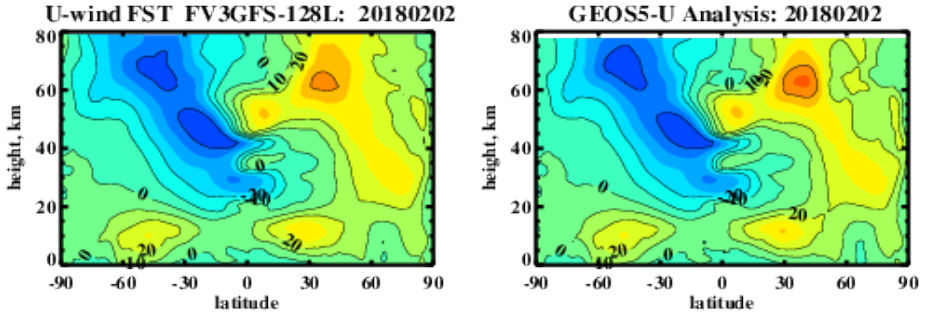


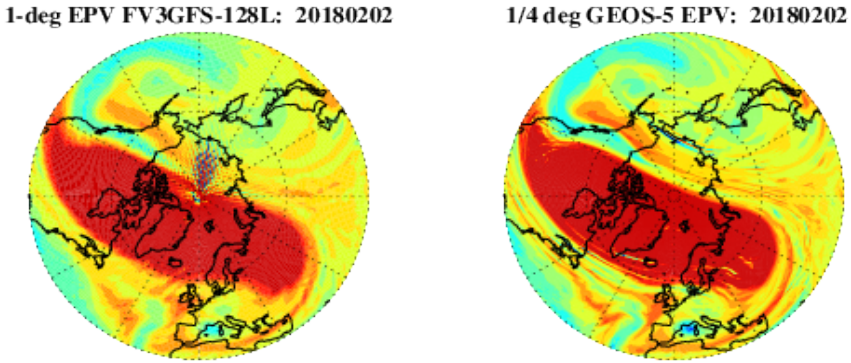
Extra work to tune FV3GFS (64L, 128L) to remove numerical dampiing near the model top

MERRA – Modern Era Retrospective analysis for Research & Application of NASA/GMAO

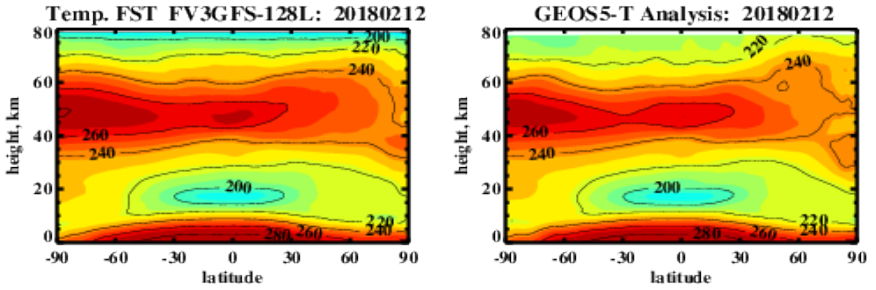
FST: FV3GFS-128L vs AN: GEOS-5
Feb 12 , Onset of SSW

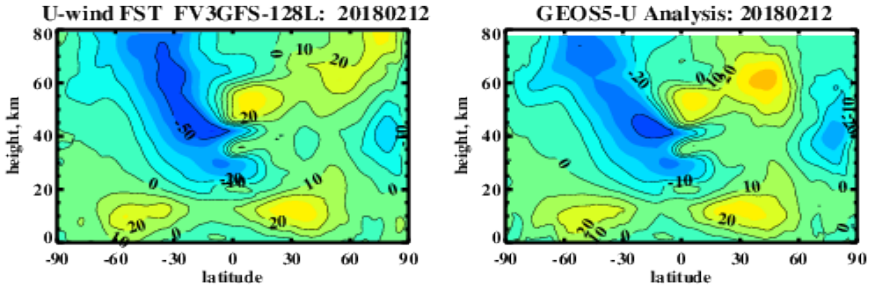


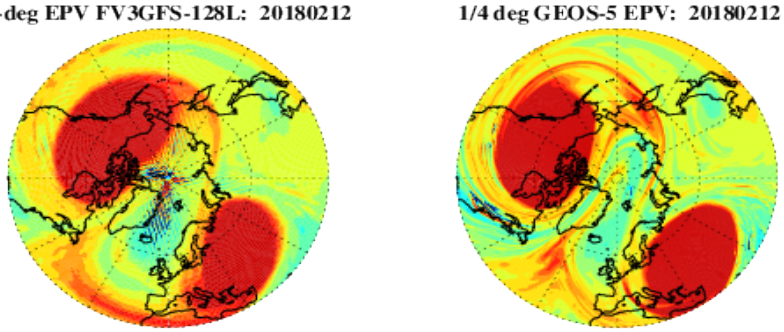




Balanced Initialization of FV3GFS by GEOS-5



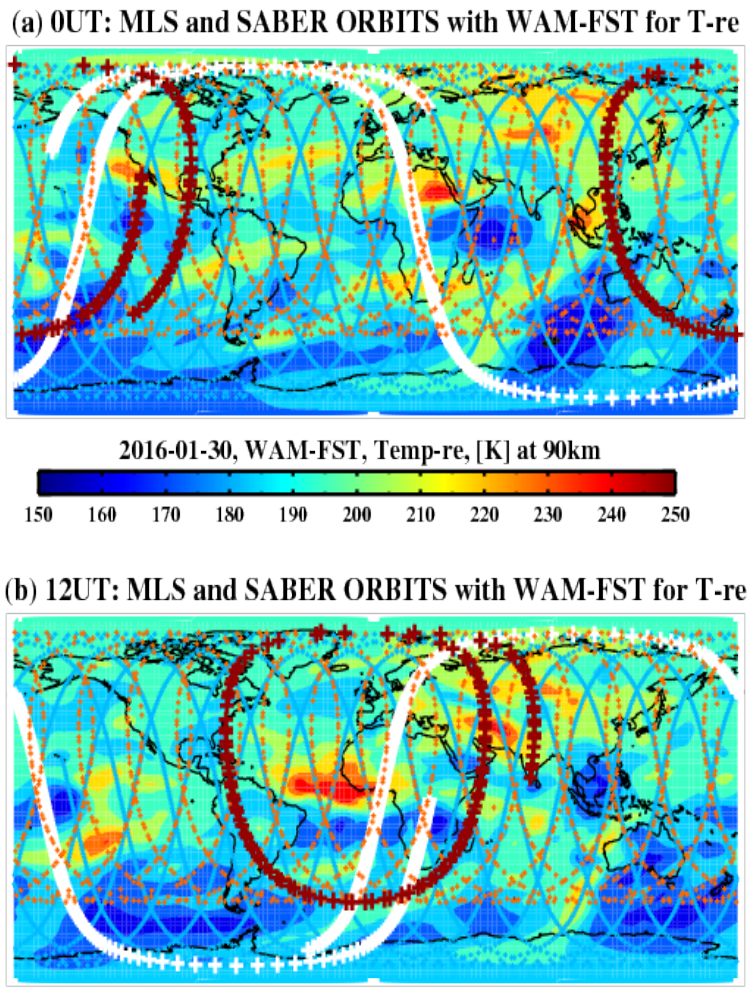


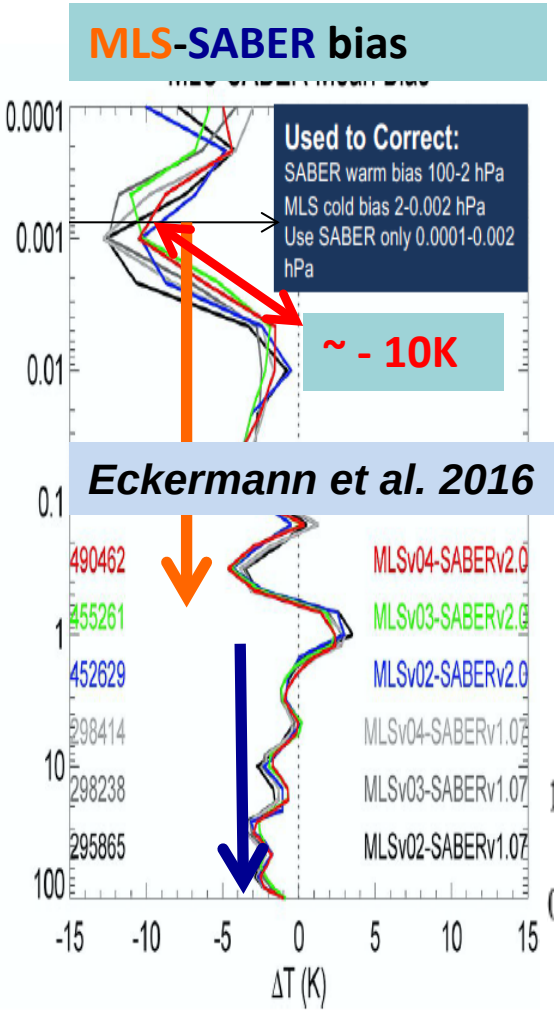


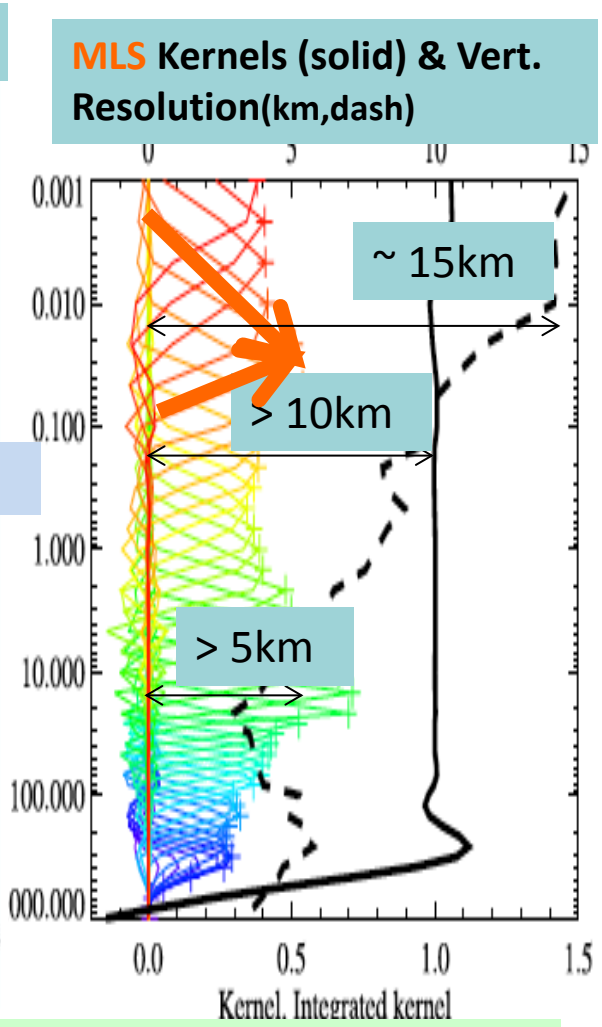
Before onset of SSW -2018
Feb 2 (start day of FST -Feb 1)

New FV3GFS-128L 10-day forecasrt successfully now predict SSW-2018 onset
Next step: assimilate MLS & SABER data

SABER and MLS Temperature Vertical Profiles: Data Coverage (SABER: ~1800 profiles per day; MLS: ~1800 profiles), Vertical Resolution (SABER 2.5 km; MLS > 3.5-15 km) and Data-Data discrepancy



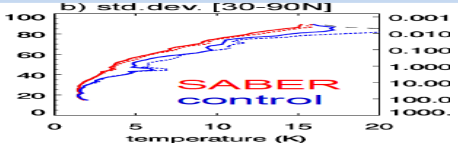




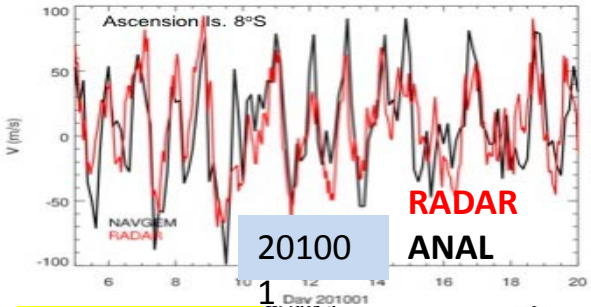
> 1 hPa: Vertical Mapping to MLS-data space with Averaging Kernels

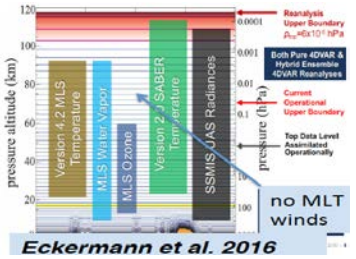
RETROSPECTIVE ANALYSIS of MLS/Aura and SABER/TIMED data (2005-present)

CMAM-3DVAR with SABER-Temp (TL-90)
S. Polavarapu (2005-11 Env Canada/YU/TU)

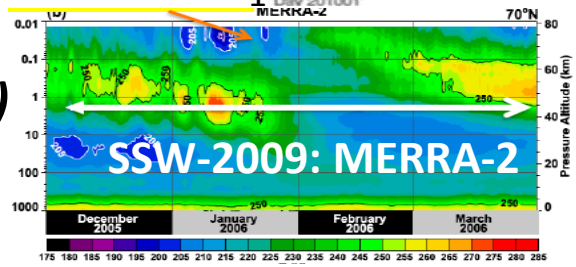


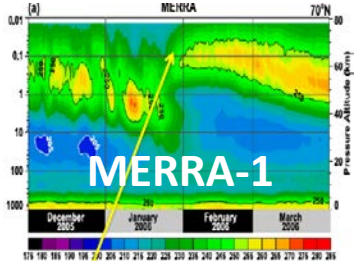
NOGAPS-ALPHA (3DVAR-FGAT, 2008) => HT-NAVGEM (4DVAR-Ens,TL-115km, 2016 T, O_3 H_2O - MLS & SABER-T) ***K. Hoppel, S. Eckermann (NRL).***





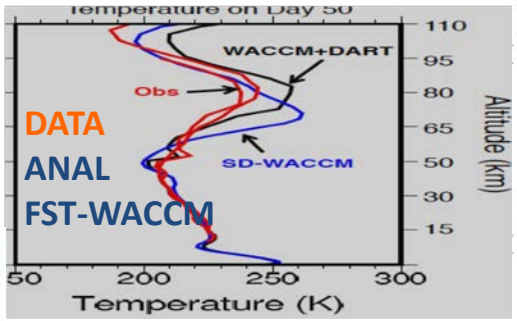
MERRA-2 (GSI-3DVAR, TL-80km, MLS-T/O3, 2004-) ***R. Gelaro et al. (NASA/GMAO, 2017)***

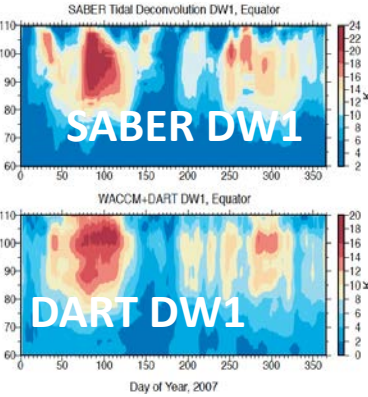


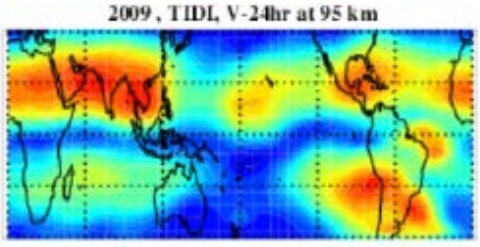


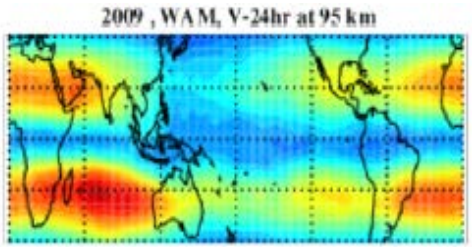
WACCMX-DART (ENKF-6hr, CCM, TL-500km SABER-T; MLS-T), ***N. Pedatella et al. (NCAR).***

WAM-GSI-3DVar, (TL-500km, O_3 & T of SABER & MLS), ***Yudin et al. (CU/SWPC/NWS)***

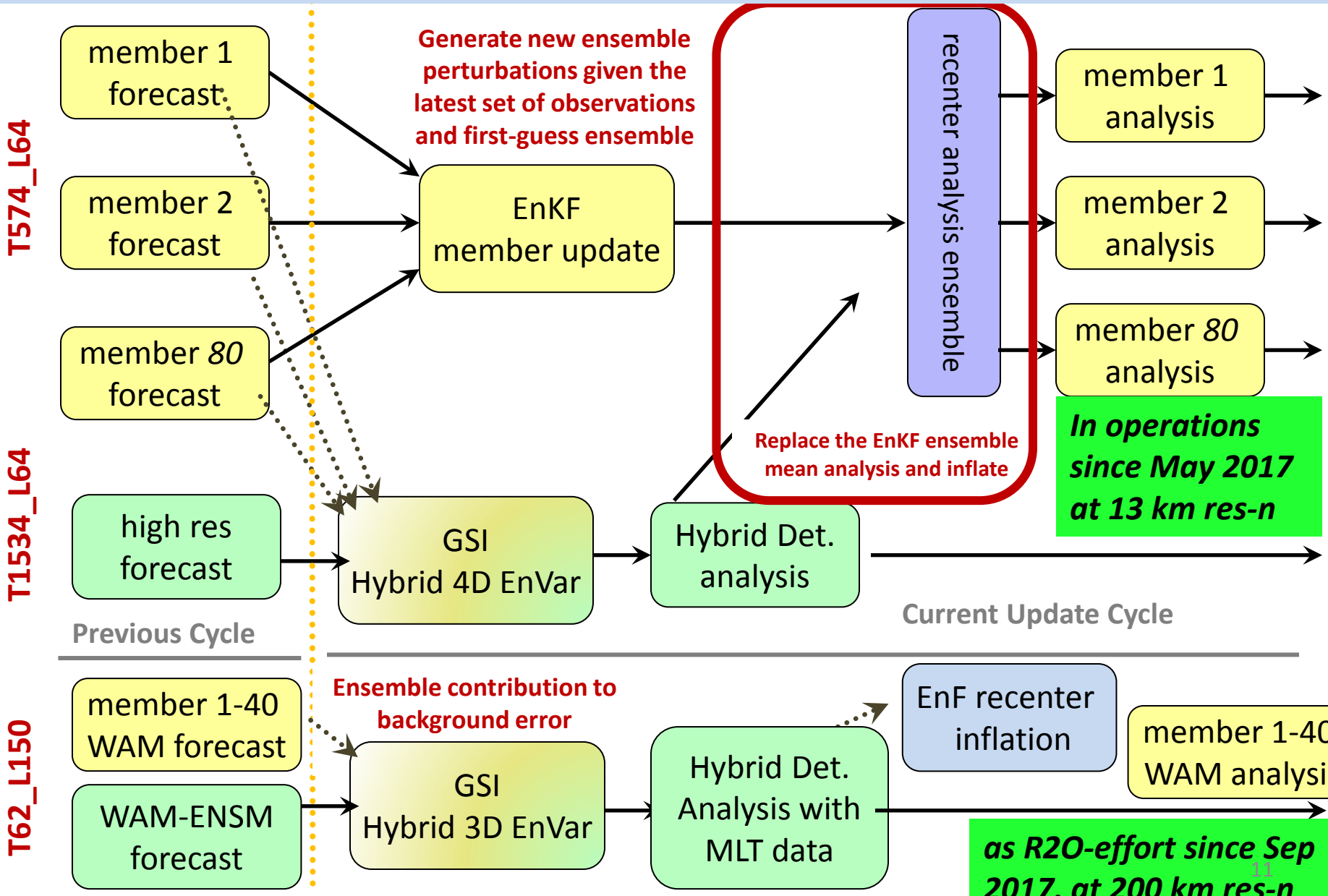




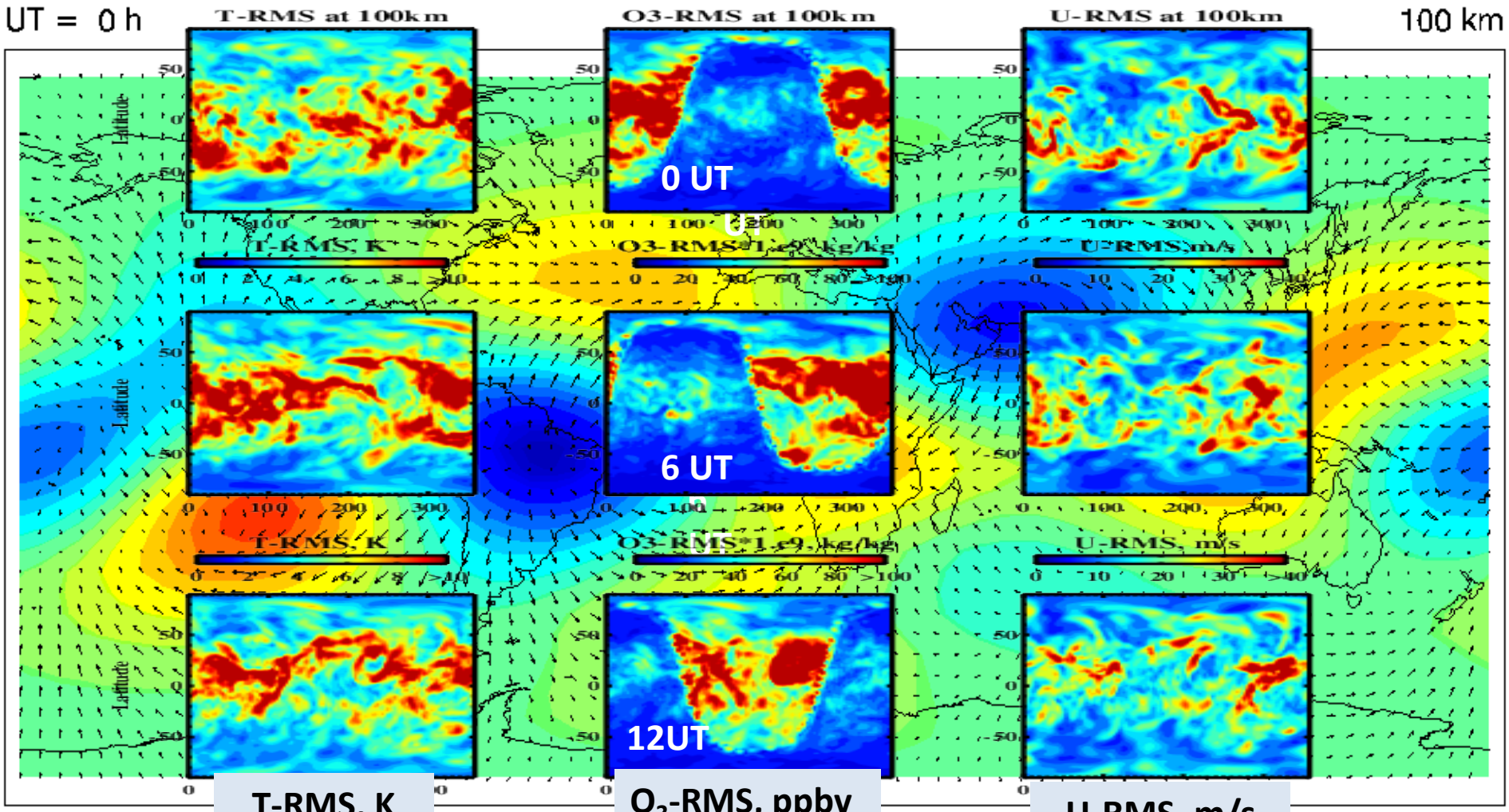




NOAA GDAS/GFS (55km –TL) Operational Hybrid 4DEnVar and WAM-3DEnVar R2O effort (500km –TL, bottom)



WAM: Ensemble-based Errors of the “Hour” at ~100 km

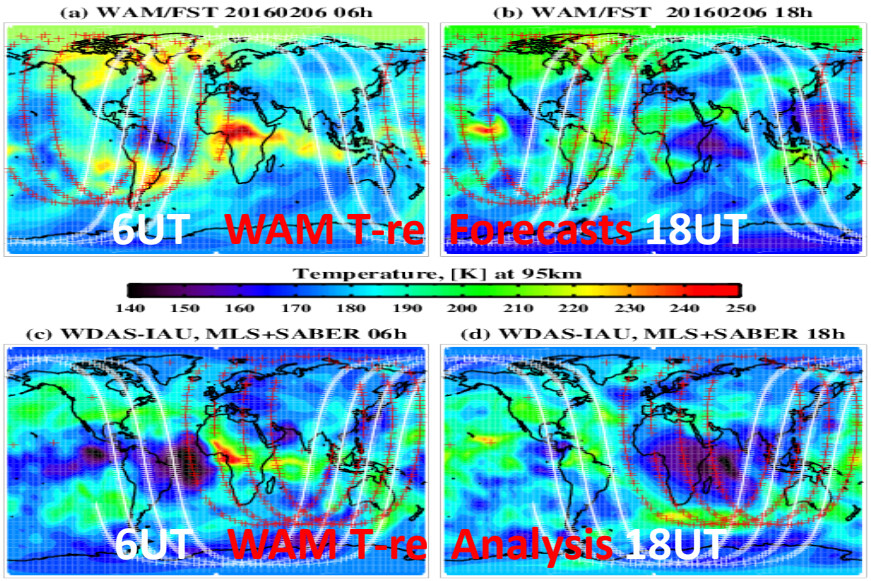


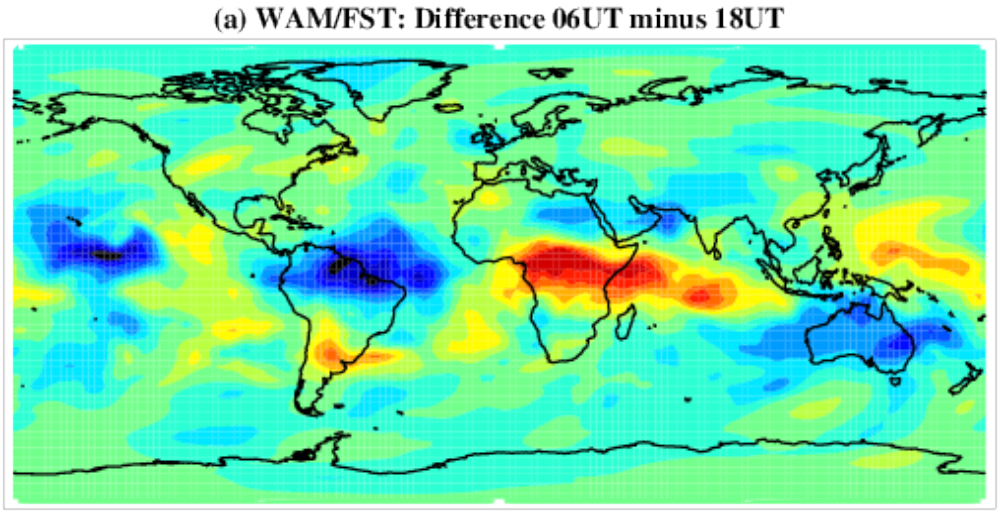
T-RMS, K | **O_3-RMS, ppbv** | **U-RMS, m/s**

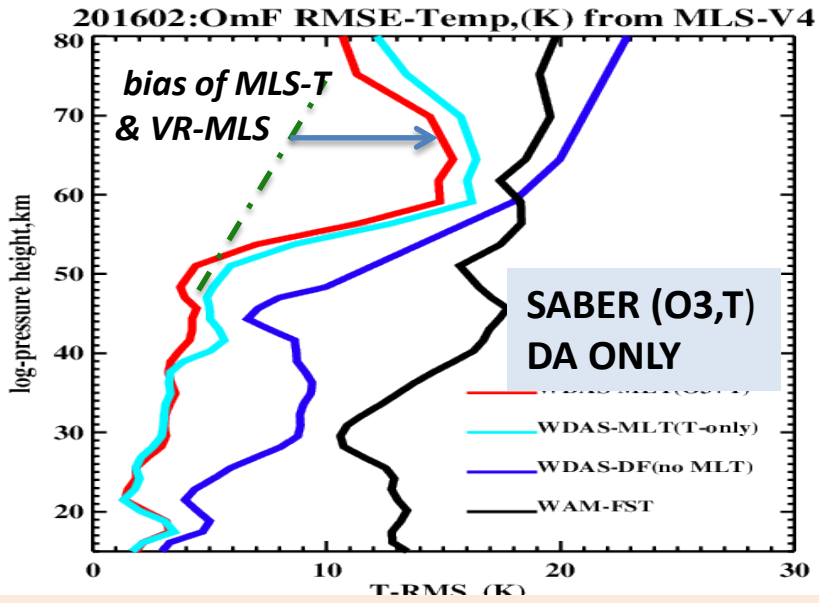
New Diurnally Variable WAM errors

Animation of SABER Temp-re anomalies &TIDI winds, TIDI team at University of Michigan

100 km: Diurnal Cycles in WAM and WAM-WDAS, 20160206



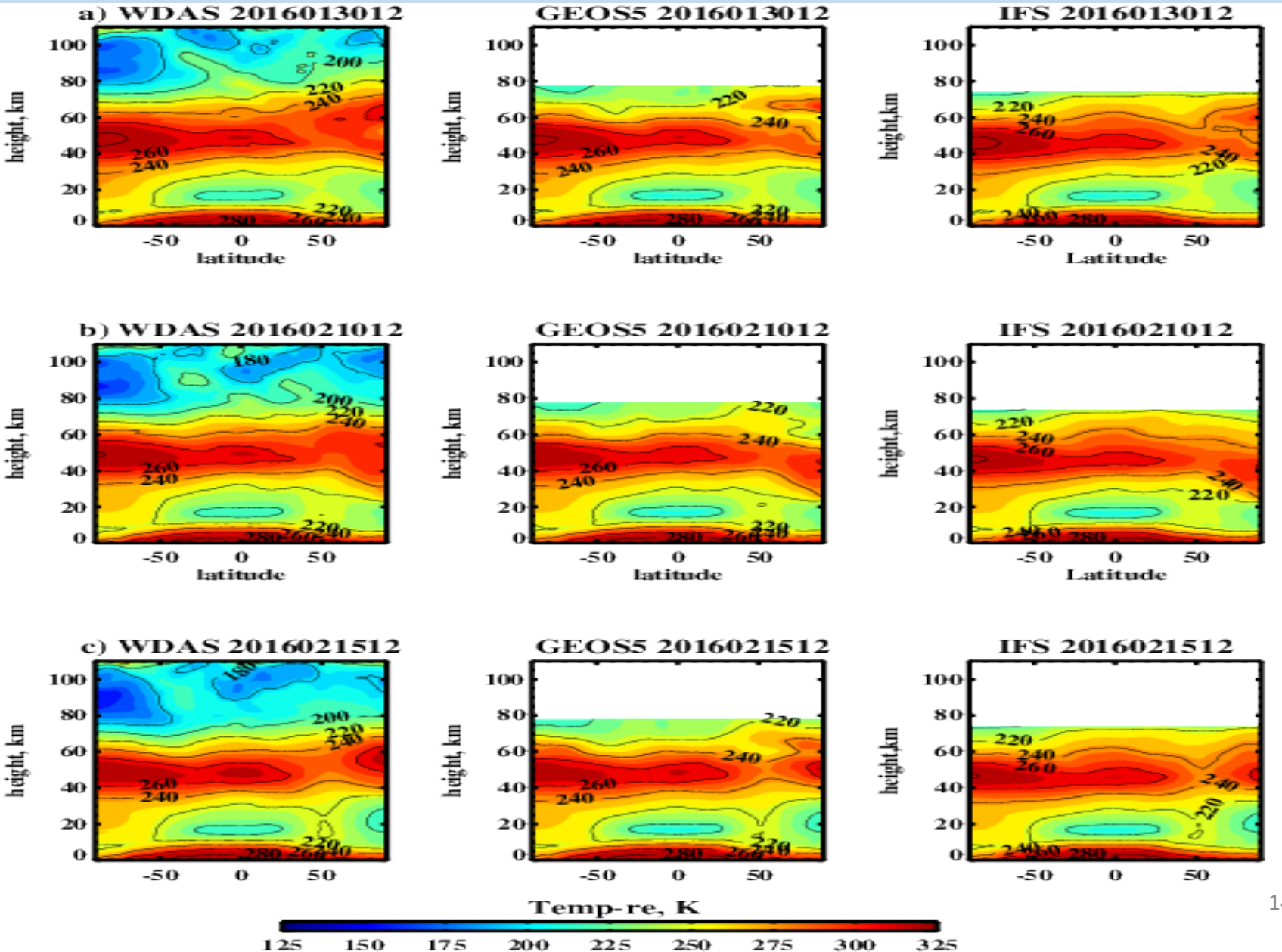




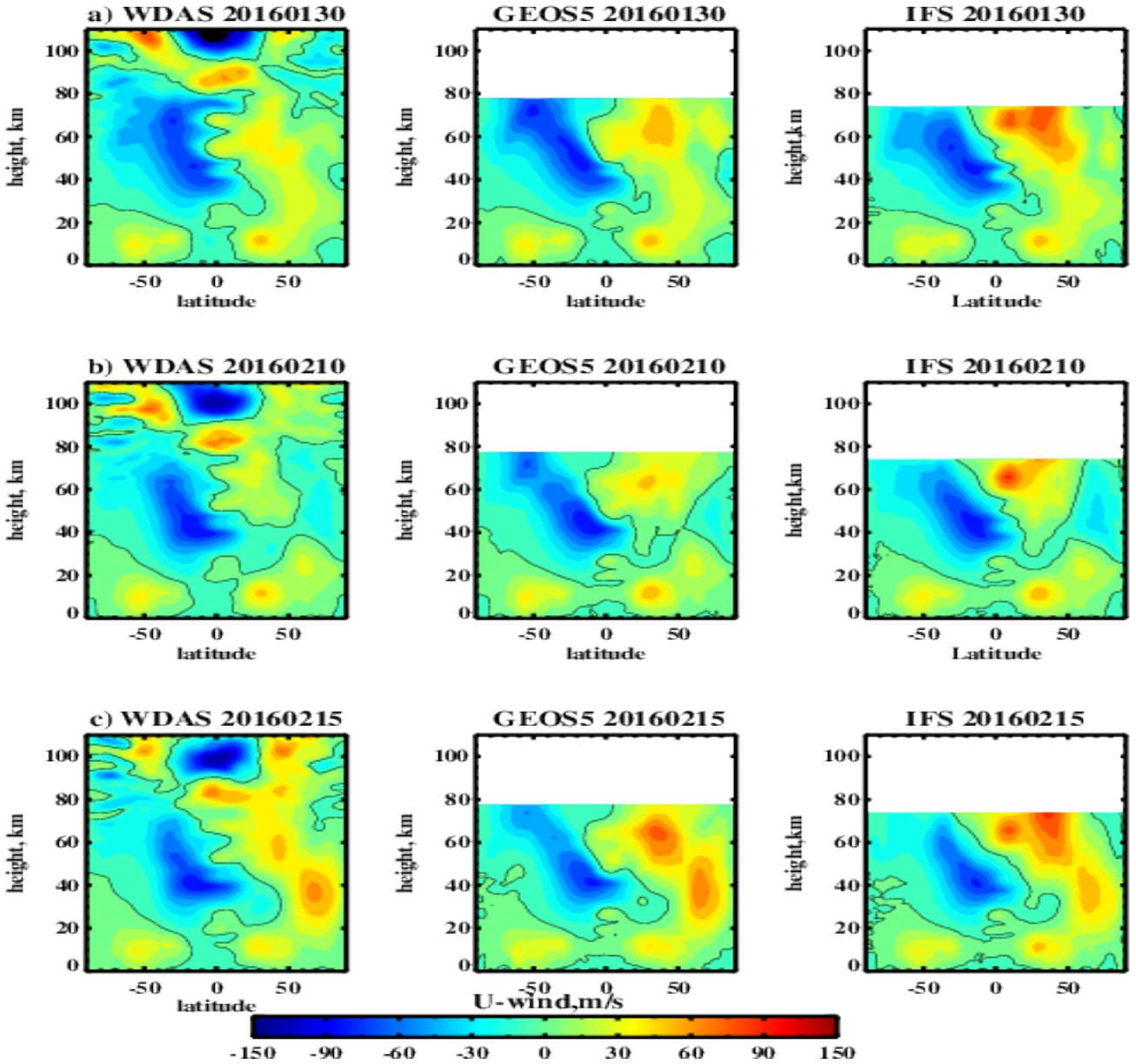
RMS of DA & FST relative to non-anal. MLS-T

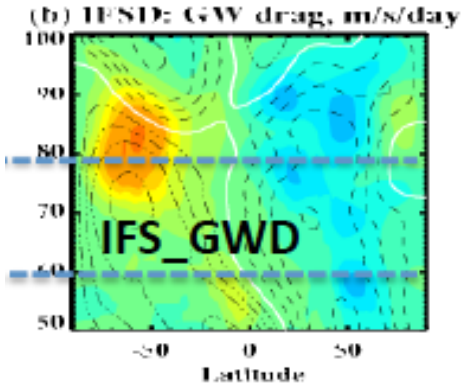
Temperature Analysis: WAM-DAS vs GEOS-5 and IFS/ECMWF

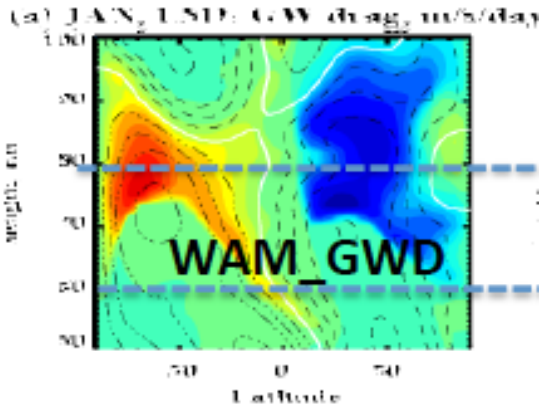
(Jan-Feb 2016 at 12 UT, Stratospheric Pulsations => Density-Temp in MLT)



WDAS vs GEOS-5 and IFS, Jan-Feb 2016, Zonal Winds







No WIND data > 35 km

2-Year Accomplishments and Work during 3-rd Year of the Project Extension

- **Two VE spectral configurations of NEMS – GSM-91L & WAM-150L were tuned and properly initialized to perform the 6-hr A-F cycling** with the MLS and SABER data in operational GFS workflows (V14.0)
- **The vertical extension of GSI – GSIex/3DVar scheme for MLS and SABER T-re and O_3 data include the following 3 aspects:**

  (a) *tapering of Jacobians of the upper channels in the MLT*, where the radiance bias corrections need to be adapted for the "accurate" use;

  (b) *preparation of the 6-hr MLS and SABER data files for GSI-observer*;

  (c) *upgrades of the background variances* (zonal mean fields) for GSIex.

  (d) *diagnostics of data-data and model-data persistent errors* for appropriate bias correction scheme and data quality control;

- **The successful trial performance of GSIex in GSM-91L and WAM-150L for Arctic winters (Jan-Feb) of 2016 and 2018;**
- ***Project extension, Sep 2017-Aug 2018: Transfer 2-Yr results into FV3GFS-128L and FV3WAM with GSIex/3DVar and 3DEnVar***

Collaborations between EMC, SWPC, GFDL, JCSDA and CU

Collaborative work includes the following themes:

- further diagnostics and improvements of wave dynamics (GWs and tides), physics and photochemistry of WAM (CU-CIRES and SWPC);
- development and update of DA schemes in GSI (EMC, CU and JCSDA) with modifications of the GFS workflows for WAM (CU-CIRES and EMC);
- Knowledge of the FV3 dycore (CU-CIRES and GFDL), related to numerical dissipation and wave simulations (GWs) for FV3GFS-128L

Collaboration between NOAA Testbeds/Centers, EMC & CU:

Kate Friedman, Adam Kubaryk, Daryl Kleist (EMC), Svetlana Karol and Tim Fuller-Rowell (CU-CIRES) worked with PI, Valery Yudin to perform the DA experiments and WAM ensemble predictions in the GFS operational workflows,

Collaboration between JCSDA, GMAO and CU-CIRES

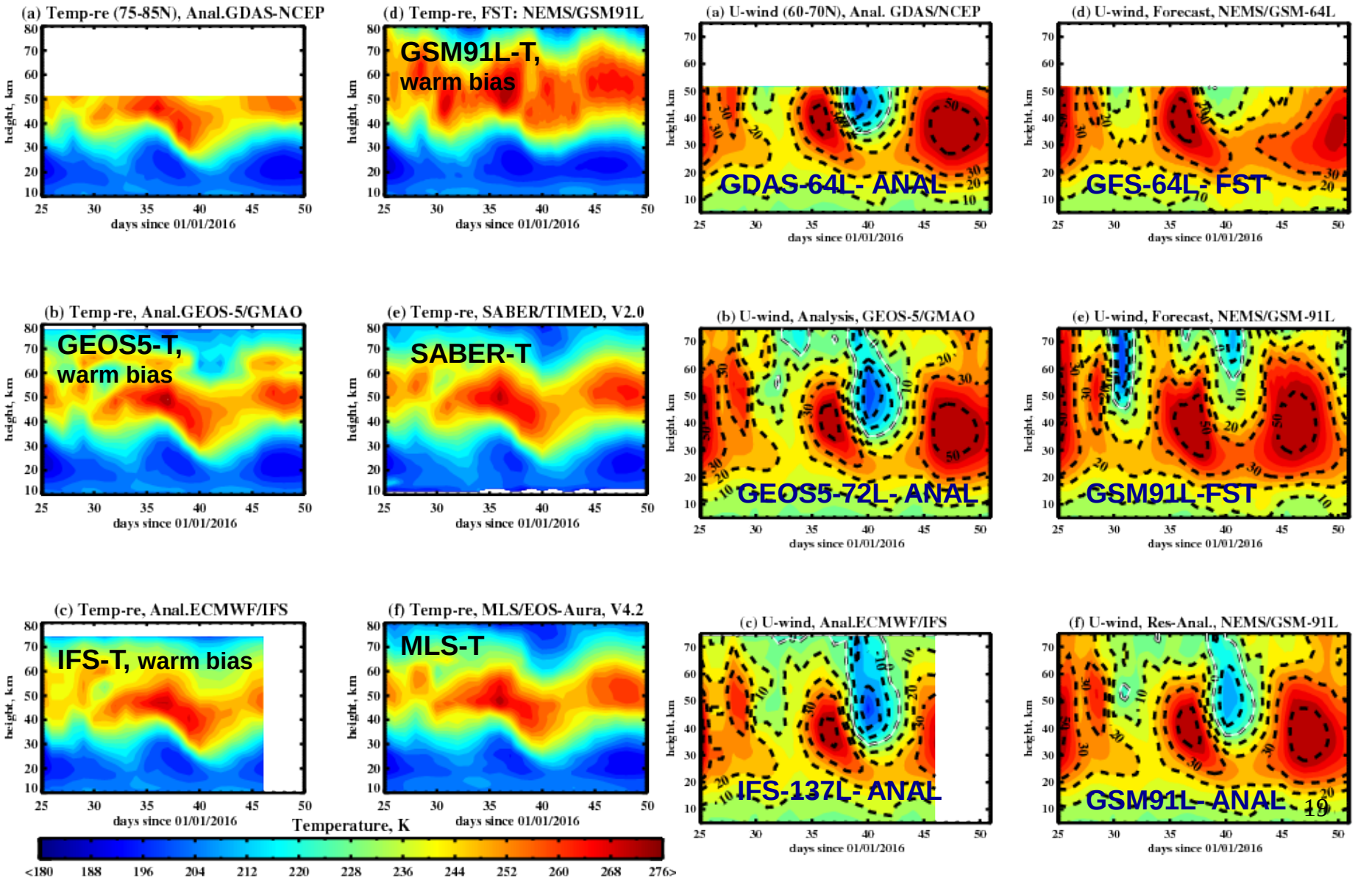
Thomas Auligne (JCSDA) and PI coordinated consultation between GMAO of NASA/GSFC and CU-CIRES on the data analysis of the MLS O_3 and T data

PI would like to acknowledge the productive consultations with *Shian-Jiann Lin and Lucas Harris*, on the FV3GFS-128L development during his GFDL visit in Sep 2017.

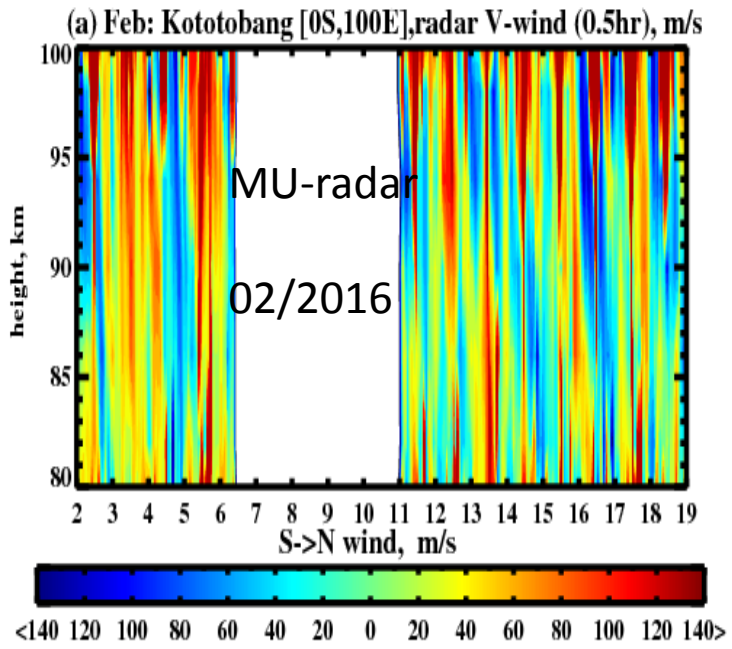
Thank You

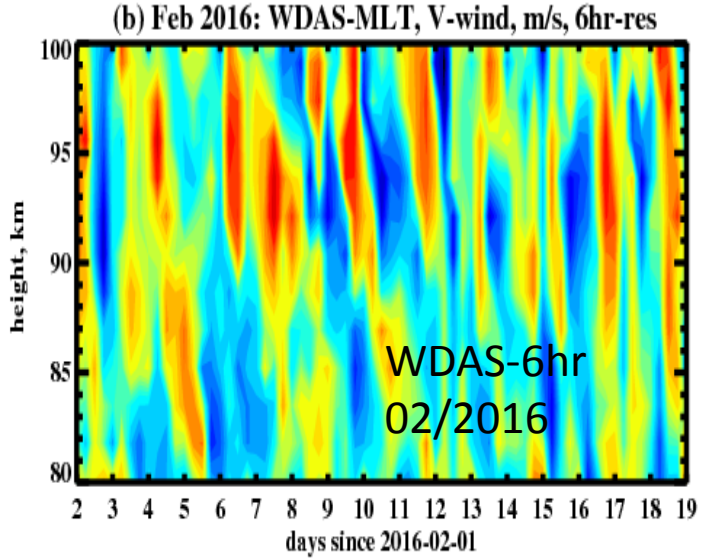
Arctic Polar Temperature & Winds: Analyses vs Forecasts

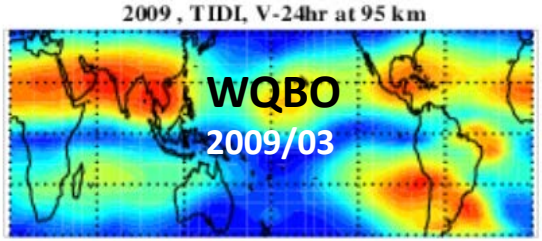
Jan-Feb 2016 (Analyses: GDAS-64L, GEOS-5, ECMWF, and GDAS-91L with MLS & SABER data; FST->GSM-91L with NGWs; GSM-64L)

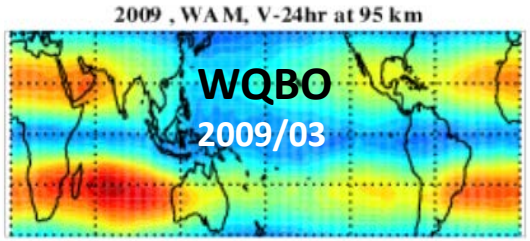


MLT Wind Verifications by independent wind data: Radars & TIDI

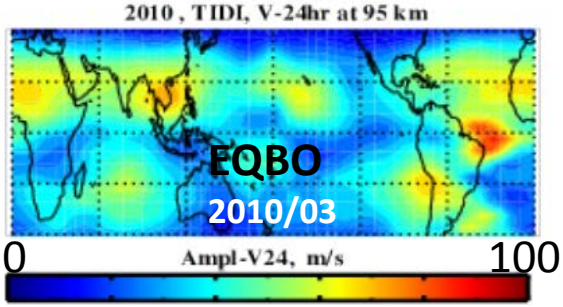


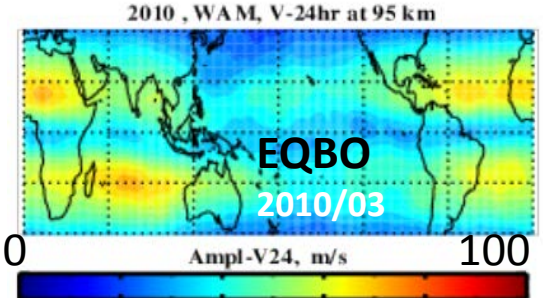






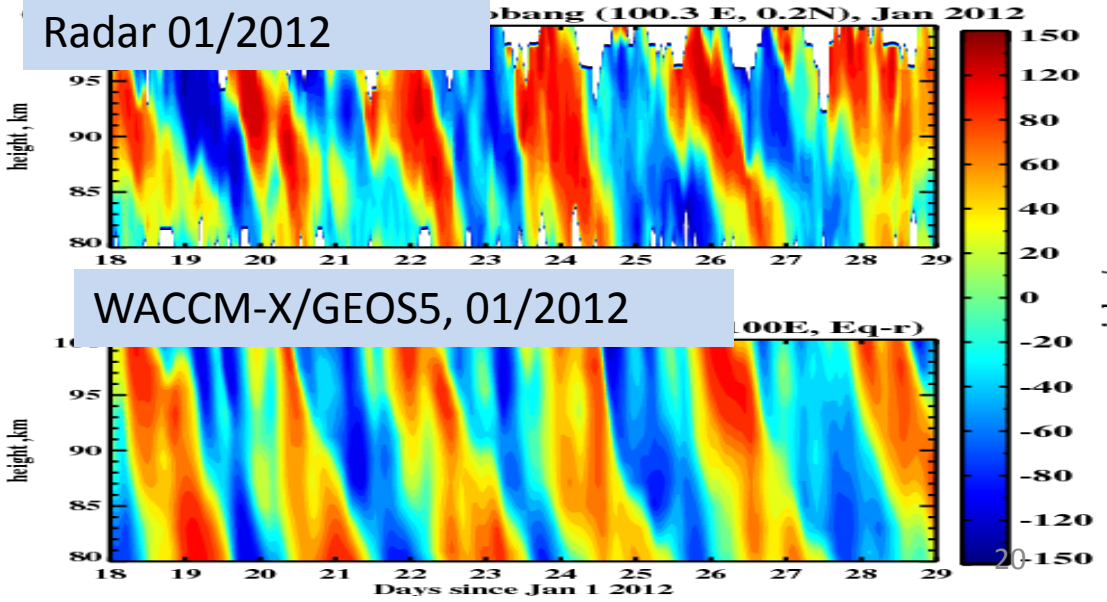
TIDI 24-hr V- Ampl. March 95 km WAM 24-hr V-Ampl.



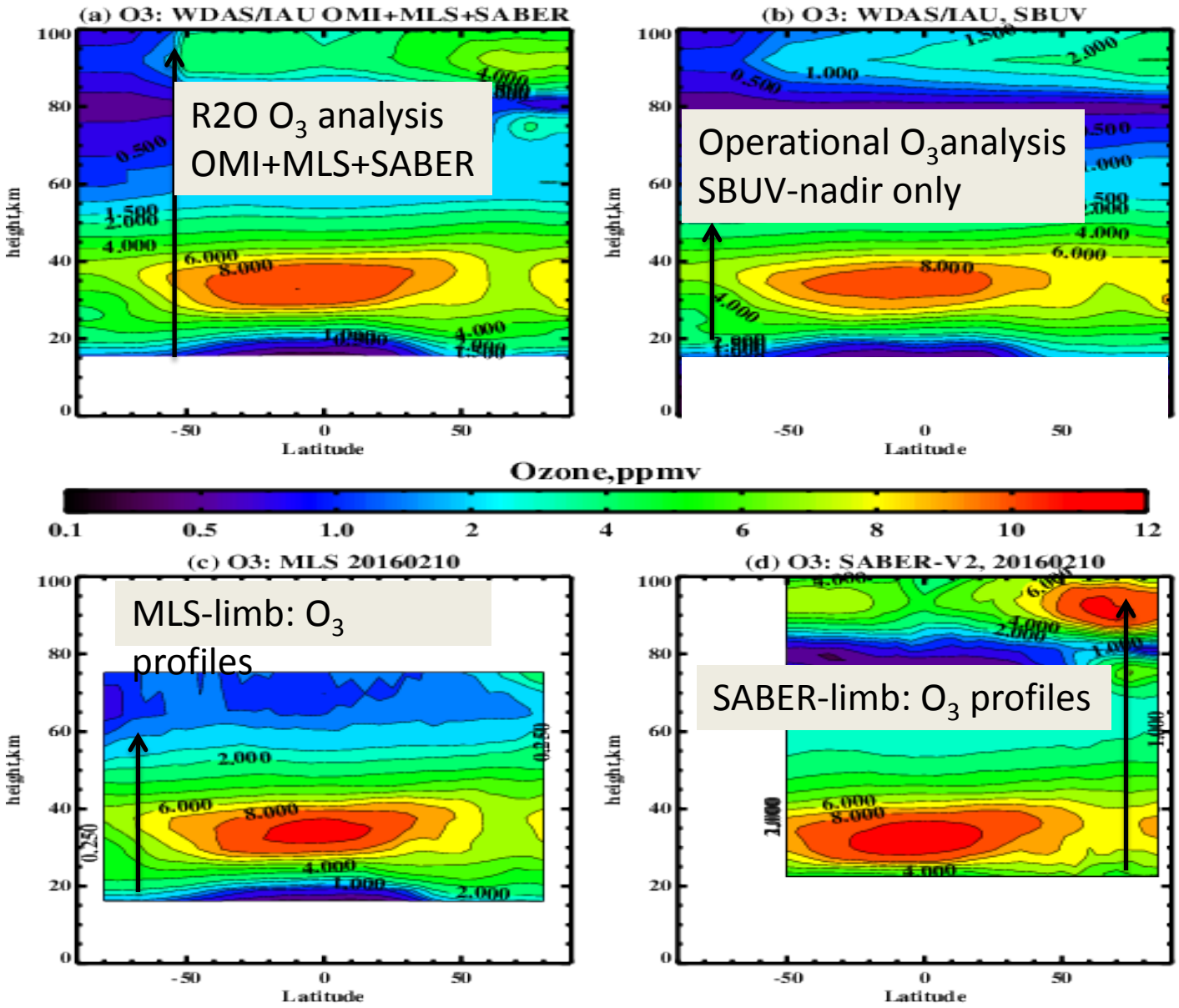


Radar 01/2012

WACCM-X/GEOS5, 01/2012

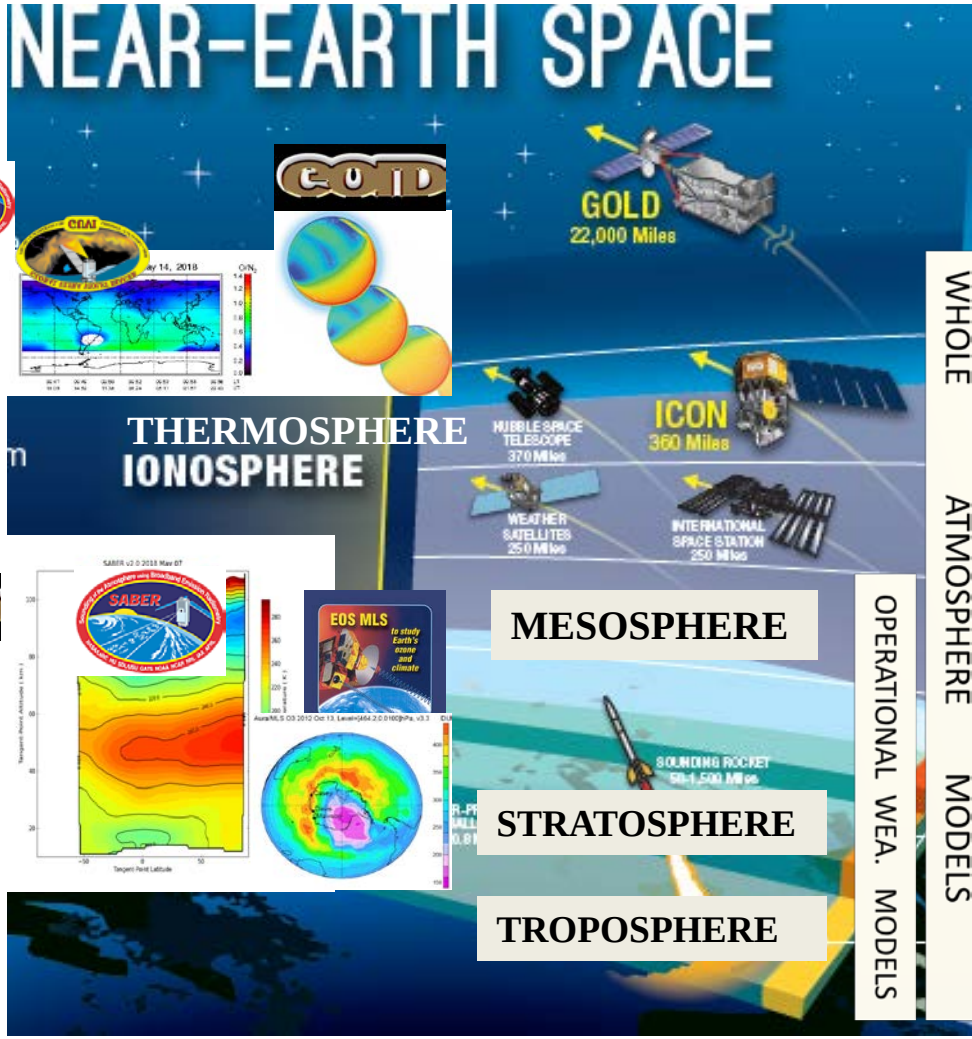


2016-02-10: Ozone DA in WAM (OMI+MLS+SABER) vs WDAS-SBUV



Towards the Near-Real Time Data Analysis with MLS, SABER, GUVI and GOLD Temperatures and Composition

- **New MLS v4.2 NRT Data (T, O_3, 3hr latency; supported by GEOS-5 DAS)**
- **SABER v2.0 Data (T, O_3, ~7-10day latency now; possible consideration)**
- **GUVI v13 Data (O/N_2 ~3-10day latency now; possible consideration)**
- **GOLD Western Disk Data (T, O/N2; NRT-delivery is under consid;** *Launch: Jan 25, 2018*)
- **Goal of NASA's GOLD-ICON Explorers:** ***What is the global-scale response of the ITM to Space weather above and Terrestrial weather below?***
- **To achieve it: Missions needs Integrated Space-Terr. Weather Analysis-Forecast System Support + combined support from TIMED and MLS-Aura sensors.**



Background image from NASA's NEW-ICON-GOLD.pdf

Simple Verifications at VG of GDAS & GEOS-5