Unified GW Physics and Data Analysis in the Vertically Extended Atmosphere Models

Enhancing and Connecting High-Impact Space and Terrestrial Weather Forecasts and Applications

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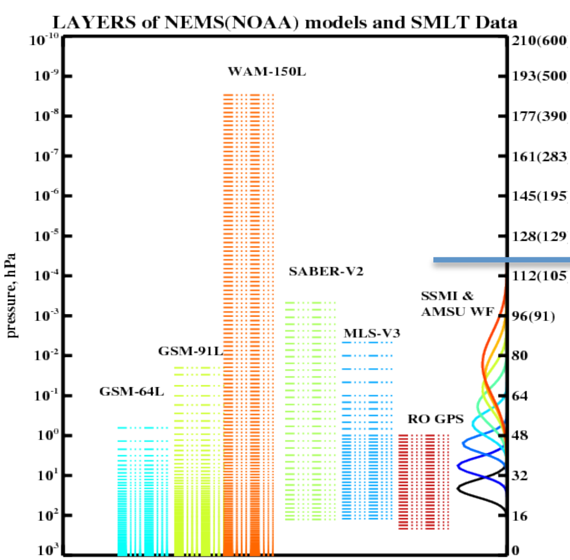
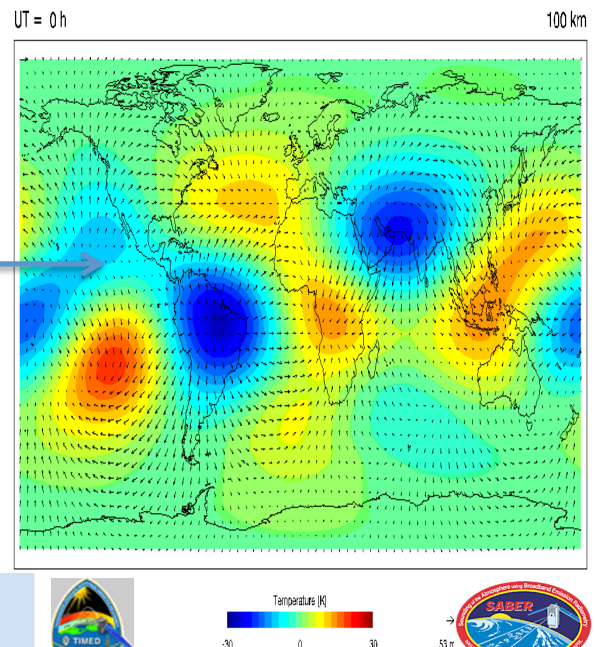
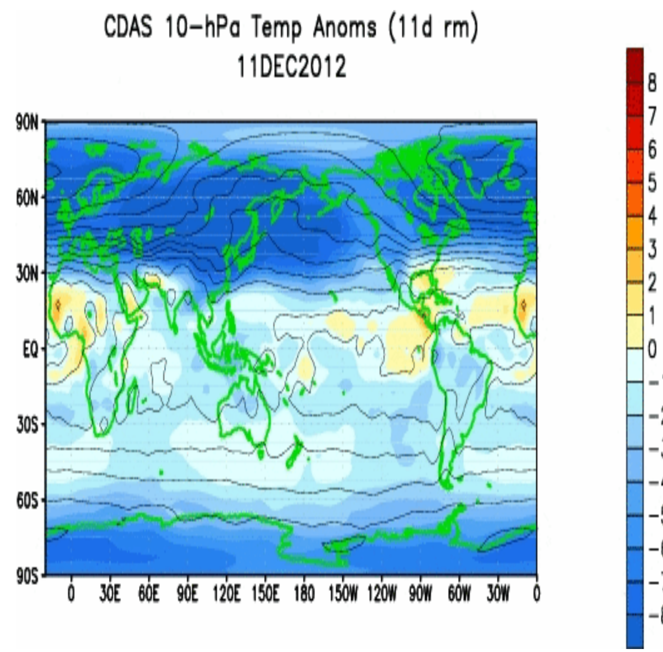
Motivation: *Develop VE NEMS Models to improve forecasts for Terrestrial & Space Weather Applications: 3-TESTBEDS/Centers:* **EMC/SWPC/JCSDA** with collaborations NRL and GMAO





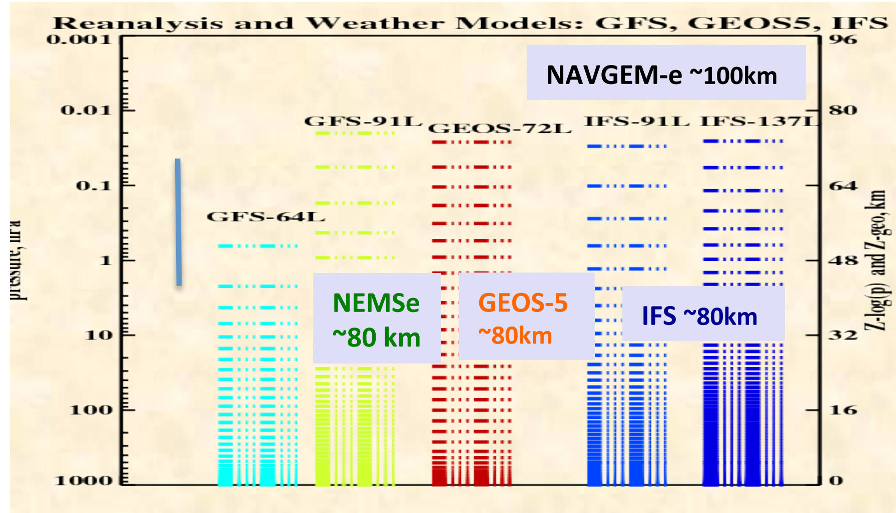


NGGPS PI Meeting
College Park, MD, Aug 2 2017

Vertically Extended (VE) Global Models of NOAA

Motivation to develop VE for GFS:

(1) To be on the same page with NWP systems that resolve the stratosphere;
(2) Create direct connection between Terrestrial and Space Weather predictions in the WAM framework.

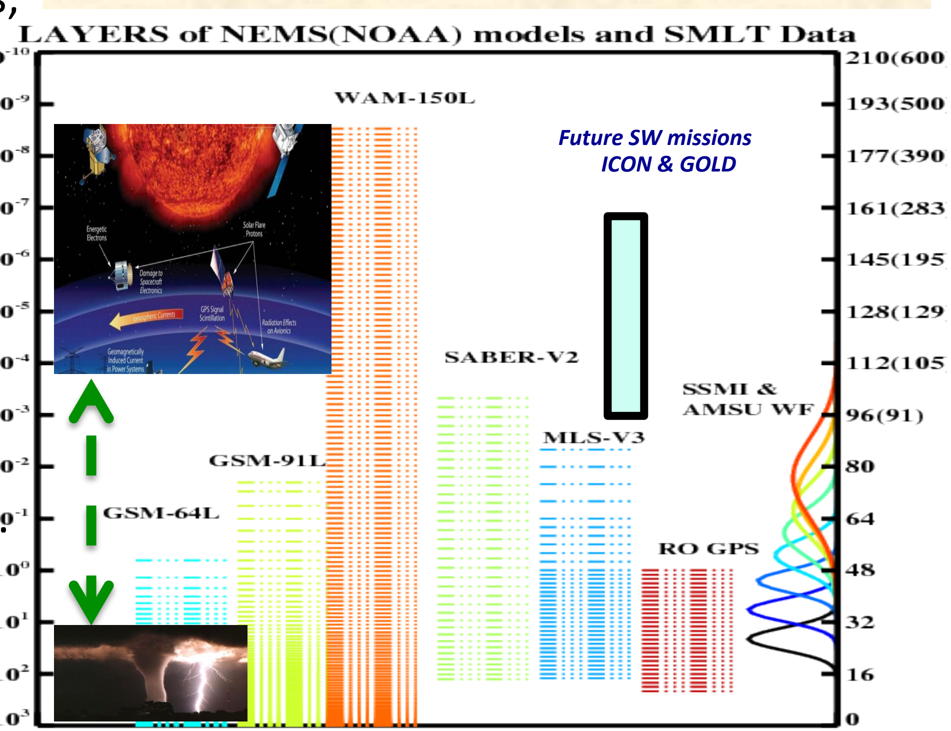


Key upgrades to extend models > 50km:

(1) Radiation and Chemistry with 24-hr cycles;
(2) Gravity Wave (GW) Physics;
(3) Tune-ups/orchestration of numerical dissipation with GW eddy mixing/drag, and radiation with GW heating/cooling;
(4) Initialization of VEM with realistic tides

Verification, Validation and Metrics:

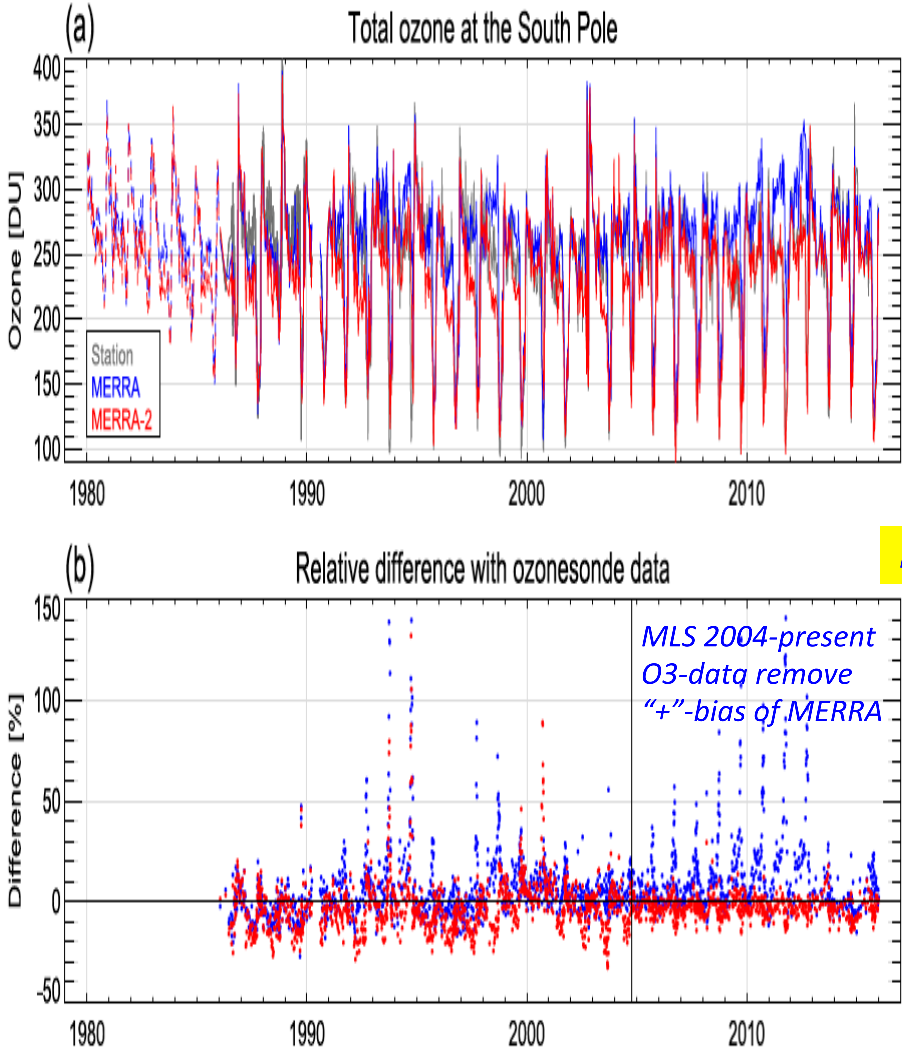
(1) Whole Atmosphere Range: 30-500km
(2) SMLT data collections, first for 20-150 km.

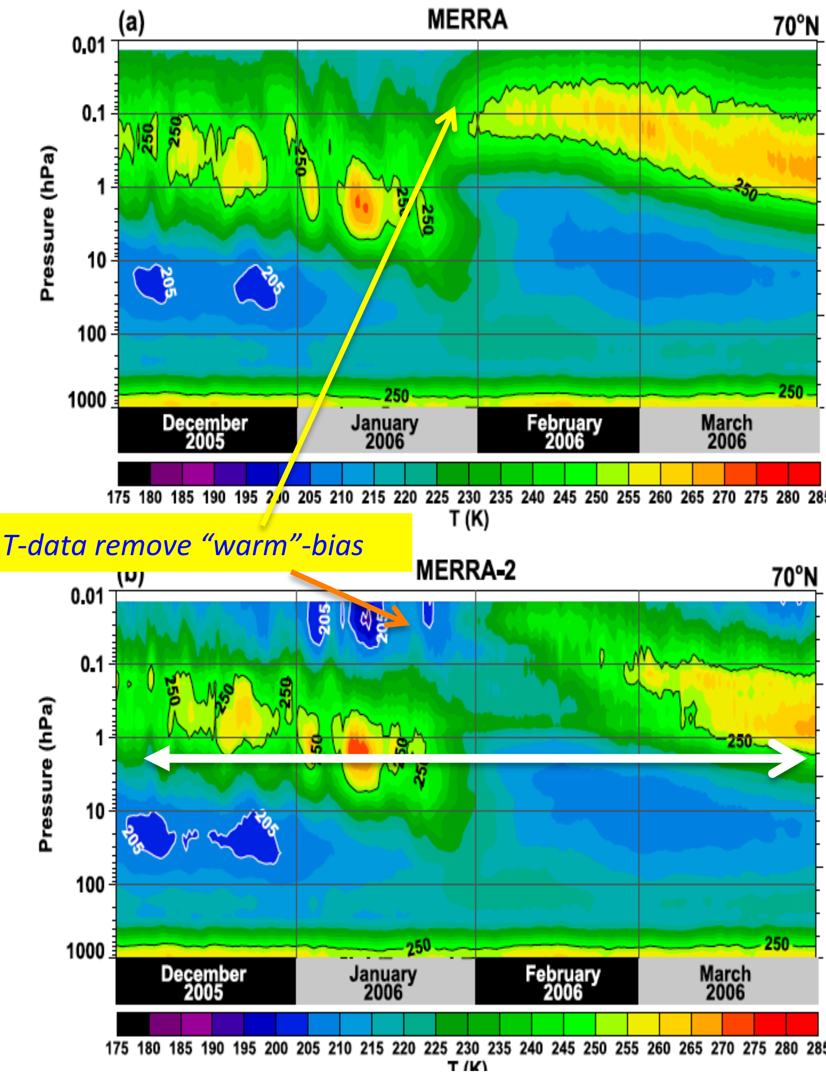


Extension of DA: GSI-SMLT; GSI-WAM (WDAS)

Collaborating with GMAO & NRL groups to adapt & extend analysis of SABER and MLS data to ~110km

MLS: Improvements of MERRA-2 vs MERRA due to analysis of MLS Ozone (South Pole) and Temperature (70N, 2006) profiles





Ron Gelaro et al., MWR, 2017

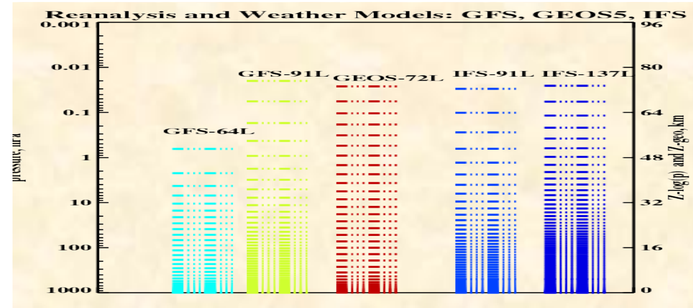
Spectral Vertically Extended Configuration of NEMS/NGGPS: NEMS/GSM-91L, WAM-150L and Suite of Observations

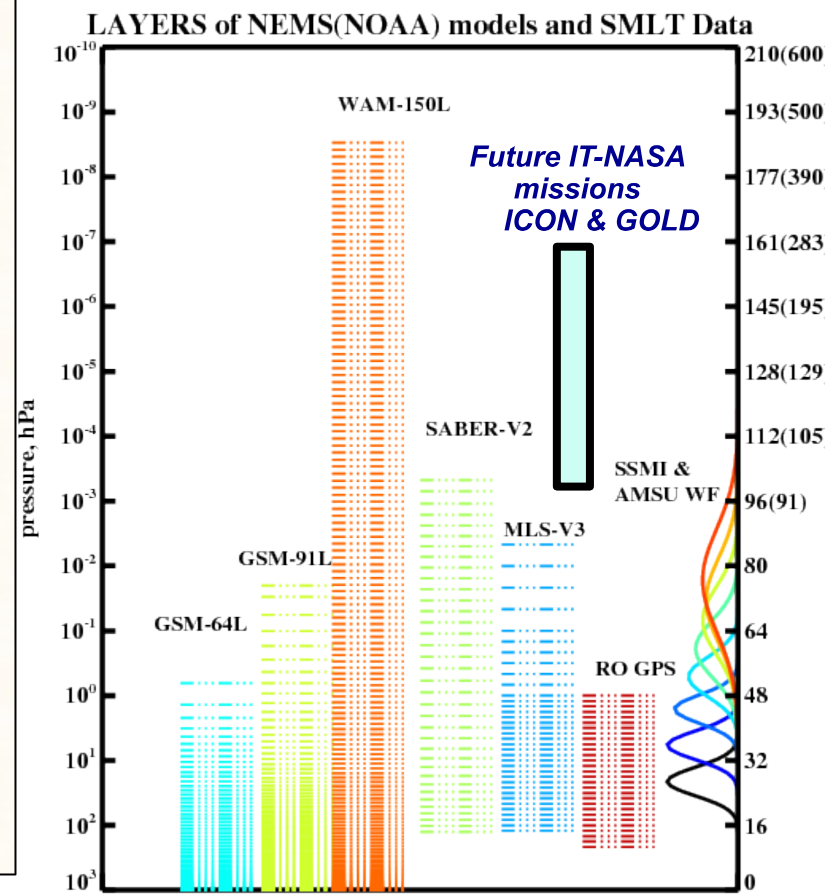
- **Vertical levels of NEMS/GSM-91L** follow IFS-91L and match GEOS5-72L(~80 km);
  Decreased (~3-times) **Rayleigh fric.**
  > ~50 km with inv. scale 15 days + UGWP

- **WAM, TL~500km: adapted GW solvers with dissipation for :** (a) Linear saturation with dis-n; (b) IFSD-2000; (c) DSPD-Hines-97'; d) Alexander/Dunkerton-99D. **Previous** (IFS, NOGAPS, GMAO) **choices for GW intensity at ~ 500-700 hPa** *to replicate latitudinal and seasonal GW activity in the troposphere from the data.*

- **GW physics acts in** 4- azimuths and tested for **T62 ..->..T670; Stoch. & Determ. In progress** for NEMS-91L : eddy mixing; non-LTE radiation; **resolution-aware formulations of GW-schemes (in FV3-?)**

- **SMLT data => in WDAS & GSI-91L**



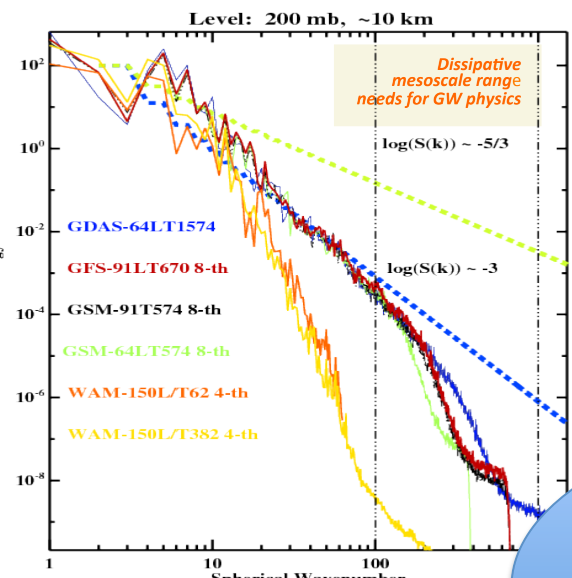


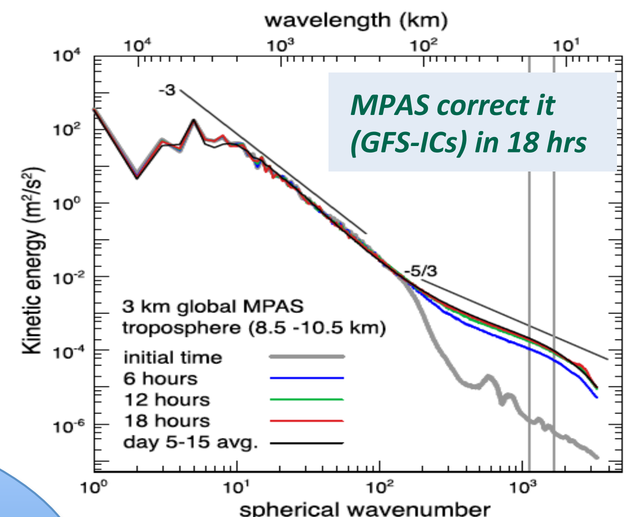
Motivation and Formalism for Unified Gravity Wave Physics

Mesoscale GWs transport momentum, energy (heat) , and create eddy mixing in the whole atmosphere domain

→

Breaking and dissipating GWs deposit:
(a) momentum; (b) heat (energy); and create (c) turbulent mixing of momentum, heat, and tracers





SGS and RS GW effects on the large-scale flow: BD-circulation, QBO & SAO in the STRAT-RE & MESOS-RE; Tides and PWs, tracer mixing

Unified: ***a) all GW effects due both dissipation/breaking; b) identical "GW" solvers for all "GW" soueces; c) ability to replace solvers.***

To properly incorporate GW effects (a-c) unresolved by DYCOREs we need GW physics

Unified Formalism (Sources-Propagation-Effects) for UGWP

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

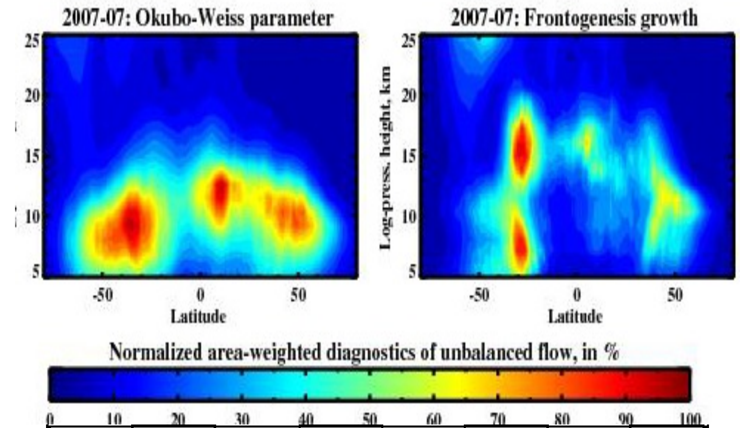
2. ***GW Propagation:*** Unified solver for "propagation, dissipation and breaking" excited from all type of GW sources.

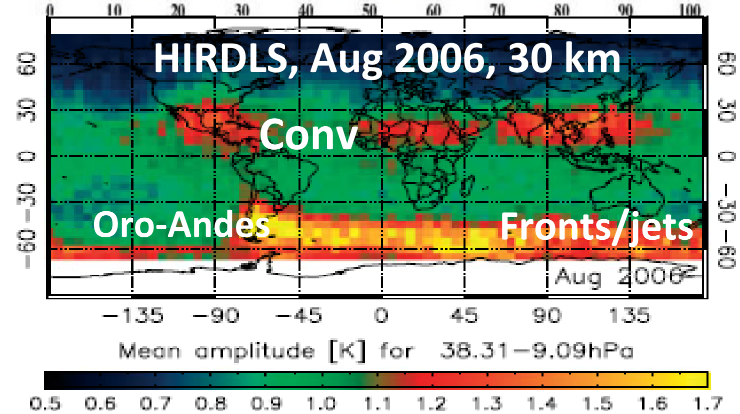
3. ***GW Effects:*** Unified representation of GW impacts on the 'resolved' flow for all sources (energy-balanced schemes for momentum, heat and mixing).

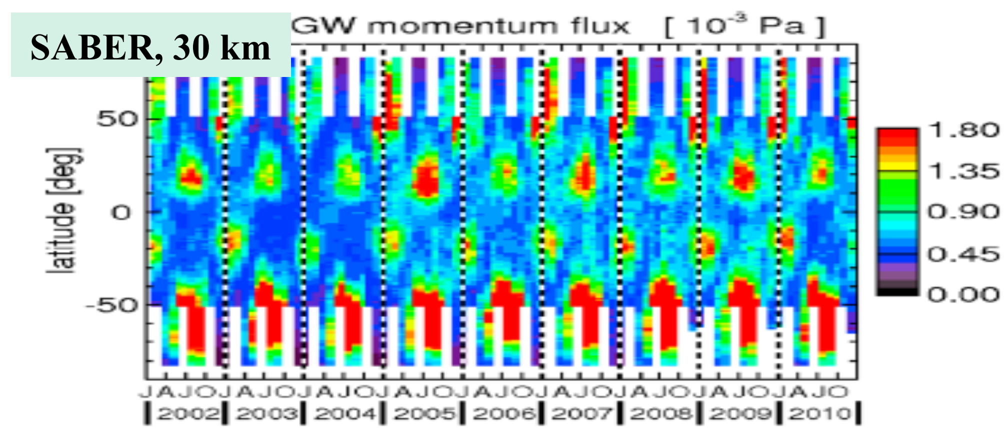
4. ***Resolution-awareness of sub-grid GW schemes*** in *all* aspects of wave physics

$$\Delta x / \Delta z \sim \omega / N$$

Resolved mesoscale (s >30-100) may guide to centers of sub-grid GW activity (triggers); Sat-te data for GWs (s>6)



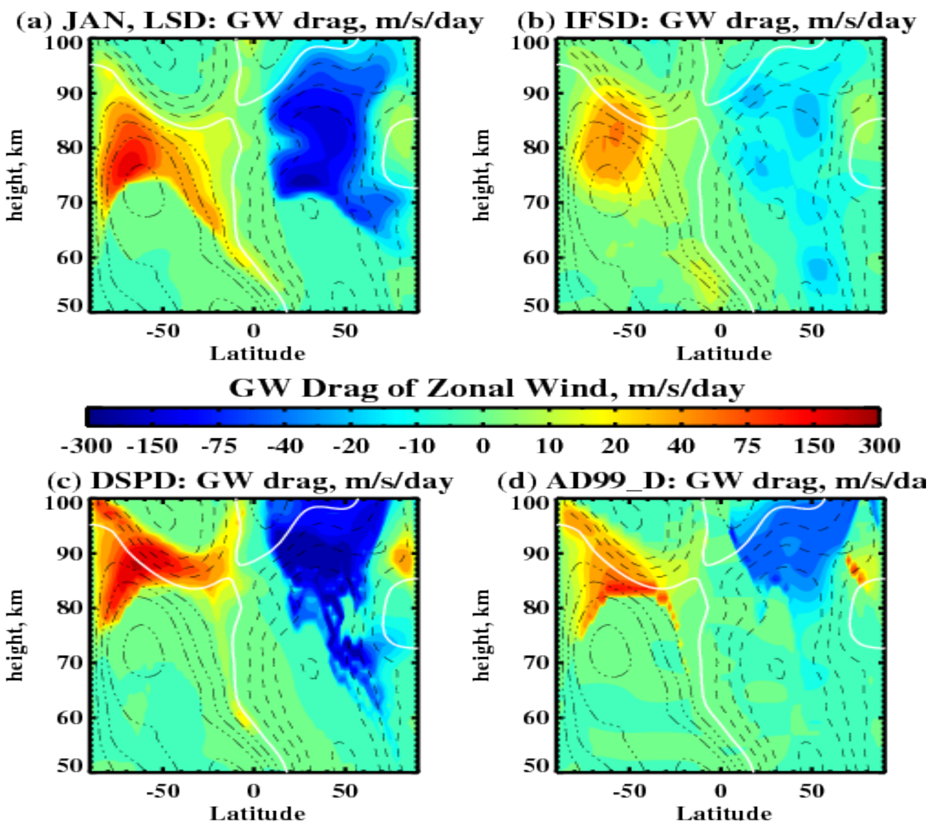


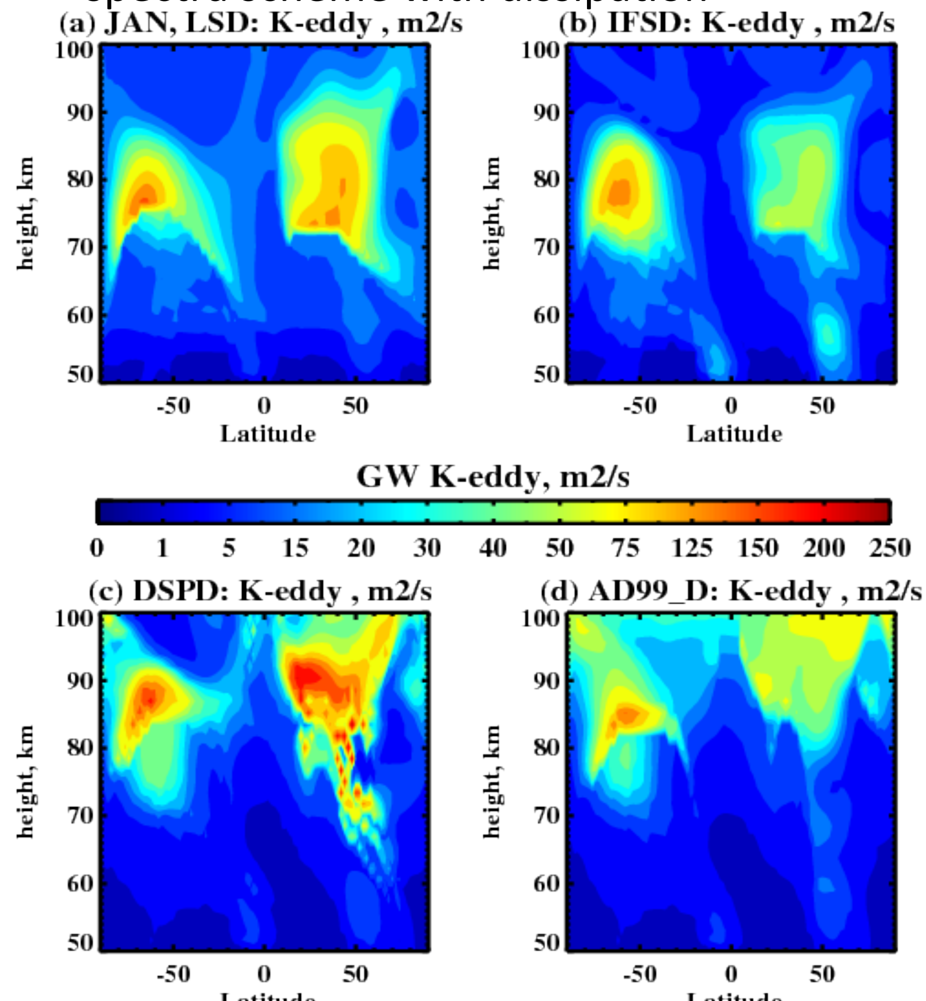


Examples of Standalone Diagnostics of 4-GW solvers:
GW drag (m/s/day, left) and Eddy Mixing (K-eddy m2/s, right)

(a) LSD -Linear multiwave GW scheme with dissipation

(b) IFSD - Orr (2010) “empirical” broad spectra scheme with dissipation

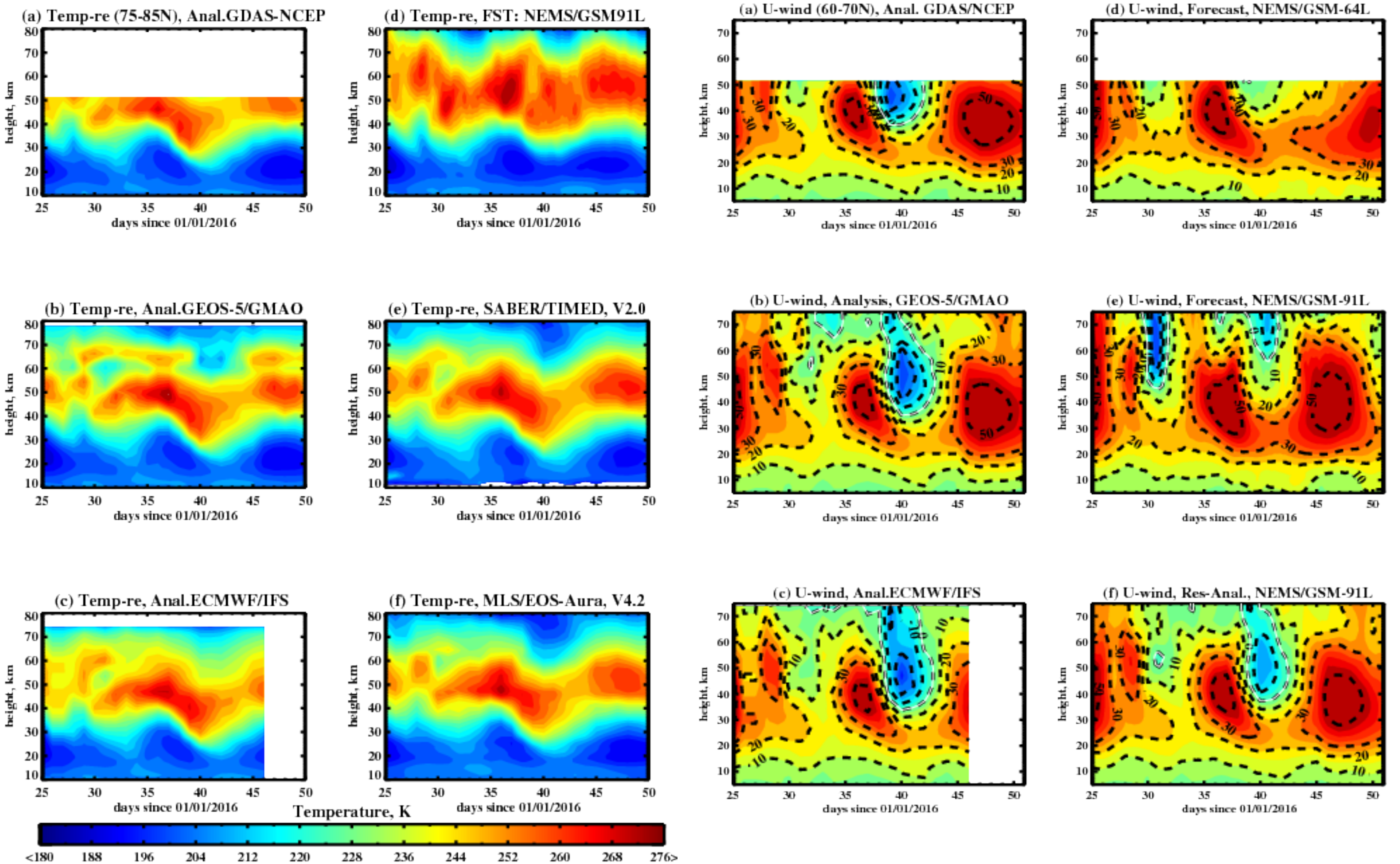




(c) **DSPD** –Doppler Spread GW scheme of Hines (1997) with dissipation

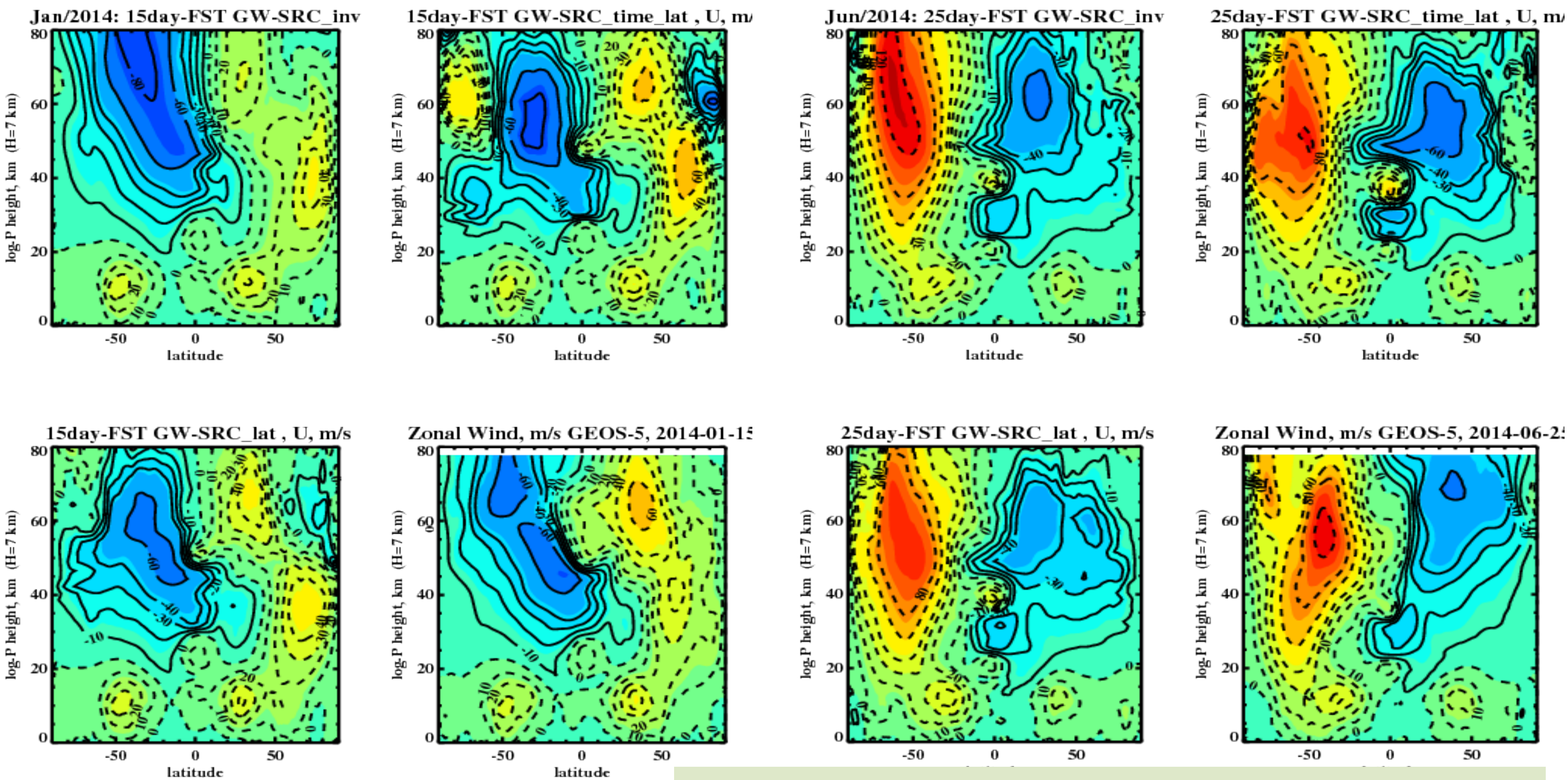
(d) **AD99_D** - Alexander and Dunkerton GW broad spectra scheme with dissipation

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



NEMS/GSM-91L: Selected Testing vs GEOS-5:

2014 Jan, 15day FST 2014 Jun, 25day FST

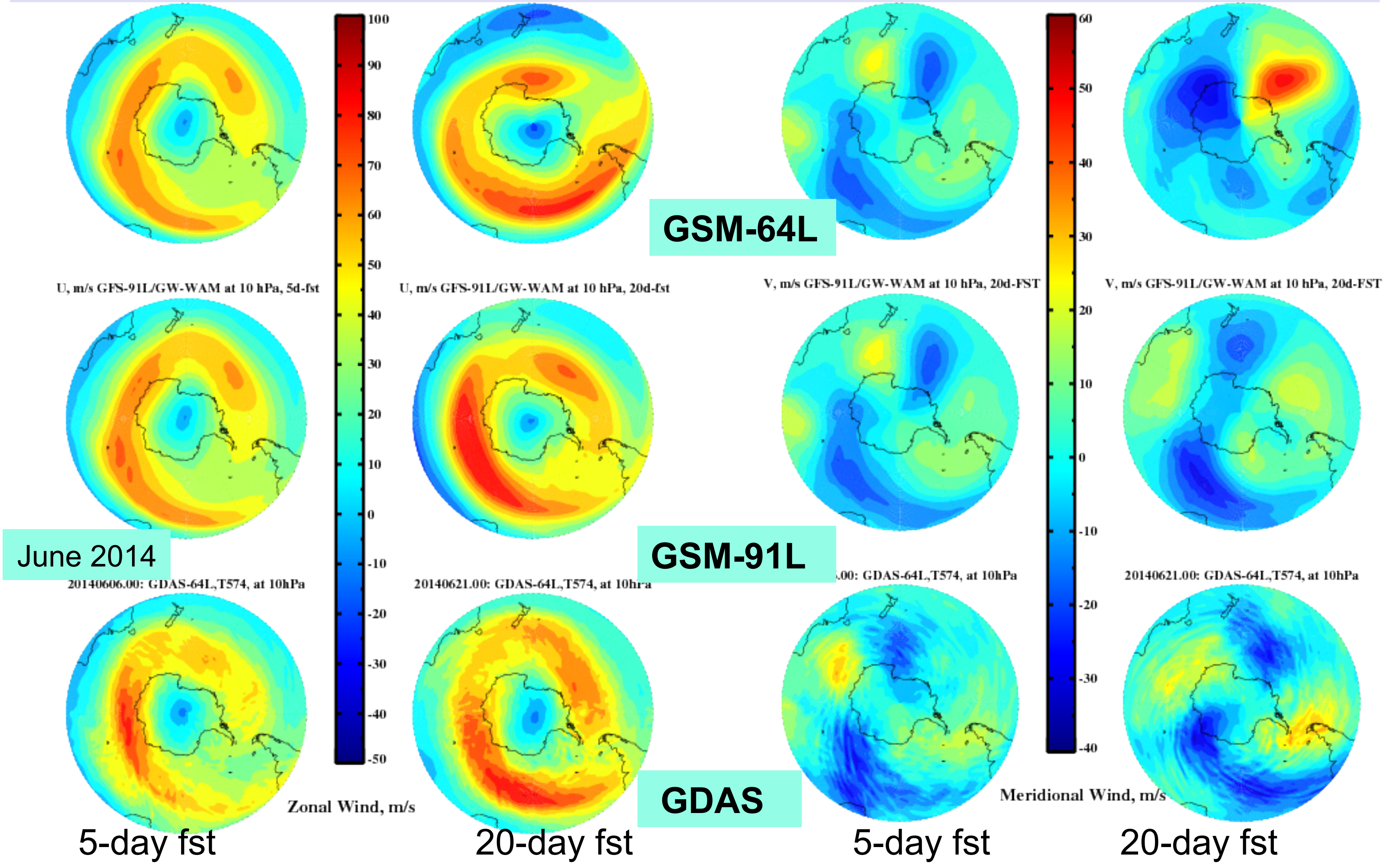


GSM-91L with various GW source functions and GEOS-5 analysis

Sensitivity runs to GW-sources*: *constant, time-lat dependent (top rows) & latitude-dep GEOS-S GW source function & GEOS-5 (bottom)

The 5- and 20-day Forecasts of the South Ocean Zonal (right) and Meridional (left) Winds by GSM-64L, GSM-91L and GDAS,

June 6 and 21 of 2014, 10mb



WAM-IPE, NOAA and CIRES,

Akmaev et al.(2014), Yudin et al. (2015-16), Fuller-Rowell et al. (2017)

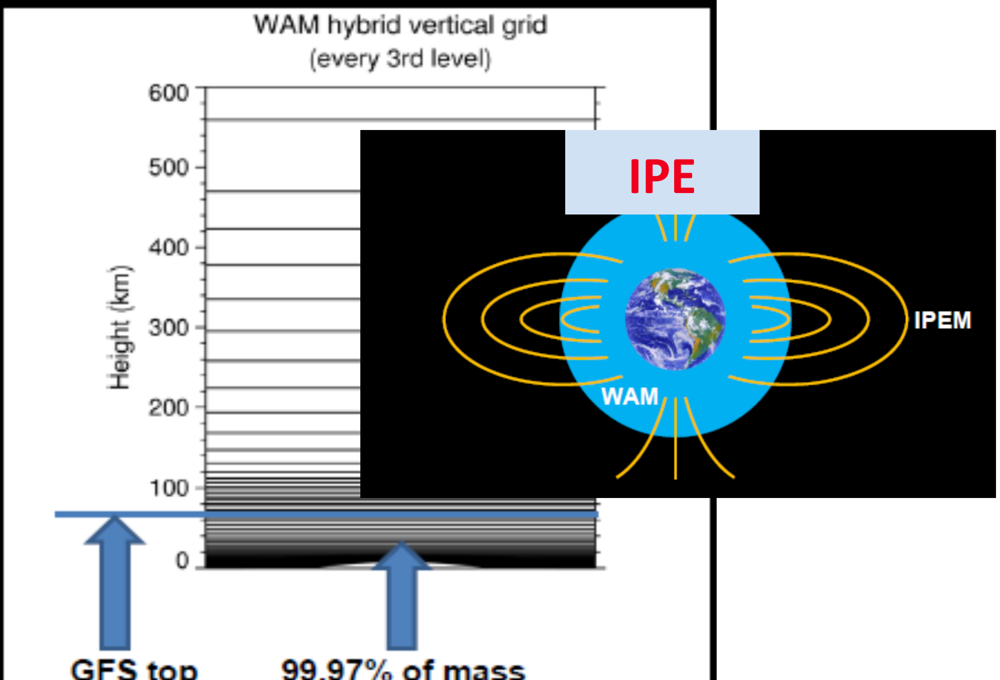
WAM = Extended GFS

Whole Atmosphere Model

- p_{top} = 1.5×10^{-7} Pa
- T62L150 (~ 2°×2°, ~ 0 – 600 km)
- Free or A/F cycle (WDAS) runs
- Composition dependent *R* & C_p
- Height dependent *g(z)*
- Timing ~ 5.5 min/day on 32 CPUs

Physics

- Horizontal & vertical mixing (no "sponge")
- Radiative heating: EUV, UV, & non-LTE IR
- Empirical ionosphere & electric fields: ion drag & Joule heating
- Major species composition



IDEA (WAM+GIP) forecast of plasma drift @ Jicamarca (Wang et al., 2014) compared to observations (Goncharenko et al., 2010).

2016/17 WAM-R2O UPDATES:

(1) Non-stationary GW physics; high horizontal resolution WAM simulations (T254, T382).

(2) Eddy mixing of tracers, momentum and potential temperature by unstable GWs

(3) Updates of the iononspheric and solar modules . observed EUV, and empirical aurora drivers.

(4) Online diagnostics (NETCDF-based) for tides, PWs, and GWs

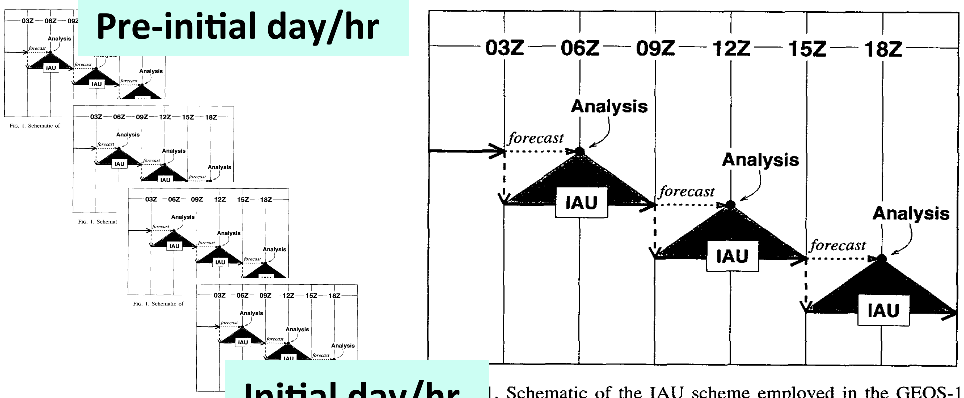
(5) Balanced Initialization of WAM by GDAS and GEOS-5

Balanced Initialization Technique for WAM-2017

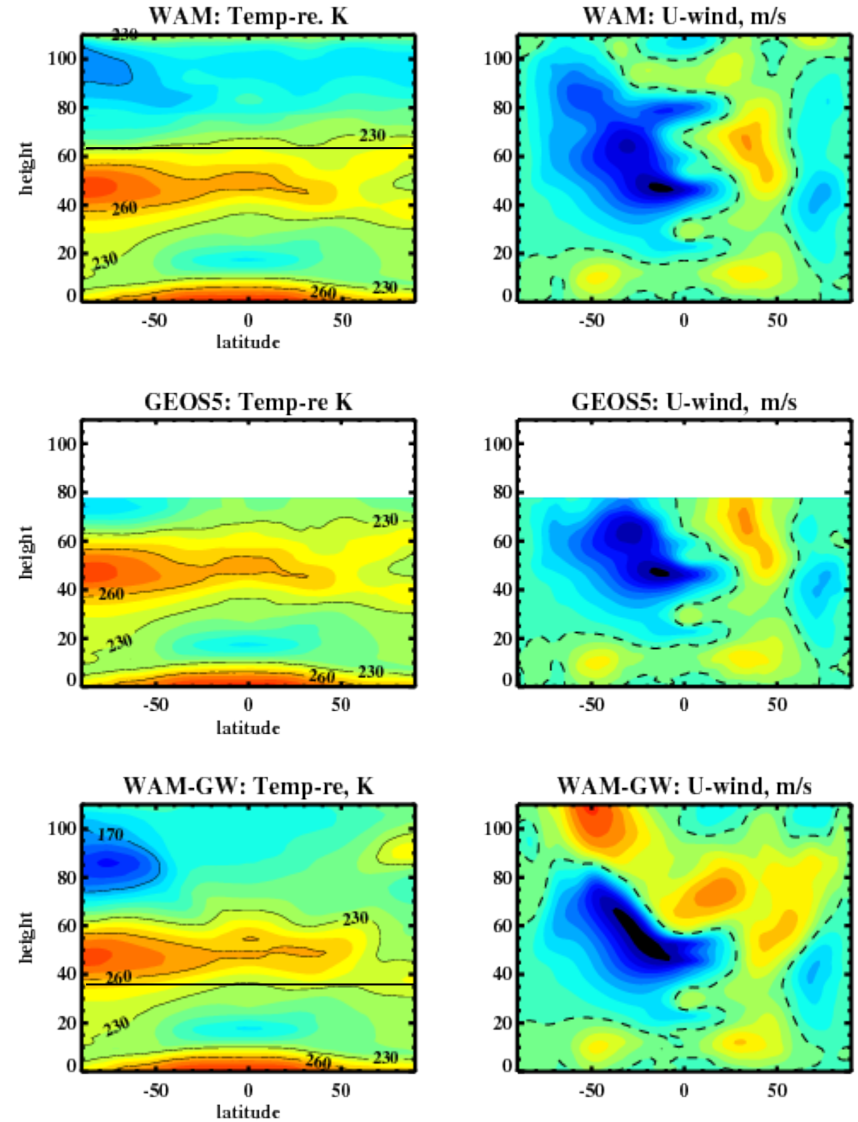
Balanced Initialization Technique –BIT

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

Give opportunity to VE models accept during 3-6 spin-up days the analysis state" by the assigned "Initial Day-Hr" in the data analysis domain and CONNECT UPPER LAYERS with "realistic" LOWER LAYER DYNAMICS.



Incremental Analysis Update – IAU, Bloom et al.1996



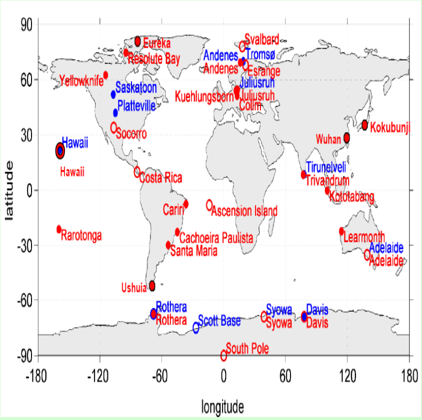
WAM with AT of GEOS-5, 2013/01/28

Metrics for WA model evaluations in SWP systems:

(1) Seasonal cycles of global wave amplitudes and phases, quasi-stationary PWs, tides (24-hr, 12-hr, 8-hr), two-day waves, ultra-fast Kelvin waves and annual variations of prevailing (zonal mean) flows.

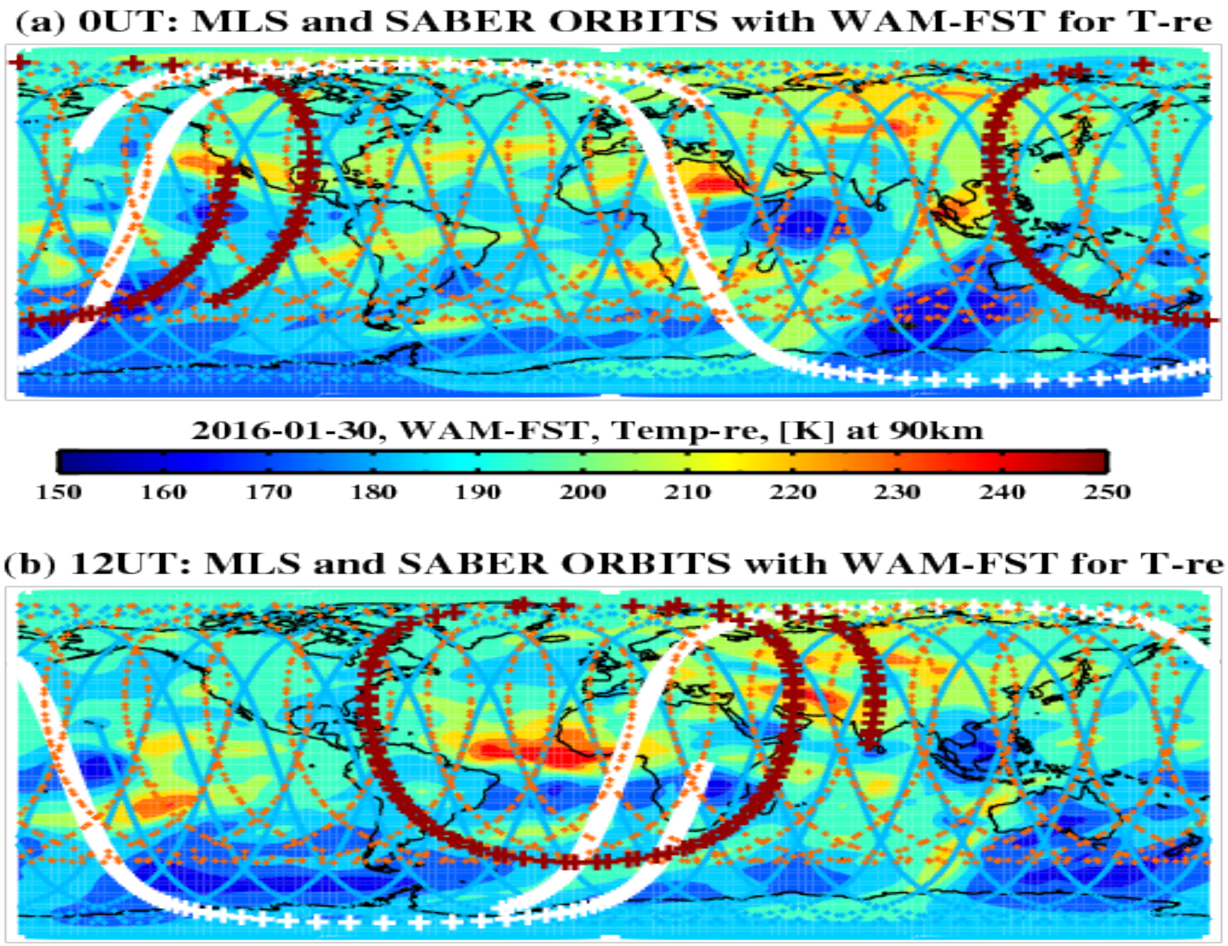
(2) Year-to-year variations driven by the dynamics of the lower atmosphere (QB0-like modulations, SSW events) and solar cycles from the top.

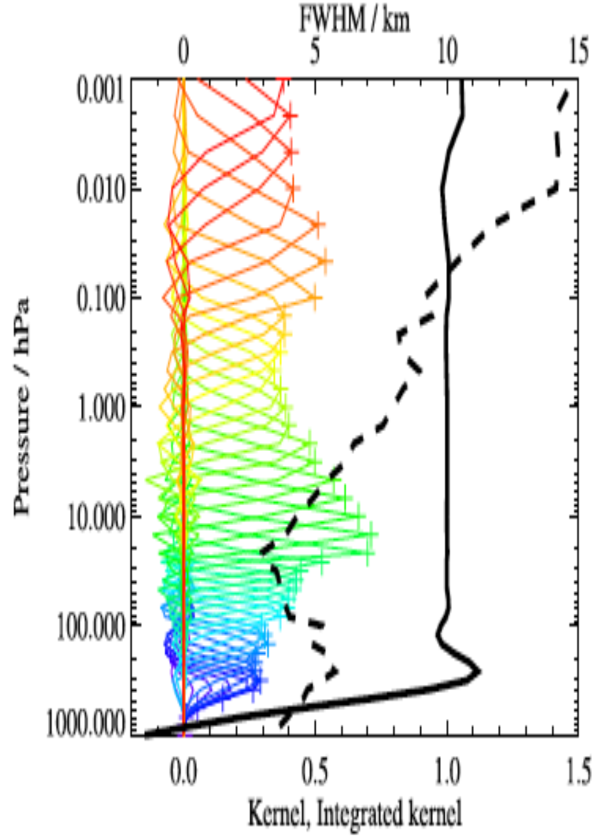
(3) Day-to-day variability triggered by the tropo-spheric weather (storms/hurricanes) and solar-geomagnetic inputs (geo-storms SEP, etc.)



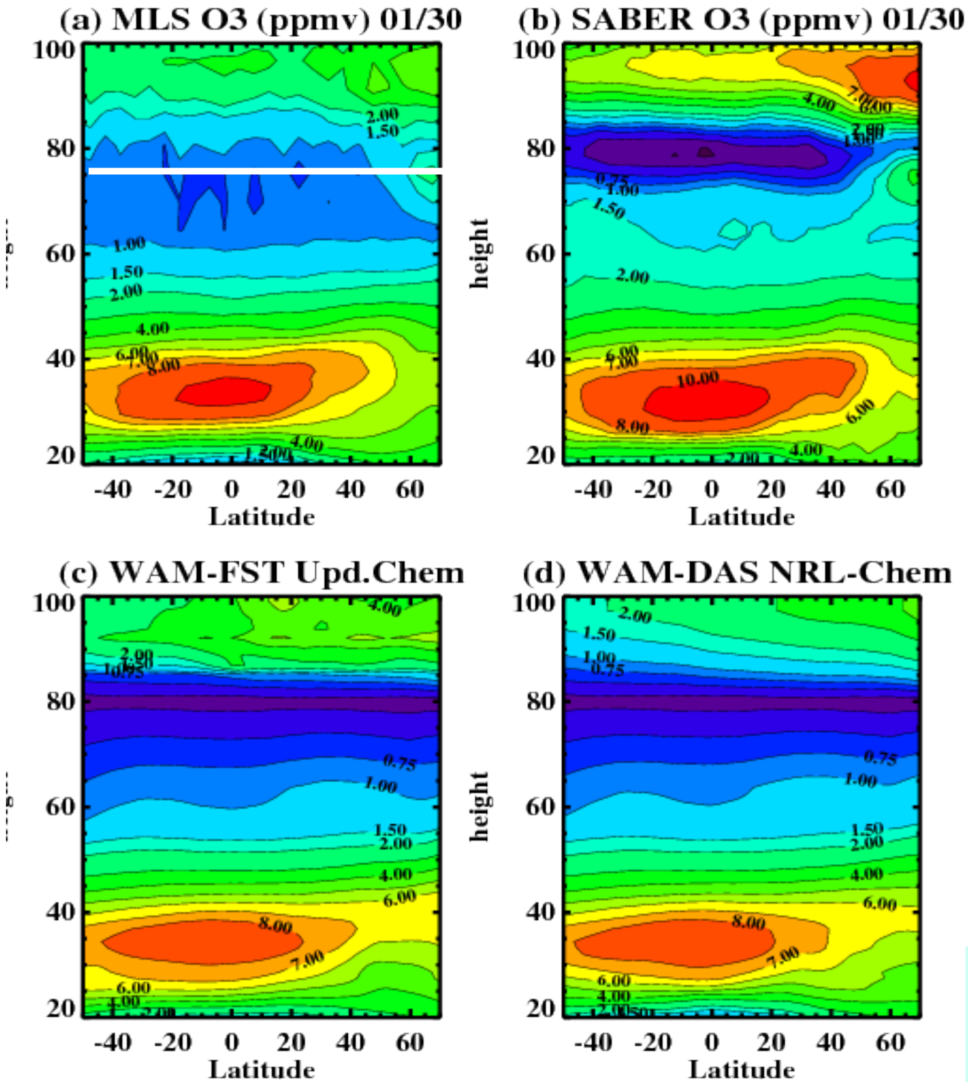
Data flows: ***UARS, TIMED, Aura, radar and lidar systems, imagers, rocket campaigns + future missions GOLD & ICON***

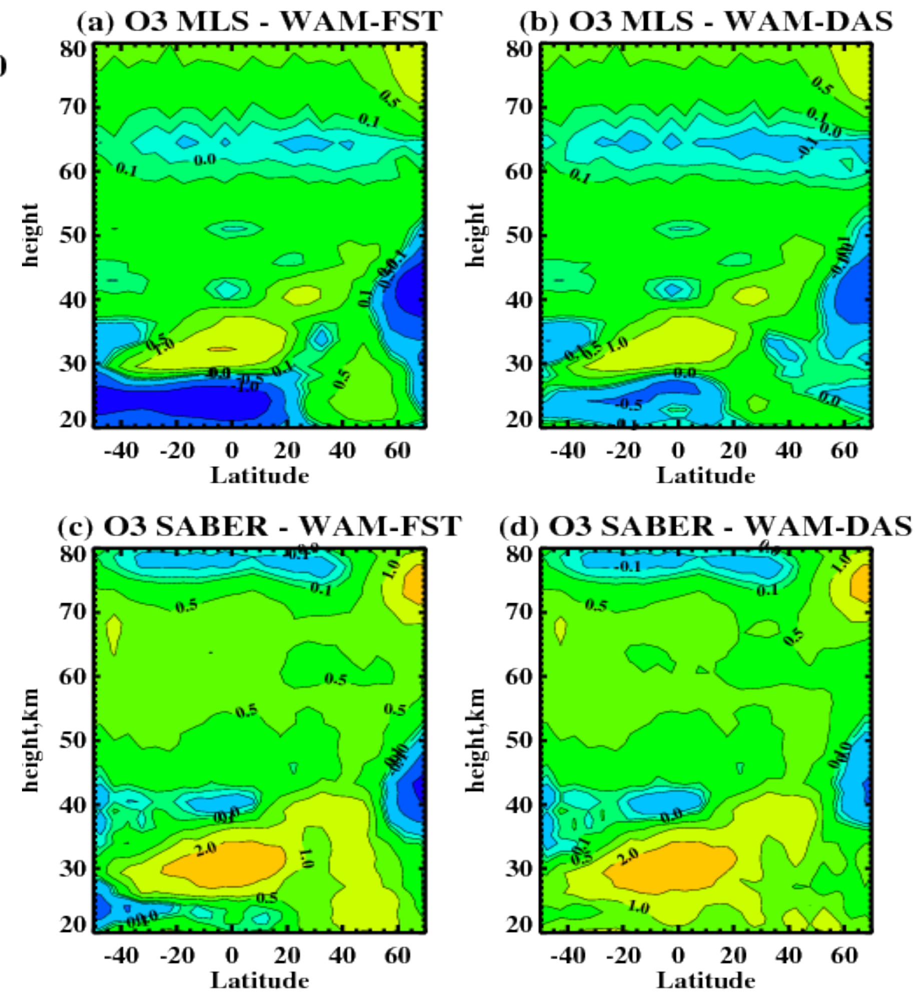
Annual and Diurnal Variations of Ozone and Temperature in WAM-2017 vs MLS and SABER





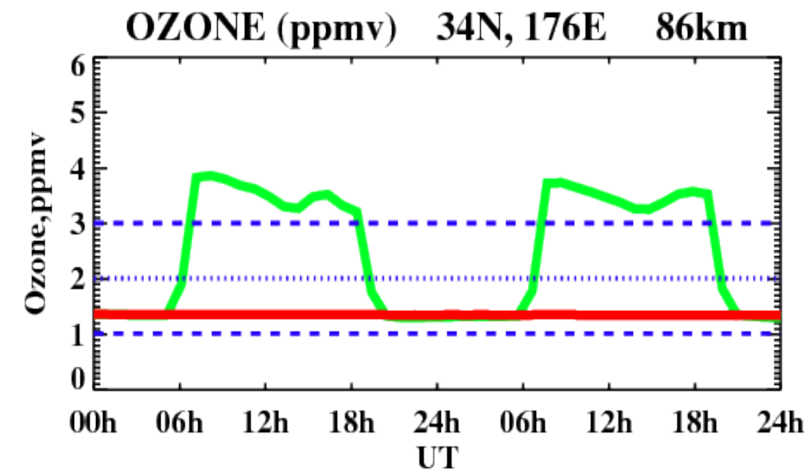
Zonal Mean Ozone: Jan 30, 2016

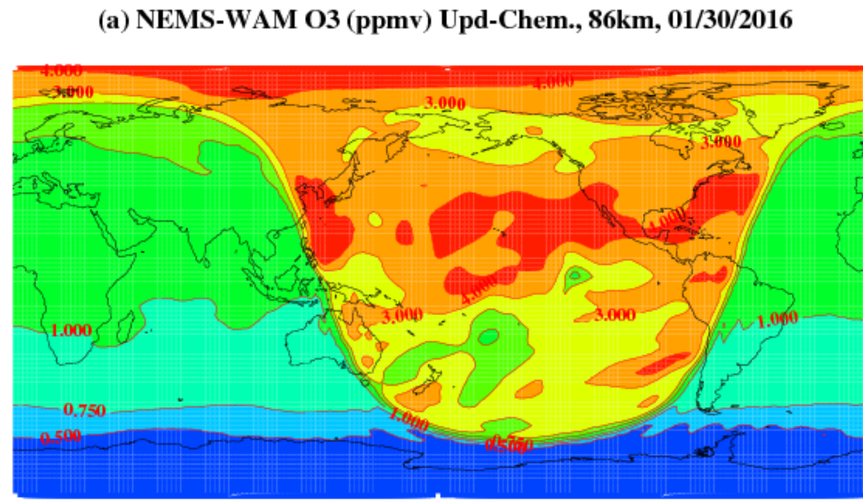




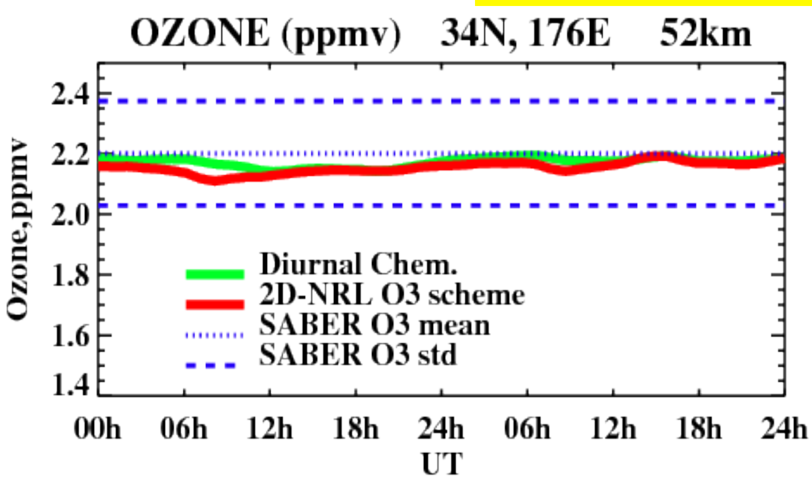
SBUV O_3 data cannot remove the systematic “deficit-bias” in the tropical middle stratosphere; needs for MLS-O_3

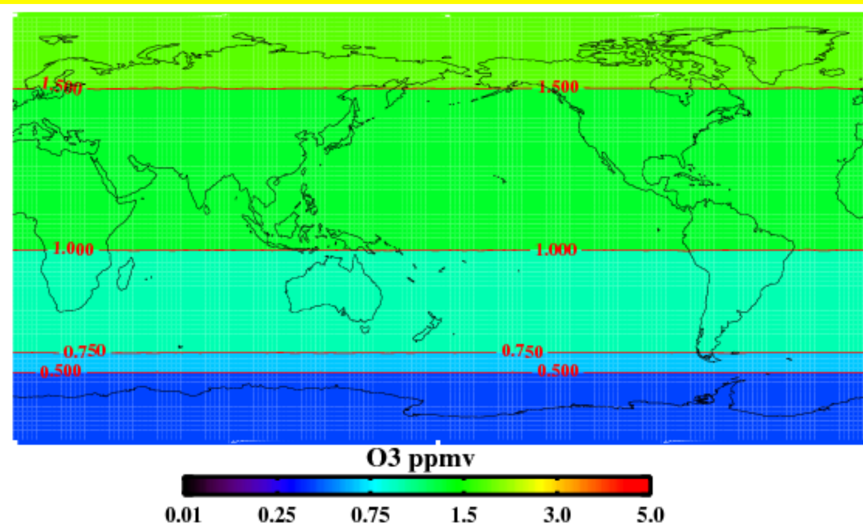
Diurnal Variations of Ozone in WAM (Jan-2016)



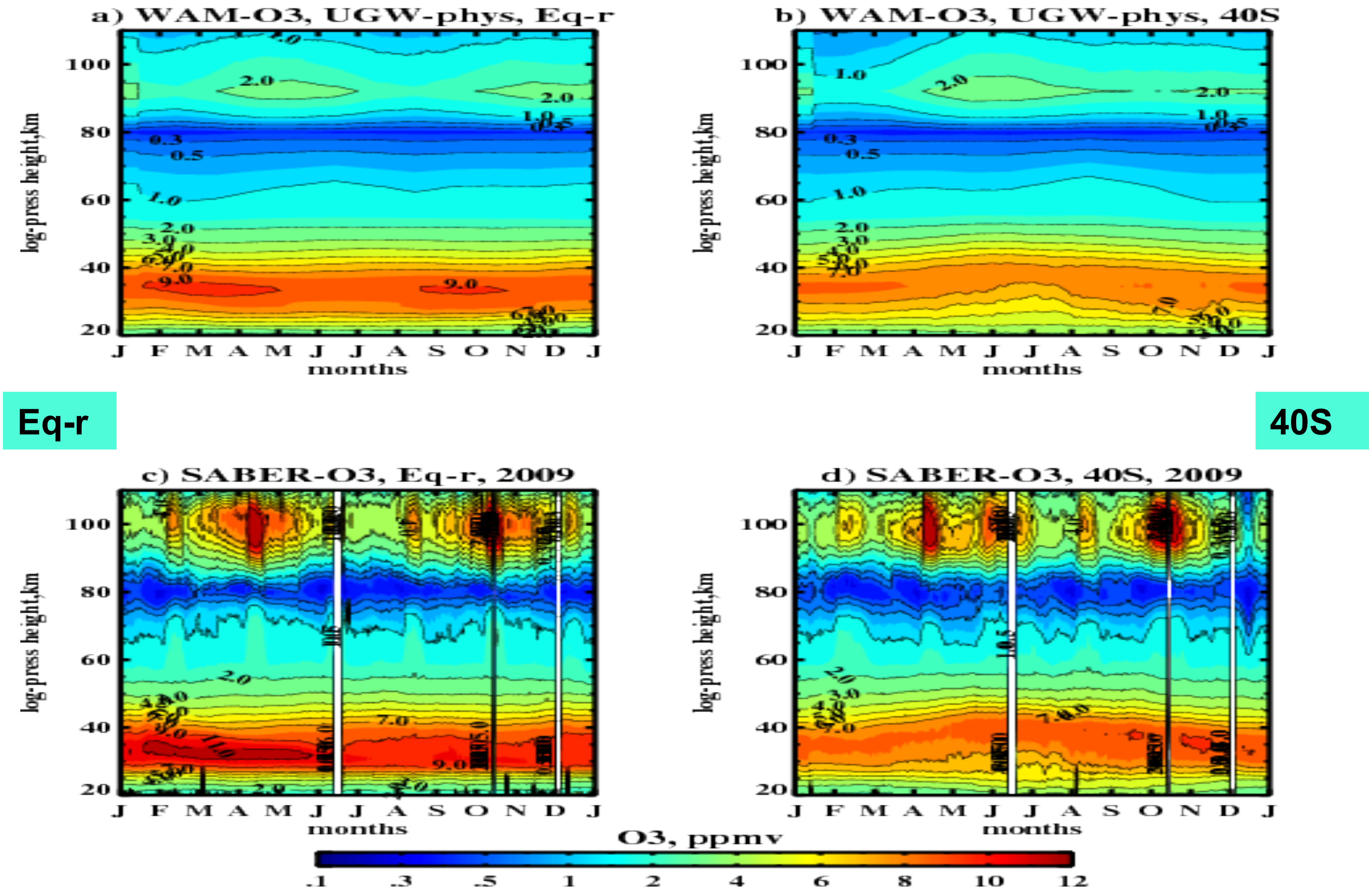


At ~86 km O3-maps completely depends on DIURNAL VARIATIONS of CHEMSITRY as seen by SABER/TIMED

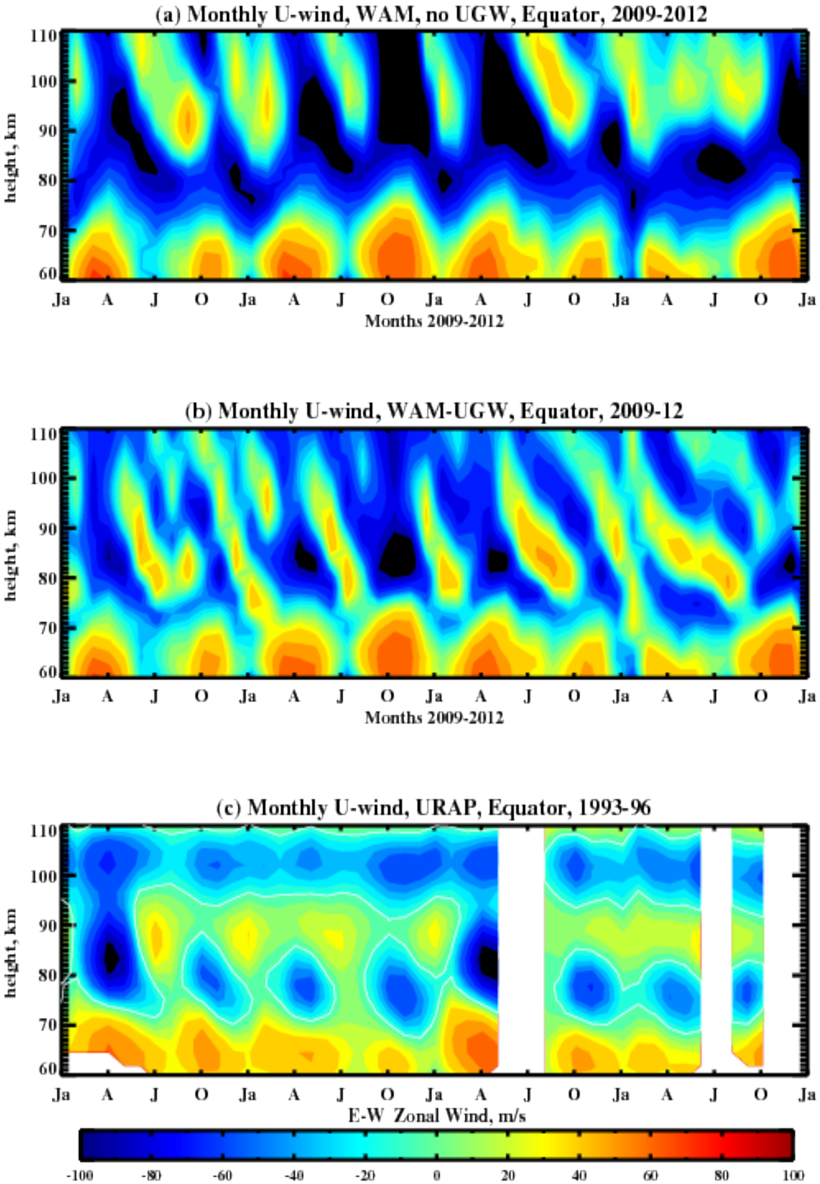


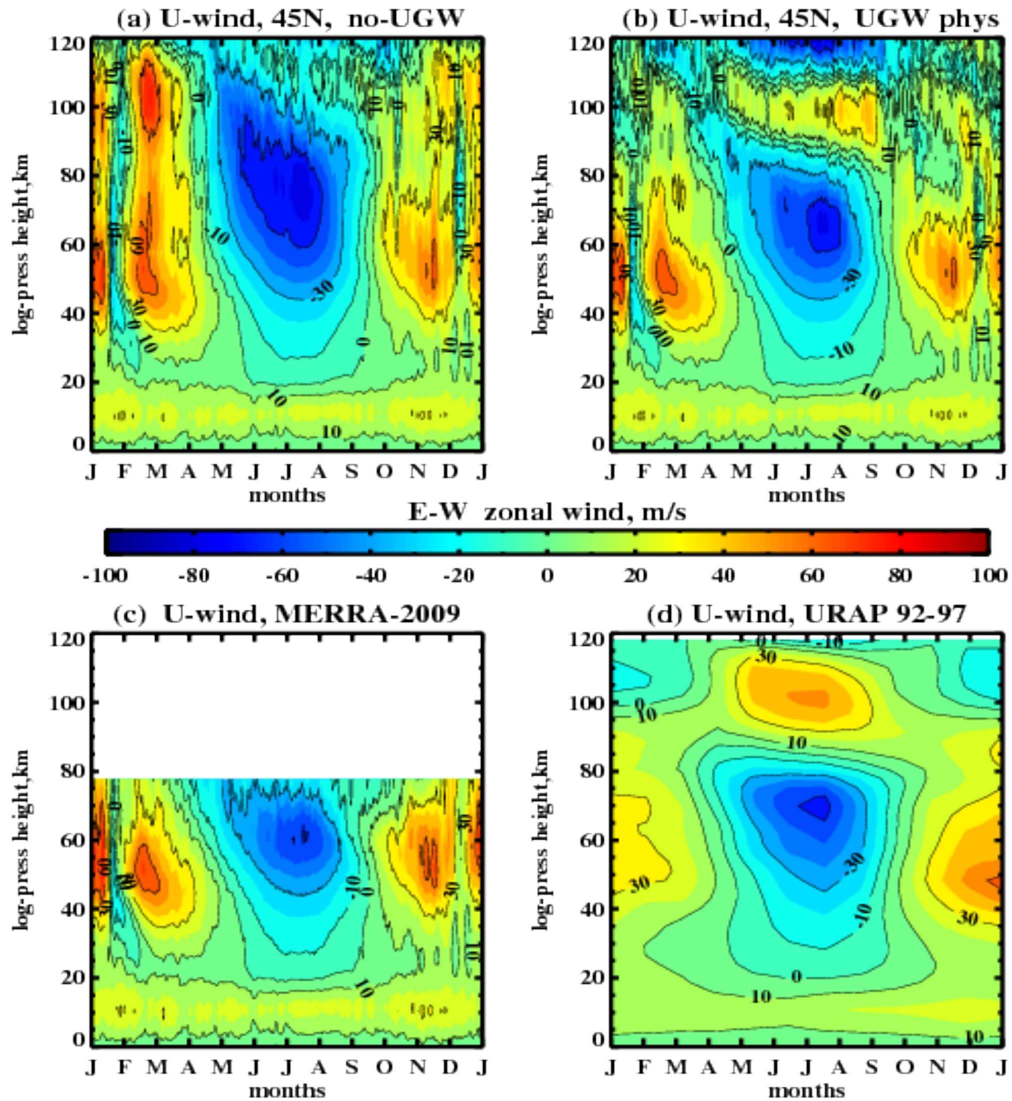


Annual O_3 Variations in WAM (top) and SABER (bottom)

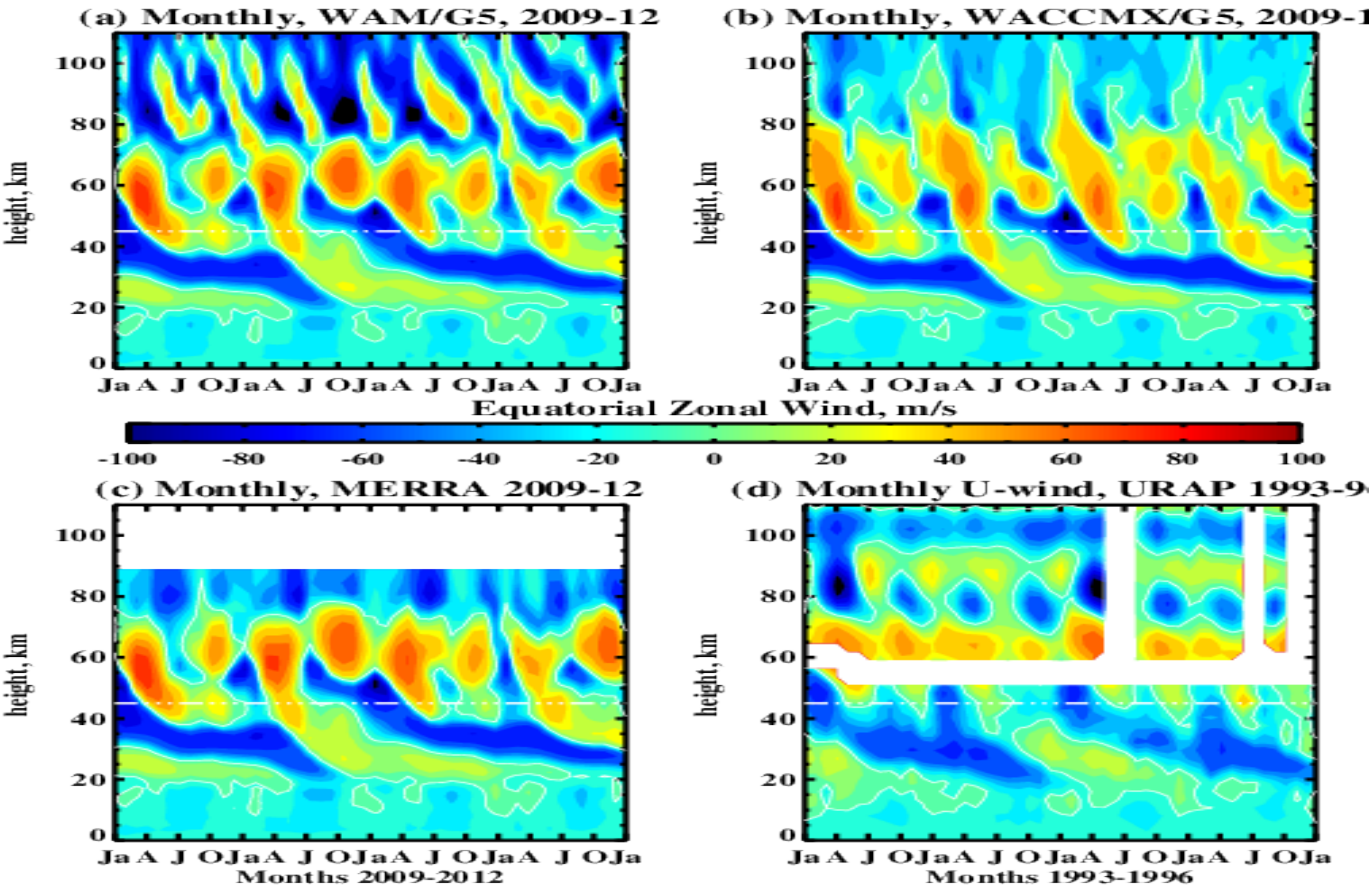


Zonal Winds: SAO/QBO and Annual Cycles: Role of GW schemes in WAM-GEOS5

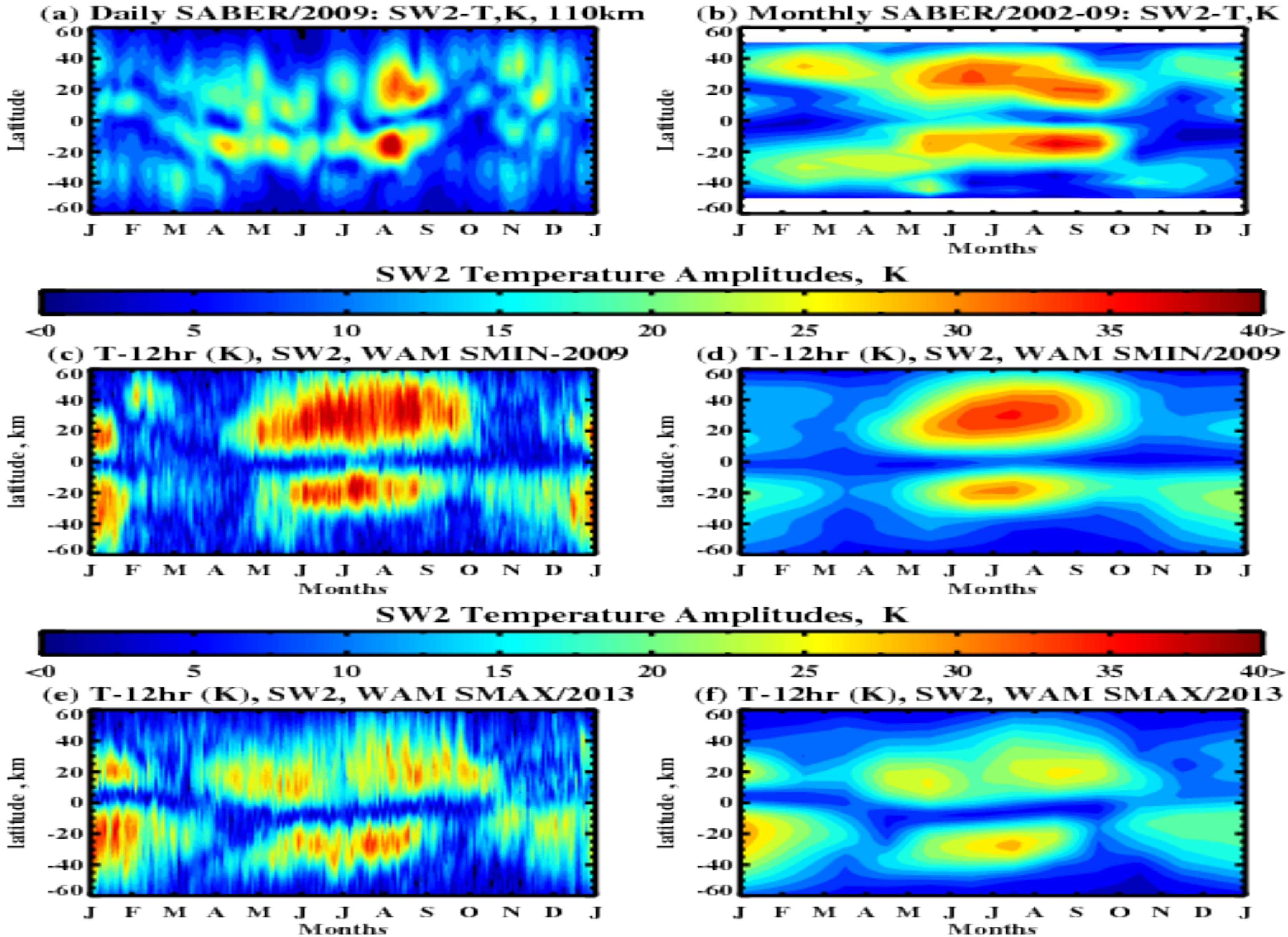




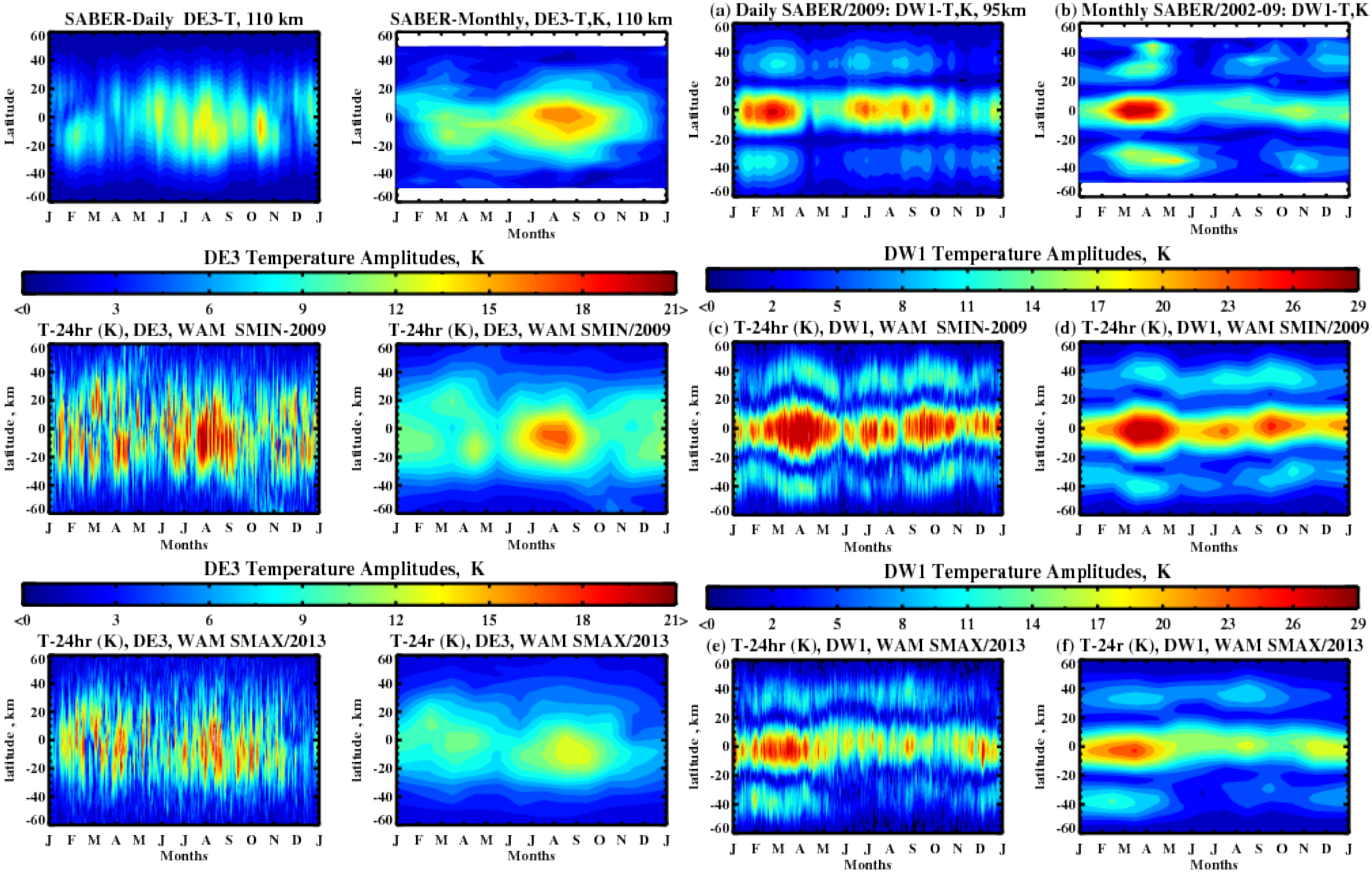
Equatorial Zonal Winds (2009-2012)
WA models (top) and data (bottom)



Annual Variations of 12-h tide (SW2), 2009, 2013: WAM/G5



Tidal Metrics: Seasonal and D-2-DVariations of 24-hr Modes: (DE3 & DW1) and Solar Min (2009)- Max(2012), WAM/GEOS5

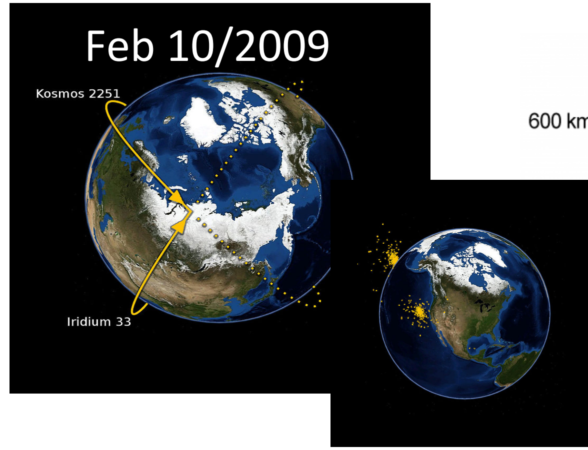


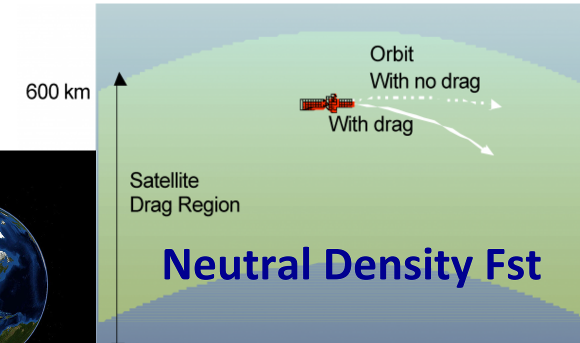
Space Weather Predictions for Navigation and Communication

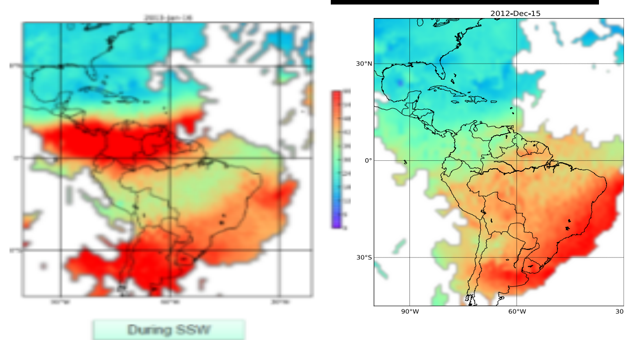
- To keep track of spacecraft and objects to avoid collisions;
- To "expect" unusual behavior of plasma and neutral densities due to geo- storms and SSW.

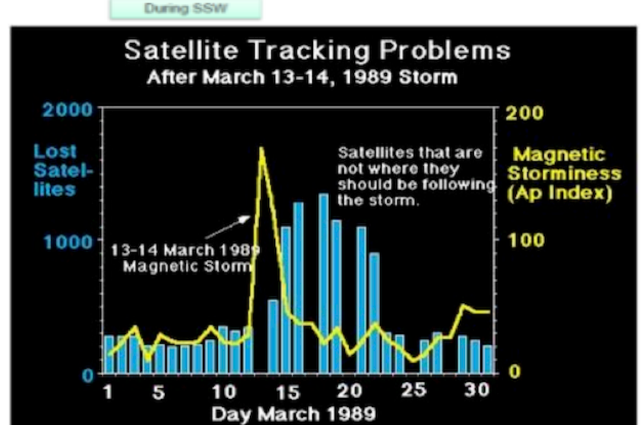
- Examples of SSW-2009: 4-hr earlier arrival of TEC-max to the America Sector (17UT => 13UT) during several days after SSW;

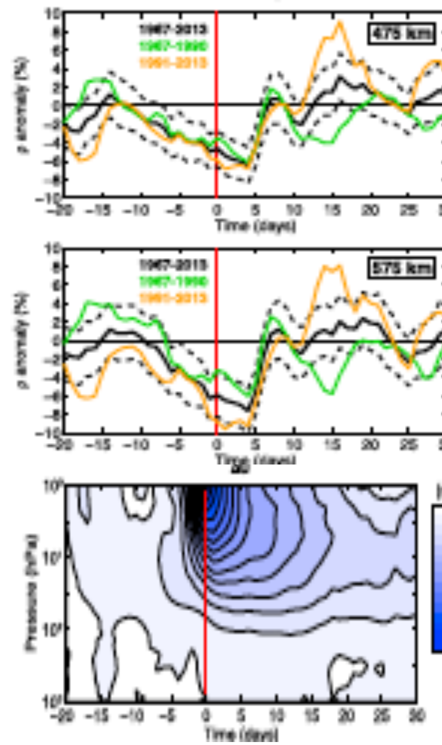
- Fast Reduction (10%) and Growth(5-10%) of the Arctic Neutral Density (*Jan 23-Feb 10*); not yet accepted/predicted by navigation models.
- Geo-Storms: Mar 13-14 1989











Summary

1. Current status of the VE NGGPS/NEMS models, GSM-91L and WAM-150L.

2. Initial implementation of UGWP in these spectral models. Upgrades of radiation and ozone chemistry in WAM-2017 and BIT by IAU.

3. Meteorology of the troposphere and stratosphere forces the observed variability of the simulated mean flow and simulated tides (d-2-d; seasonal; y-2-y), as seen from MLS and SABER data.

4. SSW events – good examples for day-to-day variability of tidal (wave) dynamics in WAM and sub-seasonal/seasonal forecasts in the wintertime troposphere-stratosphere.

5. MA/thermosphere data need to be assimilated to improve VE model predictions and understand observed sub-seasonal and diurnal cycle anomalies (reduction/variation of the density for navigation and in the future WAM-IPE predictions of plasma).

Sudden Stratospheric Warming, as the high impact Events for both Tropospheric Dynamics and Space Weather, Jan 2013