High Altitude Data Assimilation at the Naval Research Laboratory: Recent Results and Future Directions

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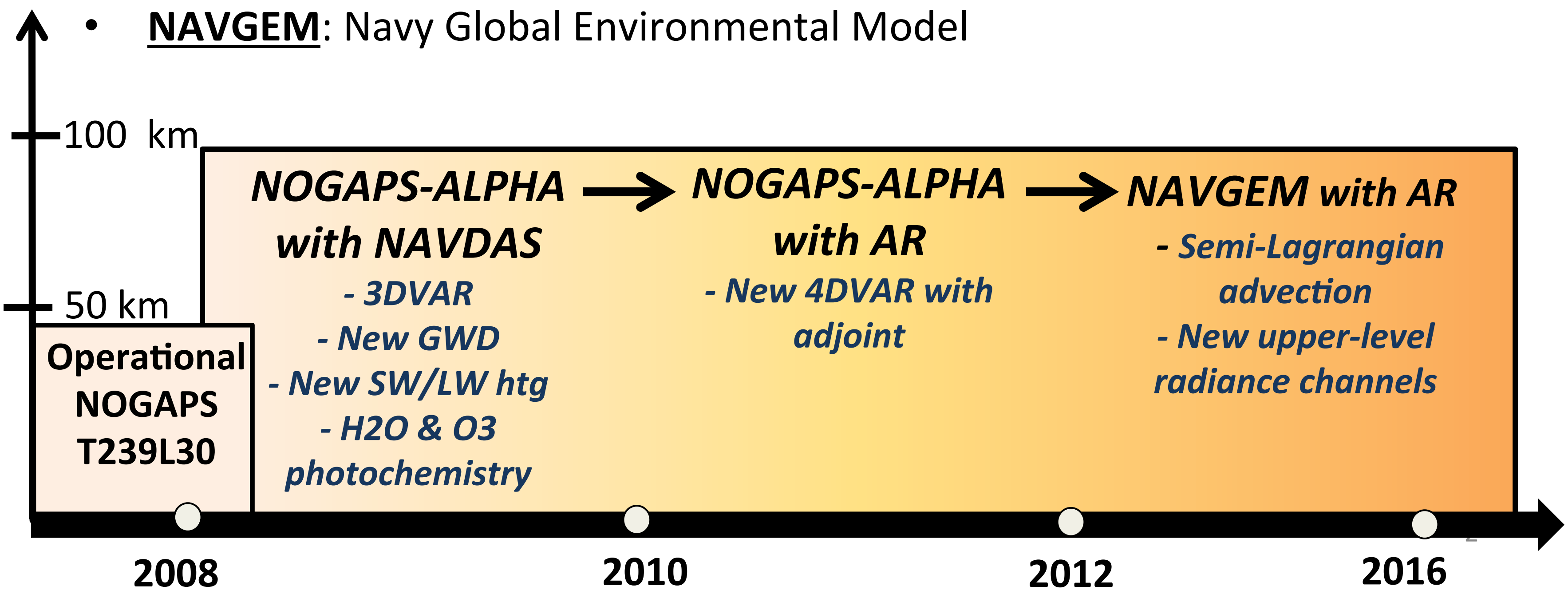
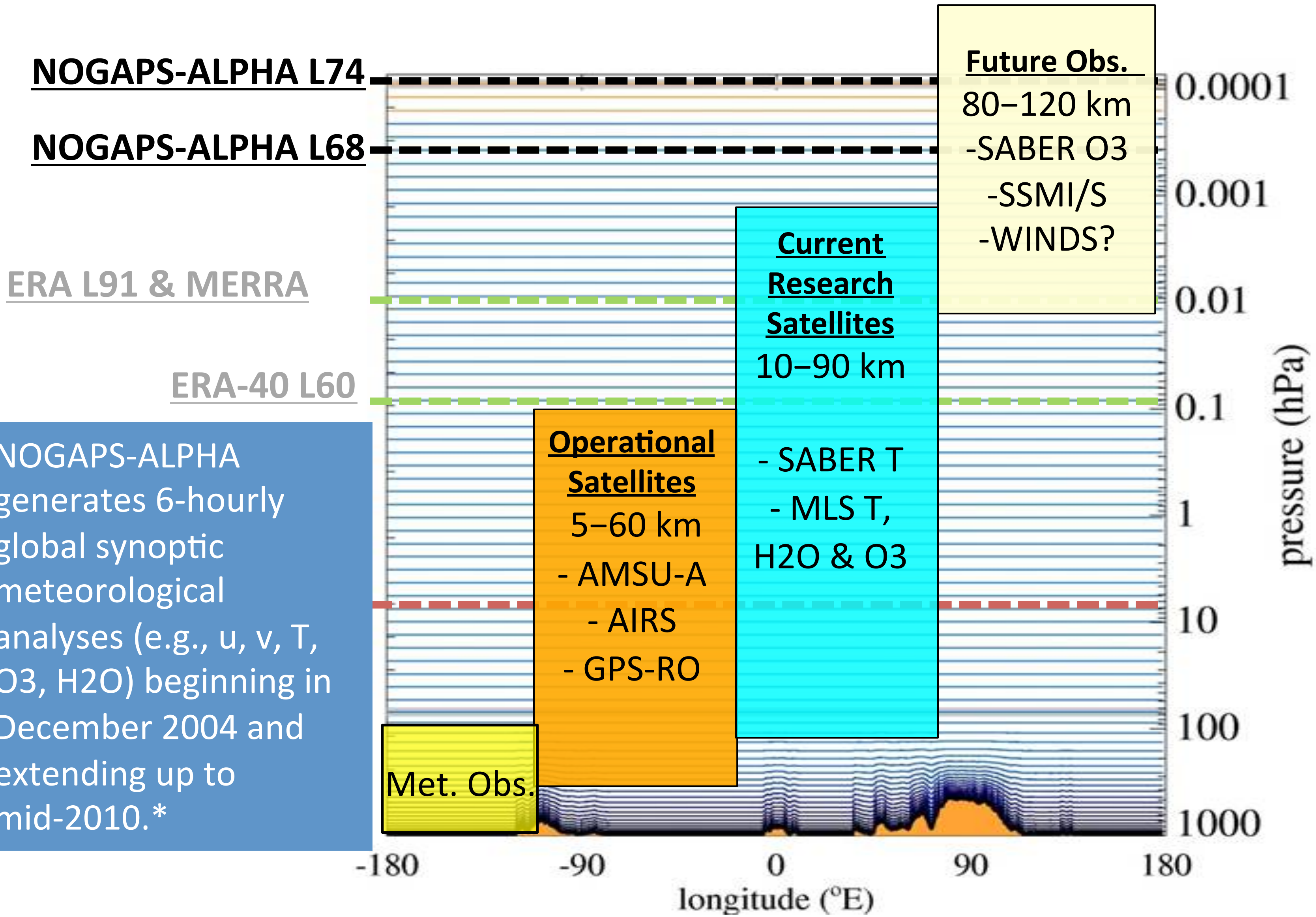
High Altitude Data Assimilation at NRL

- Collaboration between NRL's Space Science, Remote Sensing, and Marine Meteorology Divisions.
- Initially based on high-altitude version of the Navy Operational Global Atmospheric Prediction System (**NOGAPS**) *[Hogan and Rosmond, 1991]*
- **NOGAPS-ALPHA**: Combines NAVDAS 3DVAR assimilation with global spectral NWP model (T79, T239, T479) from 0 - 90 km (L68, L74, L139) *[Hoppel et al., 2008; Eckermann et al., 2009]*.
- **AR**: Accelerated Representer *[Rosmond and Xu, 2006]*
- **NAVGEM**: Navy Global Environmental Model



Vertical Domain of NOGAPS-ALPHA

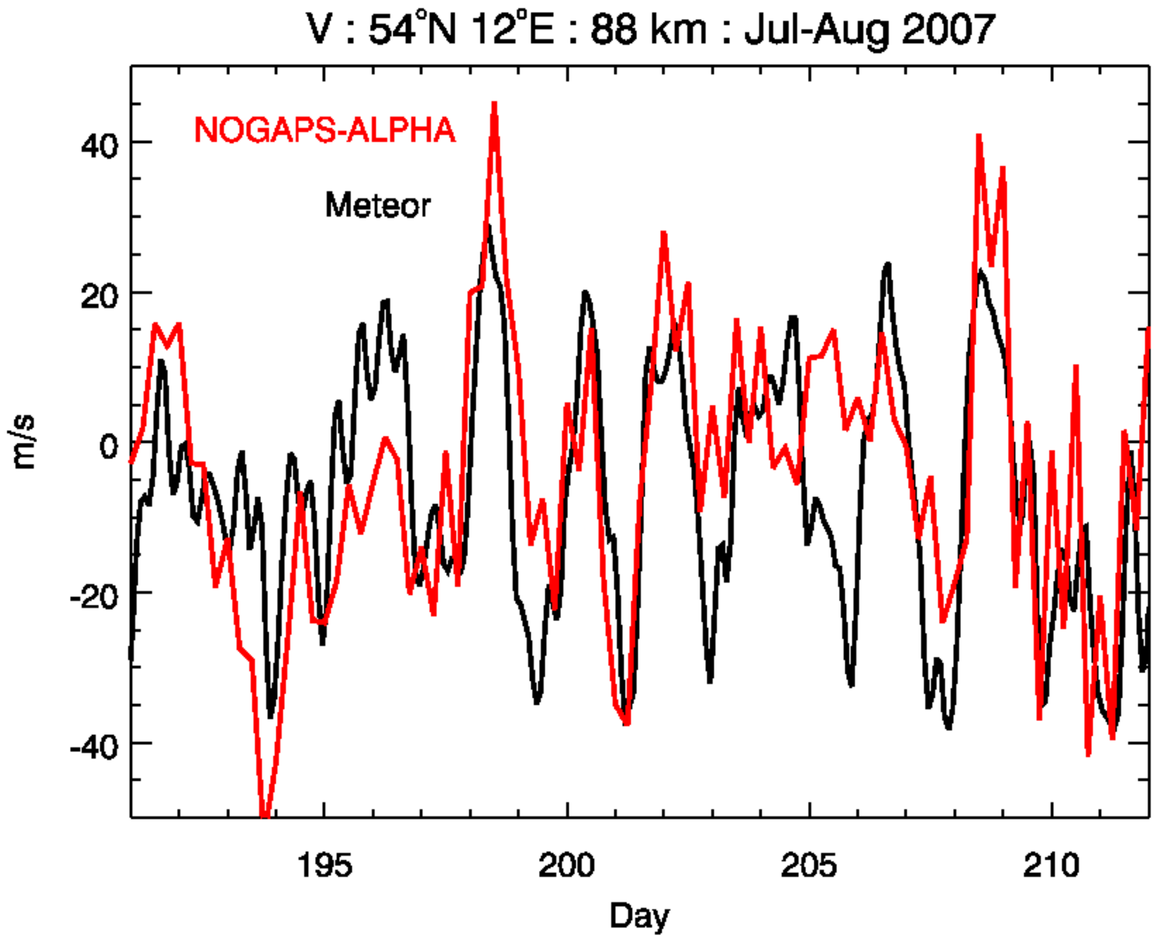


NOGAPS-ALPHA generates 6-hourly global synoptic meteorological analyses (e.g., u, v, T, O3, H2O) beginning in December 2004 and extending up to mid-2010.*

Recent NOGAPS-ALPHA Results

2 Day Wave in the Northern Hemisphere
Summer 2007-2009

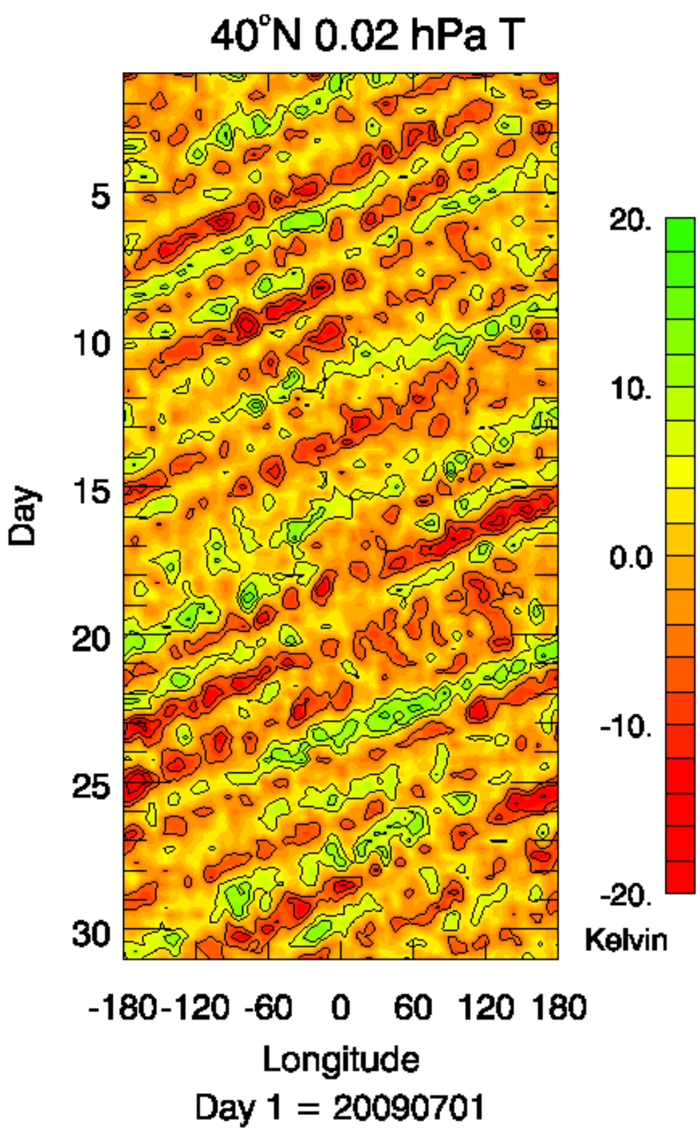
NOGAPS-ALPHA Analyzed Winds

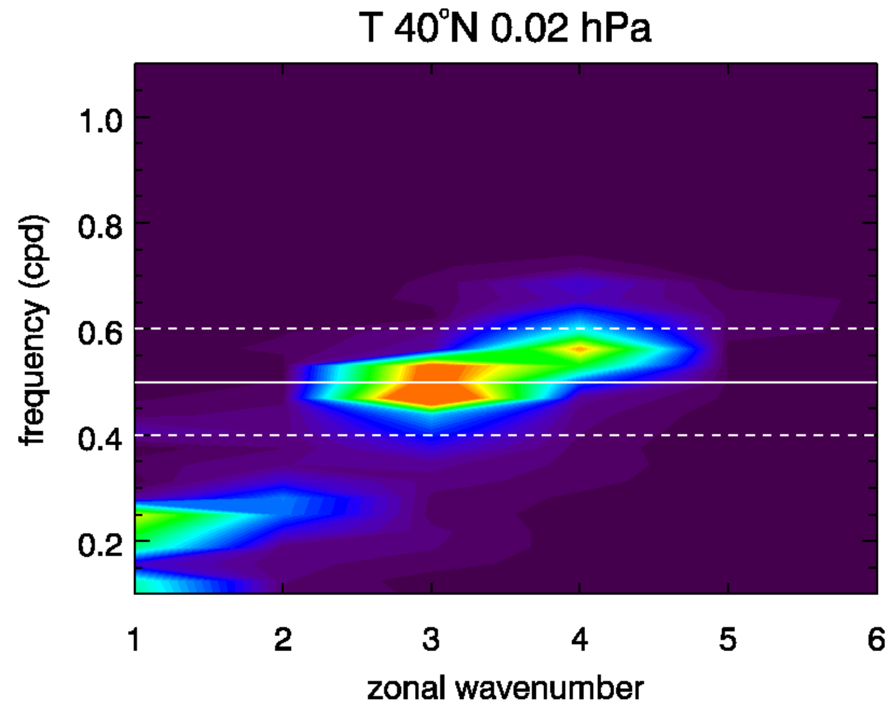


NOGAPS-ALPHA does not directly assimilate horizontal winds. Instead, wind increments are computed based on assimilation of middle atmospheric temperatures, subject to physical constraints from the forecast model

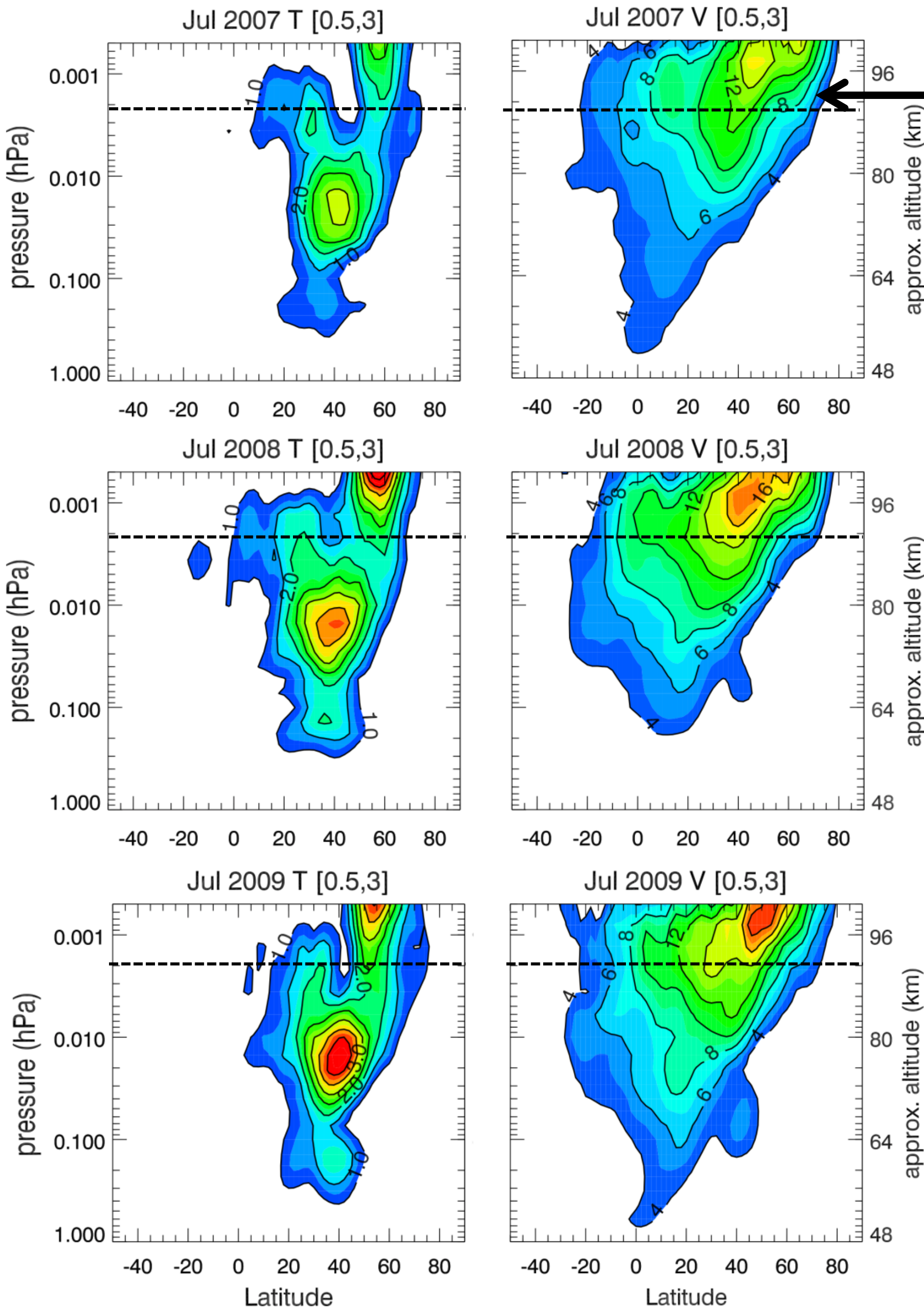
Comparison of NOGAPS-ALPHA meridional winds with meteor radar winds at 88 km from Kuhlungsborn during July-August 2007.

Meteor winds courtesy W. Singer, Leibniz Inst. Atmos. Phys.



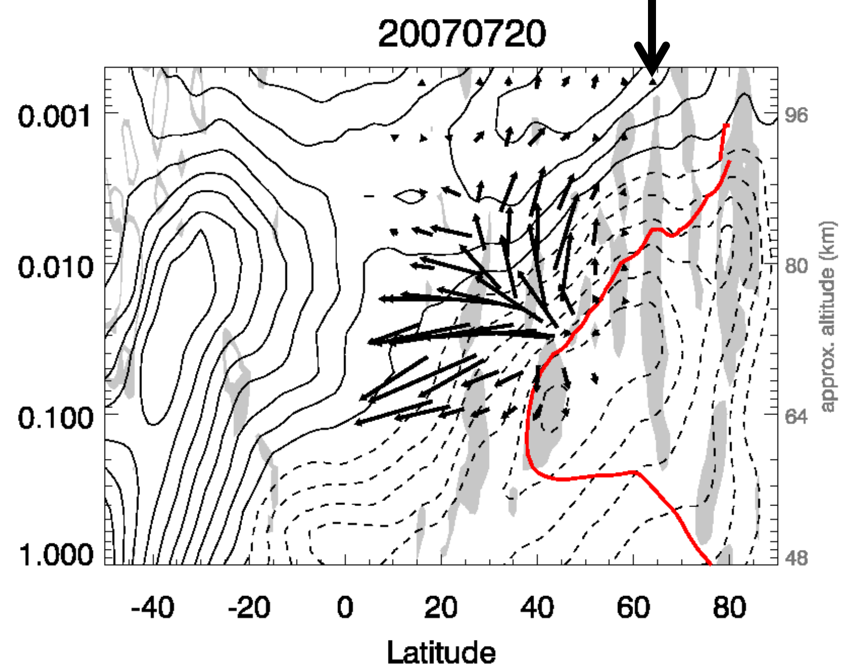


2-Dimensional Fast Fourier Transform (2DFFT) is used to isolate the spatial and temporal characteristics of the 2DW in the 6-hourly NOGAPS-ALPHA wind and temperature fields.

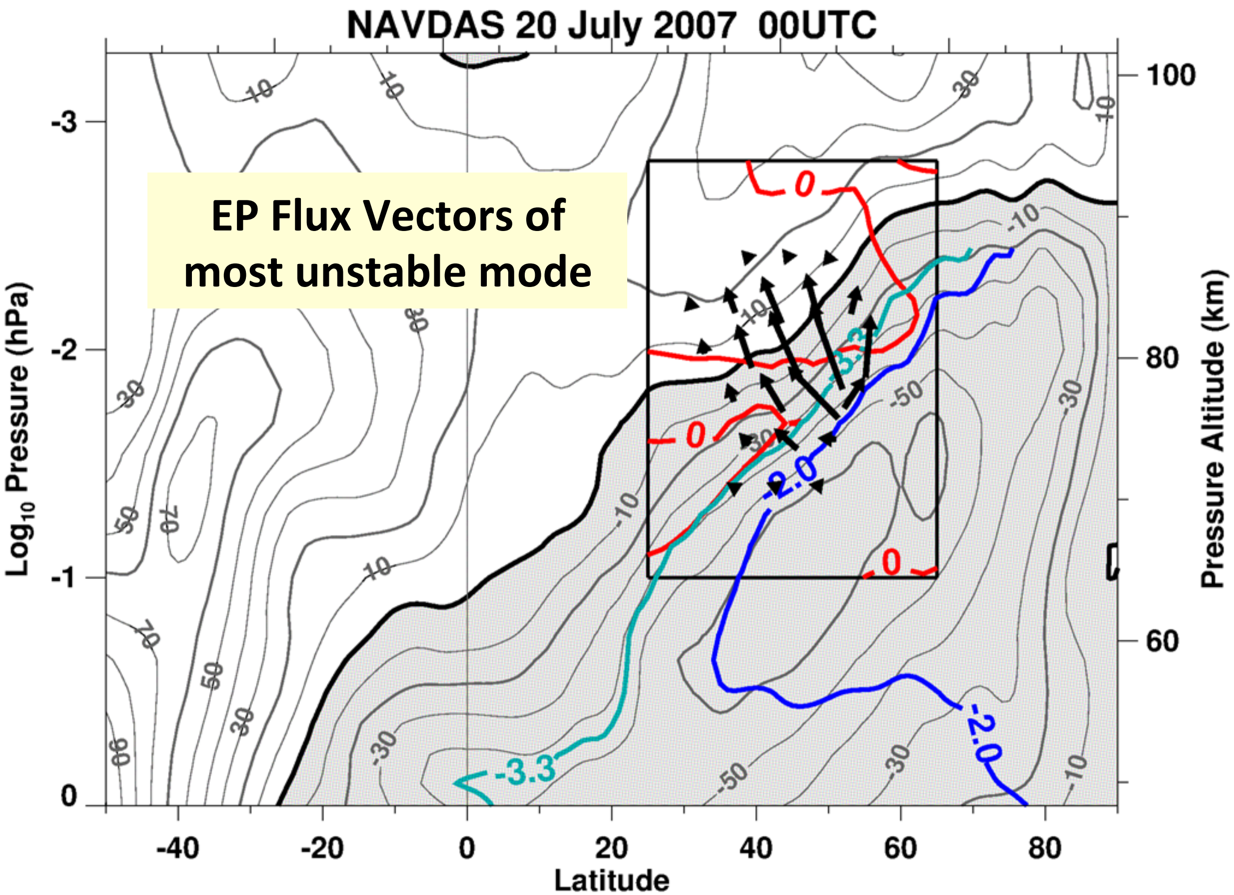


Monthly mean amplitudes of 2DW in T and V for July ’07, ‘08, and ’09

EP-fluxes computed from filtered u, v, T fields indicate source region near critical line (red contour) where Qy < 0 (shading)



NOGAPS-ALPHA Analyzed Winds in Linear Instability Model



The most unstable mode can be found using an eigenvalue approach:

$$\boldsymbol{A}x = c\,\boldsymbol{B}x$$

where x is the gridded stream function and c (the phase speed) is the eigenvalue. ***A*** and ***B*** depend on the horizontal wavenumber, k, and ***A*** depends on U and Q_y.

Linearized quasi-geostrophic potential vorticity equation:

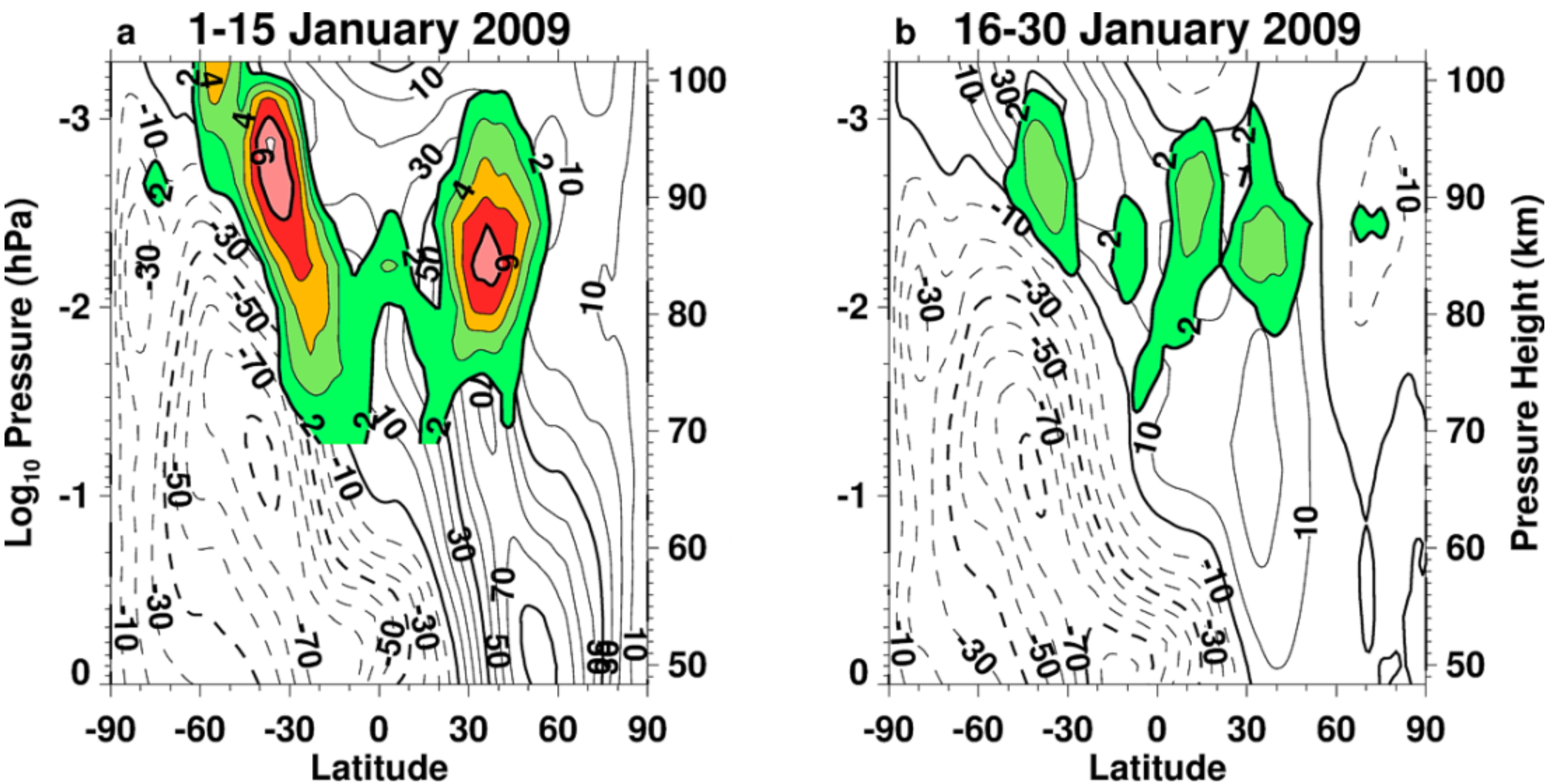
$$q_t + Uq_x + v\,Q_y = 0$$

where U is the zonal mean zonal wind and Q_y is the zonal mean potential vorticity gradient.

NOGAPS-ALPHA and WACCM

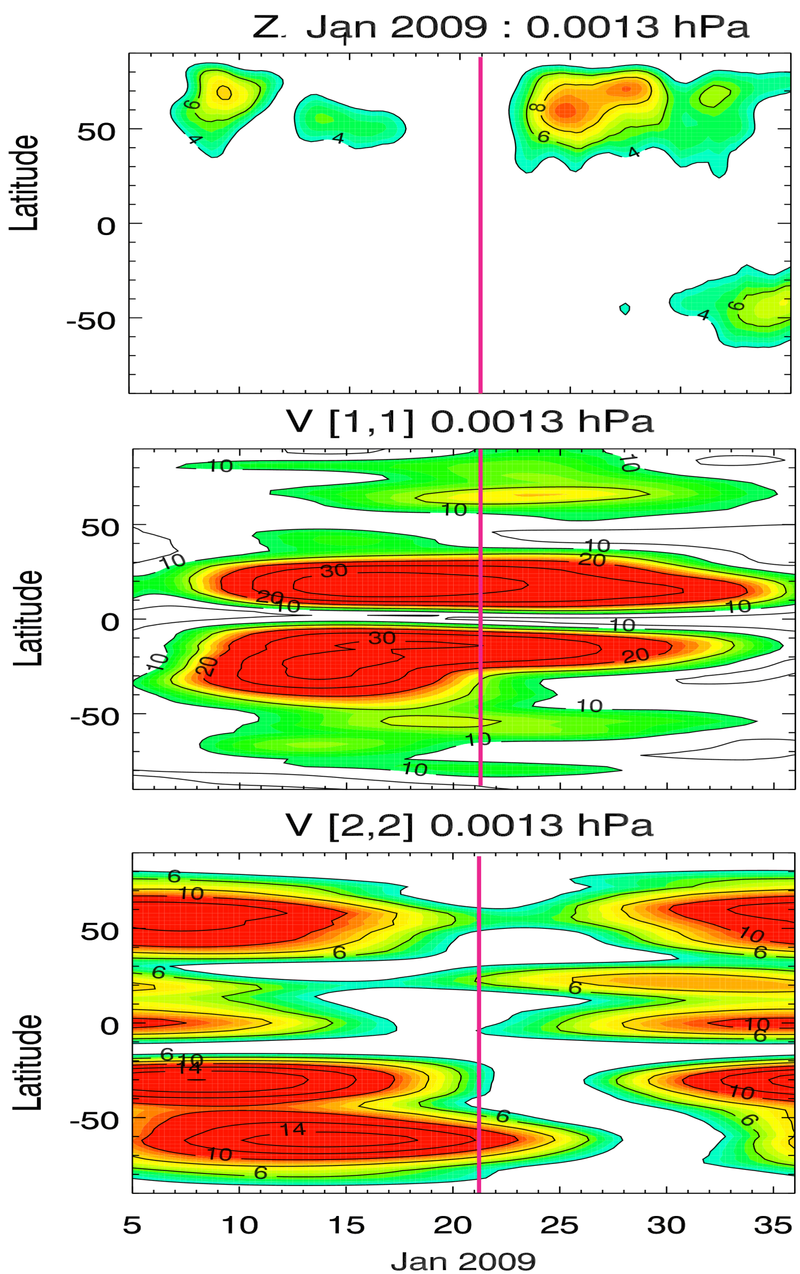
Combined Data Assimilation & Modeling of Jan 2009 SSW

Changes in Tidal Structure Before and After Jan 2009 SSW



NOGAPS-ALPHA winds (contours) and amplitude of migrating semi-diurnal tide in meridional wind (shading)

Changes in Tidal Structure Before and After Jan 2009 SSW



NOGAPS-ALPHA Wave 1
Geop. Ht. Amplitude

NOGAPS-ALPHA Migrating Diurnal Tide Amplitude

NOGAPS-ALPHA Migrating Semi-diurnal Tide Amplitude

Combined Data Assimilation & Modeling

Altitude

NOGAPS-ALPHA

High-altitude Data Assimilation System

0–90 km

Met. obs. + NASA satellite data

*Global **6-hourly** output*

(winds, T, O3, H2O)

WACCMX

Whole Atmosphere Community Climate Model

0–500 km

Full spectrum variability in solar irradiance

Auroral effects, ion drag, Joule heating

Fully interactive photochemistry, radiation, dynamics

Ocean/atmosphere interactions

"Specified Dynamics" (SD)

UA-OBS

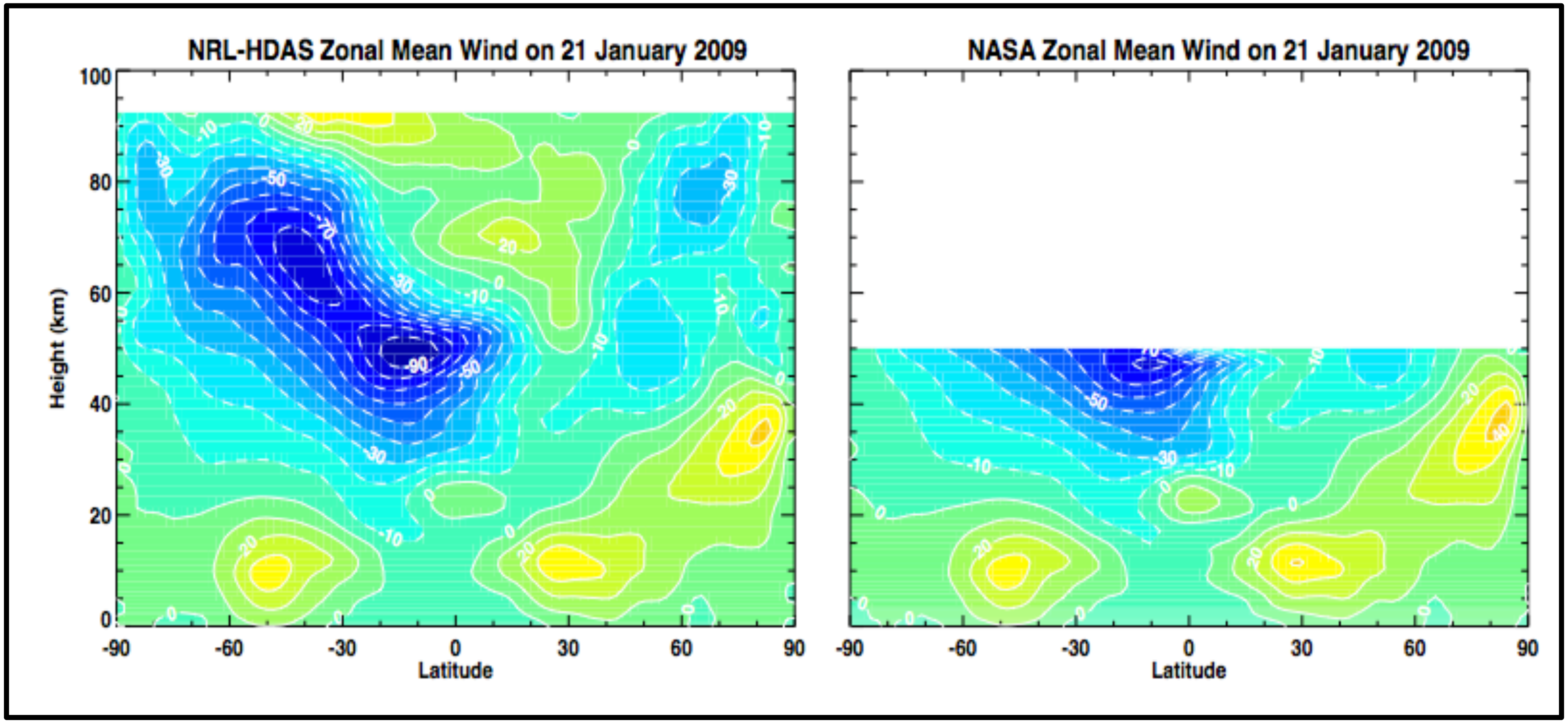
Upper Atmospheric Observations

100–500 km

Satellite-based density, temperature & composition (GRACE, CHAMP, TIMED)

Ground-based temperature & winds (lidar, radar)

Using NRL analyses as input for WACCM, we can examine upper atmospheric response to realistic lower atmospheric forcing

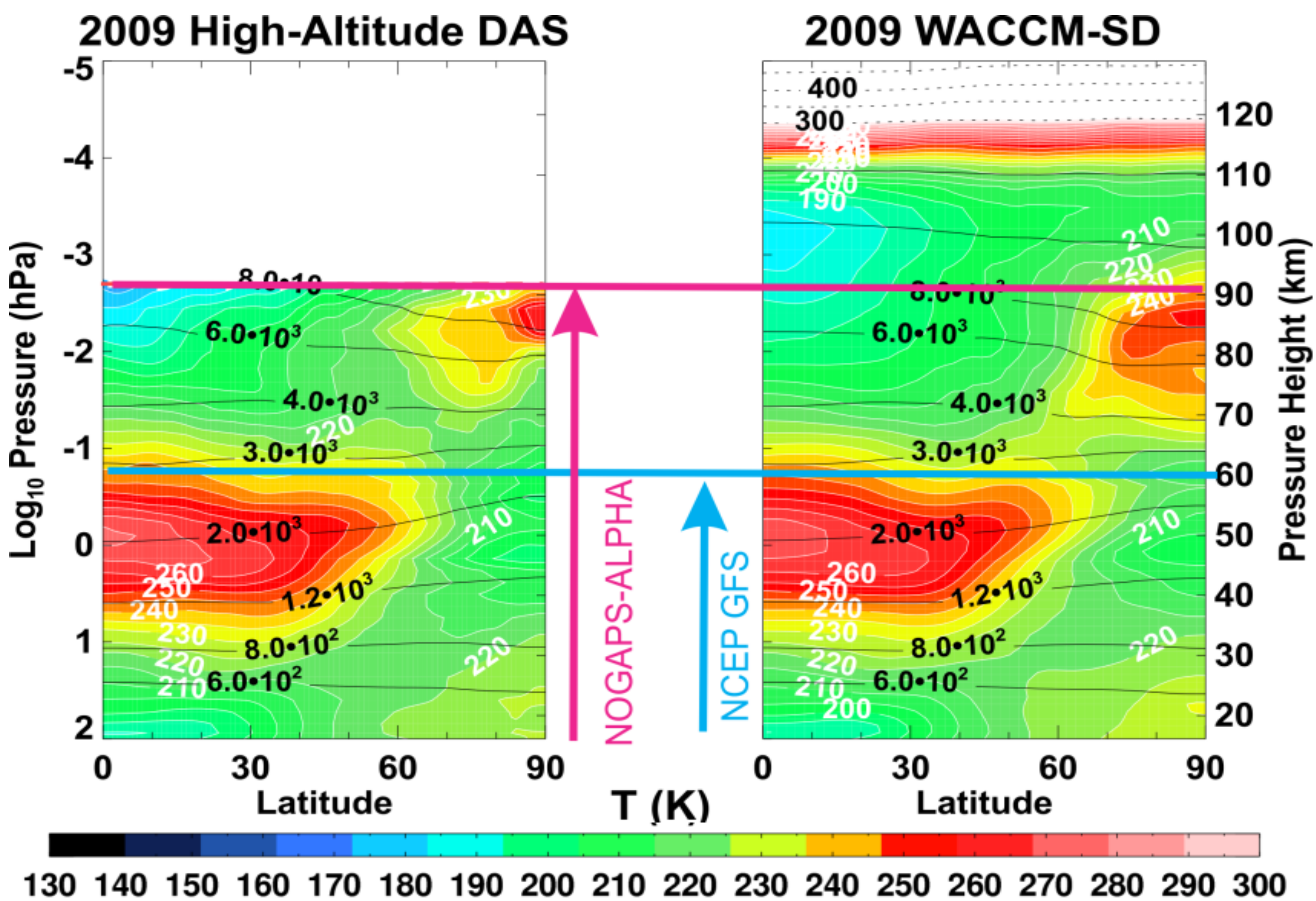


Original WACCM-SD configuration used NASA meteorological fields up to 50 km (right).

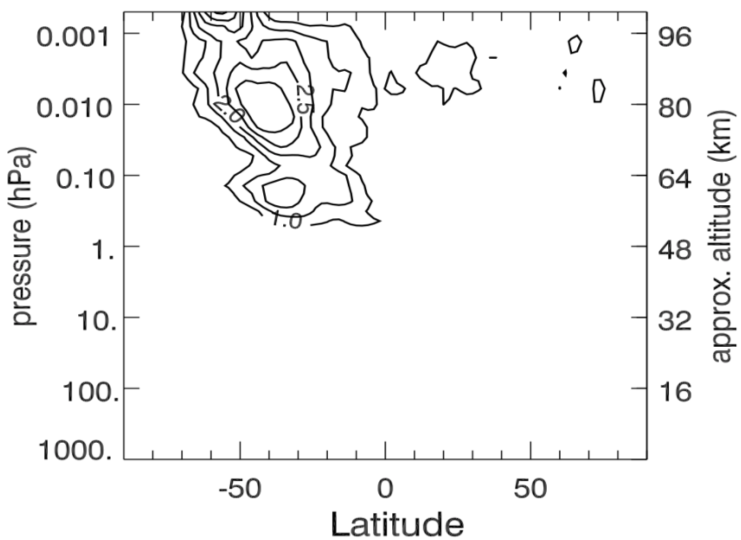
We run WACCMX-SD using NRL analyses from 0-90 km (left) to drive daily, seasonal, and interannual variability in the lower atmosphere.

This approach can capture "bottom-up" mechanisms driving dynamical variability in the upper atmosphere.

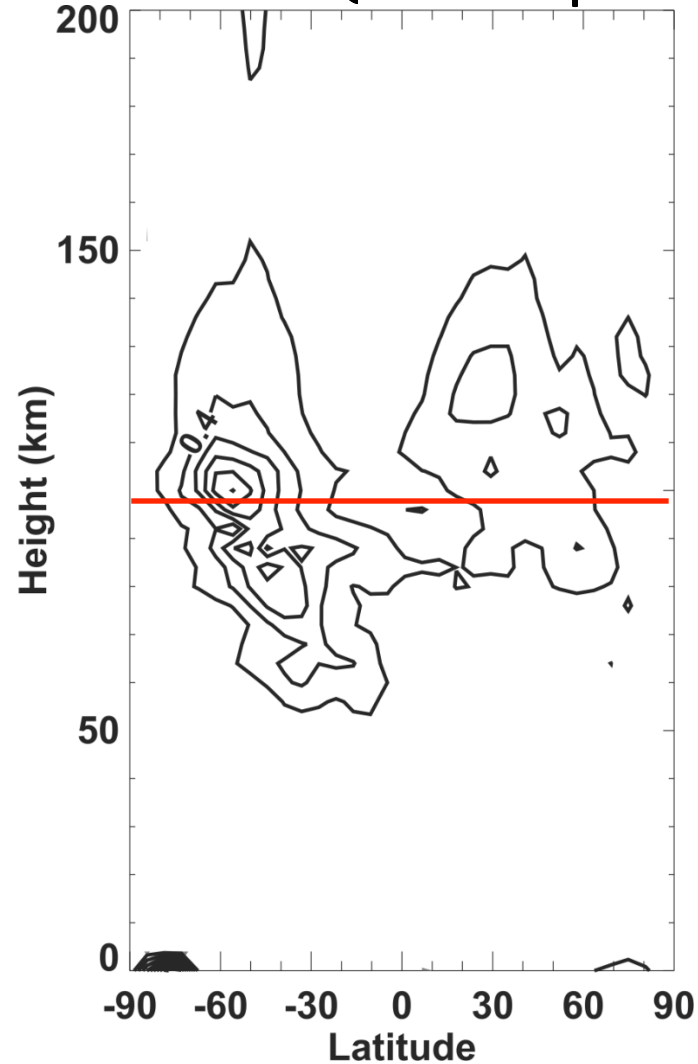
Zonal Mean Temperature 13 Feb 2009



NOGAPS-ALPHA Q2DW T Amp Jan 2009



WACCMX-SD Q2DW T Amp Jan 2009



NAVGEM

The Future of NRL High-Altitude Data Assimilation

NAVGEM 1.0

Dynamics

- Semi-Lagrangian/semi-implicit advection allows for longer time steps
- T359L42 (37km, ~0.04 hPa)
- Prognostic H2O and O3

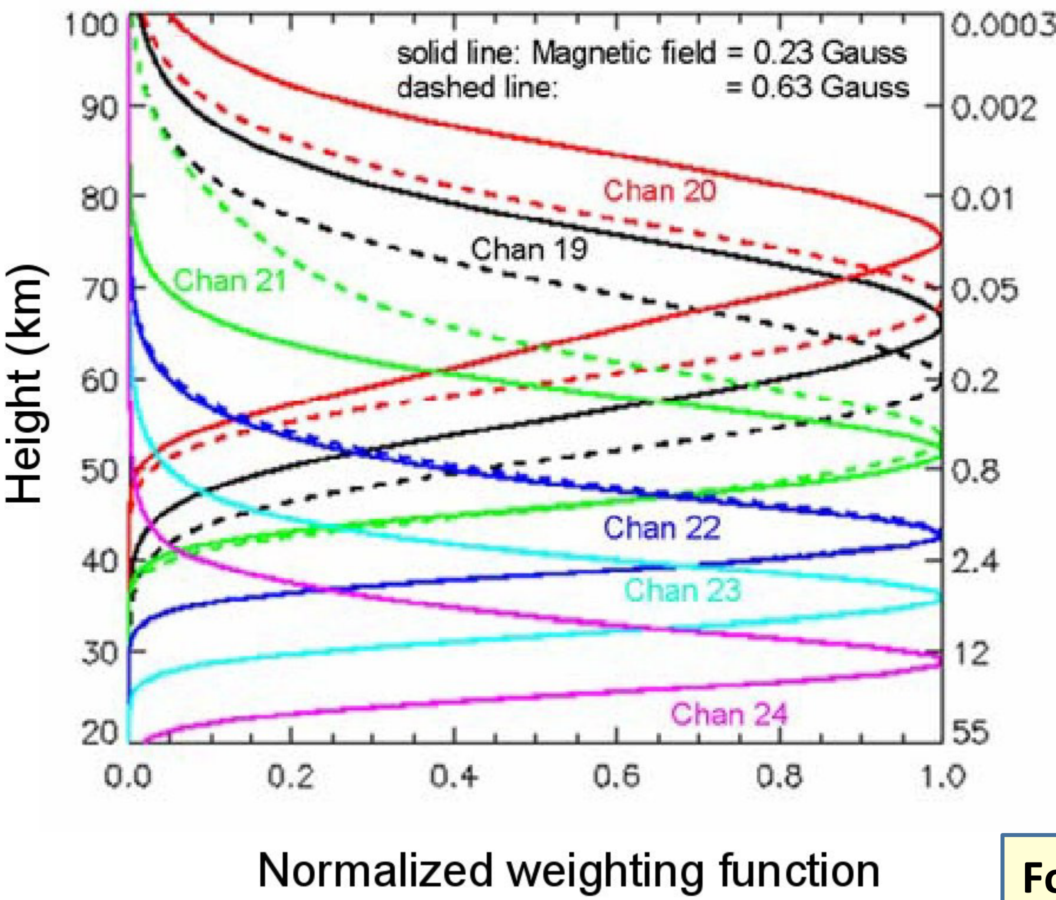
Physics

- Simplified Arakawa Schubert scheme for deep convection parameterization
- Shallow cumulus mixing scheme
- Improved treatment of surface roughness

Satellite Obs.

- AMSU-A (4 NOAA satellites)
- MetOp IASI/AMSU
- MODIS and AVHRR polar winds
- QuikScat, ERS, and ASCAT
- AQUA AIRS/AMSU
- Geostationary winds
- DMSP SSMI and SSMIS
- WindSat

Extending NAVGEM through the middle atmosphere: Radiance assimilation



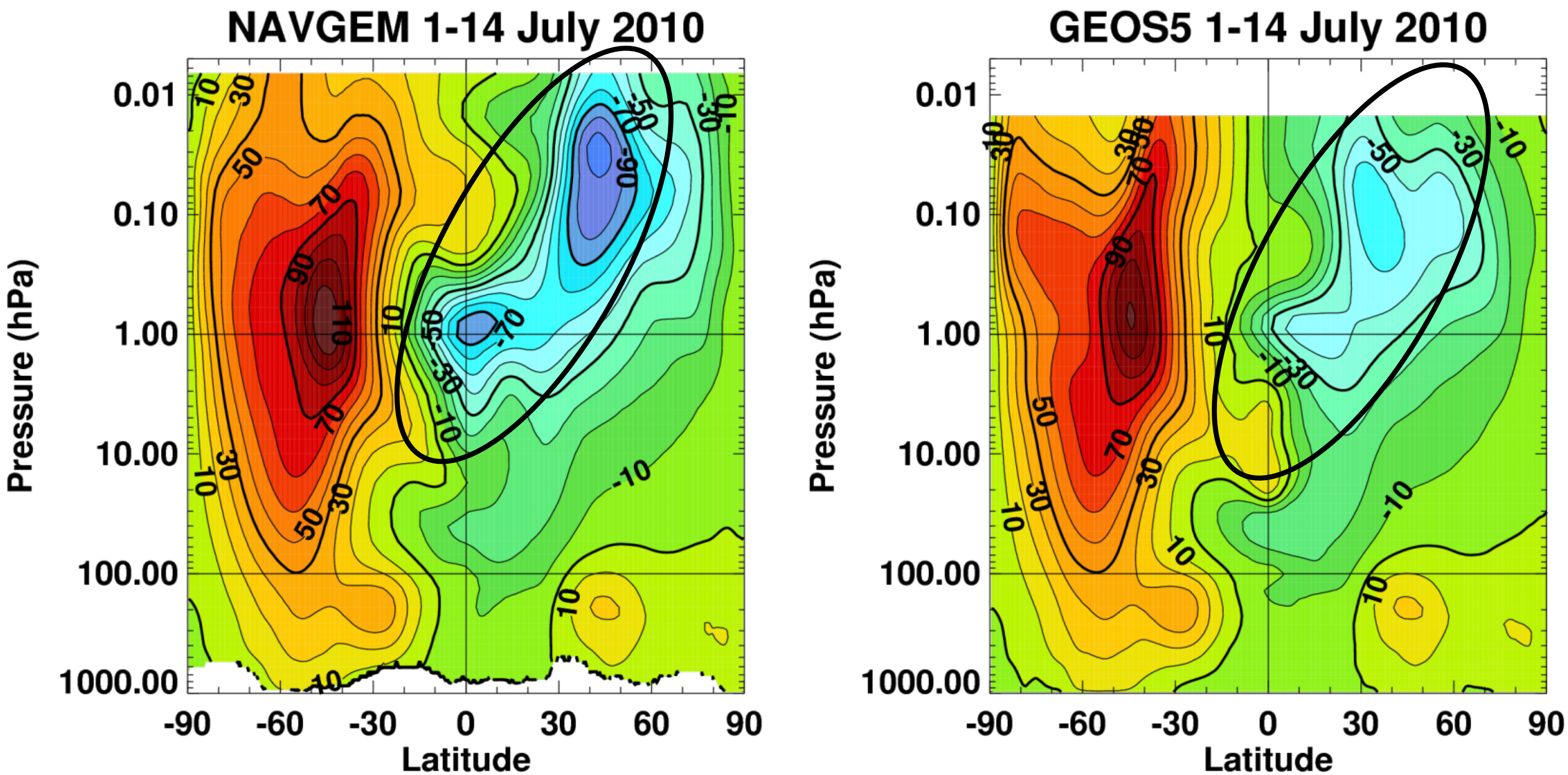
Upgraded NAVGEM to use Community RadiativeTransfer Model (CRTM) Version 2

This allows SSMI/S Upper Atmosphere Sounding (UAS) channels to be assimilated

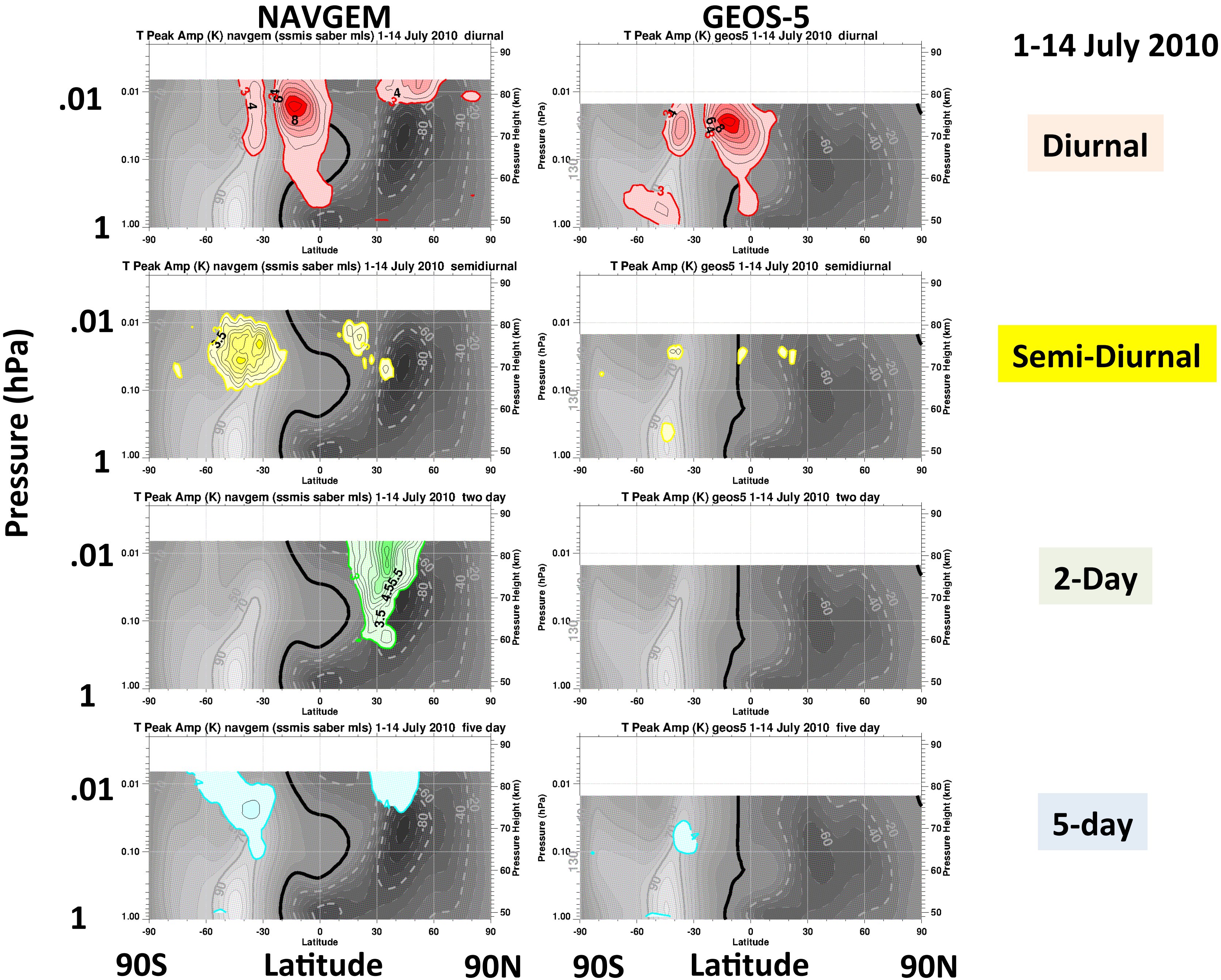
Goal is to transition from T319L42 → T425L64 (new top at 0.005 hPa or ~83 km)

For more details, see poster by Karl Hoppel et al. this afternoon.

Comparison of NAVGEM with GEOS5

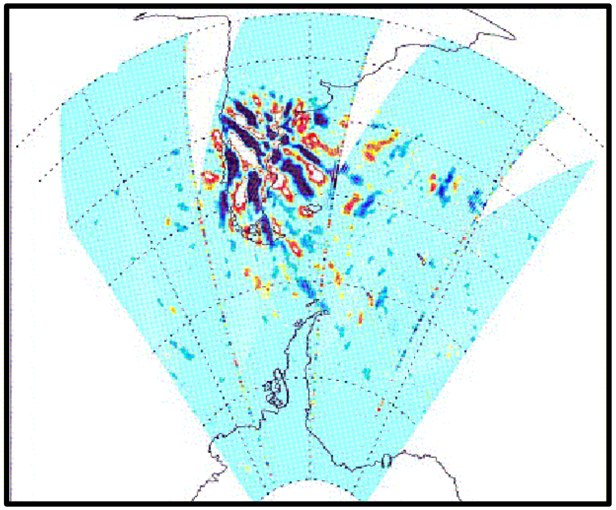


Currently, NAVGEM and GEOS-5 systems have similar top altitudes, however the assimilation of the higher SSMIS channels 19 and 20 produce stronger mesospheric wind shears and greater instabilities in NAVGEM.

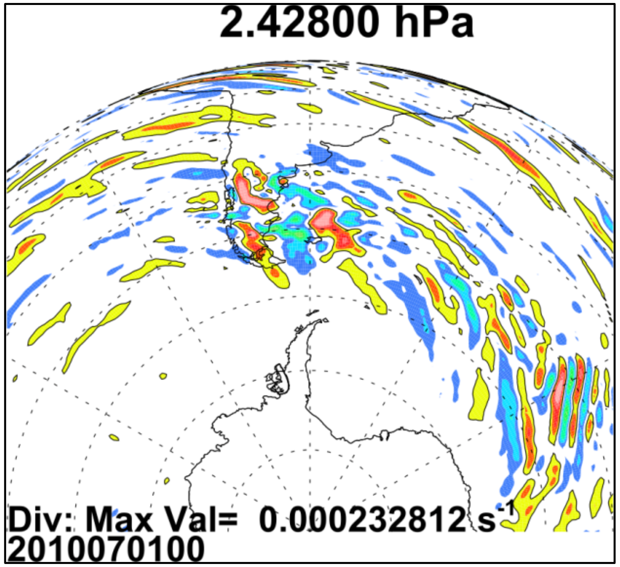

NAVGEM
GEOS-5
1-14 July 2010
Diurnal
Semi-Diurnal
2-Day
5-day
Pressure (hPa)
.01
1
90S
Latitude
90N
T Peak Amp (K) navgem (ssmis saber mls) 1-14 July 2010 diurnal
T Peak Amp (K) geos5 1-14 July 2010 diurnal
T Peak Amp (K) navgem (ssmis saber mls) 1-14 July 2010 semidiurnal
T Peak Amp (K) geos5 1-14 July 2010 semidiurnal
T Peak Amp (K) navgem (ssmis saber mls) 1-14 July 2010 two day
T Peak Amp (K) geos5 1-14 July 2010 two day
T Peak Amp (K) navgem (ssmis saber mls) 1-14 July 2010 five day
T Peak Amp (K) geos5 1-14 July 2010 five day
Pressure (hPa)
Pressure Height (km)

Mountain Waves in NAVGEM Analysis

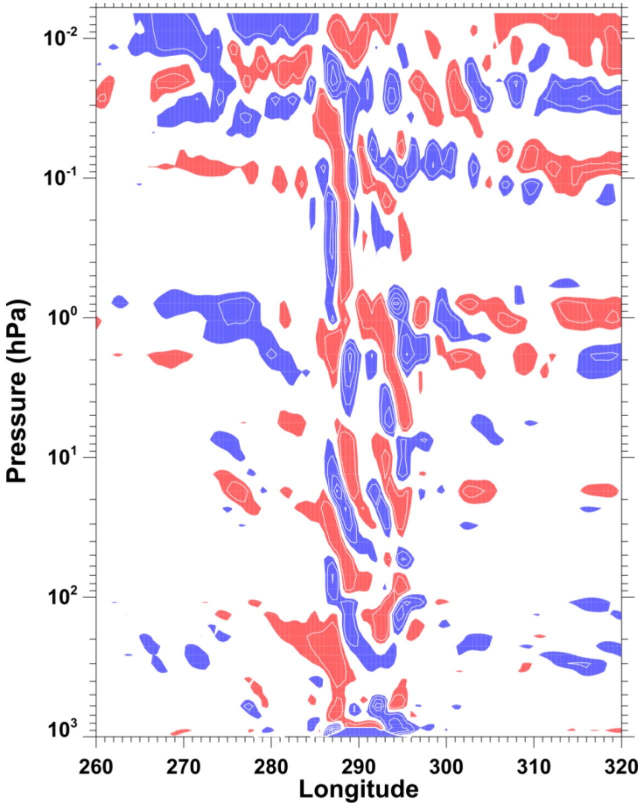
Aqua AIRS T_B 1 July 2010 2.5 hPa



NAVGEM Divergence 1 July 2010



NAVGEM Divergence (Normalized)
1 July 2010 42S



Future Improvements to NAVGEM

- T319L42 → T425L64 (new top at 0.005 hPa)
- Improved SW/LW heating (RRTMG)
- NPP (CrIS/ATMS) assimilation capability
- Ozone assimilation (SBUV/2 and NPP OMPS)
- Middle atmospheric GWD using stochastic parameterization of *Eckermann* (JAS, 2011)
- Diurnal ozone photochemistry

Summary

- NOGAPS-ALPHA meteorological analyses offer a unique view of middle atmospheric dynamics up to 0-90 km. They are currently available for select periods between Dec. 2004 – Jun 2010*.
- A new "reanalysis" is planned to cover entire period 2005-present using new high-altitude NAVGEM system.
- Future of high-altitude data assimilation will depend on new instruments to replace existing ones (e.g., Aura MLS, TIMED SABER).

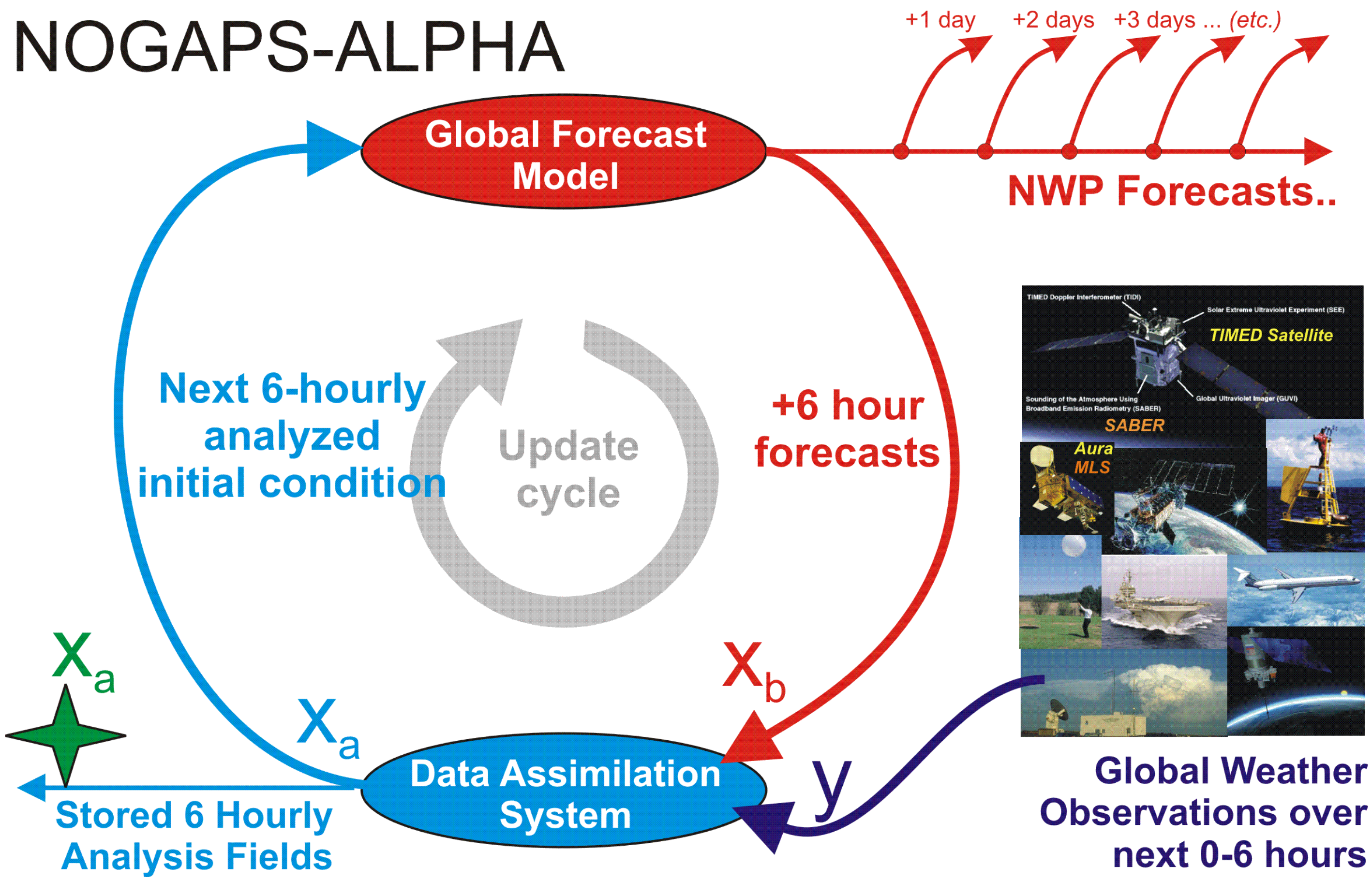
Please contact me if you are interested in using the data

END

Acknowledgments

- This work was supported by the Office of Naval Research and by NASA Heliophysics Guest Investigator Program Award NNH09AK64I.

NOGAPS-ALPHA



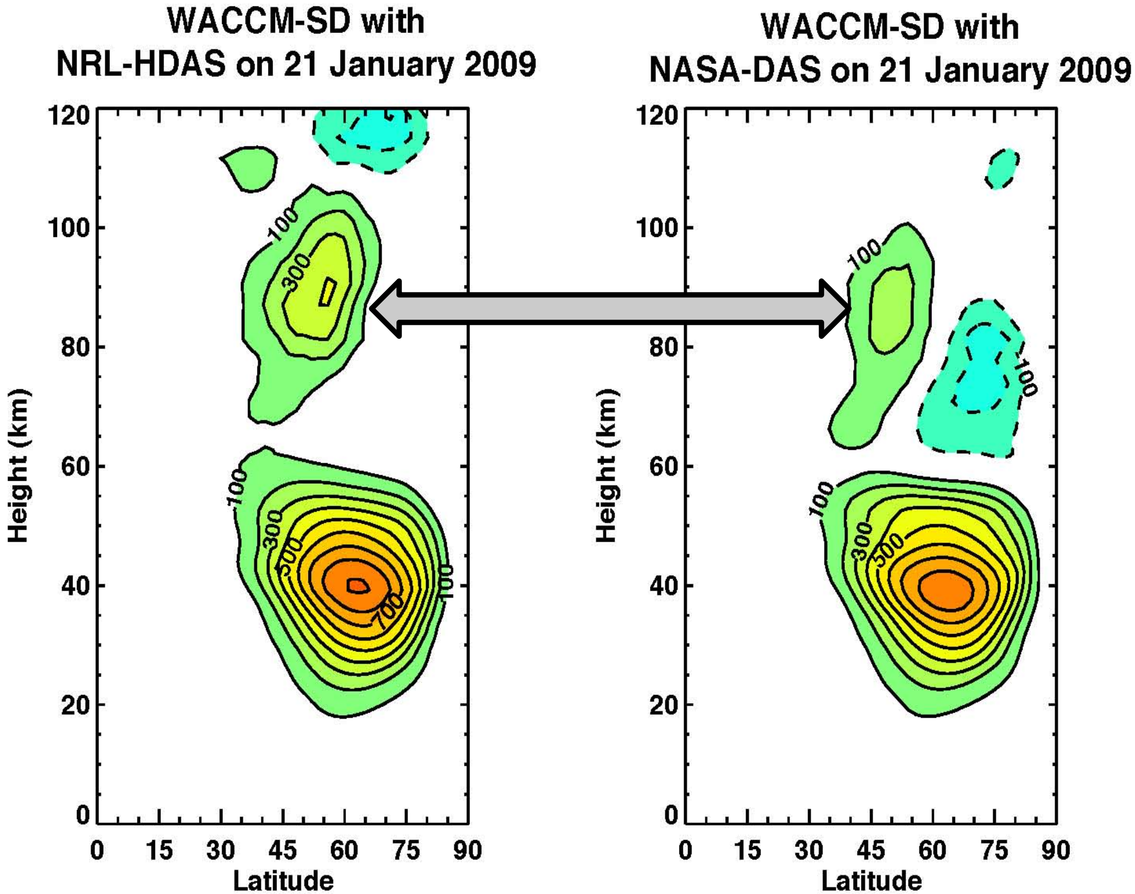
NRL Data Assimilation and WACCM

- The NCAR Whole Atmosphere Community Climate Model (WACCM) can be configured in "specified dynamics" (SD) mode where model circulation is specified using meteorological fields from data assimilation

- One advantage of the NRL meteorological fields is the ability to specify the dynamics over a very deep atmospheric layer 0 – 90 km.

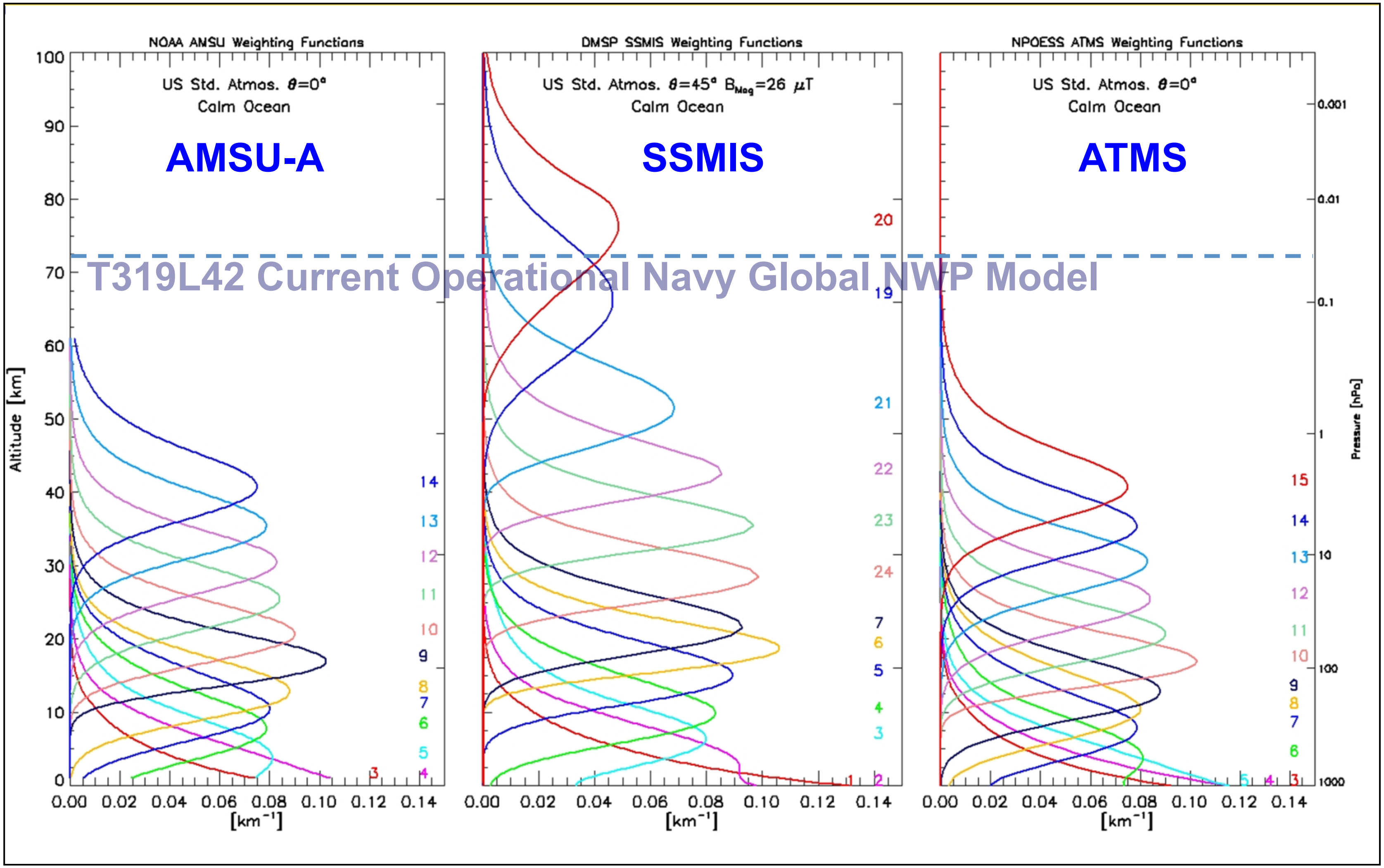
- Combining NRL high-altitude data assimilation with WACCM can extend the vertical range over which we can study planetary scale waves in the mesosphere and thermosphere (e.g., the 2-day wave)

PLANETARY SCALE WAVES VERTICAL MOMENTUM FLUX (VT)



- Using NRL-HDAS fields (left) produces larger momentum flux from 80 to100 km compared to using NASA fields (right).
- Results below 50 km are very similar.
- Lack of wind information above 50 km underestimates "bottom-up" forcing by 200%.

Microwave Atmosphere Sounding Capabilities



NOGAPS-ALPHA:

Advanced Level Physics-High Altitude

- Global spectral forecast model (T79), 68 hybrid σ-p vertical levels (L68) from surface to 5x10^{-4} hPa *(see Eckermann et al., JASTP, 2009)*

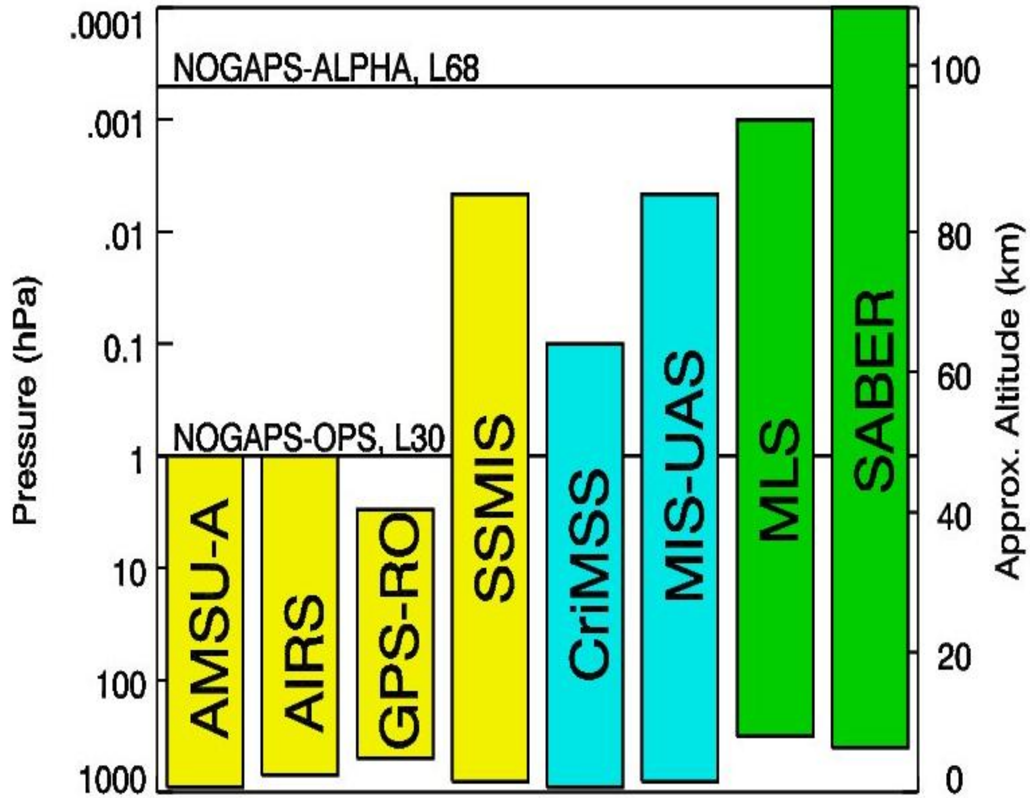
- Middle atmospheric gravity wave drag, parameterized O3 and H2O photochemistry, non-LTE cooling

- 3DVAR assimilation of standard meteorological observations plus Aura MLS profiles of O3, T & H2O and SABER T profiles

- Provides global synoptic fields (e.g., u, v, T, H2O) every **6 hours** on pressure levels up to ~90 km

- Analysis period: Dec. 2004 – Mar. 2010 (not inclusive).

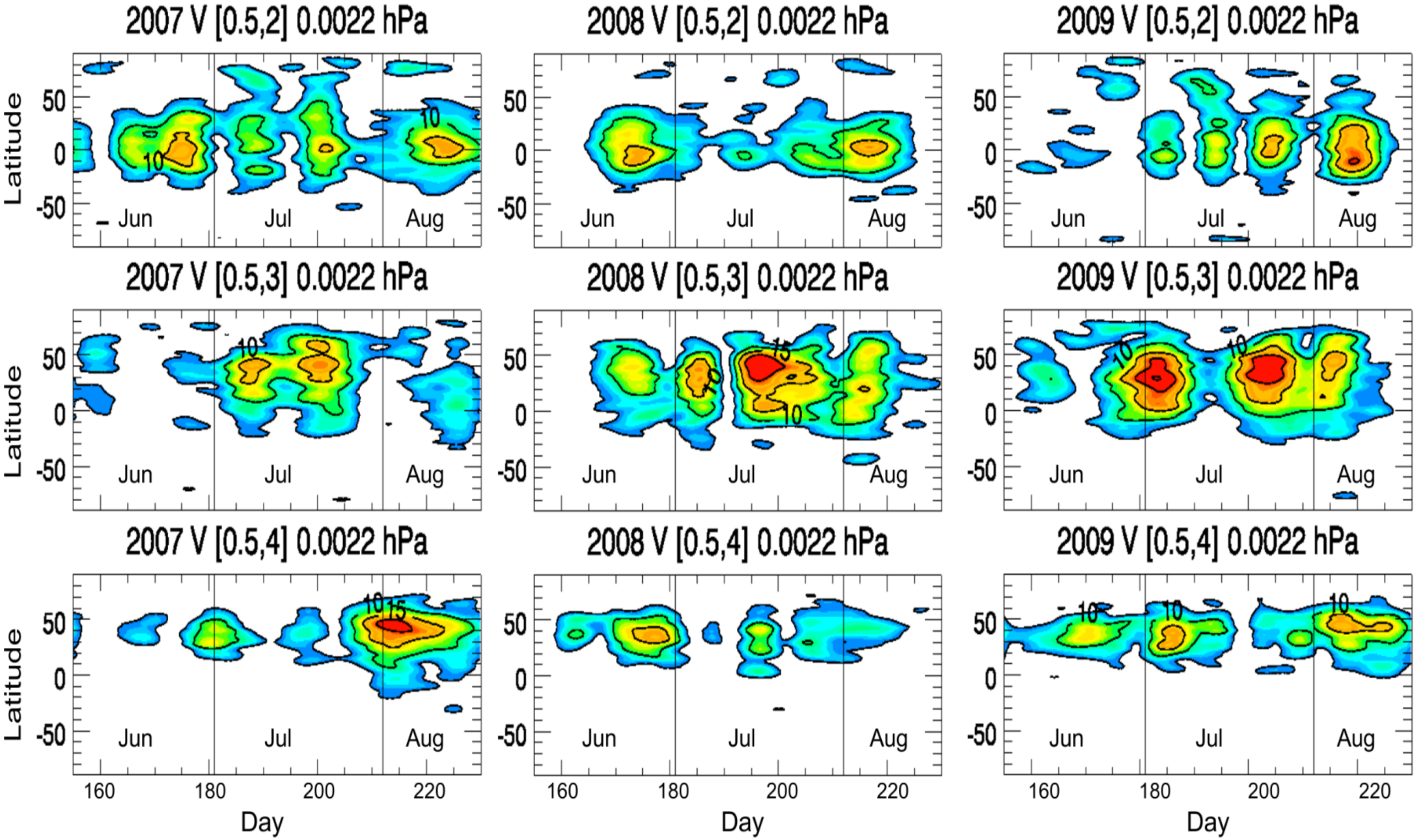
From Hoppel et al., ACP, 2008.



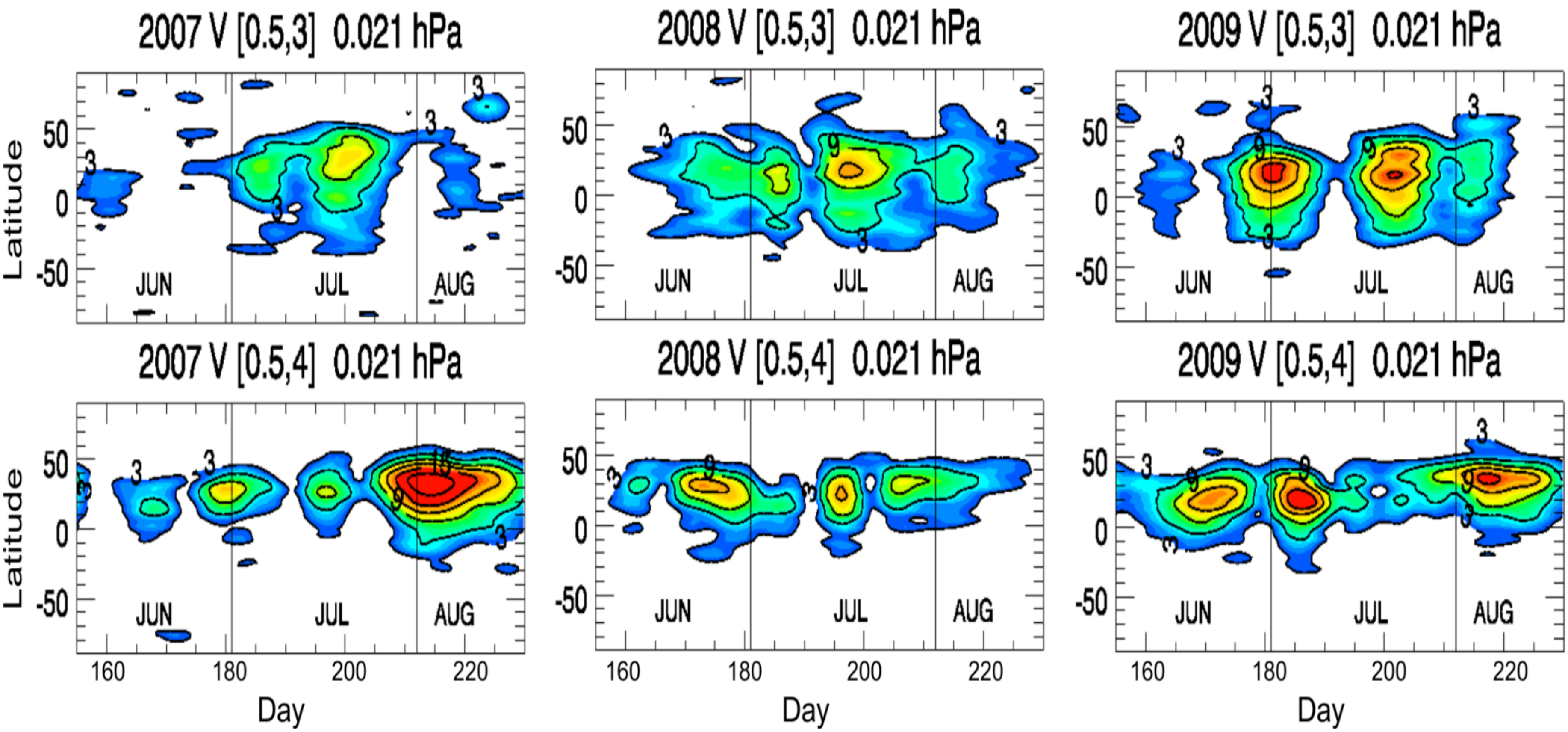
Current operational

Future operational

Research

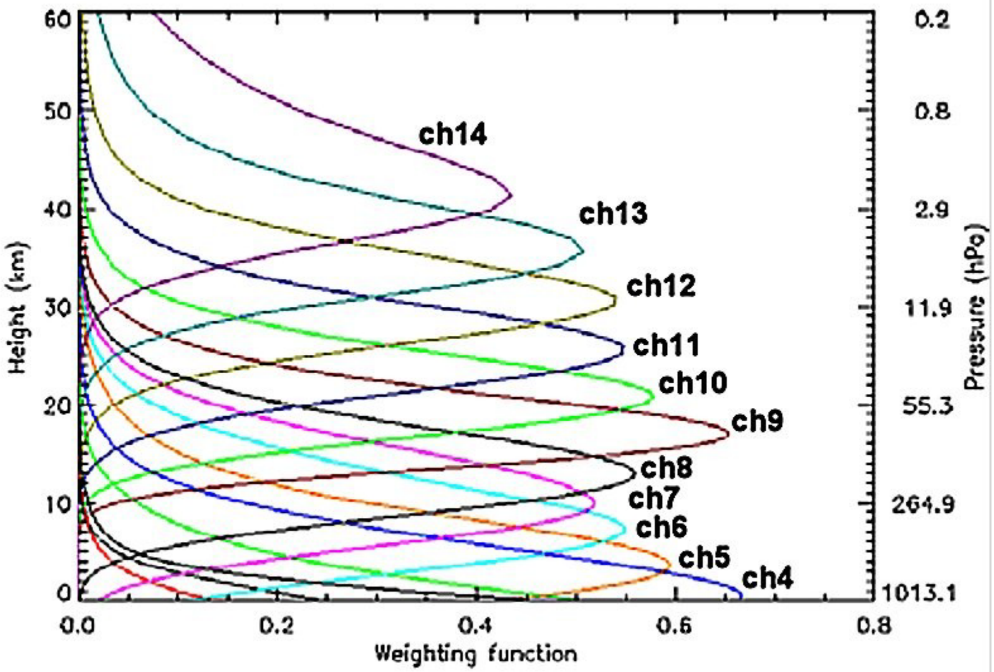


2007 V [0.5,2] 0.0022 hPa
2008 V [0.5,2] 0.0022 hPa
2009 V [0.5,2] 0.0022 hPa
2007 V [0.5,3] 0.0022 hPa
2008 V [0.5,3] 0.0022 hPa
2009 V [0.5,3] 0.0022 hPa
2007 V [0.5,4] 0.0022 hPa
2008 V [0.5,4] 0.0022 hPa
2009 V [0.5,4] 0.0022 hPa
Latitude
50
0
-50
Jun
Jul
Aug
10
15
160
180
200
220
Day

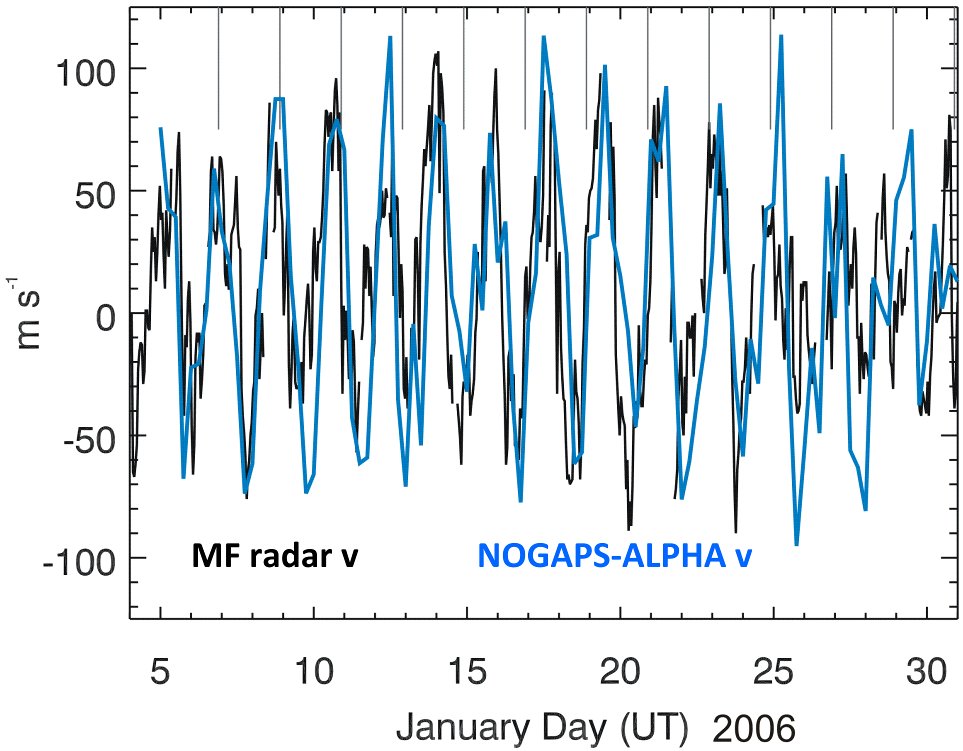


2007 V [0.5,3] 0.021 hPa
2008 V [0.5,3] 0.021 hPa
2009 V [0.5,3] 0.021 hPa
2007 V [0.5,4] 0.021 hPa
2008 V [0.5,4] 0.021 hPa
2009 V [0.5,4] 0.021 hPa
Latitude
50
0
-50
JUN
JUL
AUG
160
180
200
220
Day

AMSU-A Weighting Functions



NOGAPS-ALPHA Analyzed Winds

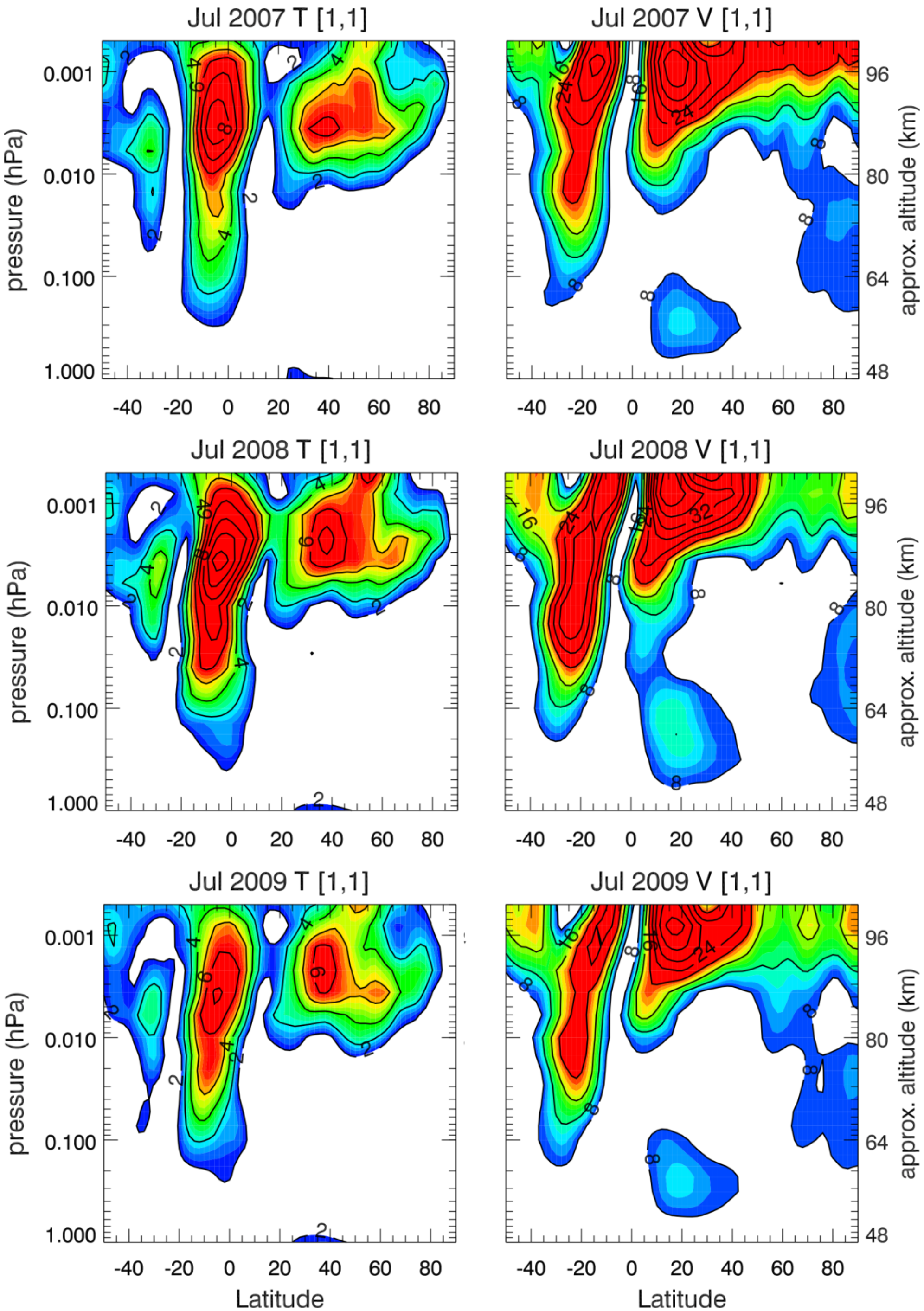


From McCormack et al., GRL, 2010

MF winds courtesy R. Vincent, U. of Adelaide

NOGAPS-ALPHA does not directly assimilate horizontal winds. Instead, wind increments are computed based on assimilation of middle atmospheric temperatures, subject to physical constraints from the forecast model

Comparison of NOGAPS-ALPHA meridional winds with MF radar winds at 88 km over Adelaide (35^{o}S, 138^{o}E) during January 2006.



Jul 2007 T [1,1]
Jul 2007 V [1,1]
Jul 2008 T [1,1]
Jul 2008 V [1,1]
Jul 2009 T [1,1]
Jul 2009 V [1,1]
pressure (hPa)
0.001
0.010
0.100
1.000
approx. altitude (km)
96
80
64
48
-40
-20
0
20
40
60
80
Latitude