Large-Scale Dynamics of the Mesosphere and Lower Thermosphere (MLT) Affecting MLT Gravity Wave Dynamics during DEEPWAVE As Derived from High-Altitude (0-100 km) Global NAVGEM Reanalyses of the 2014 Austral Winter

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3. Remote Sensing Division, Naval Research Laboratory, Washington, DC
4. Marine Meteorology Division, Naval Research Laboratory, Monterey, CA

Acknowledgements: DEEPWAVE was made possible through financial and/or in-kind support from many U.S. and international organizations, including NSF, NCAR/EOL, NRL, DLR, NIWA, the Australian Antarctic Division, the New Zealand MetService, the Australian Bureau of Meteorology, PAE Ltd., and the ECMWF. The U.S. Naval Research Laboratory (NRL) research component was supported by the Chief of Naval Research through the NRL base 6.1 research and platform support programs.

Ongoing NRLDC DEEPWAVE Projects

- **High-Altitude (0-100 km) Global NAVGEM Reanalysis of 2014 DEEPWAVE Austral Winter**
- **Large-Scale Dynamics of the Mesosphere and Lower Thermosphere during DEEPWAVE**
- Resolved and Parameterized Orographic and Nonorographic Gravity Wave Drag in NAVGEM during DEEPWAVE
- “Missing” Gravity-Wave Drag from NAVGEM Analysis Increments
- Stratospheric Gravity Waves in AIRS and CrIS 15µm and 4.3 µm Radiances
- Deep Gravity-Wave Dynamics over Auckland & Macquarie Islands during RF23
- Ray Tracing Study of Deep Large-Scale Gravity Waves before and during RF22
- Nonorographic Gravity Wave Dynamics over Southern Ocean (e.g. RF25)
- PV dynamics of the DEEPWAVE Austral Winter

Discussion for Today

- **High-Altitude (0-100 km) Global NAVGEM Reanalysis of 2014 DEEPWAVE Austral Winter**
- **Large-Scale Dynamics of the Mesosphere and Lower Thermosphere during DEEPWAVE**
- Resolved and Parameterized Orographic and Nonorographic Gravity Wave Drag in NAVGEM during DEEPWAVE
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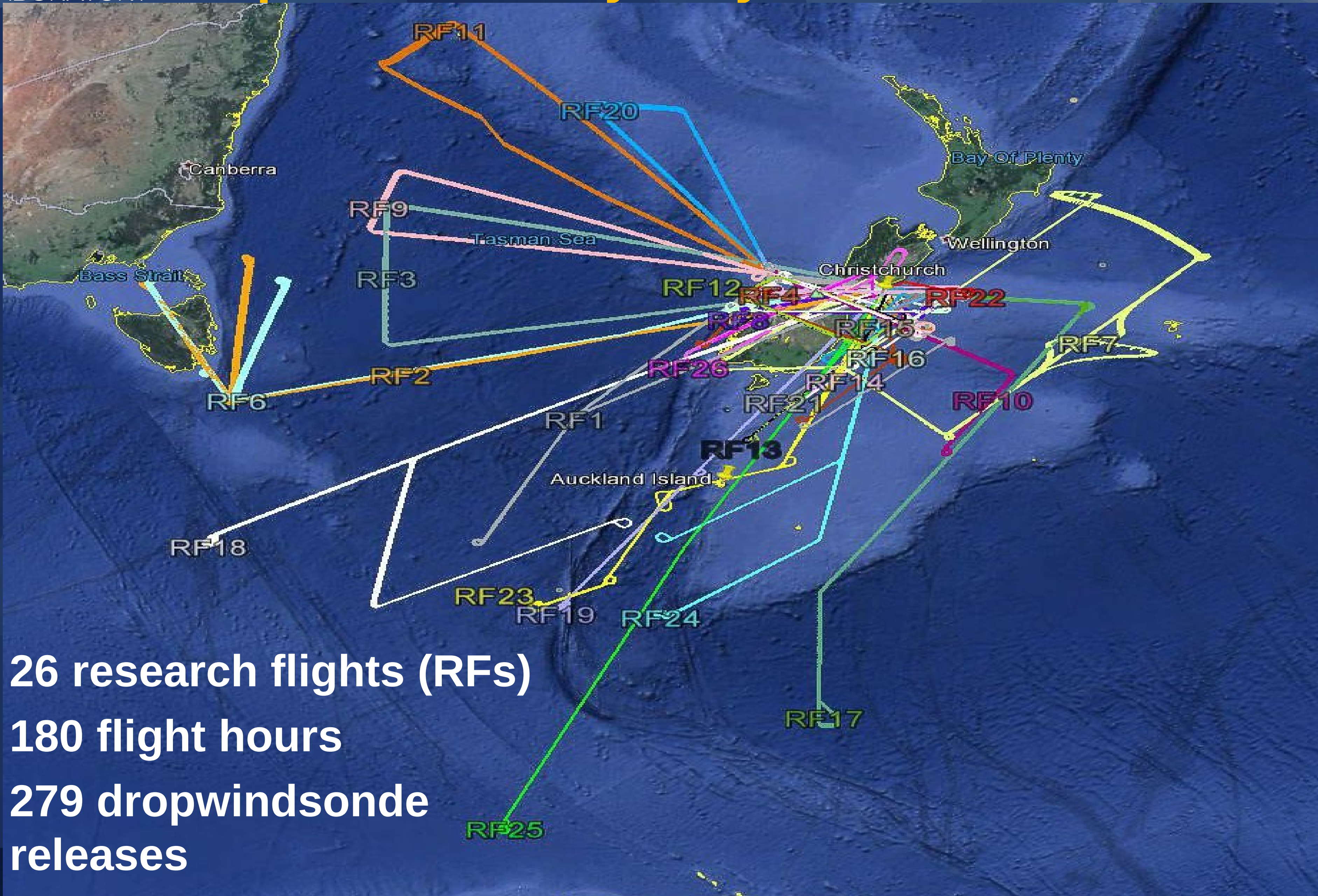
- Nonorographic Gravity Wave Dynamics over Southern Ocean (e.g. RF25)
- PV dynamics of the DEEPWAVE Austral Winter

NAVGEM DEEPWAVE Reanalysis

Science Motivation

The Deep Propagating Gravity Wave Experiment: May-July 2014

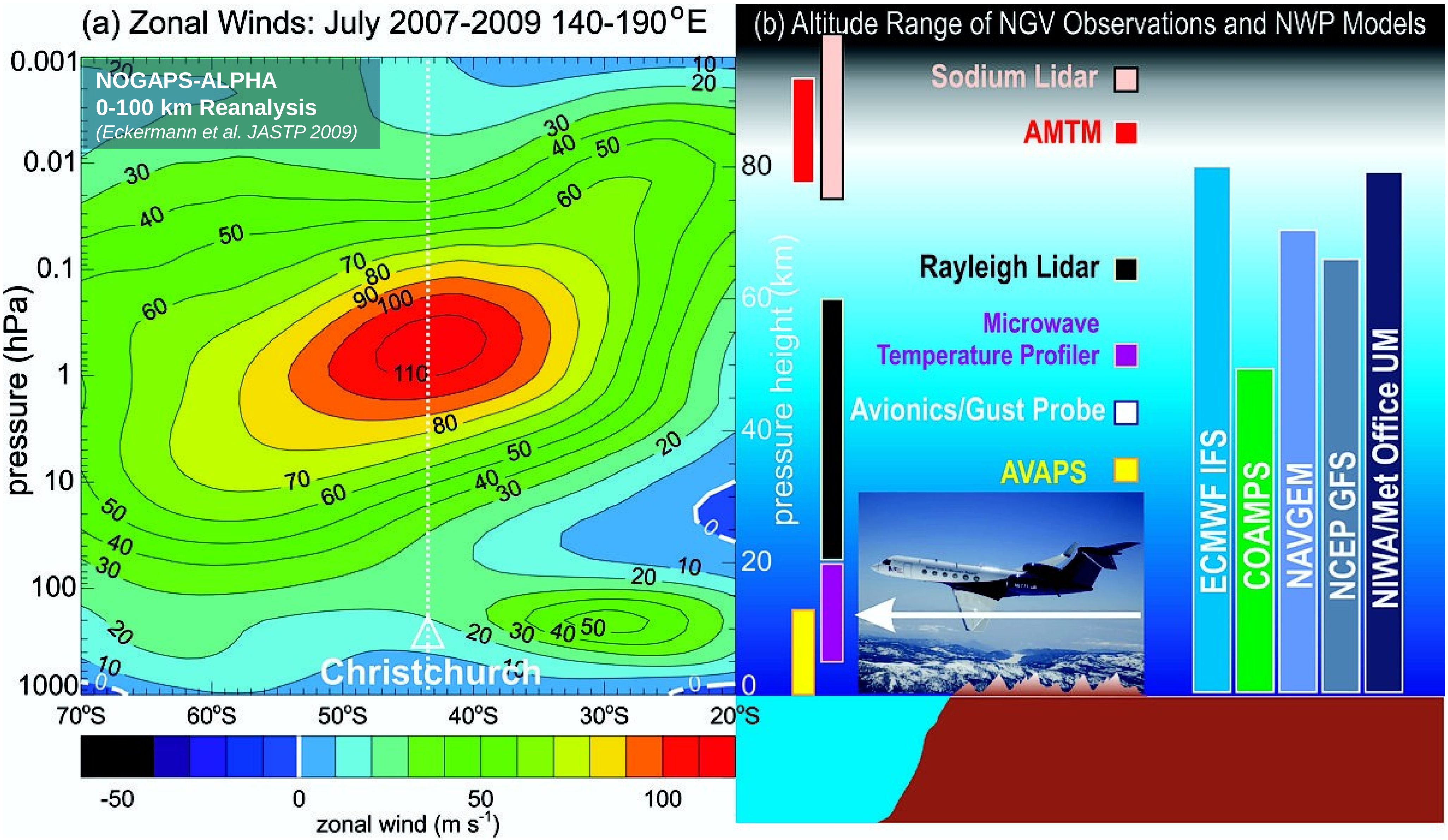


26 research flights (RFs)

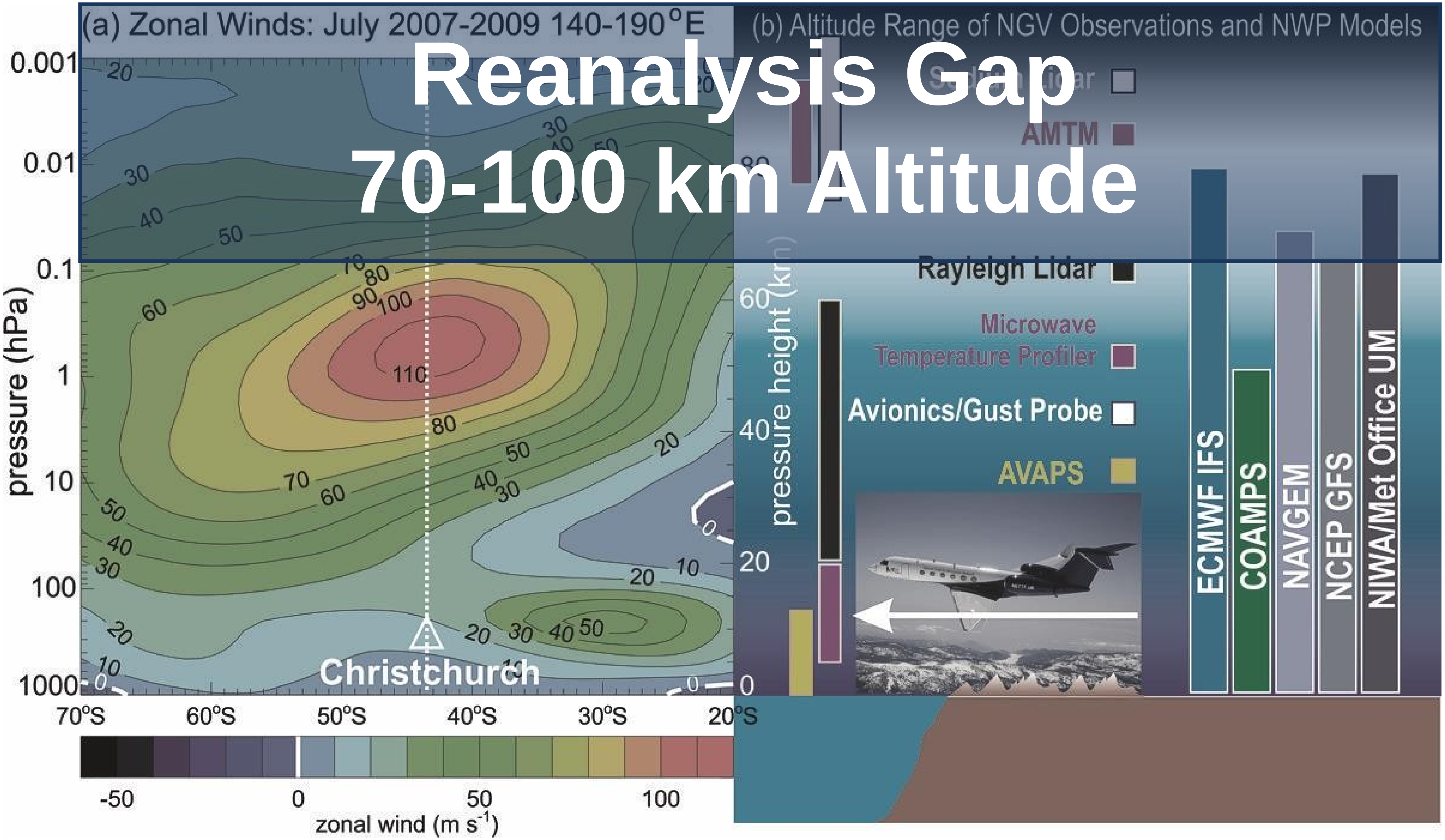
180 flight hours

279 dropwindsonde releases

The Deep Propagating Gravity Wave Experiment (DEEPWAVE): May-July 2014



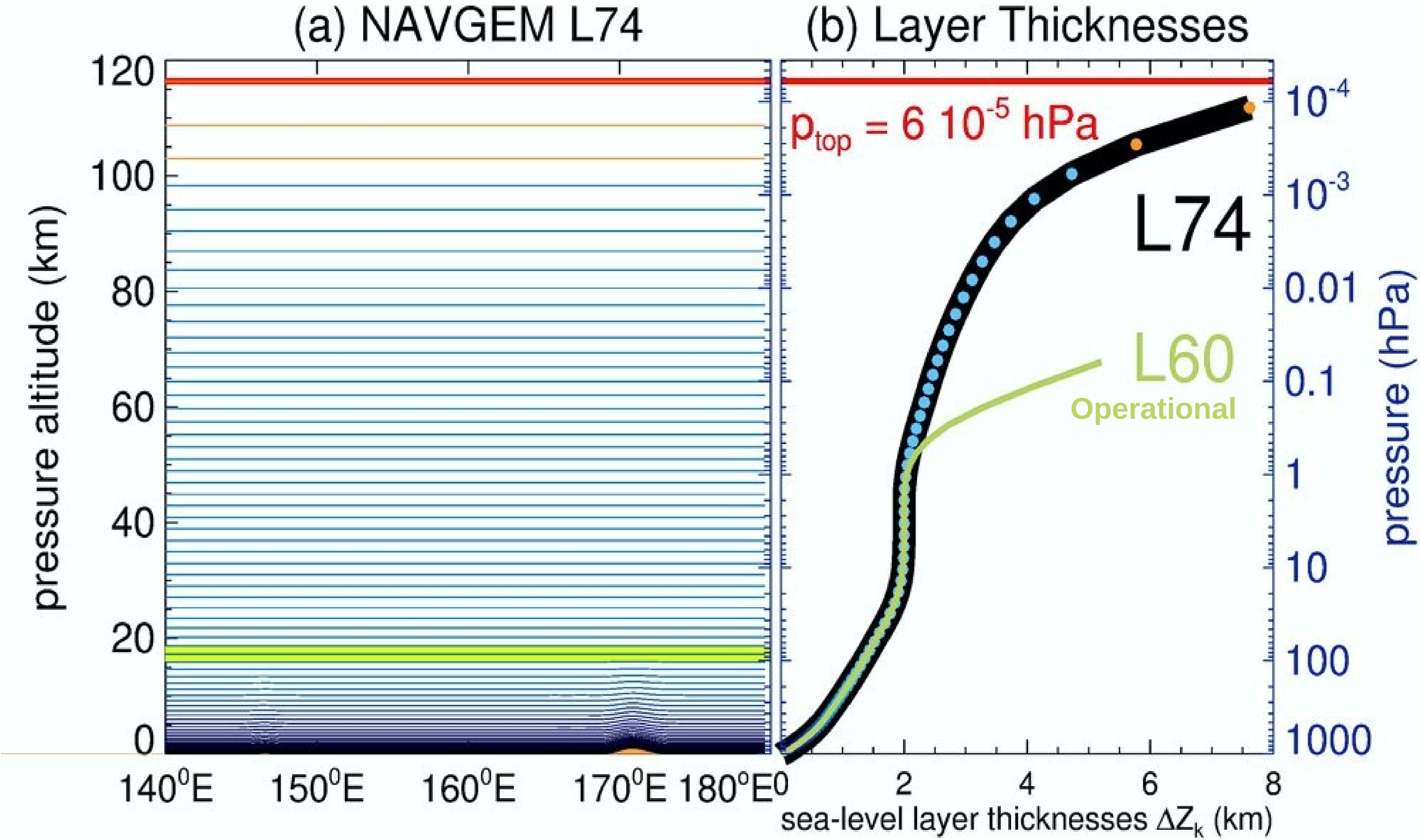
Reanalysis Gap from ~70-100 km Altitude Inhibits DEEPWAVE Gravity-Wave Science



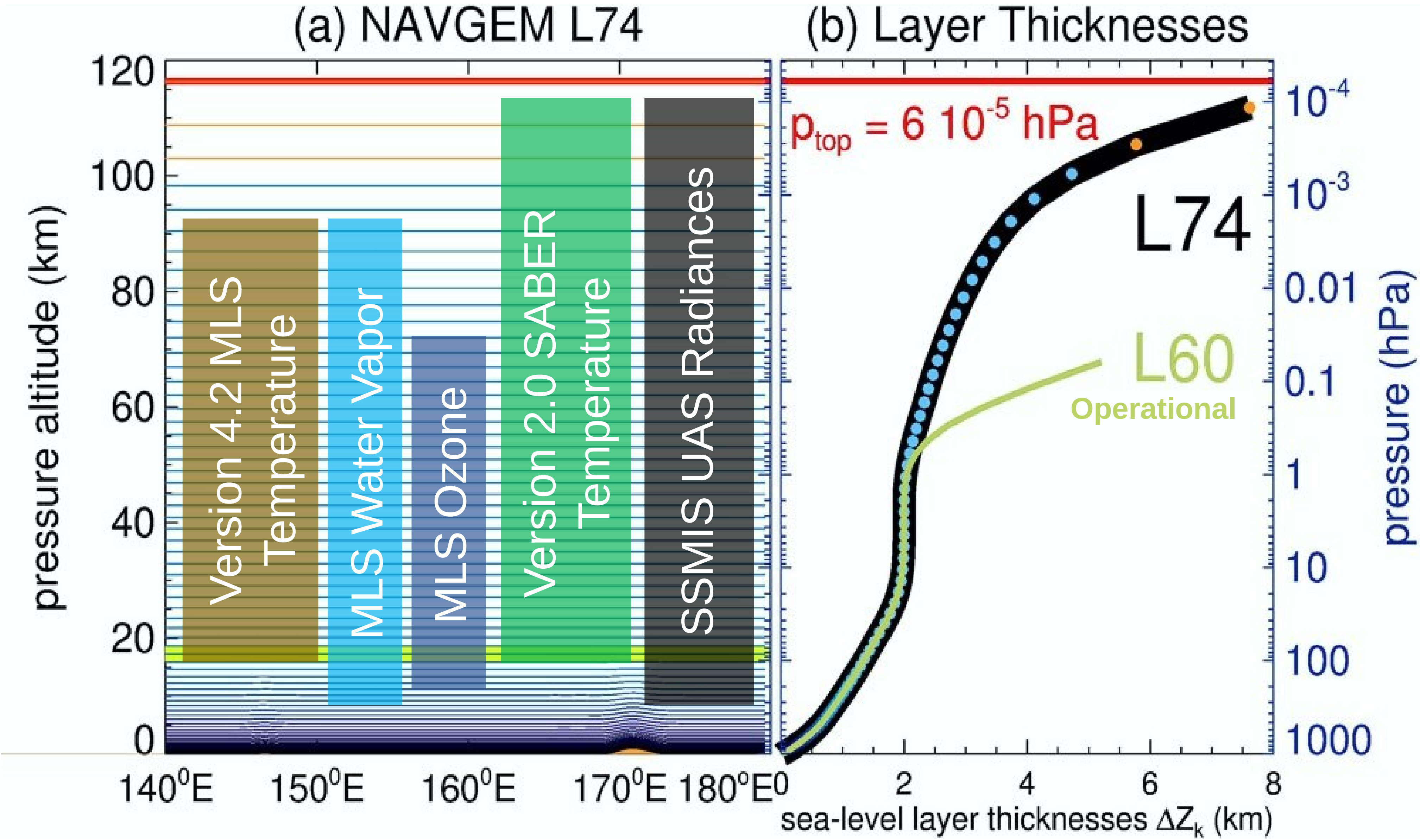
NAVGEM DEEPWAVE Reanalysis

Research Reanalysis Runs into Mesosphere & Lower Thermosphere (MLT): 0-100 km

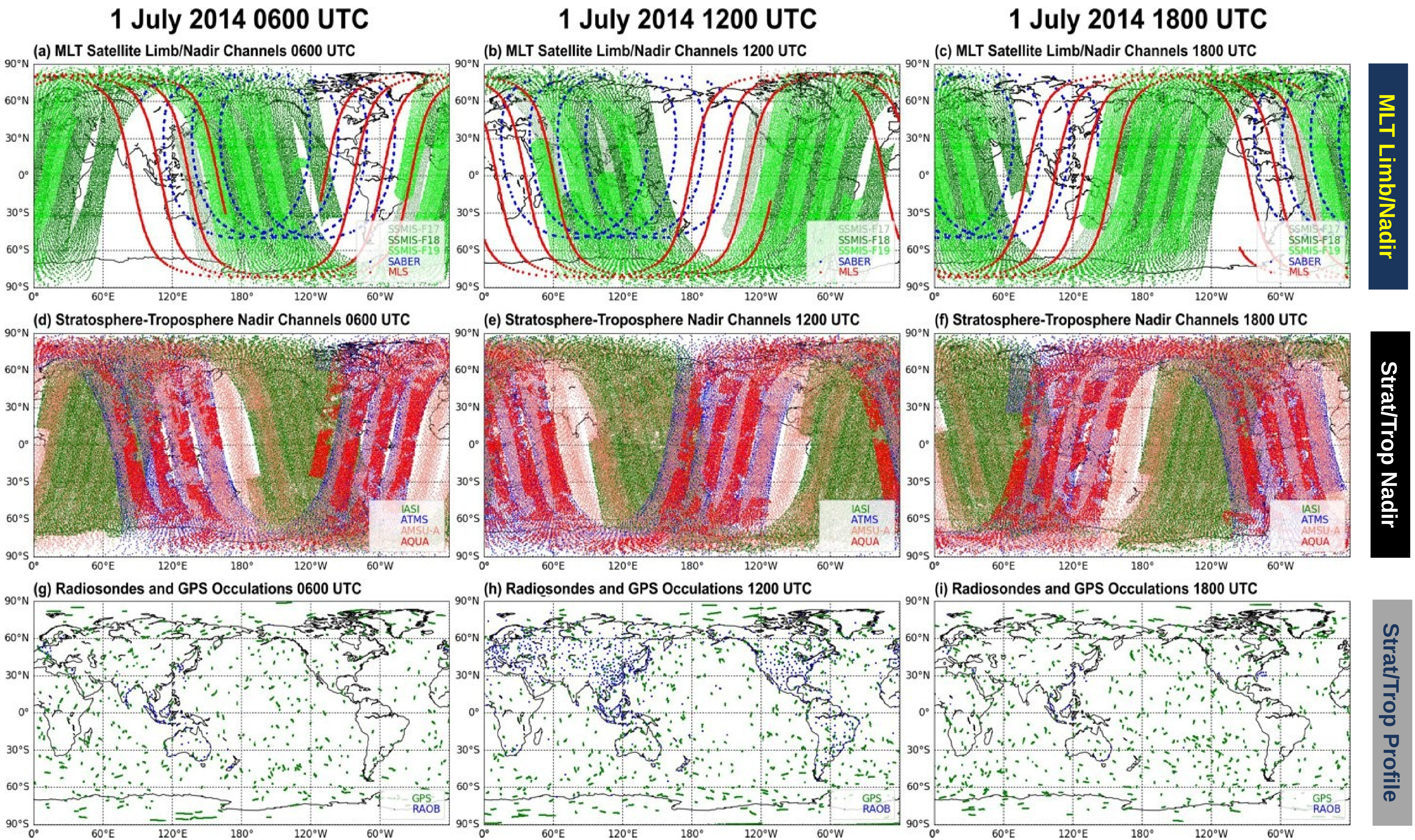
NAVGEM Vertical Layers 0-100 km



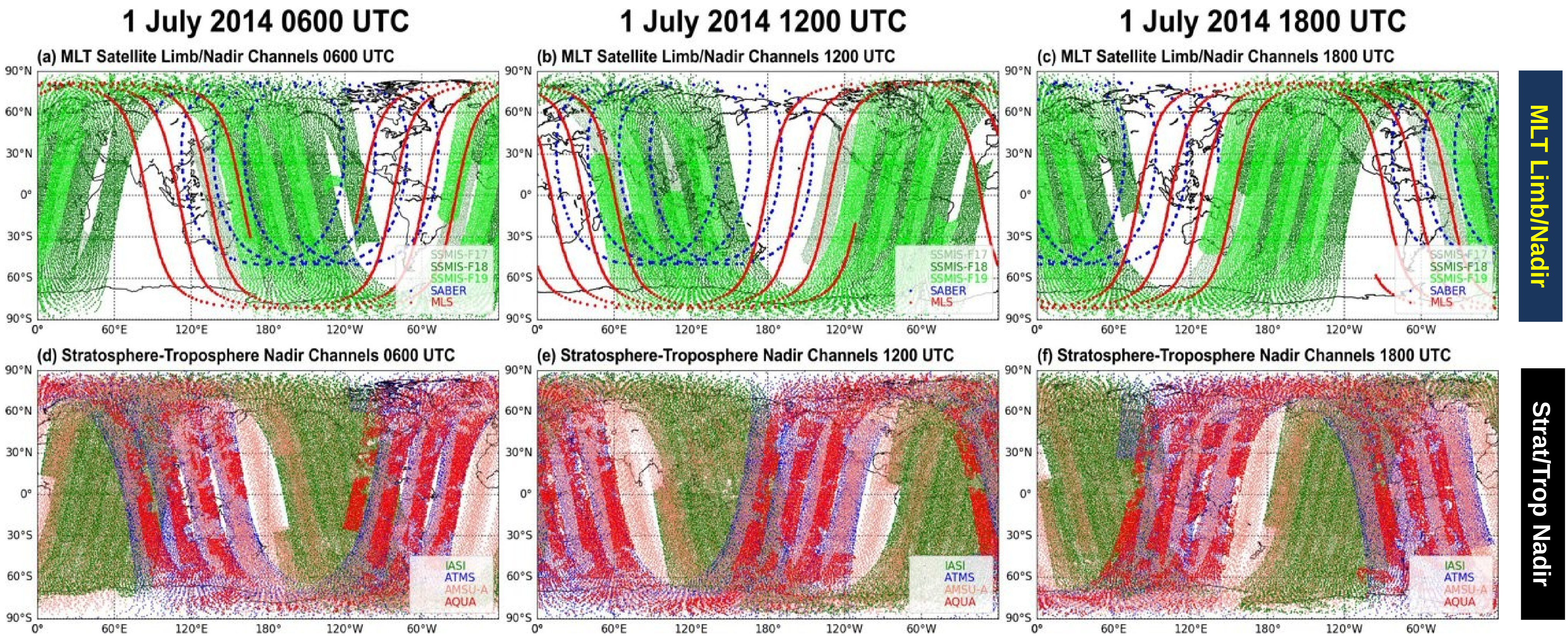
NAVGEM MLT Satellite Channels



Sample 6-Hourly Geographical Coverage



Sample 6-Hourly Geographical Coverage



~ 3.3 million atmospheric observations assimilated every 6-hour cycle (superobbed)

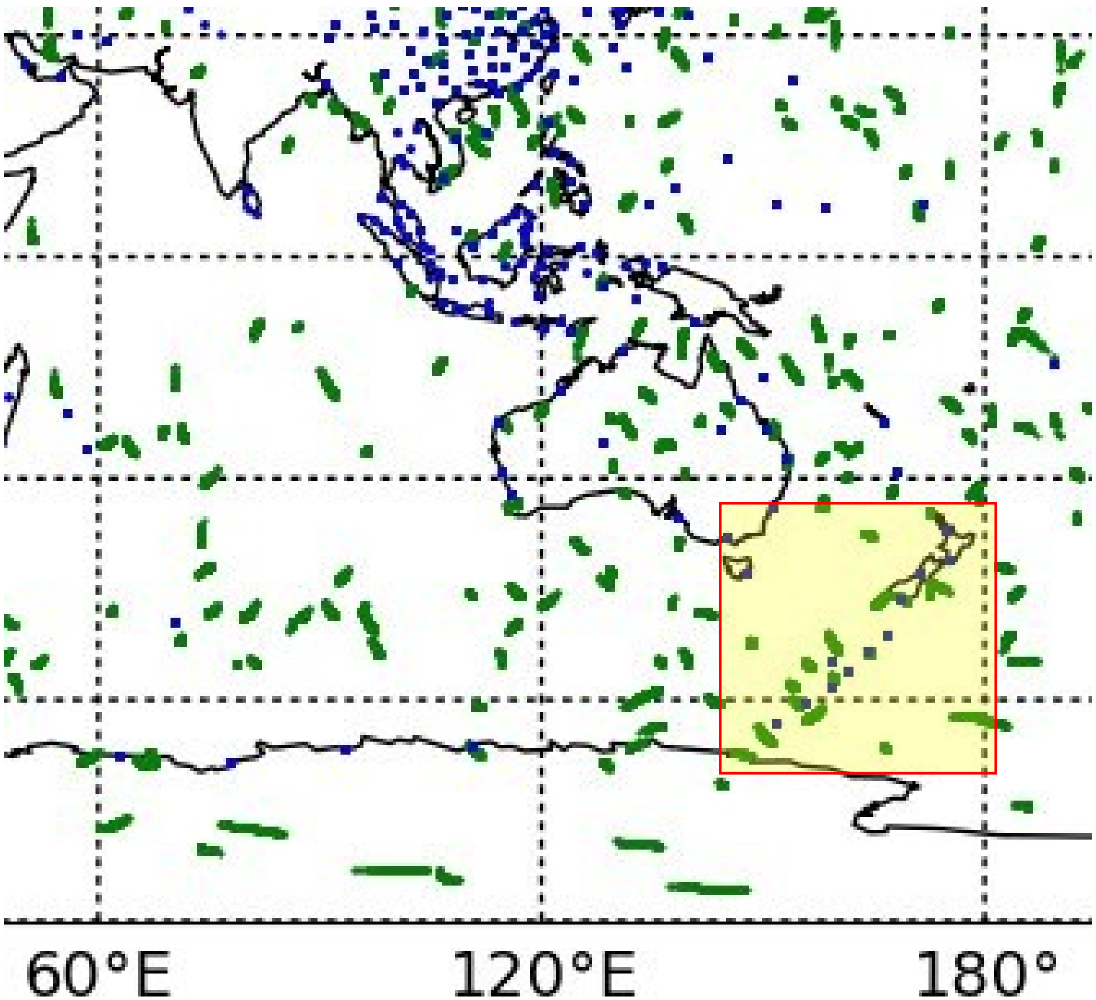
~ 0.25 million MLT observations assimilated every 6 hours

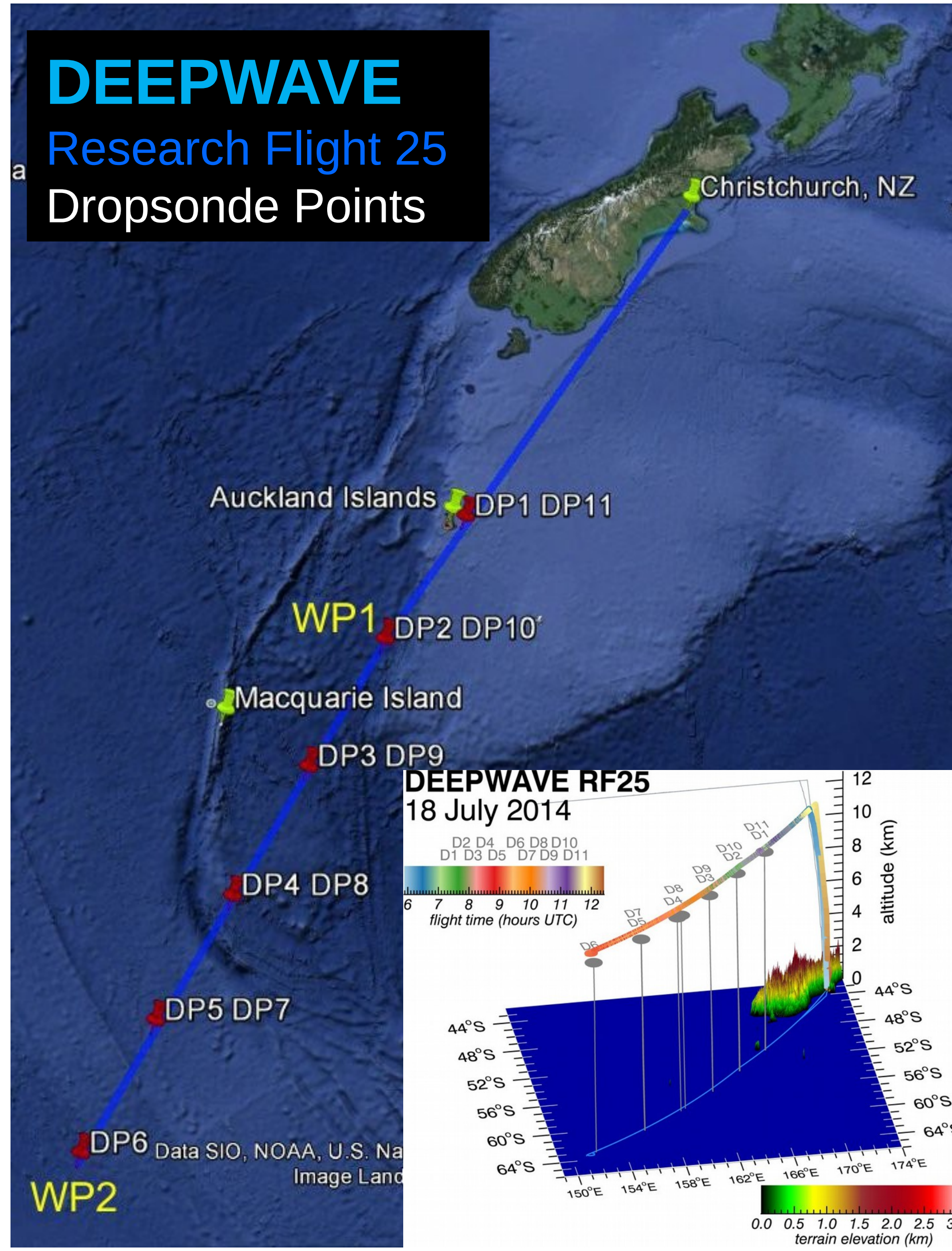
- ~30,000 SABER limb observations
- ~110,000 MLS limb observations
- ~110,000 SSMIS UAS nadir observations (3 instruments on F17, F18 & F19)

NGV DEEPWAVE Dropsondes Assimilated

Radiosondes & GPS Occultations

18 July 2014 1200 UTC Update Cycle





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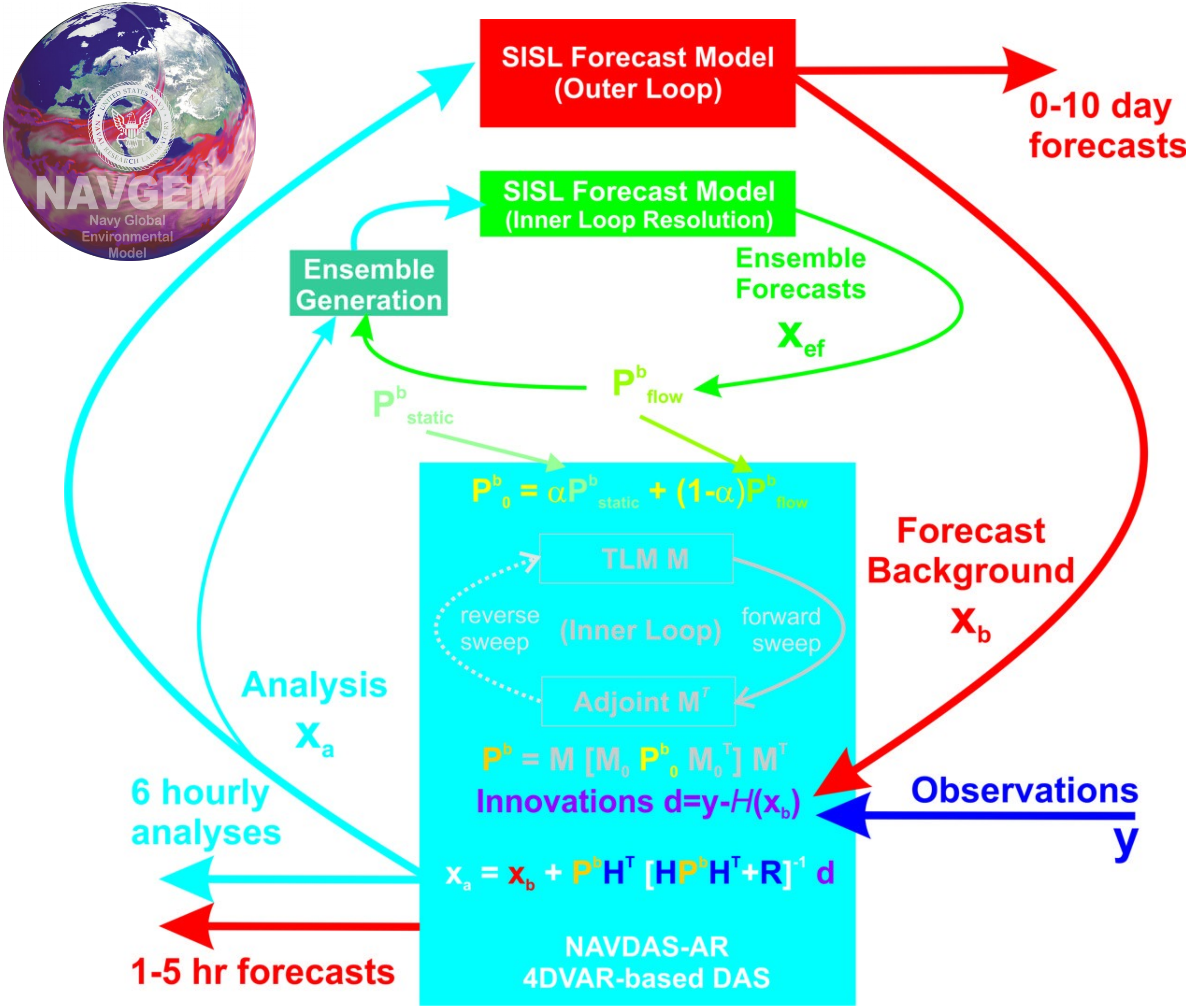
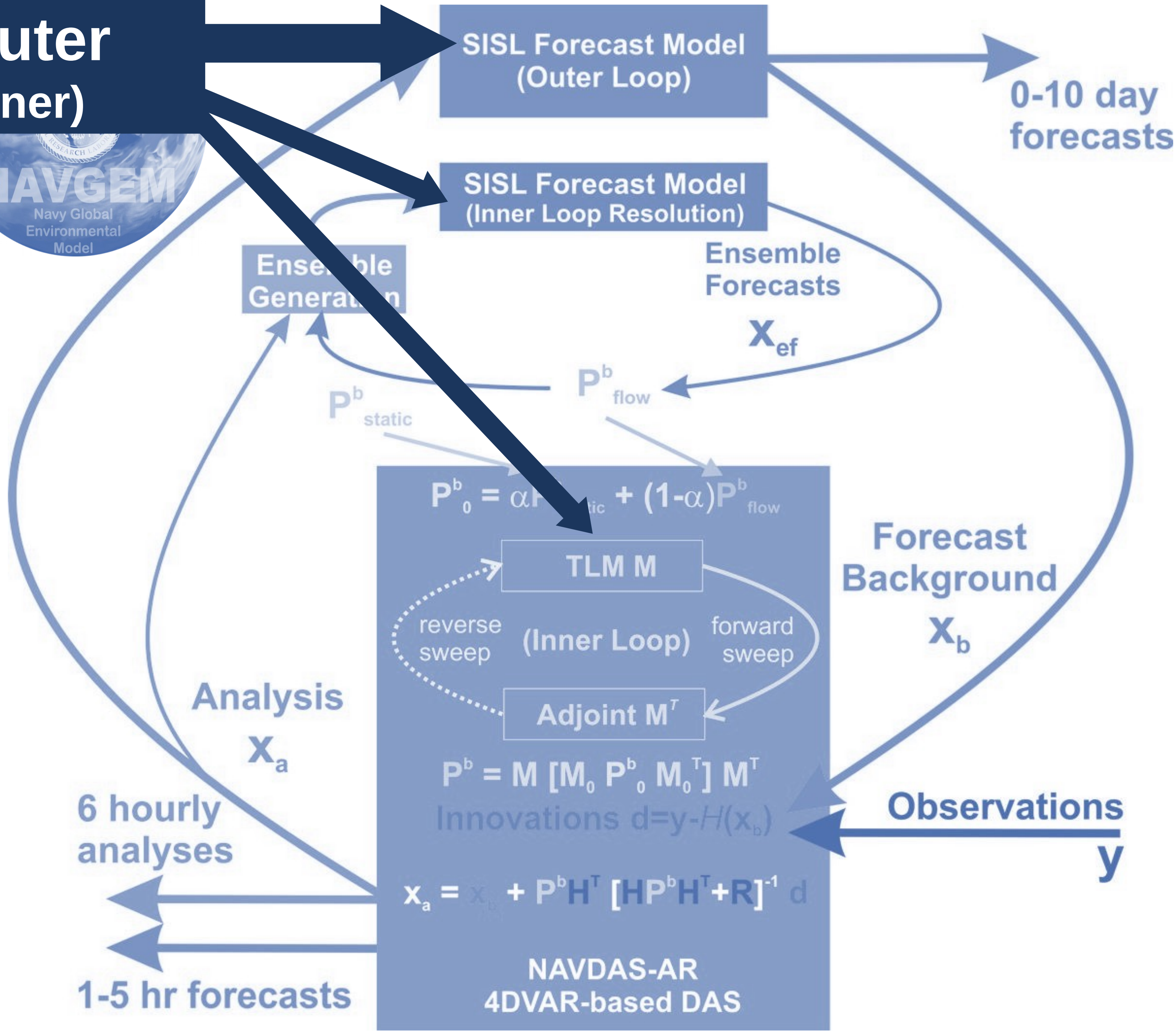
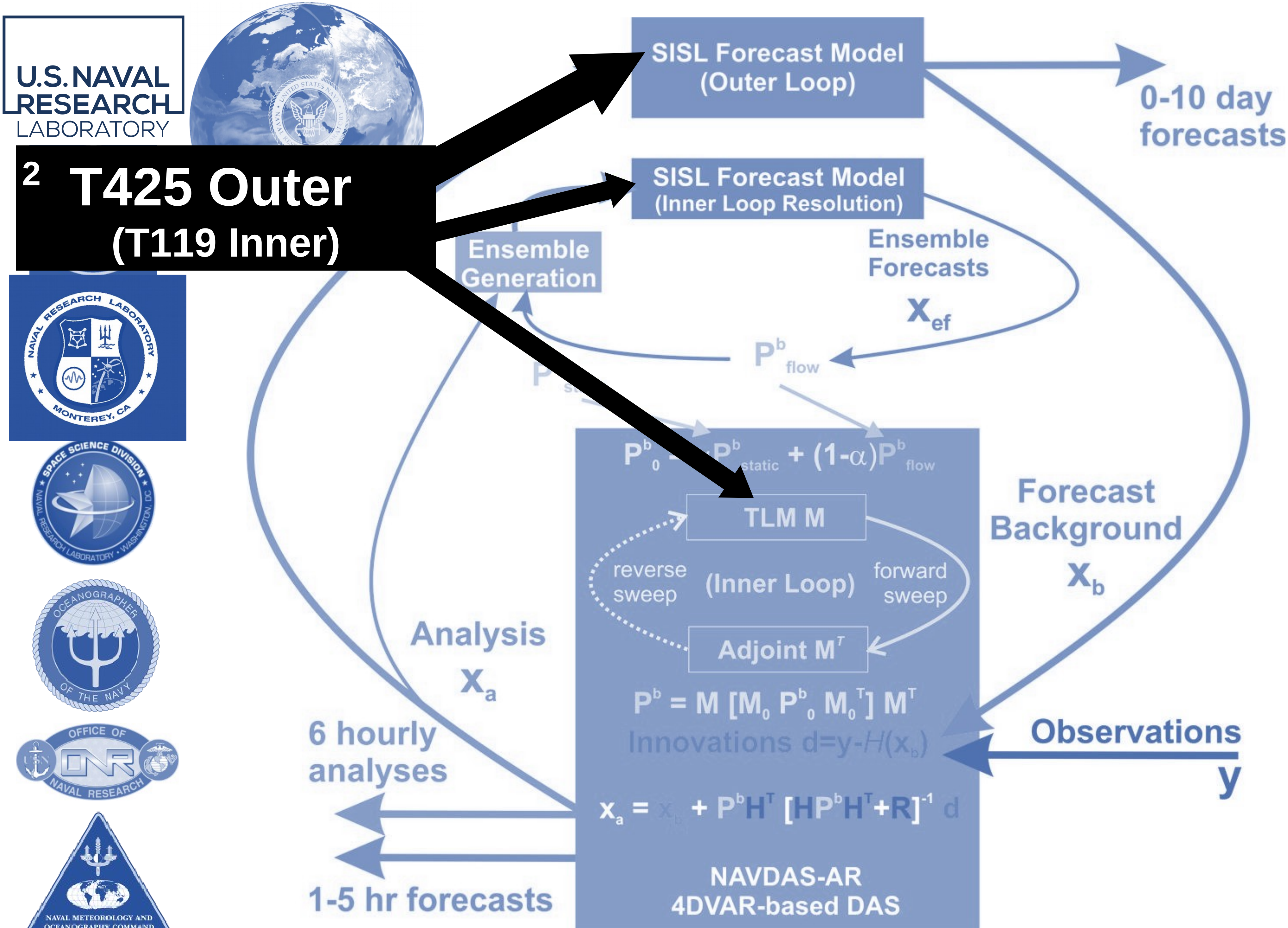


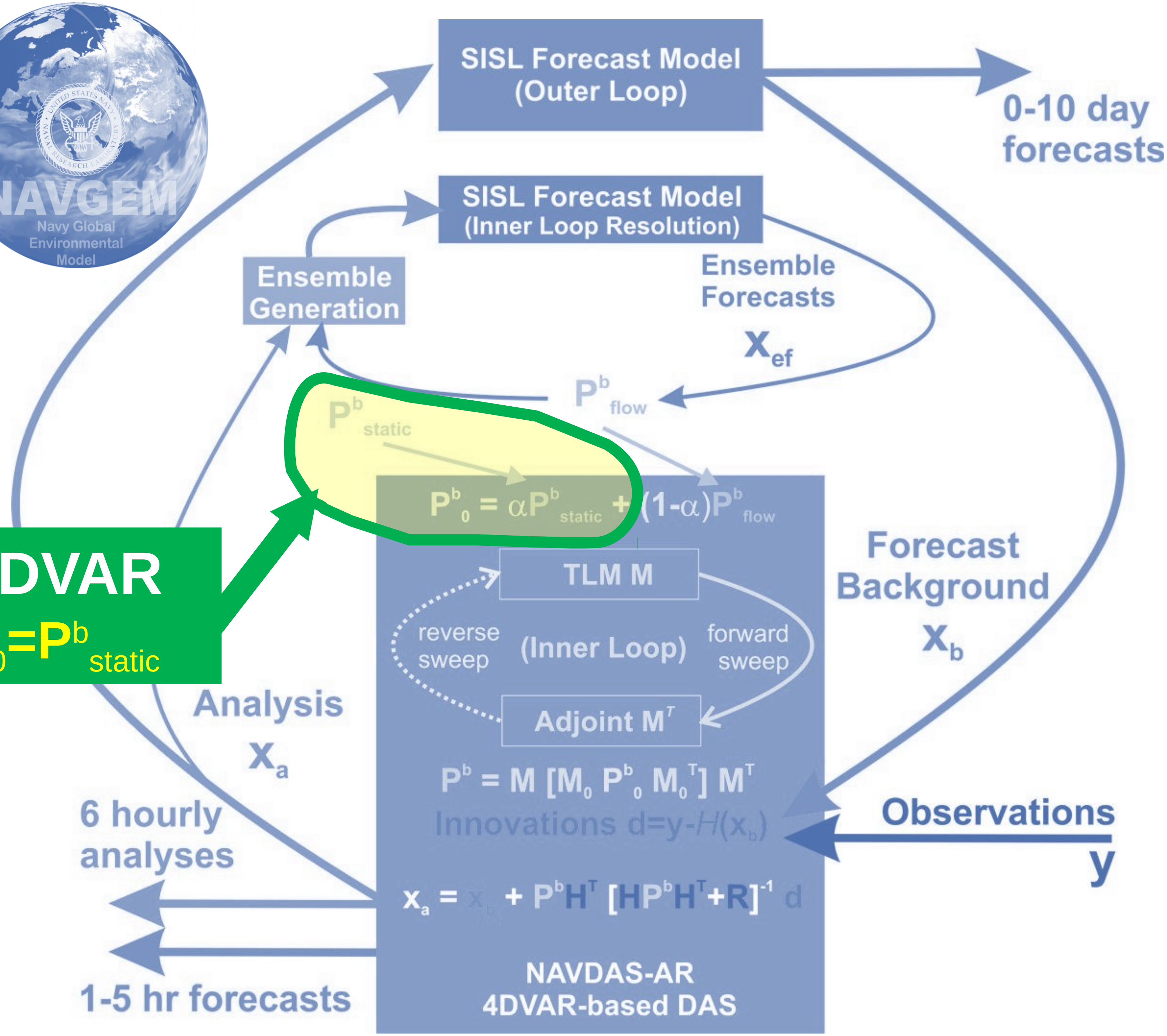
1 T119 Outer (T47 Inner)

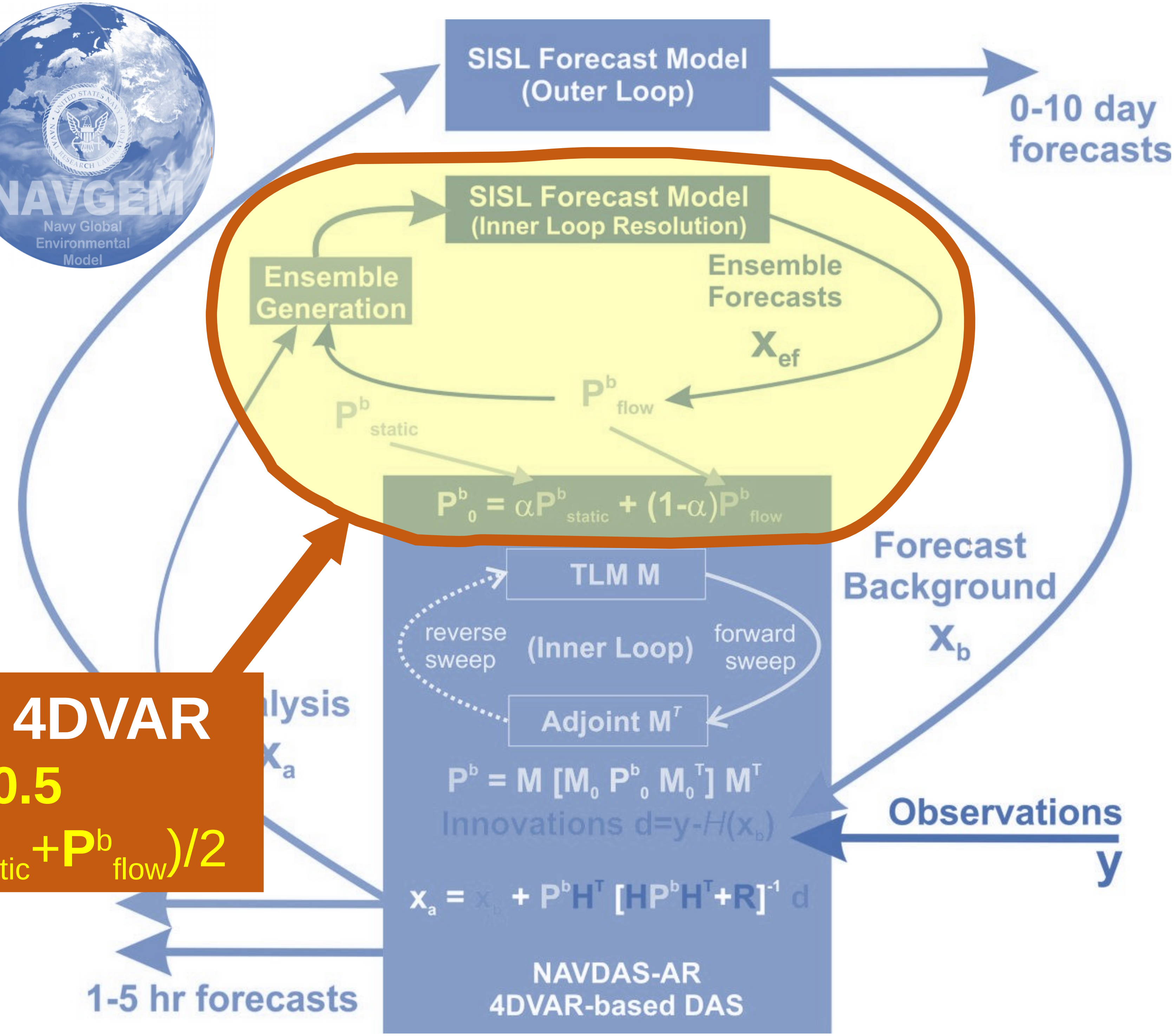



2 T425 Outer
(T119 Inner)
SISL Forecast Model
(Outer Loop)
0-10 day
forecasts
SISL Forecast Model
(Inner Loop Resolution)
Ensemble
Generation
Ensemble
Forecasts
x_{ef}
P^b_{flow}
P^b_0 = αP^b_{static} + $(1-\alpha)P^b_{flow}$
TLM M
reverse
sweep
(Inner Loop)
forward
sweep
Adjoint M^T
$P^b = M [M_0 P^b_0 M_0^T] M^T$
Innovations $d=y-H(x_b)$
$x_a = x_b + P^bH^T [HP^bH^T+R]^{-1} d$
NAVDAS-AR
4DVAR-based DAS
Forecast
Background
x_b
Observations
y
Analysis
x_a
6 hourly
analyses
1-5 hr forecasts

3 **Pure 4DVAR**

$\alpha=0 \quad P^b_0=P^b_{static}$



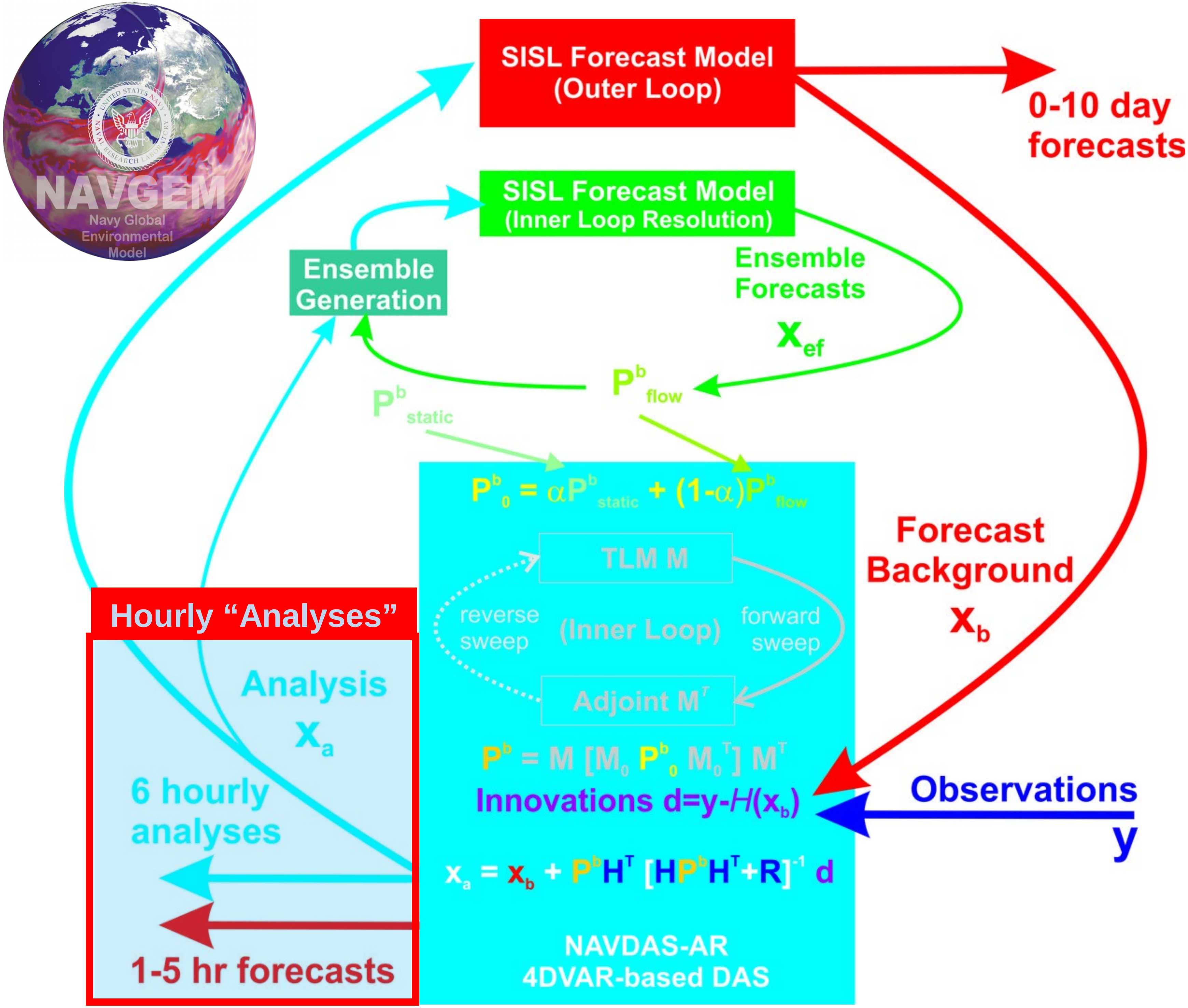


4

Hybrid 4DVAR

α=0.5

$P^b_0=(P^b_{static}+P^b_{flow})/2$


NAVGEM
Navy Global Environmental Model
SISL Forecast Model (Outer Loop)
0-10 day forecasts
SISL Forecast Model (Inner Loop Resolution)
Ensemble Generation
Ensemble Forecasts
x_{ef}
P^b_{flow}
P^b_{static}
$P^b_0 = \alpha P^b_{static} + (1-\alpha) P^b_{flow}$
TLM M
reverse sweep
(Inner Loop)
forward sweep
Adjoint M^T
$P^b = M\,[M_0\, P^b_0\, M_0^T]\, M^T$
Innovations $d = y - H(x_b)$
$x_a = x_b + P^b H^T\,[H P^b H^T + R]^{-1}\, d$
NAVDAS-AR
4DVAR-based DAS
Forecast Background
x_b
Observations
y
Hourly "Analyses"
Analysis
x_a
6 hourly analyses
1-5 hr forecasts

DEEPWAVE Reanalysis Runs

4 Reanalysis Experiments

	Synoptic	GW Resolving
Pure 4DVAR:	T119L74	T425L74
Hybrid 4DVAR:	T119L74	T425L74
(Inner Loops)	T47L74	T119L74

Details

- All experiments started ~20 March 2014 and run out to end of September (T119/47 hybrid-4DVAR was run to end of December)
- MLT physics includes orographic and nonorographic gravity wave drag and simple initial parameterizations of exothermic chemical and O_2 heating
- 1 hour time cadence (6 hourly analysis plus 1-5 hour forecasts) to improve discrimination of tidal modes in MLT analysis

NAVGEM DEEPWAVE Reanalysis

MLT Validation on Hemispheric Scales

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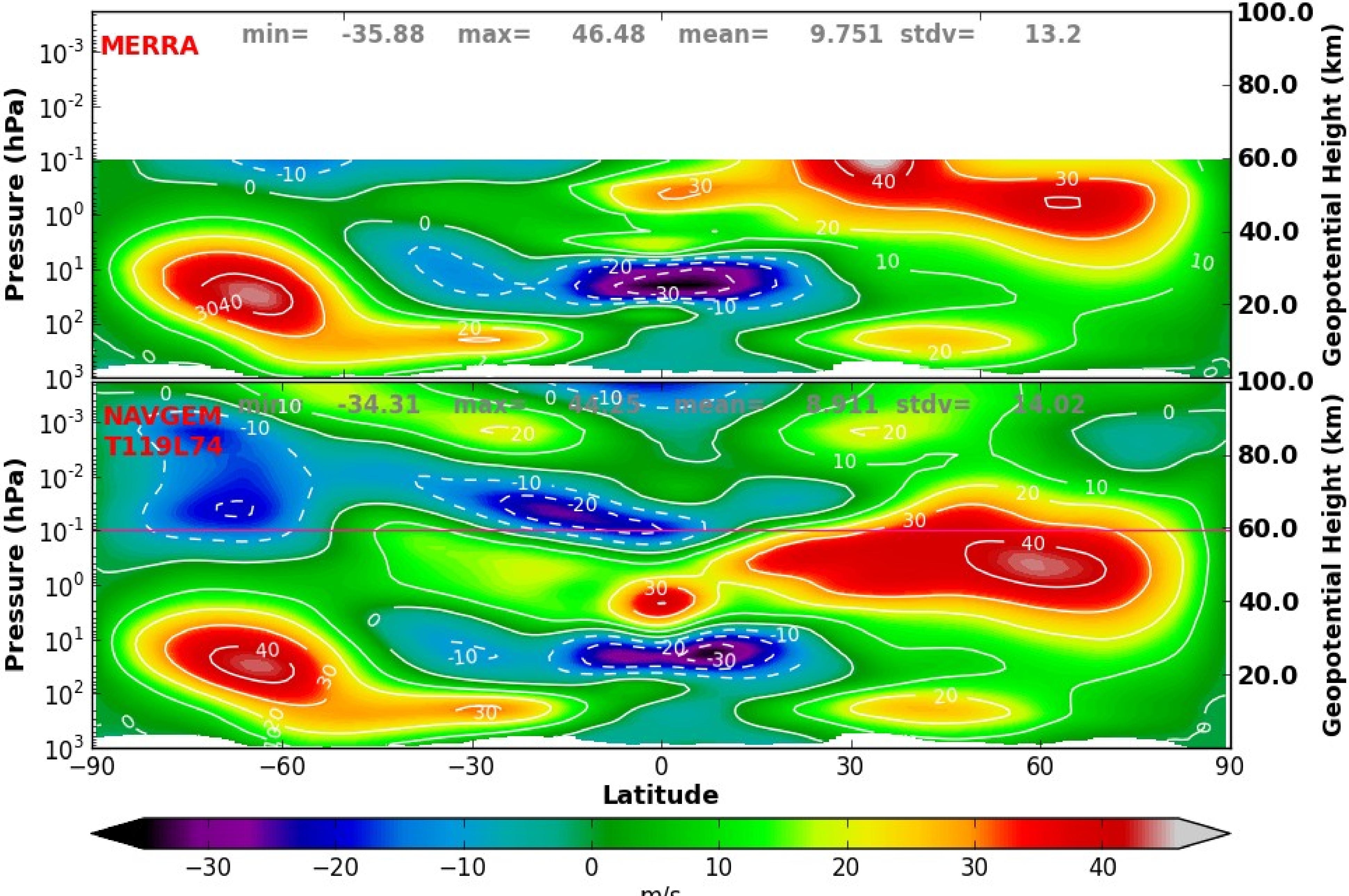
Zonal Mean Zonal Winds: 2014 DEEPWAVE Austral Winter (NAVGEM v. MERRA2)

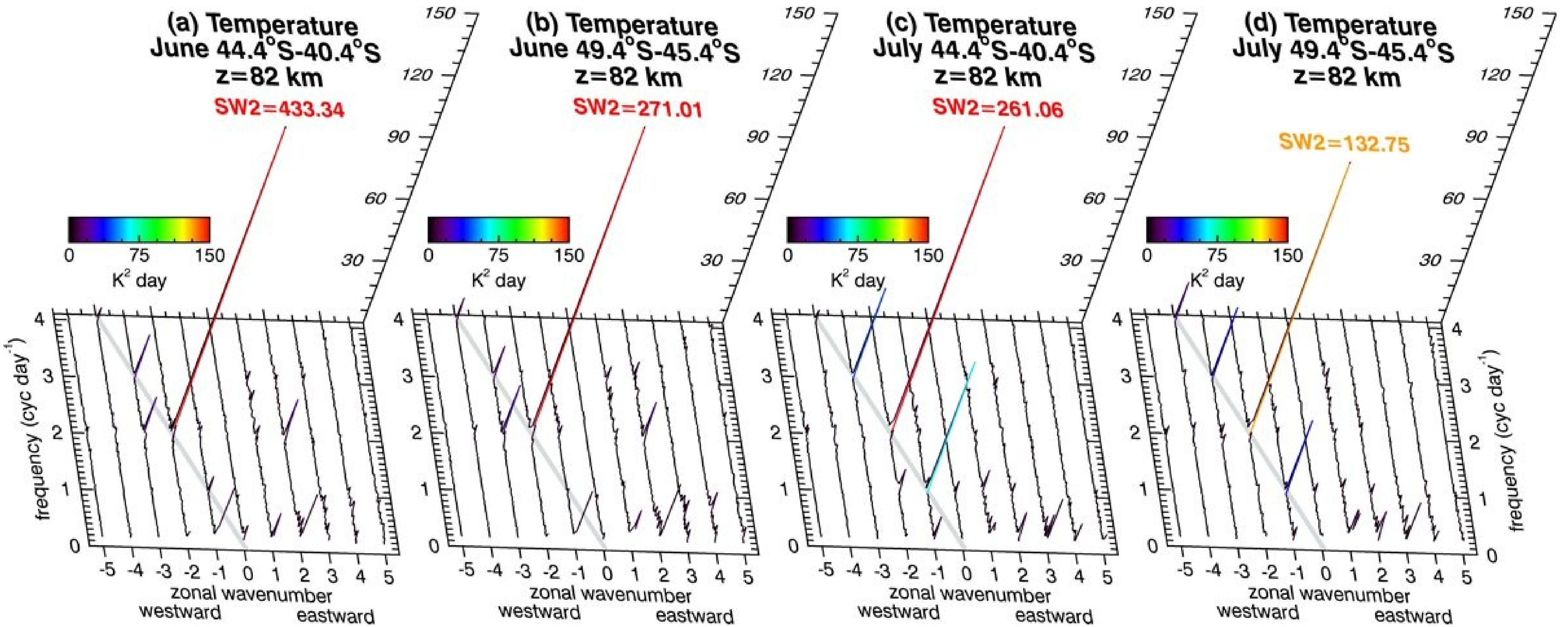
MERRA-NAVGEM Monthly Mean Zonal Wind October 2014



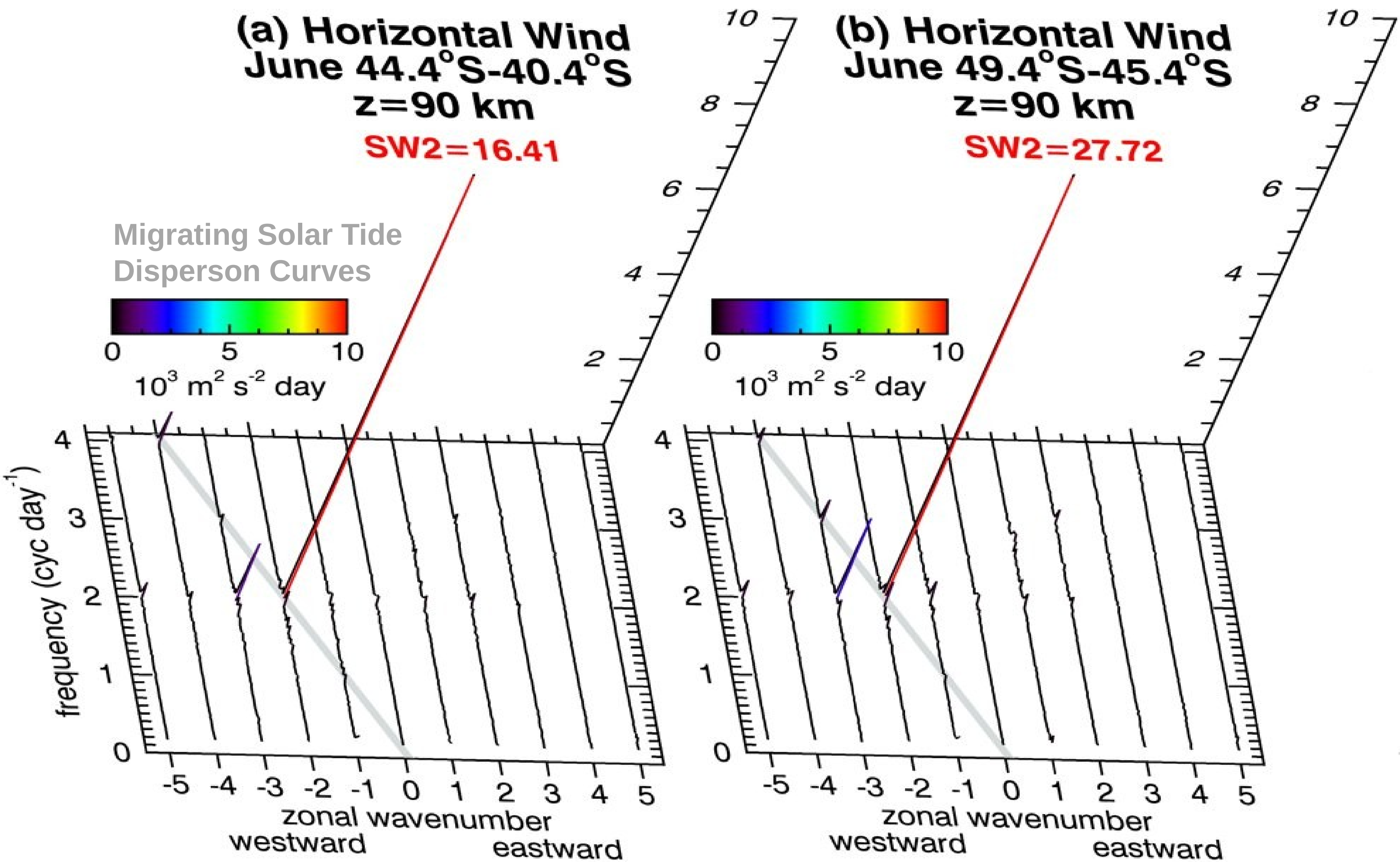
NAVGEM DEEPWAVE Reanalysis

2D Space-Time (Hayashi) Spectra of Reanalyzed MLT

Temperature Spectra: Dominated by Migrating Tides, with Semidiurnal Dominant



MLT Winds at 40-50°S Dominated by Migrating Semidiurnal Tide during DEEPWAVE Period



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NAVGEM DEEPWAVE Reanalysis

Harmonic Fits to MLT Reanalysis in Localized DEEPWAVE Regions

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4-Day Sliding Harmonic Fits to Reanalysis

Least squares fit to

$$F(t) = a_0 + \sum_{j=1}^{3} a_j \cos\left(\frac{j2\pi}{24} - b_j\right)$$

that picks up:

4-Day Means (a_0)

Diurnal Tide (a_1,b_1),

Semidiurnal Tide (a_2,b_2)

Terdiurnal Tide (a_3,b_3)

slide forward in
1 hour steps

Fitted Product

One hour time series of:

Fitted means $a_0(t)$

Tidal Amplitudes $a_j(t)$

Tidal Phases $b_j(t)$

fitting 4-day window

reanalysis time series at given (x,y,z)

harmonic fits
at central time

slide forward in
1 hour steps

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4-Day Sliding Harmonic Fits to Reanalysis

Least squares fit to

$$F(t) = a_0 + \sum_{j=1}^{3} a_j \cos\left(\frac{j2\pi}{24} - b_j\right)$$

that picks up:

4-Day Means (a_0)

Diurnal Tide (a_1,b_1),

Semidiurnal Tide (a_2,b_2)

Terdiurnal Tide (a_3,b_3)

that picks up:

4-Day Means (a_0)

Diurnal Tide (a_1,b_1),

Semidiurnal Tide (a_2,b_2)

Terdiurnal Tide (a_3,b_3)

slide forward in 1 hour steps

Fitted Product

One hour time series of:

Fitted means $a_0(t)$

Tidal Amplitudes $a_j(t)$

Tidal Phases $b_j(t)$

fitting 4-day window

reanalysis time series at given (x,y,z)

harmonic fits at central time

slide forward in 1 hour steps

4-Day Sliding Harmonic Fits to Reanalysis

Least squares fit to

$$F(t) = a_0 + \sum_{j=1}^{3} a_j \cos\left(\frac{j2\pi}{24} - b_j\right)$$

that picks up:

4-Day Means (a_0)

Diurnal Tide (a_1, b_1),

Semidiurnal Tide (a_2, b_2)

Terdiurnal Tide (a_3, b_3)

Least squares fit to
that picks up:
4-Day Means (a_0)
Diurnal Tide (a_1, b_1),
Semidiurnal Tide (a_2, b_2)
Terdiurnal Tide (a_3, b_3)

slide forward in 1 hour steps

Fitted Product

One hour time series of:

Fitted means $a_0(t)$

Tidal Amplitudes $a_j(t)$

Tidal Phases $b_j(t)$

fitting 4-day window

harmonic fits at central time

slide forward in 1 hour steps

reanalysis time series at given (x,y,z)

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4-Day Sliding Harmonic Fits to Reanalysis

Least squares fit to

$$F(t) = a_0 + \sum_{j=1}^{3} a_j \cos\left(\frac{j2\pi}{24} - b_j\right)$$

that picks up:

4-Day Means (a_0)

Diurnal Tide (a_1, b_1),

Semidiurnal Tide (a_2, b_2)

Terdiurnal Tide (a_3, b_3)

that picks up:

4-Day Means (a_0)

Diurnal Tide (a_1, b_1),

Semidiurnal Tide (a_2, b_2)

Terdiurnal Tide (a_3, b_3)

slide forward in 1 hour steps

Fitted Product

One hour time series of:

Fitted means $a_0(t)$

Tidal Amplitudes $a_j(t)$

Tidal Phases $b_j(t)$

fitting 4-day window

reanalysis time series at given (x,y,z)

harmonic fits at central time

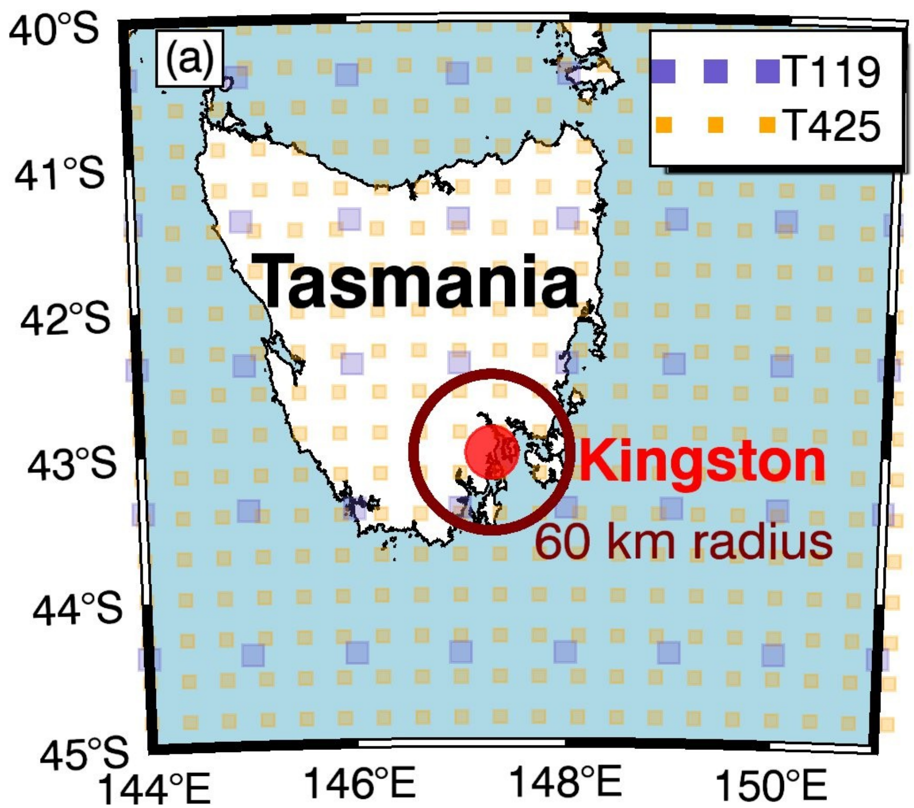
slide forward in 1 hour steps

NAVGEM DEEPWAVE Reanalysis

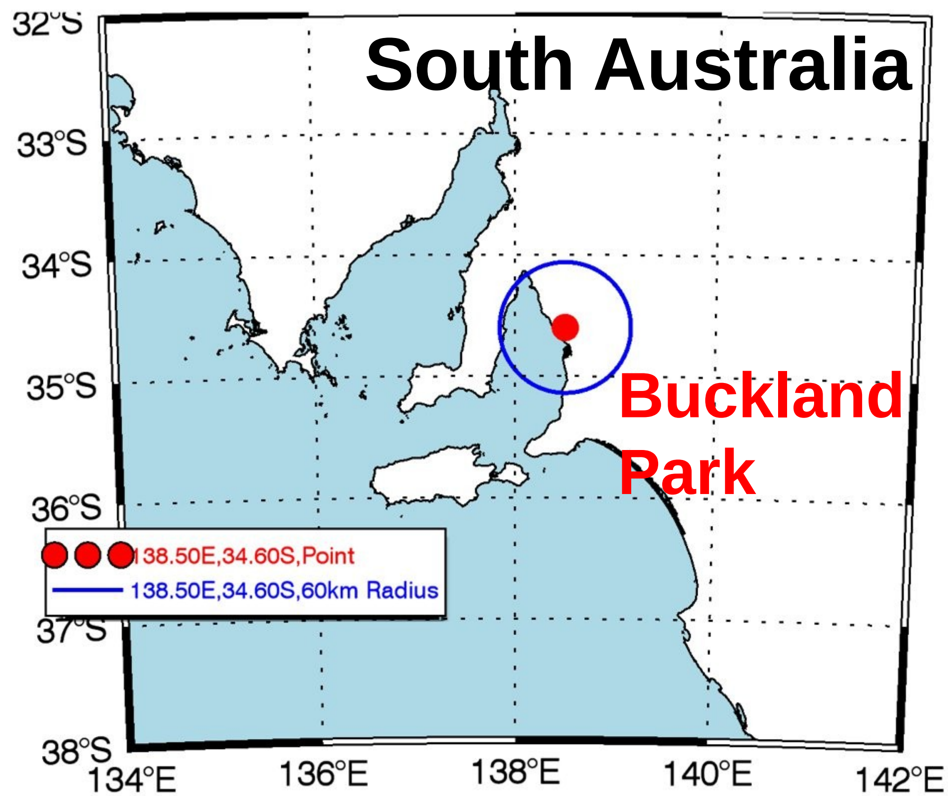
Validation: Reanalyzed MLT Winds Versus Meteor Radar Winds

Meteor Radars Measuring MLT Winds During DEEPWAVE

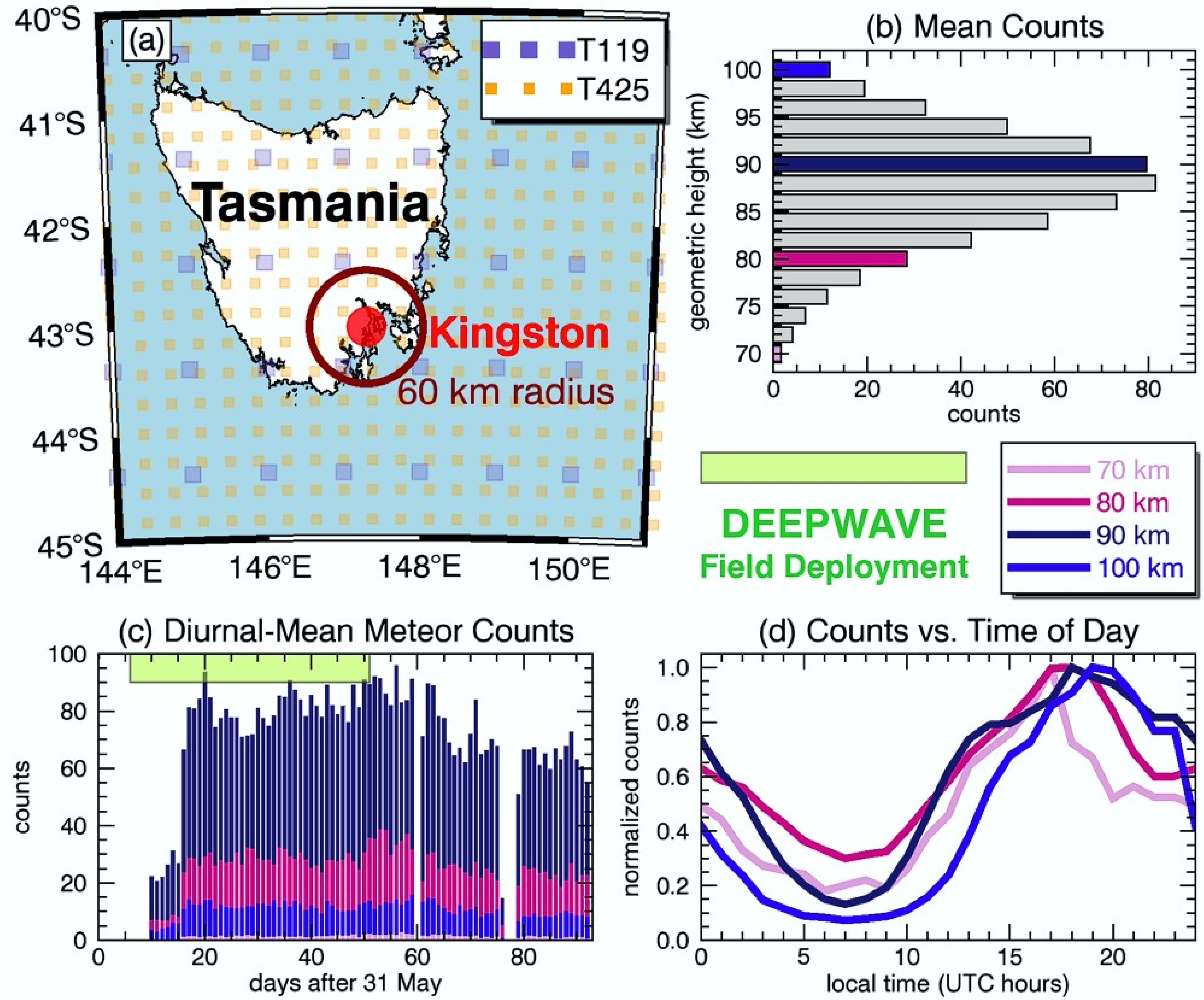
Kingston, Tasmania



Buckland Park, Australia



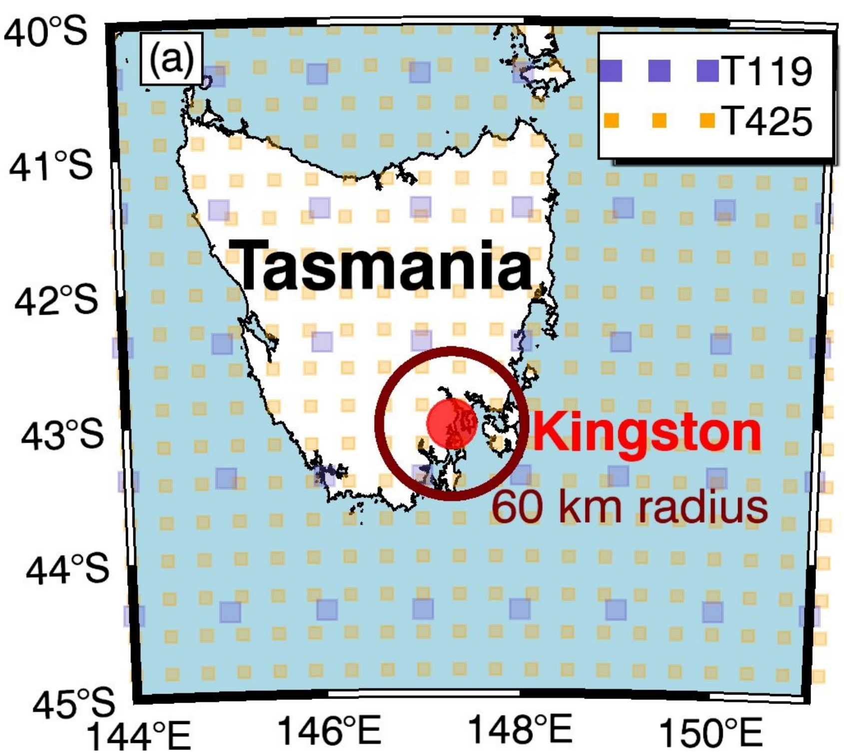
Kingston Meteor Radar Winds

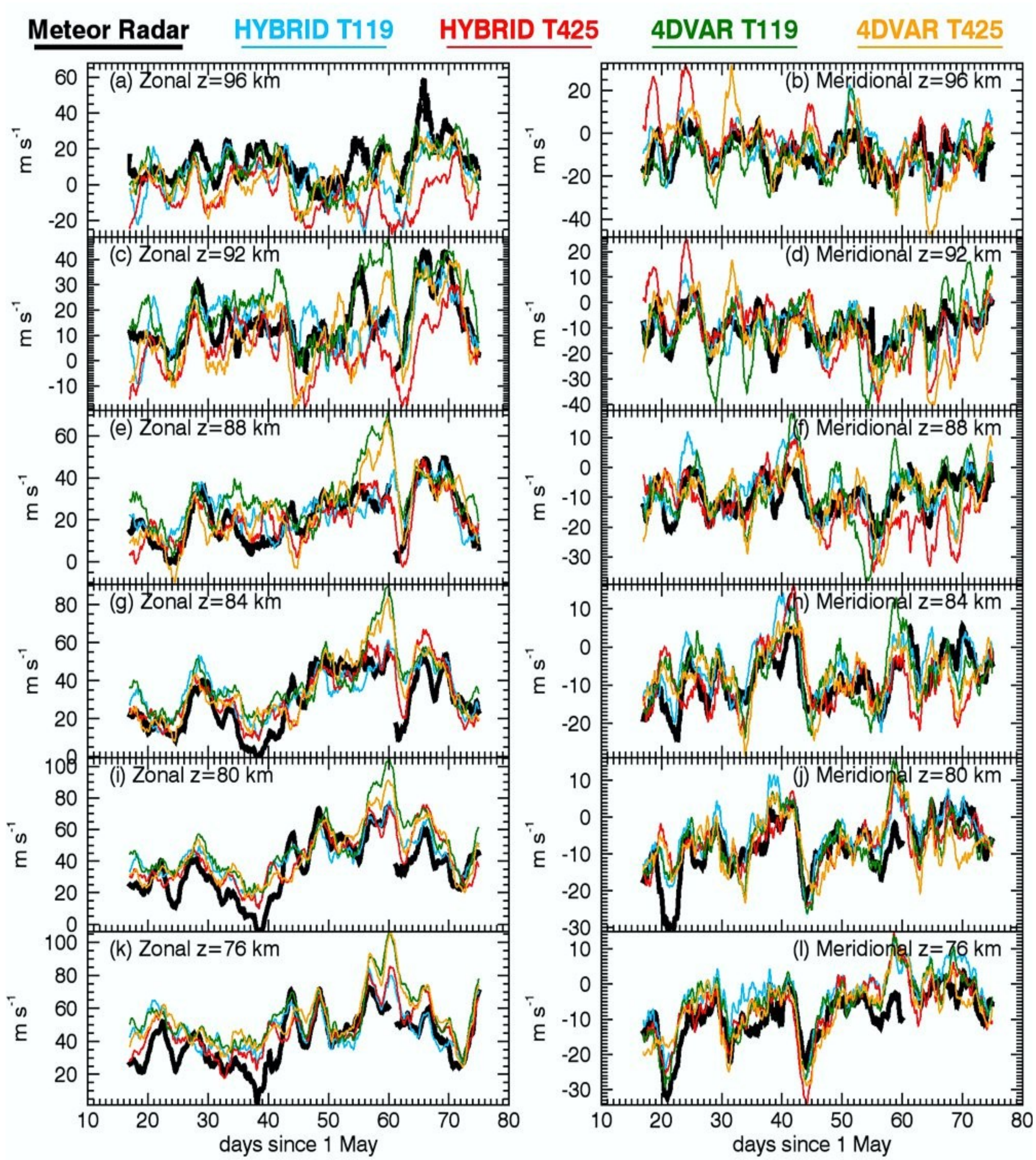


MLT Wind Analysis vs. Meteor Radar Winds:

Sliding 2-day Mean U&V Winds: z=76-96 km

Meteor Wind Radar Deployed Temporarily in Tasmania during DEEPWAVE





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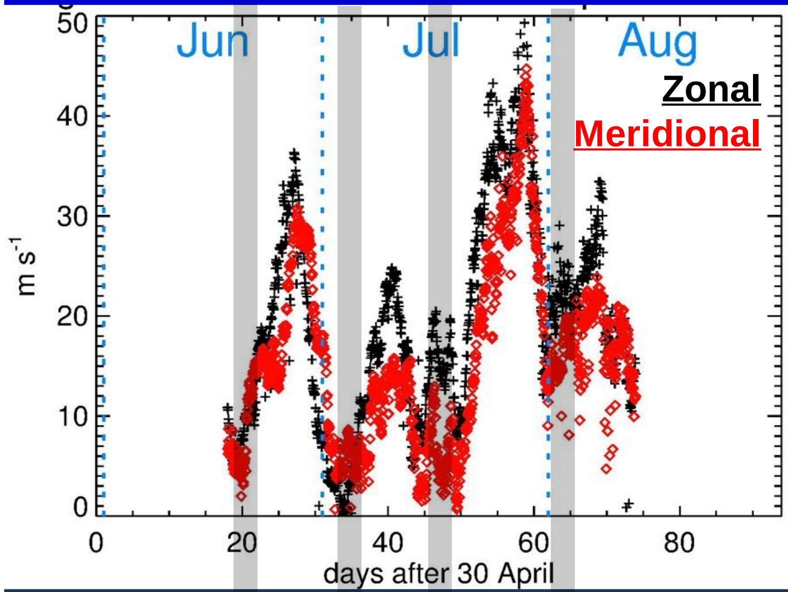
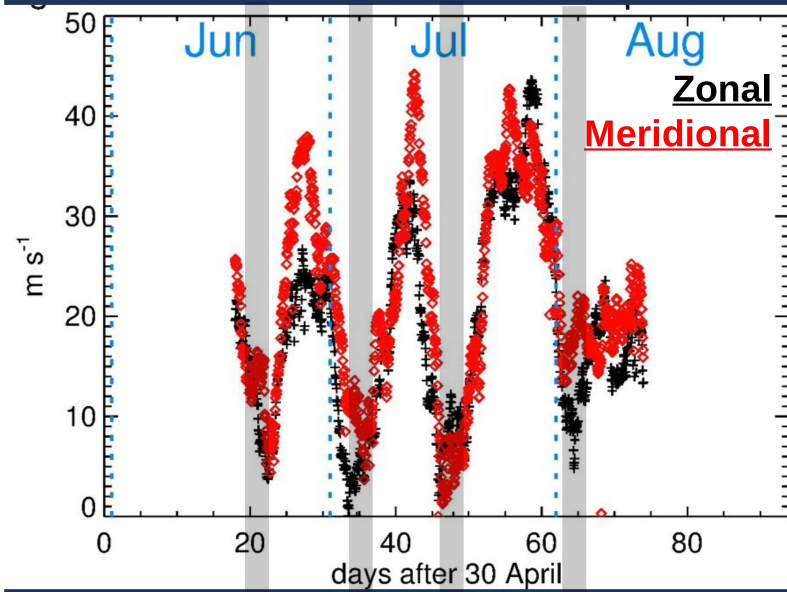
Semidiurnal Tidal Wind Amplitudes: z=88 km

Harmonic Fits Using 4-day Sliding Windows

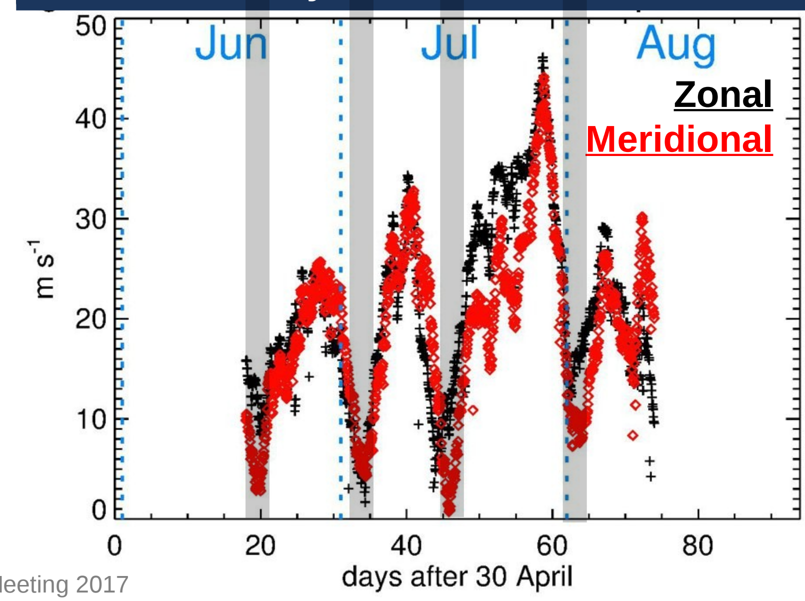
Kingston Meteor Radar : z=88 km



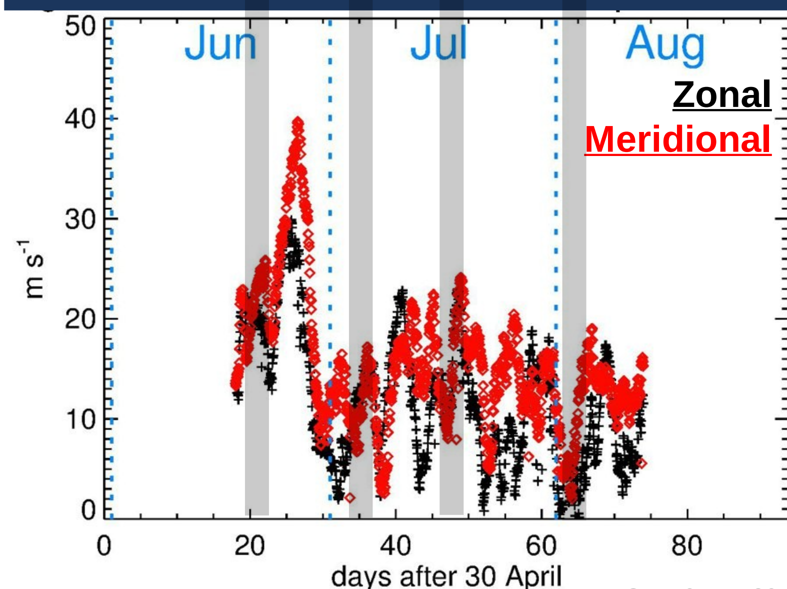
T425 Hybrid-4DVAR : z=88 km



T119 Hybrid-4DVAR : z=88 km

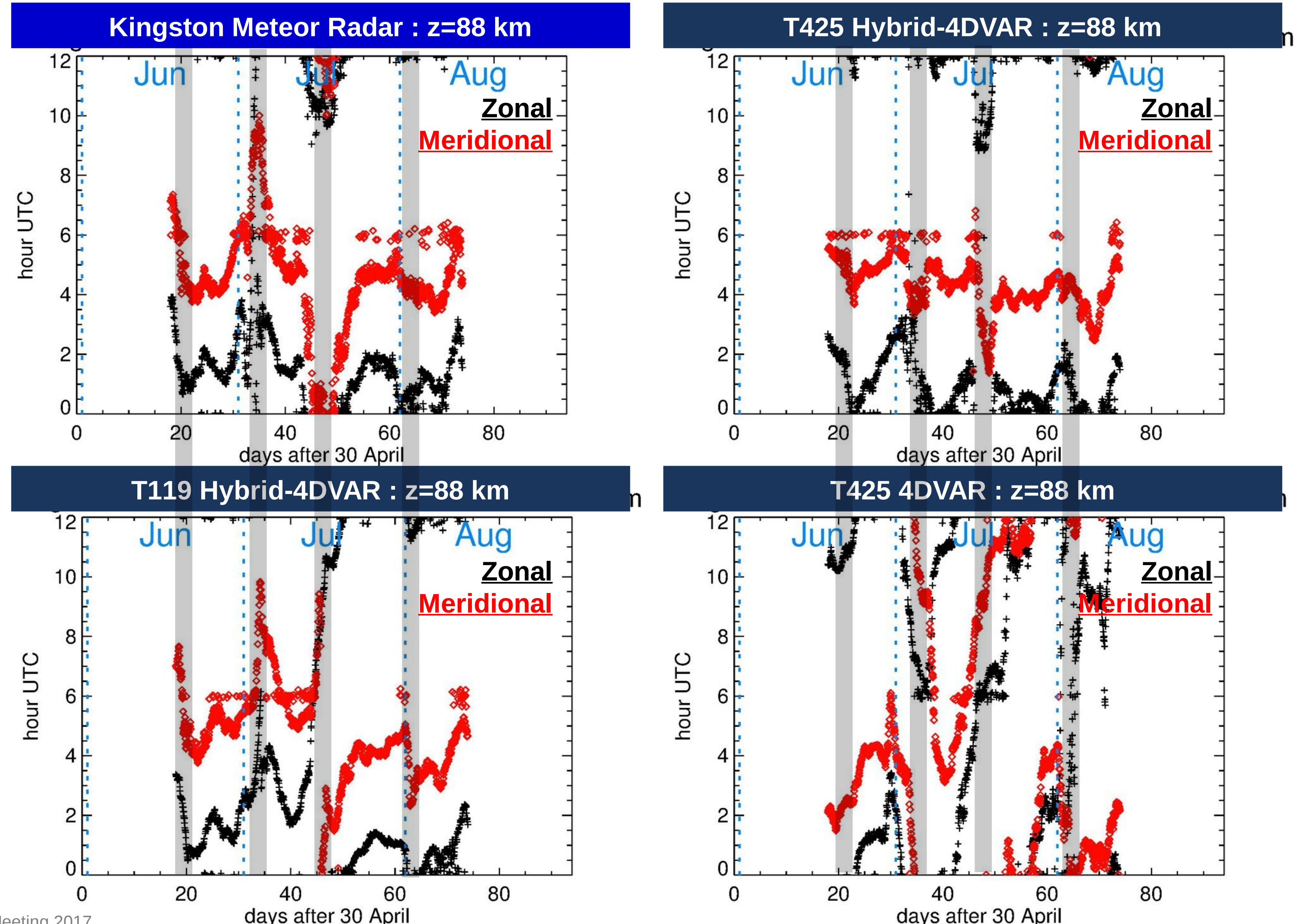


T425 4DVAR : z=88 km



Semidiurnal Tidal Wind Phases: *z*=88 km

Harmonic Fits Using 4-day Sliding Windows



MLT Wind Analysis vs. Meteor Radar Winds:

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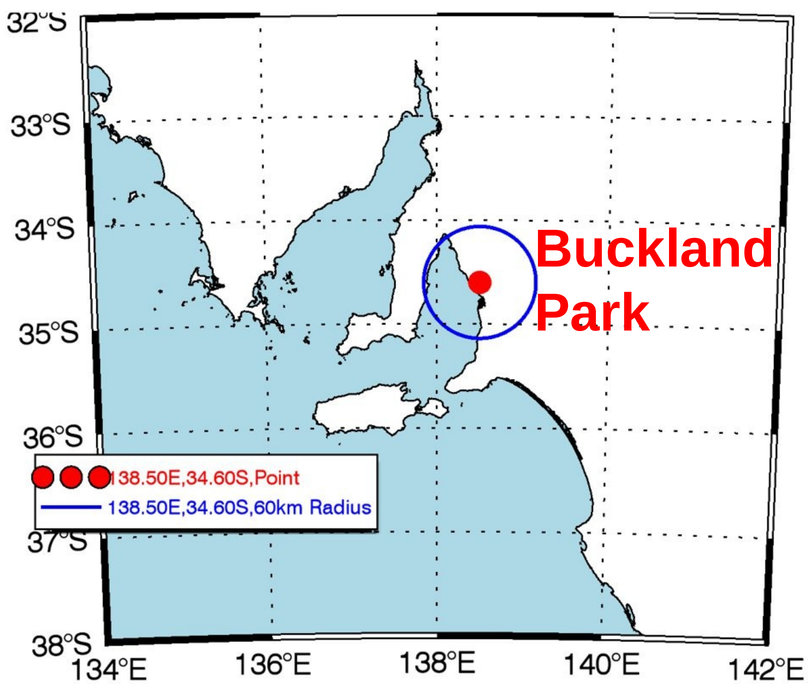
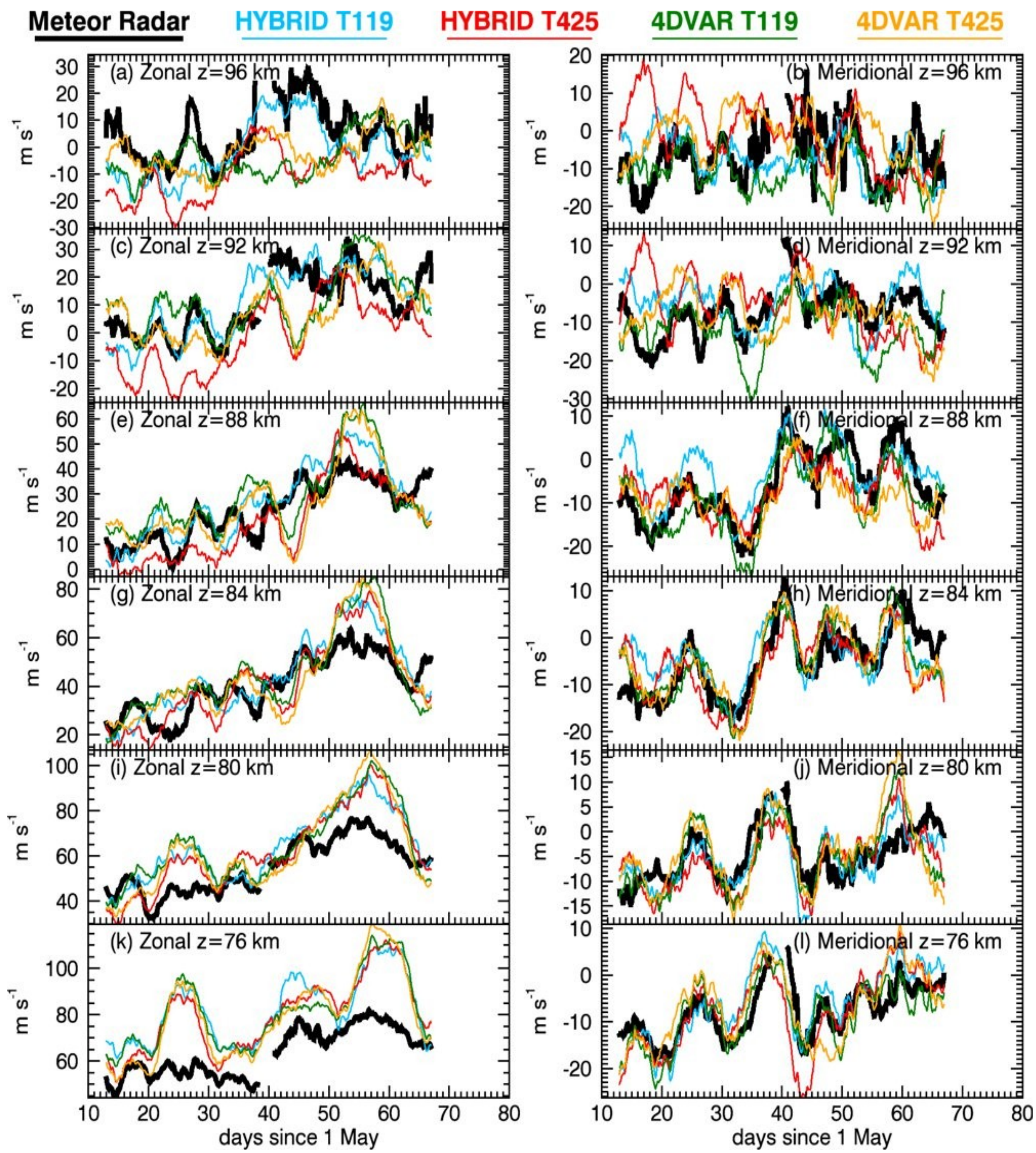
Sliding 2-day Mean U&V Winds: z=76-96 km

Meteor Wind Radar Deployed at Backland Park (South Australia) during DEEPWAVE

buckland averaging boxes

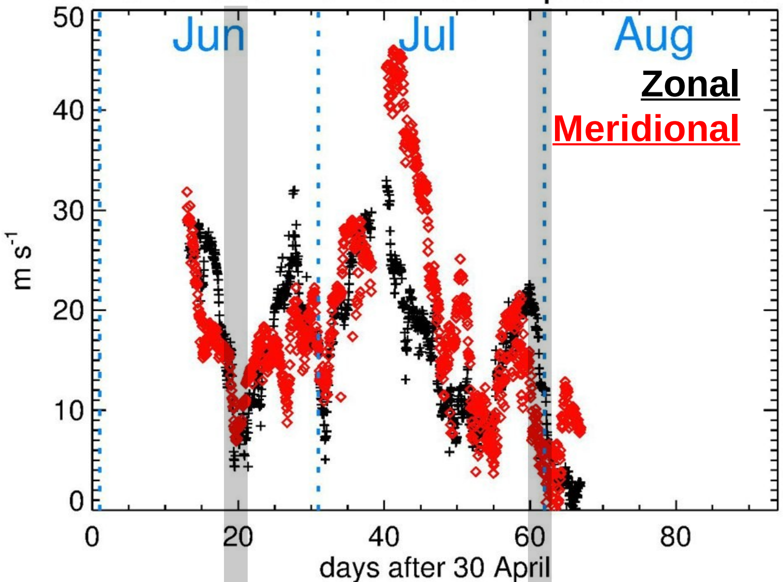




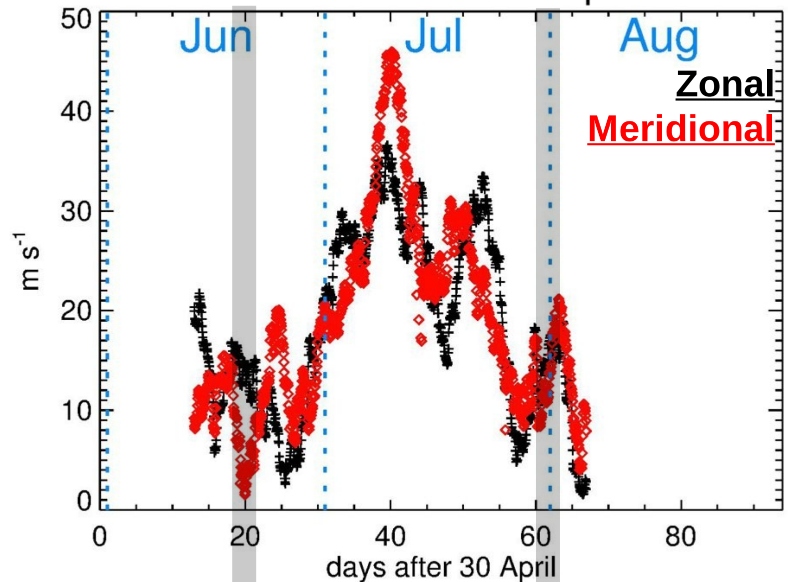
Diurnal Tidal Wind Amplitudes: *z*=80 km

Harmonic Fits Using 4-day Sliding Windows

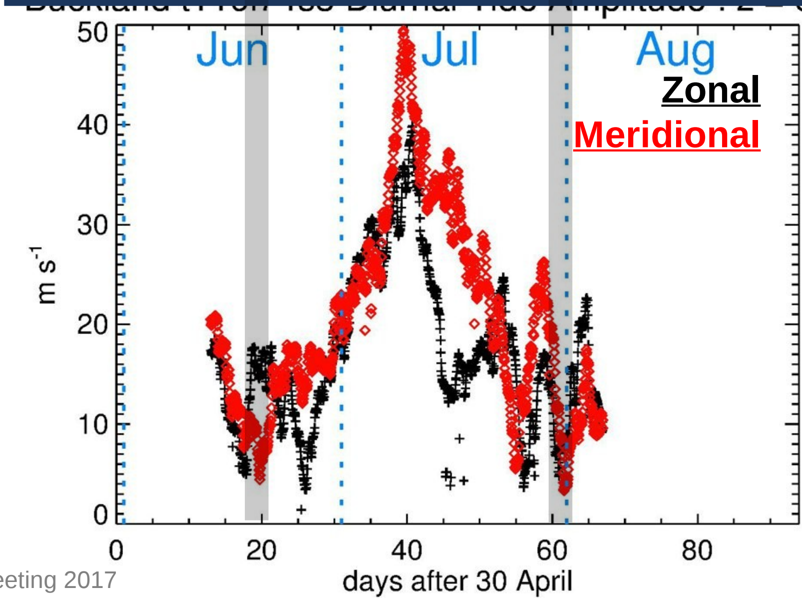
Buckland Park Meteor Radar : z=80 km



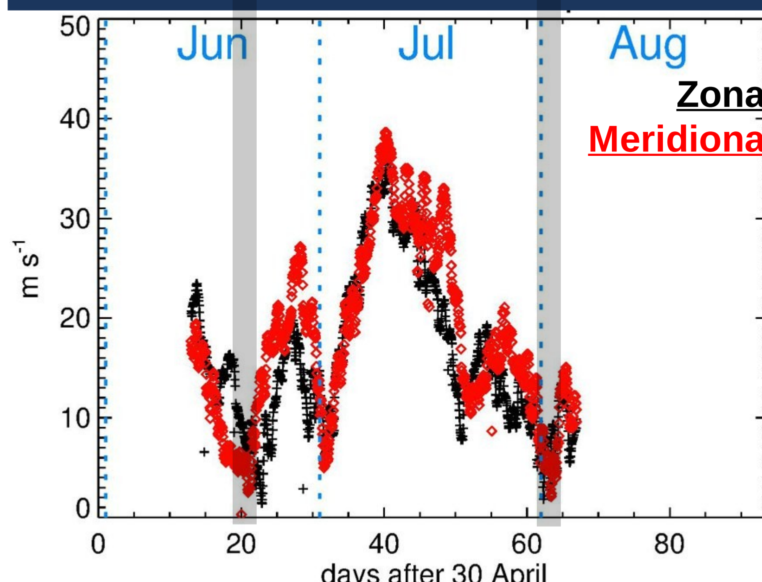
T425 Hybrid-4DVAR : z=80 km



T119 Hybrid-4DVAR : z=80 km



T425 4DVAR : z=80 km



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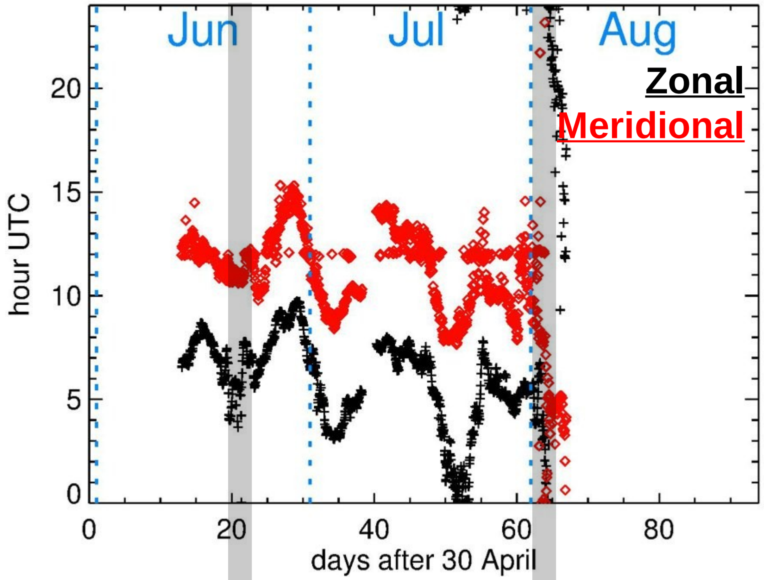
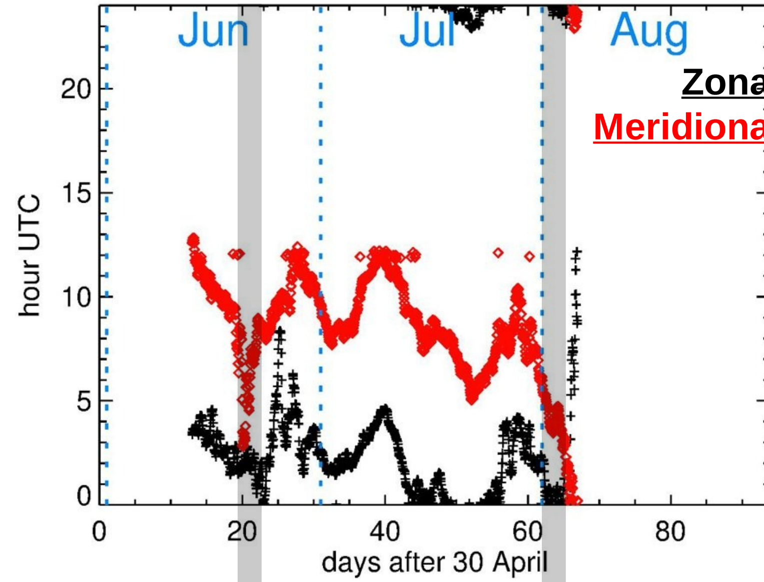
Diurnal Tidal Wind Phases: z=80 km

Harmonic Fits Using 4-day Sliding Windows

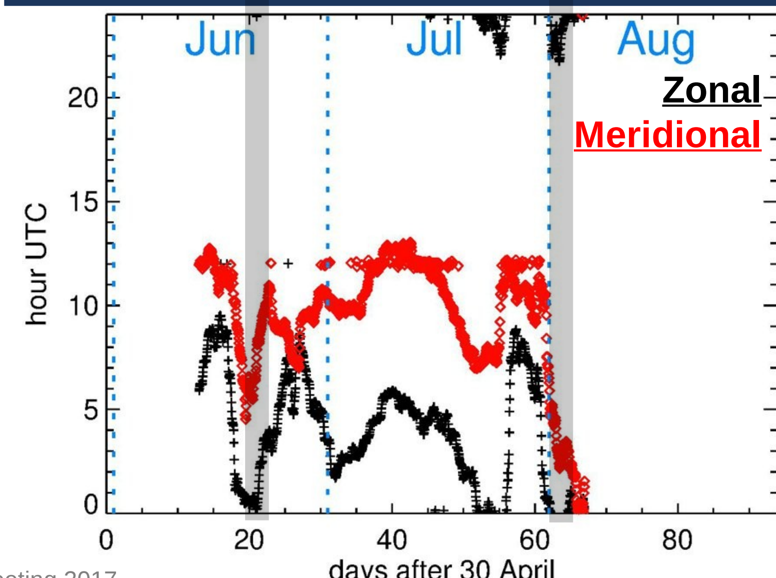
Buckland Park Meteor Radar : z=80 km



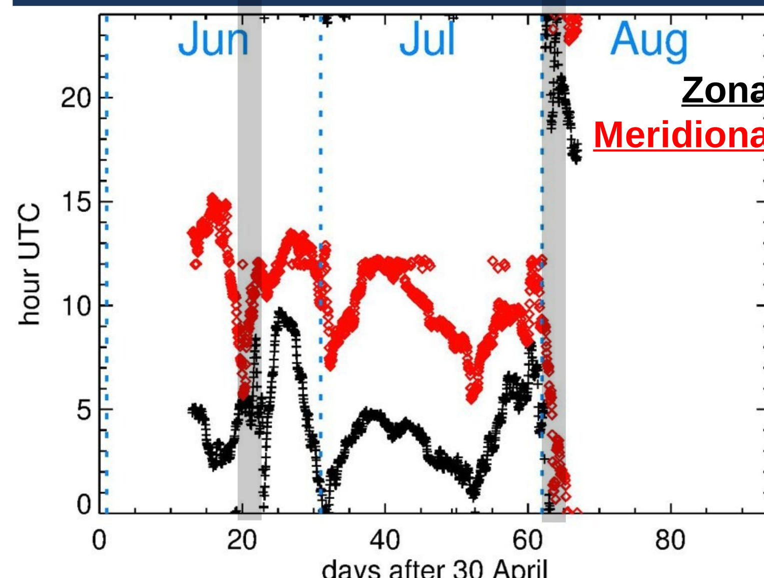
T425 Hybrid-4DVAR : z=80 km



T119 Hybrid-4DVAR : z=80 km



T425 4DVAR : z=80 km



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NAVGEM DEEPWAVE Reanalysis

Monthly Mean MLT Wind and Tidal Structures for DEEPWAVE Science

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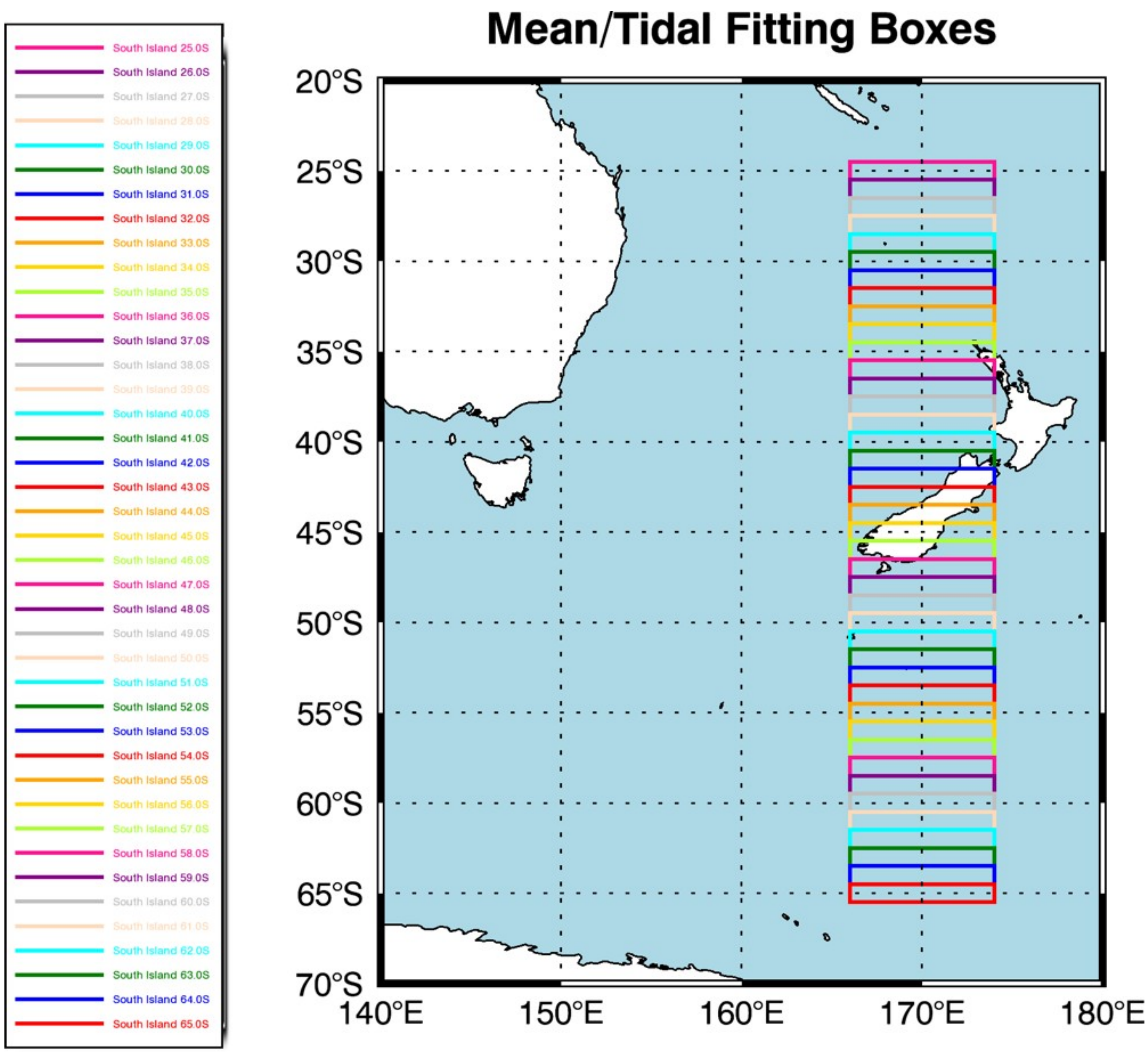
Mean and Tidal Fits to Reanalysis for DEEPWAVE MLT Science Guidance



- Define a main 166°-174°E South Island longitude zone (following, e.g., Kruse et al. JAS 2016)
- Define 1° latitude averaging boxes from 25°-65°S (41 boxes in all)
- Average reanalysis fields within each of these boxes
- Perform harmonic time series analysis of winds and temperatures within each box to study time variations of means and tidal amplitudes as a function of latitude

June Semidiurnal Temperature Amplitudes

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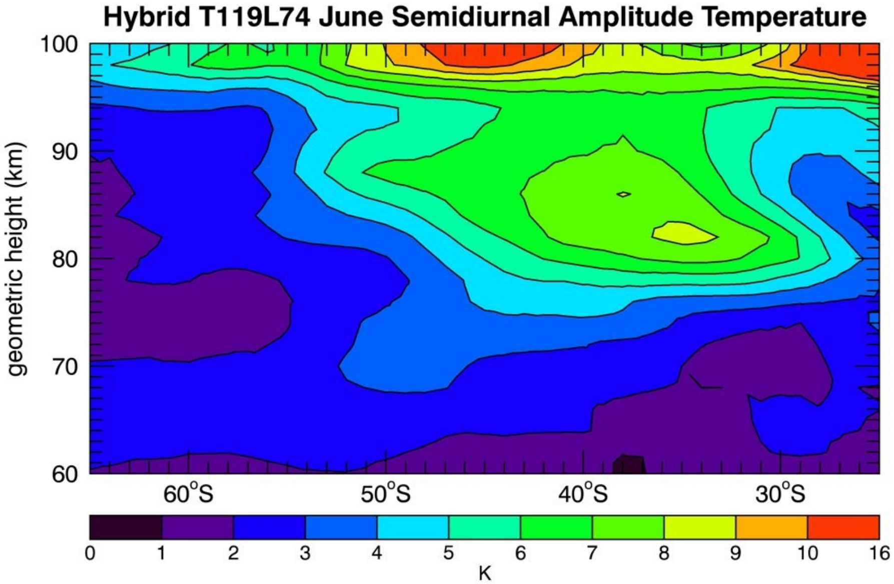
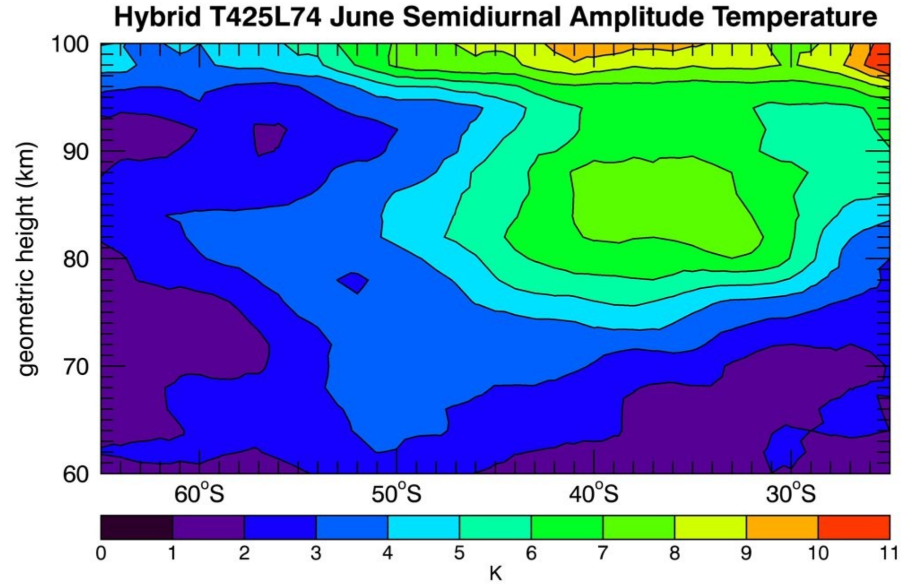
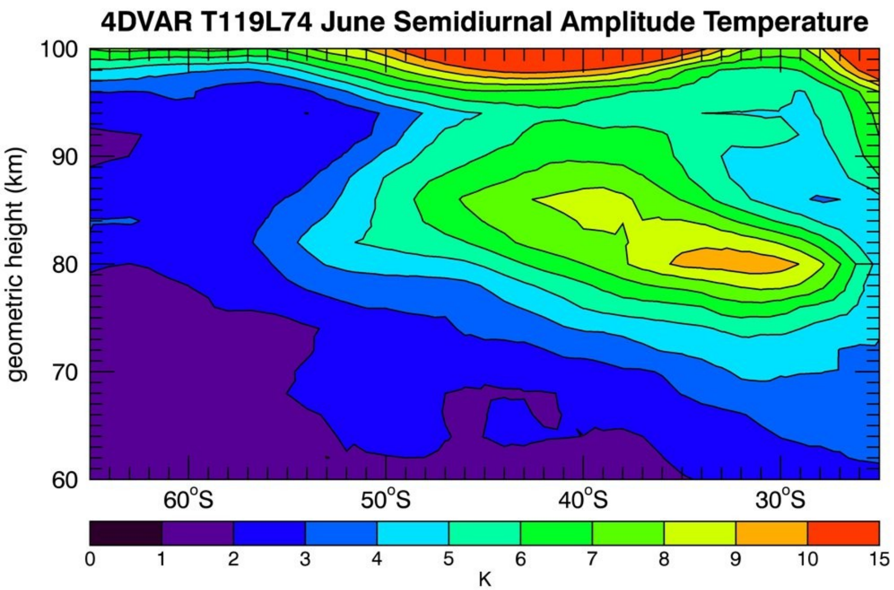
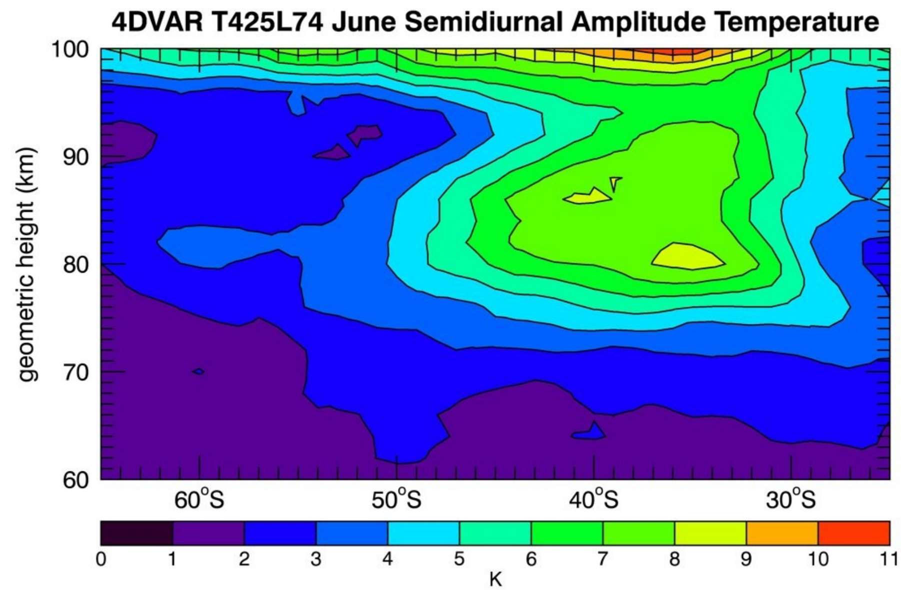
	T119 Outer (T47 Inner)	T425 Outer (T119 Inner)
Hybrid 4DVAR		
Pure 4DVAR		

July Semidiurnal Temperature Amplitudes

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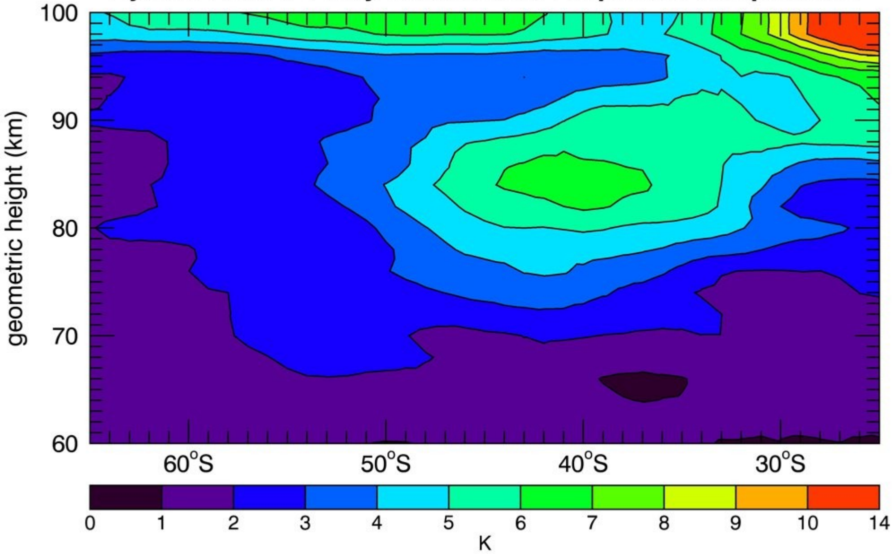
T119 Outer (T47 Inner)

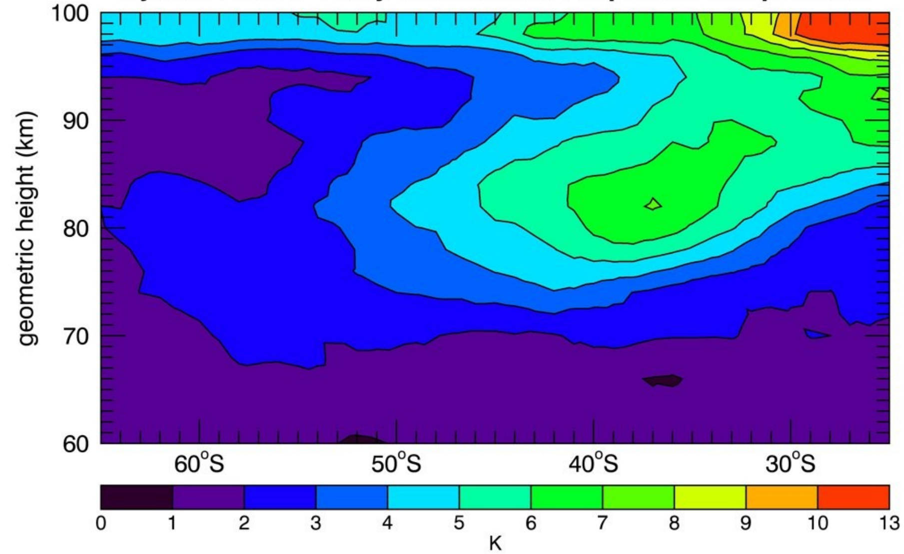
T425 Outer (T119 Inner)

Hybrid 4DVAR

Hybrid T119L74 July Semidiurnal Amplitude Temperature

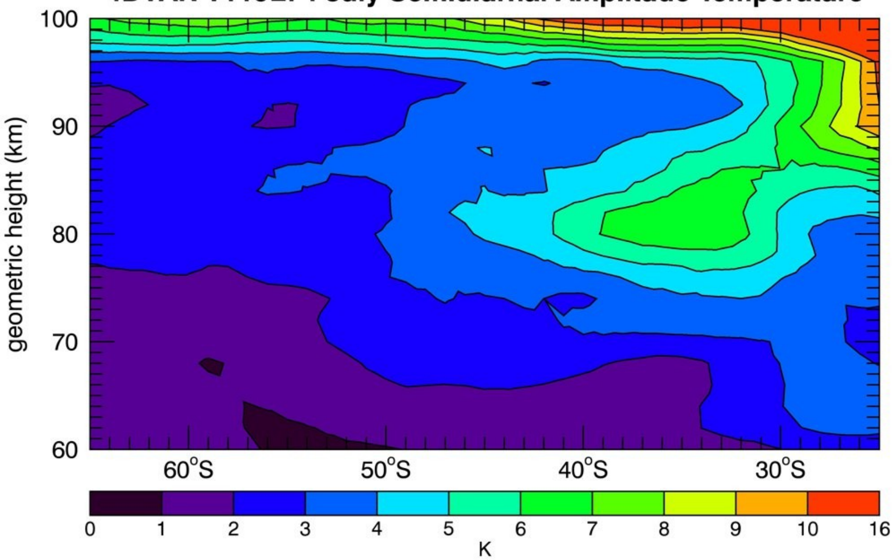


Hybrid T425L74 July Semidiurnal Amplitude Temperature

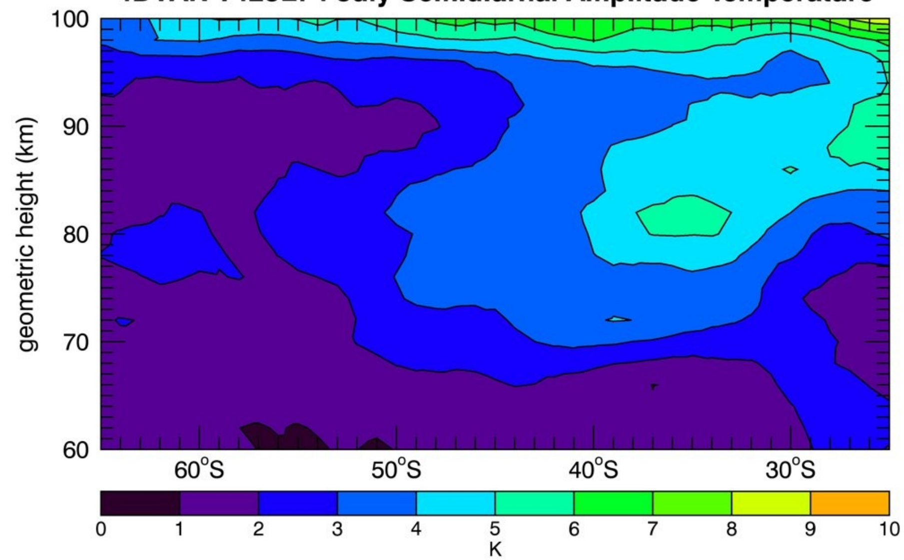


Pure 4DVAR

4DVAR T119L74 July Semidiurnal Amplitude Temperature



4DVAR T425L74 July Semidiurnal Amplitude Temperature



June Semidiurnal Zonal Wind Amplitudes

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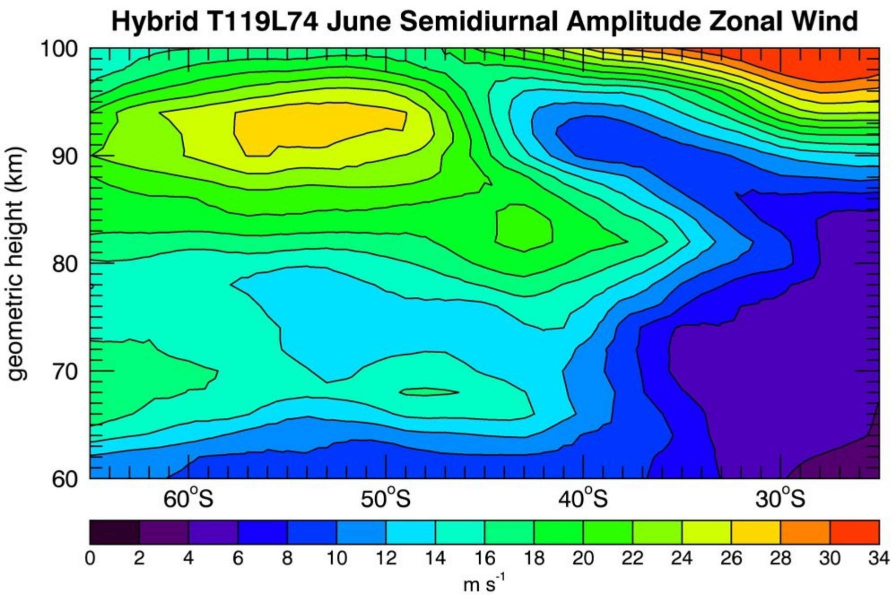
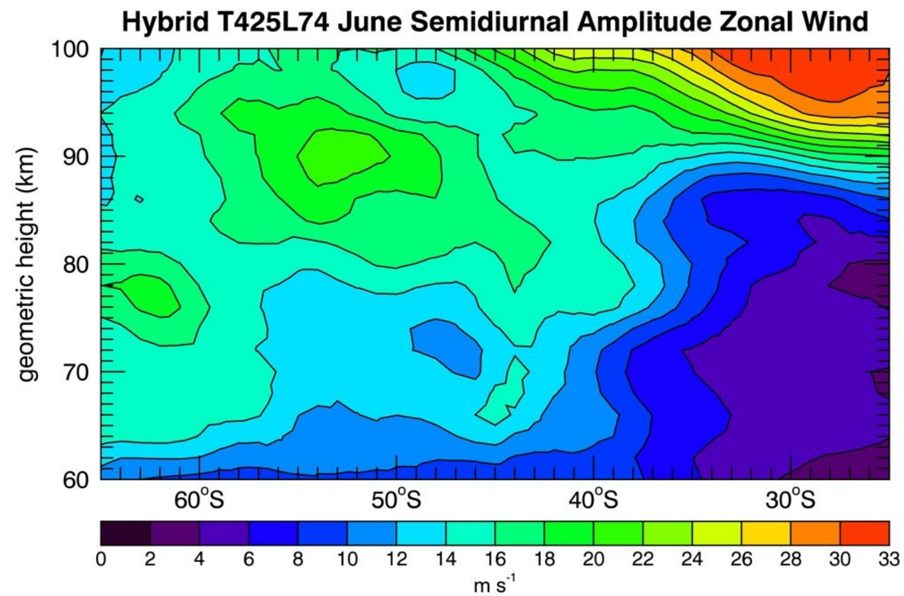
T119 Outer (T47 Inner) | T425 Outer (T119 Inner)

Hybrid 4DVAR





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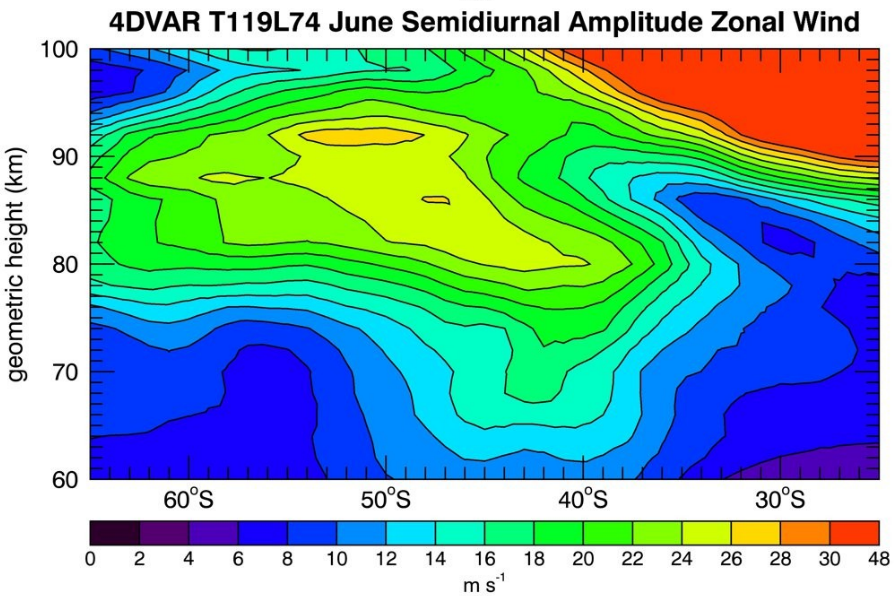
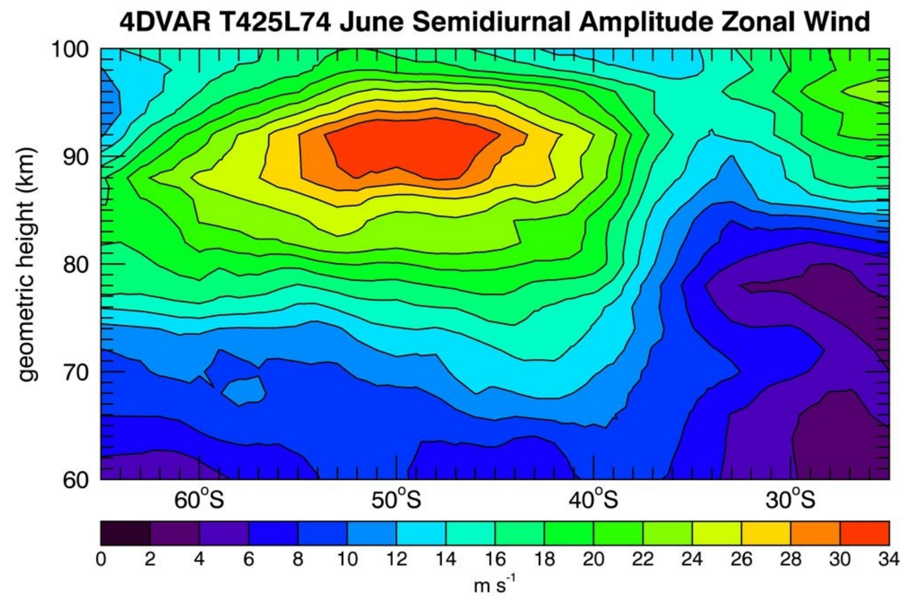




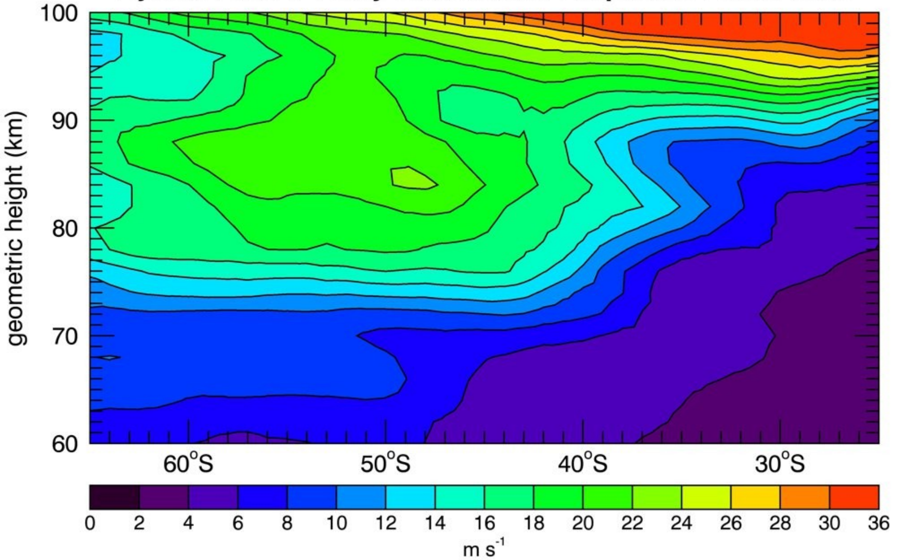
July Semidiurnal Zonal Wind Amplitudes

U.S. NAVAL RESEARCH LABORATORY

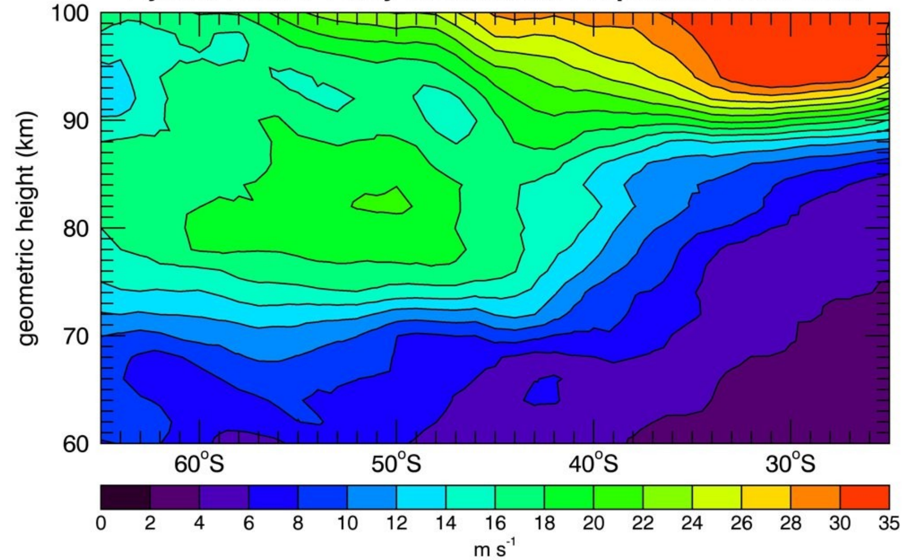
	T119 Outer (T47 Inner)	T425 Outer (T119 Inner)

Hybrid 4DVAR

Hybrid T119L74 July Semidiurnal Amplitude Zonal Wind

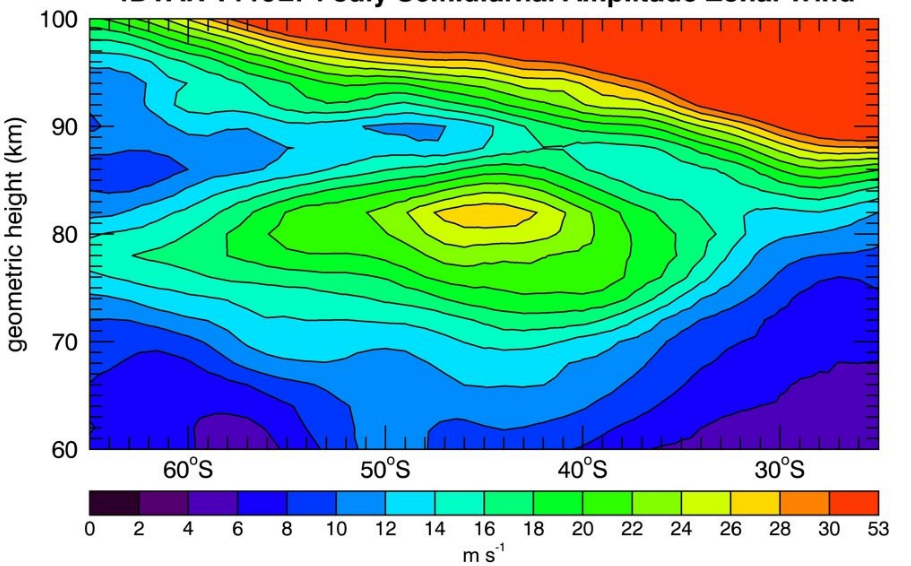


Hybrid T425L74 July Semidiurnal Amplitude Zonal Wind

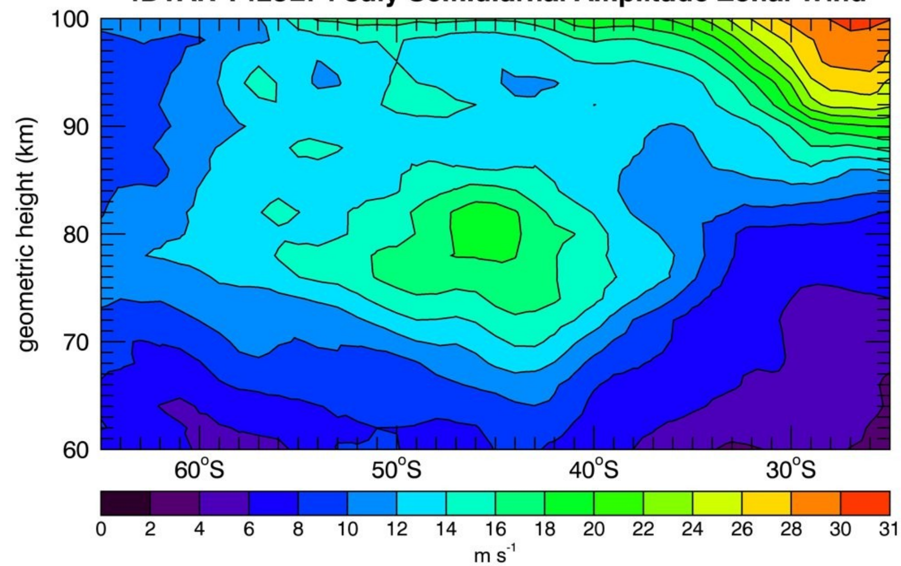


Pure 4DVAR

4DVAR T119L74 July Semidiurnal Amplitude Zonal Wind



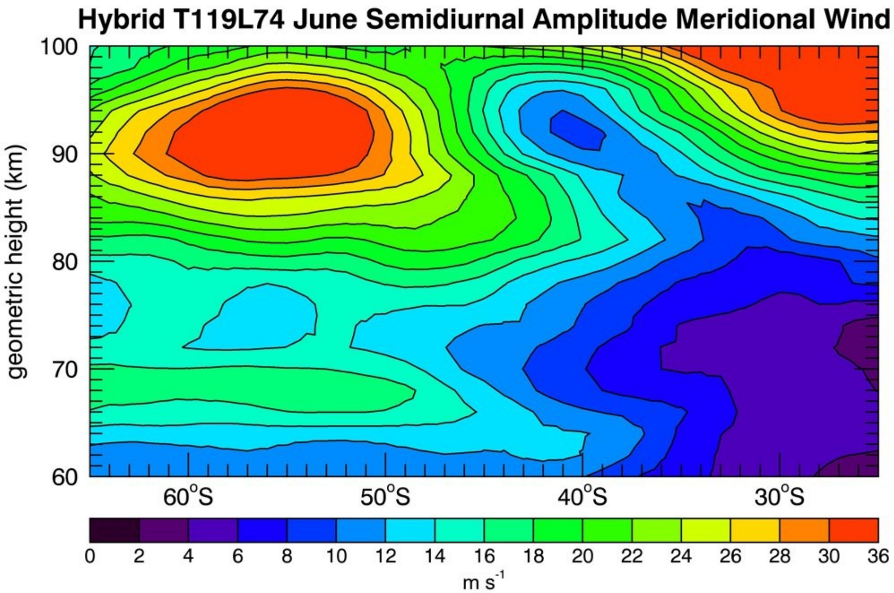
4DVAR T425L74 July Semidiurnal Amplitude Zonal Wind

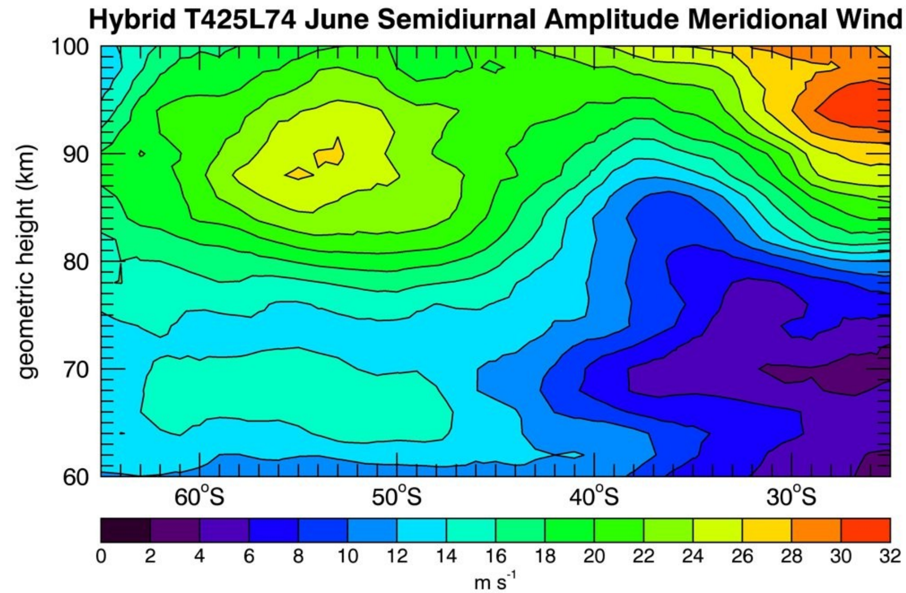


June Semidiurnal Meridional Wind Amps

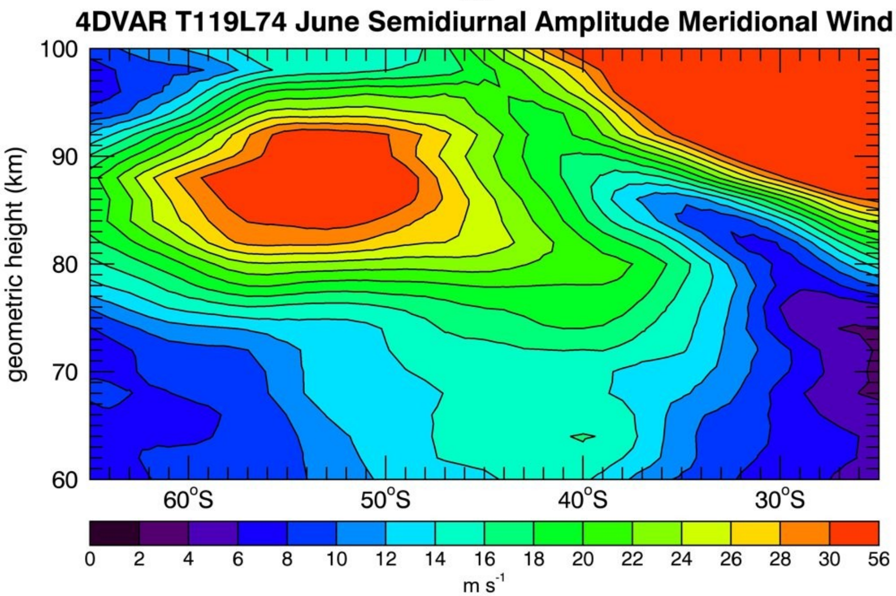
T119 Outer (T47 Inner) | **T425 Outer (T119 Inner)**

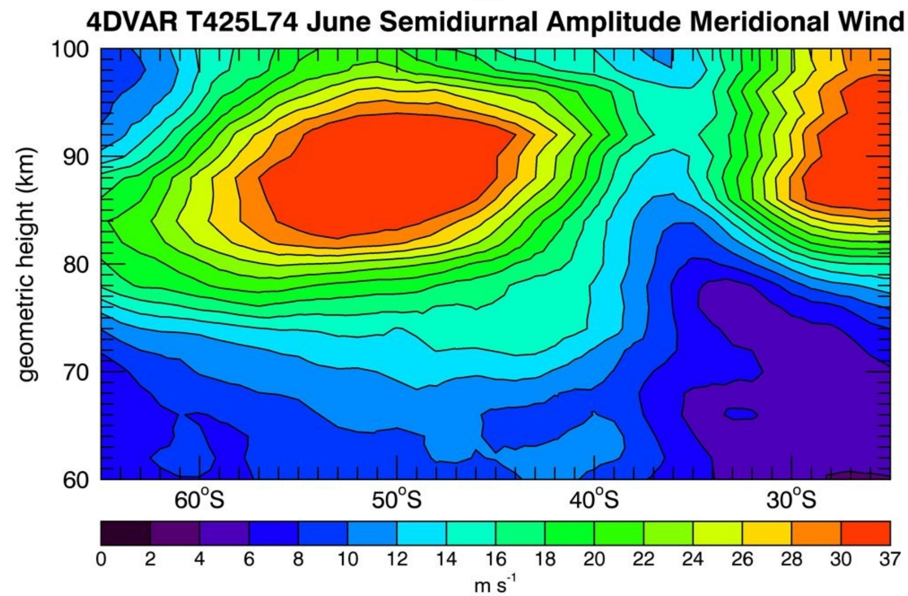
Hybrid 4DVAR





Pure 4DVAR



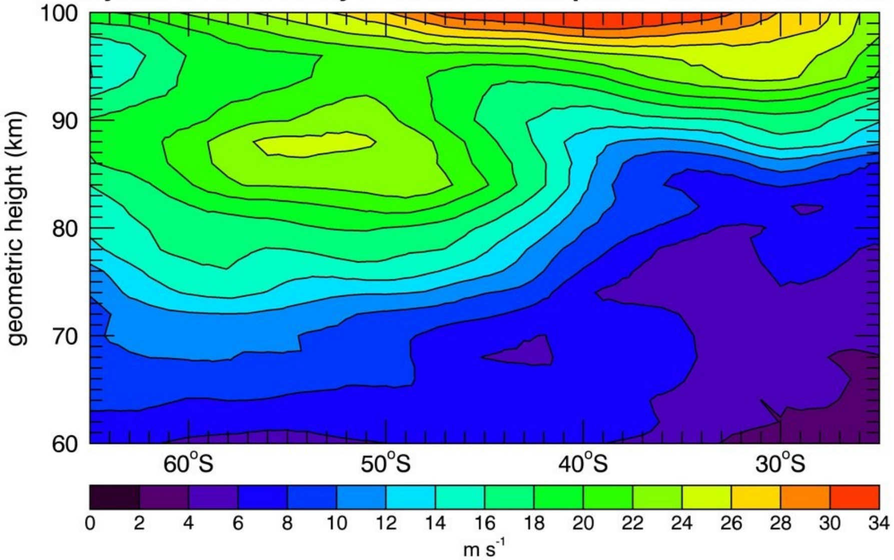


July Semidiurnal Meridional Wind Amps

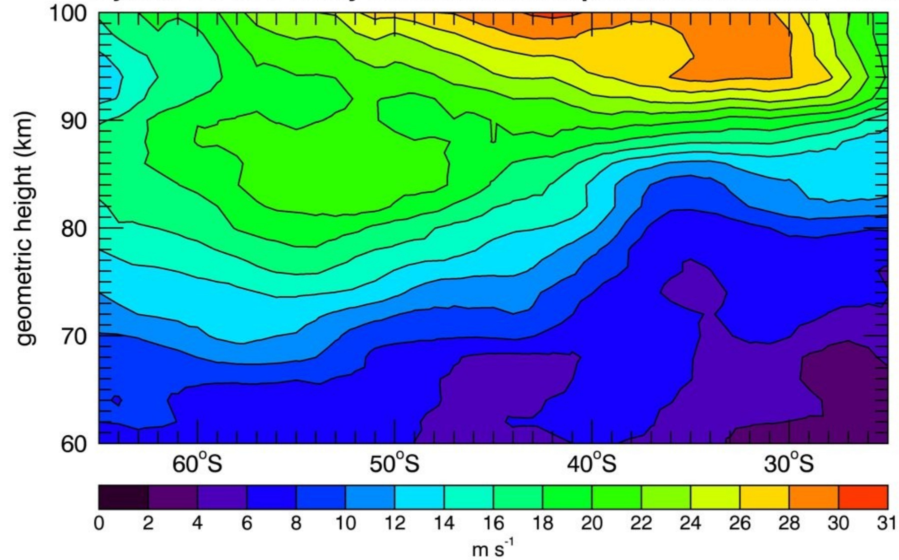
T119 Outer (T47 Inner) | **T425 Outer** (T119 Inner)

Hybrid 4DVAR

Hybrid T119L74 July Semidiurnal Amplitude Meridional Wind

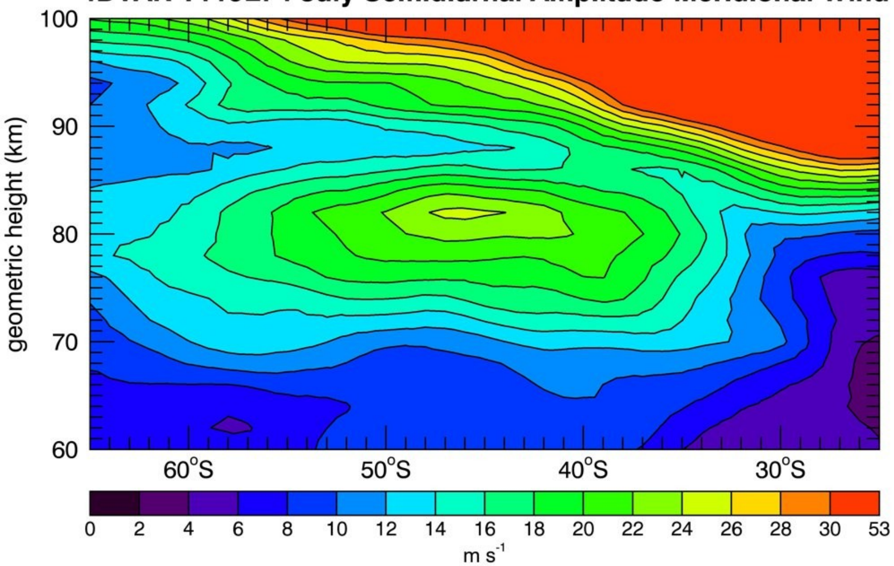


Hybrid T425L74 July Semidiurnal Amplitude Meridional Wind

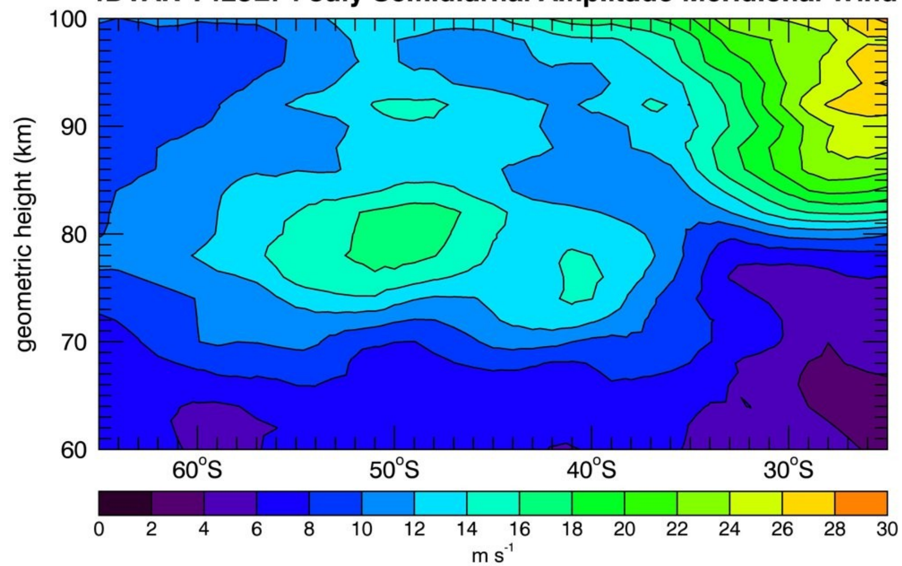


Pure 4DVAR

4DVAR T119L74 July Semidiurnal Amplitude Meridional Wind



4DVAR T425L74 July Semidiurnal Amplitude Meridional Wind



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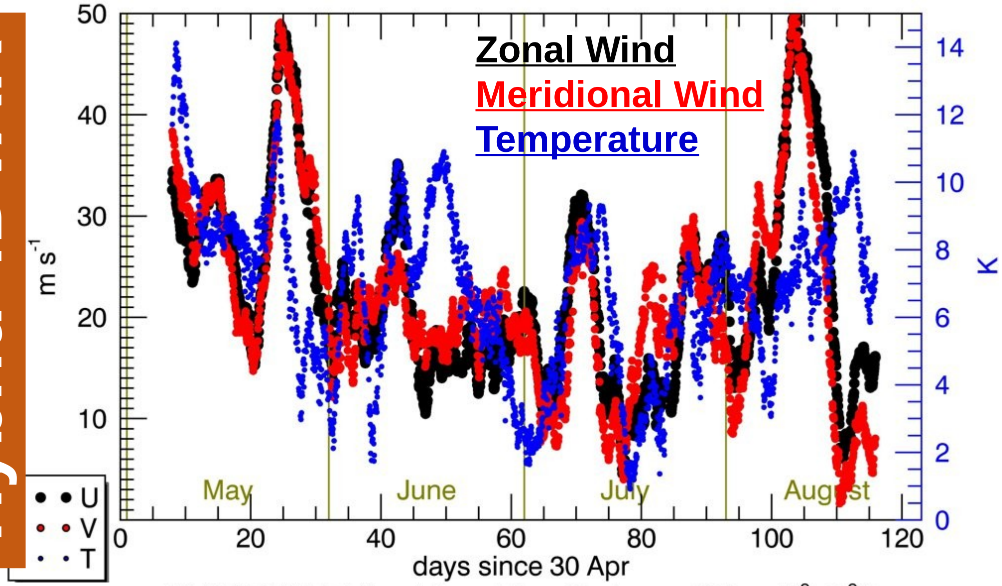
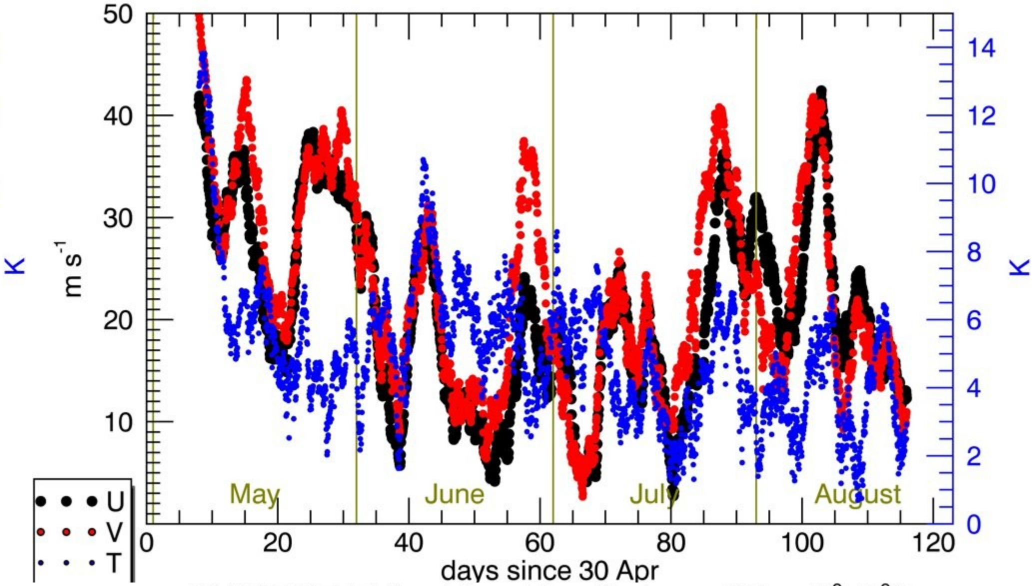
Time Series of Semidiurnal Tidal Amplitudes over South Island 41°-47°S at *z*=88 km

T119 Outer (T47 Inner)

T425 Outer (T119 Inner)

Hybrid 4DVAR

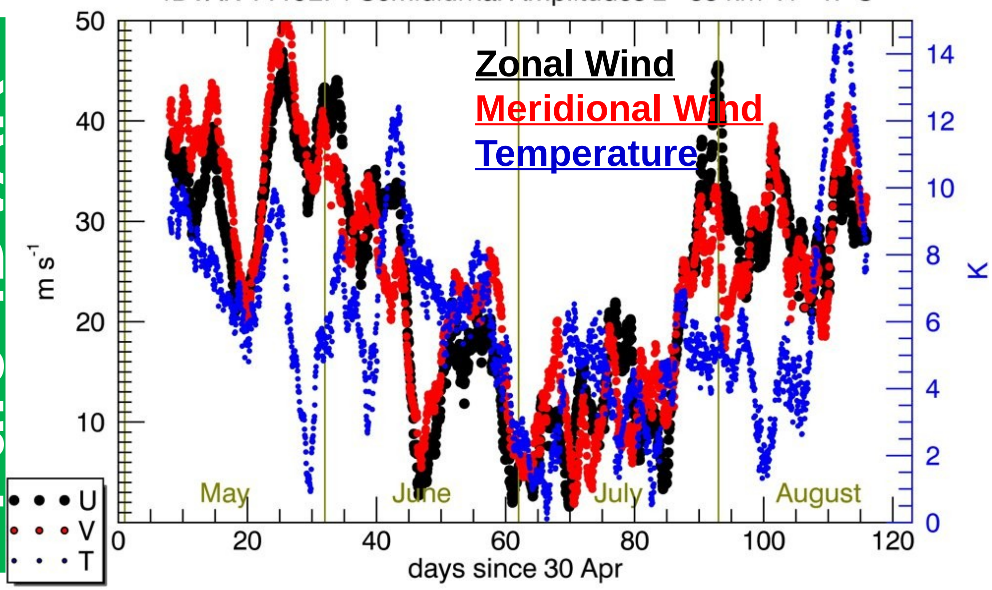


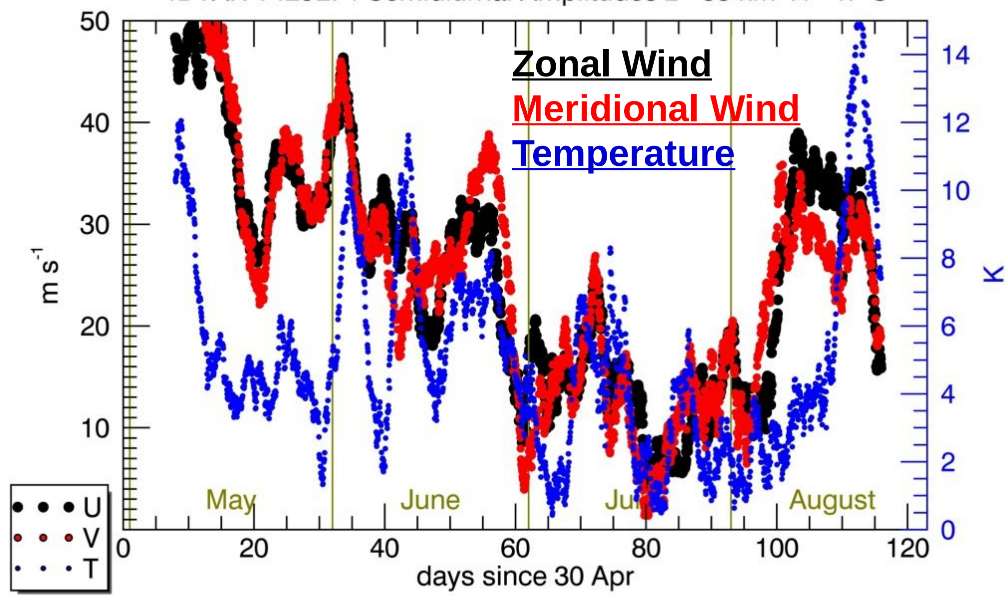


4DVAR T119L74 Semidiurnal Amplitudes z=88 km 41°-47°S

4DVAR T425L74 Semidiurnal Amplitudes z=88 km 41°-47°S

Pure 4DVAR





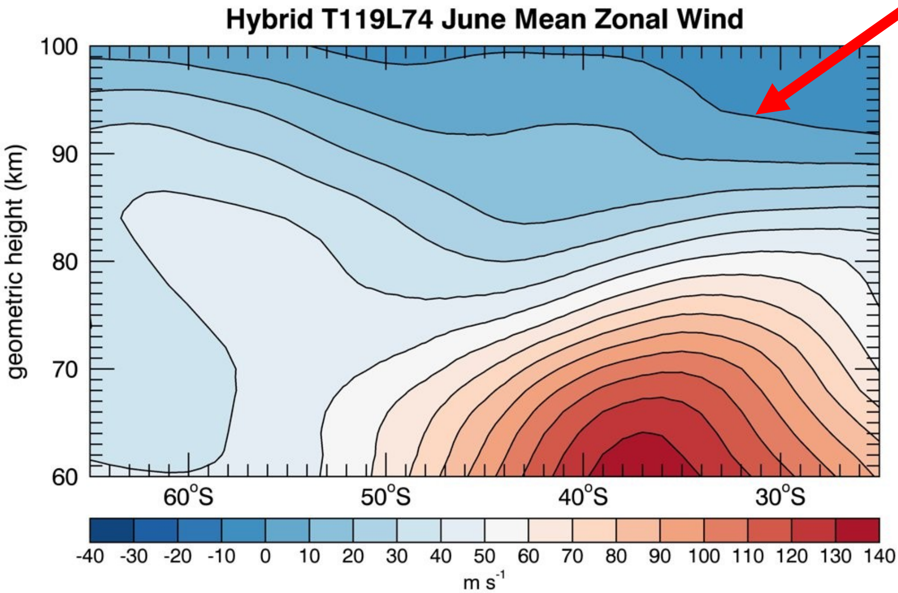
June Mean and Diurnal Tidal Winds T119L74 Hybrid

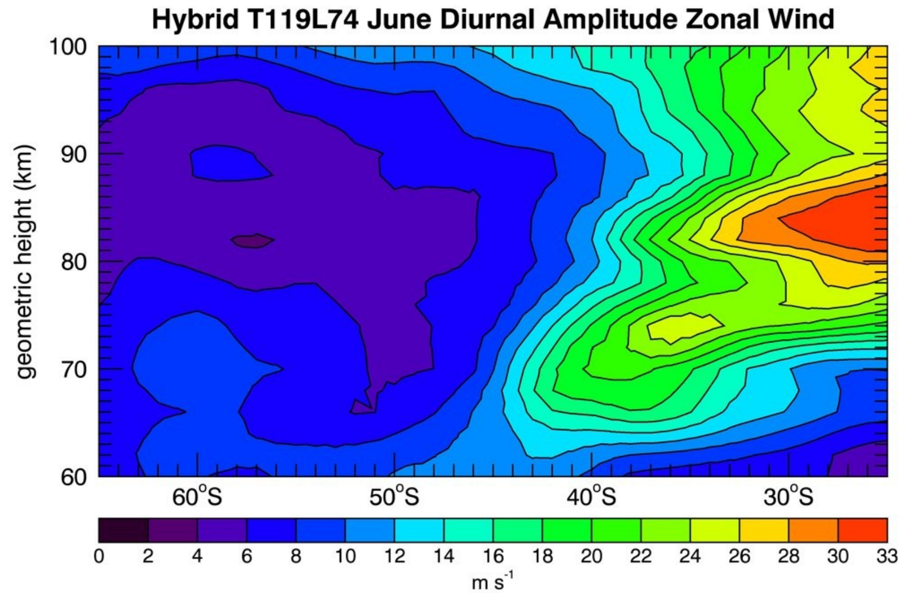
Zero Wind Line

Mean

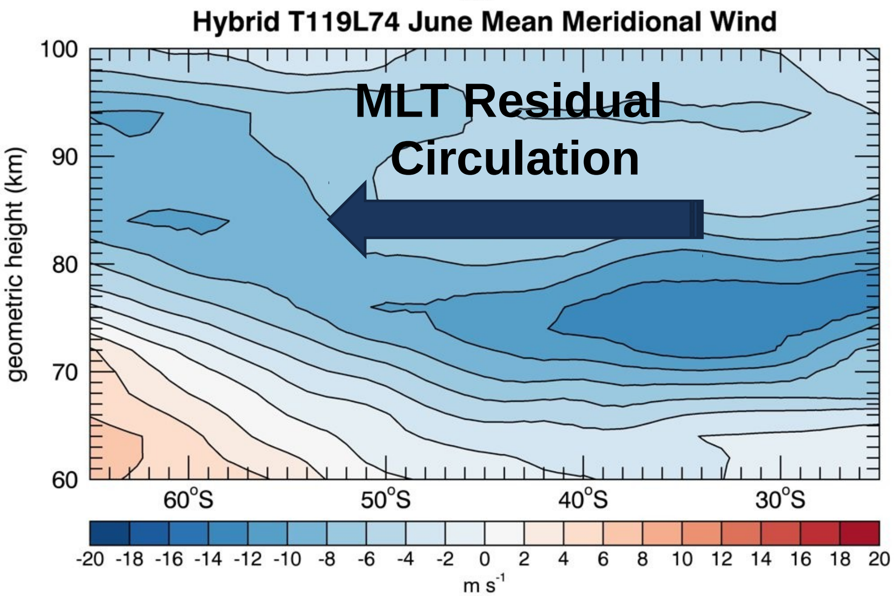
Diurnal Amplitude

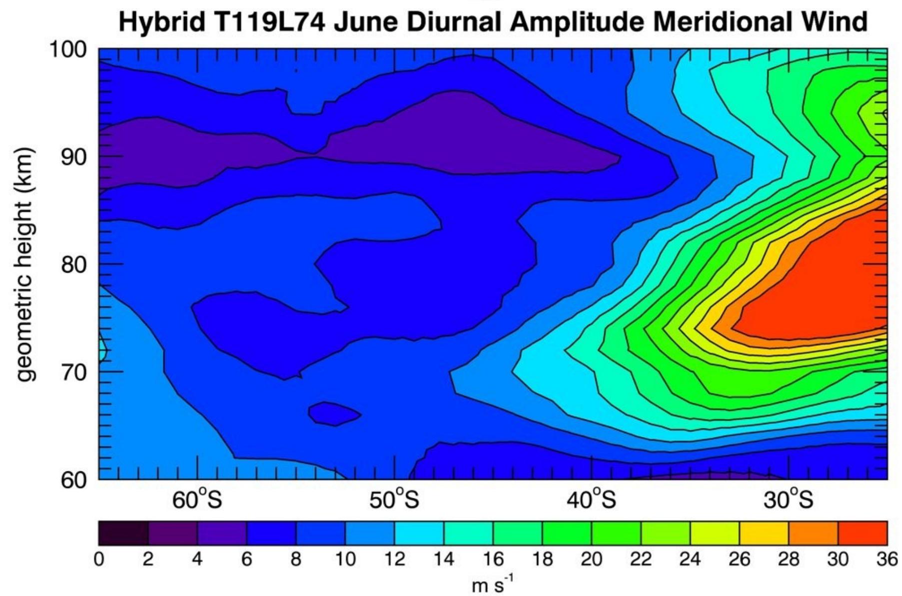
Zonal



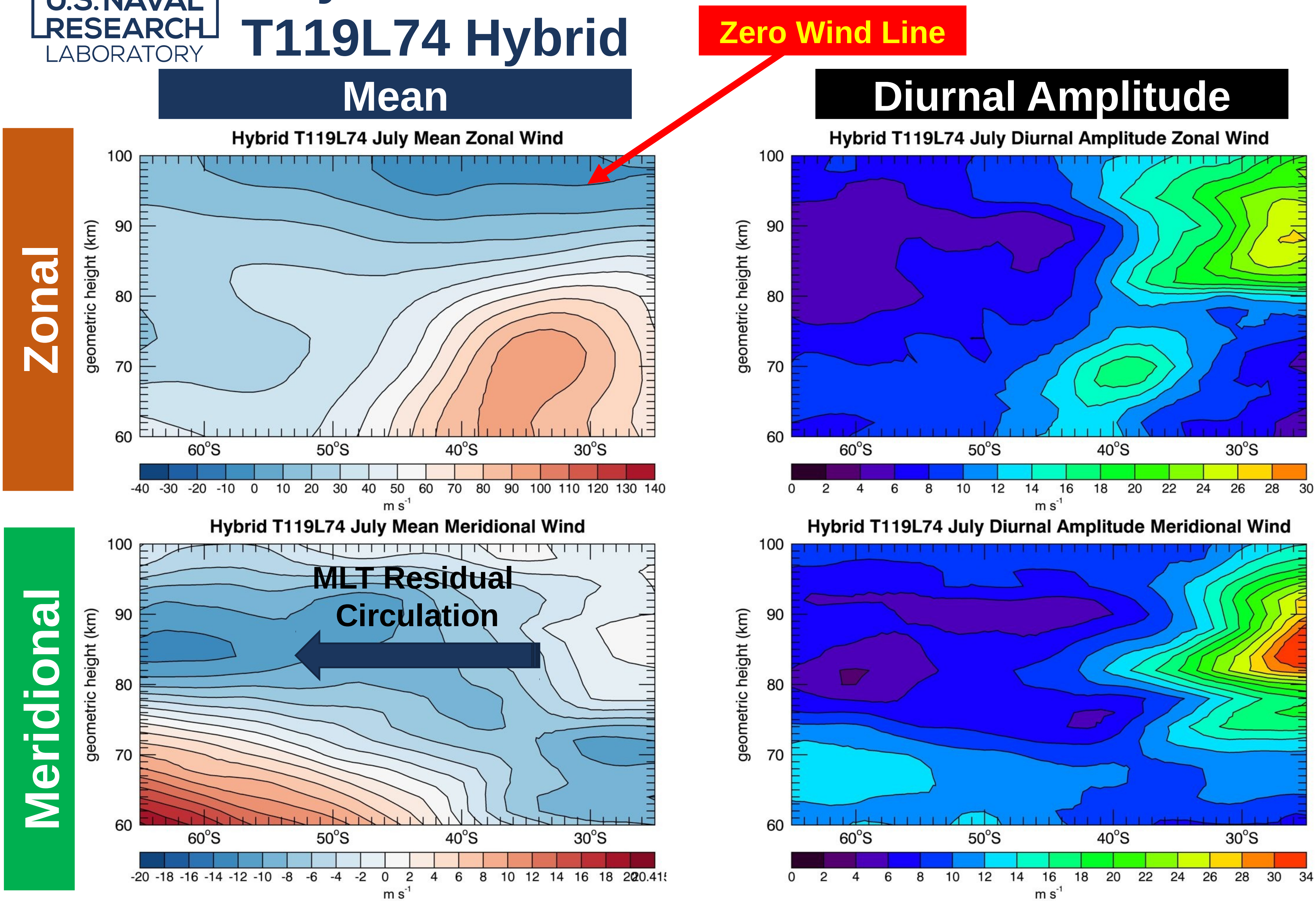


Meridional





July Mean and Diurnal Tidal Winds
T119L74 Hybrid



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Take Homes

- MLT Dynamics in and around the South Island were dominated by large-amplitude migrating semidiurnal wind and temperature tides during the DEEPWAVE austral winter of 2014, suggesting strong semidiurnal tidal modulation of MLT gravity waves generally (as reported, e.g., by Eckermann et al. 2016 over the Auckland Islands during RF23)
- Tidal amplitudes show vacillations over 15-20 days that are also seen in meteor radar winds
- Diurnal tidal amplitudes were much weaker over the South Island and poleward: stronger diurnal tidal amplitudes are confined mostly to latitudes equatorward of New Zealand
- Mean winds over the South Island (4-day local means with tides removed) remained eastward up to ~100 km altitude providing a stable propagation channel for orographic gravity waves in the absence of tides
- Mean and tidal winds in NAVGEM reanalysis show skill in comparison to independent meteor radar observations at Kingston and Buckland Park
- Hybrid-4DVAR results generally outperform pure 4DVAR in MLT wind validation.

Science Customers for High-Altitude NAVGEM DEEPWAVE Reanalysis Products

Time Cadence: 6-hourly, 3-hourly or hourly analysis

Vertical Levels

- Native: Hybrid sigma-pressure levels
- Regridded Options: isobaric (constant pressure) levels, constant geopotential height levels, constant geometric height levels, isentropic (constant potential temperature) levels

Horizontal Gridding

- Native: full (T119) or reduced (T425) Gaussian grids
- Regridded Options: equispaced latitude-longitude grids

Global Data or Subsets of selected Horizontal and Vertical Ranges

Analyzed Variables (on any of the above horizontal and vertical grids)

- Zonal Wind, Meridional Wind, Vertical Wind, Pressure (omega) Velocity
- Temperature, Potential Temperature, Absolute/Relative Vorticity, Ertel's Potential Vorticity, Modified Potential Vorticity, Divergence, etc.
- Specific Humidity, Ozone Volume Mixing Ratio, etc.

Other Physics Parameters

- e.g., subgridscale (parameterized) orographic and nonorographic GWD

Backup Slides

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NAVGEM DEEPWAVE Reanalysis

Resolved Gravity Waves in Reanalysis

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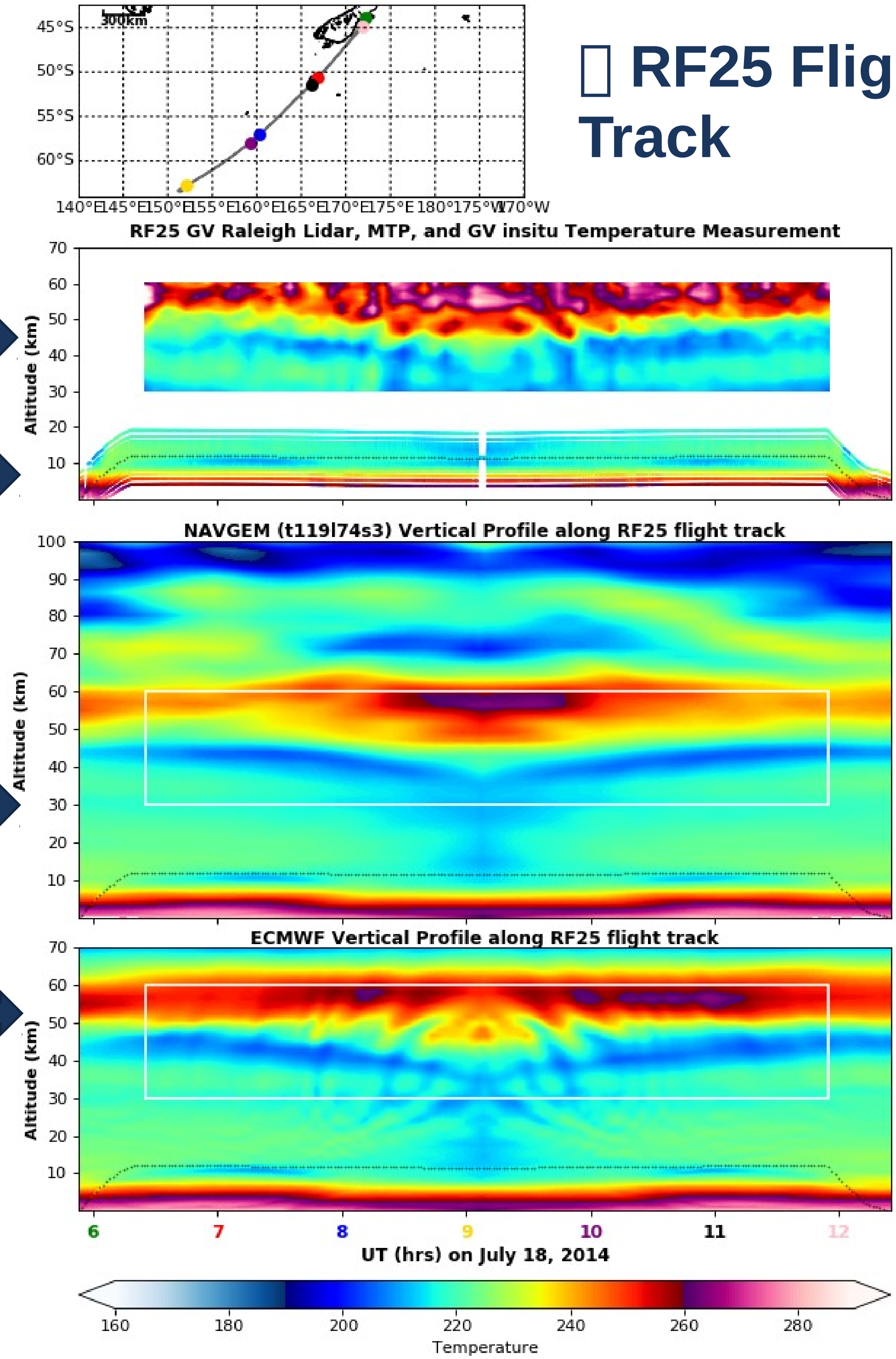
RF25 Temperatures



RF25 Flight Track

Airborne Rayleigh Lidar Temperatures 30-60 km

Airborne MTP Temperatures ~5-20 km

NAVGEM T119L74 Hybrid-4DVAR Reanalysis 0-100 km

ECMWF IFS T1279L139 Operational Analysis 0-70 km

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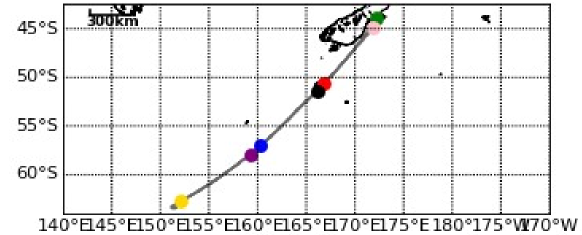
RF25 Temperatures



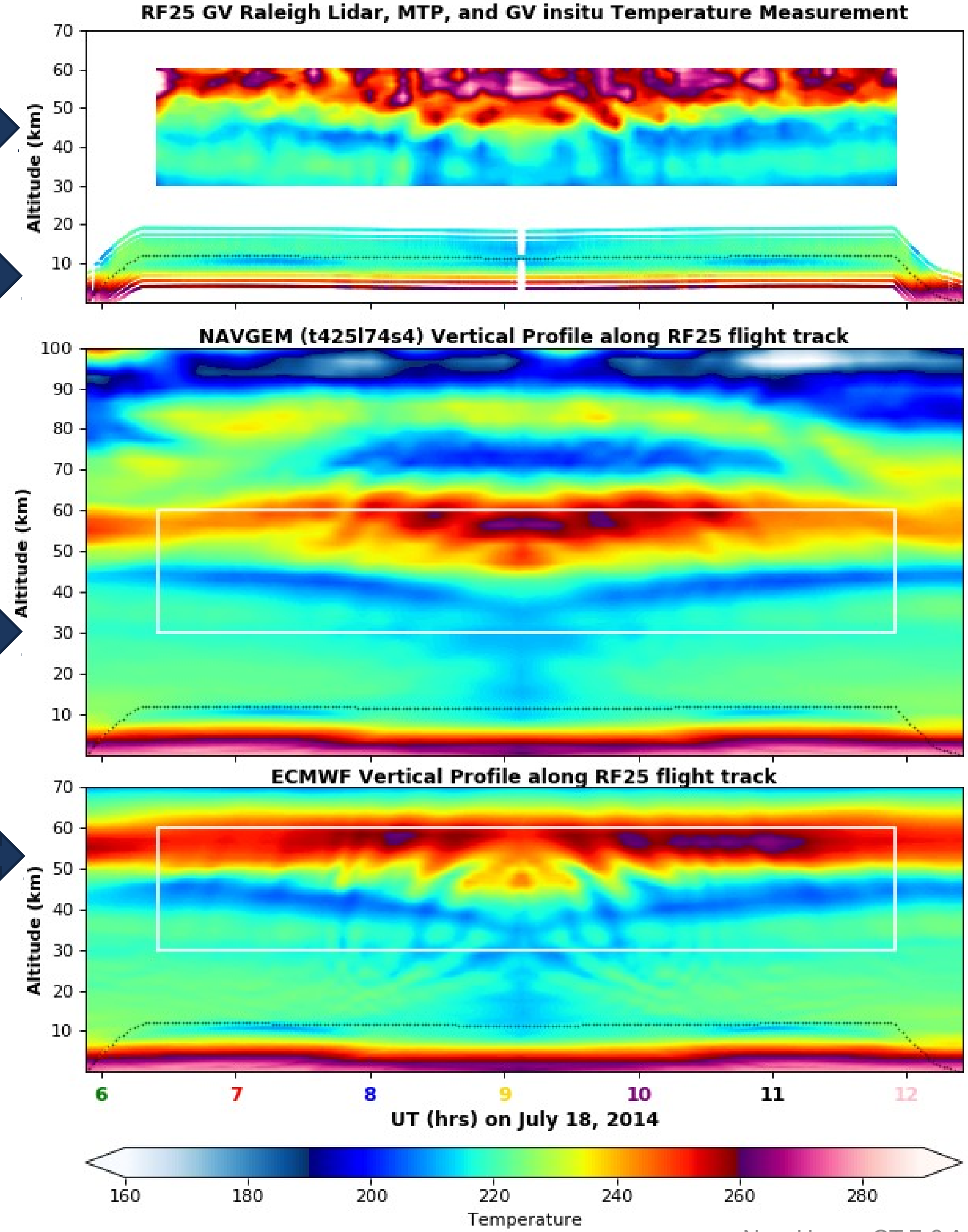
RF25 Flight Track

Airborne Rayleigh Lidar Temperatures 30-60 km

Airborne MTP Temperatures ~5-20 km

NAVGEM T425L74 Hybrid-4DVAR Reanalysis 0-100 km

ECMWF IFS T1279L139 Operational Analysis 0-70 km



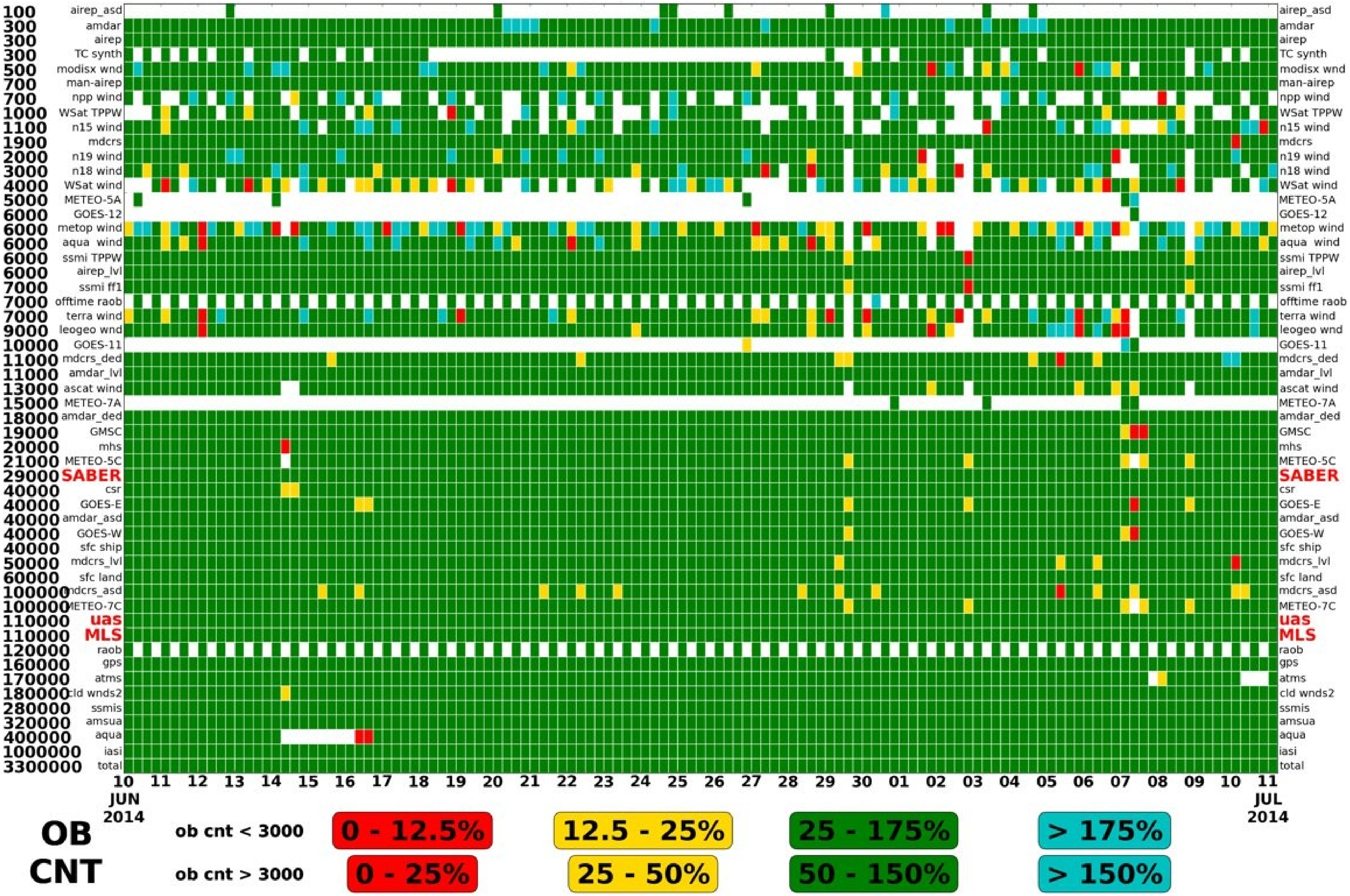
Summary

- NAVGEM reanalyses have been generated from 0-100 km to support DEEPWAVE GW science during austral winter of 2014
- Reanalyzed MLT winds agree well with meteor radar winds acquired over Tasmania, including a dominant large-amplitude vacillating semidiurnal tide
- Resolved gravity waves show skill relative to observations and ECMWF IFS

Planned DEEPWAVE Science Using These Products

- “Missing” gravity wave drag using analysis increments (following McLandress et al. JAS 2012)
- Role of resolved and parameterized MLT gravity wave drag in closing stratopause jets
- Understanding large-amplitude vacillating migrating semidiurnal tidal winds in MLT during DEEPWAVE & role of GW-tidal interactions
- MLT gravity-wave event modeling and transmission studies using NAVGEM winds and temperatures from 0-100 km

Observation Assimilation Statistics



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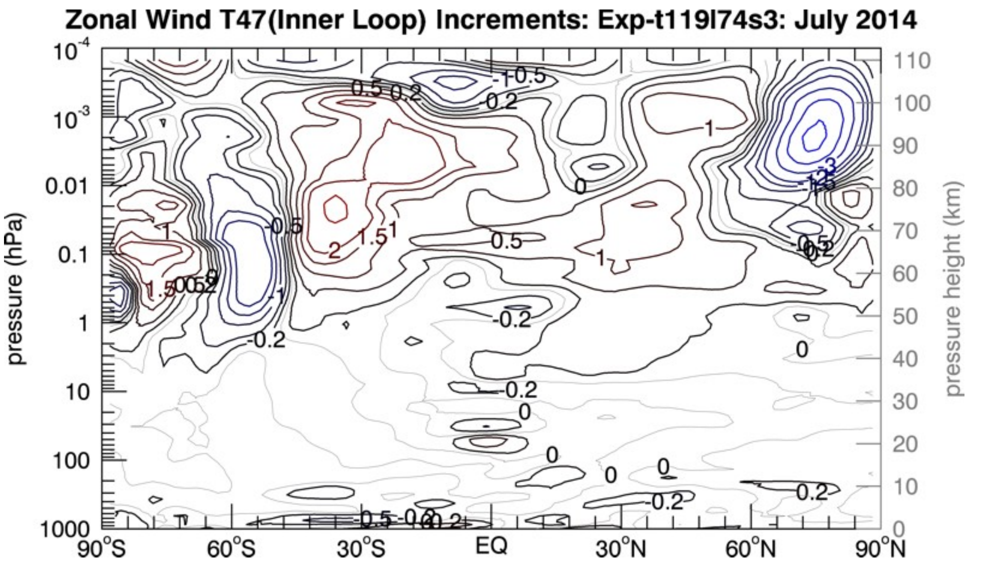
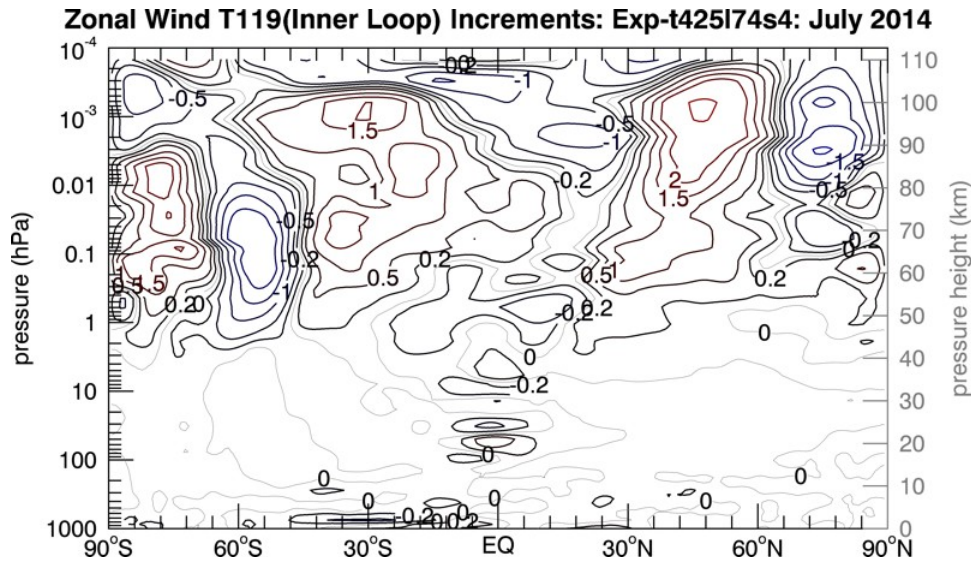
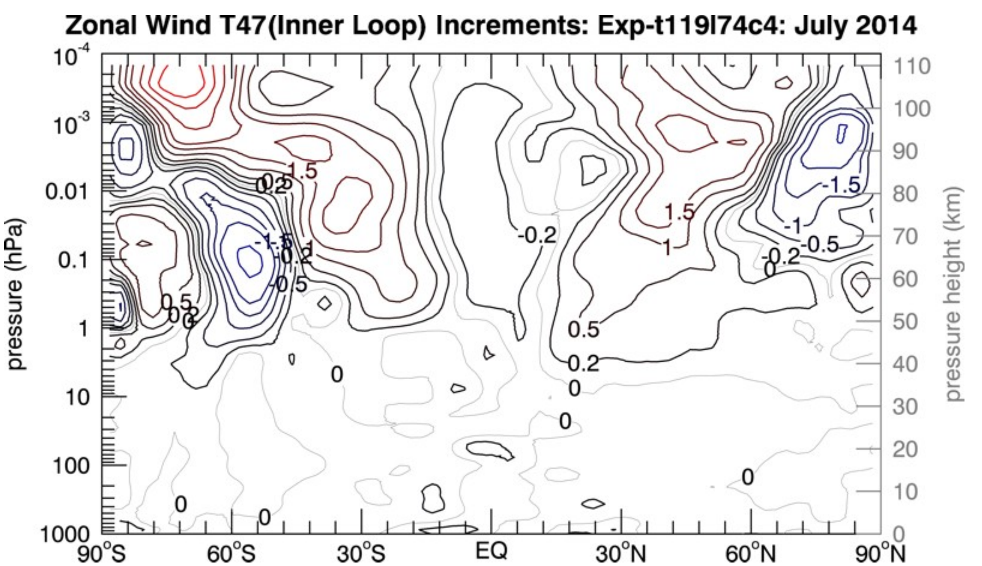
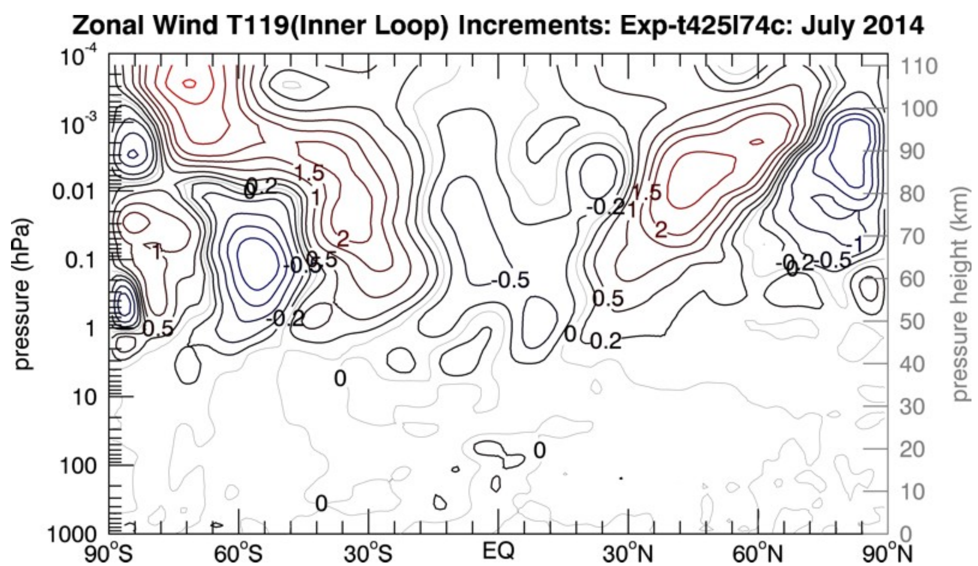
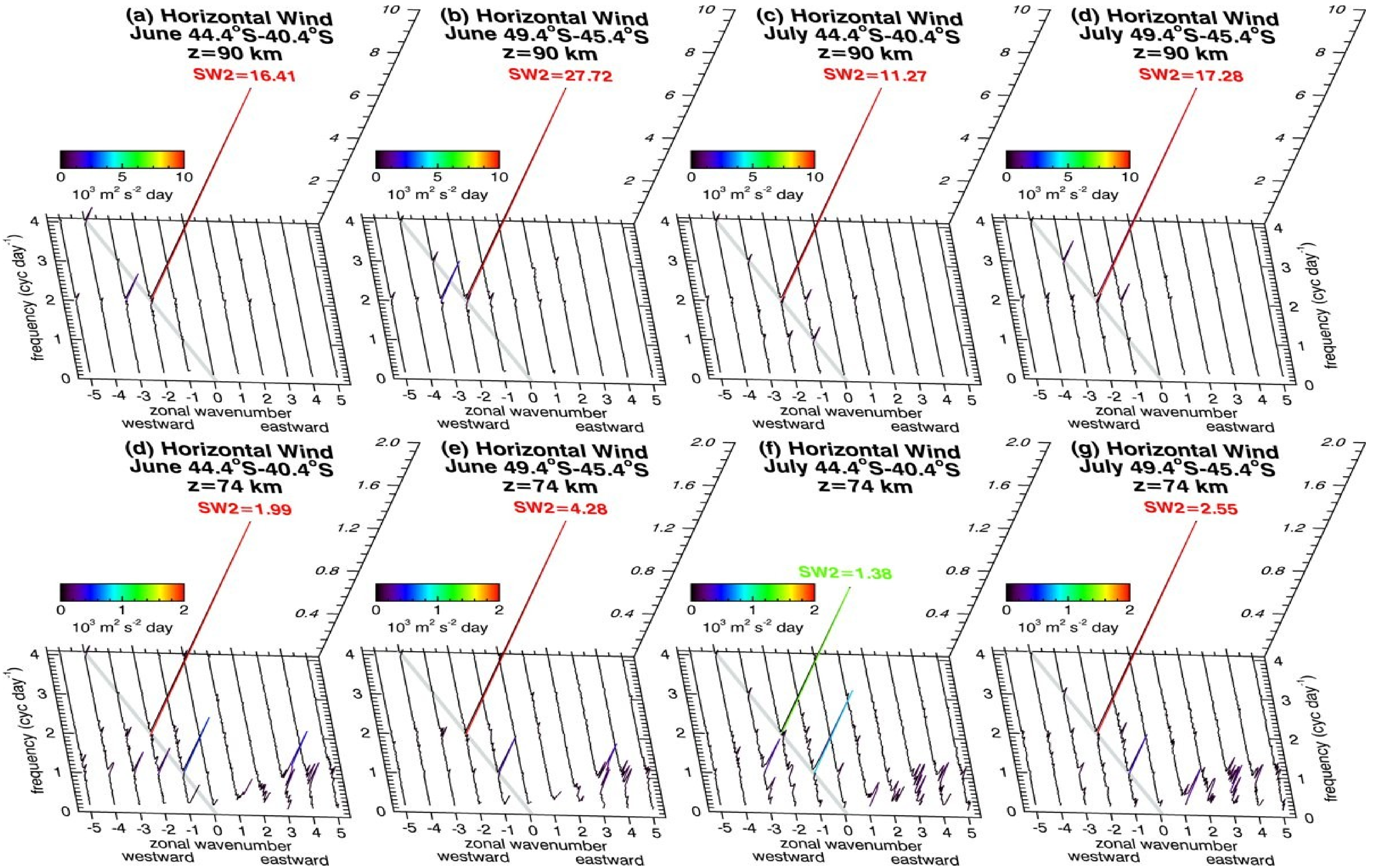
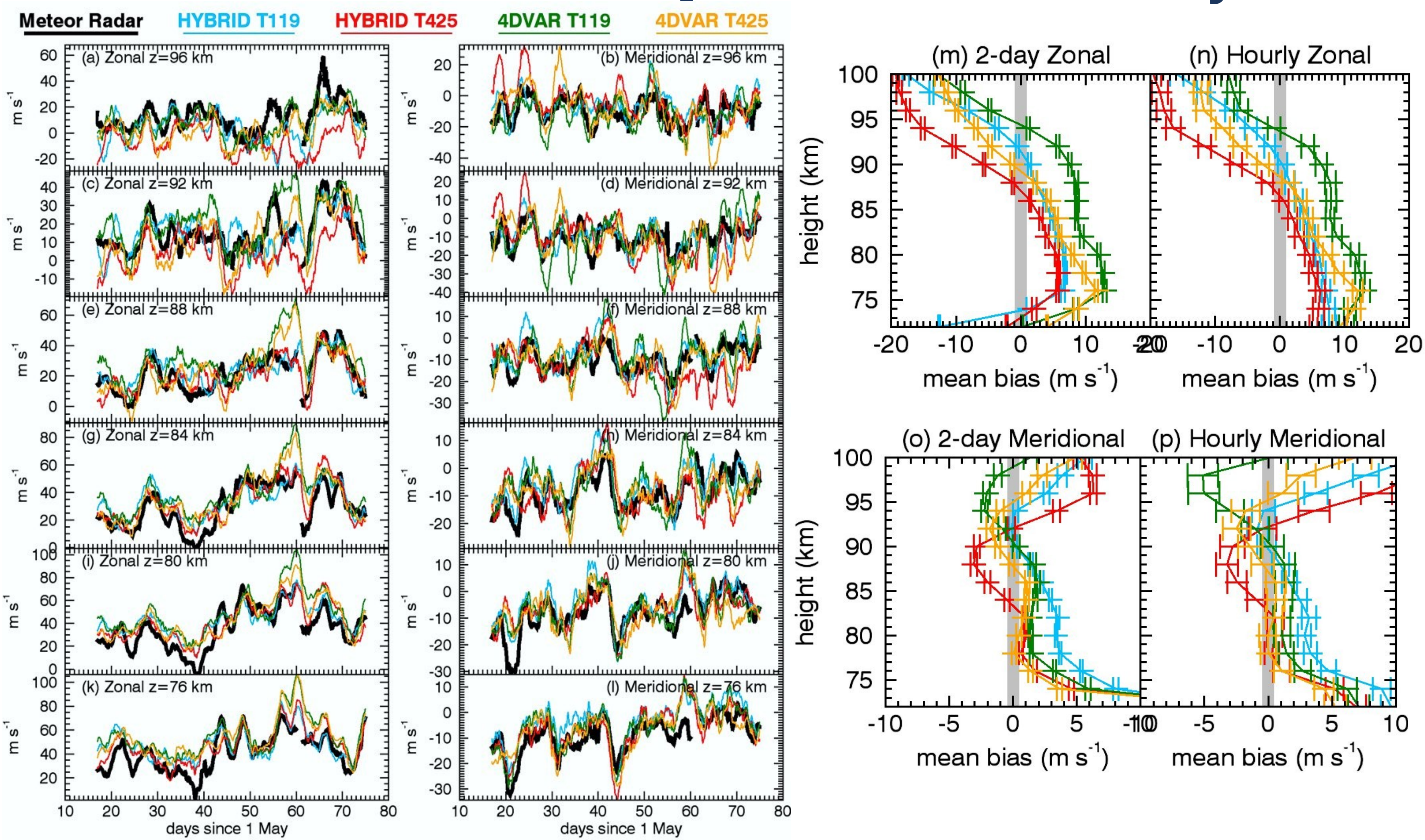
July Zonal-Mean Zonal-Wind Increments

	T119 Outer (T47 Inner)	T425 Outer (T119 Inner)
Hybrid 4DVAR		
Pure 4DVAR		

MLT Winds and Temperatures Dominated by Migrating Semidiurnal Tide during DEEPWAVE



MLT Analysis vs. Radar Winds: "a0" fits on 2 day windows vs. hourly



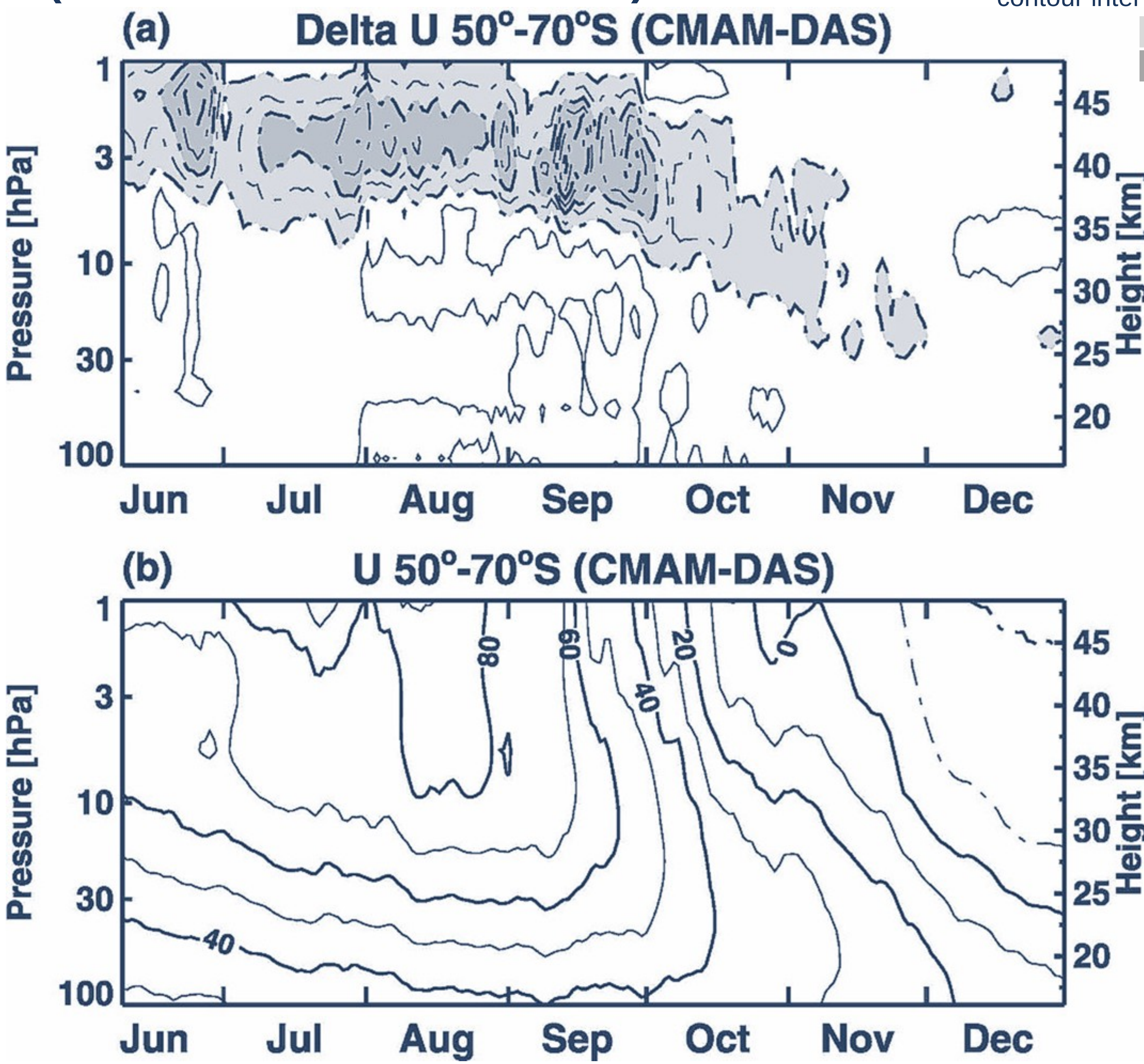
CMAM Zonal-Mean Zonal Wind Increments

(McLandress et al. JAS 2012)

contour interval 0.8 m s-1 day-1

< -0.4 m s-1 day-1

< -2.0 m s-1 day-1



Zonal Wind Increments and “Missing” GWD

- Several recent studies have argued that zonal-mean zonal wind increments in the extratropical austral winter stratosphere reveal “missing” GWD in models (Orr et al. J. Clim. 2010; McLandress et al. JAS 2012; Kruse et al. JAS 2016)
- In particular, McLandress et al. (2012) argued that systematic negative (westward) increments at ~60^{o}S indicated a missing source of GWD in models, either from subantarctic islands in Southern Ocean or meridional refraction of GW into the vortex jet from higher and lower latitudes
- How does this work?

(1) Temperature increments specify zonal-mean zonal wind from meridional momentum balance

$$\cancel{v_t} + \cancel{\frac{uv_\lambda}{a\cos\phi}} + \cancel{\frac{vv_\phi}{a}} + fu + \cancel{\frac{u^2\tan\phi}{a}} + \frac{\Phi_\phi}{a} + \cancel{wv_z} + \cancel{Y} = 0,$$

geostrophic balance

(2) Zonal wind increments (corrections) in zonal momentum equation map to gravity-wave drag

$$u_t + \cancel{\frac{uu_\lambda}{a\cos\phi}} + \cancel{\frac{v\left(u\cos\phi\right)_\phi}{a\cos\phi}} - fv + \cancel{\frac{\Phi_\lambda}{a\cos\phi}} + \cancel{wu_z} + X = 0,$$

geostrophic balance

zonal wind increments (bias) must then be removed by a balancing GWD *X*, (mean v responds)

NAVGEM DEEPWAVE Reanalysis

Wind Increments and "Missing" Gravity Wave Drag

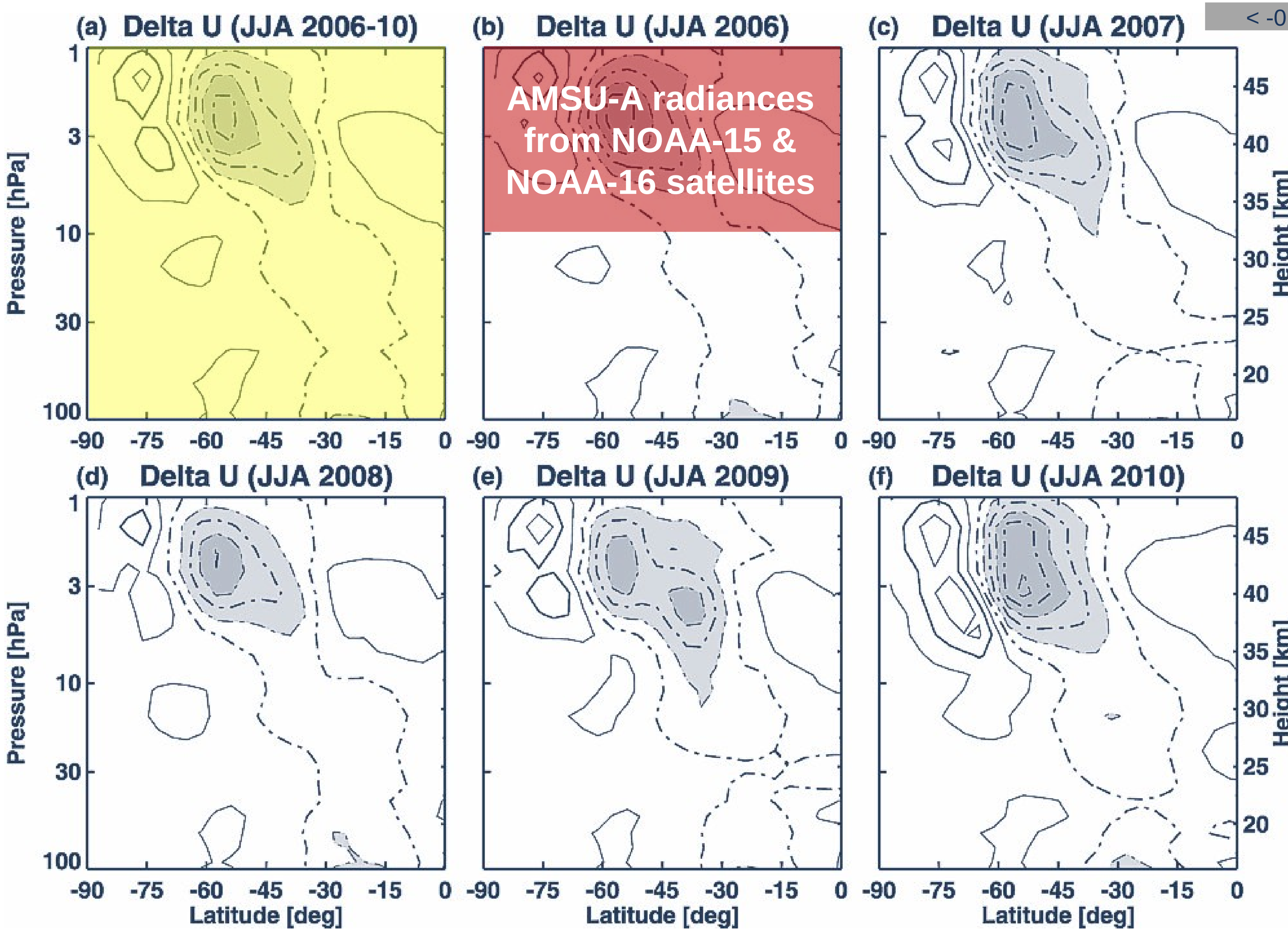
CMAM Zonal-Mean Zonal Wind Increments

(McLandress et al. JAS 2012)

contour interval 0.15 m s⁻¹

< -0.225 m s⁻¹

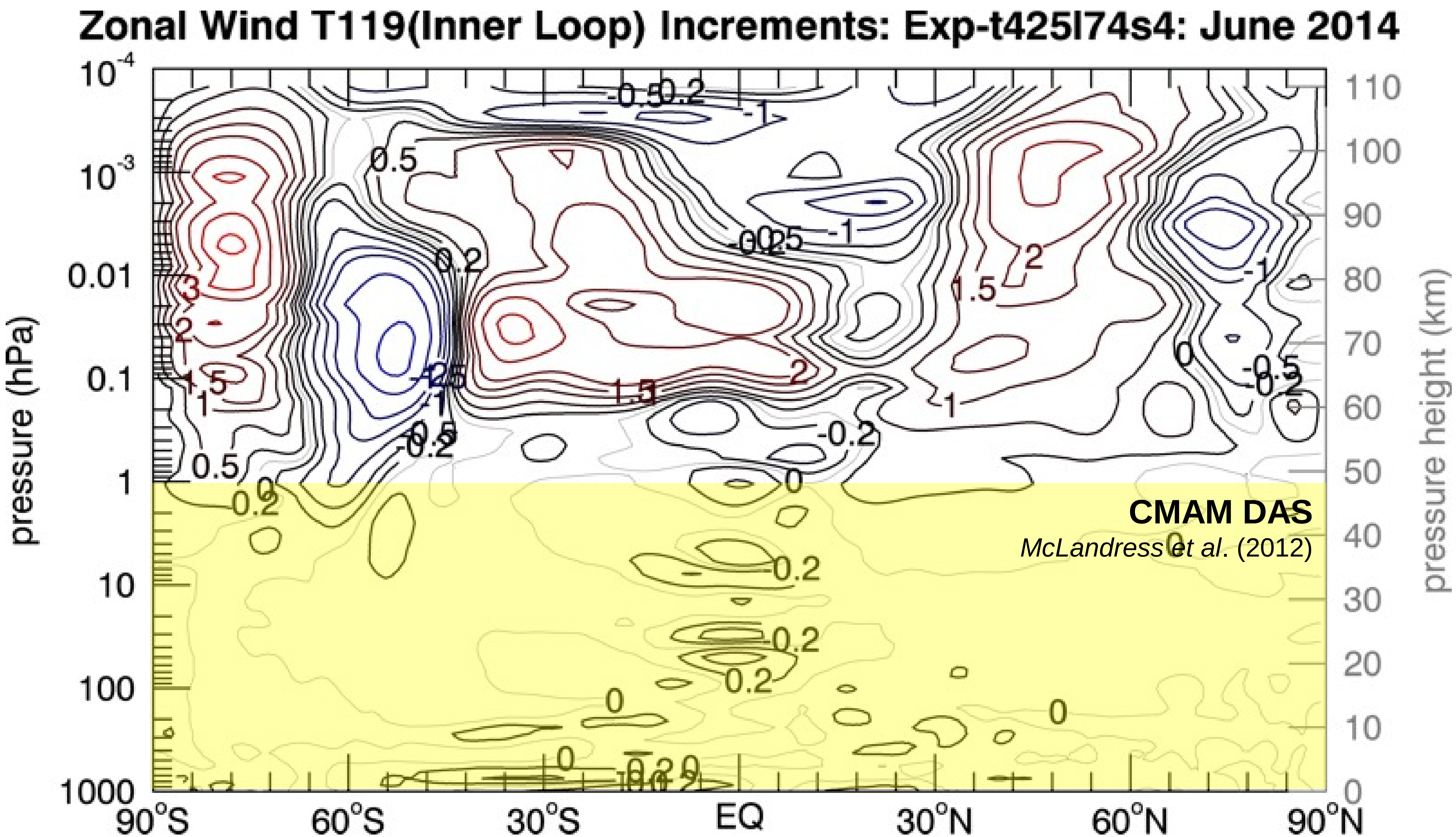
< -0.525 m s⁻¹



June Zonal-Mean Zonal-Wind Increments

Hybrid 4DVAR

T425 Outer (T119 Inner)



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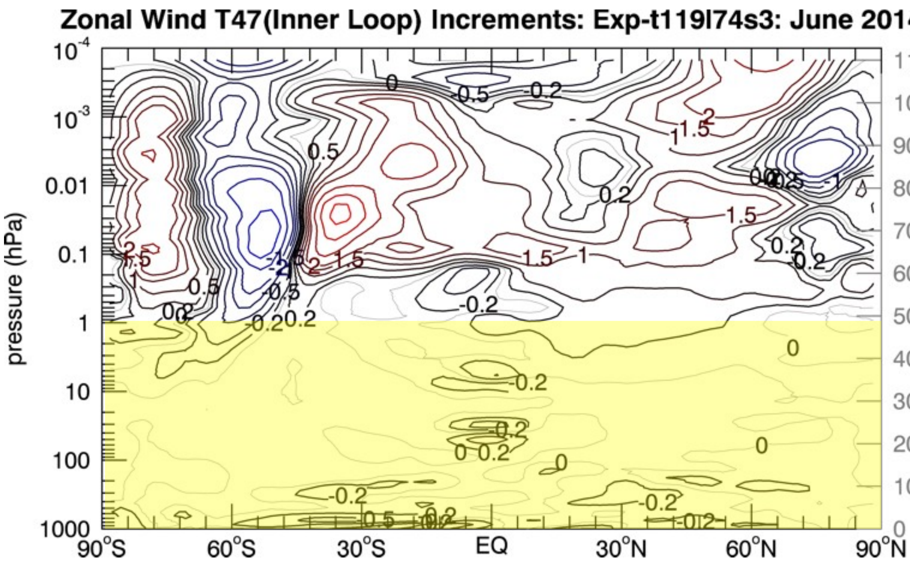
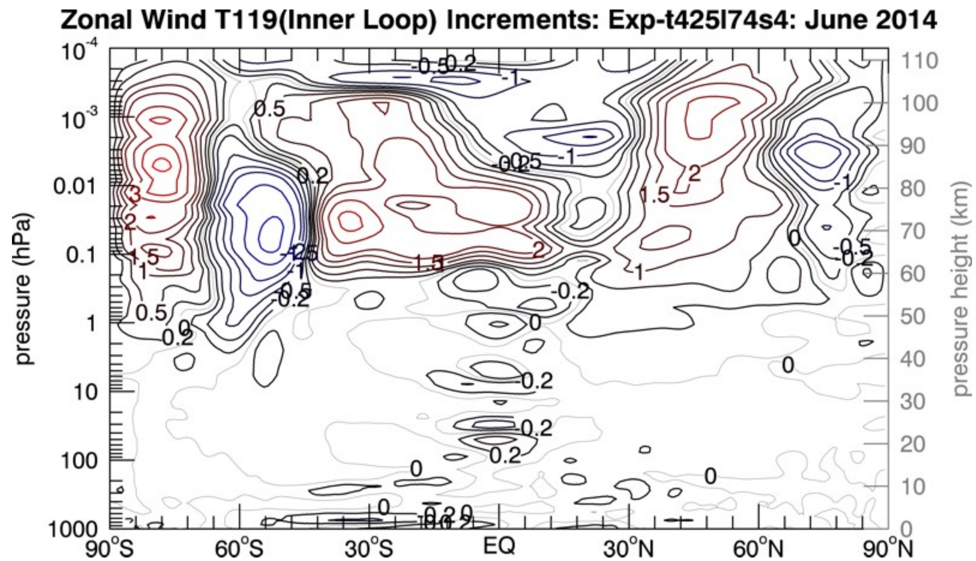
June Zonal-Mean Zonal-Wind Increments

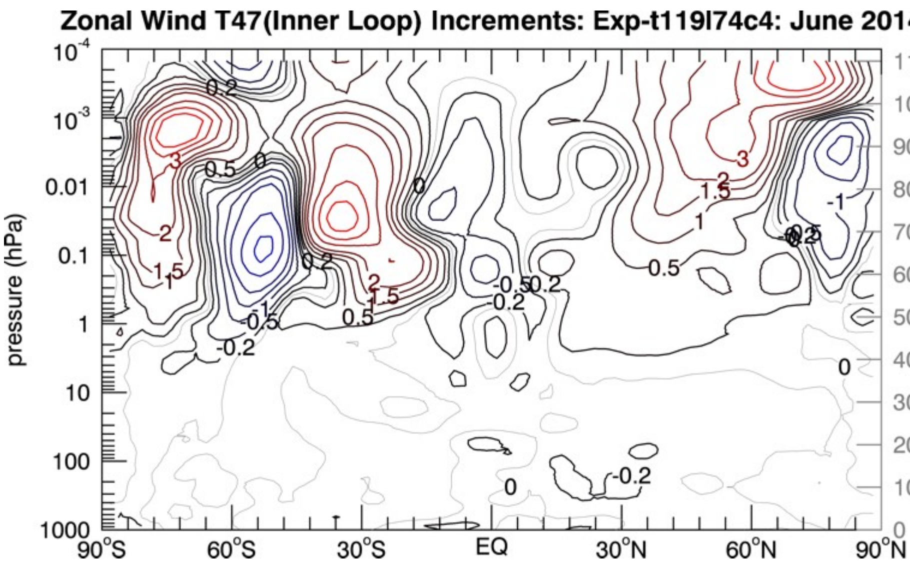
T119 Outer (T47 Inner) | **T425 Outer (T119 Inner)**

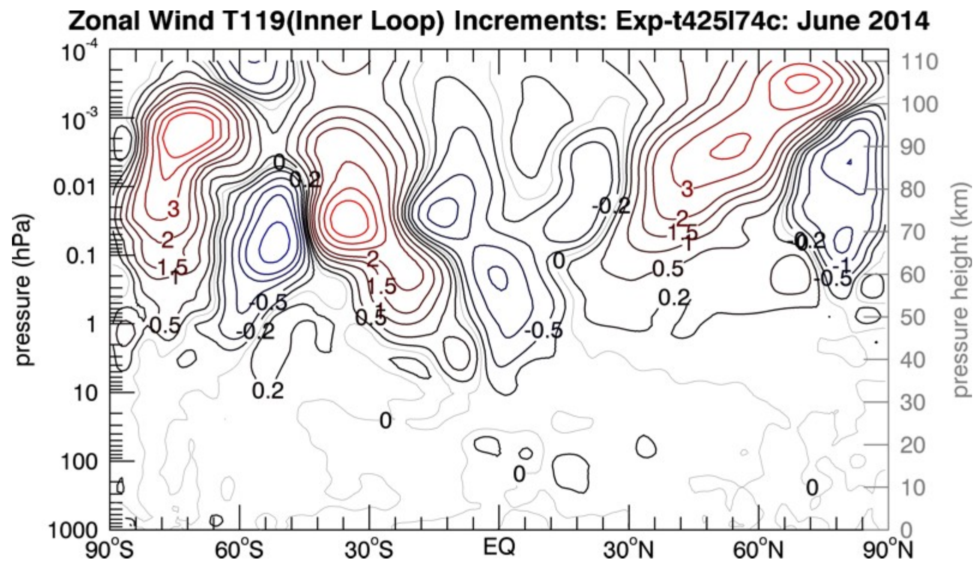
Hybrid 4DVAR



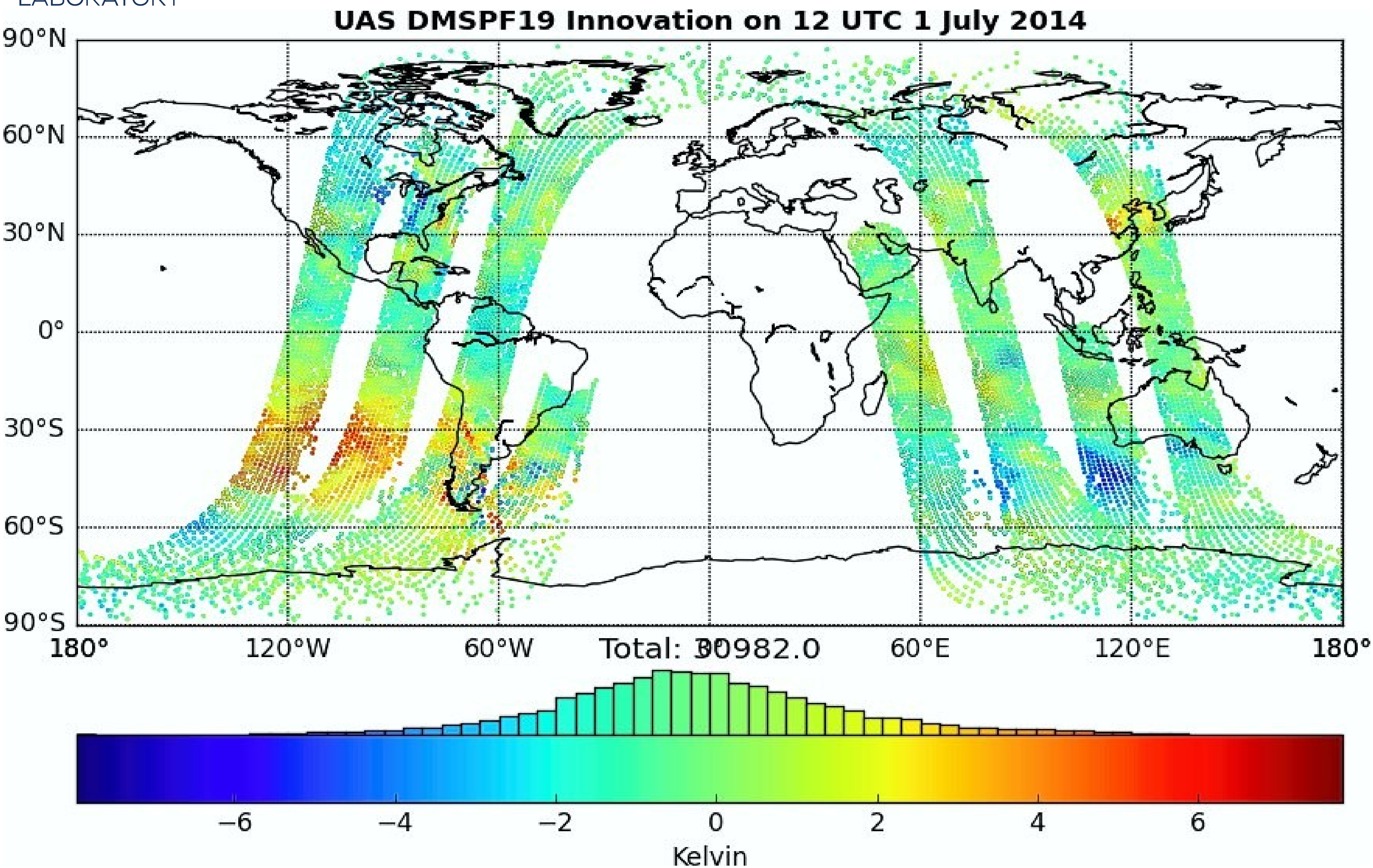


Pure 4DVAR

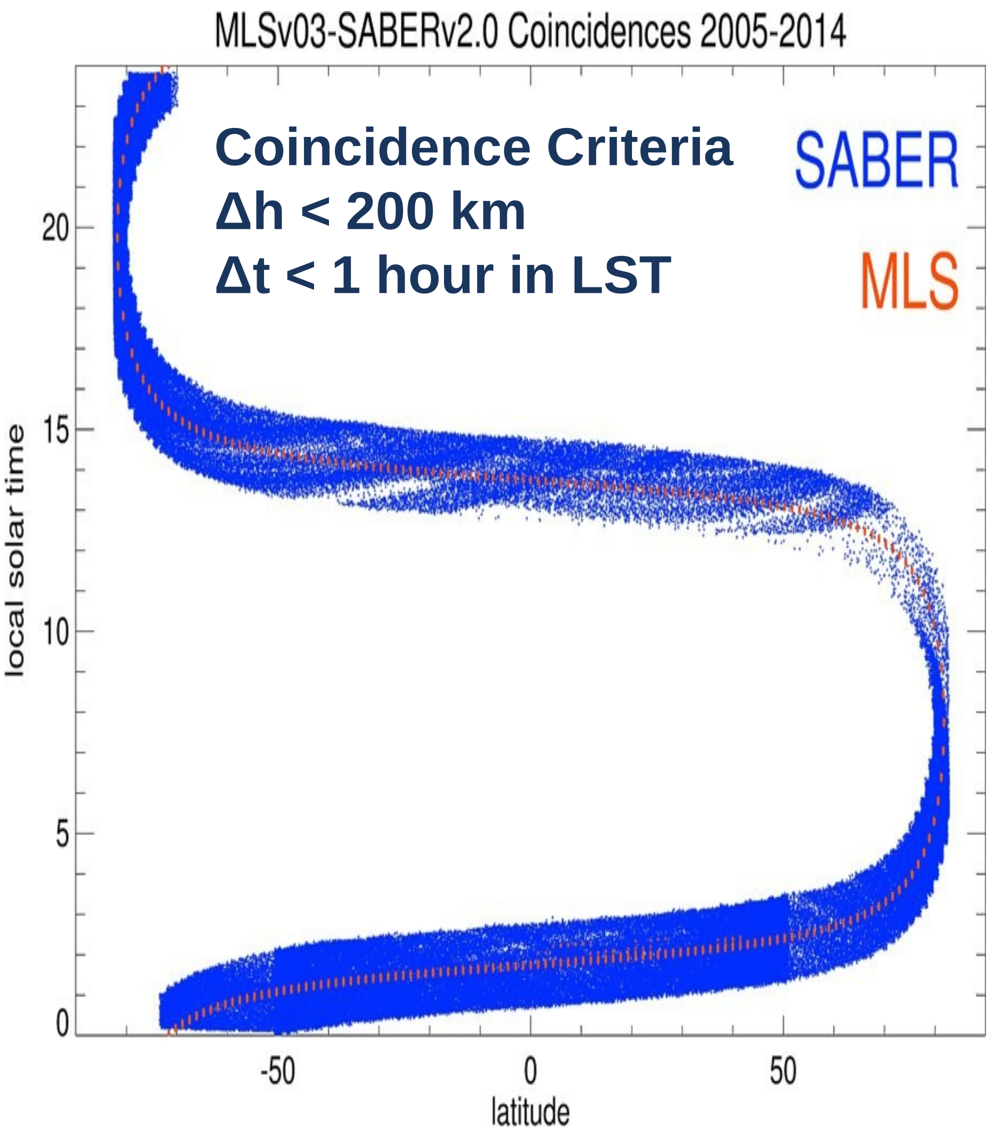


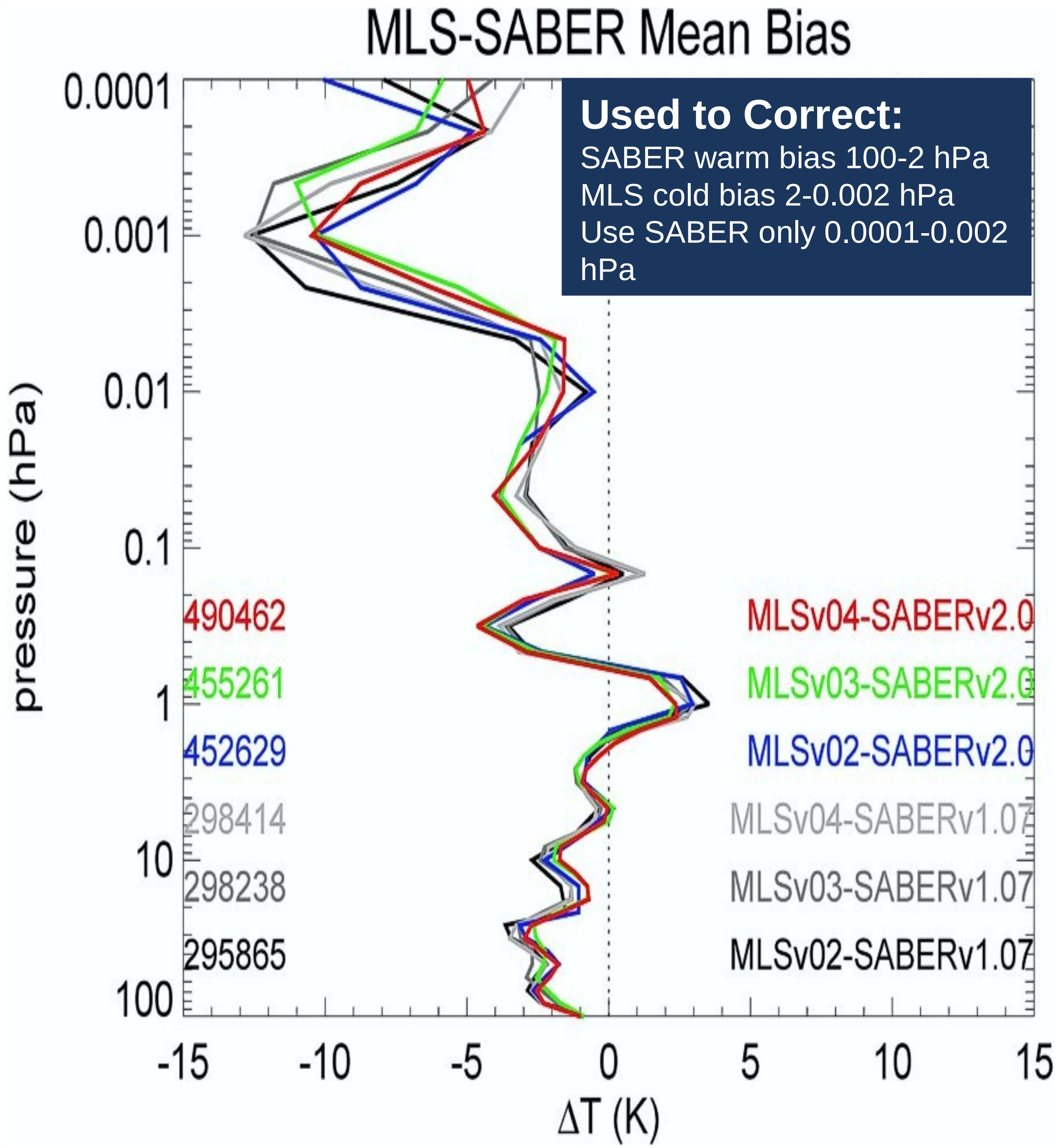


Sample Channel 20 SSMIS UAS Innovations



SABER-MLS Biases from 11-Year Coincidences





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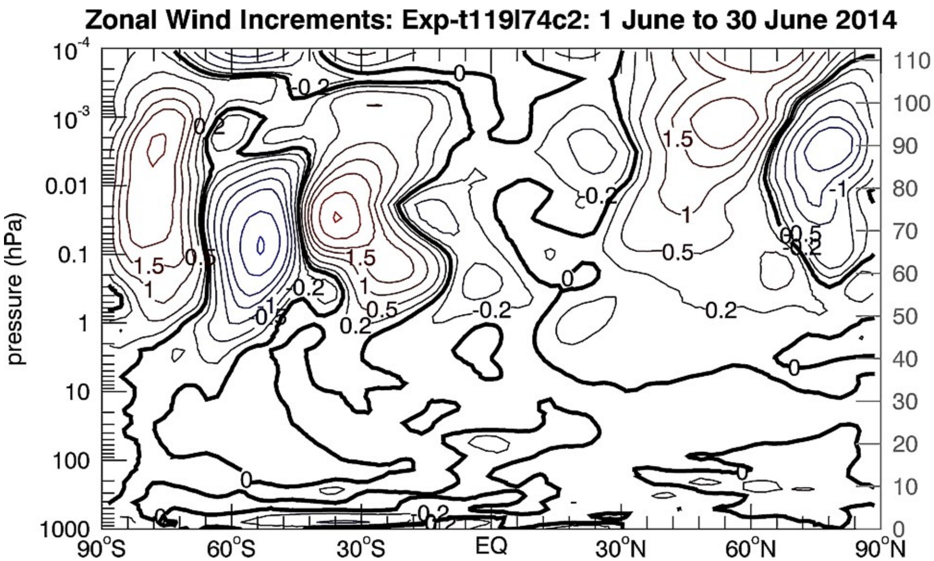
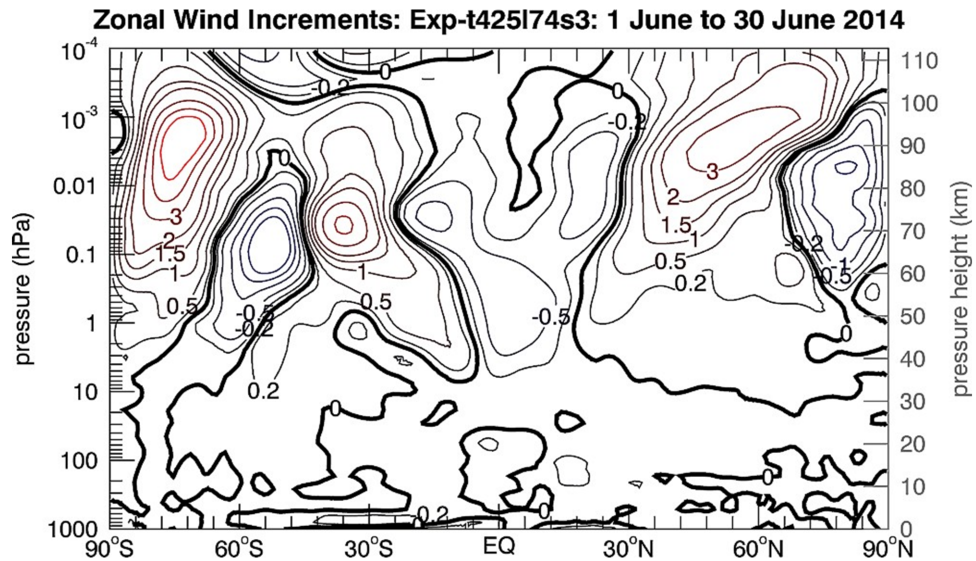
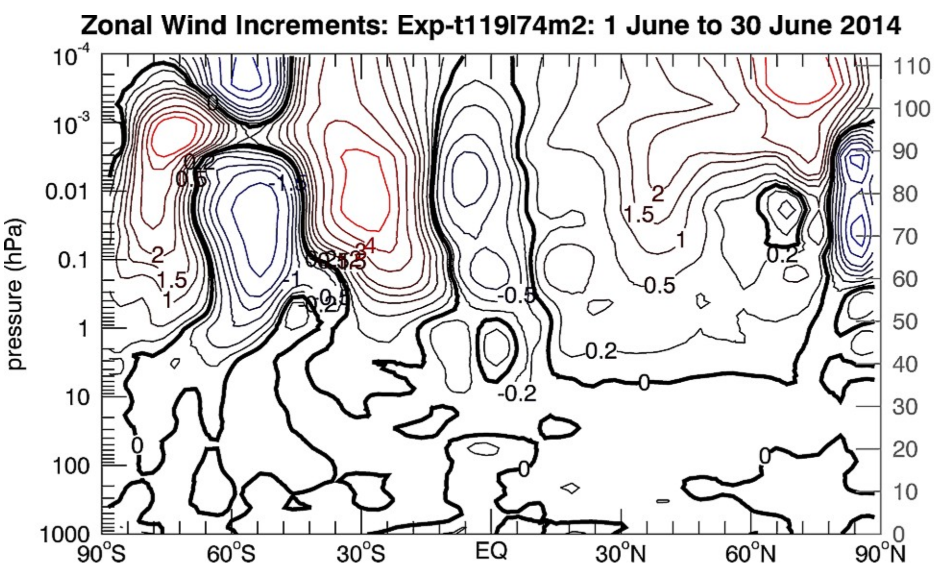
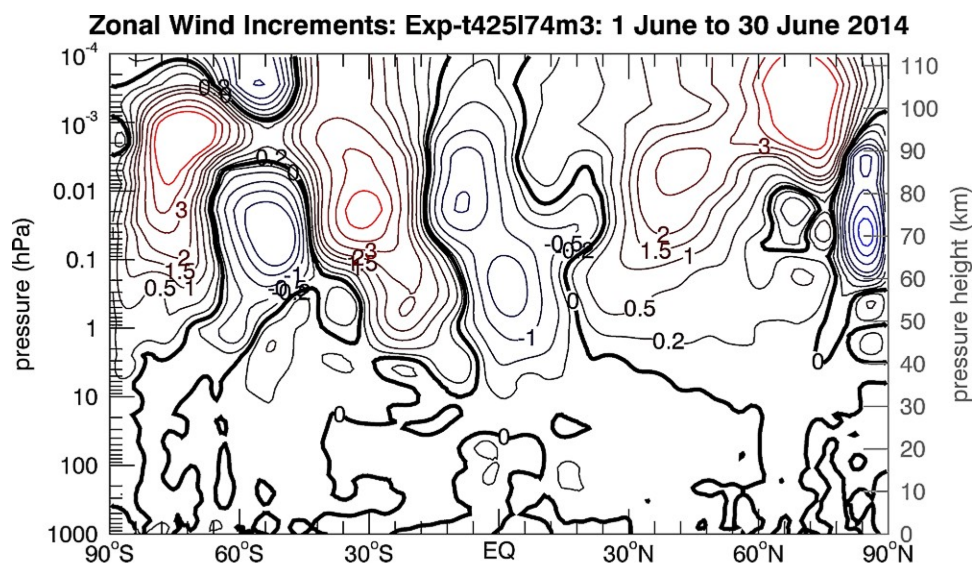
Old June Zonal-Mean Zonal-Wind Increments

	T119 Outer (T47 Inner)	T425 Outer (T119 Inner)
Hybrid 4DVAR		
Pure 4DVAR		

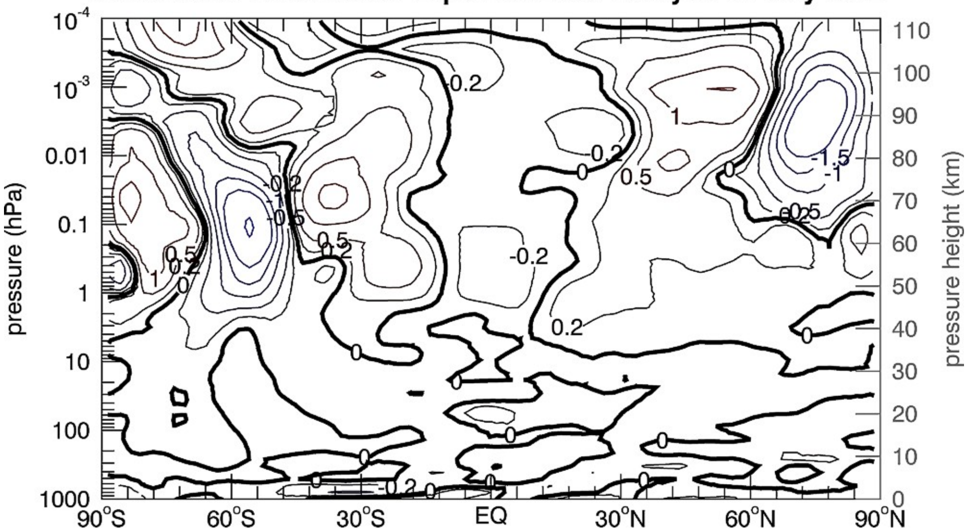
Old July Zonal-Mean Zonal-Wind Increments

U.S. NAVAL RESEARCH LABORATORY

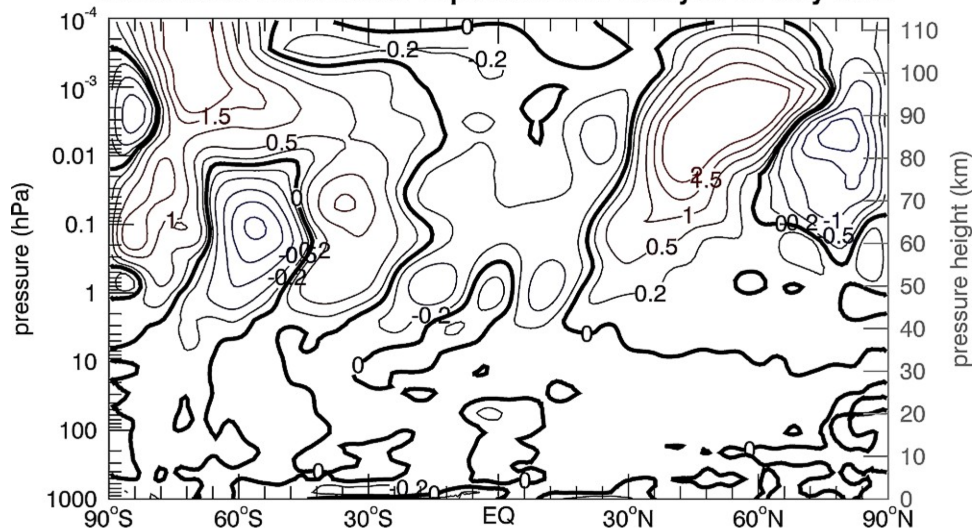
T119 Outer (T47 Inner) | T425 Outer (T119 Inner)

Hybrid 4DVAR

Zonal Wind Increments: Exp-t119l74c2: 1 July to 31 July 2014

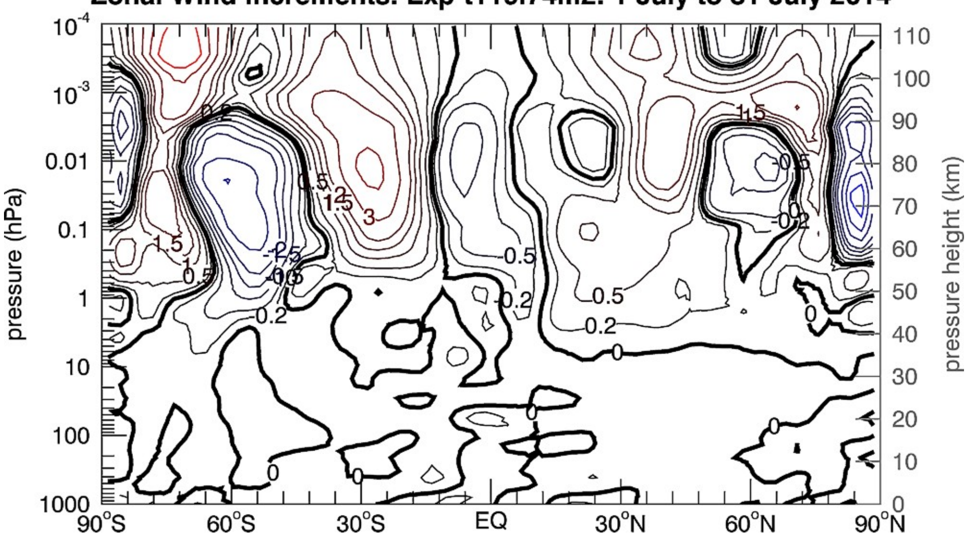


Zonal Wind Increments: Exp-t425l74s3: 1 July to 31 July 2014



Pure 4DVAR

Zonal Wind Increments: Exp-t119l74m2: 1 July to 31 July 2014



Zonal Wind Increments: Exp-t425l74m3: 1 July to 29 July 2014