

NRLDC DEEPWAVE Science: A Progress Report



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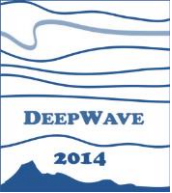


Acknowledgements

NRL's DEEPWAVE research and support is/was supported by:

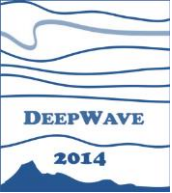
- The Chief of Naval Research (CNR) through the NRL base 6.1 and 6.2 research program
- The Office of Naval Research (ONR) Departmental Research Initiative (DRI) "Predictability of Seasonal and Intraseasonal Oscillations."
- The National Science Foundation
- The Oceanographer of the Navy through PMW-120/SPAWAR 6.4 transition contracts
- NASA through the Heliophysics Division SR&T and GI programs.





Outline of Topics To Be Discussed

- **NAVGEM 0-100 km Reanalysis for 2014**
- Fourier-Ray Model of RF23 MLT Mountain Waves over Auckland Island
- Ray Modeling of RF23 flight-level data over Auckland Island and Macquarie Island
- Ray Models of Lateral Refraction of RF22 Mountain Waves
- Parameterization Tests for RF23
- Quick Looks at Suomi VIIRS Day-Night Band Imagery
- we're doing more.....

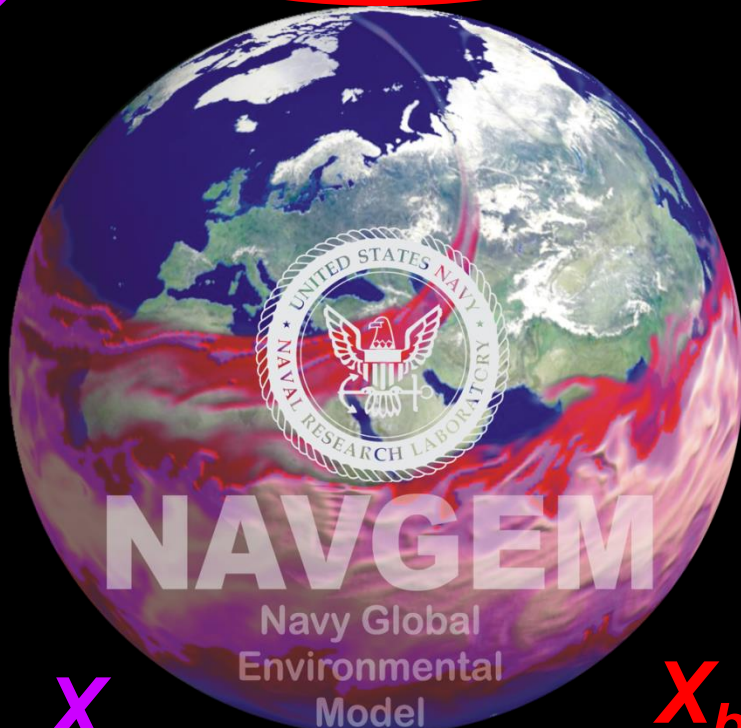


Motivation for a 0-100 km DEEPWAVE Reanalysis Project

- DEEPWAVE gravity wave observations from 0-100 km altitude, with a concentration of MLT observations from ~75-95 km (AMTM, Na lidar, NZ airglow imagers)
- Existing centers (ECMWF, NASA GMAO, NOAA, FNMOC, Met Office, NIWA) issue reanalyses up to 60-70 km only.
- **There is a “reanalysis gap” from ~60-100 km which needs filling for DEEPWAVE science**
- Lots of interest since our May progress report, **but how accurate are MLT winds and semidiurnal tides?**
- We have expended huge amount of work identifying biases/errors, improving reanalysis quality, and validating against DEEPWAVE MLT observations

NAVGENM

Navy Global Environmental Model



NAVGENM
Navy Global
Environmental
Model

Global SLSI
Forecast Model

0-10 Day
Forecasts

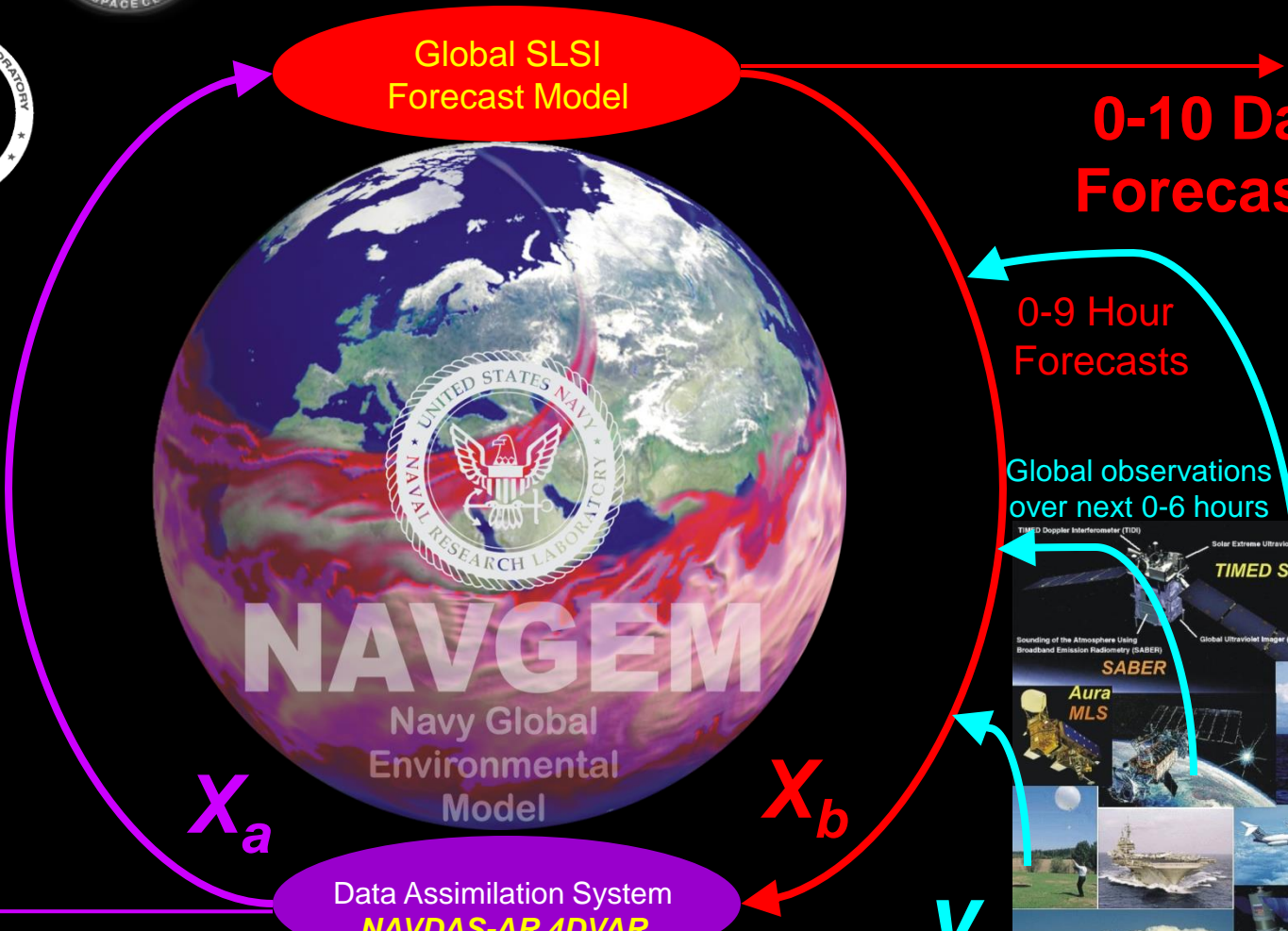
0-9 Hour
Forecasts

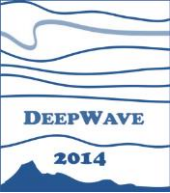
Global observations
over next 0-6 hours



Data Assimilation System
NAVDAS-AR 4DVAR

6 hourly global
analysis fields





NAVGEM Satellite Assimilation

Radiances Imagers/Sounders

DMSP F16 SSMIS ~~LAS, UAS~~, Imager
 DMSP F17 SSMIS LAS, UAS, Imager
 DMSP F18 SSMIS LAS, UAS, Imager
 DMSP F19 SSMIS LAS, UAS, Imager
 METOP-A AMSU-A, IASI, MHS
 METOP-B AMSU-A, IASI, MHS
 NASA EOS Aqua AIRS, AMSU-A
 NOAA 15 AMSU-A
 NOAA 16 AMSU-A
 NOAA 18 AMSU-A, MHS
 NOAA 19 AMSU-A, MHS
 NOAA NPP ATMS, CrIS, VIIRS
 GCOM-W1 AMSR-2
 Megha-Tropiques MADRAS, SAPHIR
 OceanSat-2
 MSG Severi
 MSG-II HIR
 Jason-1 (SSH, SWH)
 Jason-2 (SSH, SWH)
 Cryosat2 (SSH, SWH)
 Aquarius (Salinity)
 Geo Clear-sky: GOES, MTSAT, GMS

 FY-3A,B,C,D,E,F MWTS,MWHS,MAIRS
 MERSI

 FY-RM 1,2
 Meteor 3M MTVZA

Satellite Derived Polar and Geostationary Winds

Coriolis WindSat Ocean Wind Vector
 DMSP F16 SSMIS Ocean Wind speed
 DMSP F17 SSMIS Ocean Wind speed
 DMSP F18 SSMIS Ocean Wind speed
 METOP-A AVHRR, ASCAT
 METOP-B AVHRR, ASCAT
 NASA EOS Aqua MODIS
 NASA EOS Terra MODIS, MISR
 NOAA NPP VIIRS

 Meteosat 9
 Meteosat 10
 MTSAT
 NOAA GOES E
 NOAA GOES W
 NOAA GOES-R
 KMA COMS

 FY-2E,F,G,H (Geo Winds)
 FY-4A,B,C (Geo Winds)
 FY-4A,B,C IR Spectrometer, MW??

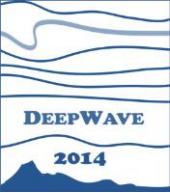
GPS Radio Occultation

C/NOFS CORISS
 COSMIC FM1-6
 GRACE-A
 MetOp-A GRAS
 MetOp-B GRAS
 SAC-C
 TerraSAR-X
 TanDEM-X
 COMS

Other Satellite Products

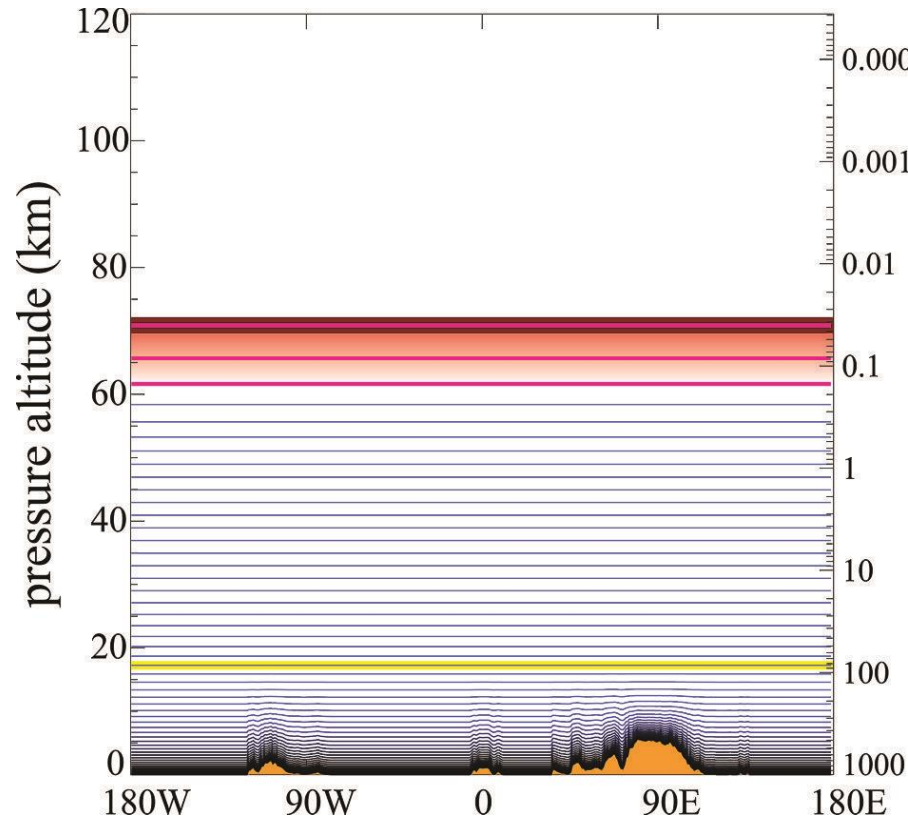
NASA EOS Aura MLS, HRDLS, OMI
 NASA TIMED SABER
 NOAA SBUV
 JPSS NPP OMPS
 SMOS
 SMAP
 FY-3A,B,C,D,E,F TOU

 Coriolis WindSat TPW
 DMSP F16 SSMIS TPW
 DMSP F17 SSMIS TPW
 DMSP F18 SSMIS TPW

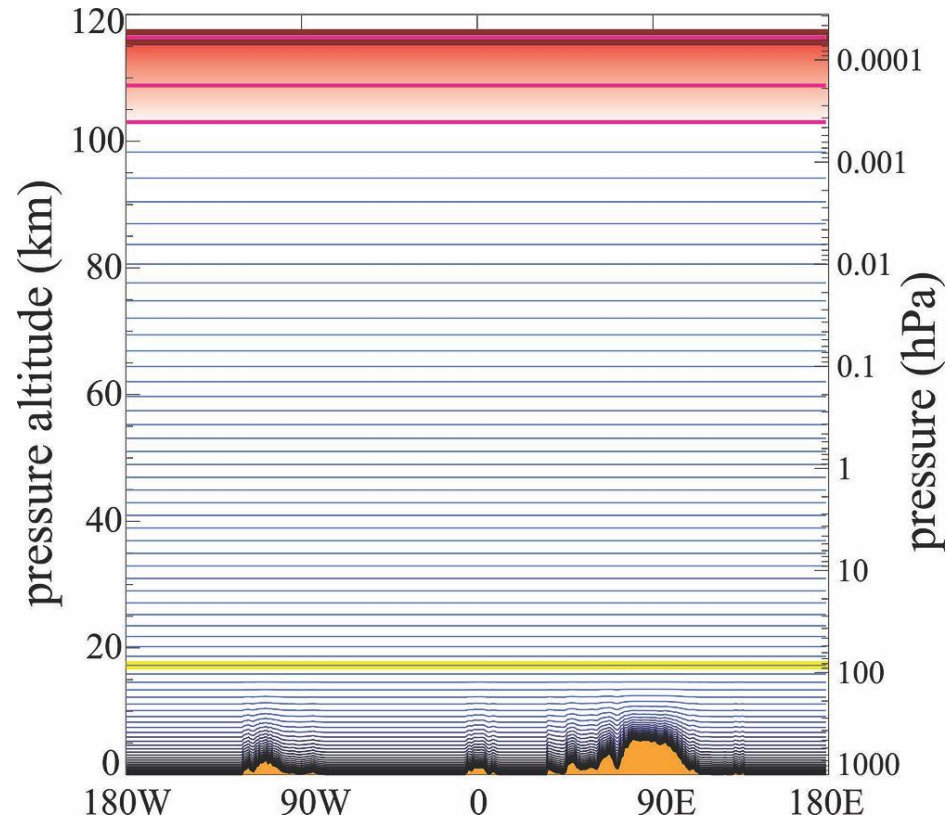


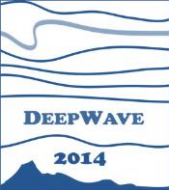
NAVGEM Changes

NAVGEM 1.3 Operational T425L60



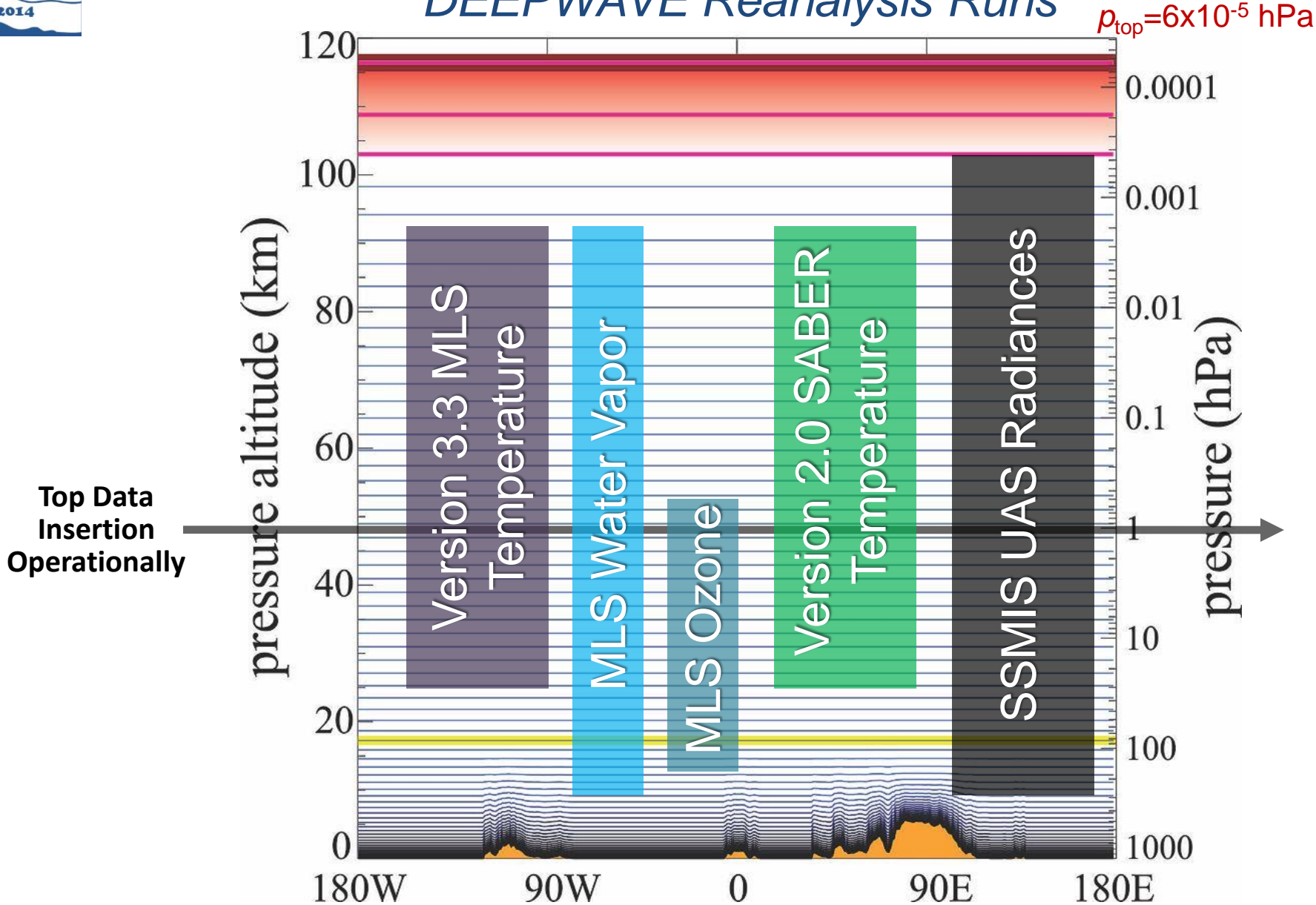
High-Altitude NAVGEM T119L74





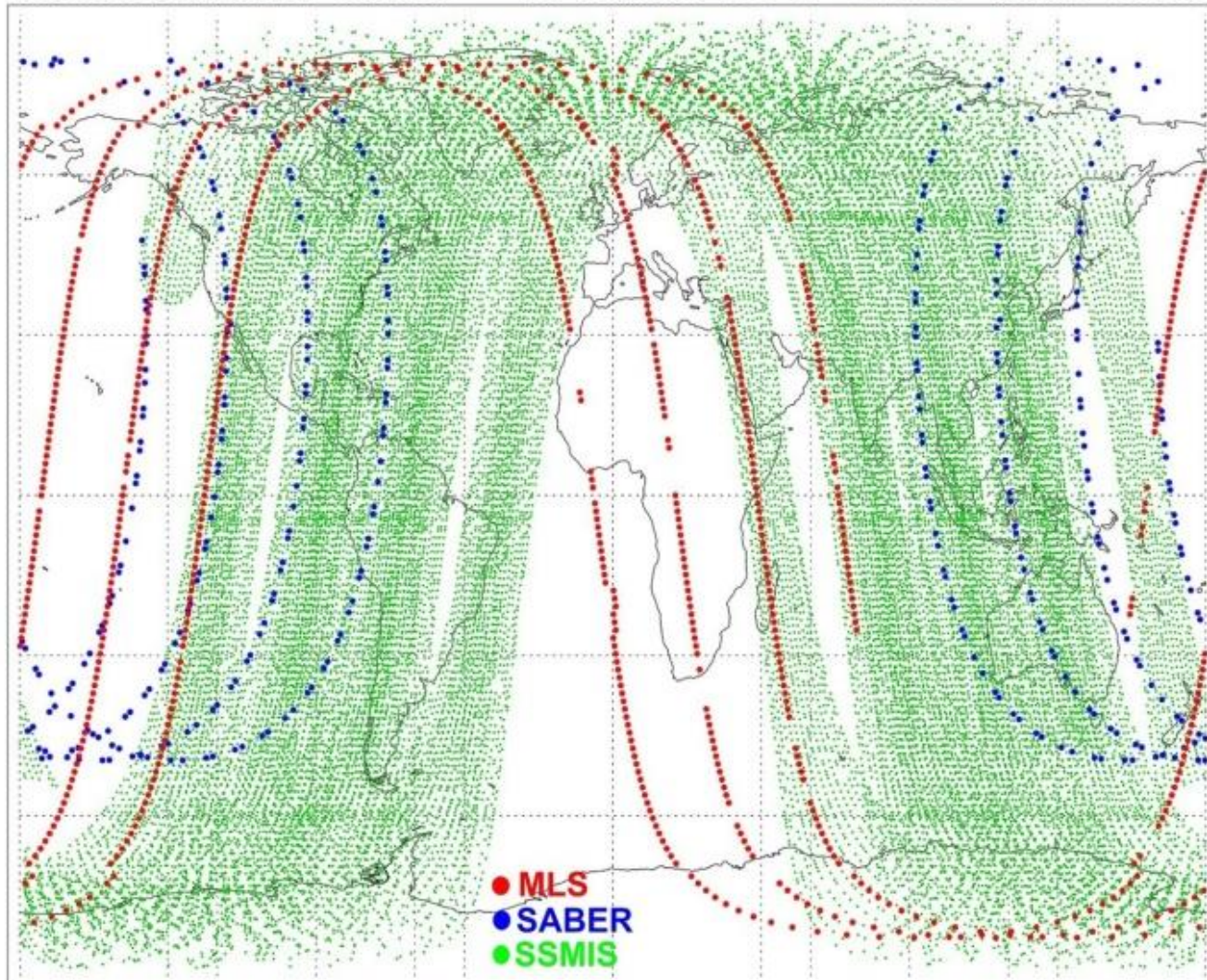
NAVGEN T119L74

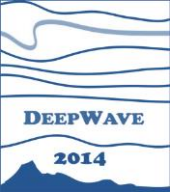
DEEPWAVE Reanalysis Runs



Spatial Coverage in 6 Hours

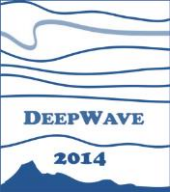
Observation Points: 10 June 2010 0900-1500 UTC





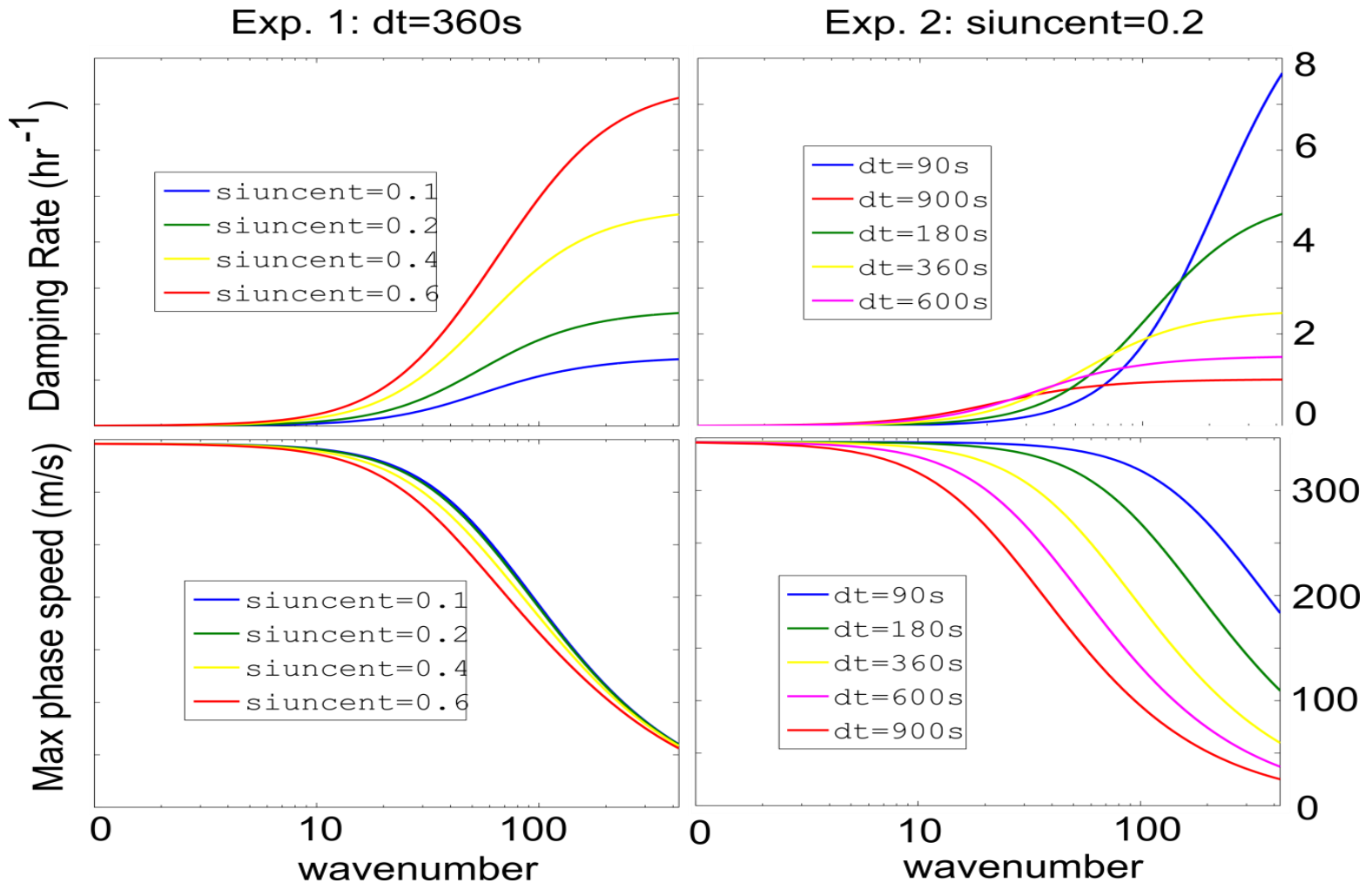
Global Model Physics Modules Needed for Upper Levels

- Dynamical Core fixes to reduce high-wind numerical instability, energy losses, & decentering damping of resolved gravity waves
- High and low horizontal resolution experiments (T119/T425)
- Heating due to UV O₂ and O₃ photolysis (including airglow losses & quantum yields for chemical/heat partitioning)
- Parameterization of Net Exothermic Chemical Heating
- Non-LTE CO₂ longwave cooling to space
- Downward Diffusion of Thermospheric Heat
- Subgrid-scale Gravity-Wave Drag (Momentum Deposition)
 - Orographic Sources of Gravity Wave Drag (OGWD)
 - Nonorographic Sources of Gravity Wave Drag (NGWD)
 - Frictional Heating (KE Dissipation)
 - Momentum/Heat Mixing due to GW-Induced Turbulence
 - NGWD not carefully tuned as yet
- All experiments have AMSU-A, ATMS, GPS, SSMIS (non-UAS), SABER, MLS, Aqua (AIRS) and Metop IASI activated with variational bias correction (varBC)

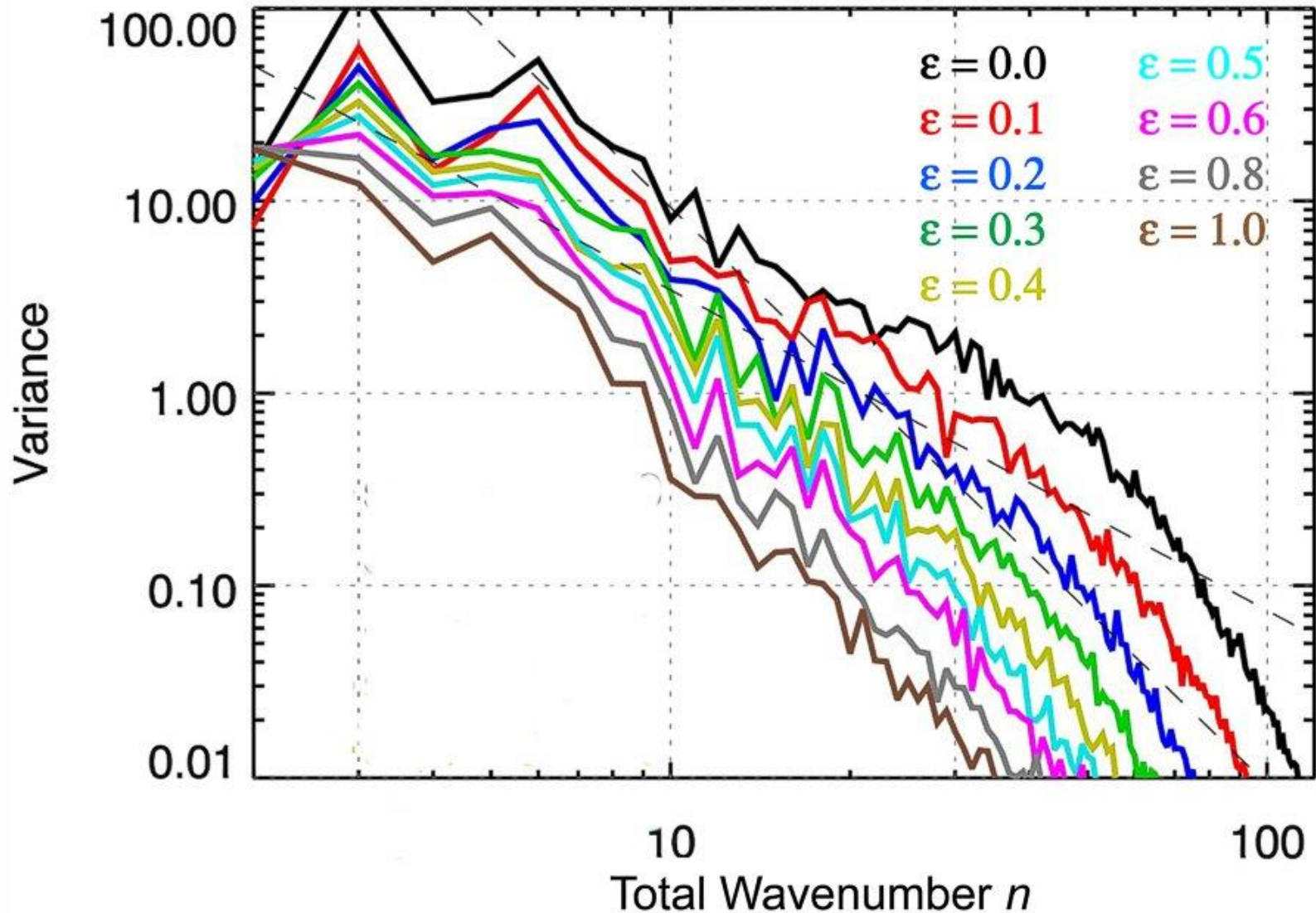


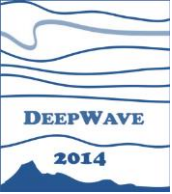
Damping Rates of Fastest Waves for NAVGEM T425L60

credit: Kevin Viner



Divergence Spectra from 288 Hour NAVGEM Forecasts at 0.01 hPa (80 km)

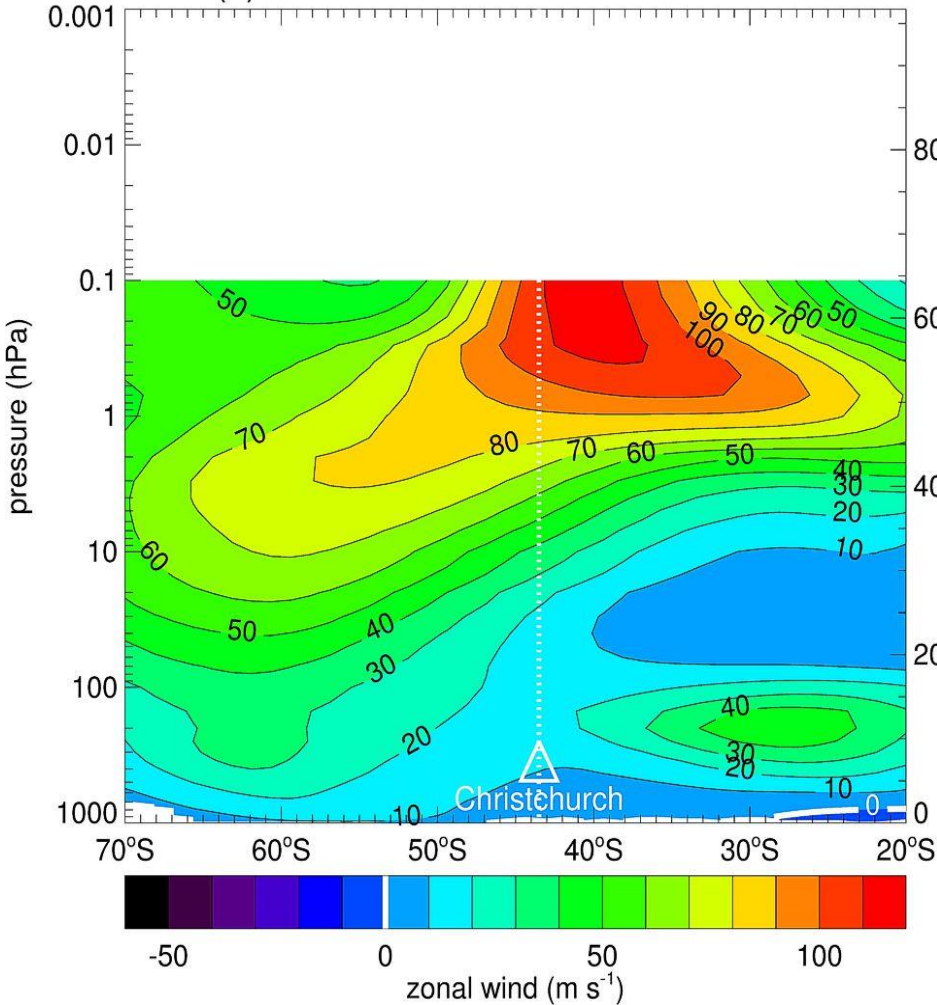




“Zonal Mean” (140-190E) for June

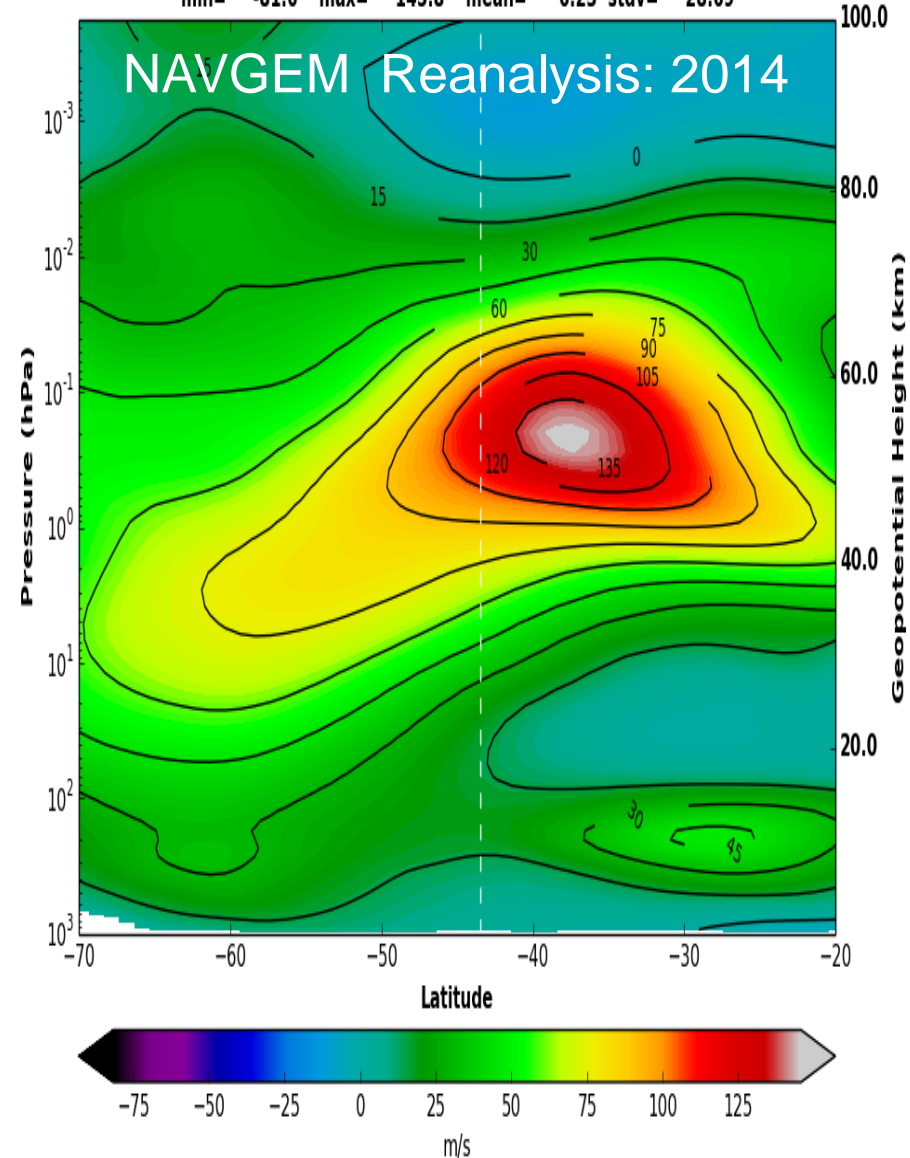
NASA MERRA Reanalysis: 2014

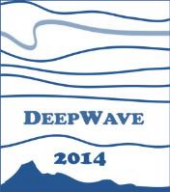
(a) Zonal Winds: June 2014 140-190°E



Zonal Winds: June 2014 140-190° E

min= -81.6 max= 145.8 mean= 6.23 stdv= 28.69

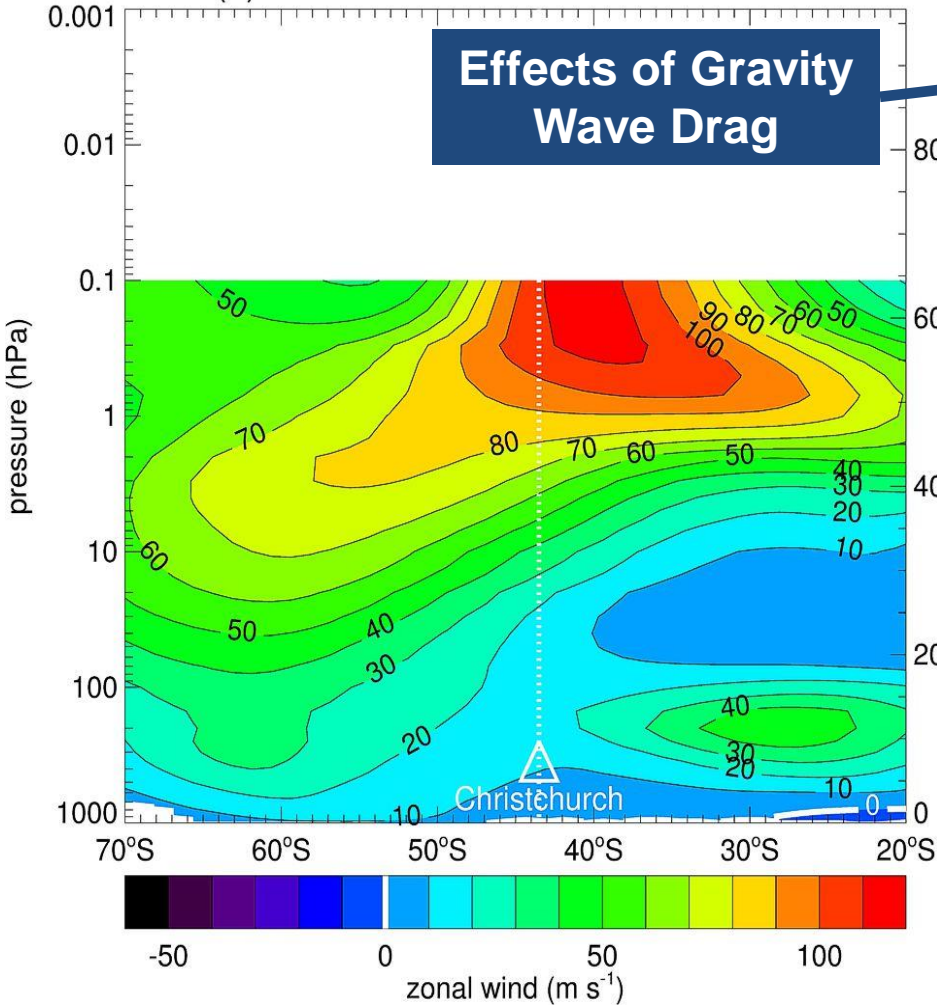




“Zonal Mean” (140-190E) for June

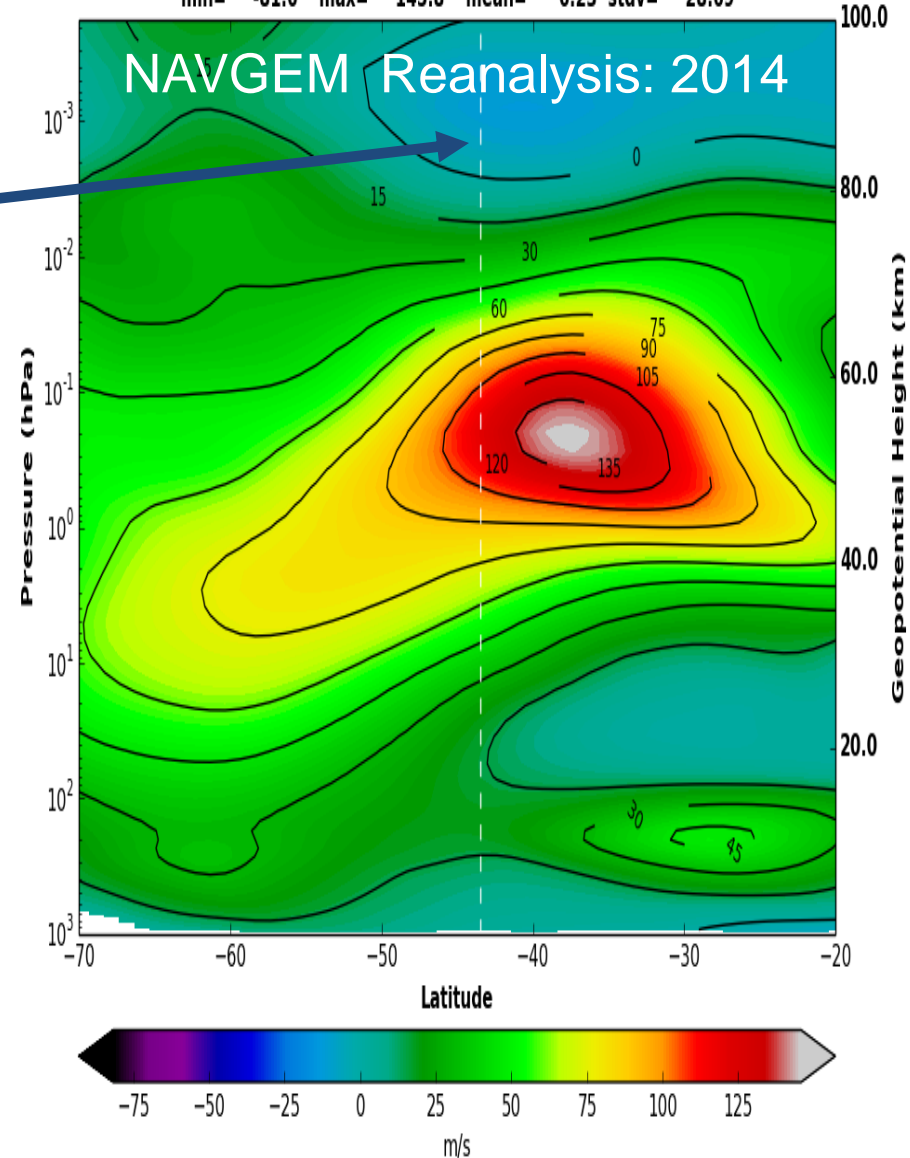
NASA MERRA Reanalysis: 2014

(a) Zonal Winds: June 2014 140-190°E



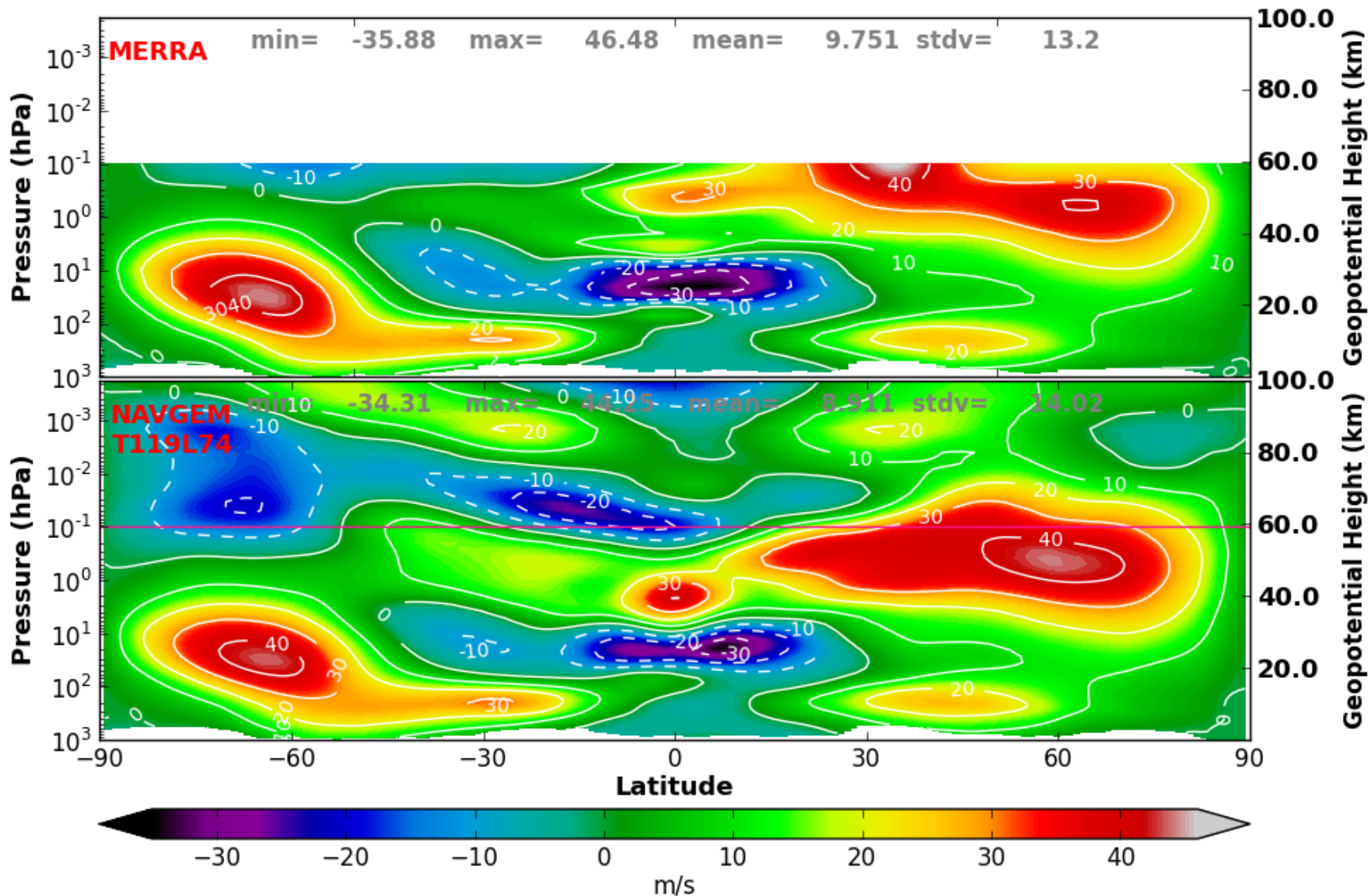
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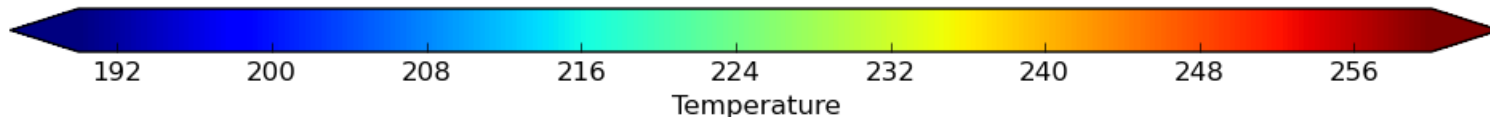
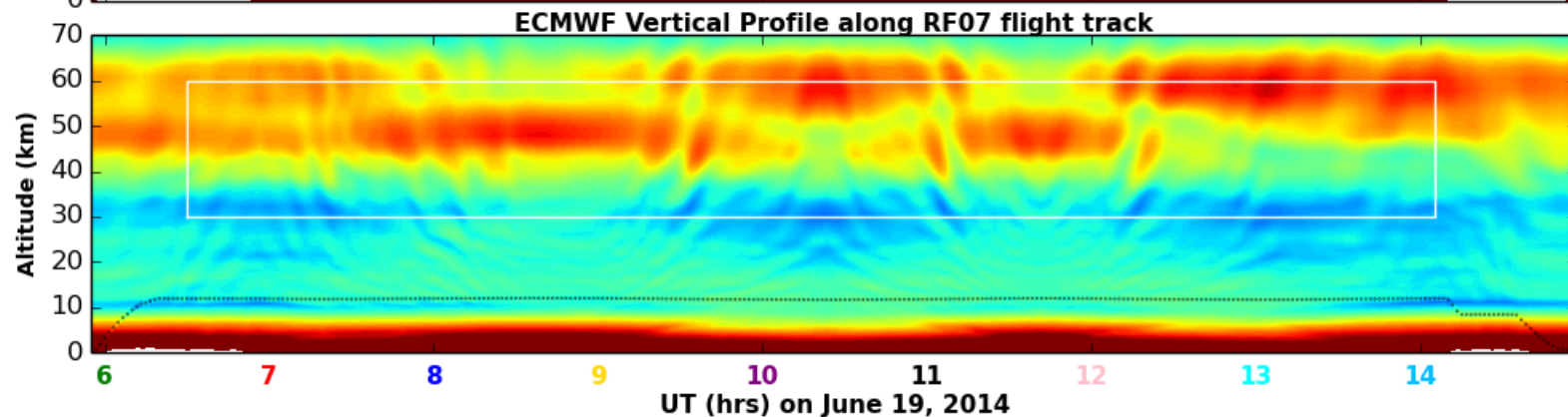
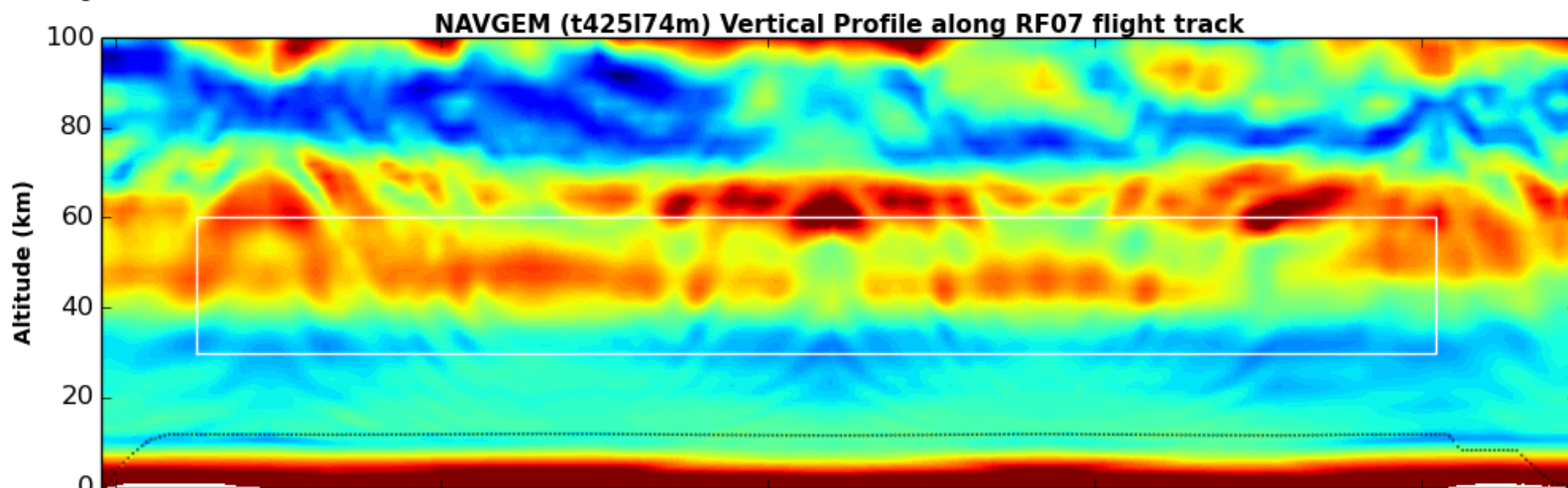
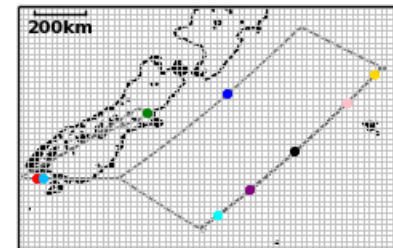
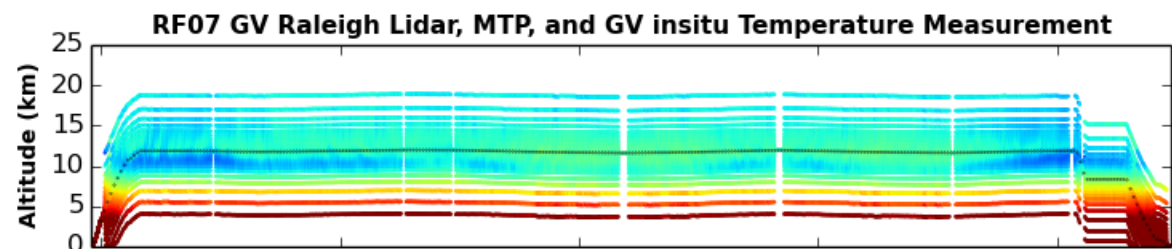


Zonal Winds: NAVGEM v. MERRA

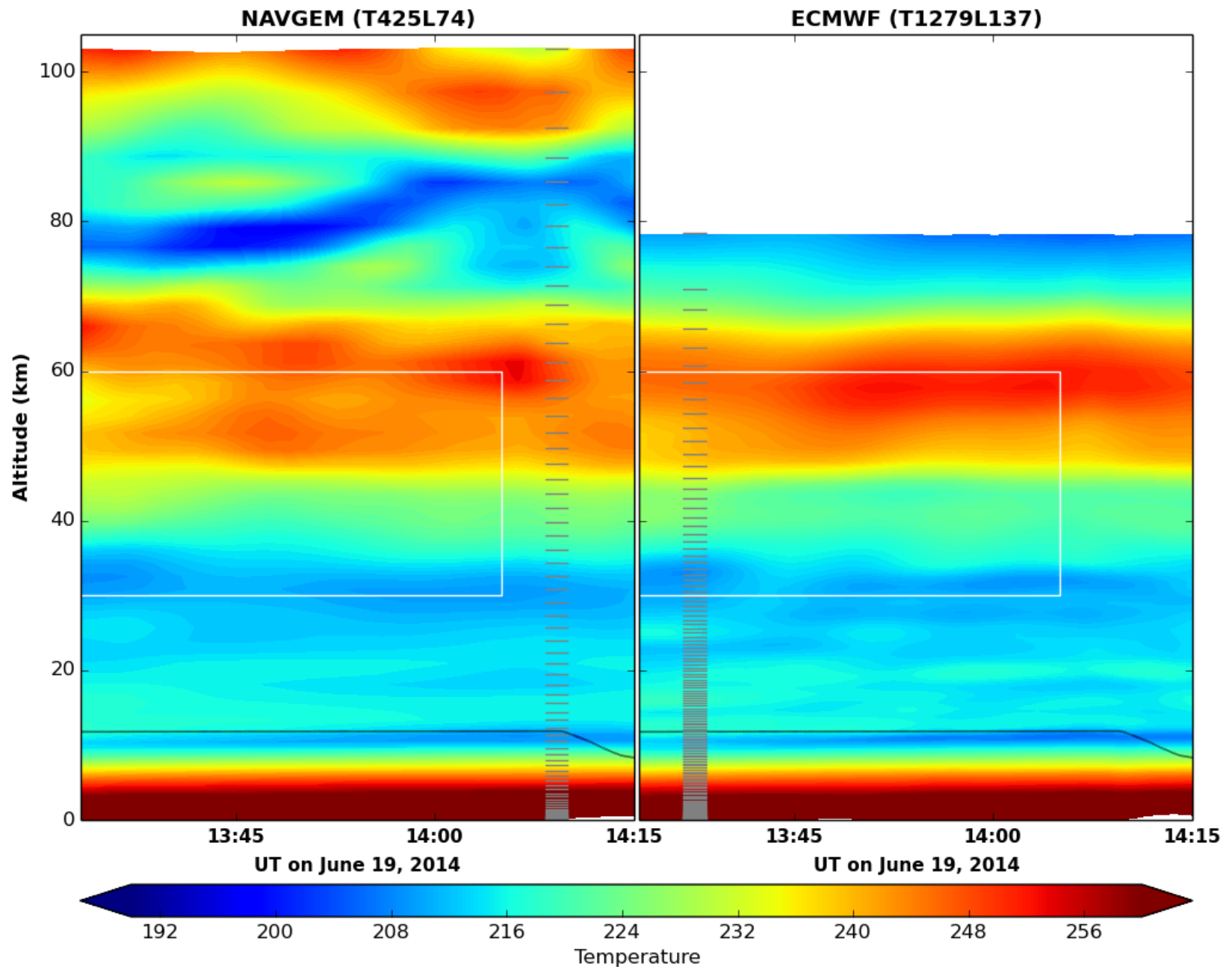
MERRA-NAVGEM Monthly Mean Zonal Wind October 2014



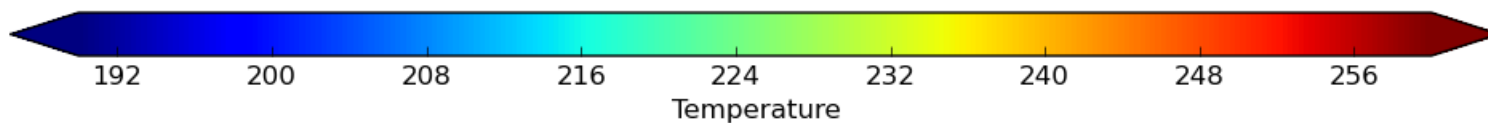
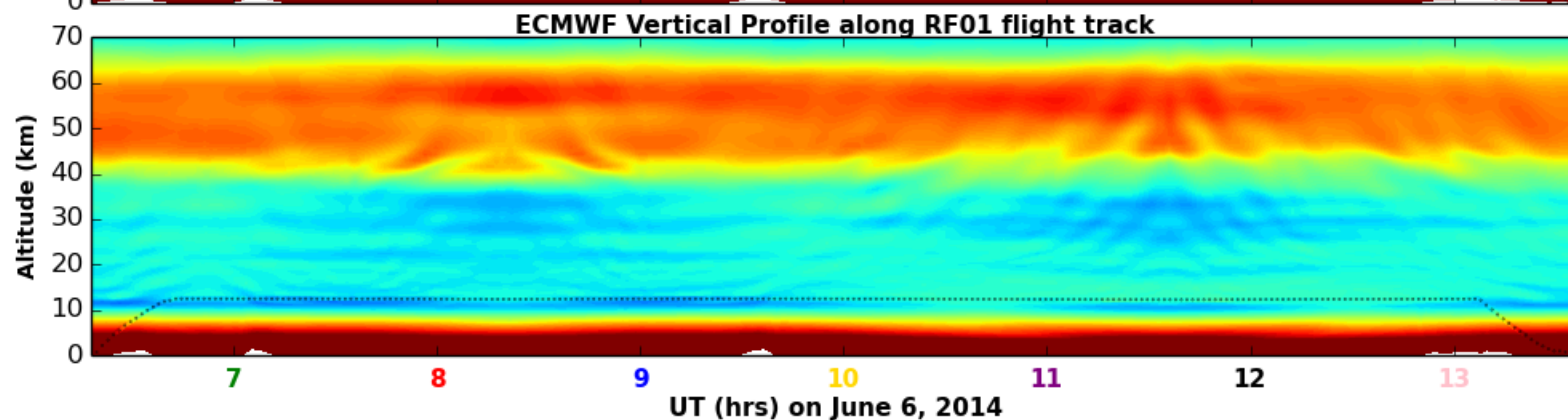
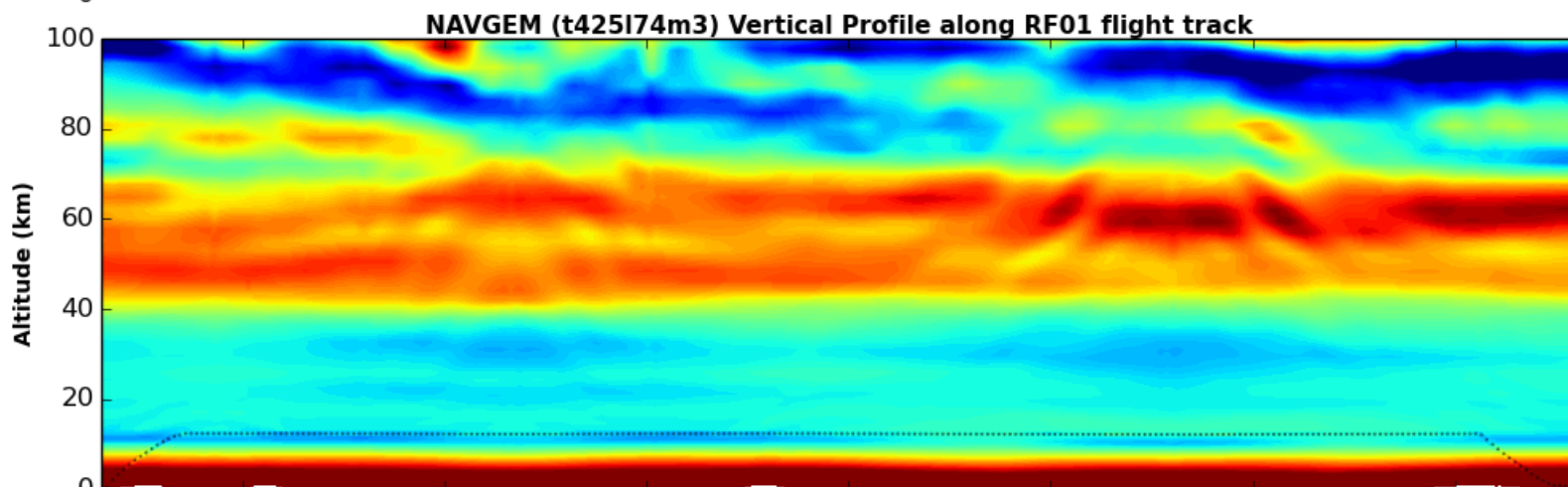
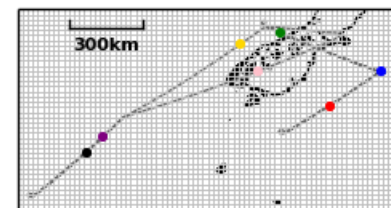
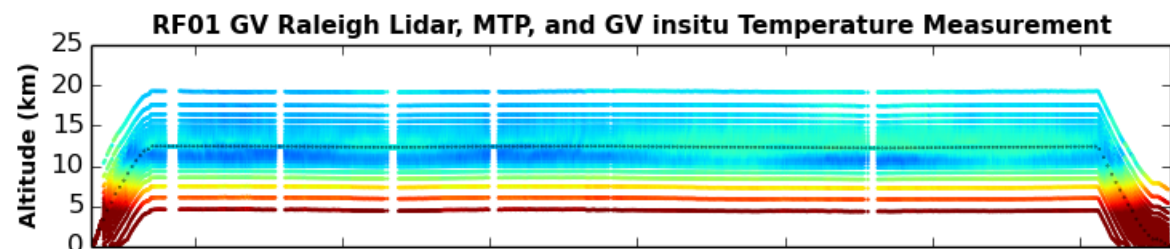
DEEPWAVE Model Measurement Comparison



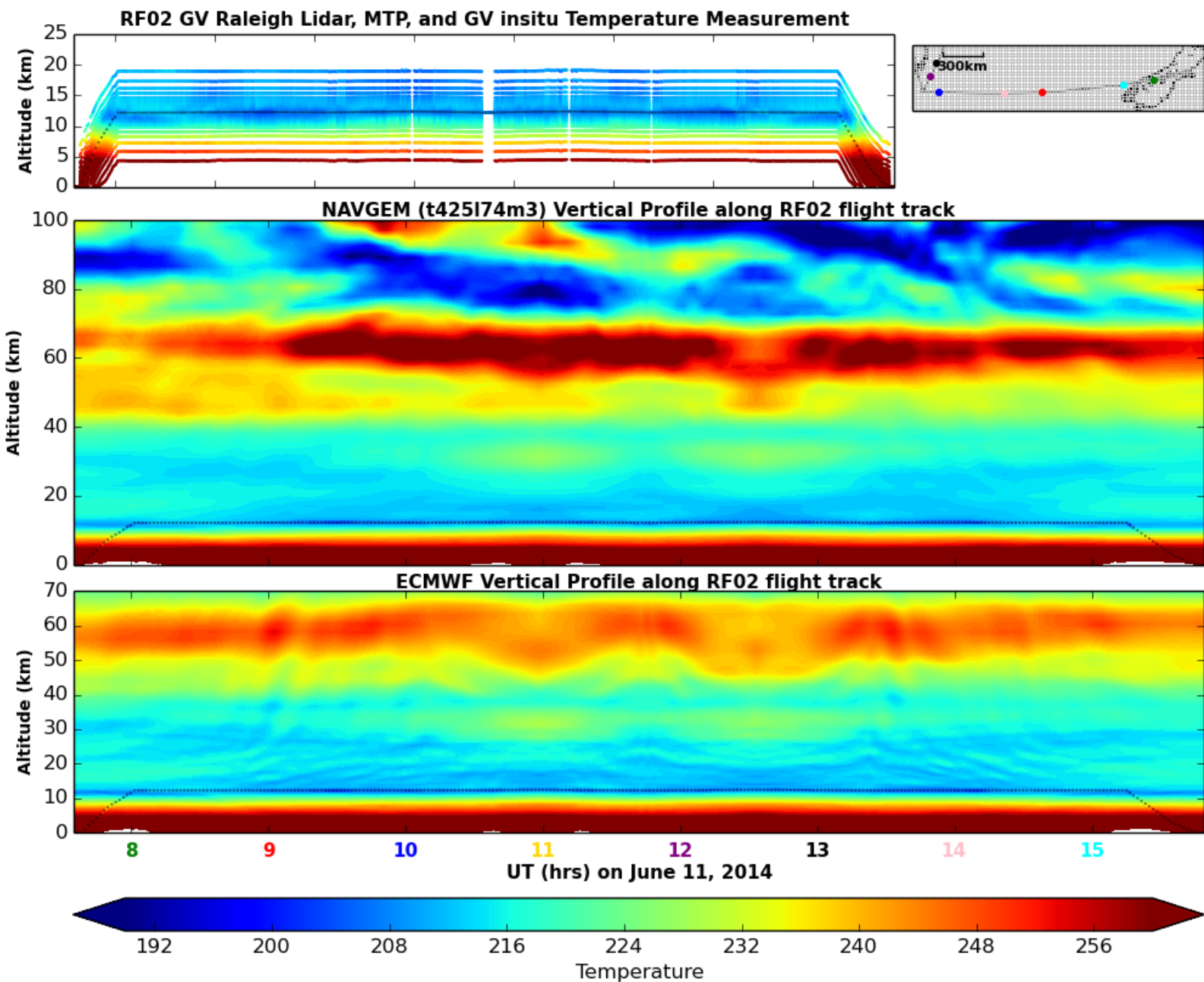
DEEPWAVE RF07 NAVGEM vs. ECMWF Comparison



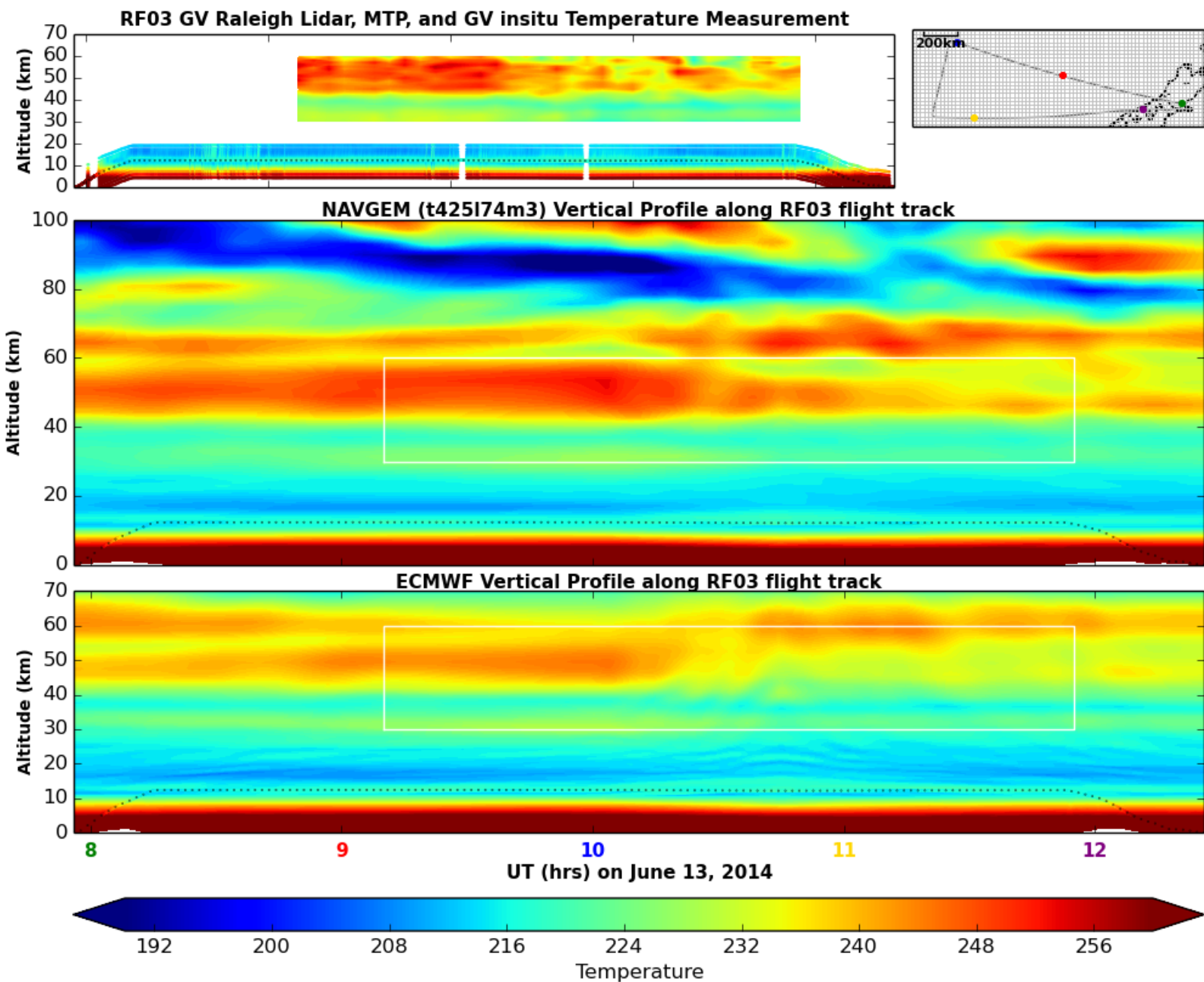
DEEPWAVE Model Measurement Comparison



DEEPWAVE Model Measurement Comparison

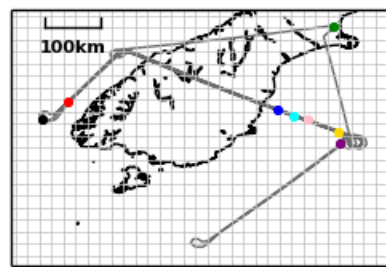
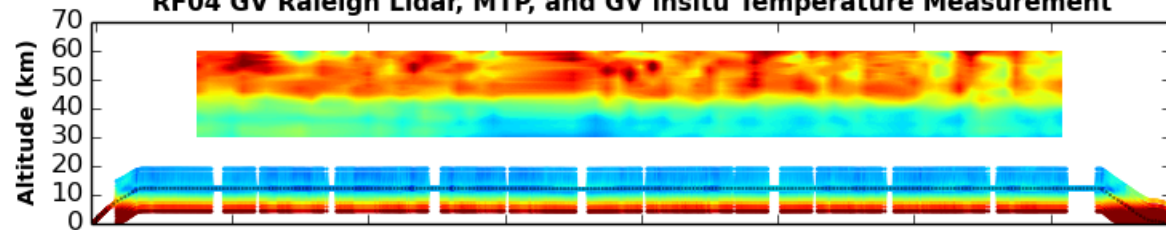


DEEPWAVE Model Measurement Comparison

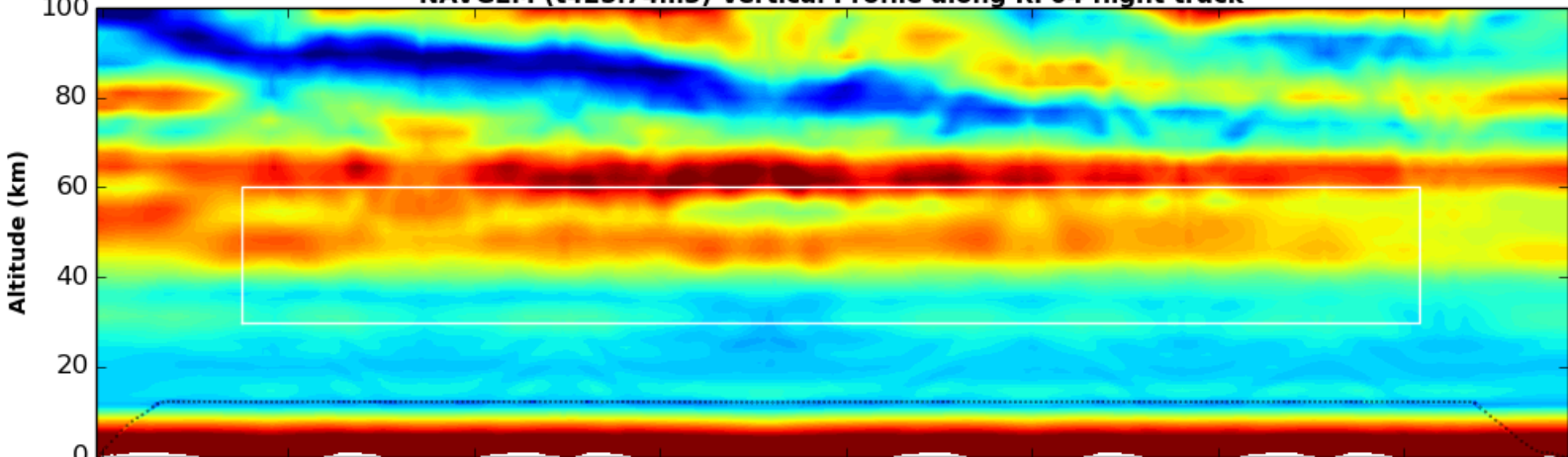


DEEPWAVE Model Measurement Comparison

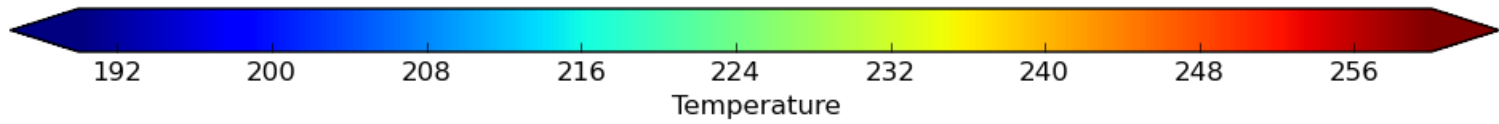
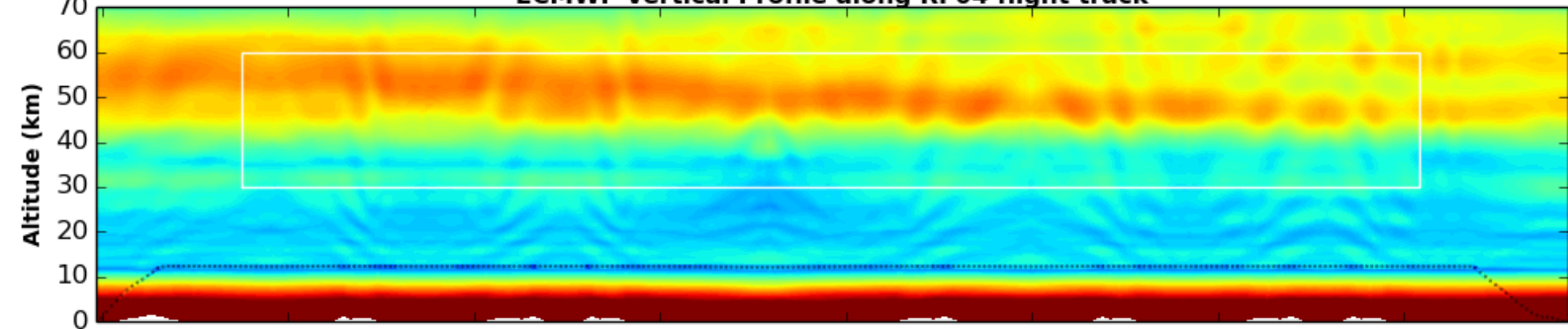
RF04 GV Raleigh Lidar, MTP, and GV insitu Temperature Measurement



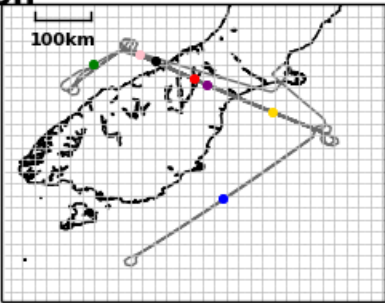
NAVGEN (t425i74m3) Vertical Profile along RF04 flight track



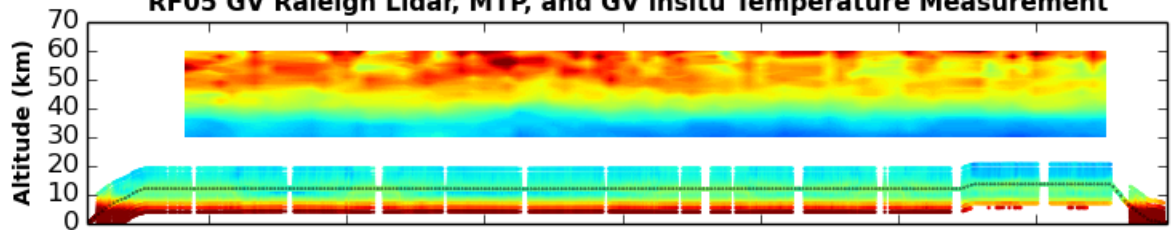
ECMWF Vertical Profile along RF04 flight track



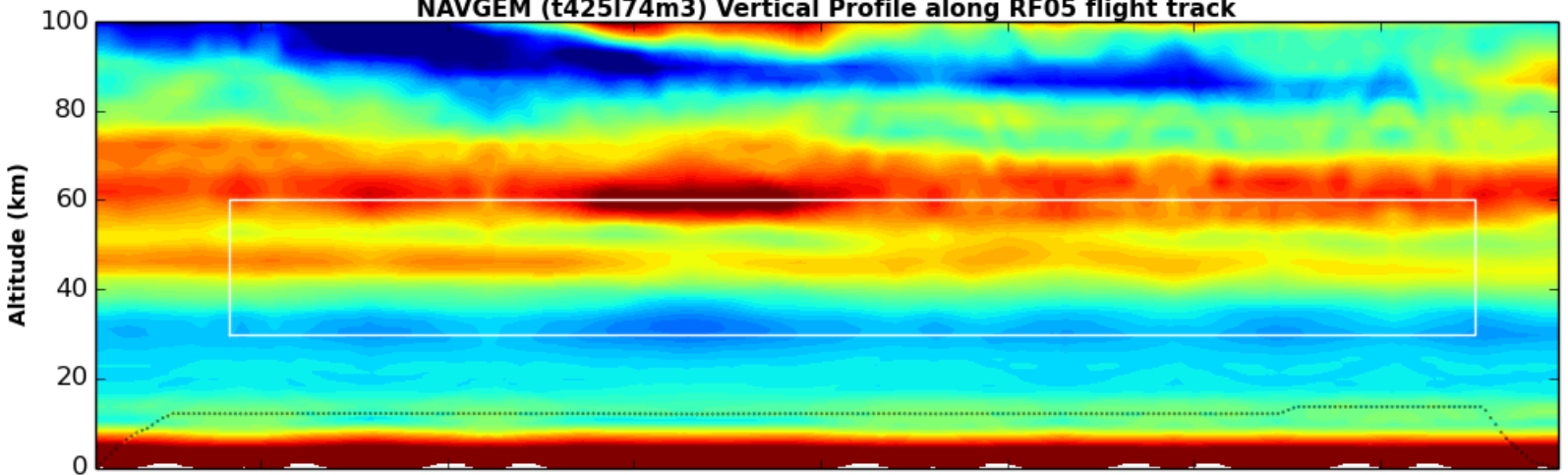
DEEPWAVE Model Measurement Comparison



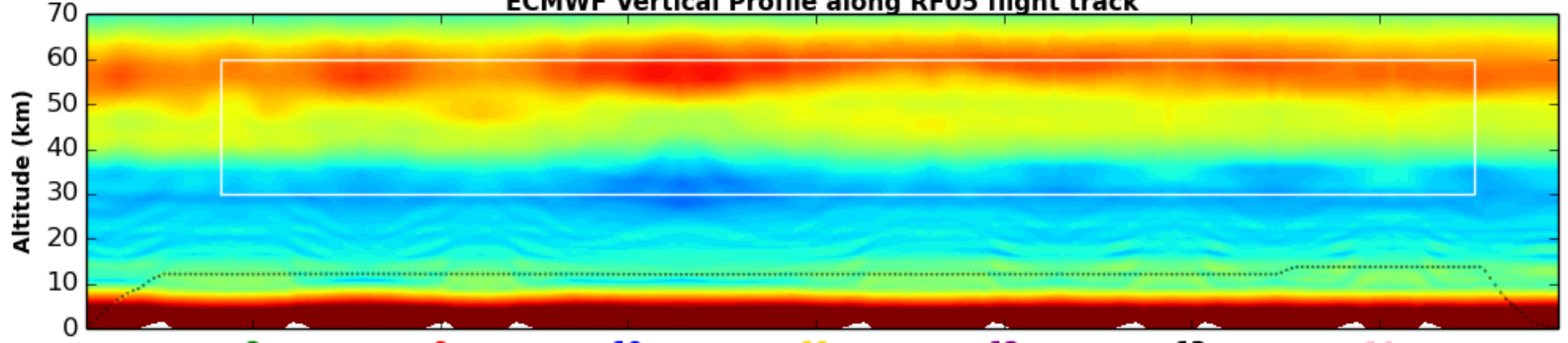
RF05 GV Raleigh Lidar, MTP, and GV insitu Temperature Measurement



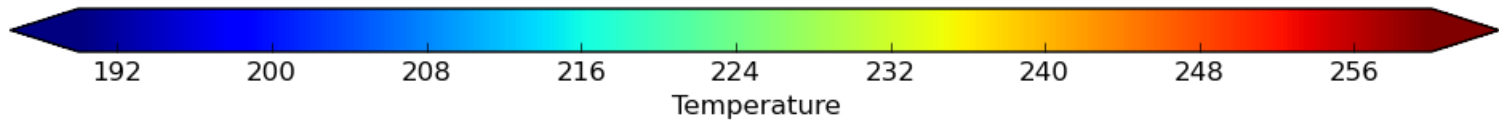
NAVEM (t425i74m3) Vertical Profile along RF05 flight track



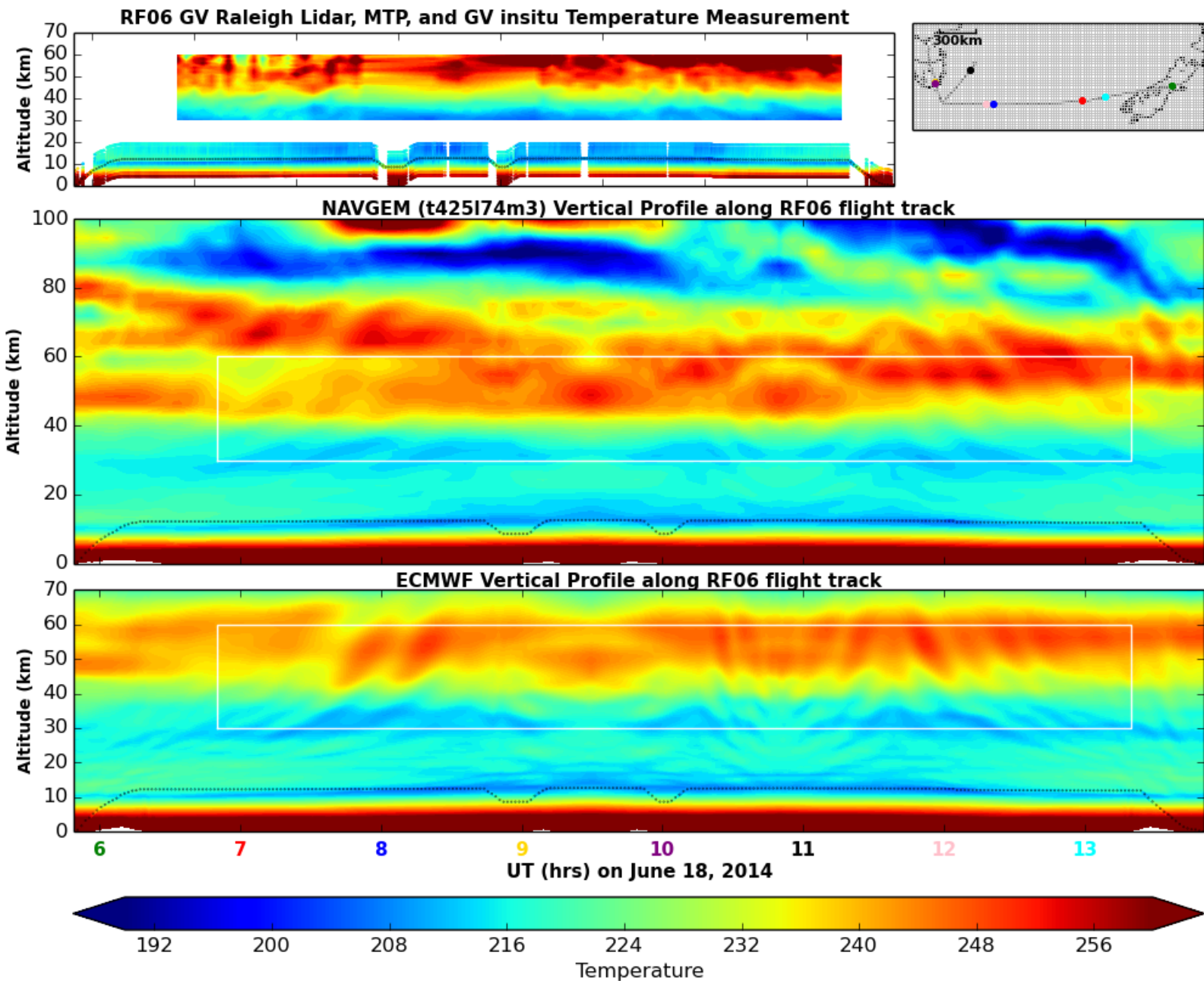
ECMWF Vertical Profile along RF05 flight track



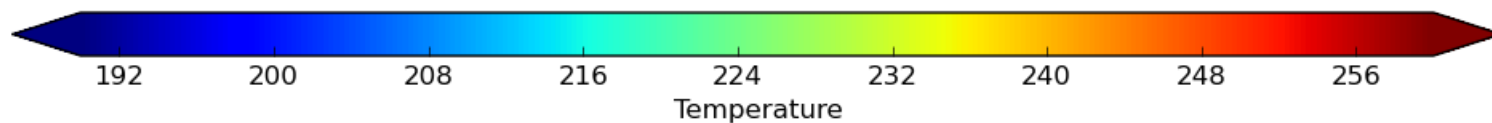
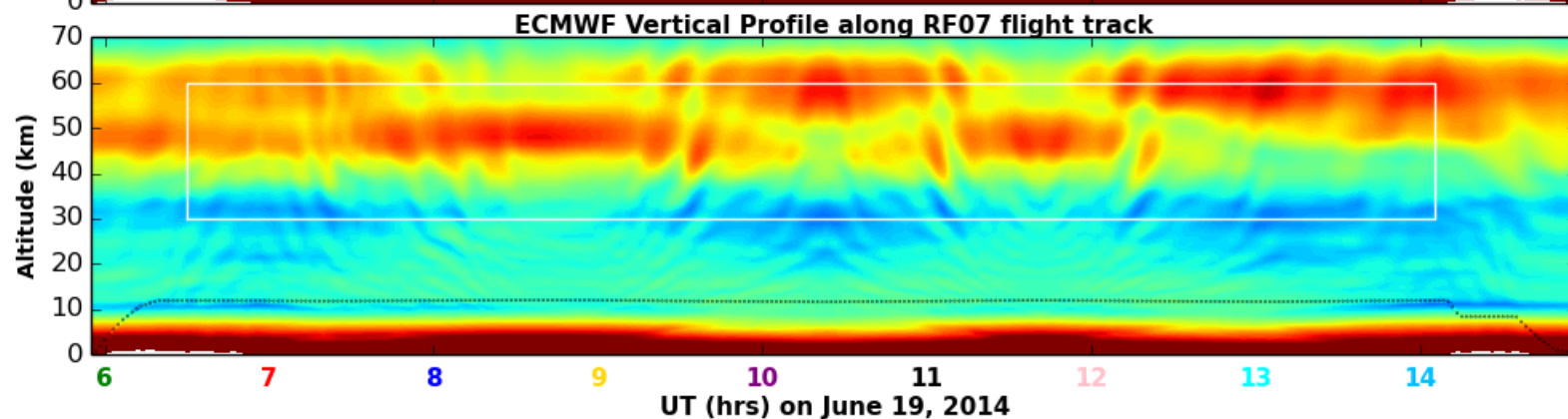
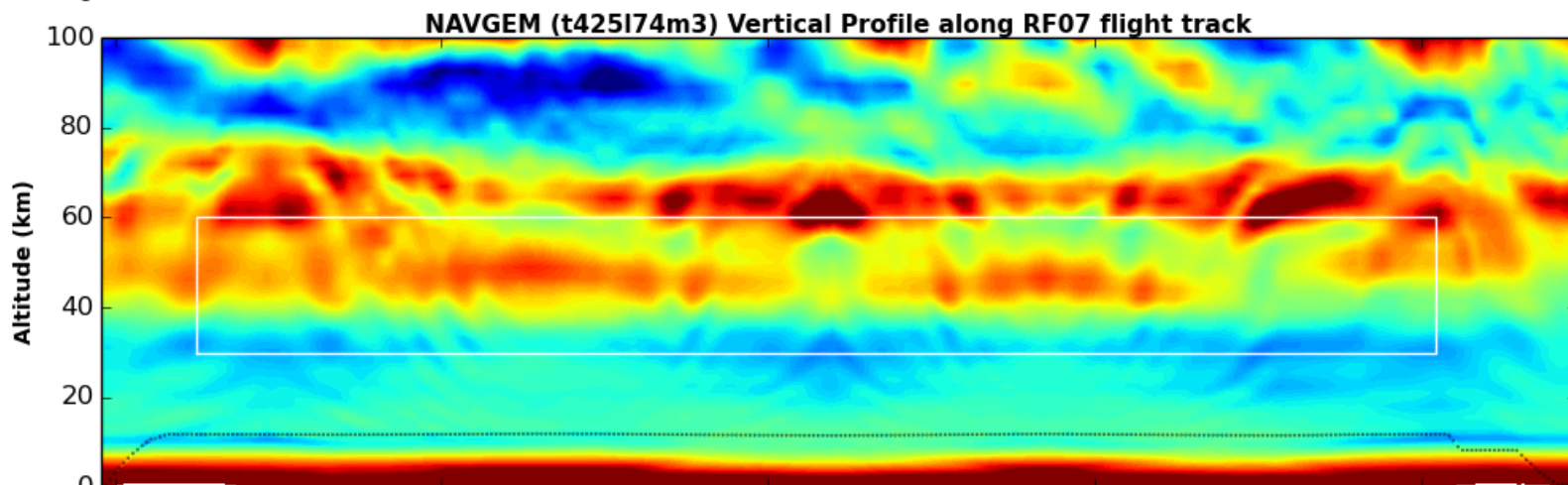
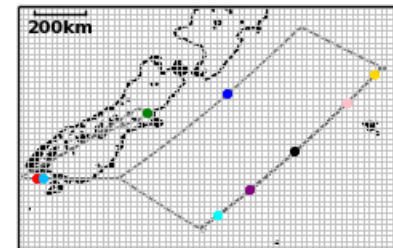
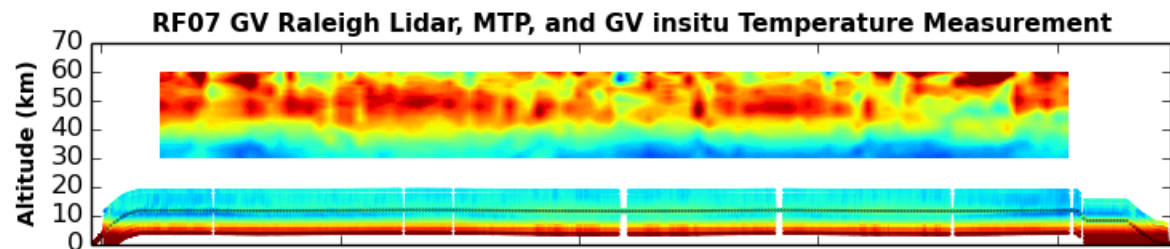
8 9 10 11 12 13 14
UT (hrs) on June 16, 2014



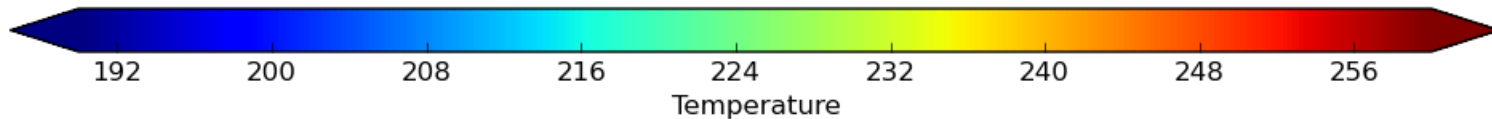
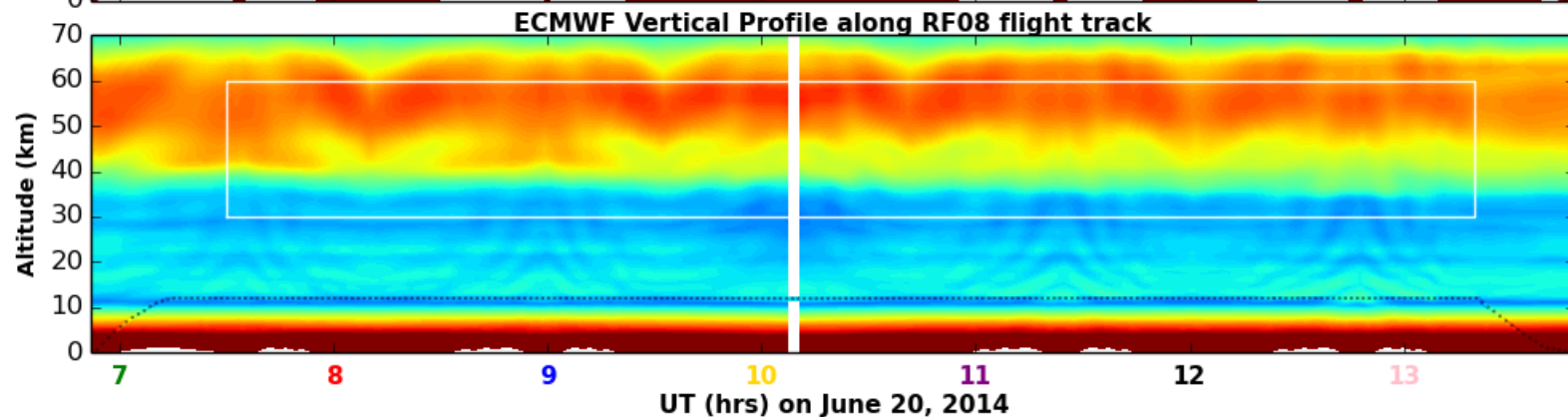
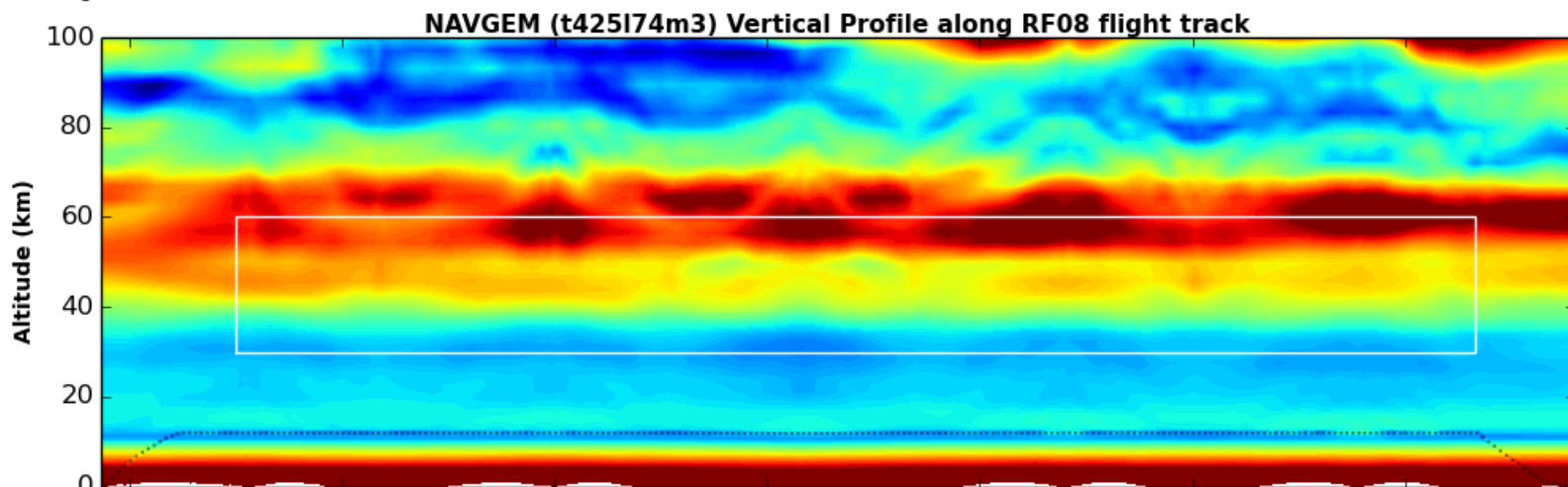
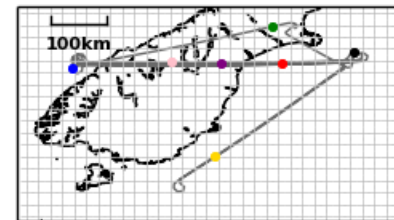
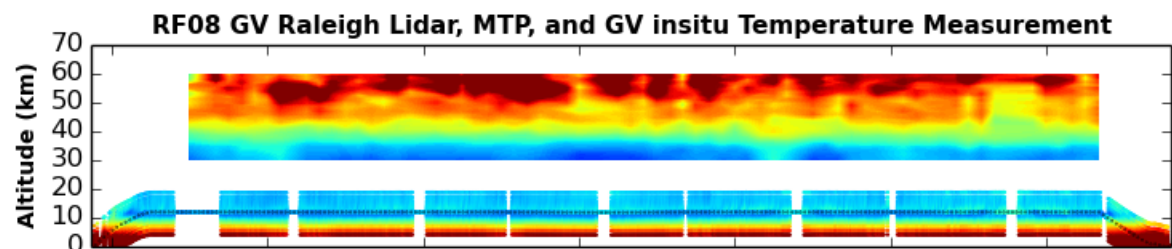
DEEPWAVE Model Measurement Comparison



DEEPWAVE Model Measurement Comparison

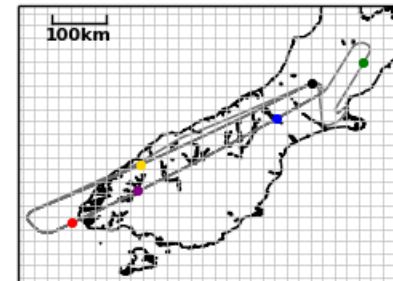
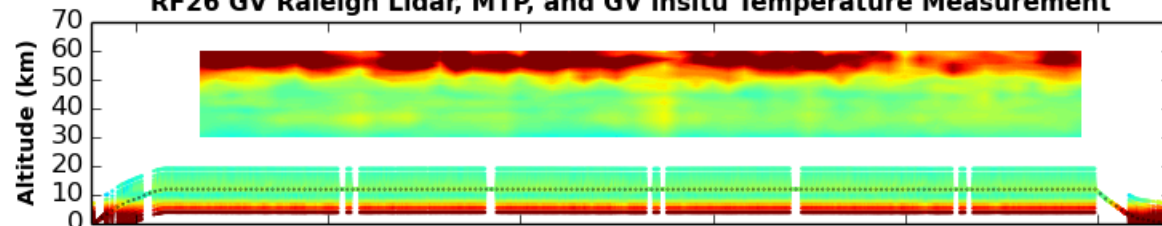


DEEPWAVE Model Measurement Comparison

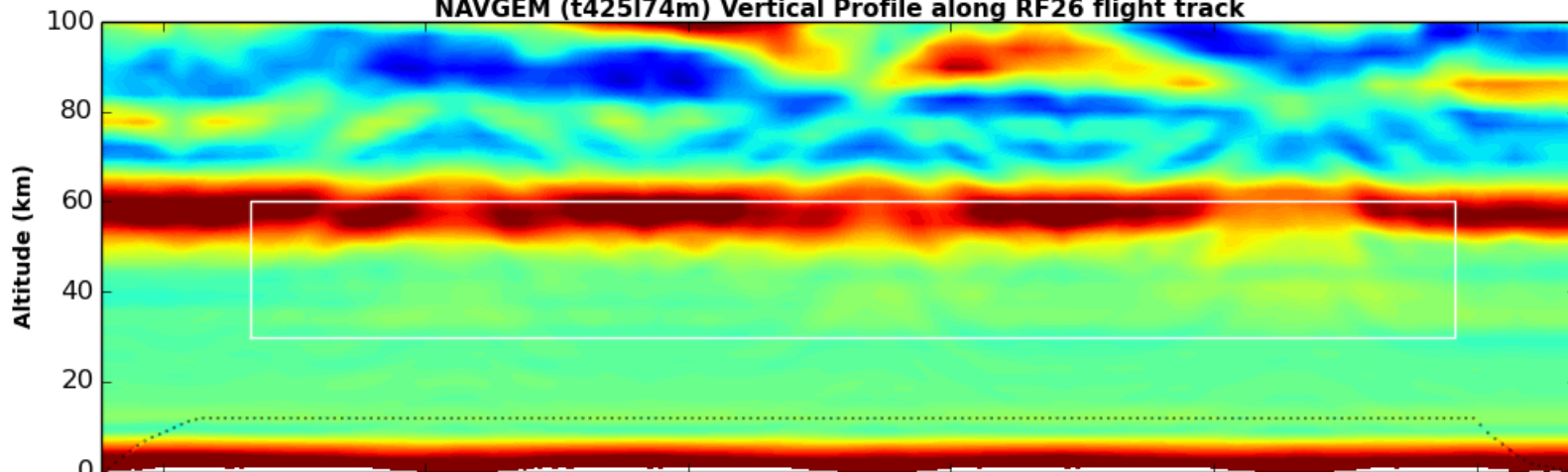


DEEPWAVE Model Measurement Comparison

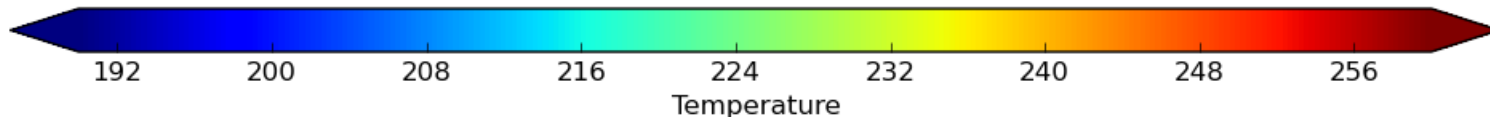
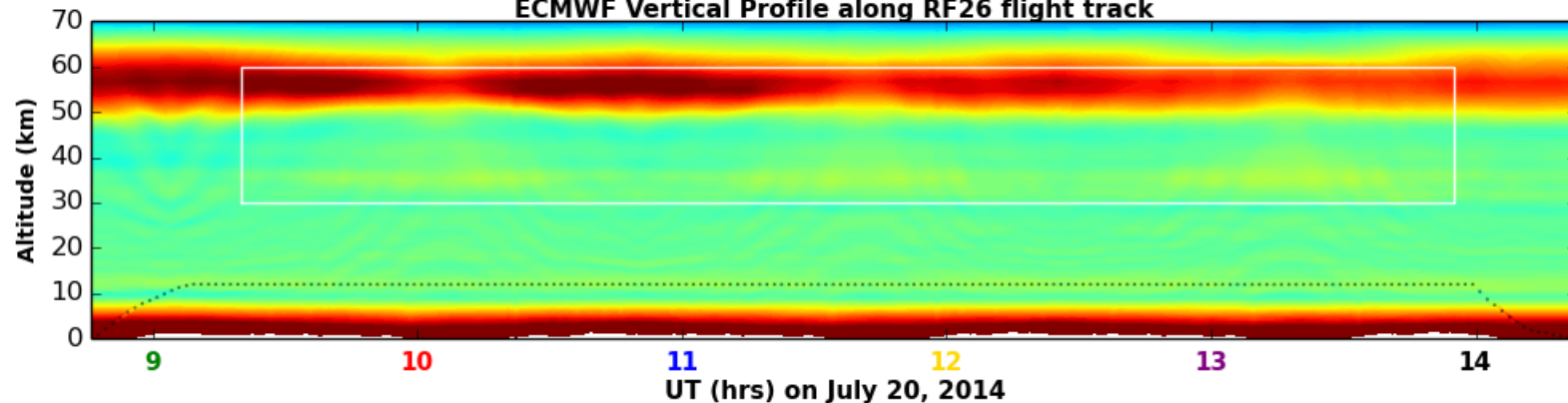
RF26 GV Raleigh Lidar, MTP, and GV insitu Temperature Measurement



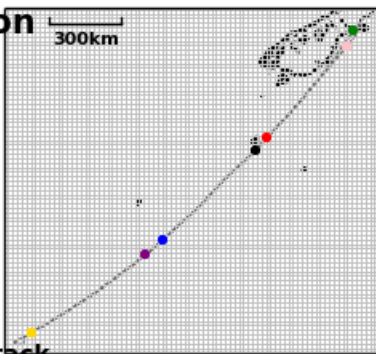
NAVEM (t425174m) Vertical Profile along RF26 flight track



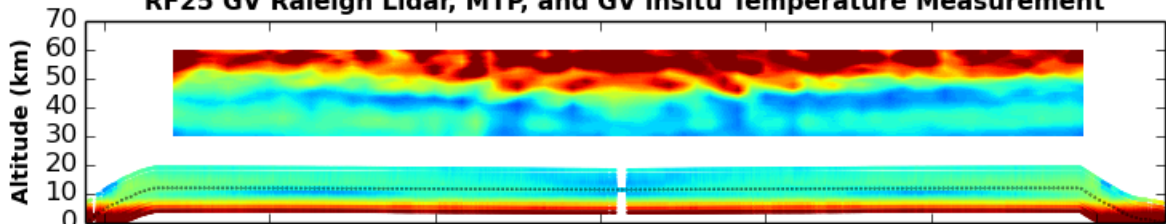
ECMWF Vertical Profile along RF26 flight track



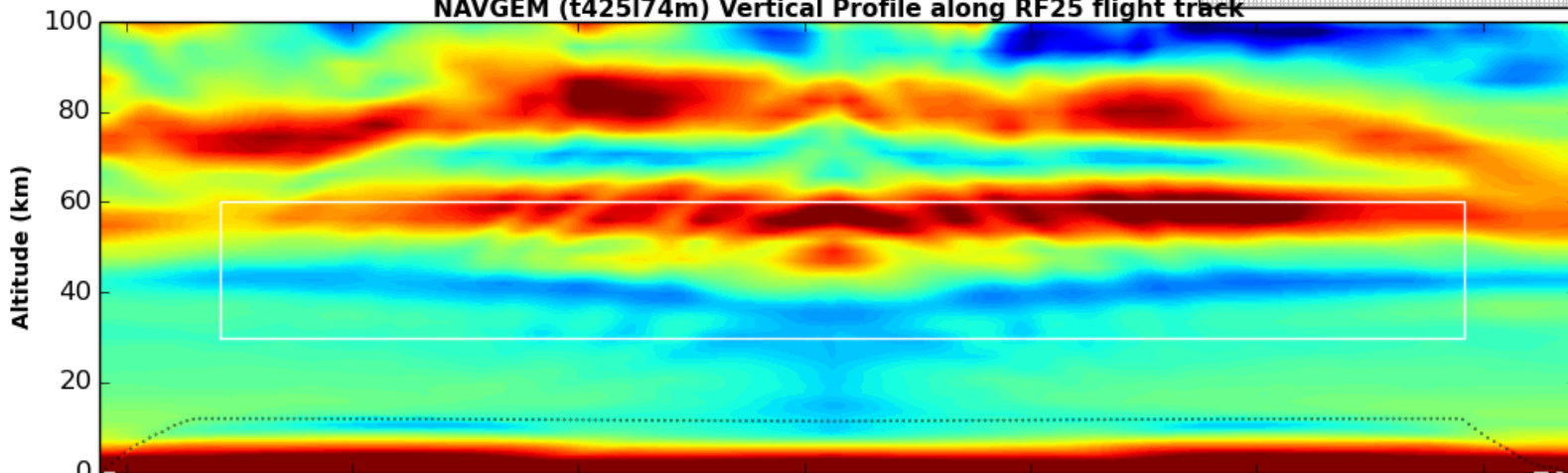
DEEPWAVE Model Measurement Comparison



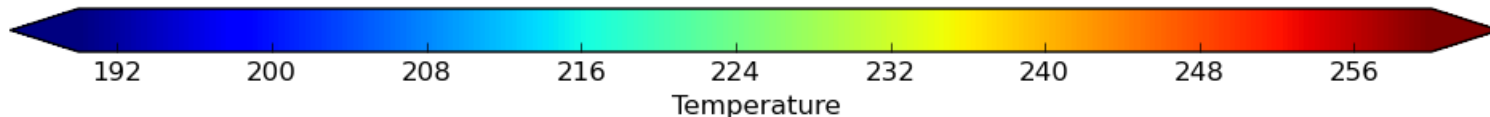
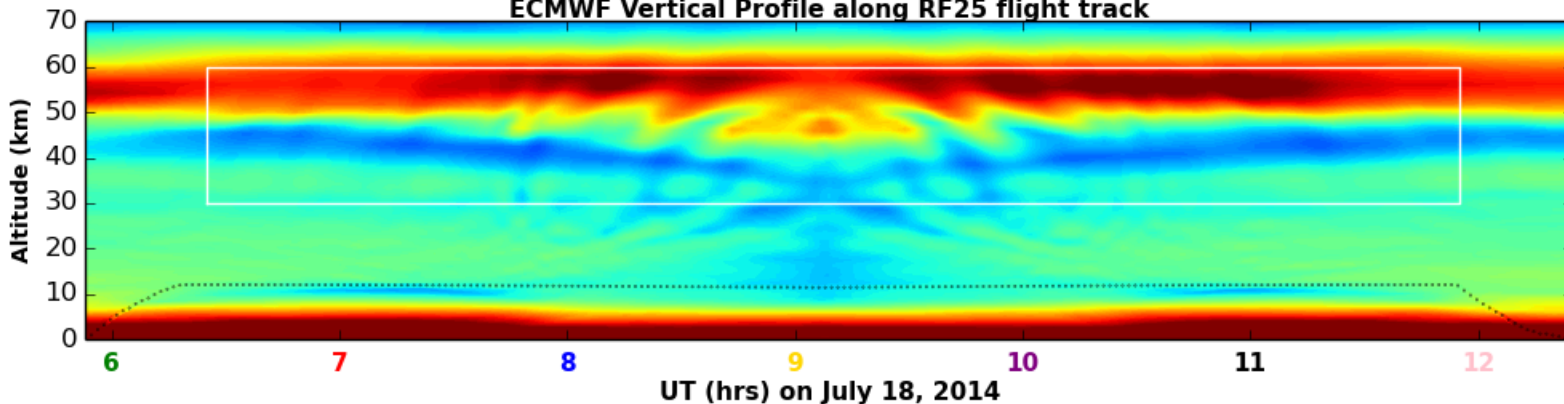
RF25 GV Raleigh Lidar, MTP, and GV insitu Temperature Measurement



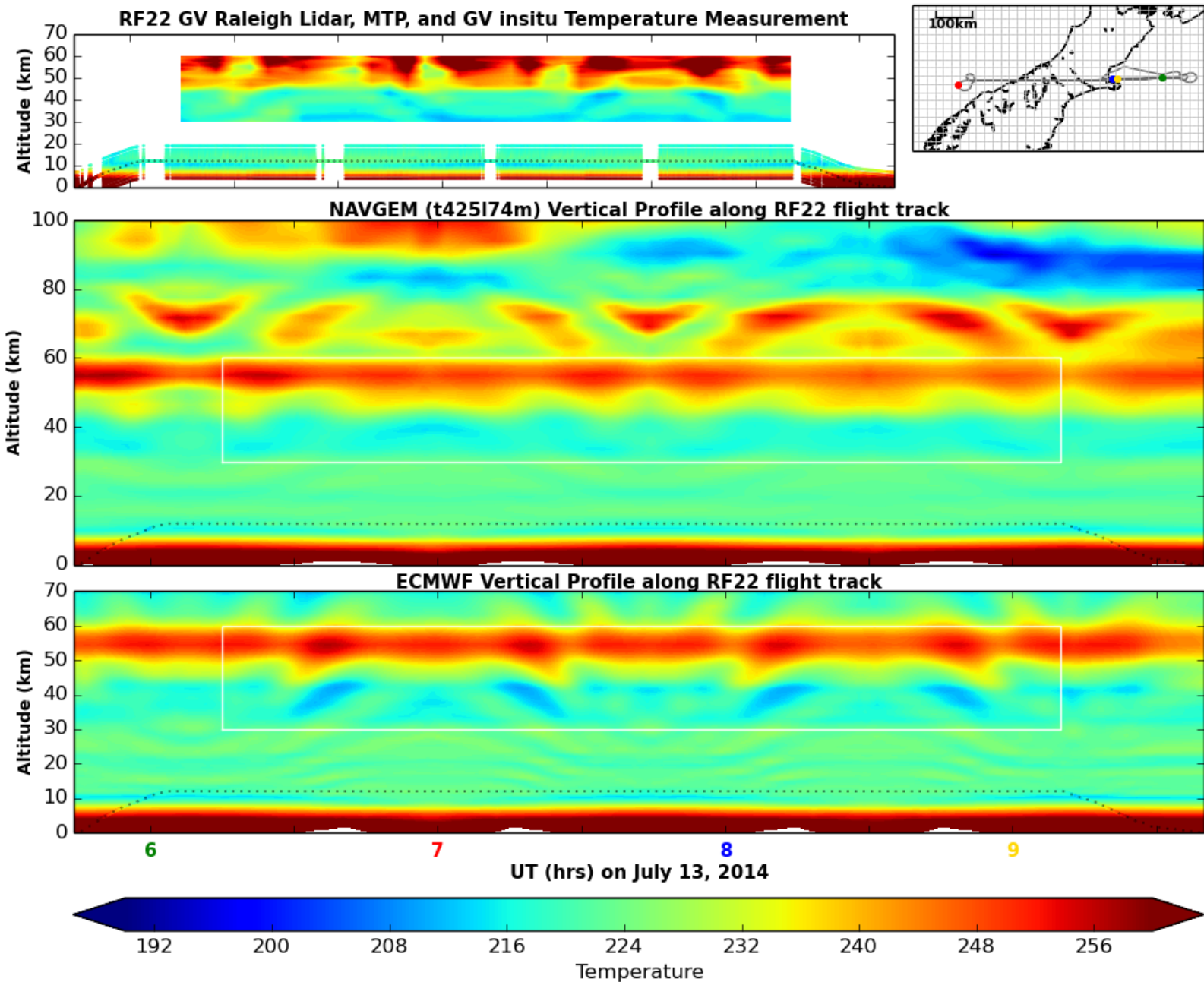
NAVEM (t425174m) Vertical Profile along RF25 flight track



ECMWF Vertical Profile along RF25 flight track

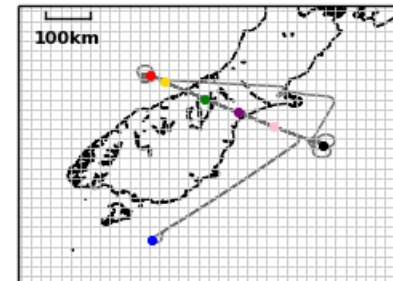
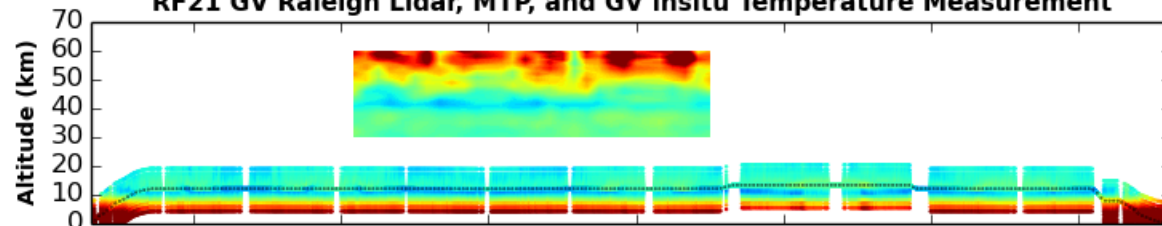


DEEPWAVE Model Measurement Comparison

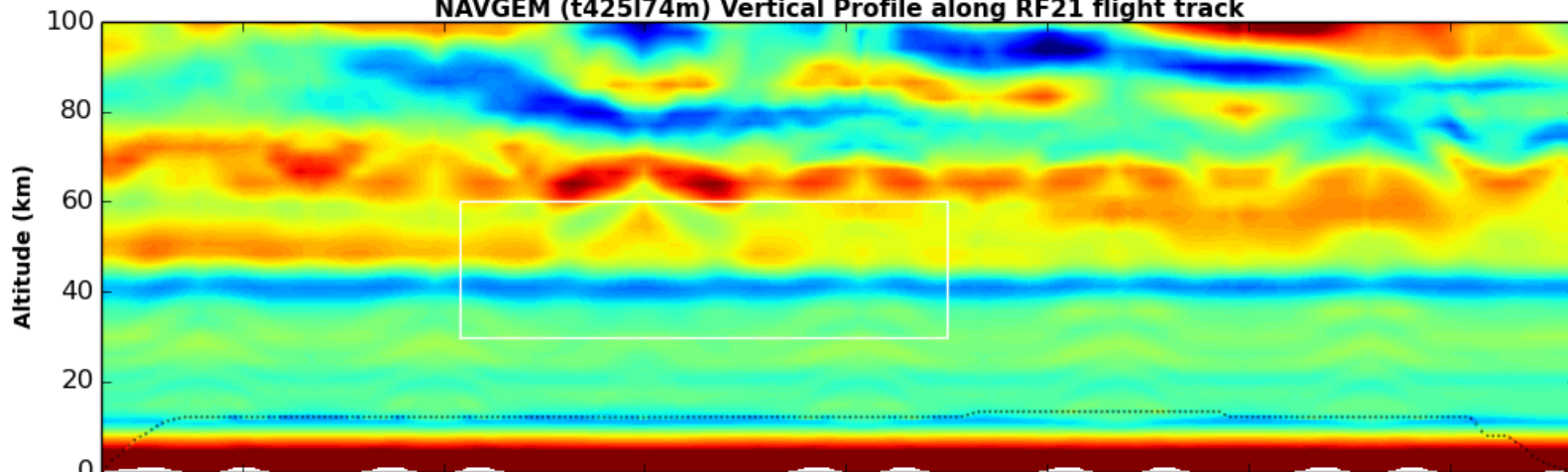


DEEPWAVE Model Measurement Comparison

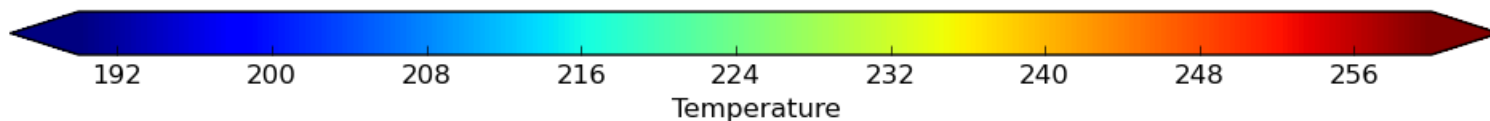
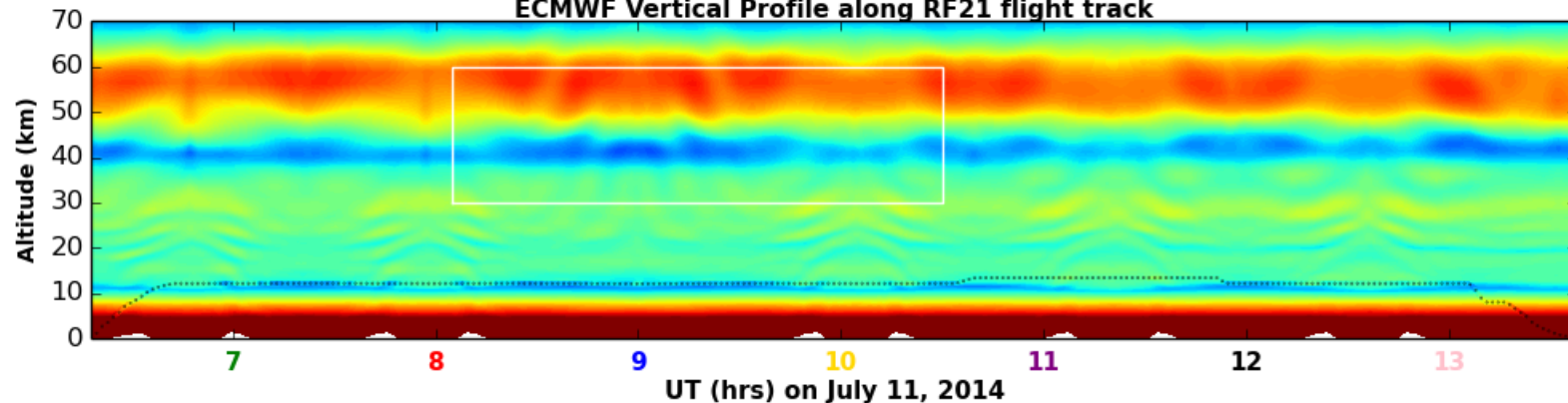
RF21 GV Raleigh Lidar, MTP, and GV insitu Temperature Measurement



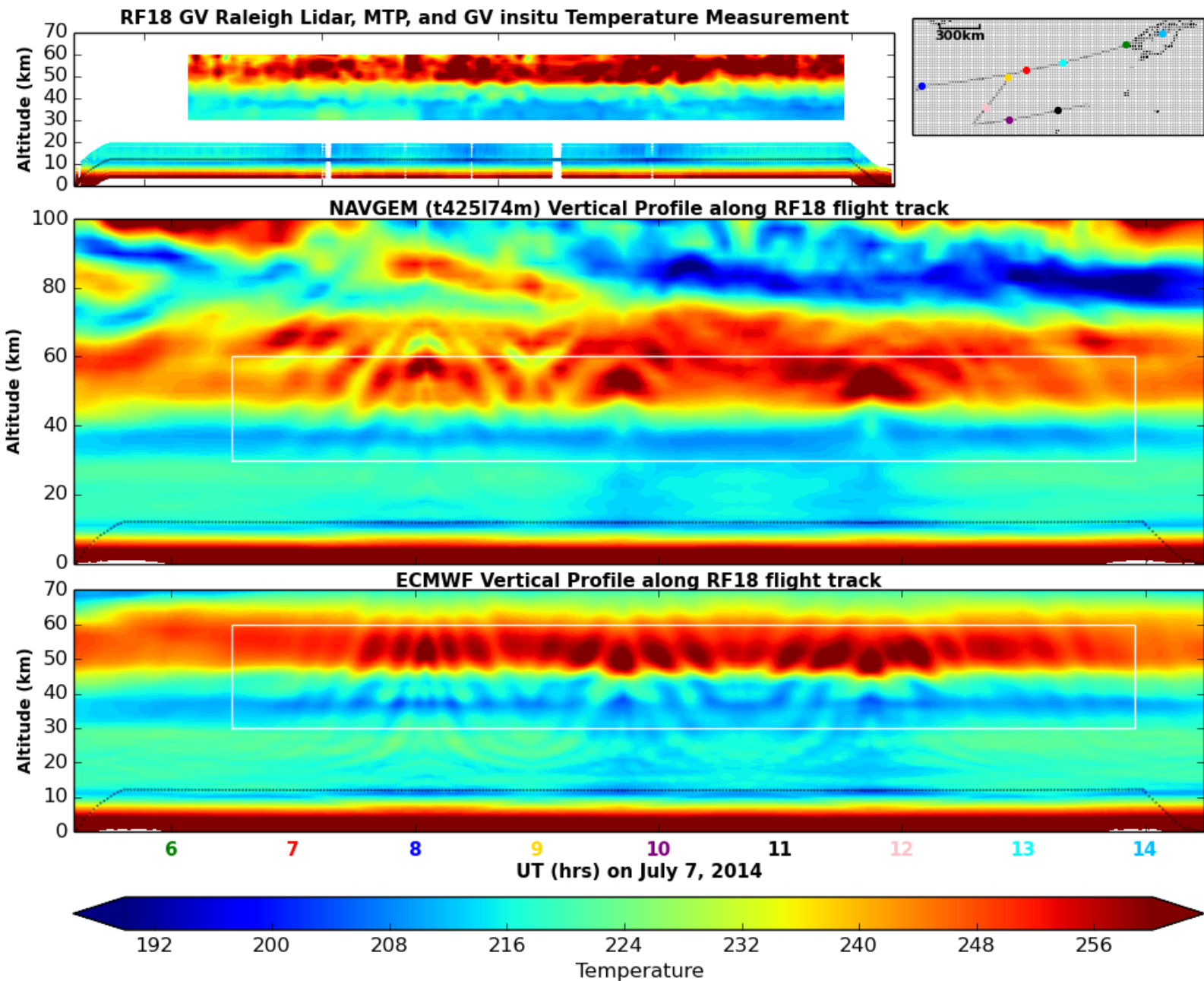
NAVEM (t425174m) Vertical Profile along RF21 flight track



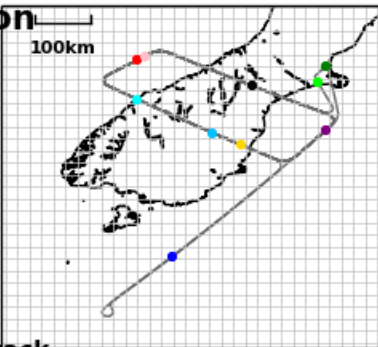
ECMWF Vertical Profile along RF21 flight track



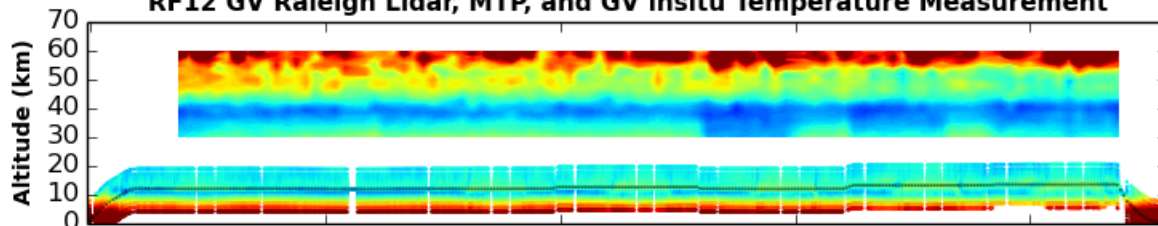
DEEPWAVE Model Measurement Comparison



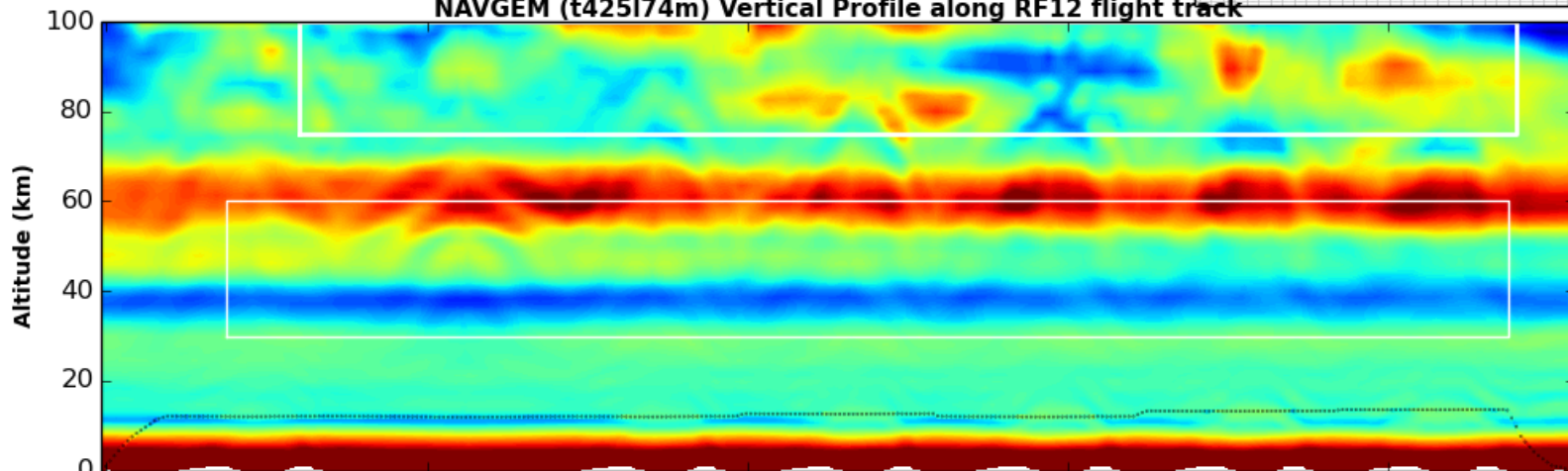
DEEPWAVE Model Measurement Comparison



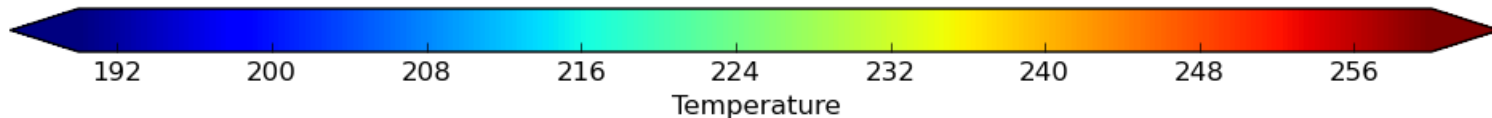
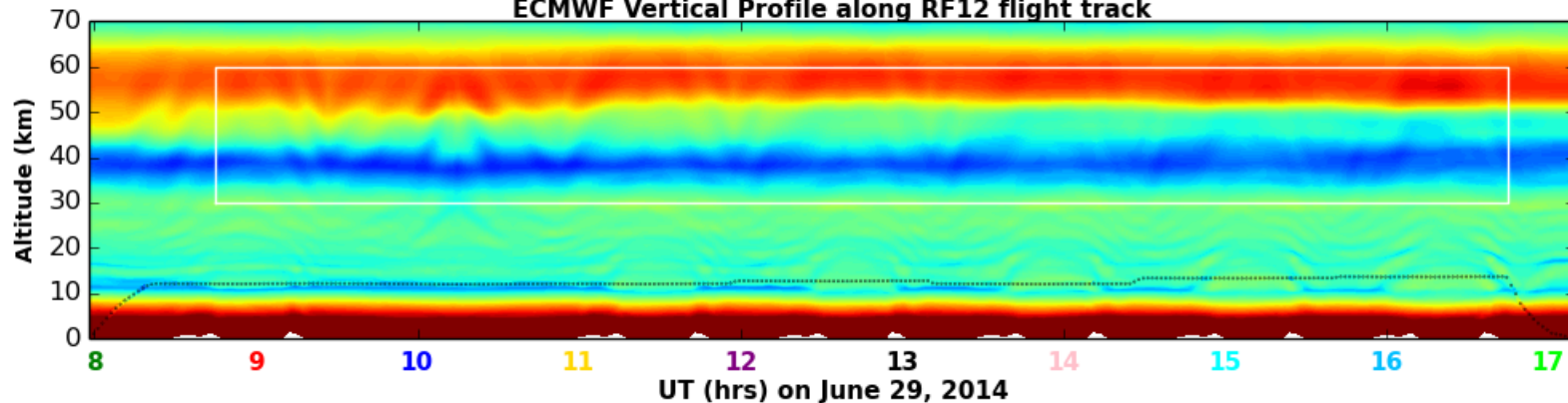
RF12 GV Raleigh Lidar, MTP, and GV insitu Temperature Measurement



NAVgEM (t425174m) Vertical Profile along RF12 flight track

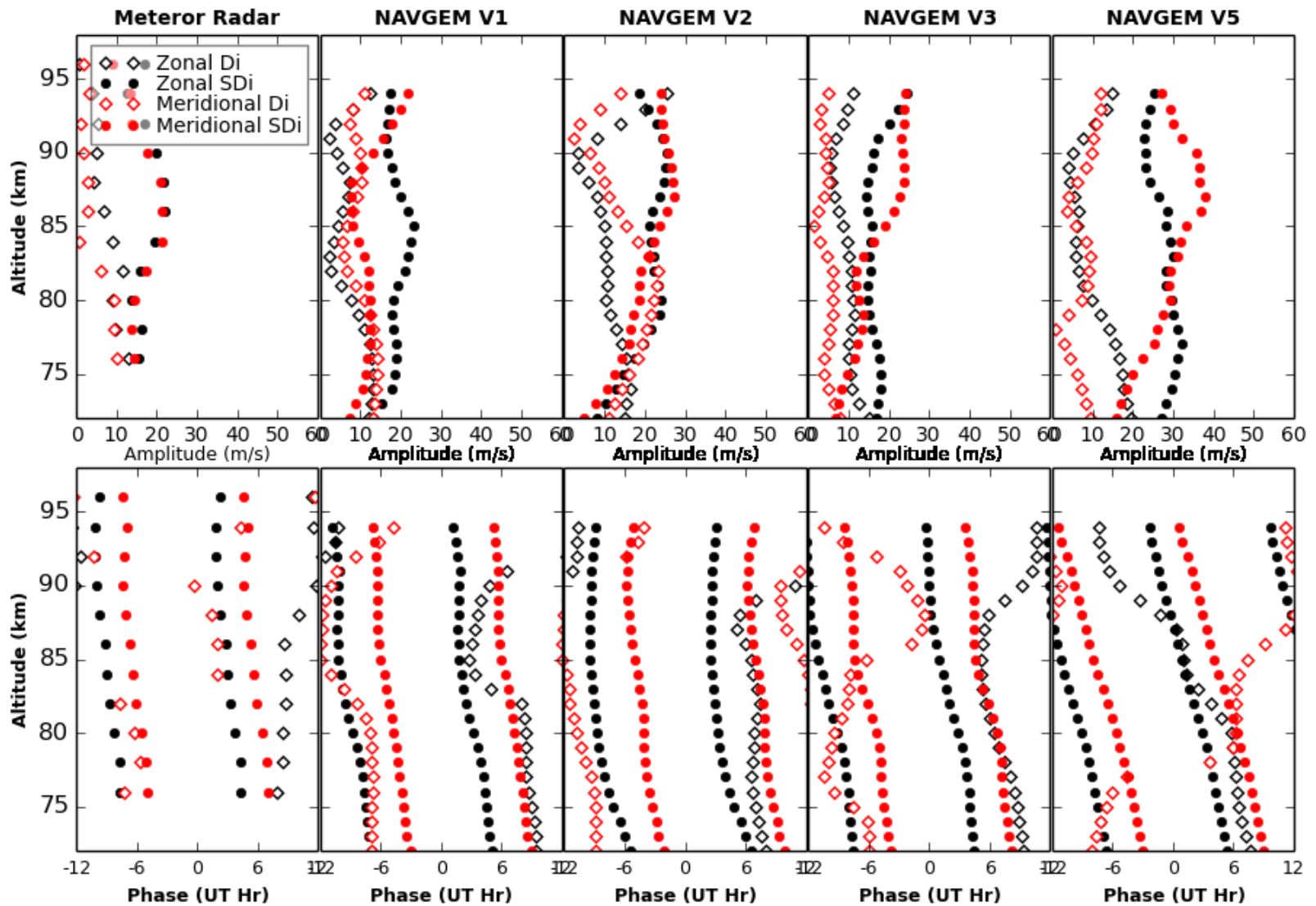


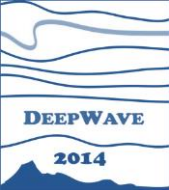
ECMWF Vertical Profile along RF12 flight track





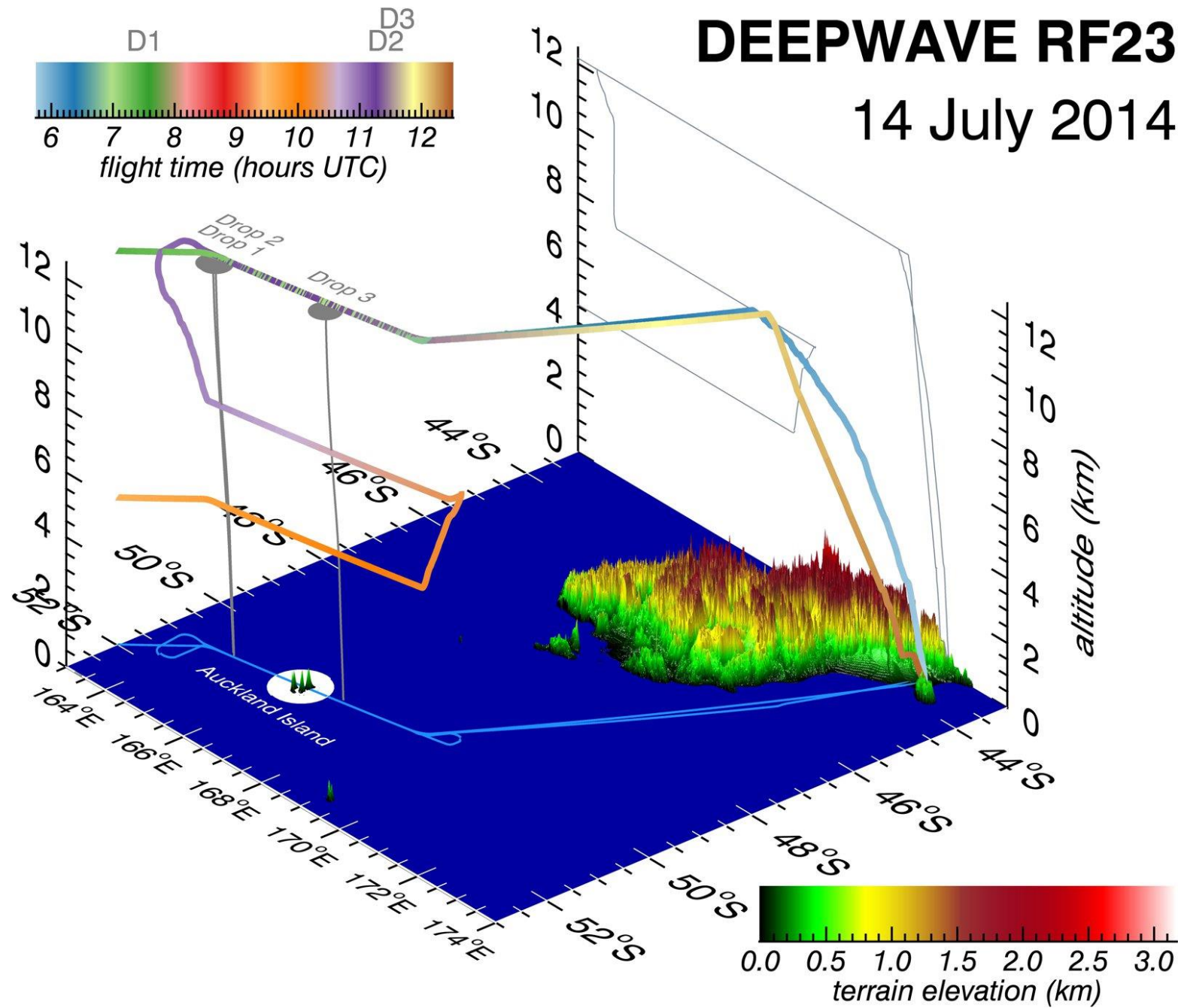
Tidal Analysis over Kingston on 2014062500



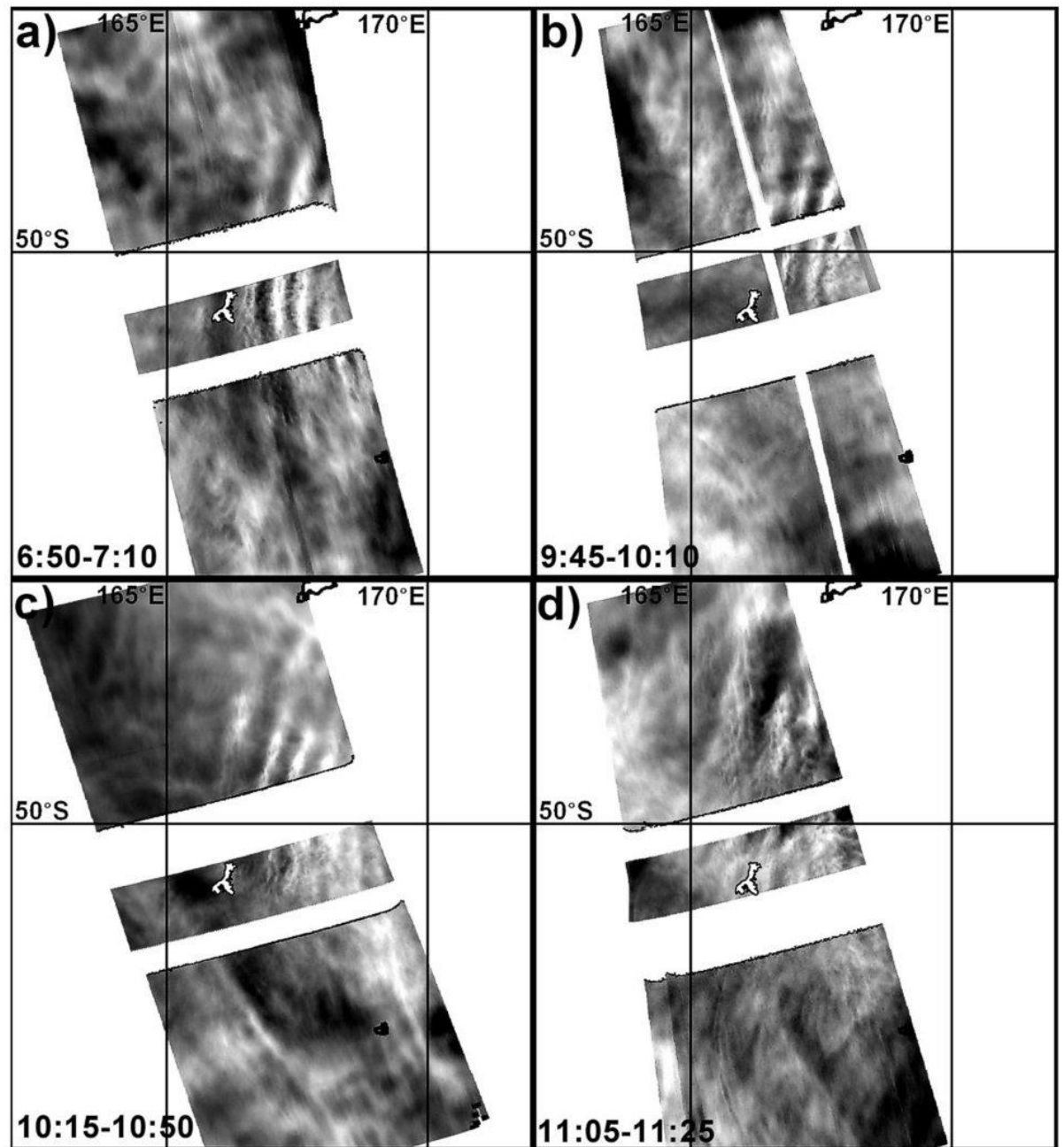


DEEPWAVE RF23

14 July 2014

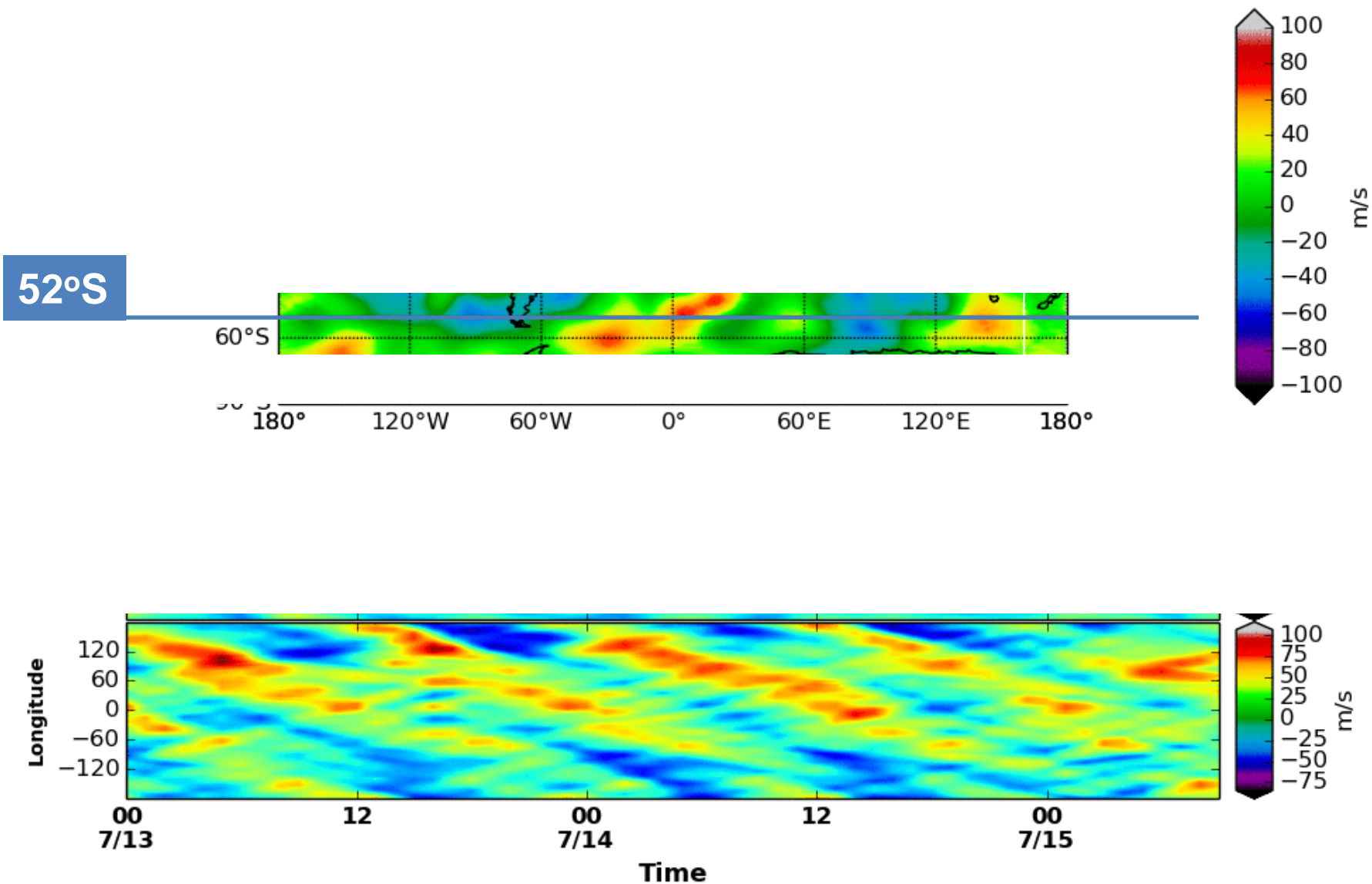


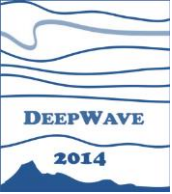
RF23 AMTM





Large Semidiurnal Tides ~90 km

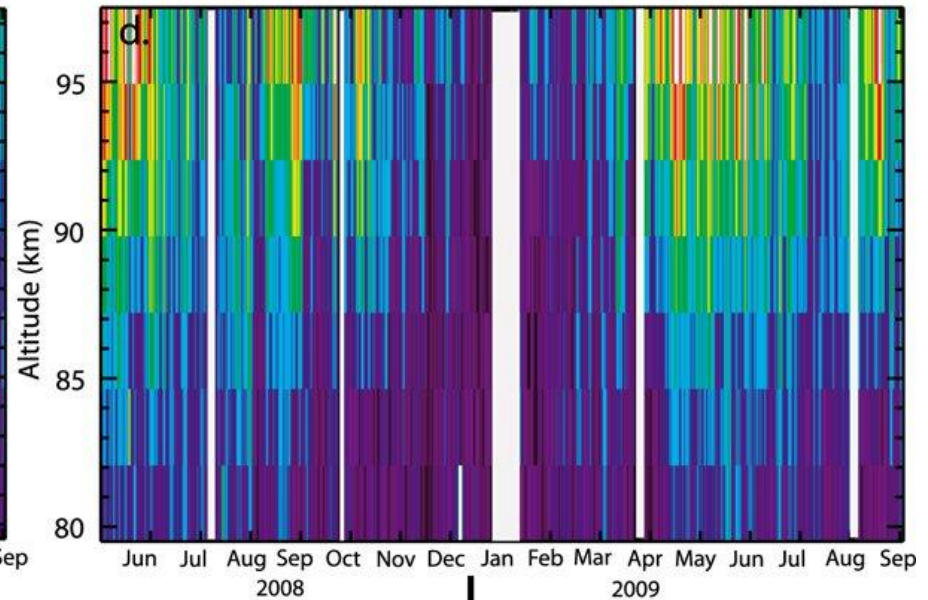
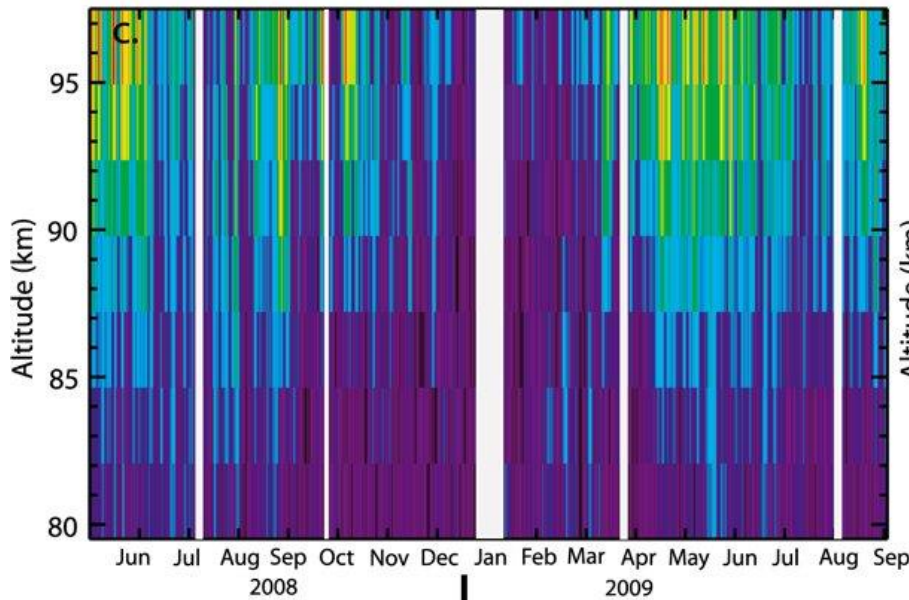
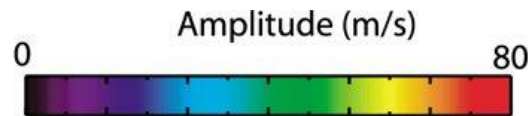
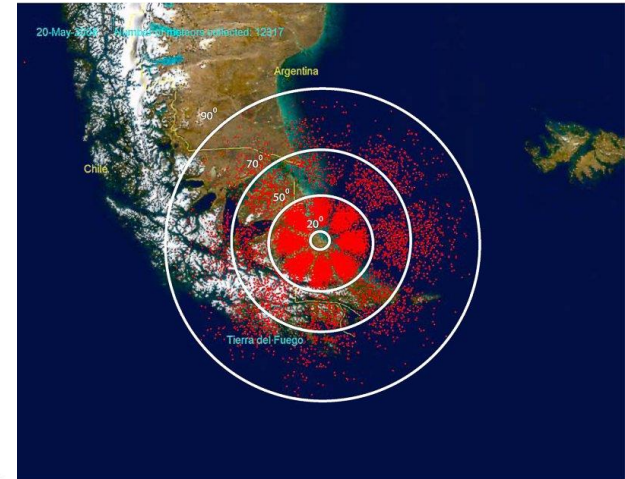


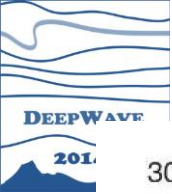


Semidiurnal Tidal Amplitudes at ~90 km & 53.8°S

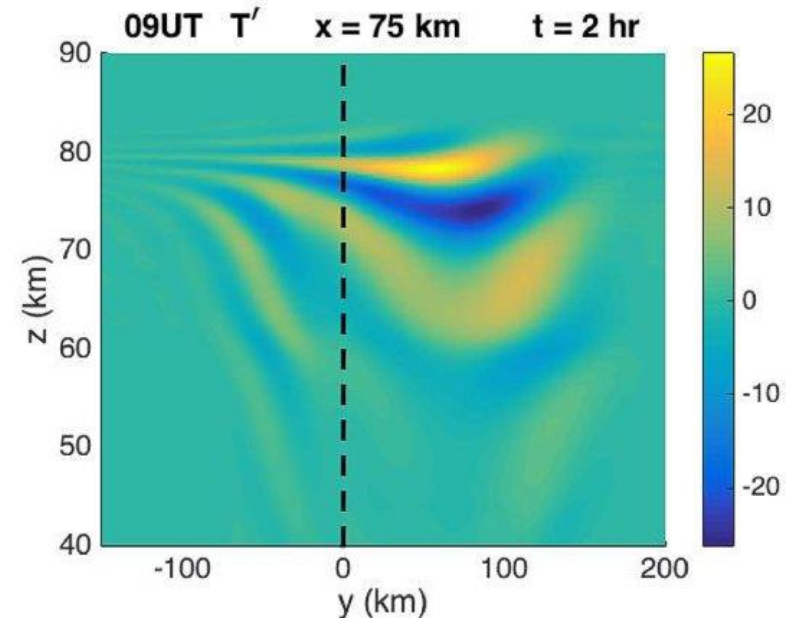
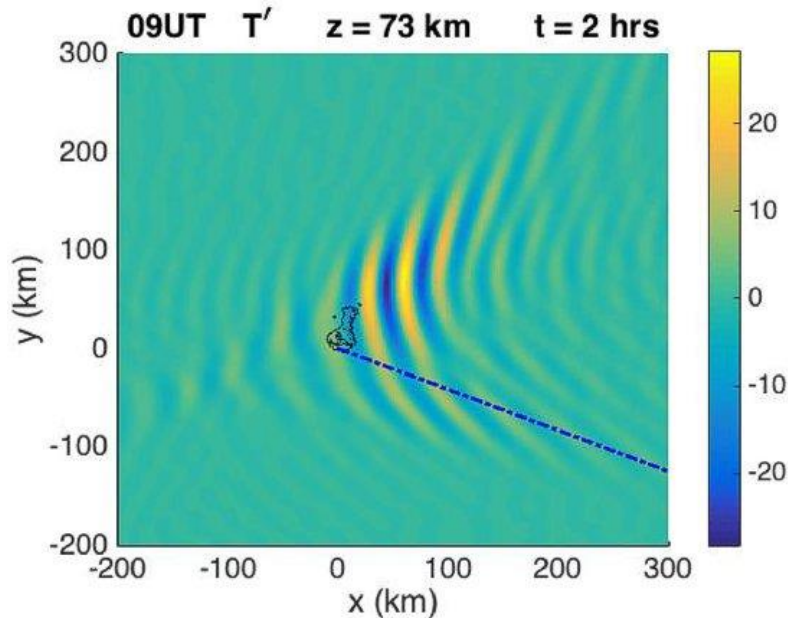
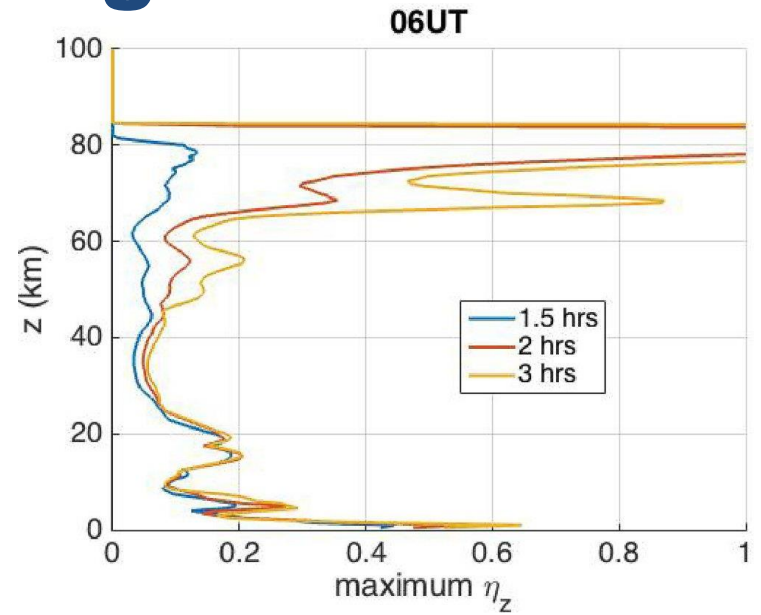
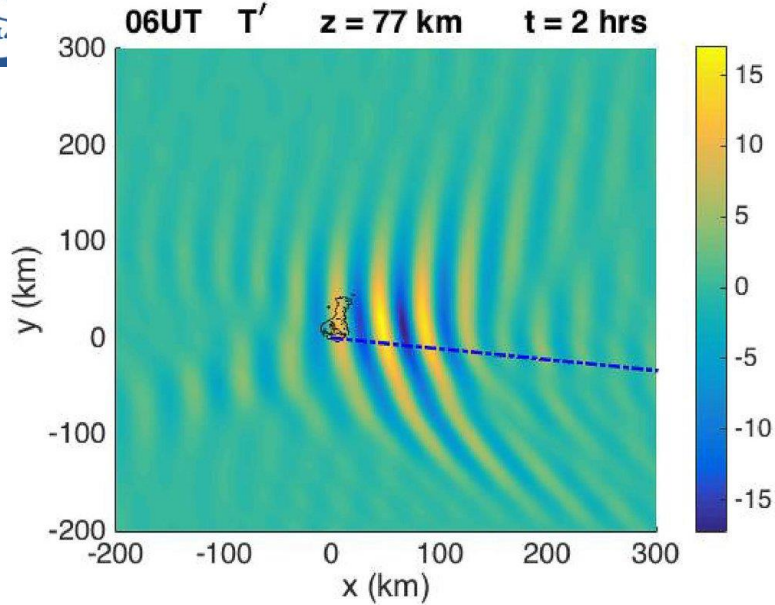
Winds at 80-95 km measured by Southern Argentina Agile Meteor Radar (SAAMER)

Fritts, D. C., et al. (2010), Southern Argentina Agile Meteor Radar: System design and initial measurements of large-scale winds and tides, *J. Geophys. Res.*, 115, D18112, doi:10.1029/2010JD013850.

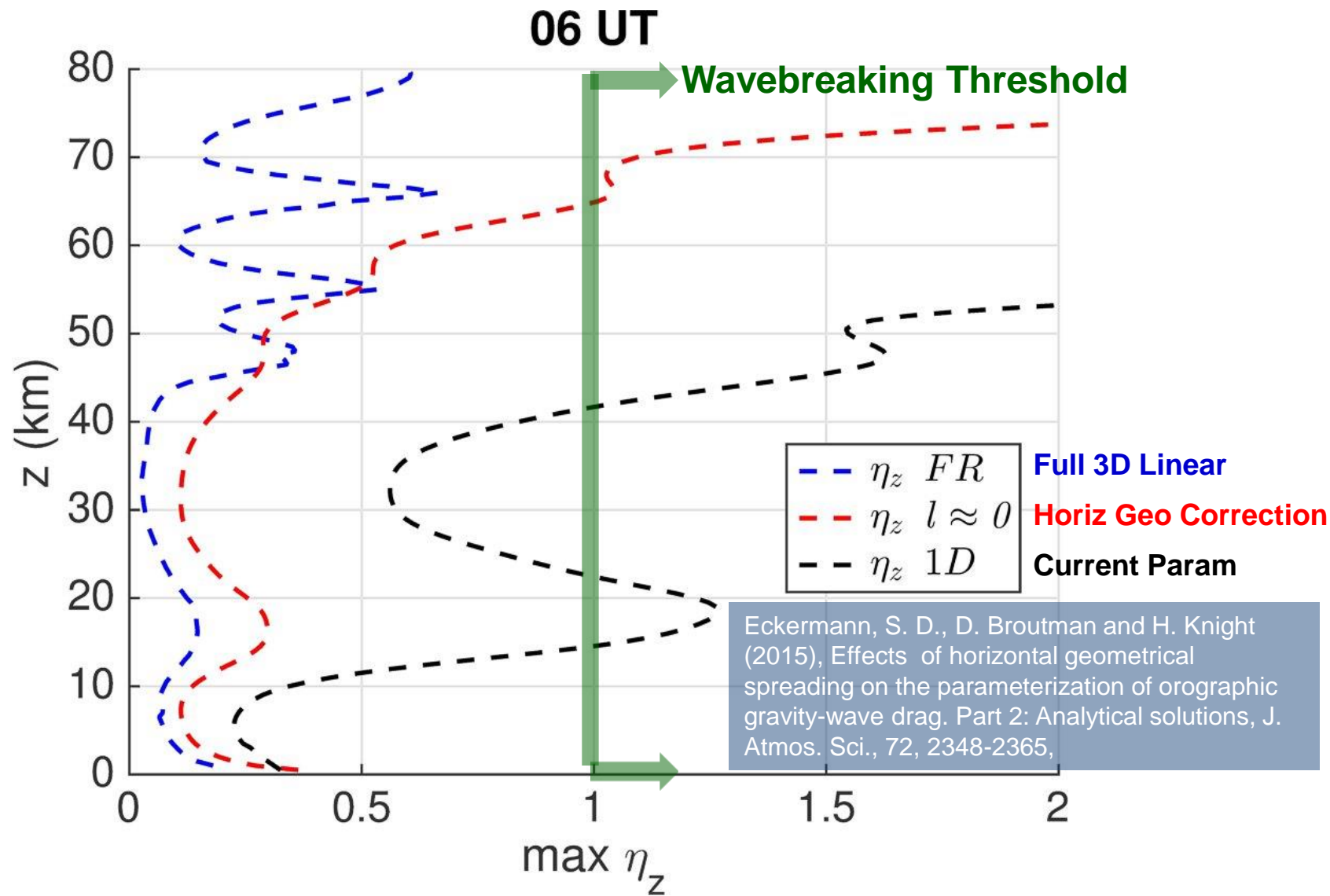




Fourier-Ray Modeling for RF23

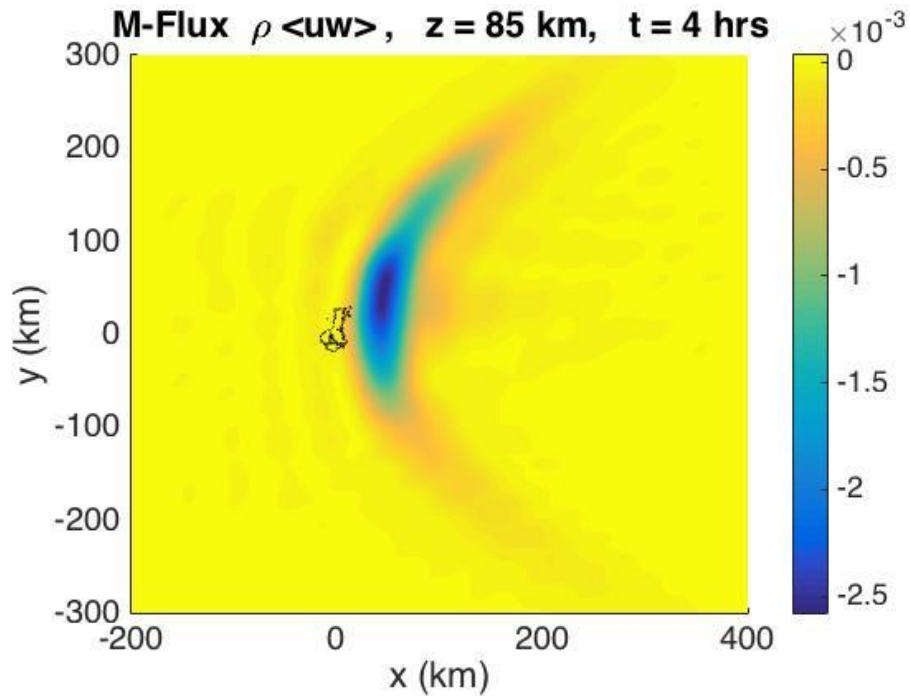


Test of New NAVGEM OGWD Parameterization Physics for RF23

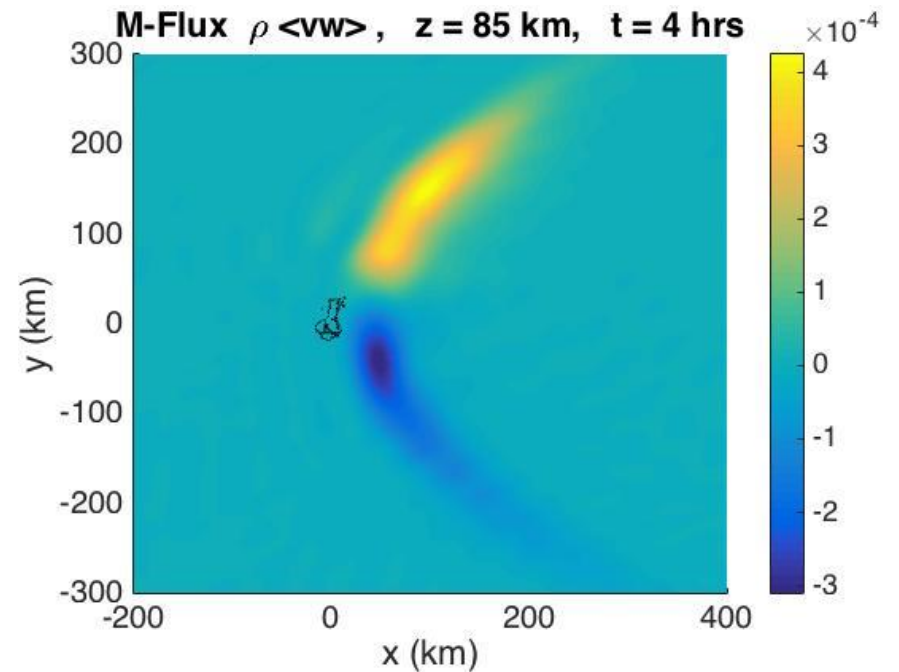


Momentum Fluxes at 85 km

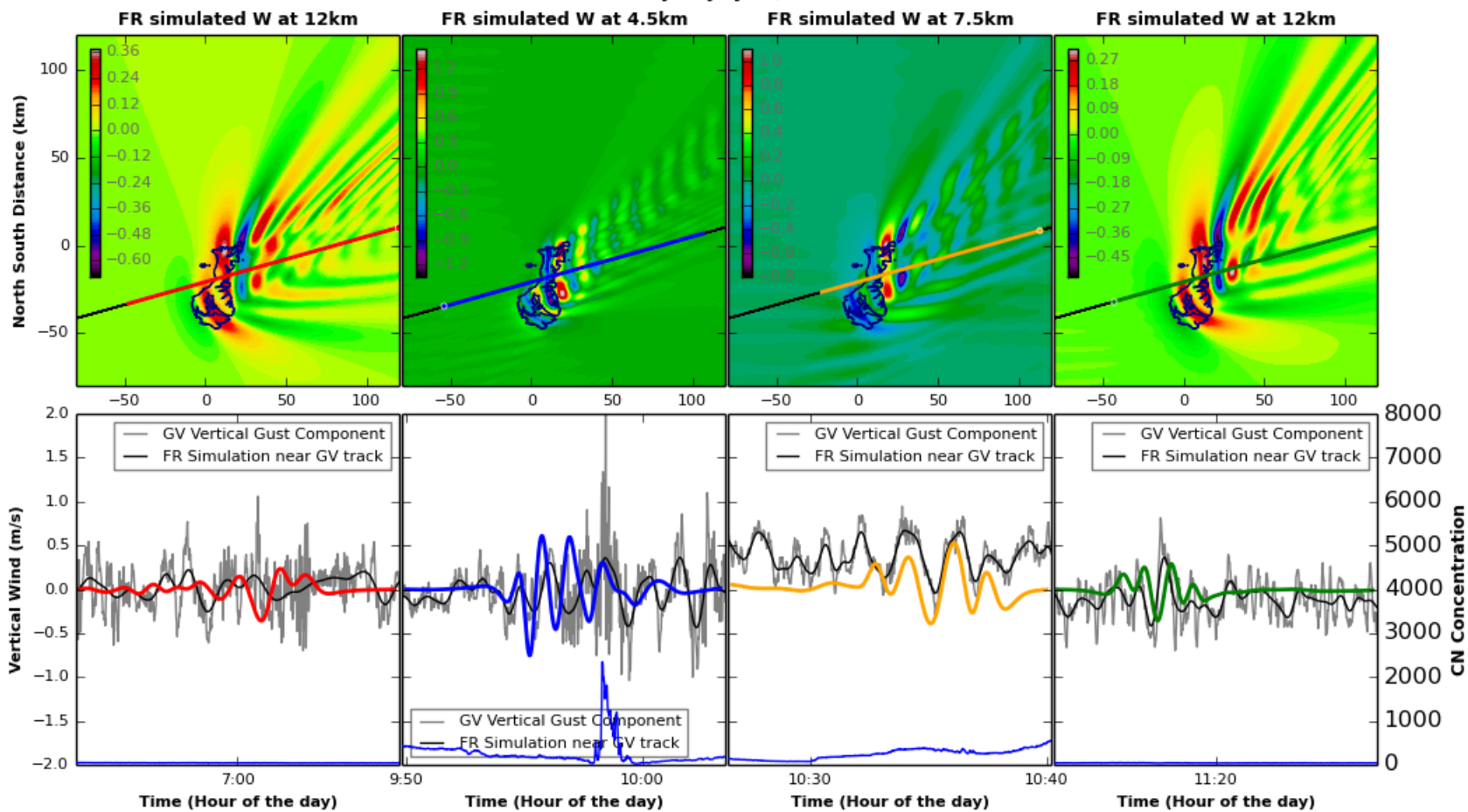
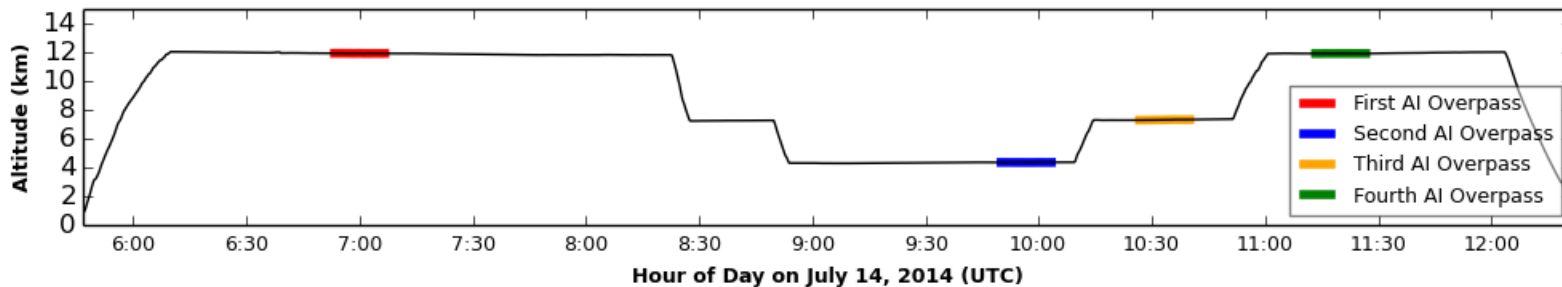
$$\rho \langle uw \rangle$$



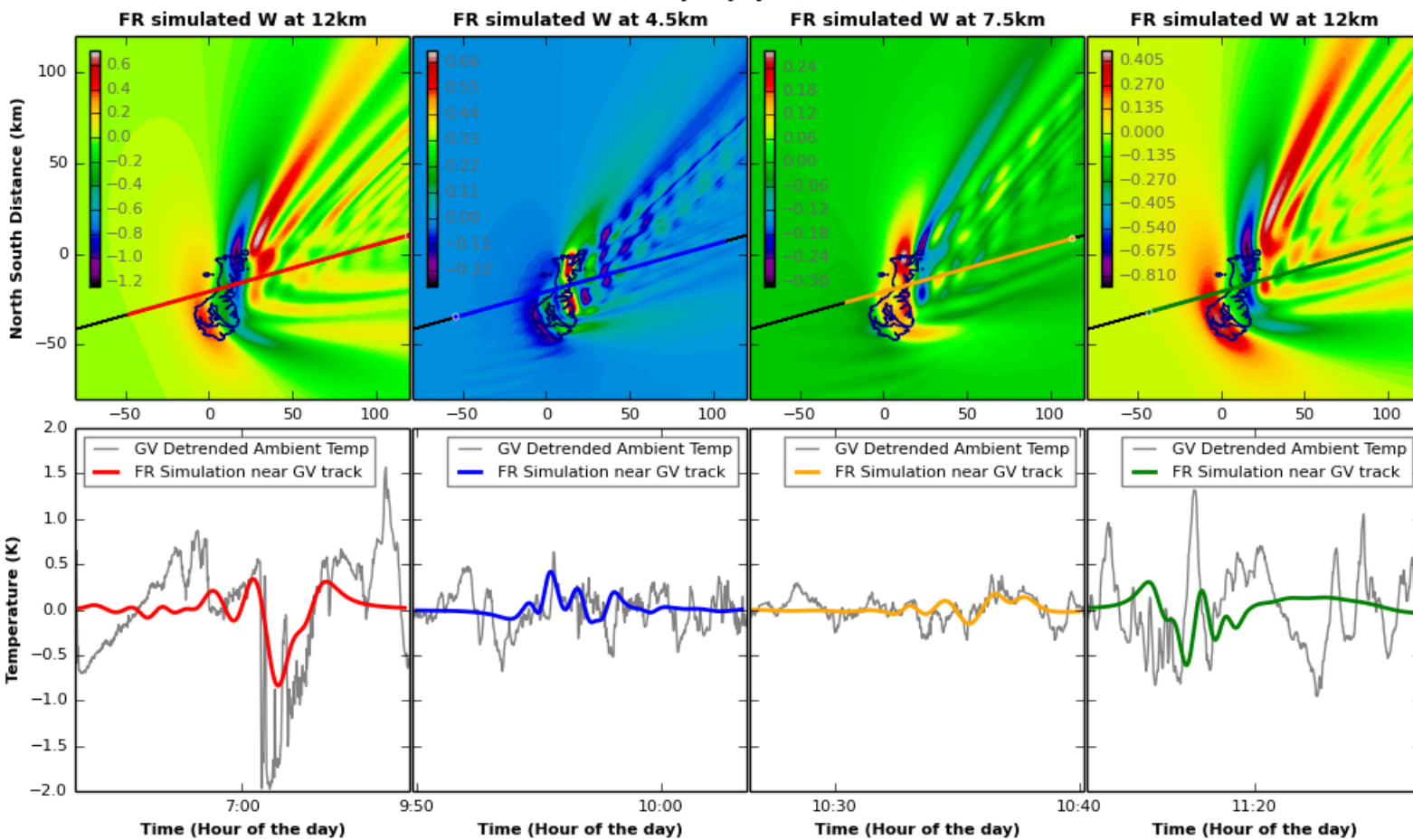
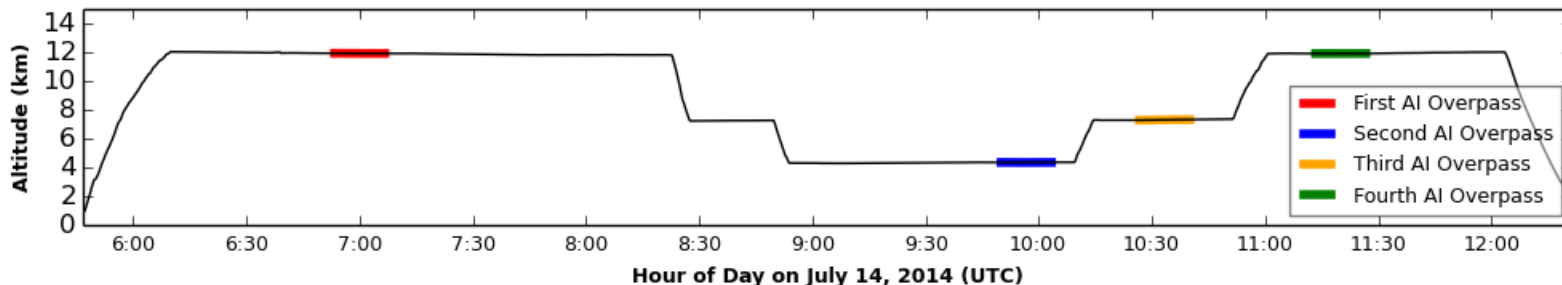
$$\rho \langle vw \rangle$$



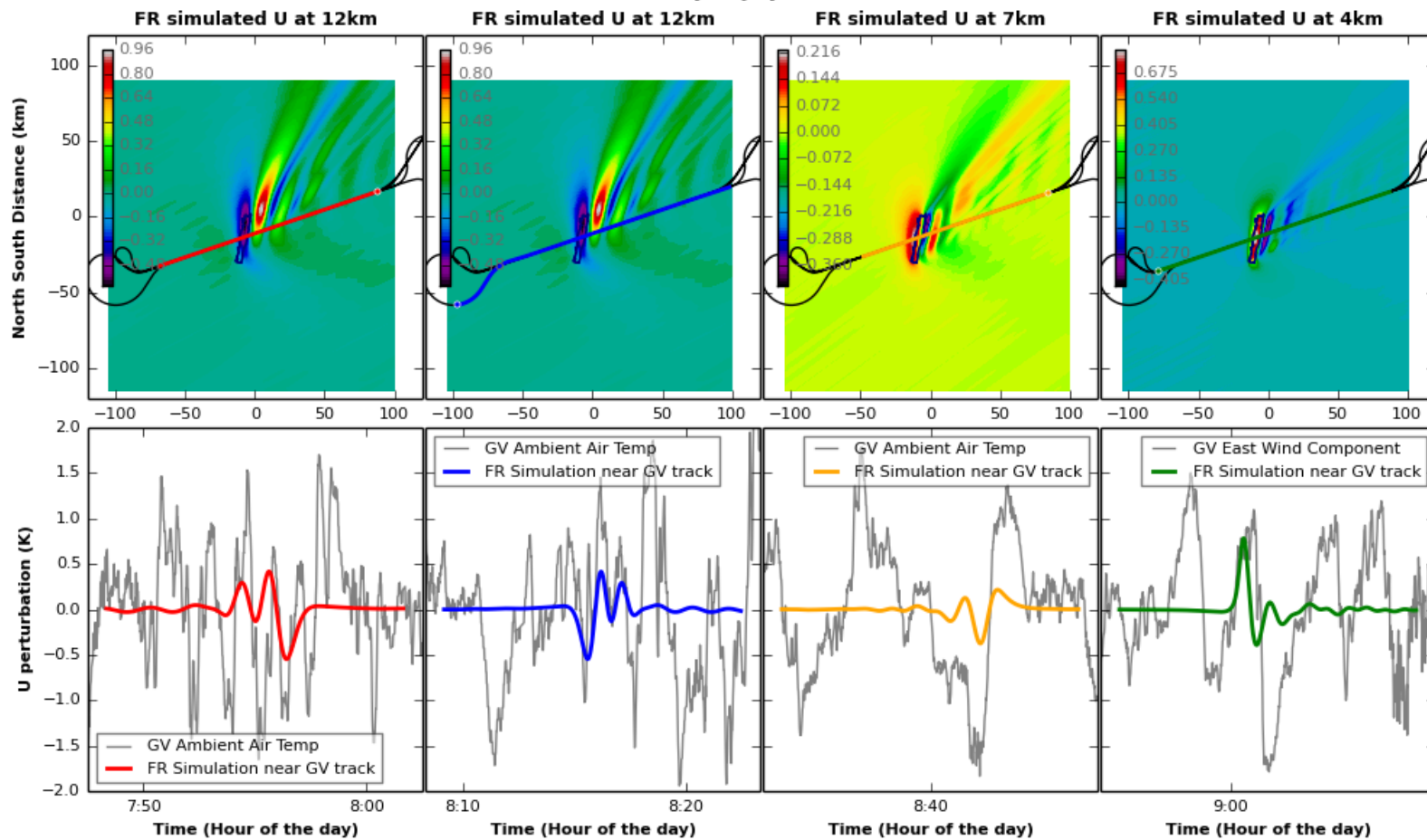
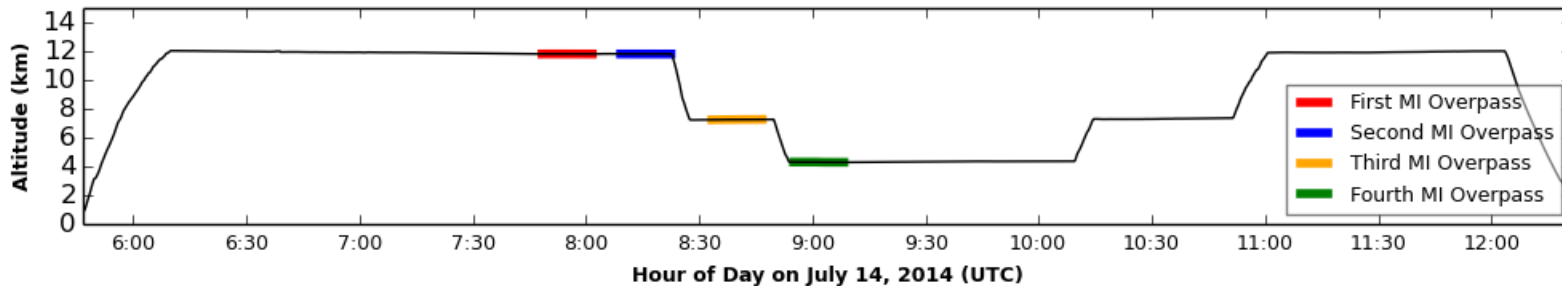
RF23 Avionics GPS Altitude



RF23 Avionics GPS Altitude

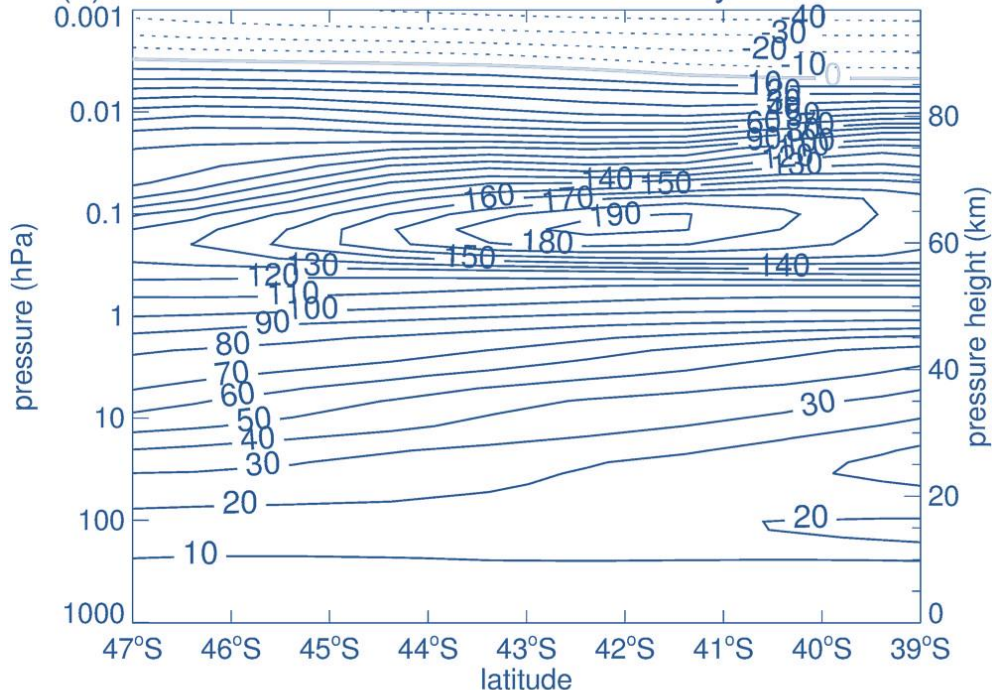


RF23 Avionics GPS Altitude

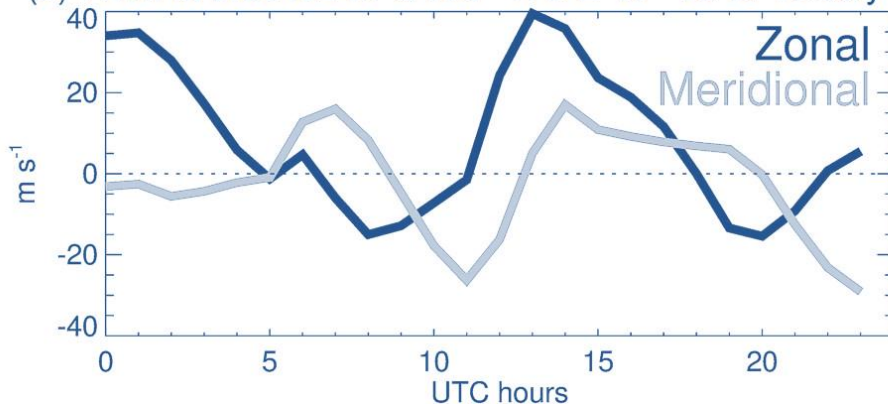


RF 22 Zonal Winds: 13 July 0600Z

(a) Mean Zonal Winds 165°-179°E: 13 July 2014 0600 UTC



(b) Wind at 0.00402 hPa 165°-179°E 40°-46°S: 13 July 2014



For RF22 and RF23 NAVGEM MLT reanalysis over South Island yields:

1. weakening or reversal to mean easterlies
2. Strong semidiurnal tides

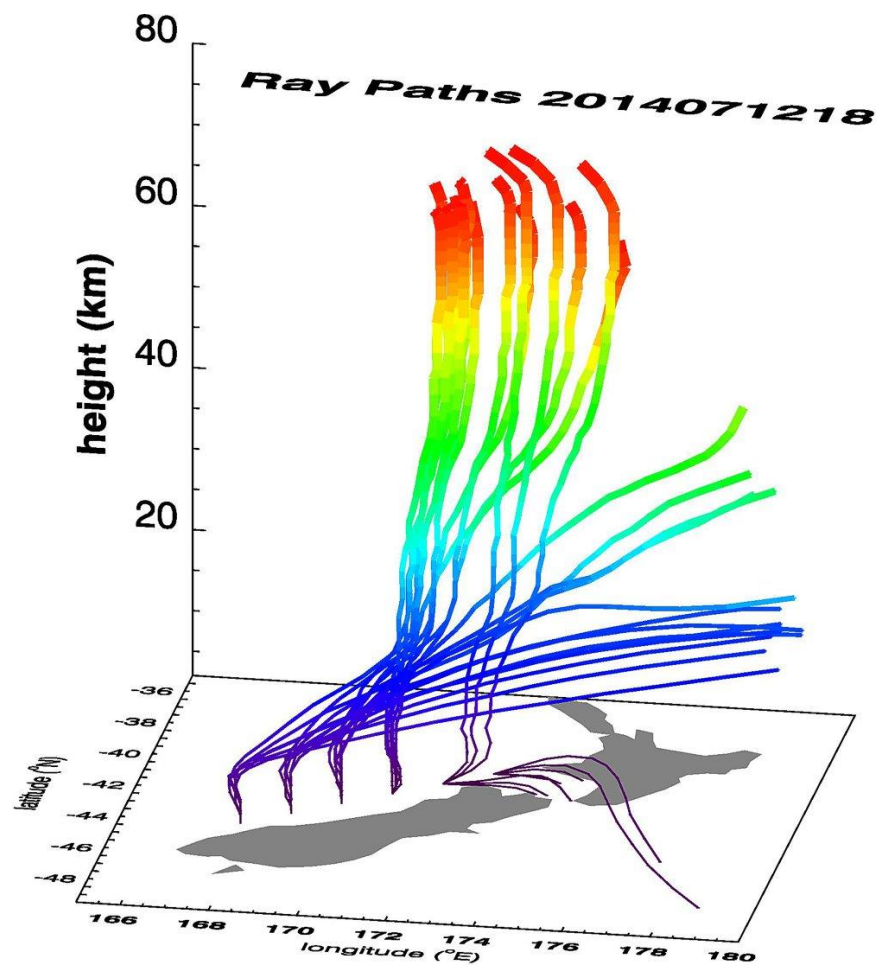
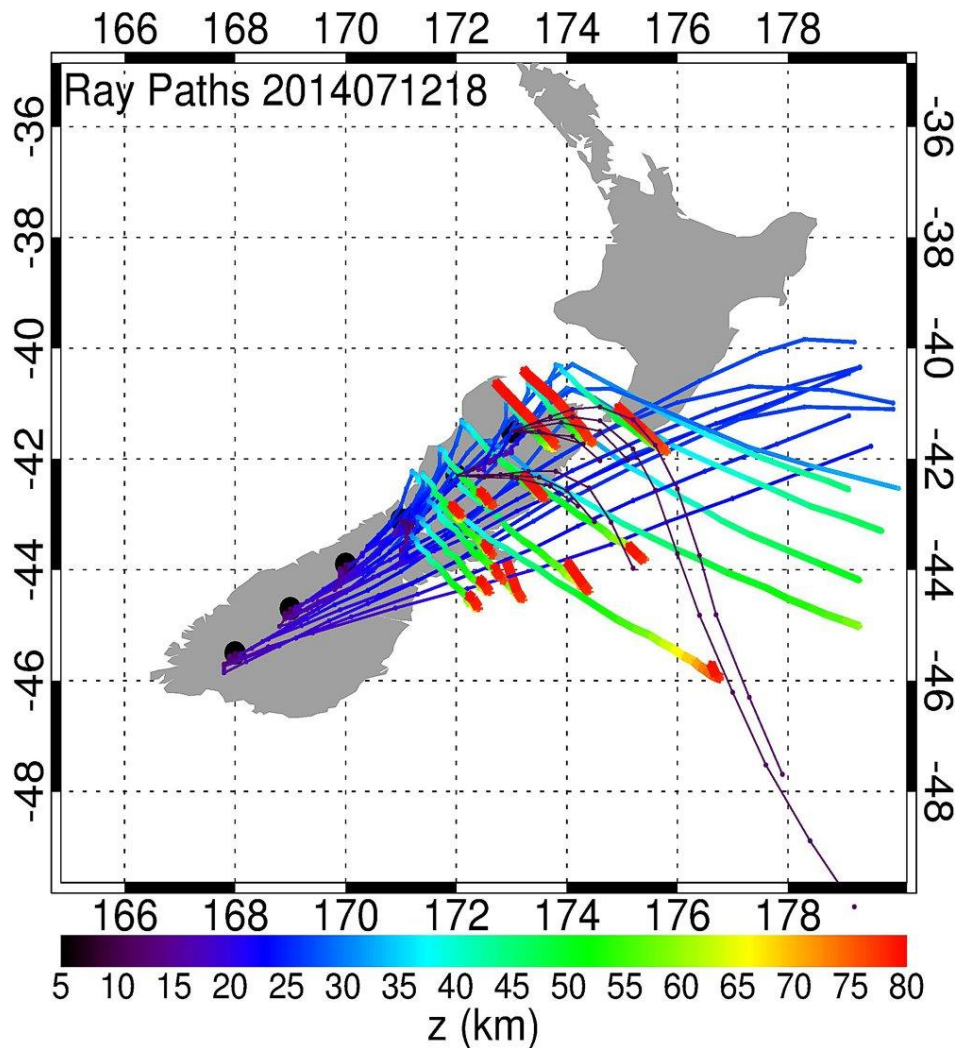
MLT MW observations suggest westerlies persist to ~90 km

Untuned NGWD with large phase speeds may be responsible

Limited radar observations suggest semidiurnal tides $\sim 10 \text{ ms}^{-1}$ amplitude in winter MLT over New Zealand (Stening et al. JASTP 1995)

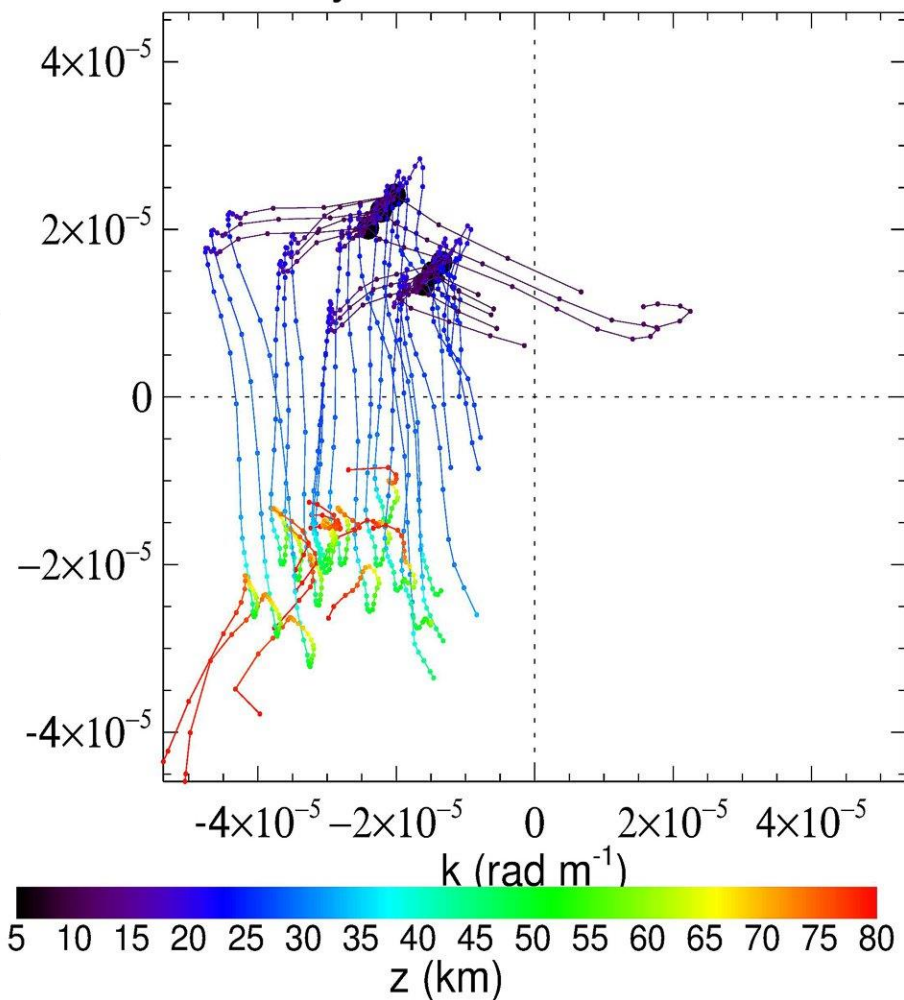
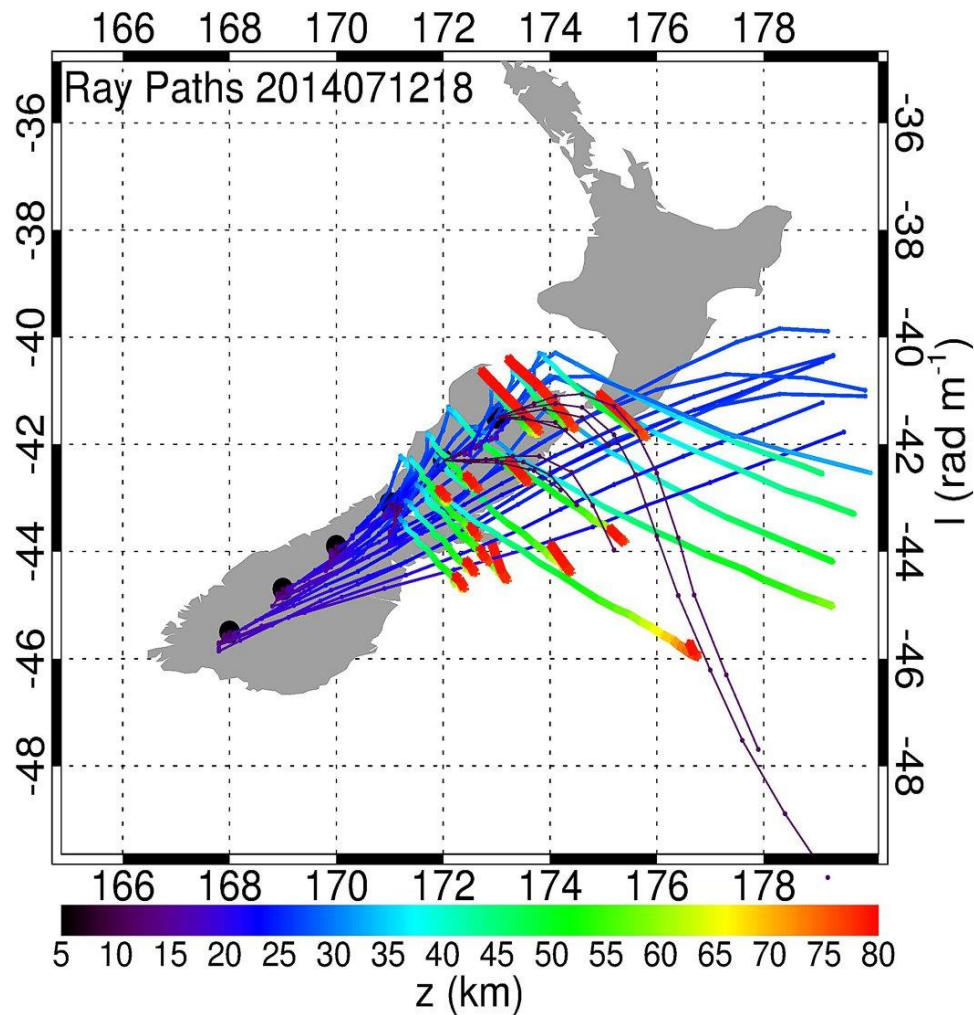
Really want to compare to Kingston meteor radar winds

Spatial Ray Trajectory: 12 Jul 18Z



Lateral Refraction: 12 Jul 18Z

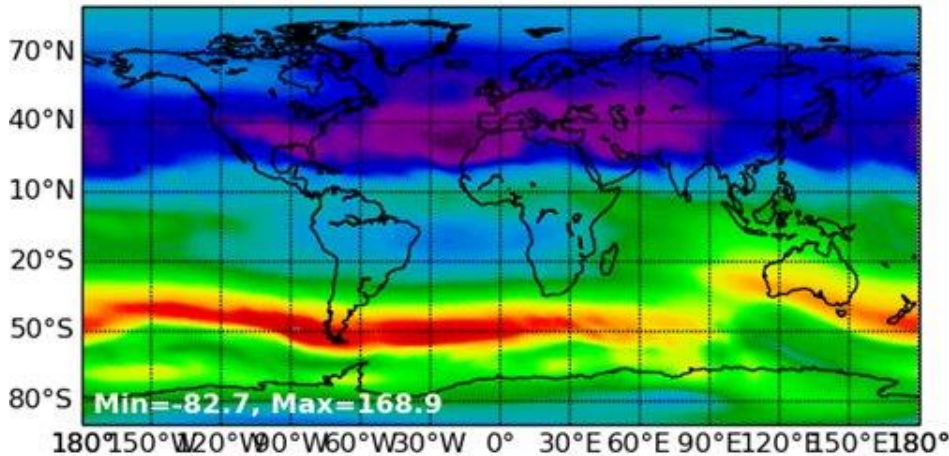
Ray Paths 2014071218



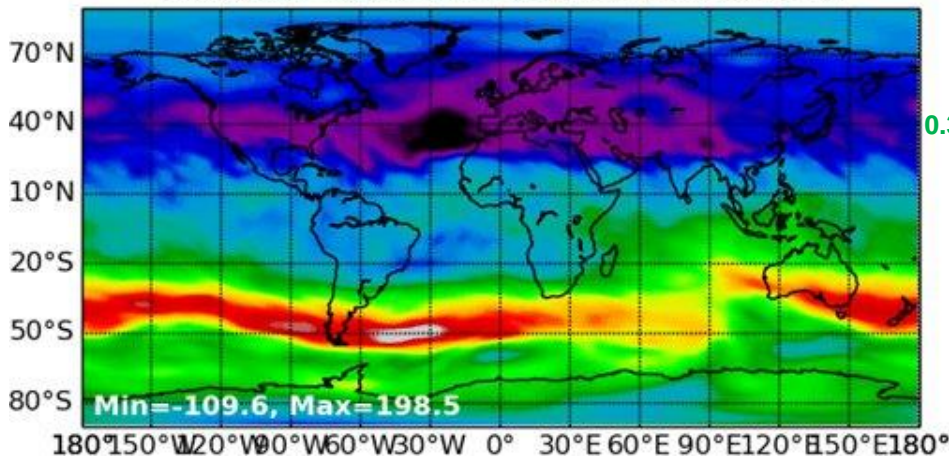
MERRA v. NAVGEM for RF22

0.3 hPa: 13 July 2014 0600 UTC

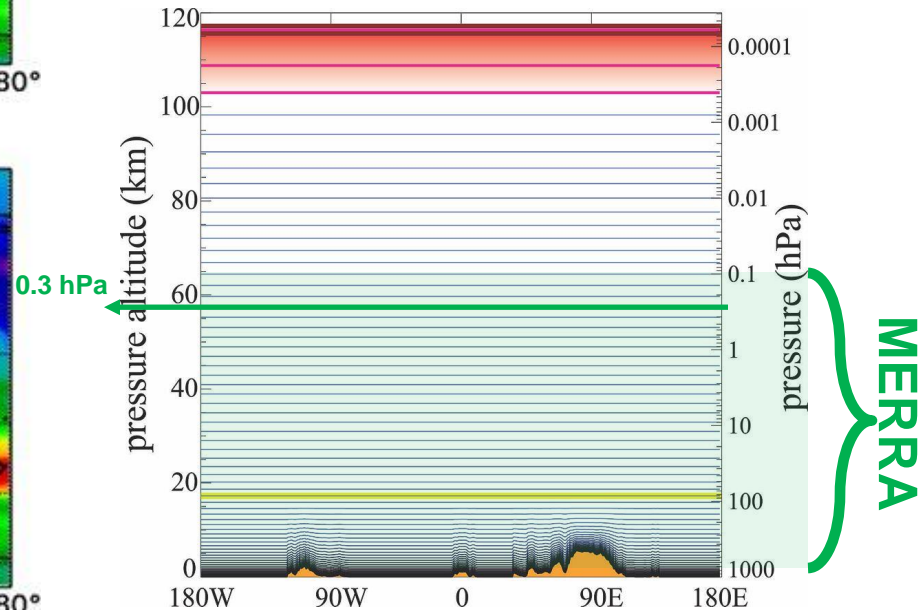
MERRA 2014071306 on 3.00e-01 hPa



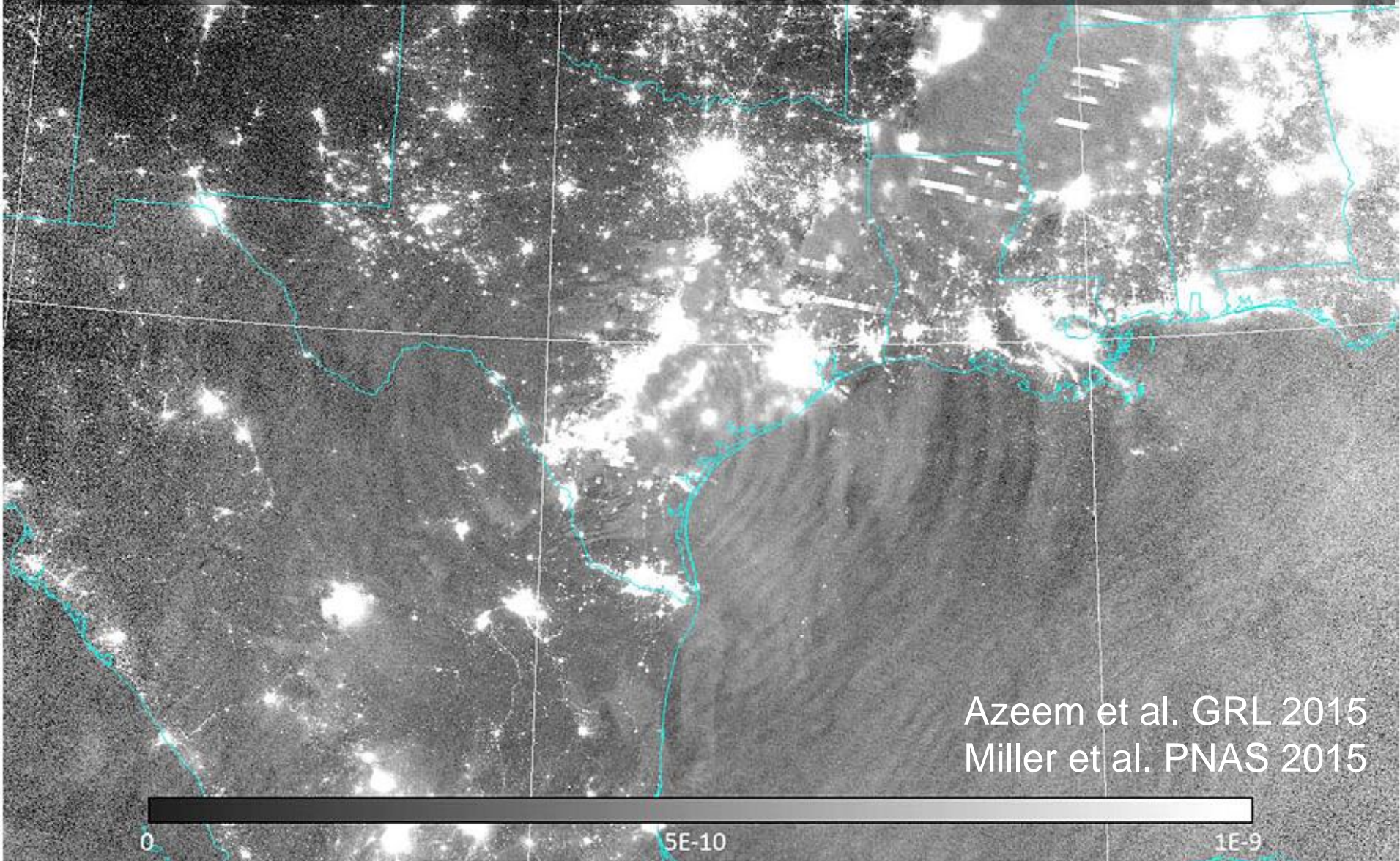
NAVGEM 2014071306 on 2.73e-01 hPa



Strong deformed stratopause jet over New Zealand agrees well with MERRA



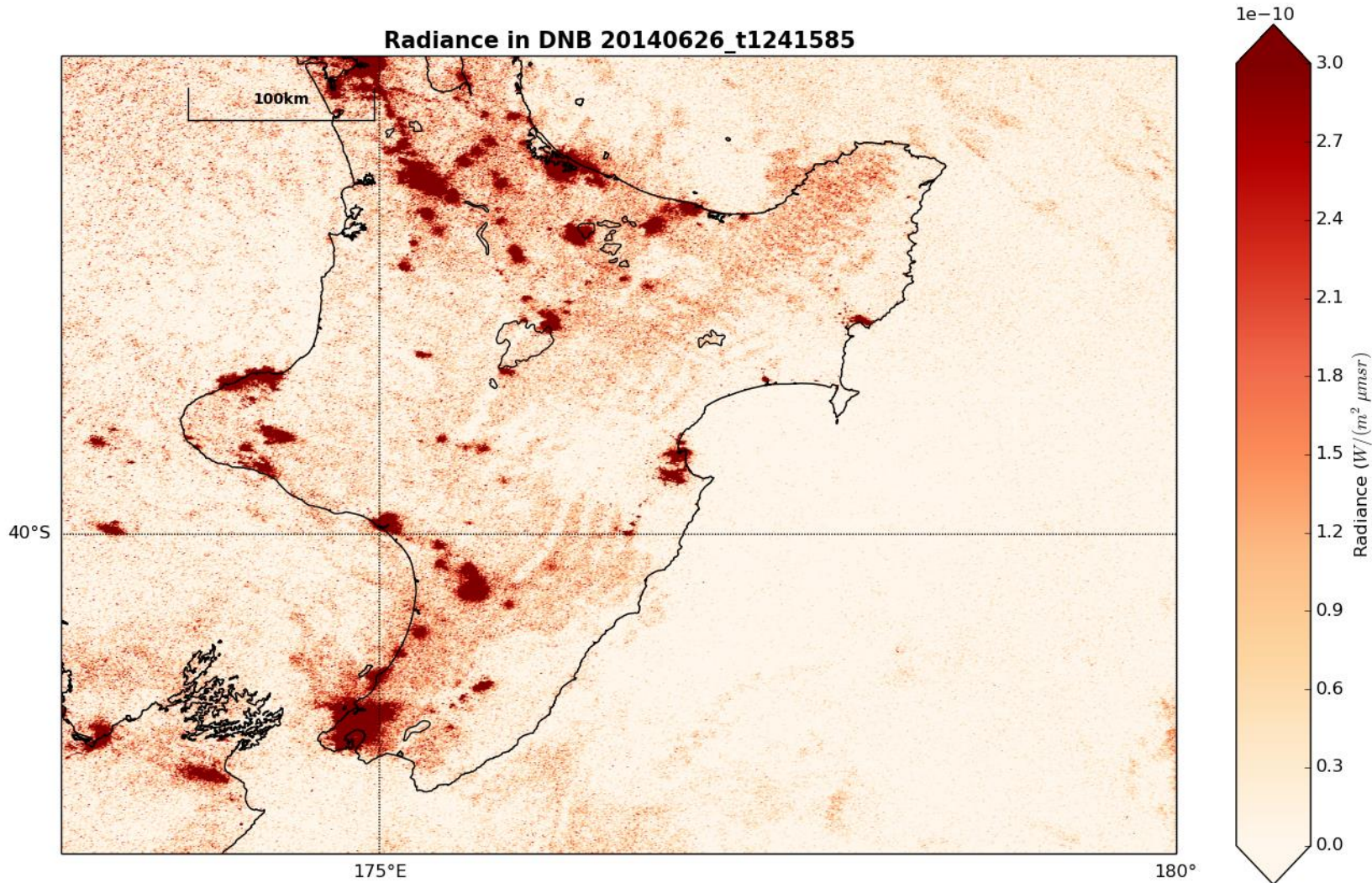
Suomi VIIRS DNB New Moon Data

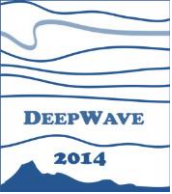


Azeem et al. GRL 2015
Miller et al. PNAS 2015

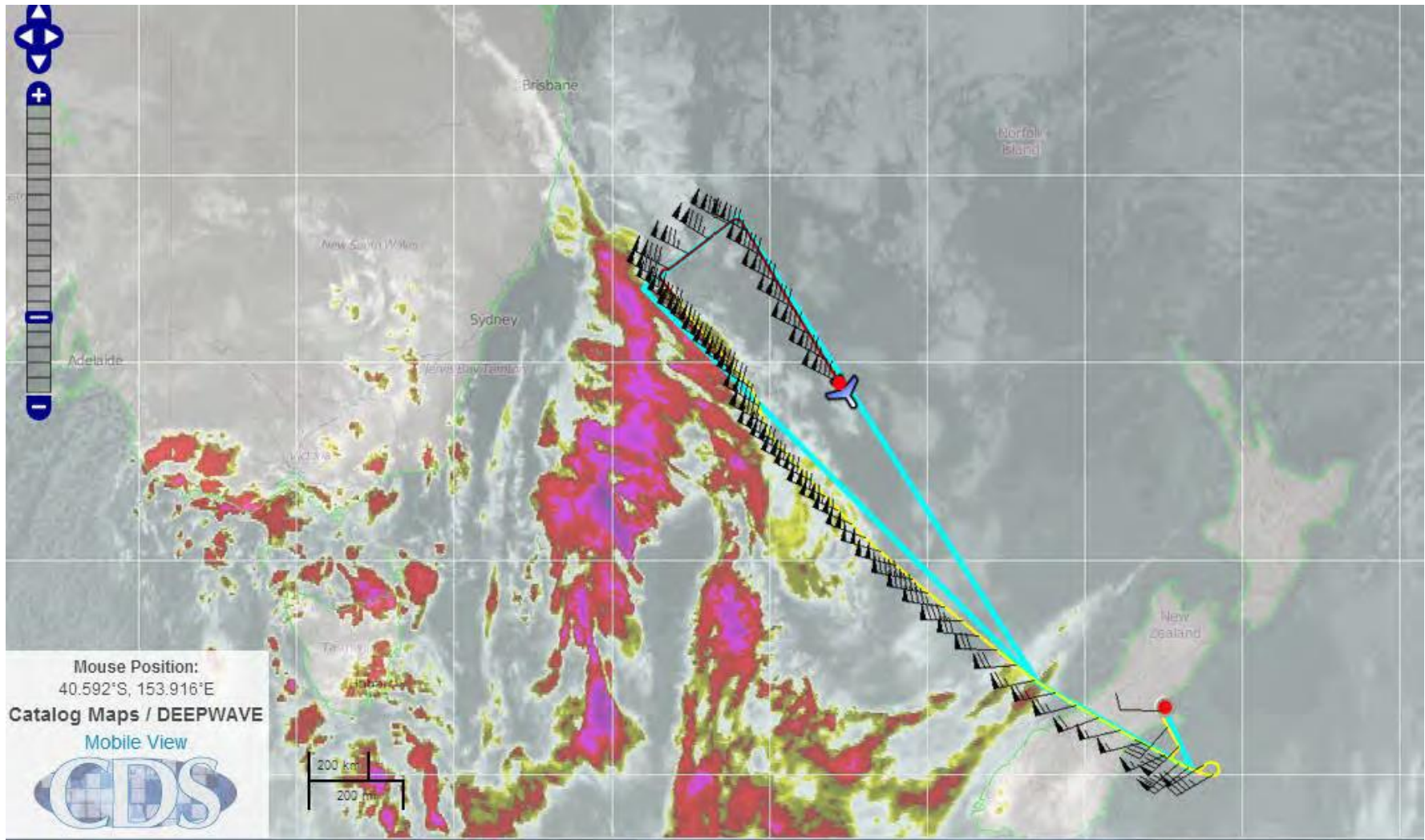


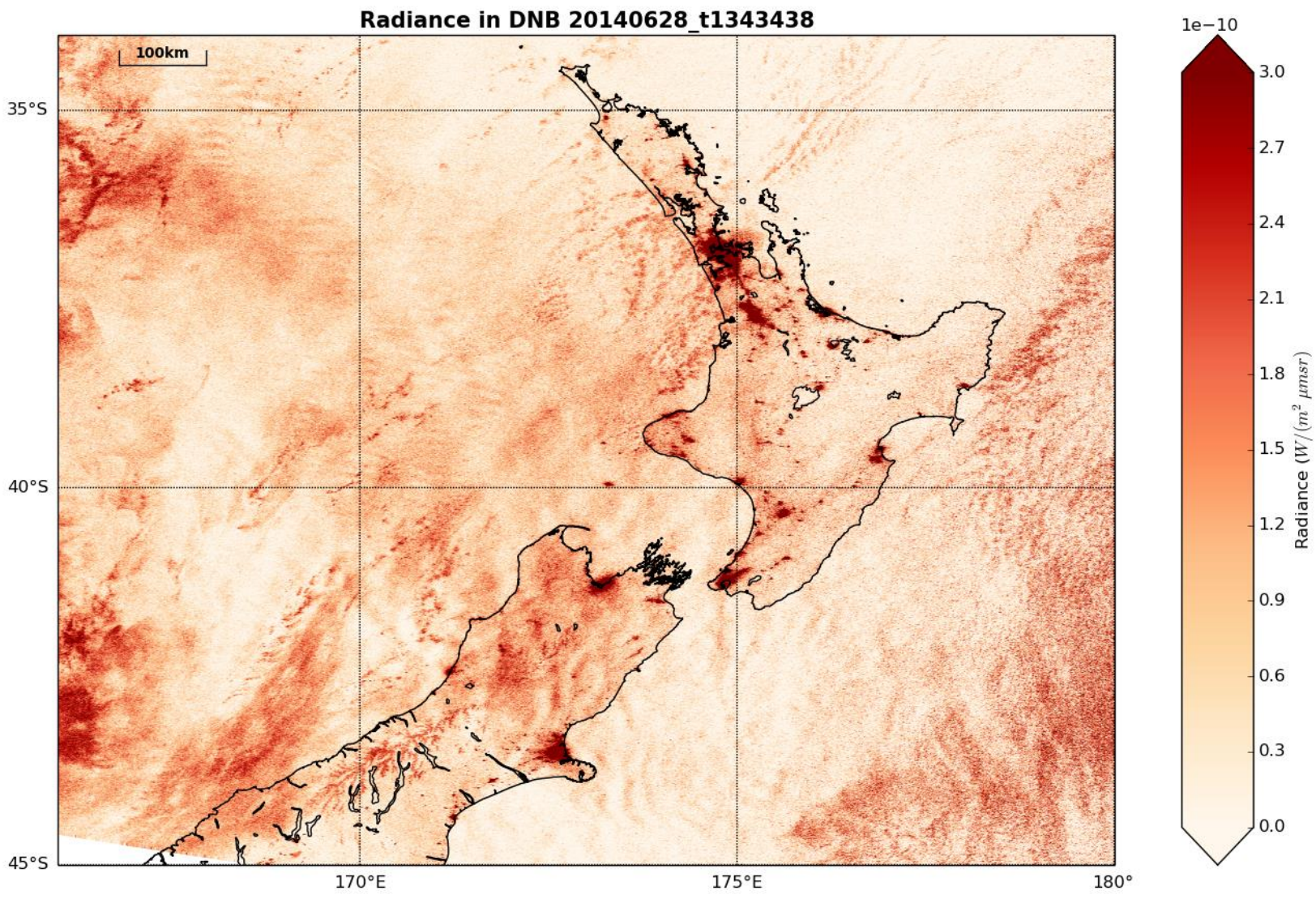
Suomi VIIRS DNB New Moon Data

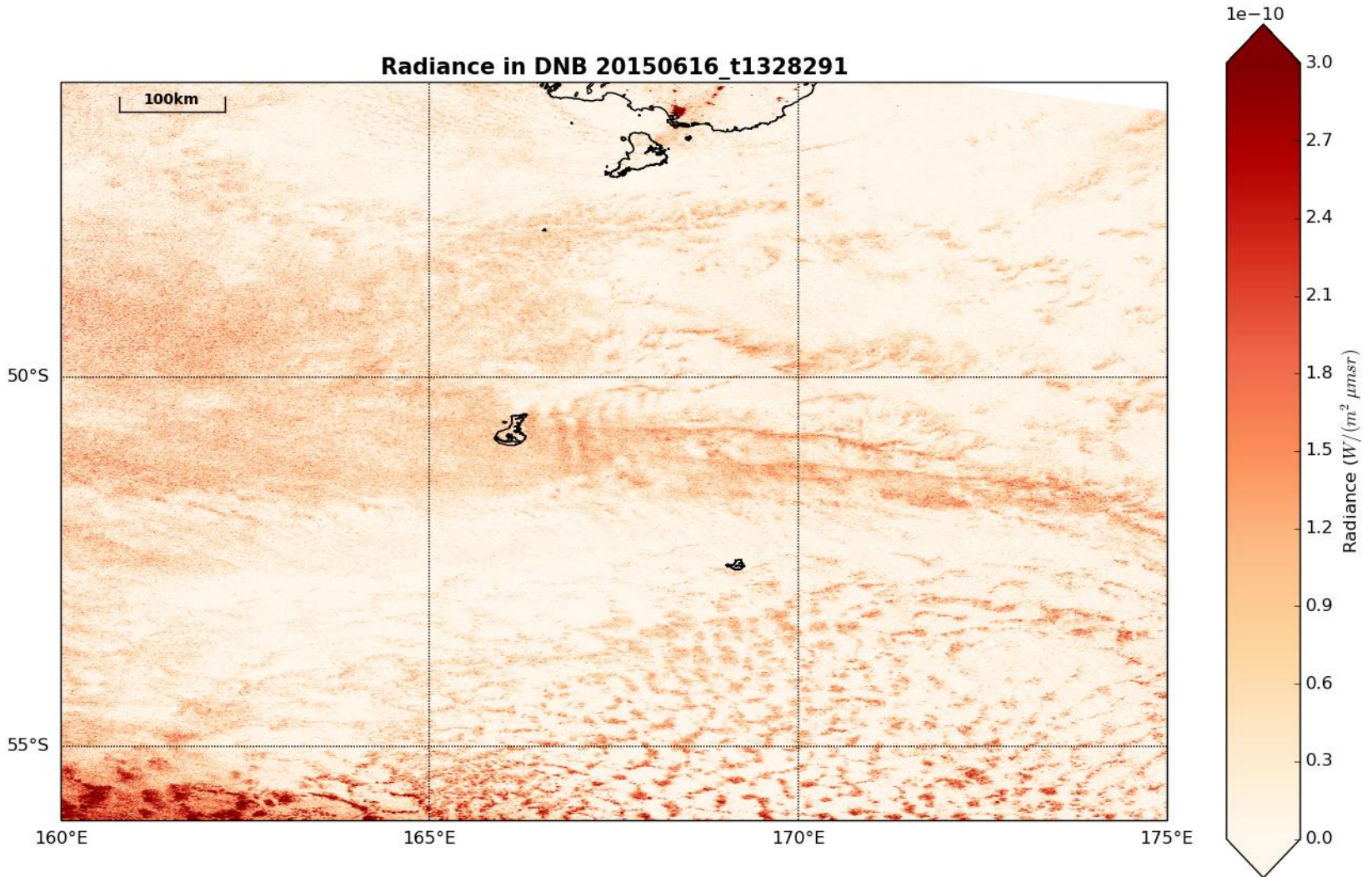




RF11 Predictability Flight 28 June 2014

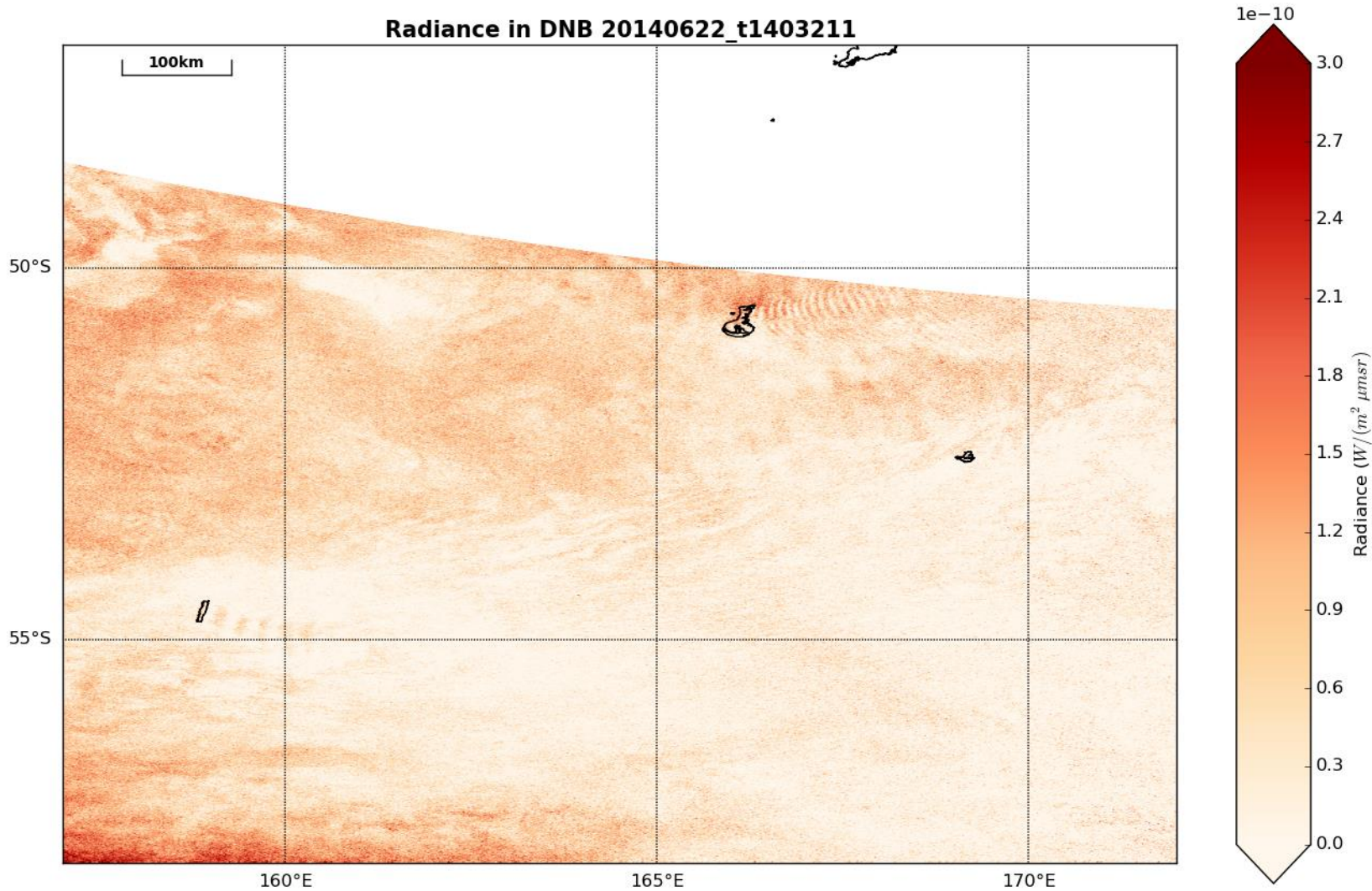


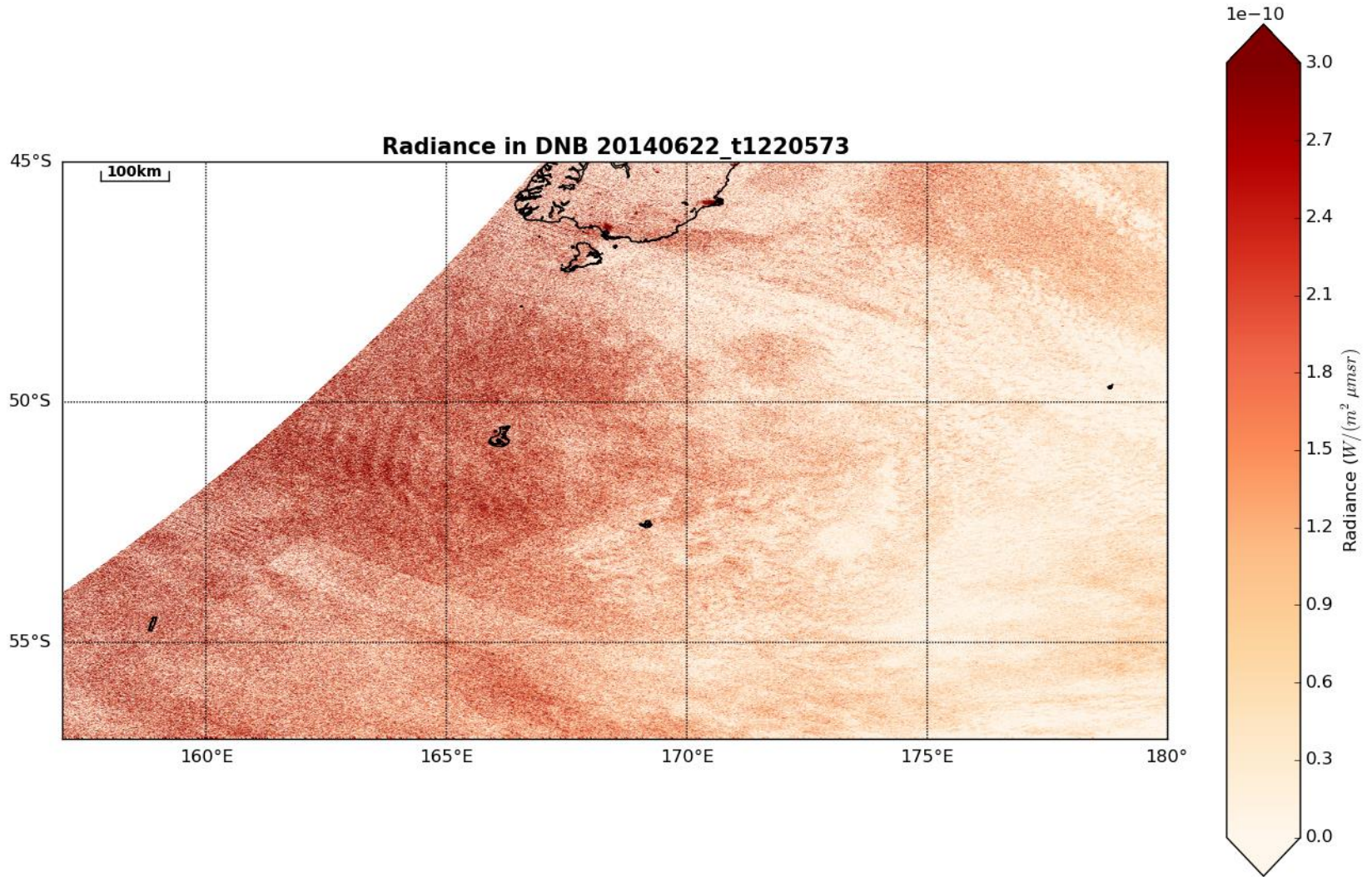






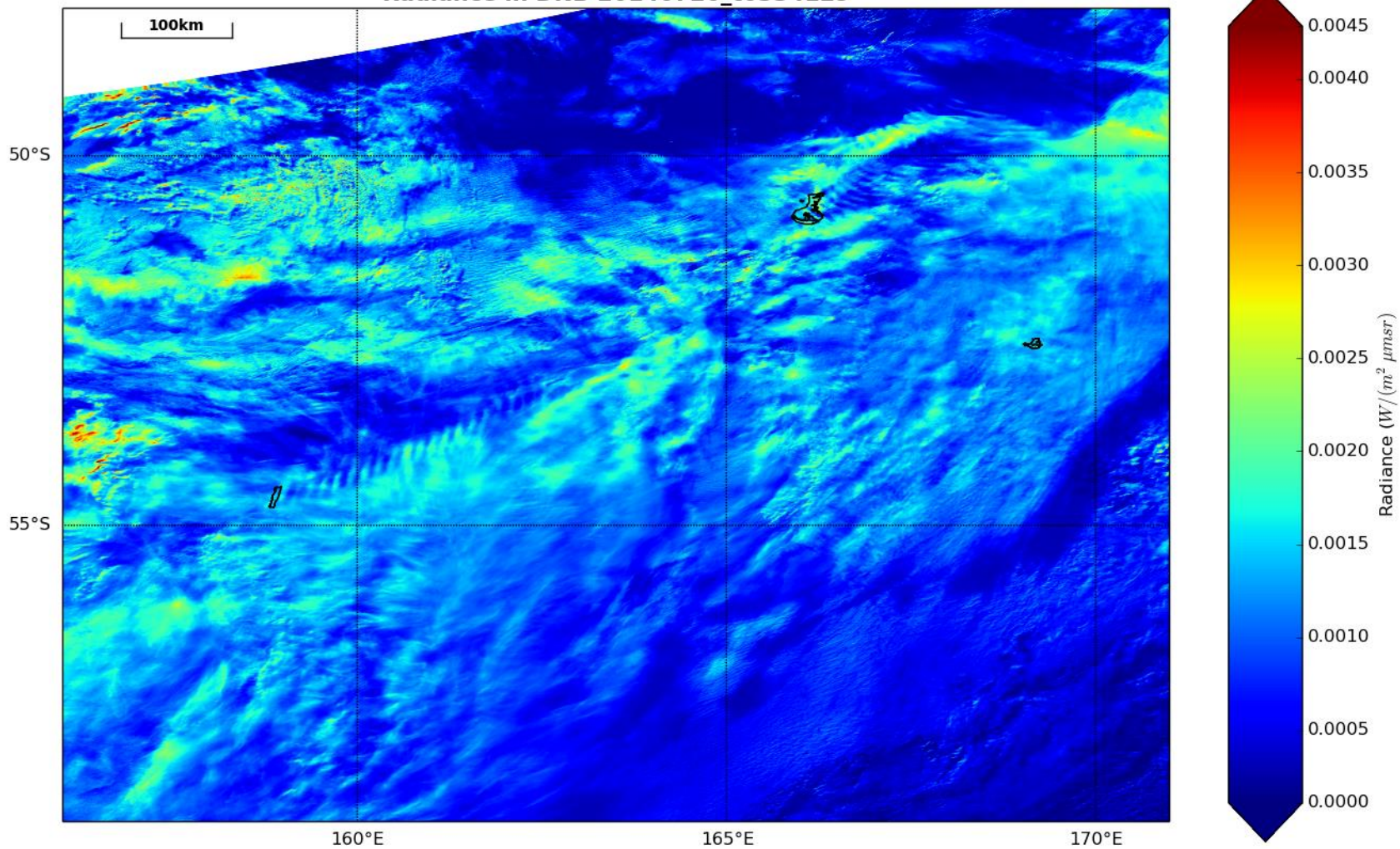
Radiance in DNB 20140622_t1403211

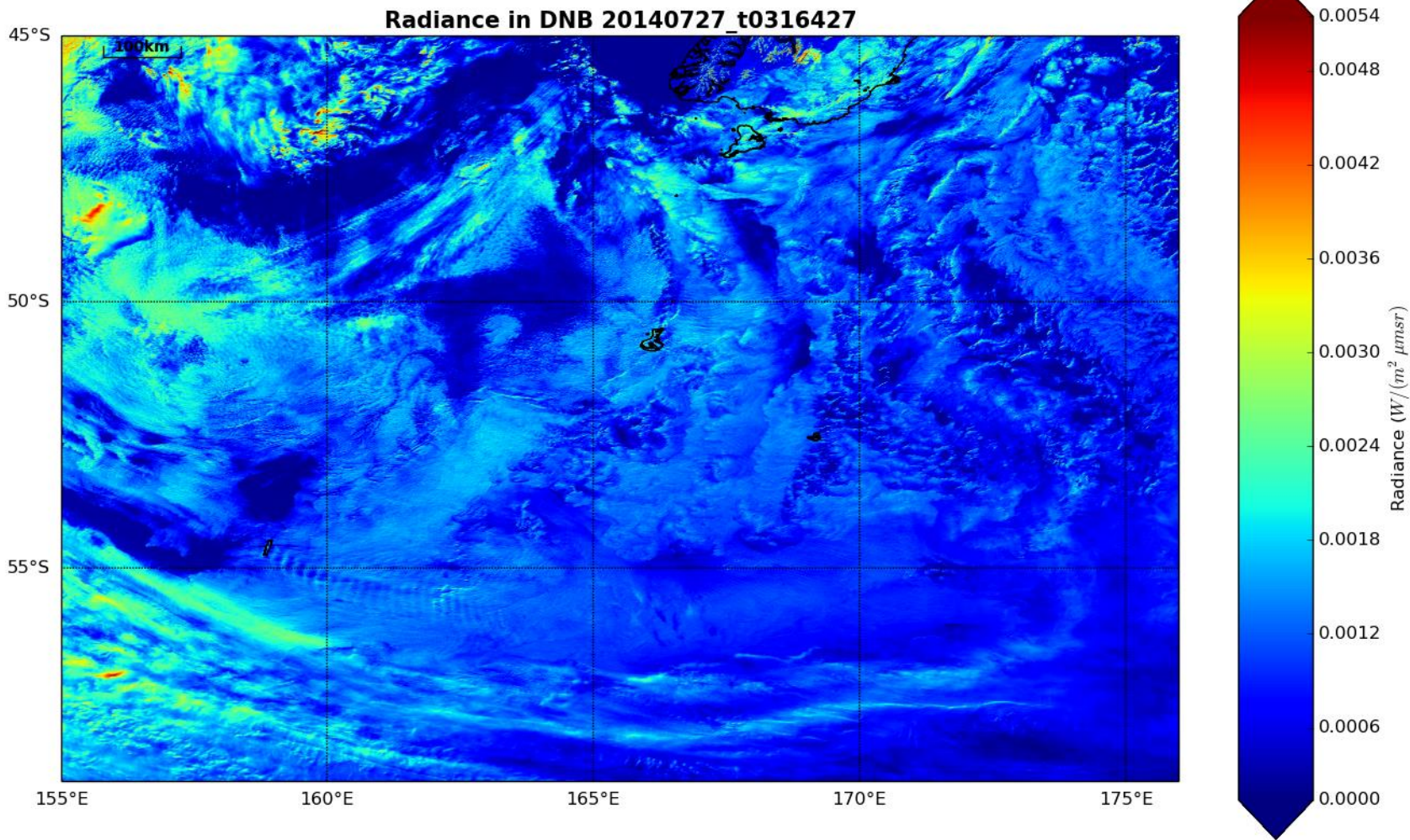


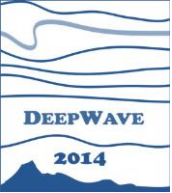




Radiance in DNB 20140726_t0334129

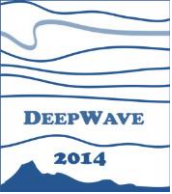






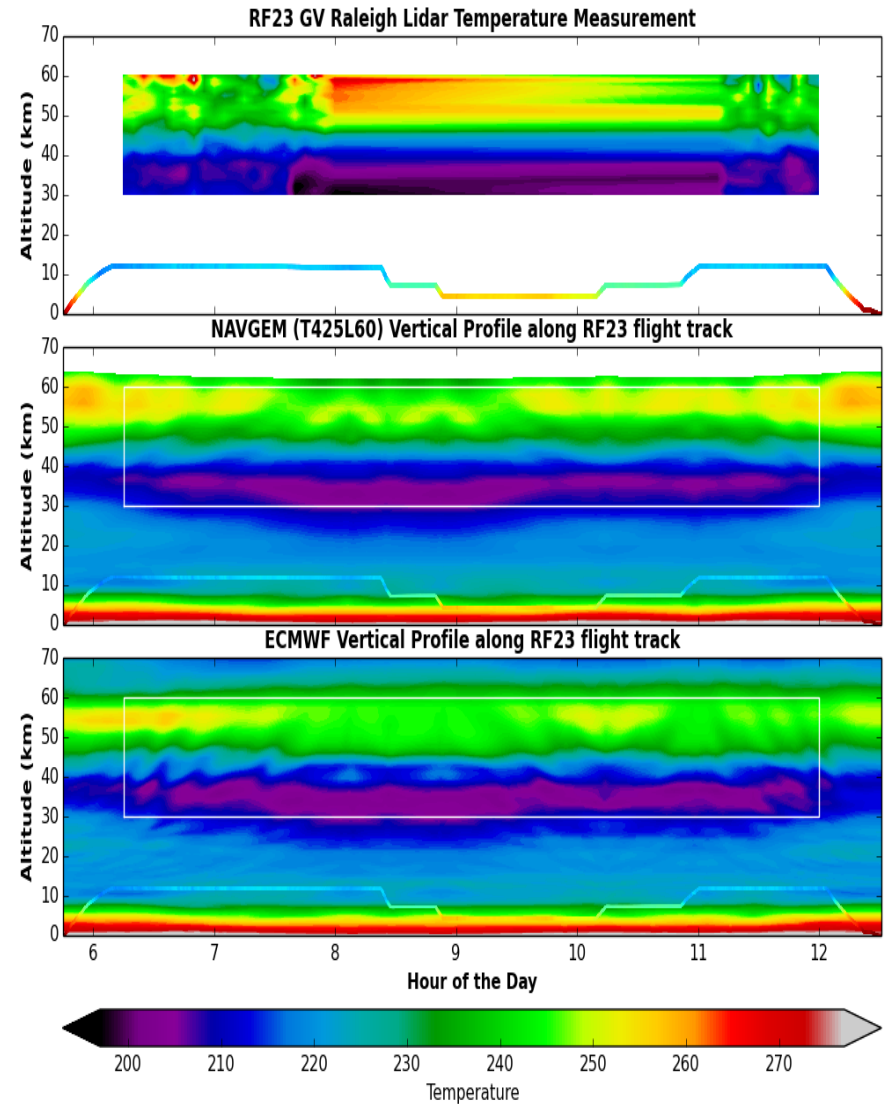
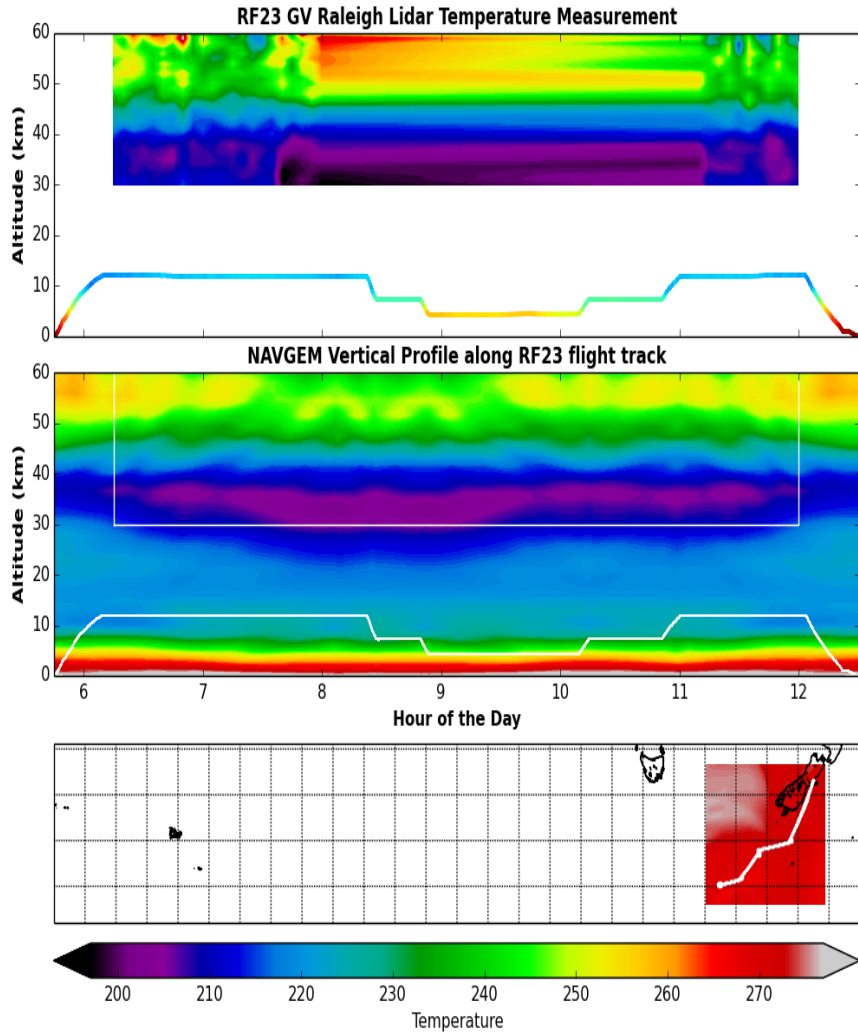
Plans for Next 6 Months

- Finalize write up AIRS wave forecasting work for AMS journal
- Finalize NAVGEM DEEPWAVE production system and generate final T425L74 (or higher vertical resolution) analyses for science studies
- Submit paper on the NAVGEM DEEPWAVE reanalysis project
- Finalize RF23 Auckland Island paper (Broutman et al. JAS 2015)
- Submit RF22 on lateral refraction of large-scale wave
- Use RF23 as test case for new NAVGEM orographic gravity wave drag parameterization
- Collaborate with Chris Kruse on AIRS/WRF comparisons
- Collaborate with Andreas on RF26 nonorographic waves
- Collaborate with Jim on horizontal shear modeling for gravity waves other than RF22 (using COAMPS idealized shear simulations)

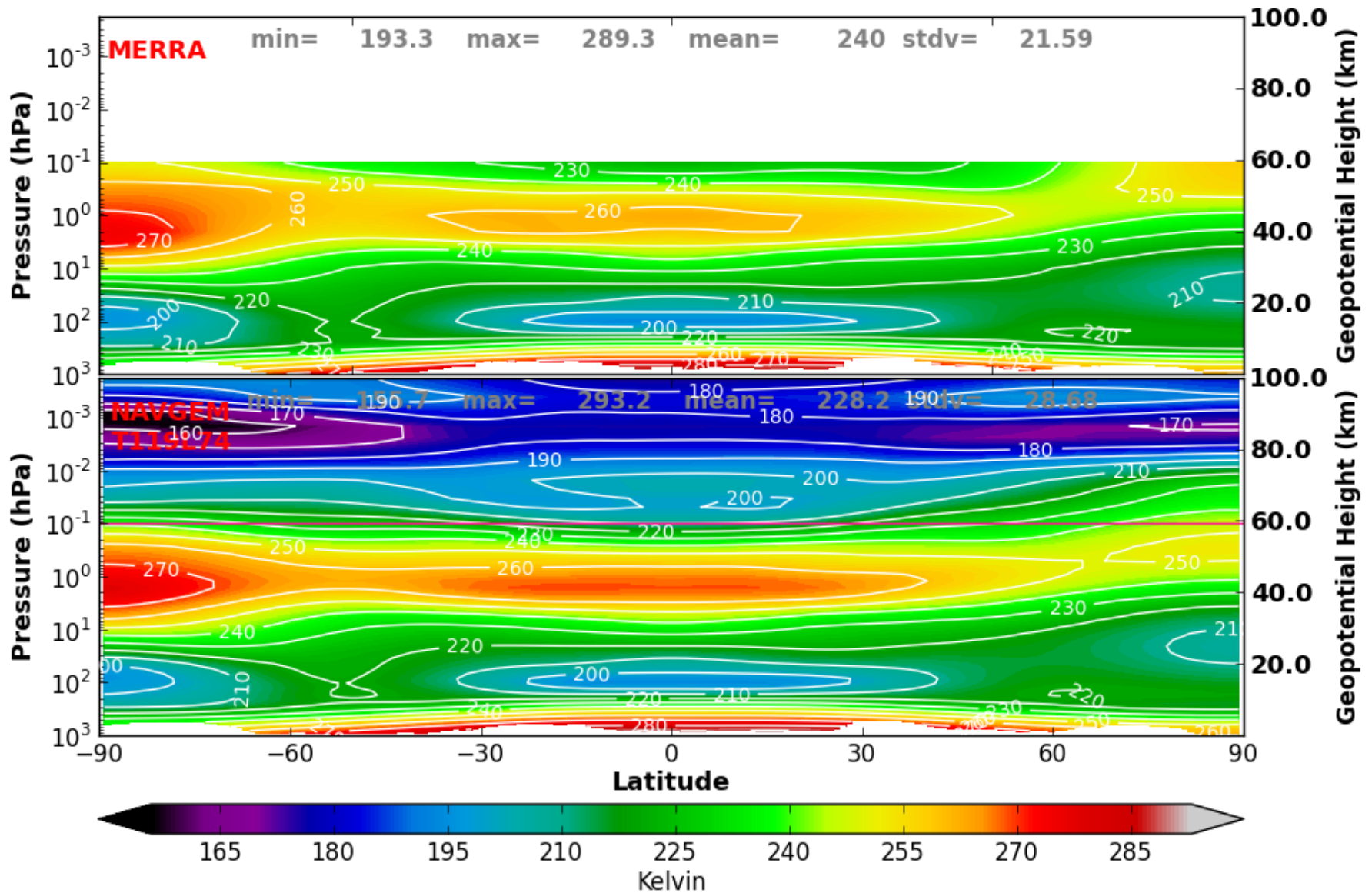


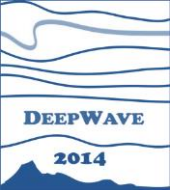
BACKUP SLIDES

Sections Along RF23 Flight Track



MERRA-NAVGEM Monthly Mean Temperature October 2014

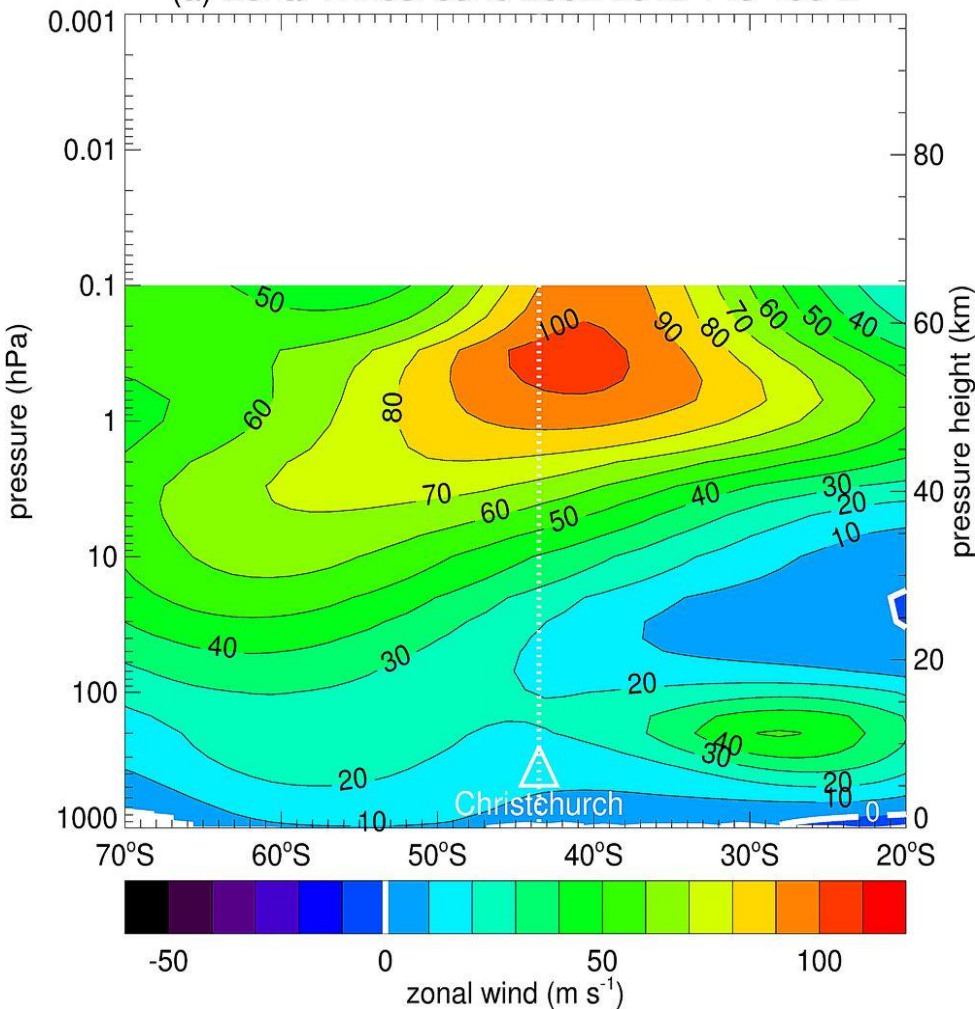




Zonal Mean Winds for June

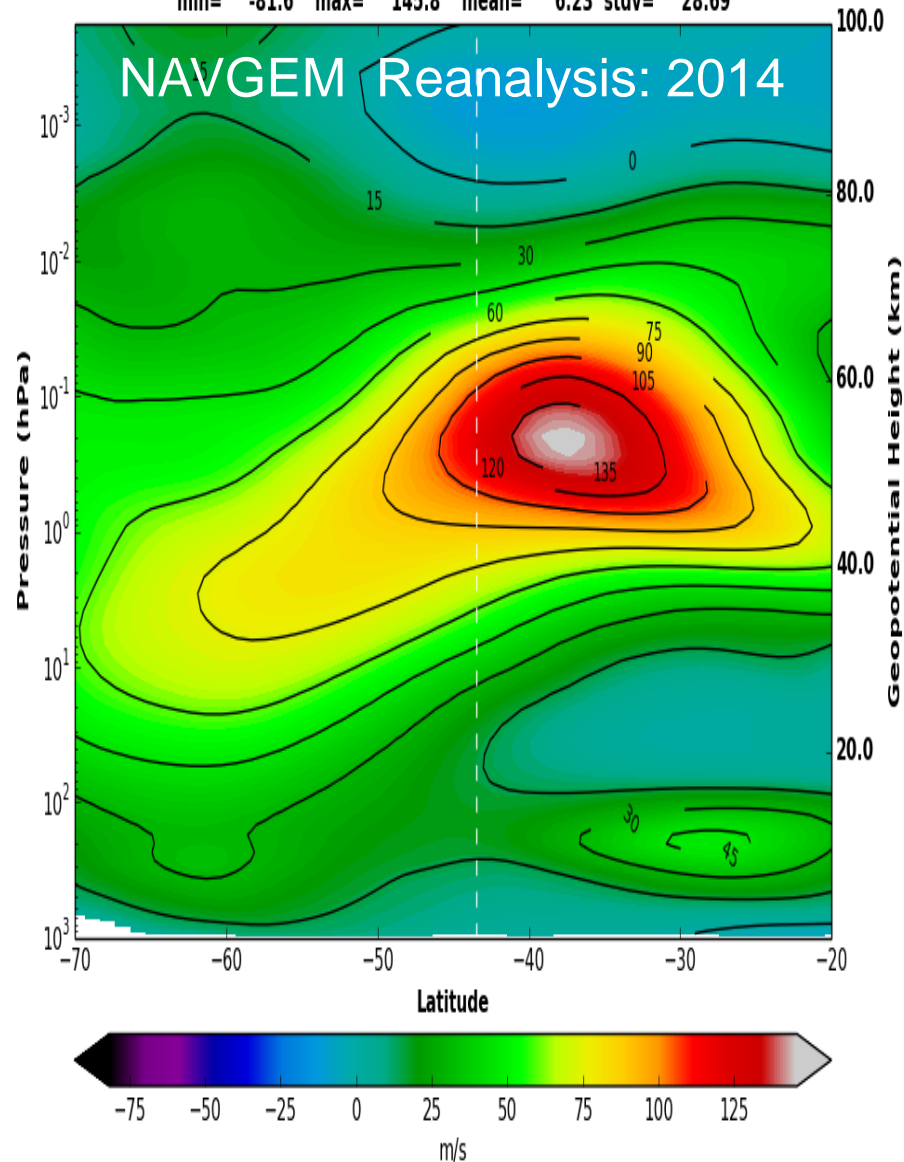
NASA MERRA Reanalysis: 2002-2012

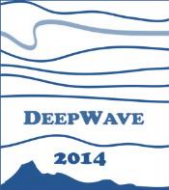
(a) Zonal Winds: June 2002-2012 140-190°E



Zonal Winds: June 2014 140-190° E

min= -81.6 max= 145.8 mean= 6.23 stdv= 28.69





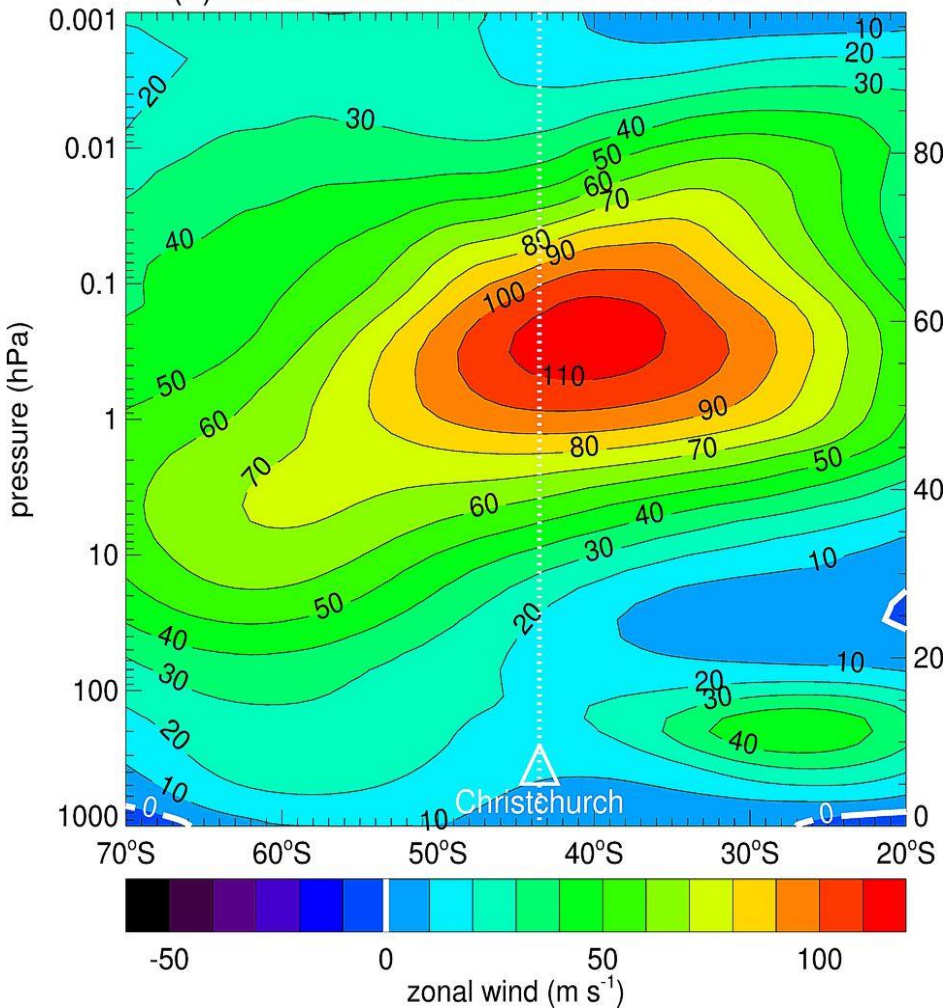
“Zonal Mean” (140-190E) Zonal Winds for June

Zonal Winds: June 2014 140-190° E

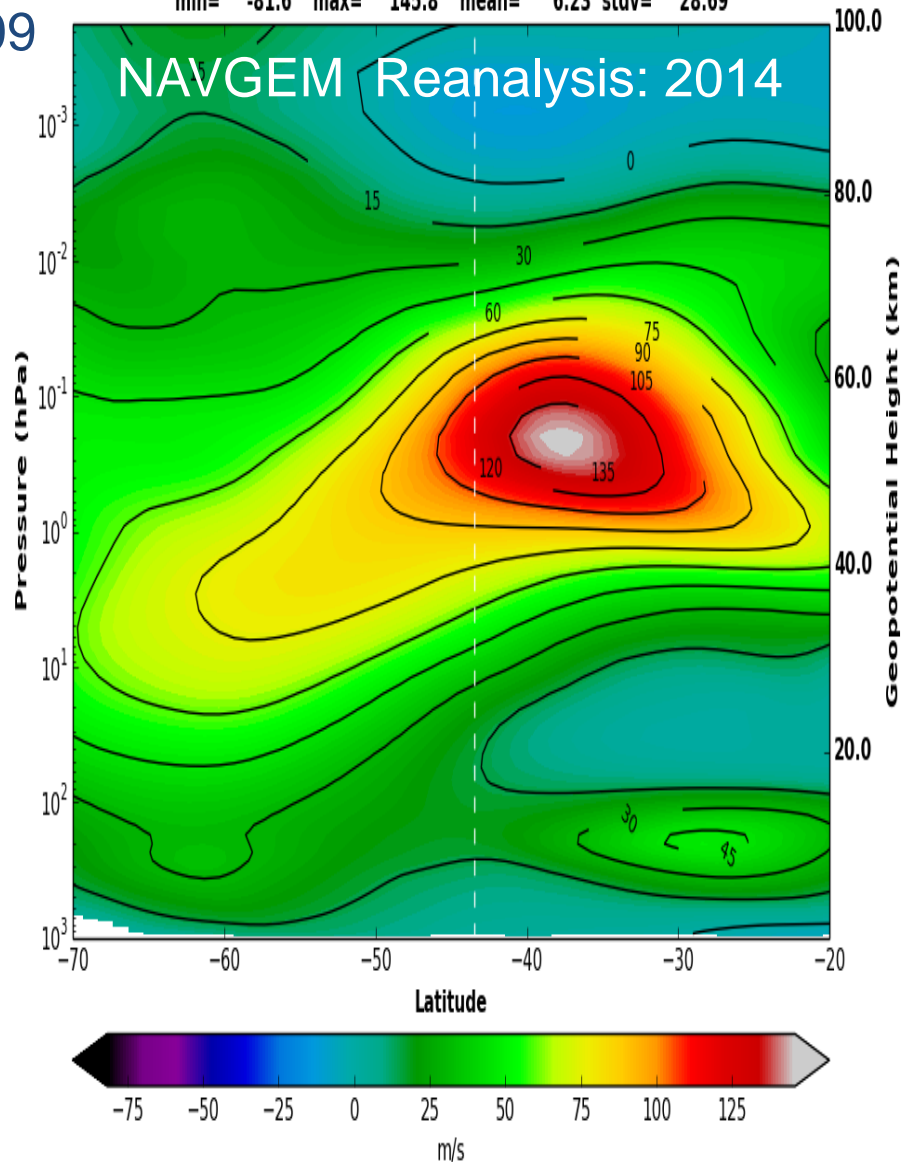
min= -81.6 max= 145.8 mean= 6.23 stdv= 28.69

NOGAPS-ALPHA Reanalysis: 2007-2009

(a) Zonal Winds: June 2007-2009 140-190° E

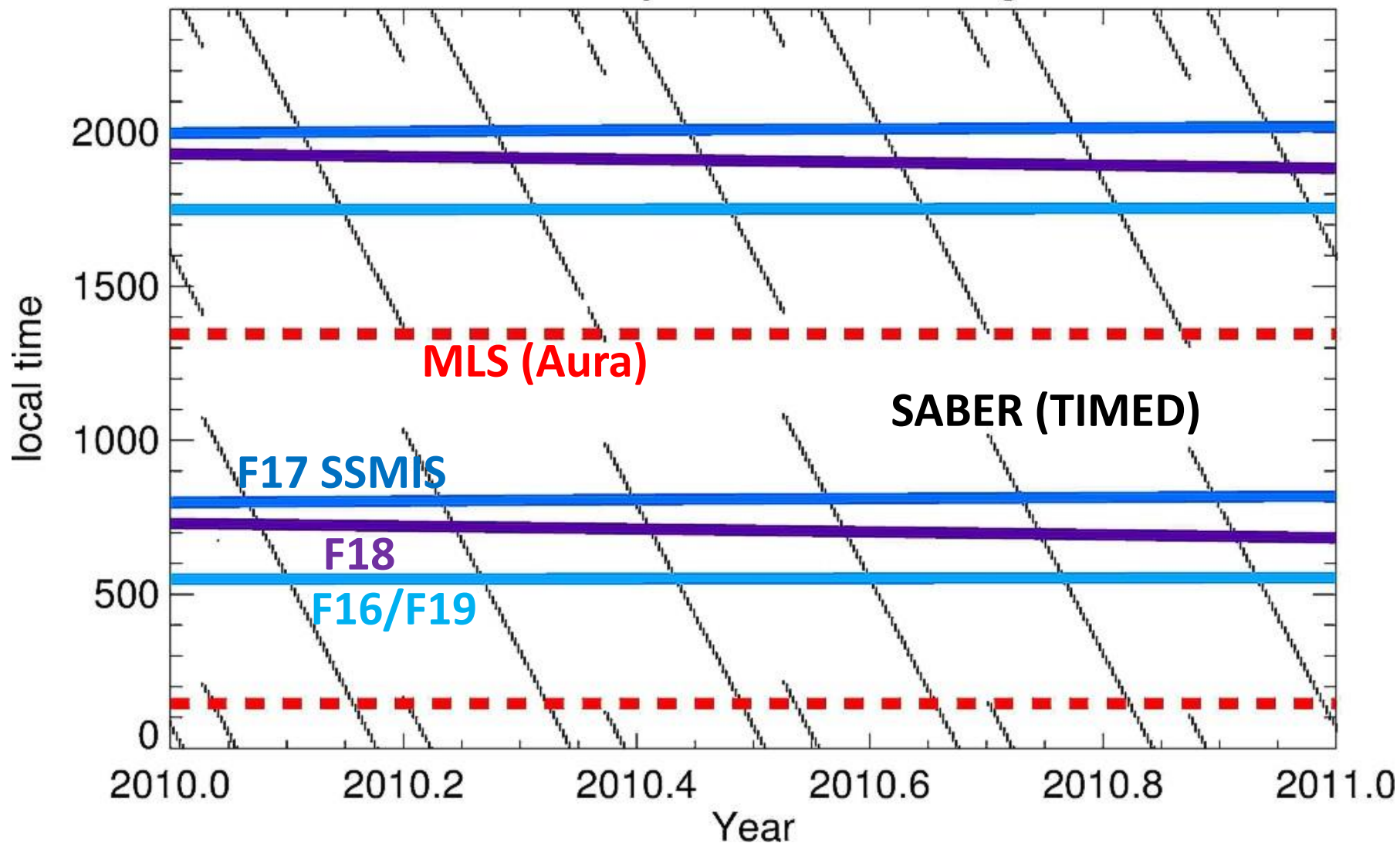


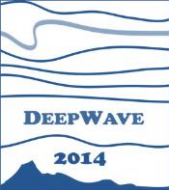
NAVGEM Reanalysis: 2014



Local Time Coverage in MLT

Limb & Nadir Equatorial Crossing Times

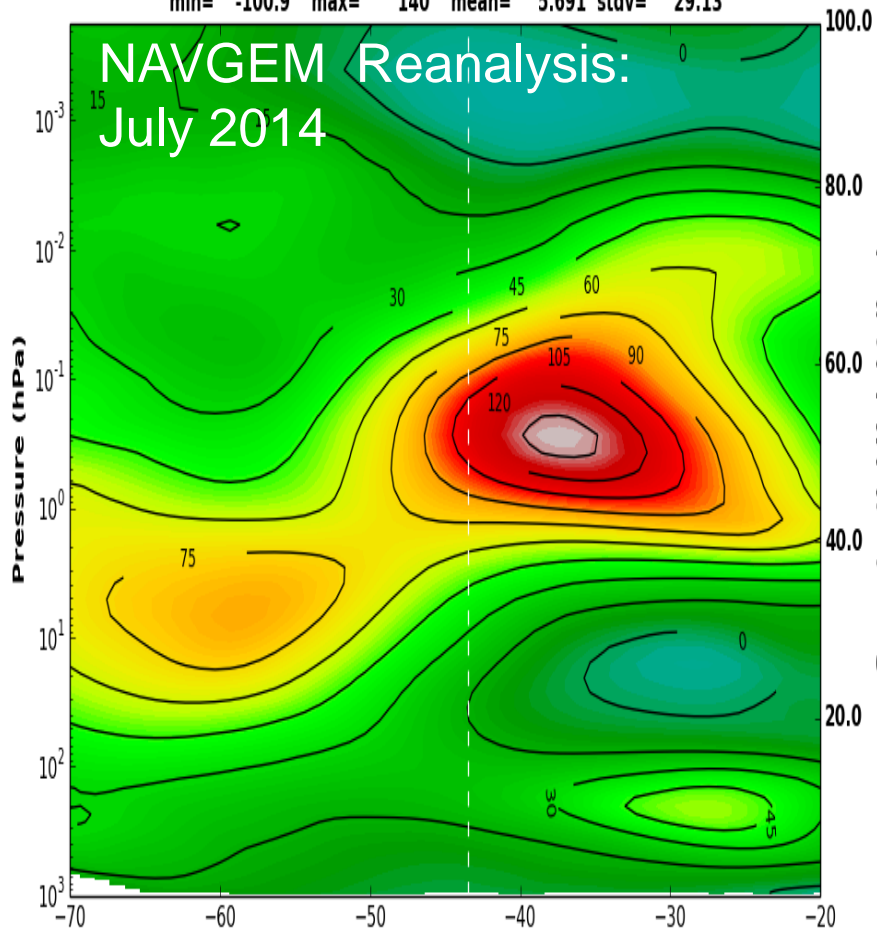




NAVGEM: June vs. July 2014

Zonal Winds: July 2014 140-190° E

min= -100.9 max= 140 mean= 5.691 stdv= 29.13



Zonal Winds: June 2014 140-190° E

min= -81.6 max= 145.8 mean= 6.23 stdv= 28.69

