OSSEs in the JCSDA

Presentation at AMS annual meeting

Observing System Simulation Experiments in the Joint Center for Satellite Data Assimilation, *18th Conference on Satellite Meteorology, Oceanography and Climatology/ First Joint AMS-Asia Satellite Meteorology Conference*, **Lars Peter Riishojgaard et al.**

Impact of Different Wind Lidar Configurations on NCEP Forecast Skill. *16th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface (IOAS-AOLS*), **Zaizhong Ma et al.**

Posters

Internationally Collaborative Joint OSSEs - Progress At NOAA, T. N. Krishnamulti Synposium, **Michiko Masutani** (EMC) et al.

Joint OSSEs at NOAA, Evaluation of DWL, JPSS, and DWSS, *Eighth Annual Symposium on Future Operational Environmental Satellite Systems*, **Michiko Masutani** et al

Observing System Simulation Experiments in the Joint Center for Satellite Data Assimilation

Lars Peter Riishojgaard[1,2], Zaizhong Ma[1,2],
Michiko Masutani[3], Jack Woollen[3],
Dave Emmitt[4], Sid Wood[4], Steve Greco[4]

[1]*Joint Center for Satellite Data Assimilation*
[2]*University of Maryland College Park*
[3]*NCEP Environmental Modeling Center*
[4]*Simpson Weather Associates*

Role of a National OSSE Capability

- Impact assessment for future missions
  - Future operational observing systems (NOAA)
  - Decadal Survey and other science and/or technology demonstration missions (NASA)
  - Other agencies (e.g. DoD/DWSS)
- Objective way of establishing scientifically sound and technically realistic user requirements
- Tool for assessing performance impact of engineering decisions made throughout the development phases of a space program or system
- Preparation/early learning pre-launch tool for assimilation users of data from new sensors

Joint OSSE history

- NASA/NOAA collaboration started in 2007, involving NASA/GSFC, NOAA/NESDIS, NOAA/NWS, NOAA/OAR
- Centered around common use of Nature Run provided free of charge by ECMWF
- Coordinated through JCSDA
  - Informal, loosely structured nature, lack of common funding stream has presented challenges
- Successful joint validation of ECMWF Nature Run
- Some collaboration on simulation and calibration of observations
- ADM experiments (GMAO)
- GWOS experiments (JCSDA)
- UAS experiments (OAR)

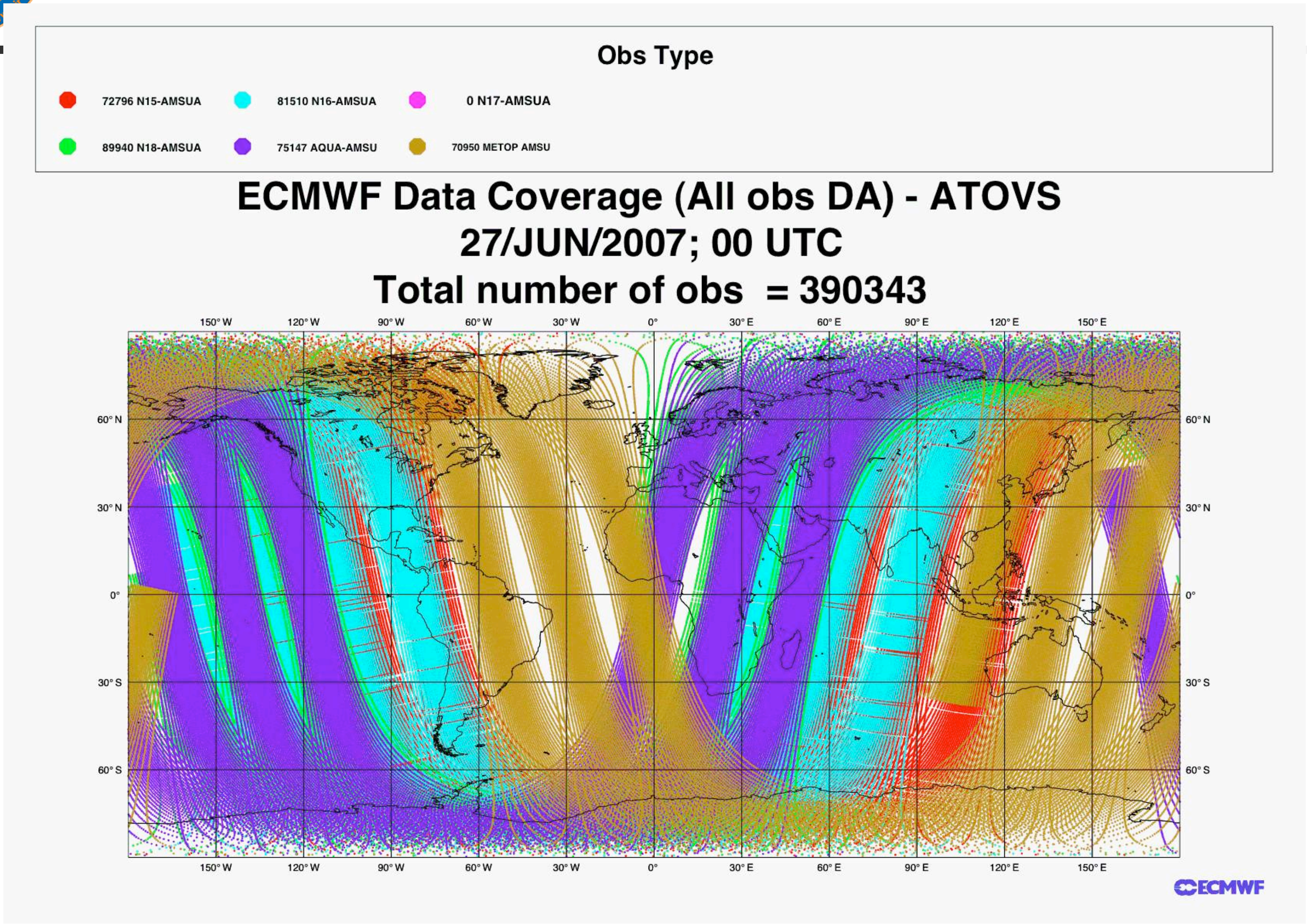
Wind Lidar OSSEs

- Impact experiments for GWOS mission concept
  - NASA Tier-3 Decadal Survey mission concept
  - Four telescopes, full vector winds on either side of spacecraft
  - Two technologies, direct and coherent detection
- Experiments funded under Wind Lidar Science element of NASA's ROSES 2007
- GWOS observations simulated by Simpson Weather Associates using DLSM

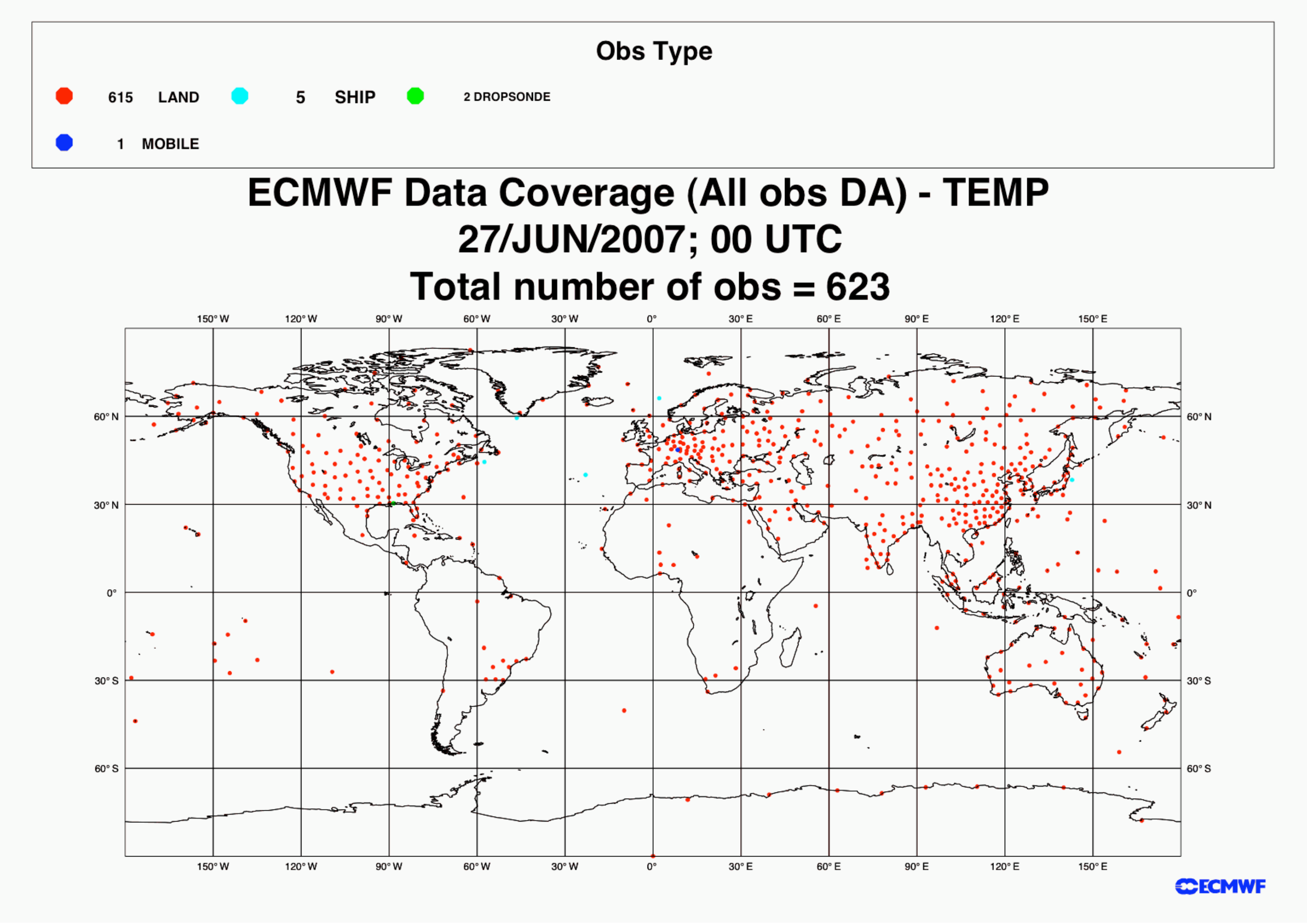
Which upper air observations do we need?

- Numerical weather prediction requires independent and global observations of the **mass** (temperature) and **wind** fields
- The global three-dimensional mass field is well observed from space
- No existing space-based observing system provides vertically resolved wind information => horizontal coverage of wind profiles is sparse

Temperature profiles (AMSU; 6 hours)



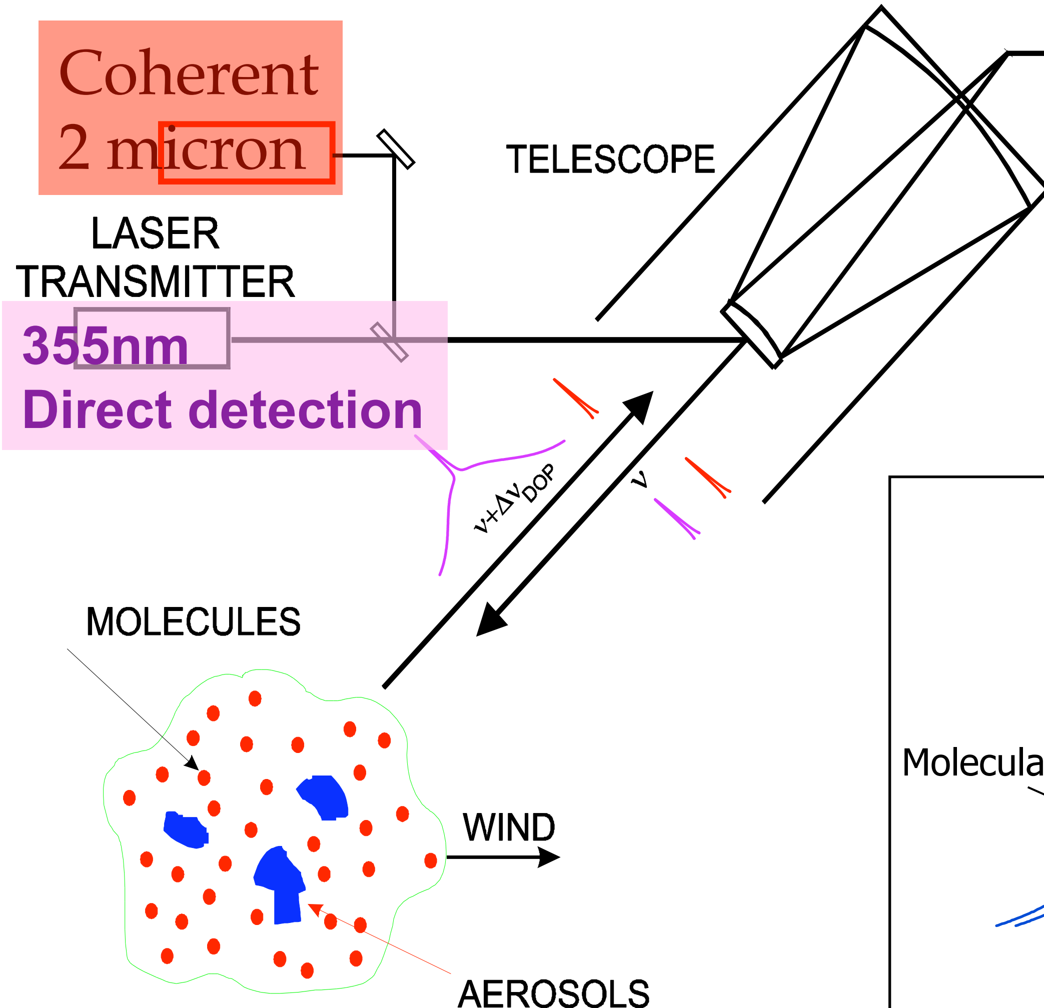
Observed wind profiles (RAOBs, 6 h)

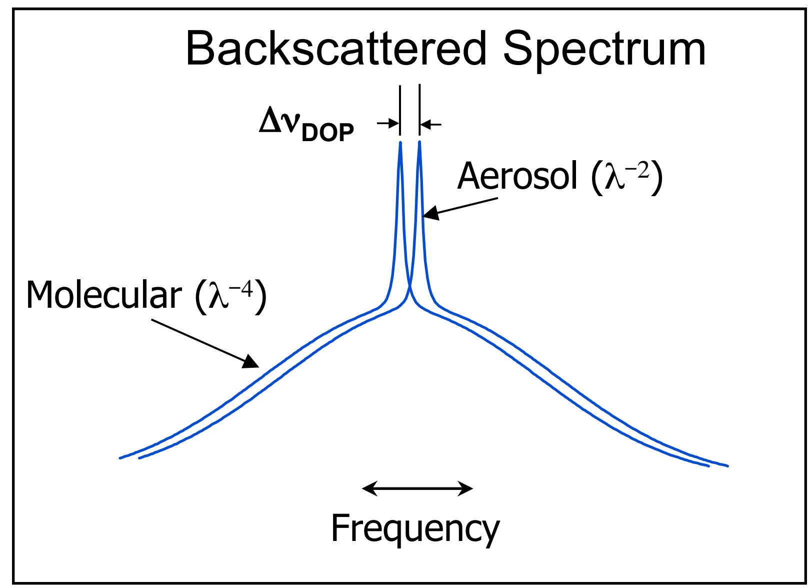


Doppler Lidar Measurement Concept

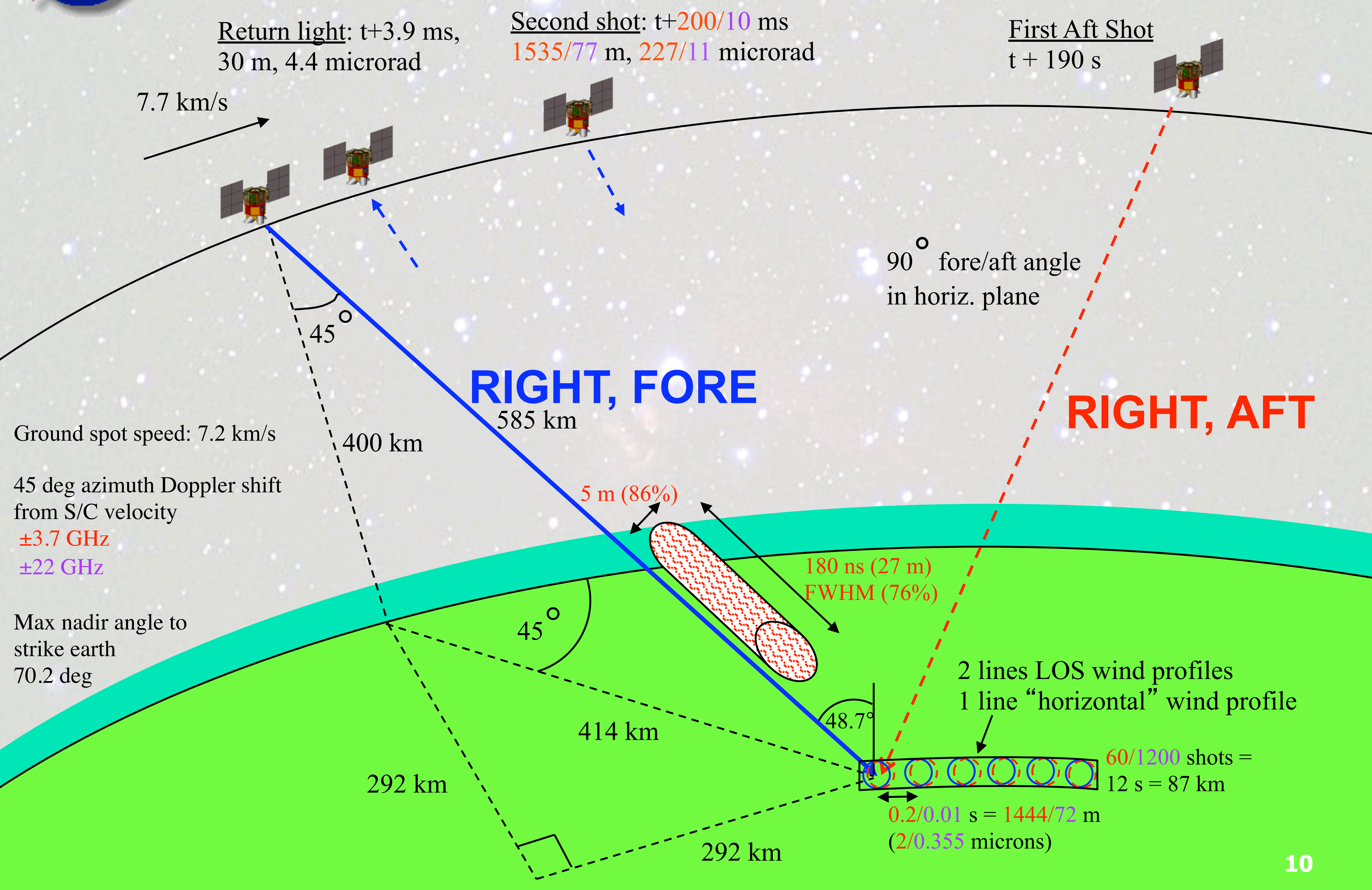
DOPPLER RECEIVER - Multiple flavors - Choice drives science/ technology trades

- Coherent or heterodyne aerosol Doppler receiver
- Direct detection molecular Doppler receiver

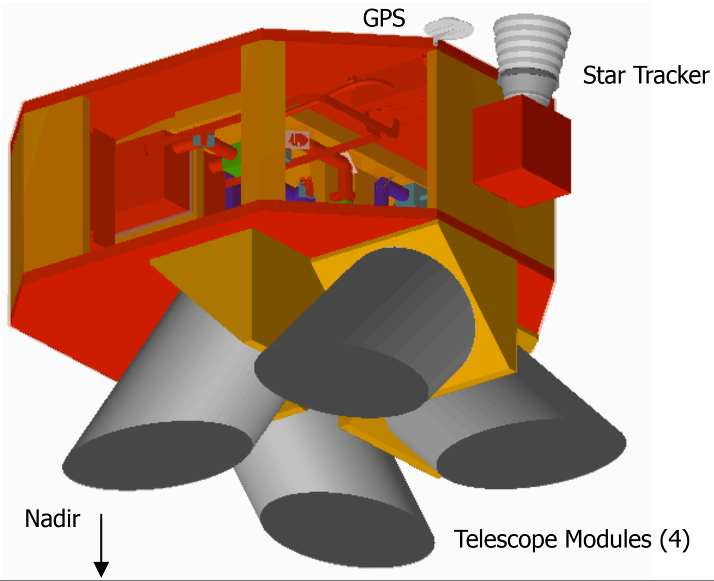




Hybrid Doppler Wind Lidar Measurement Geometry: 400 km



GWOS ISAL Instrument Quad Chart



Features of the Instrument Concept

- Utilizes Doppler lidar detection method
  - Coherent (aerosol) detection @ 2 μm
  - Direct (molecular) detection @ 355 nm
- Direct channel laser based on GLAS;
- Direct channel receiver based on TWiLiTE IIP
- Coherent channel laser and receiver based on DAWN IIP
- Telescopes are shared among all lasers
- Pointing and knowledge requirements met with co-located star tracker and GPS

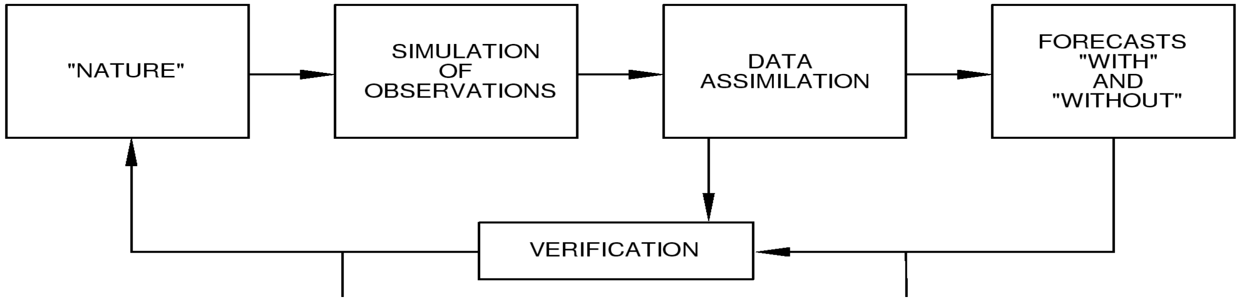
Payload Data

Dimensions	1.5m x 2m x 1.8m
Mass	567 Kg
Power	1,500 W
Data Rate	4 Mbps

Technology Development Needs

- **Direct detection system requires 6 billion shots for mission lifetime (2 years)**
  - Direct channel baseline is 3 lasers + 1 backup
  - Demonstration of reliable performance at higher or lower lifetimes will determine number of lasers for direct detection channel, impacting mission cost
- **Coherent detection system requires demonstration of the 316M shot lifetime in a fully conductively cooled laser**
- **Both Lidar technologies require aircraft validation flights**

Observing System Simulation Experiments

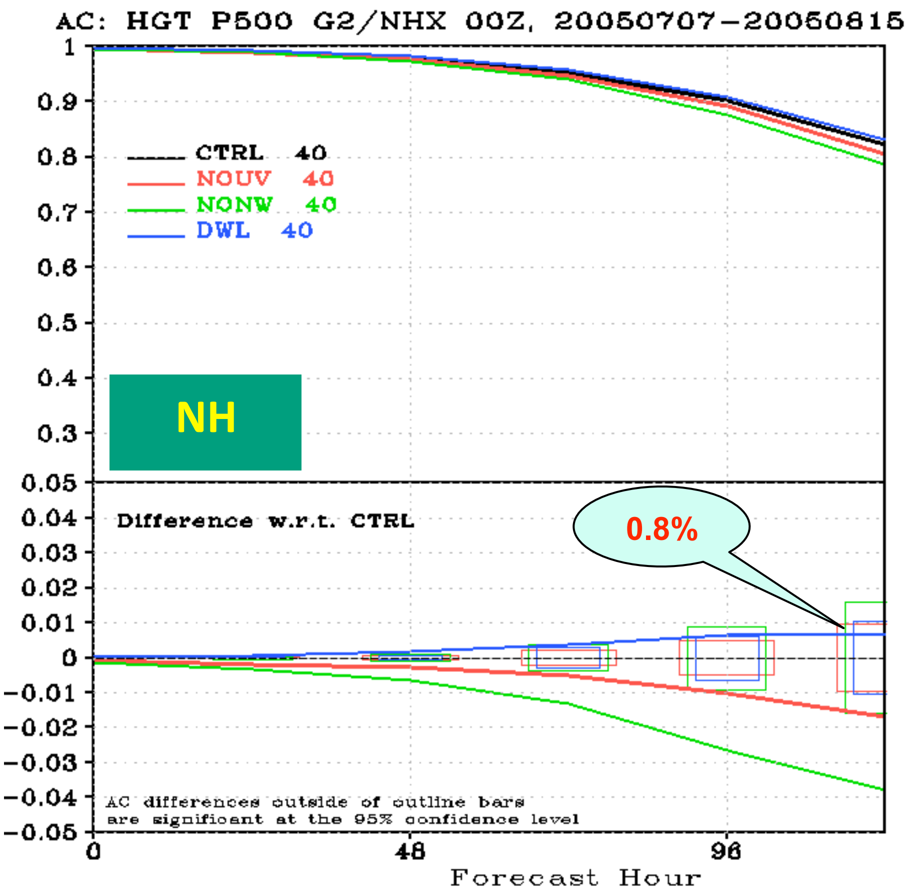


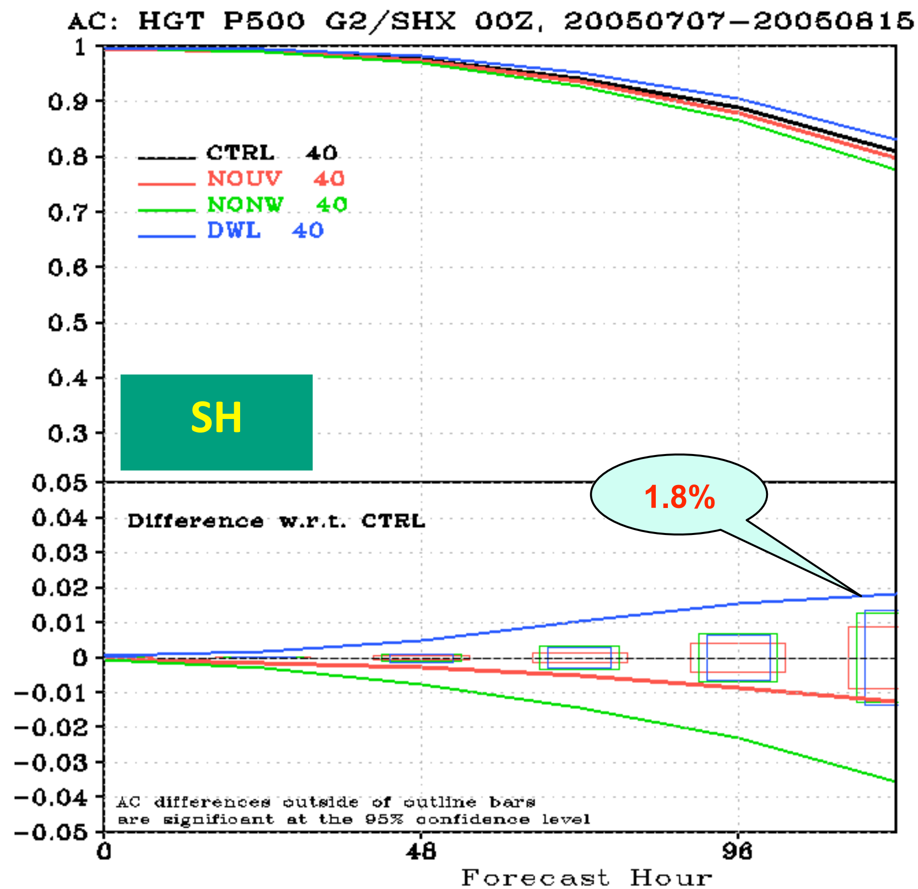
- Data assimilation system(s)
  - NCEP/EMC Global Forecast System (T-382) coupled with GSI
- Nature run
  - ECMWF T-511, commissioned for Joint OSSE
    - 13 month period (May 2005-June 2006)
    - Validated extensively through Joint OSSE collaboration
- Simulated observations
  - Reference observations, including satellite radiance data (all observation)
  - Perturbation (“candidate”) observations
  - GWOS observations simulated by Simpson Weather Associates
- Diagnostics capability
  - NCEP operational verification system

Experimental setup

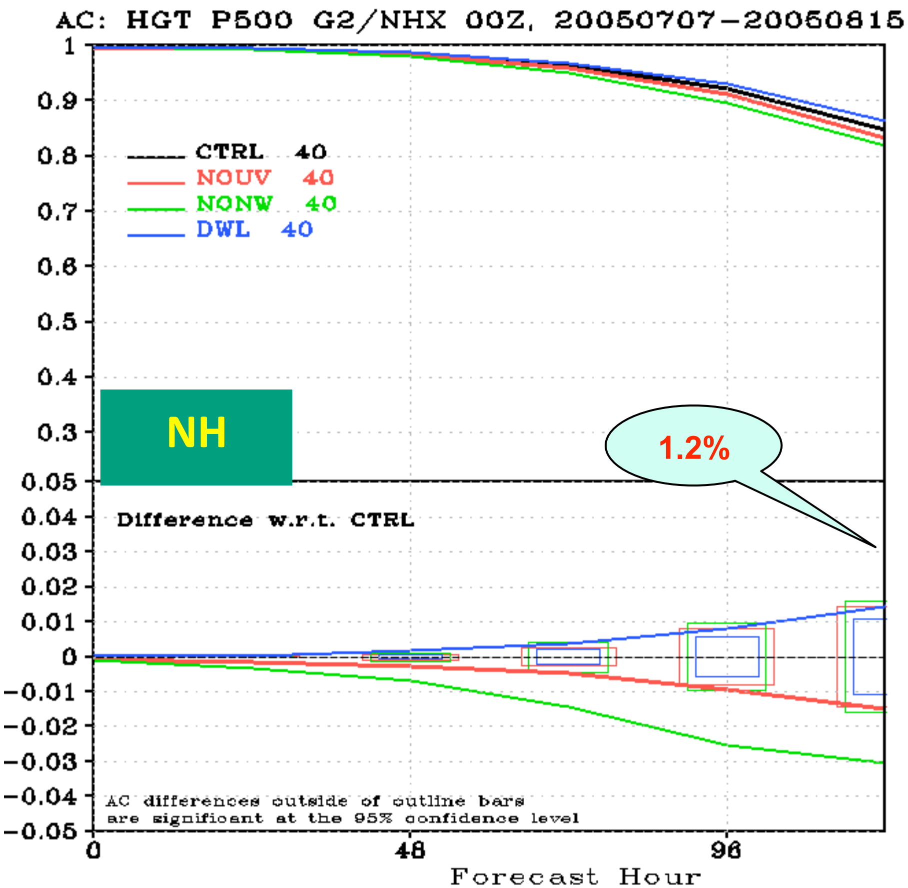
- NCEP GFS at a range of horizontal resolutions between T-126 and T-382 (previous operational resolution at NCEP; NR cannot accommodate current T-574 resolution)
- "OSSE period": July 01-Aug 15, 2005 (simulated)
  - Five-day forecast launched every day at 00Z
  - Most observing systems used for routine operational NWP included, except GPSRO and IASI (will be included once we simulate 2010/11 GOS)
- Four experiments, all verified against Nature Run
  - CRTL: Observations as assimilated operationally by NCEP
  - NOUV: as CTRL, but without RAOBS (220, 221 and 232)
  - NONW: as CTRL, but without any wind observations
  - DWL : as CTRL, plus simulated GWOS lidar wind data
- Experiments done with "perfect data"
  - No observation error added (simple random errors tested; no significant changes to conclusions)
  - Simulated with assumed observation errors used in operations

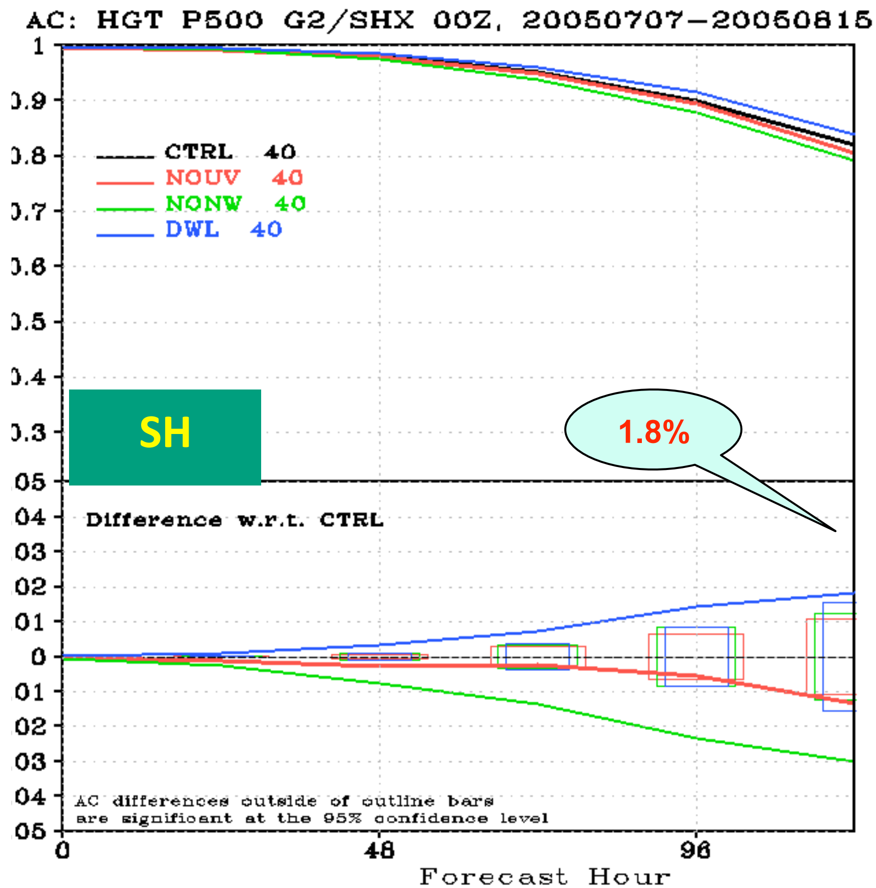
500hPa HGT anomaly correlation coefficients (T126)





500hPa HGT anomaly correlation coefficients (T382)

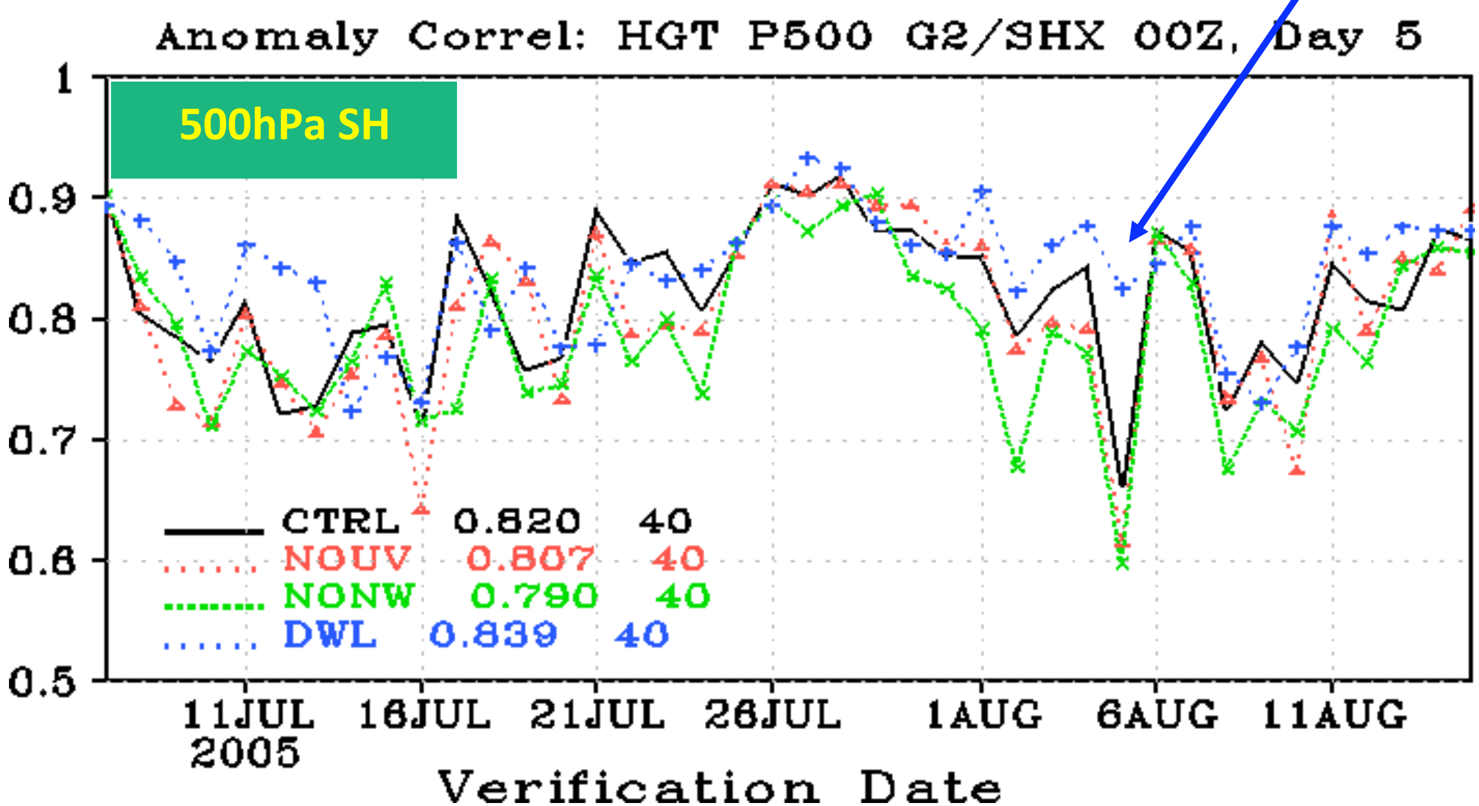




Impact of DWL observations is larger at the higher resolution (T382), even though skill of control is higher

Time series of 500hPa geopotential height AC

Candidates for additional study

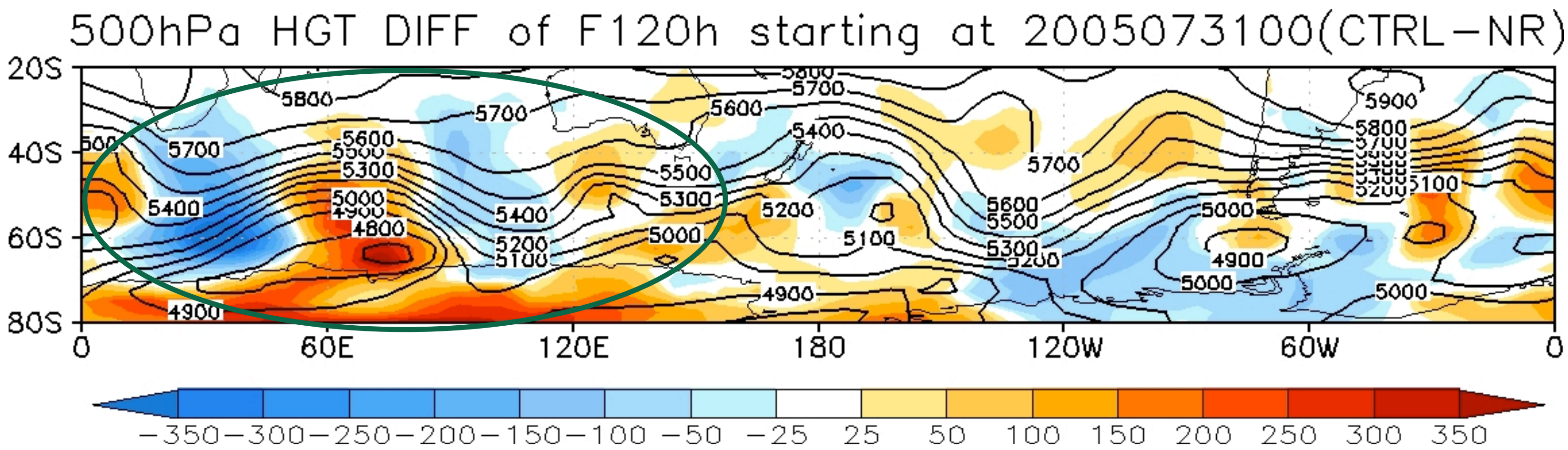


Special Case Study:

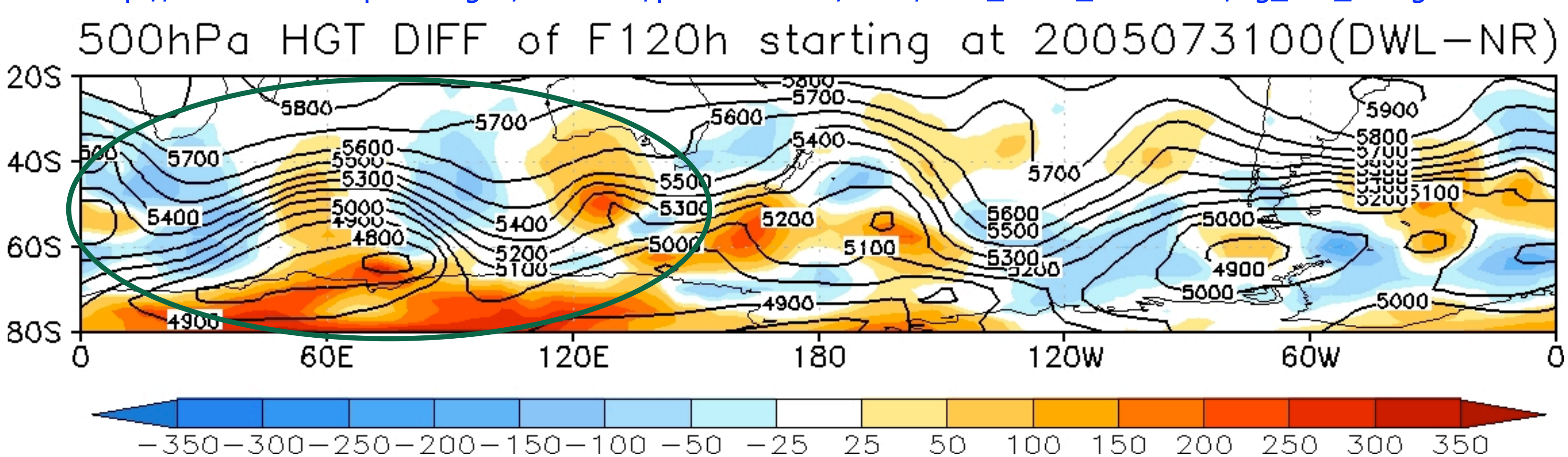
5 days forecast starting from July 31st

Open the link for the movies

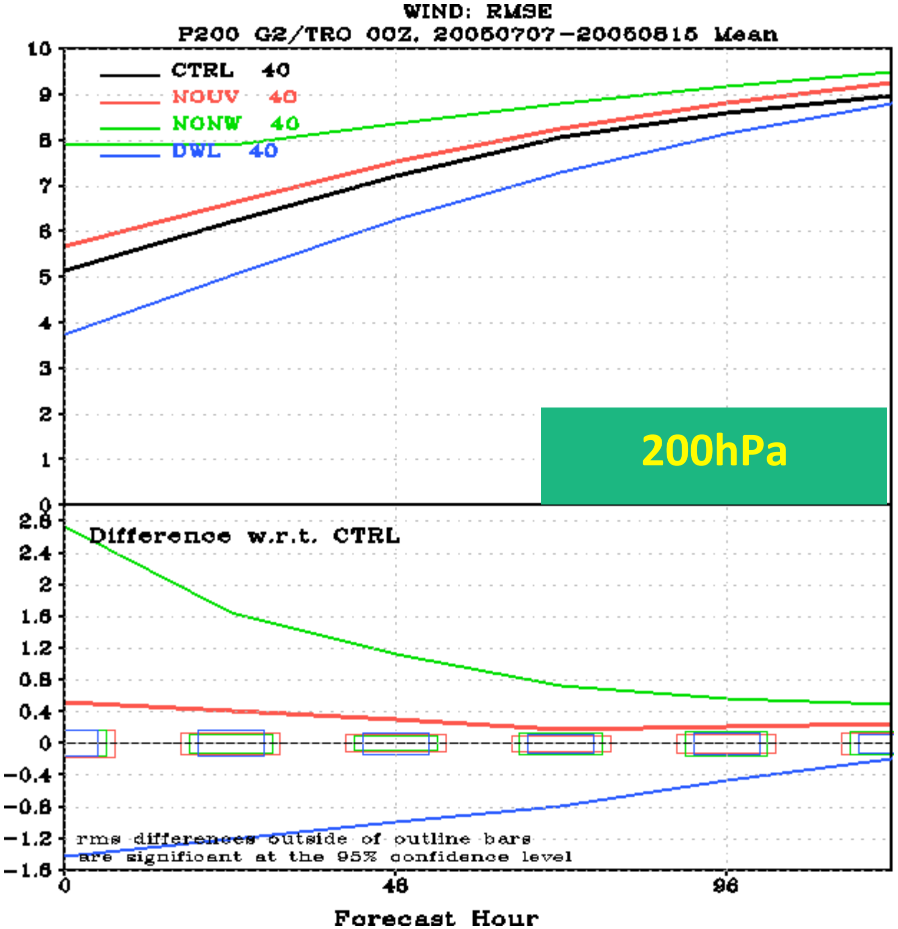
http://www.emc.ncep.noaa.gov/seminars/presentations/2012/WLS_OSSE_20120214/fig_ctrl_100.gif

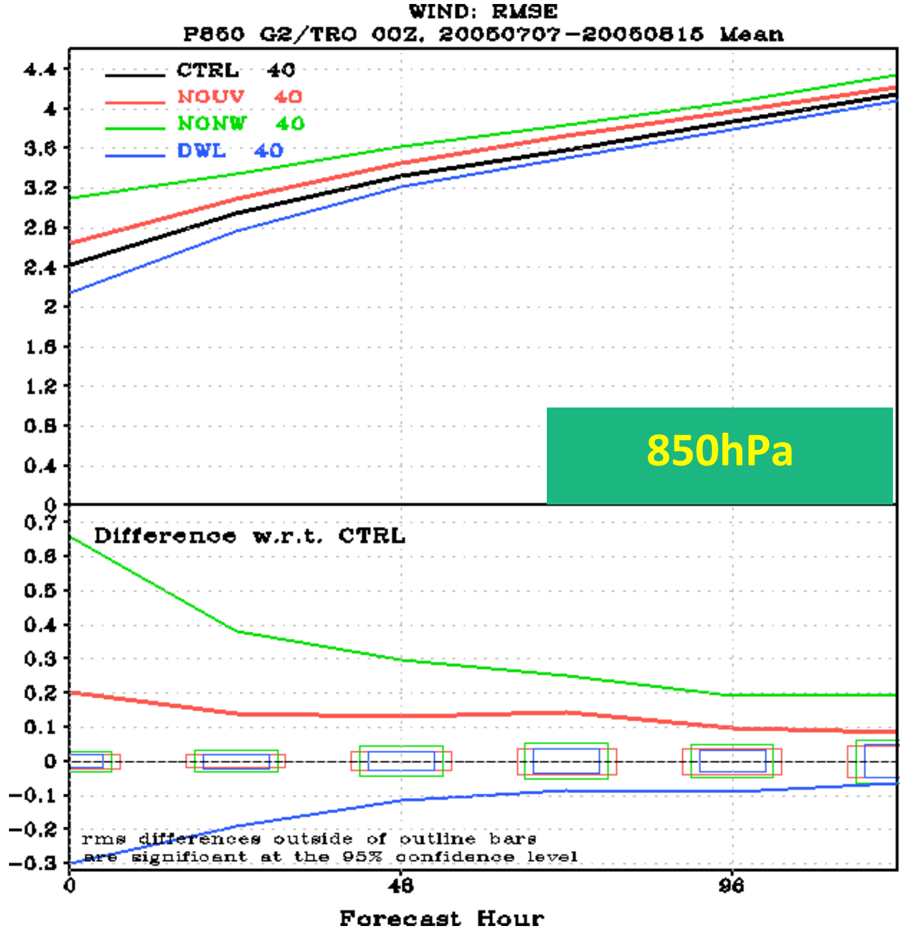


http://www.emc.ncep.noaa.gov/seminars/presentations/2012/WLS_OSSE_20120214/fig_dwl_100.gif



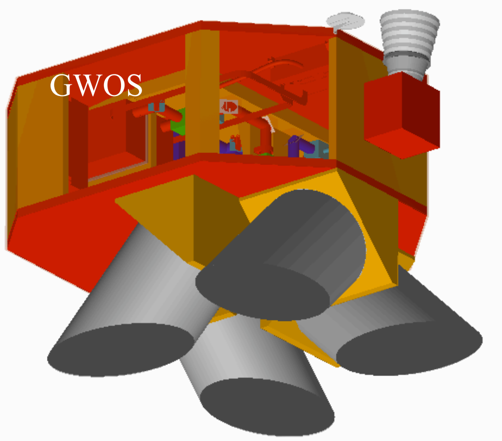
RMSE: 200, 850hPa Wind error in tropics (T382)





Single LOS or Vector Winds?

- Important configuration issue for GWOS (impact vs. cost); ESA's ADM/ Aeolus wind mission has single Light-of-Sight (LOS).
- Experiments need to be performed with variable number of perspectives:
  - One; single line of sight, similar to ADM/Aeolus
  - Two; full horizontal wind vectors, left or right side of satellite track
  - Four; full GWOS coverage; wind vectors on both sides of satellite track

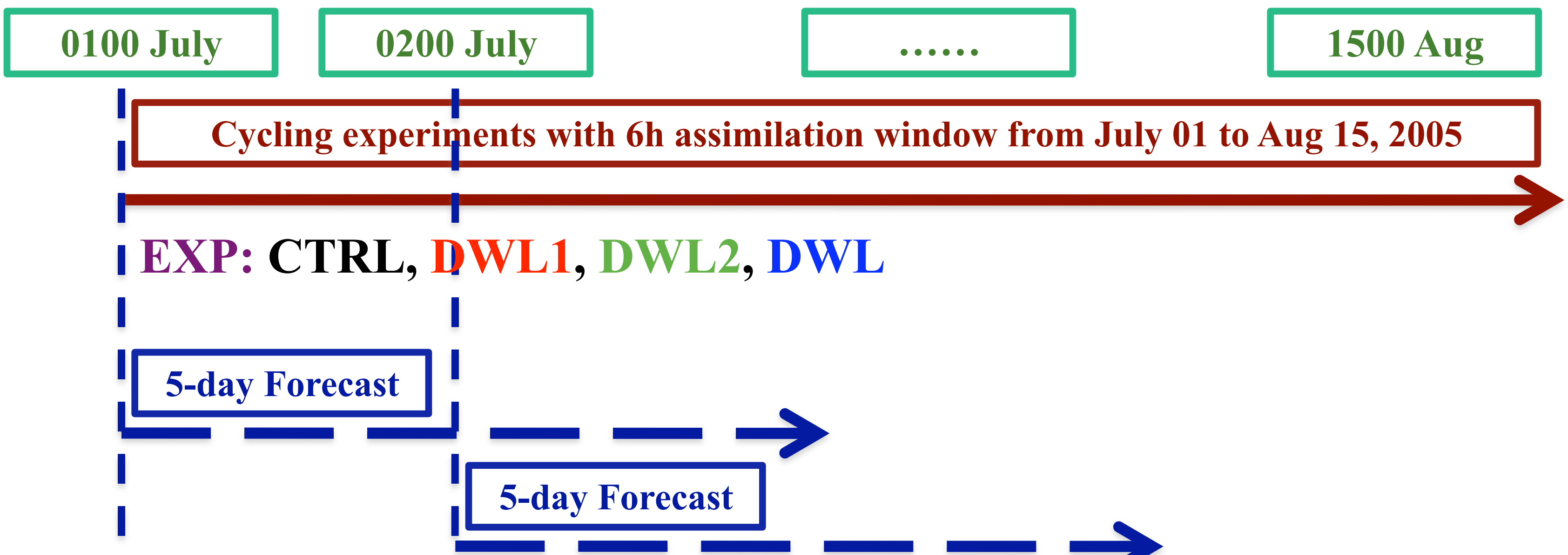


Impact of Different Wind Lidar Configurations on NCEP Forecast Skill.

Experiment Design

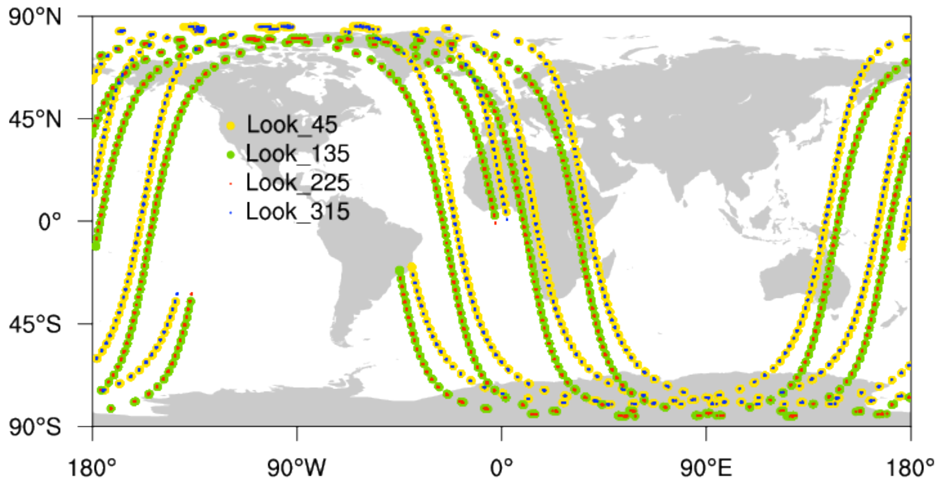
Four experiments, all verified against Nature Run

- **CTRL** :Observations as assimilated operationally by NCEP ;
- **DWL1**: As CTRL with one-telescope DWL data added, single perspective (**45°**);
- **DWL2**: As CTRL with two-telescope DWL data added, two-perspective (**45° and 315°**);
- **DWL** : As CTRL with four-telescope DWL data added (**four looks**);

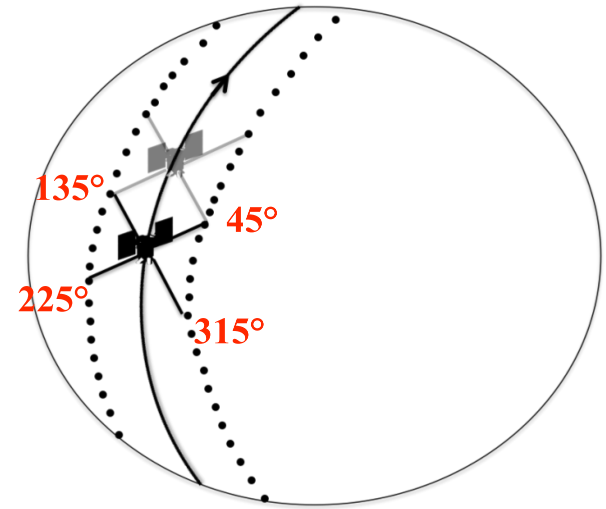


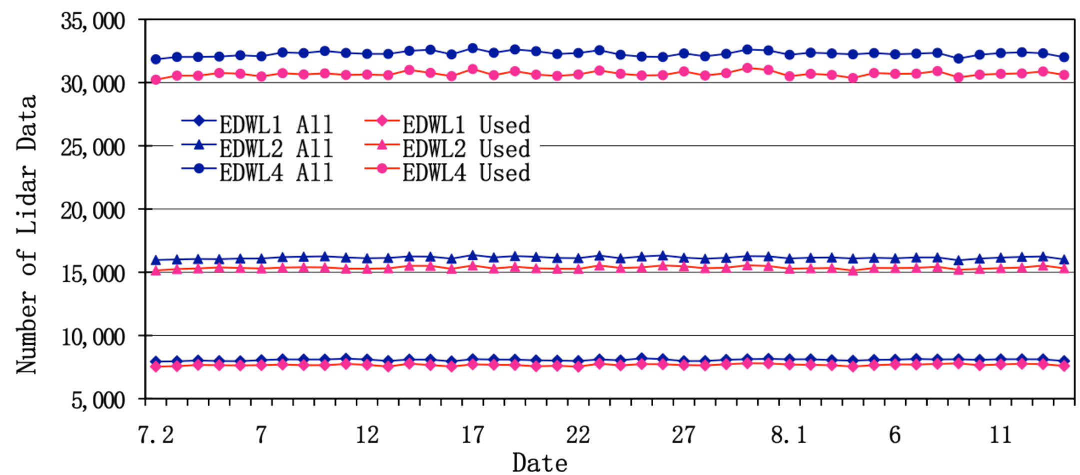
Five-day forecast launched every day at 00Z

GWOS Lidar Wind obs



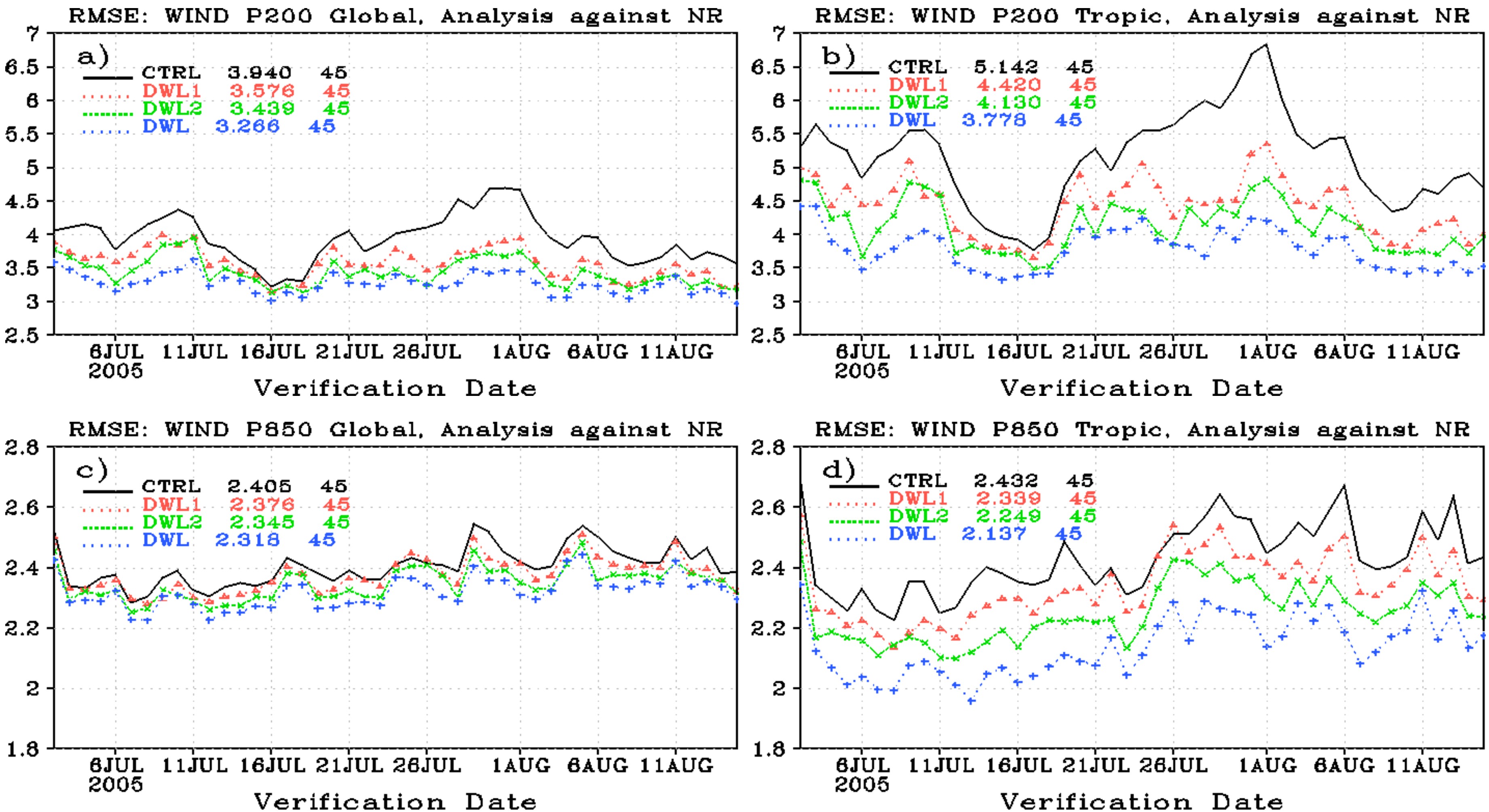
Distribution of Lidar observations at 2005072100





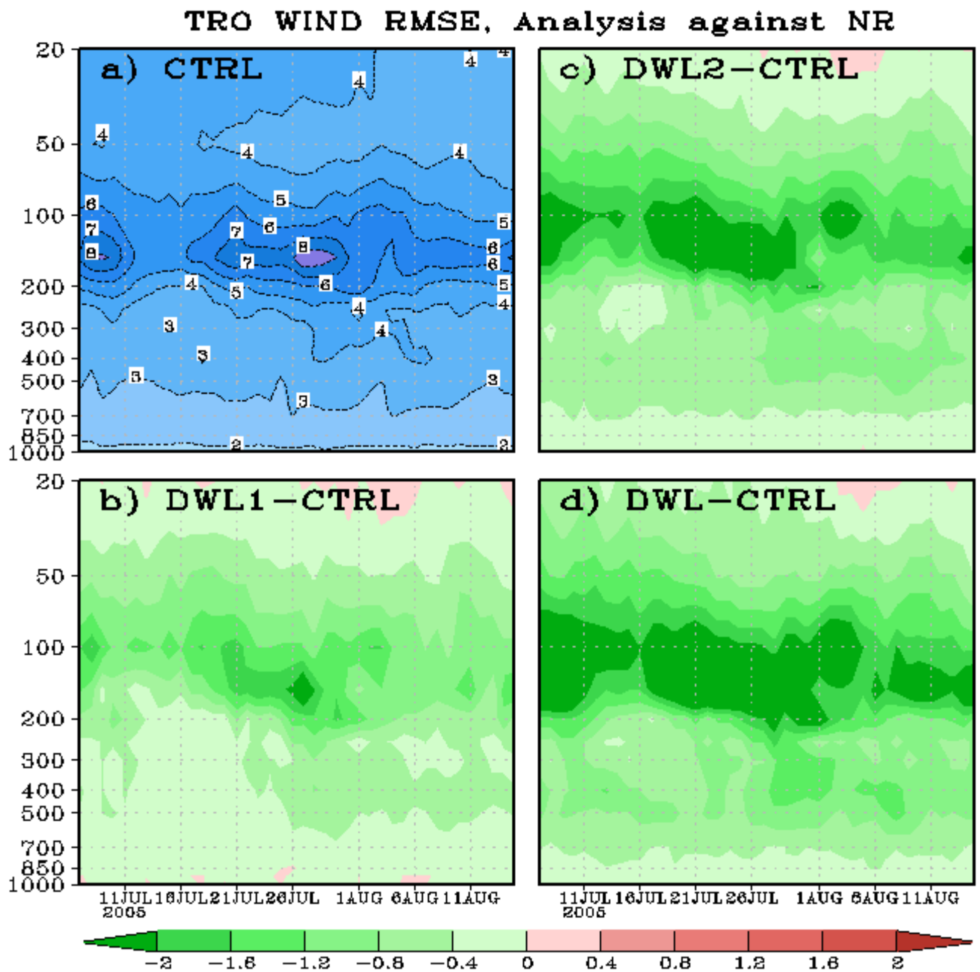
Number of Lidar obs per analysis cycle (shown only for 00Z)

Analysis Impact: Wind

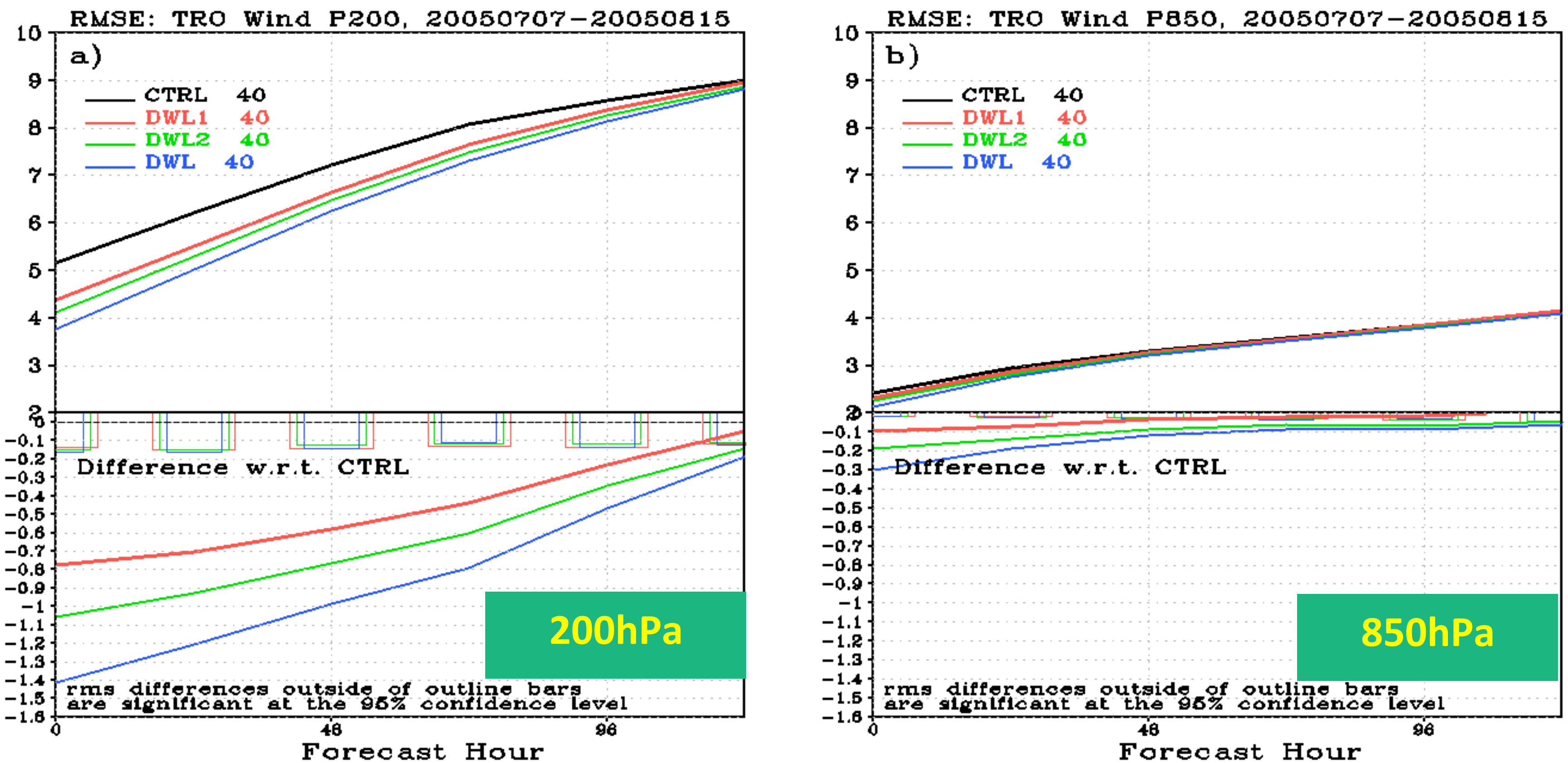


Analysis Impact: Wind …

(Tropical Wind RMSE)

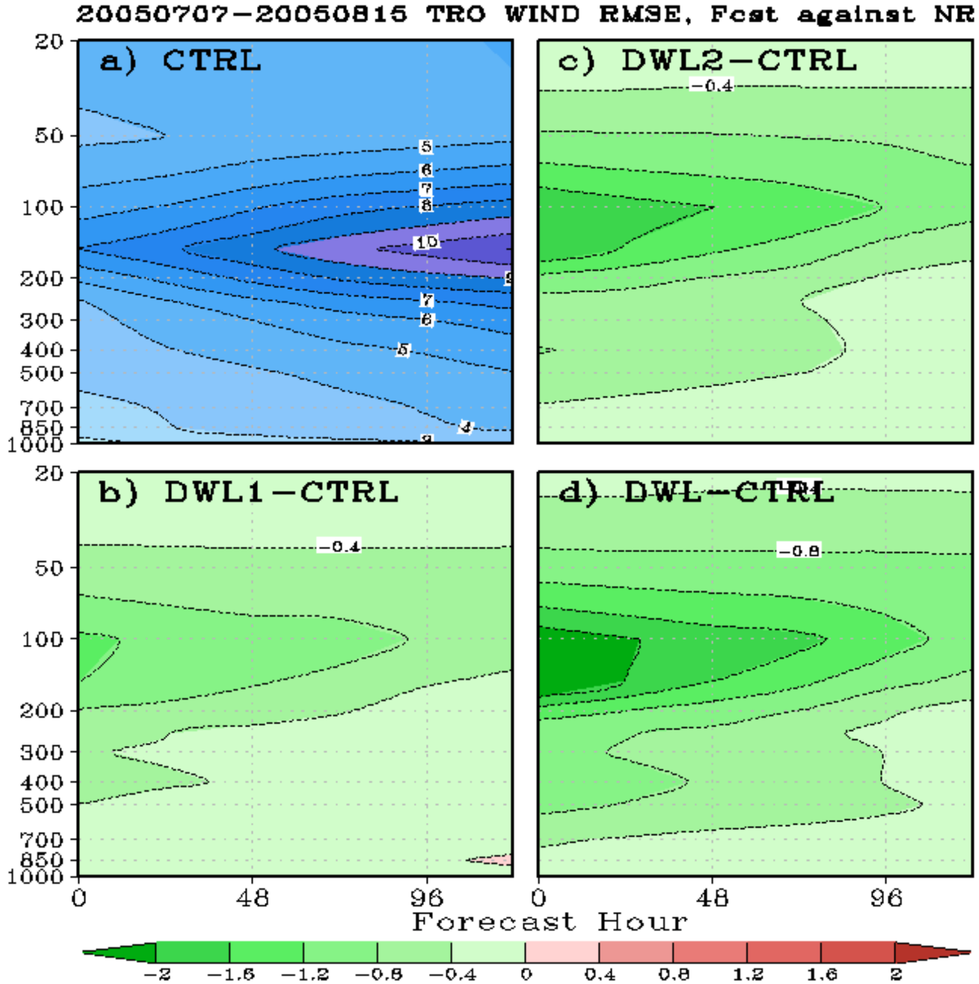


Forecast: Tropical Wind
(RMSE at 200, 850hPa)



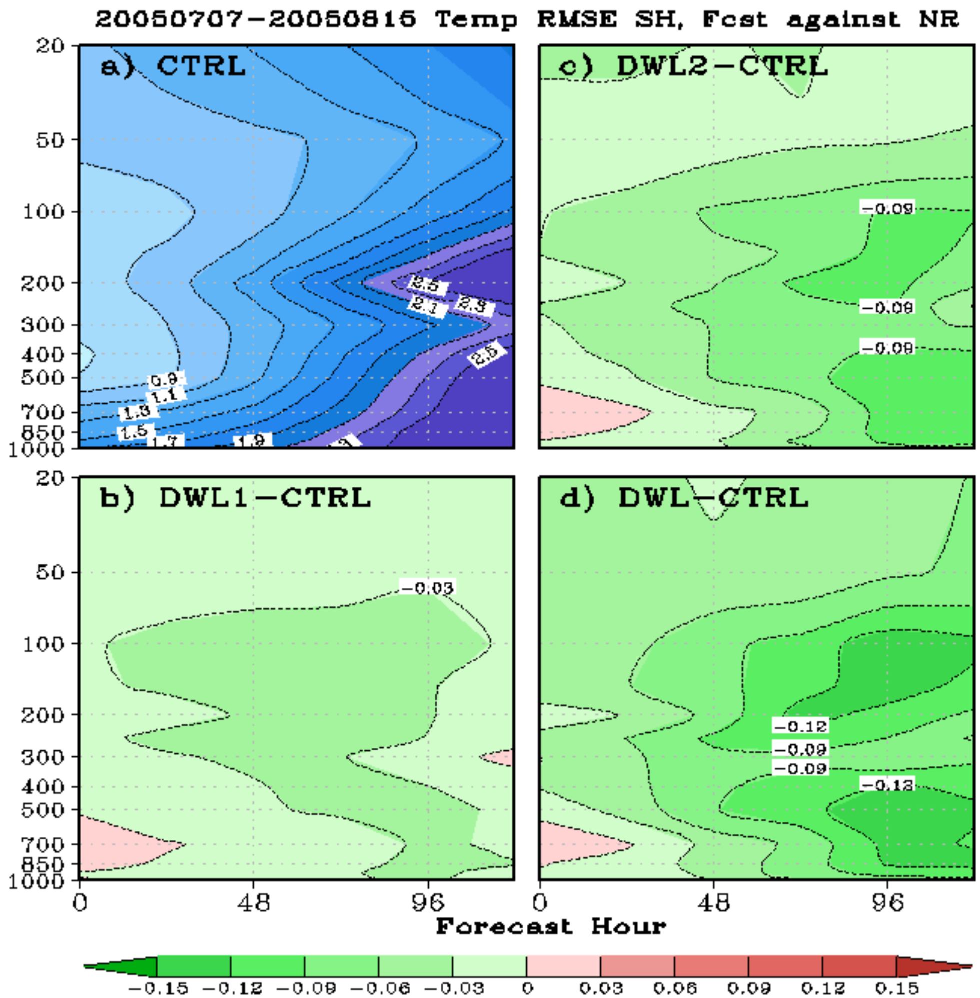
Forecast: Tropical Wind …

(RMSE for the whole pressure levels)



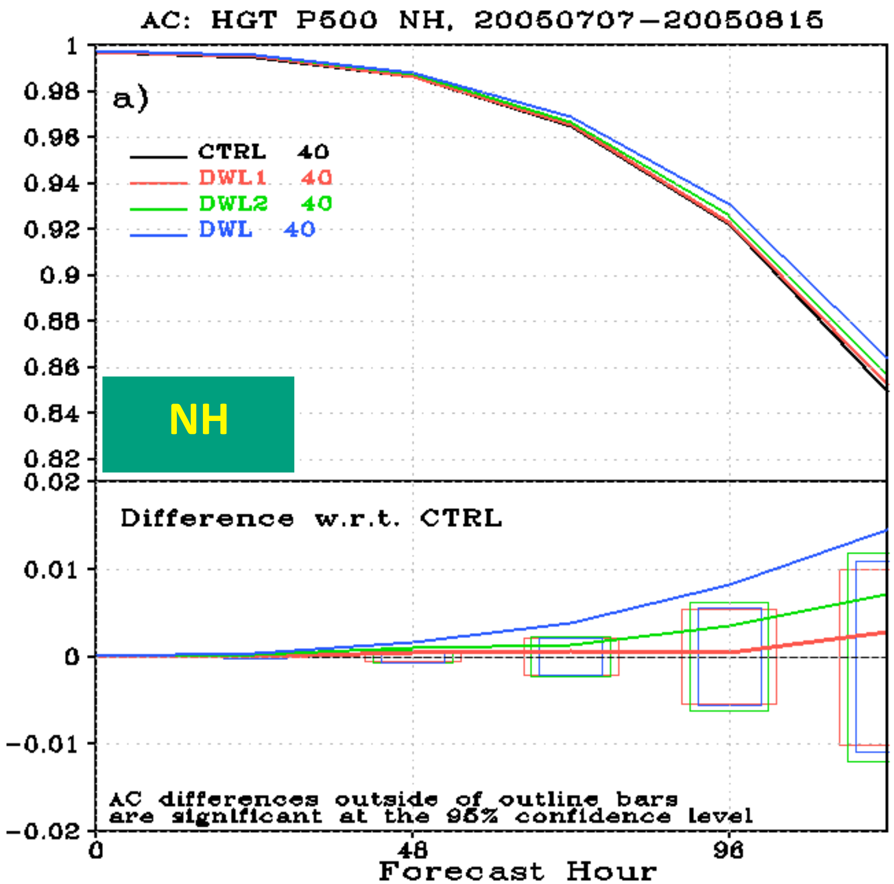
Forecast: Tropical Temperature

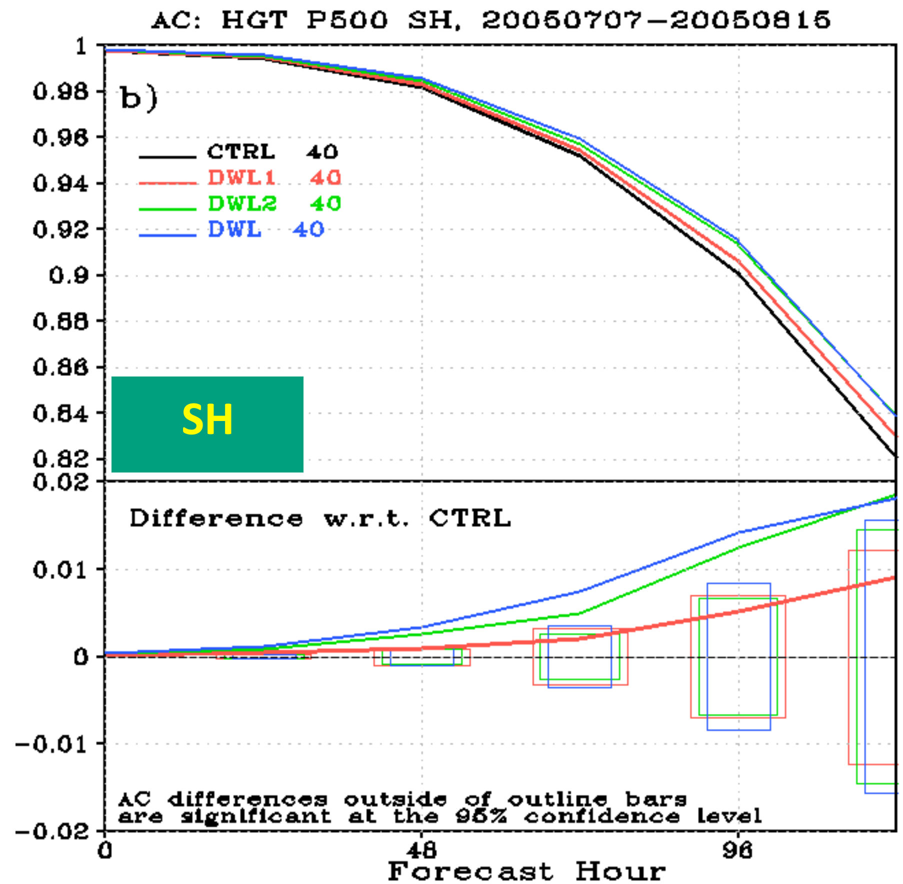
(RMSE for the whole pressure levels)



Forecast Impact: Geopotential Height AC

(500 hPa AC coefficients)





Summary and conclusions

- The lack of vertically resolved wind observations continues to be a major shortcoming of the Global Observing System
  - Here shown in the context of a modern, satellite radiance based assimilation system
- A comprehensive OSSE system has been developed under the Joint OSSE collaboration
- Results simulating expected impact of GWOS observations on NCEP GFS system are very encouraging
  - Small positive impact in NH extratropics (summer)
  - Larger positive impact in SH extratropics (winter)
  - Large positive impact in tropics; hurricane relevance
  - Two perspectives, more coverage lead to larger impact

Plans for WLS OSSE

- Experiment in opposite season (NH winter/SH summer)
- Increased horizontal resolution (T-574 and higher; requires new Nature Run)
- Detailed case studies
- Separate assessments of the impacts of Direct Detection and Coherent Detection
- Other orbits, e.g. different altitude, lower inclination
- Impact on applications other than NWP
- Other OSSEs planned (e.g. DWSS; funding being negotiated with DoD)

Joint OSSE data set

Joint OSSE Nature run

and

Simulated Observations

Joint OSSE Nature Run Data

Joint OSSE Nature Run by ECMWF
Spectral resolution : T511, Vertical levels: L91, 3 hourly dump

13 month long. Starting at 12Z May 1, 2005
Daily SST and ICE: provided by NCEP

Andersson, Erik and Michiko Masutani 2010: Collaboration on Observing System Simulation Experiments (Joint OSSE), ECMWF News Letter No. 123, Spring 2010, 14-16.

Copies are available to designated users for research purposes & to users known to ECMWF
User list is maintained by Michiko Masutani (NOAA/NCEP)
contact: michiko.masutani@noaa.gov

Complete Nature Run data set is posted at NASA/NCCS portal
http://portal.nccs.nasa.gov/osse/index.pl
Password protected. Accounts are arranged by **Ellen Salmon (Ellen.M.Salmon@NASA.gov)**
Limited data set is available from NCAR
http://dss.ucar.edu/datasets/ds621.0/matrix.html
Contact: Chi-Fan Shih chifan@ucar.edu and Steven Worley worley@ucar.edu

Simulated observation for Control experiments
- Entire Nature run Period -

Michiko Masutani and Jack Woollen (NOAA/NCEP/EMC)

Simulated radiance data,

Only Clear Sky radiance are posted

(Cloudy radiance are also simulated. Radiance with mask based on GSI usage is also simulated. But these data are not posted.)

BUFR format for entire Nature run period

Type of radiance data and location used for reanalysis from May 2005-May2006

Simulated using CRTM1.2.2

No observational error added

Conventional data

Entire Nature run Period

Restricted data removed

Cloud track wind is based on real observation location

No observational error added

Simulation of radiance data at NOAA
Jack Woollen and Michiko Masutani

Step 1. Thinning of radiance data based on real use

GOES and SBUV are simulated as they are missing from the GMAO dataset.

PrepBUFR is simulated based on CDAS distribution and quality controls.

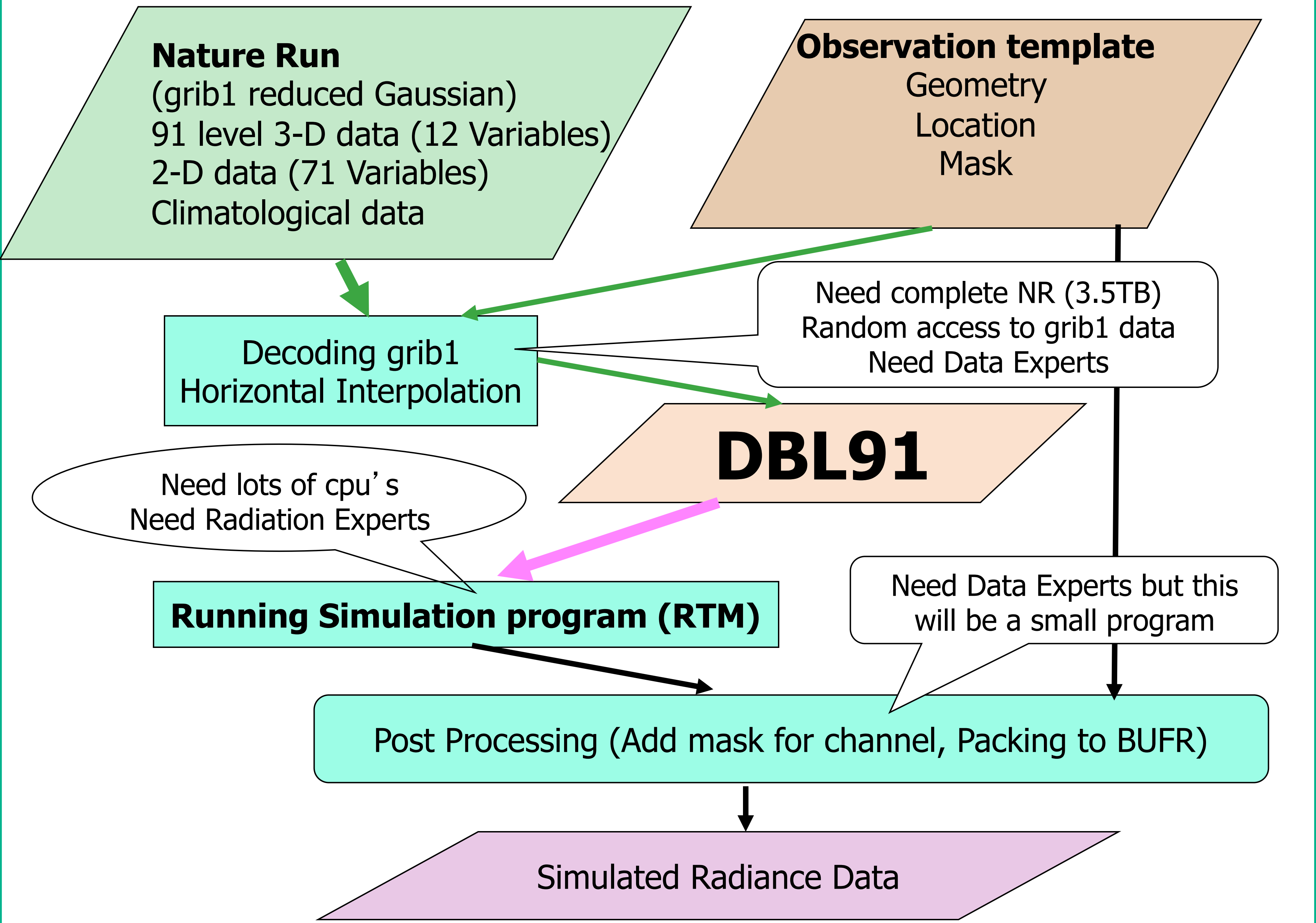
Radiance data for instruments used in 2005-2006 are generated at the foot print used by the NCEP reanalysis.

Simulation was conducted using CRTM 1.2.2.

Some calibration and validation will be conducted by NCEP and NESDIS. However, users are expected to perform their own calibrations and validation.

Step 2. Simulation of radiance data using cloudy radiance

Cloudy radiance is still under development. The simulation of cloudy radiance was completed but may be repeated with a newer version of CRTM when it is ready.


Nature Run
(grib1 reduced Gaussian)
91 level 3-D data (12 Variables)
2-D data (71 Variables)
Climatological data
Observation template
Geometry
Location
Mask
Need complete NR (3.5TB)
Random access to grib1 data
Need Data Experts
Decoding grib1
Horizontal Interpolation
DBL91
Need lots of cpu's
Need Radiation Experts
Running Simulation program (RTM)
Need Data Experts but this
will be a small program
Post Processing (Add mask for channel, Packing to BUFR)
Simulated Radiance Data

Evaluation of simulated GOES and AMSUA at the 1st step (12hr fcst) of the Nature Run simulated with 2005 template
Tong Zhu (NESDIS)

Observation and simulation of GOES-12 Sounder 18 IR channels at over North Atlantic region at 1200 UTC October 1, 2005.

Tong Zhu (NESDIS)

Observed

Simulated

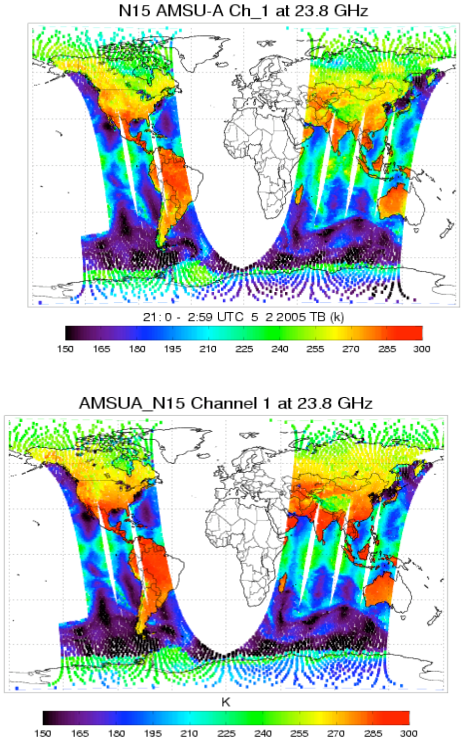
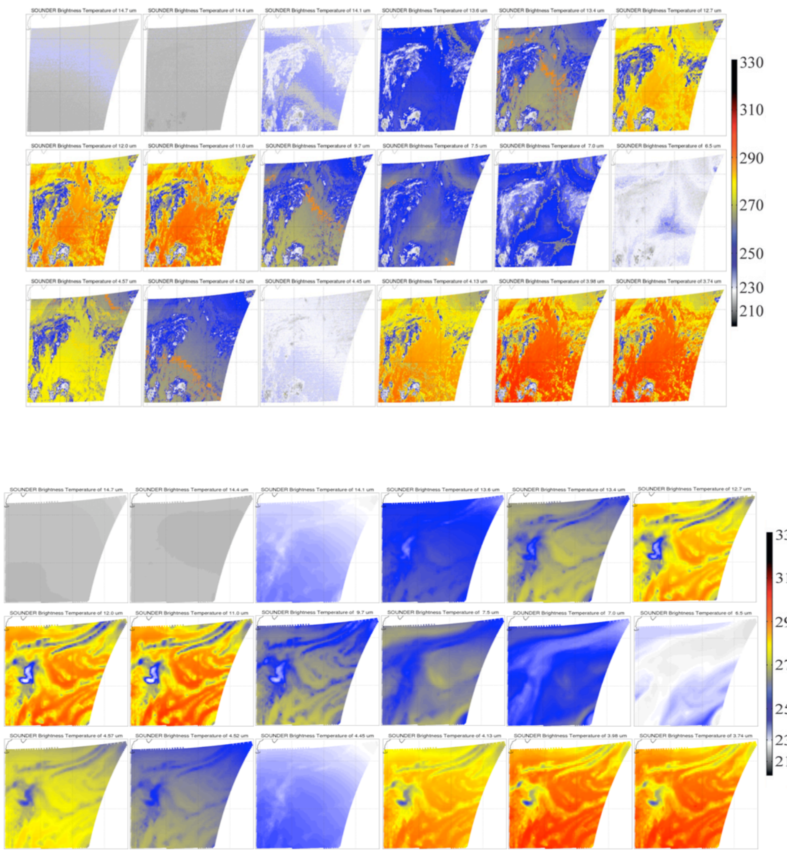


Fig. 1 NOAA -15 AMSU-A Channel 1 brightness temperature at GSI analysis time 0000 UTC May 2, 2005, time window 6 hours from (left) observation, (right)) CRTM simulation with NR atmospheric profiles.

These figures are expected to be very similar.

Observed

Simulated



These figures do not have to be same as weathers are different , but similarities are observed.

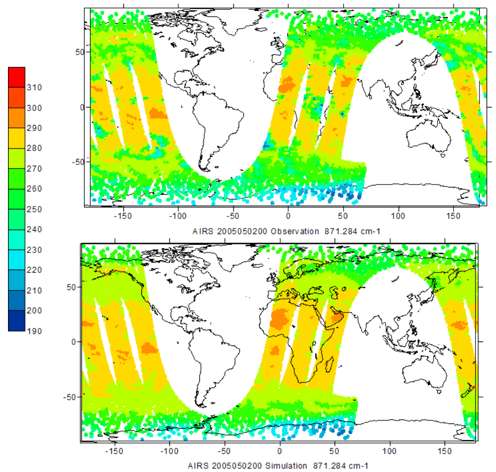
Evaluation of simulated AIRS and IASI at the 12hr fcst of the Nature Run simulated with 2009 template

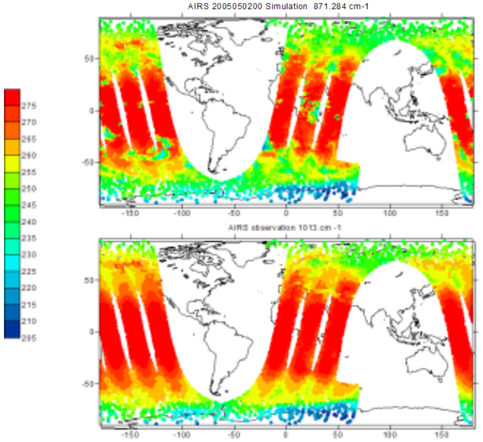
Haibing Sun (NESDIS)

AIRS

Observed

Simulated

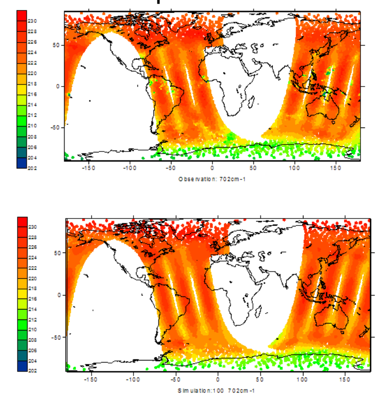




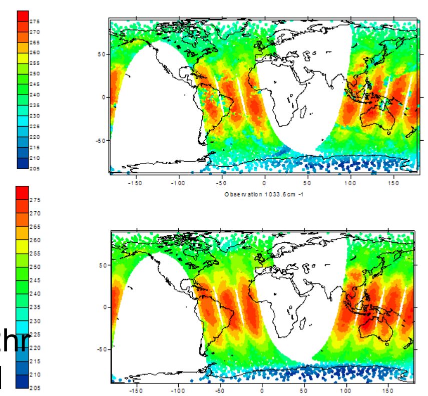
IASI simulation Evaluation at CO_2 Absorption Band

Observed

Simulated

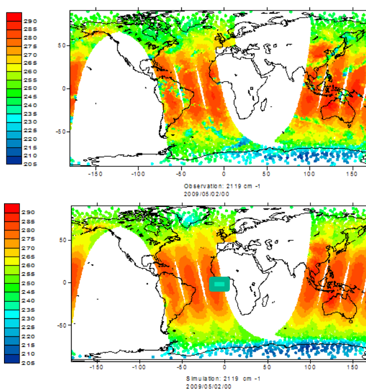


IASI simulation Evaluation at O_3 Absorb band

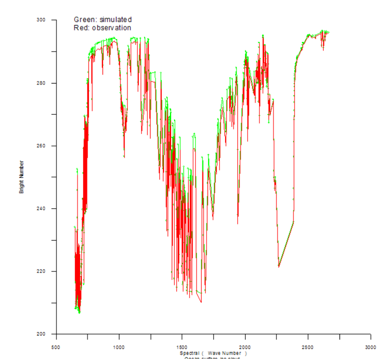


IASI

IASI simulation Evaluation at Windows channel



IASI Simulation over ocean (Clear atmosphere)



The Nature run start at May 1st 12z. At 00z May 2nd (12hr forecast), the Nature Run fields are still very close to real atmosphere and simulated radiance can be compared with real observations.

Data Distribution

NASA/NCCS

http://portal.nccs.nasa.gov/josse/index.pl

Contact:

Ellen Salmon Ellen.M.Salmon@NASA.gov

Bill McHale wmchale@nccs.nasa.gov

NCAR

Currently saved in HPSS **Data ID:** ds621.0

http://dss.ucar.edu/datasets/ds621.0/matrix.html

Contact: Chi-Fan Shih chifan@ucar.edu and Steven Worley worley@ucar.edu

Additional Data posted at Joint OSSE Home page http://www.emc.ncep.noaa.gov/research/JointOSSEs/

[Simulation of TC vital]
TC vital was simulated using software originally written by Tim Marchock and currently developed by Guan Ping Lou of NCEP.

Software used for simulations are all posted.
CRTM used for simulation. CRTM1.2.2 (Different from the version posted at JCSDA website)

Conventional data posted at NASA/NCCS

Restricted data removed

NCCS Portal - JOSSE http://portal.nccs.nasa.gov/josse/index.pl

GODDARD SPACE FLIGHT CENTER

+ NASA Homepage
+ NASA Center for Climate Simulation

NCCS Data Portal - Joint OSSE

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This data must not be used for commercial purposes and redistribution rights are not given. Originating institutes must be given credit in any publications in which this data is used.

If you are interested in using the data or need assistance please contact the originating institute.

For more information about Joint OSSE and the data sets, please visit the Joint OSSE website.

Dataset	Originating Institute	Contact
NCEP Obs	NOAA/NCEP	Michiko Masutani (Michiko.Masutani@noaa.gov)
NCEP-NESDIS	NOAA/NCEP NOAA/NESDIS	Michiko Masutani (Michiko.Masutani@noaa.gov)
NCEP_prebufr	NOAA/NCEP	Michiko Masutani (Michiko.Masutani@noaa.gov)

Path: /josse

File/Directory	Size	
NCEP-NESDIS	8.0K	go to dir
NCEP_Obs	8.0K	go to dir
NCEP_prepbufr	8.0K	go to dir

USA.gov + Privacy Policy and Important Notices

Curator: Bill Ma..ale
NASA Official: P..l Webster
Last Updated: 04/..2/2007

Path: /josse/NCEP_prepbufr

File/Directory	Size	
README	144	View/Download
real.v1110	8.0K	go to dir
simulated.v1110	8.0K	go to dir

Real

Path: /josse/NCEP_prepbufr/real.v1110

File/Directory	Size	
200505	8.0K	go to dir
200506	8.0K	go to dir
200507	8.0K	go to dir
200508	8.0K	go to dir
200509	8.0K	go to dir
200510	8.0K	go to dir
200511	8.0K	go to dir
200512	8.0K	go to dir
200601	8.0K	go to dir
200602	8.0K	go to dir
200603	8.0K	go to dir
200604	8.0K	go to dir
200605	8.0K	go to dir

File/Directory	Size	
REAL_prepbufr_2005070100.gz	12M	View/Download
REAL_prepbufr_2005070106.gz	9.6M	View/Download
REAL_prepbufr_2005070112.gz	12M	View/Download
REAL_prepbufr_2005070118.gz	11M	View/Download
REAL_prepbufr_2005070200.gz	11M	View/Download
REAL_prepbufr_2005070206.gz	9.1M	View/Download
REAL_prepbufr_2005070212.gz	11M	View/Download
REAL_prepbufr_2005070218.gz	11M	View/Download
REAL_prepbufr_2005070300.gz	9.9M	View/Download
REAL_prepbufr_2005070306.gz	8.2M	View/Download
REAL_prepbufr_2005070312.gz	11M	View/Download
REAL_prepbufr_2005070318.gz	9.8M	View/Download
REAL_prepbufr_2005070400.gz	9.8M	View/Download
REAL_prepbufr_2005070406.gz	8.2M	View/Download
REAL_prepbufr_2005070412.gz	9.8M	View/Download
REAL_prepbufr_2005070418.gz	9.9M	View/Download
REAL_prepbufr_2005070500.gz	11M	View/Download
REAL_prepbufr_2005070506.gz	8.7M	View/Download
REAL_pre		
REAL_pre		
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REAL_pre		
REAL_pre		
REAL_pre		

Simulated

Path: /josse/NCEP_prepbufr...

File/Directory	Size	
200505	8.0K	go to dir
200506	8.0K	go to dir
200507	8.0K	go to dir
200508	8.0K	go to dir
200509	8.0K	go to dir
200510	8.0K	go to dir
200511	8.0K	go to dir
200512	8.0K	go to dir
200601	8.0K	go to dir
200602	8.0K	go to dir
200603	8.0K	go to dir
200604	8.0K	go to dir
200605	8.0K	go to dir

File/Directory	Size	
OSSE_prepbufr_2005070100.gz	5.5M	View/Download
OSSE_prepbufr_2005070106.gz	5.0M	View/Download
OSSE_prepbufr_2005070112.gz	5.8M	View/Download
OSSE_prepbufr_2005070118.gz	5.2M	View/Download
OSSE_prepbufr_2005070200.gz	5.1M	View/Download
OSSE_prepbufr_2005070206.gz	4.7M	View/Download
OSSE_prepbufr_2005070212.gz	5.5M	View/Download
OSSE_prepbufr_2005070218.gz	5.1M	View/Download
OSSE_prepbufr_2005070300.gz	4.9M	View/Download
OSSE_prepbufr_2005070306.gz	4.2M	View/Download
OSSE_prepbufr_2005070312.gz	5.0M	View/Download
OSSE_prepbufr_2005070318.gz	5.0M	View/Download
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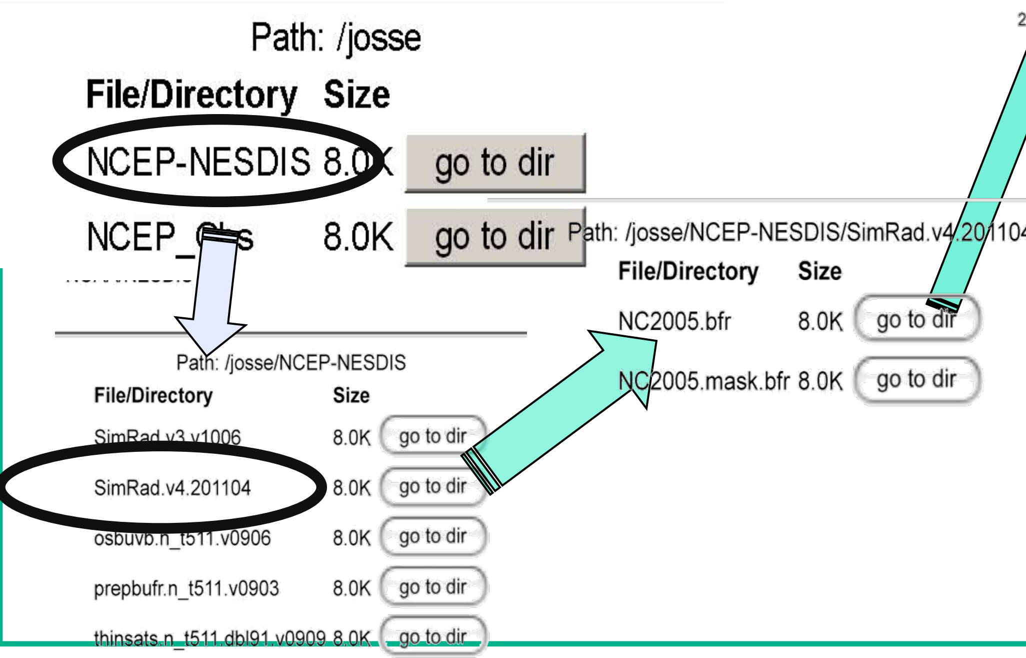
OSSE_prepbufr_2005070718.gz	5.1M	View/Download
OSSE_prepbufr_2005070800.gz	5.5M	View/Download

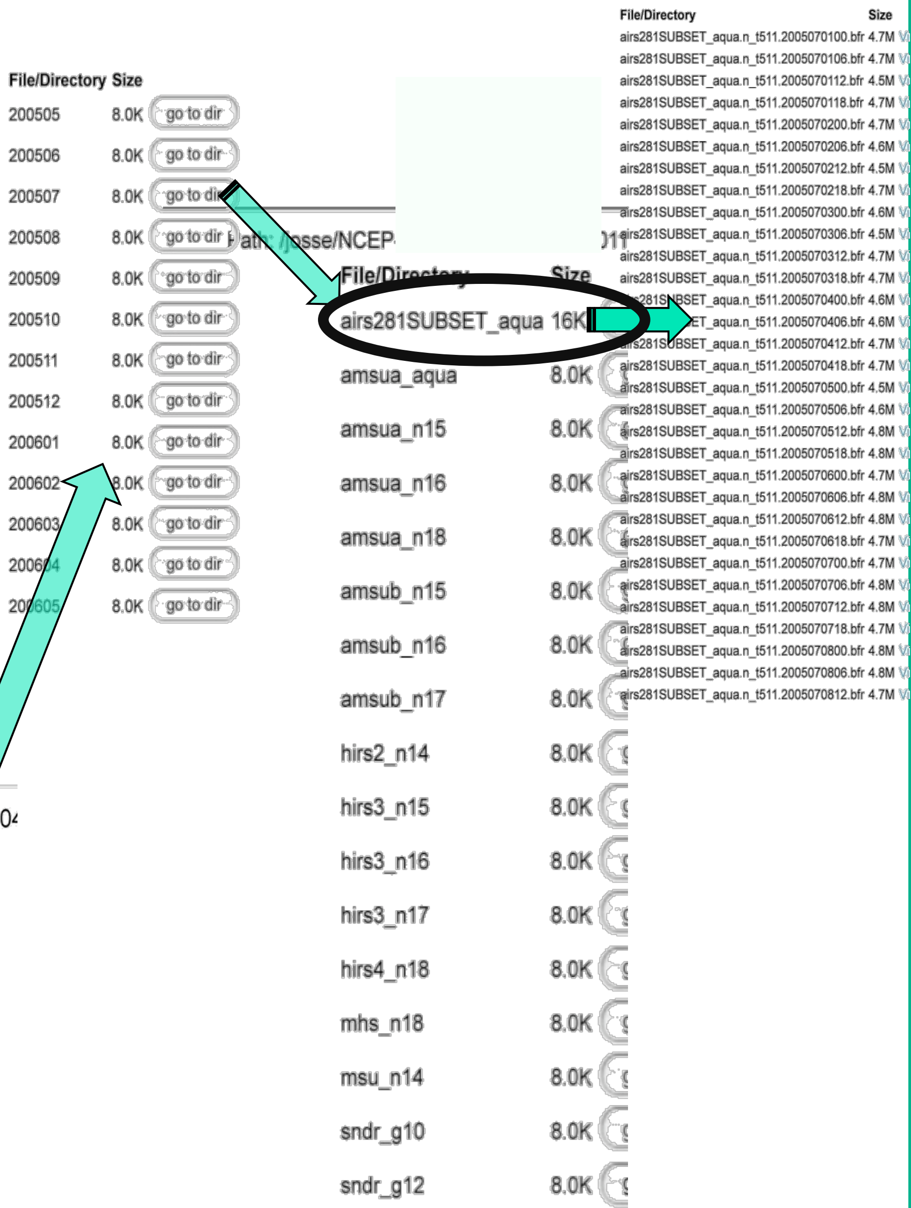
Radiance data at NASA/NCCS

Simulated radiance data, with and without MASK in BUFR format for entire Nature run period

Type of radiance data used for reanalysis from May 2005-May2006

Simulated using CRTM1.2.2





Joint OSSE Data set at NCAR

Currently saved in HPSS , Data ID: ds621.0
http://dss.ucar.edu/datasets/ds621.0/matrix.html

ECMWF Joint Observing System Simulation Experiment (OSSE) Nature Run

Data Description View More Detail	Email a Question
All Data by Access Option	@
NR2006 - T511NR 20050501-20060601 nature run to study data impact on large scale events	@
CLOUD - Cloud analysis from 200505-200606	@
T799NR - T799NR including T799Oct05 and T799Apr06	@
ObsRadiance - Observed radiance	@
SmuClrSkyRad - Simulated clear sky radiance	@
Real.v1110 - real observations without restricted data in ncep prepbufr format	@
Simulated.v1110 - simulated observations in ncep prepbufr format	@

NCAR Contact:
Chi-Fan Shih chifan@ucar.edu **Steven Worley** worley@ucar.edu

Hurricane Case study

Michiko Masutani

Investigate design for OSSE experiments.

Experiments comparison between model resolution and GWOS data to find out the best resolution for the WLS OSSE

Effect of observational error in data impact

Atlantic Hurricane in the nature run for the analysis period of 9/25-10/10

L22810 REALE ET AL.: PRELIMINARY EVALUATION OF THE ECMWF NATURE RUN L22810

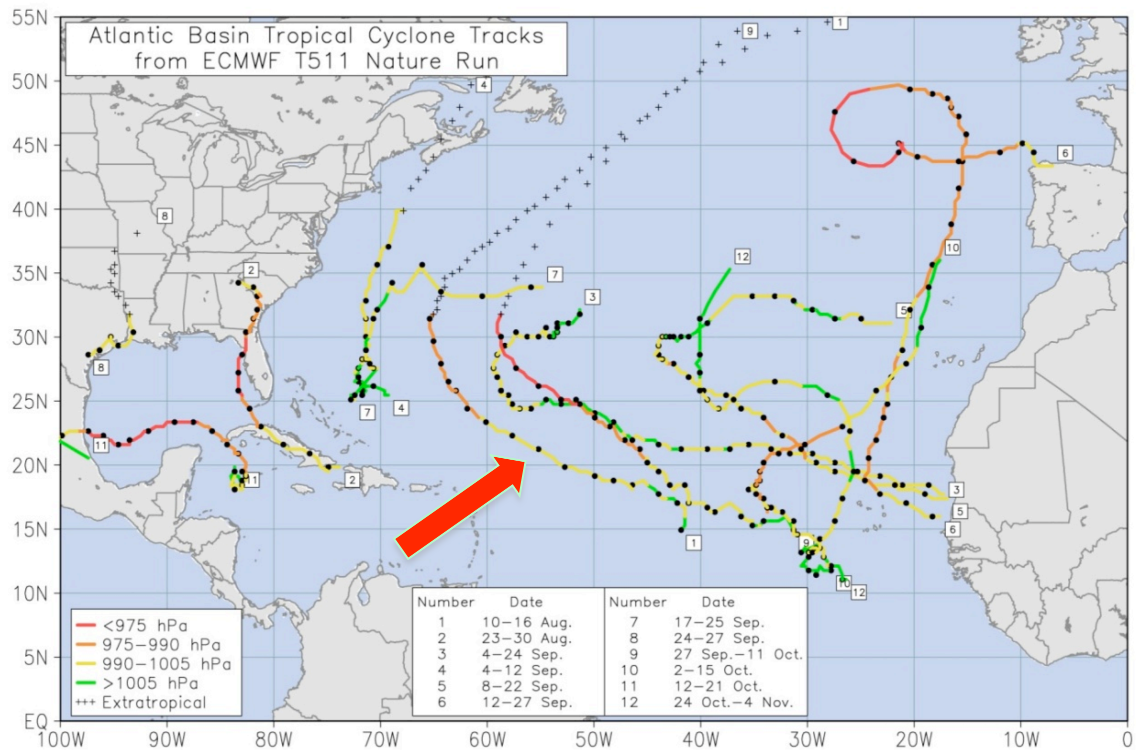


Figure 3. Atlantic TCs in the NR 'hurricane season.' Different colors show center pressure in the full resolution surface fields. Crosses indicate extratropical storms defined when the 200 hPa minus 850 hPa shear exceeds 10 ms^{-1}. Tracks are from original full-resolution T511 surface fields.

Simulated observation
Control data: Observation type and distribution used by reanalysis for 2005.
Observational error is not added to the control data but calibration was performed to demonstrate the impact of observational error in control data.

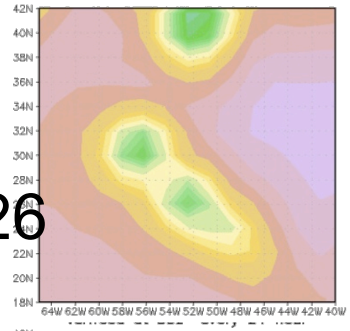
DWL data: GWOS concept DWL simulated by Simpson weather associates.

The figure produced by Joe Terry

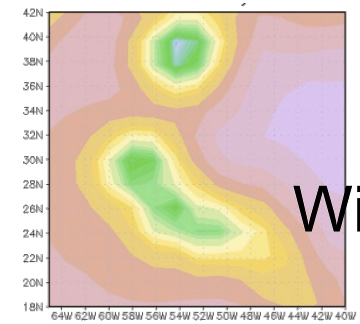
Minimum Mean Sea level Pressure
The verification period:
Sep28-Oct13, 2005
in 72 hour forecast
Evaluated at 00Z only

This display indicates the hurricane track and intensity

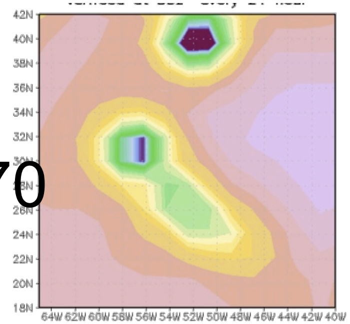
T126



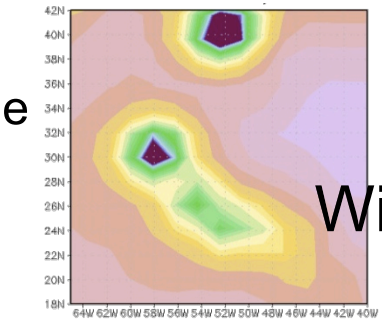
T126 With DWL



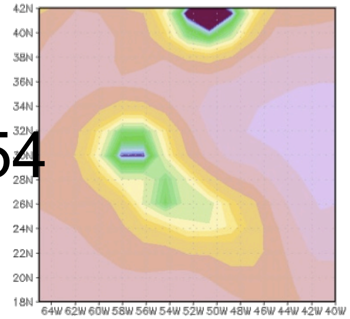
T170



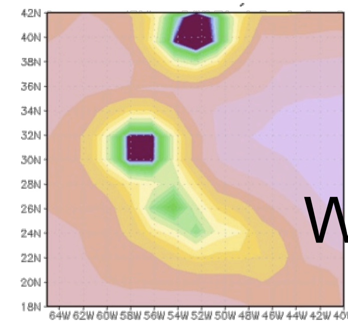
T170 With DWL



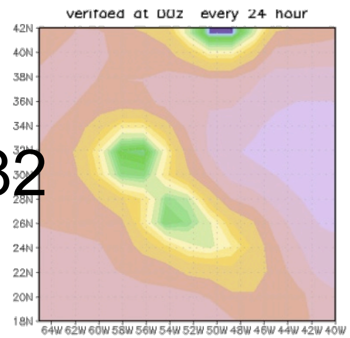
T254



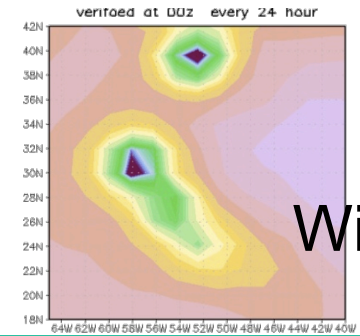
T254 WithDWL



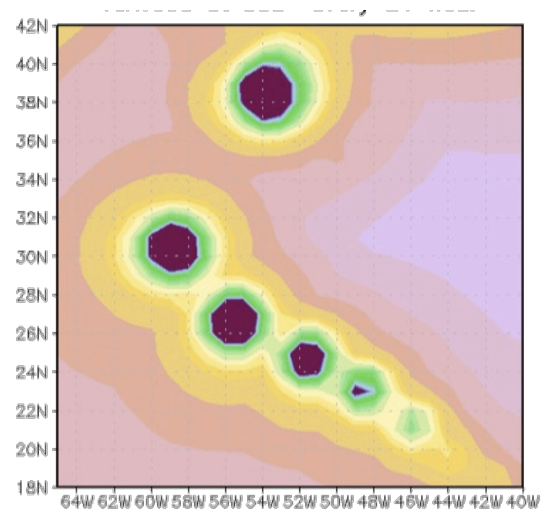
T382



T382 With DWL

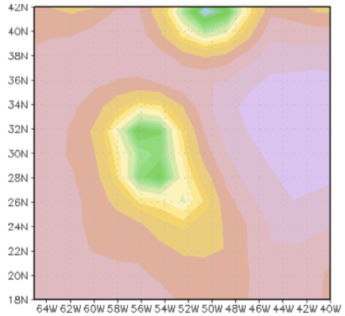


Nature run
Truth



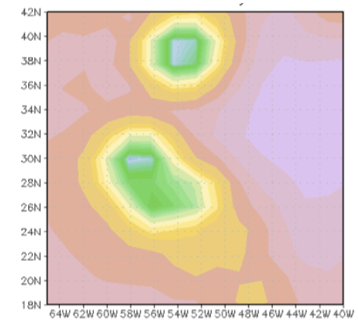
Evaluation of observational error in radiance

T170 with large obs error in radiance



Add DWL

T170 with large obs error in radiance
DWL added



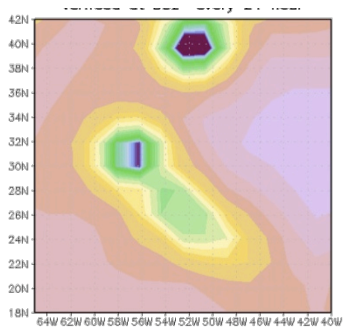
Improve radiance data

Minimum Mean Sea level Pressure
The verification period Sep28-Oct13, 2005
72 hour forecast evaluated at 00Z only

Improve radiance data

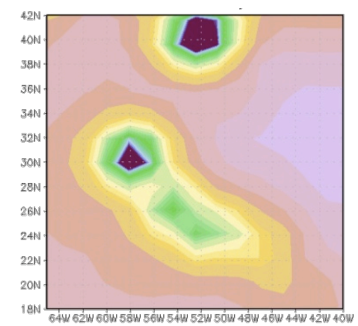
Better radiance data help track and intensity forecast. DWL also will improve intensity forecast s even with perfect radiance data.

T170 No obs error in radiance



Add DWL

T170 no obs error in radiance
DWL added

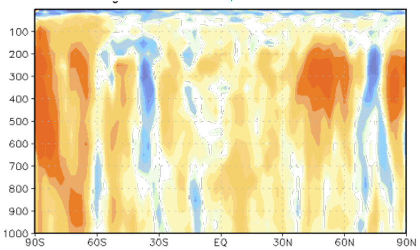


Impact of resolution vs. GWOS DWL

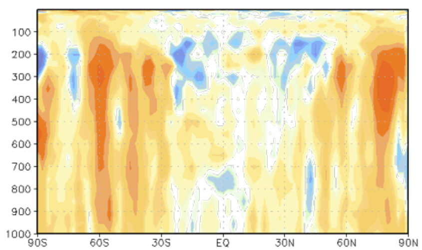
Reduction of RMSE from NR in meridional wind
Zonal averaged
The verification period
Sep28-Oct13, 2005
in 72 hour forecast
Evaluated at 00Z only

Improvement by Increasing resolution

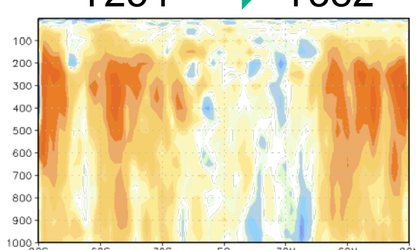
T126 ➡ T170



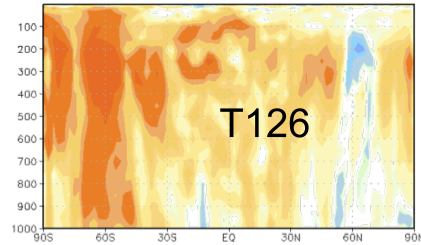
T170 ➡ T254

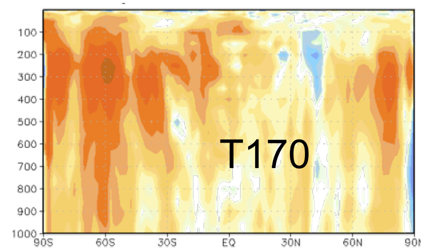


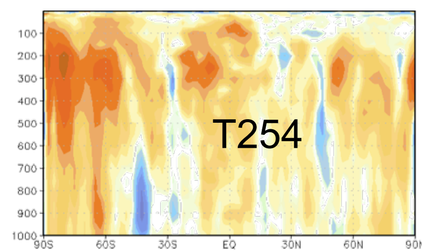
T254 ➡ T382

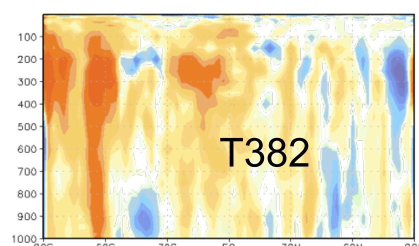


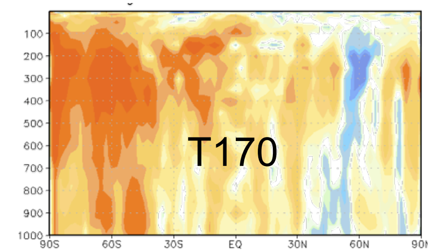
Improvement by Adding GWOS DWL











Add large error to radiance data

More verification planned.

Add forecast from 12z. Try DWL with other configuration.
Produce hurricane track diagnostics.

Initial Summary of Hurricane OSSE

OSSE with control observation without observational error is useful to provide initial outlook of data impact a new type of observation.

Some interesting findings

◆DWL improves both intensity and location of a hurricane at all resolution even with perfect control observation.

◆In hurricane season, increasing model resolution will be more effective in large scale forecast. Improvement due to adding DWL is mainly over hurricane.

◆ Random error do not have significant impact in large scale, but more impact in smaller scale.

◆With better radiance data impact of DWL was enhanced.

◆At least T170 resolution is required to utilize DWL data for hurricane forecast . Impact of DWL is larger in T254 than in T170 model forecast. T382 model for OSSE with T511 Nature run may not be the best.

Further work on Hurricane Case study

◆Add various observational errors to control observations and study data sensitivity to the data impact. This by itself is a major important project.

◆Increase forecast frequency to 12 hour to get better statistics

◆Produce standard EMC skill package and hurricane diagnostics for better comparison.

Acknowledgement

The nature runs for Joint OSSEs were produced by Dr. Erik Andersson of ECMWF. We appreciate GMAO to providing initial satellite data for calibration at ESRL. GMSO also provided code to add random error to simulated data and ESRL provided amplitude used for their experiments.

Beyond wind lidar OSSEs

- OSSEs for JPSS (JPO)
- OSSEs for DWSS (CAPE, OSD)
- GPSRO
- GOES-R