

GNSS Radio Occultation activities at NOAA

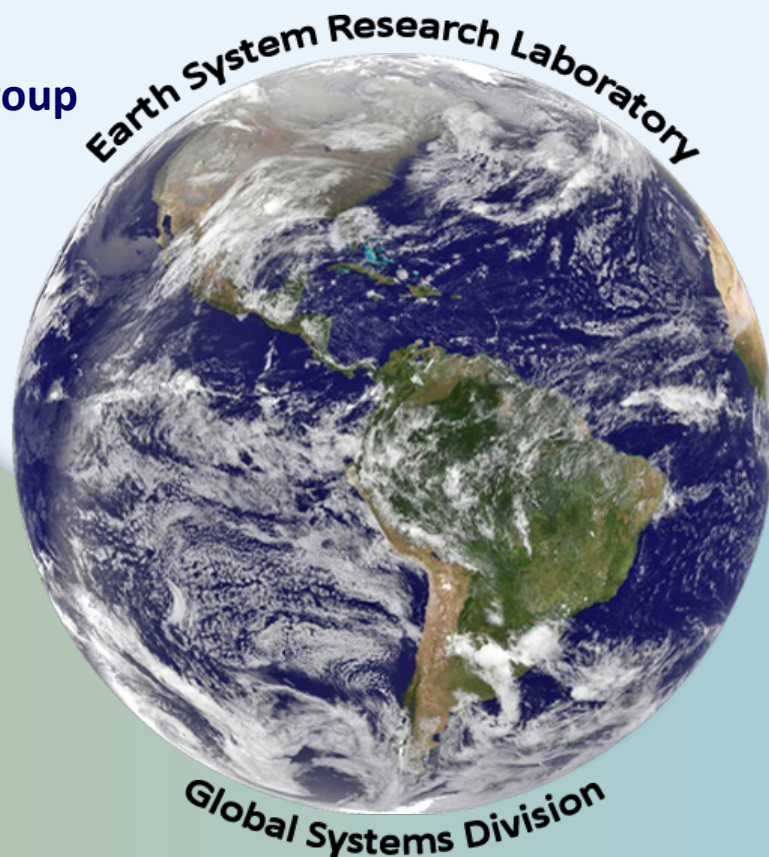
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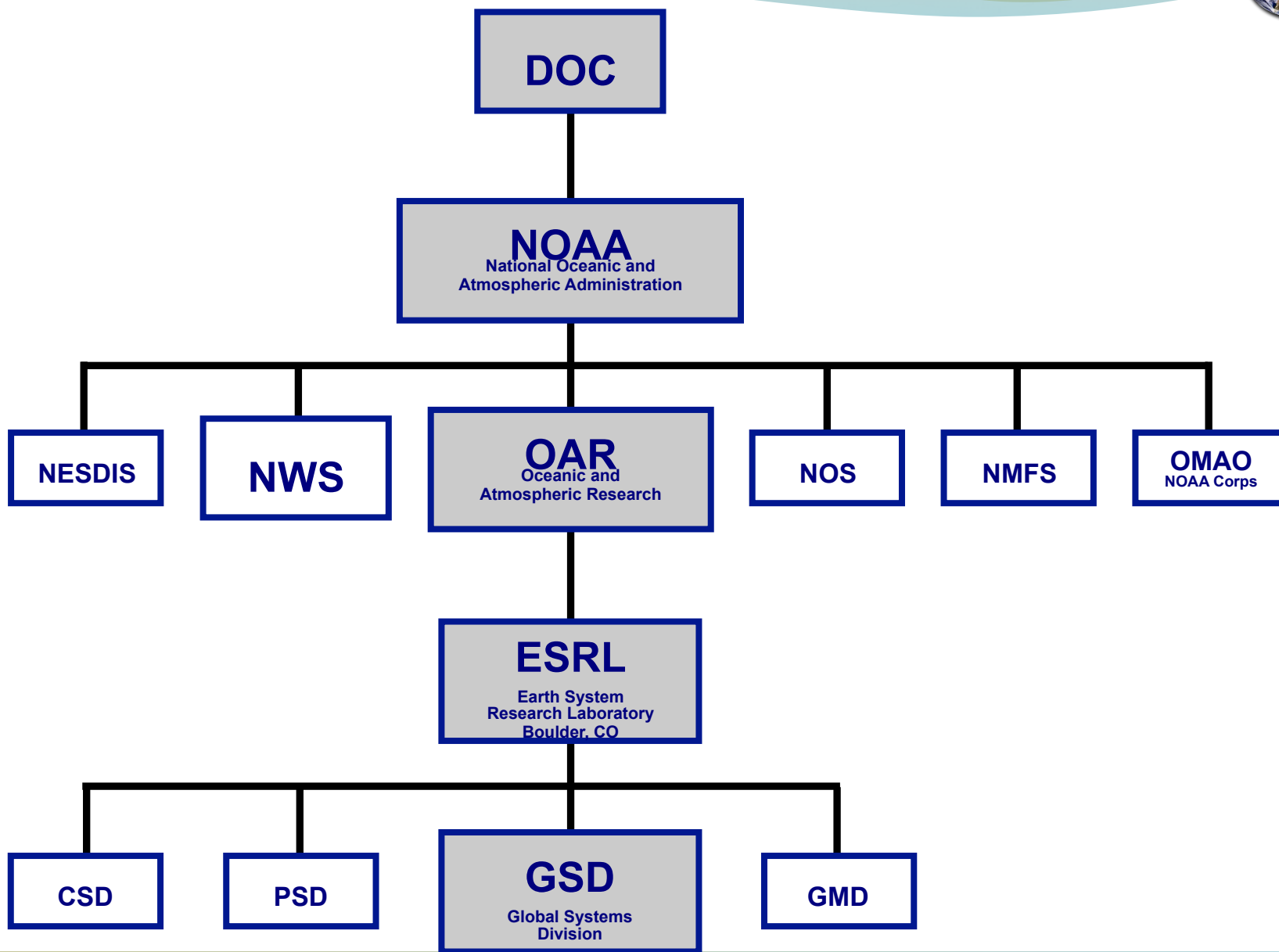
4th IROWG

Melbourne, Australia, April 2015



Outline

- Introduction to the Global Observing Systems Analysis (GOSA) Group
- GOSA activities
 - 1) Observing System Simulation Experiments (OSSEs)
 - 2) Observing System Experiments (OSEs)
 - 3) GNSS Radio Occultation algorithm development (in support of COSMIC-2)
 - 4) NOAA ground-based GPS observations (GPS-Met)
- Outlook





Office of the Director

ITS

IT Security
Data Systems
Network Management

Administration

Resource Management
Contracts/Procurement
Communications

Groups

GOSA
- Obs. Impacts OSSE/OSE
- GPS-MET/-RO

Branches

Evaluation & Decision Support Branch

- Aviation weather
- Verification
- AWIPS

Environmental Modeling Branch

- Regional to Global
Modeling and data assimilation
- Prob. Forecasts

Advanced Technology & Outreach Branch

- Adv. Computing &
Visualization
- Science Education (SOS)
- MADIS

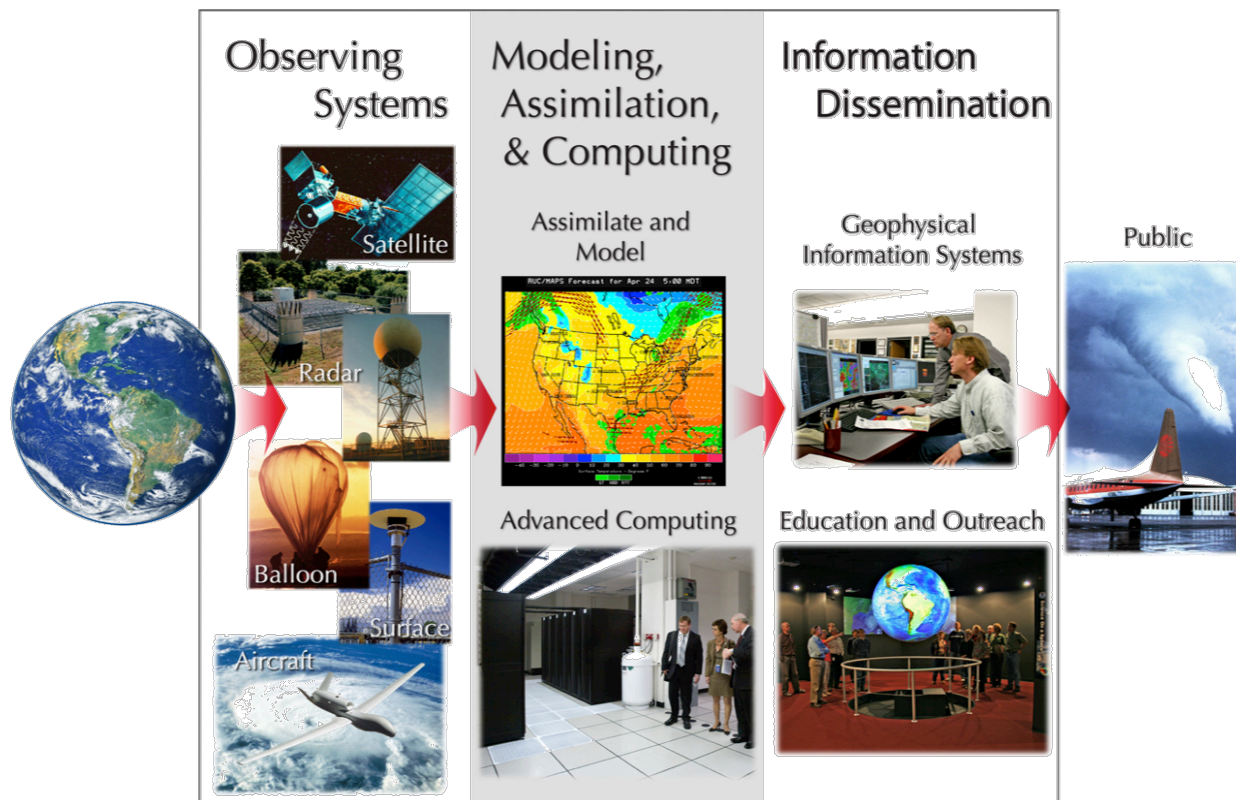
CIRA and CIRES: satellite meteorology and NWP/DA expertise, grad students, postdocs, fellows



“We don’t make the forecasts,
we make the forecasts better...”



Global Systems Division



Transferring science and technology to the
National Weather Service

GOSA Group

- Recently formed – September 2014
- Maximize and optimize the uses of current and future global observations to improve numerical weather prediction forecast skill in NOAA's models. This includes algorithm development, management, and science support
- Quantitatively evaluate the complementarity of different observing systems through OSSEs and OSEs to help NOAA management prioritize mission designs in a cost-effective way
- **Why is GOSA so important?** OSSEs save Taxpayer \$\$ as they allow to analyze tradeoffs in the design and configuration of proposed observing systems (e.g. coverage, resolution, accuracy and data redundancy)



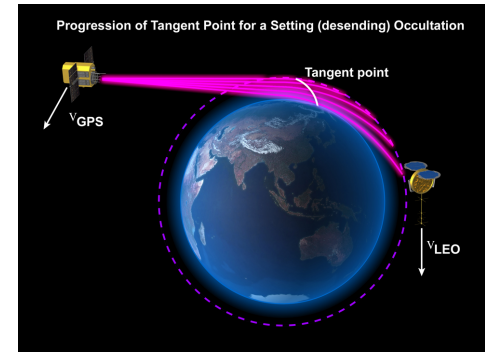


OSEs and OSSEs

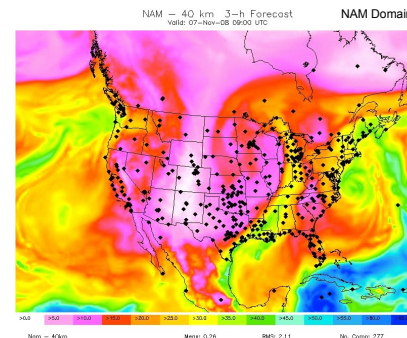
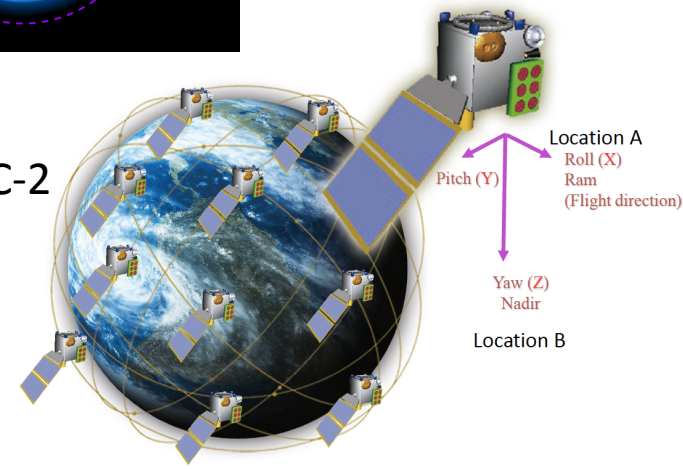
- Observing System Experiments (OSEs) allow the evaluation of the impact of current observations in weather forecasting
- Observing System Simulation Experiments (OSSEs) provide a rigorous, cost-effective approach to evaluate the potential impact of new observing systems, alternate configurations and deployments of existing systems, and to optimize observing strategies. They are also used to prepare for the utilization of new types of data and to optimize the utilization of existing data
- Both OSEs and OSSEs are necessary to quantitatively evaluate the benefits of observations in weather forecasting

GOSA leading science activities

- Improve the use of Current Observing Systems and evaluate the impact of Future Observing Systems: OSEs and OSSEs with Radio Occultation observations (COSMIC-2 and commercial options)
- Mitigate the Risk of Satellite Observing Gaps: OSEs and OSSEs with Radio Occultation and Unmanned Aircraft System observations, complementarity of JPSS and Radio Occultation observations
- Key component of the of NOAA's Quantitative Observing System Assessment Program (QOSAP) across-line offices that attempts to coordinate and prioritize OSSE efforts
- Ground-based GPS network (GPS-Met)



COSMIC-2





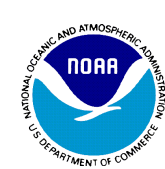
(1) OSSEs: with RO

- Investigate the benefits of increasing the number of assimilated GNSS RO profiles on global weather forecast skill
 - NCEP's Global Data Assimilation System (GSI/GFS)
 - Focus on current and future RO constellations, including commercial and non-commercial options
 - Conduct preliminary OSSEs with a sub-optimal configuration set up
 - Follow-up with more rigorous OSSEs (ongoing effort to be completed by Dec 2015)
- Configuration setup for preliminary OSSEs:
 - T511 ECWMF Nature Run (~ 40 km)
 - NCEP's global data assimilation system is T382 with non-hybrid GSI analysis – operational configuration is T574 with hybrid GSI
 - RO observation is refractivity – operational configuration assimilates bending angle, a less derived product
 - Assimilation of RO profiles stops at 30 km – operational configuration assimilates up to 50 km
 - All observations are assumed error-free except for satellite radiances, which have biases added on



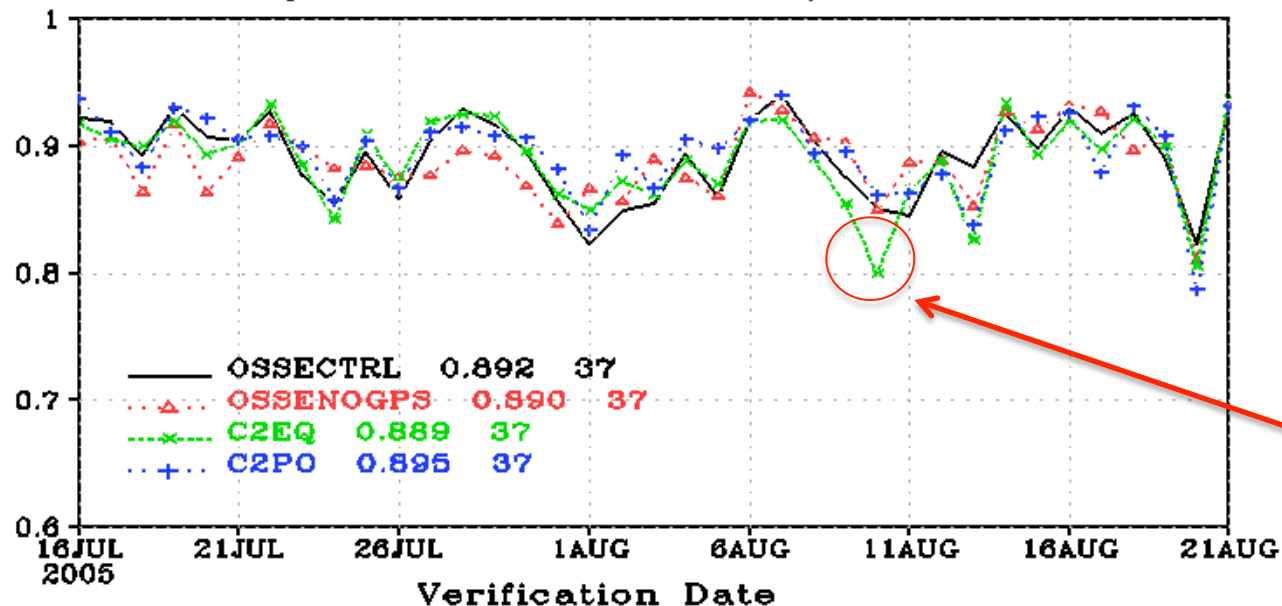
Preliminary OSSEs with RO

- Experiments ran from 2 July 2005 to 21 August 2005
- Verification covers the period of 16 July – 21 August 2005
- RO missions being considered:
 - Current RO constellation: primarily COSMIC (6 satellites)
 - COSMIC-2, both equatorial (6 satellites) and polar (6 satellites) components
 - GeoOptics (commercial, 12 satellites) – further evaluation is ongoing work
 - Planet IQ (commercial, 12 satellites) – further evaluation is ongoing work
- Experiments:
 - **OSSENOGPS: control without RO observations (0 RO satellites)**
 - **OSSECTRL: control, all observations (6 RO satellites)**
 - **C2EQ: control + COSMIC-2 equatorial (12 RO satellites)**
 - **C2PO: control + COSMIC-2 equatorial + COSMIC-2 polar (18 RO satellites)**

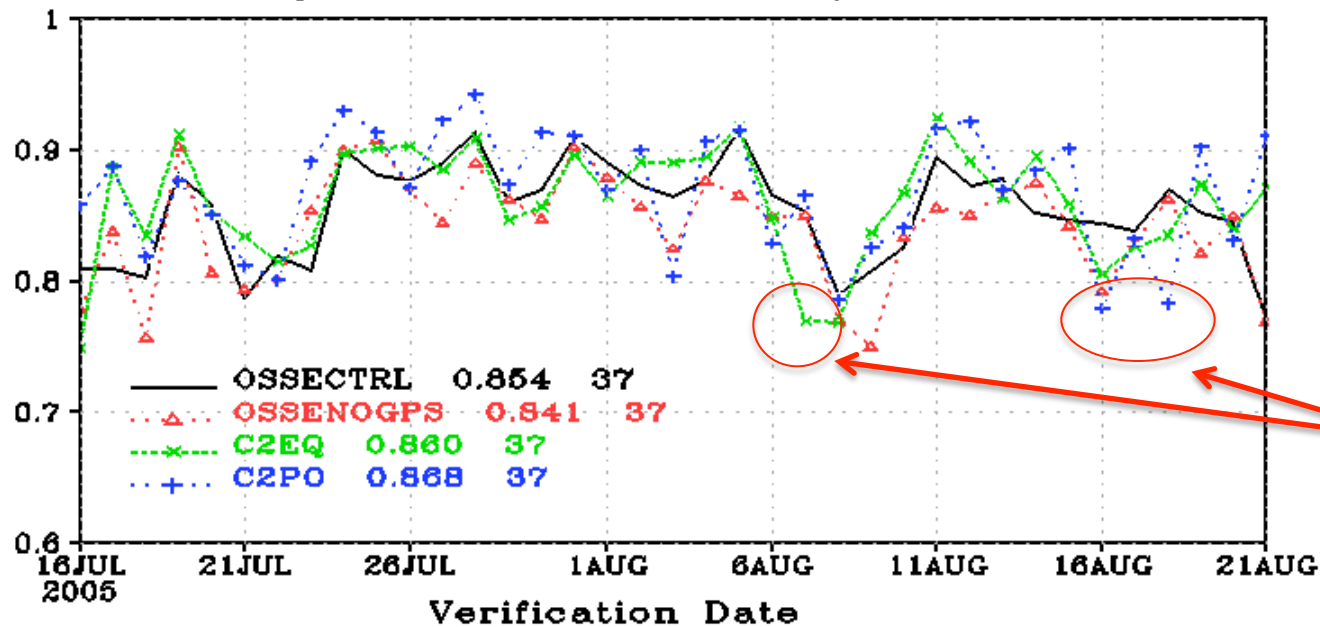


Day 5

Anomaly Correl: HGT P500 G2/NHX 00Z, fh120

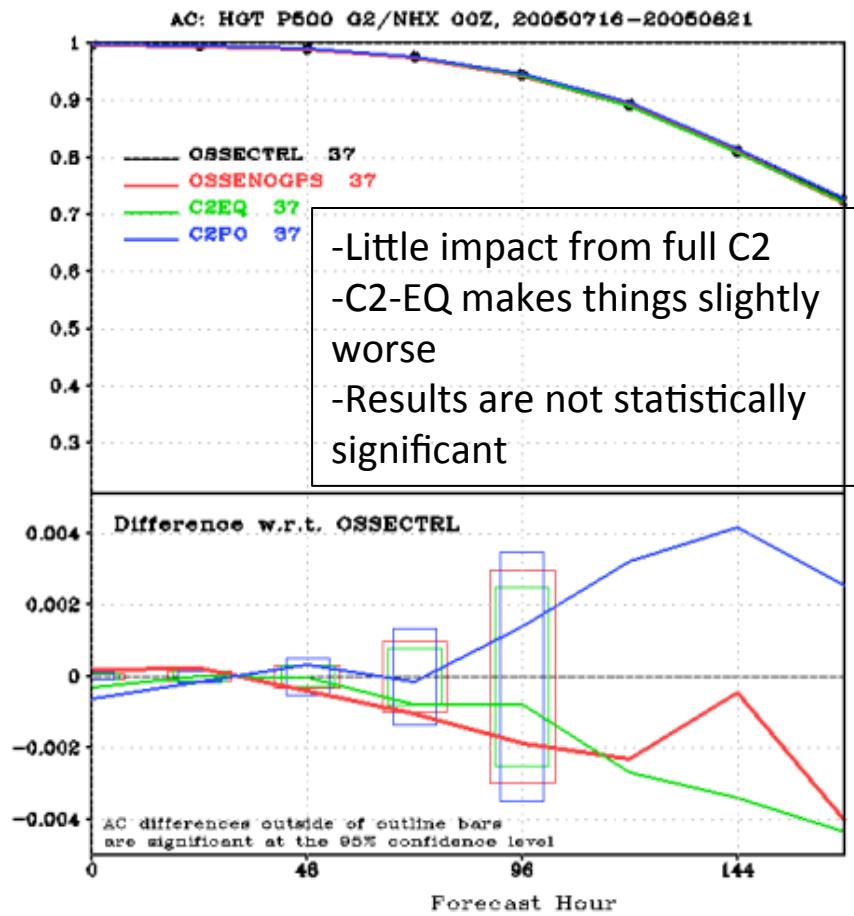


Anomaly Correl: HGT P500 G2/SHX 00Z, fh120

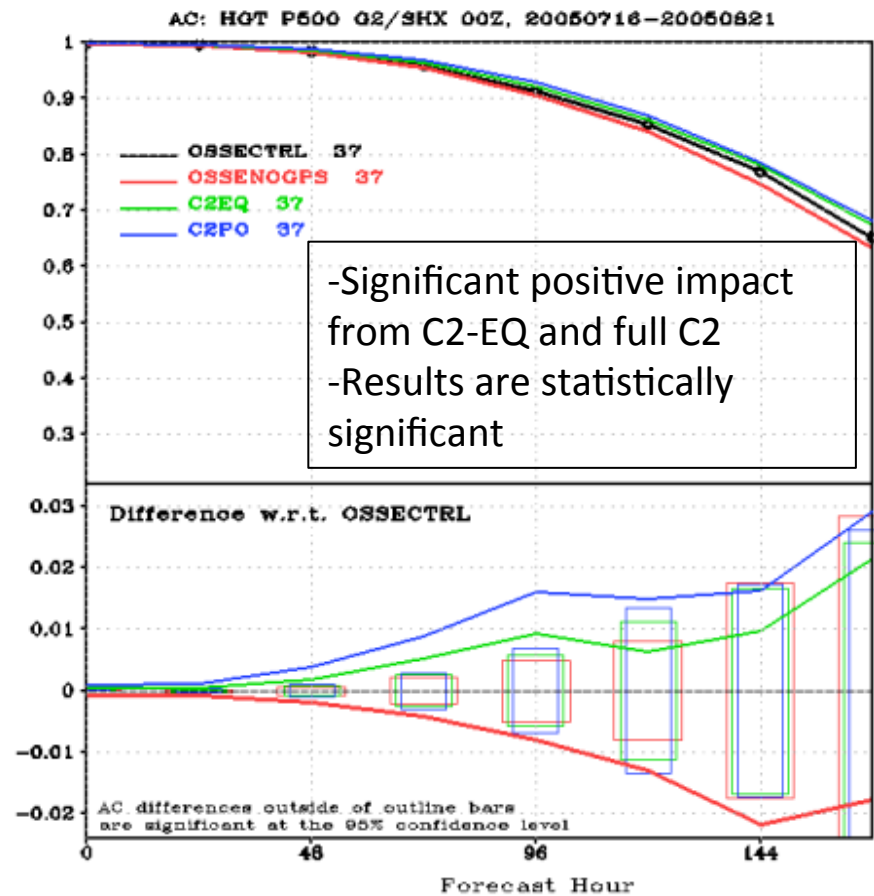


Anomaly correlation of 500-mb gph

NH



SH



Forecast hour



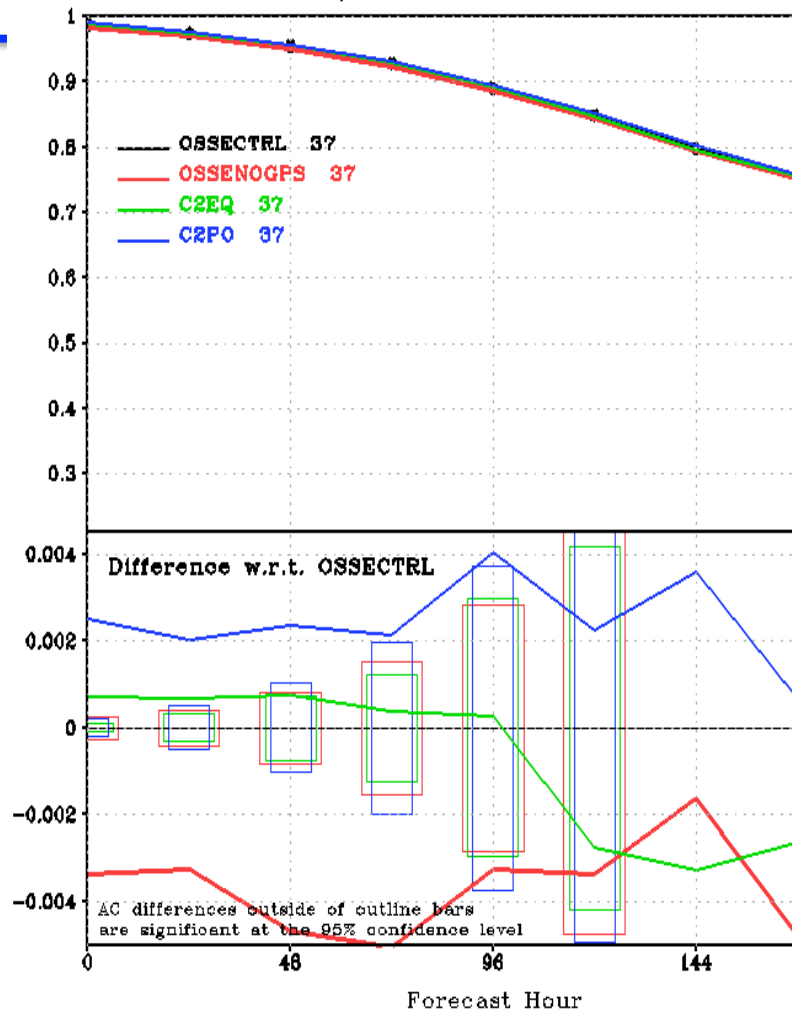
NH

Temperature, AC at 250 mb

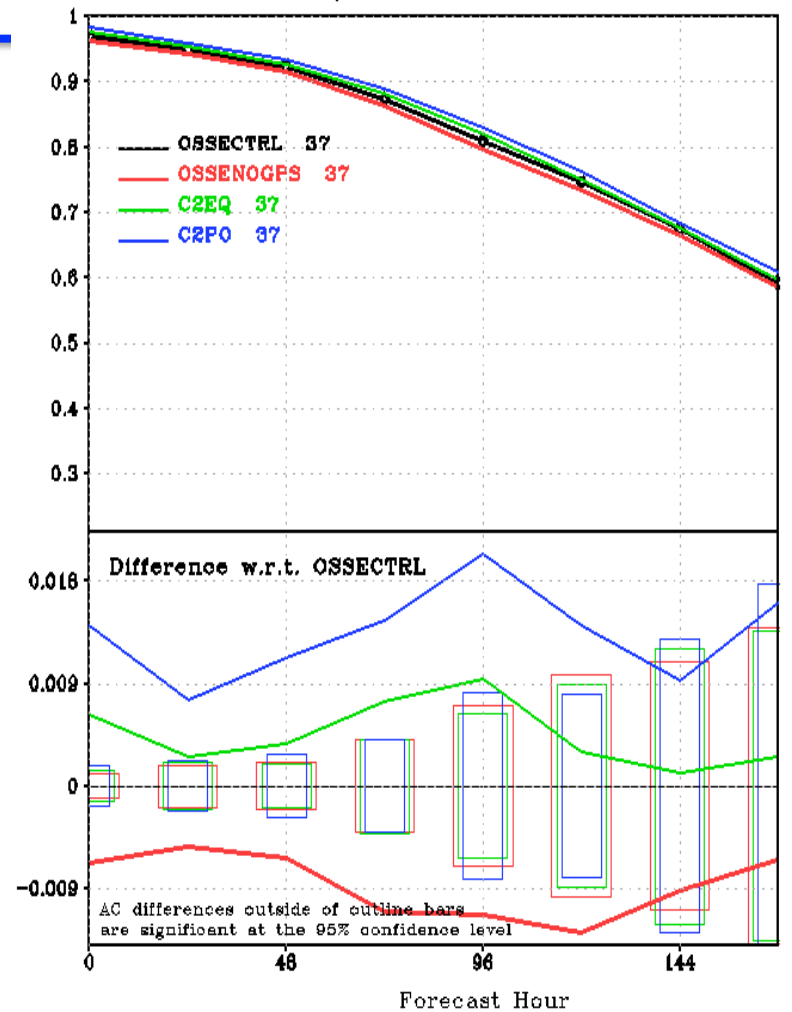
SH



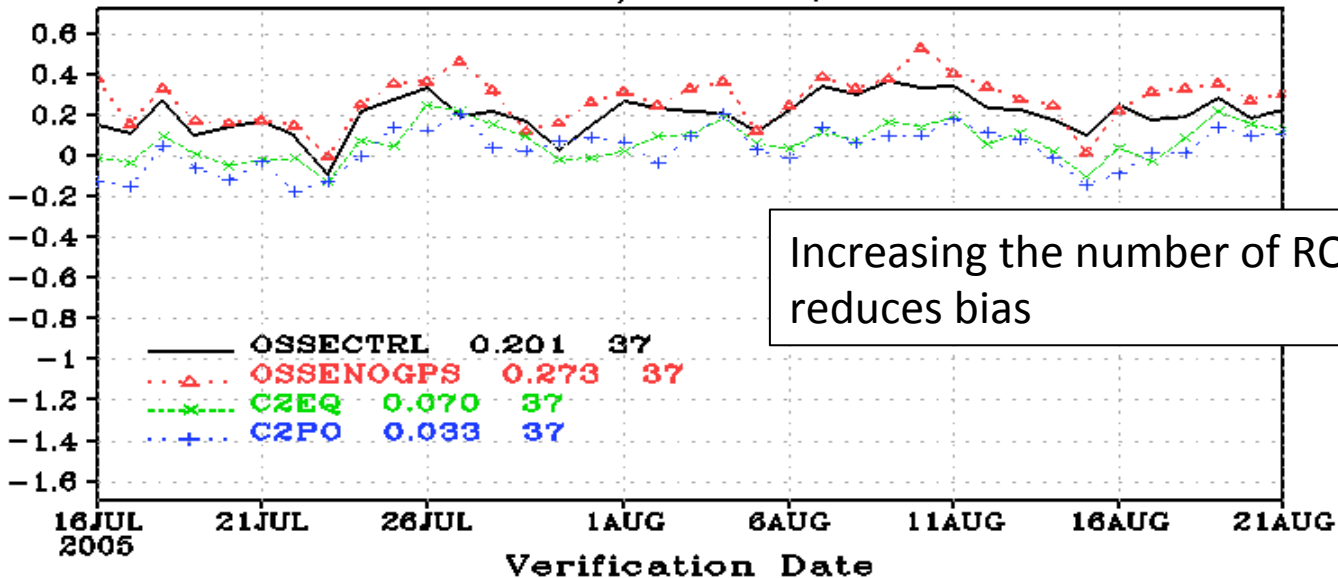
AC: T P250 G2/NHX 00Z, 20050716-20050821



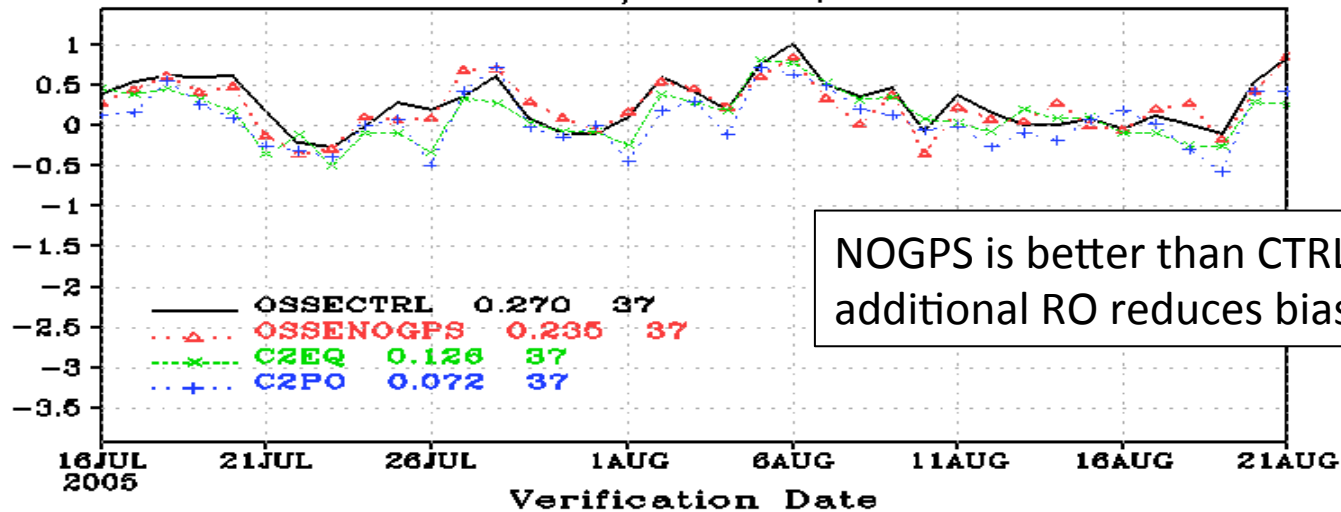
AC: T P250 G2/SHX 00Z, 20050716-20050821



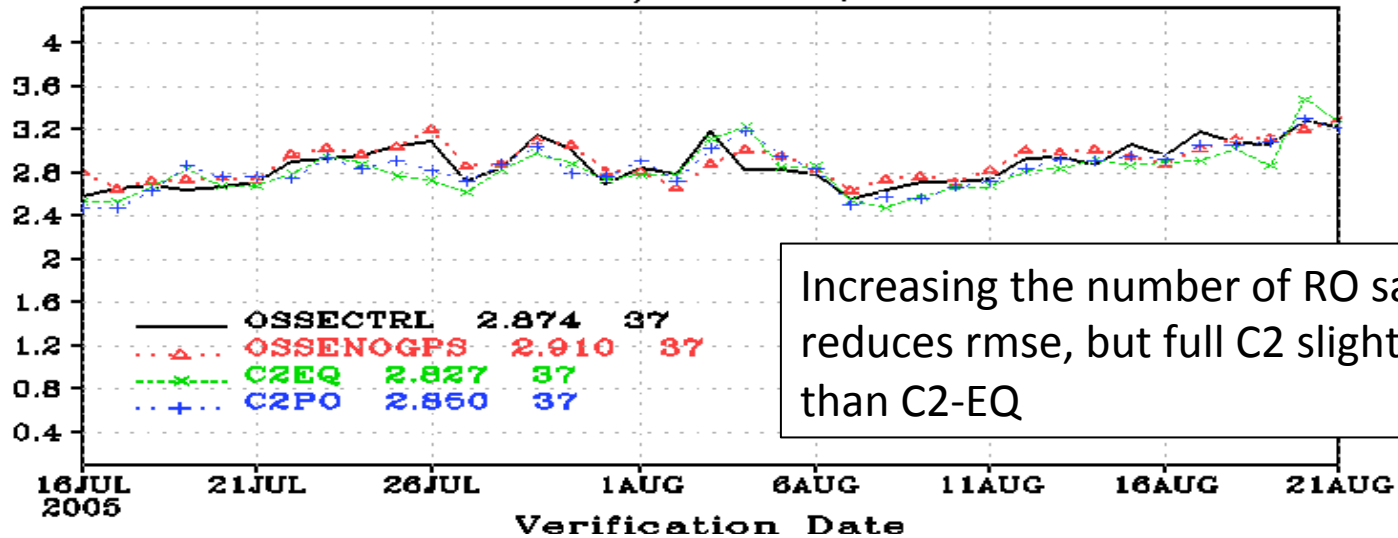
WIND: Bias
P850 G2/TRO 00Z, fh72



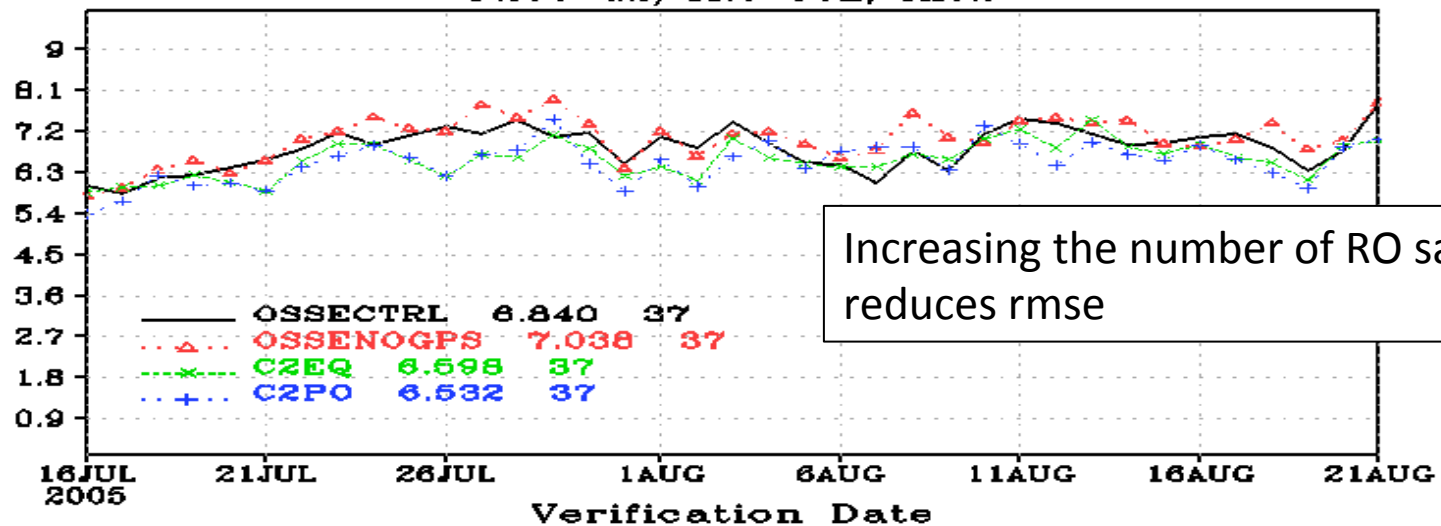
WIND: Bias
P200 G2/TRO 00Z, fh72



WIND: RMSE P850 G2/TRO 00Z, fh72



WIND: RMSE P200 G2/TRO 00Z, fh72





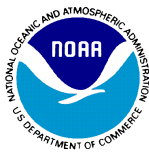
Preliminary RO OSSE results

- Overall, increasing the number of assimilated RO satellites from 6 to 18 results in better weather forecast skill: 18 satellites is better than 12 satellites; 12 satellites is better than 6 satellites
- There is a lot of room to optimize the assimilation system
- Some cases need to be evaluated with more detail to understand how results can be improved (e.g. “dropouts”)
- Results (not shown here) seem to indicate that with this sub-optimal OSSE system saturation might be reached with 30 satellites
- These preliminary studies do not use the state-of-the-art OSSE system



Next steps for RO OSSEs

- Investigate the differences between the analyses and forecasts (horizontal maps and vertical cross sections) from the different RO configurations
- Evaluate results for individual cases – why we sometimes see “dropouts” with the assimilation of RO? – This will likely be improved with the use of the hybrid GSI system in the more rigorous experiments
- Sanity check: adding RO observations to a poor baseline should result in an increase of weather forecast skill
- Repeat experiments with a state-of-the-art OSSE configuration
 - Higher resolution Nature Run
 - Random errors added to the observations
 - Hybrid GSI in DA system
 - Higher horizontal resolution in DA system
 - Bending angle forward operator instead of refractivity operator
 - Extending the top of the RO profiles from 30 to 50 km



(2) OSEs: Data Gap mitigation activities

- ATMS observations on Suomi-NPP were assimilated into the operational NCEP's global data assimilation system starting in May 2012
- Suomi-NPP was placed in early afternoon orbit, providing similar information to the existing polar orbiting satellites with MW sounders (AMSU-A and MHS on NOAA-18/19, AMSU-A on Aqua, and AMSU-A on NOAA-15)
- As a consequence, previous studies showed in general neutral impact of ATMS in the NCEP's system
- Due to the delay in the launch of JPSS-1, a "gap" or significant reduction in the U.S. MW satellite data is possible
- MW soundings are consistently the number one observing system contributing to NWP forecast accuracy
- In addition, there might a significant loss of RO observations
- RO observations are complementarity to MW and IR observations and have been shown a significant positive impact on global NWP forecasts worldwide



Motivation

- Goal of the study is to investigate the impacts on the skill of NCEP global forecasts due to a loss of the NOAA and AQUA MW and all RO soundings
- Two extreme scenarios are considered
 - MW instruments from NOAA-15/18/19 and AQUA have not reached the end of their life before JPSS-1 is launched
 - MW instruments from NOAA-15/18/19 and AQUA are lost before JPSS-1 is launched
- Evaluate the impact of losing all RO observations in both extreme scenarios
- Results of the study might be considered pessimistic (worse case) as all systems are not likely to fail before there are some replacements
- Extreme cases will indicate relative importance of these losses – will provide significant signal

Experiment Design

Experiment	Description
1 <i>CTL</i>	Control experiment, March-April 2013 operational NCEP's global data assimilation system.
2 <i>noRO</i>	<i>CTL</i> without RO observations
3 <i>noATMS</i>	<i>CTL</i> without ATMS observations
4 <i>noUSAMSU</i>	<i>CTL</i> without AMSU-A/MHS on NOAA-18/19, AMSU-A on Aqua, and AMSU-A on NOAA-15
5 <i>ATMS Only</i>	<i>CTL</i> without AMSU-A/MHS on NOAA-18/19, AMSU-A on Aqua, AMSU-A on NOAA-15, and RO
6 <i>RO Only</i>	<i>CTL</i> without AMSU-A/MHS on NOAA-18/19, AMSU-A on Aqua, AMSU-A on NOAA-15, and ATMS

- All forecasts begin at 00 GMT and ran for 8 days from 21 February to 30 April 2013. The first seven days are used for model spin-up and the forecast comparisons cover the period 28 February – 30 April 2013
- Horizontal resolution of the operational NCEP's global data assimilation system at the time of this study is T574 (~ 27 km) with 64 levels in the vertical
- All the experiments used the hybrid version of the NCEP's global data assimilation system
- RO observations (~ 0.4 M/day) versus U.S. MW observations (~ 2.1 M AMSU-A/day)

AC 250-mb Temperature

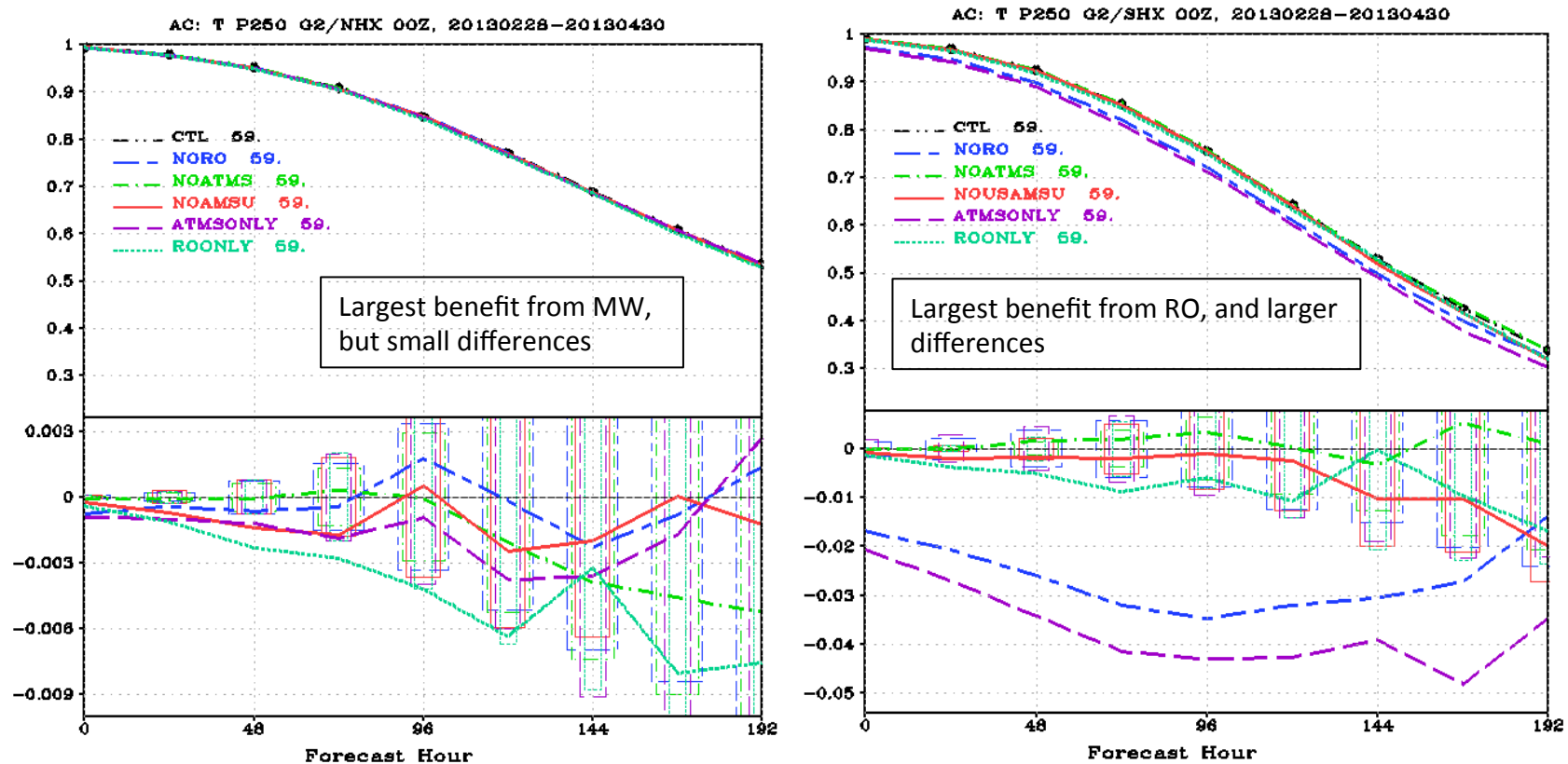


Fig. 4. Top: Anomaly correlation score as a function of the forecast length for the 250-mb temperature field in the NH (a) and SH (b) for all six experiments. The differences from the CTL are shown in the lower panels. Bottom: Difference of AC scores with respect to CTL in the (a) NH and (b) SH. Vertical bars indicate limits of statistical significance at the 95% confidence levels; curves within the corresponding bars are not statistically significant.

Fit to Radiosonde (Temperature)

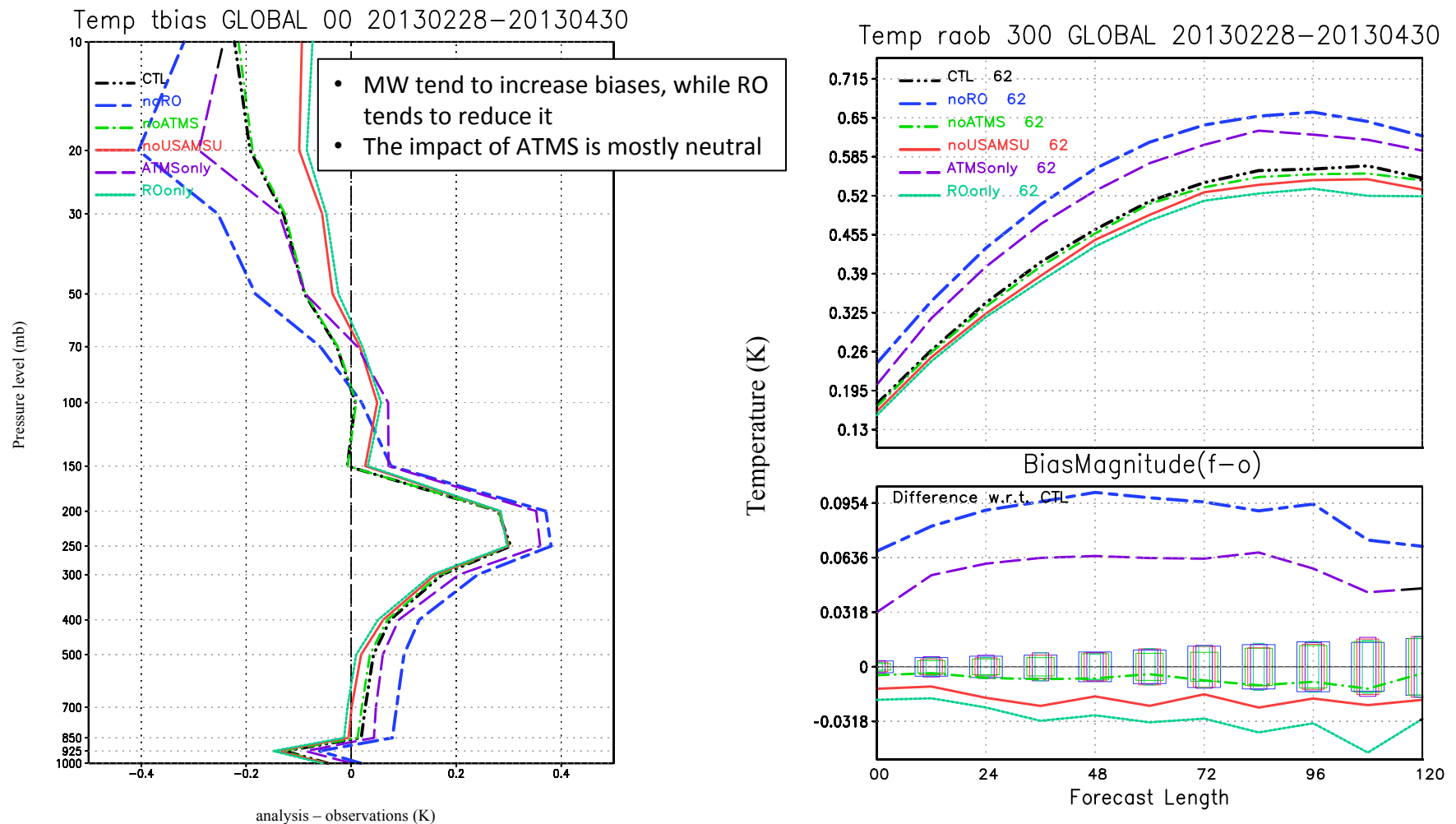


Fig.5. Global temperature biases of analyses relative to radiosondes in all six experiments.

Results

- A slight loss of accuracy in the NH extratropics forecasts occurs with the loss of all U.S. MW data, and this loss is not mitigated with RO observations
- In the SH extratropics, the loss of RO data produces a much larger negative impact on the forecast than does the loss of the U.S. MW observations
- The role of ATMS in mitigating the loss of the other MW sounders is mixed, but generally neutral
- Thus the potential “gap” in RO may be a more serious risk to global forecasts accuracy than potential gaps in the U.S. MW observations
- The global biases in analyses and forecasts seem to increase as the number of MW observations increases, particularly in the stratosphere – the modest amount of unbiased RO only partially reduces these biases
- An increase of RO observations should further ‘anchor’ the model resulting in improved bias corrections of the satellite radiances
- *Cucurull L., and R. A. Anthes, 2015: Impact of Loss of Microwave and Radio Occultation Observations in Operational Numerical Weather Prediction in Support of the US Data Gap Mitigation Activities, Wea. Forecasting, 30, 2, 255-269.*

(3) COSMIC-2: RO algorithm development

- Improve the assimilation of the RO observations in the lower troposphere, in particular under super-refraction (SR) conditions (top of the PBL)
- Is there any useful information in the observations below a SR layer?
- Given the indetermination and the larger uncertainty associated with these observations, can the analysis benefit from their assimilation?
- NBAM (NCEP's bending angle method) is used to assimilate bending angle observations in the operational configuration
- An upgraded version of NBAM (NABAM, "A" for "Advanced") is being developed to better address rays that cross a model super-refraction layer, particularly when the tangent point is close to the model super-refraction layer
- In the meantime, and primarily under this project as well, an additional QC to directly detect and reject observations that might have been affected by SR conditions (either in the model or in the retrieval) were implemented and became operational at NCEP in January 2015
- *Cucurull L., 2015: Implementation of a quality control for GNSS Radio Occultation observations in the presence of large gradients of atmospheric refractivity, Atmos. Meas. Tech., 8, 1275-1285, doi:10.5194/amt-8-1275-2015*

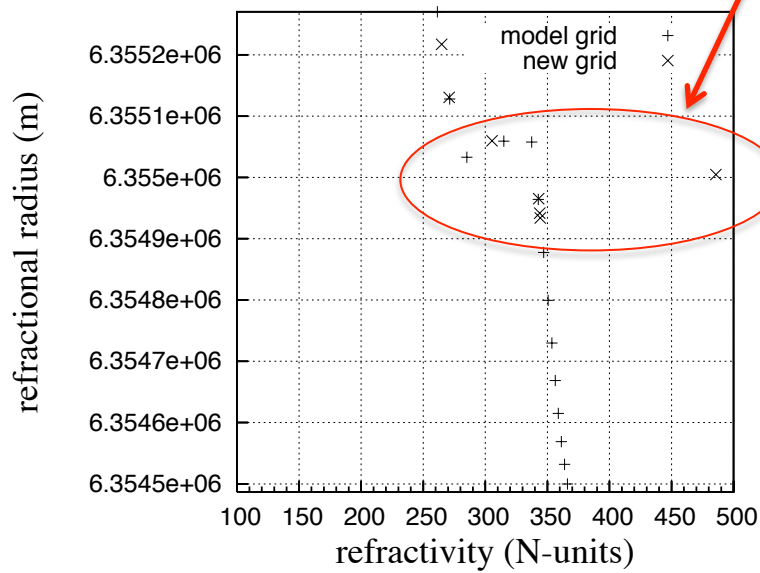
Introduction to NABAM

Model profile at the location of an observation below a model SR layer in model grid and NBAM integration grid

NBAM

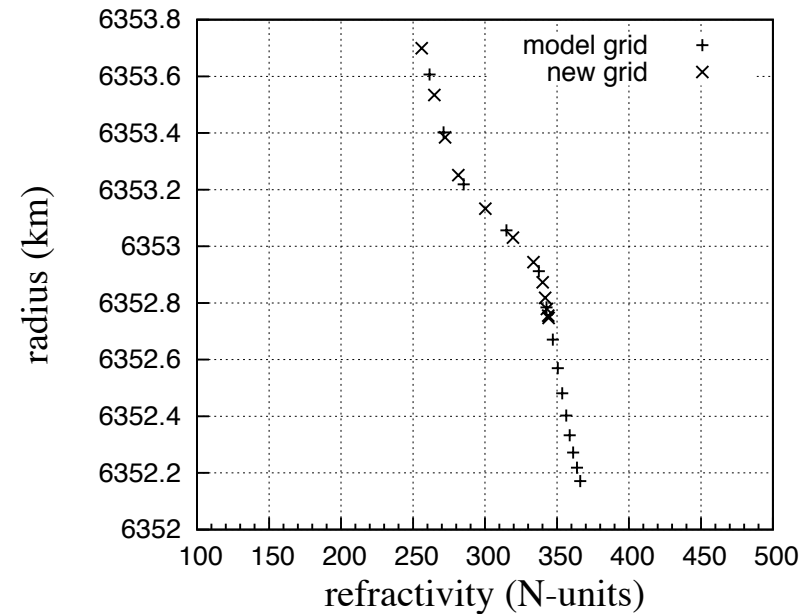
discontinuities

1 SR layer

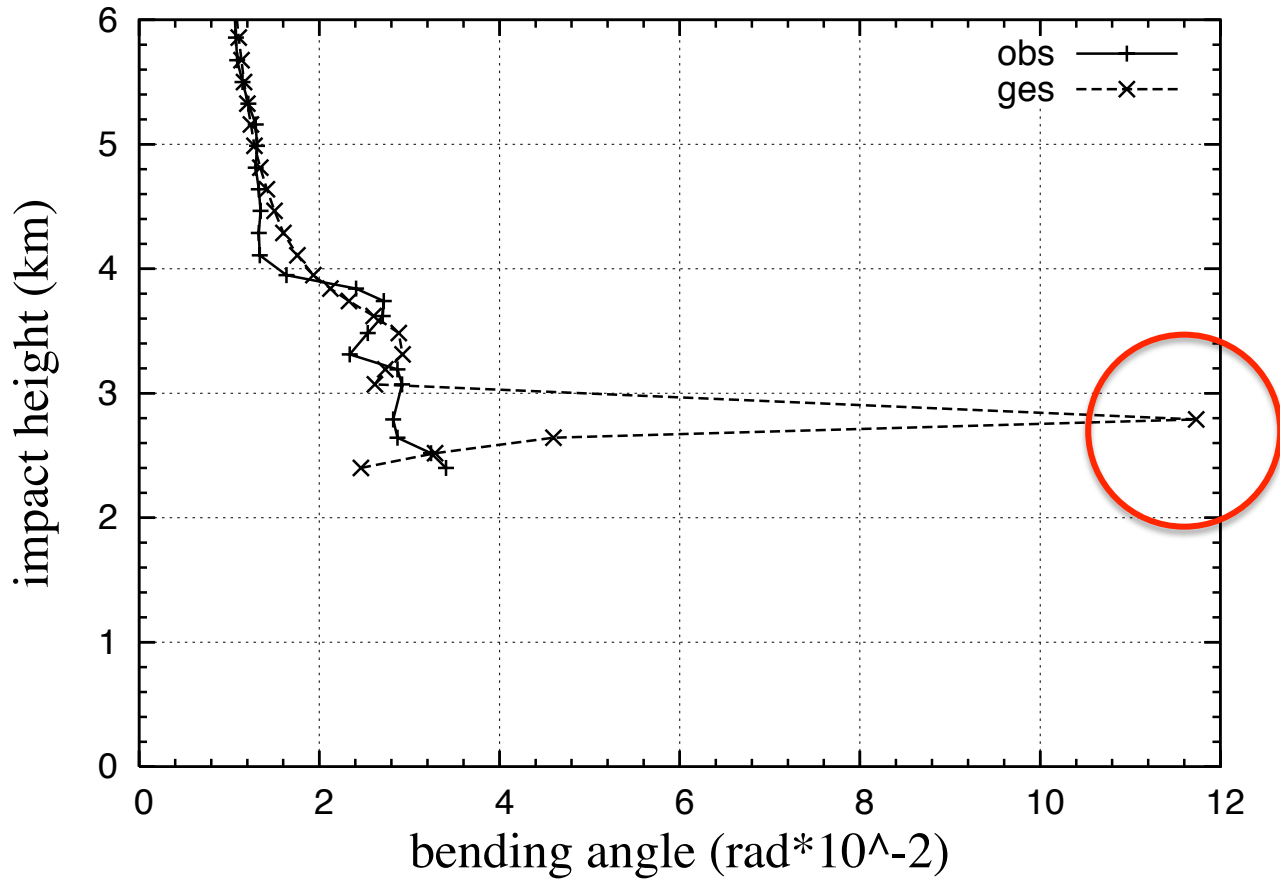


NABAM

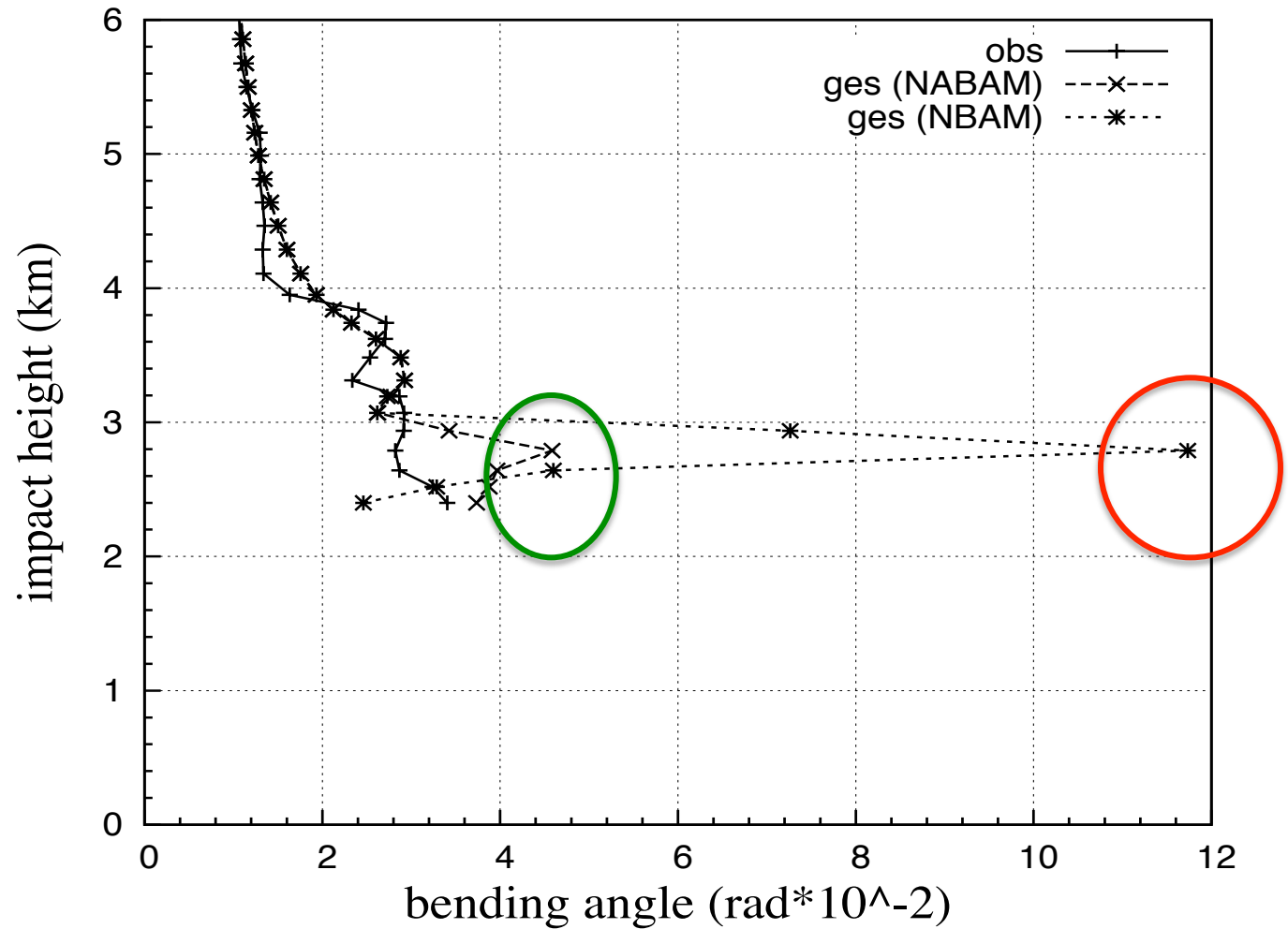
1 SR layer



Limitations of NBAM



NABAM vs NBAM





Outlook

- GOSA Group has been established (in coordination with NOAA'S QOSAP Program) to coordinate OSSE efforts to help NOAA management prioritize mission designs in a cost-effective way
- Both OSEs and OSSEs are necessary to quantitatively evaluate the benefits of observations in weather forecasting
- NOAA is fully committed to Radio Occultation observations – see P. Wilczynski's talk on COSMIC-2
- GOSA is engaged in ongoing R&D to quantify impacts of additional GNSS RO measurements on operational forecast models (e.g., what is the saturation point?)
- GOSA has a formal agreement with NWS and NESDIS to support GNSS RO research and associated R2O
- GOSA is transitioning its ground based GPS application to the private sector