Progress in GPS-RO assimilation at NOAA

Lidia Cucurull
Office of the Director, Global Systems Division
Earth System Research Laboratory (ESRL) / CIRES
NOAA Office of Oceanic and Atmospheric Research

Collaborators: Rick Anthes (UCAR), Jim Purser (EMC), Sergey Sokolovskiy (UCAR), Zaizhong Ma (JCSDA), Jack Woollen (EMC), Bob Atlas (NOAA/AOML), ...

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ECMWF/EUMETSA ROM-SAF workshop on applications of GPS RO measurements, 16-18 June 2014, ECMWF, Reading, UK.

Outline

- OSSE/OSE activities within NOAA/OAR
- Complementarity between RO and satellite radiances (microwave and infrared)
- Impact of the loss of RO and ATMS on operational weather forecasting
- RO data assimilation into NCEP's GDAS

OSSE/OSE activities

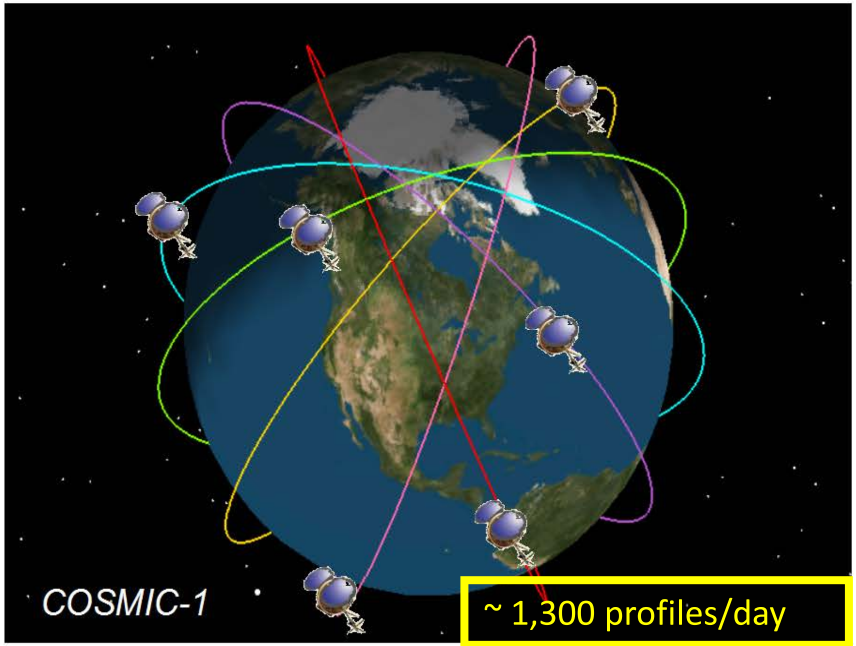
- As part of the US Sandy Supplemental Bill, the project "Establishment of a NOAA Laboratory Activity for Observing System Simulation Experiments" was funded under the "NOAA Weather Satellite Data Mitigation Gap Reserve Fund of the Sandy Supplemental" Funding Opportunity
- Project period: Jan 2014 – Dec 2015
- Led by NOAA/OAR/AOML (Dr. Bob Atlas), in partnership with NOAA/OAR/ESRL, NESDIS, JCSDA, NASA, etc
- Primary goal is to develop a new OSSE capability (ECMWF T1279 NR, NASA/GMAO 7 km NR)

OSSE/OSE activities (cont'd)

- GNSS RO is an important component of this project:
- (1) Perform Observing System Experiments (OSEs) with current NCEP's global data assimilation system and existing satellite data:
- Evaluate of the impact of current RO versus the impact of ATMS on S-NPP in the presence and absence of the other microwave sensors in the early afternoon orbit
- Results will be used to calibrate the Observing System Simulation Experiment (OSSE) system later in the project

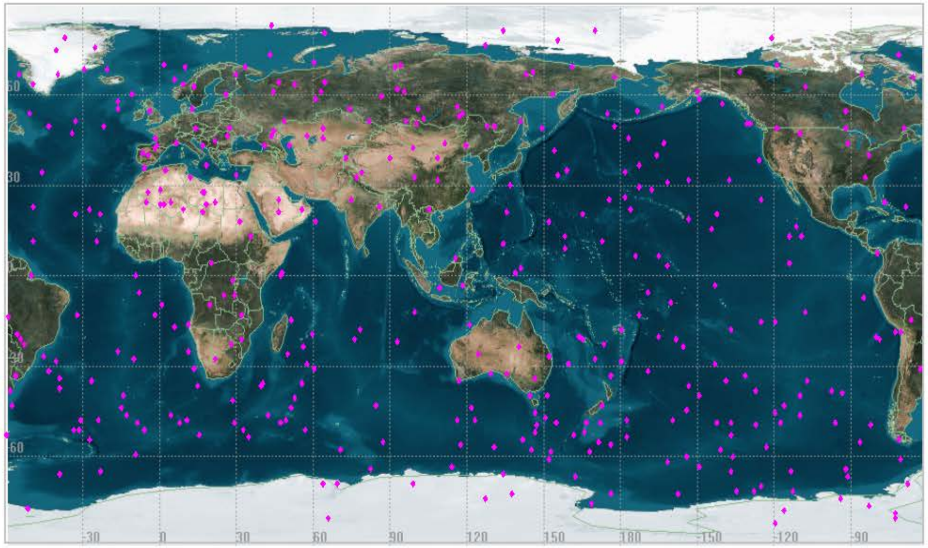
OSSE/OSE activities (cont'd)

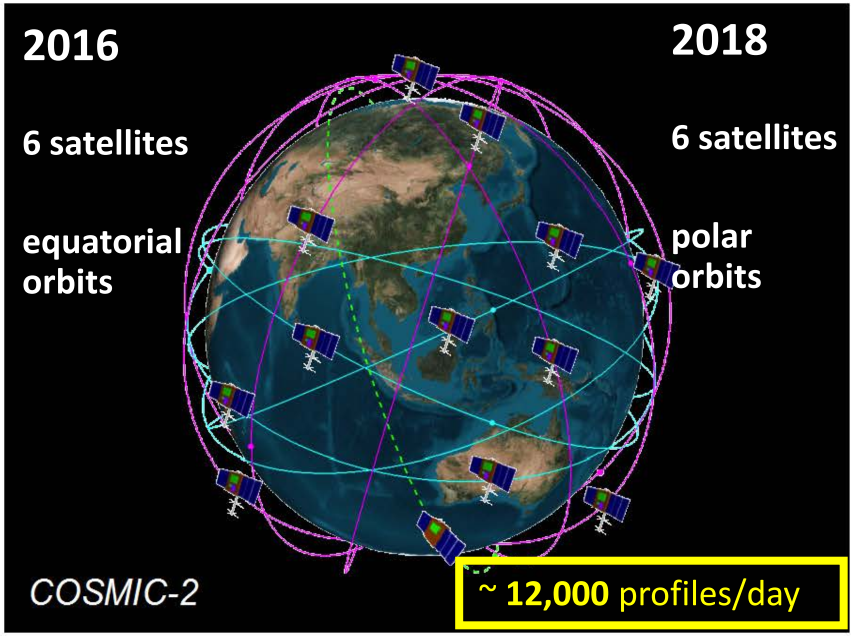
- (2) Conduct preliminary OSSEs to investigate how much could future RO constellations mitigate a delay on the launch of JPSS-1, using S-NPP as a proxy for JPSS-1 – bending angles up to 50 km
- The RO constellations that may be evaluated include COSMIC-2 (equatorial and polar components), GeoOptics, and PlanetIQ. The value of these additional observations will be evaluated incrementally



~ 1,300 profiles/day

COSMIC-1 Occultations – 3 Hrs Coverage





2016

6 satellites

equatorial orbits

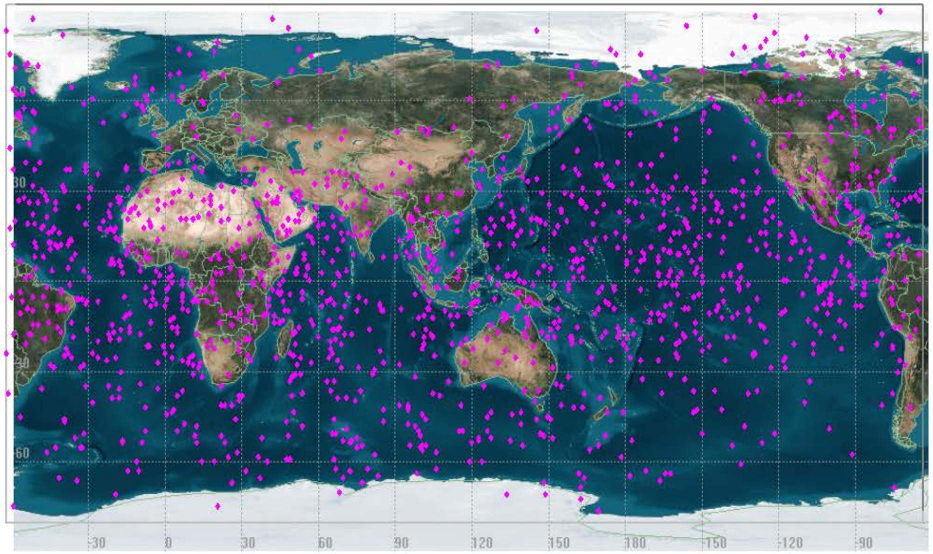
2018

6 satellites

polar orbits

~ **12,000** profiles/day

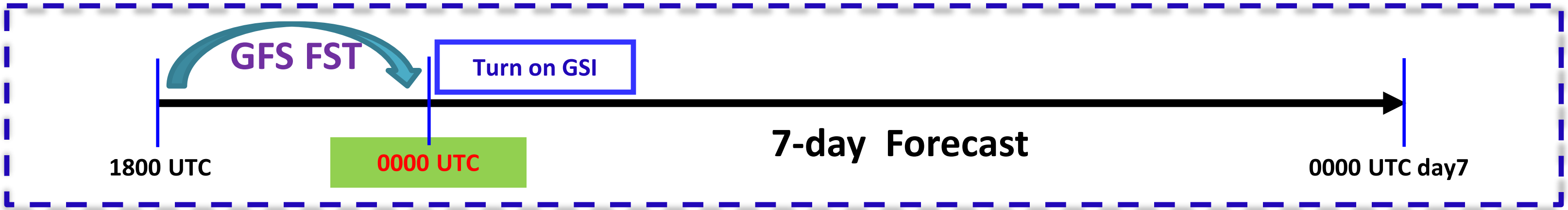
COSMIC-2 Occultations – 3 Hrs Coverage



Courtesy of UCAR

Qualitative GPSRO OSSEs

(with Zaizhong Ma and Jack Woollen)



- Period: **45 days** (July 02 00z ~ Aug.15 00z, 2005)
- "Old" ECMWF Nature Run (T511) & lower resolution than NCEP's operational GDAS
- Two experiments
  - **CTRL**: A control run in which all relevant observations from observing systems (conventional and space-based) are assimilated as 2012 operational configuration. It uses refractivities up to 30 km.
  - **NOGPS:** Same as CTRL, but without GPSRO refractivity observations
- Experiments with COSMIC-2 are about to start

Types of Data Simulated

Set A (2005-06 period)

AIRS (Aqua),
AMSU-A (Aqua, NOAA-15, 16, 18),
AMSU-B (NOAA-15, 16, 17),
HIRS2 (NOAA 14),
HIRS-3 (NOAA 15, 16, 17),
HIRS-4 (NOAA-18),
MSU (NOAA-14),
MHS (NOAA-18)
GOES sounder (GOES-10, 12)

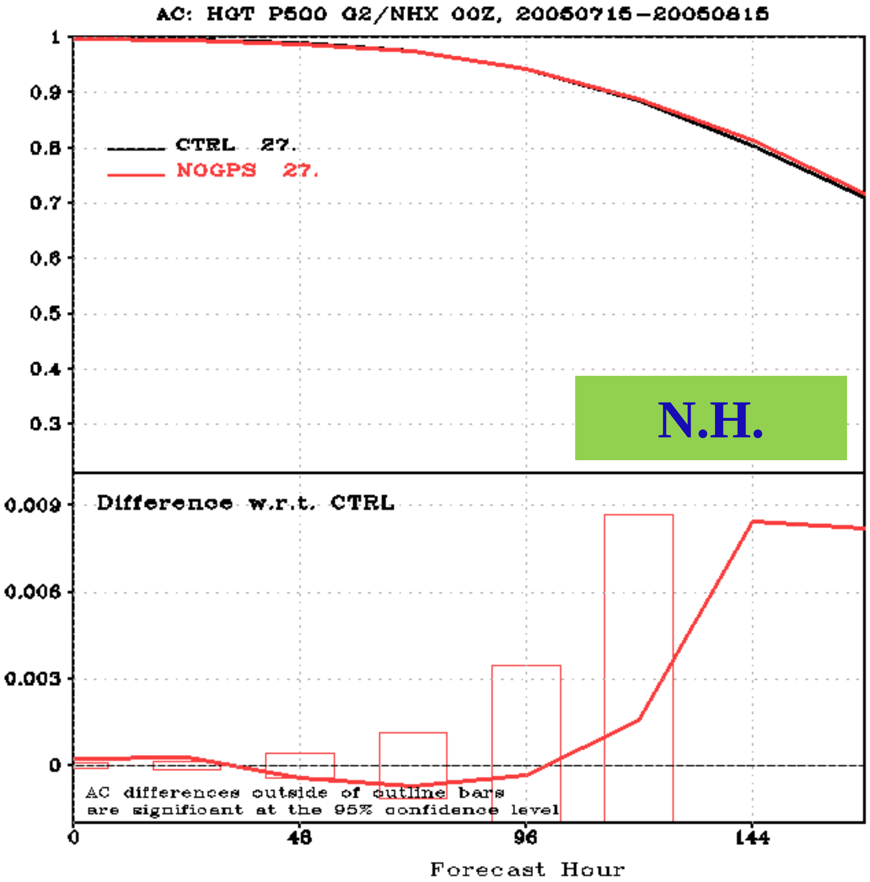
All conventional data available in 2005-06

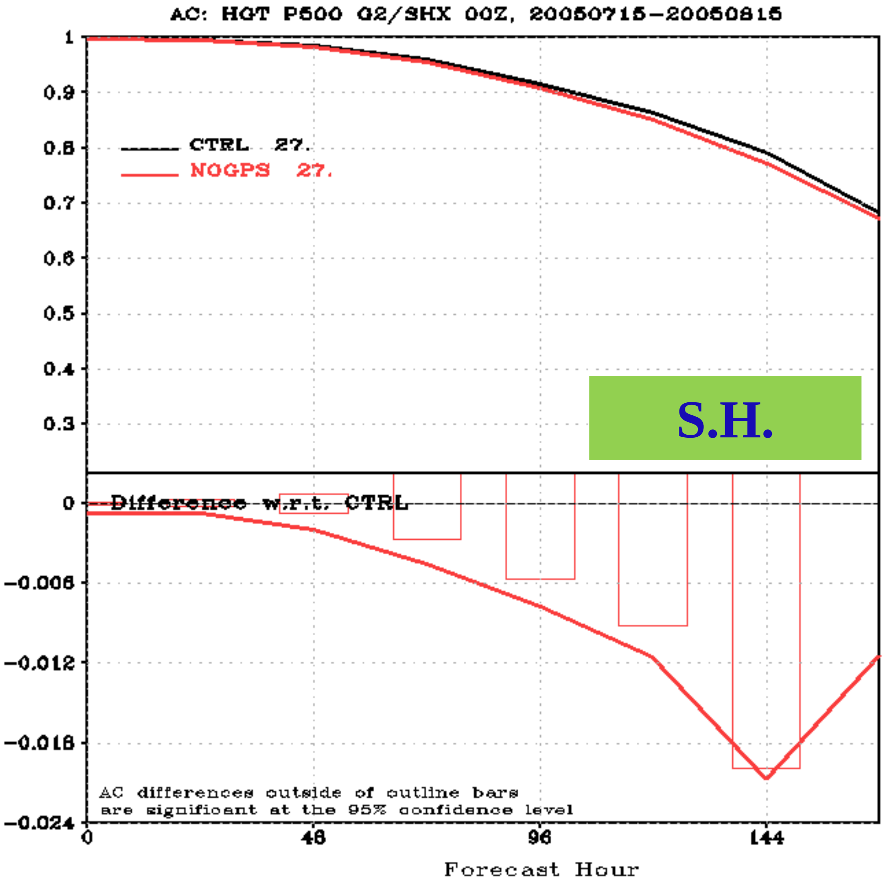
Set B (2011-12 period)

IASI(METOP-A), AIRS(AQUA),
ATMS(NPP), **CrIS(NPP)**
HIRS-2(NOAA14),
HIRS-3(NOAA 15, 16, 17),
HIRS-4(NOAA 18, 19, METOP-A),
AMSUA(NOAA 15, 16, 17,18,19, AQUA, METOP-A),
AMSUB(NOAA 15, 16, 17),
MSU(NOAA 14), HSB(AQUA),
MHS(METOP-A,NOAA18,19),
SSMIS(DMSP F16), SEVIRI(MSG)
GOES sounder (10,12, and 13)
GPSRO **(refractivity)**

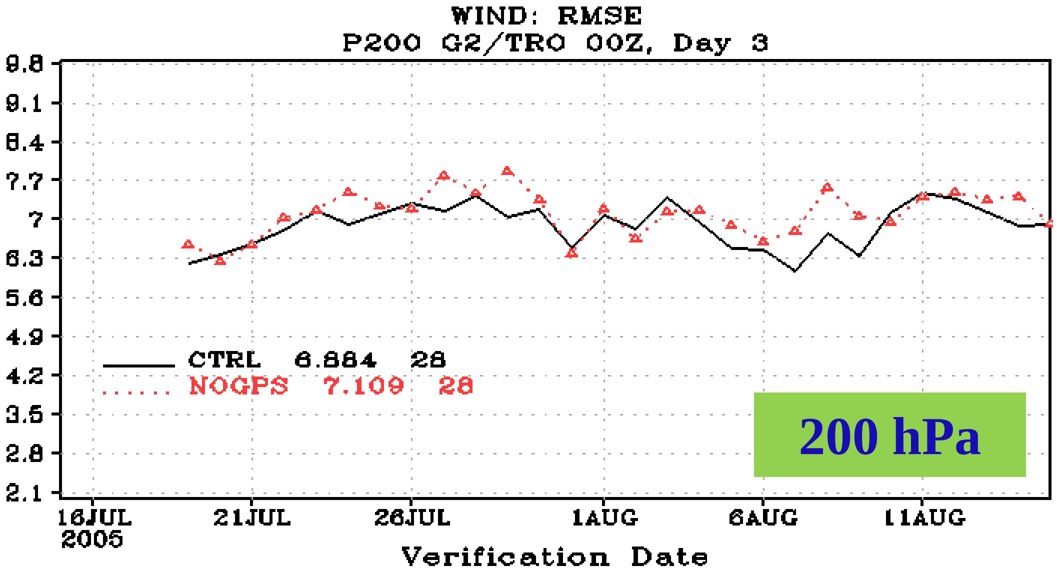
All conventional data available in 2011-12

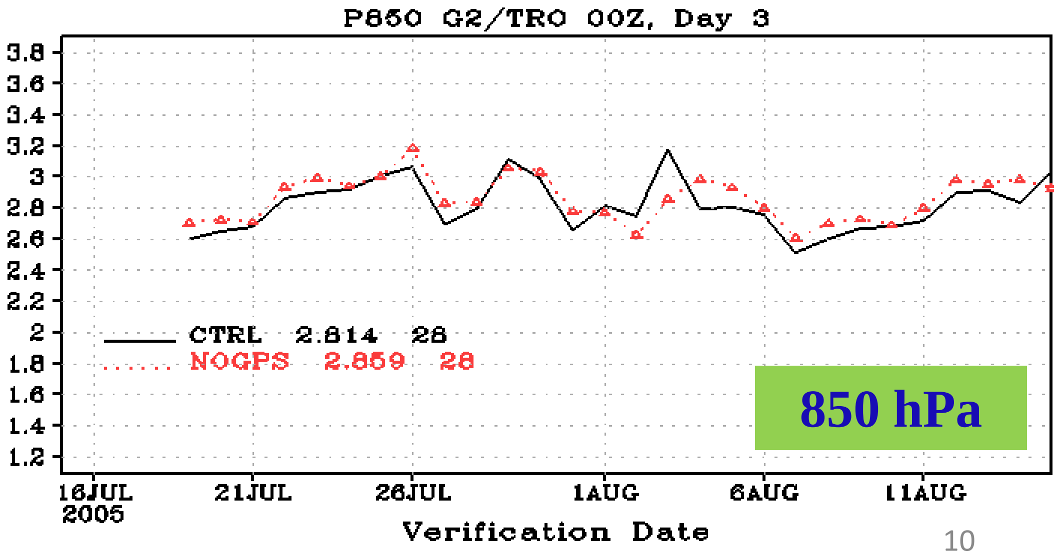
AC score of Geopotentional height at 500 hPa





Day 3 Tropical Wind RMS





Similarities/differences MW, IR, RO

(with Rick Anthes)

- RO limb soundings and passive MW & IR nadir-viewing observations are together the most effective observational systems in reducing forecast error
- The limb-viewing and nadir-viewing systems are highly complementary
- The assimilation of satellite radiances in operational weather forecasting benefits from the assimilation of unbiased observations (i.e. RO) that reduce the drift of a weather model towards its own climatology
- The goal of the study is to investigate the differences and similarities between the assimilation of RO, MW, and IR observations in the NCEP’s global data assimilation system (GSI/GFS)
- Results of the study are under current review (Cucurull and Anthes 2014a, MWR)

Experiment Design

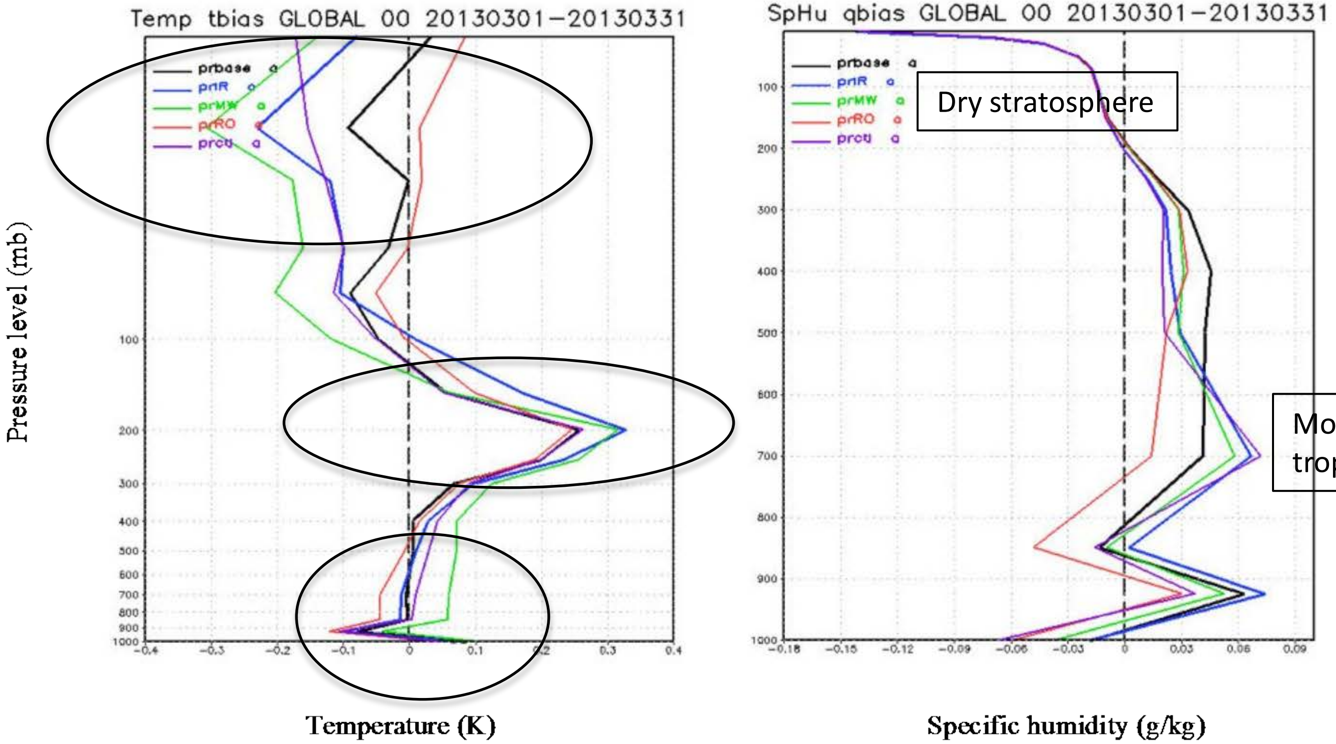
- Six experiments
  - ***CTL***, operational configuration with all the observations
  - ***BASE***, CTL without IR, MW and RO
  - ***IR***, BASE with IR added
  - ***MW***, BASE with MW added
  - ***RO***, BASE with RO added
- All experimental forecasts begin 00 GMT and ran for 8 days
- Time period: 21 February – 31 March 2013 (first seven days used for model spin-up)
- NCEP’s global configuration (hybrid GSI, T574, 64 levels in the vertical)
- We looked at fit to radiosondes; horizontal maps of the analysis differences & RMS differences; vertical profiles of global and temporal averages of mean differences, RMS differences and correlations; and anomaly correlation score

Fit to Radiosondes

- IR, MW, CTL are cold in stratosphere
- Warm bias in the upper troposphere
- MW produces the largest coldest bias in stratosphere and the warmest bias in the troposphere

Temperature

Moisture

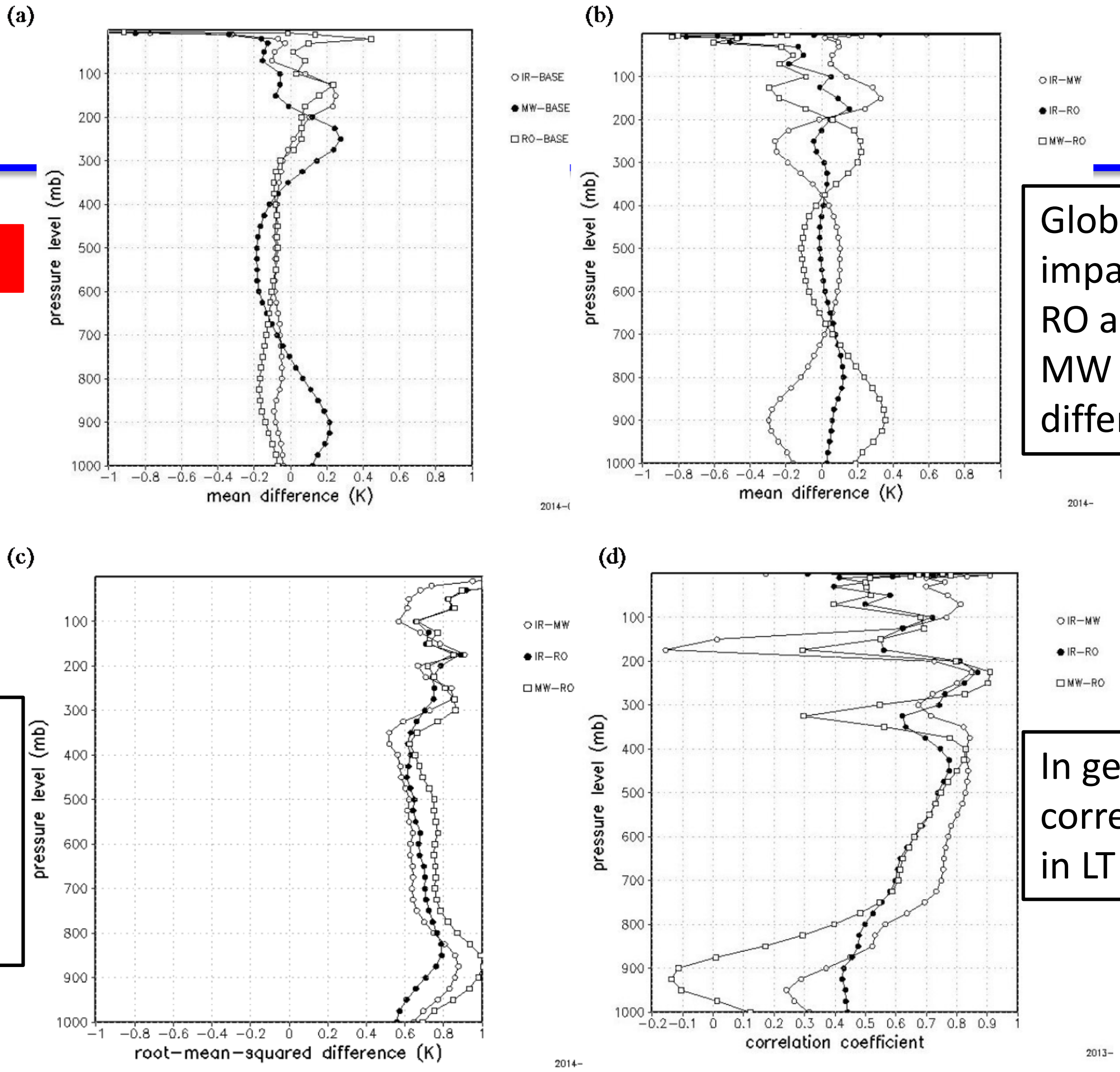


Dry stratosphere

Moist troposphere

Fig. 2: (a) Temperature (K) and (b) specific humidity (g/kg) fit to radiosondes of *CTL* (purple), *BASE* (black), *IR* (blue), *MW* (green) and *RO* (red).

Temperature



Global mean impacts of IR and RO are similar, MW quite different

Largest variability in LT, and between MW and RO

In general, high correlation except in LT

Fig. 12 Vertical profiles of (a) global monthly mean IR, MW and RO analyses minus *BASE* temperatures, (b) global monthly mean *IR-MW*, *IR-RO*, and *MW-RO* temperature impacts, (c) RMS differences for *IR-MW*, *IR-RO*, and *MW-RO* temperature impacts, and (d) correlation coefficients between monthly mean *IR-MW*, *IR-RO*, and *MW-RO* temperature impacts.

Moisture

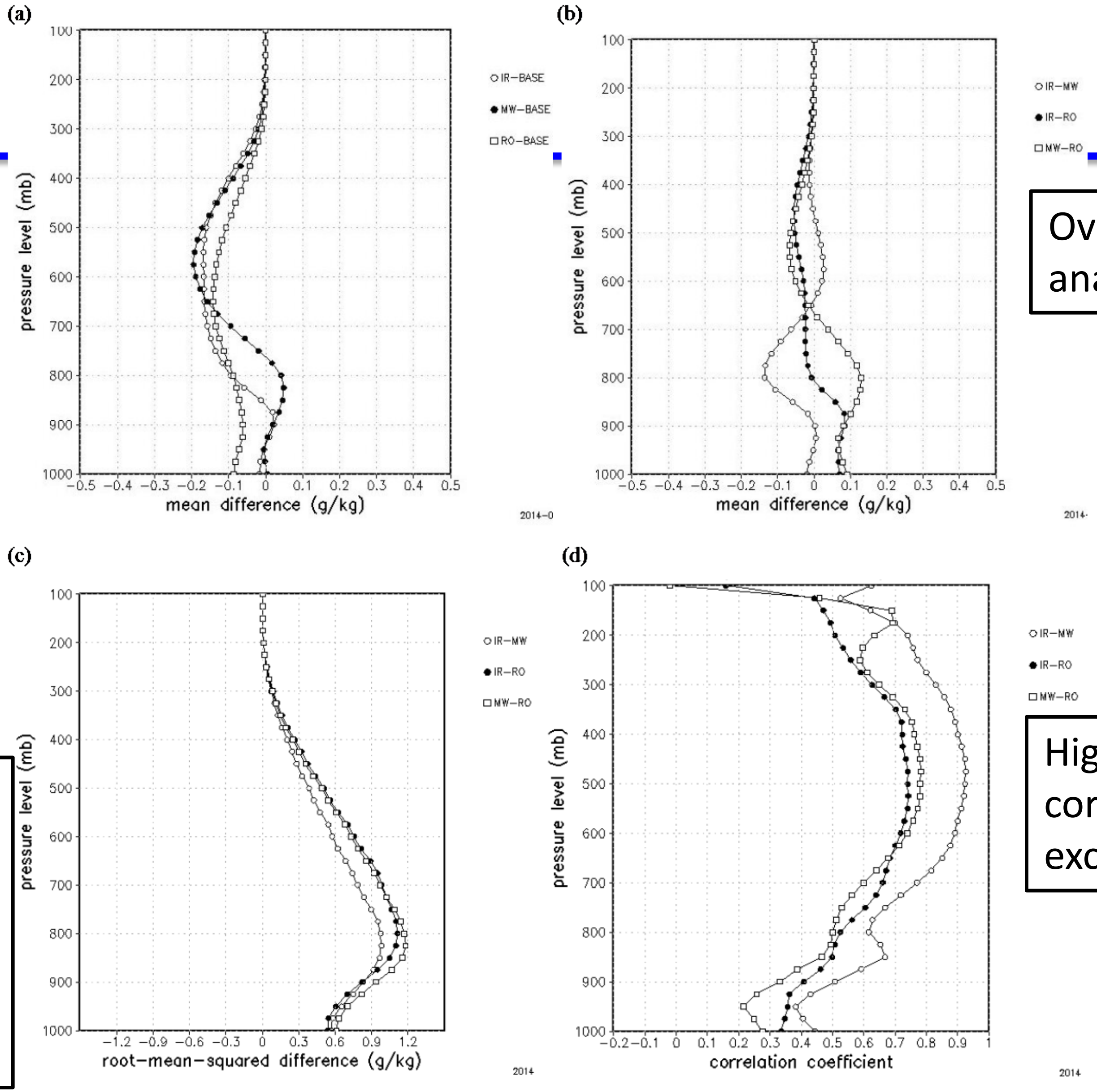


Fig. 13 Vertical profiles of (a) global monthly mean IR, MW and RO analyses minus *BASE* specific humidity, (b) global monthly mean *IR-MW*, *IR-RO*, and *MW-RO* specific humidity impacts, (c) RMS differences for *IR-MW*, *IR-RO* , and *MW-RO* specific humidity impacts, and (d) correlation coefficients between monthly mean *IR-MW*, *IR-RO*, and *MW-RO* specific humidity impacts.

Overall, drier analyses

Overall, small rms differences; smallest between IR and MW

High correlations except in LT

500 mb AC geopotential heights

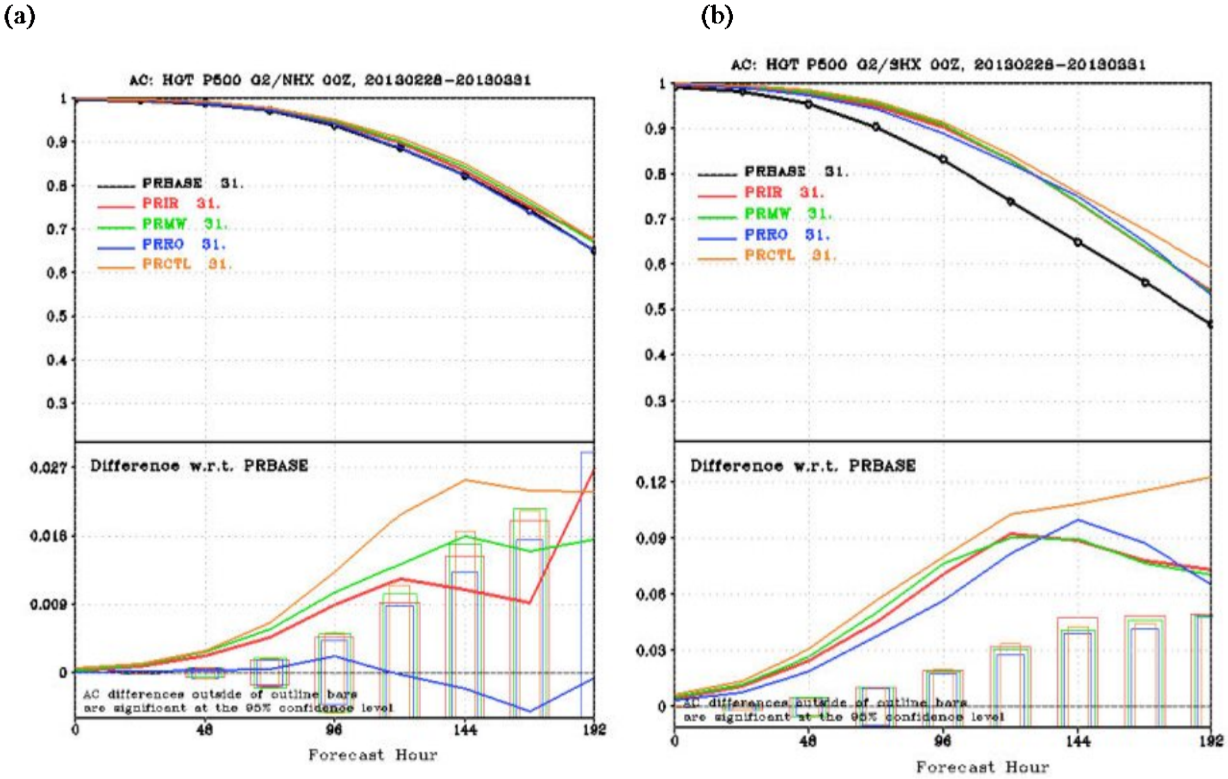


Fig 15: Anomaly correlation score for the 500 mb geopotential heights for *BASE* (black), *IR* (red), *MW* (green), *RO* (blue) and *CTL* (orange) for (a) Northern Hemisphere and (b) Southern Hemisphere. Lower parts of figure show differences with respect to *BASE*, with positive being an improvement. Bars show limits of statistical significance at the 95% confidence level; values above bars are statistically significant. Only the *CTL* experiment differences are statistically significant after day 5 in the NH. In the SH, all differences are statistically significant for all forecast lead-times.

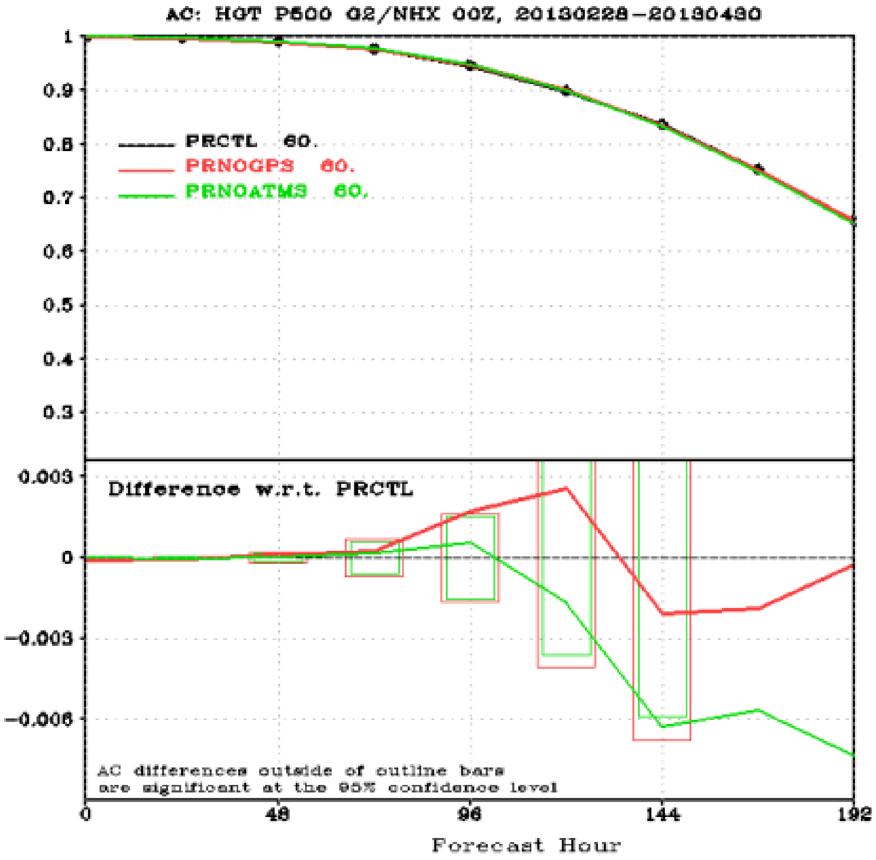
Impact of loss of ATMS and RO

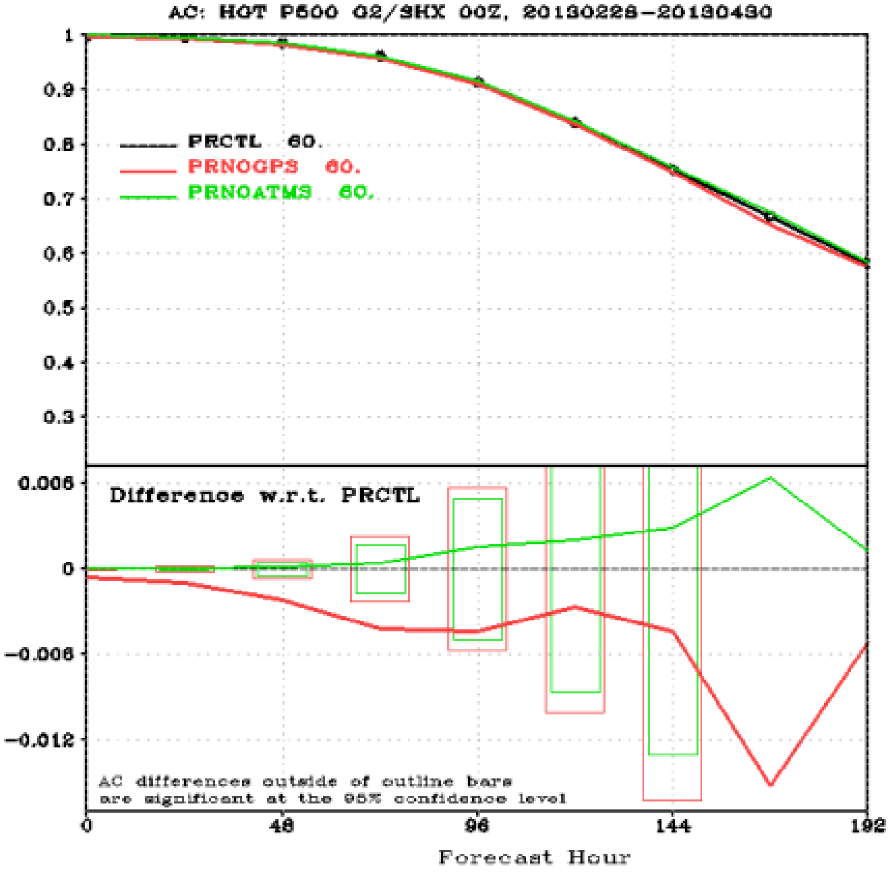
(with Rick Anthes)

- A follow-up study to analyze the impact of loss of MW and RO observations in operational NWP has been conducted in support of the U.S. Data Gap Mitigation Activities

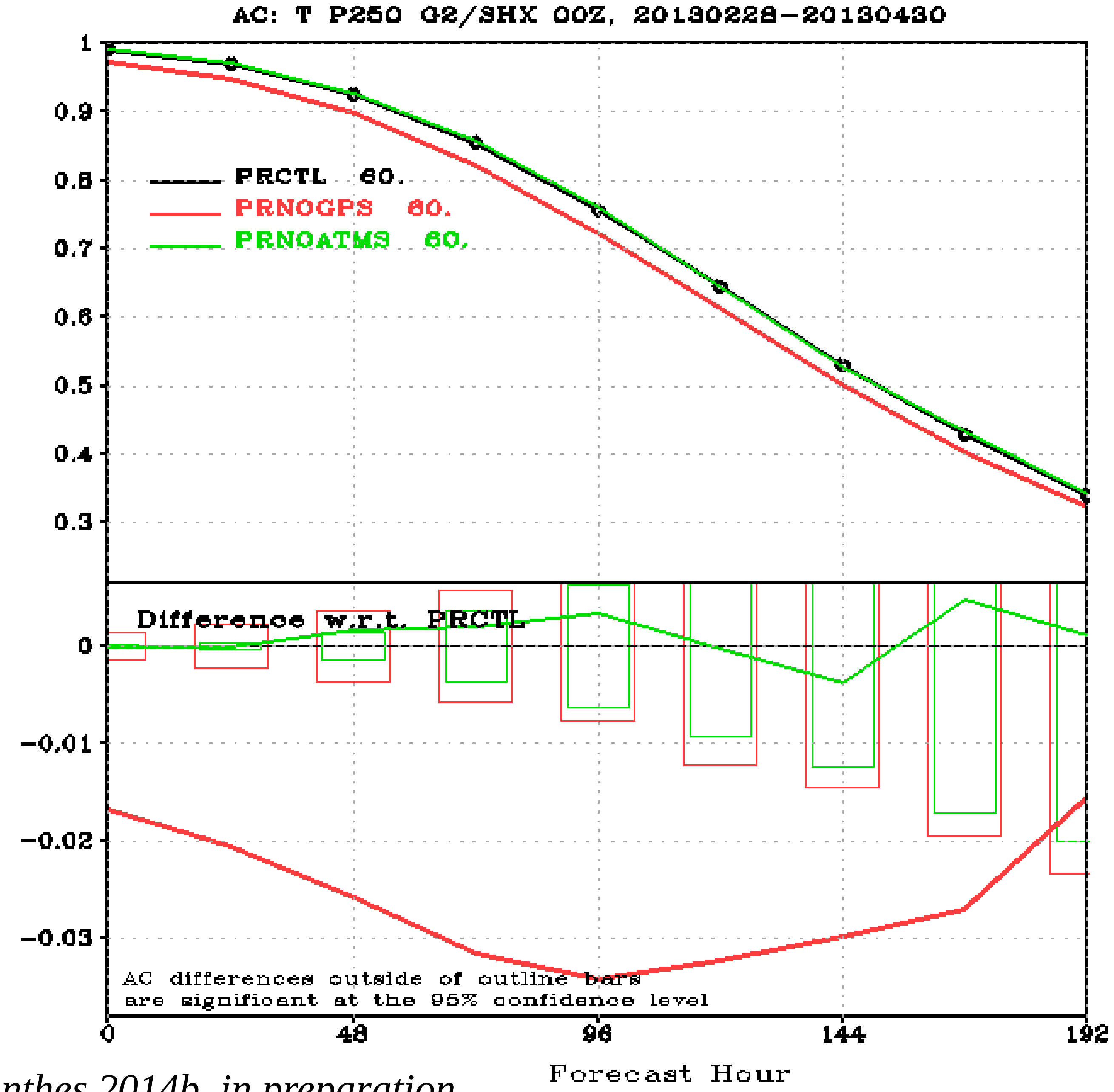
Impact of loss of MW and RO

- Time period: March-April 2013
- NCEP's operational configuration
- Verification done against consensus analysis (average of NCEP, ECMWF and UK Met Office analyses)
- Experiments:
  - prctl: control, operational configuration with all the observations
  - prnogps: prctl without RO observations
  - prnoatms: prctl without ATMS observations
- A potential gap in RO is a serious problem (see next slides)





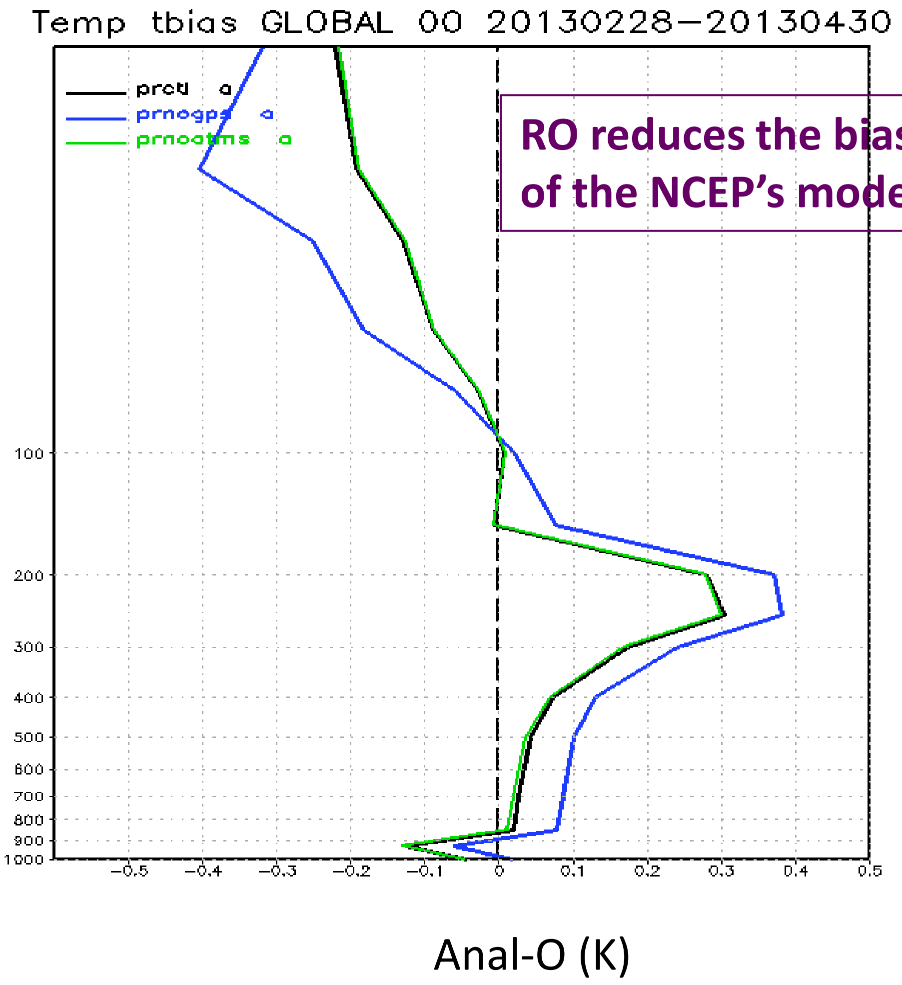
Cucurull and Anthes 2014b, in preparation



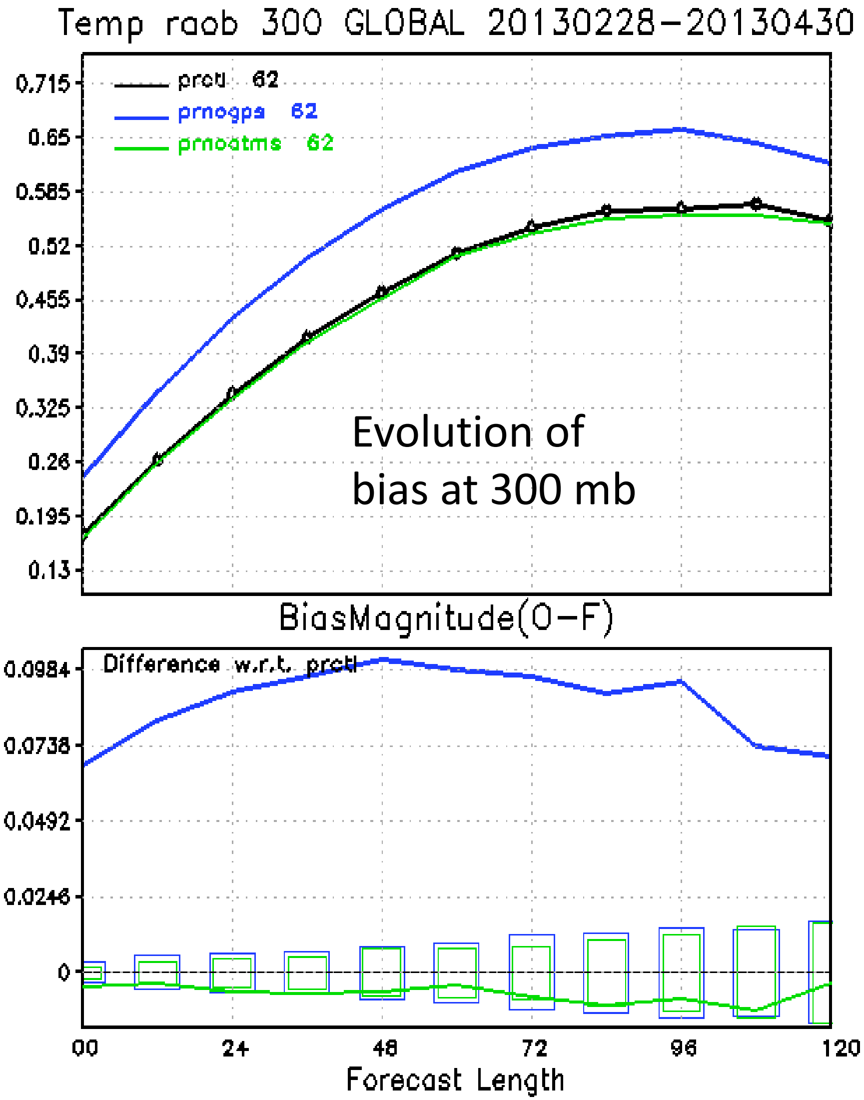
AC differences outside of outline bars are significant at the 95% confidence level

Cucurull and Anthes 2014b, in preparation

Fit to radiosondes



RO reduces the bias of the NCEP's model



Evolution of bias at 300 mb

Cucurull and Anthes 2014b, in preparation

RO data assimilation into NCEP's GDAS

(with Jim Purser and Sergey Sokolovskiy)

- Improve the assimilation of the observations in the lower troposphere, in particular under super-refraction (SR) conditions (top of the PBL). (We are also planning on implementing variational quality control procedures for RO)
- SR occurs when the gradient of atmospheric refractivity is so large (~ -157 N-units/km) that the ray doesn't leave the atmosphere.
- Rays that have tangent points inside an elevated atmospheric SR layer are internal (ie. are trapped within the layer).
- Regions of high occurrence frequency of SR are the west coast of major continents in the subtropical oceans and trade wind regions
- Under SR, the assimilation of GPS RO below the height of the SR layer is an ill-conditioned problem: there is an infinite number of atmospheric states that would reproduce the same exact GPS RO profile

RO data assimilation (cont’d)

- When profiles of bending angles are inverted into refractivities at the processing centers, one of the possible solutions is retrieved: the one that has the lowest refractivity value
- Therefore, refractivity observations are negatively biased under SR conditions at and below the height of the SR layer. In this case, observations need to be rejected in data assimilation
- On the other hand, observations of bending angle still contain the indetermination - observations might be rejected in a data assimilation system.
- From an observational point of view, we cannot know for sure whether SR occurred (S. Sokolovskiy is working on this)
- We must address this issue in the GSI in preparation for the large amount of observations that COSMIC-2 and other GNSS RO missions will bring

Bending angles and SR

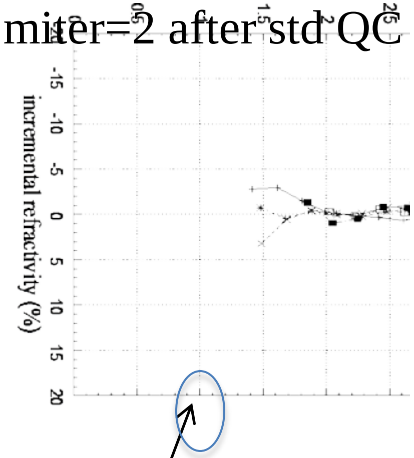
- Is there any useful information in the observations below a super-refraction layer?
- Given the indetermination and the larger uncertainty associated with these observations, can the analysis benefit from their assimilation?
- NBAM (NCEP's bending angle method) is used to assimilate bending angle observations in the operational configuration
- An upgraded version of NBAM (NABAM, "A" for "Advanced") has been developed and its being tested 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, 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) has been implemented and will become operational in FY14
- Note that this SR QC only rejects a few observations that might have passed the existing QC procedures. (Most of the observations are already currently rejected)

Refractivity profiles: additional SR QC

<u>New SR QC (below 3 km)</u>: obs is rejected if either the model or the observational gradient of refractivity reaches half the critical gradient. If this happens, the rest of the profile below that observation is rejected as well.

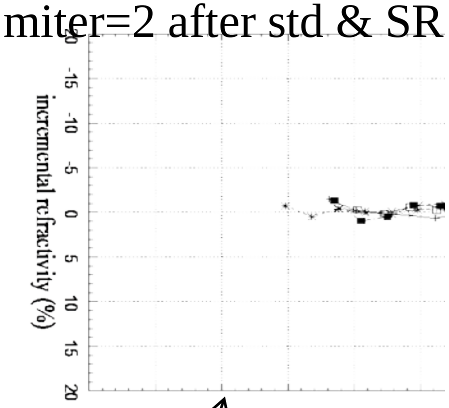
half critical gradient

miter=2 after std QC



before

miter=2 after std & SR QC



after

Preliminary QC for bending angles under SR

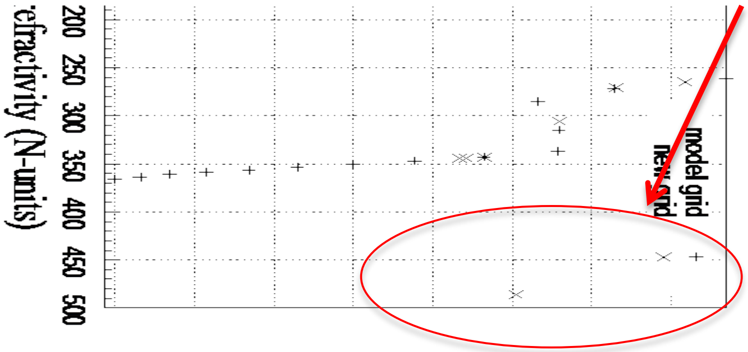
- Model side: if model detects 75% of the critical value around the height of the observation (we look at several model layers surrounding the observation), the observation is rejected if at/below the model “SR” layer. If several layers exist, we chose the top layer.
- Observation side: if bending angle > 0.03 rad and model detects at least 50% of critical gradient around the observation height, we select the observation within the profile with the largest bending angle. Any observation within the same profile and below the selected observation is rejected.

Introduction to NABAM

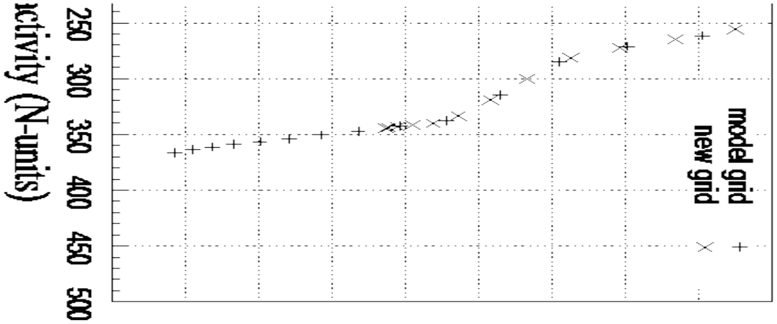
Model profile at the location of an observation below a model SR layer in model grid and NBAM integration grid

NBAM

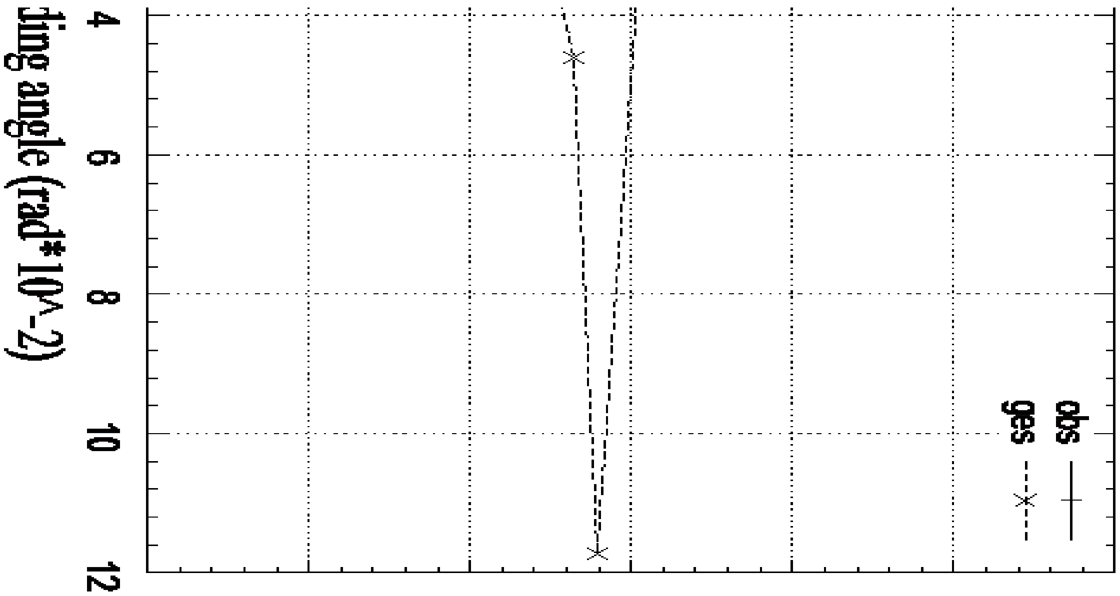
discontinuities



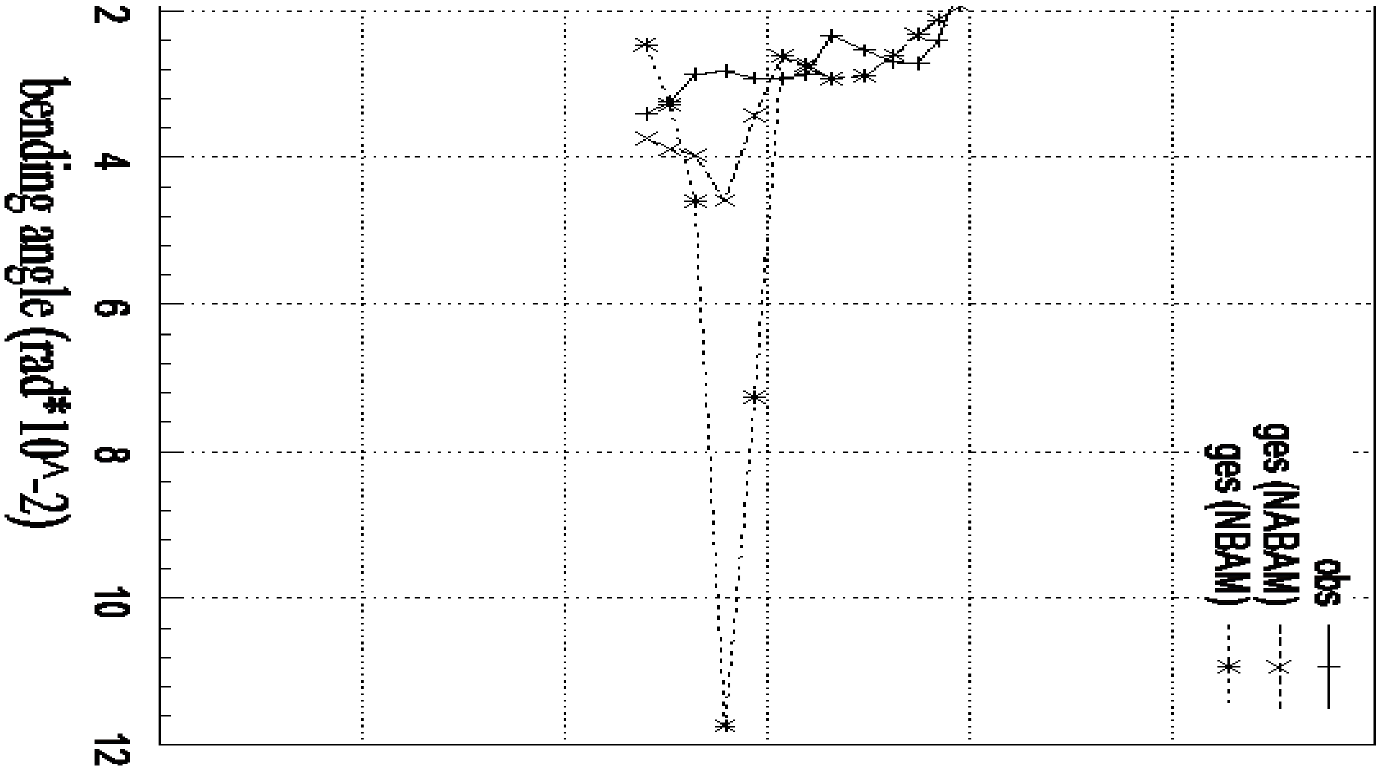
NABAM



Limitations of NBAM

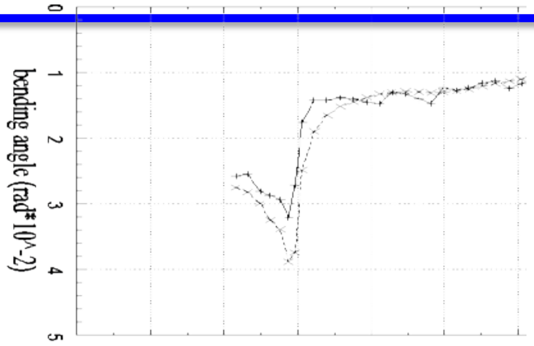


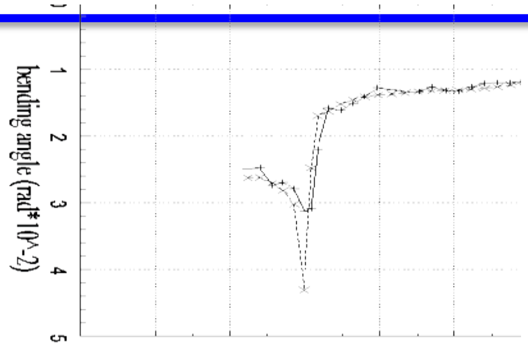
NABAM vs NBAM

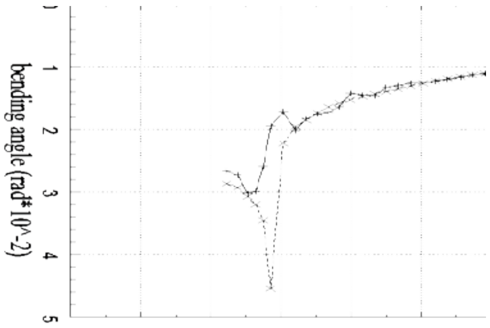


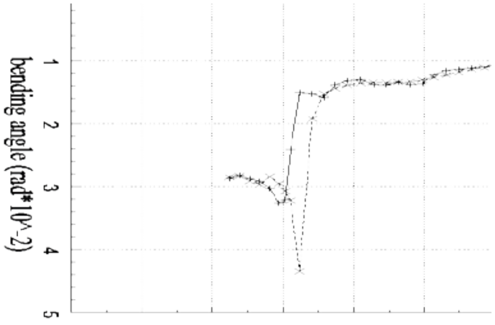
SR profiles (likely)

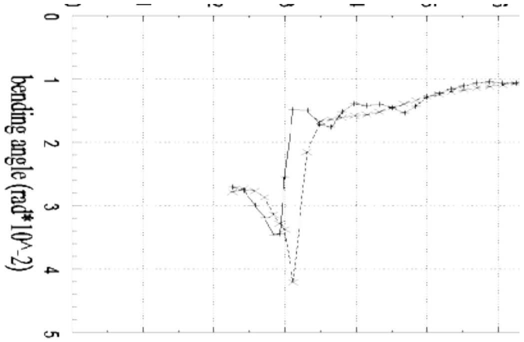
PBL height from GPS RO observations











That’s it!

Thanks!