Progress in GPS-RO assimilation at NOAA

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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
(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
2016

6 satellites
equatorial orbits

COSMIC-1

~ 1,300 profiles/day

2018

6 satellites
polar orbits

COSMIC-2

~ 12,000 profiles/day

COSMIC-1 Occultations – 3 Hrs Coverage

COSMIC-2 Occultations – 3 Hrs Coverage

Courtesy of UCAR
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 Geopotential height at 500 hPa
Day 3 Tropical Wind RMS

**200 hPa**

**850 hPa**
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 the stratosphere
- **Warm bias** in the upper troposphere
- **MW** produces the largest coldest bias in the stratosphere and the warmest bias in the 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).
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.
Overall, drier analyses

Overall, small rms differences; smallest between IR and MW

High correlations except in LT

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.
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.
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
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Fit to radiosondes

RO reduces the bias of the NCEP’s model

Evolution of bias at 300 mb

Cucurull and Anthes 2014b, in preparation
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
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

New SR QC (below 3 km): 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

mite=2 after std QC
mite=2 after std & SR QC

before

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.
Limitations of NBAM
NABAM vs NBAM
SR profiles (likely)

PBL height from GPS RO observations
That’s it!

Thanks!