Assimilation of GPS RO observations at NCEP

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Outline

- Current status
  - GPS RO Satellites
  - Assimilation algorithms
- Introduction to NBAM (NCEP's Bending Angle Model)
  - To be implemented operationally at NCEP in May 2012
- Differences between the assimilation of refractivities and bending angles using NBAM
  - Standalone case
  - Parallel test
- Conclusions

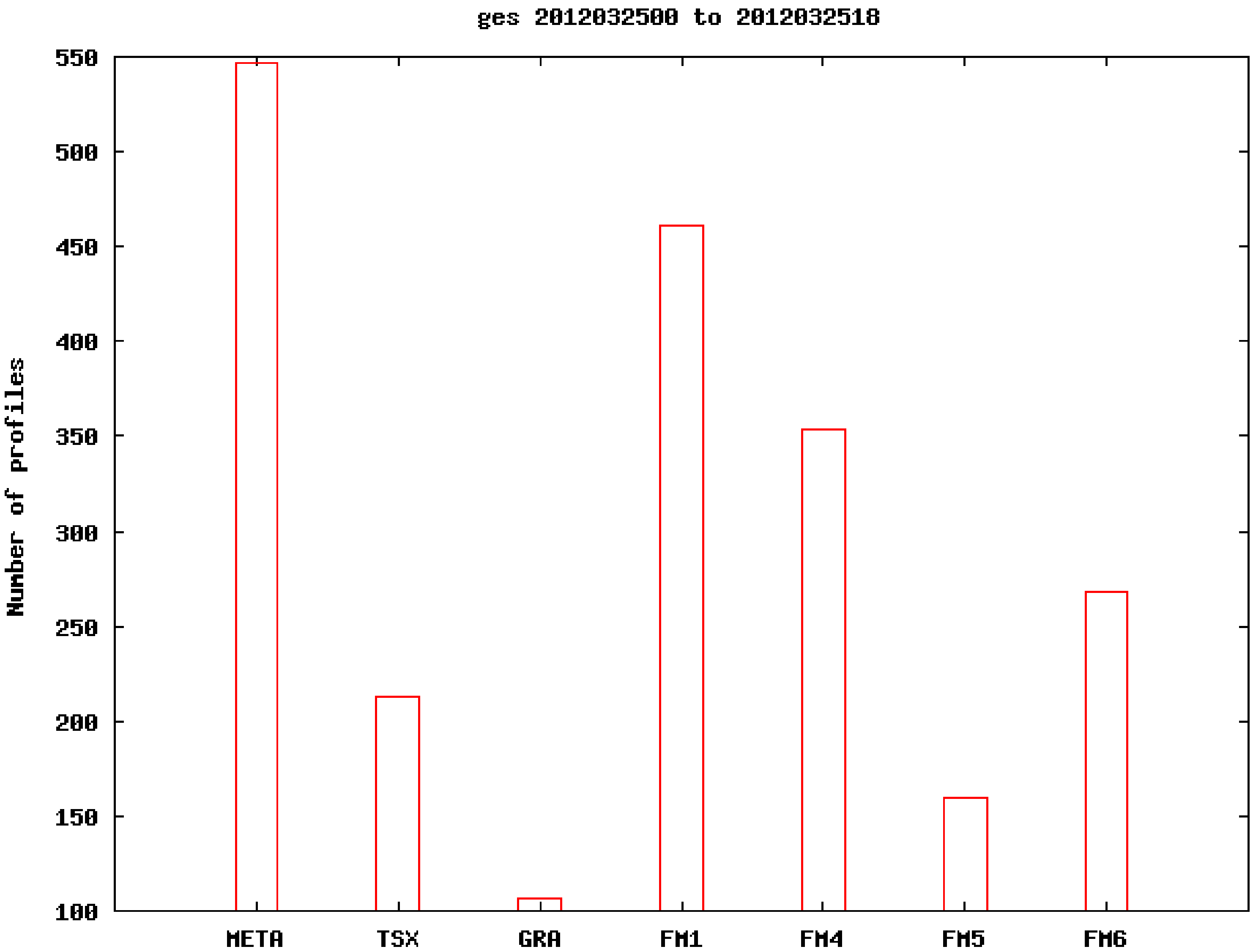
GPS RO sensors

- NCEP Global Data Assimilation System (GDAS) assimilates operationally the following RO instruments for total daily soundings of ~ 2,000:
  - **COSMIC 1-6** (since May 2007)
  - **Metop/GRAS** (since February 2010)
  - **GRACE-A** (since February 2010)
  - **SAC-C** (since May 2011)
  - **C/NOFS** (since May 2011)
  - **TerraSAR-X** (since May 2011)
- Looking forward to hearing on the status of GPS RO on Oceansat-2 (launched in 2010), Megha-Tropiques (launched in October 2011), and SAC-D (launched in June 2011)

- Near-operational monitoring of the systems above can be found in:

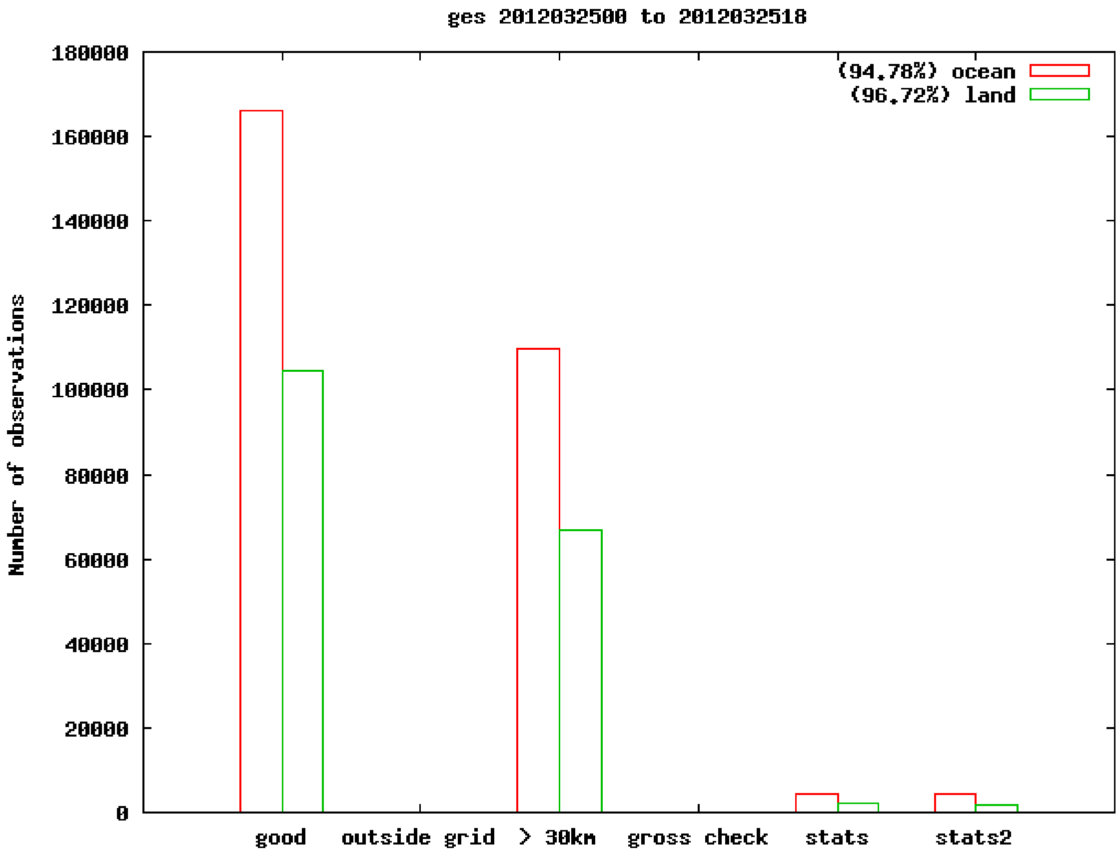
http://www.emc.ncep.noaa.gov/gmb/gdas/ under "GPSRO Monitoring"

Number of profiles 25 March 2012



Quality control

- We assimilate 95-96 % of the observations that we “can” assimilate. These numbers do not consider observations:
  - outside the model vertical grid
  - above 30 km (maximum height being assimilated)



Assimilation algorithms

- Operational GDAS assimilates refractivity observations up to 30 km (*Cucurull 2010*, *WAF*, **25**,2,769-787).

$$N = 77.60\frac{P_d}{T} + 70.4\frac{P_w}{T} + 3.739 \times 10^5\frac{P_w}{T^2}$$

- Relatively *easy* to implement (interpolation of modeled pressure, water vapor and temperature values from the model grid points to the location of the observation).
- However, the resulting modeled refractivity would only match the *observed* refractivity (assuming perfect model and retrieved refractivities) if the atmosphere were strictly spherically symmetric.
- Ignores the existence of horizontal gradients of refractivity in the atmosphere (global spherical symmetry approximation).
- Some climatology or auxiliary information is necessary to retrieve refractivities from bending angle profiles.
- Under super-refraction conditions, conversion of bending angles to refractivities formally results in a negative bias below the height where super-refraction occurs.

Bending angle observations

- Make use of approximation of local, rather than global, spherical symmetry around the ray path tangent height.
- Not weighted with climatology information.
- Do not suffer from the formal negative bias in the lower troposphere caused by super-refraction conditions.
- Measurement errors are less correlated than refractivity profiles because there is no use of an Abel transform.
- Retrieved earlier than refractivity in the processing of the GPS RO observations, which makes it more attractive from a data assimilation point of view.
- However, their use in data assimilation algorithms is more challenging due to the large variability of the vertical gradients of refractivity.
  - Lower vertical resolution of NWP models compared to the GPS RO observations.
  - Ionospheric-residual noise in the mid-upper stratosphere due to the ionospheric compensation.

Bending angle observations (cont’d)

- A forward operator to assimilate bending angle observations has been developed, implemented and tested at NCEP. Quality control procedures and observation error characterization have been tuned accordingly.
- An earlier version of this forward operator was available at NCEP in 2006 (*Cucurull et al. 2007*). The updated bending angle code has many improvements over the earlier version.

Assimilation of bending angles: NBAM

$$\alpha(a) = -2a\int_a^{\infty} \frac{d\ln n / dx}{(x^2 - a^2)^{1/2}}\,dx$$

$$(x = nr)$$

- The standard bending angle forward operator is singular at the lower limit of the integral and under super-refraction conditions.
- NBAM avoids the singularity in the integrand in both cases by evaluating the integral in a new grid.
- The integral is then evaluated in an equally spaced grid, so the trapezoidal rule can be easily and <u>accurately</u> applied.
- NBAM does not require the refractivity to decay exponentially with height (only above the model top).
- NBAM makes use of a quadratic interpolator that preserves continuity of the refractivity values and their derivatives in both the model model vertical grid and the new integration grid.
- QC and observation errors have been tuned similarly to refractivity.
- As all the implemented FO at NCEP, the drift of the tangent point is taken into account (*Folsche et al*., 2011; *Cucurull*, 2011; *Healy*, 2011, *pers. comm*.)

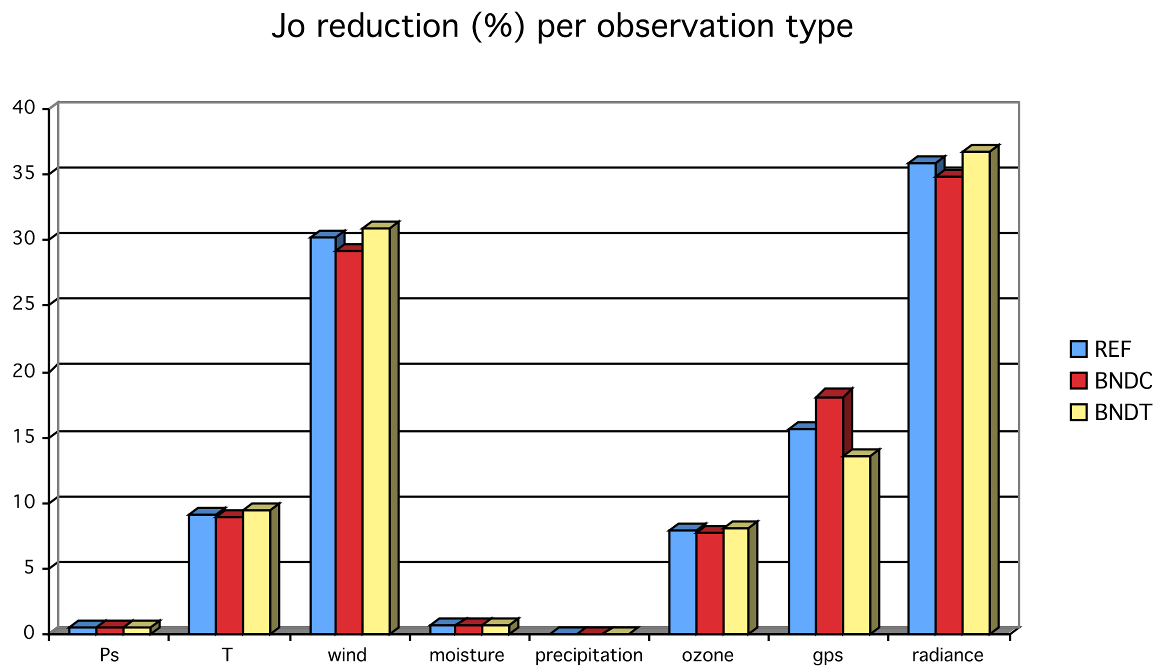
NBAM characteristics (cont’d)

- Enables the assimilation of GPS RO observations up to 50 km – QC procedures and observation error structures have been tuned up to this height.
- Algorithms to include the compressibility factors in the computation of the geopotential heights have been implemented to compute a more accurate forward operator for GPS RO (following *Aparicio et al. 2009*).
- Both refractivity and bending angle codes have the option to use the compressibility factors.
- When the compressibility factors are used, the GPS RO forward operators use a more accurate set of refractive indices (Rüeger coefficients).
- The use of compressibility factors will affect the assimilation of GPS RO observations as well as all the observations that use geopotential heights. In fact, any subroutine within the assimilation code that makes use of the geopotential heights will be affected by the changes.
- Details on the design and implementation of NBAM can be found in *Cucurull et al. 2012, submitted to JGR.*
- <u>Since NBAM reverses the procedure of assimilating refractivities, it still suffers from errors induced by deviations from spherical symmetry.</u>

NBAM in a standalone case

The reduction of the initial cost function provided by a group of observations type *x* during the minimization process in a variational approach can be computed as

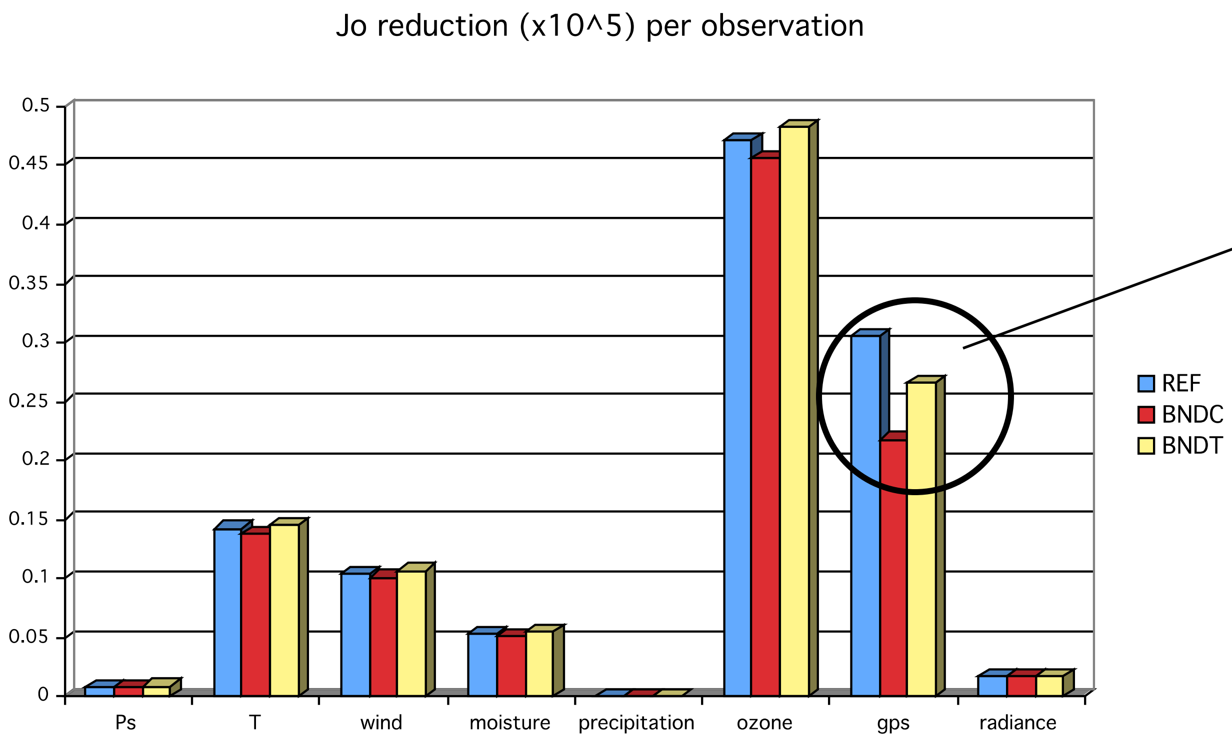
$$reduction_x = \frac{J_{o\_x} - J_{f\_x}}{J_o - J_f},$$



REF = refractivities up to 30 km
BNDC = bending angles up to 50 km (NBAM configuration)
BNDT = bending angles up to 30 km

1- Radiances: ~ 35%
2- Winds: ~ 30%
3- GPSRO: ~ 18% in BNDC

NBAM in a standalone case (cont'd)



There exists some correlation between observations within a profile

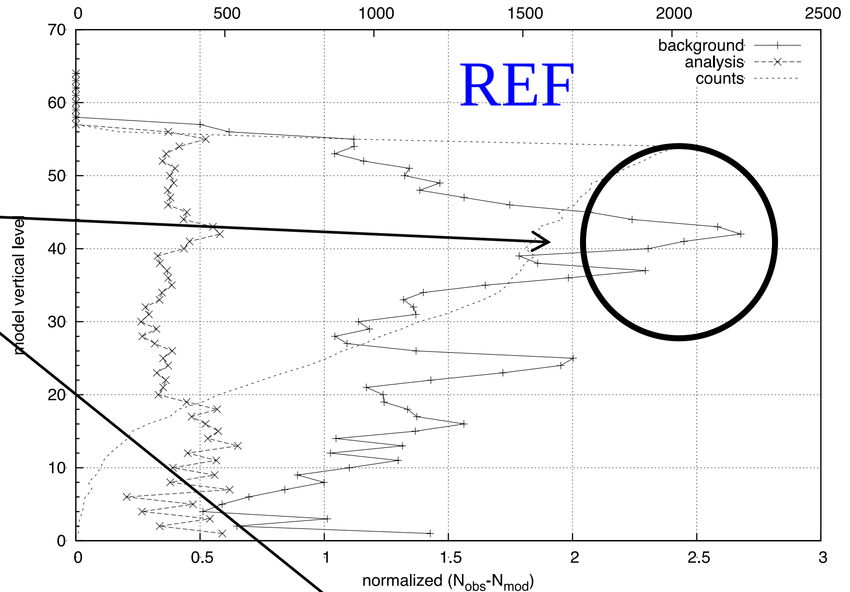
1- Ozone (~17,000 obs) – used very efficiently and/or weighted very strongly.
2- GPSRO (~51,000 obs in REF/BNDT and ~83,000 obs in BNDC)

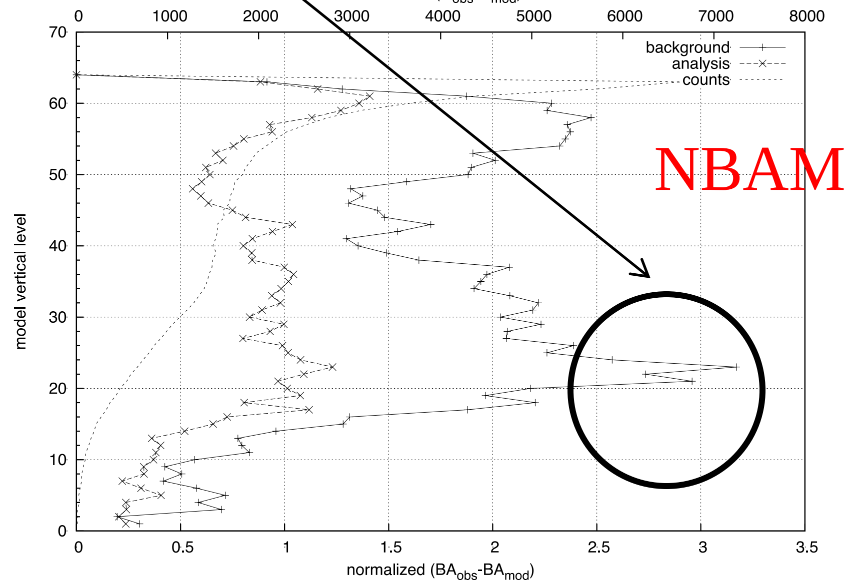
NBAM in a standalone case (cont’d)

- Different pattern in normalized differences between observations and model simulations for refractivity and bending angle assimilation

- GPS RO information content will project at different vertical ranges of the atmosphere

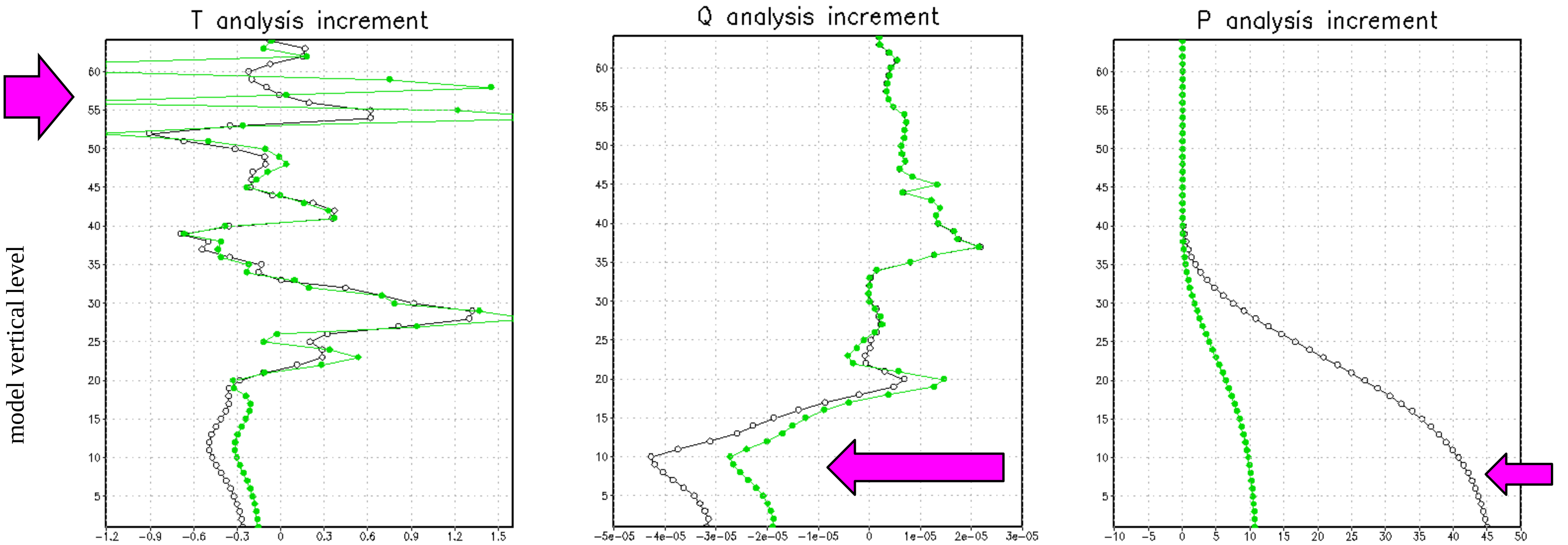
- The fit of the analysis to the GPS RO observations will depend on the specifications of the background error covariances & on all the observations and corresponding errors being assimilated.





NBAM in a standalone case (cont'd)

model vertical level



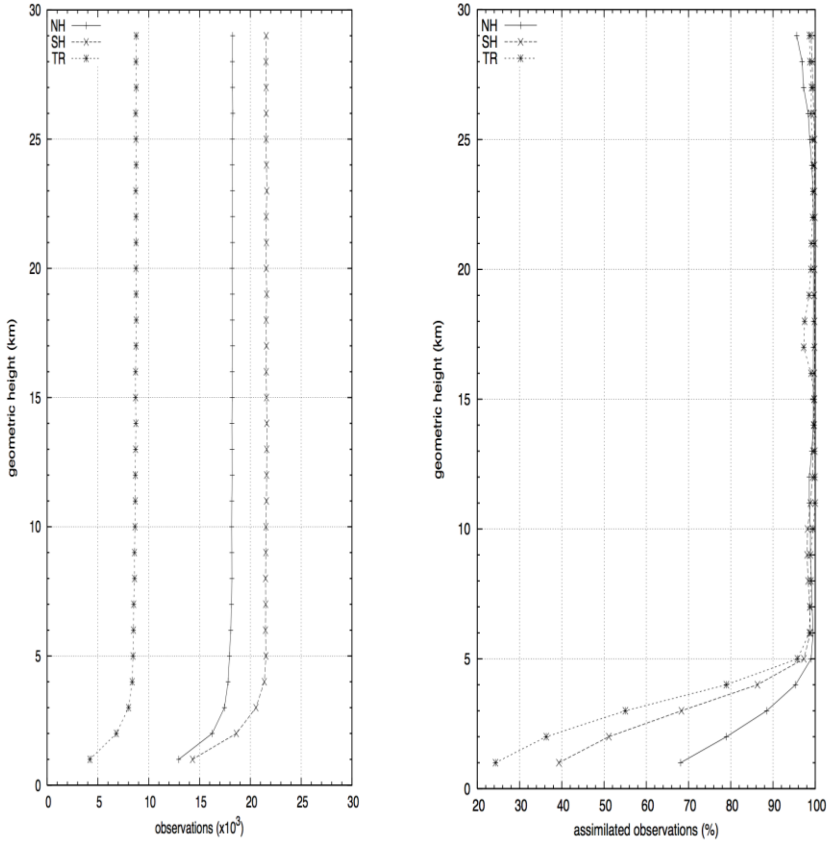
temperature analysis increment (K) specific humidity analysis increment (kg/kg) pressure analysis increment (Pa)

Analysis increments (i.e. departures from the background field) for the assimilation of a single GPS RO profile (lat=47N, lon=70W), along with all the the other observations, using **REF** and **NBAM**.

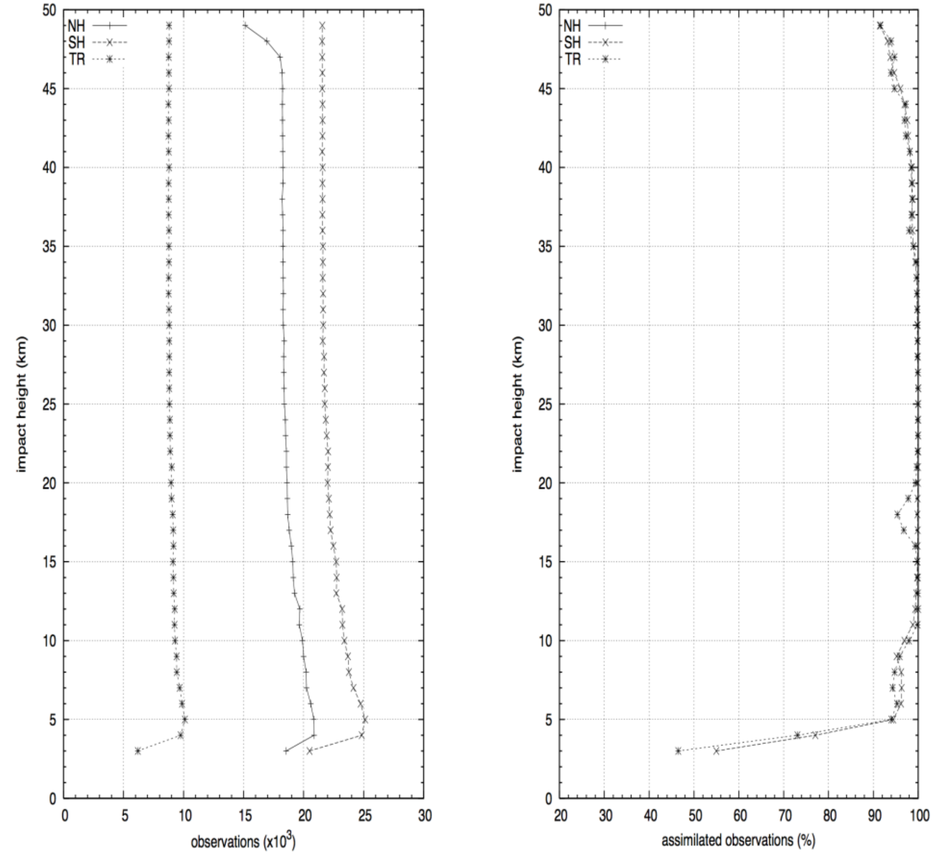
NBAM: Parallel testing

- Period: 2 February 2011 – 22 March 2011.
- **PRREF**: assimilation of refractivities up to 30 km.
- **PRBNDC (NBAM)**: assimilation of bending angles up to 50 km & use of compressibility factors & updated refractive indices.
- Both experiments use the operational GFS model, GSI T382L64.
- Results are averaged over the entire campaign.

Quality control (FM4)



PRREF



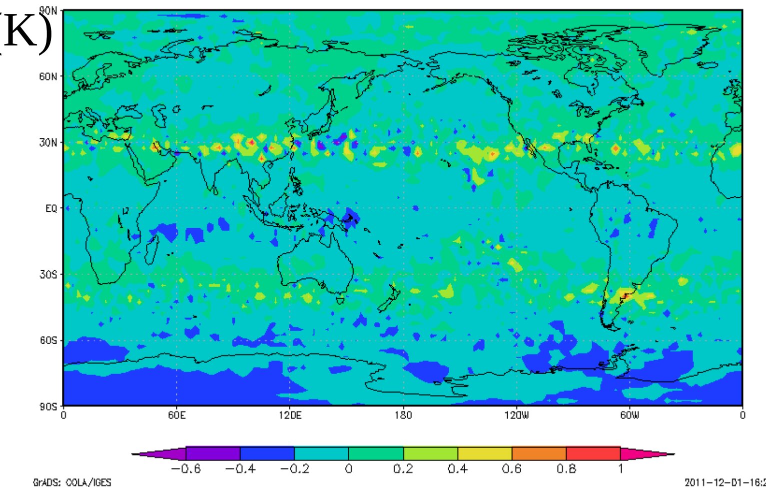
PRBDNC

Analysis differences: Tropopause

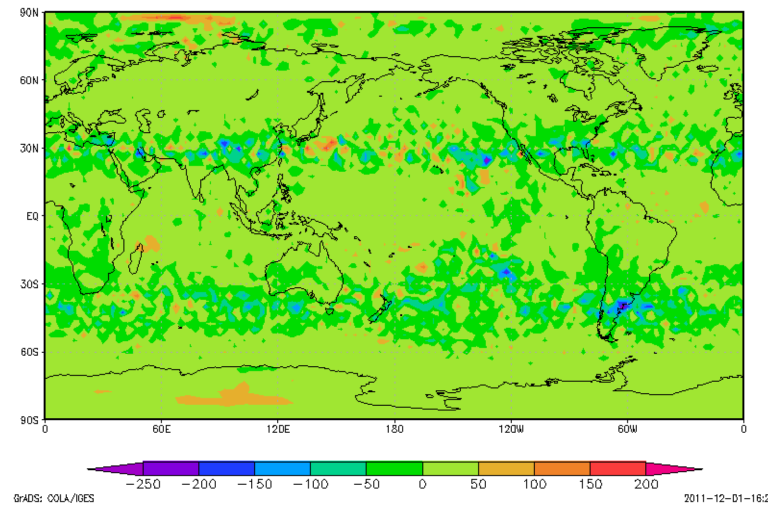
- NBAM produces warmer tropopause around 30N and 30S by ~0.5K, and lower tropopause geopotential heights.

- Different forward operators, and type of observation to be assimilated, can reflect changes in the tropopause characteristics.

PRBNDC-PRREF Tropopause Temp (K)

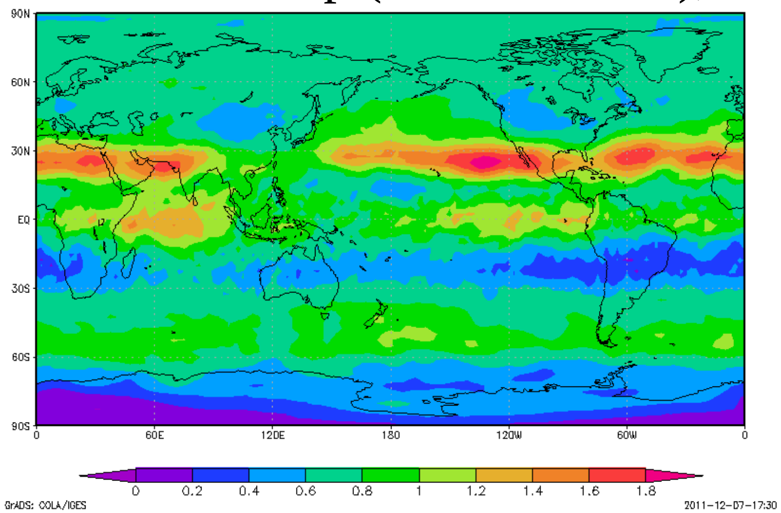


PRBNDC-PRREF Tropopause geop height (m)

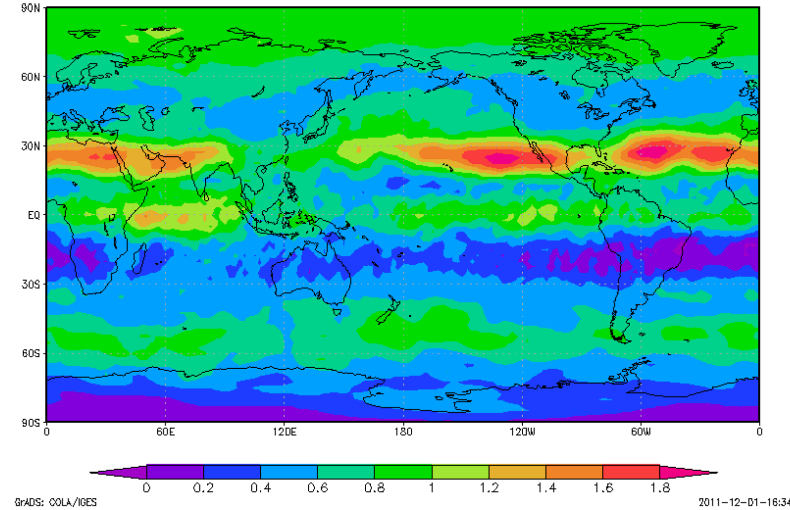


Role of high-level observations in PRBDNC

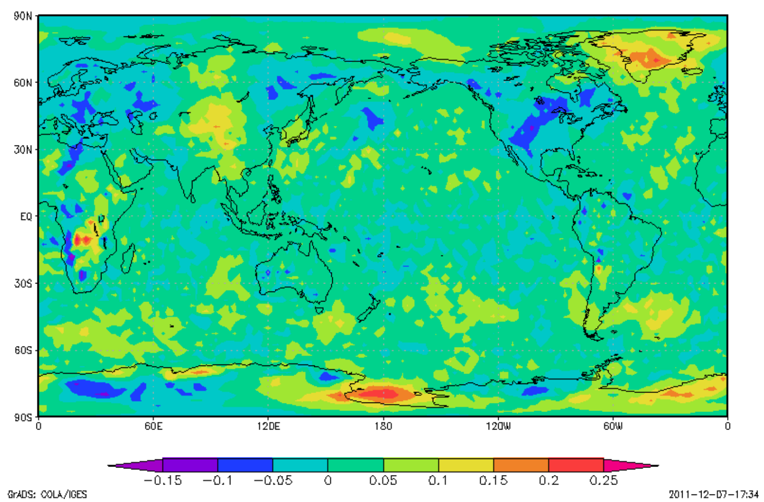
PRBNDC Temp (50km – 30km), 10 mb



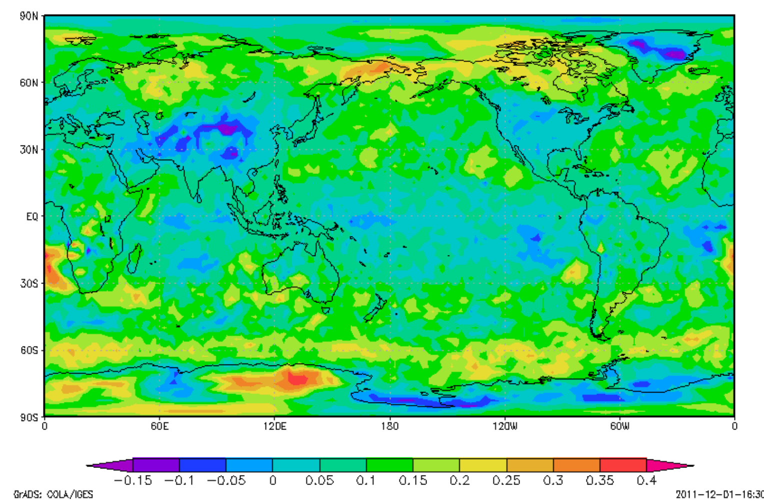
PRBNDC – PRREF Temp, 10 mb



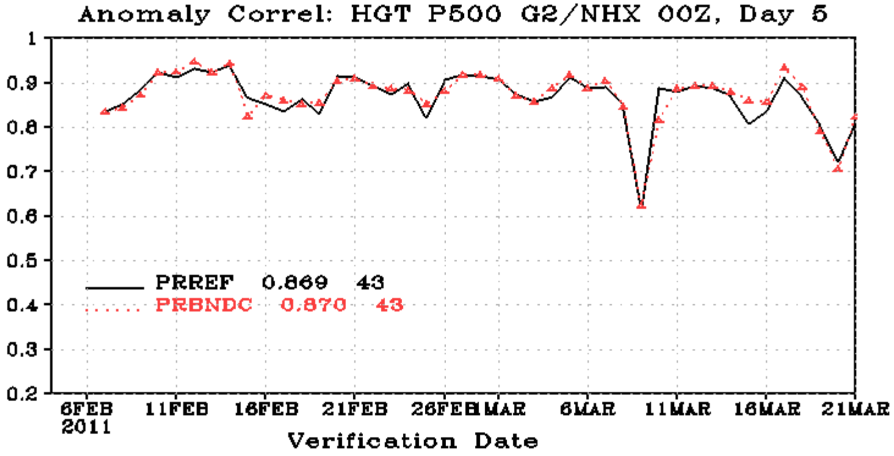
PRBNDC Temp (50km – 30km), 850 mb

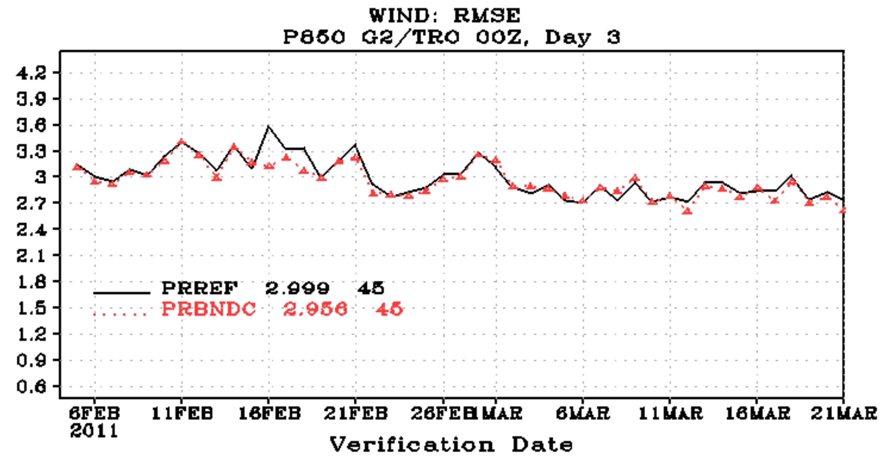


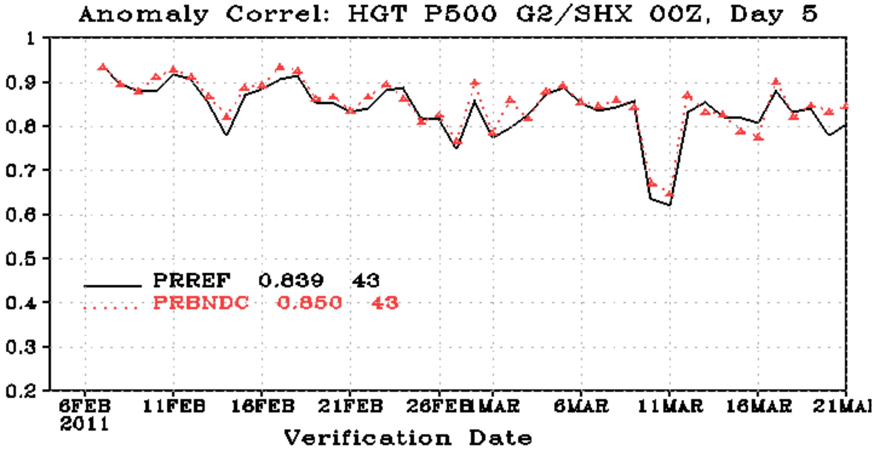
PRBNDC – PRREF Temp, 850 mb

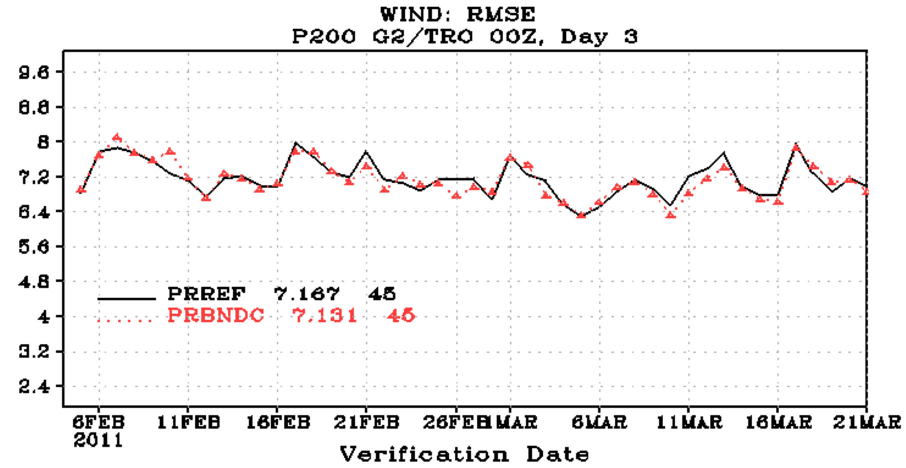


Dynamic forecast skill









Conclusions

- **A New methodology to assimilate GPS RO observations has been developed, tested and implemented at NCEP**.
  - Slightly better results for all fields and pressure levels.
  - Being an earlier product than refractivities, there is less need to retune the QC and observation errors every time that the processing centers make changes to their processing software. (There is also less room for introducing errors while processing the data).
  - Not affected by a formal negative bias in LT under super-refraction conditions.
  - No need for auxiliary climatological/meteorological information to retrieve the observations.
- **Assimilation of GPS RO observations using NBAM is scheduled to replace the assimilation of refractivties operationally at NCEP in May 2012.**