Assimilation of GPS radio occultation measurements at NCEP

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JOINT CENTER FOR SATELLITE DATA ASSIMILATION

NOAA NASA JCSDA Navy Air Force

History

April 2000, a small team of senior NASA and NOAA managers release a white paper[1] containing plans to improve and increase the use of satellite data for global numerical weather models.

The white paper provided a specific recommendation to establish a Joint Center for Satellite Data Assimilation (JCSDA).

This white paper came in response to a growing urgency for more accurate and improved weather and climate analyses and forecasts.

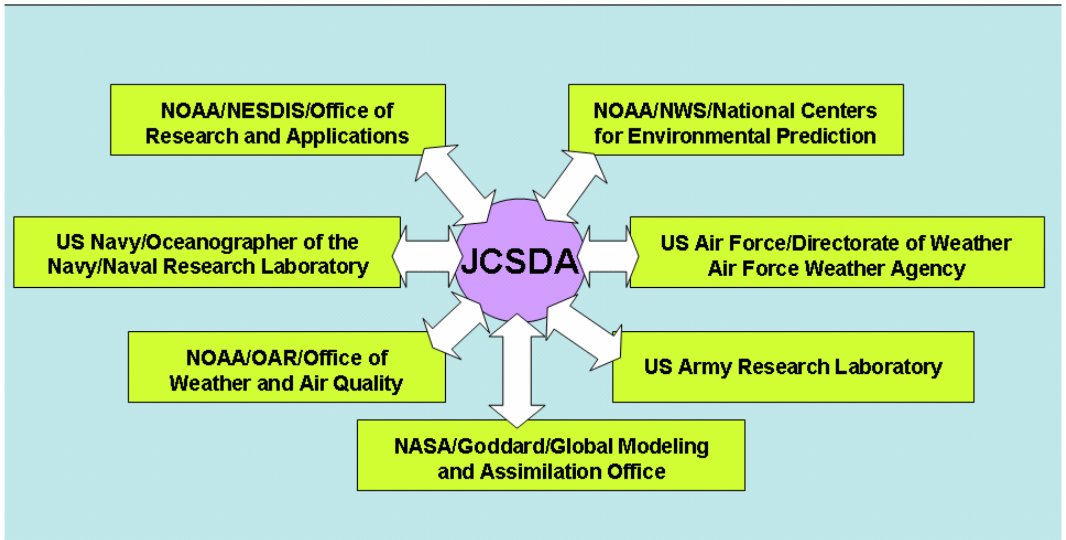
These improvements could only be made possible by the development of improved models and data assimilation techniques, which allow models to utilize more and better quality data.

[1] *A NASA and NOAA plan to maximize the utilization of satellite data to improve weather forecasts. Franco Einaudi, Louis Uccellini, James F. W. Purdom, Alexander Mac Donald, April 2000.*

History

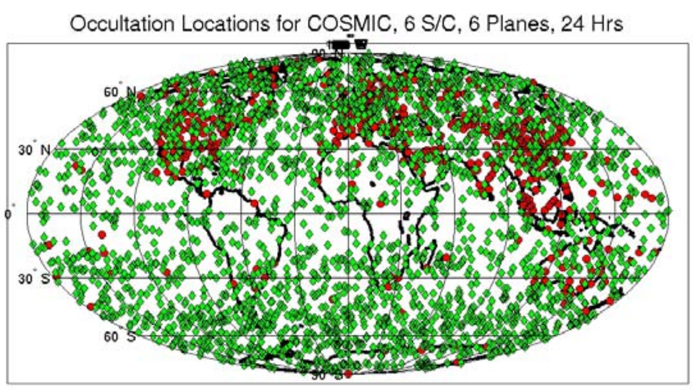
In 2001 the Joint Center was established[2] and in 2002, the JCSDA expanded its partnerships to include the U.S. Navy and Air Force weather and oceanography agencies.

[2] *Joint Center for Satellite Data Assimilation: Luis Uccellini, Franco Einaudi, James F. W. Purdom, David Rogers: April 2000.*

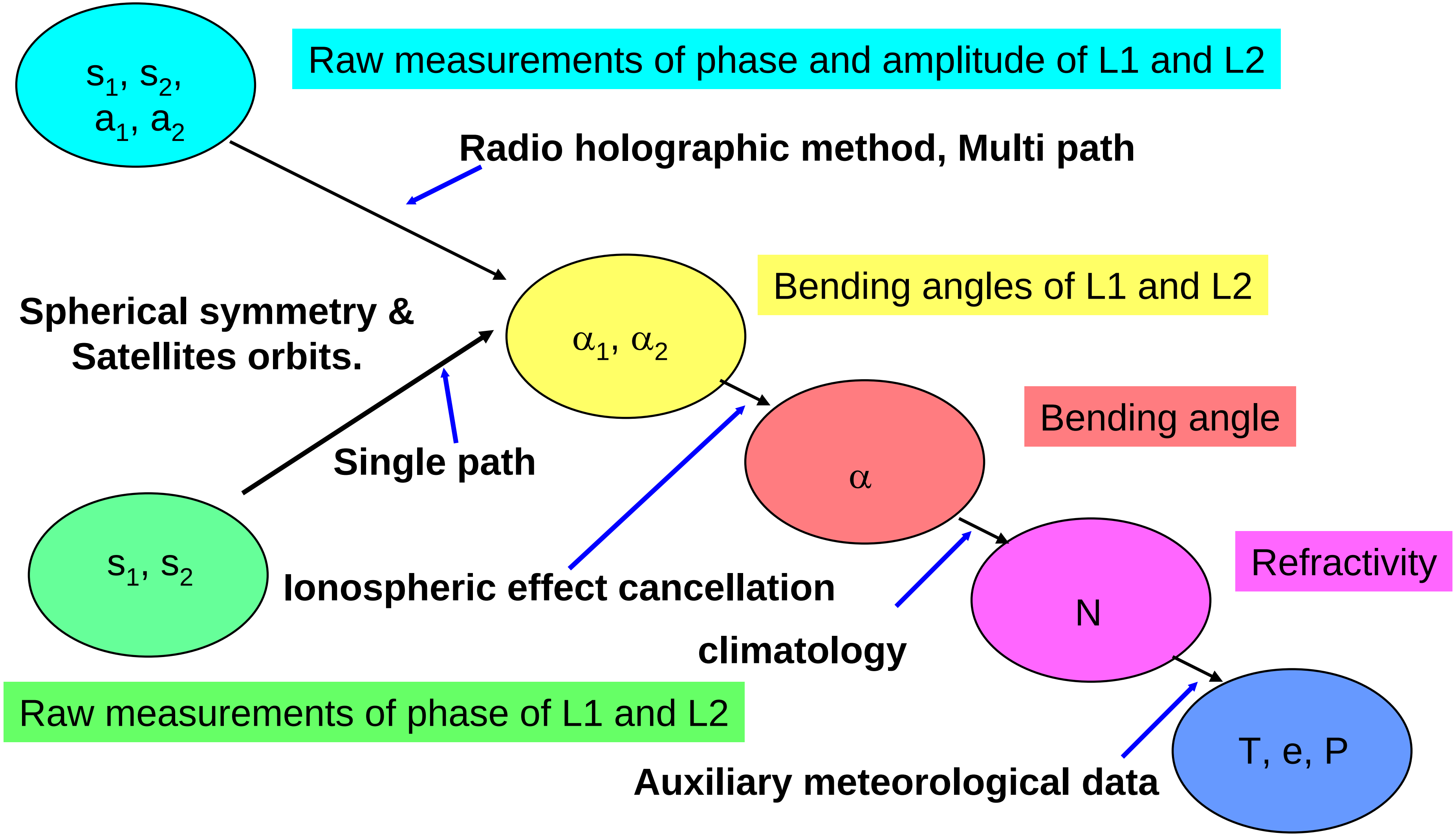


Characteristics of GPS RO observations

- Limb sounding geometry complementary to ground and space nadir viewing instruments
  - High vertical resolution (~100 m)
  - Lower horizontal resolution (~200 km)
- All weather-minimally affected by aerosols, clouds or precipitation
- High accuracy (equivalent to < 1 Kelvin from 5-25 km)
- Equivalent accuracy over ocean than over land
- Independent of radiosonde calibration
- No instrument drift
- Global coverage
- No satellite-to-satellite observational bias
- Inexpensive compared to other sensors



GPS RO: what to assimilate?



Achievements at the JCSDA

- The JCSDA developed, tested and incorporated into the new generation of NCEP's Global Data Assimilation System the necessary components to assimilate two different type of GPS RO observations (refractivity and bending angle). These components include:
  - complex forward models to simulate the observations (refractivity and bending angles) from analysis variables and associated tangent linear and adjoint models
  - Quality control algorithms & error characterization models
  - Data handling and decoding procedures
  - Verification and impact evaluation algorithms

Forward Model for Refractivity

$$N = 77.6\frac{P}{T} + 3.73\times10^{-5}\frac{P_w}{T^2}$$

- (1) Geometric height of observation is converted to geopotential height.
- (2) Observation is located between two model levels.
- (3) Model variables of pressure, (virtual) temperature and specific humidity are interpolated to observation location.
- (4) Model refractivity is computed from the interpolated values.
- The assimilation algorithm produces increments of
  - surface pressure
  - water vapor of levels surrounding the observation
  - (virtual) temperature of levels surrounding the observation and all levels below the observation (ie. an observation is allowed to modify its position in the vertical)

- QC of the data based on the statistics of a month comparison between observations and model simulations of N
- Errors for N have been tuned to account for representativeness error

Forward Model for Bending Angle

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

$$(x = nr)$$

- Make-up of the integral:
  - Change of variable to avoid the singularity

$$x = \sqrt{a^2 + s^2}$$

  - Choose an equally spaced grid to evaluate the integral by applying the trapezoid rule

Forward Model for Bending Angle (cont)

- Compute model geopotential heights and refractivities at the location of the observation
- Convert geopotential heights to geometric heights
- Add radius of curvature to the geometric heights to get the radius: r
- Convert refractivity to index of refraction: n
- Get refractional radius (x=nr) and dln(n)/dx at model levels and evaluate them in the new grid. We make use of the smoothed Lagrange-polynomial interpolators to assure the continuity of the FM wrt perturbations in model variables.
- Evaluate the integral in the new grid.

- QC of the data based on the statistics of a month comparison (same period as used for N) between observations and model simulations of BA
- Errors for BA have been tuned to account for representativeness.

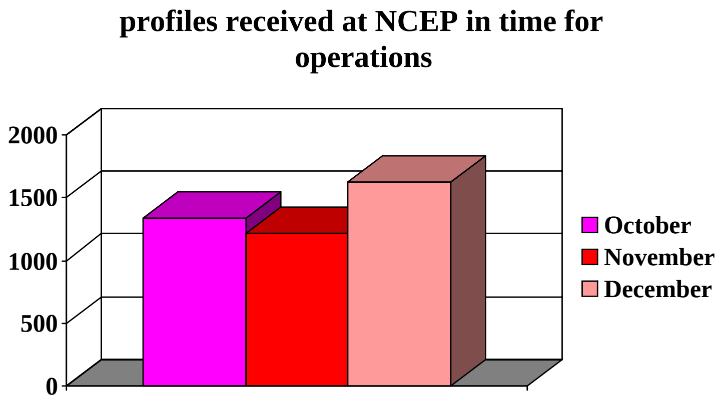
COSMIC operational

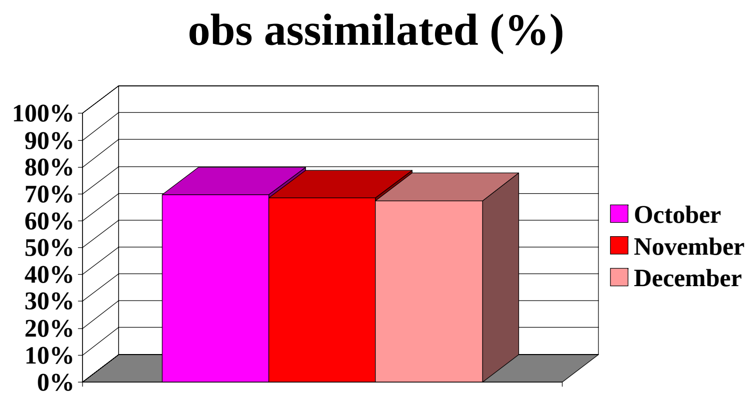
- Pre-operational implementation runs showed a positive impact in model skill when COSMIC profiles were assimilated on top of the conventional/satellite observations.
- As a result, **COSMIC became operationally assimilated at NCEP on 1 May 2007**, along with the implementation of the new NCEP's Global Data Assimilation System (GSI/GFS). [Profiles of refractivity were selected for implementation in operations, while the tuning of the assimilation of bending angles will be analyzed at NCEP soon].
- **The assimilation of observations from the COSMIC mission into the NCEP's operational system has been a significant achievement of the JCSDA. [Operational assimilation one year after launch!].**

COSMIC observations at NCEP

- We assimilate rising and setting occultations, there is no black-listing of the low-level observations (provided they pass the quality control checks), and we do not assimilate observations above 30 km (due to model limitations).
- In an occultation, the drift of the tangent point is considered.

Average COSMIC counts/day at NCEP (2007)





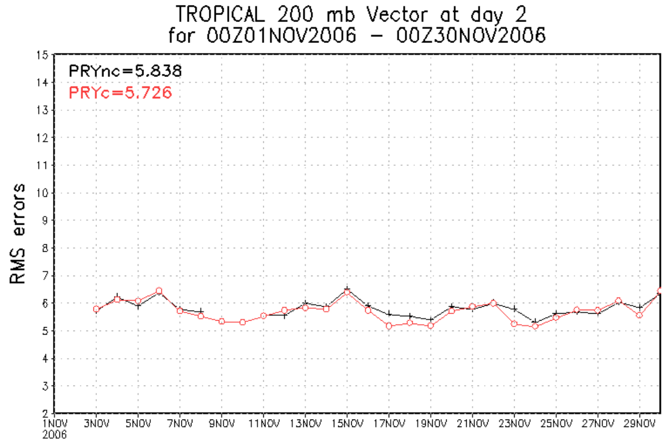
The remaining ~30% received, but not assimilated, is due to:

- Preliminary quality control checks (bad data/format)
- Gross error check
- Statistics quality control check (obs too different from the model-obs statistics)

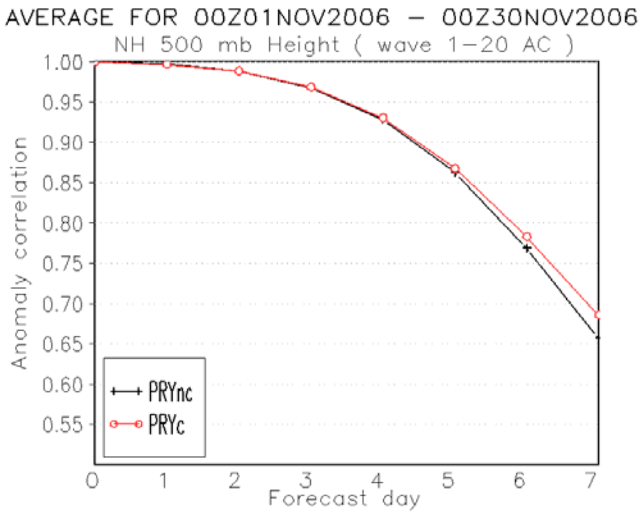
Pre-operational implementation run

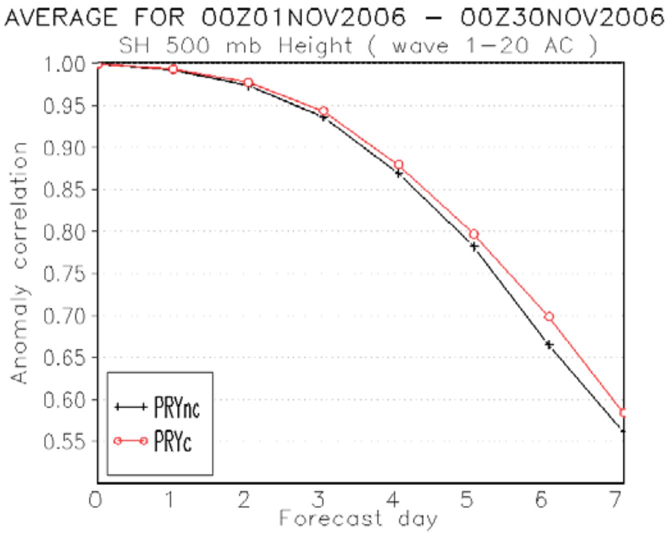
- PRYnc (assimilation of operational obs),
- PRYc (PRYnc + COSMIC refractivity)
- We assimilated around 1,000 COSMIC profiles per day

rms error (wind)

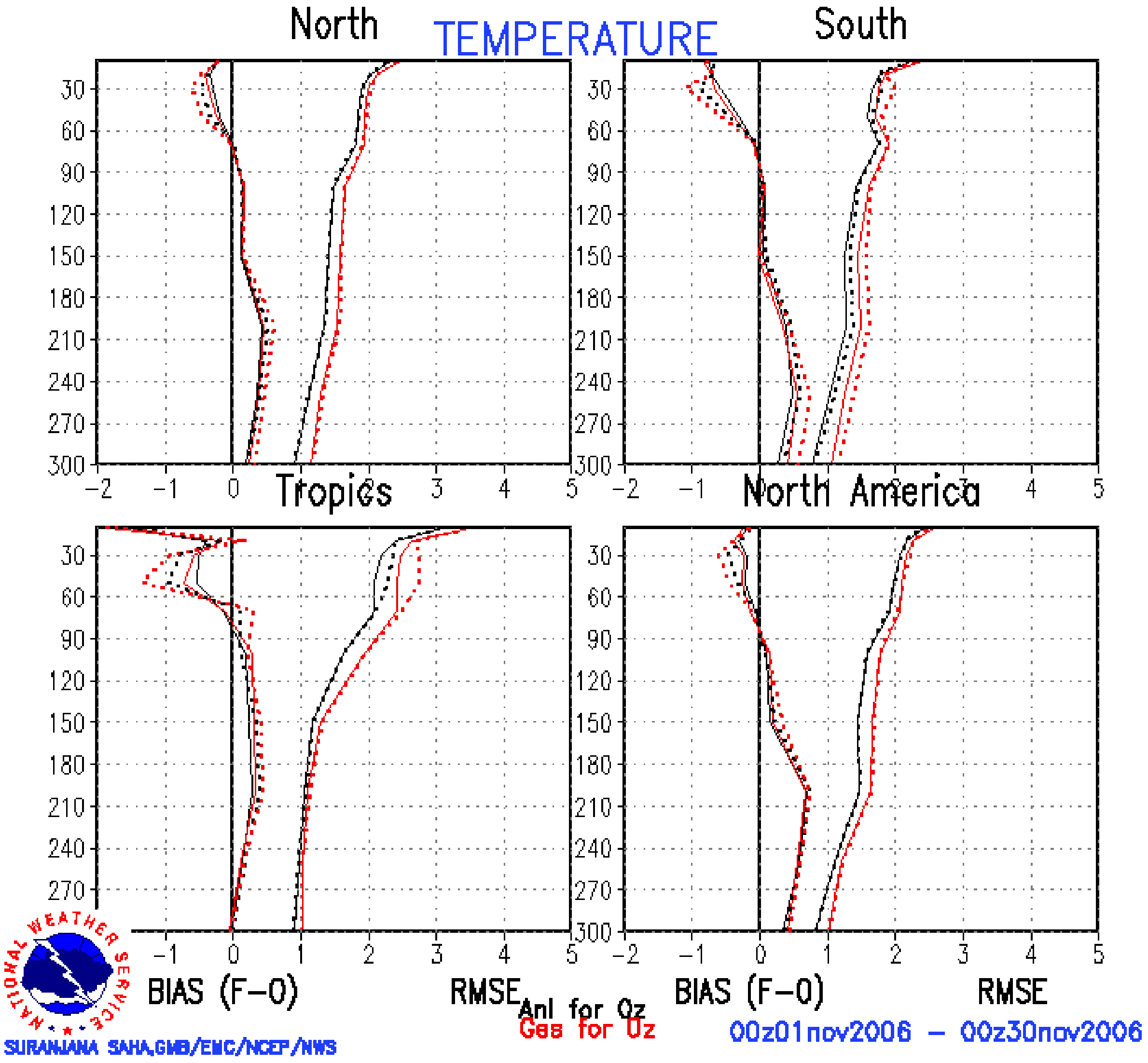


Anomaly correlation as a function of forecast day (geopotential height)





Pre-operational implementation run (cont)



- Dashed lines: PRYnc
- Solid lines: PRYc (with COSMIC)

- Red: 6-hour forecast
- Black: analysis

Recent achievements

- Monitor transition of COSMIC data into operations.
- Improve diagnostic files for GPS RO in the GSI code.
- Generalize the GPS RO code in GSI to use any vertical coordinate system.
- Analysis of more impact studies with COSMIC for different areas and periods. (The use of COSMIC improves model skill).
- Improve assimilation of GPS RO over areas of complex topography.
- Testing, evaluation and feed-back to UCAR on stratospheric bug-fixed profiles. (UCAR improved the quality of the profiles in the stratosphere in November 2007).
- Correct weights associated to the vertical levels surrounding a GPS RO observation in GSI.
- Transition of (GFZ) CHAMP & GRACE-A data into the operational tanks.

On the side …

- Evaluation & assimilation of GPS RO data into the new NCEP's reanalysis system (CFSRR project; NCEP/EMC).
- Assess the use of COSMIC data to retrieve ABL heights for assimilation into the real-time mesoscale analysis system (RTMA). [Co-I in NASA-funded Homeland Security project (within the Air Quality Group at NCEP/EMC)].
- Use of GPS RO derived products of temperature and water vapor to validate other satellite instrument data and to extend the NOAA/NESDIS 1dvar capability to include GPS RO (POC at NOAA/NESDIS).
- Evaluation of the requirements needed to add the GPS RO capability to conduct OSSEs within the international Joint OSSE project (PI for CEOS Category 1 action WE-07-1_3).
- POC at NESDIS/OSD & NWS (and EMP) for user requirements for GPS RO data. [Evaluation/planning for a possible GPS RO follow-on mission].

Current and future plan

- Update quality control checks & observation error characteristics for GPS RO data in NCEP's system. (Some parallel runs are underway).
- Improve (refractivity) forward operator for GPS RO data.
- Evaluation, testing, tuning and (likely) assimilation of GPS RO from (GFZ) CHAMP & GRACE-A (in pre-operational mode) and MetOp/A GRAS (when available). [Possible availability of SAC-C data in real-time as well. Negotiations are underway].
- Develop the necessary code infrastructure to monitor the GPS RO statistics (perl-based statistics tool developed in collaboration with Doug Hunt from UCAR/CDAAC) and transition to operations.
- Assimilation of COSMIC observations (and other GPS RO missions) into NCEP's regional model (NAM).
- Improve the performance of the assimilation of observations of bending angle (switch to bending angle in operations? Global and regional systems?).
- Explore more complex forward operators to take into account horizontal gradients of refractivity (2D forward operators).