CGMS-35, NOAA-WP-17
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Agenda Item: II/3
Discussed in WGII

IMPACT OF COSMIC GPS RADIO OCCULTATION IN NUMERICAL WEATHER PREDICTION

In April 2006, the COSMIC mission (a joint project between the US and Taiwan) launched six Low-Earth Orbit (LEO) satellites into a circular polar orbit from Vandenberg Air Force Base, California. With the implementation of the new NCEP's Global Data Assimilation System on May 1st 2007 into operations, the assimilation of GPS RO observations from the COSMIC mission became operational at NOAA/NCEP. Observations from both raising and setting occultations are assimilated and there is no rejection of the low-level observations from the assimilation system, provided they pass the quality control checks.

IMPACT OF COSMIC (CONSTELLATION OBSERVING SYSTEM FOR METEOROLOGY, IONOSPHERE AND CLIMATE) GPS RADIO OCCULTATION OBSERVATIONS IN NUMERICAL WEATHER PREDICTION

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1 INTRODUCTION

In April 2006, the COSMIC mission (a joint project between the US and Taiwan) launched six Low-Earth Orbit (LEO) satellites into a circular polar orbit from Vandenberg Air Force Base, California. Each of the LEO satellites carries a GPS RO receiver to measure time delays of the GPS signals travelling from the GPS to the LEO satellites. As a GPS satellite occults behind the Earth's atmosphere, one can retrieve accurate information on the thermodynamic state of the atmosphere traversed by the ray path. In order to derive useful atmospheric information from time delay measurements, several processing steps and assumptions need to be made. (The geometry of a radio occultation is depicted in Figure 1).

Over the past few years, the US Joint Center for Satellite Data Assimilation (JCSDA) and NCEP Environmental Modeling Center (EMC) have developed a new Global Data Assimilation System. This system includes the capability to assimilate two different forms of GPS RO retrieved-observations. The first type of data is the bending angle, the change in the raypath direction accumulated along the raypath due to the gradient of refractivity perpendicular to the trajectory of the ray. The second type of derived-observation is the refractivity, which in the neutral atmosphere at the GPS frequencies (microwave range) is a function of temperature, water vapor pressure and pressure. Soundings of refractivity are derived from soundings of bending angle after several assumptions and processing steps.

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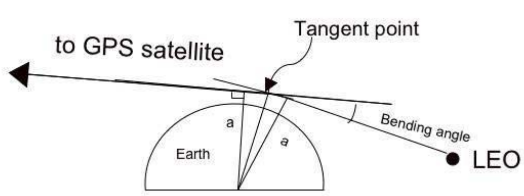


Fig.1 Cartoon representing the geometry of a GPS radio occultation.

2 FORWARD OPERATORS

Over the past few years the US JCSDA has developed two different strategies to effectively assimilate GPS RO observations into NCEP's model. The first forward operator simulates observations of refractivity (*N*) as a function of the geometric height, and it is computed from model variables of temperature, pressure and water vapor pressure as follows:

$$N = 77.6(\frac{P}{T}) + 3.73 \times 10^5 (\frac{P_v}{T^2}), \qquad (1)$$

where P is the total atmospheric pressure (in hPa), T is the atmospheric temperature (in Kelvin), and P_v is the partial pressure of water vapor (in hPa).

The second approach simulates observations of bending angle (α) as a function of the asymptote miss distance (or 'impact parameter') a (See Fig.1). The forward operation to compute bending angles from model variables requires the evaluation of a complex integral:

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

$$(x = nr)$$

where n is the index of refraction of the atmosphere and r is the radius of a point on the trajectory of the ray. The magnitude x is the refractional radius. The impact parameter remains constant along the trajectory of a ray for an spherically symmetric atmosphere. In addition to the forward models for refractivity and bending angle, the corresponding tangent linear and adjoint codes have also been developed, tested and implemented into the operational NCEP's Global Data Assimilation system.

The quality control procedures and error characterizations have been developed separately for the assimilation of bending angles and refractivities. In the current design of both forward operators the effects of the horizontal gradients of refractivity have been neglected and the assumption of spherical symmetry of the atmosphere is implicit when assimilating profiles of refractivity and bending angle.

In the GPS processing technique, profiles of N are derived from profiles of α under the assumption of spherical symmetry of the atmosphere. The same assumption is used when deriving bending angles from GPS raw measurements. However, the effects of neglecting the horizontal gradient component are small in the derivation of α but are much more significant in the retrieval of N. This along with the fact that some auxiliary meteorological information is necessary in order to obtain refractivities from bending angles makes the use of the bending angle more desirable for assimilation than the use of refractivities. On the other hand, the larger variability of α due to vertical refractivity gradients makes its assimilation more challenging. In the modeling counterpart, the procedure is reversed, that is, profiles of bending angle are derived from simulated profiles of refractivity.

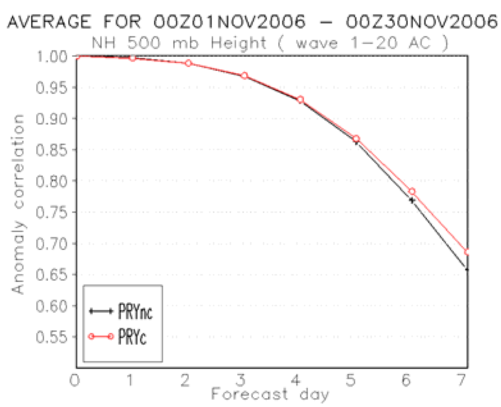
3 IMPACT STUDIES WITH COSMIC

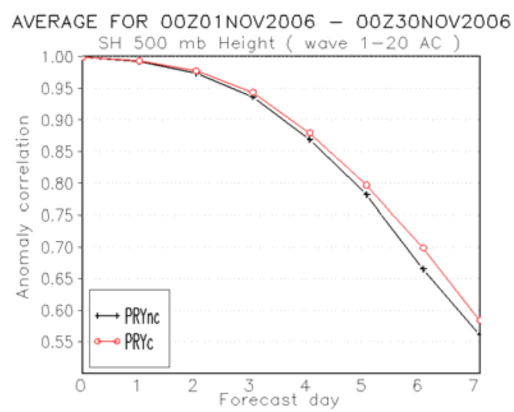
Preliminary experiments with COSMIC showed better model skill when profiles of refractivity were assimilated into the system than with the use of bending angles. As a result, the use of refractivity was selected for operational implementation at NOAA/NCEP. The tuning of the system to improve the model skill when assimilating soundings of bending angle is under current research at the US JCSDA.

Impact studies with COSMIC show an increase of the anomaly correlation (AC) scores as a function of the forecast day for mass and humidity fields. A significant overall reduction of the model bias and root-squared error is also achieved when profiles of COSMIC are assimilated in the system.

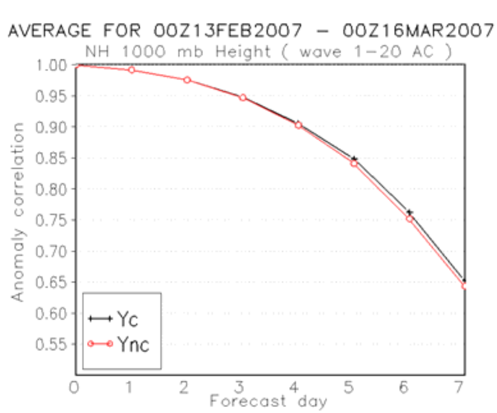
AC scores for the geopotential height field for two different periods are shown in the figures below. The benefits from COSMIC are found in both hemispheres. Improvement in model skill when assimilating COSMIC is also found for other variables and model levels.

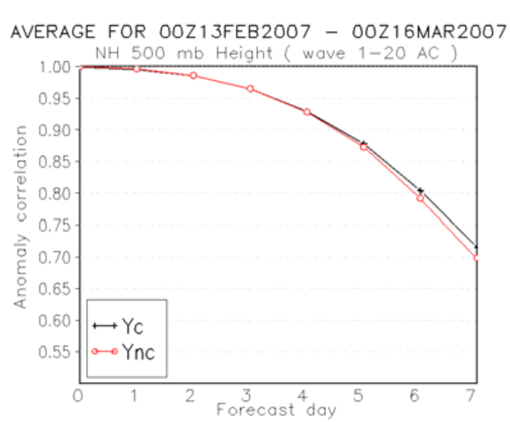
Period: 1-30 November, 2006.
PRYnc = control (assimilation of conventional and satellite observations)
PRYc = PRYnc + assimilation of COSMIC profiles





Period: 13 February – 16 March, 2007.
Ync = control (assimilation of conventional and satellite observations)
Yc = Ync + assimilation of COSMIC profiles





4 CONCLUSIONS AND RECOMMENDATIONS

GPS RO data are minimally affected by aerosols, clouds or precipitation, are independent of radiosonde calibration, are not expected to have instrument drift, and satellite-to-satellite instrument bias. The promising results found with COSMIC in weather forecasting seems to indicate that the GPS RO observations provide a unique and value piece of information to the assimilation system. GPS technology is a limb sounding geometry complementary to ground and space nadir viewing instruments, characterized by high vertical resolution and lower horizontal resolution

Future work at the US JCSDA includes to improve the use of GPS RO observations (bending angle instead refractivity), account for horizontal gradients of refractivity in the forward operator in order to reduce the representativeness error of the forward models, and assimilate operationally GPS RO data from the CHAMP and other GPS RO missions (e.g. from METOP-I).

The specific actions to be conducted within the JCSDA regarding the use of GPS RO observations at NOAA are itemized below:

- Monitor the use of COSMIC data into operations.
- Understand why the assimilation of bending angle has not been performing as well as it used to do with the previous parallels runs (with different versions of the assimilation model).
- Improve the performance of the assimilation of bending angle.
- Preparation for using CHAMP data into operations along with COSMIC. As CHAMP data is being processed by a different center, a detailed analysis of the profiles –and corresponding tuning in the code- needs to be conducted before CHAMP can be assimilated in operations.
- Improve some diagnostic files available from the NCEP’s global data assimilation system to better monitor the GPS RO observations.
- Generalize the GPS RO code to use any vertical coordinate system, so the code will work with the new vertical coordinate system that the model community expects to implement next year.
- Development of more advanced forward operators that takes into account horizontal gradients of refractivity. Demonstrate the benefits of this new type of forward operators to fully exploit the information contained in the GPS RO data.
- Transition to operations for the use of COSMIC (and other missions) into the NCEP’s regional assimilation system.