2.3 CONSTELLATION OBSERVING SYSTEM FOR METEOROLOGY IONOSPHERE AND CLIMATE (COSMIC): AN OVERVIEW

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1. INTRODUCTION

The Global Positioning System (GPS) satellite constellation was developed for precise navigation and positioning. The GPS today consists of 28 operational satellites that transmit L-band radio signals at two frequencies (L1 at 1.57542 GHz and L2 at 1.2276 GHz) to a wide variety of users in navigation, time transfer, and relative positioning and for an ever-increasing number of scientists in geodesy, atmospheric sciences, oceanography, and hydrology.

Atmospheric soundings are obtained using GPS through the radio occultation (RO) technique, in which satellites in low-Earth orbit (LEO), as they rise and set relative to the GPS satellites, measure the phase of the GPS dual-frequency signals. From this phase the Doppler frequency is computed. The Doppler shifted frequency measurements are used to compute the bending angles of the radio waves, which are a function of atmospheric refractivity. The refractivity is a function of electron density in the ionosphere and temperature, pressure, and water vapor in the stratosphere and troposphere.

A review of GPS RO sounding technique can be found in Kursinski et al. (1997) and a special issue of *Terrestrial, Atmospheric and Oceanic Sciences* -- TAO (2000). Comparison of RO soundings from GPS/MET (GPS Meteorology) experiment with correlative data indicated that the RO soundings possess the equivalent temperature accuracy of ~1 K in the range from the lower troposphere to 40 km (Ware et al., 1996; Kursinski et al., 1996; Rocken et al., 1997). Evaluation of RO soundings from two follow-on missions, CHAMP (CHAllenging Minisatellite Payload) (Wickert et al. 2004) and SAC-C (Satellite de Aplicaciones Cientificas-C), by Hajj et al., (2004) and Kuo et al., (2004), has substantiated the results of GPS/MET.

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The GPS RO sounding technique, making use of highly coherent radio signals from the GPS has many unique characteristics, including: (i) high accuracy, (ii) high vertical resolution, (iii) all weather sounding capability, (iv) independent of radiosonde or other calibration, (v) no instrument drift and (vi) no satellite-to-satellite bias (Rocken et al. 1997; Kursinski et al. 1997; Kuo et al. 2004). These characteristics make GPS RO data ideally suited for climate monitoring and global weather prediction. Anthes et al. (2000) provided many examples on the possible applications of GPS RO data to meteorology and climate.

2. BRIEF DESCRIPTION OF THE COSMIC MISSION

COSMIC (Constellation Observing System for Meteorology, Ionosphere and Climate) is a joint mission between Taiwan and U.S., with a goal to demonstrate the use of GPS RO data in operational weather prediction, climate analysis, and space weather forecast. COSMIC will launch six LEO satellites in late 2005. Each satellite will carry three atmospheric science payloads: (1) a GPS radio occultation receiver for ionospheric and neutral atmospheric profiling and precision orbit determination; (2) a Tiny Ionospheric Photometer (TIP) for monitoring the electron density via nadir radiance measurements along the sub-satellite track; and (3) a Tri-Band Beacon (TBB) transmitter for ionospheric tomography and scintillation studies. With the ability of performing both rising and setting occultation, COSMIC is expected to produce approximately 2,500 GPS RO soundings uniformly distributed around the globe per day. The COSMIC data will be available in near-real-time (within 2 hr of observations) to support the use of GPS RO data in operational numerical weather prediction. The Brazilian EQUARS mission will be launched in early 2006, and will provide an additional 500 GPS RO soundings per day. Typical distribution of the combined COSMIC and EQUARS GPR RO over a 24-h period is shown in Fig. 1. Further information on the COSMIC Program can be found at: http://www.cosmic.ucar.edu/

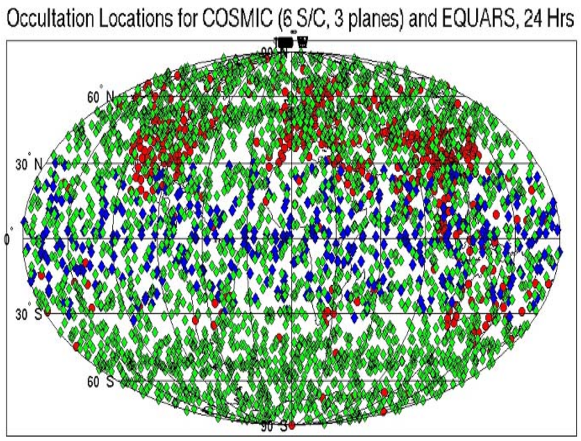

Figure 1. Typical GPS RO sounding locations from COSMIC (in green) and radiosonde sites in red. The figure also shows, in blue, the expected sounding locations from the Brazilian EQUARS mission. EQUARS is expected to overlap at least with part of the COSMIC mission and would nicely complement COSMIC in the tropics.

3. ASSIMILATION OF GPS RO DATA

Although COSMIC won't be launched until late 2005, recent data assimilation studies making use of data from on-going missions have already demonstrated positive impacts of GPS RO data on research and operational numerical weather prediction. Healy et al. (2004) performed a forecast impact study using 16 days of CHAMP GPS RO data from May and June 2001, in addition to conventional and satellite observations which are used in operational forecasts at the U.K. Met Office (UKMO). Using the UKMO global 3DVAR system, Healy et al. (2004) assimilated approximately 160 CHAMP RO soundings per day globally. Their results showed that these GPS RO soundings improved temperature analysis and forecasts in the upper troposphere and lower stratosphere. A significant impact was found in the Southern Hemisphere where 24 to 96 hour forecast 250hPa temperature RMS differences were reduced by ~0.1K (Fig. 2).

Recently, Wee and Kuo (2004) assimilated the GPS RO data from CHAMP and SAC-C missions using an updated version of MM5 4DVAR system, and assessed their impact on short-range prediction of an intense cyclone that took place in December 2001 over the Ross Sea. The intensity of the December 2001 storm (which has a minimum pressure of 936 hpa) had not occurred near McMurdo Station over the 46 years of record keeping. Wee and Kuo (2004) performed parallel data assimilation experiments with and without the

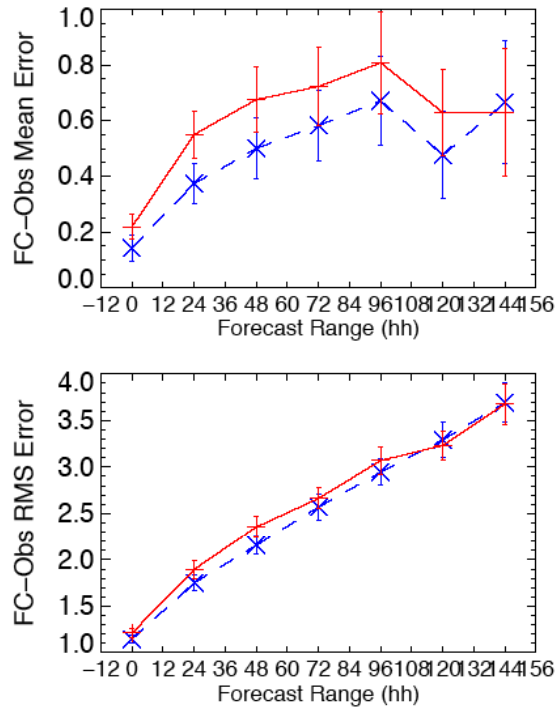

Figure 2. Mean and RMS fit to radiosonde temperature observations at 250 hPa in Southern Hemisphere (latitude south of 20oS) as a function of forecast range for control (red) and GPS RO assimilation (blue-dashed) experiments. (From Healy et al. 2004).

use of GPS RO data over an 8-day period for this storm. Continuous assimilations with a window size of 12-h were carried out over 48 hours (e.g., 4 cycles). For this case, various types of observations were collected and processed. The CHAMP and SAC-C GPS RO data were obtained from the COSMIC Data Analysis and Archive Center (CDAAC) at UCAR. Other observations collected include TEMP (rawinsonde and pibal), SYNOP (surface, ship, drifting buoy, and PAOB), aircraft observations (AIREP, PIREP, and AIRCAR), ATOVS retrieved soundings from NESDIS (NOAA 15 and 16), MODIS/Terra retrieved soundings, satellite motion vectors, SSM/I retrievals (rainfall rate, total liquid water, precipitable water vapor, and surface wind speed) from DMSP 13-15, and QuikSCAT surface wind vector.

A significant positive impact of GPS RO data on short-range forecasts was found for experiments with 48 hours of continuous assimilation. Figure 3 shows the 66-h forecasts of mean sea level pressure, valid at 0600 UTC 14 December 2004, from three experiments. The first experiment is the cold start run, initialized with the NCEP AVN analysis at 1200 UTC 11 December 2004. The

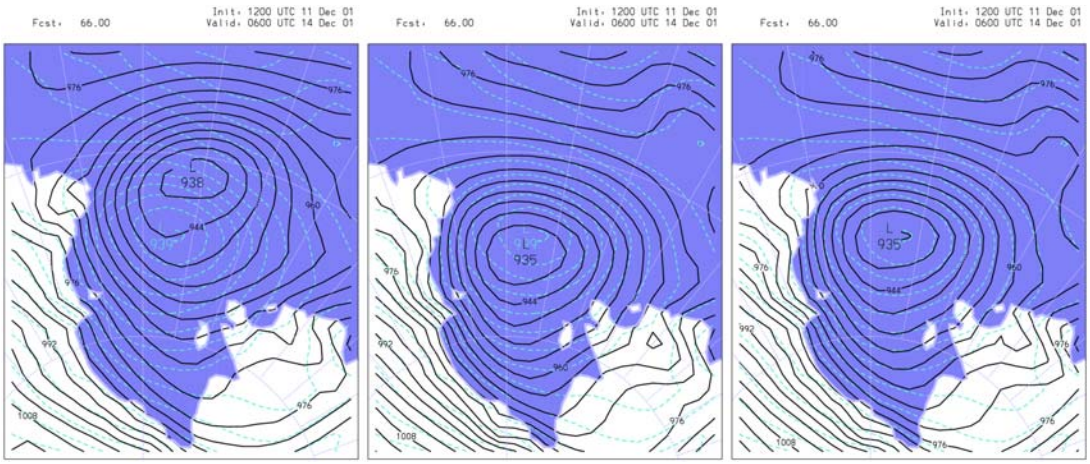

Figure 3. The 66-h forecasts of mean sea level pressure initialized at 1200 UTC 11 and valid at 0600 UTC 14 December 2001. Dashed contours represent mean seal level pressure from ECMWF analysis and solid lines represent the forecast from a) the cold start run initialized with NCEP/AVN analysis, b) No GPS experiment, and c) GPS experiment. (from Wee and Kuo 2004)

second experiment (designated as the No GPS experiment) has the benefits of continuous 48-h assimilation of all available observations between 1200 UTC 9 through 1200 UTC 11, with the exception of GPS RO data. The third experiment (called GPS experiment) is similar to the second experiment, except the GPS RO data are included in the 48-h continuous assimilation. The corresponding ECMWF analysis (dashed line) is also shown in Fig. 9 as verification. The results indicated significant forecast errors for the cold start run. The No GPS experiment improved considerably over the cold start run, which suggests the effectiveness of continuous 4DVAR assimilation of available observations. The assimilation of GPS RO data, in addition to other available observations, led to the prediction of an almost identical pressure pattern with the verifying ECMWF analysis. These results show that the GPS RO data have the potential to significantly improve weather prediction over traditionally data poor regions of the world.

The assimilation of GPS RO data over an extended period (e.g., 48 h) improved all parameters in all forecast ranges. Moreover, the amount of positive impact as a result of GPS RO data assimilation increased proportionally to the length of the analysis period. With continuous cycling assimilation, the analysis errors were kept to a degree comparable to those of the NCEP operational analysis. A significant error reduction was noted over the interior of the Antarctic continent when the forecasts were verified against observed GPS RO data (not shown).

With the launch of COSMIC and EQUARS, we will obtain almost an order of magnitude more GPS RO soundings than the combined CHAMP and SAC-C missions. Results from the assimilation experiments based on the limited CHAMP and SAC-C GPS RO soundings provide strong support that the COSMIC and EQUARS data will make a significant contribution to operational weather prediction and climate analysis.

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