Real-time Analysis of COSMIC Data
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Abstract
UCAR has analyzed GPS radio occultation data since the launch of GPS/MET in 1995. Presently the Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) project office at UCAR is processing data from the CHAMP mission and developing software for the COSMIC Data Analysis and Archival Center (CDAAC). CHAMP data are processed within about 12 hours of data collection (as soon as they become available to the CDAAC). COSMIC data will be processed in real-time, immediately upon reception at CDAAC to deliver results to Numerical Weather Centers within 180 minutes of data collection, on average. To meet this goal the CDAAC plans to use ground based global 1-sec GPS data, predicted GPS orbits and, of course, low-latency data from the 6 COSMIC low-Earth orbiters (LEOs).

Keywords: GPS, LEO, climate, weather prediction, low latency, radio occultation

1. Introduction
The joint Taiwan / US Constellation Observing System for Meteorology, Ionosphere, and Climate (ROCSAT3/COSMIC) is a six-satellite constellation that will provide globally distributed remote sensing data after launch in late 2005.

The COSMIC mission will provide data for weather, climate, space weather and geodetic research. One of the most important goals, that distinguishes this mission from previous radio occultation (RO) missions, is that COSMIC shall provide RO data to observational weather centers to demonstrate positive impact on weather forecasting. Therefore we will process the RO data at the COSMIC Data Analysis and Archival Center (CDAAC) at UCAR in post processing for climate research and case studies and in near-real time for weather prediction.

We have processed RO data for climate research and for validation of weather data since 1995 as illustrated in Figure 1.

Figure 1 These latitude band statistics show the evolution of atmospheric temperature from 1995-2004 based on GPS/MET, SAC-C and CHAMP observations at two (10 and 50 mbar) height levels.

All data in Figure 1 have been processed with the same software in a consistent
fashion. Figure 1 is based on GPS/MET results from 1995 to 1997 when high-quality solutions were possible only during certain time periods (Rocken et al. 1997). The long gap until 2001 is the time before the launch of CHAMP. While scientists have just begun to extract scientific information from RO data the hope is that the data shown here form the beginning of a long-term uninterrupted and much denser RO time series for climate research.

The historic RO results can also be used for model testing.

Figure 2 shows one such comparison for the 50 mbar height level. It can be seen that at this height level RO and the models agree quite well from the equator south to 70 degrees S. In the polar region the NCEP model displays a +/- 2 degree difference relative to RO with NCEP winters appearing too cold and NCEP summers too warm. A similar but smaller amplitude seasonal signal can be seen for the ECMWF model comparison.

While the usefulness of RO can clearly be demonstrated with the results obtained so far, the utility of the data for weather forecasting from COSMIC requires the availability real-time RO results.

2. Real-Time CDAAC

Based on discussion with operational numerical weather prediction (NWP) centers the requirement was formulated that the CDAAC has to deliver neutral atmospheric products (signal bending, refractivity, temperature, pressure, height) within 180 minutes of data collection. This 180 minute requirement refers to the average latency and not the maximum age of the results CDAAC will attempt to provide the results faster than that.

The ionospheric science and data assimilation community is requesting CDAAC data and products even sooner than the neutral atmospheric community. This is feasible because some ionospheric products such as line-of-sight total electron content (TEC) do not depend on precise orbits, GPS clock determination and can thus be generated faster than bending angles and refractivity profiles. However, CDAAC space weather processing is not yet as far developed as its neutral atmospheric
analysis capability and this paper will focus on the neutral atmosphere requirement.

Before profiles of neutral atmospheric bending, refractivity, and temperature and pressure (above the onset of significant moisture) can be computed the CDAAC needs to receive (a) data from the LEO satellites, (b) predicted GPS satellite orbits, (c) data from a global network of fixed ground based GPS receivers. For the determination atmospheric water vapor in the lower troposphere the CDAAC requires (d) predicted global weather fields.

3. LEO Data

In their final constellation the COSMIC satellites will orbit at 700-800 km altitude 72 degree inclination orbits. Each satellite will pass once per orbit over one of the two dedicated COSMIC ground stations at Kiruna Sweden and Fairbanks, Alaska. These ground stations are currently installed and they will receive the ~9 Mbyte science data dump from each satellite pass. The data from each of these dumps is expected to contain ~30 RO soundings plus all the other GPS observations, spacecraft data needed for the science data inversion (such as attitude information), and data from the Tiny Ionospheric Photometer (TIP) science instrument. The data downloaded from the LEO are expected to arrive at the CDAAC within 5 minutes of the completion of the data dump.

4. GPS Orbits

CDAAC is planning to use IGS ultra-rapid (IGU) orbits for processing of real-time data. These orbits are predictions of satellite positions in time. The IGU orbits for COSMIC will be 6-hour predictions. The 3D position errors of these predicted orbits will be better than 0.2 m rms and thus good enough for CDAAC to meet its precision orbit determination (POD) goal of 0.1 mm/sec in velocity. Details of the CDAAC real-time orbit determination strategy are explained by Schreiner et al (2004) in this issue.

5. Global Fiducial Data

CDAAC requires data from a global network of fixed GPS receivers for the precise determination of the LEO orbits and for the removing errors due to GPS satellite and receiver clocks. The global GPS data have to be dual frequency observations at a 1Hz sampling rate. The IGS is operating a network of sites that generate such data in support of LEO missions as shown in Figure 3.

Figure 3 Shows the stations of the IGS network that generate 15-minute files of 1-sec sampling rate dual-frequency GPS data in the “Hatanaka-compressed” data format.

Data from the network shown in Figure 3 are collected in 15-minute files and then made available by NASA’s Crustal Dynamics data Information System (CDDIS at cddis@gsfc.nasa.gov). The data from different stations arrive at CDDIS with varying delays.

CDAAC has an automated process that checks for new 15-min LEO files at CDDIS every 10 minutes. Figure 4 shows the delays with which these files appear fluctuates between sites and different time periods. The top panel in Figure 4 shows a histogram of the average delay for a 10-day period. The bottom panel shows the delay during one specific, more recent day. Because CDAAC presently only checks for data every 10 minutes the actual delay with which the data appear at CDDIS will be on
average 5 minutes shorter than what is shown in Figure 4.

Figure 4 shows the number of stations with 15-min LEO files that appear on the CDDIS web site vs. the delay with which these sites become available. The top panel shows average values for days 61-70, 2004, the bottom panel shows the average for the 96 15-minute file from the more recent day 125, 2004.

As can be seen in the lower panel of Figure 4, the most recent data from most stations appear with a latency ranging from 30 to 180 minutes. Clearly most of these data arrive too late to be useful for CDAAC’s real-time processing.

To obtain lower latency data COSMIC has contacted the IGS and CDDIS to inquire if there are plans to reduce latency. COSMIC is also in touch with groups that are collecting or are planning to collect real-time streamed data. These data will be available during COSMIC but an agreement for their use has yet to be negotiated.

In addition the COSMIC program office has taken the first to establish its own real-time fiducial sites to augment the existing network. We have purchased three GPS receiver for installation at Department of Energy / Atmospheric Radiation Measurement (DOE/ARM) sites in the tropical western pacific. The sites at Darwin, Manaus and Nauru are operated by DOE/ARM and will provide near-real-time satellite communication links for sending the data to CDAAC.

![Figure 4 showing number of stations with 15-min LEO files](image)

6. Numerical Weather data

For the generation of real-time water vapor profiles CDAAC will employ a 1-DVAR method that requires information from a numerical weather prediction. CDAAC will also use this numerical weather prediction field for data quality control (QC) before sending data to users. Users can choose whether to rely on CDAAC’s QC or to conduct their own. The source of, and detailed requirements for this predicted numerical weather data have not yet been decided.

7. Summary

The CDAAC has processed all available historic RO data in a consistent way. The data are now used for climate studies and
for comparison with models and with other data sources. While CDAAC is continuing to process all available RO data as close to real time as possible it is also preparing for the near-real time analysis during COSMIC.

While significant work has yet to be done to finalize the CDAAC real-time processing and data availability and ingestion capabilities in time for the launch of the COSMIC satellites we foresee no major problems.

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References