Abstract
The COSMIC Data Analysis and Archival Center (CDAAC) at UCAR has processed radio occultation data from the GPS/MET, CHAMP, and SAC-C missions in both post-processing and near real time modes of operation. The GPS data processing at the CDAAC is performed with the Bernese software package. A recent upgrade of the Bernese software to version 5.0 has improved the CDAAC CHAMP satellite velocity estimation from ~0.5 mm/sec 3D rms to approximately the ~0.1 mm/sec level in post-processing when using a ground GPS network with approximately 50 stations. This improved orbit quality will increase the accuracy of radio occultation retrievals, especially at high altitudes. In this paper, the approaches used for post-processed and near real-time precise orbit determination of LEO satellites at the CDAAC are described. An assessment of the orbit quality is then performed using CHAMP GPS data.

Keywords: GPS, LEO, POD, orbit determination, radio occultation

1. Introduction
The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) is a six-satellite constellation that will provide globally distributed remote sensing data after launch in late 2005. The primary payload on each spacecraft, a GPS receiver developed at JPL and manufactured by Broad Reach Engineering, will provide raw dual-frequency GPS pseudorange, carrier phase and amplitude measurements for orbit determination and radio occultation (RO) profiling of the neutral atmosphere and ionosphere. These data will be downloaded every 100-minute orbit to the COSMIC Data Analysis and Archival Center (CDAAC) at UCAR in Boulder, CO. The CDAAC will process the GPS data into RO profiles within 3 hours of the observation on average for near real-time assimilation into weather forecast models and 1-2 months after data collection (post-processing) for more precise climate studies. In order to provide accurate RO retrievals, it is necessary to precisely compute the excess Doppler that is due to the refraction of the GPS signals by the Earth’s atmosphere. This requires precise knowledge of the relative LEO to GPS orbital velocity. The COSMIC mission requirement for LEO velocity uncertainty is 0.1 mm/s 3D root mean square (rms).

The LEO precise orbit determination (POD) functions at CDAAC are performed with the Bernese [Hugentobler et al., 2001] GPS data processing package. To date, the CDAAC has been using Bernese version 4.3 to provide dynamic model fits to LEO precise point position kinematic solutions [Bock et al., 2001] with a resulting orbit accuracy at the 50cm (0.5 mm/s) 3D rms level for CHAMP. Figure 1 shows the level of impact that 0.5 mm/s orbital velocity error has on RO refractivity error. The CHAMP

Figure 1: RO fractional refractivity retrieval error due to LEO velocity error.
dynamic orbit determination with Bernese version 4.3 is limited to near this level due to gravity and drag mis-modeling that are significant at the 400-km CHAMP altitude. Fortunately, more flexible dynamic (i.e. reduced-dynamic) orbit determination, and kinematic positioning procedures have been implemented into the new Bernese version 5.0 software. The reduced-dynamic procedure allows for the estimation of pseudo-stochastic velocity pulses at user-defined epochs and is analogous to frequent estimation of non-conservative force parameters such as drag and solar radiation pressure [Svehla and Rothacher, 2002]. These new LEO POD techniques have been applied using zero-difference (requires precise high-rate GPS clocks) and double-difference observations to determine CHAMP orbits that are consistent with SLR data at the 4-5 cm rms level [Svehla and Rothacher, 2002]. Those results were determined when using a large GPS ground network with over 100 stations. In an effort to minimize CDAAC CPU processing time, in this work we attempt to determine the CHAMP POD quality that can be obtained with a global network of approximately 50 GPS stations (see Figure 2).

In this paper, an overview of the zero-difference reduced-dynamic approach used for post-processed and near real-time LEO POD is presented. An assessment of the orbit quality is performed by comparing CHAMP orbits from CDAAC with JPL Quick orbits. Then, some conclusions and implications for COSMIC POD are discussed.

2. CDAAC Post-processing LEO POD Strategy

The CDAAC post-processing LEO POD strategy uses a reduced-dynamic approach with undifferenced (zero-difference) carrier phase observables. It is performed on one month batches of data from the ~50-station GPS ground network and from the LEO missions of interest. IGS final GPS orbits and Earth orientation parameters (EOPs) as well as available weekly solution station estimates are held fixed in the processing. Non-IGS (not provided in the IGS weekly solutions) stations are estimated as monthly averages along with all station zenith tropospheric delays (ZTDs estimated at 1-hour intervals) throughout the month. This process uses an efficient stacking of double-difference normal equations to provide station troposphere estimates that are based on monthly station position estimates. Then, all known quantities (IGS orbits, EOPs, station coordinates, ZTDs) are held fixed in a process to estimate GPS satellite clock offsets that are required for zero-difference processing. This process computes high-rate (30-sec) clock offsets by aligning phase-derived clocks to a priori IGS clock offsets [Bock et al, 2000].

The LEO POD zero-difference processing is performed over 24 hour arcs. A diagram that illustrates the processing flow is shown in Figure 3. This processing can be divided into two main tasks: 1) data pre-processing or cleaning (first two columns) and 2) orbit improvement or estimation (third column). An a priori orbit is required for both tasks and is obtained by fitting a dynamic force model based orbit (without stochastic velocity pulses) to pseudorange kinematic point position estimates. The a priori orbit used for the orbit improvement procedure

Figure 2: CDAAC GPS ground network with approximately 50 stations.
uses one 24-hour arc. However, for the data cleaning (cycle slip fixing) procedure, the a priori orbit is broken into four 6-hour arcs to improve the orbit accuracy. The full-up dynamic model state consists of:
- 6 initial conditions (Keplerian elements)
- 9 solar radiation pressure parameters (bias and ONCE/REV [ONCE per orbital REVolution] accelerations in radial, transverse, and normal directions)
- pseudo-stochastic velocity pulses in radial, transverse, and normal directions every 18 minutes

The EIGEN1S Earth gravity model is used out to degree/order 140 [Reigber et al., 2002].

The zero-difference processing strategy above is computationally efficient (as compared to double-difference) due to the smaller number of observations and carrier phase ambiguities. The data processing shown in Figure 3 takes approximately 4 minutes to complete on a Pentium III 2 Ghz class computer for a 24-hour orbit.

3. CDAAC Near Real-Time LEO POD Strategy
The near real-time LEO POD approach presented below is currently being evaluated in a near real-time re-analysis mode of operation (i.e real-time simulation). It is similar to the post-processing approach in function, but it must process the ground and LEO data as they arrive at the CDAAC in near real time. Predicted IGS Ultrarapid orbits and EOPs will be used. Figure 4 illustrates the near real-time data and processing flow. The ground data will arrive at the CDAAC by streaming or via 5-15 minute low latency files. The near real-time ZTD estimation will be performed every hour (or more often if Bernese obtains...
performed for one month of the CHAMP mission, August 2002 (2002.213-2002.243). The software is fully automated and requires no user intervention. External orbit overlaps with JPL Quick orbits (genesis.jpl.nasa.gov) were computed and provide an upper bound (worst case) for the CDAAV CHAMP orbit quality. An example external orbit overlap result is given in Figure 5, which shows the radial, transverse and normal velocity differences between the UCAR and JPL orbits for one day (2002.214) in August 2002.

**Figure 5:** External orbital velocity overlap comparison between UCAR and JPL Quick CHAMP orbits for Aug 02, 2002 (2002.214).

The root sum square (rss) of the three component differences gives a 3D rms error of ~0.17 mm/sec. Figure 6 shows the external overlap results for the entire month of August in 2002. The average 3D rms difference for Aug 2002 is 0.14 mm/sec. If both UCAR and JPL orbits are assumed to have similar magnitude random uncertainties, then an estimate for the orbit error magnitude for one of the centers should be smaller by a factor of \((2)^{1/2}\), or approximately 0.10 mm/sec 3D rms \((0.14/(2)^{1/2})\). The external overlaps of position are shown in Figure 7 and have a 3D rms difference for Aug 2002 of 14.0 cm. The orbit comparisons, however, do show significant mean differences of ~4.7 \pm 1.6 cm, -1.0 \pm 1.4 cm, -3.3 \pm 1.2 cm, in the radial, transverse and normal directions, respectively. The orbital velocity
comparisons also exhibit a significant mean error in the radial direction of \(-0.05 \pm 0.02\) mm/sec. The reason for these mean differences is not understood and is the subject of further study. The improvement in neutral atmospheric retrieval accuracy due to the improved CHAMP orbit accuracy is not shown here due to lack of time and will be presented in the future.

The CDAAC is now using Bernese version 5.0 for LEO precise orbit determination. Post-processing orbit quality using a reduced-dynamic approach with zero-difference observations is at the 0.1 mm/sec 3D rms level as determined from external CHAMP orbit overlap comparisons. A GPS ground network of only \(~50\) stations was used to obtain this POD quality. Near real-time precise orbit determination that uses a similar reduced-dynamic zero-difference processing approach is currently being tested. POD for the COSMIC satellites may be more difficult than for CHAMP due to having two POD antennas with small ground planes (i.e. more multipath). Thus, the COSMIC team will be performing anechoic chamber tests (May 04) with a satellite mockup to measure the phase centers and pattern variations of the POD antennas when mounted on the satellite. These measured phase centers and pattern variations will be used for COSMIC POD after launch.

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References
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