Preparing for COSMIC: Inversion and Analysis of Ionospheric Data Products

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Abstract

The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) is scheduled for launch by the end of 2005. COSMIC will consist of six low earth orbiting satellites in planes separated by 24° to provide global atmospheric and ionospheric observations. One of the goals is to demonstrate near real-time processing of data products for numerical weather prediction and space weather applications. Each COSMIC satellite will carry three payloads: (1) a GPS occultation receiver with two high-gain limb viewing antennas and two antennas for 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. The data from all these payloads will be processed at the COSMIC Data Analysis and Archival Center (CDAAC). Here we give an overview of the ionospheric data products from COSMIC and focus on the plans and preliminary simulation studies for analyzing the ionospheric occultation data and combining them with ground-based GPS, TIP, and TBB observations.

Ionospheric data products

Currently CDAAC plans to provide the following baseline ionospheric data products from COSMIC:

- GPS receiver:
  - High-resolution (1 Hz) absolute total electron content (TEC) to all GPS satellites in view at all times (useful for global ionospheric tomography and assimilation into space weather models)
  - Occultation TEC and derived electron density profiles (1 Hz)
- Tiny Ionospheric Photometer:
  - Nadir intensity on the night-side (along the sub-satellite track) from radiative recombination emission at 1356 Å
  - Derived F-layer peak density and critical frequency (f0F2)
  - Location and intensity of ionospheric anomalous structures
- Tri-Band Beacon:
  - Phase and amplitude of radio signals at 150, 400, and 1067 MHz transmitted from the COSMIC satellites and received by chains of ground receivers
  - TEC between the COSMIC satellites and the ground receivers

Ionospheric profiles from occultations

During the first months after launch, the COSMIC satellites will gradually be lifted into their final orbits. Thus, at the beginning of the mission (whole mission for two of the satellites), the ionospheric occultations will start at a relatively low altitude, similar to the altitude of the German CHAMP satellite at the beginning of its mission. As practice, CDAAC has therefore begun the processing of a subset of the CHAMP ionospheric radio occultation data. **Figure 1a** shows a few examples of derived electron density profiles from CHAMP differential (L1-L2) phase observations, using the not always valid assumption of local spherical symmetry (presumable giving rise to large errors below the F-layer).

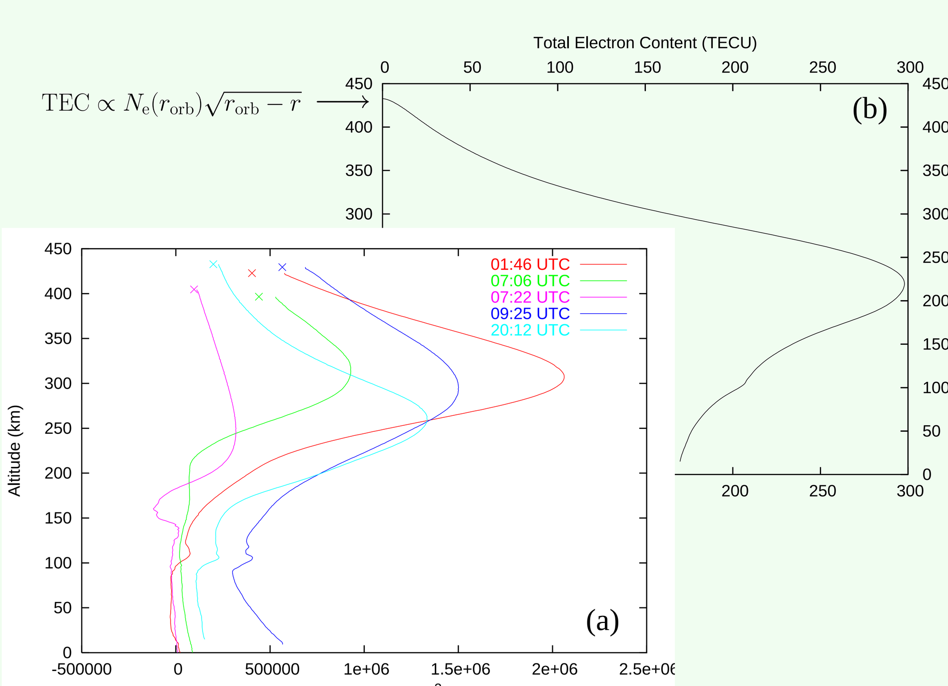

Figure 1: (a) Examples of retrieved electron density profiles from CHAMP occultations on August 31st, 2002. Crosses indicate CHAMP Langmuir Probe data at the beginning of the occultations. **(b)** Estimated TEC (normalized to zero at the top) for the occultation at 20:17 UTC.

The electron density at the orbit altitude was obtained from the estimated TEC data using linear regression of the square of the TEC near the orbit altitude (**Figure 1b**). Thus, the electron density at the orbit at the beginning of an occultation can be derived from the occultation data (model-independent, only requiring near circular orbit). In **Figure 1a** the crosses indicate the in situ electron density provided by the Planar Langmuir Probe on board CHAMP. The comparisons to the uppermost points of the electron density profiles indicate a systematic error in either our approach or in the Langmuir Probe data, something that will be looked into in the near future.

The profiles have been processed from so-called calibrated TEC, an approach introduced by Schreiner et al. (1999) to estimate the occultation TEC below the orbit. For the processing of CHAMP data, the calibration method was modified using the estimated electron density at the satellite orbit and assuming exponential decay of the electron density above the orbit (CHAMP does not collect positive elevation angle data necessary to apply the original calibration).

Combining TIP and occultation data

The TIP will provide nadir observations of radiative recombination emission at 1356 Å, with a temporal resolution of several seconds. These observations will give information about the horizontal ionospheric gradients along the sub-satellite track, and can be used in conjunction with the GPS occultation data to estimate the 2D electron density structure in the occultation plane (assuming that the occultation plane is near coincident with the orbit plane). **Figure 2** shows the setup for a simulation experiment, using the IRI-90 ionosphere, where the occultation takes place in a region of large horizontal gradients. Synthetic data were obtained as integrated electron density (occultation data) and integrated squared electron density (radiation data). These data were then inverted using weighted least squares according to assumed error covariances.

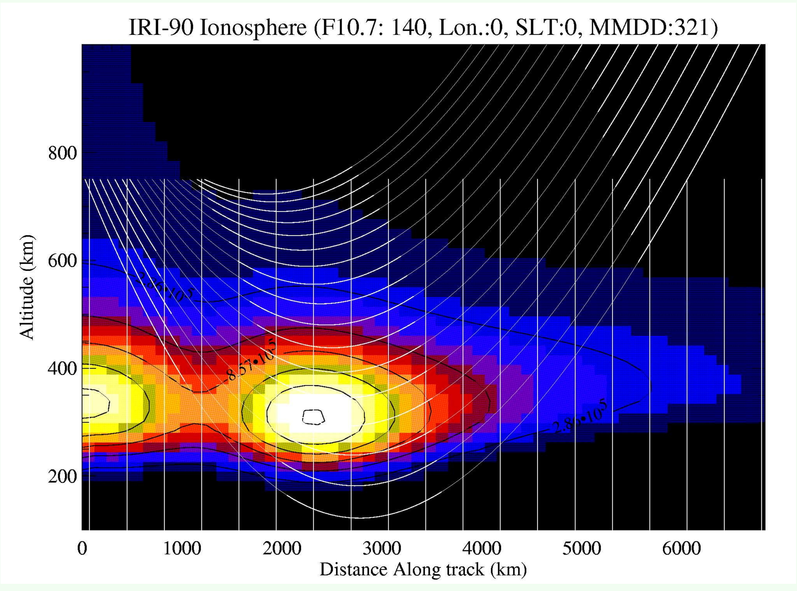

Figure 2: Simulations of GPS occultation measurements (curved lines across the image) and TIP measurements (vertical lines) through the IRI-90 ionosphere.

The reconstruction algorithm was based on a parameterization of the vertical structure assumed to be a generalized Chapman profile, with the parameters being the height and density at the F-layer peak, as well as three parameters describing an altitude dependent scale height. Fifty-six parameters were used to parameterize the horizontal variation via the F-layer peak density.

Figure 3 shows the fractional reconstruction error as compared to the "truth" (the IRI-90 ionosphere) in the simulation experiment. The result indicates the great value of the TIP measurements in conjunction with the occultation data.

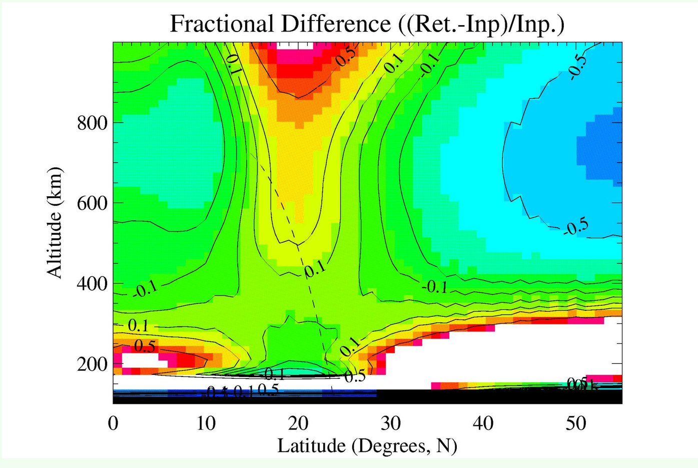

Figure 3: Fractional error of 2D retrieval as compared to the IRI-90 ionosphere. Dashed line rising from approximately 24°N represents the tangent point trajectory.

Ionospheric scintillations

One of the objectives of the TBB is global monitoring of ionospheric scintillations (Bernhardt et al., 2000). Ionospheric scintillations on satellite to ground links are often associated with plasma bubbles or sharp electron density gradients. Measurements of phase and amplitude scintillations at 150, 400, and 1067 MHz, will provide valuable data for scintillation studies and for generation of global scintillation maps.

Another kind of scintillations will be measured with the GPS occultation receiver around 100 km altitude. It is hypothesized that this kind of scintillations arises as a result of sporadic E-layers (Gorbunov et al., 2002). **Figure 4** shows an example from the GPS/MET experiment where the phases and amplitude at the beginning of a setting occultation (50 Hz, neutral atmosphere) exhibit large oscillations, characteristic of multipath propagation, presumably caused by a sporadic E-layer. Thus, it might be possible to detect sporadic E-layers globally using the occultation data. Additionally, it will be possible to localize ionospheric irregularities along the occultation path (Sokolovskiy et al., 2002) and investigate the vertical structure associated with sporadic E-layers by inversion based on thin screen model wave propagation.

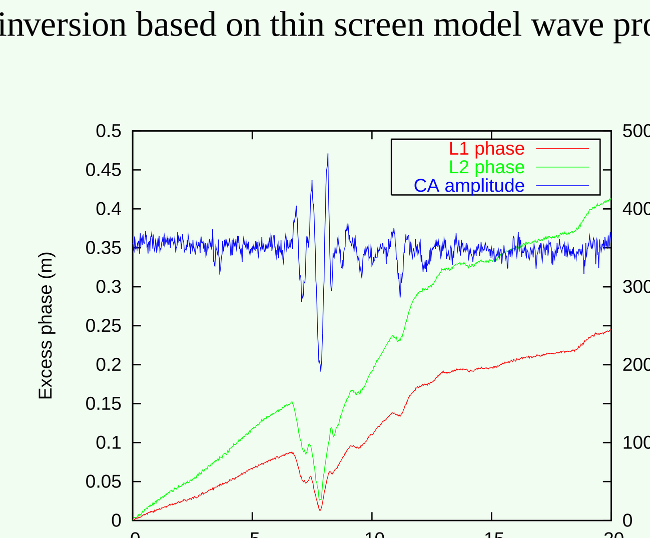

Figure 4: Excess phase and amplitude over the first 20 s of a GPS/MET occultation (50 Hz) which occurred near 30°N, 105°W at 8:09 UTC on February 4th, 1997.

Ionospheric tomography and assimilation

The ionospheric radio occultation (RO) data from COSMIC (1 Hz sampling rate) will contain valuable high-resolution information about the vertical electron density gradients, but also entangled information about the horizontal structure in the occultation plane. One way of separating the vertical and horizontal information is to combine the RO data with a priori information from an ionospheric model. This can be done within the framework of ionospheric tomography using the RO TEC data. **Figure 5** shows the result of combining the data from a GPS/MET occultation with the NeUoG climatological ionospheric model (Leitinger et al., 1996). In the tomographic reconstruction algorithm, the ionosphere was divided into 1000 layers and 45 horizontal bins over a 60° span. The inversion took into account very large a priori uncertainties and error correlations in the NeUoG model, such that the occultation data were heavily weighted, while the NeUoG model mostly contributed with important information about large-scale horizontal gradients.

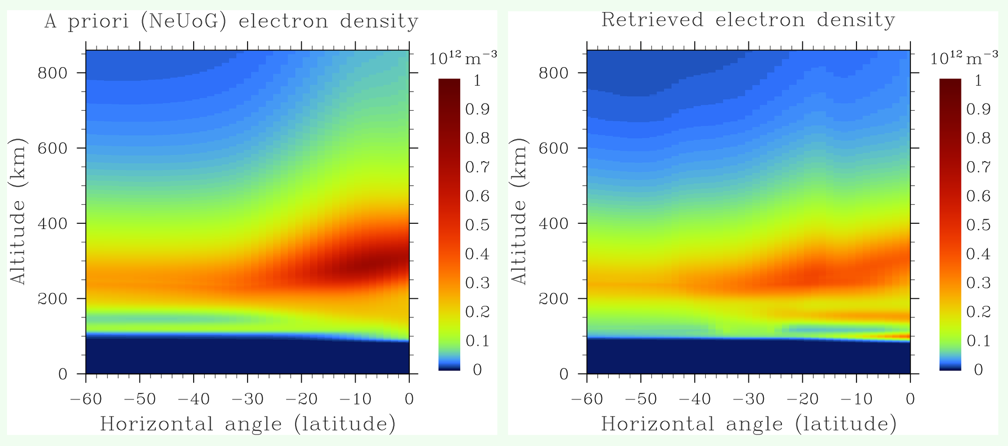

Figure 5: A priori (left) and tomographically reconstructed (right) electron density in the occultation plane for an ionospheric GPS/MET occultation which occurred near 28°S at ~9:30 LT on February 20th, 1997.

An alternative approach which will be considered for the COSMIC data is two-dimensional variational analysis (or assimilation) of the retrieved electron density profiles using a refractive index mapping operator (Syndergaard et al., 2004). With such an approach it will be possible to include correction for multipath propagation generated by sporadic E-layers (cf. **Figure 4**), something which tomographic reconstruction does not allow for.

It will also be considered to include data from Global Ionospheric Maps (GIMs) (**Figure 6**), as well as—when applicable—the data of similar nature from the TIP and the TBB transmitter. GIMs of vertical TEC are generated on a regular basis from a global network of ground-based GPS receivers. The GIMs available from the Jet Propulsion Laboratory (JPL) has a temporal resolution of one hour and a spatial resolution of 2° by 2°.

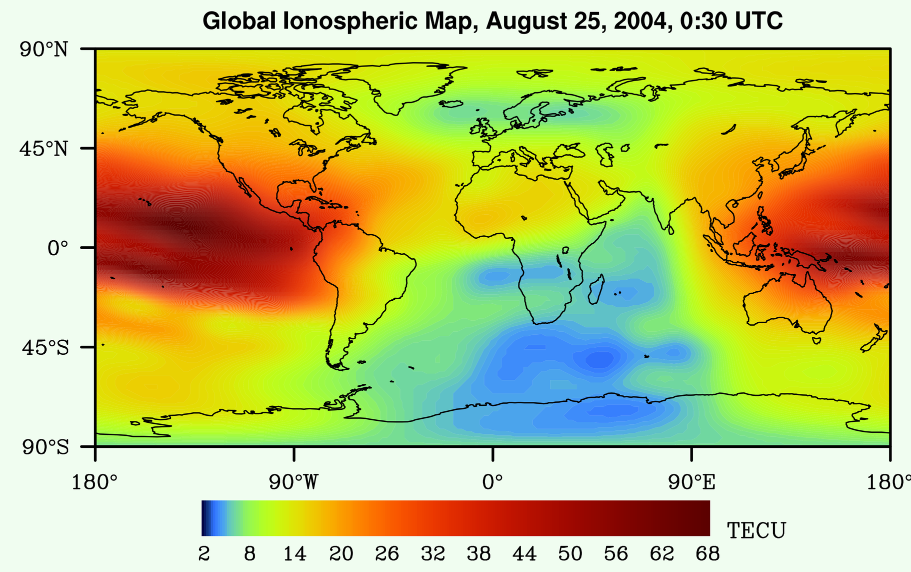

Figure 6: Example of Global Ionospheric Map; data by courtesy of JPL.

It is expected that the information on horizontal electron density gradients from ionospheric models, GIMs, TIP and/or TBB observations, in combination with the occultation data, will improve electron density profiling for COSMIC, and perhaps even allow high-resolution estimates of the 2D electron density distribution in the plane of occultation.

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