Coming Soon: Near Real-time Ionospheric Data Products from COSMIC

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Abstract

The Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) is expected to provide a wealth of data in near real-time for ionospheric and space weather research, as well as for numerical weather prediction (of the neutral atmosphere). COSMIC will consist of six low earth orbit (LEO) satellites, each carrying three instrument payloads for ionospheric and plasmaspheric monitoring. 1) A Global Positioning System (GPS) receiver, connected to two high-gain limb viewing antennas and two antennas for precise orbit determination (POD), will observe the total electron content (TEC) to all GPS satellites in view at all times, and will provide profiles of the electron density via the radio occultation technique. 2) A Tiny Ionospheric Photometer (TIP) will measure the ultra-violet emission due to recombination of oxygen and electrons in the ionosphere along the sub-satellite track. 3) A Tri-Band Beacon (TBB) will transmit radio signals on three frequencies (150, 400, and 1067 MHz) which will be received by chains of receivers on the ground with the main goal to determine the line-of-sight TEC and ionospheric scintillation levels. The ionospheric data products from COSMIC will be made available to the community from the COSMIC Data Analysis and Archival Center (CDAAC) in Boulder, Colorado, within 150 minutes of collection in orbit. COSMIC is scheduled for launch by the end of 2005.

Table 1: Anticipated near real-time ionospheric data products from COSMIC, their formats and expected latency.

Data description	Level/Name	Main products	Resolution	Format	Latency
Raw GPS receiver data from the POD antennae – one file per COSMIC POD antenna per dump	level 1a podGps	- time - phases - pseudo-ranges - SNRs	temporal: 1 sec	BINEX 0x7f-00	$\lesssim 115$ min
IGS Ultra-Rapid GPS orbits (including 24 hr predicted orbits) – one file every 6 hr	level 1a gpsOrb	- time - position - velocity	temporal: 15 min	SP3	0 min
Precise LEO orbits – one file per COSMIC satellite per dump	level 1b leoOrb	- time - position - velocity	temporal: 1 min	SP3	$\lesssim 140$ min
Absolute TEC to all GPS satellites in view – one file per COSMIC satellite per GPS satellite per arc	level 1b ionTec	- time - Rx & Tx pos. - absolute TEC - code biases	temporal: 1 sec	NetCDF	$\lesssim 145$ min
Ionospheric occultation excess phases and amplitudes – one file per GPS occultation	level 1b ionPhs	- time - SNRs - Rx & Tx pos. - Rx & Tx vel. - excess phases	temporal: 1 sec	NetCDF	$\lesssim 145$ min
Ionospheric occultation profiles from orbit altitude and down – one file per GPS occultation	level 2 ionPrf	- time - lat., lon. - tangent altitude - occ. TEC - electron dens.	vertical: 2–3 km	NetCDF	$\lesssim 145$ min
Raw TIP (Tiny Ionospheric Photometer) nadir radiance data – one file per COSMIC satellite per dump	level 1a tipBin	- time - counts	temporal: 1 sec	TIP native binary	$\lesssim 115$ min
Radiances from the TIP – one file per COSMIC satellite per dump	level 1b tipLv1	- time - counts - calib. coeff. - Rx position - surface lat., lon. - radiances	temporal: 1 sec	NetCDF	$\lesssim 145$ min

Ionospheric Data Products and Formats

The COSMIC Data Analysis and Archival Center (CDAAC) has defined a series of ionospheric data products that will be made available to the user community in near real-time once the mission starts. These products and their formats are summarized in **Table 1**. The latency is basically determined by an initial maximum of about 100 minutes before the data collected by each satellite are down-linked to one of two receiving stations (Fairbanks or Kiruna), plus transfer to CDAAC and processing time. It is not yet clear if CDAAC will be the center for the processing of the TBB data. These data will be collected at dedicated ground stations currently being installed in various countries all over the world.

Besides the products described in **Table 1**, CDAAC will also work to combine different data types. This could include combination of the 1 Hz occultation data from the POD antennas, with high rate (50 Hz) occultation data collected below ~ 140 km, via the limb antennas, to obtain electron density profiles with very high vertical resolution (~ 100 m) through the E- and D-layers. CDAAC also considers to provide global scintillation parameters from the two limb antennas and from the TBB data (if processed at CDAAC) as well as higher level products from the TIP data (e.g., F-layer peak density). The detailed definition of any of these products has yet to be worked out.

Absolute TEC calibration

Using data from the German CHAMP satellite (e.g., Heise et al., 2002), we here show preliminary results of ongoing efforts at CDAAC for estimating the absolute TEC (using data from the POD antenna), which include the estimation of the receiver differential (L1-L2) code bias (DCB). The data processing also includes an automatic editing algorithm (Blewitt, 1990) for detection and correction of cycle slips in the phase data.

For a particular day, the CHAMP receiver DCB is estimated as a weighted average of paired observations, based on the assumption that $\mathrm{TEC_A}\sin\theta_\mathrm{A} = \mathrm{TEC_B}\sin\theta_\mathrm{B}$, where θ_A and θ_B are the elevation angles of the line-of-sight to two GPS satellites (A,B) in view at the same time. The above assumption is only considered valid as long as both θ_A and θ_B are larger than 45° and when the estimated vertical TEC above the CHAMP satellite is less than 3 TECU. The receiver DCB for the day is then calculated as

$$\mathrm{DCB_{leo}} = \frac{\sum(\sin\theta_\mathrm{B} - \sin\theta_\mathrm{A})(\widehat{\mathrm{TEC}}_\mathrm{A}\sin\theta_\mathrm{A} - \widehat{\mathrm{TEC}}_\mathrm{B}\sin\theta_\mathrm{B})}{\sum(\sin\theta_\mathrm{B} - \sin\theta_\mathrm{A})^2} ,$$

where the summations are over all paired observations with the restrictions mentioned above. The $\widehat{\mathrm{TEC}}$ symbolizes the TEC based on L1-L2 phase data, leveled to pseudo-ranges, and includes a correction using the known GPS satellite transmitter DCBs. Thus, at the end of the day $\mathrm{TEC} = \widehat{\mathrm{TEC}} + \mathrm{DCB_{leo}}$.

Figure 1 shows the estimation of the CHAMP receiver DCB for 50 days centered at the 2003 Halloween ionospheric storm (day 302–305). The accuracy of the estimated DCB is about 1 TECU. For near real-time processing it will be necessary to predict the DCB based on the previous days estimations, perhaps using smoothed estimates of the DCBs over several days, as indicated in **Figure 1**. The upper panel of **Figure 4** shows the absolute TEC as a function of time and elevation angle for all GPS satellites in view on Oct. 29, 2003 (the first day of the Halloween storm). For COSMIC there will be six satellites, each with two POD antennas, i.e, a total of twelve DCBs to solve for.

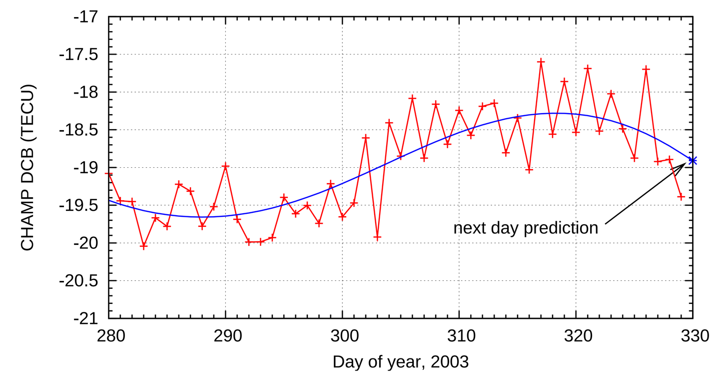

Figure 1: Estimated CHAMP POD antenna differential code bias (DCB) over 50 days in Oct/Nov, 2003 (red), and a least squares fit (blue smooth curve), upon which a next day prediction can be based.

Electron density from occultation data

The observations from the COSMIC GPS receivers will also be used to provide model-independent estimates of the electron density at the orbit altitudes, and the occultation data will be combined with GPS-derived Global Ionospheric Maps (GIMs) and/or TIP data to mitigate the effects of horizontal gradients when calculating the electron density profiles below the orbit altitudes.

At elevation angles close to zero, the orbit electron density, $N_\mathrm{e}(r_\mathrm{orb})$, is related to the occultation TEC below the LEO satellite orbit, $\Delta\mathrm{TEC}$, as a function of the ray path tangent altitude, r, as

$$\Delta\mathrm{TEC}(r) = 2N_\mathrm{e}(r_\mathrm{orb})\sqrt{2r_\mathrm{orb}(r_\mathrm{orb} - r)} .$$

This equation is a first order approximation; it can be shown that higher order terms on the right-hand-side depends on the satellite relative velocities, the electron density scale height, and the horizontal gradients.

Figure 2 shows a scatter plot comparing the electron density at the beginning of the occultations, derived via the equation above (using data from the CHAMP limb antenna), with the electron density measured by the Langmuir Probe on board CHAMP.

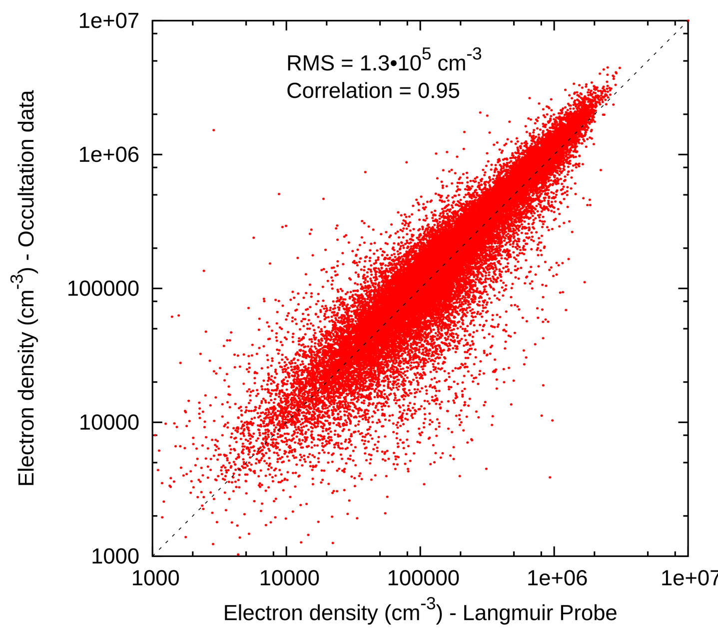

Figure 2: Comparison between more than 40000 samples of electron density from the CHAMP Langmuir Probe and the electron density at the orbit altitude as derived from the CHAMP occultation data.

For COSMIC, $\Delta\mathrm{TEC}$ will be obtained using the approach introduced by Schreiner et al. (1999), where the data collected at positive elevation angles are subtracted from the data collected at negative elevation angles. For the processing of CHAMP data, only the occultations where data collection starts very close to zero elevation angle are processed.

The middle panel of **Figure 4** shows the Langmuir Probe data during Oct. 29, and the GPS-derived orbit electron density at the beginning of the occultations on that day. Although both **Figure 2** and **Figure 4** show good agreement most of the time, there are still some large outliers which require improved quality control of the GPS occultation data. The GPS-derived orbit electron density is used as an upper boundary condition in the derivation of electron density profiles.

GIMs of vertical TEC are generated on a regular basis from a global network of ground-based GPS receivers (**Figure 3**). For near real-time processing, CDAAC will most likely implement a simple approach (Hernández-Pajares et al., 2000) using the vertical TEC from GIMs to mitigate the effects of horizontal gradients in the retrieval of electron density profiles. The profiles in the bottom panel of **Figure 4** were derived using the not always valid assumption of local spherical symmetry, presumable giving rise to large errors below the F-layer (e.g., the profile at 19:52 UT). The GIMs currently available from the Jet Propulsion Laboratory (JPL) have a temporal resolution of one hour and a spatial resolution of 2° by 2°. The six COSMIC satellites will provide a total of about 2500 electron density profiles per day.

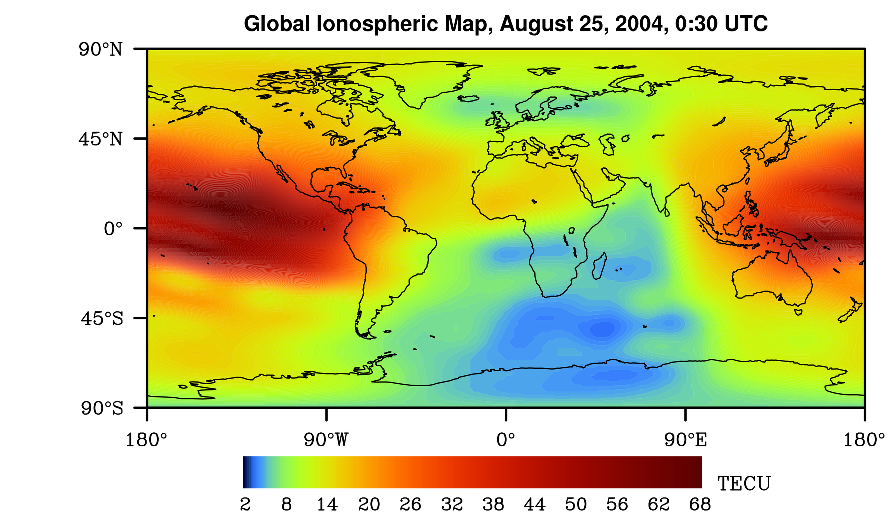

Figure 3: Example of Global Ionospheric Map; data by courtesy of JPL.

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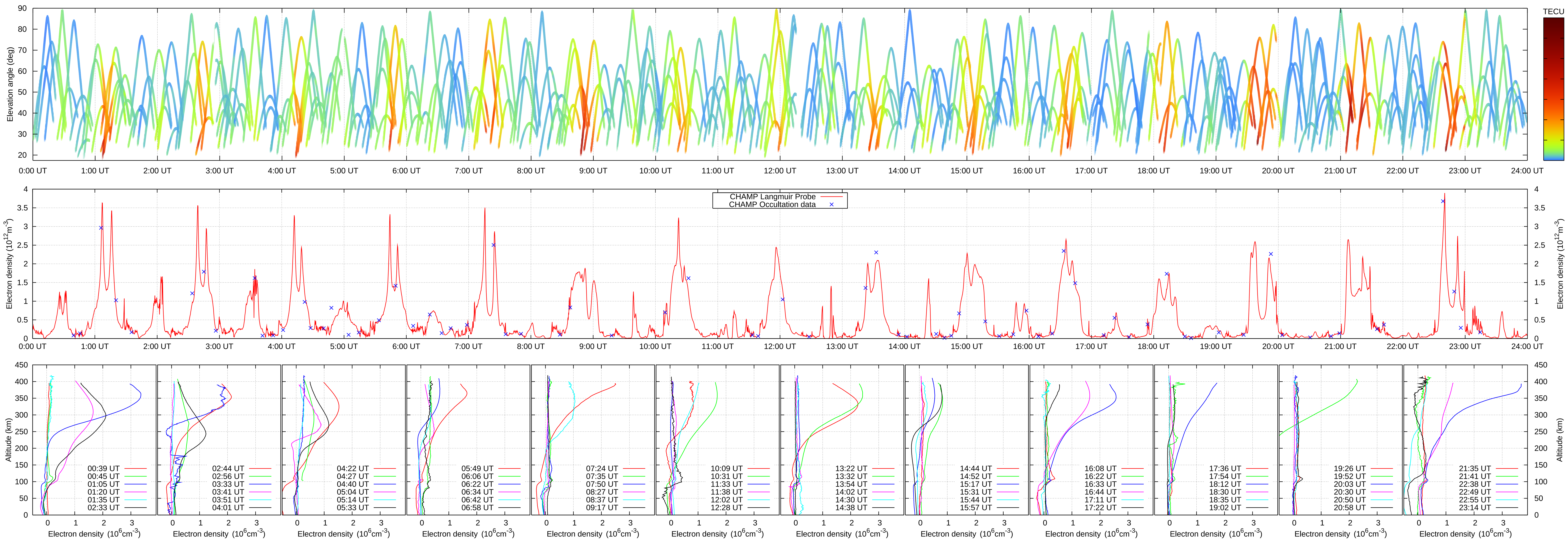

Figure 4: **Upper panel:** Absolute TEC as a function of time and elevation angle for all GPS satellites in view on Oct. 29, 2003. **Middle panel:** Electron density measured by the Langmuir Probe, and GPS-derived orbit electron density at the beginning of occultations. **Lower panel:** Derived electron density profiles using the orbit electron density as upper boundary condition.