A TOPSIDE IONOSPHERE/PLASMASPHERE MODEL FOR OPERATIONAL APPLICATIONS

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ABSTRACT

To retrieve electron density profiles from ionospheric GPS radio occultations measured onboard a Low Earth Orbiting (LEO) satellite whose altitude is close to the peak density height, a topside ionosphere/plasmaspere (TIP) model is needed for applying a model assisted retrieval technique. The actual TIP model currently used for operational data analysis of GPS radio occultation measurements onboard CHAMP is presented (RMS error of 1.0 MHz / 45.2 km for f0F2 / hmF2). Further improvements of the operationally used topside ionosphere model should enable more accurate retrieval results.

INTRODUCTION

As it has been shown by the GPS/MET instrument, flown on the Microlab-1 LEO satellite [1] GPS radio occultation technique in the ionosphere is a rather simple and relatively inexpensive tool for profiling the electron density of the entire ionosphere from satellite orbit heights down to the bottomside. No other profiling technique (bottomside/topside vertical sounding, incoherent scatter) unifies profiling through the entire ionosphere with global coverage.
LEO missions such as CHAMP [2] or SAC-C carrying a dual frequency GPS receiver onboard, offer a unique chance to improve our knowledge about the ionospheric behavior and to monitor the actual state of the ionosphere on a continuous basis.
The German CHAMP satellite was successfully launched by a COSMOS rocket from the Russian launch site Plesetsk on July 15, 2000. Besides accurate measurements of the gravity and magnetic field also radio occultation measurements of the atmosphere/ionosphere are carried out routinely by a space qualified GPS receiver especially developed by the Jet Propulsion Laboratory/USA.

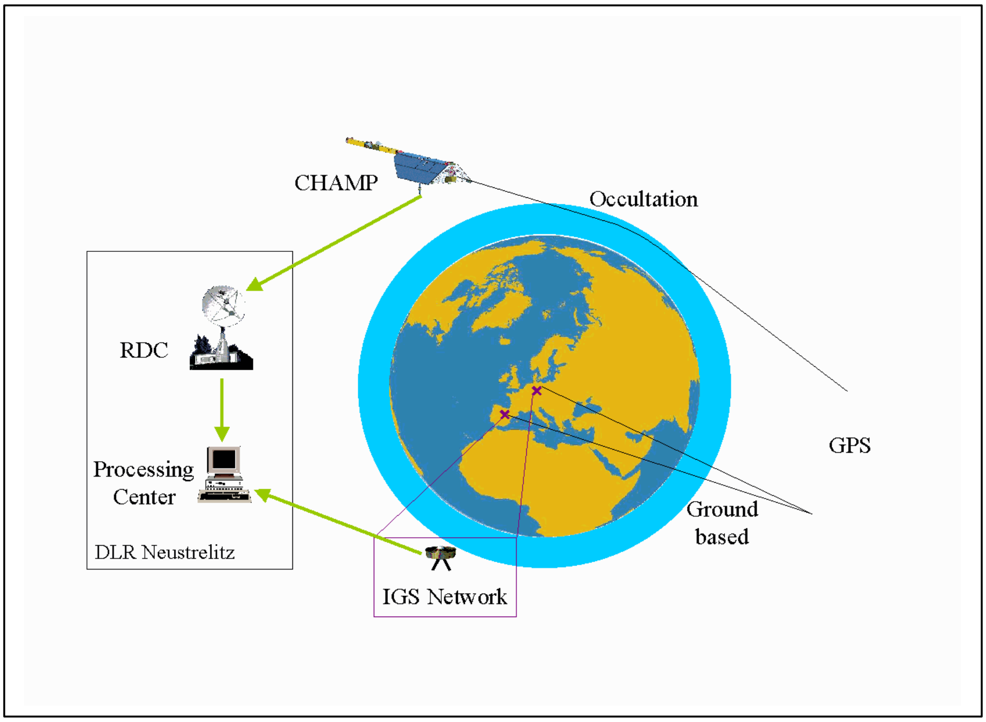

Fig. 1. Schematic view on ground and space based GPS measuring facilities used in DLR/IKN Neustrelitz.

DATA BASE

Whereas first neutral gas limb sounding measurements onboard CHAMP have been started on February 11, 2001 [3], the first ionospheric radio occultation measurements have been carried out onboard CHAMP two month later on 11 April (see http://www.kn.nz.dlr.de -> Spaceborne GPS)
The ionospheric radio occultation (IRO) technique has a large potential for measuring the vertical electron density structure of the ionosphere with high data coverage on global scale on a routine basis [1], [4].

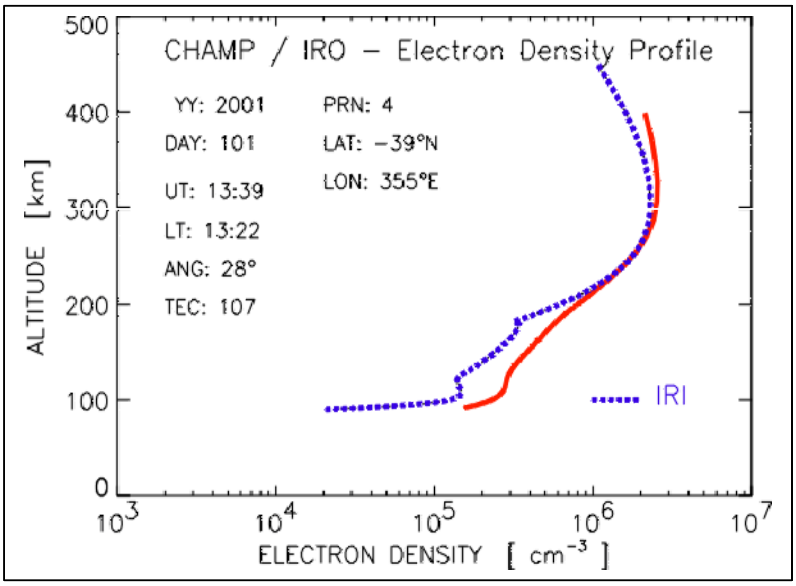

Fig. 2. One of the first electron density profiles retrieved from GPS radio occultation data measured onboard CHAMP on 11 April 2001 in comparison with a corresponding profile derived from IRI.

Since horizontal gradients may be large (e.g. during storms, in the crest region) we preferred to establish a tomographic approach that divides the ionosphere in different spherically shells. In contradiction to the classical Abel inversion that requires a spherically layered ionosphere, the tomographic approach allows an easy use of additional information obtained from ground based GPS or other ionospheric measurements.
Considering CHAMP, the dual frequency carrier phases of the GPS signals are used to compute the total electron content (TEC) along the 1 Hz sampled occultation ray paths for subsequent data inversion to retrieve vertical electron density profiles.
At orbit heights above 700 km (e.g. GPS/MET, SAC-C) the upper boundary condition, i.e. the TEC above the satellite orbit height can be assumed to be constant in a first approximation because it is relatively small. The situation changes substantially when considering the rather low orbit height of CHAMP ($h < 455$ km). So the retrieval algorithm has to take into account that the above lying ionosphere electron content may amount 50% or even more of the measured TEC signal used for inversion. Thus, for CHAMP the upper boundary condition needs a special consideration in particular due to the fact that the orbit height will reduce continuously from about 420 km at present down to 300 km at the end of the mission.
To overcome this problem an adaptive model assisted technique has been developed [5]. Here, as a first guess, the topside ionosphere electron density above the satellite orbit height is given by a parameterized topside ionosphere/plasmasphere model.
Applying this technique, CHAMP provides up to 150 globally distributed electron density profiles per day (cf. Fig. 2). Peak density and height agree with corresponding ionosonde parameters with standard deviations of 18% and 13%, respectively [5].

TOPSIDE IONOSPHERE /PLASMASPHERE MODEL

To improve the operational retrieval of vertical electron density profiles from CHAMP a suited topside ionosphere /plasmaphere (TIP) model of the spatial distribution of the electron density is needed.
Principally, the TIP model consists of an ionospheric electron density model (IM) and an plasmasphere model (PM). The electron density Ne(h) of the TIP model currently used so far can be described by the formula:

$$Ne(h) = NmF2 \exp(0.5(1 - z - \exp(-z))) + N_{P0} \exp(-h / H_P) \quad (1)$$

with $z = (h - hmF2) / H_{TS}$ (2)

h: height, NmF2 and hmF2: peak electron density and height, H_{TS} : topside scale height

N_{P0}, H_P : plasmasphere basis density and scale height

At the beginning of the occultation retrieval the free parameters NmF2, hmF2 and H_{TS} in (1) and (2) are adjusted by an iterative process. The plasma scale height H_P is fixed at a value of 10000 km. The iteration results in a rather 'smooth' transition from TIP electron densities to the first values computed from the IRO data. This procedure yields directly the scale height at the upper boundary of the retrieved electron density profile.
The latitudinal dependence of day-time scale heights obtained between 11 April and 12 August 2001 are plotted in Fig. 3.

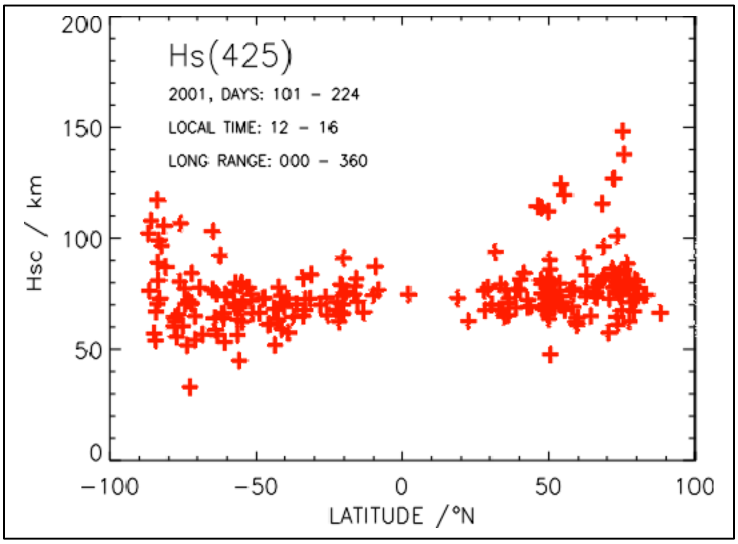

Fig. 3. Latitudinal distribution of the IRO derived plasma scale heights H_{TS} at 425 km height during day-times (10-15 LT) on the days 100 - 244 at all longitude zones.

It is worthwhile to note that the scale heights are apparently higher at the northern hemisphere where summer conditions exist.
In the new TIP model the value of the plasma scale height is modeled as a function of the geophysical conditions. The more adequate description of this crucial parameter shall provide a more accurate and reliable IRO retrieval for CHAMP measurements.

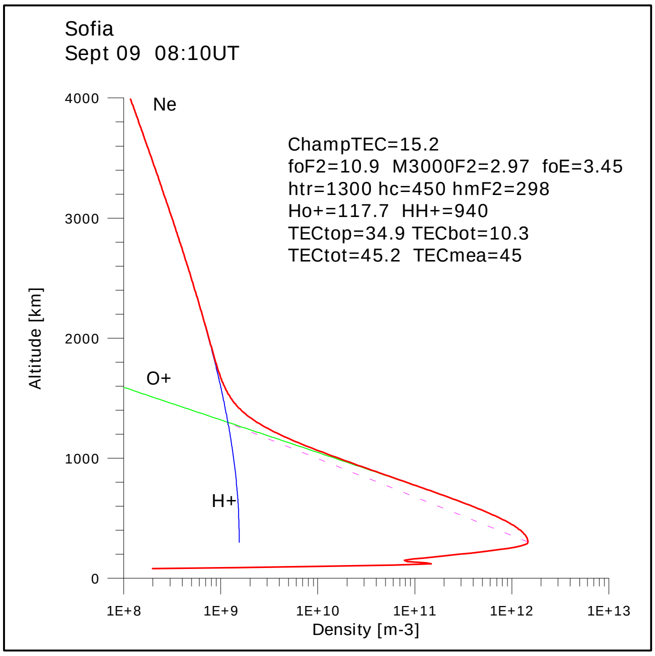

Fig. 4. Example for an improved TIP model for the 9 September 2000 at 08:10 UT over the Sofia vertical sounding station. The model is feeded by the ionosonde data and checked by independent GPS derived vertical TEC estimates over Sofia.

As an alternative to the simple Chapman layer for IM in (1) a composite global scale model, based on CCIR and URSI F2 layer peak model coefficients is considered. This model uses the CCIR foF2 and M(3000)F2 for estimating F2 peak density and height and the bottomside electron density profile through the Dudeney and Bradley empirical formula. These estimates are then used to reconstruct the vertical electron density profile above the CHAMP height.

The plasmasphere model (PM) shall include an empirical electron temperature model, based on Akebono plasmasphere electron temperature (Te) data. Principally, the PM includes two vertical scale heights: one for the O^+ dominated ionosphere above the CHAMP orbit height and another for the H^+ plasmasphere respectively. The two scale heights are coupled at the O^+- H^+ transition height, provided by a respective empirical model.

The model parameters are adjusted/checked independently by using 0.1 Hz sampled topside GPS measurements onboard CHAMP currently used for satellite positioning since the beginning of the mission [6].

Fig. 4 shows an example of a two-component TIP model under consideration to describe the ionospheric and plasmaspheric electron density. The model is feeded by the Sofia ionosonde NmF2 and hmF2 data. The height-integrated electron densities (TECbot, TECtop) may be compared with the vertical TEC derived from ground based GPS measurements as an independent check [7].

The effectiveness of the new TIP model to improve the retrieval results of IRO measurements is tested by its application to the operational ionospheric radio occultation retrieval of current CHAMP data.

SUMMARY AND CONCLUSIONS

To retrieve electron density profiles from ionospheric GPS radio occultations measured onboard a Low Earth Orbiting (LEO) satellite such as CHAMP whose altitude comes close to the peak density height, a topside ionosphere/plasmaspere model is needed. Initial retrieval results obtained by applying a model assisted retrieval technique are promising. Preliminary validation studies of the derived profiles with ionosonde data reveal a RMS error of 1.0 MHz and 45.2 km for f0F2 and hmF2, respectively.

Further improvements of the topside ionosphere model should enable more accurate retrieval results.

ACKNOWLEDGEMENTS

The authors are very grateful to all the colleagues from the international CHAMP team making available the IRO measurements. The work is supported by the NATO Collaborative Linkage Grant EST.CLG.977103.

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