About the Potential of GPS Radio Occultation Measurements for Exploring the Ionosphere

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Summary. The GPS radio occultation technique onboard LEO satellites such as CHAMP is a rather simple and relatively inexpensive tool for profiling the electron density of the ionosphere from satellite orbit heights down to the bottomside. The paper addresses the capabilities of the ionospheric radio occultation (IRO) technique for monitoring the global ionosphere on a routine basis to derive value added data products and to study particular ionospheric processes such as perturbations. The model assisted retrieval technique, operational data processing and the validation of vertical electron density profiles are discussed. These profiles may not only be used to validate unknown models, they provide also a good data basis for developing new models of ionospheric key parameters such as the critical frequency f0F2, the peak height hmF2 and the scale height H. Such models are helpful to improve retrieval procedures and tomographic reconstruction techniques. Due to the operational data processing capabilities the data products may contribute to space weather monitoring of the ionosphere.

Key words: Ionosphere, GPS, radio occultation, electron density, total electron content

1 Introduction

Low Earth Orbiting (LEO) satellites are capable of monitoring the ionospheric ionization on a global scale. This has been demonstrated already by several satellites such as Microlab-1 with the GPS/MET experiment (e.g. Hajj and Romans, 1998, Schreiner et al., 1999), Oerstedt , CHAMP (Jakowski et al., 2002) or SAC-C.

In this paper we review the capabilities of Ionospheric Radio Occultation (IRO) measurements onboard GPS equipped LEO satellites for probing the ionosphere. This is illustrated by presenting results obtained from CHAMP (Reigber et al., 2000) data analysis that has provided electron density profiles since 11 April 2001.

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2 Observations and Data Processing

After receiving the CHAMP GPS data in the DLR Remote Sensing Data Center Neustrelitz they are immediately processed by an operational data processing system (Wehrenpfennig et al., 2001). For retrieving the vertical electron density profiles from IRO measurements a model assisted technique has been applied (Jakowski et al, 2002). According to the requirements of potential users in science and space weather applications the deduced electron density profiles are available within 3 hours after data dump. Subsequently, the computed ionospheric radio occultation (IRO) data products are submitted to the international science community via the Information and Science Data Center (ISDC) of GFZ Potsdam.

From about 200 IRO measurements onboard CHAMP about 150 electron density profiles (EDPs) are successfully retrieved per day (Fig. 1). More than 80000 profiles have been collected so far, forming a powerful data base for more detailed studies. In parallel with first studies, validation work has to be continued to gain more detailed knowledge on the accuracy and reliability of IRO data (Jakowski et al., this issue).

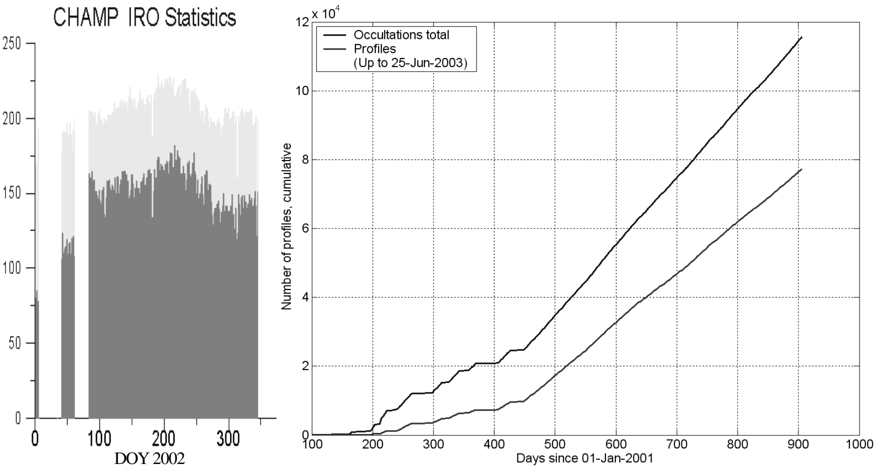

Fig. 1. Left: IRO retrieval statistics showing the number of observations (gray) and successful EDP retrievals (dark). Right: Cumulative number of observations and EDP's retrieved so far

3 Global Monitoring of Ionospheric Key Parameters

If a LEO satellite has a near polar orbit, all parameters may be derived on a global scale. This is a big advantage compared with other techniques that provide only local (ionosondes) or regional (incoherent scatter) information of the vertical electron density structure.

Typical key parameters of the ionosphere are the peak electron density NmF2 and the corresponding height hmF2. The peak density NmF2 is correlated with the frequently measured critical frequency f0F2 by the relation NmF2 = 0.0124 x $(f0F2)^2$ in SI units.

Fig. 2 clearly indicates the strong latitudinal dependence of the ionospheric ionization and the so-called seasonal anomaly in the peak density as well as in the ionospheric total electron content (ITEC). ITEC is the integrated electron density profile calculated up to 1000 km height taking into account that the electron density values above the CHAMP orbit height contribute via the adjusted model used in the retrieval technique. Whereas seasons were separated in Fig. 2, local time and longitude dependencies are not considered.

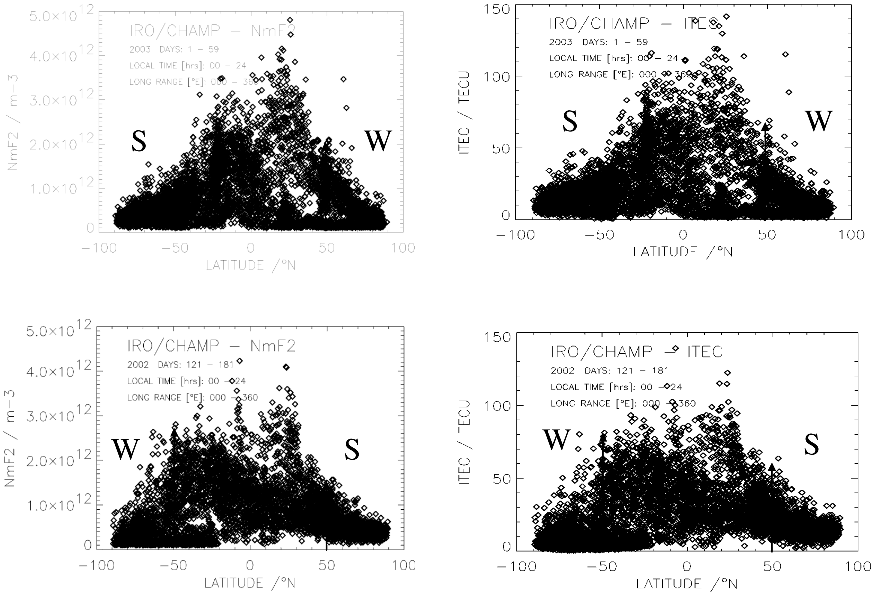

Fig. 2. Latitudinal dependence of the ionospheric ionization characterized by the electron peak density NmF2 and the ionospheric total electron content ITEC at summer and winter seasons as well. Local time and longitudinal dependencies are ignored.

The seasonal anomaly indicated here at 50° latitude is well pronounced in both the critical frequency f0F2 and the ionospheric electron content. It is interesting that, independently from season, the northern crest is much more pronounced than the southern one. This observation needs further investigation for possible local time and longitude dependencies.

The knowledge of the vertical electron density distribution enables us to extract the plasma scale height Hs that describes the shape of the electron density profile as a function of plasma temperature at diffusive equilibrium conditions.

To get a first order estimation of the plasma scale height, we extracted the scale height at 425 km height being aware that a certain influence of the adjusted topside ionospheric model still exists. More accurate estimations of the scale height will be obtained at a later stage after more comprehensive validation. Nevertheless, these preliminary estimations will help us to improve the retrieval process (Stankov and Jakowski, this issue). The scale height Hs(425) is plotted in Fig. 3 (upper panel) in comparison with the equivalent slab thickness τ_b = TEC(hmF2)/NmF2 of the bottom side electron density profile (lower panel) again for summer and winter seasons. What is apparently seen is a slight increase of the scale height and the slab thickness towards the summer hemisphere. This fact can easily be explained by enhanced plasma temperatures due to higher solar energy input at the summer hemisphere. The similar behaviour of the bottomside slab thickness τ_b and the topside scale height is probably the reason why it is possible to extrapolate bottomside scale height to the topside for estimating the electron density profile above the F2 layer height (e.g. Belehaki and Tsagouri, 2002).

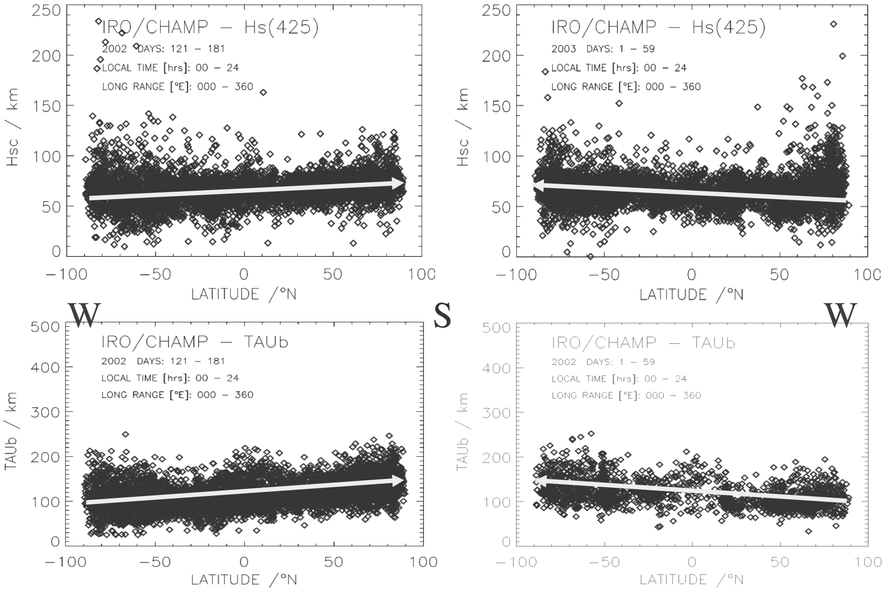

Fig. 3. Latitudinal dependence of profile shape parameters such as the ionospheric scale height at 425 km height Hs(425) and the equivalent slab thickness τ_b of the bottomside ionosphere. Local time and longitudinal dependencies are ignored.

4 Ionospheric Perturbations

Ionospheric perturbations are far from being understood in detail. IRO measurements are able to provide valuable information on the vertical distribution of ionization perturbations driven by highly dynamically forces such as neutral winds and electric fields. The left panel in Fig. 4 indicates pronounced wavelike structures in the IRO TEC data. Because the retrieval algorithm greatly smoothes out the structures, we prefer studying these phenomena by analyzing the TEC data derived from differential GPS carrier phases. The right panel in Fig 4 shows the global distribution of wavelike structures as shown in the left panel. The strength of these structures superposed on the basic TEC providing the EDP after retrieval is evaluated by an arbitrary scale indicating high dynamics at high scale values. Considering the observations during northern summer (May–July 2002), we find a strong enhancement at southern high latitudes i.e. during winter. In addition to this, enhanced TID activity is also observed close to the geomagnetic equator as expected. The pronounced TID activity in high latitude winter indicates eventually a tracing of atmospheric gravity waves (AGW's) coming from lower atmosphere layers.

Lower temperatures in winter may modify the atmospheric filter function in such a way that AGW's may penetrate more favorable than under summer conditions.

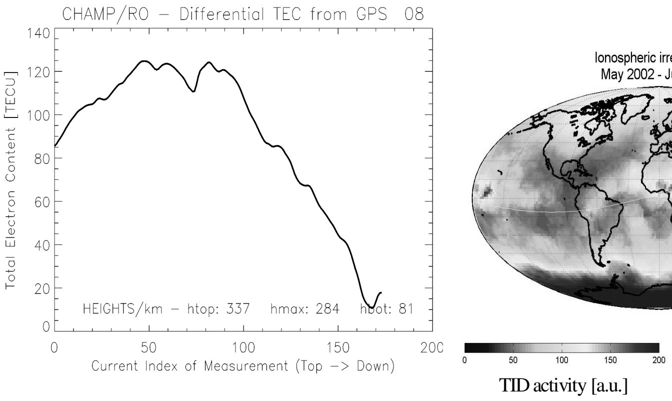

Fig. 4. Left panel: Relative TEC data (uncalibrated) as observed during an individual occultation event (here with GPS satellite PRN 8). Right panel: Map of the global TID distribution during Northern Summer May- July 2002

5 Development and test of models

The continuously growing number of observation data is an excellent basis for evaluating and developing ionospheric models (Jakowski et al., this issue). By averaging electron density profiles under certain geophysical conditions such as season, local time, latitude or longitude, one gets information about the ionospheric climatic behaviour described in models. To support such activities, the computation of value added products is foreseen. Fig. 5 gives an impression of such a product that includes averaged electron density profiles as a function of geographic latitude at 15°E (coincidence radius 10°). The upper panel, showing daytime conditions, indicates a strong latitudinal dependence not only in the ionization as expected from Fig. 2, but also in the profile shape. Getting global information on vertical EDPs is an advantage of the IRO method. If validation is good, such studies may indeed lead to new findings in the ionospheric physics. These preliminary results shall not be overestimated but what can be seen clearly, is a strong geographical asymmetry of the profile shape at the 15° E meridian indicating a significant northward shift of the geomagnetic equator and the corresponding low latitude crest.

The global development of the vertical redistribution of storm-time ionospheric plasma may be studied in a new more effective way. Present-day global TEC mapping techniques (e.g. Jakowski, 1996) are only able to deliver the horizontal ionization distribution and its dynamic during storms. Having information from both sources, the mechanism of ionospheric storms can be explored much more effectively. Further improvement is possible, if ground based vertical and space based horizontal directed TEC measurements from a common data pool.

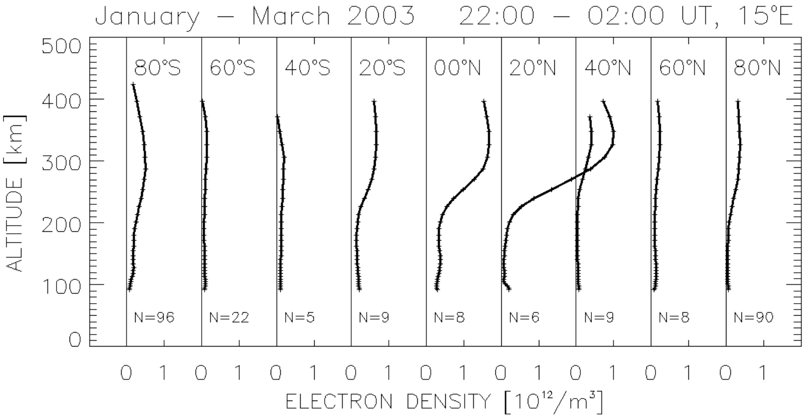

Fig. 5. Averaged EDPs obtained from January–March 2003 along the 15°E meridian choosing a coincidence radius of 10 degrees. The upper panel shows day-time results whereas the lower panel shows night-time results.

6 Conclusions

It has been shown that the reception of GNSS signals onboard LEO satellites provides a powerful tool for sounding the vertical structure of the ionosphere on global scale (on CHAMP about 150 EDPs per satellite and day).

Ionospheric key parameters such as NmF2 (f0F2), hmF2 and ITEC may easily be monitored on global scale. The same is valid for shape parameter scale height and slab thickness.

Although validation work is not yet finished, it can be concluded that CHAMP IRO data clearly indicate the winter anomaly effect of the F2 layer at high solar activity conditions.

Since the vertical structure of ionospheric perturbations (TIDs) may be detected and analysed there is a good potential for new findings in understanding perturbation mechanisms.

Value added data products contribute to developing and testing ionospheric models.

It is evident that IRO data provide valuable information for vertical tomographic reconstructions and models of the ionosphere

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