Improving the determination of electron density profiles combining ground and LEO GPS data

Miquel García-Fernández, Manuel Hernández-Pajares, J. Miguel Juan, Jaume Sanz, Raul Orús

group of Astronomy and Geomatics / Universitat Politècnica de Catalunya
Applied Mathematics Department IV, module C3, Campus Nord
c/Jordi Girona 1-3, s/n
08034 Barcelona, Spain
Email: mgarcia@mat.upc.es; manuel@mat.upc.es

ABSTRACT

In this paper we study the performance of the technique that, using both ground and Low Earth Orbiting GPS data, improves the accuracy of the electron density profile retrieval. This algorithm also presents the advantage of a minimum computation load, allowing its potential application in real-time. Some key points of this strategy are: firstly, to compute a Vertical TEC using either a model or real data, and secondly, this TEC is used to take into account the horizontal gradients in a modified Abel inversion technique for ionospheric sounding, that overcomes the traditional spherical symmetry assumption. The accuracies of both TEC and electron density profile determinations are studied by comparing them with another types of ionospheric data, coming from ionosondes in regions with high electron density gradients (geomagnetic equator), including data collected under geomagnetic activity.

INTRODUCTION

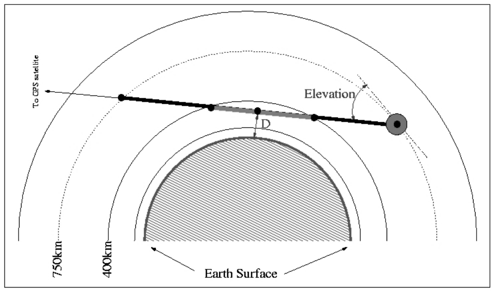
As it is known, GPS Radio Occultations obtained from Low Earth Orbiters are widely used to obtain vertical profiles of Ionospheric electron density by means of Abel inversion techniques [1]. The traditional approach to these techniques is to consider spherical symmetry to invert occultations. Nevertheless an occultation may cover wide areas in which this assumption may be wrong. An overcoming of this approach is necessary, specially when Vertical Total Electron Content (VTEC) variation along each ray is not linear.

Reference [2] proposed a method to overcome the traditional assumption of spherical symmetry stating that a vertical profile could be expressed as the product between a VTEC and a normalized shape function. In this context it was shown how the results compared with the traditional approach were improved in mid-latitudes and quiet geomagnetic conditions. This paper extends the study of the performance of this method to geographic locations at lower latitudes, where the effect of VTEC gradients are significantly greater, affected by the Equatorial Anomaly.

To shown some examples of performance in the scenario indicated above, this paper is organized as follows: in section *separability hypothesis* it will be briefly introduced the essence of the suggested approach, in section *Examples of performance* there are included several subsections where particular cases in non-quiet conditions will be discussed. The paper ends with a section containing the *Conclusions and Outlook*.

SEPARABILITY HYPOTHESIS

The assumption of spherical symmetry stands that the electron density profiles are equal regardless the geographical location, but in general one cannot expect this behavior. An occultation may cover wide areas (see Fig. 1), moreover part of the occultation may occur near (or in) the Equatorial Anomaly or during high geomagnetic activity (circumstances where the VTEC behavior is not linear [3]). To take into account these effects the inversion algorithm is given information about the distribution of the VTEC. In fact, the key point of this VTEC information is to provide data about its variation rather than the value of VTEC itself. The clue for the improvement with respect spherical symmetry relies in the fact that the VTEC is not considered to be constant nor linear (which is not realistic under the scenarios indicated above), a certain geographical dependency is taken into account (this dependency can be obtained from a model or real data). In the approach of this paper, to obtain information about the VTEC variation, the IRI model has been considered.



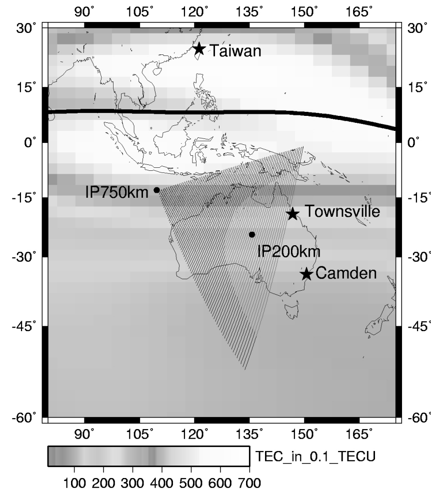


Fig. 1 (Left) plot shows a single ray of an occultation indicating the portion of ray under the GPS/MET orbit and under 400km. Distance "D" is the Impact parameter or Tangent point. (Right) plot shows the coverage of an occultation (Occulted GPS PRN16 with GPS/MET at 4hUT) near the Equatorial Anomaly and Australia (at 13hLT), the occultation shows the portion of rays under 750km and 400km

To diminish the effect of the electron density above the GPS/MET orbit and the instrumental biases, the two uppermost rays of the occultations are used to compute this contribution and the uppermost value of the normalized profile. After these values are obtained it is assumed that the former value is constant for all occultation and it is subtracted to the STEC observation.

Once the profiles are inverted it is convenient to consider a procedure to evaluate the validity of the result obtained. To do this in quick way in this paper it has been considered the comparison of the profile peak of electron density with the one provided by an Ionosonde. The reason to consider an Ionosonde is because this is a source of data external to the algorithm, thus the value of the NmF2 obtained with the two methods are independent between them. Moreover, since the profile is computed from the ray with highest Tangent Point [5] downwards, the accumulated error increases in this direction. Thus the deviation from 0 of the electron density value at the lower boundary of the profile (approximately 100km) gives an additional criteria on the goodness of the computed profile.

EXAMPLES OF PERFOMANCE

In [2] there was shown the performance of separability hypothesis in mid-latitudes and quiet geomagnetic conditions through two kinds of comparison, considering synthetic data obtained from IRI model and real data. The present work uses the same basis to evaluate the examples of retrieved occultations obtained in lower latitudes. Thus, these examples are organized considering synthetic data constructed from IRI model and real data. The days selected for these tests correspond to the data set of days 1995 October 18th and 19th. The DST parameter variation for both days can be seen in Fig.2.

IRI Simulation

Differences between spherical symmetry and separability in the Abel inversion can be seen through a simulation with IRI. The Slant TEC observed by the GPS/MET has been computed with IRI and it has been applied Abel inversion techniques on this synthesized data. It has been considered as an example the same real occultation depicted in the map of Fig.1 to perform this test. The resulting profiles can be compared with vertical profiles obtained with IRI.

The key point is to see that assuming separability one obtains more realistic results than those obtained with spherical symmetry. Fig.3 shows the example of occultation retrieved with IRI simulated data. It has been plotted two IRI vertical profiles of electron density, one at the location where the tangent point is 750km and the other where the tangent point is near to 200km (near the electron density peak occurrence place, see Fig.1 to see the locations of these points). Since separability hypothesis algorithm provides normalized shape function besides the VTEC for each impact parameter, this allows exporting this profile to places of the nearby locations where the occultation has taken place simply by

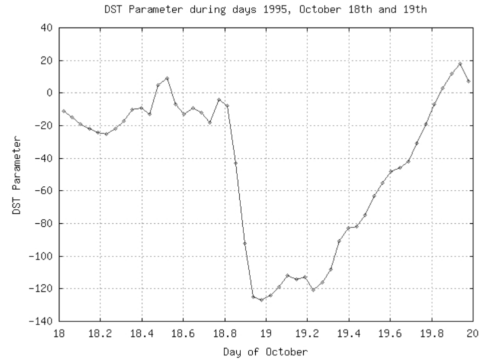


Fig. 2 DST Parameter for days 1995 October 18th and 19th

multiplying by the corresponding VTEC value. Note that both profiles of IRI in Fig.3 could be reproduced with the profile obtained with separability assumption simply by multiplying by the VTEC value at the corresponding locations of the IRI vertical profiles. It has to be mentioned, nevertheless, that doing this there could be a slight mismodelling of the hmF2 since there has not been included any specific model for it.

In this scenario there is a significant variation in the density profiles as it can be seen in Fig.3, so spherical symmetry is not adequate to retrieve the occultation. It can be seen that the retrieved profile with separability matches closely the vertical IRI profile where the impact parameter is 200km. This matching is an indicator that due to the fact that adequate VTEC variation values (in this case taken from IRI model) are considered to invert the occultation, the error of mismodelling is reduced. On the other hand spherical symmetry assumes no VTEC variations, giving a result between the two IRI vertical profiles.

Looking at the value of electron density near 100km (lower Ionosphere boundary) one can see that the value is lower (in fact closer to IRI as well) using separability. This indicates that the error computed with this method is lower than assuming spherical symmetry, following the explanation of the previous section.

Real Data

This section deals with the performance of the separability approach in disturbed conditions (area near Equatorial Anomaly, high geomagnetic conditions). Fig.4 shows several examples comparing this approach with the traditional spherical symmetry assumption and the corresponding NmF2 value given by Ionosonde. In regions where VTEC gradients are small, the results obtained with the two methods are very similar (Fig.4, upper plots), but as these gradients evolve in a non-linear behavior (specially in regions close to the equatorial anomaly, disturbed geomagnetic

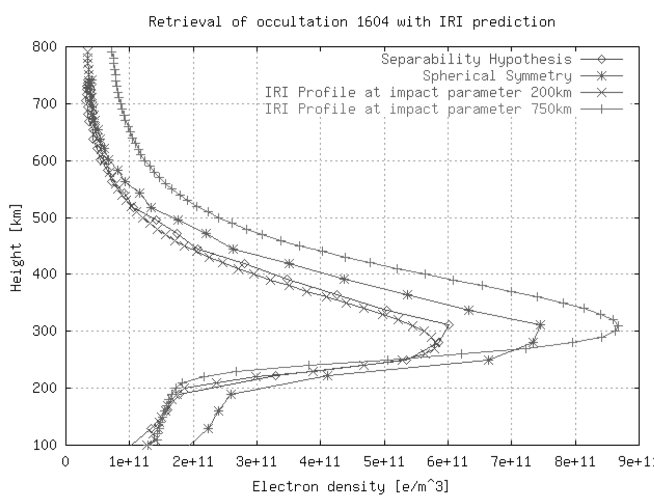


Fig. 3 Comparison between spherical symmetry and separability hypothesis with simulated IRI data.

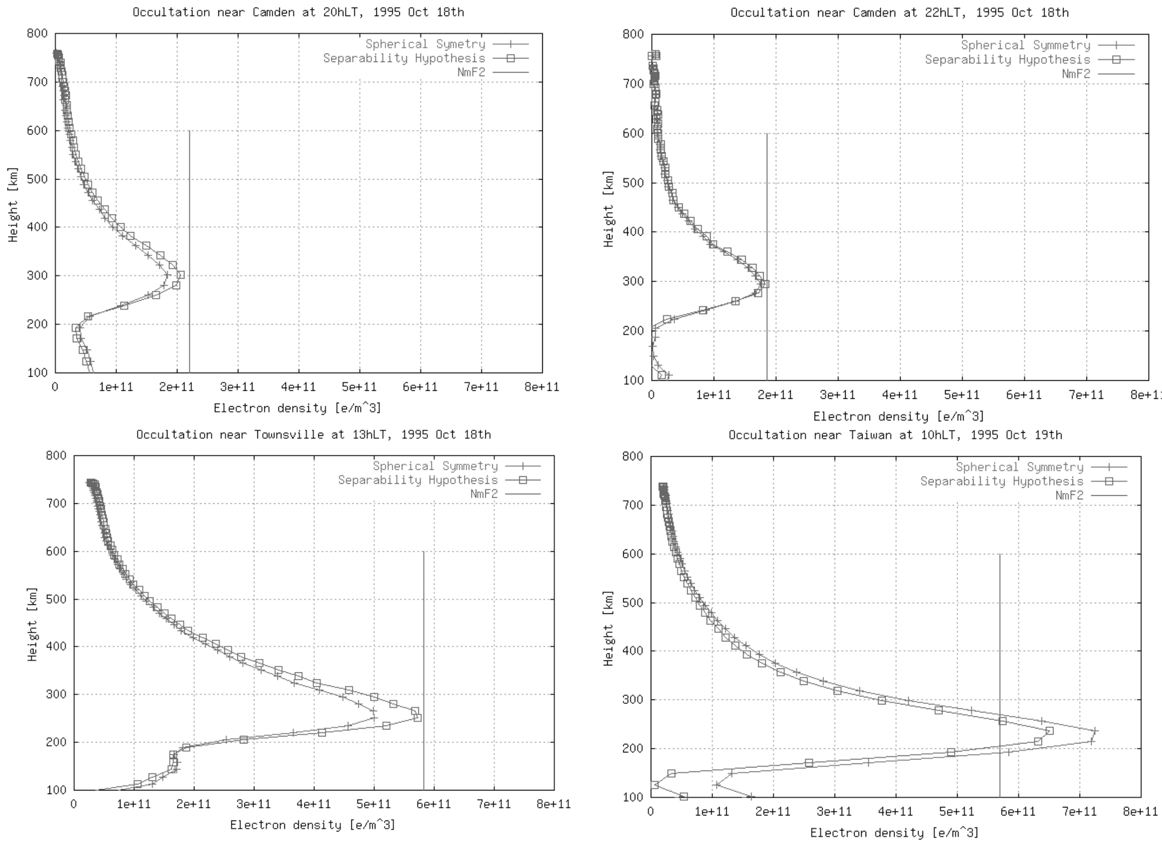


Fig. 4 Several examples of profile retrieval using real data. Upper plots correspond to occultations near Camden while lower plots are profiles obtained from occultations taken place in tougher scenarios.

conditions) the two approaches give different results. The lower plots of Fig.3 are specially relevant, the lower-left one shows the difference of performance for an occultation taking place near the equatorial anomaly at noon (in local time), it can be seen how spherical symmetry gives poorer results compared with separability approach. In the case of lower right, it is showed an example of poorer performance of the separability approach, in this case the scenario is even tougher than the one described before. This shows an example of retrieval of an occultation taking place near Taiwan (in the geomagnetic anomaly) during the 13h local time of 1995 October 19th (note in the DST parameter depicted in Fig.2 the occurrence of a Ionosopheric storm). The error of the electron density peak estimation for the separability hypothesis result is 14% while in the case of spherical symmetry the error is of 26%.

In all cases it can be seen that the profiles obtained with separability assumption offer better performance because of the agreement in the f_0F2 estimation and the lower values of electron density in the lower boundaries.

CONCLUSIONS AND OUTLOOK

This work is an extension of [2] where there were presented successful statistics of occultation at mid-latitudes. This paper shows different examples in which an overcoming of spherical symmetry assumption by means of separability hypothesis results in more realistic profiles of electron density in areas near the equatorial anomaly. It has been shown that this improvement can be obtained with data coming from models, but an additional improvement could be expected if real VTEC data is used (for instance, data coming from the Global Ionospheric maps delivered by IGS in IONEX format [4]).

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