EXPERIMENTAL EVALUATION OF INVERSION METHODS APPLIED TO IONOSPHERIC RADIO OCCULTATION OBSERVATIONS

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ABSTRACT

The new technique of radio-occultation can be used to study the Earth's ionosphere. In this technique dual-frequency radio signals propagating at low elevation angles provide information on the total electron content (TEC). The first such experiment was the GPS/MET mission, in which a GPS receiver on board a low-Earth-orbit satellite collected such data during selected periods between 1995-1997.

In this paper ionospheric radio occultations are validated using vertical profiles of electron concentration from inverted ionograms, obtained from ionosondes sounding in the vicinity of the occultation. The electron concentration profiles from radio occultation were obtained by analysis based on the Abel transform. Results indicate that the Abel transform works well in the mid-latitudes during the daytime, but is less accurate during the night-time.

INTRODUCTION

Radio occultation is a new technique that can be used to study the ionosphere, offering potentially global and continuous measurements. The Global Positioning System (GPS) to Low Earth Orbit (LEO) satellite paths essentially make long, near-horizontal measurements of relative total electron content (TEC). These measurements are not simple to interpret, since the satellite transmission paths map out a complicated and continuously changing measurement geometry. Nevertheless, a strong advantage of this system is that it provides measurements over the oceans and into remote polar caps, thus enabling the ionosphere to be studied on a truly global-scale. Current missions include OERSTED, SAC-C and CHAMP. Several other such missions are planned over the next decade.

The radio occultation technique using GPS was tested for the first time between 1995 and early 1997 with the GPS/MET mission [1; 2]. Tens of thousands of occultations were collected during its operation, many of which have been used to study the Earth's ionosphere. The Abel transform is the conventional method to analyse the tropospheric occultations and it was natural to adopt this approach for the ionospheric studies. It allows the vertical profile of electron concentration to be obtained, nominally at a single location between the two satellites. However, this approach is reliant on the assumption of spherical symmetry, limiting the vertical resolution that can be obtained to well above the Fresnel limit. The resulting profile is therefore some average of the ionosphere traversed by the occulting paths. In this paper Abel-transform profiles of electron concentration from radio occultation data are evaluated using independent observations made by ionosondes

Another possible approach to utilising radio occultations is to use a four-dimensional inversion. In conventional ionospheric tomography, the measurements (satellite-to-ground) are geometrically biased and consequently as early as 1994 Hajj et al. [3] suggested using radio occultations in a tomographic framework to provide the so-called 'missing horizontal rays' and improve the vertical resolution. The simultaneous inversion of both satellite-to-ground and satellite-to-satellite GPS data in a single algorithm provides a greatly improved geometry in comparison to that found when using either data set independently. The merits of the different inversions are discussed.

METHOD

Prime GPS/MET data were analysed by colleagues at JPL, USA using the Abel transform. A nominal occultation latitude and longitude of the occultation was assigned from the 300 km altitude intersections. Ionosondes within a horizontal radius of 600 km of the nominal occultation point were identified and all ionograms recorded within 1 hour UT were inverted using the POLAN technique (WDC, RAL, UK). These inverted ionograms have been used to assess the vertical ionospheric electron-concentration profiles.

RESULTS

Due to the page limitations the results are described very briefly, but will be presented more extensively in a future publication. Figures 1-12 show comparisons between inverted ionograms and GPS/MET profiles of electron concentration. The GPS/MET profiles are shown in red. Fig. 1 shows the GPS/MET profile at 61.3° N, -152.2° E at 1655 UT and that from the College ionosonde at 64.9° N, -147.5° E at 1700 UT on 29 June 1995. The profile shapes show good agreement between the two measurements for this summertime morning (LT) ionosphere. Fig. 2 shows a less successful comparison for the bottomside gradients during the nighttime over the UK. Strong spatial/temporal electron-density gradients are present, evidenced by the decrease in electron density in the consecutive ionograms. Fig. 3 is of note for the inflection in both the inverted ionograms and the occultations between 100 and 160 km, probably caused by some impact-ionisation auroral E. Fig. 4 shows an F1 layer in the GPS/MET data that has been interpreted by the ionogram inversion as an F2 layer. Fig. 5 is for a summer daytime ionosphere with very little temporal gradients present; a really excellent agreement can be seen in the E, F1 and F2 layers. In contrast, Fig. 6 is a similar location but a nighttime comparison and shows poor agreement on the bottomside. Fig. 7 shows a clear E, F1 and F2 layer in both the occultation and ionograms. A problem with the ionogram inversion can be seen here with the introduction of an artificial F1/F2 valley. Nevertheless, the comparison is generally good, although the GPS/MET ends on a positive density of around 0.5 at below 100 km, whereas ideally the inversion should finish close to zero at these altitudes. Figures 8-11 show reasonable daytime comparisons. Figure 12 demonstrates the possibility for the Abel inversion to go negative, a clear signature of a problem with that inversion since it is physically impossible.

DISCUSSION AND CONCLUSIONS

A detailed validation has been made of the bottomside ionospheric electron density derived from radio-occultation measurements. For the limited cases that have been investigated here, the Abel inversion technique appears to be valid for daytime ionospheres. In particular, features such as the E layer (including auroral E), the F1 and F2 layers are easily recognised. The Abel transform (for GPS/MET radio occultation) seems to be a reasonable approach to derive an averaged vertical profile from the occultation data. A simple test to check its validity can be done by noting whether the inversion has produced negative densities (since this is physically impossible) and that it is close to zero density below 100 km. One significant advantage of the occultation observations is the potential to view the E-F1 and F1-F2 valley regions. It also seems to be reliable away from ionospheric structure.

The study has also revealed some interesting limitation of the ionosonde inversions. In one case the presence of the F1 layer caused an incorrect inversion of the ionosonde data, where it was interpreted as an F2 layer. Another problem for ionogram inversion is defining the depth of the valley region between the E and F layers.

Recent research with the new CHAMP satellite has resulted in more detailed validations of the occultation inversion, by taking into account horizontal gradients. This is particularly of interest at high-latitudes where gradients are stronger and the trough may invalidate assumptions of spherical symmetry. It is also important in the equatorial regions dominated by the anomaly, where the peak height and density change rapidly. Special scanning programs using incoherent scatter radar are planned to make a more definitive case-study.

The long near-horizontal paths through the ionosphere of the radio occultation experiments lend themselves toward tomographic approaches [3; 4]. The combination of ground-based GPS data with radio occultation (such as CHAMP) could overcome some of the limitations of each technique and allow the distribution of free electron concentration to be imaged more accurately.

ACKNOWLEDGMENTS

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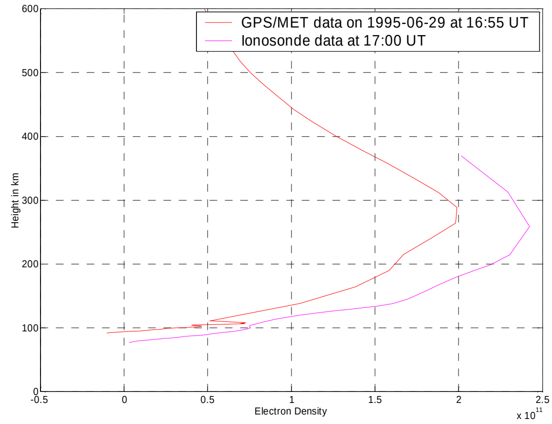

Fig 1. GPS/MET (61.3° N, -152.2° E) (red) and College ionsonde (64.9° N, -147.5° E) profiles at 1700 UT (magenta) for 29 June 1995.

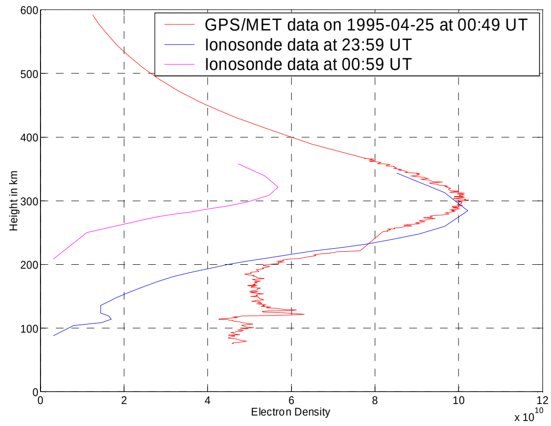

Fig 2. GPS/MET (52.8° N, -3.8° E) (red) and Chilton ionsonde (51.6° N, -1.3° E) profiles at 2359 UT (blue) and 0059 UT (magenta) for 25 April 1995.

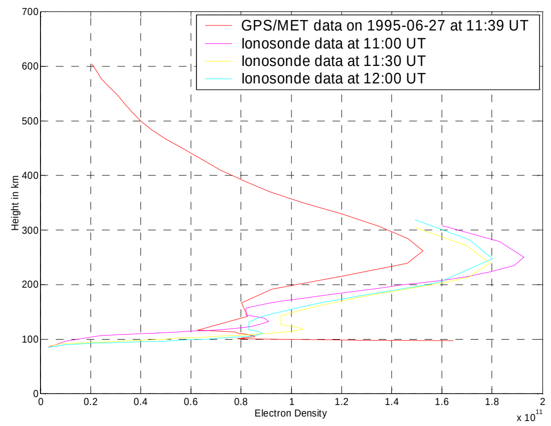

Fig 3. GPS/MET (68.9° N, -151.2° E) (red) and College ionsonde (64.9° N, -147.5° E) profiles at 1100 UT (blue), 1130 UT (yellow) and 1200 UT (cyan) for 27 June 1995.

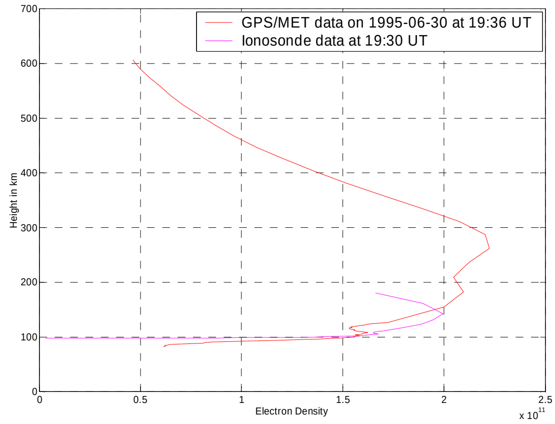

Fig 4. GPS/MET (59.8° N, -213.0° E) (red) and College ionsonde (64.9° N, -147.5° E) profiles at 1930 UT (magenta) for 30 April 1995.

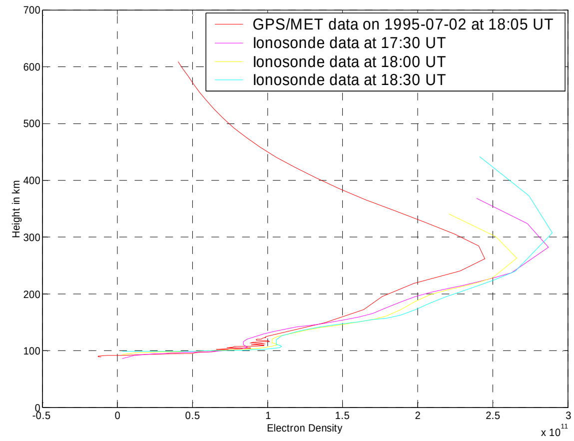

Fig 5. GPS/MET (63.3° N, -147.0° E) (red) and College ionsonde (64.9° N, -147.5° E) profiles at 1730 UT (magenta), 1800 UT (yellow) and 1830 UT (cyan) for 02 July 1995.

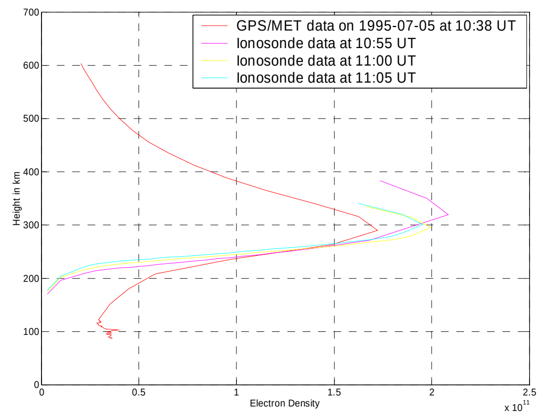

Fig 6. GPS/MET (59.8° N, -150.1° E) (red) and College ionsonde (64.9° N, -147.5° E) profiles at 1055 UT (magenta), 1100 UT (yellow) and 1105 UT (cyan) for 05 July 1995.

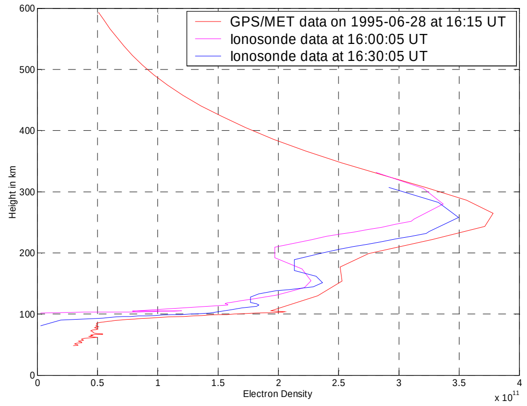

Fig 7. GPS/MET (28.4° N, -82.9° E) (red) and Eglin AFB ionsonde (30.4° N, -86.6° E) profiles at 1600 UT (magenta) and 1630 UT (blue) for 28 June 1995.

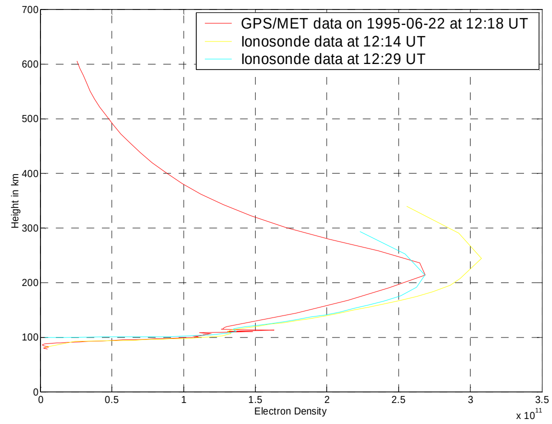

Fig 8. GPS/MET (56.9° N, -10.2° E) (red) and Lerwick ionsonde (60.1N, -1.18E) profiles at 1214 UT (yellow) and 1229 UT (cyan) for 22 June 1995.

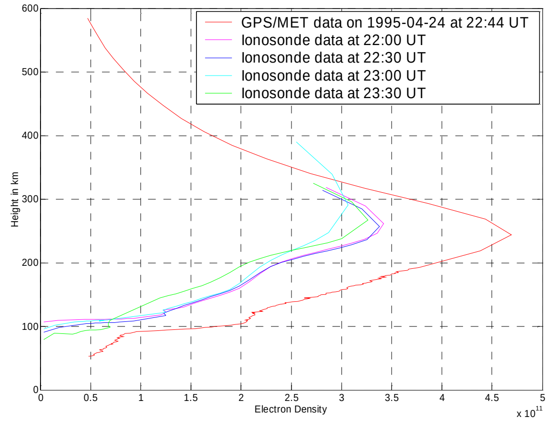

Fig 9. GPS/MET (33.1° N, -120.7° E) (red) and Point Arguello ionsonde (34.7° N, -120.3° E) profiles at 2200 UT (magenta), 2230 UT (blue), 2300 UT (cyan) and 2330 UT (green) for 24 April 1995.

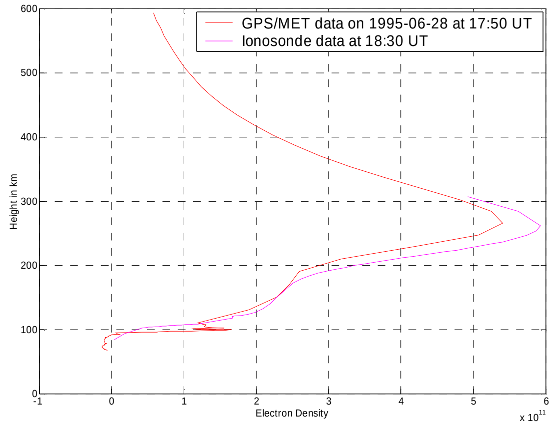

Fig 10. GPS/MET (38.9° N, -121.4° E) (red) and Point Arguello ionsonde (34.7° N, -120.3° E) profiles at 1830 UT (magenta) for 28 June 1995.

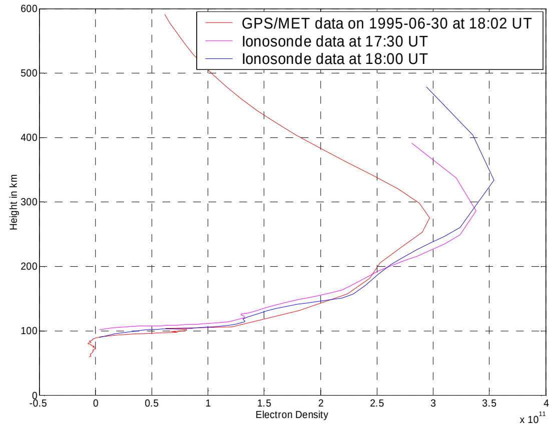

Fig 11. GPS/MET (36.3° N, -122.2° E) (red) and Point Arguello ionsonde (34.7° N, -120.3° E) profiles at 1730 UT (magenta) and 1800 UT (blue) for 30 June 1995.

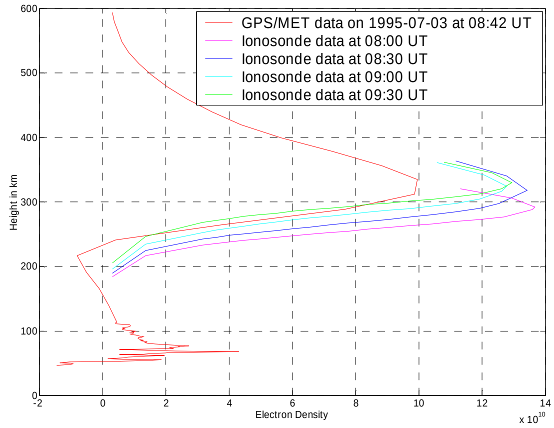

Fig 12. GPS/MET (35.2° N, -120.9° E) (red) and Point Arguello ionsonde (34.7° N, -120.3° E) profiles at 0800 UT (magenta), 0830 UT (blue), 0900 UT (cyan) and 0930 UT (green) for 03 July 1995.