

GPS Atmosphere and Ionosphere Methods used on Ørsted Data and Initial Application on CHAMP Data

Georg Bergeton Larsen, Per Høeg, Jakob Grove-Rasmussen, Martin B. Sørensen

Danish Meteorological Institute, Lyngbyvej 100, DK-2100, Copenhagen, Denmark

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Summary. The launch of the Ørsted satellite started a range of activities to verify GPS occultation measurements of the Earth atmosphere and ionosphere based on observations of GPS signal delay from a low Earth orbiting satellite. The Ørsted satellite followed the GPS/MET satellite experiment as the second mission in space to perform these types of measurements. Now the CHAMP satellite and also the SAC-C satellite are producing GPS occultation measurements in large numbers in long time-series and the data are just available since November 2001. The aim of this paper is to present an overview of the retrieval techniques used on the observations with the TurboRogue receiver on Ørsted and the results obtained both for the atmosphere and ionosphere. The results of CHAMP occultations using Ørsted processing tools will be presented and compared with Ørsted.

Key words: GPS, occultation, ionosphere, Ørsted, atmosphere

1 Introduction

The Danish Ørsted satellite was launched on February 23, 1999 with the primary mission to measure the Earth magnetic field. One of the other scientific instruments onboard is the TurboRogue GPS (Global Positioning System) receiver developed by JPL. This made Ørsted the second satellite capable of measuring GPS occultations following the very successful GPS/MET limb sounding experiment [1]. Today two other missions, CHAMP (CHALLENGING Minisatellite Payload) [2] and SAC-C, are providing very accurate GPS limb sounding measurements.

The first Ørsted measurements of GPS occultations were performed on April 17, 1999, and a dedicated measurement campaign was successfully completed in the period from February 3-22, 2000. In this period the TurboRogue was measuring continuously in a 24 hrs mode resulting in an average number of 50 daily profiles.

The technical constraints on the Ørsted GPS occultation measurements arise from a combination of low antenna gain and platform dependant parameters such as attitude control made data processing a difficult task. The antenna was pointed perpendicular to the velocity direction for most of the observations resulting in less observed occultations and only limited measurements below 10 km in tangent height. Data gaps every 10 second were observed in most profiles, this was repaired and was only a very small limit on the accuracy. Measurements of the L2

frequency were not reliable resulting in the dominant limit on retrieval accuracy and an alternative approach described below was necessary to perform corrections for the ionosphere term. Despite these technical difficulties we have succeeded to derive profiles of both temperature in the lower atmosphere and electron density in the ionosphere.

2 Atmosphere profiles

A single frequency method was developed and used on the measured occultations to perform the ionosphere correction. The contribution from the ionosphere can be expressed in terms of the total electron content (TEC). Usually TEC is derived using both GPS frequencies, however accepting less accuracy then TEC can be derived as shown in equation (2) using the pseudo range measurements obtained at 1Hz. The Ørsted processing procedure can be summarised as follows [3],

- Ørsted input data: L1, C1. Fiducial station input: L1, C1, L2
Cycle slip detection and correction
- Data filtering through a regularisation method
Regularisation of all ingoing signals L1, L2*(derived based on L1-C1)
Data gap filling
- Orbit arc construction (initial orbits; 10 Hz interpolation)
- Double differencing
Zero-order troposphere correction
First-order relativistic correction
Second-order ionosphere correction
- Ionosphere correction on phase (L1-L2*)
- Bending angle construction
Bending angle bias correction (Based on the MSIS90 model)
- Abel transform
- Retrieval of atmosphere parameters

All the profiles measured during the Ørsted GPS campaign in February 2000 have been validated against data from ECMWF (European Centre for Medium-Range Weather Forecasts) as part of the CLIMAP project [4]. The results are presented in fig. 1. as temperature differences compared to the ECMWF analysis. A total of 921 occultations split in polar and equatorial regions are used in the statistics. The standard deviation grow large close to the surface caused by the limited number of measurements below 10 km in tangent height. The best accuracy is achieved close to the tropopause and can be roughly summarised to be less than 1 K in mean difference and with about 3 K standard deviation.

Using the Ørsted processing algorithms on CHAMP measurements taking as input the RINEX files, and using initial orbits computed with the GIPSY/OASIS tool [5] we have computed a limited number of temperature profiles from Novem-

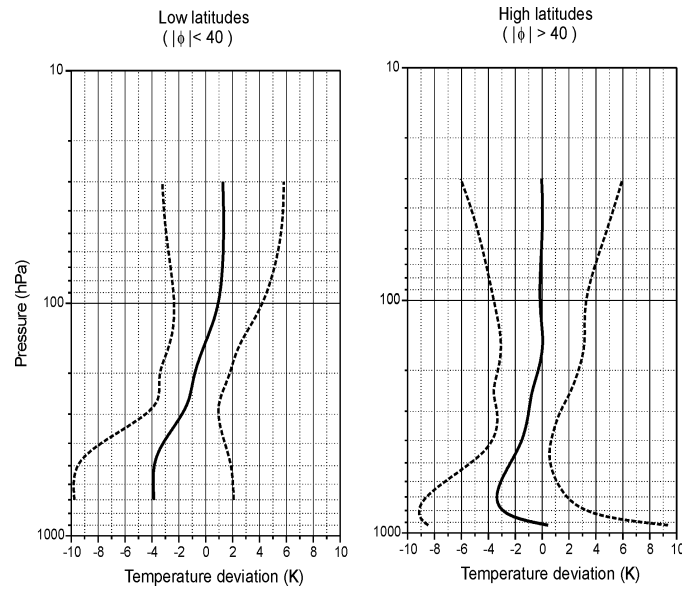


Fig. 1. Statistics comparing Ørsted temperature profiles with ECMWF. Left side represents the equatorial region and is based on 432 profiles. Right hand side contains 489 profiles for the mid/polar regions. The solid curve is the mean difference and the dashed curves represent one standard deviation.

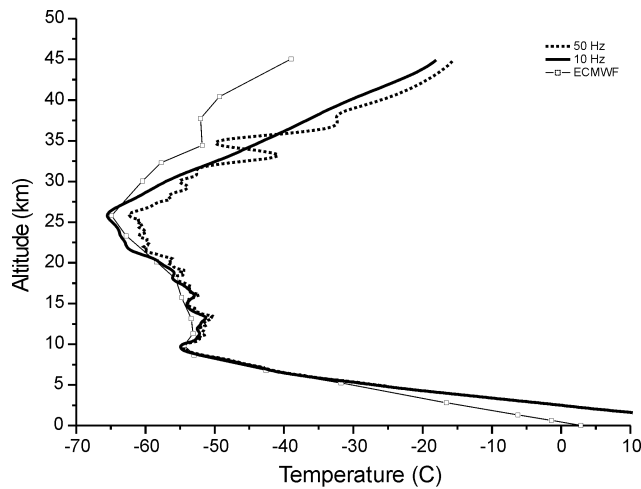


Fig. 2. Temperature profiles derived using CHAMP data. Two different processing methods were applied in this example, one using the 10 Hz method which the Ørsted method was designed at, and one using the full 50 Hz sampling of the CHAMP data.

ber 5, 2001. In fig. 2 we show an example of a CHAMP temperature profile and compare it with data from ECMWF. A close match is observed between 5-20 km. The Ørsted sampling rate was only 10 Hz and the filtering method used on the phase delay is a regularisation method with parameters tuned for 10 Hz sampling. The resulting bending angles are subsequently bias corrected using a model fit to bending angles derived based on the MSIS90 model. The model bending angle is based on a zonal selection. In fig. 2 above 20 km the resulting temperature profiles show clear differences. This is caused by the difference on the filtering parameters between 10 and 50 Hz and the selected bending angle model, which is different in the two cases.

3 Ionosphere profiles

The Satellite-to-Satellite Total Electron Content (SS-TEC) is derived using only the L1 signal. This is possible by combining the measured carrier phase, L_1 , and the C/A pseudo range, C_1 . The effect on the signal caused by the ionosphere has opposite sign for phase and pseudo range:

$$L_1 = \int_1 (1 - C \frac{N_e}{f_1^2}) ds \quad \text{and} \quad C_1 = \int_1 (1 + C \frac{N_e}{f_1^2}) ds \quad (1)$$

where N_e is the electron density, $C = 40.3 \text{ m}^3\text{s}^{-2}$ and $f_1 = 1.57542 \text{ GHz}$. Combining these two equations we obtain the following expression for the SS-TEC:

$$I = \frac{f_1^2}{2C} [C_1 - L_1] \quad (2)$$

where I is the SS-TEC. The ionosphere occultation measurements are performed at a sampling rate of 0.1 Hz, corresponding to a vertical resolution of about 30 km.

The ray path of a radio wave traveling through the ionosphere suffers a small bending, α , caused by the gradients in the background electron density. Expansion of the appropriate equations to first order results in the following simple and sufficiently accurate expression for the (approximate) bending angle [6], since the bending angle α is very small in the ionosphere, of the order 10^{-2} degree,

$$\alpha \approx \frac{C}{f_1^2} \frac{dI}{da_0} \quad (3)$$

Here a_0 is the impact parameter of the straight line connecting the Ørsted and the GPS satellite computed to first order.

Under the assumption of local spherical symmetry, the index of refraction and subsequently the electron density is then derived from the bending angle [7], [8]

through the use of the Abel transform. The bending angle is extrapolated above Ørsted orbit height using an exponential [9].

Fig. 3 shows a recently measured electron density profile, which is located close to a digisonde station. This measurement is part of a campaign from February 16-22, 2002 to measure the ionosphere cusp region using both satellite data from CHAMP, SAC-C and Ørsted and with radar measurements from ground at Svalbard and Tromsø. A close agreement between the Ørsted profile and the digisonde is observed.

The geometry of this particular occultation is favorable, with an azimuth angle less than 5 degrees, but still a small negative bias caused by the assumption of spherical symmetry is seen for heights below 200 km. To overcome the assumption of local spherical symmetry the Ørsted TEC measurements of both occultation links and GPS satellites tracked above orbit height have been combined in a tomographic solution of electron density to produce two-dimensional maps of electron density [10].

4 Summary

Validation of GPS occultations measured by the Ørsted satellite has shown that despite many technical difficulties useful profiles of both the neutral atmosphere and the ionosphere have been obtained. The accuracy of temperature profiles is reduced by roughly a factor of two compared to the results from GPS/MET [1] and a similar factor is expected for CHAMP. This reduced accuracy on Ørsted

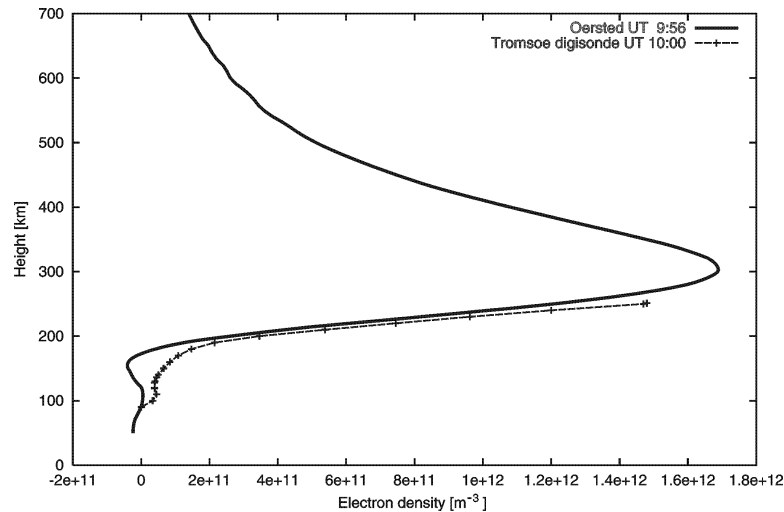


Fig. 3. Ionosphere occultation from February 20, 2002 compared against a digisonde measurement. Distance between the tangent point of the Ørsted profile and the digisonde is about 300 km.

profiles is caused primarily by the lack of L2 measurements. The ionosphere profiles also have reduced accuracy; the TEC obtained has a standard deviation of about one TEC unit. This limits in particular nighttime retrievals when the electron density is low.

In the recent February 2002 campaign the Ørsted satellite, now 3 years since launch, has provided the best quality GPS data yet observed. The attitude control of the satellite is very stable and the occultation antenna is pointing directly in the anti-velocity direction. More Ørsted GPS measurements are planned during the next couple of months to compare and combine with CHAMP and SAC-C occultations.

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