Direct determination of electron density profiles from GNSS occultation data

Angela Aragon-Angel, Manuel Hernández-Pajares, J.Miguel Juan, Jaume Sanz, Pere Ramos-Bosch
Res. *group of Astronomy and GEomatics, gAGE/UPC, Barcelona, Spain*
e-mail: ***angela@ma4.upc.edu*** web: ***http://www.gage.es***

The main purpose of this work is to test the Improved Abel transform applied to L1 bending angles, to retrieve electron density profiles from COMIC/FORMOSAT-3 occultation data.

INTRODUCTION

Information about the vertical distribution of electron density in the ionosphere can be retrieved from GPS radio signals tracked by GPS receivers on board a Low Earth Orbit (LEO) satellite. A wide used radio occultation inversion technique is the Abel transform which, in the ionospheric context, allows to retrieve electron densities as a function of height from STEC (Slant Total Electron Content) measurements. The classical approach of the Abel inversion assumes spherical symmetry of the electron density field in the vicinity of an occultation:

$$N_e(LT, LAT, H) = \Phi(H)$$

Where LT stands for the local time, LAT for latitude and H for height (radial component). However, in practice, the footprint of an occultation generally covers wide regions that may suffer from ionospheric spatial variability and this hypothesis can not be guaranteed. Indeed, inhomogeneous electron density in the horizontal direction for a given occultation is believed to be the one of the sources of error when using the Abel inversion.

IMPROVED ABEL INVERSION

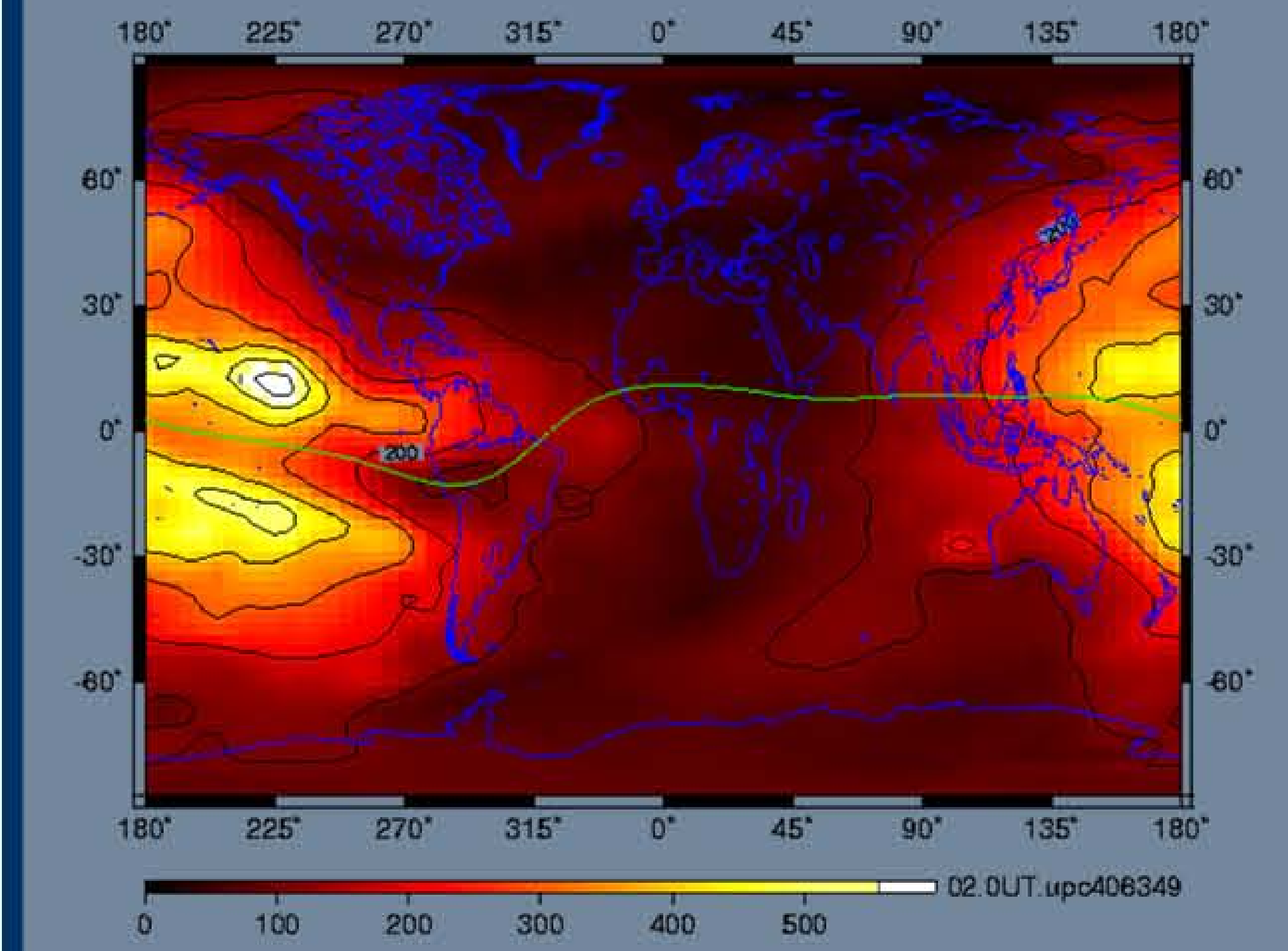
In order to correct the error due to the spherical symmetry assumption, the separability concept developed by Hernandez-Pajares et al. (2000) overcomes this limitation considering that the electron density can be expressed by a combination of VTEC (Vertical Total Electron Content) data assuming the horizontal dependency and a shape function which assumes the height dependency that is common to all the occultation observations.

$$N_e(LT,\ \ AT, H) = VTEC(LT, LAT)\ \boxed{F(H)}$$

In the above mentioned paper, the main observable to apply inversion was the LI observable (the geometric free combination) which has the advantage of its simple computation. An alternative to invert the profile is to use as main observable the so-called bending angle of the signal calculated from the observational excess phase. It overcomes the different signal path between L1 and L2 and it can be used not only for ionosphere but aso for thopospheric retrievals.

In this work, the separability approach has been applied to measured L1 bending angles instead of the LI observable.

EXPERIMENT SCENARIO

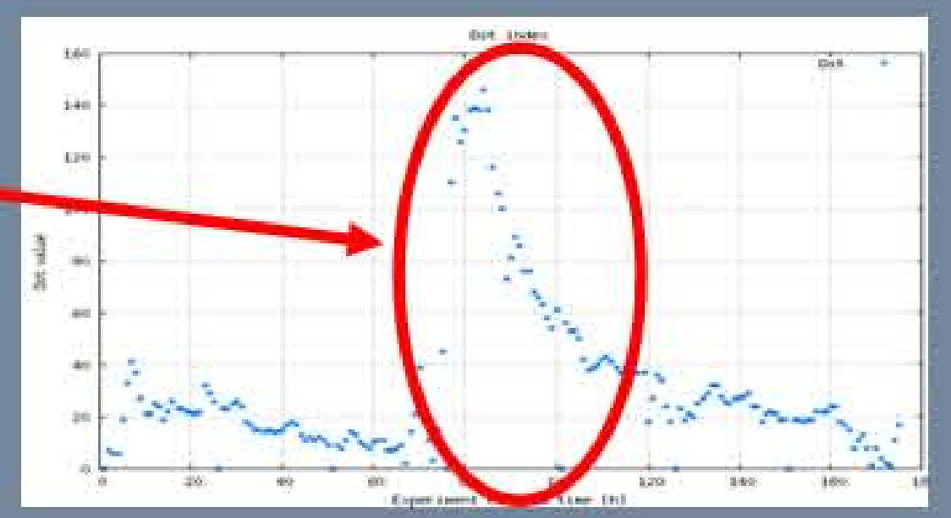


The analyzed period corresponds to one week of COSMIC/FORMOSAT-3 data ranging from 12th to 18th of December 2006. Inspite of 2006 being a quiet year in terms of ionospheric variability, a solar flare on Dec. 13th produced strong radio blackouts and an associated solar storm, a geomagnetic storm on Dec. 14th and strong to severe geomagnetic storming through Dec. 15th.

On the right side, a VTEC map for Dec. 15th at 2UT is provided showing an outburst of electron density for latitudes below 15º and longitudes around 225º.

The Kp index for these days is depicted below along with the Dst index:

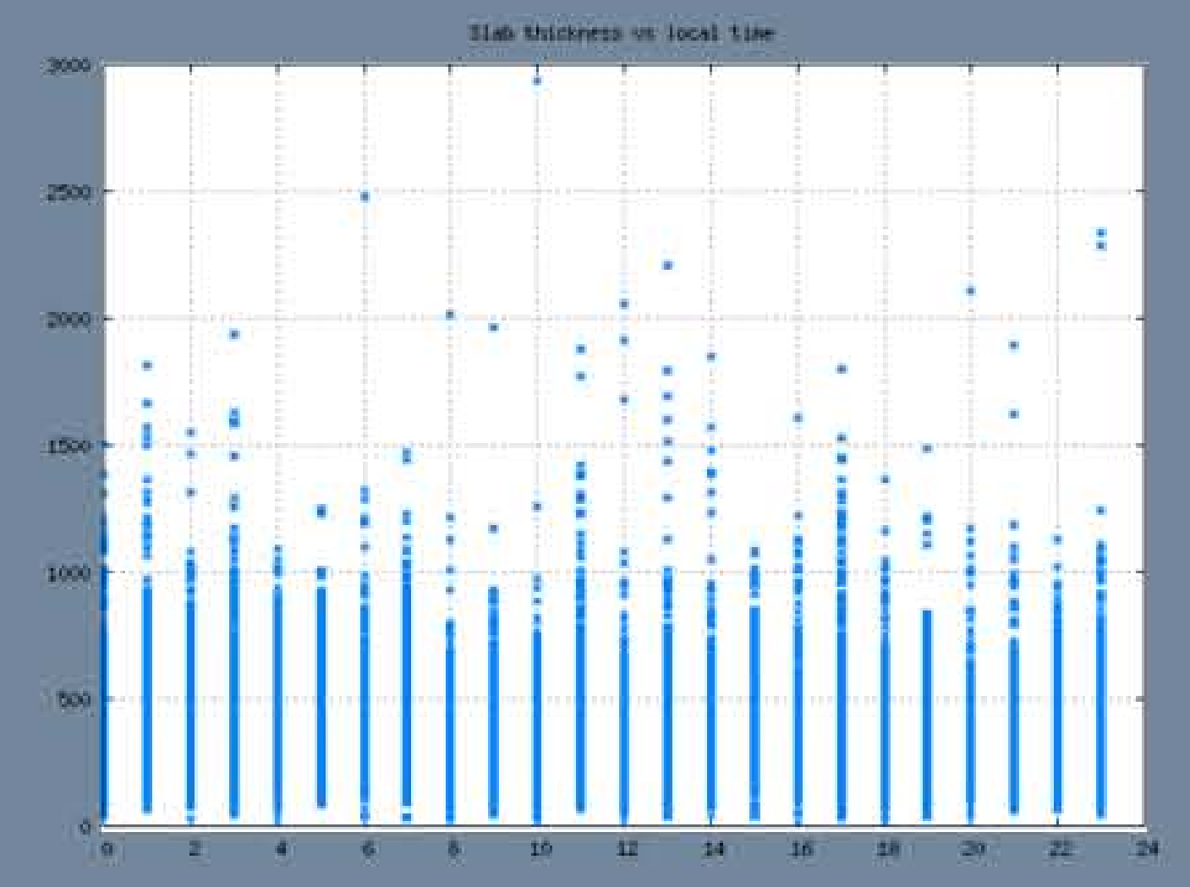
Most disturbed days



RESULTS

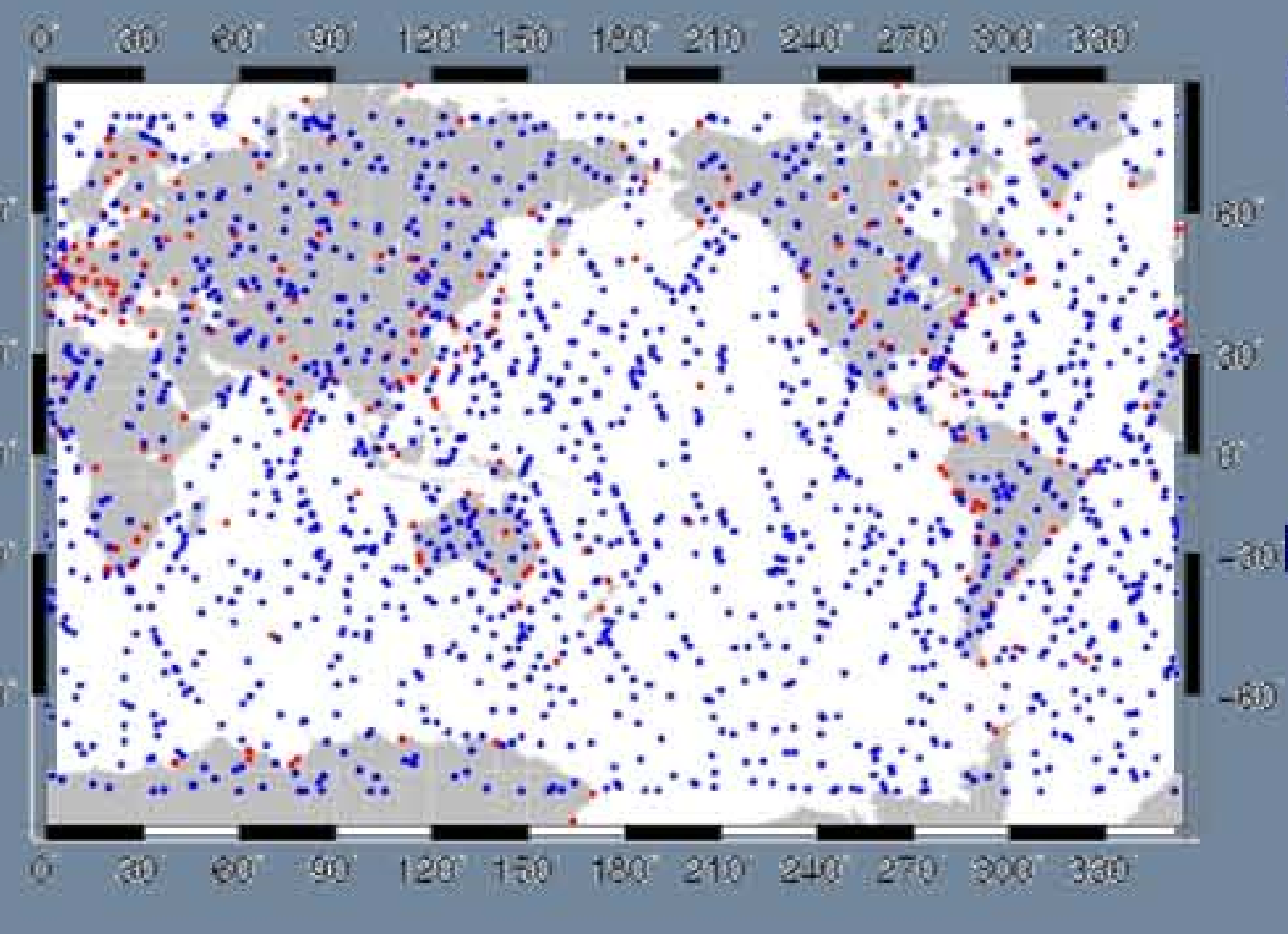
Solved radio occultations have been compared to co-located ionosonda data (one hour centered at the epoch that the occultation took place and a maximum co-location distance of 2000km) available at the SPIDR server http://spidr.ngdc.noaa.gov/spidr. Combining VTEC information with ionosonde derived F2 layer peak electron density (NmF2), a measurement of the shape of the electron density profile can be obtained, the ionospheric slab thickness which has been used to rule out comparisons, either due to unrealistic ionosonde measurements and/or interpolated VTEC:

$$\tau = \frac{VTEC}{NmF2}$$

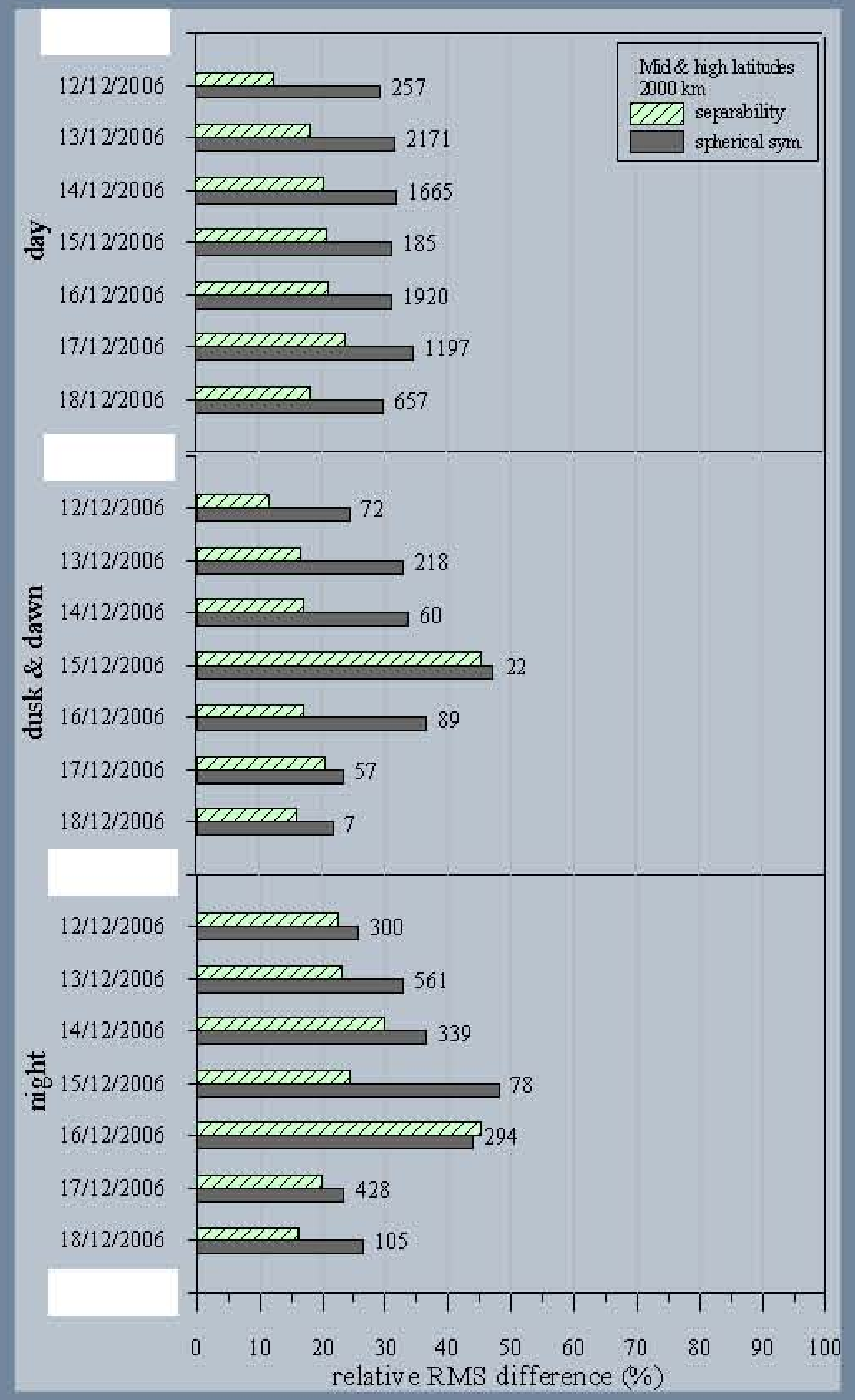


The dispersion of the slab thickness values versus local time is shown for the studied period. The threshold of slab thickness values has been set from 75km up to 830km.

The footprint of the processed FORMOSAT-3/COSMIC occultations are shown in blue (only highest impact parameter depicted per occultation) in next figure for the whole data period. Ionosonde locations are shown in red.



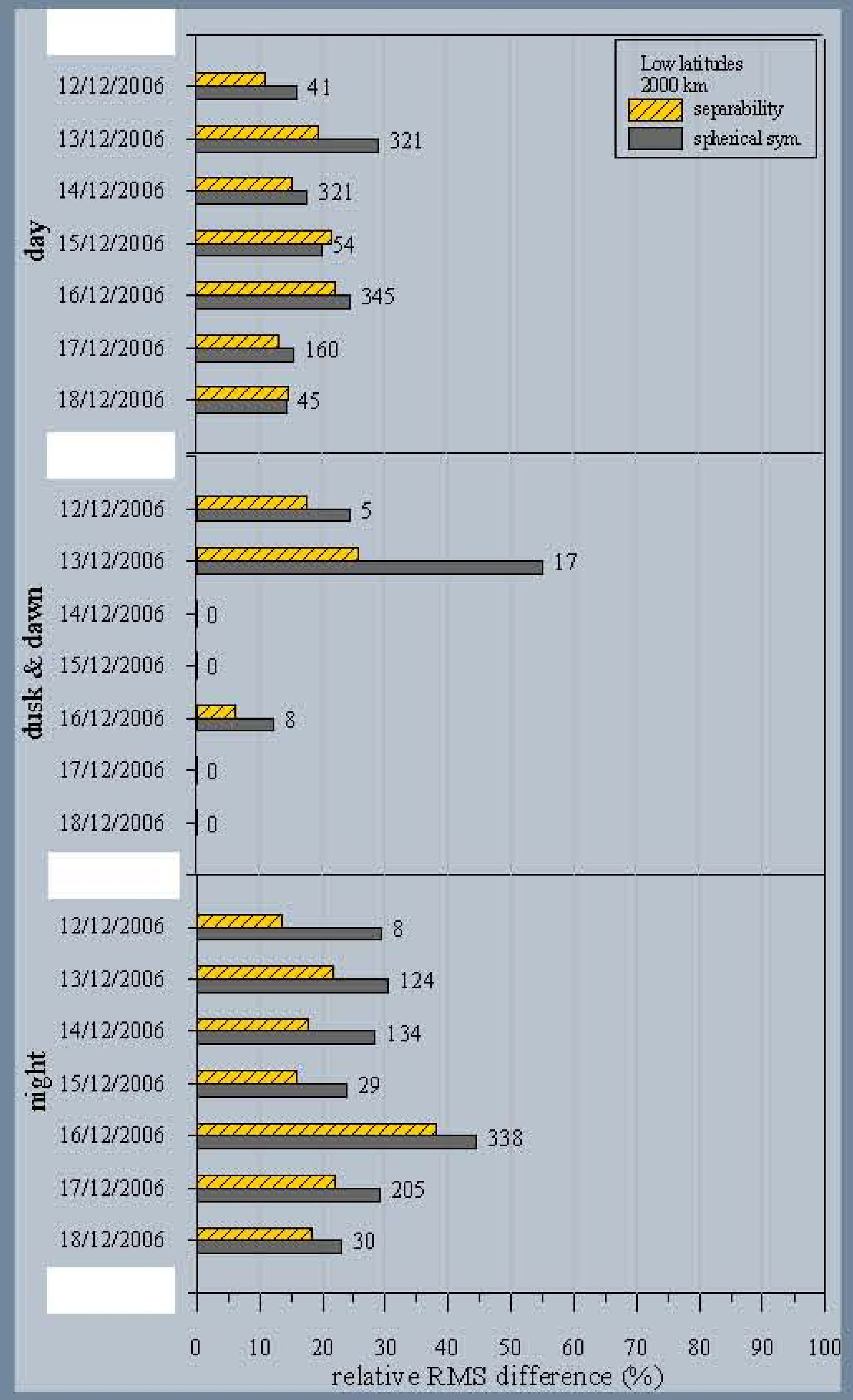
FORMOSAT-3/COSMIC overcomes one of the main limitations of previous LEO missions: sparcity and scarcity of data.

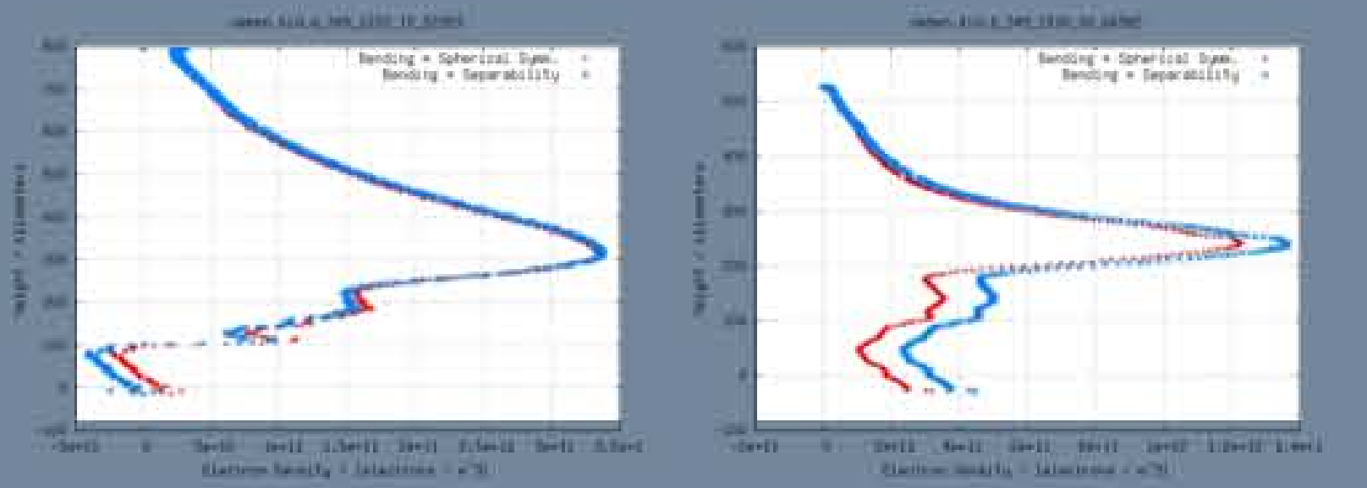


Frequency comparisons: directly from the F2 layer frequency peak (foF2) of ionosonde measurements: the electron density values retrieved by Abel inversions from the occultation events corresponding to the maximum electron density at F2 layer (NmF2) is transformed into critical frequency values (foF2) to perform the comparisons with ionosonde frequencies. The occultations have been sorted taken into account not only their latitude but also the period of the day in which they occurred in order to have straight forward intercomparisons:

- ➢ Low latitudes (ranging from -30º up to 30º) and Mid-High latitudes
- ➢Day/ Dawn and Dusk/ Night

The two figures at both side depict the F2 layer critical frequency relative RMS difference comparisons versus ionosonde of relative error with co-location distance up to 2000km for low and mid-hight latitudes. The number of estimations is also shown.





Example of two solved occultations for Dec. 15th 2006. The one on the right shows the discrepancies btw spherical sym. and separability.

Height comparisons: an estimation with an accuracy of about 4- 5% of the real height of the F2 peak layer (hmF2) can be obtained using the M(3000)F2 parameter (maximum usable frequency for transmissions up to 300km divided by the foF2 frequency), and the critical frequencies at the F2 and E layers (foF2 and foE respectively, both expressed in km). The table on the right presents the hmF2 height relative RMS difference comparisons from derived ionosonde Dudeney height. The absolute RMS is expressed in km. Both, the classical Abel transform and the improved Abel provide equivalent results for hmF2 determination.

		Nr. Comp.	SEP. RMS [%]	SYM. RMS [%]
Low	Day	2187	**30.1**	**29.5**
Low	D&D	13	**23.1**	**22**
Low	Night	2599	**27.1**	**26**
Mid&high	Day	12657	**37.5**	**37.3**
Mid&high	D&D	1783	**38.9**	**39.7**
Mid&high	Night	9860	**29.9**	**30.1**

CONCLUSIONS

The improved Abel transform which implements the separability approach to the Abel inversion provides a more accurate determination of electron density profiles (generally ~20% better although for some of the analyzed days the performance was quite equivalent –15th and 16th of December 2006, the most perturbed in terms of Dst index-) than the Abel transform when retrieving electron density profiles form radio occultations. Therefore, based on this work considering L1 bending angles, the improved Abel transform provides a very powerful tool for accurate radio occultation retrievals. A deeper study of such disturbed days would be required.

See more details in:

- Garcia-Fernandez, M., M. Hernandez-Pajares, M. Juan, and J. Sanz, Improvement of ionospheric electron density estimation with GPSMET occultations using Abel inversion and VTEC information, Journal of Geophysical Research, Vol. 108, No. A9, 1338, doi:10.1029/2003JA009952, 2003.
- Hernandez-Pajares, M., J. M. Juan, and J. Sanz, Improving the Abel inversion by adding ground data LEO radio occultations in the ionospheric sounding, Geophysical Research Letters, Vol. 27, 2743–2746, 2000.
- Hernández-Pajares M., J.M. Juan, J. Sanz and J.G. Sole, Global observation of the ionospheric electronic response to solar events using ground and LEO GPS data, Journal of Geophysical Research-Space Physics, Vol.61, p.1237-1247, 1998.

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