PRECISE TIME SERIES DETERMINATION IN THE EUROPEAN SEA LEVEL SERVICE (ESEAS) PROJECT.

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Abstract

In the framework of the European Sea Level service (ESEAS) project, 4 years time series has been computed using the Precise Point Positioning (PPP) approach. The processing has been carried out using both, the IGS and JPL precise orbits and clocks, and the performance of such products has been compared.

Moreover, the effect of the 2nd order ionospheric correction term has been assessed following the work of [1], having variations up to 1cm when this term is neglected, depending on the latitude location.

1 Introduction

The European Sea Level service (ESEAS) project started in 2001 with the aim to continue and improve the work that was being developed by the European Sea Level Observation System (EOSS) initiated through the COST Action 40, see [2]. The main task that is being carrying out inside the ESEAS project is to enhance exploitation of sea-level and related databases for both scientific and non-scientific users. The UPC is involved in such project as Analysis Center in order to process GPS data of the ESEAS network to get precise time series coordinates.

When such precise time series coordinates have to be computed, a user can consider different strategies in order to solve that problem. In this context, the Precise Point Positioning (PPP) approach is one of the most common used strategy in order to get such time series determination with GIPSY/OASIS II software, see [3]. Thus, one of the main choices, when PPP approach is used, is to decide which kind of GPS precise products have to be used. In this sense, there are several precise products available in the GPS community, which are combined in order to get a more precise final product, the IGS final orbits and clocks. These products consist of a set of precise orbits, with a final accuracy below 5 cm, and precise satellite clocks, with a final accuracy below 0.1 ns. And they have a latency of about 13 days, see http://igscb.jpl.nasa.gov/components/prods.html for more details about IGS products. Other precise orbits and clocks available to be used are the JPL products. The accuracy of these final JPL orbits are comparable to the IGS ones. Moreover, the JPL products are available in two forms. The fiducial and the non-fiducial solutions. The first one is the most common used, with the orbits constrained to the reference frame by some worldwide fiducial GPS stations. The non-fiducial approach implies free reference frame solution. Thus, the computation is done without any constrained reference frame. In spite of that, a free solution is obtained which is more precise since it is not influenced by the apriori constraints. Then, in order to get the final solution, only a Helmert transformation has to be done, see [3] for details.

At this point, very accurate time series can be determined, but some recent studies, see [1] and [4], have shown that the omission of the 2nd order ionospheric term in the ionosphere-free phase combination can introduce an error up to 1 cm in the precise coordinate determination, depending on the geographical location.

Therefore, in this work, 4 years time series have been computed with both, the IGS and JPL precise orbits and clocks in order to analyze the performances of both products, obtaining that the JPL products have less dispersion for the whole period. Additionally, it has been computed a 2-years time series, comparing the effect of the 2nd order correction, obtaining the variations on the coordinate determination along a longitude sector.

2 Comparison between JPL and IGS products

2.1 Strategy and Scenario

In order to process the data provided by the ESEAS FTP server, the GIPSY/OASIS II software has been used and being operated in precise point positioning (PPP) mode. Thus, the comparison has been carried out computing time series estimation for 20 European stations, see figure 1, through 4 years with both IGS final and JPL final precise products. In principle, the strategies for both products should be similar. In fact, the common parts of the strategy are:

- Elevation cut-off mask of 7^o.
- Ocean loading model correction (H. Scherneck model using the FES99 parameters).
- Sampling interval of 300 seconds.
- Niell tropospheric mapping function.

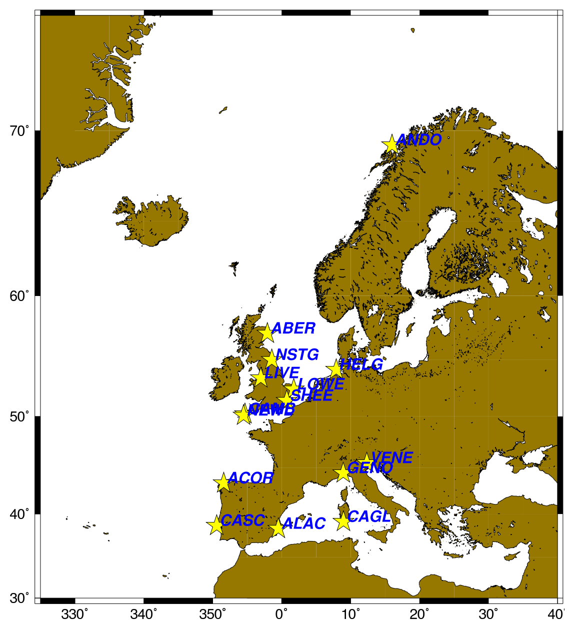

Figure 1: Plot showing the stations involved in the JPL vs. IGS comparison

When the JPL products are used, the processing is performed in the GIPSY *standard* way. Nevertheless, when the IGS products are used, it is possible to weight the data observations as a function of the final RMS solution of the satellite orbit determination due to the fact that this information is included in the header of the sp3 orbits files. This allows to get a more precise solution than when those weights are not used.

2.2 Results

In order to evaluate the accuracy of the different products, the RMS of the stations time series has been computed after detrending data from effects such as the tectonic drift. In order to do that, in this work a simple linear approximation has been computed to detrend data. Thus, once the outliers has been removed, the RMS regarding to the zero mean has been computed obtaining the results of table (1).

In a general point of view, it can be seen that the JPL solutions present less RMS than the corresponding IGS ones. In spite of that fact, the two solutions are almost compatible, and the errors can be due to the strategy process. It has to be noted that the different strategies can cause differences on the height rates estimation between 2.8 and 5.6 mm/yr, see table (2), that are compatible with the geocenter motion. This *motion* is due to the fact that the IGS products use the daily realized center of mass of the earth as geocenter, whereas JPL use the centre of figure of ITRF2000 as geocenter. This difference cause a difference between the ITRF2000 and the real earth center of mass of about 3 mm/yr, see [5] for details.

Latitude RMS (mm)	JPL	IGS
$ABER_{lat}$	3.3	6.5
$ACOR_{lat}$	5.1	7.1
$ALAC_{lat}$	3.8	7.3
$ANDE_{lat}$	6.1	10.7
$ANDO_{lat}$	3.7	6.8
$CAGL_{lat}$	3.6	7.3
$CAMB_{lat}$	3.6	7.2
$CASC_{lat}$	3.7	6.9
$CEUT_{lat}$	3.3	6.9
$GENO_{lat}$	3.4	7.0
$HELG_{lat}$	3.7	6.7
$LAGO_{lat}$	3.8	7.0
$LIVE_{lat}$	4.2	6.9
$LOWE_{lat}$	3.4	6.7
$MORP_{lat}$	10.1	8.1
$NEWL_{lat}$	3.8	6.8
$NSTG_{lat}$	6.1	7.6
$PMTG_{lat}$	4.0	7.6
$SHEE_{lat}$	4.8	7.7
$VENE_{lat}$	4.4	7.8

Longitude RMS (mm)	JPL	IGS
$ABER_{lon}$	4.8	7.7
$ACOR_{lon}$	6.5	7.4
$ALAC_{lon}$	4.3	7.1
$ANDE_{lon}$	8.7	10.4
$ANDO_{lon}$	4.6	6.7
$CAGL_{lon}$	5.3	8.3
$CAMB_{lon}$	4.6	7.4
$CASC_{lon}$	7.6	7.1
$CEUT_{lon}$	4.3	6.4
$GENO_{lon}$	4.2	8.7
$HELG_{lon}$	4.4	6.2
$LAGO_{lon}$	4.8	7.3
$LIVE_{lon}$	4.5	6.7
$LOWE_{lon}$	3.7	6.6
$MORP_{lon}$	9.3	10.3
$NEWL_{lon}$	6.9	7.0
$NSTG_{lon}$	9.0	9.2
$PMTG_{lon}$	3.6	6.1
$SHEE_{lon}$	3.7	6.8
$VENE_{lon}$	3.8	7.8

Radial RMS (mm)	JPL	IGS
$ABER_{rad}$	9.2	10.7
$ACOR_{rad}$	15.7	18.2
$ALAC_{rad}$	7.0	10.0
$ANDE_{rad}$	10.7	11.5
$ANDO_{rad}$	8.2	10.6
$CAGL_{rad}$	10.0	12.2
$CAMB_{rad}$	7.6	11.0
$CASC_{rad}$	7.8	10.9
$CEUT_{rad}$	19.4	18.7
$GENO_{rad}$	8.6	11.5
$HELG_{rad}$	9.0	10.2
$LAGO_{rad}$	6.6	10.2
$LIVE_{rad}$	6.7	10.1
$LOWE_{rad}$	6.8	9.8
$MORP_{rad}$	16.2	16.4
$NEWL_{rad}$	7.7	10.6
$NSTG_{rad}$	13.7	14.3
$PMTG_{rad}$	6.2	9.0
$SHEE_{rad}$	7.8	12.2
$VENE_{rad}$	10.7	13.7

Table 1: Tables showing the RMS of Latitude, Longitude, and Height components after detrending the corresponding time series.

(mm/yr)	JPL	IGS	JPL-IGS
$ABER$	5.7	0.2	5.5
$ACOR$	-2.4	-6.4	4
$ALAC$	-0.3	-3.4	3.1
$ANDE$	-0.2	-5.0	4.8
$ANDO$	1.2	-4.4	5.6
$CAGL$	1.6	-2.4	4
$CAMB$	-1.1	-4.8	3.7
$CASC$	2.3	-1.2	3.5
$CEUT$	-10.2	4.7	-14.9
$GENO$	2.6	-3.8	6.4
$HELG$	0.1	-3.6	3.7
$LAGO$	2.1	-1.9	4
$LIVE$	0.6	-3.5	4.1
$LOWE$	-0.3	-4.3	4
$MORP$	-0.6	-4.0	3.4
$NEWL$	-0.9	-4.0	3.1
$NSTG$	0.7	-4.4	5.1
$PMTG$	-3.4	-6.2	2.8
$SHEE$	1.0	-4.0	5
$VENE$	52.1	43.2	11.1

Table 2: Differences between the JPL and IGS height rate estimation.

3 2nd order ionospheric correction

3.1 Theoretical basis

As it well known, the ionospheric term in the GPS observables can correct about 99.9 % of the delay caused by the ionosphere, see [6]. Thus, with the increasing improvement of the GPS precise positioning techniques, the effect of the additional terms of the ionospheric approximation has to be taken into account in order to reduce the ionospheric mismodelling since the main observable used in geodesy is the *Ionospheric free combination*. Thus, from the Appleton-Hartree formula, it can be deduced the following approximation corresponding to the second order ionospheric term for the GPS signals, see [4] for details, which can be applied to correct, for instance, the observables contained in the RINEX files with the STEC provided by the IONEX files, see [7], and the magnetic field provided by a model:

- For the Pseudorange observable:

$$\delta iono_P = \frac{s}{f_i^3}$$

- For the Phase observable:

$$\delta iono_L = -\frac{s}{2 \cdot f_i^3}$$

with,

$$s = 7527 \cdot c \cdot Bo \cdot cos(\beta_{Bo}) \cdot STEC \quad (1)$$

Being c the speed of light on vacuum (m/s), Bo is the magnetic field (Tesla) in the ionospheric pierce point (IPP), β_{Bo} is the angle between the ray station - satellite and the magnetic field Bo, $STEC$ (TECU) is the Slant Total Electron content.

Thus, the ionospheric contribution to the Phase ionospheric free combination becomes:

$$\delta iono_{Lc} = \frac{s}{2 \cdot (f_1 + f_2) \cdot f_1 \cdot f_2} \quad (2)$$

And it can reach up to several centimeters at noon in solar maximum and close to the geomagnetic equator (see figure 2 for an example). This can affect the coordinates estimation at subcentimeter level.

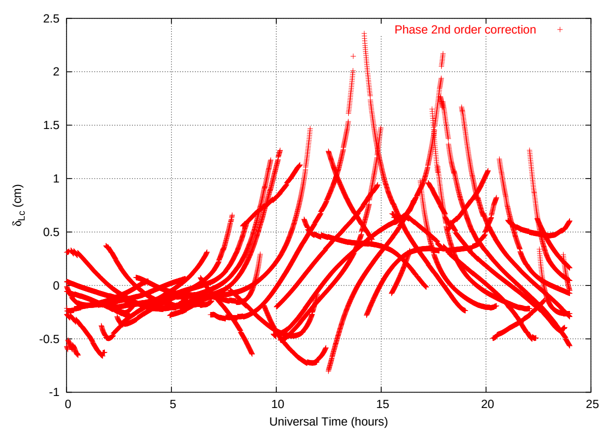

Figure 2: Plot showing the 2nd order ionospheric term in the ionospheric free combination for the station COCO.

3.2 Scenario

For this study, several stations distributed in a longitude band centered at 120^o from about 70^o to -65^o of latitude have been used, see figure 3. With this station distribution, it is possible to study the distribution of the 2nd order ionospheric term as function of latitude. It is expected that the most significant effects would be at the equatorial zones which present higher TEC values. The International Geomagnetic field has been used to compute the 2nd order ionospheric term (Geopack routines model, see [8]. This gives a more realistic Magnetic field approximation than the Dipolar Magnetic field model. The Total Electron Content (TEC) has been computed from the UPC IONEX file, see [9] for details, downloaded from The Crustal Dynamics Data Information System (CDDISA) server (ftp://cddisa.gsfc.nasa.gov/gps/products/ionex)

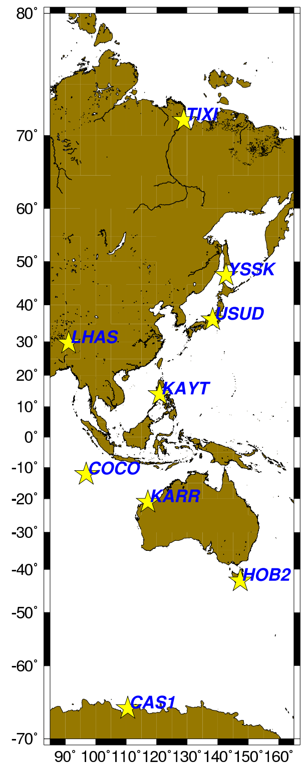

Figure 3: Plot showing the distribution of the stations that have been used in the 2nd order ionospheric study

Then, in order to compute the time series with and without the 2nd order ionospheric term, the GIPSY/OASIS II software has been also used in PPP mode with final precise JPL non-fiducial products, and it has been processed with the same features that in the previous section.

3.3 Results

When the second order correction is taken into account, the coordinates time series estimation can vary up to 1 cm, in this case, most part of the correction belongs to the latitude component, see [3], and, as it could be expected, it reaches the maximum value at low latitudes, see figure 4.

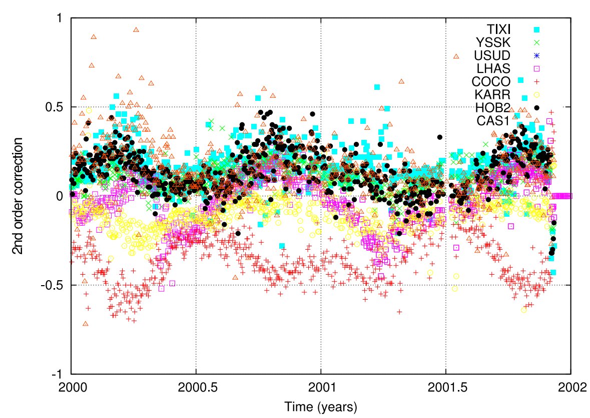

Figure 4: Plot showing the different behavior of the latitude 2nd order ionospheric correction for all the stations

For the other coordinates the effect is not so high such as in the latitude component, see figure 5.

Looking at the different series, the station COCO has an special signature which is highly correlated (correlation index of 0.98) with the global mean TEC extracted from the UPC IONEX file, see figure 6.

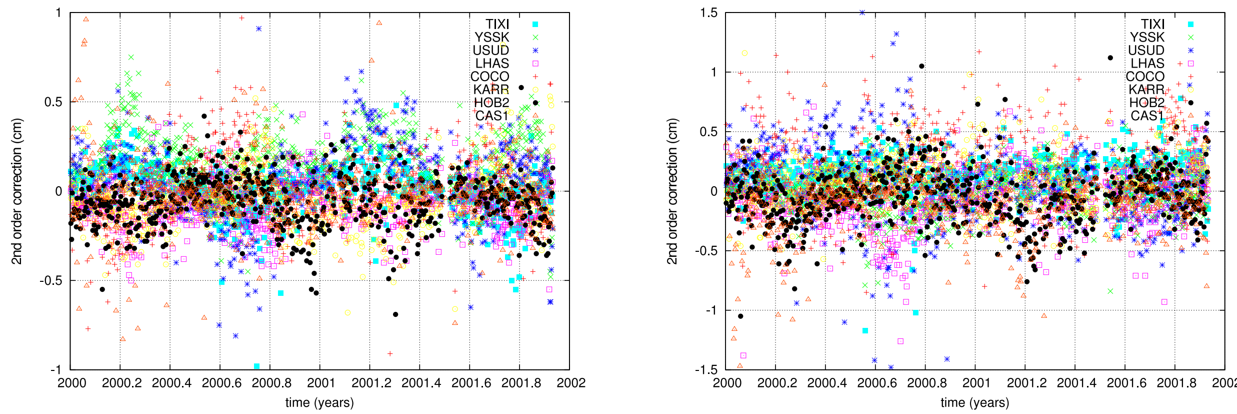

Figure 5: Plots showing the 2nd order correction in longitude (left plot) and radial (right plot) components as a function of time for all the stations

Thus, this can be related with the location of that station, since it is below the South equatorial anomaly that are the responsible of the major part of the global mean TEC.

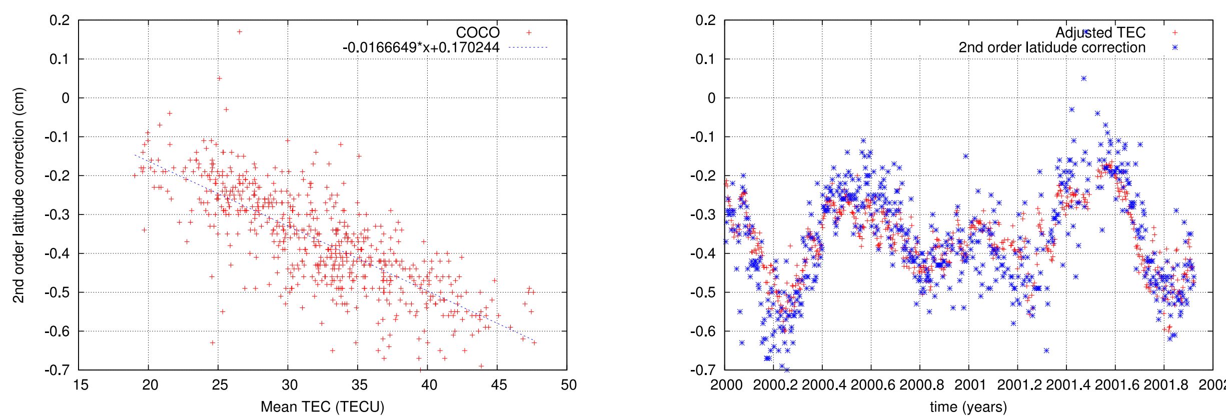

Figure 6: Plot showing the correlation between the mean daily TEC with the second order ionospheric correction at COCO. In the left hand side there is depicted the corresponding linear adjustment, and in the right hand side there is depicted the 2nd order latitude ionospheric correction and the adjusted TEC as a function of time.

3.4 Effect on several ESEAS sites

Since the main objective of the UPC inside the ESEAS project is to compute precise coordinates time series, the effect of the 2nd order ionospheric term should be taken into account. From the previous section it can be deduced that the effect of such correction will be at subcentimeter level, and it is highly correlated with the Global mean TEC. On the other hand, the main input needed by the ESEAS project is the radial component of the time series. Moreover, it is well known that the horizontal component can be computed with 2-3 times less noise than the vertical one. Thus, the effect of the 2nd order ionospheric correction is not as clear as in the latitude component, mainly due to the estimation error and the geometry of the problem.

Therefore, it has been computed the effect of the 2nd order ionospheric correction for three ESEAS stations widely distributed in latitude over Europe for the year 2001. As it can be seen in figure 7, the radial component are noisier than the latitude one. In this case the effect on the latitude component are almost the same for the three stations.

Looking at figure 7 it can not be seen clearly an improvement on the radial component, but it is clear that exists some displacement of about 0.5 cm in the latitude component with a maximum value at autumn.

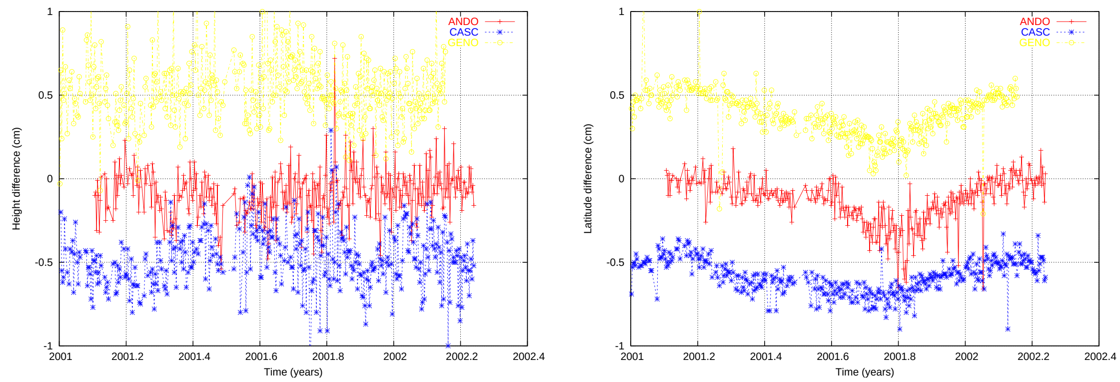

Figure 7: In the left hand side it is depicted the effect on the radial component of the 2nd order ionospheric correction and in the right hand side there is depicted the corresponding latitude correction, all for the year 2001. Notice that the stations GENO and CASC have been shifted +0.5cm and -0.5cm respectively.

4 Conclusions

There are three main conclusions of this work:

- The time series computed with IGS products present more dispersion than the JPL ones. In this sense, it has been shown that there is a difference of 3.5 to 5.6 mm/yr in the height rate computation that can be due to the geocenter motion.
- The 2nd order ionospheric correction can vary the coordinates estimation up to 1 cm. It shows that there exists a high correlation between the daily 2nd order latitude correction and the Global mean TEC.
- The 2nd order ionospheric correction should be taken into account in order to substract the remaining ionospheric mismodelling in precise time series determination.

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6 References

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