# New activities and products at GOP analysis center
## (period 1999-2000)

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## 1. Introduction

Beside the standard weekly contribution to the EUREF permanent network, Geodetic Observatory Pecný (GOP) LAC has performed many further activities related to the routine GPS data processing. We can distinguish between two main directions. At first, there are still some general questions about new strategies for EUREF subnetwork processing – mainly the possibility and reliability of the low elevation data inclusion. On the other hand, during the last years various non-geodetic applications have been under the investigation, where still high accuracy is required even for the regional network solutions. Hence, the second GOP LAC activities are mostly dealing with one of such an interdisciplinary project – GPS processing for weather numerical forecasting. Within this task, we present here only very brief overview of our last achievements, results, products and possible future services. Nevertheless, we have to state the both activities are finally useful one to another.

## 2. New strategies for EUREF analysis

Since version 4.0 (and mainly 4.2) the Bernese GPS software offers many new options for very precise methods of GPS network analysis. We have decided to test the reliability of low elevation observations inclusion in our EUREF subnetwork processing. Already ROTHACHER et al. [1998] presented the positive impact of such a strategy especially for the height component repeatability (because of its better decorrelation with the total zenith delay parameters). Further, in the paper the improvements of the horizontal positions by the estimation of additional horizontal tropospheric gradients was also proved (due to included modelling of azimuthal dependance of the tropospheric refraction).

During a period of about 3 months, we have included the additional testing strategies described in Tab. 1 into our routine EUREF subnetwork analysis procedure. The valuation was based on the following steps:

- routine estimation of free network solutions for all the individual results,
- later combination of free network solutions for each variant,
- Helmert transformation comparisons of daily solutions to the combined solution,
- Helmert transformation comparisons between variants (both daily and combined).

Tab. 1: New strategies for EUREF subnetwork solution (Niell – Niell mapping function used, WGT – elev. dependent weighting, ELE – low elev. data included, GRD – horizontal tropospheric gradients estimated)

| Solution | | Strategy |
|---|---|---|
| **GOP** | **(A)** | Standard (Saast.) |
| **W__** | **(W)** | Niell + WGT |
| **WE_** | **(E)** | Niell + WGT + ELE |
| **WEG** | **(G)** | Niell + WGT + ELE + GRD |

Tab. 2: The consistencies of different solution variants: individual (a) and comparative (b) validations

| Solution comparisons | Tot RMS [mm] | Component RMS X [mm] | Y [mm] | Z [mm] |
|---|---|---|---|---|
| **GOP** | 2.13 | 1.10 | 0.93 | 2.90 |
| **W__** | 2.04 | 0.98 | 0.83 | 2.83 |
| **WE_** | 1.95 | 1.06 | 0.81 | 2.66 |
| **WEG** | 1.94 | 1.01 | 0.84 | 2.64 |
| **GOP ´ Niell** | 0.45 | 0.17 | 0.18 | 0.65 |
| **GOP ´ W__** | 1.64 | 0.63 | 0.70 | 2.31 |
| **W__ ´ WE_** | 1.83 | 0.53 | 0.49 | 2.72 |
| **WE_ ´ WEG** | 1.40 | 1.20 | 1.08 | 1.37 |
| **WEG´ GOP** | 1.95 | 1.38 | 1.36 | 2.21 |

Table 2 shows mean total and component RMSs for Helmert transformations of each daily coordinate sets to the unique combined set. The transformation was always performed for all the available sites, the residuals were expressed in the local system. At first, looking downward for the total RMS of inner consistency for individual strategies (a), slight improvement can be visible. The height component (Z) is the major contributing here.

Looking at the second part (b) of the table, there is no significant influence (as expected) in case of using Niell mapping function [NIELL,1996] instead of simple *cos(z)*

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mapping for 15 degrees observation cut-off angle. Clearly, we can recognize the influence of elevation dependent weighting and lowering cut-off angle for analysed data as significant for height component estimation. On the other hand, introduction of horizontal tropospheric gradient, horizontal components are the most influenced (with respect to previous comparisons and significanlty lower RMS for Z component).

Table 5 contains complete RMS statistics for all sites in GOP EUREF subnetwork. Few sites can be identified here as a problematic when setting up the elevation dependent weighting and/or processing lower elevation data. Unfortunately, not all the sites listed here are storing the data bellow 15 or 10 degree elevation mask. MOPI represents the worst behavioring site with nearly 2 cm of systematic bias in height. Stations TUBI, TRAB and ZECK were affected mostly by MOPI site due to baselines typically chained to MOPI. Nevertheless, except MOPI site there are even another clear biases for sites EIJS, TROM and MDVO, while the last one is also the most affected in the horizontal position – but significantly less then in the up component. Combining lower cut-off angle with elevation dependent weighting usually reduces greater part of any systematic bias in the height. Figures 1,2 shows the time scaled developments of non-influenced (BOGO) and strongly influenced (MOPI) sites by Helmert comparisons of each daily/weekly solution between various strategies. The comparisons are ordered relatively one to another to separate clearly the impacts of individual strategy's addition.

If one isn't well familiar with sketched problem, and he would use any of "problematic" sites from EUREF reference frame constraining them with a different processing strategy, he can introduce a significant bias in his solution. The serious example could be given by the project of tropospheric monitoring in the next paragraph. Low elevation data are usually requested here and site positions constrained to known values. The height component bias from reference frame would be introduced approximatelly by its one third part directly into the ZTD estimates!

## 3. Near real-time analysis for the atmospheric monitoring

Since January 1999 GOP LAC have started the project of GPS atmospheric monitoring by routine processing of regional network of permanent GPS sites. The goal was to get the experience with routine near real-time analysis and to find the best strategy for high accurate ZTD results within 2 hours latency only. Related to this task, the long-term study of precise GPS orbit products was performed by monitoring and testing its availability for near real-time processing results:

- Stable procedures for NRT and post-processed analysis were prepared and well tested.
- Various solution strategies were tested [DOUŠA,2000].
- Zenith total delays (ZTD) were routinely evaluated with latency less During the year 1999 we have achieved following then 1.5 hours (NRT) and 18-28 hours (post-processed reference solution). Validation of NRT wrt. post-processed solution can be characterized by standard deviation of about 1mm in precipitable water vapor.
- Selected results were validated in precipitable water vapor values by the use of the data from available radiosonde profiles. The standard deviation is about 0.8mm for post-processed solution and 1.2mm for NRT respectively.

Our NRT processing strategy has used CODE P2 (48 hours) predicted orbits (in 1999), the special satellite exclusion procedure based on day-to-day arc consistency check and simultanious partial orbit re-estimation. The solution is based on the combination of last 12 hourly normal equations (NEQs). Post-processed solution uses IGS rapid orbits and it is based on daily NEQs finally combined into 3 days solutions. IGS rapid orbits are of high quality, they are fixed in the processing checked only by satellite exclusion procedure like by NRT mode.

Validation of both (NRT and post-processed) strategies by radiosonde data profiles integrated into the precipitable water vapor (PWV) is given in Tab.3. The bias here are specific for each site and cannot be validated more accurately now due to missing local GPS site and radiosonde information. For the site GOPE, these results are also plotted in Fig.3.

In the early of 2000, we have checked the impact of subdaily orbit products. Table 4 shows the statistics based on the NRT PWV comparisons to the unique post-processed reference solution (using the final IGS orbits here). In the table, we use the following orbit abreviations: **CO2** – CODE P2 (2 days) predicted orbits, **IGU** – IGS ultra-rapid orbits, **GOH** – GOP hourly orbits (full PRN set), **GTH** – GOP hourly orbits (5 older – mostly problematic satellites – were a priori excluded), **IGS** – IGS final orbits used here in simulated NRT mode. Orbits are handled with different approach is identified in the table as following: SEP (satellite exclusion procedure) using one of the criterions ( arc – day-to-day arc consistency check; ovr – arc-overlaps check for subdaily products; sp3 – SP3 accuracy code). Abreviation EST means partial relaxation of the orbits in the same run as final ZTDs are estimated.

Tab. 3: The validation of NRT and Post-processed solutions by radiosonde data [mm of PWV].

| | | | | **GRAB** | | | **GOPE** | | | **PENC** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bias | Sdev | # | Bias | Sdev | # | Bias | Sdev | # | Bias | Sdev | # |
| **Post** | -0.49 | **0.85** | *57* | -0.73 | **0.87** | *25* | 0.00 | **0.85** | *105* | -2.28 | **0.93** | *36* |
| **NRT** | -0.09 | **1.19** | *54* | -0.15 | **1.33** | *26* | 0.40 | **1.25** | *96* | -1.16 | **1.39** | *38* |

Tab. 4: The impact of the subdaily orbits (and the way of their using) on PWV estimation (behind the slash, there are given the statistics for results extracted with 1 hour more latency)

| Used orbits and quality valuation | **BOGO** | | **GOPE** | | **ONSA** | |
|---|---|---|---|---|---|---|
| | Bias[mm] | Sdev[mm] | Bias[mm] | Sdev[mm] | Bias[mm] | Sdev[mm] |
| **CO2**, SEP(arc) | 0.58 / 0.41 | **1.15 / 1.03** | 0.52 / 0.32 | **1.25 / 1.16** | 0.58 / 0.41 | **1.00 / 0.94** |
| **CO2**, SEP(arc), EST | 0.51 / 0.52 | **1.07 / 1.01** | 0.78 / 0.74 | **1.16 / 1.06** | 0.59 / 0.65 | **0.96 / 0.86** |
| **IGU**, SEP(sp3) | 0.57 / 0.50 | **1.24 / 1.16** | 0.47 / 0.40 | **1.16 / 1.11** | 0.58 / 0.50 | **1.15 / 1.08** |
| **IGU**,.SEP(ovr) | 0.45 / 0.34 | **1.11 / 1.02** | 0.54 / 0.38 | **1.14 / 1.05** | 0.55 / 0.44 | **0.95 / 0.87** |
| **GOH**, SEP(ovr) | 0.24 / 0.27 | **0.78 / 0.70** | 0.14 / 0.15 | **1.06 / 0.93** | 0.38 / 0.39 | **0.81 / 0.70** |
| **GTH**, no SEP ! | 0.35 / 0.34 | **0.73 / 0.62** | 0.23 / 0.21 | **0.93 / 0.80** | 0.53 / 0.49 | **0.72 / 0.57** |
| **IGS**, SEP(arc) | 0.02 / 0.02 | **0.56 / 0.47** | 0.15 / 0.12 | **0.79 / 0.66** | 0.12 / 0.09 | **0.57 / 0.48** |
| **IGS**, SEP(arc), EST | 0.40 / 0.39 | **0.82 / 0.72** | 0.47 / 0.46 | **0.93 / 0.85** | 0.38 / 0.38 | **0.81 / 0.67** |

Looking the table downwards, it can be clearly seen: with shorter prediction there is the positive impact in the encreased accuracy, stability and even the simplicity of the analysis procedure ! Note, that the last line represents the solution with re-estimated final IGS orbits, which shows negative impact and characteristic bias for the re-estimation.

Finally, Fig.4. shows the comparison of NRT results with respect to post-processed one for our original strategy using CODE P2 re-estimated orbits (NRT-HA) and GOH/GTH hourly orbits (NRT-GA/NRT-FA). The RMS part of the plots demonstrates some kind of stability problems with long-term predicted and re-estimated orbits. The original strategy looks very good here, but it is a bit over-estimated since the CODE P2 orbits were of very high quality for this period.

## 4. Near real-time data center

Assistant data center in GOP (ftp://pecny. asu.cas.cz/LDC/) was designed as the "independent intelligent cash" for various kinds of near real-time processing in LAC GOP. Nevertheless, it can partially well serve to any user analysing GPS data even in post-processing mode. The main benefits of using the data center in GOP LAC can be expressed in the following:

- *helps* in short-time (1-5 hours) internet disconnections
- *alternates* any single data center drop-out
- *unifies* the data and the name formats
- *collects* actual GPS system informations
- *maintains* informative files for routine NRT processing
- *suites* for complete collecting NRT data and products for any testing purposes.

The directory structure contains the areas for GPS RINEX data, precise orbits and EOPs, ionospheric and tropospheric products, GPS system information, permanent site description logs, Bernese user supporting files and many others mostly temporary archived sources. GPS data are stored only in hourly files with standard plus Hatanaka compression and they are regularly deleted after few days (usually set up for 4-5 days). On other hands, the orbits and other related products are stored for a longer period of half or one year.

The data center is based on mirroring selected ftp data/product sites at given intervals from half a day to 10 minutes period updates. There are only minimum actions within the center – mostly manipulations of the file names, format types, file compressions, concatenations etc.

## 5. Hourly orbit product

The main demand for seting up a precise subdaily orbit product arises from many projects dealing with GPS meteorology applications. Any longer (1-2 days) orbit predictions are more or less uncertain, mainly in the along-track component. Our own experience [Douša,2000] as well as the presentations of other groups [e.g. Ge, 2000] has proved the possibility to derive the zenith total delays with high accuracy even in near real-time. In all cases it was possible because of use of any realiable orbit re-estimation strategy hand by hand with individual satellite quality valuation.

We have decided to test the possibility of GPS orbit determination on hourly basis. Since February 2000, IGS provides combined ultra-rapid product (twice a day) containing 1 day fitted and 1 day predicted orbits. Nevertheless, it is still necessary to use 3-15 hours predictions. With our hourly orbits, this period can be minimized up to 1-2 hours only.

Finally, we have proved the availability of such a product even in the time (August 2000) with limited and somewhere sparse hourly global GPS network configuration. The GOP hourly orbit product can be briefly summarized as:

- *determined* 24´ day with 1-1.5 hours delay
- *evaluated* by the Bernese GPS software V4.2a (fixed for hourly normal equations with orbital parameters)
- *estimated* from the global network of approx. 50 sites *based on* 48 hours fitted arcs *provided* by 24 h fitted and 24 h predicted ephemerides in SP3 format file
- *contains* the full set of all the available satellites
- *benefits* especially for the accurate along-track position in NRT
- *available* in GOP data center (from IX/00)
- *can not be fully guaranteed* due to dependency on the NRT data flow.

Figure 5. compares position differences of various orbit products (available in near real-time) with respect to the final IGS product.

## 6. Summary

Apropriate analysis of low elevation data and its impact for the precise coordinate estimation is still very questionable. In this paper, it was demonstrated the analysed sites behave rather differently by new strategies using elevation dependent weighting and/or low elevation dat. The strategy of data weighting points up some already existing specific site problems – different quality of the data in various elevations, "uknown" anthena phase center variation mainly due to a specific radome, etc. Finally, we should emphasize the necessity of clear description of the strategy for EUREF network analysis since choosen strategy influence directly the EUREF/IGS reference frame coordinates. Any user should be then careful while selecting reference sites and using apropriate analysing strategy.

Even most of our forces are focused at the field of near real-time processing, these GOP AC activities were presented very briefly here. The increase of the total quality and the stability of our near real-time ZTD results is clear. We are ready to test the practical possibility of the GPS contribution to the numerical weather prediction. We hope to approach this task during the next year within the ongoing EC project COST 716 specialized on this topics.

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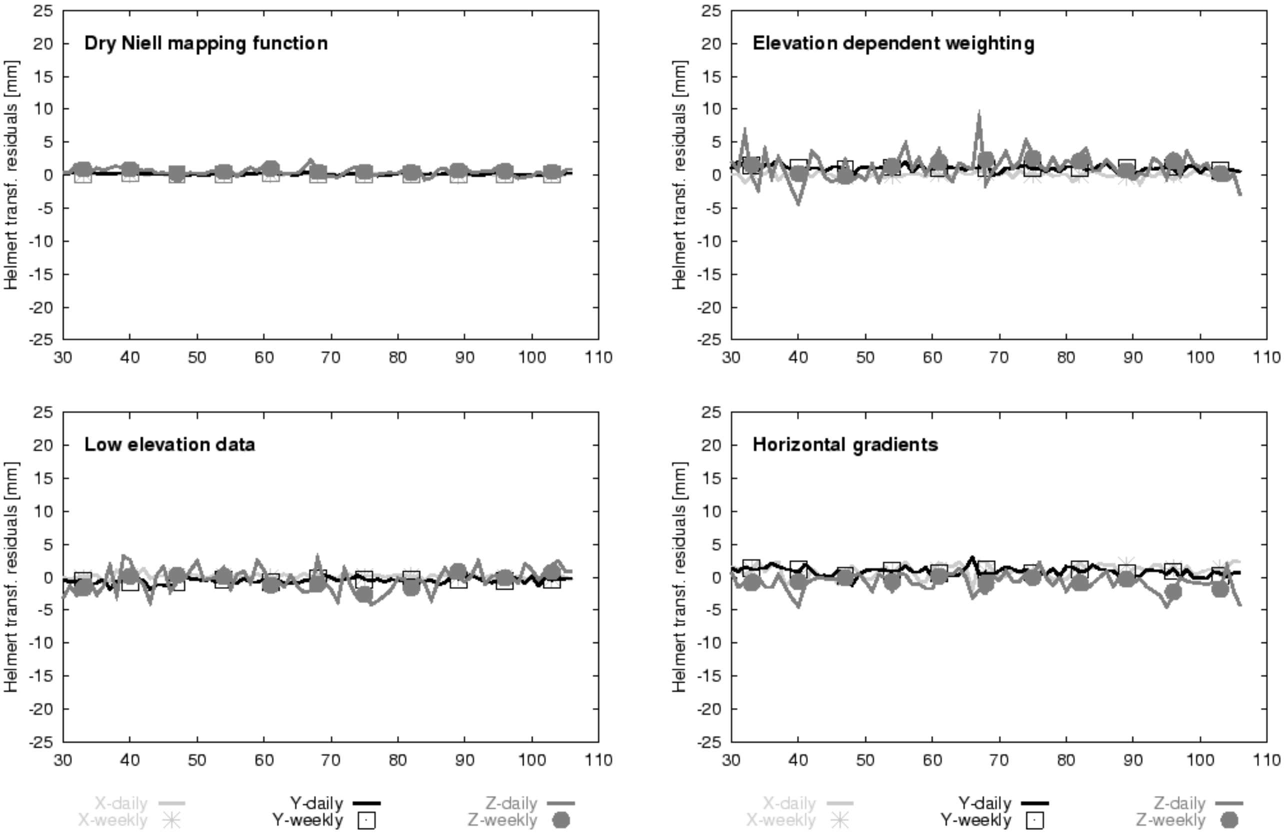


Fig. 1: Site BOGO – coordinate comparisons between different strategies (sequentially one to another which better expresses the influence of each strategy introduction – Tab. 1). Horizontal axes represent date in DoY

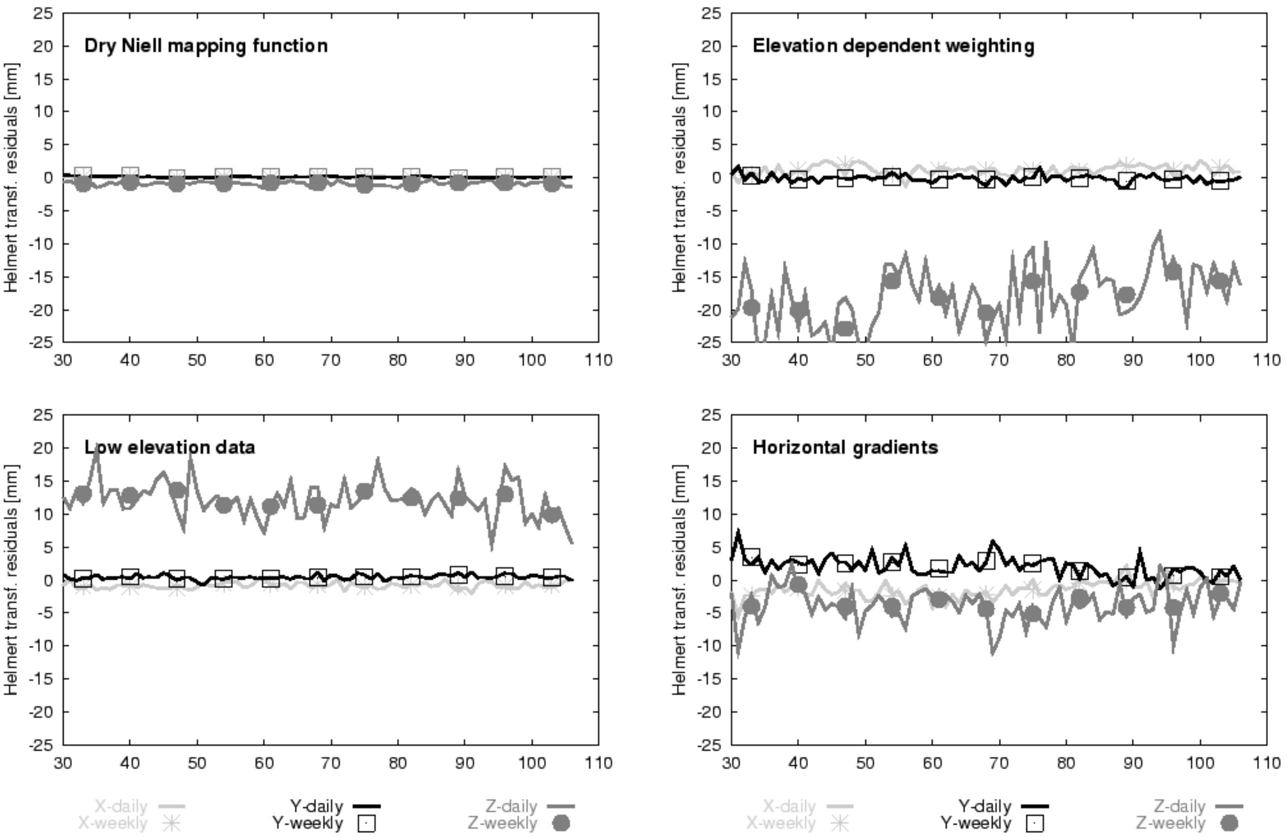


Fig. 2: Site MOPI – for the caption see Fig. 1

Tab. 5: RMSs from Helmert comparisons: 4 variants with respect to standard (GOP) solution. F_N solution differs from W__ only by mapping function, other abreviations for variant identification are explained in Tab.1

| site | F_N ´ GOP | | | W__ ´ GOP | | | WE_ ´ GOP | | | WEG ´ GOP | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | X[mm] | Y[mm] | Z[mm] | X[mm] | Y[mm] | Z[mm] | X[mm] | Y[mm] | Z[mm] | X[mm] | Y[mm] | Z[mm] |
| **BOGO** | -0.04 | 0.88 | 0.71 | 0.07 | 1.02 | 1.18 | 0.19 | 0.54 | 0.76 | 1.10 | 1.36 | 0.02 |
| **VIS0** | -0.03 | 0.37 | -2.66 | 0.09 | 0.37 | -2.73 | 0.10 | 0.09 | -0.66 | 0.64 | 0.74 | -0.69 |
| **EIJS** | -0.28 | -0.51 | 8.03 | -0.27 | -0.70 | 9.13 | -0.18 | -0.17 | 1.82 | -0.25 | 0.32 | 2.27 |
| **OBER** | 0.31 | -0.18 | 0.01 | 0.27 | -0.20 | -0.17 | 0.16 | -0.04 | 0.68 | 0.42 | 0.17 | -0.18 |
| **GOPE** | -0.36 | -0.23 | 1.90 | -0.38 | -0.17 | 2.07 | 0.09 | -0.23 | -1.64 | -0.91 | -1.19 | 0.25 |
| **GRAZ** | -0.37 | -0.19 | -1.34 | -0.41 | -0.09 | -1.18 | -0.28 | 0.08 | -0.23 | -0.64 | -0.14 | -0.42 |
| **MOPI** | 1.11 | -0.18 | -16.83 | 1.17 | -0.09 | -17.93 | 0.35 | 0.35 | -5.80 | -1.01 | 2.35 | -9.56 |
| **ONSA** | -0.13 | 0.35 | -1.38 | 0.02 | 0.37 | -1.08 | 0.10 | 0.04 | 1.14 | 0.20 | 0.66 | 1.15 |
| **KIR0** | 0.04 | -0.81 | 1.03 | -0.24 | -0.88 | 0.91 | -0.40 | -0.23 | -0.66 | -0.82 | -0.91 | -0.70 |
| **MAR6** | -0.02 | 0.22 | -1.31 | 0.04 | 0.21 | -1.55 | 0.04 | 0.07 | 0.19 | 0.54 | 0.73 | 0.29 |
| **TRO1** | 0.83 | -0.37 | 5.22 | 0.81 | -0.35 | 6.03 | -0.64 | 0.15 | -0.59 | -1.73 | 0.04 | -0.35 |
| **LLIV** | 0.75 | -0.55 | -0.15 | 0.83 | -0.75 | -1.57 | 0.32 | 0.34 | -3.71 | 0.39 | 0.51 | -2.60 |
| **MDVO** | 1.28 | 1.35 | 5.34 | 1.58 | 1.49 | 6.36 | 1.21 | 1.25 | 6.52 | 2.51 | -0.51 | 9.22 |
| **MANS** | 0.56 | -0.04 | 0.38 | 0.63 | -0.26 | 0.45 | 0.09 | -0.22 | -0.24 | 0.13 | 0.03 | -0.41 |
| **TUBI** | 0.23 | -1.32 | -10.51 | 0.38 | -0.49 | -10.84 | -0.58 | 1.51 | 2.47 | -1.19 | 1.23 | -3.18 |
| **RIGA** | -0.08 | 0.20 | -3.89 | 0.11 | 0.27 | -3.58 | 0.27 | 0.26 | 2.19 | 0.91 | 0.63 | 2.68 |
| **SVTL** | 0.37 | 0.92 | 2.73 | 0.65 | 0.79 | 3.43 | 0.59 | 1.08 | 7.10 | 0.11 | 1.02 | 5.75 |
| **UZHL** | -0.28 | 0.15 | -1.86 | -0.22 | 0.37 | -1.65 | -0.25 | 0.53 | 2.79 | -0.18 | 0.63 | 1.03 |
| **TRAB** | 0.72 | -0.99 | -9.44 | 1.34 | 0.38 | -8.62 | 0.73 | 2.64 | 5.47 | 0.44 | 1.42 | 1.95 |
| **ZWEN** | 0.14 | -0.29 | -3.39 | 0.45 | -0.33 | -3.08 | 0.42 | 0.39 | 3.06 | 0.60 | -0.36 | 2.88 |
| **ZECK** | 0.88 | -2.18 | -12.87 | 1.79 | -1.63 | -13.21 | 0.82 | 1.28 | 1.57 | -0.36 | 0.56 | -213 |

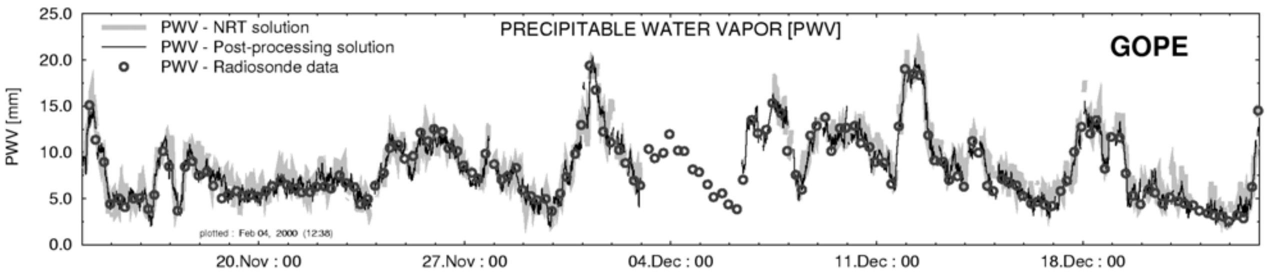


Fig. 3: NRT PWV and post-processed PWV results validated by radiosonde integrated profiles

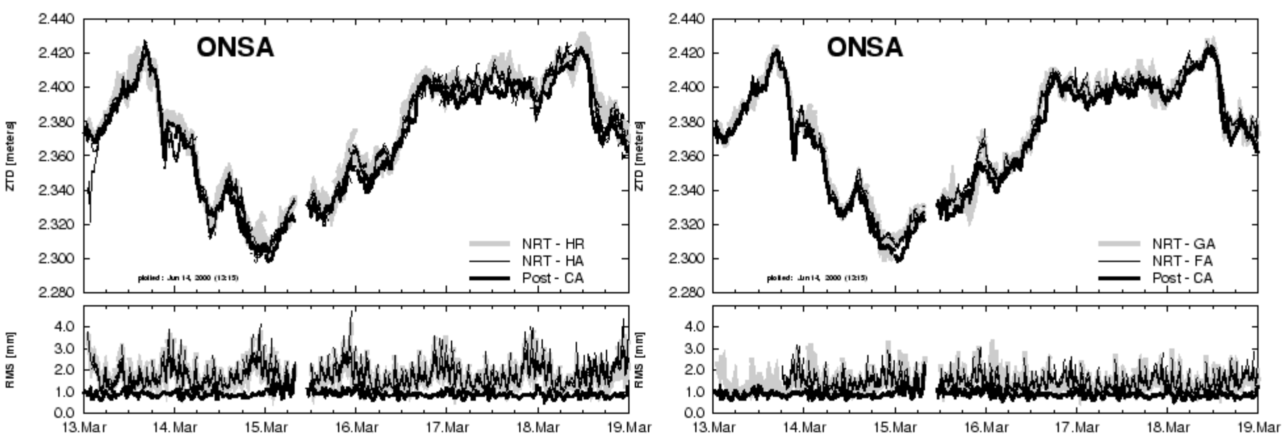


Fig. 4: NRT ZTD estimation with relaxated CODE P2 orbits(left) and fixed GOP/GTH hourly orbits (right)

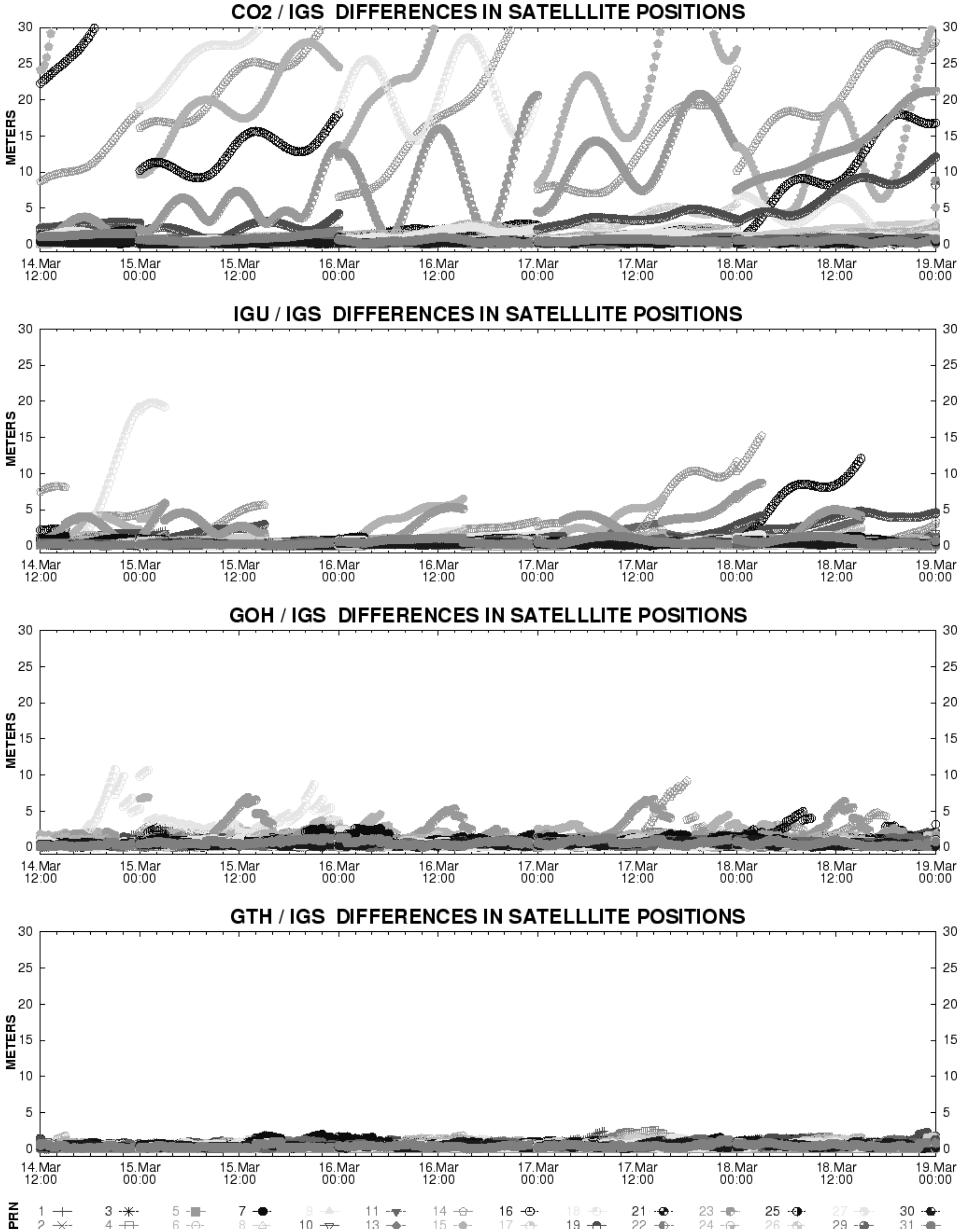


Fig. 5: Various orbit position differences with respect to final IGS product. From above to bottom: CO2 (48 h predicted CODE orbits), IGU (ultra-rapid IGS), GOH (hourly GOP) and GTH (GOP special tested hourly product with a priori 5 older satellites exluded)