# Using the IGS Real-Time Service and G-Nut/Tefnut for Nowcasting Severe Weather

Royal Observatory of Belgium

Research Institute of Geodesy, Cartography and Topography

Eric Pottiaux (1), Pavel Vaclavovic (2), Jan Dousa (2) and Carine Bruyninx (1)
(1) Royal Observatory of Belgium – (2) Geodetic Observatory Pecny, Czech Republic

Mail to : Eric.Pottiaux@oma.be

## Introduction

Today, GNSS meteorology relies on the assimilation of GPS-based hourly-updated Zenith Tropospheric Delays (ZTDs) for Numerical Weather Prediction (NWP). Neither information about the atmospheric heterogeneities (e.g. horizontal gradients) nor multi-GNSS observations are used operationally. Compared to current operational GPS meteorology (NWP), monitoring and forecasting severe weather (nowcasting) requires [4]

1) Higher spatial and temporal resolutions,
2) Information about the asymmetry in the atmosphere and
3) Provision of this information with almost no latency (optimally less than 5 min).

This requires a complete real-time approach, from the acquisition of the GNSS observations, orbits and clocks up to the generation of the tropospheric products and their delivery. Such applications can now be investigated thanks to

1) The IGS Real-Time Service (started in April 2013) and
2) The ongoing developments of GNSS processing software capable of estimating tropospheric products in real-time.

G-Nut/Tefnut [1] is one of these real-time GNSS software and is developed at the Geodetic Observatory Pecný (GOP), Czech Republic. The Royal Observatory of Belgium (ROB) and GOP are investigating the use of G-Nut/Tefnut for the exploitation of the Belgian dense GNSS network to provide tropospheric products in real-time for nowcasting applications, focusing on the asymmetry and multi-GNSS aspects. This poster presents the developments and firsts results from this new collaboration.

## Benchmark Campaign

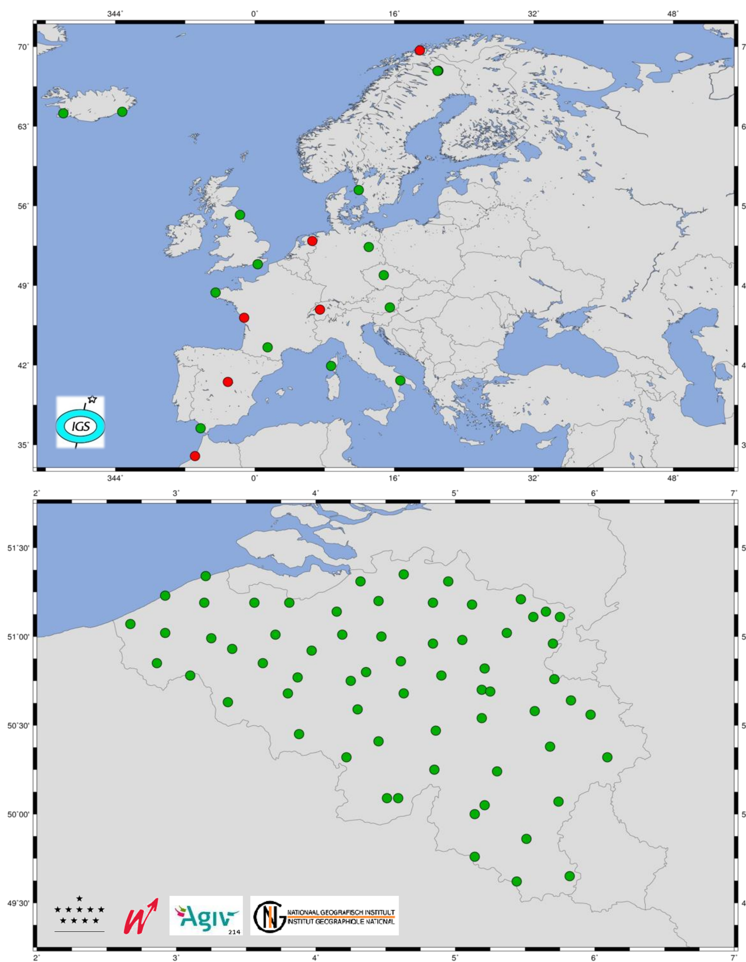

*Figure 1: Network of GNSS stations used to benchmark our developments. Top: IGS Stations – Bottom: The Belgian dense network (Green dots: GPS+GLONASS stations. Red Dots: GPS-only stations).*

Figure 1 shows the network of permanent stations selected to benchmark our developments. It includes 23 European IGS stations (top) and the 67 stations from the Belgian dense network (bottom). Most of the stations are tracking both GPS and GLONASS signals (green dots). The analysis period covers January-April 2014. The processing strategy is summarised in Table 1. The results are compared to two reference datasets: 1) the IGS Final troposphere Product [3] and 2) a Bernese [2] PPP solution ran at ROB. Both estimate troposphere parameters with a time resolution of 5 min (with a similar strategy as in Table 1).

| | |
|---|---|
| Processing type | Precise Point Positioning / Ionosphere-free |
| Adjustement method | Square root Kalman |
| Observation systems | GPS observations |
| Number of GNSS stations | 90 stations |
| Observation window length | 24 hours |
| Observation cut-off angle | 3° |
| Observation period | 01/01/2014 → 30/04/2014 (4 months) |
| References frame / Antenna models | IGb08 / Absolute calibration models (IGS08) |
| Orbit and Earth orientation parameters | IGS final products |
| Ocean tidal loading model | FES2004 model |
| A priori tropospheric model | Saastamoinen + Dry GMF |
| Tropospheric correction model | Estimated + Wet GMF |
| Time resolution ( ZTD and horizontal gradients) | Every 5 minutes |
| Relative constraints for ZTD | Random walk: 1.0 mm/sqrt(h) |
| Relative constraints for horizontal gradient | Random walk: 0.1 mm/sqrt(h) |

*Table 1: Main characteristics of the G-Nut/Tefnut setup tropospheric products.*

## 1D Atmospheric Parameter – Zenith tropospheric Total Delays (ZTD)

**Remarks:**

- In all comparisons, we only considered the G-Nut/Tefnut estimates after the convergence period (reset each day) which was identified based on the formal error of the estimates (e.g. 1D coordinates std. dev. < 6 mm).
- As a first step in our investigations, these results were obtained using the IGS Final orbit and clock product and GPS-only observations.

**Main Facts:**

- Fig. 2-5: comparing G-Nut/Tefnut ZTDs w.r.t. ZTDs from the IGS Final Product or the ROB PPP Product gives similar results over the 23 IGS sites → we can use the ROB PPP Product to compare over the 90 GNSS stations.
- Fig 4-5: G-Nut/Tefnut ZTDs compares w.r.t. reference products with biases and standard deviations typically below 10 mm. It thus satisfies the precision and accuracy requirements for nowcasting in Belgium.
- Fig 7: averaged over the 90 sites, the ZTDs estimated by G-Nut/Tefnut show a 2mm bias and a std. dev. of 7mm.
- The Kalman backward smoothing usually improves the ZTD differences std. dev. by 10 to 20 % (i.e. 1 to 2 mm).

**ZTD Reference: IGS Final Product**

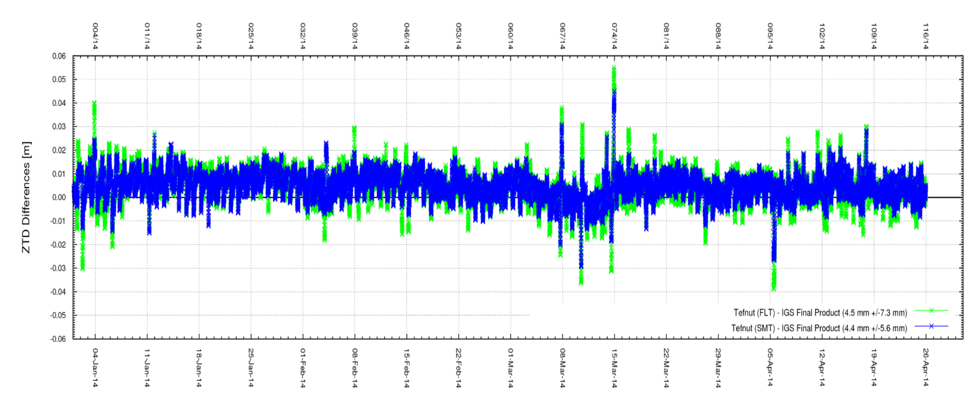

*Figure 2: ZTD Differences between the estimates produced by G-Nut/Tefnut and the IGS Final troposphere product for the station Onsala, Sweden. Green curve: using only a forward Kalman filter. Blue curve: using also the Kalman backward smoothing capability.*

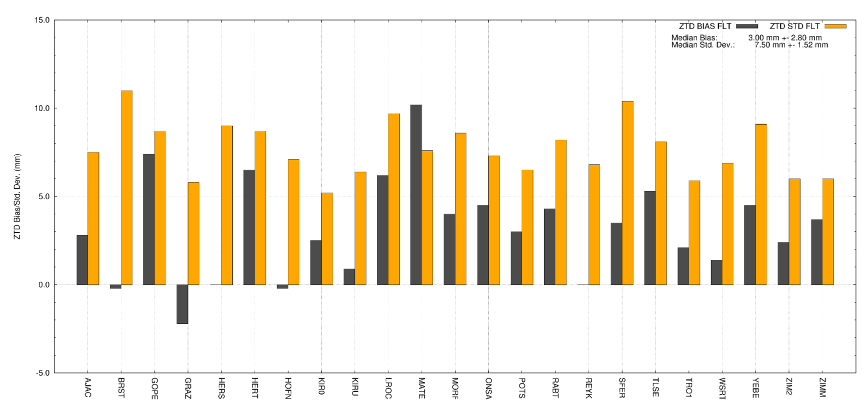

*Figure 4: Mean (in grey) and standard deviation (in orange) of the ZTD differences between the G-Nut/Tefnut estimates and the IGS Final troposphere products for the 23 IGS stations.*

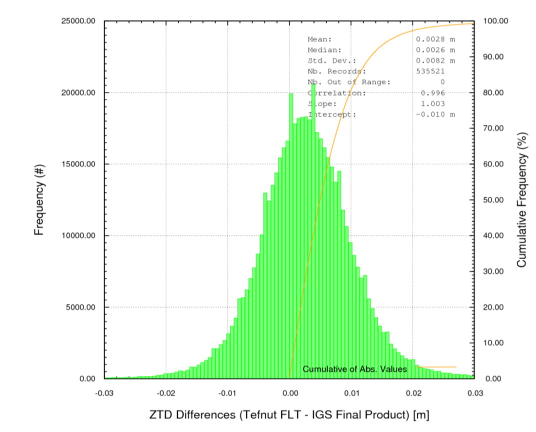

*Figure 6: Histogram of the ZTD differences between the G-Nut/Tefnut estimates and the IGS Final troposphere product for the 23 IGS stations.*

**ZTD Reference: ROB PPP Product**

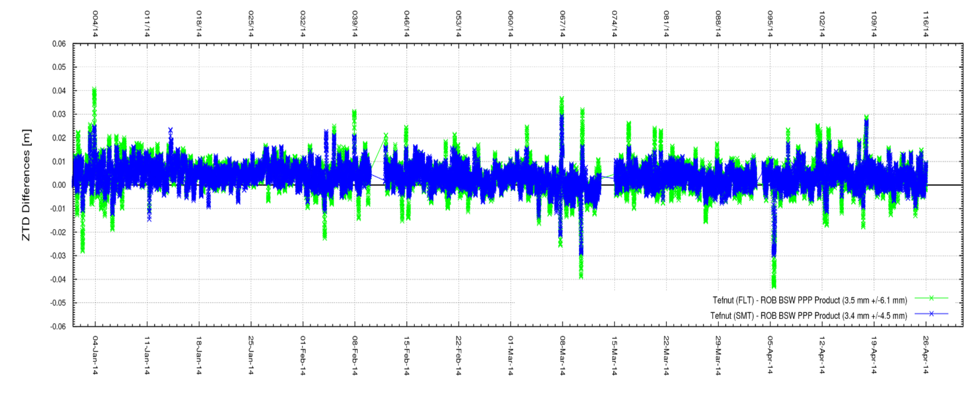

*Figure 3: ZTD Differences between the estimates produced by G-Nut/Tefnut and the ROB Bernese PPP troposphere product for the station Onsala, Sweden. Green curve: using only a forward Kalman filter. Blue curve: using also the Kalman backward smoothing capability.*

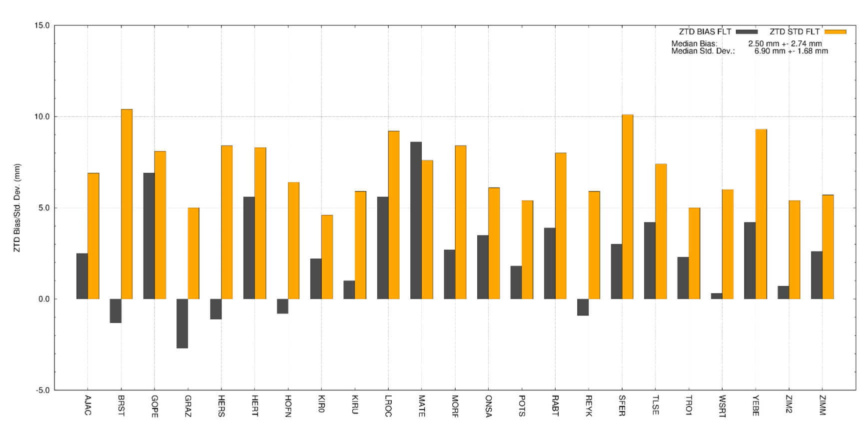

*Figure 5: Mean (in grey) and standard deviation (in orange) of the ZTD differences between the G-Nut/Tefnut estimates and the ROB PPP troposphere products for the 23 IGS stations.*

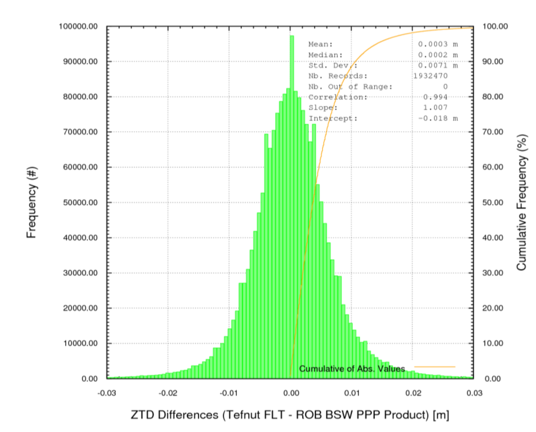

*Figure 7: Histogram of the ZTD differences between the G-Nut/Tefnut estimates and the ROB PPP troposphere product for the 90 stations.*

## 2D Atmospheric Asymmetries - Horizontal Gradients (GRD)

**Remarks:** Same as above.

**Main Facts:**

- Fig. 8-11: comparing G-Nut/Tefnut GRDs with GRDs from the IGS Final Product or the ROB PPP Product gives similar results but the std. dev. when comparing with the latter is slightly larger due to relaxed relative constraints (ROB: 1mm, IGS: 0.1mm).
- Fig. 13 and 15: averaged over the 90 sites, the GRDs estimated with G-Nut/Tefnut have (almost) no bias and a std. dev. of 0.73mm.
- No requirement exists yet for using GRDs in meteorology (task for COST ES1206) → no point of comparison.

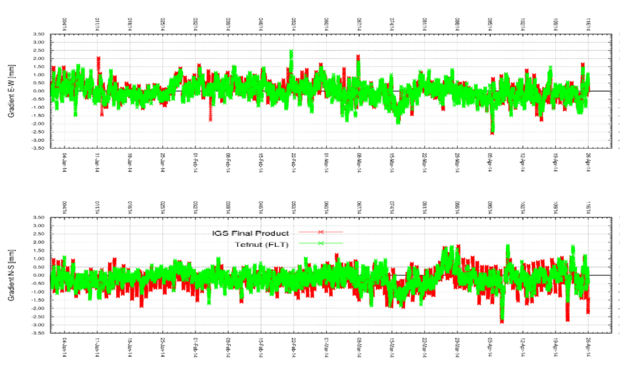

*Figure 16: Time series of the horizontal gradients differences (bottom: North-South, top: East-West) between the G-Nut/Tefnut estimates and the IGS Final Products for Onsala, Sweden.*

**GRD Reference: IGS Final Product**

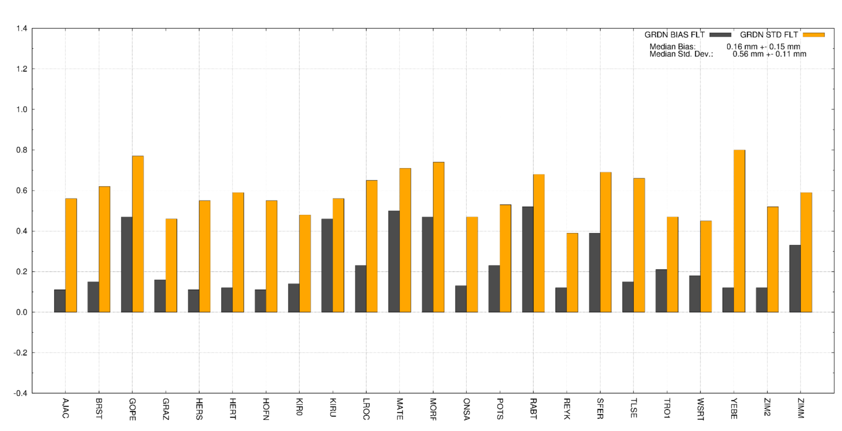

*Figure 8: Mean (in grey) and standard deviation (in orange) of the gradient North-South differences between the G-Nut/Tefnut estimates and the IGS Final troposphere products for the 23 IGS stations.*

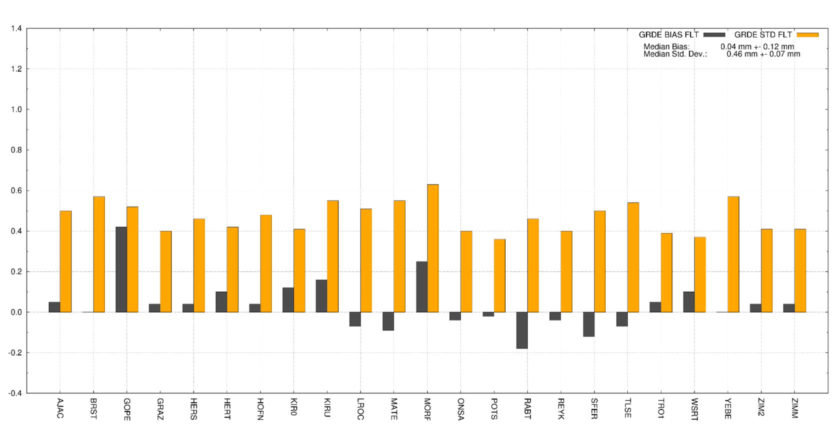

*Figure 10: Mean (in grey) and standard deviation (in orange) of the gradient East-West differences between the G-Nut/Tefnut estimates and the IGS Final troposphere products for the 23 IGS stations.*

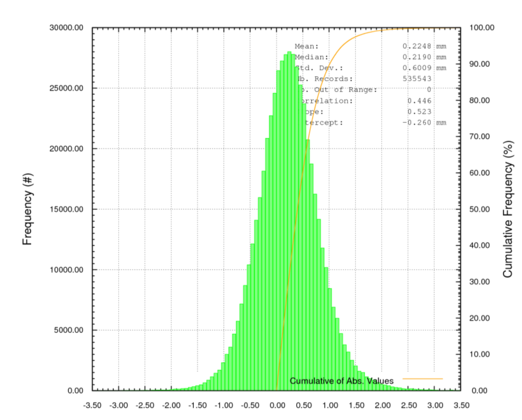

*Figure 12: Histogram of the gradient North-South differences between the G-Nut/Tefnut estimates and the IGS Final troposphere product for the 23 IGS stations.*

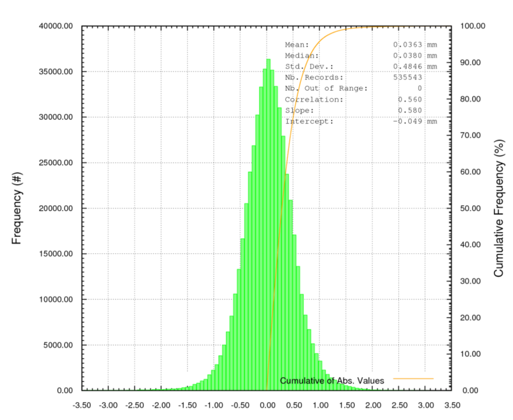

*Figure 14: Histogram of the gradient East-West differences between the G-Nut/Tefnut estimates and the IGS Final troposphere product for the 23 IGS stations.*

**GRD Reference: ROB PPP Product**

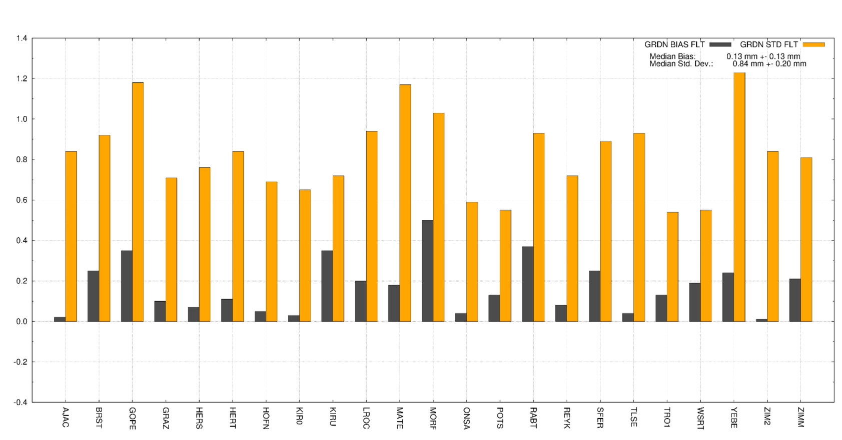

*Figure 9: Mean (in grey) and standard deviation (in orange) of the gradient North-South differences between the G-Nut/Tefnut estimates and the ROB PPP troposphere products for the 23 IGS stations.*

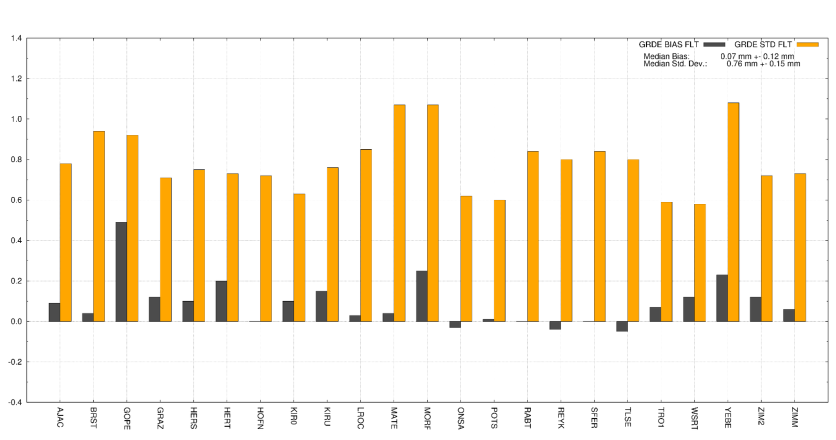

*Figure 11: Mean (in grey) and standard deviation (in orange) of the gradient East-West differences between the G-Nut/Tefnut estimates and the ROB PPP troposphere products for the 23 IGS stations.*

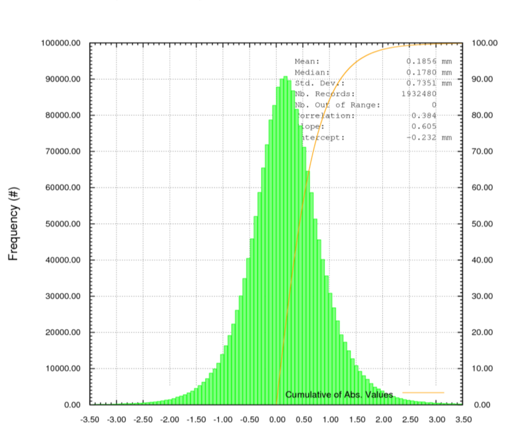

*Figure 13: Histogram of the gradient North-South differences between the G-Nut/Tefnut estimates and the ROB PPP troposphere product for the 90 stations.*

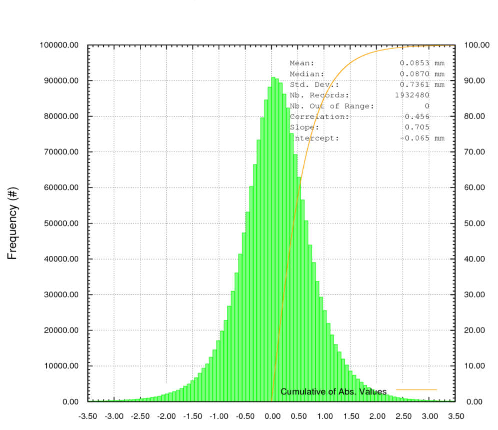

*Figure 15: Histogram of the gradient East-West differences between the G-Nut/Tefnut estimates and the ROB PPP troposphere product for the 90 stations.*

## On-going & Future Investigations

- Setup a real-time benchmark campaign and carry out a long-term evaluation based on the IGS real-time service to confirm the results obtain above in operational conditions.
- Extend the test period from January 2012 – now.
- Investigate the added-value of processing multi-GNSS observations in G-Nut/Tefnut for nowcasting.
- Further investigate the backward smoothing of the troposphere parameter estimates.

## References and Acknowledgements

This research has been carried out in the framework of the Solar-Terrestrial Centre of Excellence (STCE) and was supported by the EU COST Action ES1206. The development of the G-Nut/Tefnut software is supported by the Czech Science Foundation (P209/12/2207) and by the Ministry of Education, Youth and Sports (LD14102). We gratefully thank all colleagues and agencies for providing their data and precise products.

[1] Dousa J., Vaclavovic P. (2014) Real-time zenith tropospheric delays in support of numerical weather prediction applications. Advances in Space Research (2014), Vol 53, No 9, pp 1347-1358, doi:10.1016/j.asr.2014.02.021
[2] Byram S. and Hackman C. (2012), Computation of the IGS Final Troposphere Product by the USNO, IGS Workshop 2012, http://www.igs.org/assets/pdf/Poland%202012%20-%20P06%20Byram%20PO33.pdf
[3] Dach R. et al. (2007), Bernese GPS Software Version 5.0.
[4] E-GVAP II Product Requirements Document (PDR, version 1.0 – 21 December 2010) prepared by the U.K. Met Office.

EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Solar-Terrestrial Centre of Excellence