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1. Contribution to the EPN

1.1 EPN Central Bureau

The Royal Observatory of Belgium (ROB) continued to manage the EUREF Permanent Network Central Bureau. Since June 2016, ROB integrated 38 new stations in the EPN network (11 stations in Germany, 2 in Spain, and 7 in Finland).

Next to the core EPN network, ROB also collects and validates the metadata of the EPN densification network. As a result, ROB is today providing access to a unique collection of GNSS metadata for more than 1500 European GNSS stations.

A brand new web site for the EUREF Permanent Network (EPN, http://www.epncb.oma.be/ or http://www.epncb.eu/), including the results of our new multi-GNSS monitoring procedures, went on line in Nov. 2016. The web site includes now

- ✓ Improved GNSS data quality checks (multi-GNSS) on both RINEX 2 and RINEX 3, done using the G-nut/Anubis software (Václavovic and Dousa, 2016)
- ✓ Improved station position time series,
- ✓ Improved GNSS data availability and data latency checks on both RINEX 2 and RINEX 3,
- ✓ Full implementation of long RINEX 3 station names,
- ✓ Extended monitoring of real-time data streams, now also including RTCM3.2 and all 3 regional EPN broadcasters,
- ✓ Extended station list with more station metrics,
- ✓ More intuitive menu structure to navigate through the web site.

For more details, we refer to the presentation “Enhanced Assessment of EPN Station Performance” by Bruyninx et al. (EUREF 2017 symposium).

ROB is also developing a completely new on-line GNSS station metadata management and dissemination system. The system will be used in EPOS[1] and in the EPN. In fact, Operational Centres will have to upload their station metadata just once and then these metadata will be updated automatically within all metadata systems of the networks to which the station contributes. The transition from the present EPN on-line site log validation and submission tool will be done gradually, one Operational Centre (or data provider) at a time. It will start in the late summer of 2017. At the same time, also EPOS data providers will start using this new system. More details are provided in the presentation “A new GNSS station metadata management and dissemination system in support of multiple networks”, by Fabian et al (EUREF 2017 symposium).

[1] *European Plate Observing System integrates European Research Infrastructures for solid Earth science to monitor and understand the dynamic and complex solid-Earth System.*

1.2 Data Analysis

ROB continued to deliver daily rapid and final position and tropospheric zenith path delay estimates to EUREF. Since May 2016, 24 new stations were added in the ROB network (ADAR00GBR, ARIS00GBR, AUBG00DEU, CHIO00GBR, DIEP00DEU, DILL00DEU, EDIN00GBR, FINS00FIN, GELL00DEU, GOR200DEU, HEL200DEU, HOFJ00DEU, IJMU00NLD, LDB200DEU, LEIJ00DEU, LERI00GBR, MET300FIN, PMTH00GBR, SCIL00GBR, SHOE00GBR, SNEO00GBR, SWAS00GBR, VIR200FIN, and VLIS00NLD), bringing the total of EPN stations submitted to EUREF at 99.

Since Aug. 2016, the ROB analysis centre is processing RINEX 3 data (if available) instead of RINEX 2. Since Jan. 2017, the new epn_14.atx antenna calibration model is used and the solutions are tied to the new IGS14 reference frame.

2. Services and Products Based on the EPN

2.1 Ionospheric Products and Space Weather impacts

We continued to maintain the near real-time ionospheric products generated by the ROB-IONO software using GNSS data from the EPN. Ionospheric maps are displayed online at www.gnss.be and IONEX data are available at ftp://gnss.oma.be. In 2016, four abnormal ionospheric activities due to space weather event were identified and reported (http://gnss.be/ionospheric_event.php).

2.2 Tropospheric Products and E-GVAP Analysis Centre

ROB maintained its GNSS analysis centre participating to the E-GVAP program (Pottiaux and Bruyninx, 2016) and provided European meteorological institutes with near real-time (NRT, i.e. hourly) tropospheric Zenith Path Delay (ZPD) estimates for assimilation in the Numerical Weather Prediction (NWP) models. The developments done last year (switch to Bernese GNSS v5.2, updated modelling, better spatial coverage, and GPS+GLONASS analysis) are now used operationally. In addition, two new contributions to E-GVAP are now operational: 1) a hourly global analysis (~290 stations, mainly IGS sites) to support global NWP models, and 2) a processing running every 15 minutes to support nowcasting applications in the Benelux + U.K. area based on the processing of real-time observations from ~225 EPN and national GNSS stations.

3. Research Activities

3.1 Long-term Stability of GNSS-based Tropospheric Zenith Path Delays

Within the Belgian national project CORDEX.be (Termonia et al. 2016), ROB completed a reprocessing activity to produce GNSS-based tropospheric products for the verification and validation of high-resolution climate model runs over Belgium. The validation and verification process is now undergoing. The second focus (in collaboration of with the Royal Meteorological Institute (RMI) of Belgium and several participants of the COST Action ES1206 GNSS4SWEC) concerned the homogenisation of IWV (Integrated Water Vapour) time series derived from the IGS-repro 1 product: synthetic datasets of different complexity levels have been created to benchmark the existing homogenisation tools participating in our activity. A first blind test exercise (based on these synthetic datasets) was carried out to examine the performance of each tool, provide feedback to the operators (aiming at enhancing their tool), and to try to pinpoint a proper scheme for the actual homogenisation of the IGS-repro 1 tropospheric product (e.g. a combination of the results from the different tools + selected metadata). Finally, we collaborated with the RMI on the evaluation of the atmospheric water vapour in the regional climate model ALARO coupled to the land surface scheme SURFEX using GNSS observations (Berckmans et al., 2016). Results based on the EPN-repro 2 tropospheric product are presented at the EUREF symposium 2017.

3.2 COST Action ES1206 (GNSS4SWEC) on GNSS, severe weather and climate

ROB continued to co-chair WG2 of the E.U. COST Action ES1206 “Advanced GNSS Tropospheric Products for monitoring Severe Weather Events and Climate” (GNSS4SWEC) and focusses on

1. using real-time GNSS observation and orbit and clock products to provide real-time troposphere estimates computed with the GNut TefNut Software in support of severe weather forecasting/nowcasting;
2. producing Slant Tropospheric Delays (STDs) with the Bernese GNSS software based on the benchmark campaign setup in GNSS4SWEC (Kačmařík et al 2017);
3. on the trends and homogenisation of IWV time series derived from the IGS repro 1 tropospheric product.

We co-organised a topical workshop in Jan 2017, Warsaw and held the final GNSS4SWEC workshop at ESTEC, in Feb. 2017, Noordwijk, the Netherlands.

3.3 Research on Space Weather impact

ROB reprocessed the entire EPN to produce IONEX files since 1998. Based on this new data set, we developed an empirical model in order to predict the vertical total electron content (vTEC) over Europe using only one solar index in entrance. Among all the tests, the optimal model to predict the vTEC every 15 min. presents mean differences with observed values of 2.4 ± 2.8 TECu and 10.0 ± 25.2 % for the relative differences. Differences larger than 15 TECu occurred during abnormal ionospheric activity correlated to space weather events (Figure 1, Bergeot et al. 2015).

The EPN data were used to study the impact of the March 17, 2015 event (i.e. the Saint Patrick storm) on the ionosphere (García-Rigo et al. 2016) in the frame of the new Real Time Ionosphere Monitoring Working Group (RTIM-WG), which is part of IAG's Sub-commission 4.3 on "Atmosphere Remote Sensing". In the future, this WG will develop a procedure to automatically compare available real time ionosphere products.

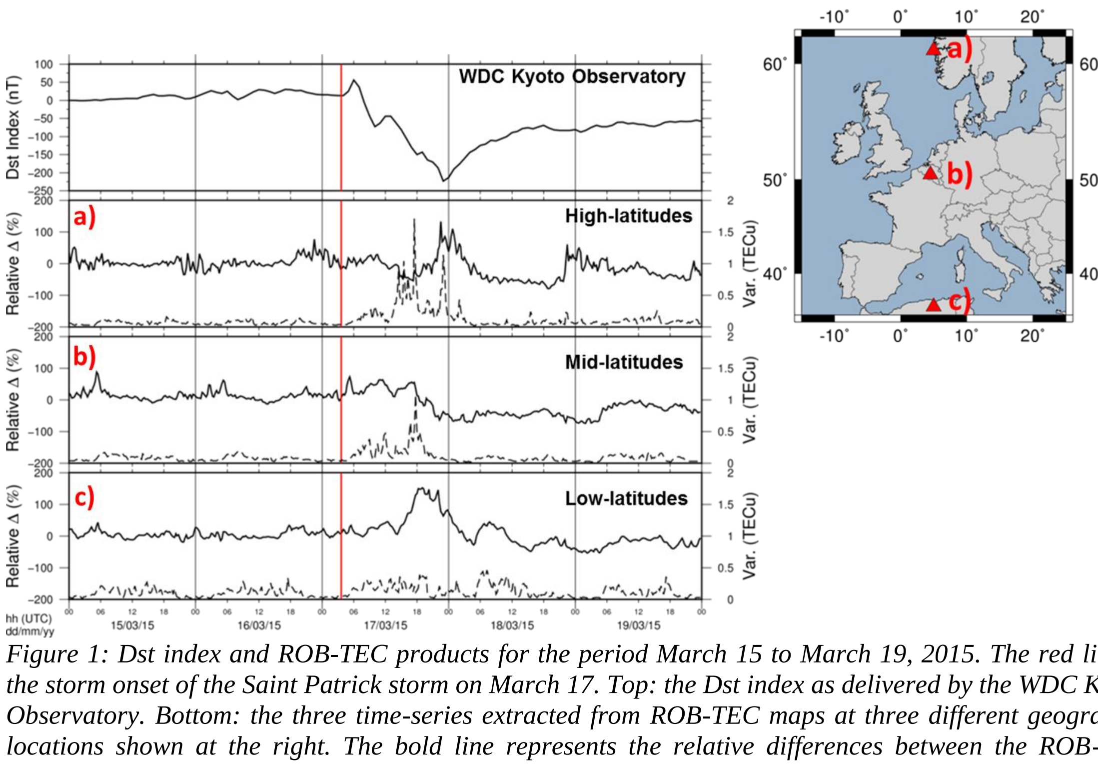

Figure 1: Dst index and ROB-TEC products for the period March 15 to March 19, 2015. The red line is the storm onset of the Saint Patrick storm on March 17. Top: the Dst index as delivered by the WDC Kyoto Observatory. Bottom: the three time-series extracted from ROB-TEC maps at three different geographic locations shown at the right. The bold line represents the relative differences between the ROB-TEC values and the median from the 15 previous days. The dashed line is the variability of the vTEC estimated in NRT.

Level	GNSS ΔC/N0 Fade	Effect
Quiet	< -1dB-Hz	None
Moderate	> -1 dB-Hz	SRB detected but should not impact GNSS applications
Strong	> -3 dB-Hz	Potential impact on GNSS applications
Severe	> -10 dB-Hz	Potential failure of the GNSS receivers

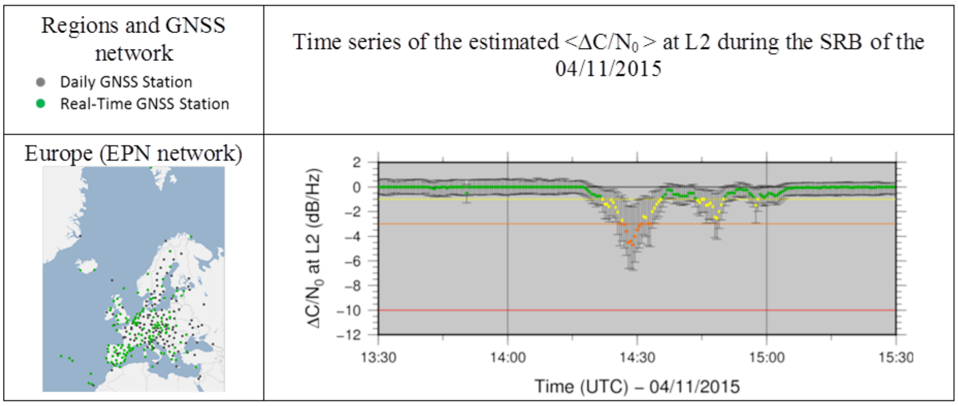

Figure 2: Top: the 4-level index for SRB impacting GNSS signal reception. Time Series of the fade of carrier to noise density (ΔC/N0) at the L2 GPS frequency during the solar radio burst of November 4, 2015 in Europe.

ROB continued to investigate the impact of Solar Radio Bursts (SRB), emitted close to the GNSS frequencies, on GNSS receivers. Based on normalized GNSS Carrier to noise density (C/N_0) observations of each satellite-receiver pair gathered from a regional network, the median of abnormal C/N_0 fades ($<\Delta C/N_0>_{L1,\ L2}$) is estimated to identify and quantify the impact of SRB on GNSS signal reception . We maintained a near-real time 4-level index alert detecting and quantifying solar radio bursts impacting GNSS signal reception (Chevalier et al. 2016). As an example, the private company Fugro started to use our SRB alert system. No SRB event affecting GNSS occurred in 2016.

3.4 Step-wise Analysis of the Quality of GNSS Network-based Processing

Over the last decades, the number of permanent GNSS stations included in the various ROB's network-based GNSS analysis centres (e.g. for EPN and for E-GVAP) increased significantly. Handling and monitoring the processing of such a big amount of GNSS data and meta-data is the next key challenge that should be achieved to keep all our GNSS products of high quality, reliable, and manageable. For this reason, a new tool 'ROBER' was developed by ROB to monitor and analyse the intermediate and final products of a GNSS network solution produced by using the Bernese GNSS software V5.2. The tool extract the significant Key Performance Indicators (KPI) for each step of the processing, store the metrics and products into databases, carry out statistical analysis, include a web-based user interface to graphically analyse the metrics and provide reports, and cross-check with meta-data. Finally, a number of decision models have been tested to identify and to automatically correct for situation that may cause a degradation of the reliability and the precision of the network solution and final products. This tool was presented during the symposium 2017 (poster "ROBER: A New Tool for Step-wise Analysis of the Quality of GNSS Network-based Processing" by Chatzinikos at al.).

4. AGN (Active Geodetic Network)

Since 2002, the National Geographic Institute (NGI) performs a daily and weekly solution for all the permanent GNSS stations in Belgium that are part of the three Belgian RTK networks. We continue

doing this work to see the stability of those stations. At the moment, there are 67 stations in our network calculation. The weekly results can be found on our website.
We have been calculating new coordinates for the station HOUT 13155M001. This station is situated in the eastern part of Belgium, where mining activities took place between 1930 and 1992. As we have mentioned in our previous reports, this area is undergoing a uplift of about 0.8 cm a year.

Because of this phenomenon, the coordinates of this GNSS station have to be adapted on a regular basis.

Since the beginning of 2015, we are taking part in the EPN Densification project and we deliver every week a solution to this project from all those permanent GNSS stations. We have been delivering all our weekly solutions starting from week 1656 (2 October 2011) up to week 1932.

5. Towards a new quasi-geoid and height-conversion model

The models that are disseminated by the NGI to transform ellipsoidal height to 'Ostend height' (levelling reference) were established in 2003, combining gravimetric data and more than 3000 GPS-levelling points. Tests have shown that the standard deviation of this transformation is 2 cm. We think that the accuracy can be augmented through a better analysis of the gravimetric data, which is rather inhomogeneous. Next to that, during the last decade, a new set of GNSS-levelling points, with a better quality, has been observed.
During our first test of creating a new height-conversion model we have been analyzing the reason why some points where rejected. In some areas, we had doubts about the homogeneity of our leveling network. A leveling network will be homogeneous in the area where the observations where done in a same time span. But obviously, you might get some inhomogeneity in the whole network because of the long span it took to do the complete leveling (from 1981 till 2000).

To analyze this problem we have been recalculating our network in one block.

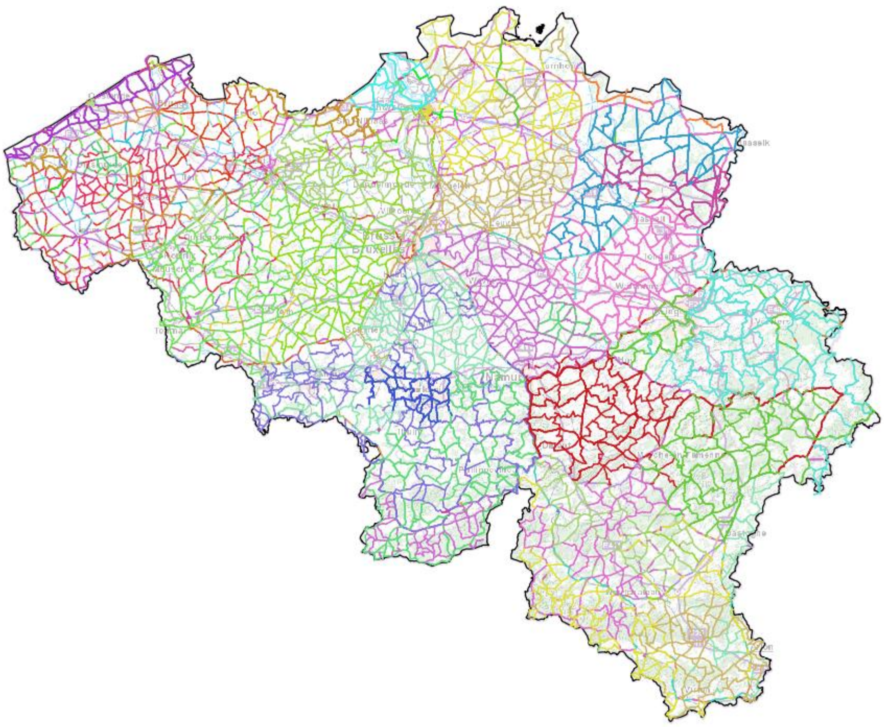

Figure 3: All the leveling observations, each color indicates a different year of observation.

In Figure 3 you can see all the leveling observations which have been used for determining our leveling network.
In this approach, we do not make any distinction between points of first, second or third order. All observations have been put together in one block. This block contains 35891 observations. We have fixed the fundamental point, which is at the Royal Observatory of Belgium (ROB) at his height of 100.174m. The least squares method was used to do the recalculation. The aim of this exercise is in the first place to analyse if the network is homogeneous, and not to recalculate all levelling benchmarks.
We have been detecting 12 places with big errors (between 3 cm and 10cm). In three of those places the errors have been already solved by performing new field observations.
The results for the small errors (between 0cm and 3cm) of this computation is represented in Figure 4 . In this figure, we see the observations which were rejected during the least squares adjustment (in red color), according to the constraints which we applied. New field observations for those rejected observations are planned for this year.

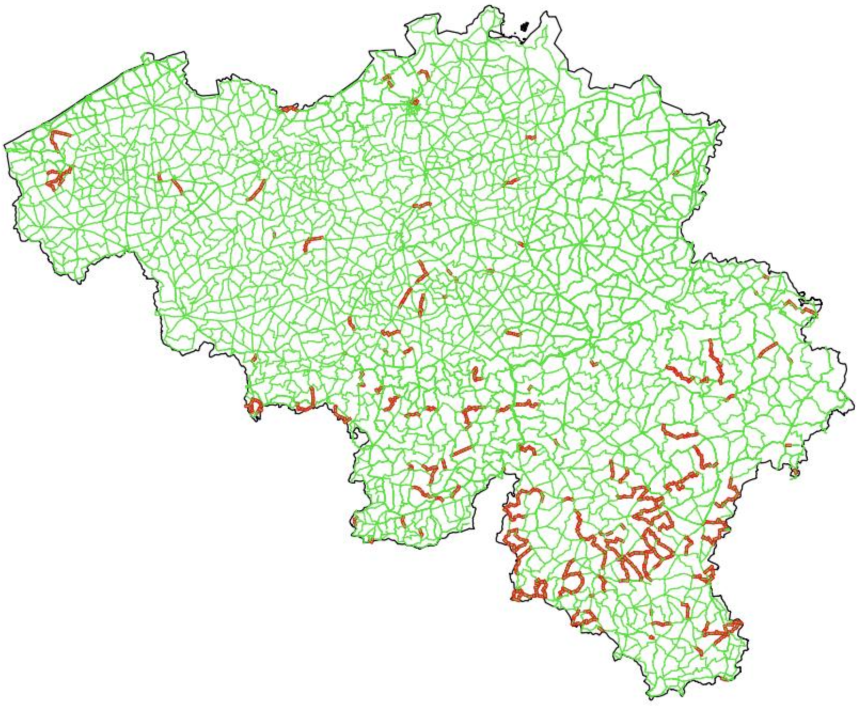

Figure 4: Results of the least squares adjustment. The rejected observations are in red color.

Acknowledgements

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