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The Royal Observatory of Belgium (ROB) is heavily involved in the EUREF Permanent Network (EPN) and is processing GNSS observations from the EPN since February 1996. Nowadays, the errors due to the reference frame definition and the Earth's atmosphere (ionosphere and troposphere) still remain the main limiting factors when performing high accuracy GNSS positioning. In that framework, the ROB carries a long-term research program that aims to better understand these error sources, to improve their mitigation in GNSS data processing and to provide specific products for the scientific community.

1. Ongoing Research based on the EPN and the National Densification Networks

1.1 Reference Frame Definition

Within the EPN a new Special Project dedicated to the coordination of the EPN re-processing has been set up (Völksen, 2009). During the project Pilot Phase, optimal processing strategies are investigated such as the need to add (or not) global IGS stations to the EPN re-processing.
Within that frame ROB investigated the impact of the reference frame definition and the size of the network on the reliability of cumulative positions, velocities and residual position time series obtained using the EPN. For that purpose, thirteen years (1996-2008) of weekly GPS solutions of 299 globally distributed stations have been used. Weekly regional solutions (with the same coverage as the EPN) and global solutions have been stacked using CATREF (Altamimi 2007a) to obtain respectively regional and global station positions, velocities, and residual position time series. In both cases, the estimated long-term solutions have been tied to the ITRF2005 (Altamimi 2007b) under minimal constraints using a selected set of reference stations.
The results show that, based on identical sets of weekly positions, the estimated long-term positions and velocities can differ (up to 2 mm in the horizontal and 8 mm in the vertical for the positions and up to 0.5 mm/yr in the horizontal and 2 mm/yr in the vertical for the velocities) due to a network effect which depends on the selection of the reference stations. In addition, the disagreement between the global and regional solutions (both positions and velocities) is amplified when the regional reference stations cover a smaller geographical area.
It was also demonstrated that the regional network underestimates the amplitude of the annual (27% reduction of the annual signal in the height component) and semi-annual signals in the residual position time series in all components. In addition, the phase of the annual and semi-annual signals is altered.
This investigation evidences the possible limitation of regional networks to produce reliable station positions, velocities and especially residual position time series (Legrand et al., in press).

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1.2 Precise Point Positioning

The software ATOMIUM, developed by ROB and dedicated to Precise Point Positioning (PPP), has been upgraded (Baire et al, in press). First, the possibility to use GLONASS data was introduced, so that PPP can now be done for combined GPS and GLONASS data, using combined orbits and clock products as those provided by the ESOC analysis centre of the IGS (International GNSS Service). Second, the tropospheric wet delay estimation was modified, adding relative constraints between successive estimations, which improves both the clock estimation as the tropospheric delay estimation. In its present version, ATOMIUM estimates daily station positions with a cm precision, 15-minute tropospheric zenith path delays and epoch-by-epoch station clock synchronisation errors with respect to the IGS time, with a 100ps uncertainty.

1.3 Ionosphere

1.3.3 Impact of the Halloween 2003 ionospheric storm on kinematic GPS positioning in Europe

Using dual frequency data from 36 EPN stations, the influence of the Oct. 30, 2003 Halloween geomagnetic storm on kinematic GPS positioning has been investigated. The Halloween storm induced ionospheric disturbances above the northern part of Europe and Scandinavia. It was shown that kinematic position repeatabilities for this period are mainly affected for stations in northern Europe with outliers reaching 12 cm in the horizontal components, and 26 cm in the vertical component. These magnitudes are shown to be possibly due to the second-order ionosphere delays on GPS signals, not accounted for in the kinematic GPS positioning analysis performed. In parallel, we generated hourly TEC (Total Electron Content) maps on a 1°x1° grid using the dense EPN network. These TEC maps do not use any interpolation, provide a high resolution in the time and space domains, and therefore allow to better evidence small structures in the ionosphere than the classical two-hourly 2.5°x5° grid Global Ionospheric TEC Maps (GIM). Using the hourly 1°x1° TEC maps, we reconstructed and refined exactly the zones of intense ionosphere activity during the storm, and we showed the correlation between the ionospheric activity and assessed the quality of GPS-based kinematic positioning performed in the European region.

1.3.2 A two-stage mid-latitude instability process: Gradient-drift and Kelvin-Helmholtz Waves?

A fine resolution (0.5° latitude x 0.5° longitude x 30km vertical) reconstruction of the ionosphere above Europe on 30th October 2003 has been made, using the MIDAS 2.0 imaging algorithm and GNSS data from the EPN, Flemish Positioning Service (FLEPOS/AGIV), the Wallonia Continuous Operating System (WALCORS), French Réseau GNSS Permanent (RGP) and the German Integrated Geodetic Network (GREF). Results show a possible two-stage instability process (primary Gradient Drift Waves and secondary Kelvin-Helmholtz Waves) not previously reported as seen in the mid-latitude ionosphere. The possible effects on the results of inter-frequency biases is being investigated, along with modelling to demonstrate the resolution limits of the particular MIDAS 2.0 algorithm parameter/input data combination used.

1.3.3 Assessing the added-value of dense GNSS networks and multi-GNSS observations for tomographic applications

The increasing number of GNSS (GPS, GLONASS, Galileo) satellites and ground receivers will in the next several years significantly increases the number of radio navigation signals probing the Earth's atmosphere. From these multiple observations, it is expected that a better monitoring and modelling of the ionosphere and the troposphere utilizing tomographic imaging will be possible. In this frame, ROB evaluated the potential of the EPN for atmospheric tomographic applications

over Europe by investigating the geometry of the satellite-receiver GNSS ray distribution traversing the atmosphere.
Performing tomography consists in sub-dividing the atmospheric layers (ionosphere and troposphere) into voxels to reconstruct the water vapour and electron concentrations from GNSS measurements of TPD (Tropospheric Propagation Delay) and STEC (Slant Total Electron Content). To obtain reliable and accurate reconstructions, it is important to use a sufficient number of GNSS signals well distributed throughout the zones of interest.
It was demonstrated that for the tropospheric layer, inter-station distances within the EPN (~100 km) are too large and therefore a sufficient coverage of GNSS signals is not insured over our zone of interest (i.e. -10° - 40° lon., 25° - 70° lat.). It has been shown that using dense networks having inter-station distances of ~30 km was necessary to obtain a well covered zone.
For the ionospheric layer, the EPN fulfils the requirements for tomographic applications in central Europe and it can be expected nowadays to obtain a reliable tomography with a resolution of 0.5° by 0.5° by 30 km height (Figure 1). Indeed, at an altitude of 300 km where most of the important ionospheric disturbances occur, voxels over the central Europe are traversed by a minimum of 5 GPS signals for at least 80% of the time of the day (Figure 2). The strength of the EPN for ionospheric tomography lays in the fact that it is a large network extending beyond European borders with uniformly distributed ground stations. Moreover, extending this network to the North (Norway, Finland and Sweden) and to the South (North Africa) would enlarge the zone of continuous coverage along the day. To obtain better resolutions, we investigated the added value of dense national networks in addition to the EPN. However this local densification of the EPN generates in-homogeneity in the signal distribution which is not optimal in for tomographic reconstructions. Therefore a wise densification of the EPN by adding a selection of uniformly distributed stations could take advantage of the available GNSS data in Europe, while avoiding any in-homogeneity. In the next several years, multi-GNSS observations from the EPN will lead to a significant and uniform enhancement of the spatial coverage and number of rays in each voxel (+150%). Multi-GNSS applications together with a wise densification and an enlargement of the EPN will improve the spatial and temporal resolution of atmospheric tomography over Europe.

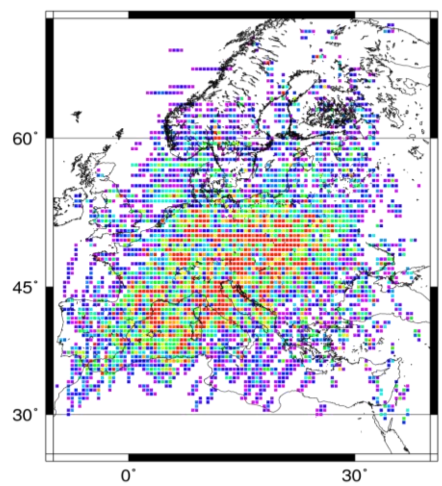

Figure 1: Number of GPS rays per voxel at 300 km using the EPN from 10 to 10h20

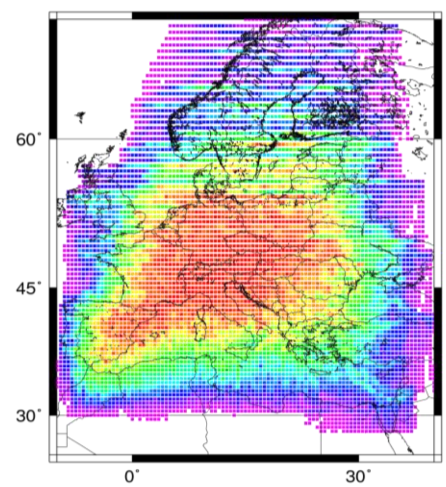

Figure 2: Percentage of epochs during one day for which the voxel is traversed by a minimum of 5 GPS rays using the EPN (if 100% the voxel is traversed all day long by at least 5 rays)

2. Services and products based on the EPN

2.1 E-GVAP Analysis Centre

The ROB participates as an official analysis centre within the EUMETNET EIG GPS Water Vapour Program (E-GVAP II, Pottiaux, 2009a). In that context, ROB provides the meteorological institutes with near real-time Zenith Path Delay (ZPD) estimates from a European regional network of permanent stations (Fig. 3) for data assimilation in operational Numerical Weather Prediction models. During the year 2009, about 45 new sites were added to this network to improve its spatial coverage and its density. The network covers Europe and includes now about 210 GNSS stations, most of them belonging to the EPN and to the IGS permanent network. In addition, several of these GNSS stations are located nearby other instruments such as radiosondes, water vapour radiometers... This co-location allows ROB to assess the accuracy of its ZPD estimates by cross-technique comparisons (Pottiaux et al., 2009b). The near real-time tropospheric ZPD estimates delivered by ROB were also compared with the observations from the Onsala (Sweden) Water Vapor Radiometer (data provided by Prof. G. Elgered, Chalmers University, Sweden). The comparison, carried out using data from the first 9 months of 2009, revealed a bias of -1.6 mm solely. This shows the excellent accuracy achieved for the ROB near real-time tropospheric ZPD. The precision of the ZPD estimates is assessed by cross-comparisons to other GNSS-sources of ZPD data, such as the EPN combined product. The latter comparison showed that 93% of our ZPD estimates have a precision better than 5.5 mm. It was also demonstrated that all requirements for GNSS-meteorology are achieved by the ROB E-GVAP analysis centre (Pottiaux, 2009a).

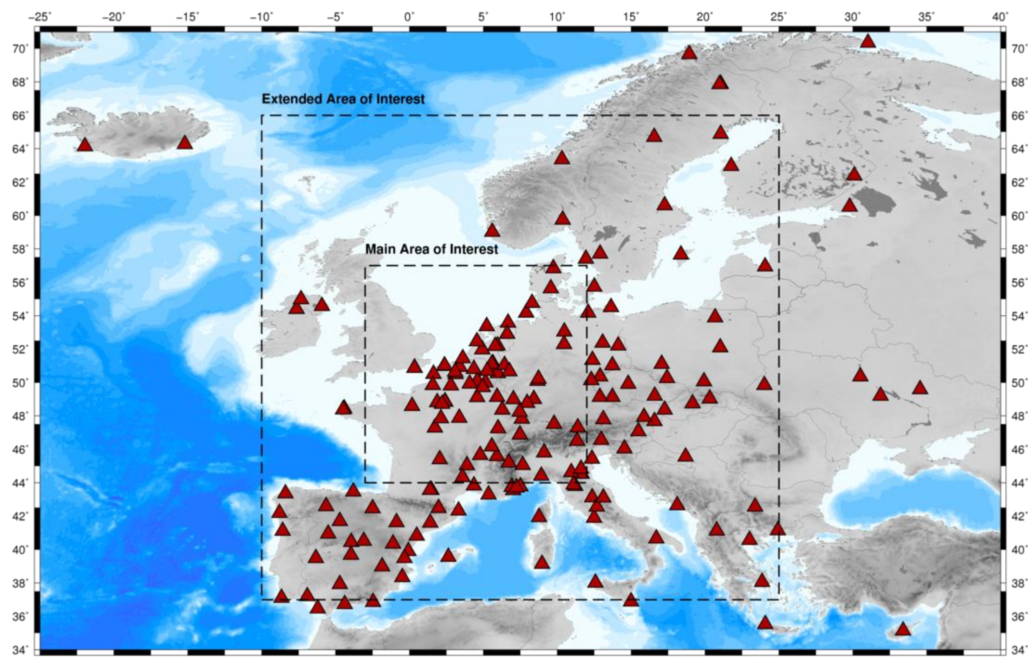

Figure 3: GNSS network processed in near real-time in the framework of E-GVAP (Status: November 2009). A few stations, notably in Greenland and in the Atlantic regions, are located outside the map area

3. Contribution to the EPN

The ROB contributes to the EPN with:

- 4 permanent tracking stations (all submitting hourly data) : BRUS, DENT, DOUR and WARE ; BRUS, DENT and WARE are streaming real-time data;
- An EPN Local Data Center (ftp://gnss.oma.be/gnss/data/rinex/daily), providing access to the GPS stations operated by ROB;
- An historical EPN data center, providing access to all historical EPN data especially targeting reprocessing activities;
- An EPN Local Analysis Center processing an EPN subnetwork located around the Benelux (see http://epncb.oma.be/_productsservices/analysiscentres/subnetwork.php?lac=ROB). As its contribution to the EPN reprocessing Pilot Project, ROB reprocessed the subnetwork it processes for EUREF for the year 2006 using the reprocessed CODE orbits.
- An EPN NTRIP caster to relay the EPN streams from the main EPN NTRIP caster at Bundesamt für Kartographie und Geodäsie (BKG), Germany. This way, ROB guarantees load sharing with the main EPN broadcaster and overall communication traffic reduction. At present about 140 EUREF streams are provided. At startup, all streams were relayed from the the main EPN NTRIP caster at BKG. As this created however a single point of failure, now gradually a shift is made to use the several national casters over Europe as sources for the NTRIP stream relay. At present 11 different casters are used as sources. Users can apply for an account by filling in the web form on http://gnss.be/data.php#NTRIPaccess.

In addition, the ROB hosts the EPN Central Bureau (http://www.epncb.oma.be/). For details we refer the interested reader to the paper ″The EPN Infrastructure: Status, Monitoring and Plans″ by Bruyninx et al. (in this volume)

4. RTK networks in Belgium

Since 2002 there are three RTK networks in Belgium, one for each region (Brussels, Flanders and Wallonia). All of them are managed by governmental agencies. The station in Brussels has been upgraded from GPS to GNSS at the end of last year. The hardware of the reference stations in Flanders are gradually being replaced during 2010. By the end of the year this should be completed and the RTK users will be able to use both GPS and GLONASS signals.
If everything turns out as planned, similar replacements will take place for the third network (in Wallonia) during the course of next year.
The change of the hardware has no influence on the policy of the dissemination of the RTK and rinex data, meaning that it still remains a service for free, as it was in the past.

References

Altamimi, Z., Sillard, P., Boucher, C. (2007a), CATREF software: Combination and Analysis of Terrestrial Reference Frames, LAREG Technical, Institut Géographique National, Paris, France

Altamimi, Z., Collilieux, X., Legrand, J., Garayt, B., Boucher, C. (2007b), ITRF2005: A new Release of the International Terrestrial Reference Frame based on Time Series of Station Positions and Earth Orientation Parameters. J. Geophys. Res., 112, B09401, doi:10.1029/2007JB004949

Baire Q., Bruyninx C., Defraigne P., Legrand J. (in press), Precise Point Positioning with ATOMIUM using IGS Orbit and Clock Products: First Results, Bulletin of Geodesy and Geomatics, submitted

Bergeot N., Bruyninx C., Defraigne P., Pireaux S., Legrand J., Pottiaux E., Baire Q. (2010), Impact of the Halloween 2003 Ionospheric Storm on Kinematic GPS Positioning in Europe, GPS solutions, submitted

Legrand J., Bergeot N., Bruyninx C., Woppelmann G., Santamaria-Gomez A., Bouin M.-N., Altamimi Z. (in press), *Comparison of Regional and Global GNSS Positions, Velocities and Residual Time Series*, IAG Symposia Series

Legrand J., Bergeot N., Bruyninx C., Wöppelmann G., Bouin M.-N., Altamimi Z. (2010), Impact of regional reference frame definition on geodynamic interpretations, Journal of Geodynamics, Volume 49, Issues 3-4, pp. 116-122, doi: 10.1016/j.jog.2009.10.002

Pottiaux E., (2009a), GNSS Near Real-Time Zenith Path Delay Estimations at ROB: Methodology and Quality Monitoring, Bulletin of Geodesy and Geomatics, 2009(2), pp. 125-146

Pottiaux E., Brockmann E., Soehne W., Bruyninx C., (2009b), The EUREF-EUMETNET collaboration: First experiences and potential benefits, Bulletin of Geodesy and Geomatics, 2009(3), pp. 269-288

Völksen C. (2009), Draft Charter for the EUREF Working Group on Reprocessing of the EPN, http://epn-repro.bek.badw.de/Documents /charter_repro.pdf