Chapter 7
STSM Reports

Guergana Guerova

Abstract In this section are presented the Short Term Scientific Mission (STSM). STSM is a very efficient tool for knowledge transfer between the network partner. Based on submitted and evaluated application funding is provided for a visit between 1 week up to 3 months. GNSS4SWEC funded 22 STSM, which took place in the period 2013–2017.

STSM Applicant: *Mr Furqan Ahmed, University of Luxembourg, Luxembourg (LU),* furqan.ahmed@uni.lu

STSM Topic: *Impact of Assimilating GNSS-derived ZTD from Luxembourg and the Greater Region into NWP model AROME*

Host: *Jean-Francois Mahfouf, Meteo-France, Toulouse (FR),* jean-francois.mahfouf@meteo.fr

The main objective of this short-term scientific mission (STSM) under COST Action ES1206 was to investigate whether the densification of the GNSS network over Luxembourg and the Greater Region would show an improvement in the weather forecasts for this region based on MétéoFrance's regional NWP model AROME. It also addressed the question if there would be any benefits for MétéoFrance to include ZTDs from these additional GNSS stations in future.

Methodology The hourly NRT ZTD solution generated at the UL, namely UL01, contains ZTD estimates from a European network of GNSS stations, which include stations belonging to IGS, the EPN and the Reseau GNSS Permanent (RGP). To densify the network over Luxembourg and the Greater Region, six stations from SPSLux (Luxembourg) and 22 from WALCORS (Wallonie, Belgium) were also processed. In total the GNSS network approaches 200 stations. A dataset containing

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ZTD (and IWV) estimates from UL01 for a period of approximately 1 month (July 17–August 20, 2013) was prepared in the form of 1-hourly COST-716 format files and was then converted into the BUFR format. Please note that the term "GNSS" will imply only the Global Positioning System (GPS) in this summary.

Followed by the generation of the GNSS-derived NRT ZTD dataset, forecast experiments were conducted using the 3D-variational (3D-VAR) data assimilation system of the AROME NWP model. For the period of July 17–August 20, 2013, three forecast experiments were conducted using the AROME 3D-VAR NWP model:

i. One experiment without any GNSS ZTD observations
ii. One experiment with GNSS ZTD from the operational EGVAP solutions assimilated
iii. One experiment with GNSS ZTD from UL01 in addition to operational EGVAP solutions assimilated

Results and Conclusions As a result of the assimilation of the GNSS-derived ZTD, the AROME 3D-VAR short-range forecasts were found to be closer to the observations that are sensitive to humidity which implies that through the assimilation of GNSS-derived ZTD, the 3-h prediction of the humidity field by AROME becomes closer to the truth. The investigation of the impact on objective forecast skill scores revealed a small positive impact on screen-level relative humidity and the 24-h precipitation accumulations. The categorical scores were found to be systematically improved when the UL01 data were assimilated in addition to the operational EGVAP ZTD observations. Examination of three precipitation case studies confirmed that the GNSS-derived ZTD observations affect the predicted location and intensity of rain systems that generally improved the quality of the numerical forecasts. It was found that the additional ZTD data provided by UL01 significantly modified rainfall patterns with, most of the time, a better location and intensity of precipitating cells. Furthermore, this STSM was the first instance when the ZTD from SPSLux stations was compared to a non-GNSS reference ZTD. As one of the results of this STSM, it was found that the ZTD from the SPSLux stations have a significant bias. Therefore, after this STSM, the reason for this bias in the ZTD estimates from SPSLux stations was investigated and the biases were mitigated.

Recommendations It is of high interest that a similar set of experiments, as performed in this STSM, be performed again with the new SPSLux data after the removal of the biases. This will further help understanding the impact of NRT ZTD from Luxembourg on the quality of AROME 3D-VAR forecasts for Luxembourg.

Furthermore, the results of this STSM suggested that the E-GVAP Test Solution UL01 should be made an E-GVAP Operational Solution to routinely benefit NWP activities.

Publication of Results The results from this study were published in a peer reviewed journal with an impact factor of 2.518 (Mahfouf et al. 2015).

STSM Applicant: Dr Kalev Rannat, Tallinn University of Technology, Tallinn (EE), kalev.rannat@dcc.ttu.ee

STSM Topic: Improved processing and use of GNSS Zenith Total Delay and Integrated Water Vapour data for Climatology.

Host: Jens Wickert, GFZ German Research Centre for Geosciences, Potsdam (DE), wickert@gfz-potsdam.de

The purpose of this STSM was to initiate a long-term study on quantifying the impact of GNSS data quality and collocation issues for inter-comparison experiments supporting climatological investigations. In general, this study consists of two tasks – one is related to GNSS data processing and the IWV derivation from the ZTD data and another is related to quantifying the effects of distances (both horizontal and vertical shifts) between different GNSS instrumentation used during inter-comparison experiments at collocated sites. The motivation for this STSM was to get additional information and to improve expertise in organizing raw GNSS observation data flow and routine quality check for meteorological purposes. This expertise will be used for preparing the GRUAN (GCOS Reference Upper Air Network) network operational (i.e., by working out technical requirements for sending GNSS data from GRUAN sites to the GNSS Data Processing Centre (GFZ) for offering GRUAN IWV product to end users).

The STSM started at GFZ Potsdam and lasted 5 days. The work was planned on the following subtopics:

- acquisition of raw data and the methods for data quality control, practical issues by using data from collocated sites (use cases, where the ground level meteorological data and GNSS-observational data does not come from the same site, but from some kilometres afar);
- reprocessing of some data samples taken from Sodankylä (GRUAN site), using different processing methods (PPP and DD), comparing and analysing the results with those, calculated earlier (by using GAMIT);
- investigating the possibilities for improving the quality of raw data and the final product (GNSS IWV) using reprocessing results and the expertise from GFZ.

One of the main results was introducing personal contacts with researchers of GFZ and finding common interests in further research. A lot of practical experience and know-how was collected (from numerous personal communications) during this STSM. Common interests were found in experimental work planned to Sodankyla and dedicated to collocation issues. This work will support both COST ES1206 efforts and GRUAN scientific part and will last for years. For quantifying the effects of distances (both horizontal and vertical shifts) between different instrumentation (incl. GNSS and Radiosondes) during inter-comparison experiments the collocated sites from Sodankyla have been chosen - Pittiövaara (SODA) and Tahtela (SOD1), hosted by FMI. To validate the effect of distances and heights while using surface meteorological data from radius of 20 km, extra RS will be launched at Pittiövaara (using a mobile RS launcher). Resulting IWV time series derived from RS and GNSS will be compared (additionally with MWR and FTIR if possible). These experiments need to follow meteorological conditions (e.g. wind speed and direction), to estimate the impact of balloon drift on the results of IWV time series obtained by different techniques. GFZ can process GNSS data both with PPP and DD methods (EPOS software). It gives an independent proof for planned intercomparison results from Sodankyla.

The work will not end with this STSM. It will continue in frames of GRUAN scientific activities and the ongoing COST ES1206, by using data sets from many sites. The aim is to help GRUAN GNSS-sites to support GRUAN data analysis with the best available and continuous observational data. Additionally, it supports COST ES1206 WG3 efforts in validating IWV time series for trends' analysis. The results of intercomparison experiments from Sodankyla are planned to be published as an ISI journal article.

STSM Applicant: *Mr Tomasz Hadaś, Wroclaw University of Environmental and Life Sciences, Wroclaw (PL),* tomasz.Hadaś@up.wroc.pl
STSM Topic: *Neutral atmosphere delay model for Precise Point Positioning*
Host: *Marcelo Santos, University of New Brunswick, Fredericton (CA),* msantos@unb.ca

The purpose of this STSM was to investigate the application of neutral-atmospheric delay models in real-time Precise Point Positioning (PPP). Grantee used his original GNSS positioning software GNSS-WARP and developed it by implementing UNB3 neutral atmosphere delay model and VMFs. Both models can be used alternatively, as well as jointly e.g. by taking zenith delay values from UNB3 and mapping functions from VMF. The resulting kinematic coordinates were compared with true, static coordinates of station WROC (plot 'dNEU'), and the error of coordinates component were provided from covariance matrix (plot 'mNEU'). One can see (Fig. 7.1) that generally the coordinates are accurate and precise at the level of 10 cm for horizontal components and 20 cm for vertical component after about 45 min of convergence. Unfortunately, there are regular picks in both plots, that are related with IODE mismatching between RTS stream and ephemeris data. This bug requires additional checking to be implemented in the software.

The performance of the program was initially verified by comparing the exemplary results with the one obtained by GAPS, when the same set of data was processed, both in kinematic and static positioning. For this purpose, a basic module for RINEX files processing was also implemented. The differences in coordinates between two software are below centimetre level. Even though, the sources of differences have been identified, which is the basis for further development of the GNSS-WARP software. The grantee and the host institution declared a future collaboration related with the development of the GAPS. The grantee can share his experience on using the IGS RTS products and help further development of the software, to become multi-GNSS real-time software as well.

STSM Applicant: *Dr Witold Rohm, Wroclaw University of Environmental and Life Sciences, Institute of Geodesy and Geoinformatics, Wroclaw (PL),* witold.rohm@igig.up.wroc.pl
STSM Topic: *Application of GNSS tomography for severe weather studies*
Host: *Jonathan Jones, Met Office, Exeter (UK),* jonathan.jones@metoffice.gov.uk

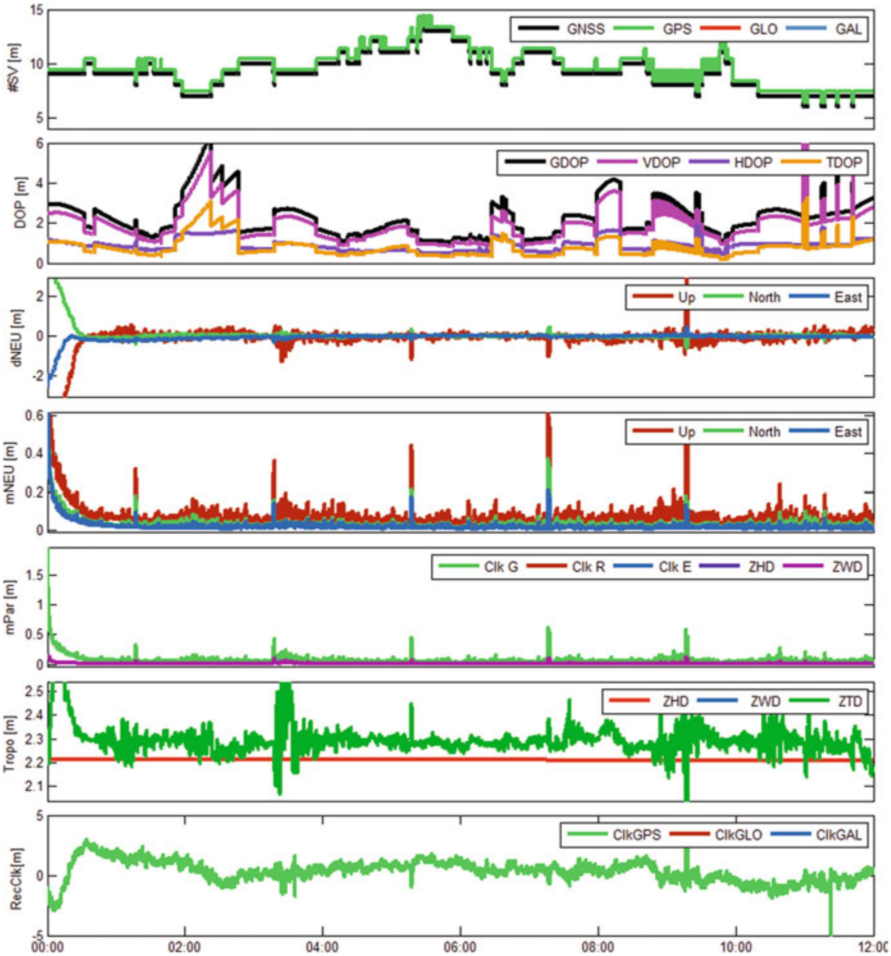

Fig. 7.1 Exemplary performance of GNSS-WARP during 12 h of fully-kinematic data processing for station WROC (IGS RTS IGS03 stream, 1 s sampling, a priori troposphere: Vienna Mapping Functions, elevation cut-off angle: 5°)

Numerical weather prediction (NWP) models are commonly used by all meteorological agencies to forecast short-, mid- and long- term variation of troposphere. Models are based on seven governing fundamental equations of: motion (three directions), continuity, conservation of mass, energy and mixing ratio. The NWP models in general has two major functional parts Data Assimilation (to set up boundary condition, initial conditions and subsequently add observations) and forecasting part that is govern by a number of partial differential equations describing 3D motion of air masses.

One of the important data source for DA is GNSS. The GNSS provides instantaneous, all-weather and precise position all-round the world. However, as signal propagates through the atmosphere it is refracted and bended. The magnitude of these effects are directly linked, at least in the troposphere, with: temperature, pressure and water vapour content. As GNSS community is interested mostly in the positioning the atmosphere effects were considered to be a nuisance parameter, estimated and removed from the solution. Nowadays, as the distribution and variability of water vapour is of great interest to all members of NWP community and become valuable product that can be assimilated in weather models.

This short-term scientific mission (STSM) aims to improve the understanding of Data Assimilation in NWP models in GNSS community and stimulate development of new more meteorology-oriented GNSS products. It also brings some advanced GNSS processing techniques such as GNSS tomography for NWP community consideration. The selected region of interest is located in the south of England and covers four receivers CHIO, POOL, SANO, SOTN, data are available through the E-GVAP ftp repository. The test stations are located on different heights (~60 m height difference) with inter-station distance of 20–35 km. The investigated case study covers the heavy rain period, between 3rd and 13th of February 2014, the south and south west of UK was flooded along Thames basin. Time resolution of GNSS ZTD is 15 min, therefore the GNSS tomography profile is also available every 15 min.

The preliminary results show that in the normal weather conditions GNSS tomography retrieves the profile quite well i.e. the initial profile from deterministic models (such as GPT or UNB3M are used to initialise TOMO2 model) is shifted to the correct location (the bias of deterministic models is removed). The bottom part of the profile as there are limited number of intersecting rays in the surface layer and it will translate to the problems in retrieving bottom part of the troposphere. The inversion profile has not been reproduced well as it is located in the troposphere region that is barely scanned by the GNSS observations. Further investigations with synthetic data are required to assess whether the quality of the retrieved profile could be improved. Moreover, synthetic simulations should be performed to study minimal requirements for "tomography towers" in the advent of introducing new satellite systems and new, more precise, retrievals of Slant Total Delays.

The forward model for GNSS tomography H has not been fully constructed yet. The concept is quite straight forward; the NWP model variables converted to the wet refractivities at the nodes should be merge (averaged) together to obtain tomography equivalent scale of the model element. The observation errormatrix is available from Kalman filtering as a covariance matrix of the filtered state. However, before assimilating the tomography outputs, more synthetic and real case studies have to be run to assess whether the strict quality requirements imposed by Met Office could be achieved.

STSM Applicant: *Mr Pavel Václavovic, Research Institute of Geodesy, Topography and Cartography, Zdiby (CZ),* pavel.Václavovic@pecny.cz
STSM Topic: *Developing of ultra-fast tropospheric products*
Host: *Eric Pottiaux, Royal Observatory of Belgium, Brussels (BE),* e.pottiaux@oma.be

One topic which the STSM was aimed at was implementation of tropospheric gradients estimation into the G-Nut/Tefnut software (Vaclavovic and Dousa 2013) developed at the Geodetic Observatory Pecný in Czech Republic. The increasing demands for real time and near real time tropospheric products being used for Numerical Weather Prediction (NWP) nowcasting or severe weather monitoring were motivations for improving such new software focused on the troposphere monitoring. As long as observations at low elevation (below 10°) are processed, the troposphere asymmetry must be considered to improve the repeatability of station coordinates and also the precision of other parameters.

The adjustment procedure in the PPP is the Kalman filter coping with various parameter dynamics. Ambiguities are estimated as float values and thus they require a certain time to converge. A backward smoothing algorithm can be applied for reaching estimated parameters with same precision during the entire processing interval. The algorithm can be exploited in the offline or in the near real time processing. The mentioned algorithms were tested and enhanced.

Results The software G-Nut/Tefnut was significantly improved and tested during the STSM. Two approaches for tropospheric gradients modelling were implemented: (1) tilting atmosphere, (2) algorithms provided by (Chen and Herring 1997). Both techniques were tested using data from the dense Belgian permanent stations network.

Statistics of the G-Nut/Tefnut ZTD results was determined for the daily solution (20th September 2012) of the ANTW station with respect to the results from the BSW. Table 7.1 summarizes biases and standard deviations.

Table 7.1 shows lower standard deviation for the smoothed ZTDs which corresponds with the expectation. On the one hand, the improved precision is due to avoiding the convergence period. On the other hand, the backward smoothing exploited data from the entire interval and the standard deviation is better than that of the simple forward filter even when parameters from the convergence period were rejected.

The STSM started very close collaboration between GOP and ROB. The software is being developed at GOP and seriously tested using the dense Belgian network data at the ROB. The collaboration consists of the user feedback and software developments according to potential requirements.

STSM Applicant: *Mr Tzvetan Simeonov, Department of Meteorology and Geophysics, Sofia University, Sofia (BG),* simeonov@phys.uni-sofia.bg

Table 7.1 Biases and standard deviations for ZTD with respect to the BSW solution

Estimation procedure	Data description	Bias [m]	std [m]
Forward filter	All data	0.001	0.010
	Without convergence period	0.000	0.009
Backward smoothing	All data	0.001	0.006
	Without convergence period	0.000	0.006

STSM Topic: *Tropospheric products processing for Bulgarian ground-based GNSS network*

Host: *Felix Norman Teferle, University of Luxembourg, Luxembourg(LU),* Norman.Teferle@uni.lu

The Sofia University GNSS Analysis Centre (SUGAC) is the first AC in South-East Europe with a focus on deriving atmospheric products from ground-based GNSS networks The SUGAC uses the NAPEOS GNSS software for this purpose. The mission was foreseen for gaining experience with the software while a license from ESA is granted. A comparison with the BSW is envisaged as a next step. The SUGAC is established in collaboration with the Bulgarian network, contributing to EUPOS. The stations, chosen for initial processing are from East to West: Varna (VARN), Burgas (BURG), Shumen (SHUM), Stara Zagora (STAR), Lovech (LOVE), Rozhen peak (ROZH) and Montana (MONT).

NAPEOS has several key features:

- Multi-GNSS processing, incorporating GPS, GLONASS and the European GALILEO
- Includes processing of undifferenced and double-differenced data, although the latter has not been maintained for some time
- User-friendly interface
- The license is free of charge

The analysis centre at the Research Unit in Engineering Science of the University of Luxembourg (Uni. Luxembourg) uses NAPEOS since 2011. The tropospheric products processed during the STSM were be used for comparison with the numerical weather prediction model (WRF) for Bulgaria. The GNSS derived water vapour proved to have very high correlation with the WRF model (above 0.9) for the whole period for the complete dataset. GNSS IWV from this processing has a positive systematic bias, compared to the model simulations. The results of this work are included in Sect. 3.7.2 "Supporting new analysis centres, new networks, transfer of knowledge" of the WG1 report for the COST action. The work from this STSM will be continued with the establishment of autonomous near real-time processing of the regional ground-based GNSS network in Southeast Europe in support of the EUMETNET E-GVAP.

STSM Applicant: *Mr Peter Szabo, Climate Modelling Group, Hungarian Meteorological Service, Budapest (HU),* szabo.p@met.hu

STSM Topic: *Tropospheric products from GNSS and ALADIN-Climate regional climate model for East-Southeast Europe*

Host: *Assoc. Prof Guergana Guerova, Department of Meteorology and Geophysics, Sofia University, Sofia (BG),* guerova@phys.uni-sofia.bg

Methodology and Data The STSM aims to intercompare GNSS tropospheric products with the ALADIN-Climate regional climate model. This version (5.2) of ALADIN-Climate used at the Hungarian Meteorological Service (HMS) has a horizontal resolution of 50 km integrated over the whole European continent. The simulation used in this study has the lateral boundary conditions derived from ERA-Interim reanalysis fields, which means it can also capture main weather patterns in Europe. Water vapour path is computed in ALADIN-Climate by subtracting solid and liquid phase from total amount of water in the atmosphere.

Regarding observations, Sofia station from IGS-repro1 GNSS data-set was used. The station is located in the Plana mountain about 20 km from Sofia and is equipped with an AR25 Leica antenna.

Activities and Results Firstly, the conversion of ZTD to IWV was checked for the observations–due to different literature, also to calculate ZTD in the model. After that, we could intercompare IWV and ZTD (besides pressure and temperature). Evaluation of ERA-Interim was not considered at this stage.

Calculated were correlations between G1/G2 model grid points (two closest points) and observation, variance and mean, coefficient of variation, diurnal cycle, annual cycle, different thresholds in the distribution. We also looked into detail of different weather situations, e.g. the IWV model simulations during the 2007 heatwave over Bulgaria. Some findings:

- Since G1 is at lower altitude, it overestimates IWV values by 0.36 mm as annual bias while at G2 by 1 mm. Diurnal IWV cycle is relatively well simulated (Fig. 7.2). The simulated IWV minimum is at 00:00 UTC for G1 and G2, while the observed minimum is at 06:00 UTC. The magnitude of the diurnal cycle is higher in the observation than in the model.
- Temperature correlation with the observation is very high in both model grid points, with no significant difference in them (Fig. 7.3). Modelled ZTD and IWV correlation with their observed values are lower (0.67–0.75), and they are the best at 12:00 UTC. Pressure values correlate better at G1 with observation, while both ZTD and IWV have higher values at G2.
- Annual IWV cycle is fairly captured in the model in both lower and higher altitude points (Fig. 7.4). Simulated IWV peaks in July, while the observed one in August. Since G1 is at altitude 250 m below G2, IWV values are always mm higher than at G2. Somehow in the 2nd half of the year, the simulated IWV at G2 is underestimating the observed one and values are closer at G1.
- Zooming in the data, big differences at some time steps can appear (Fig. 7.5). During the heatwave of July 2007, modelled IWV values happen to overestimate by 10–15 mm the observed ones. Regional climate models with the boundary conditions of reanalyses cannot capture all weather events at all times, but they supposed to capture these synoptic-scale events better.
- Percentage of different thresholds (5, 15, 25, 35 mm) of the distribution shows that at no single times occurred values above 35 mm in Sofia (not shown). At G1 the probability of very high values is 0.26%, while at G2 it is virtually zero. Except the threshold of above 15 mm, G2 captures better the values for the selected 4 thresholds than G1.

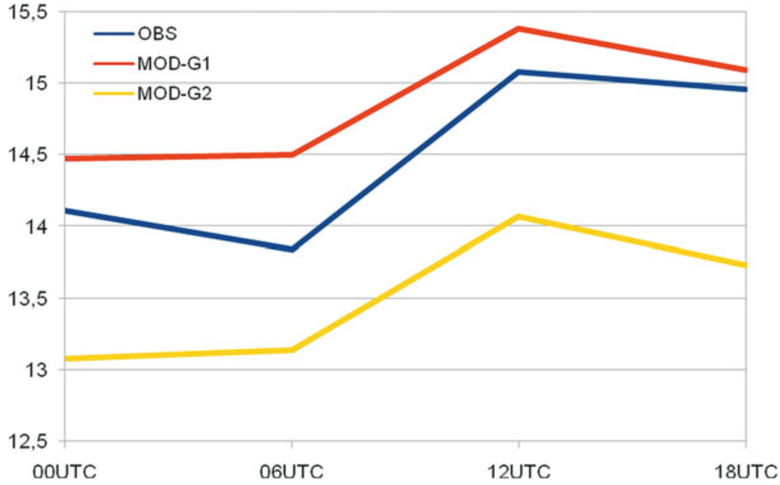

Fig. 7.2 Diurnal cycle of the averaged IWV (mm) in the observation and model grid points

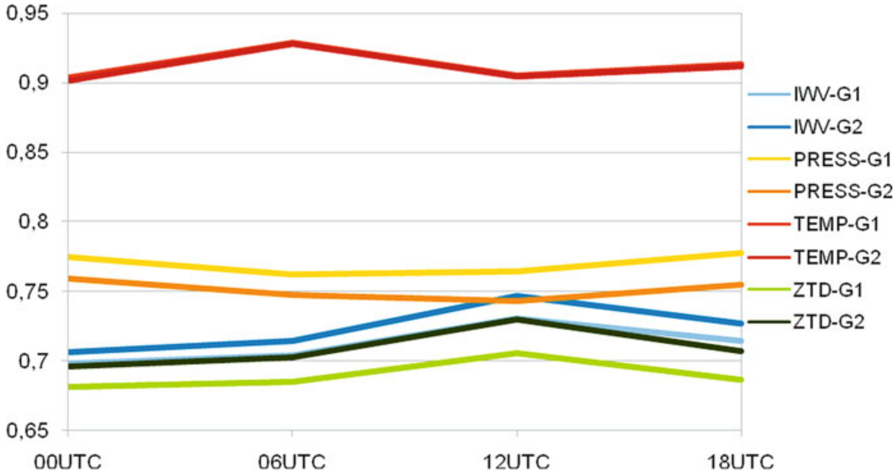

Fig. 7.3 Correlation of observed and modelled (G1/G2) values for IWV, PRESS, TEMP and ZTD

Further Plans We would like to investigate more GNSS sites with available meteorological variables, to include more years (availability from 1995 to 2007), a more homogeneous period and smoother orography, also, stations with different climates in order to test ALADIN-Climate over Europe.

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STSM Topic: *Installing new analysis centre for near real-time GNSS troposphere monitoring in Turkey*

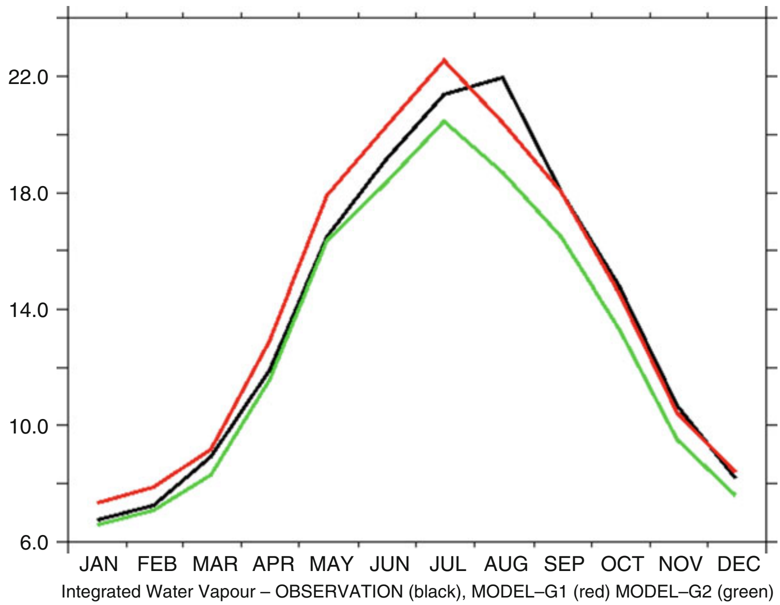

Fig. 7.4 Annual cycle of IWV (mm) for the observation (black) and model grids (G1-red, G2-green)

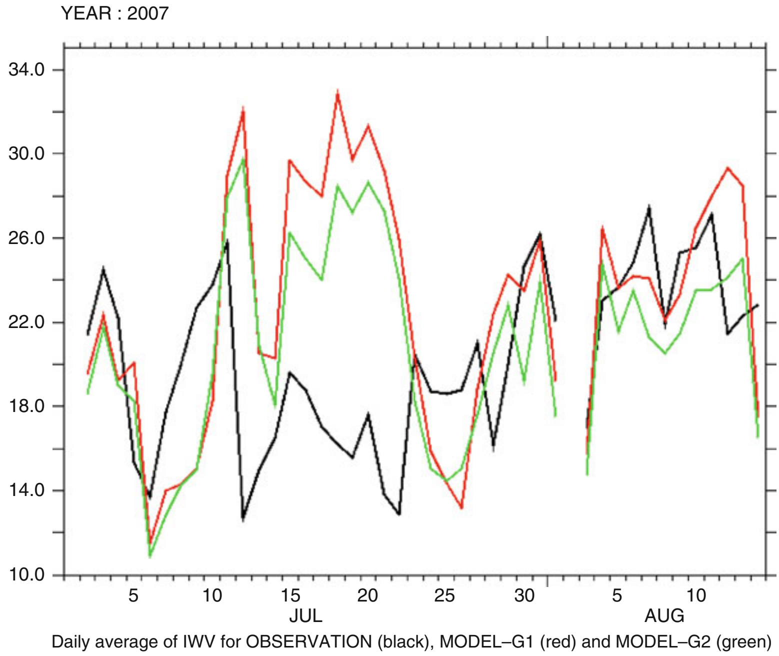

Fig. 7.5 Daily averaged IWV (mm) for the observation (black) and model grids (G1-red, G2-green) over 2007

Host: Emine *Tanir Kaykci, Karadeniz Technical University, Dept. of Geomatics Engineering, Trabzon (TR),* etanir@ktu.edu.tr

STSM Topic: *Installing new analysis centre for near real-time GNSS troposphere monitoring in Greece*

Host: *Christos Pikridas, Aristotle University of Thessaloniki, Dept. of Geodesy and Surveying, Thessaloniki (EL),* cpik@topo.auth.gr

STSM Topic: *Installing new GNSS analysis centre for troposphere monitoring in Iceland*

Host: *Benedikt Gunnar Offeigson, Icelandic Meteorological Service, Reykjavík (IS),* bgo@vedur.is

Three short-term (4–5 days) STSMs have supported the transfer of knowledge aimed at exploiting the developments and long-term expertise in GNSS near real-time (NRT) analyses for the troposphere monitoring. The main goal was to establish four new analysis centres of the EUMETNET GNSS Water Vapour Programme (E-GVAP, http://egvap.dmi.dk) with the support of Geodetic Observatory Pecný (GOP), Czech Republic. For this purpose, GOP offered the TropNET system developed and completed for an easy setting and maintenance of all necessary activities associated with the NRT tropospheric parameter estimates. Four agencies were ready to install the system for setting up an analysis centre contributing with new data to the E-GVAP service:

- AUT – Aristotle University of Thessaloniki (Greece)
- BEU – Bulent Ecevit University in Zolgundak (Turkey)
- KTU – Karadeniz Technical University in Trabzon (Turkey)
- IMO – Icelandic Meteorological Office (Iceland)

The Trop-NET system has been developed as a set of modules and utilities which include data and product downloads and conversions, archiving and cleaning, provides data processing in a fully self-sufficient operation including estimates of precise station coordinates tied to the realization of the international terrestrial reference frame, perform the quality control and validation of all input data and products, reports errors and warnings from the operation, provide quality control of the tropospheric products, their conversion, evaluation and submission to the E-GVAP. The GNSS data analysis uses the BSW and for different installations it supported versions 5.0/5.2. All the STSMs included several tasks from which only some were necessarily performed at the facilities of the new analysis centres:

- hardware consultation and preparation, Linux environment installation and settings, BSW installation and testing,
- installation of GOP' Trop-NET processing system from the shared repository maintained by GOP, system adaptations specific to each individual analysis centre,
- station meta data preparation, repository organization including the mirror of observations from the EUREF reference stations, precise IGS orbit products and processing models,

- testing the functionality of the system modules – data download, data processing, tropospheric products evaluation,
- initial backward processing of 1–2 months followed by operational near real-time processing,
- the system and product education and training,
- support in preparing submissions to E-GVAP,
- product validations in GOP-TropDB and the online monitoring service provided by GOP at http://www.pecny.cz/COST-TropNET.

Over past 1–2 years, all four analysis centres have contributed operationally to the E-GVAP providing 220+ new stations and stable basis for further extensions. More analysis centres were also supported remotely by consultations, by sharing the TropNET system and by processing data in the GOP solution.

STSM Applicant: *Ms Gokhan Gurbuz, Bulent Ecevit University, Zonguldak (TR),* gokhanngurbuz@gmail.com

STSM Topic: *GNSS Processing for tropospheric delay. Develop a near real-time GNSS processing system for the Turkish GNSS stations (Istanbul and Ankara).*

Host: *Szabolcs Rozsa, Budapest University of Technology and Economics, Budapest (HU),* rozsa.szabolcs@epito.bme.hu

My STSM carried out by the hosting of Dr. Szabolcs Rozsa from the Budapest University of Technology and Economics (BME), Hungary. The purpose of the STSM was the realization of the near real time GNSS processing system of the Turkish GNSS stations and relating research activities. The STSM began with a meeting on how to proceed in STSM and discussion of the work plan. BSW50 on UNIX platform is installed while information about the software, processing techniques, adjustment of a network, tropospheric parameter estimations, and near-real time processing has been answered by Dr. Rozsa. He also shared invaluable knowledge of GNSS processing, especially about near real time GNSS processing.

With the help of Dr. Rozsa, we installed and set up a near real time GNSS processing scheme for BSW50 using a network based on EUREF and IGS stations in the vicinity of Turkey. The processing scheme was tested on a data set of 3 weeks. Dr. Rozsa shared the knowledge of automated processing in BSW50 and how to write the appropriate scripts in UNIX environment. Thanks to that information now I am able to write any scripts, which helps me with GNSS processing. I learned how to update the script provided by the colleagues in Budapest. To conclude the STSM a short project was carried out to process ground based GNSS data during a severe weather event happened in Istanbul. The estimated ZTDs were converted to PWV using local surface meteorological observations. The PWV estimations were compared to radiosonde reference values, too. I would like to greatly thank the COST Office for allowing me to visit Budapest University of Technology and Economics.

STSM Applicant: *Ms Karina Wilgan, Wroclaw University of Life and Environmental Sciences, Wroclaw (PL),* karina.wilgan@igig.up.wroc.pl

STSM Topic: *Parameterized refractivity models and GNSS path delays in view of GNSS Severe Weather Monitoring*

Host: *Alain Geiger, Institute of Geodesy and Photogrammetry, ETH Zurich, Zurich (CH),* alain.geiger@geod.baug.ethz.ch

During this STSM a study on parameterized refractivity models and GNSS path delays was conducted. The refractivity values as well as ZTD can be expressed as a functions of meteorological parameters. For various applications, it is necessary to know the values of tropospheric parameters at locations that do not coincide with actual measurement locations. The Geodesy and Geodynamics Lab at ETH Zurich has developed a software package COMEDIE (Collocation of Meteorological Data for Interpretation and Estimation of Tropospheric Path delays) to interpolate and extrapolate meteorological parameters from real measurements to the arbitrary locations. The collocation algorithms were used to calculate the total refractivity field over a western part of Switzerland. The grantee has also implemented the ZTD horizontal gradients models into the software to investigate if they bring any improvements for the interpolation of the refractivity.

The tropospheric parameters were calculated from two main data sources: ground-based meteorological measurements (air pressure, temperature and water vapour used to calculate total refractivity) and GNSS (ZTD and horizontal gradients). From those data sources, different datasets of input data were constructed: ZTD/Ntot, ZTD/Ntot/GRAD and Ntot only. Using the particular input dataset, the total refractivity profiles over Payerne were calculated to assess which dataset has the best agreement with the reference radiosonde measurements. The dataset with the best performance of total refractivity interpolation was ZTD/Ntot with the absolute biases from 0 to 6 ppm and standard deviations 3–10 ppm. Excluding the ZTDs from the collocation results in worsening the interpolation above the 2 km by over 10 ppm. Introducing the horizontal gradients was presumed to improve the interpolation, but for the vertical interpolation at Payerne the refractivity field from the dataset with gradients was worse by about 0.5 ppm than the interpolation without gradients. Another way to assess the refractivity models obtained using COMEDIE is to compare them with ground-based data from all meteorological stations at the surface level. Except for two stations, the absolute biases of the residuals were at the level of 0–4 ppm with 7–8 ppm standard deviations for both datasets - including and excluding the gradients. The interpolation with gradients was unfortunately worse than without, but only by about 0.1 ppm.

STSM Applicant: *Dr Riccardo Biondi, International Centre for Theoretical Physics (ICTP), Trieste (IT),* riccardo@biondiriccardo.it
STSM Topic: *GNSS atmospheric water vapour detection for extreme events*
Host: *Hugues Brenot, Belgian Institute for Space Aeronomy, Brussels (BE),* Hugues.Brenot@oma.be

Within the project CONSYDER FP7-PEOPLE-IEF "Convective systems detection and analysis using radio occultation" I am analysing GPS RO profiles from different missions (COSMIC, METOP, GRACE, CHAMP and SACC) to understand if severe storms leave a significant signature in RO profiles. The combined use of GNSS ground based receivers for measuring the atmospheric water vapour content and the GNSS RO profiles is a big challenge for forecasting and monitoring such kind of extreme events.

The experience of Dr. Brenot on GNSS water vapour detection and atmospheric water vapour tomography together with my experience on GNSS RO profiling will lead in a short-term period to structure a new collaboration and hopefully new proposals for studying, detecting and monitoring extreme events and in long-term period to the development of a new algorithm for understanding the 3D structure of strong convective systems.

Research Activity We have selected some specific case with extreme weather events in Belgium in August 2010 and August 2011 and a long wet period in United Kingdom from October 2013 to February 2014 and we have decided to focus our work on these events. We also started to collect meteorological parameters such as wind speed and rain rate at the ground for evaluating the storm's strength. The short term objective is to initialize and validate the IWV tomography by using co-located RO profiles. The long term objective is to relate the IWV trend before the rain and the storm's thermal structure to the storm intensity. The GPS RO profiles were downloaded from two different data centres (UCAR and Wegener Centre) which provide water vapour in different units (water vapour pressure in mbar and water vapour in Kg/Kg respectively) and with different tangent point reference. The first step was to create a homogeneous dataset for being compared to the IWV in terms of units, vertical and horizontal resolution.

Belgium Extreme Events We have found about 30 RO profiles co-located with the two extreme events in Belgium but unfortunately just two of them were suitable for this study: 15th of August 2010 (not shown) and 18th of August 2011 (Fig. 7.6). The reasons of such small number are different: the short temporal range of the events (just a few days); the technical problems for retrieving the RO water vapour profile below 10 km of altitudes; the Belgium area is comparable with the GPS RO horizontal resolution. Due to this very small number of available occultations we have decided to work in a wider area and a large temporal range, so we selected all the GPS RO in United Kingdom in the period October 2013–February 2014.

United Kingdom Wet Winter We have found in total about 5000 RO profiles on UK area during the period October 2013–February 2014. We report here a specific case of selected extreme weather event in November 2013. The event passed over UK the 12th of November moving South East the day after. Several GPS ROs were co-located with this event as reported in Fig. 7.6. In both cases it is evident the decrease of IWV just before the event (Fig. 7.7, we just show the UK case).

The study has been deepened with the tomography of the single events (to be published soon) and with the STSM of Rita Nogherotto with the study of tropical cyclones at La Reunion.

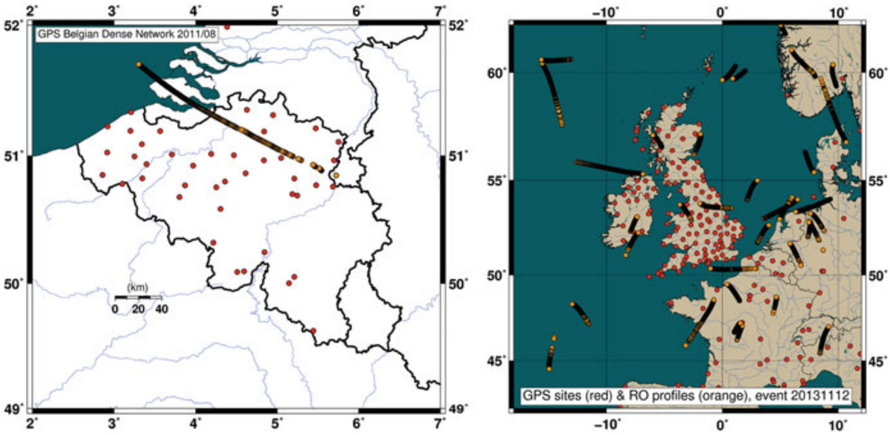

Fig. 7.6 (Right) GPS RO co-located with the extreme event over Belgium the 18th of August 2011. (Left) GPS ROs co-located with the extreme event over UK the 12th of November 2013. Red dots are the ground based GPS stations of the Belgian network. Orange dots are the GPS RO tangent points coordinates

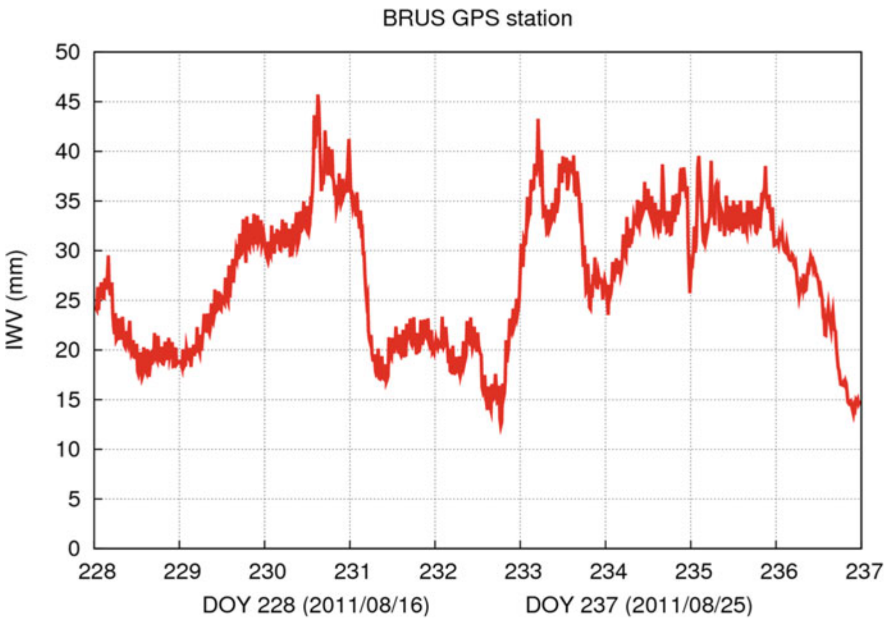

Fig. 7.7 Integrated Water Vapour (IWV) from the 16th of August 2011 to the 25th of August 2011. We can see the IWV dropping down before the extreme event the 19th (DOY 231)

STSM Applicant: *Mr André Sá, Polytechnic Institute of Guarda, Rua do Milagre das Rosas, Lote 36°, 3dt°, Coimbra (PT),* andregvsa@gmail.com
STSM Topic: *Tomography as a tool for atmospheric studies*
Host: *Witold Rohm, Wroclaw University of Environmental and Life Sciences, Wroclaw(PL),* witold.rohm@igig.up.wroc.pl

A tomographic software for water vapour reconstruction based on Global Navigation Satellite Systems (GNSS) observations was developed at Space & Earth Analysis Laboratory (SEGAL – Laboratory of University of Beira Interior). This software is designated SEGAL GNSS Water Vapour Reconstruction Image Software (SWART) and uses parallelized Algebraic Reconstruction Techniques (ART) for the inversion. The research objectives of the STSM were: (a) to validate the quality of tomography retrievals for SWART and; (b) apply the model to investigate severe weather/deep convection events. During the STSM, SWART was analysed and improved (introduction of initialization values/a priori conditions and stop criteria convergence). As an outcome SWART is now being used to produce a COST paper "Cross-validation of GNSS tomography models and methodological improvements using CORS networks".

STSM Applicant: *Ms Katarzyna Stepniak, University of Warmia and Mazury in Olsztyn, Olsztyn (PL),* k-stepniak@wp.pl
STSM Topic: *Impact of processing parameters on the ZTD estimates and adaptation of ZTD screening methods*
Host: *Olivier Bock, IGN – LAREG, Paris (FR),* Olivier.Bock@ign.fr

The main scientific objective of the STSM was performance assessment of tropospheric ZTD screening methods and analysis of the IWV variability over Poland. During the STSM, the estimated ZTDs were compared (1) to ZTD estimated from several EPN analysis centres, (2) to ZTD computed from ERA-Interim reanalysis. Moreover, the adaptation of the screening method developed by Dr. Bock for ZTD data produced with the Gipsy software to those I produced myself with BSW was carried out. The ZTD screening method, based on the analysis of formal errors of ZTD and coordinate estimates, was tested. Subsequently, I learnt about the ZTD to IWV conversion methods developed in Working Group 3 and applied them to the ZTD data for Poland.

STSM Applicant: *Dr Michal Kacmarik, Institute of Geoinformatics, Technical University of Ostrava, Ostrava (CZ),* michal.kacmarik@vsb.cz
STSM Topic: *Validation of GNSS Slant Delays*
Host: *Galina Dick, Helmholtz-Centre Potsdam – GFZ German Research Centre for Geosciences, GPS/Galileo Earth Obs, Potsdam (DE),* dick@gfz-potsdam.de

The main purpose of the STSM at GFZ Potsdam was to initiate an extensive validation of STD from independent measurement techniques - GNSS, Water Vapour Radiometer (WVR) and Numerical Weather Prediction (NWP) models ray-tracing. Hosting institution GFZ Potsdam has a long-term experience with

GNSS slant delays estimation, NWP model ray-tracing, WVR operation and GNSS meteorology products validation.

Firstly, two tools were developed by the recipient. A set of scripts called WVR_POTS_STD, which serves for (pre-) processing of observations from WVR operated by GFZ Potsdam. Its main purpose is a conversion of original slant integrated water vapour (SIWV) values to STDs needed for the validation with an effort to minimally distort the original SIWV observations. The second tool suits for an automatic validation of STDs delivered in a new TRO-SINEX format including generation outputs in a form of tables and figures.

Secondly, an initial validation of STDs was realized. There was a logical decision to use the Benchmark dataset prepared within COST ES1206 Action (Douša et al. 2016) for this purpose. It covers a 56-day long period in May and June 2013 which included severe weather events. In total, a subset of ten GNSS reference stations located at six different places were selected for the validation. Within them three collocated stations can be found which compromise of two or three individual GNSS reference stations situated very close to each other. Three institutions delivered slant total delays from their GNSS processing using different software and strategies for this initial validation (GFZ Potsdam, GO Pecný, VSB-Technical University Ostrava). Moreover, STDs from WVR located at GFZ Potsdam as well as STDs from ray-tracing via NWP models NCEP GFS and ECMWF ERA-Interim delivered by GFZ Potsdam entered the initial validation.

Results of comparisons within individual sources of STDs, over both whole Benchmark period and individual days, at original elevation angles of STDs as well as in the simulated zenith direction were presented in the full version of the STSM report and are not mentioned here due to their preliminary value and considerable extent. Detailed results of the extensive STD validation which was kicked off by this STSM can be found in a paper published by Kačmařík et al. (2017).

STSM Applicant: *Ms Rita Nogherotto, The Abdus Salam International Centre for Theoretical Physics, Trieste (IT),* rnoghero@ictp.it

STSM Topic: *Tropical cyclone intensification, water vapour distribution and GNSS measurements*

Host: *Jimmy LECLAIR DE BELLEVUE, Laboratoire de l'Atmosphère et des Cyclones – CNRS 8105 Universitie de La Reunion, Saint-Denis (FR),* jimmy.leclair-de-bellevue@univ-reunion.fr

The mission aimed at studying the tropical cyclone Bejisa occurred in the South-western Indian Ocean in January 2014 by using:

- Integrated Precipitable Water Vapour (PW) from ground-based GNSS measurements (provided by the *Laboratoire* de l'Atmosphère et des Cyclones LACy-CNRS, Reunion Island (France))
- RO profiles (provided by the Wegener Centre for Climate and Global Change, Graz (Austria))
- Weather stations measurements (provided by different meteorological institutes)
- and models (the new high resolution *model AROME* (Météo-France)).

The purpose was to co-locate the storms best track (from Meteo-France) with GNSS stations and derive the *Integrated Precipitable Water Vapour* PW.

Another goal was to use the RO profile to determine the cloud top altitude and to find the relationship between cloud top altitude, storm intensity and PW variation.

Bejisa cyclone event was also used for a first evaluation of the numerical prediction model AROME, operational at Météo-France.

GPS observed PW anomalies in the three analysed stations (VACS, in Mauritius islands, ABPO in Madagascar and REUN in Reunion island) respect to the period 2008–2015, show that it is an observable general trend that PW starts to increase before the cyclone, reaches its maximum during the closest approach of the cyclone, decreases to a minimum immediately after its passage, and finally recovers to its nominal value a few days later.

AROME model was able to represent well the trend of the PW but behaving differently according to the station: for VACS we found that the bias and the RMSPE assumed almost the same value, indicating that a significant part of the error in the model was due solely to the persistent bias of ~1 cm. For ABPO and REUN the results were remarkable as both the bias and the RMSPE were very low (3% and 15% the bias and 9% and 21% the RMSPE).

For the RO study we analysed the bending angle anomalies and the temperature anomalies respect to the climatological value in the same area. The cyclone's thermal structure presents a warmer core and a cold cloud top confirming results of previous studies.

STSM Applicant: *Dr Tomasz Hadaś, Wroclaw University of Environmental and Life Sciences, Wroclaw (PL),* tomasz.Hadaś@up.wroc.pl

STSM Topic: *Optimization of real-time GNSS troposphere delay estimation algorithms*

Host: *Felix Norman Teferle, University of Luxembourg, Luxembourg (LU),* Norman.Teferle@uni.lu

The purpose of this mission was to optimize ZTD stochastic modelling (random walk setting). In GNSS data processing the station height, receiver clock and tropospheric delay (ZTD) are highly correlated to each other. Although the ZHD of the troposphere can be provided with sufficient accuracy, ZWD has to be estimated, which is usually done in a random walk process. Since ZWD temporal variation depends on the water vapour content in the atmosphere, it seems to be reasonable that ZWD constraints in GNSS processing should be geographically and/or time dependent. We propose to take benefit from numerical weather prediction models to define optimum random walk process noise. In the first approach we used archived VMF1-G data to calculate a grid of yearly and monthly means of the difference of ZWD between two consecutive epochs divided by the root square of the time lapsed, which can be considered as a random walk process noise. Alternatively, we used the Global Forecast System (GFS) model from National Centres for Environmental Prediction (NCEP) to calculate random walk process noise dynamically in real-time. We performed two representative experimental campaigns with 20 globally distributed IGS stations and compared real-time ZTD estimates with the

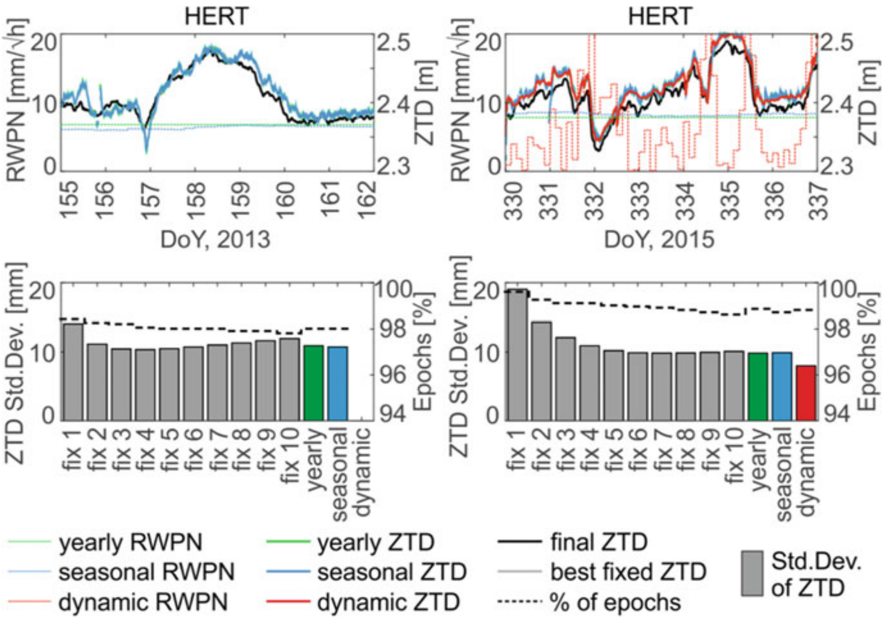

Fig. 7.8 Comparison of wet RWPN, ZTD time series, standard deviations of real-time ZTD residuals with respect to the final ZTD and solution availability among variants for station HERT

official ZTD product from the IGS. With both our approaches, we obtained an improvement of up to 10% in accuracy of the ZTD estimates compared to any uniformly fixed random walk process noise applied for all stations (Fig. 7.8). The results are published in Hadaś et al. (2017).

STSM Applicant: Ms Katarzyna Stepniak, University of Warmia and Mazury in Olsztyn, Olsztyn (PL), katarzyna.stepniak@uwm.edu.pl
STSM Topic: Improved methods for reprocessing of GNSS data for climate monitoring over Poland
Host: Olivier Bock, IGN – LAREG, Paris (FR), Olivier.Bock@ign.fr

The goal of the work was to determine the most accurate and homogeneous processing strategy to reprocess ground-based GNSS data for climate monitoring applications. We investigated impact of network design strategy on the quality and homogeneity of relative (double difference) strategies and afterwards, compared to standard BSW obs-max solution. We found out that the strategies have limitations and are prone to ZTD outliers and gaps. Investigation of various case studies helped to identify the weaknesses of these strategies. We proposed and tested an alternative baseline strategy that overcomes the most severe limitations and yields ZTD time series with much less outliers and gaps. We also described an efficient outlier detection method for the final screening of the reprocessed ZTD time series and assess the quality of final ZTD data by comparison with ERA-Interim reanalysis. The new strategy is recommended by us to use to estimate ZTD time series for meteorology and climate monitoring applications in moderate-size networks (e.g. national scale).

STSM Applicant: *Ms Anna Klos, Military University of Technology, Warsaw (PL),* anna.klos@wat.edu.pl

STSM Topic: *Analysis of ZTD time series from reprocessed GPS solutions*

Host: *Felix Norman Teferle, University of Luxembourg, Luxembourg (LU),* Norman.Teferle@uni.lu

The Short Term Scientific Mission (STSM) titled: "Analysis of Zenith Total Delay Time Series from Reprocessed GPS Solutions" was hosted by University of Luxembourg and supervised by prof. Felix Norman Teferle. Within and thanks to the funds of COST ES1206 Action, I performed an analysis of ZTD time series obtained by BLT (British Isles continuous GNSS Facility and University of Luxembourg Tide Gauge Benchmark Monitoring (TIGA) Analysis Centre) as one of its activities as IGS analysis centre. The analysis included 44 globally distributed stations situated in 5 different climate zones. The ZTD series were sampled every 1 h. Series varied in length between 1995 and 2015. We modelled the ZTD data as the sum of trend, seasonal signals and breaks. The seasonal signals can reflect seasonal changes with periods of tropical year and its harmonics along with diurnal and semi-diurnal changes. Stochastic part or so-called residua is a misfit between real data and deterministic model of initial value, trend, seasonal component and breaks. We made a deep search through climate literature and found out that climatologists describe noise in all climate time series as autoregressive model (AR), mainly being of 1st order (e.g. Mann and Lees 1996; Matyasovszky 2013). If ZTD series are analysed in terms of climate changes it should show similar noise character to climate time series. We examined few different noise models to be fitted into residuals: white noise, power-law plus white noise and different kinds of autoregressive model. The analysis was performed with the Maximum Likelihood Estimation (MLE) approach. We found that 4th order of autoregressive model is a preferred one to describe the ZTD residuals. We computed the ratios between ZTD trend uncertainty estimated with white and autoregressive noise model. We found, that up until now, the uncertainties of ZTD trends were underestimated by a factor of up to 10. This means, that some trends, used to the analysis of climate change might have been insignificant.

Conclusions In this research, we aimed at evaluation of uncertainty of ZTD trend. To date, all analyses were performed with the assumption of white noise. This is not a proper one, when one concerns on climate implications. We recommend that an autoregressive noise model is used, when ZTD trend is going to be estimated with a high accuracy.

STSM Applicant: *Mr Kamil Kazmierski, Wroclaw University of Environmental and Life Sciences, Wroclaw (PL),* kamil.kazmierski@igig.up.wroc.pl

STSM Topic: *Real-time troposphere delay gradient estimation with multi-GNSS PPP*

Host: *Marcelo Santos, University of New Brunswick, Fredericton (CA),* msantos@unb.ca

The main purpose of this mission was to implement real-time tropospheric gradient estimation module into GNSS-WARP software. This visit was a perfect opportunity to improve GNSS-WARP software, implement additional modules and exchange experience connected with Precise Point Positioning. At the very beginning of my stay I had an opportunity to get to know how GAPS performs PPP calculation, as well as which parameters are estimated during the processing and in what way. After that I was able to make an implementation of tropospheric gradient estimation module into GNSS-WARP software. During the implementation work Chen & Herring linear horizontal gradient formulation was used. Additionally, two parameters were added as extra parameters into the last square adjustment and then estimated in each observation epoch (according to RINEX file interval).

In order to validate the obtained results COST Benchmark data were used. Only one Analysis Centre, Agenzia Spaziale Italiana (ASI), provided information about tropospheric gradients stored in COST format. The second source of reference data came directly from Rosa Pacione who works with ASI. Those results were obtained from PPP processing and provided data in 5 min intervals. As a testing period the dates between 4 and 11 June 2013 (155-161 DoY) were selected. During processing RINEX files served as sources of observations. The real-time data available for this period were provided by IGS and covered both orbit and clock corrections for GPS. Eight European stations were selected as a test stations set (BRST, BRUX, BUCU, NICO, ONSA, SFER, WROC, ZIMM). For the selected stations tropospheric gradients and their statistics were calculated.

The mean BIAS for tropospheric gradients with reference to Rosa Pacione data is smaller than −0.30 mm for NS direction and + 0.20 mm for EW direction. Standard deviation and root mean square error (RMS) equal about 0.6 mm and 0.7 mm, respectively. The results obtained from comparison with COST benchmark data are comparable. The results obtained for tropospheric gradients for NS direction are biased negatively and for EW direction they are biased positively in most cases.

Additionally, during my stay at UNB multi-GNSS positioning function was implemented. As additional systems GALILEO and BeiDou were implemented. We have still some problems connected with appropriate corrections joining for BeiDou ephemeris. In real-time stream decoded by BKG Ntrip Client (BNC) v.2.12 the parameter IOD is recalculated in order to eliminate mistakes during processing. We have still some problems with appropriate BeiDou IOD calculation and at this moment BeiDou is excluded from the precise solution.

During STSM the main aims were achieved and the presented results are promising. Conducted works shown that tropospheric gradient estimation using real-time products estimation performs well. The results are not highly accurate in comparison with the reference data. It may be connected with the quality of real-time products. The differences may occur due to the different strategies in GPISY and in GNSS-WARP. In the near future we hope to finish the work connected with operating BeiDou during processing.

The grantee and the host institution declared future collaboration connected with the development of GNSS-WARP as well as GAPS software. The host confirms the above execution and benefits of this STSM, considering it as successful.

STSM Applicant: *Ms Karina Wilgan, Wroclaw University of Environmental and Life Sciences, Wroclaw (PL),* karina.wilgan@igig.up.wroc.pl
STSM Topic: *Lookup tables of refractivity coefficients for the conversion from zenith path delays to integrated water vapour*
Host: *Hugues Brenot, Department of Atmospheric Composition, Royal Belgian Institute for Space Aeronomy, Brussels (BE),* hugues.brenot@oma.be

The purpose of this STSM was to conduct a study on the refractivity coefficients obtained from ERA-Interim and to test the sensitivity of the different steps to obtain the ZWD from ZTD and IWV from ZWD in the stand-alone GNSS strategy. The refractivity of the atmosphere can be expressed as a function of meteorological parameters with the refractivity coefficients k_1, k_2, k_3. Usually these coefficients are used as constants, but the development of satellite techniques requires re-evaluation of the existing formulas. We calculated new k_1 coefficients based on the hydrostatic formulation of ZHD considering long-term historical outputs of ERA-Interim. The overall plan for k_1 is to calculate ZHD from hydrostatic formula and compare it to ZHD integrated from ERA-Interim using the k_1 parameters at the updated frequency of the GNSS signal. The value of the k_1 from the adjusted formula is latitude dependent, which can be easily presented as a simple function of the latitude. The k_1 coefficient is not time dependent, thus, there is no need to present a look-up table for this coefficient. The simple latitude dependent formula is sufficient. Furthermore, we investigated the behaviour of the k_2 coefficient, which depends on water vapour partial pressure and temperature. The meteorological parameters were again taken from ERA-Interim reanalysis. We calculated the values of the k_2 for every vertical profile (up to 60 km above the ground) and then retrieved the mean value for each profile. The k_2 values are also latitude dependent but not in a less systematic way than k_1 coefficients. Using the ERA-Interim reanalysis we also compared different ways to calculate proportionality factor κ used in the conversion between integrated water vapour and zenith wet delay. The proportionality factor κ values are also latitude and time dependent, thus, we proposed a look-up table for κ based on month of the year and latitude.

STSM Applicant: *Ms Anna Klos, Military University of Technology, Warsaw (PL),* anna.klos@wat.edu.pl
STSM Topic: *Selected Issues of Homogenisation of Synthetic ZTD Data with Noise Characteristic Derived from Reprocessed GPS Solutions*
Host: *Felix Norman Teferle, University of Luxembourg, Luxembourg (LU),* Norman.Teferle@uni.lu

The Short Term Scientific Mission (STSM) titled: "Homogenisation of Synthetic ZTD Data with Noise Characteristic Derived from Reprocessed GPS Solutions" was hosted by University of Luxembourg and supervised by prof. Felix Norman Teferle. Within and thanks to the funds of COST ES1206 Action, I performed an analysis of synthetic ZTD time series obtained by simulations basing on parameters derived from real changes of ZTD. During the following STSM, the parameters estimated from real ZTD data were used to perform Monte Carlo simulations based on seasonal changes and noise character derived from real data. A set of synthetic series was then subjected to a blind test to detect simulated epochs of breaks. I intended to confirm or deny that simulated breaks can be easily detected when different amplitudes of periodic terms and noise process are being simulated. However, the main thing I had to keep in mind was that most methods, including manual inspection, will not tell whether the estimated epochs of breaks are due to Gaussian behaviour of series, AR regime-like shifts or true breaks. The epochs of breaks are usually reported by individual station, but a manual or statistical inspection is always needed, since few breaks might have been unreported. This reason made me to undertake this research on how one may be misled with reporting the breaks, when the autoregressive process is being assumed. In this case, the breaks reported manually or statistically can result from AR regime-like behaviour of series rather than real changes in ZTDs. In this way, we can artificially change values of trend and misinterpret it. Once the ZTD series were simulated, we made blind tests and used statistic method called STARS (Sequential t-Test and Regime Shifts) at the same time to detect epochs of breaks under different conditions of deterministic parameters.

Conclusions Few points were raised during this STSM and will be discussed and analysed as further cooperation. Breaks are mostly determined with epochs reported by each individual station, but manual inspection is needed. Some statistic methods are used to this task, however, their results have to be carefully checked. We used STARS to indicate on epochs of breaks but this is a semi-automatic method. All results have to be properly checked, as due to regime-like behaviour of AR it is almost impossible for statistical methods to properly detect epochs of breaks. This fact was also reported earlier by climatologists. If reported breaks were not checked carefully before being taken into consideration, they will totally change the character of stochastic part. Also, we need to be aware of regime-like behaviour of noise process.

STSM Applicant: *Ms Anna Klos, Military University of Technology, Warsaw (PL),* anna.klos@wat.edu.pl
STSM Topic: *On the homogenisation and characterisation of IWV time series from IGS repro1 and its comparison to ERA-Interim*
Host: *Eric Pottiaux, Royal Observatory of Belgium, Brussels (BE),* Eric.Pottiaux@oma.be

The short-term scientific mission I attended was hosted by the Royal Observatory of Belgium and the Royal Meteorological Institute of Belgium, under the supervision of Dr. Eric Pottiaux and Dr. Roeland Van Malderen. We examined the properties of the IWV data retrieved from GPS observations and compared these with the IWV values calculated with the ERA-Interim model. The entire analysis was performed for the IGS repro1 dataset of 120 stations, prepared by Dr. Olivier Bock for the purpose of the data homogenisation activities of the sub-WG3 'data

Homogenisation'. The differences of IWVs were examined with the Maximum Likelihood Estimation (MLE) approach to estimate the parameters which characterize the dataset, as trend, seasonal signals, breaks and noise character. Thereafter, three synthetic datasets were created basing on the parameters we estimated for real IWV records: 'Easy', 'Less-complicated' and 'Fully-complicated', each containing 120 stations. The datasets differed in a complexity of parameters and noise model. The 'easy' dataset includes only pure white noise, while the 'less-complicated' also includes the autoregressive process of first order in addition to the white noise. Finally, the 'fully-complicated' also includes trends and gaps. In all three variants, seasonal components and breaks of known epoch and amplitude were introduced.

Conclusions The synthetic datasets were used to benchmark the performance of various statistical homogenization tools. These three synthetic datasets were subjected to homogenisation task and shared with the homogenisation activity leaving the epochs of breaks blinded. The synthetic datasets we created within this STSM, will be used to assess the ability of different homogenisation tools to report epochs of breaks when different parameters are found in the series. The tool which performs the best will then be used to homogenise the real IWV dataset before trend is being estimated.

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