1st ES1206 - GNSS4SWEC Workshop Munich, February 26-28, 2014

Day 1

Weds 26/02/14, 09:00-12:30, Room U151 • 09:15-09:45

International GNSS Service - products and models for precise GNSS analyses

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The International GNSS Service (IGS) is a scientific Service of the International Association of Geodesy (IAG) since 20 years. Since its beginning it grew to a voluntary federation of some 250 contributing organizations and institutions from about 90 countries worldwide. The IGS operate the world largest global GNSS tracking network consisting of some 450 stations, makes highest quality data and products freely available to users, and provides essential input for the realization of the International Terrestrial Reference Frame (ITRF). The Multi GNSS Experiment (MGEX) is preparing the IGS for the new era with more than 100 navigation satellites in the sky. The IGS Real-time Service launched one year ago is approaching Full Operational Capability. Main product of the IGS are daily precise GNSS satellite orbits and clock corrections as well as precise station coordinates and velocities. Daily troposphere zenith path delays with a temporal resolution of 5 minutes are generated based on a precise point positioning (PPP) approach for more than 300 stations by the IGS Associate Analysis Center at US Naval Observatory in Washington, USA. In this presentation the performance of these products as well as underlying models are illustrated and further directions are addressed.

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Use of numerical weather model data in space geodetic techniques

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Atmospheric effects play a key role in space geodesy. Observations from techniques such as Global Navigation Satellite Systems (GNSS) or Very Long Baseline Interferometry (VLBI) are affected by the atmosphere in various ways. Most importantly, the signals at microwave frequencies from satellites or extragalactic radio sources are delayed in the atmosphere by up to tens of metres at low elevation angles. The solid Earth below the stations is deformed by up to a few centimetres depending on the variation between high and low pressure systems, and orbits of low satellites not only react to the changing density distribution in the atmosphere but are even slowed down by atmospheric drag. Finally, the atmosphere is changing the rotation of the Earth by exerting torques on the surface of the Earth. In this overview presentation it is shown how data from numerical weather models is used to assess and model the effects mentioned above. Special attention will be given to tropospheric delay modelling, where there are different possibilities to exploit the data: Ray-tracing per observation is the most rigorous approach but can hardly be realized for a huge amount of GNSS observations. Zenith delays and mapping functions which reflect the true state of the atmosphere can be determined from numerical weather models every three or six hours. And longer time series of numerical weather model data or climatology data can be applied to generate so-called blind models which can be used without additional information from external sources. GPT2w, a recent blind model, is introduced.

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The Chinese BeiDou Navigation Satellite System And Its Precise Applications

Maorong Ge et al

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The Chinese BeiDou Navigation Satellite System, abbreviated to BDS, is planned to be established in three steps or phases: demonstrational system, regional system and global system. On December 27, 2012, the regional system was officially announced to provide positioning services over the Asia-pacific region with a constellation of five Geostationary Earth Orbit (GEO) satellites, five Inclined Geosynchronous Earth Orbit (IGSO) satellites and four Median Earth Orbit (MEO) satellites. It is no doubt that BDS will play a very important role in satellite navigation industry, and contribute to human civilization and social development along with the other GNSS systems. In this contribution, we first give an overview of the history, system configuration, development schedule, and current progress of the system. Afterwards, we concentrate on the precise positioning based on BDS observations only, mainly the related work we carried out together with our Chinese cooperative partners. It includes precise orbit determination (POD) and precise clock estimation (PCE), precise point positioning (PPP) in both static and kinematic case, in post-mission and (simulated) real-time mode, network solution of short and median inter-station distance. To validate the BDS derived products, the corresponding positions and zenith total delay (ZTD) computed from GPS data are utilized as references. Finally, multi-GNSS data processing will also be discussed in order to demonstrate the significant improvement in both accuracy and reliability.

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Introduction to GNSS detection of local delay anisotropy induced by water vapour

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The GNSS technique uses the signal emitted by a constellation of satellites and recorded by several ground-based stations. Using a precise estimation of the positions of the stations, the least-square adjustment of two tropospheric parameters can be obtained. The first paramater (so-called ZTD) describes the isotropic contribution of the troposphere, corresponding to the mean zenith total delay of the neutral atmosphere. The second parameter (so-called the horizontal delay gradient) characterises the anisotropic contribution induced by a tropospheric structure (e.g. a blob of water vapour). Using mapping functions, ZTD and gradient can be used to estimate the slant total delay of the neutral atmosphere (so-called STD) for any defined direction (e.g. the direction of each GNSS satellites considered in calculations). Because this reconstructed STD is the result of the adjustment of two tropospheric parameters (ZTD and gradient), a third tropospheric parameter (so-called residual) can be applied as a specific STD-correction in direction of a satellite. This presentation will show the validation of these three tropospheric parameters and their limitations. Finally, we hope to bring a discussion about their improvement and the next development.

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GNSS tomography: current status and road ahead

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The Global Navigation Satellite Systems (GNSS) signal's troposphere delay between satellite and receiver, is commonly used as a data source for GNSS tomography. The path delays in the direction to satellites can be converted to a 2D (vertical profiles) or 3D distribution of atmospheric refractivity (total or wet), or water vapour density using tomographic inverse transform. In principle this, approximated as linear, inverse problem is ill – conditioned and ill - posed, which results in complexity of the problem. In the frame of IAG and COST action GNSS tomography groups exists. These groups are tackling current challenges of GNSS tomography modeling in finding the best way to include space based GNSS observations, to deliver more reliable slant delay processing methods, to test robust algorithms to account for outliers in observations, to determine trustworthy precision and accuracy measures, to address problems linked with near real time processing. GNSS tomography research is also gaining a momentum in Asia, Africa and Oceania, in the advent of introducing new satellite systems and increasing number of applications. In this paper the results of testing, based on the Numerical Weather Prediction (analysis steps), radiosonde data and ZTD estimates are presented. The reference model setup is identical for all tomography models which guarantees minimal impact of interpolation between models. The real observations (SWD and SIWV) were generated as a mandatory input data. The experiment consists simulation data processing with minimum and maximum apriori data as well as processing the real observations with different approaches. Following nodes of GNSS tomography processing have been considered: preprocessing of path delays, voxel model outline and construction, observation selection, raytracing algorithms, a priori observations, observations noise, inversion method, wet refractivity \ refractivity and water vapour retrievals. The results shown in this paper discuss discrepancies between reference model and tomography models and differences amongst models, stemming from assumptions, inversion method, constraints schemes, a priori information usage. It also points out to future development and reviews current state-of-the-art GNSS tomography solutions.

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Application of the GINPOS software for testing external tropospheric products in precise GNSS positioning

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In relative GNSS positioning, the correlated tropospheric effects are usually reduced by double differencing of the observations and applying standard atmospheric models. However, with a growing distance between the receivers, the tropospheric errors decorrelate causing large residual errors affecting positioning quality. These errors mostly concern the height component of the user position and are related to a high correlation of this component with zenith tropospheric delays (ZTD). This is why the troposphere is considered as an ultimate accuracy limiting factor in geodetic applications of GNSS. Currently, the most popular solution in the state of the art applications is to estimate ZTD together with station coordinates in the common data adjustment. This approach requires long data spans, e.g., at least 30-60 minutes. However, in instantaneous, kinematic and fast static positioning when short data spans (even single epochs only) are available, this method in not feasible and the troposphere is very difficult to model. Therefore, external tropospheric information is required in order to provide accurate position. This can be achieved by a network of the reference GNSS stations, from the ground meteorological data or from the numerical weather models (NWM). In this contribution we present possibilities of the validation of different tropospheric products using the GINPOS software developed at the University of Warmia and Mazury in Olsztyn. Our studies concern instantaneous, kinematic and fast-static positioning. The research carried out up to now show that external ZTD products can improve both the accuracy and the integerity of the precise positioning. But on the other hand, mismodelling of the troposphere may disrupt ambiguity resolution and, therefore, prevents the users from obtaining accurate position.

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The Potsdam Mapping Factors: Rapid direct tropospheric mapping

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Precise GNSS positioning requires an accurate Mapping Function (MF) to model the tropospheric delay. To date the most accurate MF is the Vienna Mapping Function 1 (VMF1) because it utilizes data from a numerical weather model which is known for high predictive skill (Integrated Forecast System of the European Centre of Medium range Weather Forecast). Still, the VMF1, or any other MF which is based on the VMF1 concept, is a parameterized mapping approach and this means that it is tuned for specific elevation angles, station and orbital altitudes. At this workshop we show the systematic errors caused by such tuning on a global scale and we like to stimulate a discussion about the two options we see: (1) to mitigate the errors by improving the parameterized mapping approach or (2) to eliminate the errors by a (ultra-) rapiddirect mapping approach; the so-called Potsdam Mapping Factors (PMFs).

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Sensitivity of GPS measurements and estimates during extreme meteorological events: the case study of mesoscale convective systems in West Africa

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Six permanent GPS stations have been deployed in West Africa within the framework of the African Monsoon Multidisciplinary Analysis (AMMA) project in order to monitor precipitable water vapor (PWV). This quantity is indeed widely employed to compute water budgets and study atmospheric processes. But in Sahel, 90% of annual rainfalls are produced by Mesoscale Convective Systems (MCSs) and PWV estimates tend to be less accurate during these extreme meteorological conditions: temperatures fall, GPS PWV estimates reach a local maximum and GPS phase residuals show strong variations that are spatially and temporally correlated. We observed that GPS phase residuals, which give insight into anomalies of the air refractivity, clearly reveal the passage of MCSs similarly as reflectivity measurements from MIT C-band Doppler radar.
The aim of this study is to evaluate the quality of the GPS PWV estimates during these events and possibly improve their estimation process. We carried out methodological and sensitivity tests on the parameterization of atmospheric delays and especially on the Gauss-Markov process which constrains the temporal variability of the GPS PWV estimates. During MCSs events, differences between GPS PWV estimates from GAMIT (2 cm.h -1/2 random walk for zenith tropospheric delays) and GIPSY (5 mm.h^(-1/2) random walk for zenith tropospheric delays) standard processing can for instance reach +/- 3.8 kg.m^(-2). Standard GPS PWV estimates are thus subject to caution during these intense events. Thus, stability of tropospheric gradient estimates have been discussed. We therefore investigate the influence of the Gauss-Markov process parameterization on the GPS phase residuals and we observe they are slightly impacted unlike ZTD or tropospheric gradients estimates.

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Investigation of the properties of discrete mesoscale mapping functions

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The paper presents the results of analyses of numerical experiments concerning GPS signal propagation delays in the atmosphere and discrete mapping functions defined using them as a base. The delays were determined using data from the mesoscale nonhydrostatic weather model operated in the Centre of Applied Geomatics Military University of Technology. A special attention was paid to investigate temporal and spatial characteristics of GPS slant delays for low angles of elevation. The conducted investigation proved that the temporal and spatial variability of the features depends on a large extent on current weather conditions. The problem of GNSS products assimilation to the NWP models will be also discussed.

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The atmospheric information content of GPS slant total delays

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Radio signals which are transmitted by GPS satellites and received by a ground-based station allow the estimation of the Zenith Total Delay (ZTD). Clearly, the ZTD is of limited value in weather forecasting because it does not contain information about horizontal (and vertical) atmospheric gradients. In this work we show that the estimated Slant Total Delays (STDs), i.e. the atmospheric induced signal travel time delays between the GPS satellites in view and the station, contain the desired additional information. To do so, we first determine artificial STDs in a Numerical Weather Model (NWM) by point-to-point raytracing and retrieve NWM refractivity gradients through a non-linear least square analysis. Then, we repeat this exercise but use real STDs instead to retrieve GPS refractivity gradients. This procedure is done station-by-station for ~200 stations in Germany and maps of NWM and GPS horizontal refractity gradients are generated. The remarkable close agreement between the maps (inspection by eye) leads to the conclusion that STDs carry the signature of the atmospheric asymmetry. The statistics supports this finding and since STDs are available in near-real time as well they are considered a valuable new data source for weather forecasting.

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Producing IWV Maps for Guiding Nowcasting of Severe Weather

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The Royal Observatory of Belgium (ROB) processes Global Positioning System (GPS) signals to provide Zenith Tropospheric Delay (ZTD) estimates in support of European meteorological services with aiming at data assimilation in operational Numerical Weather Prediction (NWP) models. Therefore, ROB develops and maintains an analysis center participating to the EUMETNET EIG GNSS water VApour program (E-GVAP) which provides hourly-updated ZTDs from about 350 European GNSS stations.
In this presentation, we explain the enhancements foreseen for this service to further support high- resolution NWP and the forecasting of severe weather. We also present a severe weather case study selected fop benchmarking our developments. For this severe weather case, we combined our tropospheric parameters with meteorological observations from the Belgian and Dutch automatic weather stations and data from the Integrated Surface Database (ISD) to produce Integrated Water Vapor (IWV) maps for use in guiding nowcasting along with weather radar images.

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Intense precipitation case studies in Bulgaria for 2012

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One of the applications of the Global Navigation Satellite Systems (GNSS) Meteorology is to study intense precipitation events. This work is a contribution to the working group two of the COST Action GNSS4SWEC and targets the use of Integrated Water Vapour (IWV), derived with the GNSS Meteorology method, during convective events with heavy precipitation in Bulgaria. Twenty two case studies were made for 2012. The main focus of this work is on four mesoscale convective systems case studies: 20 May 2012, 10 June 2012, 14 June 2012 and 26 July 2012. For the analysis of these case studies are used various techniques, including 2D IWV maps, Meteosat products and radar images.

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The combined use of GPS radio occultations and ground-based GPS receivers for detecting continental storm intensity

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The Global Positioning System (GPS) Radio Occultations (RO) method provides estimation of atmospheric parameters with high vertical resolution and global coverage. This technique has already demonstrated excellent skills for detecting and monitoring storms, but the accurate determination of water vapor is still an issue. On the other hand, ground–based GPS receivers are able to provide accurate determination of Integrated Precipitable Water Vapor (IPWV), but they do not profile the atmosphere vertically and they do not provide global coverage. Both GPS RO profiles and ground–based GPS water vapor sounding data have definitely contributed to improve weather forecasts. The land convection is usually stronger than oceanic convection and in the last decades its associated storms became a big issue, especially for the northern and central european countries, causing many deaths, injuries and damages due to flash-floods and strong winds. The combination of GPS RO profiles and IPWV from ground-based GPS receiver will be used within the CONvective SYstems Detection and analysis using Radio occultation (CONSYDER) project for detecting and monitoring the land convection intensity and the ground-based GPS network will be used for validating the water vapor estimation from RO.

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First Results of the Hungarian NRT GPS Processing in the Framework of E-GVAP/COST-1206

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Since November 2013 the SGOB processing center - established with the cooperation of the Department of Geodesy and Surveying of the Budapest University of Technology and Economics and the Satellite Geodetic Observatory in Penc – started the provide ZTD estimates on a near real-time basis to the E-GVAP community. Currently the processing is done for 77 permanent GNSS stations on an hourly basis. The majority of the stations are the stations of the Hungarian Active GNSS Network (GNSSNet.hu), but EUREF and IGS stations are also used in the processing. Since the GNSSNet.hu stations were not processed by

the existing processing centers, altogether 51 new sites were added to the E-GVAP network. The paper introduces the applied GNSS processing strategy and shows the first results of the comparison of our solutions with the solutions of some existing processing centers (ASI, BKG, GOP1 and METO). Moreover, local radiosonde observations were also used to assess the performance of our results. The comparisons show that the results fit well to the results of other processing centers.

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Assimilation of GPS ZTD observations in mesoscale AROME model at Hungarian Meteorological Service

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Thanks to the Global Navigation Satellite Systems (GNSS) more information about atmospheric water vapour content is available and proved to be beneficial for NWP purposes. One of such useful product of GNSS is the GPS Zenith Tropospheric Delays (ZTD) observations from ground-based stations which data has high spatial and temporal resolution over Europe. Aside from the station network of EUMETNET E-GVAP, additional GPS ground-based stations from Hungary are also ready to provide GPS ZTD observations by the colleagues of BME which is essential from the mesoscale NWP point of view. At OMSZ an AROME 2.5km mesoscale model is running operationally and assimilating recently conventional observations through its 3 hourly RUC (Rapid Update Cycle). Concerning the results of DFS (Degree of Freedom for Signal) diagnostic, the importance of humidity information in AROME data assimilation system is the biggest among assimilated parameters. Hence this and the above mentioned fact the assimilation of GPS ZTD has good potential regarding the Hungarian AROME model forecasts. For preliminary tests the BME colleagues kindly provided data samples which fit to the E-GVAP data format and almost ready for assimilation. Additional pre-processing is required to remove systematic bias from data which was made during a 15 days period. Then this static bias correction was applied for an active assimilation impact study for early summer period of 2013. The preliminary results of this study was promising where 2m relative humidity and precipitation forecasts were slightly improved by GPS ZTD assimilation in AROME.

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Comparison of ZTD values with their model counterparts generated by a multi-physics ensemble

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A multi-physics ensemble consisting of WRF model instances with different physics parameterizations is currently run in pseudo-operational regime as the basis for data assimilation experiments. ZTD model counterpart is currently being tested and evaluated for the ensemble members as the first step for the assimilation of ZTD data. Statistical properties of ZTD model values compared to observed ZTD from the EGVAP database will be presented and discussed.

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Error correlations of Zenith Total Delay observations from Ground-based GNSS receivers in a high resolution NWP model over the UK

G.V. Bennitt, H. Johnson, and P. Weston

The Met Office has been assimilating Zenith Total Delay (ZTD) observations from Ground-based GNSS receivers into its 1.5km horizontal resolution NWP model, the UKV, since 2010. The UKV is a non-hydrostatic grid-point model covering the British Isles, Northern France, Western Belgium and the Western Netherlands, assimilating observations with a 3D-VAR assimilation scheme using a three hour time window, every three hours. On average, 230 ZTD observations are assimilated into the UKV every three hours at each analysis time, representing most of the currently available GNSS receiver sites within the model domain. Previous studies have suggested that correlations exist between ZTD observations in both space and time, and for best practise, we should allow for these in our assimilation system. We have examined the temporal and spatial error correlations of ZTD observations in the UKV, based on the covariance of the innovations and residuals. Contrary to suggestions by previous studies, we find that the diagnosed temporal error correlations tend to be shorter than the current assimilation window for the UKV (three hours). We find no significant spatial correlation in ZTD observations within the UKV domain.

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Day 2

Thurs 27/02/14, 09:00-12:30, Room L155 • 09:05-09:35

The need for reference observations of water vapor in the troposphere and stratosphere

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Atmospheric water vapor is a key component of the global hydrological cycle and the most important climate feedback. The lower troposphere contains most of the precipitable water vapor and influences the amount of precipitation. Water vapor in the upper troposphere is the dominant radiate trace gas and controls the atmospheric radiative balance. Climate trends of water vapor and temperature in the upper troposphere and lower stratosphere are still uncertain. To address this problem, the climate community has undertaken large efforts to instigate a reference quality network to ensure the future record. These efforts have been taking shape as the GCOS Reference Upper Air Network (GRUAN). GRUAN places a strong emphasis on what defines a reference observation of an upper air essential climate variable (ECV). Upper air observations of ECVs by in situ techniques, in particular the observations of temperature and water vapor, often suffer from poorly characterized biases and random variations, which may impact the ability to detect long term changes in these parameters. Key aspects of a GRUAN measurement revolve around traceability of the measurements to recognized standards, documented uncertainty estimates, measurement technology redundancy, extensive metadata collection, and archiving of raw data in addition to processed data. Establishing long term climate series also requires that the measurement program accommodates a strategy to manage changes in instrumentation. A detailed understanding of the instrumentation and the associated processing algorithms provide the tools to manage instrumental change in a consistent manner.

Thurs 27/02/14, 09:00-12:30, Room L155 • 09:35-10:05

Using homogeneous precipitable water vapor time series derived from global GPS observations to validate this parameter in the NCEP/DOE reanalysis

SIBYLLE VEY, REINHARD DIETRICH, AXEL RÜLKE, MATHIAS FRITSCHE, PETER STEIGENBERGER AND MARKUS ROTHACHER

Tropospheric parameters from a GPS reanalysis carried out in a common project of the Technical Universities in Munich and Dresden were converted into precipitable water (PW) using surface pressure observations from the WMO and mean atmospheric temperature data from ECMWF. PW time series were generated for 141 globally distributed GPS sites covering the time period from the beginning of 1994 to the end of 2004. The GPS-derived PW time series were carefully examined for their homogeneity regarding the influence of changes in the GPS antennas and radomes as well as changes in the number of recorded observations. The focus of this study is on interannual changes in precipitable water. Over Europe, large parts of North America, and Iceland and in the region south of 30°S, these changes are very small. The range of the PW variations on interannual time scales is less than 2 mm in these areas. However, in the southeastern part of North America and north Australia, these anomalies in precipitable water show a range of up to 6 mm. In the tropics, PW anomalies with a range of up to 10 mm were found. The validation of the

NWP model from NCEP shows that the differences between the modeled and observed PW values are time dependent. Over Europe and large parts of North America the seasonal cycle and the interannual variations in the PW from GPS and NCEP agree very well. The results reveal a submillimeter accuracy of the GPS-derived PW anomalies. In the regions mentioned above, NCEP provides a highly accurate database for studies of long- term changes in the atmospheric water vapor. However, in the Southern Hemisphere large differences in the seasonal signals and in the PW anomalies were found between GPS and NCEP. The seasonal signal of the PW is underestimated by NCEP in the tropics and in Antarctica by up to 40% and 25%, respectively. Climate change studies based on water vapor data from NCEP should consider the large uncertainties in the analysis when interpreting these data, especially in the tropics.

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Reprocessing Activities as possible contribution to GNSS4SWEC

E. Brockmann, O. Bock , R. Dach, G. Dick, J. Dousa, U. Hugentobler, R. Pacione

Presently, various reprocessing activities are realized for different applications. The IGS reprocessing activity has the focus to give input to an updated International Terrestrial Reference Frame ITRF2012. In Europe several global analysis centers will contribute with globally reprocessed networks. Furthermore, orbit and earth rotation parameter products are generated which then may serve as input for other reprocessing activities with focus on other parameters. The EUREF Reprocessing activity repro2 is such an application which will generate densified results for the European Terrestrial Reference Frame. Similar to this COST action, a benchmark campaign should ensure a proper contribution of probably more than 10 analysis centers. On top of these activities many analysis centers generate series which even include more densified networks.
The paper gives a rough overview about some of the current reprocessing activities, shows similarities and outlines the planned time schedule of these activities. Due to the fact that also troposphere parameters are generated – sometimes only as by-product – synergies with the GNSS4SWEC project are discussed. Furthermore, a working plan for common WG1 and WG3 collaboration is proposed.

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How to homogenize GNSS ZTD series ?

X. Collilieux, O. Bock, E. Lebarbier, J. Gazeaux, P. Bosser

15-year long zenithal troposphere delay time series derived from space geodetic techniques, and especially GNSS, are now available. Because they have been shown to be very precise, GPS derived products are now assimilated in meteorological models since they provide a measurement of the integrated water vapour content over the stations. In addition, long series provide a precious source of independent information for validating climate models and space mission measurements. It is known that such series show fictitious offsets related to instrumental errors. If not corrected, those may affect the trend of the series and cause misinterpretation of the climate phenomenon under study. Homogenization consists in detecting and correcting such offsets. Because the number of stations has drastically increased during the past decades, reliable and automatic methods based on solid statistics are required to homogenize the series. In this presentation, we will discuss homogenization problems in different fields (climate/meteorology, biostatistics, geodesy) and review previous COST experiences coping with such problems (ES0601 and ES0701) and describe their main conclusions. Then, we will describe GNSS ZTD series properties and establish the specifications of the homogenization methods required to properly correct them.

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GNSS Atmospheric Water Vapor Retrieval methods

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Atmospheric water vapour is the most abundant green house gas involved in the climate feedback loop. It may be measured by several instruments as in-situ radiosondes, satellite-based and ground-based microwave radiometers, GNSS data. However the GNSS direct tropospheric parameter is the Zenith Total Delay (ZTD) from which Integrated Water Vapour (IWV) can be inferred if surface pressure and mean atmospheric temperature are provided. These conversion parameters can be obtained from different sources: collocated pressure and temperature sensors, empirical models (e.g. GPT/GPT2), Numerical Weather Models (e.g. ERA-Interim). Interpolation schemes as well as altitude corrections are often applied to get such meteo variables at the GNSS site location. This presentation reviews the methodology currently applied in the conversion from GNSS ZTD to IWV. As a start-up in the activities of the WG3 ‘‘Use of GNSS tropospheric products for climate monitoring’ of the COST Action ES1206 ‘Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate (GNSS4SWEC)’ an inventory of methods as well as of data sources used in the conversion has been carried out. A summary of this inventory will be presented as well.

Thurs 27/02/14, 09:00-12:30, Room L155 • 11:45-12:10

A literature survey on IWV intercomparison studies

Roeland Van Malderen
Royal Meteorological Institute of Belgium

Within GNSS4SWEC WG3, an inventory of IWV intercomparison studies and sites has been compiled, based on contributions by the COST action ‘s participants. In this presentation, we try to distillate some general findings from this literature survey of IWV techniques intercomparison studies including the GPS technique. We try to figure out the impact of observational constraints for some techniques (e.g. clear sky) and the geographical location or height of the sites on the IWV differences. Or, should we conclude that the reported systematic differences between different techniques are study-dependent and do they consequently show no overall consistent pattern? Finally, we try to identify the techniques that are most suitable for recording IWV time series for climate applications.

Thurs 27/02/14, 09:00-12:30, Room L155 • 12:10-12:25

Atmospheric water vapor measurements at a high latitude GRUAN site

Kalev Rannat, TUT, Rigel Kivi, FMI

The GCOS Reference Upper Air Network (GRUAN) was established to provide long-term high-quality climate records. Instrumentation at GRUAN sites includes the Global Navigation Satellite System (GNSS) receivers and various other sensors providing redundant measurements of climate parameters. Water vapour is one of the primary variables within the GRUAN network. Here we have chosen a northern high latitude GRUAN site Sodankylä (67.4 °N, 26.6 °E, 179 m above mean sea level) to study accuracy of integrated water vapour retrievals under relatively dry sub-arctic conditions. We provide integrated water vapour (IWV) comparisons using two GNSS receivers, radiosondes RS92, a Fourier Transform Infrared (FTIR) spectrometer, a microwave radiometer and a Cimel sunphotometer. In addition we study differences in IWV amounts based on two GNSS receivers within a relatively short distance.

Thurs 27/02/14, 14:00-17:30, Room B001 • 14:00-14:40
Overview of GNSS Data Processing Techniques and Data Quality
J. Dousa

Thurs 27/02/14, 14:00-17:30, Room B001 • 14:40-15:20
Operational Ground-based GNSS assimilation
G.V. Bennitt

Since the concept of GNSS Meteorology was first introduced in the early 1990s, numerous studies have set out to exploit signals from GNSS satellites in meteorology. The first operational assimilation of Ground-based GNSS atmospheric observations started more than a decade later in the mid-2000s. The Met Office was one of the first NWP centres to assimilate Ground-based GNSS observations operationally, and has been continuing to refine its assimilation methods since that time. With reference to the strategy of other centres who operationally assimilate Ground-based GNSS observations, we present some of our current methods, and our considerations for future assimilation. We also include the results of some recent impact studies and diagnosis of error correlations.

Thurs 27/02/14, 14:00-17:30, Room B001 • 15:20-15:40
Overview of GNSS Data Assimilation at MeteoFrance
Jean Francois Mahfouf

Thurs 27/02/14, 14:00-17:30, Room B001 • 16:00-16:20
GPS Slant Total Delay Assimilation with a Storm Scale 4D-Var on an MCS Event
Takuya Kawabata

Thurs 27/02/14, 14:00-17:30, Room B001 • 16:20-17:00
GNSS Data Assimilation and GNSS Tomography for Global and Regional Models
Michael Bender

Thurs 27/02/14, 14:00-17:30, Room B001 • 17:00-17:30
E-GVAP
Henrik Vedel

1st ES1206 - GNSS4SWEC Workshop Munich, February 26-28, 2013

Day 3

Fri 28/02/14, 9:00-12:00, Room B001 • 10:10-10:30

Comparative Analysis of Real-Time Precise Point Positioning Zenith Total Delay Estimates

Furqan Ahmed1, Pavel Vaclavovic2, Felix Norman Teferle1, Jan Dousa2, Richard Bingley3, and Denis Laurichesse4

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2) Geodetic Observatory Pecny, Research Institute of Geodesy, Topography and
3) Nottingham Geospatial Institute, University of Nottingham, United Kingdom
4) Centre National d'Etudes Spatiales, France

The continuous evolution of Global Navigation Satellite Systems (GNSS) is increasing the interest of the meteorological community in the use of GNSS observations for operational meteorology. The assimilation of near real-time (NRT) GNSS-derived zenith total delay (ZTD) estimates into local, regional and global scale numerical weather prediction (NWP) models with 3-hourly to 6-hourly cycles is a usual practice as of now. However, the development of NWP models with high update cycles e.g. the Rapid Update Cycle (RUC) with 1-hourly cycling for nowcasting and monitoring of extreme weather events in recent years, requires the estimation of ZTD with sub-hourly latencies, i.e. few minutes, while maintaining an adequate level of accuracy for these. The availability of observations and products in real-time (RT) from the IGS RT service and associated analysis centers makes it possible to compute precise point positioning (PPP) solutions in RT, which provide ZTD along with position estimates. This study presents a comparison of the RT ZTD estimates from three different PPP software packages (G-Nut/Tefnut, BNC2.7 and PPP-Wizard) to the state-of-the-art IGS Final Troposphere Product employing PPP in the Bernese GPS Software. Overall, the ZTD time series obtained by the software packages agree fairly well with the estimates following the variations of the other solutions, but showing various biases with the reference. The application of PPP ambiguity resolution in one solution or the use of different RT product streams shows little impact on the ZTD estimates.

Fri 28/02/14, 14:00-17:00, Room B001 • 14:00-14:30

The GEWEX water vapor assessment (G-VAP) – first results from inter-comparisons and stability analysis.

Marc Schröder (DWD), Maarit Lockhoff (DWD), Lei Shi (NOAA)

In a Joint Letter from the Global Climate Observing System (GCOS) and the World Climate Research Programme (WCRP) the general need for coordinated international assessments of climate products was formulated. Such assessments are important mechanisms for improvements and to enhance and promote utilisation. The GEWEX Data and Assessments Panel (GDAP) has initiated a Water Vapor Assessment in 2011, further on referred to as G-VAP. The major purpose of G-VAP is to:

• Quantify the state of the art in water vapour products being constructed for climate applications, and by this;

• Support the selection process of suitable water vapour products by GDAP for its production of globally consistent water and energy cycle products.

Since the start of G-VAP in 2011 two workshops have been conducted. The results of these workshops

together with feedback from the first GDAP meeting were used for setting up the G-VAP assessment plan. This plan (available at www.gewex-vap.org) summarizes scope and goals of the assessment, introduces science questions and provides details on the planned technical and scientific activities.

Major elements of G-VAP are:

• All three parts of the GCOS Essential Climate Variables (ECV) on water vapour and their consistency are considered: Total Column Water Vapour, Upper Tropospheric Humidity as well as water vapour profiles and their related temperature profiles;

• The assessment focuses on overall characteristics of participating satellite data records and reanalyses as determined from inter-comparison and comparisons against in situ observations as well as against ground-based products;

• In this characterisation process the data records are not ranked according to their quality.

Rather, the application areas and requirements of the individual data records as well as the GEWEX requirements are documented;

• G-VAP will provide a database that includes collocated products and validation data of sufficient quality and long-term stability to be the main repository for the current assessment.

A general overview of G-VAP will be given. The focus of the presentation will be on observed inconsistencies among the long-term satellite data records as observed by the (inter-)comparisons and the stability analysis. First explanations for observed inconsistencies will be given.

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Weds 26/02/14, 17:30-20:00, Foyer, C003 and C007
Poster session WG1

Summary of tropospheric products provided by Geodetic Observatory Pecny (GOP)
Jan Douša, Pavel Václavovic
Research Institute of Geodesy, Topography and Cartography, Ústecká 98, Zdiby 250, The Czech Republic, jan.dousa@pecny.cz

The Geodetic Observatory Pecný (GOP) has a long-term experience in the estimation of precise tropospheric parameters from GNSS permanent stations, in particular under the limited timeliness of near real time and, recently, real time. More than a decade, the GOP zenith total delays (ZTD) contributed to various projects in Europe (COST-716, TOUGH, E-GVAP, E-GVAP II) and the operational ZTD hourly updated product flows via the meteorological observation exchange network – GTS - to the end users worldwide. Recent developments at GOP consisted of a) implementation and assessment of the global hourly ZTD product of about 170 stations, b) implementation of routine multi-GNSS (GPS+GLONASS) ZTD European product, and c) implementation of ultra-fast/real-time ZTD product. This presentation provides a summary and long-term evaluation of all these products.

Development of the tropospheric augmentation model in support of precise point positioning
Michal Eliaš, Jan Douša, Pavel Václavovic
Geodetic Observatory Pecný, Research Institute of Geodesy, Topography and Cartography
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Tropospheric models in support of geodetic positioning usually consist of input climatological, or meteorological, data along with the physical or mathematical background formulation. Recently, we have developed an augmentation tropospheric model that is suitable for supporting Precise Point Positioning. It is based on data from the numerical weather prediction and using modified algorithms and parametrisation and which can be a basis for various further improvements. In the presentation, we compare the performance of the initial augmentation model in a closed loop with respect to the existing other approaches. We assess it with help of reference data sets from the IGS/EUREF final tropospheric products. Another step consists of the demonstrating its potential for support of the Precise Point Positioning, in particular to reduce a convergence time of kinematic solutions.

GNSS meteorology processing activities at WUELS. Current status, results and plans
Jan Kaplon, Jan Sierny, Karina Wilgan, Tomasz Hadas, Witold Rohm, Jaroslaw Bosy, Pawel Hordyniec
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GNSS&Meteo group at Wroclaw University of Environmental and Life Sciences, Poland is continuously working on GNSS meteorology since 2010. Currently group maintain real-time (RT) service collecting GNSS and meteorological data and near real-time (NRT) services for estimation of Zenith Troposphere Delay (ZTD), Zenith Hydrostatic Delay (ZHD) and Integrated Water Vapour (IWV) over the territory of Poland. Data are obtained with high resolution from EPN stations and Ground Base Augmentation System (GBAS) called ASG-EUPOS (www.asgeupos.pl). The GNSS data are available from ~124 reference stations located in Poland and neighbour countries, with the average 70km distance between stations. The ground meteorological observations in the area of Poland and neighbour countries are available from: ASG-EUPOS stations included in EUREF Permanent Network (EPN), airport meteorological stations (METAR messages stations) and stations managed by national Institute of Meteorology and Water Management (SYNOP messages stations). The first part of the paper presents the methodology of ASG-EUPOS GNSS data processing for NRT ZTD and ZTD horizontal gradients estimation in double-differenced mode (under Bernese GNSS Software V5.0) as well as new results from PPP mode (under Bernese GNSS Software V5.2) and their validation with respect to Rapid and Final troposphere products. The second part is describing the quality assessment of meteorological parameters interpolation methods for determination of ZHD at GNSS sites performed on GNSS stations equipped with meteorological sensors. The third part concerns the comparisons of ZTD from GNSS data and meteorological parameters from SYNOP stations with data from COAMPS numerical weather prediction system (NWP). The last part describes the IWV calculation, validation and visualization over the area of Poland.

Water Vapour Estimation using GPS

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The project titled “water vapour estimation using GPS” is supported by the Scientific and Technological Research Council of Turkey. This project aims to determine the total zenith delays and the precipitable water vapour accurately and reliably from CORS-TR (The Turkish Network-RTK) data and to produce numerical models based on time and position. The numerical total zenith delay model produced from the project will be used for real-time kinematic GNSS (Global Navigation Satellite Systems) (RTK GNSS), PPP (Precise Point Positioning) applications, precise positioning with GNSS. Moreover, numerical precipitable water vapour model will be used for weather forecast and prediction of extreme meteorological events for short-term studies. For long-term studies the model will be used as a basic variable in climate research.

COST ES1206: Contribution of the Vienna University of Technology

Möller Gregor, Böhm Johannes, Elke Umnig, Fabian Hinterberger, Weber Robert
Vienna University of Technology, Vienna, Austria

In May 2013 the European COST action (European Cooperation in Science and Technology) ES1206 started with the aim to investigate advanced GNSS tropospheric products for monitoring severe weather events and climate. In order to coordinate such a wide area, three working groups (WG) are established according to the specific activities in advanced GNSS processing techniques (WG1), severe weather monitoring (WG2) and climate monitoring (WG3). In the framework of the working group meeting from 26-28 February 2014 in Munich we give an outline presentation about our research activities with respect to WG1. This includes our efforts to set up an automatic processing scheme in order to derive zenith tropospheric delays (ZTDs) in near real-time from GPS and GLONASS observations at about 90 Austrian sites. Then we will capture our research activities in the field of GNSS tomography. We would like to present our national research project GNSS-ATOM and show first results pointing out the impact of upcoming Galileo signals on atmospheric tomography. Subsequently we are going to present the new tropospheric error correction model GPT2w which is an enhancement of the Global Pressure and Temperature (GPT) model. It provides several meteorological parameter and mapping function coefficients on a global grid of 1° x 1° - derived from 10 years ECMWF ERA-Interim data from 2001-2010. In blind mode or operated with additional information about the current state of the atmosphere it might be used as a priori model for high precision GNSS data analysis. In addition we are going to summarize our further developments related to the current activities in WG1.

GNSS permanent station network infrastructure in Greece: Current Status and Future plans.

Chris Pikridas, Symeon Katsougiannopoulos, Nicholas Zinas

GNSS permanent station network infrastructures are currently widely deployed and operated in Greece by both public and private organizations numbering more than 200 stations across the country. Their primary use is for cadastral surveying purposes and precise positioning applications. The Department of Geodesy & Surveying of the Aristotle University of Thessaloniki (Auth) is responsible for the collection of daily RINEX files from 75 GNSS permanent stations and for the monitoring of RTCM data streams. This poster will provide an overview of the current GNSS permanent station infrastructure in Greece, comment on existing raw GNSS data archives and present processing results via Bernese software of Zenith Tropospheric Delay time series.

Recent Developments towards enhanced Multi-GNSS Processing and Tropospheric Products at ROB

Eric Pottiaux, Julie Berckmans and Carine Bruyninx
(1) Royal Observatory of Belgium (ROB)
(2) Solar Terrestrial Center of Excellence (STCE)

The Royal Observatory of Belgium (ROB) processes Global Positioning System (GPS) signals to provide Zenith Tropospheric Delay (ZTD) estimates in support of European meteorological services with aiming at data assimilation in operational Numerical Weather Prediction (NWP) models. We present the recent developments made at ROB to extend this service towards a multi-GNSS processing system providing new and enhanced tropospheric products using the latest Bernese software version 5.2. As a first step, we studied the benefits of including GLONASS observations w.r.t. a GPS-only processing system, focusing particularly on the reliability and stability of the ZTD estimation. We also studied the sensitivity of the new multi-GNSS ZTD estimates with respect to the relative constraints imposed during the parameter estimation. In our setup, relative constraints of 0.007m provide a good balance between reducing the noise and allowing for the natural variability of the ZTD. We also show that the new multi-GNSS ZTD estimates generally agree with the GPS-only estimates at the level of 1-2 mm and that the multi-GNSS parameter estimates have slightly improved reliability and stability. In a second step, we studied the capability of simultaneously estimating multi-GNSS tropospheric horizontal gradients and ZTD parameters, focusing again on the benefits brought by adding GLONASS observations. Therefore, we setup horizontal gradient estimation with a time resolution of 1 hour. We studied the sensitivity of the new multi-GNSS gradient estimates to the relative constraints and the impact of simultaneously estimating gradients on the estimated ZTD values. The results show that loose horizontal gradient constraints (e.g. 5m) degrade the quality of the ZTD estimation and that gradients must be estimated using quite tight relative constraints.The previous results are combined in our final setup which estimates multi-GNSS ZTD and horizontal gradients with a time resolution of 1 hour.

First Results of the Hungarian NRT GPS Processing in the Framework of E-GVAP/COST-1206

Sz. Rózsa1 , A. Kenyeres2
1 – Department of Geodesy and Surveying, Budapest Univ. of Technology and Economics
2 – Satellite Geodetic Observatory, Institute for Geodesy, Cartography and Remote Sensing

Since November 2013 the SGOB processing center - established with the cooperation of the Department of Geodesy and Surveying of the Budapest University of Technology and Economics and the Satellite Geodetic Observatory in Penc – started the provide ZTD estimates on a near real-time basis to the E-GVAP community. Currently the processing is done for 77 permanent GNSS stations on an hourly basis. The majority of the stations are the stations of the Hungarian Active GNSS Network (GNSSNet.hu), but EUREF and IGS stations are also used in the processing. Since the GNSSNet.hu stations were not processed by the existing processing centers, altogether 51 new sites were added to the E-GVAP network. The paper introduces the applied GNSS processing strategy and shows the first results of the comparison of our solutions with the solutions of some existing processing centers (ASI, BKG, GOP1 and METO). Moreover, local radiosonde observations were also used to assess the performance of our results. The comparisons show that the results fit well to the results of other processing centers.

Tomographic determination of the Spatial Distribution of Water Vapor using GNSS Observations

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Humankind has been trying to predict the weather for millennia and always recognized importance of better understanding the weather and climate by monitoring it´s major parameters. In this respect, water vapor plays a major role in many atmospheric processes concerning physics, thermodynamics and dynamics. The knowledge of the spatial and temporal distribution of water vapor in the lower atmosphere (troposphere) is crucial for accurate quantitative prediction of precipitation and better understanding of many atmospheric processes like deep convective events. Studies about the use of GNSS observations with focus on meteorology started about 20 years ago [Bevis et al., 1992]. GNSS has large advantages since it is a system that works under all weather conditions, with continuous unattended operation, good time resolution and an ever increment in the number of stations at many regions. GNSS observations are nowadays a well-establish tool to measure the water vapor content in the lower atmosphere. The present work focuses on the study of the geometry and dynamics of moist convection, shallow and deep, through the use of 4D images of the atmosphere water vapor field, obtained from high-density GPS networks (i.e. tomographic inversion). For this, the SWART (SEGAL GNSS WAter Vapor ReconsTruction Image Software), a software package for GNSS water vapor reconstruction, has been developed. This package currently consists of four C++ programs. The C++ programs gather the necessary information to calculate the slant delays and to generate a file with the reconstructed image. The output consists in 2D slices of the 3D water vapor images in latitude, longitude or altitude. SWART is based on LOFTT_K (LOgiciel Français de Tomographic Troposphéric version Kalman) [Champollion, 2005] with some improvements, namely in the matrix inversion method. While LOFTT K uses the Single Value Decomposition method SWART uses ART algorithms (parallelized).The ART algorithms have the advantage of having high numerical stability even with inaccurate initial data, matrices with high condition number and are also computationally efficient and easily parallelized [Bender et al., 2011]. We present the results of the comparison with LOFTT_K to validate SWART together with several tests covering diverse grid sizes and different number of receivers for the same water vapor reconstruction. It is also analyzed the importance of the initial values for the image reconstruction. All these tests were realized with synthetic data, except for the grid area, which is from Marseilles, France. Finally, we present the current status of the analysis being carrying out for dense network in Belem, Brazil which data was acquired in the framework of the project CHUVA during September, 2011.

References :Champollion C., 2005: Quantification de la vapeur d'eau par GPS (modèle 2D et tomographie 3D) – Application aux précipitations intenses. Thèse de doctorat, Laboratoire de Dynamique de la

Lithosphère (Université Montpellier II).

Sofia University GNSS Analysis Centre

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The Sofia University GNSS Analysis Centre (SUGAC, suada.phys.uni-soa.bg) aims to process in near real time the regional ground-based GNSS stations in South-East Europe using the NAPEOS software. The SUGAC will provide operational data for the needs of EUMETNET E-GVAP and COST ES1206 projects. The SUGAC plans for the future include:

- processing in near real time beginning by the middle of 2014,
- processing tropospheric products for meteorological case studies (intense precipitation and fog),
- computing multi-GNSS tropospheric products (GLONASS + GPS by 2016),
- development of GNSS tomography,
- development of new GNSS research applications.

The SUGAC is operated by members of the GNSS Meteorology group at the Department of Meteorology and Geophysics of Sofia University and will foster collaborations with national and international partners.

Proposal from department of geomatics engineering at KTU (Turkey) and its vision in COST ES1206 umbrella

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This report outlines the proposal from department of Geomatics Engineering at Karadeniz Technical University (KTU), Trabzon, Turkey to contribute activities of WG1 of ES1206 and planned activities for future. Analysis of Turkish National GNSS sessions will be one of the specific interests to improve coverage of tropospheric products in Europe. Our report will cover proposal concerning the establishment of Analysis Center (AC) under WG1 at department of Geomatics Engineering at KTU and its future visions in terms of possible contributions to COST Action ES1206. As this department has experience being an analysis center of IVS-International VLBI Service (IVS KTU GEOD Analysis Center) since 2009, the hardware and software facilities is in sufficient condition at KTU. All necessary hardware equipments (two workstations, one server, and one printer) accompanying MATLAB compiler were provided by the University budget. The department provides a separate laboratory room for IVS AC to conduct the investigations with in IVS umbrella. So far VieVS (Vienna VLBI Software) developed at Institute of Geodesy and Geophysics (IGG), Vienna University of Technology (TU Wien) has been used by myself especially for analysing different kinds of IVS VLBI sessions. From now on, besides VieVS, we use a GNSS software, Bernese. Therefore, with all above mentioned facilities at department of Geomatics Engineering at KTU, we intend to take care GNSS data for improving coverage of tropospheric products in Europe and VLBI data as well for inter technique comparison.

Evaluation of benchmark results from zenith total delays estimated in real time

Pavel Vaclavovic, Jan Dousa

A benchmark campaign was started in February 2013 at the Geodetic observatory Pecny (GOP) for the assesssing of Zenith Total Delay (ZTD) estimated from GNSS data in real time in order to support nowcasting or severe weather events monitoring. For this purpose, we developed the Tefnut application which is derived from the G-Nut software library. Our solution is based on the Precise Point Positioning technique (PPP) exploiting the real time precise orbits and clocks provided by the International GNSS Service (IGS). Since February 2013, real time ZTDs have been continuously derived for 36 stations selected worldwide for benchmark campaign. Resulted ZTDs can be characterized by the standard deviation of 6-9 mm when compared to the EUREF and IGS final tropospheric products. The precision requirement for the nowcasting, initially defined during the EU TOUGH project, has been thus already accomplished. Site-specific biases of up to 15 mm (from a monthly statistics) are however still observed being caused by incomplete models in the software. These biases are stable enough to be effectively reduced before a usage of real time ZTDs in meteorological applications. The benchmark campaign included both static and kinematic coordinate solutions. The latter resulted in a slightly worse ZTD precision only, which might be encouraging to develop a system for exploiting also receivers on moving platforms for this type of applications. The G-Nut/Tefnut software is being enhanced steadily and we will focus on further improvements towards higher accuracy of estimated tropospheric parameters as well as an for extensions towards multi-GNSS and advanced tropospheric products monitoring the atmospheric asymmetry too.

Real-Time Tropospheric Delay Estimation at BKG – potential input for WP1 sub-groups

Andrea Stürze, Wolfgang Söhne, Yüksel Altiner
Federal Agency for Cartography and Geodesy (BKG)

The Federal Agency for Cartography and Geodesy (BKG) has been participating to the E-GVAP (EUMETNET EIG GNSS water vapour programme) so-called near real-time GNSS solutions with two different contributions for several years. While the legal solution is using hourly data RINEX files derived at the station the test solution is based on 15 minutes files derived from real-time data streams enabling sub-hourly processing. With the upcoming real-time data streaming using the open data policy of the International GNSS Service (IGS) and the launch of IGS Real-Time Service (RTS) in March 2013 the Precise Point Positioning (PPP) in real-time turned out to be a promising tool not only for coordinate estimation but also for Zenith Total Delay (ZTD) parameter estimation. At BKG different real-time software is in use and under development. Beside the widely-used BKG Ntrip Client (BNC) which allows for the determination of coordinates and ZTD parameters in PPP mode and the real-time software RTNet which is used for the estimation of orbit and clock correction parameters in network mode the real-time software GEMon (GREF EUREF Monitoring) is developed in co-operation with the Technical University of Darmstadt. GEMon is able to process GPS and GLONASS observation and RTS product data streams in PPP mode. Furthermore, several state-of-the-art troposphere models, for example based on numerical weather prediction data, are implemented. Hence, it opens the possibility to evaluate the potential of troposphere parameter determination in real-time and its effect to Precise Point Positioning. An offline mode allows the investigation of the influence of different RTS products and of different a priori troposphere models, e.g., in a well-defined benchmark campaign. GPS-only as well as GPS plus GLONASS processing is possible to study of the impact of multi-GNSS processing.

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Weds 26/02/14, 17:30-20:00, Foyer, C003 and C007
Poster session WG2

Detection of blobs of water vapour and potential GNSS application for nowcasting

Hugues Brenot (1), E. Pottiaux (2) and R. van Malderen (3)
(1) Belgian Institute for Space Aeronomy
(2) Royal Observatory of Belgium
(3) Royal Meteorological Institute

GNSS technique allows to measure the mean zenith delays and the associated horizontal delay gradients over a ground-based station. The variation of the path delay (between a satellite and a station) is highly sensitive to the propagation through the wet atmosphere. For this reason the delay gradients can be used to improve the monitoring of the horizontal distribution of the water vapour around a station. Using a dense network of GNSS stations (with baselines less then 30 km, like for the Belgian one), a precise description of the 2D field of delay (and of the corresponding 2D field of water vapour content) can be established. In application for the nowcasting during severe weather conditions, GNSS measurements with a high temporal resolution (e.g. 5 minutes) can be used to describe the movement of blobs of water vapour and to generate an indicator of the initiation of convective cells.

Assimilation of zenith total delays in the AROME France convective scale model: a recent assessment

Jean-François Mahfouf1, Furqan Ahmed2, Patrick Moll1, Norman Teferle2 and Richard Bingley3
1) Météo-France-CNRS/CNRM-GAME, Toulouse, France
2) Geophysics Laboratory, University of Luxembourg, Luxembourg
3) Nottingham Geospatial Institute, University of Nottingham, United Kingdom

The Zenith Total Delay (ZTD) derived from Global Navigation Satellite Systems (GNSS) observations is presently being assimilated into many state-of-the-art Numerical Weather Prediction (NWP) models worldwide. This helps to improve the knowledge of the initial state of the atmosphere and the subsequent forecasts. The convective scale NWP model AROME is operational at Météo-France since December 2008. The AROME model has a resolution of 2.5 km and uses the three dimensional variational (3D-Var) data assimilation scheme with a Rapid Update Cycle (RUC) of 3 hours. This study presents a recent assessment of the impact of assimilation of the GNSS derived ZTD observations into the AROME 3D-Var model. Two data assimilation experiments have been performed for a recent summer period of July 17, 2013 to August 20, 2013. The first experiment uses the ZTD from the stations and analysis centers available in real time through the E-GVAP. In the second experiment, additional stations processed by the University of Luxembourg have been added to the observations from E-GVAP. A third experiment without the assimilation of any GNSS ZTD observations has been performed to serve as a baseline for the first two experiments and to provide an impact assessment of GNSS ZTD data assimilation in the AROME model. From the output of these three experiments, various parameters have been extracted and statistics for the comparisons between those have been calculated. The impact assessment has been carried out in two parts i.e. studying the impact on the model analysis and studying the impact on model forecasts.

Assimilation of GNSS ZTD with HARMONIE

Jana Sanchez, Sigurdur Thorsteinsson, Magnus Lindskog, Henrik Vedel

The HARMONIE limited area modelling system has been prepared for handling GNSS ZTD observations. The functionality of different components of the extensive observation handling system will be presented. In addition, results from data assimilation experiments demonstrating the impact of the ZTD GNSS observations will be shown. The research has been carried out within the frameworks of the international HIRLAM project and the Cost Action ES1206.

The use of GNSS tomography products inside high resolution NWP model - AROME/3DVAR

Xin Yan, Christoph Wittmann, Gregor Moeller, Robert Weber

The plan for the next two years on GPS meteorology is collaborating with Technical University of Vienna to work on the newly proved FFG project- GNSS-Atom(3D ground based GNSS Atmospheric Tomography). The work of ZAMG for the next two years will be mainly focused on investigating the methods to use the 3D GNSS tomography data provided by TU Vienna. The first approach will be a 1-DVAR method to obtain the humidity and temperature profiles. The second approach is to develop an observation operator to assimilate directly the refractivity into the forecast model. It would be interesting to compare the impact of assimilating ZTD and refractivity data on forecast quality.

Precipitable water monitoring during the storm of 27 to 29 September 2012 in the Southeast of the Iberian Peninsula (Spain) obtained with GNSS techniques

Enrique Priego, Andres Seco, Diego Ferragud, Eduardo Serna

The Spanish Mediterranean area is periodically affected by torrential rainfall events. In September 2012, one of these episodes took place with up to 50 mm of rain in a 1 hour, or even more than 100 liters in 3 hours. This study shows the spatial and temporal variability of the atmospheric water vapor content (PW GNSS) and the registered rains during this event. PW GNSS data were obtained from the 38 GNSS sites available in this Spanish Mediterranean Area. The GNSS data processing strategy demonstrated its goodness by comparison of the obtained GNSS PW values with three radiosounding observed data. It was observed a good correlation between the PW GNSS data and the registered rains. It was also observed how the influence of the landform and the distance to the Mediterranean Sea modified the rain pattern if only the PW data are considered.

1st ES1206 - GNSS4SWEC Workshop Munich, February 26-28, 2013

Weds 26/02/14, 17:30-20:00, Foyer, C003 and C007

Poster session WG3

Accuracy assessment of water vapour measurements from in-situ and remote sensing techniques during the DEMEVAP 2011 campaign

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The Development of Methodologies for Water Vapour Measurement (DEMEVAP) project aims at assessing and improving humidity sounding techniques and establishing a reference system based on the combination of Raman lidars, ground-based sensors and GPS. Such a system may be used for climate monitoring, radiosonde bias detection and correction, satellite measurement calibration/validation, and mm-level geodetic positioning with Global Navigation Satellite Systems. A field experiment was conducted in September-October 2011 at Observatoire de Haute Provence (OHP). Two Raman lidars (IGN mobile lidar and OHP NDACC lidar), a stellar spectrometer (SOPHIE), a differential absorption spectrometer (SAOZ), a sun photometer (AERONET), 5 GPS receivers and 4 types of radiosondes (Vaisala RS92, MODEM M2K2-DC and M10, and Meteolabor Snow-White) participated in the campaign. A total of 26 balloons with multiple radiosondes were flown during 16 clear nights. This paper presents preliminary findings from the analysis of all these datasets. Several classical Raman lidar calibration methods are evaluated which use either Vaisala RS92 measurements, point capacitive humidity measurements, or GPS integrated water vapour (IWV) measurements. A novel method proposed by Bosser et al. (2010) is also tested. It consists in calibrating the lidar measurements during the GPS data processing. The methods achieve a repeatability of 4-5 %. Changes in calibration factor of IGN Raman lidar are evidenced which are attributed to frequent optical re-alignments. When modelling and correcting the changes as a linear function of time, the precision of the calibration factors improves to 2-3 %. However, the variations in the calibration factor, and hence the absolute accuracy, between methods and types of reference data remain at the level of 7 %. The intercomparison of radiosonde measurements shows good agreement between RS92 and Snow-White measurements up to 12 km. An overall dry bias is found in the measurements from both MODEM radiosondes. Investigation of situations with low RH values (< 10 %RH) in the lower and middle troposphere reveals, on occasion, a lower RH detection limit in the Snow-White measurements compared to RS92 due to a saturation of the Peltier device. However, on other occasions, a dry bias is found in RS92, instead. On average, both RS92 and Snow-White measurements show a slight moist bias at night-time compared to GPS IWV, while the MODEM measurements show a large dry bias. The IWV measurements from SOPHIE (night-time) and SAOZ (daytime) spectrometers, AERONET photometer (daytime) and calibrated Raman

lidar (night-time) showed excellent agreement with the GPS IWV measurements.

A high-quality, homogenized, global, long-term (1993-2008) DORIS precipitable water dataset for climate monitoring and model verification

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A high-quality, consistent, global, long-term dataset of zenith tropospheric delay (ZTD) and precipitable water (PW) was produced from Doppler Orbitography Radiopositioning Integrated by Satellite (DORIS) measurements. DORIS measurements from 81 sites are reprocessed homogeneously from January 1993 to August 2008. The dataset was screened and homogenized. A two-level screening method was developed. The first level uses post-processing information and applies range checks and outlier checks to ZTD and formal error estimates. It rejects less than 3% of the data. The second level detects outliers by comparing DORIS ZTD data with ECMWF reanalysis (ERA-Interim) data and rejects about 1% of the data. There is consistency between the screened DORIS ZTD data, ERA-Interim and Global Positioning System (GPS) data. A linear drift in mean differences is evidenced, which potentially results from biases introduced by the progressive replacement of Alcatel antennas with Starec antennas at the DORIS sites. The DORIS PW was homogenized by applying a bias correction based on the median difference between DORIS and ERA-Interim PW data each time the station equipment is changed. The homogenized DORIS PW data were compared with ERA-Interim, GPS, radiosonde, and microwave radiometer satellite data (SSM/I and AMSRE). There is excellent agreement with GPS data, and with ERA-Interim and satellite PW data, with a correlation > 0.95 and a standard deviation of with a correlation of 0.98 and a standard deviation of differences of 1.5 kg m-2 differences < 2.7 kg m-2 data. Preliminary results of water vapor trends and variability are shown for 31 sites with more than 10 years of data and 23 sites with more than 15 years of data. Good consistency is found between DORIS PW trends and ERA-Interim trends, which demonstrates the high potential of the DORIS PW dataset for climate monitoring and model verification. Radiosonde data show less good agreement with the DORIS PW.

Analysis of long time series of reprocessed GPS precipitable water estimates

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Reprocessed GPS data provide accurate and stable estimates of zenith tropospheric delay (ZTD) and precipitable water (PW) estimates. Time series exceeding 15 years become progressively available over the globally distributed continuously-operating International GNSS Service (IGS) network and the European EUREF Permanent Network (EPN). This work aims at assessing the quality of such reprocessed ZTD solutions and using them for climate monitoring and model validation. First we assessed the quality of three ZTD solutions: (i) the reprocessed tropospheric solution produced at JPL for IGS (repro1, covering period 1995-2007), (ii) the operational IGS tropospheric solution (trop_new, covering period 2001-2010), and (iii) a reprocessed solution produced at IGN (sgn_repro1, covering period 2004-2010). All three solutions show a

good overall agreement. Slight differences are due to use of different data processing procedures (e.g. antenna model, mapping function). In several cases, doubtful metadata (e.g. logfile not updated) seems responsible of discrepancies in the operational solution which were corrected during reprocessing. The reprocessed GPS ZTD estimates were converted into PW and analysed globally and for different regions, with a focus on timescales pertinent to climate (seasonal cycle, diurnal cycle, etc.). The GPS PW estimates were also compared to the ECMWF reanalysis ERA-Interim and overall good agreement is found.

Comparison of GNSS and radiosonde integrated water vapour measurements during the HYMEX SOP

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Many GNSS stations have been operated during the HYMEX SOP. In addition to the stations from permanent networks, some temporary deployments were brought in the field, namely in southern France (and in Corsica). A number of these GNSS stations were collocated with radiosonde systems. In this work we intercompare the integrated water vapour (IWV) measurements provided by both observing systems. The main objective is to quantify the differences and investigate the magnitude of the radiosonde humidity biases as a function of type of sonde (MODEM, Vaisala, Graw), time of launch (day/night) and meteorological conditions (dry, wet, clear sky, cloudy, rainy). The period of study is primarily focused on the SOP1+2. The results are compared to past studies and results from the analysis of longer periods in the Mediterranean area. The accuracy of the GNSS data is also investigated as a function of data processing procedure. Considerations for operational radiosonde monitoring using near real time GPS data are discussed.

Development towards tropospheric parameter assessment, inter-comparison, conversion and other related aspects

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The GOP-TropDB has been developed at Geodetic Observatory Pecný (GOP) for the assessment of the tropospheric parameters contributing to GNSS-meteorology. The regular and long-term evaluation of all our products was an important task for a reliable feedback on the accuracy and further improvements. The current database represents a tool of the third generation at GOP since it is designed flexible and powerful in order to deal with various data sources like tropospheric estimates from the space geodetic techniques (GNSS, VLBI, DORIS), in situ observations (meteo data observed at GNSS sites, synoptic observations), profile observations (radiosonde, radiometers), numerical weather models and others. The main goal is to support the routine intra-/inter-technique comparisons of tropospheric or meteorological data, but various additional goals are (or will be in future) supported too – e.g. parameter conversion (e.g. ZTD, ZWD, IWV), product quality check, assessment of tropospheric augmentation model development and others. We will show how the database can serve for the routine inter-comparisons within the International GNSS Service's TropoWG as well as to support its utilization in the framework of the GNSS4SWEC project.

Study of discontinuities of the GNSS tropospheric product

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In GNSS processing it is standard to use a 24 hour processing time window. This however creates a discontinuities in the ZTD estimates between the estimates obtained at the end of the processing window and the one at the beginning of the new processing window (usually at about 00 UTC). In this work three different processing strategies of tropospheric products for station SOFI in Bulgaria are compared. Particular attention is paid to the day-boundary discontinuities in the long term series of IGS repro1 final product and the products from two Analysis Centres contributing to IGS repro2 namely CODE and GOP. Quantitative estimation of ZTD discontinuities are obtained for different seasons and years.

Water vapor climatology by geodetic VLBI

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Water vapor plays an important role as a greenhouse gas and acts as a significant energy transportation and storage medium within the global water cycle. According to the Clausius- Clapeyron relation, rising temperatures enable the absorption of increasing amounts of water vapor by the atmosphere, a mechanism known as the water vapor feedback. Already in the 90ths it has been shown by various groups that analyzing GNSS ground-based as well as radio-occultation observations can deliver valuable input for weather prediction or numerical weather models of the meteorological sciences community. Beginning in about 1984, the international geodetic VLBI program coordinated by the International VLBI Service for Geodesy and Astrometry (IVS) data archive can be exploited to provide homogeneous series of data by its networks of global extension. The 30 years of data along with homogenized in-situ atmospheric pressure registrations enable a unique, global, and consistent determination of water vapor at specific globally distributed geodetic observatories. Accurately and homogeneously derived time series of zenith wet delays, and consequently of precipitable water, can provide the basis for the water vapor climatology. The results are discussed in terms of spatial and temporal representability; their accuracy are empirically assessed by evaluation of the inherent analysis-noise and by preliminary comparison with other space-geodetic techniques. Since the measurement of atmospheric water vapor has always been problematic and insufficiently covered by established techniques, the VLBI derived results might be of interest for the climatological community, in particular for comparisons with GNSS ground-based data since the two radio techniques share almost all the analysis models. GFZ is responsible for determining and delivering the tropospheric products of IVS. Therefore, we have created a web resource for accessing this type of data. Besides the rapid combination product, we plan to perform a complete reanalysis for obtaining a new up-to-date long-term combination with a slightly revised methodology. In our paper we report about this new methodology and other recent achievements.

Assessment of integrated water vapor infered by GPS, miscellaneous measurements and atmospheric models

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Water vapor is the most important and frequent atmospheric green house gas. It influences the Earth's radiation budget, cloud evolution and with that precipitation formation. Due to its important role in the atmosphere, water vapor is also an important part of the reanalysis performed within the Hans Ertel Centre. This regional reanalysis is produced with the COSMO-DE (Consortium for Small-scale Modeling) model of Deutscher Wetterdienst. To evalutate the integrated water vapor (IWV) of the reanalysis, the Global Positioning System (GPS) network of Geoforschungszentrum Potsdam (GFZ) is used. It provides independent measurements with a good spatial coverage of the model domain. Apart from GPS, atmospheric water vapor can be derived from measurements of several other instruments. At Jülich Observatory for Cloud Evolution (JOYCE), in addition to the GPS antenna of the GFZ, a microwave radiometer, and sunphotometer provide continuous measurements of the IWV. Also for the two-months of HD(CP)² Observational Prototype Experiment (HOPE) a large number of radiosoundings is available. These measurements and the infrared and near infrared measurements of MODIS are compared to each other and the model output of ICOsahedral Nonhydrostatic general circulation model (ICON).