The EUREF - EUMETNET Collaboration: First Experiences and Potential Benefits

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Abstract

In June 2007, a memorandum of understanding was signed between EUREF and EUMETNET. The purpose of this memorandum is to create the conditions to facilitate the data exchange and to promote the increase of cooperation between the two parties. In that frame, EUMETNET recently granted EUREF the access to meteorological observations provided by national meteorological agencies member of EUMETNET. In this paper, the status of this collaboration is reviewed and the potential benefits of using these meteorological observations to validate the GNSS data processing and their derived products are outlined from the geodetic point of view.

Keywords: *EUREF, EUMETNET, GPS, GNSS, meteorological data, troposphere, zenith path delay*

1. Introduction

During the EUREF 2007 Symposium held in London, a memorandum of understanding (MoU) was signed between EUREF and EUMETNET[1] with the goal to increase synergies and collaborations between the geodetic and meteorological communities and to facilitate the data exchange between the two parties [EUREF-EUMETNET MOU, 2007].

Indeed, both communities would benefit from sharing their expertise and their infrastructures: on one hand, E-GVAP[2], which is a program running under the aegis of EUMETNET, aims at establishing a European observing system for delivering near real-time GNSS-based tropospheric zenith path delay (ZPD) estimates for operational numerical weather prediction (NWP). In that frame, meteorologists need continued access to GNSS raw data and products. On the other hand, EUREF, which is the Reference Frame Sub-Commission for Europe of the International Association of Geodesy (IAG), maintains the EUREF Permanent Network (EPN) and determines the coordinates of the continuously observing GNSS stations within the EPN to maintain the European Terrestrial Reference System. In order to improve its GNSS data processing and to validate its GNSS-derived products, EUREF needs access to meteorological observations over all Europe.

In the context of the MoU, EUMETNET recently granted EUREF with a free access to meteorological observations provided by national meteorological agencies member of EUMETNET. In this paper, the status of the EUREF-EUMETNET collaboration is reviewed and the potential benefits of this collaboration are outlined from the EUREF point of view.

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[1] *The network of European meteorological services, http://www.eumetnet.eu.org.*

[2] *The EUMETNET GPS Water Vapor Program, http://egvap.dmi.dk.*

2. Description of the Meteorological Database

The meteorological database setup by EUMETNET in the frame of the EUREF-EUMETNET collaboration is based on the already existing e-infrastructure of E-GVAP. The FTP access to the database is granted provided that a standard "condition of use" form[3] is signed. For this purpose, the EUMETNET contact person is the E-GVAP program manager Henrik Vedel[4].

Since June 2008, access to radiosonde observations and synoptic data is provided to EUREF through the meteorological database. For the time being, the database is updated daily and the latency of the meteorological observations is roughly 1 day. In the future, other types of observations, such as output from the short-range forecasting system *High-Resolution Limited Area Model* (HIRLAM) [HIRLAM, 2002], will be added to the database. More frequent updates of the database and a reduction of the latencies are also foreseen to fill the needs of user applications.

2.1. The Synoptic Observations

Synoptic observations gather hourly surface records of the pressure, mean sea-level pressure, temperature and dew-point temperature. All observations related to a specific day are included in a unique file, which contains data from more than 1280 meteorological stations in Europe. An example of the temperature and the mean sea level pressure fields reconstructed from synoptic observations is shown in Figure 1. Based on the synoptic observations, a European tropospheric zenith hydrostatic delay grid can for example be reconstructed using a Saastamoinen-based model (Figure 2) [Saastamoinen, 1973].

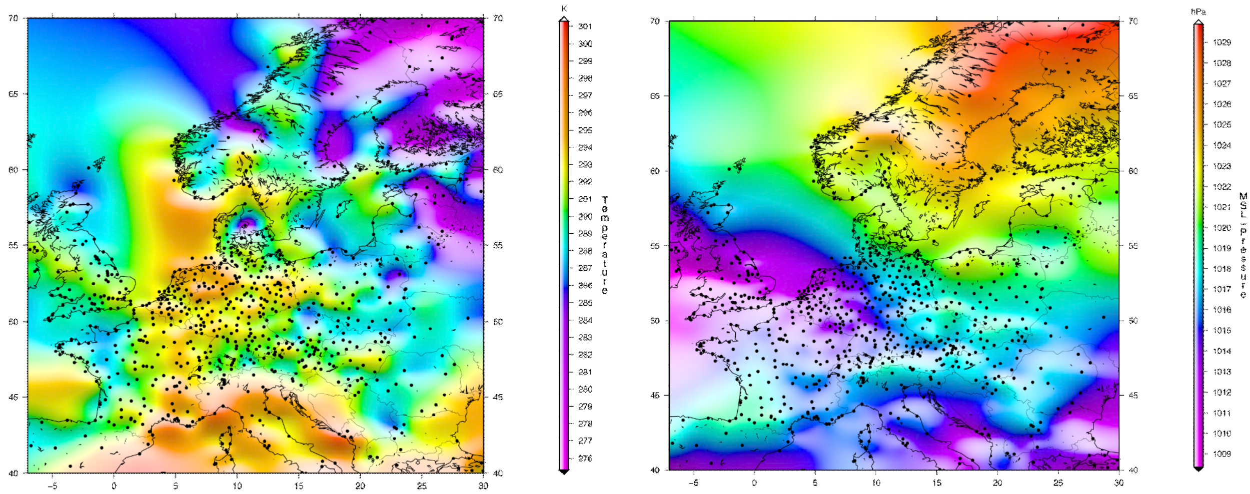

Figure 1: Temperature (left) and mean sea level pressure fields (right) reconstructed from the 1280 synoptic observations recorded on the 29th July 2008 at 00 UT (Synoptic observation sites are indicated by black dots).

[3] *Stating that the data will be used for non-commercial applications.*

[4] *Henrik Vedel, Danish Meteorological Institute (DMI), hev@dmi.dk, http://egvap.dmi.dk.*

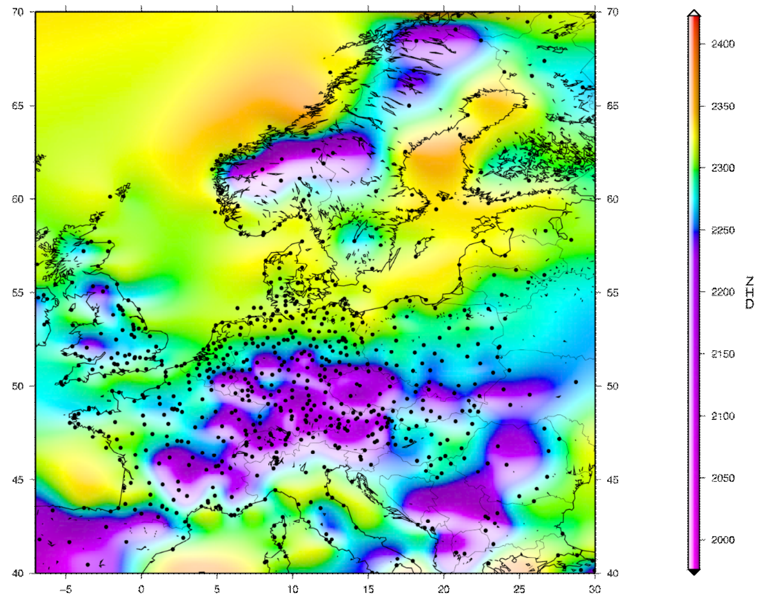

Figure 2: Zenith hydrostatic delay field reconstructed from the 1280 synoptic observations recorded on the 29th July 2008 at 00 UT (Synoptic observation sites are indicated by black dots).

2.2. The Radiosonde Observations

National meteorological agencies provide the World Meteorological Organisation (WMO) with radiosonde observations via the Global Telecommunication System (GTS). Radiosonde devices are capable of making direct in-situ measurements of air pressure, temperature and dew-point temperature while ascending through the atmosphere. When released from the ground (usually twice a day) the apparatus rises through the atmosphere at approximately 5 metres per second and terminates its ascent at an altitude of about 30 kilometres after a usual time of more than one hour [Vedel et al., 2001]. From these in-situ measurements, tropospheric zenith path delays can be computed. In the frame of the EUREF-EUMETNET collaboration, a procedure has been setup to extract the radiosonde observations from the GTS database (and additional national radiosonde data which are missing in the GTS database) within a limited grid area covering Europe and extending from -30° to 40° in longitude and from 25° to 89.9° in latitude. Again, all radiosonde observations related to a specific day are included in a unique file, which contains no less than 200 radiosonde launch site observations in this European grid (Figure 3).

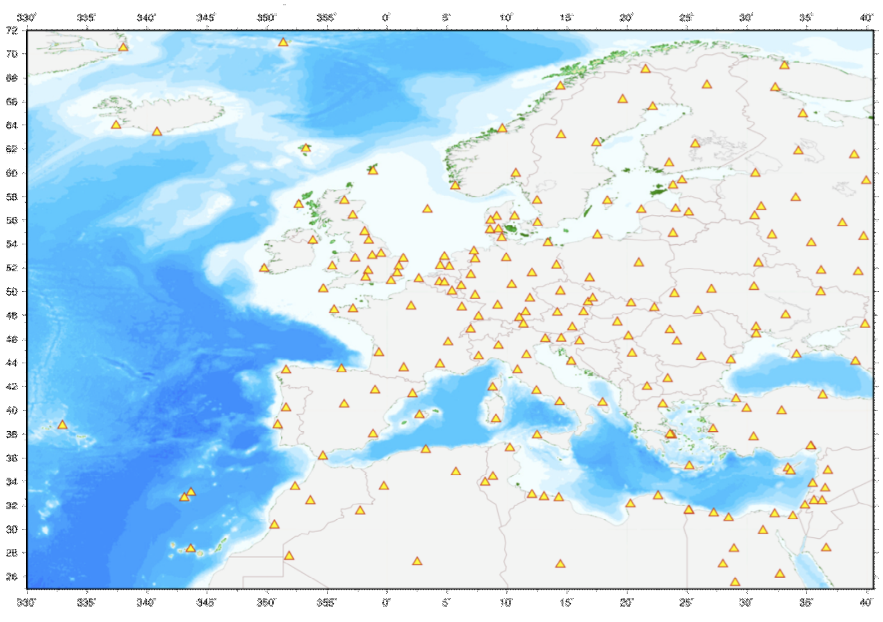

Figure 3: Radiosonde launch sites available in the meteorological database.

3. Exploitation of the Meteorological Database for Geodesy

3.1. Collocation of Radiosonde and EPN stations

The collocation of EPN stations and radiosonde launch sites (Figure 4) provides the potential to study and to validate the ZPD estimated by the geodetic agencies from EPN GNSS observations with those derived from radiosonde observations. The first step in that process is to compute ZPD from the radiosonde raw observations[5]. Therefore, a dedicated software provided by H. Vedel was used to convert the radiosonde raw observations in terms of ZPD at the height of the GNSS station [TOUGH, 2003]. The orthometric height (i.e. the height above the mean sea level) of both the radiosonde and the GNSS station is requested by the software. Therefore, the ellipsoidal GNSS station heights were transformed into orthometric heights using the new *Earth Gravitational Model 2008* (EGM2008) geoid from the U.S. National Geospatial-Intelligence Agency (NGA) [Pavlis et al., 2008]. The exact accuracy of this model is not yet well established. Nevertheless, it is expected to have an accuracy better than 10 cm and consequently, errors from using the EGM2008 model should impact the ZPD by less than 0.5 mm.

The use of radiosonde observations for GNSS-based ZPD validation has already a quite long tradition in the field of GNSS-meteorology (EU-Projects MAGIC [Haase et al., 2003], COST-716 [Elgered et al., 2003], TOUGH [Vedel et al., 2006b]). Nevertheless, up to now the comparisons were mainly done by meteorologists. For scientific applications these validations can now be realized by the EUREF analysis centres themselves.

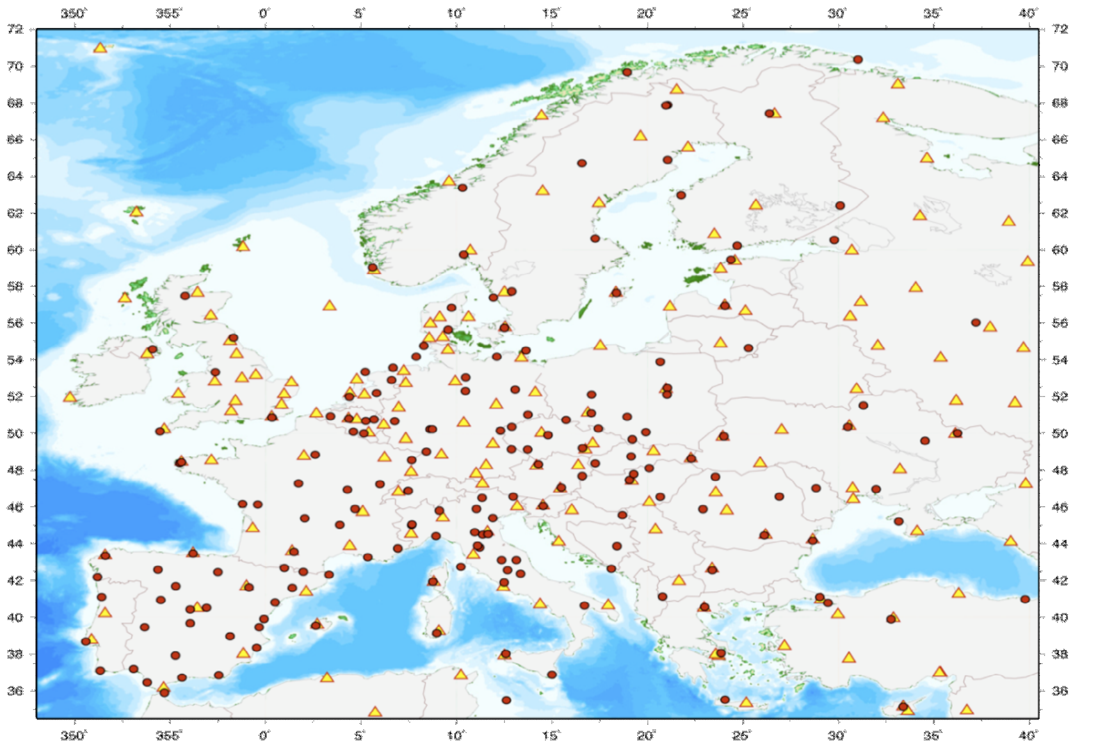

Figure 4: EPN stations (red dots) and the radiosonde observation launch sites (yellow triangles).

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[5] *Namely the pressure, temperature and dew-point temperature records.*

3.2. Tropospheric Parameters and Station Height Correlations

To be assimilated into NWP models, the ZPD provided by the geodetic analysis centres must be free of biases and artificial signals. Furthermore, following the E-GVAP requirements, the ZPD estimates must have a precision and accuracy of 1 to 2 mm of Integrated Water Vapour (IWV)[6] [Elgered et al., 2003], [Pottiaux, 2008c], [Vedel et al., 2006]. The validation of the GNSS-based ZPD and the detection of biases and artificial signals in their time series are consequently important for meteorological applications.

Moreover, within the GNSS data processing, the ZPD and the station height estimations are strongly correlated. Any error in the GNSS-based tropospheric modelling impacts the station height determination. As EUREF targets mm-precision for its station heights, special attention must be paid to the troposphere modelling during the GNSS data processing. Radiosonde observations provide a useful and independent source of information to validate the GNSS-based ZPD and supply consequently indirect, but important, information on the GNSS height estimates, such as the detection of signals in the height component due to artificial signal in the ZPD estimates.

3.3. Validation of GNSS-based Tropospheric Zenith Path Delays

The swisstopo analysis centre is active as an EPN Local Analysis Centre and as an E-GVAP analysis centre [Brockmann et al., 2006]. In the frame of the latest, swisstopo routinely produces ZPD estimates for a network of about 80 GNSS stations, 11 of which are co-located with radiosonde launch sites (Figure 5). Thanks to the EUREF-EUMETNET MoU, these 11 collocations are now routinely used to validate the GNSS near real-time ZPD estimates with respect to the radiosonde observations and to help to detect problems related to the troposphere modelling during the GNSS data processing.

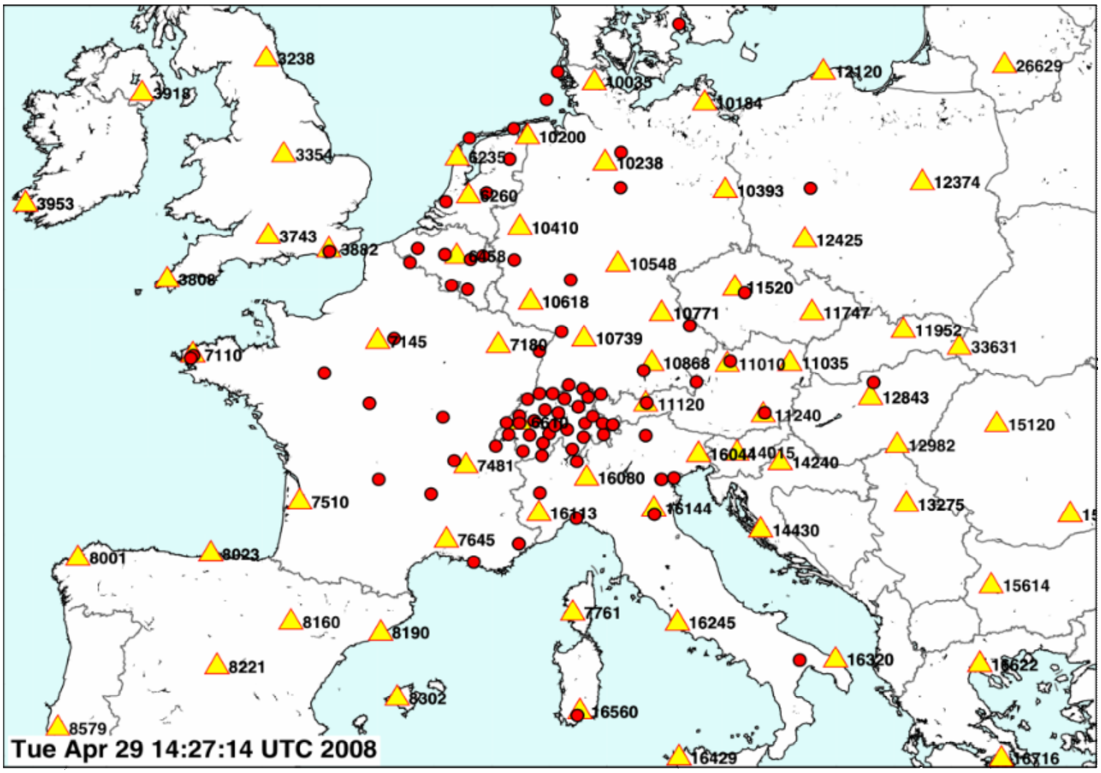


Figure 5: Radiosonde launch sites (yellow triangles) within the network of GNSS stations (red dots) processed in near real-time by swisstopo.

[6] *1mm of IWV corresponds roughly to 6.5 mm of tropospheric zenith path delay.*

As an example of this validation procedure, a comparison of the last 7 days between the real-time, the near real-time GNSS-based ZPD estimates produced by swisstopo and the radiosonde-based observations is displayed on the product validation web site (see Figure 6 for the site of Payerne, Switzerland). A fairly good agreement between the GNSS-based and the radiosonde-based ZPD is visible. A detailed analysis of the biases and standard deviations will be implemented at swisstopo, soon. This might also be of interest of MeteoSwiss, which use up to now the GNSS-derived ZPD estimates as validation for their numerical weather prediction models [Brockmann et al., 2004, Guerova et al., 2003a and 2004] and which plan to use the GNSS-based ZPD estimates in their recent newly developed COSMO-2 forecast model, which is based on a 2 km grid.

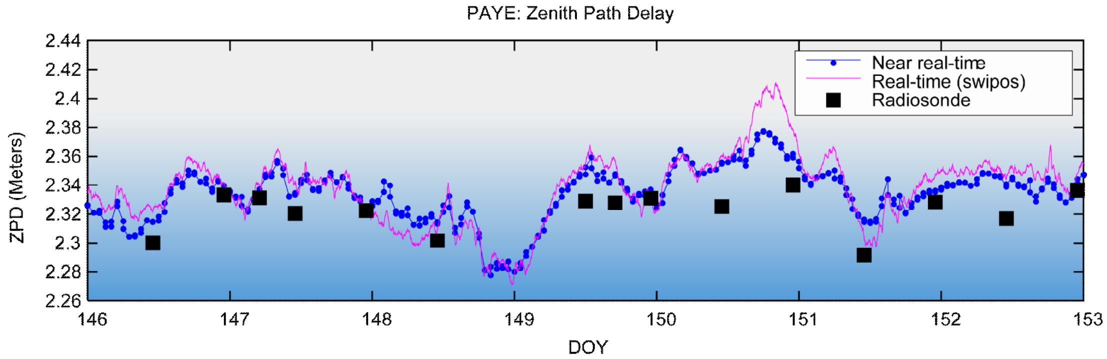


Figure 6: Validation plot extracted from the swisstopo webpage http://www.swisstopo.ch/pnac showing the time series of the real-time (pink flatted curve) and the near real-time (blue dotted curve) GNSS –based ZPD for the site of Payerne, Switzerland, for the last 7 days. ZPD computed from radiosonde raw observations are represented by black squares.

3.4. Impact of Strategy Changes on the ZPD Estimations

Even when not directly linked to the ZPD estimation process, changes in the GNSS processing strategy (e.g. elevation cut-off angle, ocean tide loading model…), may impact the ZPD estimates above the desired levels of precision and accuracy [Pottiaux 2008b]. Usually, this impact is assessed (in terms of precision) by comparing "internally" two GNSS ZPD solutions. However, radiosonde observations provide an external reference that help to assess the impact of a processing strategy change on the ZPD estimates. This statement is illustrated by assessing the impact of the reference frame change from IGS00 to IGS05 along with the switch from relative to the absolute antenna Phase Centre Variation (PCV) models. We used the EPN combined troposphere product and compared it to ZPD values derived from radiosonde observations.

A complete description of the EPN combined troposphere solution is available in [Söhne et al., 2002]. Basically, the EPN combined troposphere solution is a combination of the individual troposphere solutions provided by the 16 Local Analysis Centres (LAC). The EPN combined troposphere solution is available since GPS week 1100 and each site included in the combination is at least processed by 3 LAC.

On the 1st November 2006 (GPS week 1400), all EPN LAC applied the switch to IGS05 and absolute antenna PCV models. The time evolutions of the weekly mean bias of the individual solutions with respect to the combined solution, as well as its standard deviation, are shown in Figure 7 and Figure 8. The impact of the strategy change (IGS05 and absolute PCV models) reduced significantly the biases between the individual LAC solutions as well as their standard deviation. Currently, the weekly mean bias of the individual LAC solutions with respect to the combined solution is below 2 mm.

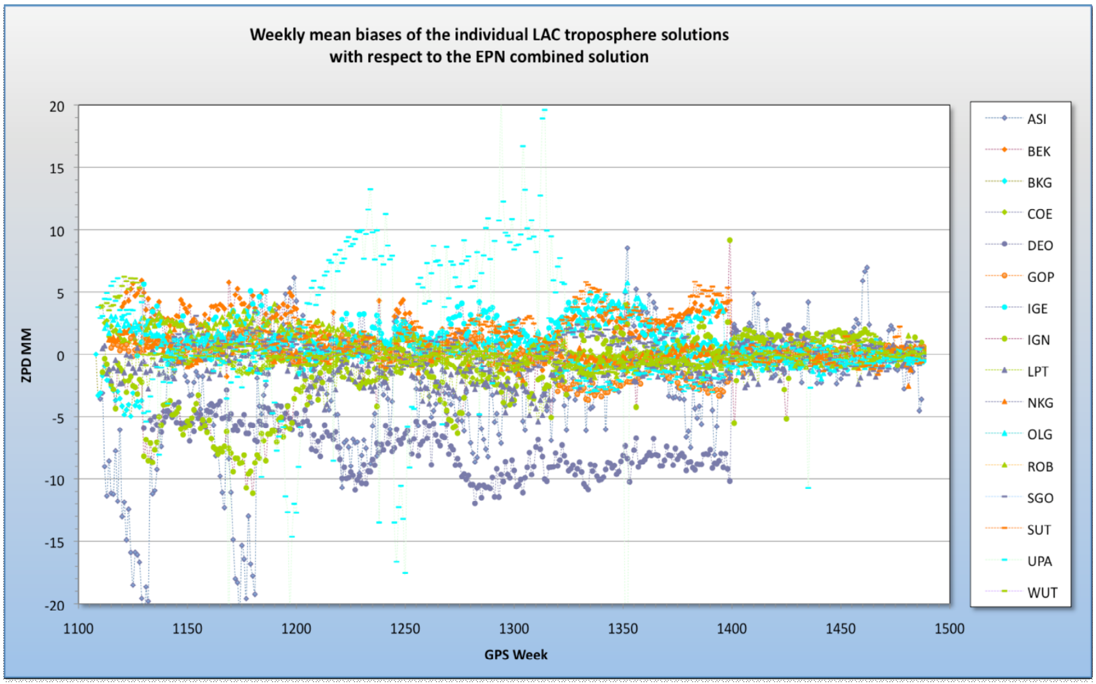


Figure 7: Weekly mean bias of the individual LAC troposphere solutions with respect to the EPN combined troposphere solution.

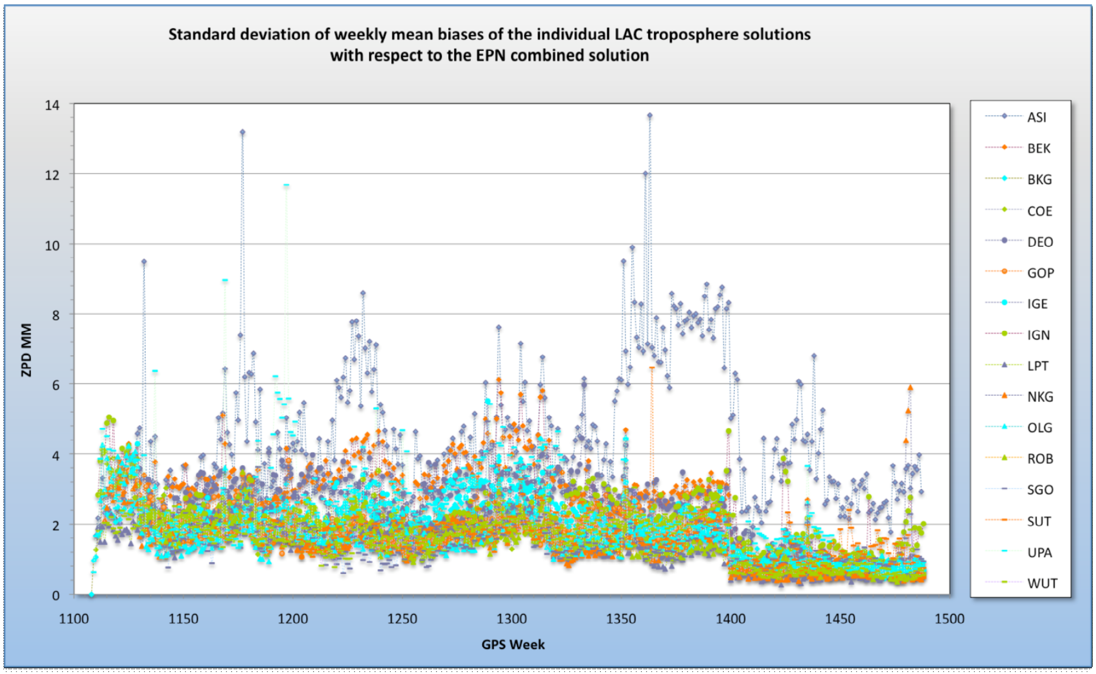


Figure 8: Standard deviation of the individual LAC troposphere solutions with respect to the EPN combined troposphere solution.

As an example, the impact of the strategy change on the ZPD estimation is assessed for the EPN twin-stations BOGI and BOGO in Borowa Gora (Poland), which are co-located with radiosonde stations. The differences between the radiosonde-based and the combined EPN ZPD solutions for both EPN stations are shown in Figure 9. During the 2004-2008 period, the EPN stations BOGI and BOGO were equipped solely with a unique antenna type: an *ASH700936C_M* for BOGI and an *ASH701945C_M* for BOGO, both with SNOW radome. Over the 2.5 years preceding the strategy change, a clear bias with respect to the radiosonde-based estimations is detected. The magnitude of these biases is of about 18 and 11 mm for the station BOGI and BOGO respectively. Higher discrepancies between the two techniques are also visible during the summer time for both stations. This is held true after the processing strategy changes. Nevertheless, after a small gap at the end of 2006 due to missing radiosonde observations, the bias between the GNSS-based and the radiosonde-based ZPD estimates is reduced to about 1 mm for both stations. This is a clear improvement brought by the switch to IGS05 and absolute antenna PCV model. The slightly too wet values for the GNSS-based ZPD estimates is an effect already mentioned in the previous EU-projects in the area of GNSS-meteorology. Depending on the used GNSS antenna, this bias could be further reduced, as shown in the case of BOGI and BOGO. Nevertheless, one needs to take into account the error budgets of each technique, resulting in a possible bias of more than the shown 1-2 mm ZPD bias. The standard deviation also showed a slight improvement after the strategy change of roughly 10%, but due to the different lengths of the time series this effect is still to be confirmed.

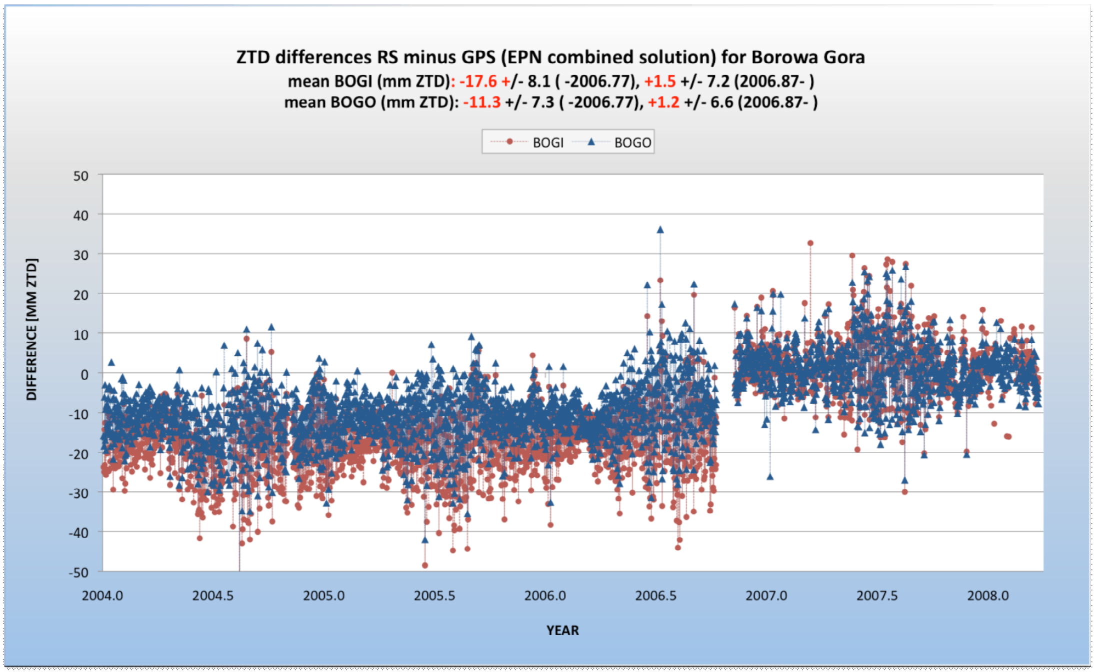
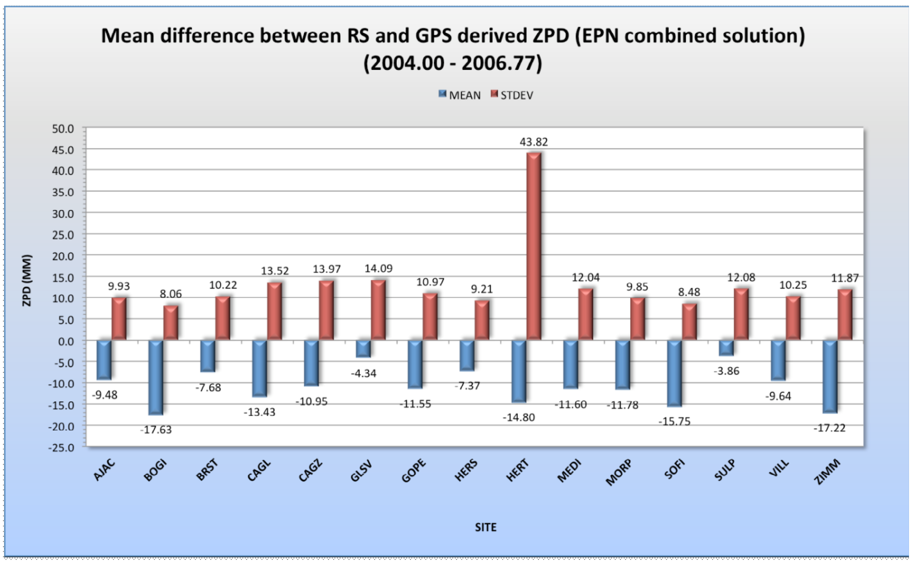
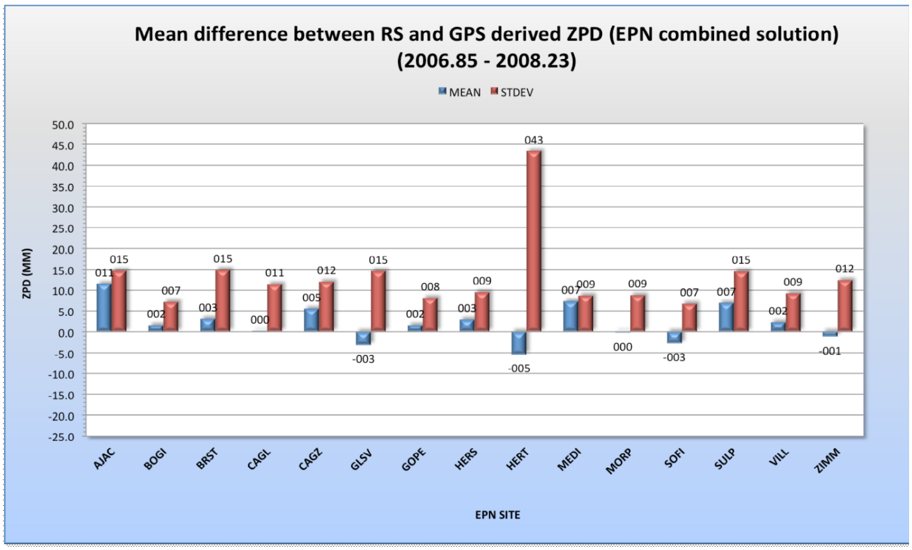


Figure 9: Differences between the GNSS-based and the radiosonde-based ZPD for the site of Borowa Gora in Poland. The blue triangles represent the ZPD obtained from the BOGO reference station while the red dots represents those of BOGI.



SITE	Nb. Obs.	Mean (mm)	Stdev. (mm)
AJAC	1605	-9,48	9,93
BOGI	1916	-17,63	8,06
BRST	1304	-7,68	10,22
CAGL	2708	-13,43	13,52
CAGZ	2722	-10,95	13,97
GLSV	1773	-4,34	14,09
GOPE	4799	-11,55	10,97
HERS	1897	-7,37	9,21
HERT	1844	-14,80	43,82
MEDI	1576	-11,60	12,04
MORP	1666	-11,78	9,85
SOFI	855	-15,75	8,48
SULP	323	-3,86	12,08
VILL	1632	-9,64	10,25
ZIMM	2058	-17,22	11,87

Figure 10: Mean biases (red bars) and standard deviations (blue bars) of the differences between the GNSS-based and radiosonde-based ZPD for a few EPN stations before the strategy change. Since HERS and HERT are co-located, the bad agreement of HERT must be put at the account of the GNSS processing.



SITE	Nb. Obs.	Mean (mm)	Stdev (mm)
AJAC	553	11,49	14,68
BOGI	911	1,53	7,17
BRST	587	3,09	14,91
CAGL	992	0,19	11,42
CAGZ	893	5,49	12,02
GLSV	869	-3,15	14,63
GOPE	1914	1,53	8,12
HERS	923	2,92	9,49
HERT	933	-5,41	43,30
MEDI	476	7,27	8,67
MORP	551	-0,20	8,76
SOFI	466	-2,74	6,73
SULP	194	6,88	14,53
VILL	853	2,23	9,22
ZIMM	1042	-1,11	12,41

Figure 11: Mean biases (red bars) and standard deviations (blue bars) of the differences between the GNSS-based and radiosonde-based ZPD for a few EPN stations after the strategy change. Since HERS and HERT are co-located, the bad agreement of HERT must be put at the account of the GNSS processing.

3.5. Detection of Biases, Trends and Signals in ZPD Time Series

The detection of biases, trends and signals in ZPD time series is important for meteorological and climate applications but also for geodetic applications. Indeed, on one hand, water vapour is the major greenhouse gas in the atmosphere [Desbois et al., 2000], [Elgered et al., 2007] and the long-term trends in the ZPD time series corresponds to the long-term evolution of the atmospheric water vapour content. The detection of these long-term trends is thus important for climate applications such as the global warming monitoring. Unfortunately, the example given in Section 3.4 taught us that, at the moment, changes in the processing strategy (i.e. the switch to IGS05 and absolute antenna PCV models) impact the determination of the ZPD above the level of accuracy requested to detect the trend expected for the global warming. Consequently, a complete reprocessing of the GNSS observations with a unique homogenous processing strategy applying state-of-the-art models is a prerequisite of the interpretation of ZPD time series.

In GNSS meteorology, the ZPD estimates are assimilated in Numerical Weather Prediction (NWP) models. To be properly assimilated in these models, the origin of biases and trends in the ZPD time series must be identified for each station and properly taken into account in the assimilation process.

On the other hand, for geodesy, the station heights remain more difficult to determine than the other coordinate components. This is partially due to the high correlation between the height component and the ZPD estimates. The detection of ZPD biases, short-term trends and artificial signals is useful to identify possible miss-modelling of the troposphere during the GNSS data processing that consequently impacts the station height determination. In that frame, radiosonde observations provide geodesists the capability to detect artificial signals in the ZPD time series.

To illustrate this point, we compared the EPN combined troposphere solution for the station Zimmerwald in Switzerland with the corresponding time series obtained from radiosonde observations (collocation distance 40 km). The time series of ZPD differences over more than 4 years is shown in Figure 12. In addition to the jump introduced by the switch to IGS05 and absolute antenna PCV models, the time series reveal a clear annual signal with amplitude of about 20 millimetres. Part of this large amplitude is probably caused by the large co-location distance of 40 km. Nevertheless, comparisons with the GNSS data of the directly co-located permanent GNSS station Payerne (part of the Automated GNSS Network of Switzerland AGNES and not part of EPN) still show some but smaller annual variations [Guerova, 2003b].

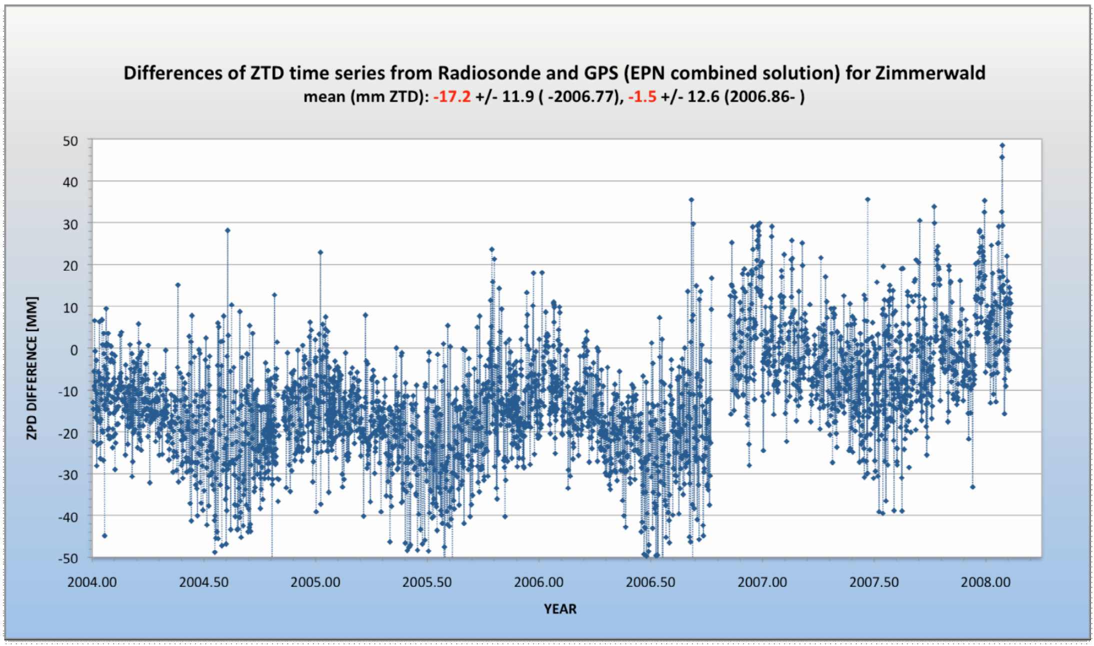


Figure 12: Annual signal in the differences between the GNSS-based and the radiosonde-based ZPD for the site of Zimmerwald (Switzerland) - co-location distance: 40 km.

4. Conclusions

In this paper we reviewed the current status of the new scientific EUREF-EUMETNET collaboration. In the frame of this collaboration, EUMETNET granted EUREF access to meteorological observations for GNSS data processing, analysis and validation. Since June 2008, radiosonde and synoptic observations are made available to the EUREF community. Based on the radiosonde observations, we demonstrated the potential benefits of this new collaboration in various geodetic applications. We showed that radiosonde observations can be used to validate the troposphere modelling strategy used during the GNSS data processing for geodetic and meteorological applications. We also showed that radiosonde observations can be used to assess the impact of a strategy change on the tropospheric delay estimation process. Finally, we showed that radiosonde observations can help in the detection of biases, trends and signals in the ZPD time series. In the future, the meteorological database setup by EUMETNET will be enriched with other source of data, which will, even more, enlarge the field of applications.

5. Acknowledgements

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6. References

[Brockmann et al., 2004], Brockmann, E., S. Grünig, D. Schneider, A. Wiget and U. Wild,: *"Applications of the real-time Swiss GPS permanent network AGNES"*, In Proceedings of the EGS XXVII General Assembly Nice, 21 - 26 April 2002, Session 9 on Evolving Space Geodesy Techniques; Geowissenschaftliche Mitteilungen, Heft Nr. 69, 2004, Schriftenreihe der Studienrichtung Vermessung und Geoinformation, Technische Universität Wien; Eds: R. Weber, W. Schlüter, U. Schreiber, O. Titov

[Brockmann et al., 2006], Brockmann E., S. Grünig, D. Ineichen, S. Schaer, *"Monitoring the Automated GPS Network of Switzerland AGNES"*, In: Torres, J.A. and H. Hornik (Eds): Subcommission for the European Reference Frame (EUREF). Riga, June 15-17, 2006

[Dach et al., 2007], Rolf Dach, Urs Hugentobler, Pierre Fridez, Michael Meindl, *"Bernese GPS Software Version 5.0"*, Astronomical Institute, University of Bern

[Desbois et al., 2000], M. Desbois and R. Roca, *"Integrated water content and Climate change"*, proceeding of the COST-716 symposium, Oslo, 2000

[Elgered et al., 2003], G. Elgered, H.-P. Plag, H. van der Marel, S. Barlag and J. Nash, *"Exploitation of Ground-Based GPS for Operational Numerical Weather Prediction and Climate Applications"*, Final Report

[Elgered et al., 2007], G. Elgered, Tobias Nilsson and Ulrika Willéen, *"Assessment of Using GNSS for the monitoring of the atmospheric water vapour content over long time scales"*, proceedings of the 1st colloquium on the scientific and fundamental aspects of the GALILEO program, Toulouse, October 2007

[Guerova et al., 2003a], Guerova G., E. Brockmann, J. Quiby, F. Schubiger and Ch. Mätzler, *"Validation of NWP mesoscale models with Swiss GPS Network AGNES"*. J. Appl. Meteorol., 42, 1, pp. 141-150, 2003.

[Guerova, (2003b)] Guerova G., *"Application of GPS derived water vapour for numerical weather prediction in Switzerland"*. PhD thesis, University of Berne, 2003.

[Guerova et al., 2004], Guerova, G., Bettems, J-M., Brockmann, E., Matzler, Ch., *"Assimilation of the GPS-derived Integrated Water Vapour (IWV) in the MeteoSwiss Numerical Weather Prediction model - a first experiment"*, In Proceedings of the EGS XXVII General Assembly Nice, 21 - 26 April 2002, Session 9 on Evolving Space Geodesy Techniques, Physics and Chemistry of the Earth, Vol.29, No.2-3, 2004

[Haase et al., 2003], Haase, J., Ge, M., Vedel, H., and Calais, E., *"Accuracy and Variability of GPS Tropospheric Delay Measurements of Water Vapour in the Western Mediterranean"*, Jour. App. Met., 42, 1547, 2003.

[HIRLAM, 2002], Per Undén, Laura Rontu, Heikki J • ärvinen, Peter Lynch, Javier Calvo, Gerard Cats, Joan Cuxart, Kalle Eerola, Carl Fortelius, Jose Antonio Garcia-Moya, Colin Jones, Geert Lenderlink, Aidan McDonald, Ray McGrath, Beatriz Navascues, Niels Woetman Nielsen, Viel Ødegaard, Ernesto Rodriguez, Markku Rummukainen, Rein Rõõm, Kai Sattler, Bent Hansen Sass, Hannu Savij • ärvi, Ben Wichers Schreur, Robert Sigg, Han The, Aleksander Tijm, *"HIRLAM-5 Scientific Documentation"*, http://hirlam.org

[Elgered et al., 2003], G. Elgered, H.-P. Plag, H. van der Marel, S. Barlag and J. Nash, "Exploitation of Ground-Based GPS for Operational Numerical Weather Prediction and Climate Applications", Final Report

[EUREF-EUMETNET MOU, 2007], *"The EUREF-EUMETNET Memorandum of Understanding"*, http://www.euref-iag.net/documentation/OtherDocuments/EUREF_EUMETNET_MoU.pdf

[Pavlis et al., 2008], Nikolaos K. Pavlis, Simon A. Holmes, Steve C. Kenyon, and John K. Factor, *"An Earth Gravitational Model to Degree 2160: EGM2008"*, presented at the EGU General Assembly 2008 Vienna, Austria, April 13-18, 2008

[Pottiaux et al., 2008a], E. Pottiaux, E. Brockmann, W. Söhne and C. Bruyninx, *"The EUREF-EUMETNET collaboration: First experiences and potential benefits"*, proceedings of the EUREF symposium in Brussels, Belgium, 2008

[Pottiaux, 2008b], E. Pottiaux, *"The Belgian Contribution to the EUMETNET GPS Water Vapour Program (E-GVAP): New Developments and Applications"*, Poster Presented at the EGU Symposium in Vienna, Austria, 2008

[Pottiaux, 2008c], E. Pottiaux, *"GNSS Near Real-Time Zenith Path delay Estimations at ROB: Methodology and Quality Monitoring"*, proceedings of the EUREF symposium in Brussels, Belgium, 2008

[Saastamoinen, 1973], I.I. Saastamoinen, *"Contribution to the theory of atmospheric refraction"*, Bulletin Géodesique, 107, pp. 13-34

[Söhne et al., 2002], Wolfgang Söhne and G. Weber, *"EUREF Permanent Network Special Project - Status Report"*, report on the Symposium of the IAG sub-commision for Europe (EUREF), Ponta Delgada, 05-08 June 2002, Mitteilungen des Bundesamtes für Kartographie und Geodäsie, Band 29 (EUREF publication No. 12), pp 85-90

[TOUGH, 2003], *"Radiosonde data specification document"*, TOUGH Deliverable n°58, http://web.dmi.dk/pub/tough/deliverables/d58.html

[Vedel et al., 2006], Henrik Vedel, Kai Sattler, Xiang-Yu Huang, Beatriz Navascues, Jana Sanchez Arriola, Jose Garcia-Moya, Claudia Facani, Rossella Ferretti, Adrian Jupp, Dave Offiler, Martin Ridal, Nils Gustafsson, John de Vries, Reima Eresmaa and Heikki Järvinen, *"GPS Data Recommendations for European Numerical Weather Prediction"*, TOUGH Deliverable D73 Report

[Vedel et al., 2006 b], Henrik Vedel, *"TOUGH Final Report"*, TOUGH Deliverable D14 Report http://web.dmi.dk/pub/tough/deliverables/d14-final-rep.pdf