TROPOSPHERIC DELAY PARAMETERS DERIVED FROM GNSS-TRACKING DATA OF A FAST-MOVING FLEET OF TRAINS

Matthias Aichinger-Rosenberger [(1)], Robert Weber [(1)]

[(1)] TU-Vienna, Austria, Department for Geodesy and Geoinformation, Email: Robert.weber@tuwien.ac.at

ABSTRACT

Within the project Greenlight, the Austrian Federal Railways have equipped a large number of trains with high-quality dual-system single frequency receivers with RTK-capability. The goals of this project are manifold, comprising the real-time train positioning to support passenger information systems or the online monitoring of cargo and many more.
In near future several hundreds of additional vehicles will be equipped with such receivers. Although the current configuration is based on GPS/GLONASS receivers, the upcoming generation will consist of combined GPS/Galileo single frequency receivers. On basis of real observation data gathered along various railway tracks in Austria this presentation studies the potential of deriving tropospheric delay information useful for numeric weather models (NWM). The challenges are to retrieve tropospheric parameters (in first place vertical delays) with sufficient accuracy from data tracked by a fast-moving object as well as the real-time or close-to-real-time data transmission between train and processing centre. Further problems arise due to signal masking, multi-path and the required modelling of the ionospheric delay. On the other hand, compared to the current static networks of a few high-quality meteorological sites and several GNSS reference stations, the beauty of the solution is to make use of a fleet of almost 1000 GNSS sensors permanently moving over the Austrian territory. The presented study is based on post-processed raw observation data. Nevertheless, taking into consideration the upcoming 5G-network roll-up also a fast data transmission, at least when the trains pass railroad stations, can be assured in future.

1. INTRODUCTION

Tropospheric delay from GNSS sensors, in particular Zenith Total Delay (ZTD), is a well-established data source for Numerical Weather Prediction (NWP) nowadays. Based on the concept of GNSS meteorology provided by Bevis et. al (1992), tropospheric delays are estimated operationally both in national and transnational networks, like the European EGVAP network. These estimates are typically based on a double-difference solution, which is able to provide the high accuracy needed for NWP data assimilation (~ 1 cm for ZTD). This has the downside of being cost-intensive since only high-end infrastructure can be used and a larger number of reference stations is needed for a stable solution.

Aside of this ‘classical’ approach, several authors, e.g. [2] or [3], have also studied the potential of low-cost GNSS receivers, in terms of tropospheric monitoring. These often only provide single-frequency (SF) observations. Most of these studies showed promising results, as long as major error sources like ionospheric delays can be modelled with sufficient accuracy. Up to now, studies concentrated on measurements from static receivers due to a more trivial data processing and more controllable measurement conditions. Precise Point Positioning (PPP) denotes the most promising approach for processing this SF data nowadays, since it provides high accuracy and does not directly rely on any data from reference stations.

In this study, we go one step beyond and make use the kinematic PPP approach to estimate ZTD values from a fleet of fast-moving trains equipped with dual-system SF receivers. The data was gathered on different railway tracks over Austria in the course of the ÖBB project Greenlight.

A higher number of challenges is faced due to the fast movement of the sensor and a large number of obstructed areas on the track (e.g. tunnels). Nevertheless, potential benefits like a very high spatial and temporal resolution can be expected, considering the high number of trains already equipped with GNSS sensors.

2. GREENLIGHT PROJECT

Greenlight is a project established in 2017 by the Austrian Railways (ÖBB-Infra) with the major goal to ensure a safe and precise localisation of trains in real-time by means of various sensor techniques. The major position technique involved is GNSS positioning. The position information can be further used for various applications within the railway infrastructure, e.g. for a very precise passenger train arrival information.

Currently more than 250 train traction units (see Figure 2) are equipped with high-quality ublox dual-system (currently GPS + GLONASS; in future GPS + Galileo) single-frequency receivers embedded in special boxes (see Figure 1). In the upcoming years more than 1000 vehicles will be equipped with this so-called rail-power boxes, which monitor not only position but also power consumption and efficiency during the drive.

Figure 1: Rail Power Box

Backbone of the GNSS positioning with dm-accuracy is the ÖBB owned GNSS reference station network TEPOS (see Figure 3). The reference network comprises 35 sites distributed over Austria with a mean spacing of about 70km. All sites are equipped with multi-system, multi-frequency GNSS receivers. TEPOS is part of the Austrian GNSS correction data service EPOSA. TEPOS provides range correction information, which allows for a positioning of fast-moving trains with almost RTK-quality. The RTK-position information is sent back to the TEPOS computer center and from there distributed to all application areas.

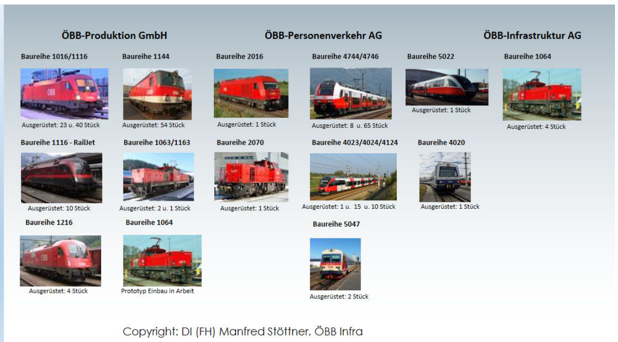

Figure 2: Fleet of currently equipped tractive units

In addition, the raw GNSS phase + code observation data is stored in the Rail Power Box for a couple of days. Raw data from a few selected train trajectories (see for example Figure 3) was made available to us to carry out this scientific investigation to test the potential use for deriving tropospheric delay information.

3. DATA PROCESSING

Data processing was carried out with the online PPP software of the Canadian Spatial Reference System (CSRS). CSRS-PPP (CSRS - Precise Point Positioning) can process GPS observations from single or dual-frequency GPS receivers operated in static or kinematic mode [5].
We processed 1-second RINEX data for two whole days, 11/05/2017 and 28/09/2017, in kinematic mode. Final orbits and clocks as well as ionospheric TEC (Total Electron Content) maps from the International GNSS Service (IGS) are used. In order to exclude low-quality observations, possibly suffering from multipath or cycle slips, we employed a Signal-Noise-Ratio (SNR) and Elevation mask. The respective values are 30 dB-Hz and 7.5°. All observations below these thresholds are excluded from processing.

4. RESULTS

In the following, the results for the two case study days are presented. In order to get an idea where the analyzed trains were traveling, we show some approximate trajectories computed using RTKlib first. The actual CSRS-PPP results are then shown for the estimated ZTD and height component, both a raw and a moving-average filtered timeseries. Finally, we present a comparison of the estimated ZTDs with values computed from ERA5 reanalysis data in order to assess the quality of the estimations. This computation is carried out using the in-house developed software ATom [4].

On both days the train moved along a North-South as well as an East-West oriented trajectory. This implies a traverse of the main alpine ridge both times, as can be seen in the Google Earth map underlying the trajectories.

4.1. Case study: 11/05/2017

Figure 3 shows the analysed trajectory for 11/05/2017. The train travelled two times the route Salzburg – Vienna back and forth, before making its final way south to Graz. Therefore, the train had to pass the Semmering at an altitude of about 900 meters. Larger obstructed areas like tunnel passages (e.g. coming to Vienna from West) can also be located.

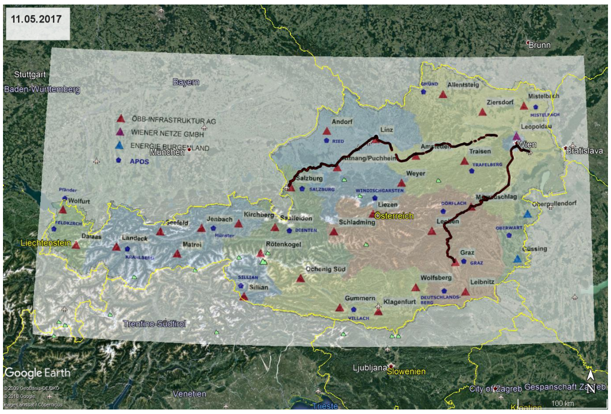

Figure 3: Train trajectory for 11/05/2017

Figure 4 shows the estimated values of ZTD (top) and height (bottom) for 11/05/2017. The original output from CSRS-PPP (red) is plotted along with a 15-minutes moving average (MA) filtered solution (blue). As one would expect, both parameters are highly anti-correlated and therefore the high-dependent variation of ZTD is reconstructed in a realistic way. For instance, the passage over Semmering (around 17 UTC) can be easily located in the ZTD timeseries by values dropping down to about 2150 mm. Areas with higher noise (e.g. 06 UTC) are mostly related to tunnel passages.

Overall, the average noise in the original output data is about 1-2 cm for this case. This is assessed here (and also for the second case) in the simple form of just interpreting differences between raw (red curve) and filtered data (blue curve).

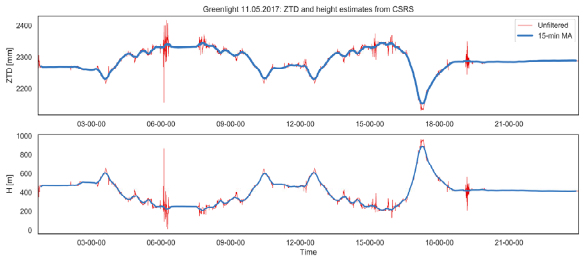

Figure 4: ZTD [mm] and height [m] estimates: Original output (red) and 15-minutes moving average (blue) for 11/05/2017

In order to obtain a first guess of the quality/accuracy of the ZTD retrieval the CSRS-PPP results were compared to reanalysis data from the ERA5 dataset. Figure 5 shows a comparison for the passage of Semmering (17 – 18 UTC). Although a clear bias of about 3-4 cm is visible, the overall agreement is quite promising, given the challenging conditions the sensor is operating in. As indicated, the mean difference between the datasets for the analyzed hour is ~3.5 cm.

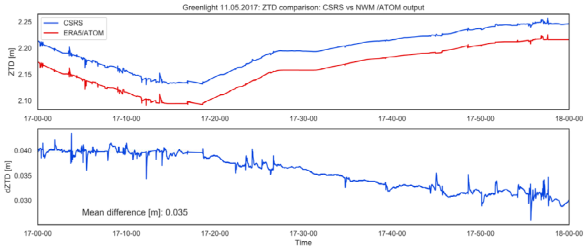

Figure 5: ZTD [m] from CSRS and NWM data and ZTD difference [m] between them for 11/05/2017

4.2. Case study: 28/09/2017

On 28/09/2017, the train started in Munich (around 06 UTC) and arrived in Salzburg around 08 UTC. From there it passed the alpine ridge southwards towards Klagenfurt, where it terminated shortly before 12 UTC. In the following, the train made its way back to Salzburg via the same route before finally terminating in Vienna at about 21 UTC.

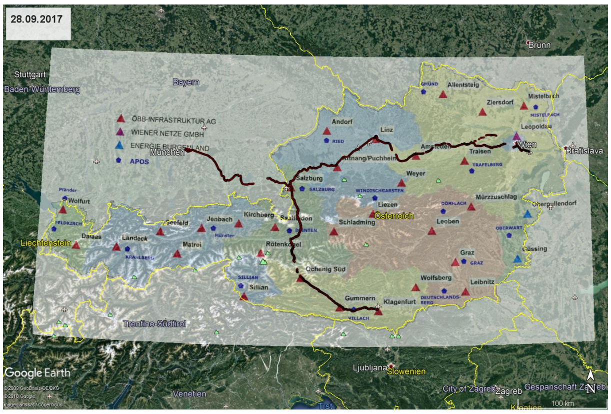

Figure 6: Train trajectory for 28/09/2017

The ZTD and height results shown in Figure 7 draw a similar picture as those from the first test case. The same quantities as in Figure 4 are presented here for 28/09/2017. Again, the expected anti-correlation is a dominant feature. The symmetric peaks allow a good recovery of the Alps passing back and forth in time. Data gaps indicated in Figure 6 are again located by higher noise in the original CSRS output. In this case, the average noise of the original output is even lower at about ~1 cm or even in the mm-subrange.

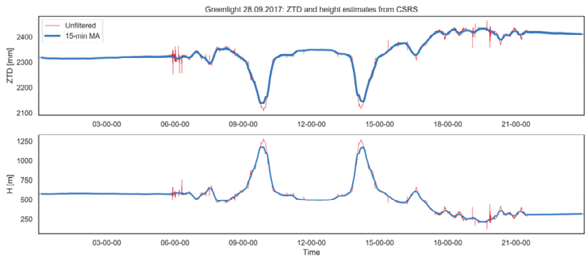

Figure 7: ZTD [mm] and height [m] estimates: Original output (red) and 15-minutes moving average (blue) for 28/09/2017

Figure 8 again shows a ZTD comparison between CSRS-PPP and ERA5. For this case, two hours (09-11 UTC) of data are compared. This time span represents one the alpine passages (Salzburg – Klagenfurt). The comparison shows an even better agreement for this test case. Again, a bias is present between the results, but this time its magnitude is only ~1 cm and even approaches zero in the last half hour. The mean difference is also reduced to ~1.3 cm. These values already approach the quality commonly required for assimilation in NWP.

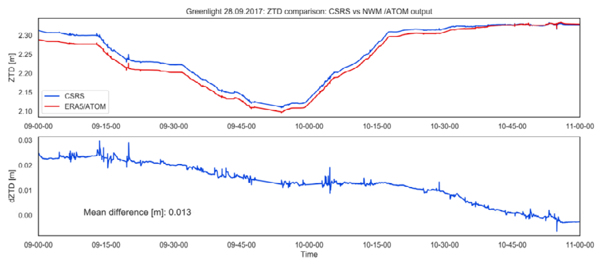

Figure 8: ZTD [m] from CSRS-PPP and ERA5 data and ZTD difference [m] between them for 28/09/2017

5. SUMMARY

In this study, we employed kinematic PPP processing to tracking data from fast-moving trains in order to retrieve ZTD estimations along the track. The data was gathered and provided by the Austrian Federal Railways in the course of the project Greenlight. Two test datasets were analyzed, each consisting of 24 hours of 1-second RINEX data. These were measured using a ublox dual-system SF-receiver, operated on the trains. Data processing was carried out using the CSRS-PPP online software operated by the Geodetic Survey Division of the Natural Resources Canada.

First results already indicate a promising level of reachable accuracy compared to ZTDs calculated from NWP output. The deviations between the datasets are in the cm-subrange, in the best test case already approaching NWP accuracy requirements for beneficial data assimilation.

Further work on this topic will incorporate a different processing sequence to derive an alternative dataset for comparison. Furthermore, the quality assessment will be based not only on NWP-derived but also on ZTDs derived from ray-tracing. Finally, a study on the benefits of assimilation of this train data into a NWM will be conducted in order to quantify their potential for improving (especially precipitation) forecasts in NWP.

6. ACKNOWLEDGEMENT

The authors want to express their gratitude to the Greenlight project team of ÖBB-Infra for making available the raw GNSS observation data of train trajectories in order to support this investigation.

7. REFERENCES

1. Bevis, M., Businger, S., Herring, T., Rocken, C., Anthes, R., Ware, R., (1992), GPS meteorology: Remote sensing of atmospheric water vapour using the global positioning system, Journal of Geophysical Research: Atmosphere, Volume 92.

2. Deng, Z., Bender, M., Dick, G., Maorong, G., Wickert, J., (2009), Retrieving tropospheric delays from GPS networks densified with single frequency receivers. Geophysical Research Letters 36. L19802. 10.1029/2009GL040018.

3. Krietemeyer, A., Veldhuis, M., Van der Marel, H., Realini, E., Van der Giesen, N., (2018), Potential of Cost-Efficient Single Frequency GNSS Receivers for Water Vapour Monitoring, Remote Sensing, 10, 1493.

4. Möller, G., (2017), Reconstruction of 3D wet refractivity fields in the lower atmosphere along bended GNSS signal paths, Department of Geodesy and Geoinformation, Higher Geodesy, TU Wien

5. Tetreault, P., Kouba, J., Héroux, P., Legree, P., (2005). CSRS-PPP: an internet service for GPS user access to the Canadian spatial reference frame. Geomatica. 59. 17-28.