GPS and GLONASS Data Analysis using Stations from the EUREF Permanent Network

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1. Introduction and Motivation

The EPN (EUREF Permanent Network), consists of 190 permanent GPS stations from which about 25 are also tracking GLONASS satellites. The primary purpose of the EPN is to maintain and provide access to the European Terrestrial Reference System (ETRS89) and EUREF does this by making available the tracking data from its stations and generating weekly coordinate estimates for all of them. Up to now, all coordinate estimates have been based on only GPS data and no GLONASS data was used.

However with the :

- growing number of commercially available GPS+GLONASS receivers
- recent revitalization of GLONASS (with a constellation of 18 satellites expected in 2007)
- availability of short latency precise IGS orbits for GLONASS and consistent GPS+GLONASS CODE orbits

it has become worthwhile to investigate the advantages and disadvantages of adding GLONASS data to the routine data analysis of the EPN. This experience will also be very useful for the future when GALILEO data will be included in the EPN because GLONASS is now standing where GALILEO will stand within a few years: an incomplete constellation and a mixed network.

2. Set up of the Data Processing

- Bernese 5.0 software, allows a computation in GPS-only mode and GPS+GLONASS mode
- Orbits : precise a priori orbit information is used and no orbit improvement is done
  - GPS-only: IGS final orbits/clocks
  - GPS+GLONASS: A) IGS final GPS and GLONASS orbits (independent combination for GPS and for GLONASS)
    Accuracy: GPS < 5 cm ; GLONASS < 15 cm *(http://igscb.jpl.nasa.gov/)*
    B) CODE orbits (fully consistent GPS+GLONASS orbits, one common estimation, no GLONASS clocks)
    Accuracy : GPS : 2.5 cm and GLONASS : 5 cm *(SLR validation, from C. Urschl)*
  - both in IGb00 reference frame (IGS realization of ITRF2000)
  - 29 GPS satellites + 13 GLONASS satellites
- Tidal displacements: Solid Earth tides (IERS2003 model), Ocean tide loading (GOT00.2), No correction for atmospheric tide loading
- 10° elevation cut off, double difference carrier phases are basic observable

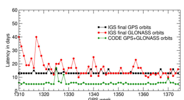

Figure 1: Latency of IGS and CODE orbits

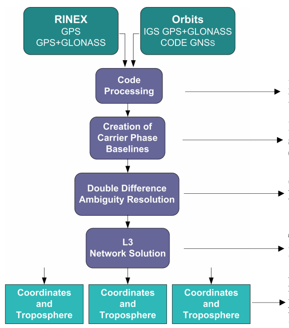

Figure 2: Data processing method

- Code Processing: Determination of receiver clocks. No GLONASS sat. clocks used
- Creation of Carrier Phase Baselines: Baselines with maximal number of common GPS+GLONASS observations are selected ; this baseline configuration is used for the GPS-only as well as for the GPS+GLONASS processing
- Double Difference Ambiguity Resolution: GPS ambiguity fixing (QIF), using CODE ionosphere model. No ambiguity fixing for GLONASS
- L3 Network Solution: Tropospheric modeling using piece-wise linear functions. Dry-Niell a priori mapping function, wet-Niell estimated each hour
- Coordinates and Troposphere: Repeatabilities of daily coordinates. Datum definition: 3 translation conditions (minimum constraint) to EPN realization of ITRF2000. Comparison of multi-session coordinate sets obtained using GPS-only and GPS+GLONASS

- Two networks have been analyzed in order to asses the influence of adding GLONASS data to the GPS–only analysis

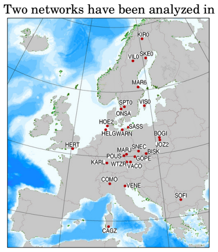

Figure 3: GPS/ GLONASS network consisting of 25 GPS/ GLONASS stations belonging to the EPN (status Jan. 2006).

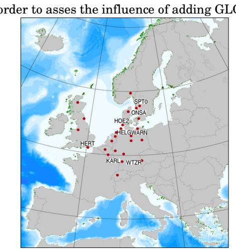

Figure 4: Mixed GPS and GPS/GLONASS network (20 GPS and 8 GPS/GLONASS stations)

Network 1 (Fig 3): Oct. 1, 2005 to Feb. 28, 2006 (GPS wk 1343 - 1361)

Network 2 (Fig 4): Feb. 5, 2006 to April 1, 2006 (GPS wk 1361 - 1368)

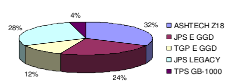

Figure 5: GPS/GLONASS receivers used within the EPN

3. Results for Network of GPS/GLONASS Receivers

Network based on all GPS/GLONASS stations included in the EPN (Figure 3).

Data Quality & Availability

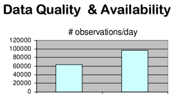

Figure 6: Number of observations included in data analysis

When processing the network of 25 GPS/GLONASS stations, the additional GLONASS satellites increase the number of observations with 47% . The associated maximal reduction of the formal errors has a factor of 1.2. However, in our case, the introduction of the GLONASS data also increases the number of parameters to be estimated considerably (with 47%). These additional parameters are the GLONASS ambiguities. Consequently no significant improvement in terms of formal errors can be expected from adding GLONASS data to GPS.

Several of the GPS/GLONASS stations provided data of degraded quality. The most striking example is the station SNEC (Snezka, Czech Republic) whose coordinates wandered away (see Figure 7), especially in the height component, because of a receiver malfunctioning. The SNEC data have therefore been eliminated starting from GPS week 1349 at the first symptoms of the receiver error.

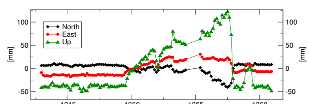

Figure 7: Coordinate time series for the GPS/GLONASS station SNEC

Starting January 1st, 2006 the data from the ASHTECH Z-18 receivers at JOZ2 (Jozefoslaw, Poland) and GOPE (Ondrejov, Czech Republic) became unusable. After the midnight epoch of January 1st these two receivers started tracking all GLONASS satellites with a one-second delay causing the pseudoranges to be increased by 300.000 km. As a leap second was introduced at this date, a link to this event was suspected. The other ASHTECH Z-18 receivers in the EPN behaved normally. The problem at JOZ2 and GOPE was narrowed down to the TEQC software used to convert the native data to the RINEX format. The problem was solved by updating TEQC to its latest version from Dec. 15, 2005.

The data for the station SOFI (Sofia, Bulgaria) had to be discarded from the processing because of a lack of reliable data caused by a malfunction of the station PC.

As can be seen in Figure 8, in addition to the problems mentioned above, the three Italian GPS/GLONASS stations (CAGZ, COMO and VENE) are missing in almost 20% of the final solutions. These data are regularly missing at all the Data Centers (without correlation between the missing days from the different stations).

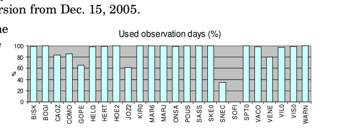

Figure 8: Percentage of used observation days

Coordinate Repeatabilities

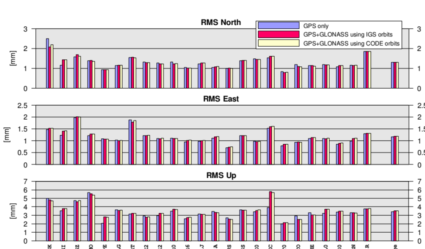

Figure 9: Coordinate repeatabilities obtained using GPS-only, GPS+GLONASS with IGS orbits, GPS+GLONASS with CODE orbits

Following the scheme displayed in Figure 2, daily coordinates have been estimated for the remaining stations in the network: first using only GPS data (and final IGS orbits/clocks), and secondly using GPS as well as GLONASS data. The last processing was done once using IGS orbits and once using CODE orbits. The GPS-only analysis was done using IGS final orbits.

Figure 9 shows no significant differences in the repeatabilities of the station coordinates depending on the observations and orbits used.

An exception is the station SNEC with a significant degradation of the Up-RMS caused by the introduction of GLONASS data.

The inspection of the coordinate time series of SNEC (Figure 10) shows that the degradation of the RMS is the caused by a few outliers in the GPS+GLONASS solution of GPS wk 1345.

We have also drawn the coordinates time series of the nearby station POUS, which as can be seen in Figure 11, shows an offset in its height-component when the GPS-only results are compared to the GPS+GLONASS estimates. However, in these coordinate time series, no special events are noted.

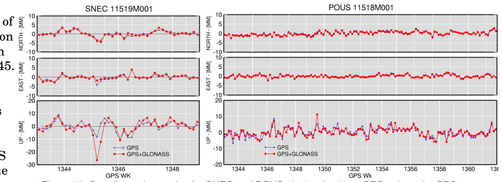

Figure 10: Coordinate time series for SNEC and POUS obtained using a GPS-only and a GPS+ GLONASS analysis (using IGS orbits)

Comparison of Estimated Coordinates & Zenith Total Delays

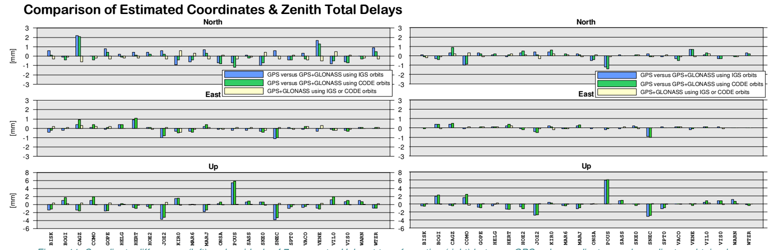

Figure 11: Coordinate differences (left) and residuals of 7-parameter Helmert transformation (right) between GPS-only coordinates, and coordinates obtained using GPS+GLONASS data, respectively with IGS orbits and with CODE orbits

Figure 11 shows that adding GLONASS data to a GPS-only analysis changes the coordinates up to 2.5 mm in the horizontal components. However, these differences are mainly due to differences in the reference frame. After a Helmert transformation, the horizontal differences are below 1.5 mm, with a general RMS of 0.4 mm. In the up-component, the coordinate differences between GPS and GPS+GLONASS are mostly below 4 mm, but reach for one station (POUS) up to 6 mm. The general RMS is 1.8 mm, which is reduced to 1.4 mm by the Helmert transformation. In all cases, the GPS+GLONASS-based coordinates obtained using IGS or CODE orbits, agree at the 1-mm level.

The origin of the difference between the GPS-only and GPS+GLONASS estimates for the up-components of POUS (6 mm) is unclear. As a by-product of our analysis tropospheric Zenith Total Delays (ZTD) are estimated each hour. As can be seen in Figure 12, GPS+GLONASS underestimates, for all stations except POUS (!), the ZTDs compared to GPS only. It is clear that the station POUS is showing an atypical response to the introduction of GLONASS. Figures 13 and 14 show examples for the stations VACO and JOZ2.

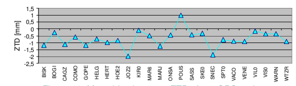

Figure 12: Mean bias between ZTDs from GPS and GPS+GLONASS

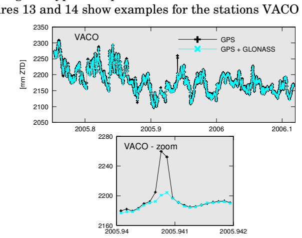

Figure 13: Comparison of ZTDs based on GPS-only and on GPS+GLONASS observations

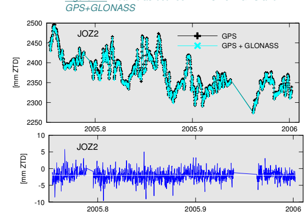

Figure 14: Top: ZTDs from GPS and GPS+GLONASS; Bottom: ZTD(GPS+GLONASS) – ZTD(GPS)

4. Results for Mixed Network of GPS & GPS/GLONASS Receivers

Network (Figure 4) consisting of 20 GPS stations and 8 GPS/GLONASS stations. Both the GPS-only as the GPS+GLONASS estimations have been computed using IGS orbits.

Data Quality & Availability

The introduction of the GLONASS data increases the amount of used observations with 14%. A similar increase is also noted in the number of estimated parameters.

Coordinate Repeatabilities & Comparison of Estimated Coordinates

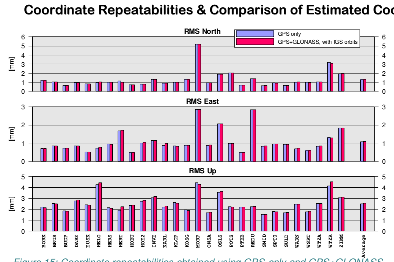

Figure 15: Coordinate repeatabilities obtained using GPS-only and GPS+GLONASS

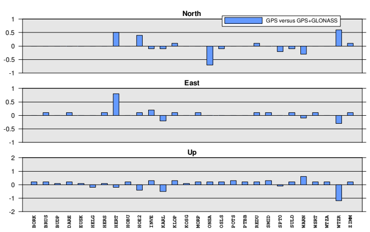

Figure 16: Coordinate differences between GPS-only and GPS+GLONASS coordinates

As expected, the repeatabilities of the estimated coordinates are independent of the introduction of the GLONASS data (GPS/GLONASS stations are: HELG, HERT, HOE2, KARL, ONSA, SPT0,WARN, WTZR).

In addition, no significant changes in the coordinates can be seen. We can therefore conclude that, for this specific network, GLONASS data can be introduced in the data analysis without any problems. However, to avoid influencing the site velocities, the introduction of GLONASS should be done simultaneously with the introduction of the absolute PCV and the switch to ITRF2005.

5. Summary

The goal of this study was to investigate the advantages/disadvantages of analyzing combined GPS/GLONASS data in a regional network of GPS and GPS/GLONASS receivers.

For all tests, we used the Bernese 5.0 data analysis software, which allows to process GPS-only or GPS+GLONASS observations using identically the same processing strategy (except for the ambiguity resolution).

We have compared the GPS-only and GPS+GLONASS coordinates obtained in the two networks :

- a regional network consisting of 25 GPS/GLONASS stations (all GPS/GLONASS included in the EPN at Jan. 2006)
- a typical regional network of mixed GPS and GPS/GLONASS stations (20 GPS and 8 GPS/GLONASS stations).

We compared the GPS+GLONASS coordinates obtained from the GPS/GLONASS network using on one hand the IGS orbits and on the other hand the CODE orbits. The CODE orbits are consistent GNSS orbits, while the IGS computes separately its combined GPS and its GLONASS orbits. The GPS-only coordinates were computed using the IGS final orbits. A first conclusion is that the GPS+GLONASS-based coordinates obtained using either IGS or CODE orbits agree in all three components at the 1-mm level after applying a 7-parameter Helmert transformation between both.

From the two networks processed, we can see that adding GLONASS data to the GPS data does not significantly change the repeatabilities of any of the station coordinates. For some stations, the repeatabilities are slightly better using GPS-only, for others, the repeatabilities improve when adding GLONASS.

In the GPS/GLONASS network, the differences between the GPS-only coordinates and the GPS+GLONASS coordinates show that adding GLONASS data can change the coordinates at the level of 1-2 mm in the horizontal components and between 2 to 6 mm for the vertical component. For the horizontal components, the coordinate differences are mainly caused by reference frame differences between the two regional networks. For the vertical component, one of the stations in the network shows an offset of almost 6 mm when GPS-only coordinates are compared to GPS+GLONASS coordinates. The cause of this difference is not clear presently and will be subject of further study.

In the mixed network, which corresponds to the reality, all coordinate differences are below the 1 mm level.

6. Final Remark

The EPN Analysis Centres have agreed at their Workshop in Padua, Italy, 15-16 March, 2006, to add (on a voluntary basis) the GLONASS data to their subnetworks.