Using Stacking to reduce site-specific errors and to improve the quality of GNSS-based coordinate time series within GURN (GNSS Upper Rhine graben Network)

Andreas Knöpfler, Michael Mayer, and Bernhard Heck
Geodetic Institute, KIT

Abstract

Within the last decades, positioning using GNSS (Global Navigation Satellite Systems; e.g., GPS) has become an indispensable tool for the monitoring of geodynamic processes. For instance, in many projects aiming for the determination of the time-dependant behaviour of the Earth's surface, the monitoring design was switched from campaign measurements to **continuously operating sites**. Benefiting from improved GNSS hardware and from further developed data processing strategies as well as from additional GNSS (e.g., GLONASS), displacements can nowadays be derived GNSS-based with mm ... sub-mm accuracy.

Satellite Geodetic History in the Upper Rhine Graben

Geodetic Measurements using satellite techniques have a long tradition in the Upper Rhine Graben. In the framework of EUCOR, the project URGENT (Upper Rhine Graben Evolution and NeoTectonics) took place in the years 1999-2003. EUCOR (EUropean COnfederation of Universities on the Upper Rhine) is the union of the seven universities of the Upper Rhine Graben and was established in 1989.

Within this cooperation, GPS campaigns have been carried out in 1999, 2000, and 2003. These campaigns were suffering from the small number of occupied sites (approx. 30) as well as from poor and inhomogeneous spatial resolution and from the poor amount of GPS data (2 x 24h), especially. But the results and experiences gained within this interdisciplinary and transnational project were quite promising. Therefore, in order to continue and intensify this work, the GNSS Upper Rhine graben Network (GURN) was established in April 2008 as a geo-scientific cooperation.

GNSS Upper Rhine graben Network (GURN)

GURN actually (March 2014) includes German, French and Swiss continuously operating GNSS sites.

The data of the German sites is mainly provided from SAPOS® Baden-Württemberg and SAPOS® Rheinland-Pfalz. Most sites are enabled to track GPS and GLONASS data and are actually updated to be capable for future GNSS signals (e.g., Galileo).

The data of the French sites have several origins: RENAG (Universities and research institutes), RGP (network of IGN), Teria, Orpheon, EOST. Thus, the sites were established for scientific resp. business purposes.

Additionally, one IGS site (HUEG), one EPN site (KARL) and two GREF sites (DILL, BFO1) are included. A further extension of the network in northern direction is planned.

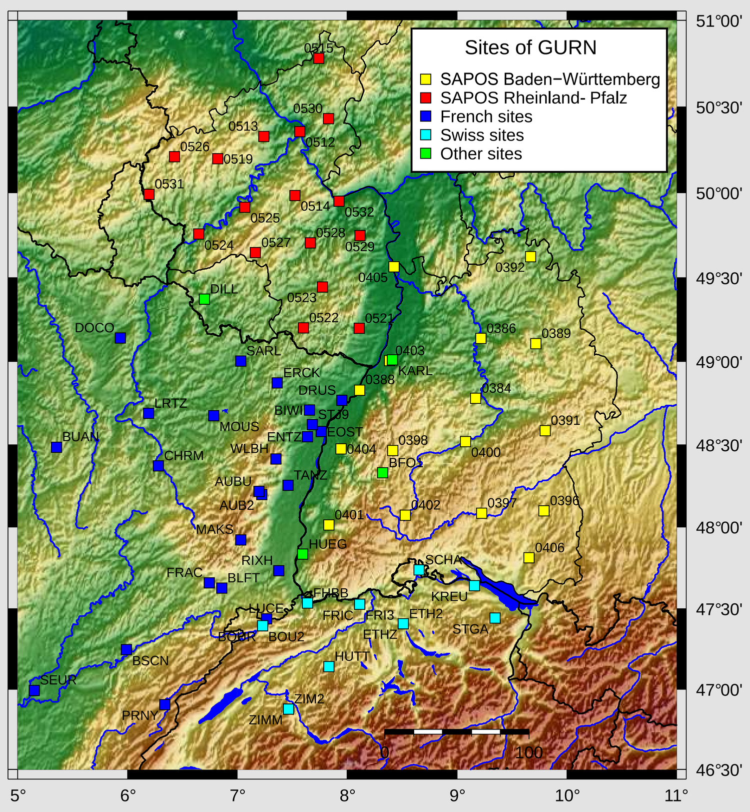

Figure 1: Map of GURN in the actual configuration (March 2014) with sites in Germany, France, and Switzerland.

The resulting network covers the whole URG region homogeneously with about **80 permanent operating sites**. Between the sites, the mean distance is 40-60km. The database of GURN starts in 2002, when SAPOS® Baden-Württemberg started to archive their data. The data archive of SAPOS® Rheinland-Pfalz starts in 2004. Most of the French sites where established after 2006, swisstopo provides data for GURN since 2009. Hence, the time series comprise max. 12 years.

Motivation

One main goal of GURN is to determine a **revised, sophisticated geodynamical model for the region of the Upper Rhine Graben** using results OF GNSS data processing. In this area, site velocities in the range of mm or even **sub-mm per year** are expected. The permanently operating sites in GURN were established for different purposes. Some few sites were explicitely installed in order to monitor geodynamic processes with a good coupling to the ground using a massive fundamentation and a pillar type setup (e.g., ERCK, see Figure 2 left). Most GURN sites were installed to be used as reference stations for positioning services which enable users to achieve realtime positioning accuracies within a few cm. Therefore, the sites are mainly located on roof tops in order to guarantee obstacle-free signal tracking and due to security and logistic aspects (e.g., 0528, see Figure 2 right).


Figure 2 left: site ERCK (operated by EOST), right: site 0528 (operated by SAPOS® Rheinland-Pfalz).

The individual environment of each site causes **site-specific effects;** including especially **multipath** effects, which occur when the satellite signal is reflected on its way to the antenna (see Figure 3). These effects can cause positioning errors in the range of several cm. Further, the monumentation of the site can imply **seasonal signals** in the coordinate time series (see Figure 4 left) and shadowing by vegetation may result in stronger noise (see Figure 4 right).

Within an **advanced GNSS data processing**, special care has to be set to the handling of the receiver antenna model. Therefore, most GNSS **receiving antennas** on the sites are calibrated individually using techniques like robot or chamber calibration in order to derive calibration values on absolute level. Strictly speaking, these results are only valid at the location of the calibration due to remaining effects of the environment. Hence, errors remain as artefacts even in calibration results of high quality and propagate into coordinate estimates.

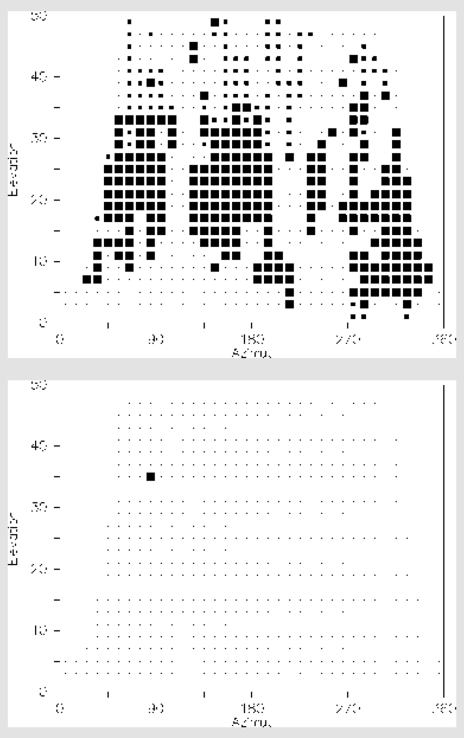
Figure 3: Multipath maps; top: site 0387 with strong impact of multipath, bottom: site 0403 with no significant impact of multipath. Small/medium/large dots: no/small/large impact of multipath.

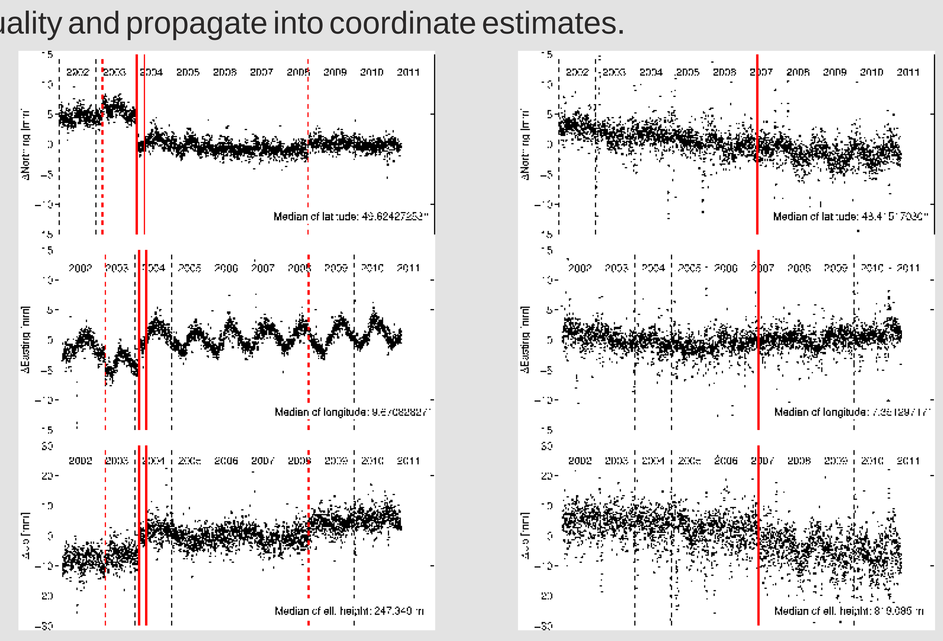
Figure 4: Coordinate time series of two GURN sites. Coloured vertical lines mark equipment changes on sites. Left: site 0392 with strong seasonal signal on easting component, right: site WLBH with strong scattering due to shadowing by vegetation.

Challenges in GNSS data processing

The estimation of 3D positions based on GNSS observations of permanently operating sites within an accuracy of few cm is nowadays state-of-the-art. Position qualities of mm-level can be achieved within a **sophisticated data processing** based on adequate handling of limiting effects using appropriate models (e.g., atmosphere), external data (e.g., satellite orbits) or calibration values (e.g., GNSS antennas). Despite the considerable improvements that have been achieved within GNSS data processing, a generally valid **multipath model is still lacking**. Furthermore, effects due to imperfect calibrated receiver antenna models have to be taken into account as well. Therefore, site-specific effects (e.g., multipath) represent still a major error source in precise GNSS positioning affecting coordinate estimates.

Residual stacking in space domain

One very promising strategy to mitigate site-specific errors is to stack the observation residuals with respect to their signal direction (elevation, azimuth). Assuming, that signals from certain directions cause **identical artefacts** in residual time series, the stacking of the residuals for single cells of the antenna hemisphere over several days enables to detect and reduce systematic effects; random errors are negligible due to averaging over an appropriate chosen time span.

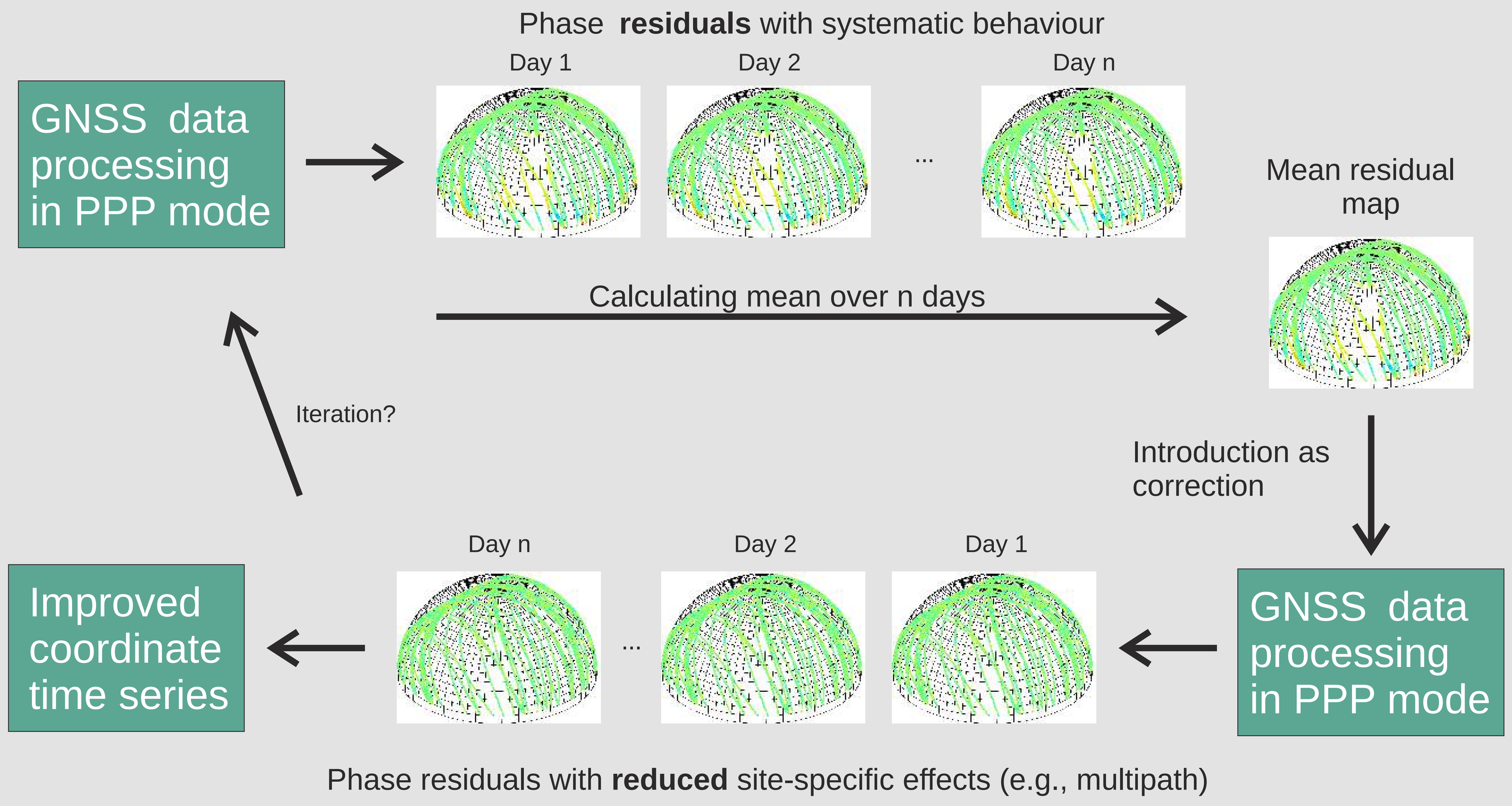

Figure 5: Scheme of stacking procedure within GNSS data processing.

Figure 5 illustrates the scheme of the stacking procedure within the iterative GNSS data processing. Within the first processing step, phase residuals for each single site and each processed day are calculated. They contain the systematic signature of the environment (e.g., multipath-based) and remaining errors of the antenna model. Mean values of the residuals in given cells are determined using spacial stacking of these residuals over an appropriate number of days.

The estimated **mean residual map** represents corrections for certain directions (elevation, azimuth) from the site to the satellite. Introducing this stacking map as correction into a second processing step, only significantly reduced noise should remain in the calculated residuals.

Preliminary results for the Upper Rhine Graben

A **first result** of the GNSS data processing for selected sites of GURN is given in Figure 6. This processing was done without the above mentioned stacking technique. The site velocities were estimated by a robust linear regression approach between known changes of the hardware on the sites. **Hardware changes** can cause **discontinuities** in time series (e.g., see Fig. 4 left). Most of the time series are still too short to derive reliable site velocities. This is obvious, e.g., for site 0395: the two estimated movement rates have similar length but point in two different directions.

Within geodynamical monitoring there is a conflicting interest between scientific and commercial use of the GNSS sites. For scientific aspects, a long time span of unchanged site equipment is prefereable to reduce the possible impacts on the time series; for commercial aspects, the operators providing realtime positioning services tend to change their equipment after five to eight years in order to fulfill the users need for state-of-the-art hardware.

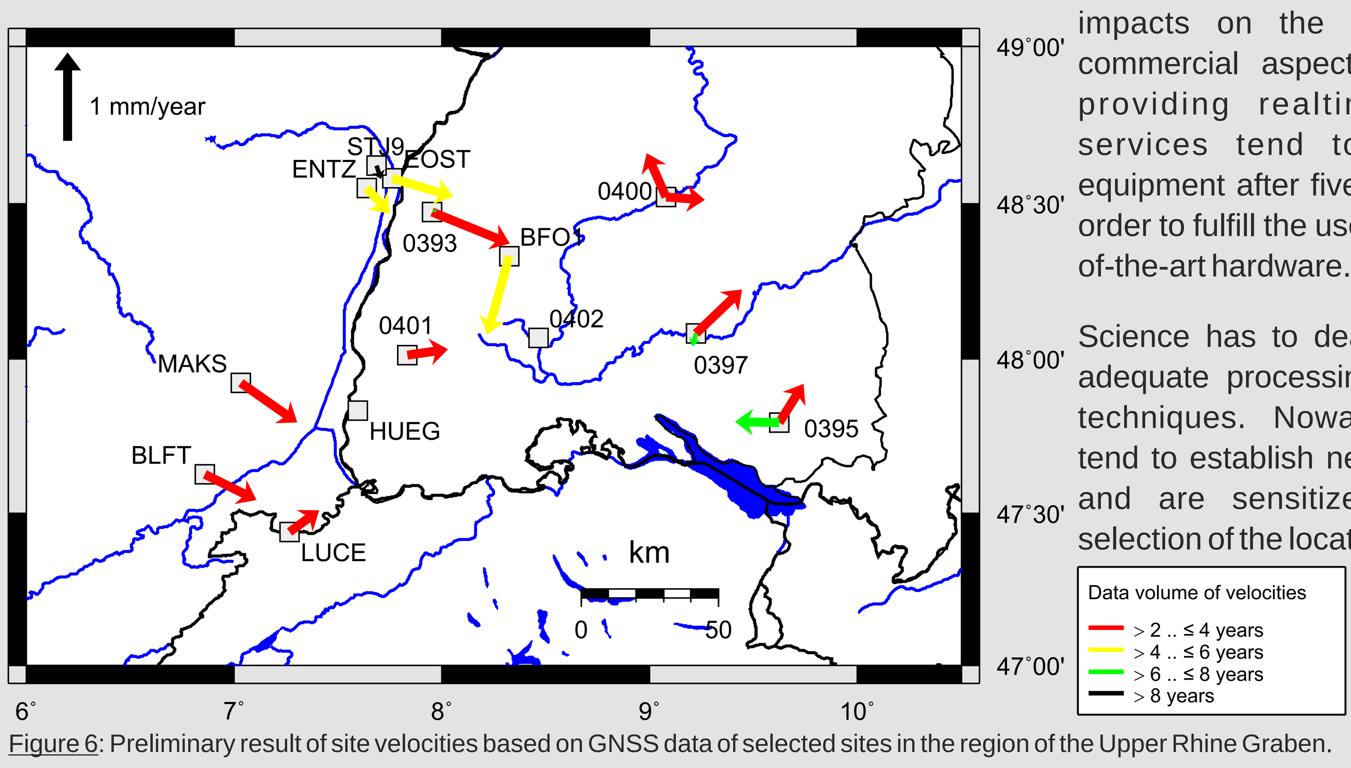

Figure 6: Preliminary result of site velocities based on GNSS data of selected sites in the region of the Upper Rhine Graben.

Science has to deal with this using adequate processing and modelling techniques. Nowadays, operators tend to establish new sites as pillars and are sensitized to a careful selection of the location for a new site.

Further investigations

Modelling site-specific effects using spacial residual stacking in an iterative GNSS data processing offers new possibilities in order to improve the quality of GNSS-derived coordinate time series. Therefore, the next investigations will cover the following aspects:

- Test of different strategies to introduce the stacked residuals into the GNSS data processing
- Check of different spacial resolutions for the size of the stacking cells
- Test of different time spans to calculate the residual maps
- Statistical testing for a robust estimation of the stacking maps
- Analyses of the impact of residual stacking on coordinate time series