Site-Dependent Effects in High-Accuracy Applications of GNSS

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Abstract

The known characteristics for antennas used in GNSS applications, prior to its deployment in various installations are not enough to perform site specific calibration. The antenna characteristics change due to site specific error sources in its surrounding. Six years of data from a number of European IGS and EPN sites, as well as stations in the Swedish GNSS network SWEPOS, have been analysed. Near by objects are clearly visible in the polar plots, and we see characteristic signatures in the elevation dependent plots, which may have a bad impact especially on the application of troposphere water vapor estimation using GNSS.

1. Introduction

Ground-based networks of Global Navigation Satellite System (GNSS) receivers are in wide-spread use in many applications requiring high accuracy. The repeatability of estimated coordinates obtained from GNSS carrier phase data have reached millimeter-level. This level of precision is required for studies of crustal deformations associated with e.g. the post glacial isostatic adjustment in Fennoscandia (Bergstrand 2006; Lidberg 2007). In addition, high accuracy is required when obtaining estimates of tropospheric water vapour from GNSS measurements for use in climate research and numerical weather predictions.

In order to achieve the high accuracy, all sources of error must be mitigated. Apart from errors caused by the atmospheric signal propagation path delay and satellite orbits and clocks, the errors related to the GNSS antenna and its environment must be considered. The local GNSS environment consists of the antenna, the mounting construction, and objects in the surrounding. These error sources may therefore be attributed to:

- the antenna itself
- the antenna radome cover (additional signal path delay)
- the station design (monument and mounting)
- the local surrounding (especially multipath).

The antenna used at permanent GNSS stations has in itself a known characteristic i.e. Phase Centre Variations (PCV). The known antenna PCV is however changed when the antenna is used in field measurements or in a permanent installation. These unknown additional characteristics are due to site-dependent error sources since the antenna couples electromagnetically to objects in its near-field. In order to establish a full calibration of the antenna installed on its foundation and interacting with its local environment, in-site calibration is required.

2. Data analysis

Six years of data (1999-2004) was analysed with the GIPSY-OASIS II software using the Precise Point Positioning strategy. The elevation cut-off angle was set to 0°, and the analysis was done using daily computations. The resulting post-fit phase residuals was used to create monthly mean values as a function of elevation angle, and total mean values presented in a polar representation. The resolution in the polar representation is 2°x5° in elevation and azimuth angle respectively. See Figure 1.

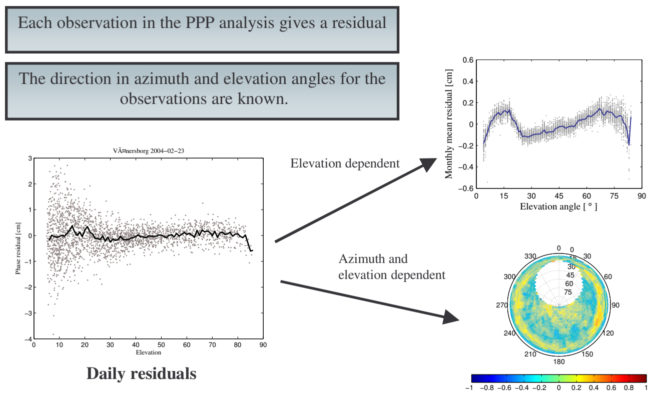

Figure 1. *Visualisation of the used analysis method. Carrier phase residuals with assigned azimuth and elevations (of the ionosphere free linear combination - LC or L3) are "stacked" into monthly means and plotted with respect to elevation angle, as well as stacked into azimuth and elevation "pixels" for visualization in the sky-plot.*

All the 21 fundamental stations in the SWEPOS network (Persson et al. 2007), and some of the densification stations for the network RTK service, usually with a roof-top mount, have been analyzed. Additionally, a few European IGS stations have been analyzed for comparison.

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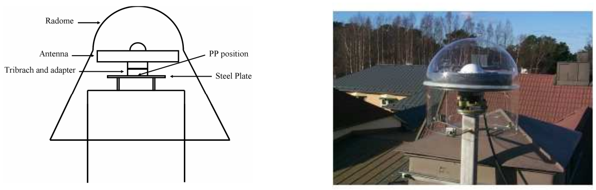

***Figure 2. Left:** Sketch of the pillar top at the fundamental SWEPOS stations with an attached GNSS antenna and covered by a radome. **Right:** Photo of a typical roof-top mount.*

3. Results

In Figure 3 are shown elevation dependent phase residual plots from 4 typical fundamental stations in the SWEPOS network. The typical “SWEPOS pattern” in these plots is found in all (more or less) SWEPOS stations with a concrete pillar monument and a 34 cm diameter steel plate for attaching the GNSS antenna (see Granström, 2006, for the complete study). This “SWEPOS pattern” is most likely related to multipath effects at the pillar top, where the antenna is attached to the steel plate using a tribrach and adapter (Figure 2).

Results from simulation of the effect from multipath on the antenna PCV, following Jaldehag 1995, is given in Figure 4.

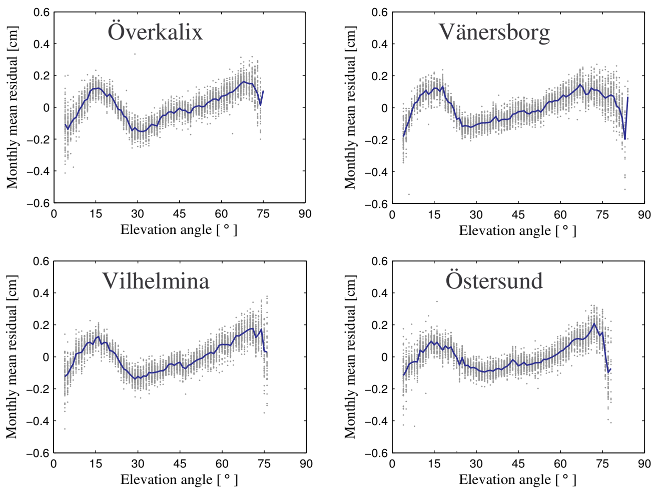

***Figure 3.** Monthly means of carrier phase residuals of the ionosphere free linear combination (LC or L3) from 4 typical SWEPOS stations, plotted with respect to elevation angle to the satellites. The general pattern of these plots is typical for SWEPOS stations with a concrete pillar monument and a 34 cm diameter steel plate for attaching the GNSS antenna.*

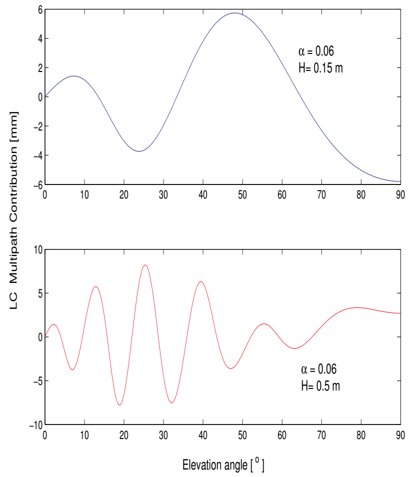

***Figure 4.** Results from simulation of contribution from multipath to the antenna phase centre variation following Jaldehag 1995.In the upper plot the antenna is placed 0.15 m above a flat ground. In the lower plot the distance is 0.5 m.*

In Figure 5 are shown elevation dependent plots of carrier phase residuals, as well as sky plots from thee fundamental SWEPOS sites. Note the somewhat different signature in the elevation dependent plot (compared to the typical “SWEPOS pattern”) at Onsala. This is most likely due to the lower monument, the different pillar top design, and the installed micro wave absorbing material around the GNSS antenna. Note also influence from the surroundings in the sky plots from Hässleholm and Onsala, where some near by objects are visible as increased phase residual values.

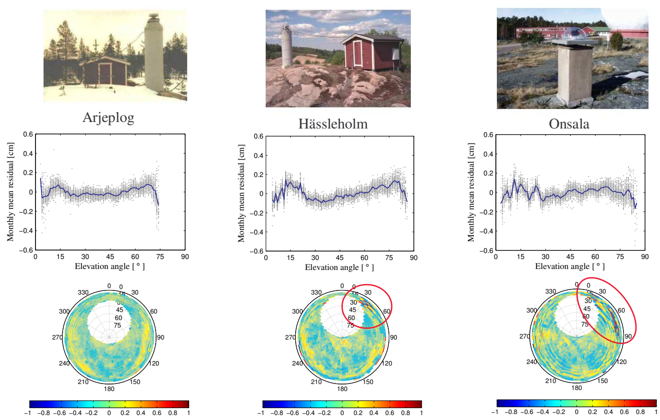

***Figure 5.** Elevation plot and sky plot of phase residuals at the SWEPOS sites Arjeplog, Hässleholm and Onsala (also IGS site). Note the enlarged residuals in the sky plot for Hässleholm in the direction of the instrument hut, and for Onsala in the direction of the 20 meter VLBI antenna.*

Figure 6 shows disturbances from the local surroundings, visible as increased phase residuals in the elevation dependent and/or sky plots. At Lovö, multipath from the fence is visible in the sky plot. At Skellefteå, the close by instrument hut can easily be identified. At Visby, multipath from the flat limestone bedrock shows up as a high frequency signature in the elevation plot, superimposed on the typical SWEPOS pattern.

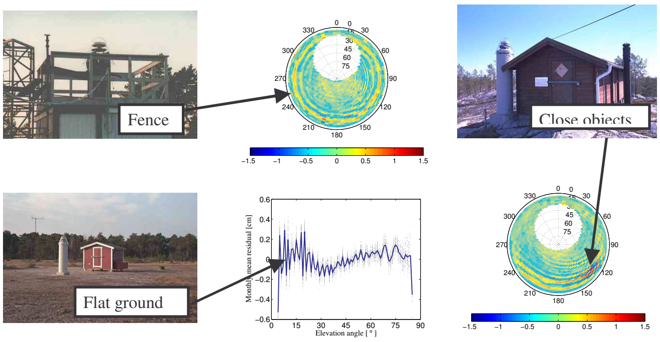

Figure 6. *Disturbances from the local surroundings visible in the plots from Lovö (upper left), Visby (lower left), and Skellefteå (right). See text.*

Results from analysis of two of the densification stations, Nynäshamn and Stavsnäs, established for the SWEPOS network RTK service, are shown in Figure 7. At these stations, the monuments do not include the large 34 cm diameter steel plate, but have a much smaller plate for attaching the GNSS antenna through tribrach and adapter. Therefore the “SWEPOS pattern” is less pronounced. Note also the in general larger residuals at the RTK-stations compared to the fundamental stations.

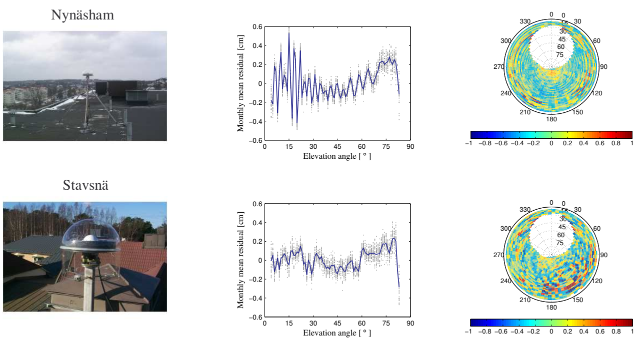

Figure 7. *Phase residuals from the roof top mount network RTK stations Nynäshamn (top) and Stavsnäs (bottom). See text.*

As a comparison, the IGS stations Wettsell (WTZR), Tromsö (TRO1) and Metsähovi have also been analyzed using the same method. Because the design of the monuments is different, the “SWEPOS pattern” is not clearly found at these stations. However, the magnitude of the residuals is comparable to the sites in SWEPOS, and signatures in the elevation plots can be identified. At Wettsell we can also see disturbances from the local surroundings in the sky plot.

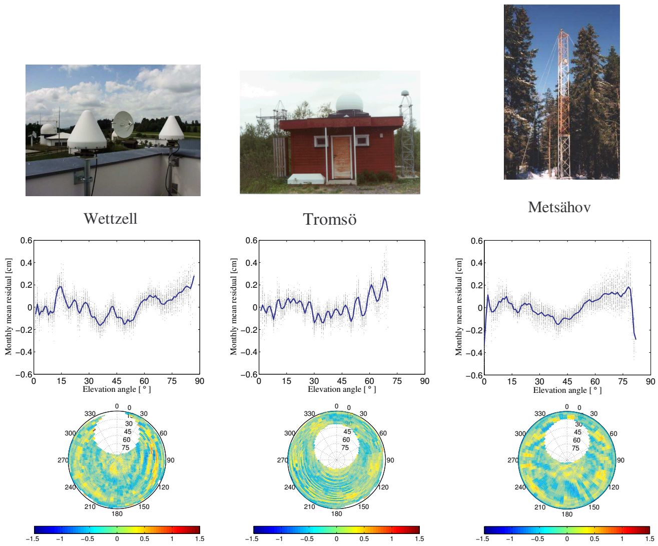

Figure 8. *Phase residuals from the three Europen IGS stations Wettsell, Tromsö, and Metsähowi. See text.*

4. Future work

In order to increase our knowledge and understanding of the effects we see in the results presented above, a separate GNSS monument have been built at the Onsala Space Observatory. The monument is close to a standard SWEPOS pillar (but lower), and have the possibility to precisely disturb the location of the pillar plate and the radome internally and with respect to the concrete pillar. See Figure 9. Investigations of the impact from these parameters are currently on-going.

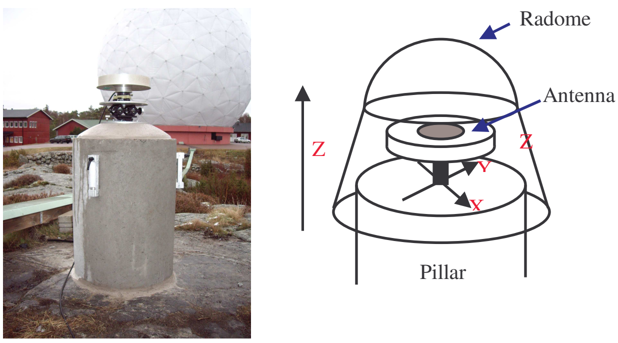

Figure 9. *The new laboratory GNSS monument at Onsala Space Observatory. See text.*

The effect of the site dependent effects presented above will show up as biases in computed positions or estimated water vapour content. To be able to increase the precision and reliability in current and future applications of the now available infrastructure of permanent GNSS stations, the site dependent effects should taken into consideration, and preferably mitigated.

One way would be to re-design and re-build existing GNSS stations. However, such a measure would seriously decrease possibilities for studies where long term undisturbed time series is needed, such as geodynamic studies and studies of climate change.

A much better approach is therefore calibration of the existing GNSS stations. Two approaches may be identified, the statistical approach and the in-situ calibration method (Figure 10). The statistical approach is similar to what has been presented above in the sense that the residuals from one period in time are identified, and then used as corrections for further analysis. The in-situ calibration involves a comparison to a reference antenna close to the GNSS station.

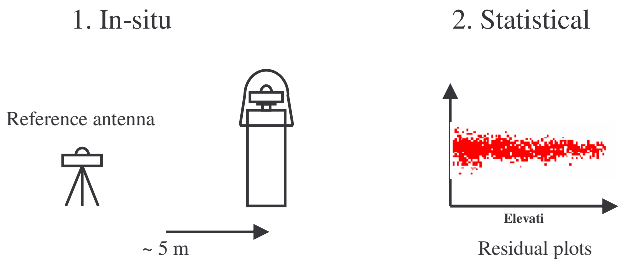

Figure 10. *GNSS station calibration using the In-situ method and the statistical approach respectively.*

It may be noted that the statistical approach is a kind of relative method. The in-situ method on the other hand can be used to determine e.g. differences in height between nominal value of antenna phase centre with respect to the antenna reference point (arp), and its actual value at the station. This may not be important for water vapour estimates, or even precise determination of station velocities, but is crucial in precise position determination.

Therefore our intention is to perform in-situ calibration of the 21 fundamental SWEPOS stations that are the defining stations for the Swedish realization of ETRS89, SWEREF 99. In order to reduce impact on station calibration from disturbances on the reference antenna, we plan to use several (probably 3) reference antennas at each site.

5. Conclusions

We have investigated phase observation residuals at all the 21 fundamental stations in SWEPOS, as well as some densification stations, and some European IGS stations. It can be concluded that:

- Stations with similar design and equipment suffers from similar elevation dependent effects
- Surfaces and objects in the near-field of the station could cause disturbances in the post-fit phase residuals correlated to its distance to the antenna.
- The additional unique features in the residual patterns for each station are related to its local environment.
- The recommendation is to avoid reflecting surfaces close to the antenna and keep vegetation below the horizon mask

Mitigation of site dependent effects is important in order to achieve increased accuracy in positioning, as well as for the estimation of the water vapour content in the atmosphere. If the in-situ station calibration method is applied, it is crucial to reduce the effect caused by disturbances at the reference antennas, either by having them well isolated from site-dependent error sources, or by applying an analysis strategy where the disturbances on the reference antennas can be eliminated.

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