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Estimating the Geocenter from GNSS Observations

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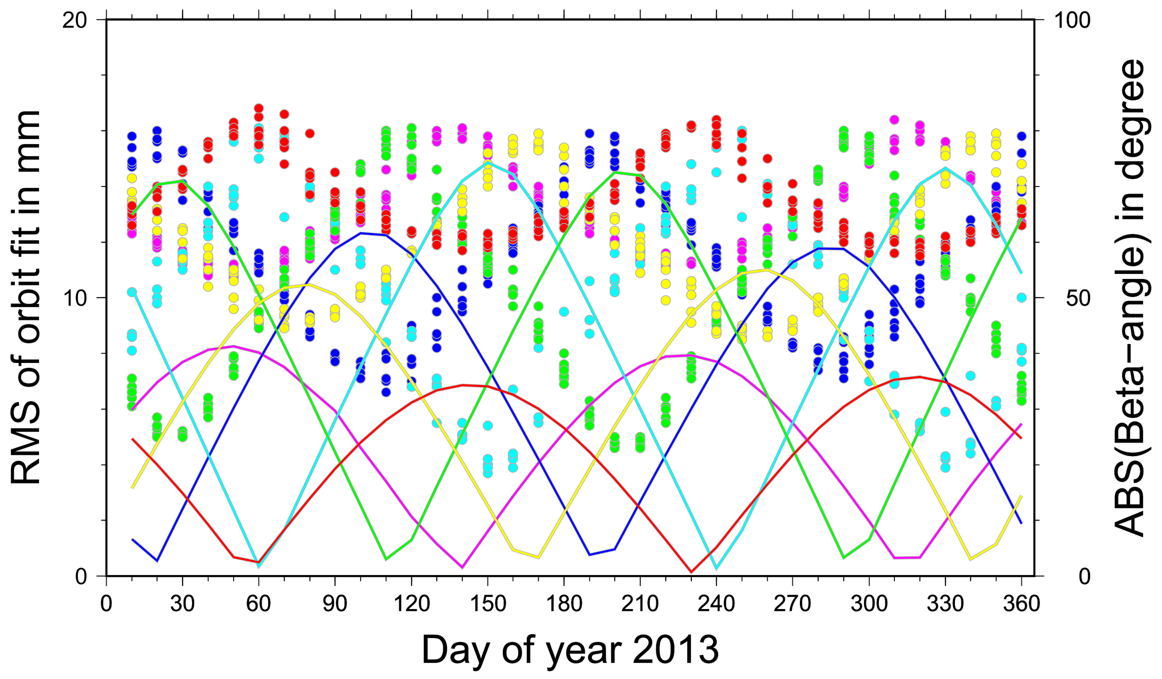
Introduction

The satellites of the Global Navigation Satellite Systems (GNSS) are orbiting the Earth according to the laws of the celestial mechanics based on the gravitational law. As a consequence, the satellites are sensitive to the instantaneous center of the mass of the Earth. The coordinates of the (ground) tracking stations are referring to the center of figure as the conventional origin of the reference frame, which is supposed to be the long-term mean location of the center of mass. The difference between the center of mass and the center of figure is the instantaneous geocenter.

Sensitivity of the orbit model

The precise orbit files contain the positions of the GNSS satellites in the Earth fixed reference frame with a sampling of 15 minutes. The satellite positions can perfectly be represented by a GNSS satellite trajectory if consistent Earth rotation parameters (ERP) and orbit model is applied as it has been used when the precise orbit file has been computed from the GNSS observations. This assumes that the center of mass and the origin of the terrestrial reference frame coincide.

If these two points are not identical anymore - the terrestrial frame may be shifted by, e.g., 10 cm towards the Z component - a discrepancy is introduced, which changes the shape of the satellite orbits. The RMS of the orbits with respect to the shifted satellite positions is given in Figure 1 for GPS and GLONASS satellites (computed every 10 days during the year 2013 based on CODE solution for the IGS-final product series).



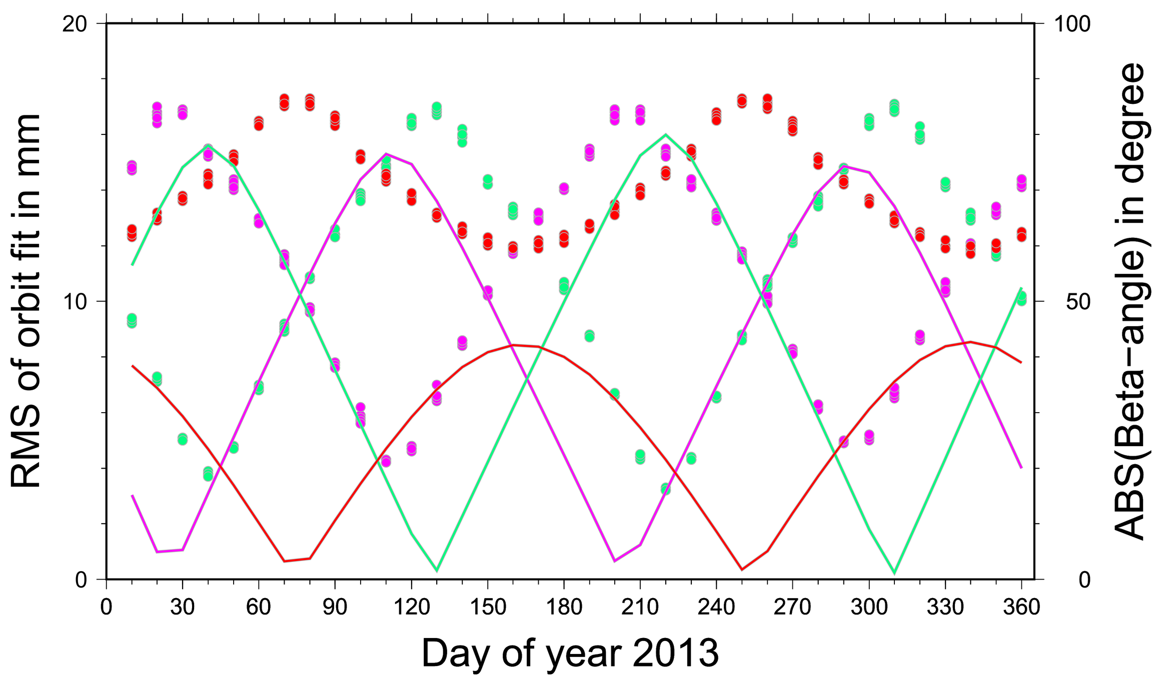


Figure 1: RMS from fitting the satellite positions with a consistent orbit model gives an RMS of exact zero for each satellite. When shifting the satellite positions by 10 cm towards the Z coordinate axis, the RMS of the fit increases like shown in the two plots (top: GPS; bottom: GLONASS). The colors indicate the orbital planes; the elevation-angle of the Sun above the orbital planes (called beta) are plotted w.r.t. the right axis. The closer the beta angle comes to 90 degree the better the discrepancy can be compensated by parameters estimated for the orbit model (the RMS of the fit becomes smaller).

Poster compiled by Rolf Dach, April 2014
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Studying the correlations using simulated GNSS observations

Simulation scenario

The geometry from the CODE contribution to the IGS final solution has been assumed as true. A network of 90 globally distributed stations was assumed (see Figure 2).

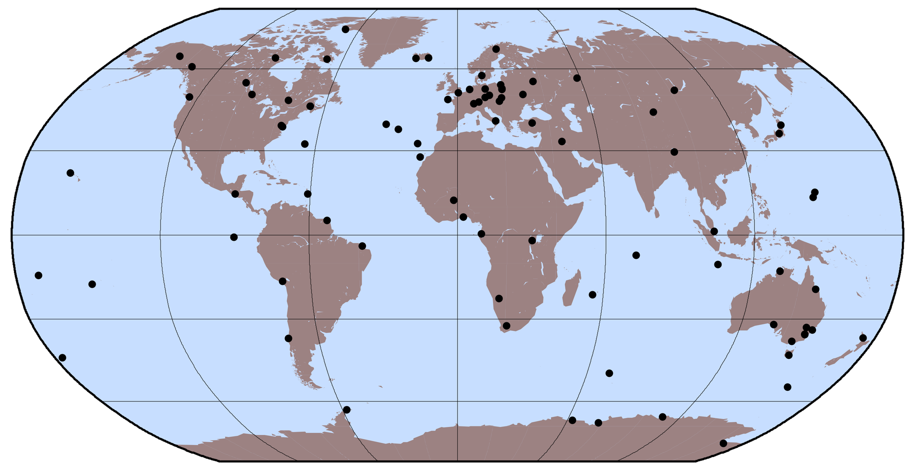


Figure 2: Network of stations where GPS and GLONASS measurements have been simulated based on the geometry given by CODE orbit and coordinate solutions for every 10th day in the year 2013.

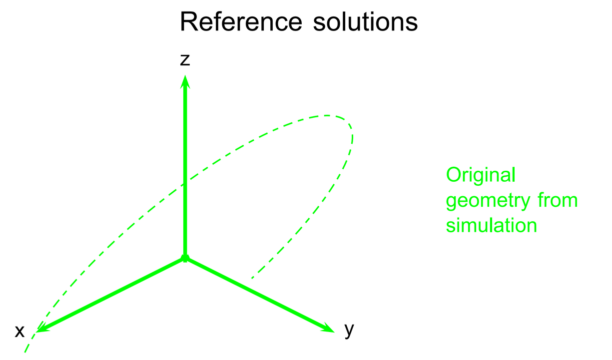
Measurements without noise have been simulated with the consequence that

- phase measurements can serve for a solution where the ambiguities are freely estimated with real values.
- code measurements may be used for a solution where all ambiguities are fixed to their correct integer values.

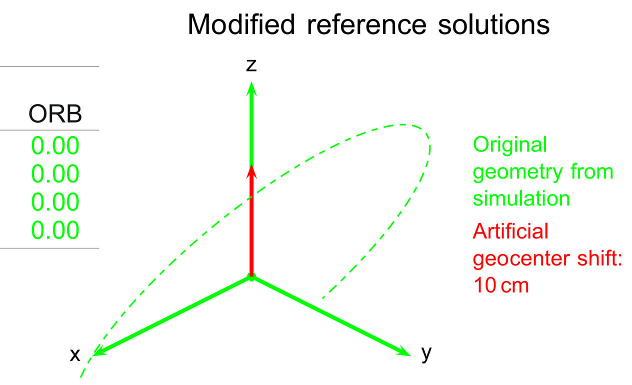
List of parameters considered when analyzing the simulated data:

- station coordinates: daily
- troposphere parameters: every 2h for vertical; daily for gradients
- orbital elements: 15 parameters of the CODE-model per satellites (constraints according to CODE's operational solution); daily
- Earth rotation parameters: offset and drift; daily
- geocenter: daily
- station and satellite clock parameters: every epoch
- ambiguities: once per satellite pass

Reference solutions:



Solution setup		Results			
Datum	GCC	Chi2	CRD	GCC	ORB
NNR+NNT	estimate	0.00	0.00	0.00	0.00
NNR	fixed	0.00	0.00		0.00
NNR+NNT	fixed	0.00	0.00		0.00
NNR	estimate	0.00	0.00	0.00	0.00



Solution setup		Results			
Datum	GCC	Chi2	CRD	GCC	ORB
NNR+NNT	estimate	0.00	0.00	0.10	0.00
NNR	fixed	0.00	-0.10		0.00
NNR	estimate	0.00	0.00	0.10	0.00
NNR+NNT	fixed	≠0.00	≠0.00		≠0.00

Figure 3: When analysing the simulated observations, all residuals become zero if the solution is consistently generated (left panel). If the coordinates are shifted by 10 cm towards the Z component the resulting effect can be compensated by related parameters as long as they are available in the parameter estimation setup (first three lines in the right panel). Otherwise the discrepancies are distributed to all other parameters to be estimated (primary station coordinates, satellite orbits and clocks, see Section on Error Propagation) according to the principle of the least squares adjustment.

Inspecting the Covariance matrix

To investigate the potential correlations between parameters of interest Figure 4 shows the a posteriori covariance matrix obtained from solutions based on the simulated code observations.

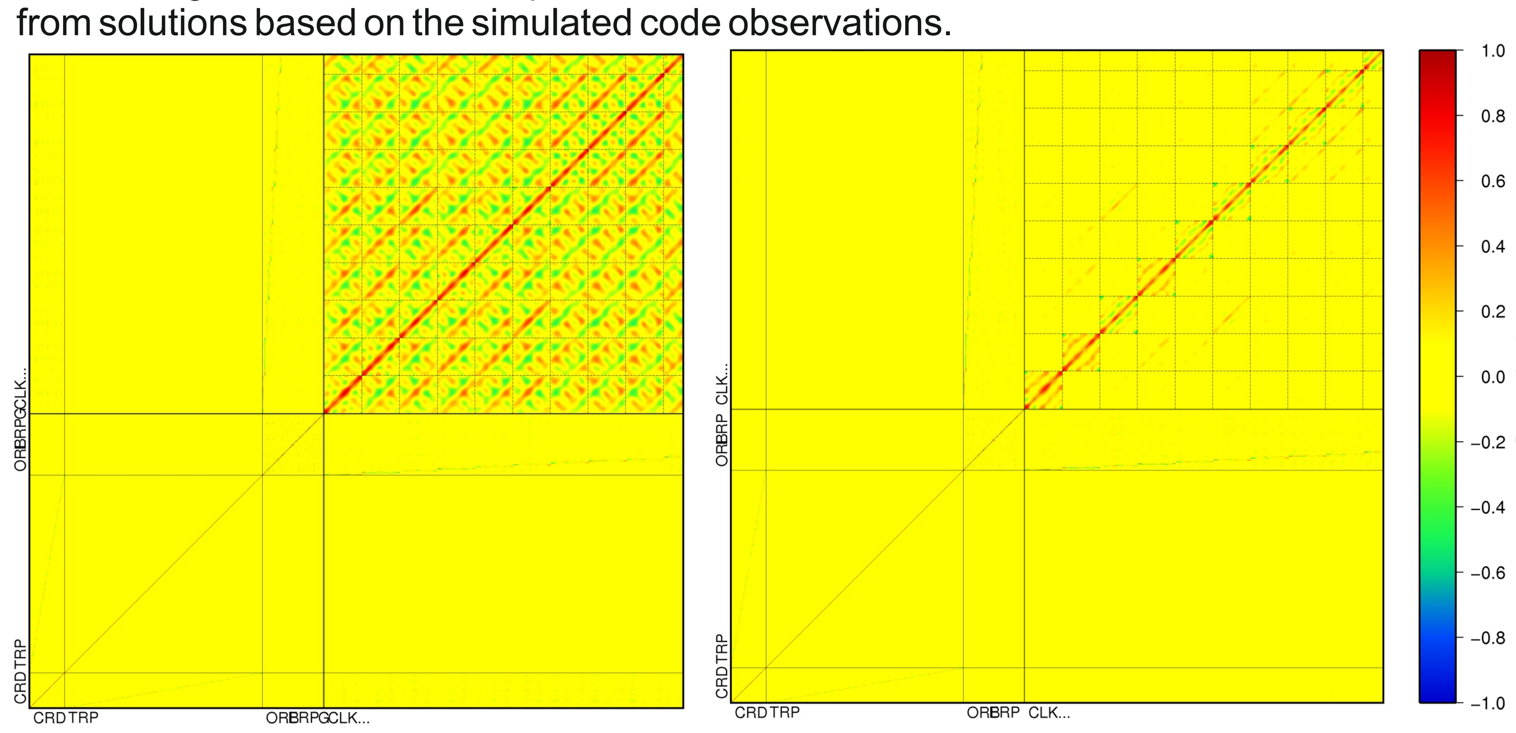


Figure 4a: Datum: NNR+NNT; GCC: est. **Figure 4b**: Datum: NNR+NNT; GCC: fixed

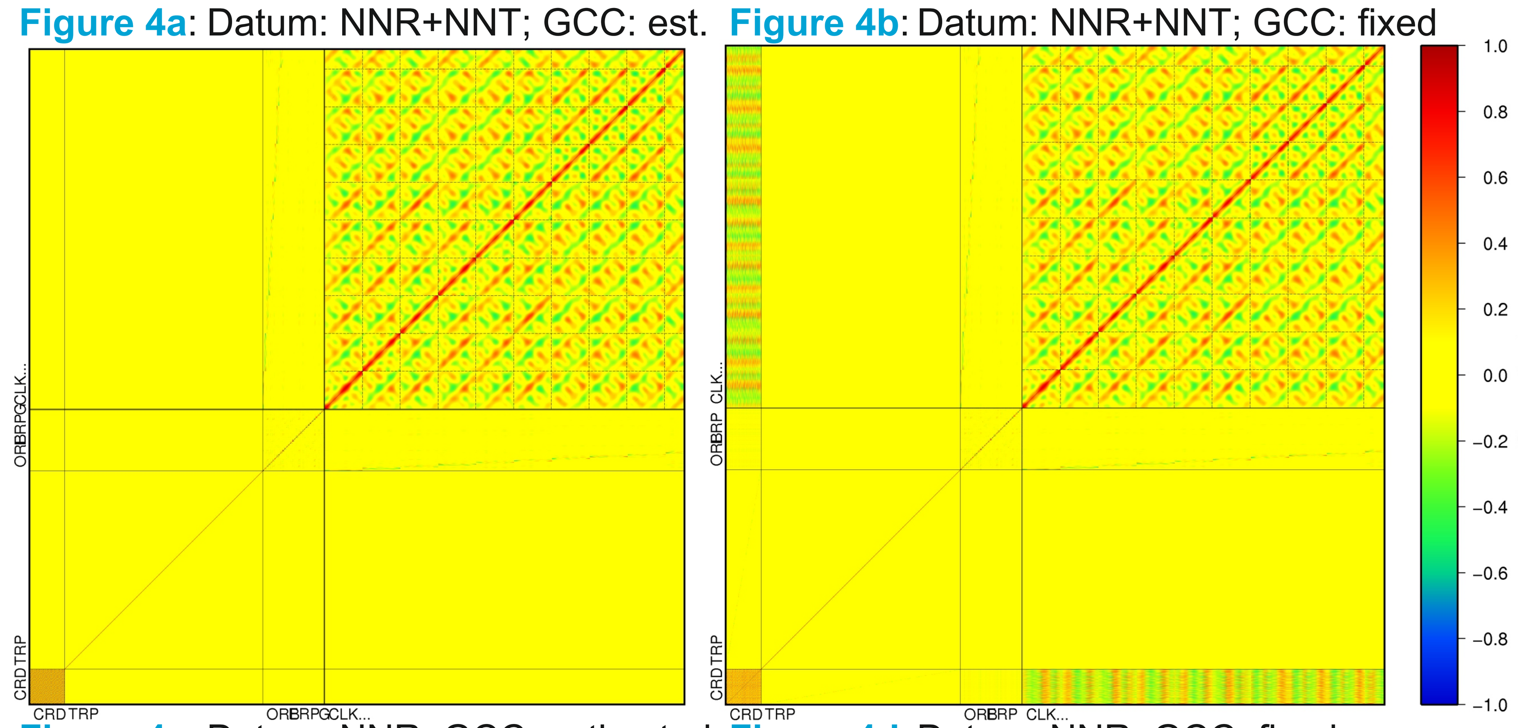


Figure 4c: Datum: NNR; GCC: estimated **Figure 4d**: Datum: NNR; GCC: fixed

Error Propagation

If the instantaneous center of mass is forced to the origin of the reference frame (Datum: NNR+NNT; GCC: fixed) there is a discrepancy with respect to a "relaxed" solution (Datum: NNR+NNR; GCC: estimated).

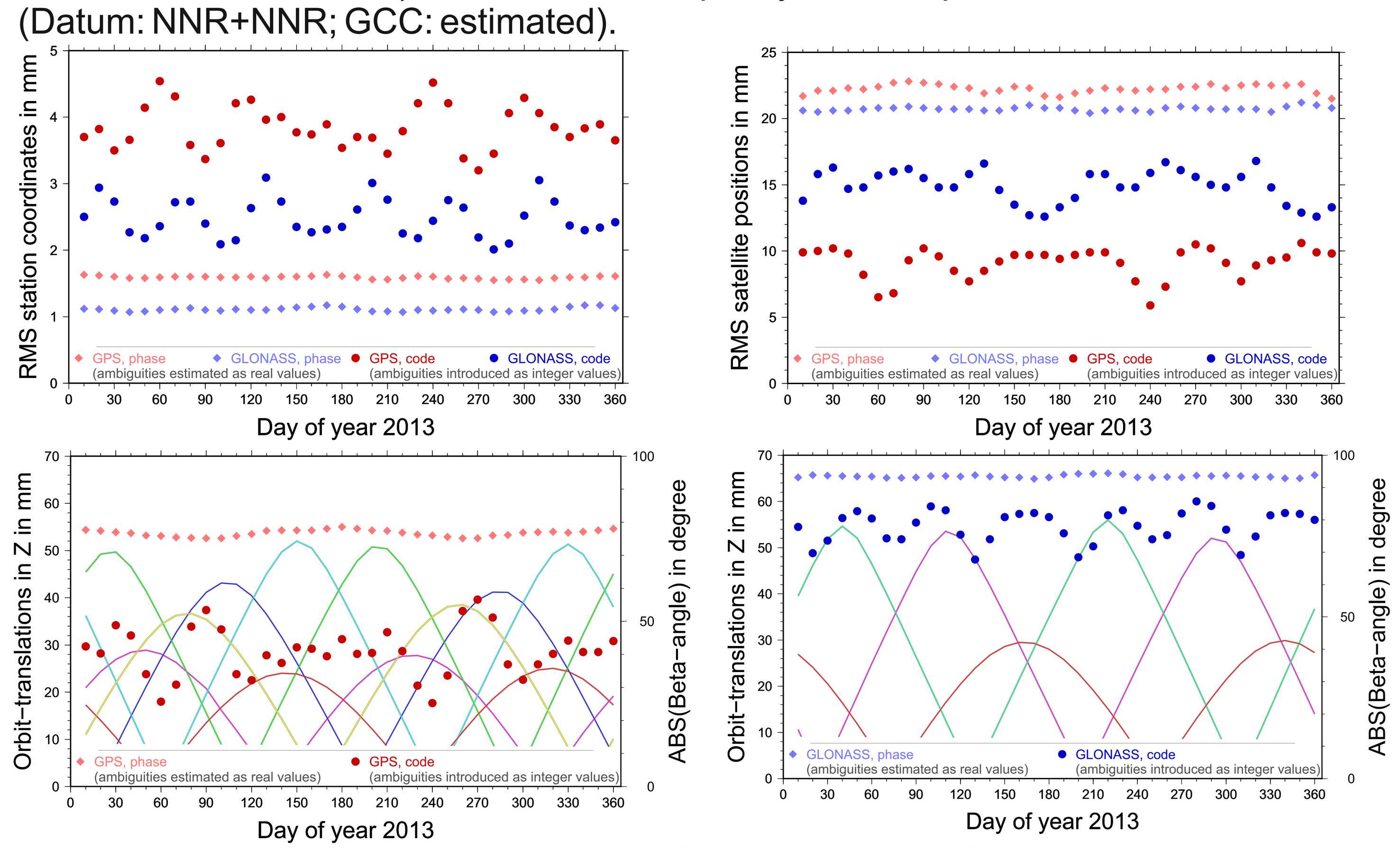


Figure 6: An artificial geocenter shift of 10 cm towards the Z component is introduced when processing the simulated data. The results for the coordinates (top left: RMS) and the satellite positions (top right: RMS; bottom translation in Z) are compared using a Helmert-transformation.

The results underline the importance of the ambiguity resolution (otherwise the estimated real valued ambiguities may easily absorb a big amount of the geometric effects). The plots also illustrate, that the GLONASS orbits are much more sensitive to the geocenter discrepancy than the GPS orbits.

Conclusions from the covariance matrices in Figures 4+5:

- The expected correlations between satellite clock and orbit parameters are clearly visible.
- NNT is essential for the datum definition, independent whether the geocenter is estimated or fixed. Otherwise in particular the station coordinates become singular.
- There are high correlations between GCC parameters and satellite clock parameters. *They are, on the other hand, in the same order of magnitude like the correlations between station height and troposphere, compare Figures 5a+b.*

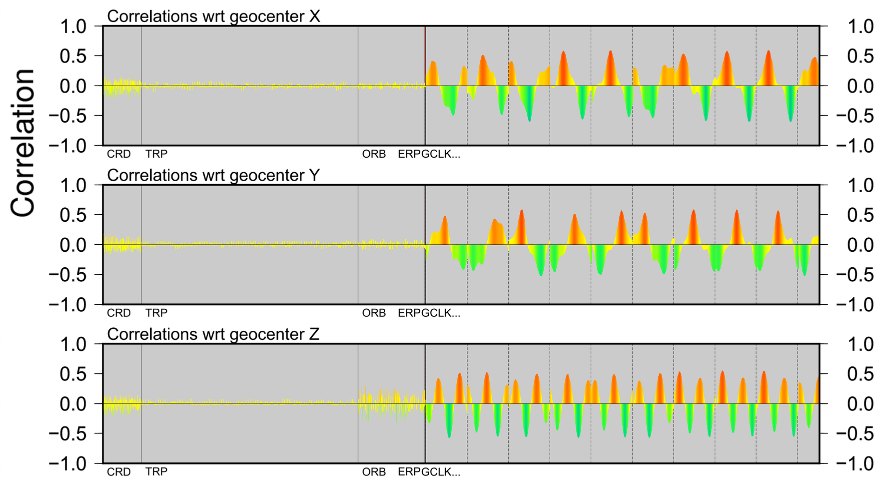


Figure 5a: Extract for the GCC parameters from the covariance matrix displayed in Figure 4a.

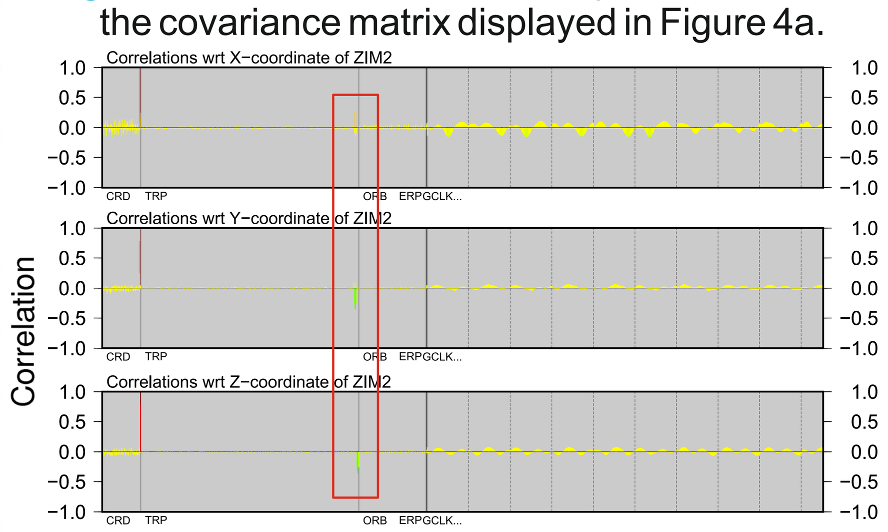


Figure 5b: Extract for the station coordinates (ZIM2) from the covariance matrix from Figure 4a (note the correlation with the troposphere parameters, indicated with the red rectangle)

Conclusions

The simulation study has clearly shown that GNSS is sensitive to the geocenter as the deviation of the instantaneous center of mass from the origin of the reference frame.

If the geocenter is not estimated, its influence propagates into the other parameter (station coordinates, satellite orbits and clocks) of the GNSS analysis according to the error propagation laws of least squares adjustment.

The geocenter parameters are highly correlated with other parameters in the GNSS data analysis but the level of correlations is comparable with correlations between other parameters typically estimated in the GNSS data processing.

Closing Remarks

- The simulated shift of 10 cm towards the Z component is about ten times larger the expected geocenter variation. It was used to increase the resolution of the numbers in the file formats.
- It is confirmed by the results from the CODE reprocessing results that the geocenter estimates for the X and Y components give reasonable values (confirmed by SLR measurements) whereas the Z component contains artefacts from the orbit modeling (in particular from GLONASS).

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