On the Weighting of GPS Phase Observations in the EUREF Network Processing

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Abstract

Elevation dependent weighting is recommended for the processing of the observations collected by the EUREF permanent network. In order to examine the performance of the weight function $P = \cos^2 z$ compared to equal weighting $P = 1$, a European network of 32 stations is analysed during three periods of 10 and 11 days respectively. The analysis comprises systematic variations of the elevation mask between 8/ and 20/ in all network adjustments. There are pros and cons for each of the two options. However, there are also arguments claiming an additional sin z term in the weight function. Therefore, an alternative weight function $P = \cos^2 z + a \cdot \sin^2 z$ is also tested. As a result the latter function with $a = 0.3$ is recommended.

1. Introduction

The processing of the observations collected by the EUREF Permanent Network (EPN) is presently shared among 16 analysis centres. The strategies of the data analysis are regularly discussed and aligned to guidelines agreed upon. Since September 2001 elevation angle dependent weighting associated with an elevations mask of 10/ should be applied by all analysis centres. Those not capable of varying the weight function in the network adjustment are recommended to set the elevation mask to 15/. Using the Bernese GPS software (Hugentobler et al. 2001), done by almost all analysis centres, the recommendation implies the application of the weight function $P = \cos^2 z$ with z being the zenith distance. Besides $P = 1$ this is the only presently available option. Elevation dependent weighting aims at accounting for the increasing noise and modelling errors with increasing zenith distance. Unlike, the idea behind equal weighting is to exploit the full information inherent in low elevation data for improving the height and troposphere estimation and for decorrelating both parameter types; however, remaining gross errors may significantly bias the solution. We are not aware of a trade-off between both weighting strategies based on the analysis of sufficiently extensive data sets. Therefore, we perform a comparison by processing three observation periods of an EPN sub-network comprising 32 stations. Considering the sensitivity of network adjustment results to the applied elevation angle cutoff, the analysis includes also systematic variations of the elevation mask setting. As there are contributors to the GPS measurement error budget, which depend on sin z instead of cos z, an alternative weight function including an additional $\sin^2 z$ term is also tested.

2. Weight Functions

The performance of the two weight functions $P = 1$ and $P = \cos^2 z$ was independently of the Bernese software compared in a theoretical study by Vermeer (1997). The result was a clear vote in favour of the cosine zenith distance weighting, in particular if troposphere and receiver clock parameters are to be estimated simultaneously with station heights. This scenario applies to the EPN processing, even if clock parameters are eliminated by creating between satellites observation differences. However, it should be noted that Vermeer (1997) assumes that the standard deviations of GPS phase observations increase with 1/cos z. This assumption was based on results of an analysis of adjustment residuals by Elósegui et al. (1995). Among others, main reasons for a zenith distance dependence of residuals are atmospheric effects, multipath and antenna gain.

On the other hand, if one transforms Bernese software double difference phase residuals to zero difference residuals applying the strategy proposed by Braun et al. (1998), then the cosine zenith distance dependence appears not as clear. Instead, these residuals increase rather slowly from zenith to about 60/, and only beyond they tend to increase more rapidly. Such a behaviour might be suggested by the high agreement of tropospheric mapping functions down to at least 70/, before they diverge remarkably. Thus, one argument for modifying the weight function $P = \cos^2 z$ is to diminish its rapid decrease even at medium zenith distances. Another issue is the fact that there are also contributors to the error budget of GPS observations which do not depend on 1/cos z but on cos z. Examples are:

- Various mainly vertical loading effects, which are either not yet modeled at all or cannot be modeled sufficiently accurate; among these are ocean loading, atmospheric pressure loading, snow/ice and water loading.
- Vertical instabilities of the effective electrical antenna phase centre with respect to the model accepted in the data processing, e.g. due to signal strength variations.

Therefore, we include in our analysis in addition to $P = 1$ and $P = \cos^2 z$ an extended weight function $P = \cos^2 z + a \cdot \sin^2 z$ with $0 < a << 1$. Figure 1 displays the weight functions used in the sequel. Besides $P = 1$ and $P = \cos^2 z$, the menu of the Bernese adjustment program GPSEST offers to select model numbers for additional weight functions. However, these are not yet realized in the subroutine WGTELV. We have used this option to select the extended weight function and the coefficient a via the menu, e.g. requesting model 3 corresponds to a setting $a = 0.3$.

functions including the $\cos^2 z$ term perform very similar. The repeatabilities are the best at elevation masks around 10/ and become only slightly worse with increasing elevation angle cutoff. Unlike, equal weighting performs considerably worse at elevation masks of less than about 15/; this indicates the presence of remaining modelling deficiencies or outliers at very low elevation angles, which, when not downweighted, affect the solution. Above elevation masks of about 15/ there is no obvious difference between equal weighting and any of the elevation dependent
weight functions. On the average, these findings hold for all three analysed periods.

In case of the vertical component a strong dependence of the repeatabilities on the elevation angle cutoff is evident from figure 3. Note the scale difference between the upper and lower part of the display. As can be seen, again the differences between the three weight functions including the $\cos^2 z$ term are rather small and not systematic at all. The comparison of $P = 1$ and $P = \cos^2 z + 0.3 \sin^2 z$ in the upper part of figure 3 demonstrates firstly the poor performance of equal weighting below, say, 12/ elevation angle. Secondly, the superiority of equal weighting beyond that elevation mask and its weaker dependence on elevation mask variations are obvious. Considering that the choice of the weighting strategy in connection with the cutoff angle setting is primarily relevant for the height determination, we conclude:

- C If for any reason the elevation angle cutoff is set to about 12/ or higher, or if no observations are available below this mask, then equal weighting should be applied;
- C If the elevation mask is less than 12/, elevation dependent weighting is clearly preferable; although the three tested weight functions perform very similar, we propose to include an $a \cdot \sin^2 z$ term with a . 0.3.

Table 1: Repeatabilities of the north (N) and east (E) position components of daily network adjustments for all tested weight functions and elevation masks

Period	Cutoff	P = 1		P = cos²z		P = cos²z + 0.3 sin²z		P = cos²z + 0.5 sin²z	
Year, Days	Angle [/]	N [mm]	E [mm]	N [mm]	E [mm]	N [mm]	E [mm]	N [mm]	E [mm]
2000, 269 - 278	08	3.06	3.16	2.46	2.21	2.45	2.22	2.49	2.27
	10	2.87	2.67	2.44	2.23	2.44	2.24	2.47	2.29
	12	2.70	2.57	2.45	2.25	2.45	2.25	2.46	2.28
	14	2.66	2.49	2.50	2.27	2.50	2.27	2.51	2.40
	16	2.67	2.43	2.63	2.29	2.62	2.30	2.62	2.42
	18	2.71	2.30	2.69	2.30	2.58	2.29	2.63	2.36
	20	2.80	2.32	2.79	2.37	2.77	2.36	2.82	2.24
2001, 273 - 283	08	3.13	3.50	2.48	3.02	2.49	3.04	2.54	3.07
	10	2.85	3.24	2.46	3.02	2.46	3.01	2.49	3.06
	12	2.74	3.11	2.51	3.10	2.49	3.09	2.51	3.09
	14	2.70	3.08	2.57	3.17	2.55	3.13	2.54	3.11
	16	2.69	3.13	2.65	3.21	2.64	3.21	2.60	3.12
	18	2.71	3.18	2.72	3.30	2.72	3.28	2.70	3.23
	20	2.75	3.20	2.82	3.35	2.79	3.33	2.77	3.29
2002, 244 - 254	08	3.68	2.89	2.67	2.19	2.68	2.19	2.71	2.22
	10	3.40	2.70	2.67	2.17	2.67	2.19	2.69	2.21
	12	3.14	2.53	2.70	2.17	2.68	2.18	2.70	2.19
	14	2.95	2.38	2.66	2.17	2.67	2.16	2.67	2.18
	16	2.82	2.34	2.72	2.23	2.72	2.22	2.71	2.23
	18	2.90	2.35	2.86	2.27	2.84	2.29	2.80	2.25
	20	2.97	2.36	2.95	2.33	2.91	2.31	2.92	2.34