ON THE USE OF NON-PERMANENT GPS STATIONS FOR GEOKINEMATICS

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Abstract

Continuous data acquisition at the permanent GPS stations together with appropriate uniform strategy of data processing and use of suitable reference system make the basis for generating time series of GPS solutions that can be applied to interpret variations in positions determined in terms of geokinematics. Distribution of such stations is frequently insufficient to provide data on geokinematics in the region with required spatial resolution. The network of permanent GPS stations is therefore densified with the stations where GPS observations are conducted only periodically in the framework of time-limited observational campaigns.

Variations in the GPS-derived positions of such non-permanent GPS stations need a special care when interpreted in terms of geokinematics effects as referred to relatively short time and based on limited data set.

The differences between vector components obtained from different GPS campaigns can be viewed as a composition of two components. First one composed of quasi-stable or slowly changing terms has a systematic character. The second one composed of periodic and casual terms has a random character. The approaches of effective lowering of biases with use of repeated measurements, calibration and metrological tests of both antennas and receivers are reflected in numerous publications.

The problem of reliable precision estimate has to be carefully considered. The analysis of time series of GPS-solutions based on overlapped sessions is a useful tool to estimate biases and to improve the reliability of detection of geokinematics phenomena using data from non-permanent GPS stations. The results of numerous numerical experiments with use of EPN data processed with the Bernese v.4.2 software are presented. Practical suggestions concerning the use of non-permanent GPS stations for geokinematics are given. A special concern was paid for the determination of the optimum length of the campaign and the length of filtering window applied to process time series of GPS solutions.

Fig. 1. Map of the vectors investigated on the background of Central European EPN network

Data from the permanent GPS stations, widely used for positioning and navigation as well as for modelling dynamics of the atmosphere, provide also useful information on geokinematic effects. It could be used for estimation of the level of geodynamic activity in the area investigated and for determination of the character and parameters of the motion of the Earth crust in both regional and local scales. Installation and running of permanent GPS stations is however quite expensive. Therefore the networks of non-permanent, periodically operating stations monumented and located in the area of interest, e.g. NCEDC are used for different geokinematic projects .

Data acquired at non-permanent GPS stations is affected by specific biases due to e.g. antenna set up, changes of receiver parameters, software changes, as well as by random errors. Some problems with the estimation of station coordinate variation may occur due to network solutions that are used to detect regional and local geokinematic effects. Such solutions are ambiguous; they depend on the strategy applied (Malkin and Voinov, 2000; Poutanen et al., 2001) and not always the increase of the number of stations in the network results in reduction of random errors (Kenyeres et al., 2002).

Besides random errors such as receiver noise and non-modelled atmospheric effects the quasi-random errors of regular character affect GPS solutions, e.g. effects of changes in satellite configuration that although purely deterministic they affect almost randomly GPS solutions.

Study on determination of the length of observing session, observation strategy, data processing strategy in terms of minimization of random errors in GPS solutions is the subject of the paper.

Numerical experiments were conducted with use of GPS solutions obtained over 4 months from February to May 2001 (Krynski and Zanimonskiy, 2003) as well as 6 years long time series of GPS solutions (Wielgosz, 2002). They are based on data from BOGO, BOR1, JOZE, HFLK, LAMA and UZHL EPN stations processed with the Bernese v.4.2 software. Daily sessions with 1h overlap were processed using QIF strategy to generate time series of GPS solutions.

Distribution of chosen stations (Fig. 1) allows for comparison of vector components in different combinations to separate station-dependent errors from distance-dependent ones. That separation was made with use of correlation analysis.

Examples of characteristic variations in vector length are shown in Fig. 2. They exhibit the evidence of artefacts that are apparently caused by temporal malfunctioning of receiving systems at the stations (event A-most probably at BOR1 station, event B-at LAMA station and event C-at BOGO station). Such artefacts could be eliminated but it requires the analysis of high temporal resolution and sufficiently long time series of GPS solutions as well as additional data, e.g. internal accuracy estimate available in the output of both commercial and scientific GPS software (Krynski and Zanimonskiy, 2003). Examples of time series of weekly solutions obtained by averaging daily solutions over 7-day intervals are given in Fig. 2b..

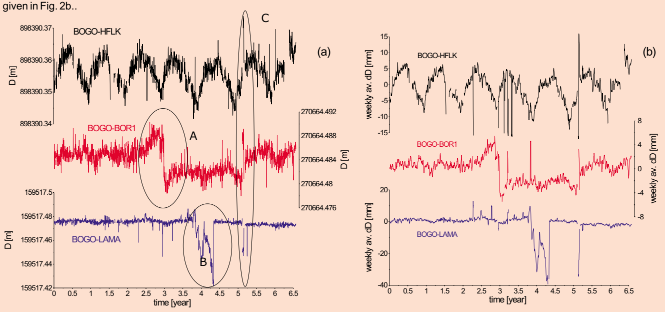

Fig. 2. Time series of daily solutions for length of vectors joining BOGO with three other EPN stations (a) and time series of weekly solutions obtained by averaging daily solutions over 7-day intervals (b)

The usefulness of high-resolution (as compared with duration of artefact effect) time series of GPS solutions for data quality estimation will be shown. Time series of rms of daily GPS solutions within 7-day window is given in Fig. 3. One could expect that the analysis of a number of time series of GPS solutions could provide the estimate of quality of those solutions, separate intervals containing questionable quality of GPS solutions (A, C and D zones or zone B where the artefact effect related to malfunctioning of receiving system had occurred).

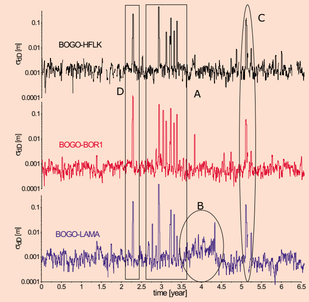

Fig. 3. Time series of rms of daily GPS solutions within 7-day window

The attempt of detection and estimation of linear drift in time series of GPS solutions is illustrated in Fig. 4 that shows the rates of change of weekly averaged length of three vectors over a year interval.

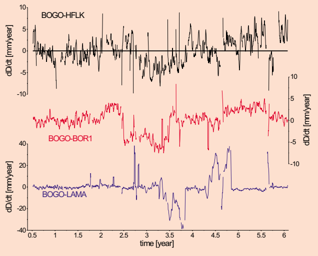

Fig. 4. Time series of rates of change of weekly averaged length of three vectors over a year interval

Fig. 4 shows that the problems related to the receiving system become a substantial limitation for the use of data from non-permanent GPS stations for determination of linear drift in station coordinates. In case of some vectors, however, e.g. BOGO-HFLK vector gross errors could be unambiguously detected so the existing random errors remain the main factor determining the level of the accuracy of linear drift estimation. The dependence of the level of random errors in vector length (dispersion within data window and dispersion of average over data window) on the length of data window is shown in Fig. 5.

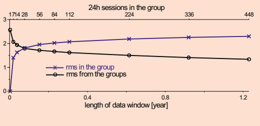

Fig. 5. The rms of BOGO-HFLK vector length from single sessions in the group of daily sessions and rms of average solutions from the groups of daily sessions versus the length of data window

Accuracy of the rate of linear drift of the vector length derived for different data windows and varying time intervals between observation campaigns after removing outstanding GPS solutions is given in Table 1.

Table 1. RMS of the rate of linear drift ΔD/Δt [mm/year] for different data windows and varying time intervals between observation campaigns

Span of observation campaigns [years]	Length of data window (length of observation campaign)			
	1 day	1 week	1 month	1 year
1	3.65	2.91	2.45	1.47
2	1.98	1.59	1.34	0.94
3	1.32	1.06	0.93	0.53
4	0.85	0.73	0.60	0.38
5	0.67	0.55	0.47	0.22
6	0.51	0.39	0.35	-

The extension of observation campaign to one month at non-permanent GPS station network results in reduction of dispersion of GPS solutions by 30% only as compared with the corresponding one for daily GPS solutions. Moreover, one year long campaign provides dispersion in the vector length at the level of 1.5 mm. The rate of change of linear drift could thus be estimated from weekly solutions and solutions based on two years data with accuracy not exceeding 4 mm/year and 3 mm/year, respectively.

Time series of overlapped GPS solutions can be applied to increase temporal resolution of GPS solutions and reliability of random errors estimation (Krynski and Zanimonskiy, 2003). Variations of BOGO-JOZE vector length obtained from processing 24h sessions without overlap (a) and overlapped with 1h shift of sessions processed (b) are shown in Fig. 6. Due to higher temporal resolution of time series of GPS solutions the effects of externally perturbed satellite measuring system, in particular of ionospheric storms, could be detected and eventually removed (Krynski and Zanimonskiy, 2002a)

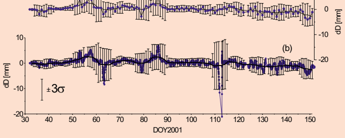

Fig. 6. Variations of BOGO-JOZE vector length obtained from processing 24h sessions without overlap (a) and overlapped with 1h shift of sessions processed (b)

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Typical time series of vector length for three vectors spanned on LAMA, BOGO and UZHL stations of nearly the same longitude (Fig.7) exhibit similarity in variations. Those variations are in addition roughly proportional to the distance.

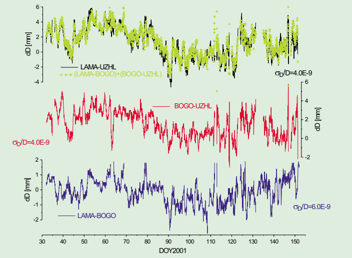

Fig. 7. Time series of vector length for three vectors spanned on LAMA, BOGO and UZHL stations of nearly the same longitude

The quality of determination of linear drift in station coordinates as well as in vector components needs to be estimated in order to make use of data from permanent GPS station network for regional and local geokinematic research. The simple model of such a drift is a one-parameter model (Borkowski et al., 2002). Single parameter could be more precisely determined then multiple parameters representing more complex models. Investigations and accuracy estimation could be performed in both time and spectral domains. Both approaches were applied in the following research.

First of all the model of linear drift has been specified in both time and frequency domain. The model of linear drift of vector length with the rate of 1 mm/year and its spectral representation are shown in Fig. 9a and Fig. 9b, respectively.

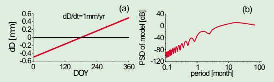

Fig. 9. The model of linear drift of vector length (a) and its spectral representation (b)

Similar variations to those in Fig. 7 were obtained for the length of vectors originating at JOZE station. Strong correlation between the corresponding vector components if not fully taken into account may cause network solutions unreliable. On the other hand, however, it makes possible to apply heuristic methods of comparing variations in vector components of pairs of vectors containing one common station (the method was used to remove outliers in the solutions shown in Fig. 2 and Fig. 3). Such comparison resulted in conclusion that LAMA, BOGO and UZHL station can be considered as stable while JOZE station may exhibit substantial variations in meridional direction. The same character of variations of JOZE station was already addressed in literature (Hefty, 2003). In a similar way variations of BOR1 station in west-east direction were detected. Such virtual variations of coordinates of those stations were also derived on the basis of different data set (Krynski and Zanimonskiy, 2003) with use of both Bernese and Pinnacle software. They were considered as artefacts (Krynski et al., 2002). It was shown (Cisak et al., 2003) that virtual variations of coordinates are at some level correlated with variations of TEC that grow with geomagnetic disturbances (Krynski and Zanimonskiy, 2002a)

Variations in vector length (a) and vertical component (b) for the pairs of vectors with one common station are shown in Fig. 8.

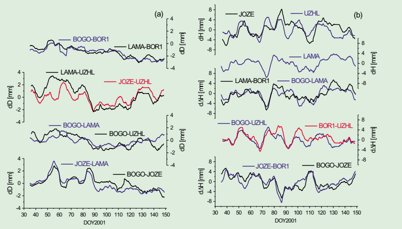

Fig. 8. Variations in vector length (a) and vertical component and possible vertical motion of some stations (b) for the pairs of vectors with one common station

Investigations of random and quasi-random errors in determination of rate of linear drift were based on the results and procedures developed earlier (Krynski and Zanimonskiy, 2003; Wielgosz, 2002). The procedure for the estimation of vector length using data from limited data window will be shown on the example of BOGO-LAMA vector.

Fragments of time series of vector length computed from 24h data sessions with the Bernese v.4.2 software are given in Fig. 10.

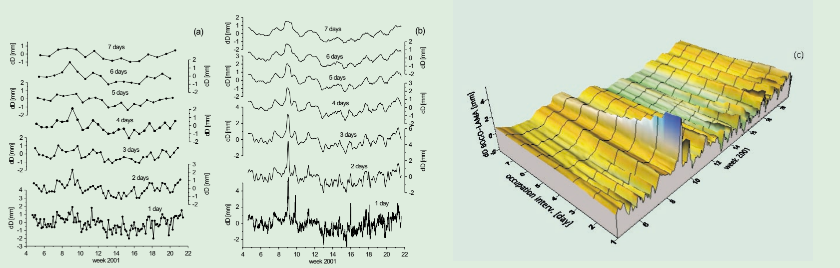

Fig. 10. Time series of BOGO-LAMA vector length without overlap (a) and with overlap (b) with data window varying from 1 to 8 days; 3D image of variations of vector length in terms of current time and length of data window (c)

The consecutive graphs differ in length of smoothing window (modelling the length of observing campaign at non-permanent stations) from one day to one week. The graphs in Fig. 10a correspond to principles of forming time series of GPS solutions applied in EUREF projects (Kenyeres et al., 2002), i.e. daily solutions form weekly groups and are averaged to weekly solutions. The graphs in Fig. 10b correspond to time series of GPS solutions from overlapping sessions. 3D image of variations of vector length based on overlapping sessions against current time and length of data window is given in Fig. 10c. Spectral characteristics of the corresponding signals are given in Fig. 11. Spectral characteristics of the variations of GPS solutions in high frequency band obtained on the basis of overlapped observing sessions were analysed earlier (Krynski and Zanimonskiy, 2003).

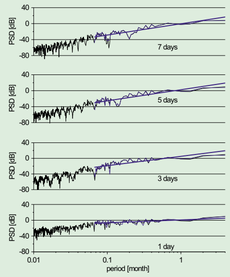

Fig. 11. Spectrum of variations of BOGO-LAMA vector length for different lengths of data window

Dispersion (expressed by standard deviation) of BOGO-LAMA vector length in terms of the length of data window is shown in Fig. 12. Statistics of that dispersion is given in Table 2.

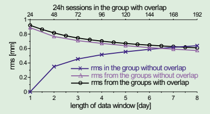

Fig. 12. Dispersion of BOGO-LAMA vector length in terms of the length of data window

Table 2. Statistics of dispersion in the solutions of BOGO-LAMA vector length [mm]

Length of data window [days]	solutions without overlap				solutions with overlap			
	min	max	mean	rms	min	max	mean	rms
1	-2.00	4.20	-0.08	0.89	-2.90	5.70	-0.05	0,92
2	-1.80	3.05	-0.08	0,77	-1.98	4.44	-0.05	0,82
3	-1.57	2.37	-0.09	0,71	-1.71	3.10	-0.05	0,75
4	-1.43	2.07	-0.09	0,67	-1.59	2.44	-0.05	0.71
5	-1.32	1.72	-0.10	0.64	-1.39	2.05	-0.05	0.67
6	-1.17	1.50	-0.10	0.61	-1.32	1.73	-0.05	0.65
7	-1.11	1.31	-0.11	0,59	-1.18	1.51	-0.05	0,63
8	-1.01	1.25	-0.12	0.57	-1.10	1.36	-0.05	0.61

Combination of spectra of drift model together with variations of vector length, considered as random process, were used for determination of linear drift parameters. Time series of BOGO-LAMA vector length averaged over week intervals as well as a model of its linear drift are shown in Fig. 13a while the spectra of the model and of variation increments of vector length (one year shift) are given in Fig. 13b. Comparison of the observed signal with the model of linear drift in both time and spectral domain (Fig. 13) indicates a non-reliable estimate of model parameters, e.g. rate of change (at the level of 1 mm/year). It is thus necessary to enlarge time interval between observation campaigns.

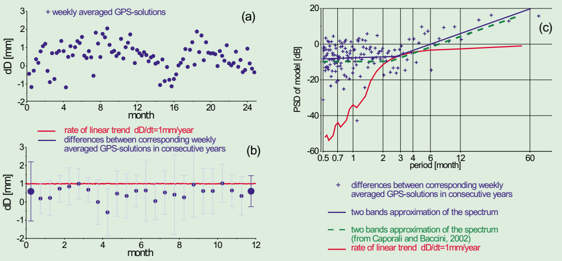

Fig. 13. Time series of weekly averaged BOGO-LAMA vector length (a) and the model of the rate of its linear drift in time domain (b) and in spectral domain (c)

Conclusions

1. The presence of hardware problems essentially limits continuity in monitoring of drift in GPS solutions represented by vector components or station coordinates. Complex analysis of the GPS solutions for several vectors makes however possible to separate and remove blunders. Accuracy of the estimation of drift rate becomes thus limited by remaining random errors. The more vectors taken to analysis the higher is probability of elimination of outstanding solutions. The use of overlapped sessions provides additional data that strengthens the results of statistical analysis and increases reliability of outlier's estimation.
2. Random errors of GPS solutions for the vectors components and station coordinates are characterized by a wide spectrum in frequency domain. An effective tool for suppression random effects in a range of the periods from a day up to a month is averaging of the GPS solutions over a week interval.
3. Random errors in the band from several months till one to two years substantially affect the estimates of drift parameters. For the determination of rate of linear drift of about 1 mm/year at 1σ level it is necessary to use continuous observations from at least 3-years. The same results could be obtained when using data from a month duration campaigns repeated every 3-4 years, or daily campaigns with 4-5 years repetition.
4. Although the detection of geokinematic effects is usually based on data from multi diurnal GPS solutions the determination of drift parameters requires prior statistical analysis of daily solutions that provides a strict control for outliers. Outstanding daily solutions that remain in the data set processed may substantially deform the resulting drift parameters.