Multi-year solution of the GOP EUREF subnetwork

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Abstract

The Geodetic Observatory Pecny (GOP) analysis center started its contribution to the EUREF permanent GPS network in January 1997. At the beginning of 2002, we achieved already 5 years of the EUREF subnetwork evaluations. Although the network scope has been extended (today up to 33 sites), about 13 sites provide already a long time span (>4 years) of the results.

This paper is aimed for the combination of all available weekly results into the unique multi-year solution. The main interest is given on the coordinate monitoring, the changing trends together with identifying the artificial effects in the coordinate time-series.

Besides, we reconstrained all the existing daily solutions and we have solved for the tropospheric parameters from the beginning of the GOP contribution in 1997. The zenith total delays (ZTD) of the sites, being included at least 4-5 years in processing, were fitted by two-parameter seasonal model, an additional offset and a linear trend. We have got a first insight into the long-time tropospheric influence on the GPS signal, which can be useful for the climatologic studies in the future.

1. Combination approach

We have combined 260 weekly GOP solutions (approx. 5 years), into an unique multi-year solution using the Bernese GPS software V4.2, program ADDNEQ, [HUGENTOBLER et al., 2001]. For all the coordinates, the linear changing rates were introduced as the additional parameters with a priori values from the model NUVEL1-A. For all sites processed less than 1 year, the 'velocity' parameters (the components North, East, Up - N,E,U) were tightly constrained to the a priori values. Concerning the height coordinate change, four variants of tightly constraining were set up, see Table 1.

Table 1. Variants of the height constraining.

Variant	Height constraning (tight)
N-E	all sites
UP-0	sites processed < 2 years
UP-1	sites processed < 4 years
UP-2	sites processed < 2 years + TUBI

Variant N-E thus applies only horizontal velocity estimation, while the most of the vertical velocities were loosly estimated in the variant UP-1.

The ITRF00 coordinates (epoch 2000.0) were introduced as the a priori values. The datum was realized with a free network approach (Helmert transformation using sites BOGO, GRAZ, KIR0, MDVO, ONSA, RIGA, TRO1, ZECK and ZWEN (all the these sites are marked 'N' in Fig.1).

The final combined solution was evaluated in the iterative procedure to eliminate identifiable troublesome events such as:

A) a change of the antenna/radome/receiver,

B) a change in the analysing strategy,

C) a change in the models applied in the processing,

D) an unique physical movement of the station.

In these cases, the coordinates of the respective sites were estimated independently for specified periods. Nevertheless, the velocities of such sites should be setup uniquely in normal case.

2. Results from multi-year solution

There were significant jumps identified in the preliminary coordinate residual time-series. Figure 2 shows already smoothed series of 12 sites (processed at least 4 years), where the coordinate residuals are plotted after applying the velocities in the North, East and Up components (N,E,U). The events on sites were took into account here and they were marked using the vertical arrows. The individually estimated coordinates were identified by an additional char (A,B,C) to the domex. The events were obviously correlated to the known problems described in Section 1. The case A) is related to the sites EIJS, GOPE, GRAZ and MOPI, the case C) (change in the phase center variation model) is related to BOGO, GOPE, MDVO and MOPI. Some other biases, especially for the short time-span, were neither well clarified, nor easily separated due to very short intervals. The influence of the snow and ice (e.g. on MOPI radome) is a typical example and these cases were particularly solved by the pre-eliminating of all site parameters for the problematic weekly solutions. Thus, they were excluded from further stacking.

The station TUBI represents an interesting phenomenon due to the earthquake observed in Turkey in the beginning of the its analysed period (1999, Aug 17). This event, clasified as case D) in Section 1, caused the site position change on the decimeter level. Althought we have included only the observations after the earthquake, the post-earthquake continuous movements were still obvious during a year afterward. The changes are not linear as obvious from the residuals in Fig. 3 (left) when applying a simple NUVEL1-A velocity model. We have thus estimated a piece-wise linear

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trend for TUBI movements by separating the estimated parameters (both coordinate and velocities) into 4 stacking periods: successively – TUBI-A (3 months), TUBI-B (6 months), TUBI-C (6 months) and TUBI (12 months), see Fig. 3 (right). Using this approach we achieved a homogenious residuals in the time series and we have got better view into the evolution of the TUBI movements after this phenomenon. The estimated velocities are shown in Figs 4, 6 and Tables 2, 3.

The Figure 4 compares the absolute velocities from the IGS-00 solution, the model NUVEL1-A and estimated variant N-E (Table 1). Four piece-wise horizontal velocities for TUBI site (solution N-E) are clearly converging to the NUVEL1-A model, but only 1 year afterward! The figure also confirms the appurtenance of site DRAG to the African tectonic plate, showing better consistency than to the Euroasian plate.

The horizontal estimated velocities (relative to the model NUVEL1-A) are displayed in Fig. 6 and Table 2. The stations processed at least 4-5 years resulted in the values between 0-2mm/year (the sites in the core of the network maximally 1mm/year). Nevertheless, there are some tendencies in these horizontal velocities common to the areas like - Caucasus region, Scandinavian peninsula, Iberian peninsula, Russian part of Europe - but corresponding sites were mostly not included in the GOP EUREF subnetwork for a long time and we should wait for more subsolution.

Table 3 compares the variants of the height velocity estimates (see also Table 1). The reasonable results are achieved in variants UP-1, UP-2 rather than UP-0 where the problem is for the TUBI site due to its estimates splitted into 4 short periods. The difference between variants UP-1, UP-2 is not significant, all sites processed at least 2 years were able to estimate vertical velocities in our case. Nevertheless, some of these velocities are quite significant (MAR6 and ZECK, >4mm/year). MAR6 trend might correspond with the central effect of the Scandinavian postglacial rebound.

The Figure 5 summarizes the RMS from the coordinate repeatabilities after applying the velocities. Clearly, the estimation of vertical velocities (UP-0, UP-1 and UP-2) improves significantly the repeatability of the Up component by the sites BOGO, MAR6, ZECK and ZWEN with respect to the N-E variant. Generally, there is no obvious argument in favor of any variant UP-0, UP-1 or UP-2. There is even no difference between variants UP-0 and UP-2, except the TUBI results are worse by UP-0, where Up velocities are evindently not reasonably estimated. The RMS derived from the coordinate repeatabilities can be summarized as 1-2mm for the horizontal components and 3-5mm for the vertical. The exceeding vertical results of 8mm and 6mm can be identified by MDVO and ZWEN, respectively.

Finally, we plan to implement the regular generation of the multi-year solution as the final step of our routine weekly EUREF analysis. Most of this work thus should be automated during the upcoming time.

3. Long-time ZTD trend?

Since 2001, a new official EPN product has been evaluated within the special project for the tropospheric monitoring [Soehne et al., 2002]. It concerns the estimation of the tropospheric zenith total delays (1 parameter/hour for each station), which are combined into the unique EPN solution based on the individual LACs' daily submissions. As recommended at the 3rd EUREF LAC Workshop [Bruyninx, 2001] the coordinates of these daily ZTD products are heavily constrained using corresponding weekly LAC EUREF solution (tightened to IGSyy/ITRFyy realization).

After restoring and reconstraning the GOP archived daily normal equation (files in Bernese format), we extracted the GOP daily ZTDs for the whole period of 5 years backward. The ZTD time series (Fig.7) were fitted with a two parameter seasonal model plus additional initial offset and its trend. Only 12 sites processed at least 4-5 years were used in this cases (MOPI was excluded due to many problems with the height estimation). Interestingly, in all twelve cases we have got a positive trend with the mean value of 1.9mm/year for the ZTD, Fig.8 (right). The maximum of the ZTD is located within 3 days to July 29, Fig.8 (left). Considering that the error in the station height causes about 3 time smaller bias in the corresponding ZTD, we can state that mean -6mm/year change in the height should be present to explain these ZTD trends. Considering the stable influence of the dry troposphere, this trend can be also the effect of increasing the water vapor amount in the atmosphere (i.e. the global warming effect). In the latter case, the value of mean ZTD trend should correspond to 0.2mm of a precipitable water vapor (PWV) increase over a year.

Acknowledgements

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Table 2. Horizontal relative velocities (variant N-E).

Site-id	North [mm]	East [mm]
BOGO 12207M002	+0.00	+0.00
BORK 14268M001	-0.86	+0.56
CHIZ 10020M001	+1.49	+4.97
DRAG 20710S001	-0.23	-4.02
EIJS 13533M001	-0.90	-0.58
GOPE 11502M002	-0.07	-0.26
GRAZ 11001M002	0.65	+0.55
KIR0 10422M001	-2.38	-2.12
LLIV 13436M001	+1.33	+0.64
MALL 13444M001	-1.09	+3.28
MANS 10091M001	+0.61	+1.13
MAR6 10405M002	-1.73	-0.90
MDVO 12309M002	+0.12	-2.45
MOPI 11507M001	+0.76	+0.05
OBER 14208M001	+0.25	+0.27
ONSA 10402M004	-1.23	-0.83
OROS 11207M001	+0.00	+0.00
OSJE 11902M001	+1.29	-0.74
OSLS 10307M001	-2.19	-0.93
POLV 12336M001	+0.00	+0.00
RIGA 12302M002	-0.79	-0.84
SULP 12366M001	+0.00	+0.00
SVTL 12350M001	-2.06	-0.41
TRAB 20808M001	+3.73	+0.36
TRDS 10331M001	-0.95	-2.15
TRO1 10302M006	+1.20	-0.10
TUBI 20806M001A	-41.71	+77.84
TUBI 20806M001B	-13.22	+21.37
TUBI 20806M001C	-9.68	+9.34
TUBI 20806M001	-3.61	+0.60
TUBO 11503M001	+0.00	+0.00
UZHL 12301M001	-0.09	-0.60
VALE 13439M001	-0.60	+5.03
VIS0 10423M001	-1.29	-0.93
ZECK 12351M001	+2.19	+0.07
ZWEN 12330M001	-0.31	-1.51

Table 3. Height velocities for three GOP multi-year variants

Site-id	UP-0 [mm]	UP-1 [mm]	UP-2 [mm]
BOGO 12207M002	-0.01	-0.01	-0.01
BORK 14268M001	—	—	—
CHIZ 10020M001	—	—	—
DRAG 20710S001	—	—	—
EIJS 13533M001	-1.67	–	-1.59
GOPE 11502M002	-1.34	-1.25	-1.31
GRAZ 11001M002	-2.55	-2.47	-2.52
KIR0 10422M001	+0.14	–	+0.18
LLIV 13436M001	-0.31	–	-0.27
MALL 13444M001	—	—	—
MANS 10091M001	-1.25	–	-1.20
MAR6 10405M002	+4.50	+4.59	+4.54
MDVO 12309M002	+0.48	+0.57	+0.52
MOPI 11507M001	-0.16	-0.04	-0.11
OBER 14208M001	-2.69	-2.62	-2.66
ONSA 10402M004	-2.20	-2.11	-2.16
OROS 11207M001	—	—	—
OSJE 11902M001	—	—	—
OSLS 10307M001	—	—	—
POLV 12336M001	—	—	—
RIGA 12302M002	+0.79	+0.89	+0.84
SULP 12366M001	—	—	—
SVTL 12350M001	-0.21	-0.12	-0.17
TRAB 20808M001	+0.63	–	+0.63
TRDS 10331M001	—	—	—
TRO1 10302M006	+1.47	–	+1.52
TUBI 20806M001A	-36.02	–	–
TUBI 20806M001B	-13.84	–	–
TUBI 20806M001C	+30.81	–	–
TUBI 20806M001	-7.55	–	–
TUBO 11503M001	—	—	—
UZHL 12301M001	-0.88	–	-0.81
VALE 13439M001	—	—	—
VIS0 10423M001	+1.09	+1.18	+1.13
ZECK 12351M001	+4.76	+4.86	+4.82
ZWEN 12330M001	-1.50	-1.41	-1.46

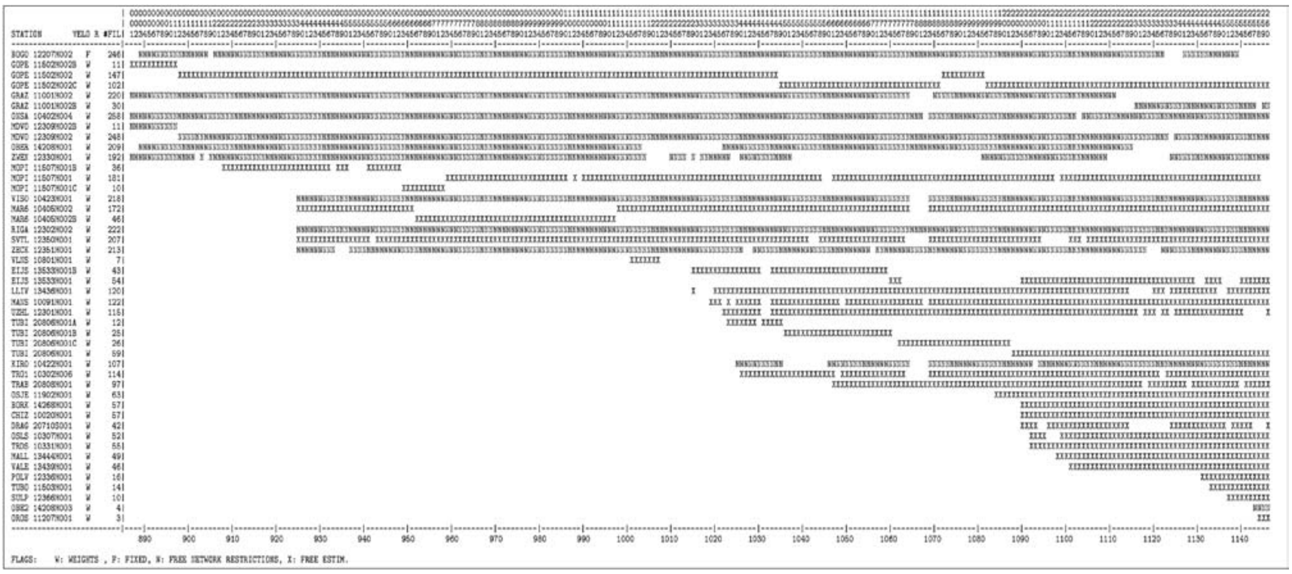

Figure 1. Weekly site inclusion in the multi-year solution (1997-2002).

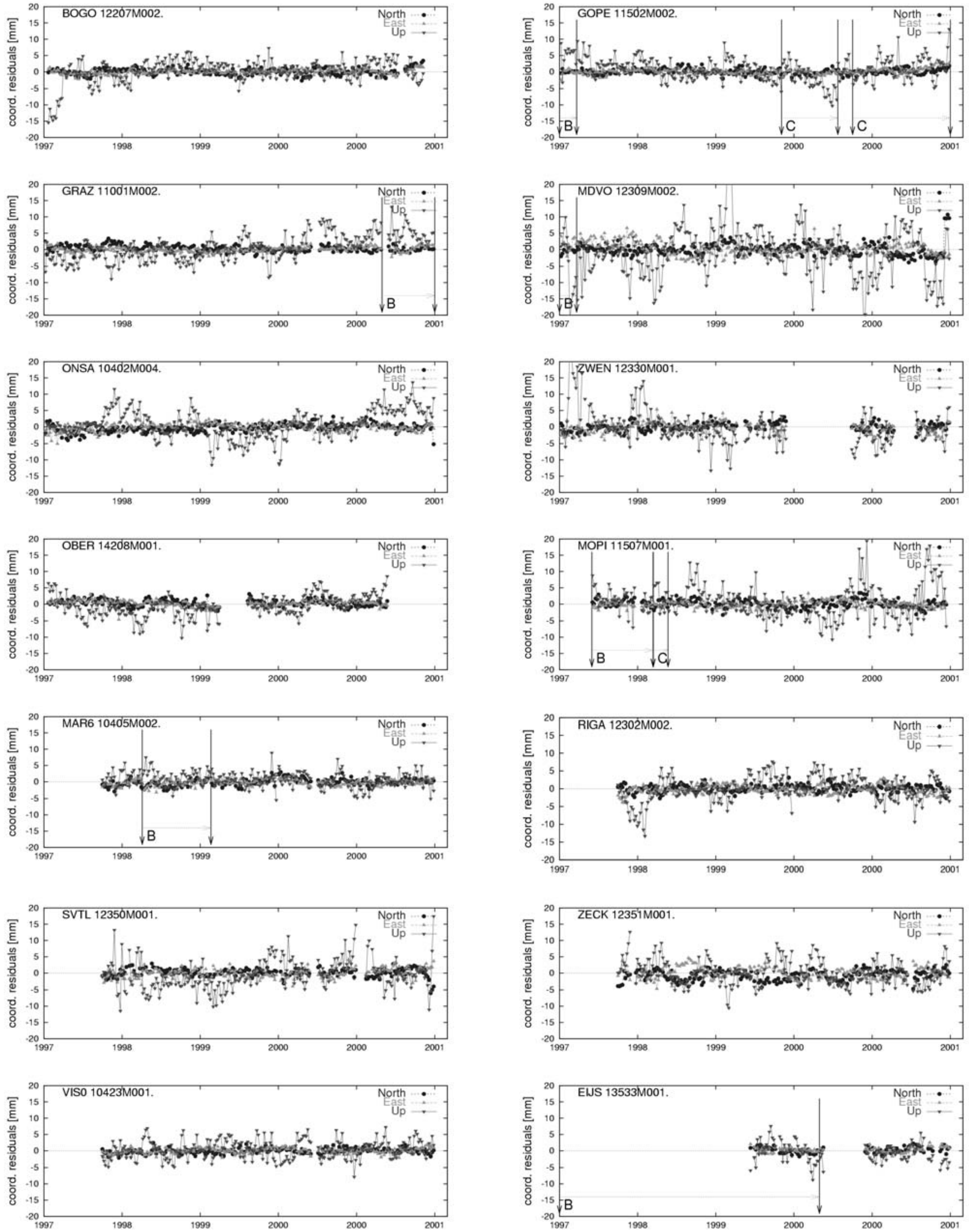

Figure 2. Time-series for 14 sites analysed more than 4 years in GOP. The multiple site identifications for coordinations are also displayed

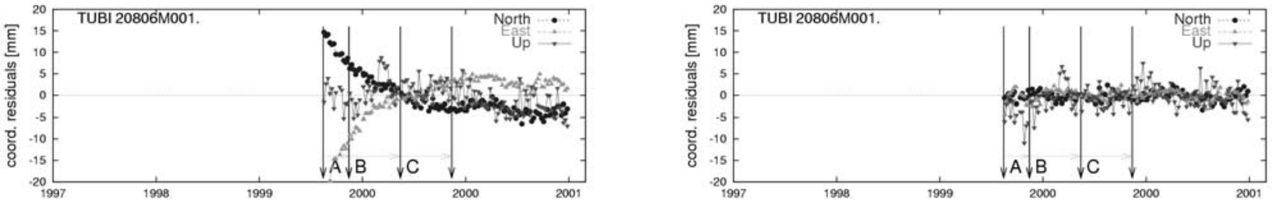

Figure 3. Time-series for TUBI site affected by the strong earthquake in 1999. The left figure shows the only linear trend ('velocity') in the estimated horizontal position during a whole period. The right figure shows the residuals after applying step-wise constant horizontal movements (the velocity components are splitted in ¼ , ¾, 1¼ pieces of years followed after the earthquake).

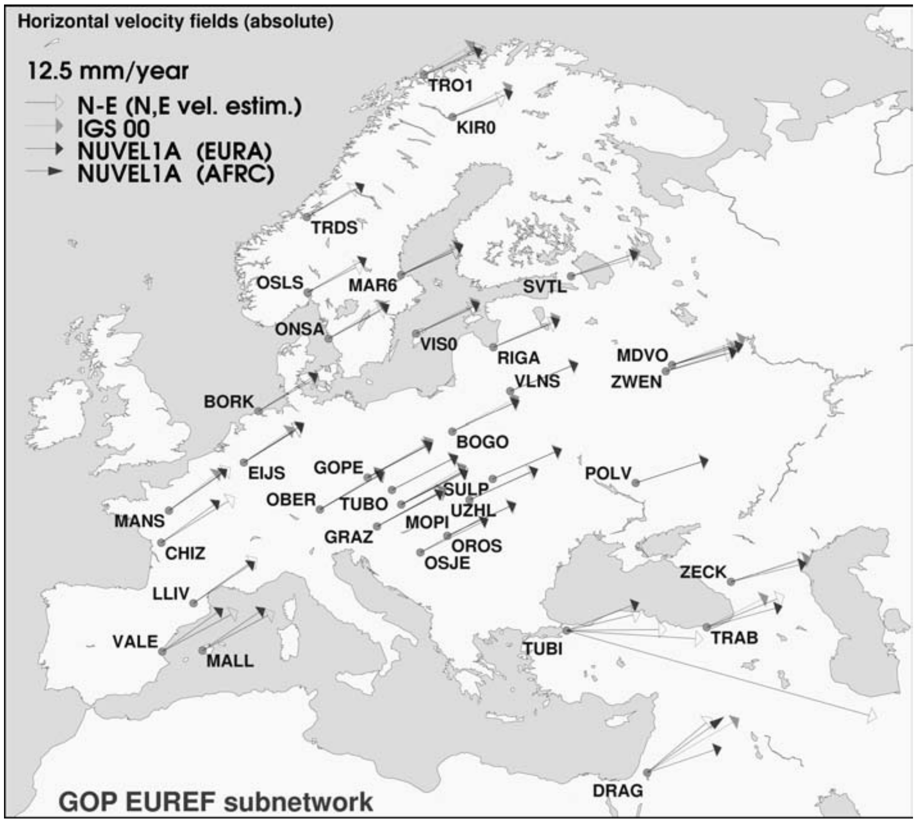

Figure 4. Map of the absolute horizontal velocities for GOP solution (N-E). For comparative purposes, the IGS solution (IGS-00) and the NUVEL1-A model (applying both - EURA and AFRC - plate model for station DRAG) are displayed. Site TUBI shows 4 consequative post-earthquake period velocities.

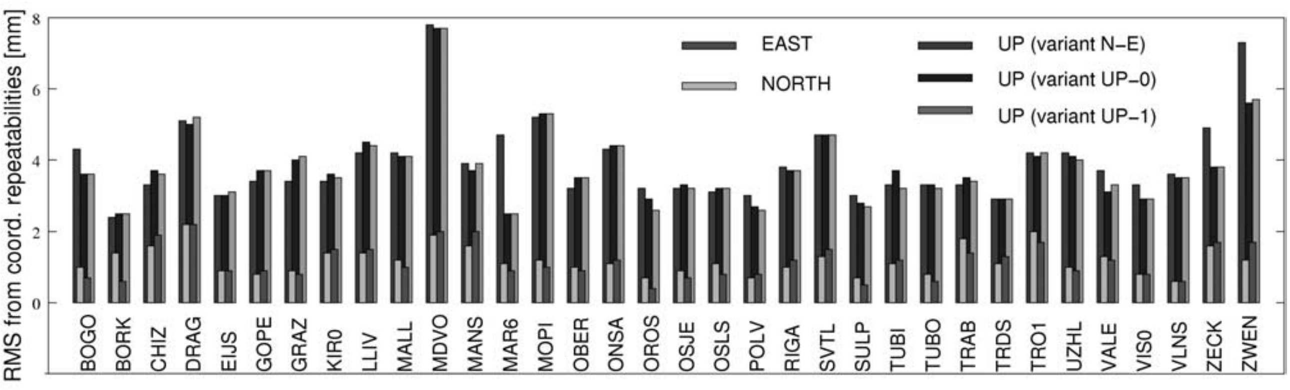

Figure 5. The site coordinate repeatabilities. The North and East components are displayed for all the variants. The Up component for the variant N-E, UP-0 and UP-1 (see Table 1) are shown separately.

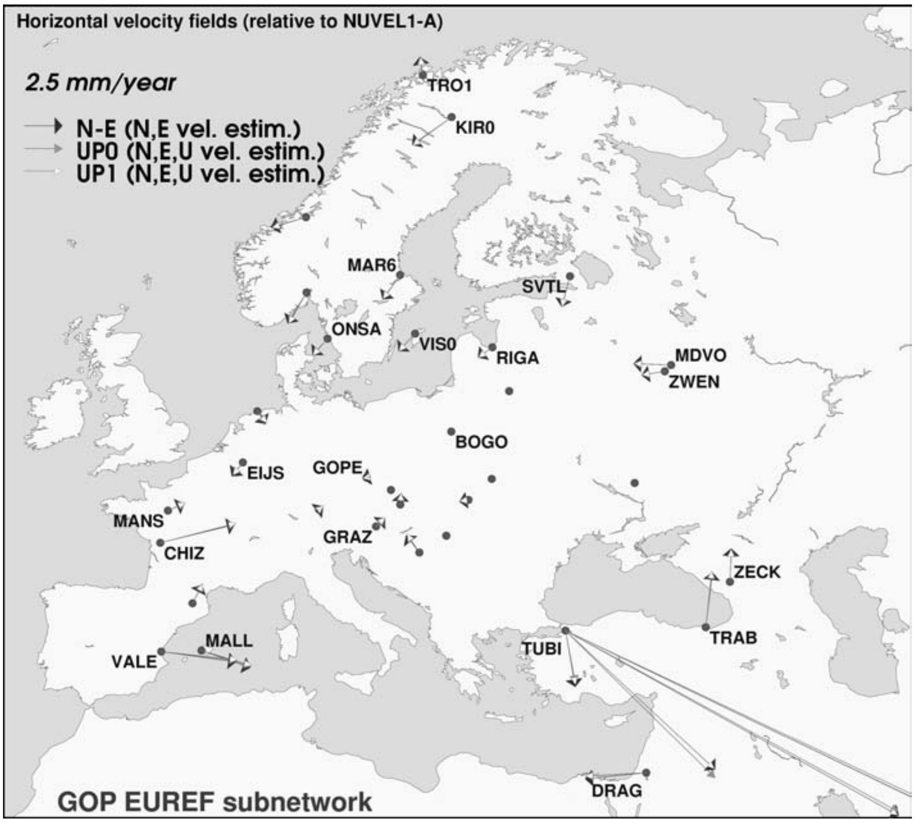

Figure 6. Map of the relative horizontal velocities for three GOP solutions. The reference velocity field is the model NUVEL1-A. Station DRAG is assumed to be located within AFRC plate. Site TUBI velocities demonstrate 4 periods after the earthquake.

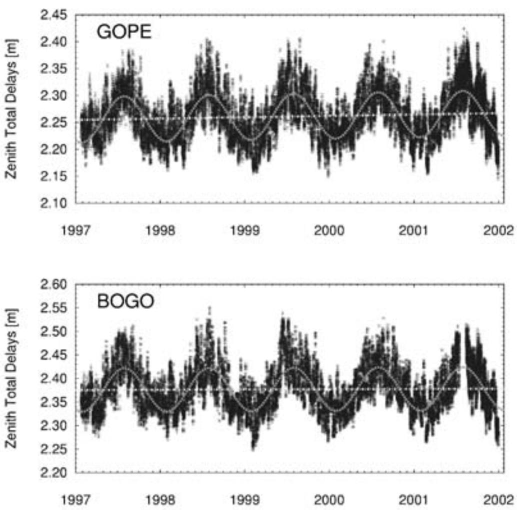

Figure 7. The zenith total delays evaluated during 1997-2002 analysis and its 2-parameter fitting for a seasonal effect. The initial offset and long-time linear trend are estimated simultaneously.

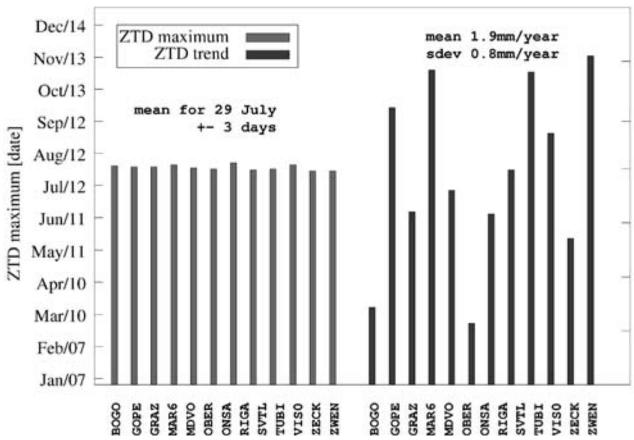

Figure 8. The results for sites analysed at least during the last four years are summarized here. Left columns show the location of the ZTD maximums in the yearly cycle. The right columns show the linear trends for ZTD values.