The First Austrian Velocity Field derived from GPS

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1. Introduction

GPS was used for determining coordinates and their changes in time in Austria and the adjacent regions since 1986. The coverage of the area by campaigns with a geodynamical target is quite good comprising 200 markers within an area of about 150 000 km^2. However, due to lack of money, persons and time only two to three epochs could be measured within 1992 and 2005. Observations before 1992 turned out to be insufficient at all with respect to their precision to detect the expected small movements. The problem was recognized already about 1995 and the policy of geodynamical monitoring turned to build up and run permanent GPS stations. With the establishing of APOS (Austrian Positioning System) the numbers of permanent stations in the Eastern Alps exploded from about 10 in 2000 to presently (August 2006) 78 and will increase to approximately 110 in 2007. The disadvantage from the geodynamical point of view is the short time span because 50% are operating shorter than two years. Nevertheless the inspection of time series demonstrates that velocity estimations can be done with a precision of better than 1 mm/year for most of them. The time series are one result of the network AMON (Austrian Monitoring Network) which is processed at a weekly basis according to the guidelines used for EPN[1] . Given the precision of the time series (average r.m.s. of residuals 1.5 mm lateral, 3 mm vertical), the large seasonal variations and the awkward work to detect blunders in a time series of two to three epochs no campaign data have been used for assisting the velocity estimation. This leads to gaps in the area (Lower Austria, Central Eastern Alps) which are expected to be covered only about 2010. This study is only the first picture of crustal surface movements in the Eastern Alps and their surroundings therefore.

2. Status of AMON

Because the network is still growing Figure 1 gives only the status of the network at time of investigation and must be updated for the new stations. The web-page http://gps.iwf.oeaw.ac.at should be consulted for an actual status. Putting aside some preliminary analysis in 1996 the dedicated network for monitoring the Eastern Alps started in 1999. Apart from the IGS and EPN stations in that region national permanent stations are included. With the start of APOS as a RTK network several stations around the Austrian borders in Germany, Italy, Slovenia and Switzerland are included. Stations in the Czech Republic, Hungary and Slovakia will follow. Most of the RINEX data of the stations are not public, the analysis results can be retrieved from ftp://olggps.oeaw.ac.at/pub/products/wwww (GPS week) however. As usual coordinates, zenith delays and SINEX files are the main products at a daily basis. For the adjustment the Bernese Software (BSW version 4.2, version

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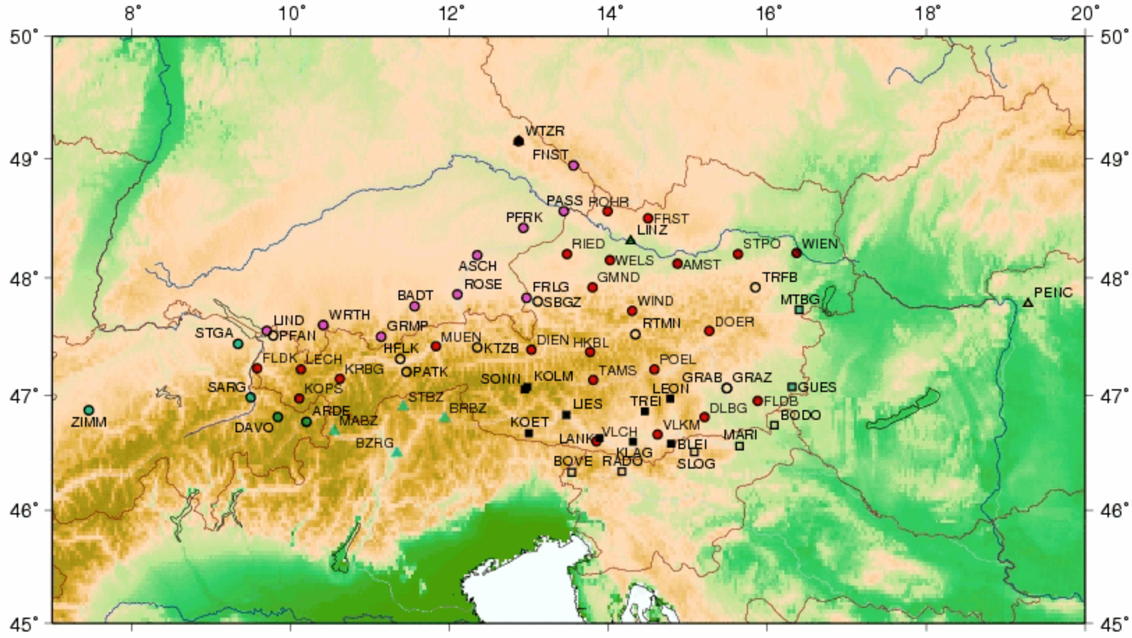
[1] Guidelines for EPN Analysis Centres, December 3 2002, http://epncb.oma.be/_organisation/guidelines.

5.0 is expected to be used since autumn 2006) was used. The alignment of the network is done by using the coordinates and velocities of ITRF2000 for GRAZ. Because of the problems at these stations in 2005 the alignment was changed to HKBL (Hauser Kaibling) after inspecting the time series for reliability. The alignment is updated every year to get stable coordinates every year for comparison (e.g. ITRF2000 epoch 2006.0). Phase eccentricities from IGS are used together with NGS values for those antennas which are not included into the official IGS file. No individual corrections for antennas and domes are yet applied. All markers have domes numbers, the non-official marker numbers can be clearly distinguished by their “fantasy numbers”, e.g. 00000S001.



World Stress Map Rel. 2004
Heidelberg Academy of Sciences and Humanities
Geophysical Institute, University of Karlsruhe

Figure 1. GPS permanent stations of AMON (June 2006).

3. Velocity Estimation

For velocity estimations only the weekly results and BSW 5.0 are used. The analysis starts by transforming the normal equations from their BSW 4.2 to the BSW 5.0 format removing the constraints. After some tests at the beginning it was found that most of the offsets computed in the EPN Time Series Project have to be applied to get rid of the jumps detected in the time series. Also most of the outliers to be removed were found to be the same as in the AMON screening. Therefore the values of http://www.epncb.oma.be/_dataproducts/timeseries ->Cleaned timeseries (before June 2006) were used. This implies that also the EPN coordinates and velocities in ITRF2000 for the reference stations should be applied. Consequently the values of GRAZ, HFLK, PENC, PFAN, WTZR and ZIMM were taken from http://www.epncb.oma.be/_trackingnetwork ->Station coordinates. Because this set of minimum constraints (Altamimi 2004) to ITRF2000 (EPN version) in coordinates and velocities showed to be a little bit distorted by concentrating most stations in the West STPO was introduced as an old station with a very stable time series. Its coordinates and velocity were estimated first and then introduced. The procedure of velocity estimation is done at

OLG (Observatory Lustbuehel Graz) some times a year. The process described below is always the same. The results refer to the analysis of July 2006.

The first step is the stacking of normal equations by applying the offsets and outlier removals already known. The reference is kept by the reference stations applying a Helmert translation for each week. The residuals of the first analysis are checked manually by inspecting the graphics of the time series. An outlier is defined as an **isolated** value which deviates 10 mm laterally and/or 20 mm vertically from the time series. The definition has to be restricted to isolated weekly results because the seasonal variations of some stations exceed the threshold. Cutting away all values above the threshold would distort the frequency analysis heavily. The difference between jumps and a series of outliers was difficult to define. For discerning between a pair of jumps (one forth, one back) and a series of outliers (e.g. snow coverage at wintertime) simply the experience with the station was used. Fortunately only two stations were to be found indecisive (LEON, LINZ). In one case (LEON) the time span between the pair of jumps was decided to treat as an outlier for unknown reasons, in the other case nothing was done, with the risk of getting wrong velocities which was promptly the case. After applying the new corrections together with the old ones the rerun results into improved results. The cleaned time series together with the estimated velocities can be seen at the web page http://gps.iwf.oeaw.ac.at. A major concern is a reasonable estimation of the accuracy of the velocities. The BSW internal error estimations are much too optimistic giving 0.01mm/year for stations not too young. Lacking the CATS software which estimates the r.m.s. of the EPN velocities one can only guess that also the AMON velocities have error values of ±0.1-0.5 mm/year.

4. Comparison and Interpretation

All velocities are almost parallel reflecting the fact that the region is situated at the “stable” part of the Eurasian plate. To get a better insight into the movements and probably to find some intraplate movements with a geophysical background the ITRF2000 rotation of Eurasia (Altamimi 2002, Kierulf et al. 2003) was removed. The remaining velocities can be interpreted as residual velocities within ETRS89. Figures 2 (lateral) and 3 (vertical) show the velocities of 63 stations, the values are listed in Table 2[2]. The differences between the velocities estimated by EPN and those from OLG in Table 1 show an agreement (mean difference) within 0.2 mm/year laterally and 0.6 mm/year vertically for seven sites. It is assumed that this will be approximately the expected precision of the estimation. On the other hand many residual velocities show values even below these assumed one sigma values. To be sure a signal exceeding the values of 0.6/1.8 mm/year (= 3 sigma) should only be interpreted as a real movement. A group of stations younger than two years with quite big velocities (e.g. BOVE, RADO, SLOG, TAMS etc) should not be considered until the values are confirmed in the future. The only exemption is KOPS where it can already be proved that the station undergoes a local movement. The older twin on a different pillar did not show up with such velocities but fitted very well to the surrounding stations. The velocity differences on a distance of 30 meters are 6.6/2.8/-1.3 mm/year which confirmed the personal communication that the pillar was built within an artificial hill and may not reach bedrock. The remaining largest velocities of GRMP and MUEN seem to be also local after first investigations. The highest vertical velocities apart from the stations already mentioned seem also to be connected to local problems, especially equipment changes.

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[2] There are 10 more stations, but most of them too young, which means below half a year. Two twin stations (GRAB, KOPS) are not listed too.

For the remaining small to tiny values a geophysical interpretation seems to be too early. Laterally one might see four clusters of movements. The Alpine Forelands in the North are Eurasian stable together with the Bohemian Massif. The Danube valley in Austria might experience a small movement to the East, the Pannonian Basin. A similar movement could be seen also in the Southeast. The Alps themselves seem to move generally to the North (between Northwest and Northeast). All these movements are in the order of 1-2 mm/year and therefore very small. It is astonishing that both zones of higher seismic activity (Inn Valley, faults at the Eastern fringe of the Alps) do not show up with larger values than 1 mm/year. Vertically there are mainly two groups. In the West there is small rise of 1-2 mm/year which might express the uplift of the Alps. The stations of the Danube valley are slowly going down by 1 mm/year. This may have reasons because all stations are connected to the Alluvium. The station WIEN was proved to be affected by the digging of a new subway tunnel removing much water from the underground. In that case GPS-derived velocities, gravity and levelling showed the same rate.

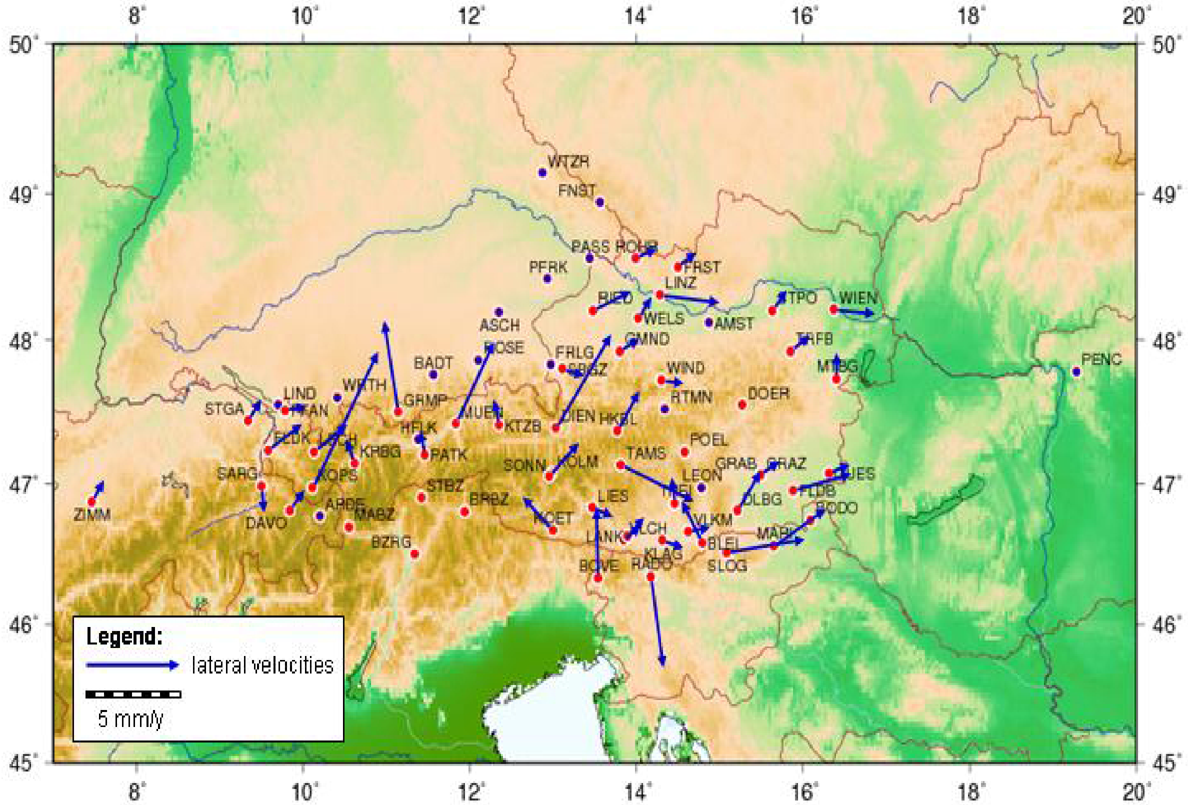

Figure 2. Residual velocities of GPS permanent stations of AMON (lateral).

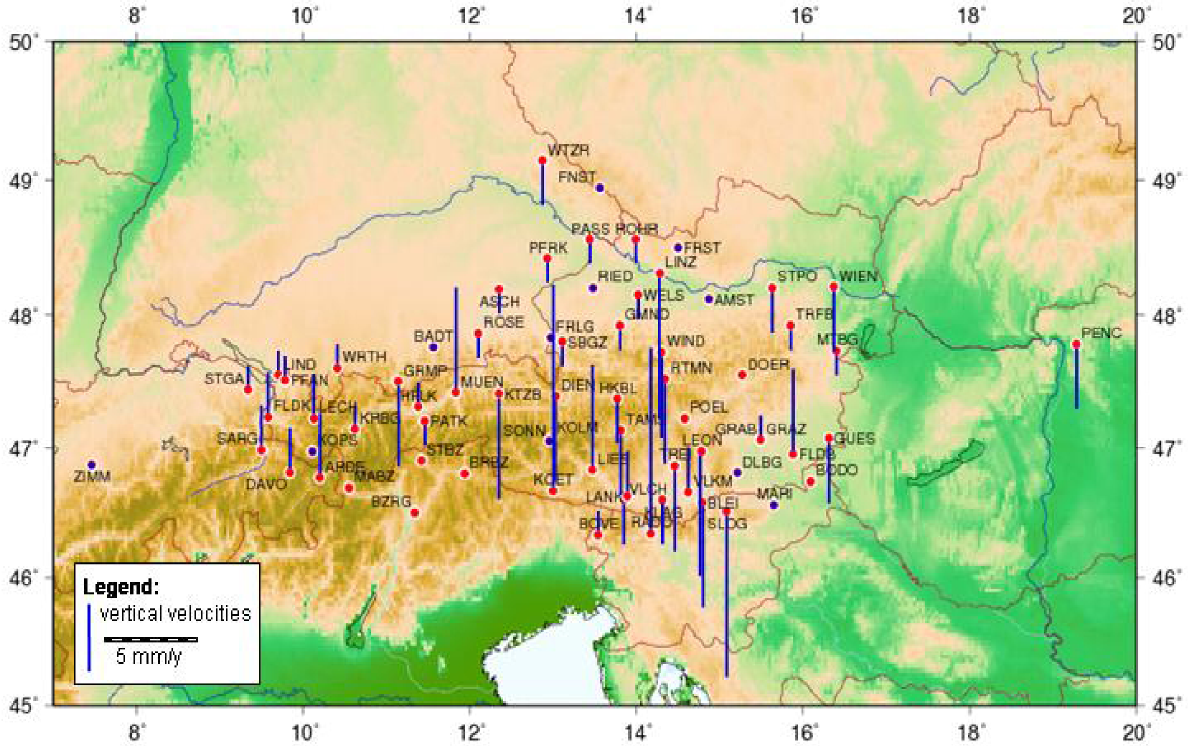

Figure 3. Residual velocities of GPS permanent stations of AMON (vertical).

5. Conclusions

The network AMON can be seen as a densification of EPN for the Eastern Alps. For six years the analysis was done in accordance to the guidelines of EPN. For velocity estimations the network results have been aligned to EPN as best as possible. As a result the estimated velocities are close to those of EPN with an estimated accuracy of better than 0.5mm/year. The relative short time span of many stations and the expected small intraplate movements postpone a detailed connection to geodynamic models to the future. All large movements can be derived from local effects or are at least strongly suggested to be connected to. Generally it can only be stated that the Eastern Alpine Zone is moving against its Northern Forelands with about 1-2 mm/year. It can be expected that within some years a dense (30 km) velocity field can be derived with about 0.5 mm/year accuracy.

6. References

Altamimi, Z., 2002, Boucher, C., The ITRS and ETRS89 Relationship: New Results from ITRF2000, EUREF Publication No. 10, Mitteilungen des Bundesamtes für Kartographie und Geodäsie Band 23, Frankfurt/Main, pp. 49-52.

Altamimi, Z., 2004, Towards a dense European velocity field, EUREF Publication No. 13, Mitteilungen des Bundesamtes für Kartographie und Geodäsie Band 33, Frankfurt/Main, pp. 84-88.

Kierulf H. P., H-P Plag, O. Kristiansen and T. Nørbech, 2003, Towards the True Rotation of a Rigid Eurasia, EUREF Publication No. 12, Mitteilungen des Bundesamtes für Kartographie und Geodäsie Band 29, Frankfurt/Main, pp. 118-124.

STATION	DV_N [MM/A]	DV_E [MM/A]	DV_U [MM/A]
GRAZ 11001M002	0.4	0.4	-0.6
HFLK 11006S003	-0.5	-0.2	1.3
PENC 11206M006	0.4	-0.7	-0.3
PFAN 11005S002	0.0	0.1	-0.7
SBGZ 11031S001	-0.2	0.0	-0.5
WTZR 14201M010	0.0	-0.1	-1.1
ZIMM 14001M004	0.3	0.1	-0.2

Table 1. Differences between EPN and AMON velocities at common sites

STATION	V_N [MM/A]	V_E [MM/A]	V_U [MM/A]	AGE
AMST 00000S001	0.2	-0.2	-0.1	>1 year
ARDE 00000M000	0.3	0.1	2.8	>2 years
ASCH 00000S001	0.1	0.0	-0.9	>2 years
BADT 00000S001	-0.3	0.2	0.3	>2 years
BLEI 00000S002	1.6	-0.9	-5.0	>3 years
BOVE 00000S001	2.9	-0.1	0.6	>1 year
DAVO 00000M000	0.4	-0.3	2.1	>2 years
DIEN 00000S001	4.5	2.9	-4.1	<1 year
DLBG 00000S001	1.3	0.8	-0.2	>3 years
FLDB 00000S001	0.9	3.3	4.4	>1 year
FLDK 00000S001	1.0	1.4	2.4	>3 years
FNST 00000S001	-0.2	-0.1	0.1	>1 year
FRLG 00000S001	0.2	-0.1	0.3	>2 years
FRST 00000S001	0.5	0.7	0.0	>1 year
GMND 00000M000	0.7	1.1	-0.5	>3 years
GRAZ 11001M002	0.8	1.2	1.0	>10 years
GRMP 00000S001	3.5	-0.7	-4.3	>2 years
GUES 11045M001	0.2	0.5	-2.9	>3 years
HFLK 11006S003	0.2	0.3	0.6	>10 years
HKBL 11039S001	1.4	0.8	-2.1	>5 years
KLAG 00000S002	-0.3	-1.1	-2.2	>3 years
KOET 11046M002	1.3	-1.3	10.4	>3 years

KOPS 00000M002	6.5	3.4	0.3	>1 year
KRBG 11043S001	1.3	-0.5	1.1	>4 years
KTZB 11038S001	1.4	-0.4	-5.2	>2 years
LANK 00000S002	0.5	0.6	-1.8	>2 years
LECH 00000S001	1.1	1.4	2.0	>3 years
LEON 00000S002	0.2	0.3	-6.3	>2 years
LIES 00000S002	-0.3	-0.8	4.8	>2 years
LIND 00000S001	-0.1	0.0	1.1	>2 years
LINZ 11033S001	-0.3	-2.7	6.7	>2 years
MARI 00000S001	1.6	2.5	-0.2	>2 years
MTBG 11030M001	0.5	0.0	-1.4	>3 years
MUEN 00000S001	3.6	1.8	5.1	>2 years
PASS 00000S001	-0.2	-0.2	-0.6	>2 years
PATK 11029S001	1.3	-0.4	-1.4	>10 years
PENC 11206M006	0.3	-0.2	-2.5	>10 years
PFAN 11005S002	0.1	0.8	0.7	>10 years
PFRK 00000S001	0.0	0.3	-0.5	>2 years
RADO 00000S001	-3.9	0.6	8.9	<1 year
RIED 00000M000	0.9	1.9	-0.4	>3 years
ROHR 00000M000	0.4	0.9	-0.6	>3 years
ROSE 00000S001	-0.2	0.1	-1.0	>2 years
RTMN 11037S001	0.1	-0.1	-3.6	>5 years
SARG 00000M000	-0.6	0.1	1.8	>3 years
SBGZ 11031S001	-0.2	0.7	-0.7	>6 years
SLOG 00000S001	0.6	4.4	-7.6	<1 year
SONN 00000S002	1.4	1.4	-0.3	>2 years
STGA 00000M000	0.5	0.3	1.3	>2 years
STPO 11041S001	0.4	0.3	-2.2	>5 years
TAMS 00000S001	-1.8	4.0	-3.3	<1 year
TREI 00000S002	1.3	-0.2	-4.3	>2 years
TRFB 11047M001	0.8	1.0	-0.6	>2 years
VLCH 11036S001	0.8	0.8	1.6	>5 years
VLKM 11040S001	0.3	1.4	2.2	>5 years
WELS 11044M001	0.5	0.3	-1.4	>4 years
WIEN 11035S001	-0.1	1.7	-3.1	>5 years

WIND 00000S001	-0.1	-1.2	-3.6	>2 years
WRTH 00000S001	0.2	0.3	1.4	>2 years
WTZR 14201M010	0.1	-0.2	-2.2	>10 years
ZIMM 14001M004	0.7	0.4	0.1	>10 years

Table 2. Residual velocities (ITRF2000 rotation of Eurasia removed) of AMON sites