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The Intra-Plate Velocities of GPS Permanent Stations of the Eastern Alps

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Abstract

Since 2000 the GPS (Global Positioning System) permanent stations in Austria are monitored at a weekly basis, applying the international guidelines of analysis centres of IGS [1] (IGS = International GNSS Service, GNSS = Global Navigation Satellite System) and EPN (European Permanent Network). The number of stations was about 80 at the beginning of 2007. Station velocities have been derived from coordinate time series by taking into account offsets and detecting outliers. The estimated velocities have a precision of 1 mm/year laterally and 1–3 mm/year vertically. These velocities are reduced by the rotational velocity of the Eurasian Plate, derived from ITRF2000 (International Terrestrial Reference Frame 2000) [3], in order to investigate intra-plate movements. Apart from some local movements the velocities are in the range of 0–3 mm/year, but can already be grouped into different clusters. The movement of the Alpine Forelands is identical to the rotation of the Eurasian Plate whereas the region between the Alps and the Dinarides seems to undergo an eastward movement. Within the Eastern Alps the situation is still unclear due to some reasons, e.g., young stations, poor coverage and local movements.

Kurzfassung

Seit 2000 werden GPS (Global Positioning System) Permanent Stationen nach den internationalen Richtlinien der Analysezentren IGS [1] (IGS = International GNSS Service, GNSS = Global Navigation Satellite System) und EPN (European Permanent Network) wöchentlich ausgewertet. Die Anzahl der Stationen betrug 80 zu Beginn des Jahres 2007. Von den Zeitreihen der Koordinaten wurden Geschwindigkeiten unter Berücksichtigung von Sprüngen und Erfassung von Ausreißern abgeleitet. Die geschätzten Geschwindigkeiten weisen eine Präzision von 1.0 mm/Jahr lateral und 1–3 mm vertikal auf. Um die Bewegungen innerhalb einer Platte untersuchen zu können, wird die Rotationsgeschwindigkeit der Eurasischen Platte, welche vom ITRF2000 (International Terrestrial Reference Frame 2000) [3] hergeleitet wurde, von den geschätzten Geschwindigkeiten abgezogen. Abgesehen von einigen lokalen Bewegungen bewegen sich die Geschwindigkeiten in einem Schwankungsbereich von 0 bis 3 mm/Jahr, können aber bereits in verschiedene Gruppen unterteilt werden. Die Bewegung des Alpinen Vorlandes ist identisch der Rotation der Eurasischen Platte, wohingegen die Region zwischen den östlichen Alpen und den Dinariden einer Bewegung nach Osten zu folgen scheint. Innerhalb der Ostalpen ist die Situation aus verschiedenen Gründen, wie z.B., dem geringen Alter mancher Stationen, der mangelhaften Flächendeckung und lokaler Bewegungen, nach wie vor unklar.

1. Introduction

The European Terrestrial Reference System ETRS89 is derived from the International Terrestrial Reference System (ITRS) by removing the rotation of the Eurasian Plate. It was designed to keep the changes of the coordinates within an acceptable range for national mapping agencies. Austria adopted the system in 2003. The realization of ETRS89 is derived from the ITRS realizations (e.g. ITRF2000). Austria covers a part of the Eurasian Plate, which cannot be considered as totally stable. Significant deviations from the rotation of this plate show up in some parts. The residual motion is less than 10 mm/year, but can already be determined. The following article describes the present state of velocity estimation from about 80 GPS permanent stations in and around the Eastern Alps. The GPS network is still being augmented. Many stations are not older than two years. Hence, former results [4] need to be refined. However, there is already an overview of the situation, providing a range of possible intra-plate velocities in Austria and its neighbourhood. Two questions should be answered. First, how will the Austrian reference network be deformed by station velocities for the next decade, and second, is it possible to detect the causes of these residual velocities, related to the geokinematic situation of the Eastern Alps.

2. Coverage

The AMON (Austrian Monitoring Network) consists of about 80 stations in Austria, Germany, Switzerland, Italy, Slovenia, Hungary, Slovakia and the Czech Republic. Table 1 shows an overview of the station owners and the number of stations under their responsibility. AMON includes several different types of antennas and radomes. Further information can be found at ([10] → AMON network).

The GPS stations of the AMON are divided in two groups in Figure 1. Those marked with white squares were used for velocity estimations, as they cover many years of observations and show very stable velocities.

Agency, Country	Link	#
BEV, AT	http://www.bev.gv.at	29
ÖAW, AT	http://www.oeaw.ac.at	4
BLVA, DE	http://www.geodaten.bayern.de/bvv_web/blva	10
KELAG, AT	http://www.kelag.at	9
Swisstopo, CH	http://www.swisstopo.ch	5
BEWAG, AT	http://www.bewag.at	2
Geodetska Uprava, SI	http://www.gu.gov.si	5
BKG, DE	http://www.ifag.de	1
LINZ AG, AT	http://www.linzag.at	1
FÖMI, HU	http://www.fomi.hu	4
Ufficio Geodetico, IT	http://www.provincia.bz.it/catasto-librofondiario/4103/geodetico.htm	4
GKU Bratislava, SK	http://www.gku.sk	2
Zememericky Urad, CZ	http://geoportal.cuzk.cz	2

Table 1: Overview of the station owners

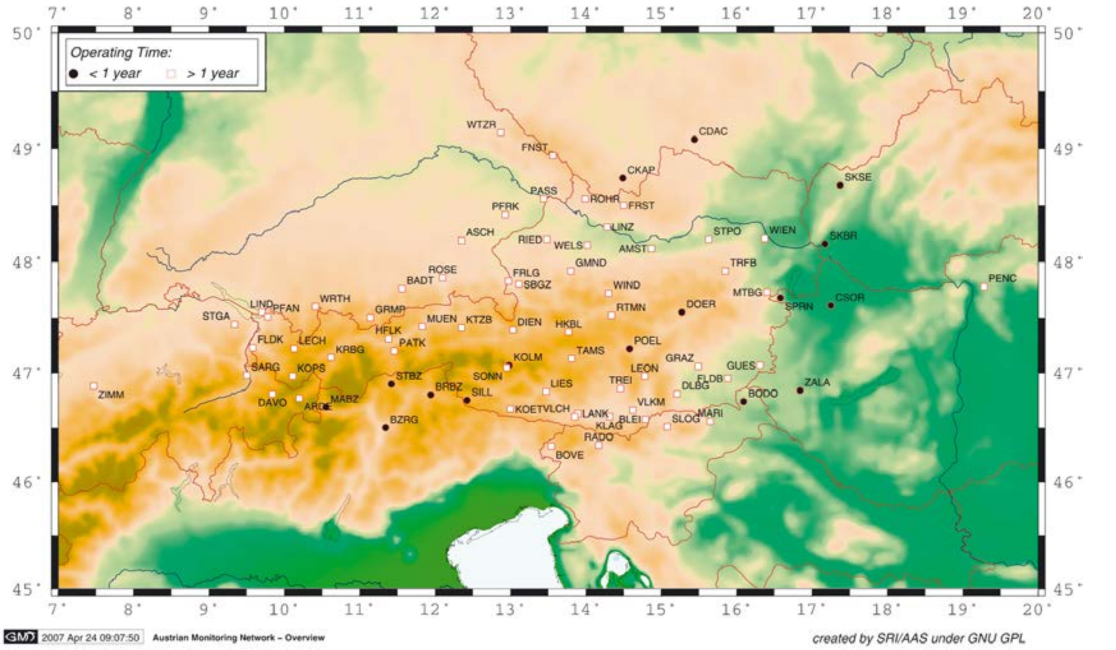

Figure 1: GPS Stations used for velocity estimation (white squares)

< 0.5 year	0.5 – 1 year	1 – 2 year	> 2 years
BADT (2), CDAC, CKAP, CSOR, SILL, SKBR, SKSE, SPRN, ZALA	BODO, BRBZ, BZRG, DOER, KOLM, MABZ, POEL, STBZ	AMST, BOVE, DIEN, FLDB, FRST, KOPS (1), RADO, SLOG, TAMS	ARDE, ASCH, BADT (1), BLEI, DAVO, DLBG, FLDK, FNST, FRLG, GMND, GRAB, GRAZ, GRMP, GUES, HFLK, HKBL, KLAG, KOET, KOPS (2), KRBG, KTZB, LANK, LECH, LEON, LIES, LIND, LINZ, MARI, MTBG, MUEN, PASS, PATK, PENC, PFAN, PFRK, RIED, ROHR, ROSE, RTMN, SARG, SBGZ, SONN, STGA, STOPP, TREI, TRFB, VLCH, VLKM, WELS, WIEN, WIND, WRTH, WTZR, ZIMM

Table 2: Age of the stations

Stations, which are in operation for less than one year show velocities strongly varying in size and direction. For this reason these stations marked by black filled circles will only be considered for future velocity estimations. Table 2 shows the age of the stations.

3. Velocity Estimation

Estimation of station velocities follow a similar procedure used in the Time Series Project of EPN [11]. Weekly solutions, derived from daily solutions, were stacked together to form the "RAW Time Series". Then outliers and offsets were defined. Outliers, which are characterized by a single value, which differs from the neighbouring weeks by more than 10 mm, were removed. Offsets are estimated if more than 10 consecutive weeks differ from the previous ones. According to the average r.m.s. of the weekly repeatability, which is about one millimetre for the lateral and about 2.5 mm for the vertical component, it was possible to detect offsets down to two millimetres. All normal equations were used since the start of AMON in 2001. This implies that the normal equations processed with the Bernese Software (BSW) version 4.2 [5] had to be first converted into the format of BSW 5.0. For the a priori changes (outliers, offsets, dome numbers, split of time series) a file with extension .STA was created and updated for each velocity computation. The software needs this file to be able to consider the changes in the processing. Outliers and offsets of the EPN stations were taken and checked to see if an improvement occurred in the time series. Most of them are applied, however, for the stations GRAZ, HFLK and LINZ they had to be modified. Additionally the changes and deletions already known by the OLG (Observatory Lustbuehel Graz) were added. As a reference, the ITRF2000 coordinates/velocities were chosen for the stations GRAZ, HFLK, WTZR and ZIMM. To strengthen the network, the EPN coordinates of PENC and PFAN were added in the same system, because jumps at those stations are already applied. To balance the reference for the area of Austria a nine years old station with a very smooth time series, STPO (St. Pölten), was added in the East. Their respective coordinates and velocities were estimated, while the a priori values were only used for the datum definition.

The first combination of normal equations leads to time series, which are comparable to the type of "CLEANED Time Series" of EPN. Afterwards the series were checked for new outliers and offsets, and for revisions of former changes. If necessary the changes were introduced and the combination was repeated. From a total of 78 stations, those including less than 53 weeks of observations were removed from the investigations. Most of the stations experience seasonal changes in their coordinates, especially in the height component. Because the amplitudes can reach 20 mm, it is unadvisable to consider their velocities, yet. Therefore, 14 stations plus the test station WIEB were removed from investigation, thus leaving 63 stations providing observations for velocity calculation. The still growing network makes it necessary to repeat the combination. Presently a cycle of 2–3 months seems to be sufficient to monitor the stations for outliers and offsets. A yearly velocity estimation should be sufficient to integrate additional stations into a reliable velocity field. The lower time limit where a station velocity can be seen as well determined amounts to one year. Compared to earlier studies [7] this shows an improvement of the estimation in the last years due to this investigation of a regional area, the station densification and the modernization of analysis strategies.

4. Results

For the 63 stations mentioned above the rotation of the Eurasian Plate defined by ITRF2000 was removed thus clearly revealing the differences of velocities over the network area. For comfort the residual velocities are called "intra-plate velocities" without preconditioning the tectonic interpretation. For some stations it is possible to check the derived velocities from other references, like ITRF2000, ITRF2005 and EPN. For that reason the full values are compared in Table 3. It should be noted that the system velocities (−0.2/0.1/−1.8 mm/year) of ITRF2005 [9], relative to the other systems are removed.

Apart from the SBGZ velocity in ITRF2000, which is ostensibly obsolete, the values in Table 3 are very similar. The differences at the 1mm/year level are mostly caused by the application of offsets to the coordinate time series. As the seven stations are at least observing since 1999, the length of the time series has almost no influence. The offsets may affect the time series considerably, e.g., when the equipment is changed triennially.

STATION	VELOCITIES [MM/YEAR]						SYSTEM
	VEL_X	VEL_Y	VEL_Z	VEL_N	VEL_E	VEL_U	
GRAZ 1001M002	−16.4	18.9	9.8	14.5	22.61	−0.2	AMON
	−16.9	18.2	8.9	14.4	22.1	−1.3	ITRF2005
	−17.6	18.1	8.2	14.5	22.1	−2.3	ITRF2000
	−14.9	19.2	10.8	14.1	22.5	−2.3	EPN
WTZR 14201M010	−15.8	17.4	8.5	14.3	20.5	−1.1	AMON
	−15.3	17.4	9.6	14.6	20.4	0.0	ITRF2005
	−15.7	17.2	8.7	14.4	20.3	−0.9	ITRF2000
	−15.7	17.2	8.6	14.3	20.3	−1.0	EPN
ZIMM 14001M004	−13.0	18.8	10.9	15.1	20.3	0.8	AMON
	−12.8	18.2	10.9	15.0	19.7	0.9	ITRF2005
	−13.8	18.5	10.0	15.1	20.1	−0.4	ITRF2000
	−13.1	18.8	10.6	14.9	20.3	0.5	EPN
HFLK 11006S003	−13.7	18.6	10.3	14.2	20.9	1.0	AMON
	−15.0	18.2	10.6	15.4	20.8	0.3	ITRF2005
	−13.4	18.7	11.1	14.5	21.0	1.8	ITRF2000
	−15.5	18.5	9.4	14.9	21.2	−0.9	EPN
PENC 11206M006	−18.4	17.3	7.3	13.5	22.4	−2.4	AMON
	−18.1	17.3	7.6	13.5	22.3	−2.0	ITRF2005
	−16.6	18.1	8.2	12.7	22.6	−0.4	ITRF2000
	−18.5	17.6	6.9	13.3	22.7	−2.7	EPN
SBGZ 11031S001	−14.9	18.8	9.4	13.9	21.7	0.1	AMON
	9.7	25.8	41.7	16.7	22.9	41.2	ITRF2000
	−15.4	18.6	9.1	14.1	21.6	−0.5	EPN
PFAN 11005S002	−13.3	19.0	10.5	14.4	21.0	1.1	AMON
	−13.7	18.7	11.2	15.2	20.8	1.3	ITRF2000
	−13.1	19.1	10.8	14.4	21.0	1.4	EPN

Table 3: Comparison of station velocities of ITRF2005, ITRF2000 and EPN with AMON

AMON … Results from the OLG network AMON
EPN … Results from the European Reference Frame (EUREF) [6] Permanent Network, Special Project Time Series
ITRF2000 … Results from the International Earth rotation and Reference systems Service (IERS) solution of ITRF2000
ITRF2005 … Results from IERS solution of ITRF2005

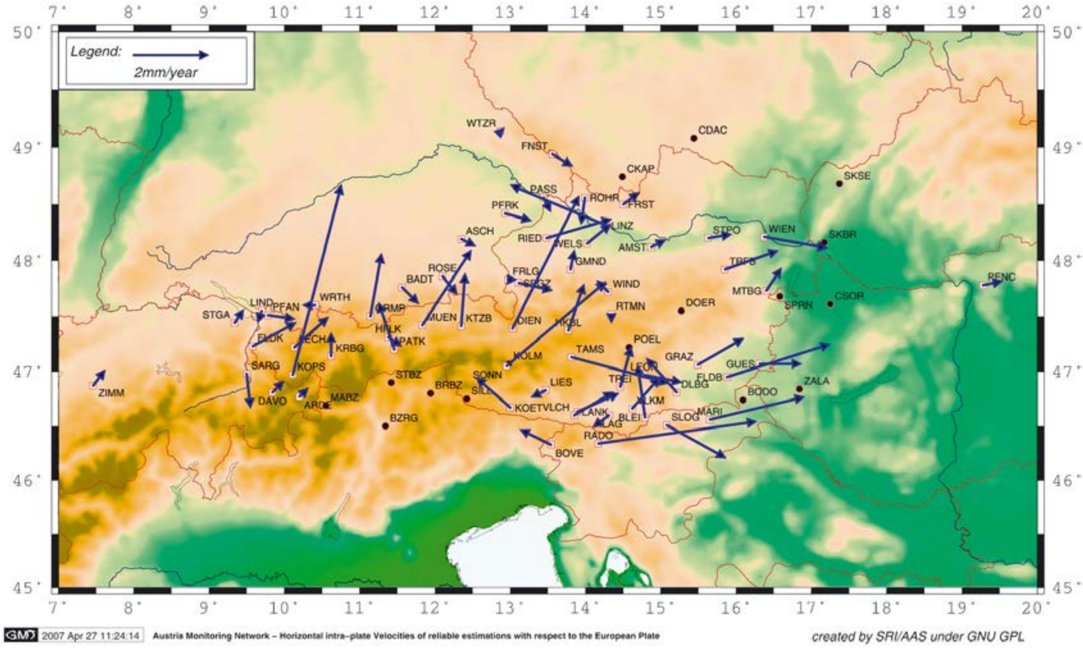

Figure 2: Horizontal velocities of reliable estimations (AMON), with respect to the Eurasian Plate

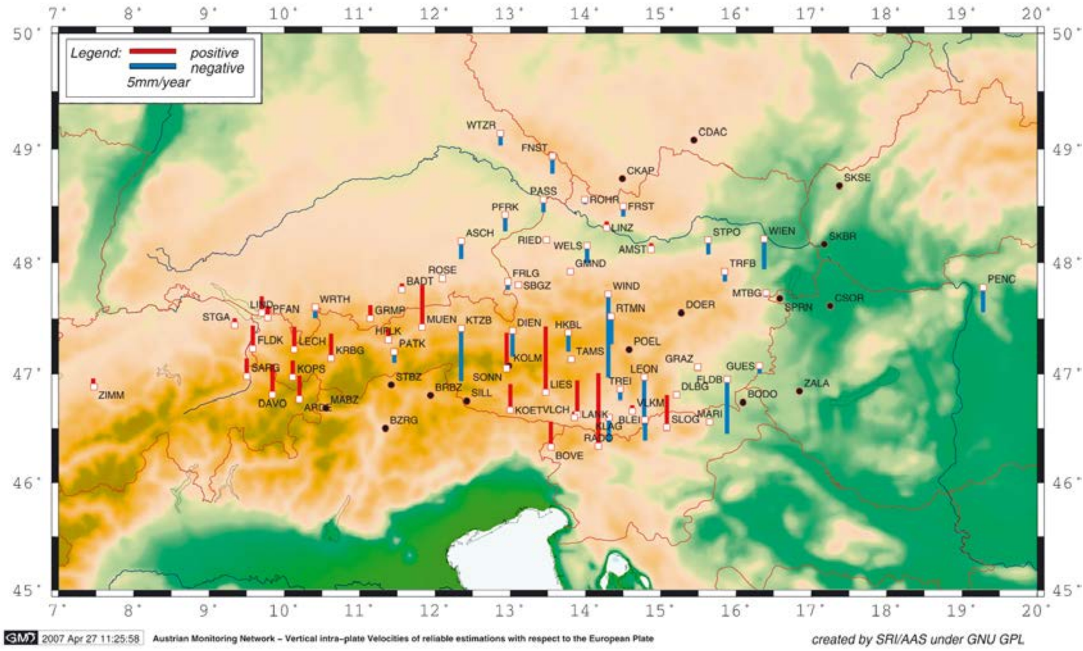

Figure 3: Vertical velocities of reliable estimations (AMON), with respect to the Eurasian Plate

The horizontal velocities in Figure 2 show the smallness of the "intra-plate velocities". The average velocity is about 1mm/year. The large deviations in velocity (>2 mm/year) at the stations DIEN, GRMP, SONN, KOPS, KTZB, LINZ, MUEN, TAMS and WIEN can be considered as local movements, or to due the short time series with offsets, which can not be estimated yet. The movements in the Southeast seem to be a real feature, which might be a structure moving into the Pannonian Basin. The stations in the Northern Alpine Forelands have a similar rotation to the one of the Eurasian plate, but the feature changes in the Alps. Presently, the station coverage is still too poor to discern between different groups. Figure 3 shows the vertical movements where only the small part of the Eurasian movement in ITRF2000 was subtracted. Again some stations show a local behaviour, mainly arising due to antenna changes. Two features can be recognized, a slight rising of the Alpine stations and a constant height or slightly falling in the forelands. Those quite old stations in the West, quasi unaffected by antenna changes, might give the best impression of the rising of the Alps.

5. Conclusions

Presently a large part of the Eastern Alps is already covered by GPS permanent stations. The station velocities can be derived from the time series produced by network adjustments similar to the international standards of EPN. The application of offsets and outliers lead to "cleaned time series" where velocities can be estimated with a residual error of about 1mm/year or better in the lateral components, and 1-3mm/year in the vertical component. The residual velocities with respect to the Eurasian Plate show significant deviations from a unique rotation. Beside individual station problems, which can be solved in the next years, local movements may be discerned from velocity groups. For a national network the general distortion reaches about 10–20 mm per decade over the Austrian territory. Because the local movements can be much higher it is advisable to include at least three stations for transformation in every densification. Nevertheless, even in ETRS89 station coordinates and those derived from them cannot be considered as constant for a generation. There should be a procedure either to apply velocities from a velocity field to every precise network and refer the coordinates to a certain epoch, or at least to apply an official overall change of all coordinates of the Austrian reference network, for every decade. The geokinematic interpretation is just starting. The next step should be the construction of a velocity field. Subsequently, a stress field could be derived and used for investigations in geodynamics. It should be noted that up to now the geological background of the individual stations has not been investigated and therefore common movements cannot be easily assigned to a geological structure. The seismological experiments CELEBRATION2000 and ALP2002 [8] have provided a huge amount of information related to geological structure. Last but not least, this paper is just a starting point for more up-to-date intra-plate studies over Austria.

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References

[1] *Dow, J. M., Neilan, R. E., Gendt, G.*: The International GPS Service (IGS): Celebrating the 10th Anniversary and Looking to the Next Decade, Adv. Space Res. 36 vol. 36, no. 3, pp. 320-326, 2005. doi:10.1016/j.asr.2005.05.125.

[2] *Ihde, J., Baker, T., Bruyninx, C., Francis, O., Amalvict, M., Kenyeres, A., Mäkinen, J., Shipman, S., Simek, J. and Wilmes, H. (2005)*: Development of a European Combined Geodetic Network (ECGN). Journal of Geodynamics, n. 40, pp. 450-460

[3] *Altamimi, Z., Sillard, P., Boucher, C. (2002)*: ITRF2000: A New Release of the International Terrestrial Reference Frame, J. Geophys. Res, 2002

[4] *Haslinger, C., Stangl, G. (2006)*: The First Austrian Velocity Field derived from GPS, EUREF Publication No. 16, Mitteilungen des Bundesamtes für Kartographie und Geodäsie, Frankfurt/Main, (in print).

[5] *Hugentobler, U., Dach, R., Fridez, P., Meindl, M. (2006)*: Bernese GPS Software, Version 5.0, Draft

[6] *Adam J., W. Augath, C. Boucher, C. Bruyninx, A. Caporali, E. Gubler, W. Gurtner, H. Habrich, B. Harsson, H. Hornik, J. Ihde, A. Kenyeres, H. van der Marel, H. Seeger, J. Simek, G. Stangl, J. Torres, G. Weber, 2002*: Status of the European Reference Frame – EUREF, International Association of Geodesy Symposia, IAG Scientific Assembly, Springer, ed. J. Adam and K.-P. Schwarz, Vol. 125, pp 42-46

[7] *Blewitt, G., Lavallée, D., (2002)*: Effect of annual signals on geodetic velocity, Journal of Geophysical Research, Vol. 107, No. B7, 10.1029/2001JB000570,2002

[8] *Brückl, E., Mitterbauer, U., Behm, M. and Working Groups CELEBRATION 2000&ALP2002, 2006*: Studies on Crustal Structure and Gravity in the Eastern Alps. In Geodetic Deformation Monitoring: From Geophysical to Engineering Roles. IAG Symposium 131. F. Sanso and A.J. Gil (Eds). Springer, pp.181-192.

[9] http://itrf.ensg.igns.fr/ITRF_solutions/2005 – Webpage of ITRF 2005

[10] http://gps.iwf.oeaw.ac.at/ – Webpage of the Observatory Lustbuehel Graz

[11] http://www.epncb.om.be/_dataproducts/timeseries – Webpage of the European Permanent Network / Special Project / Time Series

[12] http://gmt.soest.hawaii.edu/ – Webpage of Generic Mapping Tools

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