RECENT DEFORMATION ANALYSIS PROJECTS OF THE GEODETIC INSTITUTE OF THE UNIVERSITY KARLSRUHE (TH)

Projetos de análise de deformações recentes do Instituto de Geodésia da Universidade Karlsruhe

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ABSTRACT

Within the framework of the project-related exchange program ProBrAl founded by the German academic exchange service DAAD the German researchers Michael Mayer and Andreas Knöpfler, both members of the Geodetic Institute of the University Karlsruhe (TH), gave an overview of two actually running research projects, which are using GPS measurements collected within observation campaigns in order to detect highly precise deformation rates. These two interdisciplinary projects are analysing the tectonic behaviour of the Earth's surface in the highly active regions Antarctic Peninsula and Romanian Vrancea basin. Besides the data basis and the specific scientific goals, recent results were presented.

Key words: Research projects of the GIK; Deformation Analysis; GPS measurements.

RESUMO

No âmbito dos projetos relacionados ao ProBrAl - programa de intercâmbio fomentado pelo Serviço Alemão de Intercâmbio Acadêmico (DAAD) - os pesquisadores alemães Michael Mayer e Andreas Knöpfler, ambos colaboradores científicos do Instituto de Geodésia da Universidade de Karlsruhe (TH), apresentaram os resultados de dois atuais projetos de

pesquisa interdisciplinares realizados na Península Antarctica e na bacia de Vrancea, na Romênia. Nestas pesquisas, foram processadas observações do GPS provenientes de campanhas destinadas à aquisição de informações de alta precisão para o estudo do comportamento dos movimentos tectônicos que afetam as regiões investigadas. Os objetivos dos projetos foram apresentados, considerando as particularidades dos dados e os resultados alcançados.
Palavras Chave: Projetos de Pesquisa do GIK; Análise de Deformações; Levantamentos GPS.

1. INTRODUCTION

The International GNSS Service (IGS), formerly the International GPS Service, is a federation that pools especially permanent GPS and GLONASS station data. The permanent IGS network is consisting of nearly 400 continuously operating (24 h per day, tracking rate: 15 s) sites and is covering large parts of the Earth's surface. Combining GNSS (Global Navigation Satellite System) data and observations of other space geodetic techniques like VLBI (Very Long Baseline Interferometry) and SLR (Satellite Laser Ranging) the International Terrestrial Reference Frame (ITRF) is created. Analysing the time-dependant behaviour of the ITRF sites, statements concerning global plate tectonic motions could be made. If highly precise analyses of the geological processes of small areas have to be carried out, the IGS network has to be densified in order to improve the spatial resolution and the accuracy of the determined motion rates. This could be done by means of repeated observation campaigns using measurements of GNSS like GPS.

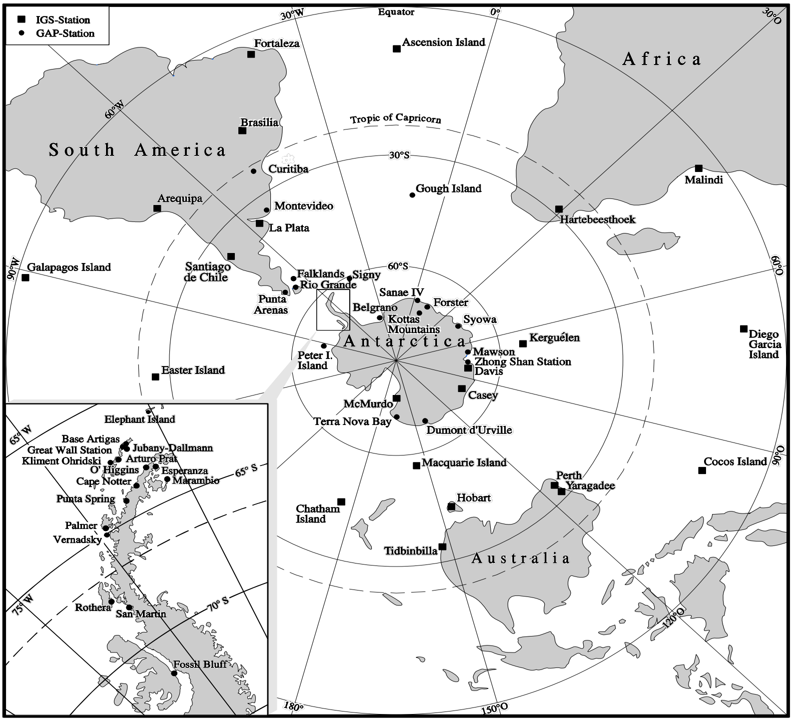
2. BACKGROUND

The GIK (Geodetic Institute, University Karlsruhe (TH)) has wide experiences in organising and performing observation campaigns in order to investigate geoscience-related questions interdisciplinary based on GPS observations. Besides the both in the following discussed recently running projects located in the area of the Antarctic Peninsula (chapter 3) and in the Romanian Vrancea basin (chapter 4) the SFB 108 and the ENTEC bundle projects have to be mentioned in this context as well. Both international and interdisciplinary projects did benefit from the contribution of the GIK. The SFB 108 analysed stress and stress release processes of the lithosphere of the Eastern Alps (VAN MIERLO ET AL. 1997). The verification of the determined movement rates is described in SCHMITT AND LEMP (2001). Within the bundle project ENTEC (Environmental Tectonics: The Northern Alpine Foreland Natural Laboratory) the kinematics and the dynamics in the Upper Rhine Graben area were determined using GPS besides other sensors; for details see ROZSA ET AL. (2005a) and ROZSA ET AL. (2005b).

3. HIGHLY PRECISE DEFORMATION NETWORK ANTARCTIC PENINSULA

Within the past decades the GIK did carry out successfully various geodetically and glacially motivated expeditions in polar regions, see e.g. LINDNER (1984), LINDNER AND RITTER (1985), and HINZE ET AL. (1990). These polar experiences together with the above briefly described history in establishing, maintaining, and analysing deformation networks opened up the chance to participate in the BMBF[1]-founded bundle projects called Reference Network Antarctica I and II (DIETRICH ET AL. 1998, DIETRICH ET AL. 2000). The main goal of these projects was to establish a highly precise time-dependant reference frame of Antarctica. Therefore, several German research groups co-operated and carried out measurement campaigns, especially in the region of the so-called Antarctic Peninsula, highlighted in Fig. 1 (bottom left).

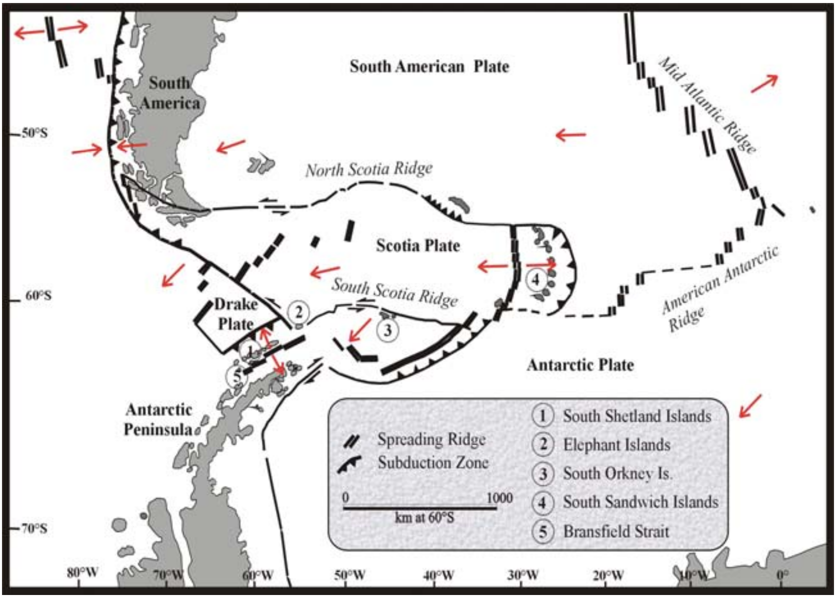
Figure 1-The sites of the Reference Network Antarctica.



[1] Federal Ministry of Education and Research of Germany

The GPS data were collected continuously with a tracking rate of usually 15 s in the Antarctic summers within the time span January 20th - February 10th in the framework of the Scientific Committee of Antarctic Research (www.scar.org). Besides others, one main goal of the GIK working group was to analyse the GPS data collected at sites located on the Antarctic Peninsula, in order to determine plate tectonic motions of this highly active region. The geological situation of this region is shown in Fig. 2 according to VEIT AND MILLER (2000).

Figure 2-The geological situation of the vicinity of the Scotia Plate.



For further details of the activities of the GIK related to the Reference Network Antarctica projects, which are not treated in the scope of this paper, see HECK ET AL. (1996) and MAYER ET AL. (2000a, b) respectively.

In Tab. 1 the eight years covering data base is described using the parameter number of sites. Based on these data detailed studies concerning GPS modelling techniques were carried out in order to improve the precision and the accuracy of the estimated cartesian co-ordinates. These data were transformed in horizontal and vertical co-ordinates, which are the basis of the afterwards conducted co-ordinate-based deformation analysis using confidence intervals (HECK ET AL. 1977). Thus, improving the results of the

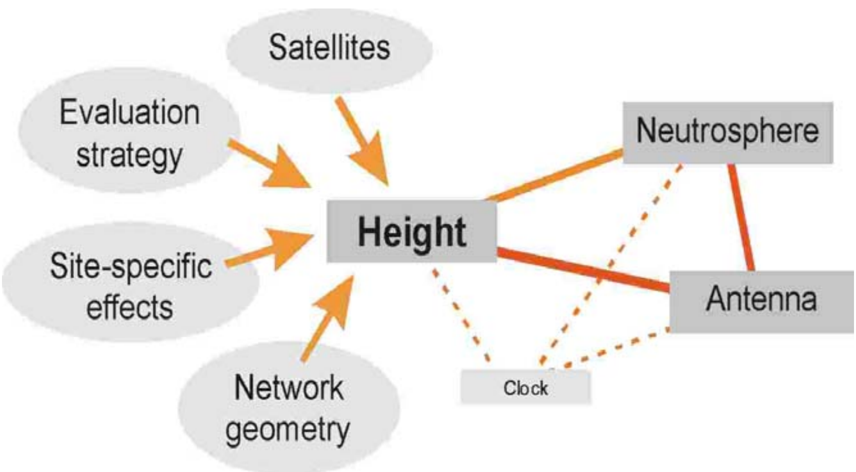
GPS data evaluation the precision and the accuracy of the derived site motions are improved as well.

Using the GPS data of the densification network of the Antarctic Peninsula the importance of an optimum data processing strategy was clearly shown, especially due to small site motions. Fig. 3 sums up the most important affecting factors of GPS-based height determination.

Table 1-Yearly numbers of sites of the densification network Antarctic Peninsula.

	Sites			
Campaig	IGS	**SCAR**	Others	Sum
1995	0	13	3	16
1996	1	7	2	10
1997	1	2	2	5
1998	1	15	4	20
1999	1	0	6	7
2000	1	0	4	5
2001	1	0	4	5
2002	1	3	4	8

Figure 3-The Bermuda polygon.



It is a well-known fact that the determined height component values are highly correlated with the handling of the Earth's atmosphere (e.g. neutrosphere) and the antenna modelling, in literature this dependence is usually described using the term Bermuda polygon (BEUTLER 1998), see Fig. 3. Besides these factors other parameters like network geometry, site-specific effects (e.g. multipath), orbit quality, and operator noise, which is mainly depending on the data evaluation strategy (e.g. cut-off angle), significantly impact the GPS results.

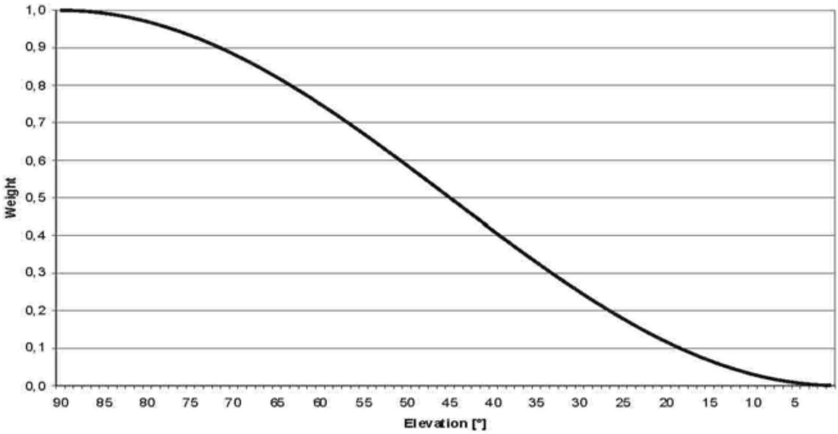
To guarantee a correct and extensive GPS model for the neutral atmosphere within the data processing the parameters, which are affecting the usually used models of the neutral atmosphere, were investigated in detail. In the analysed area almost no radiosounding profiles are available and in addition the number of sites, which register surface meteorology, is small, therefore numerical weather model data of the National Center for Environmental Prediction/NOAA CIRES AMIP-II DOE Reanalysis (NCEP 2004) were used to verify the standard neutrospheric models of GPS-based data processing. For example, this is important due to the fact that most standard neutrospheric models were developed for mid-northern latitudes. Especially, representative temperature and water vapour gradients were determined, thus enabled a modified and an adapted neutrospheric modelling based on the approach of ASKNE AND NORDIUS (1987).

To overcome the incorrectness of the stochastic model of standard data processing strategies (e.g. decreasing weight with increasing zenith angle z, identical weighting for both wavelengths, azimuthal isotropy) site-specific and observation campaign related weight functions based on the signal strength of the GPS data were developed. In contrast to standard processing approaches, these weight functions consider the azimuthal signal direction as well as elevation angles E. In Fig. 4 the GPS standard weight model is shown, which is based on the formula

$$w^2 = \sin^2 E = \cos^2 z \,. \tag{1}$$

In contrast to this often incorrect modelling Fig. 5 shows the resulting site-specific campaign-dependant weighting of the site O'Higgins for L1 and L2 observations. Within this approach it is assumend that the signal strength of GPS observations is highly correlated to the quality of the signals. The signal quality itself is especially deteriorated due to the Earth's atmosphere, multipath effects, and characteristics of the instrumentation. It is clearly visible that the most zenithal GPS observations do not show the best quality, in addition, an identical weighting for both frequencies does not seem to be appropriate.

Figure 4-Standard weight model of GPS observations.



Handling all above mentioned parameters carefully the repeatability of the campaign-related co-ordinate time series of the sites, which are the basis of deformation studies, could be improved significantly compared to a standard data evaluation strategy and the determination of relative movement models of the Antarctic Peninsula was feasible. In Fig. 6 the time series resulting from standard and respectively developed improved data evaluation strategy is shown. As a representative example the site O'Higgins (campaign 1998) is chosen. Some important characteristics of the improved data evaluation strategy are listed in Tab. 2.

Figure 5-Improved site-specific campaign-dependant weight model of GPS observations; campaign 1998; site: O'Higgins; left (right): L1 (L2) frequency.

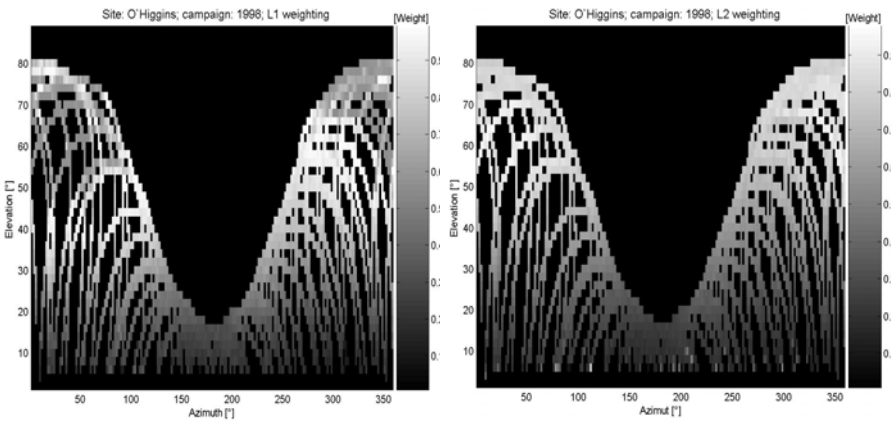
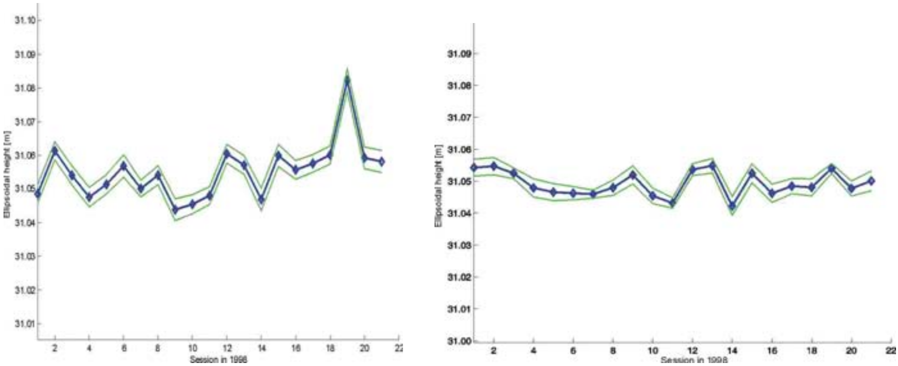


Figure 6-Time series of the height component of the site O'Higgins; campaign 1998; left (right): Standard (improved) data evaluation strategy.



The calculated horizontal movement models do not differ significantly compared to known plate-tectonic models. Due to the time span of collecting GPS data in the area of the Antarctic Peninsula relative vertical movement rates, e.g. yearly rates in the range of 4 mm in the area of the Bransfield Strait, were determinable analysing various tectonically motivated deformation scenarios. In Fig. 7 two deformation scenarios are given, exemplarily. The corresponding estimated vertical movement rates are given in Tab. 3 and Tab. 4. In both scenarios four groups of sites are built consisting of at least one site, whereby the stable Peninsula block, the Elephant Island block (EIB), the South Shetland Islands block (SSB), and the south-eastern Bransfiled Strait block (SEBSB) are created.

Table 2-Characteristics of the improved data evaluation strategy.

Parameter	Handling
satellite positions	precise IGS orbits
ambiguity fixing strategy	adapted QIF strategy
stochastic modelling	site-specific and campaign-dependant, based on signal strength
ionospheric modelling	adapted local model
neutrospheric modelling	standard atmosphere-based prediction model, according to an NCEP-based improved Askne and Nordius approach, site-specific piecewise constant zenithal neutrospheric parameters (3 h)
minimum elevation angle	10

Table 3-Yearly relative height movements with respect to the deformation scenario shown in Fig. 6 left image.

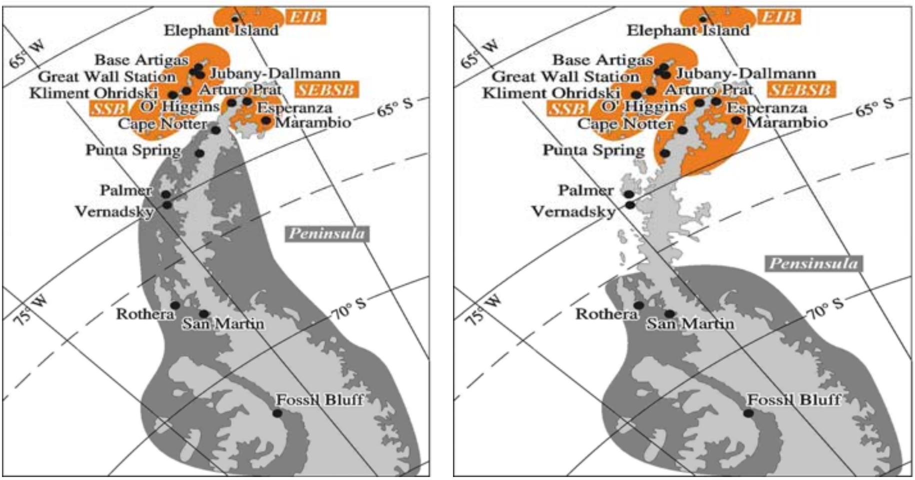
Vertical movement rate	Block	Confidence interval [mm/a]
-6.0	SSB	±5.6
-3.1	SEBSB	±5.4
-9.1	EIB	±8.2

Table 4-Yearly relative height movements with respect to the deformation scenario shown in Fig. 6 right image.

Vertical movement rate	Block	Confidence interval [mm/a]
-5.2	SEBSB	±5.3
-2.1	SSB	±5.2
-7.7	EIB	±6.3

For a comprehensive and detailed description and discussion of all important affecting factors of the data evaluations and deformation analyses in the area of the Antarctic Peninsula see MAYER (2006).

Figure 7-Meaningful deformation scenarios.

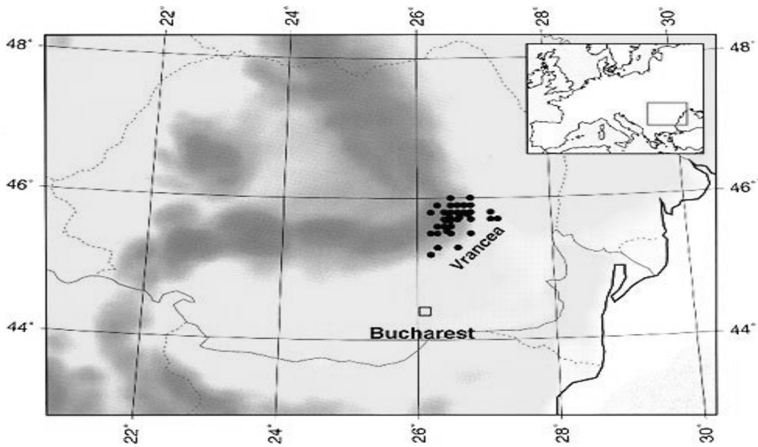


4. THREE-DIMENSIONAL PLATE KINEMATICS IN ROMANIA

The Romanian Vrancea region is an area in eastern Europe with a lot of seismic activity. A lot of strong earthquakes with magnitues greater than seven take place there, e.g. the last ones have been observed in 1986 (magnitude 7.1), in 1990 (magnitude 6.9), and in 2004 (magnitude 5.9) (CRC461 2005). The average recurrance rate makes another strong event highly probable within the next two decades. When the Collaborative Research Center 461 (CRC461) was established in 1996, this area was chosen in order to analyse and understand the tectonic processes and develop realistic models and predictions of ground motion. A further aim in this multidisciplinary research project is the prognosis of potentional damage in case of strong earthquakes as well as risk reduction by means of appropriate civil engineering concepts.

The subproject B1 (Three-Dimensional Plate Kinematics in Romania) of the CRC461 deals with the determination of 3D movements and deformation using GPS. The velocities are an important input parameters for modelling the tectonic scenarios and are derived from GPS measurements in the CRC deformation network. This network consisted within the first observation campaign (1997) of a few CRC sites and was enlarged over the years. Some sites have been destroyed and the following measurements were carried out on backup sites in close neighbourhood to the centre markers. In addition, some sites of the Central European GPS Geodynamic Reference Network (CEGRN) were observed by co-operating institutions, see Fig. 9.

Figure 8-Topographic map of Romania; Carpathian mountains indicated in dark grey. The damaging earthquakes occur at intermediate depth (70 - 180 km) and are clustered in a small area in the south-eastern Carpathians (Vrancea) (source: www-sfb461.physik.uni-karlsruhe.de).

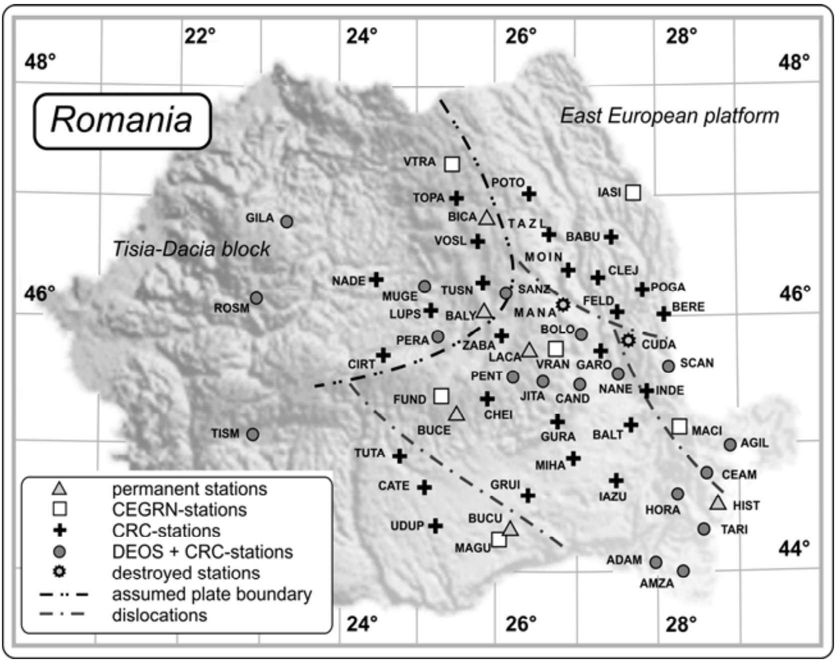


Besides the GIK campaigns, the partners of the Department of Earth Observation and Space Systems (DEOS) of the Technical University of Delft (Netherlands) carried out campaigns as well. The campaigns 2004 and 2006 were carried out together by the CRC461 and DEOS. An overview of all campaigns concerning the number of occupied sites is given in Tab. 5 also.

Due to the technical progress and the fact that different institutions were co-operating different GPS equipment was used. Within the CRC campaigns Leica 200/300 and 500 receiver and antenna series were used. DEOS performed measurements using Leica 500 series. CEGRN did utilise different Trimble instruments. In Tab. 5 an overview of the used GPS equipment is given.

In addition to the data collected at campaign sites, data of appropriate European IGS sites were considered to build up a reference frame for the Romanian deformation network. Furthermore precise IGS orbits were used, which are published via internet (garner.ucsd.edu/pub/products). Also Earth rotation parameters calculated at the International Earth Rotation and Reference Systems Service (IERS, www.iers.org) were introduced in the processing.

Figure 9-Deformation network of the CRC461.



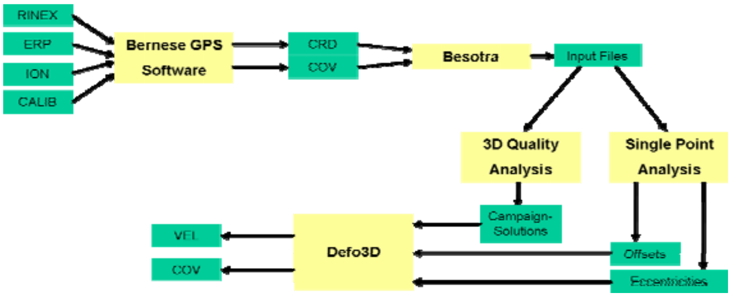
Within the data evaluation by means of Bernese GPS Software Version 4.0 and 4.2 relative GPS antenna models according to the National Geodetic Survey (NGS, www.ngs.noaa.gov) were used. During the re-processing of all campaign data using the Bernese GPS Software Version 5.0 absolute calibration values of the IGS have been considered.

In order to determine deformation rates based on results of the GPS processing (co-ordinates, variance-covariance matrices) a strategy and an appropriate software developed at the GIK was used. In a first step the files were transformed (Besotra) into a specific ascii-format in order to carry out single point analyses, where the co-ordinates, variances and covariances for single sites are extracted. In the next step deformation analyses were carried out using the GIK software Defo3D (see Fig. 10). Final results are single point velocities and corresponding variances as well as covariances.

Table 5-Campaigns of the CRC461 deformation network.

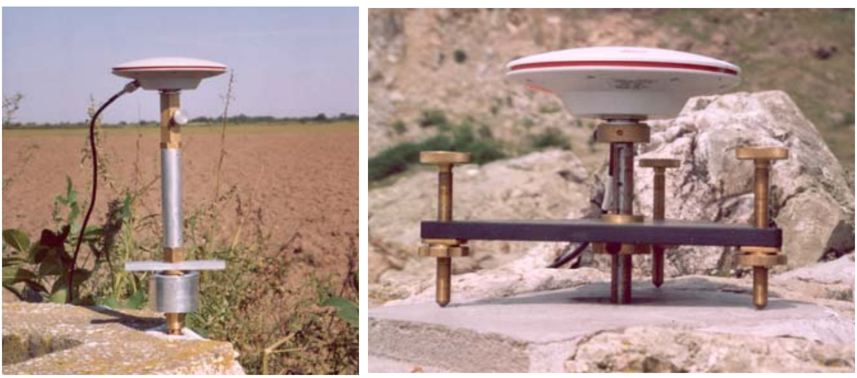
	Sites and equipment			
Campaign	Period (DOY)	Institution(s)	Number of	GPS equipment
1995	148-154	CEGRN	6	Trimble 4000
1996	162-167	CEGRN	6	Trimble 4000
1997	155-161	CEGRN	6	Trimble 4000
	270-275	CRC461	26	Leica 200/300
1998	232-239	CRC461	27	Leica 200/300
1999	165-170	CEGRN	6	Trimble 4000
	184-195	NATO	12	different Ashtech
2000	232-240	CRC461	33	Leica
2001	130-138	NATO	12	different Ashtech
2002	183-207	DEOS	50	Leica 500
	250-268	DEOS	50	Leica 500
2003	224-234	CRC461	57	Leica 500
2004	221-231	CRC461	57	Leica 500
2005	184-198	DEOS	32	Leica 500
2006	226-236	CRC461	49	Leica 500

Figure 10-Schema of the processing.



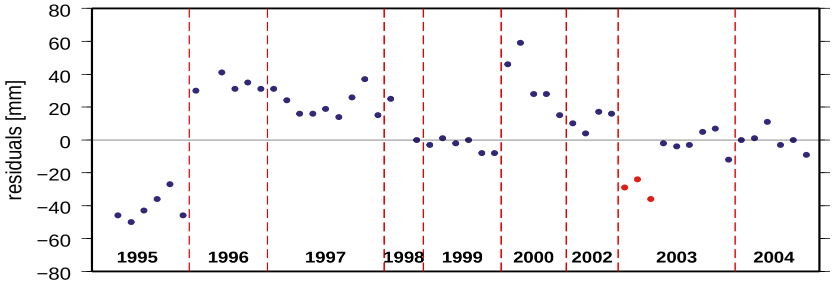
Performing high quality deformation measurements with small expected velocity rates over a long period of time is very demanding. It is recommended to use an identical instrumentation within the whole time span of the project on each site in order to minimize effects of the receiver antenna modelling as well as site-specific effects like multipath on the results. Within this project this fundamental demand could not be fulfilled, due to the fact that different institutions performed measurements and each institution used different GPS equipment. In addition, this bundle project lasts for nearly ten years, within this time span there was much progress in receiver and antenna technology, so the institution changed the generation of GPS equipment at least once during the period of the deformation measurements. Furthermore the deformation network grew from a few sites to more than 50 sites, therefore additional equipment was needed to perform simultaneous data collection.

Figure 11-Antenna setup: CRC adapter (left), triangular plate (right).



Another important fact which has to be taken carefully into account is concerning to the destruction of some markers. In such cases there are two changes in procedures appropriate. If a rest of the bolt remained, a triangular plate (see Fig. 11 right) was used, if not the measurements were dislocated to a backup marker near the centre marker. Anyway, the continuous time series of this site is broken and herewith the quality of the results has to be invested carefully.

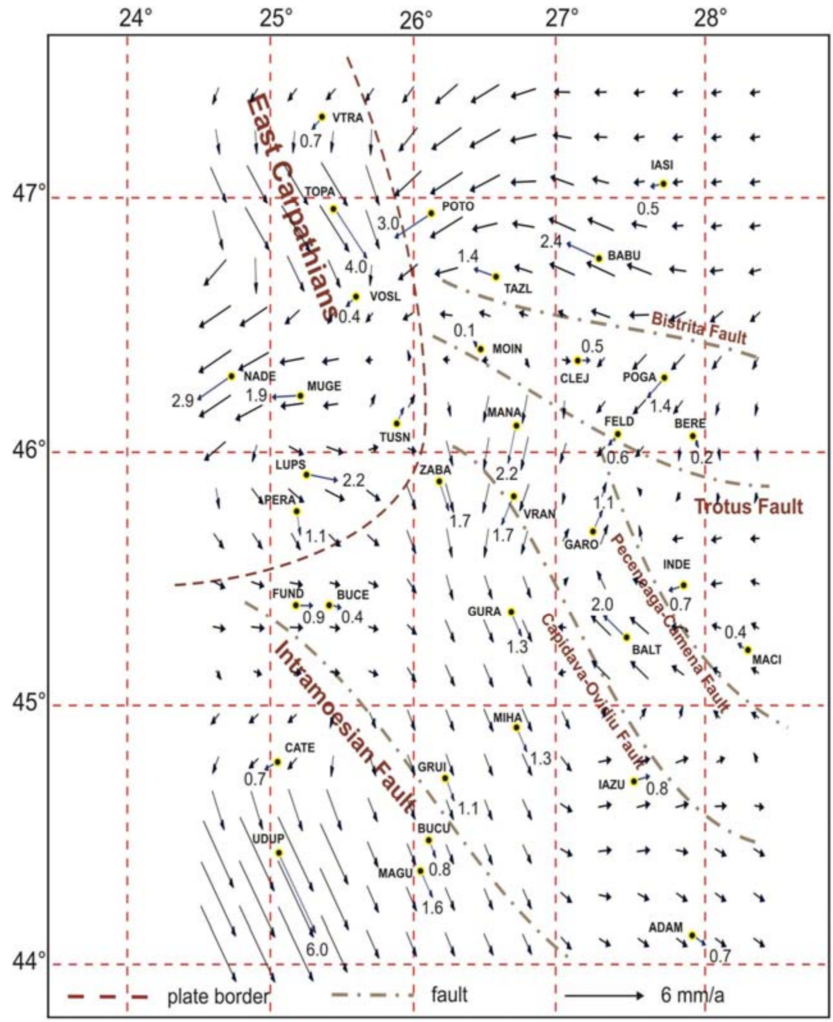
Figure 12-Height residuals of the site FUND.



In Fig. 12 the behaviour of the height residuals of the site FUND is shown. It is apparent, that parts of some campaigns as well as complete campaigns do not fit into the trend; e.g. the daily solutions of the first three days of the campaign of 2003 do behave significantly different compared to the other six daily solutions. Within this campaign the site was occupied three times for three days with different equipments of the same type (Leica 500 series). The height offset could be caused by a site-dependant behaviour of the used antenna. Due to a special adapter (see Fig. 11 left) the antenna height is constant. The shown adapter has to be screwed into the marker, which was drilled in concrete or bedrock and set vertical by using a bubble level.

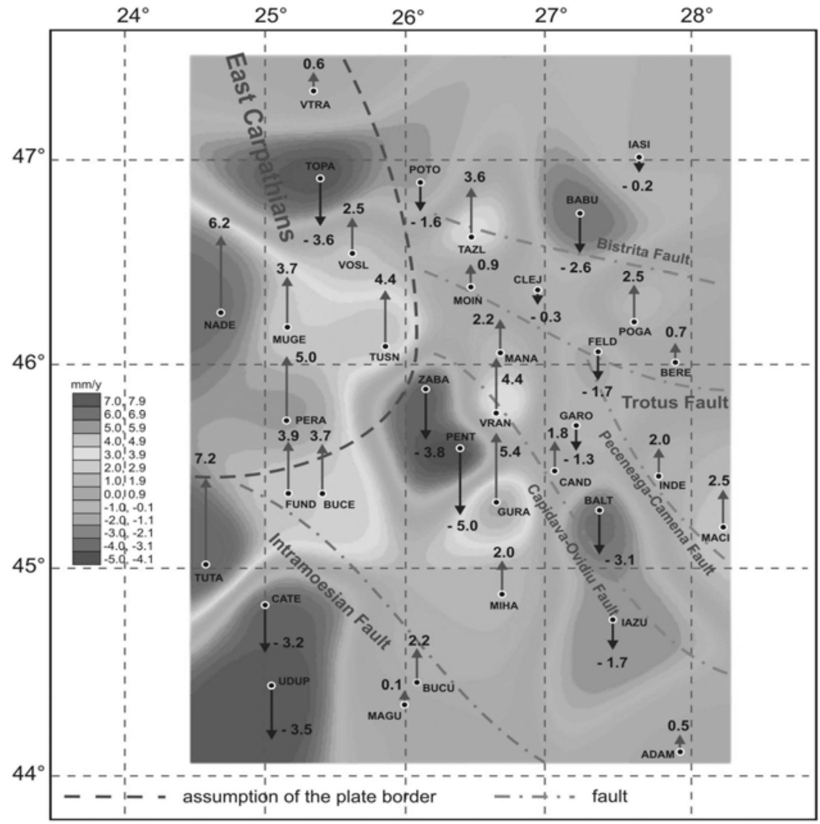
In order to handle this problem, the software Defo3D offers the possibility to estimate individual instrumentation-specific offsets. It has to be emphazised that these additional parameters have to be handled with care. Preliminary results of the deformation analysis are shown in Fig. 13 and Fig. 14 (CRC461 2005). In Fig. 13 the horizontal velocity field of the Romanian Vrancea region is presented, in Fig. 14 the vertical velocity field

Figure 13-Results of the deformation analysis of the Vrancea region in mm per year: Horizontal velocities.



The plots cover the time span 1995 - 2004. In the central part of the project region an area of subsidence (dark grey) is resulting, in the south-eastern part of the Carpathian Mountains an uplift trend is clearly visible (grey to light grey).

Figure 14-Results of the deformation analysis of the Vrancea region in mm per year: Vertical velocities.



ACKNOWLEDGEMENT

The authors would like to thank DAAD (German Academic Exchange Service) for the financial support in the framework of the project *PROBRAL: Hochgenaue Positions- und Höhenbestimmung mit GPS: Modellierung von Fehlern und Transformation in Gebrauchshöhen*.

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(Recebido em setembro/07).