Tectonophysics 602 (2013) 300–315

Contents lists available at SciVerse ScienceDirect

Tectonophysics

journal homepage: www.elsevier.com/locate/tecto

Recent surface displacements in the Upper Rhine Graben — Preliminary results from geodetic networks

Thomas Fuhrmann [a], Bernhard Heck [a], Andreas Knöpfler [a,*], Frédéric Masson [b], Michael Mayer [a], Patrice Ulrich [b], Malte Westerhaus [a], Karl Zippelt [a]

[a] Geodetic Institute, Karlsruhe Institute of Technology (KIT), Karlsruhe, Germany
[b] Institut de Physique du Globe de Strasbourg, CNRS Strasbourg University, Strasbourg, France

ARTICLE INFO

Article history:
Received 23 February 2012
Received in revised form 5 September 2012
Accepted 3 October 2012
Available online 12 October 2012

Keywords:
Upper Rhine Graben
GNSS
Levelling
Recent crustal motions
Horizontal and vertical intraplate velocity field

ABSTRACT

Datasets of the GNSS Upper Rhine Graben Network (GURN) and the national levelling networks in Germany, France and Switzerland are investigated with respect to current surface displacements in the Upper Rhine Graben (URG) area. GURN consists of about 80 permanent GNSS (Global Navigation Satellite Systems) stations. The terrestrial levelling network comprises 1st and 2nd order levelling lines that have been remeasured at intervals of roughly 25 years, starting in 1922. Compared to earlier studies national institutions and private companies made available raw data, allowing for consistent solutions for the URG region. We focussed on the southern and eastern parts of the investigation area. Our preliminary results show that the levelling and GNSS datasets are sensitive to resolve small surface displacement rates down to an order of magnitude of 0.2 mm/a and 0.4 mm/a, respectively. The observed horizontal velocity components for a test region south of Strasbourg, obtained from GNSS coordinate time series, vary around 0.5 mm/a. The results are in general agreement with interseismic strain built-up in a sinistral strike–slip regime. Since the accuracy of the GNSS derived vertical component is insufficient, data of precise levelling networks is used to determine vertical displacement rates. More than 75% of the vertical rates obtained from a kinematic adjustment of 1st order levelling lines in the eastern part of URG vary between −0.2 mm/a and +0.2 mm/a, indicating that this region behaves stable. Higher rates up to 0.5 mm/a in a limited region south of Freiburg are in general agreement with active faulting. We conclude that both networks deliver stable results that reflect real surface movements in the URG area. We note, however, that geodetically observed surface displacements generally result from a superposition of different effects, and that a separation in tectonic and non-tectonic processes needs additional information and expertise.

1. Introduction

As central and most prominent segment of the European Cenozoic rift system, the seismically and tectonically active Rhine Graben is of continuous geo-scientific interest (Lemeille et al., 1999; Ziegler, 1992). Its southern part, called Upper Rhine Graben (URG), is located in the border triangle between Germany, France and Switzerland and extends from Basel to Frankfurt. The approx. 300 km long and 40 km wide segment is bounded on the French side by the Vosges Mountains and on the German side by the Black Forest. Preceded by volcanism (late Cretaceous), the rifting was initiated during late Eocene starting with broadly E–W resp. ENE–WSW extension and lasted until Aquitanian time (Villemin and Coletta, 1990). Today, the URG is characterised by small uplift and subsidence rates less than about 0.5 mm/a and by a quasi-compressive, left-lateral strike–slip tectonic regime. The maximum horizontal stress-axis is oriented NW–SE. The URG is considered to be the seismically most active region of northwest Europe with significant probability for the occurrence of destructive earthquakes (Meghraoui et al., 2001).

The evolution and neotectonics of the URG have been intensively studied by a consortium of 25 universities and governmental agencies from Germany, France, the Netherlands and Switzerland for a 10 year period lasting from 1999 to 2009. This multi-disciplinary research and training programme, called URGENT, was initiated by the geo-scientific institutions of the European Confederation of Upper Rhine Universities (EUCOR), comprising Basel, Freiburg, Strasbourg and Karlsruhe. URGENT aimed at a better understanding of the seismic hazard, neotectonics and evolution of the Upper Rhine Graben and surrounding areas, as well as the management of water resources (see http://comp1.geol.unibas.ch).

Within this paper, the focus will be on the recent crustal motions detected using observations of Global Navigation Satellite Systems (GNSS, e.g. GPS) and precise levelling in order to contribute to a better understanding of the processes that affect the URG region. Geodetic measurements allow pinpointing areas of active deformation, assessing the magnitudes and rates of displacements and, thus, delivering important

* Corresponding author at: Geodetic Institute, Karlsruhe Institute of Technology (KIT), Englerstrasse 7, D - 76131 Karlsruhe, Germany. Tel.: +49 721 6084 2303; fax: +49 721 6084 6552.
E-mail address: andreas.knoepfler@kit.edu (A. Knöpfler).

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http://dx.doi.org/10.1016/j.tecto.2012.10.012

Table 1
URG-related residual velocities of Tesauro et al. (2005, 2006) with respect to a Eurasian plate rotation free ITRF2000 solution.

Site	Time span	($V_{north} \pm \sigma_{Vnorth}$) [mm/a]	($V_{east} \pm \sigma_{Veast}$) [mm/a]	Publication
KARL	05/09/2001–06/25/2003	0.81 ± 0.68	0.02 ± 0.68	Tesauro et al. (2005)
STRA	03/22/2000–11/06/2003	0.27 ± 0.56	-0.21 ± 0.56	Tesauro et al. (2005)
KARL	05/09/2001–05/19/2004	0.7 ± 0.6	0.2 ± 0.6	Tesauro et al. (2006)
STRA	03/22/2000–05/19/2004	0.3 ± 0.5	-0.2 ± 0.5	Tesauro et al. (2006)

boundary conditions needed to verify the predictions of geomechanical models. Due to significant increasing of exploration activity in the URG (e.g. geothermal energy, raw oil, groundwater management), the need for precise geodetic information with high spatial and temporal resolution – as fundamental basis for researchers and decision makers – is increasing. Accordingly, geodetic measurements have been an integral part of the EUCOR-URGENT activities. At that time, however, the geodetic efforts were not able to resolve active deformation in the URG area unambiguously, since the available networks and datasets were not dense enough, neither in space nor in time. A major problem was that many datasets were restricted to national use only. Therefore, most studies were based on a limited amount of data that was freely available.

Meanwhile, the situation has improved considerably. In this paper, we report first results from two scientific projects that focus on a comprehensive processing of unified datasets from Germany, France and Switzerland. We will show that the resolution of the transnational space geodetic and terrestrial geodetic networks in the URG area is sufficient to detect even small displacement rates well below 1 mm/a, and we will present case studies where tectonic processes might be reflected in GNSS and levelling results. The paper will close with an outlook concerning a rigorous fusion of geodetic methods planned for the future.

2. GNSS-derived horizontal velocity field of the Upper Rhine Graben area

Within this section, previous investigations related to GNSS data are reviewed (Section 2.1) in order to enable a comparison with the new results gained within the GNSS Upper Rhine Graben Network GURN. The GURN initiative is described in Section 2.2. Section 2.3 is dedicated to the data evaluation strategy used to derive a preliminary horizontal velocity field (Section 2.4).

2.1. Previous investigations

Space geodetic measurements have been used since many years to detect tectonic displacements in the area of the URG. At the beginning of EUCOR-URGENT, only the American Global Positioning System (GPS) was available. Nowadays, also the Russian system GLONASS is in full operational capability, while the European initiative Galileo as well as the Chinese GNSS Compass is currently developed. In the following, we will use the general term GNSS that comprises all available satellite positioning systems.

The early geodetic GPS measurements suffered from a little number of occupied sites and a low data volume. Due to the sparsity of permanent stations, three campaign measurements were performed in 1999, 2002 and 2003, each one covering a time period of a few days. Average RMS errors of the derived coordinates were of the order of 2 mm for the horizontal and 4 mm for the vertical component, respectively, which are an order of magnitude larger than the expected tectonic displacements accumulated within a few years (Rozsa et al., 2005a, 2005b). The results thus remained inconclusive. Nevertheless, it was decided to continue these studies with the strongly increasing number of permanent GNSS stations in the region and the continuous improvement of the processing strategies.

Besides the GNSS campaigns mentioned above, in particular two research teams dealt with velocity fields based on permanent GNSS measurements. In order to derive horizontal intraplate velocities of central Western Europe, Tesauro et al. (2005) analysed and compiled heterogeneous datasets of velocities of permanent GPS sites stemming from various network solutions and analyses (ITRF2000, EPN,[1] AGNES,[2] REGAL,[3] RGP[4]). In the URG only two sites, KARL (Karlsruhe, Germany) and STRA (Strasbourg, France; identical with STJ9), were taken into account. See Table 1 for residual ITRF2000-based velocities with respect to the European Plate. The displacement rates were slightly reduced with an extended database (Tesauro et al., 2006).

Nocquet and Calais (2003) contributed to the understanding of intra- and interplate deformations of Central Europe with respect to processes that drive continental deformation and control associated seismicity. Therefore, datasets of ITRF2000, EPN, RGP, and REGAL (weekly resp. daily solutions) were rigorously compiled on normal equation basis. Again, only the aforementioned two stations were taken into account. The time series cover approx. 2–3 years. Jumps within coordinate time series were handled solving for different positions and constraining velocity values to be identical for the entire time series. The derived velocity rates are shown in Table 2. Nocquet and Calais (2003) carried out detailed studies focussing on the representativeness of published as well as calculated Euler pole values. Therefore, the strategy of calculating intraplate velocity values differs compared to Tesauro et al. (2005, 2006) resulting in reduced velocities.

Table 2
URG-related residual velocities of Nocquet and Calais (2003) with respect to a Eurasian plate rotation free ITRF2000 solution.

Site	Time span [years]	($V_{north} \pm \sigma_{Vnorth}$) [mm/a]	($V_{east} \pm \sigma_{Veast}$) [mm/a]
KARL	1.9	0.12 ± 0.55	0.27 ± 0.41
STJ9	2.7	-0.03 ± 0.67	0.40 ± 0.53

2.2. GNSS Upper Rhine Graben network — GURN

The transnational cooperation GURN was established in September 2008 by the Institut de Physique du Globe de Strasbourg (Ecole et Observatoire des Sciences de la Terre, EOST, Strasbourg, France) and the Geodetic Institute (GIK) of Karlsruhe University (now Karlsruhe Institute of Technology, Karlsruhe, Germany). Within GURN, the two institutions cooperate in order to carry out geo-scientific research in the framework of the transnational project TOPO-WECEP (Western and Central European Platform; http://www.topo-wecep.eu/, Cloetingh et al., 2007), which is the successor of the above mentioned EUCOR-URGENT initiative. GURN was established as a long-term project in order to derive site velocities resp. displacement rates with respect to time series of daily estimated site coordinates based on a highly precise and highly sensitive network of permanently operating GNSS sites.

When GURN started, the network consisted mostly of permanently operating sites of SAPOS®[5] Baden-Württemberg and different data providers in France (e.g. EOST, Teria,[6] RGP). In 2009, GURN was extended to the south by cooperating with swisstopo (Switzerland)

[1] EPN: EUREF Permanent Network (link: http://www.epncb.oma.be)
[2] AGNES: Automated GNSS Network for Switzerland (Brockmann et al., 2011)
[3] REGAL: Réseau GPS permanent dans les Alpes, France (link: http://kreiz.unice.fr/regal)
[4] RGP: Réseau Géodésique Permanent Français, France (link: http://rgp.ign.fr)
[5] SAPOS®: Satellite Positioning Service of the German surveying agencies (link: http://www.sapos.de)
[6] Teria: GNSS Network for France (Gaudet and Landry, 2005)