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THE EARTH CRUST SURFACE MOVEMENTS IN SW POLAND FROM GPS AND LEVELING DATA [1]

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Abstract

Permanent and periodic satellite GPS observations in SW Poland are realized since 1996. The results of these observations are used for the earth crust surface movements determination. Values of the movement velocities are significant for horizontal as well as vertical components. The vertical movements determined by GPS were compared with the vertical movements obtained by repeated leveling measurements, performed in the 50'ties, 70'ties and 90'ties of the 20th Century. The calculated movements are discussed in relation to tectonics in the paper.

INTRODUCTION

The Sudety Mts. with their northern foreland in the Bohemian Massif constituted frames for the folding Alpides. The area was broken into several tectonic blocks, as a result of intensive tectonic thrusts. The blocks are separated by tectonic zones extending from NW to SE and characterized by large amplitude of movements. The whole of the rigid Earth's crust had been fractured right to the MOHO zone. Three main tectonic zones were identified in the analyzed region: the Sudetic Marginal Fault, Intra-Sudetic Fault and Middle Odra Fault Zone (fig. 1).

The Sudetic Marginal Fault makes up morphological and tectonic edge separating the Sudety Mts. from Fore-Sudetic Block, which in turn is separated from the Sudetic Monocline by Middle Odra Fault Zone. Numerous tectonic fault zones, graben and horsts, dividing them into smaller tectonic structures, were identified inside these units. Movement amplitudes in local tectonic graben and horsts reached 500 to 700 m. The major structures of this kind on the Fore-Sudetic Block include: the Paczków and Roztoki-Mokrzeszów graben, as well as the Kamieniec Ząbkowicki and Strzegom horsts. Basaltic volcanism and hydrothermal processes are often associated with strong compensatory movements. These are pronounced in the uplifted Sudety Mts. ridges such

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[1] **This work has been supported by the COST Action 625: 3D Monitoring of Active Tectonic Structures.**

as: Izerskie, Kaczawskie, Karkonosze, Orlickie, Bystrzyckie, Sowie and Bardzkie, as well as Śnieżnik Massif.

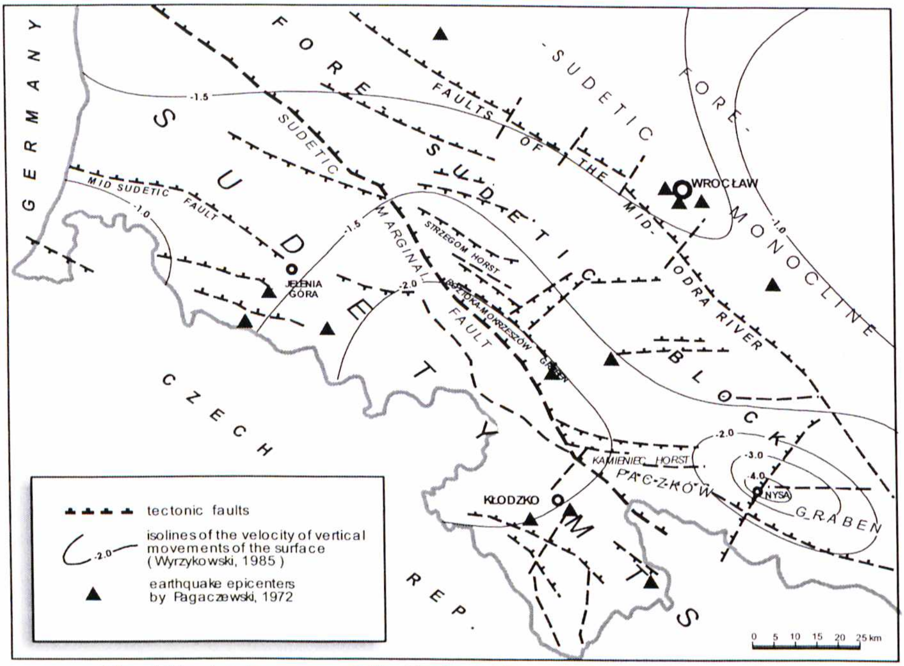

Fig. 1 Tectonic zones of the Sudety Mts. And Fore-Sudetic Block

Tectonic movements in this region were reactivated in the Quaternary, as a result of three glaciation periods between 800 000 and 100 000. Glacioisostatic compensation after continental glacier withdrawals triggered off vertical movements of geological structures reaching 150 m in the upper Odra valley.

The late Pleistocene tectonic movements continue till the present-day. This fact is confirmed by historical records listing several tens of earthquakes with 5,5° MSK magnitudes, since the 10th century. Repeated leveling line measurements that have been performed since the end of the 19th century reveal vertical movements of the upper lithosphere in the Sudety Mts. and Fore-Sudetic Block in the –(1,5-6,0) mm/year range *(Wyrzykowski, 1985)*.

In the paper the results of permanent and periodic satellite GPS observations in SW Poland realized for earth crust surface movements determination are presented. Values of these movements are significant for horizontal as well as vertical components and theirs relation to geology and tectonics were discussed. Results of vertical movements determined by GPS were compared with the vertical movements obtained by repeated leveling measurements.

THE GEOSUD GEODYNAMIC NETWORK

In the frame of the KBN research project GEOSUD (GEOdynamics of SUDetes) a research network, covering the Eastern Sudety Mts. and Fore-Sudetic Block, was established in 1996. It comprised points selected from the existing research areas

("Śnieżnik Massif", "Paczków Graben" and "Stołowe Mts."), as well as new stations *(Cacoń et al., 1998; Cacoń, Dyjor, 1999).*

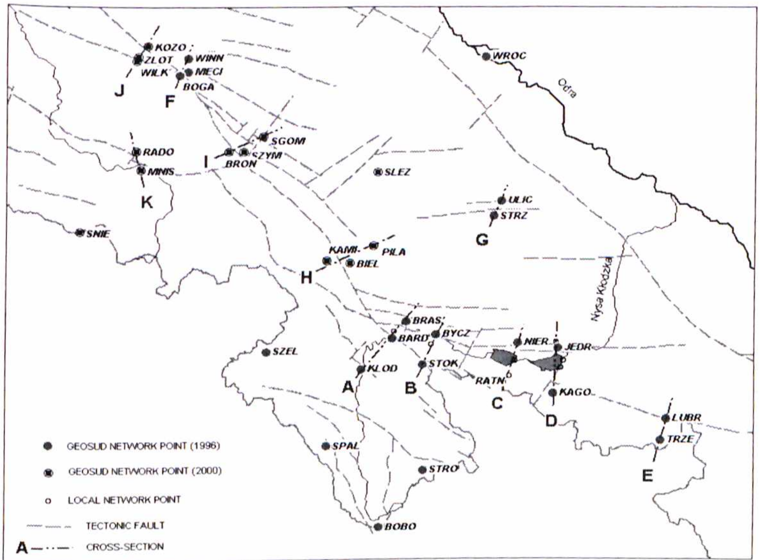

Fig. 2 Geodynamic network GEOSUD

Selection of these points' location was conditioned by geological and tectonic structure, as well as the need to place observation stations directly on crystalline rock outcrops. Supplementary geodynamic "profiles" located in the western part of the research area completed the GEOSUD network in 2000 (fig. 2) *(Cacoń, Dyjor, 2000).*

FIELD MONITORING AND GPS DATA PROCESSING

Principles of GPS observations in research networks have changed gradually. In 1996 observations were performed in short 3-4 hour sessions with each point measured at least twice and in different vector configurations. Since 1997 measurements of the GEOSUD network have been carried out synchronously with Czech network SILESIA and points selected from both networks created regional geodynamic network SUDETY *(Schenk et al., 1999)*. In the GEOSUD network 6 to 8 hour sessions were performed on points making up research profiles with 48-hour measurements on points constituting frame of the SUDETY network which was linked to a EPN station. Since 2000 ("GEOSUD II" project) observations on all points in research profiles have been carried out in two repeated 12-hour sessions and two independent 24-hour sessions on the basic points of the SUDETY network.

Between 1996 and 1999, ASHTECH receivers (Z12 and MDXII models) were used in GPS observations *(Kontny et al. 2000)*. ASHTECH Z-Xtreme receivers replaced MDXII since 2000. Additionally TRIMBLE 4700 and ASHTECH Z-FX receivers were used on recently included points ("GEOSUD II" project).

The satellite GPS observations were processed with BERNESE v.4.2 software *(Hugentobler et al. 2001)* according to the strategy designed for local geodynamic

networks ***(Bosy and Kontny 1998, Bosy et al. 2003; Schenk et al. 2002).*** **Sketch of the independent baselines used in Bernese solution is shown on the figure 3.**

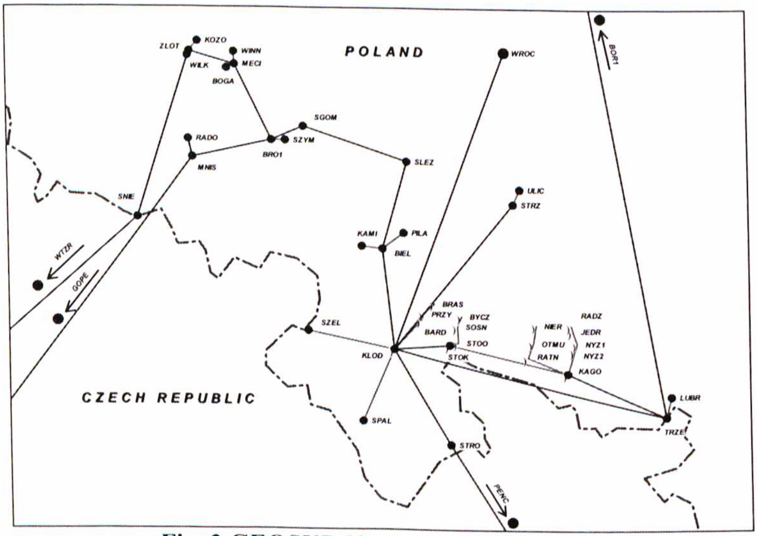

Fig. 3 GEOSUD Network GPS baselines

Characteristics of solution quality for particular measurement campaigns are given on the figure 4.

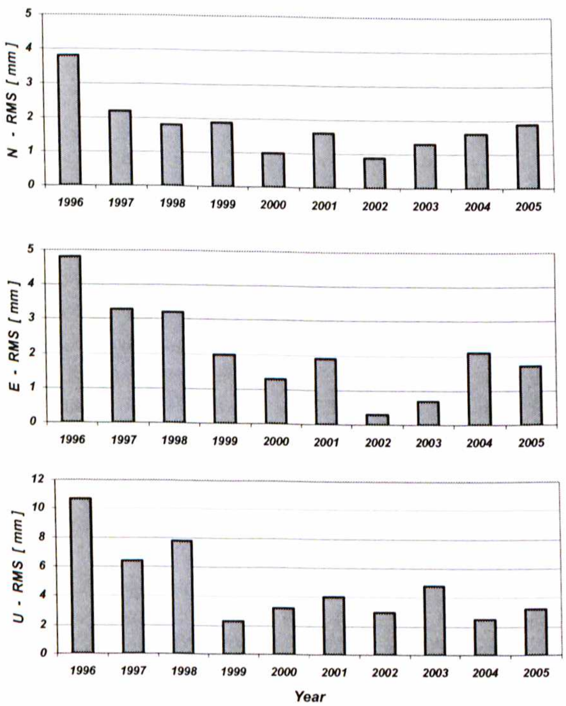

Fig. 4 GPS measurements accuracy – unweighted mean RMS of sessions

The clearly poorer accuracy for 1996, 1997 and 2001 campaigns results from non-homogeneity of observation data (different session lengths and antenna changes on points within single campaign).

OUTLIER TESTING

Estimators of the least squares method (LS) are strongly affected by outliers *(Hampel et al., 1986)*. The most of the GPS professional software (e.g. BERNESE) use the LS method to estimate the coordinate and velocity components. To avoid outlier influences the methods of robust estimation, the Huber's method of M-estimation (M) *(Huber, 1981)* and the Least Median of Squares method (LMS) *(Rousseeuw and Leroy, 1987)* were used. The velocity of individual sites were calculated from time series by the LS, M and LMS methods (see figure 5).

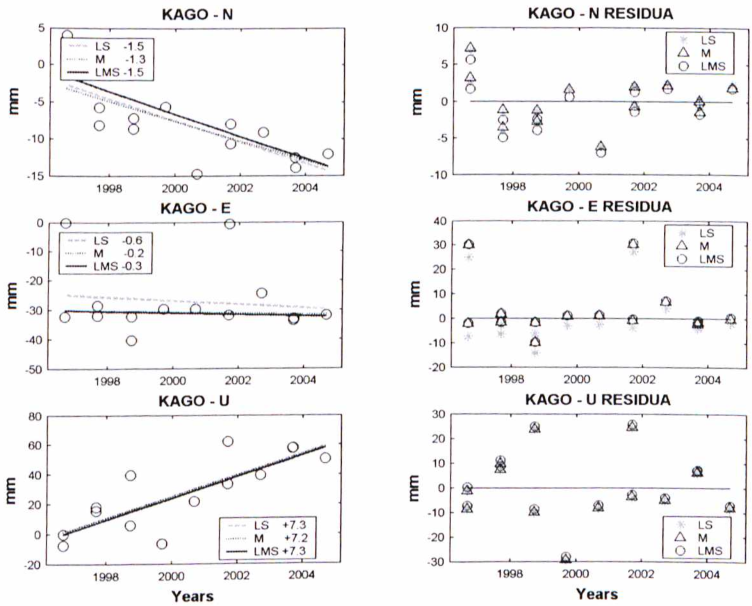

Fig. 5 Diagrams of the single point velocity estimation
LS – Least Squares, M – Robust M-Estimation with logistic weight function
LMS – Least Median of Squares

VELOCITY ESTIMATION

The GPS data of daily sessions of each annual campaign were processed by BERNESE software *(Hugentobler et al., 2001)*. Then site velocity components and satellite antenna phase center corrections were estimated. The linear model of site velocities and the unaffected by gross errors M-estimation method with the "logistic" weighting function were applied *(Kontny, 2003)*. The GPS observations on the local network with reference to selected permanent IGS/EPN stations allowed the velocity within the ITRF2000 reference frame and their reduction to intraplate velocities using geokinematic model APKIM2000 *(Drewes, Angermann, 2001)* to be calculated (figure 6).

STRATEGY OF VELOCITY ESTIMATION FOR LOCAL GPS NETWORK „GEOSUD"

Step 1 **Independent solution for each day, fixing weekly ITRF coordinates of one IGS point (BERNESE - NEQ files)**

↓

Step 2 **Transformation of current ITRF coordinates of reference points (IGS, EPN, SUDETES) from reference epoch 1997.0 to each observation day using current ITRF velocities**

↓

Step 3 **Transformation results from** *step 1* **to reference frame determined for each observation day computed in** *step 2* **(BERNESE - CRD and COV files)**

↓

Step 4 **ITRF Velocity estimation of GEOSUD Network Points using own MATLAB tools (robust M-estmation with logistic weight function and estimation of antenna offsets)**

↓

Step 5 **Relative (Local) Velocity estimation of GEOSUD Network Points by removing plate movement trend calculated from APKIM2000 Model (Drewes, Angerman 2001)**

Fig. 6 Steps of the velocity estimation procedure

The horizontal velocity vectors of the GEOSUD network points' linear movement with their 95% confidence ellipses estimated for the period 1996-2005 are presented on the figure 7.

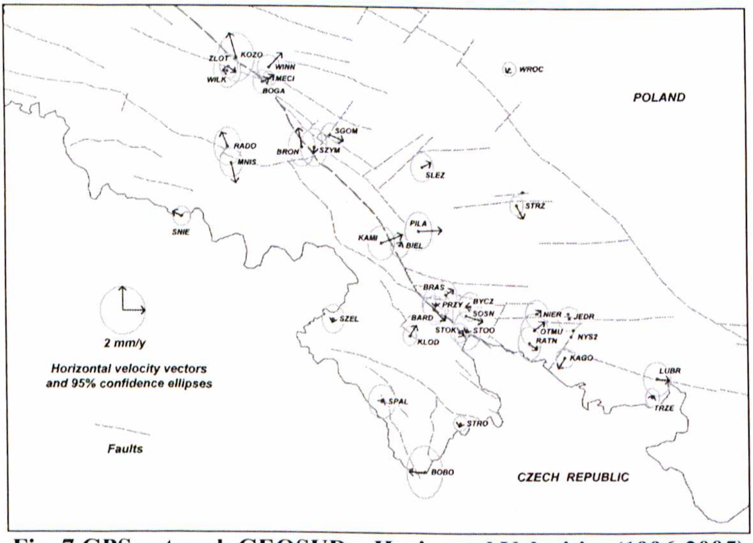

Fig. 7 GPS network GEOSUD – Horizontal Velocities (1996-2005)

Horizontal deformations of the Sudeten and Fore-Sudeten area for the observation period 1996-2004 were analyzed by Cacon et al. ***(2005).***

VERTICAL MOVEMENTS DETERMINATION

The Polish national 1st class leveling network is shown on the figure 8. Four leveling campaigns were performed: 1926-1937, 1947-1960, 1974-1979 and 1997-2003.

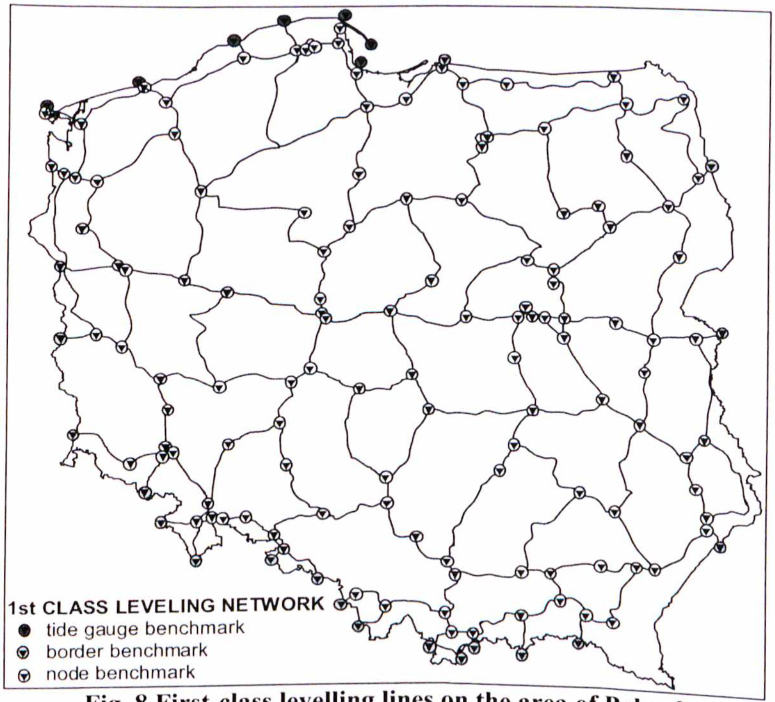

Fig. 8 First-class levelling lines on the area of Poland

The first reliable determination of vertical crustal movements on the area of Poland was carried using the leveling measurements from the years 1947-60 and 1974-79 *(Wyrzykowski, 1985)*. The map of vertical crustal movements for Poland is presented on the figure 9.

In 2003 the fourth leveling campaign has been finished in Poland. This campaign, together with the previous one carried out in 1974-1982, gave a very good opportunity to determine the new model of the land uplift in the area of Poland. The computation of relative land uplift, computation of land uplift referred to the mean sea level and modeling the land uplift by the least square collocation method was done by Kowalczyk *(2005, 2006)*. The new model for the whole territory of Poland is presented on the figure 10.

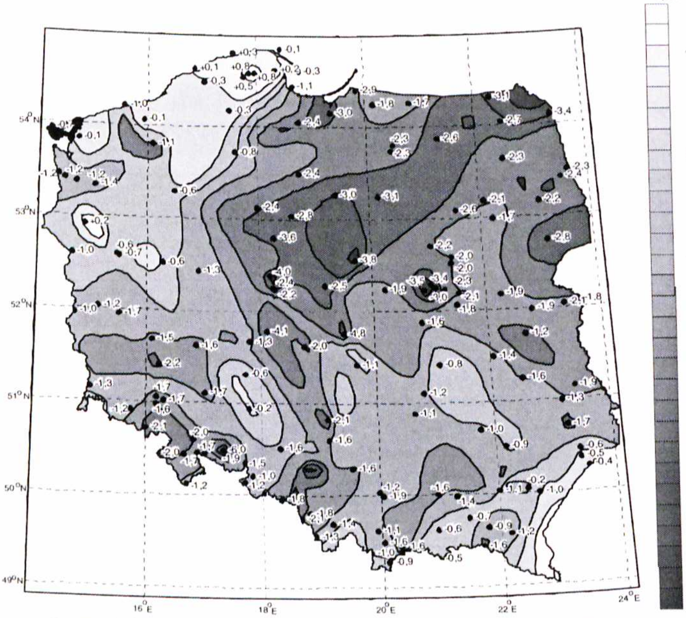

Fig. 9 Model of the surface vertical movement of the Earth crust on the area of Poland according to Wyrzykowski (1985)

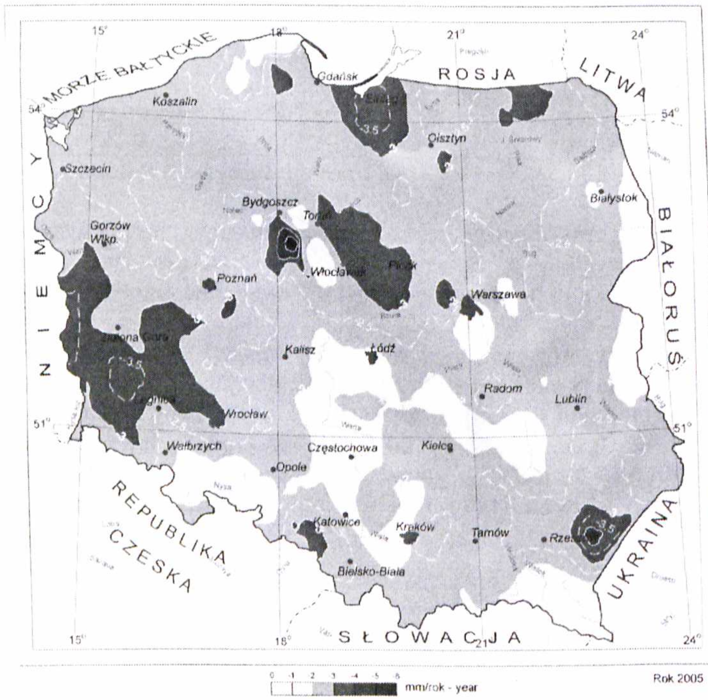

Fig. 10 Model of the surface vertical movement of the Earth crust on the area of Poland according to Kowalczyk (2006)

Vertical movements of the Earth crust surface for the area of Sudeten and Fore-Sudetic Block resulting from Wyrzykowski and Kowalczyk models are shown on the figures 11 and 12 respectively.

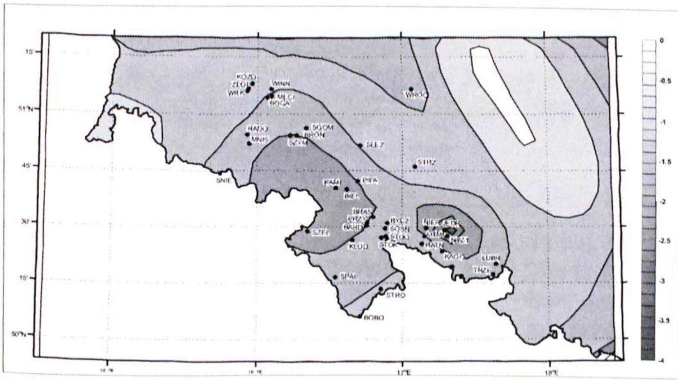

Fig. 11 Model of the surface vertical movement of the Earth crust on the area of SW Poland according to Wyrzykowski (1985)

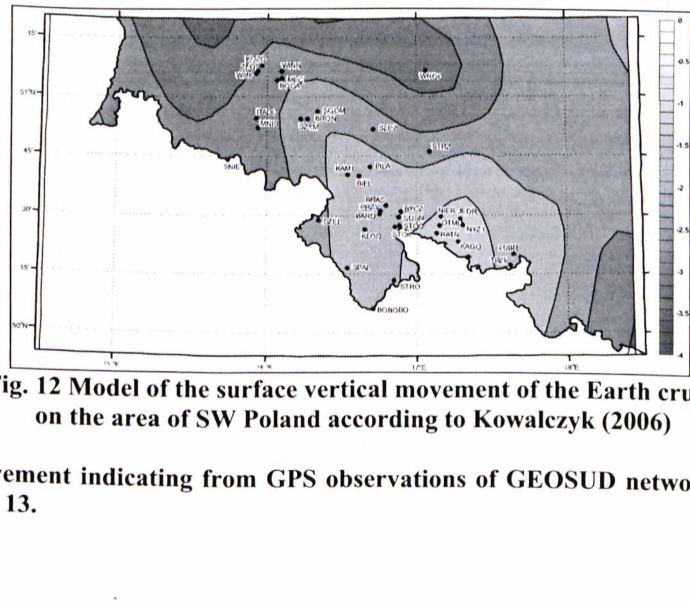

Fig. 12 Model of the surface vertical movement of the Earth crust on the area of SW Poland according to Kowalczyk (2006)

Vertical movement indicating from GPS observations of GEOSUD network are shown on the figure 13.

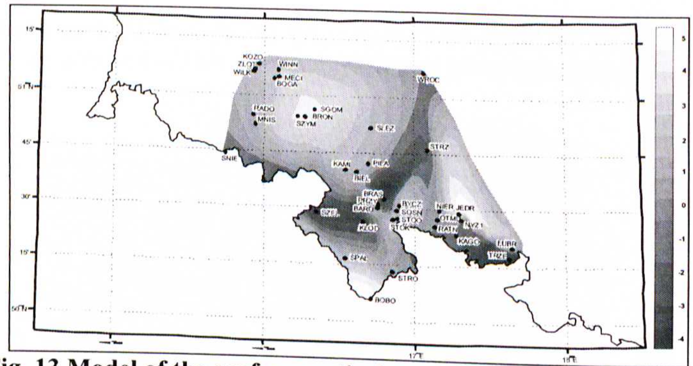

Fig. 13 Model of the surface vertical movement of the Earth crust on the area GEOSUD Network on the basis of GPS results

The accuracy of the vertical velocity determination (RMS 1-4 mm/y) from such short time series of epoch GPS measurements (5 - 9 years) unfortunately is not sufficient for comparison GPS results with leveling data.

CONCLUSIONS

Present-day results of nine year monitoring of the crustal movements in Lower Silesia (Sudetes and Sudetic Foreland) using epoch GPS observations indicate heterogeneous, local movements with mean velocities not exceeding of 1 to 2 mm/year. General picture of the horizontal velocity vectors is not clearly correlated with tectonics and difficult to interpretation. The Sudetic Marginal Fault zone near Bielawa, Strzegom and Złotoryja appear to be the most tectonically active, in view of GPS, and leveling results. Vertical movements derived from GPS and leveling measurements are not fully congruent and have to be analyzed in detail.

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