REGIONAL 2.5D MODEL OF DEFORMATIONS IN CENTRAL EUROPE FROM GNSS OBSERVATIONS: GENERAL ASSUMPTIONS OF PROJECT

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1. INTRODUCTION

The aim of project, started at the end of 2010, is to examine the possibility of construction of the present-day deformation model for Central Europe (focused on Poland) based on EUREF Permanent Network (EPN) and Polish multifunctional satellite network (ASG-EUPOS) data. It was a common sense that the ASG-EUPOS sites should not be used for geodynamical investigation purposes due to insufficient stabilization and fixing of antennas and not passable observation time span (the system has started in June 2008). In our experiment we are going to examine if using advanced mathematical analyses method we will be able to extract a credible geodynamical information from this set of "incredible" data. In order to build kinematic model of deformations, we are going to choose, from over 150 stations, these ones which best meet the measurement quality criteria, but also taking into account their localization in respect to structure of tectonic background. Robustness of geodetically-defined kinematic model in description of recent geodynamics will be tested by numerical finite element modelling of stress and strain distribution in analyzed region. Simplified mechanical model of the lithosphere will incorporate geological and geophysical data including tectonically defined discontinuities. Results of model predictions will be evaluated by comparison with measured present-day stress and strain. The set of data for geodynamic considerations could be broaden radically, allowing for characterization of strain field discontinuity.

2. DATA

The satellite observations, which will be used for this project will come from EPN network, densified by the data form Polish national network ASG-EUPOS. The stations chosen for the project are presented in figures 1 and 2.

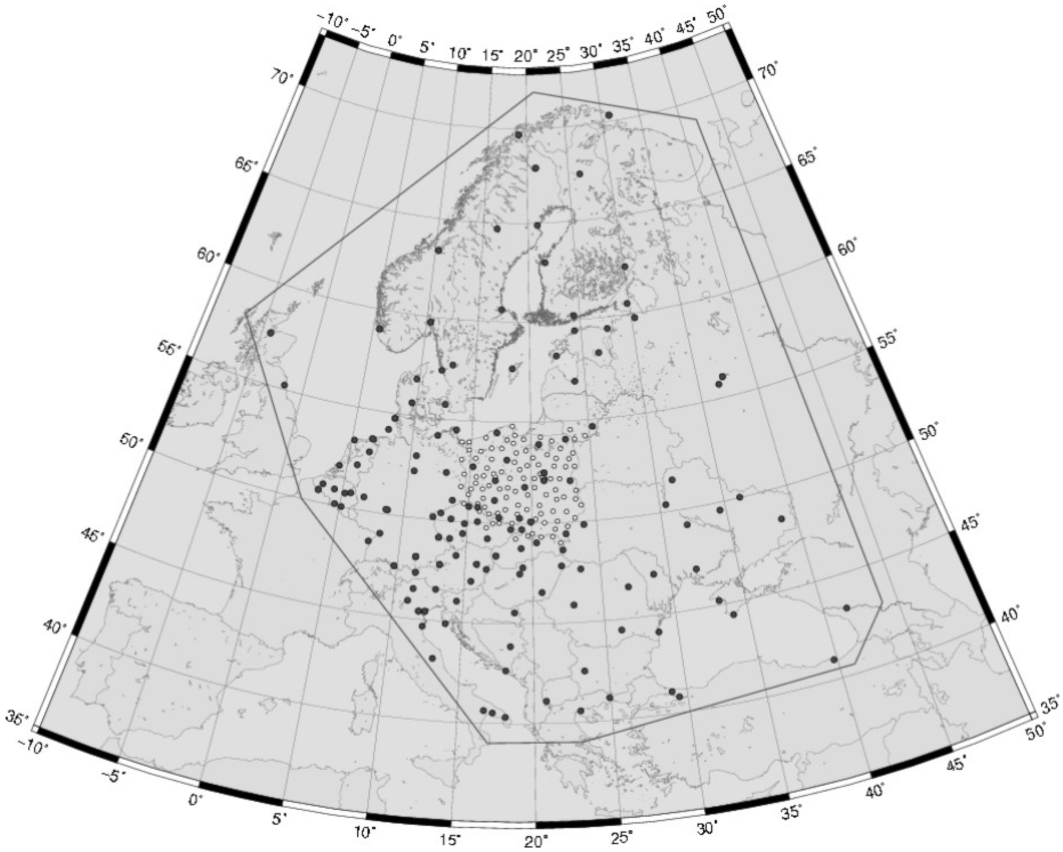

Fig. 1. EPN sites chosen for the project.

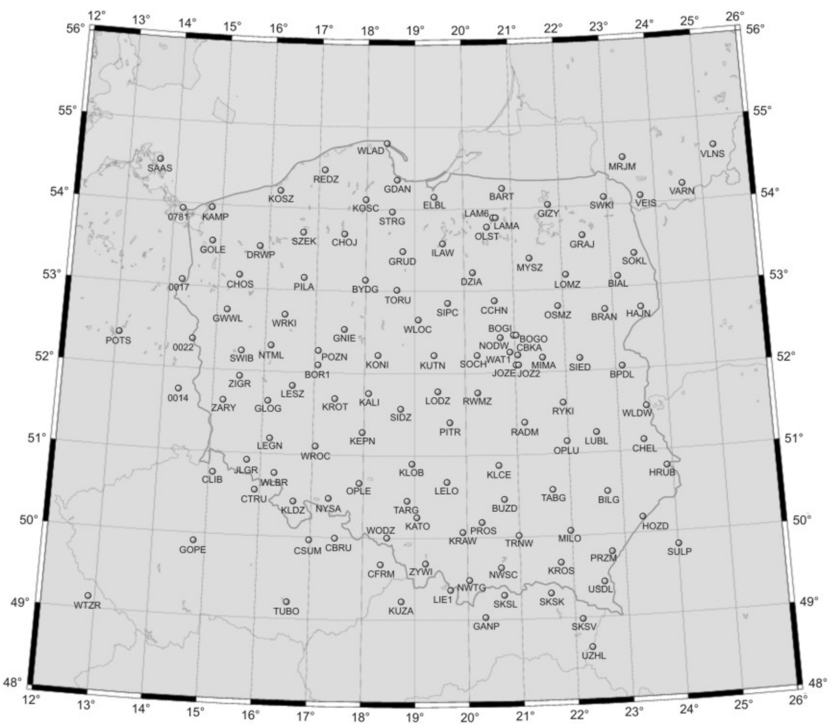

Fig. 2. ASG-EUPOS sites chosen for the project.

3. DATA PROCESSING MODULE

All measures were made according to EPN resolutions (3 degree mask and weighting observations using cos2z functions). The software used is Bernese 5.0 Bernese, Bernese Processing Engine (BPE, a set of perl scripts and „bash" system layer for automatic processing of GPS observations in Bernese) and Super BPE (a type of tasks dispersing on the cluster nods) modules are used. In pre-processing the full sampling rate of 30 seconds was used. The phase observations will be analyzed whereas code observations were used to estimate clock corrections. The method of double differences using an iono-free linear combination of frequency will be applied in this research as well as the absolute model of antennas' phase centres for stations, wherever feasible. The dry component of the Saastamoinen model with Dry-Niell mapping functions will be used a priori. For the wet part continuous piecewise-linear troposphere parameters will be estimated in 1-hour intervals without any a priori model using Wet-Niell mapping function. Loose relative and absolute constrains of 5.0 m will be applied. In addition continuous piecewise-linear east-west and north-south troposphere gradients with parameter interval of 24 hours will be estimated with no a priori constrains. Final adjustment will be based on the ionosphere-free combination of frequencies and the CODE (The Centre for Orbit Determination in Europe) global ionospheric model used to increase the number of solved phase ambiguities in the QIF, L5/L3 and L1/L2 methods. In this solution precise orbits and Earth Rotation Parameters (ERP) provided by the International GNSS Service (IGS) will be used. They are available with a delay of several days but provide capability to obtain results of high credibility. The method of phase ambiguities determination will depend on the length of the baselines between the individual antennas. For long baselines the QIF method with the CODE ionospheric model will be applied, for lines up to 200 km – L5/L3, for shorter than 20 km – L1/L2. The solid Earth tides will be eliminated using the IERS2003 model while the ocean tides with FES2004. No atmospheric loading corrections will be applied due to the lack of procedures in Bernese software. The final coordinates will be expressed in the ITRF2005 and ETRF2000 both at epoch 2005.0.

4. DATA VERIFICATION MODULE

Residual time series of solutions' (ETRF2000) will be analyzed to test the used models and to find error sources that could possibly affect solutions by decreasing their reliability (in the terms of precision). There are many doubts regarding proper antennas' placement – as they are mostly placed on the roofs, there were questions if data from these sites can be used for the purpose of geodynamical study, like intra-plate velocity or strain estimations. Analysis of daily solutions is supposed to prove that the majority of Polish sites give fully valuable data. Some factors that may cause a precision decreasing can be avoided or eliminated in the future. Time series of daily solutions will be analyzed in the context of:

- **long-term oscillations,**
- **seasonal disturbances,**
- **significant linear trends that could be assigned rather to buildings' than geodynamic movements.**

Periodic oscillations that can be noticed on several sites are probably related to the thermal influence. Since such sites are distributed evenly through the whole country, this effect obviously depends also on antenna placements by comparing time series to meteorological data it was proved that the highest peaks reaching few centimetres

occurred during extreme snowfalls. As the results of geodetic determinations and calculations there will be obtained:

field of plate velocities (ITRF);
field of intraplete velocities (ETRF);
horizontal strain rate analyses;
strain ellipses.

5. COMPARATIVE MODULE

At this stage results geodetic determinations will be compared to:

geological data about tectonic structure and neo-tectonic movements;
geophysical data about tectonic strain in the upper layer of the Earth's crust.

So far, stress directions in Poland, determined for almost 100 sites (see figure 3), show uniform but pretty consistent pattern (Jarosinski et al., 2006). In the East European Craton (eastern Poland) stresses keep stable direction with depth and change gradually across the region which suggests relative stability of the craton. Off of the craton, in the Trans-European Suture Zone stresses rotate very often, both with depth and between wells that point out to mobilization of this part of the crust. Dominant strike-slip stress regime in Poland prevails horizontal deformations. The recent stress picture will be improved soon due to good deal of new data stem from shale and tight gas exploration. Degree of consistency between the strain and stress directions should characterize deformations: if they are controlled by strain of continuum (good agreement) or by dislocations separating tectonic blocks (discrepancy between stress and geodetic strain directions).

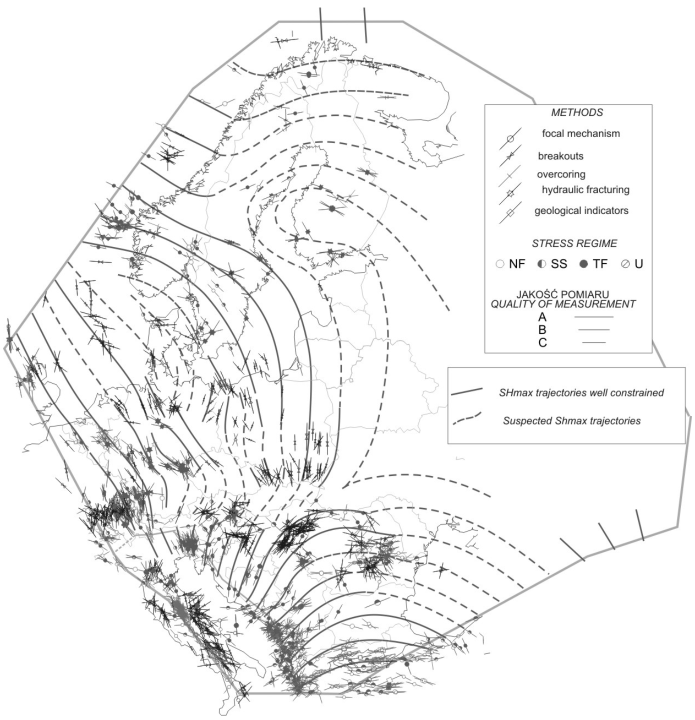

Fig. 3. Indicators of the recent stress field of Central Europe based on the World Stress Map database (Reinecker et al. 2003), supplemented by Roth & Fleckenstein (2001) and Jarosiński (2005a). SHmax trajectories are shown: well constrained (solid red line) and suspected (red dashed line). Stress regimes: NF- normal faulting, SS strike-slipfaulting, TF thrust faulting, U unknown.

In the next step, we are going to check consistency of the results of satellite geodesy measurements for central Europe by a mean of the finite element modelling of stress and strain using plane stress model and viscoelastic mechanics. Until now, an elastic model with contact elements was performed for this part of Europe (see figure 4), which was suitable for the present-day stress study but inappropriate for strain rate considerations. Based on the results of previous investigations it was predicted that the stress field in Central Europe is governed first of all by the push of the Adria block driven by advancing Africa, subordinate extension of retreating slab in the Hellenic subduction zone and the push of the North Atlantic ridge.

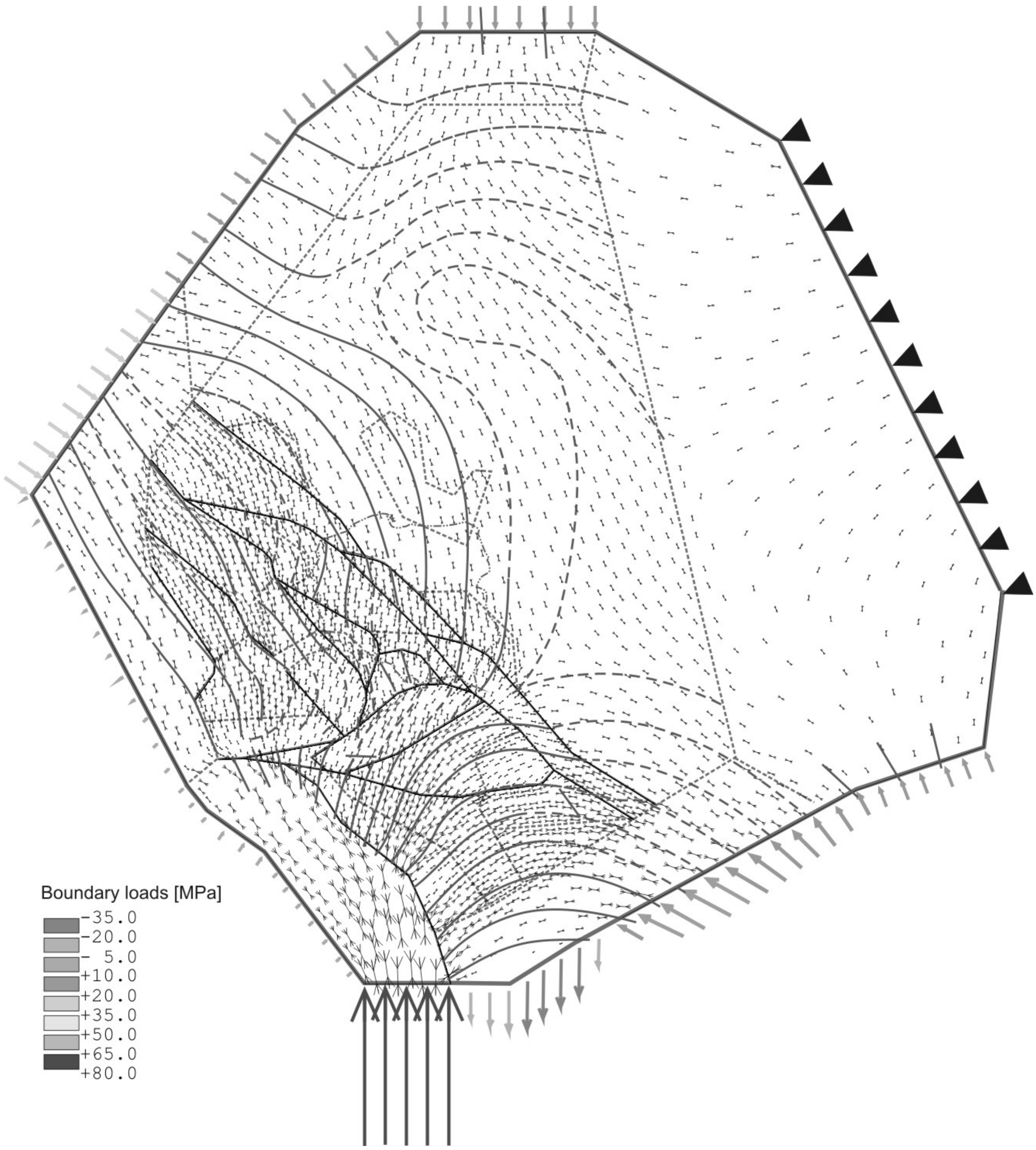

Fig. 4. Comparison between the modelled SHmax directions (arrows inside the model) and stress directions from data (trajectories). Arrows attached to the model's boundary indicate directions and magnitudes of external tectonic loads. Size of arrows and colour-scale indicate magnitudes of external loads averaged over a 100 km thick lithosphere. Black triangles point to the fixed boundary.

6. DEFORMATION MODELLING MODULE

The finite element method (FEM) is a numerical method for solving a differential or integral equations. This method could be used in many scientific areas because of its diversity and flexibility. The main advantage of this method is conversion from analytical problem to algebraic one. It means that it could be used for analysis in the cases of complex geometry models as approximate method. Mathematical description of every task is always the same. FEM requires the discretization of the domain (continuum) into subregions or cells called finite elements – the elements of finite dimensions and as simple form as possible.

On each element there are defined the specific points called nodes. Nodes always lie at the ends of linear element or on the edges that connected the adjacent flat or spatial elements. Triangular elements are the most popular because triangle element is always convex one. These elements are also the most convenient option to approximate complex geometry of domain. Each finite element has to be described by the shape function. These functions are used to interpolate the nodal displacements of any element to any point within each element. Shape functions interpolate studied phenomenon inside element and on its boundaries in local coordinate system. Solution of the problem consists of creation of the local stiffness matrices for each element and defined global matrix by aggregation of appropriate components of elements' matrices. Imposing of boundary conditions is also needed. The final stage of solution is solving system of linear equations and finding the final quantities. In essence, a complex problem reduces to considering a series as greatly simplified problems. FEM allows to avoid long and complicated analytical calculations in study of complex shapes and uses computer simulations to study distribution of forces in continuum model.

ABAQUS is a high-performance, general purpose finite element program, designed primarily to model the behaviour of solids and structures. Application offers powerful and complete solutions for both routine and sophisticated engineering problems. ABAQUS is among the more trustworthy codes. For this reason it is used in many different engineering fields throughout the world. It enables to do linear or nonlinear, static or dynamic types of analysis for a large spectrum of problems. It can deal with bodies with various loads, temperatures, contacts, impacts, and other environmental conditions. ABAQUS includes the following features:

- **abilities for both static and dynamic problems;**
- **ability to model complex shape changes in solids, in both two and three dimensions;**
- **a very extensive element library, including a full set of continuum, beam, shell and plate elements;**
- **a sophisticated capability to model contact between solids;**
- **an advanced material library, including the usual elastic and elastic – plastic solids; models for foams, concrete, soils, piezoelectric materials, and many others;**
- **capabilities to model a number of phenomena of interest, including vibrations, coupled fluid/structure interactions, acoustics, buckling problems, and so on;**
- **possibility to import geometry from a many different CAD software packages.**
- **each finite element analysis in ABAQUS applications involves four fundamental stages:**
  - **modelling (pre-processing);**
  - **finite element analysis (processing);**
  - **generating results (post-processing).**

7. EXPECTED RESULTS

First of all, we would like to verify if the satellite geodetic data from permanent stations, which are not dedicated to geodynamic measurements, can give meaningful information about crustal movements. However, due to minor geodynamic activity of Poland, which at the initial stage of survey can be characterized by low seismic activity, we do not expect spectacular motions. The precision of satellite geodetic methods are still not enough to measure a strain in craton areas. Nevertheless, the major portion of Poland covers Trans European Suture Zone, which can reveal notable deformations that we hope to point out. In the best case, having such a great number of stations, we will be able to show heterogeneity of deformation field and correlate it with major fault zones.

ACKNOWLEDGMENTS

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