Geometrical Analysis of Deformation Measurement using Continuum Mechanics by Web Application

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Key words: deformation analysis, continuum mechanics, XML, WMS, displacement vectors

SUMMARY

XML web application to on line calculation of deformation analysis from repeated positional geodetic measurement is described. Parameters of deformation field (strain and compression tensors, total dilatation) are determined in a quadratic network covering the total area of interest. Displacement vectors from repeated (stage) measurements at given stations of geodetic network serve as calculation input. The calculation is based on continuum theory of mechanics and as basic pre-requisite is homogeneity of the area in question. Nevertheless, it is a purely geometric solution.

Application makes use of WMS (Web Map Services) developed on the base of standards of Open Geospatial Consortia to graphic representation of calculated results in the form of GIS. User needs not own any geographic data to GIS creation and he may complete his actual thematic map of his chosen area, he may determine its content by himself and fill in graphical representation of results of deformation analysis calculation based on geodetic data as another layer.

There are also given examples of practical application based on reduction of repeated geodetic measurement demonstrating practical independence of calculated values of deformation tensors on rotations and translations of coordinate systems. This reflects the fact that the deformation analysis is a more objective indicating instrument of dynamics of the place in question than sole calculation and representation of vectors of station dilatations.

Essential principles, advantages and significances of applied technologies are shortly outlined to make clear chances of above-mentioned services. Application is at disposal to all interested after registering to on-line calculation using Internet.

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1. INTRODUCTION

Analysis of horizontal deformations for determination of geodynamics of the territory in question does do belong to work solved by many geodesists in their everyday praxis. This is the reason why geodesist do not have the software needed to its solution normally at hand. Such calculations are quite fastidious and requirements on theoretical knowledge as well. At this moment possible using of web applications seems to be reasonable. The following could be mentioned as their main advantages:

- The user does not need to have necessary theoretical knowledge to solve more complicated work — it is quite enough to be acquainted with principles of solution, its matter-of-fact and limitations in application;
- The user does not need software normally needed for calculations that are not common or complicated;
- Calculations realised as on-line web application guarantee that needed methods and procedures comply with given applications that may arise from given technology and enable later comparing with calculation based on another software;
- XML web applications make application interconnection of different producers. Individual application servers may be based on technologies of various companies; nevertheless they are intercommunicative thanks to standardized interface. The existing XML interface and its DTD description is required naturally.

The user could have at his disposal a tool for calculating that would solve successfully also work that is not quite common in praxis.

2. DESCRIPTION OF THE APPLICATION, INPUT AND OUTPUT VALUES

We shall describe quite shortly the principle of deformation analysis based on repeated measurement of a geodetic network. We shall think only about the geometric solution and all needed for this paper will be very simplified.

Parameters of discretely formulated field of displacements are calculated first. Such displacements are interpolated values in a graticule. Based on such values parameters of also discretely calculated field of deformation represented by strain tensors (extensions and compressions). Theoretical solution and derivation of formulas in question may be found in many publications — e.g., [Altiner 1999], [Talich 1994] and [Talich, Kostelecký, Vyskočil 1993]. We shall hint shortly its principle to know at least what is the result of calculation.

We do not determine position of points in a normal way as it is done by geodesists, but we want to determine their displacements and later the network deformation regarded by us to be deformation of the territory in question (in the case of fulfilled conditions regarding distribution of geodynamical points, homogeneity of the territory in question, etc.). The calculation is based on the theory of continuo mechanics.

As it was told earlier, the principle of geodetic methods applications is based on repeated measurement and comparison of results of individual stages of measurements. Obtained differences in positions of points represent their displacements. The vector of point displacement is

$$\mathbf{d}_i = (u_1, u_2, u_3)_i^T = \mathbf{x}_i^o - \mathbf{x}_i^t$$

Where $\mathbf{x}_i^o$ (resp. $\mathbf{x}_i^t$) is the vector of P_i point coordinates of fundamental (resp. actual in t-time) stage. This vector may be expressed as a function of coordinates:

$$\mathbf{u} = (u_1, u_2, u_3)^T = \mathbf{u}(\mathbf{x}) = (u_1(\mathbf{x}), u_2(\mathbf{x}), u_3(\mathbf{x}))^T = \mathbf{d}, \quad \mathbf{x} = (x, y, z)^T$$

The strain tensor in P_i is defined as a gradient of the function in this point:

$$\mathbf{E}_i = \begin{pmatrix} \varepsilon_{11} & \varepsilon_{12} & \varepsilon_{13} \\ \varepsilon_{21} & \varepsilon_{22} & \varepsilon_{23} \\ \varepsilon_{31} & \varepsilon_{32} & \varepsilon_{33} \end{pmatrix}_i = \mathrm{grad}(\mathbf{d}_i) = \begin{pmatrix} \frac{\partial u_1}{\partial x} & \frac{\partial u_1}{\partial y} & \frac{\partial u_1}{\partial z} \\ \frac{\partial u_2}{\partial x} & \frac{\partial u_2}{\partial y} & \frac{\partial u_2}{\partial z} \\ \frac{\partial u_3}{\partial x} & \frac{\partial u_3}{\partial y} & \frac{\partial u_3}{\partial z} \end{pmatrix}_i$$

In the displacement field is valid next relation, see [Welsch 1983]:

$$\mathbf{d}_i = \mathbf{E}_i \, \mathbf{x}_i + \mathbf{t}$$

where
- $\mathbf{d}_i$ is the displacement vector,
- $\mathbf{E}_i$ is the displacement gradient,
- $\mathbf{x}_i$ is the coordinate vector,
- $\mathbf{t}$ is the vector of translation elements.

The strain tensor may be divided into two parts:

$$\mathbf{E}_i = \mathbf{e}_i + \mathbf{\Omega}_i = (e_{jl})_i + (\omega_{jl})_i \quad j,l = 1,2,3$$

where:
- $\mathbf{e}_i$ is the symmetric tensor of deformation,
- $\mathbf{\Omega}_i$ is the antisymmetric tensor of rotation,
- $e_{jl} = (\varepsilon_{jl} + \varepsilon_{lj}) / 2$,
- $\omega_{jl} = (\varepsilon_{jl} - \varepsilon_{lj}) / 2$.

$$
\mathbf{e}_i = \begin{pmatrix} e_{11} & e_{12} & e_{13} \\ e_{12} & e_{22} & e_{23} \\ e_{13} & e_{23} & e_{33} \end{pmatrix}_i = \begin{pmatrix} \varepsilon_{11} & \frac{1}{2}(\varepsilon_{12}+\varepsilon_{21}) & \frac{1}{2}(\varepsilon_{13}+\varepsilon_{31}) \\ \frac{1}{2}(\varepsilon_{12}+\varepsilon_{21}) & \varepsilon_{22} & \frac{1}{2}(\varepsilon_{23}+\varepsilon_{32}) \\ \frac{1}{2}(\varepsilon_{13}+\varepsilon_{31}) & \frac{1}{2}(\varepsilon_{23}+\varepsilon_{32}) & \varepsilon_{33} \end{pmatrix}_i
$$

$$
\Omega_i = \begin{pmatrix} 0 & \omega_{12} & \omega_{13} \\ -\omega_{12} & 0 & \omega_{23} \\ -\omega_{13} & -\omega_{23} & 0 \end{pmatrix}_i = \begin{pmatrix} 0 & \frac{1}{2}(\varepsilon_{12}-\varepsilon_{21}) & \frac{1}{2}(\varepsilon_{13}+-\varepsilon_{31}) \\ -\frac{1}{2}(\varepsilon_{12}+-\varepsilon_{21}) & 0 & \frac{1}{2}(\varepsilon_{23}+-\varepsilon_{32}) \\ -\frac{1}{2}(\varepsilon_{13}+-\varepsilon_{31}) & -\frac{1}{2}(\varepsilon_{23}+-\varepsilon_{32}) & 0 \end{pmatrix}_i
$$

It could be written:

$$
\mathbf{d}_i = (\mathbf{e}_i + \mathbf{\Omega}_i)\,\mathbf{x}_i + \mathbf{t}
$$

We could determine the deformation parameters from $\mathbf{e}_i$ and $\mathbf{\Omega}_i$. This may be dome as a 3D solution as well as in plane. Such plane could be e.g., parallel with XY or XZ or YZ or in a more general way any plane of the local coordinate system to which space displacements will be projected.

It holds e.g., for displacements projected to XY of the local coordinate system:

$\Delta = e_{11} + e_{22}$	- total dillatation
$\gamma_1 = e_{11} - e_{22}$	- shear strains
$\gamma_2 = 2e_{12}$	- shear strains
$\gamma = \sqrt{\gamma_1^2+\gamma_2^2}$	- total shear
$\varepsilon_1 = \frac{1}{2}(\Delta + \gamma)$	- maximum strain
$\varepsilon_2 = \frac{1}{2}(\Delta - \gamma)$	- minimum strain
$\varphi = \frac{1}{2}\,\mathrm{arctg}(\gamma_2/\gamma_1)$	- direction of axis of maximum strain
$\psi = \varphi + \frac{1}{4}\pi$ pro $\omega_{12} > 0$	- direction of shear strain
$\psi = \varphi - \frac{1}{4}\pi$ pro $\omega_{12} < 0$	- direction of shear strain

It is worth noting that all displacements depend on selected coordinate frame. On contrary, all deformation parameters of last equations except the ψ and φ directions are on used coordinate frame independent, and insensitive to translation and rotation. It means that **only deformations represent an objective measure to detect real geodynamic trends in the territory under review**. This is also the reason of their calculation and practical application.

Parameters given in last equations are also resulting values determined by the web application. Factual relations of calculation applied in this web application are described in more detail in [Kostelecký 1986] based on the described earlier classic off-line programming application. This application was the source of creating the actual XML web application.

Summarizing we find as **application input**:

- Approximate coordinate values of given points of geodetic network;
- Displacements values of given points of geodetic network (coordinate differences of individual stages of measurement);
- Numbers of given points of geodetic network;
- Text commentaries and other by application on-line required information (type of coordinate system, parameters of grid (quadratic net) used to interpolation and calculation, scales of network, displacements and deformation, selection of representation elements, etc.);
- Special entry is represented by figures of map background offered by servers with WMS. (This will be treated in more detail later).

Note: As input may serve instead of preliminary coordinates and displacements values of given points values of coordinates from two stages of geodetic network measurement and applications based on their difference will determine displacements values.

Application output are represented by:

- Calculated values of interpolated dilatations in a grid (discrete representation of displacements field);
- Calculated values of deformations in the same grid (also in discrete representation);
- Graphic representation of translations and deformations on a map;
- Possible input of topographic background in the map with results using WMS;
- Output values are in XML (GML, SVG) format, there is also the text record and graphic ESRI Shapefile.

Inputs are on-line transmitted by client via Internet application to server. At the present state of semi finished application the input data have the format of simple text file and in some cases in XML format.

Outputs are transmitted from server to client. They are either in a simple text format of computer record or in XML format. This format consists of a **GML** file containing point data about input points, computed translations and deformations including reliability of network used by the client. Another XML output is the SVG file. Last possible graphic output is represented by **ESRI Shapefile** [ESRI].

3. WMS AND ITS APPLICATION FORM

Last time more and more Internet map application rise. These applications are using the Web Map Service – WMS. They are mostly services defined by Open Geospatial Consortium (OGC – http:// http://www.opengeospatial.org/) [OpenGIS].
He main contribution of web map services defined according to the Open Geospatial Consortium is **GIS data sharing in distributed Internet environment.** Users can share

maps and applications and do not need to have such data in their computer or server. A typical example is the on-line representation of complex thematic map containing data from different servers in the Internet viewer (thin client) or any desktop GIS programme (thick client).

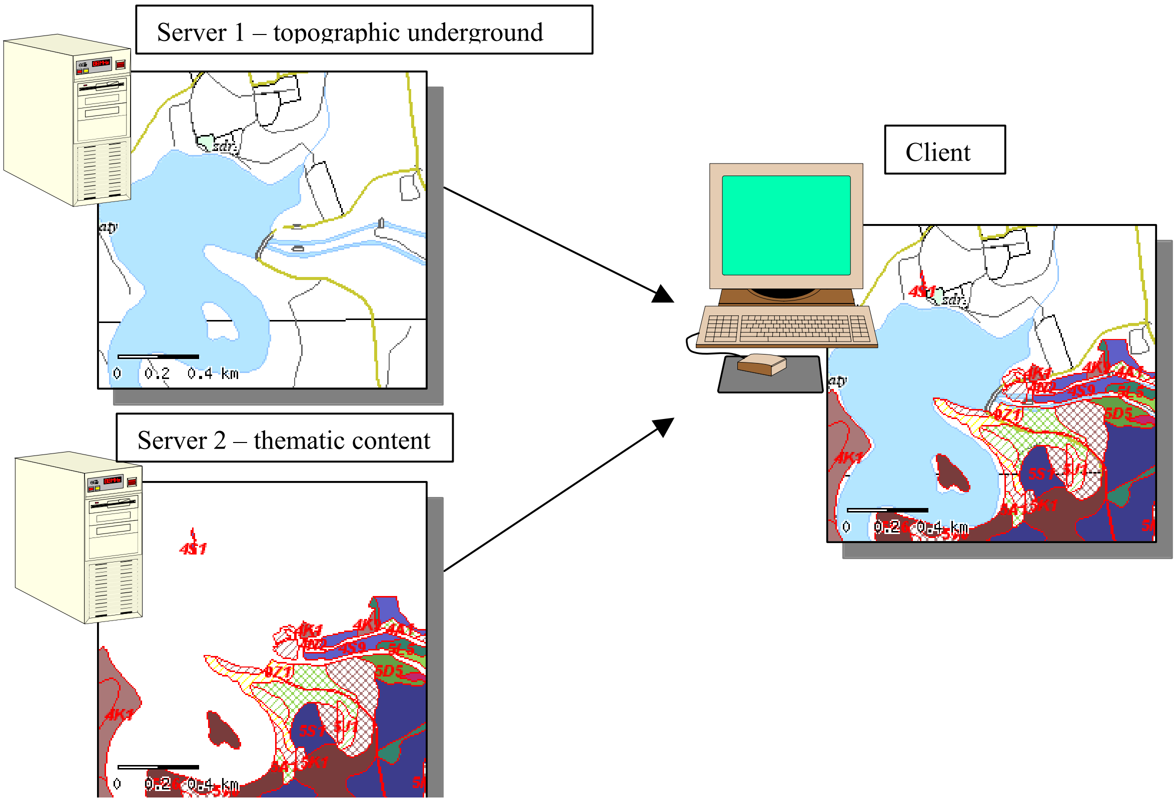

Fig. 1: Example of WMS

And exactly the same way a complex data infrastructure can be formed at any scale, i.e., at national or supranational one. Figure 1 schematically presents an example of a client on-line forming his own thematic map using backgrounds from different servers via Internet or Intranet.

Main advantages of practical application of Web Map Services (WMS) are derived, i.e., from their on-line rendition. Let us name at least some of them for our application:

- The user does not need having necessary data in his computer;
- The user has access only to the final picture formed from data in the WMS case. This may reduce the risk of misuse and not allowed dissemination of original data;
- A simple application is generally sufficient at the user side and access and data using (thin client, e.g., web browser);
- The user uses but services and data that he needs indeed;
- The user does not depend on any software platform and normally even does not distinguish what software the server in question does use.

In our presented application of deformation analysis is the WMS used to **including topographic underlay to graphic representation of input values of determined applications.** The user receives thic way a well-arranged output showing geodynamic activity of the studied region.

This function is supported by freeware (Open Source license) **mapping server Mapserver** from the University Minesotta, USA [Mapserver]. It is a very efficient CGI application offering many functions of map drawing via Internet and supporting the WMS according the OGC specifications. It works in UNIXU (e.g., Linux), as well as in Microsoft Windows.

4. EXAMPLES OF APPLICATIONS

The first example is the application of **monitoring of movements in the undermined territory of the Ostrava-Karviná Coal Basin in the Czech Republic** where trigonometric network renewal took place between 1974 and 1980. The accuracy of measurement of trigonometric network in the frame of its renewal is not large, nevertheless compared with accuracy of special geodynamical networks it may be stated that large motions are to be expected in this undermined region and that even the classic technology of that epoch may identify them. Results are shown on figures 2 and 3.

We see quite clearly that simplified interpretation of results offers identifiable regions where the given and also interpolated motion converge and their corresponding regions with high values of compressions or extensions. Motions (of more than 0,5 m) and their corresponding deformations are really large and this gives clear and reliable determination of such regions. Fig. 3 illustrates details of one region demonstrating given motion at the points of geodetic network and deformations based on these data.

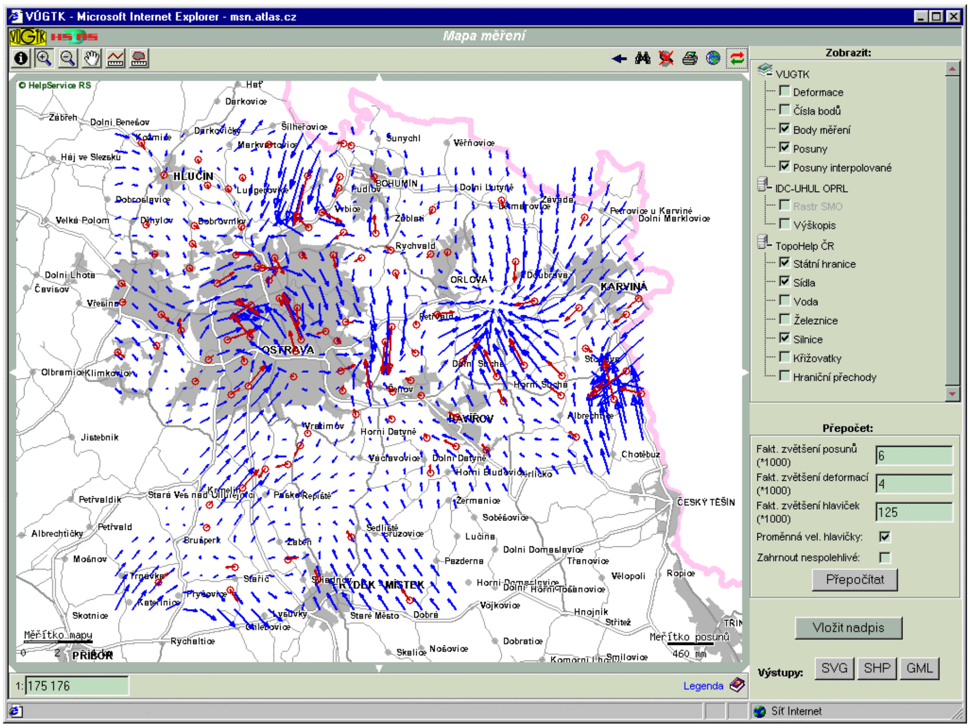

Fig. 2: Resulting interpolated movements of Ostrava network

The second example is **evaluation of GPS measurement on the Czech-Polish boundary** in the frame of the **GEOSUD** network since 1996 [Cacon at al. 2005]. Figures 4 and 5 give field of final motions interpolated in a quadratic network. In the case of fig. 4 the measured displacements are in ITRF, their values were more than 2 cm and fig. 5 shows the same displacements after being reduced to the "local" system chosen according the suitable model of tectonic plate motion. Here they are up to 4 mm large.

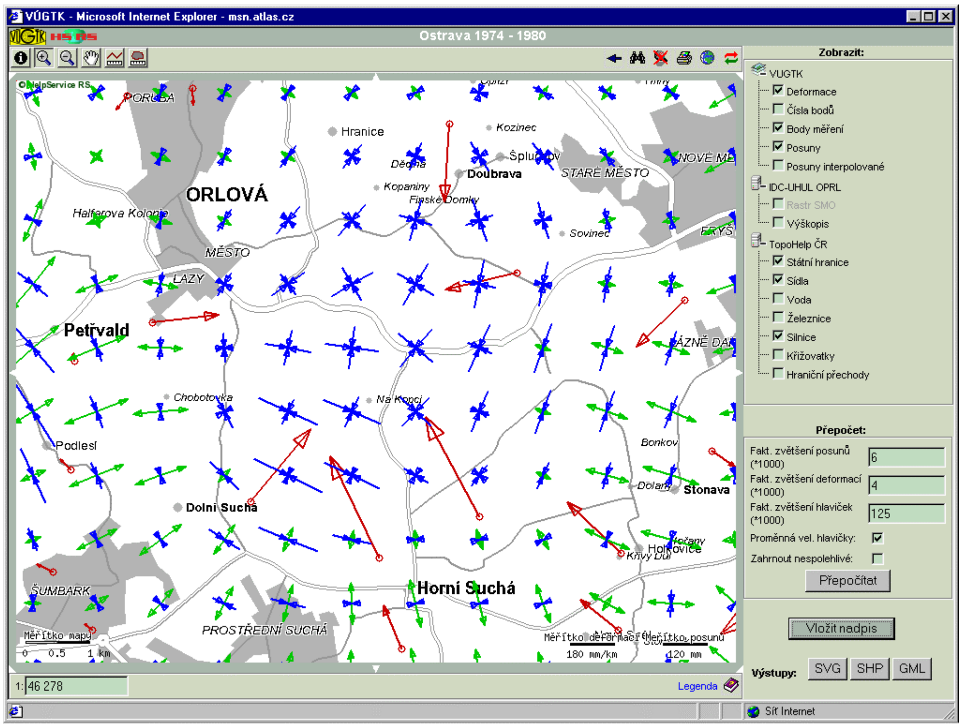

Fig. 3: Outline with given displacements and determined deformations of Ostrava network

While the GPS kind of measured displacements follows mostly the motion of the whole tectonic plate in the same direction the sort of "residual – local" displacements is after their reduction quite different. Even so the residual values of the deformation field determined from both of fields are quite identical (fig.6) and calculations confirm the independence of tensor deformation values on rotations and translations of coordinate systems. This is a proof showing that calculation of tensor values does not need reduction according the tectonic plate motions.

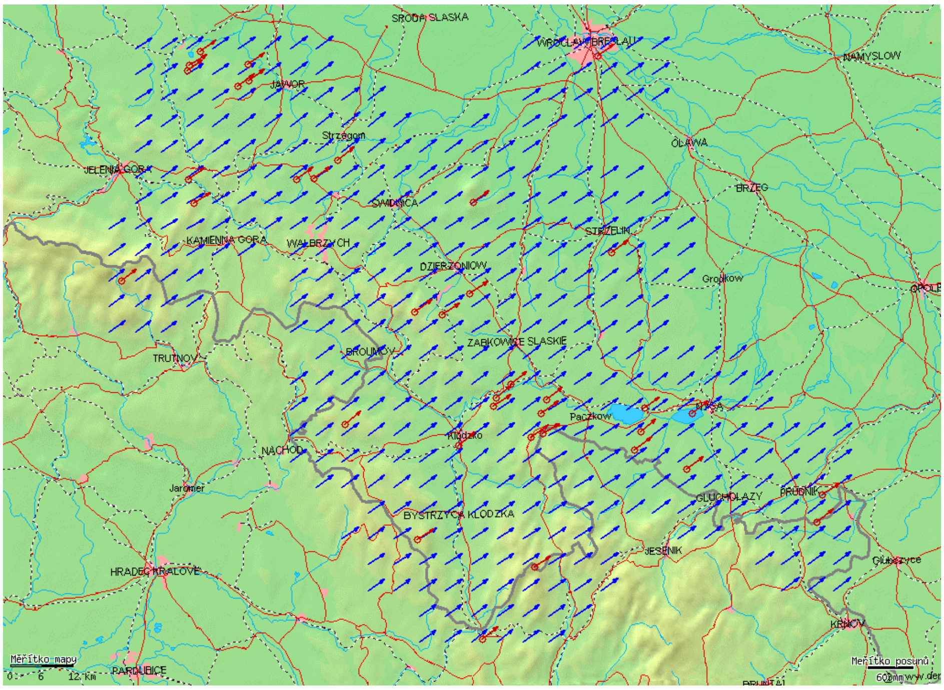

Fig. 4: Measured displacements in ITRF

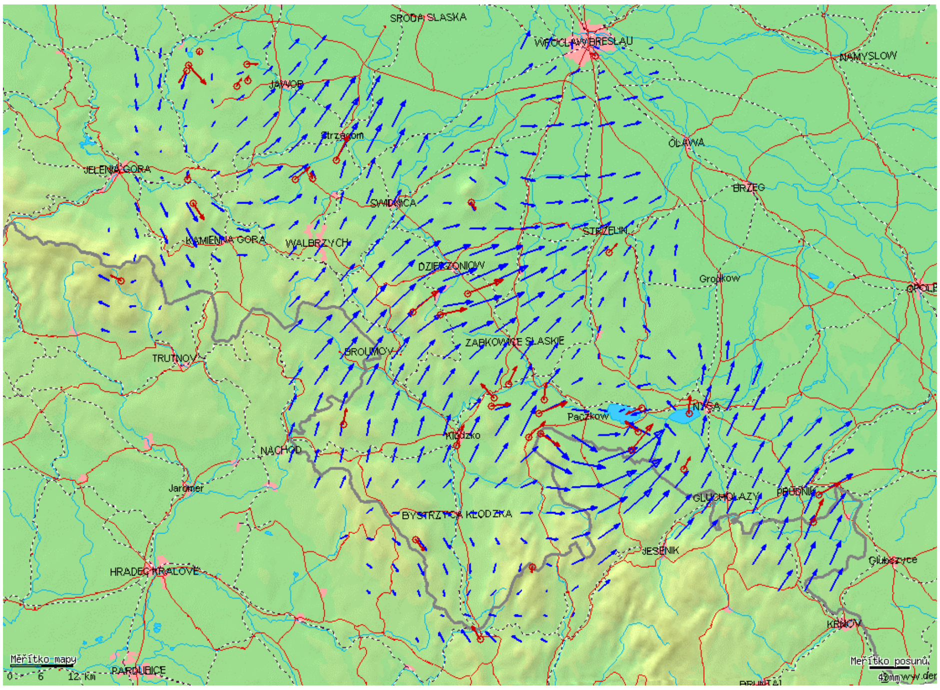

Fig. 5: “Local” displacements after reduction using tectonic plate motion model

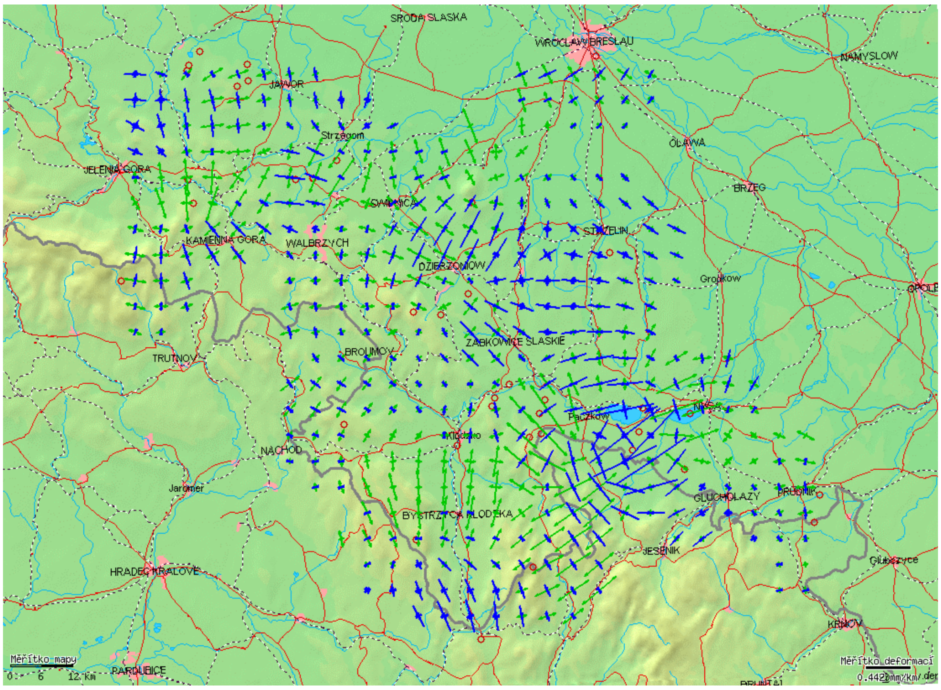

Fig. 6: Resulting deformation field

5. CONCLUSION

This paper was written as basic information about the existence of web application to on-line calculation of analyses of horizontal deformations from repeated geodetic measurements. This application is free at disposal of all persons interested in applying it on URL: http://www.vugtk.cz/~deformace/. An ordinary user does not need either detailed theoretic knowledge of deformation analysis computing nor the necessary SW tool. Calculations are done on-line on server, the user gives only the way to his data and becomes back a protocol about computation including graphic representation of results. He may also include topographic underlay in his graphic representation using the WMS and thus have more easy interpretation. Input data may be included in plain text file format or XML format. Using XML format makes more easy applying to other applications preceding forming input data in processing (e.g., application of adjusting geodetic position networks or GPS calculations). Other details are on the above referred web pages.

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BIOGRAPHICAL NOTES

Milan Talich was graduated from the Czech Technical University in Prague, Faculty of Civil Engineering, Department of Geodesy and Cartography. Then he was engaged in the Research Office of Geodesy, Topography and Cartography (VÚGTK), working since 1987 in the International Centre on Recent Crustal Movement (ICRCM) at geodetic networks processing and geodynamic problems. In 1992 - 1993 he was at one-year stage in the Institute of Applied Geodesy in Frankfurt/Main (IfAG), where he compiled the Czech, Slovak and Hungarian parts of the European Reference System (EUREF) GPS network. Then he was engaged in solutions of GPS processing oriented to geodynamic applications and to questions related to deformation analysis of those data. Since 1995 he solved some problems of informatics in the Branch Information Centre (ODIS) of the VÚGTK. At present he works at information systems oriented to web information as a leader of ODIS. In 2002, Milan Talich presented his doctorial thesis "Information Systems to On-Line Providing of Geodetic Information and Their Creation".

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