

WEB APPLICATION TO DEFORMATION ANALYSIS OF REPEATED GEODETICAL MEASUREMENT USING WMS

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Abstract: The paper describes XML web application to on-line calculation of deformation analyses of repeated geodetic measurement using Internet. Parameters of deformation field (extension and compression tensors) are determined in a square network covering the area in question. Calculation input is represented by vectors of movements of repeated measurements (in stages) on given points of survey network. Calculation is based on application of theory of continuum and as basic condition is homogeneity of surveyed territory. This application simultaneously uses Web Map Services (WMS) developed on the base of Open Geospatial Consortium standards as applied to graphical representation of calculated results as GIS. Such services e. g., on-line construction of thematic maps, defined by the user from data given by servers offered the WMS services, in a window of an Internet viewer. The user does not need to own any geographic data to create GIS. Nevertheless he is able to compose his actual thematic map of the chosen territory with content that is defined by himself and add to it graphic representation of results of deformation analysis his survey data as next layers. Principles, advantages and importance of applied technologies are explained shortly too, to make the reader understand chances given by these services in full extend. Further are examples of practical application on locations of area of coal basin Ostrava (NE Bohemia) and on the Czech-Polish border line. These examples demonstrate in praxis that values of calculated deformation tensors are independent on rotation and translation of coordinate systems. This speaks for the fact, that deformation analysis is more objective proof of dynamics on the territory in question as the sole calculation and representation of displacement vectors. Application is ready to on-line calculation using Internet for all interested people.

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., [1], [2] and [3]. 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

$$\mathbf{d}_i = (u_1, u_2, u_3)_i^T = \mathbf{x}_i^0 - \mathbf{x}_i^t$$

Where \mathbf{x}_i^0 (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:

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

In the displacement field is valid next relation, see [4]:

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

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:

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

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

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

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

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 done 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:

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

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 [5] 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** [7].

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://www.opengeospatial.org/>) [8].

The 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).

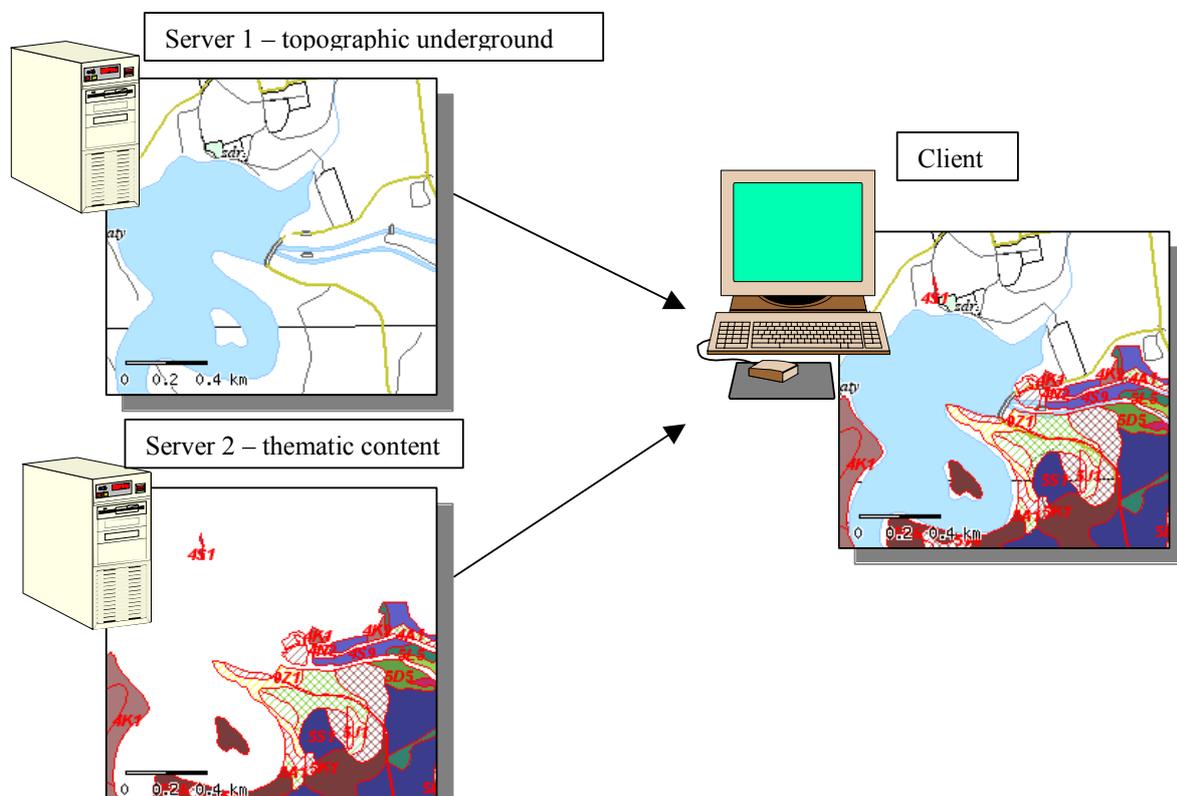


Figure 1: Example of WMS

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 do **including topographic underlay to graphic representation of input values of determined applications**. The user receives this 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 Minnesota, USA [9]. 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.

The second example is **evaluation of GPS measurement on the Czech-Polish boundary** in the frame of the **GEOSUD** network since 1996 [10]. 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.

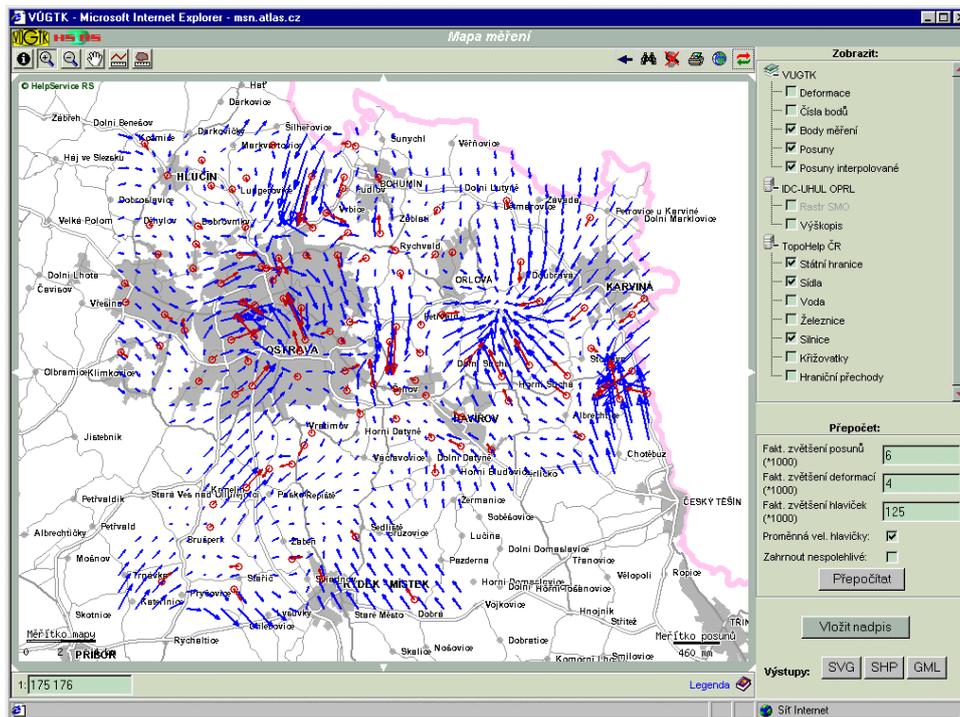


Figure 2: Resulting interpolated movements of Ostrava network

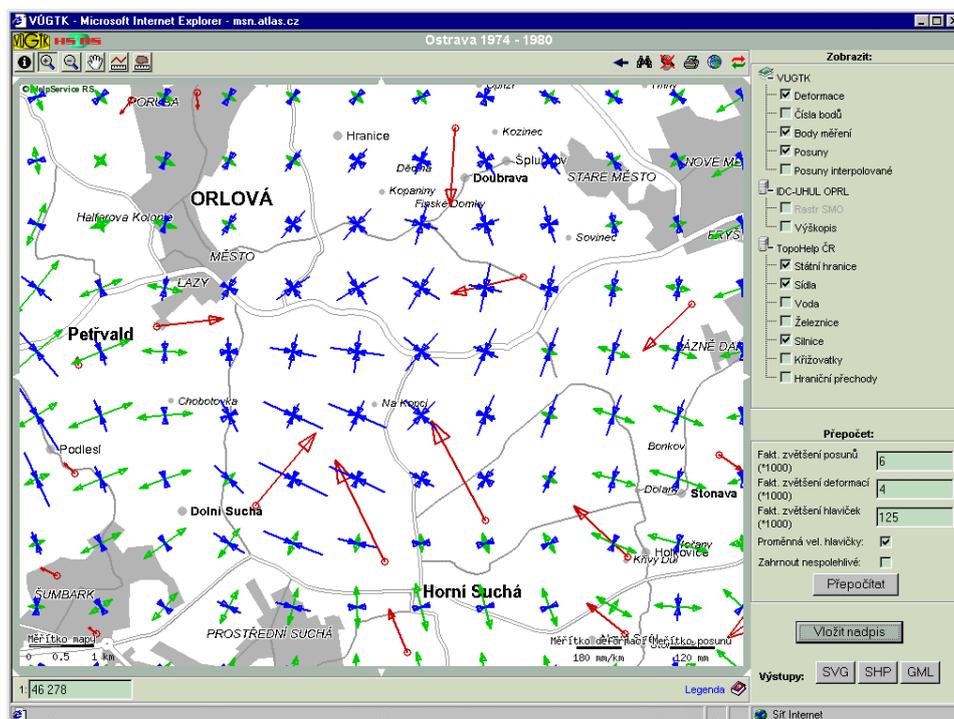


Figure 3: Outline with given displacements and determined deformations of Ostrava network

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.

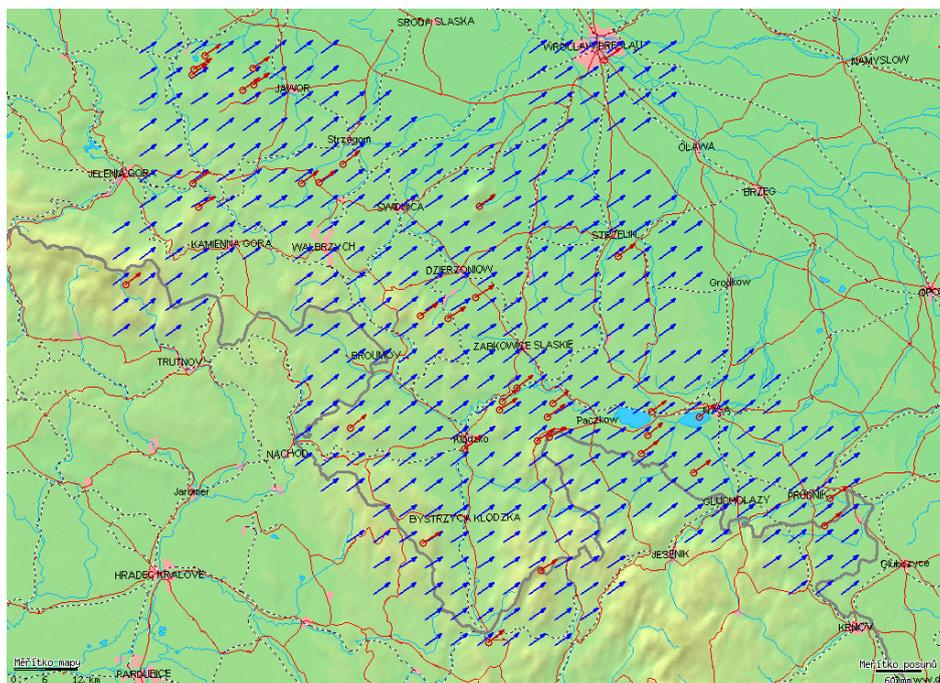


Figure 4: Measured displacements in ITRF

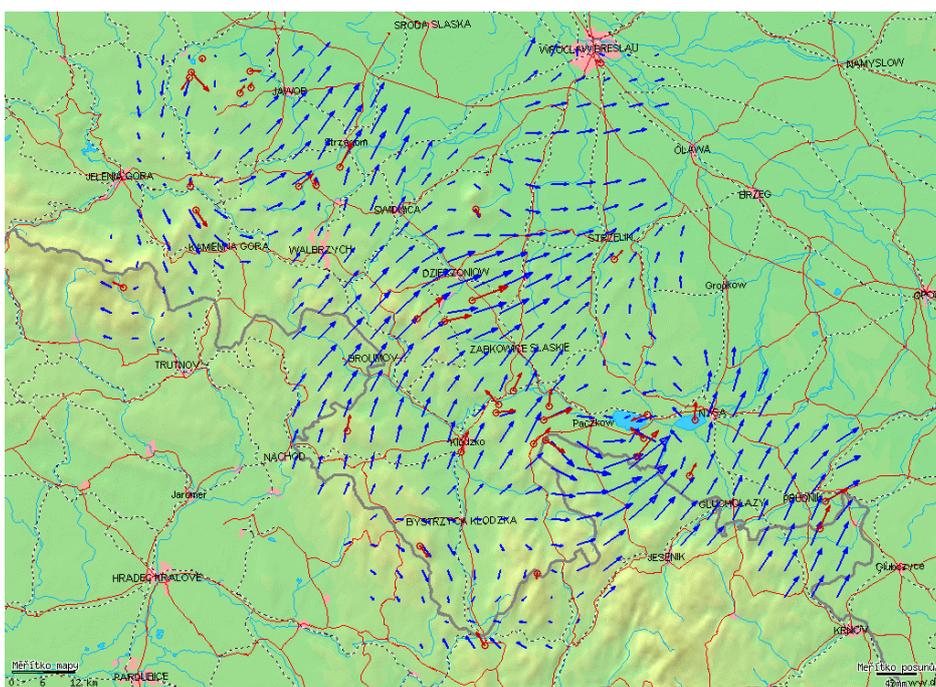


Figure 5: “Local” displacements after reduction using tectonic plate motion model

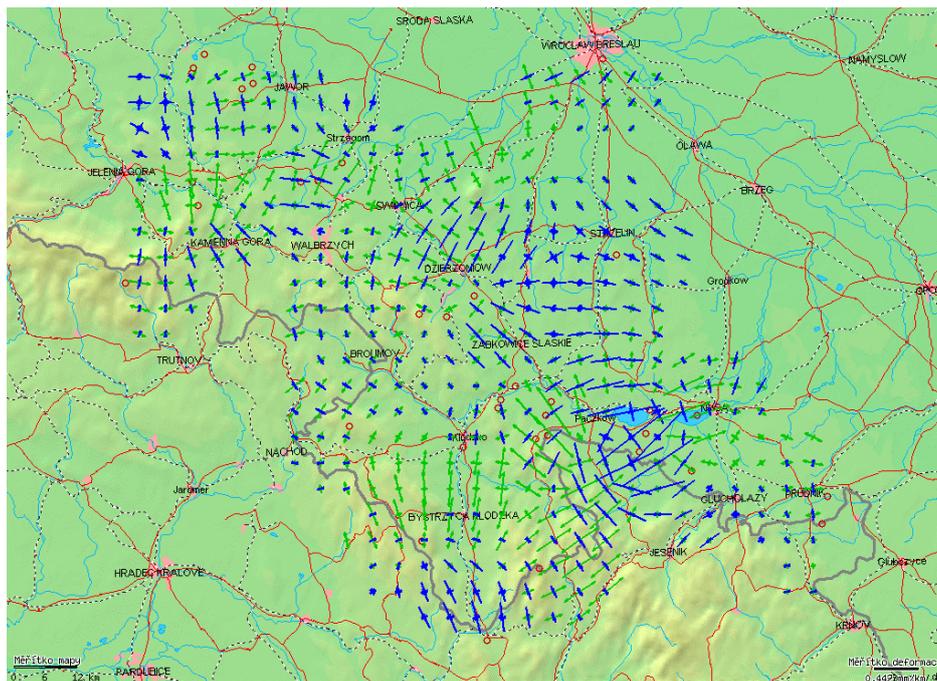


Figure 6: Resulting deformation field

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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