How to Create Strain Maps by On-Line Tools

Milan TALICH, Czech Republic

SUMMARY

The paper shows how to a create strain maps from a repeated geodetic measurements by appropriate on-line tools and explain why applying of the theory of continuum is useful to deformation analyses obtained from repeated positional survey in geodesy. The independency of resulting deformation parameters to applied coordinate frame is shown, too.

By correct processing of repeated geodetic measurements the errors originated from erroneous pre-requisites about stability of some selected points that are taken during normal calculation as stable (in the stable part of such location) will be completely eliminated. When compared to the sole listening of displacements then the strain maps enable to present deformation parameters in much more objective way and serves as a tool to demonstrate the relatively geodynamical trends of the territory in question.

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1. INTRODUCTION

Analysis of deformations of the terrestrial surface or of building constructions does not belong to problems that many geodesists solve in their everyday praxis. The main goal of deformation analysis is determination of deformation mechanism if we look at the object as at the mechanical system under deformations according the laws of mechanics of continuum. After such geometric analysis physical interpretation of results may follow.

Geometrical analysis, describes the change in shape and dimensions of the monitored object, as well as its rigid body movements (translations and rotations). The goal of the geometrical analysis is to determine in the whole deformable object the displacement and strain fields in the space and time domains.

Physical interpretation is based on the relationship between the causative factors (loads) and deformations.

Geodetic monitoring of deformations should follow in two steps. The first one is determination of displacements of selected points on the object in question (standard task). After it determination of displacement field in continuous form by their interpolation (generalized task) can follow. The second step is determination of deformations parameters by geometric analysis of continuum mechanics (strain analysis). Determination of displacements in the first step is usually done by repeated observation of geodetic network. But realisation of the second step is not so much usual among geodesists. Nevertheless strain analysis offers many conveniences.

Homogeneous territory or object in question is the required condition, of course. It means that if such condition is not fulfilled, then only division of the whole territory to several homogeneous parts must be tried and calculations has to be done for each one of them separately.

In addition, geodesists usually do not have necessary SW tools for the calculation in their disposal. Calculations are rather difficult, as well as required theoretical knowledge. Thus it is advisable to use the potentiality and characteristic of web applications for calculations to solve the above mentioned task. The most important advantages are the following:

- users do not need to master detailed theoretical knowledge to solve more difficult calculations, it is sufficient if they understand principals of the solution, real meaning and constraints for the application,
- users do not need to own software for less common or more difficult calculations,
- web application is still up-to-date, the user do not have to bother with either installation, nor updating,
- platform independence – web application may work under any operation system,
- calculations made on-line using the web application guarantee the compliance with given calculation methods and techniques and enables the comparison with calculations made by different SW,

-   web applications with XML interface simplify interconnection of applications from different producers. Each application servers may be based on technologies from different companies, but thanks to standardized interface they may communicate together. The necessary condition that must be fulfilled is the existence of XML interface with its description.

This is the way how users get in their disposal a computing tool that assists in solving tasks that may be for them quite unusual.

2. THE CALCULATION METHOD

On the basis of points displacement changes of geodetic network, that are stated by their repeated survey, we first calculate parameters of discretely expressed field of displacements, i.e. displacements interpolated into grid, and further we calculate parameters of discretely expressed field of displacements, characterized by stress tensor (of extension and compression). Theoretical solution and derivation may be found in a number of publications e.g. (Szostak – Chrzanowski et al., 2006), (Talich, 1994) a (Talich et al., 1993). The whole calculation is based on the theory of mechanics of continuum.

Input values for the calculation are at the first place **displacements (movements) of given, or measured points** of the geodetic horizontal network. We take into account the coordinates needed for calculation and graphical displays of results, eventually numbers (labels) of these points. The other input values are different values specifying the way of the grid definition, into which the interpolation will be made and specifying parameters for own implementation of the interpolation of displacements of such points in the field of displacements in the grid.

Output values are besides the interpolated displacements of points in the chosen grid, **parameters of points deformations of the same grid**. We speak about axis of maximum and minimum strain, direction of the axis of maximum strain, total dilatation and total shear.

It is important to note that all displacements depend on the selected coordinate frame. On the other hand, all **parameters of deformation**, except directions, **are independent on the used coordinate frame**. This proves the importance of calculations of parameters of deformation and their application. It is not necessary to consider how to choose conditions for placing the geodetic network in the coordinate frame (to choose the fixed points). In other words, which of the points of the network to consider as stable, and which not. The only thing it is necessary to comply with is the calculation of network adjustment as the free network, i.e. to choose only necessary number of conditions for its placement in coordinate frame, and thus do not "deform" the network. They are in the case of horizontal network with stated size (with at least one measured length) three, and in the case of positioning network without stated size four. Different conditions in the case of free network with stated size would mean application of translation and rotation and related to it, the calculation of deformation is independent. Thus using different conditions we get always the same values of parameters deformations. That means that **mistakes from bad** (mistaken, erroneous) **expectations based on stability of selected points**, that we during common calculations of displacements from repeated measurements consider as stable, are totally eliminated. It means that deformations are more

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objective criterion for disclosure of real relative geodynamic trends in the reviewed terrain. More details about these advantages of using continuum mechanics for deformation analysis are in (Talich, 2008).

The next advantages of the application of the theory of mechanics of continuum for deformation analysis from repeated geodetic survey have been mentioned in detail in e.g. (Szostak – Chrzanowski et al., 2006). It discusses the development of integrated access to monitoring and analysis of deformation from geodetic survey including physical interpretations. Mechanics of continuum is suggested as a basis for communication in multiprofessional access to geodetic and geotechnical monitoring.

3. DEFORMATION ANALYSIS APPLICATION

The above mentioned calculation is implemented in web application "Deformation Analysis" (see figure 1) at URL: **http://www.vugtk.cz/~deformace/**. Application is still being developed, and especially last year a lot of new functions and improvements were added.
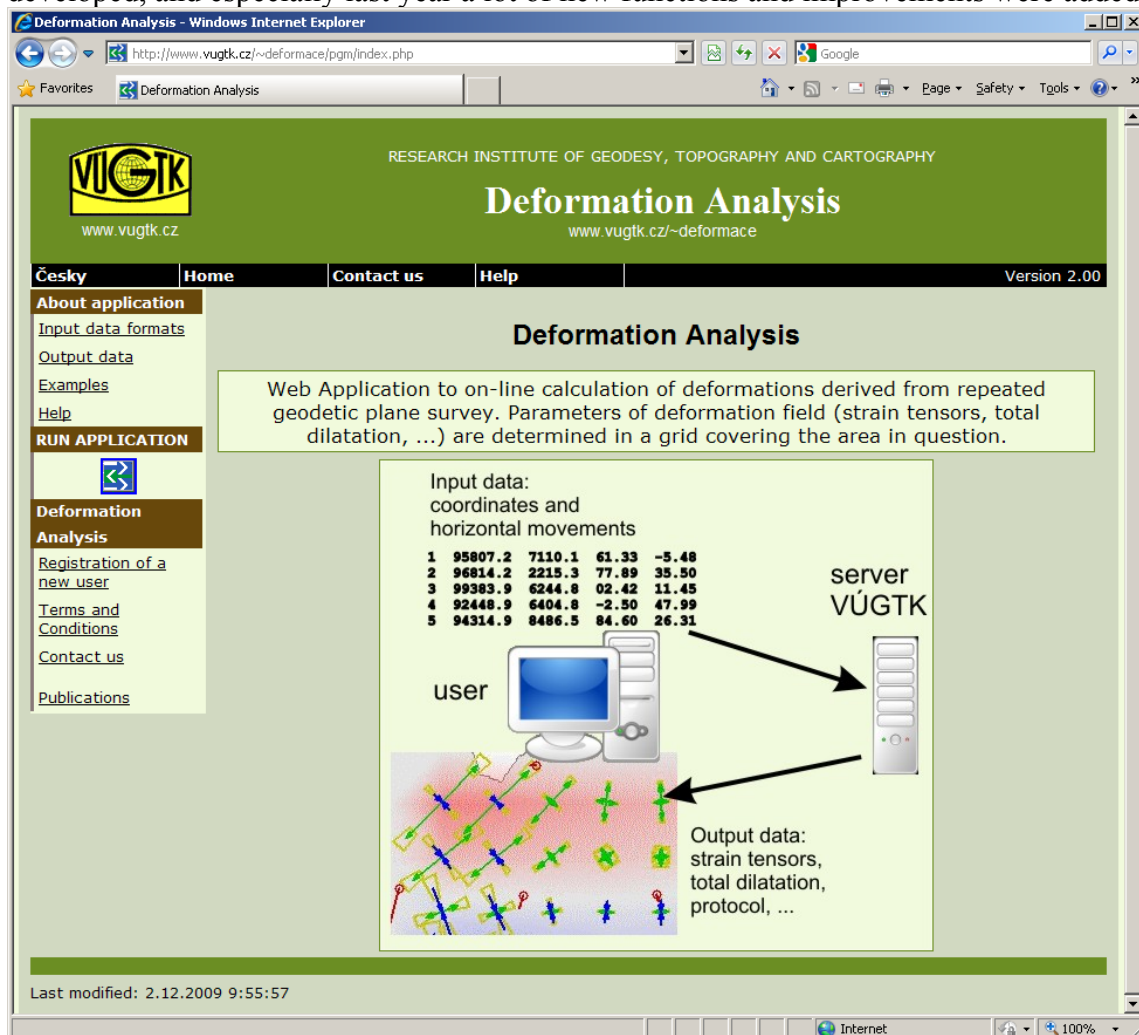

Figure 1: Title page of Deformation Analysis Application

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Before you start the application, it is necessary to prepare input data. We may enter displacements of given geodetic points by using 1 or 2 files. If 1 file only is the input file, then it contains approximate coordinate values of given points of the geodetic network and values of displacements (coordinate differences from each measurements). We may also use 2 files as input files, where the application seeks the common points inserted in both files and calculates point displacements from their coordinates.

Input files may be in the format of simple text files or in its own format XML. The advantage of this format is that it contains other supplementary information necessary for calculation, which in other cases have to be input by hand using the input form. Input form is shown in figure 2.
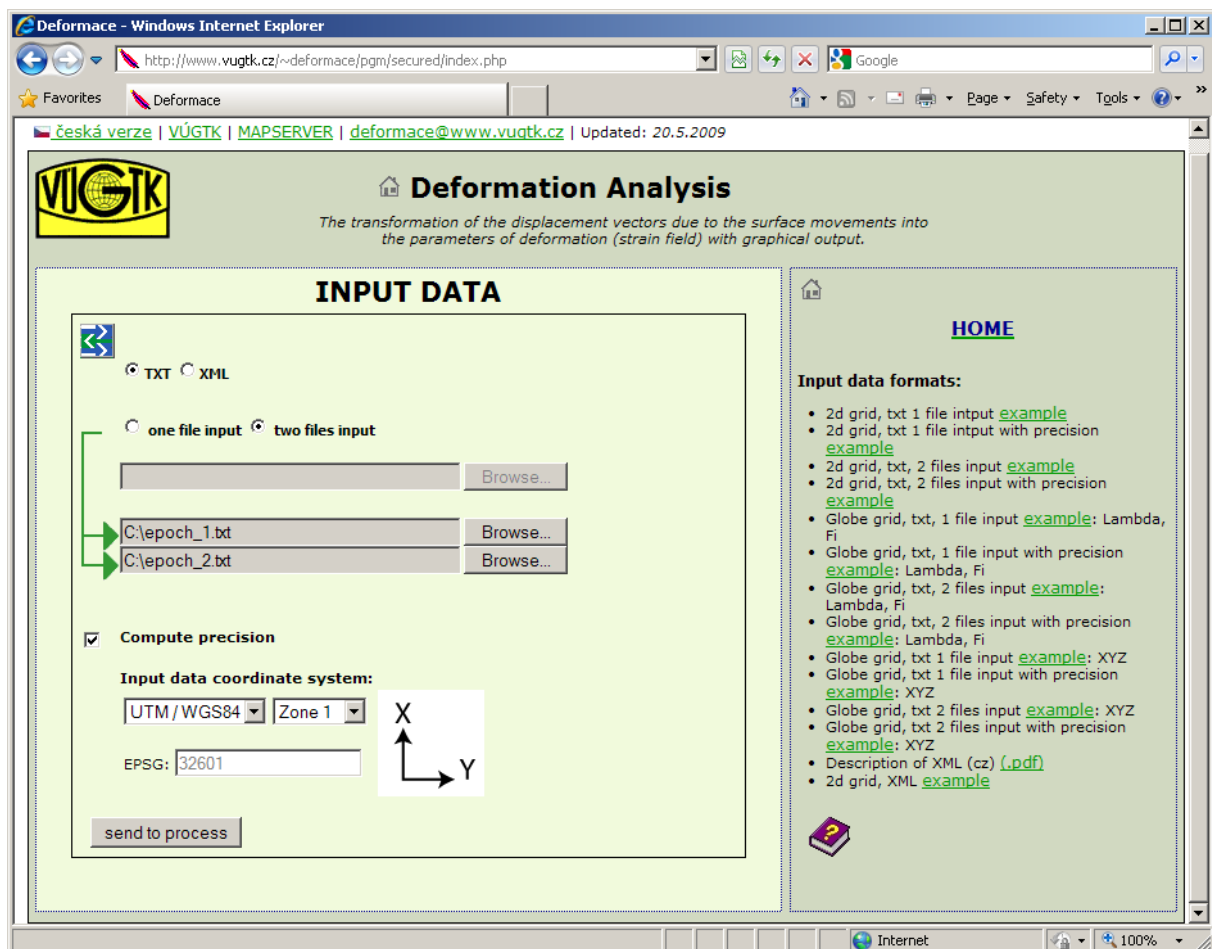

Figure 2: Input form of Deformation Analysis Application

When entering the simple text file we must enter in the input form also other parameters, as coordinates system of input points, and further the order of coordinates in the file. The form offers several coordinate systems, but it is also possible to add a coordinate system using code EPSG (European Petroleum Survey Group). EPSG was scientific organization that created worldwide databases of geodetic systems, nowadays used by many applications. Thus if the

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user knows EPSG code of his coordinate system, he may enter it by hand. The last possibility is to enter local system if the points were measured in the local system. However, in this case it will not be possible to display the resultant deformations together with other map layers.

After input data are entered, another form follows the previous one, where the parameters of the grid for interpolation are chosen. The interpolate form is in two forms, depending on the interpolation being made in the plain or in the sphere. If the user decides to use coordinate system WGS 84, it is required to perform calculations in the sphere to satisfy the condition of deformation calculation in the grid.

Selection of parameters of the interpolated grid is very important and sometimes it is difficult to select the optimal number of grid rows and columns and it is necessary to repeat the calculation for several times.

Own interpolation of the grid and calculation of deformation tensors will follow. Values of interpolated displacements into grid, and values of deformation field in the same grid are calculated. User then may display protocol on the calculation, where all important information on calculation, the interpolated values of displacements and values of deformation tensors in their numeric form are included. Now it is possible to display the results in graphic form. Before that, it is necessary to enter map projection, in which the results will be displayed. The application offers several possibilities or the user may enter EPSG code by hand.

To display the results freeware (Open Source license) Map Server from the University of Minesotta, USA (http://mapserver.gis.umn.edu/) is used. It is very effective application that provides a number of functions for map designing in the Internet. It enables to display map layers offered by other map servers using the service WMS (Web map service) according to specifications OGC (Open Geospatial Consortium).

This is very advantageous. The user does not have to have needed map data on his computer. There are many map servers on the Internet, that using WMS offer their content and their number is getting larger.

In our application for deformation analysis service WMS is used for entering topographic underground into graphic display of results of deformation calculations. The user gets well-arranged output, from which it is obvious where is the exact geodynamic activity located in the reviewed terrain.

In map server for graphic display, the results of deformation calculations are divided in the following layers:
  - Points of the measurement (given points of the geodetic network)
  - Numbers (labels) of the points of the measurement
  - Displacements in the points of the measurement
  - Displacements interpolated in the grid (Displacements field)
  - Deformation – axis of maximum and minimum strain in the grid (Strain field)
  - Accuracy of deformation

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- Shear strains
- Total dilatation

These layers may the user independently switch on or off together with other map layers, which leads to required display of results. In figures 3, 4 and 5 examples of different outputs are shown.
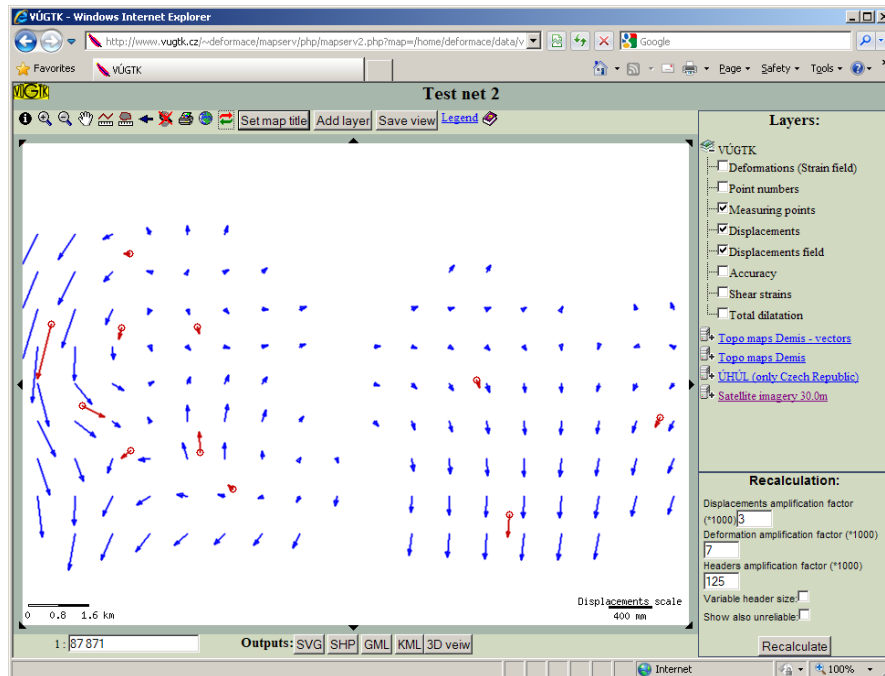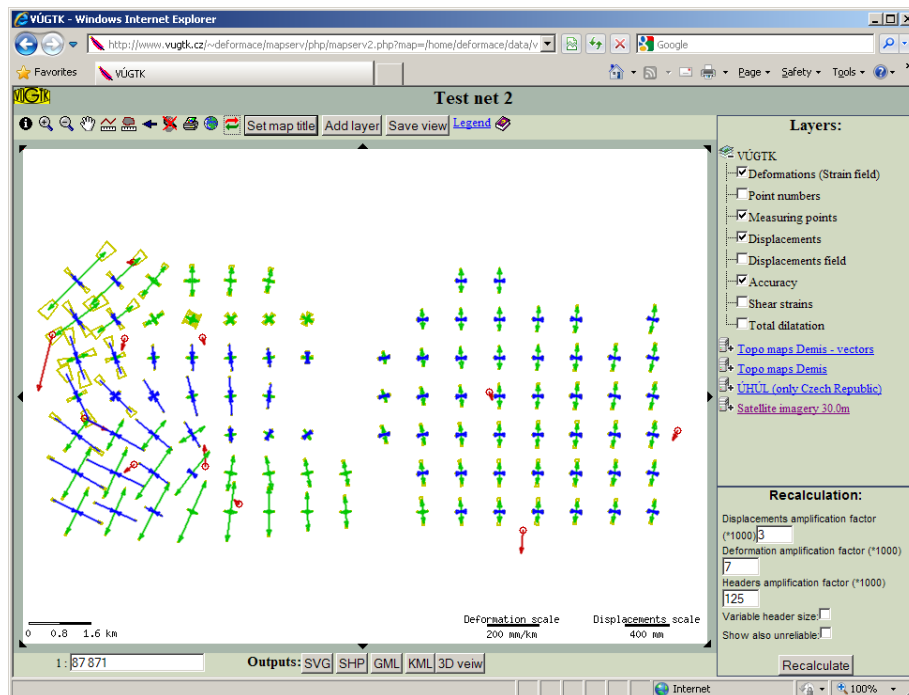

Figure 3: Output of Displacements field

Figure 4: Output of Strain field with Accuracy

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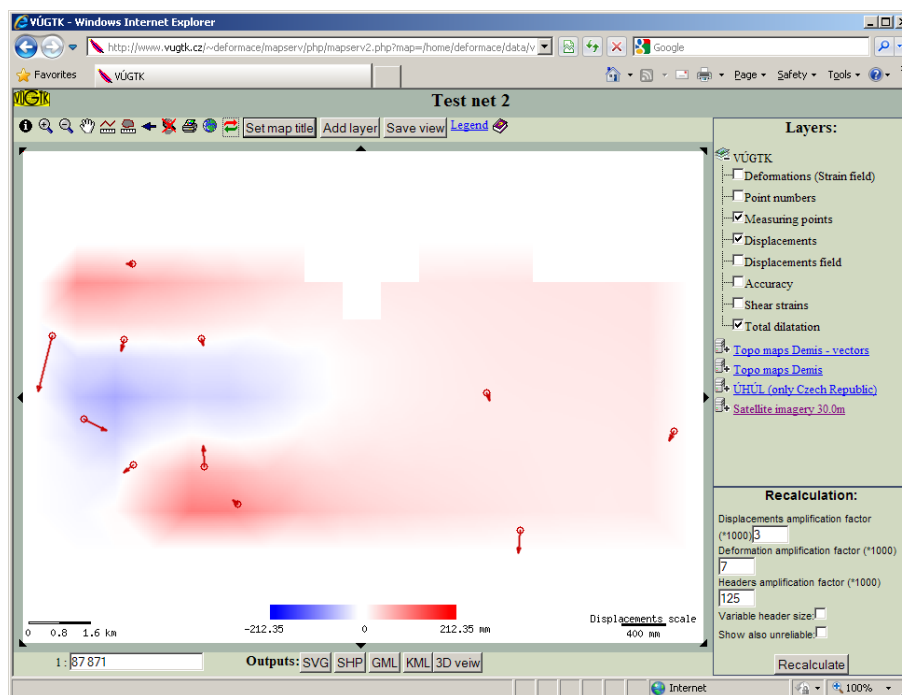Sydney, Australia, 11-16 April 2010

Figure 5: Output of Total dilatation

In addition, application offers map display with deformations in 3D (figure 6). For this purpose the application uses the program extension Java3D that enables to work in programming language Java with 3D graphics. The advantage of this solution is that the user does not have to install any other program, it is sufficient to use common internet viewer supporting Java. Program uses the cut of the map with layers, that are switched on in the map server. In 3D display it is also possible to adjust the basic setup, as height distortion or setup of the model lightening. Moreover, it enables output to a printer or to a file.

If the user is not satisfied with this simple 3D view, the map application enables also export of results in format KML and their further display in program Google Earth. Other possibilities of export are in format XML (GML, SVG), or ESRI Shapefile.

In the (Talich and Havrlant, 2008) are some examples of the usage of this application.

4. CONCLUSION

The aim of this article is, above all, to present web application Deformation Analysis for on-line calculations of deformation analysis from repeated geodetic measurements, which uses the theory of mechanics of continuum and thus, enables the user to use all advantages of this theory. This application can be found at URL: **http://www.vugtk.cz/~deformace/** and is at the disposal for everyone who is interested. Therefore common user does not have to have either detailed theoretical knowledge on calculation of the deformation analysis, or needed SW tool. The calculations are done on-line on the server, the user only input path to his data, and on the other hand, receives the protocol on the calculation including graphic display of

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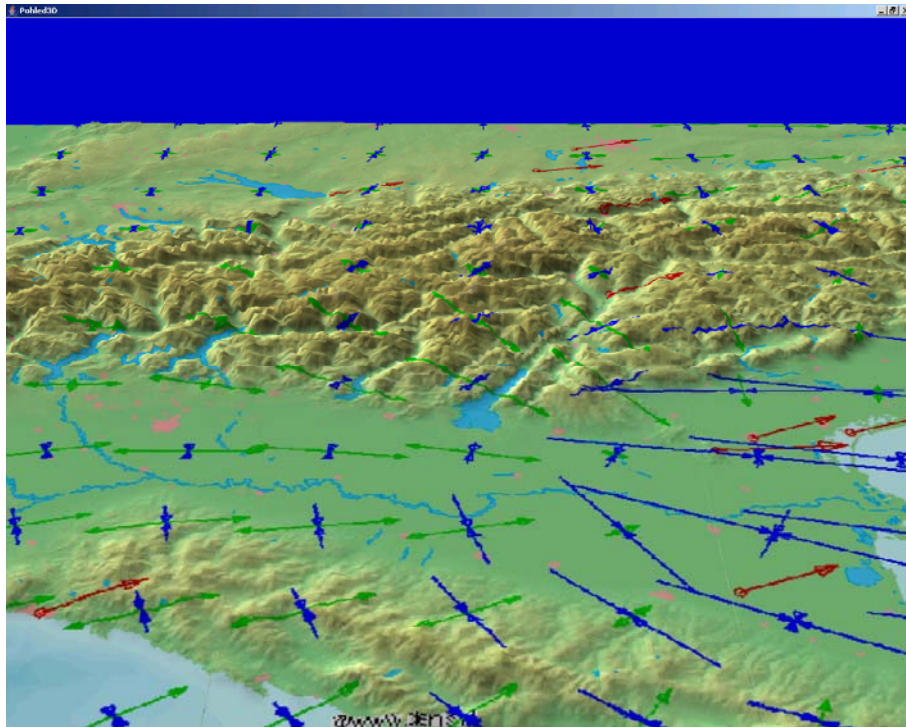Sydney, Australia, 11-16 April 2010

Figure 6: Deformation display in 3D

the results. Optionally, he may include topographic underground into the graphic results display using the service WMS, which will make easy the interpretation. The application is still being developed and its functionality is being extended.

REFERENCES

Talich, M., (2008). Practical Advantages of Using the Mechanics of Continuum to Analyse Deformations Obtained from Geodetic Survey. In: *Measuring the changes - joint symposia of 13th FIG International Symposium on Deformation Measurements and Analysis and 4th IAG Symposium on Geodesy for Geotechnical and Structural Engineering, LNEC, Lisbon, Portugal, May 12-15 2008.*

http://www.fig.net/commission6/lisbon_2008/papers/pas07/pas07_03_talich_mc056.pdf

Talich, M. and Havrlant, J. (2008). Application of deformation analysis and its new possibilities. In: *Measuring the changes - joint symposia of 13th FIG International Symposium on Deformation Measurements and Analysis and 4th IAG Symposium on Geodesy for Geotechnical and Structural Engineering, LNEC, Lisbon, Portugal, May 12-15 2008.*

http://www.fig.net/commission6/lisbon_2008/papers/pst02/pst02_05_talich_mc057.pdf

Kostelecký, J., Talich, M. and Vyskočil, P. (1994). Crustal Deformation Analysis in the International Center on Recent Crustal Movements. *Journal of the Geodetic Society of Japan* - 40/4 (1994), p. 301-308.

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Szostak – Chrzanowski, A., Prószyñski, W. and Gambin, W. (2006). Continuum Mechanics as a Support for Deformation Monitoring, Analysis, and Intrpretation, In: Kahmen, H. and Chrzanowski, A. (Eds.), *Proceedings 3rd IAG / 12th FIG Symposium,* Baden, May 22-24, 2006, Baden, ISBN: 3-9501492-3-6.

Talich, M., Kostelecký, J. and Vyskočil, P. (1993). Modelling of Horizontal Movements and Computing Method of Deformation Fields at the International Center On Recent Crustal Movements. In: *Zpráva o řešení vědeckého projektu 4-01-60 Geodézie a dynamika Země v roce 1993 (Report about solution of research project 4-01-60 Geodesy and dynamic of the Earth in 1993)*, VÚGTK, 1993, p.104-115.

Talich, M. (1994). Using GPS Data for Deformations Analysis. In: *1994 IERS and IGS Workshops Paris and Saint Mandé,* 1994, March 21-25, p.6.

Talich, M., (2006). *Web Application to Deformation Analysis of Repeated Geodetical Measurement Using WMS*. In: Kahmen, H. and Chrzanowski, A. (Eds.), *Proceedings 3rd IAG / 12th FIG Symposium,* Baden, May 22-24, 2006, ISBN: 3-9501492-3-6.

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 and vice-director of VÚGTK. In 2002, Milan Talich presented his doctorial thesis "Information Systems to On-Line Providing of Geodetic Information and Their Creation".

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