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Contents

Study of the gravity field of the Earth in Slovakia

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Abstract: In this contribution the investigations of the gravity field in the territory of the Slovak Republic the period 2011–2014 are presented.

Key words: geodynamics, gravity field, gravimetry, Earth's rotation, GPS (Global Positioning System)

1. Geodesy

The main problem treated in *Janák et al. (2011)* is the determination of accurate mean values of the topographical effects from point values known on a regular geographical grid. Three kinds of topographical effects are studied: terrain correction, condensed terrain correction and direct topographical effect. The relation between the terrain roughness and optimal density of the points to be used in the computations is investigated in five morphologically different areas of Canada. The results are applied to produce maps of a minimal density of points needed for sufficiently accurate determination of mean topographical effects for Canada.

Three different global gravity model solutions have been released by the European GOCE Gravity Consortium: a direct solution, a time-wise solution and a space-wise solution. To date, two releases of each solution have been issued. Each of these solutions has specific positives and weaknesses. In the paper *Janák and Pitoňák (2011)* was analyzed the differences between each solution in Central Europe by means of comparison with respect to the EGM2008 and GOCO02S global gravity models. In order to make an independent comparison, the global GOCE models are tested by the SKTRF (Slovak Terrestrial Reference Frame) network in Slovakia.

In *Janák et al. (2012)* various isostatic models, namely the models of Airy-Heiskanen (A-H) and Pratt-Hayford (P-H), the combination of the Airy-Heiskanen model (land area) and the Pratt-Hayford model (ocean area), the first (H1) condensation model of Helmert as well as a crust density model are analyzed for a GOCE-like satellite orbit in two selected regions: Japan and central part of Europe. The different topographic-isostatic effects are compared with respect to the degree of smoothing of the measured satellite gradiometric data. The results of this paper can serve as a base for further investigations of the suitability of particular reduction models for downward continuation.

In *Bucha and Janák (2013)* a novel graphical user interface program GrafLab (GRAvity Field LABoratory) for spherical harmonic synthesis (SHS) created in MATLABs was presented. This program allows to comfortably compute 38 various functionals of the geopotential up to ultra-high degrees and orders of spherical harmonic expansion.

Fast spherical harmonic synthesis (SHS) at multiple points based on the lumped coefficients approach was published in *Bucha and Janák (2014)*.

Results obtained as a solution to the geodetic boundary-value problem, where two different sources of input boundary data are combined together, are presented in *Janák et al. (2014)*.

Reference frames

The precession-nutation variations in right ascension after introduction of Celestial Intermediate Origin were analyzed in *(Husar, 2013)*. The apparent paradox has been explained, namely that for some groups of stars despite of almost complete elimination of motion of CIO on the equator the variation of right ascension can accede the equinox related variations. The mathematical and statistical background for rigorous combination of epoch-wise observed and permanent 3D geodetic networks were studied by *(Hefty and Gerhatova, 2011)*. The refinement of horizontal velocity field in Central Europe using the reprocessed permanent and epoch-wise networks is subject of combination presented in *(Hefty et al., 2011)*. The final intraplate horizontal velocities pattern of the Central Europe region was obtained after thorough inspection of all individual velocities, smoothing and interpolation of all available reprocessed data. For detection of displacements in long term time series used for network coordinate adjustment an adaptive algorithm was proposed in *(Bezrucka, 2013a)*. Besides detection of sudden position changes in reference stations, the general behaviour of the long term station stability is evaluated.

Positioning and GNSS related analyses

The high-frequency GNSS observations for monitoring and interpretation of short-term position variations are studied in (*Papco et al., 2011*). The potential of 1-Hz sampled GPS observations for high-rate variations using the Precise Point Positioning is demonstrated in *(Hefty and Gerhatova, 2012a, b)*. In *(Bezrucka, 2013b)* is proposed a method for compression of non-observation RINEX data which significantly improves the management of large-volume data sets e.g. of recording meteo-observations used for GNSS troposphere modeling.

2. Geodynamics

Geodynamics in Central Europe

The Central European Geodynamic Reference Network is active since the early 1990´s with a consistent and systematic activity of measurement, processing and scientific interpretation of the GPS data. The GPS observations were continuously analyzed and also several re-analyses were performed and results are presented in *(Barlik et al., 2011; Hefty and Gerhatova, 2011; Bogusz and Hefty, 2011)*. The analysis of repeated absolute gravity measurements in the Czech Republic, Slovakia and Hungary is presented in *(Pálinkáš et al., 2013)*. The data of this study demonstrate that considering instrumental and hydrological effects on gravity are crucial for a correct interpretation of repeated absolute gravity measurements. Monitoring of Earth´s surface deformation in the mountain areas by GPS measurements is presented in *(Papco, 2013)*. The GPS observations were continuously analyzed *(Hefty et al., 2011)* for determination of regional geokinematical trends and identification of local anomalies. The possibility detection of seismic displacements in central Europe by analysis of high-rate was studied in *(Hefty and Gerhatova, 2012)*. The risk in geodynamics active areas on the base of geodetic and geophysical data was presented in *(Hefty et al., 2012)*. The repeated absolute gravity measurements in the area of Slovakia were analyzed in *(Mojzes and Mikolaj, 2012)* and in the Tatra Mountains *(Mojzes et al., 2012).*

Deformation of Earth's surface by local loading effects

The mass of structures influences a deformation of the Earth´ surface up to long distance from area of realization. More deeply knowledge of mechanical properties of materials and modern computer equipment allow construct very precisely model reaction of the Earth´s surface on loading effects in time. Geodesists and geophysicists need to know these laws and theirs time evolution. The mathematical modeling of the Earth elastic surface deformation caused by loading effects was studied in *(Mojzes et al., 2011* and *Mojzes et al. 2012)*. The precise geodetic measurements are suitable for estimation of Young´s modulus of elasticity. The theory for computation of Young´s modulus from precise leveling was applied in the Gabčíkovo water dam *(Mojzes et al., 2014)*. The role of near topography and structures effects in vertical gravity gradients was studied in *(Zahorec et. al., 2014)*. These effects are needed in processing of exact microgravity measurements.

Modeling of hydrological mass variations

Time series of GPS and gravity measurements can be used to characterize geodynamic processes. However, these measurements can by strongly influenced by hydrological processes, especially water mass variation. The influence of hydrological effects should be modeled and applied to processing of absolute gravity measurements. This methodology was studied in *(Mikolaj and Mojzes, 2011)* and results will be used for data processing in the National Centre for Diagnostic of the Earth surface Deformation in the area of Slovakia. The application of global and local hydrological models in processing of time series of repeated absolute gravity measurements is presented in *(Mojzes, 2013)*.

Gravimetry – Global studies of the earth crust and mantle

Studies of the global crust and mantle based on spectral (spherical harmonic) analysis and synthesis and stripping.

In *Tenzer et al. (2012a)* spatial and spectral analysis of refined data for modeling the crust -mantle interface and mantle - lithosphere structures was presented. Spectral harmonic analysis and synthesis of Earth's crust gravity field were published in *Tenzer et al. (2012b)*. Spectral expressions for modeling the gravitational field of the Earth's crust density structure in *Tenzer et al. (2012c)* and depth-dependent density change within the continental upper mantle in *Tenzer et al. (2012e)* are presented. In *Tenzer et al. (2013)* global model of the upper mantle lateral density structure based on combining seismic and isostatic models was published and in *Tenzer et al. (2012d)* global crust-mantle density contrast estimated from EGM2008, DTM2008, CRUST2.0, and ICE-5G was described. Uniform spectral representation of the Earth's inner density structures and their gravitational field was published in *Tenzer et al. (2011b).* Contributions of the far-zone gravity field corrected for the effect of topography by means of Molodensky's truncation coefficients was computed in *Tenzer et al (2011a).*

3. Gravimetry – Integrated density modeling – Tectono-structural regional studies

Modeling and nonlinear 3D inversion methods were used to study the structure and properties of the lithosphere and asthenosphere in selected regions *(Grinč et al., 2013; Bielik et al., 2013a; Prutkin et al., 2014a; El Bohoty et al.. 2012; Brimich et al., 2011b; Bielik et al., 2013b; Hlavňová et al.. 2014; Pohánka et al., 2011; Kalinina et al., 2011; Gribovszki et al., 2013a; Gribovszki et al., 2013b),* with focus on the Carpatho-Pannonian region. Integrated geophysical modeling that fits simultaneously several observed fields/parameters: gravity anomalies, geoidal undulations, topographic heights, and heat flow was used to obtain vertical sections of the lithosphere and/or asthenosphere at selected profiles *(Krajňák et al., 2012; Dérerová et al., 2012; Grinč et al., 2014; Dérerová et al., 2014).*

Gravimetry and geodynamics – Inversion of temporal gravity changes

The following studies *(Vajda et al., 2012; Prutkin et al., 2014b; Vajda et al., 2014; Brimich et al., 2011a; Brimich and Kohút, 2014)* were devoted to inversion and interpretation of temporal gravity changes observed in volcanic areas in order to analyze volcanic unrest. Signal decomposition in terms of regional trend removal and depth-wise decomposition of the signal of sources based on the triple harmonic continuation procedure were applied. Approximation of sources by line segments served for identification of sources as well as for determination of the 3D geometry of the star-convex compact source bodies ("potato-shape" bodies)

Microgravimetry – Archeological prospection

Microgravimetric observations and their inversion and interpretation in archeological prospection, identifying hidden buried cavities was published in *(Pánisová et al., 2012; Pánisová et al., 2013)*. Special attention paid to reduction of gravitation effect of buildings and manmade structures as well as to precise terrain corrections.

Gravimetry – Methodology

A Matlab based program was written for stable downward continuation of geophysical potential fields using Tikhonov regularization *Pašteka et al. (2012)*. Synthetic calculation based on digital terrain models was introduced to predict the vertical gravity gradients needed in various applications in applied geophysics, microgravimetry, and absolute gravimetry *Záhorec et al. (2014)*. The application of a novel methodology for 3D nonlinear inversion of potential field data to structural tectonophysical studies in basin settings was tested *Prutkin et al. (2011)*. The methodology consists of several steps, two optional processing steps: regional trend determination and removal, depth-wise decomposition of the signal of sources based on the triple harmonic continuation, and two inversion steps: approximation of sources by 3D line segments, and determination of 3D shapes of two classes of source objects: undulating layer boundaries (interfaces, contrasting contact surfaces) and star-convex closed isolated homogenous bodies ("potato-shape" source bodies). The results of the gravimetric measurements in Slovakia were published in *Brimich (2011)*.

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Geomagnetic and aeronomic studies in Slovakia in the period 2011–2014

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Abstract: Some important scientific activities in the period 2011–2014 of geophysically orientated institutions in Slovakia are reported. The presented activities are related to the topics: (1) Theories of geomagnetic field generation, (2) Ground based geomagnetic observations, (3) Paleomagnetic results, (4) Mantle induction soundings and magnetometry, and (5) Solar terrestrial studies.

This report informs about scientific activities of geophysically orientated institutions, namely:

I. Geophysical Institute of Slovak Academy of Sciences, Bratislava, including Geomagnetic Observatory Hurbanovo.
II. Department of Astronomy, Physics of the Earth and Meteorology, Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, including AGO Modra (Astronomical and Geophysical Observatory Modra).
III. Institute of Experimental Physics of Slovak Academy of Sciences, Košice (including observatories in Stará Lesná, Skalnaté Pleso, Lomnický Peak) and Department of Nuclear and Subnuclear Physics, P. J. Šafárik University, Košice.
IV. Other institutions that perform geophysically relevant research.

The report consists of a number of Sections (in brackets are [corresponding subeditors – including individual contributors]): (1) Theories of geomagnetic field generation [Brestenský – Guba, Marsenić, Šoltis], (2) Ground based geomagnetic observations [Valach–Revallo, Váczyová et al.], (3) Paleomagnetic results [Valach–Túnyi], (4) Mantle induction soundings and magnetometry [Valach–Hvoždara], and (5) Solar terrestrial studies [Kudela–Revallo, Valach, Ondrášková]. The list of PhD dissertations in geophysics (geomagnetism) defended in the period 2011–2014 is in Appendix 1. Some results of these PhD theses are related to this contribution.

1. Theories of geomagnetic field generation

(Guba and Anderson, 2014; Marsenič and Ševčík, 2011; Marsenič 2014; Šoltis and Brestenský, 2013; Šoltis and Šimkanin, 2014)

Rotating magnetoconvection

Rotating magnetoconvection; Stability of sheared magnetic fields

Numerical stability analyses of sheared magnetic fields continued by an analytical treatment of the problem where a thin shear electromagnetic layer was present. It was shown previously that under some conditions such a layer might be a source of a localized resistive instability and then it is called the critical layer. This study *(Marsenić and Ševčík, 2011)* attempts to analytically support the numerical results obtained for the critical-layer mode in *Marsenić and Ševčík (2010)* and its equality with the tearing mode. The aim was mainly to advert to the underlying physics. The examined model was a rotating horizontal layer of a finitely conducting fluid where a sheared basic-state magnetic field was present. The shape of the field was defined by the function *hyperbolic tangent* in which argument there was a parameter γ defining steepness of the shear. This paper presents an analytical treatment of the problem assuming $\gamma >> 1$. The approach consisted in separation of the computational domain into an outer region where the diffusionless limit (Elsasser number Λ goes to infinity) applies and an inner region (the critical layer) of finite conductivity. According to the tearing-mode theory in classical systems, the solution in the inner region was sought as long- wavelength with respect to the width of the critical layer. The obtained solution showed features that were in a good qualitative accordance with the numerical ones and confirmed relevance of the simplifying physical assumptions made in each region. The convection in the critical layer was strictly conditioned by a sharp magnetic shear. If the shear region was removed by further positioning of the critical level towards the perfectly conducting boundary, the localized convection disappears. It is in compliance with the fact that the system is stabilised by a perfectly conducting boundary with respect to the tearing mode.

Rotating magnetoconvection; Anisotropic diffusivities influence

The influence of anisotropy of thermal diffusivity and viscosity, on the model of rotating magnetoconvection in the horizontal plane layer was investigated *(Šoltis and Brestenský, 2013)* using a linear stability analysis. The layer rotates about the horizontal axis in the *x*-direction and is permeated with a homogeneous magnetic field in the horizontal *y*-direction. The layer is heated from below and cooled from above and a uniform temperature gradient is sustained. The instabilities, i.e. stationary and/or nonstationary convection, are investigated in the form of horizontal rolls (in the same way as in the *V* case *(Šoltis and Brestenský, 2010))*.

The typical values of input parameters are not only geophysically relevant ones, i.e. $E_z \ll 1$, $\Lambda \leq O(10)$ and $q_z \leq O(1)$, but they also involve values comparable to values frequently used in geodynamo simulations. Due to the considered limits for diffusion coefficients, $\nu \gg \kappa \sim \eta$, attention was mainly focused on the MAC dynamics. A comparison of two models, the cases *H* and *V*, with different, horizontal and vertical, orientations of the rotation axis, respectively, was done. There are many differences in convection between the cases *H* and *V*. The important difference is that a certain type of mode occurs only in the *H* case and not in the *V* case, for all investigated α, the anisotropic parameter defined as ratio of thermal diffusivities, $\kappa_{xx} / \kappa_{zz}$ in various directions. The anisotropy (of SA or BM type) may be caused by stratification or rotation with magnetic field. The rotation axis in the vertical direction, *V* case, is always perpendicular to the axis of the rolls, which has a significantly different effect in comparison with the *H* case with a horizontal axis of rotation. The effect of the *SA* anisotropy on the stationary convection is qualitatively very similar in both *V* and *H* cases.

More significant differences between the *H* and *V* cases are in the nonstationary case. In the *H* case there is no constraint on the nonstationary convection with respect to the value of the Elsasser number Λ, but in the *V* case the nonstationary convection does not exist for Λ smaller than some onset Λ, which is a function of α.

The qualitatively opposite effect of *SA* anisotropy on the stationary and nonstationary convection is valid in the *V* case, where R_c for OC modes is a decreasing function of α, opposite to the stationary case. An analogous difference (but for other modes) was also found for the *H* case. The definition of two different Rayleigh numbers based on various thermal diffusivities components is discussed and analysed. One can only indicate that in the spherical geometry, the choice of the Rayleigh number is much more complex in a rotating fluid with anisotropic diffusion coefficients.

Numerical simulations of Geodynamo

Šoltis and Šimkanin (*2014*) present an investigation of dynamo in a simultaneous dependence on the non-uniform stratification, electrical conductivity of the inner core and the Prandtl number. Computations are performed using the MAG dynamo code. In all the investigated cases, the generated magnetic fields are dipolar. Their results show that the dynamos, especially magnetic field structures, are independent in their investigated cases on the electrical conductivity of the inner core. This is in agreement with results obtained in previous analyses. The influence of non-uniform stratification is for their parameters weak, which is understandable because most of the shell is unstably stratified, and the stably stratified region is only a thin layer near the CMB. The magnetic field at CMB is in the case of non-uniform stratification a little weaker than for uniform one but this difference is almost negligible. Their results show that the thin stably stratified subshell very slightly destabilize the dynamo at all the investigated values of *Pr* (magnetic fields are weaker in the case of non-uniform stratification). The teleconvection is not observed in their study. However, the influence of the Prandtl number is strong. The generated magnetic fields do not become weak in the polar regions because the magnetic field inside the tangent cylinder is always regenerated due to the weak magnetic diffusion.

Mechanisms for observable geomagnetic field variations

The study *Marsenić (2014)* presents a kinematic hydromagnetic problem investigated in order to follow the effects of a prescribed three-dimensional convection on an initially given magnetic field. The vertical velocity profile was *z*-dependent, *z* being the vertical coordinate, and consisted of two parts; one appropriate to the diffusionless region of the main volume of the fluid and the other appropriate to the resistive boundary layer at the rigid wall. The induction equation for the vertical component of the magnetic field was solved analytically in Cartesian geometry in these two distinct regions. Besides the horizontal transport of the magnetic field in the main volume, there was also field distortion due to the vertical velocity gradient; the upwelling flow caused it to weaken while the downwelling caused intensification. The resulting form at the surface of the main volume was a time-varying magnetic field, which then penetrated the boundary layer. This thin region, where the velocity rapidly tends to zero, behaves like a solid conductor, thanks to the assumption of a steady flow in the main volume. It generally attenuates the magnetic field.

Depending on the velocity field configuration in the main volume, it may also cause a sinusoidal variation of the magnetic field in z. Under appropriate conditions, a reversed magnetic field was obtained on the surface. In the context of the geomagnetic secular variation, this might be an explanation of the westward drift of reversed magnetic flux patches. The general advantage of the presented approach is the fact that it offers simple mechanisms for the main features of the geomagnetic secular variation and does not contradict the generally accepted frozen-flux hypothesis.

Mushy region at the inner core/outer core boundary

A mathematical model for convection and diffusive transport of heat and solutes in a primary mushy layer during the solidification of a ternary alloy was developed by *(Guba and Anderson, 2014)*. They focused on the influence of phase change effects, such as solute rejection, latent heat release and background solidification, in a linear stability analysis of a non-convecting base state. They identified how different rates of diffusion (double diffusion) as well as how different rates of solute rejection (double solute rejection) play a role in the system. Novel modes of convective instability that can exist under statically stable conditions were identified and parcel arguments to explain the physical mechanisms behind these instabilities were proposed.

2. Ground-based geomagnetic observations

(Dolinský et al., 2013; Duma et al. 2012ab; Valach et al., 2013)

The regular geomagnetic observations for the Slovak Republic territory are performed at the Hurbanovo Geomagnetic Observatory of the Geophysical Institute, Slovak Academy of Sciences. The geographical coordinates of the observatory are (47.86°N, 18.19°E) and its altitude is 112 meters. The Hurbanovo Observatory operates at the same place since the year 1893. Its operation was only interrupted for several years due to the World Wars I and II. Since the year 1998, it is a reliable member of the world-wide network of geomagnetic observatories in a frame of INTERMAGNET project.

Main equipment of the observatory includes: digital variometer station TPM made in Belsk Observatory, Poland, and another digital variometer, Magson, gained on the co-operation basis with GeoForschungs Zentrum Potsdam and Volkswagen Stiftung, Germany. For the absolute geomagnetic measurements there are used DI-fluxgate magnetometers, types ELSEC 810 and Lemi, and proton magnetometers, types ELSEC 820 M2 and PMG-1. The magnetovariational data in one minute sampling interval are supplied via internet to the INTERMAGNET centre in Edinburgh and Paris. The magnetovariational data in one minute sampling interval are supplied via internet to the INTERMAGNET centre in Edinburgh and Paris, from where they are available for the whole geomagnetic and space weather community. The definitive data of X, Y, Z geomagnetic components are published on the CD-ROM prepared by INTERMAGNET. Information about the geomagnetic activity is also published on the web site of the observatory, www.geomag.sk.

Old geomagnetic registrations of Hurbanovo Geomagnetic Observatory were scanned to a digital form – bitmap pictures. Now, the data are available for the research of the geomagnetic field variations back to the beginning of the 20th century. The data gaps which occurred in the first half of the 20th century were reconstructed by means of artificial neural networks *(Valach et al. 2013)*.

The members of the observatory staff regularly perform field measurements at the observation points of the national magnetic repeat station network, which is a part of the European repeat station network. The measurements are coordinated by the MagNetE Group. The measurements were accomplished for the 2012.5 and 2014.5 epochs. The accuracy of the magnetic ground survey, which was reduced to the epoch 2007.5, was evaluated in *(Dolinský et al. 2013)*. The map if isogones (distribution of the magnetic declination) in Europe was compiled from the previous repeat station surveys, including the Slovak repeat stations. It was published in *(Duma et al., 2012a, b)*.

Measurements of the magnetic declination is determined regularly at selected Slovak airports.

3. Paleomagnetic results

(Márton et al., 2013; Jelenska et al., 2011; El-Hemaly et al., 2011; Túnyi and El-Hemaly, 2012; Vetchfinski and Tunyi, 2012; Vetchfinskii et al., 2013)

In the field of paleomagnetic research, Albian-Santonian red pelagic marls from 14 localities, distributed along a strike length of ca. 400 km were investigated *(Márton et al. 2013)*. The primary aim was to obtain paleomagnetic constraints for the mechanism of formation of the arc. The research was related to the Pieniny Klippen Belt (PKB), which is a narrow arcuate structure separating the Central and Outer Western Carpathians formed during several Cenozoic deformational stages. Well defined hematite-based ancient magnetization components at 13 localities was revealed, which were dated using fold- and inclination tests. A within-locality fold test was negative for two localities exhibiting large CCW rotations of similar magnitude situated at the two ends of the PKB. Remanences of pre-folding age were documented for 11 localities, with an overall mean paleomagnetic direction of D = 311 degrees, I = 53 degrees, and alpha(95) = 11 degrees. The authors of the study suggested that general CCW rotation most probably took place during the Miocene, together with Western Central and Outer Carpathians. They concluded that the present shape of the arc can be partly due to oroclinal bending and that this must have happened before Oligocene since paleomagnetic declinations for neighboring Paleogene basins in the Central and Outer Western Carpathians reveal a uniform CCW rotation of ca. 50 degrees magnitude, irrespective of the position of the localities in relation to the Carpathian arc.

The Bajocian and the Oxfordian-Kimmeridgian crinoidal limestones of the PKB, Western Carpathians and the Bathonian-Callovian neptunian dykes which cut them were studied in *(Jelenska et al. 2011)*. The sampled sections were Babina, Mestecko, Vrsatec, Bolesovska dolina and Szaflary. More southern palaeolatitude of the Pieniny Klippen Belt was found than expected. This points to a close vicinity of the PKB to the African plate in the Jurassic. The results from the Polish part of PKB which emerged in the latest years showed the same palaeolatitude for the Callovian-Kimmeridgian limestones. The low palaeomagnetic inclinations measured in the Bajocian crinoidal limestones show that the southward drift may have started earlier than previously expected.

In *(El-Hemaly et al. 2011; Túnyi and El-Hemaly, 2012)*, the limestone samples of the Eocene to Pliocene age from the Egyptian pyramids, Khufu and Khafre, and quarries were studied.

The aim of this research was to find out the directions of the magnetic polarization vectors of their building blocks. This is important, because it enables to verify the hypothesis according to which the blocks were produced in situ by a concrete technique. The results were as follows: The paleodirections of three sampling locations exhibited the common north-south orientation. This suggests that they may have been produced in situ by a concrete technique. On the other hand, one block from one sampling location of the Khafre pyramid evidently came from the adjacent quarry. It is likely that the block from one sampling position of the Khufu pyramid comes also from the same quarry. The authors concluded that even if the concrete technique was used, the pyramids were constructed from a mixture of natural and artificial limestone blocks.

In the field of methodology in paleomagnetism, induced magnetic anisotropy (IMA) was studied in *(Vetchfinski and Tunyi, 2012)*. It was demonstarted that the IMA can remember the pressure at which it was formed. The phenomena of the magnetic memory of rocks associated with paleointensity, paleotemperature, and paleostress were discussed in *(Vetchfinskii et al., 2013)*. The superposition of several paleotemperatures and paleostresses were studied too. It was found that under certain conditions, a rock can remember information on several paleotemperatures (paleo-heating events), as well as the respective intensities of the geomagnetic field of the past.

4. Mantle induction soundings and magnetometry

(Semenov et al, 2013; Hvoždara, 2012; Hvoždara and Vozár, 2011; Hvoždara and Majcin, 2011, 2013; Majcin et al., 2012)

A series of paper dealing with analytical modeling of the geoelectric, magnetometric and geothermic problems were published during the period 2011–2014.

In *(Semenov et al, 2013)*, a comparison of two approaches to the induced magnetic fields in the Earth was presented. One of them was that induction is generated by the time-variable exciting field; the second approach was that the motional induction is caused by movement of the conductive planet in the outer magnetic fields. The sources were modelled analytically. The synthetic diurnal magnetograms were used for the deep sounding by the magnetovariation spatial gradient method. Sounding results using both approaches were found different above the 2D inhomogeneous mantle. The precessions of the magnetospheric belt current pole for daily sampling frequency were presented. For this purpose several geomagnetic observatory data in the northern hemisphere were used.

Hvoždara (2012) presented also an algorithm and numerical results for the boundary integral equations (BIE) method of the forward D.C. geoelectric problem. A three-layered Earth was considered. It contained a prismoidal body with sloped faces in the second layer. This situation was considered because it occurs in the sedimentary basins. The graphs with numerical results presented isoline maps of the perturbing potential and the resistivity profiles for the source field which was due to the pair of D.C. electrodes at the surface of the Earth.

An analytical solution of the forward magnetometric problem for the oblate spheroid (rotational ellipsoid) as a causative body was published in *(Hvoždara and Vozár, 2011)*.

A mathematical model for the stationary geothermal field for the two-layered Earth which includes a three-dimensional perturbing body below the first layer (in the substratum) was presented in *(Hvoždara and Majcin, 2011)*. Numerous graphs are shown for the disturbance of the heat flow on the surface of the Earth or inside the first layer.

Mathematical modeling of the stationary geothermal field for the three-layered Earth which includes a three-dimensional perturbing body below the first layer, over the halfspace substratum, was presented in *(Hvoždara and Majcin, 2013)*. The theoretical formulae were based on the generalized theory of the double-layer potential and boundary integral equation. The numerical calculations were performed for the 3D prismoids, the thermal conductivity of which was greater than that in the ambient second layer. Numerous graphs were shown for the disturbance of the temperature and heat flow distribution on the surface of the Earth or inside all three layers.

The qualitative and quantitative analyses of the heat flow refractions on the subsurface structures with contrasting thermal conductivities were made on the selected structure configurations *(Majcin et al. 2012)*. The presented results are applicable for the solution of some problems of the applied geothermics and also for the modeling of the thermal state of the lithosphere.

5. Solar terrestrial studies *(a, b, c)*

(a, Miloš Revallo and Fridrich Valach)

In the Geophysical Institute of the Slovak Academy of Sciences, Bratislava and Hurbanovo, a number of issues important within the frame of the solar terrestrial relations as well as space weather forecast were studied. Attention is focused especially on predicition of geomagnetic activity using the models based on the method of artificial neural networks.

Solar terrestrial relations and Space weather forecast

(Revallo et al., 2014; Saiz et al., 2013; Valach et al., 2014, 2011)

In *(Valach et al., 2011),* two models for prediction of solar energetic events were presented. The models were based on a linear filter and on a special type of dynamic artificial neural network known as the layer-recurrent neural network. As input the following parameters were used: the X-ray flare class for flares originating close to the centre of the solar disk; observed type II and IV radio bursts, and the position angle, width, and linear speed of observed full or partial halo CMEs. The models were designed to provide forecasts of proton fluxes with energies exceeding 10 MeV at the L1 libration point.

The space weather discipline involves different physical scenarios, which are characterized by very different physical conditions, ranging from the Sun to the terrestrial magnetosphere and ionosphere. Thanks to the great modeling effort made during the last years, a few Sun-to ionosphere/thermosphere physics-based numerical codes have been developed. However, the success of the prediction is still far from achieving the desirable results and much more progress is needed. Some aspects involved in this progress concern both the technical progress (developing and validating tools to forecast, selecting the optimal parameters as inputs for the tools, improving accuracy in prediction with short lead time, etc.) and the scientific development, i.e., deeper understanding of the energy transfer process from the solar wind to the coupled magnetosphere-ionosphere-thermosphere system. The paper *(Saiz et al., 2013)* represents the collection of the most relevant results related to these topics obtained during the COST Action ES0803. In an end-to-end forecasting scheme that uses an artificial neural network, we show that the forecasting results improve when gathering certain parameters, such as X-ray solar flares, Type II and/or Type IV radio emission and solar energetic particles enhancements as inputs for the algorithm. Regarding the solar wind-magnetosphere-ionosphere interaction topic, the geomagnetic responses at high and low latitudes are considered separately. At low latitudes, we present new insights into temporal evolution of the ring current, as seen by Burton's equation, in both main and recovery phases of the storm. At high latitudes, the PCC index appears as an achievement in modeling the coupling between the upper atmosphere and the solar wind, with a great potential for forecasting purposes. We also address the important role of small-scale field-aligned currents in Joule heating of the ionosphere even under non-disturbed conditions. Our scientific results in the framework of the COST Action ES0803 cover the topics from the short-term solar-activity evolution, i.e., space weather, to the long-term evolution of relevant solar/heliospheric/magnetospheric parameters, i.e., space climate. On the timescales of the Hale and Gleissberg cycles (22- and 88-year cycle respectively) we can highlight that the trend of solar, heliospheric and geomagnetic parameters shows the solar origin of the widely discussed increase in geomagnetic activity in the last century.

The study *(Valach et al., 2014)* deals with the relation of the southern orientation of the north-south component Bz of the interplanetary magnetic field to geomagnetic activity (GA). A method was suggested of using the found facts to forecast potentially dangerous high GA. It was found that on a day with very high GA hourly averages of Bz with negative sign occur at least 16 times in typical cases. Since it is very difficult to estimate the orientation of Bz in the immediate vicinity of the Earth one day or even a few days in advance, a neural network model was suggested, which assumes the worse of the possibilities to forecast the danger of high GA - the dominant southern orientation of the interplanetary magnetic field. The input quantities of the proposed model were information about X-ray flares, type II and IV radio bursts as well as information about coronal mass ejections (CME). In comparing the GA forecasts with observations, the values of Hanssen-Kuiper skill score ranging from 0.463 to 0.727 were obtained, which are usual values for similar forecasts of space weather. The proposed model provides forecasts of potentially dangerous high geomagnetic activity should the interplanetary CME (ICME), the originator of geomagnetic storms, hit the Earth under the most unfavorable configuration of cosmic magnetic fields. It can not be known in advance whether the unfavorable configuration is going to occur or not; the only finding is that it will occur with the probability of 31%.

A model to forecast 1-hour lead Dst index was proposed in *(Revallo et al., 2014)*. The approach is based on artificial neural networks (ANN) combined with an analytical model of the solar wind-magnetosphere interaction. Previously, the hourly solar wind parameters have been considered in the analytical model, all of them provided by registration of the ACE satellite. They were the solar wind magnetic field component Bz, velocity V, particle density n and temperature T. The solar wind parameters have been used to compute analytically the discontinuity in magnetic field across the magnetopause, denoted as [Bt]. This quantity has been shown to be important in connection with ground magnetic field variations. The method was published, in which the weighted sum of a sequence of [Bt] was proposed to produce the value of Dst index. The maximum term in the sum, possessing the maximum weight, is the one denoting the contribution of the current state of the near-Earth solar wind. The role of the older states is less important - the weights exponentially decay. Moreover, the terms turn to zero if Bz is negative. In this study, more comprehensive model is set up on the basis of the ANNs. The model is driven by input time histories of the discontinuity in magnetic field [Bt], which are provided by the analytical model. At the output of such revised model, the Dst index is obtained and compared with the real data records. In this way we replaced those exponential weights in the published method with another set of weights determined by the neural networks. We retrospectively tested our models with real data from solar cycle 23. The ANN approach provided better results than a simple method based on exponentially decaying weights. Moreover, we have shown that our ANN model could be used to predict Dst 1 h ahead. We assessed the predictive capability of the model with a set of independent events and found correlation coefficient CC=0.74±0.13 and prediction efficiency PE=0.44±0.15. We also compared our model with the so-called Dst-specification models. In those models, the Dst index was derived directly through an analytic or iterative formula or a neural network-based algorithm. We showed that the performance of our model was comparable to that of Dst-specification models.

(b, Adriena Ondrášková)

Schumann resonance (SR) studies continued at the Department of Astronomy, Physics of the Earth and Meteorology, Comenius University in Bratislava using the data from AGO (Astronomical and Geophysical Observatory, Modra).

Schumann resonances

(Ondrášková et al. 2011, Ondrášková and Ševčík 2012, 2013, 2014, Ševčík and Ondrášková 2012, Kysel et al. 2012, 2014)

Unfortunately, measurements of the vertical electric field component of SR at AGO were interrupted by lightning in August 2009. Nevertheless, by this time, enough data were collected to cover an interval of nearly 8 years, including both the solar cycle maximum and minimum. These data enabled not only analysis of the SR frequency variability on the solar cycle time scale but also changes in the effective lightning areas from the solar cycle maximum toward the solar cycle minimum. Although the patterns of the daily and seasonal variations remain the same in the solar cycle minimum as in the solar cycle maximum, they are significantly shifted to lower frequencies during the minimum. Analysis of the daily frequency range suggests that the main thunderstorm regions during the north hemisphere summer are larger in the solar cycle maximum than in the minimum *(Ondrášková et al., 2011).* A decrease by 0.29 Hz in both first and second mode frequency from the latest solar cycle maximum to the deep minimum of 2009 is found in the data from AGO *(Ondrášková et al., 2011; Ondrášková and Ševčík, 2012)*. This extraordinary fall of the fundamental mode frequency can be attributed to the unprecedented drop in the ionizing radiation in X-ray frequency band.

SR signal consists of the continuous background and many transient features that superimpose on the background. The latter are associated to the isolated huge lightning discharges. A method for automatic searching for transients has been developed and number of transients in all data sequences has been counted. Obtained number of transients revealed a characteristic pattern of the daily variation, which repeats from year to year. Moreover, it has been found that it is closely similar to the daily variation of the SR mode cumulative amplitudes *(Ševčík and Ondrášková, 2012)*.

Since April 2007 to 2012, 334 sprites, optical transients above some +CG discharges, have been captured by automated all-sky TV system at two stations in Slovakia, located at AGO and Arboretum Mlyňany. This number of observations enabled statistics. Sprites have been found most abundant in August and have been preferable observed in western and north-western directions with respect to our stations *(Kysel et al., 2012).* Further study has showed that majority of sprites (87%) occurred in clusters rather than alone (13%). About half of the sprites were of mixed type while more than one third of the sprites could not be classified due to low TV camera resolution. Though all-sky video detection systems are not an efficient device for analysis of morphological properties of sprites, their recordings can be used for determination of sprite location based on the triangulation methods, as 40 sprites in 10 nights have been observed simultaneously from two stations *(Kysel et al., 2014)*.

A new computer code for determination of the Schumann resonance mode frequencies has been developed at the Department of Astronomy, Physics of the Earth and Meteorology. In this new code, the complex demodulation (CD) method in iterative procedure was used instead of Lorentz function fitting (LFF) of DFT spectra method, which was used previously. First tests using the electric field component recorded at AGO showed that convergence is reached well before 30 iterations when signal from 327.68 sec. long sequences (65536 samples) was processed. In case 20.68 sec. long signal sequences, majority terminated before 5 iterations and only a fraction reached convergence between 5 and 10 iterations. Several data sequences that gave more than 1 Hz deviations from average frequency were found to correspond to data sequences heavily corrupted by noise and neither the LFF method gave physically plausible results in these times (*Ondrášková and Ševčík, 2013*).

The iterated CD method has been applied on short (20.68 sec.) and long (327.68 sec.) measured sequences and the resulting frequencies of the first four SR modes have been determined. It has been shown that calculated frequencies of individual short sequencies are more scattered than calculated frequencies of long sequencies. The iterated CD method has been applied to all recorded sequencies and it has been shown that the mean daily variation (the daily frequency range) of long data sequencies are very similar to that obtained by the LFF method, both being greater than the daily variation obtained from short sequences. Computational feasibility of the CD and LFF methods applied on data of equal length have appeared comparable. Modal frequency computation by CD method using short data sequences have been faster likely due to lower number of necessary iteration steps. No matter what spectral technique, calculated modal frequencies have shown clear decrease from 2002 (solar cycle maximum) to 2008 (solar cycle minimum). Solar cycle variation in modal frequency has been found greatest when Lorentz function fitting is used (*Ondrášková and Ševčík, 2014*).

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(c, Karel Kudela)

The activities of Space Physics Department of IEP SAS Košice is tradionally targeted to the study of energetic particle dynamics in the magnetosphere of Earth; modulation of cosmic rays (CR) in the heliosphere and to solar flares accelerating particles to high energies. The studies are based on data from ground based observations including that at high mountain Lomnický štít (real-time measurements available at http://neutronmonitor.ta3.sk) as well as on various available satellite energetic particle data, including those from own experiments (at http://space.saske.sk). Studies are mainly provided in the frame of international collaborations.

Energetic particle dynamics in the magnetosphere

(Baranets et al., 2012; Baláž et al., 2013ab; Lazutin et al., 2011; Lazutin and Kudela, 2012; Jansen et al., 2011; Kuznetsov et al., 2014acd)

Analysis of measurements on satellite IK-25 and its sub-satellite by *Baranets et al. (2012)* reported the acceleration of particles in the active satellite experiment in the ionospheric plasma. Precipitation of electrons in a rocket experiment at high latitudes is summarized by *Baláž et al. (2013a)*. Description of the experimental device measuring fluxes of energetic electrons in mission SPEKTR-R is in paper *Baláž et al. (2013b).* Magnetospheric influence on solar energetic protons at low orbit is analyzed by *(Lazutin et al., 2011)*. Review paper (chapter in book) on the magnetosphere can be found in *(Lazutin and Kudela, 2012)*. Possibility of one type of measurements which can be used for satellite and ground based observation of radiation is reported by *(Jansen et al., 2011)*. With the use of scientific devices working onboard CORONAS-F described in *(Kuznetsov et al., 2014a)* the variations of fluxes of trapped and solar particles analyzed during intervals with enhanced geomagnetic activity have been reported in papers *(Kuznetsov et al., 2014 c; d)*.

Solar flares accelerating particles to high energies

(Firoz et al., 2011ab, 2014; Kurt et al., 2013; Kuznetsov et al., 2014b; Velinov et al., 2013; Žigman et al., 2014)

Papers *(Firoz et al., 2011a; 1011b; 2014)* analyze the mechanisms behind ground level events (GLE). Selected results based on measurements of high energy solar gamma rays and neutrons can be found in papers (*Kurt et al., 2013; Kuznetsov et al., 2014 b)*. Influence of galactic cosmic rays and solar particle events on ionosphere is discussed and reviewed by *(Velinov et al., 2013)*. The effect of GLE on December 13, 2006 on VLF propagation is reported in paper by *(Žigman et al., 2014)*.

Modulation of cosmic rays

(Bobik et al., 2011, 2012, 2013; Torre et al., 2012; Kudela, 2012; Sabbah and Kudela, 2011; Chowdhury et al., 2013)

Results on study of modulation, antiprotons and of electron-positron component in the heliosphere using simulation technique are published by *(Bobik et al., 2011; 2012; 2013)* and by *(Torre et al., 2012)*. Modulation studied from experimental observations and quasi-periodic variations of CR observed on Earth's orbit are analyzed by *(Kudela, 2012; Sabbah and Kudela, 2011; Chowdhury et al., 2013)*.

Space weather

(Kudela, 2013; Papailiou et al., 2011ab, 2012; Kancírová and Kudela, 2014ab; McKenna-Lawlor et al., 2012; Kubančák et al., 2014; Kollár et al., 2011; Mavromichalaki et al., 2011)

The IEP SAS Košice results of the studies related to space weather effects can be found in *(Kudela, 2013; Papailiou et al., 2011ab, 2012; Kancírová and Kudela, 2014b)*. Performance of one of the models for prediction of shock arrival to the Earth during solar cycle 23 is checked by *(McKenna-Lawlor et al., 2012)*. Based on 31 years of observations, the comparison of cloudiness to CR as measured at mountain altitude (2634 m, Lomnický štít) is discussed in paper by *(Kancírová and Kudela, 2014a)*. Neutron monitor measurements at that position are compared with dosimetric data in paper *(Kubančák et al., 2014)*. The possibilities of the measurements and its update are reported by *(Kollár et al., 2011)*. Measurements at Lomnický štít are composite part of network of european and other CR stations (data in real time at http://neutronmonitor.ta3.sk). The applications of the created and continually updated data base are summarized by *(Mavromichalaki et al., 2011)*.

Planetary studies

Approach to corrections of magnetic field measurements done on Venus-Express mission are in paper *(Pope et al., 2011)*.

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Catchment and river processes: review of experimental research and mathematical modeling in hydrology in Slovakia from 2011 to 2014

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Abstract: Accelerating research leading to increased knowledge on hydrological processes on various spatial and temporal scales have been in the focus of hydrology in recent years. Studying hydrological processes on plot, hillslope, catchment and continental scales, land-atmosphere interactions, the impact of land use and climate change on the hydrological cycle and extreme events, etc., have been at centre of interest. This report reviews hydrologic research in Slovakia from 2011 to 2014. It also gives references to national and international projects and PhD. dissertations in hydrology from the same period.

Key words: catchment processes, hydrological regime, landuse and climate change, floods, droughts

1. Introduction

Signals of changing climate and recent extreme flood and drought events in Europe have stimulated public discussion also on the issue of whether the frequency and severity of these events have been increasing, to what extent such changes could be attributed to anthropogenic influence and how to measure and model processes describing them. Therefore the study of hydrological processes on plot, hillslope, catchment and continental scales, land-atmosphere interactions, the impact of land use and climate change on the hydrological cycle and extreme events has been at centre of interest among environmentalists, hydrologists and water resources managers also in Slovakia. This report follows previous reviews from 1999, 2004, 2007 and 2011 and summarizes results and outcomes of the main research programs in hydrology in Slovakia from 2011 to 2014 in Slovakia. Papers in Slovak and English and local and international research projects were reviewed and references to publications in English, main international research projects and defended PhD. thesis are given.

2. Soil-water-plant-atmosphere interactions on the catchment scale

Estimation of the components of the water balance in mountain and lowland forests and agricultural ecosystems, the interpretation of infiltration, evaporation, transpiration, capillary inflow and the seepage of water into lower horizons by means of monitoring and mathematical modeling resulted in an advanced quantitative analysis of the water balance equation. The increase of the availability of spatially distributed data such as digital elevation models, land use *(e.g. Feranec et al., 2014)*, and soil information made the use of distributed hydrologic models convenient in studying these issues. Several studies were aimed also at the development of methodologies for the spatial interpolation of hydro-meteorological data for hydrological mapping and rainfall runoff modeling and design discharge computations *(e.g. Parajka et al., 2012; Krajčí et al., 2014)*.

Several modeling and experimental studies using data from agricultural and mountainous experimental plots and catchments tried to venture answers to the questions how to predict the hydrological effect of land use change and how to give adequate physical interpretation of the parameters and structures of distributed rainfall-runoff models *(Holko et al., 2011c; Adamec et al., 2012; Machlica et al., 2012; Oreňák et al., 2013).* The need to develop an increased understanding of the erosion and transport processes on the plot and catchment scales under the specific physiographic conditions of Slovakia was stressed *(e.g. Lackóová et al., 2013).* The impact of natural vegetation on runoff formation was estimated; in particular, changes in the water balance and its components were analysed. Changes in the water balance of experimental catchments, including sediment and nutrient transport, have been investigated with respect to climate, land use and societal changes *(Holko et al., 2012b; Holko et al., 2013; Střelcová et al., 2013; Lichner et al., 2014)*.

With special interest taken in the component of subsurface and groundwater runoff, runoff components have been estimated by mathematical rainfall-runoff models, water balance studies, runoff separation methods and isotope methods. Both the modeling and separation methods have also confirmed the important role of subsurface flow also during floods. Tracer techniques have also been used to study the movement of precipitated water and transit times in catchments *(e.g. Holko et al., 2012a; Holko et al., 2013; Penna et al., 2014; Koczka Bara et al., 2014).*

Taking into account the two main problems related to determining evapotranspiration in mountainous environments, i.e. the availability of input data and the high spatial variability, evapotranspiration in mountainous basins of Slovakia has been studied both by experimental methods and mathematical modeling. Several methods for the modeling and approximation of potential and actual evapotranspiration at different elevations have been developed. In modeling the dependence of energy income and evapotranspiration in a very complex mountainous terrain from topographical and astronomical inputs, slopes, inclination and aspect, have been taken into account *(e.g. Mati et al., 2011; Novák, 2012; Hlaváčiková and Novák, 2013; Hrvoľ et al., 2012; Hrvoľ et al., 2013a; Hrvoľ and Gera, 2013)*.

Research in snow hydrology has a long tradition in Slovakia *(Holko et al., 2011b)*. Snow hydrology research was mostly oriented towards distributed simulation of snow accumulation and melt using both energy-based and temperature-index approaches *(Bartík et al., 2014).* Research has also concentrated on determining overall trends in the spatial and temporal distributions of snow density, height and water equivalent in several mountainous catchments. The validation of snow models by means of satellite images was tested *(Parajka et al., 2012; Krajčí et al., 2014).* Spatial and temporal variations of snow water equivalent in a large mountain catchments over long periods were analyzed and the impact of climate change on the snow water equivalent was studied. Estimation of snow redistribution by wind has also been outlined *(Nikolova et al., 2013; Hríbik et al., 2012; Parajka et al., 2012; Bartík et al., 2013; Nikolova et al., 2013; Kotríková et al., 2014; Krajčí et al., 2014)*.

The impact of land use and water management on stream water quality was analyzed using water quality data the observed by the regular network of the Slovak Hydrometeorological Institute and experimental basins. A higher frequency sampling of the data (daily for duration of several years) was used for a more precise estimation of the pollutant loads and their temporal variations in surface streams. Relationships for estimation of the pollutant yields from the unit area in Slovakia were derived (e.g. *Onderka et al., 2012; Slobodník et al., 2012; Sokáč et al., 2013; Miklánek et al., 2013)*. Results will serve the purpose of the implementation of the EU WFD in Slovakia *(Slobodnik et al., 2012).*

The impact of forestry, agriculture and urban activities on the quality of surface water was analyzed in several studies (*e.g. Su et al., 2011; Sokáč et al.,* *2013; Zeleňáková and Čarnogurská, 2013; Sokáč et al., 2014).* Fluctuations in the loads of nitrogen, phosphates, sulphates and chlorides were analyzed. The applicability of different types of time series models for predicting the concentrations of pollutant were tested *(e.g. Valent et al., 2011)*. It was concluded, that nitrate concentrations in surface waters have decreased in Slovakia after 1989 as a result of the lower application rates of inorganic nitrogen fertilizers in course of the decrease in agricultural production in Slovakia *(e.g. Onderka, et al., 2012; Zeleňáková and Čarnogurská, 2013).*

The quantitative aspects of groundwater formation and regimes were studied regionally. Research also oriented towards the influence of human activities on the natural groundwater regime and surface-groundwater interactions *(e.g. Pálinkášová and Šoltész, 2012; Orfánus and Šoltész, 2014).* Several studies were concerned with the interrelationship between surface waters and groundwater under withdrawal *(e.g. Fendeková and Fendek, 2012; Šutarová et al., 2013).* Research on the influence of human activities on the recharging groundwater amounts and water quality under different hydrologic conditions was conducted. Several numerical groundwater models based on finite elements and boundary elements were used for the analysis, prediction and control of groundwater levels at several water structures in Slovakia. The conditions under which technical measures could be used to improve groundwater regimes even in extreme hydrologic conditions, were also sought *(e.g. Fendeková et al., 2011; Pásztorová et al., 2011; Velísková et al., 2014; Šoltész and Baroková, 2014; Baroková 2014).*

3. Soil-water-plant-atmosphere interactions on point, plot and hillslope scales

Research on water, ion and energy transport interactions involving the soil-water-plant-atmosphere system (SWPA) interactions on point, plot and hillslope scales has focused mainly on the following problems:

- quantitative characterizations of the soil water, energy and dissolved matter regimes in the SWPA system *(e.g. Novák, 2012; Lichner et al., 2013a; Pásztorová and Skalová, 2013, Vitková et al., 2013)*,
- measurement and calculation of water and energy transport intensities between plants, spoils and atmosphere depending on plants properties and environmental factors *(e.g. Fodor et al., 2011; Lichner et al., 2011;*

Gömöryová et al., 2013; Lichner et al., 2013b; Hlaváčiková and Novák, 2014),

– estimation of bulk canopy resistance of different canopies and methods of its estimation for routine use in transpiration and evapotranspiration calculations *(e.g. Mati et al., 2011; Novák, 2012; Hlaváčiková and Novák, 2013; Hrvoľ et al., 2013a; Střelcová, et al., 2013)*,
– improvement of parametrization of mathematical models of water, energy and solutes transport including pedotransfer functions as useful tools of indirect soil physical characteristics estimation using known soil characteristics *(e.g. Skalová et al., 2011; Novák et al., 2011; Kováčová and Velísková, 2012; Novák and Kňava, 2012; Lichner et al., 2014)*,
– soil crust, soil-water repellency at several sites on actual *soils (e.g. Lichner et al., 2012; Orfánus and Bedrna, 2012a; Orfánus and Bedrna, 2012b)*.

Estimation of the components of the water balance in forests and agricultural ecosystems resulted in an advanced quantitative analysis of the water balance equation *(Novák et al., 2011)*.

4. River morphology and ecology

Qualitative and quantitative investigations of the effect of river morphology on ichthyological fauna in both natural and regulated segments of selected rivers were conducted (e.g. fish species composition, species diversity, the abundance and biomass of particular species, the mean individual weight and the ichthyomass were monitored during the spring and autumn seasons, etc). Factors affecting fish population density were also specified. It was observed that in a natural stream segment, the number of species, the diversity of species and equitability indices were higher than in regulated ones *(Demeterová et al., 2011; Macura et al., 2012; Vojtková et al., 2013).*

Several projects were focused at the study of river and floodplain processes (flow regime, development of river channel and floodplains, sediment transport) by means of numerical and physical models in order to analyze the impacts of human interventions at the environmental quality of the river and of the adjacent areas. Morphologically stable and environmentally sensitive river training measures were also sought with the aim to support the creation of natural range of instream and bankside habitats for fisheries, flora and fauna, and to protect the wetland ecosystems *(e.g. Miklánek, 2012; Koczka Bara et al., 2014;*

Šulek et al., 2014; Velísková et al., 2013; Vojtková et al., 2014; Zachoval et al., 2014).

5. Climate change and hydrometeorological processes

Diverse hydrometerorological time series, such as precipitation, air and water temperature, water quality and runoff were analyzed within the framework of the Slovak National Climate Change Program (SNCCP) in several studies in order to detect climate change signals in data series using statistical methods *(e.g. Melo et al., 2011, Pekárová et al., 2011; Faško et al., 2012; Hrvoľ and Gera, 2013; Hrvoľ et al., 2013a; Hrvoľ et al., 2013b; Melo et al., 2013; Zeleňáková et al., 2013; Novotná, et al., 2014)*. Attention was paid to the detection of teleconnections in the region of Central Europe and the modeling of time series *(Labudová et al., 2013; Fendeková et al., 2014; Szolgayová et al., 2014).*

Several analogous, incremental and GCM (General Circulation Model) based climate change scenarios were also constructed within the framework of the SNCCP *(e.g. Lapin et al., 2012a; Lapin et al.,2012b; Lapin and Melo, 2012)*. It was attempted to construct physically plausible scenarios of monthly and annual time series for air temperature, precipitation and air humidity. The several GCMs with coupled systems of atmospheric and ocean circulation were downscaled. Attempts to design scenarios of extreme monthly and daily precipitation totals also started *(e.g. Kyselý et al., 2011; Gaál et al., 2014b)*. According to these scenarios an increase in annual temperature, small changes in long-term precipitation totals, and a remarkable increase in short-term precipitation extremes may be expected in Slovakia in the warm half-years in the future. On the other hand, more frequent and longer periods of meteorological drought will occur mainly in the Slovak lowlands.

Several spatially lumped conceptual hydrological rainfall-runoff models were used in the climate change impact studies. The models were calibrated under a variety of different hydrologic situations in a number of catchments, which represent a wide spectrum of runoff regimes. Simulated runoff from different models exhibits the same character of changes in the seasonal distribution of flows. In the northerm parts of Slovakia the mean monthly discharges should increase in the winter low flow period, spring flows could (partly substantially) decrease. Flow regime in the summer and the autumn will show stationary behavior with moderate decrease of runoff. The extremity of the decrease of mean monthly flows accelerates with the widening time horizon of the scenarios. In the southern areas the scenarios show a tendency towards creation of a stable dry period with low flows substantially below the values from the baseline time series. The whole territory of Slovakia can become more vulnerable to drought in the summer and in the autumn *(e.g. Fendeková and Fendek, 2012; Štefunková et al., 2013; Vitková et al., 2013; Novotná et al., 2014)*.

6. Hydrological extremes

Large floods and droughts occurred in some regions of Central Europe also during the period covered by this report (e.g. by *Hall et al., 2014; Zeleňáková et al., 2014).* Recent extreme flood events in Europe have also stimulated public discussion on the issue of whether the frequency and severity of floods have been increasing in Europe and Slovakia and if such changes could be attributed to anthropogenic influence *(e.g. Jeneiová et al., 2014; Kjeldsen et al., 2014).* This initiated increased interest in the flood and drought formation in catchments of various regions. Lumped and distributed rainfall runoff models were used to reconstruct past extreme events *(e.g. Blaškovičová et al., 2011; Demeterová et al., 2011; Fendeková and Fendek, 2012; Banasik et al., 2014; Valent et al., 2014; Zeleňáková et al., 2014).* Knowledge of the formation of extreme precipitation and floods and data on rare events was needed for the development and use of regional formulae for design rain and peak flow estimates in structural design. Several extreme events were individually investigated, and the formation of the floods in ungauged basins was reconstructed using data from at site hydrological surveillance and available data from the hydrological and meteorological network together with radar and satellite data *(e.g. Holko et al., 2011a; Kyselý et al., 2011; Pekárová et al., 2012; Pekárová et al., 2013a; Pekárová et al., 2013b; Pekárová et al., 2014; Gaál et al., 2014a).*

Characteristics of measured and historical flows waves were also frequently statistically analyzed *(e.g. Melo et al., 2014).* Regional flood frequency distributions were also sought *(Šimor et al., 2012; Salinas et al., 2014a, b).* Valuable knowledge of the formation of extreme flood runoff and data on rare events needed for the frequency analysis of peak flows and joint analysis of several flood characteristics (e.g. peaks and volumes. etc) in structural design was gained *(Gaál et al., 2012; Bačová-Mitková and Halmová, 2014)*. An assessment of the historical floods in several rivers was preformed. An analysis of this dataset did not indicate a significant increase in extremeness of the flood regime in general. The results of such an analysis on the Danube were summarized in a monograph *(Pekárová et al., 2014)*. The various risks associated with flooding were characterized by relations based on informative values deduced from the actual conditions of the Slovak Republic *(Zeleňáková et al., 2011; Solín and Skubinčan, 2013; Solín et al., 2014).*

7. Conclusions

Attempts to increase the understanding of hydrological processes on various scales have been the focus of the international scientific community in recent years. This report reviews the response of hydrologic research in Slovakia in the period 2011 to 2014 to these challenges of global hydrologic research. The published results of the main research programs in hydrology were reviewed herein and references to papers published in English provided. References to national and international projects and PhD. dissertations in hydrology from the same period in the Appendix.

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Selected achievements in Meteorology and Atmospheric Sciences in Slovakia in 2011–2014 Report to IAMAS

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Abstract: Comparing several previous Reports to IAMAS only a selection of the reviewed papers published in international and in Slovak Journals and monographs are presented in this Report. We consider that these sources can contribute to spread more effectively national scientific information abroad. It is an advantage that except the textbooks and papers for education nearly all cited papers and contributions have been published in English language. Only such references are included here where as coauthors are specialists on meteorology, climatology and atmospheric sciences from Slovakia. Information on the hydrology and water cycle papers are included in the Report to IAHS even if contain meteorology and climatology parts.

1. Weather forecast, modeling of atmosphere processes

This field of meteorology has widely developed in Slovakia mainly since 1990, when new computer technology was installed at the Slovak Hydrometeorological Institute (SHMI), new education subjects have been established at the Comenius University and collaboration with the METEOFRANCE on Aladin Arpege atmospheric models has started. The progress in this field can be clearly seen also from the titles and short abstracts of two selected attached references by the Slovak specialist M. Belluš et al. (2011). The Central European limited area ensemble forecasting system ALADIN-LAEF (Aire Limitée Adaptation Dynamique Développement InterNational – Limited Area Ensemble Forecasting) has been developed in the frame of the international cooperation ALADIN and the Regional Cooperation for Limited Area modeling in Central Europe (RC LACE). It was put into pre-operation in March 2007. The main feature of the pre-operational ALADIN-LAEF was dynamical downscaling of the global ensemble forecast from the European Centre for Medium-Range Weather Forecasts (ECMWF). In 2009, ALADIN-LAEF has been upgraded with several methods for dealing with the forecast uncertainties to improve the forecast quality. Those are: 1) Blending method, which combines the large scale uncertainty generated by ECMWF Singular Vectors with the small scale perturbations resolved by ALADIN Breeding into atmospheric initial condition perturbations; 2) Multi-physics approach: Different physics schemes are used for different forecast members to account for model uncertainties; 3) Non-Cycling Surface Breeding (NCSB) technique, which generates surface initial conditions perturbations. This paper illustrates the technical details of the updated ALADIN-LAEF and investigates its performance. Detailed verification of the upgraded ALADIN-LAEF and a comparison to its first implementation (dynamical downscaling of ECMWF ensemble forecasts) are presented for a two-month period in summer 2007. The results show better performance and skill for the upgraded system due to the better representation of forecast uncertainties.

The further progress in this field was published by *Belluš et al. (2014).* A blending method for generating initial condition (IC) perturbations in a regional ensemble prediction system is proposed. The blending is to combine the large-scale IC perturbations from a global ensemble prediction system (EPS) with the small-scale IC perturbations from a regional EPS by using a digital filter and the spectral analysis technique. The IC perturbations generated by blending can well represent both large-scale and small-scale uncertainties in the analysis, and are more consistent with the lateral boundary condition (LBC) perturbations provided by global EPS. The blending method is implemented in the regional ensemble system Aire Limitée Adaptation Dynamique Développement International-Limited Area Ensemble Forecasting (ALADIN-LAEF), in which the large-scale IC perturbations are provided by the European Centre for Medium-Range Weather Forecasts (ECMWF-EPS), and the small-scale IC perturbations are generated by breeding in ALADIN-LAEF. Blending is compared with dynamical downscaling and breeding over a 2-month period in summer 2007. The comparison clearly shows impact on the growth of forecast spread if the regional IC perturbations are not consistent with the perturbations coming through LBC provided by the global EPS. Blending can cure the problem largely, and it performs better than dynamical downscaling and breeding.

2. Upper atmosphere meteorology, ozone, aerosols, atmospheric chemistry, greenhouse gases emission, environmental impacts

Special departments for upper atmosphere monitoring, atmospheric chemistry and air quality measurements and analyses exist within the SHMI. These departments are involved also in greenhouse gases (GHGs) emission inventory and connected climate change issues. Some activities in this field have been carried out also by the Slovak University of Agriculture in Nitra and the University of Technology in Zvolen. In the 6th Slovak National Communication on Climate Change *(Princová et al., 2013)* it was summarized the inventory of GHGs emission and the up to present climate change in Slovakia. Important part of its content are also: review of Slovak mitigation measures (reduction of GHGs), scenarios of climate change scenarios for Slovakia, assessment of vulnerability of different socio-economic sector on expected climate change and design of adapting measures to reduce negative and utilize of positive climate change impacts. Several papers on the topics mentioned above have been presented in previous Slovak National Reports to IUGG (2007, 2011), and also at conferences and workshops. That is why we selected only five of newer information published in reviewed meteorological journals and proceedings. Ground ozone is regularly measured in Slovakia at about 8 stations only since 1993 (now about 20 stations in all Slovakia). The Observatory at Stará Lesná and the SHMI branch at Gánovce are specialized also on solar radiation measurements and analyses, including the UV-B fraction and upper atmosphere monitoring. The ground ozone concentration can be very high in the area of the Tatras Mts. and it is comparable with other European mountains. It was found a very close correlation of nocturnal and the highest daily concentrations of ground ozone at the Stará Lesná Observatory. New model of daily UV radiation sums calculation enables to assess typical UV values for Slovakia during cases of extreme total ozone and cloudiness conditions. The purpose of the chapter by *Bičárová et al. (2013)* is to investigate the EMEP ozone measurements situated in different landform areas of Europe during the last decade period 2000–2009.

The MicroStep company in Bratislava is engaged in meteorological observations and analyses in different polluted areas. In collaboration with the Division of Meteorology and Climatology (OMK) at FMFI UK several valuable studies have been issued. Two of them are included into this Report. One is on fog prediction in the coastal areas by *Bartok et al. (2012a)* and the second one on the low cloud detection published by *Bartok et al. (2012b)*.

Division OMK FMFI UK collaborates also with the FMFI UK Department of Nuclear Physics. Just one common paper as an example is presented here on the Aerosol radioactivity record in Bratislava (Slovakia) following the Fukushima accident (a comparison with the global fallout and the Chernobyl accident), published by *Povinec et al. (2012)*. Several other papers have been published on Fukushima accident and radionuclides emission from the Fukushima accident in the air over different regions in the northern hemisphere also in collaboration with Gera M. from the OMK Division but not cited here.

3. Evapotranspiration and radiation balance

Changing climate impacts water and radiation balance of the Earths surface, including of active surfaces modified by vegetation. Now some newer results on evapotranspiration calculations and analyses in Slovakia are presented here. Radiation balance is measured only at low number of meteorological stations, so that is why only calculated values using other meteorological elements are presented here.

With regard to optimization of the factors of field crop harvest formation in semi-arid areas the phenomenon of soil drought is of key importance of paper by *Mati et al. (2011)*. This article deals with the problem of soil water management in connection to soil fertility in the area of East Slovakian Lowland, characterized by the complexity of its agro-ecologic conditions. In clay–loamy soils of the corresponding area, soil water content at the level limited by the threshold point and field water capacity ensures that the average value of actual evapotranspiration intensity varies between 2.69 and 3.89 mm per day^{-1}.

The monograph by *Novák (2012)* presents evapotranspiration as a process of water movement from evaporating surfaces to the atmosphere. However, water movement from the soil to the evaporating surface or roots, and water extraction by roots and water movement to a plant's leaves are mentioned only marginally. A wide variety of methods for the calculation of evapotranspiration as a whole, as well as the components of its structure (e.g., transpiration, evaporation) have already been published. The aim of this book is to focus attention primarily on water movement in the soil root zone and soil water extraction by roots.

Analyses by *Hrvoľ et al. (2012)* bring the model computation of the mean monthly, annual and vegetation season totals of the potential and actual evapotranspiration at 31 selected stations on the territory of Slovakia for the period 1951–2010. The processing made it possible to compare these characteristics for two climatologic normal periods, i.e. 1951–1980 and 1981-2010. Using an example of meteorological stations Hurbanovo (lowland) and Podbanské (mountains), situated in different humid climatic conditions, the change in distribution of the monthly actual evapotranspiration totals has been analyzed. On the other hand, in the warmer period 1981–2010, the higher frequency of extreme actual evapotranspiration monthly totals has been confirmed at both stations. The mean monthly, annual and vegetation season totals of the evapotranspiration from the forest cenose were presented by *Hrvoľ et al. (2013a)* and were determined by the method worked out and used in Russia. Evaporation from the forest with snow cover was computed by Kuzmin's formula. Computation was made for 30 selected stations in the period 1951–2010. The processing made it possible to compare this characteristic for two climatologic periods, i.e. 1951-1980 and 1981-2010 as well. At the most stations an increase of the mean annual evaporation totals was computed, as well as those for 2 vegetation period.

Paper by *Hlaváčiková and Novák (2013)* presents comparison of the daily reference crop (grass vegetation cover) potential evapotranspiration results calculated by the two modifications of the Penman-Monteith type equation. The first modification was published in FAO recommendation *(Allen at al., 1998)*, PM-FAO, the second is modification according to *Budagovskiy (1964)* and *Novak (1995)*, PM-BN. Both are used in soil water simulation models HYDRUS-1D and GLOBAL.

The monograph chapter by *Hrvoľ and Gera (2013)* deals with the altitudinal change of the sensible heat and latent heat fluxes dependence on the net radiation on the territory of Slovakia for the summer and the vegetation seasons in the period 1951–2010. Components of the energy balance of the active surface (the net radiation, the sensible heat flux, the latent heat flux, the soil heat flux) as well as the values of the mean soil moisture were computed by means of the model developed at the Faculty of Mathematics, Physics and Informatics of the Comenius University in Bratislava. This model is based on a common solution of the energy and water balance equations.

The paper by *Hrvoľ et al. (2013b)* brings the time and space distribution of the global radiation sums on the territory of the Slovak Republic. The mean monthly, annual and vegetation season sums of the global radiation were determined by means of monthly cloudiness data. Computation was made for 30 selected stations in the period 1951–2010. The processing made it possible to compare this characteristic for two climatologic periods, i.e. 1951–1980 and

1981–2010. At the most stations an increase of the mean annual global radiation sums was computed, as well as those for the vegetation period. The paper by *Hrvoľ et al. (2014)* deals with the influence of reduced soil moisture in summer 2003 on the increase of the maximum mean air temperature in this season with respect to the mean air temperature for the period 1951–2010. Computation of the maximum mean air temperature increase due to reduced soil moisture was processed for 4 stations of Slovakia with different humid conditions. The mean monthly values of soil moisture were denoted from the water balance equation by the step-by-step approximation method.

Lapin et al. (2014) presented analysis of calculated potential evapotranspiration changes in 1951–2013 in Slovakia and scenarios up to 2100 designed by data from two Regional Circulation Models (KNMI and MPI) and method of potential evapotranspiration calculation based on saturation deficit.

4. Analyses of climatic variability and extreme weather events

Climatic changes and variability can be studied in Slovakia using monthly climatic time series since 1881 (3 air temperature stations and monthly areal precipitation totals calculated from 203 precipitation stations), there are also series of another elements from several stations since 1901. Daily precipitation totals and daily temperature means have been edited in the computer format series from nearly all stations since 1951, all stations data are available in the SHMI databank since 1961, most of them from 1951 and from the Hurbanovo Observatory since 1871. Detailed studies on precipitation and other climatic elements variability in Slovakia, including daily total extremes and seasonality changes, have been prepared mainly at the SHMI, OMK KAFZM FMFI UK and SAS Institute of Geophysics. It is beneficial that also researchers from other institutions started to study variability of climatic elements and their cross-comparisons with other elements (hydrologic at Slovak University of Technology, biologic at Forestry Faculty in Zvolen and Slovak University of Agriculture in Nitra). Except the climatic changes and variability some research has been carried out also in the field of regional climatic studies. Only a selection from such analyses is presented here.

The study presented by *Nikolova et al. (2013)* is based on daily data for precipitation totals, new snow cover depths and monthly air temperature from 29 meteorological stations in Slovakia. The aim was to determine to what extend the change of monthly air temperature mean affects the snowfall in the mountainous area of Slovakia. In order to achieve the aim of the research work, the snow days and precipitation days (SD/PD) ratio is calculated for the months from October to April and the trend is investigated. On the basis of correlation analysis it is determined that the main factor for changes in the SD/PD ratio is mean monthly air temperature while precipitation plays important role only for the stations with the altitude above 1300 m. Spatial distribution of the changes in the SD/PD ration for the winter time (December-January-February) during the period 1981–2011 was investigated by cluster analyses.

Three winter months (Dec. 2011 – Feb. 2012) exhibited extreme deviations of several climatologic variables from normal also in Slovakia as presented by *Faško et al. (2012)*. While 17 days (of total 91) were colder than the normal range, 41 days were warmer (normal range for daily mean temperature is ±2.7°C from the long-term average). Southern Slovakia had only several days with snow cover and precipitation totals about 80% of normal, but some localities in the northwestern Slovakia were paralyzed by heavy snowfalls and precipitation totals exceeded 200% of normal there. General people and media spoke on century cold winter, damages topped millions of Euro. Climatologists were reserved in their statements, because of having long-term measurements and analyses since 1775.

The 3-year period 2007–2009 was substantially warmer than normal (by about 1.5 to 2.0°C, it means the warmest since the beginning of meteorological measurement) and the year 2010 had unbelievable high precipitation total in Slovakia and in round countries (in Slovakia by 65% above normal in average, by 100% above normal in the South, mostly by about 200 mm more than up to present record total). These data were published by *Lapin (2011)*. He stressed that outputs from the newest climatic General Circulation Models (GCMs) indicate a continuation of temperature as well as weather extremes increase also in the next decades. Some socio-economic sectors and natural ecosystems are vulnerable due to rush change of climatic conditions, so adaptive options need to be designed in close future to reduce possible negative impacts. As all scenarios show close trends up to the time frame 2050 they can be considered as reliable also for future climatic conditions change assessment. Scientific collaboration of several Slovak Academy of Sciences Institutes took place as well, see the forestry, hydrology and meteorology common papers by *Holko et al. (2012)*, *Bičárová and Holko (2013)*, *Bičárová and Čepčeková (2013)* and *Bičárová et al. (2014)*. Although the deforested area after windfall degradation in Nov. 2004 is large (totally about 120 km^2 in the upper Poprad and the neighbouring upper Váh river catchments), it is located in middle sections of the catchments. Headwater areas where the dominant contribution to runoff is formed (and where little forests existed anyway) were not influenced. Deforestation occurred in areas formed by moraines which have high infiltration capacity, published *Holko et al. (2012)*. The article by *Bičárová and Holko (2013)* presents the results of the analysis of time series of daily precipitation and runoff at selected places in the highest part of the Western Carpathians. It was focused on both wet and dry periods in precipitation and runoff data series. The precipitation data were analyzed for period 1961–2010. In the paper by *Bičárová and Čepčeková (2013)* daily precipitation data series obtained in the High Tatras during the period 1961–2011 were analyzed. Spatial differences reflect position of 4 rain gauge sites in altitudinal profile from 694 to 2635 m a.s.l. Hydrological research performed near the study area showed that runoff response of the small mountain catchments in the warm period of a year primarily depends on the amount of precipitation. The paper by *Bičárová et al. (2014)* focuses on evaluation of climatic data obtained at the Meteorological Observatory GPI SAS Stará Lesná according to classical daily observations carried out for period 1988–2013. Location is situated at the foothills of the High Tatra Mts. and represents submontane climate zone favourable for temperate coniferous and mixed forest vegetation.

An evaluation of changes in snow cover in the mountainous basins in Slovakia and a validation of MODIS satellite images are provided in the paper by *Kotríková et al. (2014)*. An analysis of the changes in snow cover was given by evaluating changes in the snow depth, the duration of the snow cover, and the simulated snow water equivalent in a daily time step using a conceptual hydrological rainfall-runoff model with lumped parameters. These values were compared with the available measured data at climate stations. The changes in the snow cover and the simulated snow water equivalent were estimated by trend analysis; its significance was tested using the Mann-Kendall test. Also, the satellite images were compared with the available measured data. From the results, it is possible to see a decrease in the snow depth and the snow water equivalent from 1961–2010 in all the months of the winter season, and significant decreasing trends were indicated in the months of December, January and February.

5. Climate change scenarios and impacts of climate change

The first climate change scenarios for Slovakia were prepared within the Slovak National Climate Program and the U.S. Country Studies Program projects in 1991–1997. In 1998 a new stage of such activities started at the Division of Meteorology and Climatology (Comenius University in Bratislava) under collaboration with the Slovak Hydrometeorological Institute (SHMI) adopting outputs of new General Circulation Models (GCMs) with coupled systems of atmospheric and ocean circulation. This effort continued also in 2006–2010 and new outputs from the GCMs CGCM3.1 and ECHAM5 as well as from the Regional Circulation Models (RCMs) KNMI (Holland) and MPI (German) have been tested and modified for Slovakia. Besides this also combined GCMs (RCMs) – Analogue statistical methods and dynamic methods of downscaling were applied. Climatic scenarios have been applied in analysis of vulnerability and impacts in several sectors (Water, Forestry, Agriculture etc.). General Circulation Models (GCMs) and Regional Circulation Models (RCMs) provide daily climatic data in the gridpoint scale with about 300×300 km to 25×25 km resolution. Statistical downscaling method enables to prepare data as scenarios for selected station with good statistical congruity (means, extremes, variability) with measured data in the control period (1961–1990). Physical relations among variables offer good possibilities for calculation of derived climatic variables like saturation deficit, potential evapotranspiration, snow cover etc. A sample of new elaboration of such combined scenarios for selected station in Slovakia based on 2 GCMs and 2 RCMs (3 SRES scenarios) and the time frame 2001–2100 is presented in the paper by *Lapin et al. (2012)*.

The paper by *Lapin and Melo (2011)* is devoted to brief analysis of possible climate change impacts on the sub-urban and urban areas of south-western Slovakia. Climate change due to enhanced greenhouse effect can result in about 2.5 °C mean global temperature increase until 2100. In Slovakia it is assumed as a range of 2 to 4 °C annually. On the other hand the additional warming of urban areas is caused mainly by changed heat balance of the Earth's surfaces in urbanized agglomerations (concrete, asphalt, buildings, cobblestones, etc.) and partly also by the thermal pollution (release of energy at heating and other human activities). In smaller cities the urban effect causes warming by about 0.5 °C, in the largest ones up to 2 °C annually in the long-term average sense.

Identification of the borders of climatic regions and analysis of their geographical shifts in time can help us to understand climate evolution in any territory. *Melo et al. (2011 and 2013)* tried to specify climate regions and subregions using the Konček's and Köppen's climatic classification schemes and to identify the shifts in boundaries in the Danubian Lowland (in Slovakia) during the 20th century and at the beginning of the 21st century as well as based on modified climate models outputs to outline possible trend in the future. The results of their analysis indicate that climate has become warmer and more arid in this area. Scenarios show also the additional warming and increase of aridity in this territory by the end of the 21st century.

In the study by *Štefunková et al. (2013)* the potential impact of climate change on river runoff in the upper Hron River, Váh River, and Laborec River basin was evaluated using the Hron conceptual spatially-lumped rainfall-runoff model, which was driven by regional circulation models of atmosphere. The rainfall-runoff model was calibrated with data from the 1981–1995 period and validated with data from the 1996–2010 period. Changes in climate variables in the future were expressed by three different regional climate change projections: KNMI, MPI and ALADIN-Climate for the period 1961–2100. Changes in the seasonal runoff distribution were evaluated by a comparison of the simulated long-term mean monthly discharges in the river basin outlets in future decades with the present stage.

The study by *Gaál et al. (2014)* examines projected changes in precipitation extremes, aggregated on several time scales (1 hour, 1 day, and 5 days), in simulations of 12 regional climate models (RCMs) with high spatial resolution (25 km). The study area is the Carpathian Basin (Central and southeastern Europe) which has a complex topography and encompasses the whole territory of Slovakia and Hungary as well as major parts of Romania and western Ukraine. The focus was on changes in mean seasonal maxima and high quantiles (50-year return values) projected for the late 21st century (time slice 2070–2099) in comparison to the control period (time slice 1961–1990), for summer and winter.

An analysis of daily maximum and minimum temperatures as well as of daily temperature range at selected meteorological stations in the Slovak part of the Tatra mountains region in 1961–2010 are studied by *Melo at al. (2013)*. Time series of temperature range means have been analyzed by trend analysis and other statistical tools. In the second part of this contribution the daily outputs of two regional climate change models (Dutch KNMI and German MPI, both with ECHAM5 boundary conditions) have been used for design of climate change scenarios (daily maximum and minimum of air temperature and daily range of air temperature) for selected stations in this region and the period

1951–2100. Comparisons of measured and modeled temperature characteristics (daily extremes and daily range) are included. This paper was reelaborated and completed with further analyses and will be published soon in the Meteorologische Zeitschrift in 2015 *(Damborská et al., 2015)*.

6. Agrometeorology, Forestry and Phenology

The Agrometeoroly and Forestry bioclimatology use the same climatological and precipitation stations and observed data as the other sectors, at some stations special agrometeorological and bioclimatological observations are provided (soil temperature and moisture, evapotranspiration, measurements in canopy etc.). Phenology is based on special biological observations around selected regular climatological stations neighborhood. The impact of air temperature on the formation of generative organs of the Europea hazel (Corylus avellana L.) and the onsets of related phenophases during the years 1987–2009 in Central Slovakia are analyzed in the paper by *Škvareninová et al. (2011)*. The analyses are based on the records of 10% and full onset of catkins lenghtening, inflorescence energence and flowering. Catkins lengthening was observed on February 7th and lasted 10 days on average, inflorescence emergence on February 20th and 8 days and flowering on March 2nd and 6 days. The earliest dates of phenophases onsets were observed in 2007, while the latest in 1987 and 2005.

In the study by *Lukasova et al. (2014a)* the effect of selected biometeorological variables on the onset of phenophases in three beech stands in different climatic areas (warm, moderately warm and cold) was analyzed. It was focused on two phenophases – leaf unfolding and leaf colouring. Timing of both phenophases was identified visually and using series of MODIS satellite images. The data were collected during a 13-year period (2000–2012). The paper by *Hríbik et al (2012)* evaluates results of a 6-year monitoring of the eco-hydrological influence of Norway spruce (Picea abies (L.) Karst.) and European beech (Fagus silvatica L.) forest stands on the hydro-physical properties of snow cover. This experiment was carried out in the artificially regenerated 20–25-year old forest stands approaching the pole timber stage in the middle mountain region of the Poľana Mts. Biosphere reserve situated at about 600 m a.s.l. during the peri od of maximum snow supply in winters of years 2004–2009. In the years 2007–2013 the phenological observations of common hazel (Corylus avellana L.), blackthorn (Prunus spinosa L.), and hawthorn

(Crataegus oxyacantha L.) was performed at two locations of central Slovakia situated at elevations of 300 m and 530 m a.s.l. as published by *Škvareninová (2014)*. The phenophase of first leaves of all tree species started in the second half of April on average, and was conditioned by the average daily air temperatures above 0 °C. The earliest onset was observed at both locations in 2007 due to the highest average air temperature during the observed period, which in March reached the value of 6.1 °C. The paper presented by *Pástorová et al. (2014)* analyses temporal variability of the beginning, end, and the length of growth, and of the selected spring phenological phases. The experiment was performed on three provenances of Norway spruce (Picea abies /L./ Karst.) originating from the orographical unit of Volovské vrchy, and growing in Borová hora arboretum, during the three years 2010, 2011 and 2012. The examined provenances were selected on the base of the elevation gradient from three elevations: 500 m a.s.l., 750 m a.s.l. and 1,100 m a.s.l. Tree stem circumference changes were continuously measured, and spring phenological phases were assessed.

The impact of adverse weather conditions (AWCs) on crop production is random in both time and space and depends on factors such as severity, previous agrometeorological conditions, and plant vulnerability at a specific crop development stage as presented *Lalic et al. (2014)*. Any exclusion or improper treatment of any of these factors can cause crop models to produce significant under- or overestimates of yield. The analysis presented in this paper focuses on a range of agrometeorological indices (AMI) related to AWCs that might affect real yield as well as simulated yield. For this purpose, the analysis addressed four indicators of extreme temperatures and three indicators of dry conditions during the growth period of maize and winter wheat in Austria, Croatia, Serbia, Slovakia, and Sweden.

Further analyses of phenophases and climatic/hydrologic characteristics relations were presented by *Bartík et al (2014)*, focused on snow accumulation impacts, by *Gömöryová et al. (2013)*, on soil water content impacts, by *Lukasova et al. (2014b)*, by *Mezei et al. (2014)*, *Pástorová et al. (2014)* and *Střelcová et al. (2013)*.

7. Water balance and Hydrometeorology

Meteorological conditions, changes and variability of climate influence very significantly on hydrological cycle, water management and also on short-term regime of river stages. That is why hydrologists in Slovakia collaborate very closely with meteorologists and climatologists. From plenty of papers, monographs and conference contributions on this topic only a sample have been selected for this chapter.

The study by *Bačová-Mitková and Halmová (2014)* is focused on the analysis and statistical evaluation of the joint probability of the occurrence of hydrological variables such as peak discharge (Q), volume (V) and duration (t). In this case study, it was focused on the bivariate statistical analysis of these hydrological variables of the Danube River in Bratislava gauging station, during the period of 1876–2013.

Methodology for a post-event analysis of a flash flood and estimation of the flood peak and volume are developed and tested in the paper by *Blaškovičová et al. (2011)*. The selected flash flood occurred on the 6^{th} of June, 2009 in the Svacenický Creek Basin. To understand rainfall-runoff processes during this extreme flash flood, the runoff response was simulated using the spatially-distributed hydrological model KLEM (Kinematic Local Excess Model). The distributed hydrological model is based on the availability of raster information about the landscape's topography, soil and vegetation properties and radar rainfall data. In the model, the SCS-Curve Number procedure is applied to a grid for the spatially-distributed representation of the runoff-generating processes. The consistency of the estimated and simulated values from the KLEM model was evident both in time and space, and the methodology has shown its practical applicability.

In the paper by *Pekárová et al. (2013)* the history of floods and extreme flood frequency analysis of the upper Danube River at Bratislava is analyzed. Firstly, there were described the flood marks found on the Danube River in the region of Bratislava, Slovakia, and provided an account of the floods' consequences. Secondly, there were analyzed the annual maximum discharge series for the period 1876–2012, including the most recent flood of June 2013.

Biological processes in surface waters appreciably depend on temperature of water; it was presented by *Pekárová et al. (2011)*. This paper summarizes investigations of water temperature in the Belá River. The Belá River is a mountainous stream not influenced by direct human activities, draining the headwaters of the Váh River basin in the Tatra National Park (TANAP), Slovakia. The primary aim was to identify the long-term trends and multi-annual variability of the annual water temperature at the Podbanské gauging station, using temperature readings taken at 7.00 a.m. for the period of 50 years (1959–2008). Both, air and water temperatures, show an increasing trend.

The runoff and its temporal distribution during the catastrophic flood events on river Gidra (32.9 km^2) and Parná (37.86 km^2) of the 7^{th} June 2011 was analyzed by *Pekárová et al. (2012)*. The catchments are located in the Little Carpathians Mountain, western Slovakia. Direct measurements and evaluation of the peak discharge values after such extreme events are emphasized in the paper including exceedance probabilities of peak flows and of their causal flash rainfall events.

The assessment of the water quality development in reference basins with natural regime is important for evaluation of the background values for classification of the ecological potential and status of the stream waters. Paper by *Miklánek et al. (2013)* analyses the water quality in Belá River at sampling site Liptovský Hrádok during the 20-years period 1991–2010. The series of interesting papers were presented by *Holko et al. (2011, 2012ab and 2013)*. The first one evaluates the spatial and temporal changes in streamflow flashiness in 122 mountain catchments in Slovakia and Austria. This analysis is based on daily streamflow data from the period 1976 to 2005. Influence of deforestation on hydrological cycle has been a subject of numerous studies since the beginning of the 20^{th} century *(Holko et al., 2012a)*. A temporary increase of discharges after deforestation was typically reported, but the measured data often show that flood and erosion control functions of the forests become to be evident but only in a limited way, they stressed. The third article synthesizes available information on isotopic composition of precipitation in Slovakia (the Western Carpathians). Monthly ^{18}O data from eleven stations and period 1988–1997 were used to investigate correlations among the stations, altitude, air temperature and precipitation amount effects. The mean annual altitude and air temperature gradients of ^{18}O in precipitation were 0.21‰/100 m and 0.36‰/1°C, respectively. In the fourth paper the variability of ^{18}O and ^{2}H in the snow-related part of a hydrological cycle (snowfall, snow cover, snowmelt, soil water, groundwater and streams) was monitored in mountain catchments of northern Slovakia in winters 2011 and 2012.

In the paper by *Krajči et al. (2014)* a method for estimation of regional snowline elevation (RSLE) from satellite data for seasonally snow covered mountain basins is presented. The methodology is based on finding an elevation for which the sum of snow covered pixels below and land pixels above the RSLE is minimized for each day. The methodology is tested with MODIS daily snow cover product in the period 2000–2013 in the upper Váh basin (Slovakia). The accuracy is evaluated by daily snow depth measurements at seven climate stations and additional snow regime measurements at 16 profiles in the period 2000–2013.

Numerous global and regional validation studies have examined MODIS snow mapping accuracy by using measurements at climate stations, which are mainly at open sites as it is mentioned in *Parajka et al. (2012)*. MODIS accuracy in alpine and forested regions is, however, still not well understood. The main objective of this study is to evaluate MODIS (MOD10A1 and MYD10A1) snow cover products in a small experimental catchment by using extensive snow course measurements at open and forest sites. The MODIS accuracy is tested in the Jalovecký creek catchment (northern Slovakia) in the period 2000–2011.

Another problems connected with climate and water regime of soils were presented by *Lichner et al. (2011*, *2013* and *2014)*. Vegetation cover has a major effect on water flow in soils. Two sites, separated by distance of about 50 m, were selected to quantify the influence of grass cover on hydrophysical parameters and heterogeneity of water flow in a sandy soil emerging during a heavy rain following a long hot, dry period. A control soil (pure sand) with limited impact of vegetation or organic matter was obtained by sampling at 50 cm depth beneath a glade area, and a grassland soil was covered in a 10 cm thick humic layer and colonized by grasses as showed in the first study. The heterogeneity of water flow and solute transport was assessed during radioactive tracer infiltration experiment in a black clay loam soil using modified methods to estimate the effective cross section (ECS) and the degree of preferential flow (DPF) in the second study. The results of field and numerical experiments showed that these parameters characterized the heterogeneity of water flow in the soils unequivocally. The heterogeneity of water flow was evaluated in sandy loam soil covered by grass in the third paper. The radioactive tracer infiltration experiment was performed at two parallel plots with different irrigation intensities. Effective cross section and degree of preferential flow parameters were used to evaluate flow regime during the experiment. For both plots, the heterogeneity of water flow increased with depth. The differences in irrigation intensity did not result in different values of the effective cross section and degree of preferential flow, indicating similar flow regime within the two experimental plots.

Salinization is an increasing environmental problem in case of ecosystems and the society. The assessment of total dissolved solids (TDS), pH, electrical conductivity (EC), exchangeable sodium percentage (ESP), alkalinity and the concentrations of main ions makes possible to identify salinization and alkalization degree was analyzed by *Kováčová et al. (2012)*. Five localities with highly-mineralized groundwater were monitored in the south part and south-east part of Žitný ostrov to evaluate salinity and alkality in the period 1989–2006.

The spatial and temporal patterns of surface water (SW) – groundwater (GW) exchange are significantly affected by riverbed silting, clogging or erosion processes, by altering the thickness and hydraulic conductivity of riverbed sediments. In the study presented by *Koczka Bara et al. (2014)* the flow processes between GW and SW were modeled by model TRIWACO for different infiltration resistance and drainage resistance of riverbed sediments. The model area is situated on the Rye Island, which is a lowland area with very low slope.

Hydrological data series that are measured on the Danube River are temporally limited. Instrumental flow data can be prolonged by documentary data from historical sources in archives.

Papers presented by *Melo et al. (2014ab)* deal with knowledge gained by studies of historical materials regarding the 1895 catastrophic floods on the Danube River and its tributaries as reflected in the contemporary local press and also in studies of other historical records (flood marks, chronicles, books and photos).

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Seismological and integrated geophysical research in Slovakia 2011–2014

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1. Numerical modeling of seismic motion and seismic wave propagation

The Finite-Difference Modeling of Earthquake Motions: Waves and Ruptures *(Cambridge University Press, 365 pp., ISBN 978-1-107-02881-4, Moczo, Kristek, Gális 2014)*

The first monograph of its kind includes original textbook chapters on
- the mathematical-physical model of seismic motion,
- rheological models of continuum for implementation of realistic attenuation and hysteretic stress-strain relation,
- introduction to the finite-difference method.

The monograph presents the complete theory and computational algorithm of the method developed by the team (partial results published originally in journals), new results on optimization of the finite-difference schemes, discrete representation of material heterogeneity, initiation of rupture propagation, and filtration of a slip rate.

3-D finite-difference, finite-element, discontinuous-Galerkin and spectral-element schemes analyzed for their accuracy with respect to P-wave to S-wave speed ratio *(Geophys. J. Int., Moczo, Kristek, Gális, Chaljub and Etienne 2011)*

We analyzed 13 3-D numerical time-domain explicit schemes for modeling seismic wave propagation and earthquake motion for their behaviour with a varying P-wave to S-wave speed ratio (VP/VS). The second-order schemes include three finite-difference, three finite-element and one discontinuous-Galerkin schemes. The fourth-order schemes include three finite-difference and two spectral-element schemes. All schemes are second-order in time. We assumed a uniform cubic grid/mesh and present all schemes in a unified form. We assumed plane S-wave propagation in an unbounded homogeneous isotropic elastic medium. We defined relative local errors of the schemes in amplitude and the vector difference in one time step and normalize them for a unit time. We also defined the equivalent spatial sampling ratio as a ratio at which the maximum relative error is equal to the reference maximum error. We presented results of the extensive numerical analysis.

We theoretically (i) showed how a numerical scheme sees the P and S waves if the VP/VS ratio increases, (ii) showed the structure of the errors in amplitude and the vector difference and (iii) compared the schemes in terms of the truncation errors of the discrete approximations to the second mixed and non-mixed spatial derivatives.

We found that four of the tested schemes have errors in amplitude almost independent on the VP/VS ratio.

The homogeneity of the approximations to the second mixed and non-mixed spatial derivatives in terms of the coefficients of the leading terms of their truncation errors as well as the absolute values of the coefficients are key factors for the behaviour of the schemes with increasing VP/VS ratio.

The conclusion for the computational practice is that the dependence of the errors in the vector difference on the VP/VS ratio should be accounted for by a proper (sufficiently dense) spatial sampling.

Using the SPAC Microtremor Method to Identify 2D Effects and Evaluate 1D Shear-Wave Velocity Profile in Valleys *(Bull. Seism. Soc. Am., Claprood, Asten, Kristek 2011)*

The computational method and code developed by the team at the Comenius

University in Bratislava was applied to study seismic microtremors in collaboration with the Australian colleagues.

The requirement of a layered-earth geology is a restrictive assumption when using the spatially averaged coherency spectra (SPAC) method. Numerical simulations of microtremors and SPAC observations recorded in the Tamar paleovalley, Launceston (Tasmania, Australia), are used to assess the potential of the SPAC method to identify two-dimensional (2D) effects and evaluate one-dimensional (1D) shear-wave velocity (SWV) profile in a valley environment. The Tamar Valley is approximately 250 m deep by 700–1000 m wide. It is filled with soft sediments from the Tertiary and Quaternary periods above hard dolerite bedrock of Jurassic age.

Observed coherency spectra of the vertical component are analyzed at two sites in the Tamar Valley; using two 50-m-radius centered triangular arrays above the deepest point of the valley at site DBL, and above the east flank of the valley at site RGB. Simulated and observed coherency spectra suggest the propagation of Rayleigh waves of first higher mode at the SV frequency of resonance of the Tamar Valley affects the coherency spectra recorded with pairs of sensors perpendicular to the valley (transverse-COH). Simulated and observed coherency spectra recorded above the deepest point of the valley (site DBL) with pairs of sensors parallel to the valley axis (axial-COH) are not affected by these edge-generated Rayleigh waves and agree well with the theoretical coherency spectrum computed from the preferred 1D SWV profile.

The simulated and observed results from this paper suggest that differences between the observed axial-COH and transverse-COH give an indication of the existence of the 2D buried valley. Results also suggest that the observed coherency spectra recorded on pairs of sensors oriented parallel to the valley axis can provide a reliable evaluation of a 1D SWV profile above the deepest point of a deep and narrow valley, such as the Tamar Valley.

Combining HVSR microtremor observations with the SPAC method for site resonance study of the Tamar Valley in Launceston (Tasmania, Australia) *(Geophys. J. Int., Claprood, Asten, Kristek, 2012)*

The collaboration also resulted in the study of resonance in the deep sediment-filled Tamar valley.

The presence of the deep and narrow Tamar Valley in the City of Launceston (Tasmania, Australia), in-filled with soft sediments above hard dolerite bedrock, induces a complex pattern of resonance across the city. Horizontal to vertical spectrum ratio (HVSR) microtremor observations are combined with 1-D shear wave velocity (SWV) profiles evaluated from spatially averaged coherency spectra (SPAC) observations of the vertical component of the microtremor wavefield to complete a site resonance study in a valley environment such as the Tamar Valley. Using the methodology developed in a previous paper, 1-D SWV profiles are interpreted from observed coherency spectra (axial-COH) above the deepest point of the Tamar Valley, using pairs of sensors spatially separated parallel to the valley axis. The 1-D SWV profiles interpreted at five sites suggest the depth to bedrock interface varies from approximately z = 25 m north of the city, to z = 250 m above the deepest point of the valley. Numerical simulations of the propagation of surface waves in a 2-D model representation of the Tamar Valley compare well with HVSR observations recorded on two profiles transverse to the valley axis. HVSR observations can identify the in-plane shear (SV) frequency of resonance above the deepest part of the valley on two separate profiles transverse to the valley axis. By computing the ellipticity curves from the preferred SWV profiles interpreted by the SPAC method, the antiplane shear (SH) modes of resonance expected to develop in the Tamar Valley are identified; modes which HVSR observations alone fail to locate with precision. HVSR observations suggest a complex mix of 1-D and 2-D patterns of resonance develops across the valley. The results from this paper suggest that HVSR microtremor observations can be combined with SPAC microtremor method to characterize the geology and the pattern of resonance in a 2-D narrow structure such as the Tamar Valley.

2. Seismic hazard analysis of the Slovak territory and Jaslovske Bohunice site

A new probabilistic seismic hazard analysis (PSHA) of the Slovak territory was performed in 2010–2012 due to new seismological, geological and geophysical data, and methodological progress in PSHA. The classical Cornell-McGuire procedure was followed. The earthquake catalogue for the Slovak territory and adjacent area was homogenized for the moment magnitude and declustered by the space-time windows. The time completeness of the catalogue based on different magnitude classes was analyzed.

As a part of the PSHA procedure, a new zonation for the Slovak territory and adjacent area has been developed. Due to lack of data for the considerable part of the computational area outside the Slovak territory, the zonation developed in the SESAME Project was used. Due to absence of strong-motion accelerometric data for the Slovak territory, six ground motion prediction equations (GMPEs) from other regions in the world based on similarity of the macroseismic attenuation curves were chosen. A logic-tree approach was adopted to model the epistemic uncertainty. The final logic-tree consists of 570 end branches with expertly assessed weights.

The new seismic hazard map in terms of peak ground acceleration (PGA), compatible with Eurocode 8 (Fig. 1), has been accepted by the Slovak Standards Institute as the official map in the Slovak National Annex to Eurocode 8.

A new PSHA of the Jaslovske Bohunice site was performed in 2011–2013 in relation to the New Nuclear Power Plant Project. A new seismotectonic model for the Region and Near Region was prepared based on the newly compiled seismological database and geological database for the Region and Near Region.

The 16, 50, 84 percentile and the mean PGA and pseudospectral acceleration (PSA) for the return periods of 475 years and 10 000 years were determined. The GMPEs were set to obtain the so-called rock site conditions defined by the average S-wave speed of 800 m/s in the top 30 metres. By the deaggregation of the probabilistic computation for the period of 0.2s. and for the return period of 10000 years the magnitude and the distance of the controlling

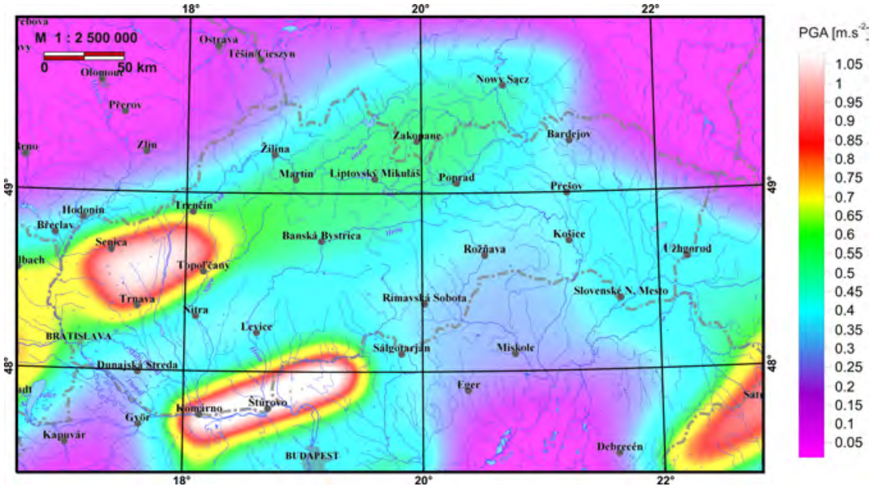

Fig. 1. The new seismic hazard map in terms of peak ground acceleration (PGA), compatible with Eurocode 8.

earthquake were determined. The average horizontal response spectrum was scaled to the value of the mean response spectrum for the period of 0.2 s to determine the review level earthquake (RLE). The vertical RLE spectrum was determined using available empirical V/H ratios.

In the Western Carpathians, so far no strong ground motions have been recorded. Therefore, for RLE we selected 13 three-component accelerograms from the PEER Ground Motion Database.

3. Analysis of earthquakes and explosions

A new strategy for weak events in sparse networks: the first-motion polarity solutions constrained by single-station waveform inversion *(Seism. Res. Let., Fojtíková and Zahradník, 2014)*

Determinations of focal mechanisms of small earthquakes (Mw 2–3), are challenging. As a rule, their signal-to-noise ratio is good only at frequencies above the microseismic noise peak (~ 0.2 Hz) and, at the same time, waveforms can be modeled only up to ~1–2 Hz at relatively near stations (up to a few kilometres). More distant stations might provide enough first-motion polarities, but the polarity solution is often highly non-unique. To overcome these problems we suggest an approach called ‘cyclic scanning of the polarity solutions’ (CSPS). The CSPS method has a great application potential in sparse networks where weak events are recorded in many stations, thus providing polarities, but only few of the stations are situated near epicentre to allow full waveform modeling. The method has been validated on a previously studied event in the Corinth Gulf, Greece and applied on weak earthquake in Slovak territory.

4. The monitoring of earthquakes

Networks of seismic stations

The Geophysical Institute of Slovak Academy of Sciences (GPI SAS) operates the National Network of Seismic Stations (NNSS), and analyses instrumental and macroseismic data from earthquakes. The seismic stations of NSSS are deployed with the intention to determine seismic source zones on the Slovak territory more precisely and to allow to record and localize any earthquake on the territory of Slovakia and adjacent region with possible macroseismic effects. Map with locations of the NNSS seismic stations is shown in Fig. 2.

The Faculty of Mathematics, Physics and Informatics, Comenius University in Bratislava (FMPI UK) operates the Local Seismic Network Eastern Slovakia (LSNES) since 2007 and analyses instrumental data for the eastern part of Slovakia. The seismic stations of LSNES are deployed with intention to better monitor and understand the seismic regime of this region. Locations of the LSNES seismic stations are also shown in Fig. 2.

Besides the two seismic networks operated by research institutions, there are two local seismic networks on the territory of Slovakia operated by company Progseis, s.r.o.. Seismic stations of these networks are deployed around two nuclear power plants Jaslovské Bohunice and Mochovce (Fig. 2) with intension to monitor in detail local seismic microactivity.

Three additional seismic stations were established for more detailed monitoring of the Malé Karpaty source zone in the scope of the EU FP7 project

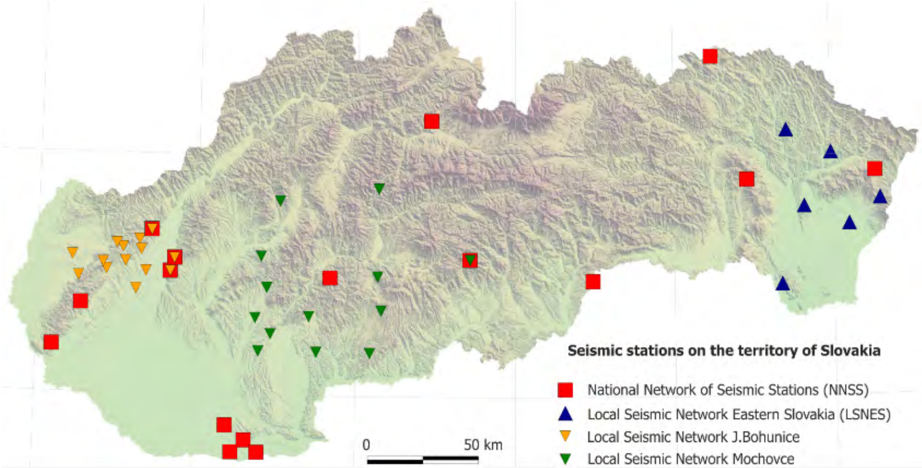

Fig. 2. The seismic stations on the territory of Slovakia.

'Advanced Industrial Microseismic Monitoring', which took place in 2009–2013. These stations have been built and are operated in cooperation of GPI SAS, Progseis, s.r.o. and Institute of Rock Structure and Mechanics ASCR (Czech Republic) since 2011 and are marked in the Fig. 2 by a yellow triangle in a red square. One seismic station in the central Slovakia is a good enhancement of NNSS and is operated in cooperation of GPI SAS and Progseis, s.r.o. This seismic station is marked in the Fig. 2 by a green triangle in a red square.

Data collection, processing and analysis

The data and the interpretation centres of the national network and of the local network Eastern Slovakia are located in the GPI SAS, Bratislava or in the FMPI UK, Bratislava, respectively. Both data centres are created in the mirror way, equipped with the similar software and functional features. The data centre collects waveforms from all stations of NNSS and LSNES and from selected seismic stations of some other institutions mainly from Central European countries. Data are collected in real time using the SeisComp/SeedLink *(Hanka et al., 2000; Van Eck et al., 2004; Hanka & Saul, 2006)* or SEMS SeedLink software, respectively. The miniSeed format is used for both data collection and data exchange. In total, data from 56 seismic stations are collected in real-time which create Regional Virtual Seismic Network in the GPI SAS (Fig. 3). More

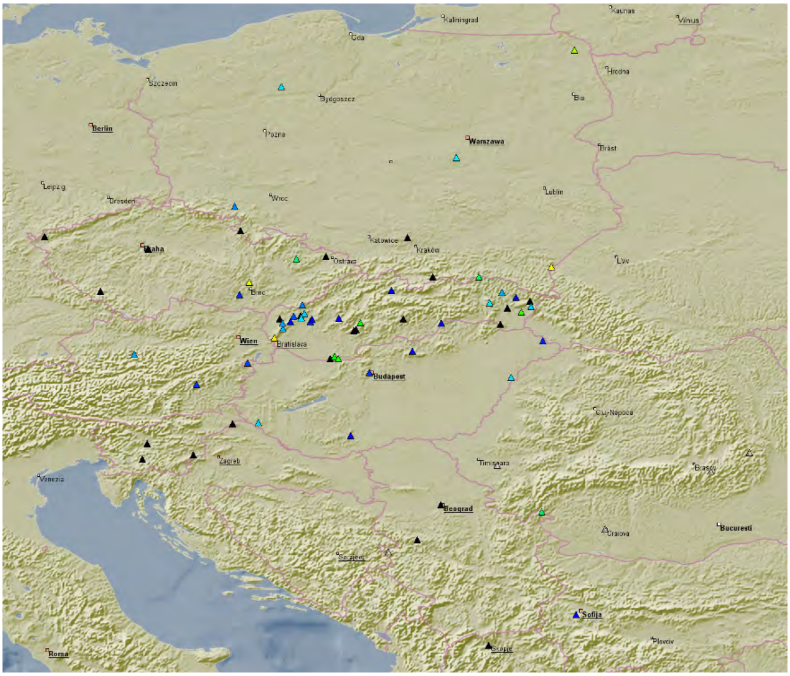

Fig. 3. Virtual Regional Seismic Network in the Geophysical Institute, Slovak Academy of Sciences, Bratislava.

information about NNSS and live seismograms from the seismic stations of NNSS are available at http://ww.seismology.sk web page. Live seismograms are archived for 30 days. More information about LSNES can be found at http://www.fyzikazeme.sk/mainpage/index_en.htm.

Seismic waveforms are exchanged with all institutions which supply data to the data center in Bratislava. In addition, the seismic waveforms are sent also to the Orfeus Data Center, De Bilt, Netherlands.

A two-step analysis of seismic events is performed – automatic and manual. In the first step the automatic analysis and localization is performed in real time by acquisition software SeisComp GFZ Potsdam *(Hanka & Saul, 2006)*.

In the second the manual analysis and localization is performed on daily basis using the Seismic Handler package since October 2003 *(Stammler, 1993)*. The results of waveform interpretation and earthquake localization are stored in a database which is in operation since 1996. Fig. 4 shows an example of a local

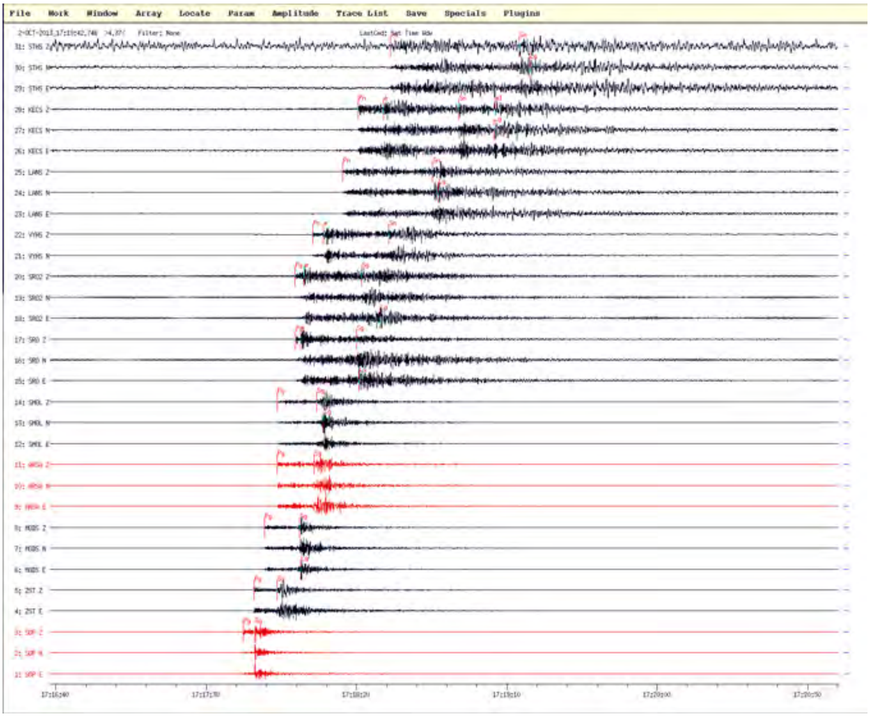

Fig. 4. An example of a manual local event interpretation using the Seismic Handler package. Displayed traces are from the Virtual Regional Seismic Network in the GPI SAS Bratislava for the October 2, 2013, M_L=4.3 local earthquake in Eisenstadt, Austria.

event interpretation for the October 2, 2013, ML = 4.3 local earthquake from Eisenstadt, Austria.

Besides seismometric data, the GPI SAS collects and analyses macroseismic data. In case of an earthquake with possible macroseismic effects on the territory of Slovakia, the GPI SAS issues public information and request for people to contact the institute if they observed macroseismic effects of the earthquake. Then macroseismic questionnaires are sent to people or people can download them from the http://www.seismology.sk web page or directly fill in questionnaires on the web. If there is a possibility of exceeding intensity 6^0 EMS-98 in some localities, an on-site macroseismic survey is performed. Macroseismic intensity is then estimated for each locality using available macroseismic observations. The macroseismic intensity is estimated in degrees of a macroseismic scale EMS 98 *(Grünthal, ed. 1998)*.

Seismic activity on the territory of Slovakia in the period 2011–2014

The seismic activity on the territory of Slovakia for the period 2011–2014 is briefly characterized in Tab. 1 and illustrated in Fig. 5a, 5b.

Using data from the seismic stations of NNSS and LSVES, 232 local earthquakes without macroseismic observations (microearthquakes) were localized with epicentre on the territory of Slovakia in the years 2011–2013. Seismic activity for the year 2014 is in the process of final reinterpretation and we can assume about 77 localized microearthquakes with epicenter on the territory of Slovakia. Microearthquakes occurred in all known Slovak seismic source zones. The two most active regions during the reported period 2011–2014 seem to be Malé Karpaty source zone (63 earthquakes) and Komárno source zone (41 earthquakes only in the Slovak part of the zone). Let us mention also Šariš area where 31 earthquakes occurred in the span of only 3 days (29.12.2011–1.1.2012).

Tab. 1. Seismic activity on the territory of Slovakia in the period 2011–2014.

Year	Microearthquakes	Macroseismically observed earthquakes (epicentre in SK)	Macroseismically observed earthquakes (epicentre outside SK)
2011	62	1	1
2012	86	6	0
2013	84	5	6
2014	77	0	5

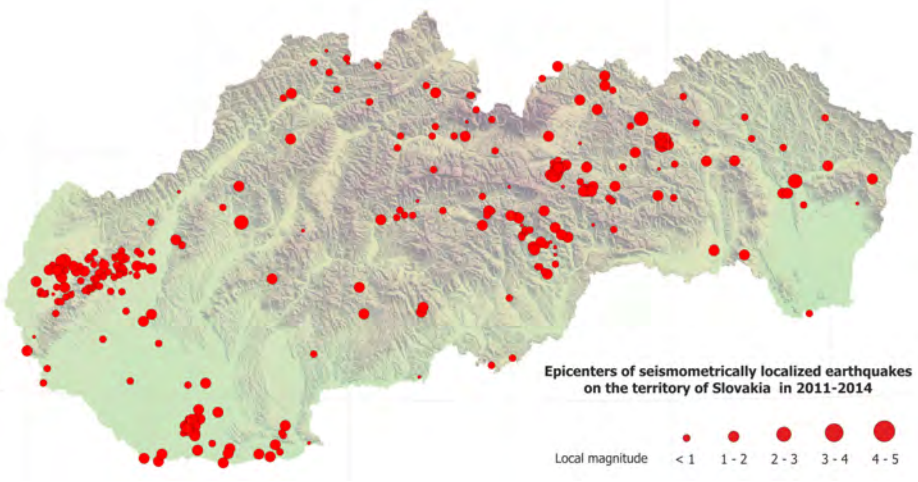

Fig. 5a. Epicenters of seismometrically localized earthquakes on the territory of Slovakia in 2011–2014. (Only preliminary results are shown here for year 2014.)

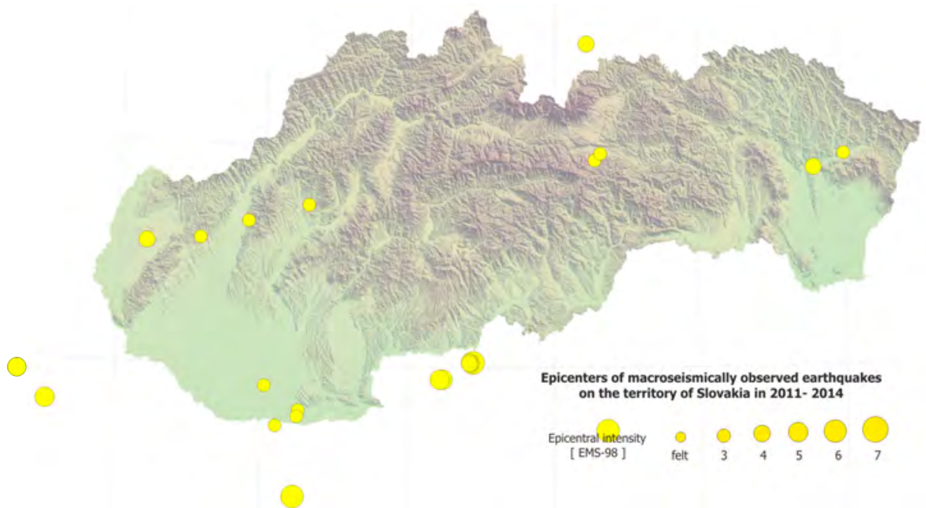

Fig. 5b. Epicenters of macroseismically observed earthquakes on the territory of Slovakia in 2011–2014.

During the period 2011–2014, 24 earthquakes were macroseismically observed on the territory of Slovakia. All macroseismically observed earthquakes were seismometrically localized. Epicentres of macroseismically observed earthquakes occurred in following parts of Slovakia – Záhorie (1 earthquake), Malé Karpaty source zone (1 earthquake), Považský Inovec (1 earthquake), Strážovské vrchy – Bánovce nad Bebravou (1 earthquake), Komárno source zone (4 earthquakes), Nízke Tatry (2 earthquakes) and Eastern Slovakia – Vihorlat (2 earthquakes). Except these earthquakes, several earthquakes with epicenters in neighboring countries were macroseismically observed on the territory of Slovakia too – Austria (2 earthquakes), Poland (1 earthquake) and Hungary (9 earthquakes). As for macroseismically observed earthquakes point of view, the most active area in the period 2011–2014 was the Slovak-Hungarian border region near Balassagyarmatti were 7 earthquakes occurred with macroseismic observations on the territory of Slovakia.

The highest reported macroseismic intensity in the period 2011–2014 was 6° EMS 98 for the earthquake with epicentre in the Slovak-Hungarian border region near Balassagyarmatti (19.1.2014). However, this intensity estimate is based on only 2 observations from the same site and therefore it´s reliability is questionable. The earthquake was felt in 50 localities on the territory of Slovakia.

Export of know-how in seismic monitoring within the framework of the official Slovak Development Aid

Slovak seismologists exported their experiences and know-how and helped to build modern seismic monitoring systems in countries of seismically active Balkan region within several projects of the official Slovak Development Aid. The two projects in period 2007–2010 were preceded by other Slovak development aid projects aimed on building new and modernization of existing seismic monitoring infrastructure in Serbia (project Development of Infrastructure for Rapid Earthquake Data Collection and Exchange DIRECTE 2004–2005) and in Macedonia (Development of Infrastructure for Rapid Earthquake Data Collection and Exchange – part2 DIRECTE2 2004–2005).

The project ShareDIRECTE (Sharing the Data from the Infrastructure for Rapid Earthquake Data Collection and Exchange 2006–2008) was a natural continuation of the previous project DIRECTE. Its goal was to apply the results of the DIRECTE project in practice and to share the obtained seismic information with governmental authorities as well as with the public and to contribute to the better preparedness of the country to strong earthquake. Thanks to the results of both these projects the Civil Protection in Serbia will be able better and more efficiently react to the emergency situations caused by strong earthquake.

The project DETERMINE (Development of Earthquake Monitoring Infrastructure for Bosnia and Herzegovina, November 2009 – February 2011) was a response to the urgent need of the state-of-the-art seismic monitoring system on the territory of Bosnia and Herzegovina. The seismic monitoring systems consisting from four seismic stations and data center were delivered to and installed in each of both entities of Bosnia and Herzegovina. The real-time continuous data acquisition from the installed seismic stations and the international real-time data exchange were established in the framework of the project. The important part of the project was education of the experts from Bosnia and Herzegovina in the field of seismic monitoring.

5. Integrated geophysical study of the continental lithosphere

Study of the basin basement

The aim of the papers *Krajňák, Bielik, Makarenko, Legostaeva, Starostenko & Bošanský (2012)* and *Bielik, Krajňák, Makarenko, Legostaeva, Starostenko, Bošanský, Grinč & Hók (2013)* was the 3D gravity modelling and interpretation of the observed gravity data in the Turiec Basin. New results related to the thickness and density of the sedimentary fill of the Turiec Basin allowed us to construct the first original stripped gravity map for this typical intramontane Neogene depression of the Western Carpathians (Fig. 6). The stripped gravity map of the Turiec Basin represents the Bouguer gravity anomalies corrected for the density contrast of its Quaternary-Tertiary sedimentary basin fill. It means that the map reflects the gravity effects of the density inhomogeneities which are located beneath the sedimentary basin fill. This map is therefore suitable for the interpretation of the structure and composition of the pre-Tertiary basement. Based on the new data analysis, three different density models of the sedimentary fill were constructed. The 3D density modeling was used to calculate the gravity effect of the density models. The stripped gravity maps were produced by subtracting the density model gravity effects from Bouguer anomalies. Regional trend was removed from the stripped gravity maps also. The residual stripped gravity maps were consequently used for geological interpretation of the pre-Tertiary basement of the Turiec Basin (Fig. 7). The pre-Tertiary basement of the Turiec Basin can be divided into northern and southern parts due to its gravity characteristics. Furthermore the northern part can be split into two domains: western and eastern. The crystalline basement of the western domain would be composed of the Hercynian crystalline basement of the Tatric Unit. In the eastern domain the basement could consist mostly of the Mesozoic complexes of the Fatric unit. The southern part of the pre-Tertiary basement of the Turiec Basin is built predominantly by Mesozoic complexes of the Hronic unit. It is suggested that the Hronic unit also forms the bedrock of the volcano-sedi-

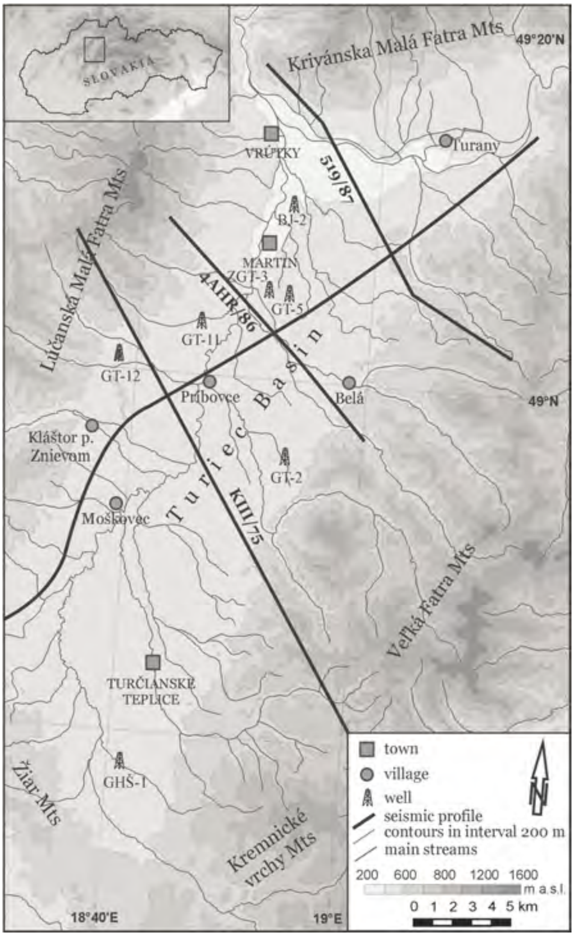

Fig. 6. Geographical position of the Turiec Basin (modified after *Kováč et al., 2011* and *Krajňák et al,. 2012).*

mentary complex of the Kremnické vrchy Mts. The resultant stripped gravity maps have also proven to be very useful for the interpretation of faults or fault systems in the study area. Various faults, particularly of NNE-SSW and NW-SE directions were discovered. The analysis of the faults indicates clearly that the contact of the Turiec Basin with the Malá Fatra Mts and the Veľká Fatra Mts is tectonic.

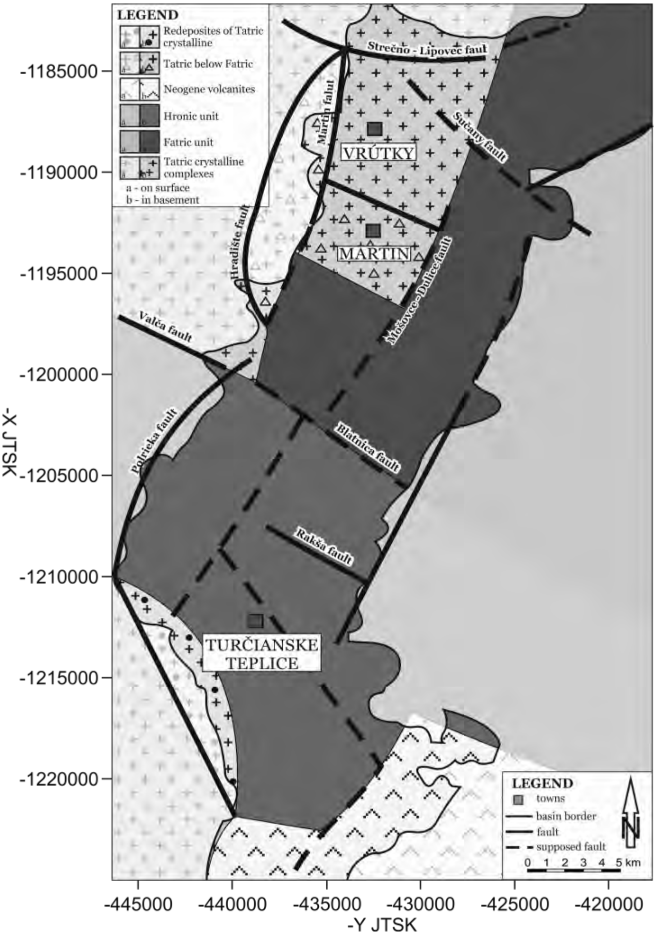

Fig. 7. A sketch of the pre-Tertiary basement structure of the Turiec Basin.

Calculation of the stripped gravity map *(Carvalho, Rabeh, Bielik, Szalaiová, Torres, Silva, Carrilho, Matias & Miranda, 2011)* was also part of the complex interpretation of seismic reflection, gravimetric, topographic, deep seismic refraction and seismicity data to study the recently proposed Ota–Vila Franca de Xira–Lisbon–Sesimbra (OVLS) fault zone and the lower Tagus Cenozoic basin (LTCB). The studied structure is located in the lower Tagus valley (LTV), an area with over 2 million inhabitants that has experienced historical earthquakes which caused significant damage and economical losses (1344, 1531 and 1909 earthquakes) and whose tectonic sources are thought to be local but mostly remain unknown. The Bouguer anomaly, base of Cenozoic, gravimetric effect of Cenozoic units and SGMs are shown in Fig. 8. A striking outcome of this map is a strong positive anomaly located at the lower Tagus estuary. It is emphasize that the obtained stripped gravity map conditioned by the thickness of the Cenozoic sedimentary infill, leading to this rather localized positive anomaly where the thickness of sediments is more than 2 km. This study contributed to improve the seismic hazard of the area and the neotectonics of the region, showed that the above-proposed fault zone is probably a large crustal thrust fault that constitutes the western limit of the LTCB. Gravimetric, deep refraction and seismic reflection data suggest that the LTCB is a foreland basin, as suggested previously by some authors, and that the OVLS northern and central sectors act as the major thrusts. The southern sector fault has been dominated by strike-slip kinematics due to a different orientation to the stress field. Indeed, geological outcrop and seismic reflection data interpretation suggests that, based on fault geometry and type of deformation at depth, the structure is composed of three major segments. These data suggest that these segments have different kinematics in agreement with their orientation to the regional stress field. The OVLS apparently controls the distribution of the seismicity in the area. Geological and geophysical information previously gathered also points that the central segment is active into the Quaternary.

In the paper of *Bielik, Rybakov & Lazar (2013)* it was analyzed factors defining the quality of geologic stripping of gravity data and use examples from our studies to illustrate the technique *(Rybakov et al., 1998, 1999)* and the advantages of the gravity-stripping process was shown.

Density and magnetic modeling of the lithosphere

It is well-known that the initial density model has to be based on a reasonable geological hypothesis and while the modeling process is non-unique, one of the interpretation aims is to define the robust parameters of the model. At this stage it is important to integrate the seismic and gravity data. One of the possibilities how to integrate these data is transformation of the seismic velocities to densi-

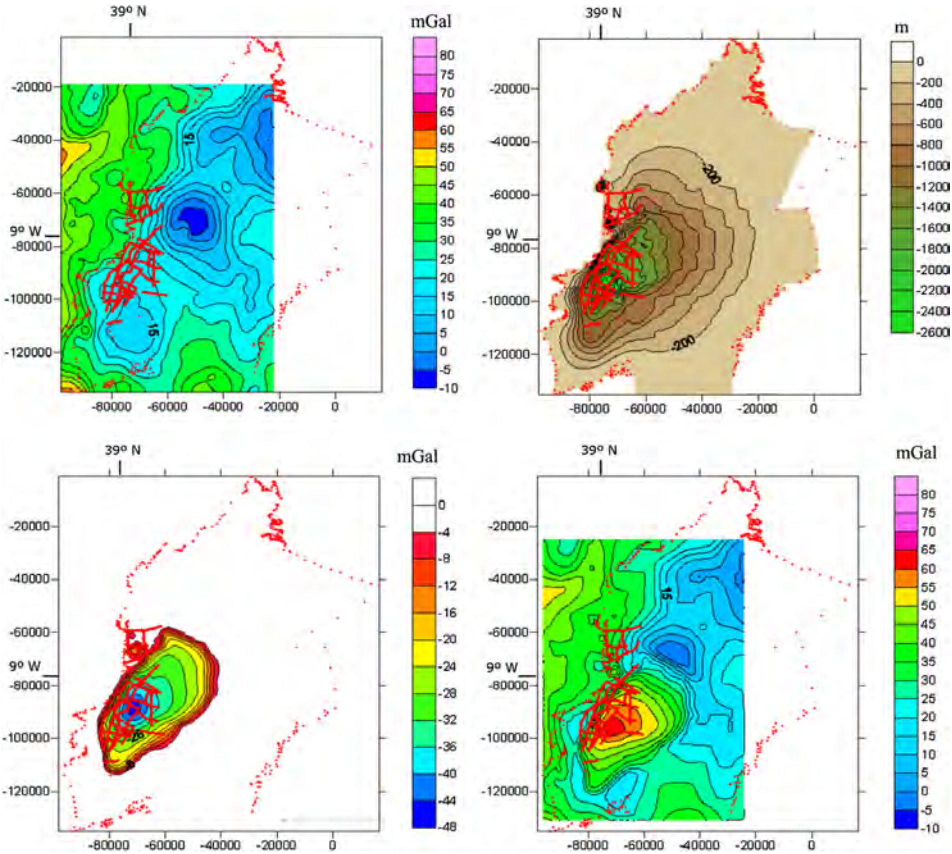

Fig. 8. Major steps necessary to produce the SGM: (top left) Bouguer anomaly map (for a density of 2.69); (top right) base of the Cenozoic map built from seismic reflection, well and geological outcrop data; (bottom left) gravity effect produced by these units; (bottom right) SGM resulting from the subtraction of (bottom left) from (top left). The red dots indicate the locations where the depth to the base of Cenozoic was available.

ties. The Sobolev and Babeyko's formulae belong to the most available relationships for this transformation. They are very complex and rigorous taking into account the PT conditions. On the other hand its application is relatively complicated. Therefore the main goal of the *Csicsay, Bielik, Mojzeš, Speváková, Kytková & Grinč (2012)* paper was to try to determine more easily the formula for transformation of the seismic velocities to densities. Based on the analysis of the results obtained using the Sobolev and Babeyko's formula on real data, it was found out that in the Carpathian-Pannonian Basin region this formula can be transformed to simpler linear velocity–density relationship with required accuracy.

The objective of papers *(Prutkin, Vajda, Tenzer & Bielik, 2011* and *Prutkin, Vajda., Bielik, Bezák & Tenzer, 2014)* was to introduce the new methodology for 3D inversion of potential field data (with focus on gravity anomalies) in terms of signal separation both in depth and in lateral sense and the method of local corrections. To introduce the methodology we have demonstrated its capabilities on a case of the Kolarovo gravity high in the Danube Basin, southern Slovakia. The methodology belongs to the realm of direct inversion methods making use of no forward modeling. It works with a preselected class of solutions: 3000 kg/m^3 from the upper layer with density 2700 kg/m^3 and estimating its depth. In this case, it does not need the approximation with 3D line segments. We invert directly the gravity data on the physical surface (without regional component). The depths of the contact surface obtained by the method of local corrections vary from 22.5 km to 7.5 km. The solution was presented in two ways: as a map of the contact surface topography (depth isolines are shown) and as 3D surface. The solution indicates that both the basement topography and the upper boundary of the dense layer below the body source bodies of compact star convex geometry, and 3D contact surfaces representing subsurface density interfaces. The goal of the *Prutkin, Vajda, Tenzer & Bielik (2011)* paper was to demonstrate that the methodology yields a suite of admissible solutions that can be further discriminated based on additional geophysical, geologic or tectonic constraints.

The quest for the best Kolarovo interpretation was the paper *Prutkin, Vajda, Bielik, Bezák & Tenzer (2014)*. It presents a new interpretation of the Kolárovo gravity and magnetic anomalies in the Danube Basin based on an inversion methodology that comprises the following numerical procedures: removal of regional trend, depth-wise separation of signal of sources, approximation of multiple sources by 3D line segments, non-linear inversion based on local corrections resulting in found sources specified as 3D star-convex homogenous bodies and/or 3D contrasting structural contact surfaces. This inversion methodology produces several admissible solutions from the viewpoint of potential field data. These solutions are then studied in terms of their feasibility taking into consideration all available tectono-geological information. By this inversion methodology it was interpreted here the Kolárovo gravity and magnetic anomalies jointly. The inversion generates several admissible solutions in terms of the shape, size and location of a basic intrusion into the upper crust, or the shape and depth of the upper/lower crust interface, or an intrusion into the crystalline crust above a rise of the mafic lower crust. Found intrusive bodies lie at depths between 5 and 12 km (Fig. 9). Our lower crust elevation rises to 12 km with and 8 km without the accompanying intrusion into the upper crust, respectively. The solutions are in reasonable agreement with various previous interpretations of the Kolárovo anomaly, but yield a better and more realistic geometrical resolution for the source bodies. These admissible solutions are next discussed in the context of geological and tectonic considerations, mainly in relation to the fault systems.

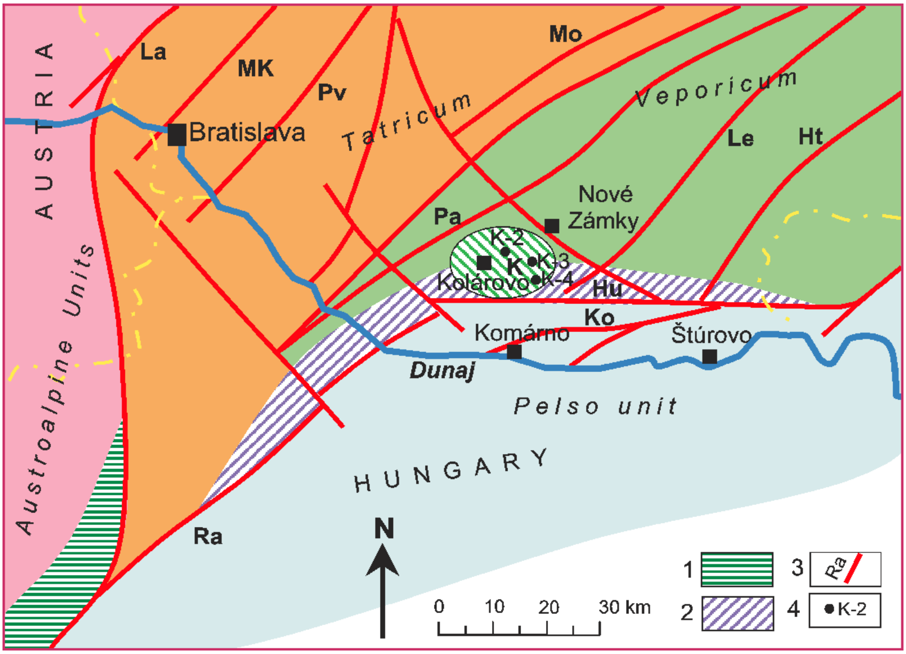

Fig. 9. The Kolárovo anomaly in its tectonic context: 1 – assumed relics of South Penninic oceanic crust; 2 – supposed relics of Meliatic oceanic crust; 3 – faults (after Tectonic Map of the Slovak Republic, Bezák et al. 2004): La – Láb, MK – Malé Karpaty, Pv – Považie, Mo – Mojmírovce, Pa –Palárikovo, Le – Levice, Ht – Hont, Hu – Hurbanovo, Ko – Komárno, Ra – Rába; 4 – Kolárovo boreholes: K – Kolárovo anomaly.

Grabowska, Bojdys, Bielik & Csicsay (2011) presented 2D density and magnetic models of the crust and upper mantle along the DSS line profile of the CELEBRATION 2000 project that crosses the most important geological units in Central Europe. These are the Alps–Carpathians–Pannonian (ALCAPA) region, the SE part of the Paleozoic Platform (PLZ), the Trans-European Suture Zone (TESZ) and a fragment of the SW portion of the East European Craton (EEC). The density and magnetic models (Figs 10 and 11) were constructed on the basis of a 2D model of *P*-wave velocity converted into density model, geological data as well as geothermal data and the results of integrated geophysical modeling for the lithosphere-asthenosphere boundary. This allowed us to construct a comprehensive geophysical 2D model of the crust and enlargement the geophysical-geological characteristics of the lithosphere in the Pannonian ba-

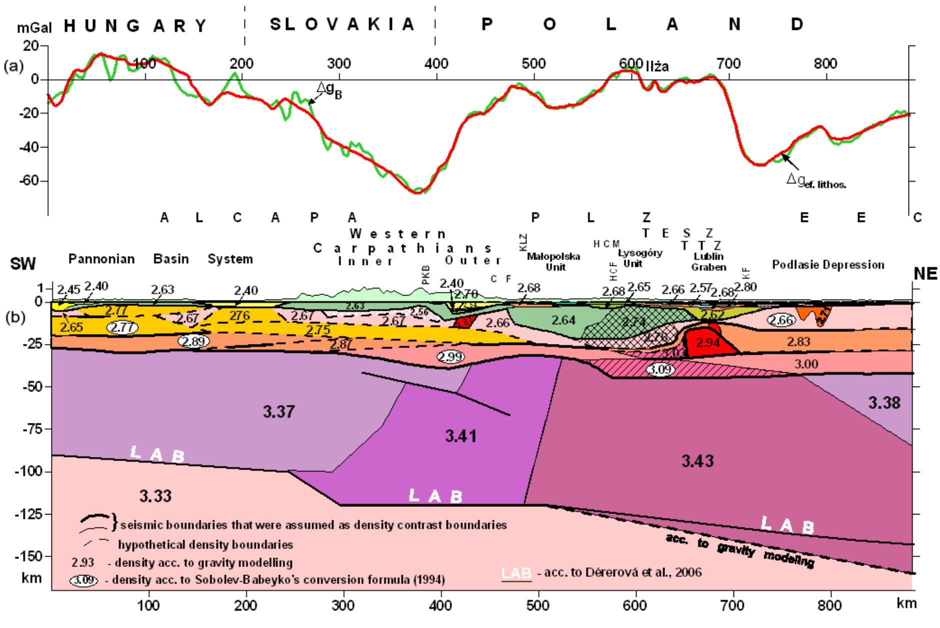

Fig. 10. The 2D density model of the crust and the upper mantle along profile CEL01 constructed on the basis of geological data (sedimentary cover), seismic and geothermal data (crystalline crust and upper mantle) and gravity modeling: Δg_B – Bouguer gravity anomaly, $\Delta g_{ef.\ lithos}$ – 2D total gravity effect calculated for the density model of the lithosphere which comprises the sedimentary cover, crystalline crust and upper mantle (a); Density model of the lithosphere (b).

sins, the Carpathian orogen, and in the transitional zone between the ALCAPA plate and the East European Craton (passing through the Paleozoic Platform). As a result, it has been provided evidence for the heterogeneity of the density in the lithospheric mantle, terrane concept of the East European Craton foreland, and confirmed the possibility of rift events along the SW boundary of the Precambrian craton in SE Poland.

Vajda, Prutkin, Gottsmann, Bielik, Bezák, Tenzer & Brimich (2014) present an inversion methodology, which consists of several steps: removal of regional trend, depth-wise separation of signal of sources, line segments approximation of sources, and inversion by the method of local corrections yielding star-convex homogenous source bodies and/or contrasting contact surfaces. It demonstrates the capabilities of the methodology in geodynamic studies when studying the movement of magma/hydrothermal fluids in restless volcanic areas on a case of the 2004 unrest of Teide volcano, Tenerife, Canary Islands. During the seismic unrest at the central volcanic complex (CVC) on

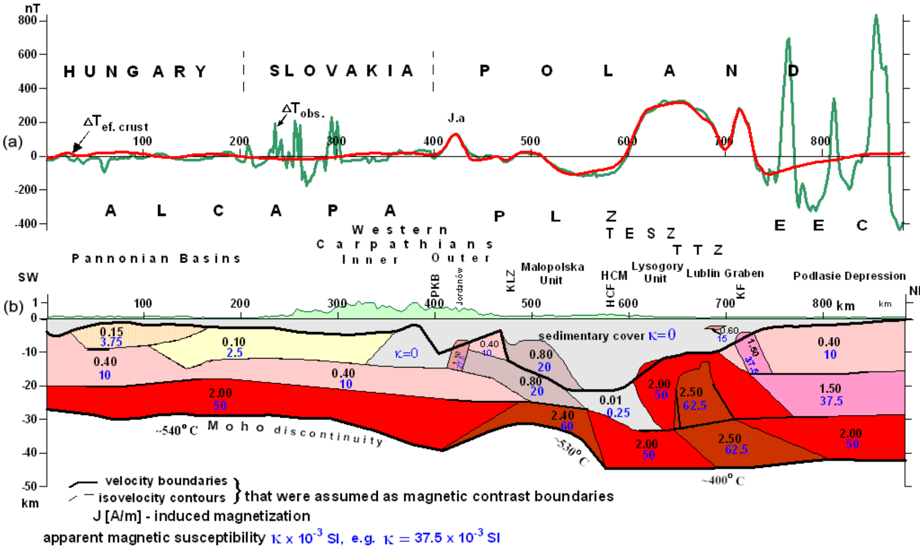

Fig. 11. 2D magnetic model of the crystalline crust along profile CEL01: T_{obs} – magnetic anomaly of the total intensity of geomagnetic field, $T_{ef.\ crust}$ – 2D magnetic effect calculated for model (a); Magnetic model constructed on the basis of seismic data, gravity data and 2D magnetic modeling. Regarding magnetic susceptibility, the top and the bottom of the layer correspond to crystalline basement and Moho discontinuity (b).

Tenerife bulk gravity increase was recorded across a network at the CVC between May 2004 and July 2005 *(Gottsmann et al., 2006)*. The paper aims at interpreting the gravity signal in terms of multiple sources using a non-linear inversion based on line segments approximation. Residual gravity changes obtained by removing a trend were best-fitted with the gravitational effect of 3 line segments *(Vajda et al., 2012* and *Fletcher et al., 1963)* that are located at depths 0–2 km b.s.l. It is suspected that these line segments are composite sources representing shallower hydrothermal fluids and deeper magma injection. To test this hypothesis, it was separated these composite sources vertically into shallow and deep sources by decomposing the residual gravity changes into "shallow-" and "deep-" fields while inverting both separately. The division level of 4 km below sea level (b.s.l.) was chosen to match roughly the upper boundary of the two seismogenic zones of *(Cerdeña et al., 2011)*. The decomposition procedure, based on stepwise upward, downward and upward sequential harmonic continuations, is described in *(Prutkin et al., 2011)*. The shallow and deep line segments obtained by the inversion are shown in Fig. 12.

Due to the spatial distribution of the shallow segments and the position of the deep one, as well as their spatial correlation with the seismogenic zones of *(Cerdeña et al., 2011)*, we interpret the shallow segments as sources of hydrothermal fluids, while the short deep segment as a magma injection at a depth of about 6 km, within the NW zone of VT events swarm identified by *(Cerdeña et al., 2011)*. This hybrid nature of the observed unrest is best explained by the migration of hydrothermafluids as a result of magma injection. The time span in between the last three historic eruptions is roughly a century (93 and 111 years, respectively). Conspicuously enough, the 2004 unrest follows a similar repeatability pattern (95 years after Chinyero). It may considered the 2004 hybrid unrest on Tenerife a failed eruption.

Temperature distribution and rheological properties of the lithosphere

Using the 2D integrated modeling method, *Dérerová, Kohút, Bielik, Bošanský & Porubčanová (2012)* and *Dérerová, Bielik, Pašiaková, Kohút & Hlavňová (2014)* calculated the temperature models of the lithosphere along transect I and II passing through the Western Carpathians. Based on the extrapolation of failure criteria, lithology and calculated temperature distribution, it was derived the rheology models of the lithosphere in the area. The results indicate clearly that the strength decreases from the Bohemian Massif via the Western Carpathians to the Pannonian Basin. The largest strength can be observed within the upper crust on the boundary between the upper and lower crust. This phenomenon is typical for all studied tectonic units: the Bohemian Massif, the Western Carpathians and the Pannonian Basin. These results suggest mostly rigid deformation in the upper crust of the units. By contrast, the lower crust in the Bohemian Massif and the Western Carpathians reflects significantly lower strength, while in the Pannonian Basin the strength is the smallest. It can be suggested that the ductile deformation dominates in this part of the lithosphere. In all tectonic units the strength within the uppermost mantle (lower lithosphere) disappears.

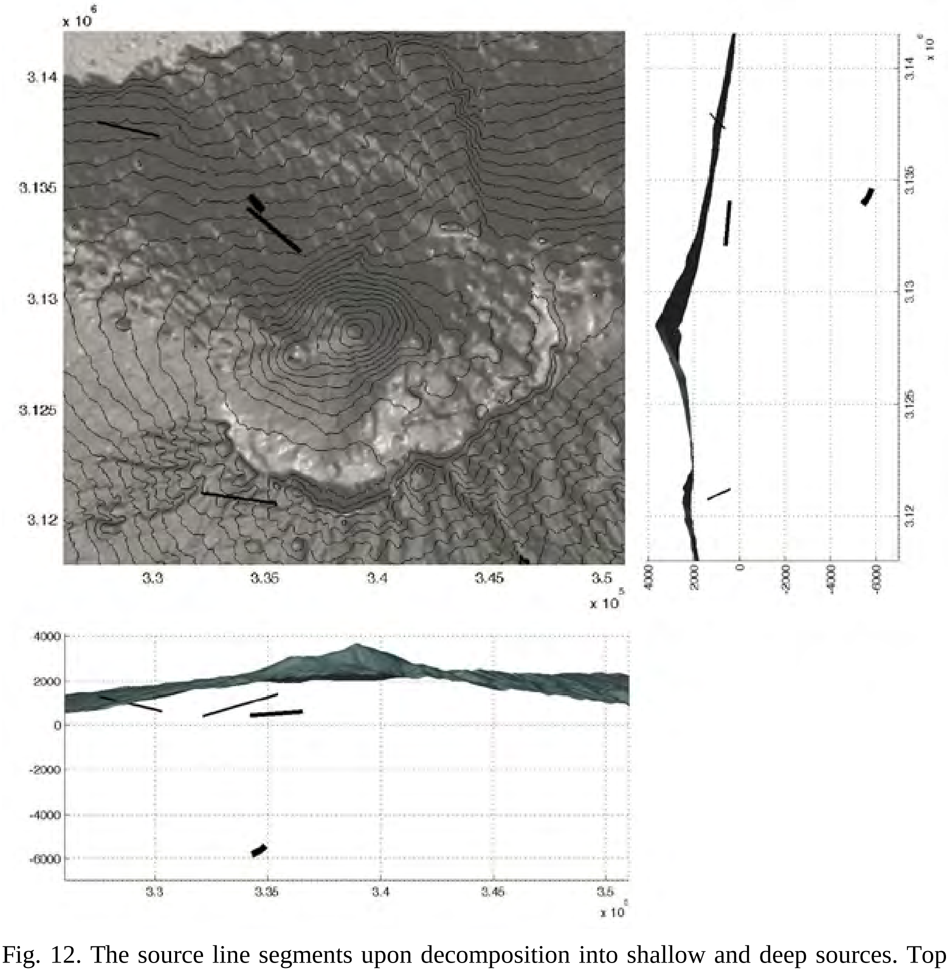

Fig. 12. The source line segments upon decomposition into shallow and deep sources. Top left plot is plan view, right plot is S–N cross-section, and bottom plot is W–E cross-section.

Integrated geophysical modeling

The aim of the paper of *Grinč, Zeyen, Bielik & Plašienka (2013)* is to present new lithosphere-scale transects based on the joint interpretation of gravity, geoid, topography and surface heat flow data, crossing the whole area from the West European Platform in the North to the Aegean Sea in the South and from the Adriatic Sea in the West to the East European Platform in the East. Wherever possible, crustal structure is constrained by seismic data. It was used a two-dimensional algorithm to determine the steady state thermal structure of the lithosphere in the Carpathians *(Zeyen and Fernàndez, 1994)*. The program used consists of a 2-D finite element algorithm to calculate the temperature distribution based on a user-defined lithospheric structure consisting of sedimentary, upper crustal, lower crustal and mantle layers, each characterized by its reference density, thermal conductivity and heat production. The body structure is as much as possible constrained by existing seismic and geological data. The thermal boundary conditions are fixed temperatures at the upper limit (Earth's surface; 0°C) and the lower one (lithosphere-asthenosphere boundary; 1300°C) as well as no horizontal heat flow across the lateral, vertical boundaries. After the calculation of the temperature distribution, the body densities are modified at each node of the finite element grid taking into account the thermal expansion coefficient. With this modified density distribution, we calculate the gravity and geoid variations and the topography. Data and model results are compared and the model is then changed interactively by trial and error until an acceptable fit is obtained. The finite element grid is defined on vertical columns every 5 km, so that we cannot model structures smaller than 10 km. It was modeled four transects (Fig. 13).

In general, the thickness of the lithosphere decreases from the older and colder Platforms to the younger and hotter Pannonian Basin with a maximum thickness under the Eastern and Southern Carpathians. The thickness of the Carpathian arc lithosphere varies between 150 km in the North and about 300 km in the Vrancea zone. In the Platform areas it is between 120 and 150 km and in the Pannonian Basin it is about 70 km. The lithosphere thickens strongly underneath the Transylvanian Basin reaching locally values of nearly 200 km. The model shows that the Moesian Platform is overthrust from the North by the Southern Carpathians and from the South by the Balkanides (Figs. 14 and 15). This overthrusting induces bending of the Platform which gives a characteristic signature in the observables. In all transects, the thickest crust is found underneath the Carpathian Mountains or their immediate foreland. In the Vrancea zone, all models place the maximum thickness not underneath the highest topography but under the Focsani foreland basin. The thickest crust outside the orogens is modeled for the Moesian Platform with Moho depths of up to 45 km. The thinnest crust is located under the Pannonian Basin with about 26–27 km which is similar to *Posgay et al. (1995)* but about 2 km thicker than *Janik et al. (2011)*.

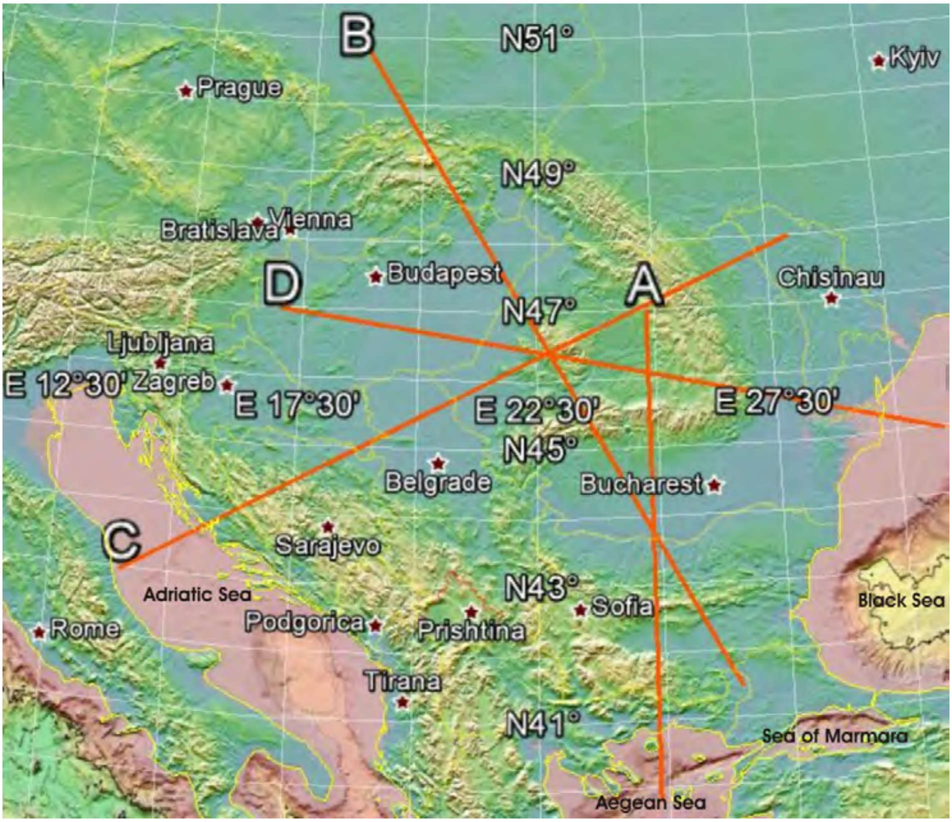

Fig. 13. Location of the presented transects A, B, C and D on Google Earth with overlain topography (SIO, NOAA, NGA, US Navy, GEBCO: SRTM30_PLUS_V8.kmz).

Lithospheric thickening is interpreted as remnants of a slab, which started to break off in the Miocene. These results are in good agreement with the results of seismic tomography and results from *Spakman (1990)*, *Wortel and Spakman (2000)* and *XXXX* They also suggest remnants of deep subduction and slab de-

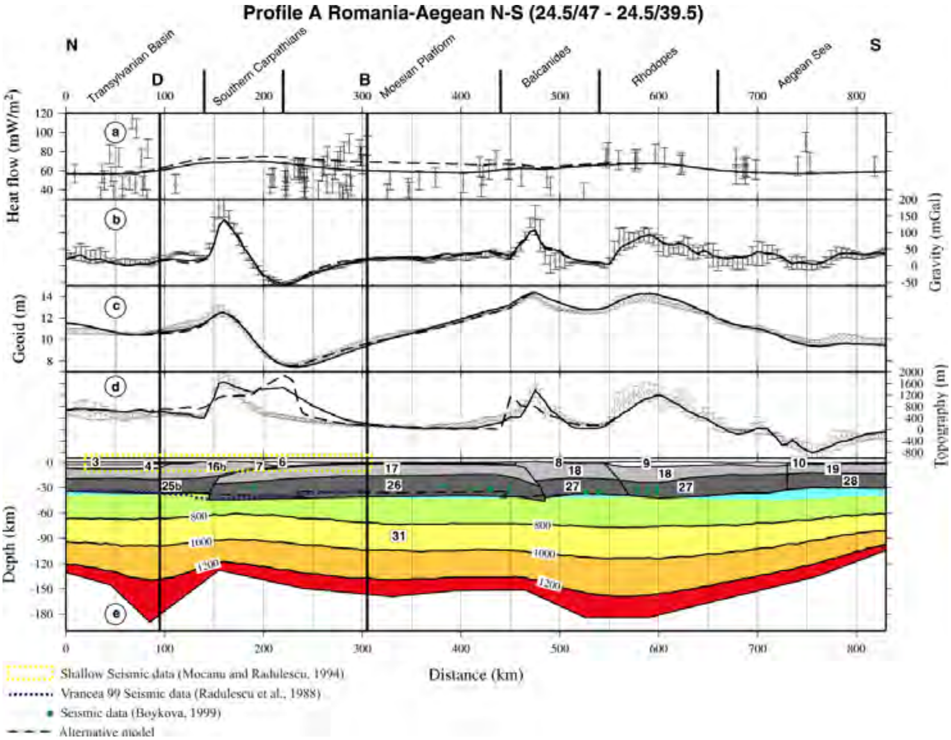

Fig. 14. Lithospheric model for transect A. (a) surface heat flow density, (b) free-air gravity anomaly, (c) geoid, (d) topography with dots corresponding to measured data with uncertainty bars and solid lines to calculated values; (e) lithospheric structure; Numbers in (e) correspond to material number in Table 1. In the lithospheric mantle, isotherms are indicated every 200°C. Numbers on top of the figures indicate the starting and endpoint coordinates of the transects. The black dashed lines correspond to the results of a model with flat lower-upper-crustal limit and Moho underneath the Moesian Platform. Dotted lines and dots show positions of interfaces obtained from different seismic experiments.

tachment below the Carpathian-Pannonian Basin region. They showed that the slab seems to be detached from the European plate (probably except for the seismogenic Vrancea zone and the Eastern and Southern Carpathian junction). A flat-lying, high-velocity anomaly at the bottom of the upper mantle not only beneath the Carpathian-Pannonian Basin region but as well as beneath the whole Mediterranean area has been interpreted as subducted lithosphere that sunk into the deeper mantle as a result of rollback and slab detachment along

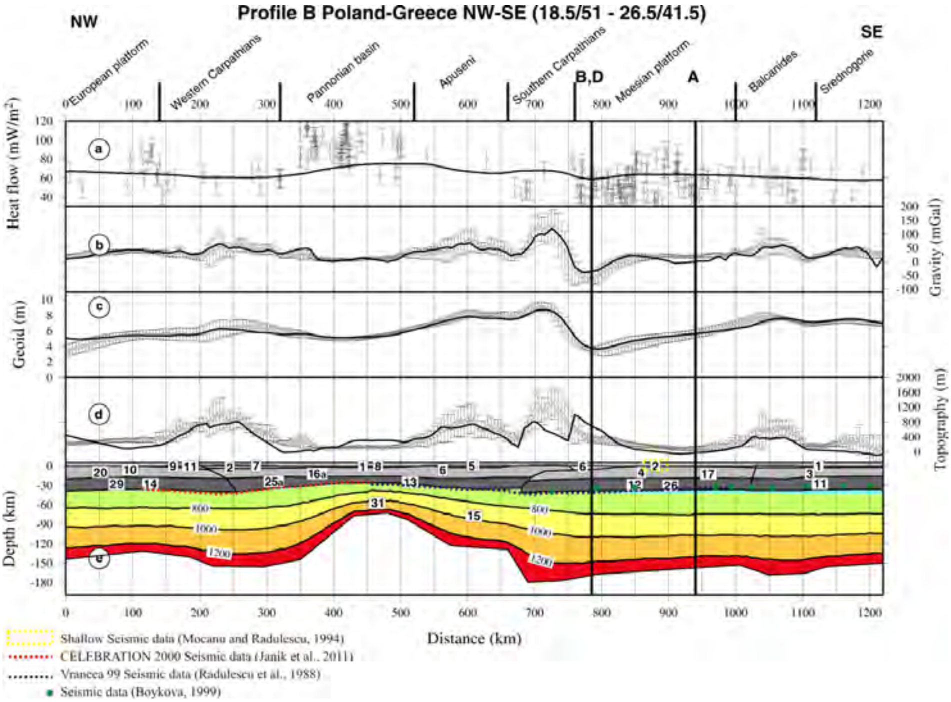

Fig. 15. Lithospheric model for transect B. For explanations, refer to Fig. 14.

strike of the Carpathian arc. This important roll-back could also explain why crustal thickening is not observed above the slab or even behind the subduction, but in front of it. The increasing thickness of the lithospheric slab from the Western Carpathians to the Eastern Carpathians supports the suggestion that the slab break-off started in the NW and propagated toward the SE, the seismogenic Vrancea zone being inferred as the final expression of the progressive subduction, slab roll-back and plate boundary retreat that were responsible for the evolution of the arc *(Tomek and PANCARDI colleagues, 1996, Kázmér et al., 2003)*.

Using a very fast 1D method of integrated geophysical modelling, *Grinč., Zeyen & Bielik (2014)* calculated models of the Moho discontinuity and the lithosphere-asthenosphere boundary in the Carpathian-Pannonian Basin region and its surrounding tectonic units. This method is capable to constrain complicated lithospheric structures by using joint interpretation of different geophysical data sets (geoid and topography) at the same time. The 1D geophysical modeling approach was initially presented by *Fullea et al. (2006)*. From a scientific point of view, it is 1D modeling and therefore only valid for large-scale structures but on the other hand, when doing this 1D analysis on many vertical columns covering an area, it gives us a 3D initial estimate of the main boundaries that we are interested at in the studied area *(Grinč, 2013)*. The Moho depth map showed significant crustal thickness variations. The thickest crust was found underneath the Carpathian arc and its immediate Foredeep. High values were found in the Eastern Carpathians and Vrancea area (44 km). The thickest crust modeled in the Southern Carpathians is 42 km. The Dinarides crust is characterized by thicknesses more than 40 km. In the East European Platform, crust has a thickness of about 34 km. In the Apuseni Mountains, the depth of the Moho is about 36 km. The Pannonian Basin and the Moesian Platform have thinner crust than the surrounding areas. Here the crustal thicknesses are less than 30 km in average. The thinnest crust can be found in the SE part of the Pannonian Basin near the contact with the Southern Carpathians where it is only 26 km. The thickest lithosphere is placed in the East European Platform, Eastern Carpathians and Southern Carpathians. The East European Platform lithosphere thickness is on average more than 120 km. A strip of thicker lithosphere follows the Eastern Carpathians and its Foredeep, where the values reach in average 160 km. A lithosphere thickness minimum can be observed at the southern border of the Southern Carpathians and in the SE part of the Pannonian Basin. Here, it is only 60 km. The extremely low values of lithospheric thickness in this area were not shown before. The Moesian Platform is characterised by an E-W trend of lithospheric thickness decrease. In the East, the thickness is about 110 km and in the west it is only 80 km. The Pannonian Basin lithospheric thickness ranges from 80 to 100 km.

Tab. 2. Parameter values that satisfy our expectations about the Moho and the LAB of the region (Figs. 16 and 17).

symbol	parameter	value
ρ_c	Reference average crustal density	2850 kg m^{-3}
z_c	Moho depth of the reference column	28 km
ρ_a	density of the asthenosphere	3200 kg m^{-3}
ρ_w	Density of sea water	1030 kg m^{-3}
z_{max}	The compensation level depth	300 km

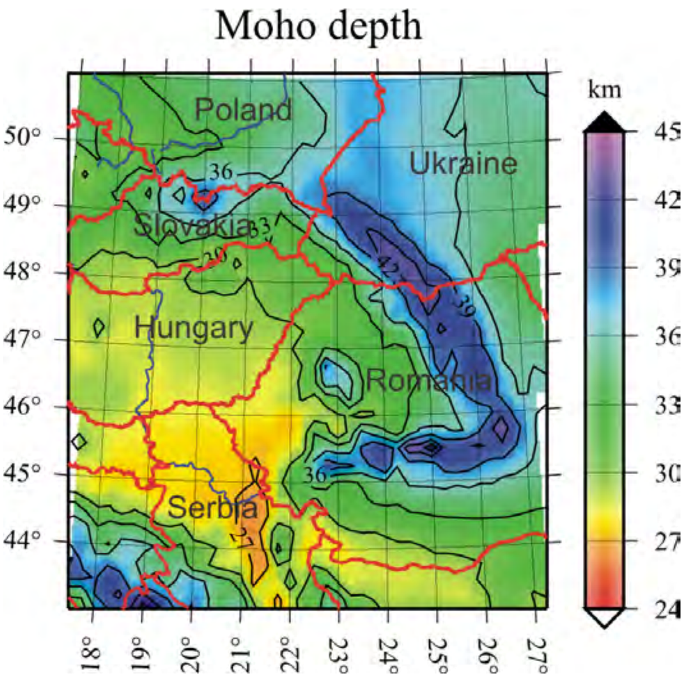

Fig. 16. 1D inversion result for Moho depth in the Carpathian–Pannonian Basin region. (see Tab. 2 for model parameters and further explanation).

Deep geophysical study of the lithosphere was included into an approach integrating geodynamics into targeted morphometric analysis *(Minár, Bielik, Kováč, Plašienka, Barka, Stankoviansky, Zeyen, 2011)*. The result of this analysis is a new morphostructural subdivision of the Western Carpathians. Nine specific morphostructural regions and sixteen subregions were defined as an improvement on the preceding qualitative subdivision of the area. The integration of geodynamics into the targeted morphometric analysis represents a prerequisite for better interpretability of the delimited regions. The new subdivision of the Western Carpathians therefore reflects first of all the Pliocene–Quaternary geodynamics that controls the development of the present-day relief. The results also help to understand the timing of the basic dome-like morphostructural formation of the Western Carpathians (which began 4–6 million years ago, with the main stage continuing until the Late Pliocene and accelerated uplift taking place since the Middle Pleistocene), as well as the mech-

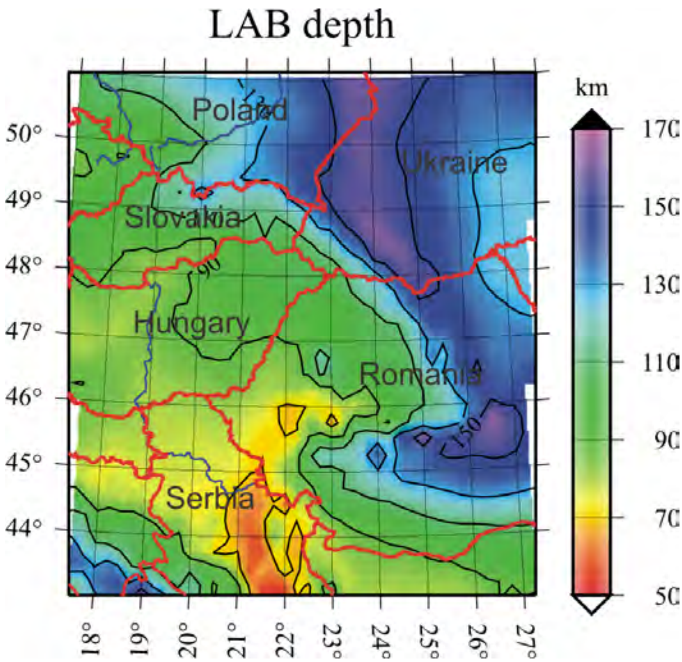

Fig. 17. 1D inversion model of the lithospheric thickness in the Carpathian–Pannonian Basin region (see Tab. 2 for model parameters and further explanation).

anism of its formation. The importance of the Middle Miocene extension for the development of the basin-and-mountain mosaic unique to the Western Carpathians is documented. The projection of the older structural boundaries into the new morphostructural regions and the increasing prevalence of the young morpholineament systems (N–S and W–E) on the southern and northern periphery of the Western Carpathians could be an indication of the gradual spreading of the Western Carpathians into the surrounding lowlands during the last stage of the morphotectonic development.

Quantifying the mass transfer from mountain ranges to deposition in sedimentary basins: source to sink studies in the Danube Basin–Black Sea system was studied in the paper of *Matenco, Andriessen, Avram, Bada, Beekman, Bielik, Kováč, Králiková, Minár, Plašienka, & Stankoviansky (2013)*.

An overview of the results based on a combined interpretation of the potential field and seismic data in the 2D and 3D space in the Carpathian-Pannonian Region was presented in the paper of *Bielik, Alasonati Tašárová, Vozár, Zeyen,* *Gutterch, Grad, Janik, Wybraniec, Götze, Grinč & Dérerová (2014)*. The interpretation of geophysical data was the background for the tectonic description of two colliding lithospheric plates. The northern one is represented by older European tectonic units consists of the East European Craton and Trans European Suture zone. The southern one – overthrusting – is built up by younger tectonic units of the Western Carpathians and the back-arc Pannonian Basin System (generating the microplates ALCAPA and Tisza-Dacia). It is suggested that present day complex structure is a result of the complicated continental collision between microplates ALCAPA and Tisza-Dacia and the south margin of the European Platform, which was accompanied by thermal back-arc extension beneath the Pannonian Basin System.

Seismic models and its geological implications

During the CELEBRATION 2000 seismic experiment, the Western Carpathians and Pannonian basin region was investigated by a dense system of deep seismic sounding profiles. Based on these results *Janik, Grad, Guterch, Vozár, Bielik, Vozárová, Hegedüs, Kovacs, Kovács & Keller (2011)* modelled the refracted and reflected waves employing 2D ray tracing for seven interlocking profiles. The resulting P-wave velocity models (Fig. 18) reveal complex structures in the crust and large variations in the depth of the Moho discontinuity (~25–45 km). In the southern part of the area, the relatively thin Pannonian basin crust consists of 3–7 km thick sediments and two crustal layers with velocities of 5.9–6.3 km/s in the upper crust and 6.3–6.6 km/s in the lower crust. In the central region, the upper crust of the ALCAPA (Alpine–Carpathian–Pannonian) microplate contains a high velocity body of Vp ≥6.4 km/s, which spatially corresponds with the Bukk Composite Terrane. The total thickness of the ALCAPA crust is 1-2 km greater than in the adjacent Tisza–Dacia microplate. To the north in the area of the Trans-European suture zone (TESZ) and Carpathian foredeep, we observe a 10–20km thick upper crust with low velocity (Vp ≤6.0 km/s). Sub-Moho velocities have average values of 7.8–8.0 km/s for the Pannonian basin, while in the Western Carpathians, the TESZ and the East European Craton (EEC) area, they are slightly higher (8.0–8.1 km/s). Lower velocities beneath the ALCAPA and Tisza–Dacia microplates could be caused by compositional variations and the significantly higher surface heat flow. Beneath some profiles, reflectors in the lithospheric mantle were found sub-parallel to the Moho but 10–20km below it. Our integrated geophysical and geological analysis indicates that the observed structure was created by collision of two lithospheric plates with only a moderate degree of convergence. The northern plate consists of older European tectonic units of the EEC and TESZ. How-

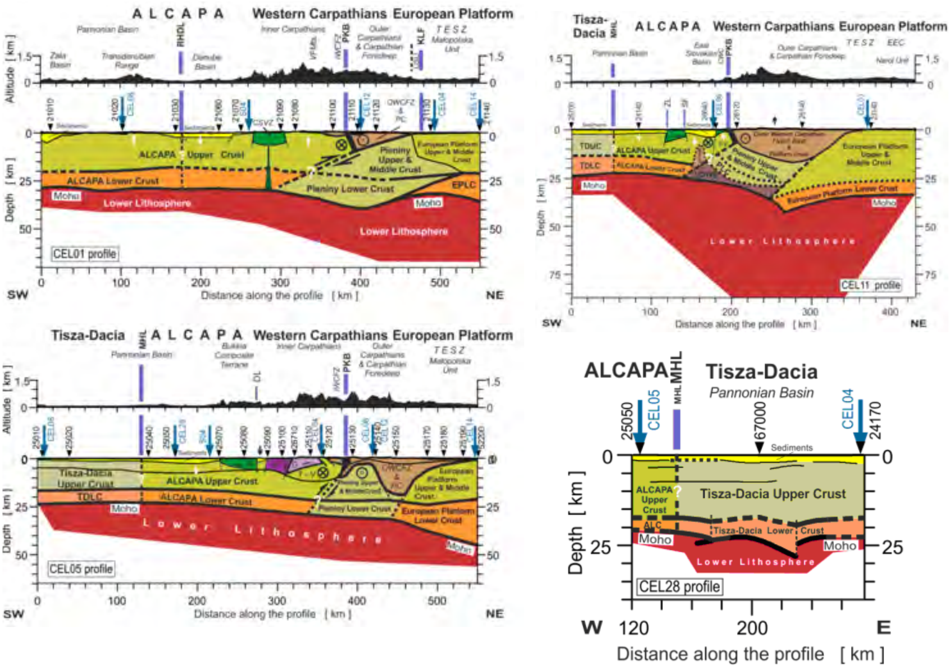

Fig. 18. Geological interpretation of two-dimensional seismic models along the CELEBRATION 2000 profiles CEL01, CEL05, CEL11 and CEL28. Legend. PP: Paleozoic Platform, EPUC: European Platform Upper Crust, EPLC: European Platform lower crust, PLC: Pieniny lower crust, USU: Upper Silesian Unit; ALC: ALCAPA lower crust, ALL: ALCAPA lower lithosphere, OWCFZ&PC: Outer Western Carpathian Flysch zone, IWCFZ: Inner Western Carpathian Flysch zone, CWC: Central Western Carpathians, VFMts.: Veľká Fatra Mts., CSVZ: Central Slovak Volcanic zone, T-V: Tatroveporicum, G: Gemericum, B: Bukkicum,M–Meliaticum, Z: Zemplinicum, UCHVB: Upper crustal high velocity body, LCHVB: Lower crustal high velocity body; TDUC: Tisza–Dacia upper crust, TDLC: Tisza–Dacia lower crust, TDUC: Tisza–Dacia upper crust, TDLC: Tisza–Dacia lower crust, TDLL: Tisza–Dacia lower lithosphere; PKB: Pieniny Klippen Belt, MHL: Mid-Hungarian line, RHDL: Rába-Hurbanovo-Dijosjenö Line, DL: Darnó line, MĽ: Margecany-Ľubeník line, SF: Sečovce fault, ZL: Zemplin line, KLF: Kraków-Lubliniec Fault; – overthrusting, – underthrusting, ↓subsidence, ↓uplift.

ever, the southern one consists of younger tectonic units of the Western Carpathians and the back-arc Pannonian basin that generated the ALCAPA and Tisza–Dacia microplates. We interpret the complex present day structure to be the result of the soft continental collision between the ALCAPA and Tisza–Dacia microplates and the south margin of the European plate, which was mainly followed by the extensional process beneath the back-arc Pannonian basin.

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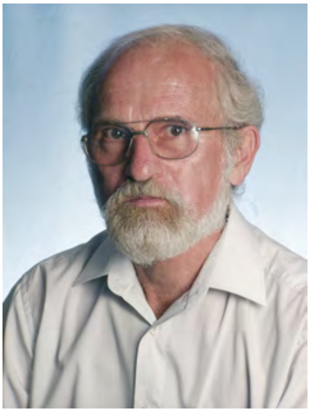

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2011–2014
International coordinator: Pavla Pekárová

UNESCO International Hydrological Programme
ERB European Network of Experimental and Representative Basins
2011–2014
International coordinator: Ladislav Holko
National coordinator: Ladislav Holko

Trans – Boundary River Management for the Kura River basin – Contract No. ENPI/2011/281 959
Funded by the European Union and Implemented by EPTISA, Spain
2012
Subcontractor: Ekoron, Ltd.
Coordinator: Dr. Peter Rončák

Environmental Protection of International River Basins Project (EPIRBP) – Contract No. ENPI/2011/279-666
Funded by the European Union and Implemented by a Consortium led by Hulla & CO. Human Dynamics
2013–2014
Subcontractor: Ekoron, Ltd.

COST 1106
Assessment of European Agriculture WaterUse and Trade Under ClimateChange (EURO – AGRIWAT)
2012–2016
National coordinator: Pavol Nejedlík

FFEM
Strenghtening capacity for data administration and exchange for monitoring and assessment of transboundary water resources in Eastern Europe, Caucasus and Central Asia (EECCA)
2010–2013
National coordinators: Boris Minárik, Ivan Machara

ClimateWater (FP7-ENV-2007-1/211894)
Bridging the gap between adaptation strategies of climate change impacts and European water policies
2008–2011
National coordinator: Lotta Blaškovičová

CEFRAME
Management and evaluation of flood risk in Central Europe
2010–2013
National coordinator: Danica Lešková

SEERisk
Joint Disaster Management risk assessment and preparedness in the Danube macro-region
2012–2014
National coordinator: Valéria Wendlová

SEE RIVER
Sustainable Integrated Management of International River Corridors in SEE Countries
2012–2014
National coordinator: Michaela Mikuličková

SLOVAKAID
Support of the implementation process of the EU Directive on assessment of the flood risks into the legislation in Georgia
2011–2013
National coordinator: Peter Rončák

SLOVAKAID
Support to development of the programme of measures focusing on the water and sanitation issues in the river basin management planning in Moldova
2014–2016
National coordinator: Peter Rončák

SLOVAKAID
Support of the implementation process of the EU Directive on assessment of the flood risks into the legislation in Montenegro
2013–2015
National coordinator: Peter Rončák

FP 6
Diagnostic Nanotech and Microtech Sensors
2007–2011
National coordinator: Miloslava Prokšová

SOUTH EAST EUROPE TRANSNATIONAL COOPERATION PROGRAMME COWANDA
Convention for waste management for inland navigation on the Danube
2012–2014
National coordinator: Júlia Šumná

SOUTH EAST EUROPE TRANSNATIONAL COOPERATION PROGRAMME COWANDA
Convention on Waste Management for inland navigation on the Danube
2010–2012
National coordinator: Júlia Šumná

SLOVAK-AUSTRIAN CROSS-BORDER COOPERATION PROGRAMME HESTIA
Harmonization and evaluation of sample collection methods for the monitoring of contaminants and their developments in the water
2012
National coordinator: Branislav Vrana

NATO´s Public Diplomacy Division in the framework of „Science for Peace“
Development of a decision support system for reducing risk from environmental pollution in the Bosna River
2011–2014
National coordinator: Jarmila Makovinská

LIFE+
Conservation of Root Vole *Microtus Oeconomus Mehelyi
2010–2015
National coordinator: Katarína Holubová, PhD.

SLOVAK-AUSTRIAN CROSS-BORDER COOPERATION PROGRAMME MoRe
The Morava River Restoration Plan
2010–2013
National coordinator: Katarína Holubová

SLOVAK-HUNGARIAN CROSS-BORDER COOPERATION PROGRAMME
Rehabilitation of Flood Plains along the shared Danube section in order to strengthen flood protection and to increase the ecological values of the river
2012–2014
National coordinator: Katarína Holubová

EC – COMPETENCE CENTER MACRO-REGIONS AND EUROPEAN TERRITORIAL COOPERATION – TRANSNATIONAL AND INTER-REGIONAL COOPEDRATION, Grant agreement an action with multiple beneficiaries
2013–2015
National coordinator: Lubica Kopčová

HUSK/1001/2.1.2/0058
The Study about the preparation status of the municipalities and other entities on dealing with the flood protection, improving the quality of their knowledge in compliance with the EU and national legislation in force (DISCOVER FLOODS)
2011–2013
Project coordinator: Martina Zeleňáková

HUSK/1001/2.12/0009
Flood modeling and logistic model development for flood crisis management (FLOODLOG)
2012–2014
Project coordinator: Endre Dobos

Vysegrad fund – Standard grant 21210018
Assessment of the quality of the environment in V4 countries
2012–2013
Project coordinator: Slávka Galaš

Vysegrad fund – Strategic grant 31210009
Sustainable rainwater management in the V4 countries
2012–2014
Project coordinator: Peter Hlavinek

COST – Cost action ES0901
European procedures for flood frequency estimation (FloodFreq)
2009–2012
National project coordinator: Ján Szolgay

RECARE – No. FP7 – 603498-22013 – 2017
Preventing and Remediating degradation of soils in Europe through Land Care
2013–2018
National project coordinator: Ján Szolgay

CarpathCC, DGE European Commission project, Specific contract No. ENV.D.1/201/612685/SR1, Framework – Contract No.
END.D.1/FRA/2011/0006

Climate Change Framework Project
2012–2013
National project coordinator: Kamila Hlavčová

FRENCH – SLOVAK Bilateral Project
Integrated geophysical modeling of the Carpatho-pannonian region assessment
2011–2013
Coordinators: Hermann Zeyen and Miroslav Bielik

COST-ES1401
Time Dependent Seismology (TIDES)
since 2014
The Action aims at structuring the EU seismological community to enable development of data-intensive, time-dependent techniques for monitoring Earth active processes (e.g., earthquakes, volcanic eruptions, landslides, glacial earthquakes) as well as oil/gas reservoirs.
Project coordinator: Andrea Morelli
National coordinator for Slovak Republic: Peter Moczo, Jozef Kristek

EC 7th FRAMEWORK PROGRAM Grant agreement 238007 (QUEST)
Quantitative estimation of Earth's seismic sources and structure

2009–2013
National coordinator: Peter Moczo (Heiner Igel – coordinator)
Participating institutions from: Czech Republic, France, Germany, Great Britain, Ireland, Italy, Netherland, Slovak Republic, Switzerland

EC 7th FRAMEWORK PROGRAM Grant Project FP7-PEOPLE-IAPP-2009- 230669 (AIM)
Advanced Industrial Microseismic Monitoring
2009–2013
National coordinator: Miriam Kristeková (Václav Vavrycuk – coordinator)
Participating institutions from: Canada, Czech Republic, Norway, Slovak Republic, South Africa Republic

EC 7th FRAMEWORK PROGRAM Grant agreement 262330 (NERA)
Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation
2010–2014
National coordinator: Peter Moczo (Domenico Giardini – coordinator)
The Bratislava team is a sub-contractor to ISTerre UJF Grenoble in the JRA1 (Joint Research Activity 1)

NATO project ESP.EAP.SFPP 983289 (LADATSH)
Prevention of Landslide Dam Disasters in the Tien Shan, Kyrgyz Republic
2009–2011
National coordinator: Miriam Kristeková (Hans-Balder Havenith – coordinator)
Participating institutions from: Belgium, Kirgiz, Russia, Slovak Republic, Switzerland

CEA, France
E2VP II - EuroseisTest Verification and Validation Project II
20011–2015
Coordinator: Fabrice Hollender

GREEK – SLOVAK Bilateral Project
Combination of probabilistic and deterministic approaches for seismic hazard assessment at regional and local scales

2013–2014
Coordinators: Costas Papazachos and Peter Moczo

FRENCH – SLOVAK Bilateral Project
Advanced numerical simulations for deterministic seismic hazard assessment
2010–2011
Coordinators: Pierre-Yves Bard and Peter Moczo

Slovak Official Development Aid Fund Project SAMRS/2009/04/24 (DETERMINE)
Development of Earthquake Monitoring Infrastructure for Bosnia and Herzegovina
2009–2011
Coordinator: Miriam Kristeková
Participating institutions from: Bosnia and Herzegovina, Slovak Republic

INTERMAGNET–
First order world network of geomagnetic observatories
From 2003
Local coordinator for Slovak Republic – Magdaléna Váczyová, GPI SAS, Bratislava
Participating institutions: multilateral

COST ES 0803
Developing space weather products and services in Europe
2008–2012
National coordinator – Karel Kudela, member of Management Committee for Slovak Republic
Laboratories from 23 countries including Slovakia, 3 labs from non-COST countries
http://www.cost.esf.org/domains_actions/essem/Actions/ES0803?

Defended PhD Theses

Institution: Faculty of Natural Sciences, Comenius University, KAEG, Bratislava, Slovak Republic
Title: Two-dimensional and three-dimensional integrated interpretation of field of attraction within the international framework CELEBRATION 2000 (in Slovak)
Student: Kristián Csicsay
Supervisor: Miroslav Bielik
Year of defense: 2011

Institution: Faculty of Natural Sciences, Comenius University, KAEG, Bratislava, Slovak Republic
Title: Application of modern geophysical methods during the survey of the central part of the Vienna Basin (3D gravity field modeling using the conversion of seismic logging measurements to density) (in Slovak)
Student: Eva Speváková
Supervisor: Miroslav Bielik
Year of defense: 2011

Institution: Faculty of Natural Sciences, Comenius University, KAEG, Bratislava, Slovak Republic
Title: Lithospheric structure in Central Europe: integrated geophysical modeling (in English)
Student: Michal Grinč
Supervisor: Miroslav Bielik
Year of defense: 2013

Institution: Faculty of Natural Sciences, Comenius University, KAEG, Bratislava, Slovak Republic
Title: Geoelectrical measurements in the central part of the Danube basin: interpretation problems and their geological-geophysical interpretation (in Slovak)
Student: Mariána Pašiaková
Supervisor: Miroslav Bielik
Year of defense: 2014

Institution: Department of Hydrogeology, Faculty of Natural Sciences, Comenius University in Bratislava, Slovak Republic
Title: Trace elements in thermal waters of carbonatic systems of the Western Carpathians
Student: Andrea Vranovská
Supervisor: Dušan Bodiš
Year of defense: 2010

Institution: Department of Natural Environment, Faculty of Forestry, Technical University in Zvolen, Slovak Republic
Title: Forestry Ameliorations as a tool for carbon sequestration in forest soils
Student: Mgr. Yousif Abdel Rahman Ahmed
Supervisor: prof. Dr. Ing. Viliam Pichler
Year of defense: 2010

Institution: Department of Hydrogeology, Faculty of Natural Sciences, Comenius University in Bratislava, Slovak Republic
Title: Changes in surface and groundwater quality in periods of water scarcity in catchments
Student: Miloš Gregor
Supervisor: Miriam Fendeková
Year of defense: 2011

Institution: Department of Hydrogeology, Faculty of Natural Sciences, Comenius University in Bratislava, Slovak Republic
Title: Pollution of groundwater of Slovakia by arsenic and antimony and its influence on water sources
Student: Ivana Ondrejková
Supervisor: Zlatica Ženišová
Year of defense: 2011

Institution: Department of Landscape Engineering, Faculty of Horticulture and Landscape Engineering, Slovak University of Agriculture in Nitra, Slovak Republic

Title:	The usage of the Digital Terrain Model of small water basin bottom for the quantification of bottom sediments
Student:	Jakub Fuska
Supervisor:	Viliam Bárek
Year of defense:	2011

Institution:	Department of Landscape Engineering, Faculty of Horticulture and Landscape Engineering, Slovak University of Agriculture in Nitra, Slovak Republic
Title:	Analyze and evaluation of the factors influencing hydro-morphological component of the small streams ecological quality
Student:	Vladimír Božoň
Supervisor:	Peter Halaj
Year of defense:	2011

Institution:	Department of Landscape Engineering, Faculty of Horticulture and Landscape Engineering, Slovak University of Agriculture in Nitra, Slovak Republic
Title:	Bottom sediments of the small water reservoirs and their expolitation
Student:	Jozef Gabčo
Supervisor:	Ľuboš Jurík
Year of defense:	2011

Institution:	Department of Landscape Engineering, Faculty of Horticulture and Landscape Engineering, Slovak University of Agriculture in Nitra, Slovak Republic
Title:	Retention and water consumption in the agricultural exploited landscape
Student:	Tatiana Kaletová
Supervisor:	Ľuboš Jurík
Year of defense:	2011

Institution:	Department of Hydrology and Biometeorology, Faculty of Horticulture and Landscape Engineering, Slovak University of Agriculture in Nitra, Slovak Republic

Title: Computaion of the erosion effective rainfalls for Slovak territory
Student: Lucia Maderková
Supervisor: Jaroslav Antal
Year of defense: 2011

Institution: Department of Natural Environment, Faculty of Forestry, Technical University in Zvolen, Slovak Republic
Title: Ecophysiological aspects of water regime and transpiration spruce and larch mountain forest in the Tatra National Park
Student: Ing. Dagmar Magová,
Supervisor: doc. Ing. Katarína Střelcová, PhD.
Year of defense: 2011

Institution: Department of Natural Environment, Faculty of Forestry, Technical University in Zvolen, Slovak Republic
Title: Genotypic variability of physiological and growth parameters of spruce
Student: Ing. Adriana Leštianska
Supervisor: doc. Ing. Katarína Střelcová, PhD.
Year of defense: 2011

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Modeling Hydrological Balance in Wetland Systems
Student: Martina Tegelhoffová
Supervisor: Kamila Hlavčová
Year of defense: 2011

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Modeling Flood Waves for Proposed Flood Protection Measures
Student: Michal Danko
Supervisor: Kamila Hlavčová

Year of defense: 2011

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Regional Assessment of the Hydraulic Properties of Vulcanite in Central Slovakia
Student: Kováčová E.
Supervisor: Jana Skalová
Year of defense: 2011

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Impact of a Channel's Hydraulic and Morphological Characteristics on the Quality of the Aquatic Habitat of a Stream
Student: Monika Jalčovíková
Supervisor: Viliam Macura
Year of defense: 2011

Institution: Department of Hydrogeology, Faculty of Natural Sciences, Comenius University in Bratislava, Slovak Republic
Title: Hydrogeochemical characteristics of the Western Carpathians cave systems on example of the Demänová system (Nízke Tatry Mts.) and caves of the Silica plain (Slovenský kras Mts.)
Student: Dagmar Haviarová
Supervisor: Zlatica Ženišová
Year of defense: 2012

Institution: Department of Hydrogeology, Faculty of Natural Sciences, Comenius University in Bratislava, Slovak Republic
Title: Estimation of usable groundwater amount in neo-volcanic rocks
Student: Alena Bágelová
Supervisor: Marián Fendek

Year of defense: 2012

Institution: Institute of Hydrology, Slovak Academy of Sciences, Bratislava, Slovak Republic
Title: Diagnostics of the soil water regime
Student: Marek Rodný
Supervisor: Vlasta Štekauerová
Year of defense: 2012

Institution: Department of Hydrology and Biometeorology, Faculty of Horticulture and Landscape Engineering, Slovak University of Agriculture in Nitra, Slovak Republic
Title: Influence of the surface soil layer on the evaportaion intensity
Student: Zuzana Lagíňová
Supervisor: Jaroslav Antal
Year of defense: 2012

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Dilution methods for estimation of discharges in natural streams in Slovakia
Student: Zuzana Danáčová
Supervisor: Ján Szolgay
Year of defence: 2012

Institution: Department of Land and Water Resources Management,Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Dilution methods for estimation of discharges in natural streams in Slovakia
Student: Zuzana Danáčová
Supervisor: Ján Szolgay
Year of defence: 2012

Institution:	Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title:	Application of local warning systems and neural networks in hydrological forecasting
Student:	Danica Lešková
Supervisor:	Kamila Hlavčová
Year of defence:	2012

Institution:	Department of Environmental Engineering, Faculty of Ecology and Environmental Sciences, Technical University in Zvolen, Slovak Republic
Title:	Modeling greenhouse gas emissions from forest fires
Student:	Ing. Tomáš Vida
Supervisor:	prof. Ing. Jaroslav Škvarenina, CSc.
Year of defense:	2012

Institution:	Department of Environmental Engineering, Faculty of Ecology and Environmental Sciences, Technical University in Zvolen, Slovak Republic
Title:	Modeling greenhouse gas emissions from forest fires
Student:	Ing. Tomáš Vida
Supervisor:	prof. Ing. Jaroslav Škvarenina, CSc.
Year of defense:	2012

Institution:	Department of Natural Environment, Faculty of Forestry, Technical University in Zvolen, Slovak Republic
Title:	The influence of meteorological conditions and water balance of the phenological phases of selected forest tree species
Student:	Ing. Ivana Pálešová
Supervisor:	prof. Ing. Jaroslav Škvarenina, CSc.
Year of defense:	2012

Institution:	Department of Natural Environment, Faculty of Forestry, Technical University in Zvolen, Slovak Republic

Title:	Evaluation of bioclimatic drought risk as a potential source of threat to biodiversity in the example of the Tatra National Park
Student:	Ing. Jaroslav Vido
Supervisor:	prof. Ing. Jaroslav Škvarenina, CSc.
Year of defense:	2012

Institution:	Department of Natural Environment, Faculty of Forestry, Technical University in Zvolen, Slovak Republic
Title:	Changes to intercept and precipitation regime of mountain spruce forests in the Western Tatras
Student:	Ing. Marek Oreňák
Supervisor:	prof. Ing. Jaroslav Škvarenina, CSc.
Year of defense:	2012

Institution:	Department of Natural Environment, Faculty of Forestry, Technical University in Zvolen, Slovak Republic
Title:	The deficit in rainfall and drought stress as factors limiting transpirations pruce
Student:	Ing. Dana Kovalčíková
Supervisor:	doc. Ing. Katarína Střelcová, PhD.
Year of defense:	2012

Institution:	Department of Hydraulic Engineering, Faculty of Civil Engineering, Slovak University of Technology in Bratislava, Slovak Republic
Title:	Research on the impact of lateral spillway parameters on the hydraulic flow characteristics using the 3D Modeling
Student:	Martin Orfánus
Supervisor:	Andrej Šoltész
Year of defense:	2012

Institution:	Department of Hydraulic Engineering, Faculty of Civil Engineering, Slovak University of Technology in Bratislava, Slovak Republic
Title:	Hydraulic Aspects of Urban Flood Protection
Student:	Katarína Kožáková

Supervisor: Radomil Květon
Year of defense: 2012

Institution: Department of Architectural Engineering, Faculty of Civil Engineering, Technical University of Košice, Slovak Republic
Title: Infiltration of rainwater from runoff
Student: Gabriel Markovič
Supervisor: Zuzana Vranayová
Year of defense: 2012

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Impact of Climate Change on a Soil Water Regime
Student: Justína Vítková
Supervisor: Jana Skalová
Year of defense: 2012

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Parameterization of Hydrological Processes in Distributed Runoff Modeling
Student: Dušan Kočický
Supervisor: Jan Szolgay
Year of defense: 2012

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Indicator Methods for Estimating Discharges in Natural Rivers in Slovakia
Student: Zuzana Danáčová
Supervisor: Jan Szolgay
Year of defense: 2012

Institution:	Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title	Detecting changes in hydrological regime of mean monthly and annual runoff on Slovak rivers
Student:	Miroslava Tegelhoffová
Supervisor:	Jan Szolgay
Year of defense:	2012

Institution:	Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title:	Application of Local Warning Systems and Artificial Neural Networks in Hydroforecasting Practice
Student:	Danica Lešková
Supervisor:	Kamila Hlavčová
Year of defense:	2012

Institution:	Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title:	Application of neural networks in water management
Student:	Martin Suchár
Supervisor:	Milan Čistý
Year of defense:	2012

Institution:	Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title:	Evaluating the Impact of Land Use Change on the Runoff Processes in a Catchment
Student:	Marcela Bulantová
Supervisor:	Kamila Hlavčová
Year of defense:	2012

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Seasonality Analysis of Low Flows and Their Regional Distribution
Student: Andrea Števková
Supervisor: Silvia Kohnová
Year of defense: 2012

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Assessing the Impact of Riparian Vegetation on the Quality of Aquatic and Terrestrial Habitats
Student: Marcela Škrovinová
Supervisor: Viliam Macura
Year of defense: 2012

Institution: Department of Hydrogeology, Faculty of Natural Sciences, Comenius University in Bratislava, Slovak Republic
Title: Mineral waters of the Flysch belt
Student: Natália Bačová
Supervisor: Marián Fendek
Year of defense: 2013

Institution: Institute of Hydrology, Slovak Academy of Sciences, Slovak Republic
Title: Runoff generation in a mountain catchment
Student: Michal Dóša
Supervisor Ladislav Holko
Year of defense: 2013

Institution: Institute of Hydrology, Slovak Academy of Sciences, Bratislava, Slovak Republic
Title: Sensitivity of temperature regime of selected Slovak water courses to hydrological extremes and climate variability
Student: Katarína Kučárová

Supervisor: Pavla Pekárová
Year of defense: 2013

Institution: Institute of Hydrology, Slovak Academy of Sciences, Bratislava, Slovak Republic
Title: Variation of water temperature in experimental alpine catchments
Student: Mária Martincová
Supervisor: Pavla Pekárová
Year of defense: 2013

Institution: Institute of Hydrology, Slovak Academy of Sciences, Bratislava, Slovak Republic
Title: Runoff generation in mountain catchment
Student: Michal Dóša
Supervisor: Ladislav Holko
Year of defense: 2013

Institution: Department of Landscape Engineering, Faculty of Horticulture and Landscape Engineering, Slovak University of Agriculture in Nitra, Slovak Republic
Title: Revitalization objects and their influence on the stream bank morpholohy and hydraulic flow characteristics into small water streams
Student: Katarína Pecháčová
Supervisor: Peter Halaj
Year of defense: 2013

Institution: Department of Land and Water Resources Management,Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Estimation of flood potential of landscape and flood forecasting with artificial intelligence techniques
Student: Viliam Šimor
Supervisor: Kamila Hlavčová
Year of defence: 2013

Institution:	Department of Physical Geography and Geoecology, Faculty of Natural Sciences, Comenius University in Bratislava, Slovak Republic
Title:	Comparison of land use changes to the precipitation – runoff events on the upper part of the river basin Domanižanka
Student:	Katarína Melová
Supervisor:	Milan Trizna
Year of defence:	2013

Institution:	Department of Natural Environment, Faculty of Forestry, Technical University in Zvolen, Slovak Republic
Title:	Use of vegetation indices for monitoring changes in phenological manifestations of beech stands
Student:	Ing. Veronika Lukasová
Supervisor:	prof. Ing. Jaroslav Škvarenina, CSc.
Year of defense:	2013

Institution:	Department of Environmental Engineering, Faculty of Civil Engineering, Technical University of Košice, Slovak Republic
Title:	Environmental risk assessment – Drought risk assessment in condition of Libya
Student:	Ibrahim Gargar
Supervisor:	Martina Zeleňáková
Year of defense:	2013

Institution:	Department of Environmental Engineering, Faculty of Civil Engineering, Technical University of Košice, Slovak Republic
Title:	Application of risk analysis in the environmental impact assessment of water structures
Student:	Lenka Zvijáková
Supervisor:	Martina Zeleňáková
Year of defense:	2013

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Estimation of the Flood Potential of a Landscape and Flood Forecasting with Artificial Intelligence Techniques
Student: Viliam Šimor
Supervisor: Kamila Hlavčová
Year of defense: 2013

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: The Assessment of the Impact of Climate Change on Runoff Processes in Slovakia.
Student: Zuzana Štefunková
Supervisor: Kamila Hlavčová
Year of defense: 2013

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Modeling Rainfall for a Frequency Analysis of Discharges in River Basins.
Student: Roman Výleta
Supervisor: Jan Szolgay
Year of defense: 2013

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Scaling of Short-Term Rainfalls over Months and the Whole Warm Season in Slovakia.
Student: Jana Látečková
Supervisor: Silvia Kohnová
Year of defense: 2013

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Flood Waves for Designing Retention Storage on Small Catchments.
Student: Peter Spál
Supervisor: Jan Szolgay
Year of defense: 2013

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Consequences of Climate Change on the Water Regime of Wetlands
Student: Mária Pásztorová
Supervisor: Jana Skalová
Year of defense: 2013

Institution: Department of Hydrogeology, Faculty of Natural Sciences, Comenius University in Bratislava, Slovak Republic
Title: Identification and classification of drought in groundwater level regime
Student: Dagmar Stojkovová
Supervisor: Miriam Fendeková
Year of defense: 2014

Institution: Department of Hydraulic Engineering, Faculty of Civil Engineering, Slovak University of Technology in Bratislava, Slovak Republic
Title: Optimization of water regime in the VSN-3 drainage system.
Student: Zuzana Pálinkášová
Supervisor: Andrej Šoltész
Year of defense: 2014

Institution: Department of Environmental Engineering, Faculty of Civil Engineering, Technical University of Košice, Slovak Republic

Title: Flood risk assessment and management in selected river basins respecting Flood Directive 2007/60/EC
Student: Lenka Gaňová
Supervisor: Martina Zeleňáková
Year of defense: 2014

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Evaulation of the Quality of Aquatic Habitats in Urban Areas.
Student: Ivan Stankoci
Supervisor: Viliam Macura
Year of defense: 2014

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Rainfall-Runoff Modeling for Frequency Analyses of Discharges.
Student: Peter Valent
Supervisor: Jan Szolgay
Year of defense: 2014

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Analysis of Changes in Hydrological Balance Elements Using Rainfall-Runoff Modeling
Student: Beáta Hamar Zsideková
Supervisor: Silvia Kohnová
Year of defense: 2014

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic

Title: Analysis of the Parameters of the SCS-CN Method in the Conditions of Slovakia
Student: Beáta Karabová
Supervisor: Silvia Kohnová
Year of defense: 2014

Institution: Department of Land and Water Resources Management, Faculty of Civil Engineering, Slovak University of Technology Bratislava, Slovak Republic
Title: Evaulation of the Quality of Aquatic Habitats Using Bioindications
Student: Jana Jariabková
Supervisor: Viliam Macura
Year of defense: 2014

Web pages

http://gpi.savba.sk
http://www.seismology.sk
http://www.nuqake.eu
http://www.fyzikazeme.sk
http://www.cambridge.org/moczo

In memory of Associated Prof. RNDr. Milan Hvoždara, DrSc. (1942–2012)

On December 15th, 2012, our beloved colleague Assoc. Prof. Milan Hvoždara, DrSc. has departed from among us in the age of 70. He is missed also as the beloved husband, father and a friend to many. In his last years Milan Hvoždara was struggling with an unforgiving disease. Even under such struggle and suffering he retained his great passion for love and life. We remember his strong and good will in fighting the illness. We nowadays recall how he kept his wonderful sense of humor and stayed cheerful. We remember how he challenged himself even in his last weeks and encouraged us to live full life, to aim for knowledge, and to live to love others.

Milan Hvoždara was born on October 10, 1942 in the town of Stará Turá. After graduating from the Faculty of Mathematics and Physics of the Charles University in Prague in 1965, he started working at the Geophysical Institute (GI) of the Slovak Academy of Sciences (SAS), where he had occupied various positions. He had completed his external research fellowship at the Geophysical Institute of the Czechoslovak Academy of Sciences in Prague in 1969. He had been awarded the scientific degree DrSc. at the GI SAS in 1989, and the Associate Professor at the Faculty of Mathematics and Physics of the Comenius University in Bratislava in 1995.

We have lost an outstanding man who during his whole life shared knowledge, hope and optimism, and who was a great support for us. We have lost one of the important scientific personalities. He was, and henceforth remains, one of the founders of the Slovak geophysics. He was well-educated in many physical and geophysical sciences. He created and taught his own school in solving mathematical problems for geo-electromagnetic fields in inhomogenous environments by modeling the conductivity inhomogeneities of the Earth. He contributed significantly to the theory of electromagnetic induction for a spherical multilayer Earth, taking into account its rotation in inhomogenous harmonic or aperiodic excitation fields. He also derived equations and wrote software for the electromagnetic induction in a layered earth with 3D anomalous bodies using the method of vector integral equations with a weak singular tensor kernel. In stationary geoelectric fields he is an internationally recognized author of original solutions by the method of boundary integral equations with complicated Green kernels. He authored sophisticated numerical routines for all of his theoretical procedures, several of them being used at domestic as well as foreign partner institutes. He also contributed into theoretical and numerical developments in gravimetry, geothermics, and thermoelestic processes in the lithosphere. Between 1967 and 2005 he was very active in the pedagogical process, giving geophysical lectures, 4 to 6 hours weekly, at the Faculty of Mathematics, Physics and Informatics and the Faculty of natural Sciences of the Comenius University. For many years he had been the head of the Geomagnetic observatory of the GI SAS in Hurbanovo. From 1989 to 1996 Dr. Hvoždara was the director of the GI SAS. He coordinated several scientific research grants and projects. During 1988–1997 he took the position of the secretary of the Scientific Council of the SAS for earth and space sciences. He chaired the Committee for Geophysics. He was a member of several editorial boards of scientific journals, as well as editor in chief of the Contributions to Geophysics and Geodesy journal published by our institute. Until his departure he was actively involved in the editorial work. His work was rewarded by numerous awards, such as Honorary Award for Merits in Advancing the Faculty of Mathematics and Physics of the Comenius University (1987), Honorary Silver Plaque of Dionýz Štúr for merits in natural sciences (1992), commemorative medals of the Geofyzika Brno company (1989). Milan Hvoždara was an outstanding teacher. His lifelong creed was to create conditions for scientific growth of the young and talented colleagues.

We will remember Associated Professor Milan Hvoždara as a very honest, friendly and human colleague, outstanding man and best friend. Those who knew him will miss him.

Dr. Ladislav Brimich
Director, GI SAS

RNDr. Igor Túnyi, DrSc., 1949–2014

Geophysical Institute of the Slovak Academy of Sciences announces with deep sorrow that our longtime collaborator and friend, RNDr. Igor Túnyi, DrSc., has died on 9 December 2014 aged 65 years.

Igor Túnyi was born on 13 November 1949 in Kokava nad Rimavicou, Slovakia. He graduated from the Faculty of Mathematics and Physics of Charles University in Prague in 1973. From August 1973 until his death he worked at the Geophysical Institute of SAS in various positions and functions. In the period 1997–2005 he acted as a director. The exception was only a short period 1980–1984, when he worked in the Slovak Geological Institute in Bratislava as a leading professional officer for geophysics and exploration of oil and natural gas in Slovakia. Between 2005 and 2011 he was a member of the Presidium of the Slovak Academy of Sciences.

In his scientific work he focused on the research of the geomagnetic field, paleomagnetic research of the Western Carpathians, the magnetic properties of meteorites and Antarctic rocks, the archeomagnetic research of archaeological artifacts and the archivemagnetic research based on the historical mining maps. He participated in the field magnetic and magnetotelluric measurements, magnetic measurements for military and civil aviation. He also studied the precursors of ground movements and the accretion effects of pulsed magnetic fields. He was a leading investigator of seven VEGA projects and of one project financed from the EU Structural Funds, and participated in three APVV projects. He authored and co-authored more than 140 scientific articles, of which more than 40 have been published in peer-reviewed journals. His writings have now 165 citations according to SCI and more than 200 citations in peer-reviewed publications at home and abroad. He was co-author of two monographs published abroad, author of one monograph published in Slovakia and participated in the preparation of 6 chapters in the book publications in Slovakia. He served in the editorial boards of two scientific journals (1 indexed in CC, 1 in SCOPUS).

He regularly participated in major domestic and international scientific events. Together with colleagues from the Geophysical Institute of the Czech Academy of Sciences, he was the founder and one of the main organizers of conferences on the paleomagnetism and the research on magnetic properties of rocks, which began to hold the biennial frequency since 1991 and are being organized until now. He was a supervisor of seven PhD students.

RNDr. Igor Túnyi, DrSc. made a significant contribution to the geomagnetism. He was always willing to share his knowledge and opinions.

Dr. Ladislav Brimich
Director, GI SAS