Research overview 2005

Department of Geophysics, belonging to the Faculty of Mathematics and Physics, Charles University, Prague, has its roots seated as deep as in the 20's of the last century. Its structure and priorities have evolved from nearly pure seismology to the present-day broad scope covering nearly all main branches of the physics of the Earth and, most recently, comprising also planetary aspects. Research is tightly coupled with education at bachelor, master and doctoral levels. In 2005, there were 19 staff members at the department (counting permanent and temporary positions), and 13 PhD students.

The MAGMA center, i.e. the Prague Center of Mathematical Geophysics, Meteorology, and their Applications, a 3-year project (2003-2005) supported by the European Commission, has been successfully completed. We hosted many researches and students from Europe; the total length of both short visits and stays longer than 1 month at the Department of Geophysics reached 67 person-months altogether in 2003-2005. For more details, see http://geo.mff.cuni.cz/magma.

In a close relation to MAGMA, the Department of Geophysics takes part in three more EC projects in 2005: SPICE, 3HAZ-CORINTH and IMAGES. SPICE (2004-2007) is the pan-European Marie Curie Reseat Training Network involving 14 universities and specialized in theory of seismic wave propagation. 3HAZ-CORINTH (2004-2006) is a research project specifically targeted on three main natural hazards in the Gulf of Corinth, Greece, viz earthquakes, landslides and tsunamis. IMAGES (2005-2008) aims at transfer of knowledge between seismologists and applied geophysicists (Schlumberger Cambridge Research), studying microearthquakes induced by oil drilling.

In 2005, we participated in submission of two new proposals for the EC Marie Curie Research Training Networks: ITSAK-GR and REAP. The REAP project (coordinated at the University of Ulster), a continuation of the previous successful PRESAP project, will involve 7 European and 1 US institution engaged in stress transfer after strong earthquakes and prediction of their aftershocks. ITSAK-GR is a new project launched by the leading engineering-seismology institution of Greece, focused on the transfer of knowledge in the earthquake strong ground motion analysis and prediction.

Fruitful cooperation with several major oil companies, lasting since 1993, has continued in 2005 in the framework of the project Seismic waves in 3D media (SW3D) coordinated at the Department of Geophysics.

International workshop Seismic waves in laterally inhomogeneous media VI was organized, jointly with the Geophysical Institute of the Czech Academy of Sciences, at the Castle of Hruba Skala on June 20-25, 2005. The 61 participants from 14 countries presented 58 oral and poster contributions. Proceedings will be published in two special issues of Studia Geophysica et Geodaetica.

Intensive popularization of the Earth science was performed in 2005. In addition to already standard presentations at the Faculty Open Day and the Day with Physics, more than five large public lectures and several TV interviews were made in connection with the disastrous mega-earthquake and tsunami in Sumatra, Dec 26, 2004. Three popularization articles were published in the Czech physical journal, viz Cizkova (2005), Zahradnik et al. (2005) and Burjanek et al. (2005).

In connection with the currently reformed study structure of the Faculty, dozens of topics were suggested for bachelor studies of the physics of the Earth, and, consequently, 7 new students appeared at our department with the potential to continue in their studies towards higher degrees.

Two MSc theses (Soucek, 2005; Rezba, 2005) and one PhD thesis (Zacek, 2005) were defended at the Department of Geophysics in 2005.

Similarly to the previous years, research at the Department of Geophysics was carried out in three directions: Geodynamics, Theory of seismic waves, and Earthquake and structural studies.

Geodynamics

Glacial isostatic adjustment of the Earth

Martinec and Wolf (2005) inverted the Fennoscandian relaxation spectrum by adapting the spectral finite-element method, originally developed for a 3-D self-gravitating spherical Earth model (Martinec, 2000), to an axisymmetric viscosity distribution. The free parameters used in the inversion are either the central-lithosphere thickness (below the former Fennoscandian ice sheet) and the upper-mantle viscosity or the peripheral-lithosphere thickness and the peripheral-asthenosphere viscosity (surrounding the former Fennoscandian ice sheet). We demonstrate that a model featuring a central lithosphere with a thickness of 200 km and a peripheral lithosphere with a thickness of 80 km underlaid by an asthenosphere satisfies the relaxation-time spectrum. We also show that the spectrum can be explained on the basis of a spherically symmetric model featuring a 100-km thick lithosphere, but no asthenosphere. Fleming and Martinec (2005) examined the dependence of GIA on the underlying viscosity structure for the Vatnajökull Ice Cap, Iceland. A four-layer spherical earth model was used, consisting of a thin elastic lithosphere, LVZ, and an upper and lower mantle. They compared the predicted GIA response arising from changes in the Vatnajökull Ice Cap with vertical-displacement rates found by GPS campaigns conducted between 1991 and 2000. The underlying viscosity structure that provides the optimum predictions consists of an elastic lithosphere whose thickness lies between 46 to 16 km, a LVZ whose viscosity is between 10^{18} to 10^{19} Pa s, and whose depth extends to between 175 to greater than 400 km. They found that the very low viscosity values sometimes evoked for Iceland are not necessary to account for the rapid uplift rates. Inter-annual variability in the mass balance of the ice cap strongly affects vertical-displacement rates. This means that values inferred from GPS surveys will depend upon the epoch at which the measurements are made, with more frequent surveys required to differentiate between inter-annual and longer-term trends.

Effect of glacial isostatic adjustment on present-day sea level change

Hagedoorn, Wolf and Martinec (2005) studied the influence of GIA caused by the last Pleistocene deglaciation on the present-day sea level. The viscoelastic deformation caused by the time-variable ice and ocean loads is simulated by computing the resulting perturbations for a spherical, self-gravitating, incompressible, Maxwell-viscoelastic Earth model. The associated variation of the earth rotation is described in terms of the Liouville equation, which is solved by means of the MacCullagh formulae. This allows the determination of the vertical displacement and geoid height and, thus, the solution of the sea-level equation. They tested several viscosity and ice models and evaluate them by comparison of the computed response with the Holocene sea-level history. Using the optimum combination of viscosity and ice models, they then estimated the influence of the last Pleistocene deglaciation on the tide-gauge measurements. A comparison between the observational and residual linear trends for the tide-gauge measurements shows a significant reduction of the variance and geographical variability for the latter, in particular for the formerly ice-covered regions of North America and Scandinavia. The favored value determined for the global mean sea-level rise is (1.46±0.2) mm/y. Soucek (2005) developed a new theory of ice-loads dynamics, which is based on fundamental laws of thermodynamics and is planed to be incorporated into the present-day sea level change modelling.

Heat generated by ice-sheets loading and unloading

Hanyk et al. (2005) studied dissipation of heat generated by ice sheets loading and uloading. They have focused on the magnitude of glacially induced deformations and the corresponding shear heating for an ice sheet of the spatial extent of Laurentide region in Maxwellian viscoelastic compressible models with a Newtonian viscosity. They used a discretization method based on the method of lines for integrating the time-dependent evolutionary equations of self-gravitational, viscoelastic flow. They have found that shear heating from the transient viscoelastic flow can represent a non-negligible mantle energy source with cryogenic origins. Volumetric heating by viscous deformation associated with these flows can be locally greater than chondritic heating by radioactivity. In the presence of an abrupt change in the ice loading history, the time average of the integral of the dissipation over depth corresponds to a mantle heat flow of the order of magnitude of mW/m^2 below the periphery of ancient ice sheets or below their central areas. However, the peak values of this integral in time are almost two orders higher. These results would suggest that some degree of volcanism may be associated with dramatic episodes in ice loading.

Rotation of the Earth

Rotation of the Earth undergoes changes due to time-varying surface load and internal mass redistribution. For a spherically symmetric viscoelastic Earth model, the movement of the rotation vector during a glaciation cycle has conventionally been computed in the Laplace-transform domain. The method involves multiplication of the Laplace transforms of the second-degree surface-load and tidal-load Love numbers with the time evolution of the surface load followed by inverse Laplace transformation into the time domain. The newly developed method by Martinec and Hagedoorn (2005) offers the possibility to model the rotational response of the Earth induced by glacial-isostatic adjustment (GIA) by time integration of the linearized Liouville equation. The theory presented there derives the temporal perturbation of the inertia tensor, required to be specified in the Liouville equation, from time variations of the second-degree gravitational-potential coefficients by the MacCullagh's formulae. This extends the conventional approach based on the second-degree load Love numbers to general 3-D viscoelastic earth models. The time-domain solution of both the GIA and the induced rotational response of the Earth is readily combined with a time-domain solution of the sea-level equation with a time-varying shoreline geometry.

Lateral viscosity changes in the upper mantle of the Earth

The large-scale gravitational signal of the Earth, together with the seismic tomographic image, provide clues to estimate the viscosity structure of the mantle. The attention of the geodynamics group was mainly paid to determination of the lateral viscosity changes in the upper mantle and to new data which could reduce strong non-uniqueness of this inverse problem. In close cooperation with L. Fleitout from ENS in Paris, O. Cadek incorporated two new pieces of information in the inversion for viscosity, namely the estimate of surface dynamic topography (i.e., deformation of the surface induced by flows in mantle) and the constraint on orientation of mantle flow from the seismic anisotropy measurements. Although these new data sets have not yet led to a significant improvement of the Earth’s mantle viscosity structure (mainly because of large data errors), their potential is obvious, and their interpretation is a challenging task for the next years.

Mantle convection models with new post-perovskite phase change and radiative transfer of heat

Quite recently, a new phase change in the deep mantle was revealed. This new phase (post-perovskite) could be the source of anomalous behaviour of the D" layer at the mantle bottom. The dynamical consequences of this deep-mantle phase transition on mantle convection with particular emphasis on the effects on lower mantle plume structures was studied in papers by Matyska and Yuen (2005 a,b). Our results show that favourable for the development of superplumes is exothermic phase transition and radiative thermal conductivity. Smaller unstable plumes are found for exothermic phase transition and constant thermal conductivity. This aspect is especially emphasized, when the radiative thermal conductivity is restricted only to the post-perovskite phase. These results revealed a greater degree of asymmetry is produced in the vertical flow structures of the mantle by the phase transitions. Mass and heat transfer between the upper and lower mantle will deviate substantially from the traditional whole-mantle convection model. Streamlines revealed that an overall complete communication between the top and lower mantle is difficult to be achieved.

Seismic resolution of the mantle flows

Behounkova et al. (2005) presented results of a 2-D tomographic inversion of synthetic data that examines the ability of seismic tomography to reveal structures created by mantle dynamic processes. The seismic velocity anomaly model was based on the density heterogeneities obtained from models of thermal and thermo-chemical convection. Both layered and whole-mantle models are employed into the study. The resolving power of the inversion of P and pP arrival times was shown and the influence of parameterization and regularization (damping) in generation false images of mantle heterogeneities was described in detail. The effect of regularization was found to be substantial and the optimum damping depended upon the wavelength of the input structures. The resolution of the inversion decreases considerably at depths greater than 1000 km, therefore the ability of the kinematic inversion to distinguish between whole-mantle and layered flows (coupled via thermal coupling) may be limited. At present, fully 3-D problem is studied, which focuses mainly to the choice of parameterization.

Conductivity of the Earth from surface and satellite measurements

Electromagnetic induction in the Earth is studied through modeling the surface and satellite measurements in order to understand the 3-D internal conductivity structure. Velimsky and Everett (2005) have created a database consisting of hourly means of the geomagnetic field components observed on quiet days in years 2001-2002 on ground observatories and Orsted and CHAMP satellite measurements covering the same time intervals. In the first part of our study, we use the potential method to estimate the model of external inducing field. Following 3-D simulations are used to evaluate the effect of heterogeneous surface conductance map on Örsted and CHAMP satellite measurements and to compare the results with observations. Improvement of up to 15 % with respect to the best 1-D model was observed in surface observatory data as well as in the Orsted and CHAMP measurements.

Velimsky et al. (2005, submitted) applied a recent time-domain approach to the global electromagnetic induction problem to vector magnetometer data observed by the CHAMP satellite. Data recorded during 11 storm events in 2001-2003 are processed track by track, yielding time series of spherical harmonic coefficients. The data are then interpreted in terms of 1-D layered electrical conductivity models. The inversion is performed by full search of model parametric space which yields sensitivity of misfit with respect to conductivities of layers and positions of interfaces. In the upper 50 km the inversion solidly recovers a conductive layer corresponding to averaged surface conductance. The conductivity of the lower mantle is established at 6 S/m assuming the upper-lower mantle interface is fixed at the seismic-based 670 km boundary. However, the satellite data favor the models with a large jump at 970 km to conductivity values exceeding 100 S/m. The resolution of the method in the resistive upper mantle sandwiched between conductive crust and lower mantle is poor. Nevertheless, an upper bound of 0.01 S/m is suggested by the data. A conductivity increase in the transition zone is not observed.

The recently published time-domain spherical-harmonic finite-element approach to the electromagnetic induction problem (Velimsky and Martinec, 2005) is beeing further developed to allow combined use of magnetic data recorded at the Earth's surface and satellite altitudes.

GRACE (Gravity Recovery and Climate Experiment)

GRACE is a joint US-German partnership mission within NASA’s Earth System Science Pathfinder program. The mission is chaired by the Center for Space Research of Texas University in Austin in cooperation with NASA’s Jet Propulsion Laboratories and GFZ Potsdam. Sasgen, Martinec and Fleming (2005) derived a spatial averaging method based on the Wiener optimal filtering, and described its application to the GRACE gravity solutions. In contrast to the more commonly used Gaussian filter, no specification of the spatial width of the filter is required. Instead, the optimal filter is designed directly from the least-square minimization of the difference between the desired and filtered signals. This requires information about the power spectrum of the desired gravitational signal and the contaminating noise. This information is inferred from the average GRACE degree-power spectrum. The Wiener optimal filter determined from the GRACE gravity-field solutions closely corresponds to a Gaussian filter with a spatial half width of 4 degree (approx. 440 km).

Planetary physics

New information on the physics of the terrestrial planets and moons provided by recent space missions is a strong motivation to apply the research techniques developed for investigation of the Earth to other Earth-like bodies. Pauer, Fleming and Cadek prepared a paper in which they presented results of their analysis of the gravity and topography on Venus in terms of mantle flow models. They demonstrated that the long-wavelength anomalies of the gravity field can be well explained by dynamic processes in the Venus mantle provided that the vioscosity increases with depth in a similar way as in the Earth. The most remarkable bodies in the Solar System are the icy satellites of Saturn and Jupiter (Enceladus, Titan, Europa). The dynamics of these bodies, which are potential candidates for hosting life's origin, is probably mainly driven by intense tidal forces. In cooperation with the researchers from the Laboratory of Planetology and Geodynamics, University in Nantes, a new project was started with the aim to develop a realistic model of heat dissipation generated by the tides in these satellites. Another project, related to Mars, will attempt to answer the question of whether Mars is still an actively convectiong body, or whether the dynamic processes in its interior died out already long ago.

Theory of seismic waves

Recent developments in seismic ray method

Important developments in seismic ray method achieved during last 20 years have been described in an extensive invited review paper by Cerveny, Klimes and Psencik (2005, in press). The paper is devoted to the basic features of the seismic ray method, its recent extensions, and future possibilities. The topics include ray histories, two-point ray tracing, controlled initial-value ray tracing, wavefront tracing, interpolation within ray cells, paraxial ray methods, third-order and higher-order spatial derivatives of travel time, second-order and higher-order perturbation derivatives of travel time, optimization of model updates during linearized inversion of travel times, coupling ray theory for S waves, quasi-isotropic approximations of the coupling ray theory, Gaussian beams, Gaussian packets, optimization of the shape of Gaussian beams or packets, asymptotic summation of Gaussian beams and packets, linear canonical transforms, coherent state transforms, Maslov methods, decomposition of a general wave field into Gaussian packets or beams, sensitivity of waves to heterogeneities, Gaussian packet migrations, higher-order ray-theory approximations, direct computation of first arrival travel times, ray method with complex eikonal, hybrid methods, ray chaos, Lyapunov exponents and rotation numbers, models suitable for ray tracing, application of Sobolev scalar products to smoothing models.

Application of Hamiltonian ray tracing, dynamic ray tracing and corresponding equations for travel-time perturbations can considerably simplify the equations for the propagation of electromagnetic waves in the general theory of relativity (Klimes, 2005c, 2005d; Tarantola, Klimes, Pozo and Coll, 2005).

Seismic waves in anisotropic viscoelastic media

Considerable attention has been devoted to homogeneous and inhomogeneous harmonic plane waves propagating in anisotropic viscoelastic media. Cerveny and Psencik (2005d, 2005e) studied, theoretically and numerically, the slowness vectors of these waves. Both inhomogeneous and homogeneous plane waves are considered. The main attention was devoted to the phase velocities, amplitude decay along the propagation direction, attenuation, attenuation angle and polarization vectors. Analysis of the obtained results reveals certain phenomena unfamiliar from studies of plane-wave propagation in perfectly elastic anisotropic or viscoelastic isotropic media.

Cerveny and Psencik (2005c) also studied the properties of the energy flux of plane waves, propagating in viscoelastic anisotropic media. A great attention was devoted to the energy velocity and to the loss factor. Both P and S waves were investigated. Numerical examples were presented.

Cerveny and Psencik (2005a, 2005b, submitted 2005) studied the polarization of plane waves, propagating in viscoelastic anisotropic media. They demonstrated that the polarization is, in general, elliptical. For homogeneous plane waves, the polarization is usually nearly linear, with large eccentricity. The eccentricity decreases with increasing inhomogeneity. Many numerical examples are presented.

Anisotropic ray theory

A simplified construction of the 4x4 paraxial propagator matrix in ray-centred coordinates has been proposed (Cerveny and Moser, 2005). In this construction, dynamic ray tracing in ray-centred coordinates is not needed, only conventional dynamic ray tracing in Cartesian coordinates is exploited. The 4x4 paraxial propagator matrix in ray-centred coordinates is then obtained by simple transformations at the initial point of the ray and at any other point of the ray, wherever it is needed.

A new algorithm of surface-to-surface paraxial ray tracing in anisotropic inhomogeneous layered media was proposed (Moser and Cerveny, submitted 2005). The algorithm is fully based on dynamic ray tracing in Cartesian coordinates. Certain important applications of the proposed algorithm in seismology and seismic exploration are discussed in detail.

Klimes (submitted 2005b) derived explicit equations for the perturbations and spatial derivatives of amplitude in isotropic and anisotropic media. The perturbations and spatial derivatives of the amplitude exponent can be calculated by numerical quadratures along an unperturbed ray in the reference medium, analogously as the perturbations and spatial derivatives of travel time.

The caustic identification algorithm for isotropic media has been generalized to anisotropic media, and the rules for the phase shift of the anisotropic-ray-theory wave field due to caustics have been derived (Klimes, submitted 2005a).

Coupling ray theory

Coupling ray theory is required for modelling propagation of S waves in heterogeneous weakly anisotropic media. Equations for the numerical common S-wave ray tracing and for the corresponding dynamic ray tracing in a smooth elastic anisotropic medium have been proposed, coded, numerically tested (Klimes, submitted 2005c). The method was applied to the calculation of coupling-ray-theory seismograms (Klimes and Bulant, submitted 2005).

Klimes and Bulant (2005, submitted 2005) derived the equations for calculating the second-order perturbation expansion of travel time along the anisotropic common S-wave ray. The second-order terms in the perturbation expansion from the anisotropic common S-wave ray to the anisotropic-ray-theory rays can be used to estimate the errors due to the anisotropic-common-ray approximation of the coupling ray theory. The authors took advantage of their experience with calculating the analogous second-order perturbation expansions along the reference isotropic-ray-theory rays.

Velocity macro models and numerical ray tracing

Construction of velocity models suitable for ray tracing from field VSP measurements and from sonic velocity logs was tested. A possibility to determine the medium correlation unction from sonic velocity logs was also studied.Capabilities of the ray tracing software developed at the Department of Geophysics have further been extended (Klimes and Bulant, 2005).

Numerical ray tracing has been tested on various 3-D synthetic structures, including the smoothed SEG/EAGE Salt Model. The finite-difference seismograms in the elastic SEG/EAGE Salt Model were compared with the ray-theory seismograms calculated using the SW3D software (Bucha, 2005).

Gaussian-packet prestack depth migration

Optimization of the shape of Gaussian beams (Zacek, submitted 2005a) enables the Gaussian-packet prestack depth migration to be applied to more complex velocity models, its accuracy to be improved.

The decomposition of the time sections into optimized Gaussian packets is of key importance in the Gaussian packet migration. The equations for the decomposition have been derived and the decomposition was numerically tested (Zacek, 2005b, submitted 2005b).

The theory used for the Gaussian packet common-shot migration was described and a numerical test was performed in the Marmousi model (Zacek, 2005a, 2005c, 2005d, submitted 2005c). The numerical test includes examples of both a single common-shot migrated section and a stacked common-shot migrated section.

K. Zacek defended his PhD thesis Gaussian packet prestack depth migration (Zacek, 2005e) on September 21, 2005.

CD-ROM with SW3D software, data and papers

Compact disk SW3D-CD-9 (Bucha and Bulant, 2005) contains the revised and updated versions of the software developed within the consortium research project Seismic Waves in Complex 3-D Structures (SW3D) together with input data used in various calculations. Compact disk SW3D-CD-9 also contains over 220 complete papers from journals and from SW3D consortium research reports. From new features of the SW3D software, let us mention the calculation of the second-order terms in the perturbation expansion from the anisotropic common S-wave ray to the anisotropic-ray-theory rays, which can be used to evaluate the errors due to the anisotropic-common-ray approximation of the coupling ray theory.

Earthquakes and seismic structural studies

Seismic stations of the Charles University in Greece

Four stations in Greece are jointly operated by the Charles university Prague and the Patras University since 1997. Each station is equipped with a weak-motion broad-band velocigraph CMG 3-T and a strong-motion accelerograph CMG 5-T. The selected data are available from http://seis30.karlov.mff.cuni.cz, updated every 4 months. The stations Sergoula and Mamousia are situated on the northern and southern coast of the Corinth Gulf, respectively, both in its western part, and are operated as stand-alone stations. The other two sites have satellite data transmission to Patras. It is Loutraki station, at the eastern edge of the Corinth Gulf, and Pylos station, close to Kalamata city, on the southwest of the Pelloponesos.

Long period disturbances on broad-band records

Strange long period pulses occasionally present on the CMG 3-T broadband records of small nearby earthquakes have been explained as normal instrumental response to a specific ground motion input, viz a sudden (step-like) horizontal acceleration, most likely connected with a local tilt provoked by the vibratory seismic motion in the immediate vicinity of the seismic instrument (Zahradnik and Plesinger, 2005). We found similar effects also on records of STS-2 and Le-3D/20s broadband instruments. The disturbances like that are very dangerous because they are not always readily "visible" in the records, but, anyway, they may significantly bias the seismic source studies (in particular during routine automatic procedures not specifically adjusted to these problems). A simple way how to detect presence of the long-period disturbances has been suggested, and a method how to "clean" the records prior any further use in seismic source studies has been proposed.

ISOLA (isolated asperities) code

Main use of our data mentioned above (combined with data from National Observatory of Athens) has focused in 2005 on a set of 6 selected small earthquakes (M<4.5), studied within framework of the EC project 3HAZ-CORINTH, coordinated by P. Bernard, IPGP, Paris. Particular attention was paid not only to the practical source-parameter retrieval, but also on further development of our new code ISOLA. The code serves for multiple point-source moment tensor inversion based on full waveform data at regional and/or local distances. The Fortran part of the code (author J. Zahradnik) has been released for public use (http://geo.mff.cuni.cz/~jz/tmp/ISOLA05C), including simple documentation and a test example. In parallel, a user friendly graphic interface in Matlab has been elaborated by E. Sokos in Patras, and its public release is expected in the beginning of 2006.

The ISOLA code was successfully applied to the 2003 Lefkada earthquake of M6.3 (Zahradnik et al., 2005). The retrieved model consists of two fault segments, well explaining two aftershock clusters: one at the Lefkada Island, and the other one at the Cefalonia Island, nearly 40 km apart and 14 seconds later. The earthquake proved to be a complex rupture process, not only as regards its space-time development, but also as regards the focal mechanism.

Z. Roumelioti from the University in Thessaloniki worked with us in Prague for six weeks as a guest of the EC project MAGMA, and successfully applied the ISOLA code to another earthquake. It was the 2001 earthquake of M6.5 at Skyros Island, Greece, previously studied by her slip inversion method based on empirical Green's functions. A paper under preparation will include also work of V. Plicka whose nonlinear slip inversion code (based on patch method of M. Valee) provided results close to the latter two methods.

Strong-ground motion simulation

I. Oprsal and J. Zahradnik made and submitted (http://geo.mff.cuni.cz/~io/tf_2005/tf_2005.htm) their strong-motion "blind" prediction within the Turkey-Flat, California, international experiment on the site-, path- and source effects. The experiment is devoted to the Parkfield, California, M6 earthquake of Sep 28, 2004. In contrast to the weak-motion "blind" experiment carried out at the same site 15 years ago, we focused on the finite-extent source effects at near-source distances and performed our composite-source modeling based on a published slip distribution. Comparison with true ground motions (existing, but kept secret till the end of this experiment) will be possible in 2006.

Two strong-ground motion simulation techniques were investigated as regards their directivity (Gallovic and Burjanek, submitted) . It was a composite-source model with fractal subevent size distribution and an integral k-squared model with k-dependent rise time, where k stands for the wavenumber. We check the simulations in 1-D layered crustal model against empirical PGA attenuation relations. We assume that any synthetic model for a particular earthquake should not provide PGA scatter larger than scatter observed in a large set of earthquakes. As a test example, the 1999 Athens earthquake (Mw =5.9) was studied. In the composite method, the synthetic data have their scatter lower than that of the empirical attenuation relations. On the other hand, the k-squared method provides a larger scatter, related to a very strong (perhaps not realistic) directivity at high frequencies. It is shown how to reduced the high-frequency directivity by a formal spectral modification.

F. Gallovic and J. Brokesova (posters at AGU 2005 and a paper under preparation) combined the integral source model at low frequencies and the composite-source model at high frequencies. They also employed their finite-extent source and numerical ground-motion simulations into framework of the probabilistic seismic hazard assessment (PSHA). Main practical application was focused on simulation of the 1980 Irpinia earthquake of M6.9, Southern Italy, using a complex multiple source model. This work was done in a close cooperation with the University of Naples (A. Zollo, A. Emolo). When comparing to the classical PSHA method based on empirical attenuation relations, the hazard maps obtained with the hybrid simulation provide considerably more detail, and allow separate analysis of the involved physical effects, such as those of the slip heterogeneity, the radiation pattern, and the directivity. The availability of synthetic waveforms also enables much easier and full consideration of realistic site effects in comparison with simple amplification factors used in the classical PSHA method. Moreover, the hazard analysis can be extended to any ground motion parameter that can be retrieved from synthetic seismograms and spectra, not necessarily just peak values.

J. Burjanek (poster at AGU 2005) further tuned his codes for calculating dynamic stress field on the fault whose slip is described by a kinematic source model. It was found that none of the studied models whose slip function has k-dependent rise time is in contradiction to recent models of the earthquake source dynamics. The strength excess, dynamic stress drop and fracture energy strongly correlate with static stress-drop distribution. However, since results are quite sensitive to spatio-temporal filtering, unavoidable in any practical retrieval of the slip distribution of real events, one has to be very careful in interpreting stress-time histories obtained from such kinematic models.

The 3-D hybrid earthquake modeling

The 3-D modeling based on a hybrid combination of the source, path and site effects, being methodically developed since 2002, has been again applied in practice. The source and path effects are modeled by the composite-source model and the discrete wavenumber method (method PEXT of J. Zahradnik), while the local site effects are modeled by the 3-D finite-difference method (I. Oprsal). The hybrid modeling proved to be an efficient tool up to frequencies of engineering interest. As such, it was successfully applied to study several deterministic strong-motion scenarios of a hypothetical future strong M6 earthquake in Basel, Switzerland (Oprsal et al., 2005). The work resulted from fruitful cooperation with ETH, Zurich, where I. Oprsal completed in 2005 his 4-year post-doc stay.

Location and structural studies

One-dimensional qP wave velocity model of the upper crust for the West Bohemia/Vogtland earthquake swarm region was developed (Malek et al., 2005). Analytical partial derivatives of the phase- and group velocities for Rayleigh waves propagating in a layer on a half-space, needed in various inversion schemes, were derived by Novotny et al. (2005). Various methods and their combinations were developed and extensively tested to simultaneously invert arrival times of seismic waves into earthquake location and 1-D crustal structure by O. Novotny, J. Jansky and V. Plicka: (i) Nearest Neighbour Algorithm (code of M. Sambridge) to search for 1-D models composed of layers with constant velocity (location performed by the conjugate gradient method), or 1-D models composed of layers with constant velocity gradients (location by the grid search), and (ii) The conjugate gradient method for both location and structural model.

Structural studies in the Gulf of Corinth, Greece

New 1-D models of the upper crust in the Egion region, Greece, were suggested (Novotny et al., submitted). They were inferred from arrival times of simultaneously relocated 133 events of the 2001 earthquake sequence, based on data of the so-called Corinth Rift Laboratory (CRL) project, and the on-going 3HAZ-CORINTH European project. For standard earthquake locations, CRL uses the HYPO algorithm and a special structural model derived from a passive seismic experiment in an broader area around the western part of the Corinth Gulf. We used an improved version of the conjugate gradients method for both structural models and location. Analytical formulae have been derived for the arrival-time partial derivatives, needed in the method. Only models composed of 4 homogeneous layers with velocity increasing with depth have been considered. A set of satisfactory models based on minimization of the travel time residuals have been found. The main result is that their velocities are higher than those in the CRL model and the recently published tomographic models.

Publications:

http://geo.mff.cuni.cz/documents/publ_05.htm