International Union of Geodesy and Geophysics

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Union Géodésique et Géophysique Internationale

33rd Conference on Mathematical Geophysics

Seoul National University, Seoul, Republic of Korea

20-24 June 2022

PROGRAM & ABSTRACTS

Geophysics in the World of Modern Mathematics
and Artificial Intelligence

Geophysics and Mathematics for Sustainable Development
(*a contribution to the United Nations International Year of Basic Sciences for Sustainable Development - IYBSSG2022*)

Preface

Welcome to the 33rd IUGG Conference on Mathematical Geophysics (CMG2022)!

The online meeting with an onsite participation of local students and invited scientists will be hosted by the Seoul National University, Seoul, Republic of Korea. The Conference aims to discuss contemporary topics in mathematical geophysics, such as data analysis, machine learning and artificial intelligence, geophysical fluid dynamics, geophysical inversions, and mathematics for natural hazards science. The detailed CMG2022 program is available at the CMG2022 website (http://www.cmg2022.org/index.php/scientific-program). The Program includes two keynote presentations by *Kwang-Yul Kim* (Seoul National University, Republic of Korea) and *Friderick Simons* (Princeton University, USA) – the inaugural recipient of the Vladimir Keilis-Borok Medal; thirteen invited speakers; and contributed oral/poster presentations.

CMG2022 is a contribution to the United Nations International Year on Basic Sciences for Sustainable Development (www.iybssd2022.org), an international program partnered by IUGG. A panel "*Basic Science and Mathematics for Sustainable Development*" will be held on 21 June during the Conference. Several distinguished scientists – *Qiuming Cheng* (China), *Motoko Kotani* (Japan), *Michel Spiro* (France), *Kathryn Whaler* (UK), and *Jaejun Yu* (Republic of Korea) – will contribute to a discussion about integration of basic science, mathematics, science education and policymaking to solve fundamental problems of nature and society and to contribute to the solutions of challenging issues of sustainability.

We acknowledge the significant work and great efforts invested in the meeting organization by the Executive Committee of the IUGG Commission on Mathematical Geophysics (CMG), acting as the Scientific Committee for CMG2022, session conveners, and the Local Organizing Committee for CMG2022.

Enjoy the CMG2022!

Alik Ismail-Zadeh, Chair, IUGG Commission on Mathematical Geophysics

Sang-Mook Lee, Chair, Local Organizing Committee for CMG2022

CMG2022

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About IUGG

International Union of Geodesy and Geophysics (IUGG) is a non-governmental, scientific organization, established in 1919. IUGG is a Founding Member of the International Science Council (ISC). The Union is dedicated to the international promotion and coordination of scientific studies of Earth (physical, chemical, and mathematical) and its environment in space. These studies include the shape of the Earth, its gravitational and magnetic fields, the dynamics of the Earth as a whole and of its component parts, the Earth's internal structure, composition and tectonics, earthquakes and elastic wave propagation, the generation of magmas, volcanism and rock formation, the hydrological cycle including snow and ice, all aspects of the oceans, the atmosphere, ionosphere, magnetosphere and solar-terrestrial relations, and analogous problems associated with the Moon and other planets. IUGG encourages the application of this knowledge to societal needs, such as mineral resources, mitigation of natural hazards and environmental preservation. IUGG is comprised of eight semi-autonomous Associations, each responsible for a specific range of topics or themes within the overall scope of Union activities. IUGG has established six interdisciplinary Union Commissions and develops relationships with other scientific bodies with similar interests.

PROGRAM

Monday, 20 June

14:00-16:00 Seoul-time (5:00-7:00 UTC)

14:00-14:30
Conference Opening
Chair: ***Ilya Zaliapin,*** Secretary of the IUGG Commission on Mathematical Geophysics

Welcome speeches
Alik Ismail-Zadeh, Chair of the IUGG Commission on Mathematical Geophysics
Kathryn Whaler, IUGG President
Sang-Mook Lee, Chair of the CMG2022 Local Organizing Committee

14:30-15:30
Keynote lecture
Chair: ***Sang-Mook Lee,*** Seoul National University, South Korea

Space-time analysis using the Cyclostationary Empirical Orthogonal Function (CSEOF) Technique:
A New Trend in Geophysical Data Analysis
Kwang-Yul Kim, Seoul National University, South Korea

15:30-16:00
Movie / Music

20:00-22:00 Seoul-time (11:00-13:00 UTC)

Theme 5. Geophysical Inversion: Theory, Algorithms, and Applications
Chair: ***Malcolm Sambridge***, Australian National University, Australia

20:00-20:30
Optimal resolution tomography
Sergei Lebedev, University of Cambridge, UK (invited)

20:30-21:00
Bayesian inversion with deep generative models
Niklas Linde, University of Lausanne, Switzerland (invited)

21:00-21:30
Towards probabilistic inversions and uncertainty quantification in large-scale seismic inversions
Daniel Peter, KAUST, Saudi Arabia (invited)

21:30-21:45

Mimetic finite difference scheme to solve direct current resistivity forward modelling problem
Deepak Suryavanshi, IISER Pune, India

21:45-22:00
Examples of the use of concept of proximity measures in geophysics
Mikhail Rodkin, Russian Academy of Sciences, Russia

Tuesday, 21 June

8:00-10:00 Seoul-time (23:00-01:00 UTC-time)

Theme 5. Geophysical Inversion: Theory, Algorithms, and Applications
Chair: ***Jan Dettmer***, University of Calgary, Canada (TBC)

8:00-8:15
Bayesian joint inversion of seismic sources in different data domains
Mahdi Hamidbeygi, University of Calgary, Canada

8:15-8:30
Uncertainty quantification for joint inversion of magnetotelluric, receiver function, and Rayleigh wave dispersion data
Pejman Shahsavari, University of Calgary, Canada

8:30-8:45
3D Bayesian potential-field data inversion with decorrelation of data residuals using 2D autoregressive models
Emad Ghalenoei, University of Calgary

Theme 3: From the Core to the Space: Different Spheres with Common Mathematics
Chairs: ***Roberto Carniel***, Università di Udine, Italy (TBC);
Alexander Fournier, Institut de Physique du Globe de Paris, France (TBC)

8:45-9:00
Fast algorithm for terrain irradiance using compressed view factor matrices
Samuel F Potter, New York University, USA

9:00-9:15
On Stormer problem solution for the superposition of axially symmetric dipole and quadrupole magnetic fields
Jorge F. Brizuela Atencio, Universidad Nacional de Tucuman, Argentina

9:15-9:30
Diffusion of water vapor at lunar polar conditions
Norbert Schorghofer, Planetary Science Institute, USA

9:30-9:45
Forward modelling of strain and inversion for focal mechanisms from distributed acoustic sensing data
Jean Lecoulant, University of Calgary, Canada

9:45-10:00
Measurement-based perturbation theory for parameter estimation in differential equations
Peiliang Xu

15:00-16:00 Seoul-time (6:00-7:00 UTC)

POSTERS
Chairs: ***Sang-Mook Lee***, Seoul National University, Republic of Korea;
Alik Ismail-Zadeh, Karlsruhe Institute of Technology;

15:00-15:07
Developing a river migration hazard map using numerical modeling and Monte Carlo methods
Brayden Noh, California Institute of Technology, USA

15:07-15:14
Analysis and comparison of rock magnetic properties of ophiolite and mid-ocean ridge mantle rocks using computational methods
Gilbert Hong, Seoul National University, Republic of Korea

15:14-15:21
A new quadrature-with-extrapolation algorithm for simulating electromagnetic fields in one-dimensional models
Pham Ngoc Kien, Seoul National University, Republic of Korea

15:21-15:28
Seismic velocity structure of the upper mantle beneath the oldest Pacific Ocean basin from finite-frequency travel-time tomography
Hyunsun Kang, Seoul National University, Republic of Korea

15:28-15:35
A preliminary machine-learning analysis of radiogenic geochemistry of the different volcanic edifices linked to the African LLSVP and their possible mantle source relationship
Hogyum Kim, Seoul National University, Republic of Korea

15:35-15:42
Harmonic decompositions analysis of the teleseismic receiver functions for the crustal anisotropic structure
Hobin Lim, Seoul National University, Republic of Korea

15:42-15:49
Earthquake precursory factors derived from earthquake catalogs with explainable machine learning
Jinsu Jang, Kangwon National University, Republic of Korea

20:00-21:00 Seoul-time (11:00-12:00 UTC)

Panel "Basic Science and Mathematics for Sustainable Development"

The aim of the panel is to raise awareness about the United Nations International Year of Basic Sciences for Sustainable Development enthusiastically supported by the International Science Council (ISC) and several ISC Members including IUGG. Distinguished panelists will discuss how basic science, mathematics, science education and policymaking should be integrated in solving fundamental problems of nature and society and in contributing to solving challenging issues of sustainability. Bringing their broad experience in mathematics, (geo)science, education, national and international scientific cooperation and science promotion, the panelists will highlight the ways of achieving sustainable development goals using basic science and science for society.

Panelists:
Qiuming Cheng, Former President, International Association of Mathematical Geosciences; Immediate Past President, International Union of Geological Sciences; Professor of the China University of Geosciences and Member of the Chinese Academy of Sciences, Beijing, China

Motoko Kotani, President-Elect, International Science Council; Executive Vice President for Research, Tohoku University, Sendai, Japan

Michel Spiro, Chair of the Steering Committee, United Nations International Year of Basic Sciences for Development; President, International Union of Pure and Applied Physics; former President of CERN Council, Switzerland

Kathryn Whaler, President, International Union of Geodesy and Geophysics; Professor, University of Edinburgh, UK

Jaejun Yu, Dean of the College of Natural Sciences and Professor, Seoul National University, Republic of Korea

Moderator:
Alik Ismail-Zadeh, Inaugural Secretary of the International Science Council; past Secretary General of the IUGG; Senior Research Fellow, Karlsruhe Institute of Technology, Germany.

Wednesday, 22 June

14:00-16:00 Seoul-time (5:00-7:00 UTC)

Theme 4. Mathematics for Natural Hazards Science
Chair: ***Salvatore Grimaldi***

14:00-14:30
Machine learning concepts and methods for addressing probabilistic hydrological forecasting challenges
Georgia Papacharalampous, Czech University of Life Sciences, Czech Republic (invited)

14:30-14:45
Multiphysics resonance of reaction-cross-diffusion waves as nucleation mechanism for earthquakes
Klaus Regenauer-Lieb, Curtin University, Australia

14:45-15:00
Probabilistic Seismic Hazard Assessment (PSHA) in Western Himalaya
Daya Shanker, Indian Institute of Technology Roorkee, India

15:00-16:00
Keynote lecture (2022 Vladimir Keilis-Borok Medalist)
Chairs: ***Alik Ismail-Zadeh***, Karlsruhe Institute of Technology, Germany;
Sang-Mook Lee, Seoul National University, Republic of Korea

Linear inverse problems and quadratic spectral estimators of planetary potential-field data collected at satellite altitude: theory and applications
Frederik J Simons, Princeton University, USA

20:00-22:00 Seoul-time (11:00-13:00 UTC)

Theme 4. Mathematics for Natural Hazards Science
Chairs: ***Salvatore Grimaldi***, University of Tuscia, Italy; ***Daniel Scherzer***, Ecole des Ponts ParisTech, France

20:00-20:30
Assessing numerical lava flow models
Einat Lev, Columbia University, USA (invited)

20:30-20:45
The power release from microstructure and its role for geohazards
Manman Hu, The University of Hong Kong, China

20:45-21:00

Impact of urban heat island on human mortality risk
Katty Huang, University College London, UK

21:00-21:30
How can contemporary climate research help understand epidemic dynamics? Ensemble approach and snapshot attractors
Tamás Kovács, Eötvös University, Hungary (invited)

21:30-21:45
Estimates of the sea-level rise rate from tide gauges: the effects of data heterogeneity
Alexander Shapoval, University of Lodz

21:45-21:52
Hydrological assessment of rain gauges' distribution: application of the fractal dimension concept
Igor Paz, Military Institute of Engineering, Brazil (POSTER)

Thursday, 23 June

8:00-10:00 Seoul-time (23:00-01:00 UTC-time)

Chair: ***Ilya Zaliapin***, University of Nevada Reno, USA

Theme 2. Geophysical Fluid Dynamics

8:00-8:30
The relationship between sedimentation dynamics and hydrological connectivity within the deltaic islands of Wax Lake Delta, LA, USA
Doug Edmonds, Indiana University, USA (invited)

8:30-9:00
Critical Tokunaga model for river networks
Yevgeniy Kovchegov, Oregon State University, USA (invited)

Theme 4. Mathematics for Natural Hazards Science

9:00-9:30
Contribution of deformation models to the 2023 U.S. National Seismic Hazard Model
Fred Pollitz, United States Geological Survey, USA (invited)

POSTERS

9:30-9:37
An alternative way of considering anisotropy in isotropic tomography inversion
Hwaju Lee, Seoul National University, Republic of Korea

9:37-9:44
The accurate pressure recovery for geodynamics using penalty method
Sangjin Park, Kangwon National University, Republic of Korea

9:44-9:51
Lithospheric strength inferred from modeling of buckling structure: implications for stress state of the East Sea (Japan Sea)
Seokhyeon Do, Kangwon National University, Republic of Korea

14:00-16:00 Seoul-time (5:00-7:00 UTC)

Theme 2. Geophysical Fluid Dynamics
Chair: ***Alik Ismail-Zadeh***, Karlsruhe Institute of Technology, Germany

14:00-14:30
Numerical simulation of magma intrusion, ascend and deposition in volcanic environments

Oleg Melnik, Lomonosov Moscow State University, Russia (invited)

14:30-15:00
On lava domes and the geometry of their vents
Catherine Meriaux, University of Rwanda, Rwanda (invited)

15:00-15:15
Mathematical and numerical models of lava dome dynamics
Natalya Zeinalova, Karlsruhe Institute of Technology, Germany

15:15-15:30
Non-linear waves and ligaments in geophysical flows
Yuli D. Chashechkin, Russian Academy of Sciences, Russia

Theme 5. Geophysical Inversion: Theory, Algorithms, and Applications
Chair: ***Kerry Gallagher***, University of Rennes, France

15:30-15:45
Trans-dimensional geoacoustic inversion for an autonomous underwater vehicle survey
Tim Sonnemann, University of Calgary, Canada

15:45-16:00
Processing strategy for airborne vector gravimetry based on spatial gravity modeling
Vadim Vyazmin, Lomonosov Moscow State University, Russia

20:00-22:00 Seoul-time (11:00-13:00 UTC)

Theme 1. Data Sciences, Machine Learning and Artificial Intelligence
Chair: ***Daniel Scherzer***, Ecole des Ponts ParisTech, France

20:00-20:30
Local and global multifactal analysis of turbulent flows
Berengère Dubrulle, CNRS, France (invited)

20:30-20:45
Regular and singular motions in a continuously stratified fluids
Artem A. Ochirov, Russian Academy of Sciences, Russia

20:45-21:00
Multi-fractal scaling behavior of the Himalayan seismicity: Implications on energy dissipation mechanism
Simanchal Padhy, Indian Institute of Technology Roorkee, India

21:00-21:15
Estimating model uncertainties in the scaling function inversion of gravity data

Mahak Singh Chauhan, National Geophysical Research Institute, India

21:15-21:30
On exploiting big data from oil and gas industry social medias: A sentiment analysis of Algerian data
Hasna Yazid, M'hammed Bougara University of Boumerdes, Algeria

21:30-21:45
Well log analysis and lithological classification by artificial neural network (ANN)
Boussa Lamia, Sonatrach Company, Algeria

POSTERS

21:45-21:52
Sediment buoyancy controls subduction kinematics and dynamics: Insight from 3D viscoelastic free subduction model
Jae-Yoon Keum, Kangwon National University, Republic of Korea

21:52-21:59
Development of finite element method-based strain calculation strategy: Application to geological structure models in compressional and extensional settings using discrete element method
Soojung An, Kangwon National University, Republic of Korea

Friday, 24 June

14:00-16:00 Seoul-time (5:00-7:00 UTC)

Theme 1. Data Sciences, Machine Learning and Artificial Intelligence
Chair: ***Enamundram Chandrasekhar***, Indian Institute of Technology Bombay, India

14:00-14:30
Integral transforms in the inversion of geophysical data: A simple and comprehensive review
Sundararajan Narasimman, Sultan Qaboos University, Oman (invited)

14:30-14:45
Prediction of ionospheric total electron content data using spatio-temporal residual networks
Nayana N. Shenvi, Goa College of Engineering, India

14:45-15:00
Applying artificial intelligence methods for simulating atmospheric CO2 concentration from polar temperature proxy records
Nasrin Salehnia, Seoul National University, Republic of Korea

15:00-15:15
Scaling spectral inversion of potential field data to infer sub-surface source distribution
Vijay P. Dimri, CSIR-National Geophysical Research Institute, India

15:15-15:30
Intermittency in drop impact flows in a wave field on a fluid surface
Yuli D. Chashechkin, Russian Academy of Sciences, Russia

15:30-15:45
Multifractal analysis of ionospheric total electron content data
Enamudram Chandrasekhar, Indian Institute of Technology Bombay, India

15:45-16:00
Estimating the parameters of truncated Gutenberg-Richter distribution: new approaches
Vladilen F. Pisarenko, Russian Academy of Sciences, Moscow, Russia

20:00-21:00 Seoul-time (11:00-12:00 UTC)

Discussion / Closing

ABSTRACTS

Development of Finite Element Method-based Strain Calculation Strategy: Application to Geological Structure Models in Compressional and Extensional Settings Using Discrete Element Method

Soojung An, Byung-Dal So

Department of Geophysics, Kangwon National University, Chuncheon, Republic of Korea

Surface strain plays a key role in investigating plate motions. Strain localization zone within various large-scale structures such as fold-and-thrust belt and continental basin incorporates many faults and fractures. These discontinuities, causing natural hazards can be identified as distorted strain patterns at the surface. Therefore, we need to focus on the surface strain distribution in a wide range of spatial and temporal scales. The discrete element method has been widely used numerical modeling technique to simulate the frictional behavior of granular materials. However, since discretely distributed particles inevitably produce voids, calculating strain, a continuum mechanics concept, is challenging. Here, we develop a new strain calculation strategy employing the finite element method, which solves the discretized governing equations in a dense mesh. In this method, we can obtain a strain field reflecting the mechanical interconnection of the whole particle system by assembling a global stiffness matrix. To verify the reliability of the developed method, we set a toy problem with analytical solutions and yield the strain of the problem. We confirm that the newly suggested method showed high accuracy and calculation speed of about 5 and 47 times, respectively than the FDM-based method, which is the conventional post-processing method for DEM. We demonstrate the two different geological structure models, fold-and-thrust belt and extensional basin, with DEM and evaluate the strain field with the developed method.

On Störmer Problem Solution for the Superposition of Axially Symmetric Dipole and Quadrupole Magnetic Fields

Jorge F. Brizuela Atencio[1], Bruno S. Zossi[2,3], Blas F. de Haro Barbas[2,3], Ana G. Elias[2,3]

[1] *Departamento de Física, Facultad de Ciencias Exactas y Tecnología, Universidad Nacional de Tucumán, Tucumán, Argentina*
[2] *Laboratorio de Ionosfera, Atmosfera Neutra y Magnetosfera - LIANM, Facultad de Ciencias Exactas y Tecnología, Universidad Nacional de Tucumán, Tucumán, Argentina*
[3] *INFINOA, CONICET-UNT, Tucumán Argentina*

The trapping of charged particles in a purely axial dipolar geomagnetic field was first studied by Störmer, with his first publications on this topic dating back to 1907. With a relatively simple treatment based on the conservation of particle's energy and magnetic field axial symmetry, he was able to determine charged particles' allowed and forbidden region boundaries, together with trapping areas, in terms of the dipole moment strength and the particle energy. There were later results for more complex fields, but always considering configurations that do not deviate far from a dipole, or multipolar axial fields but of a single component. Störmer's approach allows also the rigidity cutoff (Rc) estimation deriving out of boundaries' critical conditions. To determine Rc variation and the evolution of trapped regions during a geomagnetic field reversal, the Störmer problem is analyzed in this work considering the combined axial dipolar and quadrupolar components, with the quadrupole strength increasing at the dipole expense. The Hamiltonian for a charged particle motion in an axially symmetric field has a cyclic coordinate, which allows considering the particle's motion in a two-dimensional potential V and thus provides qualitative insight without the need for an explicit solution. Through the topology of V, it can be easily seen how the initial equatorial trapping region shifts with the increase of the quadrupolar component, to finally end in two off-equatorial regions for a dominant quadrupolar field. In the case of Rc spatial variation, a set of equations much more complex than in the case of a single axial component field has to be solved to obtain the critical conditions which would yield an analytical formula in terms of the dipole and quadrupole intensity. Otherwise, a numerical solution is possible, but in this case, estimations must be repeated for varying dipole and quadrupole intensities.

Hydrological Assessment of Rain Gauges' Distribution: Application of the Fractal Dimension Concept

Priscila Celebrini de Oliveira Campos, Igor Paz, Maria Esther Soares Marques

Military Institute of Engineering, Rio de Janeiro, Brazil

Flood resilient cities are less impacted by extreme rainfall events. In this context, this study assesses the impacts of in-situ rain gauges' network distribution on the capability of local authorities to perform an accurate diagnosis of flood occurrences. The fractal dimension concept is used to analyse the instrumentation distribution in the municipality of Itaperuna, Rio de Janeiro - Brazil, a semi-urbanized region frequently affected by floods. The results demonstrate that the analysed rain gauges' network presented a scaling break behaviour with a low estimated fractal dimension at the small-scale range. Therefore, this analysis enables the decision-makers to detect that the local instrumentation can be considered as incapable of capturing the spatial rainfall variability.

Multifractal Analysis of Ionospheric Total Electron Content Data

E. Chandrasekhar[1], Sanjana Prabhudesai[2,3]

[1] *Department of Earth Sciences, Indian Institute of Technology Bombay, Powai, Mumbai – 400076, India*

[2] *Department of Electronics and Communication Engineering, Goa College of Engineering, Goa – 403401, India.*

[3] *Presently at, Department of Earth, Planetary, and Space Sciences, University of California, Los Angeles, CA 90095-1567*

The nonlinear spatio-temporal variations in ionospheric total electron content (TEC) data often reflect their scale invariant properties, which can be well characterized by multifractal analysis. We discuss the multifractal behaviour of the TEC data recorded at 27 sites, confined to a narrow longitude band (35°W-80°W) spanning from equator to high-latitude regions (30°S to 80°N). We use multifractal detrended fluctuation analysis (MFDFA) to study TEC data during solar minimum (2008) and solar maximum (2014). The multifractal singularity spectra and the generalised Hurst exponents facilitate better understanding of the multifractal nature of any signal. The objectives of this study are to (i) understand the latitudinal dependence of the multifractal behaviour of TEC, (ii) compare the multifractal behaviour of TEC corresponding to the 27-day variation (solar rotation period) and its harmonics and the one-day (solar diurnal) periodicities, during the years 2008 and 2014 and (iii) understand the lunar tidal influence on TEC. Our results indicate that except for the one-day period, the TEC at all other periods shows a higher degree of multifractality during 2014 compared to that during 2008. Further, irrespective of the solar activity, the degree of multifractality in general decreases with increase in period for all latitude zones for periods of 27-day and its harmonics. However, the one-day period exhibits monofractal behaviour regardless of the solar activity. The influence of semilunar tidal effects (having a periodicity of about 14.5 days) as a function of latitude is clearly seen in the 13.5-day periodicity (i.e., the 2nd harmonic of 27-day variation) of TEC. It manifests in the form of decreasing differences in the widths of the multifractal singularity spectra with increase in latitude, corresponding to the years 2008 and 2014.

Intermittency in Drop Impact Flows in a Wave Field on a Fluid Surface

Yuli D. Chashechkin

Ishlinsky Institute for Problems in Mechanics RAS, Laboratory of Fluid Mechanics, Moscow, Russia

A fast video camera, a hydrophone, and a microphone were used to register the flow pattern and sound packets of a freely falling drop impact [1]. In the mode of splash formation in a target fluid at rest, the contact line between the coalescing media is broken into separate segments by thin fast trickles, which form line and cell structures at the bottom of the cavity and the crown walls [2]. The fine fibrous structure of the drop substance distribution in the target drop is preserved at all subsequent stages of the flow evolution. The parameters of primary contact sound packet and subsequent resonant pulses that are formed with a certain delay are determined. In a fluid rotating in a compound vortex, the ubstance of a drop is preserved in spiral arms on the surface and helical lines in its thickness. A fast near-surface dipole and a sinking vortex ring flow out of the colored spot in the field of capillary waves [3]. Mechanisms of the substance and energy transfer and transformations are discussed based on the fundamental equations system.

References:
Chashechkin Yu. D. Fast superfine components and sound packets in flows induced by a drop impact on a target fluid at rest. Fluid Dyn. Mater. Proces.. 2020. 16(4), 773-800. DOI:10.32604/fdmp.2020.09001
Chashechkin Yu. D., Ilinykh A. Yu. Drop decay into individual fibers at the boundary of the contact area with a target fluid. Dokl. Phys.. 2021, 66(4). 101–105. DOI: 10.1134/S1028335821040078
Chashechkin Yu. D. Transfer of a colored drop substance in a liquid layer with travelling plane gravity–capillary waves. Atmos. Oceanic Phys. 2022. 58(2). 188–197. DOI: 10.1134/S0001433822020037.

Non-Linear Waves and Ligaments in Geophysical Flows

Yuli D. Chashechkin

Ishlinsky Institute for Problems in Mechanics RAS, Laboratory of Fluid Mechanics, Moscow, Russia

The doctrine of waves, covering all branches of geophysical sciences, is based on the model equations. The difference in the symmetries of models remains an open question on the completeness of description. We use the system of fundamental equations studying the periodic flows [1]. The primary classification of structural components includes waves. Their local frequency is related to the instantaneous wave vector by the dispersion relation and ligaments constituting a family of extended but thin components. The transverse scale of ligaments is determined by various factors such as dissipative parameters, the time of formation, the process frequency, or the flow velocity. The number of ligaments is determined by the rank of the complete system or the order of its linear version. In a linear formulation ligaments are necessary to construct solutions of the generation, propagation, reflection, and attenuation of wave problems with initial and boundary conditions. In a nonlinear formulation, all flow components, both waves and ligaments, directly interact and generate new structural components [2]. The mutual actions of components with incommensurable parameters ensure a continuous restructuring of the flow. Calculations for the periodic internal waves and accompanying ligaments generation agree with the laboratory data. The transfer of results to the natural atmosphere and hydrosphere conditions is discussed.

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References:

Chashechkin Y.D. Foundations of engineering mathematics applied for fluid flows. Axioms. 2021. 10(4), 286. https://doi.org/10.3390/axioms10040286.

Kistovich A.V., Chashechkin Y.D. Fine structure of a conical beam of periodical internal waves in a stratified fluid. Atmos. Ocean. Phys. 2014. 50, 103–110. https://doi.org/10.1134/S0001433814010083

Chashechkin Yu.D. Conventional partial and new complete solutions of the fundamental equations of fluid mechanics in the problem of periodic internal waves with accompanying ligaments generation. Mathematics. 2021, 9(6), 586. https://doi.org/10.3390/math9060586.

Estimating Model Uncertainties in the Scaling Function Inversion of Gravity Data

Mahak Singh Chauhan[1], Maurizio Fedi[2]

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We inverted the scaling function for estimating the uncertainties of the model parameters. Scaling function is calculated along the ridges in a vertical section of upward continued gravity data at selected altitudes. Scaling function mathematically is the ratio of the field derivative by the field itself and, therefore, it does not depend on density or any other physical constants. We compared the scaling function inversion with the gravity inversion under the same criterion. While scaling function is inverted only for the source geometry, the gravity is inverted for the geometrical parameters and density simultaneously. We used the Talwani's parametric formula for modeling the irregular sources and Very Fast Simulated Annealing (VFSA) algorithm for optimizing the non-linear equations. We run the algorithm thousands times starting from the random initial model and collect the best model from each run in order to analyze the uncertainty in the model space. We examined the results over synthetic and real case examples. The comparison of scaling function and gravity inversion shows that the scaling function inversion is able to estimate the tilt-features of the source and overall have reduced the uncertainties. The estimated density from scaling function is also narrowly distributed, having the mean closer to the assumed value in synthetic case.

Scaling Spectral Inversion of Potential Field Data to Infer Sub-surface Source Distribution

V.P. Dimri, Shib S. Ganguli

CSIR-National Geophysical Research Institute, Hyderabad, India

Crustal or sub-surface heterogeneities exhibit scaling or fractal characteristics, and therefore the power spectrum method following scaling law can offer better insights into the sub-surface source distribution. In this approach, the physical properties are represented in terms of scaling sources and the corresponding fields as scaling quantities. Studies indicate that the scaling power spectral method provides more accurate results when compared to the conventional spectral method. To demonstrate the efficacy of the scaling spectral method, it has been applied to various potential field datasets collected from India and Germany. This study reveals that the scaling distribution of the physical property, namely, density and susceptibility agree with the measured values and the white noise assumption overestimates the inferred depth values. We also conclude that estimation of scaling exponent is critical and varies according to the geology of the area.

Lithospheric Strength Inferred From Modeling of Buckling Structure: Implications for Stress State of the East Sea (Japan Sea)

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The East Sea (Sea of Japan) is a back–arc basin that underwent a complex deformation history associated with the relative motions of major tectonic plates. Constraining the crustal type and rheology of the Ulleung Basin in the East Sea is essential for understanding back–arc basin dynamics. Based on seismic reflection data in the East Sea, previous geophysical studies reported small buckling structures with a wavelength of 60-70 km and amplitude of ~150-200 m in the Ulleung Basin. We perform finite element modeling using a wide range of rheology (i.e., oceanic/continental crust and Moho temperature) to analyze small buckling structures. The amplitude and the wavelength of the buckling structure generally increase when larger strength of the lithosphere is adopted. When a high Moho temperature (i.e., 570–640 °C) is adopted, both models with oceanic and continental crusts show surface topographies similar to the buckled morphology observed in the region. The heat flow of the numerical model corresponding to the Ulleung Basin almost coincides with the marine heat flow data in the region. Furthermore, our new finding based on the numerical modeling of buckling constrains the stress of the lithosphere beneath the western margin of the East Sea. The depth–integrated stresses of the models that produce the buckling structures are < 1.5 TN/m, which is much lower than observed at plate boundaries. Geophysical data and modeling results infer that a warm and weak mantle is below the Ulleung Basin. Thus, we argue that the Ulleung Basin does not fully support far–field tectonic stress propagation from major trenches to the Korean Peninsula. The findings of this study suggest a need for further exploration of internal factors, such as gravitational potential energy, that may influence intraplate faults in SE Korea.

Local and Global Multifactal Analysis of Turbulent Flows

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Turbulence, a phenomenon observed by physicists in natural and laboratory flows, is thought to be described by Navier-Stokes equations (NSE). It is still not known whether solutions to the NSE can develop singularities from regular initial conditions. In particular, a classical and unsolved problem is to prove that the velocity field is Hölder continuous with some exponent $h<1$ (i.e., not necessarily differentiable) at small scales. The multifractal method has been proposed to explore the regularity properties of the velocity field, and the estimate of its Hölder exponent h through the so-called multifractal spectrum. In this talk, I will first explore what are the constraints that are imposed on the multifractal spectrum, both from mathematical properties of the NSE and from empirical laws of turbulence. I will then review computation of this spectrum from turbulent data, either numerical simulations of NSE or to state-of-the art experimental measurements. Finally, I will discuss a local generalization of multifractal theory that allows to the local regularity properties of a velocity field. I will show how the application of such method allows to define a “typical irregular structure", which is found to be similar to a Burgers vortex, with non-axisymmetric corrections. A possible explanation of such asymmetry is provided by a detailed time-resolved analysis of birth and death of the irregular structures, which shows that they are connected to vortex interactions, possibly vortex reconnexion.

References:

F. Nguyen, J-P. Laval, P. Kestener A. Cheskidov, R. Shvydkoy and B. Dubrulle, Local estimates of Hlder exponents in turbulent vector fields, *Phys. Rev. E, 99*, 053114 (2019).

F. Nguyen, J-P. Laval, and B. Dubrulle, Characterizing most irregular small-scale structures in turbulence using local Hölder exponents, *Phys. Rev. E*, *102*, 063105 (2020).

B. Dubrulle and J. Gibbon, A correspondence between the multifractal model of turbulence and the Navier-Stokes equations, *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 380*, 2218, 20210092, (2022).

The Relationship Between Sedimentation Dynamics and Hydrological Connectivity Within the Deltaic Islands of Wax Lake Delta, LA, USA

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Sediment is the most valuable natural resource for deltaic environments because it is required to build new land. For land building to occur, sediment must be retained within deltaic islands that are hydrologically connected with adjacent channels. Despite this, we do not know what controls sediment retention or what governs connectivity within a deltaic island. Here we use a calibrated numerical model of Wax Lake Delta, Louisiana, USA to analyze sediment retention and connectivity for different riverine flood magnitudes, tidal amplitudes, and vegetation extents. Our results clearly show that floods and tides have opposing effects. Compared to the control, floods introduce more sediment and increase the mean sedimentation rate, whereas, tides spread sediment over a larger area and decrease the mean sedimentation rate. Vegetation has a negligible effect on mean sedimentation rates but does shift sedimentation closer to the shoreline and to higher elevations. Overall, the amount of sedimentation on an island depends on its hydrological connectivity with the surrounding distributary channels. These results show that hydrologically well-connected deltaic islands subject to tidal and riverine flooding aggrade their surfaces more evenly, which may be ideal for preventing inundation from relative sea-level rise.

3D Bayesian Potential-field Data Inversion With Decorrelation of Data Residuals Using 2D Autoregressive Models

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This study applies trans-dimensional (trans-D) Bayesian inversion to potential field data from two distinct tectonic settings: 3D salt diapirs in the presence of basement topography and a potential geothermal reservoir at a continental transform fault. The 2D potential field data are measured at the Earth's surface and typically gridded for inversions. Such data may include important spatial error correlations in the 2D acquisition space because of spatial sampling, acquisition geometry, data post-processing, etc. These spatial correlations in data residuals can produce trade-offs with spatial model resolution. Therefore, data residual correlation should be accounted for in the inversion. This study presents a hierarchical model for 2D correlated data residuals. The correlated data residuals are parametrized by trans-D autoregressive (AR) models in the 2D acquisition plane. The 2D AR model captures the correlation in two horizontal (X and Y), and a diagonal (XY) directions. Each AR direction is sampled by a reversible-jump Markov-chain Monte Carlo (rjMCMC) algorithm and can address uncorrelated data residuals by a zeroth-order AR model. The Earth model is parametrized by a hierarchy of trans-D Voronoi nodes and six planes in the 3D model space. Voronoi nodes can partition the model space irregularly, which is appropriate for imaging subsurface structures with asymmetrical shapes. To reduce the non-uniqueness issue, density values are assigned to the Voronoi nodes based on the location of the six planes. We demonstrate for simulated and field data inversions that 2D spatial correlations of data residuals are modelled and accounted for, decorrelating data residuals. For field data, plausible basement topography and salt diapirs are inferred, and the structure of a major continental transform fault is resolved.

Bayesian Joint Inversion of Seismic Sources in Different Data Domains

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Moment tensor estimation for moderate to large earthquakes is convenient with open source software (e.g., BEAT, MTfit, Grond) based on waveform, polarity, or spectral data. At regional or local distances, waveform or polarity inversions are the most common. However, moment tensor inversion often suffers from a lack of high-quality data when events do not excite long-period seismic signals with a high signal to noise ratio and/or when station coverage is sparse. We improve solutions for minor earthquakes (M<4.5) by incorporating multiple seismic data types in various data domains in probabilistic joint inversion: polarities picked on broadband signals, amplitude spectra for intermediate frequency bands, and waveforms at low frequencies. This approach aims to take advantage of the available seismic data while reducing the possibility for errors in the solution due to theory errors. Waveform noise is accounted for by non-Toeplitz covariance matrices which ensures that waveform data do not dominate the solution when sampling rates are high. An ensemble of source-parameter vectors is generated by sequential Monte Carlo sampling method (SMC). The source is parametrized on the Lune that is ideally suited for prior specification. The method is demonstrated for two induced events in northeastern BC. A moment magnitude of 4.2 event on Nov 30, 2018, and an event with the local magnitude of 1.6 on Mar 11, 2021. Results show that estimating source parameters at higher frequency ranges improves the uncertainty of source parameters. Polarity data enhance the estimation of double-couple source parameters, which in-turn allow to better resolve centroid and moment-release function parameters that are constrained by spectra and waveforms. Notably, joint inversion resolves centroid location and focal mechanism with only one waveform and a few spectra.

Analysis and Comparison of Rock Magnetic Properties of Ophiolite and Mid-Ocean Ridge Mantle Rocks Using Computational Methods

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The main goal of the study is to compare rock magnetic properties of mantle rocks from different sites along ophiolite and mid-ocean ridges, and seek correlations using mathematical methods. The main data analyzed in this study are magnetic measurements of cores drilled from areas near Wadi Lawayni of Oman, which mostly consist of heavily serpentinized Dunites and Harzburgites with frequent inclusions of gabbroic dikes. Data collection was initially done during the second phase of the Oman Drilling Project. Comparison was done with magnetic signatures of igneous rocks from mid-Atlantic ridge and ophiolite complexes of southern Europe (e.g. Pindos ophiolite). A notable pattern observed within these data is that average magnetic susceptibility differs by lithology. In general, mass susceptibility values are mainly higher in Dunite intervals compared to harzburgite intervals. In addition, NRM intensity tends to be significantly higher in mid-ocean ridge samples than in ophiolite samples. Such pattern is presumably due to the difference in density of magnetite within the mineral mesh. Overall, computational investigation reveals patterns that suggest magnetic properties of ultramafic rocks and serpentinization degree is deeply related. Magnetic measurements also reveal positive correlations with permeability and porosity. These observations are apparent evidences for low-temperature hydrothermal alterations and implies that Fe(III) was transported intensively via fluid intrusions during the serpentinization process. Such information will likely help further investigating magnetic signatures and relating them to mineral characteristics to specify how magnetic minerals has been formed and distributed in different locations.

The Power Release From Microstructure and Its Role for Geohazards

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Geohazards such as landslides, earthquakes, ice quakes, slow slip or tremor events can be interpreted as a sudden release of stored energy because of Multiphysics reaction-diffusion processes and multiscale feedbacks. Thermodynamic constraints allow prediction of the pattern of strain localisation but the dynamic evolution of the localised release of stored microstructural energy and its role in preparing the large-scale instability is hidden. We introduce a new microphysics-based approach that couples the microscale cross-constituent interactions to the large-scale dynamic behaviour, which leads to the discovery of a family of soliton-like excitation waves. These waves can appear in hydromechanically coupled porous media as a reaction to external stimuli. They arise, for instance, when mechanical forcing of the porous skeleton releases internal energy through a phase change, leading to tight coupling of the pressure in the solid matrix with the dissipation of the pore fluid pressure. In order to describe these complex multiscale interactions in a thermodynamic consistent framework, we consider a dual-continuum system, where the large-scale continuum properties of the matrix-fluid interaction are described by a reaction-self diffusion formulation, and the small-scale dissipation of internal energy by a reaction-cross diffusion formulation that spells out the macroscale reaction and relaxes the adiabatic constraint on the local reaction term in the conventional reaction-diffusion formalism. Using this approach, we recover the familiar Turing bifurcations (e.g., rhythmic metamorphic banding), Hopf bifurcations (e.g., Episodic Tremor and Slip), and present the new excitation wave phenomenon. The parametric space is investigated numerically and compared to serpentinite deformation in subduction zones.

Impact of Urban Heat Island on Human Mortality Risk

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Non-optimal ambient temperatures, both heat and cold, are associated with elevated human mortality risk. Urban-induced warming can significantly increase the risk associated with extreme heat during summer, yet urbanization could also shield against extreme cold during wintertime. Here we present a monetised risk analysis for 87 cities in Europe based on high-resolution modelled temperature data and localised exposure-response relationships. We show a non-linear relation between the level of imperviousness and risk, with opposite trends for heat and cold. While extreme heat increases the mortality costs in dense urban areas compared to the surrounding rural areas, the net annual effect is negligible due to wintertime benefits in most European cities. These results suggest that mitigation efforts should account for spatial heterogeneities of climate and vulnerability but also the seasonality of risk.

Earthquake Precursory Factors Derived From Earthquake Catalogs With Explainable Machine Learning

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Earthquake precursors are useful indicators to forecast future ruptures and their probability. Earthquake catalogs, including occurrence time, epicentral locations, and earthquake magnitude, are a crucial tool for recognizing this precursor. In this study, we trained an eXtreme Gradient Boost (XGBoost) Classifier with multi-featured datasets obtained from Global Centroid Moment Tensor (GCMT) catalog to recognize earthquake precursors for magnitude above 6.5. Training and validating datasets consist of eighty-augmented features from an earthquake catalog information (e.g., time, latitude, longitude, depth, and magnitude) in spatio-temporal windows. The window is defined as the precursory phase if an event above magnitude 6.5 occurs from this window within three months. The results of five-fold cross-validation show that the average of auc of five validation sets is 0.4-0.8 with ~0.01 deviation. Furthermore, we use earthquake catalogs from other sources (e.g., JMA, USGS, and SCSN) to prove the predictive power about untrained data. Although test performance is lower than the validation results, model performance is sufficient to recognize precursory phases. We utilize SHapely Additive explanation (SHAP) to quantify feature importance that explains the contribution of each feature for the trained model. The two most important features in the window are i) the maximum magnitude of events and ii) the time interval to the subsequent events. These two features largely contribute to classification performance. Our results support previous studies which suggest that the magnitude of each event in earthquake signal and accelerating seismicity before mainshock is a possible precursory indicator of large earthquakes. We suggest that our machine learning approach may help to analyze the earthquake precursors, providing a physics-based foundation to access earthquake precursors.

Seismic Velocity Structure of Upper Mantle Beneath the Oldest Pacific Ocean Basin From Finite-frequency Traveltime Tomography

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Understanding the detailed structure of the oceanic upper mantle can shed light on mantle dynamics related to plate tectonics. The oldest Pacific basin (160 – 180 Ma) in the west Pacific is a birthplace of the Pacific plate suitable for investigating the dynamic evolution of oceanic plate. However, due to difficulty of seismic exploration on the oceanic environment, the upper mantle structure beneath the oldest Pacific basin has remained one of the least understood part of the Pacific mantle. Oldest-1 experiment consisting of 11 broadband ocean-bottom seismometers (BBOBSs) and 7 ocean-bottom electro-magnetometers provided one-year (2018–2019) geophysical observation of the oldest Pacific seafloor located ~600 km east of the Mariana Trench. In this study, we perform finite-frequency tomography to image upper-mantle seismic structure from the BBOBS data. We measured relative traveltime residuals of teleseismic *P* phases (± 1 s) in three frequency bands within 8–32 s by applying multichannel cross-correlation method, and inverted the traveltime residuals to obtain *P*-wave velocity model. We adopt a multiscale parameterization scheme for the inversion, which transforms the model vector and inversion kernel to a wavelet domain in terms of 3-D wavelet basis functions instead of directly solving for model parameters specified at model nodes. This wavelet-based approach has advantage in maintaining a data-adaptive resolution of the model at different scales. Notable features from our preferred *P*-wave velocity model include fast velocity anomalies ($\delta \ln V_P$ = 3 – 4%) beneath centers of two large-igneous provinces for depths ~100 – 250 km. Slow *P*-wave velocity structures ($\delta \ln V_P$ = −3 – −4%) surround the fast *P*-wave velocity anomalies of the Pigafetta basin.

Sediment Buoyancy Controls Subduction Kinematics and Dynamics: Insight From 3D Viscoelastic Free Subduction Model

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The complicated dynamic force equilibrium in a subduction system influences various geological and geodynamic processes. The slab pull attributed to the negative buoyancy of the lithosphere has long been recognized as the main driving force of plate tectonics. However, the isostatic restoring force due to the light materials covering the lithosphere (e.g., sediment) is thought to be a relatively minor contributor. Because this force counteracts the gravitational pull, the resultant interaction can contribute to the force balance governing the subducting slab. Here, we developed the systematic 3D free subduction models applying different sediment distributions, thicknesses, and densities to explore the effect of the restoring force generated to compensate for isostasy on the slab pull. We found that a higher magnitude of restoring force suppresses trench retreat and decreases the trench velocity. The trench curvature was strengthened by a higher differential restoring force along the trench strike. Our results consistently showed a negative correlation between slab pull and isostatic restoring force. Furthermore, the magnitude and distribution of the isostatic restoring force along the trench strike determine the stress intensity, as well as the location of the stress concentration within a subducting slab. Our findings provide insights into the global prediction model of plate motion and megathrust seismicity. Therefore, we argue that sediment buoyancy could sufficiently affect subduction kinematics and dynamics, even more than is usually suggested by conventional subduction models.

A new Quadrature-with-Extrapolation Algorithm for Simulating Electromagnetic Fields in One-dimensional Models

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Numerical computation for a one-dimensional electromagnetic method always requires integral evaluation. Although the quadrature technique is widely used to numerically compute integral equations in the engineering community, geophysicists are more familiar with the digital linear filter algorithm. Because the former has an advantage of precision control over the latter, a quadrature-with-extrapolation algorithm has been developed to simulate the electromagnetic response in a one-dimensional model. However, this algorithm causes numerical errors at small transmitter-receiver spatial offsets. We modify the previous quadrature-with-extrapolation technique to address its numerical issue. The electromagnetic fields computed by the quadrature techniques were validated by the analytical solution in a homogeneous medium at various frequencies. We examined both electric and magnetic dipole sources in the validation. Our technique produced the same electromagnetic field compared to the analytical, whereas the previous technique showed a different response at a small offset. Also, the results of a layered-earth model suggested that our new technique supported the computation of electromagnetic fields everywhere. Because of the ability of precision control, the field computed by our technique can be used to validate that of the digital linear filter algorithm.

A Preliminary Machine-learning Analysis of Radiogenic Geochemistry of the Different Volcanic Edifices Linked to the African LLSVP and Their Possible Mantle Source Relationship

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With recent progress in computational sciences, machine learning has been implemented in various applications to provide multi-dimensional insights over traditional two-dimensional diagrams. In addition to the concurrent improvements in geochemical analysis methods, the constantly increasing trend of open access databases shared by the scientific community opens a new window of opportunity to utilize data in a regional or global context with machine learning algorithms. In this study, we constructed the geochemical database of different volcanic edifices with a possible relationship to the African LLSVP from publicly accessible data sets. Upon the database, we implemented various pre-processing, dimensional reduction methods, and cluster analysis algorithms in a comparative manner to investigate the possible structure among volcanic systems in trend or grouping. The preliminary results will be presented along with the possible future applications for source classifications of lava in the perspective of African LLSVP and related plumes.

Cautionary Remarks on the Auto-correlation Analysis of Self-similar Time Series

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A self-similar time series is defined as a continuous time series having similar shapes of disturbance or amplitudes. Its statistics are non-Gaussian, such as records of river flows, rainfall, wind speed, the concentration of Chlorophyll, and inertial amplitudes in geosciences. Spurious decorrelation structures of the self-similar time series have been reported in the time domain analysis of non-linear time series in geosciences. We examine auto-correlations of the self-similar time series to identify spurious decorrelation structures in terms of decorrelation scales and decaying patterns (e.g., single-sided and dual-sided pulses) of independent pulses. The auto-correlations of the self-similar time series do not depend on their decorrelation scales and are highly associated with the shape of individual pulses. This talk evaluates auto-correlations of modeled self-similar time series, and relevant cautionary remarks are discussed.

How can Contemporary Climate Research Help Understand Epidemic Dynamics? Ensemble Approach and Snapshot Attractors

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Standard epidemic models based on compartmental differential equations are investigated under continuous parameter change as external forcing. We show that seasonal modulation of the contact parameter superimposed upon a monotonic decay needs a different description from that of the standard chaotic dynamics. The concept of snapshot attractors and their natural distribution has been adopted from the field of the latest climate change research. This shows the importance of the finite-time chaotic effect and ensemble interpretation while investigating the spread of a disease. By defining statistical measures over the ensemble, we can interpret the internal variability of the epidemic as the onset of complex dynamics—even for those values of contact parameters where originally regular behaviour is expected. We argue that anomalous outbreaks of the infectious class cannot die out until transient chaos is presented in the system. Nevertheless, this fact becomes apparent by using an ensemble approach rather than a single trajectory representation. These findings are applicable generally in explicitly time-dependent epidemic systems regardless of parameter values and time scales.

Critical Tokunaga Model for River Networks

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The hierarchical organization and self-similarity in river basins have been topics of extensive research in hydrology and geomorphology starting with the pioneering work of Horton in 1945. Despite significant theoretical and applied advances, however, the mathematical origin of and relation among Horton laws for different stream attributes remain unsettled. In this work we capitalize on a recently developed theory of random self-similar trees to elucidate the origin of Horton's laws, Hack's laws, basin fractal dimension, power-law distributions of link attributes, and power-law relations between distinct attributes. In particular, we introduce a one-parametric family of self-similar critical Tokunaga trees that includes the celebrated Shreve's random topology model and extends to trees that approximate the observed river networks with realistic exponents. The results offer tools to increase our understanding of landscape organization under different hydroclimatic forcings, and to extend scaling relationships useful for hydrologic prediction to resolutions higher that those observed.

This is a joint work with Ilya Zaliapin and Efi Foufoula-Georgiou.

Well Log Analysis and Lithological Classification by Artificial Neural Network (ANN)

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One of the main objectives of geophysical studies is to apply appropriate mathematical techniques in order to extract the maximum information on the properties of the subsoil. Well Logs data are widely used in hydrocarbon research and reservoir characterization in sedimentary basins. Indeed, this technique allows us to analyze and interpret several rock characteristics in terms of permeability, porosity, density, resistivity, saturation, salinity, lithology and mineralogy. Thus, petrophysical properties and classification of lithofacies using well data are very important for oil exploration and reservoir characterization. For this, several classification methods have been developed in this direction in order to study the wells data among them: Artificial Neural Networks (ANN). This new technique is based on the statistical classification of measured data in sedimentary basins. The objective of this study is to apply ANN for the analysing wells data and the classification of lithofacies. The lithology will then be deduced in three different ways: The first conventional, directly exploits the recordings at the wells. The second uses two neural network (ANN) classification tools: The multilayer perceptron (PMC) and Self-Organizing Kohonen Maps (SOM). In order to present the performances of this technique, we applied these tools on real well log recordings located in the Hamra region characterized by gas production and complex geology. The results obtained by this method will then be compared with those delivered by the classical interpretation and the core data in order to assess its degree of reliability in the classification. Finally, the implementation of this method allowed us to demonstrate that it is possible to provide a reliable geological interpretation in order to define the model of the reservoir in a long term.

Optimal Resolution Tomography

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The classical Backus–Gilbert method aims to determine localized Earth-structure averages over the smallest resolving lengths possible, given the data sampling and data errors. The resolving length at a point is the width of the local averaging kernel, and the optimal kernel is the narrowest one such that the model error is below a specified level. Evaluating the model error is essential but difficult in practice. Here, we present a method for optimal resolution tomography using surface waves and empirical model-error estimation. Using phase-velocity measurements, we compute phase-velocity maps at densely spaced periods. The error of this phase-velocity model at each point can be estimated from the roughness of the phase-velocity curve it yields at this point that cannot be explained by any Earth structure. We show that this error increases nearly monotonically with decreasing resolving length. We can thus apply the Backus-Gilbert criterion and determine the optimal resolving length such that the error is just under a specified threshold. The solution at every point results from an entire-system inversion, with smoothness constraints suitable for this point. Once the optimal averaging is determined everywhere, a 3D Vs model is computed. We tested the method using 11,238 inter-station dispersion curves sampling Ireland and Britain. The model resolution varies from 39 km in central Ireland to over 800 km at the region's periphery and shows smooth lateral variations, confirming the procedure's robustness. The optimal resolving length does not scale with the density of the data coverage: some of the best-sampled locations display relatively low lateral resolution, due to systematic errors in the data and azimuthal unevenness of the sampling. This method relies on our ability to split the 3D problem into a set of 2D ones. Determining optimal resolution of tomography that relates measurements to 3D models directly remains an outstanding challenge.

Forward Modelling of Strain and Inversion for Focal Mechanisms From Distributed Acoustic Sensing Data

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Understanding induced seismicity is of significant interest to residents, governments, and the oil and gas industry. Distributed acoustic sensing (DAS) systems measure ground deformation (strain) in the axial direction of optical fibre via Rayleigh backscattering of a laser pulse. These fibres are ideally suited to deployment in wells to monitor induced seismicity due to ruggedness of fibres, dense spatial sampling, and extreme frequency bandwidth of strain recordings. We use DAS data to infer moment tensors (MT) of induced events to study fault activation. A current limitation of DAS MT inversion is the lack of forward models that predict strain. Most existing methods predict in units of displacement or velocity and methods that predict strain from displacement are based on limiting assumptions. Our forward model predicts strain in the intermediate and far fields for P and S waves in a homogeneous medium with intrinsic attenuation. This model accounts for arbitrary fibre geometry and considers the sensor response. Since DAS recordings in wells are near hypocenters, the intermediate field can be important. This forward model is applied in MT inversion for events with assumed known hypocenter locations. The forward model generates Green functions that guarantee the trace of the MT to vanish, i.e., a deviatoric focal mechanism. This choice is justified since no signs of volume change in the data are apparent. Since the DAS system records a large number of channels, the Green functions are applied to invert linearly for the MT from random subsets of DAS channels. This bootstrap procedure provides uncertainties for the inverted focal mechanism parameters, including fault orientation (strike, slip and dip), event magnitude, and source type (double couple or compensated linear vector dipole). We compare results for cases where only P waveforms are inverted to those for only S waveforms and both waveforms.

An Alternative way of Considering Anisotropy in Isotropic Tomography Inversion

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The mantle is seismically anisotropic. Yet, the isotropic mantle is often assumed for mathematical and computational convenience for seismic tomography, a tool to image the seismic velocity structure inside the earth, with a few exceptions such as Japan and west of North America where abundant data can compensate for the effect of anisotropy. In addition to temperature, composition, and water or melt content of the mantle, seismic anisotropy can influence the seismic velocity. Also, understanding anisotropy can help to construct the mantle dynamics as it may represent the direction of mantle flow (i.e. A-type olivine in the mantle rock) although the content of water or melt can rearrange the orientation of anisotropy in some cases (i.e. B- or E-type olivine). In our study, assuming seismic anisotropy is predominantly coming from the A-type olivine, we include hypothetical anisotropy models as a priori constrain in the teleseismic P-wave isotropic inversion as an alternative to the full anisotropic tomography inversion. We introduce anisotropy models in the forward calculation of the travel time based on the global reference model (AK135; Kennett et al., 1995). That is, a new set of delay-time, which is gained from eliminating the delay time imposed by the anisotropy model from the observed delay times, goes through the isotropic tomographic inversion and we repeat the same procedure in the successive delay-time calculations. The detailed configuration of anisotropy models is derived from observed shear-wave-splittings and suggested geodynamic models. We include various anisotropy models in the tomography for the three different tectonic settings including relic subduction (westernmost Mediterranean), mantle plume (travel of Canary plume), and continental margin (mid-Appalachian mountains). Our results suggest that unconsidered anisotropy in the isotropic tomography can be mapped as velocity structures and, simultaneously, it can misinterpret the current configuration of mantle flow.

Assessing Numerical Lava Flow Models

Einat Lev

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Numerical models of lava flow emplacement are one of the main tools used to forecast and to mitigate the natural hazard presented by lava flows at volcanic regions. Available models differ in the physical assumptions and input parameters they employ, but also in the ways they have been assessed. For instance, some models have been tested against idealized analytical solutions, some against laboratory and analogue experiments, and some against examples from nature. There are also differences in the level of availability and accessibility of models. I will provide a short review of available modelling tools and compare their performance on established benchmarks and recent eruptions.

Harmonic Decompositions Analysis of the Teleseismic Receiver Functions for the Crustal Anisotropic Structure

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Tangential receiver functions (T-RFs) are often used for obtaining information of seismic anisotropy of medium. However, a small amplitude of the T-RFs compared to the radial (R-) RFs, at a seismic discontinuity such as Moho, hinders exploiting the T-RFs. We adopt a theory such that correlation between R-RFs and T-RFs in backazimuth domain exists with a phase shift by 90° or 180° if the medium is anisotropic enough to be observed. Sinusoidal and cosinusoidal harmonic terms are extracted from the R-RFs and T-RFs by regression. The similarity between the terms is used as a proxy for verifying whether the amplitude variation in backazimuth is adequate to be interpreted as outcomes of anisotropic scattering of P wave of teleseismic earthquakes. We apply this approach to validate crustal anisotropy using long-operated permanent stations over 10 years in South Korea within the stable continental region. We also investigate crustal seismic anisotropy from the data from the Naenam Fault Array (NFA) consisting of 69 geophones deployed linearly across the fault where the 2016 Mw 5.5 Gyeongju earthquake ruptured in southeastern region of South Korea. The NFA is sub-perpendicular to the strike of the fault with a dense spacing of ~200 m. Because of short operation period (about a month) and limited number of usable teleseismic earthquakes with magnitude larger than 6.1, the model space cannot be constrained solely by R-RFs and T-RFs. We expect that the harmonic analysis with the permanent stations can provide first-order information for the fault-related crustal structures beneath the NFA and nearby regions that are currently the most seismically active region in Korean Peninsula.

Bayesian Inversion With Deep Generative Models

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Deep generative models (DGMs), such as those based on a variational autoencoder (VAE) or a generative adversarial network (GAN), are well suited to encode complex geological prior models. This enables the reduction of the dimension of associated inverse problems from many thousands of unknowns to a few tenths of uncorrelated latent variables with a known prior (uniform or standard normal) distribution. Further, since the spatial statistics is encoded, there is no need to rely on expensive model proposal mechanisms (e.g., sequential geostatistical sampling) to ensure that the prior is honoured. In addition to time-consuming training, the main price to pay when using DGMs is an inverse problem that can become highly non-linear and that may exhibit a multimodal posterior probability density function (PDF). Indeed, previous works with DGM-based prior encoding indicate that classical gradient-based inversion methods such as Gauss-Newton may perform poorly and that advanced Markov chain Monte Carlo (MCMC) methods often struggle to converge. We demonstrate that a recent adaptive sequential Monte Carlo (ASMC) algorithm clearly outperforms, for a given computation budget, two state-of-the-art MCMC algorithms (parallel tempering and $DREAM_{(ZS)}$) when applied to exemplary geophysical and hydrogeological inverse problems. Further, a geophysical test example demonstrates how the combination of normalizing flows (NFs) and variational Bayes (VB) provides not only better model solutions than the Gauss-Newton method but also an estimate of the posterior PDF. This latter method is suitable for applications in which fast results are needed and an approximate estimation of the posterior PDF is acceptable. Further research is needed to better understand the trade-off between the quality of the posterior PDFs obtained by ASMC and NF-VB and the total computational cost, and to develop reliable diagnostics indicating failure when the allotted computational budget is too small for a given problem setting.

Numerical Simulation of Magma Intrusion, Ascend and Deposition in Volcanic Environments

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I will present a review of numerical models that cover different aspects of the dynamics of volcano-magmatic systems. A model of a growth of magma chamber by periodic injection of dikes into country rocks with account for heat transfer, latent heat of crystallization/melting, phase diagrams and eruptions. The model is linked to zircon crystals diffusive growth that allows interpretation of magmatic processes based on measurable age and size distributions. A model of volatile rich dike propagation with account of multiple volatile species (water+CO_2), crystallization and heat exchange during the ascend. Depending on the water+CO_2 ratio of the source magma the dike can reach the surface or can be arrested at shallow depth and solidify. A model of magma ascent in a volcanic conduit with syneruptive crystallization, heat transfer to wall rocks, shear heating and non-Newtonian magma rheology. The model predicts formation of narrow shear zones within conduits with rapid variation of the temperature and crystallinity.

On Lava Domes and the Geometry of Their Vents

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Thick lava flows that are a feature of many volcanic fields on the Earth and Venus vary from sheet-like to nearly perfect axisymmetric domes. Previous work on lava domes have unexplored how such geometrical characteristics depend on the shape of the feeder vent. Here 3-D numerical models for the gravitational spreading of viscous lava erupting from elliptical vents onto a flat surface examine the impact of the vent geometry on the growth of lava domes. The aspect ratio of the vent varies from circular to fissure-like. In all cases, the initial phase of the dome's evolution is in a lava-discharge dominated regime such that spreading is insignificant and the height of the dome increases at a constant rate over the vent area. For vent aspect ratios greater than five, three successive regimes of spreading are identified: 2-D spreading in the direction perpendicular to the major axis of the vent, a transient phase such that the dome shape evolves towards that of a circular dome and a late axisymmetric spreading phase independent of the vent shape. The study provides two outcomes for highly viscous fissure eruptions. The longer the vent fissure length, the longer the early lava discharge regime and 2-D spreading perpendicular to the length of the fissure. Second, the aspect ratio of fissure-fed lava flows can be used as an indicator of the fissure length and the duration of lava discharge. While the ellipticity of some terrestrial fissure-fed flows provides evidence for viscous gravity-driven spreading terminated before the onset of the axisymmetric regime, the circular domes on Venus appear to be the result of fissure-fed eruptions sustained enough for the spreading to reach the axisymmetric regime. We propose relationships providing estimates of the fissure length and the duration of lava discharge based on fossil dome dimensions.

Developing a River Migration Hazard Map Using Numerical Modeling and Monte Carlo Methods

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We wish to suggest a hazard map of river meandering by combining existing meandering numerical models with Monte Carlo methods. A numerical model of river meandering has already been proposed by Howard & Knutson. Their kinematic model consists of computing migration rate as the weighted sum of upstream curvature of the river. However, the numerical model itself is not sufficient to predict the future meandering patterns of the river due to the high internal variability of the river and its surrounding environment. To determine the range of possible meandering patterns of rivers, Monte Carlo simulation was plied to uncertainty variables in the numerical modeling equation, which are river cutoff distance, river migration rate, and river aggradation rate. Running multiple Monte Carlo simulations shows a probabilistic hazard map of affected areas of river meandering in the future. We concluded that using a probabilistic simulation of the river meandering model can be applicable for developing river migration hazard maps, which is urgent in regions with permafrost thawing.

Regular and Singular Motions in a Continuously Stratified Fluids

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Surface and internal waves in a viscous exponential fluid are considered. Singular and regular solutions are obtained. Regular solutions are a generalization of wave motions arising in the model of an ideal fluid. Singular solutions correspond to ligaments - highly gradient flows. This type of solution arises taking into account the finite viscosity of the liquid. The phase and group velocities of regular movements and their analogues for irregular movements are investigated. All the obtained relations are constructed in physically observable variables - depending on the frequency and wavelength. This type of dependency is more convenient for experimental verification. Complete solutions to the problem of wave propagation in a viscous exponentially stratified fluid are constructed.

Multi-fractal Scaling Behavior of the Himalayan Seismicity: Implications on Energy Dissipation Mechanism

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Dynamic behavior of spatial and temporal distribution of earthquakes in Himalaya is studied. We investigate the signatures of earthquake complex scaling behaviors of the Himalayan seismicity for better understanding the observed clustering and the underlying dynamics. We analyze spatial variation in correlation dimension, D of spatial distribution over its different segments using the regional catalog of crustal earthquakes (M>3.5) and examine whether the data exhibit long-range correlations and multifractal properties. The source of multifractality is assessed by comparing the observed multifractal spectrum with synthetics obtained from random simulations. Our preliminary findings reveal multifractal nature of the distribution with persistent long-range correlations. We analyzed intermediate-depth earthquakes in the region for understanding their mechanisms. The multifractal results for crustal and intermediate-depth events are compared in terms of degree of heterogeneity: results show variations in multifractal spectrum parameter, suggesting a varying degree of heterogeneity of spatial clustering that is related to their origin. We also examined energy dissipated during earthquakes from long-term correlation of temporal distribution of crustal events; there is an indication that energy dissipation is related to occurrence of large earthquakes rather than the smaller burst of events. Numerical tests are conducted for testing the performance of the results obtained. Both observed and synthetic results agree reasonably well implying a scale-free self-similar dynamics in their occurrence.

Machine Learning Concepts and Methods for Addressing Probabilistic Hydrological Forecasting Challenges

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Probabilistic forecasting is receiving growing attention nowadays in a variety of applied fields, including hydrology. Indeed, it is increasingly understood that expected-value (else referred to as "best guess" and sometimes also as "single-point" or "point") forecasts can be most informative and useful in engineering contexts when accompanied by additional information about the predictive probability distributions. Still, probabilistic forecasting is a relatively new endeavour carrying with it numerous fresh challenges that need to be addressed in an optimal way. Notably, such challenges and their optimal solutions can vary substantially across disciplines, as the latter are characterized by different knowledge, traditions and practices to build upon. Although not a panacea to all the predictive modelling tasks, machine learning concepts and methods can provide straightforward and effective solutions to many of them, including probabilistic prediction and forecasting tasks, which in their turn include those referring to extreme events and quantities. In light of the above-outlined facts, this presentation extensively discusses several machine learning concepts and methods that have been proven useful in probabilistic hydrological forecasting. For that, it first identifies the most fundamental methodological and computational challenges in the studied field. It then identifies the most relevant machine learning concepts and methods, and explains why and how these concepts and methods can be exploited for addressing the challenges. It further discusses if and from which point of view the provided solutions could be characterized as optimal. Emphasis is placed on key ideas and information that can lead to effective popularizations and syntheses of the discussed concepts and methods, as such an emphasis could support successful future implementations and further advances. In the same forward-looking direction, potential technical solutions that could be assessed in the future are proposed.

The Accurate Pressure Recovery for Geodynamics Using Penalty Method

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Pressure is one of the crucial parameters that determine the rheological properties of the mantle (e.g., viscosity). Since partial melting depends on the pressure-temperature condition and fluid flow in the plate is driven by a pressure gradient, the pressure is highly involved in the evolution of geodynamic processes. However, in building numerical models for geodynamics, obtaining pressure has the following problems: (1) The integrated formulations of the Navier-Stokes equations make discretization complicated because the momentum equation has unknown velocity and pressure, whereas the continuity equation does not have a term for pressure. (2) Although the segregated formulations overcome (1) by sequential computation of the momentum and continuity equations, the formulations require a boundary condition for pressure. In a model with free surfaces, the pressure condition is needed even when information on pressure is not given, and incorrect pressure conditions result in an artificial error at the boundary. The penalty method, which is widely used in incompressible Stokes flow, solves the problem by mathematically removing the pressure term from the equation. The eliminated pressure term is recovered through post-processing, but there is an issue where artificial errors appear if LBB (Ladyzhenskaya–Babuška–Brezzi) condition is not satisfied. However, there is a lack of research related to geodynamics in detailing the post-treatment method of pressure in which the penalty is applied. This study presents several ways to use the penalty approach and recover pressure. We produced an extension experiments model, compared the pressure fields with each method, and showed that incorrect methods for pressure recovery could significantly impact the evolutionary process through models with viscosity dependent on pressure.

Towards Probabilistic Inversions and Uncertainty Quantification in Large-scale Seismic Inversions

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Seismic tomography has evolved tremendously over the past decades, taking advantage of high-performance computing facilities and novel algorithms. By moving towards full-waveform inversions, most of the current advances in global inversions focus on extracting as much information as possible from each seismogram. Conducting fully numerical 3D wave propagation simulations allows to increase such information content. However, the increase in computational costs of the forward problem limits the uncertainty analysis possibilities of the resulting seismic models. In this talk, we will approach the inverse problem for large-scale seismic inversions from a Bayesian perspective. We will demonstrate the capabilities of low-rank covariance matrix approximations through gradient optimizations, and sampling posterior distributions on current global-scale seismic models within Gaussian assumptions. We show further advances of variational Bayesian inversions and approximate Langevin Monte Carlo sampling on several 2D benchmark problems in quantifying uncertainties beyond Gaussian approximations. The talk will highlight our current possibilities and limitations in Bayesian approaches to address uncertainty quantification in global seismic inversions.

Estimating the Parameters of Truncated Gutenberg-Richter Distribution: New Approaches.

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Truncated Gutenberg-Richter (GR) law modelling earthquake magnitude distribution is used in modern seismological practice very widely because of its simplicity and robustness. Some new approaches to the problem of estimation of parameters of GR distribution are suggested.
Truncated GR distribution, determined on some interval [m; M] has two parameters: b-value (slope of GR law in log-scale) and M that is identified often with maximum possible regional magnitude. Standard maximum likelihood estimate (MLE) of parameter M equals $\max(m_1,\ldots,m_n)$ under any b-value. This MLE has a negative bias which reduces its efficiency. We suggest a new correction to this bias taking into account sample size n and b-value. A comparison of the new estimate with some known estimates on synthetic catalogs is performed and its high efficiency is demonstrated using the regional catalog for Baikal Rift Zone. The b-value estimation may be more adequate and robust if one utilizes some subinterval of the interval [m; M] because the slope of the GR law is rather unstable at the ends of the magnitude range. We propose some new statistical technique for determination of proper ends of this subinterval. Another new contribution refers to the extension of the maximum likelihood method to the case of digitized or aggregated magnitudes.

Contribution of Deformation Models to the 2023 U.S. National Seismic Hazard Model

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The U.S. National Seismic Hazard Model will be updated in 2023. Deformation models of the GPS velocity field will be used to inform the earthquake rate model, similar to applications of deformation models to the Uniform California Earthquake Rupture Forecast in 2013 (UCERF3) and the 2014 U.S. NSHM. Specifically, they provide estimates of slip rates on ~1000 faults contributing to the 2023 NSHM as well as distributions of off-fault moment rates. Innovations of the current application are: the inclusion of geologic slip-rate constraints on hundreds of newly added faults; the inclusion of two new (in addition to two existing) geodetic deformation models; an expansion of the creep dataset and development of a creep model for certain creeping faults in California; inclusion of earthquake cycle effects via quantitative models of the `ghost transient' for selected cycles of major faults. We find that all models can satisfactorily fit the GPS dataset within a-priori geologic slip rate bounds, but there is considerable variability in model results, especially for very low slip rate faults (<~0.1 mm/yr). This variability is quantified with empirical errors based on the coefficient of variation of the set of models on a fault by fault basis. These measures suggest that slip rates from deformation models are problematical to inform the earthquake rate model on individual low-slip-rate faults, though they may be useful for constraining the net deformation of broad subregions. Inclusion of earthquake cycle effects via the ghost transient correction produces better agreement with geologic slip rates on higher slip rate faults (>5 mm/yr), and the inferred slip rates of many of these faults increase by several mm/yr as a result of the correction. This suggests that the physics of earthquake cycle deformation is well enough understood to use systematically in deformation models with direct implications for the earthquake rate model.

Fast Algorithm for Terrain Irradiance Using Compressed View Factor Matrices

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We present a fast algorithm for solving the radiosity integral equation in the context of modeling Lambertian scattering from a rough planetary surface, such as for modeling thermal radiation or Lambertian illumination ("terrain irradiance" calculations). Shadowed regions on airless bodies receive energy in the form of scattered light, and the availability of increasingly large shape models (especially for the lunar surface) calls for the development of fast algorithms for modeling surface temperatures that are relevant for future landings and resource prospecting. Instead of using previous approaches for "radiosity" from the computer graphics literature, where the focus is a fast algorithm which accurately contours shadow discontinuities across large planar surfaces, we present a fast algorithm for radiative heat transfer on large shape models, such as lunar craters or entire planetary bodies. To this end, we have adapted techniques from the literature on hierarchical matrix factorizations, leading to a novel, hierarchical, block low-rank factorization of the radiosity system matrix. We are able to assemble this matrix in roughly $O(N^2)$ time, where N is the number of triangles the surface is discretized into. Afterwards, matrix-vector multiplies take approximately $O(N)$ time, and the storage costs are also $O(N)$. This allows us to solve long-running time-dependent problems using $O(N)$ space, each step requiring only $O(N)$ FLOPs. Unlike the kernel matrices which are typically compressed using similar methods, the view factor matrix is dense (has $O(N^2)$ nonzero entries), but has a significant portion of zero entries due to lack of visibility. We take advantage of this fact to compress blocks further. We benchmark our implementation and present numerical examples for a permanently shadowed crater at the Lunar south pole, for comet 67P/Churyumov-Gerasimenko, and other regions of interest.

Multiphysics Resonance of Reaction-cross-diffusion Waves as Nucleation Mechanism for Earthquakes

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Forecasting of earthquakes has to date been an elusive problem. Statistical and empirical methods show some promise in quantifying the nonlinear behaviour of earthquakes and are used for seismic risk assessment and reinsurance of property but the dynamic phenomenon itself is unexplained. Here we propose a fresh approach reliant on multiscale coupled feedbacks from chemical processes through fluid flow, mechanical deformation, and thermal phenomena to capture the instability. As a working hypothesis for an earthquake precursor phenomenon, we investigate the role of the energy release from microstructural modifications on the future fault plane by a resonance phenomenon of feedbacks across scales. In our companion work, presenting the role of release of microstructural power, we have shown that a reaction-cross-diffusion equation can indeed explain Episodic-Tremor and Slip (ETS) events, indicating that mineral dewatering reactions can cause an avalanche of energy release up to geodynamics scale. A particularly interesting solution of the reaction-cross-diffusion equation is the rogue-wave phenomenon where the release of system energy is focussed both in time and space. Here we investigate whether the characteristics of this solution can be considered as a candidate for an earthquake triggering event. In this context a promising avenue for earthquake forecasting could be the monitoring of release of microstructural energy in the form of quasi-soliton waves, the magnification of energy release through transition into time periodic ETS events or the final self-localising soliton wave on global system resonance that sweeps from the far-field into the future location of the earthquake.

Examples of the Use of Concept of Proximity Measures in Geophysics

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Using the concept of proximity measure is convenient for analyzing and systematizing of complex sets of natural objects, identifying the degree of proximity or difference of among groups of these objects. Proximity measure can be constructed in different ways in different cases. Several variants of construction of proximity measure in geophysics are used and discussed. The first one concerns the use of the Tanimoto measure. As a result of applying of this method to the world database on large ore deposits, the clustering scheme was obtained, some pieces of which were quite trivial and expected, while some other were not previously known. The second approach to proximity measure estimation of two types of spatially distributed point objects was based on the calculation of new notion named the mixed correlation dimension. The mixed correlation values characterize the tendency of "mutual attraction" or "mutual repulsion" objects of of two types in different spatial scales. The third method of the proximity measure estimation concerned the analysis of the chemical composition of samples and their proximity to each other and to the average chemical composition of different layers of the Earth's crust and different types of biotas. In case of sufficient data availability this method makes it possible to estimate the root depth of the examined fluid systems and to determine the dominant type of initial biomass associated with this fluid. A formal system of clustering of claustobioliths, carbonic, hydrocarbonic, and mud volcanic fluids was obtained this way also. The used methods for the degree of proximity assessing were proved to be quite convenient and effective and could be fruitful in analysis of other sets of natural objects.

Applying Artificial Intelligence Methods for Simulating Atmospheric CO_2 Concentration From Polar Temperature Proxy Records

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The Antarctic and Greenlandic ice cores provide very important archives for ancient atmospheric greenhouse gas (GHG) concentrations. Especially, abrupt climate changes that occurred in the last glacial period draw attention of scientists and many studies investigated ice core records to analyze the relations between different climate variables such as temperature and CO_2 concentration. In this regard, achieving high-resolution, precise, and continuous data of CO_2 concentration will be critical for understanding feedbacks between greenhouse gas and climate in many different regions during climate change events. With this aim, applying state-of-the-art mathematical methods can be helpful, and one of the latest ones is AI (Artificial Intelligence). Emerging machine learning and AI algorithms can lead to high-quality outcomes in climate change sciences. In this study, for the first step we collected CO_2 concentration with $\delta^{18}O_{ice}$ (temperature proxy) of Antarctic (WAIS =West Antarctic Ice Sheet) and Greenlandic (NGRIP=North Greenland Ice Core Project) ice cores, during 8.8-67 ka (ka = age of thousand years). In the second step, we attempted to apply several mathematics methods to produce the data with the same intervals. Then, by running ANN (Artificial Neural Network) and Wavelet (WL) techniques, we modeled CO_2 concentration with $\delta^{18}O_{ice}$ of WAIS and NGRIP. The training, validation, and test processes were run as 70%, 15%, and 15% of the temperature proxy data. Finally, the results confirmed that the developed model has an acceptable outcome by R^2= 0.99 and RMSE (Root Mean Squared Error) = 0.86 ppm. This modeling confirmed that using AI methods can be effective to simulate CO_2 data with the two polar temperature proxies. In the next step, we will progress this model for composite CO_2 data and extend the study period to pre-Mid Pleistocene Transition where no accurate CO_2 records are available, but glacial-interglacial cycle changes its period from 40,000 to 100,000 years.

Diffusion of Water Vapor at Lunar Polar Conditions

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Water (H_2O) is a scientific and economic resource on the Moon that is central to the lunar exploration program. Migration of water molecules in the porous subsurface is one of the processes that control the abundance and distribution of water ice in the lunar polar regions. At low temperature (roughly <160 K), migrating water molecules spend most of their time adsorbed on grain surfaces rather than in-flight. This leads to conceptual differences compared to the common description of diffusion in porous media, but molecules still follow a random walk. Under suitable conditions, diurnal temperature cycles can cause a net migration of water molecules downward, leading to sequestration of ice (a process known as "vapor pumping"). This sequestration can occur outside of the cold traps (<110 K) that are traditionally thought to host ice reservoirs on the Moon, but are difficult to access. This presentation will introduce a hierarchy of physical and mathematical models that quantify sequestration of water on the Moon. See also Astrophys. J. Lett. 927, L34 (2022).

References:
Schorghofer Norbert, Gradual Sequestration of Water at Lunar Polar Conditions due to Temperature Cycles, *Astrophys. J. Lett. L34,* 927.2, (2022).

Uncertainty Quantification for Joint Inversion of Magnetotelluric, Receiver Function, and Rayleigh Wave Dispersion Data

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Imaging features such as the lithosphere-asthenosphere boundary (LAB) beneath cratons or shallow crustal layers remains challenging. Joint inversion of electro-magnetic and seismic data provides significant resolution improvements, but uncertainty quantification is an active area of research. For example, magnetotelluric data often resolve the LAB due to their sensitivity to partial melt occurring in this region but not the Moho. In contrast, seismic data resolve the Moho but not the LAB. We apply Bayesian trans-dimensional inference, which accounts for correlated data residuals, to the joint inversion of magnetotelluric, receiver function and Rayleigh wave dispersion data to study lithospheric structure beneath the Western Canada Sedimentary Basin (WCSB). The noise model provides objective data weighting without the requirement for practitioner input and accounts for residual correlations. We consider both empirical estimation of non-Toeplitz noise covariance matrices and hierarchical autoregressive models. The trans-dimensional Earth model assumes structural coupling for each layer, which is straightforward to implement and provides meaningful results at the WCSB study sites. In addition, we consider an alternative structural coupling, where resistivity and seismic velocity parameters within a layer are treated as a trans-dimensional model. The posterior probability density is estimated by the reversible-jump Markov chain Monte Carlo algorithm with parallel tempering. Posterior statistical tests are applied to residual errors to ensure that the assumptions about noise in formulating the likelihood function are met. Joint inversion results for the Athabasca site in the WCSB show excellent fit to data without the requirement to specify data weights and remarkable improvements in resolution compared to individual inversions. The results resolve the thickness of the WCSB, the Precambrian basement, Moho, and LAB. Uncertainties on the positions and resistivities/velocities of these discontinuities are significantly reduced compared to individual inversions.

Probabilistic Seismic Hazard Assessment (PSHA) in Western Himalaya

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Seismic hazard analysis involves the quantitative estimation of ground shaking at a particular site for a particular region. Traditionally, peak ground acceleration (PGA) has been used to quantify ground motion in PSHA. In the present study, Probabilistic Seismic Hazard Analysis (PSHA) has been carried out for Western Himalaya located in the North-East part of India (Latitude 32.3^0-36.3^0 N and Longitude 73.5^0-80.5^0 E). In this region, many active faults are present. Due to these active faults, Western Himalayas is an earthquake-prone region. The highest earthquake in the region are M_w 7.8 in Kanga on 4th April 1905 and Muzaffarabad, Pakistan has also faced a Mw 7.6. Using the Gumbel Extreme Value Method Gumbel parameters, the yearly expected number, return period, probability of occurrence, and probability of recurrence for different time periods are estimated. Study also investigates seismic hazards by PSHA using Crisis 2015 software. For this purpose whole area has been divided in to three zones namely the Karakorum Fault Zone, Kishtwar Fault Zone, and Mantle Fault Zone based on seismotectonics and geomorphic criteria. For estimation of seismic hazard, a homogeneous and complete earthquake catalogues (1900 to 2021) are used. The a & b values are found out 4.72 (3.20) and 0.92 (0.7) and compared. The PGAs are calculated for different periods e.g., 225yrs, 475yrs, and 2475yrs for 20%, 10%, and 2% exceedance probabilities respectively, for different districts of Jammu & Kashmir, and Ladakh in the Western Himalayas advocating that PGA values are increasing with increasing return periods.

Estimates of the Sea-level Rise Rate From Tide Gauges: the Effects of Data Heterogeneity

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Nonlinear dynamics of the global sea-level changes representing complex interactions between various geophysical forces requires specific methods of analysis. This talk assesses the dynamics of the rates of global sea-level rises from tide-gauge data with numerous gaps accounting for the spatio-temporal heterogeneity in the local rates. With 60-70 year sliding windows, we estimate the rate of sea-level changes at specific spatial locations and derive that the probability distribution of the local rates is fat-tailed. We introduce a new methodology which transforms the local rates of sea-level changes into global ones. Motivated to verify the predictions of the dangerous rate of sea-level rises, we are focused on the upper estimates of these rates using only the statistically significant positive local rates when constructing the global rate. Given the fat tails associated with the local rates, the extreme values are eliminated as they, containing a large component not associated with the ocean, are irrelevant to the problem in question. The median and the error bars obtained with the bootstrap method, after such preprocessing of the samples, result in our upper estimates of the rate of the global sea-level rise: 1.78 ± 0.13 mm/yr over the period 1946-2015 and 1.96 ± 0.08 mm/yr over 1950-2019. These estimates favor those 1900-1950 reconstructions of the sea level performed by different groups that result in larger values. The dynamics of our estimates exhibits a general growth agreeing with the state-of-the-art despite their values being moderate with respect to those found by other scholars.

Prediction of Ionospheric Total Electron Content Data Using Spatio Temporal Residual Networks

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The spatio-temporal characteristics of ionospheric total electron content (TEC) data are modeled using the Spatio-Temporal Residual Network (ST-ResNet). The time axis is divided into recent, near and distant time and the TEC maps are fed into Closeness, Period and Trend channels to model the temporal properties. The output of these three residual networks is then aggregated with the external Interplanetary Magnetic Field (IMF) data namely, the By and Bz components of the Earth's Magnetic Field, Plasma Flow Speed, Disturbance Storm time index and Solar index F10.7. We selected the latitude region between 0ºN to 75 ºN and longitude zone 110ºW to 34ºE for the present study. The objectives of this study are i) to evaluate the performance of the model for TEC prediction using the IMF data and ii) to assess the performance of the model for different geographic locations during different solar conditions. The RMSE of 1.82 when the IMF data were not included, was improved to 1.06 when the IMF data were considered. This signifies the importance of IMF data in TEC prediction. The predicted TEC for equatorial (0 º-10 º), low (10 º-30 º), mid (30 º-60 º) and high (60 º-75 º) latitude regions have low RMSE values of 1.54, 0.95, 0.81 and 0.79 respectively. The TEC prediction was also made during the solar maximum year (2014) and during solar quiet year (2020). The RMSE for 2014 is 3.132 and for 2020 is 1.061, suggesting that the prediction capability of our model is relatively higher during low solar activity period. The results of the present study are observed to be better than those obtained by the Ordinary Kringing based Surrogate model and Standard Persistence Model, confirming that our model is well suited for prediction of TEC at different geographical locations and also during different solar conditions.

Linear Inverse Problems and Quadratic Spectral Estimators of Planetary Potential-Field Data Collected at Satellite Altitude: Theory and Applications

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Time-limited (or space-limited) functions cannot be simultaneously bandlimited (in frequency). Yet the finite precision of measurement and computation unavoidably bandlimits our observation and modeling scientific data, and we often only have access to, or are only interested in, a study area that is temporally or spatially bounded. In the geosciences we may be interested in spectrally modeling a time series defined only on a certain interval, or we may want to characterize a specific geographical area observed using an effectively bandlimited measurement device. Here, we give a theoretical overview of one approach to this "concentration" problem, as proposed for time series by Slepian and coworkers in the 1960s and made famous by David Thomson in the 1980s and beyond. We show how this framework leads to practical algorithms and statistically performant methods for the analysis of signals (linear inverse theory) and their power spectra (quadratic spectral estimators) in one and two dimensions, and for scalar and vectorial signals defined on the surface of a unit sphere. In particular, we develop procedures to invert for planetary potential fields from vector observations collected within a spatially bounded region at varying satellite altitude. Our method relies on the construction of spatio-spectrally localized bases of functions that mitigate the noise amplification caused by downward continuation while balancing the conflicting demands for spatial concentration and spectral limitation. Practical examples will be drawn from the analysis of gravitational potential data, vectorial measurements of internal and external planetary fields, and other applications.

Trans-dimensional Geoacoustic Inversion for an Autonomous Underwater Vehicle Survey

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Trans-dimensional Bayesian inference using reversible jump Markov chain Monte Carlo sampling is applied to obtain posterior probability distributions of the number of homogeneous layers, their depths, and their geoacoustic parameters. The survey site is a 14-km seabed transect on the Malta Plateau. Along the survey track, 1487 source transmissions were recorded on a 32-element linear hydrophone array towed by an autonomous underwater vehicle (AUV) and data were processed as reflection coefficients versus grazing angle and frequency. When compared to vertical seismic profiling, this analysis method yields uncertainty quantification of seabed parameters, including layer depths, without distortion that is common in seismic time-domain images. We assume a one-dimensional seabed structure for each data set which is then combined to yield a two-dimensional subsurface profile. Due to the proximity of source and array to the seabed, full wavefield effects are accounted for in predicting reflection coefficient values. To ensure efficiency, the implementation of this forward model and inversion algorithms is GPU accelerated and takes advantage of Levin integration. The implementation scales well on high performance clusters, enabling full uncertainty analysis of this large data set. Comparisons of inversion results to piston and gravity core estimates show agreement in both acoustic parameter values and depths of discontinuities. Comparisons to separately recorded wide-angle data with a fixed hydrophone and surface-towed source show similarly good agreements for two locations along the track. Results at greater depths, particularly in the basement half-space of the model, exhibit higher uncertainty and strong influence of chosen prior boundaries, consistent with the reduced sensitivity of reflection coefficients to this portion of the model space. When inverting the entire data set, dipping and terminating layers are observed along the track with high vertical resolution (~10 cm).

Integral Transforms in the Inversion of Geophysical data - A Simple and Comprehensive Review

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Integral transforms in the inversion of geophysical data particularly potential field data dates back to early 1950s with the application of the oldest of all integral transforms viz.the Fourier transform(FT) or Spectral analysis. Essentially, the Fourier transform, paves way for extracting parameters such as depth/width/dip of the subsurface 2-D and 3-D structures in frequency domain by means of simple analytical expressions. Followed by this, tools such as Hilbert transform and its modified version, the Mellin transform, Hartley transform, Wavelet transform etc gained great importance in the interpretation of geophysical data either in space domain or in transformed domain with some added advantage in some cases. It may be shown that all these transforms some way or other have intimate relations with the Fourier transform either in computation or by other means. Further, the Hartley transform essentially remain the same as the Fourier transform in which the Hartley transform being a real function where as the Fourier transform is complex, however both ensure identical results in all their applications. On the other hand, the Hilbert transform ensure precise location of subsurface targets besides yielding the source parameters as a function of real roots of the equations of potential field. Mellin transform aid in the inversion of geophysical data through some rigorous mathematical manipulations. Further, the Wavelet transforms have very limited applications in such inversion of extracting source parameters from gravity and magnetic data, however, extensively being used in processing particularly denoising of geophysical data including seismic and other data as in the case of other transforms. In all these applications, the source parameters are obtained from simple analytical expressions or empirical relations or even extended empirical relations. This presentation elucidate the importance of these tools with an example in each gravity, magnetic, self potential and VLF-EM highlighting their salient features.

Mimetic Finite Difference Scheme to Solve DC Resistivity Forward Modelling Problem

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DC Resistivity is a geophysical technique used to image the earth's subsurface. In order to solve this problem for realistic scenarios, we need to design forward modelling algorithms that work accurately for various complex geological models. In this work, we have developed an algorithm for DC Resistivity using Mimetic Finite Difference Methods (MFDMs). MFDMs are a particular class of methods designed to incorporate the properties of the physical process, like the conservation law, symmetry property, discontinuity of the coefficients, fundamental theorem of differential, and integral calculus. Moreover, MFDMs have the capability of incorporating highly distorted, non-orthogonal grids. The developed algorithm is tested on dyke models to establish the accuracy of the code. Various dyke models incorporating different levels of contrast with the background are used as test cases since the analytical solution is available for such cases. The model response is simulated on anisotropic models with discontinuous properties, and the presence of the analytical solution guarantees the accuracy of the developed numerical scheme. The numerical response are also obtained for a variable topography case. The numerical results are compared with published results for a variable topography case. The algorithm's stability is an essential factor that must be tested rigorously. We achieve the same by taking a three-layer model and obtaining the apparent resistivity curve for orthogonal grids. To test the stability, the grids of the same model are distorted from low levels to very high levels of distortion. Those grids for which the angle at the grid node is outside the 25 to 155 degrees interval are characterized as highly distorted. It is seen that even for highly distorted grids, the maximum error in surface potential lies below 1.1%. These tests prove that the algorithm is very stable with respect to grid distortion, and it can be used to analyse geo-electrical data of complex geological scenarios.

Processing Strategy for Airborne Vector Gravimetry Based on Spatial Gravity Modeling

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Airborne gravimetry is the gravity observation technique based on processing gravimeter measurements collected during survey flights. In strapdown airborne gravimetry, measurements are collected using a gravimeter based on a navigation-grade strapdown inertial navigation system (INS) and GNSS receivers. We present a processing strategy for the gravity vector estimation from strapdown airborne gravimeter measurements. The well-known problem of airborne vector gravimetry is that the gravity horizontal components (deflections of the vertical) are observed only in combination with the INS systematic errors. We propose a strategy that is based on using an a-priori spatial gravity model in the INS-GNSS integration algorithm in order to regularize the problem. The a-priori spatial model is based on parameterizing the disturbing potential by the spherical scaling functions. The unknown parameterization coefficients are estimated in the INS-GNSS integration algorithm using the Kalman filtering framework. The developed strategy was applied to processing measurements from a state-of-the-art strapdown gravimeter (produced by iMAR GmbH) flown in several survey flights in Russia. We show that the proposed strategy allows to separate the gravity horizontal components from the INS systematic errors. The obtained gravity component estimates are compared to the XGM2019 gravity data, which shows optimistic accuracy results at the level of 2-3 mGal.

Measurement-based Perturbation Theory for Parameter Estimation in Differential Equations

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Parameter estimation in differential equations first originated from a paper by Gronwall on Ann Math almost 100 years ago. The method has been currently implemented and used in statistics, chemical engineering and satellite gravimetry and many other areas of science and engineering. Earth's gravitational models have been routinely produced from satellite tracking measurements of CHAMP and/or GRACE types by major institutions worldwide, for example, NASA Goddard Space Flight Center and German Research Center for Geosciences (GFZ). These global gravitational models have found widest possible multidisciplinary applications (hydrology, environmental studies, seismology) in Earth Sciences. The method is essentially implemented by solving the differential equations of the partial derivatives of the orbit of a satellite with respect to the unknown force parameters under the zero initial conditions. We prove that the method, as currently implemented and used in mathematics/statistics, chemistry/physics, and satellite gravimetry, is groundless. In other words, it is mathematically incorrect and physically not permitted. I present three different methods to derive local solutions to the Newton's nonlinear differential equations of motion of satellites, given unknown initial values and unknown force parameters. They are mathematically correct and can be used to estimate unknown differential equation parameters. These solution methods are generally applicable to any differential equations with unknown parameters. I develop the measurement-based perturbation theory and construct global uniformly convergent solutions to the Newton's nonlinear differential equations of motion of satellites, given unknown initial values and unknown force parameters. From the physical point of view, the global uniform convergence of the solutions implies that they are able to exploit the complete/full advantages of unprecedented high accuracy and continuity of satellite orbits of arbitrary length and thus will automatically guarantee theoretically the production of a high-precision high-resolution global standard gravitational models from satellite tracking measurements of any types. In addition, I develop one more alternatve by reformulating the problem of estimating unknown differential equation parameters with unknown initial values and unknown force parameters as a standard condition adjustment model with unknown parameters.

References:

Xu P (2018) Measurement-based perturbation theory and differential equation parameter estimation with applications to satellite gravimetry. Commun Nonlinear Sci Numer Simulat, 59, 515-543. DOI 10.1016/j.cnsns.2017.11.021

Xu P (2008) Position and velocity perturbations for the determination of geopotential from space geodetic measurements. Celest Mech Dyn Astr, 100, 231–249.

Xu P (2009) Zero initial partial derivatives of satellite orbits with respect to force parameters violate the physics of motion of celestial bodies. Sci China Ser D, 52, 562–566.

Xu P (2012) Mathematical challenges arising from earth-space observation: mixed integer linear models, measurement-based perturbation theory and data assimilation for ill-posed problems. Invited talk, joint mathematical meeting of American mathematical society, Boston, January 4–7.

On Exploiting Big Data From Oil and Gas Industry Social Medias: A Sentiment Analysis of Algerian Data

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With the rapid increase in the world's population of the Internet, users are connected every day to the Internet, and in particular to social networks. Therefore, digital notoriety today is not taken lightly, it became a necessity. Indeed, in a few minutes, a bad buzz could go viral and spoil the work of companies and brands, swaying their image. The digital image of a company is made up of all the content produced and distributed by it on the web. But even more, it is mainly formed by the content that is posted by the users themselves, on blogs, forums, community platforms, social networks, etc. In fact, it is commonly considered that of what is said about a brand does not come from the brand itself, but acquires great importance. E-reputation is a concept that is developing more and more. Organizations try to better master the concepts and practices associated with e-reputation, in order to follow the rapid evolutions of the web, and the evolution of its online notoriety and oil and gas companies are no exception. In this work, a study applying two methods of sentiment analysis, lexicon based and machine learning is conducted on Algerian dialect from oil and gas social media data. Despite the several difficulties, encountered during this pioneer research in Algerian petroleum industry, related to the lack of data resources (dataset and dictionary of the Algerian dialect), such as: the extraction of data from Social media (Facebook, etc.) as well as the elaboration of the Algerian dictionary considering its diversity and richness, the obtained results are very promising.

Mathematical and Numerical Models of Lava Dome Dynamics

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Dome-building eruptions may vary from unthreatening effusion to highly unpredictable and hazardous activity including collapse of domes and associated pyroclastic flow hazards. We analyse the influence of the thermal cooling and the crystal content growth on the lava dome morphology at Volcán de Colima in Mexico during a long dome-building episode lasting from early 2007 to fall 2009 without explosive dome destruction. For this, we develop several mathematical models of lava dome dynamics including the kinetics of crystal content growth, temperature-dependence of melt viscosity, latent heat, and nonlinear heat exchange between the lava and the air. Camera images of the lava dome growth together with recorded volumes of the erupted lava have been used to constrain our numerical models and hence to fit the observation data of the dome growth at Volcán de Colima by nudging model forecasts to observations. We shall present the mathematical models and results of the ongoing modelling.

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