Institute of Geophysics
Polish Academy of Sciences

PUBLICATIONS
OF THE INSTITUTE OF GEOPHYSICS
POLISH ACADEMY OF SCIENCES

Geophysical Data Bases, Processing and Instrumentation

436 (M-34)

Achievements of the Institute of Geophysics, PAS: Annual Report 2019

Warsaw 2021 (Issue 5)

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C O N T E N T S

Editorial note

This Monograph outlines the recent achievements of the **Institute of Geophysics, Polish Academy of Sciences,** focusing on the main strategic areas: Geosystem Processes, Earth Structure and Georesources, Anthropogenic and Natural Geohazards, Climate Change and Polar Research.

The publication is a reviewed and formatted version of the **Annual Report 2019**, providing information about the research done at the seven departments (Seismology, Atmospheric Physics, Lithospheric Research, Theoretical Geophysics, Hydrology and Hydrodynamics, Magnetism, Geophysical Imaging, and Polar and Marine Research), together with the Institute's infrastructure, instrumentation, projects that have been completed or are under way, as well as editorial, educational, and many other activities.

We hope the information contained in this monograph may be useful for a broader audience, in particular those who may find the presented materials applicable in their work, or perhaps arrange a co-operation with the Institute.

The Editors
of the *Publications of the Institute of Geophysics PAS*

1. GENERAL

Beata Orlecka-Sikora, Mariusz Majdański, Beata Fromeliusz, Krzysztof Otto

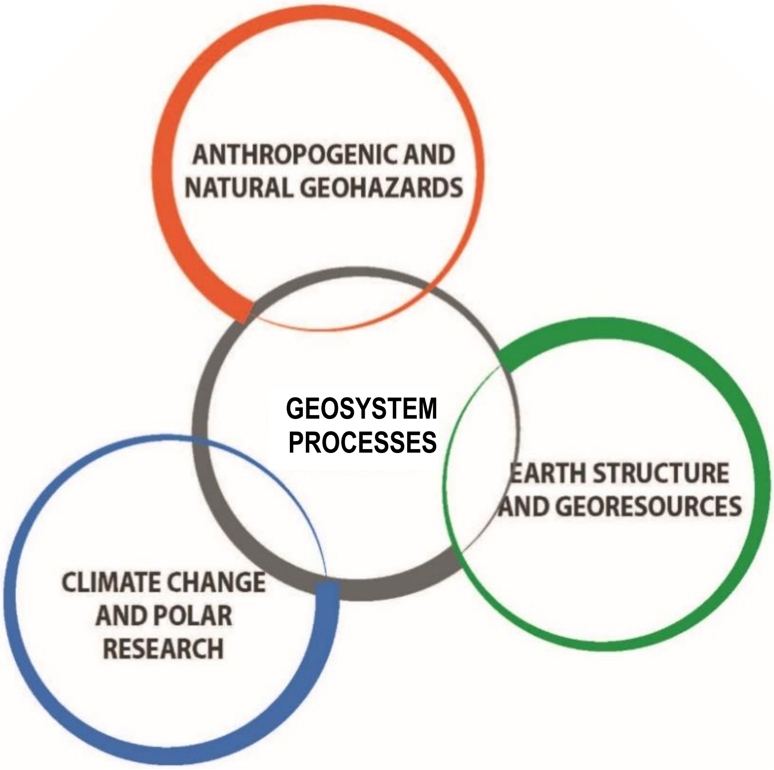
1.1 The mission of the Institute of Geophysics, Polish Academy of Sciences

Studying geophysical processes for a better understanding of the mechanisms controlling the Earth's system and risk management

- Working for the benefit of the society and economic development
- Development and maintenance of strategic research infrastructure
- Geophysical monitoring
- Training future leaders of scientific communities

1.2 Research areas

The main research areas and their interrelations



Main research areas of the Institute of Geophysics PAS.

1.3 Management

The Board of Directors:

Prof. Beata Orlecka-Sikora
Director IG PAS
(the 2nd term since Sep 2019)

Mariusz Majdański
Deputy Scientific Director

Beata Fromeliusz
Deputy Director
for Administration and Finance

Krzysztof Otto
Deputy Director
for Technical Issues

1.4 Employment structure

The structure of employment is illustrated by tables and graphs below:

The number of employees

N = 74.8	Total	Researchers	PhD students
2016	175	69	29 (6 KNOW)
2017	178	67	26 (6 KNOW)
2018	187	74	22 (6 KNOW)
2019	184	78	18 (9 DS)
Change	+9	+9	–8

The employees by function

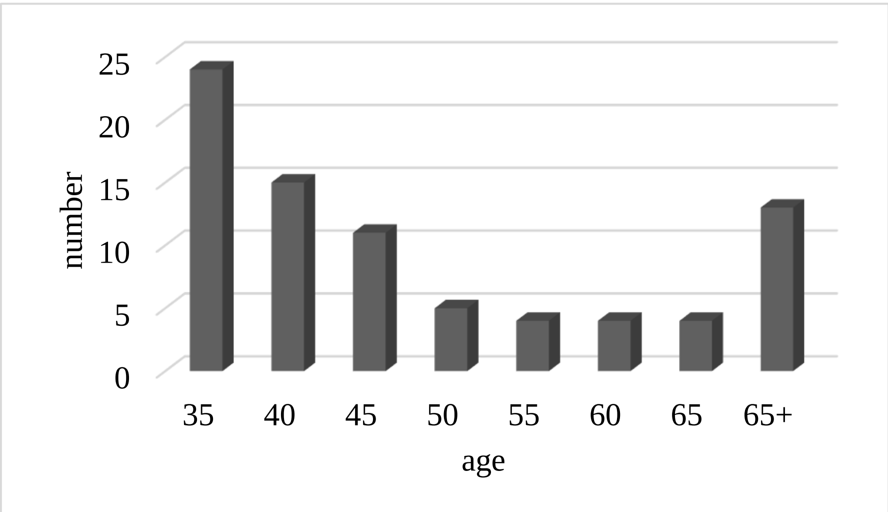
Function	Number
Polar expedition	8
Administration	59
Technicians	39
Researchers	78
Total	184

⇨

Researchers	Number
Research Assistant	12
Assistant Professor	31
Associate Professor	20
Professor	15

The employees by sex

	Female	Male
Total	80	105
Researchers	28	53
Other	52	52



Researchers' age structure.

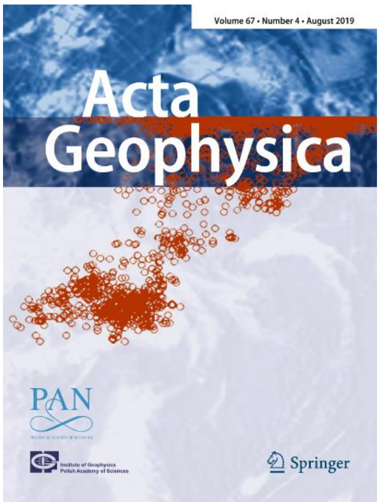
1.5 Activity of Scientific Information and Publishing Department

As in the previous years, in 2020 the activity of the Scientific Information and Publishing Department concentrated on the three titles:

- *Acta Geophysica.*
- *GeoPlanet: Earth and Planetary Sciences Book Series,*
- *Publications of the Institute of Geophysics, Polish Academy of Sciences,*

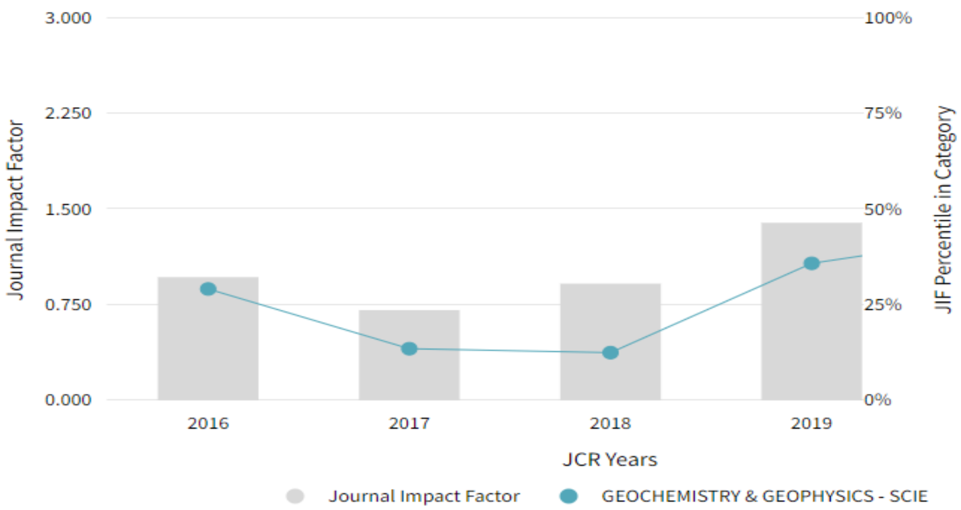
Acta Geophysica

Acta Geophysica is a leading geophysical journal published by the Institute of Geophysics and Committee of Geophysics. The Editor-in-Chief is Prof. Eleftheria Papadimitriou. In the editing of *Acta Geophysica* she is supported by eminent international experts who hold the position of Associate Editors.



Front cover of *Acta Geophysica.*

Acta Geophysica is a bimonthly journal, so six issues were published. The total number of pages (B5) was 2047, and the number of articles was 158. The impact factor amounted to 1.395.

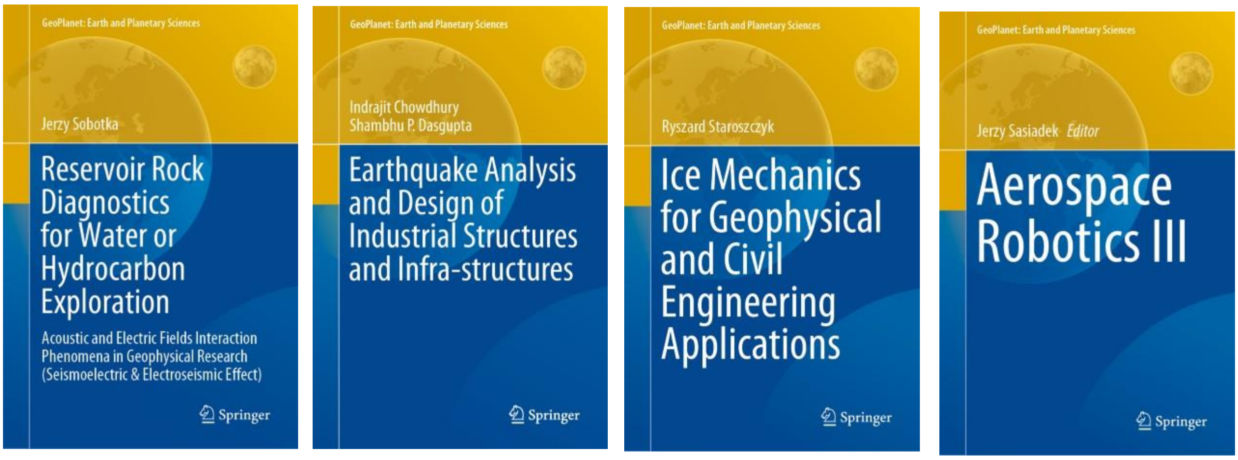


Impact Factor of *Acta Geophysica*.

GeoPlanet: Earth and Planetary Sciences Book Series

The Editor-in-Chief of *GeoPlanet Series* is Prof. Paweł M. Rowiński.
The following four books were published in 2019:

- “Reservoir Rock Diagnostics for Water or Hydrocarbon Exploration” by Jerzy Sobotka;
- “Earthquake Analysis and Design of Industrial Structures and Infrastructures” by Indrajit Chowdhury and Shambhu P. Dasgupta;
- “Ice Mechanics for Geophysical and Civil Engineering Applications” by Ryszard Staroszczyk;
- “Aerospace Robotics III” ed. by Jerzy Sąsiadek.

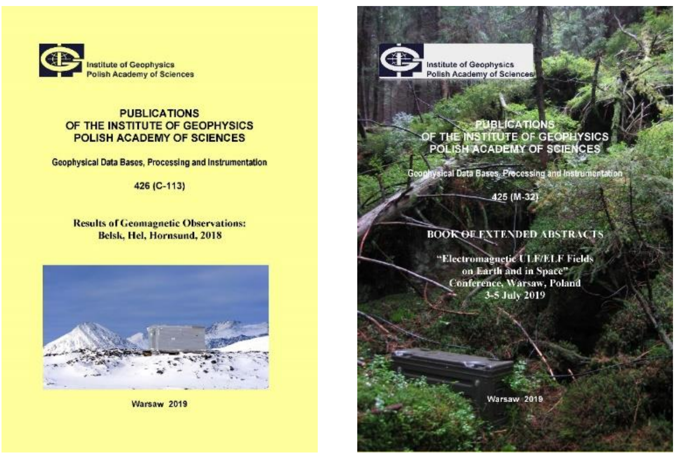


Front covers of *GeoPlanet* books issued in 2019.

Publications of the Institute of Geophysics, Polish Academy of Sciences

It is an electronic journal published by the Institute of Geophysics. It is available at https://pub.igf.edu.pl/.
The Editor-in-Chief is Marek Kubicki. In the year 2019, two issues were published:

- “Results of Geomagnetic Observations: Belsk, Hel, Hornsund, 2018” by Jan Reda, Mariusz Neska, Stanisław Wójcik, and Paweł Czubak;
- “Book of Extended Abstracts. “Electromagnetic ULF/ELF Fields on Earth and in Space” Conference, Warsaw, Poland, 3-5 July 2019” ed. by Andrzej Kułak and Anna Odzimek.



Front covers of *Publications of the Institute of Geophysics, PAS* issued in 2019.

1.6 Educational activity of the Institute in the Academic Year 20192020

The GeoPlanet and International Environmental Doctoral Schools made their debut in October 2019 and immediately turned out to be a great success, as evidenced by the great interest of candidates for the first year of studies.

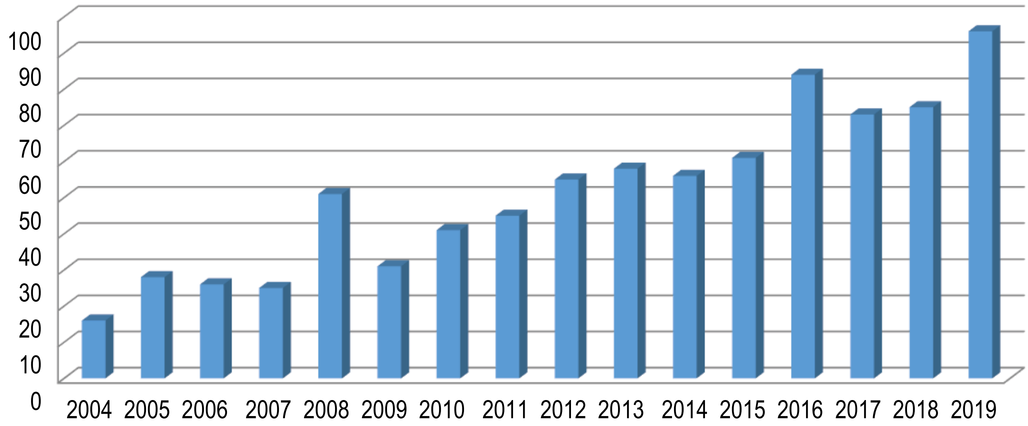
The GeoPlanet PhD School offers interdisciplinary studies in 7 scientific institutions of the Polish Academy of Sciences. The main tasks of the school include educating doctoral students in climate change, dynamics of geophysical and space processes, natural disasters and extreme phenomena on Earth, in oceans and space, protection and exploitation of natural resources (including water management), monitoring of processes occurring on Earth, in oceans and in the Solar System and developing new methods for the research and measurement of the Earth and space.

The International Environmental Doctoral School associated with the Centre for Polar Studies at the University of Silesia in Katowice (IEDS) provides the education in the field of Natural Sciences in academic disciplines: Mathematics, Earth and related environmental sciences, and in the field of the Engineering and Technology in academic discipline: Materials engineering. The aim of the IEDS is to provide a new generation of scientists with new opportunities for high-quality contributions to scientific research by offering them theoretical and practical (methodological) training, designed to stimulate their intellectual growth and boost their academic status.

1.7 Projects, commercial agreements and publications

FNP Fundacja na rzecz Nauki Polskiej	2 projects
NAWA Narodowa Agencja Wymiany Akademickiej	4 projects
National Science Centre Poland	29 projects
Ministry of Science and Higher Education Republic of Poland	25 projects
Narodowe Centrum Badań i Rozwoju	1 project
The Framework Programme for Research and Innovation HORIZON 2020	14 projects
Commercial agreements GIOŚ, PIG-PIB, KGHM SA, PGE	12 projects

JCR papers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2. DEPARTMENT OF SEISMOLOGY

Stanisław Lasocki

2.1 About the Department

Department of Seismology is the world's leading research group in the field of anthropogenic seismicity. This is confirmed by the scientific community by inviting the entire department and/or its employees to various international activities. The chapter "Anthropogenic Seismicity Related to Exploitation of Georesources" (Lasocki and Orlecka-Sikora, doi.org/10.1007/978-3-030-10475-7), recently published on invitation in *Encyclopedia of Solid Earth Geophysics* (ed. H. Gupta, Springer) is an example of this international recognition. However, the department's research activities extend also on natural seismic processes. The research activities presented here can be divided into: seismicity induced by exploitation of geo-resources, statistical properties of anthropogenic and natural seismic processes, seismicity induced by water reservoirs, engineering seismology, and natural seismicity of Poland. The first topic was a subject of the H2020 S4CE research project dealing with hydrofracturing, carbon dioxide storage, and geothermal energy, and two projects studying underground mining of the copper ore (funded by NCN and FNP, respectively). The research activity carried out in the Department in the framework of S4CE project has been focused on seismicity evolution in relation to fluid-injection. Studying the seismicity observed at The Geysers in California, USA, related to large-scale, long-term fluid injection into two wells, we found out that pressurized injections can lead to rock fracturing at stress levels below the rock toughness, i.e., subcritical fracture growth. Furthermore, it was found that, counterintuitively, high injection rates decrease the probability that induced seismic fractures coalesce into far-reaching pathways for fluid migration. These discoveries open a new perspective on managing the seismic hazard associating pressurised injections. Projects dealing with underground mining aim at aftershock studies as well as analyses of post-blasting seismic sources, to find characteristic physical properties of focal mechanisms, which might provide hints for the rockburst active prevention. Another research was aimed at tracking ground deformation corresponding to a massive collapse in a mine after an induced seismic event.

The seismicity induced by water reservoirs was studied on Czorsztyn (Poland), Song Tranh2 (Vietnam) and Lai Chau (Vietnam) reservoir cases. The studies, conducted in the framework of the NCN research project, concerned the natural seismicity on the sites, and the development of induced seismic activity associated with filling the reservoirs.

Monitoring of natural seismicity in Poland resulted in the recording of nine tectonic earthquakes in Podhale region.

Within the engineering seismology area, new approaches to ground motion prediction equations (GMPE) are investigated. In 2019 the estimates by Fahlman's Cascade Correlation Neural Network was improved.

In addition to significant research, Department of Seismology was also active in EPOS Programme. In 2019 the consortium EPOS Thematic Core Service Anthropogenic Hazards (TCS AH) was established. The consortium of 12 institutions from 8 EU countries, tightly linked to EPOS-ERIC, is currently lead by Prof. Lasocki from the department. The department newly participates in EPOS IP H2020 project and EPOS PL+ national project.

2.2 Personnel

Head of the Department

Stanisław Lasocki
Professor

Professor
Beata Orlecka-Sikora

Associate Professor
Artur Cichowicz

Assistant Professors
Grzegorz Lizurek
Łukas Rudziński
Konstantinos Leptokaropoulos
Maria Kozłowska
Dorota Olszewska
Taghi Shirzad
Monika Sobiesiak

Senior Technical Officer
Jan Wiszniowski

Research Assistants
Alicja Caputa
Szymon Cielesta
Beata Plesiewicz
Monika Staszek
Piotr Sałek
Paweł Urban

Technical Assistants
Izabela Dobrzycka
Dominika Wenc
Kaj Michałowski

Administrative Coordinator
Anna Leśnodorska

PhD Students
Izabela Nowaczyńska, Poland; Grzegorz Lizurek – PhD supervisor
Anna Tymińska, Poland; Grzegorz Lizurek – PhD supervisor
Alicja Caputa, Poland; Łukasz Rudziński – PhD supervisor

2.3 Main research projects

- S4CE: Science for Clean Energy, S. Lasocki, H2020, 2017–2020;
- SERA: Seismology and Earthquake Engineering Research Infrastructure Alliance for Europe, S. Lasocki, H2020, 2017–2020;
- EPOS IP: EPOS Implementation Phase, B. Orlecka-Sikora, H2020, 2015–2019;
- EPOS PL, D. Olszewska, POIR, OPI, 2016–2021;
- Analysis of post-blasting seismic sources recorded after rock burst active prevention, A. Caputa, NCN, 2018–2020;
- Comprehensive analysis of the impact of local production conditions, main shock parameters and stress transfer on productivity and distribution of aftershocks in induced seismicity –

research for improving the safety of natural resources extraction, M. Kozłowska, Fundacja Nauki Polskiej, 2018–2020;
- Initialization and development of anthropogenic seismic processes induced by artificial surface reservoirs, G. Lizurek, NCN, 2018–2021.

2.4 Instruments and facilities

Equipment

Seismic networks:

- LUMINEOS – seismic network for monitoring the mining-induced seismicity in Legnica–Głogów Copper District,
- BOIS – seismic network for monitoring the seismicity induced by mining in Lubelski Węgiel Bogdanka,
- SENTINELS – seismic network for monitoring the induced seismicity around Czorsztyn–Niedzica artificial lake,
- Lai Chau – seismic network for monitoring the seismicity in the vicinity of an artificial water reservoir in Vietnam,
- Hue – seismic network for monitoring the seismicity in the vicinity of an artificial water reservoir in Vietnam,
- Geodynamic monitoring of Poland,
- Monitoring of the area of past hydrofracturing operations.

Department of Seismology in cooperation with Technical Support Department is involved in seismic monitoring of potential nuclear power plant (NPP) site in northern Poland since 2015. During that time, IG PAS has been operating surface seismic stations including broadband and short period devices. In 2019 the network was extended in accordance with agreement assigned between IG PAS and PGE EJ1. The signals are recorded continuously and contain information not only about possible local seismic activity but also influences of regional earthquakes.

INFRASTRUCTURE BUILDING:

Department is leading TCS AH of European Plate Observing System. The mission of TCS AH is to integrate research infrastructures for studies on anthropogenic hazards particularly those related to the exploration and exploitation of geo-resources. The TCS AH consortium of 12 European institutions is maintaining and further developing the e-research platform IS-EPOS with the international data nodes connected to it. The platform provides open access to unique datasets called episodes, to bespoke software application and to specialised written materials from the field of anthropogenic hazards. The development of these TCS AH resources is supported in the framework of various European and national projects.

Long term service contracts:

- Supervising the monitoring of seismic impact due to mining exploitation on the OUOW “Żelazny Most” repository embankment seismic network and the stations monitoring the western foreland of OUOW;
- Monitoring of seismic phenomena within the mining area, in particular determining the energy of events and their location using IG PAS equipment;
- Geodynamic monitoring of Poland.

Laboratory

Department of Seismology is equipped with 78 modern seismic stations: 62 broadband, 6 very broadband seismometers, and 10 strong-motion monitoring devices. 48 stations are already installed in seismically active areas: two mining regions in Poland and two regions with seismicity induced by water reservoirs in Poland and Vietnam. With the exception of data embargoed by the principals, all data is on the IS-EPOS Platform (http://tcs.ah-epos.eu/).

IS-EPOS e-platform owed commonly by IG PAS and the Academic Computer Center Cyfronet AGH, whose concept has been worked out in the Department of Seismology, is a gateway for the data and research applications related to anthropogenic hazards. The data are stored in data nodes, whereas the metadata, applications, and AAAI are on the platform. There are two data nodes linked to the platform. One in IG PAS, managed by Department of Seismology, and the other is located in and managed by EOST in Strasbourg. Currently, 31 out of 36 datasets, called episodes, are available on IS-EPOS platform and stored in Polish e-Node.

2.5 Research activity and results

Brief description/abstracts/summaries of some of the achievements of the Department's staff:

FRACTURE GROWTH MECHANISMS

B. Orlecka-Sikora, **S. Cielesta**

Seismicity induced by geo-engineering operations may be hazardous for people, infrastructure and the environment. The crucial information for assessing induced seismic hazards and related risks is the knowledge of time-dependent strength of rocks and of deformations due to fluid injection. Studying the seismicity observed at The Geysers (TG) in California, USA, related to large-scale, long-term fluid injection into two wells, Prati-9 and Prati-29 we found out that

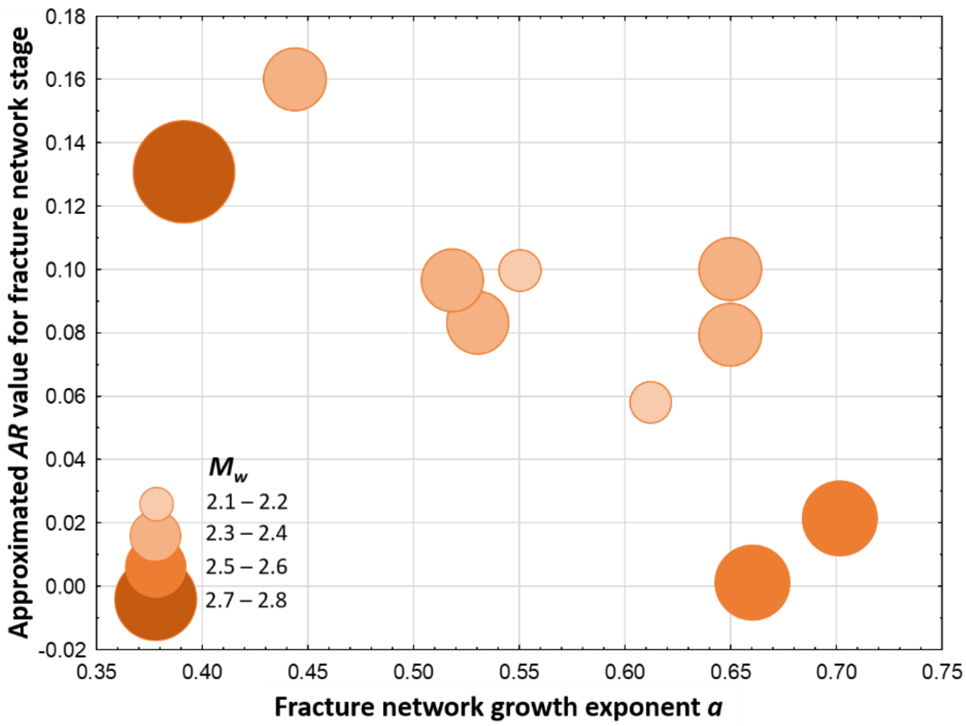

Fig. 1. The fracture network growth "a" parameter versus $|(\sigma_1 - \sigma_2)/(\sigma_1 - \sigma_3) - 0.5|$ *estimated for the consecutive 50-event windows with 10 events overlap for the analyzed dataset.*

pressurized injections can lead to rock fracturing at stress levels below the rock toughness, i.e., subcritical fracture growth (SFG). Providing evidence for subcritical mixed-mode fracture growth at TG, we evaluated the impact of the injection rate on SFG and on the maximum magnitude of analysed earthquakes. We found also that SFG is governed by the changes in stress due to the injection of water into the reservoir, and we provided the relation between the injection rate and the fracture growth rate (Fig. 1). Our approach provides a new perspective on earthquake mechanics driven by fluid injection. Recognizing the phenomenon of subcritical fracture network growth and its reaction to technological activity and combining this information with the characteristics of the stress state in the reservoir can be used to help manage seismic hazards and optimize production. Based on SFG information, we can infer when the transient fracture network growth rate is slowing, or when it implies increasing event rate and a risk of large events occurrences during operations. Seismic hazard management during fluid injection can then be supported by adjusting the injection schedule to keep the fluid pressure and the injected volume below a critical level, at which the observed maximum magnitude approaches an allowable level.

RELATIONSHIPS BETWEEN A POTENTIAL TO BUILD FAR-REACHING PATHWAYS FOR FLUID MIGRATION AND INJECTION RATES

S. Lasocki, **B. Orlecka-Sikora**

Geothermal energy production is often based on pumping cold water to deep hot rocks and extracting hot water or steam. This process induces brittle fracturing of rocks, that is seismic events, which enhances the rock permeability and increases the surface on which heat exchange takes place. However, the seismic fractures may also coalesce into undesired pathways enabling

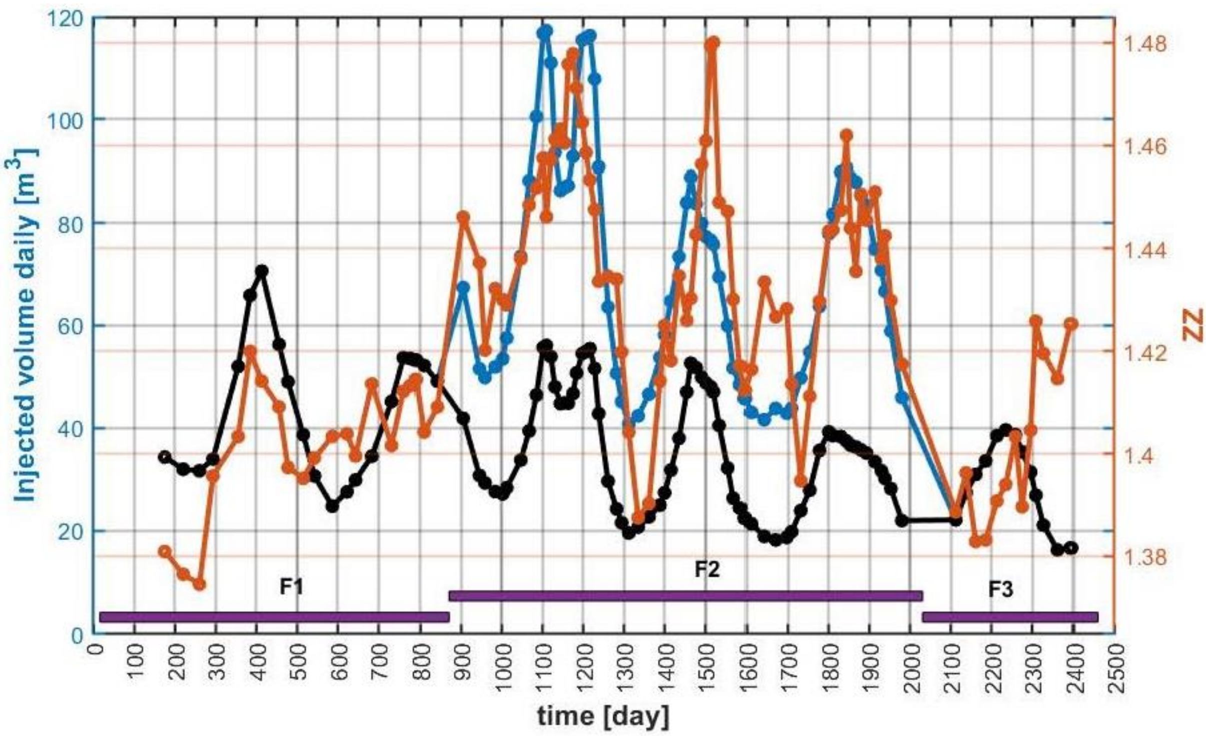

Fig. 1. Comparison of the time-variation of ZZ with the time-changes of average injection rate. Black – the injection rate into Prati9 well, blue – the total injection rate into Prati9 and Prati29 wells, brown – ZZ. The horizontal bars mark the durations of injection phases. It is seen that in the first two phases ZZ positively correlated with the injection rate whereas in the third phase the correlation was negative (after Lasocki and Orlecka-Sikora 2020).

the fluids to migrate far and reach pre-existing tectonically preloaded faults. Then the fluids decrease fault strength, and, as a result, the fault can rupture producing a major seismic event. Furthermore, the migrating fluids may contaminate groundwater. We have formulated three conditions which we expect to play a role in linking fractures and building such pathways: closeness of hypocenters; similarity of fracture planes orientations; closeness of radii, which begin at the open hole section of the injection well and on which events occur. Beginning from these three conditions, which we assume determine jointly the potential of seismic sources to build far-reaching pathways for fluid migration, we parameterize this potential by the average distance between the events in the 8D space of hypocentral coordinates, of angles of orientations of the T and P axes of the double-couple focal mechanisms, and of angular coordinates of hypocenters in the spherical system beginning at the open hole of injection well. Because the metrics of these parameters are not the same and, moreover, for some of their metrics are not Euclidean, thus, we transform these parameters to ED. This average distance, computed in the ED space, called the degree of disordering of sources, ZZ, expresses to which extent the above three conditions have been fulfilled. The chance for the seismic events with small value of ZZ, which they link and reach far is higher than in other cases. In the studied case from The Geysers geothermal field, in the injection phases where the injection rate level was high ZZ correlated positively with injection rate. Also, the amplitudes of the ZZ-changes agreed well with the amplitudes of the average injection rate changes (Fig. 1). Hence, the optimal conditions to avoid such ordering of seismic fractures that enable linking them into longer pathways, extending farther from the injection point were met for high injection rates. The higher the injection rate was, the more disordered the seismic fractures were generated, i.e., the chances to build longer pathways for undesired fluid migration decreased. This result, if confirmed in other cases of injection-induced seismicity, will open new perspectives on managing seismic hazards and optimizing technological production.

INTEGRATION OF GEODETIC AND SEISMOLOGICAL TECHNIQUES FOR BETTER UNDERSTANDING OF MINING COLLAPSE

Ł. Rudziński, **G. Lizurek**, **D. Olszewska**

The collapse of a mine roof which occured in Rudna copper mine, Poland resulted in a significant surface deformation and generated a tremor with a magnitude of *M*4.6. This study combines the seismological and geodetic monitoring of the event. Data from local and regional seismological networks were used to estimate the mechanism of the source and the ground motion caused by the earthquake. GNSS data, collected at 10 Hz, and processed as a long-term time-series of daily coordinates solutions and short-term high frequency oscillations, are in good agreement with the seismological outputs, having detected several more tremors. The range and dynamics of the deformed surface area were monitored using satellite radar techniques for slow and fast motion detection. The radar data revealed that a 2-km^2 area was affected in the six days after the collapse and that there was an increase in the post-event rate of subsidence (Fig. 1). This investigation has provided a new method for dealing with hazardous rock bursts in underground mines. The current study has proved the high potential for obtaining a broader understanding of anthropogenic hazards by combining different Earth monitoring techniques. Joint geodetic and seismological observations can complement each other and help to overcome the individual disadvantages of the separate methods. The method would be especially useful in areas with sparse seismic monitoring and/or regions with already known isotropic source mechanisms, such as mining or volcanic. The study is the next step for understand the surface effects deal with mining collapses observed previously in another mining region in Poland (see also Rudziński et al. 2019).

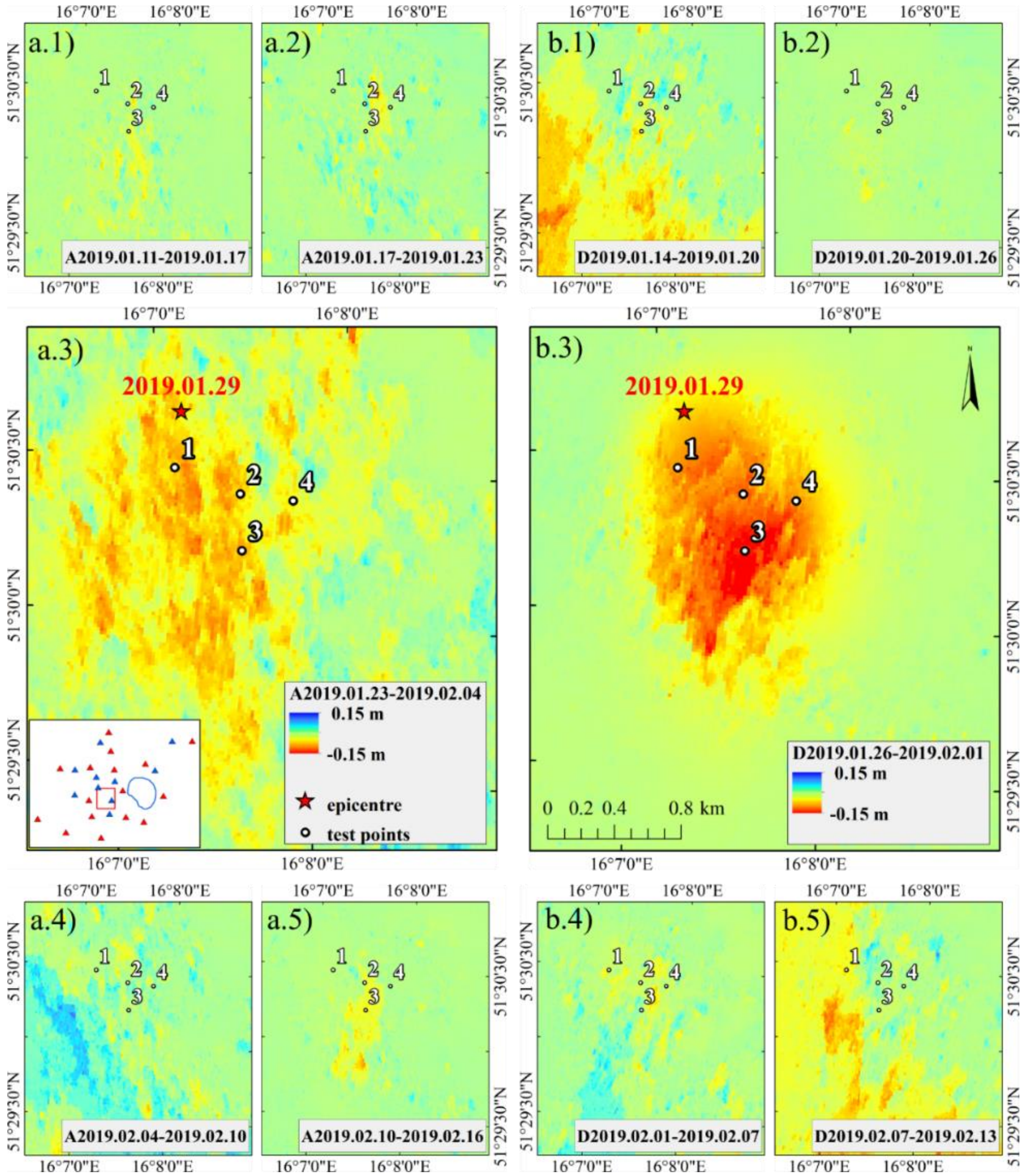

Fig. 1. Vertical deformation patterns derived from the ascending (a) and descending (b) DInSAR interferograms: (1) and (2) – pre-seismic; (3) – co-seismic – (a.3) 12-day and (b.3) 6-day; and (4) and (5) post-seismic DInSAR interferograms. The images used for each interferogram are shown in the format [YYYY.MM.DD]. The red star represents the epicenter. The inset in (a.3) shows the footprint (red rectangle) of the DInSAR results over the local LUMINEOS network. The blue polygon represents the "Żelazny Most" tailing pond (after Ilieva et al. 2020).

2.6 Visiting scientists

Jan Sileny, IG CAS, Praha, Czech Republic, 29.01.2019,
Vaclav Vavrycuk, IG CAS, Praha, Czech Republic, 29.01.2019,
Makoto Okubo, Kochi University, Kochi, Japan, 07–16.06.2019.

2.7 Publications

ARTICLES

Caputa, A., and **Ł. Rudziński** (2019), Source analysis of post-blasting events recorded in deep copper mine, Poland, *Pure Appl. Geophys*. **176**, 3451–3466, DOI: 10.1007/s00024-019-02171-x.

Cielesta, S., **B. Orlecka-Sikora**, **M. Staszek**, **P. Urban**, **D. Olszewska**, et al., **J. Jarosławski** (2019), SHEER “smart” database: technical note, *Acta Geophys.* **67**, 1, 291–297, DOI: 10.1007/s11600-018-0205-3.

Brudziński, M.R., and **M. Kozłowska** (2019), Seismicity induced by hydraulic fracturing and wastewater disposal in the Appalachian Basin, USA: a review, *Acta Geophys.* **67**, 1, 351–364, DOI: 10.1007/s11600-019-00249-7.

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Białoń, W., **G. Lizurek**, et al. (2019), Relocation of seismic events and validation of moment tensor inversion for SENTINELS local seismic network, *Pure Appl. Geophys*. **176**, 4701–4728, DOI: 10.1007/s00024-019-02249-6.

Kudlacik, I., et al., **G. Lizurek** (2019), Seismic phenomena in the light high-rate GPS precise point positioning results, *Acta Geodyn. Geomater.* **16**, 1(193), 99–112, DOI: 10.13168/AGG.2019.0008.

Mutke, G., et al., **D. Olszewska** (2019), Upper Silesian Geophysical Observation System – A unit of the EPOS project, *J. Sustain. Min.* **18**, 4, 198–207, DOI: 10.1016/j.jsm.2019.07.005.

Orlecka-Sikora, B., **S. Cielesta**, and **S. Lasocki** (2019), Tracking the development of seismic fracture network from The Geysers geothermal field, *Acta Geophys.* **67**, 1, 341–350, DOI: 10.1007/s11600-018-0202-6.

Rudziński, Ł., et al. (2019), Rapid ground deformation corresponding to a mining-induced seismic event followed by a massive collapse, *Natural Hazards* **96**, 461–471, DOI: 10.1007/s11069-018-3552-0.

Ilieva, M., **Ł. Rudziński**, K. Pawłuszek-Filipiak, **G. Lizurek**, I. Kudłacik, D. Tondaś, and **D. Olszewska** (2020), Combined study of a significant mine collapse based on seismological and geodetic data—29 January 2019, Rudna Mine, Poland, *Remote Sens.* **12**, 1570, DOI: 10.3390/rs.12101570.

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Wiszniowski, J. (2019), Estimation of a ground motion model for induced events by Fahlman's Cascade Correlation Neural Network, *Comput. Geosci*. **131**, 23–31, DOI: 10.1016/j.cageo.2019.06.006.

3. DEPARTMENT OF ATMOSPHERIC PHYSICS

Janusz Krzyścin

3.1 About the Department

The Department activities comprise the long-term monitoring and short-term observations of various unique atmospheric parameters (column amount of ozone and its vertical distribution, atmospheric electricity, lightning, aerosols characteristics, UV spectra, concentration of trace gases, waves in the tropical atmosphere) in different parts of the atmosphere: surface layer, troposphere, stratosphere, and ionosphere as well as global and regional climate modelling. The measurements are routinely carried out in Poland (IG PAS observatories: Belsk, Racibórz, Świder), and Hornsund (Polish Polar Station, Svalbard), and during short term campaigns within national and international projects. These observations provide the data examined by various statistical models and software developed in the Department. The primary tool used for climate modelling studies is the atmospheric chemistry model GEM AC. The objectives are to find out and predict variability of the atmosphere parameters and identify sources of such variability in different time scales (from days up to decades).

The Department contains five internal groups: **Atmospheric Aerosols (AA)**, **Atmospheric Electricity (AE)**, **Global Modelling (GM)**, **Ozone and UV (O_3UV)**, and **Tropical Dynamics (TD)**. Throughout 2019, the groups focused on the following subjects:

- Identification of aerosols layers in the free troposphere (based on Ceilometer soundings) and their impact on the surface UV using the Random Forest regression applied to UV radiation and aerosols data collected at Racibórz in 2019 (AA);
- Building a mobile LIDAR (Raman Lidar with YAG laser) to monitor the vertical distribution of aerosols particles – searching for cases with extreme aerosols loading in the free troposphere (AA);
- Longitudinal variability of the long-term changes of the ozone profile in the Northern Hemisphere midlatitudes in the period 1978–2018 – searching for anomaly regions (O_3UV);
- Determination of the climatological sources (more days with extreme high UV and warmer air temperature in April) of the melanoma incidence rate increase in Europe in XXI century (O_3UV);
- Development and analysis of flood database for Sumatra and case study of Makassar (South Sulawesi) flood of January 2019 (TD);
- Finding characteristics of non-linear interactions between convectively coupled Kelvin waves and local diurnal cycle in circulation over the island of Sumatra (TD);
- Quantification of the dynamical and chemical processes impact on the low ozone events in the NH midlatitudinal stratosphere (GM);
- GEM-AC model development and validation (GM);
- Detection of lightning ground flashes by our Local Lightning Detection Network in the Warsaw region to evaluate their initiation sources in thundercloud (AE);
- Analysis of main generators on the Global Electric Circuit (GEC) based on the atmospheric electricity measurements in polar and mid-latitude regions (AE).

3.2 Personnel

Head of the Department

Janusz Krzyścin
Professor

Professor
Janusz Borkowski

Associate Professors
Janusz Jarosławski
Jacek Kamiński
Aleksander Pietruczuk

Assistant Professors
Dariusz Baranowski
Agnieszka Czerwińska
Magdalena Kossakowska
Michał Posyniak
Artur Szkop

Post-Doctoral Researchers
Jakub Guzikowski
Marek Kubicki
Anna Odzimek
Izabela Pawlak
Piotr Sobolewski

Research Assistants
Piotr Barański
Jakub Wink
Sabina Kucięba

Observers
Anna Głowacka
Dorota Sawicka

PhD Students
Alnilam Fernandez, India; Aleksander Pietruczuk – PhD supervisor
Beata Latos, Poland; Aleksander Pietruczuk – PhD supervisor
Maria Kłeczek, Poland (resigned in December 2019); Jacek Kamiński – PhD supervisor
Anahita Sattari, Iran; Jacek Kamiński – PhD supervisor
Wojciech Szkółka, Poland; Krzysztof Mizerski – PhD supervisor

3.3 Main research projects

- Multi-scale interactions over the Maritime Continent and their role in weather extremes over Central and Eastern Europe, Baranowski Dariusz, Foundation for Polish Science, 2018–2020;
- Aerosols, Clouds, and Trace gases Research Infra Structure (ACTRIS-2), Pietruczuk Aleksander, H2020 Research and Innovation Framework Programme, 2015–2019;
- ACTRIS-Preparatory, Pietruczuk Aleksander, H2020 Research and Innovation Framework Programme, 2017–2019;
- Identification of processes responsible for anomalous total ozone variability in the Northern Hemisphere mid-latitudes, Kamiński Jacek, The National Science Centre (OPUS12), 2018–2020;

- Impact of the aerosols optical properties on the surface UV and photochemical smog, Pietruczuk Aleksander, The National Science Centre, Poland, 2018–2020;
- Monitoring of Total Ozone Amount in the Atmosphere and UV-B Radiation at Belsk Observatory in 2017–2020, Jarosławski Janusz, Chief Inspectorate of Environment Protection, 2017–2020;
- Impact of absorbing aerosols on the planetary boundary layer height, Posyniak Michał, The National Science Centre, Poland, 2016–2020.

3.4 instruments and facilities

Equipment

- Onset Hobo U-24-002-C (2 pieces), temperature/conductivity data logger;
- Carbon dioxide analyzer model Horiba APCA370, continuous CO2 monitoring at Belsk.

Laboratory

Mobile laboratory for aerosol and trace gases field measurements.

The lab was built on a 4-meter-long trailer with opening roof window for vertical pointing remote sensing measurements and air condition allowing four-season measurements. Build-in rack system and electrical installation allow to use series of trace gases and in-situ aerosol analysers, APOA-370 Ozone Monitor manufactured by Horiba is used now. The lab is equipped with Raman LIDAR for aerosol studies. This instrument allows for aerosol backscattering coefficient profiling at three wavelengths from UV to NIR, aerosol extinction in UV and water vapour concentrations.

3.5 Research activity and results

Brief description/abstracts/summaries of some of the achievements of the Department's staff:

GLOBAL MODELLING GROUP – SHORT SUMMARY OF ACTIVITIES IN 2019

Jacek Kamiński, **Magdalena Kossakowska**

The ozone mini holes (or low ozone events) are defined as synoptic-scale phenomena that lead to a rapid drop of total ozone, followed by complete recovery after a few days. Unlike the Antarctic ozone hole, the ozone mini holes are driven mainly by dynamical processes in the atmosphere rather than the anthropogenic chemical impact of high concentrations of chlorine and bromine. They occur between the autumn and spring seasons, with the peak during the winter over the mid-latitudes. Latest studies have shown that the amount of ozone in the lower stratosphere over the northern mid-latitudes decreases with a year-round trend of –1.4% per decade in 1998–2018. Although most of the ozone mini holes occur in winter and early spring, there are still several events during early autumn, increasing the amount of incoming solar ultraviolet radiation reaching the surface, which has a significant influence on living organisms as well as on the tropospheric chemistry.

In the project, we focus on understanding the processes that lead to low ozone events, how climate changes influence the number of ozone mini holes, and if there is a shift between those processes over the last decades. The global climate model used in this project is an atmospheric chemistry model GEM AC.

The first part of the project focused on comparing model results and reanalysis and observational datasets for the selected documented low ozone events. The modelling results are in good agreement with observations. Results are presented in Fig. 1.

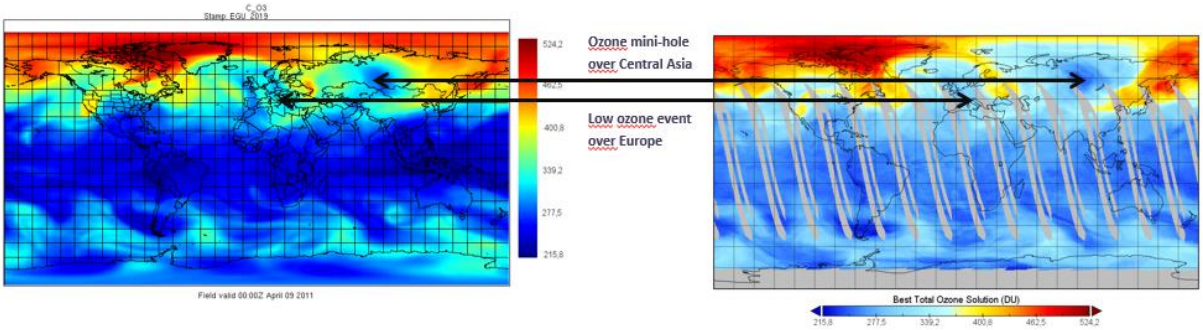

Fig. 1. Total column ozone in Dobson units calculated for 4th of April 2011, GAM AC model results (left panel) and results obtained from Aura-OMI using the TOMS algorithm (right panel).

The second initiative pertains to the application and validation of GEM-AC model (GEM-AQ was developed at York University in Canada and at WxPrime Corporation) at IG PAS. This work is directed by Professor Jacek W. Kamiński. This part of the research requires cooperation with research centres and international initiatives:

- Environment and Climate Change Canada, where the meteorological core of the GEM AC model, the GEM model, was developed and is used as an operational weather prediction model;
- The Royal Belgian Institute for Space Aeronomy, where the GEM model with physics and chemistry adapted to planet Mars is used to analyze observations from the NOMAD instrument and to carry out Martian climate simulations;
- Institute of Environmental Protection – National Research Institute, where the GEM-AQ model is used for air quality modelling over Poland and for Copernicus Services;
- Hemispheric Transport of Air Pollutants (HTAP) under the auspices of the United Nations Economic Commission for Europe (UNECE) Convention on Long-range Transboundary Air Pollution (CLRTAP) – Prof. Jacek W. Kamiński is a vice-Chair of the task force;
- The Tropospheric Ozone Assessment Report (TOAR-II) – Prof. Jacek W. Kamiński was appointed to the Steering Committee.

TROPICAL WAVES and THEIR INFLUENCE on HAZARDOUS WEATHER EVENTS

Dariusz Baranowski, **Beata Latos (PhD Student)**, **Wojciech Szkółka (PhD Student)**

Tropical dynamics group within the Atmospheric Physics Department is composed of three people and organized around the international project Equatorial Line Observations (ELO). Interactions between weather systems in the tropics (the so-called tropical waves) and their influence on high-impact and hazardous weather events have been examined. Activities of the group throughout 2019 focused on the following components:

- ELO deployment of underwater autonomous vehicles (gliders) between Java and Christmas Island (January–May 2019).

The team prepared and presented weekly weather briefings and outlooks during the deployment of seagliders (led by UK component). Weekly briefings included analysis of the current state of circulation in the atmosphere and ocean with particular interest on synoptic and intraseasonal features, analysis of surface ocean currents, dynamical structure of the atmosphere in the upper and lower levels. At the beginning of the deployment interactions between Kelvin and Rossby waves in the Java sea was observed. Anomalous westerly flow and low-level convergence over Makassar caused extreme precipitation and the biggest flood ever in this region. Weekly weather briefings allowed us to quickly assess potential dynamical precursors of this event, such as interaction between tropical waves. Weekly briefings also included forecasts and extended outlooks based on filtered products from numerical weather projections.

- Development and analysis of flood database for Sumatra and case study of Makassar (South Sulawesi) flood of January 2019.

Floods in Indonesia are a major contributor to all-natural hazards. Our analyses focus on predictability of precipitation-induced floods in various regions of Indonesia. Due to the lack of consistent, reliable and long-term flood databases, we used social media: local newspapers available online and Twitter – the social media platform. Initial analysis was performed for Sumatra during 2014–2018 period. We have found that statistics and predictors independently derived based on 3 datasets (Twitter, papers, and reports from governmental agencies) show consistent results: a vast majority of floods can be associated with the activity of convectively coupled Kelvin waves (over 90%). Although for most floods the Kelvin waves coincide with other dynamical drivers (monsoon or Madden-Julian Oscillations), for nearly 30% of floods they were the sole predictor. This result shows that such events should be considered important predictors of floods in Sumatra.

- Study of non-linear interactions between convectively coupled Kelvin waves and local diurnal cycle in circulation over the island of Sumatra.

Analysis shows a Kelvin wave signature at upper-level winds data based on gridded and local datasets. Diurnal variability of the upper-level winds was investigated in connection to Kelvin waves activity. This interaction is non-linear and likely occurs through dynamical coupling between circulation around a Kelvin wave event and local diurnal response to heating. Analysis shows Kelvin waves' impact and support for enhanced convection due to anomalous divergence at the upper level, often synchronized with the local diurnal cycle. Mr. Wojciech Szkółka defended his MSc thesis based on a model for analysis of such interactions.

LOCAL AND GLOBAL VARIABILITY OF THE ATMOSPHERE ELECTRICITY FROM FIELD MEASUREMENTS

Marek Kubicki, **Anna Odzimek**, **and Piotr Barański**

- Identification of main generators on the Global Electric Circuit (GEC)

As part of the research task, the Geophysical Observatory at Świder participated in the GloCAEM project. The GloCAEM (Global Coordination of Atmospheric Electricity Measurements) project has brought together experts in atmospheric electricity to make the first steps towards an effective global network for atmospheric electricity monitoring. Analysis of the diurnal variation in potential gradient (PG) from 17 sites has indicated that the majority of sites show corresponding daily maxima PG patterns yielding together a reliable measure of global thunderstorm generator on a day-to-day timescale. The averaging of PG during fair weather conditions over the GloCAEM sites on a daily basis also allows to identify a clear signal of global lightning activity. The averaging method minimizes any local influences on PG, such as fluctuations in aerosol concentration. There is a clear similarity between the averaged Carnegie curve and the daily averages across the GloCAEM sites, especially during the times of maxima. Thus, it will be a significant increase in the number of days from any single site possible for a determination of global electricity fields enhancing the statistics derived from individual station's observations.

- Thunderstorms in the Warsaw region in 2019

The five E-field signatures of positive single ground flashes together with their initial/pre-return stroke time development containing, or not containing, the intra-cloud preliminary breakdown (PB) pulses are selected from the storm episode in the Warsaw region on 30 July 2019. All these cases/incidents are connected to the transfer of positive charge from the thundercloud to the earth's surface. These types of ground discharges are very rare because most of the cloud-

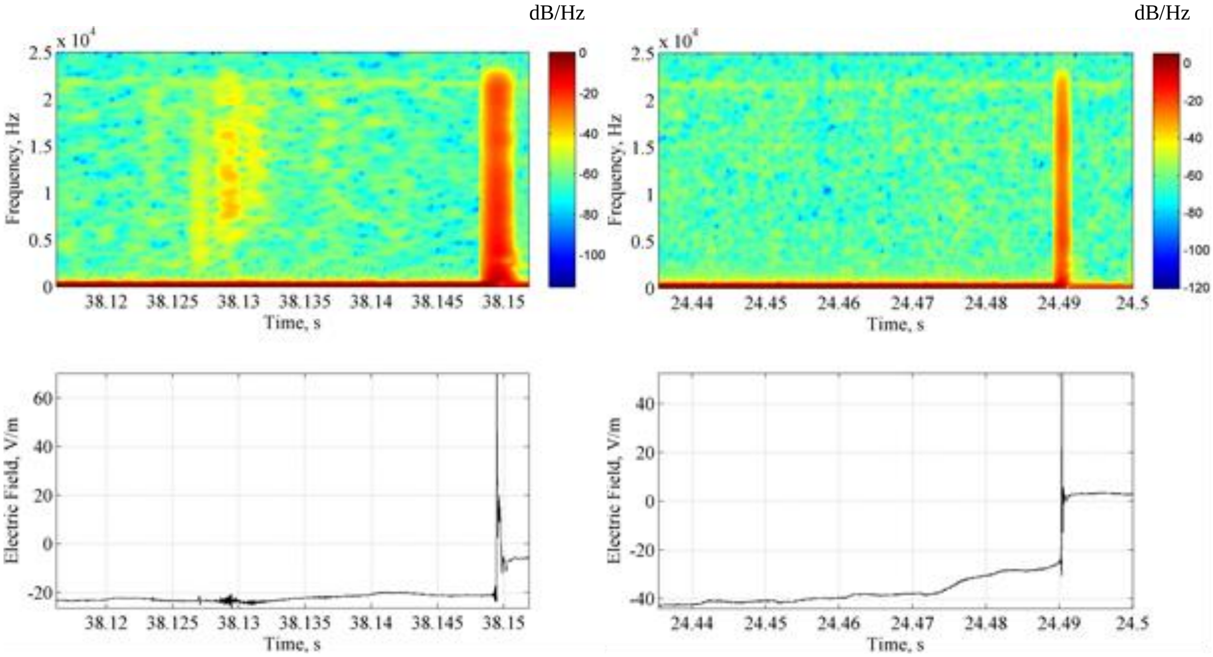

Fig. 1. The PSD spectrogram obtained from the electric field signature recorded by the LLDN-F measuring station (from the file F20190730113438.dat) during the occurrence of the positive single lightning stroke in the Warsaw region, preceded by the PB phase (left panel). The PSD spectrogram obtained from the record file F20190730115024.dat containing E-field signature of the positive single lightning stroke, which is not preceded by the PB phase (right panel).

to-ground discharges (90%), in this time of year and in our latitudes, are single and multiple negative lightning. There are two possible scenarios for initiating the considered single discharges to the ground. The first scenario assumes the occurrence of a preceding phase involving the preliminary intra-cloud breakdown discharges, the so-called PB stage. After that, the leader E-field change is followed in few tens milliseconds interval and is ended by a single lightning stroke (Fig. 1 – left panel). On the other hand, in the second scenario, the development stage of the lightning leader before the ground stroke is not preceded by any PB phase (Fig. 1 – right panel).

3.6 Visiting scientists

Jaka Paski, BMKG, Jakarta, Indonesia, 21.09–12.10.2019.

3.7 Publications

ARTICLES

Baranowski, D.B., et al. (2019), Contemporary GCM fidelity in representing the diurnal cycle of precipitation over the maritime continent, *J. Geophys. Res. – Atmos.* 1**24**, 2, 747–769, DOI: 10.1029/2018JD029474.

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Krzyścin, J.W., and **D.B. Baranowski** (2019), Signs of the ozone recovery based on multi sensor reanalysis of total ozone for the period 1979–2017, *Atmos. Environ*. **199**, 334–344, DOI: 10.1016/j.atmosenv.2018.11.050.

Nicoll, K.A., **M. Kubicki**, **A. Odzimek**, et al. (2019), A global atmospheric electricity monitoring network for climate and geophysical research, *J. Atmos. Sol.-Terr. Phys*. **184**, 18–29, DOI: 10.1016/j.jastp.2019.01.003.

Odzimek, A. (2019), Obszary polarne w badaniach globalnego atmosferycznego obwodu elektrycznego Ziemi, *Prz. Geof*. **44**, 1–2, 35–71, DOI: 10.32045/PG-2019-002.

Odzimek, A. (2019), SuperDARN w Polsce: perspektywy dla badań atmosfery, *Prz. Geof*. **44**, 3–4, 267–286, DOI: 10.32045/PG-2019-009.

Popielawska, B., **A. Odzimek**, **J. Doroszkiewicz**, et al. (2019), SuperDARN w Polsce – perspektywy, *Prz. Geof*. **44**, 3–4, 221–251, DOI: 10.32045/PG-2019-007.

Pawlak, I., and **J. Jarosławski** (2019), Forecasting of surface ozone concentration by using artificial neural networks in rural and urban areas in Central Poland, *Atmosphere* **10**, 2, 52, DOI: 10.3390/atmos10020052.

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Szkop, A., and **A. Pietruczuk** (2019), Synergy of satellite-based aerosol optical thickness analysis and trajectory statistics for determination of aerosol source regions, *Int. J. Remote Sens*. **40**, 22, 8450–8464, DOI: 10.1080/01431161.2019.1612117.

CHAPTERS

Barański, P. (2019), Electric structure of multiple cloud-to-ground flashes obtained from the local lightning detection network recordings during thunderstorm in the Warsaw Region on 25 May 2018. **In:** *Book of Extended Abstracts "Electromagnetic ULF/ELF Fields* *on Earth and in Space" Conference, Warsaw, Poland, 3–5 July 2019; Publs. Inst. Geoph. PAS* **425** (M-32), 89–98, DOI: 10.25171/InstGeoph_PAS_Publs-2019-017.

Kułak, A., and **A. Odzimek** (2019), Preface. **In:** *Book of Extended Abstracts "Electromagnetic ULF/ELF Fields on Earth and in Space" Conference, Warsaw, Poland, 3–5 July 2019; Publs. Inst. Geoph. PAS* **425** (M-32), 3–7, DOI: 10.25171/InstGeoph_PAS_Publs-2019-003.

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MONOGRAPHS

Kułak, A., and **A. Odzimek** (eds.) (2019), *Book of Extended Abstracts "Electromagnetic ULF/ELF Fields on Earth and in Space" Conference, Warsaw, Poland, 3–5 July 2019; Publs. Inst. Geoph. PAS* **425** (M-32), Institute of Geophysics, Polish Academy of Sciences, Warszawa, DOI: 10.25171/InstGeoph_PAS_Publs-2019-002.

4. DEPARTMENT OF LITHOSPHERIC RESEARCH

Tomasz Janik and Working Group[1]

4.1 About the Department

NSL1. Structure and evolution of Central Europe's lithosphere with particular emphasis on the area of Poland

The main aim of this research topic is to identify the structure and evolution of the lithosphere of Central Europe by experimental seismic methods. Large projects of deep seismic soundings are carried out in multiannual cycles, usually in broad international cooperation. In 2019, the Trans-European Suture Zone research projects included: seismic modeling along the **TTZ-South** profile (Poland-Ukraine) – interpretation is in advanced stage; the interpretation of data from the deep seismic sounding profile **RomUkrSeis** (Romania-Ukraine) was completed; materials from the Libiąż Uppermost Mantle Profile (**LUMP**) in Central Poland were published in *Acta Geophysica*; modeling along the **BalTec** profile (Baltic Sea) was advanced.

In addition to the above-mentioned projects, to which the most attention was devoted, the team also dealt with other projects: **KOKKY** and **ESO** profiles (Finland) – manuscript sent to *Pure and Applied Geophysics*, and **BASIC** profile (Sweden). Work on the latter project will be continued in the following years.

Until October 2019, passive seismic measurements in the **AniMaLS** (Anisotropy of the Mantle beneath the Lower Silesia) project in the Sudetes were continued. The research in the **PACASE** (Pannonian-Carpathian-Alpine Seismic Experiment) passive seismic project in Carpathian Mountains, planned for several years, started in a broad international cooperation.

Targeting the Central and Southeastern Europe, all the projects aim at determining the structure of the Earth's crust and upper mantle, including methods of two-dimensional modeling of the lower lithosphere along profile lines or spatial (three-dimensional) tomographic modeling, as well as methods oriented at imaging of the upper mantle structure – receiver function and shear-wave splitting. The data obtained along new generation of active seismic profiles and passive experiments are of fundamental importance for understanding the geodynamics of the European continent. They are the base of reference for other disciplines of Earth sciences. Numerous citations testify to this. Our studies are also relevant for seismic exploration.

NSL2. Structure and evolution of the northern Atlantic lithosphere in the contact zone of the Eurasian and North American plate in the Arctic and selected areas of Antarctica

The purpose of this research theme is geodynamic research in the Arctic region (the North Atlantic in the Svalbard Archipelago area) and the West Antarctic, using seismic methods. These regions are of fundamental importance in the study of geodynamic evolution of the Earth.

The department team continued interpretation of the data from the active part of the Knipovich Ridge Passive Seismic Experiment (**KNIPAS**) that had been in progress since summer 2016, in collaboration with the Alfred Wegener Institute (AWI) from Bremerhaven. Modeling of 2-D lithospheric structure along several profiles performed in the Logachev Seamount region on Knipovich Ridge in 2017 was completed. Interpretation works are advanced.

Also as part of the **KNIPAS** project, the department team cooperated with the German side in the study based on passive data. The results of these studies will broaden our understanding of the mechanisms of ocean floor spreading in oceanic ridge regions at the "ultra-slow" rate (Knipovich Ridge).

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[1]Working Group of the Department of Lithospheric Research: Monika Bociarska, Wojciech Czuba, Kuan-Yu Ke, Tomasz Janik, Weronika Materkowska, Julia Rewers, Piotr Środa, Dariusz Wójcik.

In collaboration with the University of Bergen and Hokkaido University, deep seismic soundings were performed in the North Atlantic, from the Knipovich Ridge (part of the Mid-Atlantic Ridge) to the Barents Sea. Dr. Wojciech Czuba was the head of this expedition (**KNIPSEIS**) onboard the Norwegian vessel RV G.O. Sars.

4.2 Personnel

Head of the Department
Tomasz Janik
Asociate Professor

Professor
Aleksander Guterch

Associate Professor
Piotr Środa

Assistant Professors
Wojciech Czuba
Monika Bociarska

Research Assistants
Dariusz Wójcik
Weronika Materkowska
Kuan-Yu Ke

Technician
Edward Gaczyński

PhD Students
Julia Rewers, Poland; Piotr Środa – PhD supervisor

4.3 Main research projects

- Profile of deep seismic soundings TTZ-South, T. Janik, National Science Centre, 2017–2021;
- Determination of the seismic anisotropy of the lithosphere in the Lower Silesia area, P. Środa, National Science Centre, 2017–2021;
- Structure of the Knipovich Ridge on the basis of seismic surveys – KNIPSEIS, W. Czuba, National Science Centre, 2018–2021;

4.4 Instruments and facilities

Equipment

- 90 × TEXAN portable seismic recorders with 1C 4.5 Hz geophones,
- 60 × CUBE portable seismic recorders with 40 × 1C and 20 × 3C 4.5 Hz geophones,
- 10 × Güralp CMG-DM24S3EAM broadband seismic stations with CMG-6T 30 s seismometers,
- 4 × Ocean Bottom Seismometers, semi-broadband (Güralp),
- 20 × L-4C-3D 1 Hz seismometers,

- 6 × timing system devices (for shot time recording),
- 2019 Application approved for the purchase of new 100 short-period field seismic devices (Ministry of Science and High Education).

4.5 Research activity and results

Brief description/abstracts/summaries of some of the achievements of the Department's staff:

DEEP SEISMIC SOUNDINGS: PROFILE **TTZ-SOUTH**

The TTZ-South experiment in September 2018 aimed at exploring crustal and uppermost mantle structure along the Teisseyre–Tornquist Zone (TTZ), using the seismic wide-angle reflection/refraction (WARR) method. The ~550 km long profile (see Fig. 1), following the border of the East European Craton (EEC) with the Trans-European Suture Zone (TESZ) in SE Poland (~230 km) and western Ukraine (~320 km), is an extension of earlier profiles, TTZ (1993, NW Poland; Grad et al. 1999) and CEL03 (2000, SE Poland; Janik et al. 2005). In the experiment, 320 mobile single-component seismographs recorded eleven shot points, five in Poland and six in the Ukraine, comprising 400–1000 kg of explosives in drill holes. The combined profiles TTZ, CEL03 and TTZ-South make up a 1025 km-long lithospheric transect between the Baltic Sea and Moldova. Two methods of seismic data modelling were used. 2-D tomographic inversion was applied to produce a smooth *P*-wave velocity (*Vp*) model based on first arrival travel times. This was followed by ray-tracing trial-and-error modelling and the computation of synthetic seismograms using a full waveform finite-difference code, for the final trial-and-error model. The model starting at 450 km in the NW and ending at 1025 km in the SE, shows strong lateral variations in crustal structure (see Fig. 2). Its Ukrainian segment crosses the interior of

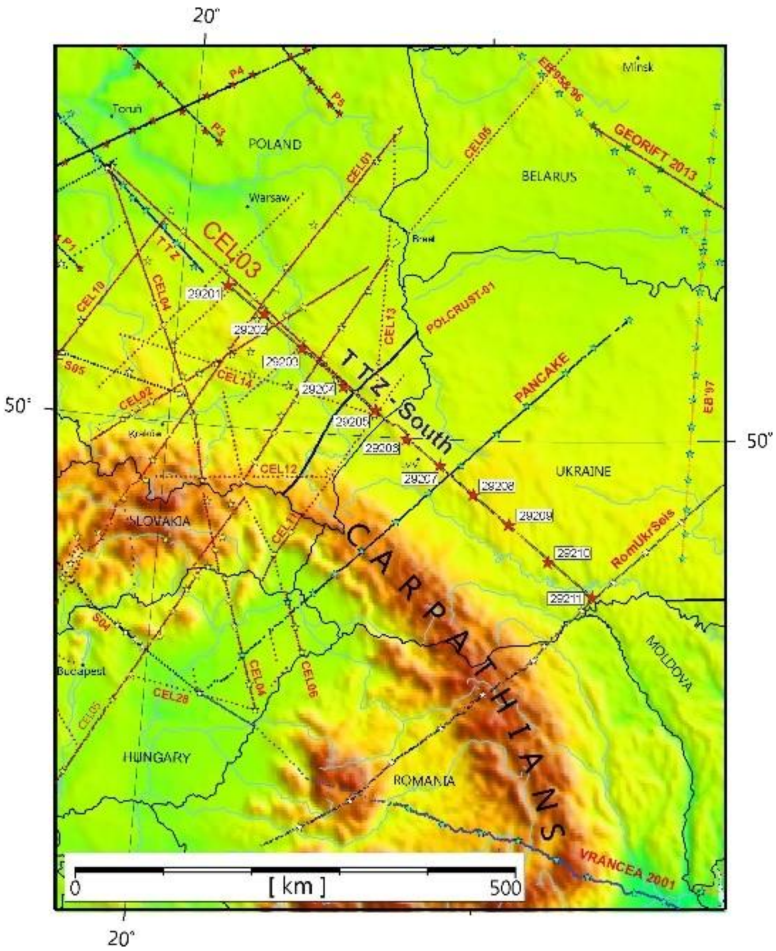


Fig. 1. Location of the composite TTZ-South profile and previous refraction seismic profiles in the study area. Stars represent shot points; dots – recording stations.

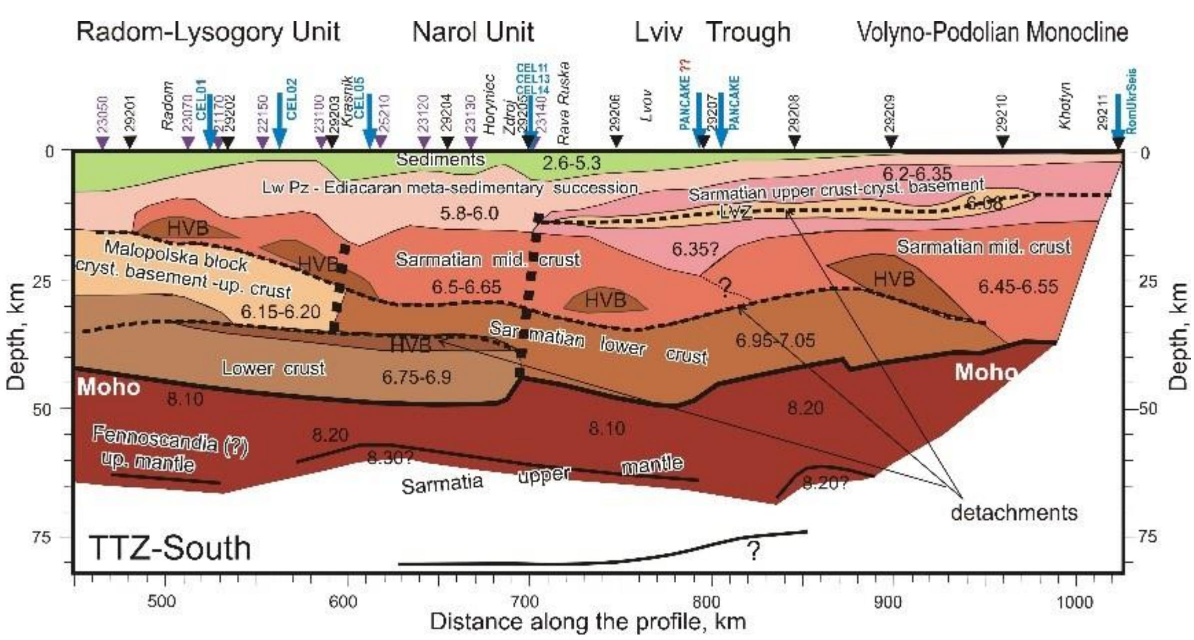


Fig. 2. Lithospheric structure derived along the TTZ-South profile from the velocity model.

the EEC, where the top of the crystalline crust (*Vp* = 6.15–6.25 km/s), occurs at ~2 km depth at the SE end of the profile and dips to ~12 km at the Ukrainian-Polish border. This segment shows a four-layer crustal structure, with a sedimentary layer and crystalline upper crust up to 15 km thick, a 10–15 km thick middle. and mainly ~15 km thick lower crust. In Poland, the profile enters and continues within the TTZ, at the border along the EEC and TESZ, which makes the structural image complex. At 630–700 km the crystalline basement occurs at ~15 km depth, corresponding to the top of the middle crust (*Vp* ~6.5 km/s below it), whose depth oscillates from 10–17 km at 490–630 km. This mid-crustal layer disappears at ~485 km at a major fault zone. From 450–490 km, the crystalline basement is either downthrown to ~15 km, where it starts to follow an upper crustal reflector, as in Ukraine, or even to >25 km, where the lower crust occurs. The central profile (600–700 km) reveals a three-layer structure with a ~15 km thick sedimentary layer, a 10–15 km thick middle crust and a ~20 km thick lower crust. From 490–600 km, a conspicuous velocity inversion occurs, where a ~10 km thick mid-crustal layer overlies one with upper crustal velocities. Another sub-horizontal velocity inversion can be traced along almost the entire Ukrainian profile segment in the crystalline upper crust. Both these laterally extensive velocity inversions may have resulted from thick-skinned thrusting due to either late Precambrian collision with terranes accreting to the SW margin of the EEC or to Variscan orogenic events. Five high-velocity bodies (HVB; *Vp* = 6.85–7.2 km/s) were detected in the middle and lower crust, at 15–37 km depth. The Moho varies substantially along the profile. It is at ~42 km depth in the NW and deepens SE-ward to ~50 km at ~685 km. Subsequently, it rises abruptly to ~43 km and sinks again to ~50 km at ~785 km. From this point until the SE end of the profile, the Moho gently shallows, up to a depth of ~37 km. Along the whole profile, sub-Moho velocities are ~8.05–8.1 km/s, and at depths of 57-63 km *Vp* reaches 8.2–8.25 km/s. Four reflectors/ refractors were modelled at mantle depths of ~57–65 km and ~80 km.

PASSIVE SEISMIC EXPERIMENTS: **ANIMALS** AND **PACASE**

The passive seismic experiment AniMaLS was organized in 2017 in the Polish Sudetes. One of the objectives is to study the anisotropy of the sub-crustal lithosphere and asthenosphere beneath the NE termination of the Bohemian Massif. The Sudetic lithosphere represents a complex mosaic of several units with distinct histories of tectonic evolution, of Proterozoic to the

Quaternary age. A temporary seismic network of 23 broadband stations was operating in the area of Sudetes mountains and Fore-Sudetic Block, covering a ~200 ×100 km large area, with ~30 km spacing between stations. Recordings were supplemented with data from 6 permanent stations of Czech and Polish seismological networks located in the study area (see Fig. 1). The obtained data – broadband seismograms of local, regional and teleseismic events recorded during ~2 years period – are analyzed using shear-wave splitting, receiver function and surface wave dispersion methods. The SKS-splitting analysis is done using cross-correlation, eigenvalue minimization and transverse energy minimization approaches. The dependence of resulting splitting parameters on the backazimuth of the event is also analyzed. The results show time delays between slow and fast S-wave components largely in the range of ~0.5–1.6 sec. The splitting is interpreted as a result of lattice-preferred orientation (LPO) of mantle olivine. The azimuths of fast velocity axis are mostly consistent and showed largely WNW-ESE direction. They correlate well with trends of tectonic units observed at the surface and with strike directions of major fault zones. This suggests that the area was subject to vertically coherent deformation throughout the lithosphere and that resulting frozen-in LPO reflects last tectonic episode, which shaped Sudetic area. The results obtained with this and other methods will be compared with previous seismic studies of the upper mantle anisotropy in the neighboring areas by various methods.

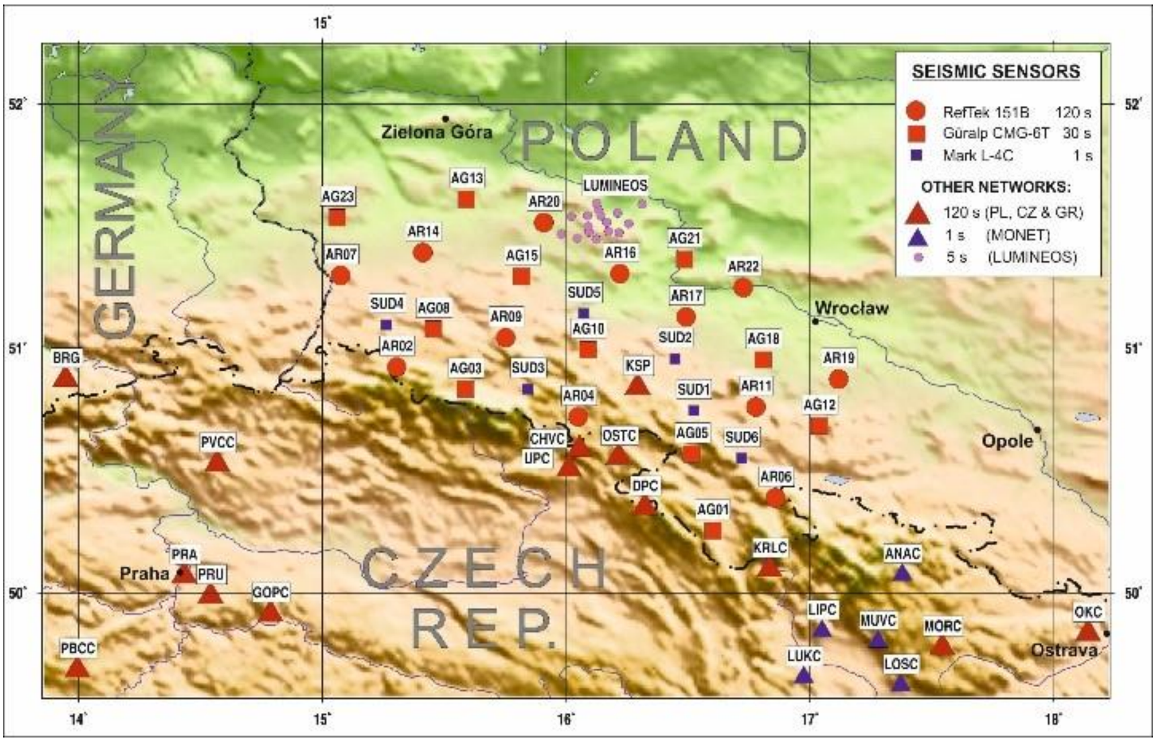


Fig. 1. Location of the seismic stations of the AniMaLS experiment in the Sudetes. Circles and squares – portable stations, triangles – permanent stations.

PACASE passive seismic experiment (Pannonian-Carpathian-Alpine Seismic Experiment), started in 2019, aims to study the structure and properties of the lithosphere-asthenosphere system of the Carpathian orogen and Pannonian Basin in order to enrich the knowledge about the tectonic evolution of the Carpathian-Pannonian area. Currently, in the frame of PACASE project, seismic measurements are carried out in southern Poland, Slovakia, Czech, Austria, Hungary, and Germany (see Fig. 2). In Poland, data are acquired using an array of 30 broadband seismometers and 3 permanent stations of Polish seismological network (OJC, NIE, KWP) with distances of about 40 km between stations. Measurements will be continued to the end of the

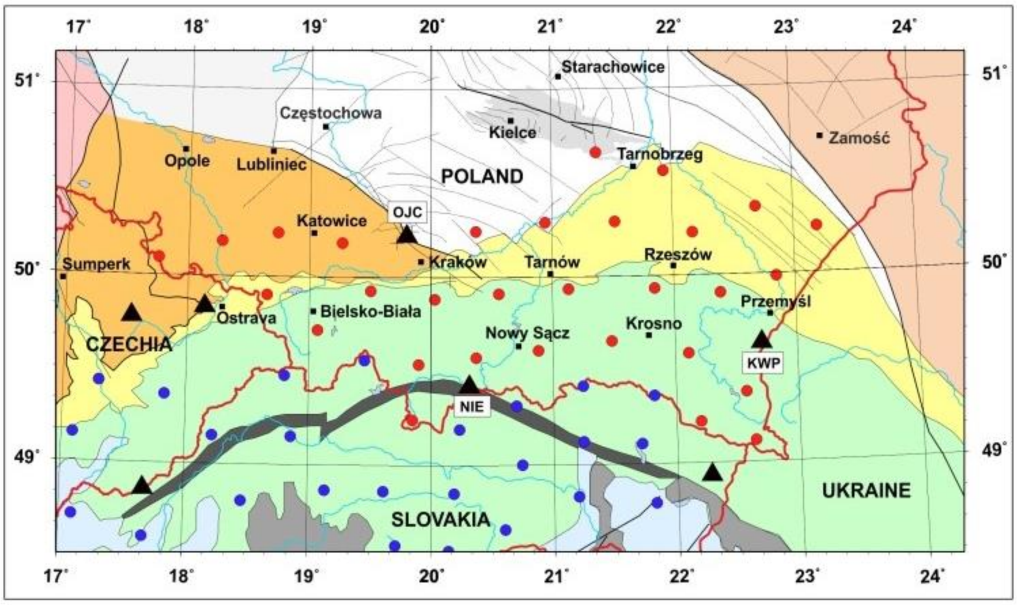
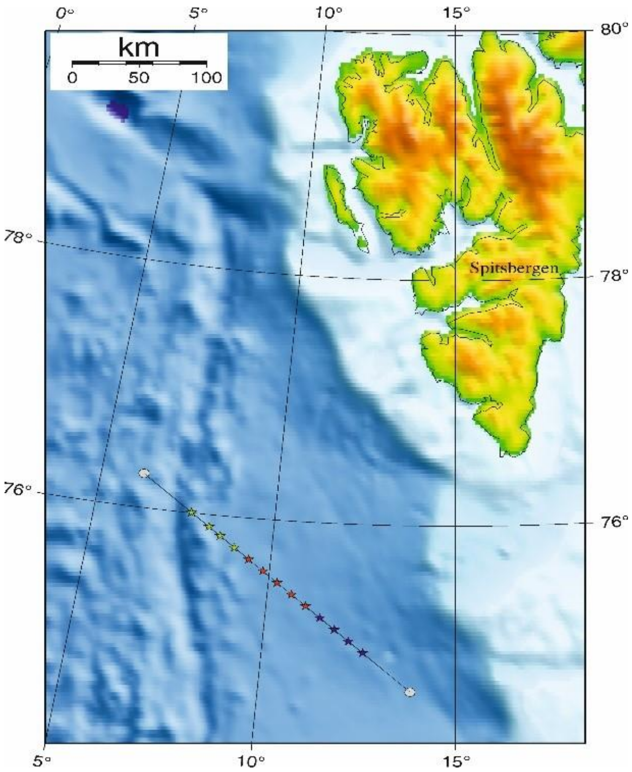


Fig. 2. Map of locations of seismic stations of the PACASE experiment. Red dots – Polish stations, blue dots – other stations used in the experiment. Map shows only a fragment of the study area.

year 2021. The data will serve for modelling of the upper mantle properties using P-wave receiver functions and their azimuthal harmonics, SKS wave splitting parameters, surface wave dispersion curves and teleseismic tomography. Results will be interpreted in terms of the structure and evolution of the crust and the upper mantle.

OFFSHORE PROJECT: STRUCTURE OF THE KNIPOVICH RIDGE BASED ON SEISMIC MEASUREMENTS – **KNIPSEIS**

The Ocean Bottom Seismometer (OBS) data along refraction/reflection profile (~280 km), crossing the Knipovich Ridge in the western Barents Sea, was acquired by use of RV G.O. Sars



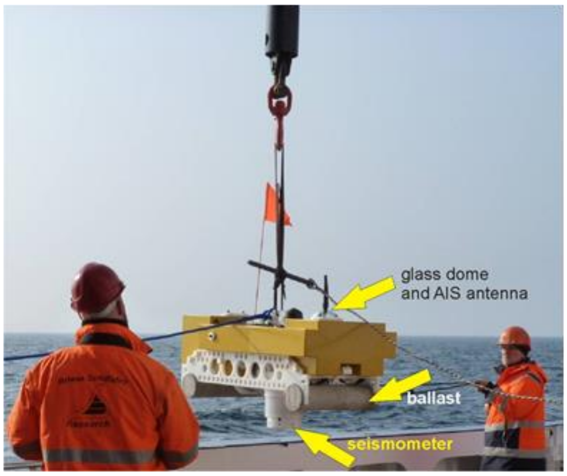


Fig. 1. The Guralp ocean bottom seismometer station. Principal parts are indicated.

Fig. 2. Location of acquired seismic profiles upon bathymetry grid.

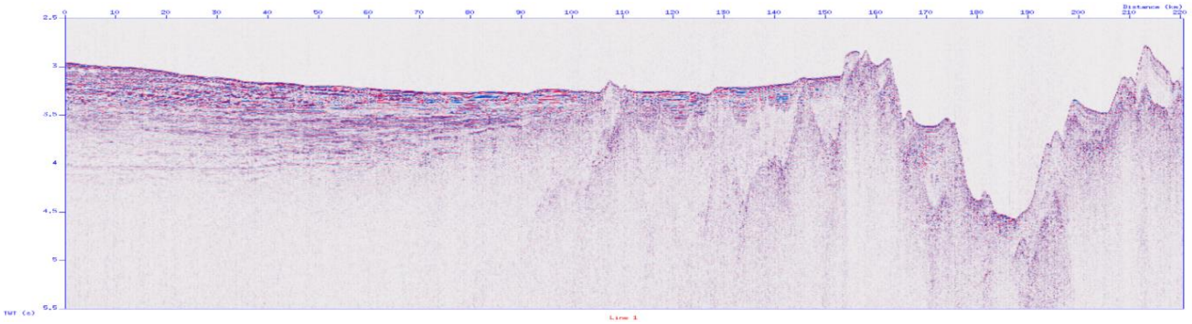


Fig. 3. Example of the streamer data along the profile.

on July 24 – August 6, 2019 in two deployments (see Figs. 1 and 2). The acoustic energy was emitted by an array of air-guns to receive and record the seismic waves at the seafloor by ocean bottom seismometers. All the stations were recovered and recorded data. Additionally, gravity, echo-sounder, and single-channel streamer data (Fig. 3) were acquired. The cruise was connected with the IG PAS project: “Structure of the Knipovich Ridge based on seismic measurements – KNIPSEIS” (grant of Polish National Science Centre, agreement: UMO-2017/25/B/ST10/ 00488). The project is co-funded by the University of Bergen. The project partners are University of Bergen, Institute of Geophysics, Polish Academy of Sciences, and Hokkaido University.

The structure of the oceanic crust generated by the ultraslow-spreading Knipovich Ridge still remains a relatively uninvestigated area compared to the other North Atlantic spreading ridges further south. The complexity of the Knipovich Ridge with its oblique ultraslow-spreading and segmentation makes this end-member of Spreading Ridge Systems an important and interesting ridge to investigate. The aim of this work is to better understand the lithospheric structure beneath the rare ultraslow-spreading ridges on an example of the Knipovich Ridge in its spreading direction. This OBS profile will provide information on the seismic crustal structure of the Knipovich Ridge as well as oceanic and continental crust in the transition zone.

4.6 Visiting scientists

Tamara Yegorova, Institute of Geophysics, National Academy of Sciences of Ukraine, Kiev, Ukraine, 3–5.09.2019,
Anna Murovska, Institute of Geophysics, National Academy of Sciences of Ukraine, Kiev, Ukraine, 3–5.09.2019,
Khrystyna Zajats, Zakhidnadra Servis, Lviv, 3–5.09.2019.

4.7 Publication

ARTICLES

Dec, M., **T. Janik** et al. (2019), Verification of the seismic P-wave velocities under Moho boundary: Central Poland case study, LUMP profile, *Acta Geophys*. **67**, 1, 41–57, DOI: 10.1007/s11600-018-0236-9.

5. DEPARTMENT OF THEORETICAL GEOPHYSICS

Zbigniew Czechowski

5.1 About the Department

Scientific activity of Department of Theoretical Geophysics is concentrated on the following issues: seismic source, fracture mechanics, fluid flows, stochastic models, time series modeling and monitoring of rotational effects.

Different aspect of subduction zone seismicity, such as slow and fast slip interplay and the slip budget, scaling relation among earthquake parameters, earthquake frequency-magnitude statistics, have been combined to reveal a consistent view on megathrust earthquake related processes. Gutenberg–Richter law has been discussed as the Gibbs probability distribution of earthquake magnitudes, with its parameters *a*, *b*, and the magnitude range as physical constraints. Stability conditions for slip, and the slow and fast slip interplay have been discussed within the asperity fault model with the slip-dependent friction context. Then, the Gutenberg–Richter law's parameters and plate interface characteristics, such as asperity distribution and properties, have been related. It has been suggested that earthquake generation processes can be treated as sampling with constraints, and that the physical processes leading to the largest megathrust earthquakes can be revealed by observing the Gutenberg–Richter law's parameters, such as its *b* value variations.

Fragmentation of solid materials is an extremely complex process involving scales ranging from an atomic scale (breaking inter-atomic bounds) up to thousands of kilometers in case of catastrophic earthquakes. To deal with such complexity we use Discrete Element Modelling (DEM) as a tool to simulate mechanical processes in Earth foci. This year we have considered a particular aspects of such simulation, namely calibrating numerical models to real materials. We have proposed a new methodology which eliminates some well known problems of DEM calibrations.

Propagation of long one-dimensional gravitational waves of homogeneous incompressible fluid in a rectangular channel with a micro-periodically uneven bed is considered. Using the mathematical theory of asymptotic homogenization, macroscopic flow equations and effective depth of the wavy channel were obtained as a result. Such issues are important from both geophysical and industrial points of view.

The time series' monitored by geophysical instruments reflect the complexity of phenomena under consideration. By applying the multivariate Mahalanobis distance method the level of complexity of seismic data containing spatial, temporal and energetic characteristics has been estimated. The analysis of the southern California earthquake catalogue (1975–2017) has led to the conclusions that in periods before strong earthquakes the seismic process is random-like but after these events it is much more regular.

Another branch of our interests is the rotational seismology. Monitoring of rotational effects in the ground was conducted in the Lower Silesian Geophysical Observatory at Książ by different types of rotational seismometers. Results were presented at the Fifth International Workshop on Rotational Seismology in Sun Moon Lake, Taiwan, 2019.

5.2 Personnel

Head of the Department
Zbigniew Czechowski
Professor

Professors
Roman Teisseyre
Wojciech Dębski

Associate Professors
Włodzimierz Bielski
Piotr Senatorski

Specialist
Krzysztof Teisseyre

Assistant Professor (Oct 2019 – present)
Piotr Klejment

Research Assistant (Feb–Aug 2019)
Piotr Klejment

PhD Student
Piotr Klejment, Poland; Wojciech Dębski – PhD supervisor

5.3 Main research project

- Introducing the stochastic Langevin-type model and procedures of its reconstruction from persistent of order p geophysical time series, Zbigniew Czechowski, National Science Centre (NCN) Opus 11, 2017–2020.

5.4 Research activity and results

Brief description/abstracts/summaries of some of the achievements of the Department's staff:

SEISMICITY OF SUBDUCTION ZONES: MODELING, INTERPRETATION, FORECASTING
P. Senatorski
The activity concerns subduction zone seismicity and megathrust earthquakes: their theory, modeling and forecasting. Different aspects of seismicity have been considered, such as (1) processes of fast and slow slips and the slip budget at the tectonic plate interface, (2) statistical scaling relations among earthquake parameters, and (3) earthquake statistics, or the Gutenberg–Richter relation. These different views have been merged to reveal more consistent picture of the phenomena.

The main results concern the link between earthquake statistics and physics. In particular, relations between the Gutenberg–Richter law's parameters, *a*, *b*, and maximum magnitude, m_{MAX}, and the constraints due to the slip budget and fault characteristics have been found and discussed. The slow and fast slip interplay have been considered within the asperity fault model context, using the slip-dependent friction formulation to deal with the slip stability problem, where asperity distribution and characteristics control stability conditions for slip movements, or fast and slow slip interplay on the fault.

The results contribute to seismicity understanding, modeling and forecasting. Probabilistic aspect of seismicity have been included into the general asperity fault model, so that the earthquake generation processes can be treated as sampling with physical constraints, where the Gutenberg–Richter law's parameters *a* and *b*, as well as the magnitude range, are the constraints. It is suggested that the physical processes leading to the largest earthquakes can be revealed by observing the *b* value variations.

Some preliminary results have been summarized in two papers published in 2019 (Senatorski 2019, 2020):

Senatorski, P. (2019), Effect of slip-weakening distance on seismic-aseismic slip patterns, *Pure Appl. Geophys*. **176**, 3975–3992, DOI: 10.1007/s00024-019-02094-7 (accessed: 22 January 2019).

Senatorski, P. (2020), Gutenberg–Richter's *b* value and earthquake asperity models, *Pure Appl. Geophys*. **177**, 1891–1905, DOI: 10.1007/s00024-019-02385-z (accessed: 16 December 2019).

DISCRETE ELEMENT SIMULATION OF BRITTLE MATERIAL FAILURE

W. Dębski, P. Klejment

Solid materials subjected to external mechanical conditions after exceeding their certain strength parameters, start to fracture. For example, in case of glaciers it leads to calving and in case of crustal rock it results in earthquakes. Despite the huge scientific progress made in recent decades, many issues of this process are still unexplained, partially because commonly used laboratory and field methods cannot provide sufficient information. A way of avoiding this expected limitation is turning attention towards a well-established in physics method of computational simulations – a powerful branch of contemporary physics.

To make numerical simulations for a problem at hand efficient, we have to answer a few basic questions. The two most elementary ones which are always addressed at start are the selection of an appropriate numerical method and a proper representation of the real situation with a numerical model, including a proper choice of parameters and their values for used numerical model. While Discrete Element Method (DEM) seems to be the most appropriate method for analysing the solid body fragmentation, the way of representing continuous material by this microscopic particle-based method is not obvious and usually requires an exhaustive calibration of numerical models to represent the real materials.

Studying this aspect of DEM simulations we obtained two significant and new conclusions. The first one is based on observations that the calibration can be performed using smaller, rescaled numerical models what significantly improves an efficiency of the calibration. It is presented in Fig. 1 where a predicted by DEM value of maximum sample strength as a function of a cylindrical sample radius is shown.

The second conclusion is that numerical porosity which naturally arises in DEM as a consequence of the discrete representation of the continuum medium can be diminished due to observed scaling of simulation results with size of particles used for building the numerical model. It is shown in Fig. 2 where scaling of the macroscopic Young modulus versus packing parameter (ratio of the volume occupied by particles to the volume of the sample) is shown.

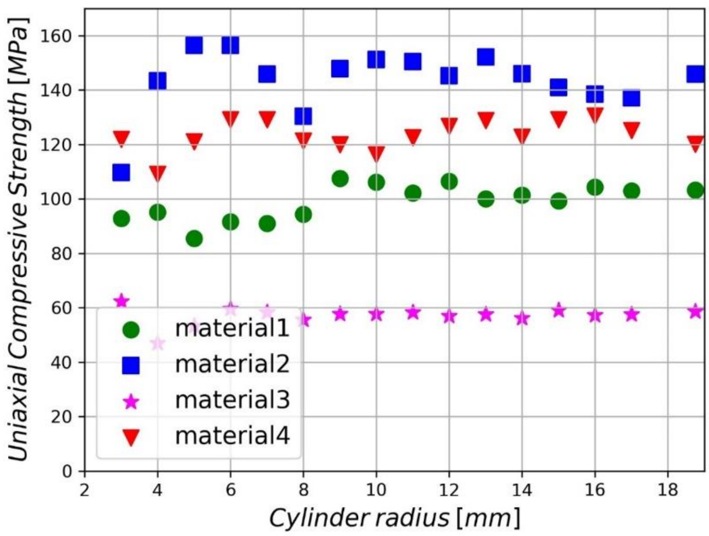


Fig. 1. Uniaxial Compressive Strength in a function of cylinder radius (after Klejment 2021).

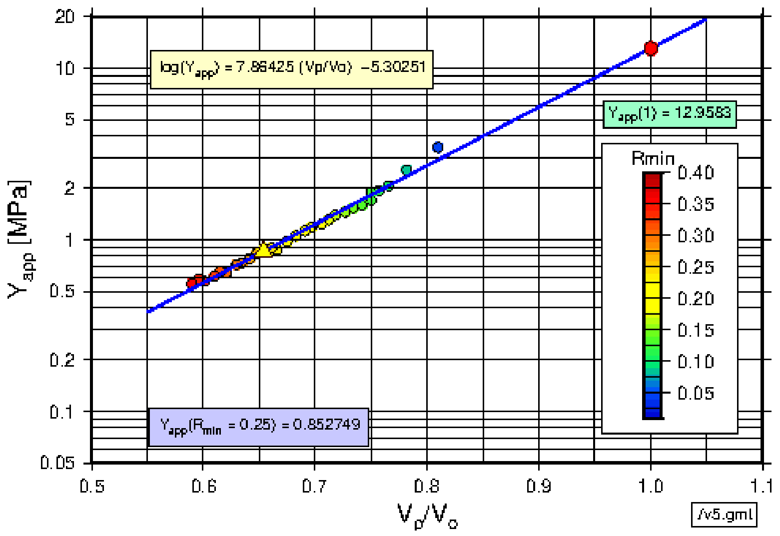


Fig. 2. Scaling of the young modulus with respect to the numerical porosity - the ratio of the volume occupied by particles to the volume of the sample.

RECONSTRUCTION OF THE TRANSITION PROBABILITY DENSITY FUNCTION FROM PERSISTENT TIME SERIES

Z. Czechowski

We introduced the generalized discrete Langevin equation for some class of non-Markov processes, namely for persistent time series of order *p*. We assumed that the next state of the process is dependent not only on the present state but also on signs of previous jumps of *p*. To this aim, the standard discrete Langevin equation is modified by introducing a new random function which determines the sign of the diffusion term. The function depends on the vector random variable (i.e., the chain of p previous signs), the random scalar variable with the uniform distribution in [0, 1], and on the vector persistence parameter (with 2*p* components). The term is keeping the tendency of increase/decrease of the process in the next step according to given persistence parameters. When all the parameters are equal to 0.5 the modified equation is reduced to the standard Langevin equation. The proposed model is a significant extension of our previous approach (Czechowski 2016) in which persistent processes of order *p* = 1 were taken into account. The generalization opens wide possibilities of nonlinear modeling of data in which persistence and antipersistence of different orders can be mixed in a time series under investigation.

In order to construct the transition probability density function, the forms of drift and diffusion functions are needed. The standard procedure (Siegert et al. 1998) of reconstruction of the Langevin equation from time series led to the proper estimation of the diffusion function but to the wrong reconstruction of the drift function in the case of the modified equation for persistent processes. To estimate the deviation in the drift we proposed a new reconstruction procedure. In order to test the efficiency of the procedure, many time series were generated by using the modified Langevin equation with different drift and diffusion functions and different persistences. This enables to compare the input functions and parameters to the reconstructed ones. Good efficiency of the modified reconstruction procedure has been shown.

Having the proper forms of reconstructed drift and diffusion functions enables derivation of the short-time transition probability density function. For the case of Markov processes, the function has a Gaussian form; however, non-Markovian features of persistent processes make the problem more complex. Therefore, a correction term appears in the formula for short-time transition probability density function. For the persistence of order 1 the correction term can be derived analytically but for higher orders numerical estimations are necessary. It should be underlined that the presented method applied to forecasting time series generates a probability distribution for the next point, rather than a single point estimate as in autoregression. The parameters in the modified Langevin model are dynamically estimated from past data. An important advantage of the proposed approach is that it offers simultaneously the reconstruction of the stochastic model of the phenomena under investigation and the method of probabilistic forecast.

Siegert, S., R. Friedrich, and J. Peinke (1998), Analysis of data sets of stochastic systems, *Phys. Lett. A* **243**, 5–6, 275–280, DOI: 10.1016/S0375-9601(98)00283-7.

Czechowski, Z. (2016), Reconstruction of the modified discrete Langevin equation from persistent time series, *CHAOS* **26**, 053109, DOI: 10.1063/1.4951683.

5.5 Visiting scientists

Luciano Telesca, Institute of Methodologies for Environmental Analysis, National Research Council, Tito, Italy, 05–11.05.2019,
Fernanda Martin, University of Chile, Department of Physics, Santiago, Chile, 05–29.10.2019,
Denisse Pasten, University of Chile, Department of Physics, Santiago, Chile, 28.01–4.02.2019,
Victor Munoz, University of Chile, Department of Physics, Santiago, Chile, 28.01–4.02.2019.

5.6 Publications

ARTICLES

Matcharashvili, T., **Z. Czechowski**, and N. Zhukova (2019), Mahalanobis distance-based recognition of changes in the dynamics of a seismic process, *Nonlin. Processes Geophys.* **26**, 3, 291–305, DOI: 10.5194/npg-26-291-2019.

Klejment, P. (2021), Application of supervised machine learning as a method for identifying DEM contact law parameters, *Math. Biosci. Eng.* **18**, 6, 7490–7505, DOI: 10.3934/mbe.2021370.

Senatorski, P. (2019), Effect of slip-weakening distance on seismic-aseismic slip patterns, *Pure Appl. Geophys*. **176**, 3975–3992, DOI: 10.1007/s00024-019-02094-7 (accessed: 22 January 2019).

Jaroszewicz, L.R., et al., **K. Teisseyre** (2019), Innovative fibre-optic rotational seismograph, *Proc. 7th Int. Symp. Sensor Sci.* **15**, 1, 45, DOI: 10.3390/proceedings2019015045.

Kurzych, A.T., et al., **K. Teisseyre** (2019), Two correlated interferometric optical fiber systems applied to the mining activity recordings, *J. Lightwave Technol*. **37**, 18, DOI: 10.1109/JLT.2019.2923853.

CHAPTERS

Bielski, W., and R. Wojnar (2019), Gravity waves in channels with corrugated bottom: asymptotic approaches. **In:** J. Awrajcewicz et al., *Applicable Solutions in Non-Linear Dynamical Systems*, Politechnika Łódzka.

6. DEPARTMENT OF HYDROLOGY AND HYDRODYNAMICS

Jarosław Napiórkowski

6.1 About the Department

Under the framework of NHH02, the following main objectives have been achieved.

- **Flood Risk Assessment Methods:** The problem of determining the design characteristics of large watercourses in the form of upper flood quantiles is still of central interest to theoreticians and practitioners. To address the above-mentioned issue, a multimodel approach has been developed, which is a robust and stable method for describing the probability distributions of maximum seasonal flows. It is claimed that this approach would largely eliminate traditional methods.
- **Modelling of transport processes:** Experimental studies are essential in trying to understand the monitoring and modelling of transport processes in water. Different studies have been performed, mainly related to: (i) monitoring and modelling of transport processes in rivers in the presence of vegetation; (ii) the settling dynamics of particles in stratified environments and in the water column with modified rheology; (iii) laboratory experiments on the incipient motion of artificial sediments. A series of field and laboratory experiments (in our Institute and external laboratories) have been performed with national and international cooperation. These included: Field experiments conducted in an agricultural ditch and small lowland rivers providing a further understanding of the influence of vegetation maintenance on flow, longitudinal mixing and retention, as well as the morphological and biomechanical traits of plants; Laboratory experiments investigating individual disk settling through a stratified water column revealing the influence of the density transition and particle geometry on settling behaviour; Experiments demonstrating that the dynamics of particles settling in ionic aqueous solutions with exopolymers depend to a large extent on non-Newtonian properties of the ambient liquid which are affected by the presence of exopolymers and the salt content.
- **Modelling of drought dynamics:** The process of transformation of drought from meteorological to hydrological drought is studied using two catchments, the Vistula Basin in Poland and the River Huai catchment in China (project https://humdrought.igf.edu.pl/). Those two catchments are situated in different climatic and geographic settings. Scientists predict that rising average global temperatures and rising anthropopressure will have an increasing impact on hydrological phenomena. The aim of this study is to present the history of drought events and find the similarities and differences that characterize the origins, development and ending of drought events in both study areas based on historical hydro-meteorological observations. The study is based on the analysis of temporal and spatial variability of a number of standardized drought indices and a comparison of their sensitivity to physio-climatic and characteristics in Polish and Chinese catchments. As a result, the factors affecting temporal and spatial drought variability – with particular emphasis on the interaction between the variability induced by natural processes and human interaction – have been identified.
- **Modelling of hydrological processes:** The first goal is to investigate the relationship between daily stream water temperatures, air temperatures, discharges by means of the logistic regression models and shallow perceptron neural networks trained by means of deep learning-based dropout, used to avoid overfitting (randomly skipping some nodes in a net during each training iteration). The proposed models are tested on six rivers in Europe and USA. We found that: (a) performances of simple logistic models are competitive against the performances of semi-physical or data-driven models; (b) when training of a particular neural network architecture that includes at least a few hidden nodes is repeated many times, dropout improves the mean performance. The second objective is investigating the relationship

between the calibration time and performance of conceptual rainfall-runoff models. It is shown that an opinion on the model performance based on different popular hydrological criteria, such as the Nash-Sutcliffe coefficient or the Persistence Index, may be misleading. This is because very similar, largely positive values of the Nash-Sutcliffe coefficient obtained on different catchments may be accompanied by contradictory values of the Persistence Index.

6.2 Personnel

Head of the Department
Jarosław Napiórkowski
Professor

Professors
Renata Romanowicz
Paweł Rowiński

Associate Professors
Ewa Bogdanowicz
Monika Kalinowska
Krzysztof Kochanek
Michael Nones
Marzena Osuch
Adam Piotrowski

Assistant Professors
Emilia Karamuz
Iwona Kuptel-Markiewicz
Anna Łoboda
Magdalena Mrokowska
Łukasz Przyborowski

Research Assistant
Arianna Varrani

Geophysicist
Hanna Baczyńska

PhD Students
Marta Majerska, Poland; Marzena Osuch – PhD supervisor
Tesfaye Senbeta, Ethiopia; Renata Romanowicz – PhD supervisor

6.3 Main research projects

- Comparison of satellite imagery and time-lapse photography to track the riverine morphodynamics of the Po River, Italy, M. Nones, ASI (Italian Space Agency), 2019–2021;
- Tracking riverine morphodynamics from satellite imagery: the case of the Po River, Italy, M. Nones, ESA (European Space Agency), 2019–2021;
- Hindcasting and projections of hydro-climatic conditions of Southern Spitsbergen, M. Osuch, National Science Center Poland, 2018–2021;

- Impact of expected climate change on water temperatures of selected Polish rivers, A. Piotrowski, National Science Center Poland, 2017–2020;
- Polish-Chinese SHENG1; Project HUMDROUGHT Human and climate impacts on drought dynamics and vulnerability, R. Romanowicz, National Science Center Poland, 2019–2022;

6.4 instruments and facilities

Equipment

- Model 801 Electromagnetic Open Channel Flow Meter
- Model 10 Field Fluorometer au-005-ce (sn. 6857)
- Fluorometer: (sn. 800606)
- YSI Professional Plus handheld multiparameter meter
- GPS LEICA gx1230gg (sn. 467006)
- ProODO Optical Dissolved Oxygen Instrument
- A wireless weather station Pro2™ Plus including UV and Solar Radiation Sensors
- ADCP – acoustic Doppler current profiler model RiverSurveyor S5 (SonTek)
- Bench Top Testing Machine 5ST (Tinius Olsen)
- ADV – acoustic Doppler velocimeter (Sontek)
- ADV – acoustic Doppler velocimeter (Nortek) (×2)
- Cameras: GoPRO HERO 3 (×1), GoPRO HERO 3+ Silver (×2), GoPRO HERO 3+ Black (×2)
- Microscope model Delta optical Genetic Pro Trino (Delta Optical)
- DJI PHANTOM 4 Drone

Laboratory

Main equipment in Hydrodynamic Models Laboratory:
– Sony video camera
– high-resolution macro image acquisition system
– refractometer
– two hydraulic channels

6.5 Research activity and results

Brief description/abstracts/summaries of some of the achievements of the Department's staff:

DROPOUT IN SHALLOW NEURAL NETWORKS FOR HYDROLOGICAL PROBLEMS
The applicability of Deep Learning methods in various fields of Earth sciences has increased rapidly in recent years, especially in classification tasks. Nonetheless, in hydrology shallow multi-layer perceptron neural networks still remain widely used in regression problems. Despite many clear distinctions between deep and shallow neural networks, some techniques developed for deep learning may help to improve shallow models. Dropout, a simple approach to avoid overfitting by randomly skipping some nodes in a network during each training iteration, is among the methodological features that made deep learning networks successful. We perform a large number of numerical experiments showing that, when used together with early-stopping, dropout and its variant dropconnect could also improve the performance of shallow multi-layer perceptron neural networks.

Shallow neural networks are applied to streamwater temperature modelling problems in six catchments located in temperate climate zones in Poland, Switzerland, and northern USA, based on air temperature, river discharge, and declination of the Sun. We found that, when training of a particular neural network architecture that includes at least a few hidden nodes is repeated many times, the dropout reduces the number of models that perform poorly on testing data, and hence improves the mean performance. If the number of inputs or hidden nodes is very low, the dropout only disturbs the training and is not recommended. However, in the case of shallow multi-layer perceptron neural networks, nodes need to be dropped out with a much lower probability than in the case of deep neural networks (about 1%, instead of 10–50% for deep learning), due to a much smaller number of nodes in the network. The larger probabilities of dropping out nodes hinder the convergence of the training algorithm and lead to poor results for both the calibration and testing data. The dropconnect variant turned out to be slightly more effective than the classical dropout. Due to space limitations, only some results obtained for testing data for Biała Tarnowska are shown in Fig. 1.

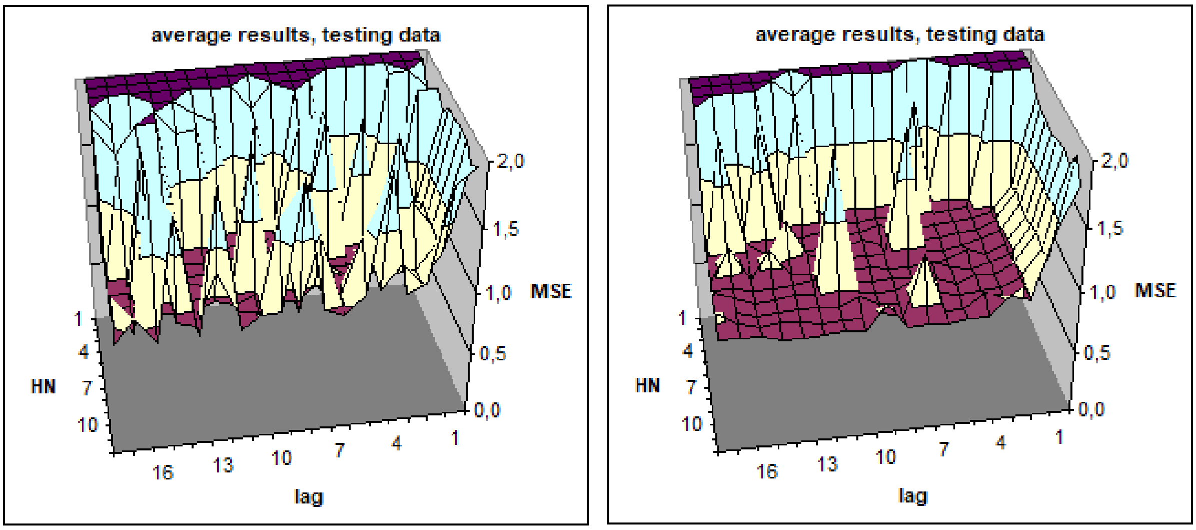


Fig. 1. Performance of shallow networks for the Biała Tarnowska catchment (Poland, testing data set) trained with dropout, related to the number of hidden nodes (HN) and lag days. The number of inputs to the network is always equal to lag +3. On the left panel, the variant without dropout is shown; on the right panel, the variant with dropout with the probability of retaining nodes set to 0.998 is given. Illustrations show the mean performance of particular variants from 50 runs performed (after Piotrowski et al. 2020).

AN ASSESSMENT OF CHANGES IN OBSERVED EUROPEAN RIVER FLOODS

Together with a group of hydrologists from other European countries, we studied changes in observed river floods. The study, with the results published in Nature (Blöschl et al. 2019), is based on the most comprehensive dataset of flood observations in Europe. It consists of river discharge observations from 3 738 gauging stations for the period 1960–2010 with catchment areas that range from 5 km^2 to 100 000 km^2. For each station, the annual maximum peak flow was extracted in each calendar year. Then the trend in each series was calculated using the Theil–Sen slope estimator and the statistical significance was assessed with the Mann–Kendall test was assessed. The results presented in Fig. 1 show a clear regional pattern in flood trends across Europe. The pattern of the trends was grouped into three regions: (1) North-West Europe with increases in floods, (2) Southern Europe with decreases in floods, and (3) Eastern Europe also with decreases in flood magnitude. In the next step, we analysed the reasons for these changes with the help of the temporal evolution of precipitation (annual maximum 7-day precipitation), soil moisture (highest monthly soil moisture in each year) and snowmelt (January to April mean air temperature as a proxy). The results suggest that increasing autumn and winter rainfall has led to increasing floods in northwestern Europe, decreasing precipitation and increasing evaporation have led to decreasing floods in medium and large catchments in southern Europe, and decreasing and earlier snowmelt as a result of warmer temperatures has led to decreasing floods in eastern Europe.

The estimated changes in flood discharges over the last 50 years are broadly consistent with recent climate projections for the next century. These indicate that climate-driven changes are already happening and add urgency to incorporating climate change adaptation strategies into flood risk management.

The results have been described in the article: Blöschl et al. (2019), Changing climate both increases and decreases European river floods.

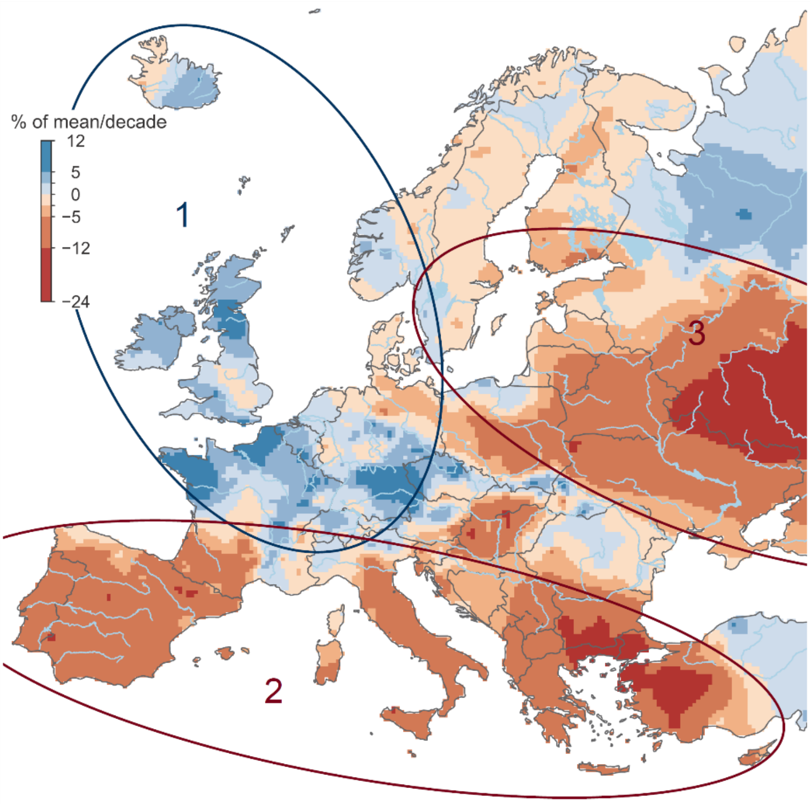


Fig. 1. Observed regional trends of river flood discharges in Europe (1960–2010). Blue colour indicates increasing flood discharges and red denotes decreasing flood discharges (in per cent change of the mean annual flood discharge per decade). The three regions with consistent results between stations and distinct drivers of changes: (1) North-Western Europe: increasing rainfall and soil moisture, (2) Southern Europe: decreasing rainfall and increasing evaporation, and (3) Eastern Europe: decreasing and earlier snowmelt. Source: Blöschl et al. (2019).

MODELLING OF TRANSPORT PROCESSES (WITH THE PRESENCE OF VEGETATION)
All scientific research related to flow and transport processes becomes very complicated in channels where vegetation is present, and although many studies have already been carried out to determine the effect of vegetation on flow hydrodynamics, there are still many open questions and problems that require further analysis. The investigations carried out, using tracer tests conducted in an agricultural ditch in Poland (Fig. 1), provide a further understanding of the influence of vegetation maintenance (fully cut vs. fully vegetated, see Fig. 2) on flow, longitudinal mixing and retention. Vegetation maintenance decreased the flow resistance (Manning's n). The flow velocity increased while the passage of the concentration peak was much

Fig. 1. The Warszawice agriculture channel, fully vegetated conditions, tracer test on 12.09.2019. Photo by M. Kalinowska.

Fig. 2. Selected sub-reach in fully vegetated (top) and fully cut (middle) conditions during the passage of the tracer. The surface coverage of vegetation was determined by computing the ratio of the vegetation-covered surface area to the total wetted surface area available from the fully cut scenario (bottom) (after Västilä et al. 2021).

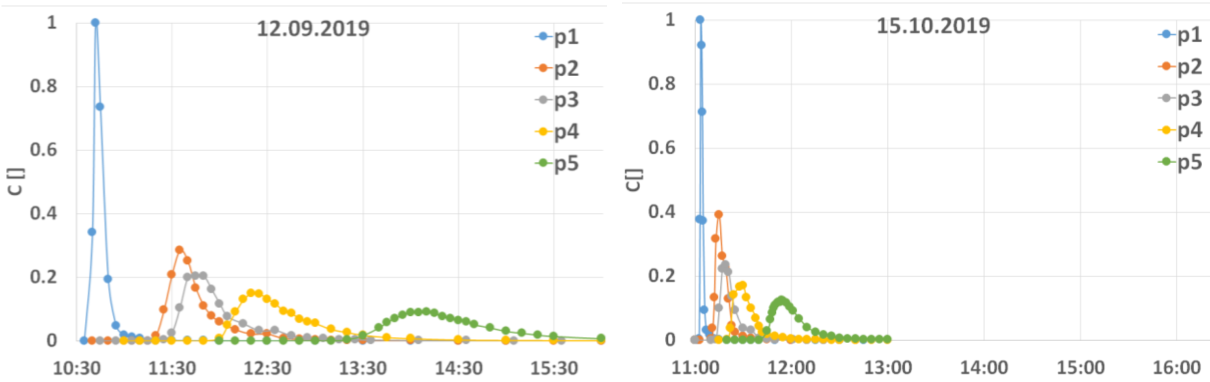


Fig. 3. Tracer concentrations in the 5 cross-sections (p1–p5) normalized with the maximum concentration in the first cross-section (p1): fully vegetated (left) and fully cut (right) conditions. The x-axis encompasses 5.5 hours in both cases (after Västilä et al. 2021).

faster (example results in Fig. 3). By decreasing the retention times, vegetation cutting increased the peak concentrations (C_{max}) by 15–38%. The relative changes in the sub-reach travel time and C_{max} were greatest for the sub-reaches with the largest change in vegetation coverage. Thus, extensive cutting of vegetation from the channel bed can lead to high, ecologically harmful concentrations of suspended matter in reaches with flashy hydrographs, which may be further exacerbated by increasing erosion and the associated mobilisation of, e.g., heavy metals and phosphorus from the channel bed.

The investigations showed that 1D analyses help to investigate the influence of vegetation maintenance scenarios on flow and mixing in small channels. Further experimental research is required on determining how effective different maintenance alternatives (e.g. spatial patterns of cutting, vegetation height, and channel geometry e.g. in two-stage channels) are in combining the needs for flow conveyance, biodiversity, and retention of nutrients.

6.6 Visiting scientists

Vincenzo Totaro, Politecnico di Bari, Bari, Italy, 05.2019–06.2019,
Kaisa Vastila, Aalto University School of Engineering, Helsinki, Finland, 08.2019–09.2019.

6.7 Publications

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Doroszkiewicz, J., **R.J. Romanowicz**, et al. (2019), The influence of flow projection errors on flood hazard estimates in future climate conditions, *Water* **11**, 1, 49, DOI: 10.3390/w11010049.

Kalinowska, M. (2019), Effect of water-air heat transfer on the spread of thermal pollution in rivers, *Acta Geophys*. **67**, 2, 597–619, DOI: 10.1007/s11600-019-00252-y.

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Västilä, K., **M.B. Kalinowska**, A. Kiczko, **E. Karamuz**, **M. Nones**, A. Brandyk, **Ł. Przyborowski**, A.P. Kozioł, and M. Krukowski (2021), Influence of vegetation maintenance on flow and mixing in an agricultural ditch: preliminary results from field investigations. **In:** M.B. Kalinowska, P.M. Rowiński, T. Okruszko, AND M. Nones (eds.), *6th IAHR Europe Congress, Book of Abstracts "Hydro-environment research and engineering. No frames, no borders"*, 321–322, DOI: 10.24425/136660.

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7. DEPARTMENT OF MAGNETISM

Waldemar Jóźwiak

7.1 About the Department

The main research directions in the Department of Magnetism include studies of the lithospheric structures using electromagnetic methods, research in the field of magnetohydrodynamics with applications to the dynamics of the Earth's interior, paleomagnetism and research in the field of environmental magnetism.

Paleomagnetic team took part in a wide range of activities in 2019. The environmental magnetism group working within NM1 task, continued the application of combined magnetic and non-magnetic methods to study the environment pollution. In particular, the scientific interests were focused on the study of traffic-related pollution, the quality of outdoor and indoor air, the pollution of river bank and soils. The collaborate efforts with other teams allowed for a multidisciplinary approach to resolve the questions concerning sources of pollution and evaluation of adverse health effects for children and adults related to exposure pathway of heavy metals. The monitoring service of the PM concentration and magnetic susceptibility to study temporary trends for three locations in Warsaw was also continued. The studies carried out within the NM2 task concerned mostly problems of paleogeographic and tectonic reconstructions. In particular, the investigations in the Carpathians (Poland and Slovakia), Africa (eastern Zimbabwe), and in the area of Svalbard were continued. The research concerned paleogeographic positions of both large lithospheric plates as well as kinematics of smaller units, such as terranes, individual tectonic blocks or nappes. We investigated also Silurian gas-bearing shales from northern Poland focusing on problems concerning organic matter preservation. We investigated detail composition and the properties of magnetic minerals in shales in relation to variable depositional environment in the sedimentary basin.

The magnetic dynamo team within the NM3 has conducted research on scale selection phenomena in magnetohydrodynamic flows and convective heat transfer. The collection of magnetovariation data was systematically supplemented as part of the NM3 task by reinterpreting archival records, as well as the use of new data from current projects. Based on these data, the construction of a three-dimensional model of the geoelectric structure for the area of Poland began. AMT/MT soundings were performed to identify the shallow geological structure in the vicinity of the Grójec fault and data was processed. A combined quantitative interpretation of the GCM and DC-R methods was used to solve the problem of flooding as an application of these methods in engineering geology. Throughout 2019 the absolute measurements and continuous recording of the Earth's magnetic field in Belsk, Hel, and Hornsund (Spitsbergen) observatories were conducted. A continuous recording of geomagnetic field changes with real-time data access has been carried out in the five permanent stations. Moreover, Schumann Resonance observations have been continued in Polish Polar Station Hornsund and Suwalki. Our observatories and permanent stations participated in the global and international networks: INTERMAGNET (International Real-time Magnetic Observatory Network), IMAGE (International Monitor for Auroral Geomagnetic Effects), EMMA (European quasi-Meridional Magnetometer Array). We were also involved in developing an empirical model for dayside magnetospheric plasma mass density.

In addition, the Department of Magnetism is responsible for Task 3 and Task 4 of the EPOS-PL project. In 2019 the works on the paleomagnetic and magnetotelluric database were continued. The Geoelectromagnetic laboratory at Belsk was officially opened. The Laboratory for Paleomagnetism and Environmental Studies was admitted to the TNA programme of EPOS MSL group.

7.2 Personnel

Head of the Department
Waldemar Jóźwiak
Professor

Tomasz Werner
head of paleomagnetic team – until 07/2019,
head of Laboratory for Paleomagnetism and Environmental Studies – since 08/2019

Professors
Magdalena Kądziałko-Hofmokl
Marek Lewandowski
Maria Teisseyre-Jeleńska

Associate Professors
Tomasz Ernst
Beata Górka-Kostrubiec
Rafał Junosza-Szaniawski
Krzysztof Michalski
Krzysztof Mizerski
Anne Neska
Krzysztof Nowożyński
Vladimir Semenov

Assistant Professors
Katarzyna Dudzisz
Sylwia Dytłow
Ashley Gumsley
Szymon Oryński

Research Assistant
Iga Szczepaniak-Wnuk

Laboratory Technician
Grzegorz Karasiński

Technicians
Paweł Czubak
Krzysztof Kucharski
Mariusz Neska
Anna Wójcik
Stanisław Wójcik

Head of Belsk Observatory
Jan Reda

PhD Students
Dominika Niezabitowska, Poland; Rafał Szaniawski – PhD supervisor
Agata Bury, Poland; Anne Neska – PhD supervisor
Dorota Staneczek, Poland; Rafał Szaniawski – PhD supervisor

7.3 Main research projects

- Diversity of technogenic magnetic particles in the soil environment depending on the emission sources and their role in transport of potentially toxic elements, B. Górka-Kostrubiec, National Science Centre (NCN) OPUS 12, 2017–2020;
- Magnetic properties of sediments applied for assessment of pollution level of heavy metals of Vistula River water within Warsaw, I. Szczepaniak-Wnuk, National Science Centre (NCN) Preludium 13, 2018–2020;
- EPOS – PL European Plate Observing System; Task 4 – CIBAL – Centre of Research Infrastructure of Analytical Laboratories, T. Werner, Operational Program Smart Growth 2014–2020, 2017–2021;
- Fire, and then the ice: calibrating southern Africa's position within the Neoproterozoic supercontinent Rodinia, A. Gumsley, National Science Center, Poland Polonez 3, 2018–2019;
- Własności magnetyczne łupków gazonośnych dolnego Paleozoiku z obszaru północnej Polski, D. Niezabitowska, National Science Center, Poland Etiuda 7, 2019–2020;
- Buoyancy driven magnetic dynamo, K. Mizerski, National Science Center, Poland Sonata Bis, 2018–2021;
- The role of lithospheric memory in the spatial and temporal localization of the intraplate deformation – investigating a deep structure of the Grójec Fault Zone based on potential field anomalies and seismic data, W. Jóźwiak, National Science Center, Poland Opus 13, 2018–2021;
- Diagramy FORC jako narzędzie do kompleksowej charakterystyki faz ferromagnetycznych, K. Dudzisz, National Science Center, Poland Miniatura 3, 2019–2019.

7.4 Instruments and facilities

Equipment

- Equipment for magnetic susceptibility measurements in the field
- Equipment for PM dust collection (environmental magnetism studies)
- Equipment for magnetotelluric survey and magnetic observations

Laboratory

Laboratory for paleomagnetism and environmental studies – list of the laboratory equipment:

- Equipment for measurements of magnetic remanence with step-wise AF/TH demagnetization
- Equipment for acquisition of magnetic remanence
- Equipment for magnetic susceptibility measurements
- Equipment for studies of magnetic hysteresis and Curie temperatures

7.5 Research activity and results

Brief description/abstracts/summaries of some of the achievements of the Department's staff:

STREET DUST IS APPLIED TO EVALUATE ANTHROPOGENIC IMPACT AND INDIRECTLY HEALTH RISKS COMING FROM HEAVY METALS EXPOSITION

Geochemical background data are used to distinguish between the sources of heavy metal (natural or anthropogenic) and to categorize the level of heavy metal pollution. The study presents the results of using different geochemical backgrounds (BG1–BG3) to establish the level of heavy metal pollution in street dust as in many cases street dust is applied to evaluate anthropogenic impact and indirectly health risks for people coming from heavy metals exposition. The individual and collective indicators were calculated with respect to the following backgrounds: (1) upper continental crust (UCC) (BG1), (2) the regional geochemical background established for Quaternary surface deposits of the Mazovian region (Poland) (parent geological material occurring in the studied area, Warsaw, Poland) (BG2), and (3) the minimal values of the concentration of heavy metals determined for the real street dust sample collectives from Warsaw (BG3).

Based on the results of the classification performed by using individual and collective pollution indicators, the pollution of street dust in Warsaw is very diverse and depends on the applied background data. Street dust is classified as unpolluted for almost all the heavy metals based on the values of indicators calculated for UCC data. The effect of traffic-related pollution can be detected more precisely based on the values of indicators calculated for GB2 and BG3. The naturally elevated concentrations of heavy metals in UCC data are responsible for the underestimation of pollution impact in street dust. When low concentration of heavy metals is only observed, the application of background data (BG2 and BG3), which better correspond to the geogenic material in street dust, allows to realistically categorize the level of pollution from moving vehicles. In an environment, traffic-related heavy metal pollution generally occurs in the form of complex mixtures.

In Fig. 1 are presented contributions of individual heavy metal concentrations to the total value of potential ecological risk index (PERI) for street dust in Warsaw, Poland. There is an interesting general pattern of distribution of individual metals: independent of the background applied, at least 90% of PERI is dominated by contribution of Cd, Cu, Zn, Pb, and Ni, whereas the rest of the heavy metal load is distributed mainly between Mn and Cr. Although, depending on the background, the proportions of Cd, Cu, Zn, Pb, and Ni are different. A similar pattern is observed for BG1 and BG3, for which PERI coming from Cd is the highest among the seven heavy metals. The second highest contribution comes from Cu, which accounted for 30% and 35% for BG1 and BG3, respectively.

For children and adults were estimated the non-cancerogenic health risk in respect to exposure pathways of heavy metals. For investigated traffic-related heavy metals elements the dermal contact is higher for adults in comparison to children, which probably results from the larger skin of adults surface interacting with toxic elements. For children, the exposure pathways of heavy metals decrease in the following order: ingestion>dermal contact>inhalation.

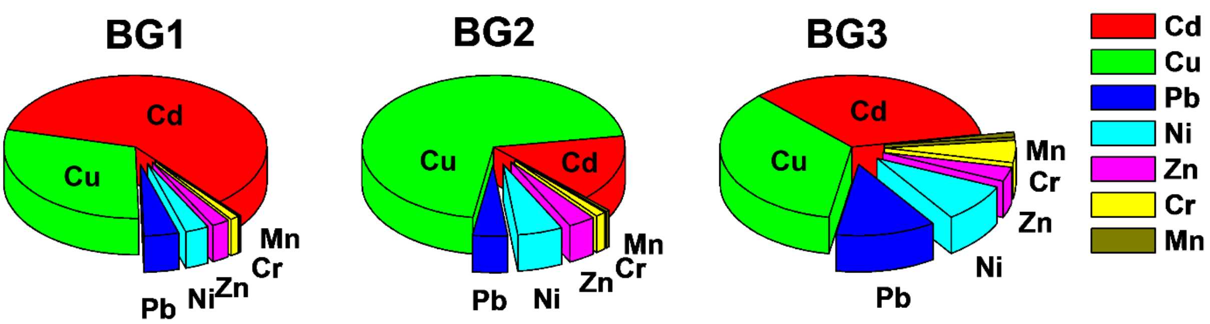

Fig. 1. Contribution of individual heavy metal concentrations to the total value of potential ecological risk index (PERI) for street dust in Warsaw, Poland (after Dytłow and Górka-Kostrubiec 2021).

MAGNETIC MINERAL COMPOSITION AS A POTENTIAL INDICATOR OF DEPOSITIONAL CONDITIONS IN GAS-BEARING SILURIAN SHALE ROCKS FROM NORTHERN POLAND

D. Niezabitowska, R. Szaniawski, and M. Jackson (Institute for Rock Magnetism, University of Minnesota)

In our studies we focused on the rockmagnetic properties of two types of Silurian gas-bearing shales from Northern Poland: the Pelplin and Jantar formations. The analyzed rocks have similar burial evolution, but different amounts of organic matter (in the Pelplin samples the TOC content does not exceed 1.5%, while in the Jantar it reaches up to 7). Additionally, spherical carbonate concretions in the Pelplin Fm. were investigated. The differences in magnetic mineral assemblage may help in better understanding of the determinants which influence water chemistry at the bottom of the sedimentary basin and thus the preservation of organic matter. In order to recognize nano-particles, not detectible in basic rockmagnetic studies, low temperature (10–300 K range) SIRM measurements were performed. The results show the presence of multi domain and superparamagnetic magnetite, which we associate with detrital and chemical origin (smectite illitization or organic maturation), respectively. The most interesting observation is the appearance of single domain hematite solely in the Pelplin Fm. (Fig. 1). We suggest that hematite in mudstones and concretions is a product of magnetite reaction in oxic conditions (with a probable activity of bacteria). This hypothesis is consistent with the presence of early diagenetic carbonate concretions and also with lower values of organic matter in the Pelplin Fm. Moreover, the hematite preserved in both mudstones and concretions in the Pelplin Fm. suggests that stable oxic conditions were present during sedimentation and early compaction process.

As the main conclusion, we propose a relationship between hematite and organic matter content in shale rocks, which may be a useful factor in understanding the preservation of organic matter. Promising results encouraged us to perform further investigation.

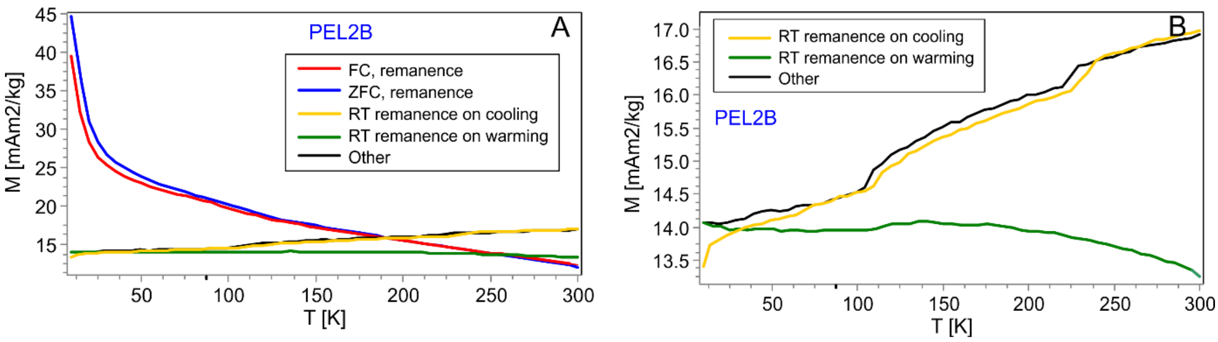

Fig. 1. The results of MPMS measurements of remanence in low-temperature range (10–300 K; –263.15 to 26.85°C) for selected samples from the Pelplin Formation: (a) ZFC and FC remanence, RT-SIRM while cooling and warming, and 'Other' curve; (b) RT-SIRM while cooling and warming, and 'Other' curve. ZFC, Zero Field Cooled; FC, Field Cooled. Room Temperature SIRM; the 'Other' curves are measurements of the RT-SIRM while cooling in a small (+5 μT) applied magnetic field (after Niezabitowska et al. 2019).

THE REDUCTION OF SOURCE EFFECT FOR RELIABLE ESTIMATION OF GEOMAGNETIC TRANSFER FUNCTIONS

We have analyzed the literature suggestions regarding possible changes in vertical magnetic transfer function (VTF) over time. We have shown that for periods above 1500 s the observed changes in VTF are caused by the source effect and we proposed how to reduce this negative impact. For calculations, we used one-minute recordings of geomagnetic variations registered between 2002 and 2017 in various geomagnetic observatories. In data processing, we used frequency-domain Egbert's algorithm and our original algorithm in the time domain. We have shown that the VTFs calculated separately from summer and winter data are different. However, our analysis shows that the variability of the VTF values obtained is misleading and results from time-changing presence of magnetic field variations that do not fulfill the assumption of plane wave. These variations are much more numerous in summer than in winter (Fig. 1). More detailed analysis has shown also that they are usually small at night and big during the day. The vertical components of these variations constitute an error correlated with input signals (horizontal components), which alters the values of the determined VTF.

Furthermore, error bars do not take this effect into account. It makes it impossible to improve the accuracy of calculations by increasing the amount of data. A good VTF estimation is only possible for carefully selected data, for which the presence of vertical component in the external field is negligible. This selection should base on the separation of b_z component into $b_{z,ind}$ and $b_{z,ext}$. Analyzing the estimated external parts of vertical components the Central European observatories we noticed a great similarity of these signals even if the induction components were clearly different, which indicates that this is a regional effect (Fig. 2). On this basis, we proposed a procedure to improve the accuracy of VTF determination by means of separation of b_z for the INTERMAGNET observatories. The separated data should be available on-line. This might be very helpful for evaluating the usefulness of the data recorded in the field.

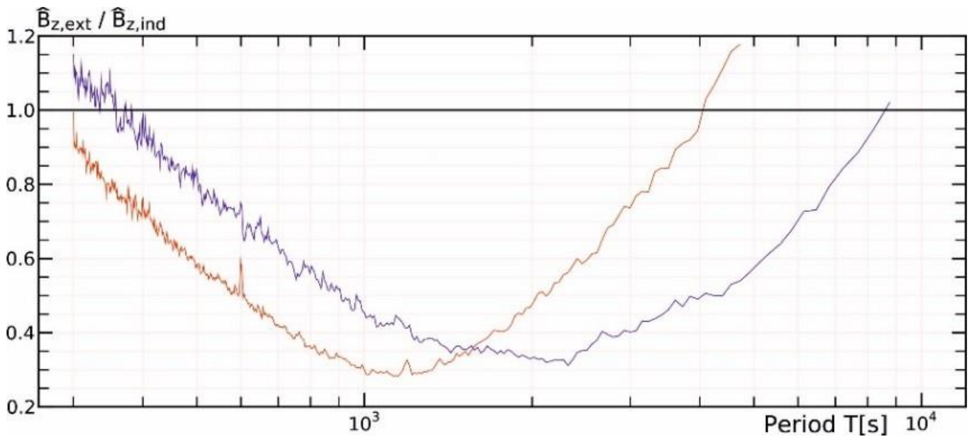

Fig. 1. Plot of the relative prediction error $\hat{B}_{z,ext}/\hat{B}_{z,ind}$ (summer in red, winter in blue) (after Ernst et al. 2020).

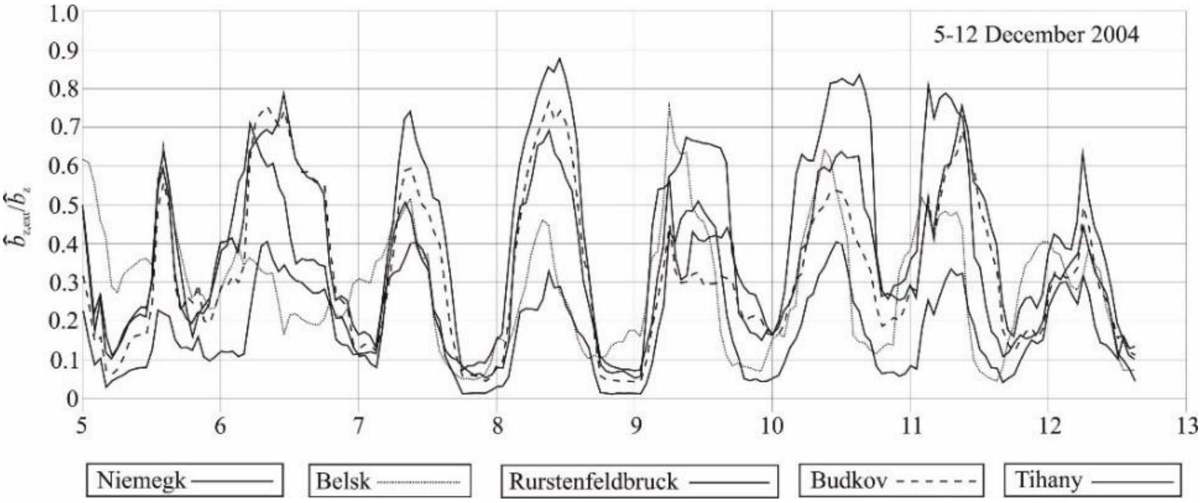

Fig. 2. Comparison of the $\hat{b}_{z,ext}/\hat{b}_z$ for a selected week for the five observatories from Central Europe (the ratio was calculated for 8-hour intervals with 1 hour moving interval) (after Ernst et al. 2020).

7.6 Visiting scientists

Emmanuel Dormy, CNRS, Paris, France, 11–17.08.2019,

Dr. Ahmed Awad Abdel-Rahman, Geomagnetism Department National Research Institute of Astronomy and Geophysics, Helwan, Egypt, 7–19.06.2019,

Achim Morschhauser, GFZ, Potsdam, Germany, 29.07–02.08.2019.

7.7 Publications

ARTICLES

Dudzisz, K., et al. (2019), Integrated rock magnetic and mineralogical study of the Lower Triassic sedimentary rocks from Spitsbergen, *Phys. Earth Planet. In*. **290**, 87–98, DOI: 10.1016/j.pepi.2019.03.009.

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8. DEPARTMENT OF GEOPHYSICAL IMAGING

Michał Malinowski

8.1 About the Department

Department activities in 2019 were focused on the two research topics. The first one deals with geophysical imaging of geological structures at various scales; the second one – with the mathematical analysis of complex systems in geophysics and the dynamics of porous media. The scale of applications ranged from near-surface to the deep crust. We have been working towards solving some fundamental research questions like the structure of the crust in Poland from re-processing of the PolandSPAN regional profiles or structure of the crust within the Nankai Trough seismogenic zone in Japan, employing innovative methods like full-waveform inversion (FWI). Another innovation was related to the use of machine learning tools: unsupervised clustering to scan ambient-noise data from a large array and to select those parts best suited for imaging, as well as unsupervised clustering of the reflectivity patterns to help in interpreting deep crustal profiles. A new NCN-funded project was started this year (SHENG) in collaboration with prof. H. Zhang from China. It is focused on the utilization of the full recorded wavefield (both active and passive) for imaging and monitoring. Our involvement in studying permafrost and ice-quakes in Hornsund resulted in the leading role in preparing a chapter on “Seismological monitoring of Svalbard’s cryosphere: current status and knowledge gaps (CRYOSEIS)” within the “State of Environmental Science in Svalbard (SESS) report 2019”. The near-surface scale was represented by a multimethod geophysical survey repeated at the Cisiec landslide site. We continued working on the marine reflection seismic data acquired offshore Poland (BalTec project). Another area is related to applied research within the broader scope of sustaining the raw material supply for Europe by supporting mineral exploration. In January 2019 we took part in the Open Seminar hosted by the University of Helsinki, summarizing the COGITO-MIN project. We are also active in the EU-funded H2020 Research and Innovation Action project called “Smart Exploration”, in which we aim to improve seismic imaging of mineralization by the use of FWI. We have been working towards development of ambient noise seismic interferometric imaging for mineral exploration using not only COGITO-MIN data, but also a new dataset provided by BHP Minerals from Australia. We also kept working on the methodology for characterization of the unconventional reservoirs (shale gas bearing), introducing direct geostatistical inversion for reservoir properties. The theoretical group was developing a universal model in the form of a stochastic cellular automaton integrating fundamental empirical laws describing statistical properties of earthquakes and enabling the study of the relationship between these laws, as well as investigating the impact of the geometry of pore space on the dynamics of dissolution processes in porous media on the level of laboratory experiments and numerical simulations. The biggest organizational achievements this year were related to kick-off meetings of the BalTec, SHENG, and CRYOSEIS projects.

8.2 Personnel

Head of the Department
Michał Malinowski
Associate Professor

Associate Professors
Mariusz Białecki
Mariusz Majdański

Assistant Professors
Yaser Alashloo
Rafał Czarny
Andrzej Górszczyk

Research Assistants
Marta Cyz
Brij Singh
Jacek Trojanowski

PhD Students
Arpan Bagchi, India; Mariusz Białecki – PhD supervisor
Michał Chamarczuk, Poland; Michał Malinowski – PhD supervisor
Wojciech Gajek, Poland; Michał Malinowski – PhD supervisor
Silvana Magni, Italy; Mariusz Białecki – PhD supervisor
Artur Marciniak, Poland; Mariusz Majdański – PhD supervisor
Miłosz Mężyk, Poland; Michał Malinowski – PhD supervisor
Quang Nguyen, Vietnam; Michał Malinowski – PhD supervisor
Bartosz Owoc, Poland; Mariusz Majdański – PhD supervisor
Rishabh Sharma, India; Mariusz Białecki – PhD supervisor
Brij Singh, India; Michał Malinowski – PhD supervisor

8.3 Main research projects

- Active and passive source multiscale subsurface imaging and monitoring based on the full seismic waveform, M. Malinowski, National Science Centre, 2019–2022;
- Linking deep and shallow geological processes in the transition from Precambrian to Palaeozoic platform in the southern Baltic Sea using new geophysical data, M. Malinowski, National Science Centre, 2018–2021;
- Crustal structure of the East European Craton margin in northern Poland based on the new geophysical data, M. Malinowski, National Science Centre,| 2016–2019;
- Three dimensional model of the lithosphere in Poland with verification of seismic parameters of the wave field, M. Majdański, National Science Center, 2016–2019;
- Relationship of permafrost with geomorphology, geology and cryospheric components based on geophysical research of the Hans glacier forefield and its surroundings. Hornsund, Spitsbergen, M. Majdański, National Science Centre, 2017–2020;
- Mechanistic explanation of a generation of (and deviations from) the universal curve of the Earthquake Recurrence Time Distribution by means of constructions of solvable stochastic cellular automata and their analytical description, M. Białecki, National Science Centre, 2018–2021;
- Sustainable mineral resources by utilizing new Exploration technologies (SMART EXPLORATION), M. Malinowski, NEC, 2017–2020.

8.4 instruments and facilities

Equipment

- A pool of seismic recorders (40 × 1C DATA-CUBE and 20 × 3C DATA-CUBE) was supplemented in 2019 with 20 1C SmartSolo recorders. We also have PEG-40 accelerated weight drop source with carriage and timing system.

Laboratory

- Facilities for seismic data processing, imaging, modelling and interpretation including local InfiniBand cluster, GPU Workstation and NAS data storage systems; Industry state-of-the art software, such as ProMAX, Reveal, Globe Claritas, TSUNAMI, VISTA, OMNI3D, Petrel, Kingdom Suite, GOCAD, Hampson Russell + in-house and academic software.

8.5 Research activity and results

Brief description/abstracts/summaries of some of the achievements of the Department's staff:

DIRECT GEOSTATISTICAL SEISMIC AMPLITUDE VS ANGLE (AVA) INVERSION FOR SHALE ROCK PROPERTIES

M. Cyz

Seismic reservoir characterization aims at prediction of the spatial distribution of the subsurface rock properties from a set of direct and indirect measurements. Commonly, obtaining rock property volumes is done in a two-step approach. At first, the elastic properties are inverted from seismic reflection data and then used to compute rock properties volumes by applying calibrated rock physics models. Such an approach is not only time-consuming, but may lead to biased results as the uncertainties related to seismic inversion may not be propagated through the entire process. We proposed a new method of an iterative geostatistical shale rock physics seismic AVA inversion to invert seismic reflection data directly for shale rock properties. The workflow (Fig. 1) consists of three main steps starting from shale properties model generation of brittleness (BI), TOC, and porosity using stochastic sequential simulation and co-simulation and calculation of the volume of shale. In the following step, elastic property volumes are calculated based on a calibrated shale rock physics model using the self-consistent approximation.

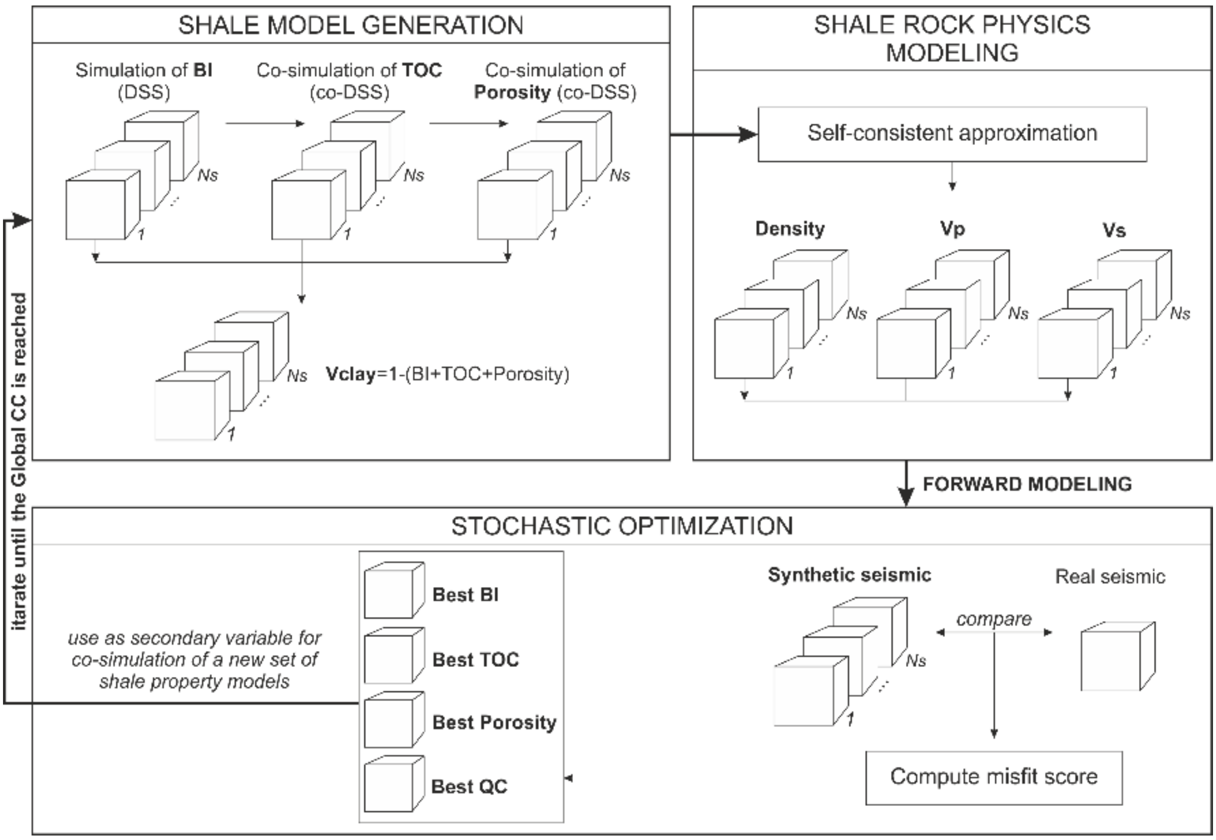

Fig. 1. Schematic representation of the geostatistical shale rock physics seismic AVA inversion methodology (after Cyz and Azevedo 2021).

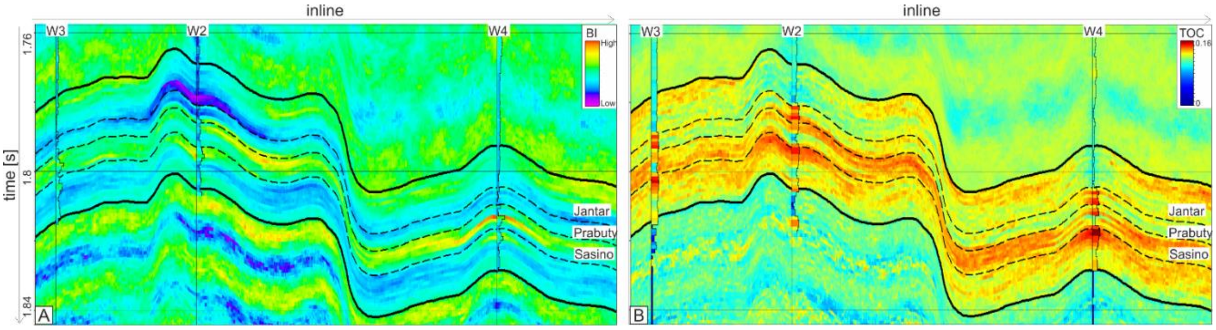

Fig. 2. Vertical well sections through best iteration models of BI (A) and TOC (B) from geostatistical inversion overlaid with input properties logs. The solid horizons mark the area of the main interest (middle zone out of 3). Dashed lines mark the top horizons of key formations (after Cyz and Azevedo 2021).

The elastic models are then used for the calculation of the synthetic seismic data. In the final step, the misfit between synthetic and real data is calculated and used as part of the stochastic update of the model parameter space. The whole process is repeated until a minimum misfit between observed and synthetic seismic is achieved. The proposed method is successfully tested on an onshore Lower Paleozoic shale gas reservoir in Northern Poland and predicted shale rock properties match those observed at a blind-well location. Figure 2 shows example sections of BI and TOC resulting from the application of direct geostatistical seismic AVA inversion.

UNSUPERVISED LEARNING USED IN AUTOMATIC DETECTION AND CLASSIFICATION OF AMBIENT-NOISE RECORDINGS FROM A LARGE-N ARRAY

M. Chamarczuk, M. Malinowski

We developed a method for automatic detection and classification of seismic events from continuous ambient-noise (AN) recordings using an unsupervised machine-learning (ML) approach. We combine classic and recently developed array-processing techniques with ML enabling the use of unsupervised techniques in the routine processing of continuous data. Automatic sorting of detected events into different classes allows faster data analysis and facilitates the selection of desired parts of the wavefield for imaging (e.g., using seismic interferometry) and/or monitoring (see Fig. 1). Seismic AN can be described by its dominant features: frequency, velocity, directionality, and energy. To quantify the frequency, velocity, and directionality, we select the following array-processing techniques: beamforming for determining azimuth and velocity, InterLoc – for location, and power spectral density (PSD) – for frequency and energy. Our basic tool for dividing the AN data into clusters is the *k*-means algorithm. We use these techniques to obtain the optimal number of classes that characterize the AN recordings and consequently assign the proper class membership (cluster) to each data sample. We test our method on a dataset from a large-number (large-N) array, which was deployed over the Kylylahti underground mine (Finland) within the COGITO-MIN project. For the Kylylahti array, the unsupervised clustering produced 40 clusters. After visual inspection of events belonging to different clusters that were quality-controlled by the silhouette method, we confirm the reliability of 10 clusters with a prediction accuracy higher than 90%. Our methodology can be applied to arrays deployed in areas where little or no prior knowledge is available about the AN content, e.g., during site-assessment recordings (Wilmore 1979), AN seismic interferometry imaging studies in remote areas (Draganov et al. 2013), or extraterrestrial terrains (Nishitsuji et al. 2016). In such cases, assumptions in terms of data processing and detection thresholds need to be limited to a minimum, and the detection process must be based on data-driven differences between event representations in preselected transformed domains. Unsupervised clustering of AN events can be treated in the future as the routine seismological processing work-ow, but it requires comparing the performance of different clustering methods.

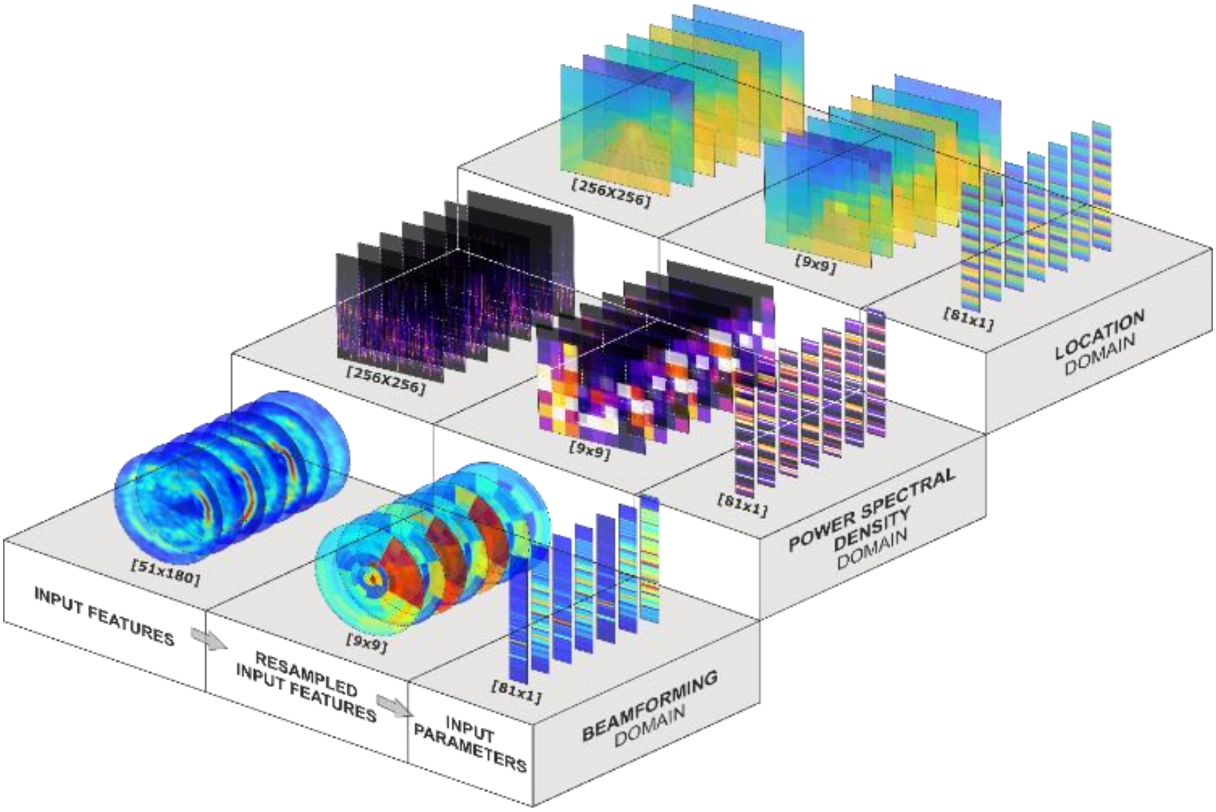

Fig. 1. Data preprocessing scheme for all array processing techniques analyzed in this study: location (top row), power spectral density (middle row), and beamforming (bottom row) (after Chamarczuk et al. 2020).

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NEAR-SURFACE GEOPHYSICAL IMAGING OF THE PERMAFROST – RESULT OF TWO HIGH ARCTIC EXPEDITIONS TO SPITSBERGEN

A. Marciniak, B. Owoc, M. Majdański

Results of seismic studies presented in this work show seasonal changes which affect the cryospheric components of the Hornsund area, Spitsbergen. The two data-sets, from autumn 2017, and spring 2018, were gathered during two expeditions, to directly compare the state of active layer and permafrost in different seasons (see Fig. 1). During the data processing steps, authors

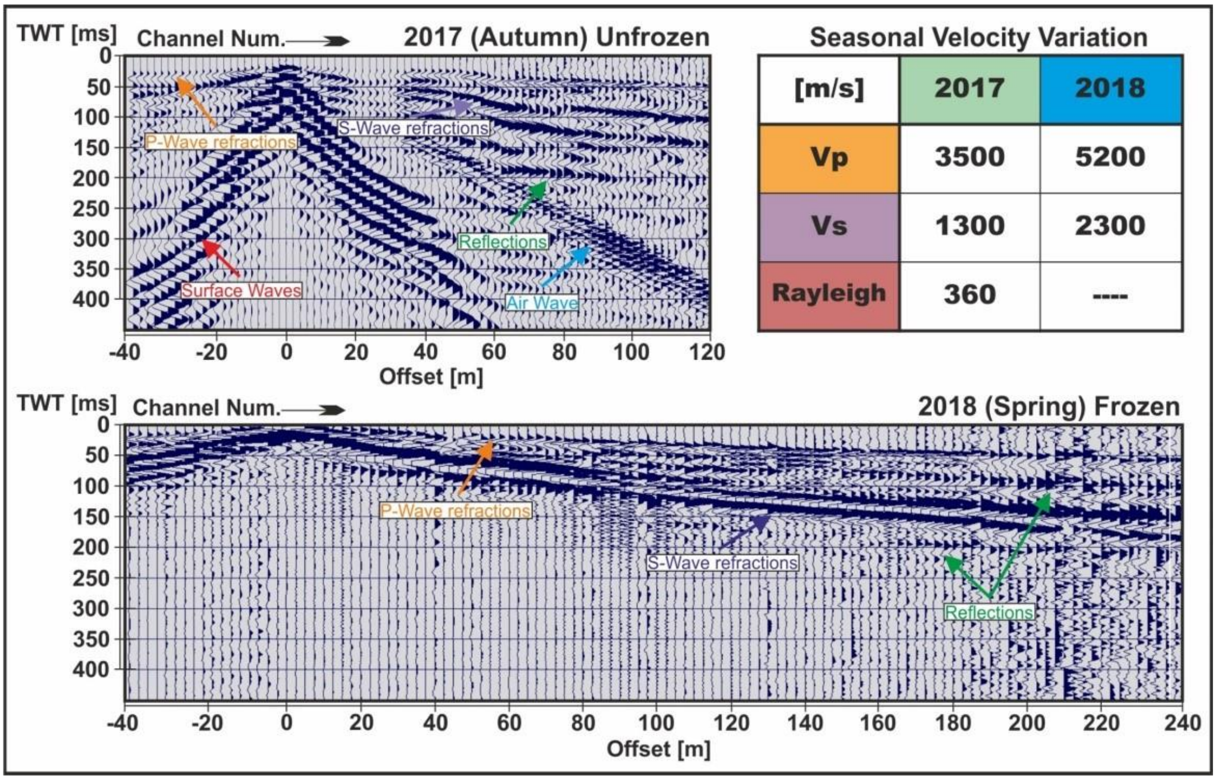

Fig. 1. Significant change of the seismic waveform characteristics observed in two different seasons: unfrozen ground in autumn 2017 (top), frozen in spring 2018 (bottom). The most significant are the first arrivals showing P-wave velocity of 3500 m/s for unfrozen and 5200 m/s in case of frozen ground confirming that seismic methods can recognize the change in the permafrost with great precision.

were able to estimate the main physical properties of the research area, necessary to further imaging of the structures with reflection seismics. Due to the acquisition scheme used, the dataset is suitable for refraction tomography, reflection imaging methods, and MASW analysis. The analysis of high-resolution seismic profiles, performed during different seasons in Spitsbergen proved to be an efficient way to estimate the seasonal changes in active layer depth as well as in possibility in differentiation between sedimentary and crystalline structures present in the research area. From the methodological point of view, researches conducted in the spring, when the land is covered by snow, delivers data with better quality. In the polar regions, where climate changes are clearly visible, estimation of the seasonal impact on the frozen subsurface structures is crucial. Especially from the ecological point of view, the modelling of changes in the permafrost layer is essential. This cryospheric component has a significant impact on the hydrology of the area and can trigger unexpected mass-movements which may also in a catastrophic way change the Arctic environment of the Hornsund area with the possible release of methane due to thawing.

8.6 Visiting scientists

Andreas Wuestefeld, NORSAR, Kjelle, Norway, April 2019 (2 days),
Niklas Alrich, University of Hamburg, Hamburg, Germany, May 2019 (2 days),
Elisabeth Seidel, University of Hamburg, Hamburg, Germany, May 2019 (2 days),
Vera Noack, BGR, Hannover, Germany, May 2019 (2 days),
Yaocen Pan, Uppsala University, Uppsala, Sweden, May 2019 (2 days),
Haijiang Zhang, University of Science and Technology of China, Hefei, China, August 2019 (1 week),

Leo Eisner, Seismik Ltd., Prague, Czech Republic, April 2019 (2 days), August 2019 (2 days),
Andreas Koehler, NORSAR, Kjelle, Norway, August 2019 (3 days),
Johannes Schweitzer, NORSAR, Kjelle, Norway, August 2019 (3 days),
Miłosz Wcisło, ISRM CAS, Prague, Czech Republic, August 2019 (2 days), November 2019 (2 weeks).

8.7 Publications

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Białecki, M. (2019), Catalan numbers out of a stochastic cellular automaton, *J. Math. Phys*. **60**, 1, 012701, DOI: 10.1063/1.5027461.

Chamarczuk, M., **M. Malinowski**, **M. Mężyk**, et al. (2019), Automatic 3D illumination-diagnosis method for large-N arrays: Robust data scanner and machine-learning feature provider, *Geophysics* **84**, 3, Q13–Q25, DOI: 10.1190/geo2018-0504.1.

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Mężyk, M., and **M. Malinowski** (2019), Multi-pattern algorithm for first-break picking employing open-source machine learning libraries, *J. Appl. Geophys*. **170**, 103848, DOI: 10.1016/j.jappgeo.2019.103848.

Mężyk, M., **M. Malinowski**, et al. (2019), Imaging the East European Craton margin in northern Poland using extended correlation processing of regional seismic reflection profiles, Solid Earth **10**, 3, 683–696, DOI: 10.5194/se-10-683-2019.

Owoc, B., **A. Marciniak**, **M. Majdański**, et al. (2019), Seismic imaging of the Mesozoic bedrock relief and geological structure under Quaternary sediment cover: The Bolmin syncline (SW Holy Cross Mountains, Poland), *Geosciences* **9**, 10, DOI: 10.3390/geosciences9100447.

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Sambolian, S., **A. Górszczyk**, et al. (2019), Building initial model for FWI from ultra long-offset OBN data by first-arrival traveltime + slope tomography. **In:** *Proc. 81st EAGE Conference and Exhibition 2019, 3–6 June 2019, London, United Kingdom,* DOI: 10.3997/2214-4609.201901562.

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Marciniak, A., **B. Owoc**, T. Wawrzyniak, A. Nawrot, M. Glazer, M. Osuch, W. Dobiński, and **M. Majdański** (2019), Near-surface geophysical imaging of the permafrost – initial result of two high arctic expeditions to Spitsbergen. **In:** *Conf. Proc. 25th European Meeting of Environmental and Engineering Geophysics, 8–12 September 2019, Hague, Netherlands,* DOI: 10.3997/2214-4609.201902454.

Owoc, B., **A. Marciniak**, S. Kowalczyk, J. Dzierzek,and **M. Majdański** (2019), An optimal combination of geophysical methods to image geological structures. **In:** *Conf. Proc. 25th European Meeting of Environmental and Engineering Geophysics, 8–12 September 2019, Hague, Netherlands*, DOI: 10.3997/2214-4609.201902409.

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Alexandrov, D., et al., **J. Trojanowski** (2019), Optimizing detection of microseismic events by receiver selection on surface monitoring. **In:** *SEG Technical Program Expanded Abstracts 2019*, 3081–3085, DOI: 10.1190/segam2019-3216224.1.

9. DEPARTMENT OF POLAR AND MARINE RESEARCH

Marek Lewandowski

9.1 About the Department

The Department of Polar and Marine Research conducts research on geological and glaciological processes in the polar systems, aiming for a better understanding of their annual-to-decadal variations, their meaning as proxies of the climate changes. The areas of investigations include Spitsbergen, arctic/subarctic Canada, and Antarctica, as well as environmental analogues to polar regions in Poland, the Caucasus, the Alps, and Chile. We focus on the physical and chemical aspects of the litho-, hydro-, and atmosphere, in cooperation with domestic and international partners in five continents. In the year 2019 we continued efforts to extend our exploration areas of exploration and research, with an expedition planned to the East Antarctica this year.

Our most significant achievements of the last year may be summarized as follows:

The effect of changes in the active layer thickness on the rainfall-runoff transformation in glaciers was evaluated. A new project has been started on complex mechanisms of recent, past, and future changes in hydro-climatological conditions and water regime in four catchments with different glacial coverage located in South Spitsbergen.

New ice cores were obtained from the firn of the Hansbreen glacier (Hornsund area), for identification of mineral phases in aeolian dust, deposited recently in the glacier. The main goal of this study was to identify source areas of the dust, as well as evaluating the influence of dust on the glacier’s albedo.

A model of climatological mass balance (CMB), snow conditions and runoff for Svalbard for the years 1957–2018, developed by an international team, allowed determining the long-term negative trend of CMB (−0.06 m w.e. a^{-1} $decade^{-1}$). The outflow from glaciers has a strong positive trend (+3.7 Gt r^{-1} $decade^{-1}$), while the runoff from land has remained almost stable (+0.2 Gt r^{-1} $decade^{-1}$).

A spectral wave model was applied to an analysis of wind wave conditions in Hornsund. The modelling results were validated against observational data within Hornsund. We analyzed the transformation of waves from the open boundary to the inner parts of Hornsund. A detailed analysis of wave conditions, identifying the dominating wave patterns and their relationships with wind and open-ocean wave forcing was performed.

Micromorphology of mineral particles is a useful proxy for reconstructing the history of mineral matter deposited on glaciers. Grains were collected from cryoconite holes on glaciers in the Alps, the Caucasus, and Svalbard. Electron microscopy and other techniques are used to better understand particles origins, transport regimes, depositional processes, biofilm formation, degradation, and grain transformation.

Geological and geochemical investigations into early Earth systems, in the Saglek Block of northern Labrador, Canada and the Tula Mountains of the East Antarctica, have led to the discovery of new localities of Eoarchean (>3.6 billion-year-old) crust. Isotope geochemistry and geochronology has revealed similarities in early Earth histories in both polar regions.

9.2 Polish polar stations

Polish Polar Station Hornsund

The Polish Polar Station Hornsund, named after prof. Stanisław Siedlecki, is a modern interdisciplinary research platform located in the southern part of Spitsbergen, the largest island of the Svalbard archipelago. It was established in 1957 and has been in operation year-round since 1978. It is the only year-round Polish research observatory in the Arctic. The main objectives of the monitoring and research programmes carried out at the Station are related to the evolution of the High Arctic environment with respect to Climate Change.

The Station is managed by the Institute of Geophysics, Polish Academy of Sciences based in Warsaw, Poland. Well-equipped scientific laboratories, satellite communication and high standard accommodation and research facilities are available for over 20 visitors, in addition to the permanent staff of about 10 members of IG PAS Polar Expeditions.

Polish Antarctic Station A.B. Dobrowolski

Polish Antarctic Station A.B. Dobrowolski is a scientific station located in East Antarctica (Bunger Hills, Wilkes Land – 66°16′29″S, 100°45′00″E). Handed over to Poland by the Soviet Union in 1959, the station currently belongs to the Polish Academy of Sciences and is managed by the Institute of Geophysics, Polish Academy of Sciences. The station remains in hibernation, but thanks to the recent progress in the development of measuring instruments, scientific data acquisition, and telecommunication networks, IG PAS has undertaken a decision to revitalize the it.

9.3 Personnel

Head of the Department
Marek Lewandowski
Professor

Professor
Piotr Głowacki

Professors of the Institute
Monika A. Kusiak

Assistant Professors
Oskar Głowacki (on an unpaid leave, Postdoc at Scripps Institution of Oceanography, University of California at San Diego, USA)
Bartłomiej Luks
Mateusz Moskalik
Adam Nawrot
Tomasz Wawrzyniak

Technical Staff
Kacper Wojtysiak (from October to December 2019)

PhD Students
Piotr Król, Poland; Monika A. Kusiak – PhD supervisor
Marta Majerska, Poland; Tomasz Wawrzyniak – auxiliary PhD supervisor
Julian Podgórski, Poland; Piotr Głowacki and Michał Pętlicki (Centro de Estudios Cientificos, Chile) – PhD supervisors
Karol Torzewski, Poland; Adam Nawrot– auxiliary PhD supervisor

9.4 Main research projects

- Measuring the melt rate of glacier ice with underwater noise, Głowacki O., National Science Foundation (NSF) Early-concept Grants for Exploratory Research (EAGER), 2019–2019;

- Badania wpływu cieleń podwodnych na ubytek masy lodowców uchodzących do morza, Głowacki O., Mobilność PLUS, Ministerstwo Nauki i Szkolnictwa Wyższego, 2019–2019;
- EU PolarNet – European polar research cooperation „connecting Science whith Society”, Głowacki P., the European Union’s Horizon 2020 research and innovation programme, 2015–2020;
- EduArctic – Engaging students in STEM education through Arctic research, Głowacki P., the European Union’s Horizon 2020 research and innovation programme, 2016–2019;
- INTAROS – Integrated Arctic observation system, Głowacki P., the European Union’s Horizon 2020 research and innovation programme, 2016–2021;
- Edu-Arctic.pl, Głowacki P., Ministry of Science and Higher Education – DIALOG programme, 2019–2019;
- Interact II – International Network for Terrestrial Research and Monitoring in the Arctic, Głowacki P., the European Union’s Horizon 2020 research and innovation programme, 2016–2020;
- Window into the earliest crust – isotopic characterization of the Enderby Land, Antarctica, Kusiak M.A., NCN OPUS, 2017–2020;
- Role of animals in shaping cryoconite hole ecosystems – effects of bioturbation and food choice, Nawrot A., NCN OPUS, 2019–2022.

9.5 Instruments and facilities

Equipment

- Marine Sedimentology – Hydro-Bios Multi Water Sampler SlimeLine 6 with Sea & Sun CT (PolarPOL); Hydro--Bios Multi Sediment Trap 24 Bottles (PolarPOL); Plastic Water Samplers 1l and 3.5l; Sediment Traps Sets; Sequoia Laser In-Situ Scattering and Transmissometery LISST-100X 2.5–500 µm with Sea-Bird MicroCat CT, BIOBLOCK and 2× Large Battery Pack (PolarPOL); Small Gravitation Sediment Corer Sampler;
- Physical Oceanography – Teledyne RDI ADCP WH300 with float (PolarPOL); Teledyne RDI ADCP Sentinel V20 with Battery Pack; SAIV A/S STD/CTD SD204 with Dissolved Oxygen and Turbidity Sensors (PolarPOL); 6× RBRsolo T (PolarPOL); 2× RBRduet TD (PolarPOL); 2× RBRconcerto CTD (PolarPOL); 2× RBRvirtuoso Tide & Wave; Valeport miniCTD; 3× Sub Sea Sonic AR-50 Acoustic Release (PolarPOL); Russell Technology XIR3000C Marine Radar System with Furuno antenna (PolarPOL); 7× Digisnap Autonomous Photographic Systems;
- Seismoacoustics and Bathymetry – Kongsberg Geoswath 4 Multibeam Echosounder 250 kHz (PolarPOL); EdgeTech Chirp Sub-Bottom 3100-P SB-216S 2–20 kHz (PolarPOL); SEABED Sub-Bottom Profiler 3010-MP 3–14 kHz; Seismoacoustic Sparker and Boomer System; EdgeTech Side Scan Sonar 4125 400/900 kHz with Depressor Wing (PolarPOL); Tritech Side Scan Sonar StarFish 990F; Wesmar Side Scan Sonar SHD700SS; CODA DA 100 Acoustic Acquisition System; Lowrance Echosounder LMS 527C DF GPS 50/200 kHz; Lowrance Echosounder HDS-9 Gen 3 50/200 kHz with Structure Scan;
- Passive Acoustic – 2× Wildlife Acoustic song Meter SM3M Submersible (PolarPOL); 2× Tascam DR-680 recorders with 4× hydrophones with 5 m and 50 m cables;
- Other Instruments for Marine Research – Diving equipment; Buster Cabin E Boat (PolarPOL); SEARIS Multipurpose Unmanned Surface Explorer MUSE with Winch and Camera System (PolarPOL); 2× Hydro-Bios Hand Winch with Motor (PolarPOL); GoPro Hero3+ Silver; GoPro Hero4 Sliver with Underwater Lights and Macro Converter;

- Hydrology/Hydrochemistry – Flow meter Nivus PCM-F with Active Doppler sensor (KDA-KP 10) – runoff ; HOBO U20 – water temperature and water level in streams; NIVUS PCM-F with Active Doppler sensor (KDA-KP 10) (2 sets) – discharge measurements (PolarPOL); Autosampler ISCO 6712 (2 sets; PolarPOL); ISCO rain gauge meters (2 sets; PolarPOL); OnSet Hobo U20 (8 sets) – water level and temperature; OnSet Hobo U24 (4 sets) – water conductivity and temperature; Sontek FlowTracker – Doppler method current meter (Polar-POL); Valeport 802 – Electromagnetic Current Meter;
- Meteorology/Climatology – Vaisala MAWS 301 – automatic weather station – 3 sets (PolarPOL) Geomorphology and cryosphere research, GNSS Leica GR25 (2 sets), GS14, GS10, GNSS Leica GS14 Professional, GNSS Leica GS10 Professional (PolarPOL); Terrestrial Laser Scanner Riegl VZ6000 (PolarPOL); Ice core driller Kovacs Coring System Mark II (PolarPOL); Georadar MALÅ ProEx with antenas (1 set PolarPOL, 1 set ZBPiM); Unmanned aerial vehicle (UAV) Phantom 4 Pro+ (3 sets); MicroMap UAV (PolarPOL); snow density meter (3 sets).

Laboratory

- XRF OLYMPUS VANTA M – advanced handheld X-ray fluorescence (XRF) device. Provides rapid, accurate element analysis and alloy identification to demand laboratory-quality results in the field;
- pH and conductivity meters (2 sets) – hydrochemistry analyses.

9.6 Research activity and results

Brief description/abstracts/summaries of some of the achievements of the Department’s staff:

WIND WAVE VARIABILITY IN HORNSUND FJORD, WEST SPITSBERGEN
A. Herman, K. Wojtysiak, M. Moskalik (published in: *Estuarine, Coastal and Shelf Science* (2019), **217**, 96–109, DOI: 10.1016/j.ecss.2018.11.001)
Abstract: In this study, the third-generation spectral wave model Simulating WAves Nearshore (SWAN) is applied to an analysis of wind wave conditions in Hornsund, a relatively small fjord in the southwestern part of Spitsbergen (Svalbard Archipelago). The model is run on a series of three nested grids with increasing spatial resolution. Wave energy spectra from a large-scale WAVEWATCH III model, wind from the Global Forecast System, and water levels from a tidal model of the Arctic Ocean are used as input data. The modelling results are validated against observational data from four coastal locations within Hornsund: one in Gåshamna and three in Isbjørnhamna/Hansbukta (I/H), which is the main area of interest in this study. Within the frequency range available in observations (<0.15 Hz), the model reproduces the total wave energy with high accuracy (bias below 4 cm, correlation above 0.9), with slight under-/overestimation of energy below/above 0.1 Hz, leading to underestimated mean wave periods (negative bias of 0.65–1.14 s, correlation 0.63–0.78). We analyze transformation of wave energy spectra from the open boundary to the inner parts of Hornsund and perform a detailed analysis of wave conditions in I/H area, identifying the dominating wave patterns and their relationships with wind and open-ocean wave forcing.
Summary: In the range of frequencies registered by the buoys (restriction of the wave logging based on the bottom pressure measurements) the correlation of the significant wave height (Fig. 1B) was in range of $R^2 = 0.89 \div 0.95$ and analogously in case of the mean wave period (Fig. 1C) in range of $R^2 = 0.63 \div 0.87$ depending on the location of grid point and nesting of the model. Produced model has enabled to assign the following features of wind waves in Hornsund.

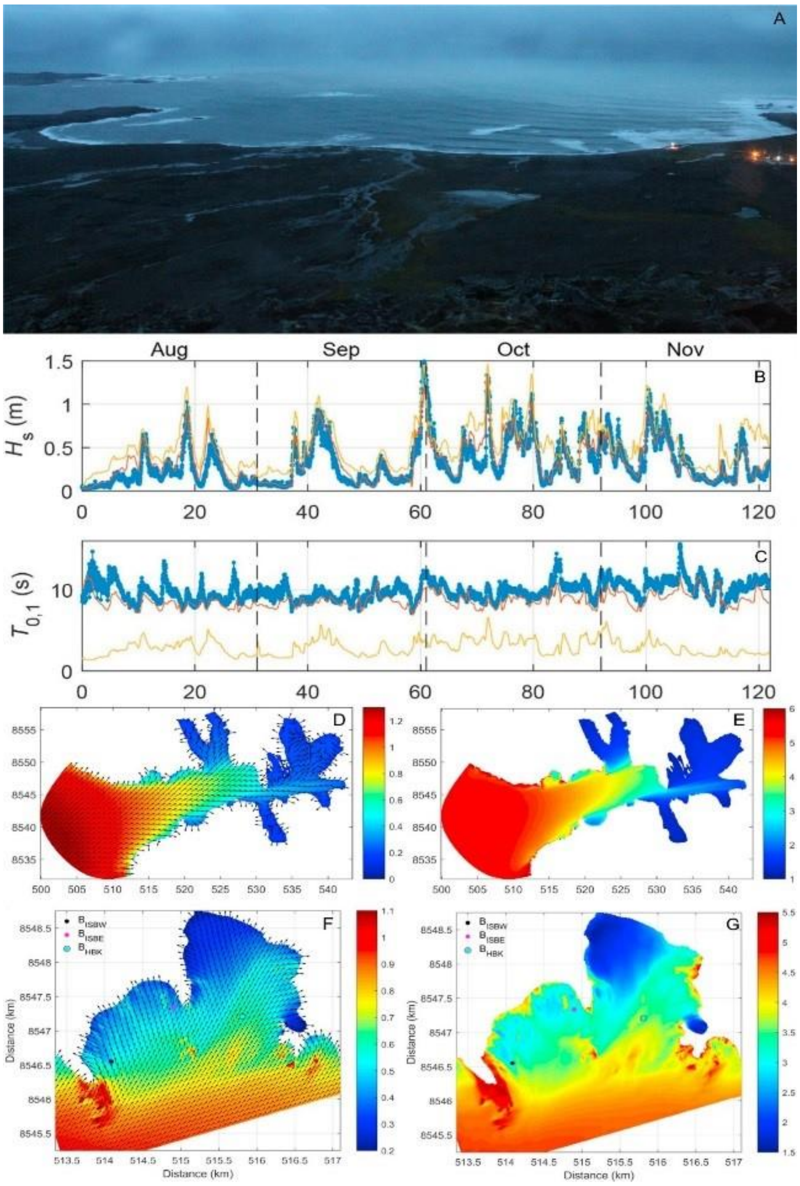

Fig. 1: (A) Wind waves in Isbjørnhamna with long waves refracting off the peninsula; (B) Comparison of the measurements of significant wave height (blue points) with the results from the model in the part of the frequency spectrum corresponding to the measured values (red line) and for the whole spectrum (yellow line); (C) Comparison of the mean wave period analogously to the wave height; (D) Spatial distribution of mean significant wave height (color scale in meters) and the directions of propagation (arrows) in Hornsund fjord; (E) Spatial distribution of the mean wave period (color scale in seconds) in Hornsund; (F) and (G) analogously to the (D) and (E) but for Isbjørnhamna and Hansbukta. In (F) and (G) the location of 3 of 4 underwater wave logging stations in Hornsund used in this study.

MICROMORPHOLOGICAL FEATURES OF MINERAL MATTER FROM CRYOCONITE HOLES ON ARCTIC (SVALBARD) AND ALPINE (THE ALPS, THE CAUCASUS) GLACIERS

K. Zawierucha, G. Baccolo, B. Di Mauro, A. Nawrot, W. Szczuciński, E. Kalińska (published in: *Polar Science* (2019), **22**, 100482, DOI: 10.1016/j.polar.2019.100482)

Abstract: Mineral grain micromorphology is a useful proxy for reconstructing the history of mineral matter deposited on glaciers. In this study, we focus on the grain shape and micromorphology of mineral particles collected from cryoconite holes on glaciers in the Alps, the Caucasus and Svalbard. We use the scanning electron microscopy (SEM) to better understand the origin, transport regime, depositional processes, biofilm formations, degradation and grain transformation (Fig. 1). Our results show that chemical and physical weathering are equally relevant in shaping mineral grains, although in polar and cold regions physical processes dominate. Grains with smooth edges owing to chemical weathering in some of the investigated

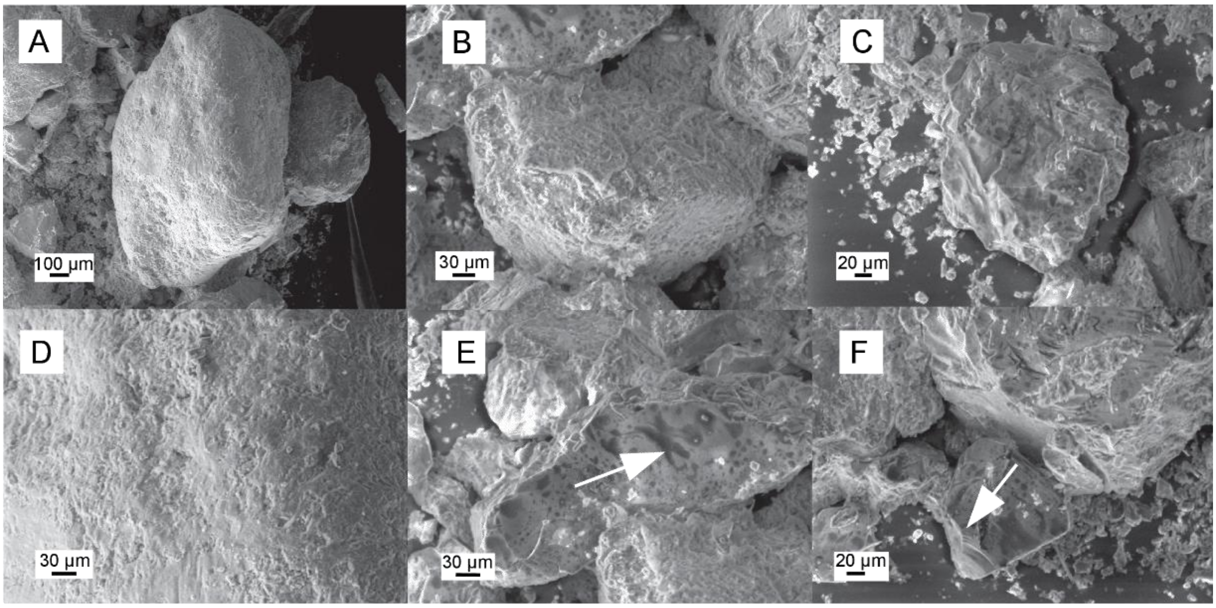

Fig. 1. SEM micrographs of sandy quartz fraction from cryoconite on the Adishi Glacier: (A) and (B) subrounded grains with less excessive (A) and more excessive (B) precipitation on the surface; (C) angular grain with fresh surfaces; (D) details on precipitation with holes; (E) fracture face (arrow); and (F) conchoidal feature with steps and gouges (arrow).

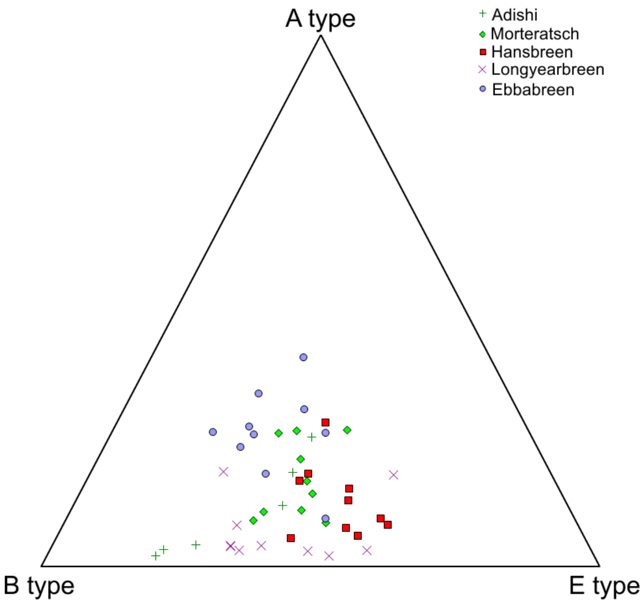

Fig. 2. Ternary diagram of the relative contribution of grains type A (interpreted as effects of physical deterioration due to physical weathering and crushing during transport), B (chemical weathering), and E (polygenetic – grains shaped by chemical weathering and subjected to crushing) in the analyzed samples.

samples, represent more than 60–70% (Fig. 2). Comparison of main grain-type abundance helped to establish that climate is not the most important factor affecting grain micromorphology on glaciers, but local rock sources and supraglacial processes. We hypothesize that grain surface roughness plays an essential role with respect to biofilm formation, while at the same time bacteria-enhanced weathering enriches micromorphology (we observed polymeric substances on some of grains) and release critical compounds for nutrient-poor glacial systems. Thus, grain type and morphology might be an important factor influencing cryoconite granules formation and productivity of cryoconite holes.

A LONG-TERM DATASET OF CLIMATIC MASS BALANCE, SNOW CONDITIONS, AND RUNOFF IN SVALBARD (1957–2018)

W. Van Pelt, V. Pohjola, R. Pettersson, S. Marchenko, J. Kohler, B. Luks, J.O. Hagen, T.V. Schuler, T. Dunse, B. Noël, C. Reijmer (published in: *The Cryosphere* (2019), **13**, 2259–2280, DOI: 10.5194/tc-2019-53)

Abstract: We present a model dataset of climatic mass balance, snow conditions, and runoff for all of Svalbard for the period 1957–2018. Output with a 3-hourly temporal and 1 km × 1 km spatial resolution is generated with a coupled surface energy balance–snow/firn/soil model. The model is forced with downscaled regional climate model fields and applied to both glacier-covered and land areas. In situ observational data from mass balance stakes, weather stations,

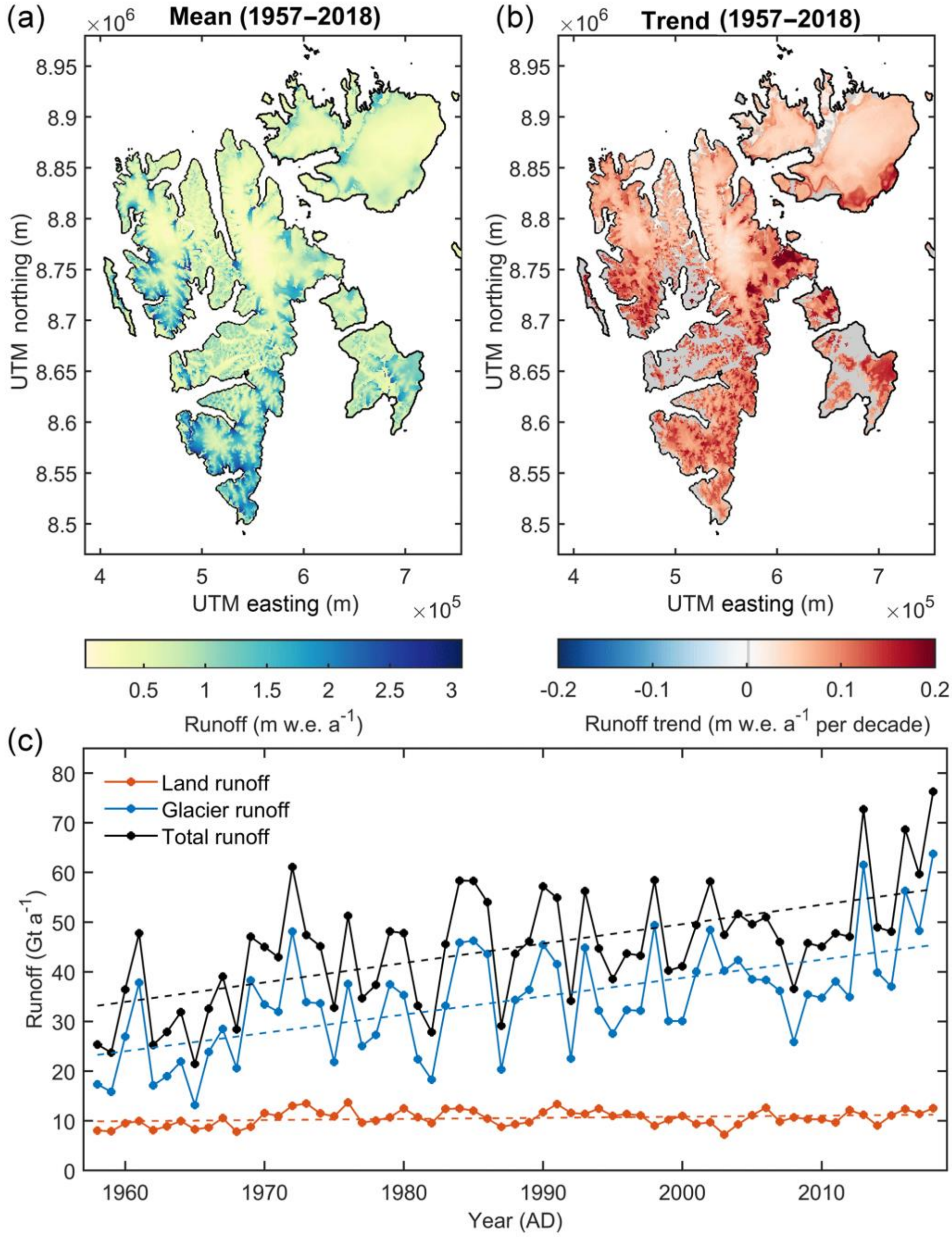

Fig. 1. Long-term mean spatial runoff distribution (a) and trends (b). In (c) time series of area-averaged annual glacier, land and total runoff (solid lines) and linear trends (dashed lines) are shown. Years in (c) are defined between 1 September (preceding year) and 31 August.

and shallow cores are used for model calibration and/or validation of the results. Based on the model output we analyse spatial variability and trends of climatic mass balance, equilibrium line altitude, glacier subsurface conditions, refreezing, seasonal snow season length, and runoff. *Summary:* We find an area-averaged positive CMB (+0.09 m w.e. a^{-1}) and a significant negative long-term trend (–0.06 m w.e. a^{-1} decade^{-1}) over the simulation period. The negative CMB trend has caused the ELA to increase (+17 m decade^{-1}) and the AAR to decrease (–0.04 decade^{-1}) markedly. These trends are significant for all of Svalbard, except for the most northern regions. Increased precipitation and melt cause the date of disappearance of seasonal snowpacks to remain stable throughout the simulation period, while increased autumn temperatures induce a significant increase in the date of seasonal snow onset (+1.4 d decade^{-1}). The average total runoff for Svalbard (44.9 Gt a^{-1}) is dominated by runoff from glaciers (34.3 Gt a^{-1}) rather than runoff from land (10.6 Gt a^{-1}). A strong positive runoff trend applies to glacier runoff (+3.7 Gt a^{-1} decade^{-1}), while runoff from land remained nearly stable (+0.2 Gt a^{-1} decade^{-1}), causing an increase in the relative contribution of glacier discharge to total runoff from 70% to 80% over the simulation period (see Fig. 1).

9.7 Visiting scientists

Grant Deane, Marine Physical Laboratory, Scripps Institution of Oceanography, San Diego, US, 16–20.11.2019,

Mandar Chitre, Acoustic Research Laboratory, Tropical Marine Science Institute, National University of Singapore, Singapore, 16–20.11.2019,

Michał Pętlicki, Centro de Estudios Cientificos, Valdivia, Chile, 31.05–16.06.2019.

9.8 Publications

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Kusiak, M.A., et al. (2019), Lead oxide nanospheres in seismically deformed zircon grains, Geochimica et Cosmochimica Acta **262**, 20–30, DOI: 10.1016/j.gca.2019.07.026.

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Pelt, W., et al., **B. Luks** (2019), A long-term dataset of climatic mass balance, snow conditions, and runoff in Svalbard (1957–2018), *The Cryosphere* **13**, 9, 2259–2280, DOI: 10.5194/tc-2019-53.

Błaszczyk, M., et al., **M**. **Moskalik** (2019), Freshwater input to the Arctic fjord Hornsund (Svalbard), *Polar Res.* **38**, DOI: 10.33265/polar.v38.3506.

Zagórski, P., et al., **M. Moskalik** (2019), Short-term development of Arctic beach system: Case study of wave control on beach morphology and sedimentology (Calypsostranda, Bellsund, Svalbard), *Pol. Polar Res*. **40**, 2, 79–104, DOI: 10.24425/ppr.2019.128368.

Stachnik, Ł., et al., **A. Nawrot** (2019), Aluminium in glacial meltwater demonstrates an association with nutrient export Werenskiöldbreen, Svalbard), *Hydrol. Process*. **33**, 12, 1638–1657, DOI: 10.1002/hyp.13426.

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Zawierucha, K., et al., **A. Nawrot** (2019), Micromorphological features of mineral matter from cryoconite holes on Arctic (Svalbard) and alpine (the Alps, the Caucasus) glaciers, *Polar Sci.* **22**, 100482, DOI: 10.1016/j.polar.2019.100482.

Podgórski, J., et al. (2019), Performance assessment of TanDEM-X DEM for mountain glacier elevation change detection, *Remote Sens.* **11**, 2, 187, DOI: 10.3390/rs11020187.

Osuch, M., **T. Wawrzyniak**, and **A. Nawrot** (2019), Diagnosis of the hydrology of a small Arctic permafrost catchment using HBV conceptual rainfall-runoff model, *Hydrol. Res*. **50**, 2, 459–478, DOI: 10.2166/nh.2019.031.

Herman, A., **K. Wojtysiak**, and **M. Moskalik** (2019), Wind wave variability in Hornsund fjord, west Spitsbergen, *Estuar. Coast. Shelf Sci.* **217**, 96–109, DOI: 10.1016/j.ecss.2018.11.001.

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Gallet, J.C., et al., **B. Luks** (2019), Snow research in Svalbard: current status and knowledge gaps**. In:** *The State of Environmental Science in Svalbard (SESS) report 2018 – an annual report,* 81–107, hal-02341867.

Leppänen, L., et al., **B. Luks** (2019), Uncertainty estimation of manual SWE measurements: experiences from three HarmoSnow field campaigns. **In:** A. Haberkorn (ed.), *European Snow Booklet – an Inventory of Snow Measurements in Europe*, DOI: 10.16904/envidat.59.

"Publications of the Institute of Geophysics, Polish Academy of Sciences: Geophysical Data Bases, Processing and Instrumentation" appears in the following series:

A – Physics of the Earth's Interior

B – Seismology

C – Geomagnetism

D – Physics of the Atmosphere

E – Hydrology (formerly Water Resources)

P – Polar Research

M – Miscellanea

Every volume has two numbers: the first one is the consecutive number of the journal and the second one (in brackets) is the current number in the series.