UNION GEODESIQUE ET GEOPHYSIQUE INTERNATIONALE
INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

Data Assimilation and Inverse Problems in Geophysical Sciences

Project report

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Project objectives

The main goal of the project is to produce a synthesis of important theoretical methods in data assimilation and inverse problems, data analyses and interpretations, and various applications relevant to major disciplines of the Union as well as to societal needs. This project will contribute to (i) the implementation actions for the IUGG Strategic Plan (2016-2023) in part 2 "Encourage closer cooperation between the IUGG groups" and part 7 "Promote fundamental research and education in the geosciences"; (ii) the Action Plan of the International Science Council (Domain Two: "The Digital Revolution"); and (iii) to the 2022 International Year of Basic Sciences for Development (IYBSD2022), an initiative of ISC unions and endorsed by ISC and UNESCO. The proposed project will provide a scientific background for an implementation of sustainable development goals. Moreover, the project contributes to science education, especially in less-affluent countries.

Project activities

Data assimilation addresses an accurate determination of the dynamical processes by combining heterogeneous observations in an optimal way. Mathematical methods of data assimilation describe specific techniques, which form optimal combinations of natural observations and a numerical model that describes the dynamic processes. Applications of inversions and data assimilation in geophysical sciences has a long history and dates to the middle of the last century (e.g., assessment of initial conditions for weather forecasts). Data assimilation has become a major numerical forecasting tool in meteorology, oceanography, atmospheric chemistry, and hydrology, and recently it started to be used in other geophysical disciplines. For years, IUGG general and scientific assemblies feature data assimilation

symposia related to specific geophysical fields or Union symposia dedicated to all IUGG disciplines. Moreover, CMG organizes biennial conferences, where data assimilation and inverse problems are persistent topics.

The major activities of the project were:

- Organization of the advanced workshop (educational activity)

- Organization of the international conference (scientific activity)

- Publication activity

The report on the activities is presented here.

1. Workshop on Data Assimilation and Inverse Problems in Geophysical Sciences

Data assimilation and modern methods of solving inverse problems provide unique opportunities to exploit such approach and collaboration by integrating data and information from disciplinary sources. These techniques become major forecasting tools in meteorology, oceanography, atmospheric chemistry, hydrology, and recently they started to be applied to solid Earth problems. To discuss state-of-the-art, applications, and perspectives of data assimilation and inverse problems in major IUGG disciplines, the IUGG Union Commission on Mathematical Geophysics (CMG), in cooperation with the Abdus Salam International Centre for Theoretical Physics (ICTP) in Trieste and the East African Institute for Fundamental Research (EAIFR) in Kigali, organized the virtual (due to COVID-19 restrictions) Workshop from 18 to 29 October 2021. The workshop secretariat received 117 applications for the workshop, 96 of them were selected and invited to the workshop, and 84 of them attended the meeting. Among them, 32% were female participants; 79% (12%) were participants from least developed countries, namely, from Africa and Middle East 33%, Asia 35%, Latin America 19%, and Oceania 3%. List of the workshop participants can be viewed here: https://indico.ictp.it/event/9609/material/6/0.pdf

Workshop participants received welcome addresses from *Kathryn Whaler*, IUGG President, and *Atish Dabholkar*, ICTP Director. World leading scientists from Australia, Canada, Germany, Italy, Republic of Korea, Russia, Spain, Switzerland, and USA lectured at the workshop and discussed with participants the topics in relation to specific geophysical disciplines. The workshop had two sessions (morning and afternoon) every working day allowing lecturers from different parts of the world to attend and deliver lectures. The workshop program including the links to lectures notes and videos can be viewed at: https://indico.ictp.it/event/9609/other-view?view=ictptimetable.

Three sessions (two oral and one poster) were dedicated to presentations by the Workshop's participants, whose abstracts were selected for presentation by workshop's directors. These sessions highlighted the research on data assimilation, direct and inverse problems in geosciences, and quantitative modeling done by the participants from Argentina, Brazil, Cameroon, Cuba, Ethiopia, Ghana, Hungary, India, Indonesia, Iran, Italy, Mexico, Nepal, Nigeria, Rwanda, Senegal, Sudan, Turkey, and UK. All the presentations were judged, and three best papers were selected. *Maibys Sierra Lorenzi* (Cuba; female scientist), Maria *Alejandra Vesga Ramirez* (Argentina; female scientist), and *Hari Ram Thapa* (Nepal) received the best paper awards (EUR 200). More information on the Workshop can be found at: http://indico.ictp.it/event/9609.
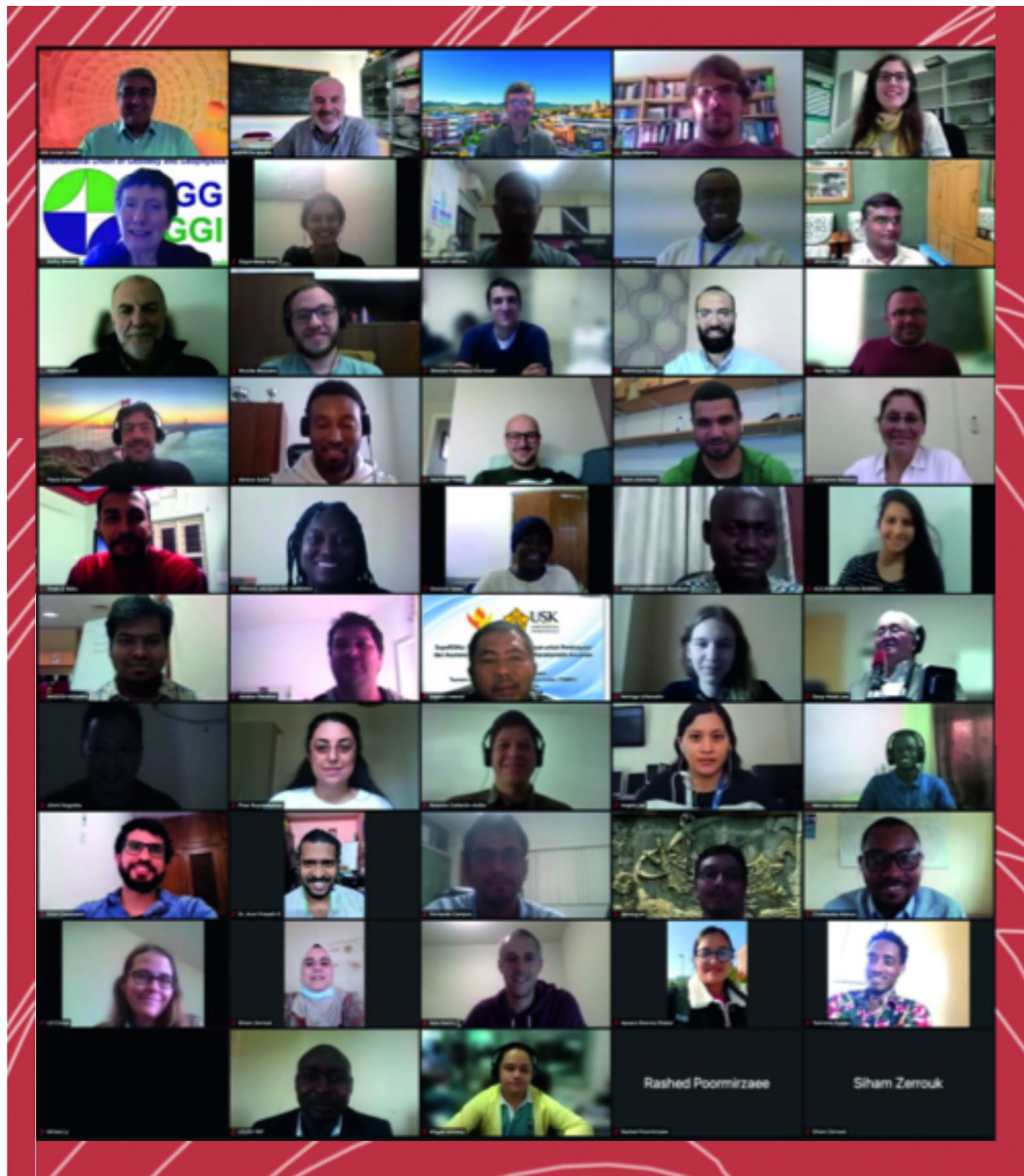
Group photo (source: ICTP)

The scientific committee of the workshop will consist of the members of CMG and a few additional experts from the participating Associations. Namely, Alik Ismail-Zadeh (Germany), Ilya Zaliapin (USA), Yehuda Ben Zion (USA, IASPEI), Roberto Carniel (Italy, IAVCEI), Enamundram Chandrasekhar (India, IAGA), William Dewar (IAPSO), Salvatore Grimaldi (Italy, IAHS), Shin-Chan Han (Australia, IAG), Ute Herzfeld (USA, IACS), Sang-Mook Lee (Republic of Korea, IUGG), William Richard Peltier (Canada, IUGG), Annick Pouquet (USA, IAMAS), Daniel Rothman, (USA, IUGG), Malcolm Sambridge (Australia, IASPEI).

2. The 33rd IUGG Conference on Mathematical Geophysics (CMG2022)

CMG2022 was held in Seoul, Republic of Korea, from 20 to 24 June 2022 in a hybrid format. The conference was organized by the Union Commission on Mathematical Geophysics and hosted by the Seoul National University. The CMG2022 Program (http://www.cmg2022.org/index.php/scientific-program) covered several important topics of

mathematical geophysics, including geophysical inversions and data assimilations. Particularly, scientific session "Geophysical Inversion: Theory, Algorithms, and Applications" was organized and chaired by Malcolm Sambridge (Australian National University, Australia), Jan Dettmer (University of Calgary, Canada), and Kerry Gallagher (University of Rennes, France). Scientific session "Data Sciences, Machine Learning and Artificial Intelligence" were organized and chaired by Daniel Scherzer (Ecole des Ponts ParisTech, France) and Enamundram Chandrasekhar (Indian Institute of Technology Bombay, India). A panel of eminent experts in geosciences, physics, and mathematics (https://www.cmg2022.org/index.php/panel-discussion/) discussed how basic science, mathematics, science education and policymaking should be integrated in contribution to solving fundamental problems of nature and society as well as challenging issues of sustainability. The panel raised awareness about the 2022 United Nations International Year of Basic Science for Sustainable Development in promoting basic sciences. More than 140 people from 33 countries attended the conference.


Group photo

3. Book "Applications of Data Assimilation and Inverse Problems in the Earth Sciences"

Many contemporary problems faced by Earth sciences and society are complex, e.g., climate change, disaster risk, energy and water security, and preservations of oceans. Studies of these challenges require an interdisciplinary approach and common knowledge. This book contributes to a closure of the gap between Earth science disciplines and assists in utilization of the growing amount of data from observations and experiments using modern techniques on data assimilation and inversions developed within the same/another discipline or across the disciplines.

This book covers basic knowledge about geophysical inversions and data assimilation and discusses a range of important research issues and applications in atmospheric and cryospheric sciences, hydrology, geochronology, geodesy, geodynamics, geomagnetism, gravity, near-Earth electron radiation, seismology, and volcanology. This book creates an opportunity to inspire more researchers to focus on data assimilation and inverse problems in

Earth sciences and to provide a useful theoretical reference and practical applications of data assimilation and inverse problems. This is a key resource for academic researchers and graduate students in a wide range of Earth and environmental science disciplines, who are specialized in data assimilation and inverse problems.
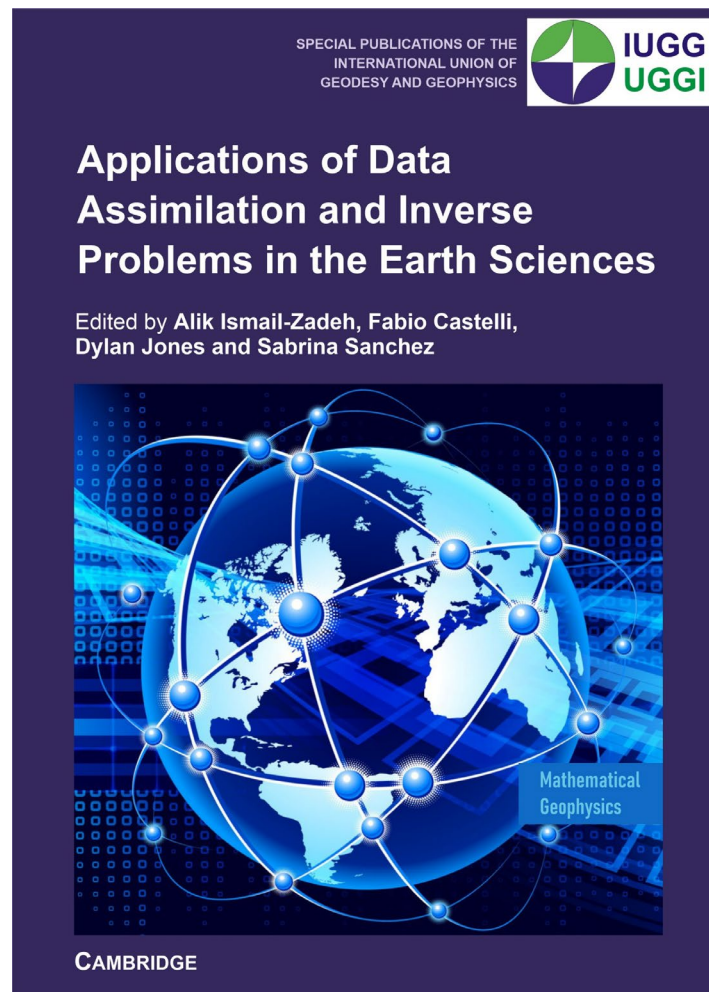
The book's editors are Alik Ismail-Zadeh (Germany), Fabio Castelli (Italy), Dylan Jones (Canada), and Sabrina Sanchez (France). The Editorial Advisory Board consists of the Members of the CMG Executive Committee. The book was published in 2023 by the Cambridge University Press as a part of the IUGG Special Publication Series.

More information about the book including its content and the authors can be found at the website of the Cambridge University Press: https://doi.org/10.1017/9781009180412.