

Sub-commission 3.4: Cryospheric Deformation

Joint with IACS

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Terms of Reference

This commission now is a joint effort of IACS and IAG, the International Association of Geodesy, which has built upon a history of separate activities in the two Associations. The overall goal of our commission is to get a better understanding of the interaction between the cryosphere - in particular the ice sheets and glaciers - and the Solid Earth. This SC has a long history as part of IAG. At the Montreal IUGG, it was decided to make this a joint sub-commission with IACS. Within IAG, SC3.4 historically has focused on resolving technical measurement issues. With the new cross-Association sub-commission, we will have a better opportunity to enhance collaboration and dissemination of these measurements within the glaciological community.

Past and present changes in the mass balance of the Earth's glaciers and ice sheets induce present-day deformation of the solid Earth on a range of spatial scales, from the very local to global. Geodetic observations that validate, or may be assimilated into, models of glacial isostatic adjustment (GIA) and/or constrain models of changes in present-day ice masses through measurements of elastic rebound are of paramount importance, as are "paleo-geodetic" observations like the history of relative sea level. Present-day ice mass changes induce an immediate elastic deformation of the Earth, while the integrated history of mass changes induces an additional viscoelastic deformation. Traditionally, these have been considered separately, which is a good approximation for long-ago load changes and regions of high mantle viscosity. In regions of low mantle viscosity (e.g. West Antarctica and Iceland), the present-day and recent past load changes must be modeled together as the rapid viscoelastic relaxation is substantial and not easily separated from the immediate elastic changes. In all cases, present-day geometric measurements (e.g., uplift rates) measure the sum of elastic and viscoelastic deformations, and these components cannot be separated without additional models or observations. Present-day gravity changes have a different sensitivity to the elastic and viscoelastic components.

In addition, it is now clear that 1-D Earth models are no longer sufficient for many problems, but 3-D models pose computational challenges, and careful inter-comparison of 3-D models is required to better understand model differences. Reference frames of GIA models are likely computed in the center of mass of the solid Earth frame, while the International Terrestrial Reference Frame (ITRF) is defined with origin at the center of mass of the Earth system (including all fluids). This means a frame origin transformation is required to allow direct comparison to measurements in ITRF and ambiguity currently exists over the exact transformation between the two.

Summary of the Sub-commission's activities during the period 2019-2023:

Most of our activities have been carried out in cooperation with other groups having similar goals, including Joint Study Group 3.1. In addition, the pandemic has hampered many of our plans, including the organization of workshops, however, we organized a highly successful online seminar series jointly with colleagues representing the World Climate Research Program (WCRP) and measurements of Paleo Sea-level (PALSEA). We also organized or co-organized several sessions at virtual or in-person scientific meetings. We co-sponsored the application of Joint Study Group 3.1 that was successful in obtaining funding for a GIA School to be held in July 2023. There is also an ongoing effort together with other related groups to develop a 3D GIA benchmarking effort.

A central activity of SC3.4 has been the organization of a virtual seminar series on sea Level, GIA and ice sheets. This highly successful monthly seminar series drew a consistent audience, with often over 100 participants worldwide to each seminar. It promoted cross-disciplinary discussions and collaborations across connected fields. Speakers included a number of early-career scientists, as well as established names. We recommend that cross-disciplinary virtual seminars continue in the next 4-year period, and the once per month frequency strikes a good balance, being regular enough to keep people engaged, but not so frequent as to be too routine.

The series was first designed to lead up to a PALSEA workshop in fall 2021 (<https://palseagroup.weebly.com/2021-meeting.html>), which included a focus on topics of strong interest to SC3.4. In September 2021, the SERCE-PALSEA workshop took place (<https://palseagroup.weebly.com/2021-meeting.html>), where empiricists and modelers from the sea level and ice sheet communities together presented their work ~30 oral presentations and 2 poster session, including a number of presentations by members of sub-commission 3.4. The interest in the seminar series was strong enough that we resumed the series again in winter 2022, leading up to the next PALSEA workshop as well as the WCRP Sea Level Conference, both held in Singapore in July 2022. We chaired sessions at both conferences with speakers and discussions focused on Earth-ice-sea level interactions.

The talks in the series were as follows, and have all been uploaded publicly here: https://mediaspace.msu.edu/playlist/dedicated/1_wic2n936/ (note that they are listed in reverse order, from most recent to oldest):

March 2021 - Bob Kopp on the IPCC AR6 process, including the topic “What is needed from the paleo and GIA community to help refine projections of future sea-level change?”

April 13th 2021 - Future directions in GIA model intercomparison and benchmarking Wouter Van der Wal - GIA and benchmarking

May 11th, 2021: Perspectives from the modern sea level and ice sheet modeling communities. Aimée Slangen, a researcher at the Netherlands Institute for Sea Research (NIOZ) and a lead author of the IPCC AR6 report, will discuss advances in modern sea level research and coastal risk and Fiamma Straneo from SCRIPPS Institution of Oceanography (UCSD) will

discuss the ISMIP6 effort and offer her perspective on how to facilitate cross-disciplinary collaboration.

June 8th, 2021 - Records of paleo ice sheet variability

April Dalton from Charles University will discuss how “The marine d18O record overestimates continental ice volume during Marine Isotope Stage 3”, and Drew Christ from the University of Vermont will present “Camp Century revisited: an ecosystem under the ice reveals Greenland’s warmer past.”

July 13th 2021 - Holocene paleo sea level records

Nicole Khan and (Stephen Chua) - Paleo sea level records

March 2022 - theme: rates and amplitudes of Pleistocene ice sheet and sea level variations.

Georgia Grant: “Continuous record of sea-level change during the intensification of North Hemisphere Ice Sheets (3.3 – 1.7 Ma)”

Jo Brendryen - “Rates of Deglacial Ice Sheet Retreat”

April 2022 - Nicholas Golledge, "Climate forced changes of the Antarctic Ice Sheet: Evidence, inference, and speculation"

May 2022 - Terry Wilson and Doug Wiens on “Cryosphere – Solid Earth Interactions in Antarctica: Insights from Geodetic and Seismic Measurements”

June 2022 Sally Brown “Impacts and adaptation to sea-level rise” and Ivan Haigh “The impact of sea-level rise on storm surge barriers”

Another key activity, jointly with colleagues representing the World Climate Research Program (WCRP) and measurements of Paleo Sea-level (PALSEA), has been to begin to organize a 3D GIA benchmark effort. Initial plans were presented to the community at the European Geoscience Union General Assembly. These were well received, which culminated in a GIA symposium at the upcoming IUGG 2023, where the benchmark efforts will be one of the main topics of discussion. Furthermore, members of sub-commission 3.4 were involved as organizers, session chairs and presenters in the 2021 and 2023 Geodesy for Climate Research symposia from IAG the Inter-Commission Committee on "Geodesy for Climate Research", which both featured several presentations on Earth-ice-sea level interactions.

The IAG SC3.4 co-sponsored a proposal to IUGG to support the 2023 Glacial Isostatic Adjustment (GIA) Training School, which was led by another IACS-IAG joint working group. The proposal was successful, and US\$5000 was awarded to support the participation of young scientists to this school, which will be held in Sweden in July 2023.

We also had extensive discussions about organizing a GIA-focused meeting, likely to be held in Canada. The meeting calendar became very crowded after the end of the pandemic restrictions, so plans did not coalesce. Those discussions are ongoing, with the possibility of a meeting in 2024. We think such a meeting will be important and encourage further planning.

Below is a summary of sessions organized or co-organized at major international scientific meetings.

- AGU Fall meeting 2020: Sessions G012 (poster) and G013 (oral): Linking Cryosphere and the Solid Earth: From Sea Level Changes and Geodetic Time Series to Earth Rheology Session conveners: Rebekka Steffen, Jeff Freymueller, Natalya Gomez, Lambert Caron, 31 abstracts submitted. This session was organized together with JSG3-1.
- EGU General Assembly 2021 (vEGU21): Session 3.1: Geodesy for Climate Change, Session conveners: Roelof Rietbroek, Carmen Boening, Henryk Dobslaw, Anna Klos, Bert Wouters, 16 abstracts submitted.
- IAG Scientific Assembly 2021: Sessions 3.2: Observations and modeling of deformation related to changing ice, Session conveners: Jeff Freymueller, Natalya Gomez, Rebekka Steffen, Erik Ivins, Bert Wouters and Hansheng Wang, 12 abstracts submitted. This session is organized together with JSG3-1.
- Geodesy for Climate Research symposium 2021. Co-organized by Bert Wouters, 61 abstracts submitted,
- Geodesy for Climate Research symposium 2023. Co-organized by Bert Wouters, 46 abstracts submitted.
- IUGG General Assembly 2023: Session JG01 - Interactions of the Solid Earth With Ice Sheets and Sea Level (IAG, IACS, IASPEI). Session Conveners: Rebekka Steffen, Bert Wouters, Natalya Gomez, Lambert Caron, Doug Wiens. (organized jointly with Joint Study Group 3.1).
- IUGG General Assembly 2023: Session JG05 Geodesy for Climate Research (IAG, IAMAS, IACS, IAPSO, IAHS). Session Conveners: Annette Eicker, Bert Wouters, John T Reager, Adam Scaife, Benoit Meyssignac.