Inter-Commission Committee on Geodesy for Climate Research (ICCC)

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President: Annette Eicker (Germany)
Vice President: Carmen Blackwood (USA)

ICCC website - https://geodesy.science/iccc/

1 Structure

Steering Committee

President:	Annette Eicker (Germany)
Vice-President	Carmen Blackwood (USA)
Representative of Comm.1:	Jeff Freymueller (USA)
Representative of Comm.2:	Rebecca McGirr (Australia)
Representative of Comm.3:	Grace Carlson (USA)
Representative of Comm.4:	Anna Klos (Poland)
Representative of GGOS:	Laura Sanchez (Germany)
Member at Large:	Fernanda Camisay (Argentina)
ECS-Rep:	Franck Ghomsi (South Africa)

Joint Working Groups

JWG C.1 Climate Variability and Climate Change in Earth Orientation Parameters
Chair: Henryk Dobslaw (Germany)
Vice-Chair: Jolanta Nastula (Poland)
Affiliations: Commission 3, IERS, GGOS

JWG C.2 Polar geodesy for understanding climate change
Chair: Ingo Sasgen (Germany)
Vice-Chair: Bert Wouters (Netherlands)
Affiliations: Commissions 2 and 3, GGOS

JWG C.3 Assessing Earth's Energy Balance with geodetic observations
Chair: Maria Hakuba (USA)
Vice-Chair: Felix Landerer (USA)
Affiliations: Commission 2, GGOS

JWG C.4 Hydrological loading: measuring and modeling
Chair: Mohammad J. Tourian (Germany)
Vice-Chair: Joelle Nicolas (France)
Affiliations: Commissions 2 and 4, GGOS

JWG C.5 Exploitation of ground-based GNSS Interferometric Reflectometry for climate applications
Chair: Makan Karegar (Germany)

Vice-Chair: Dongju Peng (China-Hong Kong)
Affiliations: Commission 4, GGOS

JWG C.6 GNSS mass-market devices in climate and environmental sensing: approaches, opportunities, challenges, and social impact
Chair: Tobias Kersten (Germany)
Vice-Chair: Balaji Devaraju (India)
Affiliations: Commission 4, GGOS

JWG C.7 Ground-GNSS trends for climate models
Chair: Marcelo Santos (Canada)
Vice-Chair: Rosa Pacione (Italy)
Affiliations: Commission 4, IGS, IVS, GGOS

JWG C.8 Optimal processing and homogenization of GNSS-PW climate data records
Chair: Olivier Bock (France)
Vice-Chair: Galina Dick (Germany)
Affiliations: Commission 4, IGS, GGOS

JWG C.9 Climate Change Signals in High Resolution Surface Water Observations
Chair: Luciana Fenoglio (Germany)
Vice-Chair: Jessica Fayne (USA)
Affiliations: Commission 2, GGOS

JWG C.10 Tailored Parameterization Strategies for Climate Applications of Satellite Gravimetry
Chair: Marius Schlaak (Germany)
Vice-Chair: João de Teixeira da Encarnação (Netherlands)
Affiliations: Commission 2, ICCT, GGOS, IGFS

2 Overview

Goals

The following specific goals were identified for the ICCC:

- to deepen the understanding of the potential (and limitations) of geodetic measurements for the observation, analysis and identification of climate signals.
- to advance the development of geodetic observing systems, analysis techniques and data products regarding their sensitivity to and impact on Essential Climate Variables.
- to advance the improvement of numerical climate models, climate monitoring systems, and climate reanalysis efforts through incorporating geodetic observations.
- to stimulate scientific exchange and collaboration between the geodetic and the climate science communities.
- to make geodetic variables more user-friendly by sharing them publicly and explaining their usefulness.

ICCC Workshop

Apart from the important work that is being carried out in the JWGs, the most important activity of the ICCC has been the establishment and continuation of the

ICCC Workshop Series "Geodesy for Climate Research". After a successful start of the workshop series during the initial ICCC period with two online events in 2021 and 2023, the 3. ICCC Workshop took place from March 24-25th, again as an online event. The scientific organizing committee was set up with the goal to represent a good geographical distribution and to explicitly include Early Career Scientists (ECS).

Organizing Committee:

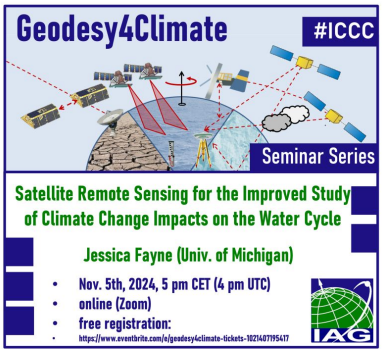
- Annette Eicker (Germany)
- Carmen Blackwood (USA)
- Balaji Devaraju (India)
- Henryk Dobslaw (Germany)
- Franck Ghomsi (South Africa)
- Anna Klos (Poland)
- Ayelen Pereira (Argentina)
- Marcelo Santos (Canada)

All presentations (orals and posters) were available for download before the beginning of the workshop to allow asynchronous viewing. The live sessions were held in 2x2h blocks each day, one in the morning (CET) and one in the afternoon to enable participation from all time zones as shown in the program overview in Fig. 1. The live meetings consisted of short 8-minutes oral presentations plus discussion time. Additionally, two poster sessions were carried out in which each presenter had the opportunity to discuss the poster and to show additional content in their own Zoom breakout room. A total of 44 abstracts were presented by scientists from 17 different countries of affiliation. A percentage of 77% of the presenters identified themselves as early career researchers (ECR).

No financial budget was anticipated for the workshop. As only free tools (or tools freely available to the organizers) were used, it was possible to offer the workshop free of charge to all participants. This resulted in more than 250 registered scientists from 59 different countries (65% ECR). Fig. 2 shows the geographical distribution of the registered participants. The strong participation from African and Latin American countries can be attributed to the very good advertisement of the workshop by the respective members of the organizing team.

ICCC Seminar Series

In order to intensify the exchange between individual researches and particular to foster connections to climate scientists, an online seminar series was established during the first ICCC period. It has been continued in 2024 with a presentation by Jessica Fayne (University of Michigan) with the title "Satellite Remote Sensing for the Improved Study of Climate Change Impacts on the Water Cycle".



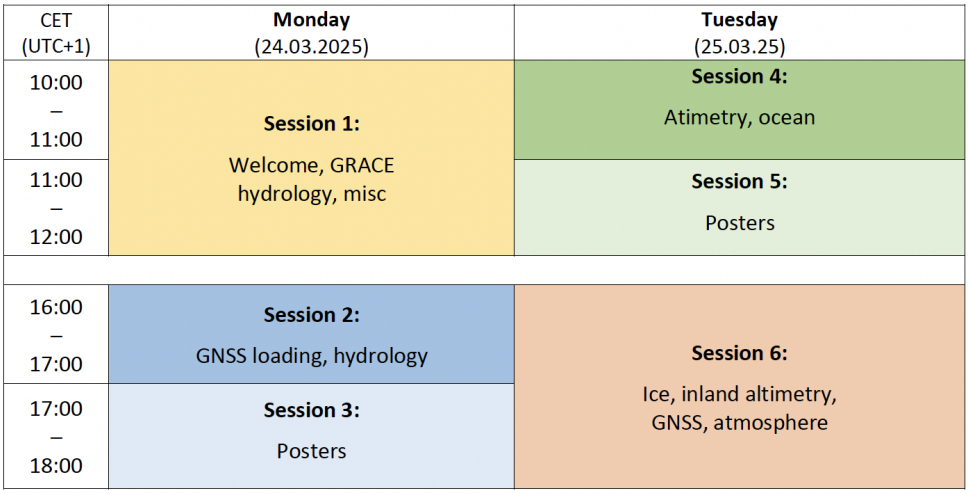


Fig. 1. Program overview of the 3. ICCC Workshop "Geodesy for Climate Research".

Dedicated conference sessions

To further promote ICCC activities, dedicated sessions have been proposed and carried out under the umbrella of the ICCC at major international conferences (e.g., EGU 2024 and 2025, AGU 2023 and 2024, IAG Scientific Assembly 2025). Additionally, various JWGs have organized specific sessions on their JWG topics.

3 Reports of JWGs

3.1 JWG C.1 Climate Variability and Climate Change in Earth Orientation Parameters

Chair: Henryk Dobslaw (Germany)
Vice-Chair: Jolanta Nastula (Poland)
Affiliations: Commission 3, IERS, GGOS

Members

- Christian Bizouard (France)
- Sigrid Boehm (Austria)
- Lara Boerger (Germany)
- Benjamin Fong Chao (Taiwan)
- Masato Furuya (Japan)
- Yavor Chapanov (Bulgaria)
- Jianli Chen (China)
- Alberto Escapa (Spain)

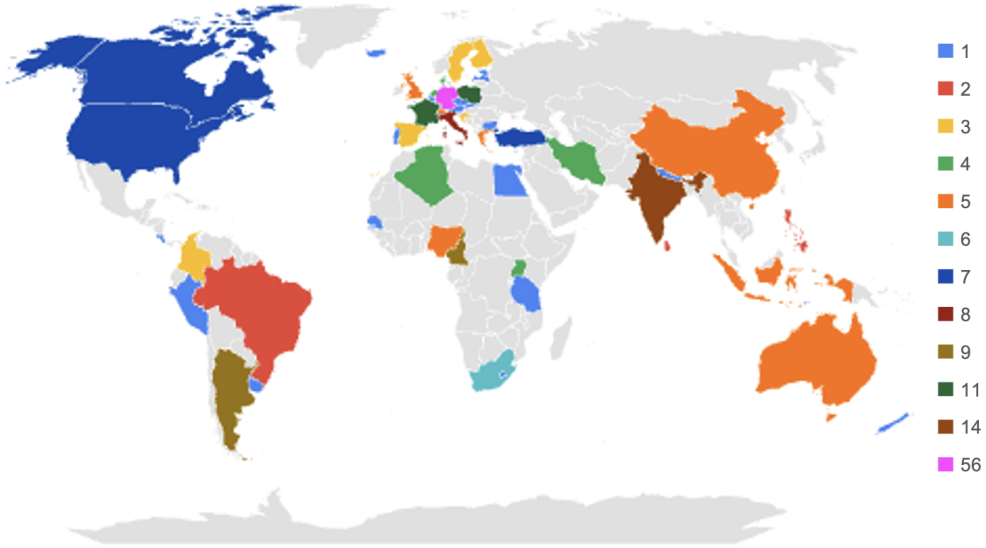


Fig. 2. Geographical distribution of participants

- José Manuel Ferrandiz (Spain)
- Laura Fernandez (Argentina)
- Richard Gross (USA)
- Sébastien Lambert (France)
- Arya Paul (India)
- David Salstein (USA)
- Michael Schindelegger (Germany)
- Adam Scaife (Great Britain)
- Florian Seitz (Germany)
- Justyna Sliwinska (Poland)

Activities during the period 2023-2025

In addition to a number of small online meetings devoted to particular technical aspects of our work, the Joint Working Group C.1 organized an in-person splinter meeting during the EGU General Assembly 2025. The event was co-organized with the Working Group on the Prediction of Earth Orientation Parameters (PEOP) of the IERS.

One of the central topics addressed during that meeting was the role of climate variability in the Earth System for the prediction of Earth Orientation Parameters. A key scientific question was raised: Can a better understanding of the impact of climate change on the observed EOP contribute to the development of more accurate prediction models? Any positive answer would reinforce the need for stronger collaboration between groups focused on EOP prediction and those studying climate-related signals.

Our Group also revisited a previous initiative involving quarterly online meetings with scientific presentations, formerly held within the Working Group on Climate Signals in EOP. It was proposed that this practice will be reinstated and extended to include both working groups, with the aim of enhancing collaboration and promoting scientific knowledge exchange.

In addition, members of the Joint Working Group C.1 contributed to the organization of Thematic Sessions focused on the observation of Earth Orientation Parameters and their interpretation with the help of numerical models during various scientific conferences including EGU General Assemblies, AGU Fall Meetings, and further meetings organized by IAG.

To further extend the data basis for the scientific collaboration within Joint Working Group C.1, GFZ is currently preparing a new set of Effective Angular Momentum (EAM) Functions that will cover the whole period of the EOP C04 series from IERS. Those include new 3-hourly Atmospheric Angular Momentum functions based on ERA5 [4], 3-hourly Ocean Angular Momentum functions based on MPIOM [3] forced with ERA5, daily Hydrological Angular Momentum functions from OS LISFLOOD [2] forced with ERA5, and finally also daily Sea-Level Angular Momentum functions [5] to ensure the closure of the global mass balance for the combined model data-set. AAM and OAM will be consistent with the latest release 07 of the GRACE/GRACE-FO non-tidal Atmosphere and Ocean De-Aliasing Level-1B Product [4].

References

[1] Hans Hersbach, Bill Bell, Paul Berrisford, Shoji Hirahara, András Horányi, Joaquín Muñoz-Sabater, Julien Nicolas, Carole Peubey, Raluca Radu, Dinand Schepers, Adrian Simmons, Cornel Soci, Saleh Abdalla, Xavier Abellan, Gianpaolo Balsamo, Peter Bechtold, Gionata Biavati, Jean Bidlot, Massimo Bonavita, Giovanna Chiara, Per Dahlgren, Dick Dee, Michail Diamantakis, Rossana Dragani, Johannes Flemming, Richard Forbes, Manuel Fuentes, Alan Geer, Leo Haimberger, Sean Healy, Robin J. Hogan, Elías Hólm, Marta Janisková, Sarah Keeley, Patrick Laloyaux, Philippe Lopez, Cristina Lupu, Gabor Radnoti, Patricia Rosnay, Iryna Rozum, Freja Vamborg, Sebastien Villaume, and Jean-Noël Thépaut. The ERA5 global reanalysis. *Quarterly Journal of the Royal Meteorological Society*, 146(730):1999–2049, 2020. URL: https://onlinelibrary.wiley.com/doi/abs/10.1002/qj.3803, doi:10.1002/qj.3803.

[2] L Jensen, R Dill, K Balidakis, S Grimaldi, P Salamon, and H Dobslaw. Global 0.05° water storage simulations with the OS LISFLOOD hydrological model for geodetic applications. *Geophysical Journal International*, 241(3):1840–1852, 2025. URL: https://academic.oup.com/gji/article/241/3/1840/8106588, doi:10.1093/gji/ggaf129.

[3] Johann H. Jungclaus, N. Fischer, Helmuth Haak, K. Lohmann, Jochem Marotzke, D. Matei, U. Mikolajewicz, D. Notz, and J. S. von Storch. Characteristics of the ocean simulations in the Max Planck Institute Ocean Model (MPIOM) the ocean component of the MPI-Earth system model. *Journal of Advances in Modeling Earth Systems*, 5(2):422–446, 2013. URL: http://doi.wiley.com/10.1002/jame.20023, doi:10.1002/jame.20023.

[4] Linus Shihora, Kyriakos Balidakis, Robert Dill, Christoph Dahle, Khosro Ghobadi-Far, Jennifer Bonin, and Henryk Dobslaw. Non-Tidal Background Modeling for Satellite Gravimetry Based on Operational ECWMF and ERA5 Reanalysis Data: AOD1B RL07. *Journal of Geophysical Research: Solid Earth*, 127(8), 2022. URL: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2022JB024360, doi:10.1029/2022JB024360.

[5] Mark E. Tamisiea, E. M. Hill, Rui M. Ponte, James L. Davis, Isabella Velicogna, and Nadya T. Vinogradova. Impact of self-attraction and loading on the annual cycle in sea level. *J. Geophys. Res.*, 115(C7):C07004, 2010. URL: http://doi.wiley.com/10.1029/2009JC005687, doi:10.1029/2009JC005687.

3.2 C.2 Polar geodesy for understanding climate change

Chair: Ingo Sasgen (Germany)
Vice chair: Bert Wouters (Netherlands)
Affiliations: Commissions 2 and 3, GGOS

Members

- Mike Bevis (USA)
- William Colgan (Denmark)
- Xavier Fettweis (Belgium)
- Dana Floricioiu (Germany)
- Kristine Larson (USA)
- Lin Liu (Hong Kong)
- Malcolm McMillan (UK)
- Brice Noël (Belgium)
- Masashi Niwano (Japan)
- Louise Sandberg Sørensen (Denmark)
- (pending conf.) Michael Zemp (Switzerland)
- (pending conf.) Mark Tamisiea (USA)
- (pending conf.) Mariia Usoltseva (Germany)
- (pending conf.) Matthias Willen (Germany)

Activities during the period 2023-2025

Future Mission Planning: Enhancing Observational Capabilities through SING

JWG C.2's future mission planning activities are closely connected with the ESA-funded project **SING – Studying the Impact of the NGGM and MAGIC missions**. The project investigates how upcoming satellite gravimetry missions—such as NGGM and MAGIC—can address key observational gaps in monitoring mass changes in the Earth system, particularly in the polar regions.

Within the **Glaciology Work Package**, JWG C.2 members Ingo Sasgen and Bert Wouters contributed to:

- Assessing the ability of future mission simulations to resolve ice mass changes in Greenland and Antarctica;
- Combining synthetic gravimetric data with surface mass balance and firn models (e.g., MAR, RACMO, GSFC Firn Model);
- Evaluating the role of **Glacial Isostatic Adjustment (GIA)** modeling, particularly in low-viscosity regions, to separate solid Earth and ice mass change signals;
- Addressing uncertainties related to geocenter motion and signal leakage in high-latitude basins.

These contributions help define science requirements for future gravity missions and advance JWG C.2's objective to support robust geodetic observations of polar climate processes.

Contributions to Objective Data Integration

As part of its data integration efforts, JWG C.2 members contributed substantively to the international **GlaMBIE (Glacier Mass Balance Intercomparison Exercise)** initiative, which synthesizes multiple observation techniques to estimate global glacier mass change from 2000 to 2023.

Group members Ingo Sasgen and Bert Wouters were key contributors in incorporating GRACE and GRACE-FO satellite gravimetry into the multi-method framework, enabling consistent comparison with altimetry, DEM differencing, and glaciological field measurements. This integration significantly improved the spatial and temporal resolution of glacier mass balance estimates, advancing one of the core objectives of JWG C.2.

The results of this collaboration are detailed in:

> Zemp, M., Jakob, L., Dussaillant, I., et al. (2025). *Community estimate of global glacier mass changes from 2000 to 2023. Nature*, 639(8054), 382–388. https://doi.org/10.1038/s41586-024-08545-z

Collaborations and Education of the Next Generation

JWG C.2 has actively supported the education and engagement of early-career scientists through targeted lectures and teaching initiatives:

- **Lecture Week with GFZ Potsdam and LUH (April 2024)**
  At the joint Lecture Week organized by GFZ Potsdam and the TerraQ Cluster in Hannover, Chair Ingo Sasgen delivered a focused lecture on polar geodesy. The session highlighted the role of satellite gravimetry in monitoring polar mass changes and understanding climate dynamics.
  Event link
- **NEROGRAV Spring School 2025, TUM**
  Dr. Sasgen also lectured at the NEROGRAV Spring School hosted by TUM, providing training on the application of GRACE/GRACE-FO data for polar climate analysis.
  Event link

- **University of Augsburg Teaching Module**
  A new practical module has been launched in 2023 by Dr. Sasgen at the University of Augsburg to introduce students to GRACE data processing for climate change studies, combining theoretical and hands-on training.

These efforts underscore JWG C.2's commitment to developing geodetic capacity in climate science through collaboration and education.

3.3 C.3 Assessing Earth's Energy Balance with geodetic observations

Chair: Maria Hakuba (USA)
Vice chair: Felix Landerer (USA)
Affiliations: Commission 2, GGOS

Members

- Anne Barnoud (France)
- Gael Forget (USA)
- Sebastien Fourest (France)
- William Llovel (France)
- Audrey Miniere (France)
- Gavin Schmidt (USA)
- Bernd Uebbing (Germany)
- Karina von Schuckmann (France)

Activities during the period 2023-2025

The geodetic measurement of Earth's Energy Imbalance (EEI) is a method of calculating the total heat uptake of the planet by inventorying the change in heat stored in its various components. This approach, often referred to as the "inventory method," relies heavily on satellite observations.

The primary components of this inventory are: the change in ocean heat content (the largest reservoir of excess heat), the melting of the cryosphere (ice sheets and glaciers), and the warming of the land and atmosphere. Geodetic measurements, particularly satellite altimetry (measuring sea level rise from thermal expansion and ice melt) and gravimetry (measuring mass changes from melting ice and ocean mass gain), provide crucial data for quantifying these changes and ultimately determining the Earth's total energy imbalance. The "geodetic EEI" measurement provides an estimate of Earth's Energy Imbalance (EEI) by inventorying changes in the planet's heat content, with a primary focus on the ocean. Since the ocean absorbs over 90% of Earth's excess heat, its thermal expansion is a key indicator of global warming.

This method utilizes a combination of satellite geodetic data. Satellite altimetry observations provide the total change in sea level, while satellite gravimetry (from missions like GRACE and GRACE-FO) measures changes in the ocean mass contribution. By subtracting the change in ocean mass from the total sea level change, we can isolate the steric sea level change—the component due to thermal expansion. This

thermal expansion is then used to calculate the change in ocean heat content, which serves as a robust proxy for the overall Earth's Energy Imbalance.

Individual members of the working group co-organized and participated in various workshops related to geodetic Earth Energy Balance research during the last reporting period:

JPL CCS workshop: Earth's Energy Imbalance and planetary heat uptake

Feb 15-16, 2023; JPL, Pasadena, CA, USA
https://climatesciences.jpl.nasa.gov/events/20230214-EEI-Workshop/index.html

The goal of this 2-day workshop was to sensitize the JPL Earth science and engineering community to the urgent need for EEI assessments and measurements, share and fully utilize NASA and other data to advance EEI assessments, and to foster collaboration between science and technology groups to use our unique resources for advances in Earth Energy balance space-observations and research. The workshop featured a variety of talks and working group activities to discuss pathways forward for indirect assessments and direct EEI measurement potentials. Discussion topics included:

- EEI significance, challenges and ways forward
- EEI variability and radiation in the climate system
- Earth's heat inventory and Ocean warming
- Earth's heat inventory and the cryosphere
- Continental heat storage and land heat fluxes
- Atmospheric heat storage
- Climate cycles and linkages

WCRP Earth Energy Imbalance Assessment Workshop (CNES/GEWEX/-NASA/NOAA/ESA)

May 15-17, 2023, ESA-ESRIN, Frascati (Rome), Italy
https://www.wcrp-esa-eeia-2023.org/
Workshop Summary Report: https://www.wcrp-esa-eeia-2023.org/workshop-report

Summary of recommendations for the geodetic assessment of EEI:

- Extend Geodetic Coverage: Expand ocean heat content estimates to include coastal and high-latitude regions.
- Refine Uncertainty: Improve the accuracy of geodetic error budgets by analyzing data sampling and including spatial correlations.
- Ensure Data Continuity: Guarantee the sustained operation of crucial satellite missions for altimetry and gravimetry.
- Integrate and Investigate: Combine geodetic data with in-situ measurements to create hybrid products and resolve discrepancies between different observing systems.

Other Activities

Various WG members presented their progress at the 9th Global Energy and Water Exchange Open Science Conference in Sapporo (2024): https://www.gewexevents.org/meetings/gewex-osc2024. Additionally, members of this WG have been presenting updates and refinements of the geodetic EEI-estimates at science team meetings dedicated to the individual geodetic observations (i.e., ocean altimetry, and time-variable gravimetry). With contributions by most of our WG members, several studies that either create, improve or utilize geodetic data for Earth Energy Balance research were published between 2023 to 2025 (see references, below).

References

[1] Lijing Cheng, Karina von Schuckmann, Audrey Minière, M. Z. Hakuba, Sarah Purkey, Gavin A. Schmidt, and Yulan Pan. Ocean heat content in 2023. *Nature Reviews Earth & Environment*, 5(4):232–234, 2024. doi:10.1038/s43017-024-00524-9.

[2] M.Z. Hakuba, S. Fourest, T. Boyer, F. Landerer, W. Llovel, G. Forget, K. von Schuckmann, et al. Trends and variability in earth's energy imbalance and ocean heat uptake since 2005. *Surveys in Geophysics*, 45:1721–1756, 2024. doi:10.1007/s10712-024-09849-5.

[3] Gregory C. Johnson, Felix W. Landerer, Norman G. Loeb, et al. Closure of earth's global seasonal cycle of energy storage. *Surveys in Geophysics*, 2023. doi:10.1007/s10712-023-09797-6.

[4] W. Llovel, K. Balem, S. Tajouri, and A. Hochet. Cause of substantial global mean sea level rise over 2014–2016. *Geophysical Research Letters*, 50(19):e2023GL104709, 2023. doi:10.1029/2023GL104709.

[5] B. Meyssignac, S. Fourest, M. Mayer, G. C. Johnson, F. M. Calafat, M. Ablain, T. Boyer, L. Cheng, D. Desbruyères, G. Forget, and D. Giglio. North atlantic heat transport convergence derived from a regional energy budget using different ocean heat content estimates. *Surveys in Geophysics*, pages 1–20, 2024. doi:10.1007/s10712-024-09852-w.

[6] K. von Schuckmann, A. Minière, F. Gues, F. J. Cuesta-Valero, G. Kirchengast, S. Adusumilli, F. Straneo, M. Ablain, R. P. Allan, P. M. Barker, H. Beltrami, A. Blazquez, T. Boyer, L. Cheng, J. Church, D. Desbruyeres, H. Dolman, C. M. Domingues, A. García-García, D. Giglio, J. E. Gilson, M. Gorfer, L. Haimberger, M. Z. Hakuba, S. Hendricks, S. Hosoda, G. C. Johnson, R. Killick, B. King, N. Kolodziejczyk, A. Korosov, G. Krinner, M. Kuusela, F. W. Landerer, et al. Heat stored in the earth system 1960–2020: where does the energy go? *Earth System Science Data*, 15(4):1675–1709, 2023. doi:10.5194/essd-15-1675-2023.

3.4 C.4 Hydrological loading: measuring and modeling

Chair: Mohammad J. Tourian (Germany)
Vice chair: Joelle Nicolas (France)
Affiliations: Commissions 2 and 4, GGOS

- Donald Argus (USA)
- Jean-Paul Boy (France)
- Peter Clarke (UK)
- Omid Elmi (Germany)
- Vagner Ferreira (China)
- Yuning Fu (USA)
- Wei Feng (China)
- Yuning Fu (USA)
- Khosro Ghobadi-Far (USA)
- Kévin Gobron (France)
- Mahmud Haghshenas (Germany)
- Makan Karegar (Germany)
- Achraf Koulali (UK)
- Matt King (Australia)
- Karine Le Bail (Sweden)
- Hilary Martens (USA)
- Anthony Mémin (France)
- Henry Montecino (Chile)
- Daniel Moreira (Brazil)
- Paulo Sérgio de Oliveira Jr (Brazil)
- Fabrice Papa (France)
- Mahdiyeh Razeghi (Australia)
- Peyman Saemian (Germany)
- Francesca Silverii (Italy)
- Alicia Tafflet (France)
- Shuang Yi (China)
- Susanna Werth (USA)

Activities during the period 2023-2025

The working group *Hydrological Loading: Measuring and Modeling* has been notably active over the period 2023–2025, promoting collaboration across disciplines and advancing research on how water mass changes deform the Earth's surface. All activities are documented on the group's website: https://hydrologicalloading.wordpress.com.

The group held its kick-off meeting on April 24, 2024, which launched a coordinated effort to identify key scientific and technical challenges related to hydrological loading. This was followed by a dedicated workshop on May 24, 2024, during which members compiled a comprehensive list of challenges. Among the central challenges identified are the difficulty in disentangling the individual contributions of different hydrological compartments, such as surface water, groundwater, soil moisture, snow, and ice, across varying spatial and temporal scales. A related concern is the need to discriminate between deformation signals caused by hydrological loading and those resulting from other sources, such as atmospheric pressure variations, thermoelastic soil responses, or processing artifacts in geodetic data (e.g., GNSS and InSAR).

Participants also emphasized the limitations in calibrating and validating individual water storage components due to the scarcity of direct observations. They highlighted the importance of sustaining and improving access to high-quality GNSS CORS

networks for hydrological model evaluation. Furthermore, it was noted that current loading models still explain only a portion of observed surface displacements—typically around 50% of the vertical and 20% of the horizontal seasonal signals—raising concerns about residual signals related to unmodeled processes or positioning errors.

Finally, the group discussed the broader challenge of distinguishing anthropogenic influences, such as groundwater overextraction or surface water management, from natural variability in deformation patterns, which complicates attribution and interpretation across Earth system components.

Building on this foundational work, the group initiated a series of monthly meetings, each with invited presentations on current research, methodological developments, and open challenges in hydrological loading. These regular meetings have created a platform for interdisciplinary exchange, bringing together researchers from hydrology, geodesy, cryospheric science, and related fields, and encouraging community-wide dialogue and collaboration.

A major milestone of the group's efforts was the successful proposal of a dedicated session at the EGU General Assembly 2025. Initially focused specifically on hydrological loading, the session attracted 16 abstract submissions. During the session review process, it was merged with a related session on Glacial Isostatic Adjustment (GIA) to form a broader and thematically integrated session entitled: *Measuring and modelling solid-Earth deformation induced by changing loads from liquid and frozen water" (G3.4/HS13.13)*

This joint session will host 27 contributions, including 10 oral presentations, demonstrating the high level of interest and the scientific importance of the topic across multiple disciplines. The outcome underscores the relevance of hydrological loading in the context of Earth system sciences and the value of continued interdisciplinary engagement. More can be found in https://hydrologicalloading.wordpress.com/2025/05/06/hydrological-loading-session-at-egu-2025/

3.5 C.5 Exploitation of ground-based GNSS Interferometric Reflectometry for climate applications

Chair: Makan Karegar (Germany)
Vice chair: Dongju Peng (Hong Kong)
Affiliations: Commission 4, GGOS

Members

- Brendan Crowell (USA)
- John Galetzka (USA)
- Médéric Gravelle (France)
- Shin-Chan Han (Australia)
- Andrew Hoffman (USA)
- Tobias Kersten (Germany)
- Kristine Larson (USA)
- Lin Liu (Hong Kong)
- Angel Martín (Spain)

- Felipe Nievinski (Brazil)
- Thalia Nikolaidou (Canada)
- Thomas Nylen (Denmark)
- David Purnell (Canada)
- Alvaro Santamaría-Gómez (France)
- Sajad Tabibi (Luxembourg)
- Kristy Tiampo (USA)
- Wei Wan (China)
- Simon Williams (UK)
- Surui Xie (USA)

Activities during the period 2023-2025

The GNSS-IR Working Group officially kicked off in May 2024 with its first member meeting and has held three meetings so far. One big milestone was the successful launch of two new sessions for major conferences: a poster session at EGU 2025 titled *G2.6: Innovating GNSS-IR for Environmental Sensing* and a new session at AGU 2025 under *GNSS-IR for Environmental Sensing*. These transatlantic sessions are designed to bring together contributions from North America and the global GNSS-IR community.

As part of our outreach efforts, we have started a new public webinar series. So far, three invited seminars have been presented. Felipe Geremia-Nievinski presented the ability of GNSS-IR to measure a 100-year flood event - a case study of the catastrophic flooding in Brazil in May 2024. Simon Williams discussed the development of the PSMSL global GNSS-IR tide gauge network and its ability to measure sea state ([3]) and Lin Liu showed how GNSS-IR can be used to monitor frozen ground dynamics. In summer 2025, Sajad Tabibi will present on soil moisture. We also created a dedicated YouTube channel for the working group, where all past and future webinars are available for viewing ([1]).

In March 2024, an online short course on GNSS-IR water level measurement was led by the working group member Kristine Larson on *gnssrefl* software ([2]).

To help coordinate all this, we have set up a mailing list, which currently has 150 subscribers. We keep the community informed about upcoming webinars, conference sessions and training opportunities.

At our member meetings, we have also defined key focus areas for the group. Three sub-working groups have been formed around the themes of: Software and algorithm development; Product generation and validation; Low-cost instrumentation. These are now central points of member activity as we continue to grow the GNSS-IR community and its applications in climate research.

References

[1] GNSSir_IAG_ICCC. gnss-ir youtube channel. https://www.youtube.com/@GNSSir_IAG_ICCC. Accessed: 2025-06-03.

[2] Larson K.M. gnssrefl: an open source software package in python for gnss interferometric reflectometry applications. *GPS Solutions*, 28(4):165, 2024.

[3] Permanent Service for Mean Sea Level (PSMSL). gnss-ir data repository. https://psmsl.org/data/gnssir/. Accessed: 2025-06-03.

3.6 C.6 GNSS mass-market devices in climate and environmental sensing: approaches, opportunities, challenges, and social impact

Chair: Tobias Kersten (Germany)
Vice chair: Balaji Devaraju (India)
Affiliations: Commission 4, GGOS

Members

- Franziska Koch (Austria)
- Robert Odolinski (New Zealand)
- Jens-André Paffenholz (Germany)
- Kristine M. Larson (USA)
- Inese Varna (Latvia)
- Shivam Tripathi (India)
- Jacek Paziewski (Poland)
- Yong Chien Zheng (New Zealand)
- Felipe Geremia-Nievinsk (Brazil)
- Makan Karegar (Germany)
- Yuanxin Pan (Switzerland)
- Günter Retscher (Austria)
- Pierre Bosser (France)
- Lucie Rolland (France)
- Raul Valenzuela (Chile)
- Alexander Lapadat (Netherlands)

Activities during the period 2023-2025

During the period of 2023 to 2025 we started building a common basis for discussion and collaboration among the individual participants.

Infrastructure and Collaboration tooling One of the central achievements was the establishment of a common platform for document creation in LaTeX, with a primary focus on manuscript preparation. For the exchange, storage, and archiving of recordings, data, and references, we have implemented a central storage solution that also allows us to provide comments on our manuscript.

We use Webex for webinars and online meetings, which facilitates the organization of Splinter Meetings like those held at the European Geophysical Union General Assembly (EGU) conference and offers the possibility of virtual participation, supported by additional hardware. For collaborative and interactive work on structures, plans, and discussions, we utilize Collabboard, an interactive whiteboard.

To keep all members of the Joint Working Group (JWG) up-to-date, we have established a Listserv called *IAG-JWG-C6-IFE* (https://listserv.uni-hannover.de/cgi-bin/wa?A0=IAG-JWG-C6-IFE), through which we distribute monthly updates.

Conference Contributions and Webinars In 2023, on October 18, we held a webinar on Geomonitoring with Low-Cost Sensors, attended by 25 participants for 1.5 hours online via Zoom. The presentations were delivered by Vincent Humphrey from MeteoSwiss, who discussed continuous observation of vegetation optical depth and water content changes using GPS sensors, and Benedikt Soja from ETH Zurich, who talked about unlocking environmental insights with GNSS data from low-cost receivers and smartphones.

In 2024, we successfully established and convened a pioneering PICO (Presenting Interactive COntent, session G2.7, Friday, April 19, 8:30-10:15 CEST, PICO Spot 1) session on April 19, marking the first time ever that a session on this topic was held at a European conference. The session was entitled with *Joint session on geoscience applications of mass-market GNSS sensors and ionosphere monitoring and modelling.* This session featured nine contributions, including seven on-site presentations and two virtual presentations, along with six presentations focused specifically on the topic of the ionosphere. This event was an important step towards our goals of establishing a platform for discussion and starting to build up a community around this topic. Moreover, at the same EGU conference on April 15, we convened for a Splinter Meeting (SPM77: Monday, April 15 12:45-13:45 CEST Room 2.96), providing a platform for discussing mass-market GNSS devices in the context of climate and environmental sensing, further contributing to our objectives. We could attract new members and interest that are actively working on our future JWG goals.

A webinar on 16 October 2024 welcomed 16 participants for a 1.6 hour session. This involved discussions on the individual research focus of the members of the JWG in relation to our objectives. Seven presentations were held, leading to fruitful discussions and the formation of subgroups, with a concentration on manuscript setup. Following presentations have been shown:

- Devaraju, B.: Characterizing the IIT Kanpur low-cost GNSS network
- Karegar, M.: Precision in the flow: GNSS-IR sensors measure river levels with centimetre accuracy - deployment of Raspberry Pi Reflectors along the Rhine river
- Kersten, T.: Stability and reliability of receiver antenna characteristics
- Nievinski, F.: Low-cost GNSS Reflectometry for near real-time water level monitoring in Brazil
- Odolinski, P.: On the feasibility of cm-level GNSS smartphone positioning
- Pan, Y.: Application of low-cost GNSS for tropospheric monitoring
- Tripathi, S.: Uncertainties and Challenges in Low-cost Hydrometry: Lessons from Field Experiments
- Paziewski, J.: Particular fields of interest in terms of smartphone & low-cost GNSS

Based on the success of the EGU2024 PICO session, we organised and convened a follow-up session at the EGU 2025 (session G2.5, Tuesday, April 29, 16:15-18:00 CEST, PICO spot 1) with the title: *Applications of low-cost, mass-market and consumer-grade GNSS in geoscience.* We could welcome nine contributions with seven on-site and two virtual presentations, and four Early Career Scientists who present their current work. The success of our goals is reflected in the acceptance of the session, especially by younger participants (early career scientists), and in the substantial

number of abstracts submitted. Alined with one of our major goals, we see a need to develop a community in this field of research that was emphasised from various speakers' perspectives. We therefore consider the realisation of our current goals to be promising.

Additionally, on May 1 we could hold another Splinter Meeting (SPM68: Thursday, May 1, 14:00-15:45 CEST, Room 2.83) at the EGU 2025 to coordinate the other major aim of our JWG, the planned manuscript. The splinter meeting was organised as a hybrid session to allow members from abroad to participate in the on-site discussion. This was important to manage the writing process of the manuscript. Furthermore, e also could attract new members, from neighbouring scientific fields.

We also ensured opportunities for regular quarterly meetings among the core group, maintaining our communication through the aforementioned newsletter.

References

[1] Ibaad Anwar and Balaji Devaraju. Assessing measurement noises from low-cost GNSS receivers and antennas. In *EGU General Assembly 2024, April 14–19, Vienna, Austria*, 2024. doi:10.5194/egusphere-egu24-14661.

[2] Pierre Bosser, Julien Ancelin, Marianne Métois, Lucie Rolland, and Maurin Vidal. Monitoring of geophysical deformations on a regional scale using the low-cost GNSS collaborative network CentipedeRTK. In *EGU General Assembly 2025, April 27–May 2, Vienna, Austria*, 2025. doi:10.5194/egusphere-egu25-11878.

[3] Yannick Breva, Johannes Kröger, Tobias Kersten, and Steffen Schön. How Observation Noise impacts the Estimation of Codephase- and Phase-Center Correction with a Robot in the Field. In *EGU General Assembly 2024, April 14–19, Vienna, Austria*, 2024. doi:10.5194/egusphere-egu24-9080.

[4] Patrick Henkel, Markus Lamm, and Franziska Koch. Precise Estimation of Snow Water Equivalent based on GPS and Galileo Measurements. In *EGU General Assembly 2025, April 27–May 2, Vienna, Austria*, 2025. doi:10.5194/egusphere-egu25-19702.

[5] Christina L. Hulbe, Holly Still, Robert Odolinski, M. Hamish Bowman, and David John Prior. Precise Positioning for Everybody. In *AGU Fall Meeting 2023, held in San Francisco, CA, 11-15 December*, 2023. URL: https://ui.adsabs.harvard.edu/abs/2023AGUFM.C11C1052H/abstract.

[6] Paul Jarrin, Lucie Rolland, Maurin Vidal, Pierre Sakic, Frédérique Leclerc, Jean-Xavier Dessa, and Sylvain Palagonia. GNSS low-cost prototype on ship for caching tsunami wave propagation. In *EGU General Assembly 2024, April 14–19, Vienna, Austria*, 2024. doi:10.5194/egusphere-egu24-17764.

[7] Tobias Kersten, Johannes Kröger, Yannick Breva, Steffen Schön, Markus Bradke, Markus Ramatschi, and Benjamin Männel. From Past to Present: Investigating Retrofitted GPS Antennas for Multi-GNSS Functionality. In *IGS Symposium and Workshop 2024, Bern, Switzerland*, 2024. doi:10.15488/18632.

[8] Zahra Bani Mostafavi, Tobias Kersten, Johannes Kröger, and Steffen Schön. Improving code and phase observations using low-cost GNSS receivers in urban areas to achieve better accuracy in geo-monitoring. In *GeoMonitoring Workshop*

2024, February 29– March 1, Technical University Braunschweig, Braunschweig, Germany, 2024. URL: https://www.geo-monitoring.org/de/tagungen/2024.

[9] Robert Odolinski, Hongzhou Yang, Li-Ta Hsu, Mohammed Khider, Guoyu (Michael) Fu, and Damien Dusha. Evaluation of the Multi-GNSS, Dual-Frequency RTK Positioning Performance for Recent Android Smartphone Models in a Phone-to-Phone Setup. In *Proceedings of the 2024 International Technical Meeting of The Institute of Navigation, January 23 - 25, Long Beach, California*, ITM 2024, pages 42–53. Institute of Navigation, February 2024. doi:10.33012/2024.19575.

[10] Kirthana Somaskandan, Ravi prakash Kumar, and Balaji Devaraju. Soil Moisture estimation using GNSS- A spatiotemporal analysis. In *EGU General Assembly 2024, April 14–19, Vienna, Austria*, 2024. doi:10.5194/egusphere-egu24-14333.

[11] Holly Still, Robert Odolinski, M. Hamish Bowman, Christina Hulbe, and David J. Prior. Observing glacier dynamics with low-cost, multi-GNSS positioning in Victoria Land, Antarctica. *Journal of Glaciology*, 70, 2023. doi:10.1017/jog.2023.101.

[12] Raul Valenzuela and Jorge Jara. GNSS-derived tropospheric water vapor and precipitation co-variability along continental Chile. In *EGU General Assembly 2025, April 27–May 2, Vienna, Austria*, 2025. doi:10.5194/egusphere-egu25-7362.

3.7 C.7 Ground-GNSS trends for climate models

Chair: Marcelo Santos (Canada)
Vice chair: Rosa Pacione (Italy)
Affiliations: Commission 4, IGS, IVS, GGOS

Members

- Anna Kloss (Poland)
- Galina Dick (Germany)
- Hannes Keernik (Estonia)
- Haroldo Marques (Brazil)
- Jonathan Jones (UK)
- Kalev Rannat (Estonia)
- Kyriakos Balidakis (Germany)
- Peng Yuan (Germany)
- Raul Valenzuela (Chile)
- Samuel Nahmani (France)
- Sharyl Byram (US)
- Thalia Nikolaidou (Canada)
- Zhang Weixing (China)
- Yibin Yao (China)
- Yidong Lou (China)

Activities during the period 2023-2025

The main objective of JWG C.7 is to estimate and analyze trends from estimated ZTD time series, generated by processing GNSS data from a selected set of IGS stations over the longest possible time period. Estimation of ZTDs is carried out by members of the JWG using various software suites.

The period covered by this report includes the establishment of the joint working group. Three online meetings took place, two in 2024 and one in 2025. They helped bring the membership closer together by discussing the objectives of the working group and defining initial tasks.

A total of 39 IGS stations, the ones with longest time series, were selected for processing with PPP packages using REPRO3 orbits and clocks for consistency.

Data processing is in progress. Five groups, within the JWG, are committed to data processing. A poster was submitted to the 2025 IAG Scientific Assembly, scheduled to take place in Rimini, Italy, aimed at presenting and discussing the results obtained by then. An in person JWG meeting has been scheduled to take place in Rimini. The work will continue toward its final report for the 29th IUGG General Assembly in Incheon, South Korea, 2027.

Publications provided by some of the WG members are listed below.

References

[1] Jingna Bai, Yidong Lou, Weixing Zhang, Yaozong Zhou, Zhenyi Zhang, Chuang Shi, Jingnan Liu. Impact analysis of processing strategies for long-term gps zenith tropospheric delay (ztd). *Atmospheric Measurement Techniques*, 16:5249–5259, 2023. doi:10.5194/amt-16-5249-2023.

[2] Kalev Rannat, Hannes Keernik and Fabio Madonna. The novel copernicus global dataset of atmospheric total water vapour content with related uncertainties from gnss observations. *Remote Sensing*, 15:5150, 2023. doi:10.3390/rs15215150.

[3] Kyriakos Balidakis, Marcelo Santos, Anna Klos, Rosa Pacione, Riley Hughes. Further analysis on long-term groud-based gnss-derived ztd trends estimated from igs repro3 products. *GGOS Topical Meeting on the Atmosphere*, October 7-9:Potsdam, Germany, 2024.

[4] Marcelo Santos, Kyriakos Balidakis, Anna Klos, Rosa Pacione, Jordan Rees. Climate trends derived from long-term ground-based gnss-derived zenith total delay (ztd). *European Geosciences Union General Assembly*, April 14-19:Vienna, 2024.

[5] Mengjie Liu, Yidong Lou, Weixing Zhang, Rong Wan, Zhenyi Zhang, Zhikang Fu, Xiaohong Zhang. Improving forecast of 21.7 henan extreme heavy rain by assimilating high spatial resolution gnss ztds. *Atmospheric Research*, 315:107880, 2024. doi:10.1016/j.atmosres.2024.107880.

[6] Rosa Pacione and Eric Pottiaux. Climate applications of geodetic tropospheric parameters. *GGOS Topical Meeting on the Atmosphere*, October 7-9:Potsdam, Germany, 2024. doi:10.5281/zenodo.13935448.

[7] Weixing Zhang, Yidong Lou, Yaozong Zhou, Mengjie Liu, Zhenyi Zhang, Shuyuan Ou, Jingnan Liu. Gnss meteorological ensemble tools (gmet): a

free?access online service for gnss meteorological applications. *GPS Solutions*, 28:202, 2024. doi:10.1007/s10291-024-01743-2.

[8] Xinxin Chen, Yidong Lou, Weixing Zhang, Jan Dousa, Linghao Zhou, and Yaozong Zhou. A case study of the "21.7" henan extremely rainfall event: From the perspective of water vapor monitored with gnss tomography. *Advances in Space Research*, 75:1719–1731, 2024. doi:10.1016/j.asr.2024.10.010.

3.8 C.8 Optimal processing and homogenization of GNSS-PW climate data records

Chair: Olivier Bock (France)
Vice chair: Galina Dick (Germany)
Affiliations: Commission 4, IGS, GGOS

Members

- Samuel Nahmani (France)
- Arnaud Pollet (France)
- Paul Rebischung (France)
- Pierre Bosser (France)
- Florian Zus (Germany)
- Markus Bradke (Germany)
- Tzvetan Simeonov (Germany)
- Jonathan Jones (UK)
- Kalev Rannat (Estonia)
- Hannes Keernik (Estonia)
- Katarzyna Stepniak (Poland)
- Anna Klos (Poland)
- Johannes Boehm (Austria)
- Alvaro Santamaria (France)
- Sylvain Loyer (France)
- Sharyl Byram (USA)
- George Liu (HK, China)
- Pierre Sakic (France)
- Julien Barneoud (France)
- Elmar Brockmann (Switzerland)

Activities during the period 2023-2025

The creation of this JWG has been validated by ICCC and IAG Commission 4 chairs in January 2024. Activities conducted in 2024-2025 include:

Networking and communication about the new JWG

- participation of the JWG leaders in the 15th GRUAN Implementation and Coordination Meeting, in Bern, Switzerland, in March 2024;

- organization of the kick-off meeting of the JWG during the IGS Workshop and Symposium in Bern, in July 2024, and participation in the IGS Troposphere Committee meeting;
- presentation of the JWG activities at the ICCC on-line Workshop in March 2025;
- promotion of reference GNSS IWV data sets in cooperation with Copernicus Climate Change Service (C3S) to at EGU, in Vienna, in May 2025
- meeting of a subgroup of JWG members at EGU, in Vienna, in May 2025;
- the next meeting with all members is planned at the IAG Scientific Assembly in Rimini, in September 2025.

Research activities

- intercomparison of ZTD estimates from IGS repro3 solutions from four analysis centers (COD, GFZ, GRG, TUG) (Breton et al. 2025)
- study of optimal processing of GNSS for long ZTD time series (Panetier et al., 2024)
- development of homogenization tools for GNSS IWV time series (Bock et al., 2024, 2025)
- development of outlier detection tools
- management and QC of GNSS station metadata
- assessment of GNSS IWV estimates with reference radiosonde data from GRUAN (Panetier et al., 2025)
- calibration of Ozone Monitoring Instrument (OMI) water vapor data on NASA Aura satellite using global GNSS IWV as validation data (Xu and Liu, 2025a)
- retrieval of water vapor data using machine learning method from the Ocean and Land Color Imager (OLCI) instrument onboard the Sentinel-3 satellite, and validation across Europe using IWV data from 1098 GNSS stations and 86 radiosonde stations (Xu and Liu, 2025b).

References

[1] Olivier Bock. Tracking biases and inhomogeneities in gnss pw time series. In *GCOS Reference Upper Air Network (GRUAN) 15th Implementation and Coordination Meeting, 11-15 March 2024*, Bern, Switzerland, 2024. GCOS.

[2] Olivier Bock and Galina Dick. Optimal processing and post-processing of gnss-pw climate data records. In *IGS Symposium, Bern, Switzerland, 1-3 July 2024*, Bern, Switzerland, 2024. IGS.

[3] Olivier Bock and Galina Dick. Optimal processing and post-processing of gnss-pw climate data records within the iccc jwg c.8. In *ICCC online workshop, 24-25 March 2025*. IAG, 2025.

[4] Olivier Bock, Khanh Ninh Nguyen, and Emilie Lebarbier. Homogenization of gnss iwv time series and estimation of climatic trends. In *EGU General Assembly 2024, Vienna, Austria, 14-19 April 2024*, Vienna, Austria, 2024. EGU.

[5] Olivier Bock, Khanh Ninh Nguyen, and Emilie Lebarbier. Homogenization of gnss iwv time series and estimation of climatic trends. In *IGS Symposium, Bern, Switzerland, 1-3 July 2024*, Bern, Switzerland, 2024. IGS.

[6] Olivier Bock, Khanh Ninh Nguyen, and Emilie Lebarbier. Homogenization of gnss iwv time series using statistical machine learning. In *EGU General Assembly 2025, Vienna, Austria, 27 April – 2 May, 2025*, Vienna, Austria, 2025. EGU.

[7] Hugo Breton, Olivier Bock, and Samuel Nahmani. Consistency and homogeneity of ztd estimates from igs repro3. In *EGU General Assembly 2025, Vienna, Austria, 27 April – 2 May, 2025*, Vienna, Austria, 2025. EGU.

[8] Khanh Ninh Nguyen, Olivier Bock, and Emilie Lebarbier. A statistical method for the attribution of change-points in segmented integrated water vapor difference time series. *International Journal of Climatology*, 44(6):2069–2086, 2024. URL: https://rmets.onlinelibrary.wiley.com/doi/abs/10.1002/joc.8441, `arXiv:https://rmets.onlinelibrary.wiley.com/doi/pdf/10.1002/joc.8441`, `doi:10.1002/joc.8441`.

[9] Khanh Ninh Nguyen, Olivier Bock, Emilie Lebarbier, and Annarosa Quarello. Pmlseg : R package to segment a time series, validate the detection with metadata and visualize results (https://github.com/khanhninhnguyen/pmlseg), 2025. URL: https://github.com/khanhninhnguyen/PMLSeg.

[10] Aurelie Panetier, Olivier Bock, Samuel Nahmani, Arnaud Pollet, Pierre Sakic, and Julien Barnéoud. Optimal processing of gnss data for appropriate zenith total delay for climate trend analysis. In *IGS Symposium, Bern, Switzerland, 1-3 July 2024*, Bern, Switzerland, 2024. IGS.

[11] Aurelie Panetier, Florian Zus, Galina Dick, Olivier Bock, and Jens Wickert. Intercomparison of tropospheric datasets from radiosonde and gnss at co-located gruan sites. In *ICCC online workshop, 24-25 March 2025*. IAG, 2025.

[12] Jiafei Xu and Zhizhao Liu. All-weather retrieval of total column water vapor from aura omi visible observations. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 18:3057–70, 2025. `doi:doi:10.1109/JSTARS.2024.3523048`.

[13] Jiafei Xu and Zhizhao Liu. Development and validation of integrated water vapor under variable cloud conditions using sentinel-3 olci near-infrared radiance measurements. *IEEE Transactions on Geoscience and Remote Sensing*, 63:1–14, 2025. `doi:10.1109/TGRS.2025.3541127`.

3.9 C.9 Climate Change Signals in High Resolution Surface Water Observations

Chair: Luciana Fenoglio (Germany)
Vice chair: Jessica Fayne (USA)
Affiliations: Commission 2, GGOS

Members

- Ole Andersen (Denmark)
- Jerome Benveniste (France)
- Christopher Buchhaupt (USA)
- Jan Martin Brockmann (Germany)
- Xiaoli Deng (Australia)

- Denise Dettmering (Germany)
- Michael Durand (USA)
- Joanna Fernandez (Portugal)
- Susanne Glaser (Germany)
- Cheinway Hwang (Taiwan)
- Per Knudsen (Denmark)
- Jürgen Kusche (Germany)
- Fernando Jamarillo (Sweden)
- Eric Leuliette (USA)
- Pascal Matte (Canada)
- Karina Nielsen (Denmark)
- Roelof Rietbroek (Netherlands)
- Louise Rousselet (France)
- Walter Smith (USA)
- C.K. Shum (USA)
- Stefano Vignudelli (Italy)
- Jida Wang (USA)

Activities during the period 2023-2025

In the C9 ICC subgroup we investigate climate change using of high-resolution (HR) altimetry at 1-D and 2-D and encourage innovative interdisciplinary research. Subgroups meet regularly in the working groups of the SWOT science team. Connection with the IAG SC25.1 High-resolution altimetry for geodetic, oceanographic, cryosphere and hydrology studies is well established. Activities conducted in 2024-2025 include:

Networking and communication

- splinter meeting during the EGU 2024 in Vienna;
- presentation by J.Fayne at EGU 2024;
- participate to inland water Working Groups in SWOT ST (DAWG, River Science and SLEW);
- participate to ocean Working Groups in SWOT ST (SWOT-DEC, SWOT/LOAC);
- team with EONES-SWOT initiative ;
- initiate the cruise for SWOT validation (ADAC-Baltic);
- coordination with SC25.1 High-resolution altimetry for geodetic, oceanographic, cryosphere and hydrology studies;
- presentation by J.Fayne at the ICCC on-line Workshop in March 2025;
- meeting of a subgroup at EGU 2025;
- planned meeting of a subgroup at Living Planet 2025;
- plan meeting with all members at the IAG Scientific Assembly in Rimini, in September 2025.

Research activities The research activities include both methodological developments and data analysis

- improved unfocused (UFSAR) and fully focused (FFSAR) processing of along-track SAR nadir-altimetry (Buchaupt at al., 2023, 2025, Chen et al. 2023, Fenoglio et al., in revision)

- validation and calibration of SWOT data
- off-nadir FFSAR processing (Chen et al. 2025)
- enhanced daily maps of water level maps
- retrieval of river discharge and storage change (Andreadis et al., 2025, Durand et al., 2024, Jaramillo et al. 2025)

References

[1] Andreadis, K. M. and Coss, S. P. and Durand, M. and Gleason, C. J. and Simmons, T. T. and Tebaldi, N. and al. A first look at river discharge estimation from swot satellite observations. *Geophysical Research Letters*, 2025. doi:10.1029/2024GL114185.

[2] Buchhaupt. C. and Egido, A. and Vandemark, D. and Smith, W. H.F. and Fenoglio, L. and Leuliette, E. . Towards the mitigation of discrepancies in sea surface parameters estimated from low- and high-resolution satellite altimetry. *Remote Sensing*, 2023. doi:10.3390/rs15174206.

[3] Buchhaupt, Ch. and Egido, A. and Dinardo, S. and Maraldi, C. and Moreau T. and Fenoglio, L. Impact of the antenna characteristics on sea surface parameters estimated from low- and high-resolution satellite altimetry. *Advances in Space Research*, 2025. doi:10.1016/j.asr.2025.02.056.

[4] Chen, J. and Fenoglio, L. and Kusche, J. Measuring off-nadir river water levels and slopes from altimeter fully-focused sar mode. *Journal of Hydrology*, 2024. doi:10.1016/j.jhydrol.2024.132553.

[5] Chen, J. and Fenoglio, L. and Kusche, J. and Liao, J. and Uyanik, H. and Nadzir, Z. A. and Lou, Y. Evaluation of sentinel-3a altimetry over songhua river basin". *Journal of Hydrology*, 2023. doi:10.1016/j.jhydrol.2023.129197.

[6] Durand, M. and Chunli, Dai and Moortgat, J. and Yadav, B.and Prata de Moraes Frasson, R. and Li, Z. and Wadkwoski, K. and Howat, I. and Pavelsky, T. M. Using river hypsometry to improve remote sensing of river discharge. *Remote Sensing of Environment*, 2024.

[7] Jaramillo et al. . The potential of hydrogeodesy to address water-related and sustainability challenges. water resources research. *Water Resources Research*, 2025. doi:10.1029/2023WR037020.

3.10 C.10 Tailored Parameterization Strategies for Climate Applications of Satellite Gravimetry

Chair: Marius Schlaak (Germany)
Vice chair: João de Teixeira da Encarnação (Netherlands)
Affiliations: Commission 2, ICCT, GGOS, IGFS

Members

- Alejandro Blazquez (France)
- Bert Wouters (Netherlands)
- Changqing Wang (China)
- David Wiese (USA)

- Erik Ivins (USA)
- Ingo Sasgen (Germany)
- Julia Pfeffer (France)
- Klara Middendorf (Germany)
- Laurent Longuevergne (France)
- Lijing Cheng (China)
- Linus Shihora (Germany)
- Martin Horwath (Germany)
- Matthias Willen (Germany)
- Michal Cuadrat-Grzybowski (Netherlands)
- Özge Günes (Turkey)
- Roland Pail (Germany)
- Thorben Döhne (Germany)
- Vincent Humphrey (Switzerland)
- Wei Feng (China)

Activities during the period 2023-2025

The working group *Tailored Parameterization Strategies for Climate Applications of Satellite Gravimetry* has been fostering interdisciplinary collaboration among its members. Through regular meetings, the group has explored parameterization strategies across various applications. Following the initial online kickoff meeting in January 2024, the working group convened in hybrid splinter meetings at several international conferences:

- **EGU24**, Vienna, Austria (April 2024)
- **GGHS24**, Thessaloniki, Greece (September 2024)
- **GSTM24**, Potsdam, Germany (October 2024)
- **EGU25**, Vienna, Austria (April–May 2025)

Members also actively contributed to scientific sessions of these conferences, as well as at the ICCC geodesy for climate workshop 2025. The next activities are planned for the IAG Scientific Assembly 2025 in Rimini. The working group continues to explore new aspects of tailored parameterization strategies and promote knowledge and data sharing among members. The overarching objective of the working group is to identify and implement spatiotemporally tailored parameterization strategies for current and future satellite gravimetry missions. To support this goal, several thematic areas were identified for deeper investigation. The following examples illustrate the diversity of topics discussed:

High-Frequency Mass Change from GRACE Level-1B (post-fit) Residuals
Presented by Michal Cuadrat-Grzybowski

An empirical method was developed to derive high-frequency mass change models using GRACE Level-1B post-fit residuals. These are converted into gridded Line-of-Sight Gravity Differences (LGD), interpolated, and translated into equivalent water height via regression against Level-2 data. This GRACE-only, model-independent approach captures sub-monthly hydrological variability, including extreme events.

Potential of future satellite gravity missions to detect extreme values *Presented by Klara Middendorf*

A simulation study assessed the ability of GRACE-C and MAGIC to detect hydrological extremes using daily TWS from the GFDL-CM4 climate model. One-in-ten-year return levels were computed using Extreme Value Theory. MAGIC, with less filtering required, produced more accurate and higher-resolution results than GRACE-C, highlighting its potential for climate model evaluation (3).

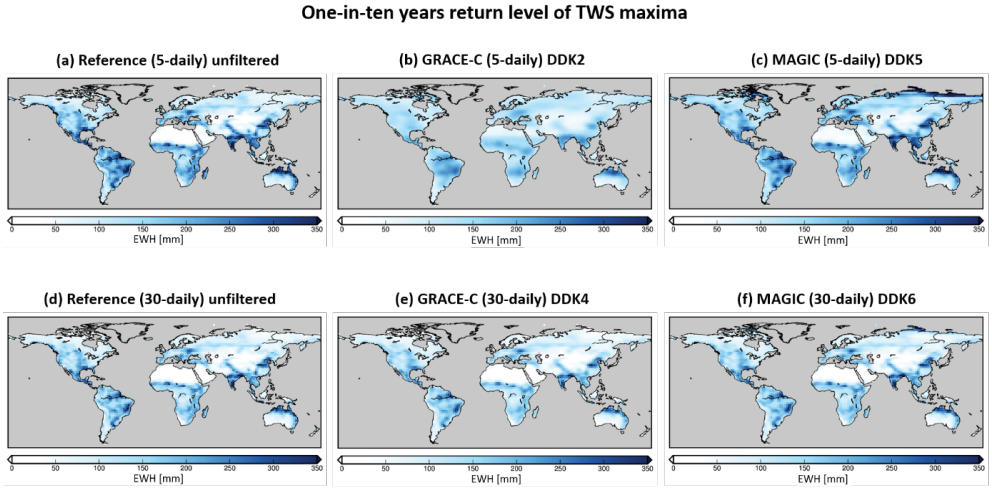


Fig. 3. One-in-ten years return level of TWS maxima for 5-daily (top) and 30-daily (bottom) solutions of (a) & (d) the reference, (b) & (e) the GRACE-C results and (c) and (f) the MAGIC results of the 50-year long end-to-end simulation study.

Towards resolving AMOC with future gravity missions *Presented by Linus Shihora*

To explore the potential of future missions to monitor the Atlantic Meridional Overturning Circulation (AMOC), OBP anomalies linked to meridional transport were extracted from the VIKING20X ocean model. These will be integrated into ESA's Earth System Model 3.0 to support simulations for missions like MAGIC, guiding the development of, e.g., tailored mascon strategies.

Regional GIA fingerprints *Presented by Matthias Willen*

Glacial isostatic adjustment (GIA) remains a major uncertainty in satellite gravimetry, causing about 3/4 of the uncertainty budget ([1]). Instead of relying solely on GIA model corrections, the use of GIA fingerprints as inversion parameters offers an alternative (4). Within the JWG, it is discussed to extend this approach to Level-1B data and explore ensemble-based and advanced model-driven parametrizations to reduce GIA-related uncertainties.

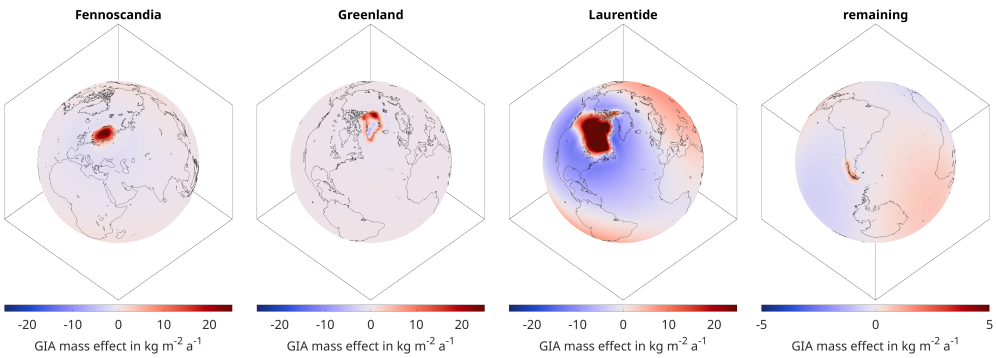


Fig. 4. Global GIA fingerprints used to parameterize GIA in Willen et al. (2022). The fingerprints are generated using a GIA modeling software with an ice history tailored to regions indicated in the headings (the Antarctic fingerprint is not shown). These fingerprints are analogous to those used by [4]

These contributions show the initial results of the JWG, which identified novel parameterization strategies that increase the temporal resolution of current satellite missions and identified first target quantities that will benefit from tailored satellite gravimetry products and improved observation systems. Looking ahead, the working group will continue to explore innovative approaches to parameterization, working towards defining application-specific requirements for spatiotemporally tailored gravimetry data products.

References

[1] Andreas Groh and Martin Horwath. Antarctic ice mass change products from grace/grace-fo using tailored sensitivity kernels. *Remote Sensing*, 13(9):1736, 2021.

[2] Laura Jensen, Annette Eicker, Henryk Dobslaw, and Roland Pail. Emerging changes in terrestrial water storage variability as a target for future satellite gravity missions. *Remote sensing*, 12(23):3898, 2020.

[3] Klara Middendorf, Henryk Dobslaw, Laura Jensen, and Annette Eicker. Return levels of dry extreme events in terrestrial water storage from satellite gravimetry and cmip6 global coupled climate models. *Journal of Geophysical Research: Solid Earth*, in review 2025.

[4] Roelof Rietbroek, Sandra-Esther Brunnabend, Jürgen Kusche, Jens Schröter, and Christoph Dahle. Revisiting the contemporary sea-level budget on global and regional scales. *Proceedings of the National Academy of Sciences*, 113(6):1504–1509, 2016.

[5] Linus Shihora, Torge Martin, Anna Christina Hans, Rebecca Hummels, Michael Schindelegger, and Henryk Dobslaw. Relating north atlantic deep water transport to ocean bottom pressure variations as a target for satellite gravimetry missions. *EGUsphere*, 2024:1–23, 2024.

[6] Matthias O Willen, Martin Horwath, Eric Buchta, Mirko Scheinert, Veit Helm, Bernd Uebbing, and Jürgen Kusche. Globally consistent estimates of high-resolution antarctic ice mass balance and spatially resolved glacial isostatic adjustment. *The Cryosphere*, 18(2):775–790, 2024.

[7] Matthias O Willen, Martin Horwath, Andreas Groh, Veit Helm, Bernd Uebbing, and Jürgen Kusche. Feasibility of a global inversion for spatially resolved glacial isostatic adjustment and ice sheet mass changes proven in simulation experiments. *Journal of Geodesy*, 96(10):75, 2022.