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

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

ICCC website - www.iccc.iag-aig.org

1 Terms of Reference

The Inter-Commission Committee on Geodesy for Climate Research (ICCC) was established in 2019 to advance the use of geodetic observations for climate research. The growing data record from numerous geodetic observation techniques (GNSS station observations, satellite radio occultation and reflectometry, satellite gravimetry, satellite altimetry, InSAR, VLBI, GNSS-controlled tide gauges, etc.) provides a new quantitative view on various variables that are relevant for climate research, such as tropospheric water vapor, thermospheric neutral density, terrestrial water storage, ice sheet and mountain glacier mass , steric and barystatic sea level, ocean surface winds, ocean waves, subsurface and surface currents, and sea ice extent and -thickness. Many of these are listed as Essential Climate Variables (ECV) according to the definition by the Global Climate Observing System (GCOS).

Geodetic methods provide unique information on the Earth's surface geometry, its large-scale mass transports such as fluctuations in Earth's water cycle, and the global energy imbalance. Time series of geodetic data start to reveal a complex picture of natural climate variability, long-term climate change, and anthropogenic modifications. Combined with other observations by means of, e.g., global or regional Earth system simulations or reanalyses, they provide excellent tools to improve our understanding of climate-related processes. Furthermore, due to their advantage of being independent of other data commonly used to drive and evaluate coupled climate models, geodetic observations have strong potential for either being used as input for numerical models as constraints (e.g. water budget, sea level budget) or for a posteriori model assessment. While it is generally recognized that geodetic data provide invaluable information for studying the planet's changing climate, programmatic obstacles, technical limitations such as the length of time series, and scientifically open questions have been identified that hamper the broader recognition of geodesy as an important source of information for climate research. The Inter-Commission Committee on "Geodesy for Climate Research" shall help to better promote and facilitate the use of genuinely geodetic data in the climate community, and to better explore the synergies between the different geodetic branches with respect to observing climate signals.

The topic of the ICC is positioned at the interface between geodesy and climate science and is of high relevance for the entire scientific discipline geodesy. Various geodetic observables provide complementary information on climate change processes.

Examples include (but are not limited to) the following: climate change related mass transport (e.g., ice melting, sea level rise, changes in the continental and oceanic water cycle as well as their impact on water resources) are among the primary signals derived from (satellite) gravity observations and can also be detected directly by geometrical measurements of volume change (satellite altimetry for water bodies/ice, InSAR over aquifers) or indirectly via crustal deformations induced by surface loads (terrestrial GNSS, InSAR, VLBI). Furthermore, by changing the Earth's moments of inertia and relative momentum term, mass transports also lead to measurable variations in Earth orientation parameters. Climate change related variations of the atmosphere affect the propagation of geodetic signals and thus can be inferred from long time series of VLBI and ground and satellite based GNSS observations. Finally, a stable global geodetic reference frame (GGRF) is an indispensable requirement for providing a uniform reference for monitoring global change processes, as has recently been recognized by the corresponding UN resolution1. However, synergies between the different geodetic observing systems for monitoring climate change have not yet been fully exploited and the interaction with the climate communities needs to be intensified in order to achieve a broader – and better recognized – use of geodetic data for climate research.

1.1 Objectives

- 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, this way also supporting activities of the IPCC
- 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

1.2 Program of Activities

- The ICCC will continue the successful workshop series established to intensify the exchange between different geodetic communities and the climate monitoring and modeling communities.
- The ICCC will continue the online seminar series "Geodesy4Climate" to specifically invite scientists from climate communities to bring them into contact with geodesists.
- The ICCC will create opportunities for communication and discussion through suggesting/organizing sessions at international scientific meetings and conferences.
- The ICCC will develop reference (best-practice) methods for evaluating/improving climate models with geodetic data and publish these methods (e.g., in a "white paper").
- The ICCC will seek to organize special issues on its topic in appropriate international journals.

- The ICCC will work towards a better recognition of geodesy as an essential provider of precise information about long-term changes in the Earth system.
- The ICCC will establish links to other climate science related bodies, e.g. the IUGG Union Commission on Climatic and Environmental Change (CCEC) or the IAMAS International Commission on Climate (ICCL).
- The ICCC will maintain a website for dissemination of ICC related information and will actively communicate results and events via social media (e.g., the former Twitter).

1.3 Structure

The structure of Inter-Commission Committees (ICCs) is specified in the IAG by-laws. The ICCC Steering Committee consists of the President, Vice-President, representatives from each of the IAG Commissions, GGOS, one Early Career Scientist (ECS) and one Member-at-large. ICCC activities are undertaken by Joint Working Groups (JWG), affiliated to two or more IAG entities.

1.4 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)
- Representative of Early Career Scientists: Franck Ghomsi (South Africa)

1.5 Overview of 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 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

Introduction

Earth orientation parameters comprising variations of both the position of the rotational pole and the spin rate are precisely observed by modern space geodetic techniques for several decades. In addition, optical astrometric observations extending back in time over more than 100 years carry information about the mass transport and mass distribution processes acting on Earth at historical times that might be explored to quantify slow and subtle variations in the Earth's climate due to both natural variability and anthropogenic impacts.

This working group will study the various contributors of the global and interactively coupled climate system to the observed changes of the Earth's orientation on time-scales from days to centennials. It will explore possibilities to validate numerical climate models and its individual components by means of assessing the angular momentum budget and the associated torques. The working group will further investigate present-day uncertainties of various Earth system state and flux variables in order to attribute residual (i.e., yet unexplained) signals in polar motion and changes in the length-of-day, and assess time-scales for potentially skillfull forecasts of Earth orientation parameters with numerical models.

Objectives

- Exploring temporal limits of predictability of individual Earth orientation parameters with (partially) coupled climate models
- Quantification of contributions from various components of the (anthropogenically altered) Earth's system to rotational variations on time-scales from days to centennials
- Assessment of angular momentum budgets of global numerical climate and Earth system models

Program of Activities

- Regular online working group seminars as well as in-person meetings aligned to major conferences
- Establishment of "best practices" for deriving angular momentum and torque estimates from numerical climate model data
- Contributions to the future development of the Global Geophysical Fluid Centre (GGFC) of the International Earth Rotation and Reference Systems Service (IERS)

Members

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

JWG C.2 Polar geodesy for understanding climate change

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

Introduction

Geodetic observations play a pivotal role in comprehending the current state of the cryosphere under climate change. Mass change data from missions like GRACE, GRACE-FO, and upcoming missions such as GRACE-C (scheduled launch 2027) and the MAGIC constellation including NGGM (scheduled launch 2032) represent crucial variables that have to be monitored space. In addition, gravity field measurements, observations like GNSS surface deformations are essential for untangling complex sources of mass change originating from various processes.

In the past decades, geodetic observations have proven to be critical for refining cryosphere change trajectories, and, particularly in assessing the sea-level contribution of ice sheets and glaciers for climate projections. Nevertheless, the exploitation of the data has not been achieved to their full potential.

Therefore, our working group focuses on facilitating the direct utilization of geodetic mass change products by the ice and polar climate modeling communities. Historically, challenges hindered the full use of geodetic data, including issues like accessibility, limitations in temporal and spatial resolution, lack of expert validation, meaningful uncertainty descriptions, misconceptions about the data, and independence from auxiliary sources entering more complex inversion approaches. This has led to restraints concerning use of geodetic data within the ice and polar climate modeling communities.

Objectives

To enhance the use of mass change data, we propose improvements in three main areas improving the interface between geodetic data providers and ice and polar climate modelers:

- Evaluate approaches for combining gravimetry with other data for downscaling
- Conduct a testcase on transient calibration of ice sheet projections using geodetic data
- Explore prospects for resolving critical processes in future gravity missions

Sequentially, these points aim to enhance mass change data, apply the data in a testcase, and anticipate limitations lifted by future missions.

Program of Activities

The means to achieve the objectives stated above are:

- In-person workshops
- Online conferences
- Regular consultations with working group leads
- Promotion of young researchers at conferences
- Dedicated scientific paper (potentially)

The involvement of early career scientists is crucial, particularly for point (3), to train the next generation of geodesists for future missions. Established links of the working group leaders to younger ice and polar climate modelers open to using geodetic data will also be utilized for point (2). Substantial experience in different satellite observations is required for point (1), which the working group leads are more than willing to share with early career polar geodesists in the context of the working group.

Members

Mike Bevis (USA)
William Colgan (Denmark)
Xavier Fettweis (Belgium)
Dana Floricioiu (Germany)
Kristine Larson (USA)
Lin Liu (China-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)

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

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

Introduction

The Earth's Energy Imbalance (EEI), defined as the long-term global mean net radiative flux at the top-of-the-atmosphere (TOA), represents the rate at which our planet accumulates heat in response to radiative forcings and feedbacks, making it a key metric for quantifying ongoing global warming. EEI is often used as a target value in global climate model tuning and to constrain the equilibrium climate sensitivity, although its accurate quantification is challenging. In principle, the absolute EEI magnitude is the small difference between large incoming and outgoing radiative fluxes at the TOA. But due to calibration and retrieval uncertainties that are one order of magnitude larger than EEI itself, EEI cannot be derived from radiometric observations, unless adjustments are made to match the global net radiative flux to independent estimates of long-term planetary heat uptake. These heat uptake estimates have ranged between 0.4 and 1.2 W m^{-2} over the past few decades.

Since the ocean absorbs about 90% of the incoming energy surplus, EEI assessments largely hinge on ocean heat uptake (OHU). To date, standard approaches to estimate OHU are: (a) to derive ocean heat content (OHC) changes from direct subsurface ocean temperatures through hydrographic profiles; (b) to derive the oceans' thermosteric expansion through sea level budget assessments using geodetic observations from space; (c) to estimate the ocean state using global ocean models and reanalyses that assimilate various ocean and atmosphere observations.

The geodetic approach estimates OHU throughout the entire ocean volume as a residual of global mean sea-level (GMSL) and ocean-mass changes (2002 to present). Changes in GMSL are caused by thermal expansion due to OHU (thermosteric changes) and by ocean mass changes (barystatic), the latter being driven by ice-mass and terrestrial water storage (TWS) changes. Subtracting the ocean-mass change from the change in GMSL yields an indirect estimate of full-column steric sea-level change, provided that corrections for glacial isostatic adjustments (GIA) and sea-floor deformations due to contemporary mass changes (GRD) are accounted for. The relation between steric sea-level change and OHU requires knowledge of the ocean's expansion efficiency of heat. The difference between the upper-ocean OHU from hydrographic observations and the geodetic full-column estimate could provide information on the sparsely observed deep-ocean steric expansion; however, to unambiguously detect the small deep OHU, requires to reduce the combined uncertainties from the hydrographic and geodetic methods.

Objectives

- Exploit geodetic observations to close Earth's energy budget and derive change in Earth's energy imbalance.
- Provide global and regional satellite-based Ocean Heat Uptake for model validation/calibration and climate analysis (e.g., variability and trends, constraints on climate sensitivity, international EEI assessments).

Program of Activities

- Take stock of and bring together groups who provide geodetic global and regional Ocean Heat Content (OHC) products.
- Intercompare methods, uncertainty derivation, and investigate regional/global discrepancies.
- Work toward best practices for deriving global Ocean Heat Uptake (OHU) and change therein.
- Work towards regional OHC estimates from geodetic data: Treatment and computation of the halosteric component and expansion efficiency.

- Assessment of global/regional OHC and OHU against in-situ observations and ocean models/reanalysis.
- Application of geodetic OHC and OHU estimates in global climate model evaluation, and study of EEI variability.
- Outstanding GRACE/GRACE-FO-centered investigations to improve EEI estimates.

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)

JWG C.4 Hydrological loading: measuring and modeling

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

Introduction

Water distribution in its various forms on Earth surface, the so-called hydrological loading, leads to the deformation of the solid Earth and gravity field variation. Spaceborne geodetic techniques, among all, contribute in monitoring and modeling of hydrological loading. Our joint working group will undertake a multidisciplinary approach, benefiting from expertise from geodesists, hydrologists and climate scientists. We will collaborate on data collection, analysis, and modeling efforts to achieve our objectives. Within this joint working group following objectives are envisaged.

Objectives

- Exploring the signature of climate change in hydrological signals
- Better understanding the hydrological loading: investigating the role of different compartments and different scales
- Feasibility assessment of the reconciliation of different measurement techniques and models and exploring their associated uncertainties
- Understanding the impact of the hydrological cycle and mass fluxes on geodetic response, aiming to enhance our understanding of the space-time scales linked to diverse deformation processes

To achieve these goals we will

- investigate how hydrological loading serves as a sensitive indicator of climate change. By analyzing long-term geodetic records and climate data, we will seek to identify distinct patterns and trends that signify the impact of changing climate conditions.
- explore the intricate relationship between hydrological compartments (e.g., groundwater, surface water, snow, ice) and different spatial and temporal scales. This will involve dissecting the contributions of individual compartments and their interaction within larger hydrological systems.
- explore the challenge of reconciling various geodetic measurement techniques (e.g., GNSS, InSAR, GRACE) and hydrological models (e.g., land surface models, hydrological models) used to study hydrological loading. We will assess the strengths and limitations of each approach and propose strategies for integration. We will conduct intercomparisons of different hydrological models and geodetic measurement techniques to understand their relative strengths and weaknesses.
- develop guidelines and roadmaps for quantifying uncertainties associated with hydrological loading measurements and modeling.

We expect the following outcomes:

- Enhanced understanding of hydrological loading's role in detecting climate change signatures.
- Insight into the contributions of different hydrological compartments and scales.
- Improved reconciliation of diverse measurement techniques and models.
- Guidelines and roadmaps for uncertainty quantification. Collaborative research publications and presentations.
- A network of experts contributing to ongoing advancements in geodesy for climate research.

Program of Activities

- Organizing workshops, webinars, and conferences to facilitate knowledge sharing and dissemination of research findings.
- Organizing Special Issue in a Suitable Journal
- Organizing summer/autumn schools (hackweeks) to transfer knowledge to students.
- Regular meetings/discussion Organizing sessions at international conferences and also, ICCC meetings

Members

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)
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Anthony Mémin (France)
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Fabrice Papa (France)
Mahdiyeh Razeghi (Australia)
Peyman Saemian (Germany)
Francesca Silverii (Italy)
Alicia Tafflet (France)
Shuang Yi (China)
Susanna Werth (USA)

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

Introduction

GNSS Interferometric Reflectometry (GNSS-IR) is a relatively new ground-based remote sensing technique based on reflected GNSS signals. It has been used to measure water levels, snow accumulation, permafrost melt, soil moisture, vegetation water content, and significant wave height. With the increased numbers of GNSS-IR developers and users, there is a need for community based resources. Our group will focus on expanding and improving the existing open source software for both geodetic and low-cost GNSS-IR sensors, archiving locations of GNSS-IR sensors, and supporting new users. Validation datasets will be archived to allow new users to develop the needed skills to install and operate GNSS-IR sites and to analyze the data from the sites.

Objectives

- Technical improvements of GNSS-IR models
- Maintain/create inventory of GNSS-IR sites that have been used to measure climate variables
- Guidelines for installing good GNSS-IR sites
- Develop and maintain low-cost GNSS-IR sensor hub

- Upgrade and maintenance of open source software/tools and use cases
- Operational showcasing initiative for (near) real-time monitoring of climate variables
- Sponsor software classes

Program of Activities

- We schedule bi-monthly meetings that alternate between member meetings and online GNSS-IR webinar series every other session
- Organizing sessions in international conferences and ICCC workshops.

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 (China-Hong Kong)
Angel Martín (Spain)
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Thalia Nikolaidou (Canada)
Thomas Nylen (Denmark)
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Sajad Tabibi (Luxembourg)
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Surui Xie (USA)

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

Introduction

At a time of urgent need to combat climate change and promote global cooperation, geo-monitoring with global navigation satellite systems (GNSS) is at the centre of attention. In particular, extreme hydrological and weather situations such as heavy precipitation and floods as well as other hazards such as landslides or rock falls often happen abruptly and are now more frequently observed under climate change conditions. In order to understand the causes and processes of such changes, long-term monitoring is of high importance. This is also the case for other short to long term changes, e.g., of the snow storage, glaciers, soil moisture, water levels, vegetation, atmosphere, and urban environments. In general, we still know too little about interrelationships of geophysical effects that act in a complex interaction, which is also due to a lack of observations, being often limited by costs, man power or accessibility. Regarding climate and environmental research, all challenges have one thing in common: they are geo-referenced and closely linked to the need to ensure high precision, reliability and repeatability. GNSS is an efficient instrument in the space segment for already 50 years. With the access to mass market products especially in the last two to three decades, geophysical processes of our planet can be monitored more (cost-)effectively also in the user domain, on different scales, from both local to global and in dimension of different time periods.

In this Joint Working Group, we intend to review and redefine methods using mass-market equipment by which dynamic geophysical processes can be monitored by geodetic means and be made available as products or reliable metrics to other disciplines working primarily in the climate and environmental sector. Central to our work is the essential question that goes beyond mere GNSS position determination: how can we exploit the power of mass-market GNSS equipment and data to meet the complex requirements of climate and environmental processes happening on the Earth surface and the atmosphere, not only achieving centimetre or even millimetre-scale accuracies, which is the main focus of positioning, but also exploring the question of what other quantities and variables in each specific domain can be effectively determined. Examples in this context would be the determination of, e.g., snow water equivalent (using GNSS carrier phases and signal strength measurements), the water vapour content in atmospheric layers as well as atmospheric and ionospheric delay (using carrier phase measurements), the wave motion and the sea level height or also the soil moisture, snow height and growth changes of plants and their foliage-effect of trees on GNSS observables (applying e.g., reflected signals). These are all essential variables, which are largely relevant in climate and environmental research.

As climate change is global phenomena, a key objective of this group is not only to bridge the boundaries of technological innovation, but also to enable collaborations and support knowledge transfer among different countries. We see GNSS technology, especially the mass market equipment, as a catalyst for international collaboration including global technology transfer and capacity building. In this way, we are not only advancing geomonitoring, but also contributing to global efforts to combat climate change and its far-reaching consequences.

Objectives

Our JWG goals involve the use of GNSS technology and geomonitoring in various surroundings ranging from fully natural to urban environments to better understand, prepare for, and adapt to the impacts of climate change, such as extreme hydrological and weather events, rising sea levels, changing precipitation patterns as well as changes in short- and long-term hydrological and cryospheric variables. We focus on monitoring and assessing environmental changes, developing techniques and strategies to make communities and ecosystems more resilient to these challenges.

To achieve our goals, we carefully classify and categorize GNSS units according to their application areas, laying the foundation for seamless integration into global geomonitoring networks. We explore the possibilities of interchangeability between high-performance and low-cost GNSS units, emphasizing their potential to make geomonitoring more efficient and cost-effective, in regions with limited resources and others.

We go on to analyse the practicality and limitations of using mass-market GNSS units in geophysical and geodetic applications, particularly in the context of climate studies. Spatial and temporal scales, result accuracy, and efficiency will be explored to, highlight the way forward.

- Investigate the limitations and capabilities of mass-market GNSS units, w.r.t. standard or high-end devices, with particular emphasis on their applicability to environmental and climate change studies (different scales and resolution i.e., time and space).
- Extend investigation to positioning quality in static and kinematic contexts as applicability to environmental and climate change studies.
- Assessing and finding ways to potentially improve the precision and reliability of mass-market GNSS instruments to meet the critical requirements of geophysical applications.
- Provide a comprehensive overview and classification of GNSS units based on their application areas. Distinguish the unique characteristics of mass-market GNSS units and highlight their potential to make geomonitoring more efficient and cost-effective, especially in resource-limited regions.
- Evaluate interchangeability and interoperability among high-performance, mass-market GNSS units to ensure seamless integration into global geomonitoring networks.
- Promote the use of GNSS technology as a tool to democratize science for international cooperation, technology transfer for effective geomonitoring, and augment climate change adaptation strategies.

Program of Activities

- Ice breaking and closing workshops
- Organising sessions at conferences (such as EGU, AGU, etc.) and (hybrid) splinter meetings
- Commission work (regular meetings)
- Annual webinars on that topic
- Paper / technical report (white paper and/or journal paper) on topics like e.g. review and categorization of devices as well as fields of application / table of scalability vs. precision, field work hints
- Enable the possibility for writing joint research proposals

Members

Franziska Koch (Austria)
Robert Odolinski (New Zealand)
Jens-André Paffenholz (Germany)
Kristine M. Larson (USA)
Inese Varna (Latvia)
Shivam Tripathi (India)
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JWG C.7 Ground-GNSS trends for climate models

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

Introduction

GNSS Zenith Total Delay (ZTD) estimates are quantities of great interest by climate modellers since atmospheric water vapour is the major greenhouse gas. Therefore, the importance of its accurate, long-term monitoring and evaluation of trends and variability, potentially serving as independent benchmarks to climatological models, both on longer trends derived from GNSS, but also shorter trends, which could be used for assimilation and validation of climate models. ZTD estimates are determined on a regular basis by several processing centers as well as by demand. It has also been demonstrated that series of ZTD estimates can be used for quality control purposes. At the same time, GNSS is reaching the "maturity age" of 30 years when climate normals of ZTD and gradients can be derived. But what would be the best ZTD series to serve the climate community? What series would offer the most realistic trends? A variety of data sets have been used, namely, the ZTD series derived by the third reprocessing campaign (REPRO3), based on a variety of processing modes and models. PPP-based ZTD estimates can also be generated by scientific software suites, including the PPP-derived IGS product. All of that converges to the opportunity to perform quality control and assess ZTD (and gradient) product best suited to climate studies.

Objectives

The main objective is to define proper quality parameters to satisfy the generation and analysis of long-term trends derived from ground GNSS and inter-annual variation. Proposed activities involve the generation of ZTD estimates using PPP by a few centers (e.g., ESA, GFZ, IGS, UNB) and the tropospheric product from IGS, all based on REPRO3, analysis of trend and harmonics and comparisons with results from the past JWG investigation based on IGS AC estimates.

Program of Activities

- Collaborate with IGS and IVS in the forthcoming reprocessing campaign
- Participate actively in IAG, AGU and EGU conferences and organize sessions
- Organize working group meetings, splinter group meetings at the said symposia

Members

Anna Kloss (Poland)
Galina Dick (Germany)
Haroldo Marques (Brazil)
Jonathan Jones (UK)
Kalev Rannat (Estonia)
Kyriakos Balidakis (Germany)
Mayra Oyola-Merced (US)
Olalekan Isioye (South Africa)
Peng Yuan (Germany)
Raul Valenzuela (Chile)
Samuel Nahmani (France)
Sharyl Byram (US)
Thalia Nikolaidou (Canada)
Yibin Yao (China)
Yidong Lou (China)

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

Chair: Olivier Bock (France)
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Affiliations: Commission 4, IGS, GGOS

Introduction

Water vapor plays a key role in the Earth's climate and weather as a dominant greenhouse gas and the most efficient actor of heat transfer from the surface to the atmosphere and from low to high latitudes. As the climate warms, the amount of water vapor in the atmosphere is expected to rise. This implies a cascade of changes in the global and regional water cycles and in weather extremes. Monitoring and understanding the spatial and temporal variability and changes of water vapor are thus of crucial importance. Not surprisingly, water vapor is one of the five priority Essential Climate Variables (ECVs) targeted by the Global Climate Observing System (GCOS). GNSS-Precipitable Water (PW) is currently one of the constituent observing techniques of the GCOS Reference Upper Air Network (GRUAN) and is called to contribute more massively to GCOS thanks to its widely expanding networks covering all the continents.

In accordance with IAG's general missions, the objectives of this WG are to coordinate the collection, processing, qualification, and interpretation of GNSS-PW observations within the geodetic community and provide scientific guidance on the usage of these data to the climate community.

The motivations for this WG are the following. There are currently no clear guidelines in the geodetic practice on how to produce the most accurate and homogeneous tropospheric parameters (ZTDs, gradients) and convert ZTD to PW. A substantial part of the issues is related with the data processing schemes which are usually tuned to produce accurate station positions and/or satellite products (orbits, clocks), in which the tropospheric parameters are of secondary interest. Whilst station heights and ZTDs are tightly correlated parameters, ZTDs are more prone to absorb short-term observation and modeling errors, and an optimal positioning scheme does not guarantee optimal ZTD estimates. A dedicated tuning of processing models and settings would thus be beneficial to produce more accurate tropospheric products from GNSS measurements (with application also to DORIS and VLBI). Another issue for climate applications comes from the presence of inhomogeneities in the GNSS time series due to instrumental changes, changes in the antenna's environment, or changes in the processing and post-processing procedures. The latter can be circumvented by considering products obtained with fixed processing and post-processing schemes, including consistent and homogeneous auxiliary data. The impact of instrumental changes is handled during the data processing thanks to station metadata (e.g. antenna and radome information provided in site-logs). The other nuisances can be corrected in post-processing homogenization procedures. The elaboration of consistent and valuable GNSS climate data records (CDRs) needs to tackle all these issues and in addition to provide uncertainty estimates associated with each observation.

Objectives

- Bring together experts from the geodetic community to establish optimal processing and post-processing strategies with the aim of minimizing biases and inhomogeneities in tropospheric products (ZTDs, PWs, gradients) and providing realistic uncertainty estimates.
- Provide recommendations on optimal processing and post-processing procedures to produce "climate-grade" tropospheric products, and coordinate their implementation with the IGS Tropo WG and ACs in the framework of future reprocessing campaigns.
- Check with the IGS Infrastructure Committee, IGS ACs, and GGOS that the station metadata information in IGS site-logs and RINEX files is consistent and up to date.
- Evaluate and stimulate the development of Quality Check/Quality Assurance (QC/QA) methods and tools for the analysis and interpretation of GNSS ZTD and PW time series (e.g. outlier detection and screening methods, bias and inhomogeneity detection and correction methods, homogenization tools, noise structure analysis, etc.).

- Provide recommendations on QC/QA methods and tools for the elaboration of consistent GNSS-PW CDRs from reprocessed ZTD solutions.
- Coordinate the intercomparison and qualification of relevant tropospheric data sets (e.g. IGS reprocessings) by comparison with reference observations (e.g. from GRUAN).
- Cooperate with GCOS and the Copernicus Climate Change Service (C3S) to establish a repository of qualified GNSS-PW CDRs (e.g. GRUAN and IGS as reference CDRs and other GNSS networks as baseline CDRs).

Program of Activities

- Organize regular meetings with WG members to share scientific results and coordinate collaborative work
- Elaborate and disseminate recommendations and associated tools for the optimal processing and post-processing/homogenization of GNSS tropospheric products
- Meetings with IGS and GGOS on related topics
- Meetings with GCOS and Copernicus to establish a repository of qualified GNSS-PW climate data records

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

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Introduction

Altimetry observations cover the global oceans, cryosphere, sea-ice, ice-covered oceans and inland water bodies, providing invaluable geodetic and climatic information for studying the Earth and ocean dynamics and geophysical features. The contribution of surface water change to the global water cycle is monitored globally by satellite altimetric observations of high spatial and temporal resolution. Satellite radar altimeter measurements of sea surface heights have been continuously collected since the early 1990's along the 10-day repeat ground tracks of TOPEX/Poseidon, Jason-1/2/3, and Sentinel-6 missions, along the 35-day repeat ground tracks of ERS-1/2, Envisat and SARAL, and the 27-day repeat ground tracks of Sentinel-3A/-3B. In high pulse repetition frequency radar altimeters, an innovative processing in SAR and SARIN modes reduces the coastal gap and provides water level at higher spatial resolution along-track. This last is increased to about 300 meters by the unfocused-SAR processing and to 0.5 meters, for an integration time of 2 sec, by the fully-focused SAR processing. Since December 2022, the Surface Water and Ocean Topography Mission (SWOT), provides globally observations of Water Surface Elevation (WSE) and water extent (WE) in rivers, lakes, reservoirs and right to the coast with an unprecedent spatial resolution. On ocean, SWOT closes for water height the observational gap between 100 km and 15 km wavelength, while observations of the surface roughness through the backscatter informs on the physical processes at and below the water surface.

To detect climate related signals, we aim to investigate water surface change, river discharge and water storage change on land and surface water level at ice margins, coast and open ocean. For adaptation effort, we look at flood hazard event and to their mapping. We consider to study the impact of the different global terrestrial reference frames, e.g. ITRF2020, DTRF2020, JTRF2020, on both the altimeter measurement processing and the altimeter-derived geophysical parameters. It is agreed that a major limiting factor in the determination of global and regional sea level rise is the uncertainty of the Terrestrial Reference Frames in origin, scale and long-term stability. We propose to investigate the gain obtained by high-resolution (HR) altimetry 1-D and 2-D measurements, and to encourage innovative interdisciplinary research and applications in climate change studies.

Objectives

- Develop an observational-based estimation of the components of the water cycle.
- Extend the existing databases of water height, discharge, water storage, runoff, water extent, sea ice coverage, sea level.
- Develop test cases for flood events to demonstrate the capability of the new space techniques for hazard mapping and early warning application.
- Derive surface component of water cycle collaborating e.g. with space gravimetry, monitor groundwater and total water storage (TWS), sea level, discharge and other Essential Climate Variables (ECV).
- Test different global terrestrial reference frames and their impact on the altimeter-derived parameters, e.g. on sea level rise.

Program of Activities

- Support the IAG International Altimetry Service (IAS) Planning Group in generation of climate-related data products and services
- Support innovative interdisciplinary scientific research and applications for climate change detection
- collaborate with agencies and shakeholders
- Provide a forum for scientific exchange and training courses
- Collaborate with existing ICCC working groups, e.g. JWG C.3, C.4, C.7
- Collaborate with study group SG 2.5.1 of IAG Sub-Commission 2.5 Satellite Altimetry (https://com2.iag-aig.org/sub-commission-25).
- Participate to international science teams, e.g. Ocean Surface Topography (OSTST), SWOT Science Teams and Validation Teams (S3VT, S6VT)
- Collaborate with GGOS Standing Committee PLATO for the improvement of the Reference Frame with Space Techniques (https://ggos.org/about/org/bureau/bno/cwg/plato/).

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

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Introduction

Satellite gravity measurements have successfully observed changes in the Earth system for more than two decades and deliver critical information on mass changes linked to climate change. To ensure continuity, the Mass-change And Geoscience International Constellation (MAGIC) is planned to be launched in the next decade, increasing the resolution of mass-change observations. Especially the long-term observation of Terrestrial Water Storage (TWS) and ocean mass are important climate indicators. TWS consists of all water storage over the continents in liquid and frozen states and has recently been declared a new Essential Climate Variable (ECV) in the implementation plan 2022 of the Global Climate Observing System (GCOS). Changes in ocean mass directly impact sea-level changes, and their measurement allows for quantifying Earth's Energy imbalance, essentially driving climate change. The importance of increased resolution and long-term sustained observing systems for TWS is underlined in the IUGG resolution no. 2 in 2023, expressing the chance to enable new science and applications of enormous societal benefit. By ensuring a long-term sustainable operation of satellite gravity missions, applications in the hydrosphere, cryosphere, and ocean can profit from tailored processing products of the long-term data record, trading spatial and temporal resolution for an optimal outcome for the respective cases.

This working group focuses on identifying and implementing spatiotemporally tailored parameterization strategies for satellite gravimetry observations designed for different climate applications. Building up from the simulation environments implemented in previous working groups, parameter models can be evaluated concerning their capabilities to represent climate-related mass transport signals and their feasibility in real data applications. To envision the possibilities that will arise with upcoming satellite gravity missions, improvements expected from MAGIC and future mission concepts shall be investigated next to current single-pair satellite GRACE-type missions. The parameter models shall be defined in close interaction with the respective applications to identify the main criteria to allow new science to emerge from the advanced parameterization strategies.

Objectives

- Create a modeled mass transport series of 30 years for different applications.
- Define temporal-tailored parameter models for specific climate applications in co-operation with the users.
- Compare the impact of local base functions, e.g., Spherical harmonics, Mascon, Slepians, etc., on specific regions and applications.
- Identify frequencies in the interannual variability and evaluate the impact on the long-term trend assessment if they are (not) considered.

Program of Activities

- Meetings within the working group to plan collaboration and share scientific results
- Specialized subgroup meetings for different climate applications
- Contribute actively to ICCC Geodesy for Climate Workshops and organize sessions

- Participation in and contribution to conferences such as GSTM, GGHS, and EGU
- Organizing splinter meetings at said conferences

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