Symposium G01: **Reference Systems and Frames**

- 8 oral sessions (**46 papers**), 1 poster session (**16 papers**)

- **Global reference frames**
  - ITRS realization, evaluation, products & contributions (*ITRF2020, JTRF2020, DTRF2020, APKIM2020, BKG, CNES, ILRS, IVS, DORIS*)
  - TRF and other geodetic products from VLBI
  - POD, GNSS/LEO space networks
  - Local ties (*legacy SX w/ VGOS, McDonald Observatory, Ishioka station, PSInSAR at co-location sites*)
  - Non-local ties (*Genesis mission, intra- & inter-technique combo sols w/ global+atmo+local ties*)

- **Regional reference frames**
  - EUREF/EPN, SIRGAS/Chile, NATRF2022/Canada, Saudi Arabia, Japan
  - Frame transformation in deforming regions
  - Regional deformation models by GNSS/CORS and InSAR
  - Analysis of GNSS position time-series

- **Other themes**
  - CM motion, handling of OTL models, new formula Cart2Curv geod coord conversion, mean-tide system

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G02: Static Gravity Field and Height Systems

- Conveners: Laura Sanchez, E. Sinem Ince, Hussein Abd-Elmotaal, Roland Pail
- 37 oral contributions (seven sessions)
- 30 poster contributions
- Three invited talks: International Height Reference System and Frame, International Terrestrial Gravity Reference System and Frame, Geopotential determination with optical frequencies
- Main topics:
  - Global gravity field modelling (7 contributions)
  - Regional gravity field modelling (16 contributions)
  - Height systems (12 contributions)
  - Methods (15 contributions)
  - Terrestrial gravity reference frames (9 contributions)
  - Gravimetry (8)

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G03: Time-variable Gravity Field

Highlights from 44 oral presentations, 16 posters

- The GRACE Follow-On mission reached its nominal five-year mission lifetime in May 2023, and is entering its extended mission phase through the end of 2026. The combined GRACE & GRACE-FO data records now span over 22 years and provide unique observations of monthly to decadal global mass changes and transport, enabling numerous applications in Earth sciences.

- Several GRACE & GRACE-FO ACs reported on improved gravity field solutions by application of e.g. stochastic modeling of instrument data and background models or co-estimation of daily low degree coefficients.

- Significant progress has been presented to fill data gaps in the GRACE/GRACE-FO time series based on HLSST and SLR data analysis.

- Space Agencies are working towards the realization of future gravity missions.

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G04 Earth Rotation and Geodynamics

- **Organizers**: Bogusz Janusz, Severine Rosat, Michael Schindelegger, Chengli Huang

- **Chairs**: Bogusz Janusz, Severine Rosat, Michael Schindelegger

- 20 oral presentations, 9 posters

- **Topics:** GNSS strain and velocity field, at global and regional scales (Corinth), tidal and non-tidal loading, superconducting and space gravimetry, Earth's rotation

- **Highlights**
  - JWG 3.2 **The IAG combined global GNSS velocity field**
  - Precession-nutation, improving models (incl. dynamic ellipticity, 2nd order effects) and forecasting using **artificial intelligence** (machine learning)
  - Polar motion, incl. Chandler Wobble (observations from sub-daily to multi-decadal) and predictions (**machine learning**), length-of-day observations (large Ring Laser Gyroscope)

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G05 Multi-signal positioning, Remote Sensing and Applications

- Solicited talks:
  - Peter Teunissen - *The DIA-estimator for positional integrity: Design and computational challenges.*
  - Attila Komjathy - *GDGPS High accuracy service for real-time GNSS applications to support public and scientific users.*
  - Peiliang Xu - *From high-rate GNSS to the technological invention of accelerometers.*
- Highlights:
  - Advancements in PPP-RTK/AR algorithms and applications.
  - New real-time services.
  - Advanced methods for positioning in urban canyons for autonomous navigation.
  - LEO-based PNT.
  - First Galileo HAS studies.
  - The next wave of GNSS tropospheric and ionospheric products and indices.
  - Advancements in low-cost positioning and applications.
  - Deep learning in positioning and error modeling.
  - Space resources exploration and utilization – a geodetic perspective!

11 oral blocks
61 presentations
34 posters

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G06 - Monitoring and Understanding the Dynamic Earth with Geodetic Observation

Basara Miyahara
GGOS President

- **12** sessions, **9** solicited talks, **86** presentations
- Session Themes
  - <u>Geodesy Contribution to Science & Society</u>
    - ✓ Geodesy Outreach & Access to Geodetic Data/Products (IHRF, DOIs, EGVs, regional collaborations..)
    - ✓ Disaster Risk Reduction (Tsunamis, Crustal Deformation Monitering..)
  - <u>Emerging hot/Interdisciplinary topics & technology</u>
    - ✓ Climate (ICCC), Marine (ICCM), Quantum Technology (QuGe)…
  - <u>Geodetic Observation & Network / Policy & Standards</u>
    - ✓ IAG Services (20th Anniversary of IDS!), geodetic products, EGVs..

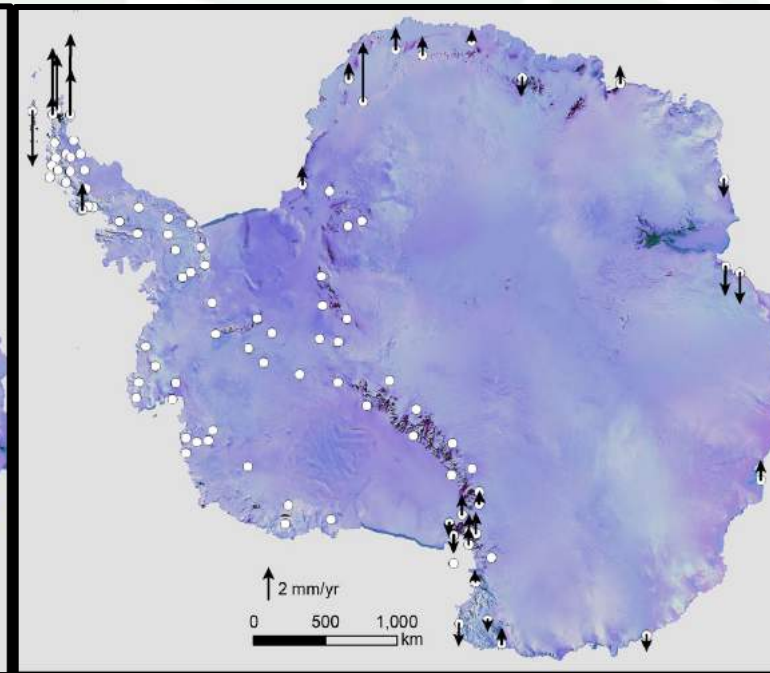International Association of Geodesy

JG01 – Interactions of the Solid Earth With Ice Sheets and Sea Level (IAG, IACS, IASPEI)

- Need for continuous observational constraints (in particular, GNSS) to study the Earth rheology and ice-sheet behaviour ⇨ particularly in Antarctica and the Arctic

US-ANET
Decommissioned
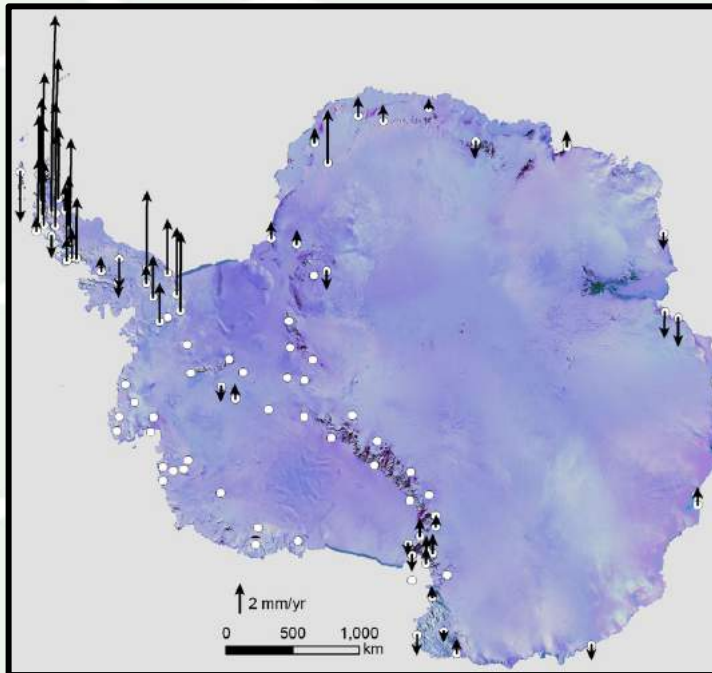
UK-ANET & US-ANET
Decommissioned

Pictures from the talk by Wilson & Whitehouse (IUGG23-2206)

- International cooperation and funds sharing to maintain GNSS stations at the poles could help to facilitate a more sustainable network

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Joint Symposium JG02 Theory and Methods of Potential Fields (IAG, IAGA)

- **Conveners:** Dimitrios Tsoulis (IAG, Greece), Maurizio Fedi (IAGA, Italy)

- **Submissions:** 29 submissions organized in 4 oral slots (all 17/07) and a Poster Session (8 P) **13 orals (1 solicited) and 8 Posters presented**

- **Some of the highlights:**
  - Parameter estimation of sampled random fields
  - Gaussian sum for Newton's kernel splitting
  - Forward modelling of Earth's topography
  - Plumb line representation using potential flow theory
  - Spherical harmonics of static and stochastic polyhedral sources
  - Crust modeling for Mercury

- **Resonance:** Interesting discussions, very good presentations of early career scientists

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JG03 - Remote Sensing and Modelling of the Atmosphere

- The Symposium JG03 consisted of 7 oral sessions JG03a to JG03g and a poster session with altogether 39 talks and 4 posters.

- A large step was made forward in modeling the electron density of the ionosphere and plasmasphere. This was achieved (1) by including more observation techniques and satellite missions, e.g., Swarm, GRACE-FO, Sentinel, Jason, COSMIC and Spire CubeSats, (2) by introducing carefully determined constraints for the key parameters of the electron density as well as (3) by considering Machine Learning (ML) techniques.

- Several presentations highlighted the use of Near Teal-Time (NRT) data, e.g. (1) for an independent validation and combination of Real-Time Global Ionospheric Maps by means of DORIS NRT data and (2) for improving the spatio-temporal resolution of tropospheric tomography products by means of NRT ground-based GNSS, InSAR and radio occultation measurements.

- A comprehensive 3D dataset of tropical upper tropospheric cloud systems has been constructed using various data sources and ML techniques. Artificial neural network models identify heavy precipitation areas, revealing the relationship between horizontal/vertical structure and providing insights for climate models.

- The HAWC satellite mission collects aerosol, cloud, and water vapor data, contributing to NASA's Atmospheric Observing System and enhancing our understanding of atmospheric component interactions.

- An invited talk was given by Thomas Aubry on the volcanic radiative forcing of climate. The case was made that small-magnitude eruptions should be taken into account in climate models.

- Latest advances in the NRT retrieval of volcanic SO_2 concentrations and aerosols physical properties have been shown.

- In general, it should be noted that the results presented in many talks (and posters) have been based on ML techniques. It must be emphasized that modeling strategies have changed significantly in recent years.

- As a negative point, at least 3 talks in JG03 were given (by read-off only) by non-authors (neither lead nor co-author) who indicated directly that they cannot answer any question and that instead questions should be emailed to the authors. In this way, any discussion on the topic of the talk was prevented. In our opinion, the talk must be given by the lead author or by one of the co-authors.

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JG04: Satellite Gravimetry for Groundwater Monitoring (joint with IAHS)

Highlights from 11 oral presentations:

- The Global Gravity-based Groundwater Product (G3P) H2020 project developed a satellite-based groundwater storage anomaly (GWSA) data set as a prototype for a future product within the EU Copernicus Climate Change Service.

- Terrestrial mass loss by sediment transport in the Ganges and Brahmaputra rivers was quantified and found above detection limit of current satellites like GRACE-FO.

- Several methods based on GRACE were proposed to estimate groundwater storage.

- A couple of presentations attempted to utilize groundwater data at different scales to estimate groundwater storage

Recommendation: Continuation of the session at upcoming IUGG General Assembly.

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JG05: Geodesy for Climate Research

- co-organized by **five associations**: IAG, IAHS, IACS, IAPSO, IAMAS

- 33 orals, 12 posters

- Large variety of **geodetic observations** used for climate research:
  - altimetry, GRACE, future gravity missions, SAR, remote sensing
  - GNSS: loading, tomography, reflectometry, radio occultation
  - Earth orientation parameters, …
  - important: synergy effects

- Large variety of **climate signals**:
  - sea level budget & Earth energy imbalance
  - hydrological mass variations, floods & droughts
  - water vapour in the atmosphere
  - ice mass change & GIA
  - ocean dynamics, ocean tides, …

=> Geodesy has turned into an important climate monitoring toolbox!

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JG06 - Monitoring Sea Level Changes by Satellite and In-Situ Measurements (IAG, IAPSO)

- The symposium had 5 solicited and 15 oral presentations, and 10 posters.
- Highlights, comments, recommendations:
  - The data-driven sea-level projection techniques and results using satellite observations (by Robert Steven Nerem)
  - Historical sea level changes and variability based on observations from 1800s to current, including in-situ tide gauge, satellite altimetry, oceanic and atmospheric data (by X Zheng et al.)
  - Updated sea-level reconstruction with joint estimation for vertical motion at tide gauges and geocentric sea-level trends at the regional scale over last 70 years (by CK Shum et al.).
  - Global and regional sea level contribution from mass loading using tide gauge, altimetry, GRACE/GRACE-FO, and from ozone changes.
    - Carsten Ludwigsen et al. produced the monthly 3D global mass change products (0.5°x0.5°) over the period 2003-2022 from improved processing steps.
  - Global and regional sea level trend and uncertainty, sea level budget and uncertainty including Antarctica and Arctic Oceans, and lake level changes
    - Fukai Pend et al. estimated coastal sea level trends in the northern South China Sea from reprocessed satellite altimetry ERS-2, Envisat, Saral and Jason-1/2/3 over the period 1996-2022
  - Low frequency oscillation's contribution to sea-level change and its acceleration
  - New algorithms for improved estimates of sea level trends, for satellite conventional and SRA altimetry observations and geophysical and environmental corrections

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