Minutes of the 3rd Workshop for the International Coordination Group of Spaceborne SAR Missions (ICGS-SAR)

Chaired by JAXA
Ureshino-Onsen, Saga Prefecture, Japan

Executive Summary

- This workshop followed the first International SAR workshop held at CalTech in 2018, and the second workshop held at ESRIN in 2022.
- SAR observations of land surfaces can provide information ranging from a detailed local focus to a global view, from near real-time information to long-term archives, available to quantify changes and understand the causes of these changes. Estimates of above ground biomass (AGB) can be mapped with low frequency SAR data. SAR data of varying frequencies is used to map rice fields, crop growth stage and water management.
- Climate, biodiversity and human society are coupled through dynamic interactions across many scales. The UN is starting to look beyond GDP to measure human well being, incorporating planetary health. Spatial data, combined with personal data, can have a precise understanding of a population's well being.
- The Japan Space Policy is undergoing an update, with a strong focus on disaster response. This includes an update of the Basic Plan on Space Policy (last updated in 2020), and two new initiatives: Space Security Initiative and Space Technology Strategy. Increased resolution (both temporal and spatial) was identified as crucial for a number of applications. A SAR constellation was also identified as important.
- <u>Space Agency SAR Activities and Plans:</u>
  - CONAE operates SAOCOM-1A and -1B, which are L-band SAR missions. SAOCOM-2 is planned for launch in 2029, with a companion satellite, SAOCOM-2A also planned.
  - CSA operates the RADARSAT family of C-band SAR missions. A significant part of the RADARSAT-1 archive is now free and open. RADARSAT-2 and RCM remain operational, with RADARSAT+ planned for continuity.
  - NISAR is a partnership between NASA and ISRO, with dual frequency SAR (L-band and S-band). The launch window opens in February 2025.
  - JAXA's ALOS series of L-band SAR missions include ALOS, ALOS-2 and the recently launched ALOS-4.
  - ESA's Sentinel-1 series continues operations, with Sentinel-1C planned for launch in December 2024, and -1D planned to launch in 2025. Harmony is a pair of passive companion satellites planned to fly in formation with Sentinel-1D. Sentinel-1 Next Generation is in development. ROSE-L

carries an L-band SAR instrument to complement Sentinel-1. Biomass is a fully polarimetric, P-band SAR mission, scheduled to launch in April 2025.
    - ASI's COSMO-SkyMed first generation (CSK) is still operational, with two second generation (CSG) also operational. ASI is also looking at the next generation - COSMO FUTURO. Other novel concepts, including small/micro/nano-satellite SAR constellations, are also in consideration.
    - ISRO operates the RISAT series, with RISAT-1A (C-band SAR) currently operational, and RISAT-1B to be launched in 2025.
    - DLR's TerraSAR-X and TanDEM-X remain operational. The follow-on mission, TerraSAR-FOX, is under consideration for launch around 2033.
    - VNSC has developed LOTUSAT-1, an X-band SAR mission, which will launch in 2025.
- Commercial Partnerships:
    - Synspective operates the StriX series of X-band satellites. StriX data is combined with ALOS-2 data for landslide risk assessment and disaster damage assessment.
    - iQPS's constellation of X-band QPS-SAR missions currently consists of 8 spacecraft, with a goal to have a constellation of 24 by 2028.
    - ICEYE operates over 30 X-band satellites, with the launch and development accelerating
    - MELCO is working to combine satellite data with IoT from home appliances to enable flood monitoring more accurately and quickly.
    - ASNARO-2 is an X-band SAR mission developed and operated by NEC, and was the first commercial SAR satellite in Japan.
    - RADARSAT-2 is a public-private partnership between CSA and MDA, and operated by MDA. MDA space is the prime contractor for the RADARSAT Constellation Mission (RCM). MDA is also developing CHORUS in partnership with ICEYE, which will operate in a leader (C-band) - follower (X-band) arrangement.
- Thematic Area 1: Polarimetric and Multi-frequency SAR Applications: The requirements for soil moisture, forest & biomass, wetlands, agriculture & crop monitoring and sea ice were presented. The requirements are summarised here.
- Thematic Area 2: Interferometric SAR Applications: The requirements for ice sheets & glaciers, hazards, solid earth, permafrost and oceans were presented.
- Thematic Areas 1 & 2 are working together on a white paper summarising the requirements.
- Thematic Area 3: Program and Mission Coordination: Successful program and mission coordination requires a shared understanding of the science programmatic, mission objectives, and data systems. Opportunities and roadblocks to coordination will vary depending on agency and mission objectives.
- Working Group 1: Present & Future Data:
    - The tables developed at the first working around the discoverability, task-ability, and cost, etc. of the different datasets will be revised.
    - CSA, ESA and JAXA shared their tasking and data sharing agreements.

  - Satellite Data Services introduced the Japan Disaster Charter, which is aiming for a fully automated system for satellite tasking, analysis and reporting in response to a disaster trigger. This could be expanded to the International Disaster Charter as well.
  - Ocean surface wind retrieval using SAR data is a potential future topic for the virtual constellation.
- Working Group 2: Future Imaging Systems:
  - JPL has developed a set of performance metrics for constellations, to evaluate and quantify the added value of coordination, given a set of observational goals. The tool currently focuses on an urgent response scenario for a hurricane, biomass estimation errors, and deformation mapping. This tool provides value in constellation optimization.
  - CSA has developed a Multi-Mission Ordering Planning R&D Tool, to simplify the tasking and ordering of SAR data, and evaluate the efficiency of combining multiple sources of data. The tools also have added benefits to understand interaction between existing and future SAR systems, and optimise the coverage of multiple SAR systems.
  - Additional constellation components could be considered to enhance the tools.
  - Additional capabilities could include flood mapping (surface water extent), disturbance/crop area, faraday rotation error model (need magnetic field), C-band polarimetric backscatter-to-biomass error model, and/or layover/shadow mask for visibility estimation.
  - The requirements developed by TA1&2 will be compiled to determine the scope and metrics.
- Working Group 3: Data exploration: To avoid overlap with CEOS WGCV SAR Subgroup activities, WG3 will focus on Level 2 data and related topics of interest, including agriculture, urban and oceanography applications. The type of satellite data for each case should be identified, alongside suitable models.
- The next workshop will be hosted by DLR in Spring 2027.

Table of Contents

Session 1: Opening Session

1.1 - Welcome to Saga

Yoshinori Yamaguchi (Saga Prefecture Governor) reported:

- Welcomed all to Saga Prefecture for the 3rd International SAR Workshop.
- Saga Prefecture was the first local government to sign an agreement with JAXA in 2021, working together on applications of SAR data for disaster prevention and agriculture.
- The JAXAGA School was established in 2021 in Saga under this agreement. Now, over 500 children have learned about space through the program. The microsatellite named SAGASAT ZERO, developed by high school students in Saga, was launched into space from the ISS in August 2024.
- When observing the SAR data image of Saga Prefecture and rotating 90 degrees, the shape resembles Godzilla. Godzilla has now been asked to be the 'Saga Shape Tourism Ambassador'.

1.2 - Welcome to ICGS-SAR 3rd Workshop

Futoshi Takiguchi (JAXA) reported:

- The power of SAR technology to observe the Earth has developed significantly since JERS-1 was launched in 1992.
- Now 15 organisations have gathered for this workshop, including space agencies from around the world and local commercial organisations.
- There are many new applications of SAR data, showing the vast potential of these missions.
- The purpose of this workshop is to promote scientific advancement using SAR missions, working together to achieve common goals.
- JAXA thanks the Saga Prefecture government for their support of this workshop, and everyone who helped organise this event.

1.3 - Workshop objectives

Charles Elachi (CalTech) reported:

- Thanked the local organising committee and JAXA staff for the organisation of the workshop.
- The first workshop was held in 2018 at CalTech, with the goal to help coordinate SAR missions internationally. This workshop was very successful, and followed up by a second workshop at ESA ESRIN in 2022.

- The ultimate goal is to have a network of SAR missions, to make SAR data more easily accessible and discoverable, with common formats and quality.
- Researchers would also like to get the data at no cost.

1.4 - Report on ICGS-SAR progress

Shinichi Sobue (JAXA) reported:

- JAXA has also invited Japanese commercial companies, and other Asian partners of JAXA. Thailand (GISTDA) would've also liked to join, but they are having their Thai Space Week this week.
- A number of recommendations were developed following the first workshop in 2018, including:
    - Archival, present and future data should be easily and electronically accessible with a standard and common format, at little or no cost.
    - Develop a mechanism to coordinate future data acquisition and coverage by present and planned systems, as well as ground reception and processing approaches for mutual benefit.
    - Take an optimised systems approach to the overall constellation of planned and proposed missions to explore the possible mutual benefit of the total constellation coverage and capabilities.
    - Coordinate and share common test sites and sites for calibration and validation.
- The group now includes three working groups and three thematic activities.
- The second workshop in 2022 aimed to progress the coordination further, bringing together members of the community to exchange information and discuss ways to facilitate coordination, and collaboration that maximises the benefit of present and future spaceborne SAR systems.

Session 2: Status of Working Groups & Thematic Areas

2.1 - Working Group 1: Present and Future Data

Shin-ichi Sobue (JAXA) reported:

- WG1 has previously compiled information about the number of satellite systems into two tables, illustrating the discovery and accessibility of archived data, and summarising the discovery, tasking, and access to present and future data. These tables may need to be updated.

- The group aims to enhance the current cooperative framework for virtual observation constellation, tasking and data sharing.
- International cooperation success stories are discussed to understand how the different satellites can work together to create a Virtual Observation Constellation.
- The tasking mechanism, including around sea wind observations to support cyclone observations, needs to be coordinated. An observation plan procedure should be developed, including around how the data will be provided, in coordination with meteorological agencies.

2.2 - Working Group 2: Future imaging systems

Paul Rosen (NASA/JPL) reported:

- WG2 has focused on mechanisms for coordination of observation requirements for future missions.
- The team has developed a database of missions, characteristics, timelines, observational goals, coordinating with the CEOS Database.
- Developed a quantitative experiment to demonstrate the value of this coordination, focused on L-band missions to quantify the improvement of observation products through mission cooperation and coordination.
- NASA/JPL and CSA have independently developed tools to quantify programmatic coordination. If these tools are seen to be effective, the team will look at how a more general tool for this group could be developed.
- A special session was held at IAC 2024 in Milan in October, with the broad objectives very similar to those of this workshop. The broad conclusion was that there is a need for SAR strategic development discussions.

2.3 - Working Group 3: Data exploration

Laura Frulla (CONAE) reported:

- The initial topics focused on establishing common test sites, maximising data exploitation, coordinating airborne campaigns and cross-validation, developing standards or common procedures for data processing, improving computational efficiencies and challenges, and looking at roadblocks to fusion and assimilation.
- It was identified that the WG3 activities may overlap with those of the CEOS WGCV SAR Subgroup. To avoid overlap, WG3 will focus on Level 2 data and related topics of interest, including agriculture, urban and oceanography applications. The type of satellite data for each case should be identified, alongside suitable models.

- New co-chairs have been identified to support Laura: Carlos Lopez (Universitat Politècnica de Catalunya) and Danilo Dadamia (CONAE). Other nominations for Co-chairs from other organisations are welcomed.

2.4 - Thematic Areas 1 & 2: Polarimetric & Interferometric SAR applications

Cathleen Jones (NASA/JPL) reported:

- There is a lot of overlap between the PolSAR and InSAR activities, and hence TA1&2 have coordinated their work closely.
- Since the last workshop, the team have reviewed the observation requirements for current, near-future, and next generation SAR systems & coordination activities.
- A more extensive and detailed White Paper on gaps & coordination activities has been developed, with input from leading scientists from 10 scientific disciplines covering land, cryosphere, and ocean applications where SAR data plays a key role. This is intended for peer-reviewed publication, and built on the recommendations from 2022 ICGS-SAR Workshop plus the IGARSS 2021 TA1/2 paper.
- Each science discipline was asked to consider the state of the art & gap analysis of limitations encountered using today's SAR missions, suggestions for current and near future SAR missions and coordination activities (2025+) that address some of the shortcomings, and suggest novel mission concepts which could resolve key uncertainties.

2.5 - Thematic Area 3: Program and Mission Coordination

Gerald Bawden (NASA) reported:

- The vision is for a fully optimised & coordinated international SAR constellation.
- This encompasses a number of areas:
    - Data availability: improving data access and availability.
    - Data analysis: collaborative analysis platforms and tools, such as the Multi-Mission Algorithm and Analysis Platform (MAAP).
    - Product generation: develop higher level products, harmonising data from across different missions.
    - Calibration / Validation: cross-agency calibration of SAR missions, including through SARCalNet proposed by CEOS. Support science applications by well defined calibration targets.
    - Ground Segment: downlink of mission data from other agencies, and data archive mirroring.

  - Mission / Hardware: jointly developed SAR missions with integrated hardware.
  - Commercial sector: an opportunity to collect data for specific observational needs.
- Successful program and mission coordination requires a shared understanding of the science programmatic, mission objectives, and data systems.
- Opportunities and roadblocks to coordination will vary depending on agency and mission objectives.

Session 4: Space Agency SAR Activities and Plans

4.1 - CONAE

Laura Frulla (CONAE) reported:

- CONAE has two operational ground stations, in Cordoba and Tierra del Fuego. A new station in Antarctica is under development.
- A number of education and capacity building programmes are run throughout Argentina, including a PhD programme on Geomatic and Space Systems and a university degree on Applied Geomatics.
- SAOCOM-1A and -1B are both operational L-band missions. SAOCOM-2 is planned for launch in 2029, to provide continuity for SAOCOM-1 observations.
- SABIA-Mar is under development, with launch planned for 2027, focusing on ocean studies (optical).
- SARE missions will be SmallSats flying in formation, launching from 2026.
- A number of SAOCOM Level 2 and derivative products are available, including Pauli decomposition, land cover classification, soil moisture map and radar vegetation index. These support agriculture applications, in particular yield and anomaly maps for soybean, wheat, maize, sunflower and sugar cane.
- SAOCOM data can be accessed through the catalogue (for existing data), via ‘one-click’ registration, or through the ESA Third Party Missions Announcement of Opportunity.
- A passive companion satellite is planned for SAOCOM-2, to intensify Antarctica monitoring and strengthen interferometric capabilities.

Discussion

- Shin-ichi Sobue (JAXA) noted that JAXA would like to coordinate with CONAE regarding the SAOCOM-2 companion satellite.
- Paul Rosen (NASA/JPL) thanked Laura and team for providing their observation plans for the WG2 analysis.

Session 3: Keynote Addresses

3.1 - SAR Remote Sensing for Land Applications

Thuy Le Toan (CESBIO/GlobEO) reported:

- SAR observations of land surfaces can provide information ranging from a detailed local focus to a global view, from near real-time information to long-term archives, available to quantify changes and understand the causes of these changes, at the scale where the changes are occurring. The ultimate goal is to take adaptation and mitigation measures to reduce adverse effects.
- SAR data can be utilised to support actions to reduce GHG emissions, inline with the CEOS Roadmap for Agriculture, Forestry and Other Land Use (AFOLU).
- Estimates of above ground biomass (AGB) can be mapped with low frequency SAR data. Wall to wall mapping with repeated measurements over multiple years is needed to quantify changes in carbon stocks from deforestation and regrowth.
- The Biomass mission was proposed to ESA in 2005, to respond to the need for low frequency SAR.
- Global biomass maps over tropical forests show large errors, using L-band and C-band SAR, plus optical and lidar data. At P-band SAR, no saturation is observed, but the ground concentration reduces the sensitivity of the backscatter to ABG.
- Biomass will use innovative SAR tomography techniques to map the 3D structure of tropical forest. The canopy layer (for ABG) and ground layer (for DEM) will be isolated via tomography.
- For carbon loss due to deforestation, AGB change from Biomass can be refined and timely assessed by combining it with forest cover change from SAR data with dense time series.
- Synergy of SAR sensors is needed for comprehensive monitoring for forest cover:
    - P-band SAR (Biomass) provides a unique capability to tackle the issue of high AGB in tropical forests,
    - L-band SAR (ALOS 4, NISAR) provides higher resolution and higher sensitivity in the lower range of AGB (< 100 t/ha).
    - C-band SAR through Sentinel-1 provides a denser time series for finer temporal resolution of forest area loss, to improve the biomass disturbance product.
    - P-, L- and C-band can together measure AGB, AGB change and quantification of loss by forest degradation and quantification of regrowth.

- 17% of anthropogenic methane emissions comes from rice crops. One solution is to implement water management practices, including Alternate Wetting & Drying.
- SAR data is used to map rice fields, crop growth stage and water management. Mapping and monitoring of rice growth using SAR data is most effective with Sentinel-1 due to the temporal resolution. Meanwhile, L-band SAR penetrates through rice plants to monitor the inundation level.
- The regular spacing of Japanese rice plants can cause issues with L-band data.
- Polarimetric L-band ALOS-2 PALSAR-2 data has been used for the detailed characterization of water regimes. However, the growth stage of the rice also needs to be known.
- The involvement of users, stakeholders and commercial sectors is necessary to bring the research potential to an effective use of SAR (and in general EO) data and products.

Discussion

- Charles Elachi (CalTech) asked how the water regime impacts the methane emissions from rice crops.
- Thuy noted that the methane emissions are due to the decomposition of organic matter without oxygen. If farmers remove the water during certain days, the decomposition will stop. L-band SAR allows for the detection of flooded fields.
- Ake Rosenqvist (JAXA) asked about the significance of the polarimetric nature of Biomass. Is it just for atmospheric correction, or is polarimetric data planned to be used within the mission?
- Thuy noted that it is primarily for atmospheric correction, however it is also advantageous to have polarimetric data for PolInSAR applications.

3.2 - Social Economic usage of SAR and EO missions

Shunsuke Managi (Kyushu University) reported:

- Publishing the encyclopaedia of Energy, Natural Resource and Environmental Economics. Many chapters mention the use of satellite data for economic analysis.
- Climate, biodiversity and human society are coupled through dynamic interactions across many scales.
- The UN is starting to look beyond GDP to measure human well being, incorporating planetary health. This is the background behind the Inclusive Wealth Report 2024.
- The Global Sustainable Development Report 2023 included information about inclusive wealth & natural capital. These indicators should be included in the next Sustainable Development agenda.

- Spatial data, combined with personal data, can have a precise understanding of a population's well being.
- It is important to understand what infrastructure and government programmes can improve a population's well being - looking beyond GDP.
- Corporate companies are also facing the impact of environmental, social, and governance (ESG) principles. Satellite data can help show the impacts of a company's actions.

Discussion

- Charles Elachi (CalTech) questioned whether policy makers understand the value of satellite data for decision making.
- Shunsuke recognised that while they have no idea how the data is processed and values calculated, they understand that satellite data can help view local impact. The Japanese Environment Minister wants to understand the change at a prefecture level, not a national level, which is what the IPCC report provides.
- Ake Rosenqvist (JAXA) noted that in Japan, there has been a lot of discussion about open data policies, in particular for the tax funded public missions. Is there an understanding about the value of open data policies?
- Shunsuke noted that the government recognises the benefit is bigger than the cost. With Japan's open data policy, academia, commercial and governmental can all benefit, in particular at a smaller scale. This adds new value to the data, and expands the applications.

Session 4: Space Agency SAR Activities and Plans (cont.)

4.2 - Collaboration with the Committee on Earth Observation Satellites (CEOS)

Guennadi Kroupnik (CEOS Principal for CSA) reported:

- CSA hosted the CEOS Plenary on October 22-24 in Montreal, as CSA was the CEOS Chair for 2024. UKSA will chair CEOS for 2025.
- The objectives of this group overlap with the objectives with CEOS. Coordination between the two organisations was discussed throughout the last year.
- CEOS has a number of activities, spanning across 5 Working Groups and 8 Virtual Constellations, as well as many other teams.
- At the recent CEOS Plenary, decisions included:
    - 38th Plenary Statement renewing CEOS Members commitment.

  - Standing up a new Biodiversity Study Team, following the work of the Ecosystem Extent Task Team.
  - CEOS Plenary endorsed the CEOS Analysis Ready Data Strategy 2024.

- Work to demonstrate the use of satellite data to map ecosystem extent has identified that multiple sensors are needed to deliver the best results.
- To avoid confusion and ensure coordination, ICGS-SAR and CEOS should ensure periodic interactions between ICGS-SAR and CEOS at different levels to ensure mutual awareness of ongoing work.
- Key topics identified for interaction include open data policies, integration of SAR with other data types, and coordination of work including CEOS-ARD SAR efforts and WGCV SAR Subgroup.

Discussion

- Paul Rosen (NASA/JPL) asked whether the activities of this group were mentioned at CEOS Plenary.
- Guennadi confirmed that it was mentioned, and there was an explicit desire to integrate the activities.
- Shin-ichi Sobue (JAXA) recognised that JAXA is the current Strategic Implementation Team (SIT) Chair of CEOS, who have agreed to continue the coordination.

4.3 - CSA

Guennadi Kroupnik (CSA) reported:

- The RADARSAT family has been flying since 1995. A significant part of the RADARSAT-1 archive (17 years) has recently been opened. The Government of Canada will process these images to CEOS-ARD standards, which will then be available freely and openly.
- CSA partnered with MDA for RADARSAT-2, which remains operational.
- The RADARSAT Constellation Mission (RCM) captured its one-millionth image of Earth on March 30 2023, a little more than three years after the start of its operations.
- The RCM National Land Mosaic at 30m resolution for all of Canada was recently produced. Circular polarisation has proven to be very effective for a wide array of applications.
- RCM data continuity was announced last year, with $1.012 billion of investment for the RADARSAT+ programme. This includes funding for a replacement satellite (RCM-R) to enhance the resilience of the RCM, as well as funding for the definition of a next-generation satellite system to maintain Canadian capabilities.

- RCM-R will be developed and deployed as soon as possible. The next-generation system will be deployed in the mid 2030s.
- RADARSAT+ also includes a free and open data policy, as well as new and expanded international partnerships. Acquisition of commercial data is also an important part of the strategy.
- Nordic countries, and NOAA, are the most prominent users of RCM data.
- CSA's collaboration with JAXA will be expanded to include ALOS-4 and RADARSAT+ as well.
- RCM increased the coverage frequency of sea-ice areas following the Sentinel-1B anomaly at the end of 2021, starting in February 2022 with a daily revisit. This was also supporting the International Ice Charting Working Group (IICWG).
- In 2022, CSA upgraded its contribution to the Hurricane Watch program, both quantitative and qualitative. This new acquisition method has increased the occurrence of hurricanes eye hits.
- CSA participates in the International Charter Space and Major Disasters, and 1990 RCM products have been delivered so far in response to 233 events.

Discussion

- Charles Elachi (CalTech) noted a number of universities use RCM data. Do they have to go through government agencies to gain access?
- Guennadi noted that universities can work directly with CSA. Some also have access through NASA.
- Makoto Higashi (ICEYE) recognised that RADARSAT started with a very clear mandate, focusing on ice, maritime transport, and maritime domain awareness (MDA). Have other governments learned from CSA's experience, in particular as the program has evolved?
- Guennadi acknowledged that MDA is still a core application for RADARSAT, however the methods are constantly improving, especially with the co-location of SAR and AIS payloads on the same spacecraft. CSA collaborates with JAXA, ESA and others on MDA. The RADARSAT applications are constantly growing, with six Canadian government departments now expert users of EO data, who have operational services and applications which depend on EO data. These departments are also interested in other wavebands, and interested in combining other sensor types.

4.4 - NASA

Gerald Bawden (NASA) reported:

- NISAR is a partnership between NASA and ISRO, with dual frequency SAR (L-band and S-band).
- In January 2024, an issue with the reflector was identified, and hence the reflector was removed and returned to California. It has now been reintegrated with the satellite in India.
- The launch window opens in February 2025.
- L-band SAR measurements will be collected across all land masses, at different resolutions. S-band measurements will be systematically collected across India, as well as a number of science targets. L-band will always be co-collected with S-band.
- NASA will publish the Jupyter Notebooks with the algorithms used to develop the Level 3 & 4 products, part of the Open Science initiative.
- An 'Urgent Response Tasking' initiative has been established, which takes advantage of USGS notifications to task NISAR to collect data for earthquakes and volcanoes worldwide, and expedite the downlink and processing.
- The tasking will also allow for the collection of data over the ocean, including for oil spills or hurricanes, as they may not be covered with the regular science observation plan.
- Urgent Response data can be requested through NASA's Disasters Response Coordination System, or through NISAR Credentialed Agency Members (USGS & NOAA). Agencies that demonstrate the need for NISAR Urgent Response data multiple times a year and are able to directly process/analyse SAR/InSAR data/products may request to become credentialed.
- The Surface Deformation & Change (SDC) study has been paused, waiting for NISAR to launch.
- AIRSAR-NexGen will be an airborne SAR platform to maintain current capabilities of UAVSAR.
- Observation Products for End-users from Remote sensing Analysis (OPERA) aims to provide free and open Analysis Ready Data (ARD) products designed for science and application stakeholders. OPERA is spearheading an innovative model within NASA that goes beyond a single mission (Landsat 8/9, Sentinel-1/2, NISAR) to develop multiple product lines.

Discussion

- Charles Elachi (NASA/JPL) noted that all NISAR data will be available through Alaska Satellite Facility (ASF).

- Gerald added that the launch date for NISAR will be decided jointly between NASA & ISRO. It will be 2-3 months after the launch of the GNSS satellite, which is currently scheduled for launch in December.
- Ake Rosenqvist (JAXA) noted that OPERA NISAR products are now CEOS-ARD compliant.

Session 3: Keynote Addresses (cont.)

3.3 - Japanese space policy and SAR satellite constellation

Seiko Shirasaka (Keio University) reported:

- Seiko is trained as an Aerospace Engineer, and is a committee member of Japan's National Space Policy. He is also a co-founder of Synspective.
- Synspective was established to support the national R&D 'ImPACT' program.
- The Japan Space Policy update was commenced in response to the March 2011 earthquake and tsunami disaster. Other factors influencing the update include national security, technological advances and sustainability.
- The Nankai Trough earthquake is expected to hit sometime within 2025-2045, with a probability of 70-80%. Information on the damage will be needed within 2 hours to form an appropriate response.
- The Space Policy Update includes an update of the Basic Plan on Space Policy (last updated in 2020), and two new initiatives: Space Security Initiative and Space Technology Strategy.
- As part of the Basic Plan on Space Policy, Japan intends to:
    - Nurture policies that anticipate the implementation and commercialization of security, space science, exploration and other missions
    - Strengthen technological development based on the space technology strategy
    - Strengthen international cooperation
    - Pursue strategic development and support of internationally competitive companies
    - Strengthen the role and functions of JAXA as a core agency for space development
    - Ensure the effective and efficient use of human, financial and other resources
- The Space Security Initiative has two primary objectives: to promote the peace and prosperity of Japan and the safety and security of our citizens through outer space; and maintain the stable use of and free access to outer space together with our allies and like-minded countries.

- Increased resolution (both temporal and spatial) was identified as crucial for a number of applications. A SAR constellation was also identified as important.
- A demonstration project for expanding the use of small SAR satellite constellations was funded through the Cabinet Office of Japan, for about $20M / year for 2022-2024.
- JAXA will host the Space Strategy fund, with themes defined on the space technology strategy. A total of $6.5B will be provided over ten years.
- In the FY2025 budget request from the Ministry of Defence, 323.2 billion yen ($2B) was allocated for the construction of a “satellite constellation”, which will be launched in FY2025, and operational from FY2027.
- JAXA leads CONSEO - the Consortium for Satellite Earth Observation, which has a wide range of members, and inputs to the committee of national space policy in Japan.

Discussion

- Makoto Higashi (ICEYE) recognised there is not enough emphasis on the criticality of the ground system to support the space segment. Improving the ground system can lead to improvements in latency and allow for near-real time operations.
- Ake Rosenqvist (JAXA) highlighted the importance of distinguishing between public missions and private companies. The two regimes are complementary, and serve different purposes. It is also important that Japan looks at free and open data to contribute to global issues.
- Seiko noted this has been discussed with board members, however the government wants to focus on the commercial area. The board recognises the importance of Japan’s role in L-band SAR missions, in particular to support X-band SAR startups. Seiko is advocating for the government to maintain JAXA’s role, and add the commercial area on top.
- Charles Elachi (CalTech) noted the 2 hour requirement will be challenging. To achieve this, international cooperation and cooperation with the private sector will be important.

Session 4: Space Agency SAR Activities and Plans (cont.)

4.6 - JAXA

Yoshihisa Arikawa reported:

- The ALOS series of L-band SAR missions include ALOS, ALOS-2 and the recently launched ALOS-4.

- ALOS-4 has wider swaths across Stripmap, ScanSAR and Spotlight mode in comparison to ALOS-2, while maintaining the same resolution. ScanSAR for ALOS-4 is four times wider than the equivalent observation from ALOS-2.
- The first PALSAR-3 observation was conducted during July 15-17, 2024, observing a 200 km swath with 3 m resolution. The Amazon rainforest was also observed with 10 m resolution and 200 km swath width, and Paris, France was imaged in Spotlight mode with 1 m × 3 m resolution. A sample of a full polarimetric SAR image with 6 m resolution was also taken over Vietnam, which will be observed globally once per year.
- Interferometric SAR between ALOS-4 PALSAR-3 and ALOS-2 PALSAR-2 was also demonstrated. More frequent and long-term monitoring will be possible by combining ALOS-4 observations with ALOS-2's future and past observations.
- Calibration and validation of PALSAR-3 products is ongoing, and will continue until January 2025.
- Global observations planned incorporate full polarimetry observations and observations of selected regions for several topics (forest, agriculture, polar/ice, land deformation, etc.). Global baselines will be produced at 6m (full pol) and 10m (dual pol) resolutions once per year.
- CONSEO is planning drills on disaster observation and data utilisation to identify the issues and future goals of cooperation between public and private SAR/optical satellites. JAXA hopes to share the information with the global community at a future workshop.

Discussion

- Makoto Higashi (ICEYE) asked whether the Ka-band downlink has issues with rain attenuation.
- Yoshihisa noted that JAXA has two ground stations, and also uses a private antenna service. A decision is made on which station to use based on meteorology conditions.
- Nuno Miranda (ESA) asked about the data policy for ALOS-4.
- JAXA is still discussing with the Japanese government, but the ALOS-4 data policy will be the same as that for ALOS-2 until 2027. Then, the government will reconsider.

4.7 - ESA

Martin Suess reported:

- ESA has three categories of missions: Science missions - to demonstrate new techniques, Copernicus missions - for operational services, and Meteorology missions - together with EUMETSAT for meteorological applications.

- Sentinel-1 is a C-band SAR with dual polarisation, with a 6-day revisit with two satellites in orbit. Sentinel-1A has been in space for over 10 years, however Sentinel-1B failed late in 2021. Sentinel-1C is planned for launch on 3 December 2024, on Vega-C. Sentinel-1D will follow in 2025.
- Sentinel-1 Next Generation is also in development, which will ensure continuity and expansion of the service. The goal is to close the north pole gap, with latitude coverage from -80 to 90 degrees. The revisit will be 3 days globally, and 0.5 days for arctic and sea ice.
- To complement Sentinel-1, Harmony will carry a passive SAR and a multi-view thermal infrared instrument. Two formations will be flown: cross-track interferometric phase, and stereo phase. Two Harmony spacecraft will be flown in formation with Sentinel-1D.
- ROSE-L will fly in the same orbit as Sentinel-1, but will carry an L-band SAR instrument.
- Biomass is a full polarimetric, P-band SAR mission, scheduled to launch in April 2025. It will have observation capabilities with interferometric SAR and tomographic SAR.

Discussion

- Paul Rosen (NASA JPL) asked about the ground system for ESA's SAR missions.
- Nuno Miranda (ESA) noted that, for ROSE-L, ESA will use Ka-band, and will not use Europe ground stations. For Sentinel-1, ground stations across Europe are used to facilitate real-time applications. ESA is aiming to make Sentinel-1C available 2.5 months after launch.
- Ake Rosenqvist (ESA) asked whether ROSE-L will have support for quad polarimetric observations.
- Martin noted ROSE-L has a quad-pol mode, but it might not be operating all the time. The operation plan is still to be determined.

4.8 - ASI

Luigi Dini reported:

- COSMO-SkyMed first generation (CSK) is still operational, with two second generation (CSG) also operational. ASI is also looking at the next generation - COSMO FUTURO.
- ASI is also supporting other novel concepts, including small/micro/nano-satellite SAR constellations.
- Focus is on reducing latency, in particular for disaster risk management and national security.
- SAOCOM satellites complement the CSK and CSG satellites, operating in the same orbit.

- ASI is funding a Phase-A study for a national L-band SAR mission, which aims to be in synergy with other L-band missions.
- GEOSAR is a concept for a Geosynchronous SAR mission, enabling super-continental access.
- Platino-1 (PLT-1) is a small satellite carrying an X-band SAR, with launch planned for the end of 2025. The 12-month Phase-1 involves formation flying with CSK and CSG.
- RODIO (Radar for Earth Observation by synthetic aperture DIstributed on a cluster of cubesats equipped with high technology micro-propellers for new Operative services) will be a series of CubeSats with receiving-only X-band SAR instruments able to collect bistatic echoes exploiting PLT-1 as an opportunity illuminator.
- SATURN (Synthetic AperTure radar cUbesat foRmation flyiNg) will be a demonstration mission of a mini-swarm of 3 CubeSats in close formation on a LEO SSO, incorporating Multiple-Input-Multiple-Output (MIMO) technology for EO.
- IRIDE NIMBUS-SAR will be a twelve satellite constellation, and will aim for 6-day coverage of the Italian landmass.

4.9 - ISRO

Nilesh M. Desai reported:

- RISAT, a C-band SAR mission, was launched in 2012. This was followed by RISAT-2B, an X-band SAR, and now RISAT-1A & -1B (C-band SAR).
- CH-2 SAR was a demonstration mission for dual frequency SAR (L & S band SAR). NISAR, dual frequency L & S band SAR, will be launched next year.
- RISAT-1A is a repeat of RISAT, and CEOS-ARD compliant products are now available to users.
- RISAT-1B will launch in 2025, to continue the C-band SAR missions.
- NISAR will use the novel SweepSAR concept to take high resolution (6 m), wide swath (240 km) SAR imagery. Polarimetric and interferometric ARD products will be generated operationally.
- The Chandrayaan-2 dual frequency SAR is continuing to provide good images of the lunar surface. Launched in 2019, it is expected to operate until 2027.
- ISRO has also developed various Airborne SAR sensors, across various wavelengths from P-band to X-band.
- ISRO is aiming for many of their SAR products to be compliant with the CEOS-ARD specifications.

- ISRO's data is disseminated through Bhoonidhi. By the Indian government's data policy, all data at resolution 5m or more is available freely for all.
- ISRO has established permanent and campaign mode calibration sites to perform radiometric, geometric and polarimetric calibration of space borne and airborne SAR sensors.

4.10 - DLR

Elizabeth Nuncio Quiroz reported:

- TerraSAR-X and TanDEM-X have been in orbit for 17 and 14 years respectively.
- The HRWS mission was stopped in 2022, following Phase-0 and Phase-A studies. DLR is now developing plans for TerraSAR-FOX, which is currently in Phase-0.
- TanDEM-X is now in the '4D' mission phase - adding time as a new information component to capture changes over time. The DEM Change Maps compared the edited DEM to the global DEM to create change indication masks.
- The fuel on board TanDEM-X is currently projected to last until 2028, and until 2031 for TerraSAR-X, however battery degradation is the main concern.
- DLR is developing methods for mapping 3d forest structures by fusing lidar and SAR data from TanDEM-X, GEDI, and Biomass to assess changes in forest height and biomass.
- Joint operations between TanDEM-X and Biomass aim to develop a global prototype algorithm for hectare-scale forest biomass estimation, conduct large-area assessments of forest biomass, and integrate the algorithm into ESA's Multi-mission Algorithm and Analysis Platform (MAAP).
- TerraSAR-X and TanDEM-X are contributing missions for the International Charter Space and Major Disasters, as well as the GEO Geohazard Supersites and Natural Laboratory (GSNL) initiative supported by CEOS Working Group on Disasters.
- The MOSAIC receiver on-board of TerraSAR-X and TanDEM-X and the Spanish PAZ mission have experienced interference issues. Airbus is developing a patch to resolve the issues, which will hopefully be uploaded to the satellites in early next year. This evolution is of interest for several satellites also carrying the MOSAIC instrument.
- The national requirements for the next German SAR mission have been collected. The mission will target civil sovereign needs, including ground movement monitoring, infrastructure monitoring, 3D/4D change detection, and DEMs.
- Phase 0 and Phase A for the new mission have been funded, and will run until the end of 2026. Aiming to launch around 2033.

Discussion

- Ake Rosenqvist (JAXA) asked with what temporal frequency will the DEM change maps be generated.
- Elizabeth noted that this is no longer part of the background mission, and the satellites can be tasked to cover a specific region if there is a need. Edits to the global DEM are done every orbit if there is capacity.

4.11 - VNSC

Vu Anh Tuan reported:

- The LOTUSAT-1 project is focused on disasters and climate change countermeasures, and includes three aspects: satellite and technology development, facility development and capacity building.
- LOTUSAT-1 is an X-band SAR mission, with resolution 1-16m. The data will be available freely for government users.
- A new facility was built for the project, and was completed six months ago. The facility includes the mission operation centre, R&D centre, satellite antenna and more.
- Launch of LOTUSAT-1 is scheduled for February 2025.
- Data will be distributed by VNSC, and can be ordered through the website. It is not yet clear if foreign governments will have to pay to access the data. VNSC is working with the government to try and make the data free for all for research.
- Five application areas will be focused on: disaster management, forestry, planning, agriculture and environmental management. Typhoons have had a significant humanitarian and economic impact on Vietnam, and hence disaster management is the first priority for LOTUSAT-1.
- VNSC also plans to develop a series of small and mini satellites.

Session 5: Commercial partnerships

5.1 - Introduction & objectives

Shin-ichi Sobue (JAXA) reported:

- Invited a number of local SAR commercial companies, as well as MDA Space from Canada, to present their capabilities and discuss with international space agencies.

5.2 - Synspective

Motoyuki Arai reported:

- Synspective's mission is to create a new infrastructure that enables the next generation to understand our Earth and achieve a resilient future.
- Synspective was established in 2018.
- Their satellites are the StriX series, with five launched to date. StriX-alpha has already been deorbited, and StriX-beta is only used for experimental purposes.
- StriX has staring spotlight mode (resolution 0.25 x 0.46 m) and strip map mode (resolution 3 x 3 m, swath 20-30 x 250 km).
- The most popular product is land displacement monitoring with InSAR, as is the disaster and environmental products.
- StriX data is combined with ALOS-2 data for landslide risk assessment and disaster damage assessment.

5.3 - iQPS

Shunsuke Onishi reported:

- QPS-SAR is an X-band SAR satellite, with up to 0.46 m resolution. The platform is equipped with thrusters, to deorbit the satellite at the end of the mission.
- By using inter-satellite communication, imagery can be delivered within 10 min.
- To date, iQPS have launched 8 small SAR satellites. The plan is to have a 24 satellite constellation by May 2028, with a final goal of 36 satellites to achieve imagery every 10 min.
- An API is provided to integrate the QPS-SAR data into user applications.
- iQPS provided emergency observation of the Mogami River following heavy rain in July 2024.
- They are looking at research and development for L-band SAR small satellites, in cooperation with JAXA.

5.4 - ICEYE

Makoto Higashi reported:

- ICEYE launched the first New Space SAR satellite in 2018. Now, ICEYE operates over 30 satellites. The launch and development of satellites is accelerating, with 20 satellites launched in the last two years.
- ICEYE supported the Icelandic government when a state of emergency was declared, and the evacuation of Grindavík was ordered. InSAR products were used to map the flow of lava.

- The Brazilian, UAE, European, Ukrainian and other governments have also contracted ICEYE to support their national priorities. ICEYE also became a Copernicus Contributing Mission (CCM) in 2021 to complement the Sentinel missions.
- Dwell mode already has a track record of unlocking direct value by Defence and Intelligence customers in real-life operational use.
- Multispot imaging mode allows more targets to be imaged in each pass.
- The Gimbal subsystem onboard ICEYE satellites allows the data to be made available to the user within minutes from acquisition.

5.5 - MELCO

Nobuhiko Yamagishi reported:

- Mitsubishi Electric (MELCO) is JAXA's prime contractor for ALOS-2 and ALOS-4.
- Works with the Japan Disaster Charter to provide rapid information on disasters.
- MELCO is working to combine satellite data with IoT from home appliances to enable flood monitoring more accurately and quickly.
- MELCO is also investigating the use of satellite data for city planning. By quantifying urban characteristics through AI, the goal is to promote balanced city planning in harmony with nature.
- Smart tasking is being considered by MELCO, in particular for the Disaster Charter. The next step is to reduce human interference to determine the area of interest.
- Regarding the archive data policy, the potential of historical data can be useful for interferometry. As a user of satellite data, it would be ideal to have one open web system to search commercial images of various vendors, as it can sometimes be difficult to find appropriate images.
- Tasking data collected using the same conditions (AOI, mode, incidence angle, azimuth angle) would be useful to collect as a background observation. In addition, background observations should be coordinated such that data gaps can be filled. To detect changes caused by a disaster, recent images from before the disaster are needed to understand the change.

5.6 - NEC

Kenichi Kawasaki reported:

- NEC aims to contribute to the realisation of a sustainable society by providing value to resolve global issues.

- ASNARO-1 is an optical satellite, and ASNARO-2 is an X-band SAR - the first commercial SAR satellite in Japan.
- NEC provides across the full value chain, from satellite development and operations, to data analysis.
- Ground deformation mapping is important for many applications, including understanding the stress on pipelines.
- The Cloud Service platform will be released by the end of the Japanese financial year (March 2025), and will provide visualisation tools for ground deformation and infrastructure. An API will also be provided.

5.7 - MDA

Minda Suchan reported:

- MDA is now traded publicly on the stock market. MDA builds communication satellites in Montreal, robotics (including Canadarm for the ISS) in Toronto, and geointelligence in Vancouver (including the RADARSAT programme).
- RADARSAT-2 is a public-private partnership between CSA and MDA, and operated by MDA. MDA space is the prime contractor for the RADARSAT Constellation Mission (RCM).
- MDA CHORUS is the next generation SAR mission for MDA. It is a two satellite system, one X-band and one C-band. The C-band satellite will be leading by about 1 hr, in front of the X-band satellite (developed in cooperation with ICEYE). The satellites will be in an inclined orbit - different to the current RADARSAT polar orbit.
- Most use cases are in the maritime domain.
- With CHORUS-C, -X and RADARSAT-2, almost global coverage can be made within one day (±62 degrees latitude).
- The X-band satellite will be automatically tasked based on rapid analysis of the C-band data.
- Launch is scheduled for Q4 2025, on board SpaceX Falcon 9.

5.8 - Discussion

Shin-ichi Sobue (JAXA) raised the following questions for discussion:

- Smart tasking: For maritime domain awareness (MDA) and disaster monitoring (such as flood monitoring), wide area observations are needed to identify target areas, which can then be targeted by high resolution satellites. Has your company considered this kind of smart tasking, in cooperation with space agencies?

- Integrated data use: X-band is very powerful with high spatial resolution and good technology for small and cost-effective satellites. Space agencies have demonstrated the value of using multiple band observations for specific applications. Does your company have any vision to promote this kind of integrated use of multiple frequency SARs in cooperation with governmental agencies?

Discussion

- Motoyuki Arai (Synspective) recognised that, theoretically, it is not so difficult, however the tasking system and ground system connection, including analytics, would be the key areas for discussion. APIs can be used to connect, but the full process cannot yet be achieved automatically due to the lack of common interfaces.
- Shunsuke Onishi (iQPS) noted iQPS is already collaborating with the Japanese government, focusing on quick delivery and quick tasking. However, the total system needs development to improve access and efficiency.
- Makoto Higashi (ICEYE) suggested that the discussions should start with the end user, and understanding their goals and requirements. ICEYE data is used following analysis of RADARSAT-2 and ALOS-4 data, to gain a better insight into the target area for the customer. However, ICEYE does not know how the data is used. It would help if a serious use case is found such that requirements can be developed.
- Shin-ichi noted the concept of 'tip and cue' - using wide area observations from public satellites, and then targeting with commercial data - is a key area for public-private cooperation. The Japanese government has a big budget to support the commercial sector, however the importance of government agencies should also be highlighted.
- Kenichi Kawasaki (NEC) recognised there is also a need for collaboration for multi-frequency observations. There is no SAR constellation which can observe at the required frequency for every application.
- Minda Suchan (MDA) noted MDA are interested in smart tasking, however there are challenges in tasking across constellations. In working with ICEYE for CHORUS, MDA ran into issues regarding operational licences and regulatory constraints.
- Elizabeth Nuncio Quiroz (DLR) recognised that X-band satellite missions are now competing with telecommunication companies for the frequencies. How are commercial companies dealing with this?
- Ake Rosenqvist (JAXA) requested that, to support the scientific community with valuable historical data, commercial companies consider developing a low priority background mission to collect time series over specific areas. There is interest from the scientific community in high resolution X-band data.

- Makoto recognised that a data company has two types of assets: the collection capability, how much you can collect and timelines, and the richness of the archive. It takes a minimum of 5-10 years to build a strong archive which can be marketable. Hence, the private sector likely needs support from the public sector to collect these background observations, noting they are not immediately marketable.

Session 6: Thematic Areas

6.1 - WG2 Analysis: L-band Constellation Performance Analysis Results

Paul Rosen, Shadi Oveisgharan and Ekaterina Tymofyeyva (NASA JPL) reported:

- The study evaluates and quantifies the added value of coordination, given a set of observational goals.
- JPL has developed a set of performance metrics for constellations as part of its Surface Deformation and Change architecture study that has been a beneficial guide to coordinate multiple instruments and missions.
- The performance of constellations is evaluated based on measurement uncertainty and spatiotemporal coverage (Performance Tool), and translating the performance metrics into a measure of scientific merit (SATM + Value Framework).
- The outputs include seasonally-varying performance heatmaps and statistics, seasonally-varying heatmaps and statistics of viable observations, and overall performance and statistics.
- The SDC architecture study found that multiple satellites were required to achieve the goals.
- This study focused on the L-band missions, and looked at NISAR, ALOS-4 (with ALOS-2 mission plan as a proxy), ROSE-L (S1 mission plan as proxy), and SAOCOM.
- The Urgent Response scenario looked at NISAR, ALOS-2 and ROSE-L, targeting constellation assets to observe coastal Florida in the event of a hurricane. Adding the revisit times together shows that the minimum revisit time reduces to sub-daily, with an average of about 1 day. The maximum revisit time (worst case scenario) is about 3 days.
- Calculated the biomass estimation error for global biomass targets. With all three satellites the error was reduced from 7.7 - 19.3 Mg/ha to 5.3 Mg/ha.
- For deformation, three types of science targets were defined (Solid Earth, Geohazards, Hydrogeodesy). Desired measurement capabilities were defined for each. When combining the observations, performance improved significantly.

- Adding co-flyers to an existing flagship mission can bring down the horizontal accuracy down to a few millimetres for a single (combined) interferogram, enabling a breakthrough in studying time-varying surface motions in 3D.
- This work can be expanded if there is interest from this group. Additional constellation components could be added.
- There are alternate algorithms for deformation and biomass which could be used, and additional science performance metrics could be studied.
- The outputs from each Agency's mission planning tools can be compared to improve coordinated mission plans.

Discussion

- Charles Elachi (CalTech) noted the requirement presented earlier by Seiko Shirasaka (Keio University) for Earthquakes, that is, data needs to be received within 2 hours. Could the team do a similar analysis as done with the hurricane scenario to understand which satellites are needed to cover the region within 2 hours?
- Thuy Le Toan (CESBIO/GlobEO) noted that for CH4Rice, a 14 day revisit is currently used. Would the constellation be able to improve this? Paul noted that NISAR will cover SE Asia in L-band, and improve the revisit time.
- Paul noted that the coverage plots included all types of operating modes. Drilling down into the specific modes would require edits to the study.
- Shin-ichi Sobue (JAXA) suggested also looking at which direction the satellite looks (right/left).
- Guennadi Kroupnik (CSA) noted CSA is finishing Phase 0 for a Ku-band SAR, focused on snow-mass equivalent. These concepts could also be added to the study.

Stephane Chalifoux (CSA) reported:

- CSA contracted MDA Space to develop a Multi-Mission Ordering Planning R&D Tool. The goal is to evaluate benefits of better coordination between RCM acquisitions, the fixed Sentinel-1 acquisition plan, commercial data purchases, and eventually the successor to RCM.
- The idea is to simplify the tasking and ordering of SAR data, and evaluate the efficiency of combining multiple sources of data.
- The tools also have added benefits to understand interaction between existing and future SAR systems, and optimise the coverage of multiple SAR systems
- The project is still underway, with a first complete prototype available. Additional features and bug fixes are underway, with completion planned by the end of this year.

- Looking to hear if this kind of tool would be valuable for this group.

6.2 - TA1: Polarimetric and Multi-frequency SAR Applications

Ake Rosenqvist (JAXA) reported:

- TA1 & TA2 have developed a white paper on observation requirements for current, near-future and next-generation SAR missions.
- This session will cover the science requirements for certain applications of polarimetric and multi-frequency SAR data.

6.2.1 - Soil Moisture

Laura Frulla (CONAE) reported:

- High spatial and temporal resolution is needed for soil moisture due to high variability.
- Long wavelength, polarimetric SAR data is required.
- By combining different acquisition times and using interferometric SAR and tomography, surface deformation (e.g. due to water extraction) and vegetation height can be measured.
- Current missions include Sentinel 1, RCM, ALOS-4 and SAOCOM-1, alongside a few UAVs. Future missions include NISAR, ROSE-L and TanDEM-L satellites.
- The current temporal resolution is currently too low for certain applications.
- Global soil moisture estimates can be provided by combining L-band data for areas with vegetation and dense vegetation, C-band for areas with sparse to no vegetation and X-band for areas with no vegetation
- The suggestion for future, novel missions would be to have a constellation of four full polarimetric SAR satellites operating at L band, with a 3-4 day repeat cycle and 5-10 m spatial resolution.
- Passive companion satellites could help to provide estimates of subsidence in agricultural areas, reducing economic and environmental risks, and promoting sustainable agricultural practices. This would help provide detailed information on vegetation structure and identification of subsurface features by using SAR tomography and 3D profiling.
- CONAE has a telemetric sensor network for in situ measurement of soil moisture, to validate SAOCOM data products. The in situ data products are available for use by contacting CONAE.

Discussion

- Nuno Miranda (ESA) noted that calibration is limited by the system. Perhaps an error bar should be associated with a dataset, so when combining datasets, each can be weighted appropriately.

6.2.2 - Forest & Biomass

Paul Siqueira (UMass) reported:

- SAR is a big game changer for estimating biomass on a global level. Multiple observations are important to improve the accuracy of the estimates.
- Dense time series of free and open C-band data from Sentinel-1 have changed the way that time-series can be used for forest characterization (RCS time series, interferometric coherence.
- A dense time-series of spaceborne quad-pol is needed to better understand the use of Polarimetry and PolInSAR in Forest Characterization and Biomass Estimation. This is an opportunity for ALOS-4 and NISAR.
- Budgetary constraints are an ever-present problem, and community development and outreach will be critical for growing support for these types of missions.
- The challenge for the current and near future of SAR is in learning on how to make best use of these observing systems, noting the growing data volumes from these complex missions. This should be through data fusion (polarimetry, interferometry, multi-frequency, etc.), bringing algorithms to the data rather than data to the algorithms (cloud computing), and harnessing machine learning.
- A follow-on P-band mission (after Biomass) will be important to ensure data continuity.

Discussion

- Shin-ichi Sobue (JAXA) noted that high temporal resolution is important, however is right or left looking more important?
- Paul agreed that consistent geometry is critical for consistent time series, however whether it is right or left looking isn't as important as consistent acquisitions.
- Martin Suess (ESA) recognised that for quad polarimetric data, observations often have a reduced swath width. For ROSE-L, the team has instead decided to degrade the resolution. Is coverage, full polarisation or resolution more important?
- Paul noted the scientific community hasn't yet determined which is more important. To date, large-scale geographic coverage for quad polarised data hasn't been available. With the new missions coming over the next 5 years, the community will be able to answer those questions. For NISAR, the dense time series of dual polarised data is preferred to lower temporal resolution quad polarised data.

- Ake Rosenqvist (JAXA) recognised it would depend on the application. For most applications, a change from 5 m to 10 m resolution would be okay. For forest characterisation, data is usually aggregated up to the hectare level, so going below 10 m wouldn't have much impact for biomass estimates.

6.2.3 - Wetlands

Ake Rosenqvist (JAXA) reported:

- The Ramsar Convention is very interested in the use of EO to support wetland inventory (location & type), assessment (condition), monitoring (changes over time), and conservation (sustained monitoring).
- Wetlands are also sources of methane and sinks of carbon dioxide, which is important for the UNFCCC Paris Climate Agreement, as well as hotspots for biodiversity, which is important for UN CBD and the Global Biodiversity Framework.
- Seasonal inundation regime, characterised by its spatial and temporal variations, is proposed as an Essential Wetlands Variable (EWV) and a prime descriptor of wetland ecosystems.
- SAR data has the capacity to detect standing water below a closed vegetation canopy. All SAR frequencies can support wetland monitoring, with sensitivity depending on the type of wetland vegetation. HH polarised data provides superior sensitivity to inundation for all frequencies.
- Fully polarimetric data is sensitive to peat and bog wetness and water table depth through polarimetric decomposition. The polarimetric phase allows for improved mapping of Wetland vegetation structure and condition (e.g. degradation). Further research is required to understand the usefulness of compact polarimetric data.
- There are a number of identified gaps:
    - L-band focuses on tropical wetlands, and there is a lack of data over temperate and boreal wetlands
    - Temporal sampling (~1.5 months) is insufficient to capture flood dynamics
    - Time series are very important. Gaps in the acquisition coverage has a severe detriment to the value of the archive
    - Systematic polarimetric observations are required for water table monitoring in peatlands
- For current missions, continued uninterrupted systematic L-band wide-swath time-series observations (DP or QP) over the world's wetlands is important. L-band observations are critical, but all frequencies are useful.

- For future missions, teams should consider adding wetlands as part of the mission objectives. Temporal revisit of about weekly would be ideal, at spatial resolution of 10-25 m. Polarimetric C-band observations are important for irrigated rice.

Discussion

- Paul Rosen (NASA JPL) asked whether the Sentinel-1 archive of VV/VH data is useful.
- Ake confirmed that these observations complement those from L-band sensors.
- Shin-ichi Sobue (JAXA) recognised that September is a busy time for disasters in Asia, hence the gaps in observations. Having both ALOS-2 and ALOS-4 in orbit will improve the gaps.

6.2.4 - Agriculture & Crop Mapping

Ake Rosenqvist (JAXA) reported on behalf of Heather McNairn:

- Accuracies needed for crop classification, to feed operational needs (not research), have required the integration of SAR + optical primarily due to lack of multi-frequency and high temporal coverage over all agricultural regions
- Machine Learning models and semi-empirical modelling have demonstrated that SAR can estimate crop bio-physical parameters including leaf area index (LAI), biomass and phenology, and can track crop development over the season.
- The greatest limitation is the limited access to multi-frequency and high temporal repeat over the regions needed to move from demonstration and to support operational needs.
- For current missions, coordination of virtual constellations to improve temporal coverages and access to multi-frequency datasets beyond research sites and localised monitoring. Agencies should consider the use of Compact Polarisation modes on current and near future missions.
- In the long term, multi-frequency observations with improved polarisation diversity beyond dual-pol (Compact Polarimetry, for example) would be ideal, with multiple frequencies on the same satellite. Different polarisations and bands can provide enhanced information.
- Temporal domain is key to success and requires that these rich data sets are available as a dense time series over large geographies.

Discussion

- Elizabeth Nuncio Quiroz (DLR) asked whether the team uses multi-modal data, including hyperspectral.

- Ake recognised that optical and SAR data are used in combination for crop monitoring. Hyperspectral data would add additional information about crop condition.
- Björn Rommen (ESA) suggested that having multiple frequencies on a single platform will be highly beneficial for many applications. L-band and C-band missions provide the large area mapping, while X-band provides more targeted observations.

6.2.5 - Sea Ice

Malin Johansson (U. Tromsø) reported:

- SAR data is used to monitor sea ice extent, concentration and type, and is provided operationally by ice centres around the arctic. The services need real time delivery of high spatial resolution, wide area coverage.
- There is currently poor Antarctic coverage, which will be addressed by NISAR.
- Distinguishing open water and sea ice can sometimes be complicated. A good noise floor is essential across all frequencies.
- Comparing L- and C-band images can help overcome ambiguities. L-band SAR coverage is especially essential during the early melt season. L-band data is also preferable for deformation.
- Data with temporal gaps of a few hours is difficult due to drifting sea ice.
- NISAR will offer simultaneous S- and L-band SAR over the Beaufort Sea, which will help showcase the usefulness of multi-frequency SAR without the need to correct the data due to drift.
- An L-band SAR constellation mission would be useful for sea ice measurements. Furthermore, simultaneous C- and L-band observations would be good, such as the tandem flight pattern for ROSE-L and Sentinel-1. Even better would be one satellite platform with C- and L-band sensors.
- RCM should use the HH+VV mode in summer over the Arctic - this is better for the melt period.
- Coordination is also needed with other sensor types including passive microwave, altimeter and optical sensors.

Discussion

- Stephané Chalifoux (CSA) asked about the potential of compact polarimetric data. Malin noted there is ongoing work looking at this.
- Paul Rosen (NASA JPL) suggested that the constellation of L-band SAR could be modelled, provided an error model could be derived. This would go for the other applications as well.

6.2.6 - Open discussion

- Have summarised the requirements from each of the applications, in a table. This can be provided as an input to the WG2 L-band study.
- Current and near future missions - most of the requirements are fulfilled. Adequate for most applications. In general, the current and near future missions are well designed.

6.3 - TA2: Interferometric SAR Applications

Cathleen Jones (NASA/JPL) reported:

- TA2 will follow a similar format to TA1 this morning.

6.3.1 - Ice Sheets and Glaciers

Eric Rignot (UCI) reported:

- Interferometric SAR (InSAR) has revolutionised the study of ice sheets and glaciers since the 1990s. Results have enabled ice sheet mass balance assessments, contributions to sea level, and identification of instabilities in West Antarctica. Projections of sea level rise by models heavily rely on these early discoveries and observations.
- There is an opportunity to revive the Polar Space Task Group (PSTG), or equivalent, for the International Polar Year in 2032.
- Currently, the grounding line of key Antarctic and Greenland glaciers is monitored using ICEYE commercial data.
- InSAR is now acquired more frequently with Sentinel-1, but coverage is limited (partial Sentinel-1 with RADARSAT-2). It has been difficult to get Antarctic coverage for RCM, ALOS-2, CSG and SAOCOM, despite many efforts.
- NISAR will do 3D mapping, detect changes over the continent, and map grounding lines. However, NISAR's long repeat cycle will miss critical grounding lines, exclude North Greenland, and cannot be phase-only everywhere.
- Recommendations for C-band missions include to maintain (and improve) existing Sentinel-1 coverage for Antarctica and Greenland and expand coverage to include ascending + descending tracks for 2D motion with phase.
- With three Sentinel-1 satellites (A, C, D), the InSAR repeat could be reduced to 4 days to cover key glaciers in West Antarctica.
- Harmony will enable 3D ice motion detection, but requires more Sentinel-1 acquisitions in ascending and descending modes.

- RCM should prioritise frames over the grounding line of fast-moving glaciers in Antarctica and provide sustained, consecutive 4-day repeat InSAR coverage for these regions.
- ALOS-2 & ALOS-4 are key missions, and should be used to collect 7-day InSAR data over critical fast glaciers with asc/desc coverage, in particular over northern Greenland.
- CSG can use the 1-day InSAR capability to maintain data collection at the grounding line of (30+) fast glaciers in Antarctica.
- ICEYE can collect time series of 1-day ascending/descending right/left looking InSAR over critical fast glaciers in Antarctica and Greenland. This is a critical capability not available from other SAR missions, and there is a potential NASA contract to continue this partnership.
- Space agencies should work together to help polar science in preparation for IPY 2032. Advances and discoveries require a fast repeat, high resolution, multi-agency constellation.

6.3.2 - Hazards

Tomokazu Kobayashi (GSI) reported:

- During the short term pre-to-post disaster period, SAR data is widely used for tropical storm winds, oil spills, flooding and geohazards.
- The first data acquisition after an event is needed ASAP to provide a quick response. Subsequent observations should be provided at short intervals to monitor ongoing hazards.
- The most significant impediment to SAR's operational adoption for disaster response is long latency in delivery of usable derived information to responders.
- Regular observations in InSAR-compatible modes are needed for pre-to-post change detection.
- Funding and maintaining processing systems providing low latency InSAR products, free of charge, is crucial for global disaster response.
- In 2015, for the Kuchinoerabu volcano eruption, the observation request was made 1.5 hrs after the eruption began. The observation was acquired about 1.5 hours later, and the data distributed 1hr after that. The InSAR analysis was completed another 2 hours later - in total it took just six hours for the data to be included in the disaster response.
- A coordinated, multi-InSAR, multi-mission disaster response system should be developed that supports both continual monitoring and imaging within hours of an event. Interagency coordination of orbits and observation plans for new missions will also be important.

6.3.3 - Solid Earth

Cathleen Jones (NASA/JPL) reported:

- Current global repeat interval spans weeks, which limits the ability to observe fast-evolving processes. Daily repeat measurements (COSMO-SkyMed, commercial SAR) exist only over selected regions (and are not free and open), and faster global routine repeat imaging is needed.
- Continuous monitoring is key for distinguishing overlapping geophysical processes (e.g., co-seismic and post-seismic fault slip, hydrological and tectonic processes). Overlap of different InSAR constellations is essential.
- 3D velocity field observations are essential for merging data from international InSAR constellations. Sentinel-1's TOPSAR mode offers diverse squint angles within burst overlap areas but lacks continuous mapping capability.
- Suggestions include increasing temporal sampling with constellations, and use closely flying radar receivers to increase line-of-sight diversity for 3D Deformation Reconstruction.
- LOS diversity can be achieved using a combination of left- and right-looking observations from ascending and descending orbits, and potentially from highly squinted geometries.
- Data quality can be improved with the use of multiple radar bands (e.g., NISAR's L- and S-band), especially in densely vegetated areas.
- Continuous monitoring is necessary, and should be achieved through daily repeat sampling with consistent geometry and wavelength from multiple satellites.
- Geostationary SAR offers daily sampling, though it sacrifices global coverage and faces issues like rotational decorrelation.

6.3.4 - Permafrost

Cathleen Jones (NASA/JPL) reported:

- Permafrost monitoring from space requires the combined use of a large set of parameters and the integration of multiple proxies and advanced data fusion strategies for assimilation into permafrost models.
- Utility of current missions for global assessment remains limited due to acquisition strategies which disadvantage high-latitude permafrost regions.
- There is a need for consistent acquisitions at pan-arctic coverage.
- For several applications, C-band with a 12 day repeat-pass is not enough. There is a need for future missions with shorter repeat-pass and lower SAR frequencies.

- Due to the diversity of the parameters studied by the permafrost community, no single SAR system can address all the needs. Permafrost monitoring requires a combination of frequencies, polarizations, acquisition strategies and modes.
- Efforts to coordinate simultaneous acquisitions of complementary SAR missions is mandatory.
- There is also a general need for SAR cal/val supersites and campaigns targeting permafrost applications.

6.3.5 - Ocean (single-pass interferometry), Non zero-baseline InSAR

Björn Rommen (ESA) reported:

- SAR effective azimuth resolution over the ocean is limited by wave motion, on the order of 100 m.
- High-resolution, wide swath (HRWS) capable SAR systems over the ocean should be operated in a narrow azimuth-beam mode, maximising the antenna gain and exploit the available resources to either increase the range resolution, minimise the NESZ (in particular for cross-polarized channels), or provide widely separated azimuth looks.
- Adding directional diversity, which is the key element in scatterometric wind retrieval, Including co- and cross-polarized channels
- Ocean sub-mesoscale (~1 km) to mesoscale (>30 km) features have lifetimes on the order of hours to tens of days. Regular cover of the sub-mesoscale by the repeat visit of any spaceborne mission is not feasible. Hence, continued algorithm developments are needed to support provision of analyses of globally sparsely sampled ocean data (using e.g. generative AI)
- High-resolution SAR ocean product validation approaches should also be developed - including perhaps the designation of coordinated super-sites.

Discussion

- Shin-ichi Sobue (JAXA) noted that JAXA is collaborating with ESA and NOAA regarding ocean vector wind observations, in particular for typhoon prediction models. The use of C-band and L-band together may need coordinated observations.
- Björn noted both wavebands would be helpful, as they can describe more features. The more satellites the better - one satellite won't be able to catch every storm.
- Nuno Miranda (ESA) recognised that his impression is that most of the SAR missions discussed are lacking ocean objectives. There is a lack of clear requirements regarding what data should be collected over oceans.

- Wave mode on Sentinel-1 is great, but not many people are using it. Some supersites should perhaps be developed to evolve ocean applications. Harmony should also improve the understanding of ocean SAR data.

6.3.6 - Topography & Tomography

Björn Rommen (ESA) reported:

- The current applications are mainly around surface deformation (reduction of volume/baseline decorrelation).
- Currently, measurements are not optimised for height.
- Dedicated missions in favour of SAR tomography or for increasing InSAR/PolInSAR height sensitivity should have:
    - Multi-pass acquisition stack collection for a single mission with controlled across-track baselines (e.g. Biomass)
    - Tandem satellite operation (e.g. TerraSAR-X+TanDEM-X)
    - Single-pass acquisition stack collection for a companion mission with controlled across-track baselines (e.g. Harmony)
    - Single-pass acquisition stack collection for interferometric cartwheel like concepts (dedicated transmitter)
- There are a number of mission concepts under development or consideration which would accommodate tomography.
- Hongtu-1 was launched in March 2023, and is the first interferometric 'cartwheel' in space. Owned and operated by Chinese company PIESAT, it is a X-band system, with 1 transmitter and 3 receiver satellites.
- North-South sensitive and 3D deformation is an active area of research.

6.3.7 - Polar Space Task Group

- One recommendation from the 2022 ICGS-SAR workshop was to Reestablish the Polar Space Task Group for an International Polar Decade.
- It is evident that SAR missions, due to their limited orbital operational duty cycle, would need coordinated efforts to ensure appropriate acquisition planning over polar and high mountain areas. The work of PSTG has been more over-encompassing in terms of the remote sensing instruments it covered (e.g. inclusion of high-resolution optical imagery).

- WMO being one of the lead organisations for the 5th International Polar Year (IPY), the coordination work of such a group or task team will contribute to international research activities within the context of the 5th IPY (and the preceding decade).
- WMO is working to finalise the Terms of Reference (ToR) – recent inputs have been provided and the final version is expected in early December.
- President of the WMO Infrastructure Commission has requested the chairs of the Advisory Group on the Global Cryosphere Watch (AG-GCW) and the Standing Committee on Earth Observing Systems and Monitoring Networks (SC-ON) to provide recommendations on the reporting structure for a new Team on Cryosphere and Polar Observations from Space (name tentative) by end the 2024, between the two Commission Structures, and with a link to the WMO Executive Council Panel on Polar and High Mountain Observations, Research, and Services (PHORS).
- A call of representatives from those groups took place on 6 November (yesterday), and a decision from the President of INFCOM is expected by January 2025. Membership will be established in early 2025, to ensure that the team has the right composition to be effective. The first meeting will be held in mid 2025.
- The team composition would strive to avoid duplication and the links to observing requirements, gap analysis and WIGOS Vision, as well as GCOS, WCRP, etc. will be established through focal points in the team or invited experts, as agreed with each entity.

6.3.8 Open discussion

- Paul Rosen (NASA JPL) asked why this is being established under WMO and not CEOS.
- Björn noted that the group focuses on the end users, to which WMO has a better connection. It was shown to be very effective in the past within WMO.
- Ramon Torres (ESA) noted there has been a significant number of agencies who have expressed interest in companion satellites. Developing separately is not efficient in terms of resources, are there any plans to jointly develop companions?
- Björn recognised that companions seem to resolve various issues, and many different technology demonstrations are coming from different agencies, all contributing different pieces. Companions are now seen as a reality which should be considered in mission planning.

Session 7: Working Group Splinter Sessions

7.1 - WG1: Present & Future Data

7.1.1 - Welcome

Shin-ichi Sobue (JAXA), Guennadi Kroupnik (CSA) & Nuno Miranda (ESA) reported:

- At the first workshop, WG1 developed a table about the discoverability, task-ability, and cost, etc. of the different datasets. This table should be revised as there have been a number of changes.
- For RADARSAT-1, the data is open, but not yet processed. It will be processed to CEOS-ARD specifications by this time next year.
- ALOS-2 data has also been partially opened, and processed to CEOS-ARD specifications.
- RCM data is partially free and open, but not everything. Public data and vetted user data is free and open, but some acquired data is not.
- TerraSAR-X has also become more open, this will have to be checked with DLR. CSK and CSG should also be revised.
- Biomass and ISRO missions are missing from the table.
- The discussion will focus on the virtual observation constellation collaborations, including emergency tasking for disasters and sea winds.

7.1.2 - Tasking & Data Sharing Reports

Stéphane Chalifoux (CSA) reported on RCM:

- CSA has an important relationship with Natural Resources Canada to provide data to users.
- RCM acquisitions are categorised into standard coverages, ad-hoc campaigns and fast tasking. Different priorities based on operational, research and development.
- Standard coverage is defined by the working group, and plans for three month periods.
- Ad-hoc campaigns have a lower priority than standard coverage, placed by authorised users.
- Fast tasking is used for emergencies - within 3 hrs the satellite can be tasked.
- SAR Toolbox within the data distribution system to simplify processing. Compact Pol decompositions are particularly popular.
- 3,200 images were compiled to make the mosaic of Canada, which is now transformed to CEOS-ARD specifications.
- The Government of Canada will process RADARSAT-1 CEOS-ARD products in the next few months. Aim in to have a 25-30 year time series of C-band data available.

- ESA-CSA data sharing is focused on sea-ice monitoring, and is part of the standard coverage background mission. CSA have supplemented the Sentinel-1 observations after the loss of Sentinel-1B.
- RCM acquisition for JAXA is focused on maritime domain awareness, which is also part of the standard coverage background mission.
- Collect data over Antarctica for the International Ice Charting Working Group.
- CSA works with NOAA to provide ocean surface wind data. NOAA are vetted users who can download the data directly.
- Upgraded the contribution to the hurricane watch program in 2022, to contribute to hurricane prediction models.
- There was a request at the second workshop for more images in the Antarctic to support calibration.
- RCM is also contributing to GEOTREES, and has finished a first test phase. The second round will start in 2025. 24 sites are being supported. This support is responding to a request that came out of this group.
- Also supporting disaster charter, where there are more and more requests for data each year. The fast tasking approach means CSA is often the first to provide imagery.
- Canada hosts mirrors of both Sentinel data (Government of Canada pulls the data) and ALOS-2 data (JAXA pushes the data).
- Access to an extensive database requires becoming a vetted user - it is relatively straightforward to get access, and CSA can help anyone interested.

Discussion

- Shin-ichi Sobue (JAXA) noted that the Japanese requirements come from government partners, who are requesting as much data as possible. They would like to use ALOS-2 plus RCM data, and are asking for an even wider ScanSAR mode, on the order of 1000 km.
- Guennadi Kroupnik (CSA) noted that, regarding tasking plans for CHORUS, CSA is waiting for it to be launched before considering how to coordinate the acquisitions.

Nuno Miranda (ESA) reported on Copernicus Sentinel-1:

- Sentinel-1C is ready for launch on December 3. The team is planning a short commissioning phase of 4-5 months, with data to be made available starting March 2025, and fully released by May 2025.

- Copernicus is a user driven program - user requirements are consolidated into the High Level Observation Plan (HLOP). A long term stable plan is developed, and disturbed only by emergency requests.
- With the loss of Sentinel-1B, the coverage has been reduced.
- International cooperation is integral to the Copernicus program. Have data mirroring arrangements with many organisations, and contingency agreements with CSA, as well as complementary tasking with CSA and ISRO.
- ESA is looking forward to new collaborations with NISAR and ALOS-4.
- The Copernicus agreement formalised the contingency plan for Sentinel-1 and RCM.
- ESA has started working with ISRO to support EOS-4 needs, with full European coverage via the Neustrelitz ground station. The data quality assessment for EOS-4 has shown an adequate level of performance, and data collection will start soon.
- By the end of 2034, Copernicus will be expanded significantly, with more missions from the expansion series.
- Data volume will increase by at least a factor of 4-6, and hence there is an urgent need to review the current data access paradigm. Will be taking advantage of the cloud and cloud native data formats. STAC catalog will be a key enabler to share the data with partners.
- The Copernicus Data Space Ecosystem (CDSE) is working on new processors and products to transfer to ZARR format. Transfer to operations will occur sometime next year, first making the data available to the users to compare and put in place the necessary migrations.
- Will reprocess the entire archive in 2026 & 2027.
- This new processor will allow for the development of NRB products compliant with CEOS-ARD specifications. Monthly NRB global mosaics will be available in CDSE.

Discussion

- Wade Albright (University of Alaska Fairbanks) asked which cloud will the data be stored in. Nuno noted it will be in CloudFerro, a European provider.
- Wade commended ESA on making Sentinel-1 free and open, which has significantly expanded the SAR user community. This policy enabled the whole community, including new space.
- Nuno noted that one of the points to consider in the reprocessing is the overall data volume. With all the layers required by the CEOS-ARD specifications, the data is huge.

The product will be developed, but the operationality is not yet clear. The GRD product will also continue to be produced.

- The redeveloped processors will hopefully also be made available so people can make their own products. Make tools available to generate ARD products on the user side.
- Gerald Bawden (NASA) noted that NISAR will also have a standard GSLC product. However, different agencies looking at different clouds, and the interoperability of these clouds can be a challenge. Can we improve the multi-mission algorithms using the cloud?
- Shin-ichi Sobue (JAXA) asked about the relationship with Euro Data Cube.
- Nuno noted this is part of the cooperation with member states, who have the capacity to put in place parallel data access for their specific needs. ESA provides the data for these programmes, including Euro Data Cube.

Shin-ichi Sobue (JAXA) reported on ALOS-2 + S1, RCM, CSK/CSG:

- ALOS-2 is still in good operation. JAXA is planning some coordination between ALOS-2 and ALOS-4, and is looking for specific applications which could use these observations. Weekly observations of quad polarimetric data may be very useful.
- JAXA has focused on coordinating with other space agencies within the Asia-Pacific region.
- ESA and JAXA are discussing the future collaboration of ROSE-L and ALOS-4.
- The observation plans for ALOS-2 and -4 are defined for a six month period, with revision every three months.
- The integrated use of Sentinel-1 C-band and ALOS-2 L-band has shown great results for many different applications. ESA and JAXA have coordinated a number of back-to-back campaigns for the two missions.
- The Japanese government is very grateful for RCM data provided by CSA. A specific area is the marine, for both ice and maritime domain awareness, but data latency is an issue.
- Sea ice monitoring is important to warn when sea ice is moving in. RCM data is used for this, alongside ALOS-2. However, the imagery is analysed manually.
- Discussing with ASI about a constellation for disaster monitoring in Japan. CSK does not participate in the disaster charter, so JAXA will establish a bilateral relationship.
- Have started a collaboration with Synspective, in particular around rice paddy fields. After the big earthquake in Noto peninsula earlier this year, the impact on this year's crop was investigated using StriX and ALOS-2 L band data. However, more high temporal X-band observations are needed.

- ALOS-2 and StriX have been used together to map potential landslide areas. It has proven challenging to overlay the two datasets.
- Coordination for disasters is already well done. Would like to expand the discussions around sea winds, sea ice and agriculture/forestry.

Discussion

- Thuy Le Toan (CESBIO/GlobEO) suggested organising some pilot campaigns to show the combination of X- and L- band data, starting from the user requirements.
- Shin-ichi Sobue (JAXA) recognised that one of the challenges is in sharing the ground observation data. For example, when working with VNSC, data from Vietnam cannot always be shared with Thailand.
- Gerald Bawden (NASA) noted a very successful example of data sharing is the Global Precipitation Mission (GPM). However SAR data is much more complex, and agencies should strive to simplify the data with higher level products. NASA's OPERA is taking Sentinel-1, Sentinel-2, Landsat, and NISAR data to produce global surface water extent. Could missions with partial open data policies be included in this as well? As the data is not released, but rather the derived products. In the name of open science, all NASA algorithms will be developed as Jupyter Notebooks on GitHub, to ensure the algorithms are developed by the community.
- Shin-ichi suggested limiting the resolution of the products to lower resolution could help with open data policies and sharing higher level products.

7.1.4 Ideas and Requests for the Virtual Constellation

Kazutaka Kumeno (SDS) introduced the Japan Disaster Charter:

- Satellite Data Services (SDS) was established in 2021, aiming to promote and expand the market for satellite services.
- Their mission is to contribute to solving global social challenges and to make a positive impact on society. One key mission is to enhance the rapid disaster response and recovery, through the establishment of the "Japan Disaster Charter System".
- The Japan Disaster Charter is a framework that utilises satellite resources from around the world to provide wide-area disaster monitoring data during initial disaster response, recovery and reconstruction. It is managed by a 24hr integrated system, combining wide-area monitoring with large satellites and agile-detailed monitoring with small satellites enables comprehensive and rapid understanding of disasters.
- The charter is currently undergoing demonstration to achieve institutionalisation and establishment of its system. Seven events have been responded to through the charter,

over two months during the rainy season. There is a high demand for SAR data due to the ability to see through clouds.

- SDS combines imagery from different satellites to fully understand the extent of the disaster.
- Having coverage across different observation times of day (LST) is important.
- Going forward, SDS would like to have a fully automated system. Currently, the collection of user requests, tasking of satellites and making analysis reports is all done manually.

Discussion

- Charles Elachi (CalTech) noted the team are working with all types of missions, both private and public. The different data formats must make the analysis hard.
- Kazutaka noted the data download is mostly automated, but tasking is the hardest part.
- This activity is done on top of the International Disaster Charter, as data is not guaranteed. Not every mission participates, making it often hard to ensure data can be acquired at the right time.
- Cathleen Jones (NASA JPL) recognised that one issue with the International Disaster Charter is the lack of automated activation to allow for rapid tasking. Most of this is possible, but it hasn't been implemented.
- Shin-ichi Sobue (JAXA) recognised the BRIDGE system which was developed by the national disaster prevention institute. Overlaying the pre-disaster data (satellite, airborne, hazard map) with the post-disaster data can be challenging as not all the data is geolocated accurately.
- Charles recognised that in a fully automated International disaster centre, there would be many different users with different requirements which would need to be accommodated.
- Gerald Bawden (NASA) noted the International Disaster Charter has a very specific mandate. End user licence agreements (EULAs) remain intact from the data provided. Commercial data can only go to the requested agencies, and can't necessarily go to the scientific community. This makes it difficult to get emergency response data for scientists to understand the interdependencies between different disasters.
- Shin-ichi recognised that to get the commercial partners involved, someone has to pay. This prototype is currently funded by the government of Japan, but more users are needed to maintain the system.

Udai Shimada (JMA-MRI) reported on Ocean Surface Wind Retrieval from ALOS-2/PALSAR-2 under Tropical Cyclone Conditions:

- Conventional scatterometers cannot observe high wind speeds, and microwave radiometers have low resolution.
- SAR can observe ocean surface backscatter even under tropical cyclone conditions, allowing the retrieval of ocean wind speeds with high spatial resolution and accuracy.
- JAXA and MRI/JMA started a joint research project in 2019 to develop tropical cyclone ocean wind products using ALOS-2/PALSAR-2.
- It is important to have observations every few hours, so coordination between satellites is necessary.
- The ALOS-2 data was able to accurately forecast the remnant of the inner eye wall of a typhoon.

Discussion

- Guennadi Kroupnik (CSA) noted Environment and Climate Change Canada (ECCC) have used C-band SAR observations for wind. Shin-ichi recognised this is already included in the CSA/JAXA agreement.
- Nuno Miranda (ESA) recognised there is likely a general lack of coordination on this aspect. Sentinel-1 is also contributing, however the community is missing the common view on who is doing what. There is also a need to understand the requirements for tasking, to develop common criteria. This could be done in a white paper, where the agencies can describe the status and next steps.
- Cathleen noted the practical implementation factor, in particular how fast a particular mission can be tasked.
- Nuno noted that meteorological agencies are often able to forecast a tropical storm's path a week in advance.
- Shin-ichi recognised this topic should be coordinated with WMO. The ocean and coastal region also provides challenges regarding data collections.

Naruo Kanemoto (Space Shift) reported on multi-frequency SAR:

- Space Shift has done some preliminary research on how to utilise L band, C band and X band SAR. It has been proven to be useful for forest monitoring.
- Priority areas include vessel monitoring, sea ice, infrastructure, agriculture/land cover, landslides, biomass.
- Integrated X- and L-band data is best (useful, commercial potential) for vessel, infrastructure and disasters. The two types of data have specific roles for each application.

- The Tip & Cue system between the L-band and X-band satellites is used for ship monitoring.
- To observe ships within 3 hrs, would need 3-4 ALOS-4 equivalent satellites to cover the full ocean. As ships move at approximately 40 km per hour, the search area is extended by a radius of 40 km every hour of delay between the initial L-band detected and the high resolution X-band imaging.
- Space Shift is working to create an algorithm to detect ships from raw data, on board the satellite, to improve real time capability.

7.1.6 Discussion and coordination of future work plan

- Shin-ichi Sobue (JAXA) noted WG1 should coordinate closely with TA1&2, to understand mission requirements.
- Cathleen Jones (NASA JPL) recognised that one large gap is that of Northern Greenland, as NISAR won't be able to image there. Hence, it is requested that JAXA provide ALOS-4 data over that region.
- Nuno Miranda (ESA) also noted mission permafrost observations, due to Sentinel-1 stopping to collect over Siberia following the loss of Sentinel-1B. Sentinel-1C should improve capacity, but Sentinel-1A is also approaching its end of life. In the case where Sentinel-1 is down to one satellite again, can this community do something to fix that gap?
- Guennadi Kroupnik (CSA) suggested that CSA and ESA could coordinate to ensure observations once per season. What is the minimum need for these observations to support GHG monitoring?

7.2 - WG2: Future Imaging Systems

Paul Rosen (NASA JPL) provided a summary of the performance tool presented earlier.

- There is nothing in the performance tool that limits it to being focused on L-band - it can handle multiple frequencies. The limitation is on the modelling side. Some modelling components may not be equally well known for all frequencies
- At the moment there are two error models: biomass and deformation. Other applications need additional error models to be developed. If the application is crop area, it is a different metric and needs its own error model.
- The inputs to the error model for biomass are speckle noise, thermal noise, backscatter time variability, calibration errors and area projection errors. Those for deformation are baseline errors, topo error, correlation noise (dependent on surface type, snow, etc), troposphere, ionosphere, etc. It is not trivial to develop a model for another application.

- For instrument performance, the tool uses several parameters as inputs, but more are probably needed. All the normal radar parameters are included: pointing, direction, modes, standard ambiguity levels.
- Regarding mission plans, many of those for SDC are derived from NISAR. But NISAR has many different radar modes - there is a lot of geographic variability, though over time the mode for each ground target stays about the same. The modes were determined by the NISAR Science Team after many years of iteration. The tool calculates where the sensor is at different times and what mode it's operating in for each observation of a ground target. No baseline variability is modelled, however some baseline error is added. Baseline variability could be included in a future version.
- Tropospheric water vapour variability is based on MODIS data.
- The Ionosphere residual model is based on WBMOD and TEC content.
- Coherence variability over time for decorrelation, in addition to models that describe surface conditions, such as snow cover, vegetation, and tree height.

Discussion

- If someone takes on the job of maintaining instrument parameters and environmental models, the community can expand the suite of science models. For example, permafrost.
- At L-Band for NISAR, a lot of ionospheric information will be derived. We could decide to keep this information and have a global ionospheric map that we can use in this analysis and other applications.
- ESA has developed some L2 error budget calculations. For Sentinel-1, they calculated error budgets with similar inputs, and the same is being done for Harmony. These can be made available and made open source, and this analysis could be a community effort. We could compare these results with the JPL performance tool.
- The performance evaluations can be helpful for identifying gaps in science knowledge, while science performance can be helpful in making the case for future missions. The approach could be expanded to justify coordination for new X-band missions. Evaluation of performance can serve as input for political/programmatic decision making.
- For the SDC study, NASA had an evaluation card with many factors (risk, cost, etc), and it was not clear that science performance was driving the final decision.
- Most missions have some different priorities, but sometimes missions have options for observation plans and architectures, and this tool can help make the decision and to optimise science capabilities from a global perspective.

- Other error models would be of interest. For Sentinel and Harmony, there are Level 2 error models. These are basic estimates, in the form of a Jupyter notebook:
    - Harmony: Deformation uncertainty, Differential DEM performance, e.g., glacier topography change (for non-zero baseline modes)
    - Sentinel-1: Rice mapping, Phase uncertainty for deformation, Soil moisture, Flood mapping, inundated area (surface water extent)
- Different algorithms for existing models for Biomass could include Thuy Le Toan's biomass error model. There is also a possibility for a model for irrigated rice. Pol-InSAR or tomography error model would be good. Someone in the group could take on the role of developing a model based on existing polarimetric data for C-band.
- Any new error models or alternative algorithms must be validated.
- Additions and refinements to existing models should include more explicit estimation of the effects of baseline error. The easiest way to do this would be to provide an orbit file with whatever baseline effects desired and use it as an input to the performance tool.
- Additional constellation components to consider are:
    - Use realistic ALOS-4 inputs rather than ALOS-2, and for this we need instrument inputs and mission plans. These can be provided in approximately March 2025, after the initial Cal/Val period.
    - SAOCOM is currently being incorporated into the analysis
    - The European Exclusion Zone for SAOCOM is needed from ASI.
    - For the ASI L-band constellations, the mission plans could be approximated based on existing missions, or we could create our own mission plans based on a description.
    - It would be good to have an actual Sentinel-1 mission plan (the current one is still notional), including Sentinel-1 C and D. This may be already published.
    - TerraSAR-FOX can be added once the mission plan is available.
    - Sentinel-1 Next Gen could also be considered.
- The team have considered, but are not including these missions now: RCM, Commercial systems such as ICEYE, and COSMO-SkyMed
- Additional science performance metrics could include soil moisture, snow water equivalent, and/or crop yield.
- A list of desired error models should be made, and tasks assigned for their development.

- For ALOS-4 is there a protocol for how ALOS-4 responds to disasters (e.g., repointing), including possible constraints? JAXA can provide this.
- "Optimised performance" should be clearly defined. Thematic areas could provide their requests/requirements and we can use these for optimising performance for a constellation of missions.

Session 8: Working Group & Thematic Area Summary Reports

8.1 - WG 1: Present and Future Data

Shinichi Sobue (JAXA), Nuno Miranda (ESA) and Gerald Bawden (NASA) reported:

- WG1 will revise the table of data availability, including new missions.
- The automated tasking of satellites for disaster applications should be explored through the Japanese prototype.
- Need to coordinate and share current methods for hurricane/typhoon tracking. This may be done through a white paper, and in cooperation with WMO.
- To improve cloud interoperability, ESA will move forward using STAC metadata for cataloguing information. This is an active development from the broader EO community, and was requested from the users. Other agencies are invited to review ESA's methodology, and consider moving forward with STAC as well.
- Surface water extent mapping with SAR, could a model similar to that used by the Global Precipitation Mission (GPM) be used to produce higher level products? For GPM, data is provided by 7 different countries, from many different satellites. A common product is developed, with a common format.

8.2 - WG 2: Future imaging systems

Paul Rosen (NASA/JPL) reported:

- The JPL performance tool provides value in constellation optimization, and the CSA tool provides value in mission planning. Possible extensions and enhancements for both tools were discussed.
- Started putting together the recommendations from the thematic area discussion, for additional capabilities:
    - Flood mapping (surface water extent)
    - Disturbance/Crop area
    - Faraday rotation error model (need magnetic field)
    - C-band polarimetric backscatter-to-biomass error model

    - Add layover/shadow mask for visibility estimation
- The requirements developed by TA1&2 will be compiled to determine the scope and metrics.
- A model validation framework and workplan will be developed.
- WG2 holds regular monthly meetings, and anyone is welcome to join.

Discussion

- Nuno Miranda (ESA) asked whether the tools will become available, or rather the outcomes be distributed?
- Paul noted that for now, it will be the latter. The team have talked about open sourcing the tool, but have decided initially to just share the output.
- Elizabeth Nuncio Quiroz (DLR) raised the issue of the protection of the X-band frequency for use for Earth observation.
- Björn Rommen (ESA) noted that space agencies are represented in the International Telecommunication Union (ITU), and these issues are being generally tracked. Within IEEE GRSS, there is a group dealing with this from the applications side.
- Franz Meyer (University of Alaska Fairbanks) noted that some data providers are protecting their data with radio frequency interference (RFI), which would be good to document and share experiences. RFI correction methods work poorly sometimes, as the standards don't work everywhere. What can we do to remove these issues?
- Guennadi Kroupnik (CSA) noted that space agencies are not authorities on frequency allocation, however they can provide technical information to national authorities.

8.3 - TA1: Polarimetric and Multi-frequency SAR Applications

Ake Rosenqvist (JAXA) reported:

- Put together an observation requirements summary table, which can be commented on here: TA1/2 Summary Tables . These tables are draft, and will be iterated over the coming weeks.
- The temporal resolution refers to the observations required (e.g. monthly to make an annual map).
- The table describes the 'holy grail' requirements - looking at the long term goals. Short term goals could also be considered.
- The recommendations from this table will be integrated into the white paper.
- The white paper will be finalised early in 2025, with a fairly complete set of recommendations for input into WG1 & 2.

Discussion

- Nuno Miranda (ESA) suggested latency should also be considered - what is needed for operational work? Latency requirements are driven by end objectives, operational vs scientific.
- Ala Khazendar (NASA JPL) suggested decoupling the requirements into threshold and goal values.
- Ake noted the cells could also be colour coded based on which requirements are met.
- Nuno recognised that for each parameter, there is a lot more detail required, including which product level. This table could also be brought back to the mission requirements table.

8.4 - TA2: Interferometric SAR Applications

Cathleen Jones (NASA/JPL) reported:

- TA2 will add to the TA1 table, with some additional InSAR relevant columns.
- Will coordinate with TA1 to finalise the white paper, including the recommendations presented by the different applications area experts.
- There was a SeaSAR meeting last year, where the topic of ocean super sites were discussed. The NISAR team was provided with a list of supersites, to help with tasking for ocean observations.

Discussion

- Ake Rosenqvist (JAXA) noted that CEOS LSI-VC have just started an activity to establish a PolInSAR science team, working with a number of scientists, to nominate a couple of PolInSAR sites.
- Nuno Miranda (ESA) noted that SeaSAR will also put together a white paper about the observation requirements over the ocean.

Session 9: Closing Session

9.1 - Coordination of spaceborne SAR Missions: Next steps and way forward

Shinichi Sobue (JAXA), Charles Elachi (CalTech) reported:

- The draft recommendations from the workshop were reviewed.
- It was suggested that these recommendations be presented at the CEOS meeting in April, where all the Principals will have gathered.
- DLR will host the next workshop, in the spring of 2027.

- JAXA will set up a call of the executive committee in the next couple of months to hand over the activities from JAXA to DLR.
- Thanked Wataya Besso and Saga Prefecture for hosting the workshop.

Discussion

- Elizabeth Nuncio Quiroz (DLR) noted DLR is delighted to host the next workshop, and looks forward to welcoming all to Germany in 2027.
- The participants thanked Shin-ichi and Charles for their leadership over the past two years.