Summaries and recommendations

SAR Missions [S2]

Summary:

The session covered a presentation on the Status of Copernicus Sentinel-1, Sentinel-1 Next Generation , and Earth Explorer 10th Harmony; Rose-L, CONAE SAOCOM , NASA NISAR, and DLR Tandem-X. Further to this, ISRO EOS-04 has been presented in S5, and EE Biomass in several sessions.

- The missions covers large range of SAR frequency, X, C, L, S, P band
- The missions ensure continuity (Sentinel61) and enable new application developments building on improved observation gaps (revisit, polarimetry,..)
- Future missions with polarimetry capability: Rose-L, Sentinel-1 NG, EOS-04ESA (and ALOS4), and multistatic mode : Harmony
- Sentinel-1 and Rose-L (same orbit, same geometry) providing an operational L and C-band observation systems
- Synergy between missions on the same goal: for biomass, ESA and NASA developed a common platform for GEDI, NISAR and Biomass
- Open access data for ESA and NASA, access via agreement with other agencies

SAR Missions [S2]

Comments and recommendations from the audience:

Enhance coordination between missions of different agencies for synergy and complementarity (if same frequency, separate acquisitions, if multifrequency, acquisitions as close as possible)

- Continuity of X-band SAR missions providing key SAR products (TerraSAR-X, Tandem-X)
- For future missions, trade-ofd of full pol vs dense time series needs to be analysed for each application domain.
- If possible, Wave mode acquisitions should be dual pol for both Rose-L and S1-NG

- Cal Val also on polarimetric and interferometric measurements.
- Include ISRO (EOS-04) data reader into ESA toolboxes (SNAP, POLSARpro)

SAR missions and Calibration [S3]

Five papers were presented in this session. Three were related to ionosphere correction for L- and P-band data, and two were associated with SAR missions.

Calibration:

- The first paper was on solving the system model with Faraday rotation using the data acquired over a single PARC over Australia. An empirical modification to Chen et al. (2011) scheme based on averaging provides the best results.
- The other two papers were on the requirements of spaceborne SAR for the observation of mid-latitude ionospheric activity and ionospheric tomographic reconstructions with polarimetric SAR acquisitions.

Missions:

- NovaSAR-1 (S-band) workflows for the generation of CEOS Analysis Ready Data for land and Compact pol ScanSAR data Calibration were presented. Most of the RISAT-1A data acquisitions are over India. But, it can acquire over any country in any mode.

Recommendations:

- An operational method for correcting ionosphere effect on SAR data including Biomass mission and related software.
- The user community would like to know the effect of ionosphere on tree height, AGB and other parameters.

SAR Missions & Calibration [S3]

Comments and recommendations from the audience:

- For forest, grassland and crop super sites its worth building on existing networks of freely available data. For example, NEON in the USA and ICOS in Europe. CSIRO in Australia has something similar.
- some negotiations with national or state governments could be needed for e.g. agricultural cover information. As many countries collect it and store spatially but wont share at fine scales due to commercial sensitivity.
- Recommendation: If possible, Wave Mode acquisitions should be Dual-Pol for both Rose-L and S1-NG

PolSAR and PolInSAR Methods [S4]

Change Detection in Multilook Polarimetric SAR Imagery With

Hoteling Lawley Trace and Determinant Ratio Test Statistics" by V. Abkari.

Proposition of a new PolSAR change detector. Compared with existing approaches, this detctor is more stable and has rigorously derived statistics. Nevertheless, the arbitrary expression (ratio of determinants) may miss polarimetric changes that are not directly related to PolSAR eigenvalues.

"Polarimetric Analysis of Permanently Shadowed Regions on the Moon Using Dual-Frequency Full-Pol Data From Chandrayaan-2 DFSAR" by U. Khati.

Analysis of L and S band polarimetric images of the moon. PolSAR allows to reveal details that were not perceived by former studies. An export of analysis technique for Earth observation to planetary applications should reveal very useful

"Constrained Tensor Decompositions for Polarimetric Time Series

Change Analysis", by N. Basargin.

Tensor decomposition is a natural way for analyzing multi-modal data and can integrate various sources of information. It allows to discrimate invariants, changes and trends in complex

data sets

PolSAR and PolInSAR Methods [S4]

Recommendations

- There is an mportant need for linking signal statistical features with bio- and geo-physical properties. This community should keep on maintaining geophyical analysis and interpretation as a core activity and a way of validating methods and techniques.

- The extension of physically decomposition techniques to complex multi-source, multi-frequency and multi-temporal data analysis should be strongly encouraged. Tensor decomposition is an elegant and efficient solution, but other approaches could be proposed too.

Comments from the audience:

- Shall we introduce a session on bistatic polarimetry (in support of Harmony and GNSS reflectometry)?

Biomass Mission Overview [S5]

Summary:

- Shaun Quegan provided a comprehensive overview of the mission's main constituents and challenges:
  Following a question to which extent private sector involved in REDD+ can assist in provision of validation data, it was clarified that the data needs for EO mission product validation would need to follow established practices with uncertainties reported (high quality standard needs).
- Michael Fehringer provided the latest mission status and satellite integration and testing activities currently ongoing at Airbus, Toulouse:
  Launch delayed until (end of) Q1-2025 due to launch failure with Vega-C launch VV22, *affecting the Vega and Vega-C launch manifest and return-to-flight of Vega-C.* **Note**: Biomass will be launched on a Vega launcher
  Clarification provided that data from Biomass will be fully open to the community
- Antonio Leanza presented the in-orbit calibration and performance verification tasks currently foreseen for the in-orbit commissioning (IOC) of Biomass:
  Following a question, it was stated that for the Biomass mission only a single transponder is available, therefore also strongly relying on additional targets of opportunity. The westward drift for antenna pattern characterisation results in baselines > critical baseline
- Sérgio Bras explained in detail – supported with animations – the operational nature and coverage patterns of the Biomass mission:
  During the spacecraft repositioning (duration 6/9/12 days) following a major cycle, a faster westward is implemented (higher orbit)
- Björn Rommen covered the large range of anticipated cal/val activities including both Level-1calibration and Level-2 product validation activities:
  Cal/Val AO to be released Q4-2023, allowing worldwide participation and covering all aspects (and more!) as presented in the talk.

Biomass Mission Overview [S5]

Observations:

- Biomass mission preparation is well underway → positive perspective
- Targets of Opportunity (manmade and natural targets) important to complement transponder measurements and also needed during the operational phase where the transponder visibility will be limited to a few times per year.

Recommendation:

- ESA to investigate to what extent the different westward drifts used during antenna pattern characterisation phase (during Phase E1) and the spacecraft repositioning following a major cycle completion (during Phase E2) can still be exploited for interferometry for high latitudes (> critical baseline at equator)
- Besides collecting high quality datasets for biomass validation also commercial providers should be considered.
- To provide accurate information on the access/dissemination of all Biomass data once it becomes available.

Biomass Mission Overview [S5]

Comments and recommendations from the audience:

- Comment on incorporating data from the private sector and varying quality -- just pointing out that there's excellent scientists working on the private sector and carrying out rigorous forest inventories that would be an excellent addition to the validation database
- **Are there any plans to put BIOMASS into a "normal" orbit with maximal coverage at the end of its lifetime**, when the propellant is low? I know that the revisit time will be low with the 50 km swath, so insar may not work, but this would still provide excellent Polsar data for a long list of applications

Biomass Products and Algorithms [S6]

Summary:

The session covered a presentation on the Biomass Processor Suite (BPS) with an overview of the operational processors and Biomass products, as well as a presentation on the interferometric processor.

Further to this, presentations on the AGB estimation algorithm and general L2 algorithm status were provided.? The last presentation covered the MAAP and BioPAL developments that are crucial to aid the mission product scientific exploitation.

Recommendations:

- To prepare activities to allow integration of a-priori forest height estimates into the Biomass AGB retrieval (e.g. using FH as additional constraint, preparing global allometries, etc)
- If GEDI AGB is used for training we should develop our own product to better understand and control biases and uncertainties. In the long term GEDI should be replaced or complemented by Biomass TOMO-SAR or PolInSAR data.
- To get a handle on environmental factor consider using NISAR L-band data, which is much denser in time than Biomass. In addition, there is a need to explore synergistic retrievals.

Biomass Products and Algorithms [S6]

Recommendations (continued):

- We should invest into AI/ML methods to combine different products and data from different missions (NISAR, Biomass, S1, GEDI,...) to derive AGB and to learn more about the information content of each dataset.
- BioPAL is a great initiative and it is very much appreciated that ESA makes the processors openly available. But it still requires expert knowledge to use these libraries. Please improve the usability to make it really open to newcomers and service providers who do not have the expert knowledge (follow open source best practices, make it modular, provide test cases and jupyter notebooks, etc). In addition, ESA could consider to organise dedicated BioPAL training sessions.
- A good opportunity could be co-processing GEDI with the BIOMASS tomographic data. For instance, detecting discrepancies in ground estimation, which could signal an unrealistic measurement of AGB. So refining the processing of GEDI with this data to obtain more robust estimates of AGB.

Biomass Products and Algorithms [S6]

- gap: suggest using colorblind friendly and perceptually uniform colormaps for the presentations (ref: https://www.nature.com/articles/s41467-020-19160-7)
- Question: As the agb~backscatter relationship is planned to be calibrated for 3x3 blocks, what is the risk for biases in agb estimated in adjacent blocks?
- Question: Will uncertainty in the agb estimated from icesat2 and gedi be propagated into the biomass agb estimates?
- Question: as soil moisture back scatter is such a big issue, have you thought about being in SMAP / NISAR soil moisture retrievals for the algorithm?
- Recommendation: We should invest into AI/ML methods to combine different products and data from different missions (NISAR, Biomass, S1, GEDI,...) to derive AGB and to learn more about the information content of each dataset.
- Comment: BioPAL is a great initiative and it is very much appreciated that ESA makes the processors openly available. But it still requires expert knowledge to use these libraries. Please improve the usability to make it really open to newcomers and service providers who do not have the expert knowledge (follow open source best practices, make it modular, provide test cases and jupyter notebooks, etc).

Biomass Methods [S7]

14:20 - 14:40 Performance Limits Of Sar Tomography For The Characterization Of Forested Areas. Specific Case Of Tropical Forests Measured In The Biomass Configuration • (ID: 195)Presenting: Ferro-Famil, Laurent

Analysis of retrieval performance for several vegetation parameters including the BIOMASS case. Model of vertical structure not very important @BIOMASS res. Parameter accuracy is actually very promising, but a note is made to take care of potential biases. A discussion on the effects of biomass data simulations might be useful to guarantee comparability with other presentations (applies to third presentation too)

14:40 - 15:00 Comparison Of Low Dimensionality Profile Models For The Characterization Of Tropical Forest Using SAR Tomography • (ID: 106)Presenting: Bou, Pierre-Antoine

Estimation of different profile models, exp volume, wavelet, parametric. Exp vol + ground makes underestimated ground, better to use narrow exponential for volume. Two deltas with decorrelation will just do for BIOMASS due to low res of the instrument.

Biomass Methods [S7]

15:00 - 15:20 Tropical Forest Parameter Estimation Using P-band SAR Tomography In Both Airborne And Simulated BIOMASS Configurations • (ID: 182)Presenting: Huang, Yue

Comparison of structure models vs SKP. Cov matching seems to work just as good as the SKP with airborne data (many looks) with dtm and tree height. With BIOMASS data as well but Cov fit improves over SKP. DTM biased with HV and also with VV. Not with HH. Possible further improvement with multi-pol fit. Questions on the portability of the procedures over urban areas were raised. Possible further development already addresses in prev presentation

15:20 - 15:40 Revolutionizing the Estimation of Tropical Forest Vertical Structure with Spaceborne GEDI and SAR Tomography • (ID: 120)Presenting: Ho Tong Minh, Dinh

GEDI height error 5 (full power) or 6 (all) m w.r.t. airborne lidar. Airborne tomo better than GEDI. DTM error = 3.5 m for GEDI (full power). Correlation of tomoSAR and GEDI turns out to exhibit a noticeable similarity. Argument that GEDI suffers from geolocalization errors, which contributes to height errors.

15:40 - 16:00 Estimating Tropical Forest Biomass and its Change by Means of Multi-mission / Multi-scale Structure Measurements • (ID: 142)Presenting: Hartweg, Benedikt

Study of applicability of allometry from GEDI (25 m) and height from BIOMASS (100 m). H100, average of hundreds biggest trees in one hectare seems to be the most sensible to AGB via allometry. Need for more parameters (dbh, crown height) to refine estimation, and/or spatially dynamic allometry. The study relied on the exploitation of the FORMIND model to simulate forest data.

Biomass Methods [S7]

- Recommendations: fitting against FORMID may be fine for exploring metrics but evaluation against field data is essential. The model system is based on allometry to relate to height. So this is circular.
- Also, that DBH is important is not new and most field based allometry is based on DBH not height.
- How about using Biomass Methods in a positive way, trying to derive from the estimation of volume of crops, what is the corresponding energy potential. Due to this Biomass (renewable sources) evaluation effectiveness, we can reach SDGs through the ultimate benefit of linking satellite data to community.In general: let's link Biomass to Energy!

Forest Applications I (S8)

- **Machine Learning in Model-Based Forest Height Inversion (ID: 213). Presenting: Mansour, Islam**
  - Successful performance of forest height inversion by integrating physical models of the vegetation into Machine Learning (ML) approaches has been achieved. The goal is to better exploit the underlying assumptions of the model by means of ML. Further analysis for the exploitation of the ALOS data is needed: at the moment, the information of entropy and eigenvalues introduces uncertainty to the ML approach. Landsat data has proven successful in contributing to enhance the underlying model assumption.
  - Comments from the audience:
  - Concern about the use of Landsat data to improve the results.
  - Stability problems concerning the use of Legendre polynomials when the order of the polynomial is high.

- **A Dual-Frequency Approach to Detect Forest Height and Structure Using Polinsar Technique (ID: 171). Presenting: Hosseini, Samira**
  - They wanted to improve AGB retrievals with L- and P-band data. They estimated forest height at L-band, and they used P-band to distinguish different tree species signatures. More studies required to analyze this.
  - Comments from the audience::
  - Question regarding the estimation of AGB. They estimates AGB at P-band, since they saw a higher sensitivity to forest structure, but they experiences better results of forest height estimation at L-band.
  - Question regarding the joint use of L- and P-band for estimation of forest height. Both bands see the same height and the same ground phase, the profile of one band could be used to estimate the height at the other band.

Forest Applications I (S8)

- **An Assessment of SAOCOM L-Band Pol-InSAR Capabilities For Canopy Height Estimates: A Case Study Over Managed Forests In Argentina (ID: 126). Presenting: Seppi, Santiago Ariel**
  - The polarimetric-interferometric capabilities of the SAOCOM-1 constellation to map forest stand height in Argentina was assessed. The high variability of the SAOCOM spatial baselines yields the need for multi-baseline classification approaches. To this purpose, they highlight the importance of statistically independent validation pixels. Further study to model temporal decorrelation instead of using a unique fixed value will be performed.
  - Comments from the audience:
  - Question regarding the use of NISAR and ROSE-L data wrt how to address temporal decorrelation. This is currently being studied.
  - The data presented is using Stripmap acquisitions. TOPSAR mode has a problem with the bursts synchronization. There is a request to make the complete metadata of the TOPSAR mode available to the users.
  - The results from SAOCOM PolInSAR data are very encouraging. More data and results over different sites would be interesting to the EO community.

Forest Applications I (S8)

- **L-Band Interferometric Coherence Time-Series For Forest Parameters Retrieval (ID: 159). Presenting: Telli, Chiara**
  - The goal is to define a model-based approach to map forest properties from time-series of InSAR temporal coherence. For this, the RMOG+ model is exploited. First results of forest height estimation show some error bias at short and taller stands that will be further addressed.
  - Comments from the audience:
  - Question regarding the necessity to define the diversity of the temporal decorrelation / baselines. This is work in progress.
  - The RMOG+ model can be further extended to model different sources of temporal decorrelations.

- **A ground finding approach over the Howland forest Based on Interferometric Phase Histogram using Spaceborne TanDEM-X InSAR and GEDI Lidar Data (ID: 150). Presenting: Yu, Yanghai**
  - Lightweight approach for forest structure estimation that only requires single-baseline, single-polarization in the context of high resolution spaceborne missions to complement existing techniques has been proposed.
  - Comments from the audience:
  - Question about the role of the vertical wavenumber, what kind of baselines are preferable for the method. It should be adapted to the data. In the results, they used a kz = 0.3 rad/m, and a HoA around 50 m. They will further explore the effect of the kz in future tests.
  - Using optical parameters to constraint structural parameter retrieval may lead to errors and should be used with caution

Forest Applications I [S8]

- Challenge: detecting water table depth in peat under forests
- I would suggest to consider GEDI horizontal geolocation error (on the order of tens of meters) when using GEDI-derived information for comparison exercises. Selection of GEDI data on more homegeneous forest areas could help to minimize the impact of geolocation errors. I would further suggest to evalute the use of different GEDI RH percentiles (e.g. RH95, RH98, RH100) for comparison exercises. According to literature, RH98 has been demonstrated by many research studies to best fit actual canopy height.
- very good point about. The GEDI simulator https://bitbucket.org/StevenHancock/gedisimulator provides a tool for correcting the geolocation issues if ALS data for the tracks is available.

Forest applications II [S9]

Summary

09:00 - 09:20 Estimation Of Mangrove Forest Vertical Structure With UAVSAR And Lidar Data Fusion Using AfriSAR Campaign Data • (ID: 200) **Use of DL, indicates need for generalized training**

09:20 - 09:40 Estimating Forest Structure Change by Means of Wavelet Statistics • (ID: 151) **Multiscale analysis beneficial to highlight changes in forest structure. Better to start from high-res data**

09:40 - 10:00 TomoSAR Sensitivity to Temperate Forest Above-Ground Biomass at P- and L-band in the TomoSense ESA Campaign • (ID: 170). **Tomography beneficial for AGB at both P and L, indicates sensitivity of tomo structure to AGB**

10:00 - 10:20 Addressing Forest Change by means of Pol-InSAR Measurements at L- and P-band • (ID: 177) **GV separation with polarimetric analysis beneficial to highlight dielectric changes. P-Band provides clearer separation**

10:20 - 10:40 SAR4Change: Deforestation Detection Using Dual-polarimetric SAR Information • (ID: 201) **Highlights importance of dense and continuous temporal sampling**

Forest applications II [S9]

Recommendations

Modern SAR systems provides many more observables than just few years ago: tomography, polarimetric tomography, multi-frequency, multi-temporal and multi-static (which comes with multistatic polarimetry) .

⇒ Retrieval of forest parameters should be approached today in a multidimensional fashion. We recommend dedicated studies that make use of available data to develop methodologies based on such multidimensional data. Use of Deep Learning/ AI is welcome, as long as it is driven by physical models and remains understandable to us

⇒ To reach out to users outside Radar processing experts we need to deliver data that are more immediately understood. Data should be well calibrated (polarimetrically and interferometrically) to facilitate users. Provision of 3D data also appears beneficial. Demo codes are welcome.

⇒ ESA campaign data should come in a standardized format concerning data and metadata and with clear definitions of the level of processing

⇒ We remark the importance of new campaigns to explore bistatic data and multitemporal acquisitions. Forest campaigns should come with a proper amount of Lidar data (airborne/TLS) and collection of in-situ parameters

Agriculture Applications [S10]

- ✓ **Sensors used**:
  - ✓ Several presentations have seen the use of Sentinel-1 for monitoring crops. This witness the usefulness of dense time series for monitoring crops, especially when it comes to classification [Zhuo et al, Gao et al] and detection [Xianfeng et al, Paillou et al].
  - ✓ Quad-pol SAOCOM L-band was also used on a work aimed at retrieving parameters, showing the importance of quad-pol and L-band when it comes to retrieving biophysical parameters that would be completely inaccessible if dual-pol C-band was used [Papale et al].
  - ✓ Conclusions: dual-pol time series are very beneficial to classify crops, but when it comes to the retrieval of most parameters, quad-pol is essential to ensure enhanced removal of ambiguities.

Agriculture Applications [S10]

- ✓ **Methodologies**:
  - ✓ Two papers considered machine learning to classify crops [Zhuo et al, Gao et al] showing the benefits of using time information to identify crops.
  - ✓ Two papers instead used more physically based rational to detect important stages or characteristics of crops [Xianfeng et al, Nathan et al]
  - ✓ One paper [Papale et al] considered a radiative transfer model.
  - ✓ Conclusions: Machine learning is proving very valuable together with time information to spot patterns in data and classify different crops. Physical based approaches are however essential to identify and attach physical meaning to specific stages and to retrieve biophysical parameters (where ML struggles with explainability and generalization).

Land Applications [S21]

- **Applications**:
  - This was a very diverse session with a large variety of different applications including urban [Colin et al], permafrost [Saporta et al], peatland [Page at al], burned areas [Dey et al] and Pol-InSAR benchmark datasets for learning-based segmentation [Huchstuhl et al].
  - 4 over 5 applications [Saporta et al, Page at al, Dey et al, Huchstuhl et al] considered quad-pol L-band data, witnessing the importance of quad-pol and L-band to monitor and extract parameters over land applications (where dual-pol could NOT be used to extract those parameters)
  - Conclusions: this session was yet another demonstration that quad-pol can be used to tackle problems in applications that extra information and enhanced capability to revolve ambiguities intrinsic in dual-pol data. Therefore, we would expect an explosion in applications once quad-pol will be provided routinely from space.

Land Applications [S21]

- **Methodologies**:
  - Three papers showed the exploitation of polarimetric observables linked to physical meaning for urban [Colin et al], permafrost [Saporta et al] and burned areas [Dey et al].
  - One paper used statistical methodologies to investigate correlation with physical parameters [Page et al]
  - One paper used machine learning methods to perform land classification [Hochstuhl et al]
  - One presentation described advances in change detection for urban areas using dual pol time-series [Colin]
  - Conclusions: most of the works showed how the exploitation of quad-pol data for biophysical parameter retrieval is in need of powerful physical models to interpret observables and explain correlations. Dual pol time series can be used for change detection in urban areas. ML on the other hand so far has shown appropriate in the learning-based segmentation of Pol-InSAR data.
  - Recommendations: the community would benefit from cataloguing labelled data together with the full datasets (when these publicly available) and sharing. ESA shall consider to include complex SAR data on the computing platform in order to allow processing time series SLC without the need to download full image.

Land Applications + Agriculture [S21] + [S10]

- **Importance of quad-pol**:
  - The persistent finding from the community is that everytime quad-pol data are available, the accuracy of parameter retrieval shows an improvement.
  - In order to get the most from data, future missions should acquire quad-pol.

- **ESA Third Party Missions**:
  - The community is happy to welcome SAOCOM data, but unfortunately we are still not able to work with TOPSAR images due to missing information needed to develop an image reader.
  - There is a current joint effort from ESA and CONAE to solve this issue asap.

- **Wishlist** :
  - For agriculture, real innovation in retrieving biophysical parameters will be boosted by having a space mission with PolInSAR capabilities in quad-pol high resolution and large baselines (this will allow to gain sensitivity on crop heights which are shorter)
  - ESA computing platforms shall include complex SAR data, preferably in a form of coregistered time series / SAR SLC data cubes

Land Applications + Agriculture [S21] + [S10]

- **POLSARpro -> Python**:
  - phase one of the project aimed at converting POLSARpro C-routines into python is on its way.
  - The Python code produced can run on MAAP or any other local or cloud platforms supporting python.
  - The community still expressed interest for these routines to be used both for educational and operational purposes (in the original nature of POLSARpro)
  - What routines do develop in **phase 2**?
    - ESA is very open to make this a community initiative, and everybody is invited to please send recommendations to ESA (e.g. to Magda Fitrzyk) on possible routines to include in future releases of POLSARproPy.
    - During discussions the following routines were already identified:
      - Removal of orientation angle
      - Change detection
      - PolInSAR Coherence loci

Biomass - Validation & Carbon Modelling (S11)

Chairs: Clement Albinet - ESA, Jérôme Chave - CNRS

- **"The Geo-Trees Initiative" - Iris-Amata Dion** - *CNRS, France.*
- **"Terrestrial Laser Scanning Has Potential to Support Cal/Val Activities of Radar Biomass Estimates" - Wouter A. J. Van den Broeck** - *Cavelab, Ghent University, Gent, Belgium.*
- **"The Dynamics Of The Amazon Forests And The Role Of Forest Structure - Linking Vegetation Modelling And Remote Sensing" - Andreas Huth** - *Helmholtz Centre Of Environmental Research - UFZ, Germany.*
- **"Understanding Of Africa's C-Cycling Is Improved By Combining Models With Multi-annual EO AGB Maps" - Thomas Luke Smallman** - *National Centre For Earth Observation & School Of Geosciences, University Of Edinburgh, United Kingdom.*
- ***"Forest Flows – Integration Of Terrestrial, Remote Sensing And Airborne P-Band SAR Data For Identifying And Quantifying The Drivers Of Forest Hydrological Processes Across Different Scales" - Dean Francis Meason*** - *Scion (NZ Forest Research Institute), New Zealand.*

  - *This session included approaches for the validation of biomass products (Dion, GEO-TREES; Meason, Forest Flows; van den Broeck, TLS activities for biomass estimation) to the uptake of the remotely sensed products in modelling frameworks (Smallman, DALEC; Huth, ForMIND).*

Biomass - Validation & Carbon Modelling (S11)

Chairs: Clement Albinet - ESA, Jérôme Chave - CNRS

Recommendations:

- Validation of biomass products is a challenging activity, as forest biomass must be measured based on tree inventories. Also, seemingly comparable forests may have very different carbon stocks.
- Emerging technology (TLS, drone) and highly-instrumented research sites (New Zealand) will play a foremost role in this validation activity.
- Irrespective of the mission, it is essential that calibration of the physical instrument but also of the algorithms be kept separate from the product validation plan.
- GEO-TREES offers a long-term plan for this validation. It requires diplomatic and interagency dialogue. The funding plan is not complete, but recent progress is noted. The bulk of the effort will be in 2024-2025.

Biomass - Multimission Context [S22]

Summary:

•The “Multimission Biomass” session focused on the estimation of biomass and biomass change using various sensor missions and Earth Observation datasets. The presentations covered different aspects related to biomass/change monitoring and highlighted the synergy between contemporary multi-sensor missions.

•The first presentation by Thuy Le Toan discussed the BIOMASS Mission and its synergy with other multi-frequency missions for the estimation of biomass and biomass change. The second presentation by Scott Goetz provided an update on the GEDI Mission and its current/future status in terms of products. Oliver Cartus (Shaun Quegan) presented on the CCCI Biomass project, which focused on global mapping of aboveground biomass and its change. Oleg Antropov presented on the evaluation of various Earth Observation datasets and methods for ESA's Forest Carbon Monitoring. Lastly, Stéphane Mermoz discussed improving early detection of forest disturbances in the tropics, while Julio-César Salazar-Neira presented on estimating biomass from low-frequency passive microwave observations.

Biomass - Multimission Context [S22]

Recommendations:

- Foster collaboration and data sharing: Given the synergy between different missions and datasets, it is crucial to encourage collaboration and data sharing among researchers and organizations working on biomass estimation. This can enhance the accuracy and reliability of biomass mapping efforts.
- Invest in advanced sensor missions: The success of missions like BIOMASS and GEDI highlights the importance of investing in advanced sensor missions capable of providing high-quality measurements for biomass data. Governments and space agencies should consider allocating resources for the development and launch of tomographic missions.
- Improve early detection capabilities: Early detection of forest disturbances is vital for effective forest management and conservation. Researchers and organizations should continue to explore innovative methods and techniques to improve the early detection capabilities in the tropics and other regions.

Biomass - Multimission Context [S22]

Recommendations:

- Enhance accuracy of biomass mapping through validation and calibration and collection of more ground data: As biomass estimation relies on Earth Observation datasets and methods, it is essential to conduct rigorous validation and calibration exercises. Ongoing efforts, such as the evaluation of various datasets and methods for forest carbon monitoring, should continue to ensure sufficient coverage and accuracy of biomass estimates.

- Explore alternative data sources: The presentation on estimating biomass from low-frequency passive microwave observations highlights the potential of alternative data sources. Researchers should further explore the use of unconventional data sources to complement existing Earth Observation datasets and improve biomass estimation accuracy.

- Role of neural network and optical data: Biomass mapping, especially through heterogeneous data fusion, can greatly benefits from the use of neural networks. Investments in this directions are recommended, including to assess the quality of the resulting multi-fusion approaches. Optical data (Sentinle-2) was found to be beneficial for biomass estimation in conjunction with other data sources, and their use is encouraged.

Biomass - Multimission Context [S22]

- Recommendation: Please keep people strictly to time. As overrunning by 10 min is disrespectful to the other speakers.
- Biomass depends on the GEDI AGB product. Why not use the Biomass FH product or a TomoSAR derived height product instead. There should be a study preparing for such a product.
- a good opportunity could be co-processing GEDI with the BIOMASS tomographic data. For instance, detecting discrepancies in ground estimation, which could signal an unrealistic measurement of AGB. So refining the processing of GEDI with this data to obtain more robust estimates of AGB

TomoSAR Methods [S13]

- “Tomographic SAR Algorithms Performance in Co-Fliers Mission Concept Formulation ” by M. Lavalle. The use of NiSAR and ROSE-L as a transmitter, together with 4 co-fliers, leads to multi-static modes: SISO, SIMO, MIMO, for purposes of STV (surface topography and vegetation structure) and SDC (surface deformation change). Performance analysis is using backprojection, beamforming and Capon. Vertical profiles are also compared with GEDI L2/L3 products.

- “ Spaceborne FDM MIMO SAR Tomography ” by S. Tebaldini.
- Spaceborne MIMO TomoSAR, a high-resolution TomoSAR system with a low number of satellites, overcomes decorrelations issues of natural media. Correlation tomography with optimal deployment of Minimum Reduncy Wavenumber illumination allows to generate a uniform virtual array of maximum length. This configuration is implemented by assuming Frequency Division Multiplexing scheme.

- “ Deep Learning based Enhancement of TomoSAR Stacks” by S. Garcia.
- Reconstructing a missing SLC image within a TomoSAR stack, uses an U-net encorder-decoder. A network is trained with a larger TomoSAR stack, and it is able to synthesize an artificial image (amplitude and phase).

TomoSAR Methods [S13]

- “ Multifrequency Polarization Coherence Tomography In Forests ” by Guliaev Roman.
- P-band TomoSAR vertical profiles can be used to support the inversion of interferometric measurements at different frequencies. The PCT at other frequencies, can help to interpret the changes of vertical profiles between TomoSAR acquisitions. The selection of basis functions is important for PCT.
-

- “ Linking Changes of TomoSAR 3-D Reflectivity Profiles and Pol-InSAR Measurements in Forest Scenarios ” by M. Pardini
- Analyse of TomoSAR profiles acquired at different time. Using TomoSAR covariance matrices, an eigen-based framework interpret the profile changes in scattering contributions. 3D changes are located with TomoSAR+ PolInSAR configurations.

TomoSAR Methods [S13]

Recommandations & Questions

1. The role of polarimetry in SAR Tomography is today not well established. The polarimetry has the potential not only to support the physical interpretation of SAR tomograms but also to provide access to important (dielectric) parameters.

What we should do with this ?

2. The synergies between TomoSAR and (Pol-) InSAR measurements are not yet fully understood. This also projects on the definition/design of future SAR missions.

What we should do with this ?

3. Forests: A framework for the interpretation / combination of multifrequency tomograms is today missing. As well as the link to physical 3D structure. Forest structure change by means of SAR tomography at the different frequencies is just at the beginning.

TomoSAR Methods [S13]

Recommandations

4. The tomographic applications in other fields, e.g. agriculture, snow, ice, … are underdeveloped !

What we should do with this ?

5. There is an important need for multi-static TomoSAR for EO applications. The optimal design of multi-static TomoSAR system with a low number of satellites should be strongly encouraged.

6. The deep learning techniques can be potentially used to provide a solution for large-scale processing of TomoSAR inversion. Is it possible to build a scalable and viable model by considering different acquisition geometries?

Comment from audience:

- Great tomographic session!
- Tomography allows for polarimetric analysis of single layers, this can create new opportunities to study dielectric properties within the vegetation and sub canopy soil moisture

Campaigns - M. Pardini & D. Ho Tong Minh [S14]

5 presentations:

- Mapping Tropical Forest in Gabon With L-/P-band Multibaseline Acquisitions: First Results From The GabonX Campaign
  - Observation of short (6-day) and long (6-year) 3-D changes in Gabon test sties. All data processing incl. phase calibration will be already performed at DLR, users will be able to use the data with no additional effort. All geocoding information provided
- Multi-Wavelength Mono- And Bi-Static Phenomenological Analysis Of Microwave Scattering From A Temperate Forest: Results From The Tomosense Campaign
  - First time monostatic-bistatic acquisitions with TomoSAR capability. Short-term decorrelation effects at C-band observed. Wide range of validation data and ground measurements. Limitation: narrow range of biomass in the test site.
- The Potential of SAR Tomography and Phase Histogram Techniques for Estimating Forest Structure: An Assessment Based on TomoSense Data
  - Information content of L-band phase histograms limited by resolution and distributed nature of scattering, although allows some retrieval (e.g. forest height)
- Tomographic Calibration And Processing For Repeat-pass Bistatic Airborne SAR: A Case Study On New TomoSense L-band Data
  - Tomographic bistatic campaigns require substantial processing efforts, yet results demonstrate feasibility of high-quality products.
- Fifth Anniversary of the TropiScat-2 Experiment: Insights for the BIOMASS Mission & Beyond
  - Overview of recent Tropiscat-2 results, extending in time Tropiscat.

Campaigns - M. Pardini & D. Ho Tong Minh [S14]

Recommendations

Forestry:

- Study of forest change requires multitemporal data, possibly PolTomo, gathered at well-characterized supersites and coincident Lidar and in-situ collection
- Use of bistatic data is just at the beginning. We recommend new multi-static (tomo-) data to investigate (3D) multistatic polarimetry
- Joint campaigns ESA/DLR/JPL/CNES/others to maximize output
- No data for tropical forest in Asia (Kalimantan forest?)

Snow and ice

- need for snow campaigns to evaluate retrieval in various conditions (varying snow depth, dry/wet, temperature, topography) and by different methodologies (polarimetry, DEM differencing, DInSAR, Tomography)

Desert/subsurface

- Anything in sight after DesertSAR was aborted?

MIMO SAR: we should get ready for a near future with constellations/formations of small sats

- campaigns supporting MIMO technologies for scientific use: applications enabled by MIMO, demonstration of processing algorithms, required hardware developments.

Access to data:

- How easy to access the data campaigns ? Free open policy or collaboration ? formal ESA portail or informal PI ?
- Campaign data should come in standardized format and level of processing (like PolSAR and InSAR calibration), proper documentation

Comment from audience:

Provision of interferometeically calibrated radar data is fundamental to reach out to new users…and old users as well

Summary-Recommedation: Cryosphere Applications

Summary:

- Three presentations on Snow-Water-Equivalent using polarimetric, interferometric, Pol-InSAR and TomoSAR
- Investigation of high frequency for snow characterisation using mono and bistatic ground based systems
- Characterisation of snow/ice volumes using a combination of different imaging techniques (PolSAR, Pol-InSAR, TomoSAR)


Svalbard March 2005 @ Irena Hajnsek

- Use of airborne and co-pol HH-VV satellite data for the investigation

Summary-Recommedation: Cryosphere Applications

Recommendation:

- Further investigation are needed in the **bistatic/multi-static** domain over snow and ice covered regions to understand what kind of added value these techniques are providing.
- **Higher frequencies** studies to investigate snow covered regions are missing and should be further supported as higher frequency are more sensitive to the snow volume.
- **Density** is an important geophysical parameter and is essential to characterise and invert snow/ice regions. Density is an essential parameter to better parameterise snow-water-equivalent. Different techniques are available to estimate SWE. Studies should be launched to close the knowledge gab and to compare different techniques.
- **SWE** is an important Essential Climate Variable and need support in a frame of a study to be quantitatively assessed. Several methods exist, these needs to be further developed to come to a operational approach.
- New **mission concepts/frequencies** are needed to measure SWE from space. A dedicated mission concepts study should be launched. It has received high interest from cryosphere scientists.

Summary-Recommedation: Cryosphere Applications

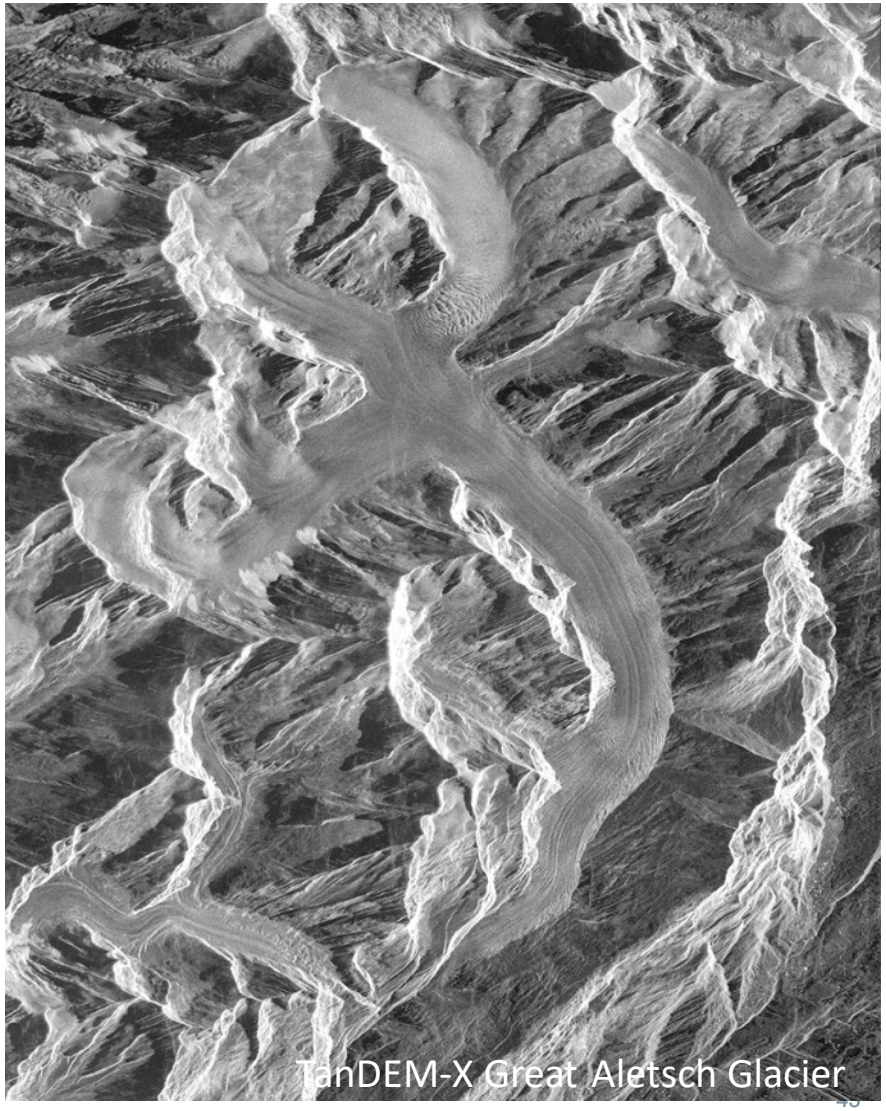
Recommendation:

Campaigns:

- Dedicated snow campaign should be launched for the investigation of higher frequencies, TomoSAR and mono/bistatic acquisitions.

Comment from the audience:

The session is clear: need for tomographic pol


TanDEM-X Great Aletsch Glacier

Ocean/Sea Ice Applications - Summary

- Mix of topics: Sea ice, ship/boat detection, Cal/Val of ISRO EOS-04 Hybrid Polarimetric Mission

- Sea ice:
  - Pol-InSAR for sea ice topography and roughness (Pol-InSAR model of sea ice structure, penetration, Different approaches for young and old ice)
  - Polarimetry for the analysis and segmentation of different sea ice types

- Experiments on automatic refugee inflatable vessel detection using different dual- and cross-pol X band datasets testing different parameters

Ocean/Sea Ice Applications - Recommendations

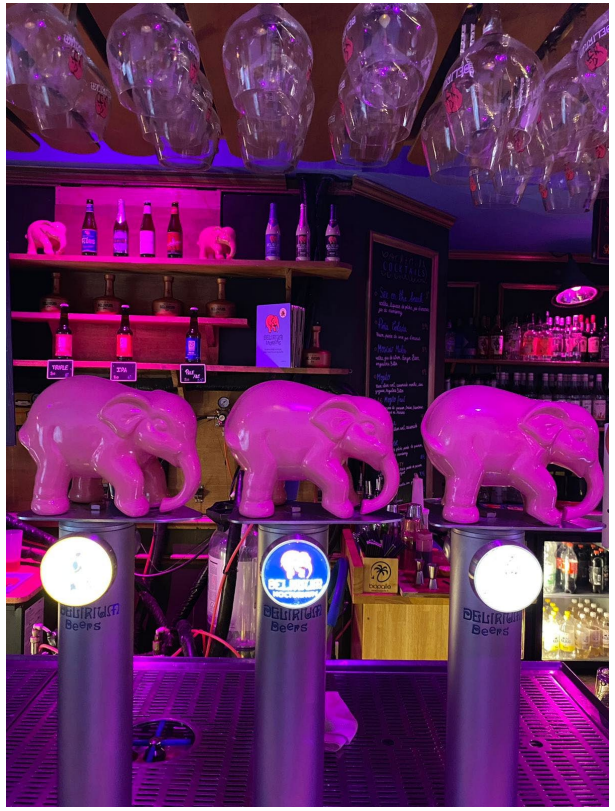
- Polarimetry is key! At least dual-pol, better full-pol

- Lack of validation data and dedicated experiments
  → Clear progress visible but more studies/data/experiments needed
  → Connect to other sea ice studies (cruises)

- Focus on fast ice (stationary ice) to gain a better understanding of temporal changes

- High resolution and near real time spaceborne SAR data for ship detection

PolSARparty session



Hydrology Applications

- **Applications and methodologies**:
  - 4 over 5 applications [Bhogapurapu et al, Papale et al, Khati et al, Paillou et al] include soil moisture detection and monitoring, with the fifth including the detection of Water Hyacinth (WH) [Isundwa et al].
  - Many diverse data were presented for soil moisture detection: L-Band UVSAR Full-pol data + ground truth data / Full-polarimetric L-band aerial data + in-situ data and ML techniques / Polarimetric decomposition models on simulated NASA-ISRO SAR (NISAR) L-Band data and ML techniques / Multi-wavelength satellite data including ALOS 2, Sentinel-1, Sentinel-2 data for paleochannels detection / Sentinel-1 data for water hyacinth detection.

- **Conclusions**:
  - ML algorithms can be an effective tool for estimating soil moisture and dielectric properties, currently based on simulated dataset. Need for further developments
  - The integration of multi-source data allows the monitoring and detection of new water bodies dynamics in Hydrology applications. Once quad-pol will be provided routinely from space, such applications will also benefit of future missions such as ROSE-L and NASA-ISRO SAR missions (NISAR).

Action List - PolInSAR recommendations

RQ 1	**Multi-mission, multi-frequency datasets**	• Create and make available free & open multi-frequency fully polarimetric and interferometric SAR data (spaceborne and airborne), user-friendly open reference datasets (well coregistered on the same grid, at L1 & L2) providing a single data access to users for all different missions, acquired on some characteristic sites like agricultural sites, forest, ocean, desert, covered with snow, coastal areas/wetlands • Inter-agency issue to be discussed in the frame of CEOS

RQ1 still OPEN: PoC ESA (Francesco/Jolanda) / DLR (Irena) / CONAE (Laura)

RQ 2 – RQ 7, RQ10 – RQ 11: totally or partially accomplished, no critical issues

RQ8 – RQ9 (polarimetric decompositions translated in Python): partially accomplished, work is ongoing, no critical issues. **This could be a collaborative action with inputs from ALL the community (Open Science). PoC ESA (Magdalena)**

Additional actions / recommendations to be identified, as a result of POLINSAR 2023 sessions and of your present/future inputs on the *POLINSAR 2023 Virtual PADLET*

Action List - PolInSAR recommendations

Some comments and recommendations from the POLINSAR 2023 audience include:

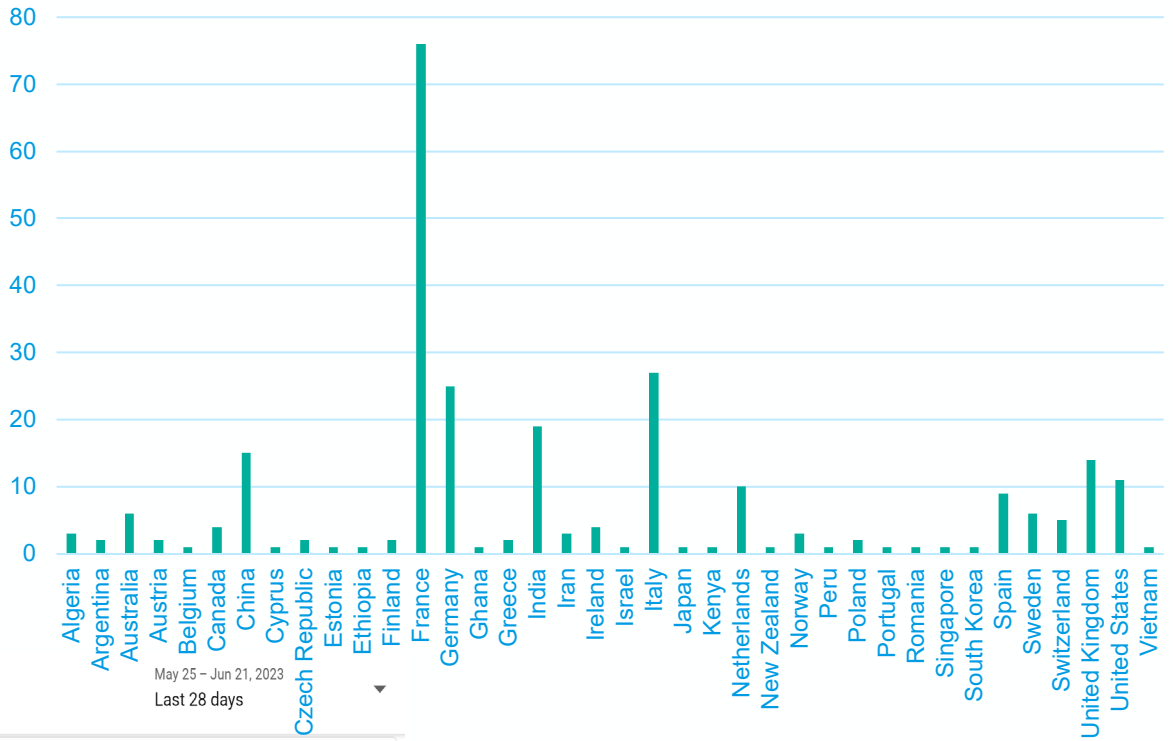
- (RQ1) For forest, grassland and crop super-sites it is worth building on existing networks of freely available data. For example, NEON in the USA and ICOS in Europe. CSIRO in Australia has something similar

- (RQ1) Negotiations with national or state governments about in-situ data needed (e.g. agricultural cover). Many countries collect and store spatially such info but do not share at fine scales due to commercial sensitivity

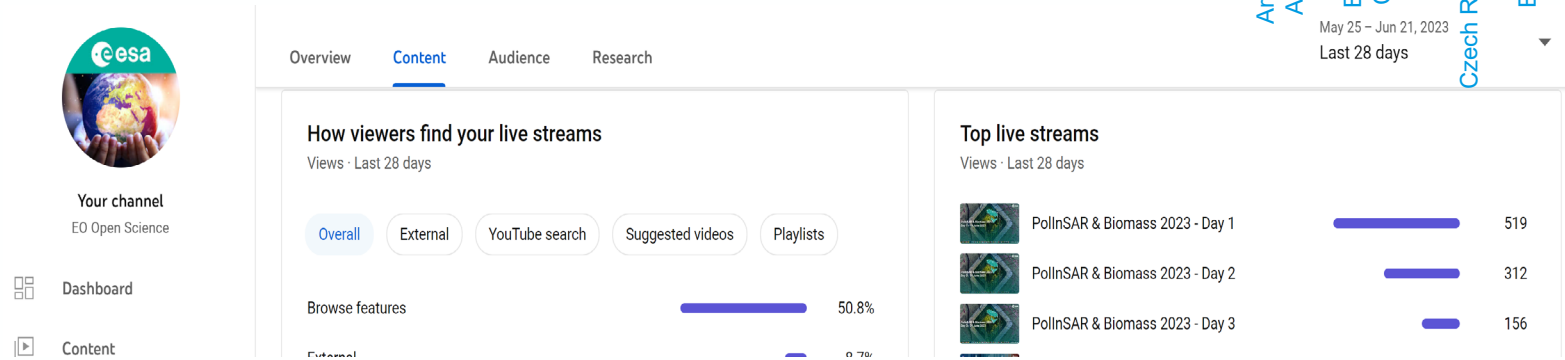
- ROSE-L and S1-NG preparation: If possible, Wave Mode acquisitions should be Dual-Pol for both missions

POLINSAR & BIOMASS 2023 IN NUMBERS

- Tot. no. of registration 218 from 41 different countries
- 200 Participants arrived in Toulouse
- Tot. no. of papers:122
- Oral: 86
- Poster: 40



On-line streaming : on YouTube

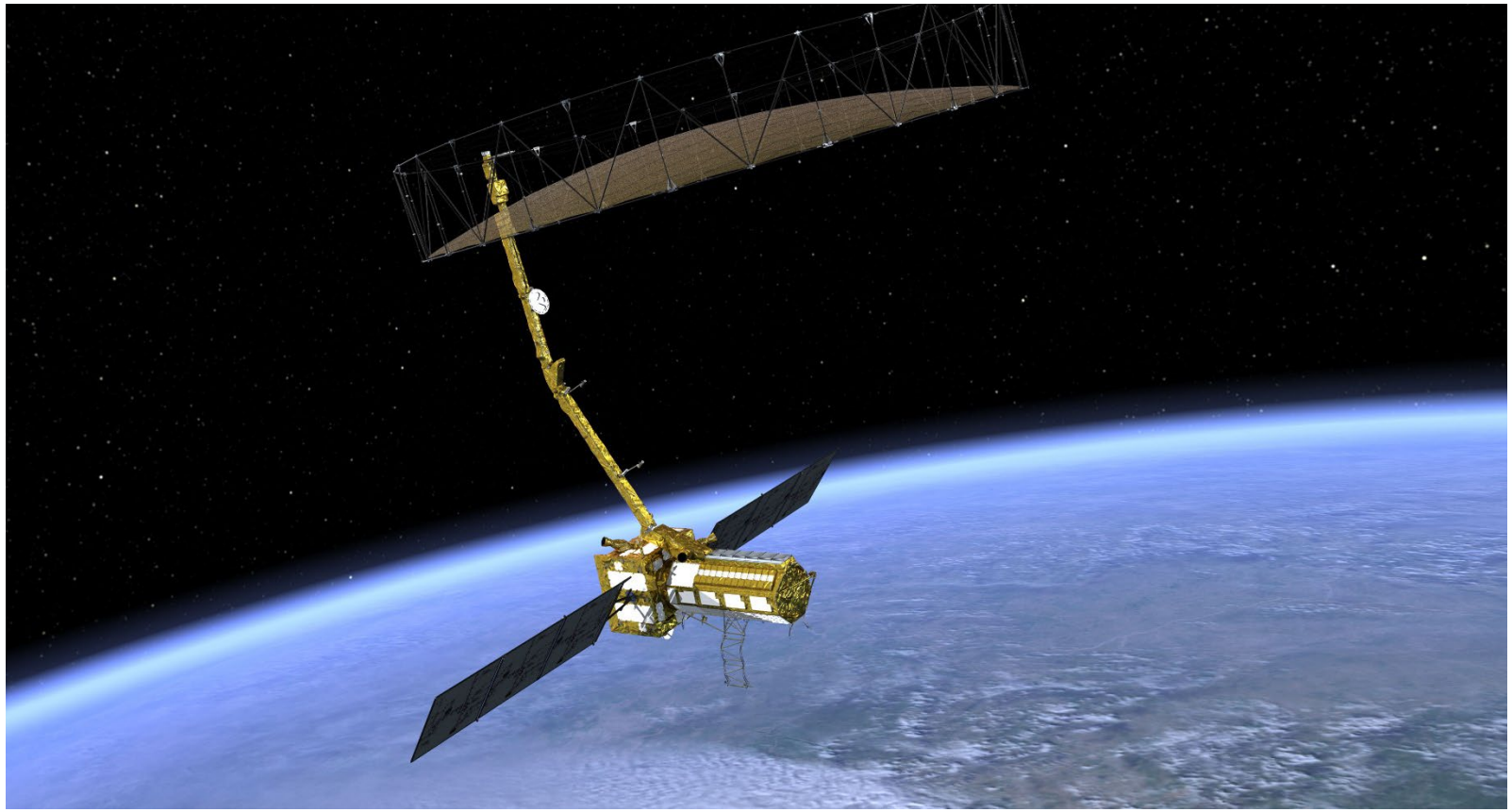


Stay tuned …

PolInSAR & BIOMASS

2025

NISAR 2024



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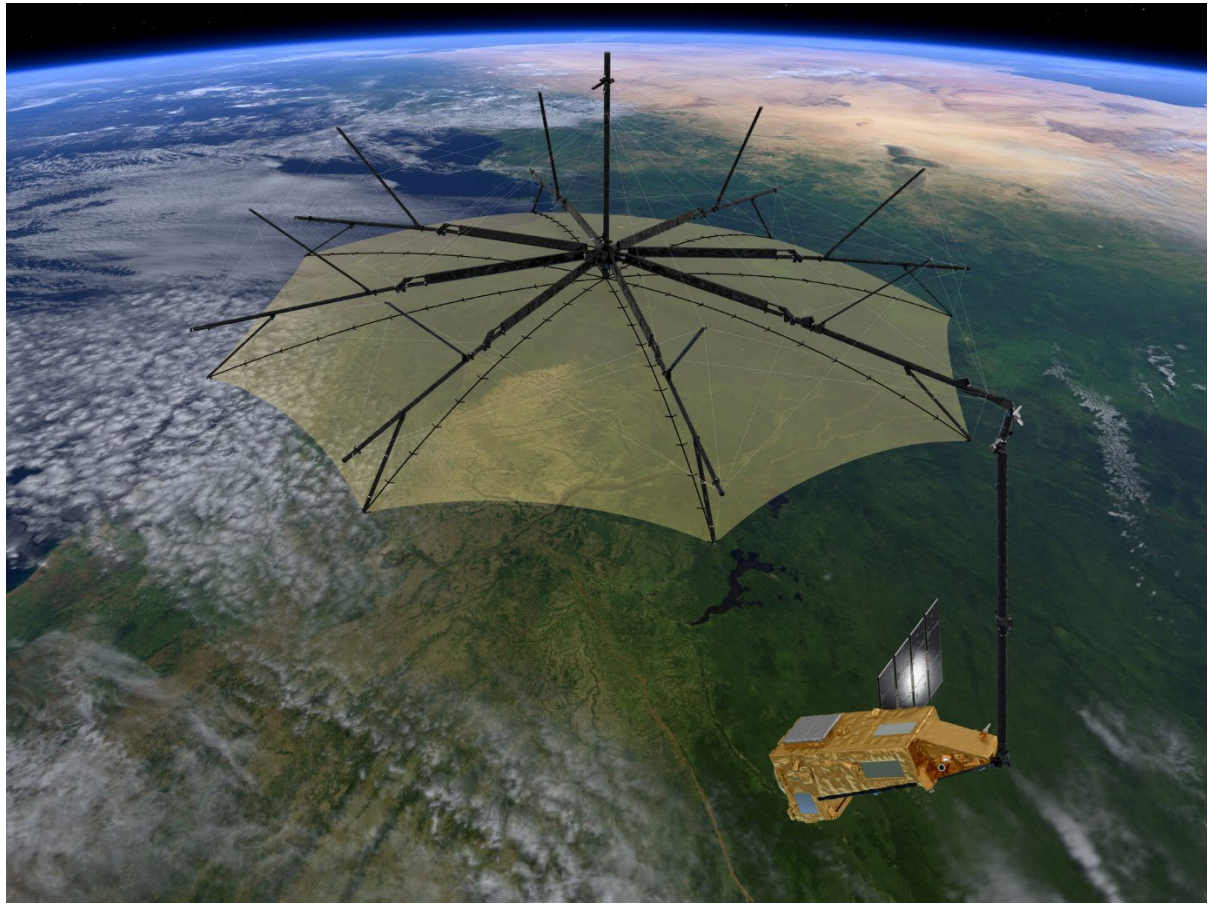

Future POLINSAR 2025

See you all at the **next POLINSAR 2025**, location to be identified (suggestions welcome!) with new sessions, new Polarimetric missions / data / results, and …. **social events!!!!**

Fête de la musique 2023 à Toulouse

PolSARPARTY to be continued