Applications of Bistatic and Multistatic SAR – Wrap-Up

A recurring theme was the need of further maturing bistatic and multistatic SAR technology. While the feasibility of bistatic SAR and InSAR has been demonstrated, significant technical and operational hurdles remain. In particular, there is still a need for systematic acquisitions, technical proofs, and dedicated campaigns. At present, industrial uptake is limited, as companies tend to wait for mature, well-defined products and services, typically after initial government investments have demonstrated feasibility.

Applications explored so far include digital elevation models (DEMs), deformation monitoring, forestry, snow and ice studies, permafrost, and subsurface penetration. Many of these areas benefit from multi-baseline and multi-frequency approaches, which offer improved accuracy compared to traditional monostatic approaches. Experiences from TanDEM-X were seen as instructive: while the mission initially focused on DEM generation, many additional applications emerged later, suggesting a similar trajectory may be expected for multistatic SAR.

Key technical issues include:

- Errors and accuracies: these depend not only on the system but also on the targets and the propagation environment (atmosphere, ionosphere).
- Bistatic scattering: fundamentally different from monostatic, requiring further study (e.g. polarimetry for larger distance separation cases).
- Synchronization and timing: long-baseline bistatic operations are more difficult due to the absence of a direct signal.
- Geometry constraints: UAVs and airborne platforms offer flexibility for campaigns and exploring configurations, but their use is limited for systematic validation.

Comparisons with LiDAR arose repeatedly, especially for forest applications, where LiDAR is often perceived as clearer and simpler. Yet, SAR offers unique strengths: contiguous coverage, independence from daylight and weather, and sensitivity to structural and dynamic processes.

Future directions point towards:

- Identifying a “killer application” that can drive adoption and investment.
- Leveraging multi-satellite constellations (two to three satellites seen as feasible and optimal).
- Enabling heterogenous constellations, e.g., where non-cooperative transmitters are leveraged by multiple satellite providers relying on common standards for synchronization and communication

- Ensuring continuity of observations to build trust and provide long-term value.
- Pursuing more campaigns across diverse test sites and configurations to improve understanding of scattering, errors, and product generation.
- Exploring multi-frequency approaches (X-band, L-band, etc.) for complementary insights.

Overall, there was consensus that multistatic SAR holds strong promise, particularly for snow, ice, permafrost, forestry and deformation monitoring. However, realizing this potential requires further investment, demonstration efforts, and sustained international collaboration to bridge the gap from proof-of-concept to operational use.

Campaigns – Wrap-Up

A first point was the critical role of funding and infrastructure. Campaigns require substantial resources, and participants noted that support is currently limited. On the European side, the availability of multistatic platforms is still an issue. To ensure scientific value, it is essential that calibrated datasets be delivered and distributed, ideally through ESA, to the broader research community. In this respect, multi-static data spaceborne data from U.S. and Chinese constellations are considered very attractive, and it is recommended to ESA to negotiate with potential providers of multi-static data the delivery of small data-sets to the scientific community for scientific research.

Requirements for successful campaigns were discussed in terms of flexibility, spatial coverage, and the ability to generate time series. A staged roadmap for infrastructure was outlined:

1. Ground-based systems, as the initial step for controlled testing.
2. UAVs, which offer high repeatability and flexibility for different geometries, though with limited spatial coverage and challenges for small baselines and smooth flight control.
3. Airborne campaigns, providing wider coverage and stronger validation capabilities.
4. Satellite assets, such as Harmony, as the ultimate enabler of systematic multistatic acquisitions.

Calibration was identified as one of the main challenges. For multistatic polarimetry in particular, calibration methods remain largely unexplored. Issues include:

- Time and phase synchronization.
- Radiometric and polarimetric calibration.
- The limitations of transponders, which are difficult to calibrate accurately.

- The need for a variety of calibration targets (spheres, corner reflectors, dihedrals, “top hats”, trihedrals at multiple angles).
- Accurate antenna beam pattern characterization, potentially stored in databases.
- The possible role of distributed targets and novel procedures for wideband system calibration.
- The importance of understanding aircraft interactions with antennas.

Missions – Wrap-Up

A key focus was on enabling technologies. Several were highlighted as crucial:

- Passive companions, which represent a promising and relatively simple approach, though not representing the full potential of multi-static SAR.
- Antenna technology, where simple, robust designs are preferred for multistatic systems.
- Synchronization, recognized as a central challenge. While GNSS-disciplined oscillators (GPSDOs) are useful, they may not deliver the accuracy required for InSAR or even focusing. Novel synchronization mechanisms are needed, tailored to mission requirements. Harmony was cited as an example where along-track interferometry drives the requirements beyond what standard solutions can provide.
- Multi-channel access in multistatic formations is crucial to enable full MIMO (Multiple-Input-Multiple-Output) technology, where all sensors are simultaneously active.
- Propulsion, where electric systems are seen as a good option, especially given the growing importance of collision avoidance and debris mitigation.
- Mechanisms against GPS jamming and spoofing, ensuring robustness of the system.
- Orbital design was recognized as a key enabler of multi-static SAR missions. Helix formations were cited as examples. Close-formation and large along-track missions involve different trade-offs, but in both cases accurate orbit control and determination is a prerequisite.

The question of constellation design vs. large monolithic satellites remains open. Fragmented apertures in constellations offer flexibility and redundancy, but introduce additional requirements for coordination, downlink capacity, and orbit knowledge. Frequency coordination and downlink bandwidth protection were identified as growing concerns as the number of satellites increases.

From an institutional perspective, the notion of “companion friendliness” was considered crucial. Companion missions must be able to operate without interfering with backbone missions, requiring standards for interfaces, synchronization links, and operational coordination. ESA’s current approach is to keep backbone missions unchanged, but “friendliness levels” could be formally defined to enable companion contributions (e.g. for Sentinel-1 Next Generation, ROSE-L, or future flagship missions). Passive companions could address missing capabilities in programs like Copernicus, such as across-track single-pass acquisitions for forestry, or by enabling 3D motion and deformation as Harmony will deliver.

Finally, the discussion stressed that multi-agency cooperation will be vital for the success of bistatic and multistatic SAR. Shared infrastructures, common standards, and coordinated mission design will be necessary to enable next-generation MIMO SAR systems and to fully exploit the opportunities of multi-SAR architectures.