GFOI R&D Session on integrating EO and ground data for enhanced forest-related biomass estimation

Workshop at ESA StatEO26, Frascati

07 May 2026, 11:45-13:30, James Cook Room

Background

The following hands-on session addressed challenges and opportunities for integrating forest biomass information from forest inventories, national statistics and Earth Observation to strengthen the monitoring and reporting of forest biomass for environmental assessments and climate action. It started with a review of the latest recommendations on using EO-based biomass products within MRV processes and international frameworks[1]. Building upon recent discussions led by the Global Forest Observations Initiative (GFOI), three different pathways leading towards the integration of these datasets were discussed, namely (1) key considerations **informing the design of new ground-based campaigns** to ensure both compatibility with and added value from EO datasets; (2) lessons learned from experiences **combining and harmonizing** different existing in-situ data (e.g., National Forest Inventories, among others) for their integration with EO datasets; and (3) assessment of inferential strategies for the **integration of EO-based biomass datasets with in-situ data** to enhance the precision of biomass estimates at different geographical scales. These discussion topics aim to support a broad range of end users in biomass estimation for forest monitoring and management purposes.

The workshop started with short presentations highlighting success stories and state-of-the-art examples on these themes, followed by a short round of questions. Afterwards, three parallel round-table discussion groups were held, focusing respectively on the three pathways for conceiving the integration of in-situ data, EO-based biomass datasets and national statistics.

The session concluded with summary presentations from the three discussion groups, followed by closing remarks and next steps. Results from these discussions aim to support a broad range of end users in biomass estimation for forest monitoring and management purposes, and its outcomes will contribute to ESA's ongoing work on forest monitoring.

Organizing team

Natalia Málaga (GFZ), Daniela Requena Suarez (GFZ), Martin Herold (GFZ), Neha Hunka (ESA), Javier Garcia-Perez (FAO), Giulia Costella (Caribou)

Location and number of participants, logistical details

James Cook Room, estimated attendance of around 30 participants. Participants ranged from Earth Observation data providers and experts, Forest Inventory experts, EO-FI Integration experts, as well as experts from Environmental monitoring and statistics agencies.

[1] https://www.reddcompass.org/mgd/resources/GFOI_BiomassMaps_Guidance-20251022.pdf

Detailed agenda

Presentation/Discussion	Speaker/Moderators	Time
Welcome words and introduction to the workshop	Neha Hunka (ESA)	11:50-11:55
Overview on GFOI recommendations on the use of EO-based biomass data in MRV procedures	Daniela Requena Suarez (GFZ)	11:55-12:00
Lightning Presentation Round	Neha Hunka (moderation)	**12:00-12:30**
Designing EO-compatible forest inventories: considerations and opportunities for improved biomass estimation	Johannes Breidenbach (NIBIO)	12:00-12:05
Harmonizing national statistics for integration with EO biomass maps to produce biomass increment estimates across Europe	Valerio Avitabile (JRC)	12:05-12:10
Integrating EO biomass maps with NFI data to enhance the precision of estimates	Natalia Málaga (GFZ)	12:10-12:15
Worldforest perspectives on the integration of NFI data information with EO products for small-area estimation: Case studies of Peru and Brazil	Christophe Sannier (GAF)	12:15-12:20
Quick Q&A		12:20-12:35
Discussion Sessions running in parallel		**12:35-13:25**
Group 1: Key considerations in the design-phase of field-campaigns	Javier García-Perez (FAO), and Giulia Costello	12:35-13:10
Group 2: Requirements and considerations when harmonizing existing NFI data to make it interoperable with EO data	Valerio Avitabile (JRC) and Daniela Requena (GFZ)	
Group 3: Current and emerging opportunities to integrate EO products with existing NFIs for enhancing biomass estimation for MRV or environmental monitoring purposes.	Natalia Málaga (GFZ) and Johannes Breidenbach (NIBIO)	
Group feedback session (5 min per group)	Daniela Requena (GFZ)	13:10-13:25
Final remarks and next steps	Natalia Málaga (GFZ)	**13:25-13:30**

Summary

Lightning presentations

The session opened with Daniela Requena (GFZ) providing an overview of GFOI's latest recommendations for using EO-based biomass products in MRV procedures included in the GFOI Rapid Response Biomass Module. Johannes Breidenbach (NIBIO) then presented results from the EU Horizon project PathFinder on the co-design of field surveys optimized for EO integration, highlighting trade-offs between plot size, field cost, and estimating precision when EO sources are used. Valerio Avitabile (JRC) showed how integrating data from 11 countries and around 78,000 NFI plots with 73 EO-derived predictors consistently outperforms using either ground data source alone for estimating biomass increment across Europe. Natalia Málaga (GFZ) introduced a methodological framework comparing design-based, model-assisted, and model-based approaches for incorporating EO-derived biomass products as auxiliary information in NFI estimates, with the goal of increasing precision estimates and improving sampling efficiency. Finally, Christopher Sannier (GAF) presented two country case studies within the WorldForest Project: Peru, where SERFOR seeks to refine national biomass estimates and replace outdated carbon maps using small area estimation with approximately 50% NFI national coverage; and Brazil, where the focus is on assessing and correcting systematic errors from global to local biomass EO-derived products and models.

Parallel discussion groups

Once the three overarching topics were briefly introduced in the lightning presentations, three parallel groups were formed around each thematic pathway. Each group addressed three guiding questions reflecting on opportunities, remaining challenges and perspectives on EO- and ground-reference data integration.

- **GROUP 1 - Field Inventory Survey Design**
  Moderators: J. Garcia-Perez (FAO), G. Costello (Caribou)
  Question 1: What does EO product/data enable in the design of new ground-based campaigns that would not be possible without them?
    - EO enables increased precision at lower cost by informing sample allocation and identifying areas of high carbon variability where field data are most needed.
    - Spatial targeting: EO products can guide where to place plots, particularly in areas of high variability, and enables pre-imputation for areas where ground access is impossible (e.g. protected reserves or conflict zones).
    - EO uniquely captures forest dynamics, disturbance, and recovery over time, which are temporal dimensions that field campaigns tend to miss by themselves, particularly without consistent re-measurements. Leveraging this temporal richness to inform the frequency, timing, and prioritization of ongoing and new field campaigns represents one of the most promising and underexplored directions for improving biomass monitoring.
    - With EO data, small area estimation (SAE) inference becomes possible, specially within areas with data scarcity scenarios.
    - There is also value in running legacy and EO-informed methods in parallel to assess discrepancies before fully data/method transitioning.

  Question 2: What are the persisting challenges in informing the design of new ground-based campaigns with EO data?

- Spatial and temporal mismatches and harmonization issues are a core barrier: co-registration errors, resolution mismatches between EO and plot size, and the short temporality of field campaigns make calibration of EO-derived trends difficult.
- Lack of local allometric equations (particularly in tropical forests) hinders the calibration of EO-derived biomass information.
- The pre-processing pipelines of some EO products remain opaque, undermining trust and transparency of the data itself.
- Institutionalization and political constraints: historical reporting obligations limit methodological change, ministries and departments often work in silos without integration mandates, and there is a distinction between lack of awareness of EO capabilities and lack of acceptance, both require different responses.

Question 3: Where do you see the most potential for impact on using EO data to inform the design of new ground-based campaigns?

- EO enables more efficient sampling designs by informing where field data are most needed (i.e., prioritizing areas of high carbon variability, active disturbance, or climate impact) and by supporting stratification using biomass or forest-type maps. Together, these reduce the number of plots required without compromising precision, freeing resources to establish longer-term monitoring locations within the inventory.
- EO can provide interim baselines for least-developed countries lacking full NFI infrastructure, ensuring no country is left behind while capacity is built over time. More broadly, integrating EO into campaign design opens new scientific questions that call for closer collaboration between the user and research communities; though inclusiveness within field teams themselves remains equally important and often overlooked.

- **GROUP 2 – Data Harmonization**

Moderators: V. Avitabile (JRC) and D.Requena Suarez (GFZ)

Question 1: What are the opportunities of harmonizing EO with ground-reference data?

- EO datasets can support the extrapolation of ground data that are otherwise limited to singular plot locations, enabling regional, national and sub-national wall-to-wall spatial assessment and monitoring of forest characteristics. In addition, EO-NFI harmonization facilitates the inclusion of land-use history to static ground measurements (especially temporary plots, without revisit).
- Harmonization activities support the higher-frequency updates of estimates, addressing the need for timely data in reporting cycles, and allow combining datasets that measure different but complementary variables.
- Harmonization activities, in addition to supporting the calibration or improvement of EO derived predictions, also open the door to near-real-time change monitoring consistent and aligned with evidence from ground reference data.

Question 2: What are the persisting challenges of harmonizing EO and ground-reference data?

- Data consistency is a core challenge: EO and in-situ data measure different land or vegetation characteristics, time series of both datasets can be inconsistent due to technological or methodological changes, and there are challenges behind the long-term provision of ground and EO data. Discontinued EO missions or insufficient funding for updated in-situ funding hamper the possibilities for long-term data harmonization activities.

- Absence of common ground data standards, including a global lack of harmonized species lists, and inadequate spatial representativity of in-situ data for EO-driven applications.
- The ground data and EO communities operate under different scientific paradigms, creating resistance to change, limited shared understanding of data sovereignty, and persistent data-sharing barriers.

Question 3: What should we address in the coming years in the harmonization of EO and ground-reference data?

- Identify and develop comparable parameters and inter-operable sampling designs between EO and in-situ data, build demonstrators, and establish common data standards including incentives for sharing anonymized interoperable datasets, when possible.
- Support the development of regional networks dedicated to EO-NFI data integration (e.g., replicating PathFinder-style efforts in other regions, supporting NFI networks) and foster increased communication between EO data providers and forest inventory experts.
- Set common goals and shared approaches across communities, keep pace with AI advances with rigorous methodological assessment, and advocate for the funding of global reference data.

- **GROUP 3 – Data Integration for MRV**

Moderators: N. Málaga (GFZ), J. Breidenbach (NIBIO)

Question 1: What does EO data enable in enhancing estimates and predictions?

- EO provides wall-to-wall coverage that enables scaling from local to global levels, leveraging different products to make predictions where no field data exist. It supports a better understanding of spatial variability, enables comparability across data sources, and informs stratification and sampling design for new field surveys, particularly in structurally heterogeneous forests. Higher temporal resolution enables more frequent change detection and annual estimates of forest variables, as well as retrospective reconstruction of gaps in historical datasets, extending the analytical reach of existing ground data.
- EO can provide training data for models.
- EO products can serve as training data for models, enhance the precision of estimates, enable small area estimation, and support sub-national and national reporting across different spatial scales.

Question 2: What are the persisting challenges on EO and ground data integration for enhancing estimates and predictions?

- Accuracy and uncertainty of EO products remain a concern, compounded by harmonization challenges: pixel-plot size mismatches, GPS coordinate errors, temporal mismatches between EO and field acquisitions, and outdated allometric models for tropical species and wood density.
- Data access barriers persist on both sides: large EO archives can be difficult to process, ground-truth data needed for method development are often restricted, sensor costs (e.g. LiDAR) limit uptake, and funding for methodological development remains scarce.
- Limited best-practice examples, poor communication between user and producer communities, and a lack of accessible guidance leave many countries without a clear path for method selection and implementation.

Question 3: Where do you see the most potential for impact on integrating EO and ground data for enhancing estimates and predictions?

- Gap-filling for countries with incomplete or no NFIs using EO-supported approaches (model-assisted and model-based), and small area estimation at sub-national scales to support forest monitoring. Furthermore, for biomass change detection, particularly where re-measured plots are unavailable.
- The consistency and continuity of EO time series, combined with sustained ground data availability, are fundamental: both data streams need to feed and reinforce each other over time to produce reliable long-term estimates.
- Federated learning as a mechanism to open NFI data repositories while preserving data privacy, allowing field coordinates to remain protected while still being accessible to the broader scientific community.
- Integration of diverse EO sources (including TLS, airborne and spaceborne LiDAR, and NISAR) combined with stronger practitioner-scientist collaboration grounded in country-level success stories.
- Capacity building is essential to translate these opportunities into practice: investing in training, tools, and institutional support will determine whether integration advances remain in research or reach operational forest monitoring systems.

Key takeaways and recommended next steps

- Most current efforts focus on using field data to calibrate EO products. Group 1 discussions highlighted the potential of the reverse, in which EO data can be used to inform where, when, and how to design ground-based campaigns while ensuring compatibility with EO products. **More demonstration cases that replicate EO-informed field survey designs (e.g. PathFinder project) in tropical and data-scarce regions are needed, to improve not only biomass estimation but also the monitoring of forest dynamics, disturbance, and carbon change over time.**
- Spatial-temporal mismatches, pixel-plot size discrepancies, GPS co-registration errors and lack of local allometric equations were well-identified data harmonization issues across groups, **with emerging methodological solutions that require validation efforts for biomass monitoring and reporting.**
- Common standards and regional networks are the priority next step for harmonizing information. Progress depends on harmonized data collection and definitions, incentives for data sharing, NFI networks and **replication of EO-ground based data integration efforts in tropical regions where the need is greatest.**
- Combining NFI plots with EO-derived predictors tends to outperform approaches that use either data source alone, particularly for filling data gaps and small area estimation, while also improving spatial and temporal analysis. **Comparative studies that benchmark integration frameworks across country and regional settings should be further encouraged, generating evidence on which approaches perform best for specific MRV applications and scales.**
- Adoption in FI-EO integration approaches can be held back by institutional and trust barriers. Different institutions may often work in parallel, and lack of transparency in both EO and NFI workflows undermines the mutual trust needed for integration. **The disconnect between NFI and EO scientific communities; as well as between practitioners and scientist, was flagged across all three groups, pointing to the need to establish and sustain dedicated interdisciplinary spaces and to invest in capacity-building and knowledge-exchange programs that bring NFI specialists and EO scientists into stronger, more structured collaboration.**
- Across all groups, participants flagged the need of clear, country-accessible guidance on how to integrate EO and ground data in practice. **Grounded country-level cases and success stories that can inform best-practice and decision-support tools are essential to move from research to operational adoption.**

Workshop pictures

The organizing team warmly thanks all presenters for sharing their expertise and the participants for their thoughtful engagement and open exchange throughout the session.