Vegetation Biomass Workshop Report

2016 NASA-ESA-Smithsonian Workshop on Calibration and Validation of Upcoming Satellite Missions on Forest Structure and Biomass

May 31-Jun 3, 2016

Smithsonian Institute, Washington DC

Report of a workshop jointly sponsored by NASA Earth Science Division, NASA Jet Propulsion Laboratory, European Space Agency, Smithsonian Institute.

Compiled and Edited By:

Sassan Saatchi
Senior Scientist, Carbon and Ecosystem Group
Jet Propulsion Laboratory/CALTECH

Natasha Stavros
Scientist, Applications Program
Jet Propulsion Laboratory/CALTECH

Michael Keller
Scientist, Sustainable Landscape Program
USDA Forest Service

Stuart Davies
Director of ForestGEO
Smithsonian Institute

Klaus Scipal
BIOMASS Project Scientist
European Space Agency

Laura Duncanson
GEDI, Science Team Member
NASA, Goddard Space Flight Center

Acknowledgements

The organizers would like to thank all the participants in the Vegetation Biomass Workshop for their scientific contributions during discussions and breakout sessions. We particularly thank Jerome Chave, Shaun Quegan, John Armston and Keryn Paul for their participation in preparing the workshop report.

Suggested citation for this report: Saatchi S, Stavros N, Keller M, Davies S, Scipal K, Duncanson L (2017) 2016 NASA-ESA-Smithsonian Workshop Report on Calibration and Validation of Upcoming Satellite Missions on Forest Structure and Biomass. Jet Propulsion Laboratory, California Institute of Technology.

Table of Contents

1. Executive Summary

This report summarizes presentations, findings and recommendations from the NASA-sponsored Workshop on the calibration and validation of upcoming satellite missions that will produce global measurements of forest Structure and biomass. The workshop was hosted by the Smithsonian Institute in Washington DC, May 31-June 3, 2016 and was attended by 57 international participants (Appendix I), representing a diverse mix of experts in remote sensing, forestry, ecology, and statistics.

The main ***goal*** of the workshop was to develop an integrated calibration and validation (CAL/VAL) plan for future satellite missions dedicated to estimation of aboveground biomass (AGB). The workshop focused on three spaceborne missions that are scheduled to be launched in the next 2-4 years: GEDI from NASA, BIOMASS from ESA, and NISAR from a joint NASA-ISRO (Indian Space Research Organization) collaboration. Although the missions have significant overlaps in science objectives and products, they use different measurement techniques and algorithms to estimate different aspects of AGB at varying spatial and temporal scales. Nevertheless, all three missions provide active remote sensing measurements of forest structure that will be converted (calibrated) to estimates of AGB, which must then be validated by ground/airborne-estimated AGB distributed globally in different forest types. These ground/airborne observations by the ecological and forestry communities were recognized as constituting a parallel, so-called "fourth mission". This fourth mission provides ground/airborne measurements of structure and algorithms for estimating AGB that have a direct link to space mission science requirements and are integral to the CAL/VAL plan for these three missions.

The synergism of missions to produce global datasets of AGB necessitate international collaboration among the scientists from each mission. By developing a collaborative CAL/VAL approach, all three space missions benefit from sharing available resources of ground/airborne measurements, reducing the cost of pre- and post-launch CAL/VAL operations while generating complementary and comparable science products that benefit the ground/airborne-based mission.

The ***objectives*** of the workshop were to:

- Discuss synergism of the three space mission observations and products
- Develop joint CAL/VAL approaches and share resources
- Engage the global ground/airborne biomass observation community in CAL/VAL activities

Accordingly, the workshop agenda (Appendix II) highlighted five topics:

1. Synergistic observations of the three space missions for developing global vegetation biomass products
2. Ground/airborne mission measurements required for the success of all three space missions
3. Development of a collaborative activity for pre- and post-launch CAL/VAL of the space missions
4. Knowledge and data gaps on global forests
5. Integration of forest science and statistics as components of the space mission product validation

The format of the four-day workshop included a combination of invited presentations and breakout group discussions. The invited talks set the context for the workshop and provided background reviews of information relevant to: the missions (ground/airborne and space), CAL/VAL requirements, sources of uncertainty in estimations of AGB, available resources among international institutions and research groups, data gaps, and potential resources for collection of data collection for pre- and post-launch CAL/VAL activities. After each presentation participants discussed each talk and introduced discussion topics such as recent technology for improving ground/airborne measurements of structure and estimations of biomass, techniques for mitigating sources of uncertainty, and critical experiments and research needs. Based on the presentations and discussions during the morning of each day as well as the objectives for that day (associated with the five topics), a series of questions were developed to guide further discussions in breakout sessions. These subsequent breakout sessions then focused deliberations for developing an integrated CAL/VAL recommendations for the missions (Section 5 & 6). These breakout sessions then reported back to the workshop as a whole on their findings. The workshop concluded with a debrief discussion and input from the participants on key findings of the breakout groups (Section 5).

Importantly, the workshop did not seek to plan any specific CAL/VAL activity for any of the missions, but rather to develop a series of recommendations for each space mission when designing their CAL/VAL plans. In particular, the workshop was able to identify which technologies, validation approaches, and ground/airborne measurements might be best if implemented for each mission. Workshop participants also identified resources, infrastructures, and capacities available within the international science community (Appendix III and IV) that are useful for validating the space mission data products.

The following are key findings that resulted from the workshop.

- The space missions have significant overlaps in science objectives, algorithms, and data products, but focus on different measurement techniques at different spatial and temporal scales that result in observations of different components of AGB.
- All three space missions have open data policies to provide all Level 1 (calibrated and geolocated instrument measurements) and Level 2 (geophysical retrievals) data products along with algorithms and documents to the public.
- Combined satellite and ground/airborne observations of vegetation structure and biomass for synergistic products can answer long-standing questions in ecological and global carbon cycle science with greatly reduced uncertainty.
- The space missions have different internal CAL/VAL plans to meet each missions' science requirements, but all plans leverage the same ground/airborne observations and require similar engagements of international institutions.
- There is a parallel "fourth mission" observing biomass that includes national forest inventories, research plot networks, and international monitoring organizations, and it is essential to include the "fourth mission" in a collaborative, synergistic CAL/VAL plan.
- Both ground/airborne and satellite observations of biomass are estimates with uncertainty that can be reduced significantly from synergism of observations and algorithms.
- Specific programmatic CAL/VAL activities would require coordination between NASA and ESA and the international community conducting ground/airborne-based forest inventory. Field campaigns such as AfriSAR was highlighted as an example of a programmatic CAL/VAL activity that fosters development of techniques for synergistic products from the three space missions.

From these findings, there were four key recommendations.

Recommendation 1: Support for synergistic data products

- Global maps of forest structure and biomass derived from all three space missions offer extended coverage, improved resolution, and reduced uncertainty and will be a significant contribution to the science and application community
- Potential new science products from the synergistic observations (e.g., spatially refined soil and vegetation moisture, or vertical profile of structure and biomass) will greatly enhance ecological and global carbon cycle science.
- Focus on synergistic products of biomass change from natural and human induced forest disturbance and recovery will directly address uncertainties in the global carbon cycle such as the location of terrestrial sinks and sources.

Recommendation 2: Support for a parallel ground/airborne biomass mission

- A parallel ground/airborne mission is the "fourth mission" that collects observations of AGB, necessary for a collaborative CAL/VAL plan.

- Although funding for this ground/airborne mission is outside the scope of the three space missions, partial support for ground/airborne data collection and maintenance of the network was recommended as part of the mission CAL/VAL plans.
- Data shared across space missions should be integrated into a central data portal.
- Work with international organizations (i.e. CEOS, GCOS, FAO, GOFC-GOLD, GOFI) is recommended for gaining more support for a central data center useful for CAL/VAL activities.

Recommendation 3: Support synergistic CAL/VAL activities

- Joint ESA-NASA airborne and ground field campaigns would augment the existing network of ground/airborne sites in regions with significant data gaps, thus contributing to space mission algorithm CAL/VAL.
- For selecting regions or sites for new CAL/VAL activities, existing AGB distributions and data products (e.g., NFI data, GlobBIOMASS and Saatchi Map) may be consulated to investigate patterns of large uncertainty or patterns of data gaps in structure or wood density
- Additional efforts to include uncertainty and error propagation methodology in algorithm and product validation could leverage formal statistical techniques (currently employed by the ground/airborne communities); as such expert statisticians could contribute to the mission science teams.

Recommendation 4: Support CAL/VAL workshops

- Annual workshops or meetings would engage a larger community of forestry and ecology scientists to contribute on synergistic space mission CAL/VAL activities.

2. Workshop Background

In May 2016, NASA, the European Space Agency (ESA) and the Smithsonian Institute (SI) co-sponsored a workshop on the synergistic calibration and validation (CAL/VAL) activities of the upcoming active remote sensing satellite missions tasked with estimating aboveground woody vegetation structure and biomass. The workshop was held at the SI in Washington DC. The motivation of the workshop was to discuss the different measurement techniques and algorithms used from each of the three upcoming active remote sensing satellites and the current methodologies for CAL/VAL of their estimates of aboveground biomass (AGB, the oven-dry weight of live vegetation in an ecosystem defined as the quantity of biomass per unit area, or Mg dry weight ha^{-1}). The workshop participants sought to generate approaches that could evaluate the individual mission (or synergistic) science products, while providing a systematic method for cross-mission CAL/VAL that is consistent with the synergistic objectives of all missions. This included identifying ground/airborne measurements of structure and estimates biomass as well as detailed discussions of uncertainties in these observations. The success of space observations depend strongly on how well AGB is quantified at local (pixel) and regional scales. Finally, the workshop participants developed a series of recommendations for CAL/VAL of the space missions' data products that included integrating existing data, identifying data gaps, and designing future ground and airborne campaigns in different forest ecosystems globally.

The source of terms and definitions of calibration and validation may be different for each mission. However, these are defined and used henceforth as:

> ***Calibration:*** *A set of operations that establish the relationship between values of a measuring instrument (e.g. reflectance, vertical profile) and the corresponding values or quantities of interest realized by standards (ground-estimated aboveground height or biomass)*

> ***Validation:*** *The process of assessing the relationship or the quality of data products derived from a measuring instrument by independent means and reporting the uncertainty*

The workshop focused on outlining CAL/VAL approaches, highlighting the most mature techniques for reducing uncertainty in science data products, and recommending a series of high-priority CAL/VAL activities that can be readily adapted to each missions' requirements and potentially adopted by each of the science teams and space agencies. Findings from the workshop include a set of practical recommendations around the integration of existing ground/airborne datasets, standardization of biomass estimation and uncertainty assessments from ground inventory, development and maintenance of a shared platform for CAL/VAL data, and mechanisms to support the needed ground observations for CAL/VAL throughout the operation of the space missions. Importantly, the workshop did not seek to develop specific CAL/VAL plans for each of the upcoming missions, nor did it identify specific synergistic science products or converge on any specific datasets or methodology for assessing the uncertainty of estimated AGB. Rather, this report documents state-of-the-art options and reliable approaches for NASA and ESA to consider in the CAL/VAL plans for each the upcoming space missions. The workshop was also considered the first of a series sponsored by NASA and ESA to guide development of CAL/VAL plans and synergistic science products that play a crucial role in linking space mission science products and uncertainty to the needs and requirements of the stakeholders and the broader user community.

Participants included members from each of the space mission science teams, experts in forest ecology, ecosystems, and climate models, as well as representatives from ground networks tasked with estimating AGB, and program managers from ESA and NASA (Participant List in Appendix I).

2.1. Forest Biomass

The structure of forests (i.e., the three- dimensional arrangement of individual trees) is a direct indicator of how much carbon is stored in the ecosystem. Carbon stored in an ecosystem has a profound effect on how the ecosystem functions (e.g., how it cycles carbon, water, and nutrients). Additionally, there is an increased need to understand local to global storage and dynamics of carbon in ecosystems, as carbon storage is a prerequisite to understanding the coupling of the biosphere to other components of Earth systems. For example, the amount of carbon in a system determines how much is eventually emitted to the atmosphere (as CO2, CO, and CH4 through burning and decay) when ecosystems are disturbed from deforestation and degradation or from climate driven stress and fire. The amount of carbon stored in the system can be estimated from AGB, which is estimated from measurements of structure (e.g., the size and density of trees) and the mass of trees. As such, AGB is considered a crucial variable for a range of applications including forest fire assessment, management of the timber industry, monitoring land-use change, and other ecosystem services such as biodiversity, and production of food and fiber as well as greenhouse gas accounting.

Although we can account for many of these applications by using operational satellite observations of forest cover change, our understanding of changes in terrestrial AGB remains rudimentary. For example, we know that changes in land use, largely from tropical deforestation and fire, are estimated to have reduced biomass globally, while the global carbon balance suggests that terrestrial carbon storage has increased; albeit the exact magnitude, location, and causes of this residual terrestrial sink are still not well quantified. There is strong evidence that the residual sinks are spread in different forest ecosystems with locations that may change due to climate change and anomaly. Yet, the magnitude and fate of these terrestrial sinks are crucial to projections of future climate and any uncertainties in the spatial locations or the temporal behavior of them directly influences the current status of global carbon cycle and climate.

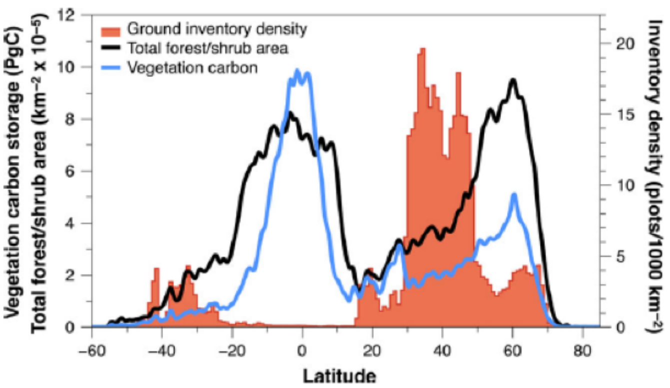


Fig.1. The distribution of woody (forest and shrub land) area and biomass, estimated by radar–LiDAR fusion compared to data avail-ability from forest inventory. The red histogram shows forest inventory plot density in 1000 km^2 grid cells[1].

Our knowledge of the distribution and amount of AGB is based almost entirely on ground measurements over an extremely small, and possibly biased, set of samples with many regions left unmeasured (Fig 1). At large scales, robust AGB estimates are acquired from ground-based forest censuses that are based on labor-intensive fieldwork (plot inventories) conducted by trained operators. As such, these plot inventories cannot be repeated frequently or at a low cost everywhere. Thus, plot inventories are limited to managed forests in a number of developed countries in the northern hemisphere where systematic sampling of forest inventory are performed on a regular basis (5-10 year cycles). Information on most carbon-rich global forests, particularly in developing and tropical countries, are missing even though this is where most living biomass is located (63% of carbon in intact tropical forests, against 15% in boreal forests and 13% in temperate forests, according to a recent and comprehensive estimate[2]). Furthermore, land use activities along with increasing disturbance from climate and human stresses are rapidly changing plot inventory requirements to include more frequent observations of forest ecosystems.

[1] Schimel, D., Pavlick, R., Fisher, J. B., Asner, G. P., Saatchi, S., Townsend, P., ... & Cox, P. (2015). Observing terrestrial ecosystems and the carbon cycle from space. *Global change biology*, *21*(5), 1762-1776.
[2] Pan, Y., Birdsey, R. A., Phillips, O. L., & Jackson, R. B. (2013). The structure, distribution, and biomass of the world's forests. *Annual Review of Ecology, Evolution, and Systematics*, *44*, 593-622.

Consequently, quantitative spatial information about global forest AGB and AGB change has become the priority of the science community and the broader community of stakeholders associated with environmental policy, forest and timber industries, and local and national institutions dedicated to the management of ecosystem services. The planned NASA and ESA biomass missions (GEDI, NISAR and BIOMASS) are considered a direct response from the space agencies to this global science and application priority.

2.2. Missions

2.2.1. GEDI (Launch: 2018-2019)

The scientific goal of the Global Ecosystem Dynamics Investigation Lidar (GEDI) is to characterize the effects of changing climate and land use on ecosystem structure and dynamics to enable improved quantification and understanding of the Earth's carbon cycle and biodiversity. Focused on tropical and temperate forests from its vantage point on the International Space Station (ISS), GEDI uses a Light Detection and Ranging (Lidar) sensor (near infrared 1064 nm wavelength) to provide the first global, high-resolution (25 m) sampling observations of forest vertical structure. GEDI addresses three core science questions: 1) What is the aboveground carbon balance of the land surface? 2) What role will the land surface play in mitigating atmospheric CO_2 in the coming decades? 3) How does ecosystem structure affect habitat quality and biodiversity? Answering these questions is critical for understanding the future path of global climate change and the Earth’s biodiversity.

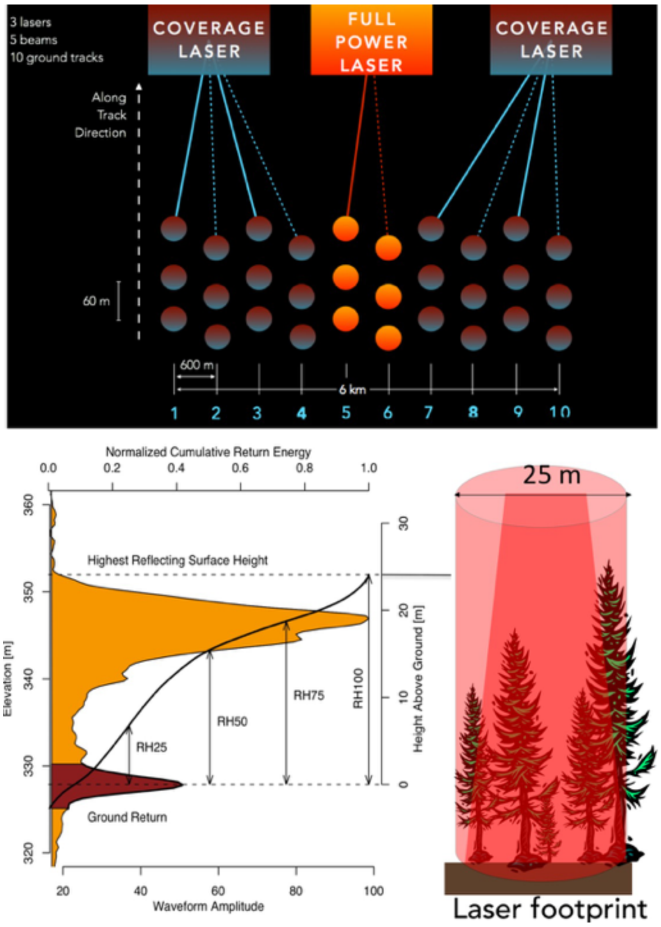


Fig 2. Distribution of GEDI footprints across the landscape from the three lasers and multiple beams (above panel) and the typical distribution of forest vertical structure captured by the GEDI footprint level waveforms.

GEDI informs these science questions by collecting ~12 billion cloud-free land surface Lidar waveform (vertical profile) observations over a two-year mission lifetime. The instrument uses three laser transmitters split into five beams that are dithered to produce 10 parallel ground tracks of 25 m footprints (Fig 2). GEDI will produce estimates of canopy height, elevation, and vertical canopy profile measurements. The 25-m (~0.0625 ha) footprint measurements are used to model AGB and then used to derive mean AGB and variance on a 1-km grid.

GEDI CAL/VAL Requirements

From its vantage point on the ISS, GEDI is focused on tropical and temperate forests between 51.5° S and 51.5° N. The GEDI biomass calibration strategy is to develop globally representative pre-launch models for footprint AGB using near-coincident airborne laser scanning (ALS) data and plot inventory data. Mean and standard error of AGB for 1-km grid cells are then estimated from the modelled footprint AGB via statistical inference. The baseline requirement for GEDI is that the standard error of AGB estimates within 80% of Level 4B gridded product at 1 km cells will be < 20 Mg ha^{-1} or 20%, whichever is greater.

Pre-launch CAL/VAL activities are focused on development and implementation of a framework for the acquisition and processing of data with which to calibrate, test, and improve models and algorithms for application to GEDI science data products. This requires:

1. The development of a global forest structure and biomass database representative of major forest types to underpin calibration of empirical biomass models and assessment of GEDI performance.
2. Simulation of GEDI waveforms from ALS data and validation of these simulations using NASA's airborne Land Vegetation and Ice Sensor (LVIS) across major forest types.
3. Selection of prediction strata that includes variance that is representative of conditions in the domain for which the empirical model parameters are being applied.
4. Use of large area (> 1000 ha) ALS data to validate assumptions of the estimators used for statistical inference of the 1-km gridded AGB mean and standard error.

Post-launch CAL/VAL activities will verify the performance of these science algorithms, update the calibration of any necessary algorithm parameters, and evaluate the science data products. Post-launch validation efforts will therefore be focused at the footprint scale. This will require LVIS campaigns to acquire waveforms and field plot data contemporaneous with GEDI orbital tracks, including areas with ALS coverage and areas under-represented in the pre-launch calibration. For areas with high signal-to-noise LVIS waveforms, height and cover metrics will be used to assess the quantity and quality of GEDI data products and provide a basis for updating the footprint-level model calibration.

2.2.2. BIOMASS (Launch: 2021)

BIOMASS, the ESA's seventh Earth Explorer mission will be launched in the 2020-21 timeframe and has the aim of providing crucial information about the state of the forests and how they are changing globally. The mission goal is to provide estimates of height and AGB in the world's forests. The science case on which BIOMASS was selected is based on its ability to provide estimates of AGB within dense tropical forests to monitor their storage and changes from disturbance at seasonal and annual frequency. The requirement for the BIOMASS mission is to estimate forest biomass with an accuracy of ≤20% for more than 67% of areas with biomass > 50 Mg/ha on a 4-ha spatial grid cell (200 m x 200 m pixels) every 6 months for a period of five years of the mission duration. This requirement is achieved by using a P-band (70 cm wavelength) Synthetic Aperture Radar (SAR) sensor, because of its unique capabilities to penetrate even

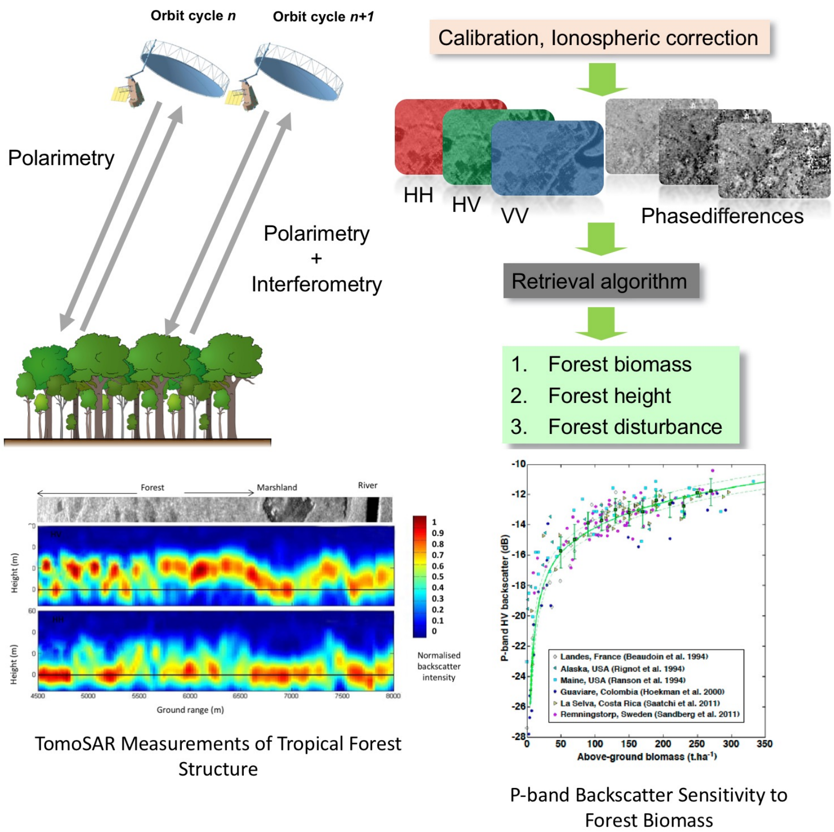


Fig. 3. BIOMASS mission P-band SAR measurements showing the configuration of space measurements and the sensitivity of backscatter power and interferometry to forest structure.

dense tropical forest. The measurements will provide radar polarimetric backscatter (HH, HV, VH, VV) and interferometric observation with PolInSAR capability for forest height estimation, and TomoSAR capability for backscatter vertical profile measurements[1].

In addition, the BIOMASS mission will provide global maps of forest height at the same 4-ha spatial scale for all forests > 10 m height with 30% accuracy, and include a 50 x 50 m deforestation map globally every 6 months. These measurements together, will significantly improve our ability to reduce the uncertainty in the global carbon cycle by providing spatially refined and temporally frequent observation of carbon fluxes in forest ecosystems.

The coverage of BIOMASS is global with a restriction, imposed by the US Department of Defense Space Objects Tracking Radar (SOTR) stations, over Europe and the North and Central Americas. Under these restrictions, only 3% of AGB carbon stock coverage is lost in the tropical forest biome, which constituted 66% of global AGB carbon stocks in 2005[2]. The loss is more significant in the temperate (72%), boreal (37%) and subtropical (29%) biomes.

BIOMASS CAL/VAL Requirements

The CAL/VAL requirements of BIOMASS are primarily focused in tropical forest ecosystems, where the bulk of mission observations are. The biomass and structure algorithms require large ground plots (> 4 ha) or Lidar-derived AGB estimates from airborne observations. These measurements must represent the variations of tropical forest structural types and allometric characteristics and must be repeated during the mission to allow validation of both biomass stocks and changes from disturbance and recovery. The existing distribution of large (10-100 ha) permanent plots, designated as supersites, and of ALS observations are considered the main source of data for algorithm calibration and BIOMASS product validation. BIOMASS has identified several components of a plan to develop the CAL/VAL methodology and datasets. These include:

1. The development of a quantitative framework and methodology to plan CAL/VAL activities.
2. The development and implementation of a Forest Observation System (http://www.forest-observation-system.net/) for international cooperation that establishes and maintains a global *in situ* forest biomass database for the BIOMASS mission CAL/VAL activities.
3. The focus of CAL/VAL mostly in tropical forests.
4. The regular re-visit of *in situ* forest plots for monitoring throughout the lifetime of the mission to account for forest dynamics.
5. The enforcement of a strict data quality expectation for measuring AGB correctly.

2.2.3.NISAR Mission (Launch 2021)

NISAR is a joint project between NASA and ISRO (Indian Space Research Organization) to co-develop and launch the first dual frequency SAR satellite. NASA will provide the L-band (24 cm wavelength) and ISRO will provide the S-band (12 cm wavelength). The mission will acquire polarimetric and interferometric observations at an unprecedented coverage in space and time, which is optimized for studying changes of the global Earth surface.

---

[1] Le Toan, T., Quegan, S., Davidson, M. W. J., Balzter, H., Paillou, P., Papathanassiou, K., ... & Ulander, L. (2011). The BIOMASS mission: Mapping global forest biomass to better understand the terrestrial carbon cycle. *Remote sensing of environment*, *115*(11), 2850-2860.

[2] Carreiras, J. M., Quegan, S., Le Toan, T., Minh, D. H. T., Saatchi, S. S., Carvalhais, N., ... & Scipal, K. (2017). Coverage of high biomass forests by the ESA BIOMASS mission under defense restrictions. *Remote Sensing of Environment*, *196*, 154-162.

NISAR will focus on the most dynamic ecosystems such as disturbed and recovering forests, inundated wetlands, and croplands. NISAR will measure aboveground woody vegetation biomass and its disturbance and recovery globally at the hectare scale; biomass accuracy shall be 20 Mg/ha or better for areas of woody biomass ≤100 Mg/ha over at least 80% of these areas. Therefore, the mission will focus on areas of low biomass, covering a significant portion of boreal, temperate and savanna woodlands. It will provide seasonal to annual observations of biomass change in the most dynamic forests impacted by AGB disturbance and recovery[1].

The NISAR mission will be able to provide L-band dual pol (HH, HV) observations every 12 days in ascending and descending orbits covering global forests every 6 days. These observations will be used to produce maps of the distribution of forest biomass at 1-ha grid cells. The NISAR radar is designed for global interferometric SAR (InSAR) measurements, but the science products produced do not include direct information on the vertical structure of forests. Rather, AGB is estimated from backscatter measurements and exploits either empirical statistical approaches or inversion of physically-based scattering models that must be calibrated over study sites globally to capture the structural and composition differences of forests in different eco-regions.

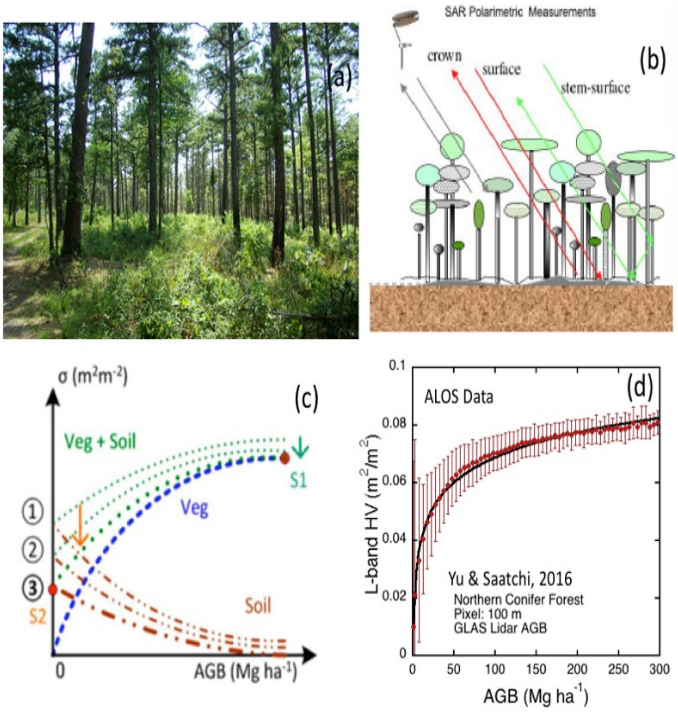


Fig 4. Schematic showing a typical northern conifer forest (a) simulated to an ensemble of trees with stems, branches, and leaves (b) exposed to L-band radar energy with dominant scattering from forest components, (c) suggesting the combined influence of structure and soil moisture on radar backscatter with reduced sensitivity to biomass at higher aboveground biomass values (Haung et al. 2015). The last panel (d) shows the sensitivity of radar backscatter at L-band HV polarization showing the sensitivity to biomass values < 100 Mg/ha with sample data from the entire northern coniferous forests (Yu and Saatchi, 2016).

NISAR CAL/VAL Requirements

The CAL/VAL data required for NISAR are similar and complementary to those for GEDI and BIOMASS. The NISAR algorithm is based on an analytical semi-empirical model with coefficients that are calibrated with structure and biomass information from ground measurements. The forest inventory data in calibration plots must be distributed in different eco-regions and must be accompanied by ALS observations to extend the ground observations and enable validation of the spatial variations of AGB. The size of plots used for calibration of the NISAR algorithm must be either > 1-ha if used directly with the SAR data or smaller (~ 0.25 ha) if used in conjunction with the ALS observations. In addition, forest inventory data can be used to evaluate and report the uncertainty of NISAR AGB at the national or regional scale and for carbon accounting and assessments. In summary, the general requirements for CAL/VAL of NISAR AGB are:

1. A systematic and quantitative framework to identify CAL/VAL regions of interests, number of plots, number of airborne observations, and measurement requirements and protocols.

[1] Yu, Y., & Saatchi, S. (2016). Sensitivity of L-band SAR backscatter to aboveground biomass of global forests. *Remote Sensing*, *8*(6), 522.

2. Ground plots to develop NISAR biomass algorithms for structurally, and ecologically distinct forest types or forest eco-regions globally. The number of eco-regions may vary depending on how sensitive the NISAR backscatter measurements are to structure and wood density variations, and the scale of data analysis (1-ha). The number of ground plots for each forest type must be enough to develop the model coefficients statistically (20-30 plots). The size of the plots depends on their use; if used directly for calibration of NISAR algorithm they must be 1-ha, if used jointly with ALS, they must be 0.25 ha. Selecting study sites with available ground and ALS data allows for extension of the number of plots to larger areas (e.g. 1000 ha) that would provide spatial biomass data to validate the performance of the algorithm locally and spatially.
3. Post-launch calibration of algorithms may be required to adjust the model coefficients to the NISAR backscatter calibration characteristics. Once the algorithms are calibrated and validated with ground plots and ALS, they can be used to estimate AGB from NISAR data.
4. NISAR AGB estimates can be validated using additional ground/airborne data at different spatial scales. Specifically, post-launch validation of NISAR AGB requires either Lidar alone (if collected in the same eco-regions or forest types as before) or Lidar and ground plots distributed globally in different forest types. The validation study sites must be distributed within the same forest types used for calibration but different locations to allow for independent and spatially uncorrelated validation.

2.2.4. Ground/Airborne Mission

To make optimum use of space borne observations, comprehensive ground based measurements of forest structure are required. The ground-based measurements are needed to develop the algorithms used in the interpretation of the satellite data and to validate the resulting products. However, the ground-based measurements and their conversion to AGB follow a similar approach as the remote sensing data. The ground measurements of forest structure must be converted to forest biomass using an algorithm that provides estimates of biomass and the uncertainty at plot scale (Fig. 5). Therefore, the ground or "fourth mission" identified in the workshop must be included in the overall goal of quantifying forest biomass and carbon stocks from NASA and ESA's remote sensing missions. Ecology and forestry scientist participation in space mission CAL/VAL must not be limited to "data providers," but as an integrated part of the overall efforts to ensure that products from the space missions have high fidelity and accuracy.

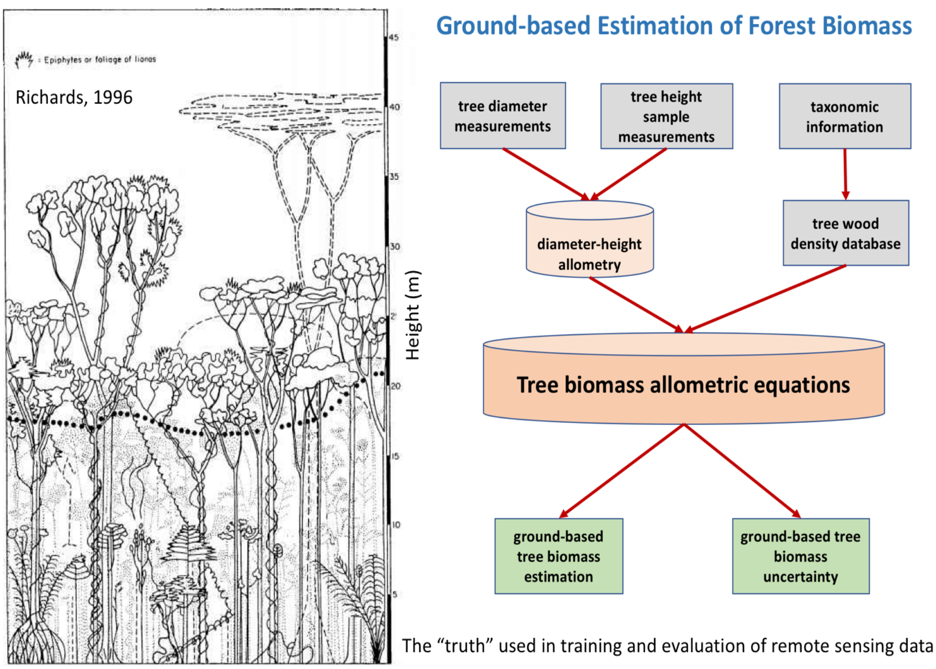


Fig. 5. The ground mission is focused on measurements of tree structure at sample plots and the estimation of the forest aboveground biomass and carbon stocks along with associated uncertainty to be used for calibration and validation of remote sensing data.

The engagement of ground-based forest observation programs requires that the remote sensing community is informed of the constraints (e.g., costs) of long-term forest monitoring for ecological research and national forest inventory. Similarly, ecologists and foresters must be informed about upcoming space missions so that they can learn how these could serve their science. The underlying data collection endeavors of the fourth mission concept depend on and impact research across disciplines. As such, they would ideally be part of a long-term research infrastructure program with its own funding mechanisms. By establishing links to space observations, these networks can reach out to a larger community, which may have access to larger resources for funding in order to maintain and improve the infrastructures, data acquisition, and distributions. In this context, ESA took a first step and implemented the Forest Observation System (http://www.forest-observation-system.net/). The Forest Observation System is a platform to collect, harmonize and share data from existing networks. Funding for this platform is maintained by ESA, but does not cover the actual collection of data and hence relies on the support from existing networks.

The ground mission, therefore, has the following goals:

1. The development of a methodology for identification and acquisition of ground measurements for biomass estimation that would be useful for CAL/VAL of remote sensing data, and backwards-compatible with existing practice of data collection in ecology and forestry.
2. The definition and implementation of a set of quality-control criteria to select ground-based measurements across forest types and eco-regions that includes identified and quantifiable sources of errors in the ground-based estimation of forest biomass.
3. The development of a database of a global network of sample plots that meet the uncertainty requirements and sample size necessary for remote sensing CAL/VAL.
4. The development of synergistic approaches to combine ecology and forestry science AGB estimates with remote sensing measurements of structure and estimates of AGB.

3. Synergistic Opportunities (Day 1 Plenary and Breakout Sessions)

Synergism of the measurements for global products was the topic of the first day of the workshop that included a review of the measurements, algorithms, and products of each mission (Section 2) with breakout sessions on mission synergies including different opportunities for synergism between ground and space observations as well as integration into ecosystem models. Specifically, each space mission has a need for validating their AGB biomass products, which requires collaboration with the international community of forest ecologists and statisticians, who have the knowledge and ground data on forest biomass distributions. This mutual need by the space missions necessitates collaboration among scientists

Table 1. Summary of the NASA and ESA space mission characteristics to be considered for the cross-mission synergistic biomass products.

Missions	Measurement	Product	Area Coverage	Grid Cell	Accuracy	Pre-launch Cal/Val Mission	Cal/Val needs	Post-launch Cal/Val	Sites
GEDI	Height	Height Metrics	50 deg Latitude	25 m footprint; 500 m grid	~ 1m (canopy top footprint level)	ALS & RT modelingj	LVIS samples globally	Model based; LVIS underflights	International crowd-sourced
	Waveform	Biomass > 50 Mg/ha	50 deg. Latitude	25m footprint (1 km grid)	20 Mg or 20% at 1 km, 80% px std. err.; mission	Footprint cal equations; sampling procedure	ALS derived biomass from ground plost at 1-km grids	Model based; LVIS underflights	NFI data Supersites, with ALS derived biomass > 100 ha
BIOMASS	HH, HV, VH, VV Backscatter	Biomass > 50 Mg/ha	Global (excluding North and Central America & Europe)	200 m (4-ha)	20 Mg/ha, annual	Radar biomass equations; algorithm	Plots >4-ha & ALS; across ecoregions	NFI & regional samples ALS & plots > 4-ha	NFI data CTFS; ForestGeo
	PolInSAR	Forest Height	Global (excluding North and Central America & Europe)	200 m (4-ha)	20% of total height	PolInSAR Height Algorithm	ALS & LVIS data distributed across ecoregions	Same approach as pre-launch	Distributed large plots
	TomoSAR Vertical Profile	TBD	Global (excluding North and Central America & Europe)	200 m (4-ha)	TBD	TomoSAR vertical structure	ALS & LVIS data distributed across ecoregions	Same approach as pre-launch	ALS and LVIS data
NISAR	HH & HV Backscatter	Biomass < 100 Mg/ha	Global Low biomass areas	100 m (1-ha)	20 Mg/ha, 80% px < 100 Mg; annual	Radar biomass equations; algorithm	Plots >1ha & ALS data across ecoregions	NFI & regional samples ALS & plots > 1-ha	NFI data Distributed large plots and ALS data
	Time series	Disturbance > 50 change in canopy cover	Global Forests	100 m (1-ha)	80% px, annual	Hi-res optical & ALOS/SAOCOM time series over selected sites	Landsat time series data, high resolution imagery	Same approach as pre-launch	Distributed globally at hot spots of deforestation

and space agencies throughout product development to enable implementation of standards for consistent validation, utilization of shared resources and data from *in situ* measurements, and integration of stakeholder requirements.

3.1. Cross-Mission Synergism

All three missions have significant overlaps in science objectives and products, but focus on different observations, covering different regions, and retrieving different components of AGB at different spatial and temporal scales. The cross-mission synergism is based on the following observations and assessments from the breakout sessions:

a. **Area coverage**, and the science products from the space missions are immediately recognized as complementary such that without the data from all the missions, wall-to-wall coverage and estimation of the global forest biomass are impossible (Fig. 6). BIOMASS focuses on tropical and sub-tropical woodlands at 4-ha, while NISAR is global but limited to areas of low forest biomass at 1-ha, and GEDI not limited by AGB, but with limited coverage collecting sample footprints within +/-50

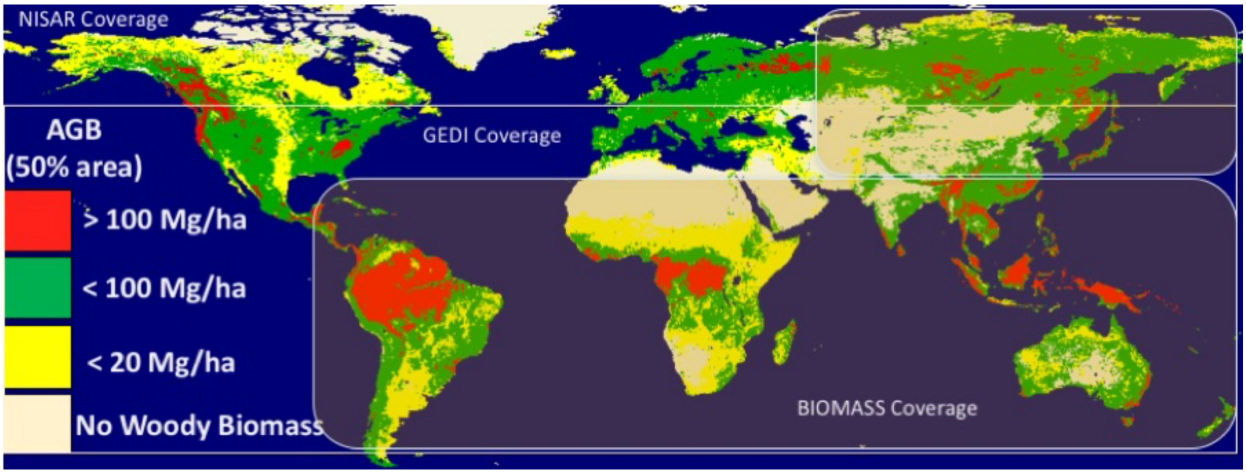


Fig. 6. Maps of coverage of ESA and NASA satellite measurements of forest structure and biomass. The background shows the global coverage area of the NISAR mission and the sensitivity of NISAR to aboveground biomass values < 100 Mg/ha (green and yellow). The BIOMASS mission coverage includes the tropical belt and a portion of the northeast Siberia and the GEDI Lidar sampling coverage from the International Space Station (ISS) between ± 50 degrees latitude.

degrees latitude.

b. **Differences in biomass** components retrieved by each space mission suggest that a synergistic global AGB product cannot be mechanistically produced by combining the maps, but rather requires a systematic data fusion approach. For reference, BIOMASS will estimate AGB when woody biomass is > 50 Mg/ha, NISAR will estimate AGB when woody and leafy biomass is < 100 Mg/ha, and GEDI will estimate AGB for the entire range from height measurements within each 25 m footprint.

c. **Leverage the sensitivities of each measurement approach to cross-calibrate space mission products** can be achieved by using the measurements and products of one mission to CAL/VAL the algorithm or products of other missions. Although every space mission has a different method for estimating AGB, thus making it difficult to directly compare between products, an approach could be used that compares either similar lower level products or leverages different algorithm sensitivities (e.g., NISAR can provide more robust estimates for forests with 20 Mg/ha than for grasslands with ≤5 Mg/ha). For example, GEDI forest height may be used to develop and verify algorithms for the BIOMASS tomography-derived tree height. Similarly, height or backscatter products from NISAR and BIOMASS missions can provide information on the spatial variability of forest structure and biomass to improve the algorithm and resolution of GEDI height and biomass gridded products.

d. **NISAR and BIOMASS measurements spatially overlap, thus enabling data fusions** such as: 1) the combined measurements of L-band P-band for improving the estimates of low biomass forests, 2) the use of higher temporal frequency NISAR observations to reduce the effects of soil moisture and vegetation phenology on the BIOMASS estimation approach, 3) the deployment of a two-frequency algorithm to enable estimation of leaf, branch, and stem biomass, and 4) the use of combined measurements to increase sensitivity of the observations for detecting low-impact forest degradation and slow recovery.

e. **Additional ecological science products** may be produced from synergistic integration of data that enables exploration of the physical characteristics of each measurement. For example, other forest variables such as basal area, volume, branch, leaf, and stem biomass, and forest stand wood density may be derived using the combined sensitivity of radar observations to dielectric constants and tree stem and crown volumes, and ability of Lidar waveforms to measure the vertical distributions and canopy gaps.

3.2. Ground-Space Synergism

An important finding was space missions must consider how their work benefits ground and airborne project objectives. One benefit is that space missions provide a means for understanding regional or global change, specifically with respect to heterogeneity of ecosystems, biodiversity, and social response (e.g., policy, economy, etc.). Another benefit is the sensitivity of the different space measurements of forest structure to better constrain allometric equations used for estimating tree height, canopy crown area and trunk diameter. The key findings from the breakout sessions can be summarized as:

a. **Forest heterogeneity and upscaling** of small-scale measurements at the plot level can be integrated with remote sensing observations to inform landscape and larger scale ecological characteristics of the forests. Variability and heterogeneity of forest structure may not be captured in research plot networks due to difficulty and cost of large-scale sampling. Space mission data on forest structure and biomass from GEDI 25 m footprints to the 100 m NISAR and 200 m BIOMASS spatial grids can help upscale detailed information of plot data to landscape (100-10000 ha) and regional scales where environmental controls and climate and land use disturbances interact with forest function.

b. **Large-scale drivers of dynamics** can be assessed by combining the measurements from ground plots to changes in remotely sensed observations of forest structure and canopy characteristics. Specifically, mission data can facilitate interpolation between ground and remote sensing measurements that would be useful for improving understanding of drivers of tree growth and mortality (from drought, pathogen outbreak, storms, etc.) as well as improving estimates for rates of carbon accumulation in secondary forests.

c. **The spatial and temporal characteristics of remote sensing data can improve relationships between forest ecological and biological characteristics**. Specifically, communities of plants consist of many species, which are thought to live within an ecological niche, that can be defined by the canopy as it reduces the rate of airflow, thus maintaining high and constant atmospheric humidity and other abiotic factors inside the forest.

d. **Carbon accumulation rate, sinks and sources** of forest ecosystems and their contributions to global carbon cycle are currently based on long-time monitoring of individual permanent research plots that include time series measurements of forest structure dynamics. These measurements are comprehensive at the plot locations but lack systematic and widespread sampling. When combined with spatially explicit remote sensing observations of forest structure and biomass, these comprehensive measurements can be potentially upscaled and extrapolated over larger scales.

3.3. Synergism with Carbon/Climate Models

Satellite observations of forest structure and biomass changes from disturbance and recovery can be integrated into Earth System Models (ESM)[1] used for simulating and predicting the response of terrestrial ecosystems to atmospheric changes in temperature, precipitation and CO_2 concentrations. Within these models, a core set of coupled modules, known as Dynamic Global Vegetation Models (DGVMs),

---

[1] Fisher, R. A., Koven, C. D., Anderegg, W. R., Christoffersen, B. O., Dietze, M. C., Farrior, C. E., ... & Lichstein, J. W. (2017). Vegetation demographics in Earth System Models: A review of progress and priorities. *Global change biology*.

represent the interactions of ecosystem carbon and water exchanges with vegetation dynamics, under given soil and atmospheric conditions. The great strength of such models are their predictive capability; by accurately representing the biophysical processes involved, these models can estimate the long-term behavior of vegetation systems under changing climate and atmospheric CO_2 concentrations. To date, when applied at the global scale, these models use generalized descriptions of the system extracted from ground-based inventories of the plant canopy structure and traits from within small sample plots. The models therefore suffer from large uncertainty in predicting carbon fluxes at larger scales. However, these generalized descriptions of vegetation surface can benefit from integrating more realistic and accurate surface parameters such as forest structure (height, vertical profile), AGB, disturbance and recovery processes, and plant functional types in terms of size and wood density. The breakout session identified several synergistic activities to link models and the products of the satellite missions for reduce uncertainty in model predictions of ecosystem responses to various current and future climate and land use disturbances:

a. **DGVMs can be assimilated with biomass stocks.** Many DGVMs have already assimilated forest biomass from radar and Lidar data at local or regional scales[1] and it is predicted that the space missions' biomass data can be readily ingested in the models. In particular, for large-scale model simulations of fluxes, regional and continental scale biomass maps can be used to provide distributions of biomass variations in modeling grid cells[2].
b. **Height-diameter or biomass relationships** are varied across landscapes and regions due to variations of edaphic factors, climate, and nutrient availability. Process-based models of vegetation (e.g., DGVMs) often include processes contributing to stand dynamics such as crowding competition and self-thinning laws. If these models are calibrated using assimilated structure data from remote sensing they can make realistic predictions of height-biomass relationships through time.
c. **AGB is an emergent diagnostic of models at the ecosystem level** as it can be directly used to set the turnover or resident time of carbon. The turnover time is derived from the ratio of total carbon to gross primary production (GPP) of ecosystems. Because changes in the turnover time of carbon in land ecosystems partially determines the feedback between the terrestrial carbon cycle and climate, maps of AGB from the space missions can be used to evaluate the models at more local scales[3].
d. **Transient changes of biomass** from land use, climate and natural regrowth are being readily ingested into models to improve the estimation of carbon fluxes spatially, which may help constrain and improve the detection of changes by remote sensing sensors. Currently, there is no clear method for how to accurately detect change via the NISAR or BIOMASS algorithms, nor is there a method by which to validate such a product. As such, detecting changes of forest structure and AGB from either NISAR or BIOMASS may be subject to large uncertainty, particularly when the changes are small. However, this uncertainty may be reduced at the aggregate scale of modeling grid cells.

---

[1] Antonarakis, A. S., Saatchi, S. S., Chazdon, R. L., & Moorcroft, P. R. (2011). Using Lidar and Radar measurements to constrain predictions of forest ecosystem structure and function. *Ecological Applications*, *21*(4), 1120-1137.

[2] Hurtt, G. C., Fisk, J., Thomas, R. Q., Dubayah, R., Moorcroft, P. R., & Shugart, H. H. (2010). Linking models and data on vegetation structure. *Journal of Geophysical Research: Biogeosciences*, *115*(G2).

[3] Carvalhais, N., Forkel, M., Khomik, M., Bellarby, J., Jung, M., Migliavacca, M., ... & Weber, U. (2014). Global covariation of carbon turnover times with climate in terrestrial ecosystems. *Nature*, *514*(7521), 213-217.

4. Ground Data (Day 2 Breakout Sessions)

Matching data needs for space mission CAL/VAL to data availability and identifying data gaps requires the review of data sources and an understanding of data quality and uncertainty. Thus, workshop participants discussed a general methodological framework that outlines the use of ground/airborne forest structure measurements and AGB estimates that can inform the space mission CAL/VAL plans. In deriving these CAL/VAL requirements for each mission, an important consideration is the need to leverage large comprehensive dataset at a few supersites versus multiple smaller plot networks or national inventory data. The plenary and breakout sessions identified four sources of data that can be integrated in the mission CAL/VAL plans: 1) National Inventory, 2) Supersites and Large Plots, 3) research plots, and 4) ALS. Appendix III and Appendix IV provide lists of identified ground/airborne data.

4.1. National Inventory

National forest inventories (NFI) are used to give unbiased carbon estimates at national or regional levels and are based on systematic or statistical sampling of the forest structure, conversion of the structure to biomass or carbon density using a model, and estimation of mean or total carbon density and the uncertainty over large regions. NFIs are considered the gold standard of forest carbon assessment at national and regional scales, particularly in some countries located in the northern hemisphere temperate and boreal regions.

There has been a significant intellectual work based on statistical techniques incorporated into these NFI systems that can contribute to the CAL/VAL plans and uncertainty assessments for each space mission. In particular, NFI data are based on a large number of small plots and model estimators that provide large-scale estimates of carbon stocks with very low uncertainty. These individual plots cannot be directly used for remote sensing CAL/VAL, but they can be used for regional scale validation. Furtheremore, the NFI plot data can be used to calibrate airborne small footprint Lidar data to predict biomass spatially that can be further resolved at grid cells compatible with measurements and AGB products from each space mission. Alternatively, sub-national spatial information at state or county levels can provide unbiased spatial variations of forest biomass that can be used for validation of AGB patterns inferred from mission products. To take full advantage for the statistical designs incorporated in the NFI data, it may be necessary to include collaborators with forest biometric and statistical expertise in the mission science teams.

When using NFI data for validating space missions, the data must be ranked depending on quality and use with different remote sensing techniques. Only well-established NFI systems (currently, predominantly from temperate or boreal forests) with accurate GPS locations and detailed information on structure and species are recommended to be used for remote sensing modeling and validation of the space mission AGB products. Using such high quality and available national inventory data to validate remote sensing products can increase the applications and use of mission products to a larger community as it will improve the quality of missions' science products by standards used in the forestry and carbon accounting communities.

The biggest disadvantage of using NFI data for space mission CAL/VAL, is the lack of access to the data due to strict government regulations for data dissemination, particularly with respect to exact plot geolocations. Large-scale validation, however, may not require coordinate locations of the plots. Yet, if it is necessary, free access to NFI data with locations may become possible through agreements with the space missions.

4.2. Supersites and Large Plots

The relation between SAR signal (backscatter intensity, PolInSAR) and Lidar waveforms when estimating AGB depends on factors known to affect the relationship between forest biomass and forest height and other structural factors such as stand-scale wood density (which we know varies along gradients of elevation, moisture, biogeography, and disturbance) and canopy height vs. basal area relationships. Having study areas with detailed measurements of forest structure provides parameters necessary for developing and calibrating the space mission algorithms. Thus, the requirements of the space mission CAL/VAL support the development of a dataset based on large plots or a combination of plots. These plots are broadly called supersites and must have the following general characteristics:

a. Representation of the global forests based on general structure and composition types.
b. The ground plots must encompass the full range of variability in biomass to enable space mission algorithm calibration.
c. The study sites must have longer records and established support for pre- and post-launch algorithm CAL/VAL.
d. Supersites used for algorithm calibration should be of high quality and follow standard protocols for data acquisition, processing, and uncertainty assessments. The sites must also include accurate coordinates that can be readily used for remote sensing data analysis.
e. The availability of aerial Lidar coverage over at least 100-1000 ha, flown over the permanent plots, with minimal quality requirements (i.e., such that 1-m canopy elevation models can be constructed)
f. The availability of at least 10-15 already established 1-ha permanent sampling plots or 25-30 0.25 ha plots if used along with airborne Lidar data. The plots should be established according the best forestry standards.
g. Potential availability of terrestrial Lidar with at least two of the permanent plots within the larger plots.
h. The availability of ancillary data to help interpret the remote sensing data such as a weather station and automated soil moisture monitoring (ideally encompassing the landscape-scale variation of soil moisture).

The Forest Global Earth Observatory-The Center for Tropical Forest Science (Forest GEO-CTFS; Figure 7) plots organized and coordinated by the Smithsonian Institute were considered for inclusion in a supersite network to be used for all three space missions' CAL/VAL activities. ForestGEO is a global network of forest research plots and scientists dedicated to the study of tropical and temperate forest function and diversity. The multi-institutional network comprises 62 large forest plots across the Americas, Africa, Asia, and Europe, with a strong focus on tropical regions. The size of each plot can be between 10-100 ha with the majority being 25 or 50 ha in size[1].

Fig. 7. Global distribution of ground-based forest observation sites with large Forest GEO-CTFS plots.

[1] http://www.forestgeo.si.edu

4.3. Research Plots

Most of the world's high biomass forests are in the tropics, and consequently successful global validation of remote sensing products requires a major contribution from developing country scientists and technicians. There are many challenges to leveraging this data for space mission CAL/VAL. First, using this data requires working with each country independently. Other challenges include the logistical complexities of organizing ground data collection, institutional collaborations, intellectual property, permits and health and safety protocols to allow remote fieldwork and plant collection across 50 countries and hundreds of protected areas, and harmonising differing existing ground biomass protocols. Consequently, any tropical partners of this effort must be adequately trained, equipped, insured, and paid[1].

4.4. Airborne Lidar Datasets

Airborne Lidar Scanning (ALS) data with the capability of collecting small-footprint data over forest canopies have been used extensively for estimating forest above ground vertical structure and biomass. The use of ALS for forests has accelerated rapidly in recent years and has been fast turning from a demonstration technology to a key tool for assessing carbon stocks of forests in different ecosystems. ALS data have been integrated in several national forest inventory approaches and are considered an alternative approach for local and large-scale estimation and monitoring of forest biomass[2] The conversion of Lidar height metrics to AGB using local models can readily provide estimates of biomass with similar uncertainty as the ground plots at 1-ha scales[3]. The Lidar-biomass models have been tested in different forest types and ecosystems and are shown to provide consistent results with similar uncertainty in AGB estimation. Therefore, ALS data, when calibrated with ground sample plots, can be used as a proxy for *in situ* observations and extend the pool of CAL/VAL plots to larger areas for all three space missions. Efficiently using ALS data for CAL/VAL will depend strongly on the following requirements.

a. ALS data must have a point density of ≥ 4 points/m^2 to provide consistent measurements of forest canopy height and ground elevation over areas of high biomass and canopy cover.
b. CAL/VAL sites can be selected in different ecoregions with ALS coverage of a minimum area of 1000 ha to allow for algorithm CAL/VAL across a gradient of topography, forest structure, and composition within the same forest type. In addition to cost and logistics of airborne campaigns, a minimum area of 1000 ha will enable validation of spatial patterns and uncertainty of AGB estimations from all three space missions.
c. For AGB estimation comparable with radar measurements from NISAR and BIOMASS and as extensions of ground plots, small-footprint ALS measurements are considered more reliable than large footprint Lidar observations (e.g. LVIS) in geospatial accuracy, locating trees, locating the ground plots.
d. UAV or Drones equipped with small but powerful Lidar sensors with point density > 100 pts/m^2 are becoming more available in the market. Drones have the potential of increasing the size of plot networks to larger areas (~ 100-1000 ha) with relatively low cost, providing an alternative to airborne campaigns to collect CAL/VAL data. However, drones will not have the capability of large-scale data collection.

---

[1] http://www.afritron.org, http://www.rainfor.org

[2] Gregoire, T. G., Næsset, E., McRoberts, R. E., Ståhl, G., Andersen, H. E., Gobakken, T., ... & Nelson, R. (2016). Statistical rigor in LiDAR-assisted estimation of aboveground forest biomass. *Remote Sensing of Environment*, *173*, 98-108.

[3] Asner, G. P., & Mascaro, J. (2014). Mapping tropical forest carbon: Calibrating plot estimates to a simple LiDAR metric. *Remote Sensing of Environment*, *140*, 614-624.

e. ALS data can be converted to forest biomass using a set of sample plots with a minimum size of 50 m (0.25 ha) in tropical forests, and possibly smaller plots in boreal and temperate ecoregions. The number of sample plots to calibrate ALS data depend on the model uncertainty and range of forest biomass. It is recommended that 20-30 plots (0.25-1.0 ha) covering the full range of biomass of a forest type or ecoregion may be enough to develop Lidar-biomass models with lowest possible

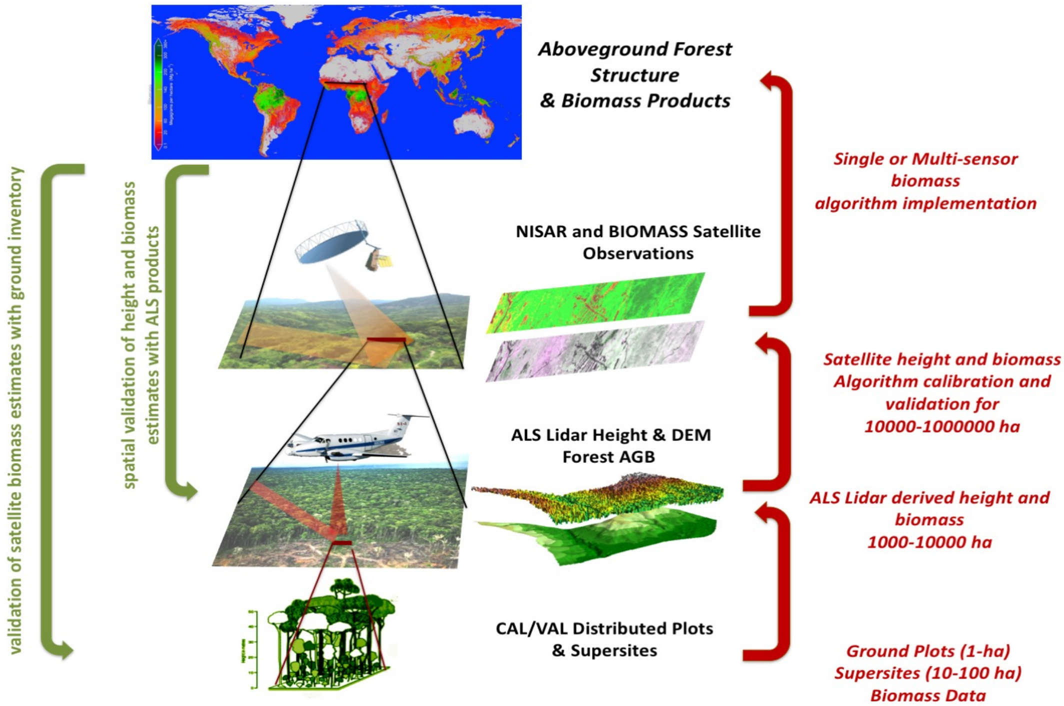


Fig. 8. Schematics of the process of calibration and validation of biomass algorithm, development of height and biomass products and validation of the final products using ground inventory data or ALS derived height and biomass.

uncertainty. The Lidar data can extend the biomass of plots to larger regions (> 1000 ha) for algorithm calibration and product validation.

f. Once the Lidar-biomass models are developed for each site, changes of biomass can be readily detected from repeated measurements of Lidar without recensus of forest structure in sample inventory plots, provided the use of the same ALS system.

g. Combining Lidar and plot data may provide a cost-effective and efficient alternative to detect changes of forest biomass for remote sensing product validation over time.

h. Differences in ALS systems, point density, and view angles must be taken into account in order to collect consistent measurements across forest types and gradients. However, with the most recent advances in Lidar technology and observation configurations, these differences are considered small if the sensors use the same configurations and point density requirements.

5. Calibration and Validation Plans (Day 3 Plenary and Breakout Sessions)

The overall goal of the CAL/VAL plan is to use data and a systematic methodology for CAL/VAL of each space mission AGB algorithm. As such, the CAL/VAL plans for each space mission are based on the mission-specific science objectives in terms of the AGB range and precision, area of coverage, temporal frequency, spatial resolution, and the characteristics of algorithms used in estimating the magnitude and uncertainty of forest biomass. Although CAL/VAL plans will be different for each mission, they overlap in their requirements for data use, overall methodology and activities.

The plan must include both pre-launch and post-launch activities to enable CAL/VAL objectives. For pre-launch the objectives are:

1. To acquire and process data with which to calibrate, test, and improve models and algorithms used for estimating AGB, and
2. To develop and test the infrastructure and protocols for post-launch validation; this includes establishing an *in situ* or airborne observation strategy for the post-launch phase.

For the post-launch activities, the objectives are:

1. To verify and improve the performance of the AGB space mission algorithms, and
2. To validate the accuracy of the AGB space mission algorithms.

Recognizing that the space mission AGB estimation algorithms may vary by forest types or eco-regions, CAL/VAL plans must also address the following questions.

1. At what scale (tree, stand, pixel, region) is the mission product designed for utility?
2. How many eco-regions (type and successional state) are statistically and structurally different within the context of the retrieval algorithms?
3. How many sites are necessary for developing high confidence in the AGB estimation algorithms?
4. What spatial and temporal sampling of biomass are necessary to validate the AGB products?

The workshop focused on addressing these questions and outlining those aspects of CAL/VAL plans that are mutual among the three missions.

5.1. CAL/VAL Methodological Requirements

5.1.1. Allometry

Allometric models are not only the core of ground estimation of forest biomass from inventory measurements, but also are critical for relating the remote sensing measurements to ground estimates of biomass, developing models and algorithms, and assessing the uncertainty. Allometric models have similar characteristics as remote sensing algorithms in that they are developed to convert measurements of structure or their proxy to forest allometric models are developed from regression analysis relating the harvested weight of trees to measurements of diameter at breast height (DBH), tree height, and wood specific gravity (wood density; often inferred from reference databases). The workshop discussed the state of allometric models of global forests and concluded that:

a. Biomass is an estimated quantity from ground measurements of tree size and wood density. This estimation has uncertainty that may vary depending on tree species or forest types globally. The uncertainty of ground estimation of biomass must be propagated through the CAL/VAL analysis of remote sensing of biomass.
b. Allometric models to estimate biomass from ground measurements are available for a large number of species in boreal and temperate regions and at the multi-species level for humid tropical forests.
c. There are regions of the world with insufficient data for allometric models such as in Cerrado woodlands of South America, different types of West and South African woodlands, dry Chaco of South America, Valdivian forests, and some particular woodlands and montane forests . The majority of these regions are within the domain of NISAR and BIOMASS and require ground estimates of biomass.
d. There needs to be prioritization of regions of interest for each space mission to allow further research and support for improving allometric models. This needs to become an integrated part of the CAL/VAL plans for each space mission.
e. There are ongoing activities among forestry and ecological science communities to develop new allometry equations or improve the existing ones. Space agencies must relay to this community for guidance on the use allometric models to develop CAL/VAL data.
f. Terrestrial Lidar data provide an alternative approach to quantify forest biomass from ground measurements and develop new allometric models for multi-species tropical forests or forests with large trees (high biomass forests) that have limited allometric equations.

5.1.2. Uncertainty

Uncertainty assessments are a necessary component of any space mission science products. As such, the uncertainty analysis is an integral part of the validation process for the global biomass products from the three space missions that provide accuracy of the AGB estimation and creditability for the product usage. For satellite-based estimations, validation often refers to comparison of AGB products with independent correlative measurements. Furthermore, the uncertainty of the product after validation must be quantified and presented to the community in a generally accepted form that can facilitate acceptance.

For biomass products, each space mission has a set of accuracy requirements that must be met through the documented validation methodology. The approach can include a variety of data sources such as ground plots, ALS data, field campaigns, or other satellite products; however, accepted standards by the forest inventory for regional and national biomass and carbon stocks estimation communities that must be integrated with each space mission validation process and uncertainty assessments. The workshop discussed these methodologies and provided guidelines that can be adopted by each space mission for developing uncertainty assessments for CAL/VAL plans:

a. The formal modes of inference used in biomass estimation from satellite data is model-based or model-assisted. The satellite data, in the case of radar imagery of BIOMASS and NISAR provide measurements on entire forest stands, and in the case of GEDI provide systematic-clustered sampling of the stands. There are formal and analytical estimators to quantify the uncertainty of estimation at different scales. The key element of model-based inference in satellite remote sensing is to make sure the model or algorithm is correctly specified and can provide unbiased estimate at specified scales.
b. CAL/VAL of the model or the algorithm is the most important element of the uncertainty analysis for all three space missions. Once the model is reliable and is verified to be an unbiased estimator of AGB without any saturation limits, the overall products remain unbiased and precise over large areas.
c. The CAL/VAL of algorithms for forest types or ecoregions (i.e. stratification) require a methodology based on ground and ALS samples that are representative of the range of structure and AGB of forests within the eco-region.
d. Pixel-level uncertainty calculation requires either large scale systematic ground samples or the use of ALS derived biomass estimation within known uncertainty. This requirement suggests that for an eco-region or stratum where the model or algorithm is developed, ground sampling or Lidar data must be available.
e. Requirements (e.g., meeting the 20% uncertainty requirement for more than 80% of grid cells for NISAR and 67% for BIOMASS) need confidence intervals that must be verified through post-launch validation process in different ecoregions or forest types with different AGB ranges.
f. Validation of the biomass products and uncertainty quantification can be performed over large areas where NFI data are available such as the forest inventory ground plots in most of temperate managed forests. For GEDI and NISAR, data from several countries can be used for large scale validation of the products. However, for BIOMASS, large-scale validation may require NFI or extensive ALS sampling in tropical countries (e.g. Brazil, DRC, Tanzania, etc.).
g. If AGB estimation algorithms are non-parametric (e.g., k-Nearest Neighbors), the prediction of AGB at pixel or grid cell level must be accompanied by uncertainty estimates that can readily provide uncertainty of inferences at regional or national scales.

5.2. CAL/VAL Data Requirements

5.2.1. Data Use

Data use refers to availability of *in situ* data and the overall approach of exploiting or making use of the data to develop the CAL/VAL plans and activities for each mission. Data use, therefore, is based on a methodology for sampling design, and a selection of plot networks, or study sites globally. The methodology for data use must address the following questions.

1. What are the main criteria to select sites that are representative and statistically meaningful? The CAL/VAL plans should include statistically representative samples of sites/plots to ensure that the CAL/VAL analysis will allow a testing of whether the mission science requirements are met.
2. To what extent do the protocols for ground data collections be standardized to allow consistency in uncertainty analysis across ecoregions and landscapes?
3. Is there a procedure for data access (e.g., data-sharing agreement) that respects the intellectual property of principal investigators?
4. What are the main approaches to scale up from *in situ* data to the resolution of remote sensing measurements or the grid cells of AGB estimation? How does the mismatch between the *in situ* data and remote sensing resolution affect the selection and use of *in situ* data?

The workshop made key suggestions during the plenary and breakout sessions that can be adopted as guidelines for data use for each space mission:

a. **No designed-based approach for selecting sites globally unless through available NFI data** because a lack of ground plots in different ecoregions and biomes, would make it difficult to develop a statistically-representative CAL/VAL approach using in-situ data globally.
b. **Statistical approaches rely on model-based or model assisted** approach[1] for AGB inference from satellite data rather than design-based. This suggests that ground plots or CAL/VAL sites have to be selected to represent the range of biomass and structure within ecoregions caused by disturbance, soil, and topography[2].
c. **Data use for algorithm CAL/VAL** must be different from data use for validation of science products. By developing a rigorous methodology for algorithm CAL/VAL, there is a strong probability that the science products in terms of biomass map have bounded and predictable uncertainty.
d. **Ecoregions or biomes can be used as the basis for selecting representative sites** across a range of biomass values for algorithm CAL/VAL. Ecoregions or biomes are separated based on species types, structural characteristics, environmental conditions (rainfall, temperature), phenology, and nutrient availability for productivity and growth. These characteristics together define the variations of biomass within each ecoregion.
e. **Requirements for algorithm CAL/VAL** must include the variations in terms of ecoregions and gradients of AGB. Sites that capture the gradient of biomass and the range of structural and landscape heterogeneity and complexity are preferred.
f. **CAL/VAL site location** must be where existing forestry and ecological studies are established or are within larger study sites with existing infrastructure and history of data collection. These sites are often representative of ecoregions and capture biomass variations. Long-term collaborations with site PIs is an important aspect for the long-lasting space missions.
g. **Number of CAL/VAL sites** for each ecoregion must be ≥2 to allow calibration of algorithm in one site and validation on different sites. This approach allows for examining the performance of the algorithm and uncertainty in sites that are within the same ecoregion, but have different landscape or structural complexity.
h. **Large-scale field and airborne campaigns** must be considered as opportunities for acquiring CAL/VAL data. These include: NASA ABoVE campaign in the boreal forests of Canada and Alaska, AfriSAR and TropiSAR campaigns, Smithsonian Large plot networks, Australia's supersites, etc.

---

[1] McRoberts, Ronald E., Qi Chen, Grant M. Domke, Göran Ståhl, Svetlana Saarela, and James A. Westfall. "Hybrid estimators for mean aboveground carbon per unit area." *Forest Ecology and Management* 378 (2016): 44-56.
[2] Ståhl, G., Saarela, S., Schnell, S., Holm, S., Breidenbach, J., Healey, S. P., ... & Gregoire, T. G. (2016). Use of models in large-area forest surveys: comparing model-assisted, model-based and hybrid estimation. *Forest Ecosystems*, *3*(1), 5.

i. **Sharing CAL/VAL site data** across the space missions allows for better coordination of efforts among scientists that collect ground data and the space mission science team members. It will help with efficient use of resources available for each satellite mission, and will ensure cross-verification. However, it is acknowledged that so long as the missions do not invest funding in maintaining the *in situ* facilities, they are bound by strict data-sharing agreements.
j. **Validation sites** for space-based AGB products can be widespread and may rely largely on NFI data for regional and national level validation of products and uncertainty assessments. Large-scale ALS acquired in different countries and regions such as the US, Canada, Scandinavian countries, Brazil, Democratic Republic of Congo, Indonesia, etc. can also be used as the spatial and regional validation of science products.
k. **Protocols for ground data collection** cannot be fully standardized across ecoregions as different sites are managed by different projects with different objectives and funding portfolios. However, some minimal compliance criteria must be met for site selection such as availability of estimates of live aboveground biomass, minimum plot size for each biome, compatibility with global good practice guidelines such as IPCC, GOFC-GOLD, CEOS sourcebook, etc.
l. **Sub-optimum plots** may be available through crowd sourcing or other applications. There are opportunities to also make use of ground plot data that do not completely follow the specified protocols of ground measurements. If uncertainty of measurements is known, these plots can still be used to calibrate ALS data. If they are systematically located across landscapes, they can be used to assess large scale heterogeneity, or mean and variance of forest biomass for comparison with remote sensing derived products. However, in view of the complexity of managing large heterogeneous databases of *in situ* biomass values, it is essential to clearly flag data quality.

5.2.2. Data Gap

Lack of ground data in terms of measurements of structure in plots, and gaps in the distribution of ground data in different forest types or landscapes are identified as the main source of uncertainty in both calibration and validation of algorithms and science products. The breakout session discussions focused on identifying data gaps for all three space missions:

a. **Data availability** was discussed in several breakout sessions and in the plenary meetings. The workshop identified a clear distinction between "existing data" and "available data." There are numerous examples of existing data that does not indicate the type, suitability or availability of that data for space mission CAL/VAL. The discussions were primarily focused on those datasets that meet the requirements and also available for the missions to use for CAL/VAL plans and activities.
b. **Tree height** measurements are not available in most ground plots, particularly in forests with a diversity of tree species and size, and irregularity of structure. Height measurements are important to improve the ground estimates of biomass, develop improved height-diameter relations, and provide samples for direct calibration and validation of height estimation from satellite sensors. Thus, selection of ground plots that include ground measurements of height or have information from terrestrial and airborne Lidar data are preferred.
c. **Elevation gradients** or sites across complex terrains are lacking across different ecoregions. Most existing ground plots are established in relatively flat landscapes to simplify the development of biomass algorithms and provide an improved relationship between remote sensing data and ground-estimated biomass. However, in some regions, remaining intact forests are disproportionally distributed across landscapes with complex topography or at high elevation. Including CAL/VAL sites that cover a range of landscape complexity can improve the CAL/VAL of AGB products and reduce the overall uncertainty of data products.
d. **Secondary/successional/logged** forests have about a 20x higher carbon sequestration rate than old growth forests in most ecosystems. The biomass of these forests is dynamic and requires repeated measurements at the annual time cycles to capture carbon accumulation rates and their contribution to global carbon sink of atmospheric CO_2. These forests are different in structure and may require different remote sensing algorithms and AGB estimation approaches. The dynamic nature of secondary forests and lack of sufficient data in different types forest

regeneration, suggests that the space missions need to add CAL/VAL sites that include a range of secondary forests in different ecoregions.

e. **Woodlands and drylands** cover a large area of global forests and are considered dynamic because of being impacted by different processes of disturbance and recovery. Ground plots in these ecosystems are either rare or small and less suitable for remote sensing analysis. Few regions in the world such as Australia have several study sites that can be included in the space mission CAL/VAL plans. However, Australia's woodland species and structure will not always represent similar ecosystems in other regions (e.g. America and Africa). NISAR, in particular, will benefit from CAL/VAL sites with plots and ALS in woodlands and dry forests.
f. **Inundated and swamp forests** are widespread globally, covering large areas of coastal vegetation of tropical and subtropical regions, a significant area of the Amazon (~ 20%) and the Congo Basin (22%). These forests are extremely under-sampled in ground plots due to the difficulty of access and dynamic inundation cycles, introducing uncertainty in measurements of forest height and structure and for both Lidar and radar remote sensing techniques. Including CAL/VAL sites in these forests, particularly for BIOMASS and GEDI that focus on high-AGB forests, will contribute to reducing the uncertainty of biomass estimation.
g. **High-latitude ecosystems** in northern boreal and tundra fall in low biomass regions. These ecosystems are changing under increasing temperature, fire and climate variability. However, they are under-sampled, particularly in North America and Eurasia. CAL/VAL sites, particularly for NISAR, with frequent observations will provide new algorithms for monitoring vegetation structure and biomass in high-latitude ecosystems.

5.2.3. Data Enrichment

The breakout group on data enrichment focused on identifying the activities or supports required to address the data gaps and improvement of available datasets to meet the requirements in terms of data quality, measurements, and spatial and temporal extents. There was an acknowledgement of the high cost of CAL/VAL plans for each space mission and the large-scale activities that cannot be readily achieved by any one or combination of missions within the timeframe of pre- and post-launch mission requirements. Therefore, a series of activities for filling the data gaps or improving data quality were identified and recommended as part of the CAL/VAL plans.

a. **Standardization of ground plots** in terms of data quality, plot size, plot shape, tree measurement geolocations, identification of ecoregions, temporal observations, and availability ALS or UAV optical observations.
b. **Data acquisition to fill data gaps** is a high priority for all three space missions. Data acquisition may include identification of new study sites with existing data, developing agreements for data availability, and finally support for ground data measurements. Among key data gaps, montane forests, secondary and successional forests in humid tropics, forest wetlands, woodland savanna, and dry forests are of high priority.
c. **Ancillary data** for the selection of CAL/VAL sites may improve the quality and enhance the application of the site. These ancillary data are not necessarily nuisance parameters, but may be functional (e.g. climate, soil, topography), surface conditions such as soil moisture separating same structure and biomass under wet and dry observations from radar, or vegetation phenology (e.g. using sites with frequent satellite imagery, phenocam, etc.), impacting both radar and Lidar observations of forest structure.
d. **ALS data** are required for CAL/VAL activities of all three space missions for a variety of reasons. Among these reasons, is the capability of extending the study sites from a few plots that may be relatively small to the spatial resolutions necessary for comparison to remote sensing pixels. ALS data will provide structure and biomass across variations of landscape (edaphic conditions) allowing for a more robust CAL/VAL of remote sensing algorithms and AGB products. Lack of enough CAL/VAL sites across all ecoregions that have ALS data may provide an incentive for NASA and ESA to support acquisition of ALS data for selected study sites with available ground plots.
e. **Terrestrial Lidar System (TLS)** data acquisition in areas where tree allometry does not exist such as the temperate high biomass regions or savanna woodlands may be the most cost-

effective approach to fill the gaps of tree allometry and ground biomass estimation. The efforts needed for TLS data collection and data processing may suggest that only high priority ecosystems must be considered for TLS-based allometric studies.

5.3. CAL/VAL Trade Space

5.3.1. Data Quality Requirements

Data acquired for CAL/VAL of the space missions includes ground surveys that may vary in quality, defined here to include measurements within the plot, plot size, ancillary data at the plot level, and completeness of uncertainty reporting. The data quality discussions itemized several trade-off areas.

1. **Data quality for CAL/VAL of algorithms may be different than AGB product validation**. Once the algorithms are calibrated and validated for uncertainty reporting over selected sites representing the forest structural types and biomass range, the requirements for validation of mission science products may more relaxed.
2. **Quality control requirements for algorithm CAL/VAL** include: plot size, measurement accuracy, quality of allometric models (local vs. regional), and uncertainty estimates. Distribution of calibration plots may be limited to areas where ongoing research activities have established standards following best practice guidance for measurements and ancillary data. Of high priority are supersites with a variety of plots, ALS, satellite and airborne radar observations of the kind used in NISAR and BIOMASS, along with ancillary information about the landscape variations of forest structure and biomass. Calibration of mission retrieval algorithms requires field sites to report uncertainty. For sites where all required information for comprehensive uncertainty reporting are not available, a "tiered data" approach may be considered, particularly over regions with limited data sets. A tiered approach would specify completeness of reporting that would include reporting uncertainty. Each tier would be clearly specified by each space mission within their CAL/VAL plans.
3. **Validation includes verifying the inference of science products over large areas** by comparing the uncertainty of inference from algorithm to inference from a reference data. The quality of validation or reference data may be dependent on how well the plot design represents the region based on probability or systematic sampling. Validation data can be derived from other satellite (e.g., GEDI) or regional airborne (e.g., US, Brazil, Congo, Tanzania, etc.) data products with uncertainty estimates that provide regional estimates of structure and AGB. Reporting of ALS data quality, area of coverage, point density, and standard processing stream are important to allow cross-sites comparison of products and use.

5.3.2. Spatial Requirements

An important challenge to CAL/VAL is that space mission products do not always align with ground sampling inventories. The most important consideration for determining which ground and airborne datasets to use is how well those data scale to match the scale of priority of the space mission product.

1. **Calibration data may include the use of the existing 50-100 supersites world-**wide (identified by the mission science teams). The supersites must represent the ecosystems and have coverage of remote sensing data used for each mission (Lidar, and radar sensors). Spatial coverage of supersites for CAL/VAL of algorithms must be large enough to provide landscape scale variations of the region (≥ 100-1000 ha depending on the ecoregion).
2. **Plot size** must be larger than the resolution of the space mission data. Complementary ALS data must be at a spatial resolution compatible with ground plots and the grid cell of mission products.
3. **Standard geospatial accuracy** is required for all plots and remote sensing data used for CAL/VAL. Large plots (≥ 1 ha) must be located within 10 m absolute georeferencing accuracy. For analysis with high resolution airborne data, plot location accuracy may be < 1 m for algorithms that use tree-based data (e.g. GEDI). Airborne and satellite data must be

accurate to within 1 pixel. Uncertainty for location accuracy must be included in the overall uncertainty reporting.

5.3.3. Temporal Requirements

Because forest AGB is changing over time either because of growth or disturbance, CAL/VAL requirements include:

1. A "Gold Standard" for Primary field sites that would have coincident acquisition recognizing that there is inherent variability in the retrieved estimates due to influences of varying environmental conditions (e.g., phenology, moisture, etc.).
2. Secondary sites with ≤2 years difference between the timing of data collection between ground, airborne and spaceborne acquisition in non-disturbed sites

6. CAL/VAL Implementation (Day 4 Breakout Sessions)

For implementation, space missions should focus on using existing infrastructure such as supersites and NFIs (Appendix III and IV), rather than building their own. Important to leveraging existing datasets is the standardization of information and data sharing agreements. As of yet, there is no standard database for all field data as field sites are managed by individual PIs/projects. Research Networks can help in developing such a database (e.g., Forest Observing System), however Research Networks do not own their data but rather strengthen collaboration across individually owned and operated research projects, as such Research Networks are an umbrella for advocacy and funding opportunity. They are designed to aggregate data from sites that address global areas of research interest and they require high-profile publications to sustain their value to the community. Such Research Networks can work with space missions to address questions of mutual interest, however there needs to be a network agreement (e.g., MOU). For ALS data, GEDI is already working with field sites to produce a standardized database. Much of the work to develop standardized databases can be shared across missions, provided all missions can agree on a data management plan that includes convergence of requirements, metadata standards, semantics, etc.

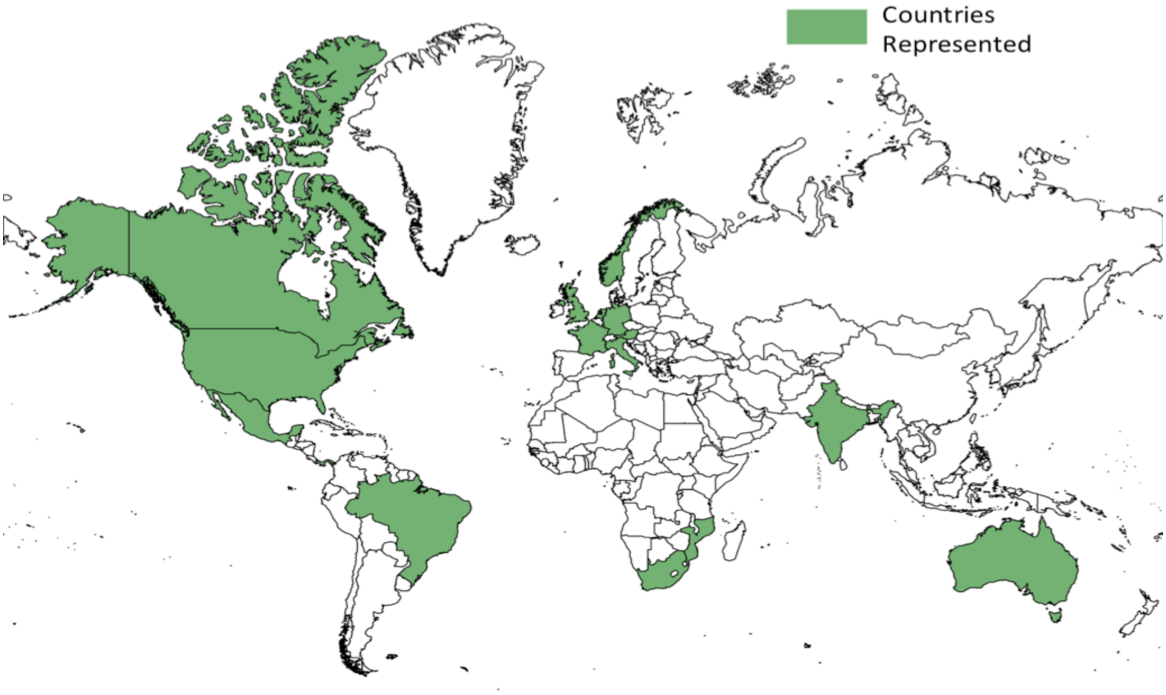
With respect to selecting representative field sites for synergistic mission CAL/VAL, supersites should be used for CAL/VAL of mission algorithms, while ground inventory plots can be used in complement for validation. Any site included in the database must meet both ESA and NASA open data policies.

In converging on CAL/VAL requirements, some biomes (type and successional state) may not be represented by the existing field site data. As such, missions may need to work together on joint campaigns, such as TropiSAR, BioSAR, ABoVE, AIRMOSS, or AfriSAR, in order to augment the availability of needed CAL/VAL data. Key to implementing a synergistic CAL/VAL plan is to first identify what those biomes are, what existing opportunities exist for analyzing the data across missions, and what the trade-off is between multi-temporal aerial campaigns vs. campaigns that cover broader spatial extent.

7. Appendix I: Participant List

Name	Role	Affliation	Country
Amy Neuenschwander	ICESAT-2 Lidar Scientist	Univ. of Texas	USA
Bruce Chapman	NISAR SDT CAL/VAL	JPL/CALTECH	USA
Carmen Meneses	Forest Scientist	CONAFOR	Mexico
Chandrashekhar S. Jha	ISRO Forestry and Ecology Group	ISRO	India
Chris Schmulius	Boreal Forests/RS	Friedrich-Schiller-University, Jena	Germany
Craig Dobson	NASA Program Manager	NASA/HQ	USA
Danilo Mollicone	Programme Manager FAO Global Forest Survey	FAO	Italy
David Kenfack	Forest Ecologist, Botanist, Africa	Smithsonian-ForesteGEO Africa	US
Dmitry Shepaschenko	Forest Ecologist Russia/Ukraine	IIASA	Austria
E. Natasha Stavros	NASA Postdoc/ NISAR cal-val planning	JPL/CALTECH	USA
Eben Broadbent	Spatial Ecologist/Secondary Forest	Univ. of Alabama	USA
Eric Kasischke	NASA Program Manager	NASA/HQ	USA
Erik Naesset	Forest Scientist/RS	Norwegian Univ. of Life Sciences	Norway
George Hurtt	Ecosystem Modeling	University of Maryland	USA
Hank Margolis	NASA Program Manager	NASA/HQ	USA
Helene Muller-Landau	Forest ecologist/modeler	STRI/ForestGEO	Panama
Humberto Navarro de Mesquita Junior	Forest Scientist/National Inventory	Brazil Forest Service	Brazil
Iris Roitman	Cerrado/Savanna Ecologist	University of Brasília	Brazil
Jack Kaye	NASA Associate Director and R&A Lead	NASA/HQ	USA
Jeff Chambers	Ecosystem Modeling	UC Berkeley	USA
Jerome Chave	Ecology/Allometry	Université Paul Sabatier	France
Jim Kellner	Ecologist/RS GEDI SDT	Brown University	USA
John David Armston	GEDI Science Team Member Cal/Val	University of Maryland	USA
John Poulsen	Forest Ecologist, Gabon National Inventory	Duke University, USA	USA
Juha Metsaranta	Canadian Forest Service	Canadian Forest Service	Canada
Kathleen Hibbard	NASA Program Manager	NASA/HQ	USA
Keryn Paul	Forest Ecologist (Australia, TERN network)	CSIRO	Australia
Klaus Scipal	BIOMASS Mission Scientist	ESA	Netherlands
Kostas Papathanassiou	BIOMASS Mission Scientist	DLR	Germany
Lars Ulander	BIOMASS Mission Scientist	Chalmers University of Technology	Sweden
Laura Duncanson	GEDI SDT	NASA/GSFC	USA
Lola Fatoyinbo	GEDI cal/val	NASA/GSFC	USA
Marco Lavalle	NISAR Mission Scientist	JPL/CALTECH	USA
Markus Reichstein	Ecosystem Modeling	MPI Jena	Germany
Mat Williams	Ecosystem Modeling	University of Edinburgh	UK
Michael Keller	Brazil, secondary forests, LiDAR	US Forest Service/Embrapa Brazil	US/Brazil
Natasha Ribeiro	Forest Engineer/Miambo Forest	Universidade Eduardo Mondlane	Mozambique
Nuno Carvalhais	GlobBiomass/Secondary Forest/RS		
Paul Patterson	Forest Scientist/Inventory Statistician	US Forest Service	USA

Paul Rosen	NISAR Project Scientist	JPL/CALTECH	USA
Paul Siqueira	NISAR Mission Scientist	University of Massachusetts, Amherst	USA
Plinio Sist	Forest Ecologist managed forests (TMFO network)	TMFO/CIRAD	France
Ralph Dubayah	GEDI SDT	University of Maryland	USA
Renaud Mathieu	Forest Science/RS	CSIR	South Africa
Sassan Saatchi	NISAR SDT, BIOMASS MAG	JPL/CALTECH	USA
Sean Healey	Forest Scientist	US Forest Service	USA
Sean McMahon	Forest ecologist/modeling	Smithsonian-ForestGEO	USA
Shaun Quegan	BIOMASS Mission Scientist	University of Shefield	UK
Simon Lewis	Forest Ecologist (RainFoR, AfriTron)	University College London	UK
Steven Hancock	GEDI Science Team Member Cal/Val	University of Maryland	USA
Stuart Davies	Forest Ecologist/Asia, (CTFS)	CTFS-ForestGEO Smithsonian	USA
Thuy Letoan	BIOMASS Mission Scientist	CESBIO	France
Tim Baker	Forest Ecologist/RAINFOR	University of Leeds	UK
Valerio Avitabile	GlobBiomass/Secondary Forest/RS	Wageningen Univ	Netherlands
Gabriel Arellano	CFTS support	Smithsonian-ForestGEO	USA



8. Appendix II: Agenda

Tuesday, May 31, 2016			
Day 1: Missions Synergism			
8:30 Coffee			
8:50 – 9:05	01	Welcome + Agenda + Workshop Deliverables/Objectives	Sassan Saatchi
9:05 – 9:15	02	NASA Welcome	Jack Kaye
Plenary Talks – Mission Overview, mission requirements, products, algorithms for biomass, cal/val requirements, what can each mission gives to the larger community (specifically ground/air truth networks to facilitate bidirectional collaboration)			
09:15 – 09:55	03	GEDI	Ralph Dubayah
09:55– 10:30	04	BIOMASS	Shaun Quegan/ Thuy LeToan
Coffee Break			
10:45– 11:25	05	NISAR	Saatchi/Siquiera
11:25– 12:00	06	Q&A	
12:00 – 13:00		*Lunch Break*	
13:00 – 13:15	07	Non-Mission Perspective	Stuart Davies/Jerome Chave
13:15-13:30	08	Charge to the breakouts	
13:30 – 15:00	09	Breakouts: Synergism of cross-mission observations and spatial domains Synergism of CAL/VAL requirements Opportunities for ground-space collaboration	
Coffee Break			
15:30: 16:00	10	Breakout Reports	
16:00 – 17:00	11	Discussion	
17:00		*Adjourn*	

Wednesday, June 01, 2016			
Day 2: Matching Needs and Availability			
8:30 Coffee			
08:50 – 09:00	01	Overview of Previous Day	TBD
09:00– 09:20	02	National Inventory	Erik Naesset
09:20– 09:40	03	Large Plots	Stuart Davies
09:40– 10:00	04	Research Plots	Tim Baker
10:00– 10:20	05	ALS Data	Michael Keller/Jim Kellner
Coffee Break			
11:00– 12:00	*06*	*Q&A on Approaches and Data Availability*	
12:00 – 13:00		*Lunch Break*	
13:00 – 14:40	07	**Regional Data & Discussions**	
	08	Australia TmFO Brazil Amazon Brazil Cerrado Miambo Africa African Savanna Secondary Forests ESA Forest Network Boreal Forest Inventory Canada India Forest Plots Afritron	Keryn Paul Plinio Sist Humberto Mesquita Iris Roitman Natasha Riebero Renaud Mathieu Eben Broadbent Dmitry Schepaschenko Juha Metsaranda Chandrashekar Jha Simon Lewis
Coffee Break			
15:00– 16:30	09	Breakouts: Plot Networks National Inventory Lidar Inventory	
16:30 – 17:30	10	Breakout Reports & Discussion	
17:30		*Adjourn*	

Thursday, June 02, 2016			
Day 2: CAL/VAL, Gaps, Uncertainty			
8:30 Coffee			
08:50 – 09:00	01	Overview of Previous Day	TBD
		CAL/VAL Requirements	
09:00– 9:30 09:30– 10:00 10:00– 10:30	02	**Allometry** **Uncertainty** **Ecosystem Modeling**	Muller-Landau/Chave Patterson/Healey Hurtt/Reichstein
10:30– 11:00	03	Q&A	
11:00 – 12:00	04	Breakouts: Data Use Data Gaps Data Enhancements	
12:00 – 13:00		*Lunch Break*	
13:00 – 15:00	05	Reports & Discussions	
		CAL/VAL Trade Space	
15:00 – 16:30	06	Breakouts Spatial/Temporal Requirements Logistics & Cost *In Situ* Data Characteristics	
16:30 – 17:15	07	Reports and Discussion	
17:30		*Adjourn*	

9. Appendix III: Ground Networks represented at Workshop

Global Biomass Data Repository

Contributor/Representative who attended the workshop

Dmitry Schepaschenko (schepd@iiasa.ac.at), Jérôme Chave (jerome.chave@univ-tlse3.fr), Stuart J. Davies, Simon Lewis, and Klaus Scipal

Country/Region

Forest Observation System (FOS; Forest-Observation-System.net) is initiated by Jérôme Chave (CNRS, France), Oliver Phillips (University of Leeds, UK), Stuart J. Davis (STRI, USA), Simon Lewis (UCL, UK), Dmitry Schepaschenko (IIASA, Austria) and Klaus Scipal (ESA, Netherlands), under support of European Space Agency. FOS (http://forest-observation-system.net/) is an international cooperation to establish a global in-situ forest biomass database to support earth observation and to encourage investment in relevant field-based observations and science. FOS aims to link the Remote Sensing (RS) community with ecologists who measure forest biomass in the field for a common benefit. The added value of FOS for the RS community is the partnering of the most established teams and networks that manage permanent forest plots globally; to overcome data sharing issues and introduce a standard biomass data flow from tree level measurement to the plot level aggregation served in the most suitable form for the RS community. Ecologists benefit from the FOS with improved access to global biomass information, data standards, gap identification and potential improved funding opportunities to address the known gaps and deficiencies in the data.

Site Locations

FOS, currently in the proof-of-concept phase includes such networks as: the Center for Tropical Forest Science Forest Global Earth Observatory (CTFS-ForestGEO), the ForestPlots.net (incl. RAINFOR, AfriTRON and T-FORCES) and the IIASA network in Northern Eurasia. FOS is an open initiative with other networks and teams most welcome to join.

Collection Dates

Plots are revisited on a 5 year rotation with initial year depending on the site/network. The oldest observation started in 1956 in Ukraine with 5-years recensus cycle and the most recently established plot is plot in Gabon in 2016.

Data Collected

A minimum set of database values include: principal investigator and institution, plot coordinates, number of trees, forest type and tree species composition, wood density, canopy height and above ground biomass of trees over 10 cm in diameter. Plot size is 1 ha (preferably) or at least 0.25 ha.

Access

The on-line database (http://forest-observation-system.net/) provides open access for both *metadata* (e.g. who conducted the measurements, where and which parameters) and *actual data* for a subset of plots where the authors have granted access.

Future Data Collection Plans

Future recensus is planned every 4-5 years depending on the availability of funding.

Opportunities for airborne field campaigns in the region

Airborne data (especially LiDAR) is an important component of earth observation, which can link sample plot measurements and satellite observations. FOS will provide airborne data where available (e.g. the ESA supersite in Gabon).

The database will be essential for validating and calibrating satellite observations and various models. The focus is to provide ground support for the future ESA Earth Explorer BIOMASS mission. We are currently exploring synergies with other ongoing projects (e.g. GlobBiomass) and other ongoing or future missions (e.g. NASA GEDI, NISAR; JAXA ALOS; ESA SAOCOM-CS).

Tropical managed Forest Observatory (TmFO)

Contributor/Representative who attended the workshop

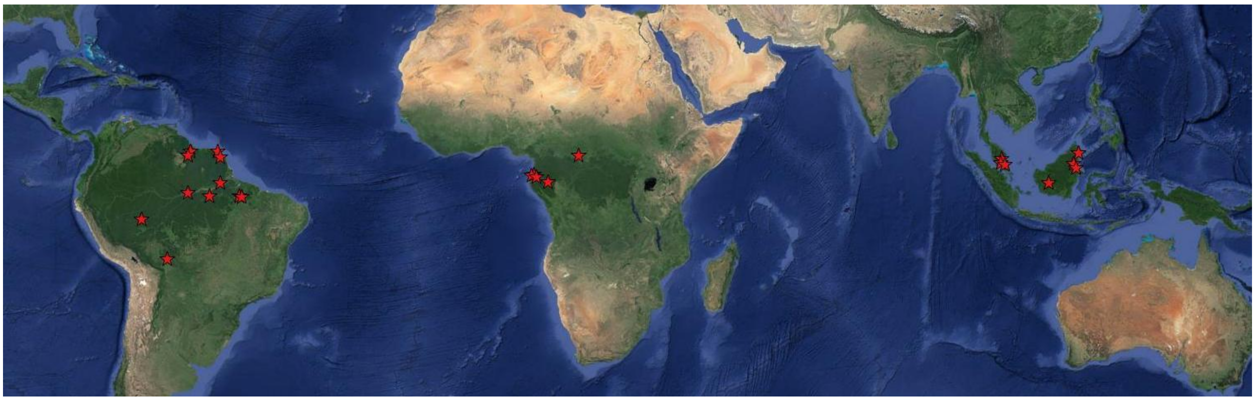
Plinio Sist, Director of the Forests and Societies Research Unit, Cirad (www.cirad.fr), France

Country/Region

The Tropical managed Forests Observatory (TmFO) (Sist et al. 2015) is an international consortium of 17 research institutes joined together to provide field plots in South America, Africa and South East Asia that capture the long-term effects of both silviculture and climate changes on the dynamics of degraded tropical forests. This it aims to improve understanding of the effect of logging on tropical forest dynamics at large spatial and temporal scales specifically in terms of recovery of timber volume, biodiversity and carbon stocks. notably addresses (1) how resilient are tropical forests to logging disturbances? (2) how do forest responses vary across regions and continents? (3) what are the trade-off between economic and environmental values? (4) what is the conservation value of managed forests?

Site Locations

The TmFO Pantropical network gathers 24 experimental sites, including 489 permanent plots, located in 9 countries (5 countries in the Amazon basin, 2 in the Congo Basin and 2 in South East Asia) across South America, Africa and South East Asia. These plots cover a total area of more than 1000 ha and gather more than 6 million trees measured.



The network gathers a total of 481 plots which represent a total inventoried area of 1106 ha. Although, the 60 control plots in undisturbed forest represent 12.5 % of the total number of plots and 25.6 % of the total area, they play a crucial role as a baseline comparison with disturbed stands. TmFO relies upon existing plot networks that jointly cover large gradients of environmental conditions and logging intensities. The mean annual rainfalls of the experimental sites according to regions were not significantly different (ANOVA, $F = 0.95$, $df = 24$, $P = 0.5$, Fig. 3). The highest variations in rainfall is recorded for the Amazon sites, as it ranges from 1020mm in La Chonta (Bolivia) to 3606 mm in French Guiana (Montagne Tortue, Table 1, Fig. 3). Such inherent variability is a real asset for the network and will enable to address questions at both local and regional levels.

In each region, the different sites span large gradients of soil, rainfall and forest type. In addition, logging intensity is also varying among sites. Such large variations are indeed considered as an asset for the network that will allow raising very general conclusions. Moreover, the problem of pseudo-replication that single sites often face will be here overcome when working at regional scale. For those reasons, we are confident in the results and scientific dynamic that will arise from TmFO.

Collection Dates

TmFO gathers existing plots which periods of census and periodicity of measurement varied from site to site. The mean period of census is 12 years with a maximum length of 40 years and 8 sites with a monitoring equal or older than 20 years (Table 1).

Data Collected

As plots were established by different organizations there was no standardized protocol of data collection, but most forest plots share similar measurement standards. The plots were included in the network conform to the following criteria: located in tropical forests with a total area inventoried ≥ 1 ha ; all trees ≥ 20 cm diameter measured with good reliable species identification; rainfall ≥ 1000 mm mean annual precipitation (extracted from WorldClim); consistent and detailed information on logging treatments (e.g. logging intensity) and logging impact (damage assessment); at least one pre-logging and at least two post-logging censuses. In all plots, trees above 20 cm DBH (diameter at breast height), and in some case above 10 cm DBH, were tagged and identified to the lowest taxonomical level. Each site was given a note on the quality of botanical identification: 1., 2, 3. In general, the sites show a rather good species identification at least at genus level (mean = 2.7).

Access

TmFO gathers data from 24 experimental sites managed by 18 different research institutions. One major goal of TmFO is to favour capacity building and data management in partners' institutions. To do so, TmFO plays as an exchange platform for researchers involved in the Observatory. In order to respect data ownership and ensure equitable co-authorship, there is no raw data shared among researchers. The management and intellectual property of a given data set resides exclusively with scientist(s) or institution(s) that own the data. For each site, one to two site leaders have been identified to coordinate TmFO's activities and performing relevant analyses. All research questions and protocols of data analysis are discussed, developed, and agreed upon by all researchers. Once these participatory steps are achieved, a summary of the data is produced, and a collaborative regional analysis is performed among TmFO researchers. Thus, for satellite calibration/validation activities using individual sites, each site coordinator must be contacted. However, for regional analysis to calibrate and validate satellite algorithms, the TmFO network can provide the consolidated data.

Future Data Collection Plans

This depends on each institution responsible for the management of their own site.

Opportunities for airborne field campaigns in the region

Airborne campaigns in the Amazon and Southeast Asia would be extremely relevant as these regions include the most long-term post-logging forest dynamics monitoring network with high quality field data.

T-FORCES, RAINFOR AND AFRITRON

Contributor/Representative who attended the workshop

Professor Simon Lewis, University of Leeds and University College London.

Country/Region

Tropical Asia (Indonesia, Malaysia, Brunei, Australia)

Site Locations

The site locations are currently unpublished, as this is a new, sister network of AfriTRON and RAINFOR. Currently there are 75 plots.

Collection Dates

Data collection varies by plot location, with the oldest plots in the 1950s, the most recent in 2014, and many others from early 2012-2014.

Data Collected

Plats are mostly 1 ha, but range from 0.2 ha to 4 ha. All trees ≥10 cm diameter are measured, tagged, and identified to species (where possible). There are over 75 multi-census plots. For the 50 plots that have ~60 trees per hectare, including all largest trees, tree heights were measured. These are permanent plots and are thus designed to be re-censused in the future.

Access

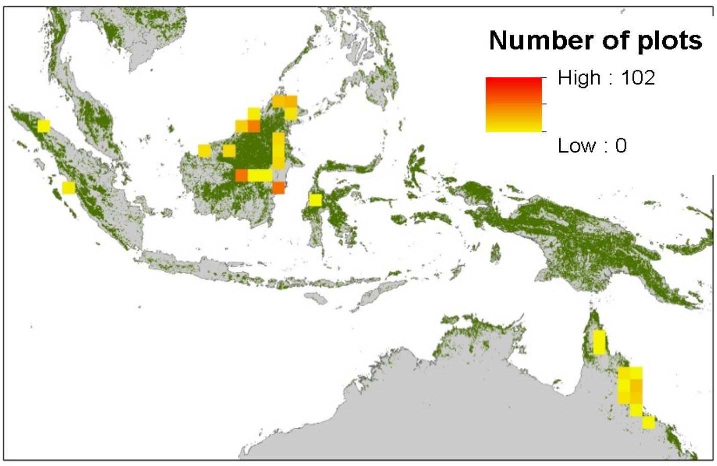
All data is owned by local partners who control access, but are usually open to collaboration. Access is available through forestplots.net.

Future Data Collection Plans

The funding for this project has ended and further efforts are unfunded.

Opportunities for airborne field campaigns in the region

There are many opportunities for synergistic airborne and field campaigns, which could follow the recent successful AfriSAR model of funding for ground data measurements alongside the airborne sensors flying over the plots.



Tropical South America

Contributor/Representative who attended the workshop

Professor Simon Lewis, University of Leeds and University College London. NB, main contact is Prof Oliver Phillips, University of Leeds, o.phillips@leeds.ac.uk)

Country/Region

Tropical South America (Brazil, Bolivia, Colombia, Ecuador, French Guiana, Guyana, Peru, Surinam, Venezuela)

Site Locations

Sites are part of the RAINFOR network (www.rainfor.org), for which plot details are described in Brienen et al. 2015, Nature and associated data: https://www.forestplots.net/data-packages/brienen-et-al-2015 (accessed 25 September 2016). Data are housed at forestplots.net.

Collection Dates

The collection dates vary by plot with the oldest plots from the 1950s, the most recent in 2016, and many from the early 2000s.

Data Collected

Most plots are 1 ha, but size ranges from 0.2 ha to 4 ha. All trees ≥10 cm diameter measured, tagged, and identified to species (where possible). There are >700 single census plots and >350 multi-census plots. There are 300 plots with ~60 trees per hectare, including all largest trees, for which height data has been collected. These are permanent plots, so they are designed to be re-censused in the future.

Access

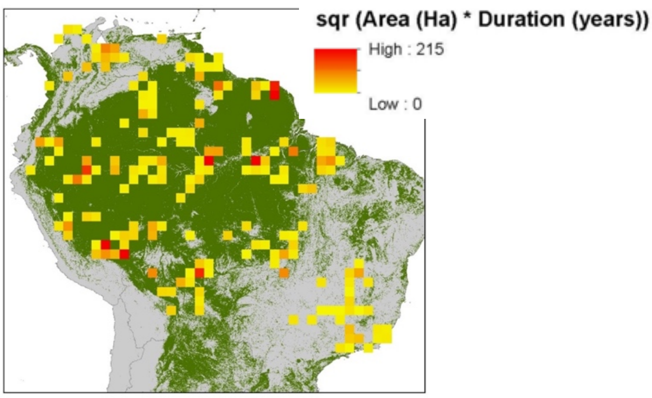
Plot data is owned by local partners who control access, but who are usually open to collaboration. A smaller subset of plot data is publicly available (see forestplots.net).

Future Data Collection Plans

The project is currently unfunded after mid-2017.

Opportunities for airborne field campaigns in the region

There are many opportunities for synergistic airborne and field campaigns, which could follow the recent successful AfriSAR model of funding for ground data measurements alongside the airborne sensors flying over the plots.



Cerrado, South America

Contributor/Representative who attended the workshop

Iris Roitman, post-doctoral scholar, University of Brasilia

Country/Region

The Cerrado biome is a wet seasonal savanna that occupies approximately 24% of the Brazilian territory. It the second largest biome in South America, with a large latitudinal gradient and environmental variation. It is the world most biodiverse savanna, and considered a biodiversity hot spot. Although the carbon content of a typical cerrado vegetation (cerrado *sensu stricto*) corresponds to aproximately 25% of the carbon of a forest, land-use changes are much faster in the Cerrado biome! Estimates indicate it has already lost approximately 50% of its original, mainly due to live stock and agricultural activities (Brazil 2016). Cerrado CO_2 emissions due to land use changes are significant. Between 1994 and 2002 net emissions due to land use changes represented 17% of total net emissions. Between 2002 and 2010, while emissions in the Amazon have decreased, they have increased in the Cerrado.

One of the main challenges for estimating Cerrado's biomass is its high structural diversity, with a wide range of grassland, savanna and forest physiognomies. The Brazilian Institute of Geography and Statisticas (IBGE) has proposed 28 different physiognomies for the Cerrado. Aboveground biomass is highly variable between and within physiognomies: grasslands with scattered trees (4 to 17 Mg. ha-1), cerrado *sensu stricto* (20 to 58 Mg.ha-1), dry, closed canopy forest (29 to 72 Mg.ha-1) (Ottmar et al. 2001).

Site Locations

There are a few permanent plot networks in the Cerrado (Rede de Parcelas Permanentes, the PPBIO project), but none of them of them use 1 ha plots. Plot dimensions for sampling cerrado vegetation are often 20 x 50 m (Felfili et al. 2005). Also, LIDAR data over 1009.01ha has been collected in the Itapirapuã and Goiás municipalities, Goiás state, Brazil.

Collection Dates

The existing permanent plots are revisited in 3 to 5-year intervals. LIDAR data was acquired June 20, 2015 and July 7, 2015.

Data Collected

Data collected in the permanent plots include mapping, but they do not include mapping trees with precision (1 m precision) if at all. Other data collected includes species identification, diameter, and height. Some researchers include soil sampling, but not all. There are two plot networks, one of which is the PPBIO-Cerrado network, which was designed to gather a broad range of data (not only vegetation) including animal biodiversity. Some of the samples are taken in lines according to the topographic contour lines. The LIDAR data was collected with an average return density of 44.79 points per square meter and an average first return density of 35.06 points per square meter (metadata available – last accessed September 28,2016:
https://www.paisagenslidar.cnptia.embrapa.br/geonetwork/srv/por/catalog.search#/metadata/c8a06ed4-e725-4674-b999-f7141d2643c4).

Access

Permanent plots are a part of two networks: 1) "Rede de Parcelas Permanentes do Cerrado" and 2) PPBIO-Cerrado. Rede de Parcelas Permanentes do Cerrado network is part of the Brazilian Forest Service, and the best point of contact for this data is Joberto Freitas (Brazilian Forest Service). The PPBIO-Cerrado network started in Amazon and the person responsible is William Ernest Magnusson (bill@inpa.gov.br) from the National Institute of Amazonian Research (INPA). LIDAR data is available, but a registration is needed.

Future Data Collection Plans

It would be possible to work with the University of Brasilia and the Chico Mendes Institute for Biodiversity (ICMBio) responsible for Brazilian Federal Conservation Units, such as National Parks to design high-quality new plots suited for calibration/validation for satellite algorithms. External funding will be needed, since there have been extreme cuts in research funding by the Federal Government in Brazil recently. In order to plan this mission, the following aspects should be considered:

- The physiognomies that would be covered – e.g., would the effort include only "wooded savanna" (which represents 29.4% of the original Cerrado vegetation) or other vegetation types such as dry forests and gallery forests?
- The number of plots for each vegetation type that are needed to be representative of structural variability
- Plot locations that are well distributed in the biome and established in non-private protected areas, such as National or State Parks and Ecological Reserves.

If future data were needed Dr. Iris Roitman or Professor Bustamante at the University de Brasilia can assist in getting authorization in the National Parks and coordinating efforts.

Opportunities for airborne field campaigns in the region

Unless future data collections adapt the sampling strategy and scale the plot sizes, there is no potential for future airborne campaigns. There has been one LIDAR flight, but no future plans for more that could complement SAR airborne flights needed for synergistic calibration and validation of the different satellites.

Brazil, South America

Contributor/Representative who attended the workshop

Humberto Navarro de Mesquita Junior

Country/Region

Brazil

Site Locations

There are two types of field sites. First, BIG continuous concessions (where each plot area mapped uses LIDAR to cover 500 to 3,000 ha/year) located in: National Forest of Jamari (started 2010), Saraca Taquera (started 2011), Jacunda (started 2014), Altamira (started 2015) and Crepori (starting 2017). These concessions cover ~869,000 ha across 14 Forest Management Units, for each of them 1/30th unit area are managed per year (with 29 years before inventorying and applying sustainable forest management in the area again). Second, the wide-spread, systematic National Forest Inventory (NFI) plots including ~15,000 20km x 20km inventory clusters of 200m x 200m with 1.6 ha area of sample plots and 3.2 ha area of sample plots in the Amazonian Region.

Collection Dates

From 2010 to current year, for concessions from 1/30th unit area every year increasing to cover the full area of concessions by surveying approximately 29,000 ha per year. The NFI has currently done 6,000 clusters and is expected to finish all of Brasil (15,000) in 2019.

Data Collected

Concession plots have both field data (X and Y position, high, DBH, and species for each tree with more than 40cm DBG) and LIDAR data collected over 1/30th unit area per year. As of 2016, the airborne LIDAR covers an area of 5,000 ha/year in different National Forests and in areas with logging to provide pre-harvest, the same year as harvest, and post-harvest for monitoring purposes.

For the National Inventory, each cluster has 40 plots of 10m x 10m data (DBH and height for trees bigger than 10 DBH), 4 plots of 5m x 5m (DBH and height for trees bigger than 5cm DBH), and 1 plot of 5m x 5m all plants smaller than 5 cm DBH).

Access

Data are available for download on LIDAR and field data for the concessions from Paisagens Sustentáveis Project and NFI data from the Brazilian Forest Service. Currently, data is available on Paisagens Sustentáveis Proect through the website:
https://www.paisagenslidar.cnptia.embrapa.br/geonetwork/srv/por/catalog.signin?node=srv

(with registration). Other data can be transferred upon request via FTP.

Future Data Collection Plans

From the concessions only 1/30th unit part of 869,000 ha (~29,000 ha) is surveyed per year, LIDAR and field inventory is expected for at least the next 30 years. An institutional goal is to increase concession from 869,000 ha to 1,300,000 ha after 4 years (institutional goal).

Opportunities for airborne field campaigns in the region

Every year we do the aforementioned LIDAR campaign and we done have some airborne data collection using other technologies, e.g., a P band airborne SAR data from BRADAR Co.

India

Contributor/ Representative who attended the workshop

Dr Chandrashekhar S. Jha, Group Director, Forestry and Ecology Group, National Remote Sensing Centre

Country/Region

India

Site Locations

There are four major sites with both LIDAR and field data collected in:

1. Uppangala, Karnataka, South India has inventory in collaboration with French Institute of India, Pondicherry and includes 7 km^2 of LIDAR, one 30-ha permanent plot, and 15 1-ha plots

2. Yellapur, Karnataka, South India has inventory in collaboration with AMAP, Montpellier, France and includes 100 km^2 LIDAR and 22 1-ha permanent plots)

3. Betul, Central India has 100 km^2 LIDAR and 13 1-ha permanent plots

4. Achanakmar, Central India has 100 km^2 LIDAR and 15 1-ha permanent plots planned to be inventoried in October 2016.

Collection Dates

Aerial LiDAR has been collected in each location:

- Uppangala – 2005 (~ 1 pt /m2) and March 2013 (>6 pts/ m2)
- Yellapur – planned between Oct - Dec 2016
- Betul – April 2014 (>10 pts/m2)
- Achanakmar – October 2014 (>10 pts/m2)
- And field inventory collected following the CTFS/Rainfor protocols in each location:
- Uppangala: 2013?
- Yellapur: 2014 and 2015
- Betul: 2015
- Achanakmar: planned to be inventoried in October 2016

Data Collected

There were two types of data including aerial LiDAR and field inventories following Rainfor/CTFS protocols, which include mapping and identifying stems >10cm DBH, recording location (+/- 1m), and measuring heights.

Access

Aerial data in restricted by the Government of India, and cannot be shared, derived products – CHM can be shared. Inventory data can be shared, with specific agreements.

Future Data Collection Plans

We are working towards expanding our network of large sites and are in the process of obtaining funding for a planned addition of 10 large sites, each with 100 km^2 LiDAR and at least 15 1-ha plots for tree inventory for biomass assessment, which would have a planned completion for 2019.

Opportunities for airborne field campaigns in the region

Aerial data collection in India is restricted, but has been done (e.g., AVIRIS-ng). ISRO/ NRSC is one of the few agencies which are permitted to collect imagery and sensor data from aerial platforms. Thus, future airborne campaigns should explore the possibility of a joint ISRO-NASA or ISRO-ESA campaign.

Australia

Contributor/Representative who attended the workshop

Keryn Paul, Principle Research Scientist, CSIRO, Australia

Country/Region

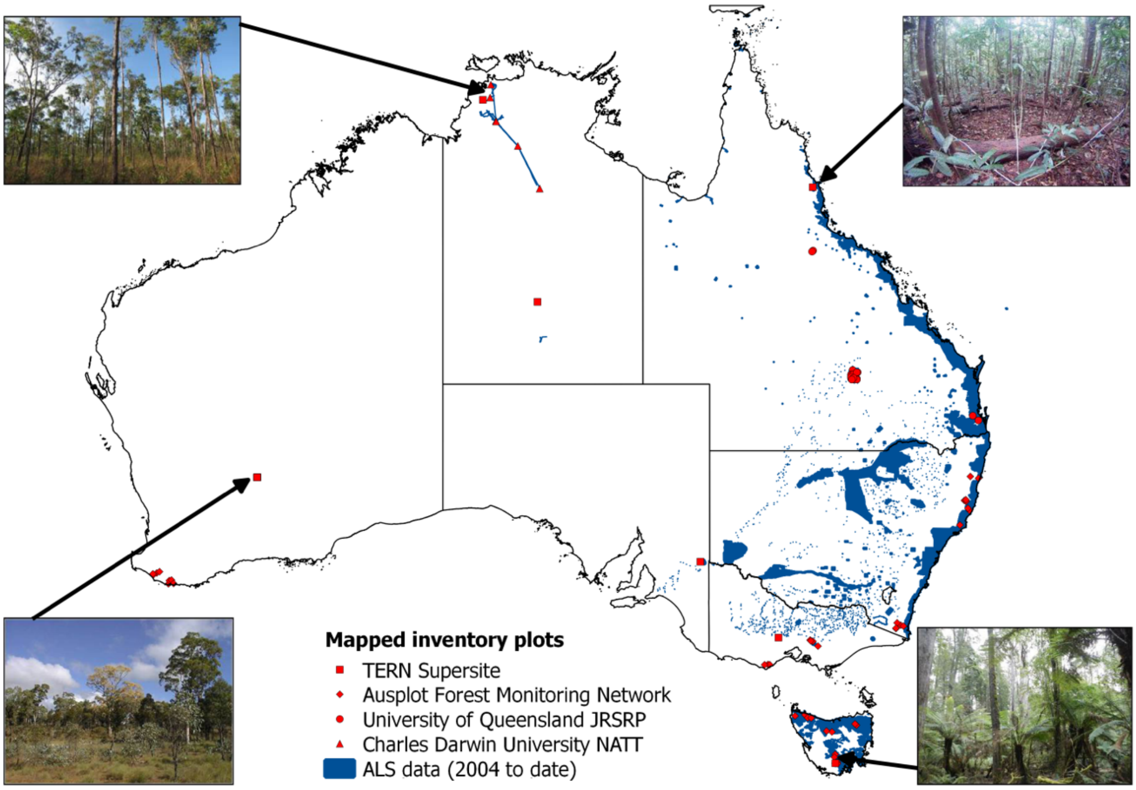
Australia

Site Locations, Collection Dates and Data Collected

Australia has many sites relevant for calibration and validation of satellite biomass retrival algorithms. Of particular interest for calibration include many of the TERN SuperSites (http://www.tern.org.au/Australian-Supersite-Network-pg17873.html; accessed 12 September 2016). Specifically:

Robson Creek: High C forest. Tropical rainforest
Warra: High C forest. Production forest in Tasmania
Tumba: Moderate C forest. Production forest in SE Aust.
Injune: Woodland in central Qld. Representative of many Aust. woodlands, including disturbed
Mulga: Mulga woodland in southern Australia. Also represents a lot of Aust.
Karawatha: Moderate C forest. Native eucalypt sclerophyll forest.
Great Western Woodlands: Plot data, ALS, de-stocked property, fire-chronosequence, low biomass
Litchfield Savanna: Plot data, ALS, TLS, fire management, low biomass
Calperum Mallee: Plot data, ALS, TLS, de-stocked property, fire recovery (2013), low biomass
Alice Springs Mulga: Plot data, ALS, low biomass

Validating retrieval algorithms can utilize the Australian Biomass Plot Library (http://onlinelibrary.wiley.com/doi/10.1111/gcb.13201/abstract; Accessed 25 September 2016), collation of stem inventory data across; 12,663 sites from most bioregions of Australia with allometric estimates of biomass applied using the Carbon Analysis Tool (CAT). The CAT software facilitates the estimation of biomass and its uncertainty through the use of log-log allometric models to predict mass from non-destructive stem diameter measurements, and a range of associated calculations. Input in stem inventory data. Output is plot- and site-level total biomass and its error. These sites use *generalised allometric models of above- and below-ground biomass* derived from 15,054 trees of shrubs that have been sampled for biomass across Australia. Analysis showed that allometric models relating biomass to stem diameter were generalizable at the level of plant functional type. A similar approach could be followed in other jurisdictions to improve the efficiency of ground-based estimates of biomass.



Collection Dates

Collection dates are variable by site:

Robson Creek: 2011 (25 ha), 2015 (1 ha plot). Understorey: 2012, 2 ha. Additional (within lidar coverage): 1 in 2013, 1 in 2015, 2 1ha plots
Warra: Plot data: 2012
Tumba: Plot data: 2015 (10 transects within the 1 ha plot – each transect is 100 x 10m)
Injune: Plot data: 2000, 2009, 2015. 34 plots (50 x 50m plots covering 60 x 40 km area)
Mulga: Plot data: 2014 (6 x 0.1 ha plots within 1ha plot)
Karawatha: Plot data: 2014 (3 x 0.25 ha plots), 2009 (33 0.5 ha plots)

Data Collected

Proposed detailed study sites useful for initial testing of NISAR, BIOMASS, and GEDI mission algorithms (Fedrigo, M & Armston, J. 2016)

Data	Robson Creek High C forest. Tropical rainforest	Warra High C forest. Production forest in Tasmania	Tumba Moderate C forest. Production forest in SE Aust.	Injune Woodland in central Qld. Represents a lot of Aust.	Mulga Mulga woodland in southern Australia. Also represents a lot of Aust.	Karawatha Moderate C forest. Native eucalypt sclerophyll forest.
Plot Data	2011 (25 ha), 2015 (1 ha plot) Understorey: 2012, 2 ha Additional (within lidar coverage): 1 in 2013, 1 in 2015, 2 1ha plots	2012	2015 (10 transects within the 1 ha plot – each transect is 100 x 10m)	2000, 2009, 2015 34 plots (50 x 50m plots covering 60 x 40 km)	2014 (6 x 0.1 ha plots within 1ha plot)	2014 (3 x 0.25 ha plots) 2009 (33 0.5 ha plots)
Destructive Harvest	-	40 Obliqua	5 Delegatensis	22 Callitris 6 Poplar box 6 Ironbark	-	-
TLS	2014 – centre of each hectare	~4 plots	Yes	2009, 2015	-	2013, 2014 (DWEL and Riegl), 2015
ALS * Warra and Injune both flown with 2 different instruments*	2012	Multiple years, 2000 onwards	2009	2000, 2009, 2015	2014	2009 2013 (two wavelengths) 2014
Aerial photos	Yes			2000, 2009, 2015		Yes

Hyperspectral RS	2012	Yes		2000, 2015	Yes	Yes
Radar (all Sentinel 1 coverage)	L band: 1992-1998, 2000, 2007-2010, 2014-	L band: 1992-1998, 2000, 2007-2010, 2014-	L band: 1992-1998, 2000, 2007-2010, 2014-	L band: 1992-1998, 2000, 2007-2010, 2014-	L band: 1992-1998, 2000, 2007-2010, 2014-	L band: 1992-1998, 2000, 2007-2010, 2014
Spot 5	Yes	Yes but clouds		Yes		Yes
Other	Drone coverage				Drone	

Access

All data is available. Contact Mike Liddell and John Armston/Richard Lucas. The Australian Biomass Plot Library is opening accessible (http://data.auscover.org.au/xwiki/bin/view/Product+pages/Biomass+Plot+Library; 12 September 2016)

Future Data Collection Plans

Future data collection is subject to the availability of funding.

Opportunities for airborne field campaigns in the region

There could be good alignment between airborne campaigns and with an Australian Government effort to improve their carbon accounting model predictions of regenerating biomass in rangelands and woodlands. It would be best to propose national-scale collaboration with Australia's network of permanent sample plots for facilitation of the ground-based assessment and ALS assessment of these plots.

Mozambique, Africa

Contributor/Representative who attended the workshop

Dr. Natasha Ribeiro, Eduardo Mondlane University

Country/Region

Mozambique, Southern Africa

Site Locations

Plots are located within the Niassa National Reserve across the miombo woodlands. These are calibration plots (for landsat and radarsat), 30 m in diameter, they are located across a fire frequency gradient from east to west of the NNR.

Collection Dates

Plot data has been collected every 5-6 years from 2004, with the most recent collection in 2015.

Data Collected

The data collected include forest biomass, DBH for trees >5 cm, tree height, soil carbon collected in the first 30cm layers, grass biomass, and tree biomass.

Access

Data is available upon request, which should be directed to Natasha Ribeiro.

Future Data Collection Plans

There are plans to continue sampling all plots every 4-5 years.

Opportunities for airborne field campaigns in the region

Currently there are no planned airborne campaigns using either LIDAR nor SAR, and the field plots are small, but it would be possible to increase plot sizes.

South Africa, Africa

Contributor/Representative who attended the workshop

Dr. Renaud Mathieu, Research Group Leader Earth Observation, Natural Resources and the Environment, Council of Science and Industrial Research (CSIR)

Country/Region

South Africa

Site Locations

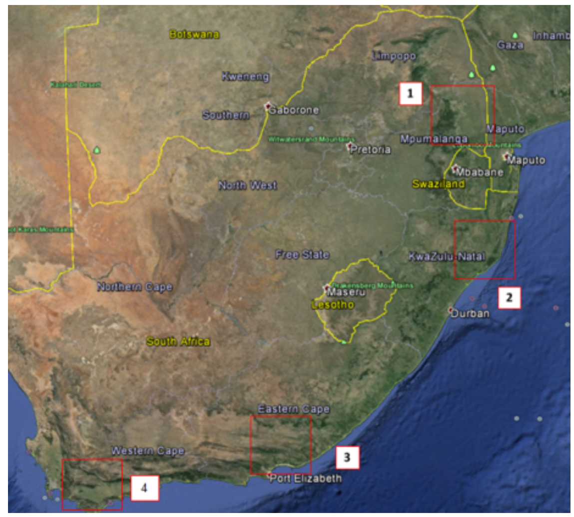
There are four pilot sites for collecting above ground biomass data and that capture the variability of South African forested landscapes:

1. Lowveld, Kruger National Park (Province Mpumalanga, Limpopo): vegetation type plantation (eucalyptus, pine, acacia), mountain indigenous forests, savannahs

2. Duku Duku area & iSimangaliso Wetland Park (province KZN): vegetation type, plantation (eucalyptus, pine, acacia), coastal indigenous forests, savannahs, mangrove

3. Addo Elephant Park area (Province Eastern Cape): vegetation type thicket

4. Alguhlas Plains (Province Western Cape): vegetation type woody alien invasive, fynbos



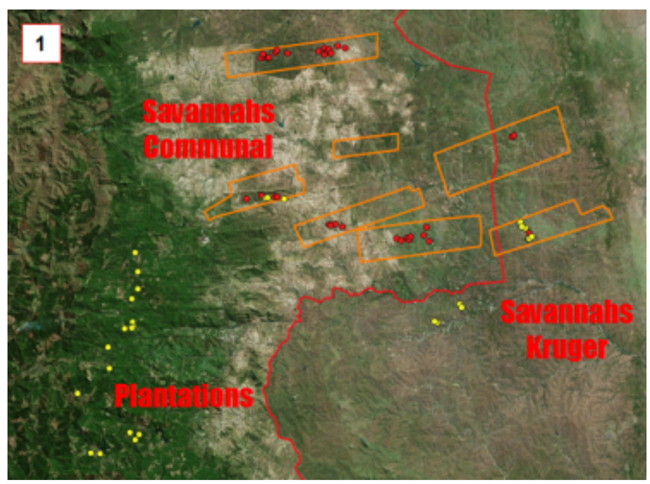


Figure. *Above yellow / red dots, some plots collected in 2012, 2015-16 respectively.*

Collection Dates

To date two field campaigns have been completed in 2012 covering 37 plots in Lowveld savannahs and in 2015-16 covering 56 plots in Lowveld / KZN savannahs, indigenous forests, and plantations.

Data Collected

Data are collected for developing regional Earth Observation products derived from both SAR and optical sensors for assessing woody biomass for carbon stocks, bush encroachment, and monitoring forest degradation. Plots are georeferenced 1-ha square plots with woody height, DBH, and species are collected. All trees with DBH > 10 cm are collected, and tree/shrub between 3-10 cm are sampled within 1-ha SAR mapping plot and nested 0.0625 ha discrete return LIDAR mapping when coincident LIDAR tracks are available (campaign 2012):

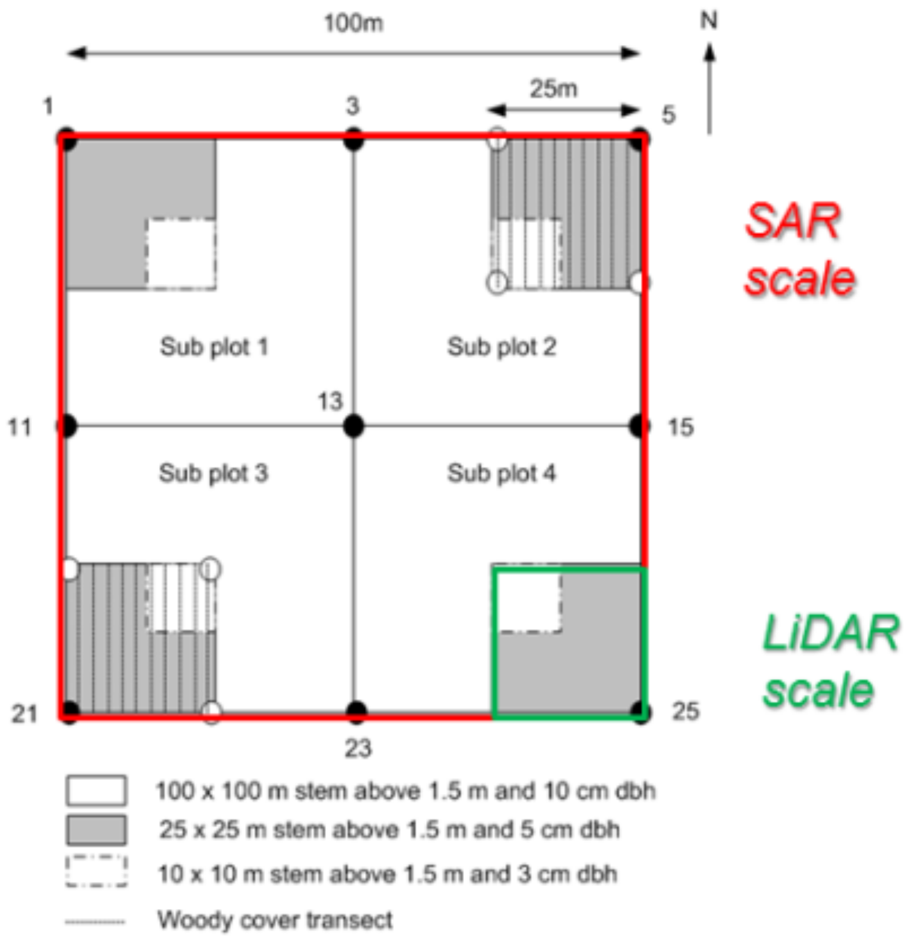


Figure. Field sampling for SAR and LIDAR AGB mapping

In addition, CSIR has also collected ad-hoc LIDAR datasets in South Africa and in the region, acquired by third parties for a variety of uses, to support SAR forest mapping. LIDAR data are discrete return airborne data, collected from 2006+.

Access

Data sharing (when owned by CSIR) possible via scientific collaboration.

Future Data Collection Plans

Currently there is no long-term funded national initiative to collect data for monitoring woody biomass in South Africa and no permanent plots have been established. Activities depend on ad-hoc research and development projects developed by individual scientists. Future funded activities at the CSIR (2016-19) will focus on national SAR-driven biomass mapping and change for 1990-2015. Data to be collected over main vegetation types will include 80-100 additional 1-ha plots, concurrent acquisition of discrete airborne LiDAR.

Opportunities for airborne field campaigns in the region

There are two main areas for which joint future airborne field campaigns could benefit future biomass satellite data. The target areas, each with unique biomass and a structural biome types as well as representing core deforestation/degraded forested biomes in Africa, include:

1. The unique indigenous mountain forests that are typically semi-arid woodlands and savannahs, broadleaved and fineleaved (20-60% cover, AGB < 70 t/ha) in SA Lowveld in the Greater Kruger National Park.

1. South African Albany thicket in the Eastern Cape (Addo Elephant Park region), which has high carbon content stored in dense impenetrable vegetation with spiny, often succulent trees and shrubs < 5m tall.

There are four benefits for conducting joint airborne and field campaigns in the region. First, there are local team expertise on both using SAR and LiDAR data for monitoring of Southern African savannahs for forest inventory and change detection as well as modelling for error budgeting. Second, there are local datasets and activities including: ~100 ground monitoring plots, a 4-ha plot and 10-year flux station with fire experiments and the Kruger field super sites (rainfall and geological gradients), existing LiDAR and hyperspectral coverage, archives of SAR data (e.g., ALOS, RADARSAT, and TerraSAR) since~1995 with good repeated coverage and moderate to high-resolution optical satellites, and long-term scientific development investigating savannah ecology, and hosting the Kruger Science meeting. Third, there is a congruence of unique logistical supports including the Tarmac airport, local and international flight connections, good logistics support from CSIR and SANParks, and plenty of accommodation and meeting facilities. Lastly, there are funded LiDAR and field campaigns planned in 2017-2018.

While there are many benefits of joint airborne and field campaigns, a larger-scale campaign (i.e., one that collects airborne data using multiple sensors) would require collaboration and support from the international community.

Tropical Africa

Contributor/Representative who attended the workshop

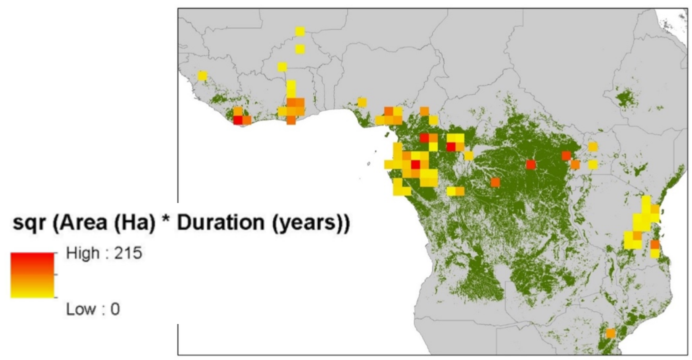
Professor Simon Lewis, University of Leeds and University College London

Country/Region

Tropical Africa (Liberia, Ghana, Nigeria, Cameroon, Gabon, DR Congo, Rep. Congo, Uganda, Tanzania)

Site Locations

African Tropical Rainforest Observatory Network (AfriTRON), see www.aftitron.org. For plot details see: https://www.forestplots.net/data-packages/lewis-et-al-2013.



Collection Dates

Collection dates vary by site with the oldest plot from 1939, the most recent in 2015, and many from early 2000s.

Data Collected

The data collected is mostly within 1-ha plots, but plot sizes range between 0.2 ha and 10 ha. All trees ≥10 cm diameter are measured and identified to species (where possible). There are >500 single census plots and >250 multi-census plots. When there are ~60 trees per hectare, which is true for 200 plots, height data is also available, including all of the largest trees.

Access

All data is owned by local partners who control access, but whom are usually open to collaboration. A smaller subset of plot data is publicly available (see forestplots.net).

Future Data Collection Plans

Data collection is unfunded after mid-2017.

Opportunities for airborne field campaigns in the region

There are many opportunities for synergistic airborne and field campaigns, which could follow the recent successful AfriSAR model of funding for ground data measurements alongside the airborne sensors flying over the plots.

Tanzania Tropical Rainforests and Dry Savannah, Africa

Contributor/Representative who attended the workshop

Erik Næsset, Norwegian University of Life Sciences, Norway

Country/Region

Tanzania

Site Locations

GEO-FCT National Demonstrator sites in high-biomass tropical rain forest (ca 80 km2) and dry savanna/miombo woodlands (16000 km2).

Collection Dates

There are two data collections. The first (A) in an 80 km2 protected rain forest includes field data in 2012 (ca 180 plots – 0.1-0.3 ha), ALS (10 p/m2) in 2012, TandemX in 2012. The second (B) in 15,000 km2 dry savanna forests includes field data in 2012 and 2014 (repeated on same plots) (ca 550 National Forest Inventory plots), ALS (2 p/m2) in 2012 and 2014 with repeated strip sample, and TandemX in 2012.

Access

The first data collection, A, is part of several research efforts in Tanzania and Norway and is most likely available upon request and the second, B, is part of the official NFI so access to the field in particular must be granted by Tanzanian authorities.

Future Data Collection Plans

There are no future plans for subsequent resamping of the first data collection, A. The second data collection, B, will include area estimation (forest/non-forest) based on 0.1 m resolution aerial imagery that was acquired in 2012 and 2014 for the 550 National Forest Inventory plots by manual photo interpretation at different resolutions (1-10m).

Opportunities for airborne field campaigns in the region

There are good opportunities for synergistic airborne field campaigns as there are competent national collaborators, a well-established National Forest Inventory, a well-established center for national coordination of carbon monitoring for forest reference emission levels and greenhouse gas inventory.