CCI

BIOMASS

User Requirement Document

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Symbols and Acronyms

AWS	Amazon Web Service
CCI	Climate Change Initiative
CCI-Biomass	Climate Change Initiative – Biomass
CEOS	The Committee on Earth Observation Satellites
CMUG	Climate Modelling User Group
ESA	European Space Agency
GEDI	Global Ecosystem Dynamics Investigtion (GEDI)
JAXA	Japan Aerospace Exploration Agency
LPV	Land Product Validation
MOLI	Multi-footprint Observation LIDAR and Imagery
NASA	National Aeronautics and Space Administration
NISAR	NASA-ISRO SAR
REDD	Reducing Emissions from Deforestation and Degradation
SAR	Synthetic Aperture Radar
SSP	Shared Socio-Economic Pathways
UNFCCC	United Nations Framework Convention on Climate Change

1. Introduction

1.1. Purpose and scope

This document sets out the conclusions from the First CCI+ Biomass User Meeting in Paris on the 25-26th September 2018 concerning user requirements for biomass information, together with additional comments arising from discussion at the Climate Modellers User Group (CMUG) meeting in Exeter on the 29-31st October 2018. It forms the basis for the Product Specification Document (D1.2).

Table 1. Applicable Documents

ID	TITLE	ISSUE	DATE

1.2. Review of current knowledge

1.2.1. Existing information from international bodies, communities and organisations.

The First User Workshop was organised in Paris on Sep 25-26th September 2018 by LSCE and Aberystwyth University. The workshop was attended by over 80 participants and enabled a direct exchange between the project team and a large range of users for global biomass datasets, including researchers in the US and Europe involved in the generation of global and regional satellite products, climate and terrestrial carbon cycle modellers and organizations involved in the implementation and financing of the United Nations (UN) Reducing Emissions from Deforestation and Degradation (REDD+) and land based climate mitigation. The sessions included :

- Climate Model Requirements for Biomass
- Climate Modellers and In Situ Data
- REDD+ Climate Change Mitigation
- The Committee on Earth Observation Satellites (CEOS) Land Product Validation (LPV) Biomass Focus Area and Protocol

The key questions addressed during the discussion and the presentations were:

- Spatial resolution required

- Spatial extent required
- Accuracy and uncertainty documentation
- Use of biomass change maps, and for which epochs
- The types of data exploration tools users would like to have

The conclusions of the First User Workshop helped to refine the CCI global biomass dataset requirements from climate and carbon modelling, ecology, geography, resource assessment, climate policy and other user families. The workshop also provided an overview of other products such as those derived from spaceborne Synthetic Aperture Radar (SAR) and Light Detection and Ranging (LIDAR) and combined with or evaluated against *in situ* observations. No competing global biomass product with similar spatial resolution to that proposed from CCI-Biomass was presented at the workshop, but future products, in particular from upcoming National Aeronautics and Space Administration (NASA) and Japan Aerospace Exploration Agency (JAXA) lidar missions, will be particularly useful in providing high resolution height and forest structure information.

The assumed requirement for AGB presented at the First User Workshop is based on:

- Wall-to-wall coverage of the entire globe for all major woody biomes at 500 m to 1 km spatial resolution.
- Temporal coverage on an annual to decadal basis.

The GlobBiomass Product produced through the European Space Agency (ESA) Data Use Element (DUE) is at 25 m spatial resolution and is available for the nominal year 2010. Proposed retreivals for above ground biomass (AGB) are <20 % error for biomass values >50 Mg ha^{-1} and 10 Mg ha^{-1} for biomass values ≤50 Mg ha^{-1}). The CCI+ Biomass project aims to produce global AGB maps for the mid 2000s (coinciding with the GlobBiomass product year of 2010 (Figure 1)) and nominally for 2017/18 and 2018/19, together with inter-period AGB change maps.

Feedbacks about this requirement were documented from discussions during the workshop and the synthesis of an online survey provided to all participants and completed by them. The following sections synthesize the feedbacks received from the climate and carbon cycle modelling communities regarding spatial resolution required, spatial extent required, accuracy and uncertainty documentation, use of biomass change maps, for which epochs, and what kind of data exploration tools users would like to have.

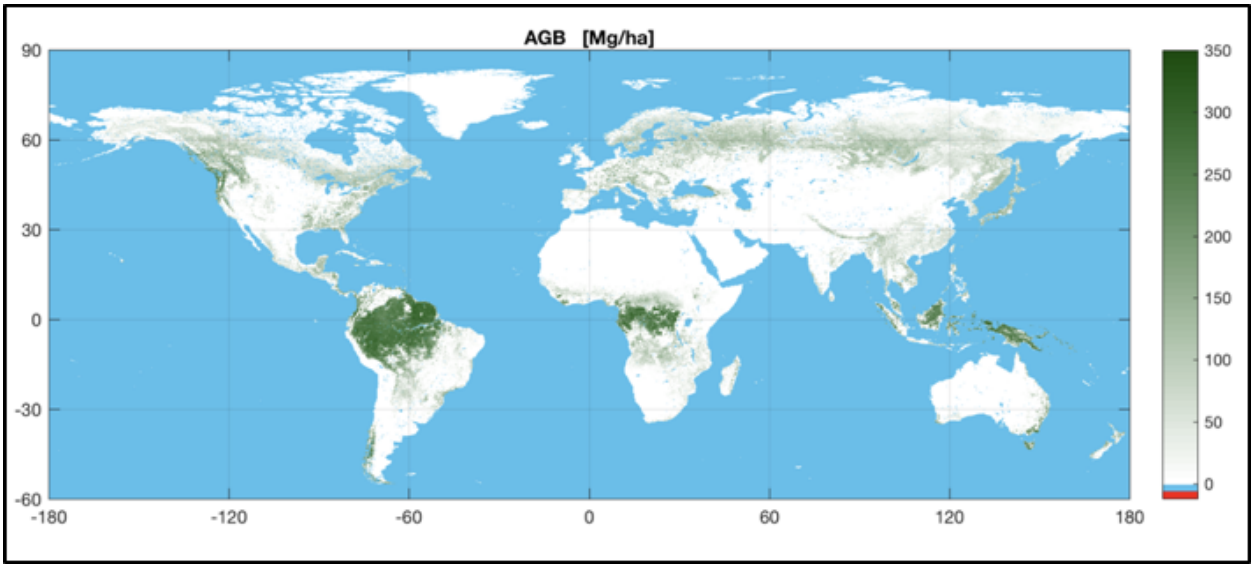

Figure 1. The ESA GlobBiomass above-ground biomass product

2. Results: User requirements

2.1. Climate community

The climate modelling community works with global Earth System Models (ESM) that include land surface model components simulating the dynamics of biomass. Initial biomass is calculated from a model spin-up in equilibrium with climate and natural disturbances. Not all climate models include disturbances, but fire is included in many climate models, drought-induced mortality is included in a few (often from empirical parameterization), while windthrow and insect attacks are generally not included. Transient biomass change is calculated in each grid-cell based on the balance between growth from the allocation of Net Primary Productivity (NPP) to different biomass compartments and mortality.

NPP in ESMs is calculated as a function of climate, atmospheric CO_2 and nutrient limitations in models that include carbon-nutrient interactions. In the CMIP6 ESM ensemble, only some models include carbon-nitrogen interactions, and no model includes carbon-nitrogen-phosphorus interactions. Several models do not include fire disturbance. However, all include anthropogenic land cover change based on annual prescribed land cover maps obtained from historical reconstruction and harmonised with future land cover change scenarios provided by Integrated Assessment socio-economic models for different Shared Socio-Economic Pathways (SSP) storylines and Representative Concentration Pathway (RCP) climate warming targets.

The typical spatial resolution of global ESMs is 0.5° to 2° with a temporal resolution of 1 hour. For historical and future simulations of the coupled climate-carbon cycle system, biomass is an essential variable as it determines the residence time of anthropogenic carbon in the terrestrial reservoir, and land use change carbon losses. In models, land use change emissions are obtained by the difference between a model run where annual land cover change forcing is applied to the models and a run where land cover is kept constant at the pre-industrial distribution.

Climate modellers indicated that seamless biomass information at the spatial resolution of the ESMs, possibly with sub-grid distribution of biomass, would be valuable for model evaluation. These maps may correspond to forest cover data for evaluation of biomass density per vegetation type (plant functional types in models).

Biomass change products would allow the uncertainty in trends of biomass during the recent period to be reduced. It was also recognised that to constrain land use change carbon emissions, pre-human 'potential' biomass maps, obviously not retrievable from EO, are needed, but the values of potential biomass have large uncertainty.

With respect to uncertainties, the climate modellers above all need unbiased estimates with uncertainties (typically described by a precision) provided for each grid-cell. Of less importance is that uncertainties should be lower than 20 %.

The preferred file format is netCDF with ftp-based delivery.

<u>Feedbacks from climate modellers about spatial resolution</u>

- Climate models run at ~0.5-1 degree for century scale simulations, ~1-10 km for annual-decadal predictions. Resolution of data should be higher to filter land cover types. Disturbance areas are possibly not simulated by models. A 1 km global product is suggested to be appropriate.
- Most modellers may use 1 km but if the high resolution maps can be related to maps of age since disturbance, biomass maps could also provide an age map to force models with cohorts of forest age.
- Some modellers suggested 100 m resolution to derive information about impacts of management and disturbances, which can be used finally at coarser resolution in land surface models.
- Sub-grid cell scale distributions of biomass i.e., forest area within biomass categories (e.g., 20 categories defined by biomass min/max range) were also listed as a desirable product to be derived from the ESA CCI-Biomass maps.

<u>Feedbacks from climate modellers about spatial extent</u>

- Global: to ensure consistency of biomass in space needed for assessing impact on climate
- A focus on solely the tropics is considered to be a limitation. Whilst carbon stocks in vegetation are much larger in theis region, changes in biomass in boreal forests will have effects on soil

carbon and permafrost carbon, which could have an even stronger impact on the global carbon balance. In addition, coverage of temperate forests is important, for instance because of possible changes in species distribution and forest management strategies in response to climate change and associated effects on the carbon balance.

Feedbacks from climate modellers about temporal frequency

- The snapshots proposed are already quite valuable.
- Users expressed a need for annual products, perhaps produced through a combination of approaches. The provision of wall to wall biomass maps at high spatial resolution every 5-10 years should be considered, with annual update estimates from spaceborne SAR and/or optical data.
- The best suited temporal frequency depends on the frequency of disturbances in each ecosystem. For disturbances, annual maps would be required, but these would only be useful for measuring change if the biomass uncertainty between timesteps is smaller than biomass changes caused by disturbances.

Feedbacks from climate modellers about temporal extent

- A recommendation is to cover the period since 2000 (possibly earlier although data may be of limited avialablity) to complete repeat biomass maps using spaceborne lidar equivalent every ~5-10 years, with use of optical and/or radar to infer annual dynamics. Mimicing of the best field-based inventories is considered but wall to wall coverage is essential. This is in part based on practical considerations and assumes growth will be relatively slow and hard to detect compared to losses.
- Maximizing overlap with legacy EO products (Landsat, AVHRR) for extension prior to 2000.

In summary, the requirements proposed for CCI-Biomass products in terms of spatial resolution and global extent were found to be suitable for meeting the needs of the climate modelling community, based on the users represented at the First User Workshop. Emphasis on the production of annual maps is noticeable.

2.2. Carbon cycle scientists

Carbon scientists cover a large range of research communities, from small scale ecological studies to large-scale regional and global budget assessments. Biomass change is a critical variable for evaluating carbon cycle models. The drivers of this change can be either slowly varying global drivers indirectly affecting biomass from NPP (e.g., nitrogen deposition, changes in forest demography, atmospheric CO_2

increase and climate change), or fast varying drivers (e.g., forest management, land use change or mortality events occurring following and as a consequence of disturbances).

The major advantages of higher resolution retrieval of AGH is that there is greater comparability with plot data and hence better opportunities to relate observed spatial patterns to underlying (turnover) processes.

Ideally, observation-based annual maps of biomass are most valuable for global and regional carbon cycle budgets, and the recently generated L-band Vegetation Optical Depth (VOD) products presented at the workshop received particular attention as a first and significant step in that direction. A possible way forward could be to calibrate VOD high frequency observations from static CCI-Biomass maps to produce annual updates of global biomass for the carbon cycle community.

With respect to uncertainties; the carbon modellers above all need unbiased estimates with uncertainties (as a precision) provided for each grid-cell. Of similar importance is in-depth evaluation of products using *in situ* data (inventory data at plot and regional level). Of less importance is that uncertainties should be lower than 20 %.

The preferred file format is netCDF with ftp-based delivery for global products, and GeoTIFF and webservices for regional data sets.

In summary, the requirements proposed for CCI-Biomass products were found suitable for the carbon cycle modelling community, although their uncertainty will remain high in the wet tropics. The analysis of biomass data into land carbon turnover, by combining them with EO products of NPP or GPP was recognised as a powerful approach to diagnose biases of current generation carbon cycle models.

<u>Feedbacks from carbon modellers about spatial resolution (additional to feedbacks from climate modellers listed above)</u>

- Resolution 30m and coarser (e.g. 100m, 250m, 1km) with uncertainties propagated at coarser scales. Resolution finer than 100m required for disturbances.
- The major advantages of higher resolution include greater comparability with plot data and better potential to relate observed spatial patterns to underlying (turnover) processes.
- The resolution of global carbon models is typically 0.5-0.25 degree, with fractional representation at sub-grid scale. Some regional models run at much higher resolution to capture fine scale. heterogeneity and provide results at very high spatial resolution. NASA pre-mission modelling studies suggest a resolution of 1 ha.

<u>Feedbacks from carbon modellers about temporal frequency</u>

- Annual maps of biomass for global and regional carbon cycle budget assessments such as performed by the Global Carbon Project each year, and different regional carbon cycle assessment initiatives (e.g., RECCAP2)

Feedbacks from carbon modellers about other requirements

- Detection of change in forest biomass needs observations of 10+ years. Continuous observation over this period is not feasible and is most likely not needed. Two points in time (of 10+ y apart) could be sufficient (e.g. 1980 and 2000).

2.3. EO and in situ community

For remote sensing observation, it was acknowledged regarding spatial resolution and extent that:

- Resolution affects data rates and size of images. Hence it is important to get the right order of magnitude correct. For SAR, it is of the order of 25 m multi-looked output products provided at the hectare level. This is the order of size at which variations are meaningful. Higher resolution will give tree-be-tree level information, which may be less useful than assemblages at the hectare level.

- Consistent data provided at extended spatial scales (e.g., continental at a minimum) is desired, preferably using the same viewing geometry and mode. Mixing data types over time can cause difficulties in interpretation. Multi-season and multi-year data are also important in order to aid interpretation of how seasons, weather and moisture affect the inferred results.

Regarding temporal frequency and temporal extent:

GEDI will be a ~2020 snapshot in time of structure (height, cover). There may be data continuity from JAXA's forthcoming Multi-footprint Observation Lidar and Imager (MOLI)

- MOLI for assessing change.
- High frequency SAR observations (> monthly) are required to separate moisture from the biomass signal and increase accuracy of change estimates
- For the NASA-ISRO SAR Mission (NISAR) mission, the temporal resolution will be twice (ascending and descending) every twelve days. As ecosystems are driven by the hydrological cycle, and for the low-biomass regime of L-band, it will be important to make a sufficient time-density of measurements in order to remove the time-dependent variations of the SAR signature. Of course, more coverage would be preferable, but it is generally recognised that the repeat period of ALOS-1 of 46 days (with changing modes) is far from optimal. Time series, such as that currently being provided by Sentinel-1, are much more relevant for ecosystems and biomass.

- From a satellite mission point of view, the long-term plans of the Sentinel time series are excellent. Scientifically, it is hard to rely on a satellite that may only be around for a few years. Long-term predictability of data availability allows investments to be made at the scientific level for making best use of the data resource. This is much more powerful than the "ideal" measurement that many of us may want for a single measurement; the guarantee of a long-term time series means that we can develop and invest in new and inventive algorithms that can make use of such data sets.

For *in situ*, the main priority is to start creating a database of openly available forest biomass plots, to which the community can contribute. This can be used for regional calibration of the global map. Ground plot size for calibrating and validating the remote sensing products must follow some general protocols:

1. Size of the plots must be sufficiently large to provide accurate estimates of biomass.
2. National inventory plots that are small in size will be used for regional estimate of biomass and cannot be used individually for calibration and validation.
3. The size of the plot must also be sufficiently large to match the pixel size of remote sensing data. For example, if biomass is being estimated at 1-ha, the size of the plot must be larger than or equal to 1-ha.
4. The effect of plot orientation and GPS location error with respect to pixel location and size will become smaller when the plot size is larger than the pixel size.
5. If plots are used in conjunction with high resolution lidar data, then the size of the plot must be large enough to make sure the lidar-biomass model is unbiased.
6. It is important that the plot size is at least 3-4 times the canopy height. For example, 25 m plots are too small to produce robust estimates of biomass.
7. Plots should be considered a component part of the missions and programs (either directly or via partnerships). We need to stop seeing these as an externality. This means that direct engagement and collaboration with the plot community is essential.

Erik Naesset's and Ron McRoberts' talks on the calibration of biomass maps and use of height maps helped to clarify the use of *in situ* data. Something that would be interesting to pursue and to publish along with ESA CCI-Biomass maps are estimates of the spatial extent over which the calibration can be applied. The NISAR team (including Sassan Saatchi) have been looking into this using ICESAT data to test the relationships between backscatter and biomass, but this should be addressed within CCI+ Biomass.

With respect to uncertainties, the EO/in situ community stress the need to arrive at a clear idea of how uncertainties can be combined when inference is made across an aggregation of pixels. McRoberts and Healey gave insights on how to achieve this, but a clear and consistent approach still needs to be developed.

Sensors such as the Global Ecosystems Dynamics Investigation (GEDI) lidar can deliver additional derived information on forest structure (e.g., at 1 km resolution), which must be provided to the users such that they can generate tailored products for their own needs. The users should not have to deal with low level data to do so.

The large & increasing amount of raw data poses the need for cloud-based application of algorithms to avoid high cost and low efficiency associated with downloading large datasets (e.g., from lidar and SAR sensors) to local machines. The use of the Amazon Web Service (AWS) is suggested as it is a more open platform than others (like google). Furthermore, algorithms need to be tested prior to the launch of new sensors to avoid reprocessing large datasets, which would inflate costs.

2.4. Modelling community

Feedbacks on *in situ* data

The role of *in situ* data in climate modelling was assessed from the point of view of both climate modellers and *in situ* data providers. For the modellers, the data considered as most useful are forest/tree density and species wood density. Both variables are necessary to assess and map biomass. For model calibration and validation, it is important that the data are representative of the EO pixel size when used conjointly; the sampling is often too sparse and the requirements are to better fit the minimum pixel size. It was noted that it would be useful to differentiate primary and secondary forests, especially in the tropics where this is a significant challenge.

The *in situ* community considers that the modellers use mostly the information provided on forest structure and composition to develop and test their models at fine scale and that improved use of *in situ* data by climate modellers requires more discussions and interactions in order to better match data collection to the model outputs and structural parameters.

3. User requirements documentation for climate change mitigation and REDD+

3.1. Background

Multiple international policies that require biomass information have been developed and adopted in recent years. Multilateral agreements include performance-based incentive systems to curb trends in forest loss in the tropics and to stimulate reforestation and forest restoration, and to enhance the goods and services provided by forests (collectively called REDD+). Most prominently, international negotiations related to climate change led to increased interest in monitoring forest biomass using space-based data. Biomass measurements are of particular significance for policies related to the UNFCCC, as countries must monitor emissions related to gains and loss of biomass and report on these regularly. Data and information on forest biomass stocks are not only required for international information/data needs, but also for national needs to support national policy formulation and mitigation activities.

While the Biomass-CCI project mostly targets climate and carbon cycle science users, ESA noted a lack of a proposed project approach for climate change mitigation and REDD+ as users as a "secondary objective". This document summarizes the current knowledge on user needs and on potential next steps for how to integrate biomass maps (such as those developed by Biomass-CCI) in national greenhouse gas (GHG) inventories.

3.2. Biomass maps for estimation and reporting using IPCC Good Practice Guidelines

Guidelines for reporting emissions and removals on the national level are provided by the IPCC Good Practice Guidance (GPG) and guidelines (GL), which countries use when reporting through their GHG Inventories or other reporting avenues to the UNFCCC. A refinement of the 2006 IPCC GL (IPCC 2006) is ongoing with a planned release for 2019, and will be the first update of the Agriculture, Forestry and Other Land Use (AFOLU) guidelines since 2006. Updates will include additional information on tropical and sub-tropical forest biomass factors, as a result of recent efforts by REDD+ countries, and more information on the role of space-based data in biomass monitoring. More specifically, the guidelines will include a new section introducing the use of biomass estimates from maps generated from space-based data. The use of biomass maps is increasingly important, as these wall-to-wall datasets have the potential to complement plot-based biomass measurements available through national forest inventories (NFIs). The characteristics and usefulness of biomass maps produced using space-data for national GHG inventories depend on multiple factors:

- The definitions for forest and biomass or AGB used to produce the map and how this definition relates to the one used in the national GHG inventory;
- The type of space-based data sources in terms of spatial resolution, temporal coverage and the degree to which the signal responds, or is sensitive to AGB;
- The method used to construct the map. Methods can range from simple interpolation of field estimates of biomass using spatial covariates to more complex modelling of AGB using field estimates, and observed space-based data signals;
- The availability and reliability of biomass-related field data, which are of better quality than the map, and are needed to produce and validate the biomass map;

- The degree to which map uncertainty is characterised and the manner in which it is used to assess systematic deviation and precision for large area estimates in support of national GHG inventories.

With these factors in mind, biomass maps can improve the stratification of field-based biomass inventories, increase data in under-sampled or inaccessible areas, and serve as an independent data source for verification purposes (provided that the field data were not used to calibrate the biomass maps used).

In general, net carbon emissions from land use change are estimated by multiplying activity data (area of change) by an emission factor (the carbon stock change per unit of change) (IPCC 2006). In this respect, the use of biomass maps for the estimation of carbon emissions at IPCC Tier 2 and Tier 3 levels can be achieved in three ways.

First, biomass maps can provide the base to estimate carbon stocks. Such analyses require consistency among the activity data and biomass maps concerning definitions, geolocation, and spatial and temporal characteristics. The use of regionally aggregated carbon stocks (e.g. using average estimates for different forest types) helps to reduce inherent pixel-level uncertainties in biomass map data for national-scale estimations. Countries have used this approach to increase data density in areas under-sampled by field inventories.

Second, biomass change and carbon emissions can be estimated directly from multi-date biomass maps. This approach provides an assessment of carbon stock changes in AGB from land use change and, in particular, also includes changes within forests remaining forests such as degradation and regrowth, management and harvest, and natural disturbances. This method requires consistent and well-calibrated biomass maps using field measured and space-based data to accurately estimate biomass changes; a quality requirement that has so far not been achieved for national GHG inventories. Improvements in both the field estimates of biomass change and remote sensing technologies in the coming years could lead to such approaches becoming efficient and accurate for GHG inventory purposes.

Third, biomass maps can be integrated with remote sensing-assisted time series of land use change and/or with IPCC Tier 3 models to derive emissions estimates. This way the biomass map data can be linked to land use to better reflect the complexity of forest-related carbon fluxes. A critical element of this type of application is the consistency among the various data sources and models concerning definitions (e.g. forest, biomass pools), and, spatial and temporal data characteristics. Map unit prediction uncertainties in biomass maps propagate to larger area estimates and can lead to substantial uncertainties in national emissions estimation if not properly considered, particularly in relation to the effect of spatial autocorrelation. The application of these three approaches requires maps which are well-calibrated for national circumstances. Many available large-area biomass maps might not be consistent with national definitions of forest and/or biomass pools, and often exhibit large systematic deviation in the estimation of carbon stock and changes for national and local assessments.

Incorporating biomass maps in national GHG inventory efforts requires a long-term perspective, such as establishing a data protocol to assure accessible data in the future. Comparability across time-scales is essential to meet the IPCC guidance for consistency. Developing countries in particular have been making significant progress in using space-based data for providing activity data and national forest inventories for estimating emission factors. These increasing capacities should help the potential uptake of novel biomass mapping and estimation possibilities by countries but so far few examples exist; additional national-scale efforts are needed to demonstrate that potential.

3.3. Result-based schemes including multilateral, bilateral and project based voluntary initiatives

Efforts to reduce emissions from deforestation and degradation, sustainably manage forests, and conserve and enhance forest carbon stocks (REDD+) in developing countries have been moving into accessing result-based payments (third REDD+ phase), which requires robust and credible systems for measuring, reporting and verification (MRV). REDD+ efforts have been re-enforced as one of the mitigation foci of the Paris Agreement. The result-based nature of REDD+ requires that GHG emissions and removals related to REDD+ activities are benchmarked against a reference level to estimate their impact in units of tCO_2-equivalent. In many cases, emissions are calculated using activity data or land use change area (e.g., forest cover gain or loss), and an emissions factor, which is essentially the carbon stock or biomass of the forest. Biomass maps offer opportunities to not just look at loss or gain in the context of forests, but to look at change which can occur to varying degrees (for example in the case of degradation or regrowth). Reporting under REDD+ frameworks is very much related to national GHG inventories; however, the objectives and requirements vary across frameworks, as outlined in Table 2.

Table 2. Various REDD+ related reporting fora, their purpose and considerations of uncertainties

CONTEXT	PURPOSE	REQUIREMENTS/CONSIDERATION OF UNCERTAINTIES
REDD+ related submissions and National GHG inventories to UNFCCC	Regular reporting required at the national level, REDD+ reports, in developing countries in the context of result-based finance, and biennial update reports (BURs) for all countries.	Key GHG source categories should be reported on Tier 2 level (using national emissions factors) in the national GHG Inventory. REDD+ FREL/FRLs and REDD+ Annexes to the BURs are assessed through specific technical assessments and reviews by UNFCCC roster of experts. The stepwise approach allows continuous improvements including uncertainty.

Green Climate Fund (GCF)	Finance for forest transformation for climate change mitigation and adaptation. Result-based payments for REDD+.	In the case of result-based payments for REDD+, these are based on the UNFCCC Technical Assessment and Technical Reviews and a further assessments through a score card where uncertainty is part of the scoring system to allocate payments.
Forest Carbon Partnership Facility's Carbon Fund (FCPF CF)	Pilot market transactions for REDD+.	An IPCC Tier 2 is required to estimate emissions and removals. Uncertainty needs to be assessed and reported. Verification of Emission Reductions by an independent third party. Potential discount based on overall uncertainty of reported and verified Emission Reductions.
Other standards (e.g. Verified Carbon Standard)	Issuance of emission reduction units for the voluntary carbon market.	Varies by standard but uncertainties should be assessed and considered. Independent verification is often part of the process. Often a preference for conservative approaches.

REDD+ readiness efforts have triggered significant investments in improving developing countries' technical and institutional capacity for forest monitoring, including the capacity to utilize space-based data and remote sensing technologies which are seen as cost effective methods. These investments and interest have spurred the forest observation community to develop new data sources through targeted research and methods (see for example http://www.gfoi.org/rd/), provide justification for space missions (incl. those for forest biomass) and develop improved guidance (for example: www.gofcgold.wur.nl/redd/).

3.4. Transparency and broader stakeholder engagements for the Paris Agreement

Enhancing transparency is fundamental to realize the bottom-up nature of the Paris Agreement, and should be understood as catalyst for action by providing, in the context of biomass data, open and consistent time series, transparent definitions, and assumptions and methodologies that will enhance the credibility and reliability of land use sector mitigation activities in both developing and developed countries. Transparency is already one of the principles of the IPCC guidance for GHG inventories together with accuracy, completeness, comparability and consistency. Open and transparent estimations are also required in cases where results have to be assessed and verified. This includes publicly available input data sources, and the full transparency of methods, including algorithms. This builds public trust in reported results, and encourages cooperation among multiple stakeholders including the collaborative design of interventions.

To better understand the user needs, a survey was undertaken with the aim of assessing stakeholders' data needs when monitoring GHG emissions in the land use sector (Romijn et al. 2018). A total of 557 answered the questionnaire and provided information on the type of organization for whom they were working. The survey results show that current open and freely available biomass datasets are not able to fulfill all stakeholder needs completely. Users were found to require detailed documentation regarding the scope and usability of the data (97 % of all survey respondents), data sources which are comparable with alternatives, uncertainty estimates for evaluating mitigation options (94% of all survey respondents), more region-specific data with greater accuracy and detail for sub-national application, and regular updates and continuity for establishing consistent time series (83% of all respondents) (Romijn et al. 2018). Specifically, on biomass data needs, the survey shows that different user groups required different levels of accuracy in terms of IPCC Tiers (**Error! Reference source not found.**). The government groups all required Tier 2 or Tier 3, with Annex 1 (developed) country experts having greatest preference for Tier 3 (74%); even more so than the research community. The NGO community were more likely to use Tier 1 information (20%). On average, 43% of respondents preferred Tier 3, while 47% of respondents preferred Tier 2.

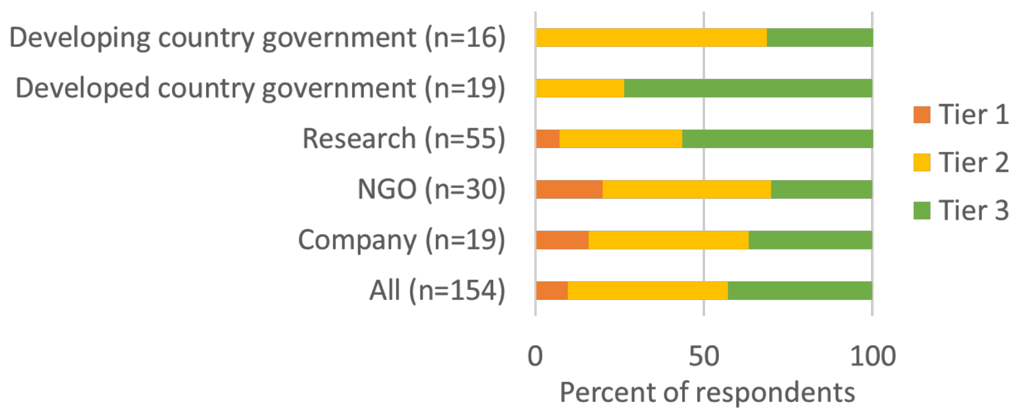

Figure 2. Desired level of IPCC tiers. Tier 1 emission factors are default values for broad continental forest types, e.g. from IPCC Emission Factor Data Base, Tier 2 emission factors are country specific data for key factors, e.g. from field inventories, permanent plots, and Tier 3 emission factors are based on detailed national inventory of key C stocks, comprehensive field sampling repeated at regular time intervals, soils data, and use of locally calibrated models. Responses are divided into groups, and ALL relates to all respondents, including the other groups, such as "local stakeholders", "donor organisations", "intergovernmental organizations", and others. Developing country governments include Non-Annex 1 governments, and developed country governments include Annex-1 governments according to the UNFCCC definition. "Research" includes universities and research institutes, and non-governmental organizations (NGO) includes International (I) NGOs. Amended from (Romijn et al. 2018).

Multiple datasets are available which can be used by stakeholders to estimate biomass (Figure 3). Several differences were found in the awareness and usefulness of these datasets. While almost all stakeholders are aware and use the IPCC guidance, the knowledge and uptake of biomass maps was much less. This emphasized the current status that available maps are not used in GHG reporting by countries. There is a significant gap between stakeholders being aware of certain data sources and whether they actually found them useful for their purpose. This highlights the large divide between what is available and what is used. NGO respondents were more likely to be aware and users of these biomass datasets than other user groups.

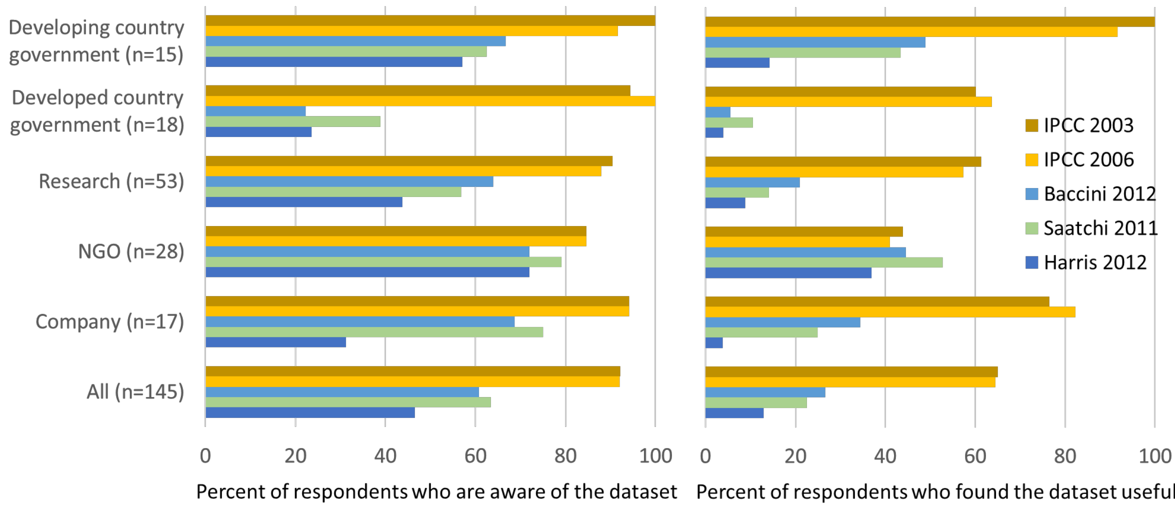

Figure 3. The top five datasets respondents were aware of: The top five datasets which the questionnaire respondents were aware of when asked "Are you aware of this dataset" (data in left panel). These datasets are IPCC 2003 (IPCC 2003), IPCC 2006 (IPCC 2006), Baccini 2012 (Baccini et al. 2012), Saatchi 2011 (Saatchi et al. 2011), and Harris 2012 (Harris et al. 2012). The bars show the proportion of respondents who were aware of the dataset, and the proportion who both used it and found it "useful" or "very useful" when responding to the question "Was this dataset useful for your research and/or business purposes?" Other response options were "somewhat useful", "not very useful" and "not at all useful". Responses are divided into groups, and ALL relates to all respondents, including the other groups. Developing country governments include Non-Annex 1 governments, and developed country governments include Annex-1 governments according to the IPCC definition. 'Research' includes universities and research institutes, and non-governmental organizations (NGO) includes International (I) NGOs.

3.5. Current gaps in using biomass map data for REDD+

While there is large need to improve biomass and carbon stock (change) estimation in developing countries, there is so far little use of existing biomass maps for national estimation and reporting. In the Biomass-CCI user meeting, there were some initial examples of countries generating and using biomass maps for the REDD+ related estimation, i.e.. as part of the Worldbank FCPF process. There some countries use biomass maps (in combination with other data) to improve quality of EFs. It was also noted that there is need for further enhancements for some countries (i.e. for degraded forests). However, the gaps and barriers for the use of biomass estimates using biomass maps for REDD+ purposes includes:

Insufficient level of detail: Different users related to different policy and management processes require different level of detail in terms of the spatial detail that should sufficient to link with national plot data and eventually activity data. Most maps are global and the interest of countries is national estimation. In terms of temporal coverage, the reference period for historical emissions by countries varies. Some users prefer a particular year, some want data that are most recent (near-real time information) or available for longer time series. There is variability in needs in terms forest definitions and in which vegetation components are considered for biomass/carbon stock estimation and whether dead biomass is included or not.

Biomass maps versus change: Most regional and global biomass maps exist as one-time products. While there is value in and need for high-quality biomass stocks data, there is an inherent interest biomass and carbon stock change information. It is only recently that estimation of biomass change over large areas from space-based data is starting to appear in the scientific literature.

Conflicting information: Urgency by researchers and scientists to improve space-based monitoring capabilities has naturally led to a diversification of methods, with positive implications in terms of innovation, and demonstrating the potential. Different datasets are available and often provide inconsistent information which confuses users. Identifying the sources of differences in these maps is difficult, due to lack of detailed descriptions/transparency, different definitions, temporal coverage, and also the lack of information on the uncertainty of the maps.

Limitations in the complementary use of field / airborne and space data: Biomass monitoring still suffers from the conceptual and technical divide between space-based data, and traditional means of gathering biomass data (i.e., collecting data in the field as part of NFIs). But lack of in-situ data in certain locations, use of different definitions of forests and biomass, and uncertainties in both field and space-based data have led to limited complementarity. Current biomass mapping from space remains largely disconnected from plot-based national forest inventory efforts.

Lack of capacity of key stakeholders: One of the main barriers to progress in general and particular relating to the uptake of space-based biomass derived data for national forest carbon monitoring, is the capacity of users such as country experts and non-technical experts to access and use the data. Despite efforts to increase capacities, a capacity gap remains in many developing countries which continues to limit the uptake of new technologies. The use of biomass maps by key stakeholders is also hindered by the lack of capacity to understand the methods that were used to produce them.

Gaps between theoretical opportunities and policy and management praxis: An often-overlooked limitation of biomass and forest monitoring capabilities arises from a gap between what is needed by users, what has been successfully demonstrated in a research environment, and what can be developed and maintained in an operational environment, such as a country's National Forest Monitoring System. The technologies offered may not meet the user requirements or be practical for operational implementation, and an analysis of user requirements should be undertaken to ensure that what is offered can be adopted successfully. In particular, investments to develop new data sources and methods are significant and often do not consider how such novel approaches can be scaled geographically and then reliably maintained at a reasonable cost by users. This problem is often especially acute in countries with low technical capacity. Unclear institutional arrangements and turnover of technical staff can create problems for responding to new requirements and technical opportunities and for sustainability of monitoring efforts.

Uncertainty characterization is missing or not suited: Currently global maps are available, but using these datasets to estimate biomass at national scale does not meet the level of uncertainty required for REDD+. Some do not provide adequate uncertainty estimates so these have to be calculated by the users, which can be difficult and this process relies on assumptions, and thus is uncertain in itself. To add to the challenge, most biomass mapping accuracy varies by forest type and biomass range. Biomass mapping typically performs poorly in high biomass and dry regions of the tropics, and uncertainties are particularly large there. Users have specific requirements on what they expect from uncertainty characterization and such user-targeted uncertainty characterization is essentially lacking from all large area biomass mapping products.

3.6. Summary of discussions and recommendations from the Biomass CCI user meeting

A dedicated REDD+ user interaction session was held during the Biomass-CCI user meeting. The session showed general interest and need for using newly available biomass mapping and estimation efforts for REDD+ purposes. The 2019 refinement of the IPCC GPG includes a new section on use of biomass maps that includes several options and potentials but overall, there is little use so far of existing biomass maps for national estimation and reporting. There were some initial examples of countries generating and using biomass maps for the REDD+ related estimation, ie. as part of the World Bank FCPF process. Many countries have generated EF data with some of them of rather limited quality and with rather little intentions to continuously improve them over time; although the idea of stepwise improvement of monitoring capacities is foreseen as part of the REDD+ readiness and implementation process.

A key consideration is to understand the role of CCI+ Biomass products for improving national-scale estimation. Generic global products have often limited use for such national estimations unless calibrated or integrated in ongoing national mapping efforts. Since IPCC requires consistency in reporting, the incorporation of new data requires potential reconsideration of the estimation and can result in general reluctance of national organizations to explore such new opportunities. To improve that situation the following key next steps have been discussed and proposed:

Need for partnerships for joint initiatives and data exchange:

- Modes of engagements between (global) biomass expert mapping community and country experts – explore the win-wins:
    - Country data/efforts supporting global cal/val
    - Use global information/knowledge to provide (independent) feedback and training/capacity building to national efforts
    - Framework for uncertainty assessments to understand sources of error and areas for improvements (national and global)
    - Concepts for countries to generate better estimates (on their own) using space-based data and enhance the efficiency and long-term sustainability of their NFI
- Develop a policy and mechanism for data sharing building upon the positive experience of the 2019 refinement

More practical country examples are needed

- Develop practical experiences on how biomass maps and other RS can improve national estimation following new IPCC guidance:
    - Bridge the divide between maps and statistical estimation for reporting
    - Compare and assess C-stocks and EF to produce emissions estimates, incl. to increase data density in under-sampled or inaccessible areas
    - Integration with AD to produce wall-to-wall maps/estimations and direct estimation of biomass change (i.e. for Tier 3)
    - Verification purposes
- Aim to achieve country ownership in context of evolving opportunities:
    - Co-creation of estimates among producers and users
    - "National calibration" of global data (NFI vs. RS)
    - Access to data through an (open-source) processing system to produce their "own" data

Approaches for continuous improvement and sustainability for national forest monitoring

- Engagement with global biomass mapping community, space agencies, and related cal/val processes (CEOS)
- Concepts and tools for countries to generate better estimates (on their own) using existing and upcoming space-based data and enhance the efficiency and long-term sustainability of their NFI
- Improved guidance and training materials based on practical experiences and their use in capacity development programs

3.7. Updated product specifications for REDD+

Based on the assessment of user needs and input and feedback from user meeting, the following product specifications have been developed for Biomass-CCI project with respect to climate change mitigation and REDD+ users

Table 3. Updated product specifications for REDD+

Global biomass mapping product specifications		
	Threshold (minimum) Requirements	Target (desired) Requirements
Product	Map of aboveground biomass with associated uncertainty	• Map of aboveground biomass (incl. belowground) • Map of change in biomass all with uncertainty estimated, definition of biomass might vary for different countries circumstances
Spatial Coverage	Global	Global with targeted/calibrated products for specific countries or other areas of interest
Spatial Resolution	At least 100x100 m / 1 ha resolution	0,25-1 ha - resolution might vary depending on forest and ecosystem type, and country needs
Temporal Extent	One time coverage for most recent period	2000-now
Temporal Resolution	One time	1 year (annual maps)
Reference System	Lat-Long (WGS-84) and equi-area projections	Provided in country-specific reference grids
Accuracy	Accuracy should be higher than existing maps. Continental-scale uncertainty estimation.	Data should unbiased and with high precision (≥ 90% rel. RMSE) for target estimation regions (i.e. countries)
Delivery Mode	FTP or Web Service	FTP or Web Service and combined with training materials on how to use the data and within country capacity development
Data Format	GeoTIFF	GeoTIFF (or other country preferred formats)

Other Requirements	• Fully documented, transparent and standardised mapping methods • Robust and standardised global validation scheme with protocol • Metadata available • Free and open access	• Fully documented, transparent and standardised mapping methods, • Metadata available, • Robust calibration and validation using available national data sources (i.e. NFI data) • Access to underlying data in an accessible processing system to produce their "own" data • Clear and transparent reporting of regional accuracy / uncertainty • Consistent spatial-temporal coverage • Consistency with forest area change data • Free and open access

4. Conclusions

The user requirements derived from the First CCI+ Biomass User Meeting in Paris from (25-26 September 2018) and the Climate Modellers User Group (CMUG) meeting in Exeter on the 29-31st October 2018 covered the needs of two different communities, the climate and carbon modelling community (the primary focus for CCI+ Biomass) and the REDD+ community. Although these two communities agree on many of the major desirable properties of the products, there are significant differences because the models are based around the grid-cell structure of climate models (which typically means that spatial resolutions of 500m or coarser are acceptable) whereas REDD+ is country-based and needs resolution of 1 ha or better. This has strong implications for whether the project can deliver the validation, accuracy and biomass change estimation needed for REDD+.