CCI Biomass: Status and future developments for global mapping of aboveground biomass and change

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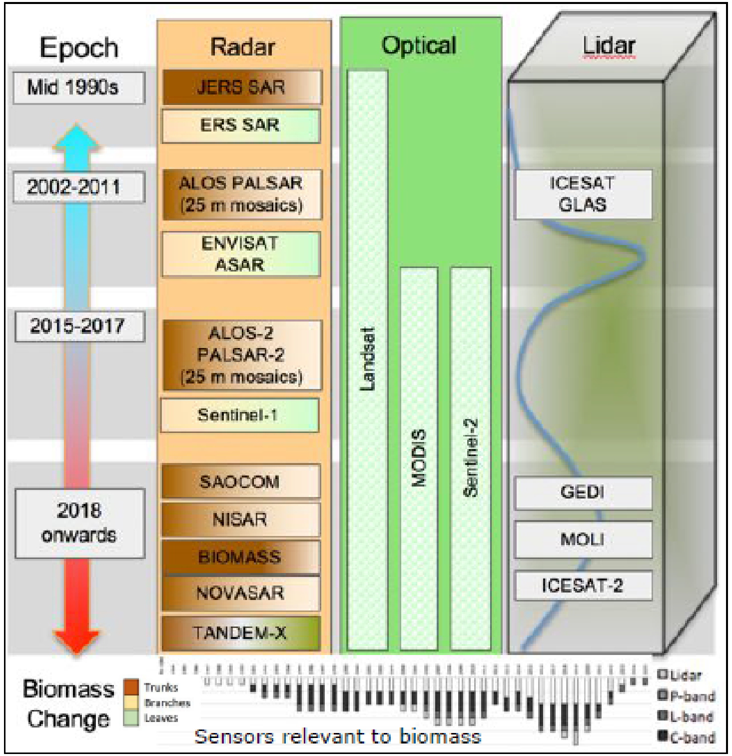
ESA's Climate Change Initiative Biomass project

CCI aims at *realizing the full potential of the long-term global EO archives that ESA, together with its Member states, has established over the last thirty years..... as a significant and timely contribution to the ECV databases required by the United Nations Framework Convention on Climate Change*

Phase 1 of **CCI BIOMASS** *aimed at the generation of three global AGB maps for 2010, 2017 and 2018 with a suite of EO data and assessment of AGB changes with an evaluation in climate and carbon models.*

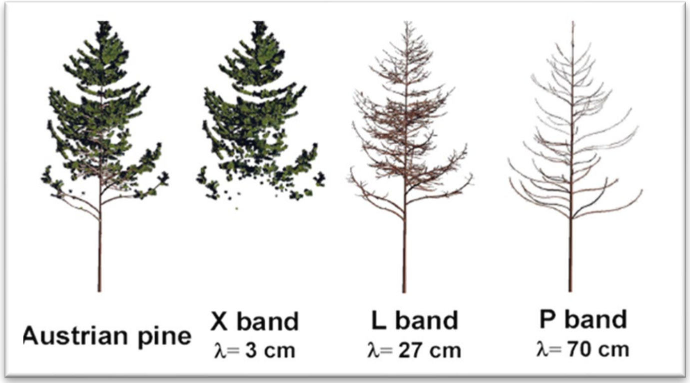
Measurement domain	Essential Climate Variables
Atmospheric	Surface: air temperature, wind speed and direction, water vapour, pressure, precipitation, surface radiation budget Upper-air: temperature, wind speed and direction, water vapour, cloud properties, Earth radiation budget, lightning Composition: carbon dioxide (CO2), methane (CH4), other long-lived greenhouse gases, ozone, aerosol, precursors for aerosol and ozone
Oceanic	Physics: temperature: sea surface and subsurface; salinity: sea surface and subsurface; currents, surface currents, sea level, sea state, sea ice, ocean surface stress, ocean surface heat flux Biogeochemistry: inorganic carbon, oxygen, nutrients, transient tracers, nitrous oxide (N_2O), ocean colour Biology/ecosystems: plankton, marine habitat properties
Terrestrial	Hydrology: river discharge, groundwater, lakes, soil moisture Cryosphere: snow, glaciers, Ice sheets and Ice shelves, permafrost Biosphere: albedo, land cover, fraction of absorbed photosynthetically active radiation, leaf area index, above-ground biomass, soil carbon, fire, land surface temperature Human use of natural resources: water use, greenhouse gas fluxes

Spaceborne EO relevant to biomass estimation



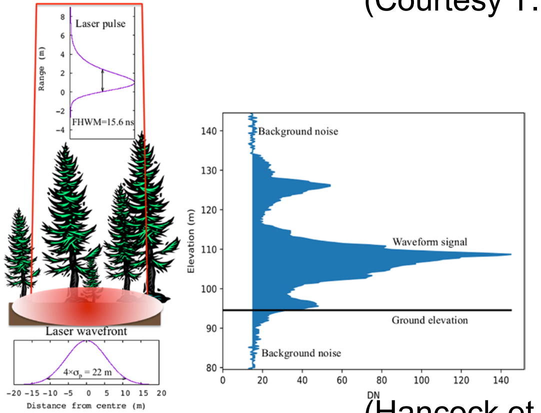
(Courtesy R. Lucas)

SAR

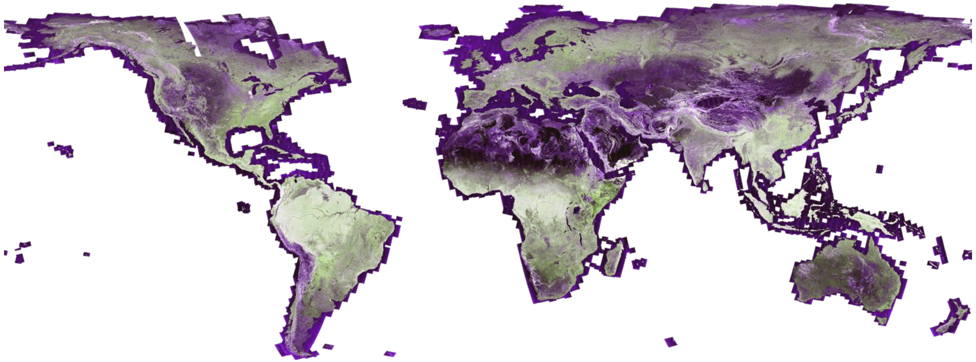


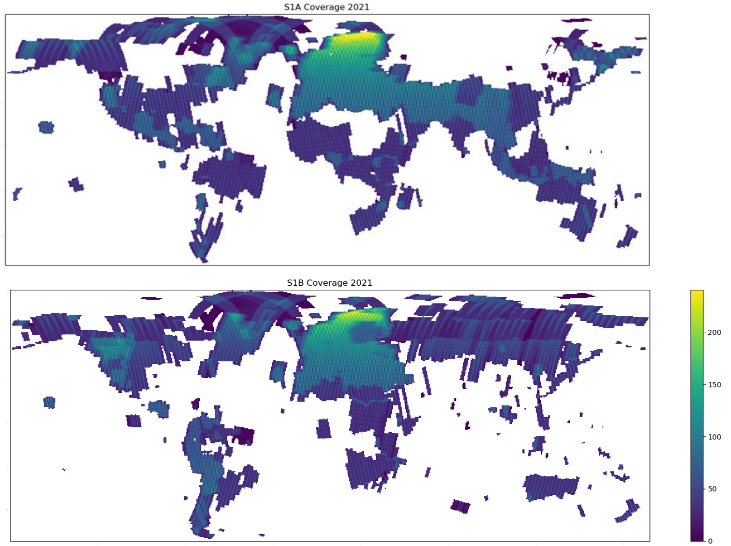
(Courtesy T. Le Toan)

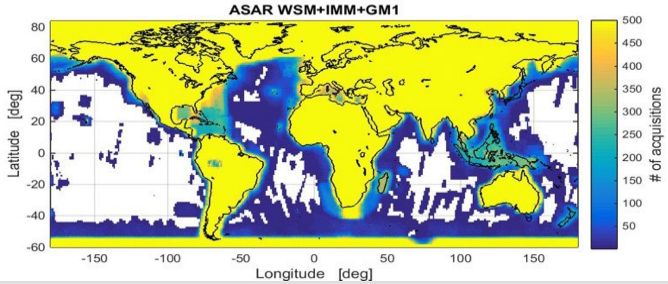
LiDAR



(Hancock et al., 2019)







Sentinel-1 for years > 2014

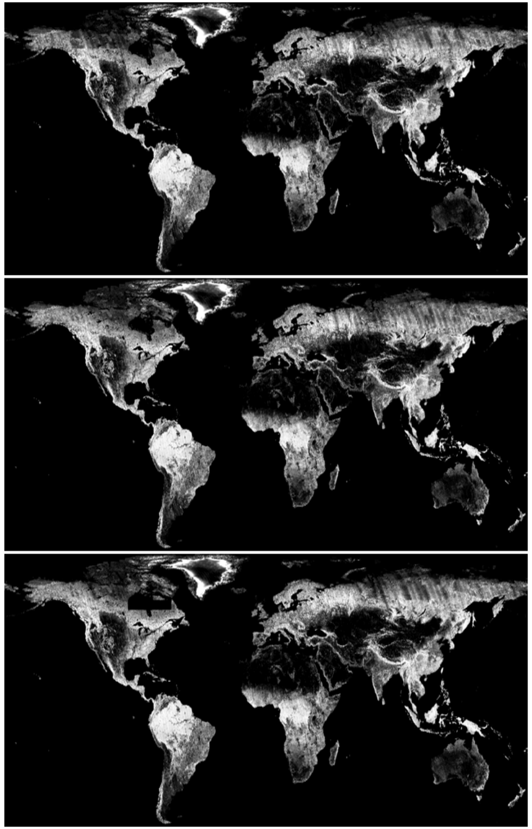
250,000 scenes per year

Almost full annual IWS coverage since 2017

Processed on AWS with Earth Big Data LLC

ENVISAT ASAR ScanSAR for epoch 2010

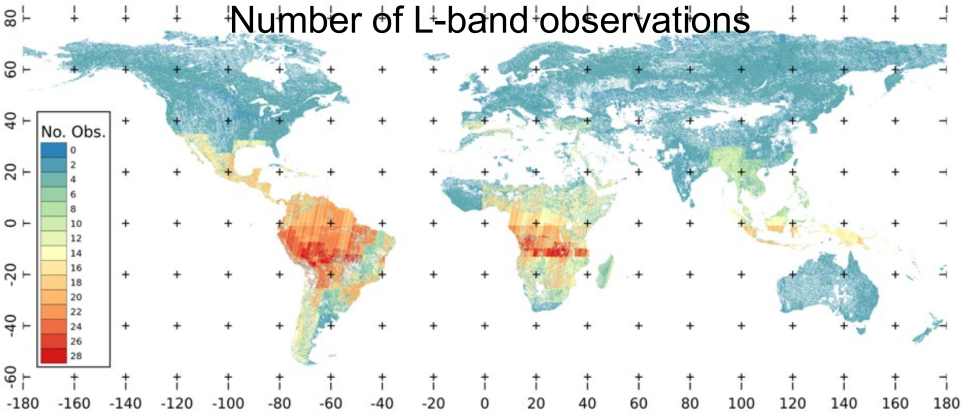
ALOS-2 Fine Beam/ScanSAR L-Band SAR



2015

2016

2017

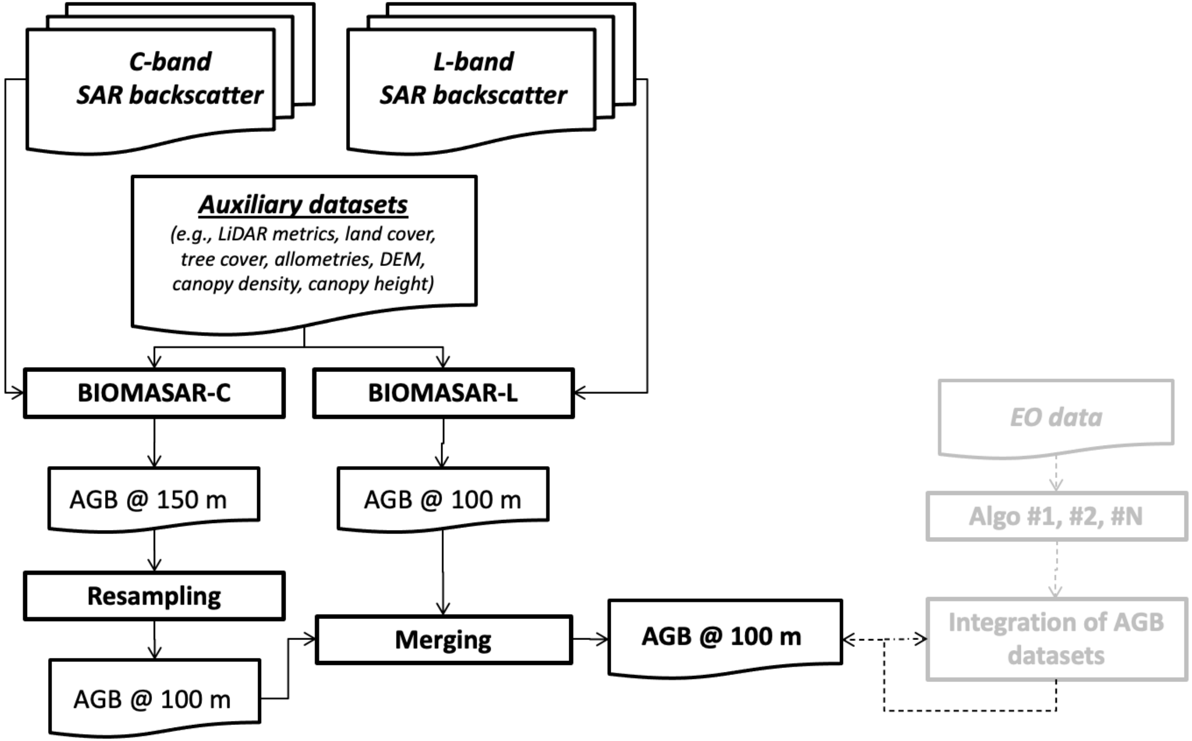


ALOS-1 PALSAR Fine-Beam Mode mosaics produced by JAXA

ALOS-2 PALSAR-2

- Global Fine-Beam Mode Mosaics
- Per-cycle ScanSAR mosaics (mostly tropics)
- Access to ALOS2 KC image strips through JAXA-ESA collaboration

CCI BIOMASS CORE algorithm

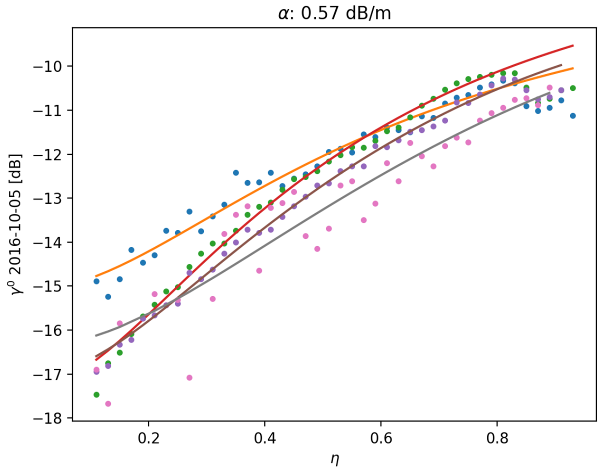


BIOMASAR

Model: $$\sigma^0_{for} = (1 - \eta(h(B)))\sigma^0_{gr} + \eta(h(B))\sigma^0_{gr} e^{-\alpha h\{B\}} + \eta(h(B))\sigma^0_{veg}\left(1 - e^{-\alpha h(B)}\right)$$

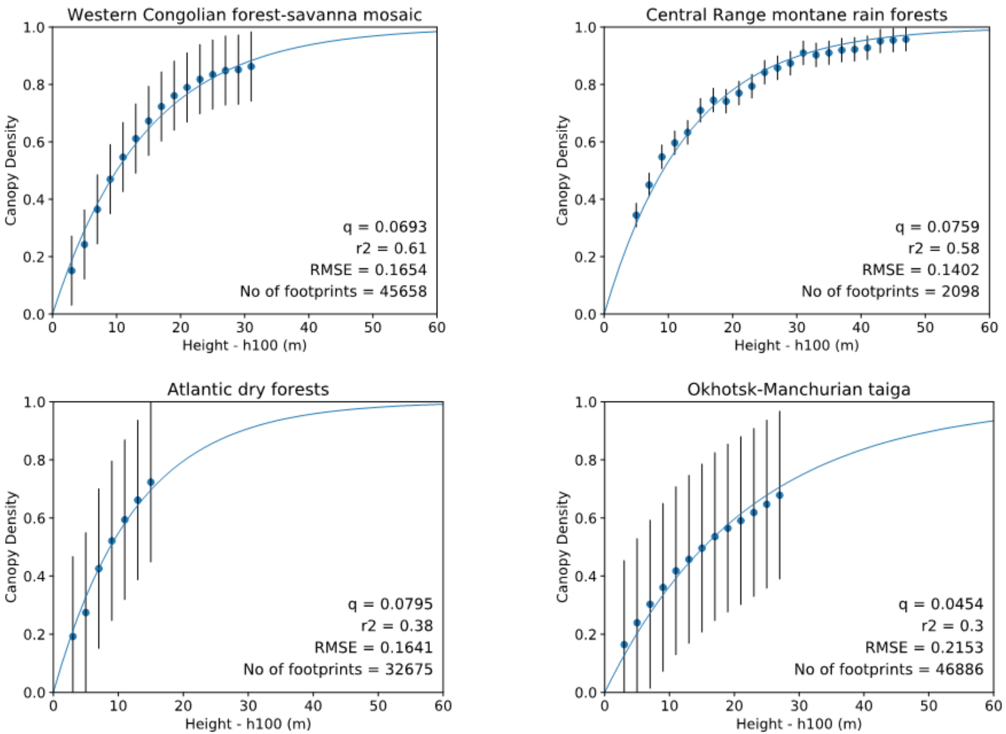
- Backscatter modelled as function of canopy density and height for each individual observation in the multi-temporal stack of images.
- Allometric relationships between density and height and height and AGB exploited to relate backscatter to AGB
- No in situ data involved in model calibration

•Flexible framework for adjusting/improving the retrieval locally



ALOS-2 LHV backscatter as function of Landsat canopy density.

Relating canopy density and height

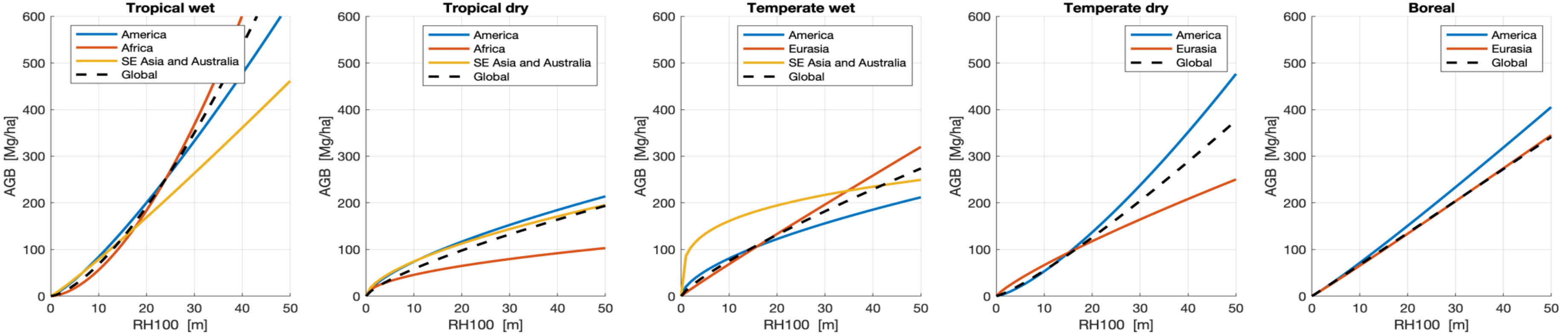


$$\eta = f(h)$$

$$CD = 1 - e^{-qh}$$

Model fitted to each of the 883 WWF ecoregions (Olson et al., 2001) using ICESat GLAS canopy density and RH100 metrics (Kay et al., 2021)

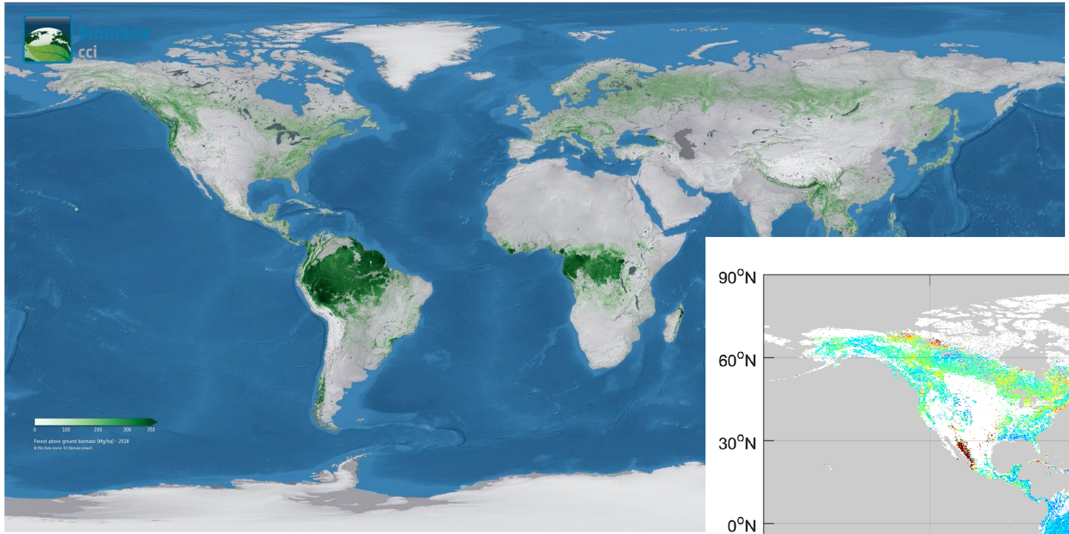
Height to AGB Allometries

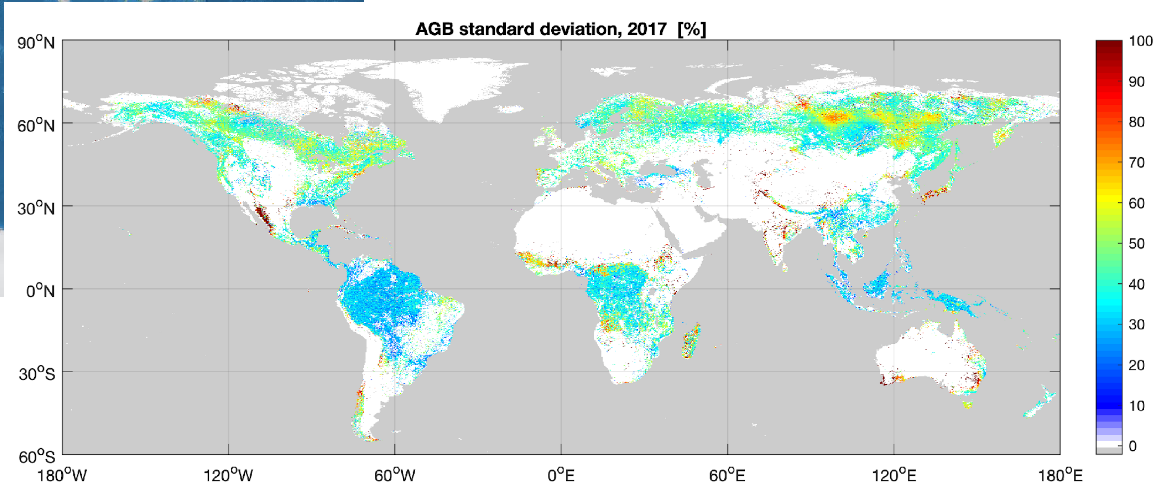


- Fitting the power-law per continent as well as per ecozone shows different trends → necessity to regionalize the allometry
- Some differences, however, are not easy to explain
- Eventually, we have more confidence in the general ecozone model fits

The CCI Biomass AGB datasets

- Global AGB maps @ 100 m for 2010, 2017 and 2018 and related standard deviation (SD)
- Currently version 3 available





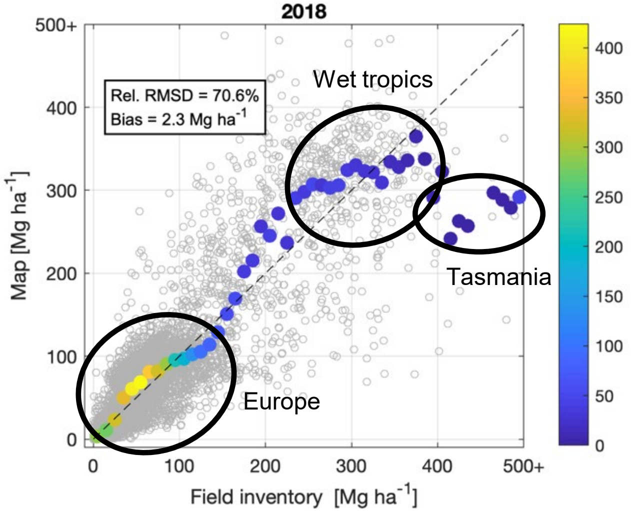
Verification of the CCI AGB estimates

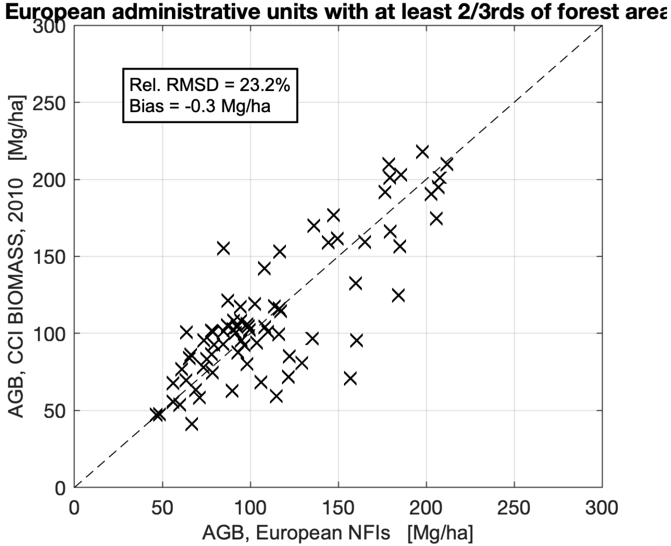
- The AGB spatial distribution is well captured but the AGB levels are not everywhere well represented
- The release of 100 m data is relevant to support the understanding of spatial distribution of AGB at coarser resolution in support of climate change studies.

Averages of plot inventory vs. CCI AGBs, year 2018

global dataset

(see CCI Product User Guide, v3)





Statistics of European NFI vs. CCI average AGBs, year 2010

(see Santoro et al., RSE, 2015, for the source of the NFI stats)

The CCI Biomass AGB change datasets

- Defined as $AGB_{y2} – AGB_{y1}$
- Two datasets are generated: 2018 vs. 2017 and 2018 vs. 2010
- Because of the strong similarity of the AGB between 2018 and 2017, the AGB change dataset for 2017 vs. 2010 is not produced
- The AGB change maps are provided together with maps of
- SD defined as the sum of the maps' variances
- quality flag that defines the level of reliability of the AGB change and is based on confidence intervals

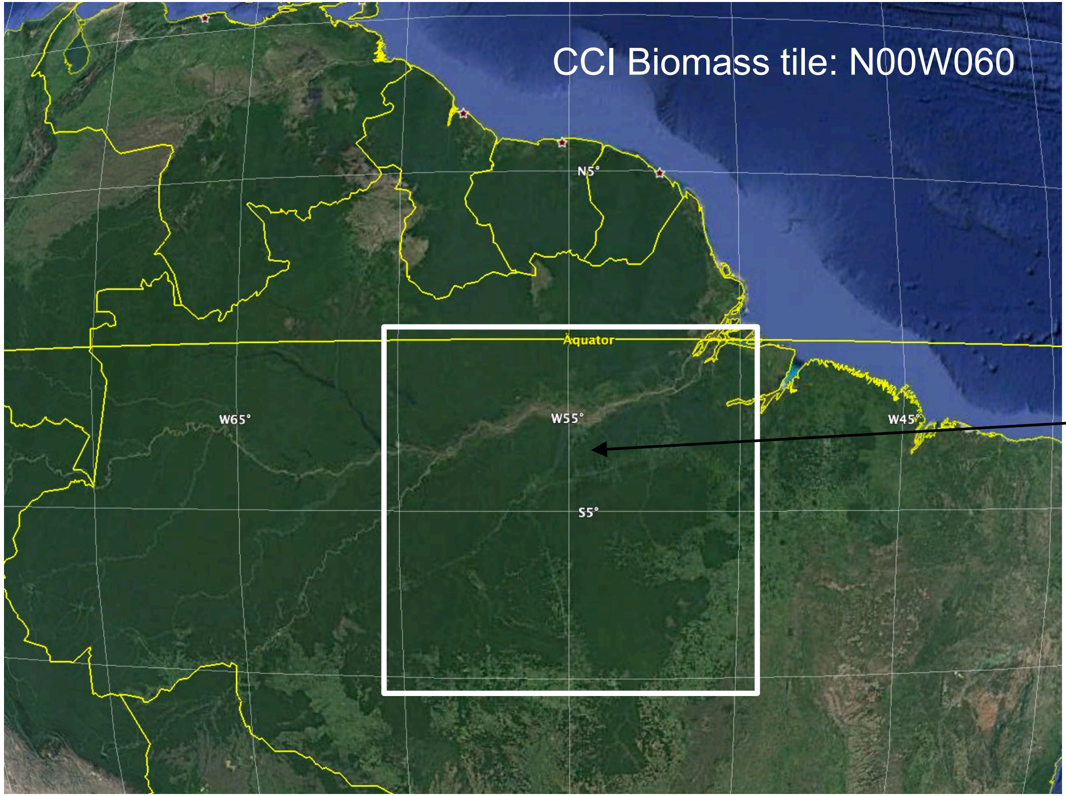
AGB change, definition of the quality flag

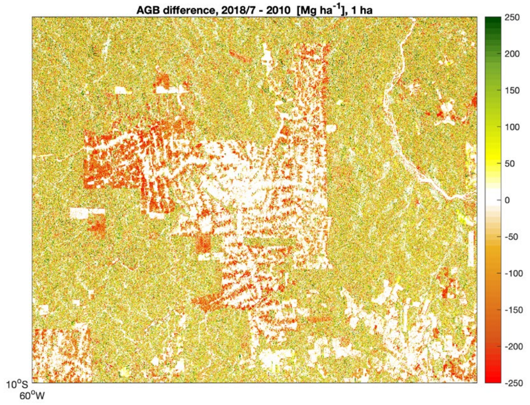
High probability
- disjoint CIs,
- either loss or gain

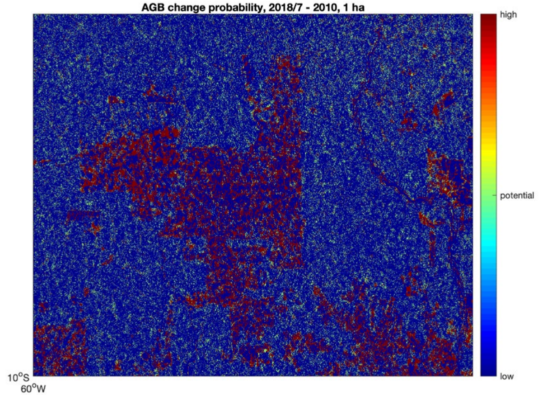
Low probability
- both AGB_i within CIs

Moderate probability
- potential loss, $AGB_2 < AGB_1 - SD_1$

AGB difference at 100 m (1 ha)







Limitations of AGB change mapping

- A signal-based definition of changes would be more proper but it is not viable given that no satellite observations sense the mass of the trees.
- The definition of AGB changes is the simplest possible: difference of AGB estimates. As a result the errors of the maps add up.
- Differences in data availability between years / processing related issues hinder change detection.
- Lack of sensitivity of C- or L-band backscatter to AGB and local errors in backscatter modelling result in local biases
- The AGB change maps capture both increases and decreases. The decreases are often in line with tree cover losses. Increases are hard to verify given the lack of datasets with similar thematic content. In summary, we do not know how much biases of the individual AGB maps impact the AGB change estimates.

Remarks on AGB changes, quality flag

- A quality flag was proposed to ease the interpretation of the AGB changes.
- Validation of AGB changes is cumbersome. With repeated NFI data, at most one can validate the dynamics at the level of averages for administrative units.
- Our definition is quite strong: the magnitude of the AGB change is ”probable” when the confidence intervals of the two estimates in time are disjoint. This aspect needs further thinking and feedback / suggestions are welcome by map users.
- Stating that the magnitude of most AGB changes is “improbable”, is a realistic statement on the current capabilities offered by satellite remote sensing to estimate AGB in time.
- The reliability of the AGB change estimates would increase by averaging to coarser spatial resolution because variances decrease. The usefulness of coarse resolution AGB changes (e.g., > 10 km) depends on the target community.

Data summary & Outlook

- The CCI Biomass project produced global maps of AGB for the years 2010, 2017 and 2018 with related changes, with a pixel size of 1 hectare.
- The CCI Biomass datasets are available on CCI data portal: https://catalogue.ceda.ac.uk/
- All project technical documents available at: https://climate.esa.int/en/projects/biomass/
- Feedback and interaction with users is strongly encouraged for mutual benefit.

CCI Biomass Phase 2

- Improve inter-annual consistency of maps
- Further refine modelling of backscatter as function of AGB considering ICESAT-2/GEDI
- Reproduce 2010/2017/2020 AGB maps, produce maps for all years between 2015-2021 as well as mid 1990ies