GAMMA REMOTE SENSING

Polarimetric and Multi-frequency SAR applications

Forest, Wetlands & Biomass

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with support by the project teams

CCI Biomass, GlobBiomass, BIOMASCAT, Forest Carbon Monitoring and BiomAP

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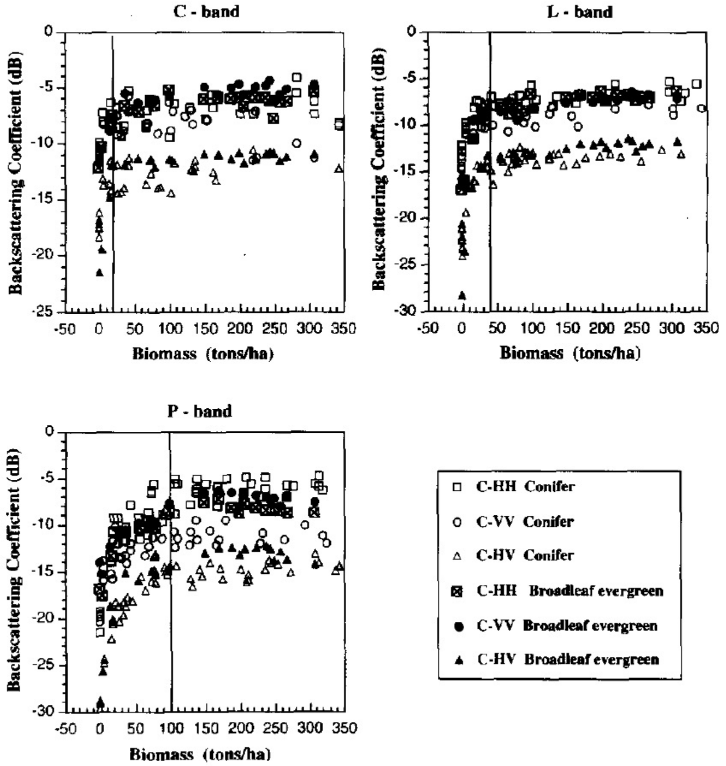
Setting the stage

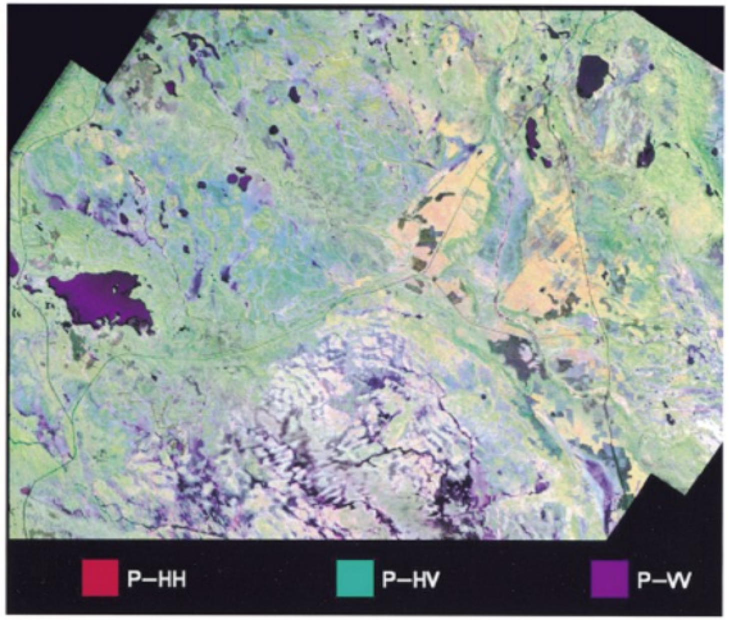
- Extensive datasets of spaceborne SAR imagery have been collected since the early 1990s
- Observations over forests and vegetation were addressed from the early days of the satellite missions because they were visibly affected by geometric and dielectric properties (signature analysis, modelling, classification, inversion)
- Depending on what type of SAR data was available, each decade produced some fundamental knowledge concerning the applications and limitation of SAR data to map and monitor forest and wetland environments

The 1990s

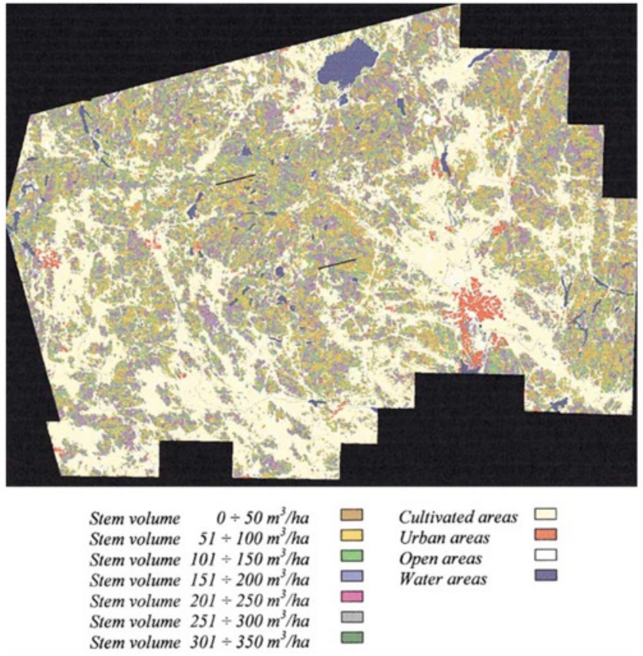
- Two missions (ERS-1/2 C-band and JERS-1 L-band), both single-pol, uncoordinated acquisitions between missions, repeat-pass interferometry, first regional-scale systematic acquisitions over forests and wetlands (JERS-1)
- Air- (AirSAR) and near-spaceborne (SIR-C) datasets: fully polarimetric, multi-frequency (X- to P-band)



(Imhoff, TGRS, 1995)



(Saatchi and Moghaddam, TGRS, 2000)



(Santoro et al., RSE, 2002)

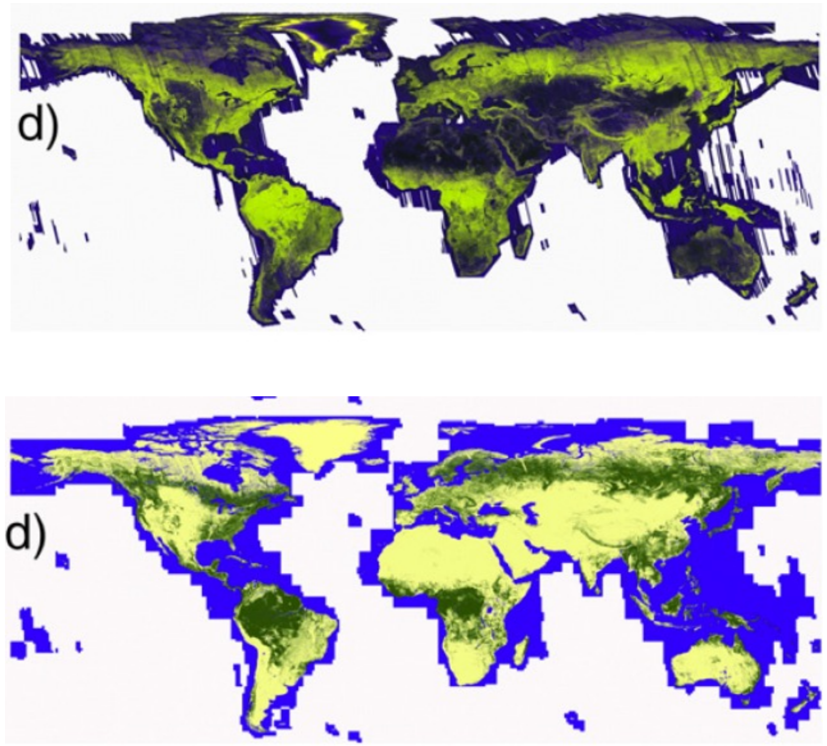
Key findings from the 1990s

- The 1990s were the “exploration” decade
  - P- and L-band backscatter most sensitive to vegetation properties than C- and X-band
  - Cross-pol backscatter more sensitive to vegetation properties than co-pol backscatter
  - More diversity captured by polarimetric metrics
  - Repeat-pass interferometric coherence with stronger sensitivity to vegetation structure than than the backscatter (C- and L-band)
  - Improved classification / retrieval accuracy when combining more observations (multi-frequency or multi-temporal)

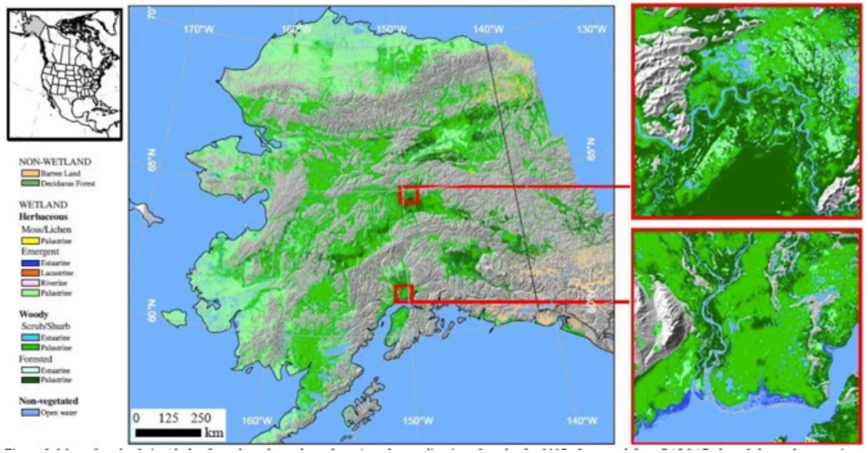
- Open questions: how robust are these findings given the limited spatial and temporal extent of the SAR data available?

The 2000s

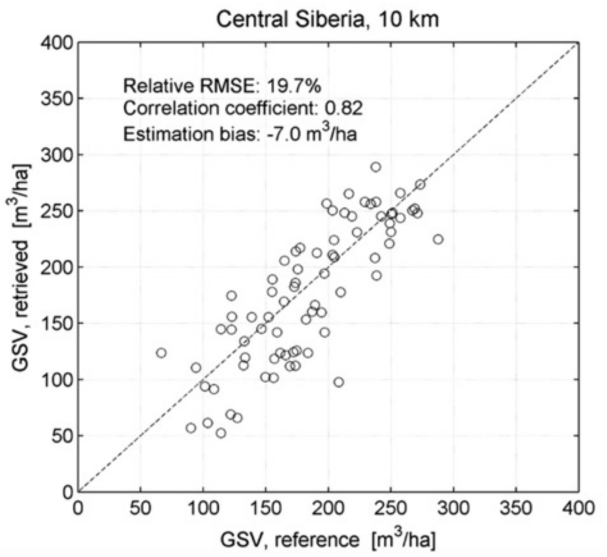
- Several missions flying X-, C- and L-band SAR; dual- or full-pol; different levels of observation strategies; mostly uncoordinated acquisitions between missions; first systematic observation strategies and consistent global datasets (ALOS L-band).



(Shimada and Ohtaki, RSE, 2014)



(McDonald et al., K&C Phase 3 Report, 2014)



(Santoro et al., RSE, 2011)

Key findings from the 2000s

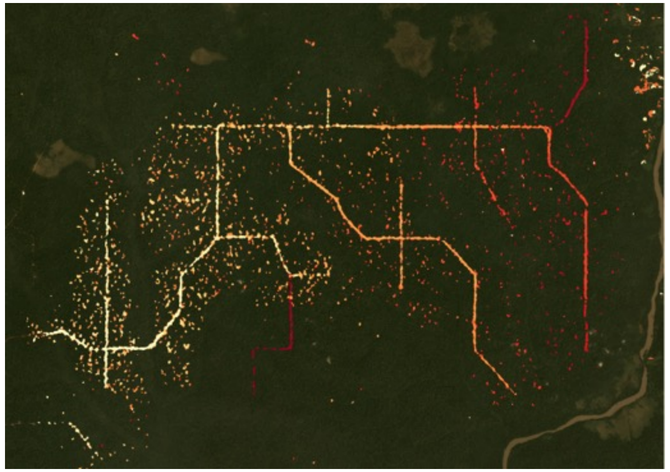
- The 2000s were the “map prototype” decade
  - Systematic observations, primarily at L-band, demonstrated regional-to-global mapping of forest cover extent, forest disturbance, forest and wetland type, forest biomass
  - Mapping was based on data from a single sensor; hardly any example exists where multi-frequency SAR data were integrated.
  - Cross-pol backscatter observations fundamental
  - The backscattered intensity was the only observable in practise. Coherence and polarimetric metrics were only marginally explored.
  - Hyper-temporal observations pushed the mapping of biomass well beyond the level assumed feasible in the 1990s

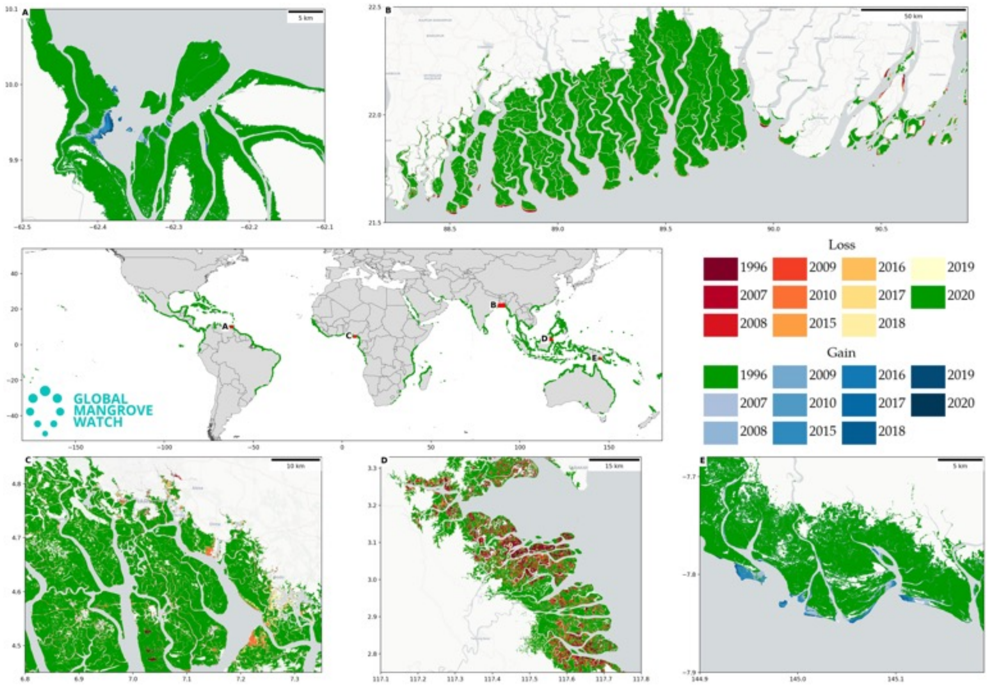
- Open question: what is the temporal consistency of such maps when repeated in time? What could be the added value of InSAR and PolSAR with adequate data?

The 2010s and today

- SAR missions from the past decade were continued or enhanced; repeated global datasets following observations strategies; first multi-decadal time series to assess changes

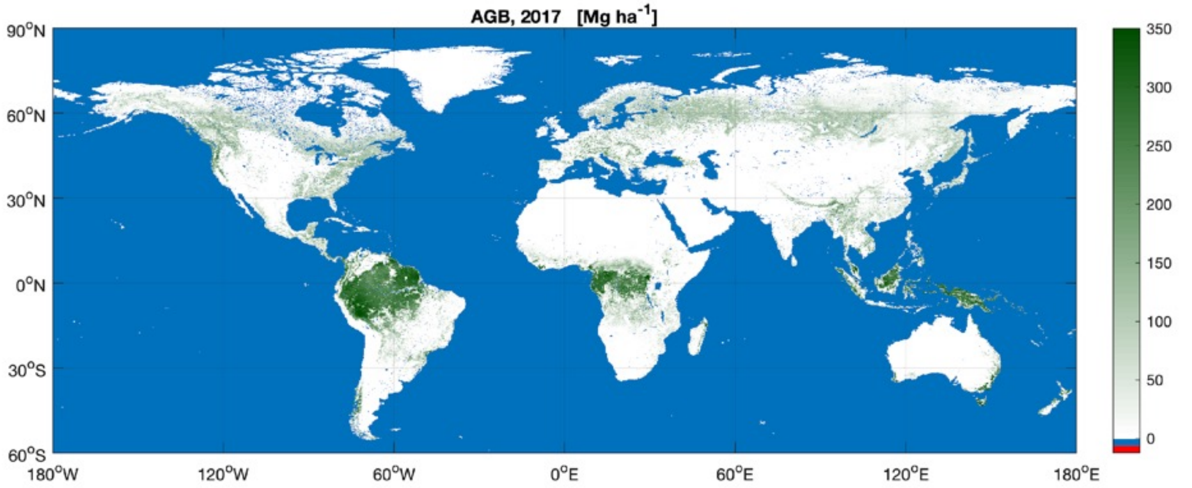
RADD alerts
(Reiche et al., ERL, 2021)





Global Mangrove Watch
(Bunting et al., RS, 2022)

GlobBiomass and CCI Biomass
(Santoro et al., ESSD, 2021)



Key findings from the 2010s

- The 2010s were the “mapping” decade, leading the way to the “monitoring” decade
  - Long-term and repeated observations are used to generate first (semi-)operational data products (disturbance alerts, biomass maps, land cover maps)
  - The level of breakthrough of a SAR dataset in thematic mapping is directly related to its availability, i.e., multi-frequency applications still very limited
  - Poor reliability of temporal dynamics when based on data from several sensors (e.g., biomass from JERS-1/ERS + ASAR/PALSAR-1 + Sentinel1/PALSAR-2)
  - Mapping and monitoring rely on backscatter data only.
  - Full potential of Full-pol and Pol-InSAR unexplored due to lack of consistent data

- Open questions: How can we perform a reliable monitoring across decades? Again, what could be the role of InSAR and PolSAR data? How can we move to operational map products?

Applications vs. SAR data

Application	
Forest mapping (extent)	One frequency and cross-pol data sufficient except for woodlands and young forest → Multi-frequency backscatter may solve ambiguity with other veg. types
Forest clearing (e.g., disturbances)	One frequency and cross-pol data sufficient but revisit time often suboptimal → High spatial (1-2 m) and temporal resolution (daily) fundamental
Forest health	Few evidences with SAR → decadal time series, weekly revisit (day/night) and (short) multi-frequency data
Forest variables (e.g., biomass)	SAR data only partially related to forest variables, regardless of frequency → (Low) multi-frequency and repeated data necessary to overcome limitations
Wetlands	Extent and species: well captured with multi-frequency and multi-temporal data → PolSAR metrics to improve classification
Short vegetation	Little knowledge → necessary to invest efforts in SAR signature analyses (primarily multi-frequency)
Dead wood	Very little knowledge so far → necessary to invest efforts in SAR signature analyses

SAR coordination actions in the near run (2020s)

Regardless of the application, we need data acquired with the same geometry and configuration.

We really do not need all the pre-processing extra-efforts to be able to combine datasets, even if acquired at the same frequency (e.g., JERS-1/ALOS-1/ALOS-2/future L-band or ERS/ASAR/Sentinel-1)

Dynamic forest environments (e.g., deforestation)

- Frequent revisit → tropics well covered, extra-tropical regions aren't
  - C-band SAR: coordinate Sentinel-1A and RCM to fill gaps, get S1-C launched
  - Coordinate L-band acquisitions (present and future missions)

Static forest variables (e.g., biomass)

- Repeated global observations, at least C- and L-band, every year with the same modes, over and over

Wetlands

- Repeated global, observations (L-band) to track dynamics (inundation), same mode over and over
- Multi-frequency polarimetric data to capture the diversity of vegetation forms (starting at biodiv. hotspots)

SAR coordination actions in the long run (2030+)

Regardless of the application, we need data acquired with the same geometry and configuration.

We really do not need all the pre-processing extra-efforts to be able to combine datasets, even if acquired at the same frequency (e.g., JERS-1/ALOS-1/ALOS-2/future L-band or ERS/ASAR/Sentinel-1)

Requirements

- (Very) frequent revisit and homogeneous global coverage
- multi-frequency data (from C- to P-band)
- InSAR and PolSAR/Pol-InSAR for a 3-D representation of vegetation (height and density) and capture diversity
- Spatial resolution: sufficient to detail individual crowns (short frequency)

Suggestions

- Space Agencies should cooperate and plan observations together
- Data policy: free and open
- Make data available in a few simple formats (raw, SLC, ARD) to avoid confusion

Additional slides

The consequence of uncoordinated acquisitions:

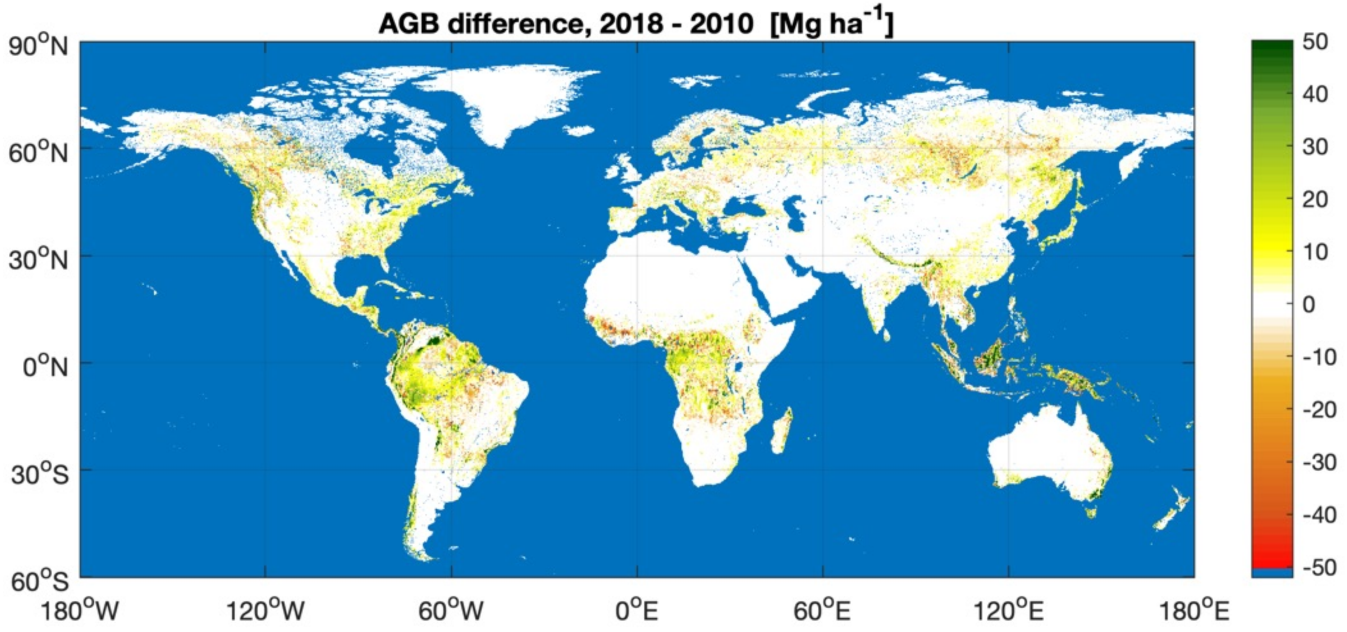
an example of unreliable biomass change estimates

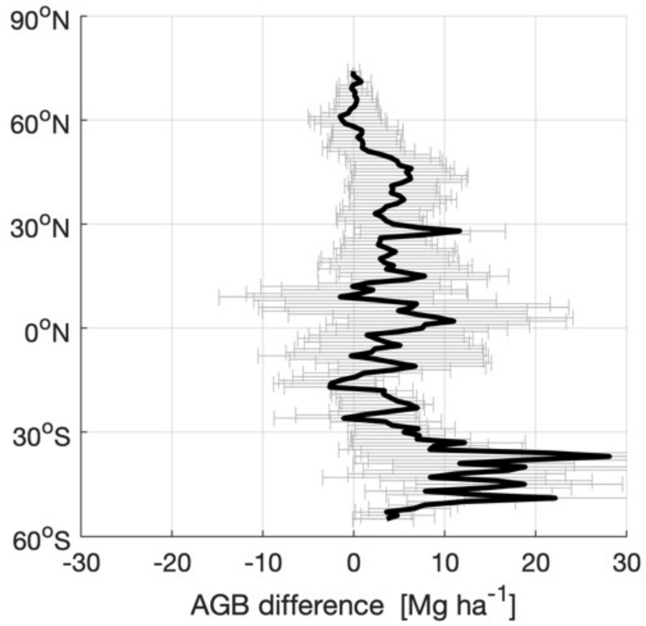
AGB change expressed as difference of AGB estimates for the years 2018 and 2010

SAR data source for 2010: Envisat ASAR and ALOS PALSAR

SAR data source for 2018: Sentinel-1 and ALOS-2 PALSAR-2

Data product: CCI Biomass, version 3





CCI Biomass tile: N00W060

Unrealistic increases of AGB between 2010 and 2018!

This is a consequence of the different SAR data sources (much poorer quality in 2010 than 2018)

Indeed the probability of change is overall low.

Reliable estimates only in areas of deforestation