ESA DUE GlobBiomass

Global Mapping of Forest Aboveground Biomass

Part 1:

Algorithm Development

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Goal:

Produce AGB map @ < 500 m with error < 30%

- We need EO datasets that are available globally
  - For mapping: ALOS PALSAR, Envisat ASAR
  - Supporting datasets: IceSAT GLAS, Landsat reflectances, Landsat/MODIS canopy density, CCI land cover, FAO ecoregions

- We need models and approaches that are applicable globally (scalable, robust, adaptive in space and time) → Parametric approaches are preferred to be in full control of the model training and inversion

- We prefer approaches that minimize the need for in situ data

- We prefer to relate to a forest variable that can be explained by the EO observations (growing stock volume having available SAR backscatter) but we do not neglect approaches relating directly to AGB as benchmark. Ultimately, the goal is to generate AGB estimates.

Potential Retrieval Approaches

Methods developed so far for spatially explicit mapping of GSV/AGB:

- Direct upscaling of in situ/inventory
  Examples: Kellndorfer et al. (2012) for the US (with SRTM, Landsat)
  Mermoz et al., (2014) for Cameroon (ALOS PALSAR)
  Beaudoin et al. (2014) for Canada (MODIS)
  ...

  Too few/small plots globally
  → Regional Benchmark

- Two-stage upscaling of in situ measurements via air- or spaceborne Lidar
  Examples: Baccini et al. (2012) for the tropics (ICESAT GLAS, MODIS)
  Saatchi et al. (2011) for the tropics (ICESAT GLAS, MODIS, QSCAT, SRTM)
  Boudreau et al. (2008) for Quebec (ICESAT GLAS, Landsat, SRTM)
  ...

  Lidar AGB estimation requires calibration data
  → Can support global retrieval

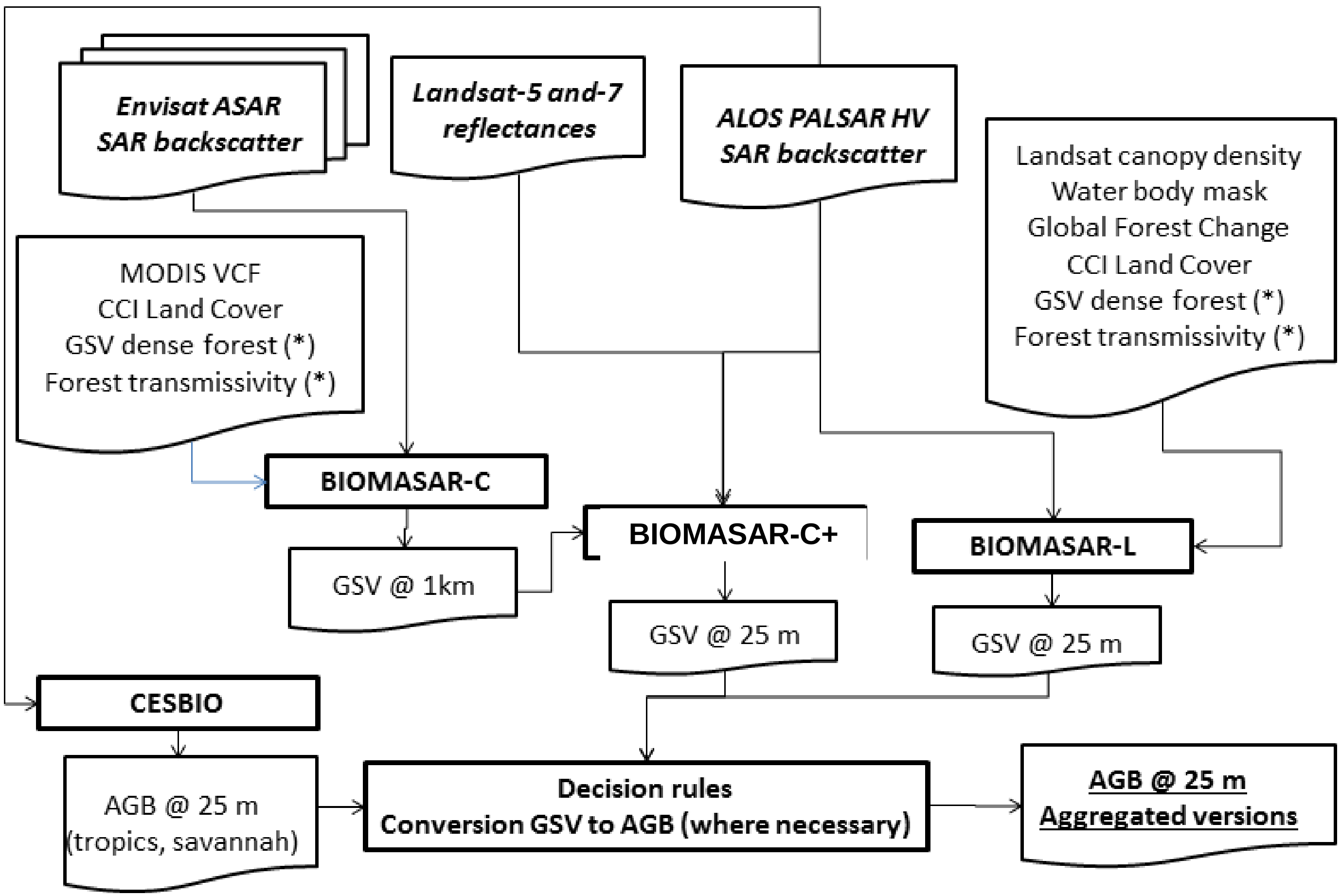
- Semi-empirical approaches with limited input from in situ data
  Examples: Santoro et al. (2011) for Quebec, Sweden, Siberia (ENVISAT ASAR)
  Santoro et al. (2015) for northern hemisphere (ENVISAT ASAR)
  Cartus et al. (2012) for Northeastern US (ALOS PALSAR)

  For C-/L-band SAR

  Limited experience in tropics

GlobBiomass
global retrieval algorithm

It is unlikely that the desired accuracy can be achieved with a single approach/data type!!!



(*) Estimation supported by vegetation height and cover from ICESAT GLAS waveforms

BIOMASAR-C

Data: Hyper-temporal C-band backscatter acquired around year 2010 with ~1,000m pixel size

Model: Water-Cloud type of model relating C-band backscatter to GSV

Model Calibration: Model calibration per image and pixel using the BIOMASAR algorithm at C-band. No in situ data required for model calibration. Calibration supported by MODIS VCF and CCI Land Cover, regional statistics of GSV distribution.

Retrieval: Model is inverted per image. Models are inverted up to a maximum GSV, which is identified with the aid of 1) in situ data and regional forest statistics (where available), 2) modeled relationships between maximum GSV and ICESAT GLAS-based estimates of forest height / density as well as WorldClim bioclimatic variables. Final GSV estimate obtained as weighted average of **many** single-images estimates of GSV

Limitation: Low resolution, short wavelength

BIOMASAR-C+

Data: Global mosaics of L-band backscatter with ~25m pixel size and acquired in 2010, Landsat reflectance mosaics for ~2013, BIOMASAR-C GSV @ 1km

Model: Multiple linear regression

Model Calibration: Model calibration per 1x1 degree tile using the BIOMASAR-C GSV map as response variable and PALSAR/Landsat imagery aggregated to 1 km scale as predictors.

Retrieval: models that were calibrated at kilometric scale are used to predict GSV @25m scale using the PALSAR/Landsat imagery at full resolution (cf. Sexton et al., 2013)

BIOMASAR-L

Data: Global mosaics of L-band backscatter acquired in 2010 with ~25m pixel size

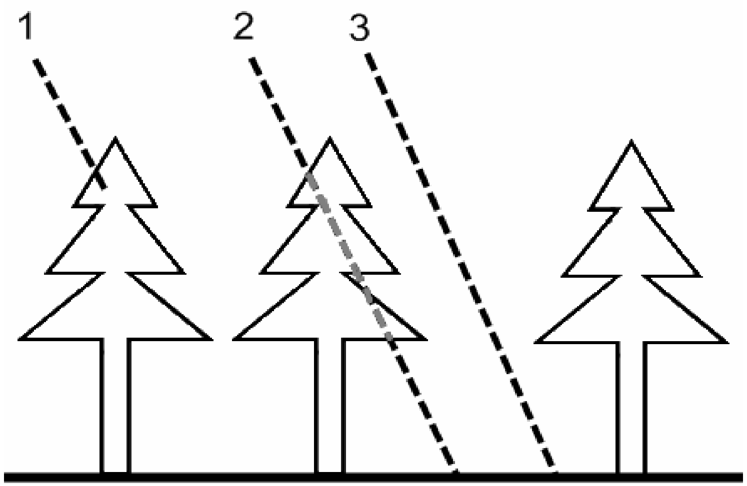
Model: Water-Cloud type of model relating L-band backscatter to GSV

Model Calibration: Model calibration per PALSAR orbit and 1x1 degree tile using the BIOMASAR algorithm adopted for L-band. No in situ data required for model calibration. Calibration supported by Landsat canopy density maps (Hansen et al., 2013), ICESAT GLAS, CCI Land Cover. Forest transmissivity at L-band simulated with GLAS height/density estimates

Retrieval: Once calibrated, models are inverted to estimate per-pixel GSV. Models are inverted up to a maximum GSV, which is identified with the aid of 1) in situ data and regional forest statistics (where available), 2) modeled relationships between maximum GSV and ICESAT GLAS-based estimates of forest height / density as well as WorldClim bioclimatic variables

Limitations: Single Observation, high biomass in tropics, temperate forests?

BIOMASAR-C/L



1) scattering from canopies (σ^0_{veg})
2) scattering from forest floor (σ^0_{gr}) attenuated by canopies
3) scattering from forest floor though canopy gaps

β – transmissivity coefficient

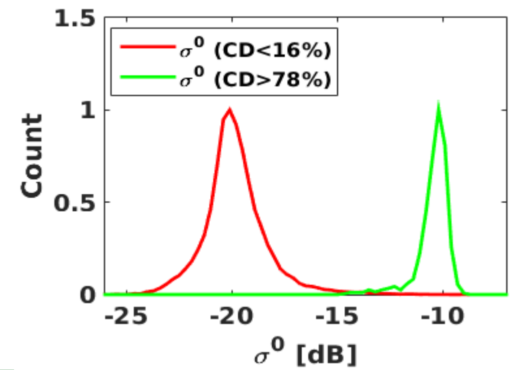
Water Cloud with gaps for modeling C-/L-band backscatter to Volume V:

$$\sigma^0_{for} = \sigma^0_{gr} T_{for} + \sigma^0_{veg} \left(1 - T_{for}\right)$$

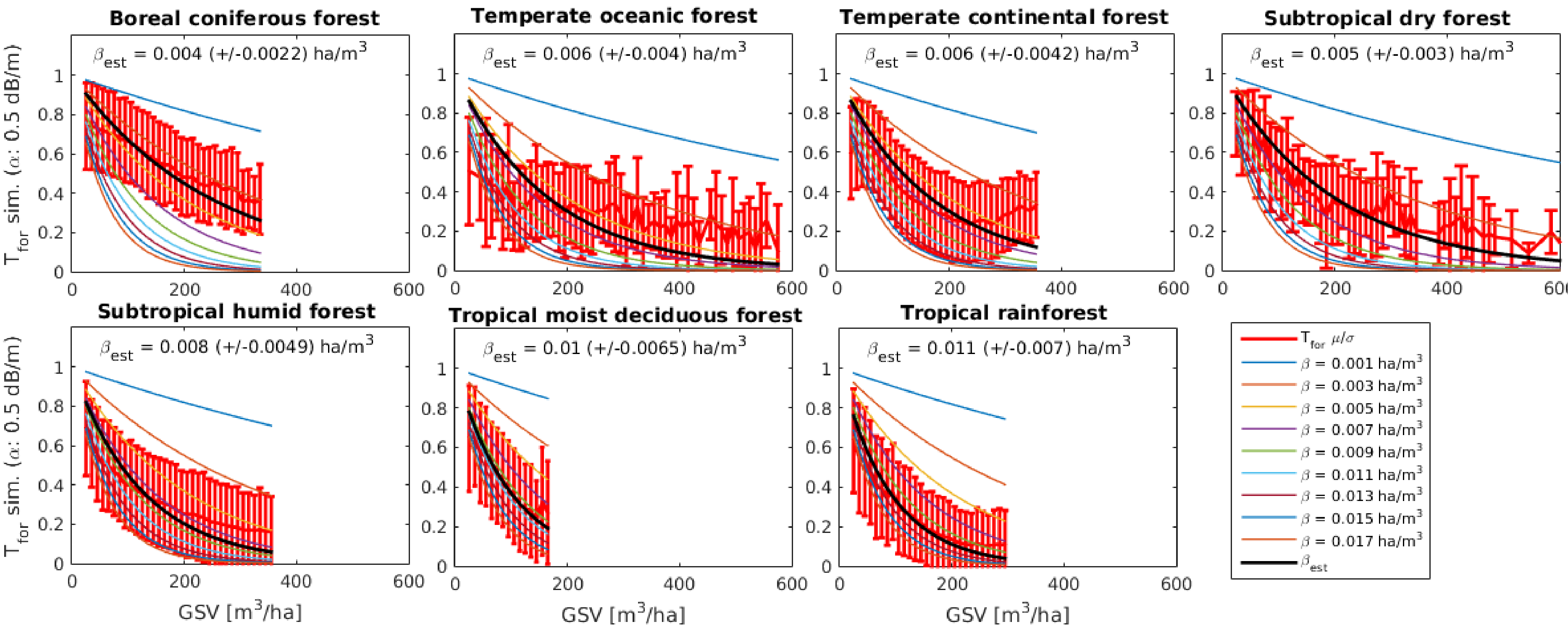
$$T_{for} = (1 - \eta) + \eta e^{\frac{-2\kappa_e h}{\cos\theta}} = \exp(-\beta V)$$

1) Calibration with the aid of VCF and ICESAT GLAS @ pixel level (in moving windows)

2) Model Inversion to estimate GSV



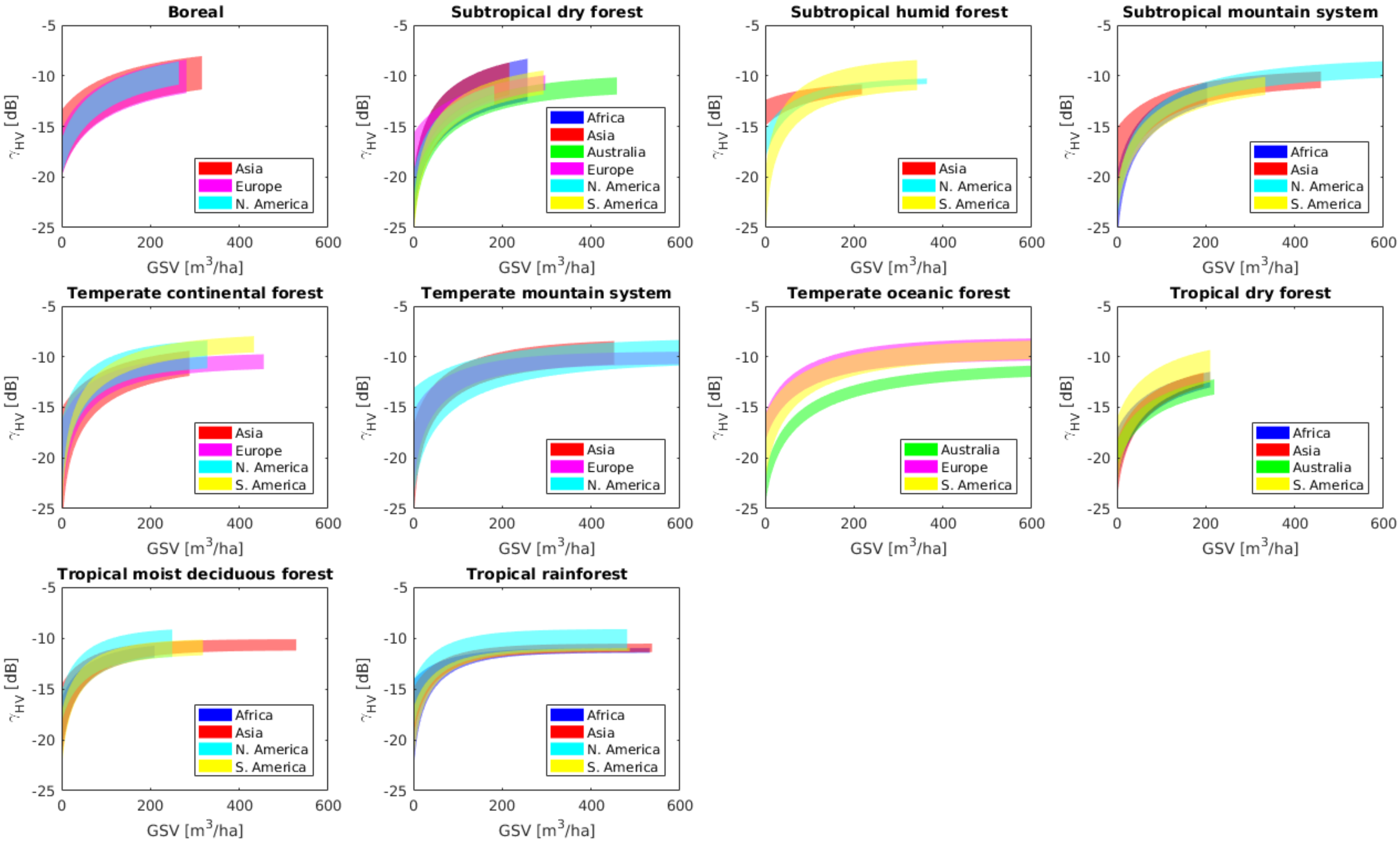
Forest transmissivity at L-band



Transmissivity as function of (optical) canopy density, η, and GLAS height, h, linked to GSV (from available maps)

→ differences in the transmissivity-GSV relationship are described at the scale of FAO ecoregions (coarse scale)

Variability of LHV Backscatter Modeled as Function of GSV



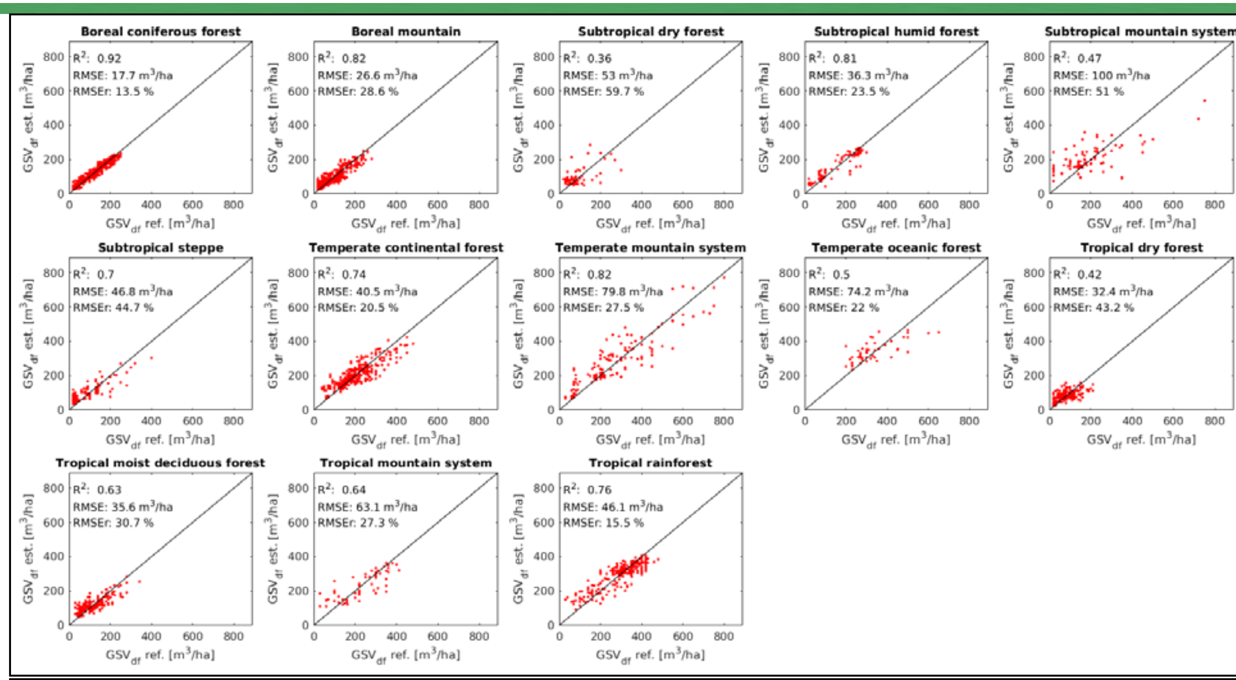
GSV of Densest Forest
Maximum Retrievable GSV

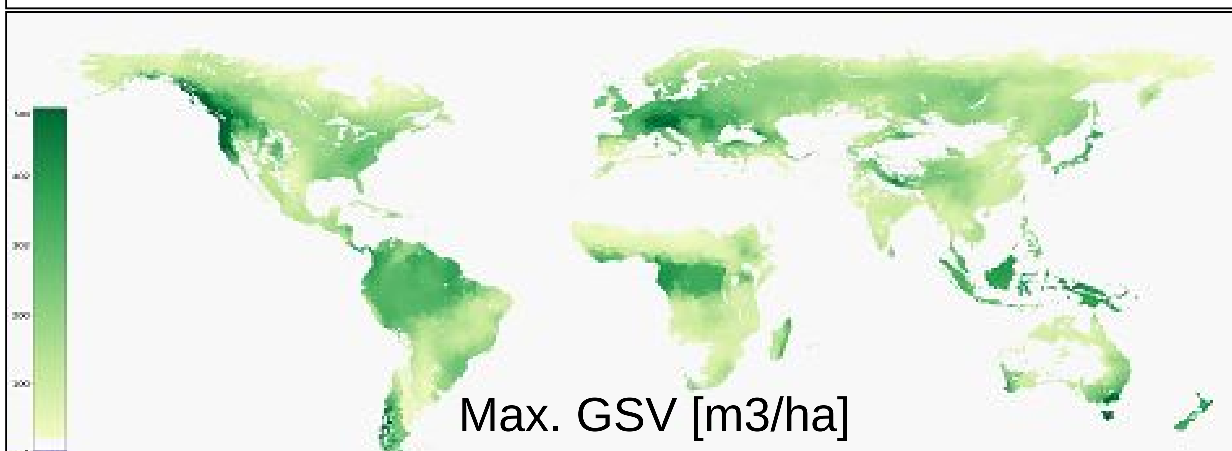
Retrieval needs to be constrained to maximum possible GSV

1) Identify max. GSV from inventories, maps, regional statistics, etc.
2) Produce map of max. GSV @ 20 km scale by modeling max. GSV as function of:

   ICESAT GLAS height and density metrics

   Environmental Factors (WorldClim)





BIOMASAR-C/L – Error Model

$$\delta(V)=\sqrt{\left(\frac{\partial V}{\partial \sigma^0_m}\right)^2\delta^2(\sigma^0_m)+\left(\frac{\partial V}{\partial \sigma^0_{gr}}\right)^2\delta^2(\sigma^0_{gr})+\left(\frac{\partial V}{\partial \sigma^0_{df}}\right)^2\delta^2(\sigma^0_{df})+\left(\frac{\partial V}{\partial h_{df}}\right)^2\delta^2(h_{df})+\left(\frac{\partial V}{\partial \eta_{df}}\right)^2\delta^2(\eta_{df})+\left(\frac{\partial V}{\partial \beta}\right)^2\delta^2(\beta)+\left(\frac{\partial V}{\partial \alpha}\right)^2\delta^2(\alpha)}$$

Speckle, thermal noise

Variability of surface scattering conditions

Variability of volume scattering

GLAS based estimates of height and density

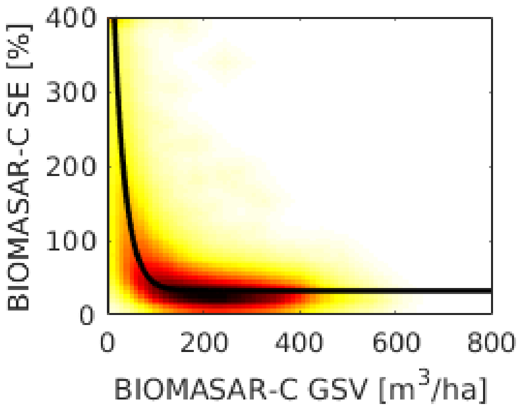
Transmissivity-GSV relationship

Based on transmissivity simulated with GLAS heights /Landsat canopy density

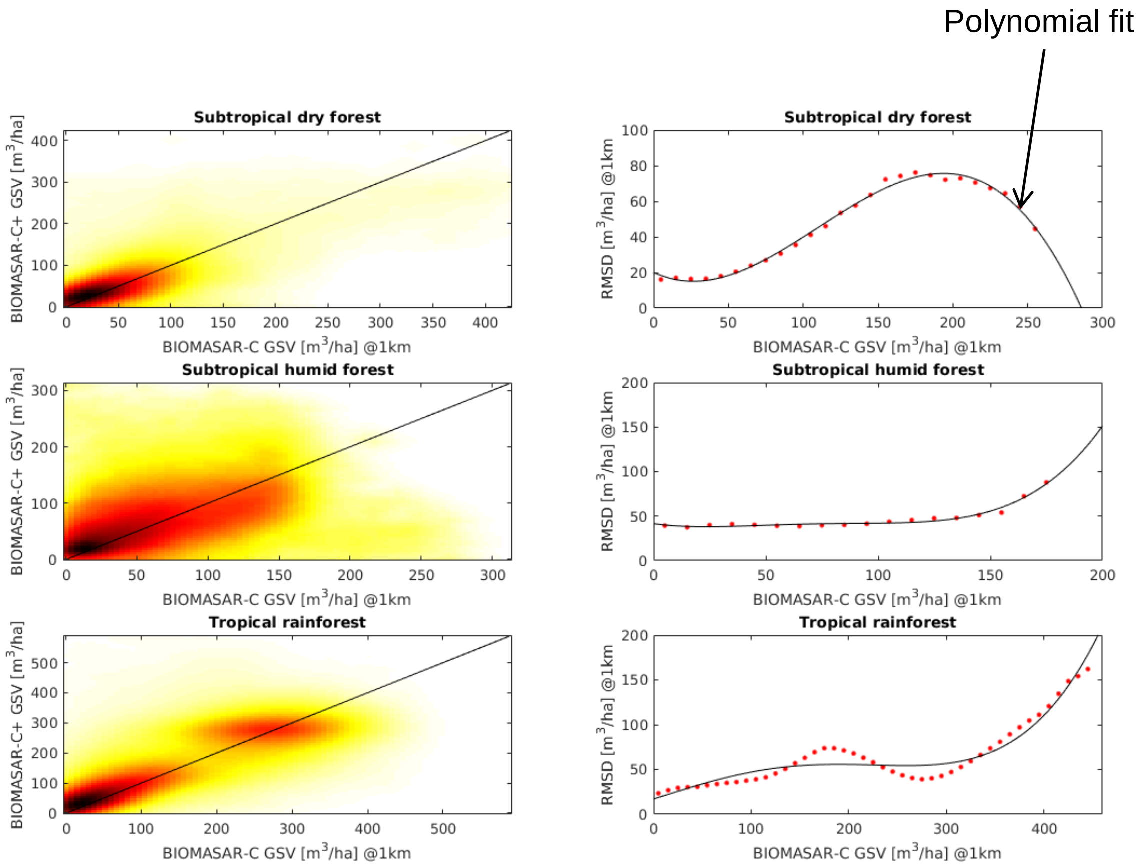
Two-way tree attenuation

BIOMASAR-C+ – Error Propagation

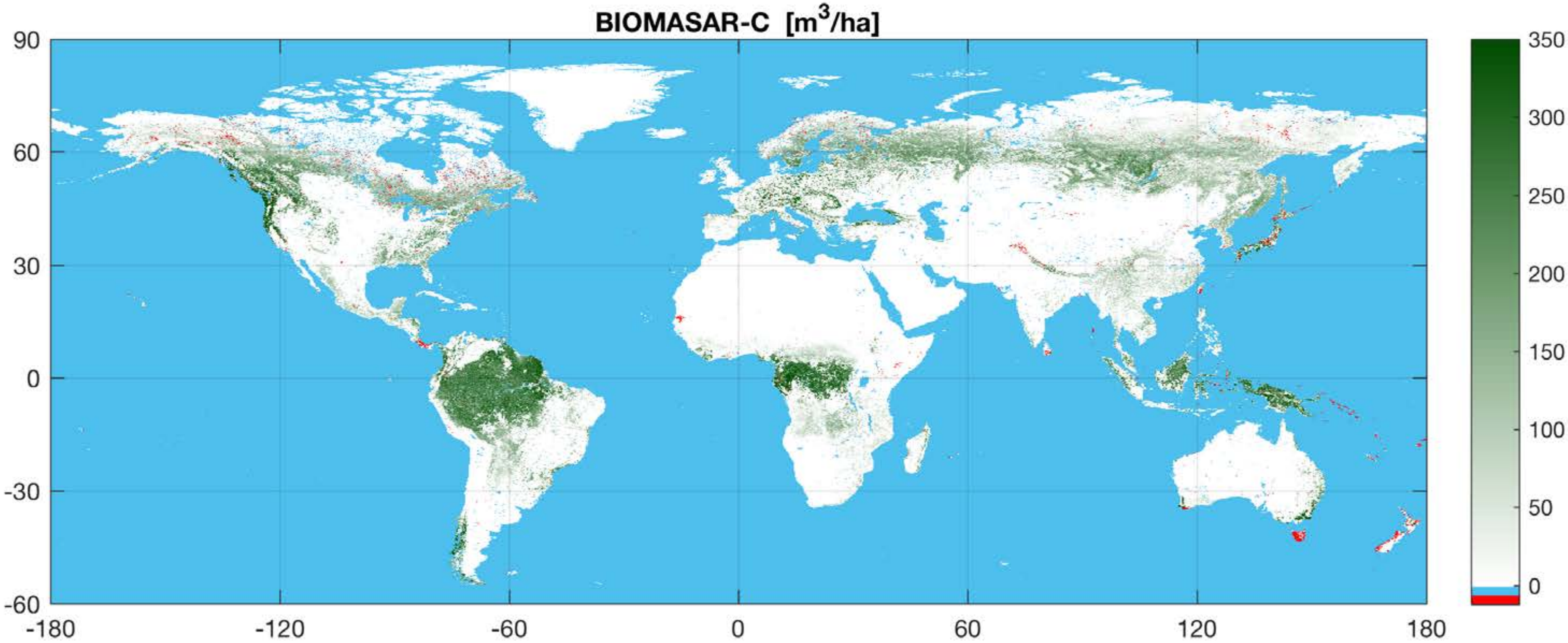
Error of BIOMASAR-C GSV, i.e., the response variable



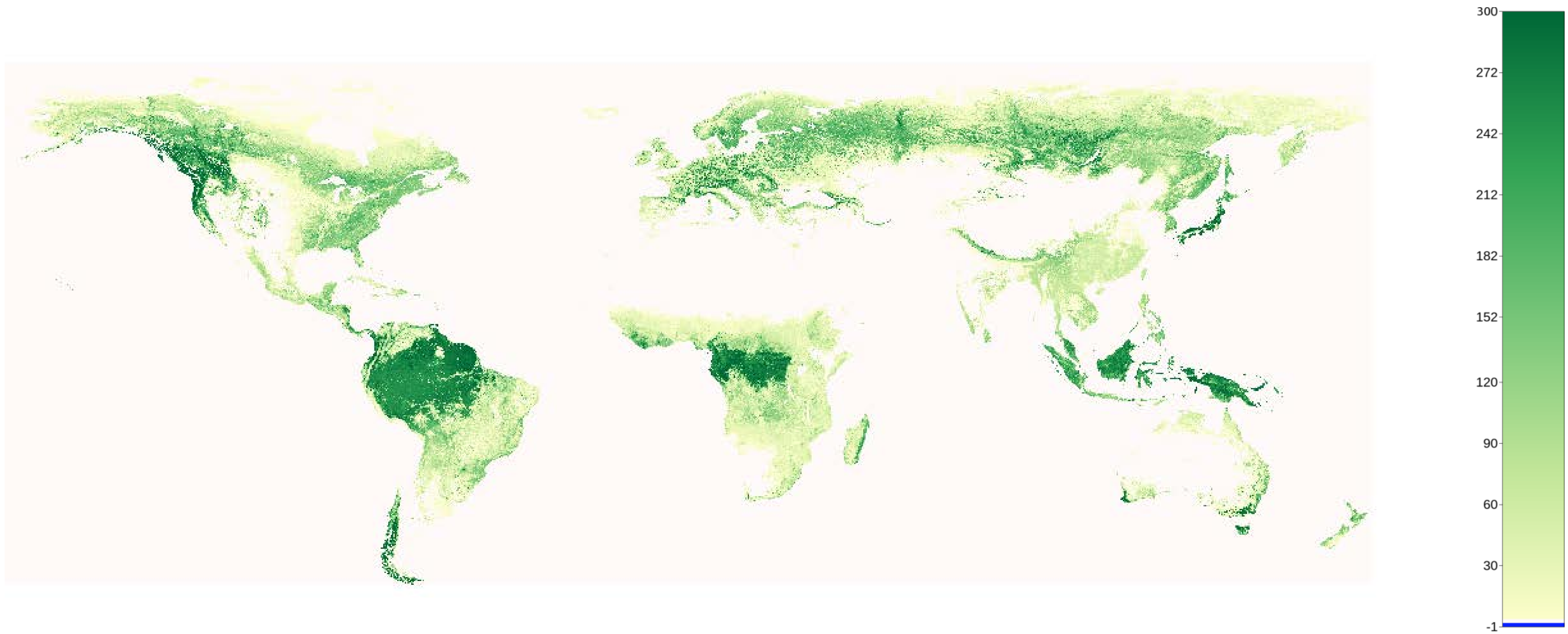
Modeling Error



BIOMASAR-C - GSV @ 1,000 m

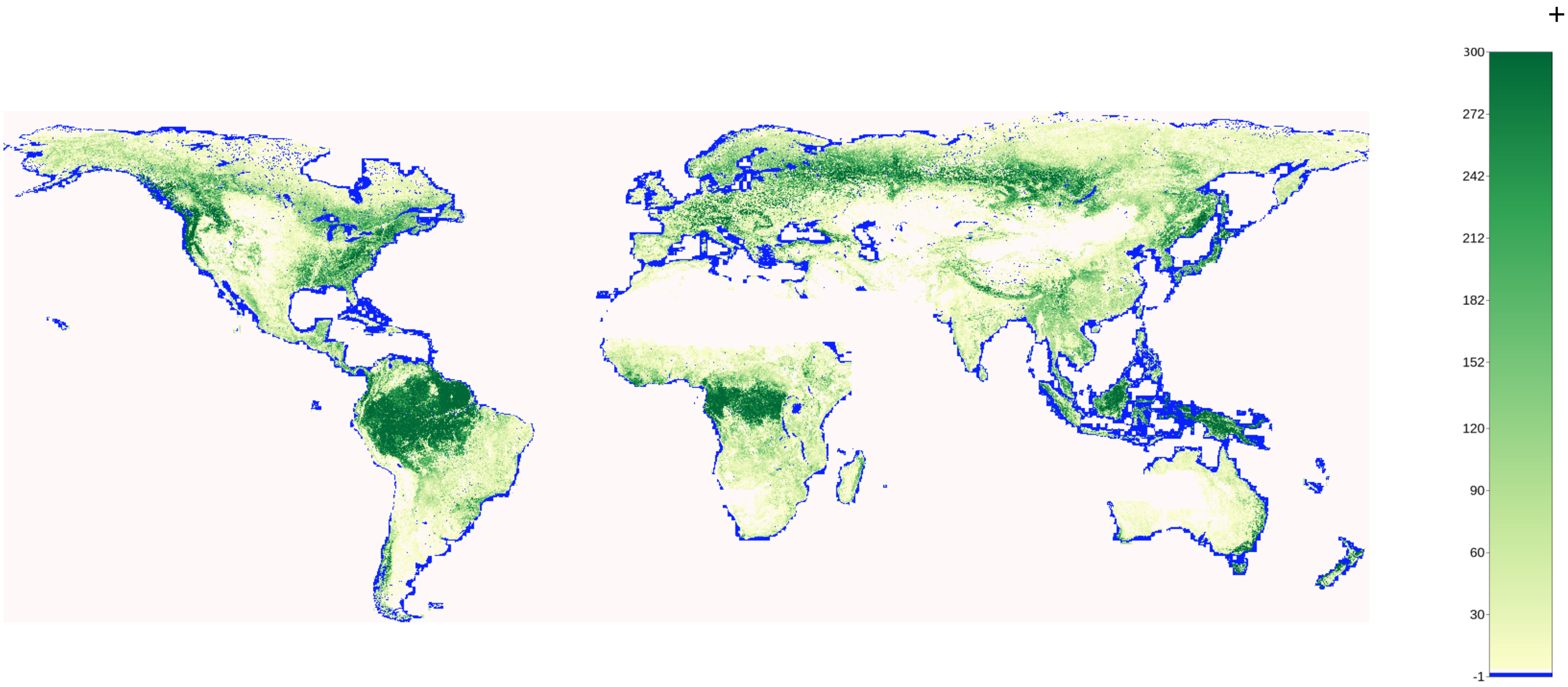


BIOMASAR-C+ - GSV @ 25 m



BIOMASAR-C GSV @ 1 km rescaled to 25 m using PALSAR/Landsat Mosaics

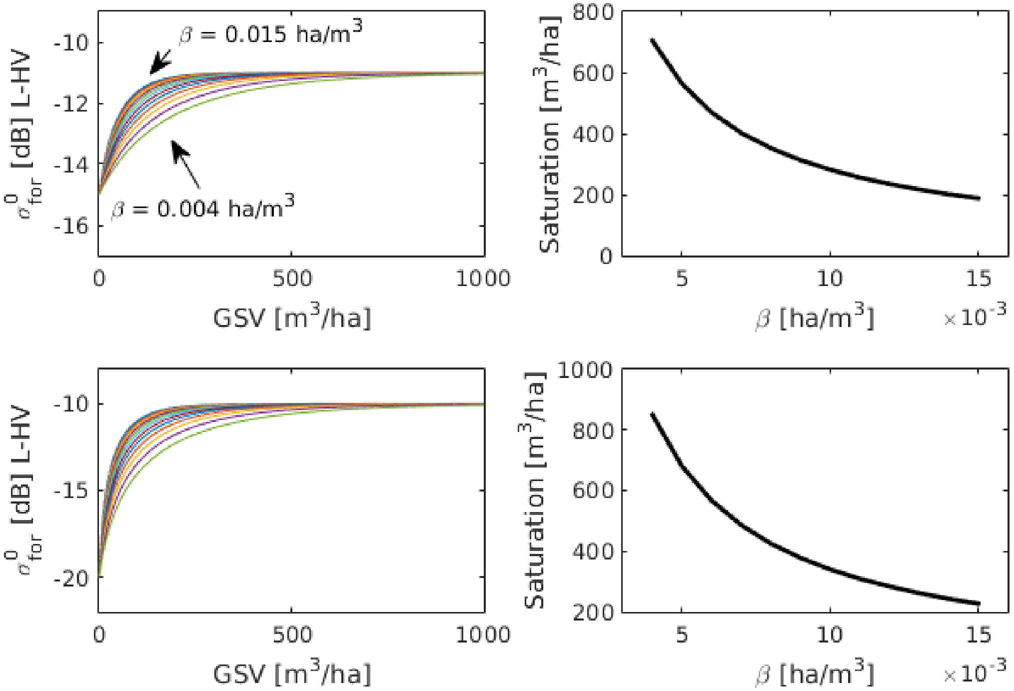
BIOMASAR-L - GSV @ 25 m



BIOMASAR-L GSV @ 25 m based on a single L-band observation!!!

Limitations – L-band sensitivity to GSV/AGB

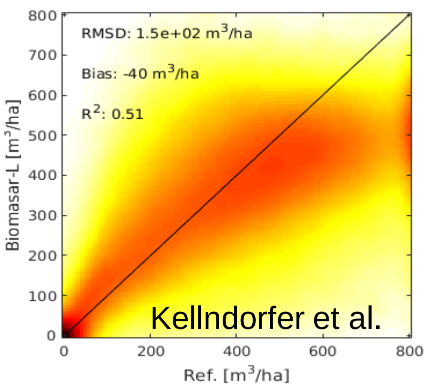
Modeling suggests differences in the sensitivity to low and high GSVs across different ecoregions!



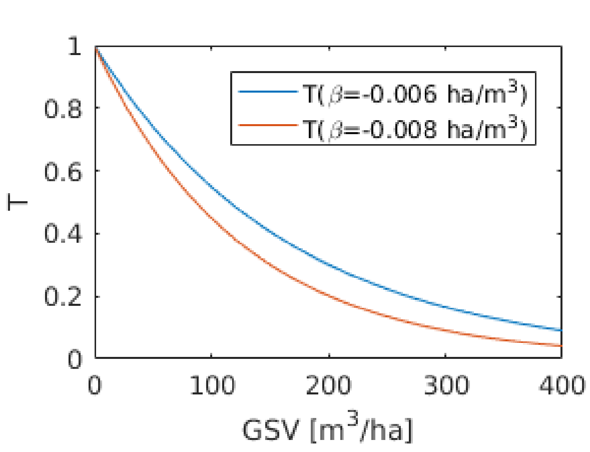
Saturation level calculated according to Hensley et al. (2014) as the GSV level for which speckle prevents a retrieval error of less than 30% at 500m pixel scale:

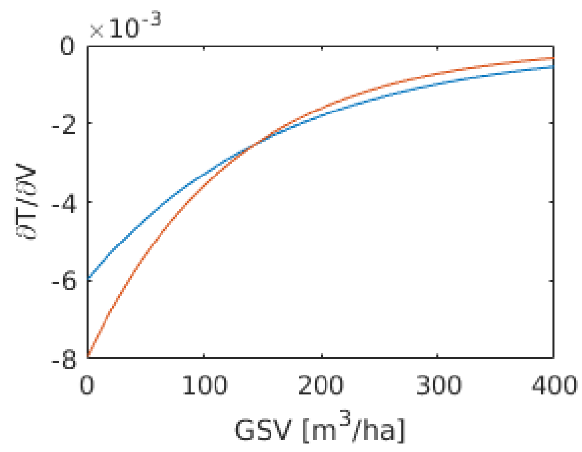
where *N* is the equivalent number of looks (ENL), *κ* the target error of the retrieval, σ(V) the backscatter modelled as function of GSV, and ∂σ/∂V the partial derivative of the model.

NBCD PNW



Merging Rule 1:
Sensitivtiy of C- and L-band to GSV





T = forest transmissivity

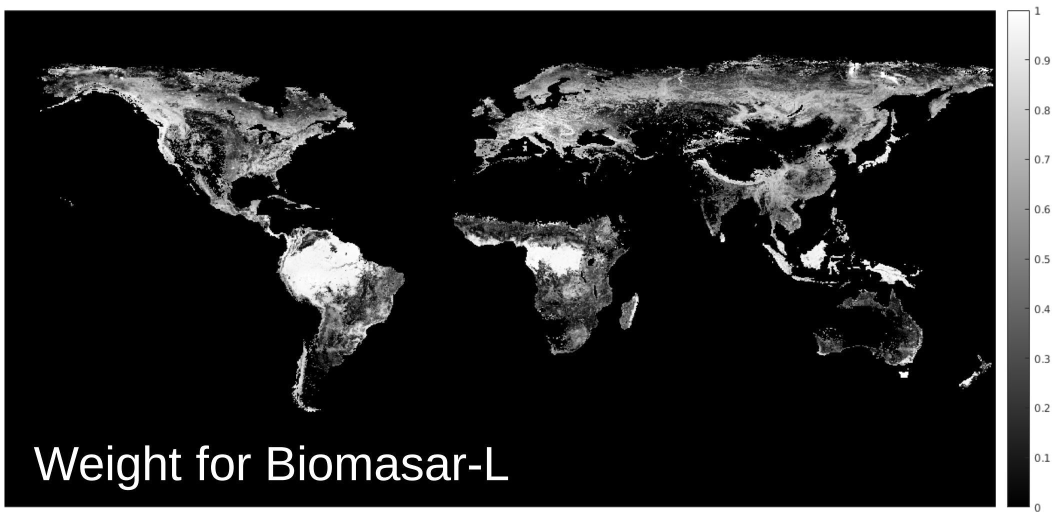
$$w_S = \left|\frac{\partial T_L}{\partial V}\sqrt{N_L}\right| - \left|\frac{\partial T_C}{\partial V}\sqrt{N_C}\right|$$

No. of L-band images = 1

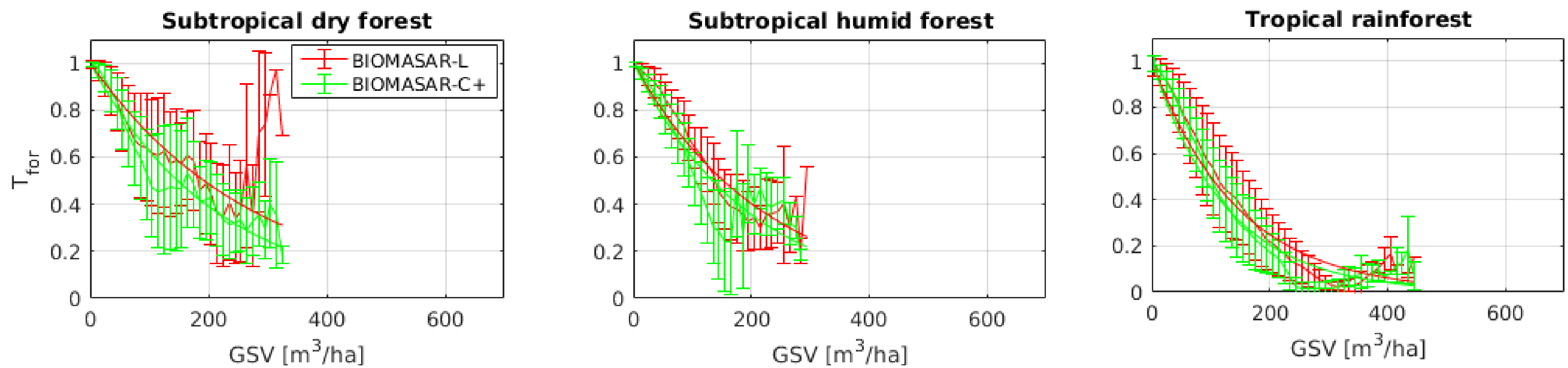
No. of C-band images

Weight derived from transmissivity-GSV relationship reflects higher sensitivity of C-band in low and L-band in high GSV ranges

Weight also considers number of images used in the retrieval.



Merging Rule 2:
Identifying local inconsistencies

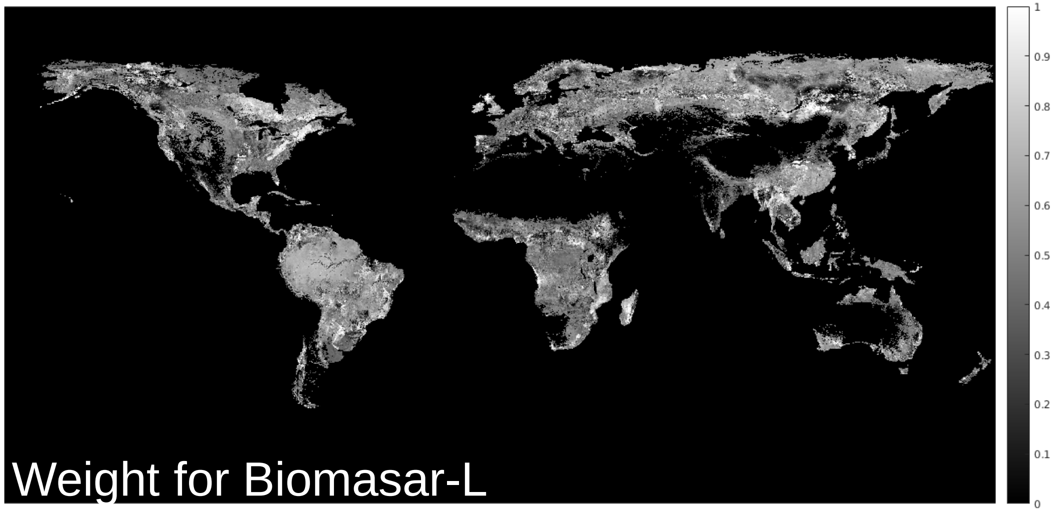


Errors because of locally failed model calibration or inversion.

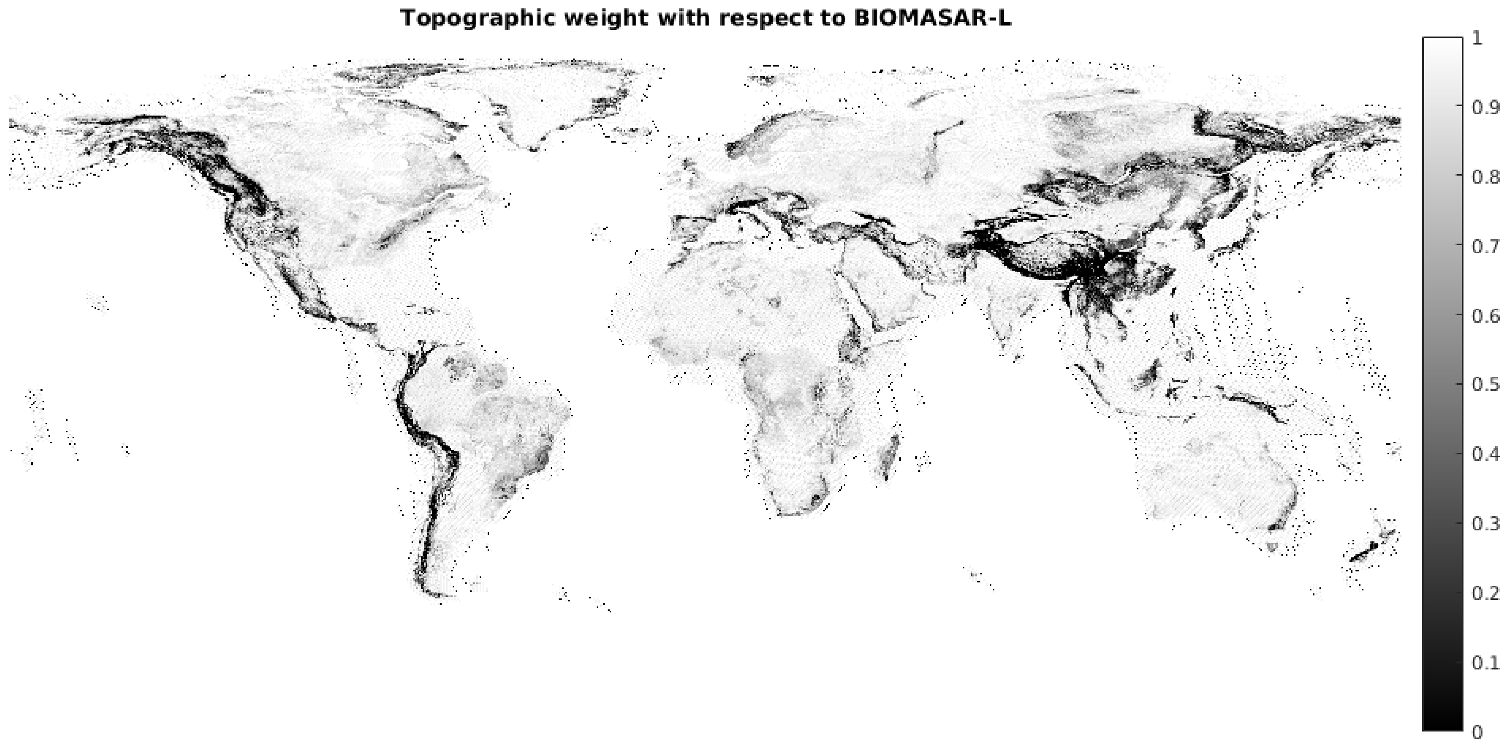
Weight characterizes if BIOMASAR-L and BIOMASAR-C+ maps are consistent with the assumed transmissivity to GSV relationship.

T is simulated based on GLAS/MODIS Height (Simard et al.) and Landsat canopy density

$$w_t = \left|T_{sim}(C) - T_{mod}(C)\right| - \left|T_{sim}(L) - T_{mod}(L)\right|$$



Merging Rule 3:
Topography related errors in the PALSAR mosaics



- PALSAR mosaics not optimally processed with respect to topography.
- BIOMASAR-C+ less affected because uses also Landsat (with different/less topographic issues)
- Weight scales with the pixel scattering area at L-band, i.e., the more pixel scattering area deviates from scattering area on flat terrain, the lower the weight for BIOMASAR-L

$\Delta_{area} = 100 \cdot \left| 1 - \sin(38^\circ) / \sin(\theta_i) \right|$ ← Percent difference in pixel scattering area as function of loc. inc. angle

The (almost) final GlobBiomass GSV map