Status of the retrieval algorithms of the Biomass mission

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**Biomass product requirements**

**Forest biomass**
- 200 m resolution
- Accuracy of 20%, or 10 t ha\(^{-1}\) for biomass < 50 t ha\(^{-1}\)
- 1 biomass map every 6 months
- Global* coverage of forested areas

**Forest height**
- 200 m resolution
- Biome dependent, ~20% for tree > 10 m
- 1 height map every 6 months
- Global* coverage of forested areas

**Disturbances**
- 50 m resolution
- 90% classification accuracy
- 1 map every 6 months
- Global* coverage of forested areas

* Global subject to SOTR restrictions
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Forest biomass is a key component in the carbon cycle

1. Biomass is ~50% carbon
2. Forests hold 70–90% of Earth’s above-ground biomass, with the majority of forest biomass located within the Tropics
3. Forest biomass is very poorly known and is a major source of uncertainty in carbon flux estimation.
4. Our objective is to measure biomass globally, and its change over time.

Biomass = dry weight of woody matter + leaves (tons/hectare)
1. The crucial information gap is in the tropics:
   – deforestation (~98% of the Land Use Change flux)
   – regrowth (~52% of the global biomass sink)
2. Biomass measurements are needed where the changes occur and at the scale of change: 1-4 hectares.
3. An accuracy of 20% at 4 hectares, comparable to ground-based observations.
4. Forest height to provide a further constraint on biomass estimates
5. Repeated measurements over multiple years to identify deforestation and growth
Why are tropical data most uncertain and so important?

Tropical biomass = 360-680 billion tons

Uncertain due to
1. biodiversity
2. poorly coordinated/sparse measurements

<table>
<thead>
<tr>
<th>C sink/source</th>
<th>2000-2007 GtC/yr</th>
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</thead>
<tbody>
<tr>
<td>Boreal</td>
<td>0.5±0.08</td>
</tr>
<tr>
<td>Temperate</td>
<td>0.72±0.08</td>
</tr>
<tr>
<td>Tropical Intact</td>
<td>1.02±0.47</td>
</tr>
<tr>
<td>Tropical regrowth</td>
<td>1.72±0.54</td>
</tr>
<tr>
<td>Tropical deforestation</td>
<td>-2.82±0.45</td>
</tr>
<tr>
<td>Tropical land use change</td>
<td>-1.10±0.70</td>
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</table>

Tropical Woodland
Subtropical Forest
Terra Firme
Tropical Forest
Riverine Forest
A single satellite providing continuous polarimetric interferometric P band SAR data over forested areas.

- Forest biomass
- Forest height
- Forest disturbance
Major recent campaigns:

- Kalimantan 2004 (Indrex)
- Remningstorp 2007 (BioSAR 1), 2010 (BioSAR 3)
- Krycklan 2008 (BioSAR 2)
- F. Guiana 2009 (TropiSAR), 2011-13 (TropiScat)
<table>
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<tr>
<th>Campaign</th>
<th>Objectives</th>
<th>Test sites</th>
<th>Time</th>
<th>Forest conditions</th>
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<td>INDREX-2 (Hajnsek et al., 2008)</td>
<td>Forest height retrieval in tropical forest and measurement of repeat-pass temporal decorrelation</td>
<td>Sungai-Wai &amp; Mawas Borneo, Indonesia</td>
<td>Nov 2004</td>
<td>Tropical rain forest. Sungai-Wai: lowland with biomass up to 600 t ha⁻¹. Mawas: peat swamp with biomass up to 200 t ha⁻¹</td>
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<tr>
<td>TropiSAR (Dubois-Fernandez et al., 2012)</td>
<td>Biomass estimation in tropical forest, multiday decorrelation</td>
<td>Paracou &amp; Nouragues French Guiana</td>
<td>Aug 2009</td>
<td>Tropical rain forest with biomass up to 500 t ha⁻¹, lowland and hilly terrain</td>
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<td>Tropiscat (Albinet et al., 2012)</td>
<td>Ground-based high temporal resolution measurements to determine long-term temporal decorrelation</td>
<td>Paracou, French Guiana</td>
<td>Oct. 2011-Oct. 2012</td>
<td>Tropical rain forest with biomass up to 500 t ha⁻¹</td>
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<tr>
<td>BioSAR-1 (Hajnsek et al., 2008)</td>
<td>Biomass estimation in hemi-boreal forest and measurement of multimonth temporal decorrelation</td>
<td>Remningstorp, southern Sweden</td>
<td>Mar-May 2007</td>
<td>Hemi-boreal forest, low topography with biomass up to 300 t ha⁻¹</td>
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<td>BioSAR-2 (Hajnsek et al., 2009)</td>
<td>Topographic influence on biomass estimation in hilly boreal forests</td>
<td>Krycklan, northern Sweden</td>
<td>Oct 2008</td>
<td>Boreal forest, hilly, with biomass up to 300 t ha⁻¹</td>
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<td>BioSAR-3 (Ulander et al., 2011a)</td>
<td>Forest change and multiyear coherence relative to BioSAR-1</td>
<td>Remningstorp, southern Sweden</td>
<td>Sep 2010</td>
<td>Hemi-boreal forest, low topography with biomass up to 400 t ha⁻¹ (includes additional high biomass stands compared to 2007 campaign)</td>
</tr>
</tbody>
</table>
A same sensor on a single satellite to deliver 3 independent information for biomass.

- **PolSAR** (SAR Polarimetry)
- **Pol InSAR** (Polarimetric SAR Interferometry)
- **Tomo SAR** (SAR Tomography)
A same sensor on a single satellite to deliver 3 independent information for biomass

Nominal phase

Images

Images + Height information

PolSAR
(SAR Polarimetry)

Pol InSAR
(Polarimetric SAR Interferometry)

Tomography phase

Images + Vertical resolution

Tomo SAR
(SAR Tomography)
P-band SAR measures biomass and quantifies landscape dynamics

Large dynamic range as a function of biomass

Yellowstone Park, 2003

-12dB
-19dB
-27dB

Backscatter intensity

Biomass (t/ha)

15 years after burn

A week after burn

60-80 years after burn
- Similar relationship is found for all forests where we have data

- Differences in forests implies the need to understand why this happens and to devise inversion techniques and stratification / training approach to deal with them.
Soil moisture and topography change the backscatter intensity in boreal forest

Remningstorp forest (Sweden)

March 2007
April 2007
May 2007

All polarisations are used to reduce environment and topographic effects

\[ \log B = a_0 + a_1 \log HV + a_2 \cdot \log(HH/VV) + a_3 \cdot \text{slope} \cdot \log(HH/VV) \]

Accounting for soil moisture variation

Accounting for topographic effect

Backscatter intensity at a single polarisation (HV)

Biomass [tons/ha]

DEM
Consistency of biomass estimates after correction of environment effects

Biomass map, Remningstorp, Sweden

Training at Krycklan

Inversion using single polarisation (HV)

Reference

March

May

Biomass (ton/ha)
Consistency of biomass estimates after correction of environment effects

Biomass map, Remningstorp, Sweden

Training at Krycklan

Inversion using single polarisation (HV)

Inversion using multiple polarisation and DEM

Reference  March  May  March  May

Biomass (ton/ha)

0 100 200 300 400
Changes in carbon stock in boreal forest

Maps of change in carbon stock from spring 2007 (ESAR) to autumn 2010 (SETHI) at Remningstorp; resolution = 200 m

Biomass will be able to detect a 10 MgC/ha change during a 4-year period.
In high biomass tropical forest, topographic effect is the disturbing factor to be removed.

Tropical forest
French Guiana

Backscatter at single polarisation (HV in dB)

Correction for effects on both geometry and scattering mechanisms caused by topography. Requires full polarimetric data.

Backscatter after topographic correction using polarimetry (t0 in dB)
Tropical forest: biomass map from PolSAR

Tropical forest, French Guiana

Training at Nouragues
Validated at Paracou

P-band SAR image (SETHI of ONERA)

Biomass map using P-band PolSAR

RMSE=64 ton.ha⁻¹
Importance for Pol INSAR: coherence remains high (> 0.7 after 1 month)

- Highest coherence with time interval < 15 days
- Decreases with rain event
Height from Pol InSAR at tropical and boreal sites

Tropical forest, Kalimantan, Indonesia

Height map from Pol InSAR

Boreal forest, Remningstorp, Sweden

Height map from Pol InSAR

Height map from Lidar

Height from Pol InSAR at tropical and boreal sites
Using dual baseline PolInSAR gives accurate height maps in boreal forest.
SAR tomography for sounding forest canopy

From *multi baseline* SAR images

→ generation of *multi layer* SAR images

- Slant range
- Azimuth
- SAR resolution cell
- SAR Tomography resolution cell

Tomographic Processor
Using tomography to understand the P-band SAR signal over forests

Boreal forest

Tropical forest
Using tomography to understand the P-band SAR signal over forests

125 MHz

Forest  marsh  river

HH  HV  VV

Paracou forest, French Guiana
Using tomography to understand the P-band SAR signal over forests

Paracou forest, French Guiana
Combined approaches for biomass estimation

- PolSAR Covariance Matrix
- Biomass Estimation from PolSAR
  - Tomography
  - DEM
  - In-situ Data
- PollInSAR Covariance Matrix
- Forest Height Estimation
- Allometric Biomass Estimation
- Biomass Estimate 1
- Minimum Mean Square (MMSE) Estimate
- Biomass Estimate 2
- Biomass Map & Error Map
Combined approaches for tropical forests

Resolution 150 m

PolSAR

PolInSAR

PolSAR+PolInSAR

Tomography

Resolution 50 m

Using interpolated DEM from SRTM
Combined approaches for tropical forests

<table>
<thead>
<tr>
<th>PolSAR</th>
<th>PolInSAR</th>
<th>PolSAR + PolInSAR</th>
<th>Tomography</th>
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Using a 30 m DEM

- RMSE < 20%
- RMSE ~10%

(Root Mean Square Error RMSE using reference plots)
The BIOMASS measurement concept has been demonstrated at different forest ecosystems, including wet tropical forests.

- Three approaches have been used to reach biomass estimates: PolSAR, Pol InSAR and TomoSAR. Combination of them to improve estimates has been shown.

- Biomass is technically mature and feasible to meet science requirements.

- If selected in May 2013, it will open the field for more new and innovative ways to use SAR data by a large community.

(\textit{PolInSAR 2015!})

To conclude:

Explore a new face of Earth and pioneer the first P-band radar in space: choose BIOMASS!