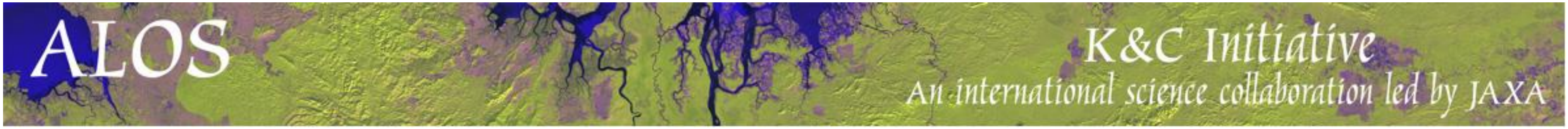

K&C Phase 4 – Final report

Retrieval of forest biomass and biomass change with spaceborne SAR

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Science Team meeting #25
Tokyo, Japan, February 5-8, 2019

Project outline and objectives

In the project, seen as a continuation of the K&C Initiative activities performed in the previous Phases 1, 2 and 3, multi-temporal ALOS-1 PALSAR-1 and ALOS-2 PALSAR-2 data were used to further develop and validate methods for large-scale biomass and biomass change mapping.

Biomass maps covering all of Sweden have been derived using PALSAR-2 data for the year 2015 and PALSAR-1 data for the year 2010.

Each map was validated with inventory data from the Swedish National Forest Inventory (NFI) and compared with county statistics from the Swedish NFI.

Project outline and objectives

To derive the PALSAR-1/2 biomass maps, a revised algorithm based on the Water Cloud Model was used (BIOMASAR algorithm).

By comparing the biomass maps of 2015 and 2010, both loss in biomass (i.e., clear-cuts, thinning cuttings, wind-thrown damages) and forest growth could be studied.

A study has been conducted using L-band (and P-band) data from the BioSAR 2007 and BioSAR 2010 BIOMASS campaigns at the test site Remningstorp in southern Sweden (Ivan Huuva et al.).

Project outline and objectives

~~Furthermore, change detection of the forest cover in terms of detecting and delineating clear-felled areas for all of Sweden will be performed using PALSAR-2 data from the years 2015 and 2016. The approach will be to use a similar methodology as developed in Phases 1 and 2.~~

~~The clear-felled areas derived from PALSAR-2 data will be compared to clear-cut maps from:~~

~~i) the Swedish Forest Agency and~~

~~ii) statistics from the Swedish NFI.~~

The above activities were not possible to perform due to lack of funding from the Swedish National Space Agency.

Project outline and objectives

The project involved analysis of more than 28 million ha of boreal and hemi-boreal forests in Sweden.

The differences in weather conditions, topography, forest properties, time of acquisition, number of observations and incidence angle range made it especially important to develop a robust methodology for future operational use.

It is suggested that the project has advanced the knowledge towards an operational use of high-resolution L-band SAR data in forestry applications.

The methods and algorithms that were developed also aimed to demonstrate the large-scale forestry monitoring goals of the JAXA's ALOS K&C Initiative

Project area – Sweden

Project outline and objectives

The project supports the 4 K&C thematic drivers, i.e. **C**arbon Cycle Science, **C**limate Change, International **C**onventions, Environmental **C**onservation.

The L-band datasets

Slant range geometry, SAR backscatter, Fine Beam Dual mode path data

All data acquired over Sweden requested

ALOS-1 PALSAR-1 (2010 biomass map)

- 104 FBD image strips, spring-to-fall 2010
- 36 AUIG frames to fill a 1% gap, summer 2008 (closest date to 2010)

ALOS-2 PALSAR-2 (2015 biomass map)

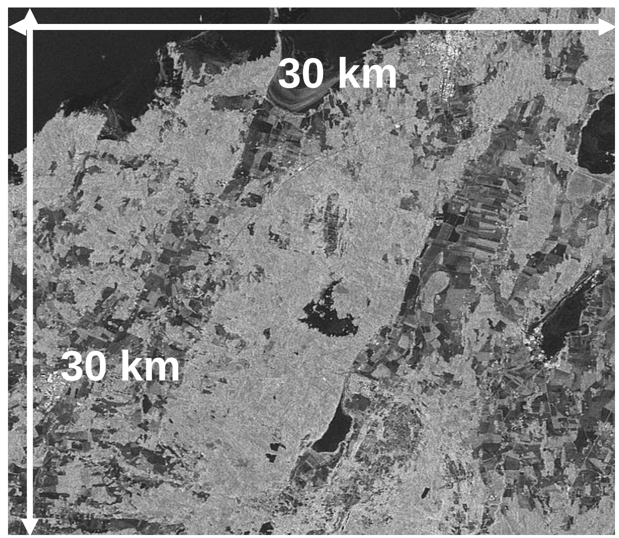
- 218 FBD image strips,
- October 2014 – October 2017
- Finally, only the spring-to-fall data used (~50% of the data obtained)

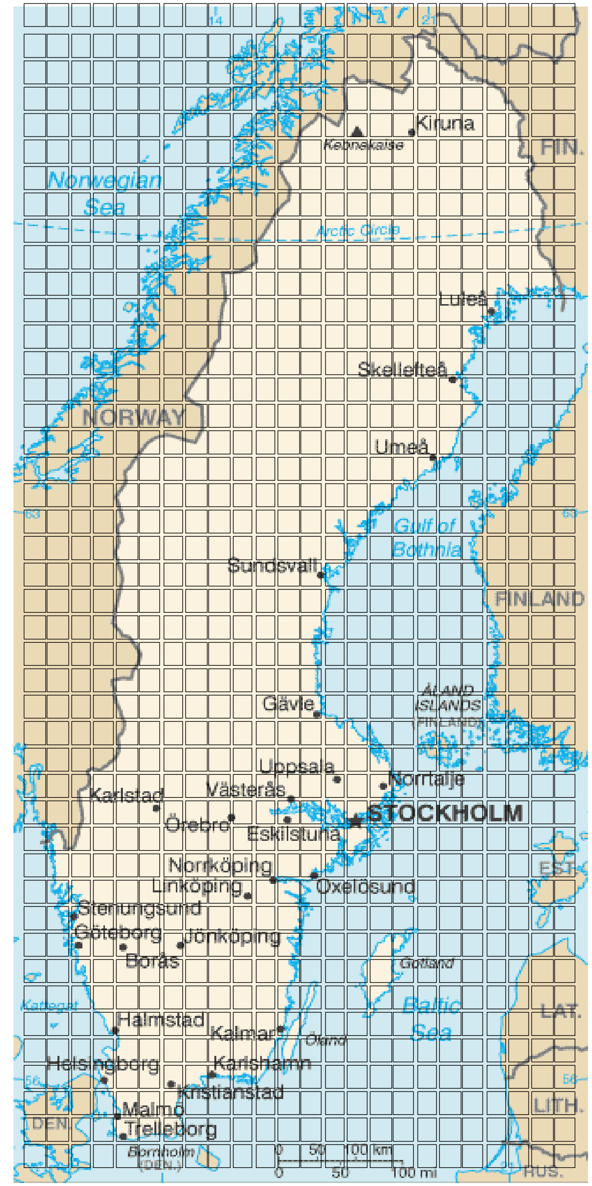
Processing of ALOS-1/2 data

Standard pre-processing techniques

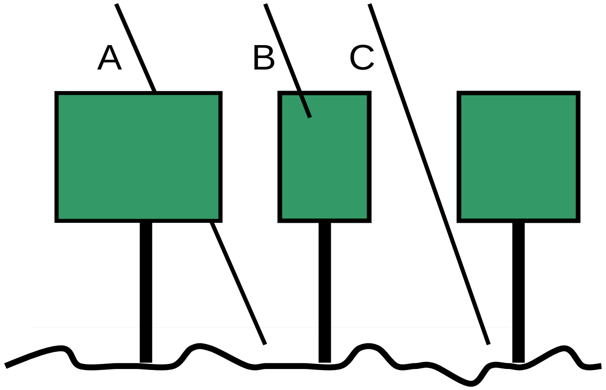
- Radiometric calibration
- Terrain geocoding
- Normalisation for pixel area
- Image tiling

Tiling system





Revisiting the Water Cloud Model



- The original Water Cloud Model expresses the forest backscatter as a function of canopy density (η), vegetation height (h) and two-way tree attenuation (α)

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

New: integrate allometry to express canopy density and height as function of “biomass”

Canopy density vs.height

- Canopy density (CD) and height metrics can be derived from ICESAT GLAS waveforms
- Observations of CD and RH100 are correlated:

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

- The slope of the exponential (coefficient q) depends on forest structural properties

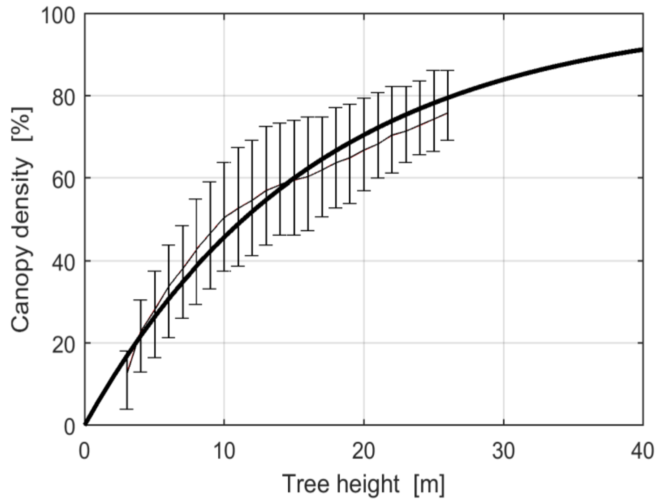
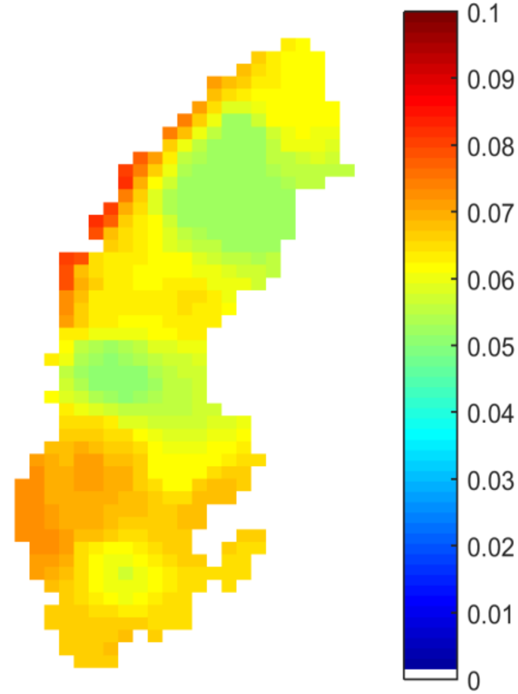


Image of coefficient q

Resolution: 30 km

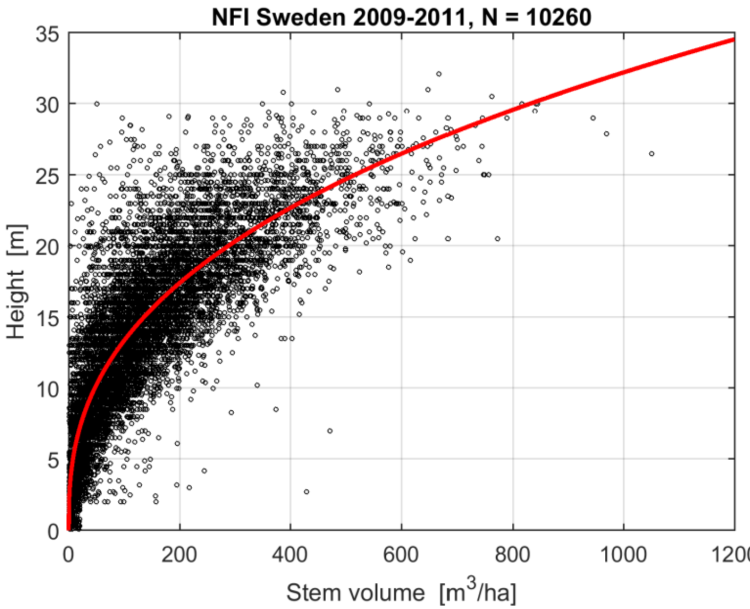


Height vs. biomass

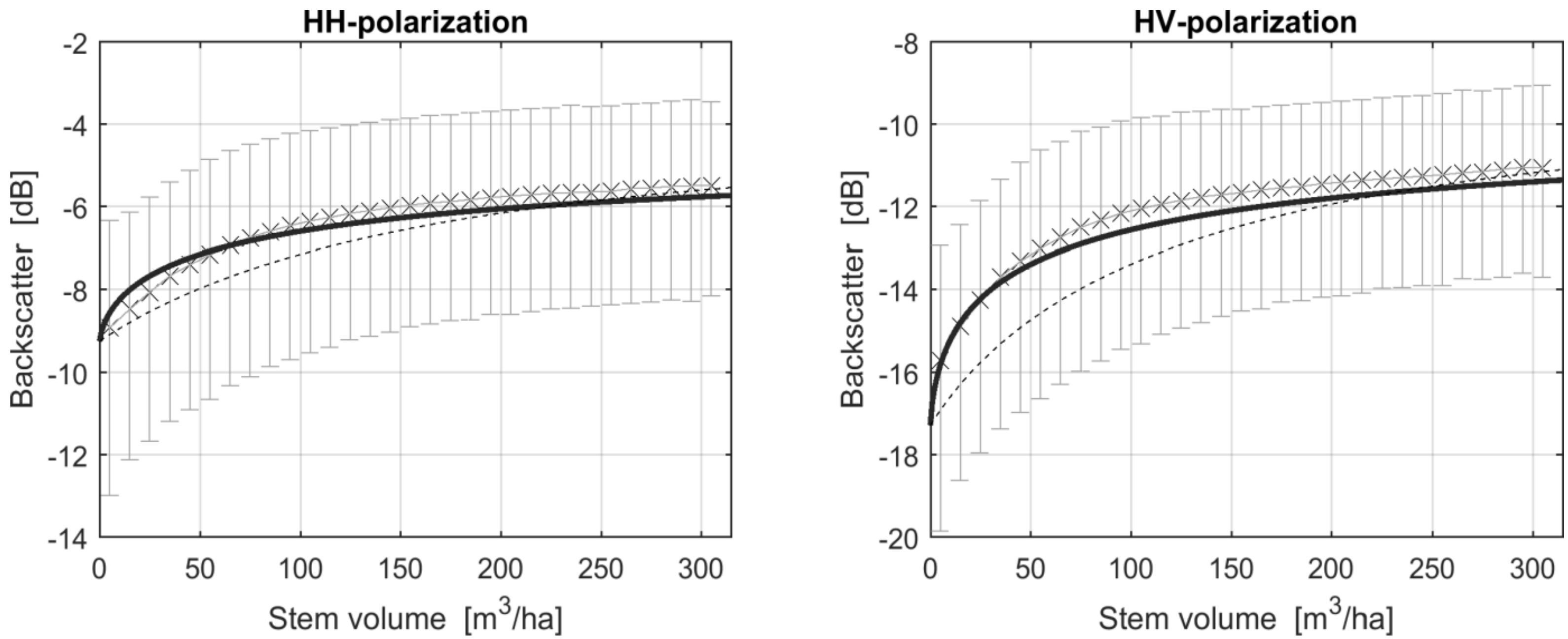
- Experiment undertaken for Sweden thanks to the availability of NFI data
- Relating measured variables, i.e., tree height and stem volume
- Relationship explained by power-law function

$$h = (aV)^b$$

- Same function valid throughout the boreal zone, albeit different model parameters



Validating the WCM



- Reference: ALS map of Sweden (https://www.skogsstyrelsen.se/skogligagrunddata)
- Observations: ALOS PALSAR

Thick line: “new” WCM (this study integrating allometry)

Dashed line: “old” WCM (direct estimation of biomass, see Pulliainen et al., 1994)

Crosses: Mean backscatter

Bars: 5th-95th percentile

„Biomass“ estimation procedure, including uncertainty

- Training of WCM was done for each ALOS-1/2 image → relating backscatter and stem volume on a tile-by-tile basis to account for spatial variability of backscatter

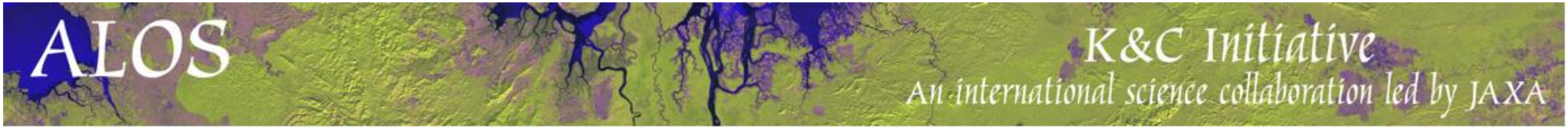
- Inversion of the WCM to estimate stem volume for each SAR image

- Weighted average of individual stem volume estimates (dynamic range)

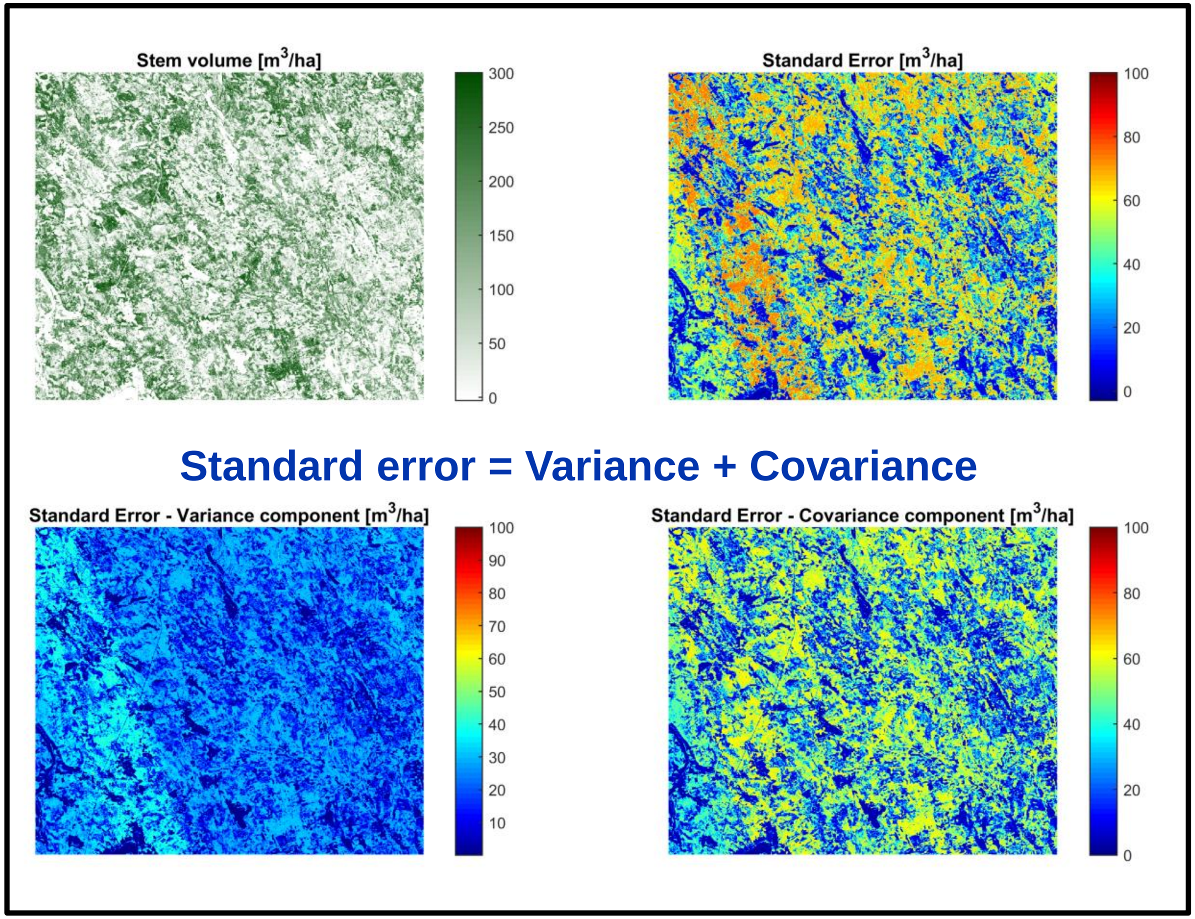
- Conversion of stem volume to total carbon density
  - Total biomass density = (stem volume × wood density) × biomass expansion
    - Wood density based on Thurner et al. (2014) for broadleaves and conifers
    - Biomass expansion: models relating stem to biomass components (Thurner et al., 2014)
  - Total carbon density = 0.5 × total biomass density

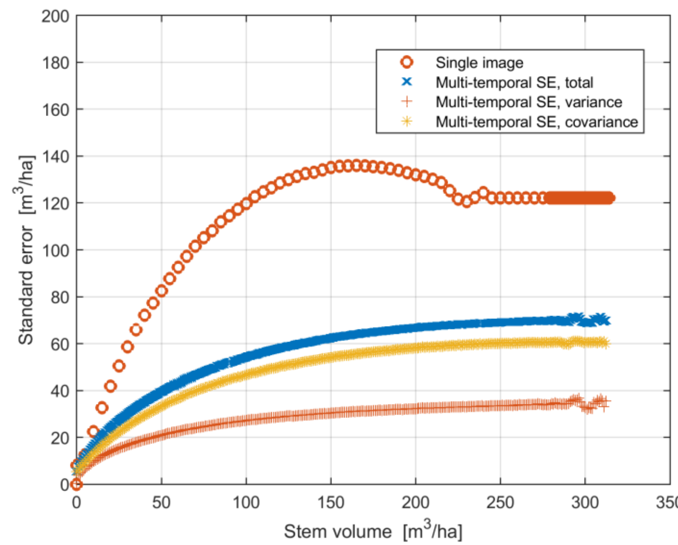
„Biomass“ estimation procedure, including uncertainty

- Modelling the uncertainty of the stem volume and total carbon density estimates
  - Models for the uncertainty of
    - the WCM parameters
    - the allometries
    - the SAR backscatter
  - Variance - covariance model for the multi-temporal stem volume
  - Models for the conversion of stem volume to total carbon density



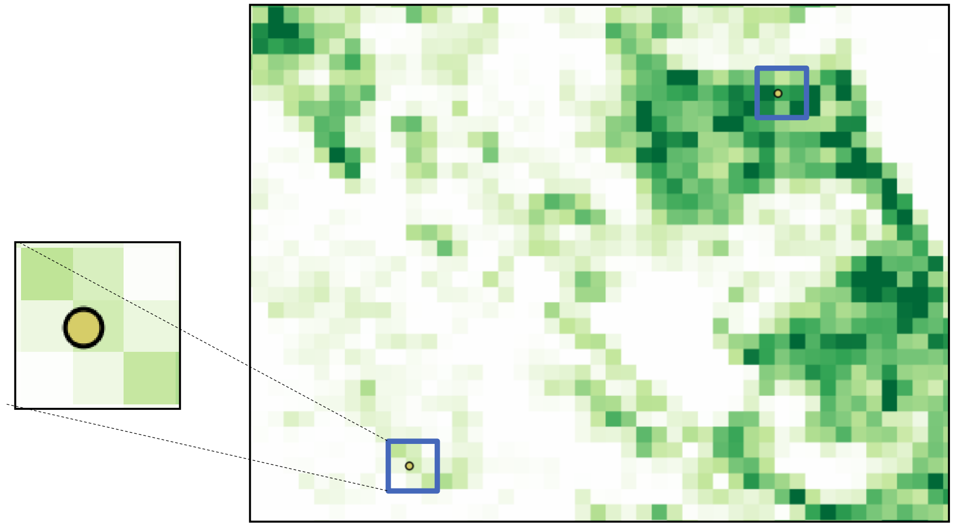
Note on retrieval uncertainties





- Correlation between observations implies error covariance. However, the multi-temporal combination of single-image reduces the standard error of the retrieval.

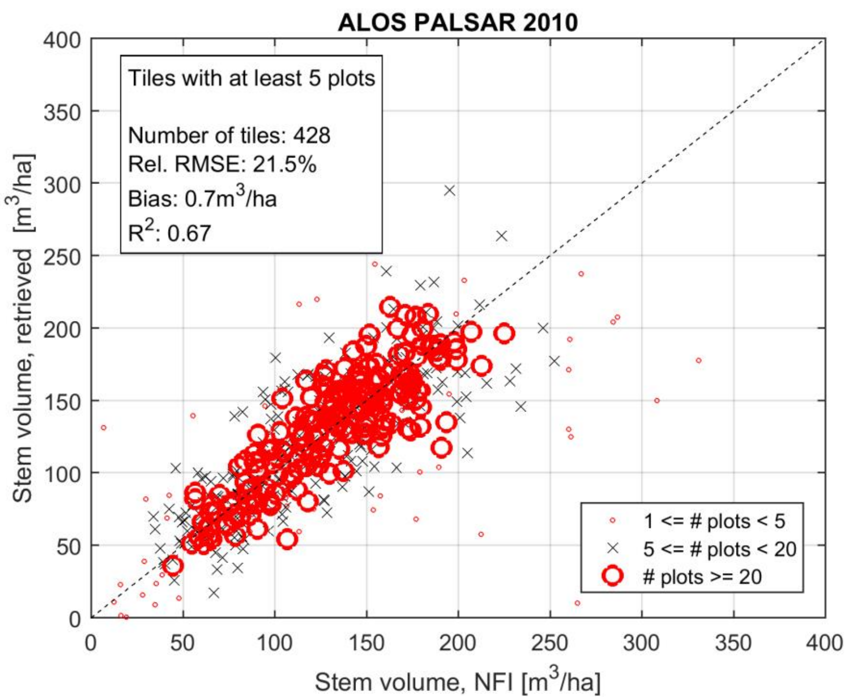
Validation protocol

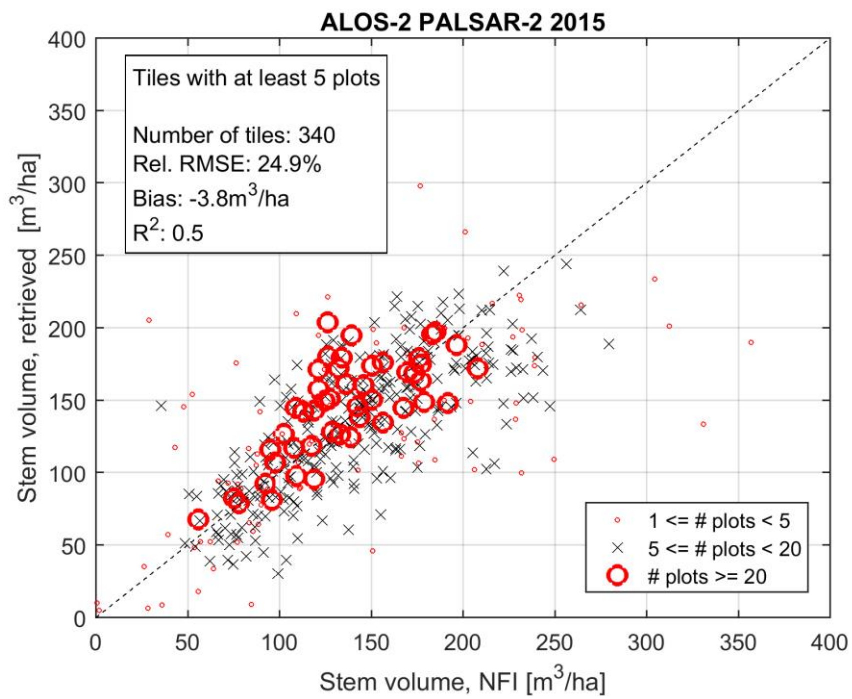


- The size of NFI plots (10 m or 7 m radius) is comparable to the size of a pixel (25 m)
- A plot, however, may not fall exactly within a pixel
- In addition, the forest represented in a plot does not match with the forest seen by the radar
- Plot vs. pixel assessment is appealing but bears complications that limit the understanding of the retrieval
- Plots are meant to derive statistics → it is more correct to assess the estimates of biomass by creating some sort of spatial averages

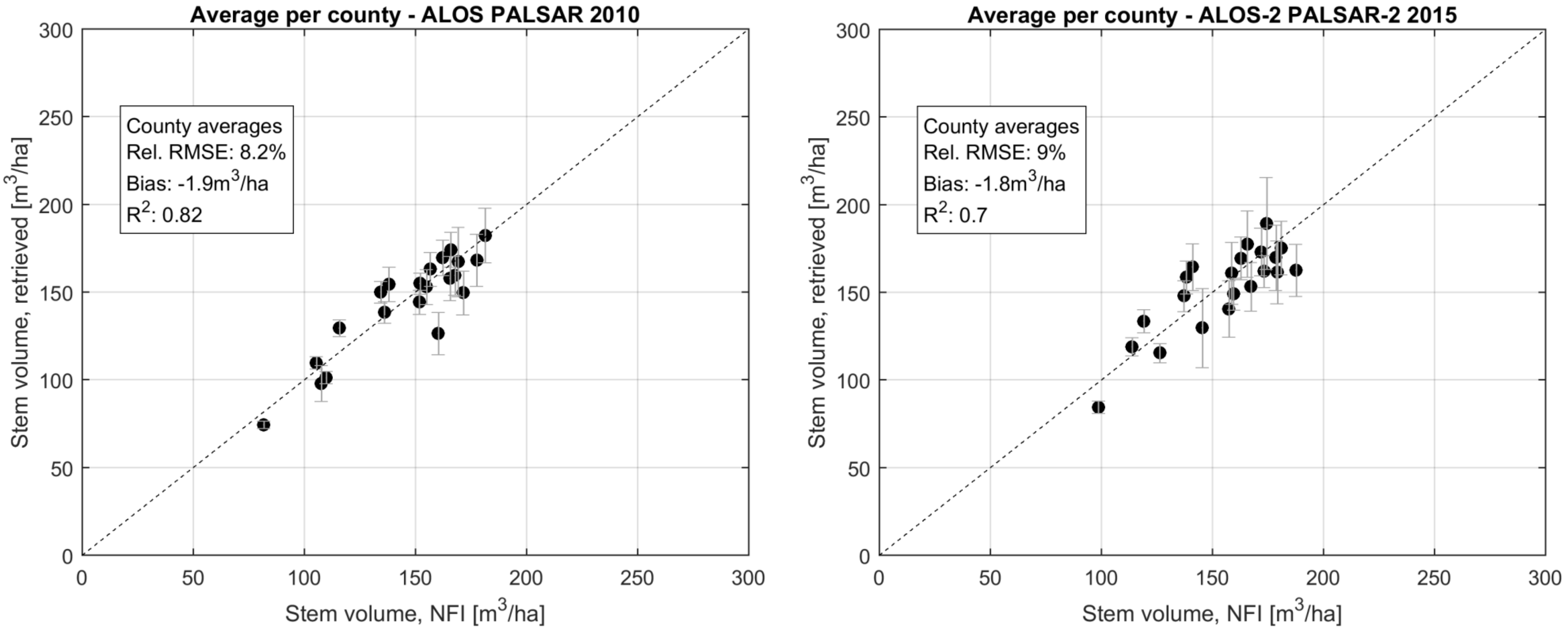
Validation of stem volume estimates

- Comparing plot and pixel averages makes more sense (i.e., the "stand" concept)
- Here, averages computed at the level of tiles (30 km × 30 km)
- Overall the estimates of stem volume are unbiased



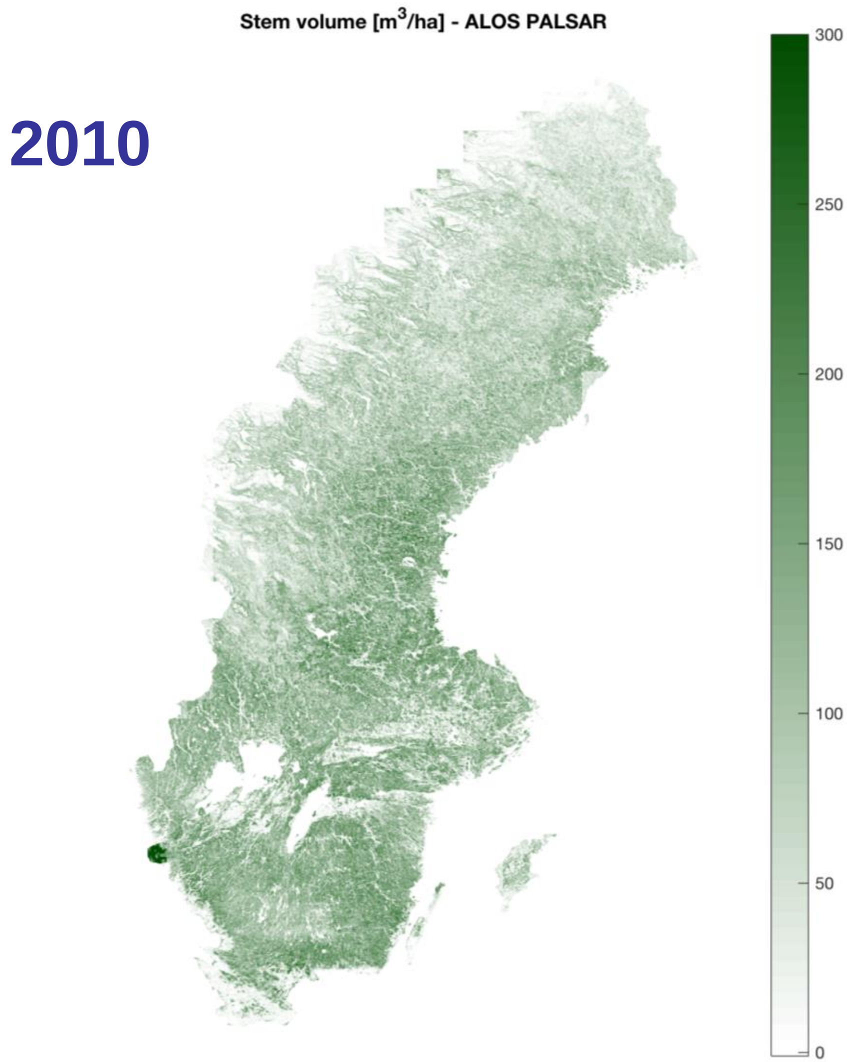


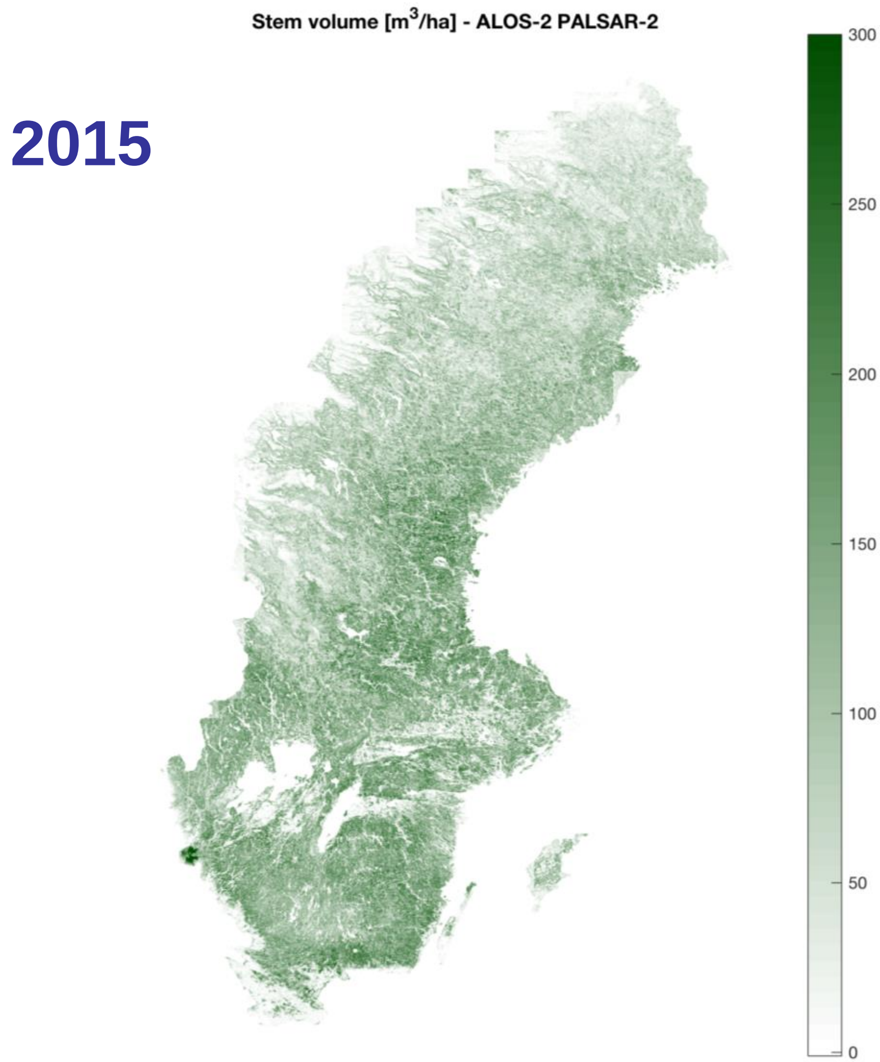
County-wise estimates



The slightly worse agreement for 2015 should be related to the patchiness in the ALOS-2 dataset compared to ALOS-1 (see presentations at KC23 and KC24)

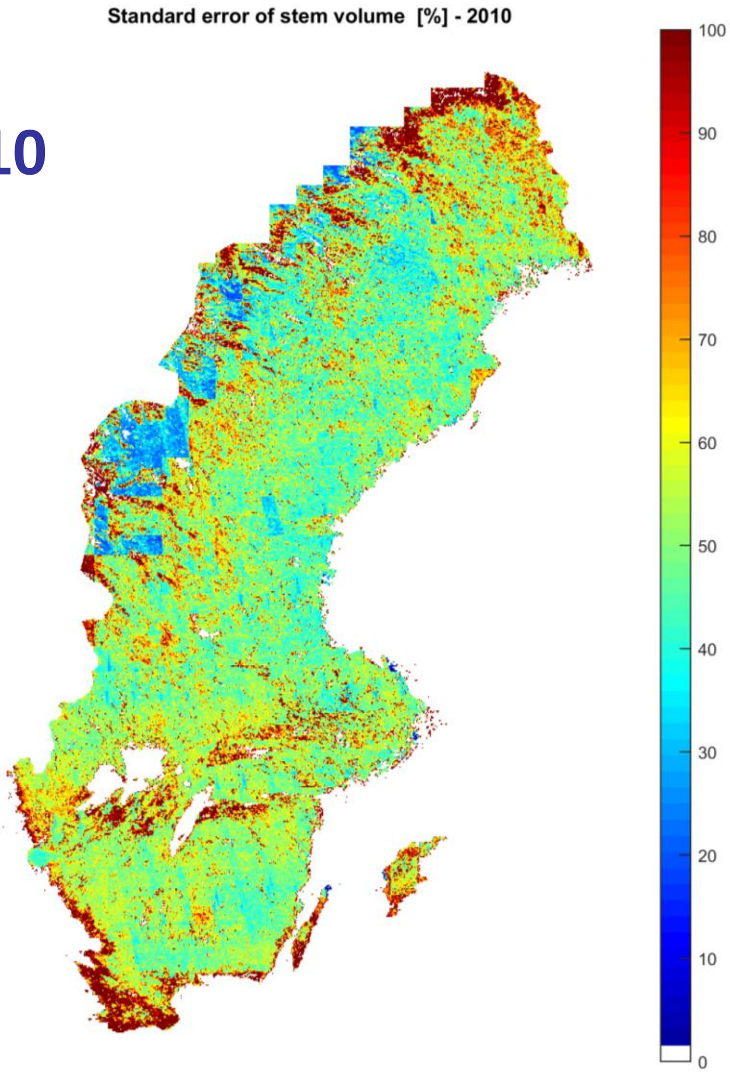
L-band stem volume estimates of Sweden



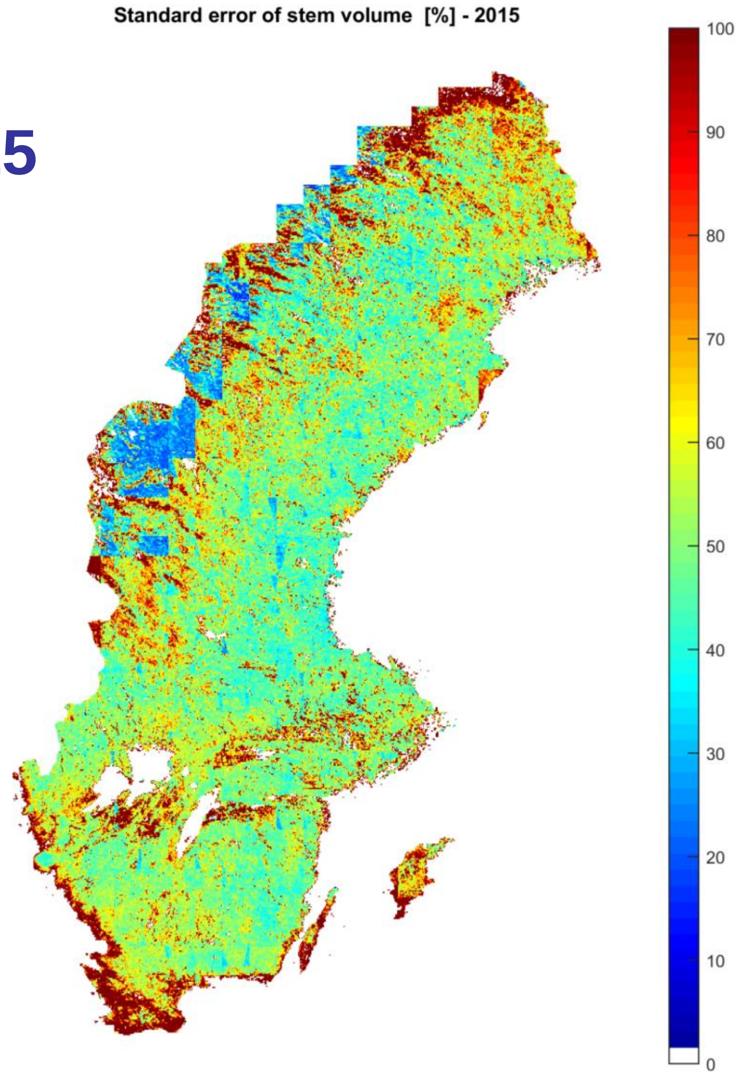


Standard error of the stem volume estimates

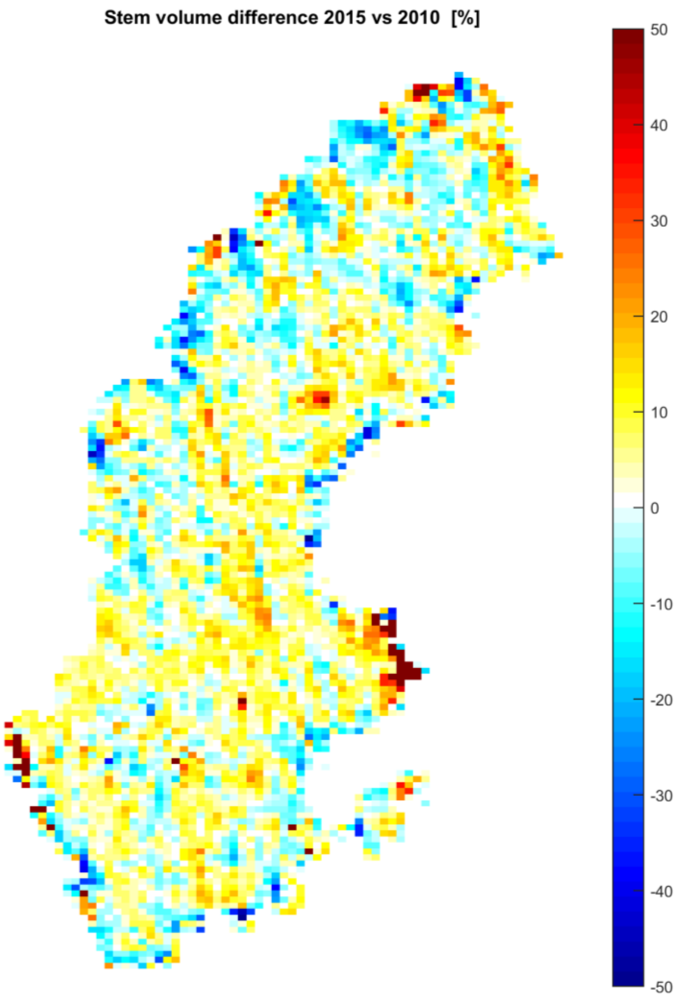
2010

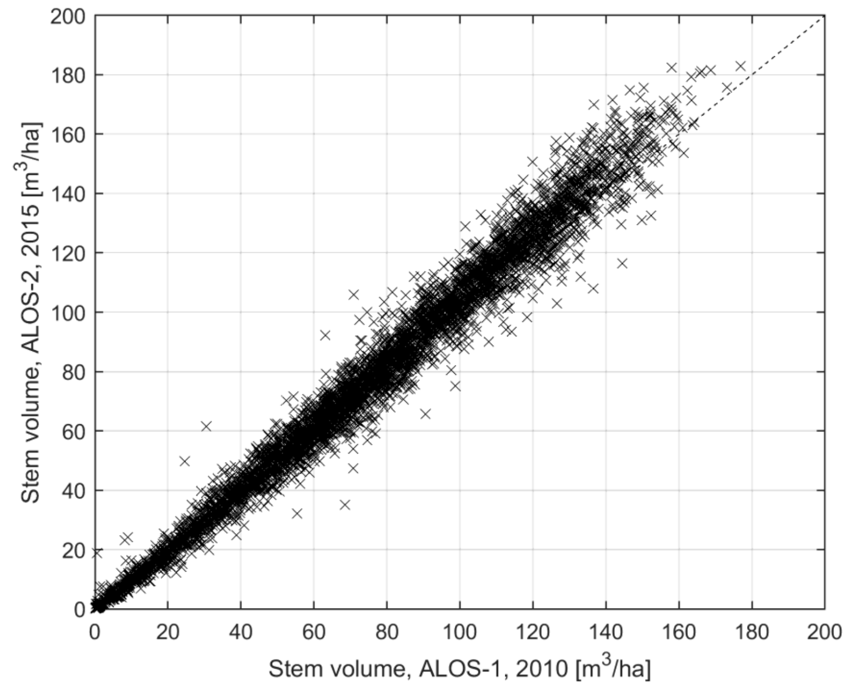


2015



Biomass dynamics between 2010 and 2015





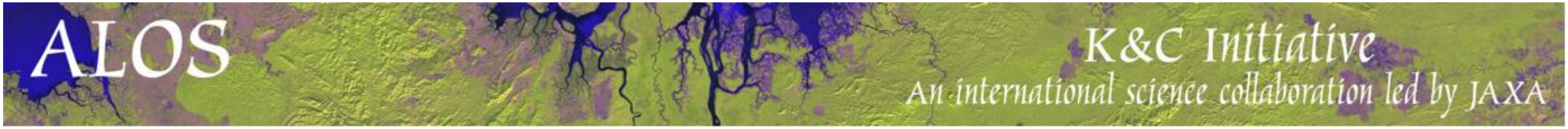
- Comparison done at 10 km to identify spatial trends
- At this scale, the uncertainty becomes negligible

Sweden's forest stem volume estimates

	L-band	NFI (*)	FAO (**)
Tot. stem volume (10^6 m^3)			
2010	*3,033*	*3,002*	*2,948*
2015	*3,104*	*3,150*	*2,988*
Area (km^2)			
2010	*254,595*	*223,790*	*280,730*
2015	*254,683*	*226,560*	*280,730*
Stem volume (m^3 /ha)			
2010	*119*	*134*	*105*
2015	*122*	*139*	*106*

- From L-band data, we estimated a 2.4% net increase between 2010 and 2015

(*) Skogsdata 2013 (inventory 2008-2012) and Skogsdata 2018 (inventory 2013-2017). Productive forest land.
(**) FAO FRA 2010 and 2015, country report for Sweden. Forest land.



Sweden's total carbon estimates (above- and belowground)

	L-band	FAO (*)
Tot. carbon (10^6 MgC)		
2010	*1,069*	*1,102*
2015	*1,098*	*1,114*
Area (km^2)		
2010	*254,595*	*280,730*
2015	*254,683*	*280,730*
Tot. carbon density (MgC /ha)		
2010	*42*	*39*
2015	*43*	*40*

- From L-band data, we estimated a 6 MgC/y increase between 2010 and 2015

(*) FAO FRA 2010 and 2015, country report for Sweden. Forest land.

Conclusions

- With ALOS-1/2 L-band backscatter (FBD), we could estimate for the first time from remote sensing the magnitude of the carbon sink in Sweden.

- The estimates of biomass at pixel level bear significant uncertainty (~50%). However, aggregated values
    - used by carbon and climate models
    - used for national statistics

  supposedly have negligible uncertainty and are unbiased

- Key to these results: the multi-temporal observations (unfrozen conditions). A single observation, as from a mosaic, would not guarantee unbiased estimates.

Deliverables

The following products are part of the deliverables:

- Biomass maps of Sweden for years 2010 and 2015.
- ~~Clear-cut maps of Sweden for the time period 2015-2016.~~
- Biomass change map of Sweden for the time period 2010-2015.
- Ground-truth data from the test sites Remningstorp and Krycklan.

Publications

Fransson, J.E.S., Santoro, M., Wallerman, J., Persson, H.J., Monteith, A.R., Eriksson, L.E.B., Nilsson, M., Olsson, H., Soja, M.J., and Ulander, L.M.H. (2016). Estimation of forest stem volume using ALOS-2 PALSAR-2 satellite images. In Proceedings of IEEE International Geoscience and Remote Sensing Symposium, pp. 5327 - 5330

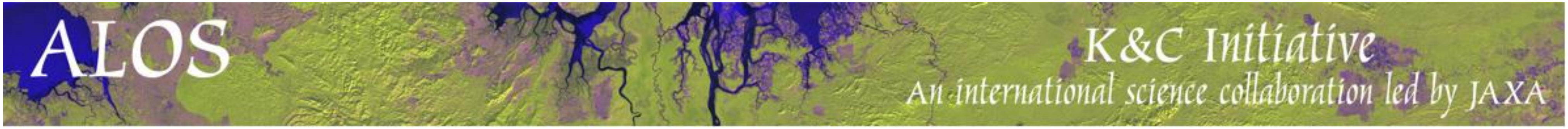
Huuva, I., Fransson, J.E.S., Persson, H.J., Wallerman, J., Ulander, L.M.H., Blomberg, E., and Soja, M.J. (2017). Measurements of forest biomass change using L-and P-band SAR backscatter. In Proceedings of IEEE International Geoscience and Remote Sensing Symposium, pp. 5818 - 5821

Publications

Santoro, M., Fransson, J.E.S. and Cartus, O. (2018), Experiences on biomass retrieval with spaceborne SAR backscatter at C- and L-band in Swedish forest, presented at 7th Workshop on Retrieval of Bio- and Geophysical Parameters from SAR Data, DLR Oberpfaffenhofen, 12-14 November 2018.

Santoro, M., Cartus, O., Carvalhais, N., Thurner, M. and Fransson, J. (2019), Dynamics of forest biomass pools estimated from spaceborne SAR data. Geophysical Research Abstracts, 21, EGU2019-16279, EGU General Assembly 2019.

Santoro, M., Fransson, J.E.S. and Cartus, O. (2019), Integrating SAR backscatter, ICESAT GLAS metrics and allometric functions towards an improved estimation of forest biomass, IGARSS 2019, Yokohama.



Publications (in the pipeline)

Santoro, M., Fransson, J.E.S. and Cartus, O., Quantifying the carbon pool of Sweden in 2010 and 2015 using spaceborne SAR observations, Carbon Balance and Management, to be submitted

Santoro, M., Fransson, J.E.S. and Cartus, O., Integrating SAR backscatter, ICESAT GLAS metrics and allometric functions towards an improved estimation of forest biomass, Remote Sensing of Environment, to be submitted

Huuva, I., Persson, H.J., Soja, M.J., Wallerman, J., Ulander, L.M.H., and Fransson, J.E.S. (2019). Measurements of biomass change in a hemi-boreal forest based on multi-polarization L-and P-band SAR backscatter, Remote Sensing, to be re-submitted

PALSAR/PALSAR-2 data access

Please list the PALSAR/PALSAR-2 data you have

(1) requested and (2) obtained.

- All requested, all obtained

Have you had sufficient data to complete your research (according to your K&C agreement)?

If not, which key data sets are missing?

- YES, this was the ideal dataset to support biomass retrieval

ALOS

K&C Initiative

An international science collaboration led by JAXA

SLU

Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

JAXA

GAMMA REMOTE SENSING

Thank you!

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Swedish National Space Board

Skogssällskapet

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European Space Agency

SKOGSSTYRELSEN
SWEDISH FOREST AGENCY

European Commission

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