

Development of Algorithms for Forest Biomass Retrieval

Executive Summary

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1 Introduction

This study, performed in the frame of the BIOMASS Phase A activities, aimed to:

1. define and implement the algorithm for the generation of the Level 2 (global) above ground forest biomass maps starting from Level 1 (and auxiliary) data;
2. evaluate the performance of the defined algorithm across the main forest ecosystems and assess the impact of key system, mission and environmental parameters that impact the performance of the developed biomass algorithm;
3. To review and propose algorithms to retrieve the L2 parameters “above ground forest biomass temporal change” and “forest disturbance”.

The Level 2 algorithms have been developed in a two stage process:

A first biomass estimate has been obtained by inverting the established relationships between polarimetric radar intensity measurements and biomass values. A dedicated inversion algorithm for each of the analysed forest ecosystems, i.e. boreal and tropical, has been developed.

A second biomass estimate has been obtained from the inversion of forest stand height from PolInSAR data which is subsequently related to biomass through appropriate allometric relations.

In a second step the two estimates are combined using a Bayesian approach in order to obtain a more accurate and robust biomass estimate.

2 Boreal Intensity-based Algorithms

The biomass estimation algorithm based on PolSAR intensity data for boreal forests has been developed and evaluated using campaign data collected during BioSAR-1 (Remningstorp) and -2 (Krycklan). The campaigns were conducted over two test sites in southern and northern Sweden, respectively, which are separated by 720 km. The data included both SAR and reference (in situ, lidar, aerial photography) data which were collected during different conditions, including seasonal (moisture changes) and topographic effects (imaging geometry changes). Data analysis resulted in the following important observations:

- Single-date data from Remningstorp with little topography show that HH and HV exhibit good sensitivity to biomass, with HH giving slightly better retrieval accuracy than HV. In contrast, VV backscatter shows poor sensitivity to biomass. However, HH and HV intensity show much more variability in Krycklan data due to the pronounced topography.
- Data from Remningstorp and Krycklan show that multiple polarisations are needed to reduce the influence of soil moisture variations as well as forest structure across test sites and dates. For example, stand-level linear polarisation backscatter decreased by up to 2-3 dB, depending on polarisation, when conditions changed from late winter (wet) to early summer (dry). Furthermore, there is a 2-3 dB average difference between Remningstorp and Krycklan due to a combination of systematic differences in forest structure, biomass distribution and topography in the two test sites.

Data analysis shows that much of the variability is mitigated by including the polarisation ratio VV/HH in the biomass estimation. The physical basis is that both forest structure and moisture have similar effects on VV and HH which are factored out by taking the ratio. However, the polarisation ratio is found to be affected by topography requiring a separate correction.

A number of biomass estimation models were evaluated based on BioSAR-1 and -2 campaign data. The objective was to find a model which could explain the data with a minimum number of training parameters. Multiple models were defined and tested against changing moisture conditions, topography and training data. It was concluded that the following linear model gave the overall best performance

$$\log_{10} B = a_0 + a_1 [Y_{HV}^0]_{dB} + a_2 ([Y_{HH}^0]_{dB} - [Y_{VV}^0]_{dB}) + a_3 u ([Y_{HH}^0]_{dB} - [Y_{VV}^0]_{dB})$$

where the backscatter (gamma naught) is given in dB and u is the ground slope based on 50-m posting DEM. The four regression coefficients a_i are determined from training data. The last term represents the topographic correction through the ground slope u . The correction should only be considered as first-order and future work should address possible improvements, e.g. by including the slope aspect relative to radar line-of-sight. Equally important, however, is to extend the campaign data base in order to obtain statistically significant and conclusive results.

One of the most important results is that the four regression coefficients are similar whether the training data comes from Remningstorp or Krycklan. This indicates that the model is stable across test sites although they are separated by more than 700 km and represent different conditions. Performance evaluation performed on stand-level data shows that biomass can be retrieved in Remningstorp with a RMSE of 40-59 ton/s, see 0. The RMSE correspond to 22-32% of the mean biomass (185 ton/ha). The opposite evaluation was also performed, i.e. training the algorithm using Remningstorp data and evaluating in Krycklan, but the conclusion is that the Remningstorp training data does not represent the range of conditions found in Krycklan and hence across-site evaluation

Table 1: Performance evaluation of intensity-based biomass algorithm. The four regression coefficients have been determined using Krycklan data from all flight headings, and the evaluation is done based on ten in-situ stands (80 m x 80 m) in Remningstorp where all trees with diameter larger than 5 cm have been measured and biomass is known to within a few percent error. RMSE is shown in tons/ha and the corresponding percentage after dividing with the mean stand biomass (185 ton/ha).

		Flight headings:		
		179°	200°	Both
Dates:	March	59 (32%)	46 (25%)	50 (27%)
	April	41 (22%)	40 (22%)	41 (22%)
	May	41 (22%)	41 (22%)	41 (22%)
	All	48 (26%)	42 (23%)	44 (24%)

is not possible. Nevertheless, results from Krycklan indicate that future work should include topographic corrections as mentioned earlier.

The BioSAR 2007 and 2008 campaign data have also been used to simulated BIOMASS satellite data, i.e. by reducing bandwidth and including additive and multiplicative noise sources. Performance evaluation based on stand-level data was again performed using simulated satellite data.

In Remningstorp, the stands used in the analysis are quite small (0.5-1 ha) which means that speckle fluctuations will be large since the BIOMASS resolution is 50 m x 50 m (4 looks). This effect was mitigated by using multiple disjoint frequency bands of the high-resolution airborne data. In this way it was possible to study the reduction in RMSE when multiple bands were averaged together. The latter corresponds to extending the size of the stands in proportion to the number of bands, i.e. the averaging of multiple bands corresponds to averaging the biomass map to a coarser resolution. Results from the analysis imply that the average RMSE reduced from 55 ton/ha (30%) for 1 ha map resolution to 43 tons/ha (23%) for 4 ha.

Across-site evaluation could not be performed in Krycklan for the reasons mentioned above. Nevertheless, the performance obtained based on training data from Krycklan was evaluated. The conclusion is similar to Remningstorp, i.e. the RMSE drops significantly when the biomass map is averaged to coarser resolution. The RMSE decreases from 52 ton/ha for 1 ha map resolution to 40 tons/ha for 4 ha.

The effect of noise and range/azimuth ambiguities in the simulated satellite data is found to have only a minor impact on the backscatter level and the retrieved biomass. A systematic difference between full resolution and simulated BIOMASS data, however, was observed which depended on backscatter level. A possible explanation is that the differences are caused by the number of dominant scattering objects in high biomass regions changing from a few in full resolution data to many in the simulated BIOMASS data.

3 Tropical Intensity-based Algorithms

This report presents the retrieval algorithms developed using TropiSAR data, and expected to be applicable to dense tropical rain forests with high biomass density (> 200 ton/ha) forests. The method based on P_band SAR intensity is based on Bayes inversion, using as inputs direct models which are distinguished in two cases.

In the first case, where the forests have high biomass, typically > 250 ton/ha, and when the radar elevation angle is $< 40^\circ$ (which is the case of the spaceborne BIOMASS mission), the sensitivity to biomass of the radar backscatter expressed in σ°_{HV} can be masked out by perturbing effects (topography, inappropriate angular compensation). A new intensity indicator called t° has been developed that was found correlated to biomass.

For the other cases, the direct model based on σ°_{HV} is used.

Concerning the performance analysis, t° is derived from polarimetric coherent data so that the simulation of the spaceborne configuration would require a more thorough analysis. Nonetheless, in the worst case of low polarimetric coherence, t° depends only on incoherent terms and the performance results from γ°_{HV} can be extrapolated.

Therefore, the performances of inversion method based on t° and based on γ°_{HV} have been respectively analysed in the case of airborne and spaceborne conditions.

For both, a Bayes inversion algorithm has been performed, using randomly selected training plots as prior information.

- (1) Algorithm based on t° : Using the TropiSAR data of forest plots with biomass ranging between 250-450 t/ha, the algorithm performance based on t° has been assessed for various randomly selected training plots. The RMSD (Root Mean Squared Difference between the estimated and the in-situ AGB) are mostly below 20 %, even in the case of the training plots from Nouragues and the validations plots from Paracou .
- (2) Algorithm based on σ°_{HV} . Two approaches have been investigated, using a) simulated data and b) TropiSAR data filtered at 6 MHz.

a) The spaceborne conditions have been assessed in the first approach using simulations of various noise sources. The direct equation relating σ°_{HV} and biomass is based on experimental data at multiple sites, most with moderate topography. First, 500 synthetic data have been simulated considering a uniform biomass distribution between 1 and 500 t/ha. These data were degraded by adding noise sources. For this analysis, 3 main types of parameters are considered: number of looks ENL linked to spatial resolution and speckle noise, within scene radiometric stability and geophysical noise. In this study, 50 data were selected randomly, and the validation is performed on the remaining 450 data. The result shows that the effect of geophysical noise is important, and that the absolute errors in biomass depend on the biomass values. In order to emphasise the errors in dense forest, statistics are derived for biomass higher than 250 ton /ha (up to 550 ton/ha). The effect of ENL/SAR resolution is obvious. For tropical forest plots (biomass > 250 ton/ha) over terrain with moderate topography, for example RMSD equals to 12% at 64 looks and to 7 % at 128 looks for a given values of within scene radiometric stability and geophysical error. Given the nominal BIOMASS resolution of (50 m, 4 looks), averaging the backscatter over 100 m (1 ha) and 200 m (4 ha) windows will increase the ENL to respectively 16 and 64 looks. In order to reach a higher ENL (e.g. 128), multi-channel filtering will be used. With 4 polarimetric channels and multitemporal data, this could be easily achieved. Radiometric stability is the most important factor, and needs to be lower than 0.5dB (within scene

variation). Finally, geophysical errors ranging from 0.09db to 0.72db lead to RMSD from 7.5 % to 19 % (with a number of looks of 64 and radiometric stability set at 0.17db). As a result, each error source has a strong impact on the biomass estimation quality and for tropical forest, a 4 ha mapping unit in order to secure the required uncertainty (<20%).

b) In the second approach, TropiSAR data at Paracou filtered at 6 MHz have been used. The results are obtained using a bootstrap process with 10^4 realisations based on 5 random forest plots used for training and 23 plots for validation. Using intensity data, the mean RMSE in biomass is 19.7% and the 1 σ confident interval is 14.6-22.8%. The biomass retrieval using 6 MHz data, is compliant with the 20% requirement ($RMSE \leq 20\%$) for 65% of the realisations, whereas the non compliant cases ($RMSE > 20\%$) represent 35% of the realisations.

4 Polarimetric Approaches

The relation between forest biomass and signatures of individual scattering components derived from polarimetric decomposition was examined. A decomposition of polarimetric SAR data into three canonical scattering mechanisms (volume, dihedral, and direct surface reflection) was utilized. The backscattering power of the three components was related to LIDAR derived biomass estimates for two boreal forest test sites (Remningstorp and Krycklan) at P-band. The impact of temporal changes induced by changing weather conditions was analysed by multi-temporal acquisitions (March, April, and May) over the hemiboreal test site of Remningstorp. Slope effects were investigated using observations acquired from varying viewing angles over the boreal test site of Krycklan. The performance was validated against inventory biomass stands.

Concerning the test site of Remningstorp, for the inventory stands in mid-range the RMSE and the correlation coefficient are almost constant over time (March, April, and May) for HH, HV, and the volume component (see Table 1). In near range, the RMSE and correlation coefficient degrade significantly with time. HH, HV and the volume component are most robust with respect to temporal changes and with respect to incidence angle. For the double bounce component the RMSE (correlation coefficient) is lower (higher) in mid-range than in near range. The co-polar channel VV and the surface component are not suitable for biomass estimation due to their lack of sensitivity.

For the test site of Krycklan, the RMSE of the cross-polarized channel HV is in general lowest for all seven headings and always below 38 t/ha (see Table 2). For the volume and dihedral components and for the co-polarized channel HH, the RMSE changes significantly with viewing angle. With respect to

Table 1 Remningstorp: RMSE of the individual relation to biomass.

RMSE [t/ha]	Near range / Heading 2			Mid range / Heading 1		
	9 March	31 March	2 May	9 March	2 April	2 May
Lidar	15.2			15.5		
Fs	127.5	181.6	169.7	154.0	156.2	88.1
Fd	95.6	60.8	71.5	43.0	44.4	50.4
Fv	22.1	38.3	48.9	37.0	40.8	40.1
HH	31.8	37.7	39.0	37.0	38.2	39.6
VV	61.3	67.4	76.5	64.4	72.6	78.7
HV	31.9	35.1	49.8	38.9	41.8	42.8

Table 2 Krycklan: RMSE of the individual relation to biomass.

RMSE [t/ha]	0103	0104	0301	0302	0303	0304	0305
	Ascending	Descending	Square loop flight				
Lidar	16.5	16.4	15.0	15.6	16.9	16.0	16.9
fd	34.8	52.2	36.2	29.3	49.5	40.7	47.6
fv	37.1	43.4	43.5	42.9	29.8	46.2	28.4
HH	41.4	44.9	42.2	37.3	34.1	43.7	34.4
HV	35.1	37.2	34.8	25.6	34.8	31.4	34.8

the correlation coefficient, the performance of the dihedral component is in general the best for all headings, followed by the performance of the channel HV. Estimating the biomass using the optimum relation from the opposite viewing angle, the inversion quality is rather stable. Subsequently, the sensitivity of polarimetric descriptors to forest biomass at P-band has been investigated using spaceborne simulated data. For the test site of Remningstorp, the RMSEs degrade in the spaceborne simulated case for all polarimetric channels and polarimetric components in comparison with the airborne original data. In general, the increase of RMSE is considerable, e.g., the RMSE increases from 39.0 t/ha in the airborne scenario to 70.2 t/ha in the spaceborne simulation for the HH channel. The best estimation accuracy is achieved for heading one (mid-range) for the HH polarization with 43.4 t/ha and for heading two (near range) for the volume component with 55.7 t/ha.

For the test site of Krycklan, the RMSE increases generally in the spaceborne scenario in comparison with the airborne original results. For the original airborne data and the simulated spaceborne data, the error varies significantly with the flight track and is lowest for the volume contribution, the HV channel, or the dihedral component. In the spaceborne scenario, for each look angle, the RMSE is below 50 t/ha for the best polarimetric descriptor.

The backscattering variability was investigated with respect to temporal, natural, structural, and topographic effects using airborne data. For all indicators, the intensity discrepancy caused by different acquisition dates is approximately 1 dB. The natural variability is lowest for the volume component and the HV polarization with around 1.5 dB, medium for the co-polarized channels HH and VV with approximately 1.7 dB, and highest for the dihedral contribution with 2 dB. The same ranking can be found for the spreading generated by structural impact where the variability amounts to maximum values of 1 dB for the volume contribution and HV, 2 dB for VV, and up to 6 dB for HH and the dihedral component. The backscatter difference between the two test sites is lowest in the volume component and HV with approximately 4 dB, medium in the co-polarizations HH and VV (5 dB), and highest for the dihedral indicator (6 dB).

The normalised backscattering variations induced by forest structure changes were examined by employing forward modelling. When varying the particle shape inside the volume from spheres to dipole-like particles, the intensity variability is limited to 1.5 dB in VV, 2 dB in HH, and 5 dB in HV for random volumes. For oriented volumes, the intensity variations are 0 dB for the VV channel and 4 dB for HH. The backscattering power in the cross-polarization is rather weak. If the orientation angle distribution is modified under the assumption of dipole-like particles, the intensity deviation attains values of 1 dB for HV, 1.5 dB for VV, and 2 dB for HH. For spheres, the backscattering power is constant in the co-polarizations over the entire range of angular distributions and the intensity is quite low for the cross-polarization because the orientation distribution does not change the polarimetric response.

The intensity spread induced by changing moisture conditions was investigated using forward modelling. By modifying the soil dielectric constant, the normalised backscattering variance is limited to 1.5 dB in all polarization channels for random volumes. For oriented volumes, the variability reaches values of 1 dB in HH polarization, 1.5 dB in VV, and 2 dB in HV. When the moisture content of the trunk and the volume is varied, the intensity difference is bounded by 0.5 dB for the co-polarized channels and by 2 dB for HV for a random volume. If the volume is oriented, the threshold lies at 0.3 dB for HV, 0.7 dB for VV, and 3.0 dB for HH.

5 Pol-InSAR Algorithms

In the frame of this study, the performance of forest height inversion by means of single- (and multi-) baseline polarimetric interferometric techniques at P-band has been assessed.

First, the appropriate inversion models have been defined and their validity and performance for different forest scenarios has been assessed. For forest height estimation two layer statistical models, consisting of a vertical distribution of scatterers $f(z)$ that accounts for the vegetation (volume) scattering contribution, and a Dirac-like component that accounts for the scattering contribution(s) of the underlying ground (i.e. direct surface and dihedral vegetation-surface contributions) have been proven to be sufficient in terms of robustness and performance.

Regarding the polarimetric characterisation of the individual components of the inversion model, the ground scattering component is strongly polarized and has to be assumed polarization dependent. The volume scattering contribution can be assumed to be polarisation independent, i.e., the vertical distribution of scatterers in the volume is the same for all polarisations.

Especially at P-band, one has to distinguish between different forest conditions / ecosystems:

- In (electromagnetically) dense(r) forest conditions (**temperate and tropical case**) the vertical distribution of scatterers in the vegetation layer has to account for a degreasing number of scatterers with depth (i.e. a “positive” distribution) due to the attenuation of the vegetation layer. At the same time the stronger attenuated ground allows to assume a two-dimensional ground scattering component (i.e. the existence of a polarisation without ground scattering) without introducing significant inversion errors.
- In low extinction forest scattering situations given in sparse(r) forests conditions (**boreal case**) the effective scatterers in the vegetation layer are located lower within the forest architecture leading to an “negative” vertical distribution of scatterers (i.e. one that increases with depth). This can be also caused by the presence of a more or less distinct under-storey favoured by “open canopy” conditions. The ground scattering becomes significant and the assumption of a two dimensional ground may lead to biased inversion results (usually to overestimated heights and/or an underestimated extinction coefficients).

Accordingly, an optimised Pol-InSAR inversion model has to be able to account for volumes with “positive” and “negative” distributions of scatterers as well as with two or three dimensional ground scattering components.

The single baseline inversion results achieved at full bandwidth (i.e. 95MHz) data indicate:

- in tropical forest conditions (INDERX-II, Sungai-Wain and Mawas) a mean correlation of 85-95% and a mean rms height error of 2-3m.
- in boreal forest conditions (BioSAR-I & BioSAR-II) a mean correlation of 70-75% and a mean rms height error of 3-6m (mean of 4m).

Topography impacts in two ways the performance of Pol-InSAR inversion.

1) The change of local incidence angle (induced by the terrain slope) implies a change of the vertical wavenumber (equivalent to a change of the effective (spatial) baseline). Accordingly, positive slopes increase the effective baseline while on negative slopes the effective baseline decreases. This can be accounted by estimating the terrain slope; using the available interferometric information (P-band DEM) or an external DEM (e.g. SRTM, TanDEM-X, etc).

2) In the presence of slope the relative weighting of the individual scattering contributions occurring changes, leading to a change of the ground-to-volume amplitude ratios spectrum. The dihedral

scattering component is strongly slope dependent (directive) and disappears fast even for weak (positive or negative) terrain slopes. On the other side surface scattering increases at positive slopes and decreases at negative slopes.

The effect of the ground-to-volume amplitude ratios modulation through terrain slope becomes amplified with decreasing vegetation density. In this sense the validation of Pol-InSAR inversion performance as a function of terrain slope on the Krycklan test site (boreal forest on sloped terrain with slopes up to 15%) is a serious test. The comparison of the height estimates obtained from the ascending acquisitions with the ones obtained from the descending acquisitions shows a mean correlation of ~80% and a mean rms height error of <4m, indicating a successful terrain compensation. This allows the conclusion that the effect of topographic variation on the Pol-InSAR performance can be mastered even in difficult (with respect to inversion performance) cases.

BIOMASS Simulations: Inversion has been performed and evaluated on simulated BIOMASS data obtained by the modification/degradation of the airborne P-band Pol-InSAR data in order to account for the system constraints of BIOMASS implementation: a lower NESZ level of -28dB, a worse range/azimuth ambiguity ratio of -20dB, the reduced system bandwidth of 6MHz and the reduced azimuth resolution of 10m. The system performance degradation induces an additional decorrelation contribution on the order of 0.9 (estimated on the data) that induces a bias (overestimation) on the forest height estimates and increases their variance. Apart of the system induced decorrelation a contribution on this decorrelation level may be attributed to the increased scene heterogeneity within the coherence estimator due to the reduced spatial resolution.

Temporal decorrelation has probably the largest impact on the accuracy of Pol-InSAR inversion as it biases the estimation of volume decorrelation and increases the variation of the interferometric phase. In consequence, forest height is biased (overestimated) and at the same time more dispersed (for the same number of looks). In the context of a single baseline, the dispersion can be compensated on cost of spatial resolution the bias (i.e. the overestimation of forest heights) cannot. Experiments in boreal (BioSAR-I) and tropical forests (TropiSCAT) indicate mean temporal decorrelation levels on the order of 0.6 to 0.9 for repeat pass times on the order of 7-16 days. These decorrelation levels are high enough to make single baseline Pol-InSAR height estimation practically useless in terms bias and variance ($\rho^2 < 60\%$ and $\text{rmse} > 6\text{m}$).

However, the performed analysis demonstrated that for moderate levels of temporal decorrelation (up to 0.7-0.8) the induced bias can be compensated when multiple acquisitions are available making possible the formation of multiple baselines with variable vertical wavenumbers (i.e. effective spatial baselines). The induced variance (partially inherent at P-band) can be only partially compensated ($\rho^2 \sim 70\%$ and $\text{rmse} \sim 4\text{m}$).

The challenge in the case of multi-baseline Pol-InSAR implementation in the BIOMASS context will be the optimisation of the spatial baseline ratio(s) in order to maximise the forest height range for which the inversion performance meets the BIOMASS requirements. This may be a critical point especially with respect to the given system constraints (i.e. system bandwidth), and mission constraints (i.e. variability of spatial baseline from pass to pass) as well as forest structure and terrain characteristics.

6 Combined Algorithms

6.1 Boreal case

The combined algorithm transforms the two biomass estimates, one from PolSAR intensity and one from PolInSAR height, into a single biomass estimate using a Bayesian approach. The conversion from PolInSAR height to biomass is performed using an allometry equation which, in this study, is defined as a regression model established by using training data from Krycklan and Remningstorp.

The two biomass estimates form an observation vector $\mathbf{b} = (b_1, b_2)$ and their joint probability density function, conditioned on a particular biomass value, is assumed to be bivariate Gaussian. In Bayesian estimation not only the measurements but also the parameters are viewed as random variables. Biomass is hence considered a random parameter, whose *a-priori* density function $p(B)$ is assumed uniform between zero and a maximum biomass value. Using Bayes' theorem, the posterior probability density function is

$$p(B|\mathbf{b}) = \frac{p(B)p(\mathbf{b}|B)}{p(\mathbf{b})}$$

Different biomass estimators can be derived from the posterior density function. In this study, we use the Minimum Mean Squared Estimate (MMSE) which is computed according to

$$\hat{B}_{\text{MMSE}} = \frac{\int B p(B) p(\mathbf{b}|B) dB}{\int p(B) p(\mathbf{b}|B) dB}$$

Since the conditional density function is assumed to be Gaussian and the *a priori* density for the biomass is uniform on $[0, B_{\text{max}}]$, no analytic closed form solution exists. Instead, numerical integration is used to obtain biomass estimates from measurements. This increases the computational time required for the retrieval method, but on the other hand it makes extensions of the proposed method straightforward. For instance, error variances which depend on biomass or non-uniform *a priori* probability densities can easily be used.

The combined algorithm has been evaluated using full resolution airborne SAR data. Regression analysis was used to define a allometric equation which converts the PolInSAR (single-baseline) heights into biomass. A stand-level analysis showed that the residual RMSE is 55 ton/ha which is larger than for the corresponding intensity-based biomass estimate which gives 40 ton/ha. The main reason for the larger PolInSAR RMSE is that the height-to-biomass allometry is clearly species dependent. Consequently, combining the PolSAR intensity and PolInSAR biomass estimates does not yield any improvement compared to the PolSAR intensity-only estimate. In some cases the RMSE is found to be larger for the combined method than for the one based on intensity only. This behaviour is attributed to the use of a simplistic model for the measurement errors. This also results in a systematic bias for biomass values close to zero. An interesting note is that topography is found to have less impact on PolInSAR than on intensity-based retrievals and further studies should exploit this fact to reduce estimation errors in topographic areas.

The combined algorithm was not evaluated on simulated BIOMASS data since the available PolInSAR (single baseline) heights showed poor sensitivity to biomass. Future studies should include:

- Use of multiple bands with simulated BIOMASS PolInSAR data to investigate statistics
- Investigations in areas with larger stands than those in Remningstorp

- Use of dual- or multi- baseline PolInSAR data for reduced errors in the height retrievals

6.2 Tropical case

For tropical dense forests (biomass > 250 t/ha), the most challenging issue is the sensitivity of SAR data to biomass, whether the data are derived from polarimetry (cf. t°) or from interferometry (cf. Pol-InSAR height). Both are characterized by a log relationship with biomass and have a weak sensitivity to biomass above 350 t/ha.

To improve the inversion result, Pol-SAR and Pol-InSAR indicators (cf. t° and the Pol-InSAR height appropriately projected) have been combined together through a Bayes inversion algorithm.

The prior information required for this Bayes method is derived from test plots (typically about 5 out of the 60 plots).

Using the TropiSAR plots of biomass between 250-450 t/ha, the algorithm performance has been assessed with various randomly selected training plots. The Bayes combination of the two indicators improves significantly the inversion algorithm robustness, proved by the fact that the RMSD and the correlation coefficients are not dependent on the training samples.

Using intensity data filtered to 6 MHz bandwidth and PolInSAR, the mean RMSE is 17.7%, and the 1σ range is 14-20%. The percentage of non compliant realisations is 16%. The test has shown that the combined Intensity and PolInSAR improves the biomass retrieval results. As mentioned above, with the use of t° , the simulation of spaceborne conditions would require a more advanced study.

7 Forest Disturbance and Regrowth

The activities in this WP have focused on:

1. Literature review for retrieval concepts which are optimised to retrieve above ground forest biomass temporal change and forest disturbance, including radiative transfer model studies and observational studies;
2. Chronosequence analysis of disturbance events;
3. Description of proposed methods to retrieve above ground forest biomass temporal change and forest disturbance.

The radiative transfer model PolSARProSim was used to model the response of a P-band SAR system to forest biomass and biomass change. The purpose of the simulations was to examine backscatter values for different forest growth and degradation scenarios, and to study whether the stated aims of the candidate BIOMASS mission were achievable. In particular we looked at the aim of the level 2 product to measure changes of biomass in the range of 70% - 30% with an accuracy of <20% measurement error.

INDREX-II campaign data at the Mawas reserve (Indonesia) have been analysed to explore whether disturbed and undisturbed areas are present that are suitable for building a chronosequence of disturbed stands. Attention focused on areas of similar fire history in the sites Mawas A and Mawas E. Figure 35 clearly shows that fire scars can easily be detected from P-band SAR. However, it became clear that fire history does not allow any inference on the degree of biomass change. After a review of the results from this analysis we concluded that it would not be scientifically sound to draw quantitative conclusions about the retrieval accuracy of biomass change from backscatter using the Mawas data in the absence of plot-based biomass estimates.

The main conclusions can be summarised in following points:

- The radiative transfer model simulation experiment has lead to reasonable simulations of HH and VV backscatter coefficients for different levels of biomass, but the computations for HV polarisation appear to be lower than observational data from a range of studies.
- Based on the 95% confidence intervals from the model simulations, P-HV backscatter change appears to be able to detect a biomass loss of 30% (forest degradation).
- P-HV is the polarisation that is most sensitive to biomass change and is least influenced by soil moisture variability. P-HH and P-VV are not as reliable and saturate earlier.
- The review of the literature has shown that very few studies have been conducted to explicitly detect biomass change from multi-temporal SAR data, and no studies on P-band have been published in this respect.
- The method of biomass change detection with the lowest errors reported in the literature (based on L-band SAR) is the direct method, in which biomass change is estimated from backscatter change directly, rather than subtracting one biomass map from an earlier biomass map retrieved from SAR. This is due to error propagation considerations.
- It is recommended to use a direct method of mapping biomass change from backscatter change from the BIOMASS mission time-series data after launch of the satellite.