BIOMASS END-TO-END MISSION PERFORMANCE ASSESSMENT

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ABSTRACT

This paper provides an overview of the BIOMASS Mission End-to-End simulator (BEES) and of the mission performance analysis performed with it. The end-to-end performance, in terms of biomass estimates error, is close to the 20% error goal set for the mission. The main sources of errors are temporal decorrelation and the limited available bandwidth, while system induced errors have a negligible impact on the final performance.

***Index Terms*—** BIOMASS, Simulator, SAR

1. INTRODUCTION

BIOMASS [1, 2] is a mission concept currently in the Phase-A study stage, proposed by European scientists in the frame of ESA's 7th Earth Explorer [3] program. BIOMASS is based on a P-band Synthetic Aperture Radar that will systematically acquire fully- (quad-) polarized image data in an interferometric mode over all major forested areas on the globe. The inversion methodology is then based on backscatter intensity measurements at different polarizations and interferometric coherence measurements at different polarizations.

BIOMASS is conceived to reduce the uncertainty in the worldwide spatial distribution and dynamics of forests leading to improved present assessments and future projections of the carbon cycle. While the world's forests contain the largest proportion of carbon in living vegetation, global and accurate quantification of stock and dynamics - occurring as a consequence of, for example, deforestation, regrowth, management or fires – remains a significant but pressing challenge. This uncertainty remains because of the lack of a systematic and reliable mechanism for differentiating biomass levels across large areas, an observational gap that would be filled by BIOMASS.

A common critical key element for the final mission selection procedure is an End-to-End mission performance assessment. For this purpose, the Biomass End-to-End Simulator (BEES) has been implemented [4]. The purpose of this paper is to present a summary of the mission performance assessment performed using this tool.

2. BIOMASS END-TO-END SIMULATOR (BEES)

Fig 1 shows the high-level diagram of BEES. Its modular design reflects not only a logical data flow within the simulator, but related also to the distributed development process, with different scientific and engineering teams being responsible for specific aspects of the simulation. In BEES, first a simplified but realistic forest scene is generated as a map of biomass (in t/ha) and canopy heights. Then, a semi-empirical forward model is used to calculate, for each grid point, the extended covariance matrix that describes the second order statistics of a repeat-pass PolInSAR acquisition. At the core of BEES, the Product Generation Module (PGM) uses this map of covariance matrices to generate random realizations of the multi-channel complex radar scattering coefficients (implicitly including speckle), which are then convolved with the end-to-end impulse response function (IRF) of the system. The PGM then introduces realistic ionospheric distortions using realizations of the Faraday Rotation (FR) map and ionospheric phase screen generated by the Ionosphere Generation Module. In addition, the PGM introduces all the relevant system disturbances: noise, cross talk, channel unbalances, and phase and amplitude drifts. The simulated multi-channel single look complex data are then passed to a Ionospheric Correction Module that estimates and compensates the ionospheric distortions, after which a L1b product consisting of estimated extended covariance matrices is generated. Finally, these are fed to a L2 retrieval module which uses a combination of PolInSAR and intensity based retrieval algorithms to estimate biomass levels and, when PolInSAR is used, canopy heights.

For illustration, Fig. 2 shows, from top to bottom, a SGM generated biomass map, the corresponding biomass estimates after the full end-to-end simulation, and the estimation error.

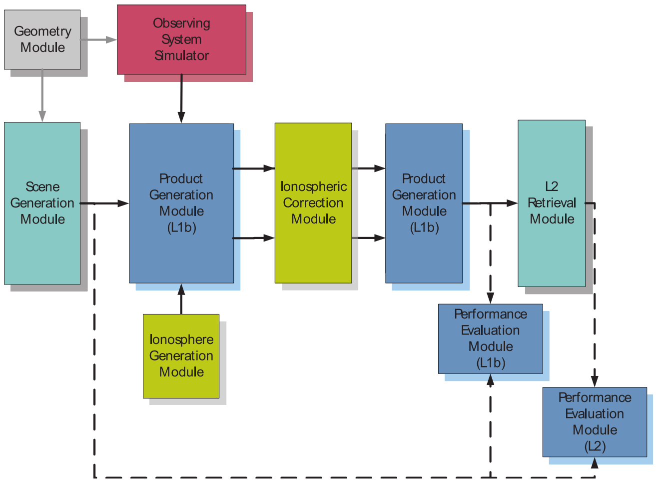

Fig. 1. Block diagram of the End-to-End simulator

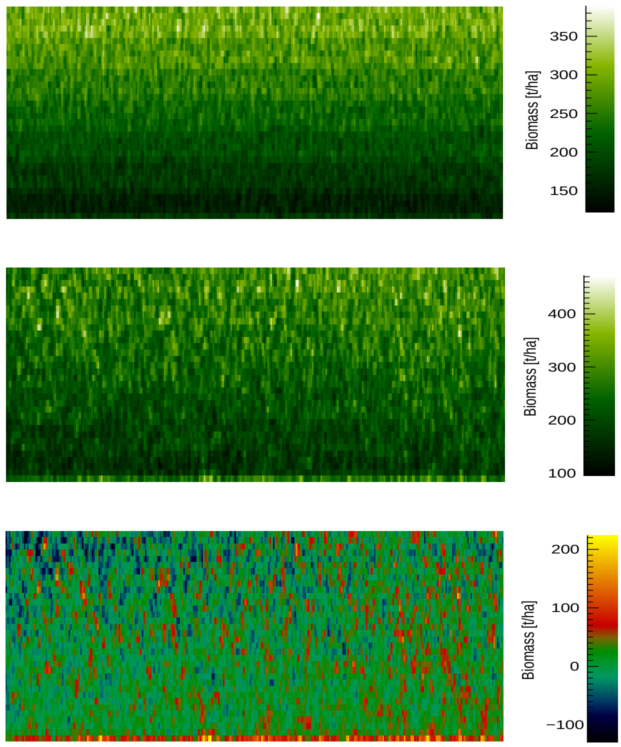

Fig. 2. From top to bottom: examples of a SGM generated biomass map, the corresponding estimated biomass, and the biomass error. The horizontal and vertical axes correspond to ground range and azimuth, respectively.

3. PERFORMANCE ASSESSMENT STRATEGY

The mission performance assessment is done at two levels. Comparing the input and output L1b data allows evaluating the performance of the system, including SAR processing and ionospheric corrections. On the other hand, comparing input and output L2 data allows assessing the end-to-end performance of the system. Note that it is possible to have a good system (good L1b performance) but still have a poor mission performance due to difficulties in the geophysical inversion. To quantify the system performance two sets of simulations have been defined:

- Diagnostic tests: these are meant to identify the possible bottlenecks. This is done by turning all disturbances off except one and evaluating the performance degradation due to this disturbance.
- General performance assessment: this is done for Boreal forests under a range of biomass levels, ionospheric conditions and temporal decorrelation scenarios.

Forest type	Boreal
Location	48°N, 110°W
$k_z\ (= 2\pi/h_{amb})$	0.14 (near range) 0.11 (far range)
Biomass level	20 to 320 t/ha
Ionosphere conditions	mild and severe
Temporal decorrelation	High ($\gamma_{tmp} = 0.61$) Medium ($\gamma_{tmp} = 0.95$)
Retrieval	Combined
Product resolution	200 x 200 m^2
Image width	Full swath ($\sim$ 70 km)
image length	7 km

Table 1. Characteristics of simulated scenarios

Table 1 summarizes the range of scenarios tested. One of the purposes of BEES was to compare the predicted end-to-end performance of two competing system designs, one by Astrium (OSS-A), and one by Thales Alenia (OSS-B). The simulated performance for both systems was very similar. The results shown in this paper correspond to OSS-B. The location is particularly affected by ionospheric disturbances because of its high geomagnetic latitude.

4. RESULTS

4.1. General performance

Fig. 3(a) shows the relative canopy height estimation bias as a function of the biomass level for the four possible combinations of ionospheric state and temporal decorrelation considered. These results were obtained by averaging over the entire scene and over 10 independent runs of BEES. The height was retrieved using a PolInSAR algorithm, using as input the estimated covariance matrices describing the joint second order statistics of the two fully-polarimetric acquisitions simulated [5]. In this, and all subsequent figures, a relative value of 1 indicates a 100% error. Figure 3(b) shows the standard deviation of the relative height error. Bias and standard deviation offer a consistent picture. Height estimation errors are higher for higher temporal decorrelation and, to a lesser extent, for severe ionospheric disturbances. In both cases this can be explained by an unaccounted for loss of coherence, which is wrongly attributed to volume decorrelation and, therefore, to an increased height. For low biomass levels, where height interferometric coherences are expected, the relative loss of coherence is higher, leading to larger errors.

Figs. 3(c) and 3(d) show the corresponding bias and standard deviation of the biomass estimate error. These biomass levels were obtained using a combined retrieval approach, using the biomass estimate resulting from the PolInSAR algorithm (after the corresponding height to biomass conversion) and the estimates inverted from the HV-channel intensity[5]. In terms of standard deviation, the biomass error is below 20% for biomass levels above 50 t/ha for the low temporal decorrelation cases, with somewhat larger errors for the high temporal decorrelation cases. There is, however, a significant bias, in particular for low biomass levels. This bias is introduced by the PolInSAR retrieval, since the intensity-based estimates were (in the simulations) unbiased. While this could invite to give more weight to this intensity based retrieval, it should be noted that the RMS error of these estimates was, in general, higher than that of the PolInSAR-based retrieval. For low temporal decorrelation cases, it may be possible to introduce systematic corrections to compensate system induced biases.

To support the interpretation of Fig. 3, Fig. 4 shows the relation between biomass and canopy height (left) and the relative coherence loss for the interferometric HH channel (right), also as a function of biomass and for the four aforementioned cases. This relative coherence is given by $\gamma_{rel} = \gamma_{L1b}/\gamma_{SGM}$, the ratio between the coherence estimated in the simulated L1b product, and the coherence set at the output of the Scene Generator Module. Note that since temporal decorrelation is introduced by the SGM, it does not affect this relative value, although it has an impact on the final performance.

4.2. Diagnostics

Table 2 provides an overview of the results of the diagnostic tests. All disturbances attributed to the system (ambiguities, thermal noise, amplitude and phase instabilities, and channel imbalance and cross-talk) have a negligible (less than 1%) impact on the RMS error of the biomass estimates. Under typical conditions, ionospheric disturbances, after the corrections included in the simulated chain, have also a small impact on the mission performance. Nevertheless, is is also clear that intense ionospheric disturbances may lead to a total performance loss for the affected acquisitions.

Disturbance	50 t/ha	250 t/ha
Mild Ionosphere	< 0.02	< 0.01
Severe Ionosphere	> 0.5	< 0.02
Ambiguities	< 0.01	< 0.01
Noise	< 0.01	< 0.01
Amp and phase errors	< 0.01	< 0.01
Channel imbal. and cross-talk	< 0.01	< 0.01

Table 2. Impact of individual disturbances on biomass estimation RMS error.

5. CONCLUSIONS

This paper summarizes the mission performance analysis of the biomass mission done using BEES. The results shown confirm that the two alternative system designs are good enough in order to have a negligible impact on the end-to-end mission performance. This mission performance is currently limited by the significant impact of temporal decorrelation, resulting in important biomass biases, and of the reduced number of looks.

Currently BEES is being extended to allow simulations of multiple (more than two) acquisitions, where it is expected that the simulations will confirm the expected large performance benefit resulting from the multi-baseline processing, and to include topography effects, requiring, in particular, the implementation of a more sophisticated forward-model. Future simulations will be extended to tropical scenarios.

6. REFERENCES

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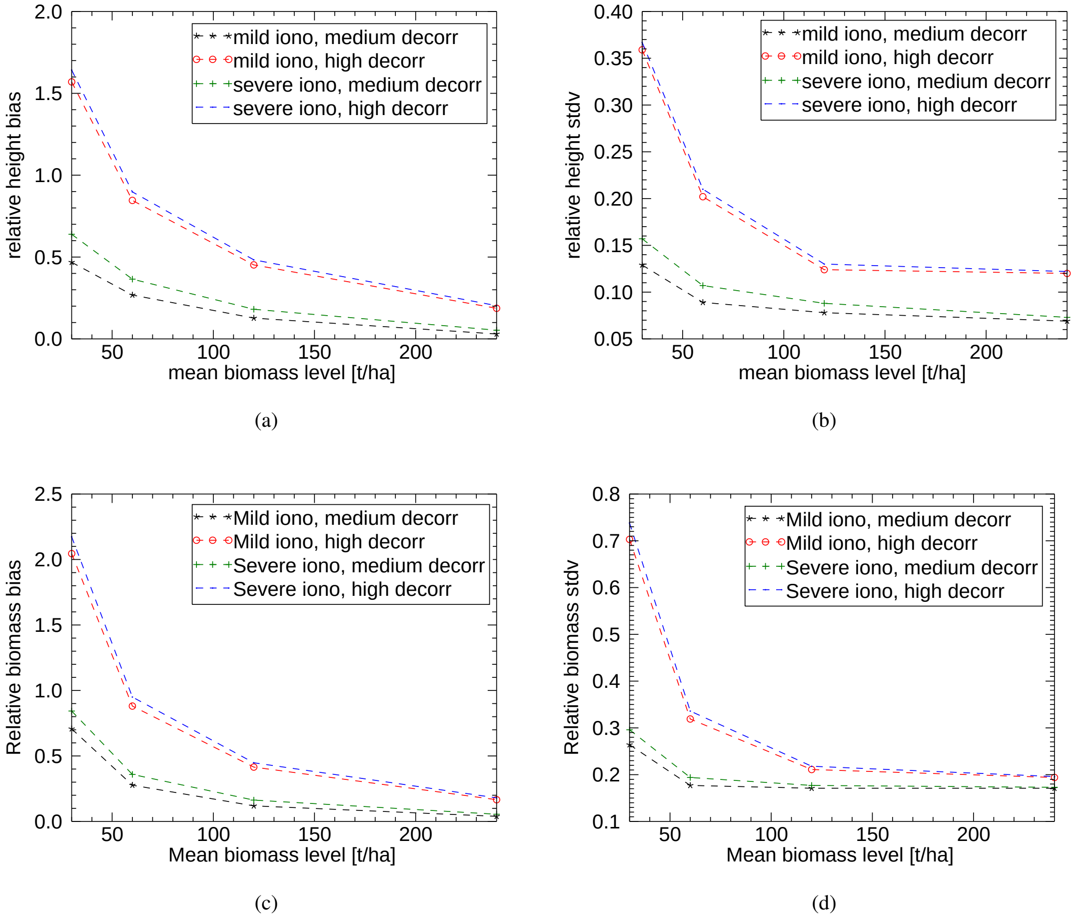

Fig. 3. From left to right and from top to bottom: height estimation bias, RMS height estimation error, biomass estimation bias, and RMS biomass estimation error.

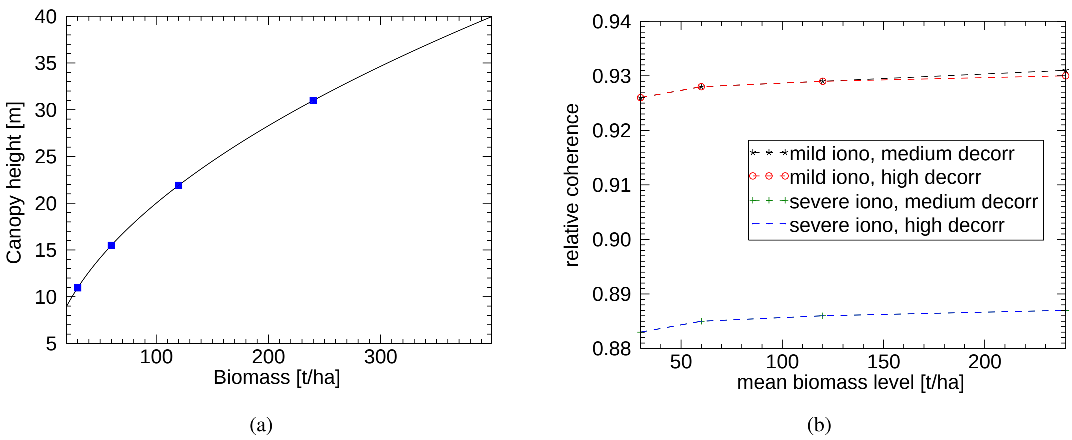

Fig. 4. Left: canopy height vs. biomass level. Right: relative coherence loss for interferometric HH channel vs. biomass level.

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