Earth Explorer 7 Candidate Mission Biomass: Addendum to the Report for Mission Selection
## APPROVAL

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<tr>
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M. Drinkwater (EOP-SM)

P. Bensi (EOP-SF)

P. Silvestrin (EOP-SF)

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## CHANGE LOG

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## CHANGE RECORD

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<thead>
<tr>
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<tbody>
<tr>
<td>D/EOP request for addition of Executive Summary, and incorporation of corrections, including revision to Table 5.7</td>
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<td></td>
</tr>
</tbody>
</table>
Table of contents:

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXECUTIVE SUMMARY</td>
<td>4</td>
</tr>
<tr>
<td>1 INTRODUCTION</td>
<td>5</td>
</tr>
<tr>
<td>2 BACKGROUND AND SCIENTIFIC JUSTIFICATION</td>
<td>6</td>
</tr>
<tr>
<td>3 SCIENTIFIC OBJECTIVES</td>
<td>6</td>
</tr>
<tr>
<td>4 OBSERVATIONAL REQUIREMENTS</td>
<td>6</td>
</tr>
<tr>
<td>5 SYSTEM CONCEPTS</td>
<td>9</td>
</tr>
<tr>
<td>6 SCIENTIFIC DATA PROCESSING AND VALIDATION CONCEPT</td>
<td>19</td>
</tr>
<tr>
<td>7 PERFORMANCE ESTIMATION</td>
<td>21</td>
</tr>
<tr>
<td>8 MISSION CONTEXT</td>
<td>25</td>
</tr>
<tr>
<td>9 PROGRAMMATICS</td>
<td>26</td>
</tr>
<tr>
<td>10 REFERENCES</td>
<td>28</td>
</tr>
</tbody>
</table>
Executive Summary

This report summarises the results of the activities performed in the context of the extension to the preparatory activities at Phase A level for the Biomass mission, which have been completed since the publication of the Biomass Report for Mission Selection (RfMS) (ESA SP-1324/1, May 2012).

The findings are presented as an Addendum to the respective sections of the Report for Mission Selection and are numbered identically for allowing the reader to cross-reference the text to the relevant parts of the Report.

The activities performed for the Biomass mission produced the following main results:

- Consolidation of the baseline observation concept based on a 17-days repeat cycle, dual-baseline implementation of PolInSAR acquisitions with an increased number of looks;

- Definition of an optional observation concept based on a tomographic orbit with 3-4 days repeat cycle, assessment of the impacts at system level and of the benefits on the mission performance;

- Consolidated estimates of the measurable changes of biomass and associated accuracy via analysis of campaign data;

- Performance assessment of PolSAR, PolInSAR acquisitions and their combination and comparison with tomographic performance using re-processed data from campaigns in French Guyana;

- Demonstration that height estimates derived from PolInSAR observations are unaffected by topography in dense tropical forests;

- Consolidation of the training and validation plan for the Biomass inversion scheme;

- Demonstration of the capability of P-Band to map rates of ice flow that are inaccessible at higher frequency but with limitations in the low-velocity regions due to ionospheric disturbances;

- Theoretical demonstration of the capability to provide a “bare Earth” DEM below forested regions using Biomass PolInSAR observations.

The intent of this Addendum to the Report is to provide ESAC and the User Consultation Meeting participants with an overview of the key findings from the Phase A extension, in preparation for the User Consultation Meeting deliberations and the subsequent ESAC recommendation for the selection of the 7th Earth Explorer mission.
1 Introduction

The Biomass Report for Mission Selection (RfS) published in June 2012 (ESA SP1324-1 2012) provides detailed information on the scientific, technical and programmatic outcome of the Biomass Phase A activities. It also identifies key issues where further improvement of the mission performance is expected or which lacked a consolidated view. During the Phase A extension these issues have been addressed at science and system level. This document describes the most significant findings, which can be summarised as:

- During Phase-A extension the mission concept was consolidated leading to two significant modifications: a change to a 17-day repeat cycle and a dual-baseline implementation of PolInSAR. This modification is beneficial in two aspects. The shorter repeat cycle directly results in less temporal decorrelation and consequently in a smaller bias of the PolInSAR inverted forest heights. In addition the dual baseline implementation of PolInSAR extends the applicability to larger height ranges. In order to reduce the bias caused by temporal decorrelation, single baseline PolInSAR has to use large baselines, which limits its applicability to height ranges that are equivalent to biomass levels greater than 250 $t/ha$. It is shown that dual baseline operation allows the bias to be compensated over a much larger height range; this operating mode is therefore adopted as part of the baseline mission scenario.

- One of the main sources of uncertainty in PolSAR inversion is the relatively small number of available looks (ENL) in the L2 0.25 $ha$ and 4 $ha$ products. Relaxation of the Total Ambiguity Ratio allows a trade-off against azimuth resolution, leading to increased ENL and improved performance.

- An important development was to show that, by using suitable orbital manoeuvres, the mission could operate throughout in a tomographic orbit, with 3- or 4-day repeat (depending on the system concept) at a given site. This option could be used in two ways. It can be built into the nominal observation concept with the benefit of a lower repeat cycle. But this option could also be used to acquire data in tomographic mode over the entire mission lifetime. While this option provides global coverage only after about 12 months (instead of 6 month) it would give major improvements in mission performance, which are still being fully worked out. This scenario appears to be compatible with the Vega launcher specifications, but firm confirmation of this is due in early 2013. Accordingly, the acquisition plan set out in the RfS is used as the baseline for most of the scientific analyses in this extension report, though with two significant modifications: a change to a 17-day repeat cycle and dual-baseline implementation of PolInSAR.

- Analysis of BioSAR data from 2007 and 2010 indicates that biomass changes of order 20 $t/ha$ are measurable and with accuracy significantly greater than absolute values of biomass.

- Reprocessing the French Guiana campaign data using a 6 MHz bandwidth has allowed the performance of PolSAR, PolInSAR and their combination to be assessed and compared with estimates from tomography under the Biomass mission specifications. This shows the value of combining PolSAR with PolInSAR for reducing the effect of topography on the PolSAR biomass estimate and smoothing out over- and under-estimates of biomass occurring in PolInSAR biomass estimates.

- It is demonstrated that height estimates derived from PolInSAR are unaffected by topography in dense tropical forest.

- A consolidated plan for training and validation of the Biomass inversion scheme is presented.

- New airborne results from the IceSAR campaign over Greenland demonstrate that P-band can map rates of ice flow that are inaccessible at higher frequencies, but in the low-velocity regions where these would be most valuable, their uncertainties are likely to be unacceptably high because of ionospheric disturbances. Further analysis is needed to ascertain whether recently developed ionosphere correction techniques can reduce this uncertainty and how changes in the repeat cycle would affect this application.

- Theoretical analysis, supported by recent campaign data, indicates that Biomass PolInSAR observations should be capable of providing a “bare Earth” DEM below forested regions with a resolution of 90 m x 90 m and ~2 m height accuracy.

To help ESAC and the community assimilate these new results, we describe them with reference to the sections of the RfS they affect. Sections that are not affected are not explicitly mentioned.
2  Background and Scientific Justification

Unchanged.

3  Scientific Objectives

Unchanged.

4  Observational Requirements

4.3 Geophysical Product Requirements

4.3.1 Coverage
As made clear in the RfS, the loss of Biomass coverage due to Space Objects Tracking Radar (SOTR) operations does not have major impacts on the primary science objectives of the mission. We here make some additional comments to reinforce this statement.

The availability of resources, capacity and well developed national forest inventory systems in N. America and Europe greatly mitigates the loss of Biomass coverage caused by SOTR restrictions, since they allow biomass maps to be produced using a combination of technologies, including airborne lidar, optical satellite sensors and height measurements from IceSAT. For example, Sweden has produced biomass maps for 96% of the country’s forest area for 2005 and 2010, and made them available online (http://skogskarta.slu.se/), and there are plans to produce a new map in 2015. A map of forest height and biomass at a spatial resolution of 30 m (based on SRTM, hence for the year 2000) for the whole of the co-terminous USA (the National Biomass and Carbon Dataset) is freely available as a digital raster dataset at www.whrc.org/nbcd. A new biomass map at a scale of 1 ha is also being produced for the co-terminous USA. These latter two maps in particular will be of great value in filling the gap in Biomass coverage concerning the mid-latitude sink from forest regeneration in abandoned rangeland in the US.

Other approaches to mapping biomass are possible for N. America and Europe, but Mexico and Central America do not have the necessary well-developed infrastructure (though substantial efforts are being made to improve the infrastructure in Mexico under the Global Forest Observations Initiative). It is valuable to take a global perspective on what the implications are for loss of information; all values quoted below are from the Global Forest Resources Assessment 2010 (FAO 2010). Central America contains less that 0.5% of the global forest area and Mexico around 1.6%, but deforestation rates are much higher in Central America than Mexico (1.23% vs 0.24%). Globally, 3.7% of the total deforestation in the tropical countries is in Central America and 2.5% in Mexico. Hence errors in biomass estimates for these countries (for example by using default values) will have limited impact on global estimates of the Land Use Change flux.

4.3.3 Temporal sampling
The RfS argues for bi-annual maps of biomass to help quantify the role of disturbances in the variation of atmospheric CO₂ concentrations, i.e. full global coverage should be achieved within 6 months. If the 4-day repeat cycle option is adopted, global coverage will be achieved only after 7 months, which is within tolerance.

4.4 Level-1 Data Requirements

4.4.4 Revisit Requirement
The main driver of the revisit requirement is the need to minimise the impact of temporal decorrelation on the forest height product. The RfS shows that temporal decorrelation translates directly into a height bias and recommends a revisit of 20-25 days in order to achieve coherence levels of > 0.85, which are required for a height accuracy of 20% set as the goal (with an accuracy of 30% set as threshold). Recent analysis of data acquired over several months from continuously operating radar installed on a tower in the tropical forest of French Guiana (the TropiSCAT campaign) shows that with 20-25 day revisit lower coherence values can
occur, especially during the rain periods. Figure 4.1 shows that data acquired during a rainy period (6-12-2011 to 14-03-2012) and a dry period (19-09-2012 to 21-11-2012) shows a slow decrease of coherence over time, on which are superimposed short term variations. Coherence during the dry season is generally higher than during the wet season and shows less temporal variation. To obtain optimal conditions for the inversion, it is therefore recommended that the revisit time should be decreased to less than 20 days, with a goal of 3-4 days.

Figure 4.1: Interferometric coherence versus temporal interval observed in Paracou (French Guiana) during a rainy period (left) and a dry period (right).

4.4.5 Error Sources Arising from the Biomass Radar System

The interferometric phase noise, which describes the quality of the interferometric image pair used for Pol-InSAR retrieval, is given by:

$$\sigma_\phi = \frac{1}{\sqrt{2N_L}} \frac{\sqrt{1-\gamma^2}}{\gamma} \quad \text{(Eq. 1)}$$

where $N_L$ is the number of looks and $\gamma$ is the coherence, as given in Eq. (4.1) of the RfS, but with an additional contribution, $\gamma_{AMB}$, due to coherence degradation caused by azimuth and range ambiguities:

$$\gamma = \gamma_{AMB} \cdot \gamma_{SNR} \cdot \gamma_T \cdot \gamma_{Vol} \quad \text{(Modified Eq. (4.1))}$$

Eq. 1 allows the number of looks to be traded against the ambiguity contribution to the coherence degradation, as expressed by Eq. (4.3) of the RfS. A re-optimisation of the allocation of different radar system errors was carried out during the Phase A extension in order to reduce the interferometric phase noise. Sections 4.4.5.1 and 4.4.5.4 below describe the changes in the radar system requirements and Section 4.4.5.5 the resulting improvement.

4.4.5.1 Resolution and number of looks

Re-optimising the error allocations allowed the azimuth resolution to be reduced from 12.5 m to around 8.5 m, increasing the number of azimuth looks from 4 to 6 for a 50 m × 50 m pixel. This is achieved by using a larger azimuth bandwidth in the SAR processing, at the cost of increased azimuth ambiguities.

4.4.5.4 Range and azimuth ambiguities

For the Phase A, a total ambiguity ratio (TAR) not exceeding -20 dB was set as the requirement. The re-optimisation led to a slightly relaxed value of TAR ≤ -18 dB in exchange for a higher azimuth resolution.
Further increase in the TAR would begin to compromise the intensity retrieval, particularly if the scene includes patches of low biomass forests surrounded by areas with much higher backscatter (e.g. > -10 dB).

### 4.4.5.5 Summary of radar system error sources

Figure 4.2 shows the value of $\sigma_\phi$ against the number of looks for a TAR of -20 dB (broken blue line) and -18 dB (red line), and for coherence values arising from other forms of decorrelation of 0.85 and 0.95 (upper and lower curves respectively). For a fixed number of looks, the increase in TAR causes a slight increase in $\sigma_\phi$, but the associated increase in the number of looks from 4 to 6 leads to an overall reduction of $\sigma_\phi$ (shown as $\Delta\sigma_\phi$).

![Interferometric phase noise versus number of looks in a 50 m × 50 m pixel for TAR = -20 dB and -18 dB, corresponding to 4 and 6 equivalent looks respectively. Two examples are depicted, in which the total contribution to the coherence from other decorrelation sources ($\gamma_{SNR}$, $\gamma_T$ and $\gamma_{vol}$) has values 0.95 and 0.85.](image)

**Figure 4.2:** Interferometric phase noise versus number of looks in a 50 m × 50 m pixel for TAR = -20 dB and -18 dB, corresponding to 4 and 6 equivalent looks respectively. Two examples are depicted, in which the total contribution to the coherence from other decorrelation sources ($\gamma_{SNR}$, $\gamma_T$ and $\gamma_{vol}$) has values 0.95 and 0.85.

### 4.4.7 Orbit/Mission Phases

The end-to-end mission performance assessment showed that PolInSAR-derived forest heights retrieved with a single baseline system are affected by large biases caused by temporal decorrelation. A dual baseline concept having two baselines counteracts these biases and increases the height and biomass range over which the forest height retrieval from PolInSAR is valid (see Section 7).
5 System Concepts

5.2 Mission Architecture Overview

As a consequence of the analyses presented in section 4.4.4, the new baseline Biomass observation concept is the double-baseline polarimetric interferometric observation method with a repeat cycle of 17 days already described in the RfS as an option. In the course of the phase A extension, an improved observation principle, compatible with the instrument design presented in the RfS, has been identified and is presented here as an option. Such concept allows a further reduction of the temporal decorrelation during the nominal phase from 17 days down to 3-4 days by keeping the satellite in the initial tomographic orbit.

5.3 Mission Analysis and Orbit selection

The baseline observation principle is the double-baseline interferometric method described in the RfS (ref. Chapter 5.3.2) with a Repeat Cycle (RC) of 17 days. For both mission concepts A and B, the total combined swath that can be achieved with the acquisitions of the 3 complementary swaths is about 160 km, as indicated in Fig. 5.1. This combined swath allows global coverage to be achieved in just 5 months with a repeat cycle of 17 days.

![Double-baseline interferometry using three interleaved swaths (major cycle). The blue lines represent the swaths, while the filled blocks are the areas where interferometric acquisition can be performed. The grey blocks represent acquisitions in the adjacent ground intervals.](image)

In order to minimise the temporal decorrelation of the interferometric acquisitions, a new observation concept with a repeat cycle as low as 3 or 4 days has been studied and is proposed here as an option. Achieving global coverage in 6 months with a 4 day repeat cycle without manoeuvres would require larger swath-widths to cover the larger inter-track distance of 679 km, which is not possible. Therefore, this concept uses orbit manoeuvres after every nine repeat cycles (defined as a major cycle) in order to introduce a ground track shift of 160 km. In such a way, global coverage is achieved by a sequence of major cycles, each followed by an orbit manoeuvre (the red dots in Figure 5.2).
The operational sequence for the mission using the optional observation concept is as follows:

- Operate for 3 × 3 repeat cycles in the tomographic orbit (major cycle);
- Perform an orbit raising manoeuvre to produce a differential ground track drift relative to the tomographic orbit;
- Perform an orbit lowering manoeuvre to return to the tomographic orbit;

This sequence is repeated continuously throughout mission.

Moving the spacecraft to a higher altitude than the tomographic orbit gives rise to a longer orbital period and a westwards relative drift in the ground track. This change and its associated delta-V (i.e. change in velocity, produced by propulsion) requirement depend on the time allocated for the drift phase. The coverage build-up for the optional observation concept is shown in Fig. 5.3.
The major impact of this concept is the need to perform additional manoeuvres, which require additional delta-V capability. The characteristics of the optional observation concept are summarised in Table 5.1.

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<th>B</th>
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<td>Orbit repeat cycle [days]</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Major cycle duration [days]</td>
<td>27</td>
<td>36</td>
</tr>
<tr>
<td>Orbit drift duration [days]</td>
<td>11.0</td>
<td>7.3</td>
</tr>
<tr>
<td>Percentage of time spent drifting [%]</td>
<td>29</td>
<td>17</td>
</tr>
<tr>
<td>Swath-width 1 [km]</td>
<td>72</td>
<td>66</td>
</tr>
<tr>
<td>Swath-width 2 [km]</td>
<td>59</td>
<td>57</td>
</tr>
<tr>
<td>Swath-width 3 [km]</td>
<td>38</td>
<td>42</td>
</tr>
<tr>
<td>Combined swath-width [km]</td>
<td>165</td>
<td>161</td>
</tr>
<tr>
<td>Fundamental interval (Si) [km]</td>
<td>910</td>
<td>679</td>
</tr>
<tr>
<td>Number of major cycles in Si</td>
<td>5.5</td>
<td>4.2</td>
</tr>
<tr>
<td>Global coverage [months]</td>
<td>6.8</td>
<td>6.0</td>
</tr>
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Table 5.1. Summary of main observation parameters for the optional observation concept.

It is worth mentioning that during the orbit drift periods the interferometric acquisitions are not possible. Nevertheless, intensity-based acquisitions can still be performed.

Also the tomographic phase can take advantage of the optional observation concept. By overlapping 6 consecutive interferometric acquisitions for each of the 3 swaths, a global tomographic coverage can be achieved in about a year.

5.4 Space Segment

5.4.1 Overview

The impact of the optional observation concept and the results of further analyses performed during the Phase A extension are reported in the sections below.

5.4.2. Satellite Configuration

The overall satellite configurations of concepts A and B are not changed except for what described in section 5.4.4. For concept B, the configuration has been updated with the addition of an extra thruster (ref. section 5.4.4.10) and repositioning the TT&C antennas (ref. section 5.4.4.8).

5.4.3 Payload

5.4.3.1 Overview

The payload concept is unchanged. Its operational concept is the dual-baseline interferometric option described in the RfS in sections 5.3.2 and 7.2. The payload concept is also fully compatible with the optional observation concept described in section 5.3 of this document. The updates at payload level are:

1) A relaxation of the TAR requirement from -20 dB to -18 dB, which allows an increase of the number of equivalent number of looks from 4 to 6;
2) The inclusion of a filter in the receiving chain to reject the out-of-band interferences from wind profilers;
3) A preliminary design of the ground calibration transponder for Concept A.

5.4.3.2 Observation Principle
With reference to Section 4.4.5, the reduction of the TAR requirement from -20 dB to -18 dB does not affect the instrument design; it only changes the azimuth integration time for the on-ground processing. All performance figures remain unchanged except the along-track spatial resolution, which is improved from 12.5 m to about 8.5 m (thus increasing the number of looks in a 50 m × 50 m pixel from 4 to 6).

5.4.3.3 Instrument Subsystems

The filter design at the input of the low-noise amplifiers (LNAs) has been consolidated through a design trade-off and simulations of LNA behaviour in the presence of strong out-of-band interference signals from wind profilers. A four-sections coaxial filter design has been defined, which is sufficient to attenuate the interference coming from typical wind profiler radars operating in adjacent bands to a level such that the Biomass LNAs are not driven to saturation. This RFI protection filter will ensure that Biomass can safely operate in the presence of such wind profiler radars. Further filtering before the ADC ensures that Biomass can safely operate in the presence of such wind profilers. This filter introduces a very small additional loss of 0.2 dB in the receive chain, which does not affect the sensitivity performance (i.e. the noise equivalent $\sigma_0$).

The implemented filter protects against interference from commercially available wind profilers. These profilers do not exploit the maximum power range allowed by the ITU regulation and the present or future existence of wind profilers affecting Biomass cannot be excluded. However, potential interference would be limited to short durations when the wind profiler is in the direct field-of-view of the Biomass SAR.

5.4.3.4 Instrument characterisation and calibration

5.4.3.4.3 External calibration

The external calibration will rely primarily on active transponders, as they can easily achieve a large radar cross-section (RCS) and can have versatile functionalities, such as receive function and non-reciprocal responses, so as to enable characterisation of the Biomass antenna and ionospheric effects. Passive point targets such as corner reflectors are of limited usefulness as they would have to be very large to achieve a sufficient RCS (e.g. a side dimension of > 10 m) and their response can only be reciprocal. With the adoption of the three-swaths observation principle, combined with orbit manoeuvring and drifting, a minimum of three transponders is required to calibrate the Biomass instrument in its three different beam pointing attitudes. This would translate in placing, as a minimum, three transponders on the magnetic equator for absolute calibration, and one or two at higher latitudes to validate the correction techniques for ionospheric effects. The geographical spacing of the transponders can be chosen to optimise the regularity of the external calibration time intervals, but is strongly constrained by the availability of suitable installation sites with the necessary infrastructure. No definitive choice has yet been made for the candidate sites.

Figure 5.4 depicts the designed Biomass transponder, which consists of a single planar antenna, transponder electronics (blue box on the back of the antenna) and antenna positioner. An antenna aperture of at least 4 m × 4 m is required in order to guarantee the required calibration accuracy, which is mainly driven by the avoidance of multipath effects through the antenna side lobes and not by the required transponder RCS. A passive planar antenna, consisting of an array of 8 × 8 square slot radiators, offers a compact and robust solution. The complete antenna and electronics assembly will have a weight of approximately 360 kg. A COTS antenna positioner from HITEC (HITEC-FM-036-XX) is presently identified as suitable for providing the elevation and azimuth tracking of the Biomass satellite, which meets the requirements in terms of the moving mass load, acceleration, pointing accuracy and environmental loads (nominal operation up to wind gusts of 30 km/h; survival/non-operational up to 100 km/h).
The following functionalities are to be implemented:
- Biomass satellite tracking in elevation (7° - 53°) and in azimuth (360°) in open-tracking mode using orbital information;
- Receive function in two polarisations with high sensitivity and dynamic range;
- Unit response for both polarisations H and V with a controlled time delay so as to separate the re-transmit signal from the incoming one, i.e. \[
\begin{pmatrix}
1 & 0 \\
0 & 1
\end{pmatrix};
\]
- Succession of unit responses for respectively H and V polarisations with controlled time delays, i.e. \[
\begin{pmatrix}
1 & 0 \\
0 & 0
\end{pmatrix} \text{ followed by } \begin{pmatrix}
0 & 0 \\
0 & 1
\end{pmatrix}.
\]

The main design parameters are summarised in Table 5.3 below.

<table>
<thead>
<tr>
<th>System parameter</th>
<th>Value</th>
<th>Comment</th>
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<tr>
<td>Radar cross-section (RCS)</td>
<td>≥ 60 dBm² for one-way antenna pattern verification</td>
<td>Subject to trade-off with respect to the amplifier loop gain for achieving the required RCS</td>
</tr>
<tr>
<td></td>
<td>≥ 80 dBm² for two-way antenna pattern verification</td>
<td></td>
</tr>
<tr>
<td>Dynamic range</td>
<td>≥ 40 dB for one-way antenna pattern verification</td>
<td>For angular range ≤ boresight ± 2° (TBC) over the bandwidth</td>
</tr>
<tr>
<td></td>
<td>≥ 50 dB for two-way antenna pattern verification</td>
<td></td>
</tr>
<tr>
<td>Antenna gain</td>
<td>≥ 22 dB</td>
<td></td>
</tr>
<tr>
<td>Cross-polar ratio</td>
<td>≤ -40 dB at boresight</td>
<td>With respect to the peak gain</td>
</tr>
<tr>
<td>Antenna backside radiation</td>
<td>≤ -45 dB</td>
<td>With respect to the peak gain</td>
</tr>
<tr>
<td>RCS absolute bias knowledge</td>
<td>≤ 0.3 dB</td>
<td>Independent calibration of the complete transponder</td>
</tr>
<tr>
<td>RCS stability knowledge</td>
<td>≤ 0.2 dB</td>
<td>Achieved through internal calibration subsystem</td>
</tr>
</tbody>
</table>

Table 5.3. Main transponder design parameters.
5.4.4 Platform

5.4.4.1 Overview

At platform level, a number of subsystems should be revised with respect to the baseline presented in the RfS in order to be compatible with the optional observation concept. The extra delta-V needed for orbit manoeuvres require the addition of a third tank for Concept A, while for Concept B a bigger tank can be accommodated (see section 5.4.4.10). For Concept B only, the need to thrust in the anti-velocity direction during the orbit transfers requires adding an extra thruster. Because of the thruster orientations, Concept A relies instead on an 180° pitch attitude manoeuvre (see section 5.4.4.10) in order to raise the orbit altitude. For Concept B, a refined S-band antenna accommodation analysis resulted in new locations for the S-band antennas (see section 5.4.4.8). For both concepts, a data volume analysis has been conducted with a new observation mask as described in section 5.4.4.6.

5.4.4.4 Thermal control

The additional 3° roll manoeuvre required to cover the third swath has a negligible effect on the thermal control. For concept A, the 180° pitch manoeuvres has no thermal impact on the satellite thermal subsystem.

5.4.4.6 Data handling and transmission

The instrument coverage mask for primary and secondary objectives has been updated as shown in Fig. 5.5 to take into account the operational limitations from the SOTR radars (see Section 9.3 of the RfS). Simulations with the new mask have shown overall compatibility of the data handling and transmission system with the data volume generated by the aggregated primary and secondary objective acquisitions.

Figure 5.5. Coverage mask for primary (white) and secondary (gray) objectives.

5.4.4.7 Electrical power and energy storage

The additional roll manoeuvre to access the third swath will require the solar array orientation to be re-optimised to maximise the performance. However, this is a small adjustment of less than 2° from the concept presented in the RfS and will not have any significant impact.

5.4.4.8 Telemetry, Tracking & Command (TT&C)

For Concept B, a TT&C antenna accommodation analysis resulted in the addition of a fourth antenna at the location shown in Fig. 5.6. This poses some challenges in the feed system design, as the EMC, thermal and mechanical aspects have to be taken into account during the feed system design. The thermal impact caused by the S-band antenna hot spot has been studied and is considered minor. The mechanical impact is limited
on the deployment mechanism. The EMC aspects have not been studied but they are considered not critical due to the fact that the S-band antenna radiates on the backside of the feed.

![Figure 5.6. TT&C antenna accommodation for concept B.](image)

**5.4.4.9 Attitude and Orbit Control Subsystem**

Detailed analysis during the extension phase showed that the AOCS design is compatible with the large reflector deployment phase.

**5.4.4.10 Propulsion Sub-System**

The propulsion subsystems of both concepts require modifications in case the optional observation principle is implemented. For Concept A the extra delta-V needed for the orbit manoeuvres results in the addition of a third tank, as shown in Fig. 5.7. The anti-velocity direction thrust will be achieved by rotating the platform by 180° in pitch before and after thrusting, since thruster plume impingement on the solar panels precludes the accommodation of an extra thruster. The operational impact of this attitude manoeuvre is considered minor (ref. 5.7).

For Concept B, it is possible to accommodate a bigger tank inside the central cone (see Fig 5.7). An extra thruster is added in the anti-velocity direction, as shown in Fig 5.8, to support the satellite manoeuvring required by the optional observation concept.
Figure 5.7. Modifications of the propellant tank system for Concepts A (addition of a third tank) and B (use of a larger tank).

Figure 5.8. Accommodation of an extra thruster in the anti-velocity direction for Concept B.

5.4.5 Budgets

The updated budgets for the baseline and optional concepts are presented in the following sections.
5.4.5.1 Mass budgets

Concerning the optional observation concept: the Concept A with the Harris reflector option becomes unfeasible due to the already limited initial launch mass margin (ref Table 5.7 in RfS). It can be noticed that for both concept A and B the optional concept is ~100 kg heavier than the baseline concept for a launch in 2019. Compared to the baseline design, for the optional Concept A the mass has increased due to the addition of a third tank (+10 kg), updated battery mass (+12 kg), the extra propellant (+60 kg) and further balance mass (+5 kg) required to ensure that the spacecraft centre of mass is within the launch vehicle requirement. In addition, the launcher adapter mass for Concept A was reduced by 18 kg. For the optional Concept B the mass has increased due to increased tank size (+7.7 kg), the extra propellant (+81 kg), additional thruster (+0.7 kg), SAR payload filters to protect against wind profilers interference (+6.7 kg) and one additional S-band antenna (+0.3 kg).

<table>
<thead>
<tr>
<th></th>
<th>Concept A with NG reflector</th>
<th>Concept B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Handling</td>
<td>51.6</td>
<td>18.4</td>
</tr>
<tr>
<td>Electrical Power S/S</td>
<td>109.8</td>
<td>67.5</td>
</tr>
<tr>
<td>Harness</td>
<td>69.3</td>
<td>78.7</td>
</tr>
<tr>
<td>X-band comm. S/S</td>
<td>11.7</td>
<td>63.5</td>
</tr>
<tr>
<td>S-band comm. S/S</td>
<td>10.7</td>
<td>8.2</td>
</tr>
<tr>
<td>AOCS</td>
<td>79.9</td>
<td>84.5</td>
</tr>
<tr>
<td>Structure</td>
<td>268.9</td>
<td>358.6</td>
</tr>
<tr>
<td>Thermal S/S</td>
<td>51.3</td>
<td>34.1</td>
</tr>
<tr>
<td>Propulsion</td>
<td>26.2</td>
<td>14.5</td>
</tr>
<tr>
<td><strong>Platform Total</strong></td>
<td><strong>679.4</strong></td>
<td><strong>728.0</strong></td>
</tr>
<tr>
<td><strong>Payload Total</strong></td>
<td><strong>202.5</strong></td>
<td><strong>206.1</strong></td>
</tr>
<tr>
<td><strong>Dry Mass Total</strong></td>
<td><strong>881.9</strong></td>
<td><strong>934.1</strong></td>
</tr>
<tr>
<td>System mass margin</td>
<td>132.3</td>
<td>144.6</td>
</tr>
<tr>
<td>Balance mass</td>
<td>55.0</td>
<td>30.0</td>
</tr>
<tr>
<td><strong>Dry Mass with margin</strong></td>
<td><strong>1069.2</strong></td>
<td><strong>1108.7</strong></td>
</tr>
<tr>
<td>Propellant with margin</td>
<td>58.8</td>
<td>34.0</td>
</tr>
<tr>
<td><strong>Wet Mass</strong></td>
<td><strong>1128.0</strong></td>
<td><strong>1142.7</strong></td>
</tr>
<tr>
<td>Launcher performance</td>
<td>1352.3</td>
<td>1360.0</td>
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<tr>
<td>Launcher adapter</td>
<td>70.0</td>
<td>74.5</td>
</tr>
<tr>
<td><strong>Launch margin</strong></td>
<td><strong>154.3</strong></td>
<td><strong>142.8</strong></td>
</tr>
</tbody>
</table>

Table 5.7. Mass budgets for baseline and optional concepts [kg].

5.4.5.2 Delta-V budgets

The delta-V budgets for the baseline and optional concepts for a launch in 2019 are shown in Table 5.8. For the optional concept, the orbit maintenance delta-V can be reduced because during the orbit drift it is not necessary to compensate the orbit ground track shift caused by the drag. This can be compensated for by raising the orbit slightly higher than required and allowing it to decay by the end of the drift phase whilst preserving the required average ground track drift rate.
Table 5.8. Delta-V budgets for baseline and optional concepts [m/s].

<table>
<thead>
<tr>
<th></th>
<th>Concept A</th>
<th>Concept B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>Option</td>
</tr>
<tr>
<td>Orbit injection correction</td>
<td>18.5</td>
<td>18.5</td>
</tr>
<tr>
<td>Orbit change between phases</td>
<td>8.2</td>
<td>N/A</td>
</tr>
<tr>
<td>Orbit maintenance</td>
<td>34.7</td>
<td>25.6</td>
</tr>
<tr>
<td>Collision avoidance</td>
<td>5.4</td>
<td>5.4</td>
</tr>
<tr>
<td>Orbit manoeuvring (option)</td>
<td>N/A</td>
<td>80.6</td>
</tr>
<tr>
<td>De-orbit manoeuvre</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>66.8</strong></td>
<td><strong>130.1</strong></td>
</tr>
</tbody>
</table>

5.5 Launcher

The launcher margins for the 17-days RC baseline concept and for the optional observation concept are in Table 5.7.

5.7 Operations and Utilisation Concept

With the optional observation concept the Biomass satellite would operate in the tomographic orbit for the full duration of the mission. The orbit transfer manoeuvres required by the new observation concept (see Section 5.3 and Table 5.2) have to be performed every 27 or 36 days for concepts A or B, respectively. The duration of the manoeuvres and of the orbit drift is 11 days (concept A) and 7.3 days (concept B). These manoeuvres have minor impact at mission operation level as they can be coupled with the more frequent orbit control ones.
6 Scientific Data Processing and Validation Concept

6.3 Auxiliary Data

6.3.2 Global In Situ Datasets

The quality of the biomass products from the Biomass mission depends critically on the availability of accurate and spatially representative ground measurements. As a result, strong links to the in situ community have been developed during Phase A. At the global scale, the parameterisation of retrieval algorithms and validation of biomass products entail three steps: (1) develop and validate a segmentation of land surfaces into biome types where different P-band SAR inversion algorithms need to be applied; (2) provide an inventory of globally available in situ ground data for PolSAR algorithm training and product validation; (3) quantify the uncertainty in the biomass products taking into account errors in the ground data.

In the temperate and boreal zones, national forest inventories provide a high-density network of ground data that have already been used to calibrate SAR products (such as ALOS-PALSAR). These nation-wide surveys provide an ideal dataset for training SAR algorithms over temperate and boreal forests and are generally of a good enough quality to distinguish forest types that are likely to return a specific SAR signal, such as forests on well-drained versus poorly drained soil. Further, an extensive literature-derived database on forest stand structure has been generated by Luyssaert et al. (2007) and includes a total of 297 sites, largely from North America and Western Europe. Each of the sites has detailed environmental information. Other temperate forest plots have been acquired by national forest inventories in the northern hemisphere, including several European countries, Canada, the USA and the former Soviet Union. An agreement with China would be highly desirable to cover this important region. However, these datasets may not be directly usable because of: (a) data ownership issues; (b) inadequate plot geolocation; (c) plot size and measurement accuracy; (d) date of measurement. These limitations will be evaluated during Phase B so as to produce ground data that can be used during the validation phase of the Biomass products.

Although far fewer primary data are available than in temperate forests, an important concerted effort to organize existing forest plot data and to fund new and repeated inventories in moist tropical forests has been jointly led by the RAINFOR and AfriTRON consortia in South America and Africa, respectively (Lewis et al. 2009). These consortia have assembled 135 plots in South America and 93 plots in Africa, of mean size 1 ha, which represent all the major tropical forest formations in both continents. The University of Edinburgh has assembled a further 42 1 ha plots in the dry tropical forests of southern Africa, a biome with significant spatial coverage and structural differences from moist forests (Williams et al. 2008, Ryan et al. 2011). In addition, the Smithsonian Institution’s Center for Tropical Forest Science (CTFS) coordinates the research efforts in over 30 large, permanent, regularly inventoried sampling plots, ranging in size from 10 ha to 50 ha. The leaders of these networks have confirmed in writing their willingness to support the mission with in situ data, ensuring access to high-quality tropical training and validation data for the Biomass mission.

Biomass estimates based on allometries and small forest inventory plots tend to be biased, and one large source of error is the spatial location of plots in the landscape. Using 29 large plots from the CTFS, we have shown that the average error made by assuming that a single 1-ha plot is representative of the biomass of the surrounding forest is about 15% of the mean. This error is larger in recently disturbed plots and in plots on terrain with steep slopes. The central limit theorem and empirical tests indicate that a four-fold increase in plot area reduces the sampling error by a factor two, so that, for an average 4-ha subplot in a CTFS plot, the error is about 9% of the mean. Similarly, for dry tropical forests in Tanzania, the mean 1-ha biomass estimate is biased by 10% compared to the mean 9-ha biomass estimate of the larger forest landscape.

Based on these data, the following training strategy is proposed for Biomass. In temperate and boreal forests, a classic SAR inversion algorithm training strategy is already viable, based on the use of geo-referenced forest inventory plots. The validation of the products will be based on larger permanent forest plots, following a protocol validated in Swedish forests and detailed in Soja et al. (in press). In the moist tropics, the number of training sites is too limited, even after combining the large CTFS plots and the RAINFOR/AfriTRON networks, and it is unlikely that these networks will expand sufficiently up to the launch of Biomass. However, small footprint LiDAR has proven effective for inferring carbon stock maps in moist tropical forests (Asner et al. 2012, Mascaro et al. 2011). Recent research suggests that, even with a
limited number of inventory plots for training, it is possible to retrieve unbiased LiDAR-based biomass maps over areas ranging from $10^3$ - $10^6$ ha. These maps have the great advantage as regards training SAR algorithms that they encompass a broad range of forest types and environmental conditions, and are therefore more representative of the landscape-scale variation of biomass than forest inventory. The use of LiDAR for landscape scale biomass mapping in the tropics is likely to expand in the coming years, although its use for repetitive large-scale mapping is prohibitively expensive. The Biomass mission should be able to take advantage of these efforts, such as the validated biomass map of currently being produced for Gabon. It would also be advantageous to acquire small footprint LiDAR coverages at a set of focal sites of around $10^4$ ha, based around the CTFS and RAINFOR/AFRITRON networks, and use them to produce calibrated landscape-scale biomass maps. The PolSAR Biomass inversion algorithms will then be trained using these high-resolution maps, and validated on separate forest sites, preferentially with large plots. A similar approach, based on the Edinburgh network, is proposed for the dry tropical woodlands, which have much lower biomass density than the moist tropics but cover very large areas and, particularly in Africa, contribute a major part of the biomass stored in forests (Baccini et al. 2012).
7 Performance Estimation

7.3 Level-2 Retrieval Performance

7.3.1 Forest Biomass Product

7.3.1.1 Performance over boreal forests

(a) PolSAR inversion performance. Further analysis of campaign data during the extension phase has shown that Figure 7.11 of the RfS is conservative in terms of expected performance. The relative error (RMSE divided by mean biomass) for the PolSAR data inversion is now 28% instead of 32% as stated on page 151 of the RfS. This new value was obtained by limiting the reference data to only include areas with the least uncertainty in biomass, i.e. areas with biomass error less than a few percent (Sandberg et al., 2011), and by updating with the new Biomass specifications (6 looks at 50 m resolution, total ambiguity ratio of 18 dB). A major reason for not reaching the relative RMSE of 22% obtained with the corresponding high-resolution SAR data (Soja et al., in press) is systematic radiometric variations of ± 1 dB observed between extracted Doppler and frequency bands due to the antenna gain pattern which have not been fully compensated. Continued progress towards meeting the 20% biomass accuracy requirement is expected by compensating these antenna gain effects and improved topographic correction using ancillary DEM data. Further gains in biomass retrieval performance are likely by using information on the spatial distribution of forest biomes in combination with refined retrieval models, the use of ascending and descending data and the combination of PolSAR and PolInSAR observations.

(a) PolSAR performance to map biomass change. Analysis of BioSAR data from 2007 and 2010 clearly indicates the potential of Biomass to measure changes in biomass stocks. Figure 7.1 shows maps of relative changes in biomass for a 200 m resolution product in Remningstorp after four growth seasons. The change maps are based on airborne PolSAR data from spring 2007 and autumn 2010, respectively, with simulated speckle according to the Biomass system specification (i.e. 96 looks at 200 m x 200 m). The HH/VV polarization ratio was used to normalize the channels for biases between 2007 and 2010 due to calibration errors and moisture variations. A biomass change estimator was formed using regression analysis based on the VV, HH and HV polarizations, with reference maps based on small-footprint laser scanning data. Comparison of the high-resolution PolSAR data with ground data indicates that the RMSE of the estimated biomass change is 20 t/ha or 13%, i.e. significantly lower than for estimating biomass itself. The figure also shows how this relative biomass change translates into absolute changes in carbon stock using a 0.5 MgC/t scaling factor.

Figure 7.1 Biomass change maps with 200 m resolution in Remningstorp from spring 2007 and autumn 2010. The maps on the left show relative (logarithmic scale) changes in biomass based on PolSAR inversion (bottom) and lidar (top). The maps on the right side show biomass change on a linear scale, translated into carbon stock changes by a scaling constant.
7.3.1.2 Performance over tropical forests

(a) Biomass recovery using 6 MHz data. At time of writing the RfS, the Paracou data had not been fully reprocessed using the 6 MHz bandwidth corresponding to the Biomass specification, but this has been carried out during the Phase A extension, leading to biomass estimates for PolSAR alone, from PolInSAR heights converted by allometry alone and the combination of PolSAR & PolInSAR as shown in Fig. 7.2; the Figure also includes a new biomass map inferred from tomography. Comparison with in situ plot data from the lower right of the region with above ground biomass (AGB) in the range 260-430 t/ha indicates RMS errors relative to the mean AGB of 22%, 18%, 19% and 13% respectively. If we therefore assume that the tomographic estimate is of greater accuracy across the whole scene, then we can see that combining PolSAR with PolInSAR reduces the effect of topography in the PolSAR estimate and smooths out the large scale patterns of over- and under-estimation of biomass derived from PolInSAR height alone. Interestingly the combined biomass product does not have a better accuracy than the PolInSAR product. This can be explained by a suboptimal correction of topographic effects which are significant for the test plots. Further improvements can hence be expected by a better topographic correction, as well as a better characterisation of the error structure.

(b) Environmental effects. An important question in recovering biomass from PolSAR measurements is the impact of environmental change induced, for example, by precipitation. Recent campaign data acquired every 15 minutes by permanent mounted radar installed on a tower in the tropical forest of French Guiana (TropiSCAT) show a diurnal cycle of 1 dB, which can be explained by temporal variation in vegetation dielectric constant, caused by xylem sap flux density, in addition to variations caused by precipitation events. However, the HH and HV backscatter measured at a fixed time between 5 and 6 a.m. (corresponding to the Biomass orbit) is very stable, as is clear from the time series in Figure 7.3 for a rainy and dry period. The plots show the backscatter measurements (indicated by dots) taken in the 5 - 6 a.m corresponding to the Biomass equator crossing time. During the dry period the temporal RMS of the HV backscatter is only 0.2 dB, increasing to 0.4 dB during the rainy period. The time series also contain trends: for HV there is a linear slope of -0.025 dB/day for the dry season and 0.008 dB/day for the wet season, whose cause is not yet understood and is the subject of further analysis. Instrument calibration effects cannot be excluded as several hardware parts had to be replaced during the campaign.
Figure 7.3: Left: daily measurements of HV (green) and HH (red) backscatter at 05:00 - 06:00 hours from 06/12/2011 to 14/03/2012 during the rainy season. Dots indicate individual measurements and the solid lines are linear fits. The pink bars give precipitation in mm. Right: Measurements at the same time during the dry season from 20/09/2012 to 21/10/2012.

7.3.2 Forest Height Products

7.3.2.2 Performance in tropical forests: improved PolInSAR height retrievals with variable topography

Newly acquired lidar data over the INDREX campaign site in Indonesia characterised by dense tropical forest with steep topography indicate that PolInSAR-derived height is insensitive to topographic variability. The top part of Figure 7.4 shows a full resolution P-band SAR HV backscatter image from the INDREX site overlaid with a scanning lidar strip. The backscatter is strongly modulated by topography, but there is no corresponding variation in the forest height map derived from PolInSAR over the same area shown in the lower image. The plot on the right indicates the good overall agreement between PolInSAR and lidar heights (RMS difference = 3.0 m) despite the wide variation in the slope indicated by the colour coding.

Figure 7.4 Top: HV backscatter map acquired over the INDREX campaign site (Indonesia) overlaid with a lidar strip. Bottom: Forest heights derived from PolInSAR data over the same area. Images are based on full bandwidth data. Right: Comparison between PolInSAR and lidar heights; the colour coding indicates the local slope in degrees where the height measurements were made.
7.4 Secondary Applications

7.4.1 Mapping ice flow

Airborne IceSAR-2012 data acquired in Greenland and degraded to the spatial resolution of Biomass suggest that over the equilibrium line of the ice-sheets, where it is difficult to measure ice velocities at higher frequencies due to temporal decorrelation, P-band data can offer a valuable complementary capability. Figure 7.7 shows an ice flow map over the Kangerlussuaq site in Greenland derived from C- and L-band satellite data, with flow velocities indicated by the colour bar. The lower part of the image is from C-band, for which velocity estimates in this case fail beyond the equilibrium line (indicated by the frayed eastern edge). The upper part is from L-band and suggests that estimates might be possible beyond the equilibrium line, but clear conclusions cannot be drawn because ALOS-PAL SAR gives only limited coverage, as indicated by the straight right edge of the L-band region. P-band could potentially provide flow information beyond the equilibrium line as is indicated by the results obtained for the site S10. In particular, interferometric techniques can be applied, thereby providing finer spatial resolution and more precise velocity measurements than are attainable with intensity-based offset tracking techniques. However, simulations indicate that interferometry will be seriously affected by ionospheric disturbances, while offset tracking is much more robust, and, up to median disturbance levels, should be able to measure the motion of fast glaciers (>100 m/y) in Antarctica, but not in Greenland and Svalbard. It must be noted that fast glaciers typically have crevasses and other features which allow offset tracking to work well at X-, C-, and L-band, so the potential advantages of Biomass would be for ice-sheets and upstream parts of glaciers, but for these slower moving ice regimes, the simulated standard deviations of the flow estimates are unacceptably high. Further analysis is required to assess whether ionosphere correction techniques can reduce this uncertainty.

![Figure 7.7: Left: Ice flow map over the Kangerlussuaq site in Greenland derived from C- and L-band satellite data, with flow velocities (predominantly east to west) indicated by the colour bar (image from Boncori et al., 2010). Right: Ice flow measurements taken at P-band during the IceSAR campaign for the site S10 compared to in situ GPS measurements.](image)

7.4.2 Mapping topography under vegetation

Theoretical analysis suggests that Biomass is capable of providing a “bare Earth” DEM below forested regions with a resolution of 90 m x 90 m (corresponding to the DTED-1 definition, e.g. SRTM) and ~ 2 m height accuracy. This DEM will be available once per year in forested areas and once for the whole mission lifetime for low SNR regions (e.g. bare surfaces). This analysis is supported by recent campaign data. Figure 7.8 shows topographic maps derived from Lidar and PolInSAR measurements obtained over a dense tropical forest site in French Guiana (a TropiSAR campaign site). The derived PolInSAR ground elevations (using lidar heights as a reference) are unbiased (see plot on right) and estimated with an RMSE of 3.7 m.
Figure 7.8 Topographic maps derived for the TropiSAR tropical forest site based on Lidar and PolInSAR.

8 Mission Context

Unchanged.
9 Programmatic

9.2 Scientific Maturity, Critical areas and Risks

9.2.2 Maturity

Major progress was made in PolInSAR inversion by implementing dual baseline acquisitions and a 17-day repeat cycle; this led to a substantial improvement in performance. Under this scenario and for an optimal spatial baseline the accuracy requirements are met for a wide range of forest heights, including the important high biomass case. Further improvements are expected from the optional acquisition scenario with a 3- or 4-day repeat cycle. This will decrease the effect of temporal decorrelation and allow optimum performance across a wide range of heights.

A performance analysis over a tropical site (French Guiana) shows that accuracies of 20% can be achieved using the PolSAR and PolInSAR observation. These results do not yet consider the availability of ascending and descending data which potentially lead to further improvements particularly over regions with variable topography.

Re-analysis of campaign data acquired over boreal forests has shown that the uncertainty reported in the RfS is conservative in terms of expected biomass retrieval performance with Biomass. The updated performance estimate, which is based on PolSAR campaign data is 28% instead of 32% as stated in the RfS. Although the performance estimate is still non-compliant in term of the 20% biomass accuracy requirement, progress towards achieving this level has been made during the Phase A extension and is expected to continue.

Very encouraging results were obtained from analysis of campaign data acquired in 2007 and 2010 over a boreal site. Validation of the high-resolution PolSAR data with ground data indicates that the RMSE of estimating biomass change is 20 t/ha or 13%, i.e. significantly lower compared to estimating biomass itself.

The validation and algorithm training strategy for Biomass was consolidated during the extension phase and strong links to the in situ community have been developed.

New airborne results from Greenland demonstrate that P-band can map rates of ice flow that are inaccessible at higher frequencies, but in the low-velocity regions where these would be most valuable compared with the use of higher frequencies, their uncertainties are likely to be unacceptably high because of ionospheric disturbances. Further analysis is needed to ascertain whether recently developed ionosphere correction techniques can reduce this uncertainty.

Performance assessment of the secondary mission objectives showed that a below canopy DEM can be derived from Biomass measurements at a resolution of 90 m and an accuracy of ~2 m, which corresponds to the DTED-1 specification.

As made clear in the RfS, the loss of Biomass coverage due to Space Objects Tracking Radar (SOTR) operations does not have major impacts on the primary science objectives of the mission. We here highlight that in the majority of the affected regions other data sources can be exploited.

9.3 Technical maturity, critical areas and risks

9.3.1 Satellite Platform

With respect to the optional observation concept as reported in chapter 5, the system maturity has been confirmed.
9.3.2 Instrument

9.3.2.2 Reflector feed-array

Unchanged for Concept A. For Concept B the addition of the TT&C antenna on the back of the feed system (as described in 5.4.4.8) will require a new feed-system design iteration to mitigate any electromagnetic compatibility issues.

9.3.2.4 Transmit unit/high power amplifier

In the context of the two parallel developments of the SSPA the GaN technology has been selected for the engineering model implementation. A road map has been identified to achieve the TRL5 status before the starting of the implementation phase.

9.3.2.5 Ground calibration

Progress in the definition of the ground calibration transponder was achieved in the phase A extension as described in section 5.4.3.4.3.

9.5 Conclusion

Based on the progress done in the Phase A extension and pre-developments activities the feasibility of the mission is further confirmed. The development schedule is compatible with a launch in 2019. The feasibility of the optional observation concept, leading to a 3-4-days RC, is affected only by the compatibility of the increased satellite launch mass with the performance of the baseline Vega launcher in the relevant orbit. A solid statement of feasibility will only be possible when the Vega performance will be confirmed, the new release of the Vega User Manual being still pending at the time of writing.
References


