Biomass: new mission selected as the 7th ESA Earth Explorer Mission

Florence Hélière, Franco Fois, Chung-Chi Lin, Klaus Scipal, Marco Arcioni, Paolo Bensi, Malcolm Davidson, Pierluigi Silvestrin, Mark R. Drinkwater, Roland Meynart


esa-estec, keplerlaan 1, 2200 ag noordwijk, the netherlands; e-mail: florence.heliere@esa.int

abstract. Earth Explorers are the backbone of the science and research element of ESA’s Living Planet Programme, providing an important contribution to the global endeavor of understanding the Earth system. The Agency prepared three candidates for the 7th Earth Explorer Core mission for which parallel Phase A activities have been performed by industrial teams. Among the three candidate missions proposed for the selection process Biomass carrying a P-band SAR for global observation of above ground biomass and associated geophysical parameters as a primary objective has been selected for implementation. Biomass has been defined in detail through two parallel and competing industrial Phase A studies and many complementary science and technology studies. This paper will give an overview of the Biomass mission and detailed information of the pay-load and observation principle to achieve the scientific objectives.

keywords. Mission, Remote sensing, SAR.

1. Introduction

The European Space Agency’s (ESA) Earth Explorer missions are the backbone of the science and research element of ESA’s Living Planet Programme, each providing an important contribution to the global endeavour of understanding the Earth system. The Agency has prepared three candidates for the next Earth Explorer Core mission with the aim of selecting the 7th mission in 2013 to be launched in the 2020 timeframe. Out of three competing candidate missions, Biomass was selected in May 2013 for implementation. Biomass carries a P-band SAR in order to fulfill its primary objective of global observations of above-ground biomass and associated geophysical parameters.

2. Biomass

The most important environmental challenge in the early 21st century is to improve our understanding of global change and how it will affect the Earth system and the feedbacks within the system. This is important so that societies can predict, mitigate and adapt to any likely impacts [1].

The carbon cycle is fundamental to the functioning of Earth, and involves many intermeshed processes in which terrestrial processes play a crucial role through carbon uptake and respiration associated with vegetation growth, and emissions from disturbance caused by both natural processes, such as wildfires and land-use change through human activities. However, the status, dynamics and evolution of the terrestrial biosphere are the least understood and most uncertain elements in the carbon cycle.

Biomass will address one of the most fundamental questions in our understanding of the land component in the Earth system, namely the status and the dynamics of forests, as represented by the distribution of biomass and how it is evolving [2].
Biomass will be implemented as a P-band polarimetric, interferometric Synthetic Aperture Radar (SAR) mission. It will exploit the unique sensitivity of P-band SAR together with advanced retrieval methods to measure forest biomass, height and disturbance across the entire biomass range every six months. The resolution and accuracy of the Biomass data products will be compatible with the needs of international reporting on carbon stocks and terrestrial carbon models. In addition, Biomass will provide the first opportunity to explore the Earth’s surface using the P-band wavelength. The data are also expected to be used for monitoring glacier and ice sheet velocities, mapping subsurface geology in deserts and mapping the topography of forest floors. Additional products and applications are likely to emerge and be evaluated during the life of the mission.

3. Biomass objective and Observation requirements

The greatest uncertainties in the global carbon cycle relate to the estimate of carbon dioxide uptake by land. The primary scientific objectives of the Biomass mission [3] are to determine the distribution of aboveground biomass in the world’s forests and to measure annual changes in this stock over the period of the mission.

Biomass will provide global maps of forest biomass stocks at a spatial resolution in the order of 4 ha, about once/twice a year over the life of the five-year mission. These maps will greatly improve on existing forest inventories and give vastly improved information for managing Earth’s forest resources.

Biomass will also provide spatially-resolved maps of biomass change, which can be linked to disturbance, degradation, land-use change, forest growth and spread. In addition, the full resolution of the instrument of around 0.25 ha will be used to detect deforestation; linking this to the coarser resolution maps of biomass will allow associated carbon loss to be estimated at scales commensurate with the processes of land-use change.

The Biomass observation requirements have been derived from these high level objectives.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument type</td>
<td>P-band full polarimetric SAR</td>
</tr>
<tr>
<td>Centre frequency</td>
<td>435 MHz (P-band)</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>≤ 6 MHz (ITU allocation)</td>
</tr>
<tr>
<td>Incidence angle (near)</td>
<td>Threshold: 23°; Target: 25°</td>
</tr>
<tr>
<td>Cross-polarisation ratio</td>
<td>≤-25 dB (threshold); ≤ 30 dB (goal)</td>
</tr>
<tr>
<td>Spatial res. (≥ 4 looks)</td>
<td>≤ 60 m (across-track) × 50 m (along-track)</td>
</tr>
<tr>
<td>Noise equivalent σ0</td>
<td>Threshold: ≤ –27 dB; Target: ≤ –30 dB</td>
</tr>
<tr>
<td>Total ambiguity ratio</td>
<td>≥ 20 dB</td>
</tr>
<tr>
<td>Radiometric stability</td>
<td>0.5 dB RMS</td>
</tr>
<tr>
<td>Abs. radiometric bias</td>
<td>1.0 dB</td>
</tr>
<tr>
<td>Dynamic range</td>
<td>30 dB</td>
</tr>
</tbody>
</table>

Table 1. Biomass observation requirements.
4. Observation principle

Addressing the primary science objectives requires repeated measurements of forest biomass at temporal and spatial scales that are compatible with the needs of national inventories and carbon flux calculations. The only economically viable way of providing this information is by satellite remote sensing. Two combined measurement will be achieved during Biomass mission: remotely sensed estimates of forest characteristics related to biomass and in situ measurements of forest biomass for calibration and validation [4, 5].

The remote sensing component of Biomass will be based on a P-band polarimetric SAR mission with controlled inter-orbit distances (baselines) between successive revisits to the same site. At each acquisition, the radar will measure the scattering matrix, from which the backscattering coefficients (equivalent to radar intensity) will be derived in each of the different linear polarisation combinations, i.e. HH, VV, HV & VH (where H and V stand for horizontal and vertical transmitted and received), and the inter-channel complex correlation. For interferometric image pairs, the system will provide the complex interferometric correlation (coherence) between the images at each linear polarisation. Polarimetric interferometric SAR (PolInSAR) coherence and Polarimetric SAR (PolSAR) backscatter observations provide independent, complementary information that can be combined to give robust, consistent and accurate retrieval of biomass [6]. In addition tomography techniques [7] involving a multibaseline polarimetric SAR acquisition will be used to complete the knowledge of the vertical structure of the forest.

![Figure 1. Biomass Observation principle based on three complementary techniques](image)

By exploiting these capabilities through a dedicated strategy, Biomass will build up a unique archive of information about the world’s forests and their dynamics.
5. Mission Concepts

The technical description of the Biomass mission is derived from the preparatory activities at Phase A level and shows how candidate implementation concepts can respond to the scientific requirements. The system description is mainly based on the results of the work performed during two parallel Phase A system studies by two industrial consortia, led by EADS Astrium Ltd. and Thales Alenia Space Italy. Consequently, two implementation concepts, marked A and B, are described in what follows.

The main architectural elements of the mission are shown in Fig. 2. The space segment comprises a single spacecraft carrying a P-band SAR, operating in stripmap mode in a near-polar, Sun-synchronous quasi-circular frozen orbit at an altitude of 635–672 km, depending on the different mission phases. The orbit is designed to enable repeat-pass interferometric acquisitions throughout the mission’s life and to minimise the impact of ionospheric disturbances.

The baseline Vega launcher will inject the satellite into its target orbit. Compatibility of the satellite with backup launchers such as PSLV and Antares has also been ensured. The mission is designed to exploit acquisitions made at dawn/dusk, i.e. 06:00/18:00 local time (at the equator), to minimise the adverse influence of the ionosphere on the radar signal. The SAR data are delivered to the Kiruna ground station via an X-band radio downlink. Auxiliary data, which are required to quantify the characteristics of the propagation path of the radar signal, are used in the end-to-end system calibration and processing of the SAR data. The Biomass mission will last five years and comprise a tomographic phase with a duration up to 1 year followed by the interferometric phase, characterised by an orbit repeat period of 17 days.
6. Mission analysis

The orbit requirements can be subdivided into interferometric baseline requirements and orbit maintenance requirements. The interferometric baseline requirements are expressed in terms of a baseline $B$ to be maintained at the equator between any orbit of cycle $n$ and the corresponding orbit of cycle $n+1$. The baseline requirement is different for the nominal and the tomographic phases and is a function of the critical baseline $B_c$. In the nominal phase, the threshold requirement is for $B$ to be less than 60% of $B_c$, with a goal of 40%. In the tomographic phase it is required that $B = B_c/3$.

![Observation geometry with interferometric baseline](image)

**Figure 3.** Observation geometry with interferometric baseline

The strategy for meeting the interferometric baseline requirement is based on the selection of an orbit with a ‘controlled drift’. The amount of drift between successive orbital cycles is chosen to match the interferometric baseline requirement. In practice, the baseline is achieved by flying the satellite in an orbit where the altitude is slightly higher or lower than that of the exact repeating orbit. Because of this small drift, the resulting orbit will have a quasi-repeat cycle of 17 days for the nominal phase.

The operational sequence for the mission using the observation concept is as follows:

- Operate for $3 \times 3$ 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. The coverage build-up for the observation concept is shown in Fig. 4.
7. Satellite Concept

The satellite configuration is strongly constrained by the accommodation of the very large antenna reflector inside the Vega launcher for which two potential implementation options exist (identified as Concept A and Concept B). The large antenna must be folded for launch and deployed in orbit to form a 12 m large stable aperture throughout the mission’s life. The overall configuration of Concept A is shown in Fig. 5 and is compatible with commercial-off-the-shelf reflectors from the US manufacturers Harris Corporation (HC) and Northrop Grumman (NG). For Concept A the reflector is illuminated by a 3×2 array of cavity-backed circular microstrip radiators, which is mounted onto the –Y wall of the satellite at the lower end (not visible in the figures).

The overall configuration of Concept B, based only on the NG reflector, is shown in Fig. 5. Here, the reflector is illuminated by a deployable 2×2 array of microstrip patch radiators, which is mounted on the spacecraft top face by means of a supporting structure.
8. Payload Concept

The SAR will operate in a stripmap mode with a swath illuminated by a single antenna beam, i.e. an imaging configuration similar to that of the ERS-1/2 SAR. Global coverage is obtained by the interleaved stripmap operations among three complementary swaths as described previously in paragraph 5. The beam re-pointing is performed through a roll manoeuvre of the spacecraft, as there is ample time over the poles for such operations. This solution using the spacecraft rolling was preferred over the possibility of electronic beam switching due to its simplicity. Both concepts are able to operate using the double-baseline interferometry mode shown in Fig. 4.

Both concepts use a single-offset reflector antenna system consisting of a feed array and a large deployable mesh reflector with a circular projected aperture diameter of 11.5 – 12 m. The selected single offset reflector geometry is characterised by a relatively short focal length in order to minimise the distance between the spacecraft and the reflector, thereby reducing the moment of inertia of the satellite. Because of this short focal length, the reflector, when illuminated by a linearly polarised spherical wave from the feed, would produce a significant cross-polar radiation (12–15 dB below the co-polar peak gain) in its main beam, which has the form of a difference pattern (narrow null along the principal elevation plane). To comply with the cross-polarisation ratio requirement, a pre-compensation technique is then implemented at the level of the feed. The feed array makes use of stacked circular patches for Concept A and of stacked square patches for Concept B. Stacking of the patches is necessary to achieve a sufficient bandwidth at the level of the feed subsystem (>10 MHz). The feed assembly is made of multilayer sandwich structure, consisting of metallised carbon or Kevlar-fibre-reinforced plastic sheets and Kevlar honeycomb or Rohacell foam core, thus lightweight. Concept A uses three pairs of radiators with tapered excitation in elevation, whereas only two pairs of radiators with equal excitation are used for Concept B.
The radio frequency and digital electronics of the Biomass SAR instrument use well-established technologies thanks to the low radar frequency (UHF band) and narrow system bandwidth (6 MHz). However, the combination of the low frequency and high peak RF power increases the risk of multipaction. Therefore, a number of specific risk-retirement activities were undertaken and specific measures were implemented in the radar front-end design.

9. International Telecommunication Union

A secondary spectrum allocation for active sensing from space exists between 432 to 438 MHz. The International Telecommunication Union (ITU) constraints (ITU-R RS.1260-1, 2003, see [8]) imposed on a spaceborne P-band SAR can be divided into technical constraints and operational constraints. The technical constraints for a P-band spaceborne SAR are the emitted signal bandwidth of 6 MHz maximum, centred on 435 MHz, and the Power Flux Density (PFD) on the Earth surface, as listed in Table 2. The 6 MHz bandwidth limits the range resolution at the 25° incidence angle to ~60 m, whereas the PFD limits the maximum peak and average emitted power by the radar. Both constraints have to be met by the system design and therefore limit the trade-off space for optimising the performance.

<table>
<thead>
<tr>
<th>Table 2. ITU Power Flux Density constraints for a spaceborne P-band SAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum peak PFD on Earth surface from antenna main-lobe</td>
</tr>
<tr>
<td>Maximum mean PFD on Earth surface from antenna main-lobe</td>
</tr>
<tr>
<td>Maximum mean PFD on Earth surface from first antenna side-lobe</td>
</tr>
</tbody>
</table>

The operation of Biomass requires coordination with the US Air Force (USAF), which is responsible for the operation of the ten Space Objects Tracking Radars (SOTR) listed in the ITU-R RS.1260-1. The restriction on the SAR to operate only outside the SOTR radar coverage area imposes a large reduction of the biomass areas of interest for the mission. The operational scenarios shown in Fig. 6 has then been derived from this restriction and remains still compatible with the achievement of the Biomass scientific objectives.
Figure 6. Biomass acquisition plan limited by the US Space Objects Tracking Radar (Red = Primary objective coverage mask, Yellow = Secondary objective coverage mask)

10. System performance

Fig. 7 summarizes the major Biomass system performance figures. Both concepts meet the requirements within the goal and threshold range. For all incidence angles, the instrument noise lies below the \(-27\) dB threshold derived from the science requirements. All the system performance at level 1b have assessed and show good compliance regarding the requirements.

<table>
<thead>
<tr>
<th>Key Parameters</th>
<th>Requirement</th>
<th>Concepts A and B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity (NESZ)</td>
<td>(\leq -27) dB</td>
<td>(\leq -27) dB</td>
</tr>
<tr>
<td>Total Ambiguity Ratio (TAR)</td>
<td>(\leq -20) dB</td>
<td>(\leq -20) dB</td>
</tr>
<tr>
<td>Geometric Resolution</td>
<td>(\leq 60) m x (50) m</td>
<td>(\leq 60) m x (50) m</td>
</tr>
<tr>
<td>Effective Number of Looks</td>
<td>(\geq 4)</td>
<td>(\geq 4)</td>
</tr>
<tr>
<td>Radiometric Stability</td>
<td>(\leq 0.5) dB</td>
<td>0.35 dB</td>
</tr>
<tr>
<td>Absolute Radiometric Bias</td>
<td>(\leq 1.0) dB</td>
<td>0.45 dB</td>
</tr>
</tbody>
</table>

Figure 7. System performance at Level 1b
11. Conclusions

This paper provides a description of the Biomass mission, as derived from the preparatory activities at phase A level, for implementation as an Earth Explorer in the frame of ESA’s Living Planet Programme. The science description has been derived from the scientific activities and campaigns supporting the mission. The system description is based on the results of the work performed during parallel phase A system studies by two industrial consortia. Two implementation concepts have been developed, which provide different options capable of meeting the scientific mission requirements. Other aspects not presented here are summarized in [3] where a complete review of the mission is included.

Biomass has now been selected for implementation and two parallel phases B1 to be started in 2013 will help to go further in the definition and consolidation of the two industrial concepts.

References