ESA'S BIOMASS MISSION SYSTEM AND PAYLOAD OVERVIEW

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ABSTRACT

Earth Explorers are the backbone of the science and research element of ESA's Living Planet Programme, providing an important contribution to the understanding of the Earth system. Following the User Consultation Meeting held in Graz, Austria on 5-6 March 2013, the Earth Science Advisory Committee (ESAC) has recommended implementing Biomass as the 7th Earth Explorer Mission within the frame of the ESA Earth Observation Envelope Programme. This paper will give an overview of the satellite system and its payload. The system technical description presented here is based on the results of the work performed during parallel Phase A system studies by two industrial consortia led by EADS Astrium Ltd. and Thales Alenia Space Italy. Two implementation concepts (respectively A and B) are described and provide viable options capable of meeting the mission requirements.

1. INTRODUCTION

The primary scientific objectives of the Biomass mission are to determine the distribution of aboveground biomass in the world forests and to measure annual changes in this stock over the period of the mission to greatly enhance our understanding of the land carbon cycle. To achieve these objectives, the Biomass sensor will consist of a P-band (435 MHz) Synthetic Aperture Radar (SAR) in side-looking geometry with full polarimetric and interferometric capabilities. The main architectural elements of the Biomass mission are shown in Fig. 1.

The Biomass space segment comprises a single low Earth orbit satellite platform carrying the SAR instrument. The SAR antenna is based on a large deployable reflector (12 m circular projected aperture) with an offset feed array and a single-beam.

The mission consists in a single spacecraft launched by Vega in 2020 and carrying a P-band SAR, operating in a near-polar, Sun-synchronous quasi-circular frozen orbit at an altitude of 637–666 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 observation principle is based on double-baseline interferometric acquisitions, with a repeat cycle (RC) of 17 days. In order to minimise the temporal decorrelation of the interferometric acquisitions, an optional observation concept with a RC as low as 3 or 4 days has been also identified.

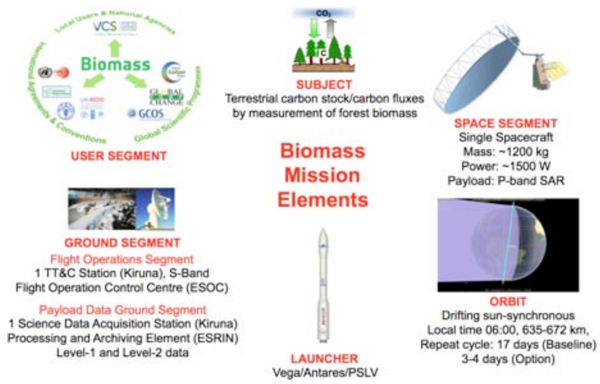

Figure 1. Biomass mission architecture.

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 followed by the nominal operational phase.

The ground segment uses the generic Earth Explorer ground segment infrastructure and comprises:

- The Flight Operation Segment (FOS), which includes the Telemetry, Tracking and Command (TT&C) Ground Station and the Flight Operations Control Centre, and;
- The Payload Data Ground Segment (PDGS), which includes the Science Data Acquisition Station, the Processing and Archiving Element and the Mission Planning and Monitoring Element.

2. OBSERVATION REQUIREMENTS

The Biomass mission shall provide global maps of forest biomass stocks at a spatial resolution in the order of 4 ha, about twice a year over the life of the five-year mission. The Biomass observation requirements derived from the high level mission requirements are summarised in the Tab. 1.

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Parameter	Requirement
Instrument type	P-band full polarimetric interferometric SAR
Centre frequency	435 MHz (P-band)
Bandwidth	≤ 6 MHz (ITU allocation)
Near incidence angle	23° (thr.); 25° (goal)
Cross-pol. ratio	≤ -25 dB (thr.); ≤ -30 dB (goal)
Spatial res. (≥ 4 looks)	≤ 60 m (across-track) × 50 m (along-track)
Noise equivalent σ0	≤ –27 dB (thr.); ≤ –30 dB (goal)
Total ambiguity ratio	≥ 20 dB
Radiometric stability	0.5 dB RMS
Abs. radiometric bias	1.0 dB
Dynamic range	30 dB

Table 1. Biomass observation 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 $n + 1$, as shown in Fig. 2.

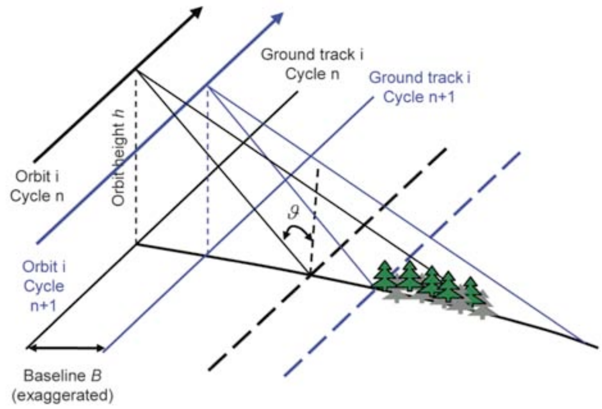


Figure 2. Interferometric observation geometry.

The baseline requirement is different for the interferometric and the tomographic phases and is a function of the critical baseline Bc. In the interferometric phase, the threshold requirement is for B to be less than 60% of Bc, with a goal of 40%. In the tomographic phase it is required that $B = Bc / 3$.

3. MISSION ANALYSIS

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 baseline interferometric phase.

3.1. Interferometric Phase (baseline)

A double-baseline interferometric mode provides two interferometric acquisitions with temporal decorrelation within the requirements in order to improve the retrieval accuracy. As shown in Fig. 3, this mode consists of a set of three acquisitions with a fixed baseline to retrieve the forest height, while the orbit repeat cycle is kept to a minimum to ensure good temporal coherence between acquisitions spaced by two repeat cycles.

In such a way, each of the three swaths is imaged over three RCs, before the satellite is rolled to observe the next one. The complete coverage is therefore achieved by matching the overall combined interferometric swath (obtained after nine RCs) of 160 km with the orbit fundamental interval, achieving an orbit RC of 17 days and a global coverage in just 5 months for the baseline interferometric phase.

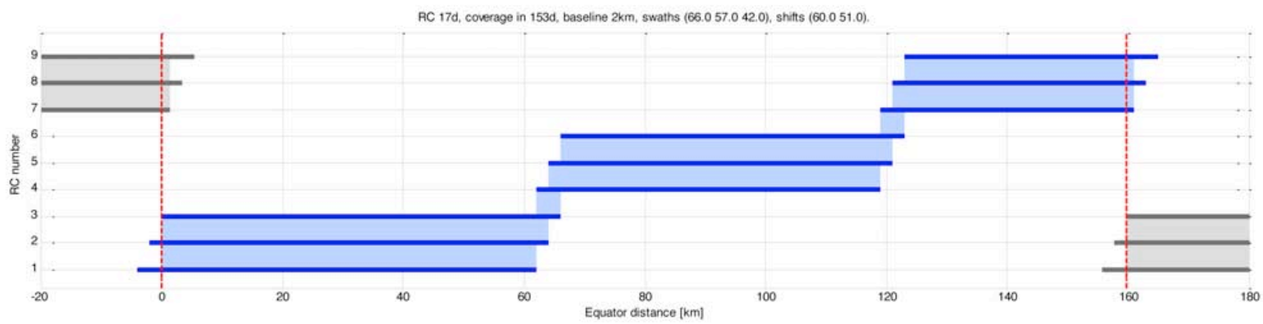


Figure 3. Double-baseline interferometry using three interleaved swaths (major cycle). The blue lines represent the swaths, while the filled blocks are the areas where interferometric acquisition can be performed. The grey blocks represent acquisitions in the adjacent ground intervals.

3.2. Optional Interferometric Phase (option)

In order to minimise the temporal decorrelation of the interferometric acquisitions, an 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 days 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 Fig. 4).

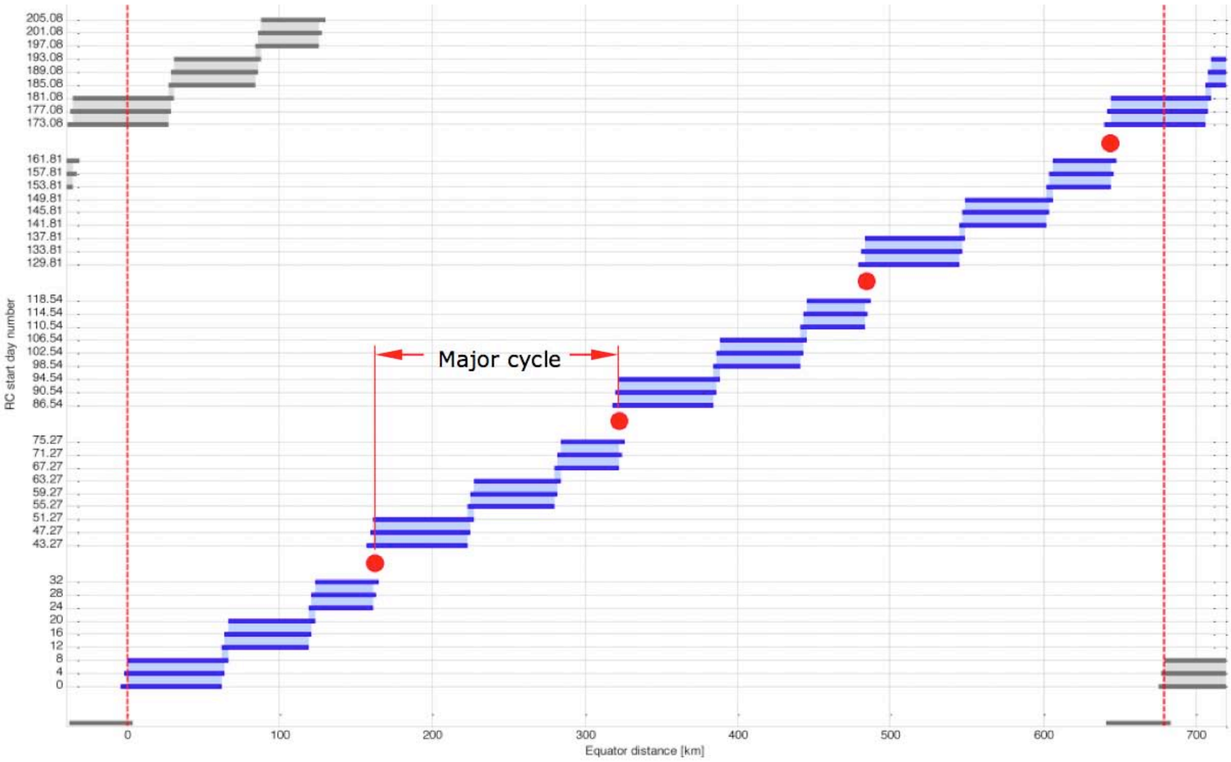


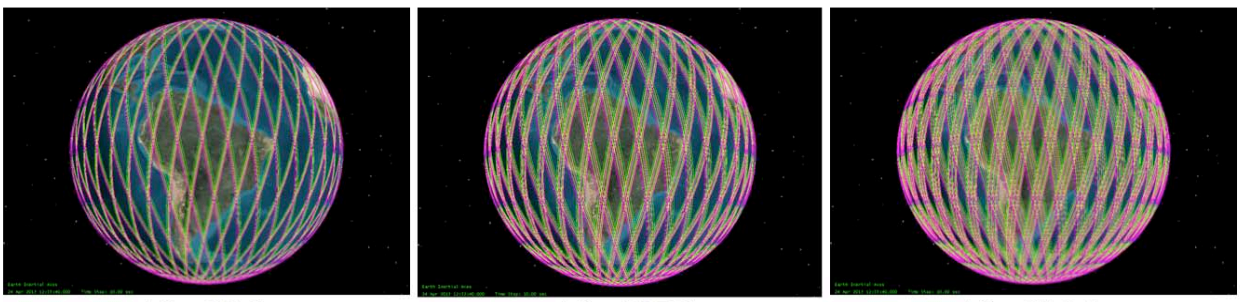
Figure 4. Coverage under the optional observation concept (for mission concept B). The red dots represent orbit manoeuvres and drifting periods. The blue lines represent the swaths, while the filled blocks are areas where interferometric acquisition can be performed.

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 initial 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.



After 9 RCs | After 18 RCs | After 27 RCs

Figure 5. Build-up of coverage under the new observation concept.

The major impact of this observation concept is the need to perform additional manoeuvres, which require additional delta-V capability. The characteristics of the optional observation concept are summarised in Tab. 2.

It is worth mentioning that during the orbit drift periods, interferometric acquisitions are not possible as the interferometric baseline is larger. Nevertheless, intensity-based acquisitions can still be performed (e.g. for secondary objectives).

Parameter	Concept A	Concept B
Orbit repeat cycle [days]	3	4
Major cycle duration [days]	27	36
Orbit drift duration [days]	11.0	7.3
Percentage of mission time spent drifting [%]	29	17
Swath-width 1 [km]	72	66
Swath-width 2 [km]	59	57
Swath-width 3 [km]	38	42
Combined swath-width [km]	165	161
Fundamental interval (Si) [km]	910	679
Number of major cycles in Si	5.5	4.2
Global coverage [months]	6.8	6.0

Table 2. Summary of main observation parameters for the optional observation concept.

Also, the tomographic phase could 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.

4. SPACE SEGMENT

The satellite configuration is strongly constrained by the accommodation of the very large reflector antenna inside the Vega launcher. This large antenna must be folded for launch and deployed in orbit to form a stable aperture throughout the mission's life.

4.1. Configuration

Both concepts A and B are based on a Large Deployable mesh Reflector (LDR) antenna system consisting of a deployable arm and an unfurlable reflector with a projected aperture of approximately 12 m. These large reflectors are produced for mobile telecom satellites in the USA, where the main manufacturers are Northrop Grumman (NG) and Harris Corp. (HC). Concept A configuration is compatible with both LDR antenna types, while Concept B is compatible only with the NG antenna. Each deployment boom is specifically designed for the Biomass concepts.
The overall configuration of Concept A is shown in Fig. 6 for the HC and NG LDRs, respectively. The LDR is illuminated by a 3×2 array of cavity-backed circular microstrip radiators, which is mounted onto to the *–y* wall of the satellite at the lower end (not visible in the figures).

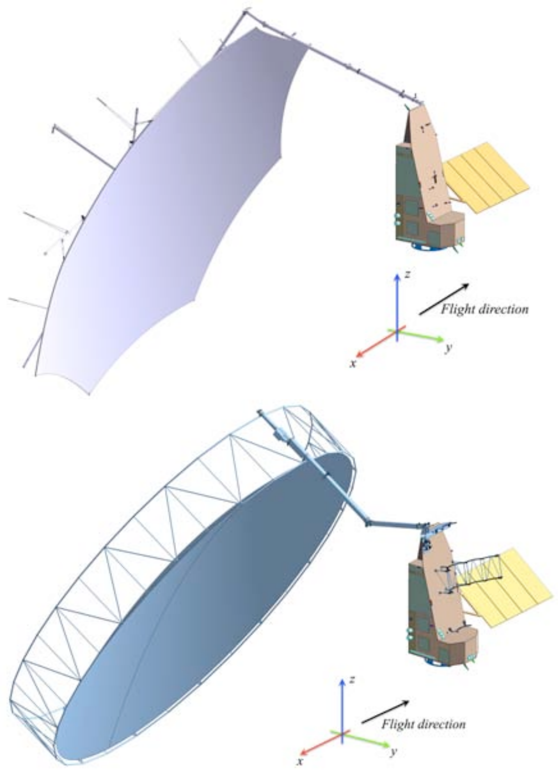


Figure 6. Concept A deployed configurations views; Harris reflector (top) and NG reflector (bottom).

The overall configuration of Concept B is shown in Fig. 7. Here, the LDR 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

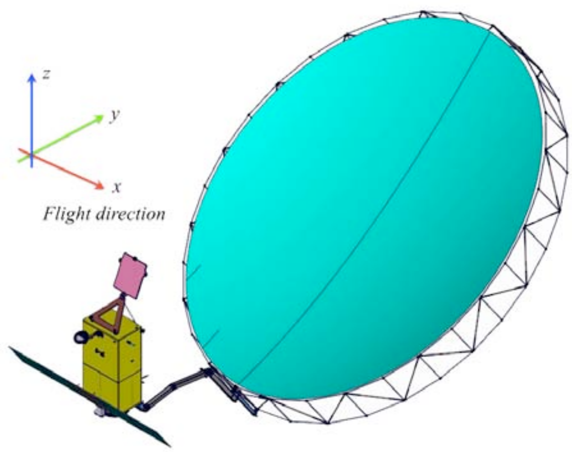


Figure 7. Concept B deployed configuration view with NG reflector.

4.2. Payload

The Biomass SAR operates 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. 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 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 ~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.

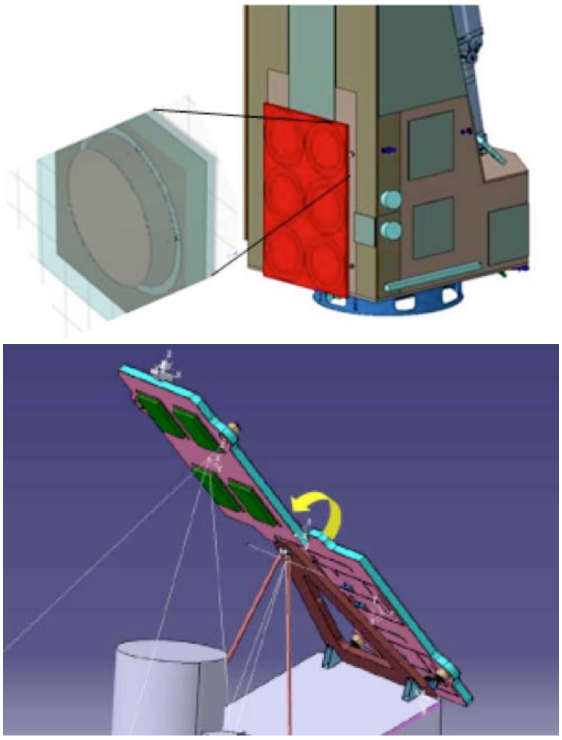


Figure 8. Feed array consisting of 3×2 stacked circular patches and body-mounted on the satellite for Concept A (top); Deployable feed array consisting of 2×2 stacked square patches on a support structure for Concept B (bottom).

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 (see Fig. 8) 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.

4.3. Mass Budgets

With respect to the baseline interferometric observation mode, the optional interferometric observation mode has an impact at system level on a number of subsystems. The extra delta-V needed for orbit manoeuvres implies the addition of a third tank for Concept A, while for Concept B a bigger tank can be accommodated. 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 in order to raise the orbit altitude. Concerning the optional observation concept, the Concept A with the Harris reflector option becomes unfeasible due to the already limited initial launch mass margin.

	Concept A		**Concept B**	
	Baseline	**Option**	**Baseline**	**Option**
Platform	745	775	759	767
Payload	218	218	213	213
Sys. margin	138	140	145	147
Propellant	67	120	34	115
Sat. Total	**1168**	**1252**	**1151**	**1242**
Adapter	70	70	74	74
Vega perf.	1352	1352	1360	1360
Lau. margin	114	30	135	44

Table 3. Comparison of mass budgets in [kg] for baseline and option for concepts A and B.

It can be noticed that for both concepts A and B, the optional observation concept is ~90 kg heavier than the baseline concept for a launch in 2020. Compared to the baseline design, for the optional Concept A the mass has increased due to the addition of a third tank (+10 kg), and 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. For the optional Concept B, the mass has increased due to increased tank size (+7.7 kg), the extra propellant (+81 kg) and an additional thruster (+0.7 kg).

4.4. Power budget

The instrument will alternate between the Ready and ON modes according to the operation plan. For the rest of the orbit, the instrument will remain in Standby mode. The summary of power budgets (including margins) for both concepts is presented in Tab. 4. The sizing case corresponds to the satellite in nominal mode with the payload (P/L) switched on. The higher power needed by the heaters in Concept A is the reason for the difference in the budgets of the two concepts. For both concepts the solar array area is of 6.8 m^2.

Operating Mode	Concept A	Concept B
Initial Acquisition	1038	654
Safe Mode	1023	583
Orbit Correction Mode	1087	764
Nominal, with P/L Ready	881	649
Nominal, with P/L ON	1298	786
Nominal, with P/L in Standby	668	596

Table 4. Power budgets (average values in [W]).

5. SYSTEM PERFORMANCE

Table 5 and Figs. 9 and 10 summarize the major Biomass system performance. Both concepts meet the requirements within the goal and threshold range. The system performance at level 1b has been assessed and shows good compliance with respect to the requirements.

Key Parameters	Requirement	Concepts A and B
Sensitivity (NESZ)	≤ -27 dB	≤ -27 dB
Total Ambiguity Ratio (TAR)	≤ -20 dB	≤ -20 dB
Geometric Resolution	≤ 60 m × 50 m	≤ 60 m × 50 m
Effective Number of Looks	≥ 4	≥ 4
Radiometric Stability	≤ 0.5 dB	0.35 dB
Absolute Radiometric Bias	≤ 1.0 dB	0.45 dB

Table 5. Summary of system performance at level 1b.

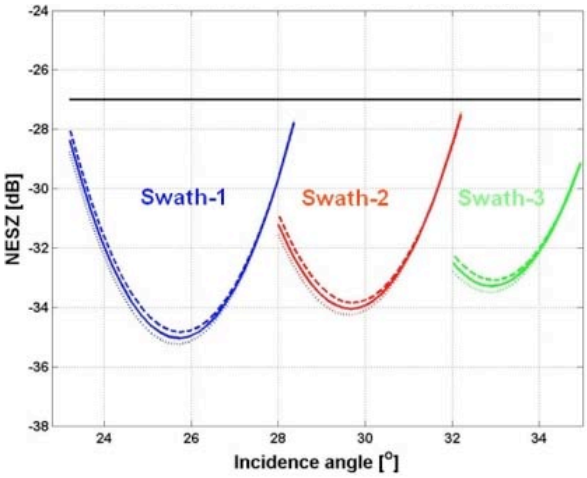


Figure 9. Noise Equivalent Sigma0 performance.

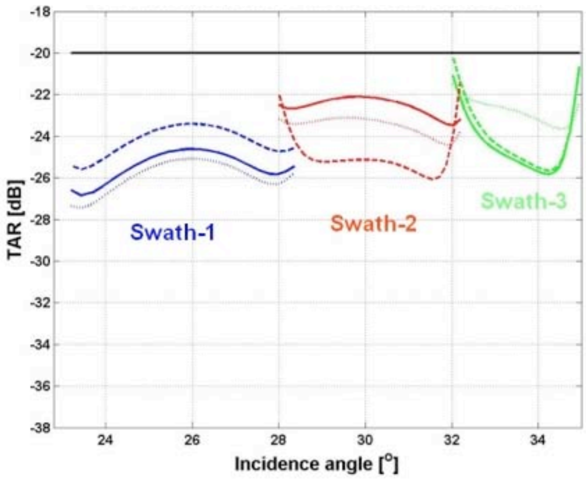


Figure 10. Total Ambiguity Ratio performance.

6. OPERATIONS CONCEPT

Biomass observations require repetitive global coverage of a specified set of regions. SAR observations are acquired on ascending and descending passes. This process lends itself to an autonomous approach for data acquisition and processing up to Level 1b. The Biomass mission is divided into a number of different phases, as listed in Tab. 6.

Operational Phase	Baseline	Option
Launch & Early Orbit Phase	1 week	
Commissioning	5 months	
Tomographic Phase	3 months	1 year
Orbit change	2 weeks	N/A
Interferometric phase	4.7 years	4 years
Disposal	9 days	

Table 6. Mission phases and durations, similar values for both concepts.

7. TECHNICAL MATURITY AND CRITICAL AREAS

The maturity of the mission concept for the satellite platform is higher than for the SAR payload. At platform level, no critical elements have been identified for the Biomass development. At payload level, some development risks are associated with specific elements of the P-band SAR payload, specifically in the feed system, the power amplifier and the instrument calibration aspects. In all cases, dedicated activities are being conducted to mitigate these risks. At mission level, the operation of the US Space Objects Tracking Radar (SOTR) systems restricts the imaging opportunities for Biomass because of the potential interference on the SOTR operation by the Biomass transmit signal. Figure 11 shows, in red and yellow, the observed areas, while the green line shows the boundary contour of the SOTR Line Of Sight (LOS) region, inside which, no Biomass operations would be allowed.

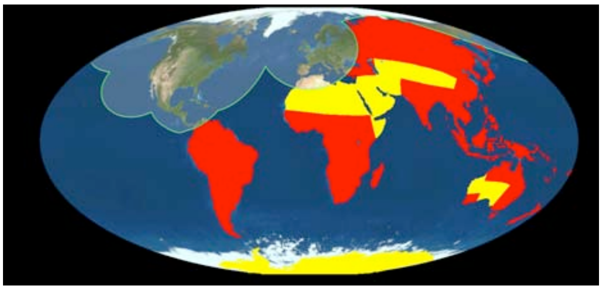


Figure 11. Biomass acquisition plan limited by the US Space Objects Tracking Radar (Red = Primary objective coverage mask, Yellow = Secondary objective coverage mask).

In terms of impact on the mission objectives, the complete loss of the SOTR LOS region will have limited effect on the primary objectives, since the only part of the critical tropical belt not covered would lie in Central America (e.g. Costa Rica). Hence, estimates of tropical land-use fluxes from deforestation and regrowth would only be slightly affected and biomass data for treaty purposes would be available for almost all developing countries.

8. CONCLUSIONS

This paper described the Biomass mission technical concepts, 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. Two implementation concepts have been studied, which are capable of meeting the scientific mission requirements. Further details, not presented here, are summarized in the Biomass Report for mission selection [1] and the Addendum [2], where a complete review of the mission can be found.

Biomass has now been selected for implementation and two parallel phases B1 to be started by the end of 2013 will allow to further consolidate and define the industrial concepts.

REFERENCES

1. European Space Agency (2012). *Report for Mission Selection*, ESA SP-1324(1), Mission Science Division, ESA-ESTEC, Noordwijk, The Netherlands, ISBN 978-92-9221-422-7, available at http://www.congrexprojects.com/13m09/selection-reports

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