BiomeSat: A Multi-Mission 6U Nanosat for Estimating Forests Health in Brazil

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Forest conservation is very important in Brazil as they are home to a great variety of plant and animal species and they maintain high amount of water and carbon stocks and flows between the land surface and the atmosphere. Forests have a substantial impact on climate, biodiversity and the availability of natural resources. Due to the large Brazilian territorial extension, remote sensing is essential for monitoring the health those forests. This work presents the BiomeSat, a 6U nanosatellite proposal for providing information on forest conditions in Brazil, with a level of spatial and temporal detail useful for monitoring. The scientific and technological mission goals as well as high-level mission restrictions and requirements. The initial conception is planned to carry a set of payloads, namely: (1) a remote sensing camera for forest health monitoring which is the primary mission, (2) a data-environmental collecting transponder (EDC) which was developed by INPE´s Northeast site, (3) an AIS transponder for monitoring vessels in the Brazilian maritime authorities and, (4) a space-weather monitor (SEM) or tracking space environment mainly TID (Total Ionizing Dose) and SEE (Single Event Effects). The nanosatellite bus is envisaged to be a multi-mission platform for other future missions and serve as a complement to INPE´s larger remote sensing satellites like Amazonia and CBERs series. BiomeSat will also be a first prototype for a prospective constellation planned to be increase time revisiting and reach near real-time monitoring as well as enabling sensor fusion to existing larger remote sensing systems. Furthermore, this mission addresses 6/17 of the United Nations (UN) sustainable development goals (SDGs): 3 - Good Health and Well-being, 6 - Clean Water and Sanitation, 9 - Industry, Innovation and Infrastructure, 11 - Sustainable Cities and Communities, 13 - Climate Action and 15: Life on Land.

1. Introduction

Forest conservation in Brazil is important for several reasons. Forests are home to a high number of plant and animal species, and high values of water and carbon stocks and flows between the land surface and the atmosphere, thus having a substantial impact on climate, biodiversity and the availability of natural resources [1]. Due to the large territorial extension, remote sensing is essential for monitoring forests in Brazil.

Thus, to contribute to the forest observation programs in the country and agricultural monitoring, it is intended to generate information on the conditions of these areas using the collected data. Specifically, it is intended to collect data on the state of forests and agricultural crops using vegetation indices, which can aggregate the effect of various disturbances such as droughts, deforestation and fire, and present less complexity for data acquisition and calculation. The 6-U cubesat platform shown in Figure 1 will be planed be implemented around BiomeSat.

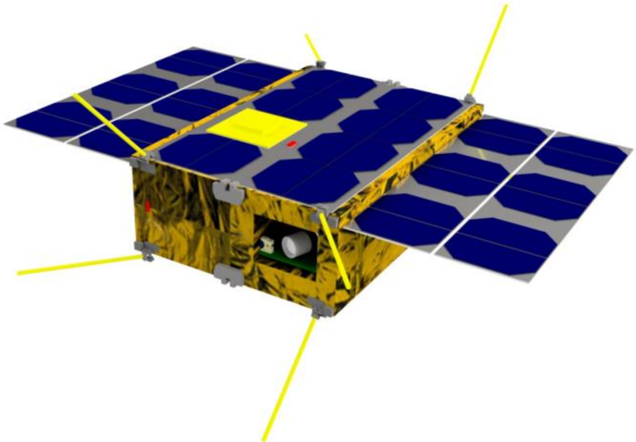


Figure 1: BiomeSat artistic view for forest health monitoring.

The BiomeSat main mission intends to continue monitoring environmental changes, deforestation and forest degradation but the imagery acquired will support applications in areas of vegetation, environment and education. Secondary mission's objectives will be performed by 3 other payloads: an environmental data collector transponder (EDC), an automatic identification system transponder (AIS) and a space-environmental monitor (SEM).

This paper is organized as follows: section 1 talks about the BiomeSat motivation; section 2 presents technological and scientific mission objectives; section 3 deals with technical planning of experiments and instruments; Section 4 refers to high level concerns for the project planning and management. Section 5 mentions about project and mission restrictions and initial requirements, finally Section 6 concludes this work.

2. BiomeSat Motivation

BiomeSat will contribute complementary to the existing bigger observation satellites available to INPE. The integration of several sensors allows reducing the influence of cloud cover in the interpretation process, as well as increasing the revisit rate to a few days. These features are extremely useful to forestry and agricultural applications.

2.1 INPE´s Legacy Missions

Brazil has technological and scientific experience in the construction and use of satellite data in the visible and infrared bands in these application areas. Annual rates of deforestation are produced based on data of 20-30 m of spatial resolution that are used as an indicator for the proposition of public policies.

INPE supports mainly the Brazilian Environmental Data Collection System (SBCDA). Currently, the SBCDA is a Brazilian satellite-based environmental monitoring system developed and operated by the Brazilian Institute for Space Research (INPE). Currently, SBCDA consists of 5 Low Earth Orbit (LEO) satellites (SCD-1, SCD-2, CBERS-4, CBERS-4A and Amazonia-1). Figure 2 shows a snapshot of INPE legacy missions covering earth observation as well as data collection missions among others satellite initiatives outside INPE.

Figure 2: INPE legacy missions on earth observation and data collection.

Data with spatial resolution of around 50-60 meters have been used in alerts for evidence of changes in forest cover in the national territory, as support for the inspection and control of deforestation and forest degradation by official institutional bodies.

2.2 BiomeSat Environmental Appeal

Climate changes are presently hitting hard the planet and BiomeSat pretty much will a key role into efforts to counterbalance the direct causes of these dreadful changes to Earth [2].

The 27th Conference of the Parties to the United Nations Framework Convention on Climate Change – COP27 [3], see Figure 3, is a follow-up to discussions on COP26 to act on a myriad of topics critical to dealing with climate emergency. Actions range from urgently reducing GHG (greenhouse gas emissions), structuring resilience, and adapting to the inevitable effects of climate change, to providing on the commitments to fund climate action in developing countries.

Figure 3: COP27 [4]: Climate chaos warnings amist the Amazon biome sanctuary.

Under the grounds of the Paris Agreement, COP27 is boosting renewed solidarity between countries in the middle of an increasing energy crisis, record GHG concentrations, as shown in Figure 4, and growing extreme weather events.

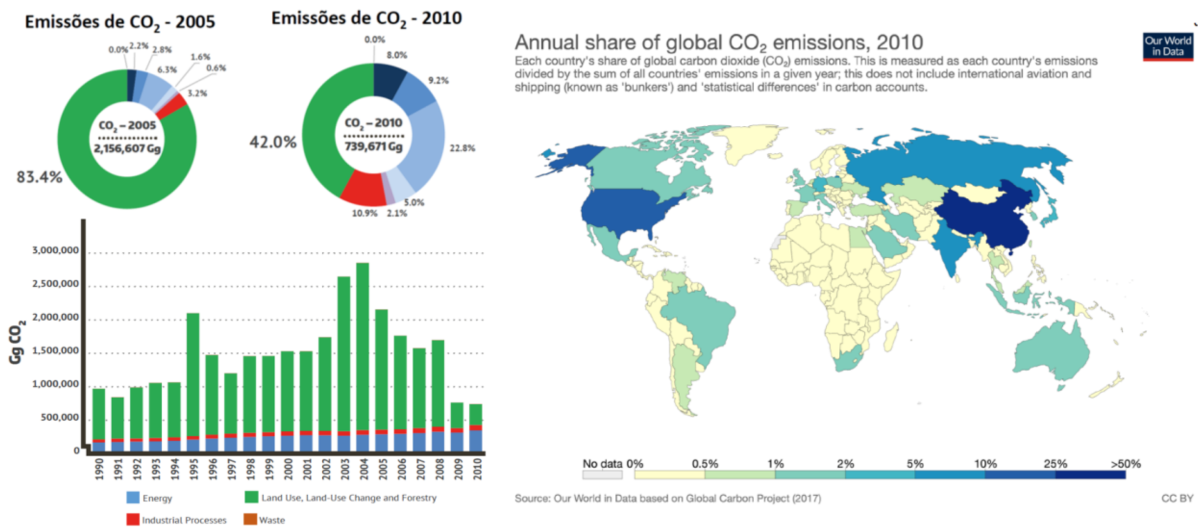


Figure 4: Dashboard of CO2 emissions [5]

In this context lies the main motivation for the BiomeSat project as the biome of Brazilian forests and, especially the sanctuary of the Amazon Forest, with its intricate advanced, and highly complex biological networks after millions of years of evolution. Forest conservation is very relevant to Brazil and world due to many facts some of them highlighted here: (1) Many plant and animal species live on them; (2) There is a high availability of natural resources and (3) Large stocks and surface-atmosphere flows of H_2O and C in a complex cycle that regulates life processes in the planet. Figure 5 devises the main links of this project to the UN sustainable goals.

Figure 5: BiomeSat main links to UN SDGs [6]

Therefore, Brazil has commitments to reduce GHG emissions and for that it will have to reduce deforestation and recovery of degraded areas as well as use of remote sensing technologies due to its large territorial extension which will drive BiomeSat mission definition next.

3. Mission Objectives

Based on the needs for the BiomeSat stated, we have split the mission goals into technological and scientific which are detailed hereafter. The choice of a 6U platform is a project decision since it will be realized a P-10 platform nanosatellite.

3.1 Scientific Mission Objectives

Using a 6U platform as a 1st constrain, the scientific is to continue the monitoring of environmental changes, deforestation and forest degradation, as well as support applications in the area of agriculture in order to obtain several benefits in different areas:

- Vegetation: monitoring of deforestation, degradation, and state of vigor of forests.
- Agriculture: estimate of planted area, vegetative vigor of crops, forecast of agricultural production, determination of areas of preservation of springs, forest reserves and agricultural areas, pointing out errors in fertilization, irrigation and soil preparation processes, regions with greater potential of production.
- Environment: assessment of the impact of fire, deforestation and drought on a given area, allowing a good rate of monitoring of environmental degradation, delimitation of continental water bodies, support for coastal management.
- Education: generation of material to support educational activities in geography, environmental sciences and other disciplines and generation of data and information for the development of scientific studies.

3.2 Technological Mission Objectives

The technological objectives are:

- Provide a 6U nanosatellite as a multi-mission platform for future other missions.

- Deliver payloads of interest to INPE´s Engineering:
  - EDC – Environmental data collection transponder developed by INPE-Natal with a high availability of natural resources;
  - Prospect a suitable thruster from the INPE´s Propulsion and Combustion group;
  - SMAE - Space Environment Monitoring System similar to one in CBERS satellites.
- Use nanosats as complements to large remote sensing satellites (AMZ/CBERs series) with lower manufacturing and launch costs.

4. Project Planning and Management

The concept of operations (CONOPs) diagram is shown in Figure 6 describes the target BiomeSat concept of operations where 4 payloads, namely: (1) a remote sensing camera for forest health monitoring which is the primary mission, (2) a data-environmental collecting transponder (EDC) which was developed by INPE´s North-east site, (3) an AIS transponder for monitoring vessels in the Brazilian maritime authorities and, (4) a space-weather monitor (SEM) or tracking space environment mainly TID (Total Ionizing Dose) and SEE (Single Event Effects).

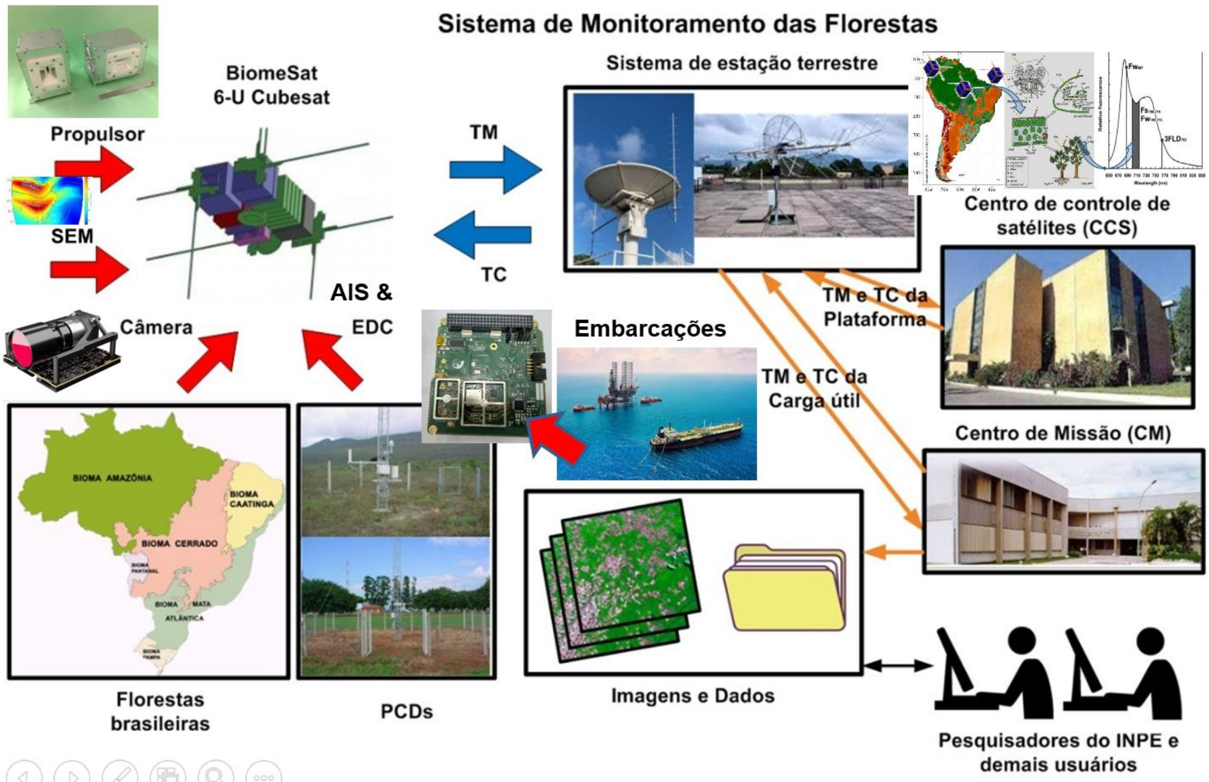


Figure 6: BiomeSat CONOPs – Concept of operations.

In order to commence the system technical planning, a desirable product is the map with estimates of photosynthesis activity [7] [8] where the target bands of interest for this phenomenon are defined helping the choice process for a suitable optical camera. Another point is estimating the orbital characterization in this case for a prospective 3U initially as shown in Figure 7.

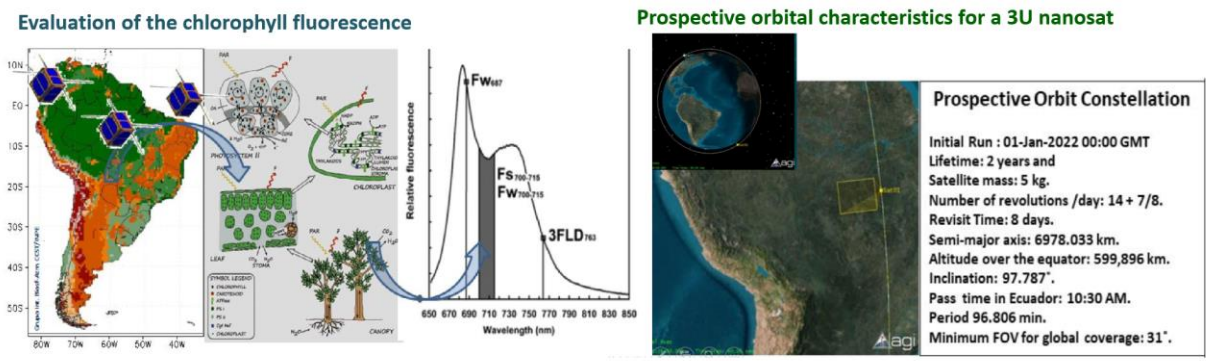


Figure 7: Photosynthesis activity estimates and early orbital characteristics 3U [7] [8] [9].

A preliminary constellation planning, see Figure 8 was performed and a sole BiomeSat can cover the Brazilian territory in 8 days in the orbit earlier mentioned, whereas 2 nanosats may drop this to 4 days.

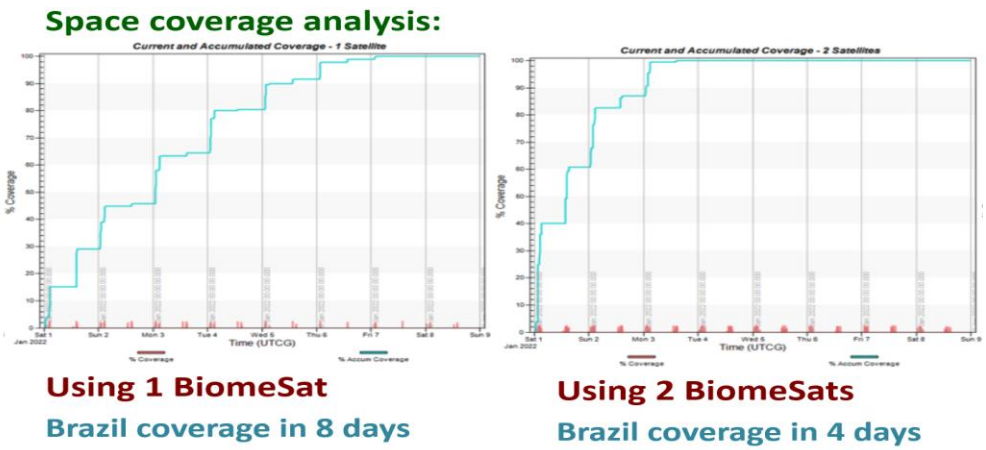


Figure 8: Preliminary land coverage for 1 and 2 BiomeSats constellation [10].

Currently, the following actions are being taken:

- Management plans still being performed
- Prospective selection of COTs equipment as pragmatic as possible
- Applications made for project financial support
- Identification of technological maturity level for equipment selection mainly for remote sensing imagers in the cubesats standard.

5. Initial Restrictions and Requirements

An early and initial mission analysis has come to the definition of some high-level requirements which were classified into operational, functional and programmatic categories:

- **Operational Requirements**: (1) Imaging only over the Brazilian territory and in sunlight; (2) Real-time image data transmission; (3) Data collection will be from

Brazilian PWDs only; (4) Continuous operation of the payload data collection and; (5) The nanosatellite must be discarded in EOL.

- **Functional Requirements**: (1) Pointing accuracy better than 1 degree; (2) Heliosynchronous orbit; (3) Revisit less than five days; (4) X-band or S-band data downgrade and; (5) The shelf life should be 24 months.
- **Programmatic Requirements**: (1) Development time between 01 to 02 years; (2) Structure will be acquired from companies specializing in CubeSats; (3) All subsystems will be acquired from specialized companies; (4) All embedded S/S software will be developed at INPE; (5) Use scalable platform for easy reuse in other 1U to 12U missions and; (6) It should be based on COTS components whenever possible.

Some restrictions were also defined such as: (1) The nanosatellite platform will be based on an architecture based on the CubeSat 6U standard and (2) The earth observation camera shall be COTS. As a result, Figure 9 shows the preliminary mechanical configuration drafted so far.

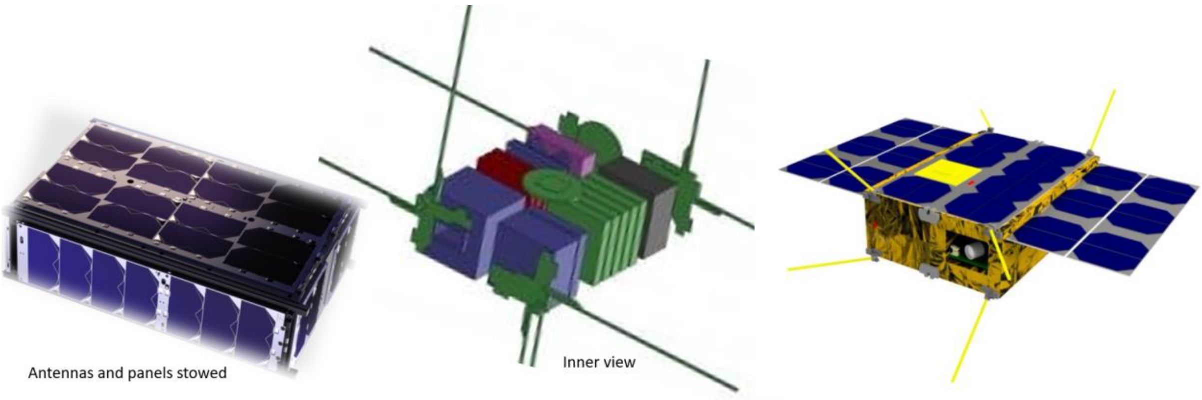
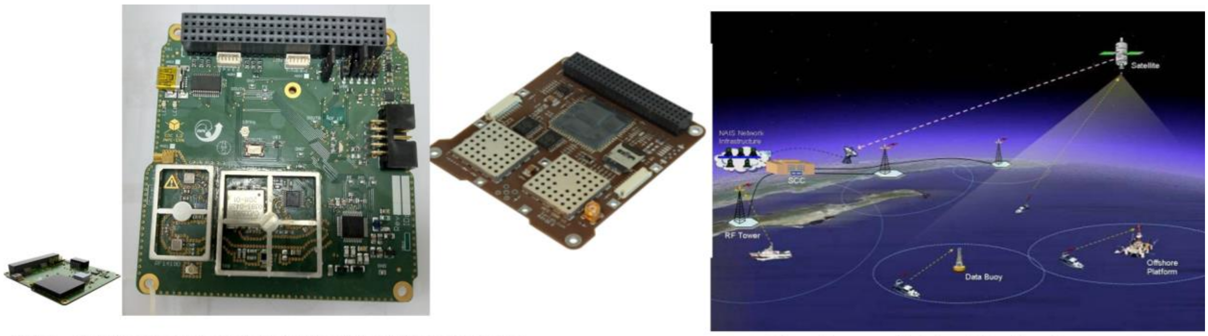


Figure 9: Preliminary mechanical configuration.

The initial conception is planned to carry a set of payloads, namely: (1) a remote sensing camera for forest health monitoring which is the primary mission, (2) a data-environmental collecting transponder (EDC) which was developed by INPE ´s North-east site, (3) an AIS transponder for monitoring vessels in the Brazilian maritime authorities and, (4) a space-weather monitor (SEM) or tracking space environment mainly TID (Total Ionizing Dose) and SEE (Single Event Effects).

The two transponders envisaged for BiomeSat are shown in Figure 10, one for environmental data collection and the other for AIS application which in our case is majorly for oil spillage tracking and vessel identification.



EDC - Environmental Data Collection Transponder

AIS – Automatic Identification System

Figure 10: EDC and AIS transponder candidates as payloads.

The automatic identification system, or AIS plays many roles: (1) Transmits a ship's position so that other ships are aware of its position; (2) Large ships, including many commercial fishing vessels, to broadcast their position with AIS in order to avoid collisions and; (3) Oil-spillage surveillance and monitoring. This last one is the major motivation for using it at this nanosatellite.

The proposal for mapping forest conditions and agricultural monitoring considers the use of vegetation indices based on images collected in bands of electromagnetic waves corresponding to the visible and infrared spectrum, Figure 11 shows some preliminary requirements and a possible candidate optical camera. Some examples of these indices that use data in the red (R), green (G), blue (B) and near-infrared (NIR) ranges include, among others, the Visual Normalized Difference Vegetation Index (Visual NDVI), the Green Leaf Index (GLI), the Visual Atmospheric Resistance Index (VARI), as well as the Normalized Difference Vegetation Index (NDVI) and similar ones. These indices are related to chlorophyll content, differences between plants, exposed soil and non-vegetable material and are therefore appropriate for estimating vegetation conditions and agricultural crops.

BiomeSat - **Preliminary** sensor requirements

Spatial resolution	260 m/px
Camera sensibility	380-750 nm
Temporal resolution	not specified
FOV	44° x 44°
Orbit classification	LEO
Orbit mean altitude	600 km
Mission Duration	24 months maximum
Orbit inclination	97.98°
Orbit eccentricity	≈ 0

SCS Gecko Imager

- Modular design
- Compatible with CubeSats
- High-speed high-capacity mass data storage
- FPGA processor for real-time image processing
- High frame rate capability (for larger optics)

Characteristics	
Form factor	< 1U
Focal length	70 mm
Image Sensor	2.2 Megapixel RGB
Mass	< 480 g
Storage	128 GB
Rad. tolerance	Tested to 30 krad TID
Space heritage	2017 !

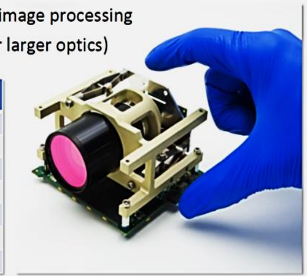


Figure 11: Preliminary Optical requirements and a candidate camera.

Next steps in this research will be published after a report from a concurrent engineering session is concluded and is programmed to send out quite soon.

5. Conclusions

This paper presented a high-level view to the BiomeSat nanosatellite which is a 6-U cubesat that carries primary an optical camera as the main payload for monitoring forest conditions in Brazil and enabling a myriad of other remote sensing applications. As secondary payload we have three other payloads: (1) an EDC – Environmental data collection transponder developed by INPE-Natal with a high availability of natural resources. (2) An AIS transponder for vessel monitoring meanly those involved in oil-spillage events. and (3) SMAE - Space Environment Monitoring System similar to one in CBERS satellites. Prospection for an electrical Thruster from the INPE´s Propulsion and Combustion group is being investigated.

The project pursues an almost complete earth observation mission (without launch), involving not only the entire mission conceptualization, sensor and platform part, but also the commissioning, camera calibration & validation, control and reception, processing and dissemination of data.

BiomeSat may enable Brazil to support future satellite constellations with direct applications to environmental monitoring and territorial management, including continent and ocean. So far, platforms and sensors aim at high resolution constellation (10m) with daily revisits. Finally, this nanosat implementation will demand several engineering, computing and science challenges from INPE.

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