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Planning for a spaceborne Earth Observation mission: From user expectations to measurement requirements

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ABSTRACT

This paper outlines the preparatory scientific activities that should precede and accompany the design and development of a spaceborne instrument for Earth Observation (EO), to guarantee fitness for purpose, ensure quality and performance, and minimize risks. This roadmap is addressed to policy and decision makers, program managers, customers and users of remote sensing products, as well as scientists involved in this field, and aims to provide the necessary background and motivation for the many steps and processes that are necessary to conduct a successful spaceborne EO mission. The paper focuses on, and is limited to, the description of a comprehensive, ideal methodology; it does not address the needs of a particular mission, or the engineering processes of design and development of the satellite hardware that will meet the user expectations. It should prove useful for the competent authorities to understand the scope and purpose (as well as the reasons for the associated implied costs) of preparatory phases, for the users and customers to express their expectations in ways that are conducive to the definition of a spaceborne EO mission, and for the scientific community to logically derive measurement requirements that are actionable by engineers to design and implement a successful mission (including both space and ground segments) that delivers relevant remote sensing products to the users.

1. Introduction

Thousands of satellites have been placed into orbit around the Earth since the launch of Sputnik-1 in October 1957. They range in mass from about 1 kg (for a CubeSat) to around 450,000 kg (for the International Space Station), and address a wide variety of operational purposes such as facilitating global telecommunications, enabling positioning and navigation support, monitoring the weather or guiding rescue operations. Most of these satellites deliver commercial services or document the state and evolution of our planet, but quite a few are designed to explore the Solar system or the universe. An increasing number of satellites originate as university student projects (training and capacity building) or explore promising new ideas (technology demonstration).

Earth Observation (EO) from space has proven a very powerful monitoring technique to support a wide range of practical applications, from the management of agriculture to international security and from climate change to water or air quality. Nowadays, information derived from spaceborne remote sensing platforms has become an essential ingredient of evidence-based policy making. Yet, delivering these products and services is far from trivial, because spaceborne satellite instruments can only measure spatio-temporal changes in gravity or in electromagnetic fields, from which other geophysical parameters and pertinent products must be inferred. The interpretation of these raw measurements in terms of information useful to users and stakeholders requires a wide range of skills and procedures that must be explored, evaluated and operationalized.

A space mission typically evolves in successive life cycle 'phases' (or 'stages', according to the standard ISO 15288) of conception, development, production and testing, utilization and support, and retirement, as part of an iterative and recursive process, until the satellite is delivered and launched into orbit, and the data are exploited in the ground segment. The terminology and precise content of these phases may vary somewhat across space

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agencies, but the general intent is the same and the methodology follows well-established principles of Project Management and Systems Engineering, as documented in NASA (2007) and ECSS (2009). Phase A consists of a preliminary detailed analysis of the goals and generates an initial design, a proof of concept. In Phase B, a baseline technical solution is proposed to meet specific requirements, schedules and specifications. These outcomes are formally evaluated to assess the validity of the requirements and the feasibility of the proposed design. Phases C and D concern the actual manufacturing, assembly and testing of the space hardware, typically including full or partial models to test all the systems and subsystems under environmental conditions relevant to prolonged operation in space. Subsequent phases involve the launch itself, the commissioning of the satellite, and the operational period, to be followed by the de-commissioning and eventual de-orbiting of the satellite at the end of its useful lifetime.

While these engineering steps are formally codified, the processes and procedures required to convert user expectations into measurement requirements and instrument specifications that can be acted upon by engineers are rather less structured: they are part of Pre-Phase A (NASA) or Phase 0 (ESA). The primary purpose of the activities conducted during that period is to define the main objectives and key measurements that will be required to meet the user expectations, and to assemble evidence that the proposed concept will actually deliver the desired outcomes. In this regard, mistakenly assuming that user needs are sufficiently known or that the necessary technology is well understood, are arguably the greatest risks to the mission. This paper outlines the steps and procedures that should be implemented either before starting with the design of a technical solution, or in parallel with Phases A and B described above, to ensure fitness for purpose, document the benefits of the mission, optimize the proposed solution in close collaboration with the engineers designing the payload instruments, mitigate the risk of cost over-runs, enable the timely delivery of a functional system, and deliver the expected products.

The stakeholders and users of an EO mission have expectations and constraints. Expectations express the needs with respect to functionality and performance, in the form of outcomes, products and services, while constraints refer to initial or boundary conditions that limit choices and options. The overall purpose of the initial phase of a satellite program is to translate these expectations and constraints into specific measurement requirements which must be verifiable, clear and concise, complete, consistent, traceable, implementation-independent, achievable and affordable, as well as necessary, while remaining consistent with established standards and best practices, budgetary limits, as well as national or international legal obligations.

Engaging in a space-based Earth Observation program therefore involves at least four major classes of stakeholders: (1) the users and customers of the system, including the sponsors, (2) the scientific community, (3) the public or private institutions or contractors capable of delivering the desired space and ground segments, and (4) the institution responsible for processing the downlinked data and turning the raw bits into geophysical products and useful, valuable information. All parties should be actively involved in the process of translating stakeholders' expectations and constraints into engineering requirements and system specifications. The ultimate success of the mission largely hinges on a close working collaboration between these partners from the outset.

In this context, the scientific community plays multiple roles, including translating the expectations of the users and customers into measurement requirements that are actionable by the engineers, developing the algorithms and methods to be implemented in the operational ground segment for the systematic generation of products and services, and supporting these users and customers in taking full advantage of those deliverables in their practical applications.

This paper summarizes some of the experience gained by the authors in this area through active participation in specific Earth Observation programs. It may help structure scientific activities around a coordinated preparatory program, with the goal of determining the optimal specifications for the satellite payload while minimizing the risks of failure. It should also inform and guide the policy makers and administrators who are or will be entrusted with the management of these programs, as well as the authorities controlling the budgets, as they need to understand the necessity of, and costs associated with, these preparatory activities.

The purpose of this paper is also critically restricted to the description of an ideal rather than a specific case. Financial affordability and industrial readiness will be discussed, though the impact of these constraints will vary greatly from country to country. The aim is therefore to provide a roadmap, a reference point, a benchmark against which to evaluate the performance, lacks and gaps of an actual program, recognizing that the development of an EO mission may suffer from perturbing factors such as technological setbacks, accidents, funding uncertainties, or even uncontrollable events such as changes in the cost of components or subsystems due to inflation or currency exchange rate fluctuations. Specifically, skipping steps or cutting corners will inevitably lead to compromises that may or may not have significant impacts on the feasibility, performance and cost of a real satellite mission. Since implementing corrective actions is usually much more expensive than following a rational, planned process, it is useful to understand how developing a satellite program should proceed under ideal conditions, and to decide where and when to take a short-cut in full knowledge of the possible consequences.

2. Background

2.1. Types of EO missions

The motivation for embarking on a new EO mission can arise primarily from the community (bottom-up) or from key national stakeholders (top-down). In the first case, a principal investigator (PI) will typically champion the mission, either from a university department, or from industry, or even from within a space agency. These missions can be officially stimulated by issuing calls for proposals that provide concrete opportunities for such projects to emerge. Budgets may be made available with the expectation that new ideas or better technologies will be demonstrated, and hopefully developed later for a more systematic application.

In the second case, a large institution such as a national or international space agency establishes broad long-term plans to deliver products and services deemed essential to promote the socio-economic development of the country (or group of countries) or to systematically monitor climate and environmental processes of broad societal significance, for instance. These missions typically arise out of government-supported national space programs and implement more mature technologies. They involve large, expensive payloads, and are expected to be cost-effective and operationally reliable over periods of multiple years. In fact, a series of multiple satellites with similar (or improving) characteristics can be scheduled from the start to ensure service continuation over long periods of time.

This distinction is so profound that different space agencies or other institutions are sometimes identified to perform these functions: in the USA, NASA is typically in charge of developing state of the art technologies and promoting cutting edge science