

Policy for Robust Space-based Earth Science, Technology and Applications

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Abstract

Over the past six decades, satellite remote sensing technology has contributed to the transformation of using earth science not only to advance science, but to improve quality of life. With satellite missions launched almost every year, new types of earth science data are being incorporated into science, models and decision-making systems in a broad array of organizations. A challenge for space agencies has been ensuring that satellite missions serve both the scientific community and the applied community of decision makers without the missions becoming unfocused and overly expensive. By understanding and considering the needs of the environmental data and applied research user community early on in the mission-design process, agencies can ensure that satellites meet the needs of multiple constituencies. This paper describes the mission development process in the European Space Agency and the National Aeronautics and Space Administration and compares and contrasts the successes of and challenges faced by these agencies in balancing science and applications within their missions.

1.0 Introduction

We examine actions by the US National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA) to increase the integration of users of satellite remote sensing observations into the earliest stages of developing these missions. ESA has begun the Global Monitoring for Environment and Security (GMES) program, whose focus is to convert observations into environmental services. The GMES project grew out of the European Space Agency and focuses on developing satellite missions to provide a broad program of imaging. With the publication of the 2007 US National Research Council's Earth Science Decadal Survey, NASA has begun working to change its mission development process to incorporate the needs of satellite data users into mission development [1, 2]. We first describe the mission development process in both space agencies and then compare and contrast the successes and challenges faced by these agencies in balancing science and applications within their missions.

1.1 Background

With the increase in information derived from satellites over the past six decades, the incorporation of Earth science data products into the mainstream environmental, meteorological and other user communities has evolved to include quantitative understanding of processes and interactions among the land, ocean, and atmosphere and real-time monitoring of weather, agriculture, water supplies, snow pack, and other environmental parameters [3-7]. These data products are the result of a series of activities that begin with the design of the remote sensing satellite mission and end with operational production of measurements that are ingested into algorithms and models to

produce the products. In this series of activities, the early stage includes research activities that “develop scientific understanding of important processes and/or demonstrate the capabilities of new analysis, modeling techniques, or measurement techniques, typically through acquiring, calibrating, and characterizing a specific set of measurements” [8]. In the later stages, operational activities “routinely and reliably generate specific services and products that meet predefined accuracy, timeliness, and scope/format requirements, as well as disseminating or making them available to a variety of users in the public, private, and academic sectors” [8].

Diverse communities have made effort to move from an ad hoc approach of integrating scientific data into operational processes to a more systematic and flexible process that is funded by adequate resources. The ‘Valley of Death’ between research and operations, discussed in a 2003 National Academy of Sciences report, can be bridged with improved supporting infrastructure that links research to operations to the user community of satellite data [9]. In Europe, the Global Monitoring for Environment and Security (GMES) strategy addresses this gap by focusing on the implementation of a common European space policy, and a need to build environmental monitoring and research capability that will serve all nations in the European Union [10]. The implementation of the GMES strategy is focused on the delivery of information and services to user needs, ongoing assessment of how needs are being met, and developing an infrastructure required to provide these services [10]. Gilruth et al (2006), in the case of the US congressionally mandated, NASA-funded Earth Observing System (EOS) Data and Information System (EOSDIS) project and Brachet (2004), in the case of GMES,

both discuss how metrics and deliverables were at the center of the relationship between users and producers, similar to those seen in EOSDIS [10, 11].

Thus the increase in the use of satellite data beyond the research community and the ever increasing ‘pull’ or need for earth observations from user communities should affect how missions are designed and implemented [12]. Precipitation, vegetation, sea ice, atmospheric variations, land use and land cover, forest dynamics and many other remote sensing derived environmental variables are regularly used by a in the public, private and educational sectors [13-16]. As the need for these data expands, the tension between research and operational sensor design and product delivery becomes more acute, requiring national space policy to ensure continual improvement of earth observations while sustaining measurements in key areas to ensure support of decision makers.

2.0 European Space Agency and Earth Applications

With ten founding nations as members and a complex funding structure, ESA’s Earth science program has always been focused on linking science to societal benefit through its European partners . Earth observation makes up 20% of ESA’s total budget. In 2004, the relationship between ESA and the European Commission (EC) on space policy was formalized in the EC-ESA Framework Agreement. The space policy of the European Union (EU) focuses on the crucial role of space for the economy and society.

The unified European Space Policy led directly to the establishment of the Global

Monitoring for Environment and Security (GMES) program. The GMES was created as an initiative for the implementation of information services dealing with environment and security. The program uses observation data received from Earth observation satellites and ground-based information, provided by ESA. These data are specifically coordinated, analyzed and prepared for end-users. The focus of the GMES is to provide a set of services to European citizens to help improve their quality of life regarding environment and security. GMES plays a strategic role in supporting major EU policies by its services. The Space Component of the GMES is managed by ESA and is currently in its pre-operational stage, serving users with satellite data currently available through the GMES Contributing Missions at national, European and international levels.

Through a unique combination of satellite, atmospheric and Earth-based monitoring systems and models to convert observations into information services, GMES will provide vital new insight into the state of the land, sea and air, providing policymakers, scientists, businesses and the public with accurate, up-to-date, global information in domains such as land, marine, atmosphere, emergency response, climate change and security. GMES overall is led by the European Union (EU). Main users of GMES will be policy-makers. GMES should allow them to prepare national, European and international legislation on environmental matters (including climate change) and to monitor the implementation of this legislation.

2.1 GMES and Satellite Missions

Easy and wide access to satellite data is a key ingredient for a mission's success. The Space Component of GMES is composed of missions called Sentinels, specifically

developed by ESA for the GMES and the needs of its member nations. An integrated ground segment ensures access to the data from the Sentinels and other contributing missions data. The ESA Sentinels are a series of 6 satellites that constitute the first series of operational satellites responding to the Earth Observation needs of the European Union [6]. The Sentinels will be launched starting in 2013 and will carry a range of technologies for land, ocean and atmospheric monitoring.

In addition to the dedicated Sentinel missions, GMES relies on Contributing Missions. These are designated, existing or planned missions from ESA and its Member States, Eumetsat and other European and international third-party operators that make their data available for GMES. Access to these data is made available through coordinated data access and dissemination for GMES Services.

Unfortunately, GMES has experienced significant challenges in sustaining its funding into the operational phase of its development (post 2013, the planned date of the first satellite launch). The European Union and ESA member states have already invested 3.4 billion € in the development phase of GMES. The funding of the operational phase of GMES is not yet secured. It is part of the EU budget negotiations 2014-2020, which will continue until end 2013. The programme will enter the operational phase in 2014, when the first dedicated spacecraft, the Sentinel missions, will be in orbit. The main programmatic challenge is therefore to ensure the programme's long-term sustainability.

2.2 ESA and GMES policy on Missions

GMES Missions being implemented by ESA are prioritized based on those that can be used for societal benefit, which has resulted in the development of the Sentinel sensors.

The Sentinel missions were selected through a process of studies, workshops and input from the environmental community that focused on the need for specific environmental monitoring services. The key to providing operational GMES services is to have an appropriate governance and business model structure in place that supports provisioning of these environmental services. The prioritization of user needs over scientific and technological advancement makes the GMES program far more oriented towards providing services than NASA, which as we discuss in the next section, has a scientific mission. Thus the Sentinel missions, once launched, can be clearly assessed for their societal values since the data resulting will be tied directly to environmental products and services to be used by the community.

3.0 Earth Science at NASA

NASA's Mission is to '*Drive advances in science, technology, and exploration to enhance knowledge, education, innovation, economic vitality, and stewardship of Earth.*' Congress enacted the National Aeronautics and Space Act of 1958 to provide for research into problems of flight within and outside Earth's atmosphere and to ensure that the United States conducts activities in space devoted to peaceful purposes for the benefit of humankind. Amendments to this Space Act subsequently enabled NASA to conduct research for Earth science and also study the phenomena in atmosphere and space. The Space Act charges NASA with the "preservation of the role of the United States as a leader in aeronautical and space science and technology and in the application thereof," to pursue "close cooperation among all interested agencies of the United States," and to widely disseminate information of NASA results [17]. As the U.S. civil space agency,

NASA has the responsibility to communicate and apply its mission products to all interested US agencies. Thus, by fostering relationships with interested entities NASA can strengthen the development of Earth science applications.

The 2007 earth science decadal survey, organized by the US National Research Council (NRC) to identify priority needs of earth scientists, developed a broad set of recommendations for new instruments, observations and climate data records [18]. The report addressed the importance of applications and “recommended a suite of satellite missions and complementary activities that serve both scientific and applications objectives for the nation.” The report stated that identifying and supporting applications of scientific data to obtain societal benefits from NASA missions should play an equal role during the formation and implementation of new missions to that of science. The report presented a vision for developing new satellite data products that have specific user communities’ needs and requirements as a rationale for mission development. Meeting this objective will require a continual evolution in the way NASA and the Earth science community does business. They will need to re-evaluate how it prioritizes, makes decisions and communicates with the user community. In particular, NASA must engage with communities of satellite data users early in process of mission development, and sustain the engagement for the entire life of the mission.

The US National Space Policy of 2010 states that one of NASA’s goals is to “improve space-based Earth and solar observation capabilities needed to conduct science, forecast terrestrial and near-Earth space weather, monitor climate and global change, manage

natural resources, and support disaster response and recovery. “NASA has assigned the responsibility for defining, planning, and overseeing NASA’s space and Earth science programs to the Science Mission Directorate (SMD). SMD organizes its work into broad scientific pursuits: conducting scientific exploration of the Earth, Sun, solar system, and universe that is enabled by access to space. SMD develops instruments and spacecraft to support NASA’s science goals and sponsors fundamental research and analysis to advance scientific knowledge [19].

NASA’s Applied Science Program, located within SMD, works primarily through partnerships with organizations that have established connections to users and decision makers. The Program supports applied science research and applications projects to promote innovation in the use of NASA Earth science, transition of applied knowledge to public and private organizations, and integration of Earth science in organizations’ decision making and services, helping to improve the quality of life and strengthen the economy. The Applied Science Program leverages investments made in other areas and works within the broader scope of the SMD organization to achieve its goals, competing with science, engineering, financial and strategic interests within and outside of the organization.

3.1 Applications of NASA Earth Science

Despite the existence of a NASA strategy for encouraging earth science applications, it has become clear that greater attention is needed to demonstrate the practical benefits of Earth observations and their applications into society. The 2007 Decadal Survey

recognized that “although promoting societal benefits and applications from basic research has been emphasized in national science policy discussions for decades, policy and decision makers at federal, state, and local levels also increasingly recognize the value of evidence-based policy making, which draws on scientific findings and understandings” [1]. The decadal survey also recognized the need for “...a renewal of the national commitment to a program of Earth observations in which attention to securing practical benefits for humankind play an equal role with the quest to acquire new knowledge about the Earth system.”

The decadal survey was the latest document to seek out how to transform NASA’s way of using its technology. In 1988, the Earth System Science Committee of the NASA Advisory Council, led by Francis Bretherton, published its landmark report Earth System Science: A Closer View. The report spelled out the need for process-oriented models that could incorporate a wide variety of observations and data to expand our understanding of the earth system. By integrating information on atmosphere, oceans, ice, land, geosphere, and biosphere and the interactions over different temporal and spatial scales, satellite remote sensing has become a foundation of earth system science research [20]. This report followed experience with the Landsat series of remote sensing satellites. After the launch of the first Landsat satellite (then called Earth Resources Technology Satellites-1) in 1972, NASA began to hire earth scientists to work with satellite data. These scientists were initially focused on describing ways in which the new sensor could improve environmental monitoring and ecosystem modeling [12, 21-24]. Science that used

satellite remote sensing data in the 1980s showed the promise for transforming our knowledge of ecosystems and the services they provide us [25].

NASA's Earth Observing System (EOS) and its suite of diverse sensors were developed in the 1990s and now form the basis for an enormous amount of earth science research and improved understanding [12]. The recognition of the value of these observations and their benefit as derived from decision-making systems has increased enormously over the past decades. As data from the EOS instruments became incorporated into an ever-widening array of processes and models used to improve environmental management, hazard identification, agriculture monitoring and other applications, it became clear that NASA's mission should include extending science results for societal benefit.

The applicability of earth observations to society can cover a broad range of issues, as recognized by the intergovernmental Group on Earth Observations (GEO) and the U.S. Group on Earth Observations (USGEO). The societal benefit areas identified by GEO, including agriculture, biodiversity, climate, disasters, ecosystems, energy, health, water, and weather, will be served by current and future satellite systems. Part of the aim of GEO is to develop, through its Global Earth Observation System of Systems (GEOSS), a proper system of earth monitoring and to provide information from the technologies to a global range of users. NASA contributes to GEO through its broad program of earth observing missions, both past and future. These missions are driven by scientific and technological goals that fit into the broader science agenda through specific mission requirements.

3.2 NASA Policy on Mission Development

Although there are many forces driving NASA towards greater sensitivity towards the needs of its partners who use its satellite data, NASA policy is currently to focus on continual advances in both science and technology. This policy is critical as it structures how NASA obtains societal benefits from its work. All NASA missions are driven by their science requirements, which determine the sensor design, data resolution and temporal characteristics, accuracy and format. These science requirements can incorporate aspects of users' needs, but only to the point where they can be justified by the overall scientific goals.

The 2007 Decadal Survey generated consensus recommendations from the Earth and environmental science and the applications communities regarding a systems approach to space-based Earth Science observations. The survey was to replace NASA mission prioritization, as it contained guidance on which missions to fund, the set of observations that were needed, and the broader purpose each mission was to serve. NASA and the remote sensing community were urged to 'focus on meeting the demands of society explicitly, in addition to satisfying its curiosity about how the Earth system works' [1]. This will require an engagement with the community of data users who have their own requirements beyond those required by science.

4.0 Policy impact on Mission Process Evolution

The scale of GMES program is significantly beyond anything being proposed at NASA, but the European experience provides context to NASA's new initiative. GMES has designed its satellite missions with a focus on scientific, government and commercial communities interested in using the satellite data produced. For example, Sentinel 1 was designed to serve organizations and institutions that monitor Arctic sea-ice extent, map sea-ice, conduct surveillance of the marine environment, including oil-spill monitoring and detect ships for maritime security, monitor land-surface for motion risks, conduct mapping for forest, water and soil management and to support humanitarian aid and crisis situations.

In contrast, NASA's mission selection process focuses entirely on the scientific contribution of a mission, with societal benefits as a secondary consideration. Although NASA has instruments that provide societal benefit, new missions – to be selected for funding - require significantly new technology, observational capacity or scientific discoveries. These requirements may preclude the missions from continuing and then sustaining the data record already established by their mission predecessors. NASA's challenge in this effort is to fuse the scientific objective of future missions with the existing societal and political priorities (an example are priorities related to understanding and monitoring climate change).

At NASA, there is no single avenue by which a mission is initiated. An original concept for a mission to obtain scientific data may come from members of the science community who are interested in particular aspects of an Earth science problem, it may come from an

individual or group, such as a scientific team working on a particular issue, who knows of an opportunity to provide unique measurements, or may be requested by NASA Headquarters to fill an identified need. As a project matures, the effort typically goes through the mission phases listed in Table 1, starting with Pre-Phase A formulation through to Operations. Formal reviews are typically used as control gates at designated “critical points” of the system life cycle. These reviews determine whether the system development process should continue from one phase to the next, or what modifications may be required.

As of 2011, NASA also started to require an Applications Plan in addition to project plans, mission operations, education and public outreach and others. The Applications plan details how the mission will engage the broader user community before and after a satellite is launched. This strategy will encourage that the mission will have a well-defined contribution to society. Early in the mission development, there usually is a selection of the Science Definition Team (SDT) and initiation of SDT meetings to provide oversight of the development of these products leading up to the Senior Review and commencement of Phase A. The plan demonstrates how members of the science leadership plan to address applications activities during each phase of the mission (Table 1).

Currently, the potential uses of data products that come out of each missions are not at the center of the actual development process-they are a secondary objective. NASA missions are primarily science driven, with their objectives being focused on providing high quality scientific results. These objectives may marginalize user observations,

products and resolutions requirements. Figure 1 shows the broad scope and breadth of the NASA orbital mission program. The involvement of the community who may use the data products often happens either during the last year or two before the launch of the instrument or after launch. This is very different from GMES approach, where data users provided the data requirements for each satellite mission designed.

5.0 Assessing Socio-economic benefits

In 2010, the Earth Science Exploration Directorate at NASA requested a study on the value of information of satellite data in natural resource management [26]. The paper describes a general framework for conceptualizing the value of information and illustrates how the framework might be used to value information from earth science data. The NASA Applied Sciences division is motivated to provide quantitative assessment of the success of its programs that focus on providing NASA satellite remote sensing data to decision makers. At the present moment this is challenging to do since all NASA missions are defined by scientific requirements as opposed to user-community requirements. Unlike in GMES, NASA has not made the goal of providing satellite-derived information that has value for societal activities explicit, and therefore it is much more difficult to evaluate the results in a way that is comparable across missions.

GMES takes assessment much more seriously than NASA. It seeks to involve stakeholders at each stage of the mission process in order to determine requirements for its environmental services, which satellite missions will contribute. The services will need to provide environmental benefit to national environmental agencies, scientists and

industry. GMES projects are assessed by their usefulness, reliability, and affordability, with the goal of conducting a Cost Benefit Analysis (CBA) on GMES projects, following a harmonized approach to typify the service costs.

As NASA moves forward with its mission applications activity, it will work towards a common methodology, such as the cost benefit analysis being implemented by GMES, to evaluate the success of the use of its data in decision-making. By integrating stakeholder needs into missions earlier in the process, NASA can improve its ability to evaluate missions' impact on society. A clear, explicit policy will help the agency take explore the broad impact of its missions, evaluate the result and ensure continued broad support for their activities.

6.0 Conclusions

As the world grapples with global environmental change, the need to have access to comprehensive data that can document the dynamic of a changing environment over decades will grow. Understanding how these datasets will be used to reduce the impact of a transforming environment through policy, regulation and economic incentives, will become increasingly important for scientific agencies' efforts to produce useful data that is both well understood and readily available for user communities. NASA and ESA have both recognized the enormous value their earth science satellite data products could bring to the people who support their programs beyond improved scientific understanding. With stronger policy requiring incorporation of applications into satellite missions, NASA and ESA can improve the global datasets available for global

environmental monitoring. To do this, both agencies must balance scientific progress with the need for consistent environmental monitoring data that enable accurate and sustained measurement of change through time.

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Table 1. Descriptions of NASA mission phases and applications activities relevant to each phase.

Mission Phase	Description	Application Activity	Work Description
Pre-Phase A	Science Working Group (SWG) is established, which establishes level 1 requirements, science goals and prepares a preliminary scientific conception of the mission	Assessment of the <i>community of practice</i> Description of the intersection of mission requirements and the needs of known applications.	Present the user community to mission team and define the scientific and policy need relevant to Mission Science objectives Workshop Report, involving the science community, the policy community and the community of practice to create optimal Level 1 requirements, with descriptions of trade-offs and required latencies for applications and optimal societal benefit
A Preliminary Analysis	The project creates a preliminary design and proof of concept specifying instrument design, orbit, altitude, ground data systems and other details. The publication of the preliminary costing plan marks the completion of Phase A.	Website establishment and database of user community individual begins. Application Plan written and posted to website	Feedback workshop of mission design study. Identification of potential Early Adopters. Data requirements discussed. Mission relevant policies identified. Identification of “important society decisions that will be made with mission science products”
B Definition	The definition phase converts the preliminary plan into a technical solution. Requirements are defined, schedules determined, and teams established around hardware. Science Definition Teams are competed and teams are chosen for each instrument and algorithm; the Science Team Leader is chosen.	Workshop conducted with targeted science communities to communicate key model, observation and applied science opportunities and requirements. Newsletters, articles and other communication strategies to expand the <i>community of potential</i> . Applications Working Group established, member of SDT designated as leader.	Early Adopters Identified, Call for Proposals and collaboration with test data Thematic groups are created and Focus groups are planned
C/D Design/ Development	This phase involves building the hardware and software, testing and verification, and ends with the launch of the satellite.	Annual workshop focused on results from organizations who are early adopters; description and provisions of test and cal/val datasets to the community of practice; conference presentations and papers; newsletters and journal articles on user interaction to expand the community of potential. Interaction with NASA HQ Applied Science prepare funding opportunities.	Early Adopter applied research presented, Mini focus groups feedback loops and articles in thematic journals. Publication of test Data feedback and results. Large Policy workshop to discuss the decision making process of existing Early Adopter research
Operations Mission Ops and Data	This phase includes flying the spacecraft and obtaining the data, processing, and delivering	Documenting decision support provided by mission data; newsletter, journal articles,	Selection of Mission Thematic Leaders (Science and Policy) assigned to Science Team.

Analysis	data to the community	conference presentations of applications of data; community interaction and support of data reprocessing and improvement; calibration/validation of data quality, format, issues.	Work into Applications Phase II- Coordination with Mission Operations and Support. -Documenting decision support provided by mission data through newsletters, journal articles, conference presentations of applications of data; -Community interaction and support of data reprocessing and improvement -Participation of calibration/validation of data quality, format, issues; -Evaluating and reporting on verified uses of mission data
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