Space Policy 29 (2013) 238–250

Contents lists available at ScienceDirect

Space Policy

journal homepage: www.elsevier.com/locate/spacepol

Earth observation from space – The issue of environmental sustainability

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ARTICLE INFO

Article history:
Received 7 February 2013
Received in revised form
1 July 2013
Accepted 16 July 2013
Available online 27 August 2013

Keywords:
Space remote sensing
Earth observation systems
Space junk
Sustainability
Sustainable management
Lidar
Forest
Biomass
Life cycle assessment

ABSTRACT

Remote sensing scientists work under assumptions that should not be taken for granted and should, therefore, be challenged. These assumptions include the following:

1. Space, especially Low Earth Orbit (LEO), will always be available to governmental and commercial space entities that launch Earth remote sensing missions.
2. Space launches are benign with respect to environmental impacts.
3. Minimization of Type 1 error, which provides increased confidence in the experimental outcome, is the best way to assess the significance of environmental change.
4. Large-area remote sensing investigations, i.e. national, continental, global studies, are best done from space.
5. National space missions should trump international, cooperative space missions to ensure national control and distribution of the data products.

At best, all of these points are arguable, and in some cases, they're wrong. Development of observational space systems that are compatible with sustainability principles should be a primary concern when Earth remote sensing space systems are envisioned, designed, and launched. The discussion is based on the hypothesis that reducing the environmental impacts of the data acquisition step, which is at the very beginning of the information stream leading to decision and action, will enhance coherence in the information stream and strengthen the capacity of measurement processes to meet their stated functional goal, i.e. sustainable management of Earth resources. We suggest that unconventional points of view should be adopted and when appropriate, remedial measures considered that could help to reduce the environmental footprint of space remote sensing and of Earth observation and monitoring systems in general. This article discusses these five assumptions in the context of sustainable management of Earth's resources. Taking each assumption in turn, we find the following:

(1) Space debris may limit access to Low Earth Orbit over the next decades.

(2) Relatively speaking, given that they're rare event, space launches may be benign, but study is merited on upper stratospheric and exospheric layers given the chemical activity associated with rocket combustion by-products.

(3) Minimization of Type II error should be considered in situations where minimization of Type I error greatly hampers or precludes our ability to correct the environmental condition being studied.

(4) In certain situations, airborne collects may be less expensive and more environmentally benign, and comparative studies should be done to determine which path is wisest.

(5) International cooperation and data sharing will reduce instrument and launch costs and mission redundancy. Given fiscal concerns of most of the major space agencies – e.g. NASA, ESA, CNES – it seems prudent to combine resources.

1. Introduction

Until the middle of the 20th century, environmental sciences could still be based on leisurely methods of data collection which were compatible with the relatively slow speed of environmental

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http://dx.doi.org/10.1016/j.spacepol.2013.07.003

changes and with the scales of studies [1]. Presently, constantly improved and updated information is a given for resource monitoring and management as they can capture the dynamic nature of environmental conditions such as climate change, water allocation, as well as soil and biodiversity loss [2].

As early as in 1969, in the first editorial of the *Remote Sensing of Environment* journal, Simonett [1] stated that “the quickening of science, and resource use, and the demands of society have increased the urgency to obtain quantitative, timely information about the environment at a variety of scales in space and time”. He posited that observations made using ground-based sensors, aircraft, and space platforms could help to meet these information requirements [1]. Three years later, the launch of the Earth’s Resources Technology Satellite ERTS-1, later renamed Landsat-1, marked the beginning of the Landsat era, thereby providing significant impetus for the development of environmental applications based on remote sensing data at local to global scales [3]. Some of the most common applications in the remote sensing world, such as agriculture or water management, can be traced back to research performed on specific landscape features identified by Kondratyev et al. [4] on one of the first Landsat 1 images recorded in July 1972. Navalgund et al. [5] classified the current remote sensing applications into the following categories: sustainable agriculture, water security, environmental assessment and monitoring, disaster monitoring and mitigation, and infrastructure development. Other fields of research such as fisheries management, weather and climate studies have also benefited from the development of the remote sensing sector [5]. More recently, remote sensing data have more been instrumental in advancing the fields of ecology, biodiversity and conservation [6].

As environmental impacts of human activity make resource management more and more complex and as, at the same time, our understanding of complex natural processes increases, our need for critical information layers at appropriate spatial and temporal scales and extents increases too [2]. The growing number of theme-specific satellites, noted by Navalgund et al. [5], reflects a technological response that can help to overcome such limitations, thereby facilitating natural resource management.

The relevance of such spaceborne theme-specific missions can be taken as a given from the measurement point of view. However, the premise that spaceborne observation can best provide information for sustainable management of Earth resources should be subjected to more critical debate. Indeed the sustainability of Earth observation from space is not as evident as it might seem, a point that is seldom discussed.

The paper, which is partially based on a previous work [7] aims to take a fresh look at measurement processes designed to support the monitoring of Earth resources and to promote debate about the role of remote sensing from space within the context of sustainable management of these resources. Sustainability is defined as the capacity to endure, and sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [8]. In this paper, we look at Earth observation sustainability from two different directions. First, given the number of space launches to date, the amount of space debris currently in orbit, and the expected number of future launches, can we safely assume access to orbit for operational environmental missions in the future? Second, given a full accounting of the environmental costs associated with space launches, are satellites necessarily the best way to sustain the flow of measurements needed to monitor the status of Earth’s environment?

The common thread of this paper is the idea that to increase efficiency and durability of observation and measurement systems designed to support sustainable management of the Earth resources, those measurement and monitoring systems should, themselves, be as sustainable as possible. In short, this means that the environmental, social, and economic cost of a mission must be less than the corresponding returns. Referring to ecological engineering principles [9,10], environmental impacts from the system production stage to its end of life should be better understood and taken into account. This would enable the design of measurement systems capable of providing valuable information for managers while minimizing their inevitable environmental impacts. Forgetting to limit those impacts when designing an observation system is liable to lead to suboptimal or even inappropriate solutions.

Section 2 examines two issues that challenge the assumption that spaceborne Earth observation systems are sustainable. Section 2.1 calls into question the basic assumption that Earth-orbiting platforms will always be available to the civilian remote sensing community. Section 2.2 focuses on the environmental impacts of space activity on the Earth and reports on how these impacts affect sustainability. Section 3 presents some unconventional points of view that, in our opinion, are required to address the sustainability issue of space-based Earth observation systems. In this section we also suggest using environmental life cycle assessment as an analysis tool that might be particularly relevant to help reaching these goals. Section 4 details possible initiatives that follow naturally if these non-traditional points of view are deemed valid and that might be taken to mitigate impacts associated with space missions and improve sustainability of Earth observation systems. We addressed some issues that are common to all remote sensing missions. In addition a study case was chosen, i.e. vegetation lidar missions, to illustrate a few case-specific possible actions. Section 5 summarizes and concludes.

2. What can put the sustainability of Earth observation from space in jeopardy?

In what follows, sustainability is considered with respect to durability, space debris, and with respect to space activity as an Earth pollution source.

2.1. Uncertainties about the durability of Earth observation from space

2.1.1. Historical context, current state and outlook for space activity

The development of the space sector began in 1957 with the launch of Sputnik, the first artificial, Earth-orbiting satellite. The total number of launches since 1957 exceeded 5000 during year 2009 (see Fig. 1) and the mean annual number of launches over the ten last years has been slightly higher than 65 [11]. Even though the number of launches per year have trended downward since the end of the cold war in 1991 (Fig. 1), the total number of operational satellites has continually increased due to a rise in both the lifetime and mean number of satellites per launch.

The development of space activities has long been driven by the political and military aspirations of the USA and Russia, the two main players in this sector. One of the peace dividends from the end of the cold war was the rise in commercially viable applications – e.g. telecommunication and Earth observation – and the emergence of new space powers, which led to the whole-scale transformation of the space sector. This transformation affected space programs but also space activity architecture as a whole, affecting both military and civilian applications [12], paving the way for the emergence of new features which are specific to the current set of active satellites. There are currently close to 1000 active satellites in orbit, operated by 41 countries and several international consortiums [13]. Fig. 2a and b shows the distribution of satellites according to orbit classes and scientific/commercial disciplines,