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Sentinel-2: ESA's Optical High-Resolution Mission for GMES Operational Services

M. Drusch [a,*], U. Del Bello [a], S. Carlier [a], O. Colin [b], V. Fernandez [a], F. Gascon [b], B. Hoersch [b], C. Isola [a], P. Laberinti [a], P. Martimort [a], A. Meygret [c], F. Spoto [a], O. Sy [a], F. Marchese [d], P. Bargellini [d]

[a] ESTEC, Noordwijk, The Netherlands
[b] ESRIN, Frascati, Italy
[c] CNES, Toulouse, France
[d] ESOC, Darmstadt, Germany

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ABSTRACT

Global Monitoring for Environment and Security (GMES) is a joint initiative of the European Commission (EC) and the European Space Agency (ESA), designed to establish a European capacity for the provision and use of operational monitoring information for environment and security applications. ESA's role in GMES is to provide the definition and the development of the space- and ground-related system elements. GMES Sentinel-2 mission provides continuity to services relying on multi-spectral high-resolution optical observations over global terrestrial surfaces. The key mission objectives for Sentinel-2 are: (1) To provide systematic global acquisitions of high-resolution multi-spectral imagery with a high revisit frequency, (2) to provide enhanced continuity of multi-spectral imagery provided by the SPOT (Satellite Pour l'Observation de la Terre) series of satellites, and (3) to provide observations for the next generation of operational products such as land-cover maps, land change detection maps, and geophysical variables. Consequently, Sentinel-2 will directly contribute to the Land Monitoring, Emergency Response, and Security services. The corresponding user requirements have driven the design toward a dependable multi-spectral Earth-observation system featuring the Multi Spectral Instrument (MSI) with 13 spectral bands spanning from the visible and the near infrared to the short wave infrared. The spatial resolution varies from 10 m to 60 m depending on the spectral band with a 290 km field of view. This unique combination of high spatial resolution, wide field of view and spectral coverage will represent a major step forward compared to current multi-spectral missions. The mission foresees a series of satellites, each having a 7.25-year lifetime over a 15-year period starting with the launch of Sentinel-2A foreseen in 2013. During full operations two identical satellites will be maintained in the same orbit with a phase delay of 180° providing a revisit time of five days at the equator. This paper provides an overview of the GMES Sentinel-2 mission including a technical system concept overview, image quality, Level 1 data processing and operational applications.

1. Introduction

Global Monitoring for Environment and Security (GMES) is a European Union (EU) led initiative designed to establish a European capacity for the provision and use of operational monitoring information for environment and security applications. This capacity is seen to be composed of three modules, which together constitute the functional GMES 'system': (1) The production and dissemination of information in support of EU policies for Environment and Security; (2) the mechanisms needed to ensure a permanent dialog between all stakeholders and in particular between providers and users; and (3) the legal, financial, organizational and institutional framework to ensure the functioning of the system and its evolution.

Many elements of the modules already exist but have been conceived, designed and managed in isolation, thus limiting interoperability and production of relevant information. The coherence, efficiency and sustainability of a shared information system for Europe will be the added value of GMES. Developing compatibility between the existing elements, establishing cooperation between the organizations and filling the gaps where necessary will achieve this goal.

Within the GMES program, ESA is responsible for the development of the Space Component, a fully operational space-based capability to supply earth-observation data to sustain environmental information services in Europe, namely Geoland2, SAFER (Services and Applications For Emergency Response) and G-MOSAIC (GMES services for Management of Operations, Situation Awareness and Intelligence for regional Crises). These Services, implemented in parallel by the European Commission, will provide value-added data and services to the GMES end-users; the European Environmental Agency (EEA) and the Member States are responsible for the in-situ component.

* Corresponding author. Tel.: +31 71 565 8868.
E-mail address: matthias.drusch@esa.int (M. Drusch).

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The Sentinel missions (Donlon et al., 2012-this issue; Ingmann et al., 2012-this issue; Torres et al., 2012-this issue) are GMES dedicated Earth Observation missions composing the essential elements of the Space Component. In the global GMES framework, they are complemented by other satellites made available by third-parties or by ESA and coordinated in the synergistic system through the GMES Data-Access system (see http://gmesdata.esa.int) versus the Services.

The GMES Sentinel-2 mission provides continuity to services relying on multi-spectral high spatial resolution optical observations over global terrestrial surfaces (Martimort et al., 2007). Sentinel-2 will capitalize on the technology and the vast experience acquired in Europe and the United States to sustain the operational supply of data for services such as Risk Management (floods and forest fires, subsidence and landslides), European Land Use/Land Cover State and Changes, Forest Monitoring, Food Security/Early Warning Systems, Water Management and Soil Protection, Urban Mapping, Natural Hazards, and Terrestrial Mapping for Humanitarian Aid and Development. The design of the Sentinel-2 mission aims at an operational multi-spectral Earth-observation system that complements the Landsat and SPOT (Satellite Pour l'Observation de la Terre) observations and improves data availability for users.

The SPOT remote sensing program was initiated in 1978 by France in partnership with Belgium and Sweden. SPOT 1 was launched with Ariane 2 on February 22, 1986. SPOT 2 joined SPOT 1 in orbit on January 22, 1990 and SPOT 3 followed on September 26, 1993. The satellite payloads included two identical HRV (High Resolution Visible) imaging instruments that were able to operate in two modes, either simultaneously or individually. The two spectral modes are panchromatic and multispectral. The panchromatic band has a resolution of 10 m, and the three multispectral bands have resolutions of 20 m with scene sizes of 3600 km^2 and a revisit interval of one to four days, depending on the latitude. Since the deorbitation of SPOT 2 in 2009, after almost 20 years of service, satellites SPOT 4 and 5 together ensure the provision of high-resolution SPOT images and of VEGETATION global images. Spot 4 offers an additional band in the short wave infra-red when compared against SPOT 1, 2, 3; SPOT 5 features an increased spatial resolution of 5 m to 20 m and higher absolute location accuracy compared to its predecessors. The continuity of the SPOT program is planned with the development of the Pleiades system, as well as Spot 6 and 7. Spot 6 and SPOT 7 will form a constellation of Earth imaging satellites providing high resolution wide-swath data up to 2023 (http://www.spotimage.com/web/en/3319-spot-6-and-spot-7-extending-spot-continuity-to-high-resolution-wide-swath-imagery.php) with scheduled launches in 2012 and 2014, respectively (http://eoedu.belspo.be/en/satellites/spot.htm). SPOT 6 and 7 will acquire observations in five bands: A panchromatic band with 1.5 m spatial resolution, blue, red and green bands, and a near-infrared band; all obtained at 6 m spatial resolution. The imaging swath will be 60 km. SPOT observations have been used primarily for cartography (e.g. Gastellu-Etchegorry, 1989; Giles & Franklin, 1996), land cover classification (e.g. Gong et al., 1992; Kanellopoulos et al., 1992) and land change detection (e.g. Jensen et al., 1995; Lu et al., 2004).

The Landsat Program started in 1972 with the launch of the first satellite. Since then Landsat data have become key observations for monitoring global change and have been a primary source of medium spatial resolution Earth observations for a wide range of applications (e.g. Special Issues on Landsat, 1984, 1985, 1997, 2001, 2003, 2004, 2006). Landsat satellites can be classified into three groups, based on sensor and platform characteristics (Chander et al., 2009). The first group consists of Landsat 1, Landsat 2 and Landsat 3 carrying the Multispectral Scanner (MSS) sensor and the Return Beam Vidicon (RBV) camera. The second group comprises Landsat 4 and Landsat 5 with the MSS and the Thematic Mapper (TM). Landsat 7 includes the Enhanced Thematic Mapper Plus (ETM+). The Landsat Data Continuity Mission (LDCM)/Landsat 8 will continue and advance the collection of Landsat data with a two-sensor payload: The Operational Land Imager (OLI) will collect image data for nine visible, near infrared and shortwave infra red bands with a 30 m spatial resolution (15 m for the panchromatic band); the Thermal Infrared Sensor (TIRS) will collect data for two longwave thermal bands with 100 m resolution. Both instruments are push broom sensors with a 185 km cross-track field of view. For more details the reader is referred to http://ldcm.nasa.gov/mission_details.html.

The Sentinel-2 mission will offer an unprecedented combination of systematic global coverage of land surfaces, a high revisit of five days at the equator under the same viewing conditions, high spatial resolution (i.e. Landsat-type), and a wide field of view for multispectral observations from 13 bands in the visible, near infra-red and short wave infra-red part of the electromagnetic spectrum. The spectral band coverage and the corresponding spatial resolutions are shown in Fig. 1.

In this paper we present the current status of the Sentinel-2 mission after the completion of the satellite's Critical Design Review (CDR), which is held at the end of phase C to judge the readiness of the project to move into phase D by assessing the qualification and validation status of the critical processes. We address the space component including the platform and the instrument, the ground segment, data and processing and the future applications. The information is based on various ESA documents, for example the Mission Requirements Document (MRD, ESA, 2010a) or the Products Definition Document (ESA, 2010b). Additional information can be found under http://www.esa.int/esaLP.

2. Mission overview

Frequent revisits of five days at the equator require two identical Sentinel-2 satellites operating simultaneously favoring a small, cost-effective and low-risk satellite. The orbit is Sun-synchronous at 786 km altitude (14 + 3/10 revolutions per day) with a 10:30 a.m. descending node. This local time was selected as the best compromise between minimizing cloud cover and ensuring suitable sun illumination. It is close to the Landsat local overpass time and matches SPOT's, allowing the combination of Sentinel-2 data with historical images to build long-term time series. The Sentinel-2 satellites will systematically acquire observations over land and coastal areas from −56° to 84° latitude including islands larger 100 km^2, EU islands, all other islands less than 20 km from the coastline, the whole Mediterranean Sea, all inland water bodies and all closed seas. Over specific calibration sites, for example DOME-C in Antarctica, additional observations will be made. The two satellites will work on opposite sides of the orbit (Fig. 2). The first launch is planned in 2013. The key features of the Sentinel-2 mission are summarized in Table 1.

The combination of the large swath of 290 km, spectral range, coupled with the global and continuous acquisition requirement with high-revisit frequency, will lead to the daily generation of about 1.6 TBytes of compressed raw image data from the constellation. The main data related to the Sentinel-2 system definition is presented in Table 2.

The 13 spectral bands span from the visible (VIS) and the near infra-red (NIR) to the short wave infra-red (SWIR) at different spatial resolutions at the ground ranging from 10 to 60 m (Table 3). The four bands at 10 m resolution ensure compatibility with SPOT 4 and 5 and meet the user requirements for land cover classification. The 20 m resolution for six bands has been a requirement for other Level 2 parameters. Bands at 60 m are mainly dedicated for atmospheric corrections and cloud screening (443 nm for aerosols retrieval, 940 nm for water vapor correction and 1375 nm for cirrus detection). The 60 m resolution is considered to be adequate to capture the spatial variability of the atmospheric geophysical parameters. The normalized filter transmissions for the 13 bands are shown in Fig. 3 together with modeled TOA radiances for deciduous forest. The resulting data rate fits the maximum downlink capacity for this mission design.