HYPXIM: A SECOND GENERATION HIGH SPATIAL RESOLUTION HYPERSPECTRAL SATELLITE FOR DUAL APPLICATIONS

Véronique CARRERE[1], Xavier BRIOTTET[2], Stéphane JACQUEMOUD[3], Rodolphe MARION[4], Anne BOURGUIGNON[5], Malik CHAMI[6], Marie DUMONT[7], Audrey MINGHELLI-ROMAN[8], Christiane WEBER[9], Marie-José LEFEVRE-FONOLLOSA[10], Mioara MANDEA[10]

(1) Université de Nantes, UMR-CNRS 6112, 2 rue de la Houssinière BP 92208, 44322 Nantes, France
(2) ONERA, 2 avenue Edouard Belin, BP 74025, 31055 Toulouse, France
(3) IPGP, Sorbonne Paris Cité, Université Paris Diderot, UMR CNRS 7154, 39 rue Hélène Brion, 75013 Paris, France
(4) CEA/DAM/DIF, F-91297 Arpajon, France
(5) BRGM, BP 6009, 45060 Orléans, France
(6) Université Pierre et Marie Curie, LOV, UMR CNRS 7093, BP 08, 06230 Villefranche sur Mer, France
(7) Météo-France - CNRS, CNRM-GAME UMR 3589, Centre d'Etude de la Neige, Grenoble, France
(8) Université du Sud Toulon Var, Laboratoire LSEET UMR-CNRS 6017, ISITV, Avenue Georges Pompidou BP 56, 83162 La Valette du Var Cedex, France
(9) LIVE UMR 7362, 3 rue de l'Argonne, 67000 Strasbourg, France
(10) CNES, 18 avenue Edouard Belin, 31401 Toulouse, France

Abstract

This paper synthesizes the mission requirements defined by a group of French scientists and defence users expert in the field of hyperspectral remote sensing to design a spaceborne mission composed of a second generation imaging spectrometer (8m) coupled with a panchromatic camera (2m). Its technical characteristics open the way for new applications in several topics: geosciences and solid Earth science, urban ecosystems, vegetation biodiversity, coastal and inland ecosystems, atmospheric sciences, cryosphere and defence. For each of them, the improvements brought by such a mission are summarized.

***Index Terms* —**Imaging spectroscopy, panchromatic imagery, mission requirements, optical sensor

1. INTRODUCTION

Twenty-five years of airborne imaging spectroscopy have clearly demonstrated the added value of this remote sensing technique to improve the understanding of Earth's functioning. Present spaceborne sensors like Hyperion (Pearlman et al., 2003) or HICO (Lucke, 2011) have opened up the way for new studies of surface chemistry. Furthermore, the growing number of scheduled spaceborne missions like EnMAP (Kaufmann, 2006), PRISMA (Galeazzi et al., 2009) or in a preparation phase like HyspIRI (Green, 2007) prove that the scientific community is highly motivated to extend the range of applications using such a techniques.

In 2008, an ad hoc group of science and defence users of hyperspectral imagery named GSH (Groupe de Synthèse Hyperspectral) has been set up on CNES initiative to address several objectives: 1) review all present applications that take advantage of imaging spectroscopy; 2) list current and future spaceborne systems; 3) specify the spectral, spatial, and temporal sampling that would provide users with original data; 4) propose a new instrument, the characteristics of which will fulfil their requirements.

This has been the starting point of the CNES Phase 0 study that aimed at evaluating the feasibility of such a platform and designing a first version of the HYPXIM system based on two main designs (Michel et al, 2010) from the mission requirements (Briottet et al., 2011). In July 2012, based on these results, CNES decided to select the most effective system of the proposed missions for a Phase A study (Lefevre-Fonollosa et al 2012).

This paper aims at presenting an update of the science requirements (§2) and provides the main mission characteristics of the HYPXIM mission (§3).

2. SCIENCE REQUIREMENTS

The following subsections describe the fundamental science and societal applications in seven domains that benefit from hyperspectral data: geosciences and solid Earth science, urban ecosystems, vegetation biodiversity, coastal and inland ecosystems, atmospheric sciences, cryosphere and defence.

2.1. Geosciences and solid Earth science

Right from the beginning of imaging spectroscopy, the geosciences community has been, and still is the moving spirit in the development of such a technology which allows rapid identification of mineral constituents in soils and rocks (Clark et al., 1990; Hunt, 1977, Hunt & Salisbury, 1970) together with their physical properties (grain size, moisture content, etc). The capability of hyperspectral sensors to provide mining and oil companies with a major source of information for prospecting but also for remediation of abandoned mine and industrial sites (EU directive 2006/21/EC) is unique. Important scientific applications also emerged from imaging spectroscopy: they include land degradation / desertification monitoring (UN Convention to Combat Desertification) in the context of global change and land use, soil quality monitoring (EC Soil Thematic Strategy, 2006), soil water and carbon storage and surface erosion (e.g. Ben-Dor et al., 2008), mapping of environmental hazards due to expansive clay soils (Chabrillat et al., 2002), oil spills, acid mine drainage (e.g. Swayze et al., 2000). Each application implies that we are able to map spatial and temporal changes in specific minerals or mineral mixtures that can only be identified by their full spectral signature. This requires spaceborne sensors covering the full VNIR-SWIR spectral range, with a high spectral resolution and a high signal-to-noise (SNR) ratio, specifically in the SWIR where most of the characteristic absorption features are located. Moreover, the main limits to successful mapping are the mixing at the sub-pixel scale and the degree of exposure of the target at the surface, although those limits have been pushed forward in recent years by the development of new processing algorithms (e.g. Adams et al., 1993). Thus, more than one scale of observation is needed to take into account for the pixel heterogeneity (for example in the presence of vegetation).

With its high spatial resolution, HYPXIM will give access to more accurate information on soil and rock composition and properties to better understand the anthropogenic forces that drive our environment, provided a high SNR in the VNIR (iron oxides) and SWIR (clay, carbonates, hydroxyls, etc).

2.2. Urban ecosystem

Since 2000, more than half of the world's population lives in cities. Such areas are characterized by a wide range of artificial and natural surface materials which induces specific effects on ecological (Arnold & Gibbons, 1996), climatic and energy (Oke, 1987) conditions. Indeed, changes in vegetation cover, air and surface temperature and air and water quality induced by urban expansion influence the microclimate of the human habitat, as well as climate dynamics and environmental changes at the local and regional scales (Shafri et al., 2012). The contribution of EnMAP towards urban development and planning, urban growth assessment, risk and vulnerability assessment, and urban climate has been recently evaluated (Heldens et al., 2011). Due to its average spatial resolution (30m), EnMAP cannot address these issues at the required local scale. Indeed, the high surface heterogeneity results from the mix of various materials, or geometric forms that produce shadows in a small area. The high spatial resolution of HYPXIM opens the way for an accurate material-based mapping. Furthermore, such a platform will improve the classification of urban elements (vegetation, sealed areas, protected wetlands, etc). While the thermal and pollution-reducing effect of vegetation canopies depends on the species, its spatial distribution and health are crucial to model some urban areas. Urban biodiversity and greenways definitions are crucial issues nowadays in urban planning. The size of most of such urban patterns of interest is less than 5 m, which justifies an instrument like HYPXIM that combines a high spatial resolution imaging spectrometer with a panchromatic sensor. It will permit the analysis of very fine structures and open the way to a new range of applications.

2.3. Vegetation biodiversity

Vegetation provides foundations for life on Earth through ecological functions: regulation of climate and water, habitat for animals, supply of food and goods. Increases in the world’s population expand the volume of consumption and production, which results in land degradation, forest destruction, and plant biodiversity loss. The reorientation of current economic models toward sustainable development is a challenge. Vegetation can be assessed at different spatial scales ranging from leaves to ecosystems or even biome (Schaepman et al., 2009). The ability to distinguish between species based on variations in their chemical composition derived from hyperspectral imagery is a future major application in ecosystem studies, since their evolution under climate change and anthropogenic forcing (invasive plants) is still a question at issue. Radiative transfer models that provide a physically consistent linkage between leaf biochemistry (pigments, water and SLA) and canopy spectral reflectance are integral to future imaging spectrometers (Knyazikhin et al., 2013). Among all the applications of hyperspectral remote sensing of vegetation, monitoring of forest biodiversity is a priority area of research for ecologists. Sampling biodiversity at more than one spatial scale allows a more complete understanding of simultaneously existing processes that operate on different time scales. The high spatial resolution of HYPXIM will facilitate the accurate location of trees, while its high spectral resolution will be well suited to their identification.

2.4. Coastal and inland ecosystems

Coastal zones are located at the interface between the land and the sea. About half the world’s population lives less than 100 km from a coastline. The expansion of coastal areas poses serious problems. According to the European Union Water Framework Directives 2000/60/EC and 2006/7/EC, the assessment of water quality in coastal and inland areas is a priority. While much progress has been made with the measurement of ocean colour using appropriate sensors, the study of coastal and inland waters that mixes suspended mineral particles, dissolved organic matter, organic and inorganic pollutants, is still challenging. It is complicated by a high spatio-temporal variation. Imaging spectroscopy can help to derive water quality variables such as the type and size of suspended particles, toxic algal blooms, and other phytoplankton species that serve as a marker of eutrophication. These variables are of great interest for various applications such as the determination of primary production in coastal waters (i.e., carbon cycle), the impact of the coastal dynamics (turbulences, tides) on the ecosystems, the marine coastal pollution and its subsequent impact on tourism activities. Highly resolved imaging spectroscopy could be used as well to complete large scale maps of macro or microscopic benthic communities, and is effective in clear water to resolve bathymetry through a better characterization of the sea floor. Besides the research activities and mainly due to legal constraints, a significant market recently emerged to set up airborne campaigns involving hyperspectral imagery to address questions associated with the management of these fragile ecosystems.

2.5. Atmospheric sciences

This domain is richly endowed with dedicated satellite missions, each targeting one or more variables of interest for atmospheric scientists. However, several innovative research topics have been identified that may emerge and benefit from further studies taking advantage of the high spatial and spectral resolutions. First, the detection and the characterization of local surface phenomena such as vegetation fires, volcanic eruptions or sources of methane will be accessible. Moreover, while significant information on aerosols and clouds can be derived from multispectral imagery with a much lower spatial resolution, some original applications emerge like the measurement of aerosol altitude by combining the measurement of gas absorption and its diffusion properties, or aerosol-cloud interactions that require a high spatial resolution. Finally, monitoring of low level atmospheric pollution could potentially be interesting provided the spatial and spectral resolutions are high enough. Promising results have been obtained recently for the monitoring of aerosols and gasses emitted by industrial sites (Thorpe et al., 2012, Deschamps et al., 2012). High resolution mapping of these concentrated local sources could help partitioning between anthropogenic and natural sources, and compliment on-going global climate monitoring efforts at coarser spatial resolutions. It remains challenging due to the low signal levels involved and to the high ground heterogeneity.

2.6. Cryosphere

Snow is one of the most reflective surfaces on Earth. Consequently any variation in its optical properties will change the surface energy budget of snow covered areas but also of the Earth energy budget and climate. Snow reflectance varies with its physical (grain shape and size) and chemical properties (impurity content, water liquid content) (Warren, 1982). Hyperspectral imagery allows an accurate determination of the snow surface properties and albedo. An accurate determination of these properties is not possible using multispectral imagers due to their limited number of spectral bands (Dozier et al., 2009)]. The high variability of topography, vegetation and snow cover properties in mountainous areas makes high spatial resolution a crucial requirement to be able to avoid mixed pixels and to properly analyze the signal from one pixel.

2.7. Defence

The defence fields of interest described by the GSH have been defined by a separate working group involved in Defence activities. The potential use of imaging spectroscopy for such activities has been largely investigated in the past 10 years, leading to the identification of a number of key applications. Three are worthy of note: the contribution to trafficability analysis; the detection and characterization of objects of interest and the detection of anomalies. DGA has subcontracted SAGEM DS and BRGM which showed that objects such as buildings and roads could be detected using hyperspectral imagery by using suitable spectral bands. Anomaly detection using simple processing strategies has been demonstrated by ONERA under DGA contract.

3. MISSION REQUIREMENTS

The selected applications are reminded for each domain and converted in terms of mission requirement in Table 1.

4. CONCLUSION

Seven scientific and defence domains of application are identified which will gain from such a mission. On the basis of these recommendations, CNES is now working on a Phase A study. A science mission group composed of scientific and Defence contributors is assisting CNES and is now working on the demonstration of the interest of such a mission. It relies on an ambitious experiment of airborne acquisitions covering these seven topics. These measurements will then be used to simulate images at space borne level to confirm the feasibility of the HYPXIM mission in terms of signal-to-noise ratio, observable radiances and quality products.

5. REFERENCES

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Table 1. Mission requirements expressed by the seven science user groups and defence users where δλ is the spectral resolution, GSD the ground sample dimension, RP the revisit period and SNR the signal-to-noise ratio, the spectral range is [0.4, 2.5µm].

Domain	δλ (nm)	GSD (m)	Swath (km)	RP	Minimum SNR
Geosciences / solid Earth science	≤ 10	<10	50 – 100	Critical in case of environmental crisis	150:1 in SWIR
Coastal and inland ecosystems	≤ 10	≤10	Variable	Critical for inter tidal monitoring	400:1 in VNIR
Vegetation biodiversity	≤ 10	≤10	Variable	Critical during the growing season	400:1
Urban ecosystems	≤ 10	≤5	20 – 50	Critical during crisis and growing vegetation season	250:1 in VNIR 150:1 in SWIR
Atmosphere sciences	≤ 10	20	10 – 50	Variable	250:1 in VNIR 150:1 in SWIR
Cryosphere	≤ 10	≤10	50-100	1-5 days	TBD
Defence	≤ 10	5-10	20	24 – 60 hours	250:1 in VNIR 100:1 in SWIR