HYPXIM: A NEW HYPERSPECTRAL SENSOR COMBINING SCIENCE/DEFENCE APPLICATIONS

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ABSTRACT

This paper synthesizes the technical requirements made by a group of French scientists and defence users expert in hyperspectral imagery to design a new space borne imaging spectrometer. This project called HYPXIM is currently in phase 0 mission study and two French aerospace companies have proposed solutions that are analysed by the CNES. These technical requirements are converted into at-sensor radiance specifications for each scientific application and the final radiance set used for the instrument design is defined.

***Index Terms* —**Imaging Spectroscopy, At-Sensor Radiance, Optical Sensor Specifications

1. INTRODUCTION

Imaging spectroscopy lately emerged as a very efficient remote sensing technique to improve the understanding of Earth's functioning. Present space borne sensors like Hyperion [1] have opened the way for new studies of surface diversity and chemistry. Furthermore, future programs like EnMAP [2], Prisma [3] and HyspIRI [4] prove that the scientific community is highly motivated to extend the range of applications using such techniques.

In parallel, in France, an ad hoc group of science and defence users of hyperspectral imagery named GSH (Groupe de Synthèse sur l'Hyperspectral) has been set up on CNES initiative to address several objectives: to establish an up-to-date view of all possible applications and specify the spectral, spatial, and temporal sampling characteristics of the required data to analyse the needs of the user community and identify current and future systems that are likely to answer them; to provide this community with systems or support, given the elements described above, and finally propose appropriate solutions.

This paper summarizes the study performed by the GSH group [5] in six different science/defence domains where imaging spectroscopy is considered to bring significant advances. It gives an overview of the at-sensor radiance specifications in each domain and a first description of the HYPXIM sensor, the phase A mission study of which is planned by the end of 2011.

2. SCIENCE REQUIREMENTS

The following sub sections describe the fundamental science and societal applications in six domains that potentially use hyperspectral data: vegetation, coastal and inland waters geoscience and solid Earth science, urban environment, atmospheric sciences, and defence. The targeted applications are reminded for each domain and converted in terms of instrument requirement in Table 1.

2.1. Vegetation

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. The assessment of vegetation health, both at local and regional scales, using biological indicators such as leaf pigment and water content, may provide useful information for environmental applications such as fire risk assessment, climate change studies, or desertification. The estimation of vegetation dry matter content enables the

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determination of the soil C:N ratio in a forest, which is related to the decomposition rate of organic matter by micro-organisms. This in turn is an indicator of CO_2 release into the atmosphere, providing new inputs to the study of the carbon cycle. Finally, 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.

Table 1. Summary table of mission requirements expressed by the five 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] (see [5] for more details).

Domain	δλ (nm)	GSD (m)	Swath (km)	RP	SNR
Geoscience / solid Earth science	≤ 10	10	50 - 100	Non critical	>100:1 in SWIR
Inland and coastal waters	≤ 10	≤10	Variable	Critical for inter tidal monitoring	< 400:1
Vegetation	≤ 10	≤10	Variable	Critical during the growing season	> 1000:1
Urban area	≤ 10	5-10	20 - 50	Critical during crisis	>250:1 in VNIR >100:1 in SWIR
Atmosphere	≤ 10	20	10 - 50	Variable	>250:1 in VNIR >150:1 in SWIR
Defence	≤ 10	5-10	20	24 – 60 hours	>250:1 in VNIR >100:1 in SWIR

2.2. Inland and coastal waters

Coastal zones are at the interface between the land and the sea. Nowadays about half the world's population live within 100 km of a coastline. The increasing use of coastal zones results in major problems. Following the European Union Water Framework Directives 2000/60/EC and 2006/7/EC, the assessment of water quality in coastal and inland areas became a priority. While much progress has been made on the measurement of ocean colour using sensors designed for this purpose, the study of coastal and inland waters that include a complex mixture of suspended mineral matter, dissolved organic matter, organic and inorganic pollutants, is more challenging. It is complicated by a high spatio-temporal variation. Imaging spectroscopy can help 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 eutrophization. It is also used to complete large scale maps of macro or microscopic benthic communities, and is effective in clear water to resolve bathymetry through a better characterisation of the sea bottom. Besides the research activities and mainly due to legal constraints, a significant market recently emerged to set up airborne campaigns involving hyperspectral images to address questions associated with the management of these fragile ecosystems.

2.3. Geoscience / solid Earth science

Right from the beginning the Geoscience community has been, and continues to be, a major proponent of imaging spectroscopy and, as such, the driver behind the development of this technology. In addition to classical tectonic information, hyperspectral sensors provide direct access to the mineral composition of exposed rocks and soils. This unique capacity constitutes a major source of information for mining and oil companies for prospecting, but also for the rehabilitation of abandoned mine sites (EU directive 2006/21/EC), recently extended to industrial sites. Important science applications for which imaging spectroscopy has proven to be of use include for example monitoring of land degradation/desertification (UN Convention to Combat Desertification), soil quality (EC Soil Thematic Strategy, 2006) and quantity monitoring, soil function (water and carbon storage) and threats (acidification, erosion) identification, mapping of environmental hazards related to swelling-shrinking clays, oil spills, etc.

2.4. Urban area

As more than half of the world's people live in cities, scientists took an interest in urban areas to improve our knowledge of such a medium for applications in human health, urban growth management, biodiversity, heat island or hydrology. The study of such areas is not straightforward because of the strong surface heterogeneity that is explained by the presence of various materials in a small surface area. The availability of high spatial resolution images opens the way for new applications to map such targets. High spectral and spatial resolution data will definitely improve the classification of urban areas both at the street and building levels, for applications in urban growth or heat island. Some recent studies showed that useful information could be obtained on aerosols to estimate anthropic emissions and

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characterise the air quality in urban environments. Finally, such sensor will contribute to improve the cartography of urban vegetation, as described above. Since the thermal and pollution-reducing effect of vegetation canopies varies according to the species, their spatial distribution is of great interest in the modelling of specific urban areas. The size of most of these 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.

2.5. Atmosphere

The GSH identified several innovative research topics which originate with the atmospheric corrections necessary for a correct use of hyperspectral images. Note that this domain is richly endowed with specific satellite missions, each targeting one or several variables of interest for atmospheric scientists. Our objective was to identify potential “spin-off” applications that may emerge and benefit from further study taking advantage of the high spatial and spectral resolutions. First, the detection and the characterization of local surface phenomena such as fires or sources of methane will be accessible. Further, while significant information on aerosols and clouds can be derived from multispectral imagery with a much lower spatial resolution, some original applications are attempted 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 (e.g. NO_2 and NO) could potentially be interesting provided the spectral resolution is high enough.

2.6. Defence

The defence fields of interest described by the GSH report mainly derive from a hyperspectral working group in the French Defence Sector. The potential use of imaging spectroscopy for defence applications has been largely investigated in the past 10 years. A number of key applications have been identified and hyperspectral sensor requirements have been derived for space based applications. Among these, three are worthy of note: the contribution to traficability analysis; the detection and characterization of objects of interest and the detection of anomalies. SAGEM DS and BRGM demonstrate, under DGA contract that, with suitably selected spectral bands, objects such as buildings and roads can be characterized using hyperspectral imagery. Anomaly detection using simple processing strategies has been demonstrated by ONERA under DGA contract.

3. AT-SENSOR RADIANCES SPECIFICATIONS AS DEFINED BY THE SCIENTIFIC / DEFENCE GROUP

Following the publication of the GSH report at the end of 2008 [5], the Strategy and Programs Directorate of CNES has decided to proceed with a phase 0 mission study of a space borne hyperspectral sensor after the user requirements listed in Table 1. The latter provides a sound basis for a satellite system capable of extending the observation capacities of the first generation of hyperspectral satellites currently under development (e.g. EnMAP, Prisma). Three main systems corresponding to micro- and mini-satellites are currently designed in the present phase 0 mission study (Table 2).

Table 2: Main HYPXIM characteristics.

	HYPXIM-C (Challenging)	HYPXIM-CA (HYPXIM-C “Advanced”)	HYPXIM-P (Performance)
Spatial resolution	Hyperspectral: 15 m Panchromatic: 3,8 m	Hyperspectral: 15 m	Hyperspectral: 8 m, Panchromatic: 2 m TIR: 100 m
Spectral coverage	0.4 – 2.5 µm		0.4 – 2.5 µm & 8 – 12 µm
Spectral resolution	≤ 14 nm	≤ 14 nm in VIS ≤ 10 nm in NIR and SWIR	≤ 10 nm ≤ 150 nm in TIR
Satellite mass	≤ 250 kg	≤ 250 kg	≤ 650 kg
Satellite volume	$600 \times 600 \times 1350$ mm^3		$1400 \times 1200 \times 2600$ mm^3
Swath	15 km	30 km	16 km
Acquisition capacity	Not available yet		

In the following we present some observable spectral radiances: mean radiance (L2) and maximum observable radiance without saturation (L4). To simulate the at-sensor radiances, the following conditions are fixed: no cloud, nadir viewing angle, target at sea level, and Julian day 180. The L2 radiances are computed according to a more complex scheme that corresponds to a favorable case (mid-latitude winter atmosphere and 60° solar zenith angle) and an unfavorable case (mid-latitude summer atmosphere and 30° solar zenith angle). For each case, an average spectral

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reflectance is computed over a specific dataset defined by the science/defence group (see [7] for more details). The L4 at-sensor radiances are computed using MODTRAN4 considering a flat Lambertian scene with the input variables listed in Table 3. For defence applications, the spectra come from a dedicated database. The estimation of L2 radiance for the atmosphere is achieved using two Hyperion images: one with a white plume acquired over the World Trade Center (September, 12th, 2001) and the other exhibiting a black plume acquired over the Eyjafjöll volcano (April, 17th, 2010). A homogeneous area of the plume is selected in each image, and the mean radiance is computed. The L2 synthetic radiance is estimated by averaging all the mean radiances for the most favourable and most unfavourable cases. Thus a global L2 (favourable and unfavourable) and L4 radiance set is built. Each of these radiances is obtained by averaging the corresponding radiances over all the themes.

Table 3. Input variables used to compute L4.

Reflectance (clouds)	1.00
Solar zenith angle	0°
Atmosphere model	Subarctic winter
Water vapor content H_2O	0.42 g/cm^2
Aerosol type	Rural
Horizontal visibility	50 km

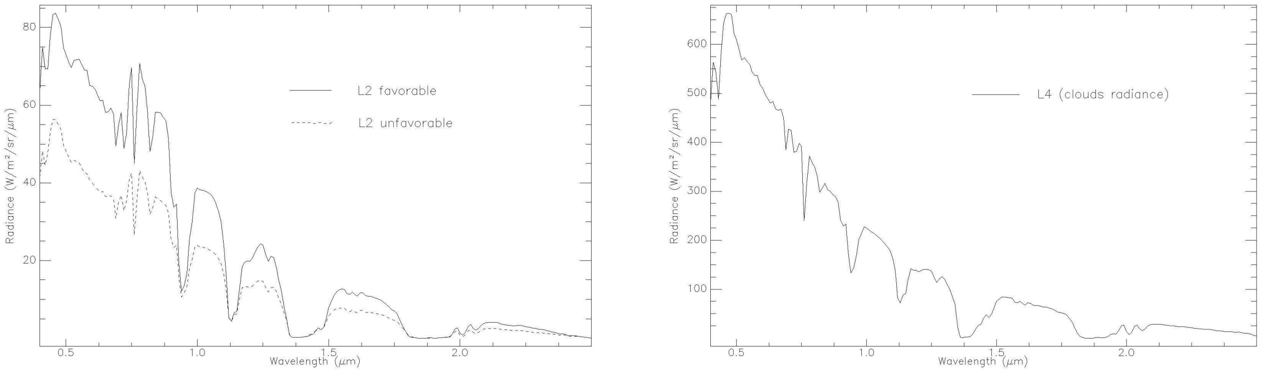

Fig. 1. L2 (favorable and unfavorable) and L4 spectral radiances as specified by the science / Defence group.

4. CONCLUSION

Six scientific/defence domains have been identified after the work conducted during 18 months by a group of science and defence users of imaging spectroscopy. On the basis of the summary note and recommendations,, CNES is working on a Phase 0 study covering two mission concepts that meet the users' requirements expressed by the GSH. This Phase 0 study should be completed in the middle of 2011 and followed by a Phase A. A mission group composed of scientific and Defence contributors assists CNES by specifying their needs in term of observable radiances. These radiances and the spatial scale required for these applications are very challenging and will define a very ambitious and innovative sensor. Note that the range of observable radiances is very broad. Furthermore, the L2 radiances are lower than the corresponding radiances of Prisma or EnMAP for several reasons: two solar zenith angles (30°, 60°), the mean reflectance levels is much lower than 0.3 and its level varies with the wavelength. These radiances are now used by CNES to evaluate the feasibility of a space borne sensor well suited for the targeted applications. The next work will focus on the impact of the SNR and the spatial resolution for identified applications.

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