Sentinels heading towards the Copernicus Expansion

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Copernicus Space Component: the dedicated Sentinels …

S1A/B: Radar Mission — 3 Apr 2014/25 Apr 2016

S2A/B: High Resolution Optical Mission — 23 June 2015/7 March 2017

S3A/B: Medium Res. Imaging and Altimetry Mission — 16 Feb 2016/1Q 2018

S4A/B: Geostationary Atmospheric Chemistry Mission — 2021/2027

S5P: Low Earth Orbit Atmospheric Chemistry Mission — 13 Oct 2017

S5A/B/C: Low Earth Orbit Atmospheric Chemistry Mission — 2021/2027

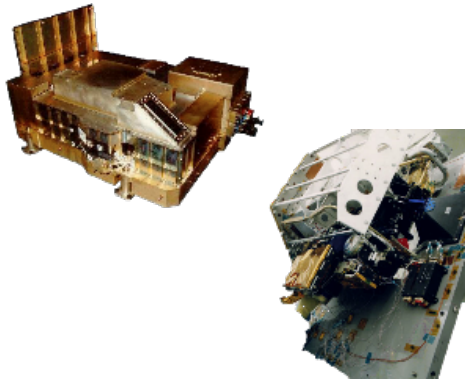
S6A/B: Altimetry Mission — 2020/2025

From GOME to Sentinel-5(P)

There is a long history observing Earth's atmospheric composition and quality monitoring

From scanning Spectrometers

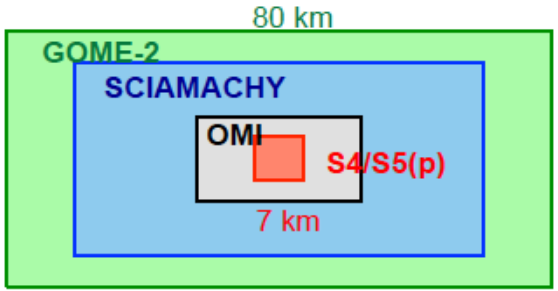
- GOME (ERS-2) 1995-2011
- SCIAMACHY (ENVISAT) 2002-2012
- GOME-2 (MetOp) 2006-



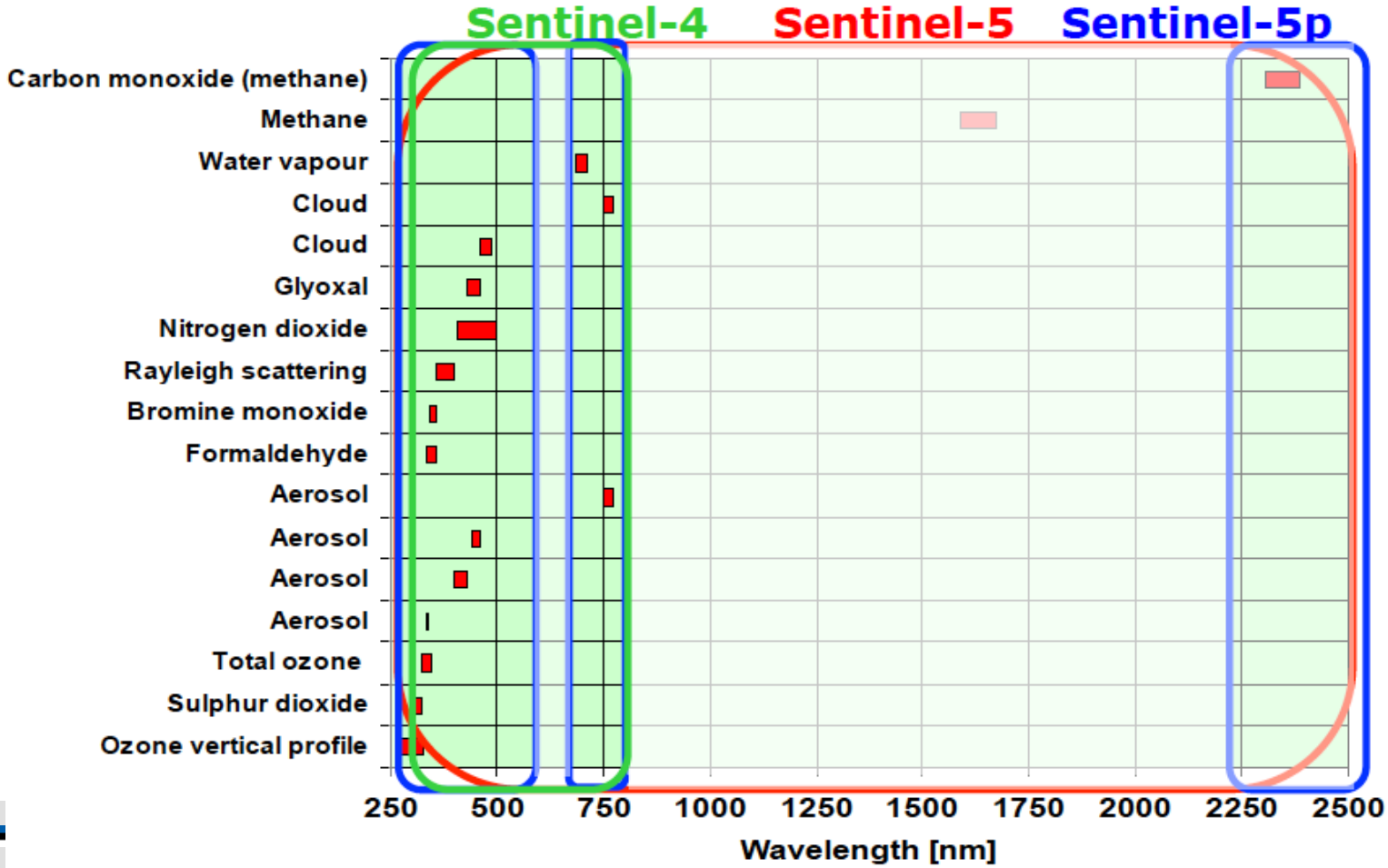
to

pushbroom imaging spectrometers

- OMI (Aura) 2004-
- Sentinel-4 (MTG) 2021/2-
- Sentinel-5 precursor 13-Oct-2017 -
- Sentinel-5 (MetOp-SG) 2020-

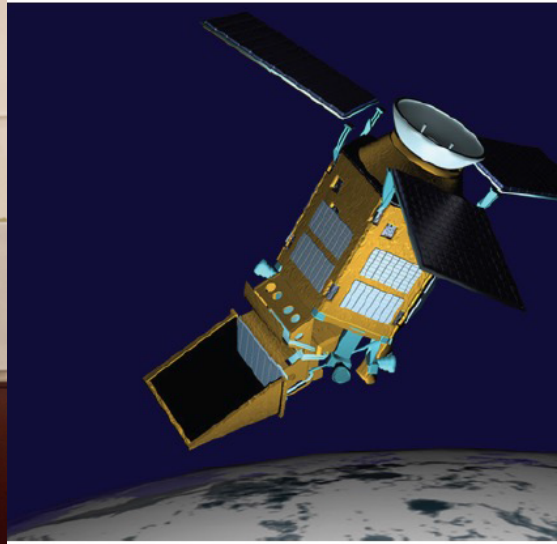


Spectral Bands of S4/S5 and S5P

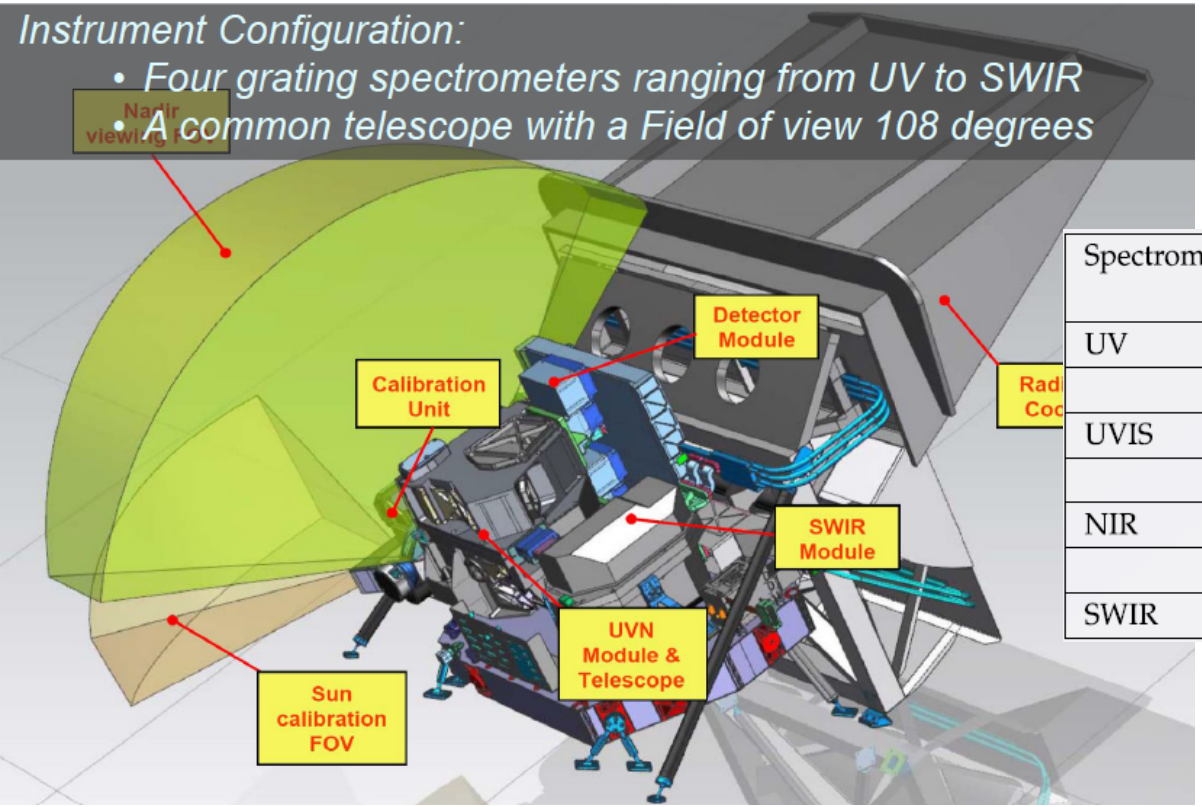


Sentinel-5 precursor

Orbit	sun-synchronous @ 824 km
LTAN	13:30
GSD	7*7 km^2
Swath	2600 km
Design	4 spectrometers UV, VIS, NIR, SWIR
Mass	900 kg
Power (av.)	430 W
In orbit lifetime:	7 years
Launch: 13-Oct-2017 (Rockot)	

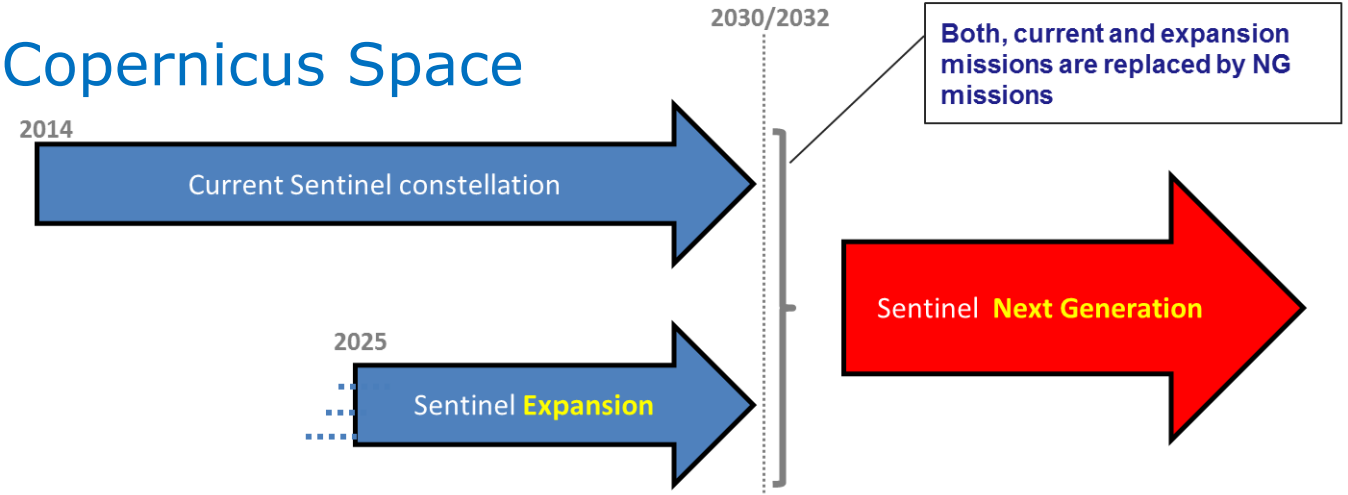


S5P instrument (TROPOMI) configuration



Spectrometer	Band	Spectral properties (nm)		
		Range	Resolution	Sampling
UV	1	270–300	1.0	0.065
	2	300–320	0.5	0.065
UVIS	3	310–405	0.55	0.2
	4	405–500	0.55	0.2
NIR	5	675–725	0.5	0.1
	6	725–775	0.5	0.1
SWIR	7	2305–2385	0.25	< 0.1

Evolution of the Copernicus Space Component



The Commission in particular

• underlined that **the (enhanced) continuity** of the existing Copernicus observation capacity is the overarching priority

• indicated a number of **major gaps potentially to be filled** by expansions to the Copernicus Space Component

6 Expansion Candidates are identified

The following candidate missions have been identified answering to the above needs:

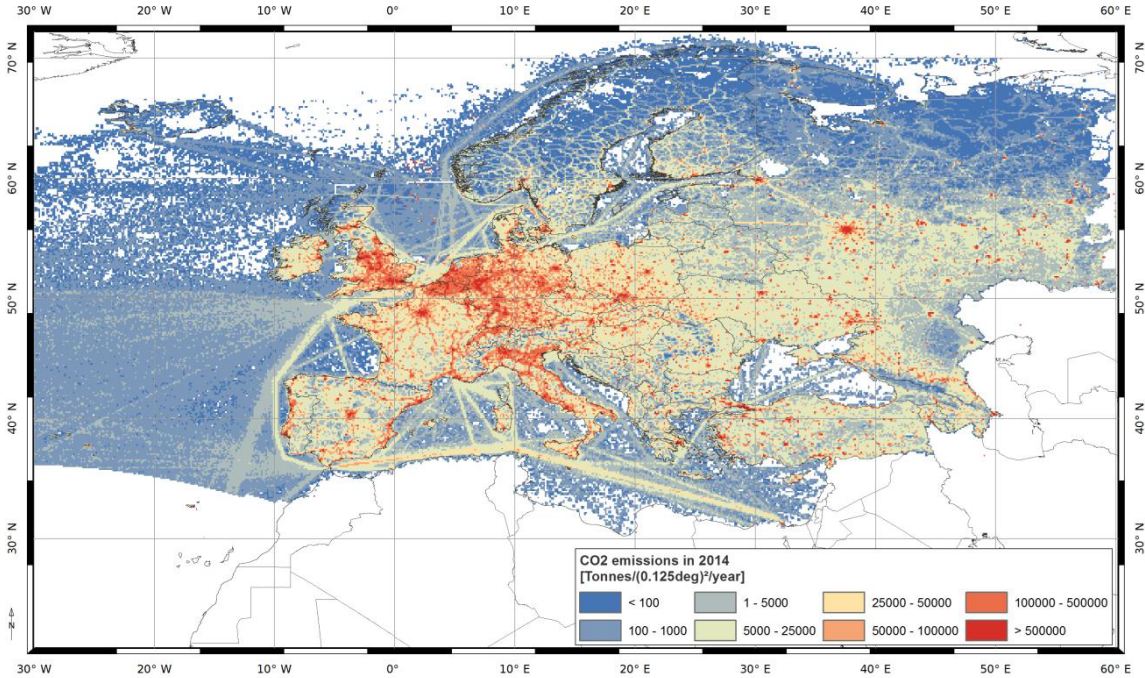
1. Anthropogenic CO2 monitoring mission
2. High Spatio-Temporal Resolution Land Surface Temperature (LST) Monitoring Mission
3. Polar Ice and Snow Topographic Mission
4. Passive Microwave Imaging Mission
5. **HyperSpectral Imaging Mission**
6. L-Band SAR Mission

For all those candidates, dedicated Phase A/B1 studies are under preparation

Anthropogenic CO2 monitoring mission

This mission aims to analyse through the use of CO2 satellite imagers the **man-made CO2 emissions and overall CO2 budget** at country and regional/ megacity scales and assess the effectiveness of the relevant COP21 decisions. This require the capability to provide satellite accurate and consistent quantification of anthropogenic CO2 emission and their trends.

<u>Observation Requirement:</u>
XCO2 precision: 0.5 – 0.7 ppm
Systematic bias < 0.5 ppm
Spatial resolution about 4 km^2
Continuously sampled swath width > 200 km



European total CO2 emissions
Kuenen et al., 2014 and 2015

High Spatio-Temporal Resolution Land Surface Temperature (LST) Monitoring Mission

This mission shall be able to complement the current visible (VIS) and near-infrared (NIR) Copernicus observations with high spatio-temporal resolution Thermal Infrared observations over land and coastal regions in support of **agriculture management services** and possibly a range of additional services.

Observation Requirement:
30-50 m to match European/African field scale variability
LST observations should optimally be acquired daily (goal), with a minimum threshold of 3-4 days

Evapotranspiration: May 2017, Po Valley - Italy

… and 3 SAR / Microwave missions …

Polar Ice and Snow Topographic Mission

This mission shall provide enhanced of **land ice elevation and sea ice thickness measurements** implementing higher spatial resolution for improved lead detection and additional capability to determine snow loading on sea ice.

Passive Microwave Imaging Mission

This mission shall provide improved continuity of **sea ice concentration monitoring** missions, in particular in terms of spatial resolution (<15 km), temporal resolution (sub-daily) and accuracy (in particular near the ice edges).

L-Band SAR Mission

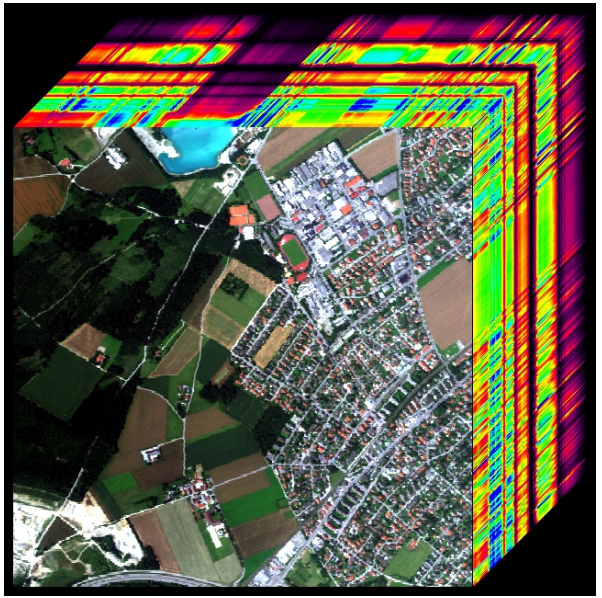
This mission is responding to the requirements expressed by both the Land Monitoring and the Emergency Management services. Its target applications are: **soil moisture, crop type discrimination, forest type/forest cover (in support to biomass estimation), food security and precision farming**. In addition the mission will contribute to the monitoring of ice extent in the polar region. Other emerging applications will be possible by the synergetic and complementary observations with C band and X band SAR systems

… last-but not Least
The Hyper Spectral Imaging Mission

This mission aims to complement Copernicus observations with an imaging spectroscopy observational capability for products, applications and services supporting the management of natural resources and related policies by providing detailed observations of key properties of terrestrial surface, inland water bodies and coastal regions. For raw material resources applications, only a **hyperspectral imager with contiguous bands can provide the spectral signatures in the Visible, Near Infrared and Short Wave Infrared (VNIR and SWIR)**, needed to identify and separate observed minerals, rocks and soils and their chemical composition. This is also the case for identifying and monitoring of mining operations and mine-waste management activities. The hyperspectral imaging mission thus aims to augment the Copernicus space component with precise spectroscopic measurements to derive quantitative surface characteristics supporting the monitoring, implementation and improvement of a range of policies in the domain of **raw materials, agriculture, soils, food security, biodiversity, environmental degradation and hazards, inland and coastal waters, snow, forestry and the urban environment**.

Hyperspectral Imaging Spectrometry (HIS): Heritage in Europe

- Hyperspectral imaging: has demonstrated mature, wide-ranging applications in mining, geology, forestry, agriculture, water quality and environmental management.
- **ESA's Proba-1/CHRIS** successfully pioneered satellite hyperspectral imaging at high spectral/spatial resolution (launch 2001; 16 years continuous operation)
  - VNIR range: 400 - 1050 nm; GSD: 17-36m
  - Swath width: 13-18 km
  - Bidirectional Reflectance Distribution Function (BRDF) measurements
- Extensive ESA experience with preparation of LSPIM and SPECTRA mission candidates
- **EnMAP (DLR)** and **PRISMA (ASI)** being readied for launch



Hyperspectral data cube (courtesy DLR)

- Rapidly growing commercial applications sector based on use of airborne, UAV and hand-held imaging spectrometry
- ESA Development of APEX airborne hyperspectral imager
- ESA International Hyperspectral Workshops & EARSeL imaging spectroscopy workshops

Hyperspectral Phase 0 currently ongoing

Phase 0 activities supporting to establish the

- Hyperspectral Imaging Mission Concept focus on
  - A: user requirements and
  - B: mission concepts
- Two parallel contracts: OHB , e-GEOS
- MTR presentations held (15-Sep and 22-Sep)
- **MTR concluded successfully (user requirements)**
- Remaining task: mission concept study
- End of Contract: February 2018

Preliminary Results: Observation requirements

Results are currently consolidated to allow to start the final task of the study: Proposition of mission concepts

Definition of Observational Requirements

Preliminary findings

OHB

High level ORs

	Parameter	Value	Source: Main Driver
Spatial	Coverage	All continental land surfaces between latitudes 56°S and 83°N (see section 4.2)	Copernicus/Sentinel-2
	Resolution	10 m (G) 20 m (B) 30 m (T)	URs: urban, geology, biodiversity
	Swath width	180 km (G) 60 km (T)	URs: agriculture, water
Spectral	Resolution & Sampling	5 nm (G) 10 nm (B) 12 nm (T)	URs: water (VNIR), geology/soils (SWIR)
	Coverage	400-2500 nm	URs: wide range of application domains
Radiometric	Dynamic range (L_{max}, L_{min})		EnMAP: wide range of application domains
	NER		EnMAP: water (VNIR), geology/soils (SWIR)
	SNR at L_{ref}	>500 at 500 nm >150 at 2200 nm	EnMAP: water (VNIR), geology/soils (SWIR)
Temporal	Temporal resolution	Cloud-free: 7 d (G) 15 d (B) 30 d (T) Geometrical: 4 d (G) 7 d (B) 15 d (T)	URs: agriculture, water
	Overpass time	10:30 mean local solar time	Sentinel-2: trade-off clouds vs radiation and angular effects
Mission-level	Data Products	L2A (geometrically-corrected surface reflectance)	URs
	Data Latency	L1C product: 5 hours for the disaster monitoring service and 12 hours for all other operational services (TBC)	Sentinel-2: disaster monitoring
	Maximum view zenith angle	10º	URs: to maximize consistency of time series

Secondary ORs

	Parameter	Value
Spatial	Uniformity (keystone)	<5% (G) <10% (T) of the ground sampling distance
	Modulation Transfer Function (MTF)	> 0.25 at the spatial wavelength of 2*GSD and > 0.64 at the spatial wavelength of 8*GSD at sub satellite point (= nadir looking, nominal orbit altitude, sea level)
Spectral	Uniformity (smile)	centre of the spectral bands shall be uniform across the FOV within <5% (G) <10% (T) of the spectral sampling
	Absolute accuracy	< 0.5 nm (knowledge of channel position and width)
Radiometric	Resolution	14-bit (G) 12-bit (T)
	Absolute accuracy	<5 %
	Sensitivity to polarization	<5%

Preliminary Summary of Observational Requirements

Final Results

Identifying the High-level Obs. Req.

e-geos AN ASI / TELESPAZIO COMPANY

- **GSD*:**
  - a threshold GSD of **30 meters** is compliant with most of the UR
  - a goal of **20 meters** would enable additional relevant URs
- **Revisit Time:**
  - a threshold of **28 days** is compliant with most of the UR
  - given the relevance of specific URs (e.g. Agriculture/Food Security), a goal of **15 days** should be achieved
- **Spectral Ranges:**
  - **VNIR** and **SWIR,** spanning from **400 nm** to **2500 nm** resulted the key spectral ranges needed for almost all URs
- **Spectral resolution:**
  - **10 nanometres** is the best choice enabling almost all identified URs
- **Signal-to-Noise Ratio** (GSD=30m, ρ=0.3, SZA=30º):
  - VNIR: **threshold=400:1, goal 600:1; @ 650 nm**
  - SWIR: **threshold=300:1, goal 300:1; @ 2100 nm**

*) The SNR values refer to a typical scenario of 30% reflectance (ρ) at a 30º Sun Zenith Angle (SZA) at top of atmosphere (TOA) for mid-latitude summer and out of the atmosphere absorption spectral windows. Moreover, the SNR values are converted to the equivalent SNR at a nominal 30-meter GSD

Observational parameter	Threshold	Goal
GSD	30 meters	20 meters
Revisit Time	28 days	15 days
Spectral ranges	VNIR, SWIR	VNIR, SWIR
Spectral Resolution	10 nm	10 nm
VNIR SNR	> 400:1 @ 650 nm (ρ=0.3, SZA=30°)	> 600:1 @ 650 nm (ρ=0.3, SZA=30°)
SWIR SNR	> 300:1 @ 2100 nm (ρ=0.3, SZA=30°)	> 300:1 @ 2100 nm (ρ=0.3, SZA=30°)

Funded by the EU and ESA

Hyperspectral Imaging Mission Expert Group (HIMEG)

Scope:

Establish High Level Requirements and Mission Requirements traceable to user needs. A set of critical user requirements in raw materials, agriculture, soils and food security are currently not met by the Copernicus space component (e.g. soil- and plant chemistry, mineralogy and related environmental impacts). A hyperspectral natural resources mission can fulfill these key user requirements and address specific ecosystem.

Main Mission Objective:

To complement Sentinel observation capabilities with high spectral resolution VIS-SWIR observations over land and coastal areas in support of natural resources management, (agricultural services, including food security biodiversity and a range of additional services by addressing in-land water quality, forestry and snow).

Science Coordinator: Michael Rast

Name	Company/Department
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Breger, Peter Dr.	European Commission, Research DG, H /5, "Space Research Activities, GMES",
Colombo, Roberto Mr.	University Milano Bicocca(UNIMIB), Earth & Environmental Sciences Department (DISAT), Laboratory Telerilevamento Dinamiche Ambientali
Féret, Jean-Baptiste Dr.	Maison de la Télédetection
Giardino, Claudia Dr.	CNR-IREA
Green, Robert O. Dr.	Jet Propulsion Laboratory, MS 306-431
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Müller, Andreas Mr.	Deutsches Zentrum für Luft- und Raumfahrt (DLR), German Aerospace Center, Earth Observation Center,
Rum, Giovanni Dr.	
Skidmore, Andrew K. Prof. Dr.	ITC, Natural Resources Department (NRS-ITC), Faculty of Geo-Information, Science & Earth Observation of the University of Twente
Zunker, Hugo Dr.	European Commission - DG-GROW, Unit K2 - Copernicus Services

Hyperspectral Imaging Mission Expert Group (HIMEG)

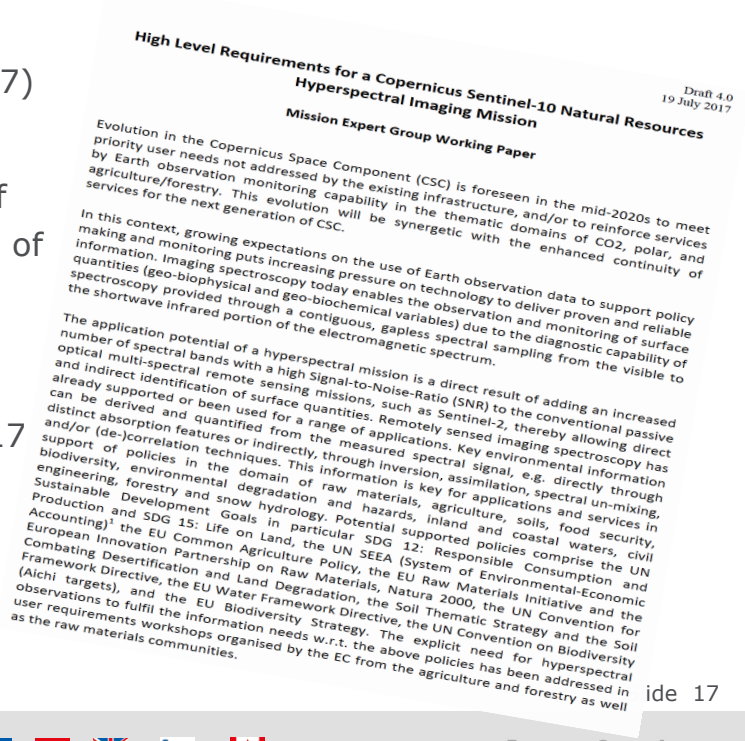
Status:

- Terms of Reference established and agreed with EC
- Mission Expert Group (MEG) Members nominated
- 1st MEG Meeting: June 28th – 29th
- Consolidated High Level Requirements (HLR) established (Jul-2017)
- 2nd Meeting: September 26th – 27th

(focusing on consolidation of observational requirements, derivation of mission requirements, identification of support activities, identification of user domains and -groups)

Next steps:

- Outline Mission Requirements Document (MRD) – October 2017
- 3rd Meeting planned for 28th–29th November 2017
- First Draft version of MRD – December 2017
- After KO of Phase A/B1 Contract, MEG will become the new Mission Advisory Group (MAG)



High Level Requirements for a Copernicus Sentinel-10 Natural Resources Hyperspectral Imaging Mission

Draft 4.0
19 July 2017

Mission Expert Group Working Paper

Evolution in the Copernicus Space Component (CSC) is foreseen in the mid-2020s to meet priority user needs not addressed by the existing infrastructure, and/or to reinforce services by Earth observation monitoring capability in the thematic domains of CO2, polar, and agriculture/forestry. This evolution will be synergetic with the enhanced continuity of services for the next generation of CSC.

In this context, growing expectations on the use of Earth observation data to support policy making and monitoring puts increasing pressure on technology to deliver proven and reliable information. Imaging spectroscopy today enables the observation and monitoring of surface quantities (geo-biophysical and geo-biochemical variables) due to the diagnostic capability of spectroscopy provided through a contiguous, gapless spectral sampling from the visible to the shortwave infrared portion of the electromagnetic spectrum.

The application potential of a hyperspectral mission is a direct result of adding an increased number of spectral bands with a high Signal-to-Noise-Ratio (SNR) to the conventional passive optical multi-spectral remote sensing missions, such as Sentinel-2, thereby allowing direct and indirect identification of surface quantities. Remotely sensed imaging spectroscopy has already supported or been used for a range of applications. Key environmental information can be derived and quantified from the measured spectral signal, e.g. directly through distinct absorption features or indirectly, through inversion, assimilation, spectral un-mixing, and/or (de-)correlation techniques. This information is key for applications and services in support of policies in the domain of raw materials, agriculture, soils, food security, biodiversity, environmental degradation and hazards, inland and coastal waters, civil engineering, forestry and snow hydrology. Potential supported policies comprise the UN Sustainable Development Goals in particular SDG 12: Responsible Consumption and Production and SDG 15: Life on Land, the UN SEEA (System of Environmental-Economic Accounting)[1] the EU Common Agriculture Policy, the EU Raw Materials Initiative and the European Innovation Partnership on Raw Materials, Natura 2000, the UN Convention for Combating Desertification and Land Degradation, the Soil Thematic Strategy and the Soil Framework Directive, the EU Water Framework Directive, the UN Convention on Biodiversity (Aichi targets), and the EU Biodiversity Strategy. The explicit need for hyperspectral observations to fulfil the information needs w.r.t. the above policies has been addressed in user requirements workshops organised by the EC from the agriculture and forestry as well as the raw materials communities.

In Parallel:
Preparation of Phase A/B1 Industrial Contract

Current work-plan:

- October — Publication in EMITS (ESA's System for Tendering And Registration)*
- Feb/Mar-2018 — KO of two contracts in parallel of Phase A/B1 system activity
- End 2018 — Preliminary Requirement Review (PRR), i.e., End Phase A
- Jun 2019 — Intermediate System Requirement Review (ISRR), i.e., End Phase B1
- Q42019 — Release of ITT for Phase B2/C/D/E1
- **Late 2019** — **Ministerial Council => Programme implementation approval?**

* CSC expansion is financed under EOEP-5 programme

Conclusion

Copernicus Space Component (CSC) Expansion:

The CSC is ready to prepare a sound baseline to fill a number of major observation gaps:

1. Anthropogenic CO2 monitoring mission
2. High Spatio-Temporal Resolution Land Surface Temperature Monitoring Mission
3. Polar Ice and Snow Topographic Mission
4. Passive Microwave Imaging Mission
5. HyperSpectral Imaging Mission
6. L-Band SAR Mission

Hyperspectral:

- User Requirements are well advanced and considered as solid,
- Observation requirements are clear, only spatial dimension (revisit, spatial resolution) needs further assessment in a mission concept study,
- Data continuity and long-term planning is considered as top requirements by all parties.