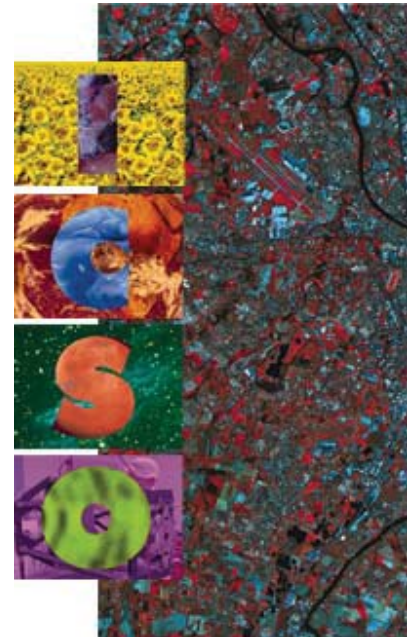


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ECOSPACE : a pre-operational satellite system and services for ocean colour monitoring

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ECOSPACE : A pre-operational satellite system and services for ocean colour monitoring

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ABSTRACT

A permanent monitoring of the oceanic algal biomass (phytoplankton), of its photosynthetic activity, ecological and biogeochemical impact, or of its long-term response to changing physical and climatic conditions, is a crucial goal of scientific programmes (such as JGOFS, GLOBEC, LOICZ), as well as of international observing systems (such as GOOS, GCOS, IGOS). After a decade without ocean colour satellite-borne sensor, several instruments have been, or will be launched. They are increasingly sophisticated in their design and operation. Their complexity results from constraints for multipurpose mission (involving not only ocean, but also land and atmosphere), or from requirements for exploratory research projects and development of new methodologies for improved ocean colour interpretation and “advanced” products.

In contrast, the proposed specific ECOSPACE mission is an ocean colour dedicated instrument, with a global monitoring vocation. It relies on known algorithms for accurate atmospheric corrections and aerosol load estimate over open ocean (about 96% of the whole ocean), and known algorithms for a meaningful quantification of the oceanic algal biomass (in terms of Chlorophyll concentration). The coastal zones are observed as well, and their particular features delineated : however, detailed studies that imply high ground resolution and more spectral channels are out of the scope of the present proposal. The ECOSPACE mission represents a feasibility demonstration ; more precisely it is a first step toward the setting up of an operational Satellite System and Services for a future continuous supply of stable, compatible, easy-to-merge ocean colour data products. In essence, such a Service would be similar to those already existing for meteorology and for some oceanic variables (e.g. sea level).

Although new approaches to management and implementation over a short time scale are needed, the ECOSPACE project relies essentially on existing scientific and technological experience developed in particular under ESA funding in the frame of the MERIS project, including sensor simulation and processor, and instrument building. Indeed, most of the ECOSPACE components are already available or in final approval processes ; costly activities on the critical path for a traditional satellite system will be greatly reduced, when not totally cancelled by use of developed μ satellite platform : PROBA from ESA or μ SAT from CNES. The same argument

holds true for the ground segment, algorithm architecture, and data management.

These platforms are compatible of piggy back on ARIANE 5 Launcher.

1. INTRODUCTION

The European Space Agency (ESA) issued the 13 July 1998, the Call for the Earth Explorer Opportunity Mission (EEOM).

The ECOSPACE (Earth oCean cOlour SPACE) proposal, submitted to ESA the 1st, December 1998 has been prepared by the Laboratoire de Physique et Chimie Marines (LPCM) and the Bedford Institute of Oceanography (research laboratory of the Department of Fisheries and Oceans, Canada) with the help of ACRI, Alcatel Space and BOMEN (Canada).

The EEOM initiative is associated with the two boundary conditions :

- the total cost for the full realization of any selected mission must not exceed an absolute financial ceiling of 80 MEUROS (1998 prices), including satellite, launcher, ground segment
- it must be feasible to launch any selected mission by the year 2002.

The ECOSPACE instrument is based on an imaging spectrometer derived of MERIS (one of the 6 core instruments of Envisat).

2. GENERAL CONTEXT

The ocean is the largest ecosystem of our planet. Beside its global role with respect to primary production (and whence to trophic food web), to CO₂ fixation, to climate, and other issues relevant to the Kyoto protocol (and IGBP and GOOS preoccupations), the ocean also includes coastal zones which form critical environments. Because of the density of population inhabiting along the coast, the various resources exploited in coastal waters, the impacts of human activity upon these coastal ecosystems are particularly important.

To understand the role, the mechanisms and response of the entire ocean at both the global and local scales, two distinct observational systems have to be simultaneously developed. Indeed, the observational requirements, driven by the nature of the phenomena under study, lead to distinct and complementary missions. It is clear that one single and simple satellite cannot meet the diverging requirements for the two scales involved and the two kinds of problems (except with a highly sophisticated and costly instrument, *i.e.*, the opposite of what is expected from the Earth Explorer programme).

Indeed, the coastal zone monitoring requires a dedicated, oriented coverage rather than a global coverage. High spatial (better than 0.5 km) resolution is needed as well as a fast repetition rate of observation for specific and often transitory events (ideally < 1 day). In addition, the optical complexity of coastal Case 2 waters entails more spectral channels and band combinations not needed when studying oceanic Case 1 waters.

Global missions dealing with oceanic waters require a planetary coverage within 2, 3 days, which can be obtained with a wide swath. With such a swath, a moderate ground resolution has to be accepted, and in effect is fully acceptable for global studies. Along this line, defined in the IOCCG/SCOR (International Ocean Colour Co-ordinating Group) report number 1 (Minimum requirements for an operational ocean-colour sensor for the open ocean), a reduced number of spectral channels (e.g., 7-8) can fulfil the requirements for an accurate atmospheric correction (therefore for an assessment of the aerosol

distribution), and for a retrieval of the phytoplankton (chlorophyll) abundance and distribution as accurate as presently allowed considering the state-of-the art in terms of algorithms. In counter part, detailed studies of coastal zones are out of the reach of such a «simplified sensor».

The ECOSPACE project proposes the launch of a simple ocean colour sensor carried by a μ sat platform, in order to demonstrate the feasibility of a permanent survey of ocean colour at global scale, by means of a future constellation of such small and low-cost satellites. The ideas underlying the present proposal have been dealt with in detail in the IOCCG/SCOR document (IOCCG, 1998), and are oriented toward answering the following question: «**Is it possible to satisfy the requirements for a specific, operational and global ocean colour mission at low cost based on simple sensor ?**»

World maps of phytoplankton pigments (see figure 1) – the main parameter derivable from ocean colour data – generated at a 2, 3 days frequency, are of interest for describing and understanding the changes in the oceanic biota at any time scale of interest, from weeks to decades. The longer the time scale, the longer-term the effects that can be caught. The community of users also evolves along the time scale, from fisheries (NRT survey, 2, 3 days), to local authorities (days to months), and to research organizations focused on biogeochemical cycles, as well as international councils on climate change (years to decades).

The parameters that can be derived from ocean colour spectra include the concentration of phytoplankton pigments (chlorophyll) and of suspended sediments, if any, and the absorption of other substances as carried for instance by rivers (other «research products» may be derived, not on an operational basis, however). Quantification of the spatial distribution of these parameters allows many processes to be surveyed and understood, as, for instance, the evolution of the heat content of the upper ocean (climate), the fate of a peculiar pollution event (coastal monitoring), the occurrence and collapse of phytoplankton blooms (fisheries, see recommendations of the ACP-EU initiative), the changes in regional or global primary productivity of the oceanic ecosystem, and also the global distribution of atmospheric aerosols including desert dusts (climate studies; aims of programs such as IGBP). All these applications are supported by state-of-the-art scientific knowledge, ensuring their feasibility thanks to already existing algorithms. Even if not explicitly referred to so far in this introduction, the international scientific community is obviously also interested in any of the use of ocean colour evoked above.

3. SCIENTIFIC AND ECONOMIC JUSTIFICATION

Scientific and economic justification are detailed in reference document [2].

ECOSPACE will give informations on :

- a. Oceanic primary production in the context of global geo chemical cycles :
 - the photosynthetic carbon fixation is nearly equally shared between land and ocean, phytoplankton use 95% on carbon fixed by ocean.
- b. Oceanic primary production in the context of fisheries/ressources management:
 - in the 21 st century, men have to develop and manage fisheries in sustainable manner
 - initiatives of EC (Ecopath with Ecosim Project) and FAO (Fishbases Project) need these informations for a better management of fisheries.
- c. Global aerosol loading in radiative budget context :
 - New generation ocean colour sensor provide the phytoplankton pigment concentration of the upper ocean as well the atmospheric aerosol optical thickness and type.
- d. Monitoring Coastal Zones and pollutions risks :

- ECOSPACE could offer informations by indirect detection (sediment coming from river flood, massive alga bloom, ...).

4. ECOSPACE MISSION CHARACTERISTICS

4.1. Orbit Parameters, Geometric Resolution And Coverage Analysis

A polar, sun-synchronous, orbit with an Equator descending crossing time between 10 a.m. and noon, or an Equator ascending crossing time between noon and 14 p.m. would be adapted for the ECOSPACE satellite. Such an orbit allows the mid and high latitudes - those where cloudiness is particularly critical for any remote-sensing system - to be more intensively covered than the inter-tropical band; the coverage of this band could be ensured in the future thanks to other satellites of the constellation, some of which being possibly installed on low-inclination orbits.

A global coverage within 3, 4 days at the equator should be attained with a swath of about 750-800 km (for a sensor placed at an altitude of about 700-800 km). A 1-km nadir resolution at ground (IFOV) is largely sufficient for global purposes, and still adapted for monitoring of coastal zones.

4.2. Spectral Information

The set of bands and the radiometric performances must allow atmospheric correction of ocean colour observations to be performed with the required accuracy, and the geophysical parameters to be derived in a meaningful way from the reflectances at the sea level. Table 2 gives ECOSPACE spectral bands.

Following the IOCCG/SCOR recommendations, the combination of the 855-890 nm and 744-757 nm channels is the most favourable for atmospheric correction (maximal avoidance of absorption bands and sufficiently spaced wavelengths). The additional channel 704-713 nm can be very useful in consolidating the interpolation toward the visible domain.

As for the retrieval of the chlorophyll concentration in oceanic Case-1 waters, both reflectance ratios $R(490)/R(555)$ and $R(443)/R(555)$ will be used. So, the combination of 438-448, 485-495 and 550-565 channels is required for Case 1 waters as well as for the detection of sediment dominated

Case 2 waters. The optimal solution for yellow-substance-dominated Case 2 waters seems to rely on a «violet» channel at about 407-417 nm, at least for a simple instrument.

Detecting aerosol absorption (e.g., desert dusts) requires that radiances be recorded around the «hinge point», i.e., at about 510-520 nm, that wavelength where ocean reflectance is roughly independent of the chlorophyll concentration.

Eight bands are therefore recommended, actually forming a set comparable to that selected for the SeaWiFS instrument. Commonality in spectral bands between several ocean colour missions provides important practical, as well as long term scientific advantages. Indeed, it would allow:

- an easy comparison between products from different sensors, even radiometric inter-calibration in fixed conditions
- a full compatibility of operational algorithms for atmospheric correction and then derivation of end products

- a meaningful data merging, at the level of geophysical products (pigment index and aerosol optical thickness) or at the level of the initial quantities (e.g., spectral normalised radiance)
- a long-term continuity of ocean colour observations, based on stable, entirely comparable parameters, and
- therefore, the building of a coherent data base for biogeochemical studies and related modelling activities, for physical studies and models (heating rate, mixed layer dynamics), and for climatological purposes involving the radiative budget and the effect of aerosol loading.

4.3. Radiometric Calibration And Accuracy

In order to detect 10 classes of chlorophyll concentration, (Chl), within each of the 3 orders of magnitude between 0.03, 0.3, 3, and 30 mg Chl m⁻³ (i.e., a total of 30 classes), errors in atmospheric correction must be kept within ± 0.002 in reflectance. Achieving this goal means that pre-flight and In-flight calibration devices (e.g., solar diffusers) and procedures lead to 5 % absolute accuracy and 2 % relative accuracy. The noise equivalent radiance in all channels (NE Δ L) must also be close to those achieved for new sensors such as MERIS, MODIS, i.e., below 0.05 W m⁻² μ m⁻¹ sr⁻¹. This is a realistic goal since the ECOSPACE instrument would be based on existing MERIS modules, for which the above constraints have been already met.

In addition, building a data base of high quality for research and application purposes requires that the calibration be maintained during the sensor life. This is only achievable through indispensable operations of vicarious calibration, in complement to the operation of on board calibration diffusers.

4.4. Dynamic range

Maximal sensitivity must be ensured above the ocean. This means that the detectors are allowed to saturate over bright targets (clouds, Sun glint or possibly most of terrestrial sites).

As an indication, maximum values for TOA radiance recorded above ocean are given in table 2 for an aerosol optical thickness of 2 at 550 nm (the ocean then is not «seen» in this case, yet valuable information about aerosols remain accessible and of interest).

4.5. Sun glint avoidance

The occurrence of sun glint patterns within the swath can be minimized in the case of a single instrument by using a permanent slight across track depointing arrangement.

4.6. Launch opportunity

Our proposed one year (limited by the mini-platform lifetime) ECOSPACE mission demonstration will be successful if simultaneously other in flight experiments (i.e., MODIS, MERIS, OCM) are operating and associated calibration/validation means are available such as those proposed for MERIS in the frame of ESA ENVISAT exploitation AO.

The HELIOS launch opportunity (year 2003, orbital altitude 700 km, ascending node 13h45) has been selected in the proposal by the scientific team in order that the Earth coverage frequency performed by the tandem ENVISAT-ECOSPACE satellites will demonstrate the global Earth coverage capability and the data services which will be provided by a consecutive operational ECOSPACE satellite constellation. This tandem gives a global coverage within 2 days at equator.

So, the satellite ECOSPACE has to be designed to fit into a piggyback accommodation aboard ARIANE 5, the loading environment is defined in the ARIANE 5 documentation.

4.7 Product Descriptions

Three usual product categories are considered here, namely Level 1B, Level 2 and Level 3 products. The content of these products will be as far as possible brought in line with already existing similar products from other ocean colour missions (e.g., SeaWiFs, MERIS). This option ensures the best possible compatibility with other ocean colour data, which is indispensable for a mission whose aims are global research and applications. Other products are user-oriented products and Browse products.

Table 3 provides the product definition and the product usefulness according to the mission objectives.

5. THE ECOSPACE SYSTEM

Given the tight schedule, the cost constraints, the low risks approach (i.e., maintain the project cost, target a fixed launch date, use on-the-shelf parts & algorithms and re-use available on ground equipment for testing & validation), and an excellent knowledge of the proposed application by the scientific-industrial team, the ECOSPACE system development strategy relies as much as possible on existing developments and capabilities, which can be modified and upgraded with reasonable effort. Critical items development within ECOSPACE will be kept to a minimum.

5.1 Instrument

The ECOSPACE ocean sensor concept is driven by the following required features:

- a large field of view of 750 km for 700 km altitude
- a small ground resolution of 1 km at nadir (for 700 km altitude)
- a spectral resolution capability
- a compatibility with mini-platform performances and environments
- a design and development based on existing parts.

The overall ECOSPACE instrument concept is presented in the Figure 4, it is based on the MERIS camera spectrometer.

The detailed block functions are as follows:

- a) the ground imager to provide a large field of view and forms an Earth image on the entrance slit of one MERIS spectrometer, the ground imager uses the design and the mechanical design of the lens of the VEGETATION payload of SPOT 4/5
- b) the spectrometer to provide the spectral resolution by diffracting the light in several bands from 407 nm to 890 nm. As the ground imager optical axis is perpendicular to the spectrometer mechanical axis, a folding mirror is introduced between them.
- c) The focal plane assembly and the detection box unit, which transform and amplify in an electrical signal the collected energy by the optical devices. At the focal plane the formed image is bi-

dimensional:

- one spatial dimension (740 columns) corresponding to the field of view and ground sample
- one spectral dimension (576 bands).

At focal plane level a primary summation of elementary bands is performed. Thus only 29 spectral micro bands are transmitted to the electronic unit. The focal plane assembly and detection box are fully recurrent from MERIS.

- d) The electronic unit includes the detection box unit to convert the analogical signal into 12 bit resolution digital form. This unit also performs spectral micro bands accumulation to reduce the data stream to be stored on board and later dumped to the ground station. At electronic unit level the image format is generated with additional auxiliary data packets from the platform telemetry. The electronic unit also supplies the power to the focal plane and detection box and interfaces the small platform for TM/TC. This electronic unit will be in a large extent recurrent boards (3) from MERIS. Nevertheless two additional boards will be designed and developed to satisfy the ECOSPACE mission requirements.
- e) The calibration subsystem is necessary to guarantee and control the required radiometric accuracy and stability. The diffuser is implemented at the ground imager entrance. It allows the Sun light to be diffused in the entire field of view of the ground imager, in order to offer a spectral calibration source to the instrument. The MERIS calibration subsystem cannot be re-used for large field of view. Thus a new calibration subsystem shall be developed taking into account the MERIS calibration background and experience. For instance, the proposed pre-concept design takes into account the following missions derived from MERIS experience:
- the diffuser has to be oriented according to the same angles which were evaluated to ensure the best light uniformity in the instrument field of view: 65° Sun incidence and same plane containing Sun direction, diffuser normal and lens axis
 - the diffuser stored position could be associated with the closure of calibration Sun aperture in order to limit the stray-light input in Earth imaging mode. This solution can even be made aperture redundant, in order to allow the diffuser removal from the Earth field of view in case of any failure in the hinge mechanism
 - a calibration baffle is installed in order to eliminate stray-light coming from the Earth and from the spacecraft reflecting external surfaces.

The 2 positions of the calibration subsystem are illustrated Figure 5.

- f) To limit the polarisation effect, the ground imager has scrambling plate near the focal plane, each plate, is constituted of 2 wedges of crystal Quartz and one wedge of fused silica, the third wedges cemented together:
- the 2 Quartz wedges provide the required depolarization effect
 - the fused Silica is designed to have the plate external faces parallel.

Table 6 give mass and volume of the different parts of instrument.

The electronic unit is located next to the camera, close to the instrument cold face with a dedicated radiator. The optical head is fixed on the support structure in a way to minimize the thermal elastic sensitivity on internal alignment. Focal plane unit is temperature controlled thanks to an internal heater

subsystem and a conductive link to the cold side radiator. The detection box has been located in a way to keep the electronic link to the focal plane as short as possible for noise control.

The instrument overall layout is presented figure 7, the dimensions are 0,6 x 0,35 x 0,5 m.

As highlighted, the ECOSPACE instrument design will be based on MERIS spectrometer and VEGETATION ground imager. Thus a cost-effective approach can be implemented for the instrument development and the model philosophy is straightforward: limited to the sole instrument flight model. Furthermore the Alcatel Space Industries Cannes Centre know-how in the optical, thermal and mechanical modelling fields allows this model philosophy.

At electronic unit level, as two new boards shall be designed and developed, an engineering model to validate its design and performances will be procured.

The instrument flight model will be used for the whole qualification, which will include the following aspects:

- mechanical (vibration test, mechanical deployment of the calibration subsystem)
- thermal (thermal balance and cycling test)
- electrical (EMC/ESD tests)
- functional
- performances (geometry, spectrometry, MTF tests).

The Ground Support Equipment (GSE) will be to a large extent based on MERIS & VEGETATION GSE. As example, MERIS & VEGETATION GSE will be re-used for the Optical Head (ground imager and spectrometer), optical subassembly (ground imager, spectrometer, focal plane and detection box) and at least for the instrument control. Electrical Ground Support Equipment (EGSE) will be developed for the electronic unit.

5.2 Payload

A L-Band antenna and transmission subsystem will be part of the ECOSPACE payload to offer real time regional data download to regional acquisition station, for instance NOAA HRPT ground stations.

The payload mass is 40 kg, the power consumption is 65 W in daylight and the dimension is 0,6 x 0,6 x 0,5 m.

The TM scenario is to dump every orbit the 1.3 Gbit on board recorded data to the Svalbard receiving station at the rate of 500 kbit/s.

5.3 Platform

Instrument mass and power budgets, data rate and volume as well as the positioning accuracy are fulfilled with a few small European platforms. Both of them are costly attractive (ESA Proba and CNES Micro-Platform, both are compatible with ASAP ARIANE 5 piggyback launch opportunity) with proposed modular technical options which are providing some system design flexibility. Those platform baseline configurations offer telemetry (down link and memory) performances that don't completely match ECOSPACE needs (1.3 Gbit and 5 Mbit/s data down load rate). Thus to guarantee the ECOSPACE Global Mission, an upgraded telemetry has to be foreseen, the memory could be implemented either at payload or platform levels. Table 8 summarizes the main characteristics of both platforms.

5.4 Operation Plan

The ECOSPACE instrument will operate in daylight (within a Sun zenith angle range of +/- 80°). The sensed data will be recorded on board and dumped every orbit to a receiving station located at Svalbard through an L-Band link. Also, the sensed data will also be continuously (except over Svalbard station) downloaded for regional users with upgraded HRPT station.

Calibration coefficients and look-up tables to process the ECOSPACE data will be accessible through Internet. In flight calibration sequences are planned every week over the South pole.

7. CONCLUSION

The ECOSPACE proposal, with instrument based on Meris camera spectrometec allows the development of a low cost satellite system (3 years, 35 MEUROS), precursor of a future operational system of 2 satellites, which give, through ocean colour measurements:

- monitoring of the oceanic phytosphere on the long term
- managing of fisheries in a sustainable manner.

Reference documents :

- 1) Meris FM performances
G. Baudin, R. Bessudo
IAF 98, Sept. 28-Oct. 2 – Melbourne.
- 2) Ecospace : a service oriented Ocean Colour Mission
Prof. A. Morel, G. Cerutti-Maori, M. Morel.
IAF 2000 Oct. 2-6- Rio.

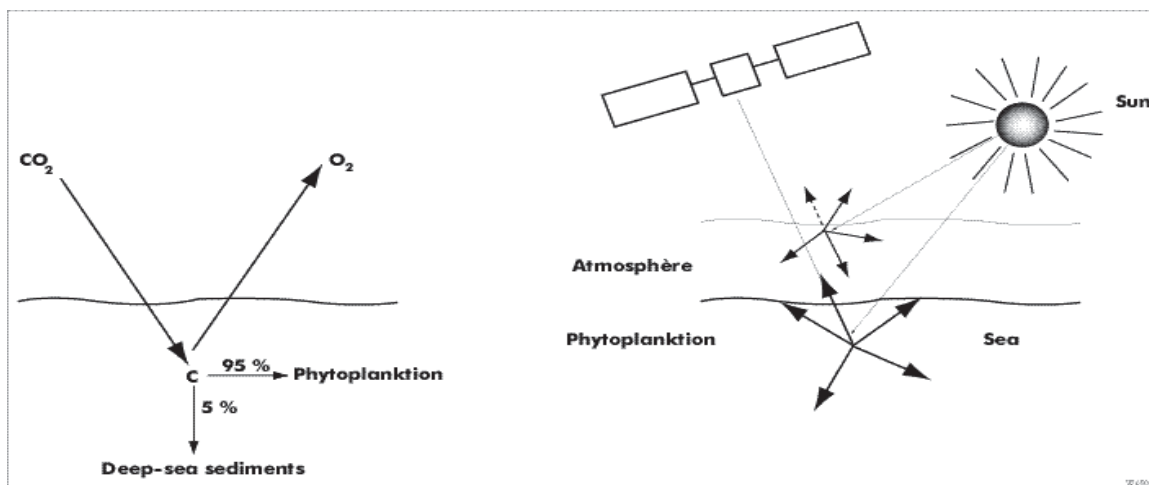


Fig. 1 – Phytoplankton detection principle

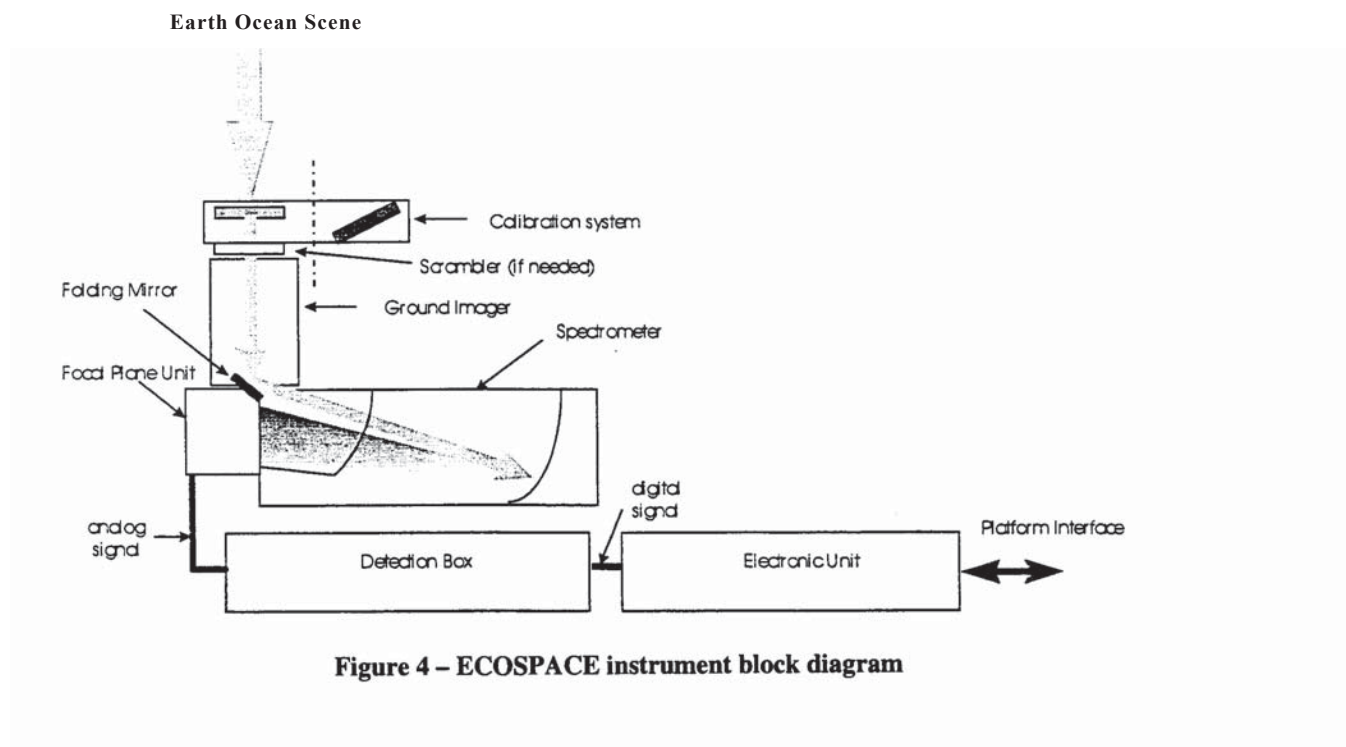
Band Centre (nm)	Bandwidth (nm)	Use	Radiance
412	10	Index of yellow substance absorption	205
443	10	Pigment index retrieval (low concentrations)	189
490	10	Pigment index retrieval (high concentrations)	172
510	10	Discrimination between aerosol types (i.e., absorbing versus non-absorbing)	157
560	10	Pigment index retrieval Case 1/turbid Case 2 discrimination	138
709	7.5	Atmospheric correction consolidation	92
750	12.5	Atmospheric correction; retrieval of aerosol load and type	82
870	30-40	Atmospheric correction; retrieval of aerosol load and type	58

Table 2 - Band set proposed for the Ecospace instrument, their typical use and the associated maximum radiance (in $\text{Wm}^{-2} \mu\text{m}^{-1} \text{sr}^{-1}$)

	Bio-optics / Oceanography	Global Bio-geochemical Cycles	Fisheries – Resources Management	Radiative Budget Studies	Coastal Pollution Monitoring	Product definition
Level 1B	X			X		Calibrated and geo-located reflectance data
2	X				X	geophysical parameters after atmospheric corrections and processing algorithms
3	X	X	X	X	X	accumulation of parameters over a time period and over the whole planet
User-oriented			X		X	products adapted to the users (fisheries, ressources, coastal management)
Browse	X	X	X	X	X	in order to support the selection of data from the ECOSPACE user service web server.

Nota : Auxiliary products used during the processing of ECOSPACE data (e.g. ozone maps, pressure maps, ...) are available on request.

Table 3 – ECOSPACE product definition and associated usefulness



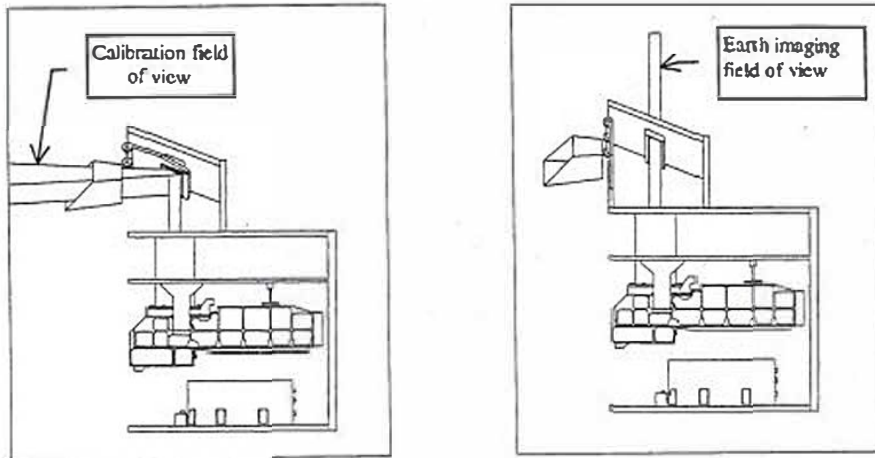


Figure 5 - Calibration principle Calibration mode and earth imaging mode

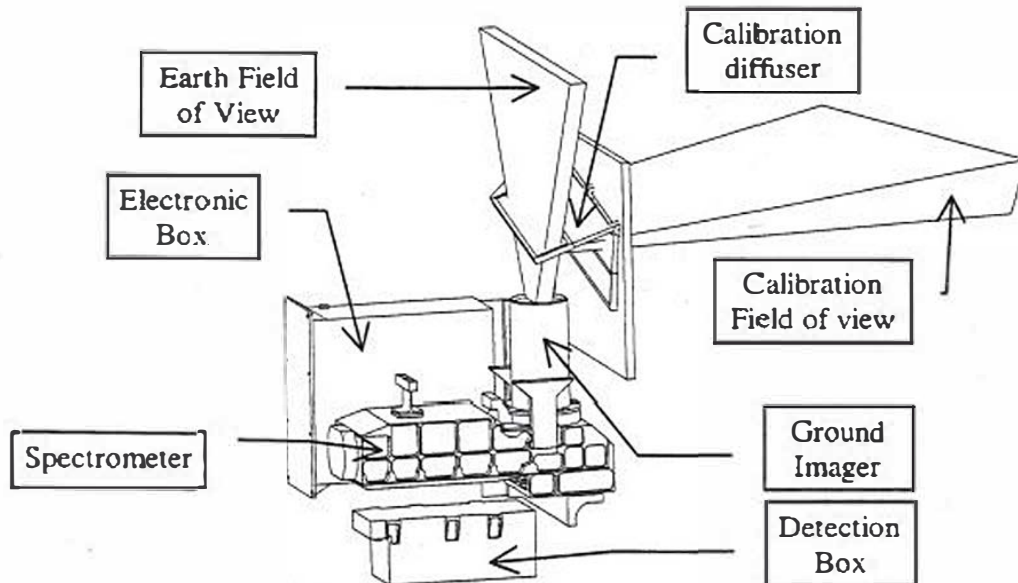


Figure 7 - ECOSPACE instrument layout

PART	MIN MASS (KG)	MAX MASS (KG)	DIMENSION
Ground Imager	1.4	1.6	140 x phi 70 mm
Spectrometer	2.7	3	330 x 116 x 120 mm
Focal plane Assembly	0.9	0.97	Na
Detection Box	0.9	0.95	205 x 96 x 83 mm
Electronic Unit	6.9	8	260 x 210 x 130
Calibration Mechanism	1	1.5	
Calibration Baffle	0.4	0.5	100 x 150 x 50
Structure & Thermal	3	4	
TOTAL	17.2	20.5	

Table 6 – Instrument Budget

CHARACTERISTICS	PROBA TYPE PLATFORM	CNES MICRO-PLATFORM
Overall satellite dimension	600 x 600 x 800	600 x 600 x 800
Overall satellite mass	< 100 kg	< 100 kg
Pointing accuracy	< 0.3°	< 0.3°
Pointing stability	< 0.05°/s	< 0.05°/s
On orbit position and attitude knowledge	GPS with 4 antennas Star Tracker	1 km for LEO orbit GPS optional
Orbit compatibly	Around 800 km	From 400 km to 1200 km for LEO orbit
Propulsion	No	Optional
Power Supply	Solar panel body mounted AsGa cells Battery: NiCd 7 Ah 28 V	Solar Array winds AsGa cells Battery: NiCd 7 Ah
Telemetry	Band S patch antenna 1 Mbit/s-CCSDS protocol	Band S 400 kbit/s-CCSD protocol
On board memory	1 Gbit	1 Gbit
Option	TM to be discussed	TM up to 20 or 40 Mbit/s Band X Memory 20 Gbits
Payload Typical Mass	24 kg	40 kg
Payload average consumption	To be determined considering satellite overall consumption 90 W peak and 30 W in eclipse	15 W to 40 W depending on the orbit

Table 8 - Main characteristics of PROBA (ESA) and micro-platform (CNES)