A CONCEPT FOR A REGIONAL COASTAL ZONE MISSION

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ABSTRACT:

Recently, applicational and technological studies have been performed by a group of scientists and industry, led by DLR, basing on experiences with ocean-colour sensor MOS-IRS. The result is a new low-cost mission concept with special emphasis on coastal-zone remote sensing, which will be able to fill an imported gap in Earth observation data, i.e. to detect the strongly needed data for a better understanding of the rapid changes of coastal areas and to provide a tool for monitoring catastrophical hazards.
The proposed low-budget mission ECOMON (Regional Ecological Research and Monitoring) will provide visible to the thermal infrared data with relatively high spectral (1.4 nm) and spatial resolution (100 m). The VIS–SWIR–TIR spectral region will be covered by 16 selectable channels in the visible, four channels in the SWIR, and one in the TIR. The swath width will be 400 km and a off-nadir tilting possibility ensures a high repetition rate of two days (for latitudes > 30°). Using mainly compact off-the-shelf technology and carrying this payload on a mini-satellite can ensure a low-budget mission with adequate performance for coastal zone observation.

1 INTRODUCTION

The background for the proposed ECOMON mission is the technological and scientific experience gained during the ongoing MOS-IRS (Zimmermann & Neumann, 1996) experiment. The imaging spectrometer MOS-IRS is on one side a technology demonstrator and on the other side quantitative and qualitatively new (hyperspectral) interpretation algorithms have been developed from the experiment’s data by many research institutes such as DLR and JRC.
With this experience the following research task has been studied together with partner research institutes and industry:

(1) to define the requirements for a regional coastal zone imager and
(2) to perform a concept study for a mission that is adequate for monitoring and management of coastal zones.

The result of the investigation are a proposed technical concept (Neumann et al., 1998) in form of a mini satellite which is able to carry the entire payload (VIS-SWIR-TIR sensors) in a 775 km sun-synchron orbit with a envisioned mission duration of 5 years. Because of low power consumption, reduced mass, small envelop of the payload, and avoidance of large solar array panels (with pantograph mechanisms), the satellite's mass and costs can be reduced significantly to < 300 kg and < 45 M€. With the help of an advanced attitude control subsystem the whole S/C can be tilt to a desired angle (up to ± 30° off-nadir). This tilt angle can be changed for every orbit and has to be chosen before the beginning of recording. The pointing accuracy will be ± 0.16° together with a precise attitude knowledge of ± 0.003°. This technical concept will be able to meet the requirements for a regional coastal zone mission.
More details on mission requirements, the sensors and spacecraft are discussed in the following sections.

2 MISSION REQUIREMENTS

In the past decades, interests of government and scientists increased to improve the observation of coastal zones because it became evident that it is time to solve major environmental problems—mainly caused by economic and social activities, such as industry and tourism. In contrast to global orientated missions, a tool is searched for monitoring and management of coastal zones. It should provide data for investigations of the high productive coastal waters, to detect and understand sources and spread of pollutions and to generate valuable data for sustainable coastal management.
This tool should also be able to provide the required data immediately in case of catastrophic hazards. A spectral range from visible to thermal infrared is necessary to account for atmospheric influences over turbid waters, and to assess near-shore land features for interaction studies. Moreover, it should allow strongly needed research on the topic of case-2 water algorithm development, the discrimination of algae types, the development of atmospheric correction algorithms and many others more. From Table 1 an excerpt of these ECOMON requirements can be retrieved.
These requirements have a high multidimensionality in terms of the required spectral, spatial and radiometric resolution, the spectral range, and the repetition rate. In a first step the orbit—together with the swath width—have been selected for guaranteeing a high repetition rate. Thereafter the spectral/spatial and radiometric requirements have been described in detail.

Table 1: Research needs and ECOMON requirements for assessment of coastal zones

Research need	ECOMON requirement
algorithm development for retrieval of water constituents in case-2 waters	➢ spectral high resolution ($\Delta\lambda$ ~ 5 nm, 400-800 nm) ➢ sufficiently large number of spectral channels (~ 10-12) ➢ absolute calibration, Sun calibration, high radiometric resolution
algorithm development for regional and seasonal specifics of case-2 waters	➢ programmability of spectral position and halfwidth
discrimination of algae types	➢ programmability of spectral position and halfwidth
development of specific algorithms to assess HAB's/red tides	➢ programmability of spectral position and halfwidth
account for atmospheric influence over case-2 waters, atmospheric correction algorithms	➢ extended spectral range (800 – 1000 nm, SWIR), water vapour channels
assess water characteristics of lakes and water reservoirs	➢ spatial resolution ≤ 100 m
assess spatial characteristics of coastal waters phenomena	➢ spatial resolution ~ 200 m ➢ swath width > 200 km
assess time dynamics of coastal wasters and lakes phenomena, e.g. algal blooms	➢ ground repetivity ≤ 2 days ➢ swath width ~ 400 km
assess near-shore land features (vegetation, catchment areas, snow/ice cover)	➢ spatial resolution ≤ 100 m ➢ extended spectral range VIS/NIR + SWIR ➢ spectral adaptation in VIS/NIR to land features
primary production in coastal waters	➢ thermal infrared
coastal dynamics	➢ spatial resolution ≤ 100 m
coastal currents, water masses discrimination	➢ thermal infrared
investigation of special events and hazards	➢ high repetivity for special events ➢ cross-track tilt capability
up-down-scaling of physical variables, data merging	➢ compatibility of selected spectral channels with other missions

3 MISSION CONCEPT

3.1 Orbit

Preliminary orbit calculations showed that a 775 km Sun-synchronous (semimajor axis = 7153 km) orbit with 98.5° inclination can fulfil the basic scientific observation requirement of orbit ground track with a repetivity after 3 days. Because of the S/C tilting capabilities it will be possible to point the whole S/C within ±30° off nadir what would increase the sensor's field of view (FOV) of ~30° to a possible field of regard (FOR) of ~87°. This FOR would represent a detection possibility within a swath of ~1570 km (for latitudes > 30°) instead of ~400 km. To demonstrate the target detection possibility Figure 1 shows the orbit ground tracks for day 1 and day 2. The swath width results from the calculated possible FOR because of tilting the 30° FOV for ± 30°. Note, that the figure does not include the ground track of day 3, which lays about 930 km eastwards of the day 2 track. The 3rd day's off-nadir tilt would realise a global repetivity after the second day.

Concluding, the off-nadir tilting possibility would ensure consecutively monitoring of catastrophic hazards within 2 days for latitudes > 30° and within 3 days globally.

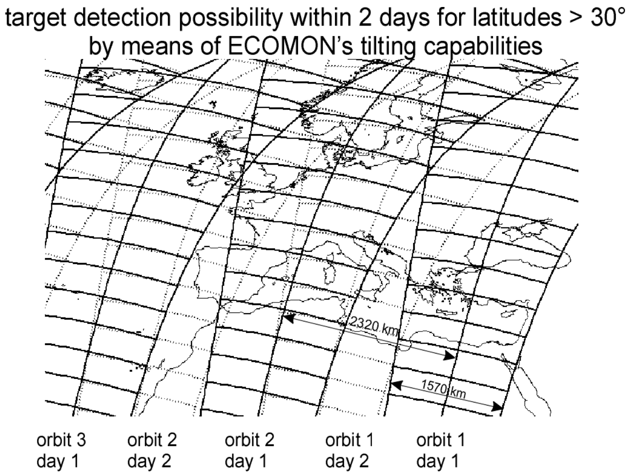

Figure 1: Descending passes for Sun-synchronous orbits

3.2 Payload

The proposed ECOMON payload consists of an Offner-type imaging spectrometer, a SWIR camera and a TIR whiskbroom scanner (see Table 15). The arrangement layout of the entire payload is mainly driven by observation requirements, design constrains for the sensor/module, calibration requirements and S/C allocation constrains (e.g. mass, power).

Table 2: Overview of the ECOMON payload

Spectral region	Number of instruments	Type of instruments	Swath [km]	No. of spectral channels
VIS–NIR (0.4 – 1.05 µm)	4	imaging spectrometer	4 x 100	ca. 16, (selectable)
SWIR (1.2 – 2.4 µm)	2	beam splitting camera	2 x 200	4
TIR (~10 µm)	1	whiskbroom scanner	1 x 400	1

3.2.1. The boundary conditions are summarised for the VIS spectrometer and the SWIR camera in the following. These requirements and constrains are not valid for the TIR scanner because of main differences in the optical layout (whiskbroom scanner) and the calibration requirements (no Sun calibration is needed).

Sensor design conditions:

- similar sensors (cameras or spectrometers) need identical mechanical, optical and electronic set-ups to reduce fabrication costs,
- each of the sensors have to work autonomously (the failure of one sensor should not have effect on the other instruments),
- the sensors' optical part have to be self-supporting and designed as closed blocks (for the easier realisation of sensor adjustment and obstruction of incoming straylight).

Calibration requirements:

- Sun calibration must be realised via diffuser to assure Sun radiance measurements during terminator crossing when the Sun illuminates the diffuser (which has a standard orientation to the Earth),
- the diffusers have to be turned into the sensors' FOVs,
- the diffusers should be placed vertical to the flight direction for achieving a uniform illumination of the pixels and spectral channels,
- the Suncal unit's aperture and the baffle system should be symmetrical regarding the seasonable mean angle Sun–flight direction to avoid straylight,
- internal control with LEDs and mini lamps has to be ensured to provide additional calibration measurements,
- the diffusers (or parts of the moving system) should also be used as shutter for enabling dark measurements,
- an illumination of the diffusers by LEDs and/or lamps should provide additional calibration of the sensors and/or diffuser.

S/C allocation constrains (for a mini satellite < 300 kg):

- mass allocation: ≤ 80 kg (sensors);
  ≤ 25 kg (sensor support)
- power allocation: ≤ 115 W (peak)
- data rate allocation: ≤ 85 Mbit/s

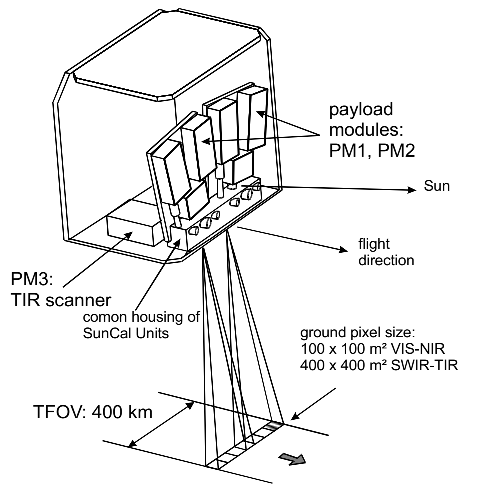

Figure 2: ECOMON S/C with three payload modules

3.2.2. ECOMON's sensor and module arrangement: The scientific payload of the proposed mission consists of three different payload modules (PM1, 2 and 3). The similar payload modules PM1 and PM2 will be mounted on the front side of the S/C. Each of the similar PMs consists of two VIS-NIR spectrometer and one SWIR camera. To makes up a TFOV's swath width of 400 km (of 200 km for each module) sensors and modules will be arranged in a fan-shaped form. PM3 is the TIR whiskbroom scanner which will be placed in the bottom part of the S/C behind PM1/2. The overall mass of the TIR scanner will be less than 25 kg; that of PM1/2 less than 45 kg. The schematic arrangement and the resulting swath are shown in Figure 2.

3.2.3. ECOMON's VIS-SWIR payload module: The proposed mounting scheme of the VIS-SWIR payload module is depicted in Figure 3. A base plate serves to support the VIS-SWIR sensors and the SunCal Unit. For each payload module (PM) the VIS/NIR and SWIR instruments and the SCU are mounted on a base plate. Whereas the VIS-NIR is covered by two similar Offner-type imaging spectrometers, the SWIR range is covered by a SWIR-camera which is placed between the spectrometer fore-optics. The three optical blocks of a PM have a common SunCal unit which is placed underneath the VIS-SWIR sensors to ensure the Sun calibration and LED, lamp calibration. The over all dimensions of one VIS–SWIR PM are about 500 x 700 x 150 mm^3; the mass is ~ 22.5 kg.

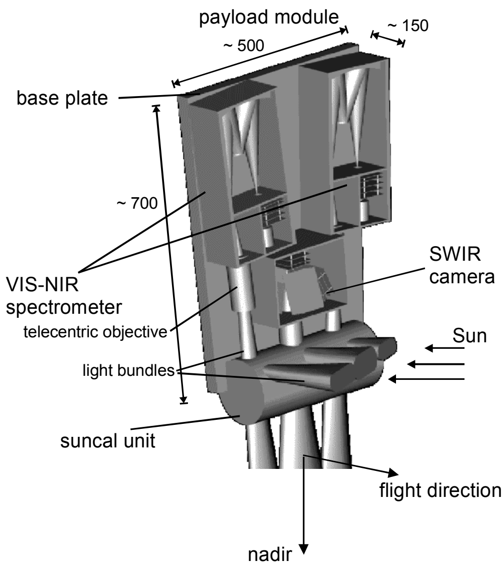

Figure 3: Mounting scheme of the payload module (PM)

An Offner-type imaging spectrometer is covering the VIS-NIR. The spectrometer prototype using a telecentric fore-optics and trapezium profile grating is currently under development at DLR Berlin. The following Table 3 gives an overview of the main performance parameters of the imaging spectrometer for the proposed mission.

Table 3: Performance data of the Offner-type imaging spectrometer (flight altitude 775 km)

Parameter	Value
Entrance optics	telecentric, 4/100
FOV	7.616 ° = 0.13312 rad (103.2 km)
IFOV (pixel size)	0.007438 ° = 0.13 mrad (100.6 m)
Spectral range	400 – 1000 nm
Basic spectral resolution	1.5 nm
Channel halfwidth	binnable up to 20 nm
Number of selected channels	16 (tbd)
Polarisation sensitivity	≤ 1 %
Second order spectrum	≤ 0.5 %
CCD-detector, 1024 x 512 elements (used)	13.312 mm x 6.656 mm
Dynamic range	16 bit
Element size	13 µm x 13 µm

SWIR camera: The research task in the SWIR range will covered by four spectral channels, i.e. three atmospheric window channels and one water vapour channel. The radiation of the ground pixel is separated spectrally and focussed on four different detectors. The spectral separation is carried out by a beamsplitter assembly. It consists of a set of prisms with dichroic coatings. The spectrally resolved radiance is detected by thermoelectric cooled line detectors. The sensor's dynamic range is between 0.02 – 10 µW/cm²srnm what will cover most of the applications in the SWIR. More instrument details can be retrieved from Table 4.

Table 4: Performance data of the four-channel SWIR camera (flight altitude 775 km)

Parameter	Value
Entrance optic	~ 4/100
FOV	14.5° (~ 200 km)
IFOV (pixel size)	< 400 m
Spectral range	1.2 – 2.3 µm
Centre wavelength	1.24, 1.38, 1.63, 2.20 µm
Channel halfwidth	0.01– 0.1 µm
Dynamic range	0.02 – 10 µW/cm²srnm
Radiometric resolution	16 bit
Number of channels	4

The thermal infrared sensor is a conventional mechanical whiskbroom scanner based on a study contribution of Kayser-Threde, Germany. This sensor type has been selected with respect to costs, availability, technical risk and complexity. Via scanner mirror, optics and filter the spectrally separated thermal radiation is focused on a single element CMT (HgCdTe) detector, which will be thermoelectrically cooled: This detector is located in an integrated dewar assembly which has a cold stop to provide effective cold shielding. Calibration blackbodies will be integrated in the unused field angles of the scanner, so that their signals can be referenced at the beginning or ending of every scanned line. In Table 5 more technical details can be found.

Table 5: TIR scanner performance data

Parameter	Value
Spectral range	10 – 12 µm
Dynamic range	12 bit
Entrance optics	~ 6/ 300
Temp. range	240 K – 340 K
ΔT	< 0.5K
FOV	30°
Ground pixel size	300 m²
Detector	HgCdTe (~ 160 K thermoelectric cooled)
Total mass	< 25Kg
Envelope	320mm x 250mm x 130mm
Power consumption (OPM)	25 W

In-flight Calibration guaranties the re-calibration of selected instrument parameters during the flight mission in providing a reference to extraterrestrial Sun irradiance or other radiance sources (e.g. lamps, blackbodies). The TIR scanner will be re-calibrated by two blackbodies of different temperatures. In contrast, the SWIR cameras and the spectrometers perform in-flight calibration by an advanced procedure: The technical realisation of this calibration approach encloses internal sources and an external calibration unit (SunCal unit). Additional shutters will guarantee to perform the calibration with internal sources and/or dark signal measurements (see Figure 4).

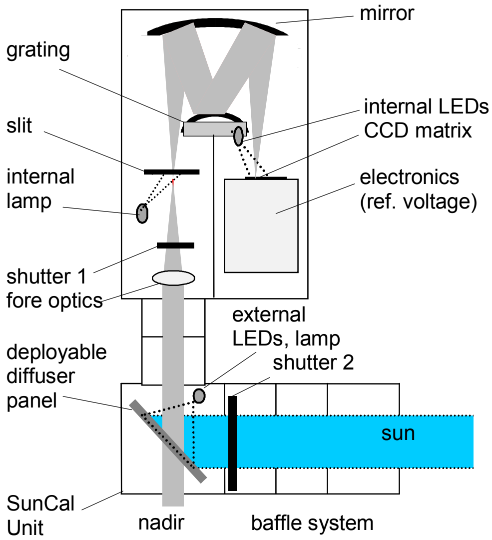

Figure 4: In-flight calibration tools for the imaging spectrometer

o Internal calibration: The internal calibration components consist of reference voltages, LEDs, mini lamps and a shutter for darkening. When shutter 1 closes the instrument, the internal calibration can be performed: after dark measurements, the check of the electronic data is ensured by reference voltage in the electronics. The CCD performance (e.g. on-chip amplifier linearity check, conversion factor determination and trap correction) is checked when the CCD is illuminated with LEDs and a characterisation of the spectrometer's spectral and geometric parameters is provided by the internal lamp.

o External calibration (SunCal Unit): The calibration cylinder of the SunCal Unit guarantees the correct alignment of the diffuser for the calibration (diffuser towards the sun during terminator crossing), for dark signal measurements, and for nadir measurements (free FOV). The calibration procedures consist of Sun, mini lamp and LED calibration. The Sun calibration is realised during terminator crossing by turning a diffuser into the FOV. The spectral radiance of the Sun illuminated diffuser depends on its BRDF, and therefore it can be used as an absolute calibration source. During lamp and LED calibration the diffuser is illuminated by the mini lamps and the LEDs, but neither the Sun light nor Earth reflectance are able to enter the SunCal unit (shutter 1 open, shutter 2 closed). The measurements of this calibration procedure allow to check (1) a possible spectrometer degradation (because light passes all optics before detected), and (2) a possible diffuser degradation in comparison with Sun calibration (Nieke et al., 2000).

3.3 Spacecraft Platform

The proposed S/C belongs to the category of mini satellites having an envelope of 1 x 1 x 1.2 m³ and a mass budget of ca. 300 kg based on a contribution by OHB-System, Germany. Because of the low power allocation of the payload (ca. 230 W in operation mode) the satellite will work with a three small panel solar generator (GaAs semiconductors). One panel is attached to one S/C side and the other two are de-folded in orbit after the launch phase. During the launch phase these panels are attached to the S/C sides. The GaAs generator will charge the batteries during the pole flyover and outside the ground station visibility, when no imaging takes place.

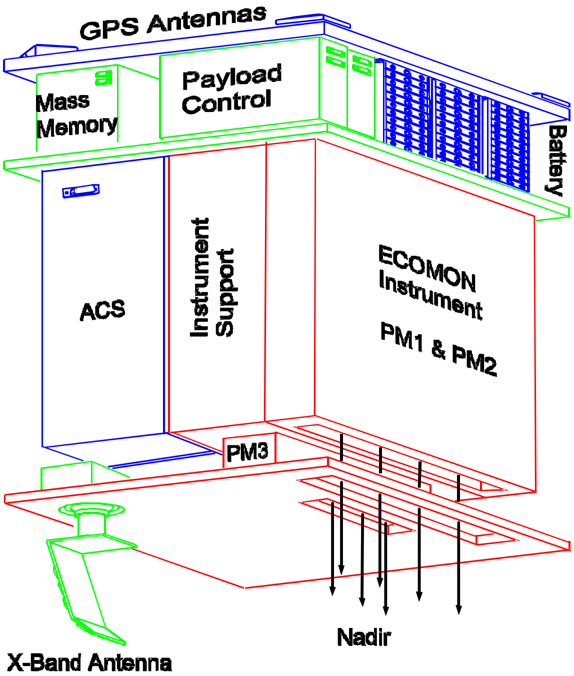

Figure 5: S/C's instrument accommodation

The main features of the S/C comprise advanced Attitude and Orbit Control Subsystem (ACS) technology allowing tilting manoeuvres of up to ± 30° along or cross track, and an instrument support subsystem to provide the capability of storing 85 MBit/s sensor output into a data storage of 25.6 GBit minimum storage capability, including the appropriate X-band downlink (100 MBit/s for real-time transmission).
Preliminary subsystem accommodation of the S/C is depicted in Figure 5. A summary of the proposed S/C is shown in Table 6.

Spacecraft Summary

Name		**ECOMON**
Life Time		5 years
Orbit		
Altitude		775 km
Inclination		98,5 °
ECT		TBD A.M.
P/L DH		
Sensor Data Rate		85 Mbit/s
Memory		33 Gbit
Science Data		26 Gbit
Downlink		100 Mbit/s
P/L High Rate Downlink		
Frequency		8200 MHz
Data Rate		100 Mbps
EIRP		32,0 dBW
Margin		7,5 dB
S/C total		
P/L +Supp. Mass		105 kg
total Mass		300 kg
Volume	width	1000 mm
	length	1000 mm
	height	1200 mm

Power Subsystem	
total Power	253 W
P/L Energy	222 Wh
total Energy	423 Wh
Power Bus	28 V
Solar Generator	
Type	GaAs
Eta	20%
Panel Area	3,5 m²
Power EOL	755 W
Gen. Power	570 Wh
Mass	27 kg
Batteries	
Type	NiH2
Capacity	644 Wh
Mass	20 kg
TMTC Link	
Frequency	2000 MHz
Data Rate	10 kbps
EIRP	-13,0 dBW
Margin	9,8 dB

Table 6: Summary of the ECOMON S/C

The S/C has to ensure a precise attitude knowledge. Therefore, the 3-axis stabilised S/C will use an ACS, which consists of star sensor, Sun sensor, gyros and wheels. This system will enable a high pointing accuracy of ± 0,03° together with a precise attitude knowledge of ±0.003°. In order to increase the regional coverage, the sensor swath will be capable of being shifted to the maximum useful off-nadir angle of about ± 30°. This can be performed by using the satellite control system to rotate the whole satellite accurately to the desired angle before recording of the remote sensing data begins.

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REFERENCES

Neumann, A, G. Zimmermann, N. Hoepffner, A. Perdigao, T. Pyhälahti, J. Gower, T. Platt, G. Coste, A. Ginati, S. Hofer (1998). ECOMON – A dedicated mission for regional ecological research and monitoring. Mission Proposal in response to ESA Call for Earth Explorer Opportunity Missions, Berlin, pp. 1– 65.

Nieke, J., M. Solbrig, K.-H. Sümnich, G. Zimmermann, H.-P. Röser (2000). Spaceborne Spectrometer Calibration with LEDs. *SPIE Conference on Earth Observing Systems V in San Diego*, USA, SPIE Vol. 4135.

Zimmermann, G., A. Neumann (1996). Imaging Spectrometer for Ocean Remote Sensing. *International Symposium of the International Academy of Astronautics (IAA)*, Berlin, Nov 4–8 1996, pp. 113–122.