FUTURE SATELLITE SYSTEMS FOR EARTH OBSERVATION MISSIONS

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ABSTRACT

This paper provides the outline of near future Earth Observation satellite systems currently investigated on national or European level. These concepts ranging from hyperspectral science and research towards operational very high resolution constellations for security services. Special topics presented are operational Greenhouse-Gases monitoring, operational coastal zone monitoring from GEO, as well as maritime surveillance:

- **Very high resolution SAR and optical mission** below 1m resolution are proposed for reconnaissance and dual-use applications. The main user requirement is a fast system response time. Regarding this topic, next generation system core elements will be presented.
- **EnMAP** is featuring innovative hyperspectral sensor systems for detailed and global analysis of eco-system parameters. The sensor provides more than 200 spectral channels from VNIR to SWIR with a spatial resolution of 30m.
- **CarbonSat** provides to the global measurement of Greenhouse Gases (CO2 and CH4) to enable reliable source/sink characterization. A constellation of Carbon-Satellites provides independent emission verification with transparency. A international operational constellation of five CarbonSat satellites is the solution to acquire daily global CO2 and CH4 measurements.
- **Ocean-Colour from GEO** will be a sustainable source of intra-daily data relevant to coastal zone services relating to environment monitoring, fisheries management and coastal water pollution. The system will provide 14 spectral channels in VNIR with 300m spatial resolution. This will complement the GMES Sentinel-3 mission where Sentinel-3 provides higher resolution and the OC-GEO provides frequent revisit.
- **Space-based Automatic Identification System (AIS) Constellation** is designed as a system of small AIS satellites for receiving logistic and navigation data from ships. The system already exists on a terrestrial basis for coastal areas but the introduction of a satellite system will enable global ship detection. Optical or radar ship detection will complement the data for the maritime surveillance.

For security applications, fast delivery of large data volumes is an issue for all very high resolution systems. GEO data relay satellites are currently investigated as a possible solution for the growing demand of data traffic from EO satellites to ground stations.

A common factor in the varied selection of missions is that high performance can be achieved with small satellites, which enables a faster development and lower overall cost. The mission concepts will be outlined as well as the key features of payloads, and overall systems.

1. INTRODUCTION

Earth Observation (EO) has become indispensable for monitoring of geo-physical processes, resources, environment and security applications. To fulfil dedicated user needs in the future, sustainable services will require more and more high-quality geo-information data at improved spectral resolutions (multispectral or hyperspectral) and/or spatial resolutions down to less than 1m.

The main bottle-neck for fast delivery of data and increased data volumes is the downlink from sensor data down to the ground station. Here existing technologies can be used for smart data relay system in geostationary orbit (GEO). The GEO provides also the best location for high frequent or intra daily observations of environmental changes, like chlorophyll, plankton, algal blooms and sediments in coastal zones.

OHB-System has successfully launched the SAR-Lupe satellite constellation for VHR SAR imaging. Based on this heritage the next generation platform for civil applications will be able to accommodate high performance EO payloads of both categories, optical as well as microwave (synthetic aperture radar - SAR).

2. SAR-LUPE CONSTELLATION

SAR-Lupe (Fig 1) is a German satellite system with the primary objective to generate SAR images with high resolution for military reconnaissance purposes. The customer is the BWB (Federal Office of Defence Technology and Procurement).
The complete SAR-Lupe system, sketched in Fig 1, consists of a space segment with five identical LEO satellites, a ground segment and a user segment.

Figure 1: SAR-Lupe System

The first Flight Model (FM1) was successfully launched on 19 December 2006 and subsequently handed over to the customer. The fifth launch was performed on July 2008 completing the satellite constellation. In cumulative orbit life-time the five SAR-Lupe satellites is therefore > 13 years.

Figure 2: SAR-Lupe Integration on COSMOS Launcher

SAR-Lupe satellites are in the 800 kg class and provide an integrated BUS / SAR system with a highly innovative SAR-sensor concept.

The SAR-Lupe satellite concept is characterised by the following features:

- Large conventional parabolic SAR antenna, which is rigidly mounted to the satellite structure to achieve a simple mechanical design
- SAR antenna dual used for imaging and data transmission
- Attitude Control System, which performs high accuracy pointing manoeuvres of the entire satellite during image acquisition and P/L data downlink.
- Integrated and modular design for satellite bus and SAR payload sensor
- Few and simple mechanisms yield reliability and cost efficiency
- Command data relaying through Inter-Satellite Link yields reduced system response time

Figure 3: SAR-Lupe Satellite

The ACS features high performance attitude knowledge and control capabilities. Its actuators comprise reaction wheels and magnetic torquers; its sensor suite consists of a star tracker assembly, a magnetometer, GPS receivers and sets of sun presents sensors and gyroscopes. The OCS allows for compensation of the altitude decay due to the residual air drag and for EoL de-orbiting. It relies on a robust mono-propellant hydrazine system.
Telemetry is done either in X-band and S-Band, and telecommand and housekeeping data are exchanged via S-band. The power subsystem features:

- 2.4 m2 solar panel of GaAs cells, 550 W @ EOL
- 2x 66Ah Li-Ion batteries
- 2900 W / 100 A peak power / current

From this concept OHB's standard medium-sized platform with agile and precise pointing capabilities is derived.

The European SAR-Lupe G/S Architecture (E-SGA) project aims on the transformation of the national SAR-Lupe reconnaissance system into a multinational system and establishment of a system union together with the French space borne reconnaissance system HELIOS II.
The FSLGS (French SAR-Lupe Ground Segment) project enables the French Defence Department to access the radar data capabilities of the German SAR-Lupe System. OHB-System as the prime contractor performs design, establishment, and operation of the E-SGA and FSLGS.

3. NEXT GENERATION VERY HIGH RESOLUTION SYSTEMS

Timely availability of VHR imagery of ≤1m is a fundamental driver for security and safety applications. Satellite missions are excellent means for providing such imagery due to their capability of providing access to any point on the Earth in a short timeframe.

Two mission concepts are being developed: A SAR mission as a reliable source for weather-independent day and night observations, and an optical mission providing panchromatic and spectral information in easy-interpretable images.

For a complete next generation VHR system, including space and ground segment, comprehensive trade-offs have to been performed:

- camera performance,
- orbits and number of satellites,
- downlink performance,
- satellite agility,
- ground processing time,
- number of ground stations,
- reliability & costs,

The figures shown below provide an overview of current OHB-System design solutions for VHR Earth observation missions. Fig. 4 outlines the satellite design for a high resolution SAR mission and for a high resolution optical mission based on two apertures.

An overview of specific features provided by the potential next generation system is listed below.

System	
System capacity	90 spot images/day (1 shift, 40% clouds)
Survivability	Resident against space environment, secured against hijacking, and Electromagnetic Counter measures (ECM)
Security	Secured and encrypted data links: satellite / ground; ground / ground
Satellite	
Image resolution	PAN: 50cm / MS: 2m at Nadir
Localization accuracy	<10 m for Level 3 processed image data (depending on the DEM accuracy)
Spot image size	15km x 15km (14Gbit)
Data storage and download	Capacity >1 Tbit (EOL), input up to 2x8 Gbit/s, output up to 1 Gbit/s
Transmission per satellite	
Transmission	X-Band (8 GHz), 600 Mbit/s using dual polarization
Images per day	90 (CR = 1,5) or 360 (CR = 6)
Ground Segment	
Processing time	< 2h from Level 0 to Level 3 for one spot image
Archive size	700 TBytes for 65.000 spot images for 7 years operation
Interoperability	Prepared for multi-user capability and for Transportable Remote Ground Station

Table 2: Overview of specific features provided by the potential next generation system

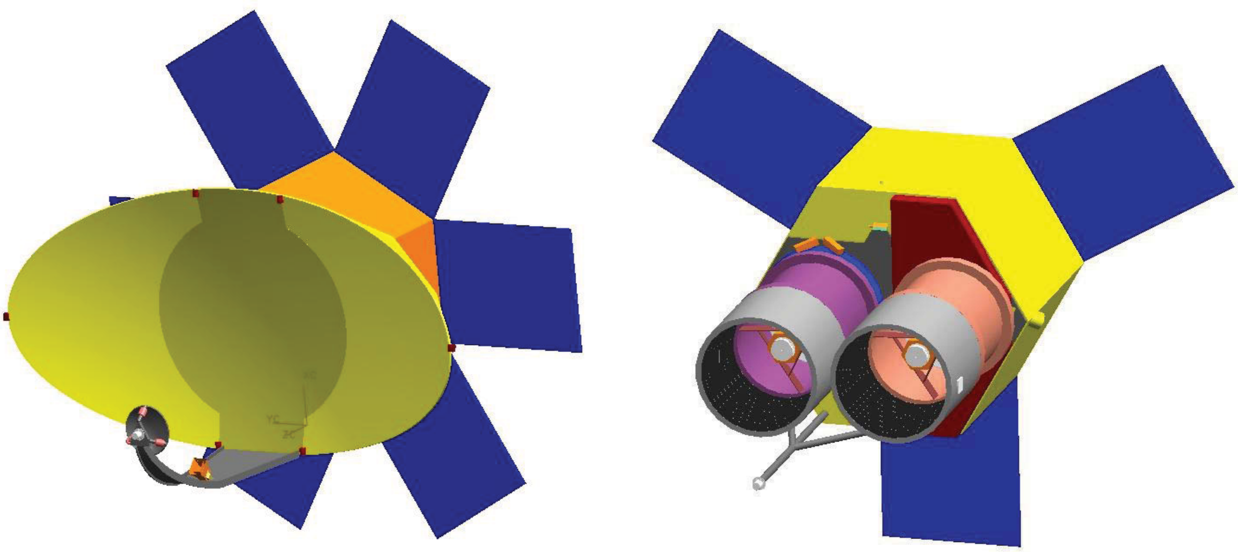

Figure 4: OHB-System Satellite Solution for future high Resolution SAR and Optical Missions

4. ENMAP

The Environmental Mapping and Analysis Program (EnMAP) is a joint German initiative founded by the DLR and lead by the GeoForschungsZentrum Potsdam, under the industrial prime ship of Kayser-Threde. The EnMAP launch is planned for 2011 comprising a mission duration of at least 5 years.
With its hyperspectral capabilities covering the visible, near- and short-wave infrared wavelengths, EnMAP will provide high quality Earth observation data on a contemporary and frequent basis. EnMAP gains information based on about 250 spectral bands in the wavelength range from 420 nm to 2450 nm and with a spectral resolution of 5 - 10 nm. The ground sampling distance is 30 m x 30 m with a swath width of 30 km. The imaging capacity of EnMAP will be at least 5000 km per day.
The EnMAP satellite platform (Fig. 5) is derived from the heritage of the SAR-Lupe mission and therefore under OHB-System responsibility. It therefore comprises an in-orbit proven platform for accurate, high resolution Earth observation purposes and provides a very suitable and cost effective solution for the EnMAP mission. Its key advantages are the full redundant, modular and flexible configuration, a highly accurate attitude control concept and a high rate payload data processing chain with broad storage and downlink capacity.
The EnMAP payload, the Hyper Spectral Imager (HSI), is accommodated in a separated compartment on top of the spacecraft platform to account for the demanding stability and thermal requirements of the optical system. Furthermore, this accommodation enables a maximum independency for easy assembly of both, the payload and the bus subsystems.

Key figures of the EnMAP satellite platform are:

Overall Satellite	
Mass at Launch	811 kg (w/o margin), incl. 50 kg propellant
Payload mass	265 kg (w/o margin)
Volume	1.8 x 1.2 x 1.1 m³
Launcher	compliant to all standard LEO launchers
Satellite Platform	
Dry Mass	496 kg
Structure	Al sandwich panel concept with internal shear frame
Thermal Control	Passive cooling of electronics with heat pipes and radiator surfaces, active temperature control of the OCS, active survival heating for P/L after recovery from safety mode
Power Generation	Solar Panel: fixed, 945 W EoL Battery: Li-Ion, 2 modules (117 Ah)
Attitude Control	3-axis-stabilised, high accuracy and agility to fulfil mission requirements, autonomous sun-pointing in normal mode and safety mode
Orbit Control	Hydrazine blow-down system, 2 thrusters with 1 N each
Data Storage	512 Gbit (EOL), including lossless compression
Downlink	X-Band, 320 Mbit/s, CCSDS compliant
Operations	Secured TM/TC via S-Band, CCSDS compliant, operated by German Space Operations Centre (GSOC)

Table 1: Overview of specific features of the EnMAP satellite platform

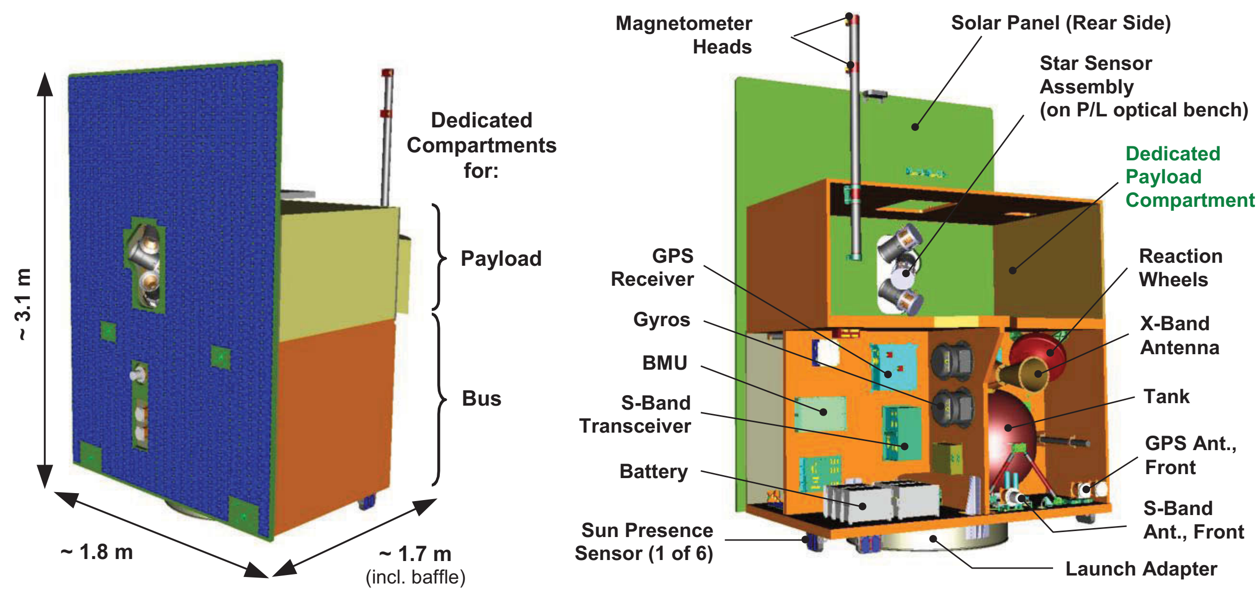

Figure 5: EnMAP satellite based on the OHB SAR-Lupe satellite bus

5. CARBONSAT

Carbon dioxide (CO2) and methane (CH4) are the most important manmade greenhouse gases (GHGs) which are driving global climate change. Currently, the CO2 measurements from the ground observing network are still the main sources of information but due to the limited number of measurement stations the coverage is limited. In addition, CO2 monitoring and trading is often based mainly on bottom-up calculations and an independent top down verification is limited due to the lack of global measurement data. The first CO2 and CH4 mapping from SCIAMACHY on ENVISAT shows that satellites add important missing global information. Current GHG measurement satellites have to collect data over a year or even longer to produce global regional fluxes products. Consequently global, timely, higher spatial resolution are required.

Figure 6: 5 Satellite daily coverage

In response to the urgent need to support the Kyoto and upcoming protocols, a feasibility study has been carried out. The proposed solution is a constellation of five CarbonSat satellites (Fig. 6), which is able to provide global, daily CO2 and CH4 measurement with high spatial resolution 2×2km².

The unique global daily measurement capability significantly increases the number of cloud free measurements, which enables more reliable services associated with reduced uncertainty, e.g. to 0.15ppm (CO2) per month in 10km² and even more timely products.

The CarbonSat Constellation in combination with inverse modelling techniques will be able to provide information services, such as global quarterly: CO2 and CH4 regional flux updates, CO2 emission reporting from hot spots e.g. the power plant and CH4 emission reporting from hot spots e.g. the pipeline/oil and gas fields.

It is proposed that the CarbonSat Constellation will be implemented through an internationally coordinated constellation (Fig. 7). Each country contributes one satellite in the constellation and establishes its own ground station to provide data for national applications. A central coordination will be set up for the constellation operation, data calibration and international data distribution. The proposed approach provides independence for each partner and is financially more feasible. The world wide transparency provided by this international forum is critical in supporting Kyoto protocol and upcoming international agreement in man-made Greenhouse emission reduction.

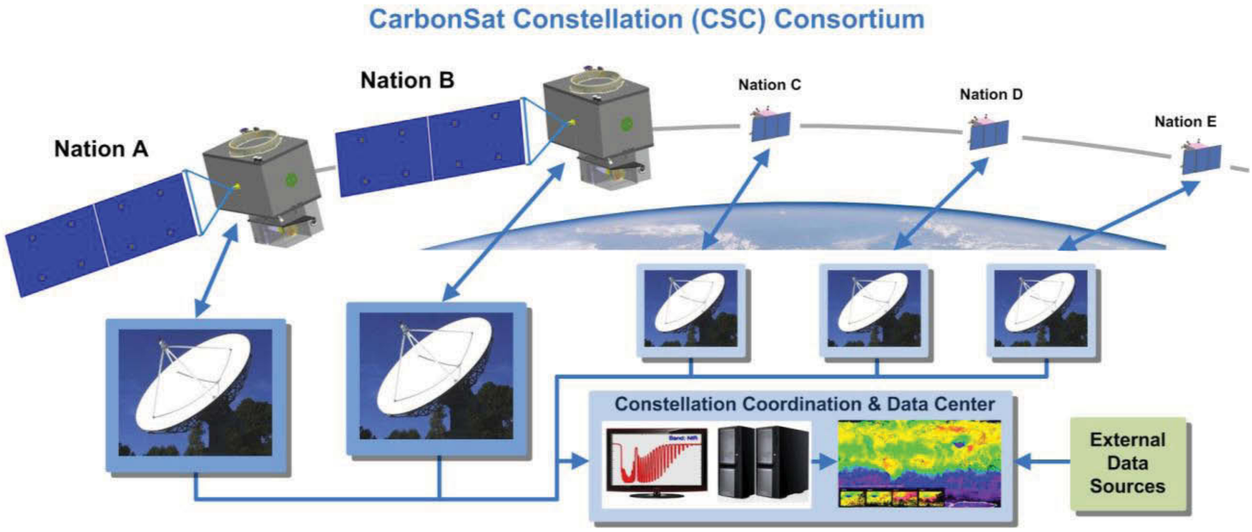

Figure 7:International CarbonSat Constellation Architecture

6. OCEAN-COLOUR FROM GEO

The objective of the mission is to provide a sustainable source of ocean colour images in coastal and in-land waters for (but not limited to) GMES marine and coastal environmental services and applications. Based on the user needs the main applications include (Fig. 11):

- Detection, prediction and monitoring of long term but especially short term biophysical phenomena
- Biogeochemical cycle analysis and associated parameters
- Detection, prediction and monitoring of noxious or toxic algal blooms
- Marine ecosystem health monitoring
- Geological and biological response to identified physical dynamics
- Coastal zone and resource management
- Enhanced marine fisheries data

Designed as a complement and extension to the Sentinel 3 mission this mission aims at a resolution of better than 300 m and a frame time of ~1 hour. This will provide multiple inter and intra-day observations over Europe of fast evolving biological or dynamical phenomena such as phytoplankton blooms (particularly the coastal toxic blooms known as “red tides”), the biological response to atmospheric events (wind forcing, storms, episodic dust events etc.), the response of coastal ecosystems to short-term effects (e.g. tidal currents), sediment transport in coastal turbid areas as well as the diurnal cycles of other biological phenomena.

Image Characteristics:

- GSD 300m
- Bands 14 (413-900 nm)
- Spectral Resolution 20 nm
- Swath width : 600 km x 600 km
- Scan width: 3700 km x 2900 km
- SNR 1000 as a goal
- Digitisation 12 bit

The payload is well suited for the Small GEO platform (Fig. 10). The mission characteristics are:

- 1 GEO 7° East
- Revisit 60 min. (30 min goal)
- Launch date 2012 planned
- Life Time 10 years design
- Mass 1918 kg
- Power 1 kW
- Downlink 50 Mbit/s Ka-Band

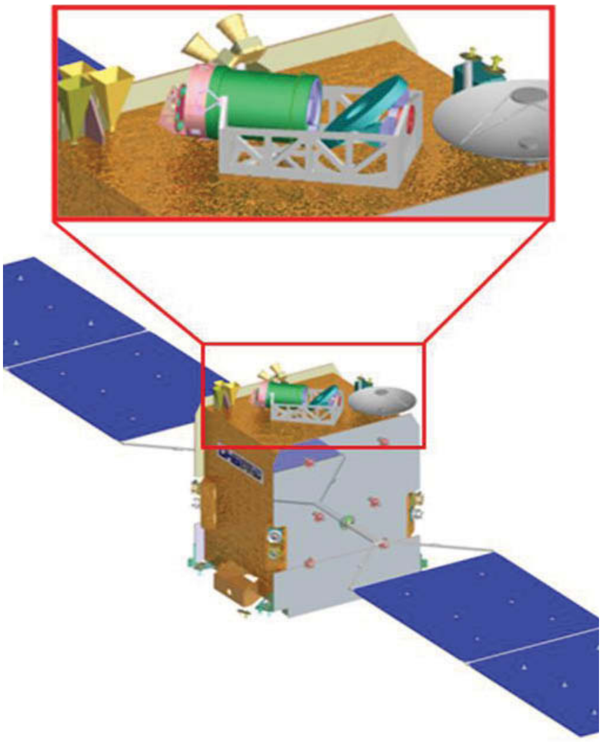

Figure 10: Payload accommodation on SGEO platform

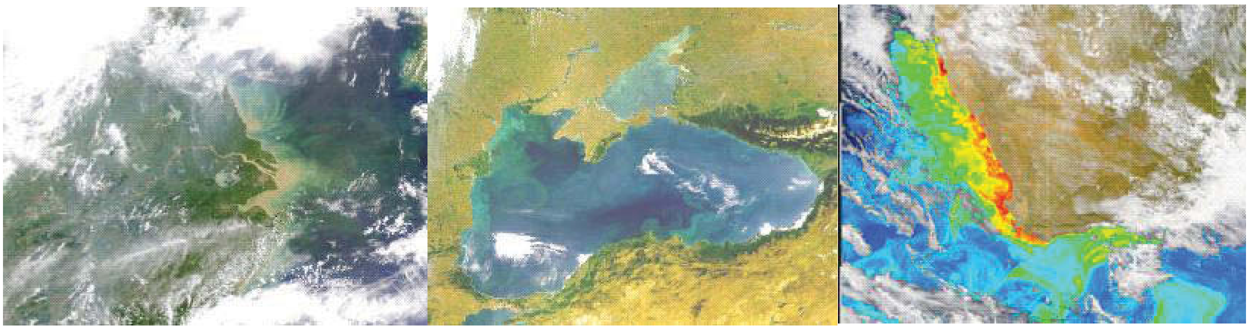

Figure 11: Yangtze river flood, Black Sea, and South-African coast Chlorophyll (images provided by the SeaWiFS project, NASA/GSFC and ORBIMAGE)

7. AIS

An important system in the field of global maritime surveillance is the Automatic Identification System (AIS), which is responsible for communicating ship- and voyage-related data of surface vessels. In order to improve the performance of the existing land-based AIS system, a consortium led by OHB has been responsible for the development of a full-fledged European space-based AIS system.

The main challenge in space-based AIS is the collision of multiple AIS messages in a single slot. In order to mitigate this problem, several innovative design options are available. A main design choice is the applied receiver architecture, being either on-board processing or digital bent-pipe. Smart solutions in digital signal processing and spacecraft antennas enable discrimination of the received AIS messages, leading to an improvement in detection performance.

The constellation has been optimized for high performance, sufficient coverage and low timeliness, resulting in 4 orbital planes consisting of 3 satellites each. Orbital parameters are 550 km altitude at 88° inclination. Assessment of the AIS constellation performance is done by using a dedicated AIS simulator applying either present-day or future traffic models. After definition of the use cases, including identification of so-called High Traffic Zones, which contain exceptionally dense traffic, the performance per use case has been evaluated.

Considering all vessels, the user requirements of 1 hour update interval with 80% detection probability for non-HTZ and 3 hour update interval with 80% detection probability for HTZ, can be met for most use cases. For critical use cases, such as North Atlantic or Mediterranean, these requirements will be met if open sea traffic is taken into account (Fig. 8). Such a situation is representative of space-based AIS complementing the already existing infrastructure of coastal stations.

Considering all global water surfaces, the system is able to provide a detection probability of 97.0% within an update interval of 1 hour. With an update interval of 3 hours, this performance increases to 98.7%.

Although a space-based AIS system might offer limited benefit to maritime security as a stand-alone system, it has much potential added value when used in conjunction with other remote sensing systems, such as SAR or optical.

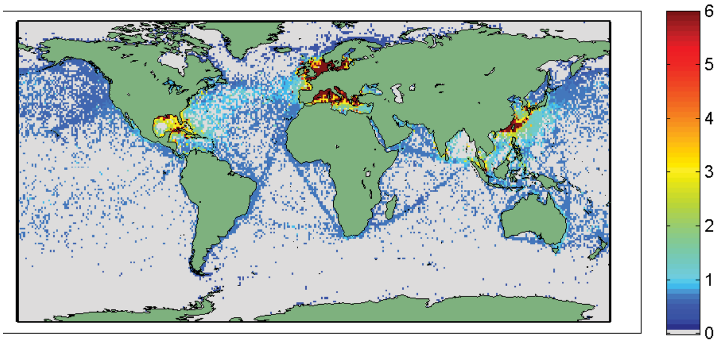

Figure 8: Global detection performance (hours) of the space-based AIS system

As the first step in the implementation of a European space-based AIS system, a so-called First Space Node (FSN) will supplement EMSA's Coastal AIS Network. This FSN comprises one or two spacecraft optimized for the monitoring of selected use cases. These spacecraft will be optionally complemented by an optical IR payload for detection of non-cooperating vessels.
A first design iteration of the optical IR payload has already been performed. It has been chosen to implement a camera operating in medium-wave infrared (MWIR: 3.7 – 4.5 µm) for optional integration on the FSN spacecraft. By operating in this band, the payload is capable of detecting the wakes of moving ships. Furthermore, it is capable to function both in day and night conditions.
In Fig. 9 the satellite configuration of the AIS + IR satellite is shown.

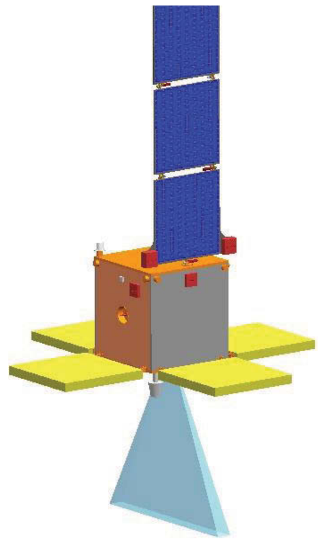

Figure 9: First Element AIS + IR-EO Satellite

Implementation of the space-based AIS system is initiated by the deployment of a First Space Node, of which Phase-B will start in the second half of 2010.

8. DATA RELAY FROM GEO (GEO-DRS)

The primary objective of the mission is to enable an increase of LEO observation time and reduce image ageing of LEO Earth observation data. A secondary objective is seen in the decrease of the system response time. As emergency response is one of the applications for the Sentinel missions a quick commanding capability of these spacecrafts enabled via the GEO-DRS could be beneficial in the future (Fig. 12).

A single GEO-DRS satellite will be able to provide the service over half the globe with a focus on Europe and Africa. The GEO-DRS satellite will comprise a bent-pipe payload with laser inter-satellite-links for data upload from LEO satellites to GEO-DRS and standard Ka/Ku-band downlinks from GEO-DRS to the ground station(s). The total data rate required for the next generation of GMES Sentinels is about 1 Gbps with peaks up to 1.4 Gbps.

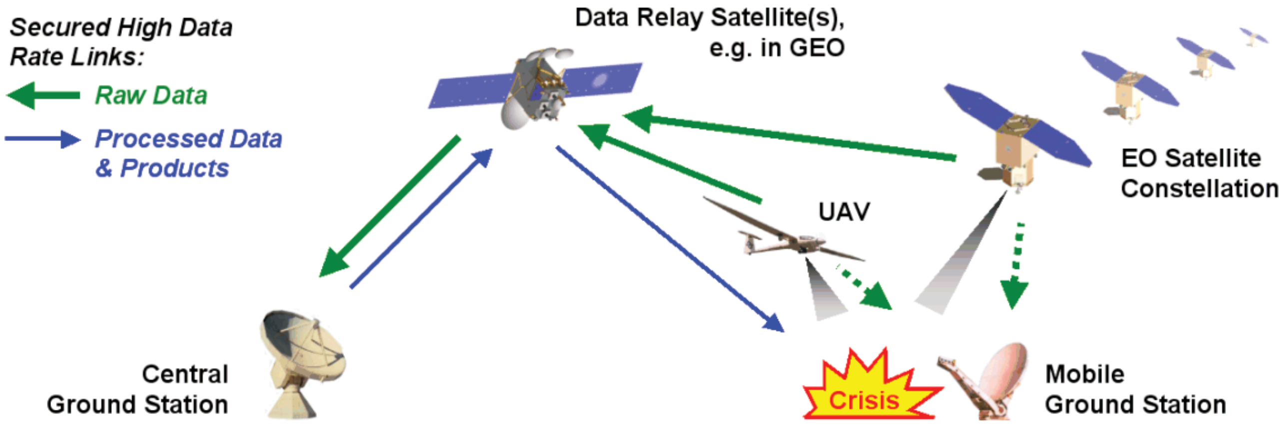

Figure 12: GEO Data Relay System for Emergency Response Services

9. CONCLUSIONS

The SAR-Lupe five satellite constellation is currently launched and this innovative VHR-SAR system will be operated for the next 10 years.

Based on this experience, OHB-System is working on the design of near future Earth observation systems for very high ground resolution. Out of the user demands for VHR imaging, global Earth coverage at very fast system response time, demanding requirements for the agility of the satellite and the constellation result.

Due to security aspects, the very high ground resolution together with a fast system response time will play a dominant role in the near future. Such systems can be implemented on national level but also a co-use with the GMES initiative could be an approach for the benefit of Europe. OHB-System can provide very cost effective solutions, enabling fast emergency response and maritime security applications. For the later also the combination of navigation signals from the ships together with EO data for ship detection can increase the situation awareness, e.g. for control of fishery zones and environment pollution.

New application as the current hyperspectral EnMAP mission will deliver new quality but also new quantity of data. The data stream has to be managed by the EO satellites and transmitted to ground.

Also the evolving performance of spectrometers allow more accurate investigation of the Earth atmosphere, e.g. for assessing the process of climate change and identify and evaluate green house gas sources and sinks from natural and man-made activities.

With its current development of the Small GEO platform, OHB provides solutions for the bottle-neck of high EO data volumes and faster system response time of VHR EO satellites. The SGEO platform is also best suited for complementary EO missions from GEO, such as for near real-time Ocean Colour observations.

10. REFERENCES

1. Website of the OHB-System AG Germany: www.ohb-system.de,