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MISSION CONCEPTS FOR FUTURE EARTH OBSERVATION APPLICATIONS

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Abstract

This paper outlines near-future Earth Observation concepts, which are currently under investigation on national and/or European level by OHB-System. These concepts comprise a wide selection of applications ranging from atmospheric science and research to operational security service constellations with very high resolution. Several of these concepts will be presented in this paper, including maritime surveillance, monitoring of biological and atmospheric constituents and security services:

- **SAR and optical missions with very high resolution** of below 1m are particularly suitable for dual-use and reconnaissance applications. In such conceptual systems, the timeliness of the data obtained and therefore a fast system response time is the main user requirement to be considered.
- **GMES – The Security Core** is a system of systems that will allow generation of ready-to-use customized products based on a combination of Earth observation, telecommunication and navigation tools provided from space-, airborne- and ground-based assets. OHB has developed two concepts to compliment existing systems to improve security over Europe. The two concepts utilise different observation methods, from different altitudes in order to address the different spatial and temporal resolution needs required of security applications.
- **Earth Explorer Core Mission** is a dedicated ESA programme to improve the understanding of the planet Earth and its changes. In the current stage of this programme (EECM #7), OHB is responsible for designing the platforms of: BIOMASS – forest biomass, CoReH2O – ice and water cycle characteristics, and PREMIER – link trace gases, radiation, chemistry and climate in the atmosphere.
- **CarbonSat** is a satellite system for global coverage of atmospheric CO_2 and CH_4 distributions. An international, operational constellation of multiple satellites is proposed to provide highly accurate products and services related to emission "hot spots " and regional densities on at least quarterly basis as an operational service.
- **Space-based Automatic Identification System (AIS) Constellation** consists of small AIS satellites, dedicated to receive logistic and navigation data from ships. The satellite system will enable global ship detection as a complementary improvement on the existing terrestrial system, improving maritime security applications.

For the versatile selection of missions a common factor is that high performance can be achieved with small satellites, which enables low overall cost and short development time of the operative system. In addition to the key features of the mission platforms, the paper will outline the mission concepts.

1. INTRODUCTION

Information regarding the Earth and the desire to monitor the globe has increased with the advancements in modern technology. The use of Earth Observation (EO) satellites has not only become indispensable for governments, but for the average person every day. EO satellites transmit information about weather forecasts and positional information to monitoring geo-physical processes, resources, and security.

As the users become more accustomed to this information, dependencies emerge along with the need for increased spatial, spectral and temporal resolutions. This increase in data quality is also linked with an increase in data quantity, which makes it challenging for sustainable services to fulfil the current and future demands, while remaining profitable.

In order to cope with the increasing demands, OHB-System has developed a range of systems, which are able to generate data for a broad spectrum of applications. These systems will be outlined in this paper.

2. SAR AND OPTICAL MISSION WITH VERY HIGH RESOLUTION

The development of dual-use systems becomes increasingly more relevant when the competition for space system funding is increased. The very high resolution SAR and optical concepts developed by OHB are able to provide such a system that can be applied to civilian, dual-use, and reconnaissance missions. This is possible because of the common driver between security and safety applications, which is the timely availability of very high resolution (<1 m) imagery. Space systems are ideal for demanding requirements of this nature because they are global by nature and are not limited to the restraints associated with national sovereignty. Additionally, the use of satellites partly removes the involvement of people, which in turn simplifies the logistics.

OHB is currently developing two mission concepts to address the need for very high resolution information. The first concept is a SAR mission that is able to provide highly reliable information, independent of weather and time of day. The second concept is an optical mission providing panchromatic and spectral information for easy-interpretable images.

Both concepts have undergone comprehensive trade-offs to develop the ground and space segment, providing a complete next generation VHR system. The trade-offs that have been performed include:

- Camera performance
- Orbit selection and number of satellites
- Downlink performance
- Satellite agility
- Ground processing time
- Ground station location and quantity
- Reliability and costs

The GMES Security Concept will include a next generation VHR system that contributes to the system of systems approach that allows the generation of ready-to use customized products. It will be a fully reactive and autonomous system, offering a large volume of diverse information and data.

An overview of specific features provided by a potential next generation optical VHR system is listed in Table 1.

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 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 1: Key figures of next generation optical VHR system

3. GMES- THE SECURITY CORE

The initiation of the GMES Security Core Service (GMES-S) was a result of the increased interest of the GMES information service implementation for security applications. The term “security” refers to the protection of European citizens and societies, European interests and values, as well as from catastrophic events caused by man and nature. The main applications of GMES-S are seen in the following areas:

- European External Actions (EEA)
- Law Enforcement (LWE)
- Schengen Border Control (SBC)
- Maritime Surveillance (MRS)

The products required to service these applications will result from the combination of Earth observation, telecommunication and navigation tools provided from space. Each domain will require its own constellation of satellites operating in a different domain; SAR, optical, thermal IR, or hyperspectral, effectively creating a system of systems.

The development of the system of systems used for GMES-S will be highly reliant on existing infrastructure such as the GMES Space Component Data Access (GSCDA) and the Sentinels which will be launched in the coming years.

Due to the demanding requirements of security information, in both spatial and temporal resolutions the cooperation between commercial and European Union satellites is mandatory. Consequently, the on-ground data handling and storage system will also require many security implementations as the information it will be handling will be extremely sensitive and high in volume.

OHB has currently developed two concepts that are intended to act as the primary compliments to the existing systems for GMES-S. The first complimentary system that has been proposed is an optical constellation in a medium earth orbit (MEO) and the second is a high resolution SAR constellation.

The necessity of an optical system characterized by very fast response and re-tasking with good detection and recognition capabilities has been the main driver behind the optical MEO concept. The extension of these abilities to worldwide coverage has led to a MEO constellation of 3 satellites, at about 11000 km altitude, each carrying a telescope able to provide products of 3 m GSD. This novel concept, providing wide strip maps and stereo imaging, can achieve global coverage (including the poles) in 5 hours.

The high resolution SAR concept is in response to often requested high resolution SAR imagery with a low timeliness for security applications. With the use of an X-band SAR (9.6GHz), typical ground resolutions of 0.75m to 0.4m are achievable. With the limitations of such a sensor, two orbital altitudes were deemed promising and were looked at in more detail. The low altitude concept uses an elliptical reflector antenna at 490 km. The high altitude concept uses a round reflector antenna at 990 km. The two concepts achieve the same kind of imaging performance although the higher altitude concept has a larger field of view, which corresponds to a much faster system response time and a shorter revisit time for a single satellite.

Some key figures for both the optical and SAR satellites concepts are detailed below in Table 2.

Optical System	Value
Satellites	3
Altitude	11 000 km
GSD	3 m
Payload Aperture	1.5 m
Payload Mass	500 kg
SAR System – High Altitude	
Satellites	6
Altitude	990 km
GSD	0.75 – 0.4 m
Sensor Diameter	4.2 m
TWT RF Power	2 x 470 W
SAR Payload – Low Altitude	
Altitude	490 km
Sensor Diameter	4.6 m x 2.1 m
TWT RF Power	470 W

Table 2: Overview of specific features of concepts proposed for GMES-S

4. EARTH EXPLORATION CORE MISSION

The "Earth Explorer" missions form the science and research element of ESA's dual strategy "Living Planet" programme. They focus on the atmosphere, biosphere, hydrosphere, cryosphere and the Earth's interior with the overall emphasis on learning more about the interactions between these components and the impact that human activities have on Earth's processes.

OHB is involved in the three current missions for the EECM programme which are, BIOMASS which will perform global measurements of forest biomass and extent, CoReH20 with the objective of detailed observations of key snow, ice and water cycle characteristics, and PREMIER which will help the understanding of the processes that link trace gases, radiation, chemistry and climate in the atmosphere. Across the three EECM programmes OHB is responsible for the platform design which has been based on the generic low earth orbit (LEO) Earth observation platform designed by OHB, called LEOBUS-1000. The LEOBUS-1000 platform is a modular platform with heritage gained from EnMap and Galileo. The main platform characteristics are similar for the three EECM missions and are detailed in the table below.

Mission	Value
Design Lifetime	5 years +commissioning
Plattform reliability	5 years: ≥85%
Launch Vehicle	Vega
Platform	**Value**
Platform Mass	< 750 kg
Platform Power	< 300 W
Downlink Data Rate	2 x 260 Mbit/s, X-band
Onboard Storage	Up to 1.3 Tbit

Table 3: EECM misson platform key figures

4.1. BIOMASS

The BIOMASS mission will have a lifetime of 5 years and will operate in a SSO orbit at an altitude of 640 km. The baseline launcher for BIOMASS is Vega.

The platform design of BIOMASS is driven by the mission's very large aperture antenna with a side-looking geometry and the launcher selection. Both of these design drivers have a significant impact on the spacecraft configuration and design. This deployable reflector will perform P-band SAR observations at 435 MHz, with a resolution requirement of 50 x 50m.

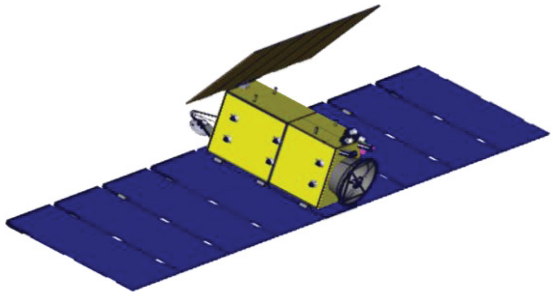

Figure 1: BIOMASS baseline configuration

Due to the nature of the payload, there is a high power demand of the spacecraft. To satisfy the demands of the payload and satellite operation the solar array needs to generate 2.7 kW of power. Additional requirements on the platform driven by the payload are the pointing requirements. The pointing performance of BIOMASS is,

- Pointing Knowledge: 30 arcseconds
- Absolute Pointing: 90 arcseconds

4.2. CoReH20

The CoReH20 mission is the first space mission providing SAR observations with Ku-band, and also the first satellite using dual-frequency, dual-polarization SAR. The mission will have a lifetime of 5 years and will have two phases of operation. The first operation phase will last 2 years in which the satellite will operate in a 3-day repeat cycle, followed by the second phase which will place the satellite in a 15-day repeat cycle for the remaining 3 years. The baseline launcher for CoReH20 is Vega.

The platform design of CoReH20 is driven by the SAR payload and the challenging sensitivity requirements. The main impact of these requirements is felt on electrical power system (EPS) due to the corresponding transmitting power that is required to obtain its performance.

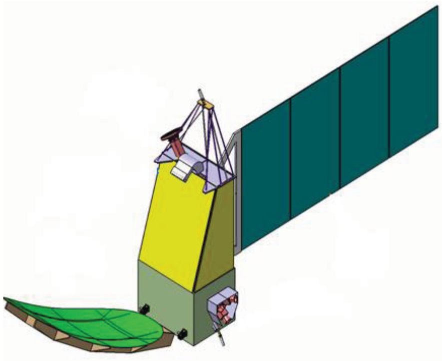

Figure 2: CoReH20 baseline configuration

Similar to BIOMASS, the CoReH20 payload has stringent requirements of the platform with respect to power generation and pointing. The CoReH20 platform produces 2.9 kW of power and the pointing performance of the platform is,

- Pointing Knowledge: 41 arcseconds
- Absolute Pointing: 131 arcseconds

4.3. PREMIER

PREMIER will be the first mission to generate atmospheric trace-gas fields at a resolution high enough to study stratospheric–tropospheric exchange, tropical convection, the Indian monsoon, forest fires/pyro-convection, and signatures of mesoscale dynamics including gravity waves. The mission is expected to operate in the same orbit as MetOp with a shift of 28° in true anomaly with respect to MetOp, such that it passes approximately 10 minutes earlier. The mission lifetime will be 4 years and the spacecraft will be launched by Vega.

The satellite will carry an InfraRed Limb Sounder/Infrared Cloud Imager (IRLS/IRCI) and the Millimetre-Wave Limb Sounder (MWLS) as the payload. The platform design of Premier is driven by high availability and high pointing requirements.

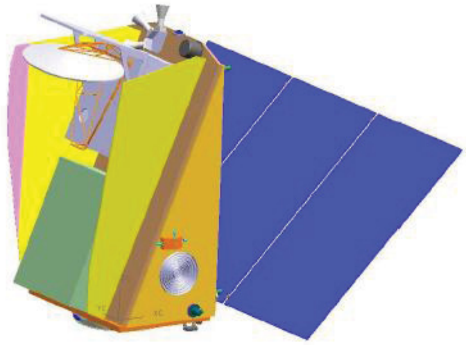

Figure 3: PREMIER baseline configuration

As the PREMIER payload is not SAR, the requirements imposed on the platform are less stringent than the other EECM missions. Although an active radar system is not used, the platform still requires a relatively large amount of power to be generated, specifically 1.7kW. Although the power requirements are not demanding, the pointing requirements are. The pointing requirements of PREMIER proved to be one of the main design drivers and are the most difficult of the EECM’s. The pointing requirements of PREMIER are,

- Pointing Knowledge: 10 arcseconds
- Absolute Pointing: <54 arcseconds

5. CARBONSAT

Global climate change is having a greater impact on the environment and society with each coming year. Two of the most important manmade greenhouse gases are Carbon dioxide (CO2) and methane (CH4) which are driving global climate change. Most of our knowledge about CO2 and CH4 sources and sinks stem from a network of highly accurate and precise in-situ surface observations (e.g., NOAA ESRL). A fundamental problem in this network is the scarcity of stations, resulting in poor coverage in many areas. The use of satellites can greatly improve this problem by performing global measurements of CO_2 and CH_4, which was seen through SCIAMACHY on

ENVISAT.

Although SCIAMACHY was able to show that satellites add important missing global information, the current satellites measuring green house gases must collect data for over a year in order to produce global regional flux products. Consequently, global, timely, higher spatial resolution measurements are required. Since, no current or planned future mission will simultaneously achieve CO_2 and CH_4 detection with high spatial resolution, good coverage and accuracy the need for CarbonSat is urgent.

With the implementation of CarbonSat into a five satellite constellation the ability to provide global, daily CO_2 and CH_4 measurements with high spatial resolution of 2km x 2km for a swath width of 500 km is realised. A depiction of the daily coverage for CarbonSat Constellation is seen in Figure 4.

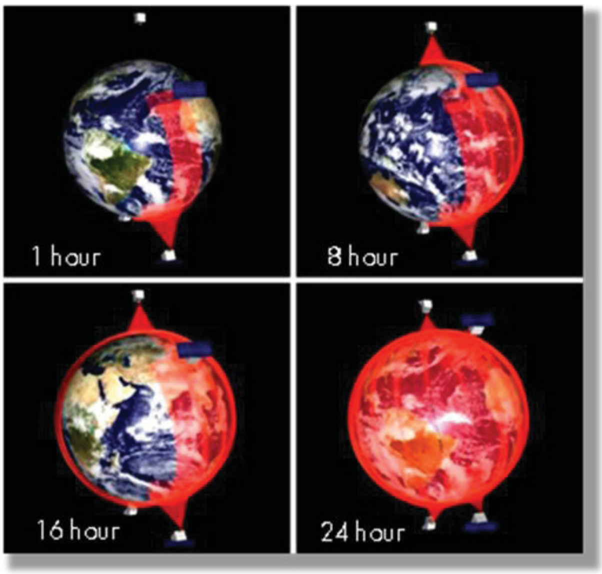

Figure 4: CarbonSat Constellation

The proposition of a CarbonSat Constellation is intended to be an international collaboration, involving several countries. The general idea is that each country will contribute one satellite in the constellation and establish 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.

Currently, there are two design concepts for CarbonSat, which include a full design and a compact design. The full design will be described in this paper because it is the baseline platform design. The full design will make use of a 3 band spectrometer with the spectral absorptions of CO_2 (~1.6 µm and ~2 µm), O_2 (~760 nm) and CH_4 (~1.65 µm) which are measured with high spectral resolution (~0.04-0.3 nm). In addition to the spectrometer units, the full design will have a Cloud and Aerosol Imager (CAI) which detects affected areas by observing in several spectral bands the same swath as the CarbonSat spectrometers. This is important because the presence of clouds and aerosols in the atmosphere can degrade accuracy of gas measurements and therefore has to be accounted for.

In order to make the full design cost-effective, the EnMap platform is used as a basis. The preliminary S/A baseline design for the CarbonSat mission will use sun pointing solar panels driven by a SADM, as seen in Figure 5. It is hence concluded that a Nadir side mounting is the best choice for the CarbonSat mission, being based upon the EnMAP P/F capabilities.

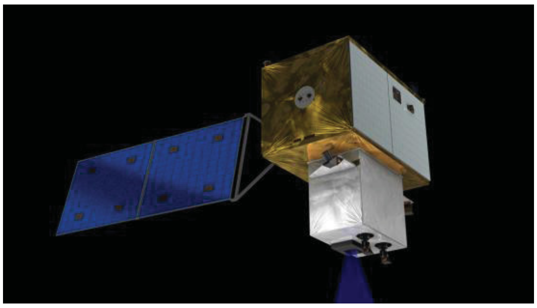

Figure 5: Example of CarbonSat Layout

The key figures for the CarbonSat spacecraft are detailed in Table 4.

Mission	Value
Design Lifetime	7 years
Platform reliability	7 years: >80%
Launch Vehicle	TBD
Platform	**Value**
Platform Mass	700 kg
Platform Power	260W
Downlink Data Rate	320 Mbit/s, X-band
Onboard Storage	Up to 1 Tbit
Propellant	62 kg

Table 4: Full CarbonSat key figures

6. SPACE BASED AUTOMATIC IDENTIFICATION SYSTEM (AIS)

AIS is a ship-borne broadcast that operates on two channels in the maritime VHF band, transmitting vessel information such as vessel identity, position, heading, nature of cargo, etc., to other ships and to shore. An extensive land based AIS system exists in Europe today and is used thoroughly to increase maritime safety and surveillance. The aim of introducing a space-based AIS system is to remove the limitations inherent in land-based AIS, therefore providing global maritime surveillance.

Implementing AIS in space does not come without its challenges. As AIS was designed to be a terrestrial system, the extension of AIS into space introduces the issue of message collision. Although challenging, there are several antenna designs and processing methods that mitigate this problem. Smart solutions in digital processing and spacecraft antennas enable discrimination of the received AIS messages, leading to an improvement in detection performance.

OHB has been readily involved in space-based AIS solutions, particularly with the Phase-A study ESPAIS that was completed for ESA. As an outcome of the study OHB proposed a constellation that was optimised for high performance, sufficient coverage and low timeliness. The constellation comprised 12 satellites on 4 orbital planes, offering polar coverage.

This solution faired very well in regards to the user requirements, which divided the detection criteria into High Traffic Zones (HTZ) and non-HTZs. Critical use cases such as North Atlantic and Mediterranean were used to evaluate the performance of the constellation. The main requirements were;

- 1 hour update interval with 80% detection probability for non-HTZs
- 3 hour update interval with 80% detection probability for HTZs

Averaged over the global ship traffic assumed for 2021 with 85,000 ships the system was able to provide a detection probability of 66% within an update interval of 1 hour and 80% for an update interval of 3 hours.

Figure 6, shows a global map of the detection performance achieved by the constellation proposed by OHB. Each point represents 80% detection probability for a certain update interval. The update interval range is from 0 to 6 hours, with 6 hours depicted in red. It is evident that the areas deemed as HTZs have a larger update interval in order to achieve 80% detection probability.

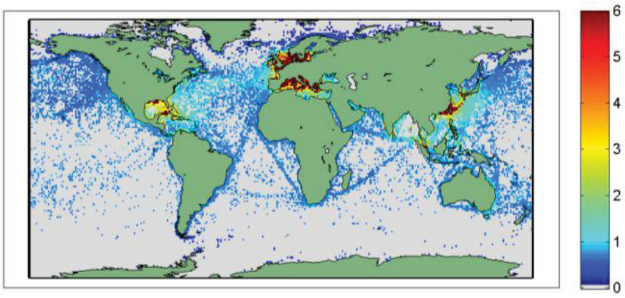

Figure 6: Global detection performance of the space-based AIS system

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 optimised for the monitoring of selected use cases. These spacecraft will be optionally complemented by an optical IR payload for detection of non-cooperating vessels.

The satellite configuration and key figures are shown in Figure 7 and Table 5. In addition to AIS, this satellite incorporates an infra-red imaging payload for detection of non-cooperating vessels.

Figure 7: First Element AIS

Mission	Value
Design Lifetime	7.5
Platform reliability	7.5 years: 80%
Launch Vehicle	PSLV
Platform	**Value**
Platform Mass	300 kg
Platform Power	270 W
Downlink Data Rate	48.8 Mbit/s, C-band
Onboard Storage	10.5 Mbit
Propellant	27 kg

Table 5: Key figures of First Element satellite

7. CONCLUSION

The increasing demand for Earth Observation satellite services with more stringent requirements is pushing the development of Earth observation satellites to a higher level. Emerging from these actions is a trend that as each satellite is built there is an increase in the desire for more timely data, with higher resolutions. Through the development of designs these requirements are often realised and proven feasible.

Based on OHB-System's experience with Earth observation satellites and this foreseeable trend, OHB has developed several mission concepts and platforms to address some of the major services regarding Earth observation data. Many of the concepts and platforms are based on the heritage of missions such as SAR-Lupe, EnMap and Galileo. The experience gained through these missions, not only increases the in-flight heritage and know-how, but also increases confidence in these future designs.

Current concepts that OHB has been working on is 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.

As security begins to play a larger role in the European space sector, the need for a system of systems to provide Europe with security is evident. This system will look at various satellite types, that utilze a wide range of payloads in order to provide the most confident information and in a timely manner. For this OHB has proposed a MEO optical constellation and a LEO high resolution SAR constellation. 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.

Regarding maritime security applications, OHB-System can provide very cost effective solutions, enabling fast emergency response and increasing maritime safety. 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.

The evolving performance of Earth observation payloads allows more accurate investigation of the Earth. This has enabled the development of such missions like the EECMs and CarbonSat which address issues regarding global climate change, environmental cycles, the atmosphere etc.

Through the development of missions and platforms such as the ones discussed in this paper, OHB has the ability to provide high performance systems with small satellites at a low overall cost and development time.