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VERY HIGH RESOLUTION SATELLITE MISSIONS FOR EMERGENCY RESPONSE AND CRISIS MANAGEMENT

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ABSTRACT

Emergency Response and Crisis management is becoming an ever increasing priority across Europe. This is evident from agreements and mechanisms such as the Global Monitoring for Environment and Security (GMES), which is a joint initiative between the European Union and the European Space Agency (ESA) and the International Charter on Space and Major Disasters. In fact, Emergency Response is one of the three fast track services identified for early implementation into the GMES framework.

Satellite imagery is becoming a critical tool for Emergency Response and Crisis Management applications. The imagery needed for these types of applications are characterised by rapid data delivery times and image products, which vary from large scale contextual maps to detailed very high resolution (VHR) images.

Obtaining VHR images from existing space missions for emergency response suffer from restricted data availability and inappropriate timeliness. Emergency response applications need a reliable and timely source of satellite imagery. These types of missions also require a robust commanding capability to enable the rapid response objective to be fulfilled.

Dual-use missions providing VHR imagery such as Pleiades (F) and Cosmo-Skymed (I) are all potential contributors to the GMES constellation. It is conceivable that these VHR missions could be considered as constellations together with additional satellite missions designed specifically for emergency response in order to optimize timeliness and availability.

In this paper two near-future VHR missions will be presented: One optical mission concept and one Synthetic Aperture Radar (SAR) mission concept. Both missions have been primarily designed to complement existing and planned GMES missions. However, both mission concepts also have useful stand-alone capabilities. Each mission concept has been designed to keep cost to an affordable level. The paper will present the key features of the orbit constellations, payloads, and resulting data products as well as both stand-alone and constellation performance. Both mission concepts are based on available technologies and could be implemented within the next 4 years.

1. INTRODUCTION – SATELLITE IMAGERY FOR EMERGENCY RESPONSE

Earth observation satellite systems provide a global infrastructure of imaging capabilities, which can be called upon in a time of crisis without the need for any other equipment than that needed for receiving the image data. It is therefore not surprising that satellite imagery plays an ever increasing role for civil protection applications such as emergency response and disaster and crisis management.

The GMES Service Element *Respond* has been established with the aim of increasing the efficiency and effectiveness of European and international humanitarian community through the appropriate and reliable application of geographic information. This includes not only pure imagery but also added-value products with GIS (Geographic Information System) overlays. The focus is on all phases of the crisis cycle where imagery and GIS products are available and cover both fast erupting crises (e.g. earthquakes and cyclones) and slowly developing crises such as famine.

The International Charter on Space and Major Disasters was created in 2000 with the aim of

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providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters through authorized users. The current members of the charter include ESA (Europe), CNES (France), CSA (Canada), NOAA (US), ISRO (India), CONAE (Argentina), JAXA (Japan), USGS (US), BNSC (UK) and CNSA (China) and each member agency of the charter commits resources to data provision when the charter is called upon.

The increasing utilisation of satellite imagery can be seen on Figure 1 showing the number of Charter activations since 2002. The column for 2008 covers the time until 15th June 2008, which extrapolated to cover the entire year would reach 36 activations. The activations of the charter only covers natural disasters and oil spill accidents thus not considering most human-caused disasters.

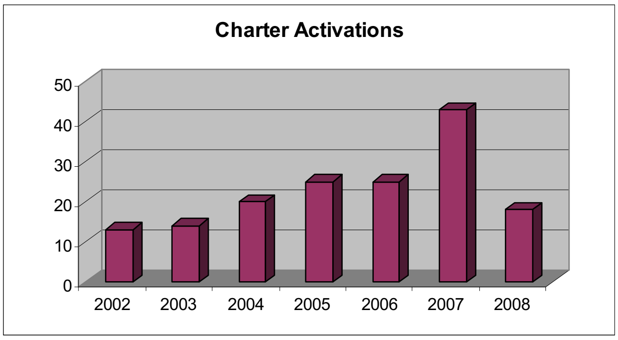

Figure 1 Activations of the Disaster Charter from 2002 to 2008

Recent charter activations with a high provision of satellite imagery and derived products are the Earthquake in China and the Cyclone in Myanmar both occurring in May 2008. The products provided for these emergencies in the frame of the charter, Respond or other sources include:

- Overview maps.
  - Resolutions: 150 – 250 m
  - Sources: Envisat, MODIS, Landsat, Radarsat

- Local area overview/damage assessment
  - Resolutions: 3m – 250 m
  - Sources: Radarsat-2, TerraSAR-X, DMC, ALOS Palsar/AVNIR-2, Cosmo-Skymed

- Damage assessment maps:
  - Resolutions: 0.5 – 6.25m
  - Sources: Worldview, Quickbird, TerraSAR-X, Spot-5, Cosmo-Skymed, ALOS Palsar/Prism

Damage assessment maps provide information down to the level of whether a road is passable or the number of houses in a village left intact. Due to the importance of this detailed information and the relative small dimensions of the each map, a large number of these maps are generated compared to the larger overview images. Among the investigated products the majority of the images were based on the highest resolution systems, where lower resolution systems like Spot-5 were used for reference [2], [3]

2. SATELLITE SYSTEM REQUIREMENTS

Pure imagery as well as value-added products are needed both at the detailed level as well as for overview images. Spatial requirements for damage assessment maps can be seen in Table 1 providing requirements for both detailed maps and overview images. Generally one can see that there is a need for satellite image products with all spatial resolutions that are available.

Important for both types of products are:

- Adequate image quality.
- Reliable image and product provision.
- Timely delivery of images and products

The adequate image quality means that the images shall be good enough for feature recognition and rough land cover classification but not necessarily more. A system designed especially for emergency response could therefore have lower requirements for signal to noise ratio than systems targeting a wider range of applications where image quality is more important. Thereby a more cost-efficient solution can be provided.

Crisis Type	Detailed Level		Overview Level	
	Desired	Max	Desired	Max
Floods	1 m	5 m	3 m	20 m
Landslide	<1 m	5 m	1 m	2,5 m
Hurricanes and Storms	<1 m	5 m	3 m	20 m
Forest Fires	1 m	10 m	5 m	50 m
Earthquakes	<1 m	5 m	-	-
Volcanoes	<1 m	3 m	2 m	1000 m
Tsunamis	<1 m	5 m	3 m	20 m
Oil Spills	1 m	2,5 m	10 m	50 m
Refugee Camp Mapping	1 m	2,5 m	-	-
Population Gatherings	<1 m	1 m	-	-
Population Movements	<1 m	1 m	-	-
Asset damage	<1 m	2,5 m	-	-

Table 1 Spatial Resolution Requirements for Damage Assessment Maps[5]

Reliable and timely delivery of images and products are related in the sense that it is necessary to be able to rely on the timely delivery of information in order to benefit from it. Products that cannot be guaranteed delivered will remain as exotic add-ons and cannot be fully included in an operational scenario.

GMES as well as the International Charter on Space and Major Disasters both utilise a number of different satellite missions to provide the required information. Satellite missions especially targeting these applications should therefore also consider this environment and identify how they optimally can provide added value to the existing and planned missions.

The following three high-level features should be considered:

Sensor Type: SAR + Optical. Both SAR and optical sensors are used at the moment and will continue to be used. SAR sensors provide all-weather day/night time imaging capability but have limited viewing geometry – especially in mountainous regions or in urban areas where high buildings cause shadowing effects. Optical imagery depends on sunlight conditions but have larger viewing geometry flexibility and can provide multispectral information.

Focus: Fast revisit / High resolution. Overview images can be provided in regular intervals by the medium resolution/large swath satellites. Fast and regular image updates however remains an unfulfilled requirement for emergency response as the high level of detail is related with a narrower swath width and usually a lower duty cycle limited by downlink opportunities for the large data volumes. Complementing the existing and planned space segment should therefore be targeting these applications.

Orbit: Sun synchronous noon/midnight orbits. Most other imaging satellite missions orbit in Sun Synchronous Orbits (SSO). New missions aiming to complement these missions should therefore also use SSO in order to provide regular intervals between the images from all missions.

Optical missions depend on the optimum sunlit conditions and therefore need to be orbiting with local times of node crossings close to noon.

SAR missions do not have this restriction and in fact most SAR missions orbit in dawn dusk orbits in order to benefit from the quasi-constant solar conditions facilitating the power generation for these power demanding missions. As most SAR missions orbit at dawn and dusk a coverage gap exist in the ~12 hours between these passes, which is irrespective of how many SAR satellites that are deployed into this orbit. A complementary SAR mission should therefore seek to close this gap by providing SAR imaging capability in between, i.e. in a noon-midnight orbit.

The following sections provide a description of the two proposed missions – one SAR and one optical - for emergency response and crisis management.

3. SAR MISSION

3.1. Mission

The SAR satellite mission consists of a constellation of three satellites orbiting in a sun synchronous orbit. The orbit has been optimised to complement the performance of the Italian Cosmo-Skymed constellation so that high resolution SAR imagery can be provided with a maximum revisit time of about 7 hours when both constellations utilise the extended swath mode with incidence angles of 20°-60° on both sides (left and right-looking).

The SAR constellation has the following features.

- No of satellites: 3
- Orbit altitude: 659 km
- Inclination: 98°
- LTAN: 00:00h

The three satellites can either be launched separately or on a joint launch with all three satellites in e.g. a Soyuz launch vehicle.

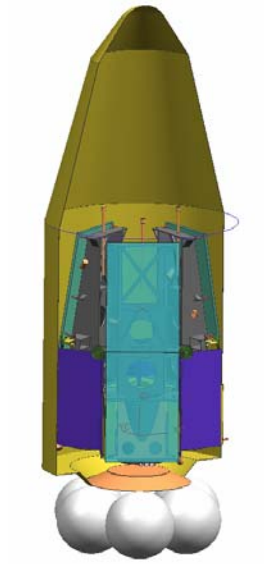

Figure 2 The three SAR satellites can all be accommodated in a Soyuz for a joint launch

To provide a fast system the satellites must be commandable in each orbit and be able to downlink the payload data in each orbit. A ground segment consisting of the ground stations Kiruna and Troll will provide a minimum contact duration per orbit of 8.2 min.

3.2. Instrument

The X-band SAR instrument is based on an active array concept, which enables electronic beam steering and the implementation of different modes with different resolutions and swath widths. This flexibility has been included in order to provide a flexible system to answer the variety of imaging needs required for emergency response applications.

The antenna design has sought to provide a relatively small antenna and light-weight antenna, which would enable a small spacecraft and enable a multiple launch concept. This approach is pursued at the expense of a higher power consumption, which has been considered less critical. The resulting antenna has an aperture of 4.43m x 1.23m and a mass of 240kg (incl. margins).

For the ScanSAR (Wideswath) mode the TOPS-SAR approach is implemented [6]. This technique uses azimuth beam steering within each beam burst so that the same segment of the azimuth beam shape is used for every burst of any given beam. This involves steering the beam in azimuth for each burst such that peak of the beam is always used for each sub-beam in the sequence. If the dwell time for each beam burst is significant, then azimuth steering of the beam during the burst may be needed. If the duration of the burst is small, simply adjusting the azimuth pointing for each burst would be sufficient.

Utilizing the TOPS technique allows the peak of the azimuth beam to be used for each beam-burst in the ScanSAR sequence. This effectively removes the scalloping effect, and the NESZ and radiometric variation approaches that of a Stripmap image. Also, by adjusting the dwell time in concert with the azimuth scan rate, the azimuth resolution can be tuned to achieve the desired value.

The instrument modes are outlined in Table 2.

Mode	Resolution	Swath width	Duty Cycle
VHR	1 m	10 km	> 1 %
HR	2.5 m	25 km	> 3 %
WS	15 m	100 km	> 3 %

Table 2 SAR Instrument Modes and Performance

3.3. Satellite

The satellite design has been tailored to the mission and the payload. The principal design drivers have been:

- Accommodation of large and heavy antenna
- Enabling of multiple launch concept
- Noon/midnight SSO
- Left- and right looking payload

The flight configuration of the VHR-SAR satellite can be seen on Figure 3. A long stiff structure has been used to accommodate the long and heavy antenna without the use of deployment mechanisms. This saves mass and adds to the overall reliability of the satellite. The bus subsystems and the payload electronics are located in the bus compartment (shown with yellow) to maintain a low centre of mass of the satellite in the launch configuration. Two deployable and rotating solar panels are used for optimised solar incidence during the sunlit parts of the orbit.

Main features of the satellite are summarised in Table 3

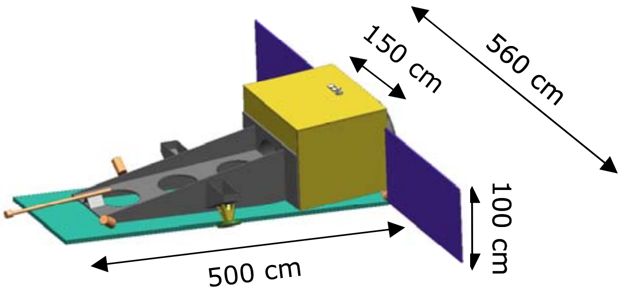

Figure 3 VHR-SAR Satellite in Flight Configuration

VHR-SAR Satellite Features	
Satellite Launch Mass (incl. margin)	~ 1000 kg
Satellite lifetime	7 years
Reliability	80 % after 7 years operation
Data Handling	Onboard electronics based on rad. hard computer (Leon-II) Onboard software reloadable
Power	28 V unregulated 890 W EOL
ACS	3-axis controlled Left- and right looking modes Star trackers and gyros for high accuracy modes
Thermal	Mostly passive system Active for P/L and propulsion system
Structure	Central tube and antenna tower in CFRP Subsystem panels in aluminium.
Mechanisms	Reaction wheel assembly Solar array drive mechanisms
Orbit Control	Hydrazine blow-down system 2 thrusters with 1 N each
TMTC	Upload/download data rate 4/64 kbit/s, full duplex
P/L Data storage	256 Gbit mass memory
P/L Data Transmission	Data rate 460 Mbps X-Band, CCSDS formatting & encryption, RS/TCM Coding, 8-PSK modulation 2x Wide coverage antennas

Table 3 VHR-SAR Satellite Features

3.4. Timeliness Performance

The performance in terms of coverage is summarised in Table 4. The performance is shown both for the constellation together with Cosmo-Skymed and as a stand-alone system. The following Figure-of-Merits are used:

- Max. response time – the maximum duration until a point can be imaged by a satellite
- Time avg. gap – the average duration until a point can be imaged
- 95% Max response time – the duration until 95% of all investigated points can be imaged

The system response time covering the time from submission of request from a user until the data is available is another important parameter for the system. This depends on the coverage performance of the constellation but also on ground segment performance with respect to tasking of the space segment, receiving the payload data, payload data processing etc.

The maximum response time for the system as a stand-alone system is estimated to be lower than 20 hours from image request to level 1b data availability.

	Maximum Response Time	Time avg. Gap	95% Max response time
Stand - alone	14.2 h	10.0 h	11.3 h
VHR-SAR + CM	7.5 h	4.1 h	5.3 h

Table 4 Coverage Performance of VHR-SAR Constellation with Cosmo-Skymed and as Stand-Alone System

4. OPTICAL MISSION

4.1. Mission

The VHR-OPT mission also seeks to provide its performance as a stand-alone system while complementing other existing and planned missions. The reference mission for the VHR-OPT is the dual satellite mission Pleiades. The mission shall combine the VHR capability with fast response time meaning that a large accessible swath must be achievable. A large instrument swath is incompatible to a cost-efficient VHR solution so instead the large accessible swath is achieved via spacecraft agility.

The spacecraft agility enables the spacecraft to quickly change and stabilise its attitude for imaging of different scenes within the accessible swath. Furthermore the agility enables the spacecraft to make image mosaics of up to 4 image strips after another thus increasing the swath width by a factor of 4 compared to conventional nadir-looking satellites. Finally the spacecraft agility enables sun pointing of the solar panels and tracking of the ground station for high-gain payload data transmission.

Mission characteristics include:

- 2 satellite constellation, phasing 180°
- Altitude 614km, SSO
- LTDN 10:30
- Off-nadir pointing: ±30 (goal ±45 deg)
- Image mosaics: 3 x 12km swath (goal 4 x 50km)

The two satellites can be launched individually or on a combined launch. To maintain the cost-efficient approach a dual launch is preferred.

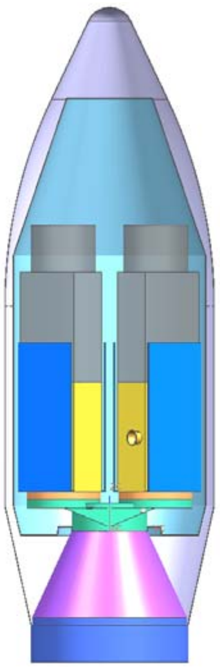

Figure 4 Two VHR-OPT satellites in Dual Launch Configuration on Vega

4.2. Instrument

The objective of the instrument design has been to provide the most cost-effective 1m resolution camera with adequate image quality as possible. Image analysis has therefore been performed in order to identify the boundaries for the required image quality (MTF and SNR) necessary for emergency response applications. The criterion has been that is should be to perform feature recognition and classification with a low error probability. A combination of MTF@Nyquist=10% and SNR=10 was found to provide very good performance for image analysis by humans, while automatic image processing seemed to benefit from somewhat higher SNR. Targeting these performance levels enables the design of a cost-efficient instrument compared other VHR optical missions with much higher values.

If needed the SNR could be increased by using the spacecraft agility to perform target pointing and thereby reduce the ground speed. Another option is to use TDI detectors to increase the SNR. This could however have a negative impact on the MTF.

The VHR-OPT instrument has the following features:

- 1m PAN
- 4m MS
- Five bands: Red, Green, Blue, PAN, NIR
- Swath width: 12 km
- 12000 pixel CCD line detector
- Telescope type: Korsch – TMA
- Dimensions. 1.1m x 0.8m x 0.8m
- Mass: 152 kg

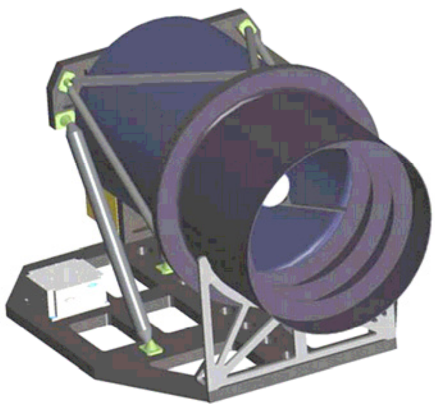

Figure 5 VHR-OPT Korsch-TMA Telescope

4.3. Satellite

The satellite has been designed for optimised payload accommodation, spacecraft agility and launcher accommodation. Three solar panels are mounted on the sides of the spacecraft and deployed after launch. The camera is mounted on top of the bus compartment which contains all bus subsystems and the payload electronics. The high gain X-band antenna for payload data downlink can be seen protruding from the bus module on Figure 6. During data downlink the entire satellite performs a slew manoeuvre to direct the antenna towards the ground station.

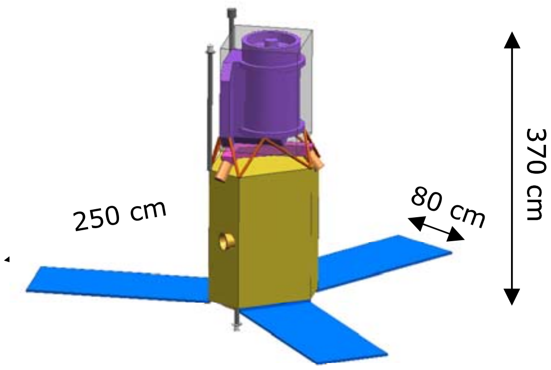

Figure 6 VHR-optical satellite

VHR-OPT Satellite Features	
Satellite Launch Mass (incl. margin)	~ 500 kg
Satellite lifetime	5 years
Platform Reliability	90 % after 5 years operation
Data Handling	Onboard electronics based on rad. hard computer (Leon-II) Onboard software reloadable
Power	28 V unregulated 820 W EOL
ACS	3-axis controlled Manoeuvres for: - Large accessible swath - Image mosaicing - P/L data transmission - Sun pointing Star trackers and gyros for high accuracy modes
Thermal	Mostly passive system Propulsion system heaters
Structure	Mono cock design based on Al sandwich panel
Mechanisms	Reaction wheel assembly Solar panel hold-down and releases
Orbit Control	Hydrazine blow-down system 2 thrusters with 1 N each
TMTC	Upload/download data rate 4/64 kbit/s, full duplex
P/L Data storage	384 Gbit mass memory
P/L Data Transmission	Downlink data rate 320 Mbps X-Band, CCSDS formatting & encryption, RS/TCM Coding, 8-PSK modulation 1 high gain antenna

Table 5 VHR-OPT Satellite Features

4.4. Timeliness Performance

The designed system will complement existing and planned satellite missions by providing a cost-efficient means for VHR imagery in PAN, MS and NIR.

Considering an off-nadir observation angle of up to 30° the coverage at latitudes of 0°, 40° and 60° in combination with Pleiades is shown in Table 6. At European latitudes the combined system of the two missions will therefore be able to provide a daily revisit of 95% of the possible target areas.

The total estimated turnaround time from image request to level 1b data availability is about 32 hours.

Latitude	Maximum Response Time	Time avg. Gap	95% Max response time
0°	3.0 d	0.9 d	1.8 d
40°	2.0 d	0.6 d	1.0 d
60°	1.0 d	0.4 d	0.9 d

Table 6 Combined Coverage Performance of VHR-OPT and Pleiades

5. SUMMARY

A SAR and an optical mission concept for emergency response and crisis management applications have been presented. The missions have been designed with the objective of providing complementary to existing and planned satellite missions to optimise their added value for the users. Both missions focus on providing very high resolution with fast turn-around times as this has been identified as a gap in the current data provision.

The SAR mission consists of a constellation of 3 satellites orbiting in a sun synchronous noon/midnight orbit to complement other SAR missions that mostly utilise a dawn-dusk orbit. Thereby a reduction of the maximum response time from ~13 hours to ~7 hours can be accomplished. The SAR sensor provides, in addition to its very high resolution mode, also the capability of high resolution and wide swath imaging to be able to offer the entire palette of detailed and overview images.

The optical mission consists of two satellites in sun synchronous orbit with a LTDN of 10:30. The satellites are designed around the instrument providing resolutions of 1m PAN and 4m MS with a swath width of 12 km. Satellite agility is utilised to increase the accessible swath width enabling mosaic'ing of 3 strips thereby enabling images of 36km x 36km. Satellite agility also enables a sun pointing configuration when not imaging and tracking of the ground station for data downlink with a fixed high gain antenna.

Both missions are designed to provide a cost-efficient solution for emergency response and crisis management applications. This have lead to e.g. joint launch concepts of multiple satellites, cost-efficient payload with adequate performance and a platform concept relying on state-of-the art components. The missions can be developed and launched within the next 4 years.

6. REFERENCES

1. Website of the OHB-System AG Germany: www.ohb-system.de,
2. International Charter "Space and Major Disasters". http://www.disasterscharter.org
3. Respond. GMES Services Supporting Humanitarian Relief, Disaster Reduction & Reconstruction http://www.respond-int.org
4. Unosat – Satellite Solutions for all. http://unosat.web.cern.ch
5. GMES Fast Track – Emergency Response Core Service. Strategic Implementation Plan (With Annexes). ERCS Implementation Group. 24.04.2007
6. De Zan, Francesco. Terrain Observations with Progressive Scan (TOPS) SAR. EUSAR 2006
7. Italian Space Agency, Cosmo-Skymed System Description and User's Guide
8. EOPortal. Pleiades-HR (High-Resolution Optical Imaging Constellation of CNES). http://directory.eoportal.org/get_announce.php?an_id=8932