Project: **Geo-Oculus**

A Mission for Real-Time Monitoring through High-Resolution Imaging from Geostationary Orbit

ESTEC Contract No.: 21096/07/NL/HE

Title: **Mission Overview**

Doc. No.:	GOC-ASG-TN-008	Issue: 1 Rev. 0	Date: 13.05.2009

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Product Assurance:	-		
Project Management:	Ulrich Schull	13.05.2009	

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Change Record

Issue	Revision	Date	Sheet	Description of Change
1	0	31.03.2009	All	First version

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1 Introduction

This document gives a brief overview of a mission that constitutes a new class of Earth-Observation missions by combining high resolution imaging with real-time imaging. Despite that it has been found that several EO-services can benefit from such a system, it is anticipated that through this mission an entire new set of EO-services becomes feasible, which have still to be identified.

ESA has identified the lack of this capability and class of EO-missions and initiated a dedicated study named Geo-Oculus. The study has analysed the mission based on a preliminary set of requirements and has found a feasible concept. In this document the findings of the study concerning

- System Architecture (chapter 2)
- Mission Performance (chapter 3)
- Performance Parameters that drive the System (chapter 6)

are summarised to give an understanding of the system concept and constraints.

In combination with the contemplative description of the key system parameters (chapter 5) and the possibilities and specifics of the geostationary orbit (chapter 4) this gives a conceive overview of the Geo-Oculus mission.

1.1 The Geo-Oculus Mission

So far, satellites for Earth-Observation (EO) specialise on high performance either in the temporal domain or in the spatial domain. Today's missions to geostationary orbit feature real-time access, short revisit times and fast data dissemination while providing rather coarse spatial resolution. High spatial resolution is linked to a low Earth orbit. In the near future a new class of EO-missions will be possible that combine both **high resolution imaging** and **real-time imaging**, and therefore will open up room for new fields of applications not feasible today.

The Geo-Oculus mission is constituted by the following key-system parameters:

- High Spatial Resolution (GSD in the order of 20 meters)
- Real-Time Control
- Agile Satellite (Pointing manoeuvres take around one minute)
- Real-Time Data Transmission (Downlinking of the data immediately after acquisition)
- Rapid Revisit Capability (Several times per day, depending on cloud cover and size of area to be monitored)
- High performance in all (classical) Earth Observation aspects (excellent radiometric and spectral performance)

2 System Overview

The term 'system' herein stands for all elements involved in the service chain, from user interface to the satellite in orbit. It shall be kept in mind that this description leaves open the integration into specific and existing systems, such as the GMES service infrastructure, and, therefore, shall be understood as a sketch of principal. The mission architecture (Figure 1.1-1) depicts these elements indicating the data flow.

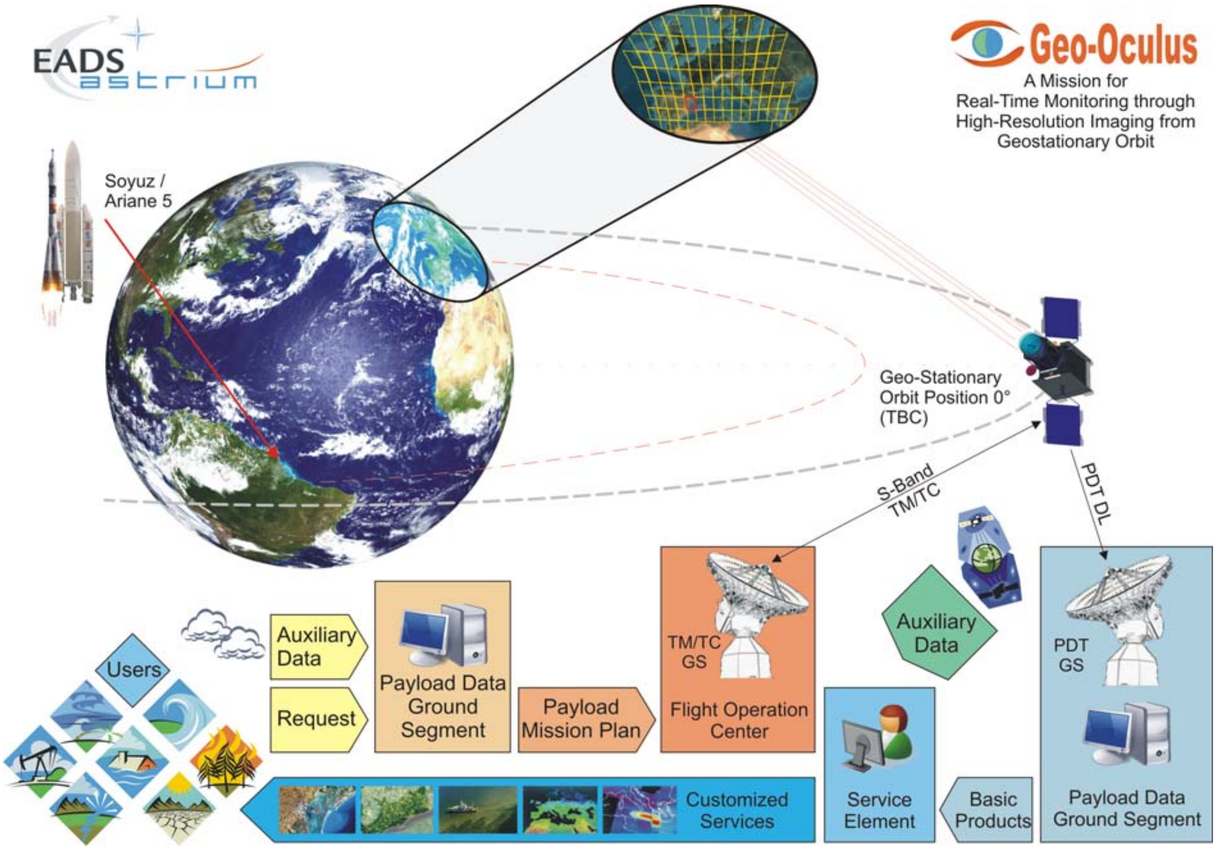

Figure 1.1-1 Mission Architecture of the Geo-Oculus Mission

On-Demand and Routine Monitoring Services

The Geo-Oculus system study unveiled two distinct kinds of services to be considered for such a mission. On-demand services, which require the swift acquisition of data upon contingent request by users, and routine monitoring services, which have a regular need for observations within a defined timeframe, must both be supported and reflected in the mission architecture.

User Interface

The user interface, which shall be based on standards, e.g. of the Open Geospatial Consortium, will allow users among others the following key-functionality:

- Access to archives
- Subscription to
  - Alert services
  - Status notification services
- Placing of observation requests for
  - Emergency situations
  - Scientific studies

The subscription services will utilise state-of-the-art communication means to inform the users about the status or occurrence of parameters and phenomena of interest to the users. This could, for example, be the alert for the appearance an algal bloom.

The possibility to place (quasi real-time) observation requests in case of incidents will be possible for pre-defined users registered to this service. The actual request will be treated with priority and actively supported by the personnel of the Payload Data Ground Segment (PDGS).

Mission planning

A preliminary Payload Mission Plan (PMP) will be created by the PDGS for each day supporting the routine monitoring services. This PMP will be continuously updated taking into account not only the recent observation requests but also the current and forecasted cloud situation to utilise the system optimally.

Space segment

Continuously commanded by the Flight Operations Center, the space segment carries out the observations. Based on the step&stare principle, the satellite points to the desired location, allows platform to stabilise from the manoeuvre, performs the acquisitions in the required channels via filter wheels and 4-5 focal planes and transmits the data to the Payload Data Ground Segment.

The instrument provides different Field-of-Views (FOV), for the high-resolution channel about 150 x 150 km², and 300 x 300 km² for the other channels. Therefore, for all applications that require the high-resolution imaging (GSD ~20 m) four times as many manoeuvres are required as for applications that can cope with the standard resolution (GSD ~ 40 m). This allows to trade resolution against coverage when required.

Data Processing and Service Provision

The PDGS performs the data processing to the level 1b, e.g. geo-referencing and ortho-rectification, and transmits the data to the Service Element where the higher level processing, which includes relevant auxiliary data from other sensors and background data from geographic information systems, is performed.

According to the type of service the customised data is provided to the users via the preferred communications system. Especially for alert and notification services, systems like Email and SMS are appropriate and fast dissemination methods.

Apart from the PDGS and the Service Element it can be considered to optionally implement direct reception user terminals for partly mobile direct reception of the data. This implies a processing of the data by the users and, therefore, can not rely on the infrastructure, background data and know-how of the PDGS and the service providers.

Spacecraft Configuration

The mission study identified a preliminary system design, which is compatible with the mission performance described in this document:

- Launch: ~ 2015 with Ariane 5 from Kourou
- Assumed mission duration: 10 years
- Orbit: GEO, inclination 0°, longitude 10°E
- Wet mass: ~ 3.6 tons
- Power budget: ~ 1.9 kW
- Instrument: Korsch Telescope, aperture: 1.5m
- Spectral range: 27 spectral channels (UV to TIR)
- Attitude control: Magnetic bearing wheels

The following figure provides the preliminary design of Geo-Oculus.

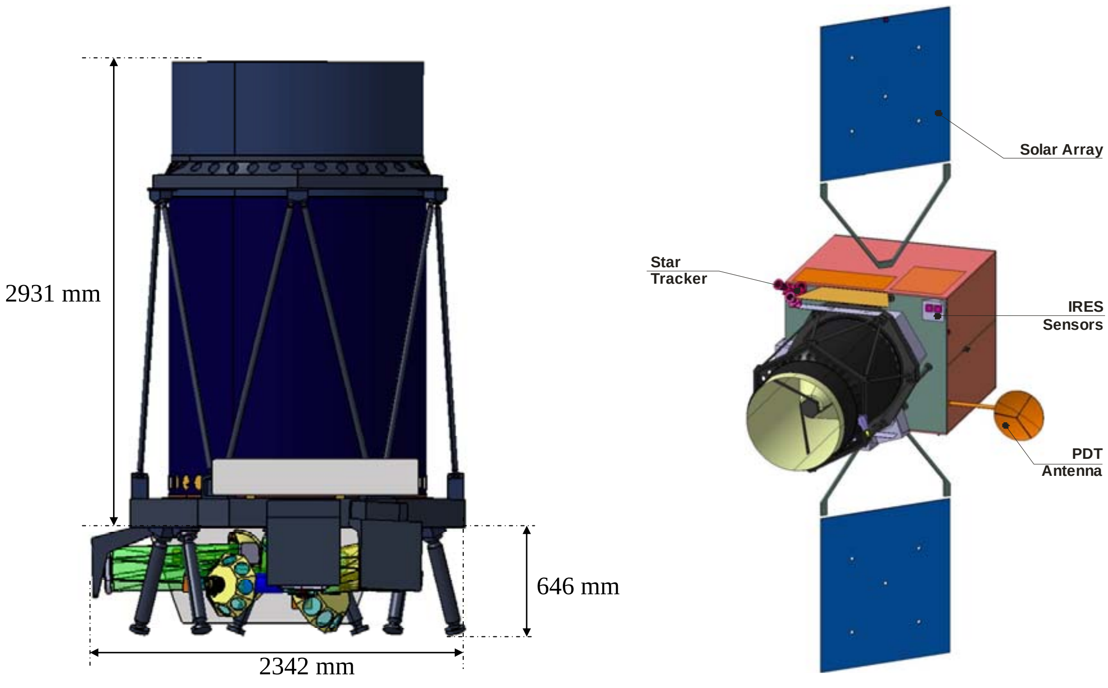

Figure 1.3-2: Preliminary instrument and system layout

The left illustration in figure 1.3-2 shows the telescope assembly, which is based on a Korsch-configuration and utilises five focal planes and filter wheels to acquire the data in 27 spectral channels ranging from UV to TIR. The current satellite layout is shown on the right. The telescope will be mounted on the nadir panel of the satellite and point to the Earth surface.

3 Mission Performance

For Geo-Oculus numerous technological challenges have to be mastered. The instrument requires a very large aperture and a precise optical characterisation that allows for image deconvolution techniques to be applied. Very large detectors with high dynamic range and fast readouts are a premise for this mission. As for the instrument also the satellite system and the ground segment are faced to stringent requirements that demand the implementation of new concepts and technologies. Defining a new class of Earth observation missions, Geo-Oculus is characterised by its unique combination of features:

High Spatial Resolution

A very large aperture of about 1.5 m combined with image deconvolution techniques to restore MTF gain a spatial resolution of about 20 m with a panchromatic channel and about 50 m for super-spectral channels in the UV to NIR in Europe (52°N).
This is in particular suited for disaster monitoring because it requires the high resolution in a panchromatic channel to analyse impact and severity for mitigation efforts. For applications with heterogenic topology, like coastal zones monitoring, such resolution significantly reduces parasitic signal from adjacent spots.

Real-Time Control

Geostationary orbit and permanent up- and downlink allow for real-time control of the system to command observations immediately with the arrival of a request by users. Furthermore optimisation of observation for regularly cloud covered areas becomes possible by e.g. the integration of now-casting information derived by Meteosat data.

Agile Satellite

The satellites attitude control system supports rapid pointing manoeuvres to access every commanded area of observation within about 1 min, depending of distance from previous site. This time also includes a tranquilisation period to settle vibrations that were induced by the attitude manoeuvre within the solar array and structure.

Real-Time Data Transmission

Through the permanent contact to the ground station the data transmission starts immediately after acquisition and essential onboard processing. Raw data become available at the ground station within few seconds after actual image take. Further on-ground processing to higher level products for delivery to the users is the dominating portion of the overall timeliness.

Rapid Revisit Capability

The agility, real-time control and real-time data transmission allow for a rapid revisit capability of the system that can be as low as two minutes for a full set of spectral channels when no other observations are conducted in parallel. While running a routine background mission, e.g. coastal zones monitoring with three complete cycles, the system is capable of three additional missions with a revisit of 10 min and six with a revisit of one hour.
Very short time-scale processes in various fields of applications can be studied at unprecedented detail in both, temporal and spatial resolution, which is reflected in Figure 1.

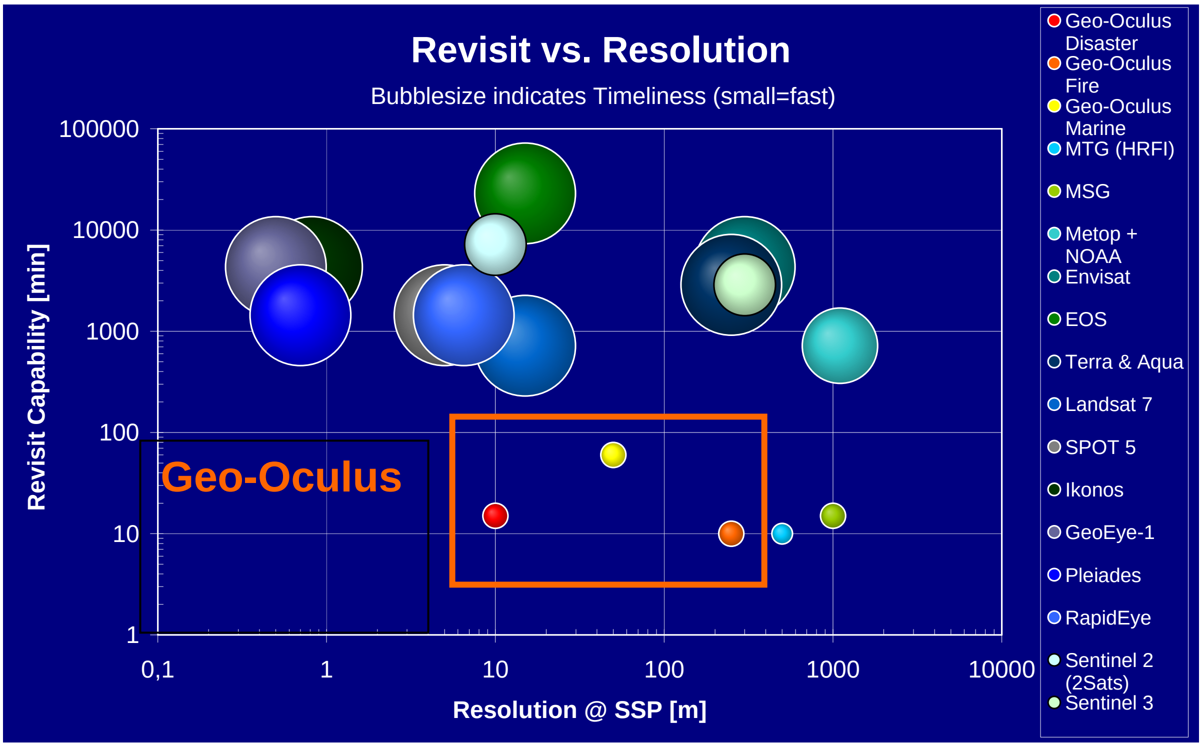

Figure 1.1-1 Comparison of Geo-Oculus with existing EO-missions in revisit, resolution and timeliness.

High Performance in all Earth Observation aspects

Its unique features position the Geo-Oculus mission in a previously unoccupied field of Earth observation, nevertheless are the shared performance characteristics at the edge of technology.

The instrument features an extended set of channels with narrow bandwidth for ocean colour. UV-channels gain potential for future applications such as oil slick detection or detection of toxicity of algal blooms. High signal to noise ratios are obtained for all channels including MWIR and TIR channels to e.g. retrieve accurate ocean constituent amounts and sea-surface temperatures.

A highest resolution panchromatic channel with 10 m GSD at sub-satellite point with a high MTF is included. The SWIR, MWIR and TIR channels provide high dynamic range suitable for high-temperature events without clipping to determine e.g. fire temperatures and hot spots.

Important synergies

Geo-Oculus provides strong assets for synergies with current and planned European EO-missions. The optimisation for cloud cover, which is considered as a central benefit of Geo-Oculus, is only possible with support data from Meteosat. On the other hand, Geo-Oculus can support other missions to improve quality of service. Some synergies, receiving and supportive, are listed below:

Receiving synergies:

- Real-time cloud cover information from Meteosat
- Incidence notification by any means
- Highest resolution support data e.g. for disaster monitoring from SPOT, Pleiades, Ikonos etc.

Supportive synergies:

- Joint observations
- Gap filling due to cloud cover

3.1 Ground Coverage of Geo-Oculus compared to Sentinel 3

When comparing the ground coverage of Geo-Oculus achievable within one day with that of Sentinel 3 the region of observation has to be limited to the defined area of interest for the considered applications. Obviously, a geostationary system with a FOV of about 300 km squared is not able to cover the full disc. Therefore, for this comparison the following region was defined:

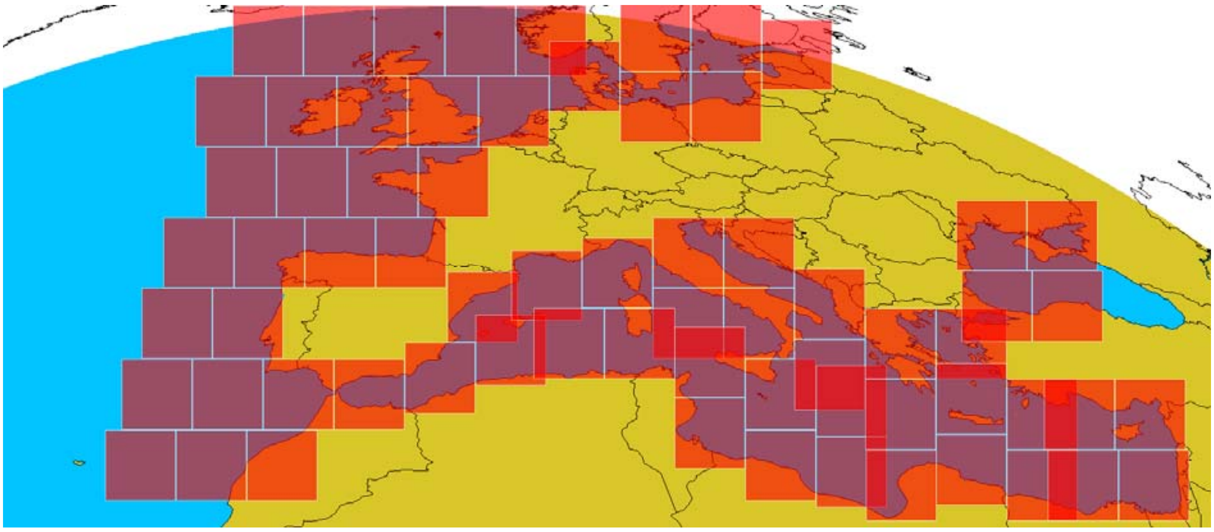

Figure 1.3-1: Considered pattern for observation, comprising 68 300km x 300km images.

The following table gives the achieved coverage of Geo-Oculus and Sentinel 3 for four selected days that are considered to be representative for the individual season or the entire year respectively.

Table 3.1-1 Daily ground coverage of Geo-Oculus compared to Sentinel 3 in different seasons

Mission	Average Day	Spring	Summer	Winter
Geo-Oculus	78 %	61 %	79 %	31 %
Sentinel 3	35 %	30 %	40 %	11 %

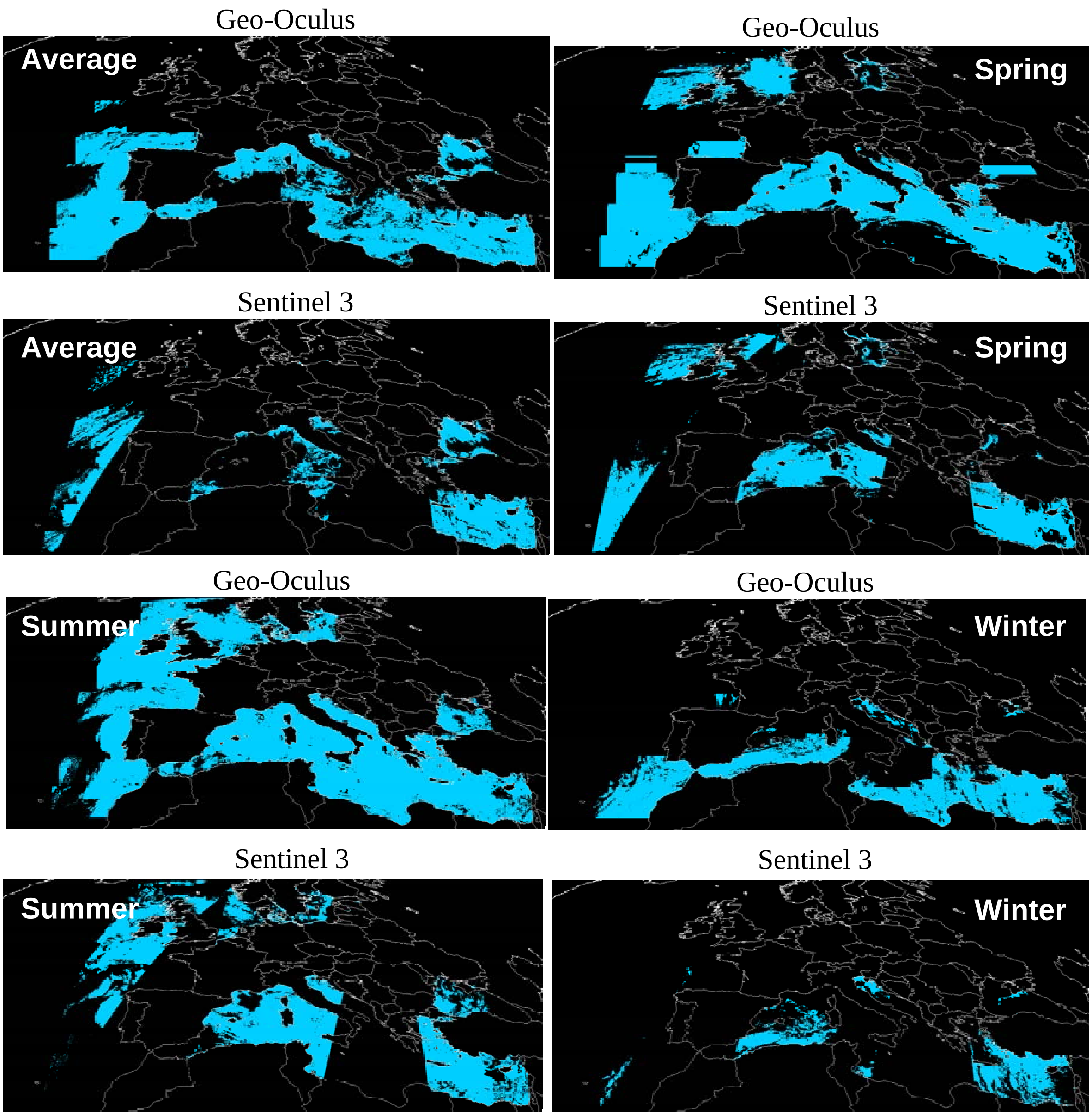

Figure 3.1-1 Daily coverage illustrations for Geo-Oculus and Sentinel 3 for representative days. Blue areas indicate achieved coverage within solar zenith angle limit of 60°.

The swaths of Sentinel 3 do not cover Europe within one day, therefore Sentinel 3 is intrinsically limited in the possible coverage compared to Geo-Oculus. Nevertheless, the illustrations above reveal that also for the areas that geometrically were acquired by Sentinel 3, the effective ground coverage is significantly lower than that of Geo-Oculus. This underlines the importance of the flexibility and optimisation of the mission plan for cloud coverage.

Additionally, when comparing Sentinel 3 and Geo-Oculus, it is important to bear in mind that the GSD of Sentinel 3 is 300 m, that of Geo-Oculus is about 50 m. A LEO mission with the same GSD as Geo-Oculus would have a reduced swath with opposed to the about 1300 km of Sentinel 3 and, therefore, could only provide a fraction of Sentinel 3's coverage.

4 Possibilities and Specifics of the Geostationary Orbit

For Earth Observation, the geostationary orbit imposes several possibilities, which are not available to LEO satellites, and supports advantageous observation methods. It is considered that based on these possibilities and methods a range of innovative EO-applications become feasible and that many existing applications can be improved or extended. Nevertheless, the geostationary orbit has also some less-beneficial specifics that must be considered for existing as well as for new applications.

Absence of "Ground Speed"

Compared to a LEO orbiter, a geostationary satellite maintains its position relative to Earth and, therefore, is not limited to integration times for the sensors depending on the resolution. The step&stare method of Geo-Oculus allows for, basically, indefinite view to the observation area and, thus, to increase the signal-to-noise-ratio (SNR) by multiple acquisitions in a row and image stapling. Due to the achievable stability of the platform of the satellite, the image quality in terms of smearing would be reduced if a single long integration would be applied.

For phenomena with very short time-dependence it could be considered to stare at the same observation area for longer periods and acquire images at high rates (~ 1 min, depending on SNR and number of channels).

Choice of local time at acquisition

The flexibility to take observations at any desired local time is only limited by the current cloud cover situation and the availability of the system. Despite this, the planning of the acquisition can be adapted whenever needed or optimised for each observation area.

Avoidance of cloud coverage

The current cloud cover situation is accessible from the METEOSAT system (i.e. MTG at the time of implementation) and the forecasting information by EUMETSAT, combined with the real-time commanding and agility of the system, allow for the optimisation of the acquisition strategy to gain maximal coverage at best possible conditions.

Flexible revisit parameters

The imaging capacity of the system is designed to enable a certain number of on-demand acquisitions without compromising the routine monitoring services. In case of incidents or for dedicated studies a monitoring service can become active to provide frequently updated data. Also for the routine monitoring services it is possible to temporarily reduce the revisit time for dedicated areas.

Joint observation with other satellites (e.g. LEO)

The flexibility of the system makes possible joint observations with other satellites, e.g. in LEO orbit, to support dedicated studies that either require the different observation principles (e.g. SAR) or different viewing geometry with the same time of acquisition. Additionally, the potential for cross-calibration of the sensors can be of interest.

Gap-filling

The possibility to avoid cloud coverage has been highlight several times as major asset of such a mission - this advantage can, to some extent, be transferred to LEO missions by gap-filling. This is especially relevant for areas where, at the local-time of the overpass of the LEO satellite, often clouds are present. Although the data characteristics are different, it is considered to be of high benefit to improve the data continuity of several LEO missions.

Invariant viewing geometry

The geostationary orbit, as the name denotes, provides a stationary or invariant viewing geometry. This implies for each spot on Earth individual and constant viewing angles. This is beneficial for time-series, nevertheless is this system not considered to be the most relevant for time-series. The drawback is that the processing has to be individually adapted to the geometry of each spot.

Implications from flexible mission planning

Despite the several advantages of a flexible mission planning, as described above, a drawback is the varying local-time of acquisition when the cloud cover situation does not allow for the desired local-time and in the case of priority missions. This has to be considered in the data processing and analysis. Also for time-series this has to be accounted for.

5 Performance Parameters driving the system

The completed system study on Geo-Oculus identified the main performance parameters that drive the system design, complexity and cost. There are some step-functions where for a small increase of the performance parameters requires a significant increase of complexity and cost. These parameters are briefly addressed in the following to make the users aware of sensible requirements in this respect.

Ground Sample Distance

The technological challenge to gain a GSD of about 20 m over Europe from the geostationary orbit implies not only the utilisation of a very large aperture (~1.5 m) and image deconvolution techniques but also a very stable platform to reduce micro-vibrations. It was found that a GSD of 23 m is feasible with considerable effort and that 20 m require several improvements and reduce the agility of the AOCS. The GSD is also relevant for the manoeuvre times described below.

Imaging Capacity and Manoeuvre Times

The imaging capacity of the system depends primarily on the FOV of the instrument, the manoeuvre times and the image acquisition time. The FOV is limited by the optics and the feasible size of the detector arrays to about 300 x 300 km^2. The time-span between the end of the last acquisition and the beginning of the next is denoted as manoeuvre time. This time depends slightly on the range of the manoeuvre (i.e. how far the system has to travel) and significantly on the level of stability that is required for the next acquisition. This level determines the tranquilisation time needed. The overall manoeuvre time for a 1° manoeuvre including the tranquilisation time for high resolution acquisition (~20 m) is about 1 min. The time needed for image acquisition depends on the number of spectral channels and the required SNR (see next paragraph) and accounts to about 1 min for 27 channels at highest SNR requirements.

In total the system can acquire images of about 30 different observation areas within one hour.

For the definition of the observation areas and the required revisit times this imaging capacity should be considered. Improving the imaging capacity would be possible to some extent if the GSD would be reduced, the number of spectral channels limited and/or the SNR reduced.

Signal-to-Noise-Ratio (SNR)

The SNR requirements, which came from Ocean Colour applications, that were used as design point during the study reached up to 1500 in the blue. These high values, which can be achieved by post-integration of several (up to about 70) individual acquisitions, impose not only relatively long overall integration times but also considerable on-board processing demands. For lower SNR values, similar to those in the green or red domain, only few acquisitions (~1 to 5) have to be post-integrated. Then these few acquisitions could be transmitted to the ground and processed their. This would allow reducing the installed on-board processing capability.

Concerning this aspect the users (especially the Ocean Colour community) are asked to consider if the information of the presence of a phenomena could be sufficient or if a detailed assessment is mandatory considering the high temporal performance of the system.

Spectral Channels and Need for TIR

The spectral range of the system analysed in the study with 27 channels from UV to TIR resulted in 5 focal planes and a rather complex instrument accommodation. Although this is considered feasible, the users are requested to challenge the need for every spectral channel to avoid costly over sizing of the instrument. This is especially relevant for the UV channels and the TIR. In the TIR the feasible GSD (~200 m TBC) is not sufficient to meet the requirements considered in the study.

Geolocation Accuracy

To gain a geolocation accuracy of about 0.5 to 1 Pixel a highly detailed database of landmarks is required for image navigation and registration (INR). This is, naturally, only possible over land and not over the ocean. In coastal areas the FOV can be positioned to include some landmarks and to achieve the desired geolocation accuracy TBC. If the requirements for the geolocation accuracy could be relaxed to some pixels, a less costly database could be applied.

6 Programmatics

Proposal: This should be filled by ESA when distributed to the users.

7 Conclusion

The intended geostationary system with high-resolution imaging, real-time control and very short revisit capability is considered to be of high potential to support and drive new EO-applications and services as well as improvements to existing services that are not possible with current and upcoming LEO satellites. Such a system provides several new possibilities in Earth Observation that have yet to be exploited. The briefly described characteristics and performance parameters of a preliminary system design provide the users with all required information to identify new applications and services. The parameters that drive the system design and the identified step-functions are highlighted to allow the users to match the requirements to the technical feasibility.

Annex A Abbreviations

AOCS	Attitude and Orbit Control System
APE	Absolute Pointing Error
CCD	Charged Coupled Device
DLR	Deutsches Zentrum für Luft und Raumfahrt
EO	Earth Observation
EOPP	Earth Observation Preparatory Programme
ESA	European Space Agency
ESOC	European Space Operation Centre
ESRIN	European Space Research Institute
FOS	Flight Operations Segment
FOV	Filed of View
GEO	Geostationary Earth Orbit
GMES	Global Monitoring for Environment and Security
GNC	Guidance Navigation and Control
GNSS	Global Navigation Satellite System
GSD	Ground Sampling Distance
GSE	GMES Service Element (ESA Projekts)
GSO	Geosynchronous Orbit
HRS	High Resolution Instrument
IGSO	Inclined Geosynchronous Orbit
IMU	Inertial Measurement Unit
INR	Image Navigation and Registration
IR	Infrared
ITT	Invitation to Tender
LEO	Low Earth Orbit
LOS	Line of Sight
MCT	Mercury Cadmium Telluride
MIR	Medium Infrared
MLI	Multi Layer Insulation
MMU	Minimum mapping unit
MSG	Meteosat Second Generation
MTF	Transfer Function
MTG	Meteosat Third Generation
MWIR	Medium Wave Infrared
NIR	Near Infrared
NRT	Near Real Time
OBC	Onboard Computer
OC	Ocean Colour
OCM	Orbit Control Manoeuvre
PDGS	Payload Data Ground Segment
PDH	Payload Data Handling
PDHT	Payload Data Handling and Transmission
PDT	Payload Data Transmission
PF	Platform
PFD	Power Flux Density
PPS	Pulse per Second
PRM	Product Requirements Meeting
QE	Quantum Efficiency
RD	Reference Document
RF	Radio Frequency
RME	Relative Measurement Error
ROM	Rough Order of Magnitude
RPE	Relative Pointing Error
RW	Reaction Wheel
SA	Solar Array
SADM	Solar Array Drive Mechanism
SAR	Synthetic Aperture Radar
SCU	Spacecraft Computer Unit
SNR	Signal to Noise Ration
SOW	Statement of Work
SSP	Sub Satellite Point
SST	Sea Surface Temperature

SWIR	Short Wave Infrared
TBC	to be Confirmed
TBD	to be determined
TC	Telecomand
TIR	Thermal Infrared
TM	Telemetry
TMTC	Telemetry and Telecomand
TN	Technical Note
TOA	Top of Atmosphere
TOC	Table of Contents
TRL	Technology Readiness Level
UV	Ultra Violet
VHR	Very high resolution
VIS	Visible
VNIR	Visible Near Infrared
WFD	Water Framework Directive
WFE	Wave Front Error