ANALYSES OF CLOUD COVER DYNAMICS FOR OPTIMISING THE MISSION PLANNING FOR HIGH RESOLUTION OPTICAL EARTH OBSERVATION FROM GEOSTATIONARY ORBIT

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Abstract

In the frame of a feasibility study for a new type of Earth observation system – a system which shall allow for high resolution near real-time optical imaging from geostationary orbit, called Geo-Oculus – a mission planning scheme for this agile Earth observation platform has been investigated utilising new approaches for significantly reducing revisit times and increasing the observed ground area. The flexible mission planning allows for optimising image acquisition by analysing and responding on the recent cloud coverage. A dedicated analysis has been raised to evaluate the impact of cloud coverage and dynamics in detail to identify appropriate optimisation approaches. The analysis comprises the evaluation of suitable meteorological input and identification of possible data handling and data analysis. Subsequently optimisation approaches for the operational timeline and the mission planning by applying meteorological data are assessed. Furthermore, the observation performance of Geo-Oculus and selected LEO systems is simulated and compared to indicate the operational benefit of such a platform.

1. INTRODUCTION

With Geo-Oculus as agile Earth observation system on geostationary orbit a system evolved capable for flexible mission planning allowing permanently optimisation by taking into account cloud coverage and cloud dynamics So far, current Earth observation satellites operating on both, low Earth orbit (LEO) or geostationary Earth orbit (GEO) are not capable to adapt their observation pattern to the current cloud coverage. LEO systems inherit the advantage of highest resolution imaging of the Earth due to the relatively low altitude. On the down-side, the orbital mechanics for low Earth orbits define the observational pattern by ground swaths. Due to this it is not feasible to optimise the operational timeline concerning cloud coverage. Conditional is also the fixed high ground speed which causes that the satellite can not remain over a certain area and thus is dependent on the cloud coverage at the moment of fly-by. If covered by clouds observing a certain area will be possible again with the next fly-by of the spacecraft. This can take several days or even weeks for a system in low Earth orbit.

Contrary to LEO, the geostationary orbit provides the advantage of permanent access to the area of observation. GEO systems with agile AOCS and real-time control allow for reacting on changing cloud coverage, e.g. by observing certain areas as soon as they become free of clouds. Current operational geostationary Earth observation systems can not provide image resolution high enough for that such an optimisation would provide significant benefit. Furthermore, the current systems are often dedicated to meteorological purposes and thus interested in atmosphere processes but not in optical observations of the Earth surface.

Unlike present Earth observation systems Geo-Oculus, a mission for real-time high resolution observation of European mainland, the European coastlines and the Mediterranean Sea, is the first system which can benefit from changing cloud scenes (hence cloud motion or cloud dissolution). This means improving ground coverage and shortening effective revisit times by updating the mission plan permanently according to recent meteorological data. This is possible by the following key features of the system:

- Location on geostationary orbit: allows for permanent up- and downlink, real-time control and permanent access to the observation area
- Large telescope (1.5 m aperture): enables high resolution imaging
- Agile attitude control system: offers rapid revisit capability and flexible mission planning

The analysis and optimisation approach is based on the preliminary system design of Geo-Oculus. Therefore this will be summarised in the following section before actual analysis, optimisation and results are presented.

2. GEO-OCULUS MISSION CONCEPT

Geo-Oculus was initiated by ESA to fill the gap between high resolution LEO observation systems and near real-time monitoring with GEO missions. It is planned as single satellite mission, allowing for real-time high to medium resolution (10m – 100m at sub satellite point) super-spectral observation and monitoring focussed on Europe and the European shorelines.

2.1. Mission Objectives

During the feasibility study for Geo-Oculus several mission objectives have been assessed for a system like this. The objectives in the following are preliminary defined for Geo-Oculus. These are subdivided into primary and secondary mission objectives. Latter can not become system design drivers. Furthermore the objectives are classified into a background mission (or routine service) and on demand services. The following table provides the currently considered Geo-Oculus mission objectives and the according requirements on spatial resolution and revisit time.

	Primary Mission Objectives				Secondary Mission Objectives	
	On Demand Services		Routine Services		On Demand Services	
Mission Objectives	Disaster Monitoring	Fire Monitoring	[illegible]	[illegible]	[illegible]	[illegible]
Description	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Revisit Time	1 hour	15 min	1 day	1 day	1 hour	1 hour

TAB 1. Geo-Oculus preliminary Mission Objectives

2.2. Preliminary System Design

The study investigated the following preliminary system parameters for Geo-Oculus:

- Lifetime: ~ 10 years
- Orbit: GEO, location 10° E
- Wet mass: ~ 3.6 t
- Power: 1.9 kW
- Payload: Korsch telescope, 1.5 m aperture, 27 spectral channels (ultra violet to thermal infrared)

Due to located on GEO the spacecraft is permanently linked to the ground segment allowing instantaneous commanding and flexible mission planning.

2.3. Operational Observation Scenario

The routine services shall be accomplished as background mission with the goal to observe the complete primary observation area (Europe, Mediterranean Sea) at least once a day. In between, the on demand missions shall be accomplished. Users (environmental and public organisations or public authorities) submit observation requests like monitoring certain disaster areas to the ground segment. There, an updated and optimised mission plan for the satellite is created, taking into account the user requests and auxiliary data (e.g. cloud coverage information) derived by synergies with other systems like Meteosat. This mission plan is sent to the satellite. The spacecraft concludes the current acquisition, points to the requested observation area, acquires the desired data, performs necessary on-board processing and sends the data to the ground station. From there, the images are released to the user. This process is planned to last not longer than 15 minutes to 1 hour (depending on the mission objective).

The observation scheme of Geo-Oculus has been chosen step & stare opposed to scanning. The pattern of the observation spots will be arranged dynamically according the user requests. The instantaneous field of view (IFOV) of each spot is about 300 km x 300 km at sub satellite point (SSP) for routine services and 100 km x 100 km at SSP for chosen on demand services.

2.4. Observation Requirements

To provide high quality images the acquisitions have to fulfil the following requirements:

– Nominal view zenith angle (VZA) of each pixel within the acquisition ≤ 60° (extended 80°)
– Nominal sun zenith angle (SZA) of each pixel within the acquisition ≤ 60° (extended 80°)
– Only cloud free pixels are scientific reasonable
– During post processing clouded pixel have to be identified and marked

Scientific reasonable images can only be provided by fulfilling the nominal observation requirements. Extended observation requirements are feasible if reduced product requirements are acceptable. They have been introduced to provide full coverage of Europe also during winter season, which is not possible for nominal observation requirements. The following image shows the primary observation area of Geo-Oculus depending on the acceptable VZA.

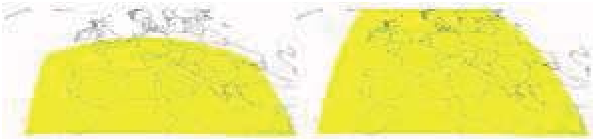

FIG 1. Geo-Oculus primary Observation area (yellow)

3. OPTIMISATION AND SIMULATION OF OBSERVATION BY GEO-OCULUS

3.1. Technical Terms concerning Optimisation and Cloud Data Analyses

The explanations of analyses and simulations contain several technical terms, which are defined below:

1) Cloud Amount (CA)

The term cloud amount describes the percentage of a defined time span (here 6.00 UTC – 18.00 UTC) when one particular area was clouded

2) Cloud Cover Changes (CCC)

This is the figure for the dynamics in the cloud scene over a certain region. It counts how many times a pixel changes from clouded to cloud free or vice versa on one day. This is based on the repeat cycle of the used cloud mask data of 15 minutes. The higher this number the higher is the dynamic of a certain cloud scene.

3) Ground Coverage (GC)

Ground coverage describes of the quantity of the observed area on ground. It is given referenced to the total regarded area, e.g. the complete area intended for observation with Geo-Oculus.

3.2. Prefacing Analysis of Cloud Coverage

The observations of Geo-Oculus are focussed on Europe, thus a prefacing analysis of the cloud situation over Europe for one chosen day provides insight into the relating cloud coverage and shows how the system will benefit if the operational timeline is optimised, taking into account cloud coverage and cloud dynamics.

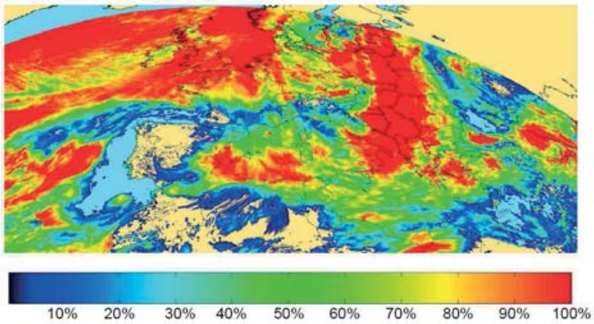

FIG 2. Cloud amount at 30.09.2005

Figure 2 shows the cloud amount over Europe at 30.09.2005 between 06:00 UTC and 18:00 UTC. Blue indicates few cloud coverage over the day and red illustrates that the particular area has been clouded nearly all day long (> 90 %). The observation area is largely clouded on that day at least about 50 %, some extent areas are clouded about 90 % even. Especially the North Atlantic and the North Sea are basically not observable that day. The Mediterranean Sea is also clouded 40 % – 60 % excepting few regions in the eastern parts. If a LEO mission is intended to observe the European coastal zones this day the cloud amount values shown in the figure indicate the probability of cloud free acquisitions. It can be assumed that the LEO mission will be capable to observe particular areas of the Mediterranean Sea and the west coast of the Iberian Peninsula, but especially the northern areas will probably not be accessible for such a mission.

Contrary to the LEO mission Geo-Oculus can access Europe all the time and in principle can acquire a cloud free image of a certain area as soon as it becomes free of clouds. Due to the geostationary location the system can benefit from changing cloud coverage when observing Europe. Generally, often changing cloud coverage through moving cloud fields provides more possibilities for observation than almost static cloud fields. The number of cloud cover changes over certain areas shown in figure 3 indicates the cloud dynamics over Europe at 30.09.2005.

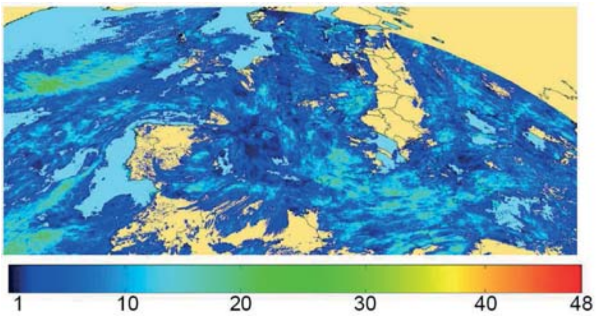

FIG 3. Cloud cover changes at 30.09.2005

The brighter an area is highlighted the higher is the dynamic. Nearly all cloud covered areas provide certain dynamic of the cloud scene (in average about 8 changes of the cloud coverage that day). Thus, nearly all points in the area intended for observation are at least short time of the day cloud free and observable preconditioning proper illumination. To reach the highest possible ground coverage an agile and flexible system is necessary, applying optimised mission planning by taking into account cloud coverage data.

3.3. Basic Optimisation Approach

Two principles for observation are planned for Geo-Oculus. The first is to combine acquisitions of different adjacent areas to one final product (so called image stitching). The second is to merge several acquisitions taken at different times of the same area (so called image stacking).

Image stitching is necessary since the whole intended observation area can not to be represented with one acquisition (300 km x 300 km FOV). This will be applied for both, background and on demand services In case of on demand missions it is assumed that about 2-3 acquisitions will be stitched. For the background mission about 70 images have to be combined to achieve full coverage. Knowing this, it is reasonable to define a dedicated acquisition pattern for the background mission. For the analyses in here a static pattern is preliminarily considered, although a dynamic grid might be preferred for operational Geo-Oculus. The applied pattern is illustrated in the following image. Each red square represents one acquisition spot of 300 km x 300 km (at SSP).

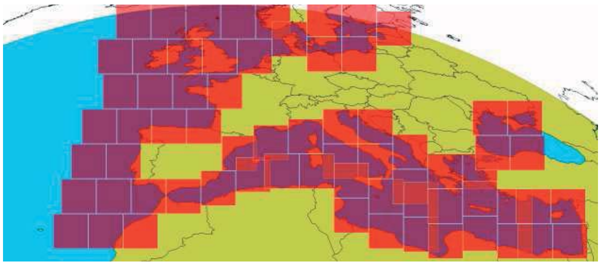

FIG 4. Static observation pattern for Geo-Oculus background mission

To provide highest ground coverage image stacking is necessary allowing benefit from changing cloud coverage since several acquisitions of the same spot taken at different times of the day. A simple example will explain: 50% of the area in a fictive spot at a certain time is clouded. All clouds concentrate in the southern part of the spot. The satellite acquires this spot. During that day the clouds move towards the north and certain time later the southern parts turned cloud free but the north of the spot is covered by clouds. Now the satellite acquires this spot a second time. By superposing the two acquisitions one image can be generated providing full ground coverage, although each acquisition has been clouded 50%.

Preliminary estimations showed that tha system can provide 210 acquisitions for the background mission per day. Thus it is possible to acquire each spot different times a day. So, it is reasonable to consider image stacking for the background mission. Image stacking will only be accomplished if the product and user requirements allow this. In case this is not allowed, several products of the same area but different acquisition times are released resulting in one cloud free overview (especially in case of natural hazards).

It is necessary to define a chronological order for acquiring all spots. The easiest way would be to define a static sequence, a priori. However, the more reasonable solution will be to define dynamical sequence according to the current cloud coverage in each spot. This shall be accomplished by the ground segment. There, regularly mission plan updates regarding user requests and including the optimised acquisition sequence shall be prepared. For this, it is necessary for the system to know about the cloud coverage state in all spots all the time. Therefore interfaces with operational meteorological systems have to be provided, since Geo-Oculus is not designed to generate these information itself. Possible input data could be Meteosat cloud masks providing every 5 to 15 minutes the recent cloud state over Europe as shown in the following section.

3.4. Appropriate meteorological Input for Analyses and operational Geo-Oculus

3.4.1. Identification of feasible Input Data

In general several types of meteorological input data are available and have been assessed. Statistical data has been refused due to low spatial resolution and the fact that current cloud situation can differ a lot from statistical values. Applying forecast data is also currently disregarded, since spatial and temporal resolution seem not capable for the real time commanding demand of Geo-Oculus. Although, forecasting (especially, nowcasting, very-short range and short range forecasting) data might be feasible for initial mission planning. However, information on the cloud coverage state at the time of acquisition is currently considered most reasonable for Geo-Oculus. Thus, data on the current cloud state is considered as baseline.

The chosen data source is Meteosat Second Generation (MSG) cloud mask data acquired from GEO, providing a spatial resolution of 3 km x 3 km at SSP and 15 minutes revisit time. The data contains information whether a pixel with known geo-location is clouded or not. Due to the short revisit time also analyses concerning cloud coverage dynamics can be conducted. At the expected time of operation this data will be provided by Meteosat Third Generation (MTG).

The delay between the cloud mask data acquisition on the meteorological satellite and implementing this data into the mission plan by the ground segment of Geo-Oculus could not be determined yet. Considered appropriate interfaces it is assumed to not exceed few minutes. The impact on the observation performance is considered insignificantly in the amount of this analysis.

3.4.2. Analysis Methodology

For the analysis on the impact of cloud coverage and cloud cover dynamics a dataset of MSG cloud mask files (CLMK) has been set up. The dataset comprises CLMKs from 30.01.2004 to 09.05.2007 in a time span from 6.00 UTC to 18.00 UTC and derived from EUMETSAT. When derived the files comprise a 3712 x 3712 pixel full disc image. For the analysis the files have been reduced to a size of 700 x 1620 pixel containing only Europe and the according coastal zones. For each day 49 files are considered. For operational Geo-Oculus this number might be differing due to different input frequency of the cloud mask data or differing operational duration each day (12 h/day assumed in the analysis). All analyses are conducted in Matlab, so far.

The analysis of each file is conducted on pixel level. Furthermore, all constraints and preconditions are implemented as matrices in the same size like the input data (e.g. masks determining coastal zones or the limitations of the area intended for observation). In conclusion different analyses can be conducted simply by superposing these matrices with the CLMK matrices.

3.4.3. Correlation of Cloud Coverage Data and Observation Requirements

To evaluate the observability of a certain pixel or a defined area the observation requirements for Geo-Oculus have to be regarded. Therefore it is necessary to calculate the geo-location for each pixel and save this in a dedicated matrix.

The view zenith angle of a certain pixel is constant due to the GEO orbit. Therefore, the VZA is calculated once for each pixel. Afterwards a mask can be generated containing the binary information whether a pixel fulfils the VZA requirement or not. A VZA mask is generated for both, nominal and extended VZA.

Contrary to VZA the sun zenith angle of each pixel changes through the day and the year and thus has to be calculated new for each handled cloud mask matrix. The according SZA masks are generated analogously to the VZA masks. By knowing the geo-location, the date and the time (UTC) the sun zenith angle can be calculated for each pixel and a mask can be created containing the binary information whether the SZA requirement is fulfilled or not (dedicated matrices for nominal and extended).

To assess the observability of a pixel in a certain CLMK all masks have just to be superposed. This procedure is the baseline of the simulation and can also be applied for the selection algorithm for the operational mission planning of Geo-Oculus in the ground segment.

3.5. Simulation of Geo-Oculus Observation Performance

3.5.1. Performance Evaluation Approach

For measuring the performance of Geo-Oculus the observation for the background mission for a complete day is simulated. The achieved ground coverage at the end of this day is assessed according equation 1.

(1) $$G = \frac{\sum p_{observed}}{\sum p_{EOA}} \cdot 100\%$$

Herein G is the ground coverage, $\Sigma\ p_{observed}$ is the sum of observed pixel and $\Sigma\ p_{EOA}$ the number of all pixel within the extended observation area (VZA ≤ 80°).

The performance of on demand missions is not assessed in here but the capacity for those can be derived from the results.

3.5.2. Specifications and Simplifications

The simulation is based on a representative mission plan for Geo-Oculus, which has been developed during the study. This plan accomplishes all mission objectives regarding their requirements.

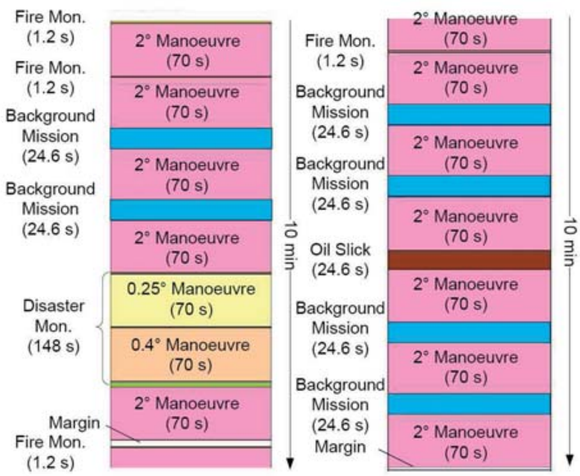

FIG 5. Baseline Mission Schedule of Geo-Oculus

Figure 5 shows the appropriate schedule. The plan is referenced to 2 x 10 minutes to meet all revisit time requirements. The size of each block represents the duration of each action. The 2° manoeuvres represen t the pointing from one spot to the next, since a 2° rotation is assumed as average manoeuvre between two spots. The small rotations are part of the disaster monitoring mission. All manoeuvres last the same time (~ 70 s). This assumption is due to the fact that most of the time is needed for vibration tranquilisation. It is assumed that this duration is independent from the size of the rotation angle in first iteration.

Since the input data is available once every 15 minutes this schedule is referenced to this time for this analysis. Conservatively this leads to 4 background mission acquisitions within one observation cycle. This acquisition frequency is considered as baseline. The number of background mission acquisitions is defined as variable parameter to represent different mission operations in the simulation; hence the more background missions are accomplished within one cycle the less on demand missions can be conducted. Maximum 9 background mission acquisitions can be accomplished per 15 minutes 9, due to the manoeuvre duration.

3.5.3. Simulator Implementation

The simulator is capable to provide the performance of Geo-Oculus for a single day. It starts with reading all available CLMK files for that day and transforming them into matrices (nominally 49). Additionally, a matrix is read containing the location and identification of all spots in the observation pattern for the marine applications. By applying this matrix it becomes possible to identify and cut out each spot of each CLMK matrix in further progress of the simulation. Each spot is identified by its number (here 1 – 68). After reading all CLMK information, the SZA values for each pixel in each CLMK matrix are calculated. In combination with the CLMK matrix it can be decided for all pixel whether one pixel is observable (cloud free and proper SZA value) or not. The analysis is accomplished for nominal and extended SZA demands. The observability information of each pixel is stored in a binary matrix in the size of 700 x 1620 for each handled CLMK matrix. In a next step all spots of the marine applications pattern are identified in this matrix and transferred into a 68 x 49 cell array. In this cell array the row represents the identification of a certain spot (e.g. row 43 = spot number 43) and the column is the number a certain CLMK, e.g. column 1 represents the observability in the first CLMK of the handled day; hence at 6.00 UTC. The following figure illustrates this.

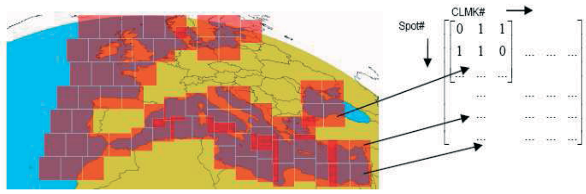

FIG 6. Transferring observability information into a cell array

With this database it becomes possible to simulate each kind of mission operation concerning the background mission, since the mission operations differ only in the acquisition sequence and the number of acquisitions per CLMK (hence per observation cycle). Even the impact of applying forecast cloud information for operational Geo-Oculus mission planning can be investigated in this way.

To achieve the final ground coverage all observed marked spots are retransferred into a 700 x 1620 CLMK size matrix and the number of all pixels which have been observed at least once is calculated.

3.6. Optimisation Algorithm

Real-time commanding and permanent access allow Geo-Oculus to focus on certain spots in any sequence. To achieve the highest possible ground coverage this sequence has to be optimised, taking into account current cloud coverage and changing cloud situation. The key task of this optimisation approach is the way of selecting the spots which are preferred for observation in each observation cycle. The optimisation has to provide best utilisation of cloud coverage dynamics. To provide this selection, a figure of merit (FOM) is allocated to each spot in each cloud mask. This ranking value takes into account on the one hand how often the spot is properly illuminated; hence how often the geometrical requirements are fulfilled. On the other hand the ranking value includes the gain on overall ground coverage when acquiring this spot. The FOM is defined in the following way.

(2) $r(i_{spot}, i_{CLMK}) = a_1(i_{spot}, i_{CLMK}) + a_2(i_{spot}, i_{CLMK})$

In this equation r is the FOM, i_{spot} is the index of a certain spot and i_{CLMK} is the number of the current handled CLMK. Thus i_{CLMK} is a figure for the acquisition time, since each CLMK has been acquired at a defined point time. The first CLMK represents the cloud coverage at 6.00 UTC a certain day, whereas the 49^{th} CLMK corresponds to 18.00UTC. The value a_1 denotes the number how often a certain spot fulfils the geometrical requirements without regarding cloud coverage at this point. It is referenced to the total number of handled CLMKs as shown in the following equation.

(3) $a_1(i_{spot}) = \frac{n_G(i_{spot})}{N_{CLMK}}$

Herein n_G is the number of CLMKs in which a certain spot fulfils the geometrical requirements at the handled day. Preliminarily it is defined that a certain spot in a CLMK is considered fulfilling the geometrical requirements if 10% of all pixels within the observation area in this spot meet the demands on SZA and VZA. N_{CLMK} is the number of total available CLMKs on a certain day. The parameter increases the higher the number of CLMKs is in which a certain spot fulfils geometrical requirements. This is a preliminary definition to regard changing illumination conditions when optimising. Another possible definition would be to increase the value the shorter the duration of proper illumination is. This point has not yet been investigated but can be regarded in further analyses.

The value a_2 represents the gain of ground coverage in one spot between two subsequent CLMKs. It is defined in the following way.

(4) $a_2(i_{spot}) = \frac{\Delta n_{observable}(i_{spot})}{\sum p_{EOA}(i_{spot})}$

The value $\Delta n_{observable}$ represents the number of pixels, which have not yet been observed, but become observable (cloud free and geometrical requirements fulfilled) through observing a certain spot during the next observation cycle. It is derived by comparing the already observed area with the following CLMK. The higher this value, the more pixels become observable in this spot in the following observation cycle. Thus, this parameter takes into account the initial ground coverage when observing a certain spot the first time and the gain of ground coverage when observing this spot different times (multiple acquisition) due to the changing cloud situation over this area. The number of pixel which can be gained by observing this spot is referenced to $\Sigma\ p_{EOA}(i_{spot})$, which describes the total number of pixels in the currently handled spot (i_{spot}). As equation 2 shows, both parameters of the figure of merit are weighted in the same amount and correlated as sum. To provide a proper selection all the spots with the highest FOM in a certain CLMK are considered to be acquired. The number of acquired spots per CLMK (hence per observation cycle) depends on the number of back ground mission objectives provided by the mission plan (baseline 4/ cycle, maximum 9/ cycle). This parameter represents a maximum value. In case that ground coverage can not be improved (e.g. in the end of the day) less acquisitions are performed.

This approach still provides potential for further optimisation such as weighting factors, or other correlation approaches (e.g. polynomial correlation). In addition other criteria can be accounted for the FOM. Especially a parameter regarding the statistical spatial distribution of cloud coverage through several years is considered to be reasonable. It will also be reasonable to investigate the impact on observation if the parameter a_1 is defined not increasing but decreasing when the time of proper illumination rises, with the goal to prefer rarely observable areas.

Results for selected Days

The performance of Geo-Oculus applying the optimised spot selection algorithm has been assessed for selected days of the analysis data set. Due to high computational effort of statistical analyses such could not yet be derived. To provide representative results anyhow, the days for detailed analyses has been selected considering statistical purposes. For this the complete data set has been analysed and days representing nearly average, the assumed worst case and best case cloud coverage and illumination conditions have been selected. The following section presents the according performance results.

3.6.1. Average Conditions

The day considered representing average conditions of the data set best is 30.09.2005. This day shows in all three necessary aspects – over-all cloud amount, cloud cover dynamics and duration of proper illumination – values near the over-all data set average. The according cloud situation is shown in figures 2 and 3. The observation performance in terms of ground coverage at this day is provided by the following diagram.

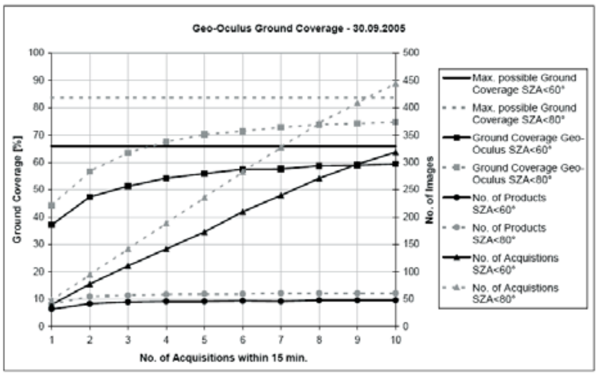

FIG 7. Ground coverage of Geo-Oculus background mission depending on the number of acquisitions per cycle – 30.09.2005

In this diagram the maximum possible ground coverage (hence each pixel which has been observable at least once that day), the ground coverage of Geo-Oculus background mission, the according number of final products (= number of different observed spots) and the number of accomplished acquisitions is shown depending on the actual number of maximum allowed background mission acquisitions per observation cycle.

The maximum possible ground coverage is about 67% for nominal SZA requirement (≤ 60°) and about 84% for extended SZA requirement (≤ 80°). The ground coverage achieved with Geo-Oculus converges on the maximum value the larger the number of acquisitions per 15 minutes grows. Regarding the current baseline of 4 acquisitions per cycle 142 acquisitions have to be performed that day for the background mission. These are combined to 46 of 68 images (= products) and finally to a ground coverage of about 51% which is about 76% of the maximum accessible area for observations on this day. In case of extended SZA 189 acquisitions have been possible that day. This provides in result 59 of 68 acquired spots and a ground coverage of 64% of the total area for observation. Thus extended observation can provide about 81% ground coverage of the maximum observable area at that day.

Increasing the number of acquisitions within 15 minutes would slightly increase the number of provided products to maximum 48 nominal and 61 extended. It can only be achieved at the expense of lower capacity for other mission objectives or a more agile system which provides less manoeuvre time.

Another effect, which can be seen when increasing the acquisition frequency, is that the gradient of the number of total acquisitions is not constant but differs slightly, since the acquisition frequency is a maximum value but has not to be reached if more acquisitions will not provide any benefit. The reason for this effect is that acquisitions not leading to increased ground coverage are not performed even if the mission plan would allow such a high number of acquisitions. This can be due to cloud conditions not providing opportunities for observation.

Focussing on the baseline mission plan (4 background mission acquisitions in 15 minutes) Geo-Oculus is capable of observing the highlighted areas in figure 8.

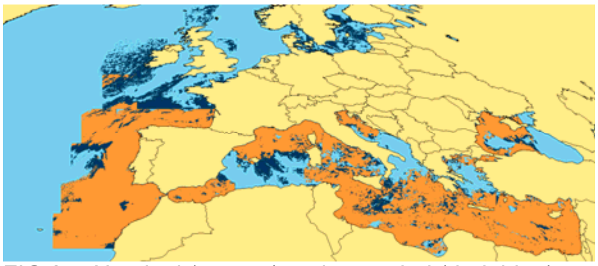

FIG 8. Nominal (orange) and extended (dark blue) Observed Area by Geo-Oculus – 30.09.2005

Geo-Oculus can observe nearly the complete Mediterranean Sea, half of the Black Sea and wide parts of the European Atlantic coast. Extending the observation parameter provides benefit especially in the northern regions of Europe.

3.6.2. Worst Case Observation Conditions

The worst case conditions for observations are high cloud amount all day long and over the whole observation area, low cloud cover dynamics and short illumination times. Statistical analyses showed that 30.12.2005 provided such conditions. The observation area has been clouded nearly completely the whole day. Only small cloud gaps occurred in parts of the Mediterranean. In addition few areas of cloud coverage changes occurred, mostly concentrated over land zones and thus not applicable for the Geo-Oculus background mission. The impacts on observation performance can be seen in the following figure.

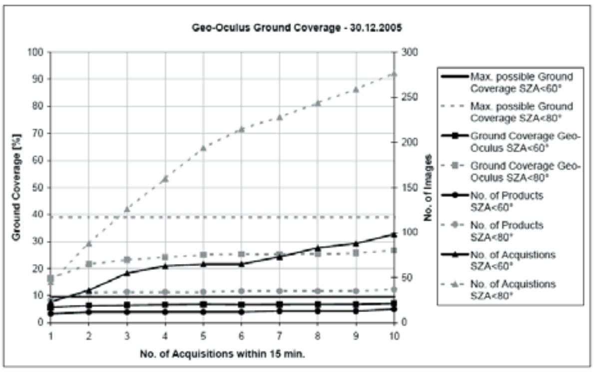

FIG 9. Ground coverage of Geo-Oculus background mission depending on the number of acquisitions per cycle – 30.12.2005

Maximum observable area is restricted to 10 % nominally and 39 % regarding extended SZA. Geo-Oculus baseline mission planning provides over all 63 acquisitions, 12 products and about 7% ground coverage. Extending observation parameter enables 160 acquisitions leading to 24% ground coverage. In general, acquisition frequencies larger than 2/cycle do not significantly increased the performance. High cloud amount and low dynamics combined with short time of proper illumination in winter leads to very constrained observability that day. The following figure shows the observed area.

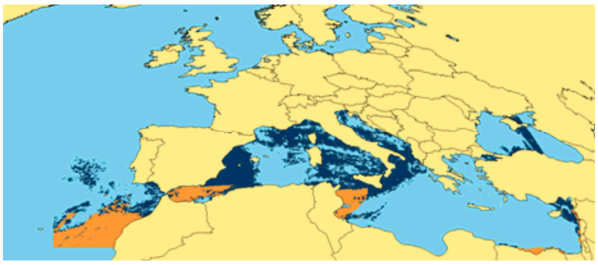

FIG 10. Nominal (orange) and extended Observed Area by Geo-Oculus – 30.12.2005

Few areas of the Mediterranean Sea and of the Atlantic coast west of Northern Africa are observable nominally by Geo-Oculus. The extended observation parameter provides at least gain on observed area in the Mediterranean and parts of the Black Sea. Thus extending observation parameters provides the most benefit on a day like this since even a high number of acquisitions per cycle will not provide significant benefit.

3.6.3. Best Case Observation Conditions

Low over-all cloud amount and high dynamics in the clouded areas together with long time of proper illumination is considered to be the best case for optical observations. A day providing these characteristics has been 30.06.2004. On this day only few large cloud fields occurred affecting e.g. North Sea, Northern Atlantic and the Atlantic coast west of Northern Africa. In addition all the clouded areas provide medium to high dynamics. The observation performance on a day like that can be seen in figure 11.

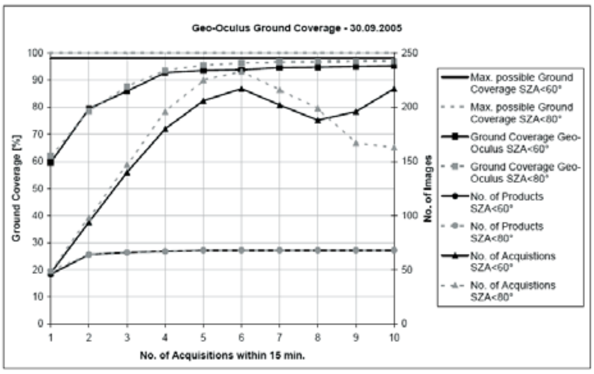

FIG 11. Ground coverage of Geo-Oculus background mission depending on the number of acquisitions per cycle – 30.06.2004

Nominal observation parameter allow 98 % ground coverage maximum whereas extending the SZA requirement provides the possibility to observe the entire observation area (100% maximum ground coverage). Geo-Oculus baseline mission planning is capable for reaching 93% ground coverage nominal and 94% extended by performing 180 (196) acquisitions. These lead to 67 (68) products in result. Thus, relaxing observation requirements provides only slight benefits for Geo-Oculus, likewise increasing the acquisition frequency. What can be seen in this case is that the total number of acquisitions is decreasing when exceeding 6 background mission acquisitions per 15 minutes. This is due to that acquisitions which are not reasonable are not performed. In case of high acquisition frequencies spots can be selected for observation (e.g. if illumination condition is very good), which are actually not leading to increasing ground coverage. Thus these spots are not considered to be observed in the anent observation cycle. This provides additional capacities for on demand objectives, since less background missions have to be accomplished.

The following plot provides the sea area which could have been observed by Geo-Oculus.

FIG 12. Observable Area by Geo-Oculus at 30.06.2004

Almost the whole area intended for observation can be covered through Geo-Oculus baseline mission operation by applying nominal or extended SZA. Slight gain can be achieved when extending SZA.

3.7. First Conclusions

So far the results of the simulation have shown that Geo-Oculus can reach about 60 % to 96 % of the actual maximum possible ground coverage. It has to be distinguished that the performance and the benefit of the optimisation are dependent on the actual cloud scene and the season depending the illumination as well as meteorological conditions. The actual performance will vary a lot but several trends can be announced yet. Naturally, summer will provide better observation conditions as winter season. But cloud coverage differs also a lot regarding subsequent days. Thus it is possible that a day in summer provides even less ground coverage than a day in winter.

In general it can be concluded that the approach of providing regularly mission plan updates applying a selection of the spots for observation achieves high ground coverage even if wide parts of the intended observation area are clouded long time a day. The advance of this technology compared with LEO missions considered for similar mission objectives is shown in the following section.

4. COMPARISON OF GEO-OCULUS AND LEO EARTH OBSERVATION SYSTEMS

4.1. Selected LEO Missions

So far, high resolution optical Earth observation is provided through LEO satellite systems. Since Geo-Oculus is the first mission for high resolution observation from geostationary orbit the simulated performance of Geo-Oculus baseline background mission operation is compared to several LEO missions. These systems are summarised in the following table.

	Sentinel 2	Sentinel 3	PostEPS
Objectives	Disaster & Land Observation with two simultaneous operating spacecrafts	Ocean colour products, altimetry & temperature measurement	Metop follow-up mission: Environmental & meteorological observation of land & sea areas
Orbit	786 km sun synchronous	815 km sun synchronous	815 km sun synchronous
Instrument Swath	290 km	1269 km	~ 3200 km
Instrument Resolution (Ground sampling distance – GSD)	10 – 60 m depending on actual mission objective	300 m for ocean colour applications	~ 1000 m

TAB 2. LEO missions taken into account for comparisons with Geo-Oculus

Sentinel 2 and Sentinel 3 are similar systems to Geo-Oculus in terms of instrument performance (Sentinel 2 – similar spatial resolution) and mission objectives (Sentinel 3 – dedicated system for ocean colour applications). Furthermore, the comparisons to Sentinel 3 and especially to PostEPS (a follow-up mission of Metop) provide the impact of significantly increased swath width on the achievable ground coverage.

4.2. Simplifications and Implementation

Evaluating the performance of the LEO systems and comparison to Geo-Oculus requires the ground tracks of the LEO systems to be mapped on the CLMK files. For this, several assumptions and simplifications have to be appointed.

First, performance evaluation takes into account only European sea areas, analogously to Geo-Oculus performance evaluation.

Secondly it is assumed that on the days, which have been picked for these analyses, all LEO systems are flying over Europe at defined points of time. Since all missions are nearly on the same altitude and passing descending node nearly at the same time, the fly-bys are assumed for each system at 8.15 UTC, 10.00 UTC and 11.45 UTC for all analysed days.

Since the satellites pass the area of interest in less then 15 minutes, the third assumption is that each fly-by can be simulated in one CLMK. Thus, during the observation the cloud scene is considered to be constant. The ground tracks have been calculated with Satellite Tool Kit (STK) and transformed into the pixel coordinate system of the applied CLMK files. As an example, the following image provides the applied ground tracks for both Sentinel 2 spacecrafts.

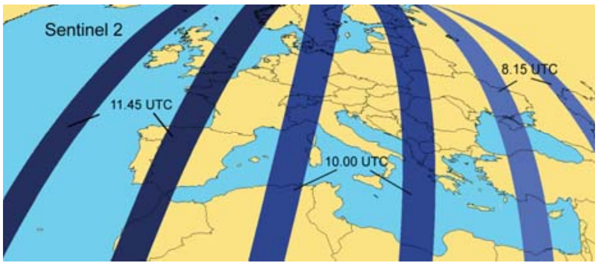

FIG 13. Ground tracks of Sentinel 2 in the analysed cloud masks

Sentinel 2 can not achieve full coverage of Europe at one day. The system design provides global revisit time of 5 days. Likewise Sentinel 3 is also not capable for full coverage at one day, instead 2 days are currently considered for global revisit. Contrary, PostEPS is capable for full coverage at one day due to the large swath width.

Furthermore it is assumed in this analysis that observation requirements of all systems are equal to Geo-Oculus requirements in terms of SZA, VZA and the area intended for observation.

Applying these simplifications implementing a performance simulator for the LEO missions is rather straight forward. Each LEO fly-by is represented by superposing a binary matrix containing ‘1’ for each pixel located within the ground track with the matrix containing binary information whether a pixel is observable (SZA requirement fulfilled, cloud free) or not. In result all elements containing ‘2’ can be considered observable by the LEO mission during the according fly-by. Final ground coverage is derived by summing up all observed pixels in the three fly-bys.

4.3. Performance Comparison considering average Cloud Coverage Conditions

The performance comparison has been performed for several selected days among the complete applied data. A comparison of Geo-Oculus and LEO mission ground coverage at 30.09.2005 is presented in here providing average cloud scenery and illumination time. The derived results are considered to approximately represent performances which can be expected in average for all systems. The following graph illustrates the advantage of Geo-Oculus concerning ground coverage for observations of European sea areas that day.

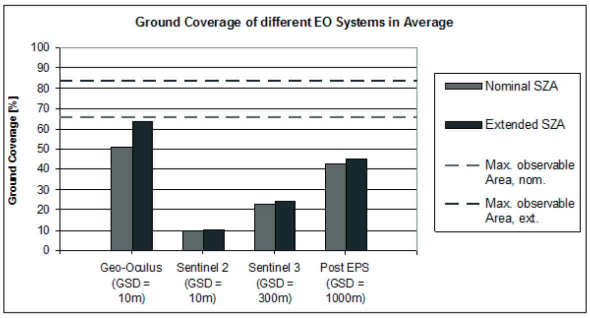

FIG 14. Ground coverage for observation of European coastal zones through different systems at 30.09.2005

Compared with the analysed LEO missions Geo-Oculus provides the highest ground coverage for observations of the European coastal zones. By allowing 4 background mission acquisitions per 15 minutes (baseline mission planning) Geo-Oculus can achieve about 50% of the entire observation area nominally and 63% extended. The ground coverage of the LEO missions account between 10 % (Sentinel-2) and 41 % (PostEPS) nominally. Only a slight increase can be achieved when extending the observation parameter SZA. Referencing the achieved absolute ground coverage to the maximum possible ground coverage shows the observation efficiency of each system. Geo-Oculus can reach 77 % (extended: 76 %) whereas the LEO systems only achieve 15 % - 64% (extended: 12% - 54%). Furthermore, the graph shows that LEO ground coverage is obviously strongly depending on the instrument’s swath width. To significantly increase the observed area the swath has to be extended tremendously. Regarding current observation technology, this can only be achieved with the expense of extremely lowering spatial resolution. For instance, Sentinel-3 can provide approximately twice the ground coverage of Sentinel 2. To achieve this, swath width has to be increased four times. In consequence spatial resolution is decreased from 10 m to 300 m ground sampling distance at sub satellite point. Concerning PostEPS shows the same effect (Twice the ground coverage of Sentinel 3 but three times increased swath width, GSD decreased to 1 km).

As an example for the observed area by a typical high resolution LEO observation the following figure shows Sentinel 2 ground coverage (highlighted blue).

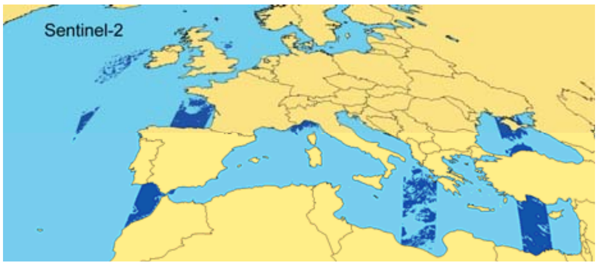

FIG 15. Observed area (blue) by Sentinel 2 at 30.09.2005

Compared with Geo-Oculus ground coverage the same day (see figure 8) fractional amount can be reached by a commensurable LEO system which comprises even two simultaneously operating satellites. The advance of Geo-Oculus is achieved by the geostationary orbit allowing permanent access to Europe, an agile attitude control system, near real time commanding and the flexible mission planning applying an optimised algorithm for defining observation sequences.

5. CONCLUSIONS AND OUTLOOK

The results of the performance simulation have shown that system like Geo-Oculus is capable of benefiting through mission plan optimisation taking into account cloud coverage dynamics. Geo-Oculus is feasible of acquiring > 75 % of the total observable area for average cloud coverage conditions according to first estimations through the performance simulator. A currently operating high resolution LEO mission with similar mission objectives is capable of observing about 15 % of the maximum observable area. Large benefits are derived due to permanent access to the observation area and optimised mission planning taking into account current cloud coverage data. This is valid for observation of particular areas of the Earth (e.g. Europe and the coastal zones). It has to be noted the advance decreases the more the observation area is extended (e.g. to full disc observations) due to strongly increased manoeuvre durations and more complex cloud coverage conditions leading to an increasing number of optimisation parameters.

Another point which is reflected by the analysis is that observation performance is strongly varying through the seasons since cloud coverage and illumination conditions are naturally depending on the seasons, too. In addition the performance will also fluctuate strongly regarding subsequent days. These variations can even exceed differences through seasonal impacts.

In conclusion, the results of this analysis lead to the following necessary requirements for further system design, if observation shall be optimised concerning cloud coverage dynamics:

– Provide regularly mission plan updates optimised concerning cloud coverage and illumination condition and on demand service requests.
– Provide mission plan update as soon as new cloud coverage data becomes accessible.
– Set up fast interfaces to cloud data providers
– Automate mission plan updating and provide fast data processing to avoid large cloud scene changes until observation is conducted. Otherwise observations will not be performed properly.

Outlook and further Analysis

The analysis conducted so far provide first estimates on the performance of Geo-Oculus for different cloud coverage conditions. To achieve statistically representative observation performance predictions it is necessary to analyse more days out of the data set in detail and even extend the data set afterwards. Furthermore, additional input data like Meteosat 8 Rapid Scan data providing 5 minutes revisit time should be taken into account for further analyses. Through the reduced revisit time the optimisation capabilities might improve and mission planning might become more sensible for on demand service requests. In addition a dynamically arranged observation pattern should be implemented for performance simulations and optimisation algorithms, since considered most reasonable for operational Geo-Oculus.

6. SUMMARY

The analysis on cloud coverage and cloud dynamics indicated MSG cloud mask data as reasonable input data for simulated and operational mission planning for a geostationary high resolution Earth observation mission as a first result. Additionally a methodology has been developed allowing analysis of cloud coverage data in order to provide an approach for optimised observation sequences. The optimisation is based on assessing the illumination conditions of each observation spot in combination with analysing the changing cloud coverage situation. The performance simulation provided that the ground coverage can be maximised in this way. Finally the comparison of Geo-Oculus with Sentinel 2, Sentinel 3 and PostEPS shows that a geostationary mission is most reasonable for dedicated observations of particular regions of the Earth.