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Results with CLIMAS, a simulation tool for cloud avoidance scheduling in optical remote sensing missions

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ABSTRACT

Cloud cover is a severe problem in optical satellite remote sensing. Depending on the local climate, often a significant part of the recorded images is not acceptable due to cloud contamination. This has a negative impact on the effective imaging capacity of the satellite observation system, i.e. the total surface area successfully imaged per unit of time.

Therefore different Cloud Avoidance Scheduling methods have been or will be implemented in a number of missions. Potentially the highest efficiency can be obtained if the pointing ability of the optical axis, if available, is used to actively select cloud-free areas. The necessary cloud information can be derived from numerical weather models (usually half a day or more in advance), from meteorological satellites (one or more hours in advance), or from a dedicated on-board cloud sensor. Depending on the local cloud statistics, the accuracy of the cloud cover prediction, the pointing capabilities of the instrument, and the performance of the tasking algorithm, it is possible to improve the effective imaging capacity by up to 100%.

The National Aerospace Laboratory NLR develops a simulator called CLIMAS (Cloud Impact and Avoidance Simulator) to support research and development activities in this field. CLIMAS uses a global cloud cover database derived from real satellite data with high spatial and temporal resolution. Various types of missions can be simulated, including constellations, with and without cloud avoidance scheduling.

Simulation results are presented of a mission dedicated to the monitoring of gas pipeline networks in Europe. This mission involves a constellation of four high-resolution optical satellites with cross-track and along-track pointing ability. It is shown that cloud avoidance scheduling significantly improves the effective monitoring frequency.

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Abstract

Cloud cover is a severe problem in optical satellite remote sensing. Depending on the local climate, often a significant part of the recorded images is not acceptable due to cloud contamination. This has a negative impact on the effective imaging capacity of the satellite observation system, i.e. the total surface area successfully imaged per unit of time.

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I Introduction

In optical satellite remote sensing cloud cover is a severe problem. Since the average global cloud cover is about 50%, at least that part of the observations will be cloud-contaminated. Depending on the meteorological circumstances and the local climate, in some areas the percentage of successful (cloud-free) images may be even far lower than average.

Obviously, this has a negative impact on the effective imaging capacity of the satellite observation system; i.e. the total successfully imaged surface area per unit of time. Also other return parameters that may be relevant to a mission are influenced such as the effective revisit time and the image delivery time. To mitigate this effect and improve the mission return, various approaches are possible.

In the case of the LANDSAT series of satellites, a cloud avoidance strategy has been applied for the first time for LANDSAT 7. Recording of cloudy areas by the nadir-pointing imaging system is minimized by means of proper on-off scheduling using cloud cover prediction data. The cloud cover data comes from a numerical weather model [1]. In this way, resources such as the on-board data memory and the downlink facilities are used more efficiently; i.e. the percentage of useful data is increased.

Alternatively, and more effective, on-board cloud detection on the acquired data can be performed followed by discarding or heavy compression of the clouded parts of the data. This has been called selective compression [2] or cloud editing [3, 4]. It requires on-board processing capacity, but the performance of this approach is better than that used for LANDSAT 7. This is due to the absence of cloud cover prediction errors and to the more precise selection of cloud-free areas.

In essence, both these methods can be considered as data selection processes. Unusable data or data that is probably unusable is simply not imaged or not stored for downlinking. The efficiency of the use of data storage and communication resources is improved, but the effective imaging capacity of the optical system is not increased.

Potentially higher efficiency is obtained if the pointing ability of the optical axis, if available, is used to actively select cloud free areas. The necessary cloud information can be derived from numerical weather models (usually half a day or more in advance), from meteorological satellites (one or more hours in advance), or from a real-time sensor. Such a sensor may be accommodated on the observation satellite itself [5] or on a microsatellite, flying ahead.

Depending on the local cloud statistics, the accuracy of the cloud cover prediction, the pointing capabilities of the instrument, and the performance of the tasking algorithm, it is possible in this way to improve the effective imaging capability of the satellite by up to 100% [6].

Traditionally, task scheduling is characterized by a long lead-time and high labor intensity and has been achieved by teams of ground planners who write, check and recheck procedures. Hence, current missions are beginning to exploit the capability of automated decision support software, to allow efficiency and functionality improvements on the more traditional methods of preplanning all activities [7]. This allows scheduling updates shortly before the associated imaging activity and opens the way for the integration of effective cloud avoidance scheduling into the process. E.g. for the ASTER observations on the Terra satellite such a dynamic scheduling system has been implemented already. The candidate-swath prioritization is also based on cloud cover prediction of 10 hours in advance [8].

The effectiveness of the implementation of dynamic, automatic cloud avoidance scheduling in a mission depends on many factors such as swath, resolution, area, time, date (cloud statistics), slewing speed, downlink data budget, mission type/scenario (i.e. monitoring, commercial imaging, science), cloud cover prediction accuracy, efficiency of implemented scheduling algorithm.

Due to the complexity of the problem and the multitude of variables only simulations can adequately assess the associated performance improvement. Therefore CLIMAS (Cloud Impact and Avoidance Simulator) has been developed at the National Aerospace Laboratory NLR to support research and development activities in this field.
This paper describes this simulator (section II) with the currently implemented scheduling methodology (section III). Section IV presents simulation results of a pipeline-monitoring mission showing the potential performance improvement when cloud avoidance scheduling would be applied.

II CLIMAS simulator and scheduling

CLIMAS' modular architecture is depicted in figure 1. The CHANCES cloud database is based on real satellite data. The database has global coverage. The spatial resolution is 5x5km and the temporal resolution is one hour [9].
Various types of missions can be simulated, including constellations, with and without cloud avoidance scheduling. Satellite orbit parameters (e.g. altitude, inclination, ascending node crossing time) and instrument parameters (e.g. field of view across and along track, instantaneous field of view, slew speed, stabilization time) can freely be chosen. Target information can be imported from a GeoTIFF file, or from XML-format file in which target areas are described. In addition it is possible to let CLIMAS randomly

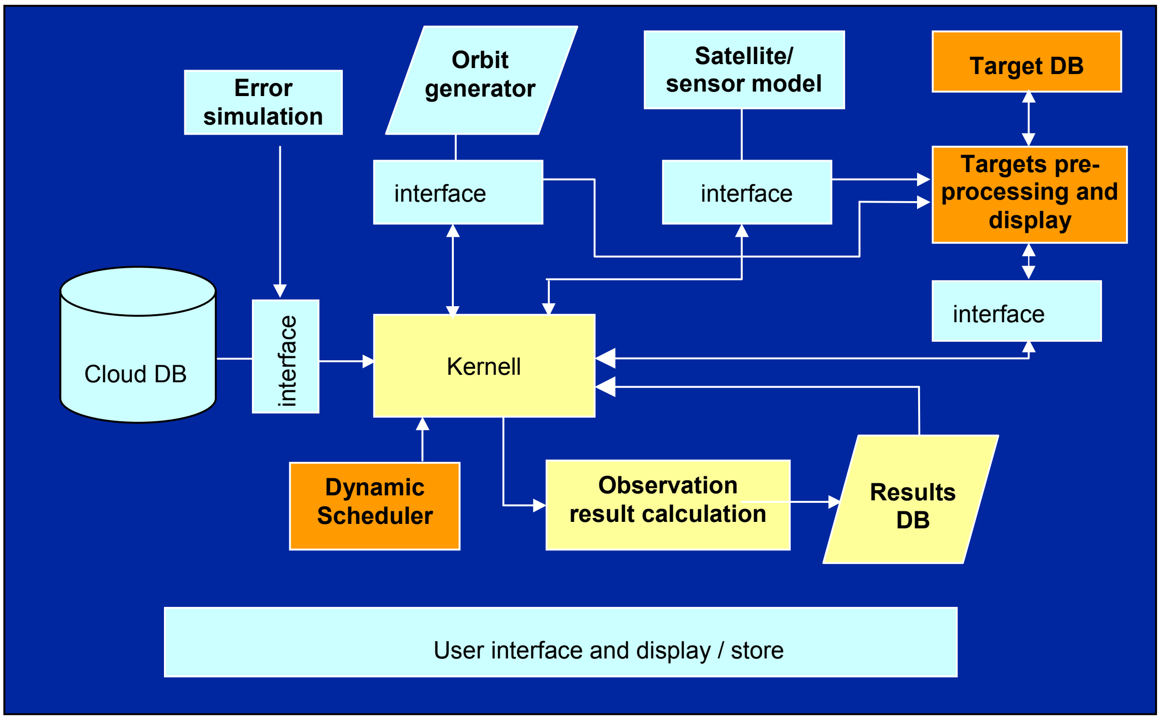
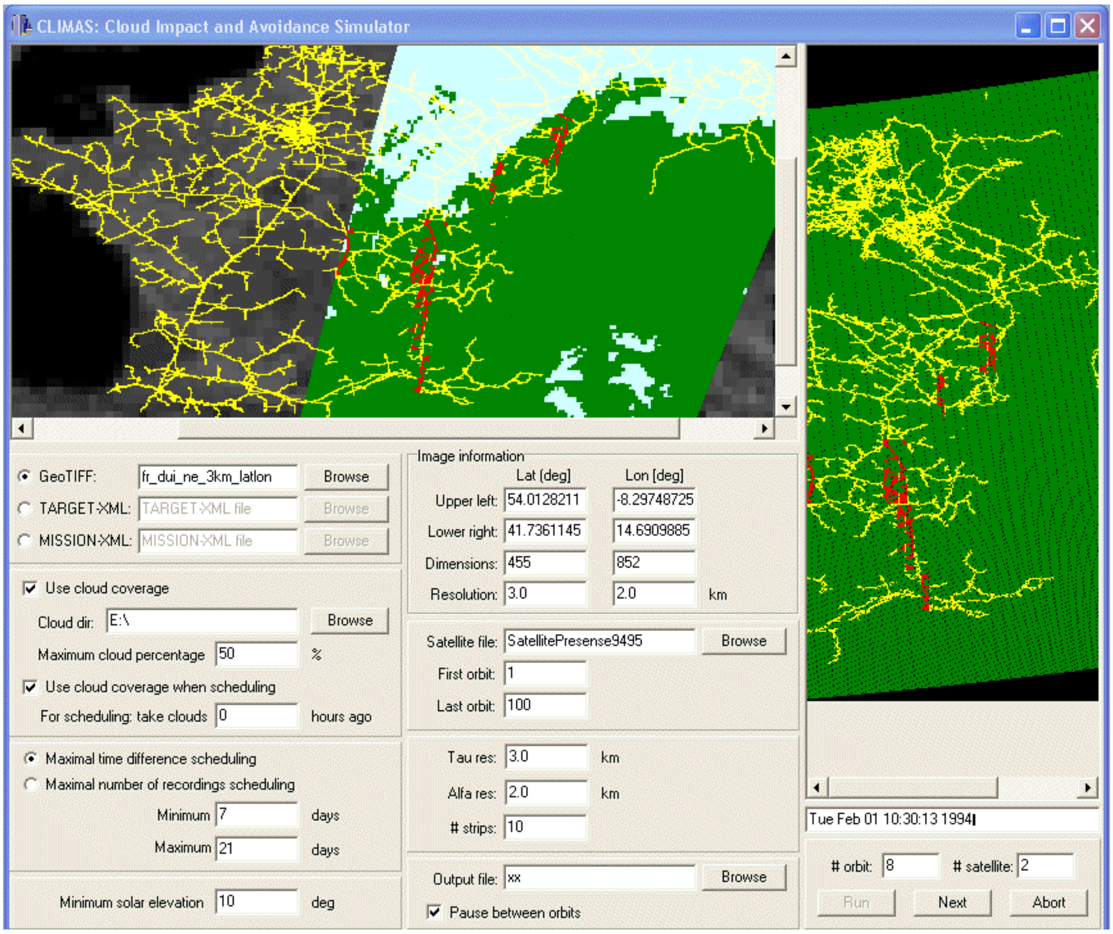


Fig. 1 CLIMAS architecture

select new targets after each pass, in order to simulate the continuous process of pending, accomplished, and new imaging requests. It is possible to select between various tasking algorithms. Moreover, the program can easily be extended with newly developed algorithms. The maximum accepted cloud percentage in a target area as well as the minimum required solar elevation can also be entered.

As a result of a simulation run, CLIMAS generates a file with for all targets the times of imaging request and the actual time(s) of capturing. With the CLIMAS software this file can be analyzed to obtain statistical information such as average delivery time, histogram of the delivery time, number of targets recorded per month, etc.


CLIMAS: Cloud Impact and Avoidance Simulator

● GeoTIFF: fr_dui_ne_3km_latlon
○ TARGET-XML: TARGET-XML file
○ MISSION-XML: MISSION-XML file

☑ Use cloud coverage
Cloud dir: E:\
Maximum cloud percentage 50 %
☑ Use cloud coverage when scheduling
For scheduling: take clouds 0 hours ago

● Maximal time difference scheduling
○ Maximal number of recordings scheduling
Minimum 7 days
Maximum 21 days

Minimum solar elevation 10 deg

Image information

	Lat [deg]	Lon [deg]	
Upper left:	54.0128211	-8.29748725	
Lower right:	41.7361145	14.6909885	
Dimensions:	455	852	
Resolution:	3.0	2.0	km

Satellite file: SatellitePresense9495
First orbit: 1
Last orbit: 100

Tau res: 3.0 km
Alfa res: 2.0 km
strips: 10

Output file: xx
☑ Pause between orbits

Tue Feb 01 10:30:13 1994
orbit: 8 # satellite: 2

Fig. 2 CLIMAS screen dump

III Scheduling approach

The simulator allows the user to define target areas in any Area Of Interest (AOI). For each pass over the AOI the area is divided into rectangular sub-areas called strips, with a width equal to the swath of the optical sensor. The length in along-track direction is an independent input parameter. Basically, with twodimensional pointing, after each strip any other strip in the AOI can be imaged. However, the order and number of imaged strips are limited by a set of constraints such as slew time, across track and along track pointing capabilities, the simulated time dependent satellite position, and the locations of candidate strips within the AOI. Whether a strip is put on the task schedule depends on the number of target area elements it contains, the imaging history of these elements and the expected cloud cover situation for these elements. A priority value is assigned to the strip in the following way.

For each strip the target elements are inspected on the time elapsed since their last successful imaging (LSET) as it is bookkeeped in the observation results database.

Target elements with LSET<LSETmin are not taken into account and the values of LSET are maximized. LSETmin and LSETmax are adjustable input parameters.

For each strip the sum of the LSET values is calculated.

If Cloud Avoidance Scheduling is enabled, then target elements with predicted cloud cover are not taken into account

The scheduler starts with the selection of the strip with the highest priority that does not violate the imaging constraints. Subsequently strips with the next highest priority are selected, etc. Note that during the selection process the imaging constraints are becoming stricter due to the increasing amount of time needed for imaging and slewing to already selected strips. Although this procedure does not necessarily result in the most optimal selection, it leads to a rather efficient task list. Especially the adoption of a fixed strip length is not optimal. However the simulator can easily be extended with alternative scheduling algorithms due to its modular architecture.

The capturing of a target element is recorded to be successful if the element appears to be not cloud covered at the acquisition moment. Of each element, the co-ordinates, the imaging times and the imaging results are stored in the observation results database.

IV Simulation results with a pipeline-monitoring mission

For the transmission of natural gas through Europe an underground network of high-pressure pipelines (15-85bar) with a length of roughly 200.000km exists. In order to guarantee the safety of this network a range of safety monitoring techniques are applied, including regular foot and vehicle patrols along the pipeline route and two-weekly aerial surveillance using helicopters.

These patrols concentrate on the detection of third party interference, soil movements and gas leakage. Although the conventional methods ensure a high level of safety in pipeline operation, the cost is also very high.

Within the EU 5th Framework project 'Pipeline Remote Sensing for Safety and the Environment' (PRESENSE) a feasibility study is carried out to develop and integrate the elements of a monitoring system which is based on remote sensing data. Objective is to improve safety, reduce survey costs and improve transmission efficiency through an increased monitoring frequency. In the initial system concept optical satellites play an essential role given the high spatial resolution and good interpretation capabilities. Limitation of optical systems however is the dependence on weather conditions, especially cloud cover.

Within PRESENSE the National Aerospace Laboratory NLR performs a study to the optimization of the high-resolution optical satellite constellation as part of the data acquisition system. The extent and effectiveness of a constellation of optical satellites has been analyzed and simulated in relation to the orbit configuration, the sensor/platform capabilities (swath, pointing), the form of the network, light/season conditions and the relation with the other sensors and platforms. Special attention has been given to minimize the negative impact of cloud cover on the effectiveness of the system by actively selecting cloud-free areas using the sensor pointing capability in combination with intelligent tasking based on actual cloud information.

For the analyses CLIMAS was used. The results are important inputs for the cost/benefit analyses and the definition of the constellation of airborne and space borne optical and SAR means for the PRESENSE monitoring system.

The results of these simulations will be presented elsewhere [10].

Here some examples are presented demonstrating the capabilities of CLIMAS.

Table 1 presents the relevant satellite and sensor parameters. Figure 3 shows a map with the network part as used in the simulations.

Table 1

Number of satellites	4
Altitude (m)	500000
Inclination (degrees)	97.3785
Number of orbits/day	15.225
Ascending node crossing time (YYMMDDHHMMSS)	940131223000 (sat 1)
Ascending node crossing longitude (degrees)	0.0 (sat 1)
Off-nadir Field of View across track (degrees)	33
Off-nadir Field of View along track (degrees)	33
Slew speed (degrees/s)	2.0
Stabilization time (s)	2.0
Instantaneous Field of View (degrees)	1.4
Use 0(ascending)/1(descending) track for acquisitions	1

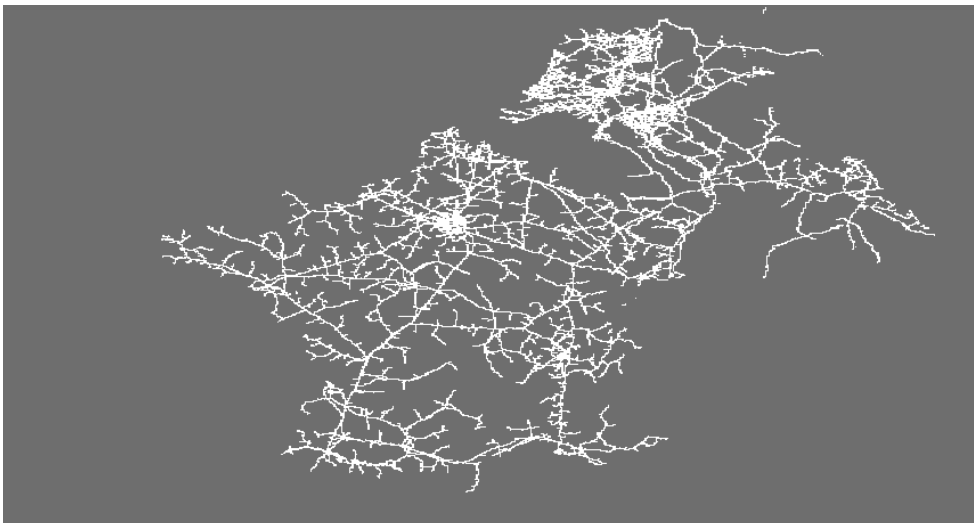


Fig. 3 Pipeline network used in the simulations

The simulations were carried out with LSETmin = 7 days and LSETmax = 21 days since the target effective revisit time for the gas network is 14 days.

Figure 4 presents the distribution of the effective revisit times of all pipeline elements with and without cloud avoidance scheduling for the case of 10 strips. This corresponds to a strip length of 138km. Clearly, cloud avoidance scheduling results in performance improvement: the average revisit time decreases from 23.8 to 14.6 days and the total number of successfully images elements increases by 62%.

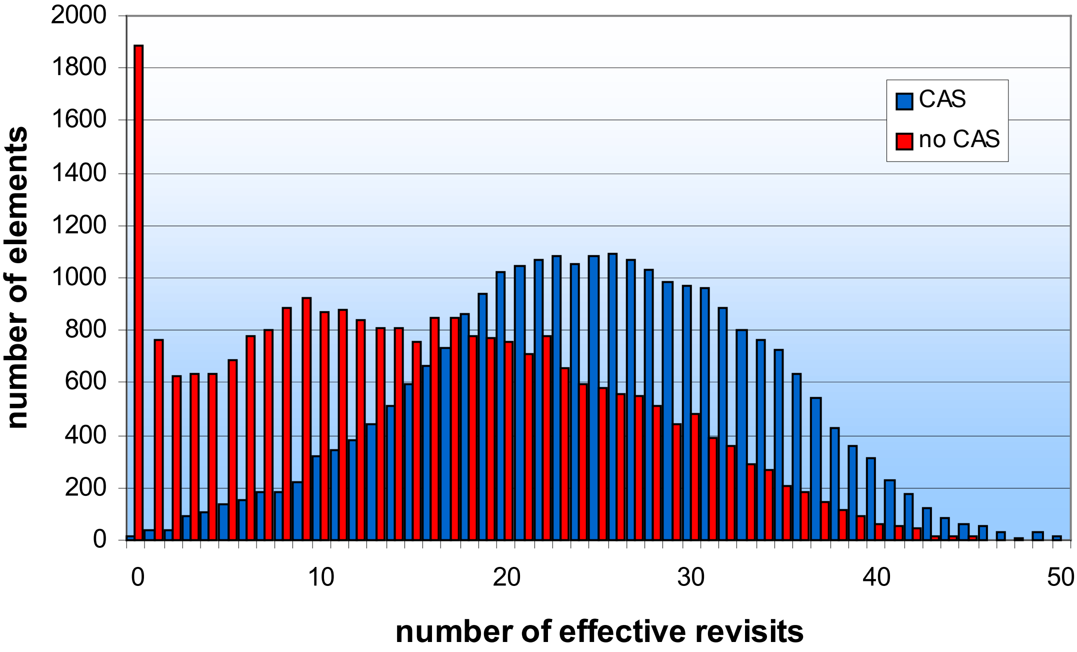


Fig. 4 Distribution of the number of yearly effective revisits per pipeline element; with and without cloud avoidance scheduling

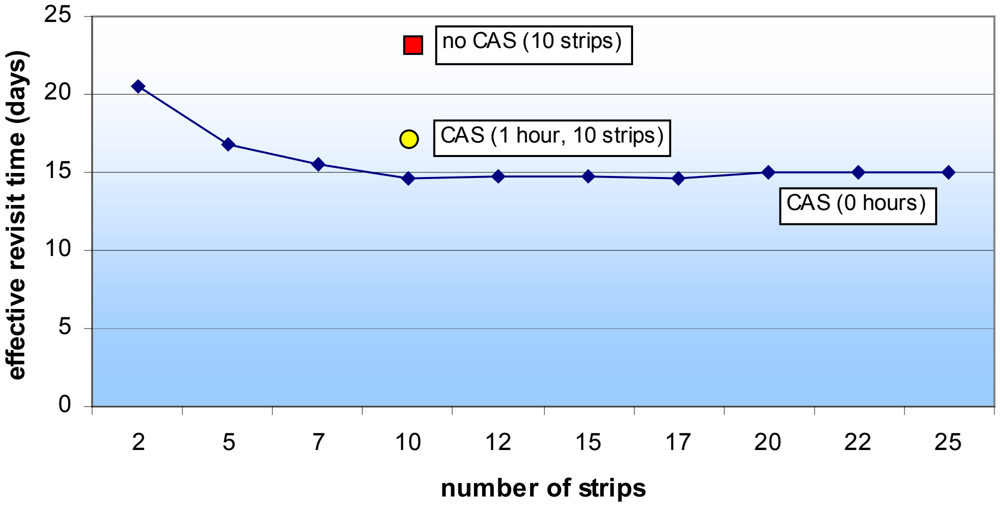


Fig. 5 Effective revisit time as a function of the number of strips

Varying the number of strips shows that 10 strips is optimal in this case. However, the optimum is very flat as can be observed in figure 5, representing the average effective revisit time with cloud avoidance scheduling as a function of the number of strips.
Both the two figures also show the results for the case of scheduling with 10 strips without cloud avoidance scheduling. Finally, the two figures include the results of a run in which cloud data of one hour earlier is used for cloud cover prediction. Obviously the performance degrades somewhat. However, in real operational systems more accurate cloud motion and weather models can be applied leading to better results [11]. Clearly, this is an issue for further research.

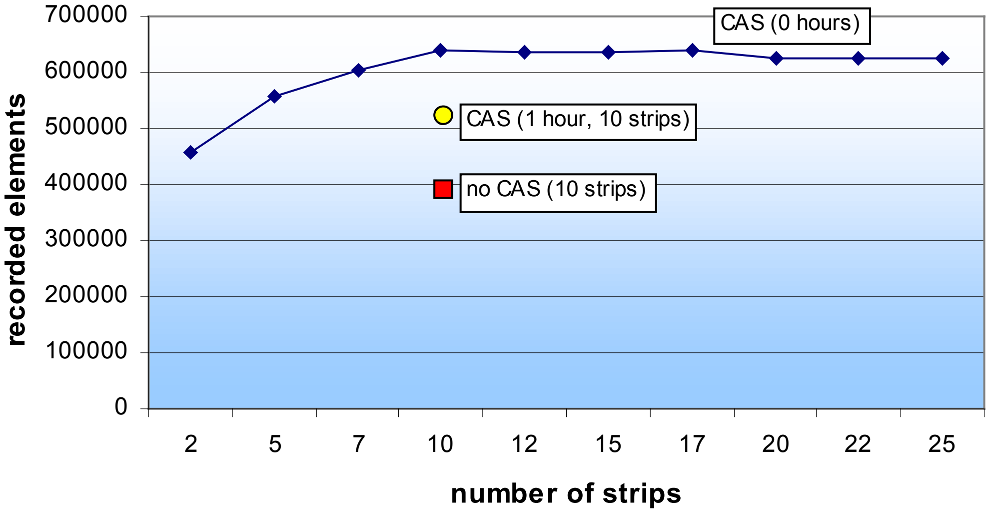


Fig. 6 Number of successful element recordings per year as a function of the number of strips

Figure 7 presents the geographical distribution of the effective revisit time as obtained with 10-strips cloud avoidance scheduling. The chosen scheduling approach of this example, in combination with only ascending-pass acquisitions, leads to the effect that East-West oriented pipelines in areas with a low network density are less often revisited. An operational system solution would be to increase the monitoring frequency of these pipelines by airborne platforms.

The simulations illustrate the potential performance improvement of efficient cloud avoidance scheduling in optical satellite remote sensing.

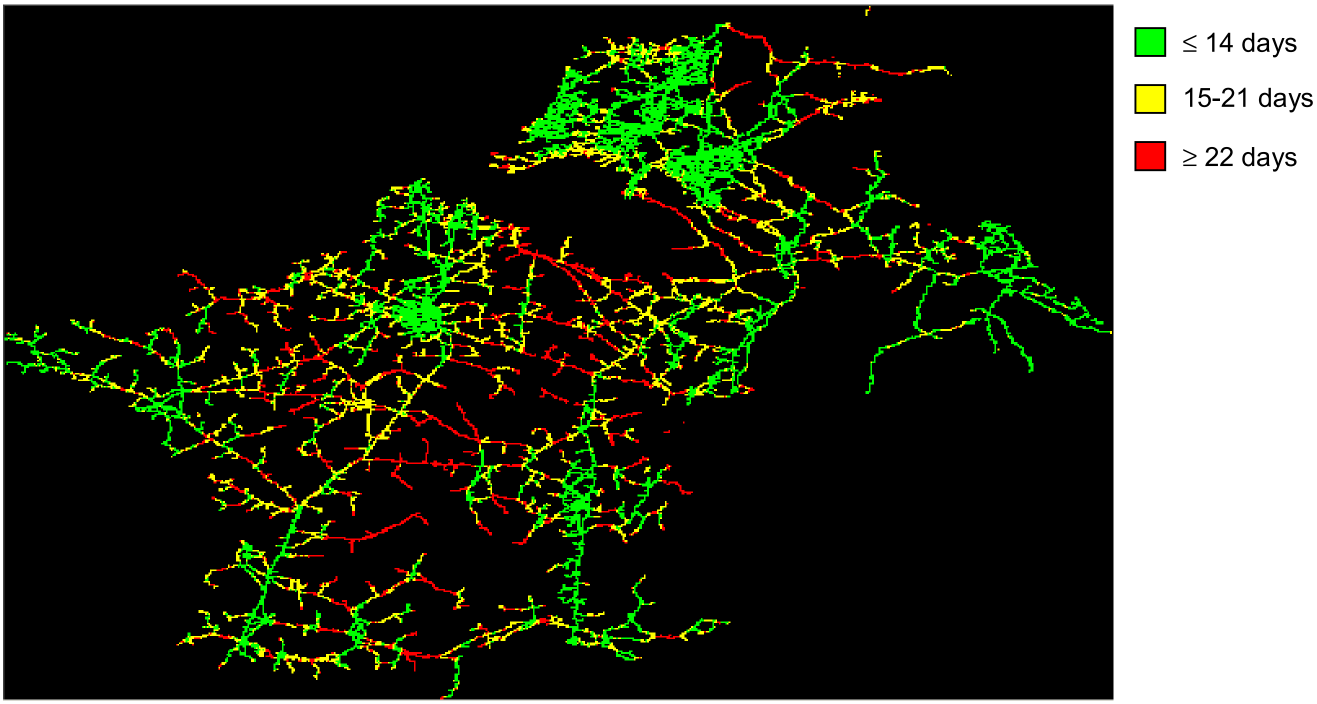


Fig. 7 Geographical distribution of effective revisit time for 10-strips cloud avoidance scheduling

V Conclusions

1. The adoption of efficient cloud avoidance scheduling in optical remote sensing missions may result in significant improvement of the mission return.
2. The CLIMAS simulation package allows quantitative assessment of the mission performance improvement due to cloud avoidance scheduling.
3. CLIMAS' modular structure and flexible target definition features allow simulation experiments for a broad range of mission types.

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