Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

NLR-TP-2002-217

On the effectiveness of cloud cover avoidance methods in support of the Super-spectral Mission for Land Applications

T. Algra

Nationaal Lucht- en Ruimtevaartlaboratorium
National Aerospace Laboratory NLR

NLR-TP-2002-217

On the effectiveness of cloud cover avoidance methods in support of the Super-spectral Mission for Land Applications

T. Algra

This report is based on a presentation held at the IGARSS Conference,
24-28 June 2002, Toronto, Canada.

Working Plan number:	1.2.D.6
Owner:	National Aerospace Laboratory NLR
Division:	Space
Distribution:	Unlimited
Classification title:	Unclassified
	April 2002

Contents

1 Table
7 Figures

(6 pages in total)

On the effectiveness of cloud cover avoidance methods in support of the Super-spectral Mission for Land Applications

Theo Algra
National Aerospace Laboratory NLR
Anthony Fokkerweg 2
1059 CM Amsterdam
algra@nlr.nl

***Abstract*-The driving application of the Super-spectral Mission for Land Applications (SMLA) is precision farming. With its optical instrument a large amount of small and scattered targets need to be imaged frequently during the growing season. This paper discusses cloud cover avoidance methods to improve end-to-end system efficiency while maintaining the effective revisit time performance. With the concept of selective imaging only selected parts of the data recorded during the track over the Area Of Interest (AOI) are stored in the on-board memory. This selection can be made based on for example meteorological satellite cloud maps acquired just prior to the pass over the AOI. The purpose is to acquire data with a higher degree of usability. Cloud editing is an on-board process of cloud detection and subsequent discarding data representing cloud cover. Also in this case it is possible to downlink more usable image data. The effectiveness of the methods has been assessed by simulations using a high-resolution cloud database. It can be concluded that in both cases the amount of usable data can be almost doubled at the cost of a slight increase of effective revisit time.**

I. INTRODUCTION

ESA is considering application oriented missions called “Earth Watch”. As a result of this a super spectral optical system of medium spatial resolution and medium revisit frequency has been identified as a key element for applications requiring high resolution spectral information for biophysical parameters and land cover. The feasibility of the Super spectral Mission for Land Applications (SMLA) has been assessed by three independent European consortia. In one of the proposed concepts, to which the results in this paper are related, the SMLA consists of one or two satellites carrying a super spectral instrument with a fixed nadir view [1]. The swath width is 320 km. The satellite or satellites will fly in a sun-synchronous orbit and are primarily intended for providing image data of the agricultural regions of Europe and North America during the growing season. One of the driving applications is precision farming. Consequently the targets are relatively small and scattered over the AOI, and the required geolocation accuracy is high.

One of the driving factors in operational remote sensing is the cost per bit. Large scale use of data will only boost up if the data becomes affordable. An important element of this cost is the data generation capacity of the satellite/sensor system. However, in practice this capacity is reduced by frequent cloud cover. For example in temperate regions more than 70% of the downloaded data cannot be used due to cloud contamination. Hence system resources like telecommunications, memories and processing units, both on-board and in the ground segment, are not efficiently used.

This paper discusses cloud cover avoidance methods [2] to increase the usability of the downloaded data and hence the data generation capacity of the satellite/sensor system, while maintaining the effective revisit time performance. In Section II two cloud cover avoidance methods are described: *selective imaging* and *cloud editing*. The effectiveness of these methods has been assessed. The analysis method and the results can be found in the Sections III and IV, respectively. Finally, Section V presents the conclusions from this research.

II. CLOUD COVER AVOIDANCE METHODS

A: Selective imaging

Selective imaging is a form of dynamic scheduling, meaning that only selected parts of the data recorded during the track over the AOI are stored in the on-board Solid State Mass Memory (SSMM). The selection can be made based on

i) cloud statistics (location dependent);
ii) weather prediction data (cloud cover);
iii) cloud maps derived from geo-stationary meteorological satellite data acquired just prior to the pass over the AOI.

The purpose is to acquire less data per track, but with a higher usability. With these methods, increasingly, the storage and downlink resources are more efficiently used. Hence the capacity of the SSMM may be reduced as can the downlink bitrate. Or, stated otherwise, with a certain download data budget (DLDB), it is possible to downlink more usable image data. Hence the effectivity of the satellite system will be increased. A reduced DLDB means that a certain probability is accepted that clear (non-clouded) data will not be stored and downloaded. Consequently, the DLDB is a parameter to be traded off against effective revisit time. The updated Satellite Operation Plan (SOP) with the times and lengths of the image areas to be stored has to be uplinked prior to the pass over the AOI.

A variant of this method is called Selective Downloading. In this case all the image data are stored in the SSMM, but only the nonclouded parts of the data are downloaded on the basis of the actual cloudiness situation and making use of the random access characteristics of the memory. This variant has usually fewer implications for the ground segment, but the disadvantage is that the SSMM can not be reduced.

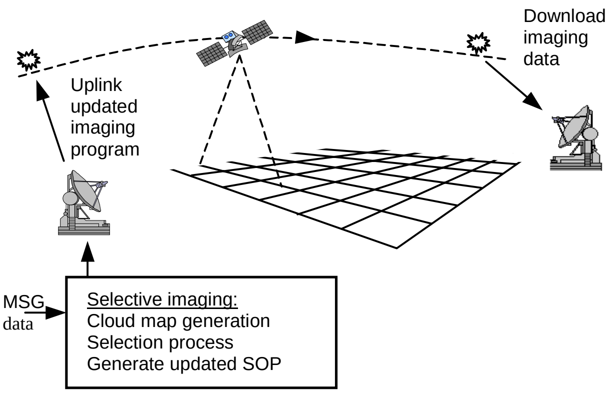

Fig. 1 Selective imaging concept

B: Cloud editing

Cloud editing is an on-board process implying that parts of the image data that are cloud covered are discarded, or represented in only one band or represented at a lower resolution. This results in significant improvement of the overall average data reduction ratio. Obviously, cloud editing improves the imaging capacity when the download budget is the bottleneck, rather than the payload capacity. Such a cloud editing process consists of the following phases:

- Subsampling and spatial low pass filtering

For the cloud editing process a lower resolution is sufficient. In view of minimising the related computational effort, this transition to low resolution is preferable.

- Cloud detection

A cloud detection process is carried out based on the information from several bands. An example of a recent and reliable algorithm that can be used is the ACCA algorithm used for LANDSAT 7 data [3].

- Selection of usable areas

Usable areas are selected resulting in usable-area maps. Several options exist to reduce the data based on this information. The unusable data is discarded or represented with a higher (lossy) compression ratio.

Obviously the total amount of data which is stored during imaging will vary. Assuming that the capacity of the SSMM is sufficient, the DLDB may be a bottleneck, in the case of a low average cloudiness level. Consequently, during or prior to downlinking, the data should undergo another selection process. Several methods are conceivable: i) the areas are selected according to a random selection scheme; ii) the areas are selected according to a frequency in line with the local cloud statistics: areas with less cloud cover are sampled at a lower frequency than areas with higher cloudiness probabilities; iii) it is possible to select areas based on the success of previous acquisitions (this would require on-board storage of previous cloud maps). In addition, selection can be also determined by uploaded prioritisation schemes in relation to the current user requests. Obviously, this presupposes that the mass memory is a random access memory. On the average, the amount of data is largely reduced. Hence also in this case both the capacity of the SSMM and the downlink bitrate may be reduced. A certain probability is accepted that clear (non-clouded) data has to be discarded. This may occur in cases of long tracks with much clear weather conditions resulting in data amounts exceeding the DLDB. Consequently the DLDB is a parameter to be traded off against effective revisit time.

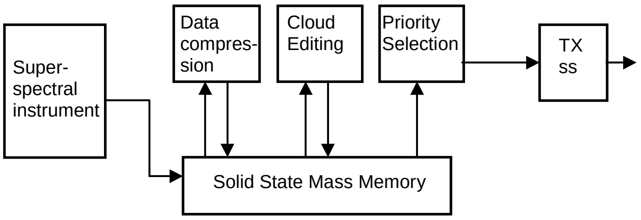

Fig. 2 Cloud editing concept

III. ANALYSIS METHOD

The analyses have been performed by simulations using a cloud database derived from a one-year Meteosat dataset of the European and North-African area. Ascending tracks with 320 km swath width were used for the simulations. The tracks are divided in along-track direction into basic image areas of 50, 100, or 200 km length. The simulator calculated the cloudiness and the data usability of each area [1]. Further, for each track the following values were calculated:

1. Total data amount
2. Average cloudiness
3. Usability of track data
4. DLDB limitation: Usability of the track data when the amount of track data is limited to a fixed value (DLDB)
5. Cloud editing: Usability of the track data when the amount of track data is limited to a fixed value (DLDB) after cloud editing
6. Selective imaging: Usability of the track data when the amount of track data is limited to a fixed value (DLDB) and where the basic areas of the track with the highest usability are selected (i.e. selective imaging)

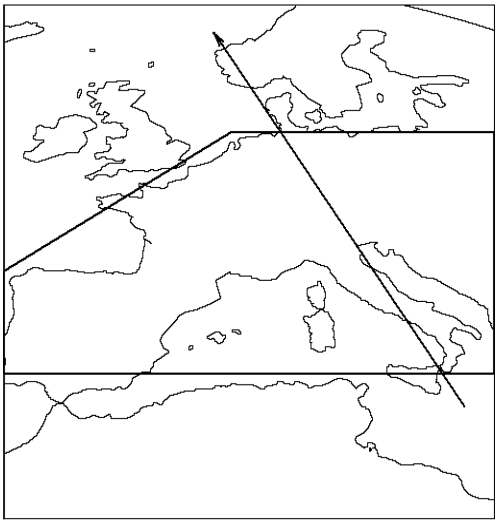

Fig. 3 Area used for the simulation

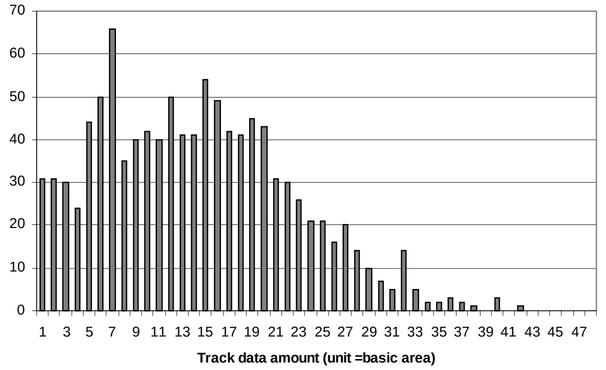

Fig. 4 Frequency distribution of data amounts per track after on-board cloud editing, basic area with length = 50 km. The unit on the horizontal axis is the amount of uncompressed data involved with the imaging of a basic area of 300x50km

The simulations include a stepwise decrease of the DLDB. For all the pixels in the Area Of Interest (AOI) the program records the number of revisits as well as cloudless revisits. This allows exploring the distribution of the effective revisit time, which is a major performance parameter.

Ad. 4: In the case that the track data amount (TDA) exceeds the value of DLDB, then the data of TDA-DLDB basic areas are discarded. These areas are selected randomly in order to avoid that the northern basic areas are more often discarded than the more southern ones.

Ad. 5: Also in this case basic areas have to be discarded when the resulting data of the track exceeds DLDB. Again the selection is random.

Ad. 6: If the track data amount exceeds DLDB, then the areas with the lowest usability are discarded.

Cloud editing was assumed to be ideal, i.e. in this case clouded pixels were not included in the track data amount. The simulations were performed using data of the months June, July and August.

Fig. 3 shows the area covered by the simulations.

IV. RESULTS

Fig. 4 shows the distribution of the data amounts recorded during the track after application of on-board cloud editing with a basic area length of 50 km. The mean data-amount is reduced by 47% due to the cloud editing process.

However, data reduction by cloud editing can only be exploited if the DLDB is decreased, in this case made lower than the maximum amount of basic-area units of data. The lower the DLDB, the more data has to be discarded on-board. In figures 5-7, the horizontal axis represents the normalized Data Download Budget DLDB. The value 1 corresponds to the DLDB that is needed to record the longest track over the AOI without data loss. Figures 5-7 show the resulting effective revisit time of the downloaded data when the data is discarded as soon as the accumulated track data equals the DLDB, with and without on-board cloud editing. Obviously, the more data has to be discarded, the higher the effective revisit time. Note that the graphs display the maximum effective revisit time that is present in 95% of the Area Of Interest.

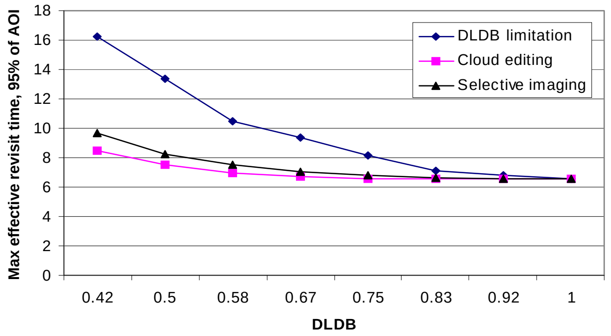

Fig. 5 Effective revisit time in days as a function of DLDB, basic area length = 50 km

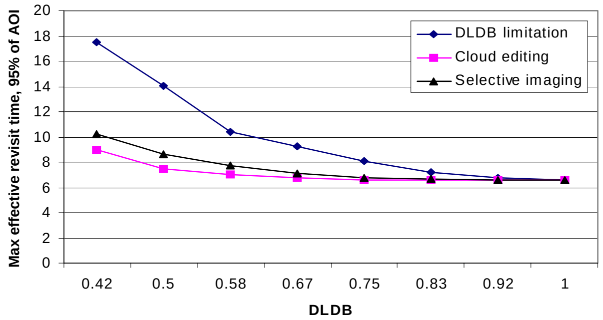

Fig. 6 Effective revisit time in days as a function of DLDB, basic area length = 100 km

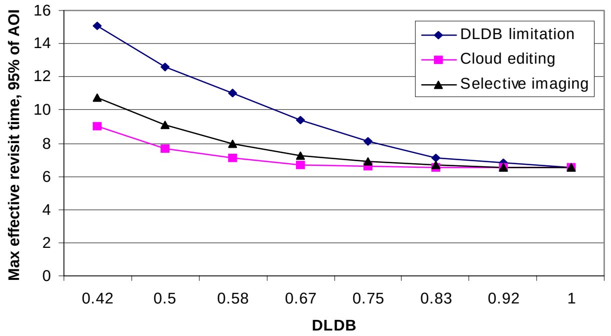

Fig. 7 Effective revisit time in days as a function of DLDB, basic area length = 200 km

Figures 5-7 also show the effective revisit time when the data discarding process is executed based on the criterion of usability of the basic area (i.e. selective imaging).

The simulations have been performed for three basic area sizes. The best results were obtained with the smallest size. From the figures 5-7 it can be concluded that cloud editing only performs slightly better than selective imaging.

A further improvement can be achieved when the track is divided in smaller areas left and right to the sub-satellite track. This doubles the amount of basic areas and allows the selective imaging process to be better tuned to the actual cloudiness situation. Refer to Table I.

As explained, with selective imaging the selection process of the data to be discarded was based in the usability of the basic area data. However, it seems logical to base the selection also on the recent history of the imaging of the local areas. For example an area that has been imaged and recorded successfully (i.e. without cloudiness) could be assigned a lower priority for the subsequent track(s). This option has been simulated and the results can also be found in Table I. The additional gain appears to be dependent on the value of DLDB.

The results show that the DLDB can be substantially decreased without significant performance reduction. A combination of smaller basic area size and the history algorithm would even improve these results. Note that the achieved DLDB reduction can also be exploited to improve the payload data rate as listed in Table I.

TABLE I
SELECTIVE IMAGING: INCREASE OF EFFECTIVE REVISIT TIME AS FUNCTION OF DLDB AND BASIC AREA SIZE

DLDB	0.75	0.67	0.5
Effective payload data rate	133%	150%	200%
320x200km	6.2%	11.8%	39.4%
320x100km	3.7%	8.8%	31.3%
320x50km	3.0%	7.1%	26.2%
160x100km	1.5%	3.9%	18.9%
320x100km with history	-	5.4%	18.0%

V. CONCLUSIONS

It is concluded that selective imaging is an attractive function to be included into the SMLA ground segment. It allows the reduction of the DLDB by more than 25% without significant performance degradation. Stated otherwise, it allows to increase the payload data rate by more than 33% with the same DLDB.

The concept of cloud editing is more complicated, requiring an on-board processor for the execution of cloud editing and file processing. The additional reduction of the DLDB as compared to selective imaging is hardly significant and does not seem to justify the cost and risk of cloud editing.

VI. REFERENCES

[1] Orrichio, D., et al, “Super spectral Mission for Land Applications Phase A Study”, Final Report, Alenia Sp., ESA-contract, to be publ., 2002

[2] Gasch, J., K.A. Campana, “Cloud cover avoidance in space-based remote sensing acquisition.”, Proceedings of SPIE - Algorithms for Multispectral, Hyperspectral, and Ultraspectral Imagery IV, Vol. 4049, pp. 336-347, 2000

[3] Irish, R., “Landsat 7 automatic cloud cover assessment”, Proceedings of SPIE - Algorithms for Multispectral, Hyperspectral, and Ultraspectral Imagery IV, Vol. 4049, 2000