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AUTOMATIC CLOUD SCREENING IN NOAA-AVHRR DAY-TIME IMAGERY

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ABSTRACT

We evaluate how much of the cloud cover can be retrieved using only visible and near infrared informations from a wide-field sensor without thermal infrared channel, such as the projected VEGETATION radiometer of the French Space Agency. AVHRR day-time imagery is used in order to simulate this radiometer. An algorithm is written making only use of the first two AVHRR channels, and is called the WSD algorithm. In order to assess the accuracy of its retrieval of the cloud cover, its results are compared to what is called a reference algorithm which on the contrary makes use of all the spectral channels, and is based upon the published work of Saunders and Kriebel. The main originality of the first test of the WSD algorithm is the combination of dynamic thresholding on both reflectance and ratio histograms in an iterative fashion. It increases the efficiency of the cloud screening in the following ways : increase the number of clouds detected, decrease the number of actually clear pixels declared as cloudy, make the detection rather insensitive to predefined values. The WSD algorithm is completed by a thresholding on the local variance of the AVHRR 2 reflectance over the ocean.

The study shows that cloud screening within a single AVHRR image is possible over Western Europe with visible only. For this area, visible range is more efficient for screening that thermal infra-red. Over the desertic soils of Niger, this is no longer true and both wavelength ranges are required for cloud filtering.

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1. INTRODUCTION

Data from meteorological satellite are easily available, cover very large areas, and are very frequent (more than four times a day for NOAA-AVHRR). They have been, and still are, widely used in meteorology and oceanography and are now of interest for land knowledge, either for climate and land parameters studies, or for continental deforestation analysis or vegetation monitoring. Except for atmospheric research, these satellite images are useful only if clouds which are present in the images are flagged out. Clouds are commonly colder and brighter than the terrestrial objects or the ocean, and this allows a bulk screening of clouds.

The experience of Ecole des Mines de Paris in cloud screening in satellite imagery is based upon the studies we are pursuing since 1978 by processing Meteosat data for the mapping of the solar energy available at the ground level (Cano *et al.* 1986 ; Grüter *et al.* 1986 ; Moussu *et al.* 1989), and also upon the work we recently did for CNES, the french space agency. Here only the later work will be dealt with.

The goal of the CNES study was to evaluate how much of the cloud cover can be retrieved using only visible and near infrared informations from a wide-field sensor without thermal infrared channel, such as the projected VEGETATION radiometer. AVHRR day-time imagery was used in order to simulate this radiometer.

Hence an algorithm was written making only use of the first two AVHRR channels. In order to assess the accuracy of its retrieval of the cloud cover, its results are compared to what is called a reference algorithm which on the contrary makes use of all the spectral channels. Among many others (see reviews in Goodman, Henderson-Sellers 1988 or Rossow 1989, for example) the scheme of Saunders and Kriebel (1988, see also Saunders 1986) was selected as a basis to our reference algorithm. It is not perfect of course but its main drawbacks are pretty well-known.

Five months of data were available over Western Europe and Niger. The data were choosen during the vegetation periods, that is from April to October for Europe and from June to October for Niger. Images were taken at about 2 o'clock p.m. The images were processed by CNES. Digital counts were converted into top of atmosphere reflectances and temperatures. The images were set into a Mercator projection. They are only weakly superimposables. This implies that images cannot be compared on a pixel basis and that an approach making use of a time-series of images is not suitable. Hence our study only deals with single images.

2. THE REFERENCE ALGORITHM

The reference algorithm is based upon the work of Saunders and Kriebel published in 1988. The original algorithm applies to day-time as well as to night-time AVHRR imagery. Here only day-time tests are of concern. They make use of the following AVHRR channels : band 1 (visible), band 2 (near infrared), bands 4 and 5 (thermal infrared). We mention that band 3 may be used to discriminate cloud from snow and ice (Gesell 1989 ; Liljas 1986), and particularly to discriminate snowy mountains from clouds. However since the purpose of the cloud screening was to provide vegetation cover, this particular aspect was not taken into account. The algorithm of Saunders and Kriebel was first implemented as described in their publications and served as a reference. Then improvements were made and compared to it. Great attention was paid to the automation aspect of the new algorithm and particularly to the influence of the threshold values on the results of a test.

The tests for cloud detection make use of the differences in signals provided by the land, the sea and the cloud. Clouds are usually brighter and colder than land and sea. Hence many clouds can be detected by setting a threshold in both channels. In the thermal channel 4 and for Europe the threshold is set to 0 Celsius in summer, to - 20 Celsius in winter and varies linearly in-between. For Niger the threshold is set to 10 Celsius throughout the year. This test is called "IR gross". The thresholding in reflectance applies to band 1 over land and to band 2 over the ocean. The thresholds can be set to predefined values or dynamically determined according to the local reflectance histogram. However in the case of the algorithm of Saunders and Kriebel, no improvement in cloud detection was found when using dynamically set thresholds rather than predefined values. This test is named "VIS gross".

Thin cirrus can be detected at least in Europe by their spectrally variable emissivities (Inoue 1987 ; Wu 1987), that is by looking to the difference in temperature between channel 4 and channel 5. It is a cloud if this difference is greater than a threshold which depends upon the temperature itself and of the scan angle. Such a dependancy is presented by Saunders and Kriebel for Great Britain, according to numerical simulations of the atmosphere made by Llewellyn-Jones *et al.* (1984) for the northern Atlantic ocean. For Niger we were unable to establish such a table likely because of the variations in soil emissivity. Yet we observe that the difference is negative over land and most of the clouds and becomes positive on the cloud edges. Thus the threshold is constant and set to 0 Celsius. This test is called "thin cirrus".

The ratio band 2 to band 1 provides a mean to cloud detection, too. Clouds are spectrally constant for low wavelength so that their ratio is close to 1. For sea outside glitter, the stronger atmospheric molecular backscattering in visible makes the ratio close to 0.5. Its value is 1 in the glitter area. As for the land in Europe, the ratio is often greater than 1.6. For Niger and more generally for soils with scarse vegetation coverage this is no longer true and the ratio for land is greater than 0.8 and usually close to 1.0. Hence this test only applies to land in Europe. It is called "VIS ratio".

Saunders and Kriebel also make use of a thresholding of the local thermal variance but only over the ocean. We rejected this test because it systematically declares as cloudy the oceanic thermal fronts within the coastal areas, as already shown by Monget, Wald (1984) and is of no peculiar use in open ocean because of its redundancy with other thermal tests.

This scheme was implemented in such a way that it provides analysis of the various contributions of each test to cloud screening and also that changes in thresholds and parameters are easy to do. Some statistics are available for each area, showing for land and ocean firstly the relative contribution of each test to cloud screening, and secondly the redundancy of the algorithms, that is the relative number of pixels detected by any combination of two or more tests. These statistics demonstrate which tests are unique in cloud screening and which are fully redundant with others. Conclusions can also be drawn out to devise the ordering of the tests which is the least consumer of computer time.

Robustness of thresholds present in the tests has been tested. Each threshold has been modified by 10 % and the different masks were compared. Not taking into account the tests "IR gross" and "VIS gross" which both use gross thresholds, the following results were found. The test "VIS ratio" is robust. Changing the threshold 1.6 by 10 % changes the number of cloudy pixels by less than 2 %. On the contrary the test "thin cirrus" is not robust. A change of 10 % in thresholds may change the number of cloudy pixels by up to 10 %. From an operational point of view, this is regrettable because this test detects many clouds in an unique fashion.

As a conclusion, it can be said that for Europe this algorithm is rather good and can be considered as a reference. Yet some drawbacks exist. Some are important such as the non-detection of clouds within the marine atmosphere boundary-layer, others are less important such as the false detection of urban areas or of mountains actually free of clouds but flagged out as cloudy. For Niger, this algorithm largely underestimates the number of cloudy pixels. All of the pixels flagged out as cloudy are detected by the "IR gross" test.

3. DETECTING CLOUDS IN AVHRR CHANNELS 1 AND 2 : THE WSD ALGORITHM

These results provide some clues to design an algorithm using only channels 1 and 2. Of particular importance is the fact that the "VIS ratio" test detects many clouds (about 94 % of the actual cloud cover over Europe) but that it also declares cloudy some actually cloud-free pixels. This is particularly true over the Sahelian area, where each pixel, cloud-free or not, is said cloudy by this test, if applied. The main originality of the first test of the new algorithm is the combination of dynamic thresholding on both reflectance and ratio histograms in an iterative fashion. Determination of cloud free modes has been improved, too. It increases the efficiency of the cloud screening in the following ways : increase the number of clouds detected, decrease the number of actually clear pixels declared as cloudy, make the detection rather insensitive to predefined values. This test is called hVr and is part of the WSD algorithm, so-called after the initials of its authors.

The WSD algorithm is completed by a test on the local variance of the AVHRR 2 reflectance over the ocean. The variance is computed within square of five pixels size. If the variance is greater than 0.4, then the central pixel is said to be cloudy.

	REFERENCE					
	FRANCE land		FRANCE ocean		NIGER land	
W	cloud	cloud-free	cloud	cloud-free	cloud	cloud-free
S cloud	97 (3)	4 (5)	97 (3)	46 (38)	60 (15)	22 (20)
D cloud-free	3 (3)	------	3 (3)	------	40 (15)	------

This table summarizes the differences observed between both algorithms. For each image, the difference between the numbers of cloudy pixels has been computed and expressed as a percentage of the number of cloudy pixels seen by the reference algorithm. Then the differences have been averaged for the land and ocean parts of the images over Western Europe and for Niger. In brackets are reported the corresponding standard deviations. The table shows that for Europe a very limited percentage of the cloud-cover escapes the WSD screening : 3 % for both land and ocean. This percentage is much higher over the desertic soils in Niger and amounts to 40 %. Those clouds escaping detection are mostly cirrus. Detection of clouds in visible over Niger is difficult because of the high reflectances of the soils and of their spectral whiteness. This table also indicates that over Europe the disagreements between both algorithms are small : 3 % and 4 %. Over the ocean, the WSD algorithm is very efficient and the 46 % account for the marine atmosphere boundary-layer clouds which go undetected by the reference algorithm. Over Niger, the disagreement is much larger and demonstrates that neither the reference algorithm nor the WSD one is self sufficient .

At last to complete our analysis of the WSD algorithm, we compare it on a pixel basis with the cloud mask provided by the reference algorithm. We conclude that over the ocean the WSD is more efficient than the reference algorithm because it is able to detect clouds within the marine atmosphere boundary-layer. Over Europe, the WSD produces less false detections, i. e. actually cloud-free pixels declared as cloudy, but misses most of the thin cirrus. Over Niger, both algorithms underestimate the actual number of cloudy pixels. Compared to the reference algorithm, the WSD performs rather well when small-size clouds are present but does miss the thin high clouds.

4. CONCLUSION

The study shows that cloud screening within a single AVHRR image is possible over Western Europe or over the ocean with visible only. For such areas, visible range is more efficient for screening that thermal infra-red. This conclusion may be extended to any area exhibiting large vegetation coverage. Over the desertic soils of Niger, this is no longer true and both wavelength ranges are required for cloud filtering. It can also be concluded that an operational scheme for cloud screening in AVHRR imagery is feasible, that, once completed by the WSD algorithm, the "thermal" part of the scheme of Saunders and Kriebel is a good candidate as a basis for devising an automated on-line software procedure.

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