AUTOMATED CHANGE DETECTION OF BLEACHED CORAL REEF AREAS*

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ABSTRACT

We have earlier investigated the value of present high spatial resolution satellites for using change detection technique to locate coral bleaching and showed, that it is possible to detect bleaching in imagery from existing satellites, even using only the system corrected digital counts. The result from the previously presented change detection analysis was mainly based on manual interpretations. A more effective and objective digital method is therefore needed. The objective has been to find a method for automated/semi-automated digital analysis of bleached areas in remote sensing imagery. A number of methods have been tested, both methods aiming at finding changes in DN levels between two image registrations and also a method that includes neighbourhood information. IRS LISS-III images taken prior to and during the 1998 bleaching event in Belize were used, in combination with our own classification and a classification of the Belize reefs obtained from the Coastal Zone Management Authority and Institute (CZMAI). The classifications were used to separate coral reefs from other substrates. The interpretations of coral bleaching, from the previous work, together with available field observations, were used as a reference to evaluate the result here.

1.0 INTRODUCTION

Satellite observations constitute one of the best opportunities to observe global changes on coral reefs. Several papers (Dustan, Dustan et al., 2000, Hochberg & Atkinson, 2000, Lee et al, 1998 and 1999, Lubin et al., 2001) have discussed the prerequisites for using satellite imagery for change detection and mapping of coral reefs, with respect to the necessary spatial, spectral, radiometric and temporal resolution of the sensor as well as the required pre-processing steps, like radiometric, atmospheric and water attenuation correction. The results from our earlier work (Ammenberg et al., 2002) showed that, in order to detect dramatic changes, like the massive bleaching that occurred in Belize 1998, it is possible to use imagery from the existing high resolution satellites, even if we use only the system corrected digital counts. The sensor used in this study will probably not be useful for discrimination of recovered corals and dead corals covered by algae, but we are confident that the data could be used for rapid assessment of the extent and severity of bleaching during the bleaching event. Of course, the actual detectability is dependant on water depth, the size of the area affected and the degree of bleaching for a colony. For a more detailed analysis of the state and type of change, other satellite imagery and field observations, should be added as a complement in the analysis. The original definitions of changes in our earlier study, were mainly derived from manual image interpretation. The basis for this interpretation was, besides the original image data, a spectral analysis of pixels corresponding to field observations of bleaching and a true colour composite of a TM image (to separate reefs from other benthic habitats). Here, we have investigated the possibilities of an automated procedure for segmentation of bleached coral reef areas. As in the earlier study, we have not performed any pre-processing before the analysis, other than geometric correction and normalisation.

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1.1 OBJECTIVES

The objective of this study was to investigate if simple change detection techniques (difference images, principal component analysis (PCA) and local texture differences) could be used in an automated process to locate the same pixels that were interpreted as changed in an earlier stage of the work. Except for geometric correction and normalisation, no other pre-processing has been made here. In this case, we have focused on finding changes, where a pixel/area has become brighter, indicating possible bleaching.

1.2 SENSOR DESCRIPTION

Two images from the LISS-III sensor onboard the IRS satellites were used in this study. The LISS-III sensor collects reflected radiation in four wavelength bands. The band definitions are shown in Table 1. As can be seen in the table, these sensors have a green, a red, a near-infrared and a mid infrared band, hence lacking a blue band. The original radiometric resolution of these sensors is 7 bits, but the data are rescaled to 8 bits before delivery. The spatial resolution is 23 meters in all bands except the last band, which have a resolution of 70 meters. One scene is covering 140x140 kilometres.

Table 1. Wavelength band definitions for the IRS LISS-III

Band no.	Start wavelength (nm)	End wavelength (nm)
1	520	590
2	620	680
3	770	860
4	1550	1700

2.0 IMAGE DATA

The first image used in this study was collected on the 28th of February 1998 and the second image on the 31st of August 1998. The image from February represents the reef state before the bleaching event and the image from August is from the beginning of the bleaching. An IRS image recorded in mid or late September would have been better, with respect to degree of bleaching, but the quality of later images were insufficient. Both images were system corrected before delivery and resampled to 20 meter resolution. The images are covering approximately the same reef area outside the Belizean coast, from Turneffe in the north to Monkey river in the south (Fig. 1). For the change detection analysis only the green band was used, as the water penetration of longer wavelengths is very limited. According to Lubin et al., 2001, it is possible to distinguish several types of bottoms down to 10 meters depth, in the green band, but we have tried to limit our observations to 5-6 meters at the most. If corals on deeper locations should be included in the analysis, it is necessary to use a sensor with shorter wavelengths than the LISS-III. Originally, the whole scenes were analysed, but here four areas, of 50x50 pixels (1000x1000 meters) each were extracted from the scenes for further analysis. All four subimage pairs included pixels/areas that were interpreted as bleached, in an earlier stage of the work. Image pair one and two are located close to Bakers Rendezvous, image pair three near Twin Cay and image pair four close to Middle Long Cay. The approximate locations of these subimages can be seen in Figure 1.

Figure 1. Areas of Investigation

3.0 FIELD DATA

A number of field observations were made during and after the bleaching event in Belize in 1998 (McField, 1999 and Kramer & Kramer, 2000). None of the listed field observations were made for remote sensing purposes and unfortunately, some of the observations were merely of the type "passing by reefs and saw bleaching" or from spot-like diving observations. Most of the observations were missing exact co-ordinates. To segment corals from other types of bottoms, a classification of the Belize reefs obtained from the Coastal Zone Management Authority and Institute (CZMAI), was used in combination with our own classification.

4.0 IMAGE PREPROCESSING

Both images were system corrected and resampled to 20 meters before delivery. The image from August was rectified using sea charts from Belize and the image from February was then registered to the August image using GCP (ground control points). The images were collected with two different LISS-III sensors, having different, but similar, response functions. With respect to the application, a decision was made, in an earlier stage of the work, to skip the radiometric correction and the following atmospheric correction etc. These kinds of corrections will probably not improve the results in this type of change detection analysis (Andréfouët et al., 2001). Instead, the extracted subimages from the February scene were normalized to fit the DN levels of the subimages from August. The normalisation was performed using the relation found by linear regression analysis of all pixels, except small groups of outliers that were removed (clouds etc), in each extracted subimage pair. The established relations were very similar for three of the four cases, with approximately the same slope and intercept. The relation derived for the image pair from Middle Long Cay had a similar slope, but a lower intercept (-7 instead of around ~33). This is most likely caused by atmospheric effects in that area.

5.0 IMAGE DATA ANAL□SIS

Three different methods were tested on the subimages with the purpose of automatically finding pixels that had been changed to the brighter between to dates. All methods were applied to the normalised subimages and the results were compared to our earlier analysis of bleaching. The first approach was to look at ordinary difference images and difference images after mean (3x3) filtering of the normalised images. The mean filtering was performed in an attempt to reduce the effect of noise and edges and bring out the major image differences. In the second approach PCA was performed on each image pair (February and August) and the second component, which should contain the anomalies, was used for comparisons with the earlier interpretations of bleaching. The last approach was to look at differences between local variations within each image, hence, change in local texture. The variation was calculated as a standard deviation in a 3x3 neighbour hood. For comparative purposes, the results from the analysis are presented areawise, in the following four chapters. The red pixels in each result image, are the result of a segmentation procedure, and they exhibits a difference equal to or lager than a predefined level, for example 7, the most commonly used level. The level used, can be seen in the figure text, as follows□ difference image(7). The corresponding subimage (February), including the earlier interpretations of bleaching in green, are displayed first in all figures.

5.1 BA□ERS RENDEZVOUS 1

There are no clouds or other obvious disturbing features in this subimage. The whole area is completely under water, but the north, central part is very shallow, as it is visible in the near-infrared band. The red pixels in the difference image (3b) are quite many and dispersed, but a higher level will exclude the pixels (marked with a green circle) corresponding to the manual interpretations. In 3c, six to seven distinct areas remains, of which two of them coincide with the earlier interpretations. No particular groupings can be found in 3d and 3e, but the location of the red pixels/areas are approximately in the same area as in 3c, plus a few extra single pixels. The result from the local texture analysis (Fig. 3e) shows a very low correspondence to our earlier results, as only one pixel is the same as the pixels displayed in green in 3a.

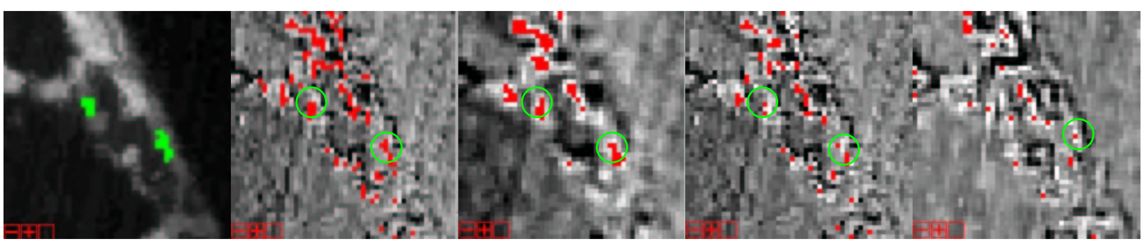

Figure 3a-3e. Subimage including interpretations, difference image (7), difference image after mean filtering (5), PC-2 (7) and local texture difference (5).

5.2 BA□ERS RENDEZVOUS 2

The second subimage is also free from clouds. The black area in the middle of figure 4b-4d is an island, and the red pixels in and in close relation to this area should be excluded from the analysis. The interpretations from the earlier analysis are very well represented in all result images except in 4e. The second principal component is quite similar to the difference image. There are four large areas in Figure

4c, except the one corresponding to the field observations. Looking at the original subimages, the general impression is that the reef has expanded in these areas, rather than that a few pixels have become brighter in comparison to the surrounding pixels. This might be a result of the resampling method used (cubic convolution), for the image from August.

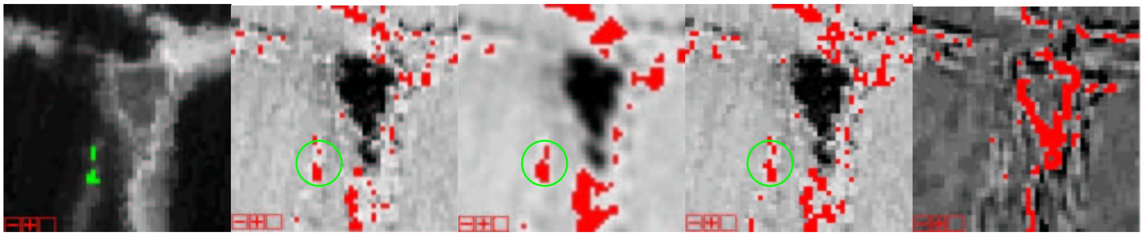

Figure 4a-4e. Subimage including interpretations, difference image (10), difference image after mean filtering (5), PC-2 (7) and local texture difference (5).

5.3 TWIN CA

Two separated pixel areas were marked in the earlier interpretation (Fig. 5a). The pixels belonging to the upper one have not been detected by any of the tested methods, except in the last (Fig. 5e), where one pixel seems to exhibit change in local texture. The results from image differencing and PC-2 are, as above, very similar. The correspondence between the pixels belonging to the lower area in the manual interpretations and the marked pixels in figures 5a-5e (green polygon) is very good, especially when comparing to figure 5b and 5d. The large group of pixels on the left side of the images, should be omitted from the analysis as the objects are located very close to the surface.

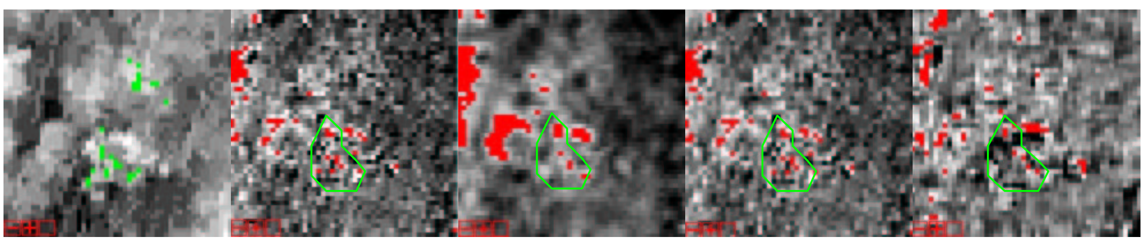

Figure 5a-5e. Subimage including interpretations, difference image (10), difference image after mean filtering (5), PC-2 (7) and local texture difference (3).

5.4 MIDDLE LONG CA

The subimage from Middle Long Cay contains a number of clouds. The areas affected by clouds are seen as black spots in all the result images. The pixels from the earlier interpretation of bleaching (Fig. 6a) corresponds very well to one of the areas of pixels marked in red in figure 6b, 6c and 6d. The lowest correspondence to the manual interpretations, was found in the local texture analysis. In 6e the level is set to three but only a few pixels are displayed in red after the segmentation procedure. If the level is set to two instead, more pixels will, of course, be included, but none of them corresponds to the green pixels in Figure 6a. An even lower level will generate a lot of red pixels, evenly distributed over the whole image.

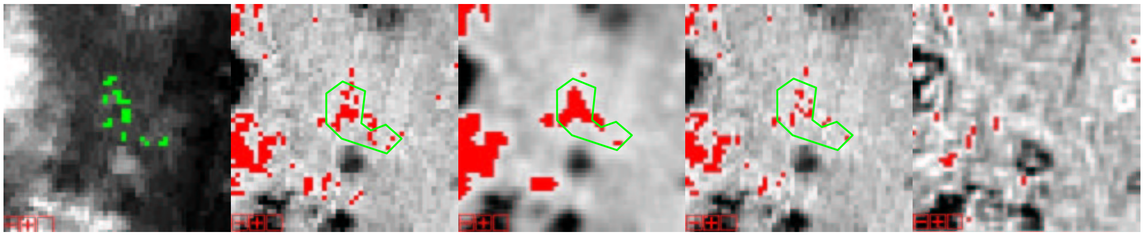

Figure 6a-6e. Subimage including interpretations, difference image (7), difference image after mean filtering (5), PC-2 (7) and local texture difference (3).

6.0 DISCUSSION

As expected, more pixels that had changed to the brighter were found in the automated analysis described above than in the interpretation performed earlier. Some of these additional pixels are probably a result of a slight mismatch between images, because of inexactness in the geometric correction. These pixels were not equally common in the mean filtered difference images. Another group of pixels, appearing after the analysis here, were omitted by us during the manual interpretation, as they were located on the reef crest. It was difficult to determine if the "change" in those pixels were significant or only due to swash and resulting whitecaps. At the moment, all these additional pixels can not be excluded from the material though, but must be considered as significantly changed. Differences in contrast can be another reason why we have missed/omitted pixels in the earlier interpretation of bleaching. It is much easier to see pixels that have become brighter if they are located on a dark background, than on a light background. This effect might also be the reason for the opposite result, namely that we have been able to pick out pixels that has undergone very small changes (a few DN levels), if they were located in a darker surrounding. These pixels will probably not turn up as changed in the automated analysis, with respect to the levels used in the segmentation procedure. If the data are mean filtered before image differencing, the resulting images seems to contain interesting areas that should be further investigated. On the other hand, it is possible that small changes, affecting only one pixel, could disappear in the process. Another approach would be to use watershed technique (Vincent & Soille, 1991) to segment regions and compare their extension between two occasions.

7.0 CONCLUSIONS

The results indicate that automated digital methods could detect the pixels earlier defined as changed/bleached, using some of the above described methods. Image differencing and PCA (PC-2) seems to give the best results and they generated, as assumed, very similar results in all cases. The benefit of using PCA, is that it will give the same result, irrespective if the input images are normalized or not. The assumption here, is of course, that the images only contain objects of similar properties. Otherwise, PC-2 will display completely different properties than the anomalies between two images. The next step will be to investigate how to optimise the results and eliminate all changes that are unlikely to be caused by bleaching. At this stage, it is difficult to draw any final conclusions, as the results from the analysis are compared to our earlier interpretations of bleaching and a few not to well defined field observations. Better field observations in the corresponding areas would have been better for validation. Differences in water level between two occasions will change the amount of reflected radiation reaching the sensor, especially in the green band (Lubin et al., 2001), and might erroneously be mistaken for coral reef change. Hence, information on water level for the two occasions can reduce the number of artefacts.

8.0 ACKNOWLEDGEMENTS

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