Extracting the Ocean Surface Feature of Non-linear Internal Solitary Waves in MODIS Satellite Images

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Abstract

The objective of this study is to integrate an effective approach to extract the linear features of oceanic non-linear internal waves in MODIS images based on the technique of Multiscale Retinex and linear feature extraction. To evaluate the performance of the integrated method, the extracted linear features were vectorized and overlapped with the original image in the Geographic Information System to investigate the localization accuracy of the extracted features, which were rarely seen before. The results indicated that the MSR method provided an enhanced image with improved color contrast and brightness, which resulted in a better quality of the extracted linear features. Finally, we compared the performance of two methods of linear feature extraction, the Canny edge detector and the Wavelet Transform Modulus Maxima edge detector. It is shown that the Canny edge detector is superior to the WTMM edge detector in terms of visualization quality and localization accuracy.

1. Introduction

Oceanic internal waves are waves traveling within the interior of the ocean, which may be generated by several sources including tidal currents, ocean frontal boundaries, and special atmospheric conditions [1]. When the internal waves flow over underwater obstacles, such as seamounts, shelf breaks, and troughs, they tend to become particle-like with large amplitudes within several kilometers, which are called internal solitary waves [7] or Non-Linear Internal Waves (NLIWs). One of the very early interests in studying these waves was their unexpectedly large shear stress as they impacted on offshore oil-drilling facilities [2]. Thereafter, the effects of internal solitary waves on fishing activities, the safety of oil drilling platforms, and the navy's antisubmarine warfare (ASW) have been investigated intensively.

Remote sensing imageries are capable of detecting the sea surface features (Figure 1) caused by NLIWs, and showing the spatial dynamics of the internal waves in a wide range of ocean area. Among the available satellite imageries, MODIS images of Terra and Aqua satellites provide a large spatial coverage with a high repetitive rate (i.e. twice in one day) in the visible band. Hence, MODIS images have been applied to investigate the dynamic of NLIWs recently. Our specific research interest is focused on the internal waves in the northern South China Sea with a goal to study the temporal and spatial dynamics of the NLIWs from a generation phase to a propagation phase and then to a dissipation phase. Integrating the extracted linear features of NLIWs from historical MODIS images using a geographic information system (GIS), the dynamics of the internal waves can be better understood.

Therefore, the purpose of this study is to integrate a proper approach to extract the linear features of NLIWs in MODIS images based on the techniques of image enhancement and linear feature extraction (LFE). In this study, the Multiscale Retinex (MSR) method will be applied to enhance the MODIS image and two edge detection methods will be used to extract the linear features of NLIWs in the enhanced image. To evaluate the performance of the integrated method, the extracted linear features will be vectorized and overlapped with the original image in the Geographic Information System (GIS) to investigate the localization error between them and the true features' boundary.

2. Methods of Linear Feature Extraction

2.1. Multiscale Retinex (MSR)

Modern satellite images posses a high dynamic intensity range of a 16-bit level, such as MODIS, ERS2/SAR, and IKONOS images. This dynamic range is inconsistent with those of the output devices of most computers that normally have an 8-bit pixel intensity level. The Multiscale Retinex (MSR) method is a human based image-processing algorithm, which provides both color consistency and dynamic range compression [4]. The single-scale retinex (SSR) is defined as:

$$R(x,y) = \log F(x,y) - \log\left[F(x,y) * G(x,y)\right] \quad (1)$$

where $F(x, y)$ is the input image intensity of a single band, * denotes the spatial convolution operation, and $G(x, y)$ is the Gaussian spatial filtering function given by

$$G(x,y) = Ke^{\frac{-(x^2+y^2)}{c^2}} \quad (2)$$

where c is the standard deviation of $G(x, y)$ that acts as a scale factor of the spatial filtering function, and k is the normalization constant such that the integral area under $G(x, y)$ equals to 1.

The MSR is the weighted sum of each single-scale retinex defined by

$$R_{MSR} = \sum_{i=1}^{N} w_i R_i(x,y) \quad (3)$$

where N is the total number of scales, and w_i is the weight associate with the i-th scale.

The choice of scale c is based on the experimentation. In general, a small scale of c provides more details but weak tonal and color rendition, while a large scale of c provides less detail but better tonal and color rendition. The Multiscale Retinex integrates the strength of each scale and prevents the weakness of each scale. The final MSR output can be calculated by using a "canonical" gain/offset to map between the retinex and the display range of output devices [4].

2.2. Canny Edge Detector

Canny [3] derived an optimal operator for edge detection based on three criteria: (1) low error rate, where image edges should not be missed by the operator; (2) the edge points should be well localized with minimized offset from the true edge; (3) the operator should have only one response to a single edge. Based on these criteria, Canny's approach defines edge points as a local maximum of the first derivative of a Gaussian smooth filter $G(x,y)$ applied to the input image $F(x,y)$. At the local maximum, the condition is defined as:

$$M(x,y) = \left(\frac{\partial}{\partial n} G_n\right) * F(x,y) = 0 \quad (4)$$

where n is the directional vector, * is the spatial convolution operation, and $M(x,y)$ is the magnitude of the convolution between the first derivative of a Gaussian smooth filter and the image $F(x,y)$. The method then suppresses any pixel that is not an edge point by tracing the local maximum of $M(x,y)$ along the maximum direction of n. Finally, the Hysteresis process is conducted to filter the remaining points with a high threshold and a low threshold, such that the high threshold identifies strong edge pixels and the low threshold preserves weak edge pixels connecting to the strong edge pixels.

2.3. Wavelet Transform Modulus Maxima (WTMM)

Mallat and Hwang [5] proved that the local maxima of the dyadic wavelet transform modulus of an image could characterize the local structure in the image; i.e. the WTMM approach could be applied to identify the location of edges or textures in an image. The wavelet transform modulus $WTMM_j(x,y)$ can be expressed as:

$$WTMM_j(x,y) = \sqrt{\left|W_j^{\,1}F(x,y)\right|^2 + \left|W_j^{\,2}F(x,y)\right|^2} \quad (5)$$

where $W_j^1F(x,y)$ is the dyadic wavelet transform of image $F(x,y)$ in the x direction at the j-th level, and $W_j^2F(x,y)$ is the dyadic wavelet transform of image $F(x,y)$ in the y direction at the j-th level. The direction of the modulus maxima is given as:

$$A_jF(x,y) = \arctan\left[\frac{W_j^1F(x,y)}{W_j^2F(x,y)}\right] \quad (6)$$

Thus, edge pixels in an image can be identified by chaining the local maximum of WTMM along the maximum direction of $A_jI(x,y)$. It is suggested by Mallat and Hwang [5] that the Quadratic Spline wavelet function is feasible in this approach. In this study, we will conduct the wavelet decomposition up to the fourth level, for investigating the properties of multi-resolution edge detection using WTMM method.

3. Experiments and Results

3.1. Study area

As mentioned earlier, our research interest is to study the temporal and spatial dynamics of the NLIWs in the northern South China Sea. The research activities in this area have flourished in recent years where the world's largest vertical movement of NLIWs was identified as 110 meters [6]. Figure 1 shows the MODIS image of Terra satellite that was taken on 16-APR-2003, 02:55GMT, and centered at 117-35E and 20-56.5N, in which the Tung-Sha Lagoon is located on the lower left corner. Figure 1 is the original MODIS image with a 16-bit intensity level, which has been enhanced by the regular linear stretch for a primitive visualization.

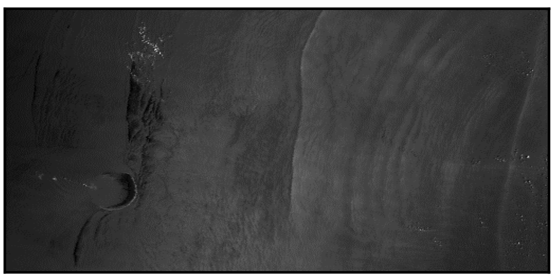

Figure 1. The original MODIS image of Terra satellite taken on 16-APR-2003, 02:14 GMT.

3.2. Image Enhancement

Although a linear stretch process has been conducted on the above image in Figure 1, it still shows a low level of brightness through the whole image and a poor contract between pixels, especially on both sides of the image due to the larger tilt angle from the sun to both sides of the area. Figure 2 shows the enhanced image applying the MSR method on Figure 1, where the illumination and contrast of the image are greatly improved; therefore, sea surface features including NLIWs and features of small scale may be clearly identified.

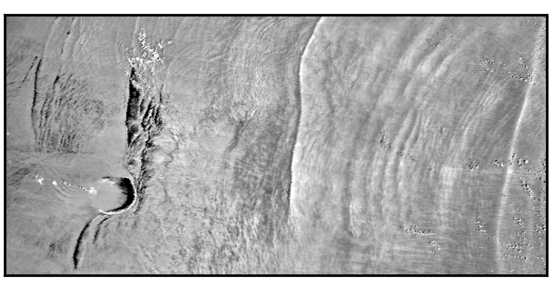

Figure 2. Enhanced image using the MSR method.

3.3. Linear Feature Extraction

Here, we compared two popular methods of edge detection, i.e. the Canny edge detector and the WTMM edge detectors, in order to better select the edge detector for the future application. Figure 3 shows the extracted ocean surface features in the enhanced image (Figure 2), using the Canny edge detector with a length filter of 20 pixels, where the spatial features of NLIWs are clearly identified. Figure 4 shows the extracted ocean surface features in the enhanced image, using the WTMM edge detector, with the Quadratic Spline wavelet function, at the second level decomposition, where the linear features seem to be irregular and less continuous compared to the result of the Canny edge detector. The result of the WTMM method at the first level of wavelet decomposition was contaminated with the noisy scene, which is not shown here.

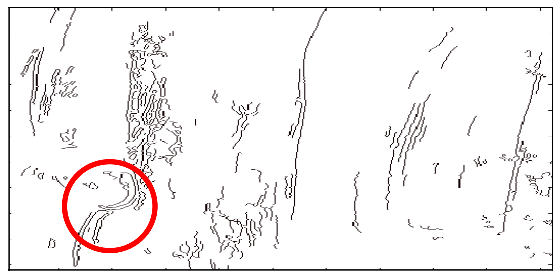

Figure 3. Extracted ocean surface features using the Canny edge detector with a length filter of 20 pixels.

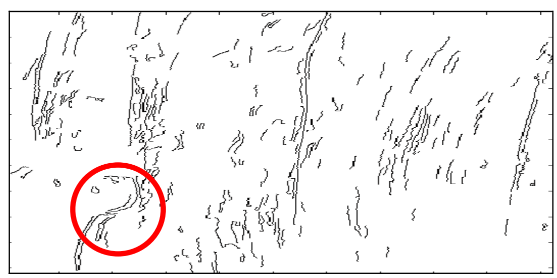

Figure 4. Extracted ocean surface features using the WTMM edge detector with a length filter of 20 pixels.

4. Discussion

Edge detectors play an important role in feature extraction, because edge is an important feature for identifying objects in images. Edge points are usually localized in the sharp change area of image intensity, which usually provides the information of object boundary or texture. For further investigating the effects of the Canny edge detector and the WTMM edge detector, we zoomed into the circled area in Figure 3 and Figure 4 as shown in Figure 5 and Figure 6. With these enlarged images, we see the extracted linear features, using the Canny edge detector, show a better shape of the Tung-Sha Lagoon (Figure 5). On the other hand, the WTMM edge detector produces irregular shape and less details of the Tung-Sha Lagoon (Figure 6).

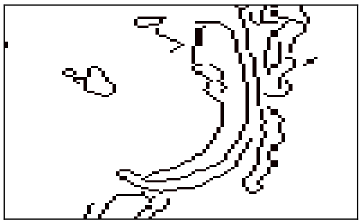

Figure 5. Extracted ocean surface features using the Canny edge detector around the Tung-Sha Lagoon.

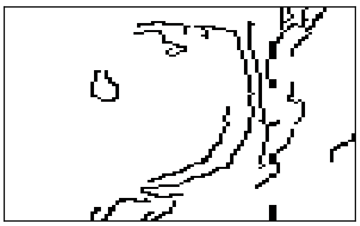

Figure 6. Extracted ocean surface features using the WTMM edge detector around the Tung-Sha Lagoon.

Furthermore, to evaluate the performance of the edge detectors, the extracted features were vectorized and overlapped with the original image in the ESRI/ArcView 9.1 GIS software to investigate the spatial offset between the true features' boundary in the image and the detected linear features. Figure 7 illustrates the spatial offset between the true location of the primary NLIW in the image and the detected line features with different edge detectors, where line 1 denotes the Canny edge detector and line 2 to line 4 denotes the WTMM edge detector of level 2, 3, 4 wavelet decomposition, respectively. It is obvious that the Canny edge detector outperforms the WTMM edge detector in terms of localization error in pixels.

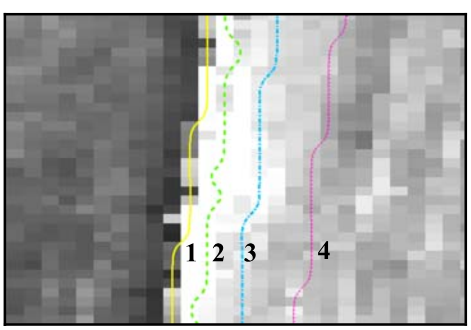

Figure 7. Comparison between the result of the Canny detector and the WTMM edge detector with the primary NLIW feature at the center of Figure 2.

5. Conclusions

In this study, we have integrated the MSR method and the edge detection methods for extracting the linear feature of NLIWs in the MODIS image. The results show that the MSR method provides enhanced image with improved color contrast and brightness, which result in a better quality of the extracted linear features. Finally, we compared the performance between the Canny edge detector and the WTMM edge detector. It is shown that the Canny edge detector is superior to the WTMM edge detector both in visualization quality and in localization accuracy. The localization quality of edge detectors is especially important when the extracted linear features will be further used for numerical analysis. This characteristic of edge detectors is rarely investigated in the literature.

6. Acknowledgement

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7. References

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