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Improving MODIS sea ice detectability using gray level co-occurrence matrix texture analysis method: A case study in the Bohai Sea

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ABSTRACT

An effective methodology for Bohai Sea ice detection based on gray level co-occurrence matrix (GLCM) texture analysis is proposed using MODIS 250 m imagery. The method determines texture measures for sea ice extraction by analyzing the discrepancy of textural features between sea ice and sea water. Sea ice extent and outer edge are recognized accurately by texture segmentation owing to significant differences in texture statistical features between ice and water. The texture analysis method can properly eliminate perturbations on sea ice extraction due to suspended sediment. It effectively solves the problem of spectral confusion and sea ice misassignment in the conventional gray-threshold segmentation and ratio-threshold segmentation methods. The method eliminates the need for threshold range setting for sea ice segmentation. Taking the Bohai Sea as an example, the results of the proposed method are validated using co-temporal HJ1B-CCD 30 m imagery by visual interpretation, and the accuracy of the method are evaluated using confusion matrix. The results show that the proposed method is superior and more reliable for sea ice detection compared to conventional methods, providing an ideal tool for precise sea ice extraction.

1. Introduction

The Bohai Sea is the most southern area in the northern hemisphere with sea ice in winter (Ning et al., 2009). The region around the Bohai Sea is an important economic development zone in China. Sea ice as a significant environmental factor in the Bohai Sea must be considered in offshore operations, ports, shipping, and marine fisheries. The monitoring of sea ice distribution and its spatiotemporal evolution plays an important role in maritime activities on the sea ice edge region. In polar and high latitude regions, the extent and outer edge of sea ice as a critical meteorological indicator reflect global climate change, and are essential for long-term global sea ice change detection and global climate change monitoring (Wang et al., 2011).

Thresholding has been widely used in sea ice detection and classification (Haverkamp et al., 1995). However, global thresholding is not always optimal for certain areas of an image (Haverkamp et al., 1995). Sea ice has been detected solely based on simple spectral characteristics of satellite imageries (Su et al., 2012; Su and Wang, 2012). As the imageries have the spectral aliasing, the extraction accuracy is affected. Conventional band-threshold segmentation or ratio-threshold segmentation do not eliminate the influence of suspended sediment on sea ice extraction. The two are therefore easily confused resulting in misassignments i.e. suspended sediment misassigned as sea ice and sea ice misassigned as suspended sediment due to their similar spectral characteristics. In addition, the extraction results obtained by threshold segmentation are noisy and patchy requiring manual intervention for their removal from the imagery. The threshold range setting also affects the extraction accuracy. Extraction based on imagery texture features will eliminate the interference from suspended sediment. It will properly settle the problem of the spectral confusion, noise and patchiness in the detection process. Additionally there is no need to consider the exact threshold range setting for segmentation, improving the detection accuracy of sea ice.

Texture analysis is an important method applied to target identification (Barber and Ledrew, 1991; Augusteijn et al., 1995), image classification (Haralick et al., 1973; Marceau et al., 1990; Gong et al., 1992; Franklin and Peddle, 1990; Anys and He, 1995; Coburn and Roberts, 2004; Hann et al., 2003; Chen et al., 1989), and image segmentation (Ryherd and Woodcock, 1996; Chen and Pavlidis, 1979). It is widely accepted that image texture and tone are used complementarily by human interpreters to recognize objects of interest (Holmes et al., 1984). Different kinds of texture analysis methods exist (He and Wang, 1990; Davis et al., 1979; Gotlieb

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and Kreyszig, 1990; Galloway, 1975; Clausi and Yue, 2004). Gray level co-occurrence matrix (GLCM) is a common method used in describing image texture by studying the spatial correlation characteristics of gray as well as the spatial distribution relationship between pixels, thus reflecting the spatial relationship between pixels and the characteristics of image elements (Davis et al., 1979; Clausi, 2002). GLCM is widely applied in the detection and classification of surface features in remote sensing images, especially in SAR and radar images (Rajesh et al., 2001; Nyoungui et al., 2002; Beauchemin et al., 1996; Shanmugan et al., 1981; Shokr, 1991), but less in optical images (Marceau et al., 1990; Gong et al., 1992).

Researchers have carried out in-depth study on sea ice identification (Barber and Ledrew, 1991), classification (Shokr, 1991; Smith et al., 1995), and detailed texture analysis (Soh and Tsatsoulis, 1999; Clausi and Yue, 2004) in the polar and high-latitude regions using SAR images. The Bohai Sea ice on the other hand is seasonal, one-year ice, and its morphological characteristics and spatiotemporal features differ significantly from sea ice in the polar and high-latitude regions (Zhang et al., 2008). There have been no previous studies applying medium-resolution satellite imagery (such as MODIS imagery) to sea ice detection, classification, and texture analysis in the Bohai Sea.

As mentioned before the surface of Bohai Sea ice in the MODIS and HJ1B-CCD imageries appears rough and cracked, whereas the sea surface looks smooth and uniform. These two textural features differ significantly. In this paper, we use MODIS 250 m imagery to carry out an analysis of textures based on GLCM, and determine the GLCM parameters and textural measures for Bohai Sea ice detection. Based on the distinct difference in texture statistical characteristics of sea ice and sea water, sea ice extent could be accurately extracted by texture segmentation. Compared to conventional methods, the proposed method is superior and more reliable for sea ice detection as demonstrated by comparison with HJ1B-CCD 30 m satellite imagery which we used to validate the detection results with higher spatial resolution.

2. Study area and data

The Bohai Sea (between 37°07'–41°0'N and 117°35'–121°10'E) is a partially enclosed sea in China, surrounded by land on three sides and connected to the Yellow Sea in the East. The Bohai Sea covers 78,000 km^2 with an average water depth of 18 m. There are three primary bays surrounding the Sea: the Liaodong bay in the north, the Bohai bay in the west, and the Laizhou bay in the south. The water temperature of the Bohai Sea varies in accordance with a northern continental climate with a mean temperature of 0 °C in February and 21 °C in August. The shoreline along the sea always freezes in winter.

MODIS data is suitable for monitoring large-scale disasters with moderate spatial resolution up to 250 m and higher time resolution of up to twice a day. Comparing with other optical remote sensing data, MODIS is an ideal data for monitoring sea ice due to its unique advantages, such as high temporal resolution, moderate spatial resolution and large-scale coverage. One-scene MODIS data used in this study were downloaded from NASA LAADS (Level-1 and Atmosphere Archive and Distribution System). They are L1B MOD02QKM data with 250-m spatial resolution after radiation calibration, including two channels (CH1: red band with wavelength of 620–670 nm, and CH2: near-infrared band with wavelength of 841–876 nm). One-scene HJ1B-CCD satellite imagery with $30 * 30$ m spatial resolution, including blue band (Band1), green band (Band2), red band (Band3) and near-infrared band (Band4) was used for validation. Both the MODIS and HJ1B-CCD data were acquired January 15, 2010 covering the whole region of the Bohai Sea without or only slight cloud coverage.

3. Methods

3.1. Pre-processing of MODIS data

Pre-processing of MODIS L1B data provided by NASA LAADS includes radiation correction and calibration, geographic references, and geometric correction for a "given geo-referenced information". The images exhibit the so-called "bow-tie" effect, a geometric distortion induced by image pixel overlapping, which must be corrected for (DSRS, 2010, http://www.sat.dundee.ac.uk/modis-bowtie.html). In this paper, the geometric correction and removal of the "bow-tie" effect were carried out using the "Georeference MODIS" tool incorporated in RSI ENVI™ software (Version 4.3). TOA (Top of Atmosphere) reflectance imageries with spatial reference information were prepared to detect sea ice.

3.2. Ratio-threshold segmentation

We can separate land, sea water, and sea ice using ratio-threshold segmentation because their spectra differ significantly in channel 1 and channel 2 of the MODIS data at TOA (Su et al., 2012). Land, sea water, and sea ice can be separated by setting threshold ranges for segmentation (Fig. 1). The following four thresholds used here are:

$$\text{land—water separation}: R_0 < (CH_1 - CH_2)/(CH_1 + CH_2) < R_1 \quad (1)$$

$$\text{water—ice separation}: R_2 < (CH_1 - CH_2)/(CH_1 + CH_2) < R_3 \quad (2)$$

where CH_1 and CH_2 are the reflectance of the first and second channels of MODIS data at TOA; R_0 and R_1 are the lower and upper thresholds of land–water separation whereas R_2 and R_3 are the lower and upper thresholds of water–ice separation. We set, R_0, R_1 and R_2, R_3 at about 0.00, 0.55 and 0.00, 0.32, respectively, based on a sampling min–max threshold statistical analysis of Bohai Sea image data.

3.3. Gray level co-occurrence matrix (GLCM)

Image texture, defined as a function of the spatial variation in pixel intensities (gray values), is useful in a variety of applications and has been studied intensively by many researchers. One immediate application of image texture is the recognition of image regions using texture properties. Texture is one of the most important visual cues in identifying various types of homogeneous regions. Image textures are one way that can be used to help in segmentation or classification of images.

In the MODIS and HJ1B-CCD imageries of the Bohai Sea, irregular watercourses, cracks and stripes occur among the accumulated sea ice. The sea ice surface is rough and uneven with distinct, irregular and unstable textural features as inferred from the various gray tones. The sea water surface on the other hand is smooth and uniform with nondescript and invariant textural features as is apparent from the stable gray tones by visual interpretation (Fig. 2). GLCM texture analysis was applied to detect sea ice based on this significant difference in textural features of sea ice and sea water. The two would be distinguished through their markedly different texture measures, enable precise discrimination of the ice (Fig. 3).

An image texture is a set of metrics calculated in image processing designed to quantify the perceived texture of an image. Image texture gives us information about the spatial arrangement of color or intensities in an image. A statistical approach is useful to ana-