Deep Learning-Based Estimation of Whitecap Coverage on the Ocean Surface

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Abstract

Whitecaps generated by wave breaking on the ocean surface play an important role in the local interaction across the air-sea interface. In this study, a progressive high-precision whitecap extraction model is first built by using the algorithm of deep learning. Compared with a traditional whitecap extraction model based on threshold value, the algorithm is found to solve problems caused by illumination condition and color change on the ocean surface, and effectively extracts fine whitecaps with complicated structures. Further, through comparisons with algorithms such as Automatic Whitecap Extraction (AWE), Iterative Between Class Variance (IBCV) and the whitecap extraction based on fixed threshold value, the present algorithm is demonstrated to be more effective and accurate for identifying whitecaps, and it reduces the amount of evaluation load, and can effectively apply for changeable ocean conditions.

1. Introduction

Whitecaps have a significant effect on the exchange of momentum, heat and CO_2 between the atmosphere and the ocean surface. Figure 1 shows the whitecaps image. Whitecap coverage is defined as the area of whitecap area per unit area of sea area. Whitecap coverage is considered to be a useful wave breaking property for quantifying various sea surface fluxes and its evaluation is important for describing the exchange process between the atmosphere and the ocean.

In this study, a deep learning algorithm is applied to extract whitecap areas from sea surface images, in order to construct a high-precision whitecap extraction model. For solving the problem of the reflected light on the sea surface and the change in the sea color, a new Semantic Whitecap Extraction model (SWE) is made to solving problems in the previous whitecap wave extraction models based on the image brightness threshold. The new whitecap extraction technology is used to determine whitecap coverage when shooting digital images under complicated sea surface conditions.

Fig. 1 Image of whitecaps on the ocean

2. Whitecaps Extraction Model

The definition of whitecap coverage is the ratio of the number of pixels that are considered to be whitecap to the number of all pixels in the image.

$$W_C(\%) = (NW/NA) \times 100$$

where N_W is the number of pixels in the whitecap and N_A is the number of pixels in the image. Various analysis methods have been proposed in previous studies. The FT method, which is the most representative method, is a method to classify whitecap regions and background regions using fixed
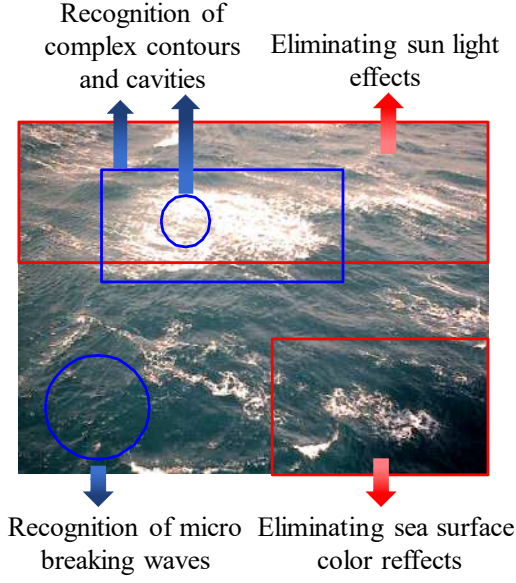
Recognition of complex contours and cavities

Eliminating sun light effects

Recognition of micro breaking waves

Eliminating sea surface color reffects

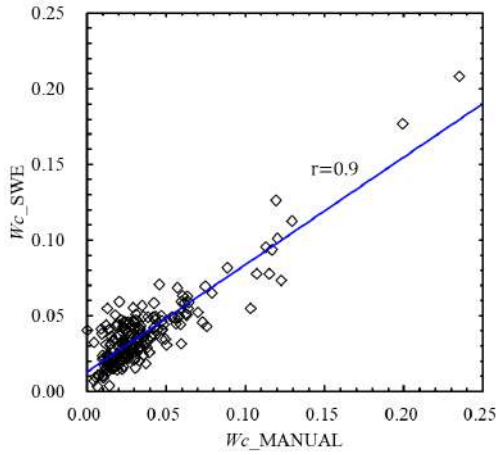**Fig. 2** Features of the SWE model

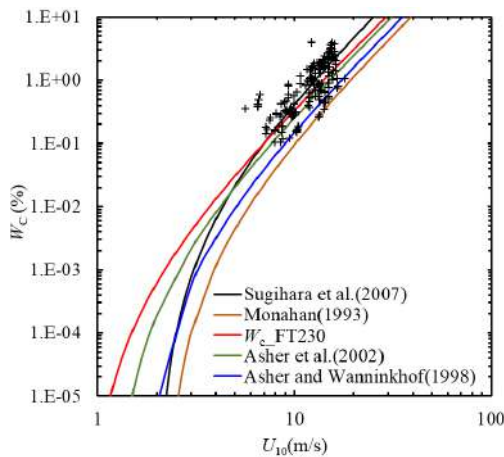**Fig. 3** Relation between Wc_SWE with Wc_MANUAL

Fig. 4 Relation between W_C with U_{10}

threshold values, which are determined by analyzing the image. The IBCV method is a binarized filter that automatically determines

the threshold value to achieve the highest class separation assuming that there are two classes in the image: a bright image part and a dark part. Furthermore, the AWE method is an algorithm that automatically determines the optimal threshold based on derivative analysis. However, it is difficult to obtain ideal results with these methods because they cannot respond to changes in sea color and reflected light.

In this study, a new extraction model called SWE (Semantic Whitecap Extraction Model)was designed by analyzing 400 labeled images to address the negative effects of sea color and reflected light, using sea-surface images under various sunlight conditions and at different times of day. As Fig. 2 shown, SWE model is trained on images of various conditions, so it is able to respond to changes in sunlight conditions and sea surface color, which eliminates the negative effects of these conditions and achieves high-precision whitecaps extraction. In addition, the developed deep learning method of whitecaps extraction uses Semantic's method, which uses not only the information of each pixel but also the information of surrounding pixels to detect the whitecaps.

3. Results and Discussion

By comparing with Wc_MANUAL, Wc_SWE with high accuracy can be known based on Fig. 3. Relationship between whitecap coverage and wind speed at 10 m above sea level as shown in Fig. 4, the results of whitecap coverage calculated by the FT and SWE methods, respectively, from the images obtained in this study. From the figure, Wc_SWE is in good agreement with the traditional empirical relationship when the wind speed is above 10 m/s. The values of Wc_SWE are relatively high, but show high consistency with the relationship of Wc_FT230, which has a very high threshold of 230 for calculating the whitewave coverage. Since the values are low because of the setting, the calculation results of the SWE method should be higher than those of the FT230 method.

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