Image Processing and Hydroinformatics for Air-Sea Boundary Process

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Name

論 文 名　:　Image Processing and Hydroinformatics for Air-Sea Boundary Process

（ 海面境界過程を対象とした画像計測手法と流体情報解析に関する研究 ）

Title

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論 文 内 容 の 要 旨

Thesis Summary

The air-sea boundary process with breaking waves is closely connected to the exchange processes of momentum, heat and gases between the atmosphere and ocean. The surface drag coefficient and the friction velocity on the ocean surface, which express the momentum transfer coefficient, have frequently been quantified on the basis of the wind speeds above the ocean surface. However, it is natural to consider that they depend on the transition process of wind-wave surface controlled by wave breaking phenomenon. It is also important to characterize wind-driven water surface flow, which is related to the transports of microplastics and drifting litters in the ocean surface layer. Understanding of the air-sea boundary process based on the relationships between wind waves, the surface flow and the Stokes drift is useful for quantifying these transport velocities. The surface flow velocity responsible for the mass transport near the ocean surface is a Lagrangian velocity, defined as the sum of the Eulerian drift velocity and the Stokes drift velocity of the dominant wind waves. However, there are insufficient experimental data to quantify the relationships between them, so that such data are of value for the progress in the research field of air-sea boundary process.

Whitecaps on the ocean surface with the generation of a large amount of bubbles, play an important role in the air-sea exchange processes. Whitecap coverage is defined by the area of whitecaps per the unit ocean surface. It has been recognized as one of important physical quantities for describing the ocean surface fluxes of momentum, heat and gases. Whitecap coverage has been evaluated by the image processing for sea surface images, but most of previous algorithms depend on the threshold of brightness and it is greatly affected by the sea surface color and the sunlight, which lead to the result that whitecap coverage becomes not accurate enough. Thus, an accurate image processing method applicable to a variety of sea surface conditions is desired to be developed on the basis of a new approach. Furthermore, the mapping of whitecap coverage over a wide region of the ocean is important for the implementation of information about the sea-state conditions and the ocean surface fluxes.

In this study, we examined the air-sea boundary process from various aspects, focusing on how the quantities such as the surface flow velocity, the Stokes velocity and whitecap coverage vary depending on the transition process of wind-wave surface associated with breaking waves. The purposes of this study are to investigate the air-sea boundary process controlled by wave breaking phenomenon on the basis of systematic laboratory experiments using wind-water tunnels, and to reveal the relations of the surface velocity and the Stokes drift velocity with the transition process. In addition, new algorithms for the image processing to estimate whitecap coverage accurately were developed by using deep-learning techniques. We carried out the mapping of whitecap coverage through the numerical simulation of ocean waves with a

wave model, called the Simulating Waves Nearshore (SWAN). The results and findings obtained from this study are summarized as follows:

In Chapter 1, we explained the background of the research topics on air-sea boundary process. In particular, the importance of this study was described on the basis of the relations of the transition process of wind-wave surface with the physical quantities such as the surface flow velocity and the Stoke drift velocity. Also, the application of whitecap coverage for research on the ocean environment was shown based on the achievements of previous studies. We stated the objectives and the outline of this thesis.

In Chapter 2, the transition of wind-driven water surface flow was investigated by means of laboratory experiments, which were carried out using two types of wind-water tunnels. In the relationships between the average wind speed, the wind wave spectrum and the friction velocity, their behaviors changed around a certain friction velocity, indicating the occurrence of wave breaking. We also confirmed the transition by wave breaking in comparison between the surface drag coefficient and the windsea Reynolds number. The dependence of the surface flow velocity on the friction velocity was revealed experimentally, and the behavior of the surface flow velocity was found to vary with the occurrence of wave breaking. We also showed the spatial mapping of the surface flow velocity and the Stokes flow velocity by using a geographic information system.

In Chapter 3, a new algorithm for the image processing, i.e., the Semantic Whitecap Extraction (SWE) was developed by applying a semantic analysis algorithm of deep learning to the estimation of whitecap coverage on the ocean surface. In this analysis, we used the image data taken at a sea observation tower in Tanabe Bay, Wakayama. The effectiveness and accuracy of the SWE algorithm were verified in comparison with the existing algorithms such as the IBCV algorithm and the AWE algorithm, and whitecap data manually extracted. It was found that the new algorithm has the advantages of automation and is not affected by the sea surface color and the sunlight. We concluded that the SWE algorithm can provide accurate extraction results of whitecaps, and can flexibly deal with changeable sea surface conditions.

In Chapter 4 is described the results of whitecaps on the ocean surface using image data taken from a ferry that piles in Genkai Sea. We proposed additionally a new algorithm, i.e., the SNet and MNet Whitecap (SMW) based on two deep-learning techniques, called the SNet and MNet algorithms, to extract whitecaps from the image data. The SMW algorithm was possible to estimate accurately whitecap coverage, which showed the good correlation in comparison on the cruise line with the energy dissipation rate due to whitecap-breaking waves simulated using by the SWAN. Thus, it was confirmed that the wide range mapping of whitecap coverage can be carried out by using a numerical wave model such as the SWAN. Finally, we made the mapping of whitecap coverage based on the numerical simulation data from the SWAN. By conducting such mapping over a wide region of the ocean surface, it is possible to visually analyze the spatial characteristics of breaking waves.

The conclusions of this thesis were described in Chapter 5 by summarizing the results and findings in this study.