学 位 論 文 内 容 の 要 旨

博士の専攻分野の名称　博士（工学）　氏名　岡地　寛季

学 位 論 文 題 名

Estimation method of sea spray concentration and evaluation of momentum transfer at the sea surface under stormy conditions
(暴風雨下における海面上での飛沫濃度分布の推定手法と運動量輸送の評価に関する研究)

Exchanges of momentum, heat and water between the atmosphere and ocean are essential variables influencing weather and climate. Under severe weather conditions such as typhoons, the role of sea spray - generated at the ocean surface - in these exchanges remains elusive. The mass of sea sprays increases at strong winds accompanied with rainfall. Large sea spray and small rain co-exist in the same diameter size class: approximately 0.1 to 1 mm. Although these exchanges are of great significance in generation and development of severe weather conditions, little is known about sea spray at high wind speeds. In this study, field observation with disdrometers, radar applied scattering theorem and analytical research on the momentum, heat and water exchanges were comprehensively conducted to estimate concentration profile and time-spatial distribution of sea spray. Based on the results, the momentum transfer at the sea surface was considered.

Introduction is in Chapter 1. In Chapter 2, the momentum exchange at the air-sea surface was investigated under typhoon-like conditions characterized by various wind speeds and rainfall intensities. The momentum exchange coefficient includes effects of sea spray and rainfall in reference to the previous study highlighting the effect of sea spray. At the wind speed in the range of 23 to 38 m/s, the coefficient decreased with the heavier rainfall intensity. At the stronger winds greater than 38 m/s, it decreased due to the effect of sea spray than the effect of raindrop. Since this result depends on the parameterizations of drop size distribution of sea spray based on the previous study, several observations were conducted in the following chapters.

In Chapter 3, a series of field observations with two types of disdrometers detecting different particle sizes were conducted at an observational tower lying 1.8 km off the coast of Wakayama Prefecture, Japan. The optical disdrometer was installed at 15-m height of the tower. The number of sea spray with diameter less than 1mm was increased at wind speeds more than 10 m/s when the meteorological radar and tipping bucket located near the tower observed no-rainfall. Another observation at the tower with the optical disdrometer containing two rainfall events successfully captured the extreme event of typhoon KROSA of 2019.

The number of rain droplets with diameter less than 1mm increased monotonically as wind speed increased. Since the rainfall intensity was constant, this trend can be recognized as an increase in number of sea spray. Furthermore, the proportions of sea spray to rainfall at rainfall intensities and hourly wind speeds (up to 30 mm/h and up to 20 m/s) were obtained, enabling us to improve the accuracy of rainfall estimates over the open ocean through radar observation.

In Chapter 4, simultaneous radar observation which has the advantage of high time-spatio resolution for vertical cross section was performed. Dynamic structures of the multi-phase flow with sea spray and rain over the ocean under severe typhoons, CIMARON, JEBE, TRAMI in 2018 were obtained. However, it can only obtain qualitative data due to specifications of this radar. Therefore, a method to analyze quantitative data, which is radar cross section representing the electromagnetic properties of materials, was proposed. Specifically, the estimation was achieved by following proposed methodologies: noise removal, conversion to reflected power, correction based on density of electromagnetic wave, estimation of radar gain, and sea clutter height estimation.

In Chapter 5, conversion methods from the radar cross section to drop size distribution and concentration of sea spray were proposed using the result in Chapter 4. This radar observation was based on the scattering phenomenon in the mixed condition of sea spray and raindrops: Mie scattering or Rayleigh scattering, and single scattering or multiple scattering. The scattering phenomenon varies depending on the particle size, number, and salinity. Therefore, sensitivity analysis was conducted to reveal scattering characteristics of such mixed situations assuming drop size distributions of sea spray and rain under various wind speeds and rainfall intensities. This analysis confirmed that scattering by sea spray and rain packed in unit volume should have been described as the Mie scattering and single scattering.

In Chapter 6, using the quantification method proposed in Chapter 4 and 5, vertical concentration profiles of sea spray under the three typhoons were estimated. The profile allowed us to estimate sea spray generation function, which is the number of sea spray generated at the sea surface assuming the vertical flux conservation law of particle. This leads us to assess the parameterizations of drag coefficient.

This study provides highly significant information on detailed structures of multi-phase flow with sea spray and rain in the surface boundary layer. It deepens our knowledge about the air-sea exchanges under severe weather conditions like typhoons and give an insight into the typhoon development.