R&D Theme

Generating and controlling the air-water turbulence field with temperature gradient and surface waves at extremely high wind speeds

Progress until FY2022

1. Outline of the project

Prediction accuracy of typhoon tracks has increased in recent years, whereas that of typhoon intensities has not been improved. One of the causes is the difficulty of representing momentum and heat transfer mechanisms across the sea surface in typhoons. In particular, momentum and heat transfer across the sea surface, which substantially influences intensities of typhoons, has not been well modeled.

The goal of this project is to develop accurate models for predicting the heat and momentum fluxes across the air-water surface under high wind-speed conditions similar to typhoons, using the largest typhoon simulation tank in the world, and to suggest experimentally and numerically whether typhoons are controlled (weakened) by manipulating the sea surface conditions.

This R&D theme aims to generate pure wind-wave fields in the typhoon simulation tank, at Research Institute for Applied Mechanics, Kyushu University, and develop advanced techniques for measuring wind-wave characteristics, which are required for computer typhoon simulations. Our previous experiments have been conducted at a short fetch of 6.5 m. However, in the ocean, wind waves are generated over an extremely wide area, and so the experiments at longer fetches are needed. Our typhoon simulation tank (Fig. 1) has long fetches up to 30 m and enables to accurately investigate the wind-wave characteristics and heat and momentum transfer mechanisms under high wind speed conditions similar to typhoons. By collaborating with our other experimental and simulation groups, we are planning to explore new approaches for controlling typhoons.

Fig. 1: Typhoon simulation tank

2. Outcome so far

① Generation of typhoon fields

Using the typhoon simulation tank, we generated pure wind-wave fields at high wind speeds up to 40 m/s and fetches up to 30 m. In such high-speed winds, a lot of droplets are generated at the water surface by wave breaking (Fig. 2). The dispersed droplets tend to collide with Eastern-style pitot tubes and prevent to measure wind speeds. Therefore, Western pitot tubes resistant to droplet clogging were used here. This enabled us to measure the wind speeds with high accuracy.

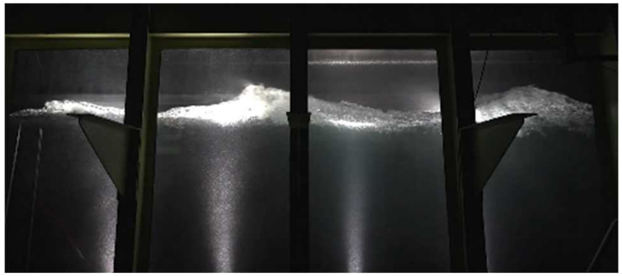

Fig. 2: Water surface with experimentally produced wind

② Measurements of wave characteristics

The characteristics of wind waves were investigated in the typhoon simulation tank. According to our previous studies, the wave height and frequency were useful for estimating the drag coefficients related to the momentum flux. Therefore, the wave heights and frequencies at various wind speeds were accurately measured using electrode wave gauges (Fig. 3).

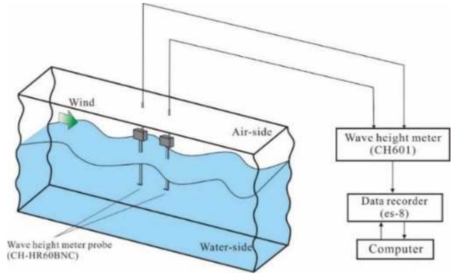

Fig. 3: Measuring wave height using electrode wave meters

3. Future plans

We will investigate whether momentum and heat fluxes across the air-water surface are controlled by manipulating the water surface conditions. This may lead to the ability to control typhoons, since the momentum and heat fluxes significantly influence the typhoon intensities. This will also allow us to provide more advanced water-surface manipulation method for changing the fluxes more effectively. If so, we will numerically confirm the potential for typhoon control in collaboration with our computer simulation group.

R&D Theme

Typhoon simulations using novel flux models and suggestions for typhoon control

Progress until FY2022

1. Outline of the project

The prediction accuracy of typhoon tracks has increased notably over the past 40 years, whereas that of typhoon intensities has not been improved. One of the causes is the difficulty of representing the momentum and heat transfer mechanisms across the sea surface in extremely high wind speed conditions using conventional transfer models for typhoon simulations because the momentum and heat fluxes significantly influence typhoon energies.

This R&D theme aims to conduct accurate numerical simulations of typhoons using the detailed parameterization of drag and heat transfer coefficients measured in the world's largest typhoon simulation tank. The simulations are performed by using the Multi-Scale Simulator for the Geoenvironment (MSSG, Fig, 1), which is a numerical model developed in JAMSTEC, and the Earth Simulator supercomputer system. The goal of this theme is to numerically suggest whether typhoons are controlled (weakened) by manipulating sea surface conditions or not.

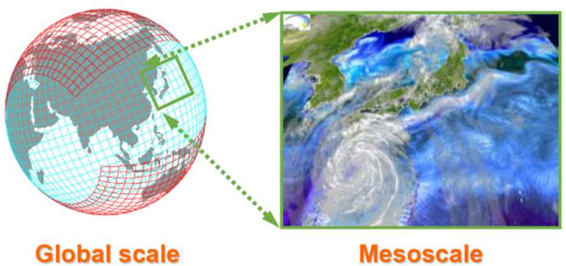

Fig. 1: Multiscale numerical model MSSG

2. Outcome so far

① Simulations for predicting typhoon intensities

The MSSG incorporates equations for computing the momentum and heat transfer between the sea surface and atmosphere. We first implemented a new flux parameterization based on laboratory measurements conducted by our project members (Komori et al., *J. Phys. Oceanogr.*, 2018) and examined how reasonably the MSSG predicts typhoon tracks and intensities using the parameterization. The test case was Typhoon T1330 (Haiyan), which developed on November 4, 2013 near Chuuk Lagoon.

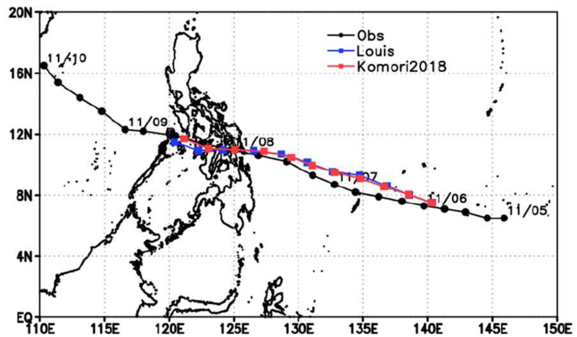

Fig. 2: Track of T1330 obtained by the simulation

② Controlling typhoon via wave modification

Further typhoon simulations were conducted by modifying the transfer coefficients for computing the momentum and heat fluxes across the sea surface. The predictions for the minimum sea-level pressure and maximum wind speed suggested that typhoons are influenced by altering the energy transfer across the sea surface.

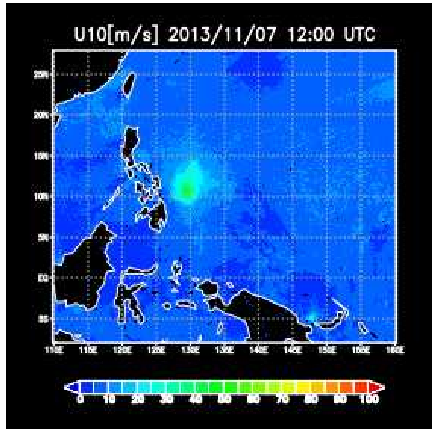

Fig. 3: Wind speed of T1330 obtained by the simulation

3. Future plans

We will conduct more accurate numerical simulations of typhoons by incorporating the latest experimental information on momentum and heat fluxes which will be provided from our experimental R&D themes. Furthermore, to contribute to the Moonshot Goal, we will conduct numerical investigation to examine whether the manipulation method of sea surface conditions, proposed by our experimental group, allows us to control (weaken) typhoons by significantly altering the momentum and heat fluxes across the sea surface.

国立研究開発法人 科学技術振興機構 Japan Science and Technology Agency

R&D Theme

Air-sea momentum transfer mechanism at extremely high wind speeds

Progress until FY2022

1. Outline of the project

In recent years, the accuracy of typhoon track prediction has been improved, but that of typhoon intensity prediction has not been improved yet. One of the main reasons is that the air-sea momentum and heat transfer mechanisms at high wind speeds in typhoons are complicated, and so it is very difficult to model the momentum and heat fluxes across the sea surface that significantly influence typhoon intensity prediction.

On the sea surface under a typhoon, friction occurs between the atmosphere and the sea surface, resulting in the transfer of the typhoon's kinetic energy to the sea surface (Fig. 1). The energy transfer due to friction has a significant impact on the track and intensity of a typhoon.

In this R&D theme, we aim to investigate the air-water momentum transfer (flux) at high wind speeds, using the world's largest typhoon simulation tank located at Research Institute for Applied Mechanics, Kyushu University. We also aim to formulate the momentum flux across the sea surface at high wind speeds and elucidate the momentum transfer mechanism.

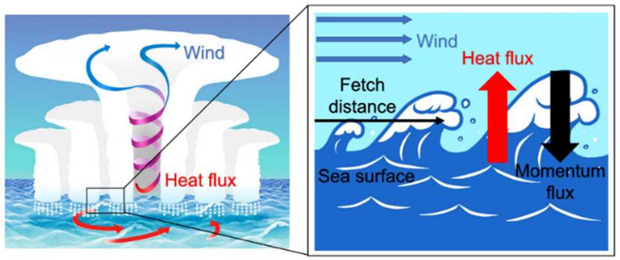

Fig. 1: Momentum transfer across the sea surface in a typhoon

Although the air-sea momentum flux has been investigated in our previous studies, the simulation tank used there had a short fetch of 6.5 m. Therefore, the results may not accurately represent the air-sea momentum flux in the wide ocean field. Consequently, we measured the momentum flux at high wind speeds up to 40 m/s and long fetches of up to 30 m using above the largest typhoon simulation tank.

2. Outcome so far

We first estimated the drag coefficient (C_D) against wind speed at a fetch of 20 m using both the momentum budget method (Fig. 2) and profiling method in the above typhoon simulation tank. The momentum budget method developed by PI & PM simultaneously enabled to measure the water levels using four water level gauges (Fig. 3) and it allowed us to accurately determine the state of friction between the atmosphere and water surface from the water level fluctuations.

We found that the drag coefficient C_D was constant at high wind speeds, whereas at low wind speeds, C_D tended to increase with wind speed. The values of C_D were generally consistent with our previous studies in different tanks, indicating that the momentum flux may not depend on the difference of fetch.

3. Future plans

In this R&D theme, we will conduct experiments at a long fetch of 30 m and to obtain a more accurate formula of the air-sea momentum flux by elucidating the momentum transfer mechanism. By offering the experimental results on momentum transfer to our simulation group, we will contribute to the improvement of the typhoon prediction accuracy.

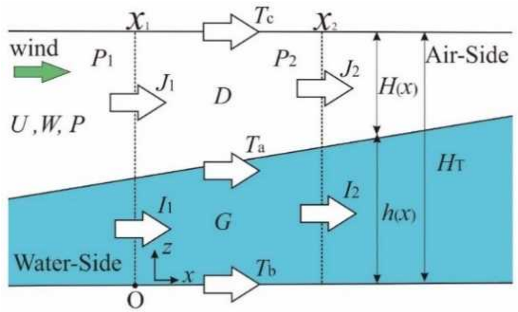

Fig. 2: Overview of momentum budget in a typhoon simulation tank. Measuring multiple momentum fluxes (I_1, I_2, J_1, J_2, T_b, T_c) in the diagram allows to estimate the momentum flux through the ocean surface T_a .

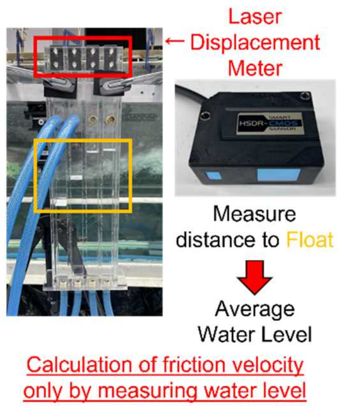

Fig. 3: Four water gauges used in momentum budget

R&D Theme

Air-sea heat transfer mechanism at extremely high wind speeds

Progress until FY2022

1. Outline of the project

The accuracy of typhoon track prediction has increased in recent years, whereas that of typhoon intensity has not been improved. One of the causes is the complexity of the momentum and heat transfer mechanisms across the sea surface in typhoons. In particular, the development of heat transfer model has been lagging.

In typhoons, heat energy is transferred from the warm ocean surface to the atmosphere (Fig. 1). The heat energy transfer has a significant impact on typhoon's intensity and track. Therefore, the goal for this R&D theme is to develop a formula for accurately estimating the amount of heat transfer (heat flux) across the sea surface at high wind speeds by using the world's largest typhoon simulation tank, located at Kyushu University's Research Institute for Applied Mechanics.

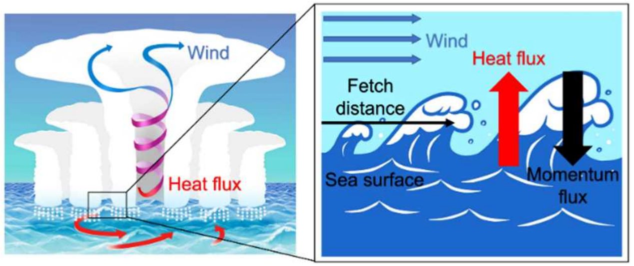

Fig. 1: Heat transfer through ocean surface in a typhoon

Studies on heat transfer across the air-water interface have been conducted by some research groups including our project members. However, the simulation tanks used there had short fetches, and the heat flux has not been measured over longer fetches such as in the ocean. Therefore, this R&D theme aims to measure the heat flux at high wind speeds up to 40 m/s and long fetches up to 30 m, using a heat budget method. The goal is to clarify the heat transfer mechanism and develop a heat transfer model that accurately represents the heat flux across the sea surface at high wind speeds.

2. Outcome so far

① Measurements of heat flux and development of heat flux formula

We have conducted heat transfer experiments using the typhoon simulation tank. Water temperatures in the tank were measured accurately by calibrating thermocouples carefully. In the heat transfer experiments, the water in the tank was first heated by a boiler. Then, wind was produced on the water surface and the temporal changes of temperature were tracked. When the temperatures in the tank were measured, we found that stratification (temperature difference in the vertical direction) occurs owing to heating, despite the water circulation in the tank by pumps. Although strong wind decreases this temperature difference, a more powerful water circulation system was required to mix the water perfectly and measure more accurate heat flux in homogeneous temperature field.

Fig. 2: Scattered water droplets and air bubble clouds

②Measurements of dispersing droplets

At high wind speeds, a lot of water droplets are dispersed above the water surface by wave breaking, and air bubble clouds are entrained into the water below the surface (Fig. 2). In order to estimate the accurate heat flux, the effects of the droplets and bubbles on the heat transfer should be investigated. Therefore, the sizes and densities of the water droplets and air bubbles, which are characteristic values of breaking wave intensity, were measured using a shadow-sizing system with high-speed cameras (Fig. 3). The shadow-sizing system enabled us to estimate heat flux across the water surface more accurately.

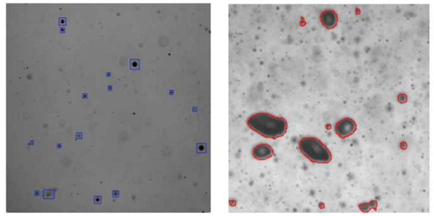

Fig. 3: Identifying particle size via shadow sizing system.
Left: Water droplets. Right: Air bubbles

3. Future plans

We will introduce a more powerful water circulation system which allows us to homogenize the water temperature filed in the typhoon simulation tank and conduct highly accurate heat flux measurements. At the same time, we will utilize the shadow-sizing system to achieve more accurate heat flux estimation at high wind speeds in the typhoon simulation tank.

In this theme, we will explore the possibility of an innovative typhoon control method by offering the accurate measurements of heat flux to our simulation group.

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