R&D item

1． Meteorological Approach

Progress until FY2023

1. Outline of the project

We will develop a more accurate numerical prediction model that represents the internal structure of typhoons in detail and that can be used to control typhoons effectively. Specifically, methods to control typhoons by seeding, lowering sea surface temperatures, weakening surface winds, changing wind direction by placing barriers and wind turbines on the sea, etc., will be considered to change typhoon intensity. We also consider methods to change typhoons with continuous weak intervention. Assuming seeding from aircraft, we will conduct laboratory experiments to investigate the details of cloud physics in convective clouds. We will select cases that have the potential to cause disasters by predicting them in advance and assimilate aircraft and ship observation data into a data assimilation system based on a high-resolution model to improve the accuracy of prediction to the extent that the effects of human intervention can be judged and to improve typhoon predictions with high accuracy.

2. Outcome so far

In FY2023, the effects of various typhoon control methods were examined in numerical simulations for a prominent typhoon that caused a major disaster in Japan. We continued to work on the development of a more accurate numerical prediction model, cloud physics experiments, and a data assimilation system to realize high-precision prediction of typhoons.

Numerical simulations of Typhoon Nanmadol 2021 were conducted to investigate the effect of seeding using the numerical model CReSS-4ICE-CCN with a 2 km grid spacing. By implementing seeding at locations with strong horizontal winds in the northern quadrant of the typhoon, we aimed for non-axisymmetric convective activity in the typhoon's inner core. In the case of seeding, the number of cloud condensation nuclei (CCN) was increased to 3×10^{9} kg^{-1} at specific locations from 5×10^{7} kg^{-1} in the control case. The rainfall area (outer rain band) that extends east of the center of the typhoon is reduced in the experiment with seeding (Fig. 1). We will identify areas with high sensitivity to seeding and investigate the intensity of typhoons when the rainfall distribution changes, which will lead to the development of more sophisticated typhoon control methodology.

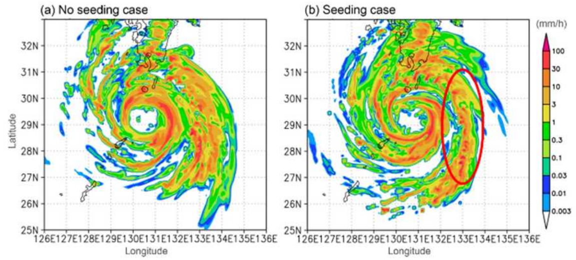

Figure 1: Precipitation distribution for the experiment without seeding (left) and with seeding (right) at 71 hours from the initial condition. The seeding greatly reduced the rainfall area east of the typhoon's center.

The effect of cooling due to seawater pumping evaporation on a specific area below 1 km altitude was investigated for Typhoon Hagibis in 2019. Using the numerical model stretch-NICAM with a minimum grid spacing of 1.4 km, we conducted experiments with cooling applied to a stational position along the typhoon path. Figure 2 shows the effects of cooling rates of 10 and 20 K/h for a radius of 50 km. At 24 hours after the initial condition, the location of the forcing becomes near the typhoon's center.

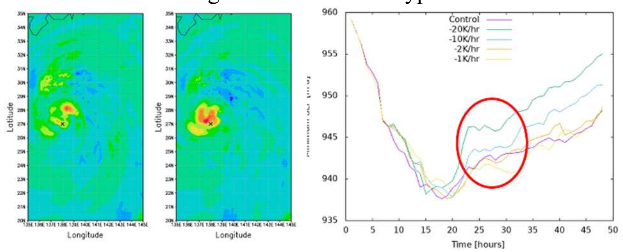

Figure 2: Left: Sea surface pressure changes after 24 hours of forcing experiments with 10 and 20 K/h cooling rates. Right: change in sea surface central pressure over time for control experiments, forcing with cooling rates of 1, 2, 10, and 20 K/h.

The atmospheric pressure change is almost proportional to the cooling rate. In the next step, we will examine the dependence on the cooling rate as small as 1 K/h and the forcing radius up to 1 km, with a moving force dynamically applied to the typhoon's center.

We conducted a large eddy simulation (LES) with a horizontal resolution of 100 m for the entire typhoon domain to investigate the effect of a resistive element that is considered a ship. In Figure 3, a wake (weak wind area) is reproduced in the downwind wake of the 100-m square resistive element in the realistic turbulent structure of the typhoon boundary layer.

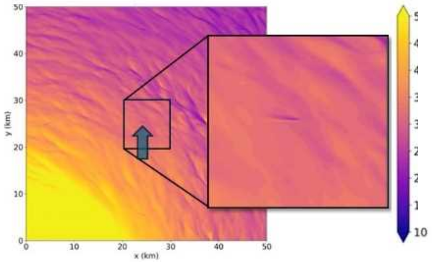

Figure 3: Distribution of ocean wind speeds according to LES. The resistance element is shown in the center of the figure.

3. Future plans

In the project's third year, numerical simulation experiments will be used to examine the effectiveness of interventions for typhoon control from various angles to identify candidate intervention methods that reduce typhoon damage to a degree acceptable to society. We will promote theoretical studies and conduct numerical simulations with specific typhoon cases to systematically investigate the relationship between the strength of external forcing and its impact on typhoon intensity. We will explore methods that can be artificially intervened to obtain significant typhoon intensity changes (around 5 m/s at maximum wind). We will identify issues in improving the accuracy of typhoon forecasting in numerical models and elucidate the mechanisms of typhoon changes. We also promote mathematical research to produce large effects with small external forces.

R&D item

2. Engineering Approach

Progress until FY2023

1. Outline of the project

Effective typhoon intervention methods for control utilizing meteorological models have been studied. However, to determine whether these methods are realistically feasible, studies on specific intervention devices need to be conducted simultaneously. In addition, while the impact assessment team can calculate the amount of damage that can be reduced by typshoon control, the cost of implementing these typhoon intervention methods must be calculated to determine whether we should conduct the typhoon control action or not.

The engineering approach team studies to address the above issues; in FY2023, our team mainly studied how to intervene in typhoons using ships and offshore structures.

2. Outcome so far

Currently, the method of weakening typhoon intensity using the large-scale deployment of ships with large sails is studied as one of the candidates for typhoon intervention methods. To evaluate the feasibility of this intervention method, a tank test was conducted in an experimental tank at Yokohama National University using a scaled model of a large sailing ship to check whether the operation of the sailing ship could be conducted under the typhoon environment (Figure 1). As a result, it was confirmed that the assumed large-size sailing ship could be operated stably in strong winds and rough waves.

Our team also estimated the degree to which the assumed large-size sailing vessels could intervene in typhoons using past typhoon track histories. A simplified system model of a typhoon power generation ship, in which the propulsive force obtained from typhoon winds by large rigid sails moves the ship and rotates an underwater turbine to generate and store electricity, was created to quantitatively evaluate how well the typhoon power generation ship could follow typhoons and how much electricity it could generate against past typhoon track histories. Our team also conducted a comprehensive cost evaluation of a large rigid sail ship as a typhoon intervention device, as shown in Figure 2.

Figure 1. Tank test in the YNU experimental tank.

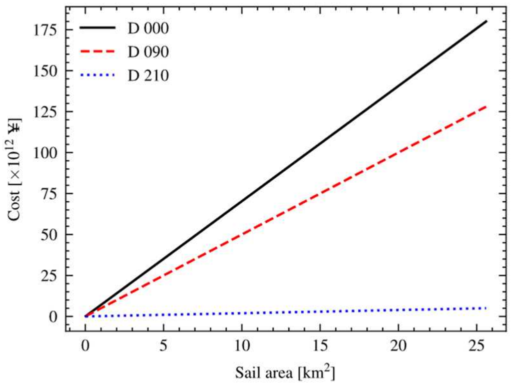

Figure 2. Relationship between the deployed area of sails and the required cost. The number D in the legend indicates the number of days of electricity generation to be conducted per year.

As an example of a more advanced typhoon intervention device study, our team has studied to develop a control method that can more efficiently influence the force and path of a typhoon by controlling wind volume and temperature with arranged wind turbines and exploring the capacity, number, installation location, and cooling capacity of the wind turbines required. In addition, our team has studied the types of state variables required for windmill control based on typhoon conditions and their estimation methods. Figure 3 shows an example configuration of a power generation unit of a heat pump ship as a typhoon intervention device. In this study, heat pump heat cycle simulations were conducted on this configuration example to estimate the required energy for the amount of cooling/heating.

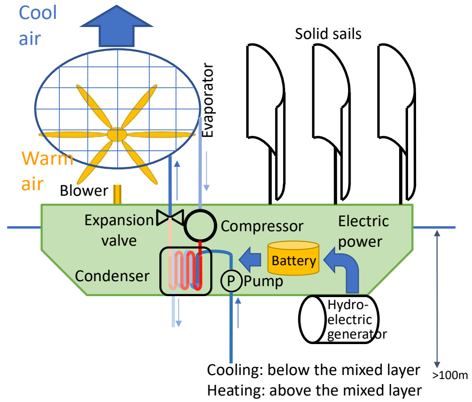

Figure 3. Example configuration of a power generation unit of a heat pump ship.

3. Future plans

Our team will conduct research to realize the methods examined in FY2023 and examine various other intervention methods proposed by the meteorological approach team. In particular, in FY2024, our team plans to develop a new chemical intervention method to control sea surface evaporation through surfactants and others.

R&D item

3． Impact Assessment of Typhoon Control

Progress until FY2023

1. Outline of the project

Typhoon control may cause climatological impacts, reduce damage, and other social impacts. It is necessary to quantify these impacts to assess social acceptability. First, estimating the secondary effects of typhoon control on the climate system is necessary. Typhoon damage includes not only human damage but also economic damage. Estimating typhoon control's economic damage reduction effects requires developing models to convert meteorological forces like wind speed and rainfall into structural or other countable damage. The impact assessment group has developed an integrated wind and flood damage assessment model for typhoon control. We are also analyzing the impact of typhoon control on other long-term socio-economic activities.

2. Outcome so far

For climatological impacts, the relationship between typhoon intensity and environmental fields was assessed using large ensemble numerical experiments using a global nonhydrostatic model. The precipitation and the probability of strong precipitation events are reduced when typhoon intensity is weakened.

For damage estimation, damage estimation models were developed for wind, storm surge, and river flood disasters, and their simple impact assessment on typhoon control effects were evaluated in FY2023.

For wind damage, a prefecture-level area averaged risk assessment model has developed. Then, the effects of the reduction of wind speeds and related damage loss by typhoon control were analyzed with a resolution of about the prefectural level. Figure 1 shows an example of the analysis. It was confirmed that an increase/decrease of 5% in wind speed can roughly increase/decrease of 50% of damage loss. For storm surge disasters, a storm surge inundation model was developed and validated to estimate the amount of damage by the storm surge inundation. For river floods, a water hazard impact assessment model was developed based on algorithm to estimate the flood inundation area ratio. Then, a coupled meteorological and hydrological damage forecasting system was developed and validated. Figure 2 shows an example of this system. It was estimated that a 50% reduction in precipitation would result in almost zero inundation.

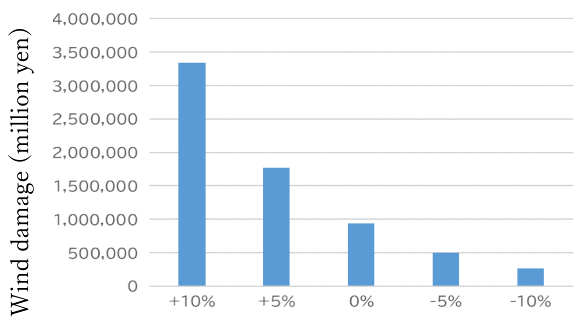

Figure 1. Sensitivity of wind damage for 2019 TC Faxai

3. Future plans

Advance the climatic impact of typhoon control using global atmospheric models, and advance the sophistication, regionalization, and integration of various types of wind and flood damage for damage estimation. This theme will further develop the impact of typhoon control effects on the damage loss based on the results of the climate control group.

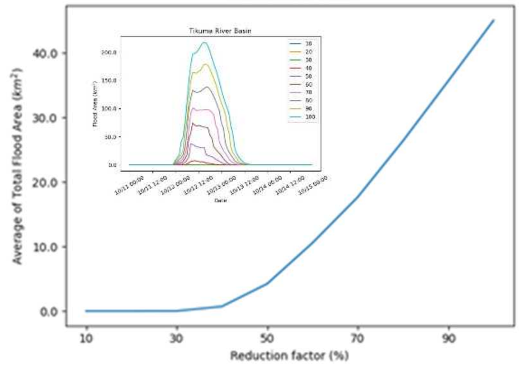

Figure 2. Sensitivity of river flooding area for 2019 TC Hagibis

R&D item

4． Examining ELSI on Typhoon Control

Progress until FY2023

1. Outline of the project

Controlling typhoons is expected to result in social benefits such as disaster prevention and mitigation. This "social implementation" of typhoon control technology has already been mentioned in the Basic Act on Disaster Management (Law No. 223 of 1961), enacted in response to the catastrophe of the Ise Bay Typhoon of 1959.

Most of weather modification, including typhoon control, may cause negative impacts on third parties other than those who benefit from them (beneficiaries). Let us assume: is it ethically permissible to apply typhoon control technology when, even if it is possible to prevent a river A from overflowing, that rain will fall in another area B, resulting in a landslide disaster? Also, if the attempt to control happens to have an unpredictable negative impact on a third party (meaning that the "control" fails), who should bear this loss and how?

This group, led by researchers in the humanities and social sciences, will examine the ethical, legal, and social issues (ELSI) that may arise from the social implementation of typhoon control. It will also serve as a hub for members participating in the Goal 8 projects.

2. Outcome so far

In FY2023, after clarifying the method for proceeding with ELSI research on the social implementation of new science and technology (Figure 1), we deepened our investigation and analysis of the issues already identified in the previous two years (putative conflicts from the standpoint of environmental justice and ethics, and legal and institutional issues) and conducted case studies based on hypothetical social implementation scenarios (Figure 2).

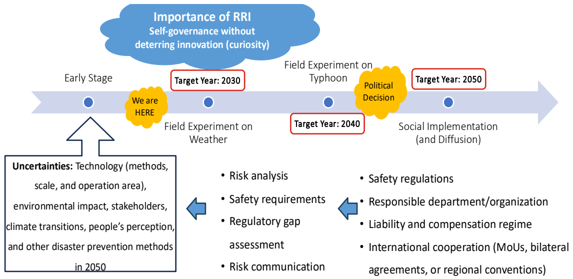

Figure 1: Path to Social Implementation

• In October 2050, a tropical cyclone is approaching to people habitant areas in a country "A," and it is predicted that it become a typhoon [which maximum intensity is [very low] hPa / which would cause [very high] of economic loss]
• [The Government / An international organization] decided to reduce the intensity of the typhoon in accordance with the national law which implements the international agreement regarding typhoon [modification / control]

Technological Assumptions	• Human intervention can be effective in mitigating disasters. • Effectiveness can be scientifically judged. • Certain uncertainties remain even at the stage of social implementation (non-zero risk).
Cost Assumptions	• Costs are within the bearable range. • Benefits exceed costs. • Benefits outweigh risks.

Figure 2: Hypothetical Scenario

Through the social implementation scenarios, we have described the issues that arise in the operational phase (the authority that decides and activates the control, the requirements of the control, the criteria for activation, the cost bearers, the operational system, and the impact evaluation system) and the desirable compensation system for the loss or damage to third parties. For example, we considered whether the control should be activated according to the amount of economic loss (if so, people who live in the area with fewer properties may not enjoy the benefit of the control); the extent to which the residual risk of the control activity should be allowed; and how the operator should compensate for the loss or damage resulting from the failure of the operation, both in the case where the control did not mitigate the damage as expected and in the case where the control adversely affected the third parties beyond the expectation.

In FY2023, we began to draft a guideline to ensure that field experiments are conducted safely. For this purpose, we have referred to existed criteria for hurricane control activities (Project Stormfury in the 1960s) (Figure 3), some principles for R&D projects of geoengineering to interfere the climate, and domestic regulations that allow private entities to modify the weather for precipitation enhancement.

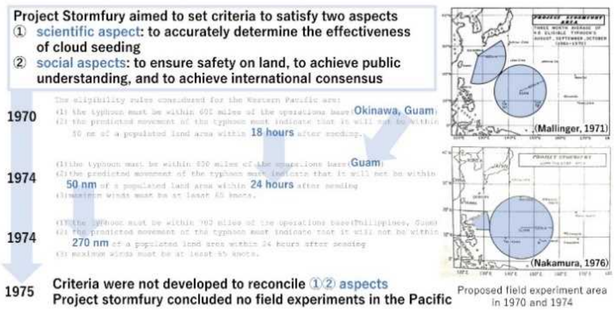

Figure 3: Criteria specified in Project Stormfury

3. Future plans

We will continue to work on drafting a guideline for upcoming field experiments in 2030. In addition, we plan to design the picture of social implementation and ecosystem at the time of 2050, involving other relevant industries such as energy and electric power.