R&D Theme

Construction and analysis of new meteorological data leading to "controllability" and design of control methods

Progress until FY2022

1. Outline of the project

Background : Extreme weather events, including tropical cyclones, are complex phenomena that exhibit vast amounts of energy. In this Goal 8, our aim is to develop a theory that would enable us to safely alter extreme weather using minimal external forces.

Objective : **We aim at establishing a systematic method for influencing the future trajectory of extreme weather events, such as tropical cyclones, through small-scale artificial interventions. This will give rise to a new paradigm in meteorological control theory.**

Method : By an integration of state-of-the-art simulations and satellite weather observations, we will construct a novel dataset of the three-dimensional structures of tropical cyclones. Then, this dataset will be analyzed via a blend of process-driven and data-driven approaches (Fig. 1).

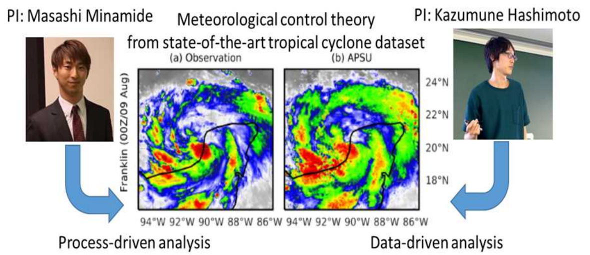

Fig. 1. Overview of the R&D theme.

2. Outcome so far

①We have successfully completed the establishment of necessary research infrastructure for the development of our tropical cyclone dataset. The generation of the dataset is currently underway.

② [Process-driven approach] Our findings suggest that **we are able to efficiently suppress the growth of tropical cyclones by strategically reducing the supply of water vapor at an appropriate location and time** (Fig.2).

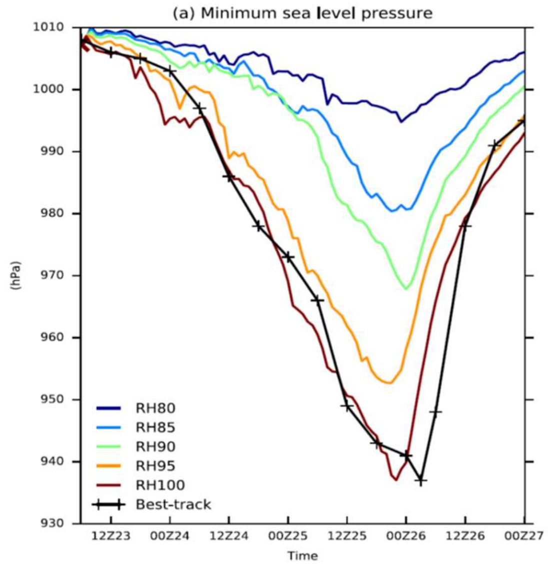

Fig. 2. Timeseries of intensity of a tropical cyclone. The black line represents observation, while the brown line represents the simulation results. The other colored lines depict the simulation results with varying reductions of water vapor: 5% (Orange), 10% (green), 15% (blue), and 20% (purple).

③ [Data-driven approach] We developed **a data-driven approach to identify low-dimensional phenomena, which are useful to control large-scale and complex fluid movements** (Fig. 3). We confirmed the efficacy of the proposed method through its application to a toy model.

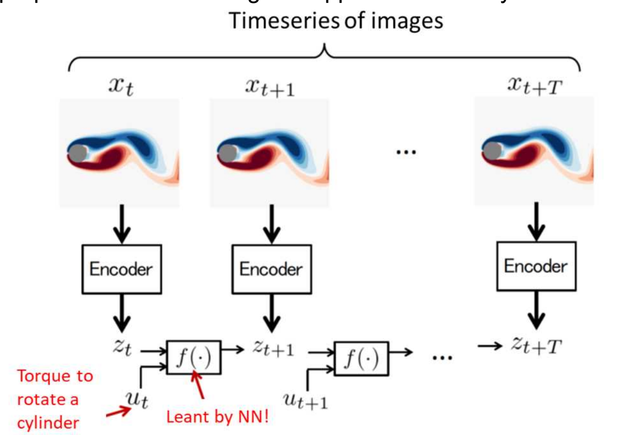

Fig. 3. Our developed data-driven control approach is applied to control the flow around a cylinder. NN means a neural network. From the restricted information of observation and forcing to control, the essential aspects of the phenomena are modelled toward efficient control.

3. Future plans

In the first year of our project, we have successfully initiated the development of the dataset and have identified preliminary evidence supporting the effectiveness of our approach to attenuate tropical cyclones. The magnitude of an artificial forcing in our numerical experiment still requires optimization. We will explore realistic and efficient methods combining process-driven and data-driven approaches.

We will explore intervention methods. This R&D theme serves as the driving force to develop an intervention method grounded in robust theoretical foundations

R&D Theme

Uncertainty quantification for meteorological control

Progress until FY2022

1. Outline of the project

Background: Research on weather control should rely on computer simulations until the safety of new intervention methods is thoroughly assessed. However, meteorological simulations inherently have uncertainties in their various modules, making it challenging to fully trust the simulation results of weather control.

Objective: We will pinpoint all potential sources of uncertainties in meteorological simulations and minimize them using observation data. Then, **we will quantify the residual uncertainties contributing the accurate assessment of weather control techniques**.

Method: We will conduct many simulations with various settings and analyze them alongside observational data using machine learning. This enables us to quantify the uncertainties of meteorological models, which have not been identified by their developers (data-driven approach). We will also comprehend the mechanisms contributing to these uncertainties (process-driven approach) (Fig.1).

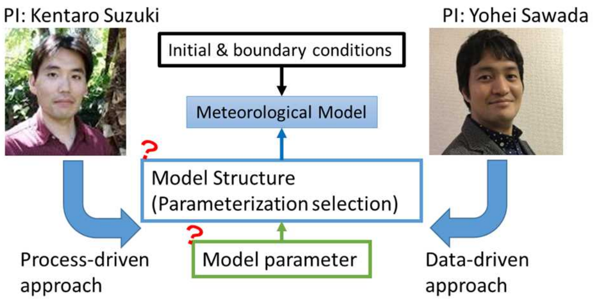

Fig. 1. Overview of this R&D theme. We are going to quantify the uncertainty from the arbitrary of the selection of model structures and parameters.

2. Outcome so far

① [Data-driven approach] We have developed a novel algorithm for uncertainty quantification of large-scale simulations, an endeavor that has previously been challenging due to high computational costs. This new algorithm has been partially applied to a real meteorological simulation. In the case of the devastating tropical cyclone Nammadol, **we realized the parameter optimization of a meteorological model based on geostationary satellite observations. However, such observations are insufficient to reduce the uncertainty in simulating the rapid intensification of Nammadol** (Fig. 2).

② [Process-driven approach] Through comparisons between satellite observations and simulations, we have gained insights into the factors that affect the representativeness of rainfall processes (Fig. 3). From FY2023, **we will perform similar analyses to interpret the results of uncertainty quantification through the data-driven approach** mentioned above.

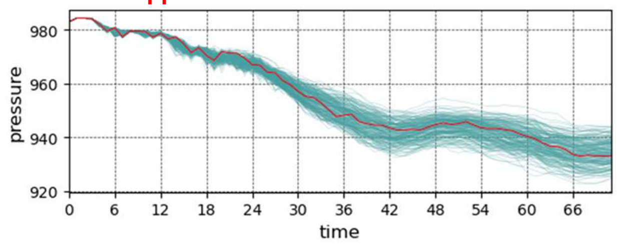

Fig. 2. Prediction of the central pressure of tropical cyclone Nammadol. The red line is truth and blue lines are simulation results obtained through parameter optimization of the meteorological model Since many combinations of model parameters can equally simulate observed variables, many of these combinations are sampled to perform simulation. Despite initiating from the identical initial conditions, the results displayed a large spread, and we could not sufficiently reduce uncertainty.

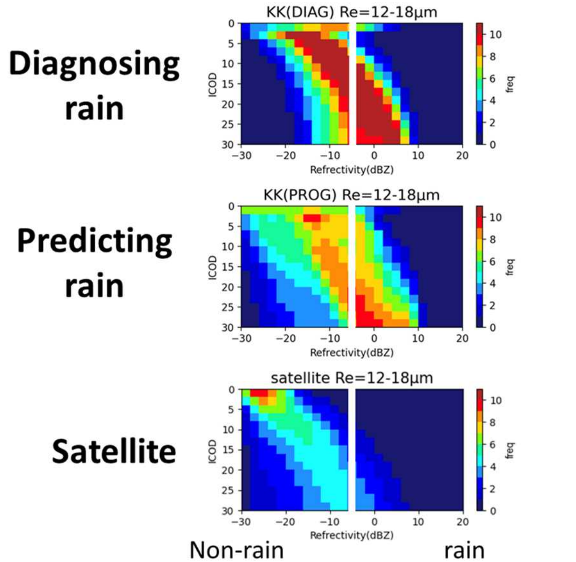

Fig. 3. 2-D histograms in which horizontal and vertical axes show radar reflectivity and height, respectively. Simulations with two different physics parameterizations are compared with satellite observations. Although this figure shows the results of the global climate model, MIROC, we will soon focus on meso-scale models soon.

3. Future plans

In the first fiscal year of this project, we have successfully completed the development of an algorithm for data-driven uncertainty quantification. This novel algorithm has been verified by relatively simple models as well as real-world meteorological applications. We will further explore to identify, quantify, and minimize all primary uncertainties in meteorological simulations.

In addition, we would like to understand and interpret these uncertainties from a meteorological standpoint and eventually achieve “explainable weather control”.

R&D Theme

Integrated probabilistic forecasting of combined flooding hazards

Progress until FY2022

1. Outline of the project

Background: To evaluate the effectiveness of weather control, it is insufficient to check the change of meteorological variables, such as intensity of tropical cyclones. It is crucial to estimate how changes in meteorological disasters affect on society, which is called "impact-based forecasting". In the realm of impact-based forecasting, the direct assessment of flooding hazards is of paramount importance.

Objective: **We will accurately assess hydrometeorological hazards, such as flooding and storm surges, with uncertainty estimates in real time.**

Method (Fig. 1): ① To combat flooding hazards, we will incorporate the functions of flood protection infrastructures such as dams and levees into the existing global hydrodynamical model. We will specifically enhance the simulation of small and medium-scale flood events in which these flood protection infrastructures are effective.

② To address coastal hazards, we will develop a statistical typhoon model and a machine learning-based prediction model for ultra-fast storm surge and high wave predictions complemented with uncertainty estimation.

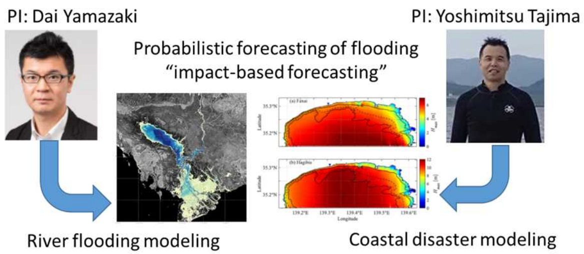

Fig. 1. Overview of this R&D theme.

2. Outcome so far

① **We have successfully integrated a computation scheme into the global hydrodynamic model, designed to simulate the operation of dams and the effects of levees**. Although it is necessary to collect the detailed information of flood protection infrastructure for future work, we have verified the proper functionality of our novel scheme in the applications in U.S (Fig. 2).

② To accelerate the computation of storm surge heights, **we have successfully replaced the expensive numerical fluid simulation with long-short term memory (LSTM).** Maintaining the accuracy of the original simulation, we can estimate water level dynamics in an instant.

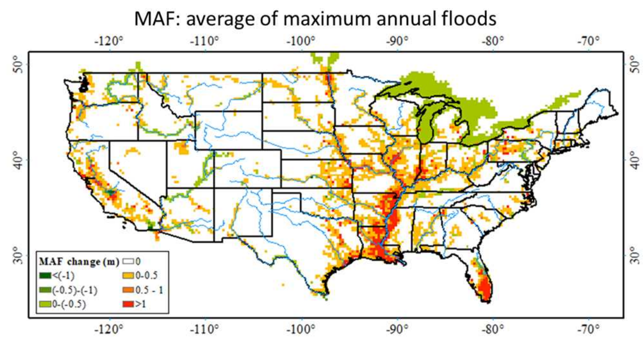

Fig. 2. The differences of estimated water levels induced by maximum annual floods between the new model which considers the effects of levees and the original model. Since levees prevent flooding, water level is overall increased by considering the effect of levees.

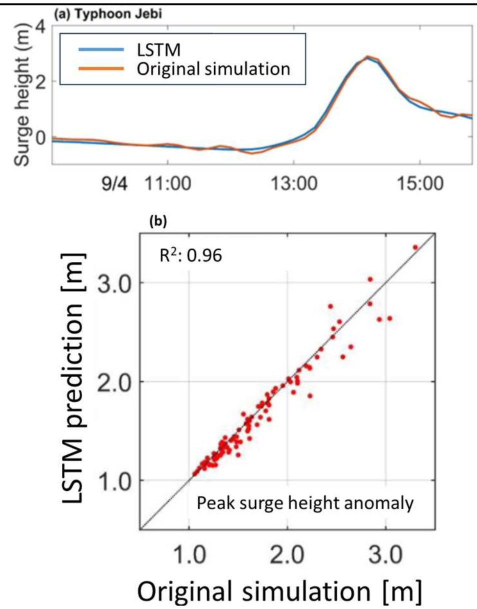

Fig. 3. Evaluation of the simulation of storm surge heights by LSTM. (a) Comparison of timeseries between LSTM and numerical fluid simulation. (b) Comparison of peak storm surge heights across many events.

3. Future plans

In flood hazard forecasting, we will estimate flood protection infrastructure objectively and globally, which will facilitate accurate flood simulations.

In terms of coastal hazard forecasting, we will consider the effects of high waves along with storm surges. In addition, we will improve the tropical cyclone prediction to drive coastal models by collaborating with other R&D themes. Our ultimate goal is to achieve ultra-fast and accurate computation of coastal disasters.

By combining all achievements, we will ultimately realize an integrated probabilistic forecasting system for combined flood hazards.

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

R&D Theme

Forecasting and controlling social impact and social decision making for weather control

Progress until FY2022

1. Outline of the project

Background: Evaluating the effectiveness of weather control requires more than just monitoring changes in meteorological variables such as intensity of tropical cyclones. It is crucial to estimate how changes in meteorological disasters affect society, which is called "impact-based forecasting". The societal impact is greatly influenced by how citizens interpret the disaster information and make decisions. However, it is currently difficult to predict these social phenomena during disaster events. In addition, we should initiate the inclusive discussion towards installing weather control technologies based on a profound understanding of our society.

Objective : ① We will understand **how individuals interpret disaster information such as weather forecasts**. ② We will comprehend and predict how disaster information is transferred through social networks and how this information contributes to preparedness actions. Then, **we will explore methods to foster appropriate behavioral changes**. ③ **We will investigate Ethical, Legal, and Social Issues (ELSI) of weather control** and identify issues essential for social decision making regarding weather control.

Methods (Fig.1): ① To investigate the individual's perception of disaster information, psychological experiments will be conducted. ② We will analyze various social statistics to examine the relationship between the accuracy of weather forecasting and social preparedness actions. Subsequently, we will develop a mathematical model to simulate social dynamics in response to disasters. ③ We will identify ELSI through workshops involving citizen participation.

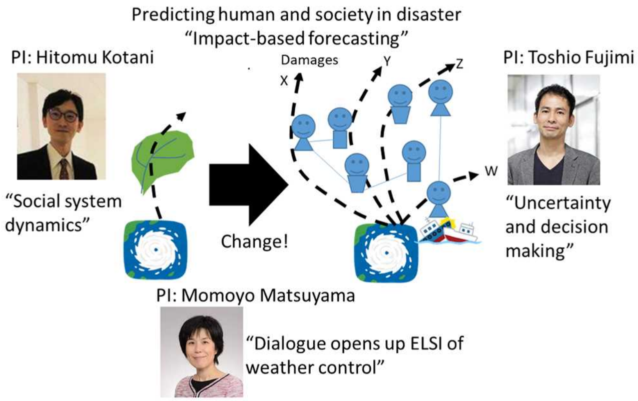

Fig. 1. Overview of this R&D theme. We aim to move beyond a regime where only a single forecast related to the natural scientific aspects of a disaster event conducted. Instead, we will predict numerous disaster scenarios as well as citizens behavior during meteorological disasters.

2. Outcome so far

① As the preparation of the psychological experiment, we developed **a virtual reality simulation of meteorological disasters** (Fig. 2). By analyzing how these simulations prompt preparedness actions, we aim to understand how human process and respond to disaster information.

② We developed **a mathematical model that realistically simulates a cry wolf effect** in which many false alarms undermine the credibility of the early warning systems.

③ **Citizen participating workshops have been conducted in Kochi and Wakayama** (Fig 3) to identify ELSI related associated with weather control.

Fig. 2. An example of virtual reality of meteorological disaster. By showing these movies to participants, we will explore decision making processes in disaster events.

Fig. 3. Citizen participating workshop

3. Future plans

We plan to collaborate with other R&D themes to deepen our understanding of how individuals and societies respond to disaster information, such as weather forecasts. Then, we will develop the methods to maximize the value of disaster information, thus promoting appropriate behavioral changes. This research will pioneer a new field of study aimed at maximizing the value of weather control technology. Questions like "what kind of weather control is appropriate?" and "how can we integrate weather control into society while maintaining effective communication with citizens? will be discussed in Our R&D theme.