

1. Development of engineering methods based on numerical computations

Progress until FY2023

1. Outline of the project

Develop a numerical weather model that can express heavy rains from when it occurs, and examine interventions to reduce heavy rains using a meteorological approach combining numerical weather models, field observations, and laboratory experiments. Develop multiple feasible engineering methods based on these examinations, while monitoring the scale of sudden heavy rains and linear convective heavy rains. Additionally, focus on the causes and early stages of heavy rain occurrence, and suppress the intensity and frequency of heavy rains.

Regarding physical quantities that can be manipulated step-by-step during cumulonimbus cloud formation, first, an offshore curtain will be used to reduce water vapor, followed by the use of a fan to diffuse heat and air current vortices. Furthermore, wind farms will be used to weaken the convergence of wind, and finally, seeding will be employed to change the cloud and rain particle formation. These processes constitute a multi-stage manipulation technique.



Figure 1. Diagram of future weather control system

2. Outcome so far

① Effectiveness of using wind turbines to suppress Isolated-Convective rainstorms

We investigated the potential of using wind turbines as a resistive mechanism to attenuate the wind speeds associated with Isolated-Convective rainstorms, aiming to mitigate the weather system. Initially, high-resolution simulations were performed to analyze the phenomenon of airflow attenuation in the wake of a wind turbine. Subsequent sensitivity experiments assessed the impact of variations in wind direction and turbulence on wake formation. A virtual model of a large-scale wind farm was then developed to examine the cluster-wake phenomenon.

Additionally, we explored the modification of heavy rainfall patterns by artificially manipulating near-ground wind speeds to hypothetically reduce the wind intensity. The experimental results from case studies of sudden heavy rainfall in Togagawa, Kobe City, during fiscal year 2008 indicated a 27% reduction in rainfall intensity. This reduction was attributed to the diminished upwelling caused by air vortices and the decreased convergence of moisture-laden winds into the center of the updraft.

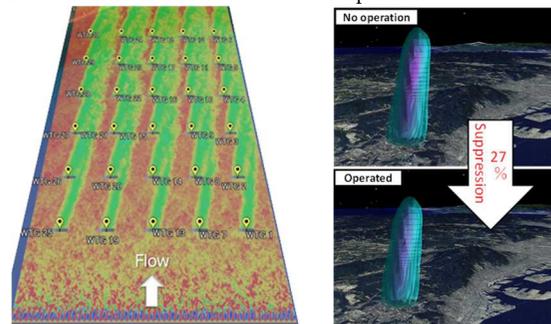


Figure 2. Wind suppression simulation around a group of wind turbines (left) and; Simulation of Isolated-Convective rainstorm suppression by manipulating the wind speed field (right)

② Effect of suppressing linear convective heavy rains by spraying dry ice

We investigated the control of cloud formation by dispersing dry ice into clouds—a process known as cloud seeding. By hypothetically increasing ice crystal nucleation through dry ice dispersion, we managed to reduce the maximum 24-hour precipitation by 15% during the heavy rainfall event of July 2020.

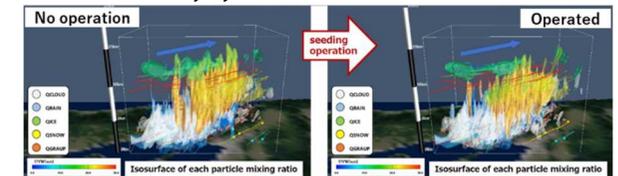


Figure 3. Simulation of suppression of heavy rainfall by dry ice dispersion

③ Suppression effect of linear convective torrential rainfall using offshore curtains

We also explored the suppression of torrential rainfall by inhibiting the high inflow of water vapor from the sea. A numerical simulation using a 1-km offshore curtain during the 2017 northern Kyushu heavy rainstorm indicated that this curtain reduced the 3-hour rainfall by 34%.

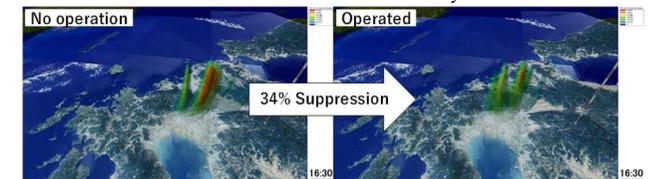


Figure 4. Simulation of heavy rainfall suppression by an offshore curtain

3. Future plans

This research aims to continue advancing numerical weather models to evaluate the impact of interventions on sudden and linear convective heavy rains. We also aim to conduct sensitivity experiments to determine if small-scale interventions can mitigate the development of heavy rains.

2. Construction of a control system

Progress until FY2023

1. Outline of the project

Develop a control system that combines observation, prediction, and decision-making to effectively suppress heavy rains by implementing multiple engineering methods at different times and stages. Additionally, the control system would be designed to intervene at multiple stages to course-correct when an unexpected deviation occurs. Furthermore, our goal is to implement multiple types of interventions at various stages to increase the regulatory effect. Specifically, we aim to develop a decision-making support system that can derive optimal solutions by combining multiple control methods in real-time by (1) simplifying the time evolution model for heavy rain events and constructing an ensemble prediction method, (2) constructing monitoring methods for regulation, (3) setting appropriate objective functions based on the output of ELSI/RRI research, and (4) optimizing algorithms.

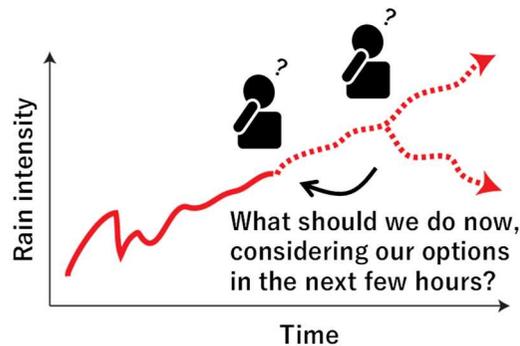


Figure 1. Schematic diagram showing decisions being made at multiple points in time and at multiple stages

2. Outcome so far

① Formulation of a decision-making problem for heavy rainfall control

The objective of R&D Theme 2 is to develop a system capable of deriving optimal solutions for operations in real time. This system integrates knowledge from Theme 1 on various operational methods and from Theme 3 on the evaluation of impacts on floods, water resources, and human societies.

Collaborative discussions were held with Themes 1,3 to identify the four essential elements required to formulate a decision-making problem: the objective function, constraints, possible interventions, and random phenomena. The proposed engineering solutions—seeding, offshore curtain, and offshore wind turbines—were developed by considering their spatial impact on weather phenomena associated with heavy rainfall and the temporal scale from the initiation of control measures to the manifestation of their effects.

Moreover, a policy was formulated to categorize the

impacts of heavy rainfall control into two groups: those that should be included in the objective function and those to be considered as constraints. The decision-making problem focuses on optimizing the timing and magnitude of engineering interventions to maximize the objective function within these constraints. Although there is considerable flexibility in determining which items should be included in the objective function or constraints, current considerations include human and economic losses in the objective function and impacts on water resources, ecosystems, and the global environment in the constraints.

② Elucidation of heavy rainfall mechanism for control

Furthermore, sensitivity experiments using numerical simulations were conducted to determine the most probable pathways or conditions that facilitate the transport of water vapor to isolated localized linear convective systems, which frequently result in heavy rainfall inland. The findings demonstrate that higher atmospheric stability promotes the convergence of water vapor between landforms, enhancing the inland transport of water vapor.

3. Future plans

Our objective is to develop a decision-making framework based on the characteristics of control methods, the relationships between the effects of control (i.e., impacts related to heavy rains and social impacts), and the scope of the decision-making problem.

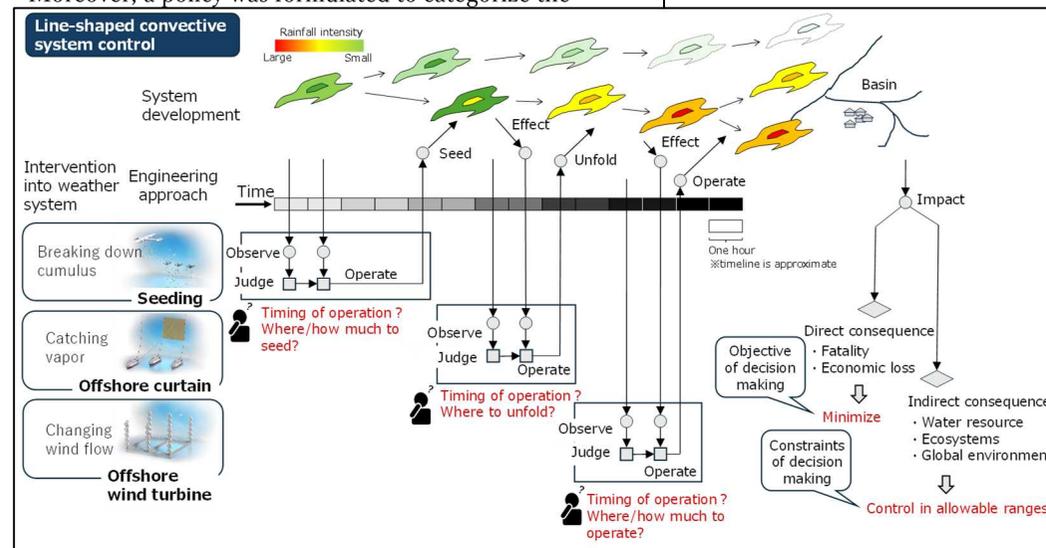


Figure 2. A decision-making diagram for line-shaped convective rainfall

3. Research on impact assessments of heavy rain control and social acceptance

Progress until FY2023

1. Outline of the project

Establish heavy rain control scenarios and evaluate the effect of controlling flood flows by heavy rain mitigation as a first step toward estimating the natural impacts of reducing heavy rains. Consider the risk of rain areas shifting due to the control of heavy rains and causing floods or droughts in other basins. Estimate the impact on water resources and society, and evaluate how a water-based society will change, by considering the behavioral changes of the residents.

Additionally, construct a conceptual model, “weather commons,” that captures the mechanism of cooperation by local residents to live with heavy rains reduced using new regulatory technologies, and clarify the conditions for its establishment. Construct social and institutional response scenarios for ELSI/RRI topics based on this conceptualization.

The awareness of “living in the bosom of nature,” where people revere and co-exist with nature, will permeate, and the scope of application of heavy rain regulation techniques will be decided within the scope of “people living their lives by borrowing the bosom of nature.”

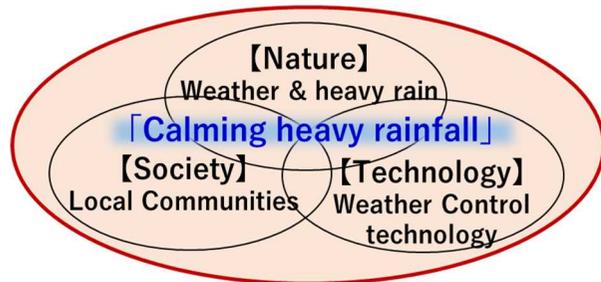


Figure 1. Conceptual diagram of “weather commons”

2. Outcome so far

① Effects of heavy rainfall suppression on flooding and inundation control mechanisms

We assessed the impact on flood inundation depth and dam storage capacity, assuming a reduction in rainfall due to heavy rainfall control. Given that the flooding was triggered by a water-related incident in a riverbed, we analyzed the necessary heavy rainfall control measures to prevent such incidents during guerrilla torrential rains by examining the relationship between the rate of decrease in rainfall intensity and the unit-width specific force, which is a fluid force index influencing evacuation strategies.

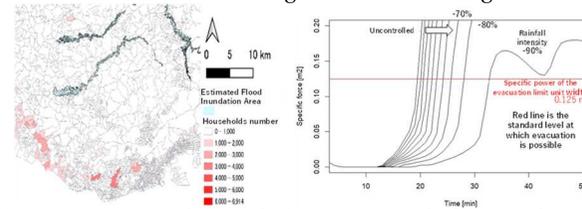


Figure 2. Expected inundation zone and the number of exposed households (left), and the calculation results of the decrease of the unit-width specific force in the river (right).

② Strategic examination for solving ELSI

ELSI refers to the ethical, legal, and social issues. It is crucial to consider the uncertainties of nature, their environmental impacts, and their effects on the disaster preparedness mechanisms of communities. Through interdisciplinary ELSI study teams focused on three core research topics, we organized and categorized ELSI concerns related to typhoon and heavy rain control into six issues, as depicted in Figure 3.

③ Examination of positioning of weather commons

The project embraced the concept of focusing technological development around societal visions rather than basing the ELSI on technological advancements. This shift in perspective was recognized as a critical governance issue for managing the weather commons. Based on existing knowledge of resource management in the “commons,” the study identified several key areas for investigation. These



Figure 3. Overview of ELSI (Results from the ELSI cross-sectional study team for the three core projects)

included the organization of local residents and stakeholders into a “commons,” promoting symbiotic relationships with weather patterns and disasters, developing non-normative ethics based on local community practices, and encouraging citizen participation in technological development. Additionally, the term “weather control” was scrutinized. The team explored linguistic choices informed by traditional views of nature and social acceptability within the context of the weather commons, ultimately proposing the term “calming heavy rainfall” for theoretical discussions.

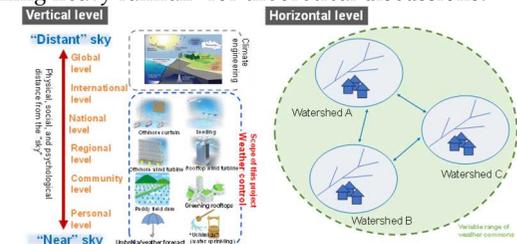


Figure 4. Hierarchy in the weather commons

3. Future plans

We have developed multiple scenarios that vary in the extent of heavy rainfall control to evaluate the effectiveness of flood flow management. Moreover, we formulated methods for assessing self-sustaining symbiotic control techniques to support the formation of a weather commons. Additionally, we are designing social and institutional response scenarios to address ELSI topics.