Quantifying Weather Controllability and Mitigatable Flood Damage Based on Ensemble Weather Forecast

R&D Theme

Mathematical Research Team: Quantifying Weather Controllability

Progress until FY2022

1. Outline of the project

The research team focuses on detecting "separatrix" in extreme weather phenomena, i.e., a point where two modes of behavior separate. At this specific point, we could steer to the desired direction with a small manipulation. However, the search for separatrix in very large-dimensional meteorological data is technically difficult. We use several compression methods, such as deep learning, to reduce the dimensions of the data and to quantify the weather controllability. Landscape analysis is also used to identify separatrix and saddle points where effective intervention is possible. However, even for phenomena with an identified separatrix, we still struggle to steer to a desired direction without an efficient manipulation. Consequently, we are attempting to create an efficient process control utilizing a technique known as Model Predictive Control (MPC).

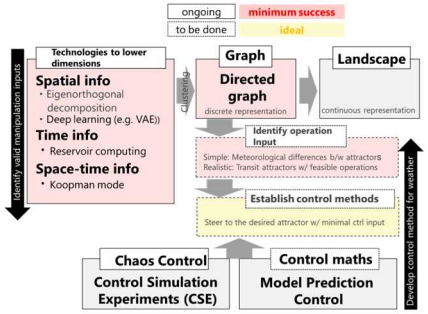


Fig. 1 Research and develop plan in mathematical team

2. Outcome so far

Principal investigators in mathematics and informatics applied their knowledges to weather and earth sciences, with three main interests (Fig. 1).

[Reduction of data dimensions]

It consists of the application of dimensionality reduction techniques, to handle large-dimensional data, that are generated by weather simulations and are a bottleneck in 1) analyzing data in an efficient way, 2) controlling extreme weather.

[Landscape analysis]

We designed a "directed graph" by grouping data using a "clustering" technique. A "Hodge decomposition" then helps to extract the "potential" and to develop an algorithm able to identify separatrix and control points. As a study case, we applied the analysis to typhoon Dolphin, which occurred in September 2020, Visualizing the landscape of typhoon Dolphin (Fig. 2), we successfully confirmed the existence of a separatrix, suggesting the location of the saddle where efficient intervention is possible.

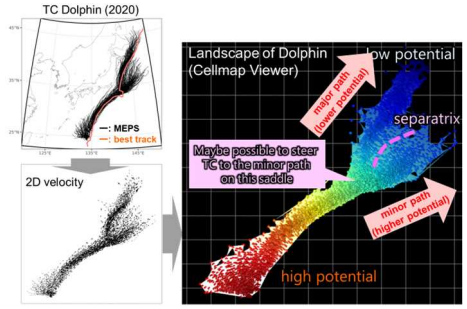


Fig. 2 Landscape Analysis of Typhoon Dolphin

[Development of control method with MPC]

Control Simulation Experiment (CSE), a technique to steer to a desired regime, is used for chaos dynamics control. However, traditional CSE requires many data samples to locate the appropriate disturbances. In this research, we have developed a technique that brings the system to the intended state with less data samples, by introducing MPC in the data assimilation process. According to a preliminary experiment, the Lorenz-63 model (simulating a chaotic system) can be guided to a chosen regime with fewer data samples and control inputs (Fig. 3).

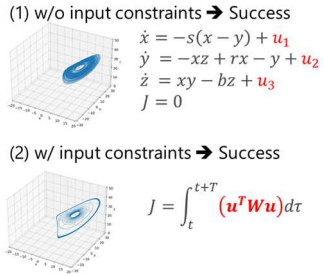


Fig. 3 MPC Experiment applied on Lorenz-63 model

3. Future plans

We will continue to improve our knowledge by:

1. Documenting separatrix detection and weather controllability for more past disaster events,
2. Utilizing the long-term large-scale ensemble weather forecasts for better dimensionality reduction techniques.
3. Promoting the use of cutting-edge technologies, such as quantum annealing computers, to solve the remaining problems on MPC.

Quantifying Weather Controllability and Mitigatable Flood Damage Based on Ensemble Weather Forecast

R&D Theme

Data Assimilation Research Team: Large Ensemble Data Assimilation Experiment

Progress until FY2022

1. Outline of the project

Data Assimilation (DA) Research Team generates ensemble weather forecast data through DA experiment. The above data serves as a crucial foundation for the entire project. For example, the Mathematical Research Team requires more than 1,000 ensemble data to lower the dimensionality of ensemble weather forecasts. DA Research Team will also test the effectiveness of the weather control inputs identified by the Mathematical Research Team in controlling the weather. Additionally, DA Research team will provide ensemble data with and without weather control for the Economic Damage Research Team.

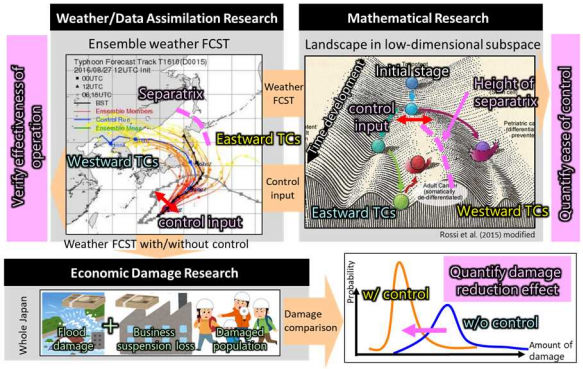


Fig.1 Relationship btw DA Research Team and other teams

Development items include the following

- Generation of a large ensemble w/ SPEEDY
- Generation of a large ensemble w/ real model.

2. Outcome so far

[Generation of large ensemble with Speedy]

Using the easy-to-handle simple weather model [SPEEDY], DA Research Team has generated training and validation data for the Mathematical Research Team to develop a method to lower the dimensionality of ensemble weather data. The data is generated by assimilating pseudo-observations with an ensemble Kalman filter (EnKF).

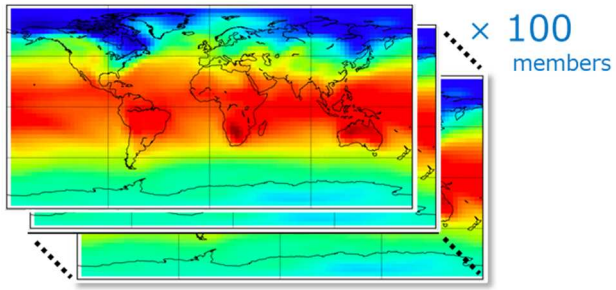
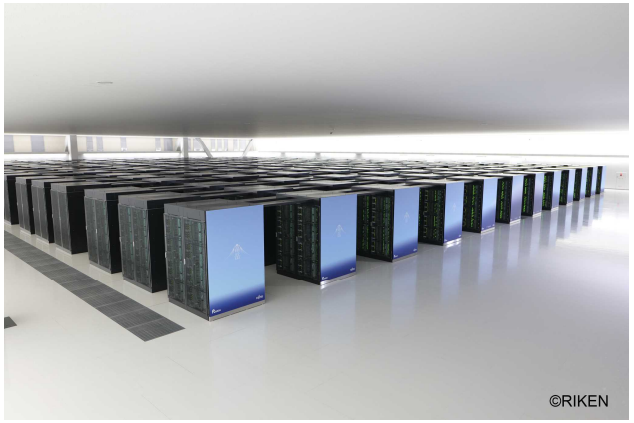


Fig.2 Image of SPEEDY large Ensemble Data

[Generation of a large ensemble with real model]

DA Research Team has begun building a research environment to create large ensemble data using realistic meteorological models. Since more than 1,000 large ensemble data is required, it is important to secure computing resources. SCALE-LETKF, which has high parallelization efficiency and is suitable for large-scale calculations, will be used for the weather model and data assimilation system. The supercomputers "Wisteria" and "Fugaku" will be used for the computer system.



Supercomputer Fugaku, the photo gallery on the RIKEN website

3. Future plans

DA Research Team will work on creating large ensemble data using real weather models. The ensemble size is expected to be over 1,000 members, and such a large-scale calculation is challenging in terms of computational science. We will provide the large ensemble data to other two research teams in this project to promote their respective research. On the other hand, based on the large ensemble data, we will evaluate the effect of the weather control operations specified by the Mathematical Research Team into the weather model.

This is an important development theme that promotes the technological development for the goals of this project, "quantification of weather controllability" and "quantification of mitigatable damage" by weather control.

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

Quantifying Weather Controllability and Mitigatable Flood Damage Based on Ensemble Weather Forecast

R&D Theme

Economic Damage Research Team : Estimation of Economic Damage Reduction Effect

Progress until FY2022

1. Outline of the project

The goal of this R&D theme is to develop a technique for estimating the amount of damage caused by floods throughout Japan to calculate the economic damage reduction by controlling the weather. Utilizing government stats and commercial databases, we will develop a new damage estimation model for estimating the amount of direct damages to residential and business properties, as well as the amount of indirect losses and affected population due to suspension of operations. Using the developed model, we seek to calculate damage risks for weather forecasts with and without weather control and to quantify the damage reduction effects.

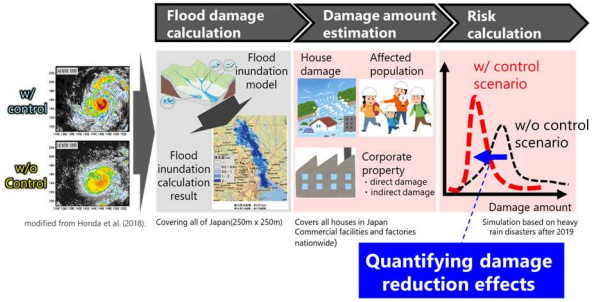


Fig.1 Flow of quantifying damage reduction effect by weather control

Development items include the following
- Creation of exposure data
- Development of damage functions
- Estimating flood damage with ensemble data

2. Outcome so far

[Creation of exposure data]

We built an exposure database for entire Japan, covering the affected population and residential properties. The data used were government statistical information (census data, housing land stats, and housing starts stats) and insurance stats information published by General Insurance Rating Organization of Japan.

- We identified the number of houses and structural classification from housing and land stats, and estimated value of buildings/houses based on construction costs obtained from housing start statistics
- We estimated the value of household goods based on the amount insured for each residential property.

Identified or inferred attribute information is sorted by city, ward, and county.

[Development of damage functions]

For the exposure database mentioned above, we have started creating damage functions to estimate flood damage. A damage function, which is constructed using statistical techniques based on historical damage data or engineering damage assumptions and simulations, expresses the link between the degree of damage and hazard intensity. We also gather official damage data, such as the Fire and Disaster Management Agency's Disaster Information and the MILT's Flood Damage Statistics Survey, in order to explain the precise damage affected by previous floods.

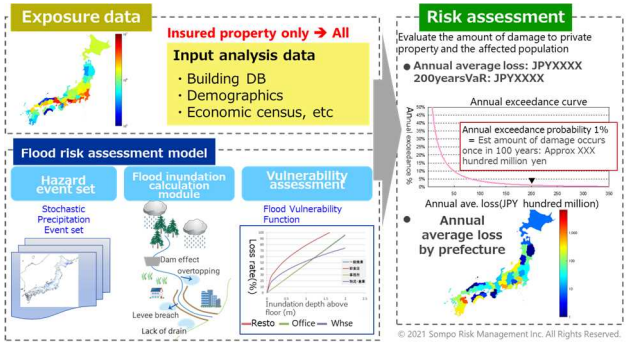


Fig.2 Elements and flow required for damage estimation

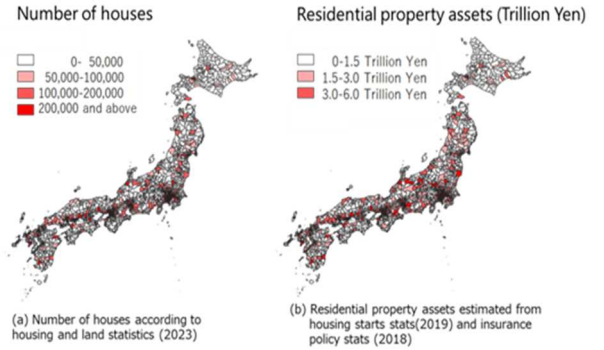


Fig.3 Number of houses and residential property Assets, from e-Stat

3. Future plans

In the future, we promote the development of an exposure database for indirect losses due to the downtime of commercial properties, and we also refer to insurance claims databases for further development of damage functions. Future work will quantify the impact of damage reduction, and evaluate the risk of damage for weather forecasts with and without weather control using the developed damage function.