Artificial generation of upstream maritime heavy rains to govern intense-rain-induced disasters over land (AMAGOI)

(海上豪雨生成で実現する集中豪雨被害から解放される未来)

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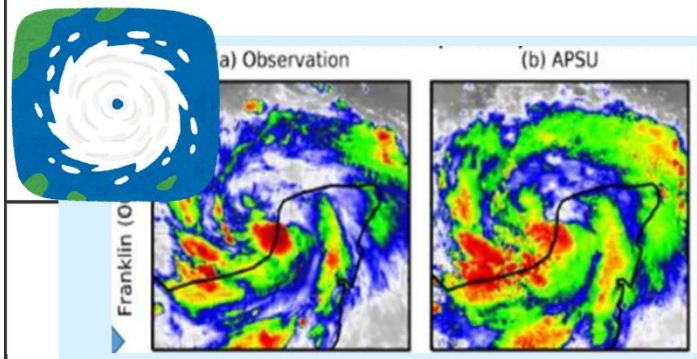
2024/10/06 MS8 Symposium

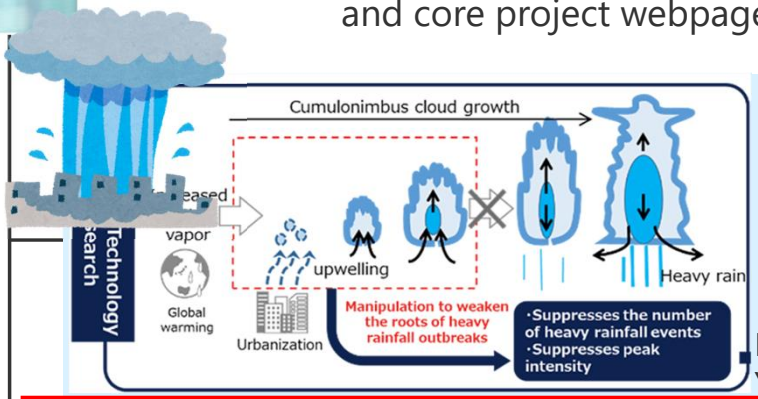
MOONSHOT RESEARCH & DEVELOPMENT PROGRAM

Japan's Moonshot Goal 8 Program & Core Projects

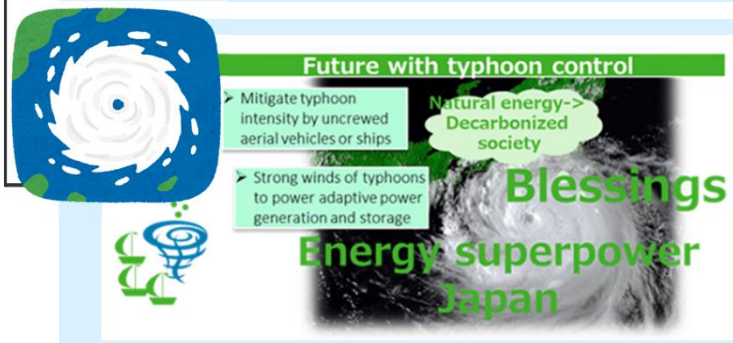
from
https://www.jst.go.jp/moonshot/en/program/goal8/
and core project webpages



Prof. Sawada (U. Tokyo)

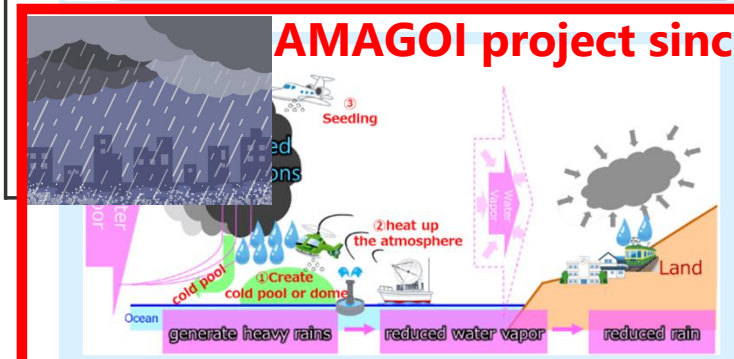


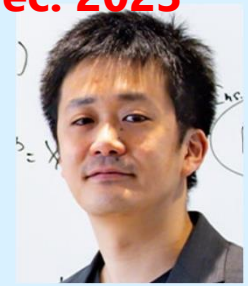
Prof. Yamaguchi (Kyoto U.)



Prof. Fudeyasu (NTU)

AMAGOI project since Dec. 2023



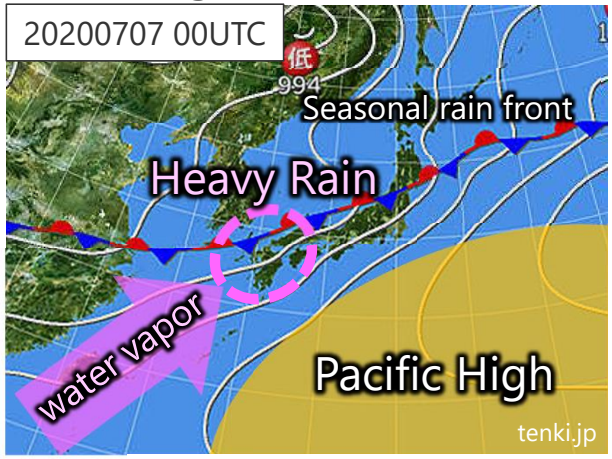


S. Kotsuki (Chiba U.)

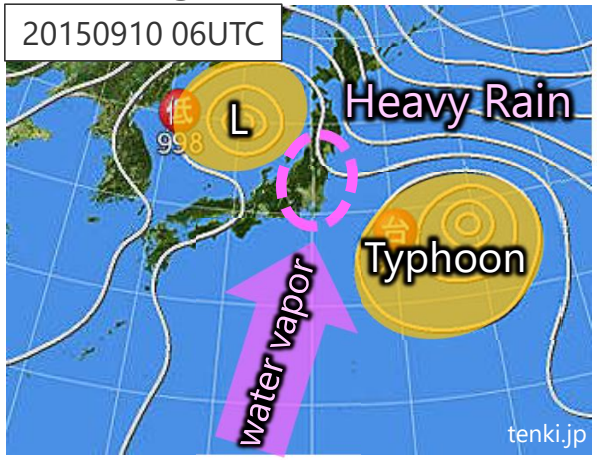
Heavy Rains and Our R & D Strategy

Examples for heavy-rain-induced disasters

July 2020 in Kyushu
(Damage: 4.1billion USD)



Sept 2015 in Kanto/Tohoku
(Damage: 2.1billion USD)



Jan 2023 in California, US
(Damage: 31 billion USD)

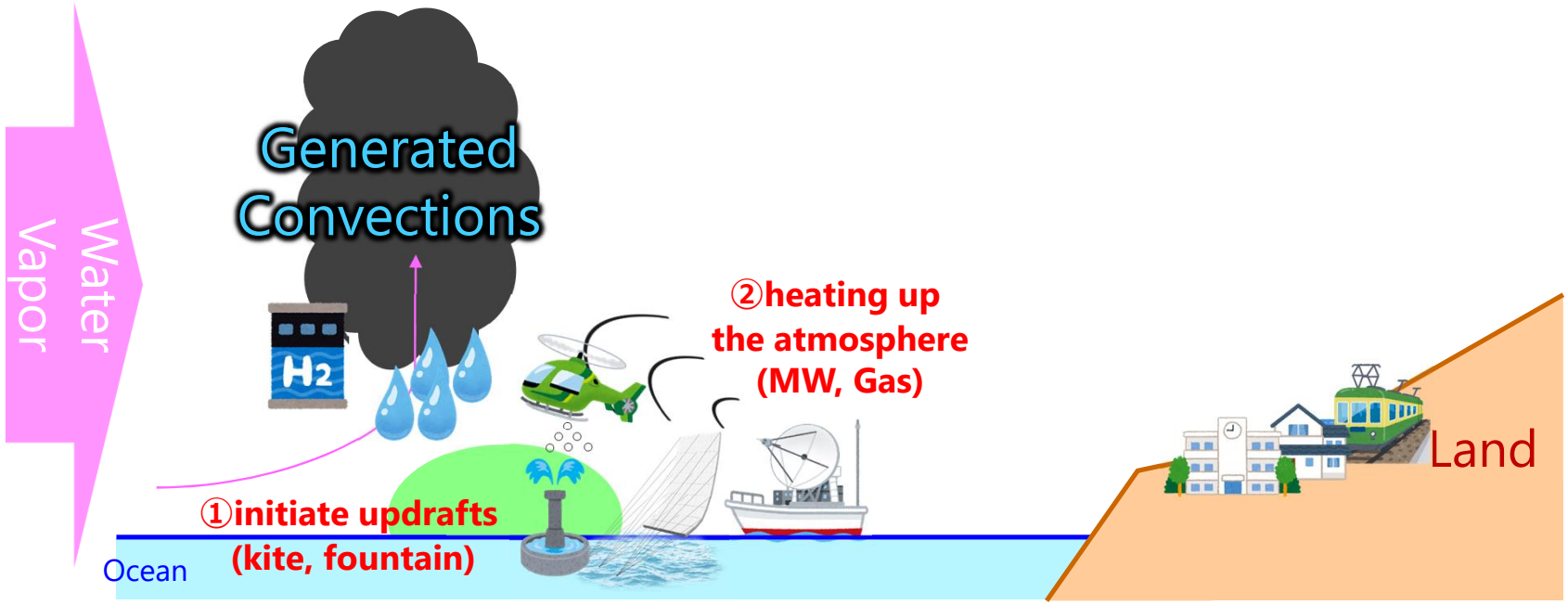
Possible strategies to mitigate such disasters

- to limit evaporation from the ocean ☹
- to change large-scale circulations ☹
- to reduce water vapor before arrival on land

➔ generating heavy rain artificially over upstream ocean

Generation of Heavy Rains

To generate heavy rains artificially, we need to
(1) <u>generate convections</u>
by lifting up dynamically (~LFC), or heating thermodynamically (~CIN)



Generation of Heavy Rains

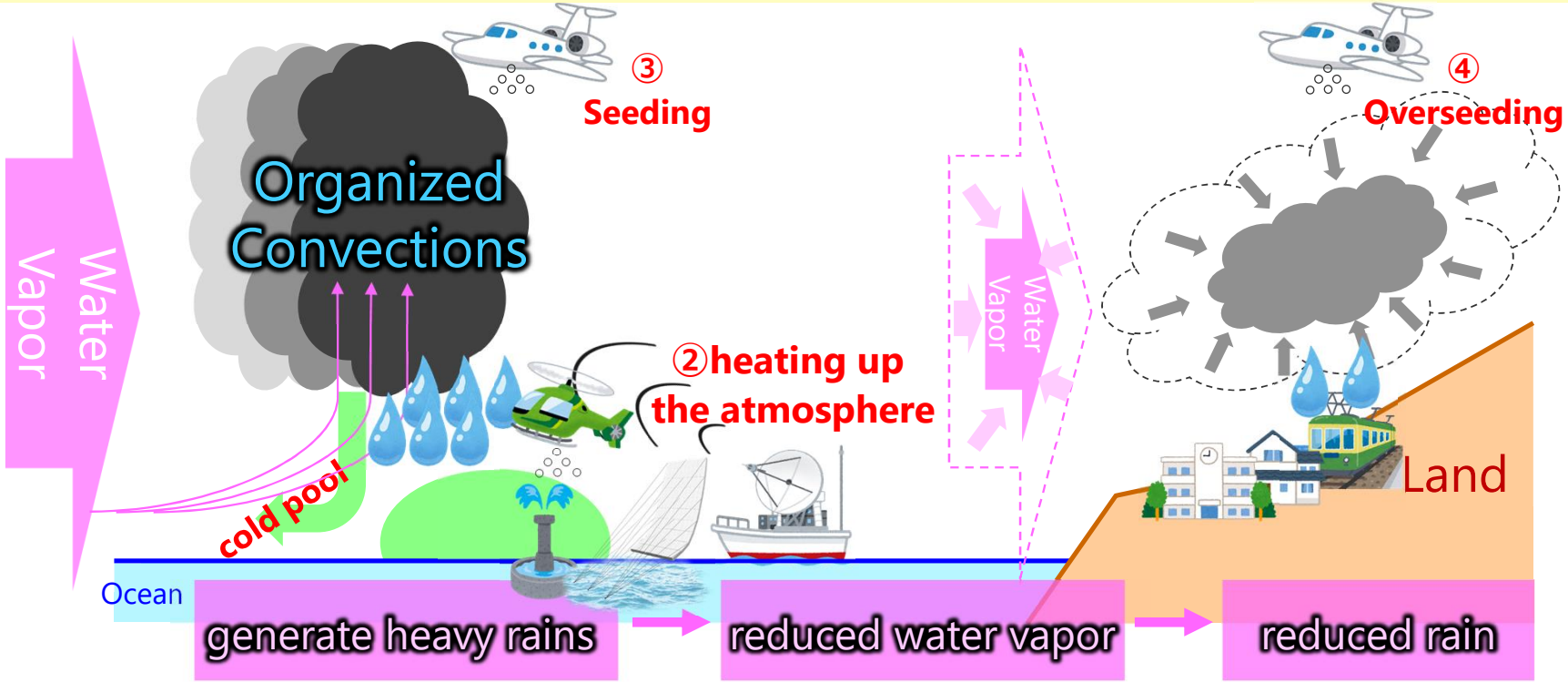
To generate heavy rains artificially, we need to

(1) generate convections

by lifting up dynamically (~LFC), or heating thermodynamically (~CIN)

(2) organize subsequent convections

by leading back-building-type successive rains using cold pool



Orders of LFC and CIN

To generate heavy rains artificially, we need to
(1) generate convections
by lifting up dynamically (~LFC), or heat thermodynamically (~CIN)

just before the heavy rain
(20210810 00UTC)

LFC : **770 m**
CIN Energy : **1.31 (J/kg)**

during a heavy rain
(20210811 00UTC)

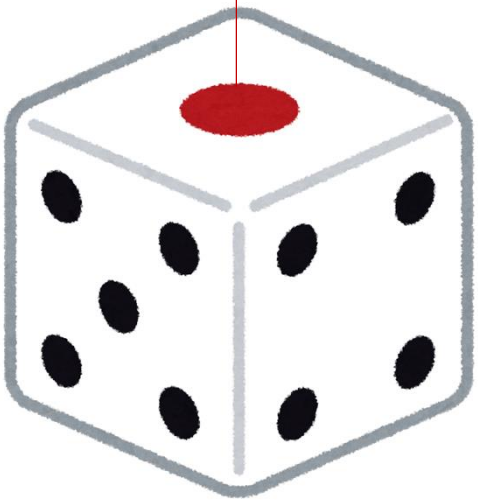
LFC : 3,200 m
CIN Energy : 47.0 (J/kg)

(Data: Kagoshima sonde of University of Wyoming, USA)

Problems to be solved toward weather control

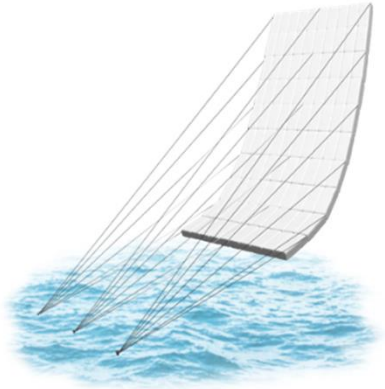
Meteorology

how to generate heavy rains?



Overseeding

Kites



Question: Can artificial interventions mitigate heavy rains?

➔ Numerical experiments with NWP models before field experiments.

Progress in Meteorology Research

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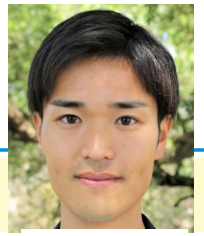
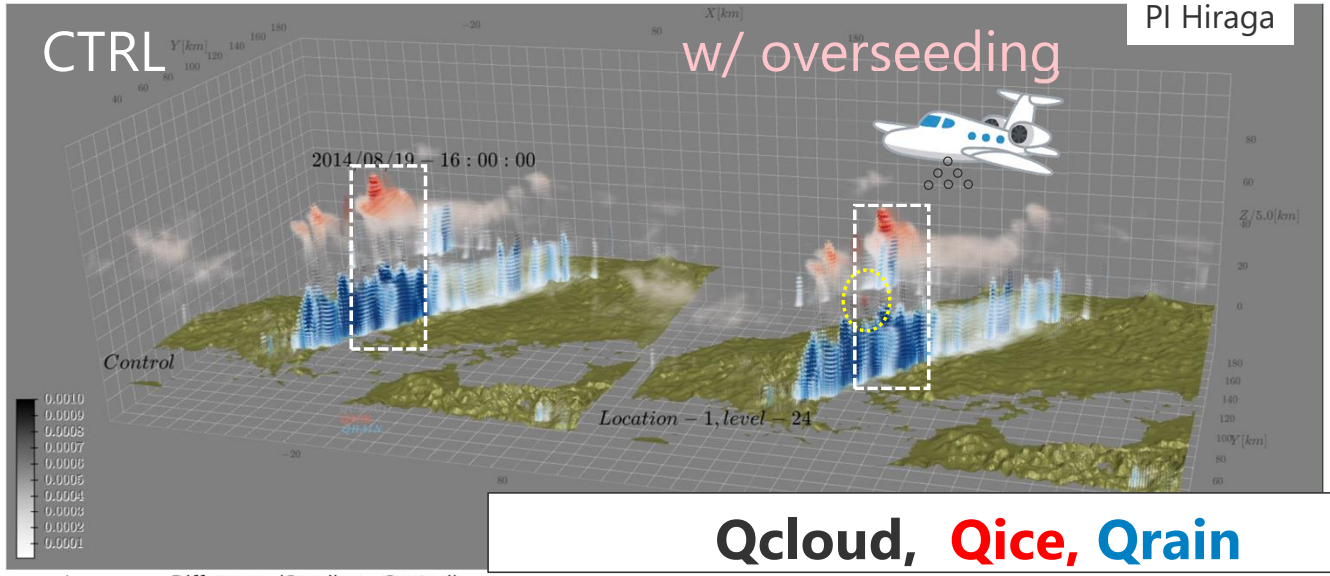
An over-seeding experiment using an NWP model (WRF)


PI Hiraga

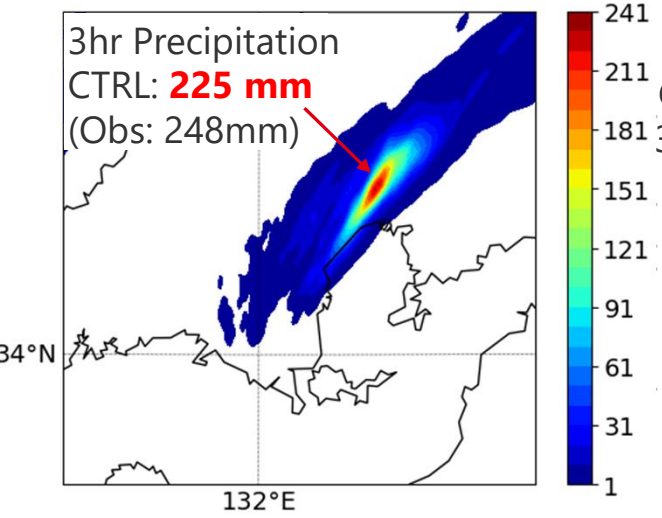

PI Kazama

Overseeding successfully reduces heavy rain by suppressing deep convections.

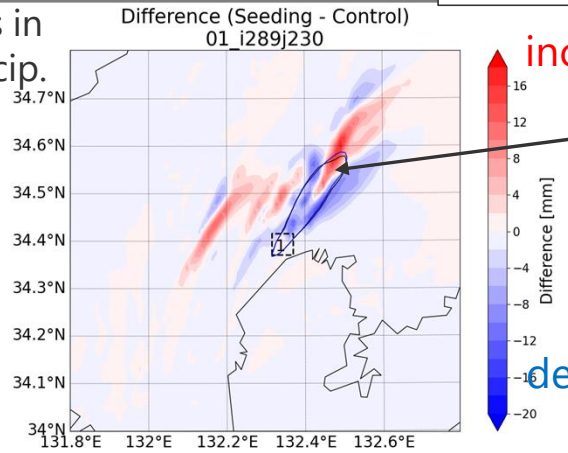
Heavy rain in Hiroshima (2014)



Qcloud, Qice, Qrain

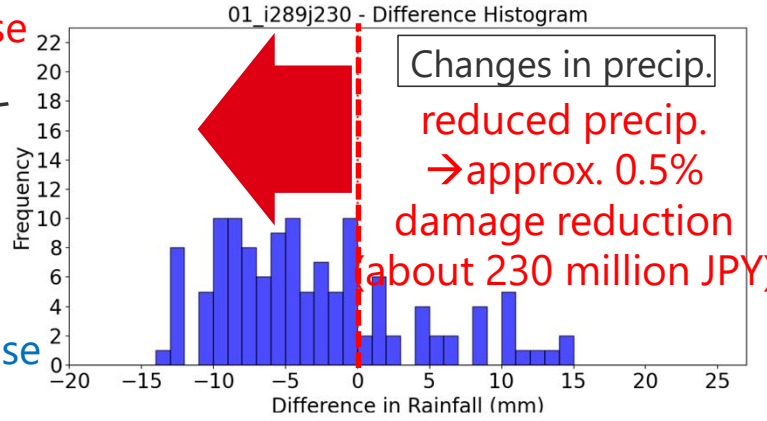


Changes in 3-hr precip.



increase

decrease



Kite experiments using an NWP model (SCALE)

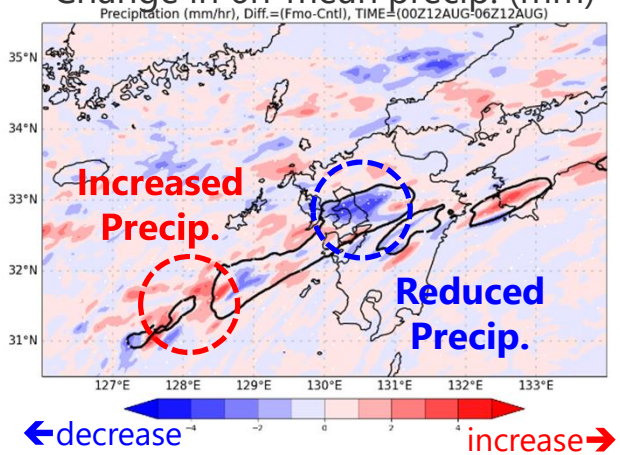
Kites increase precip. over upstream ocean, leading to reduced precip. in downstream regions.


PI Yasunaga
(Toyama U.)

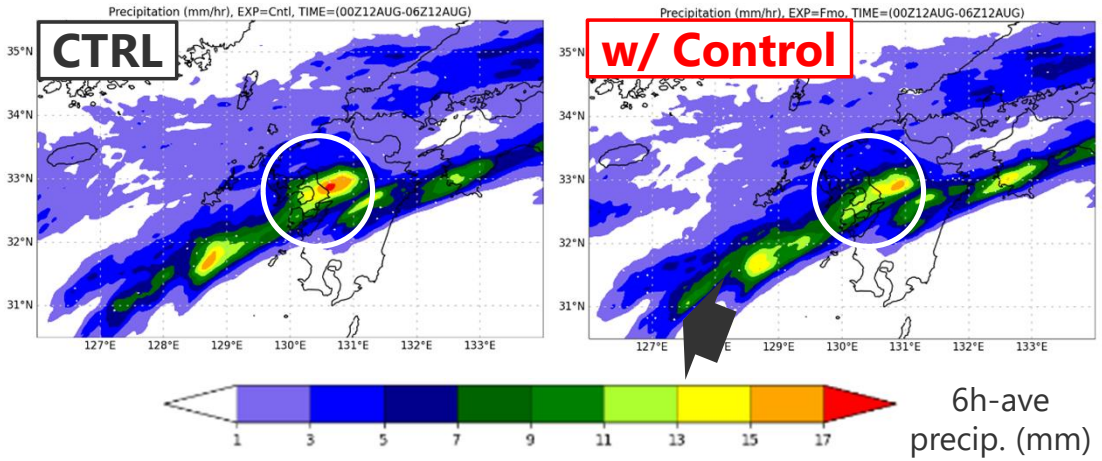

PI Okazaki
(Chiba U.)

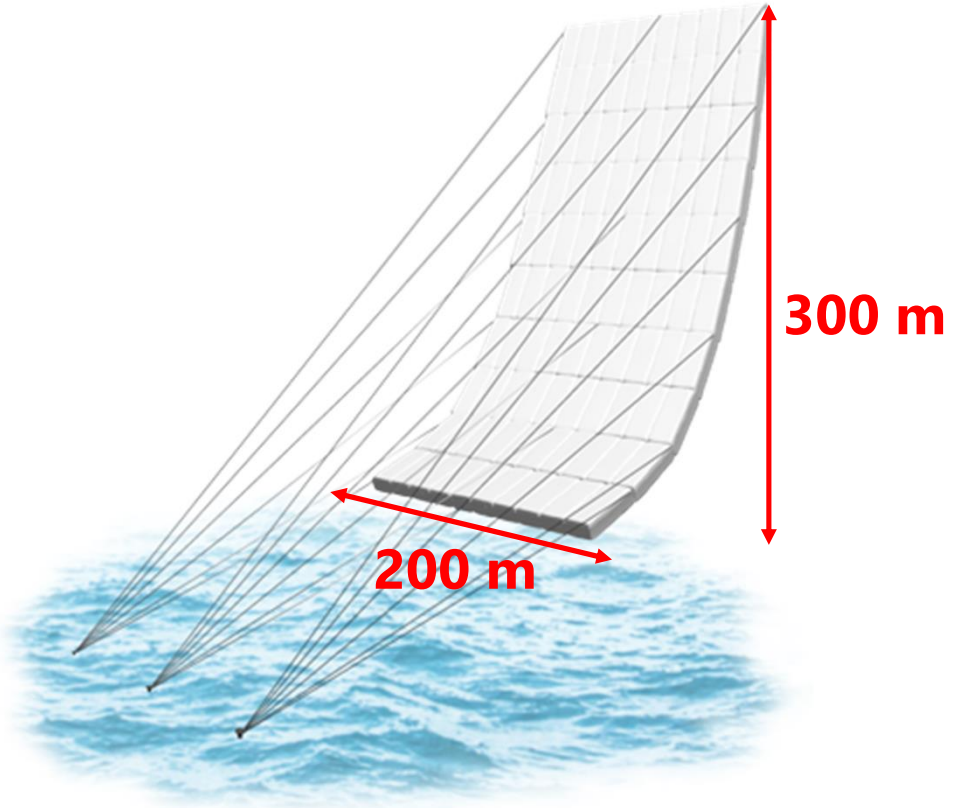
Heavy Rain (Aug. 2021)

Change in 6h-mean precip. (mm)



6h-mean precipitation (ensemble mean)





a kite (or atmospheric embankment) over ocean.

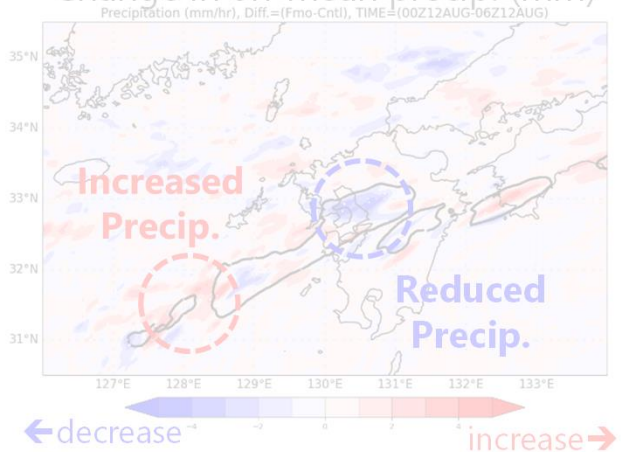
Kite experiments using an NWP model (SCALE)

Kites increase precip. over upstream ocean, leading to reduced precip. in downstream regions.

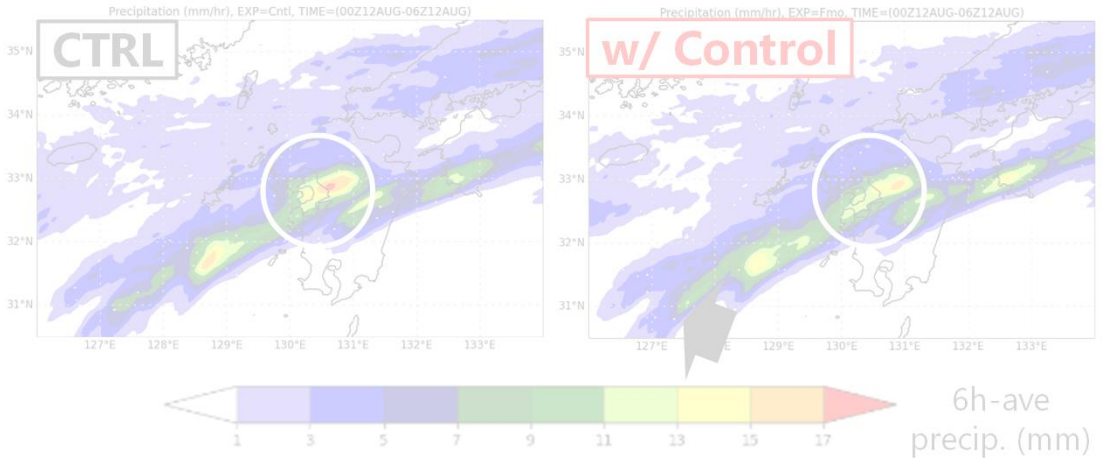
PI Yasunaga PI Okazaki

Heavy Rain (Aug. 2021)

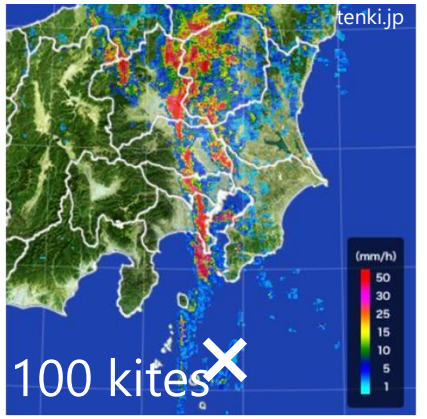
Change in 6h-mean precip. (mm)

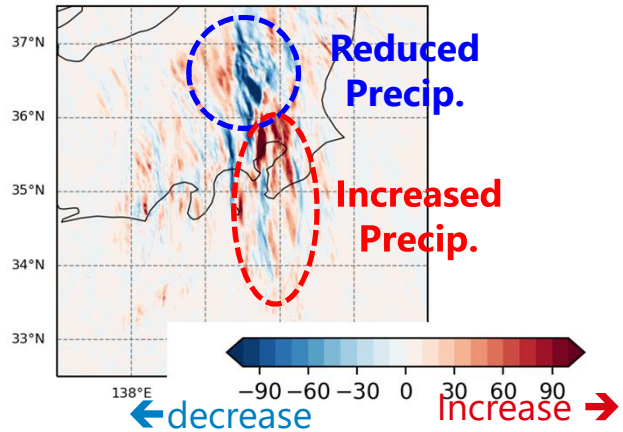


6h-mean precipitation (ensemble mean)

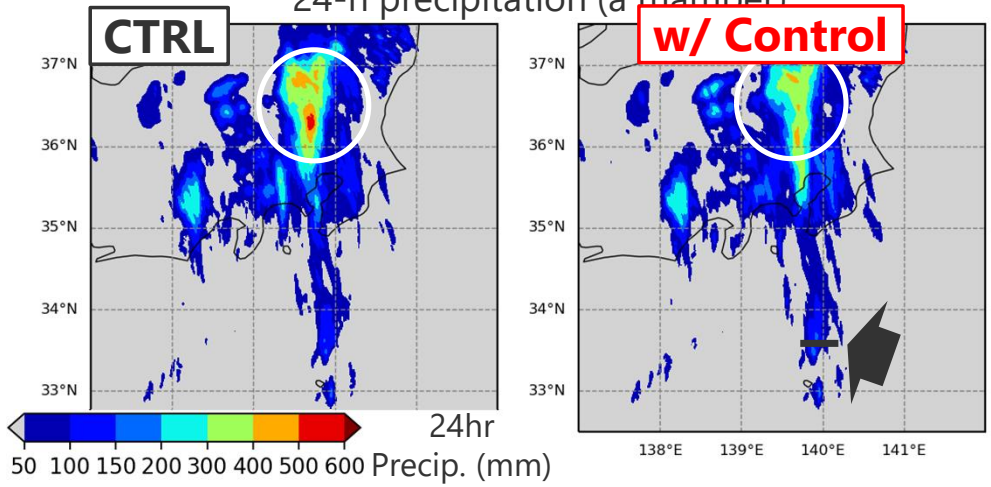


Heavy Rain (Sep. 2015)





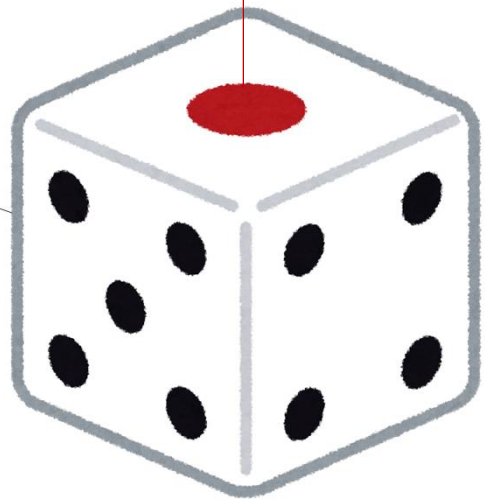
24-h precipitation (a member)



Problems to be solved toward weather control

Meteorology

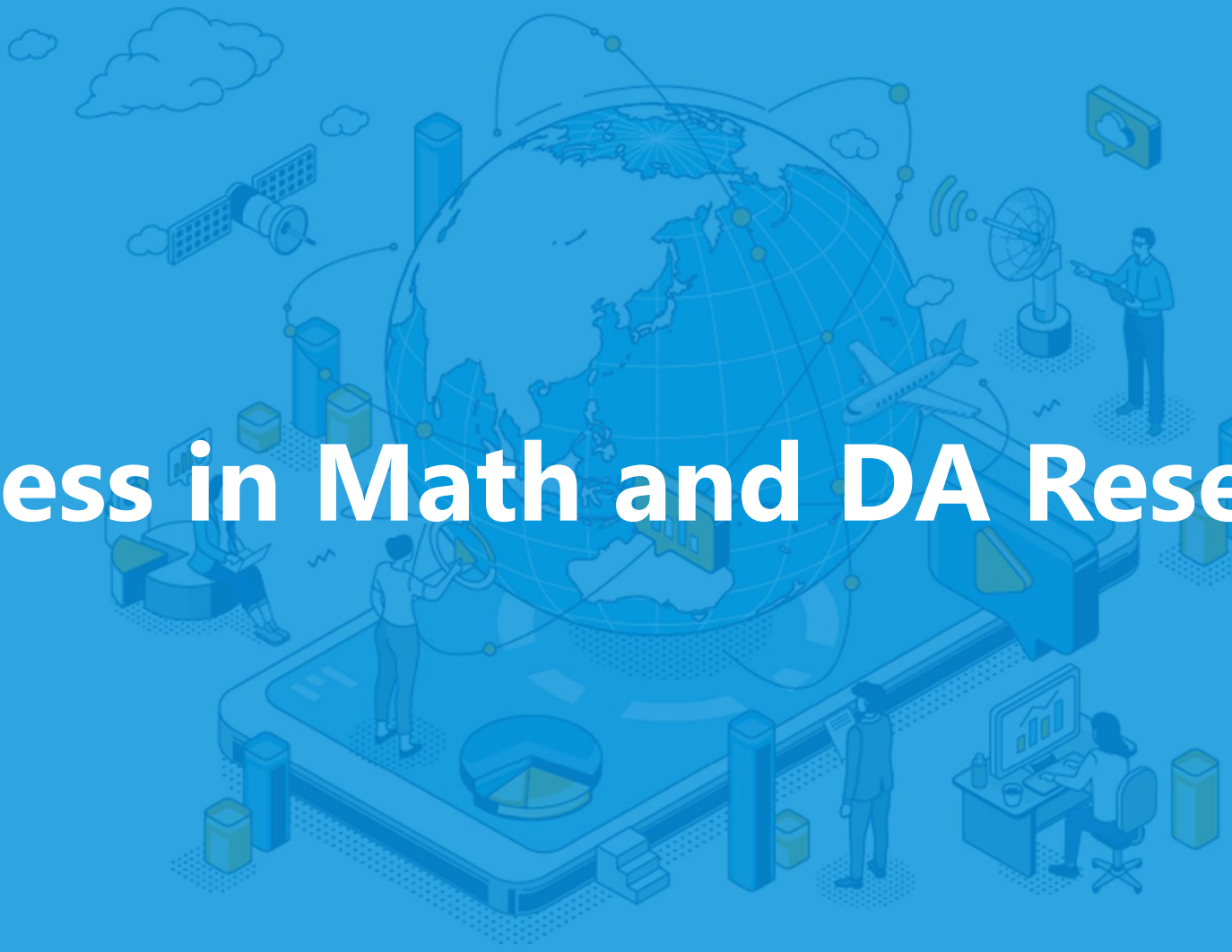
how to generate heavy rains?



Mathematics

how to optimize manipulations?

Progress in Math and DA Research



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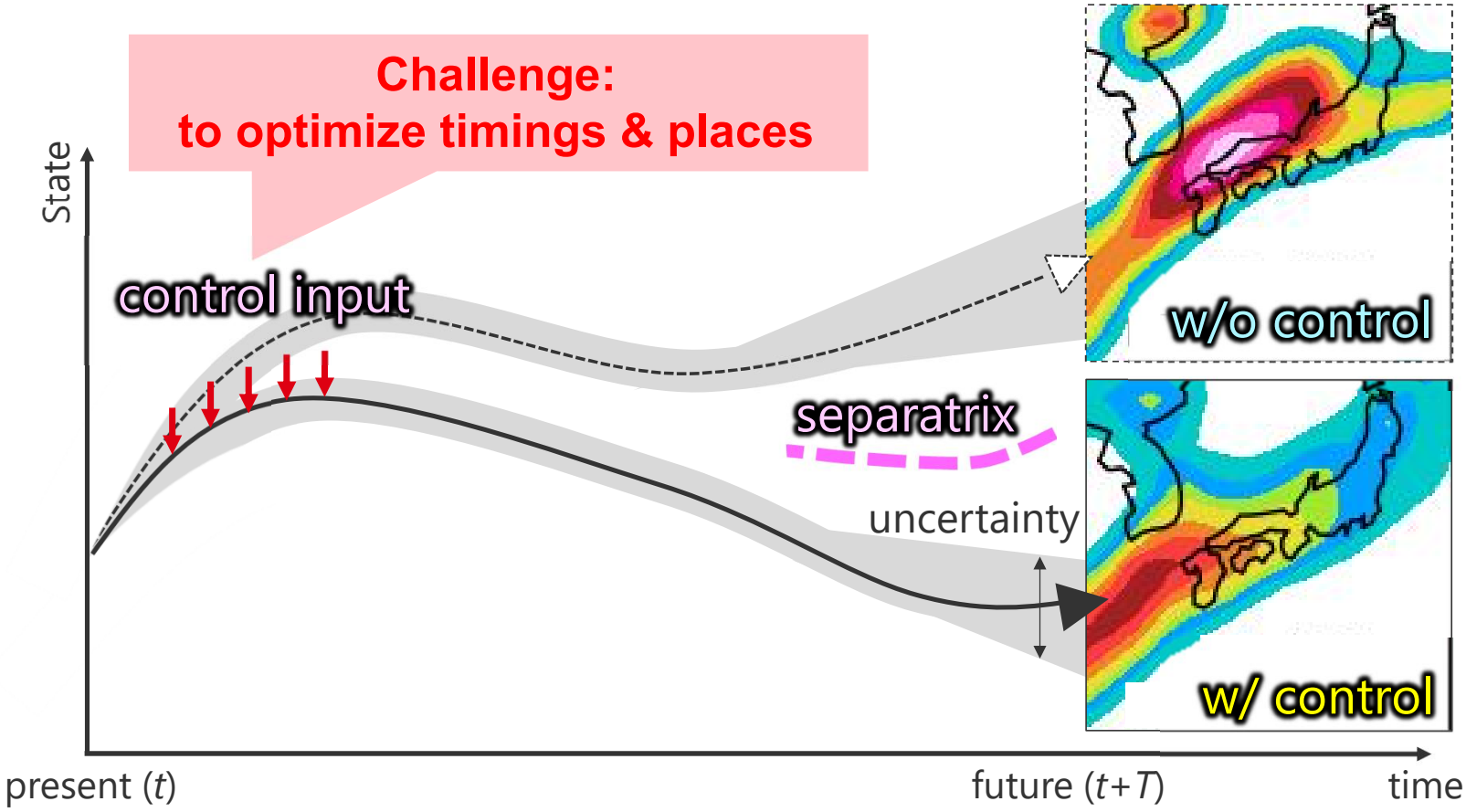
Objective of mathematical and AI researches

Mathematical weather control methods are necessary to optimize interventions.
➔ to introduce the model predictive control (MPC) into data assimilation



Our Methodological Strategy for Weather Control

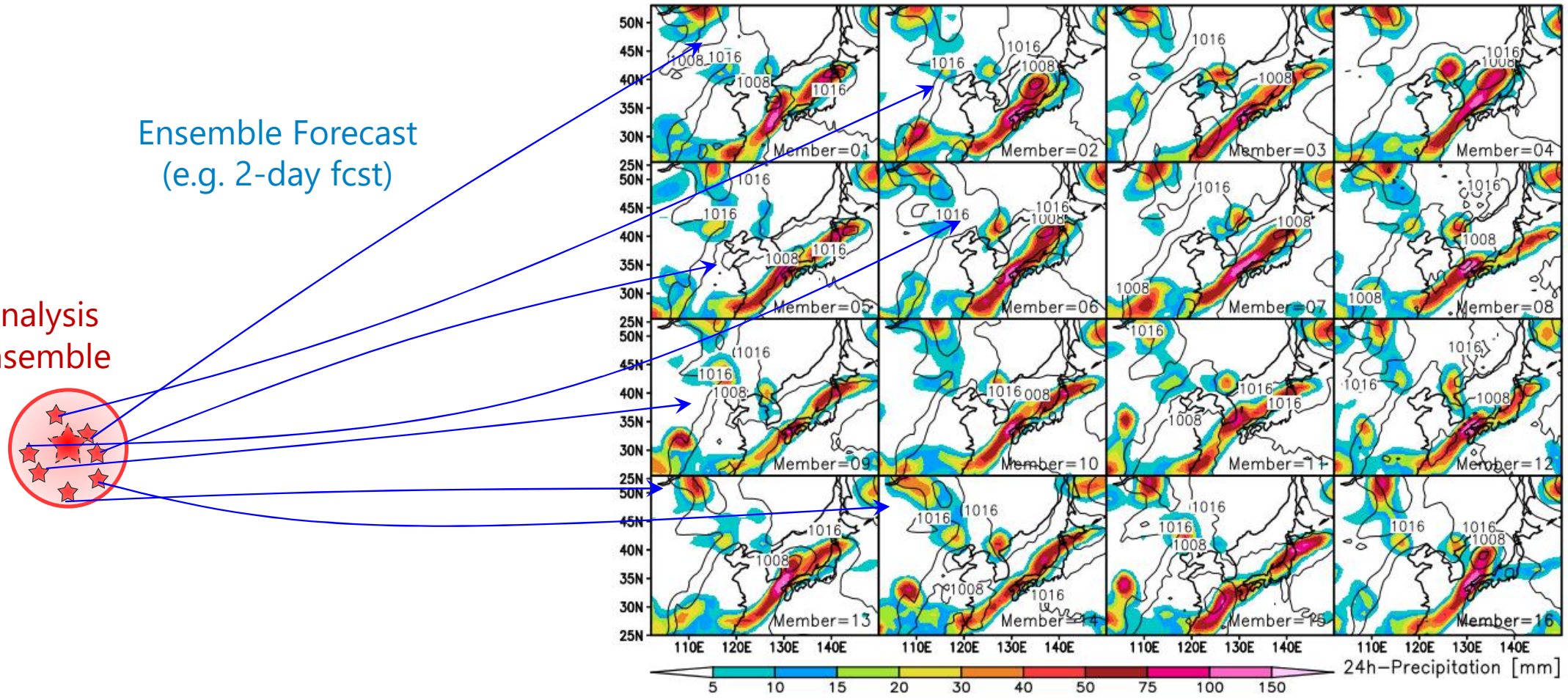
Suppose we would like to lead the atmosphere toward a desirable future

a case of heavy rain in 2018

From NICAM-LETKF 100 member forecasts

Ensemble Forecast
(e.g. 2-day fcst)

Analysis Ensemble



Our Methodological Strategy for Weather Control

Suppose we would like to lead the atmosphere toward a desirable future

Step 1. to boost ensemble forecasts
Step 2. to find a desirable trajectory by ensemble forecasts
Step 3. to optimize interventions by model predictive control (convex optimization)

Analysis Ensemble

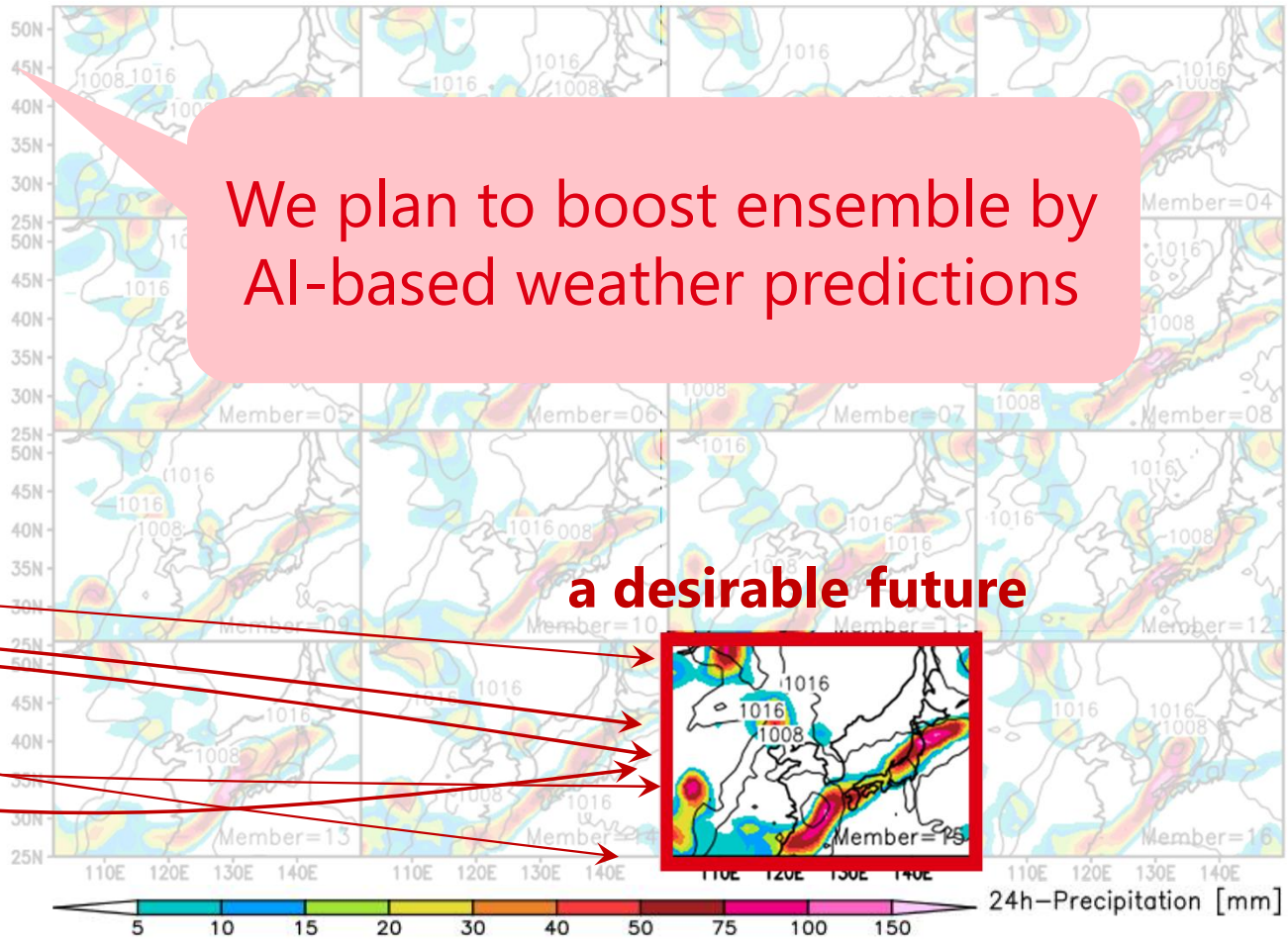
Add control inputs consecutively

a case of heavy rain in 2018

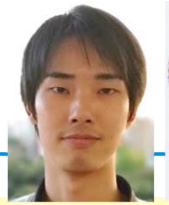
From NICAM-LETKF 100 member forecasts

We plan to boost ensemble by AI-based weather predictions

a desirable future



Step 1: Boosting ensemble predictions using AIs


PI Matsuoka PI Kera PI Kotsuki

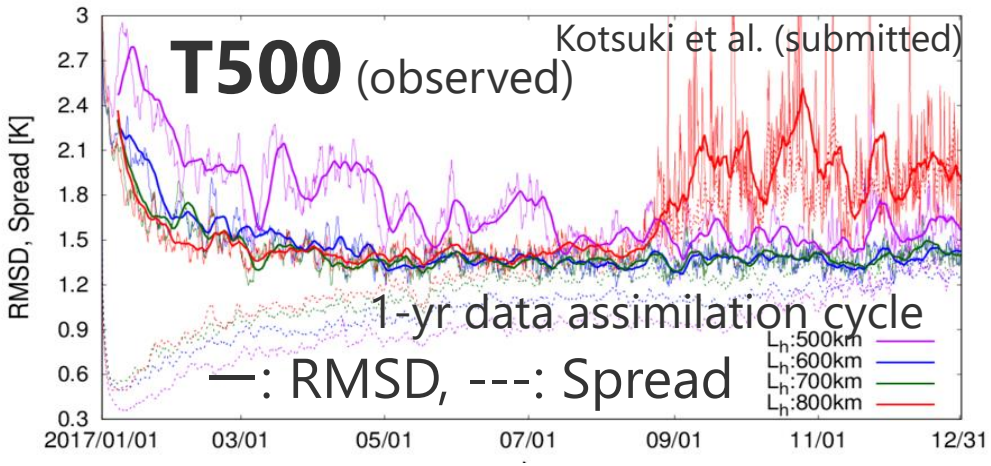
We are advancing downscaling AI to predict heavy rainfall as well as medium-range forecasts enabled by AI weather model coupled with data assimilation.

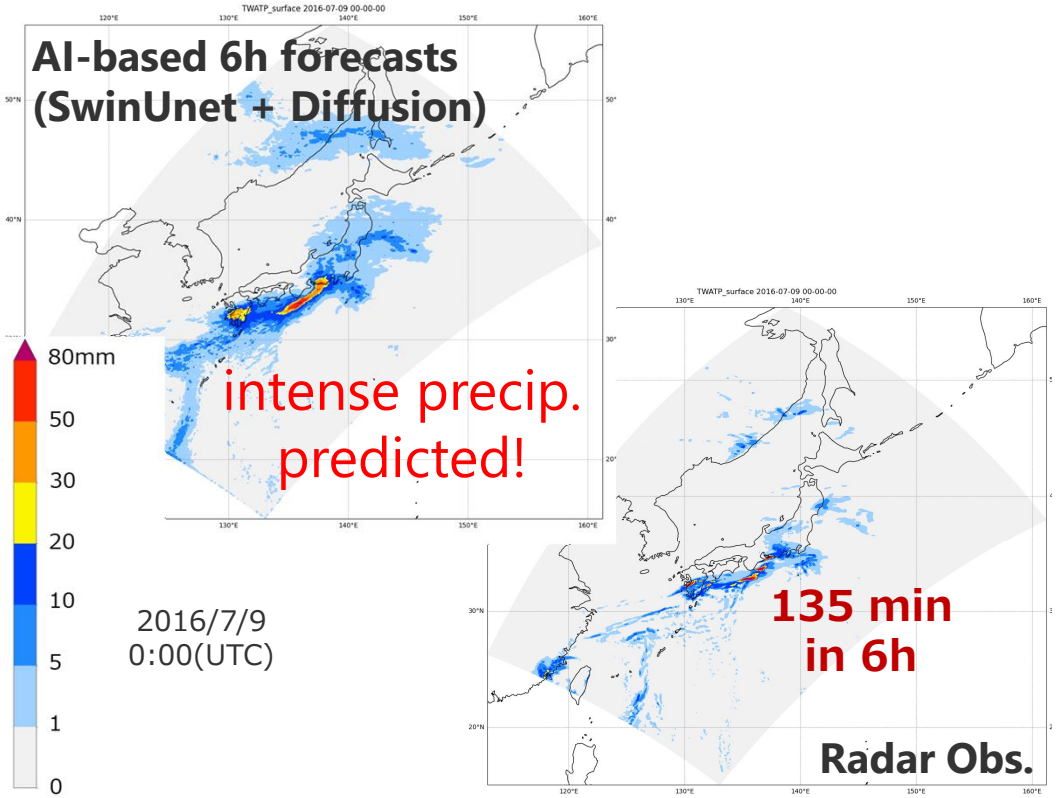
Medium-range ensemble forecasts (~5days) → **Downscaling & ensemble generation (~1day)**

AI model (ViT) (Cyber Space) | Obs (Real Word)

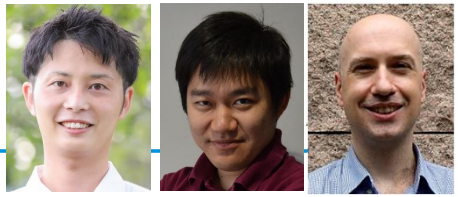
AI model ClimaX coupled with LETKF

(a) [AN] RMSE (solid) Spread (dashed) ; Temperature [K] at 500 hPa



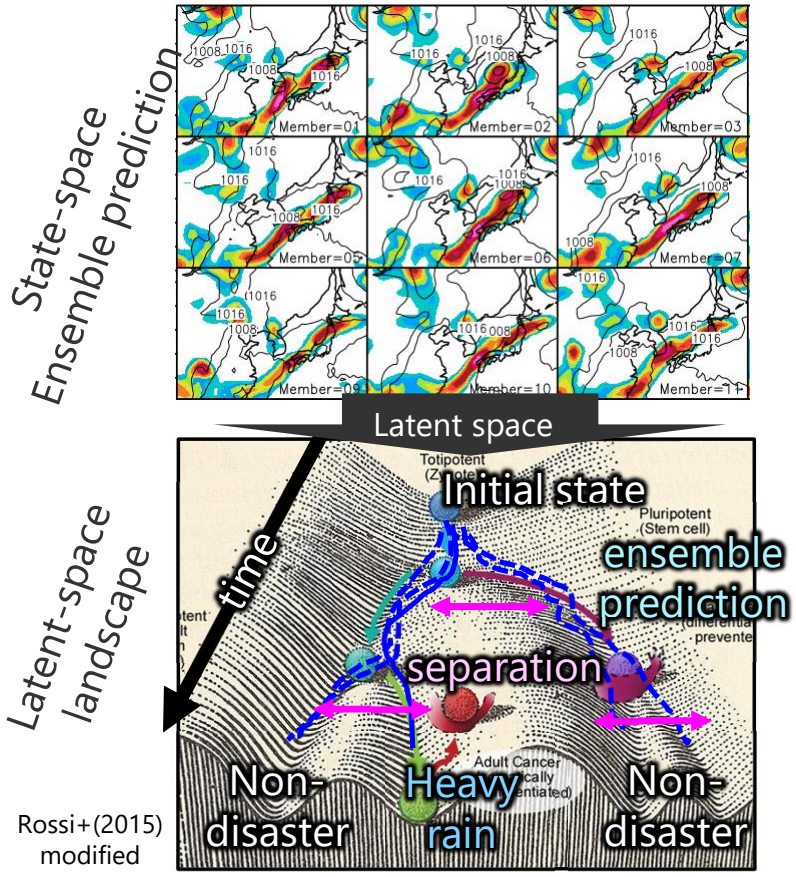


Step 2: To find preferable trajectory

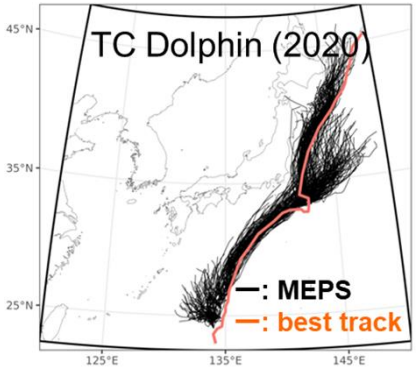


PI Imoto PI Tokuda Dr. Oettli

Hypothesis: Ensemble prediction can be interpreted as a landscape in latent space.
➔ Mathematical landscape analysis was applied to a TC forecasts

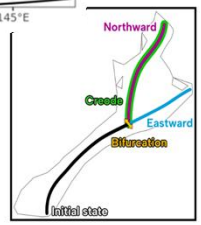


Rossi+(2015)
modified

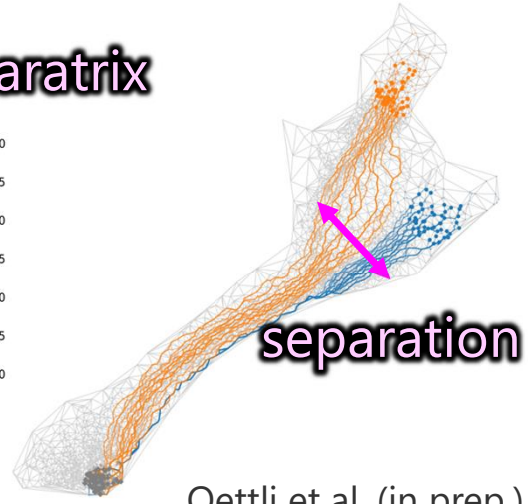


Landscape analysis
(clustering &
graph Hodge decomposition)

Hodge Potential



Trajectory Analysis



Oettli et al. (in prep.)

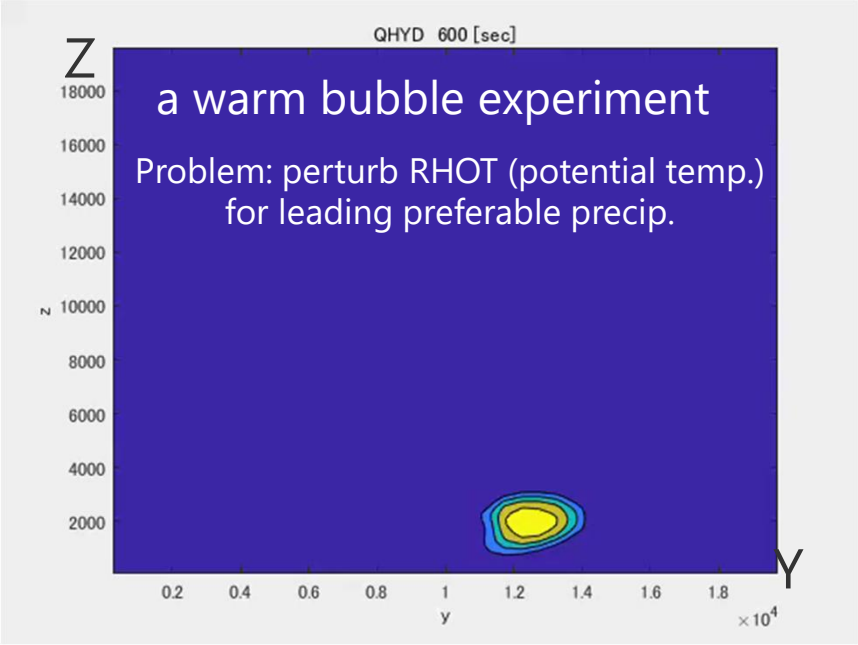
Step 3: Optimizing Interventions using SCALE-MPC

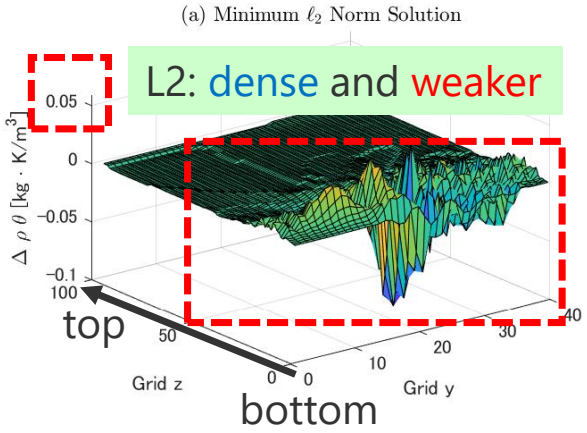
PI Ohtsuka
(Kyoto U.)

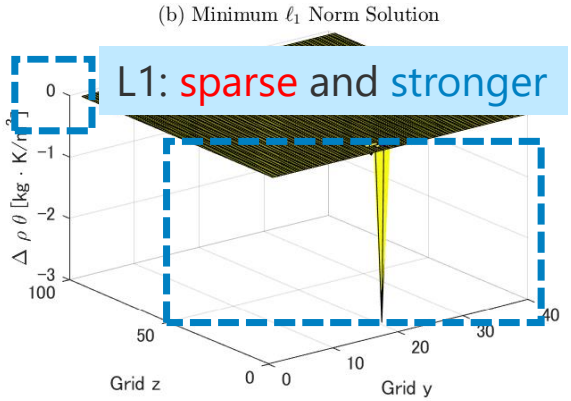
We started coupling model predictive control (MPC) with NWP model,
in which initial perturbations are optimized by solving convex optimization problem.

Convex optimization using SCALE

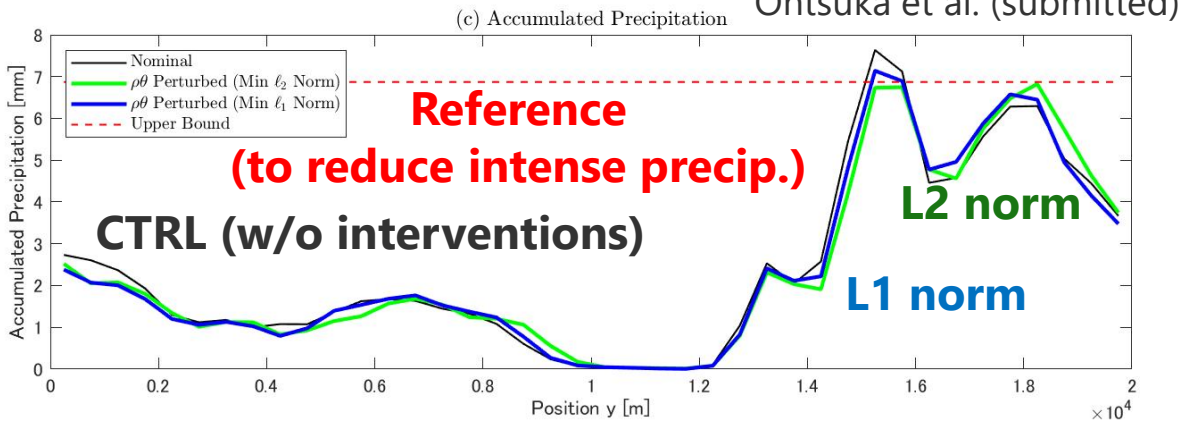
$$\min_{\Delta \mathbf{x}^{init}} \left\| \Delta \mathbf{x}^{init} \right\| \quad \text{s.t.} \quad \mathbf{S}\left(\mathbf{x}^{init}\right) \Delta \mathbf{x}^{init} = \Delta Y^{ref}$$







Ohtsuka et al. (submitted)



Summary

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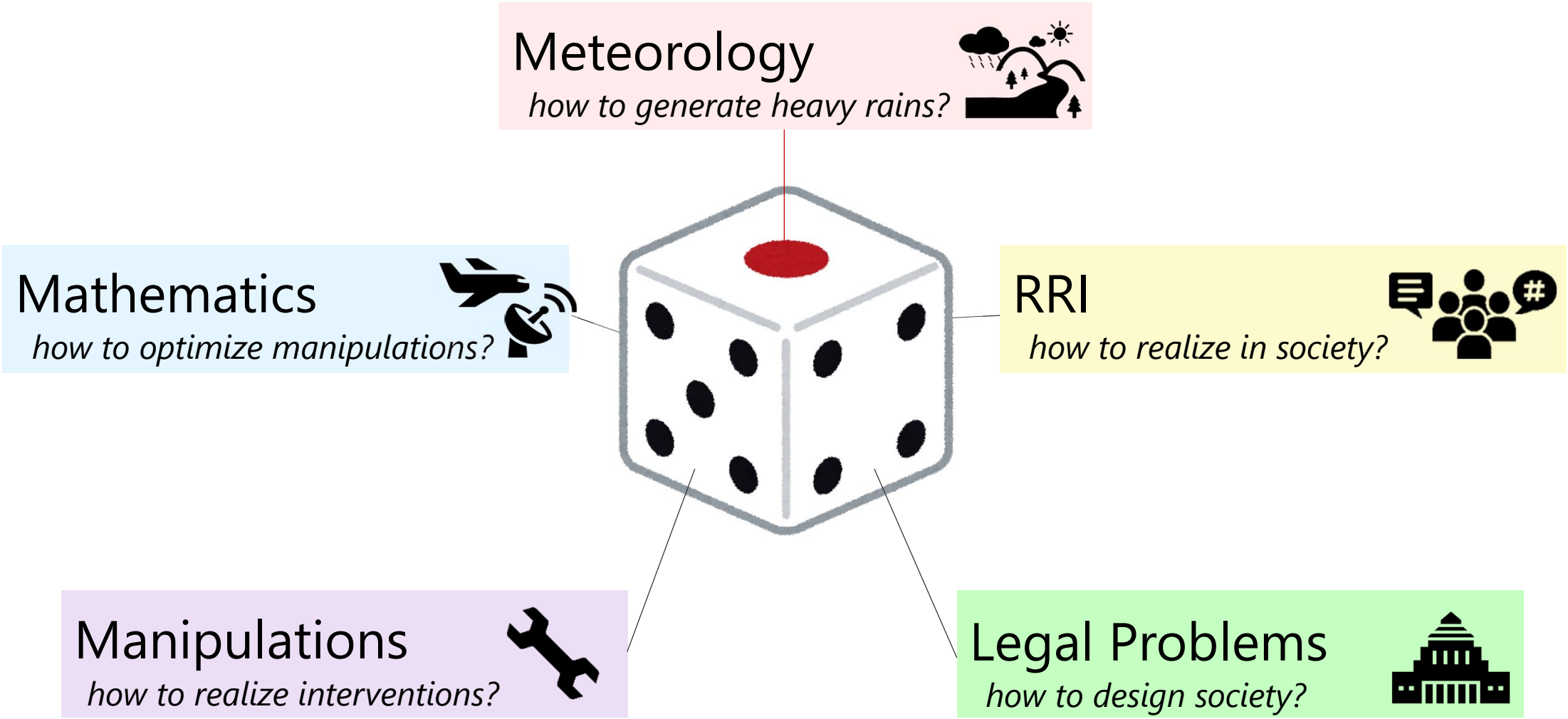
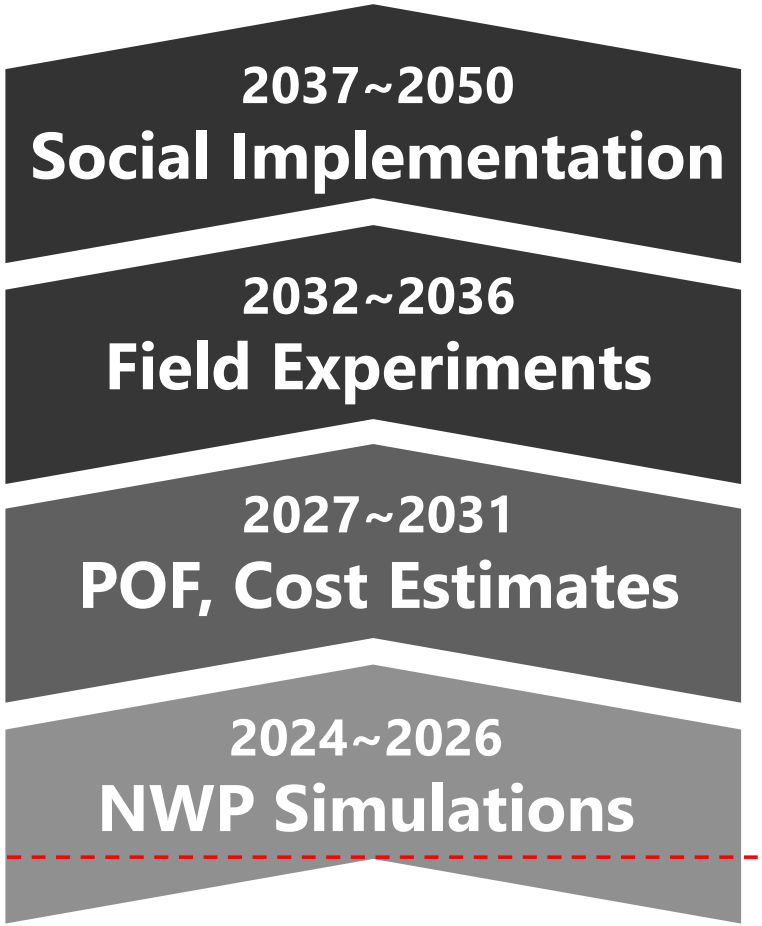
Problems to be solved toward weather control



Our Road Map toward 2050

2050: to realize a society safe from the extreme heavy rains



	Scientific R & D	ELSI and RRI Issues
2037~2050 Social Implementation	Large-scale Field Experiments	Develop Social Systems (Laws, Insurance)
2032~2036 Field Experiments	Small-scale Field Experiments	Social Agreements (Domestic & International)
2027~2031 POF, Cost Estimates	Start Developing Interventions	Cost Estimates (implementation, impacts)
2024~2026 NWP Simulations	Numerical Experiments w/ NWP models	Identify Social Issues

Summary and Future Plans

- We started a new core project for heavy rains.
- Our project needs to be enhanced for
  - engineering studies for interventions
  - international collaborations for impact/risk assessments

We are happy to take any suggestions!