OUR VISION, OUR RESEARCH

Atsushi Okazaki

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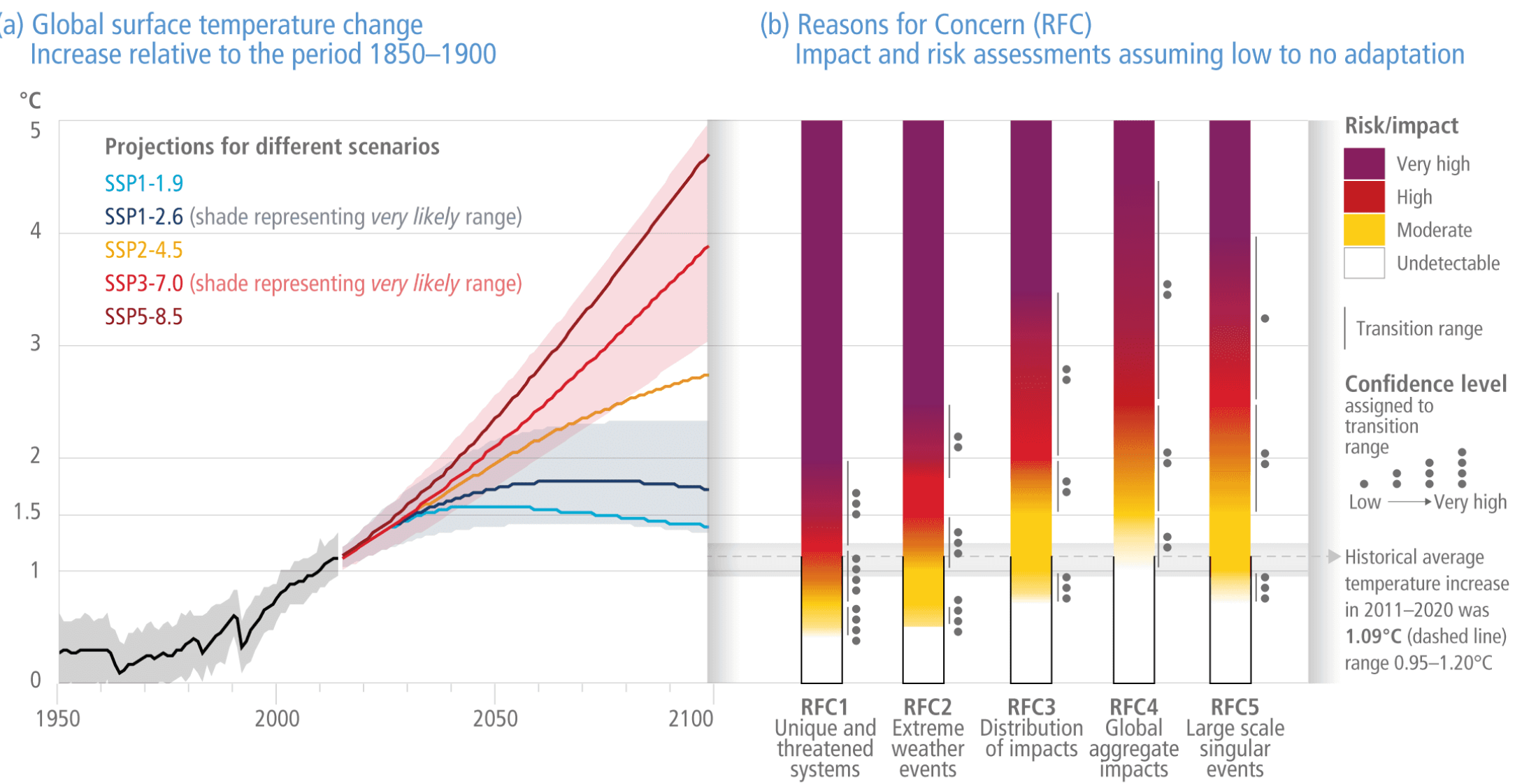
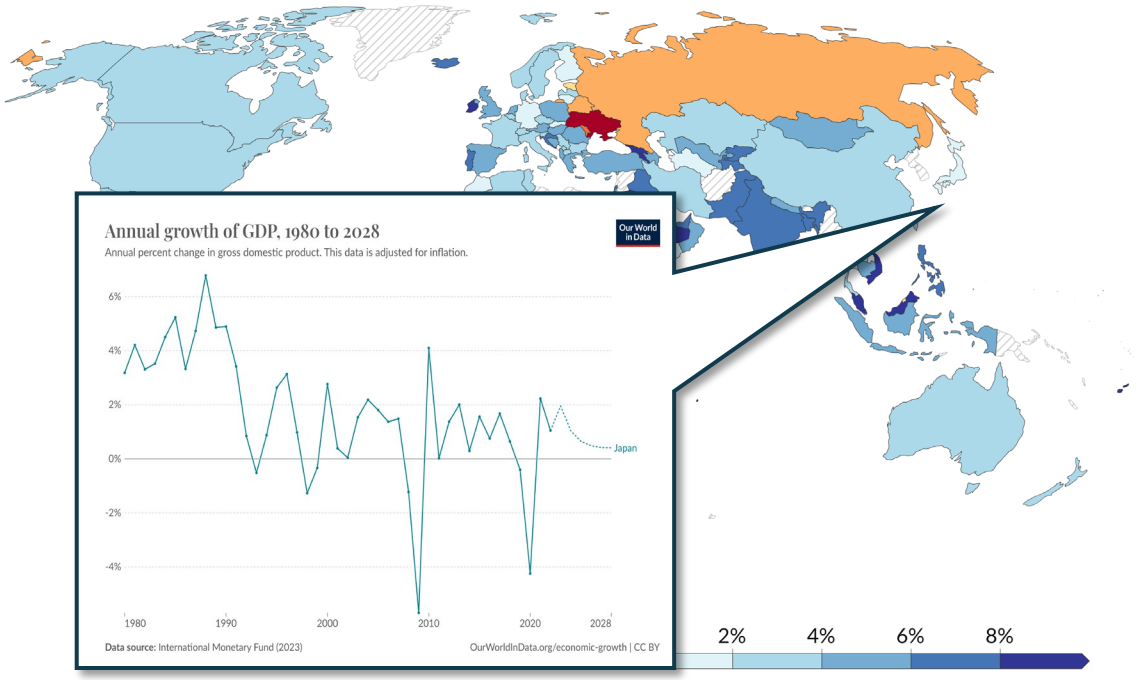
Global and regional risks for increasing levels of global warming



Our world is anticipated to be less comfortable and less safe

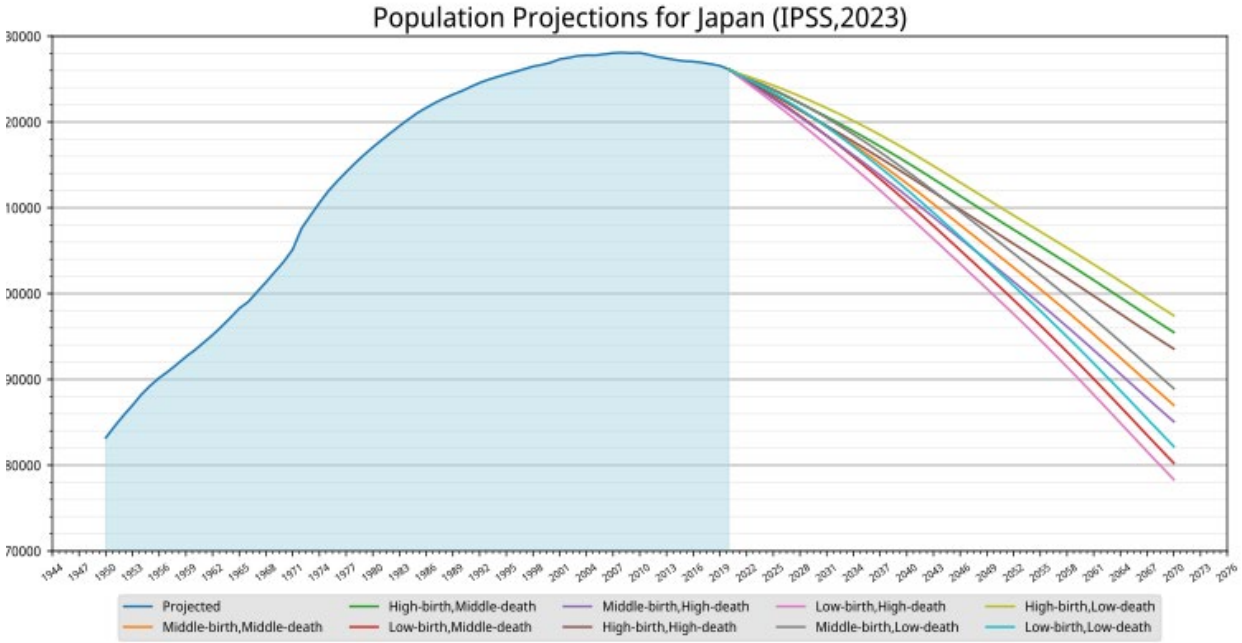
Annual growth of GDP, 2022

Annual percent change in gross domestic product. This data is adjusted for inflation.



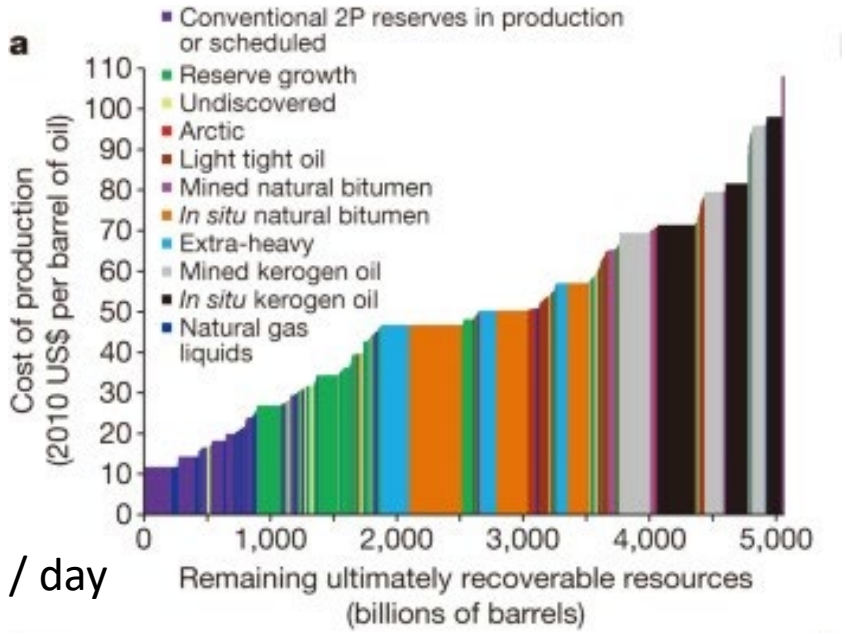
Data source: International Monetary Fund (2023)

OurWorldInData.org/economic-growth | CC BY

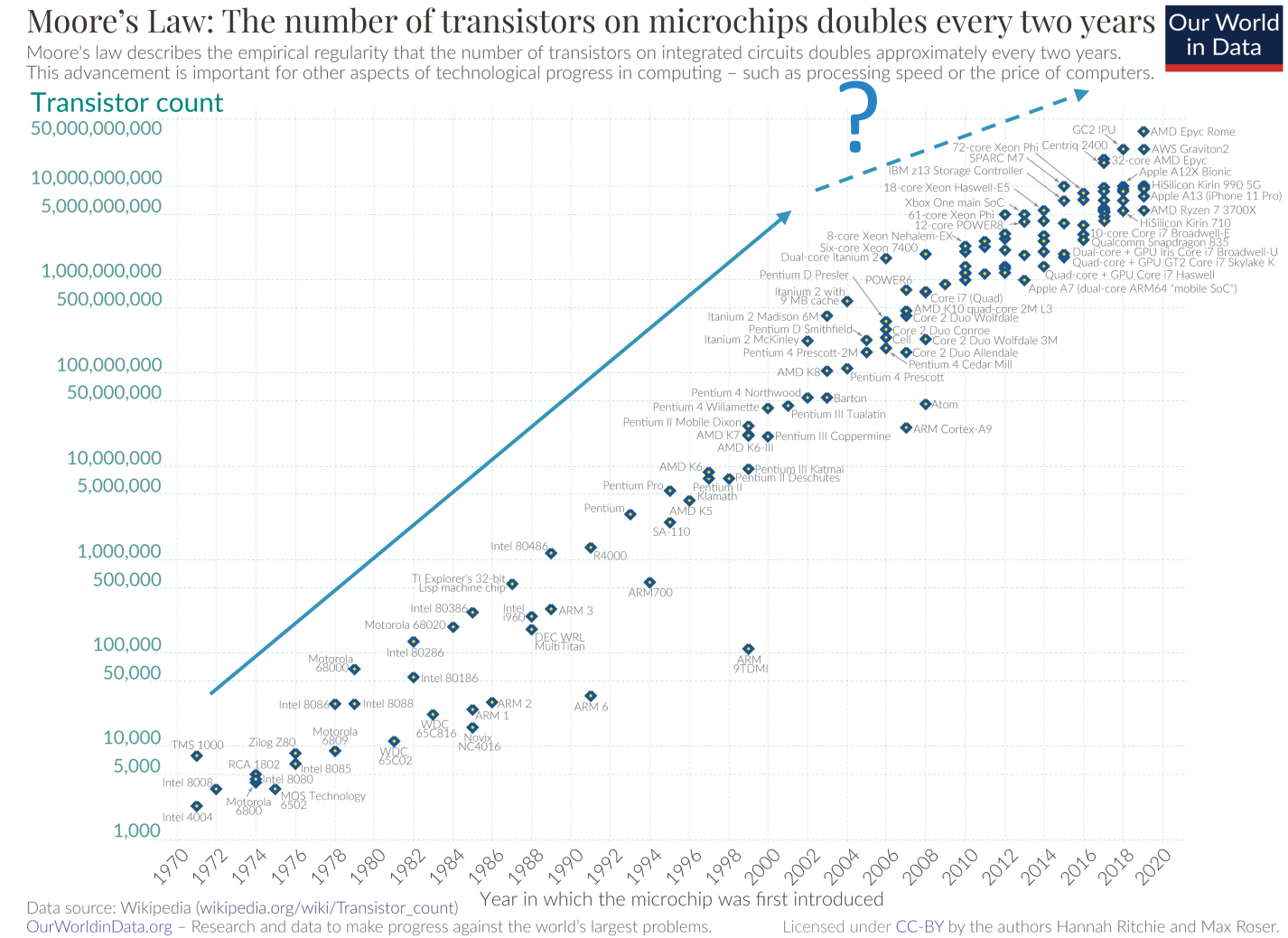


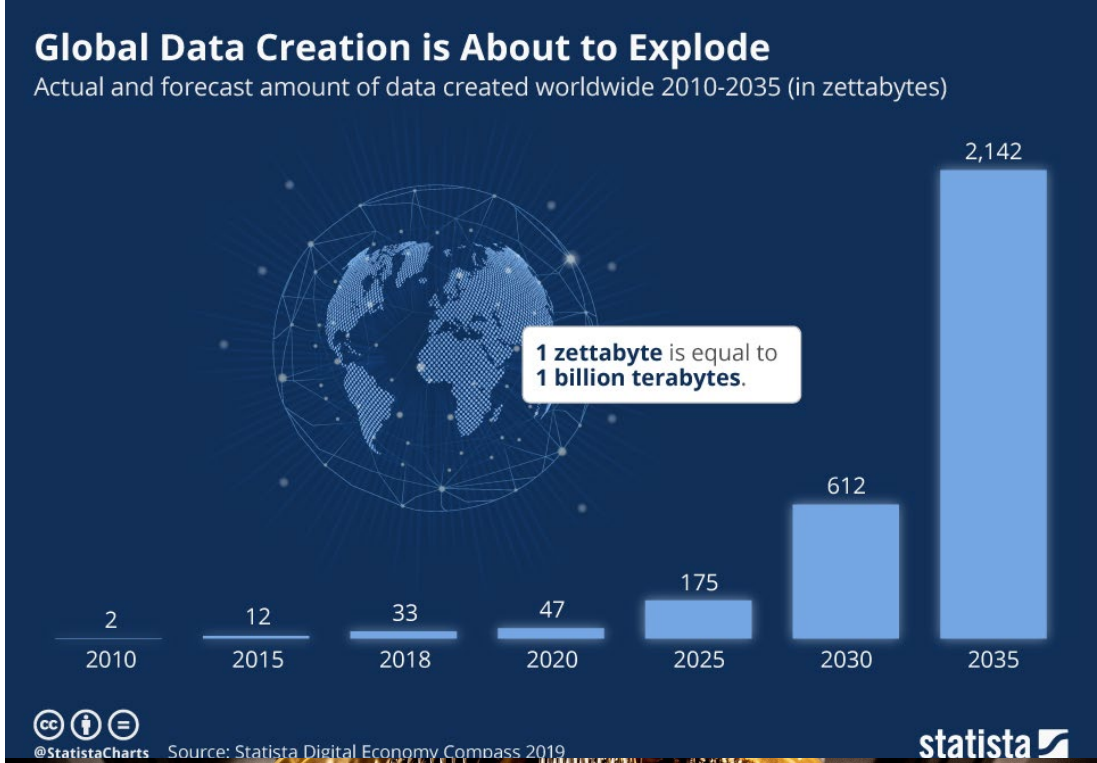
Resources we can use are in decline
= Options we can take will be limited

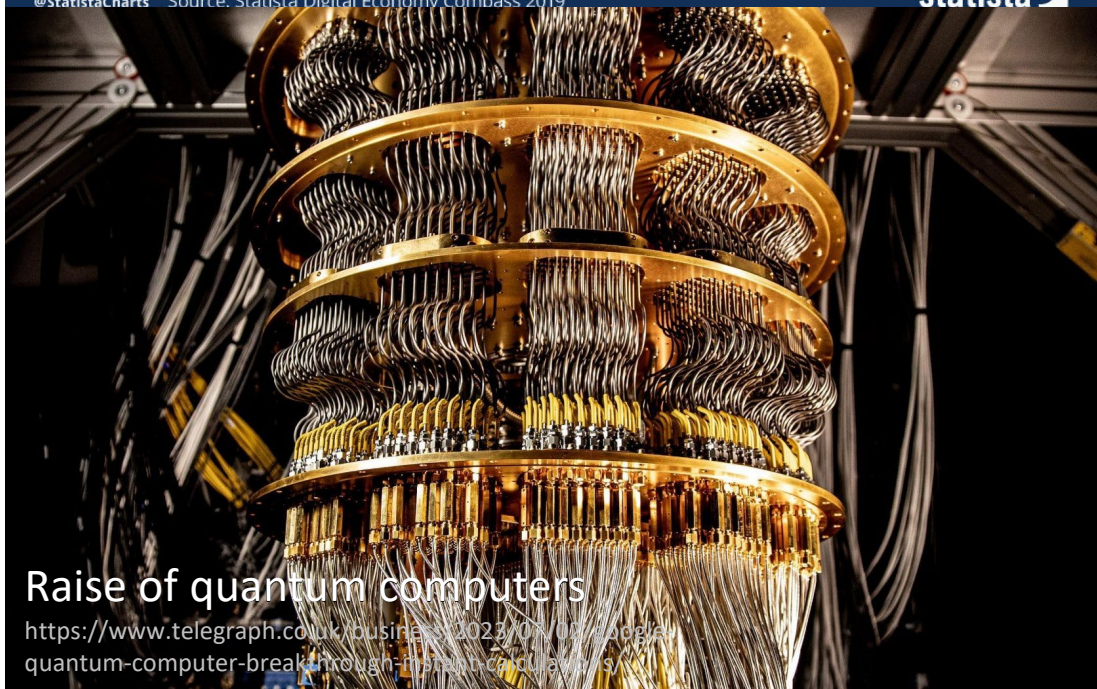
Reserves-to-Production ratio = 50 years



100 million barrel / day
= 37 billions / a



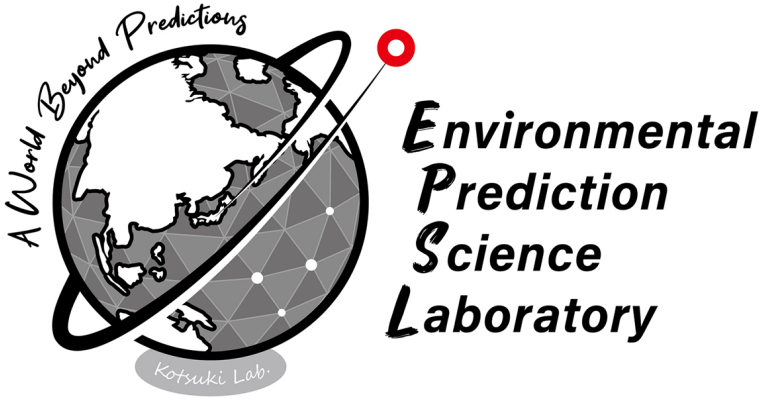




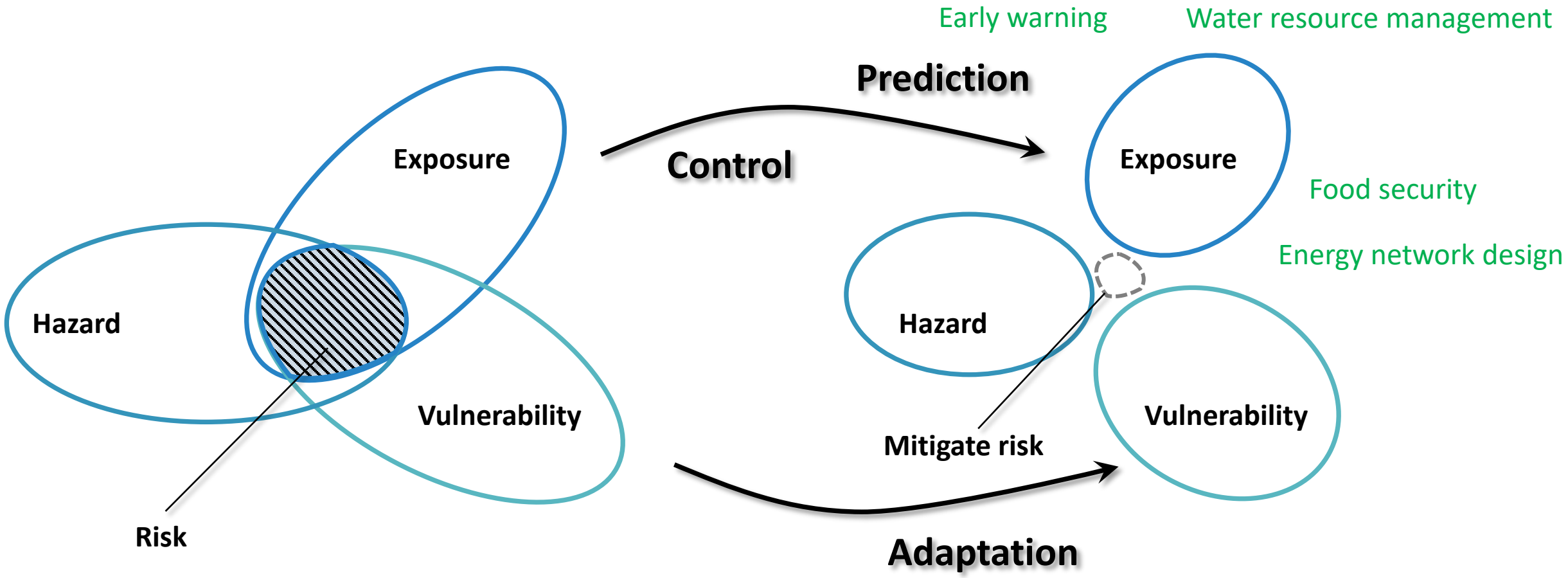
The power of computation and the data size are still growing

Our vision in this sentence

- ***Demand***: Need to predict what will happen at various scale (hourly, daily, monthly, seasonal, interannual, decadal, centennial) to be well prepared in an efficient way
- ***Our mission***: To create a new world with cutting-edge predictions and beyond
- ***Our vision***: To optimize the world with the power of prediction and data science



“OPTIMIZE THE WORLD” with the power of prediction and data science



What's necessary to realize the vision?

Prediction ● ● ● ● ● ● ● Control / Adaptation

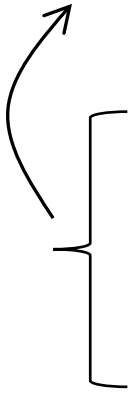
✗ Accurate prediction
(hourly ~ cenntennial)

✗ Fast prediction

✗ High-resolution prediction

✗ Control theory

✗ Risk / Impact estimation



✗ Observations

✗ Estimation method (DA, ML)

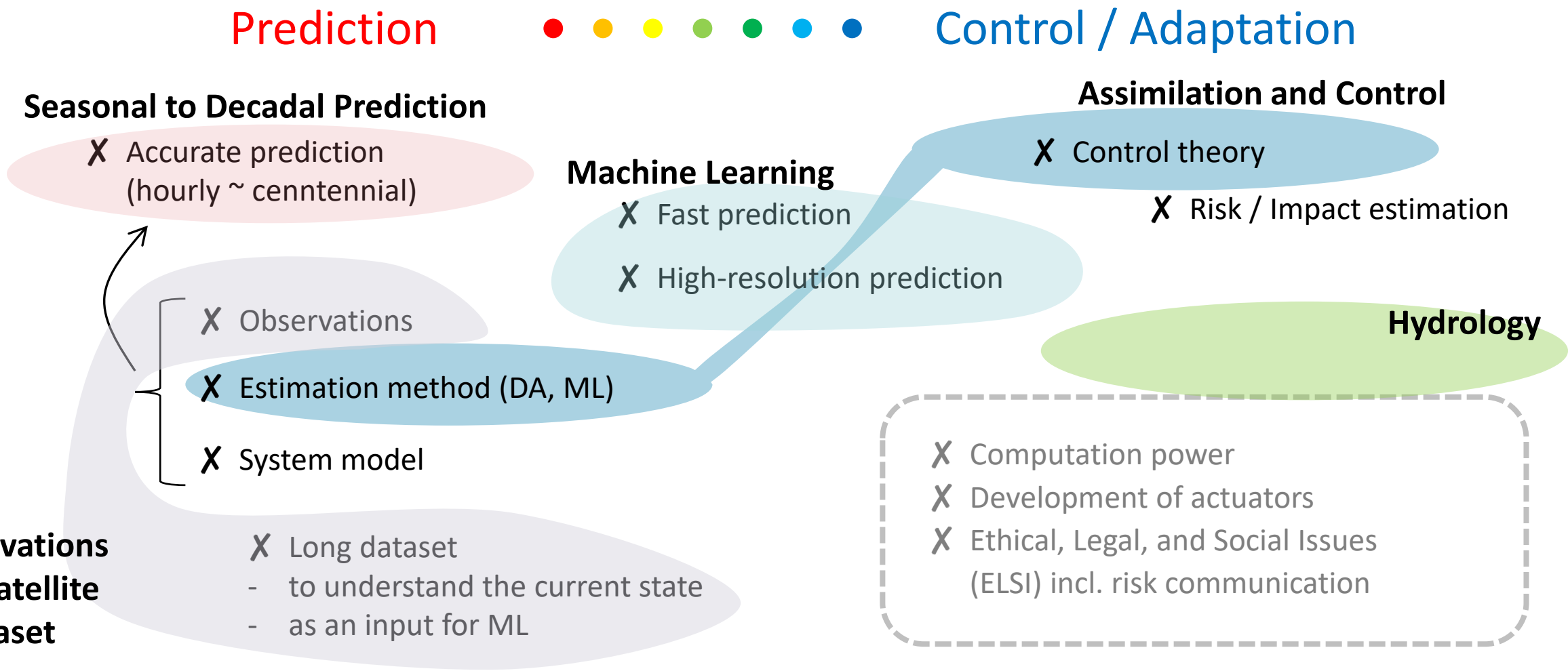
✗ System model

✗ Long dataset
- to understand the current state
- as an input for ML

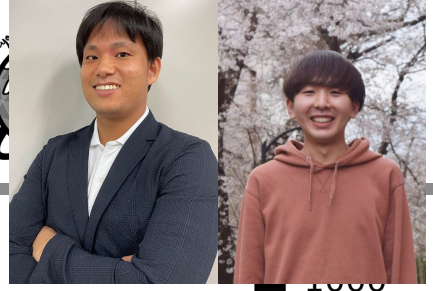
Things that is important but we do not touch

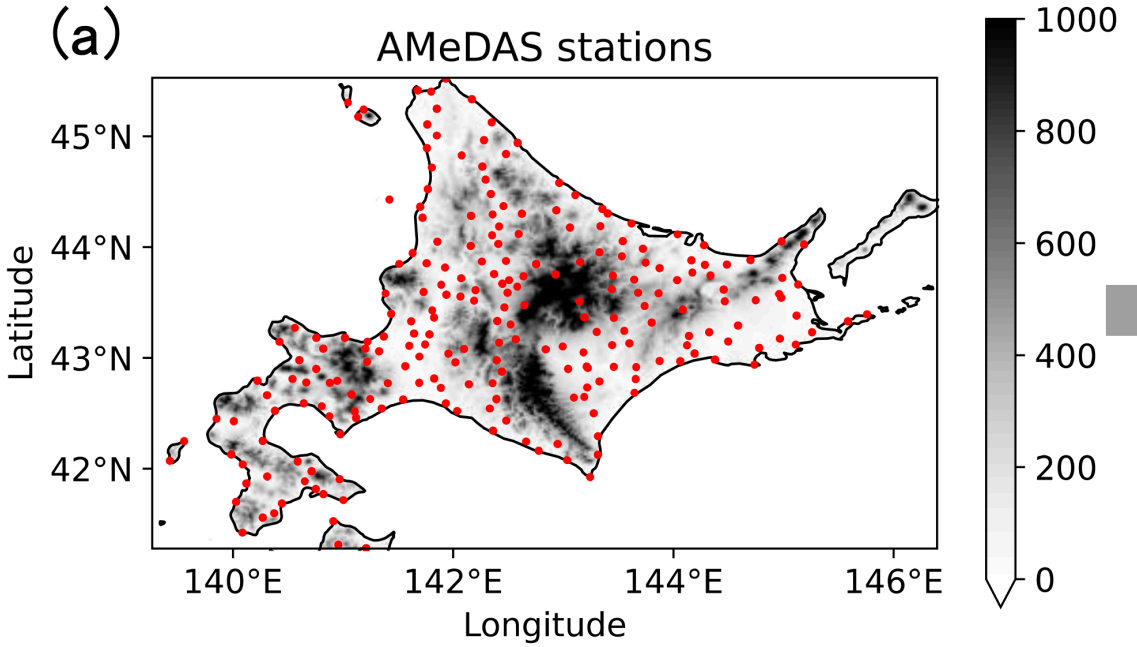
✗ Computation power
✗ Development of actuators
✗ Ethical, Legal, and Social Issues (ELSI) incl. risk communication

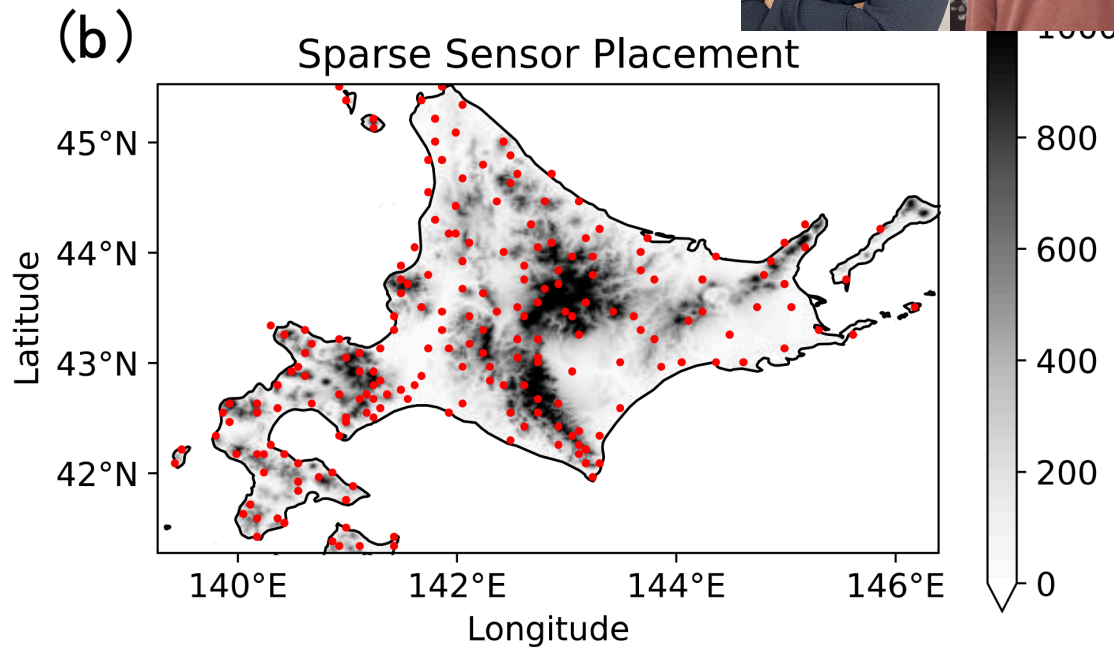
What's necessary to realize the vision?



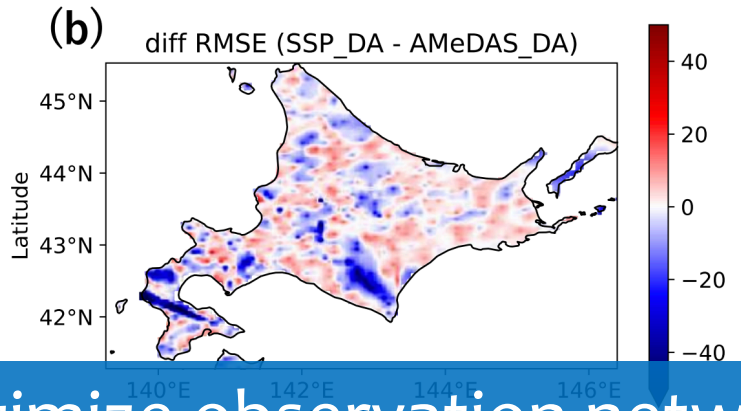
Optimization of observation network







場の復元に使用した雨量計配置	領域平均 RMSE (mm/14 days)
SSP で決定した雨量計配置	12.55
AMeDAS	14.27



Shiojiri-san & Saito-san proposed a method to optimize observation network

Improve global precipitation estimation with EnKF

Method

Precipitation estimation with EnKF

$$\mathbf{x}_t^a = \mathbf{x}_t^b + \mathbf{P}^b\mathbf{H}_t^T[\mathbf{H}_t\mathbf{P}^b\mathbf{H}_t^T + \mathbf{R}]^{-1}(\mathbf{y}_t^o - H(\mathbf{x}_t^b))$$

Analysis — Prior — Prior error covariance

CPC gauge precipitation

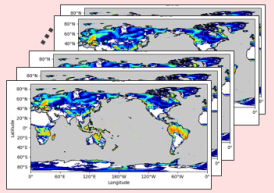
Observation error covariance

(err variance = $1.0\ \mathrm{mm}^2\ \mathrm{day}^{-2}$)

再解析ERA5

1979/01/01~1979/12/31

(365 days)



Ensemble $\mathbf{X}^b \in \mathbb{R}^{n\times m}$ $(m = 365\ \text{days})$

Prior $\bar{\mathbf{x}}^b \in \mathbb{R}^n$

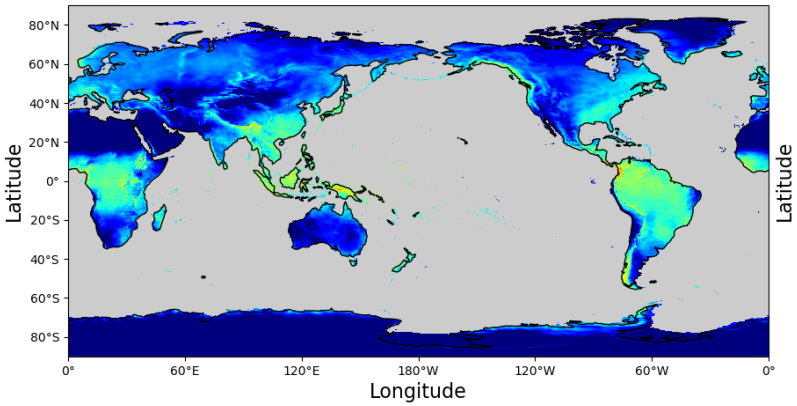
Ensemble perturbations

$\delta\mathbf{X}^b = [\mathbf{x}^{b(1)} - \bar{\mathbf{x}}^b, \ldots, \mathbf{x}^{b(m)} - \bar{\mathbf{x}}^b]$

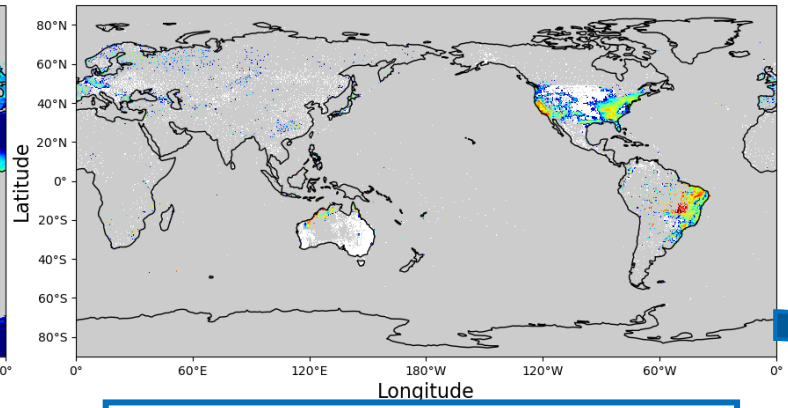
Prior error covariance

$\mathbf{P}^b \approx \frac{\delta\mathbf{X}^b(\delta\mathbf{X}^b)^T}{m-1}$

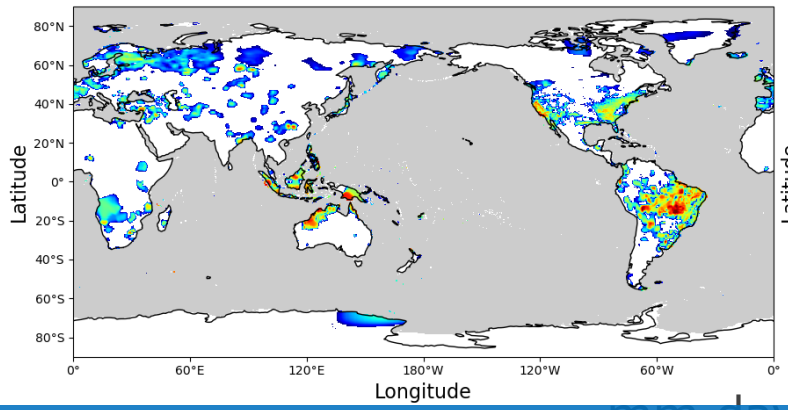
Prior



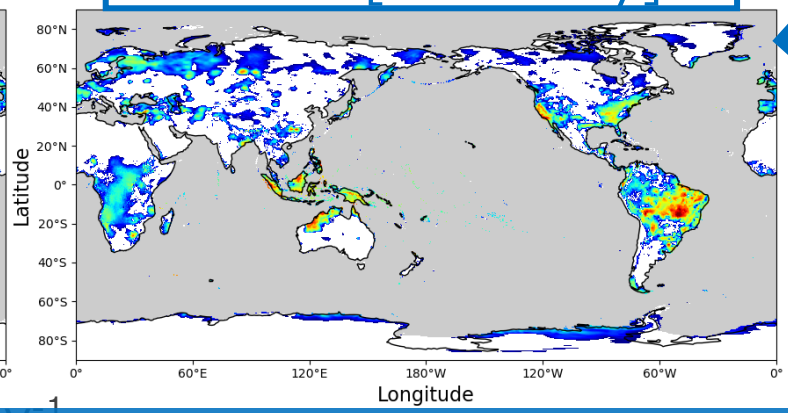
Observations



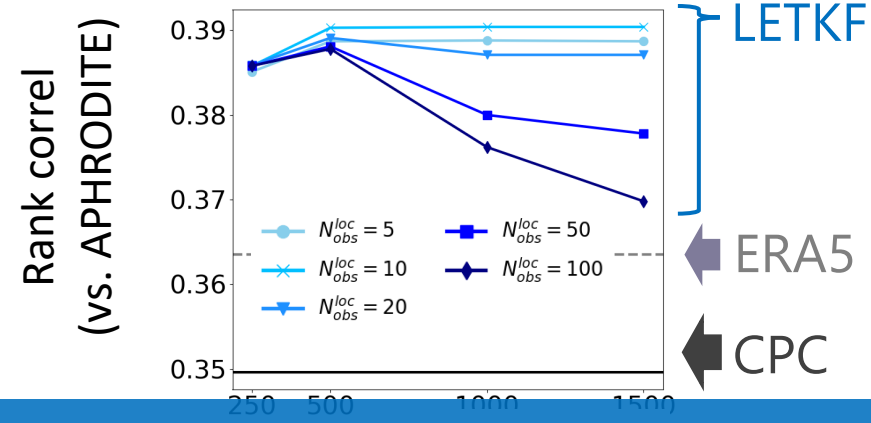
CPC



LETKF [this study]



mm day^{-1}



Muto-san developed a nicer dataset than ever!!

Ensemble forecast with RRI

研究目的

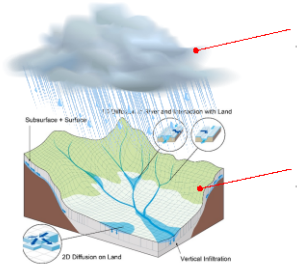
水文モデルRRI (Rainfall-Runoff-Inundation) にアンサンブルデータ同化を適用して予測精度改善

データ同化 × アンサンブル予報

- モデル状態に観測値を同化して予報の初期値を改善
- 観測地点の**上流・下流**の水位も合わせて更新
- アンサンブルで予測の不確実性を表現
  - 入力である降雨予測の誤差も考慮
- 最悪シナリオ想定の提供

3

シミュレーションに摂動を与える方法



降雨入力への摂動

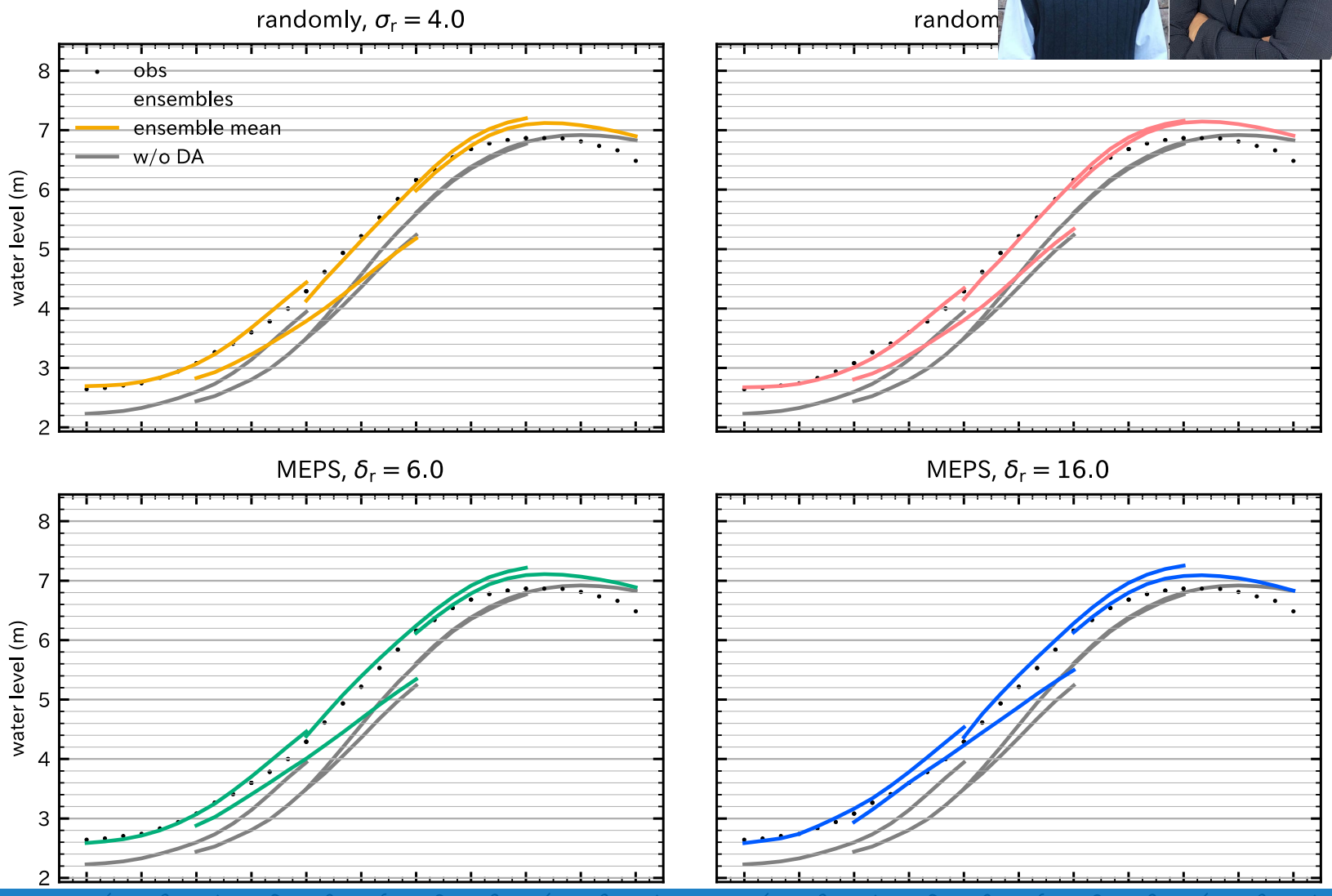
① randomly rain inflation
② MEPS rain inflation

MEPS: Meso-scale ensemble prediction system

モデルパラメータへの摂動

- マニング粗度係数
- 土層の空隙率

安定化手法	シミュレーションに摂動を与える方法	降雨入力に摂動を与える方法	randomly rain inflation
			MEPS rain inflation
		モデルパラメータに摂動を与える方法	
	局所化	単純な距離に基づく方法（euclid）	
		河川の規模を考慮する方法（river）	

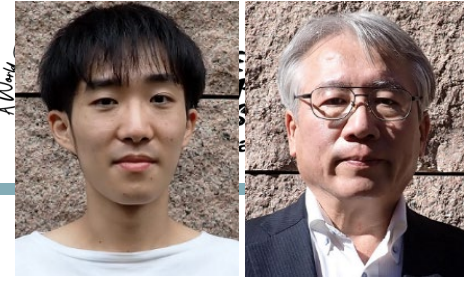


Fujimura-san proposed a method for flood prediction!

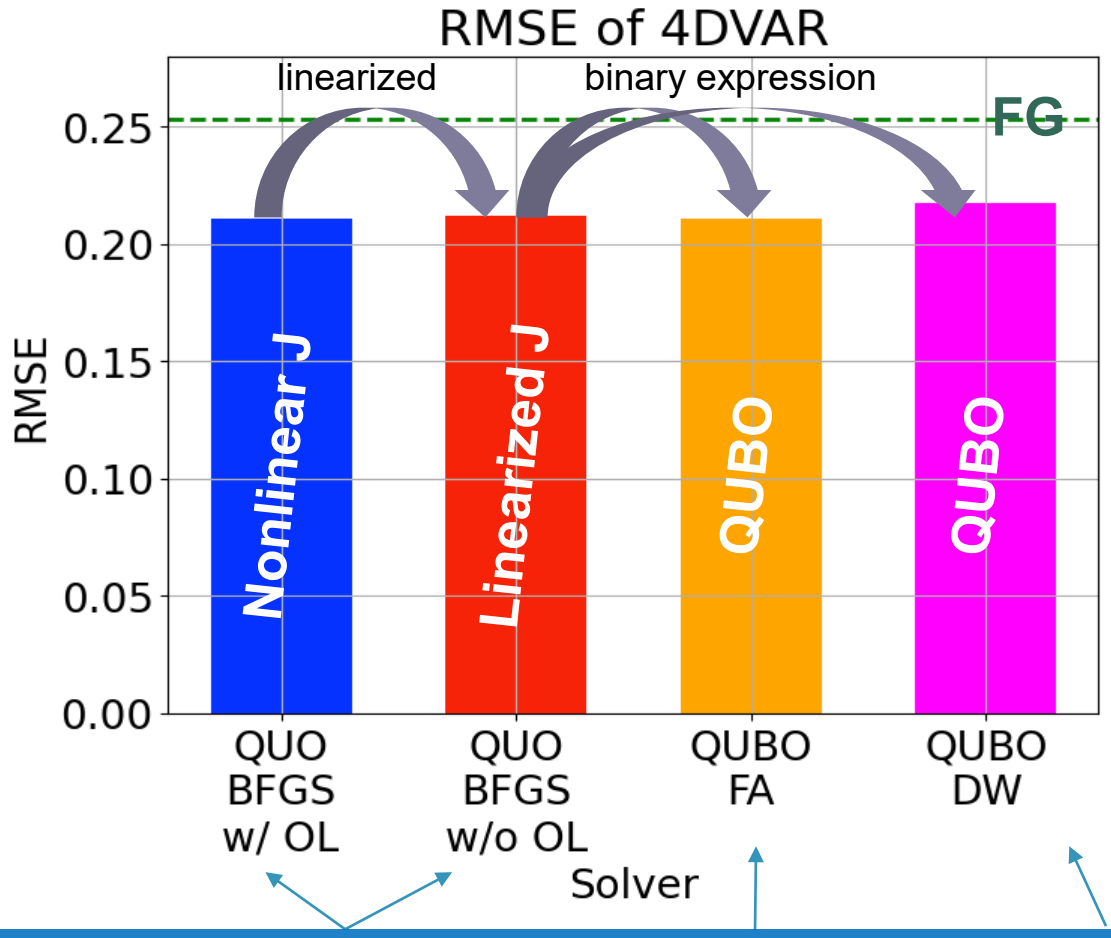
Prediction

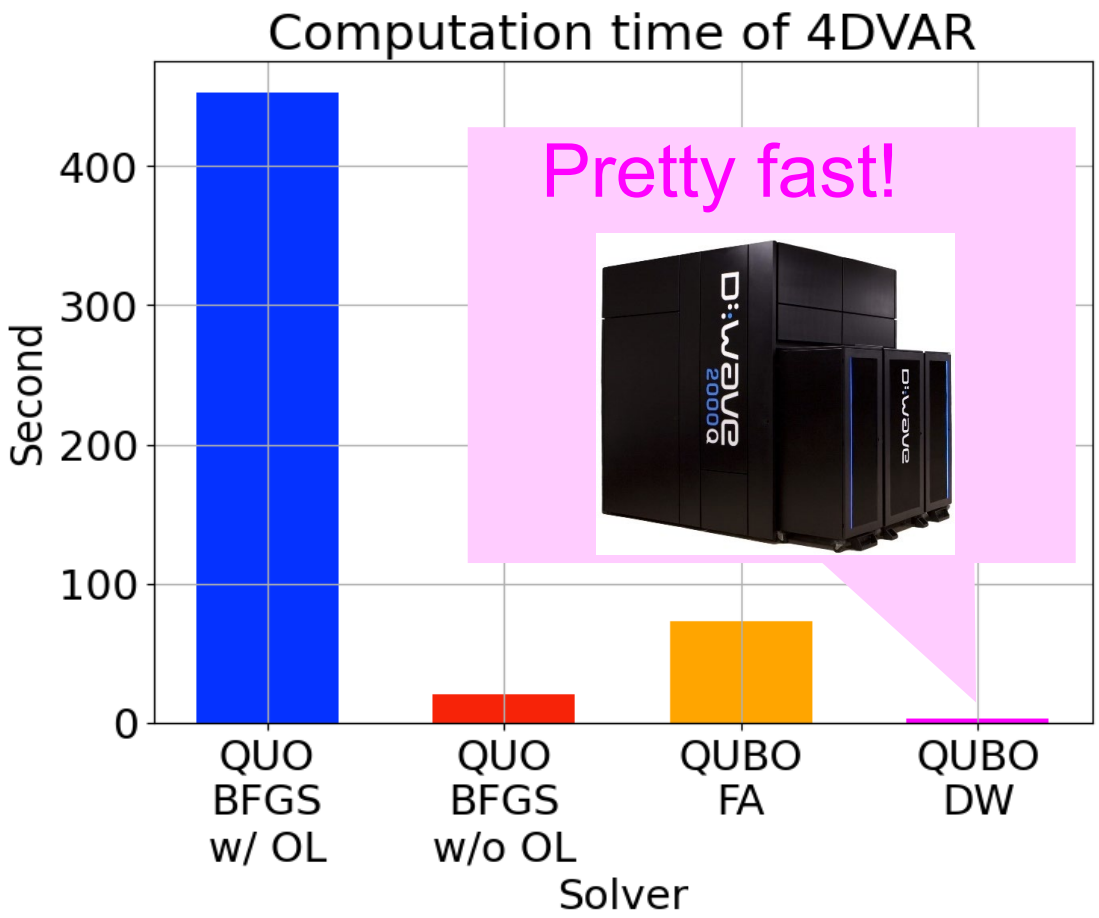
Assim & Ctrl

Quantum Annealing for 4DVAR



Average of 50 data assimilations
(window: 2days, 40 obs, **B** is manually tuned)





Scipy BFGS w/wo outer loop (w/wo TLM/ADJ updates)

Simulated QA (GPU-based)

Physical QA (D-Wave)

QAs used 4 quantum bits (QBs) for a real number due to the limitation of total QB.

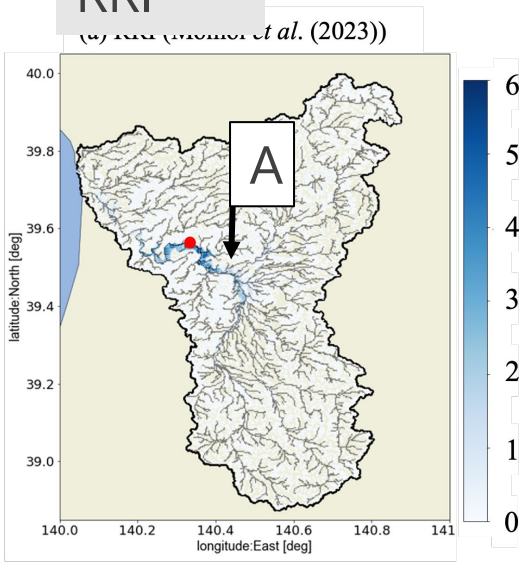
Kawasaki-san demonstrated the potential of QC!

ML Hydrology

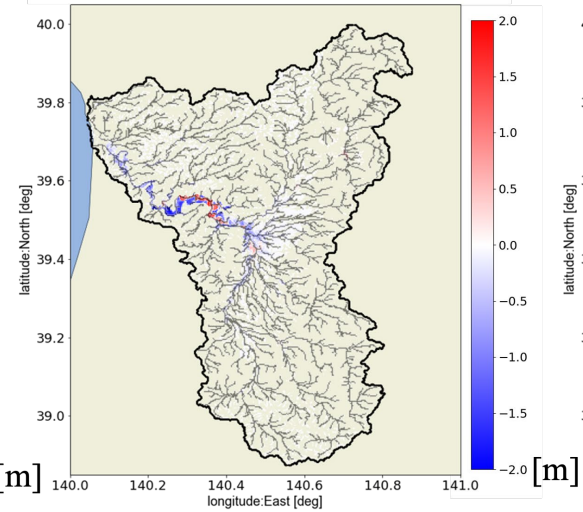
RRI emulator development

GOAL: Develop an emulator that estimates water dept timeseries

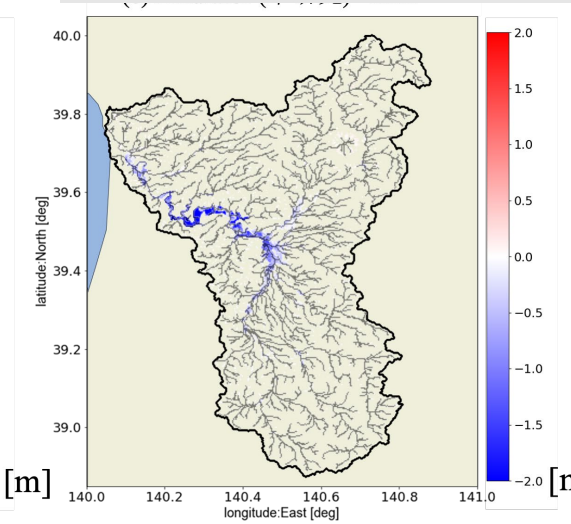
RRI



Momoi *et al.* (2023)

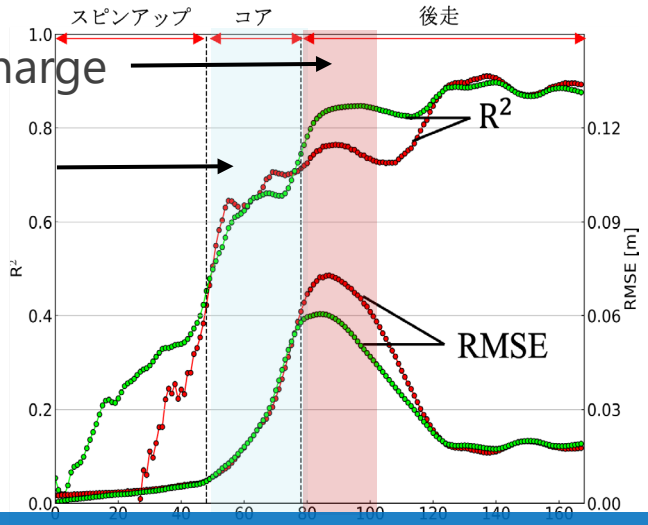


This study



Peak discharge

Strongest rainfall



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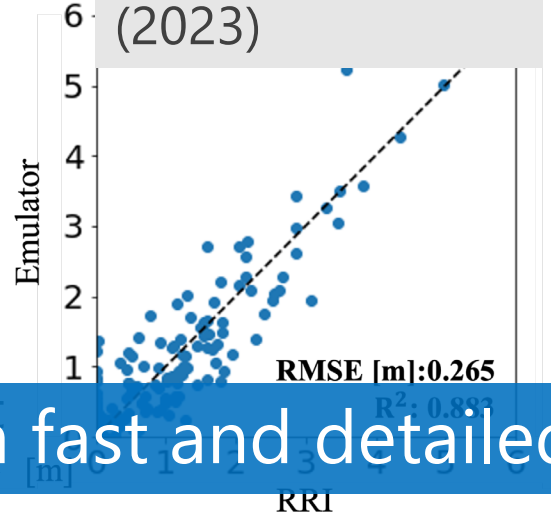

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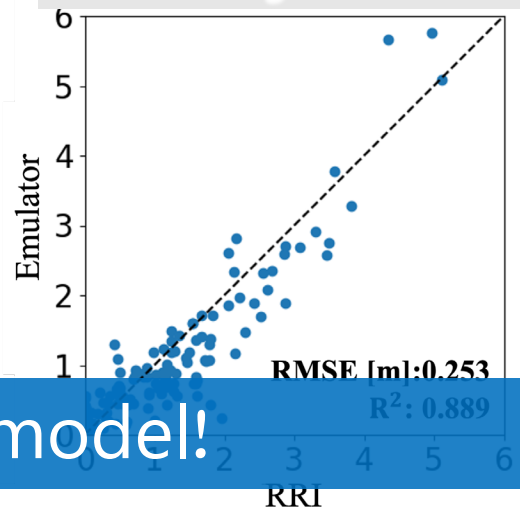
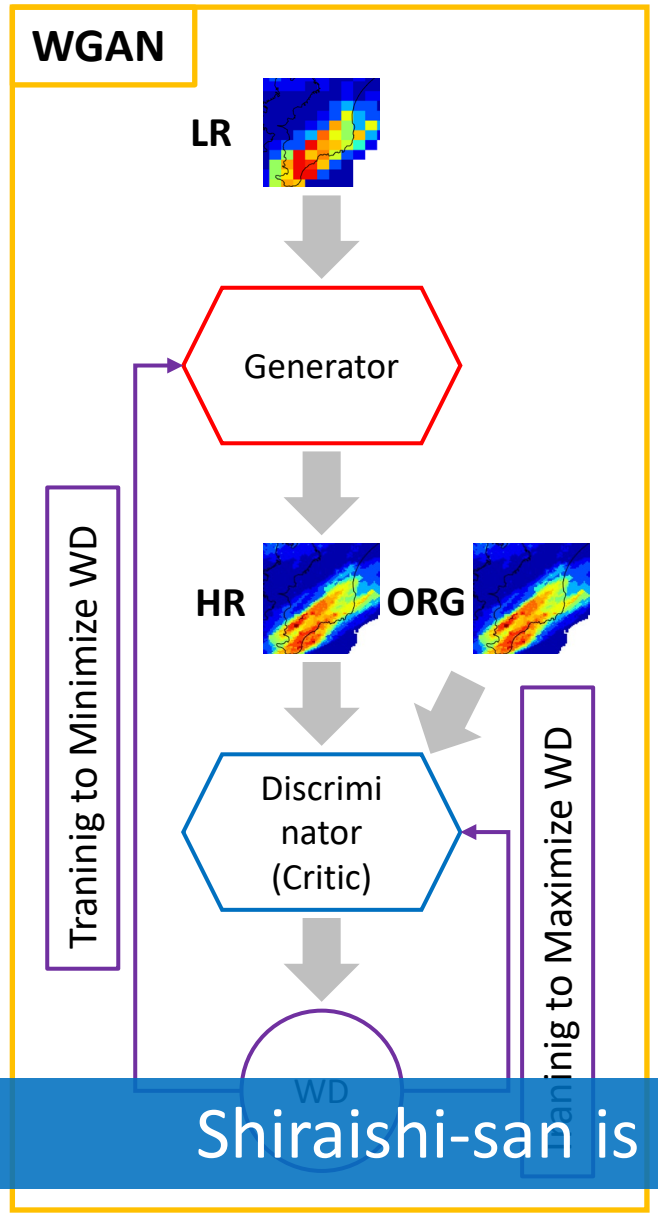


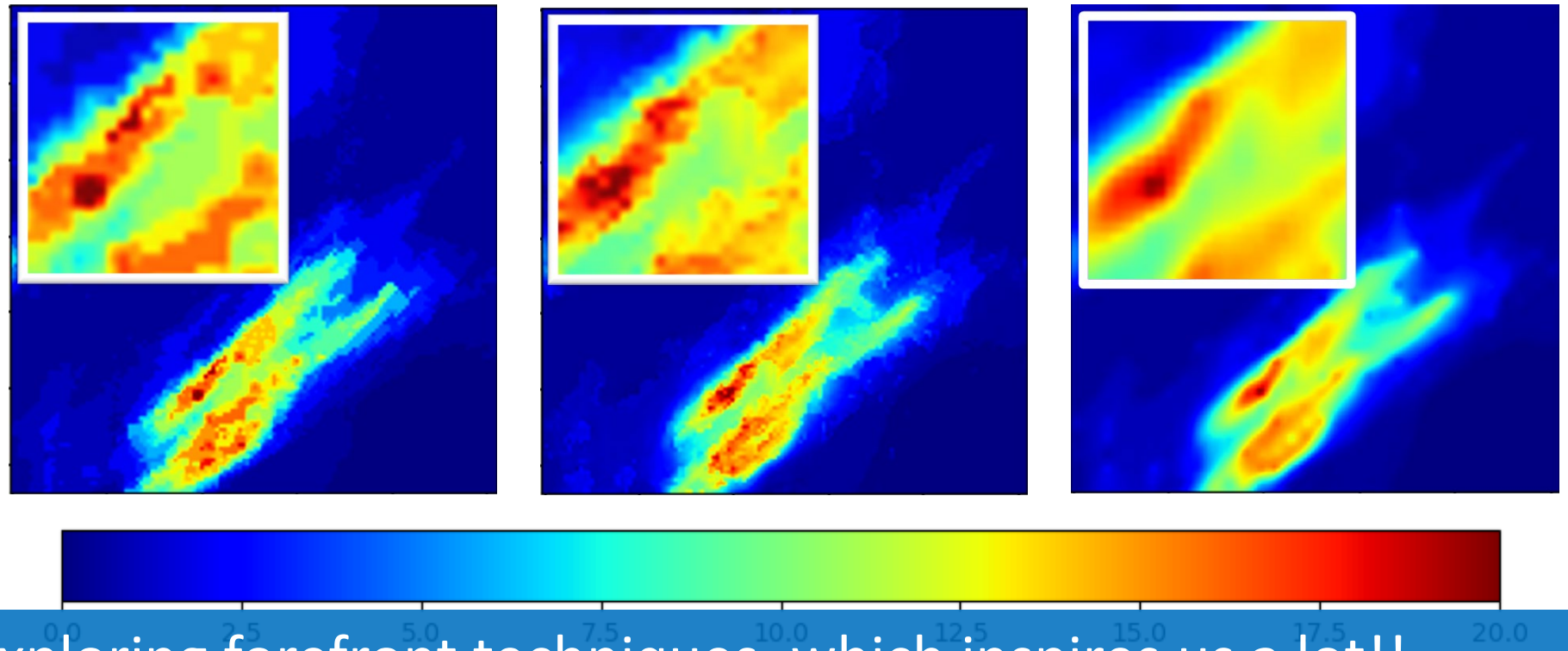
Shimabukuro-san developed a fast and detailed model!

Precipitation super-resolution



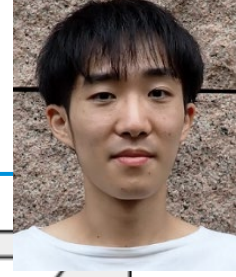
- Dowinscaling precipitation with CNN and WGAN
- WGAN is an algorithm that used Wasserstein Distance (WD) as the loss function

Original data | **Wasserstein GAN** | **SRCNN**



Shiraishi-san is exploring forefront techniques, which inspires us a lot!!

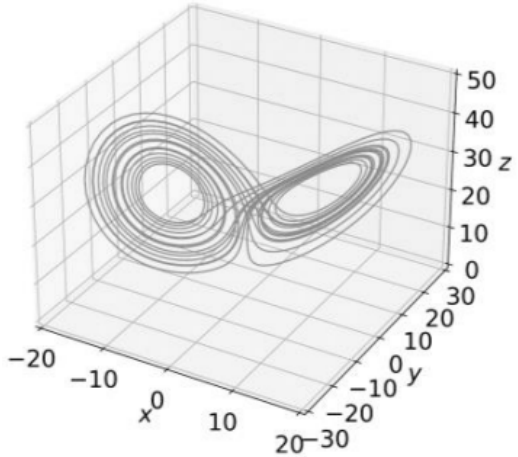
MPC & CSE Experiments w/ Lorenz 63 model



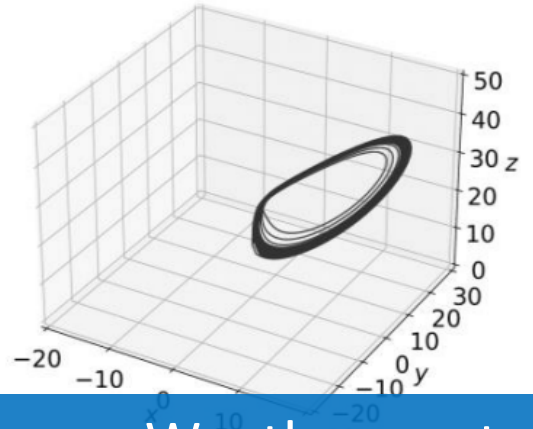
to keep L63 in right-side wing

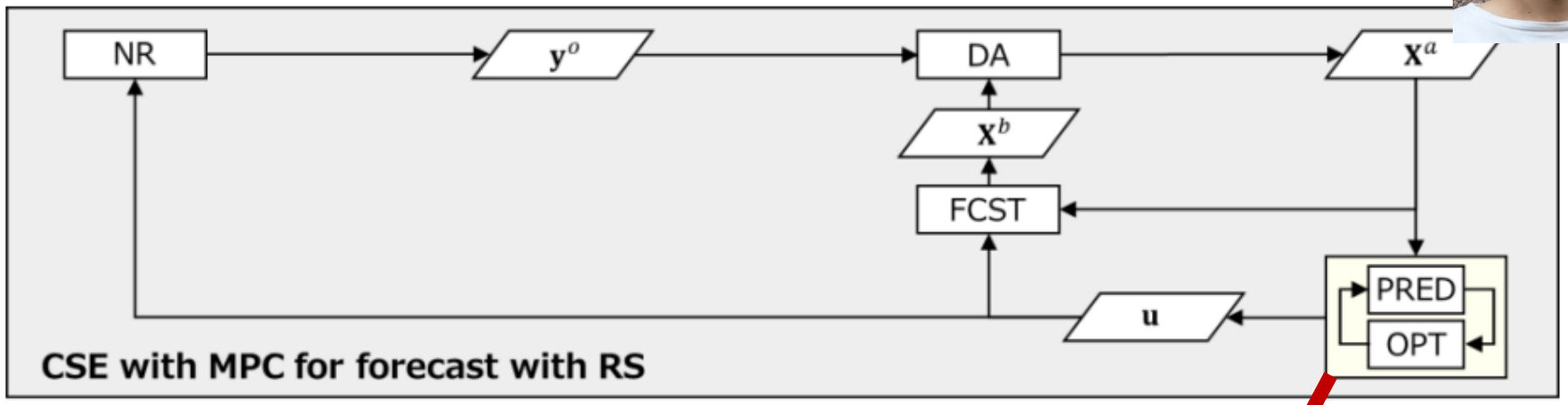
Miyoshi & Sun (2022)

(a) NR

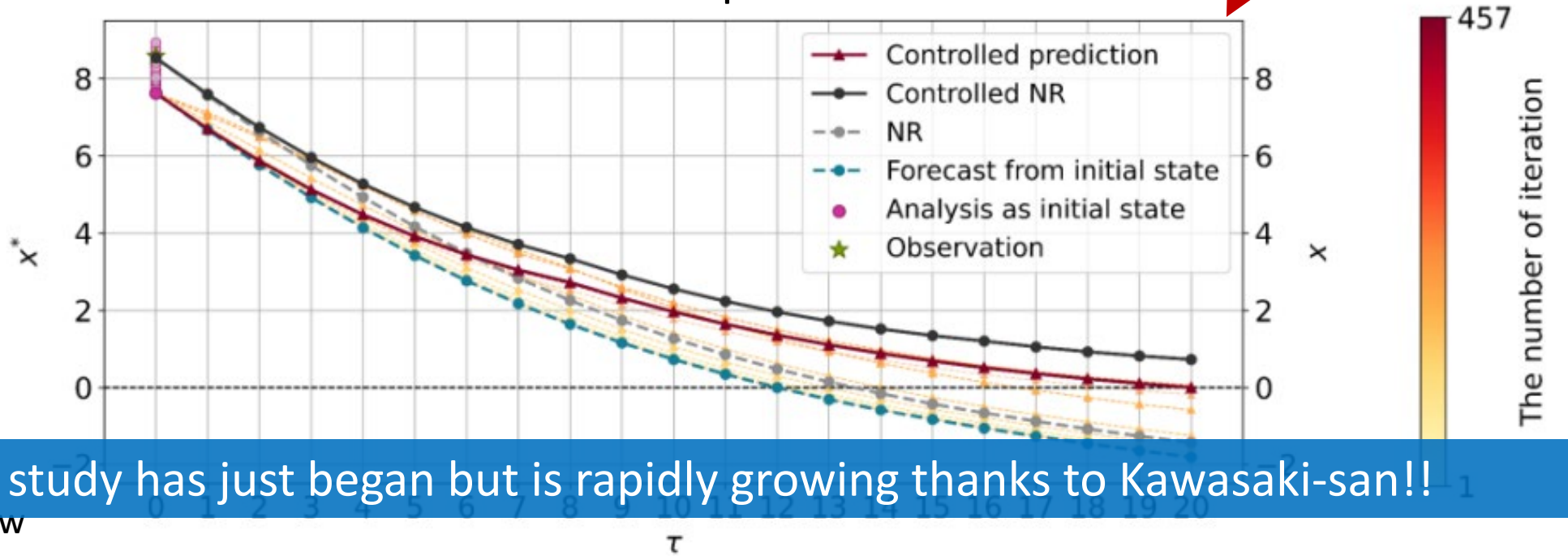


(b) Controlled NR





An MPC for a prediction



Weather control study has just began but is rapidly growing thanks to Kawasaki-san!!

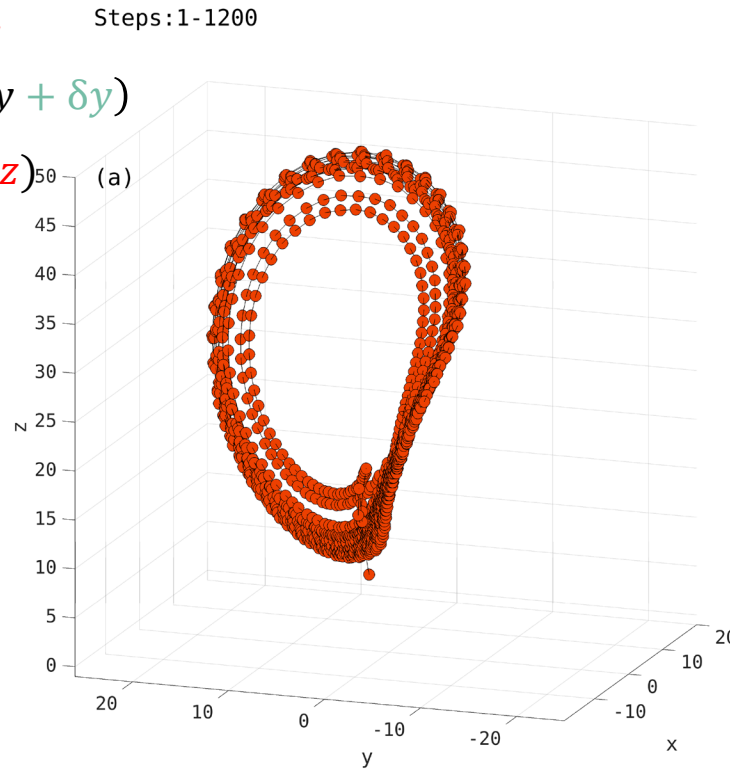
Kawasaki and Kotsuki, in review

Development of EnVAR based MPC algorithm

Settings

Model (L63; dt=0.01=1hr)

- $\frac{d(x+\delta x)}{dt} = \sigma(y+\delta y) - (x+\delta x)) + u_x$
- $\frac{d(y+\delta y)}{dt} = (x+\delta x)(\rho - (z+\delta z)) - (y+\delta y)$
- $\frac{d(z+\delta z)}{dt} = (x+\delta x)(y+\delta y) - \beta(z+\delta z)$

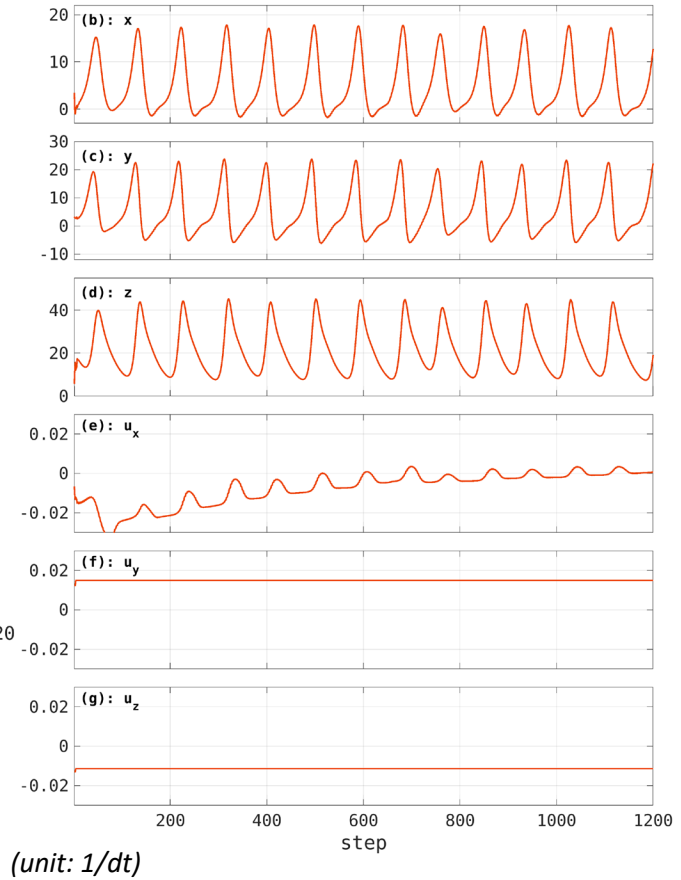


Data Assimilation

- Ens. Size: 10 member
- Constraints: x>0
- Estimate: δ x, δ y, δ z, u_x
- DA method: **EnMPC**

Horizons

- Prediction Horizon:
  10steps (=10hr)
- Control Horizon:
  5 steps (=5hr)



(unit: 1/dt)

Kurosawa-san added the essence of DA to weather control, which accelerates our work!

We've done a lot so far!!

Prediction ● ● ● ● ● ● ● Control / Adaptation

✗ Accurate prediction
(hourly ~ cenntennial)

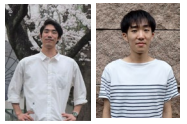
✗ Observations

✗ Estimation method (DA, ML)

✗ System model

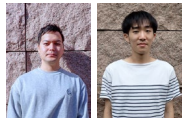
✗ Long dataset
- to understand the current state
- as an input for ML

✗ Fast prediction



✗ High-resolution prediction

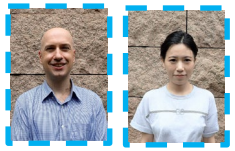
✗ Control theory



✗ Risk / Impact estimation

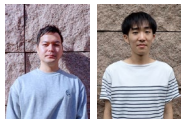
✗ Computation power
✗ Development of actuator machines
✗ Ethical, Legal, and Social Issues (ELSI) incl. risk communication

Now it's your turn!!



Prediction

Control / Adaptation



Seasonal to Decadal Prediction

✗ Accurate prediction
(hourly ~ cenntennial)

Machine Learning

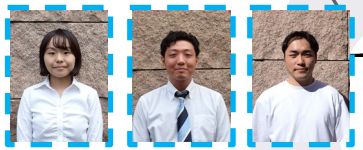
✗ Fast prediction

✗ High-resolution prediction

Assimilation and Control

✗ Control theory

✗ Risk / Impact estimation



✗ Observations

✗ Estimation method (DA, ML)

✗ System model

New PD

Hydrology

Observations incl. satellite & dataset

✗ Long dataset
- to understand the current state
- as an input for ML

New PD

Let's keep this good momentum.

Lastly but not least…

Let me tell you the essence to be a successful scientist
That is VW; Vision and work hard

Robert W. Mahley

You have to work at least 60 hours a week
when you're young to be a scientist

Fuqing Zhang

Vision without action is a daydream
Action without vision is a nightmare

Taikan Oki