

ビッグデータ同化： ゲリラ豪雨予測から気象制御への挑戦



みよしたけまさ
三好 建正

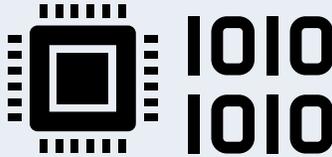
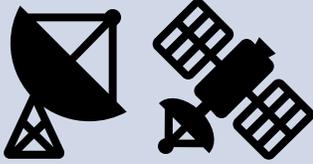
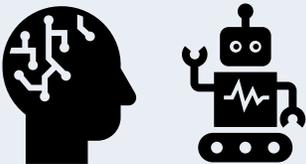
Ph.D. (Meteorology)
データ同化研究者



理化学研究所
計算科学研究センター
データ同化研究チーム



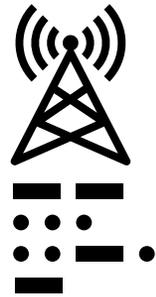
天気予報の革新の歴史

	技術革新	天気予報
1850	遠隔通信 	天気図解析
1950	電子計算機 	数値天気予報
1980	リモートセンシング ・ レーダ ・ 人工衛星 	データ同化 予測可能性
2015	AI/ML 	AI/MLを使った数値天気予報? 制御可能性?

科学の方法

帰納的推論

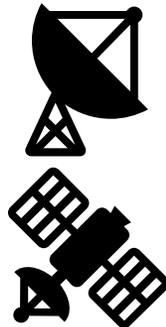
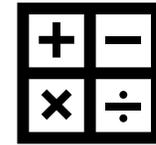
演繹的推論



経験科学
第1の科学



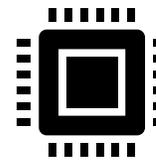
理論科学
第2の科学



データ科学
第4の科学



計算科学
第3の科学



1010
1010



Prediction Science

Inductive

Deductive

Experimental
1st Science



Theoretical
2nd Science



Data-centric
4th Science



Computational
3rd Science



理化学研究所 計算科学研究センター（神戸） RIKEN R-CCS, Kobe, Japan



TAKEMASA MIYOSHI

三好建正 (みよしたけまさ)

Team Principal

Data Assimilation Research Team
RIKEN Center for Computational Science (R-CCS)

Team Director

Prediction Science Research Team
RIKEN interdisciplinary Theoretical and Mathematical Sciences Program (iTHEMS)

大学卒業
↓
気象庁企画課 (2年)
↓
気象庁数値予報課 (1.25年)
↓
メリーランド大学
(2年, M.S. and Ph.D.)
↓
気象庁数値予報課 (3.5年)
↓
メリーランド大学 (4年)
↓
理化学研究所 (13年+)



Web of Science
ResearcherID



Google scholar
citations



Contact

Program Director, JST

Advisor, JAMSTEC

Visiting Professor, Kyoto University

Visiting Professor, University of Maryland

Research Counselor, National Meteorological Service, Argentina

Data Assimilation Research Team

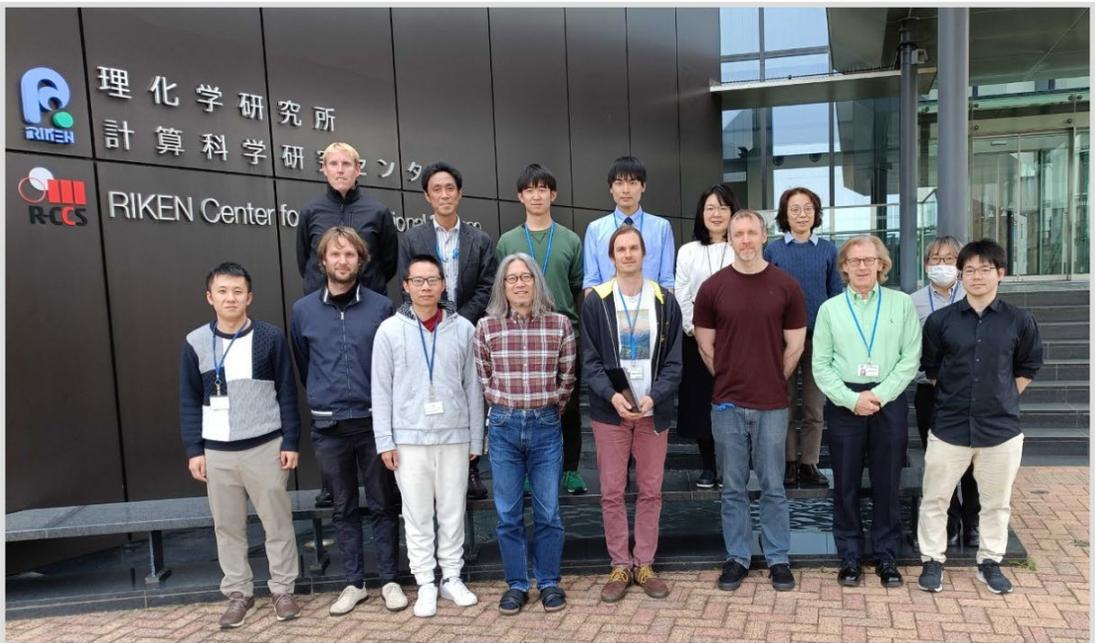
<http://www.data-assimilation.riken.jp/>

```
CALL MPI_BARRIER(MPI_COMM_WORLD, ierr)
CALL MPI_FINALIZE(MPI_COMM_WORLD, ierr)
WRITE(*,*) 'End of program'
STOP
END
```

Data Assimilation Research Team

Weather prediction is a great achievement of human intelligence by integrating advanced sensing, supercomputing, and information and communications technologies. Here, data assimilation plays a pivotal role. Connecting the most advanced radar sensing technology and supercomputers "K" and "Fugaku", data assimilation made it possible to predict sudden downpours. Data assimilation brings links to the future and expands synergistic opportunities.

- ▶ RIKEN Weather Forecast
- ▶ COVID-19 Realtime Forecast
- ▶ Youtube: AGU-TV RIKEN Digest(1 minute) / Full(5 minutes)
- ▶ Research Introduction (produced in February 2021)
- ▶ RIKEN Data Assimilation Channel



April 1, 2025 at R-CCS

History of LETKF implementation

JMA

- 2005 SPEEDY-LETKF (*Miyoshi, Ph.D. thesis*)
- 2006 NHM-LETKF (*Miyoshi and Aranami, SOLA*)
- 2007 AFES-LETKF (*Miyoshi and Yamane, MWR*)
- 2007 GSM-LETKF (*Miyoshi and Sato, SOLA*)

UMD

- 2010 MarsGCM-LETKF (*Hoffman et al., Icarus*)
- 2010 MASINGAR-LETKF (*Sekiyama et al., ACP*)
- 2010 SPRINTARS-LETKF (*Schutgens et al., ACP*)
- 2012 WRF-LETKF (*Miyoshi and Kunii, Pure and Appl. Geophys.*)
- 2012 ROMS-LETKF (*Hoffman et al., J. Atmos. Oceanic Tech.*)

RIKEN

- 2014 IsoGCM-LETKF (*Yoshimura et al., JGR*)
- 2015 NICAM-LETKF (*Terasaki, Sawada, Miyoshi, SOLA*)
- 2017 SCALE-LETKF (*Lien et al., SOLA*)
- 2022 sbPOM-LETKF (*Ohishi et al., GMD*)
- More... (e.g., AFES-Venus-LETKF, ...)

Pushing the limits

Big Data × *Big Simulations*

Big ensemble (10240 ensemble members)

Rapid update (30-second update)

High resolution (100-m mesh)

→ Future Numerical Weather Prediction



September 2012



March 2021

<https://awards.acm.org/bell-climate>

SC23 in Denver, CO (November 2023)

Specific Types of Contributions

ACM Gordon Bell Prize for Climate Modelling

Innovations in applying high-performance computing to climate modelling applications

Award Recipients

Nominations

Committee Members

FINALIST 3

Big Data Assimilation: Real-time 30-second-refresh Heavy Rain Forecast Using Fugaku During Tokyo Olympics and Paralympics

Authors: Takemasa Miyoshi, Arata Amemiya, Shigenori Otsuka, Yasumitsu Maejima, James Taylor, Takumi Honda, Hirofumi Tomita, Seiya Nishizawa, Kenta Sueki, Tsuyoshi Yamaura, Yutaka Ishikawa, Shinsuke Satoh, Tomoo Ushio, Kana Koike, and Atsuya Uno

<https://sc23.supercomputing.org/2023/09/eyes-beyond-the-prize/>



運用状況

通常運用中

「富岳」運用ステータス

運用スケジュール

[運用情報]Resource for ordinary users is reduced (available resource: 91%, due to real-time execution)

この期間、一般向けの提供資源が縮小されます。
実時間型ジョブ実行のため、提供される資源規模は、全体の約91%までとなります。
この期間、一般向けにはログインノード1は利用できません。

2021-06-02

スケジュール終了日時

2021-08-09 00:00

スケジュール開始日時

2021-07-19 15:00

During this period, the resources provided to the public will be reduced.
Due to real-time job execution, the resource size provided will be about 91% of the total.
During this period, login node 1 is not available for general use.

利用者支援

利用者ポータル

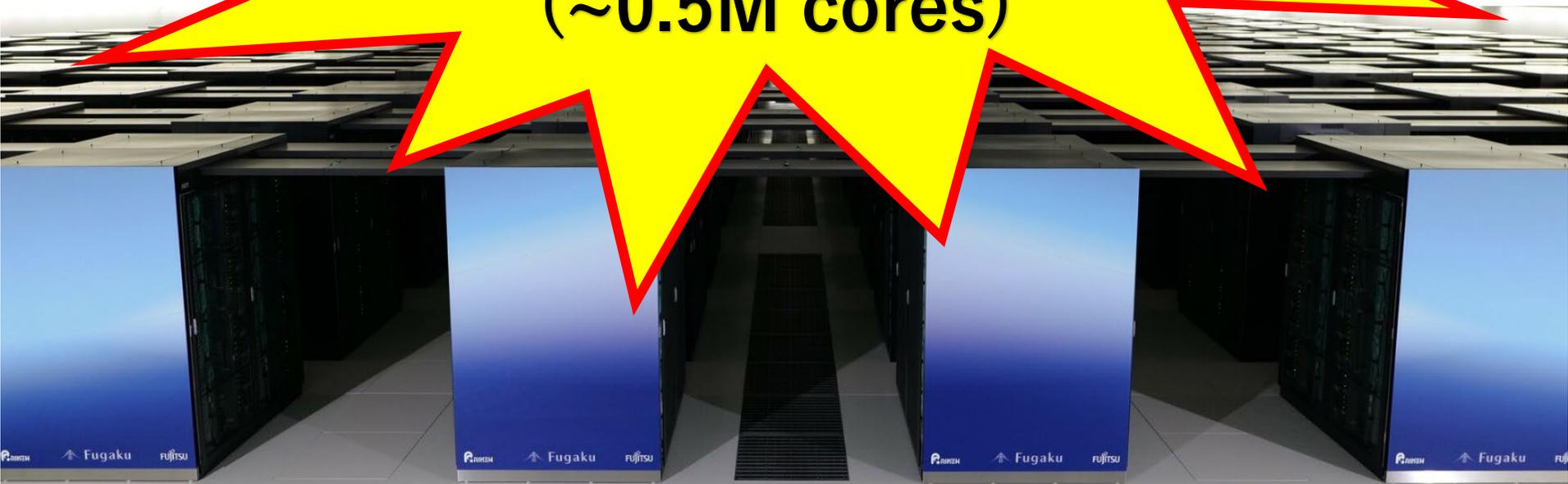
成果発表

申請

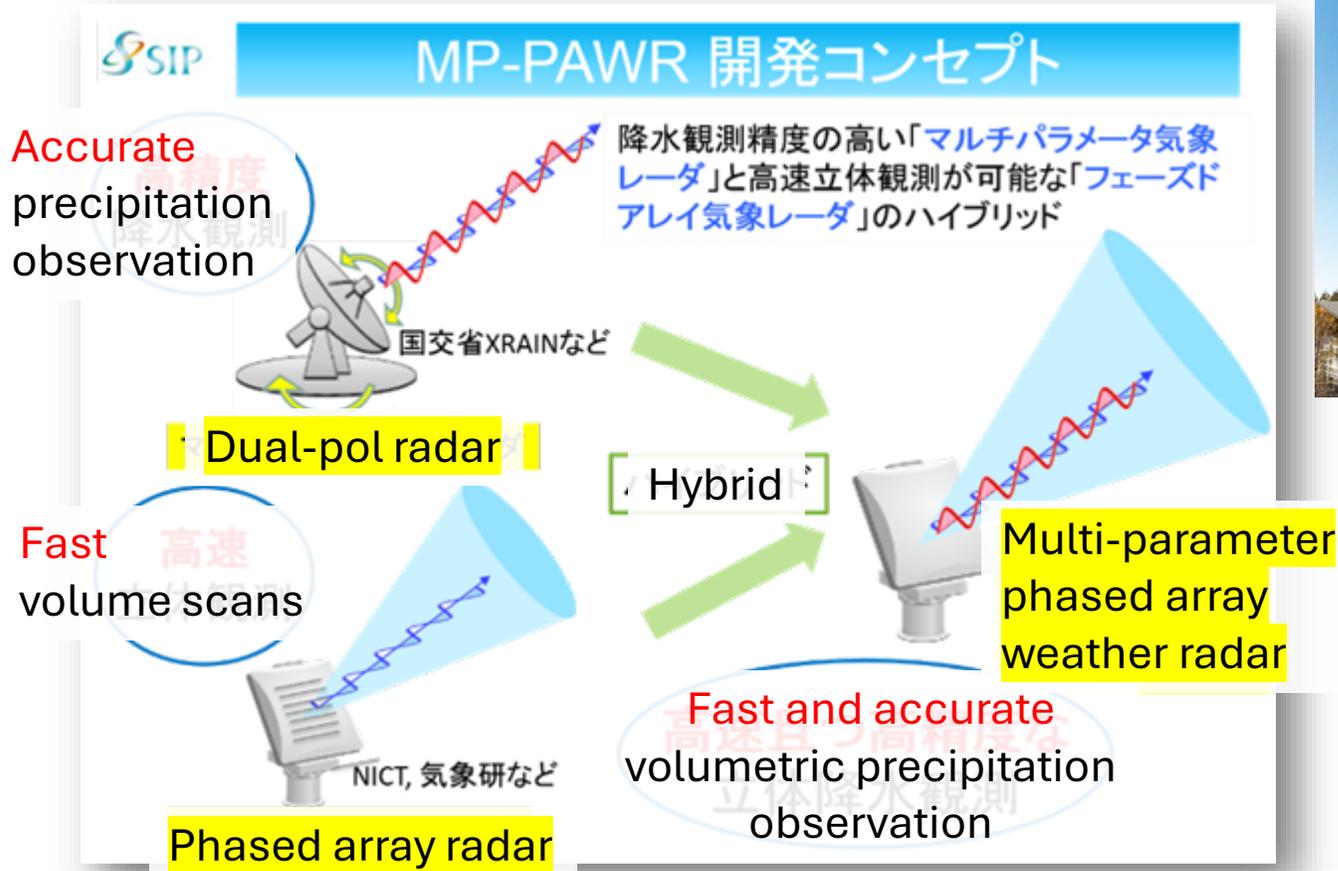
利用に関して

お問い合わせ

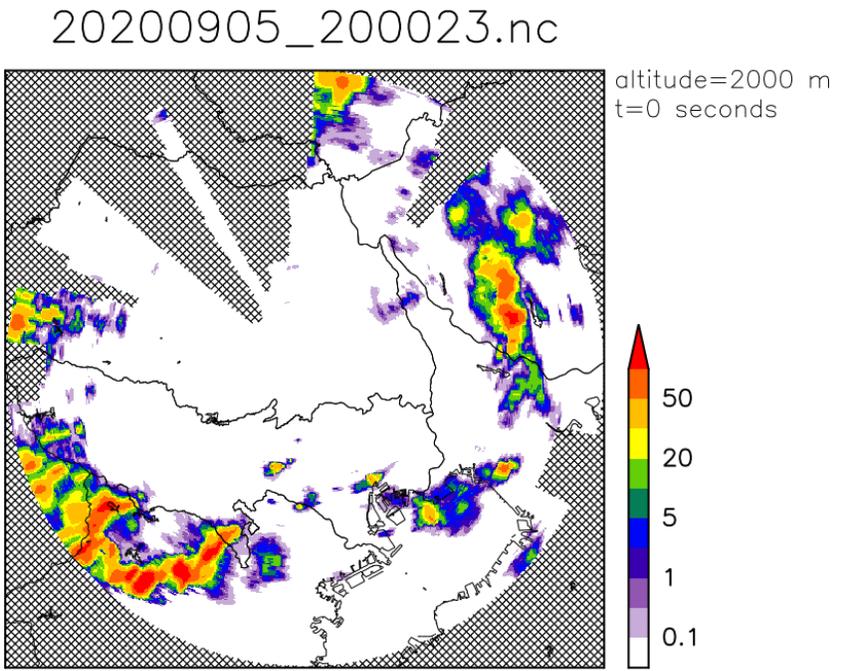
**Exclusive use of
~7% of Fugaku
(~0.5M cores)**



Multi-Parameter Phased Array Weather Radar (MP-PAWR)



(Takahashi et al. 2019)

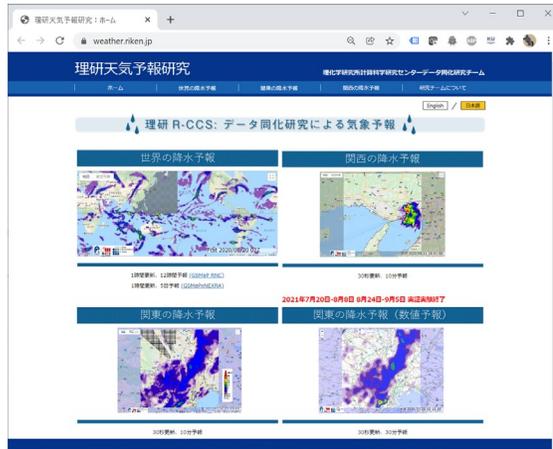


- X-Band Frequency Radar
- 75m range resolution
- ~100 elevation angles
- Full-sky scan every 30 seconds

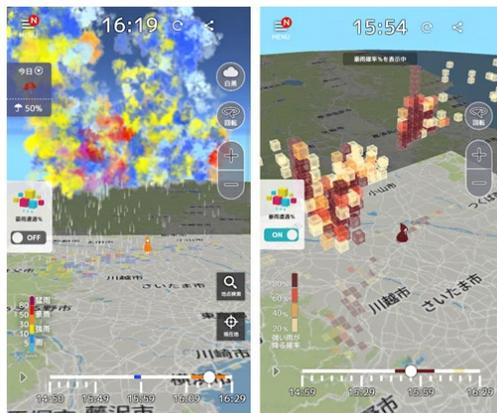
<https://www.nict.go.jp/press/2017/11/29-1.html>
(partially translated by S. Otsuka)

30-s refresh real-time workflow with “Fugaku”

Multi-Parameter Phased Array Weather Radar (at Saitama Univ.)

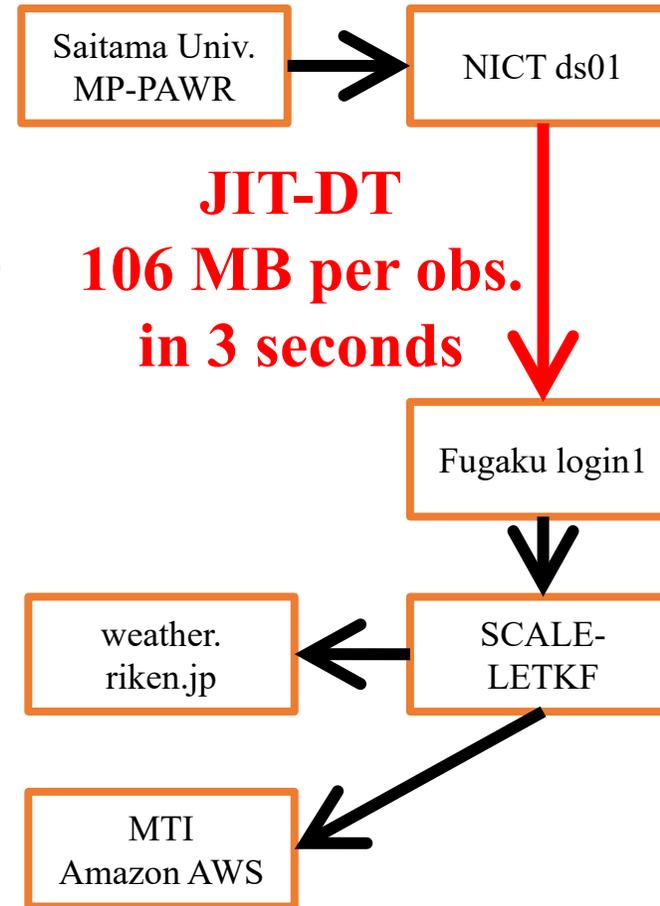


(Takahashi et al. 2019)



(MTI Ltd.)

NICT
Saitama Univ.
TOSHIBA



RIKEN R-CCS



webpage

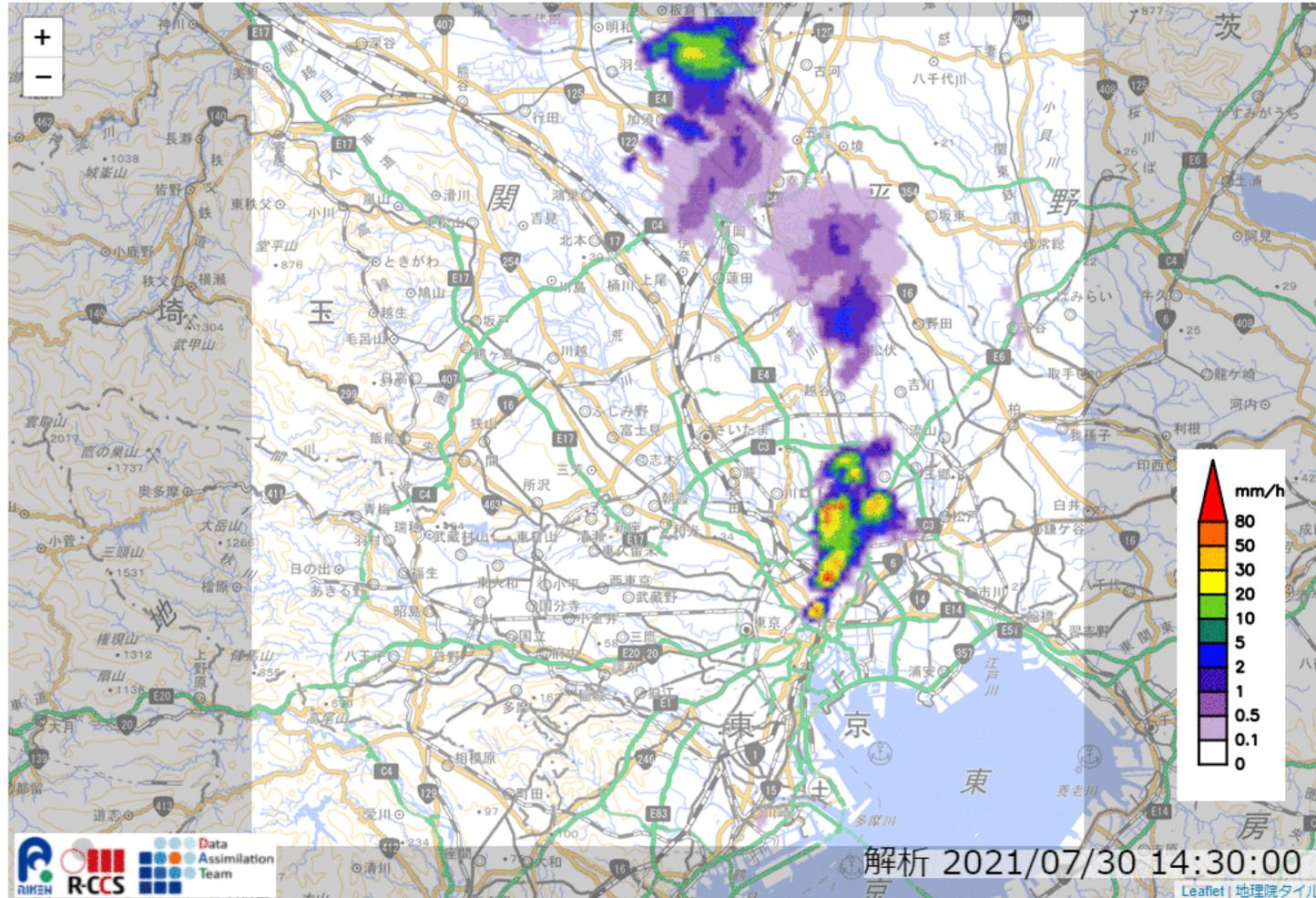
smartphone

<https://weather.riken.jp/>

予報開始時刻: 2021/07/30 14:30:00

<< 解析 2021/07/30 14:30:00 >>

予測 確率予測 観測 解析 気象庁レーダー アニメーション



Time-to-solution < 3 min.

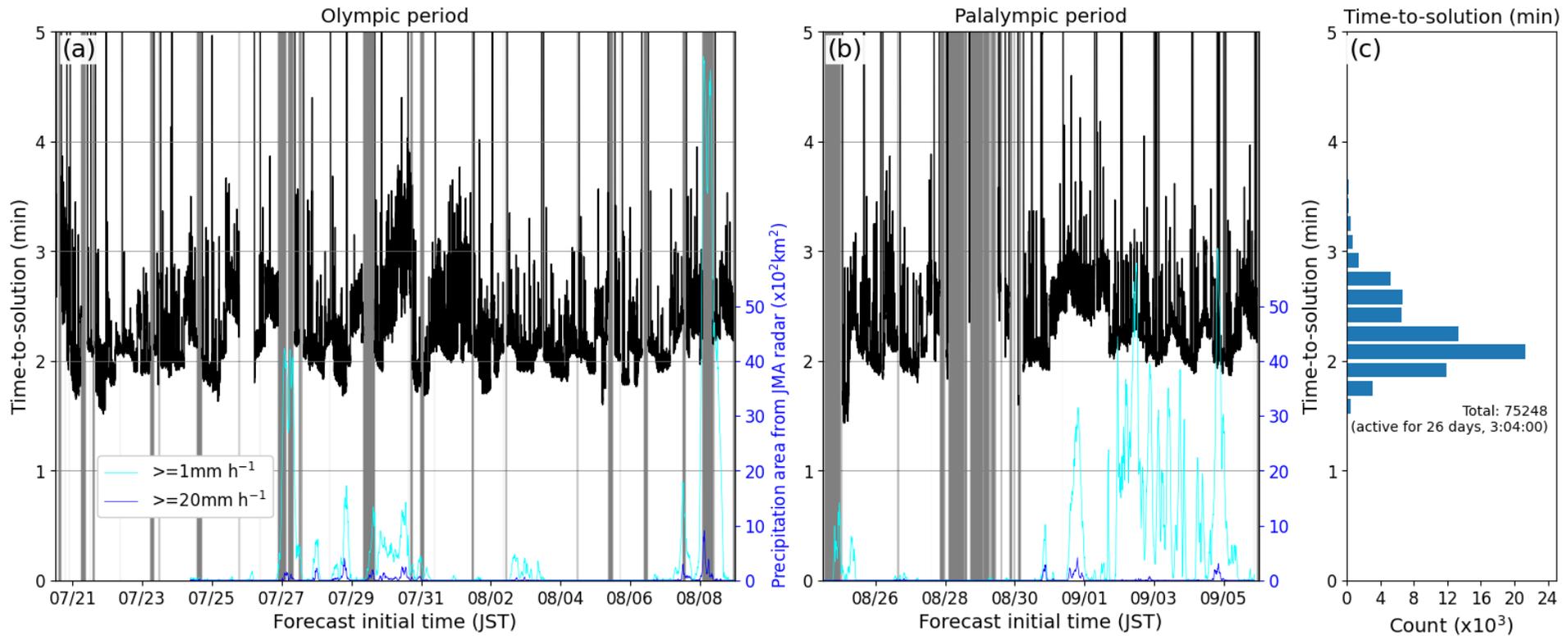


Figure 5: Every 30-second time series of time-to-solution (minutes, left axis) for each forecast initial time (JST) in 2021 for the periods of (a) Olympics and (b) Paralympics. Gray shadings show the periods when 30-minute forecasts were not produced in due course. Cyan and blue curves show the independent Japan Meteorological Agency observed rain area (100 km^2 , right axis) in the computational domain for rain rates $\geq 1 \text{ mm/h}$ (cyan) and $\geq 20 \text{ mm/h}$ (blue). (c) Histogram of time-to-solution (minutes). Total 75,248 forecasts were issued.

Skillful forecast achieved

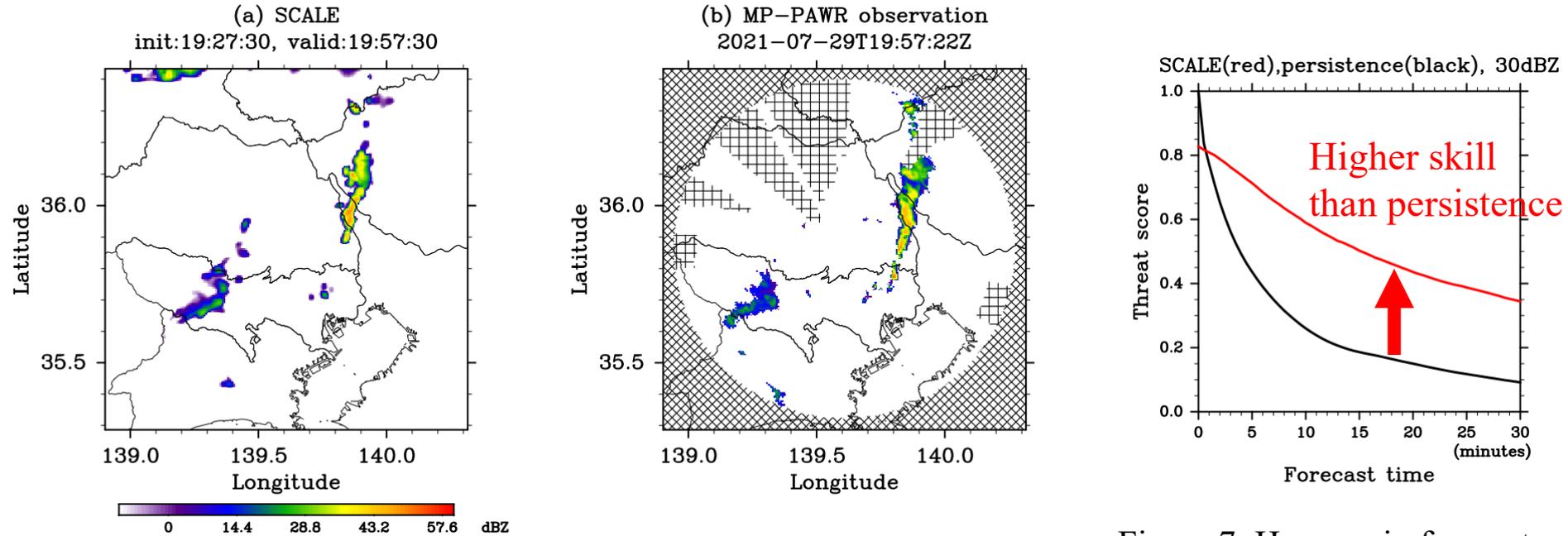


Figure 6: (a) 30-minute forecast rains at 19:57:30 UTC, July 29, 2021. Colors represent radar reflectivity (dBZ) at the 2-km height. (b) Similar to (a), but for the actual MP-PAWR observation at the closest time. Hatched areas indicate no data due to out of the 60-km range, radar beam blockage, or other reasons.

Figure 7: Heavy rain forecast skill as shown by threat scores (the higher, the more skillful) for radar reflectivity at the 30dBZ threshold for 120 forecast cases between 19:00:00 UTC and 20:00:00 UTC, July 29, 2021. Red and black lines indicate the BDA system and persistence, respectively.

Bird's-eye view

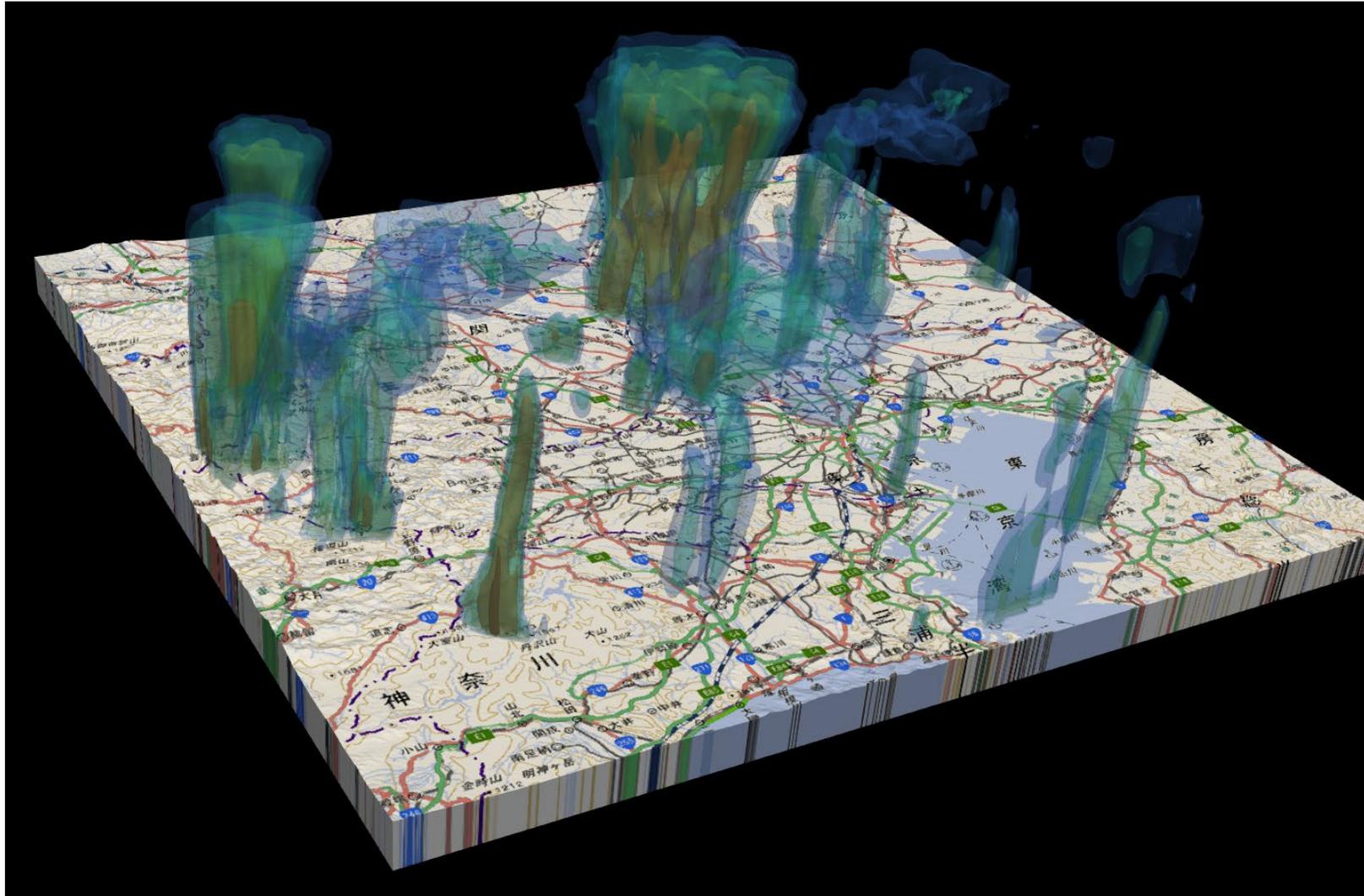


Figure 8: 3-D bird's-eye view of 30-minute forecast rains at 04:48:00 UTC, July 30, 2021. Colors represent simulated radar reflectivity every 10 dBZ for 10-50 dBZ. Vertical scale is stretched by three times. Map data is from the web page of the Geospatial Information Authority of Japan (Courtesy of H. Sakamoto of RIKEN).

120x faster, big ensemble, precision

(as of early 2023)

NWP system	Center	Data assimilation method	Forecast spacing / grid # grid points	Frequency for initialization / free forecast	Use of radar data	Ensemble forecast spacing / grid # members
LFM [6,7,8,9]	JMA, Japan	Hybrid 3DVar, 5-km grid spacing	2 km / 1581 x 1301 x 76	1 h / 1 h	Assimilation of RH from radar and radial wind	None (MEPS: 5 km / 21 members)
HRRR v4 [10,11,12]	NCEP, US	Hybrid 3D EnVar, 36 members	3 km / 1799 x 1059 x 51	1 h / 1 h	Latent heating	None
HRDPS 6.0.0 [13,14,15]	ECCC, Canada	4DEnVar perturbations from global ensemble	2.5 km / 2576 x 1456 x 62	6 h / 6 h	Latent nudging heat	None
UKV [16,17]	Met Office, UK	4DVar	1.5 km / 622 x 810 x 70	1 h / 1 h	Latent nudging heat	2.2 km / 3 members
AROME France [18,19,20]	Météo-France	3DVar	1.25 km / 2801 x 1791 x 90	1 h / 3 h	Assimilation of pseudo-RH from radar	2.5 km / 12 members
ICON-D2 [21,22,23]	DWD, Germany	LETKF 40 members	2.2 km / 542040 cells x 65 levels	1 h / 3 h	Latent nudging heat	2.2 km / 20 members
BDA2021 This paper	RIKEN, Japan	LETKF 1000 members	500 m / 256 x 256 x 60	30 s / 30 s	Reflectivity, Doppler velocity	500 m / 11 members

Future?

BIG DATA

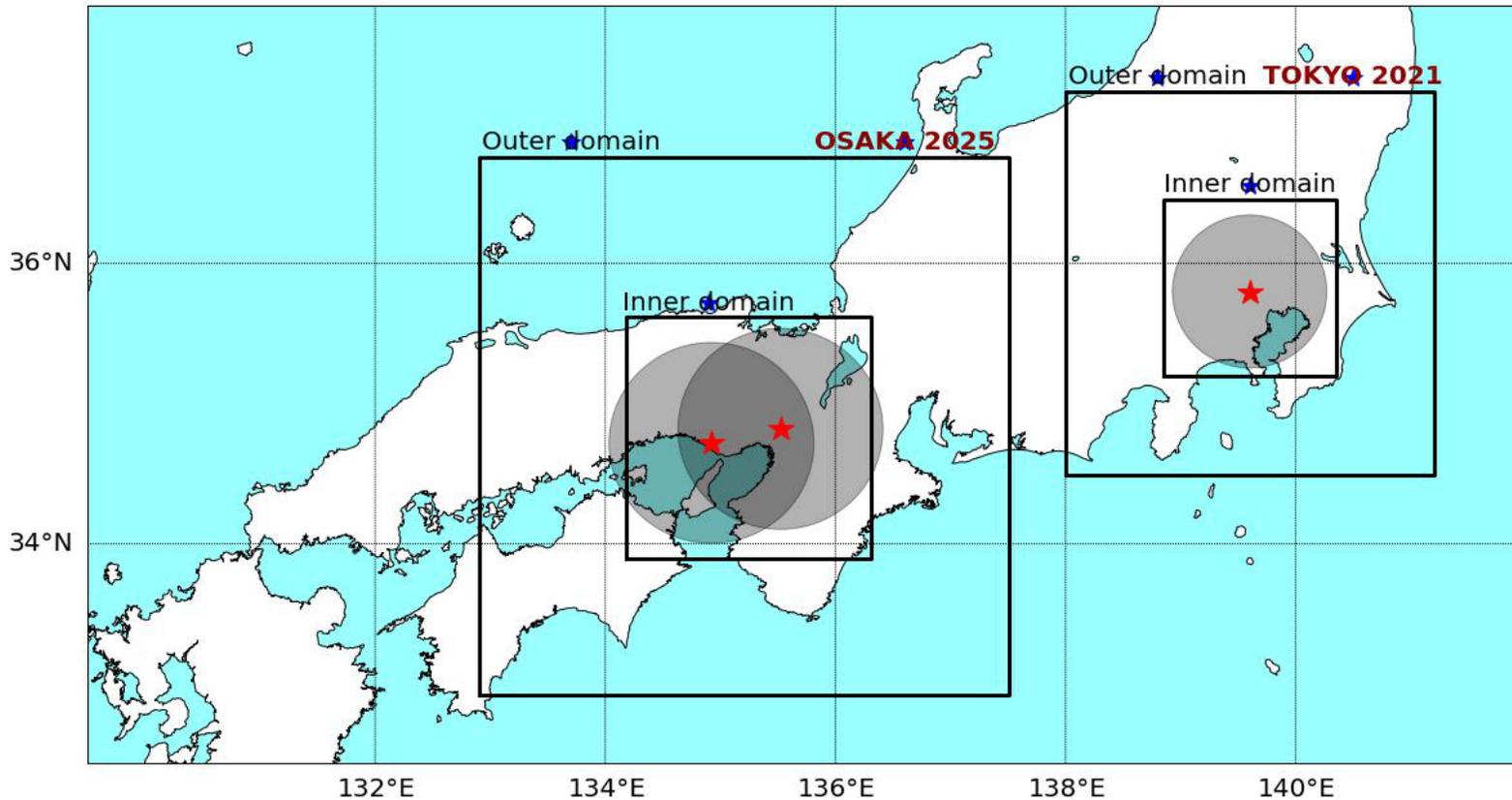
10:30–11:15 am CST

[From Gordon Bell Finalist to the Osaka Expo: The Evolution of Real-Time Forecasting on Fugaku](#)

[Takemasa Miyoshi](#)

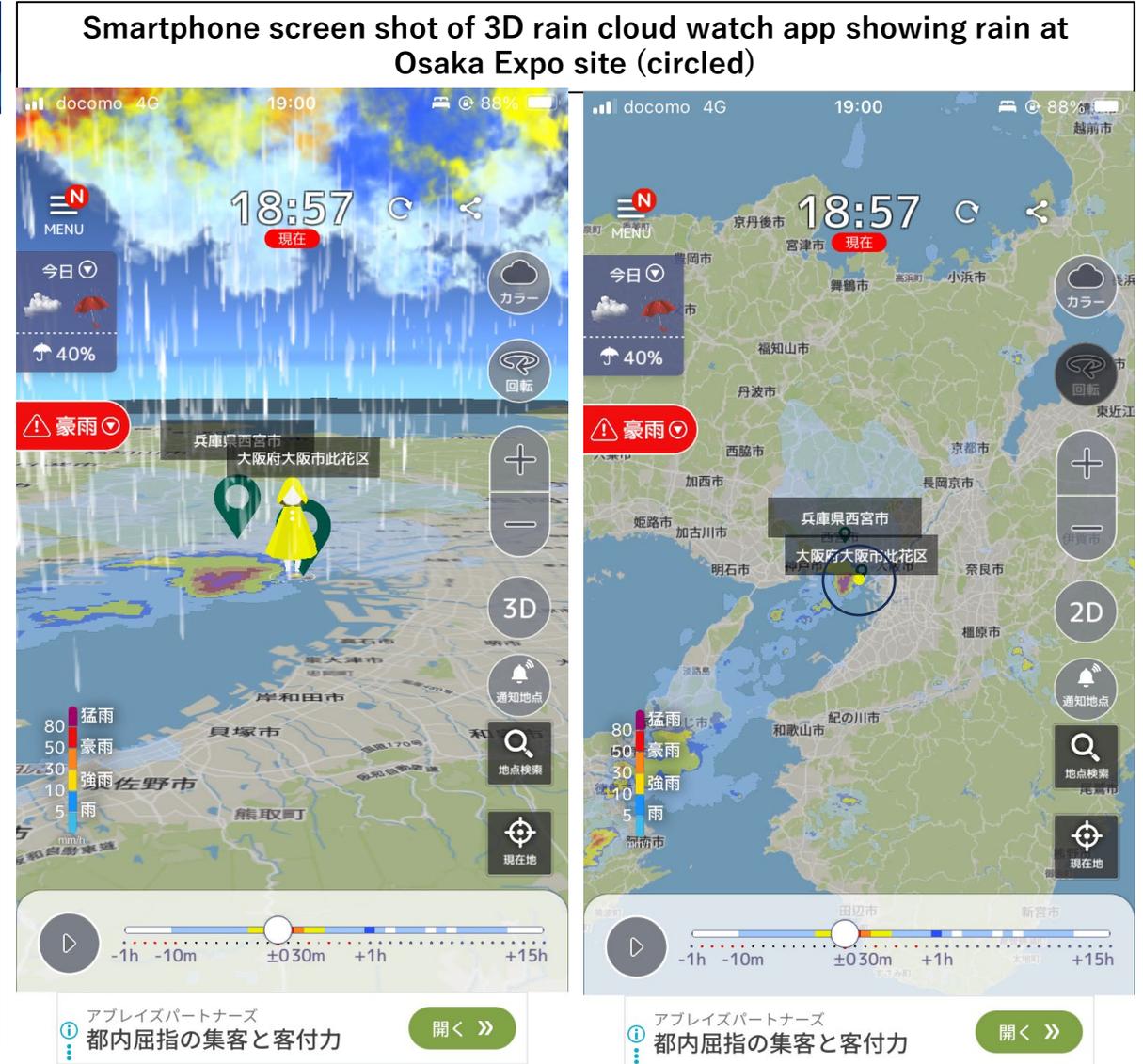
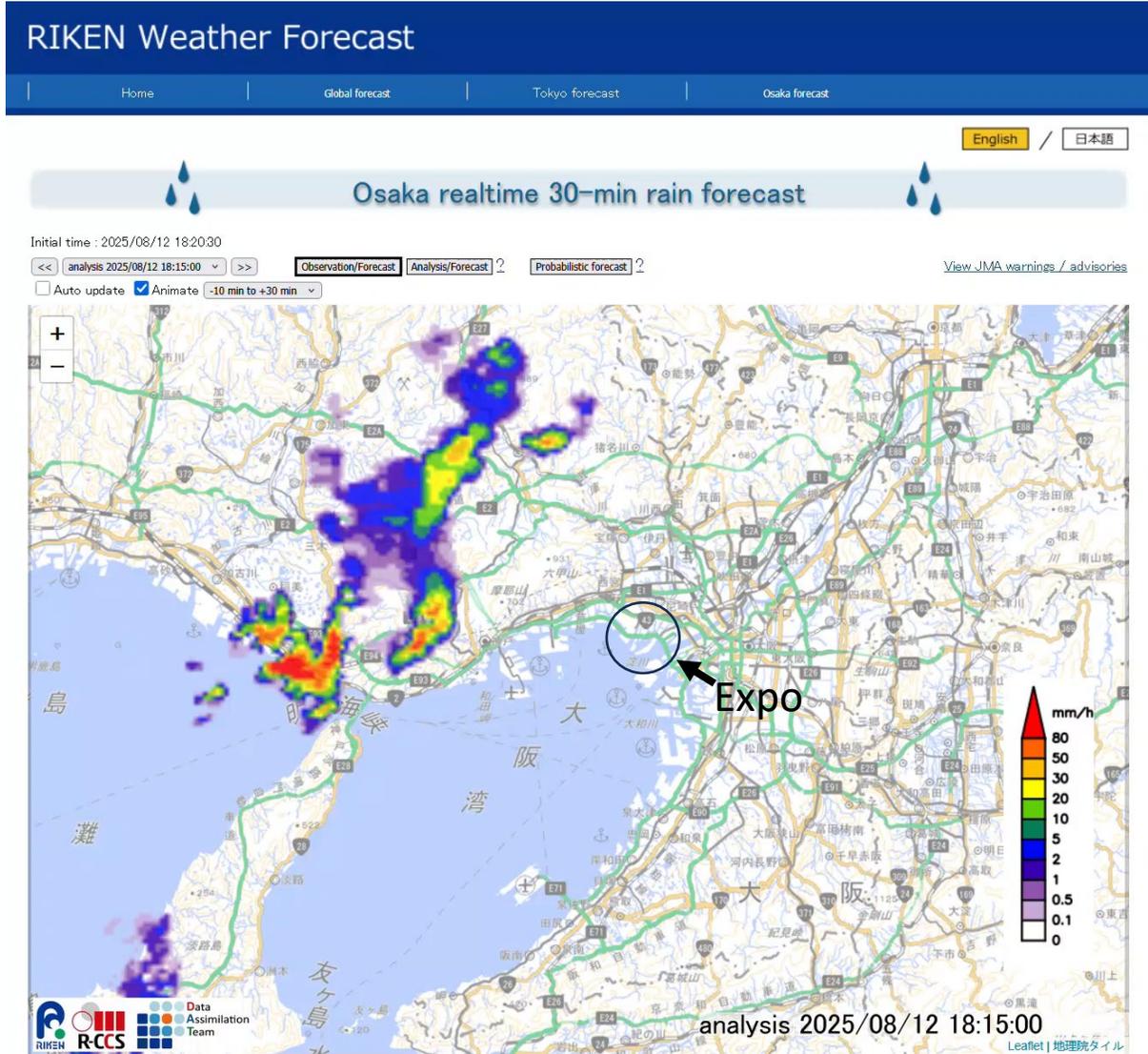
RIKEN Center for Computational Science (R-CCS)





	Osaka 2025 Real-Time Experiment	Tokyo 2021 Real-Time Experiment
Experiment Duration	1 month	1 month
Number of forecasts	>75,000	75,248
Ensemble size (LETKF)	1000	1000
Number of MP-PAWRs	2 (Kobe and Osaka MP-PAWR) 2 x Doppler wind and Reflectivity	1 (Saitama MP-PAWR) 1 x Doppler wind and Reflectivity
Inner Domain Size	192 x 192 km	128 x 128 km
Number of computational nodes	26,648 (16% of total nodes on Fugaku)	11,580 (7%)

Osaka 2025 30-minute Rain Forecast: 18:20 (local time) 12th Aug 2025



- Fast moving line of convection from west with >80 mm/hr rainfall
- Advanced warning given to visitors via smartphone app

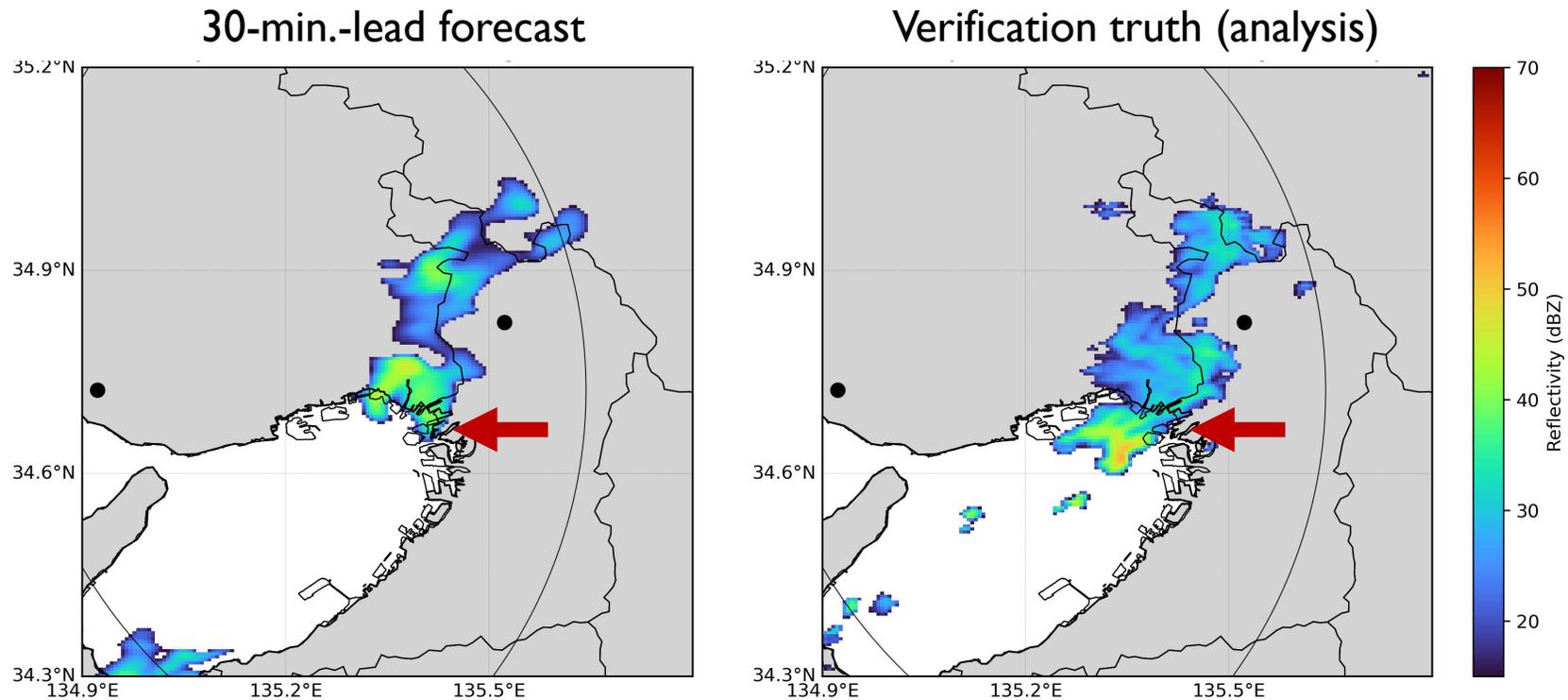
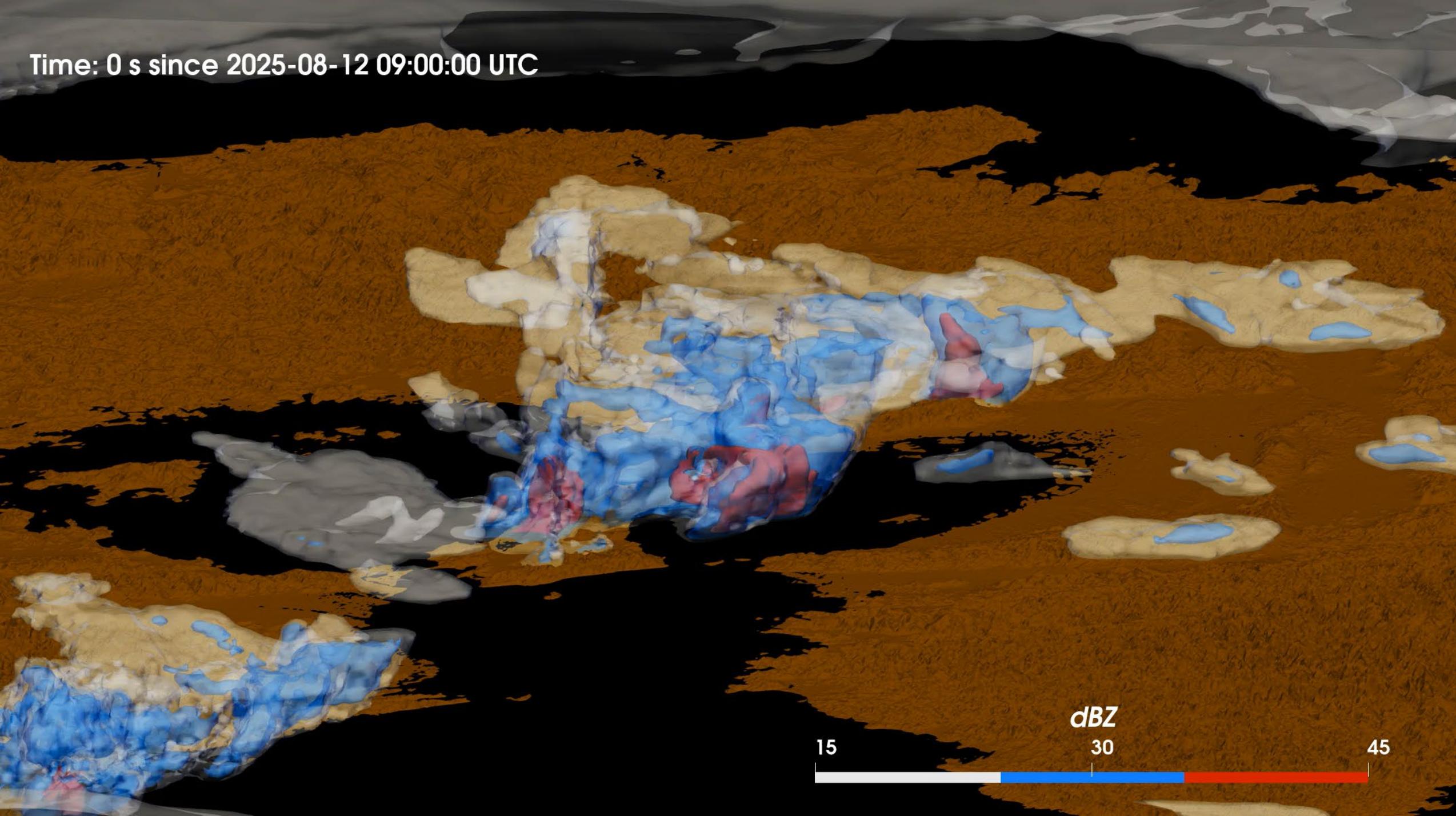
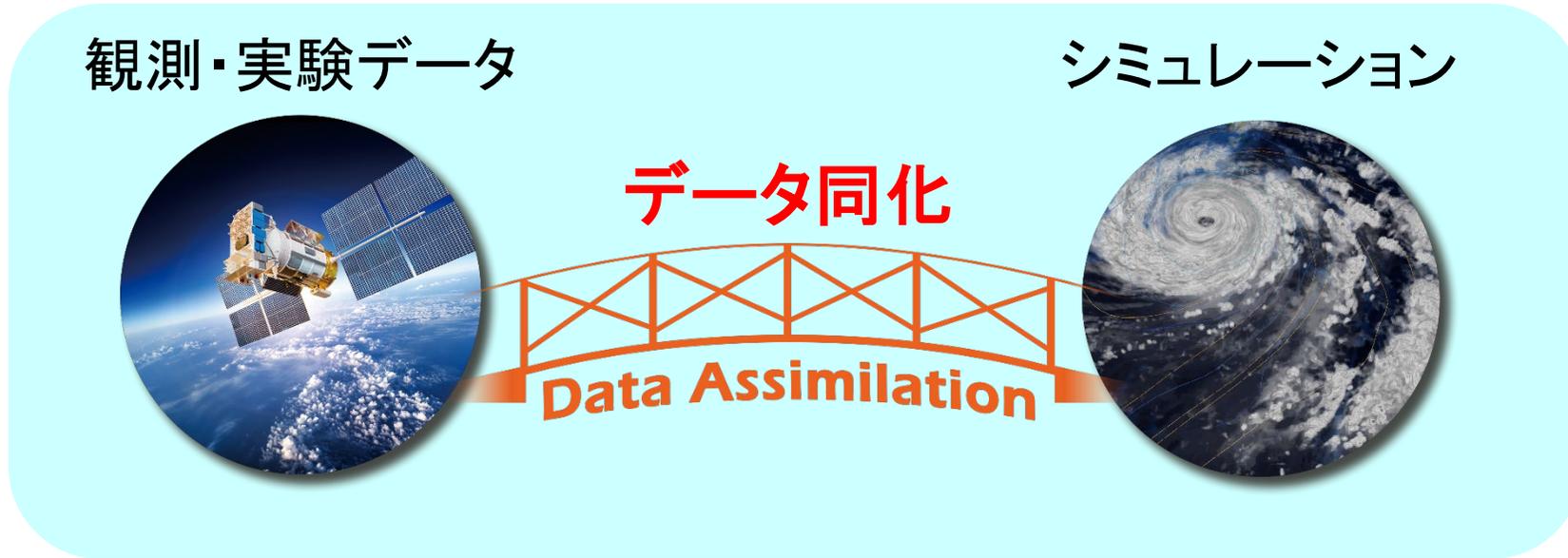


Figure. A case of forecasting rain clouds using “Fugaku” during Expo 2025 Osaka, Kansai. Rain intensity (red is stronger) at 18:53 JST 12 August 2025. Push notification via smartphone app was made successfully based on this forecast.

Time: 0 s since 2025-08-12 09:00:00 UTC



データ同化



データ同化は、シミュレーションと現実世界を結びつけ、相乗効果を生み出す。

双方の情報を最大限に抽出

データ同化

観測・実験データ

1

データ同化

+

シミュレーション

1

> 2

データ同化

Data-driven

帰納
現実世界

観測・実験データ

1

データ同化

+

Process-driven

演繹
サイバー空間

シミュレーション

1

> 2

Data-driven

帰納
現実世界

観測・実験データ

Process-driven

演繹
サイバー空間

シミュレーション

データ同化の数理

力学系 dynamical systems

統計数理 statistical mathematics

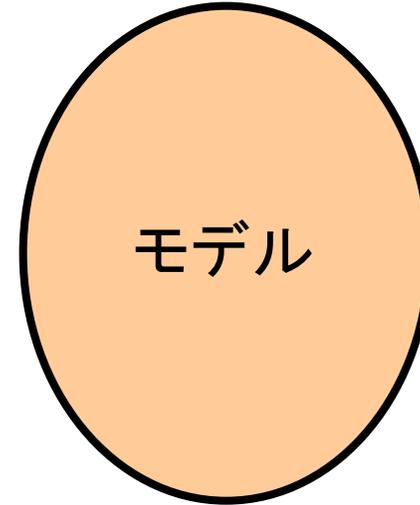
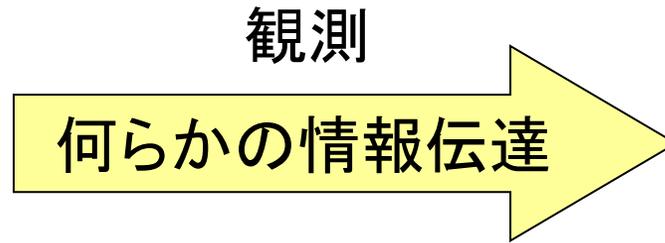
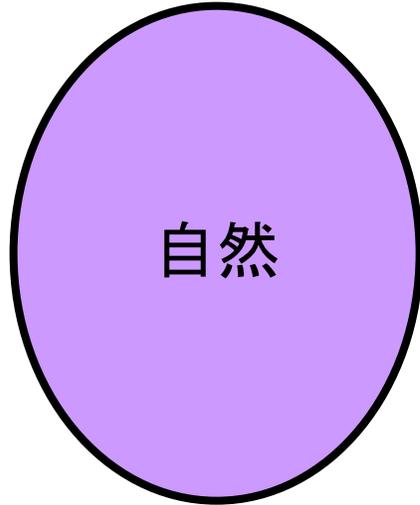
UQ (uncertainty quantification)

> 2

カオス同期 Chaos Synchronization

Master (drive) system

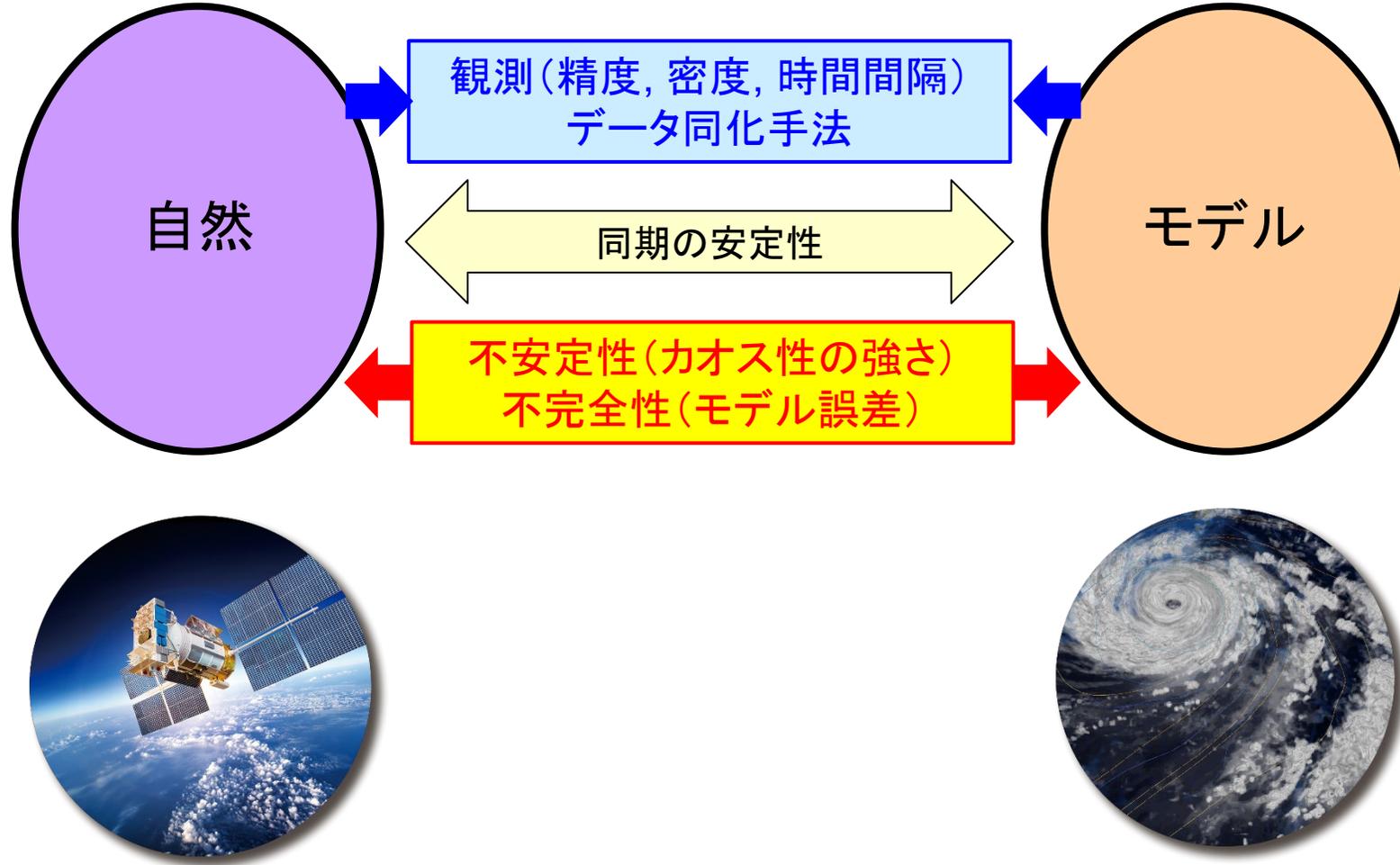
Slave (response) system



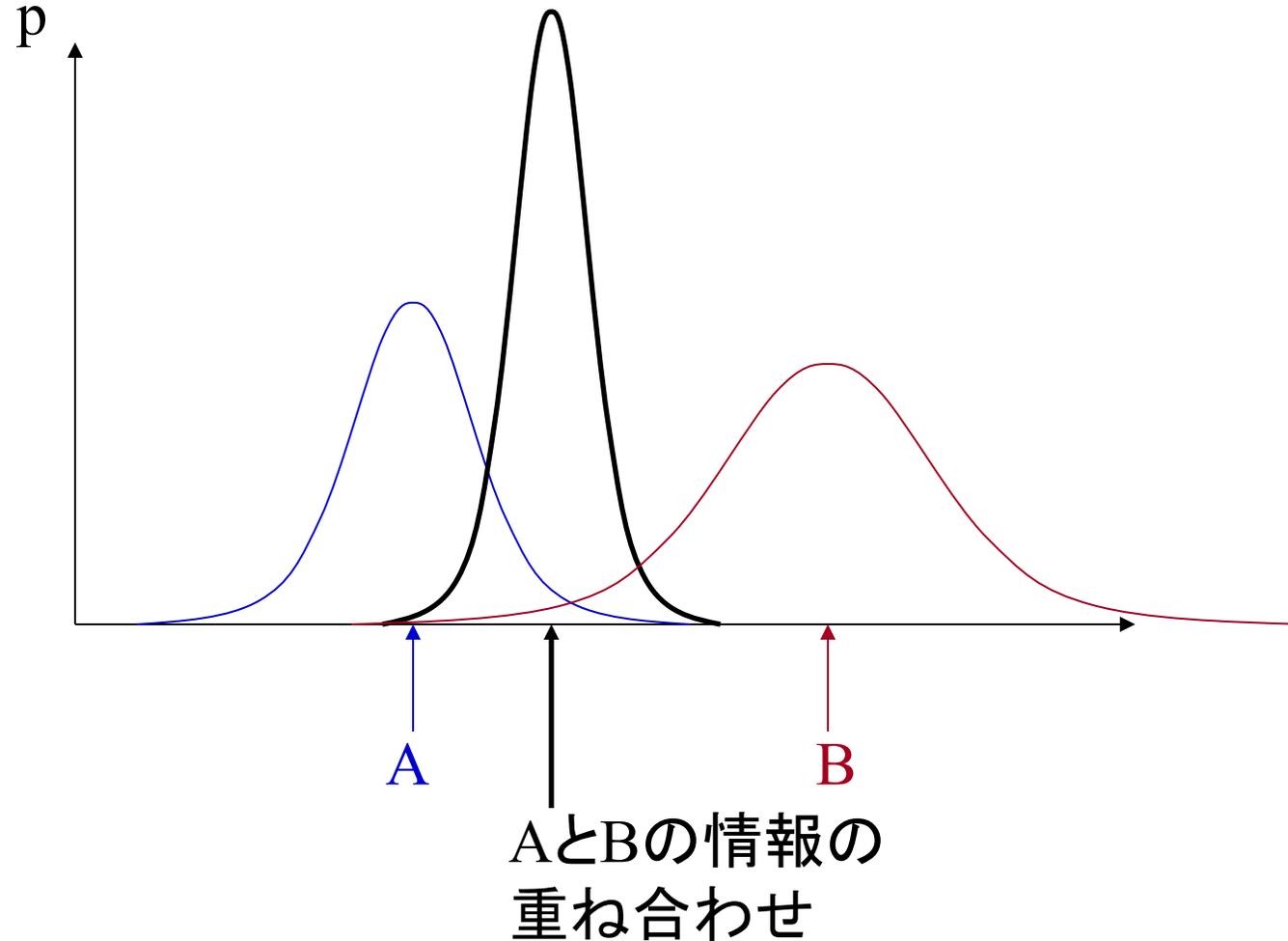
カオス同期 Chaos Synchronization

Master (drive) system

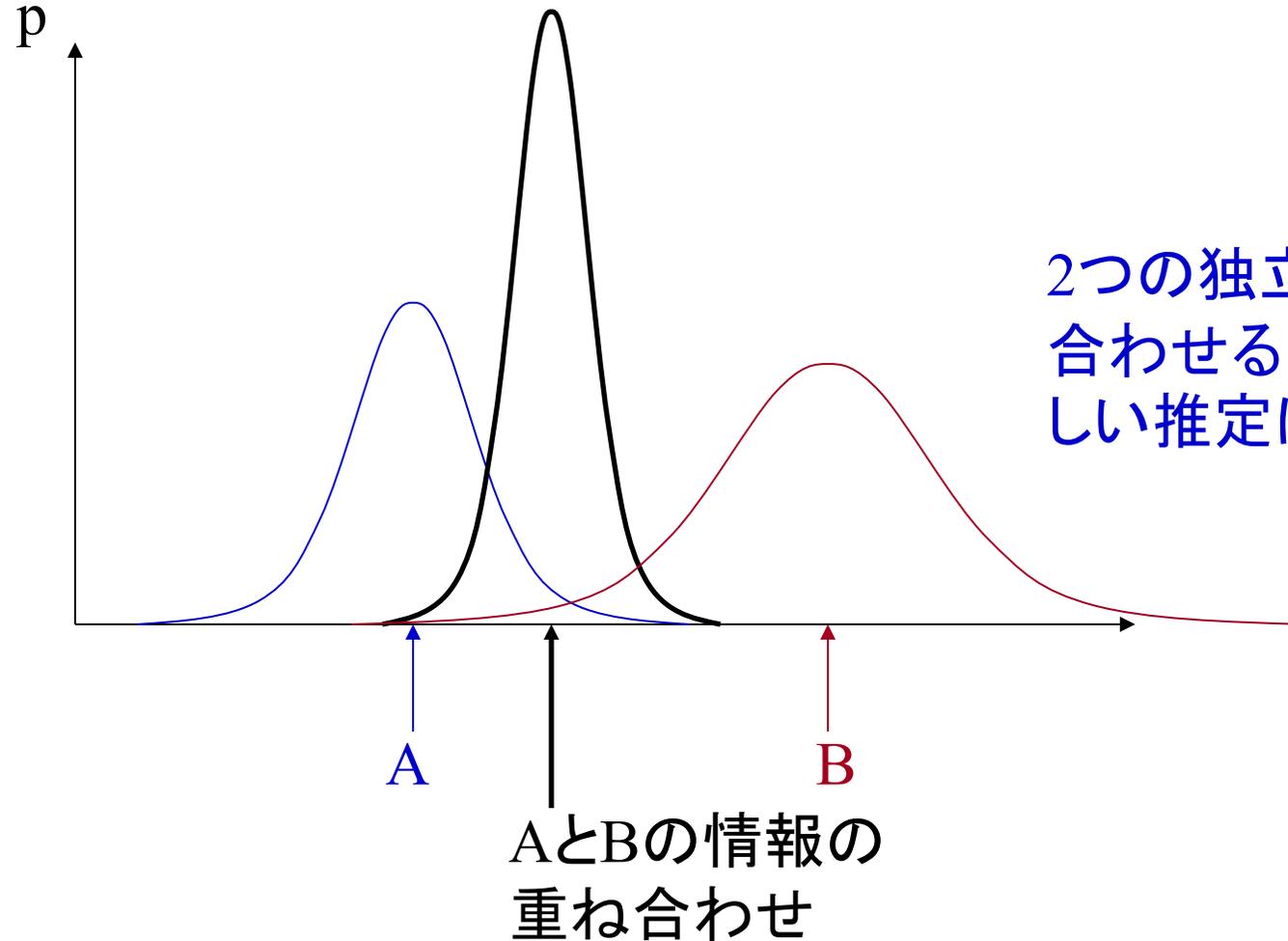
Slave (response) system



2つの情報の重ね合わせ(ベイズ推定)

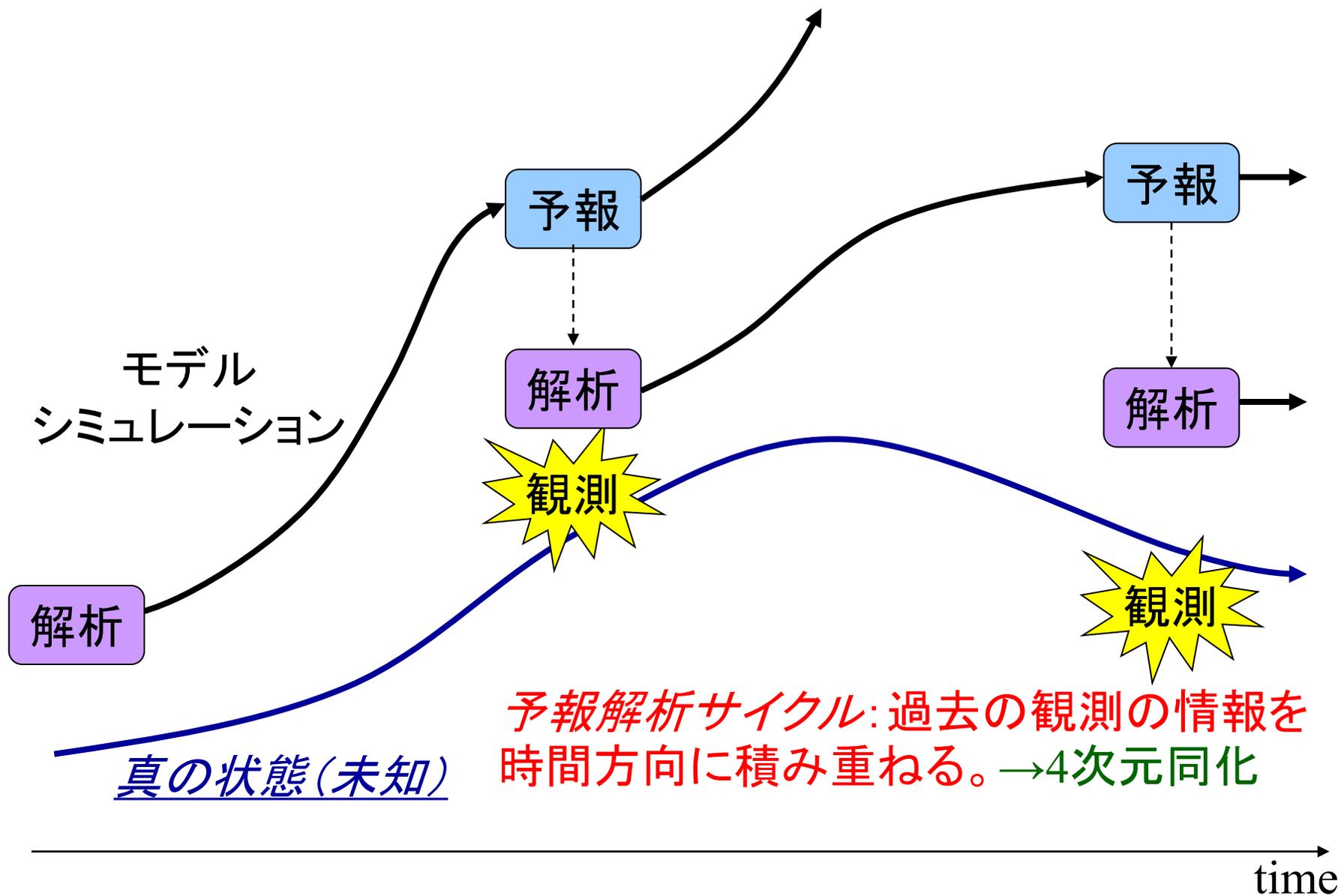


2つの情報の重ね合わせ(ベイズ推定)

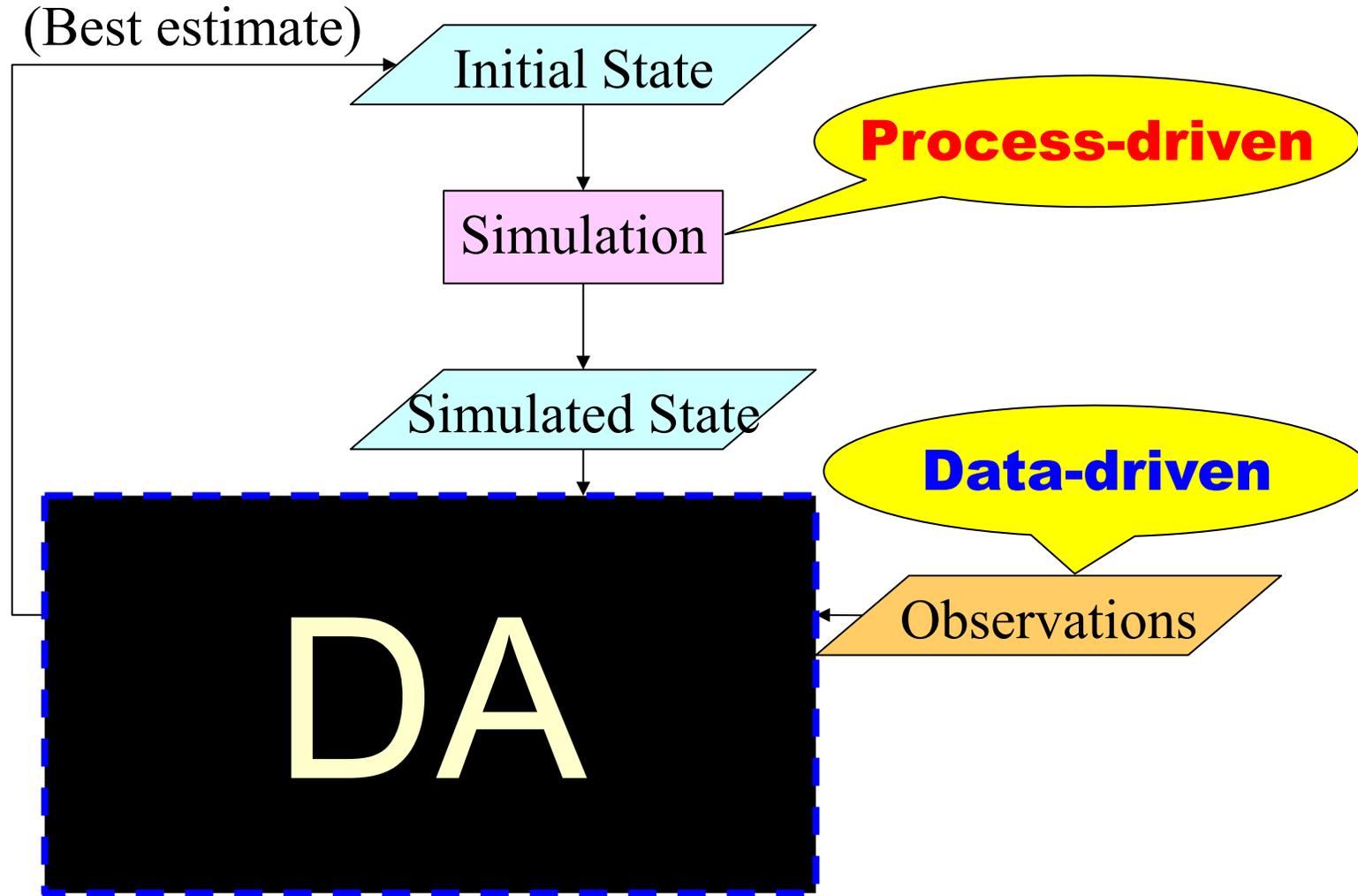


2つの独立した情報を重ね合わせることで、より確からしい推定になる

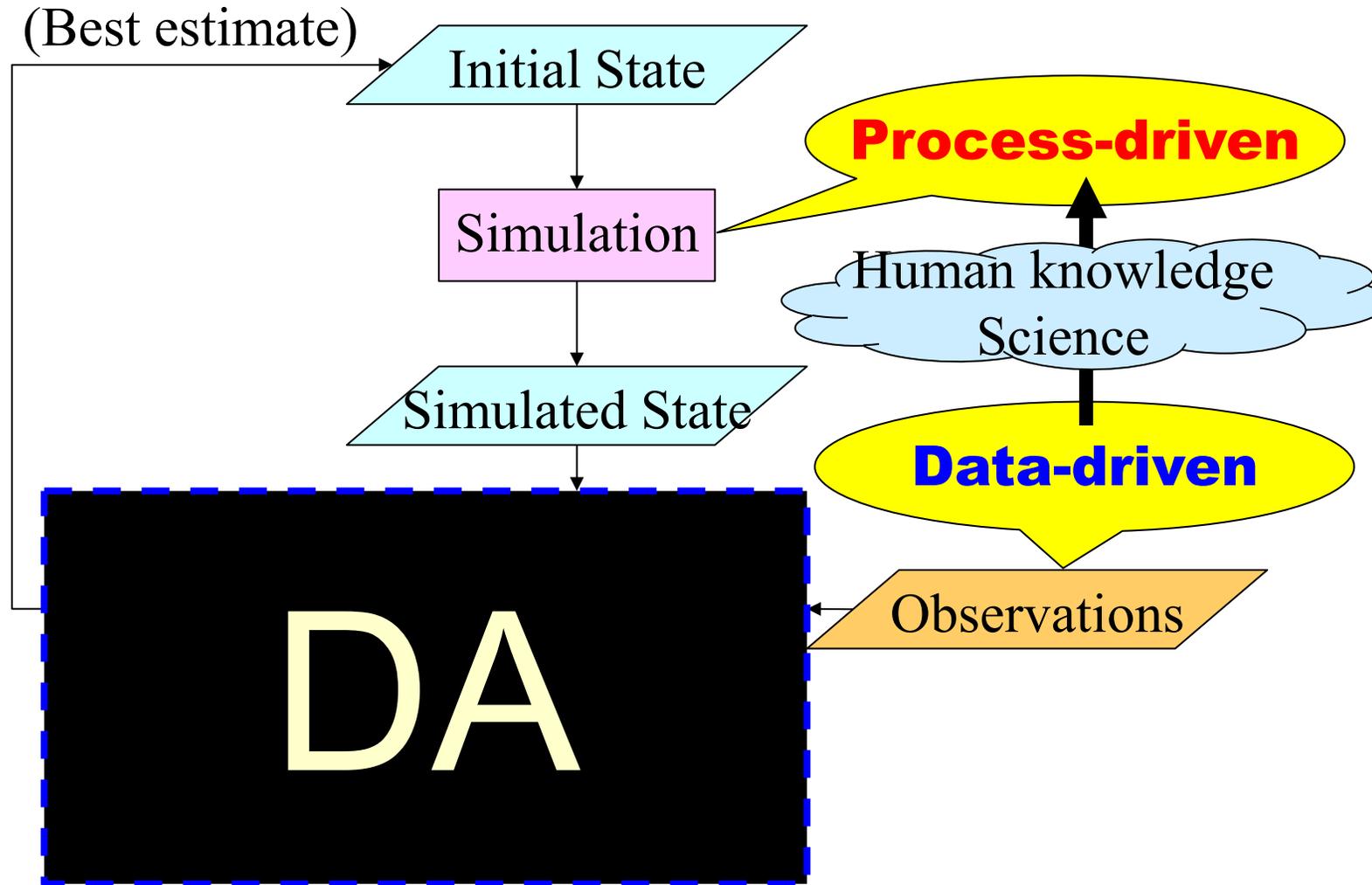
数値天気予報のしくみ



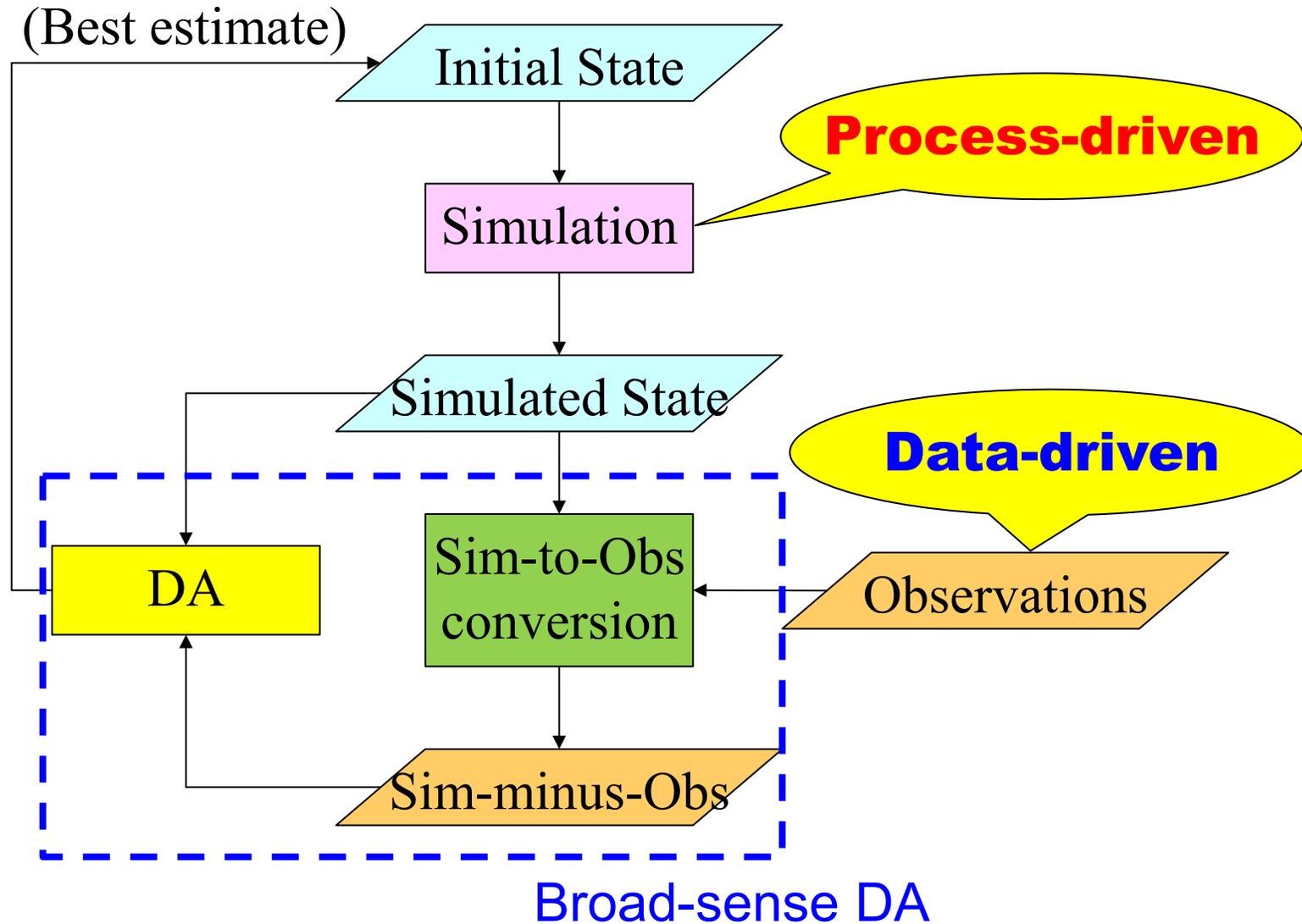
データ同化 (DA) の workflow



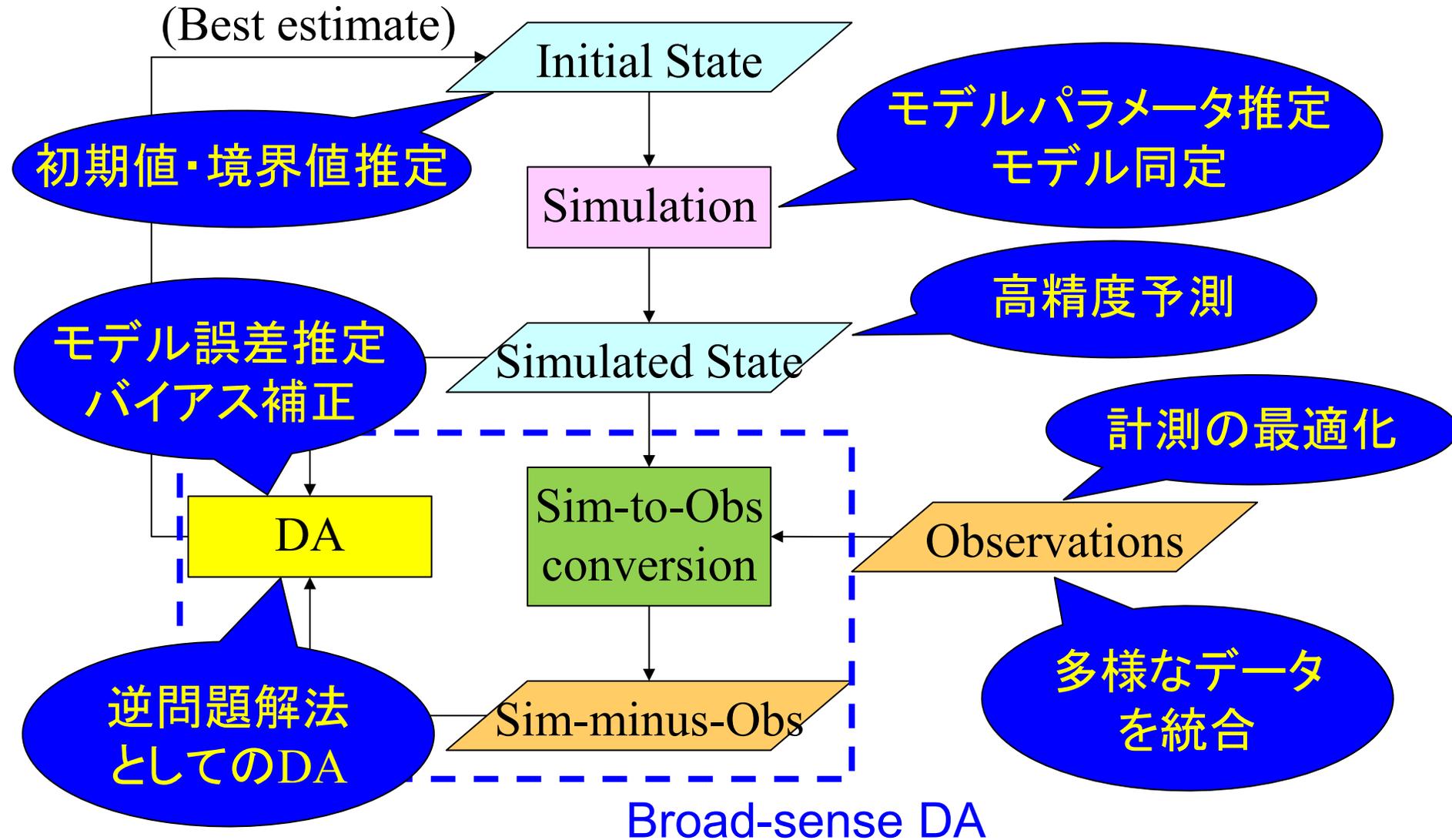
データ同化 (DA) の workflow



データ同化 (DA) の workflow



データ同化 (DA) でできること



https://www.data.jma.go.jp/jra/html/JRA-3Q/index_ja.html

気象庁第3次長期再解析(JRA-3Q)

> お知らせ

> 概要

> 利用方法

> データ
フォーマット

> 利用上の
注意

> お問い合わせ

最新のお知らせ

2026年2月2日 *New / Update !*

JRA-3Q評価論文 (Harada et al. 2026) がQuarterly Journal of the Royal Meteorological Societyから公開されました。

2025年12月2日 *New / Update !*

当ウェブサイトのアドレス (URL) を以下のとおり変更いたしました。

- 旧URL: <https://jra.kishou.go.jp/>
- 新URL: <https://www.data.jma.go.jp/jra/html/>

当面の間は新URLに自動転送されますが、お気に入りやブックマークに旧URLを登録されている場合は更新をお願いいたします。

2025年4月24日

JRA-3Q詳細セット (モデル格子データ) が気象業務支援センターから提供開始されました。

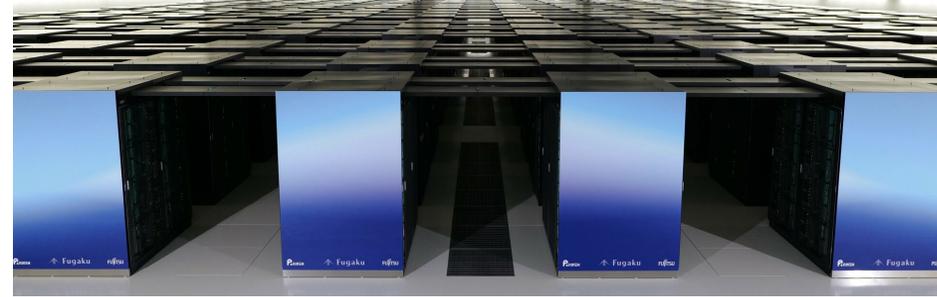
2025年2月25日

JRA-3Q総合報告論文 (Kosaka et al. 2024) が気象集誌論文賞に選ばれました。

JRA-3Q評価論文 (Naoe et al. 2025) のEarly Online Release版が気象集誌から公開されました。



September 2012



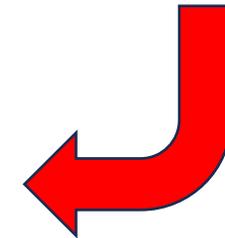
March 2021

Good for Big DA
Not suitable for ML

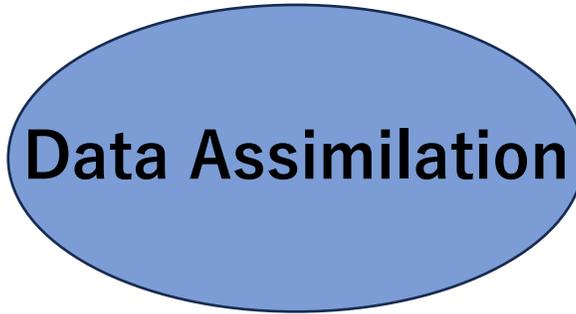


Good for both Big DA
and ML

“Fugaku Next”
(2030-?)
AI focused

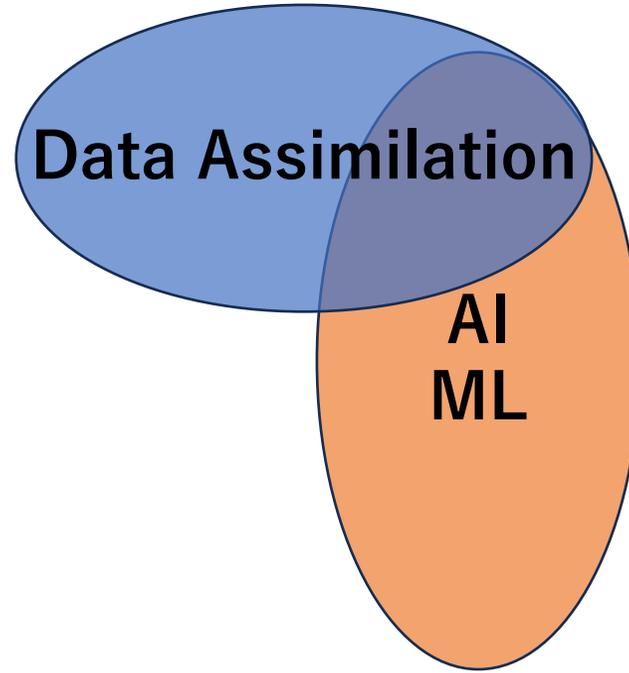


**“rich”
model**

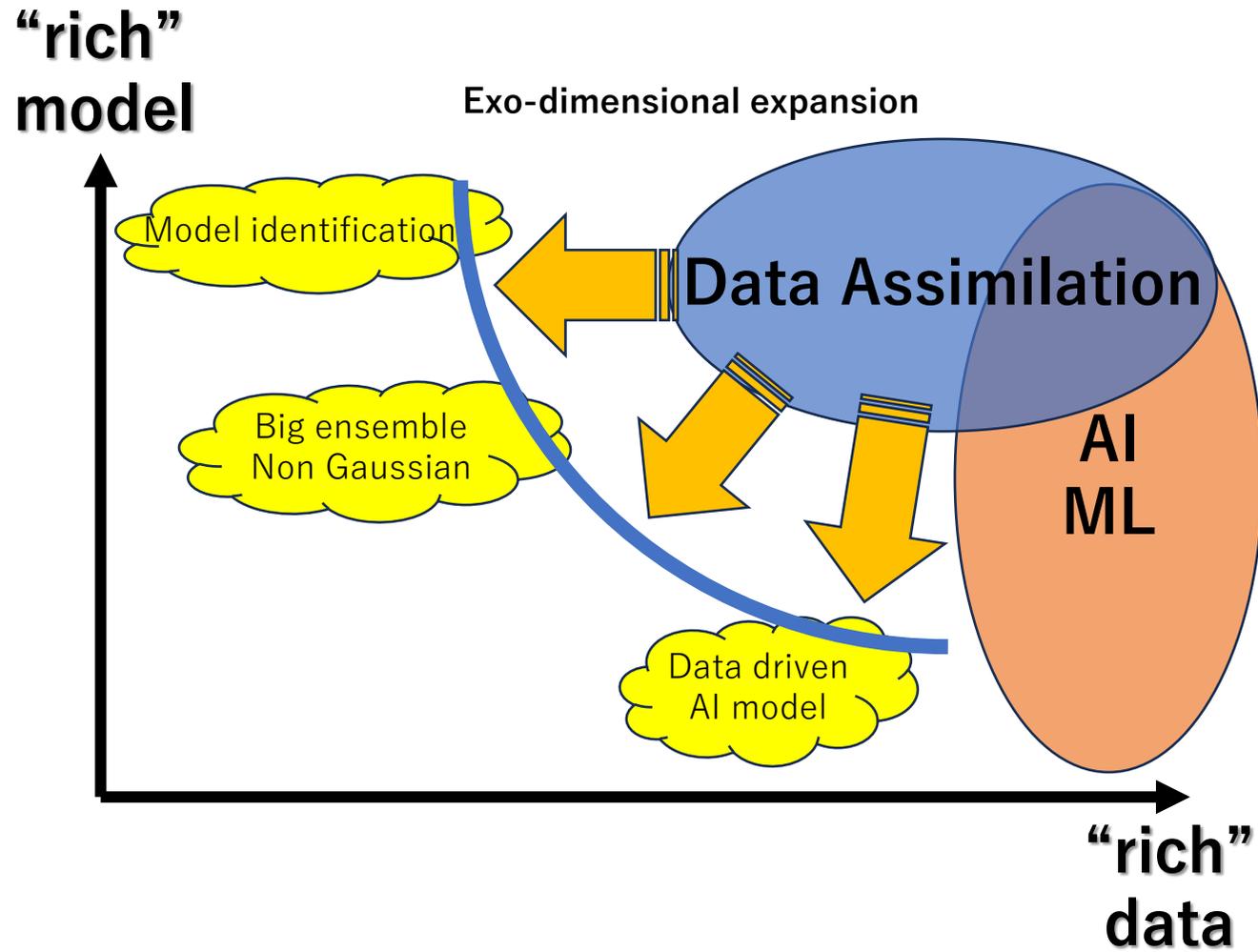


**“rich”
data**

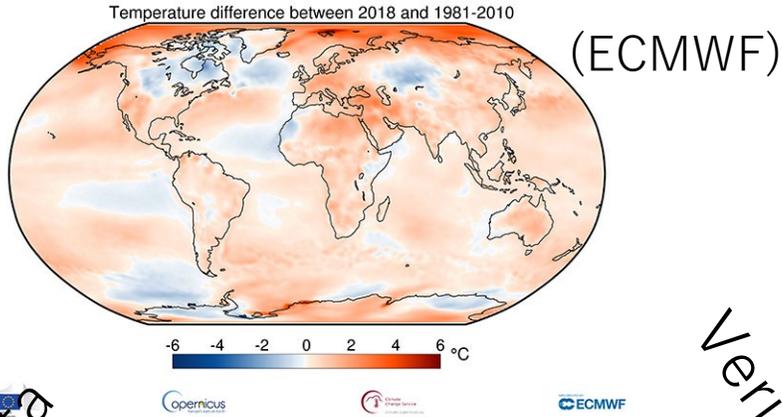
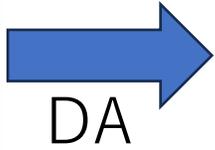
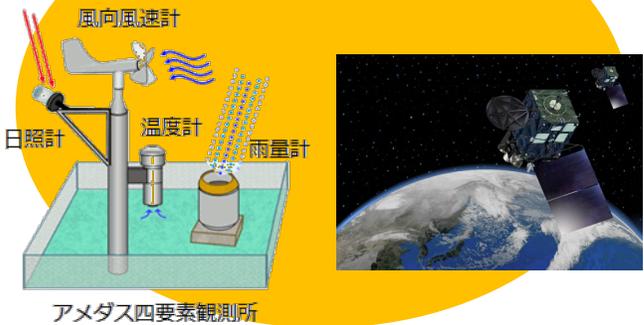
**“rich”
model**



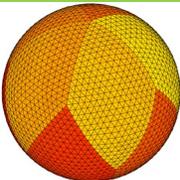
**“rich”
data**



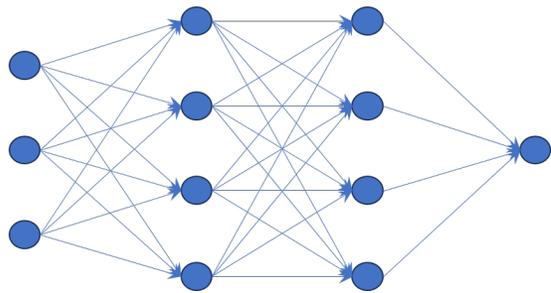
Raw observations: y



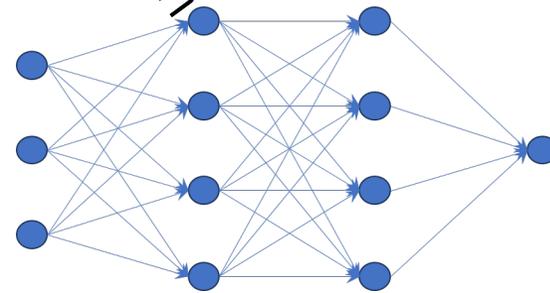
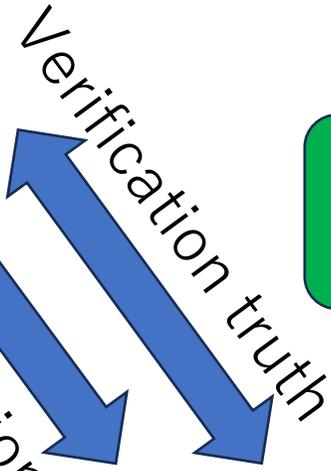
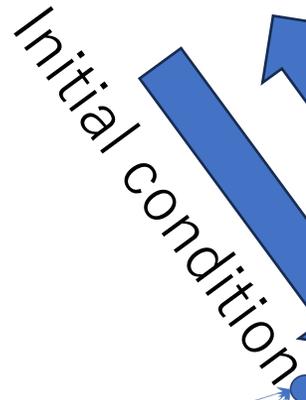
Physically-based model



(Nakano et al. 2017)



Training



Prediction

Emulation of the reanalysis data



青いほどAI気象モデルのスキルが高い
 ←驚くべき進展

ECMWF
 AIFS-ENS vs. IFS-ENS

予報スキル比較
 変数・高度・領域別
 予報時間（横軸）

Source: ECMWF Newsletter No. 185
 Autumn 2025

Precipitation nowcasting with deep learning



S. Otsuka and T. Miyoshi (RIKEN)

Acknowledgment

Y. Maejima, P. Tandeo, M. Ohhigashi, V. P. Huynh,
S. Satoh, T. Ushio, P. Baron

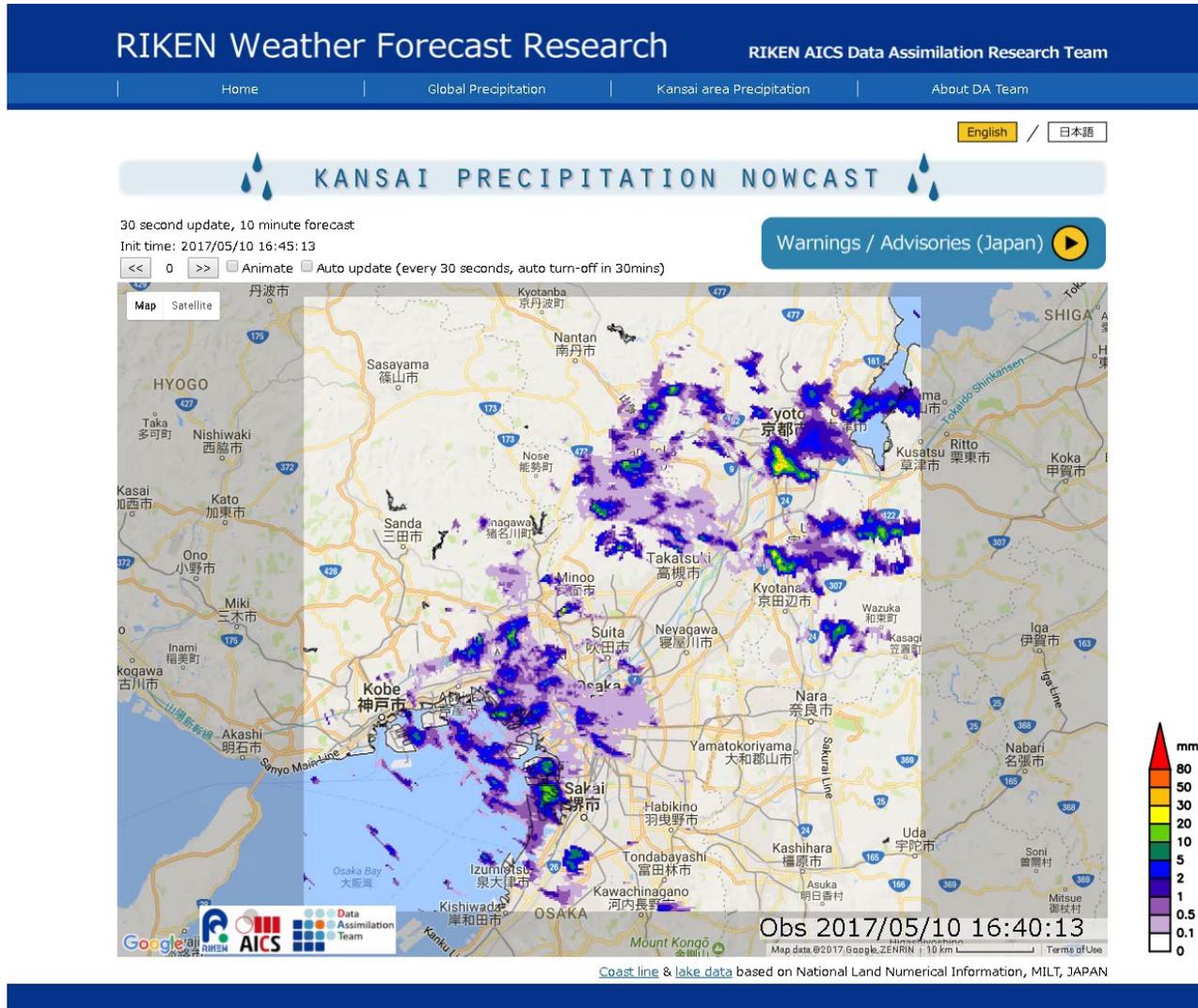
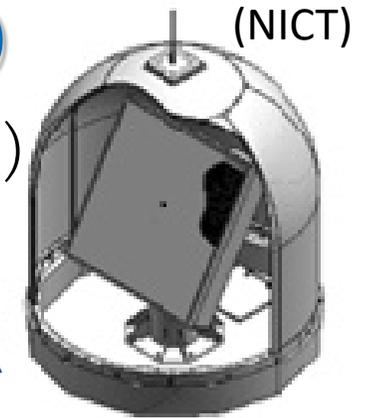


RIKEN
Center for
Computational Science

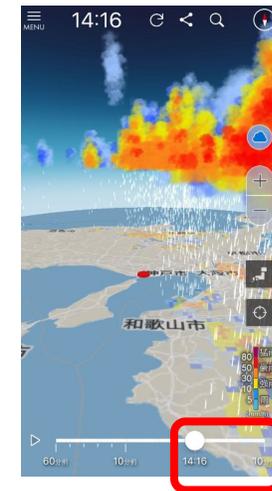


Phased-Array Weather Radar 3D nowcast (<https://weather.riken.jp/>)

Open to the public since July 2017 (Licensed by JMA)



Updated every 30

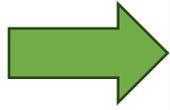


App by MTI Ltd.

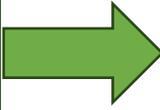
247,000+
downloaded



(NICT)



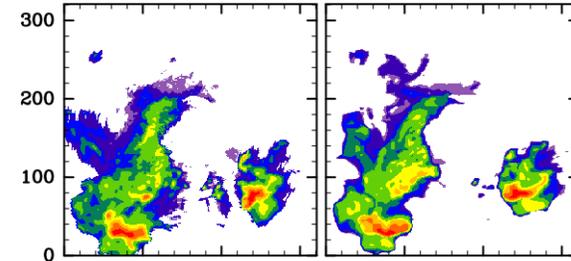
Process past observations by ConvLSTM



Generate future images by ConvLSTM

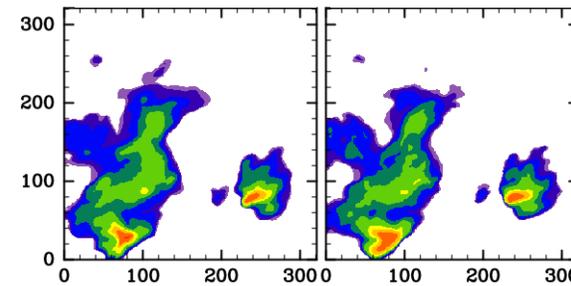
Observations by Phased Array Weather Radar

Conventional nowcasting



ConvLSTM (with observations)

ConvLSTM (with obs. + nowcasting)



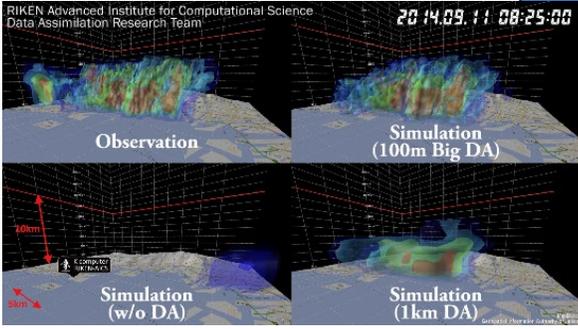
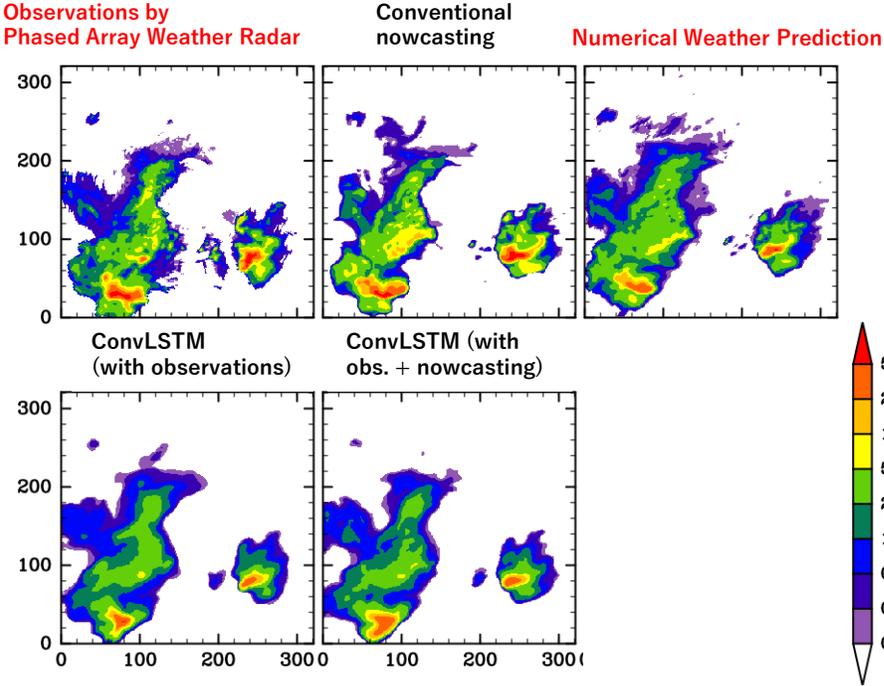


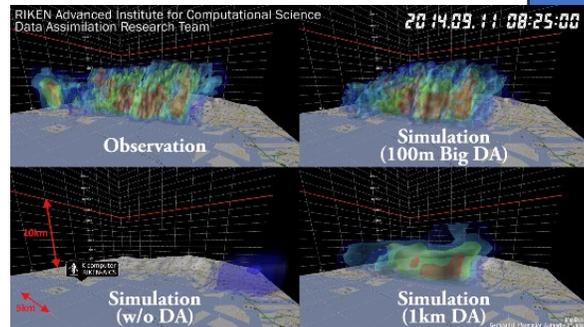
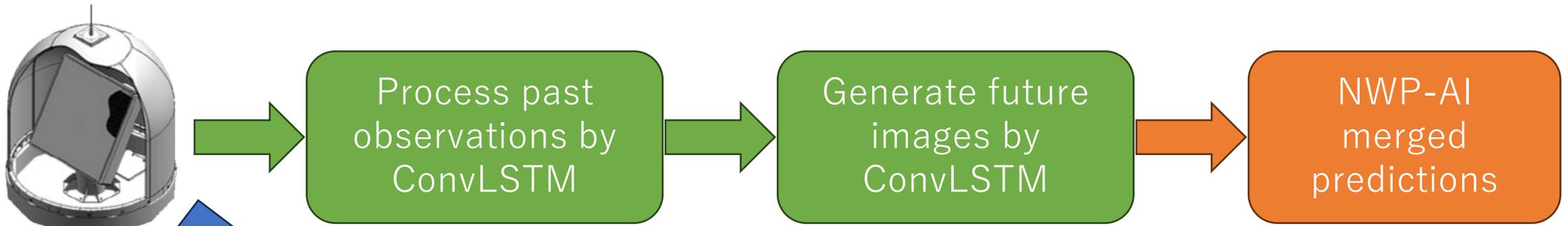
(NICT)

Process past observations by ConvLSTM

Generate future images by ConvLSTM

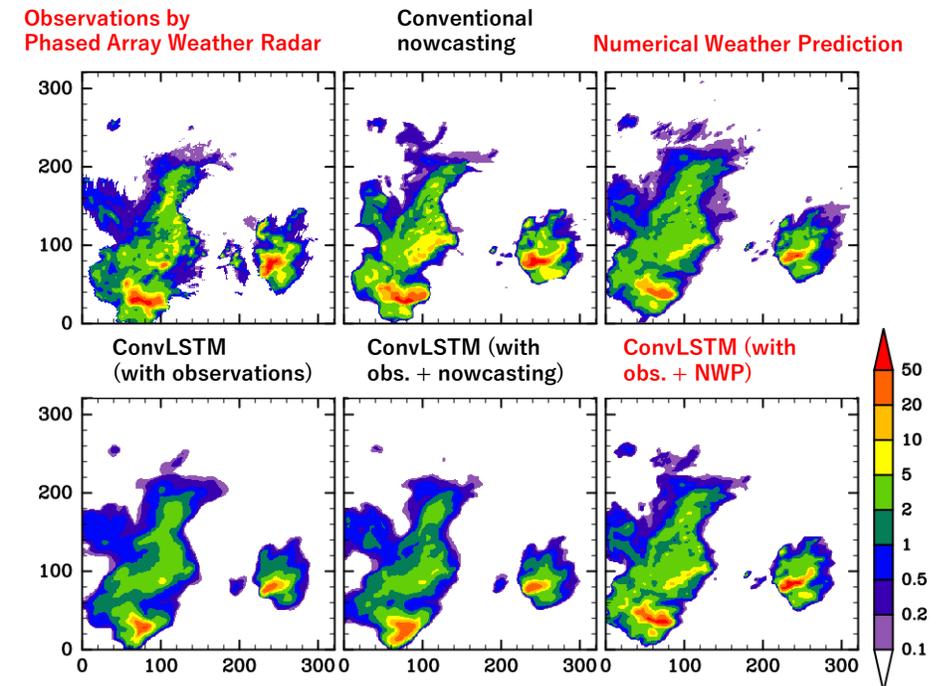
Assimilated by NWP system SCALE-LETKF





NWP results

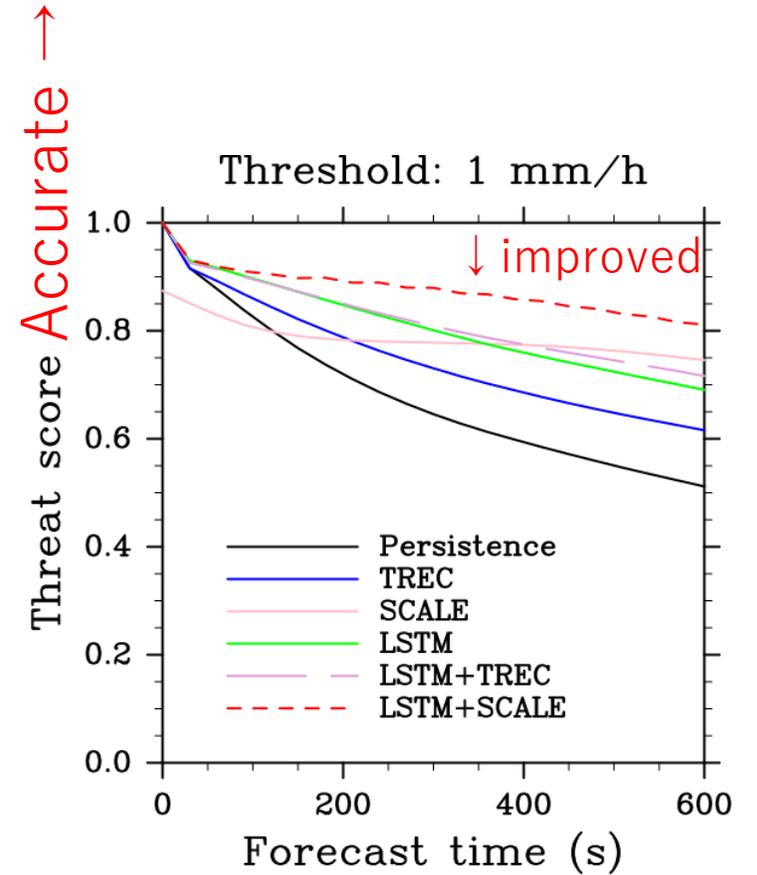
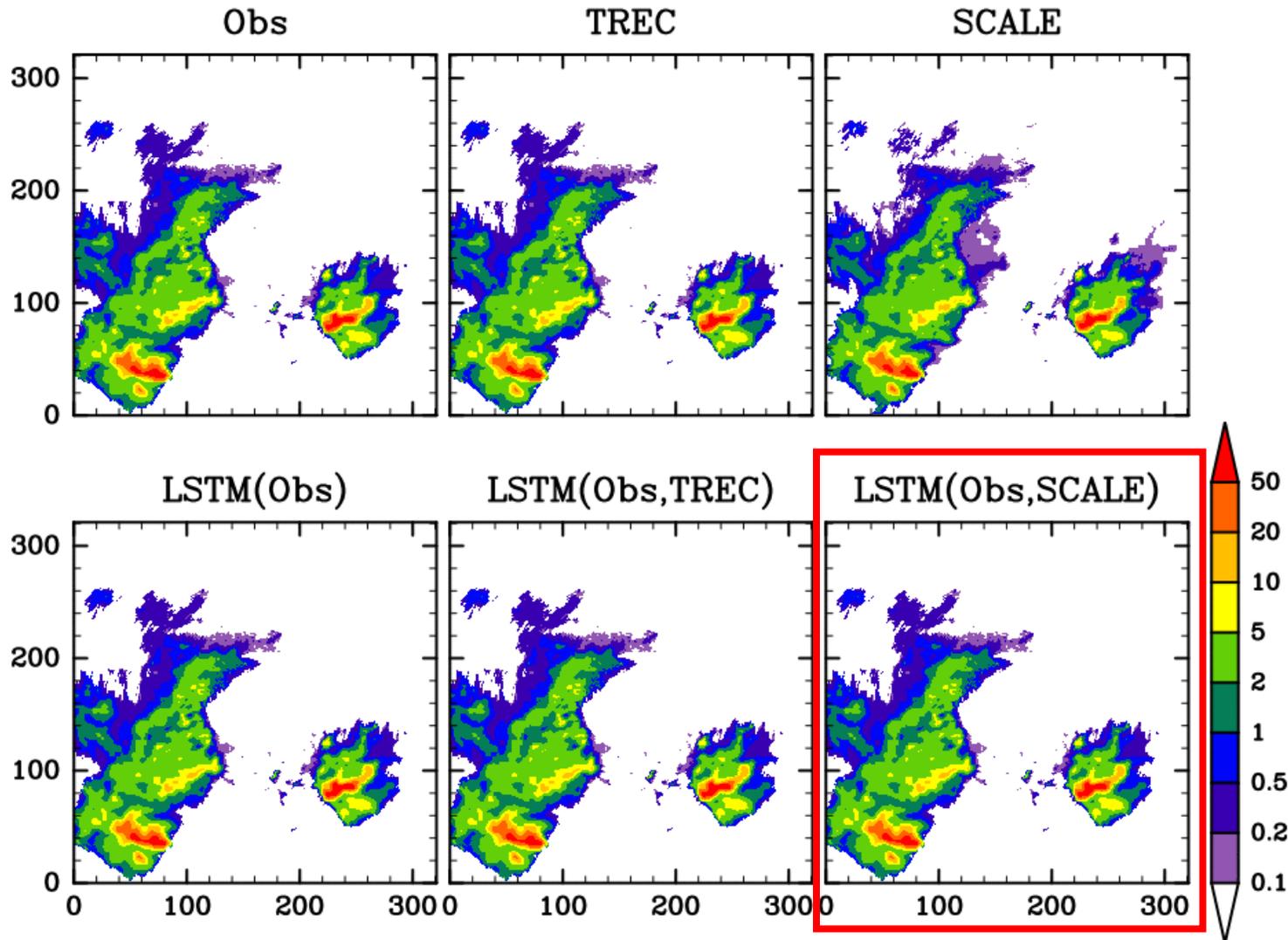
Assimilated by NWP system SCALE-LETKF



Integrating big data assimilation and deep learning for precipitation nowcasting

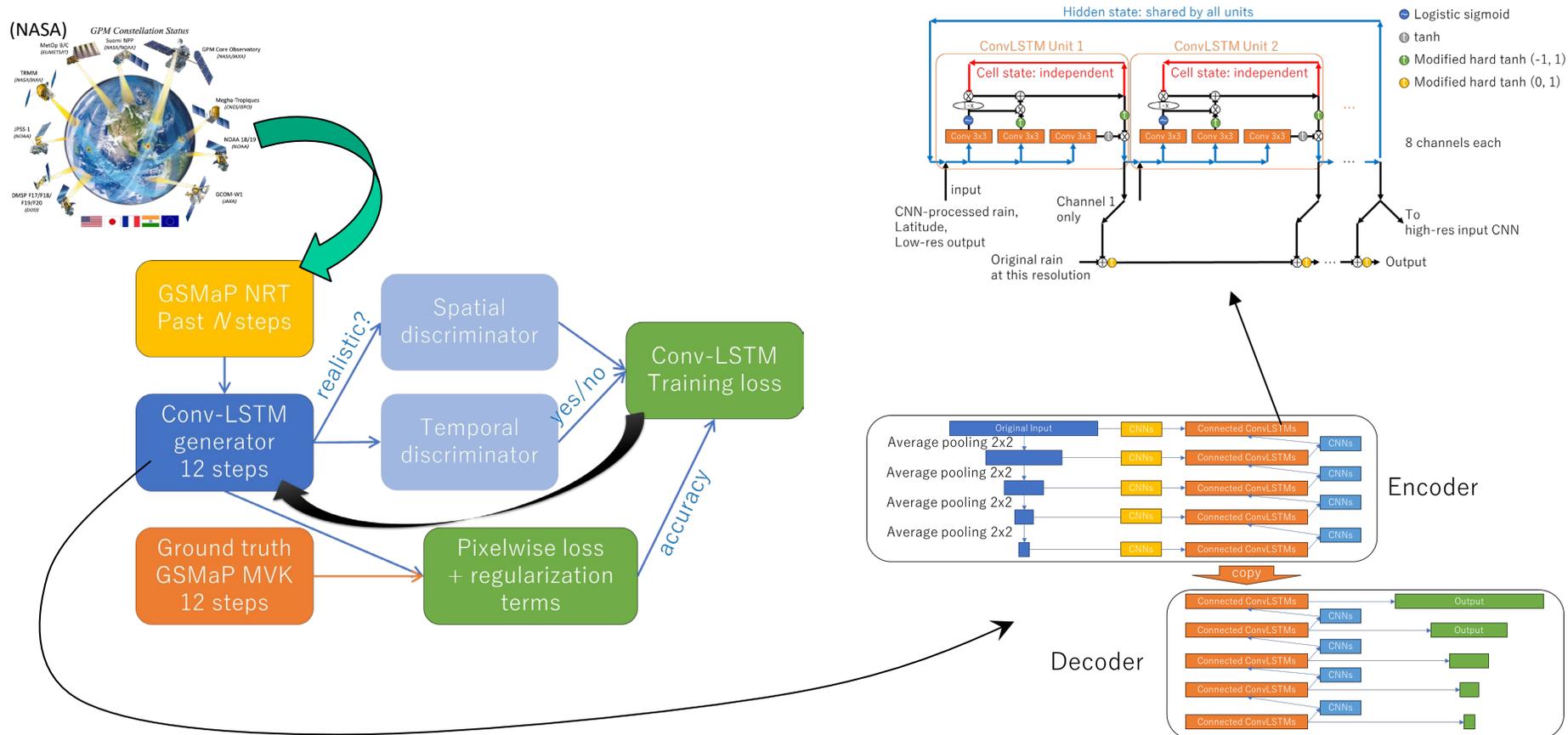
Preliminary results (rain rate @ 2km)

17:59:30 FT=0.0min



Machine Learning approach to nowcasting

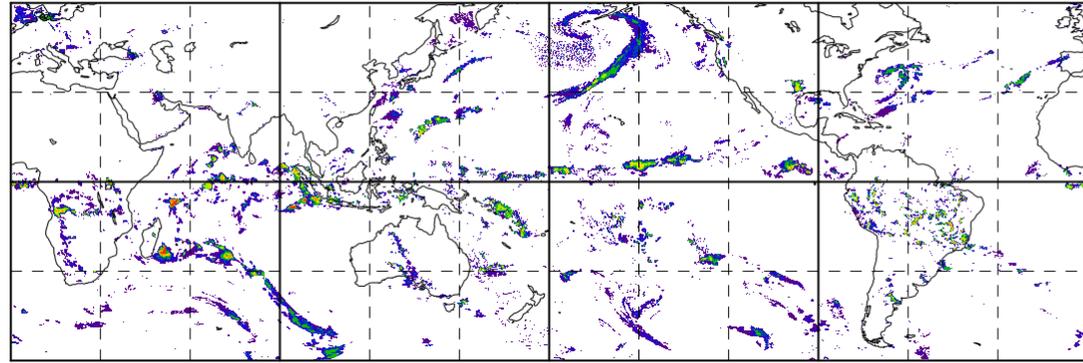
- GSMaP-based AI forecast
- ConvLSTM-based encoder-decoder
- Adversarial training



Comparison with a conventional algorithm

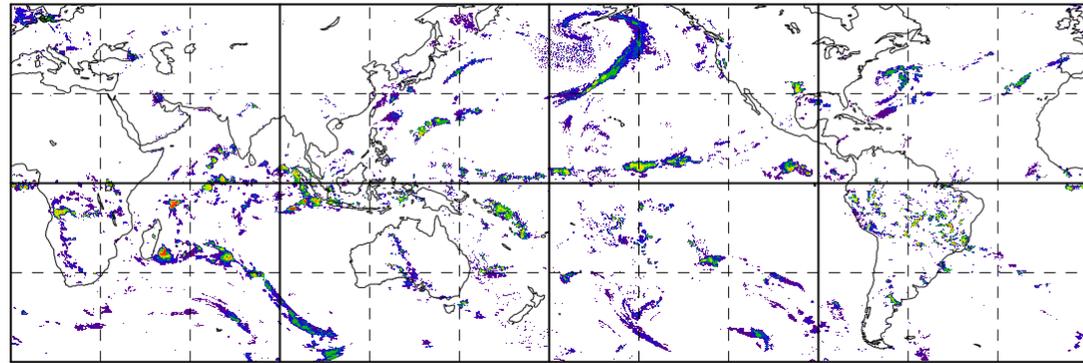
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Proposed



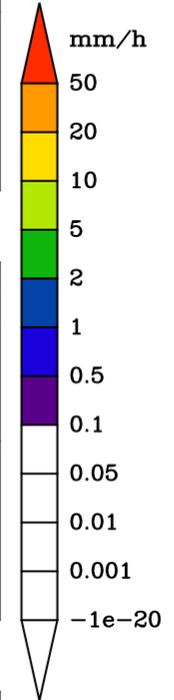
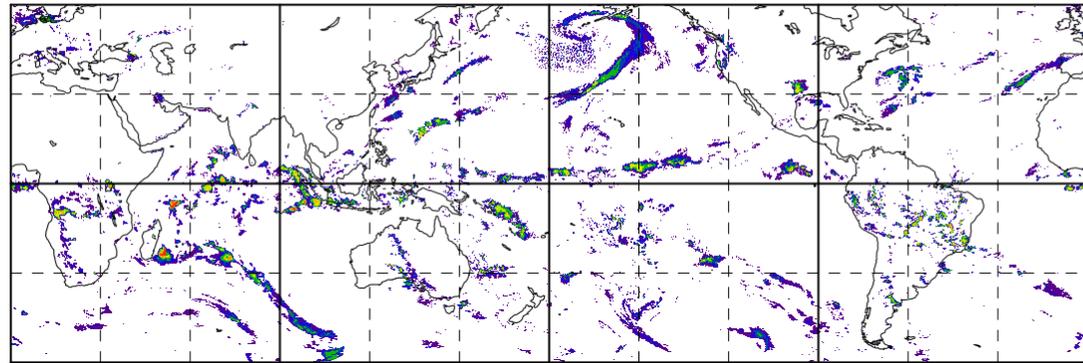
Nowcast 0.7882964489882145

**Conventional
tracking
algorithm**



MVK V8

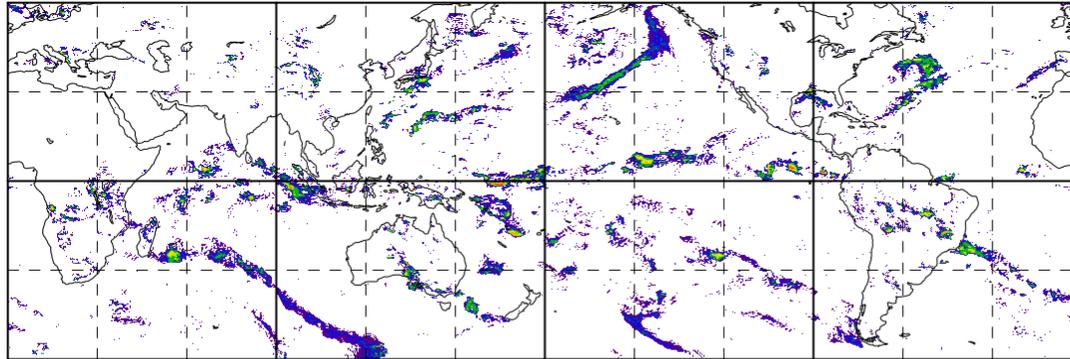
Observations



Comparison with a conventional algorithm

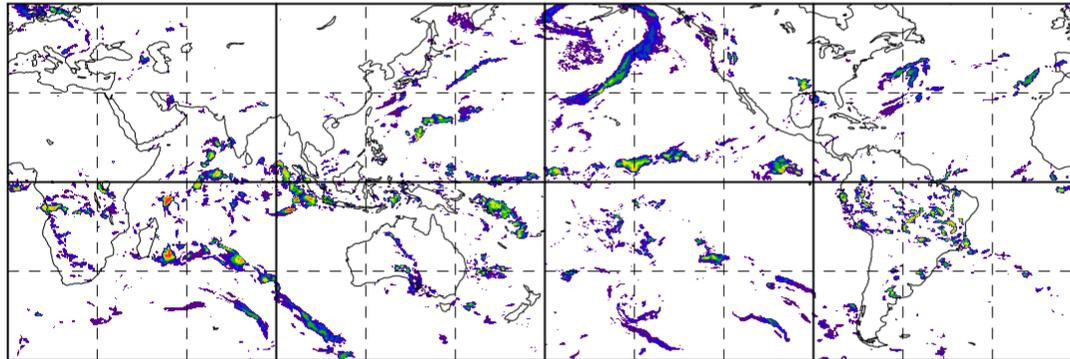
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Proposed



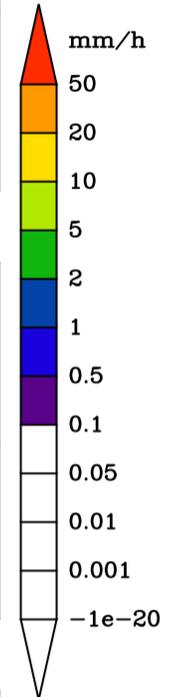
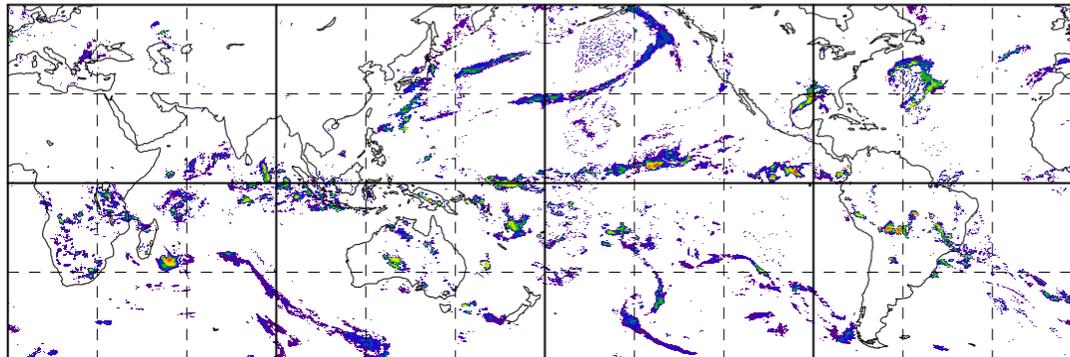
Nowcast 0.161430444468922

**Conventional
tracking
algorithm**



MVK V8

Observations

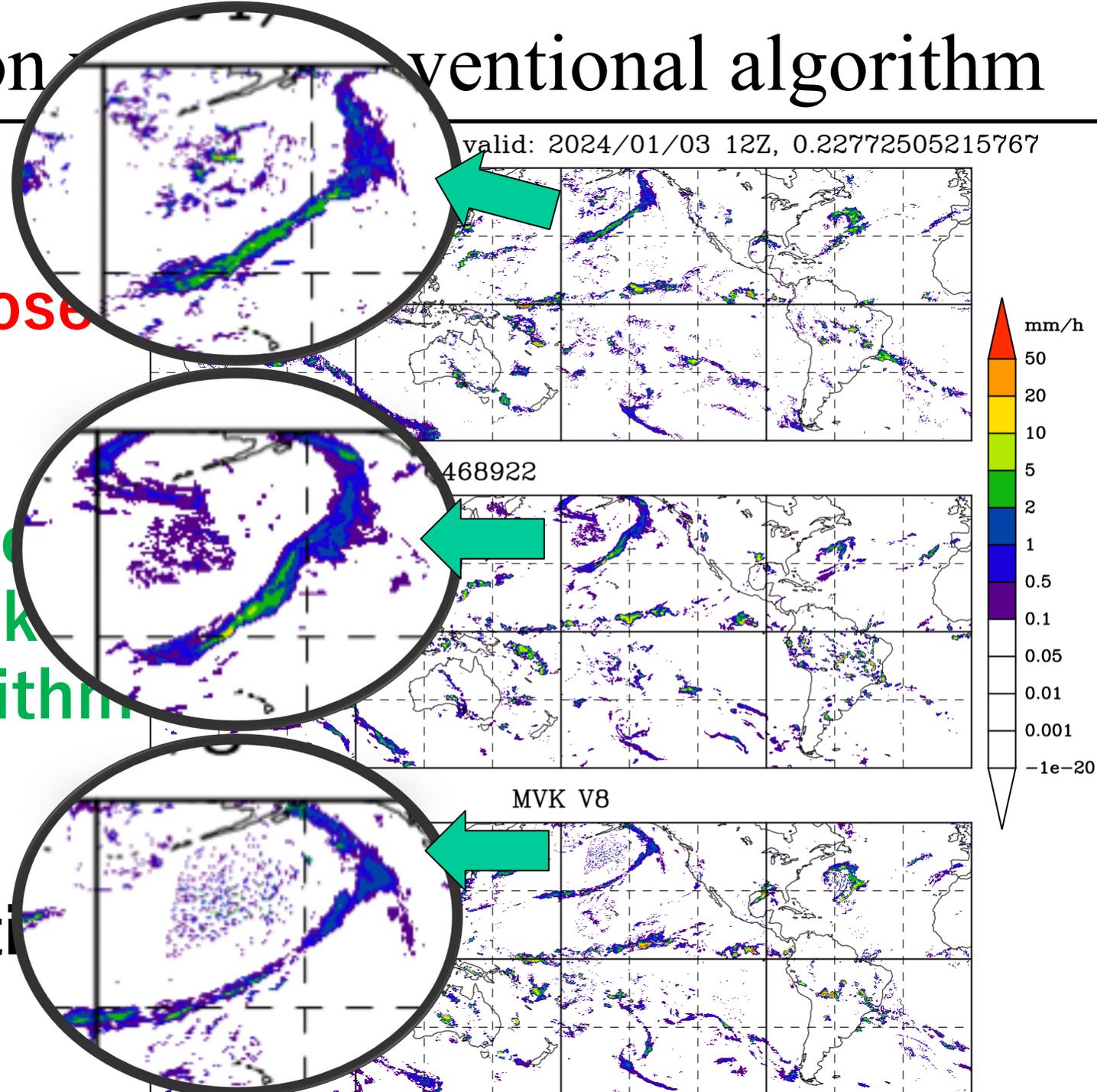


Comparison of conventional algorithm

Proposed

Conventional
track
algorithm

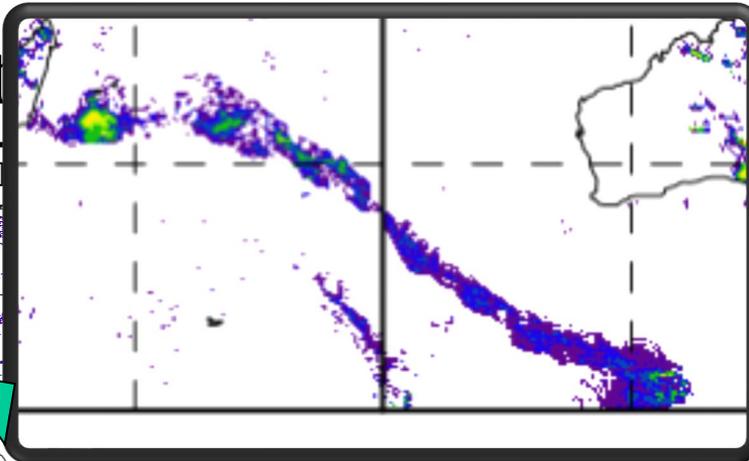
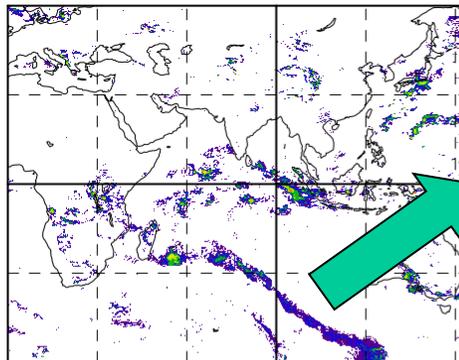
Observation



Comparison with a conventional

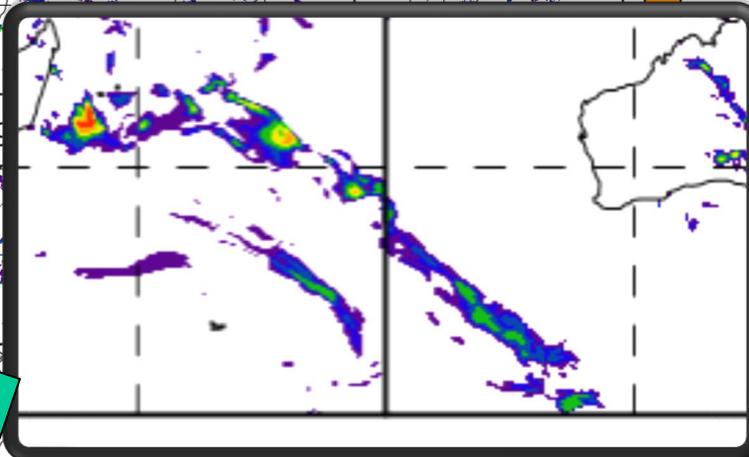
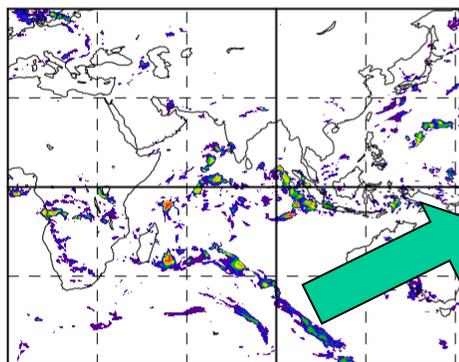
Proposed

Init: 2024/01/03 00Z, val

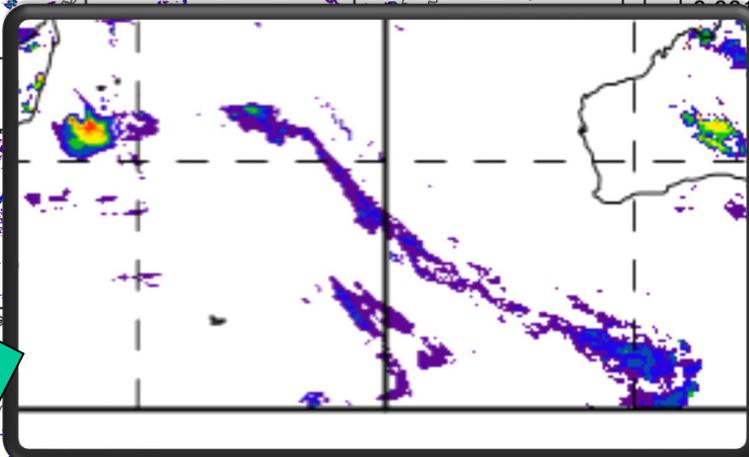
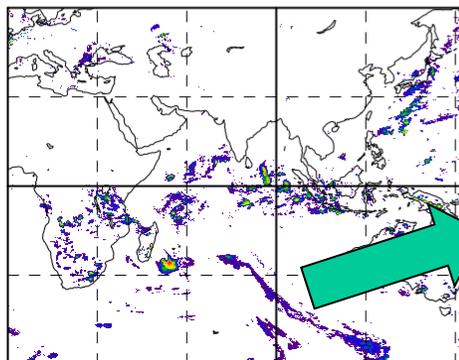


Nowcast 0.1614304444689

**Conventional
tracking
algorithm**



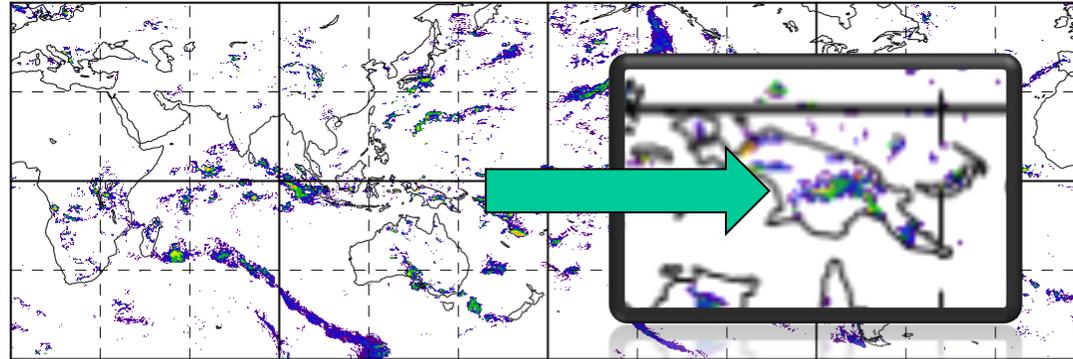
Observations



Comparison with a conventional algorithm

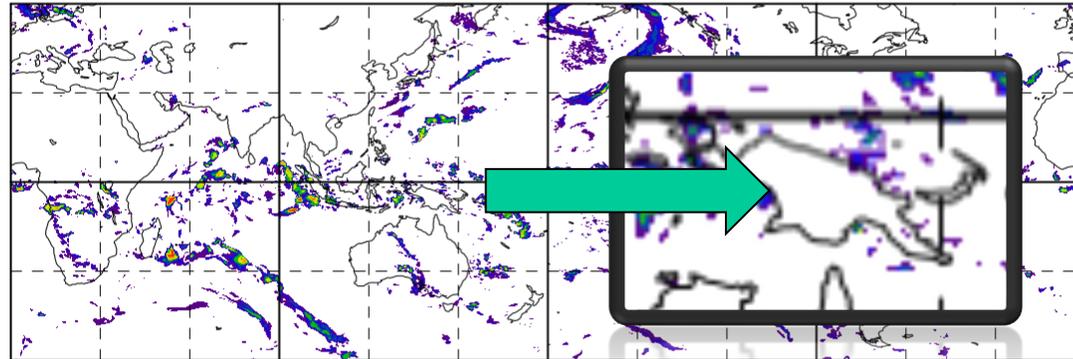
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Proposed



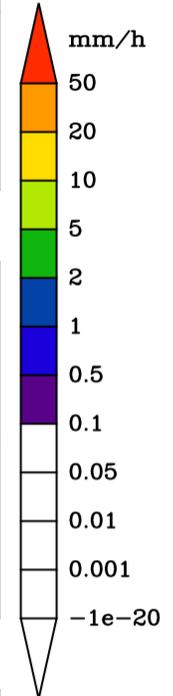
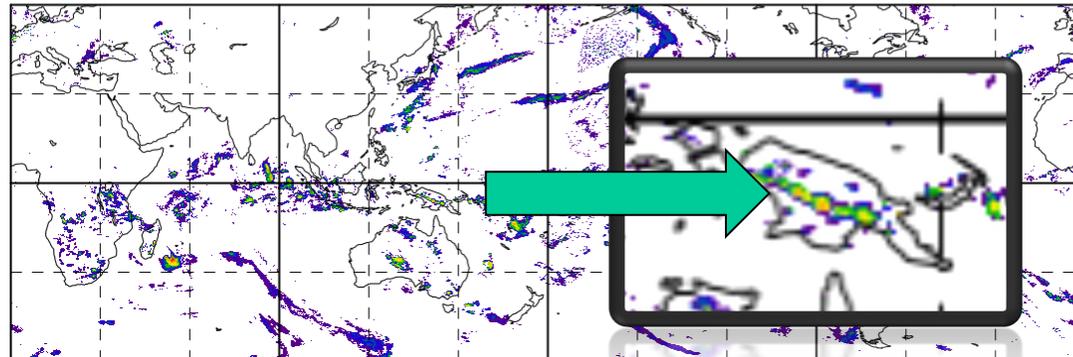
Nowcast 0.161430444468922

Conventional tracking algorithm



MVK V8

Observations



Verification scores for Jan-Dec 2024

GSMaP RIKEN AI Nowcast (GSMaP_RAIN)

Global precipitation nowcast with AI

Init: 2025/09/28 21Z

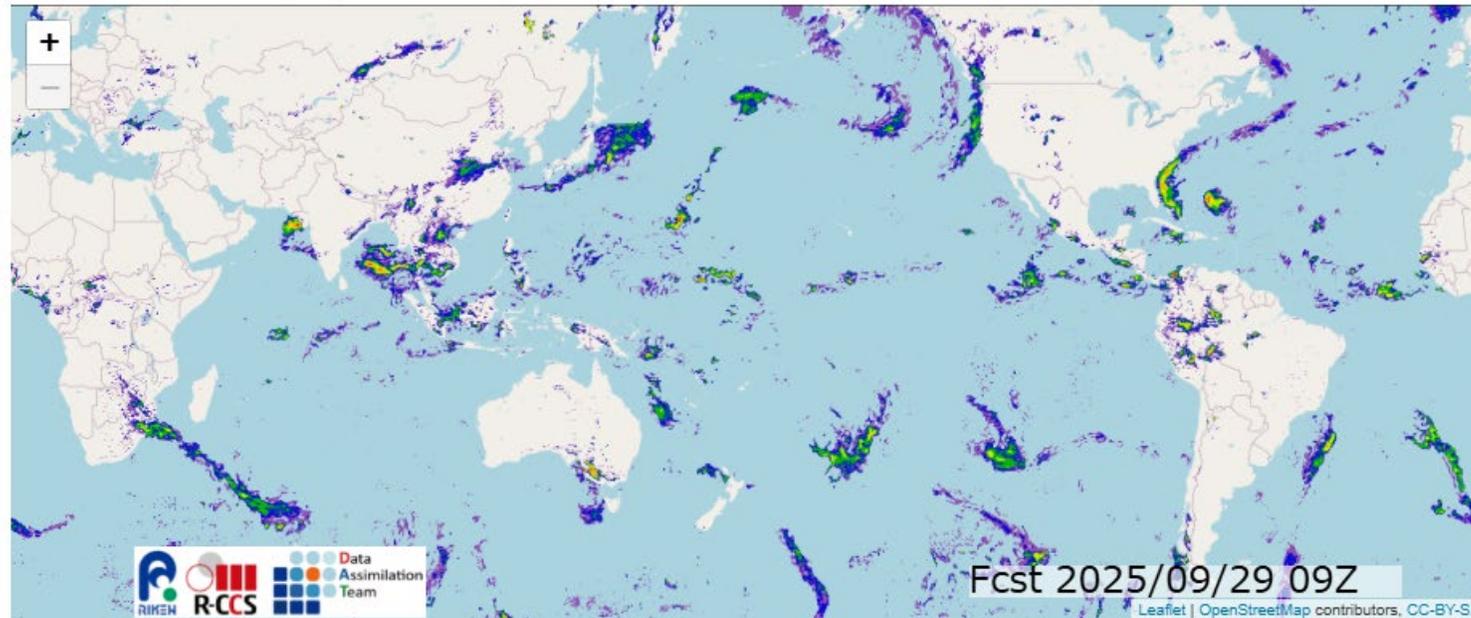


12 h



Animate

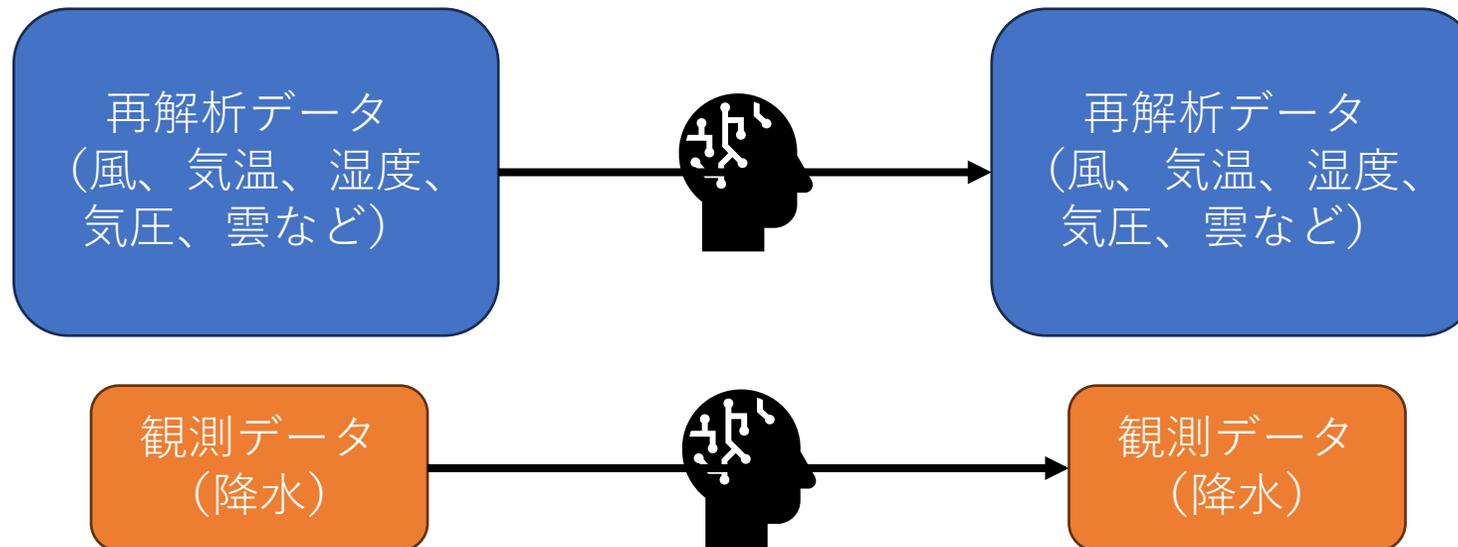
JMA's warnings/advisories



https://weather.riken.jp/en/gsmmap_rain/gsmmap_rain.html

AI気象モデル：現状 ← 近年の驚くべき進展

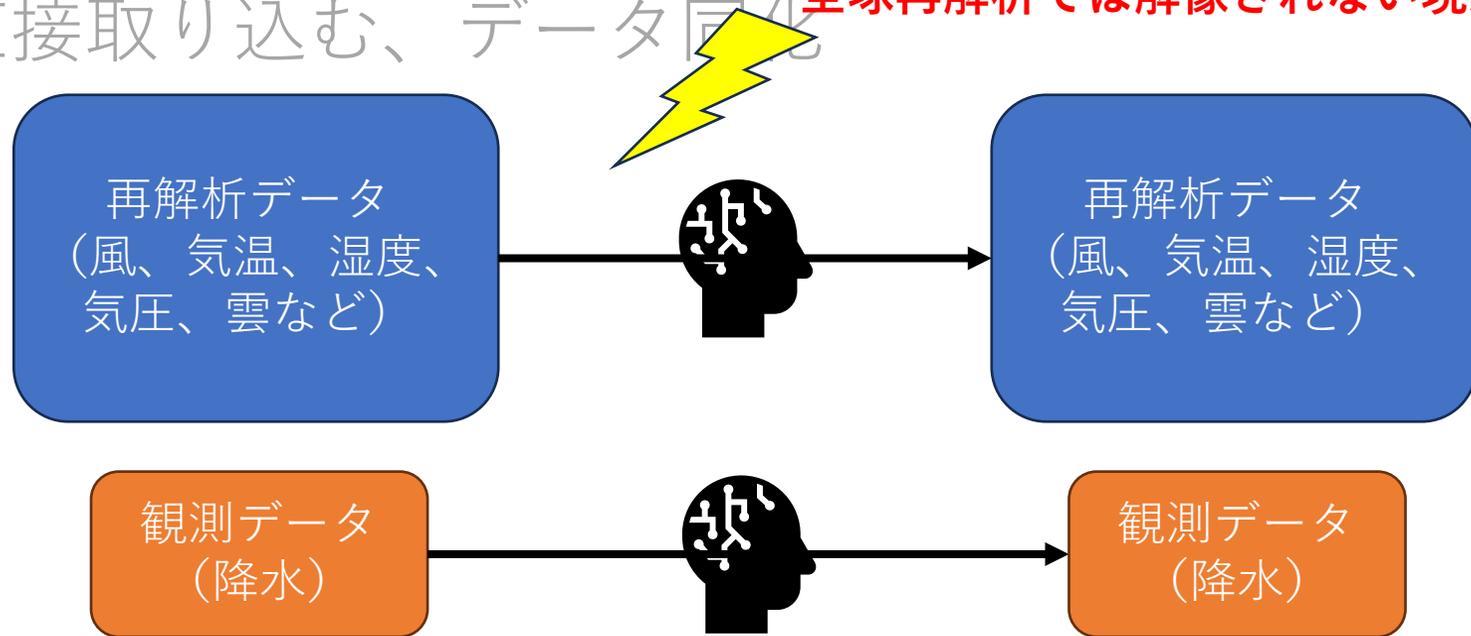
- 全球再解析データ（ERA5, 0.25度）を学習、高い予報スキル
- 特定の観測による学習、予報（スキルは低い）



AI気象モデル：チャレンジ

- 高解像度の極端現象の学習
- 様々な観測による学習、予報
- 観測を直接取り込む、データ同化

全球再解析では解像されない現象

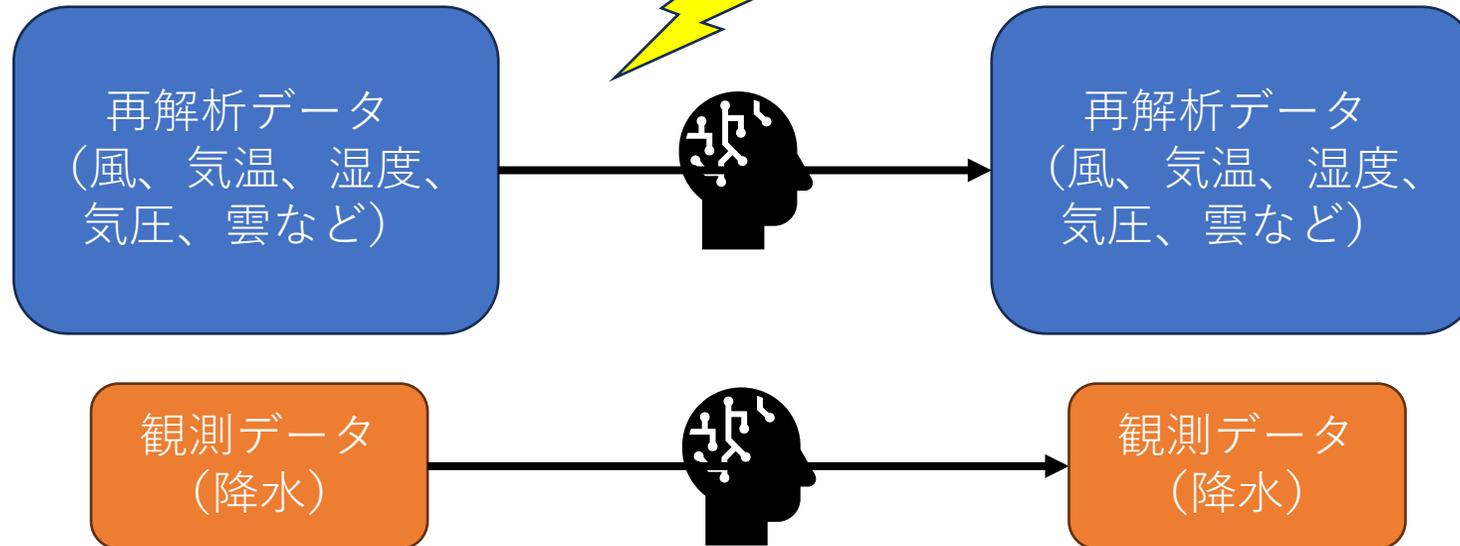


AI気象モデル：チャレンジ

- 高解像度の極端現象の学習
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- 観測を直接取り込む、データ同化

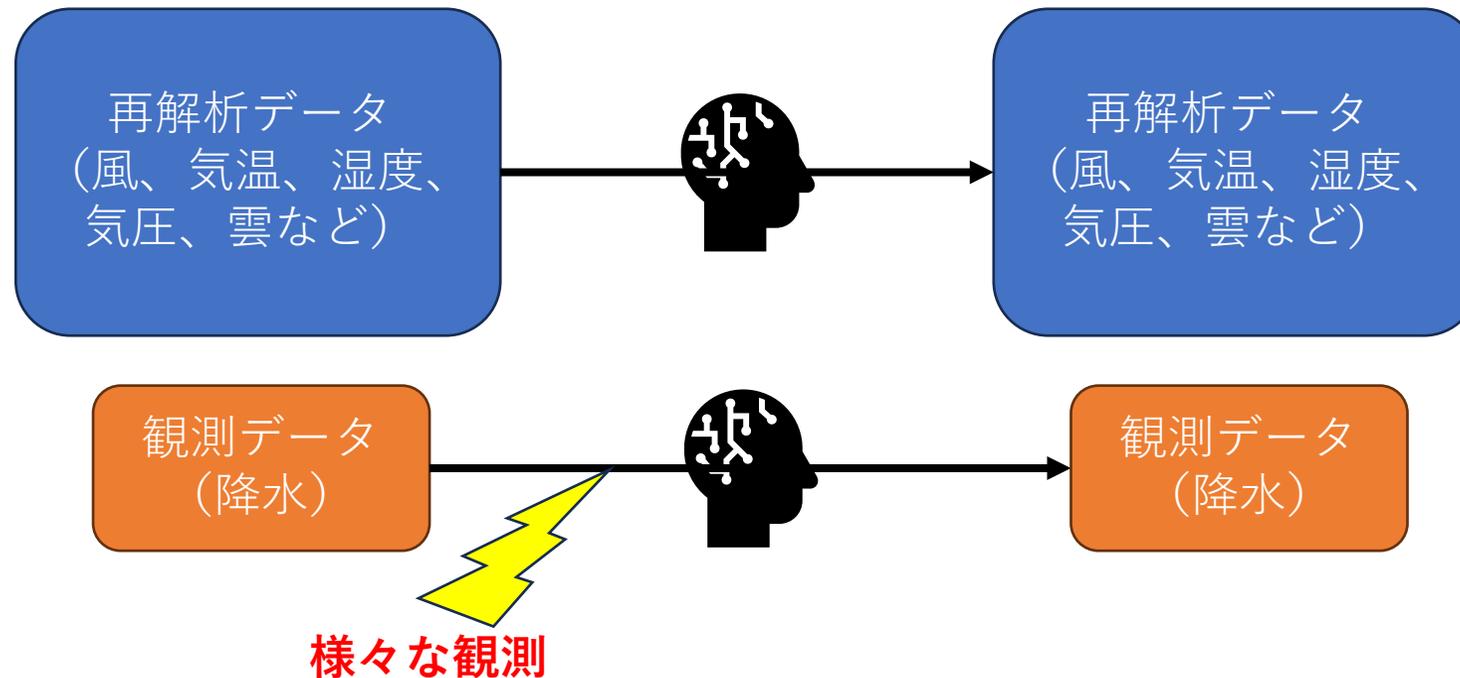
領域再解析
PINNなど

全球再解析では解像されない現象



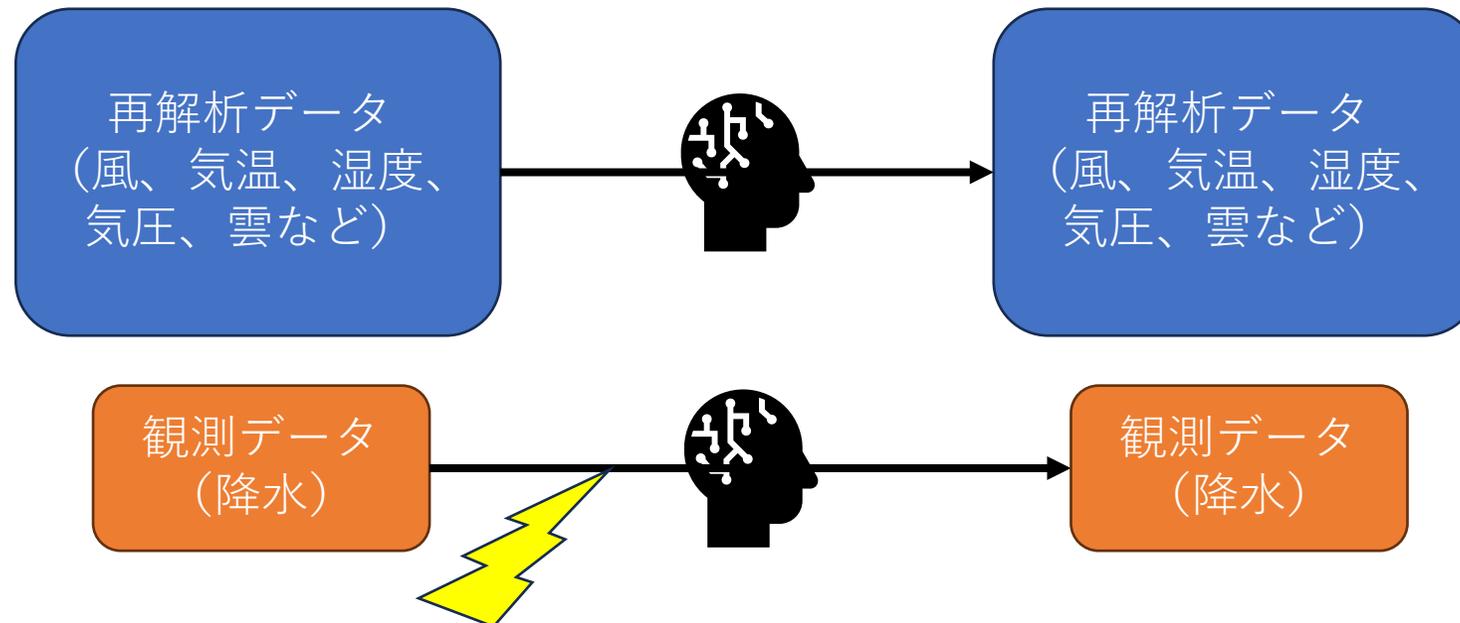
AI気象モデル：チャレンジ

- 高解像度の極端現象の学習
- 様々な観測による学習、予報
- 観測を直接取り込む、データ同化



AI気象モデル：チャレンジ

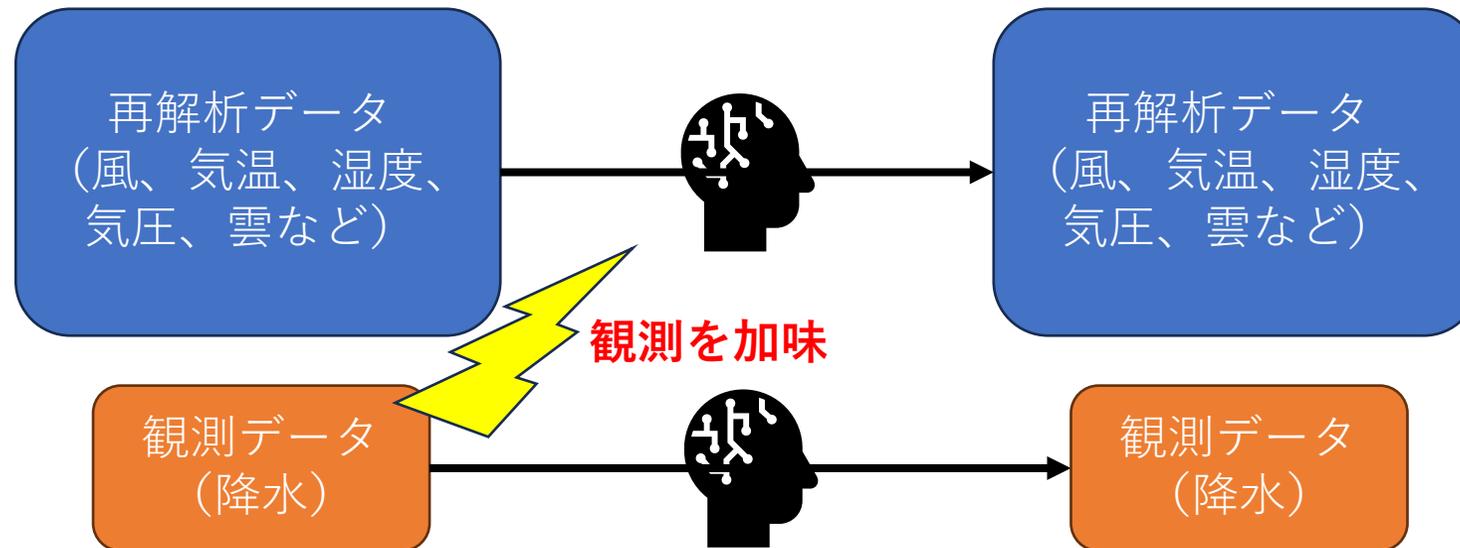
- 高解像度の極端現象の学習
- 様々な観測による学習、予報
- 観測を直接取り込む、データ同化



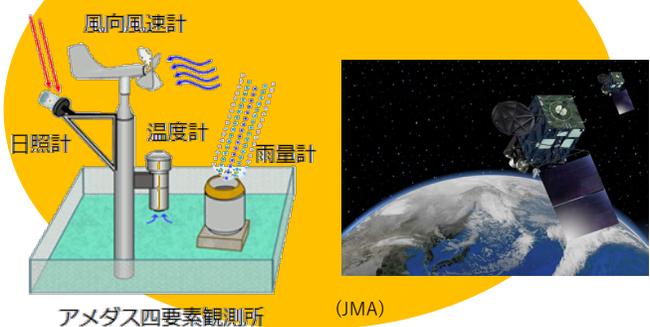
End-to-End ML → **様々な観測**

AI気象モデル：チャレンジ

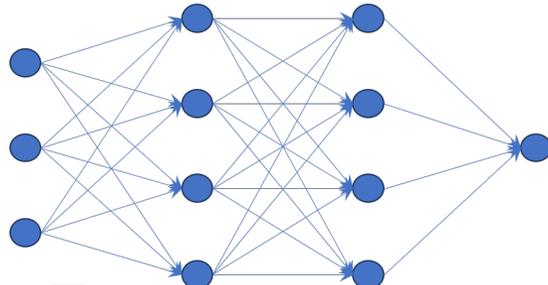
- 高解像度の極端現象の学習
- 様々な観測による学習、予報
- 観測を直接取り込む、データ同化



Raw observations: y



Latent space: ϕ



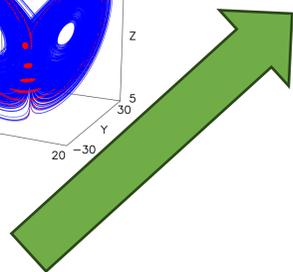
Diffusion model

Full Bayes?

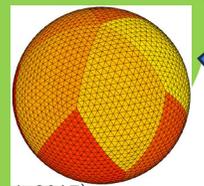
Training data

Training

Conditional distribution $p(\phi|y)$

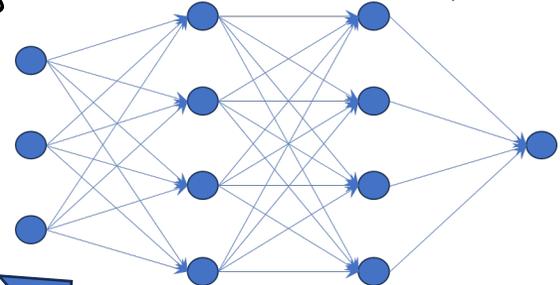


Physically-based model

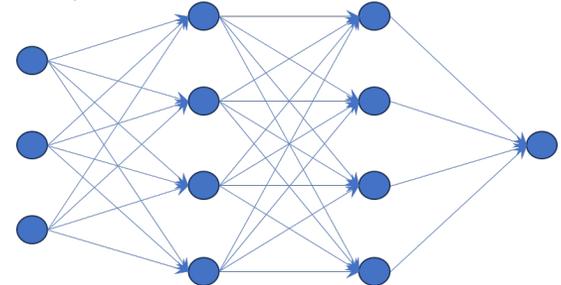


(Nakano et al. 2017)

PINN



Training



Prediction



(JMA)

事業について

プログラム紹介

新着情報

報告書・評価

もっと知る

公募情報

関係者向け

ムーンショット型研究開発事業 > プログラム紹介 > ムーンショット目標8

プログラム紹介

目標8

2050年までに、激甚化しつつある台風や豪雨を制御し極端風水害の脅威から解放された安全安心な社会を実現

プログラムディレクター (PD) **三好 建正**

理化学研究所 計算科学研究センター チームプリンシパル



2026年1月15日

理化学研究所

[← 前の記事](#) [↑ 一覧へ戻る](#) [→ 次の記事](#)

「バタフライ効果」を制御する新原理

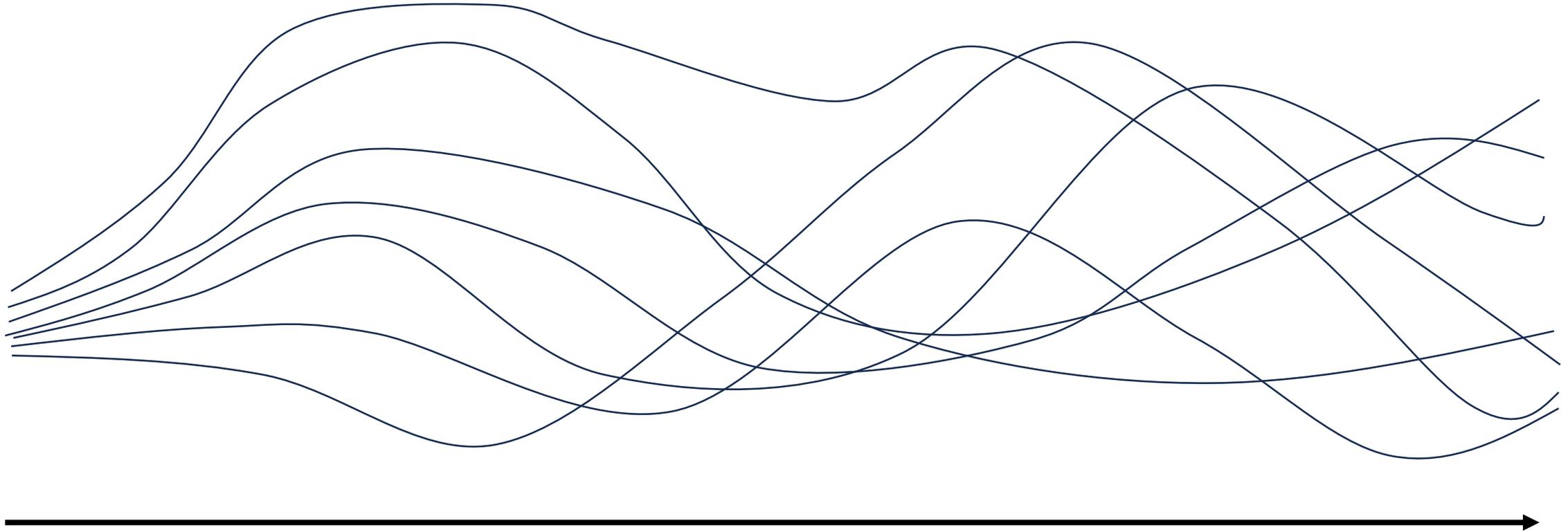
－カオスを逆手に取る「双対性原理」の提唱－

理化学研究所（理研）計算科学研究センター データ同化研究チームの三好 建正 チームプリンシパル（数理創造研究センター 予測科学研究チーム チームディレクター）は、「[バタフライ効果](#)^[1]」で知られる[決定論的カオス](#)^[2]の予測可能性の限界を逆手に取り、効率的にカオスを制御する新たな数理的枠組みを構築しました。気象予測の根幹を成す[データ同化](#)^[3]（観測を用いてモデルを自然の振る舞いに同期させるプロセス）とカオスの制御が数学的に双子の関係にあることを示す「[双対性原理](#)^[4]」を提唱しました。カオス自体を抑えるのではなく、カオス特有の高い感度を利用して、わずかな「介入」で扱いやすい「目標軌道」に自然の振る舞いを同期させます。これにより、予測限界を超えてカオスを制御する道筋を理論的に示しました。

本研究成果は、例えば、モデルで描いた「台風が被害をもたらさないシナリオ（目標軌道）」に現実の自然現象を同期させるためにわずかな変化（介入）を加えるといった、将来の極端気象を回避するための防災・減災研究に向けた理論的な道筋を示すとともに、生態系や経済学など、カオス的な振る舞いを示すさまざまな分野での応用が期待されます。

本研究は、科学雑誌『*Nonlinear Dynamics*』オンライン版（1月14日付：日本時間1月15日）に掲載されました。

「バタフライ効果」を制御できるか？



Time →

予測可能性

カオス

Time

改変可能性

≠ 制御可能性

Chaos implies effective controllability but only after the predictability limit



A duality principle for chaotic systems: from data assimilation to efficient control

Takemasa Miyoshi^{1,2}

Received: 3 September 2025 / Revised: 10 October 2025 / Accepted: 10 October 2025 / Published online: 14 January 2026
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Abstract

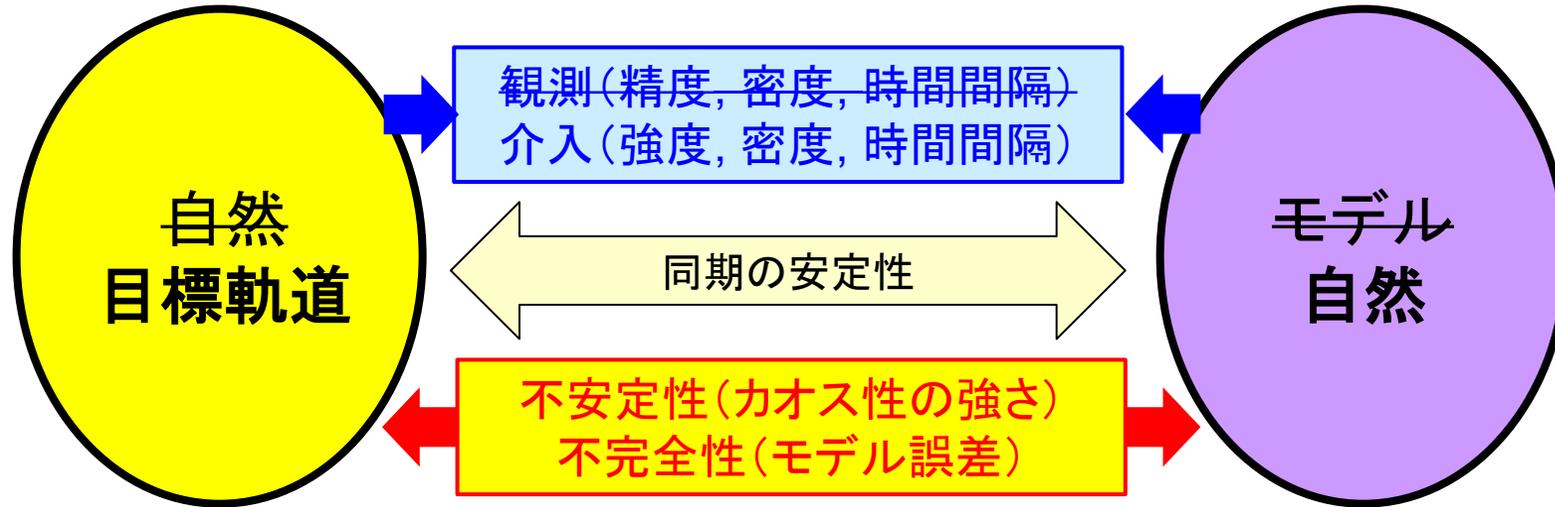
E. N. Lorenz discovered the highly sensitive nature of a chaotic dynamical system and conveyed it vividly by his famous “butterfly effect”; namely, a flap of a butterfly could cause a storm a few days later somewhere far away. Extreme weather like intense storms tends to be more chaotic and harder to predict, with increasing threat due to climate change. This motivates us to ask if we could possibly modify extreme weather in a favorable manner by taking advantage of its strong chaoticity. Here, the problem is that the causality from a flap of a butterfly to a storm formation is not trivial due to the limited predictability. Due to chaos, a small perturbation grows exponentially and leads to a different future state, but the difference becomes large enough only after the predictable range. This paper addresses this apparent paradox by presenting the first rigorous mathematical formalization of the Control Simulation Experiment (CSE) framework, an extension of the data assimilation (DA) paradigm. We then propose a duality principle based on chaos synchronization: while DA uses observations to synchronize a model to nature’s trajectory, we argue that control uses interventions to synchronize nature to a chosen target trajectory. The feasibility of this control rests on the key insight that these target trajectories can be selected to have distinct dynamical properties from the original system, reframing the challenge from taming a fully chaotic system to maintaining synchronization with a more manageable path.

Keywords Duality principle · Chaos control · Data assimilation · Chaos synchronization · Control simulation experiment (CSE) · Predictability · Nonlinear dynamics

カオス同期 Chaos Synchronization

Master (drive) system

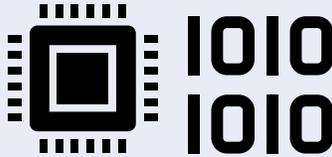
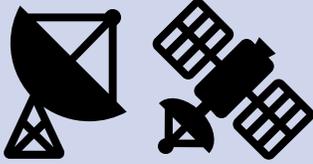
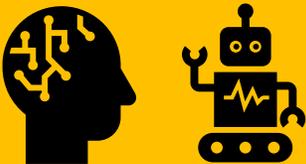
Slave (response) system



	データ同化	制御
駆動システム	自然	目標軌道
応答システム	計算モデル	自然
強制力	観測による修正	介入
力の源	観測	制御入力

表1 データ同化と制御の双対性原理

天気予報の革新の歴史

	技術革新	天気予報
1850	遠隔通信 	天気図解析
1950	電子計算機 	数値天気予報
1980	リモートセンシング • レーダ • 人工衛星 	データ同化 予測可能性
2015	AI/ML 	AI/MLを使った数値天気予報? 制御可能性?