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An End-to-End AI Large Model for 3D Ocean Dynamic Prediction Driven by Satellite Remote Sensing

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[95497 RESEARCH AND APPLICATION OF DEEP LEARNING FOR THE IMPROVEMENT OF WAVE REMOTE SENSING FROM MULTI-MISSIONS]



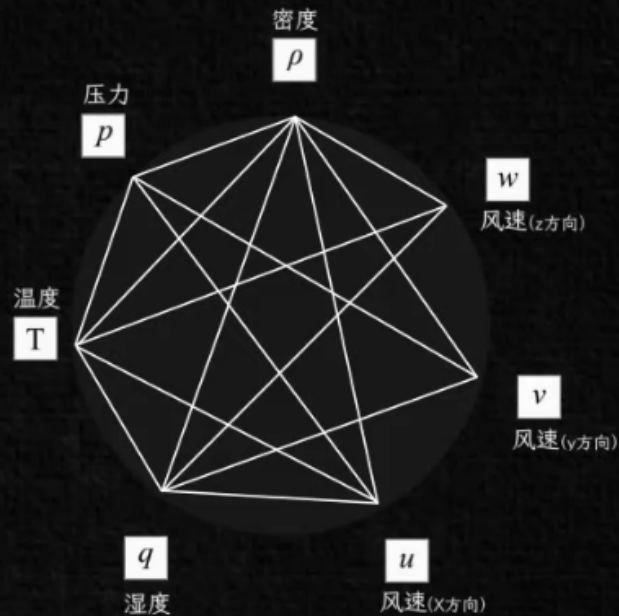
How to do the forecast?



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State Equation

$$p = \rho R T$$

Thermodynamic

$$C_v \frac{dT}{dt} = -p \frac{d\alpha}{dt} + Q$$

Water vapor

$$\frac{\partial q}{\partial t} + V_3 \cdot \nabla_3 q = S_1$$

Continuity

$$\frac{dp}{dt} + \rho V_3 \cdot \nabla_3 = 0$$

Dynamic (X axis)

$$\frac{du}{dt} = -\frac{1}{\rho r \cos \varphi} \frac{\partial p}{\partial \lambda} + 2\Omega v \sin \varphi + 2\Omega w \cos \varphi + \frac{uv \tan \varphi}{r} - \frac{uw}{r} + F_u$$

Dynamic (Y axis)

$$\frac{dv}{dt} = -\frac{1}{\rho r} \frac{\partial p}{\partial \lambda} + 2\Omega u \cos \varphi + \frac{u^2 \tan \varphi}{r} - \frac{vw}{r} + F_v$$

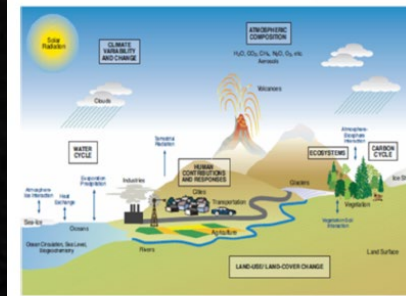
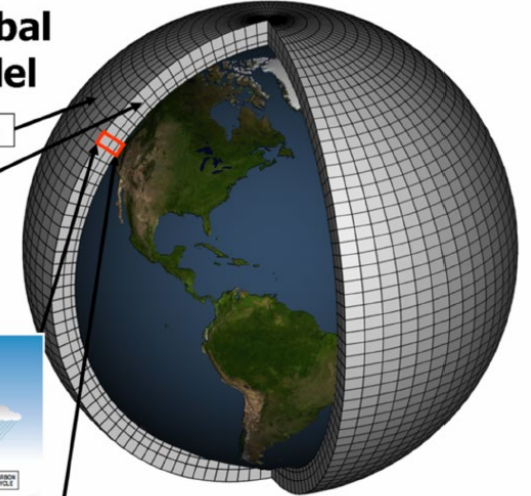
Dynamic (Z axis)

$$\frac{dw}{dt} = -\frac{1}{\rho} \frac{\partial p}{\partial r} - \frac{a^2}{r^2} g + 2\Omega u \cos \varphi + \frac{u^2 + v^2}{r} + F_w$$

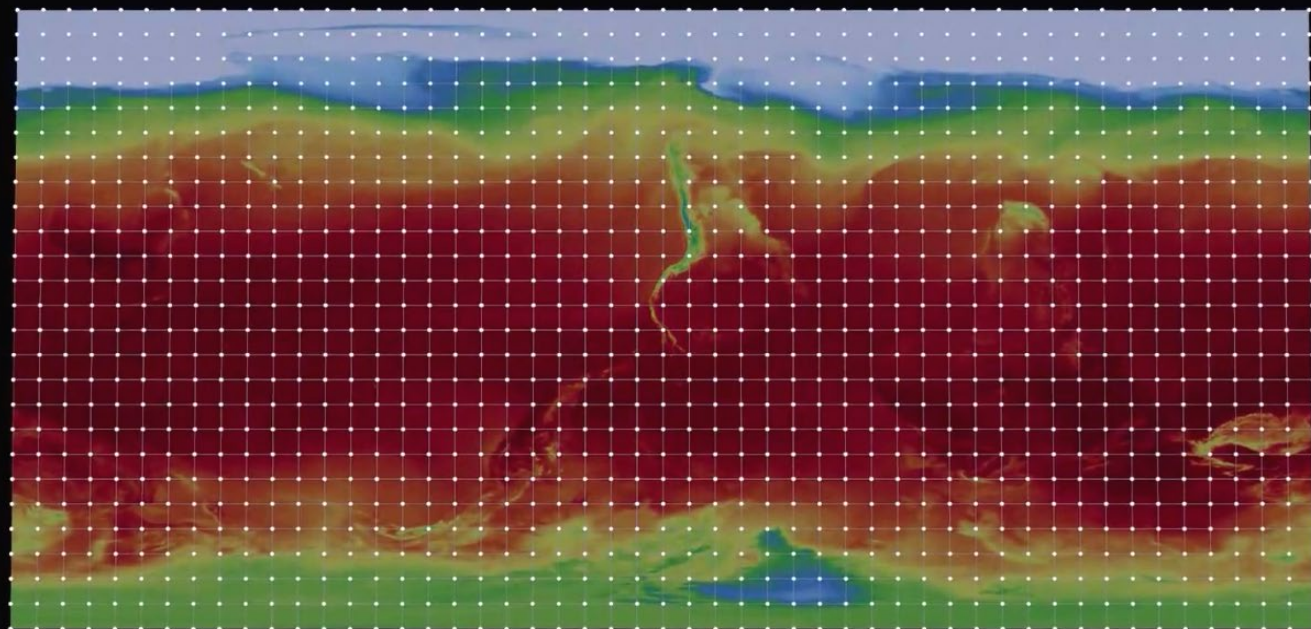
Schematic for Global Atmospheric Model

Horizontal Grid (Latitude-Longitude)

Vertical Grid (Height or Pressure)



How to do the forecast?



721

1440 x 1440 x 721

1495065600

1440



状态方程

$$p = \rho R T$$

热力学方程

$$C_v \frac{dT}{dt} = -p \frac{d\alpha}{dt} + Q$$

水汽方程

$$\frac{\partial q}{\partial t} + \mathbf{V}_3 \cdot \nabla_3 q = S_1$$

连续方程

$$\frac{dp}{dt} + \rho \mathbf{V}_3 \cdot \nabla_3 = 0$$

运动方程 (x方向)

$$\frac{du}{dt} = -\frac{1}{\rho r \cos \varphi} \frac{\partial p}{\partial \lambda} + 2\Omega v \sin \varphi + 2\Omega w \cos \varphi + \frac{uv \tan \varphi}{r} - \frac{uw}{r} + F_u$$

运动方程 (y方向)

$$\frac{dv}{dt} = -\frac{1}{\rho r} \frac{\partial p}{\partial \lambda} + 2\Omega u \cos \varphi + \frac{u^2 \tan \varphi}{r} - \frac{vw}{r} + F_v$$

运动方程 (z方向)

$$\frac{dw}{dt} = -\frac{1}{\rho} \frac{\partial p}{\partial r} - \frac{a^2}{r^2} g + 2\Omega u \cos \varphi + \frac{u^2 + v^2}{r} + F_w$$

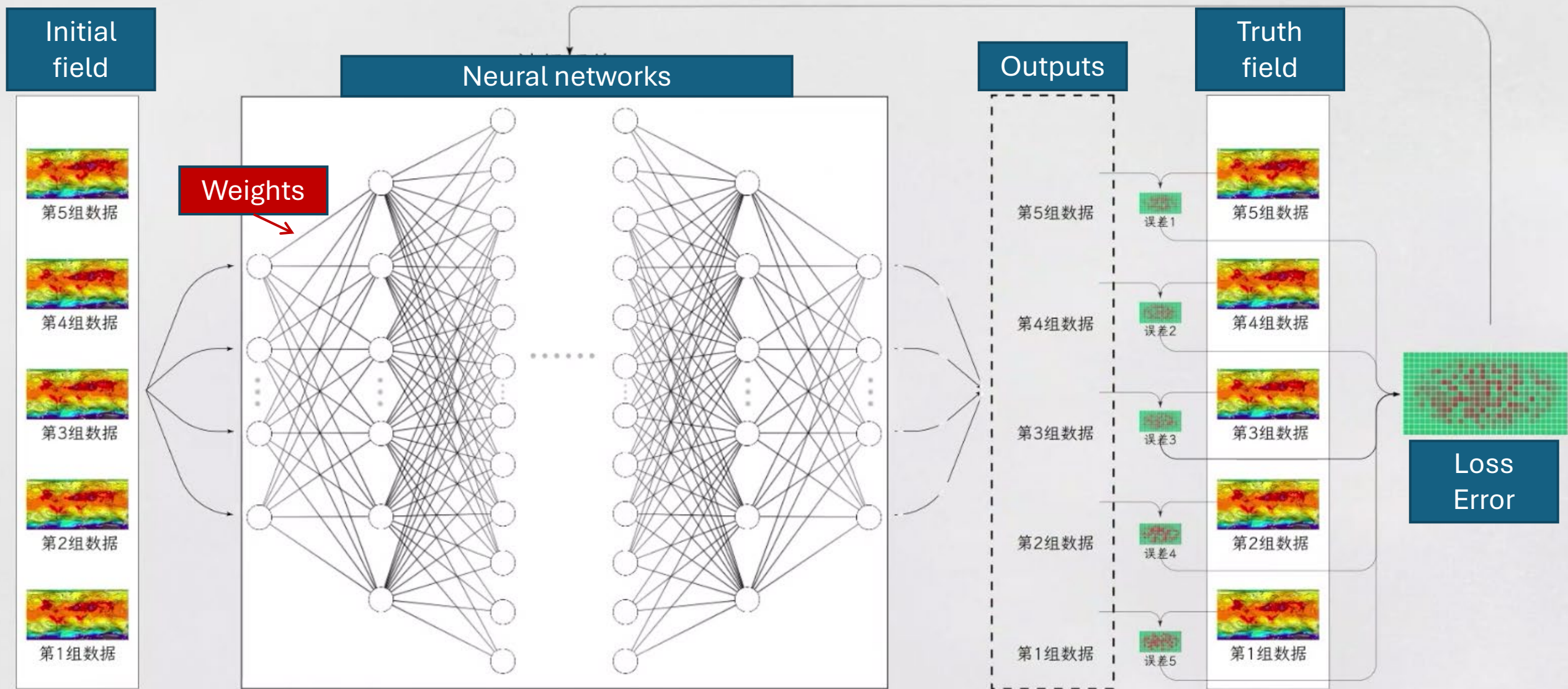
How does AI do the forecast?



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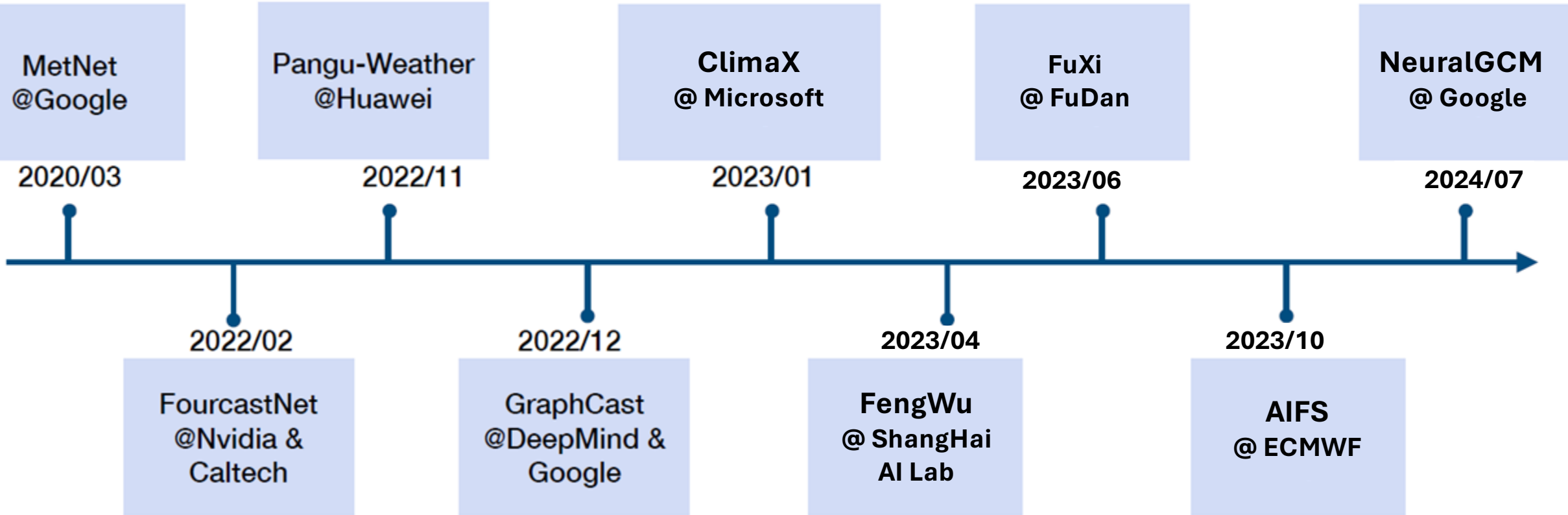
Development of AI forecast model



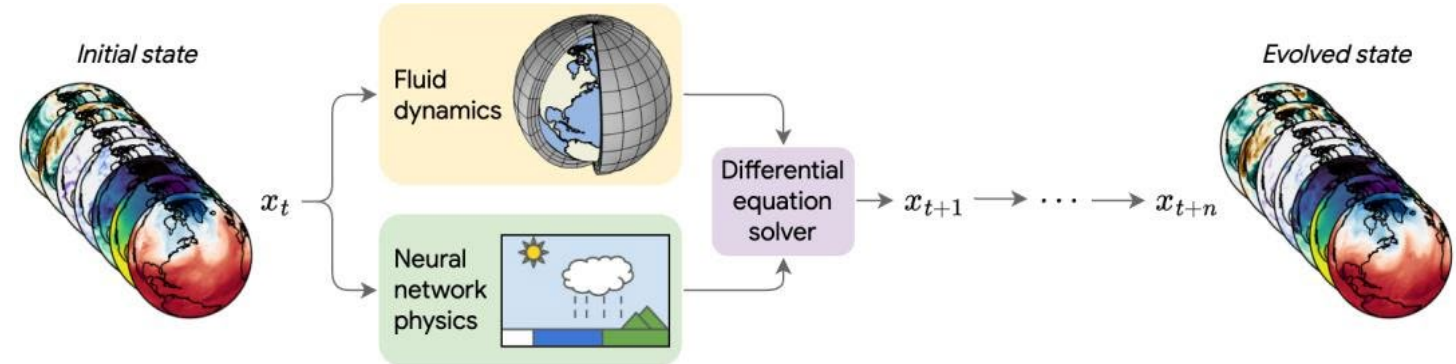
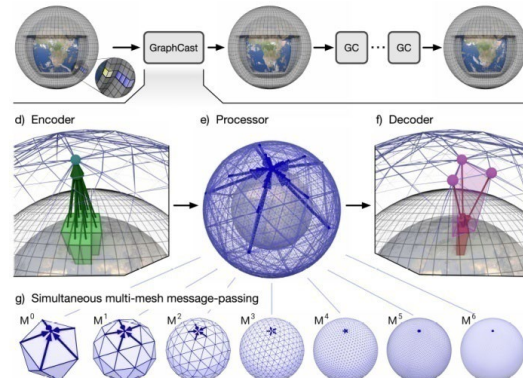
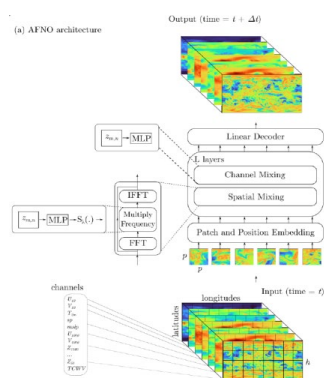
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(a) AFNO architecture



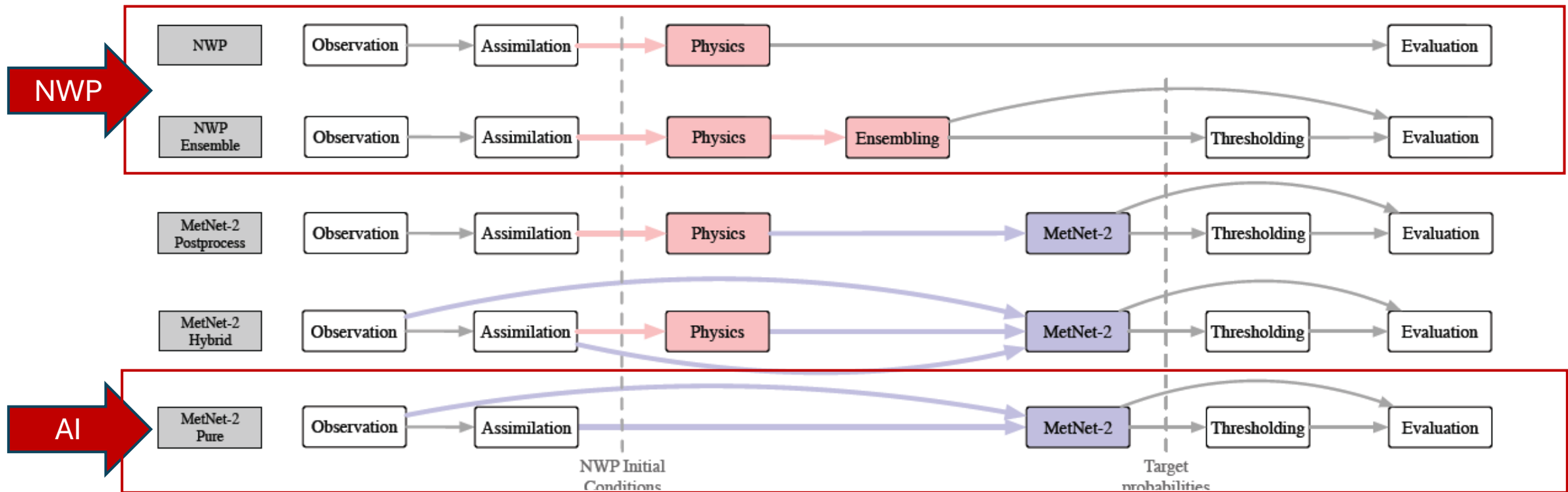
How is AI forecast model performance



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Model	Region	Type	Operational Frequency	Spatial Resolution	Temporal Resolution
HRRR	CONUS	Deterministic	Hourly	3 km	Hourly
HREF	CONUS	Ensemble	Every 6 h	3 km	Hourly
HRES	Global	Deterministic	Every 6 h	0.1°, 7–11 km	Hourly
ENS	Global	Ensemble	Every 6 h	0.2°, 14–22 km	Hourly
MetNet-3	CONUS	Probabilistic	Every 10 min	1-4 km	2-5 min

How is AI forecast model performance



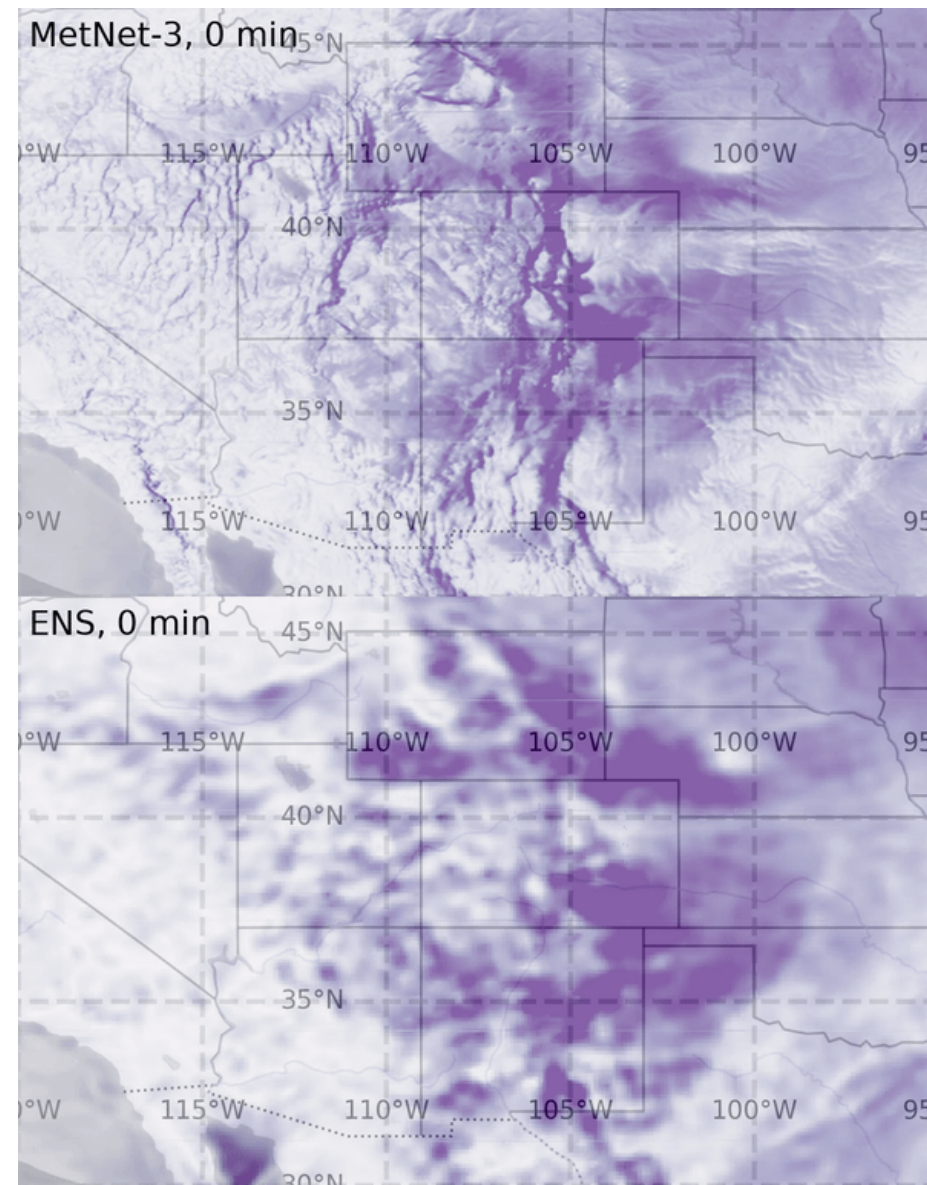
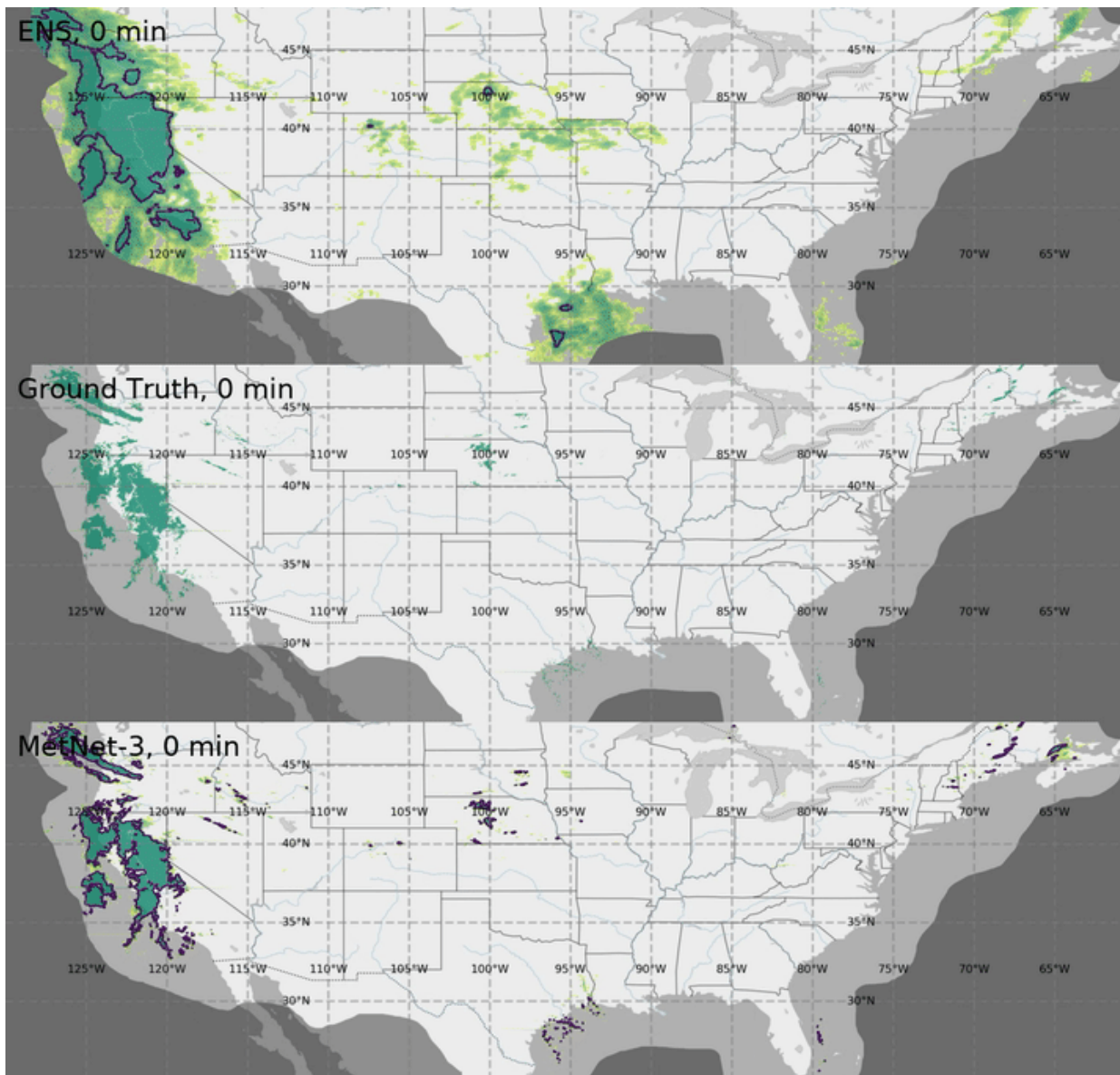
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512
GPUs

7 Days
To Train





Article

Nature: First time overperforme ECMWF IFS

Accurate medium-range global weather forecasting with 3D neural networks

<https://doi.org/10.1038/s41586-023-06185-3>

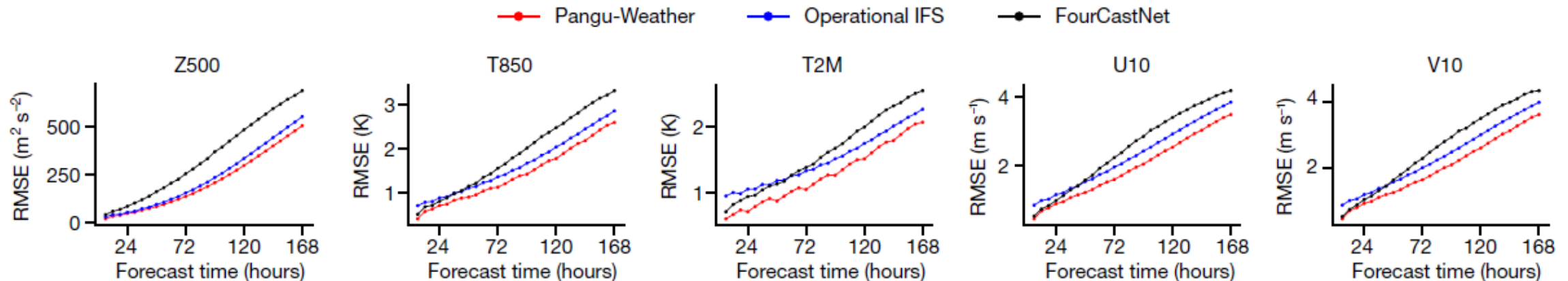
Kaifeng Bi¹, Lingxi Xie¹, Hengheng Zhang¹, Xin Chen¹, Xiaotao Gu¹ & Qi Tian¹✉

Received: 5 January 2023

Accepted: 9 May 2023

Published online: 5 July 2023

Trained on 39 years ERA5, 16 Days on 192 Tesla-V100 GPU



How is AI forecast model performance

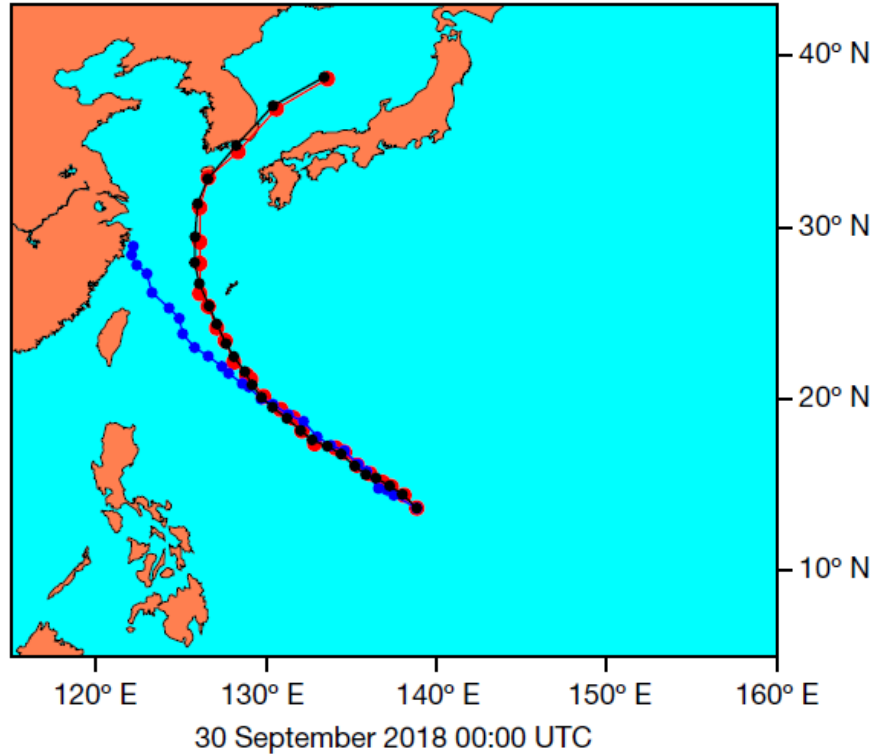


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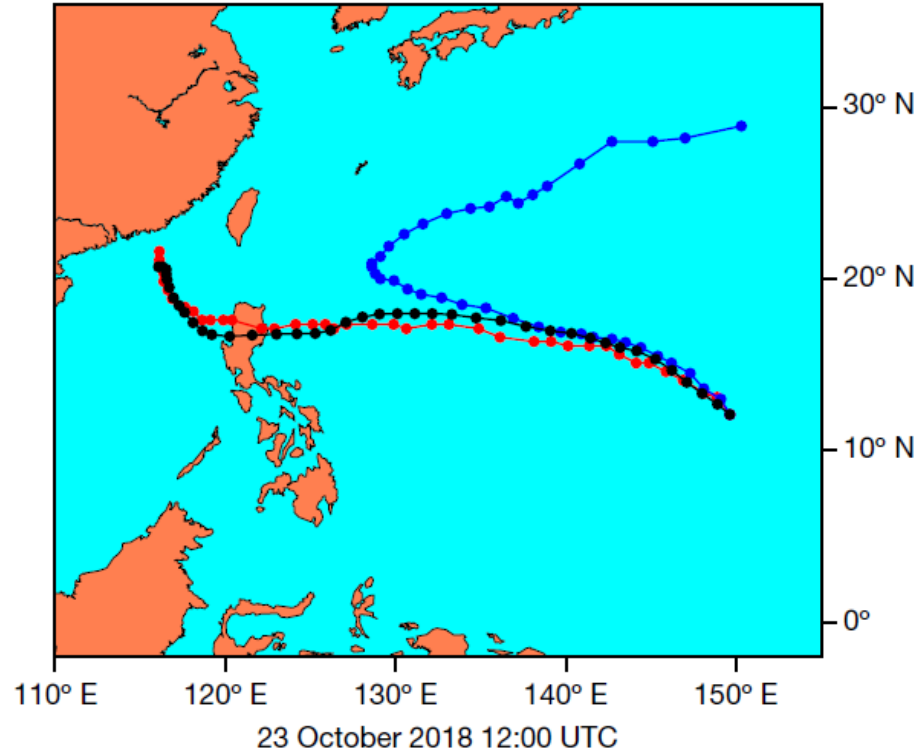


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a Track forecast for Typhoon Kong-rey

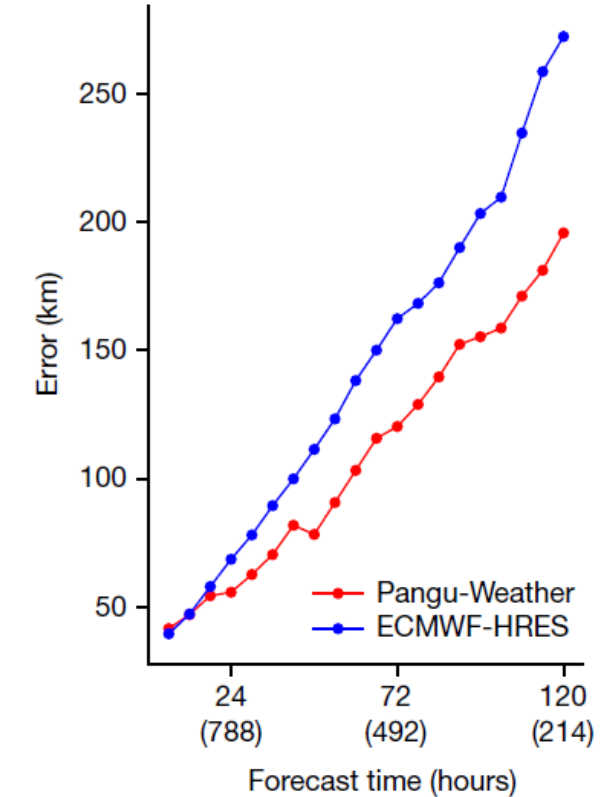


b Track forecast for Typhoon Yutu



—●— Pangu-Weather forecast —●— ECMWF-HRES forecast —●— Ground truth

c Mean direct position error



The inference cost of Pangu-Weather is **1.4s** on a single GPU,
which is more than **10,000-times faster** than the operational IFS

Development of AI forecast model



Nature	2025.5.21 A foundation model for the Earth system (Aurora)
Nature	2025.3.20 End-to-end data-driven weather prediction (Aardvark Weather)
Nature Communication	2025.3.6 Forecasting the eddying ocean with a deep neural network (WenHai)
Nature	2024.8.13 Weather and climate predicted by hybrid model
Nature Communication	2024.7.30 A machine learning model that outperforms conventional global subseasonal forecast models (Fuxi-S2S)
Nature	2024.7.22 Neural general circulation models for weather and climate (NeuralGCM)
Science	2023.11.14 Learning skillful medium-range global weather forecasting (GraphCast)
Nature	2023.7.22 Accurate medium-range global weather forecasting with 3D neural networks (PanGu)

End to End forecast



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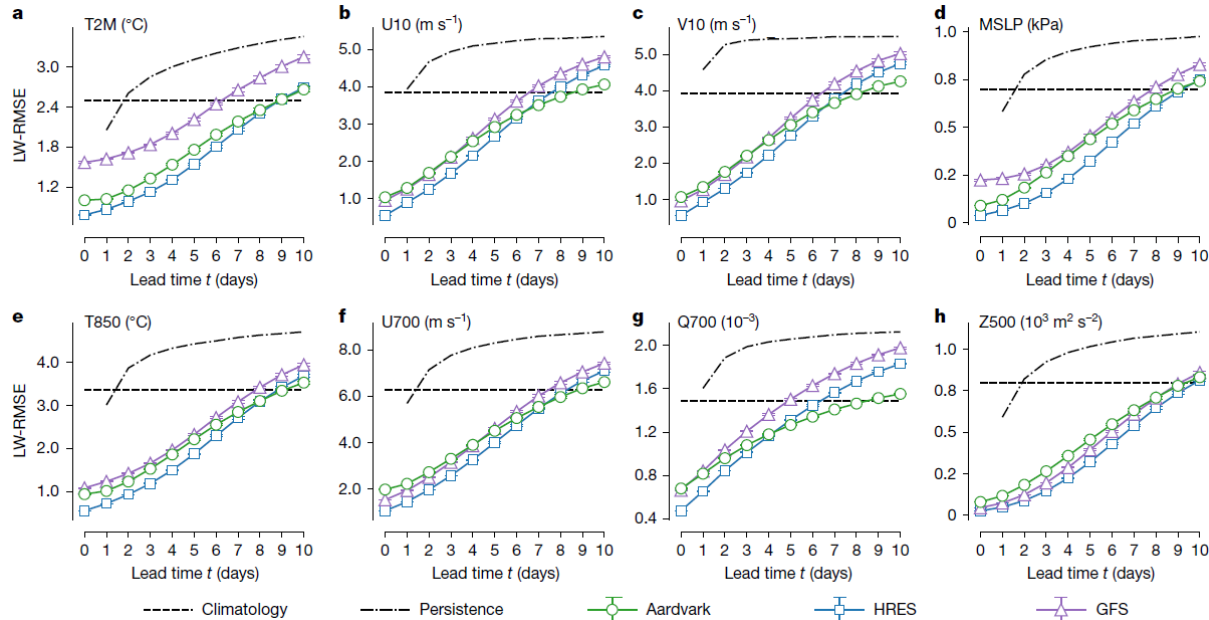
Article | Published: 20 March 2025

End-to-end data-driven weather prediction

[Anna Allen](#) , [Stratis Markou](#) , [Will Tebbutt](#), [James Requeima](#), [Wessel P. Bruinsma](#), [Tom R. Andersson](#),
[Michael Herzog](#), [Nicholas D. Lane](#), [Matthew Chantry](#), [J. Scott Hosking](#) & [Richard E. Turner](#)

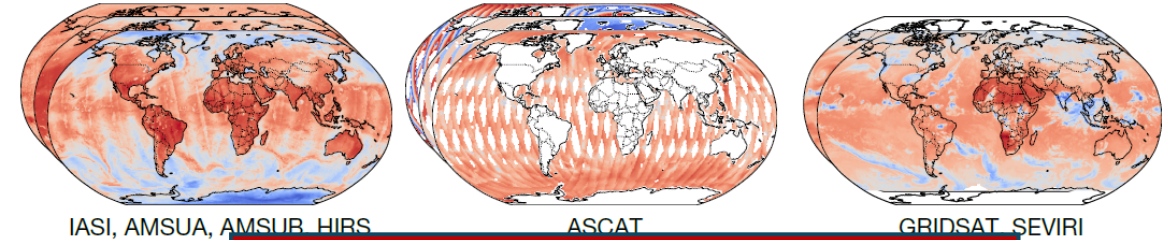
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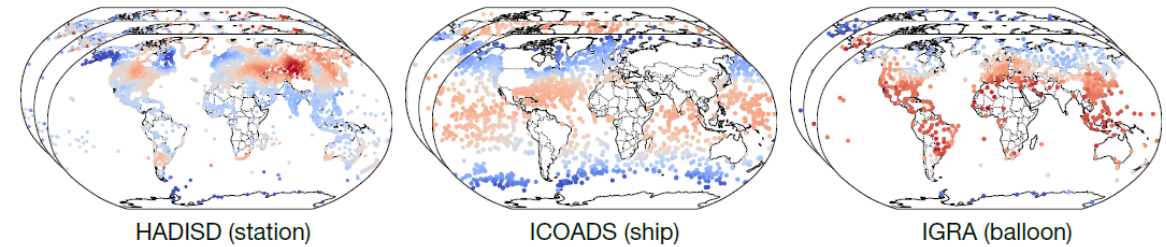


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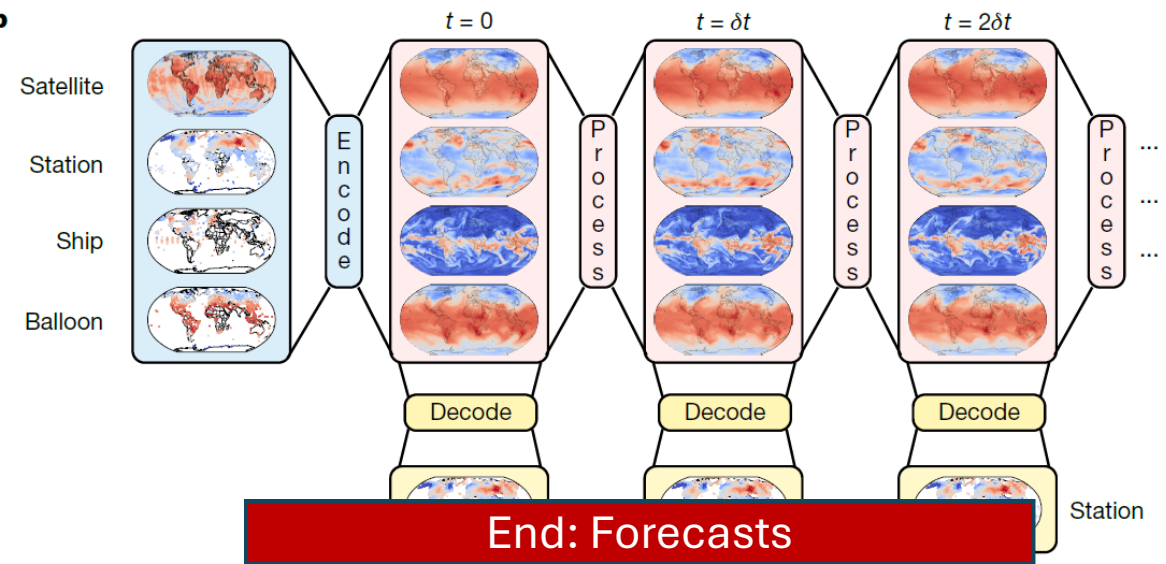
Remote sensing observations (on the grid)



End: Observations



b



End to End ocean forecast

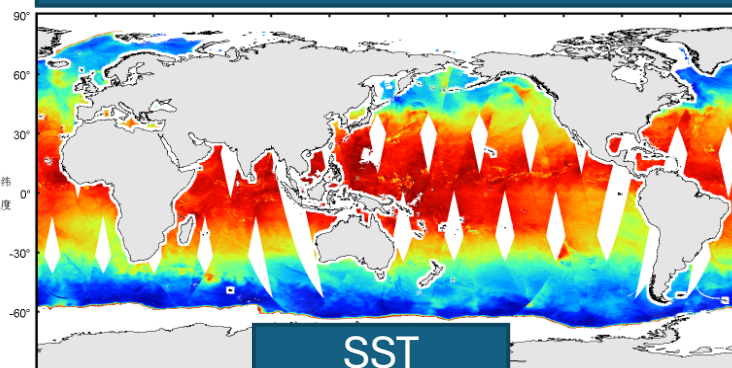


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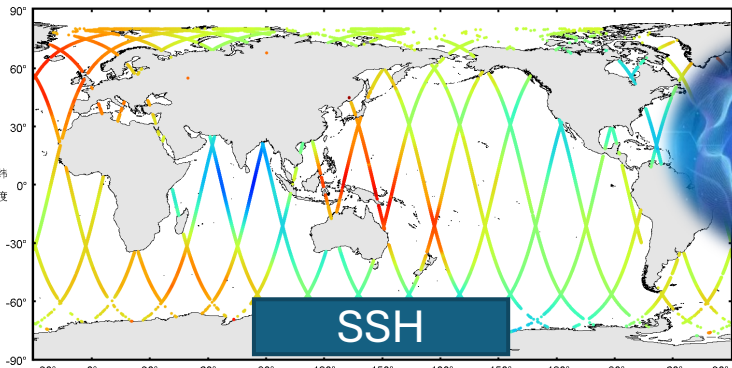


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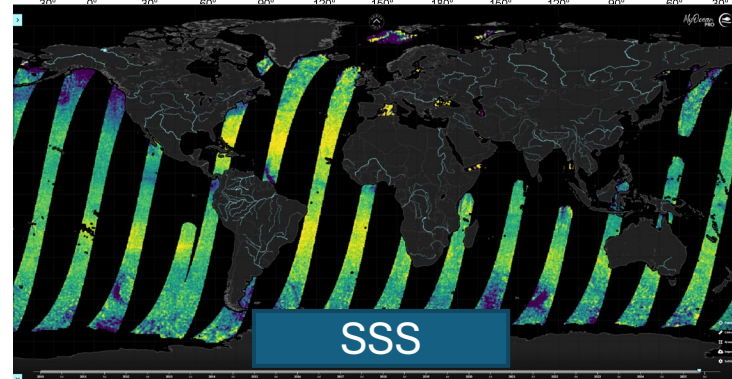
Along-track (L3)



SST

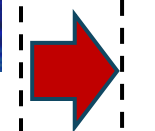
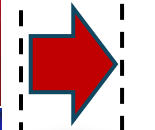
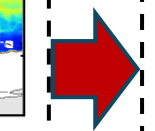
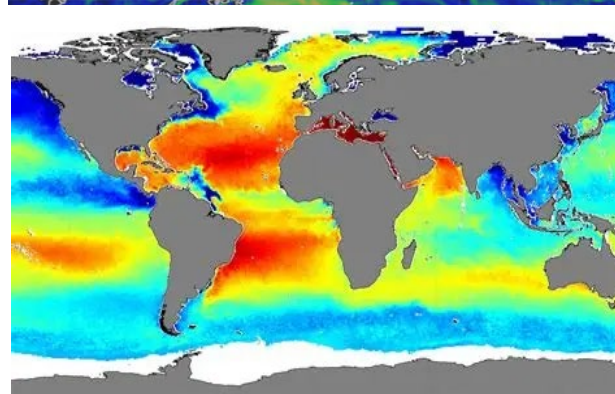
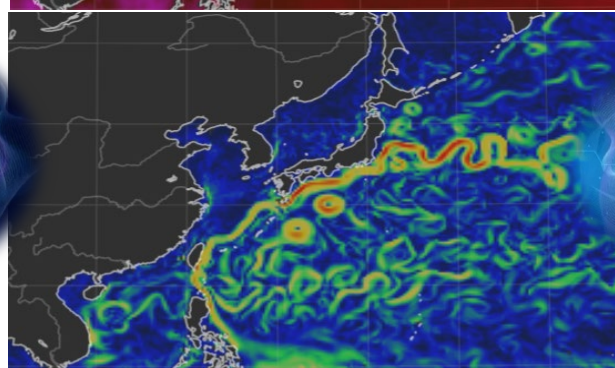
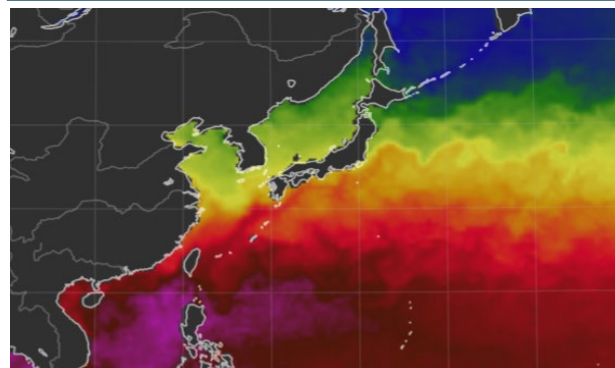


SSH



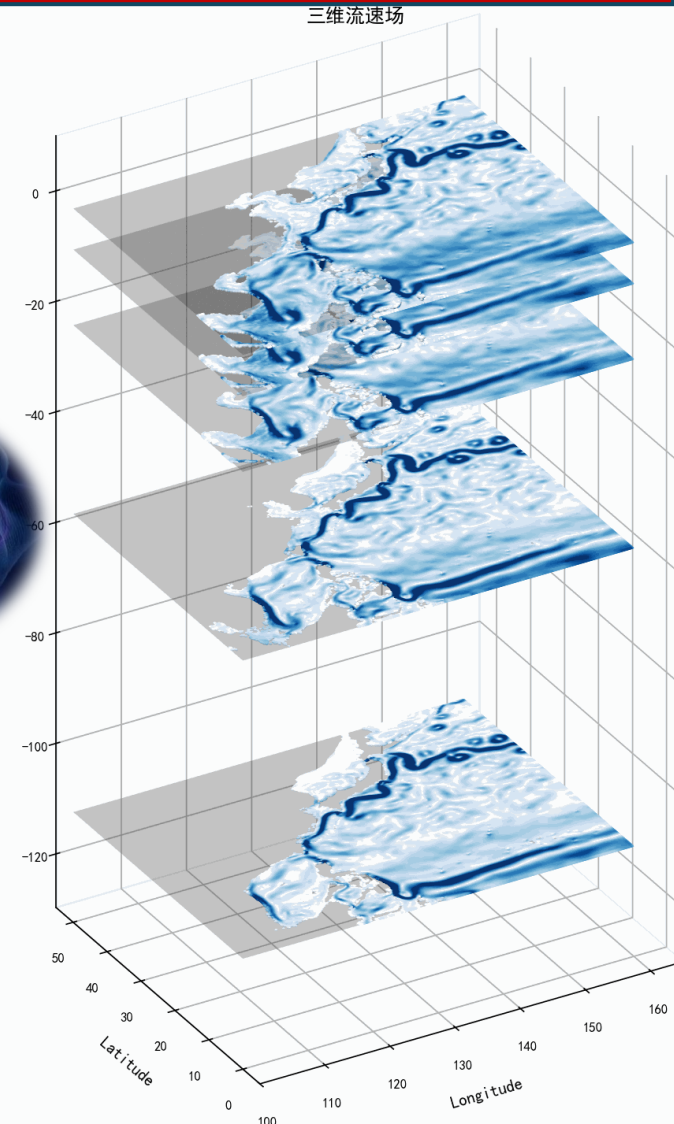
SSS

Grided Data (L4)



10 Days 3D ocean forecast

三维流速场





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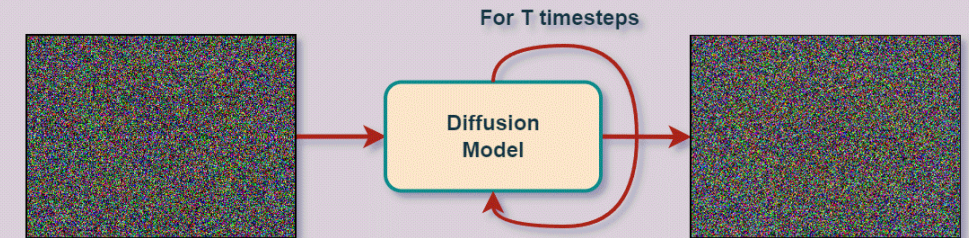


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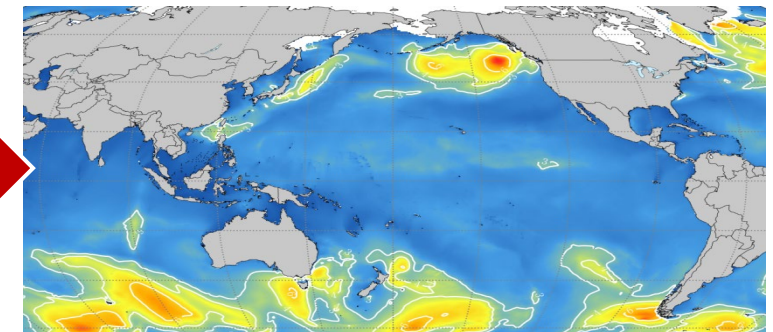
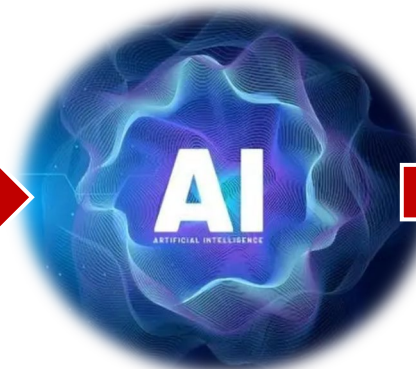
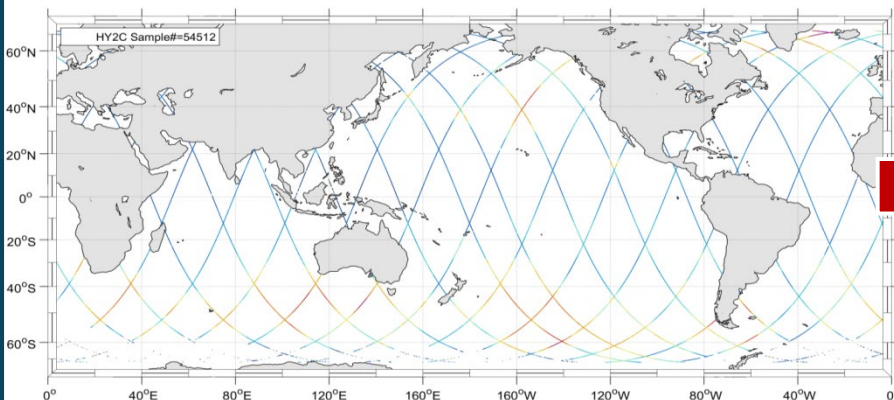
Artificial Intelligence Generated Content, AIGC



- Beautiful, snowy Tokyo city is bustling. The camera moves through the bustling city street, following several people enjoying the beautiful snowy weather and shopping at nearby stalls. Gorgeous sakura petals are flying through the wind along with snowflakes.

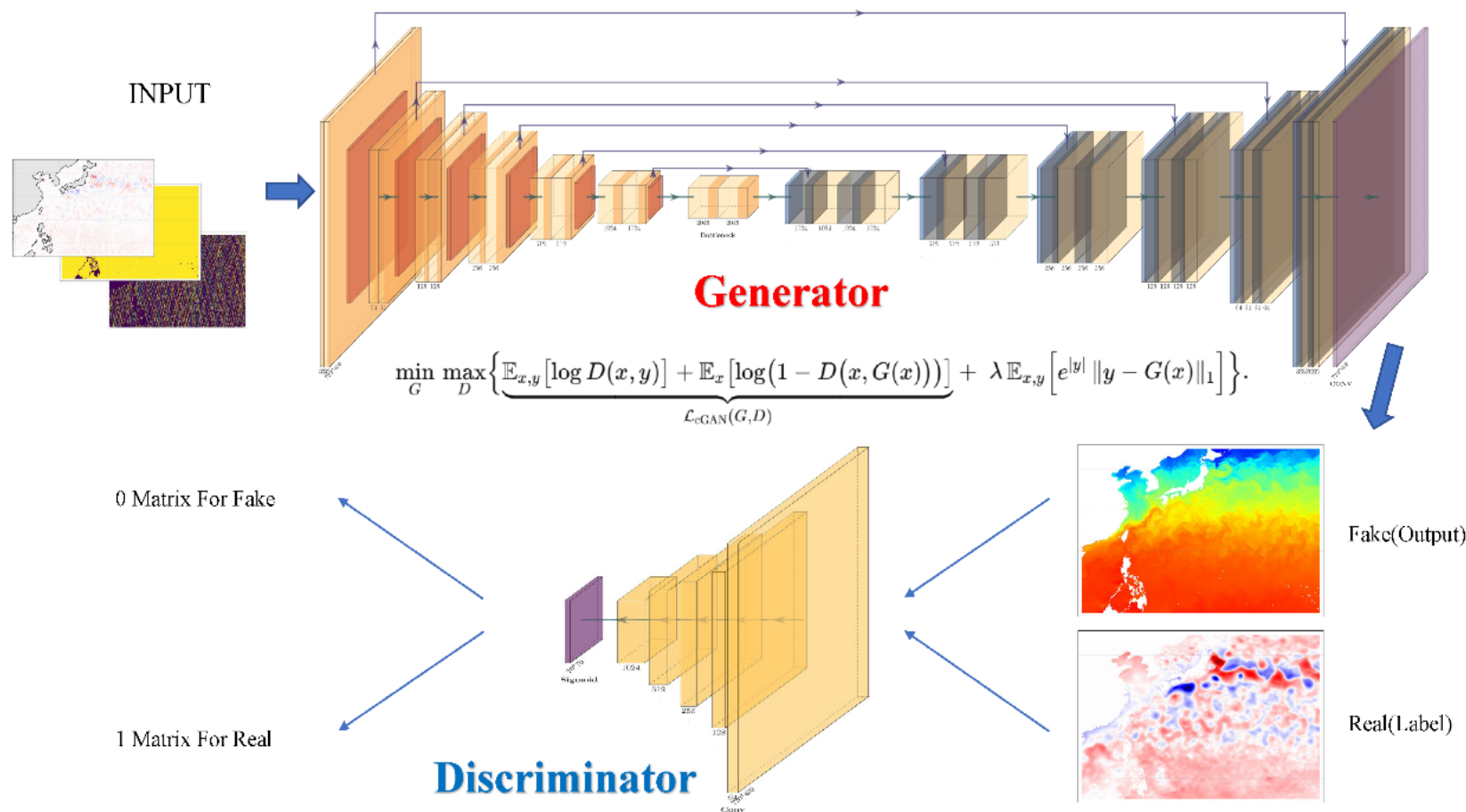


Gaps of
the
remote
sensing

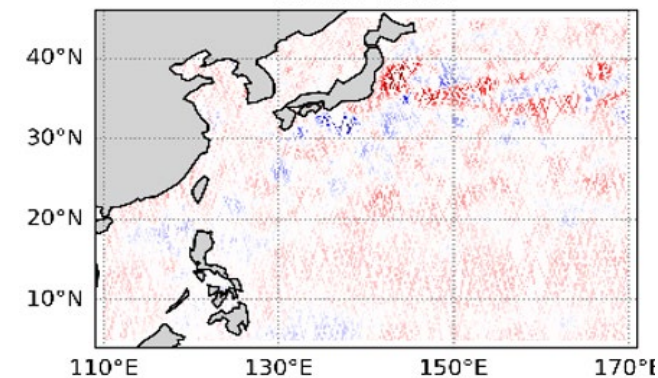




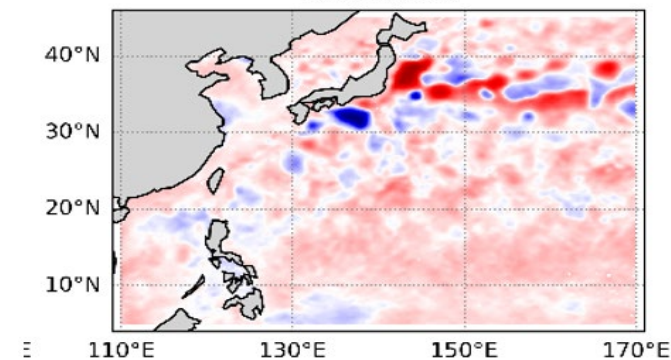
Generative Adversarial Networks, GAN



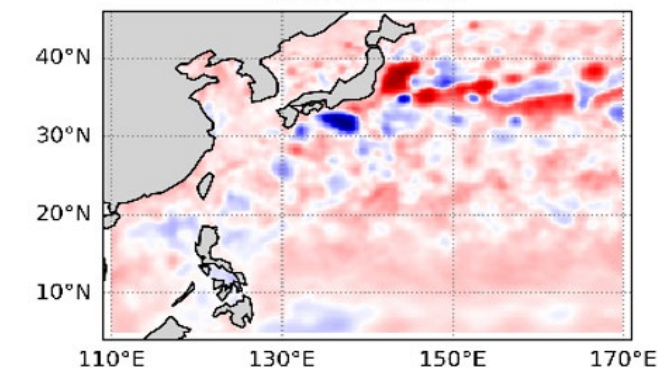
SLA L3 Tracks



GAN Result



Aviso-L4-result



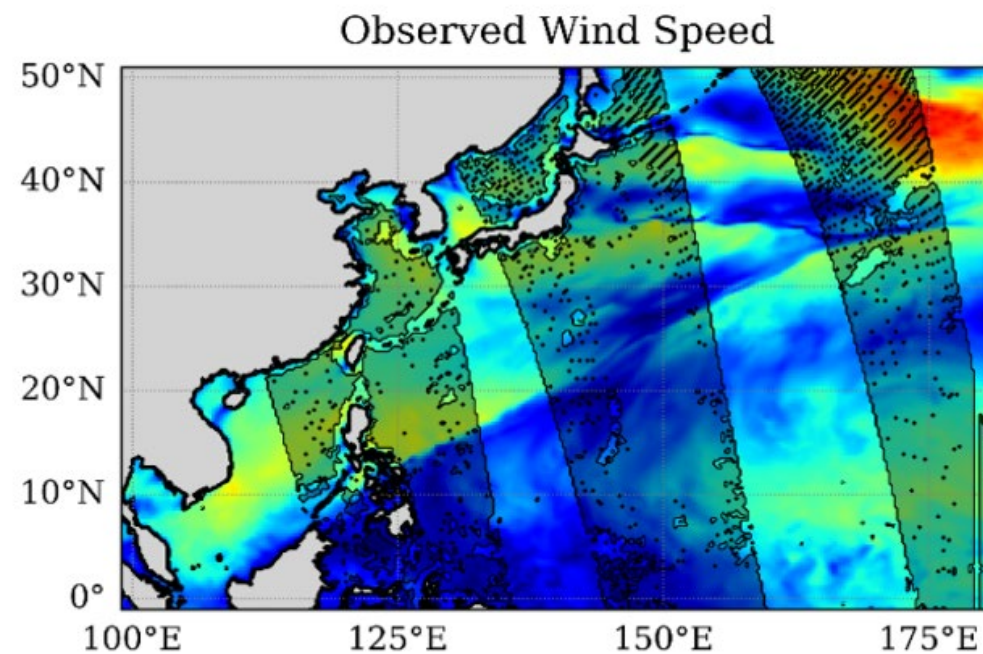
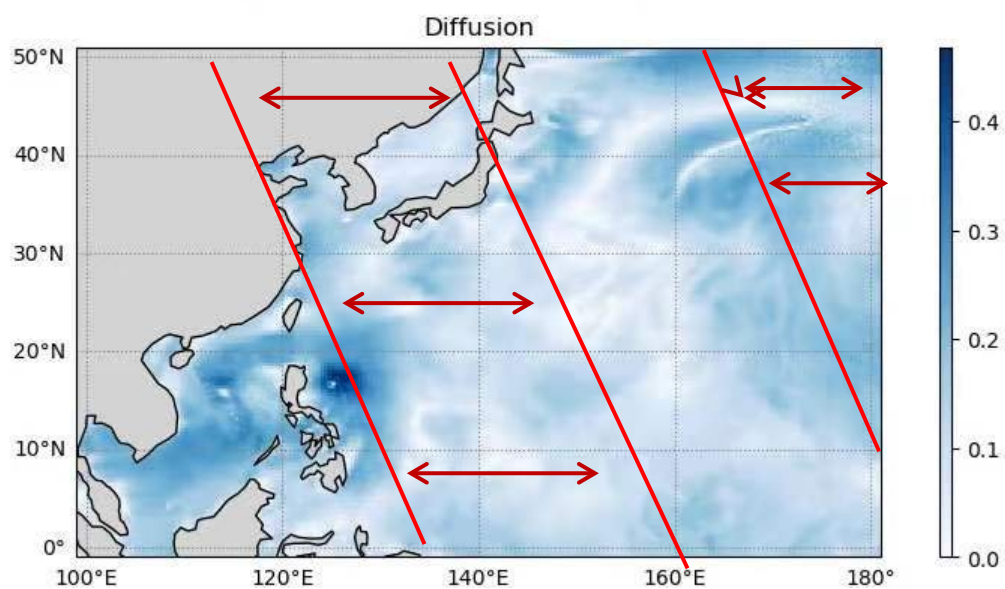
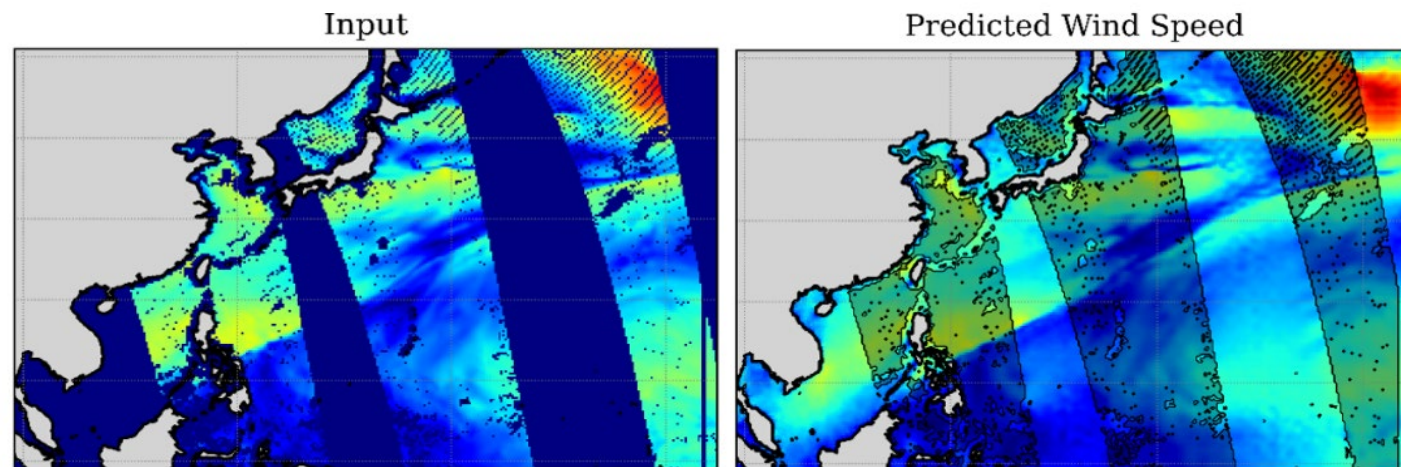
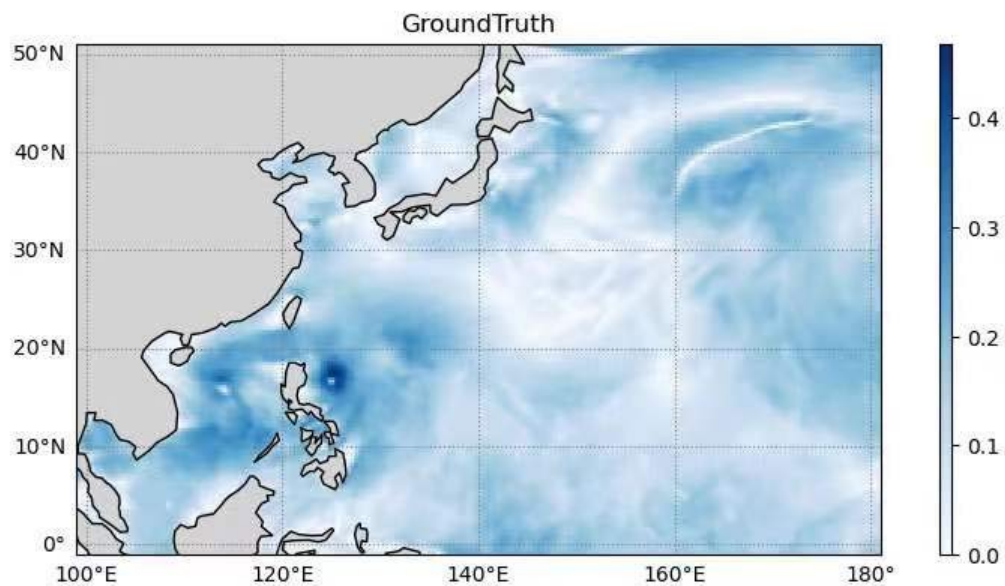
L3 to L4



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2D to 3D

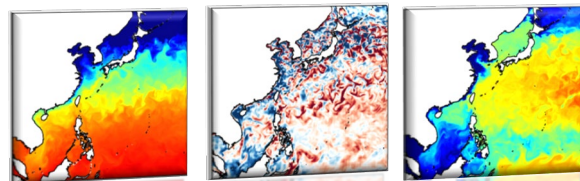


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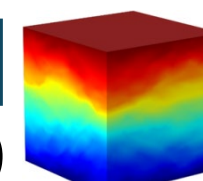
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L4 Remote Sensing
 $T_0(\text{SSH}, T, S, u, v)$



3D Parameters

$T_{0+xd}(\text{SSH}, T, S, u, v)$



Time & Bias
Embedding

Variable-Wise
Embedding

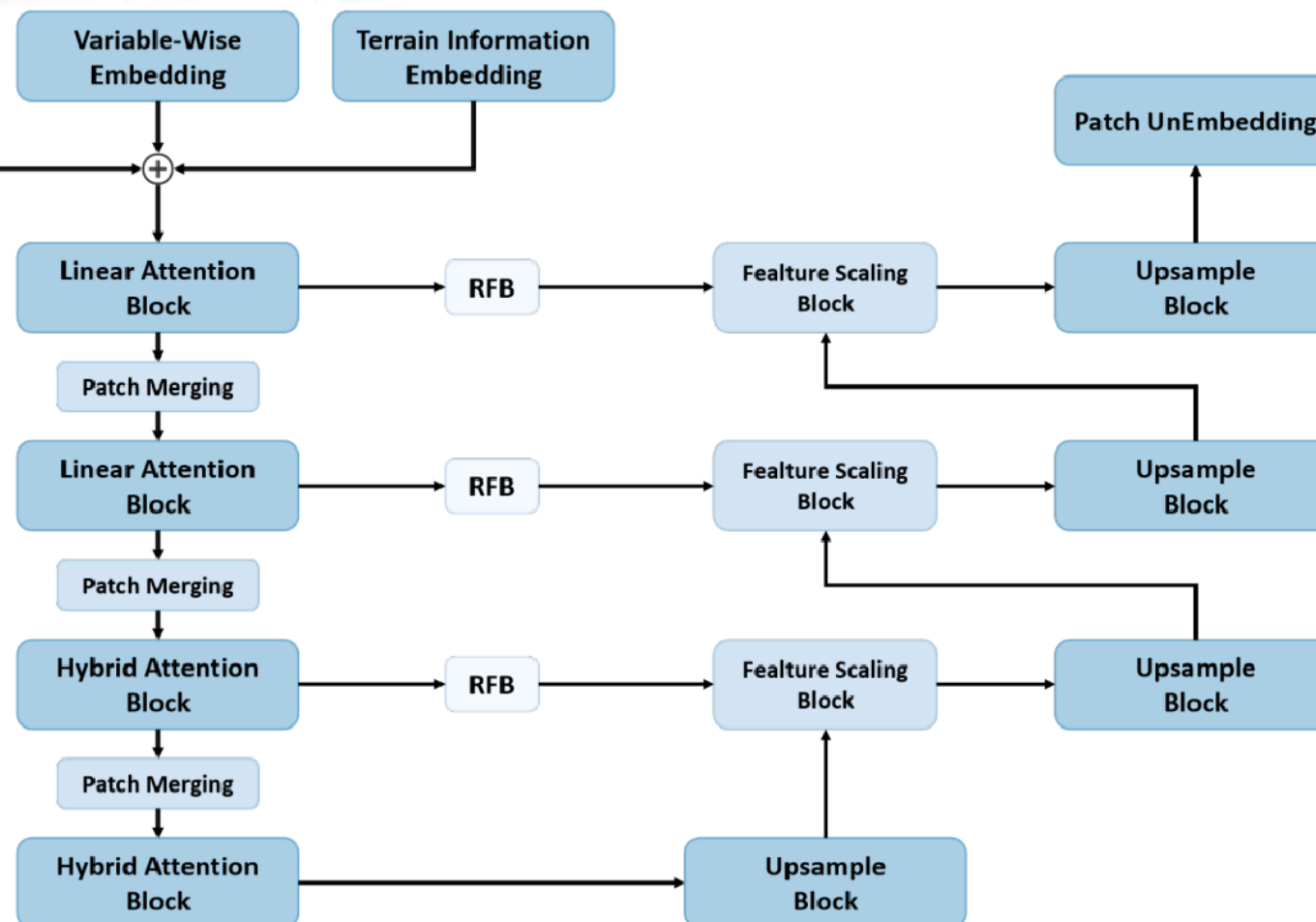
Terrain Information
Embedding

Area and Resolution

- 100~160°E, 0~50°N
- Daily, 1/8°
- Future 10 days

Traning Datasets

- CMEMS GLORYS 1/12°
- 1993~2021 Training
- 2022~2023 Testing



Depth

- 0.4940,
- 2.6457,
- 5.0782,
- 7.9296,
- 11.4050,
- 15.8101,
- 21.5988,
- 29.4447,
- 40.3441,
- 55.7643,
- 77.8539,
- 92.3261,
- 109.7293,
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- 186.1256,
- 222.4752,
- 318.1274,
- 453.9377,
- 643.5668

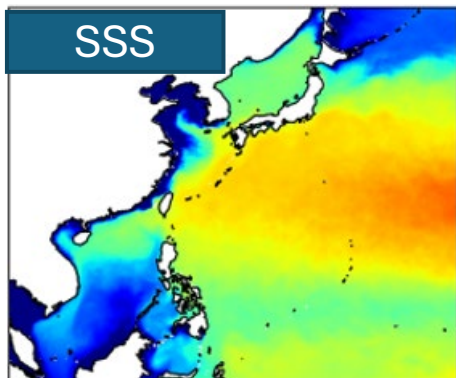
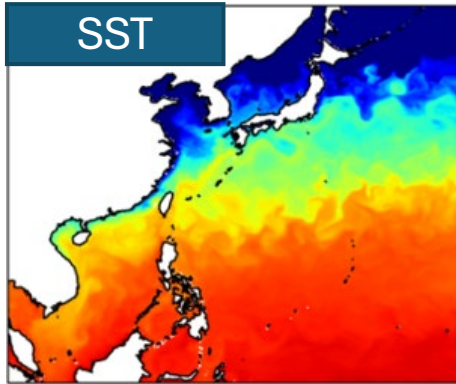
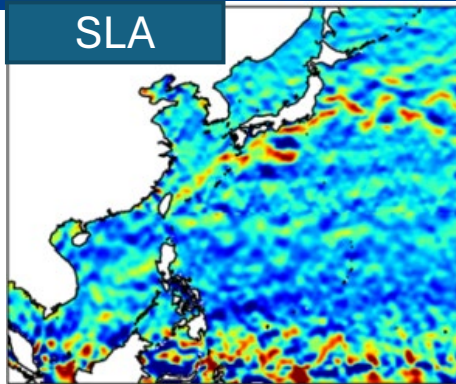
2D to 3D



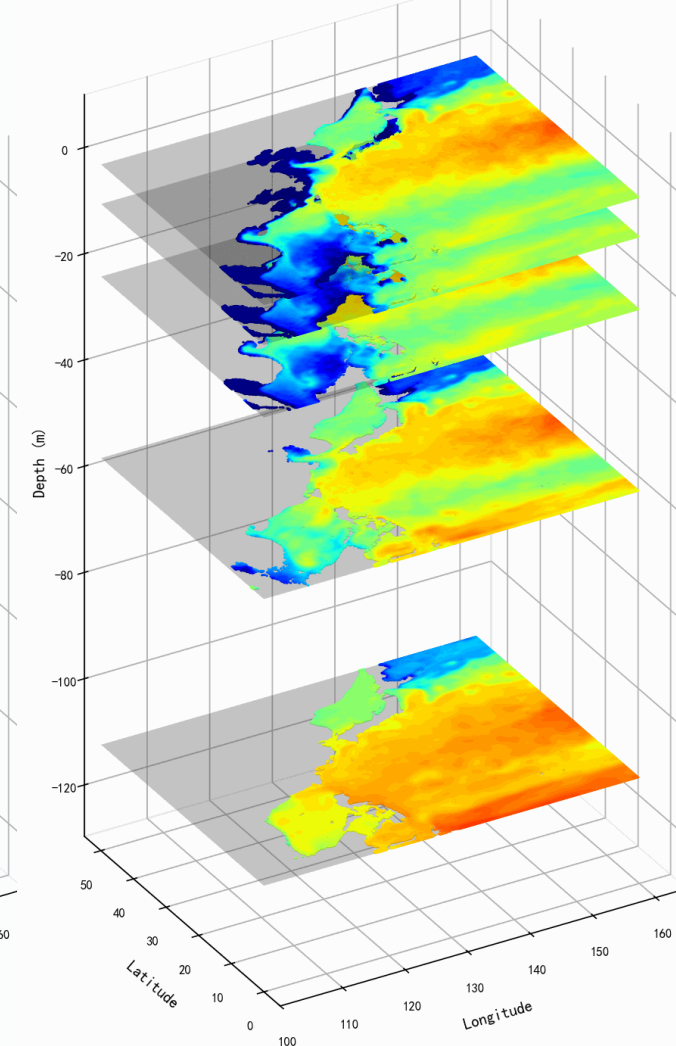
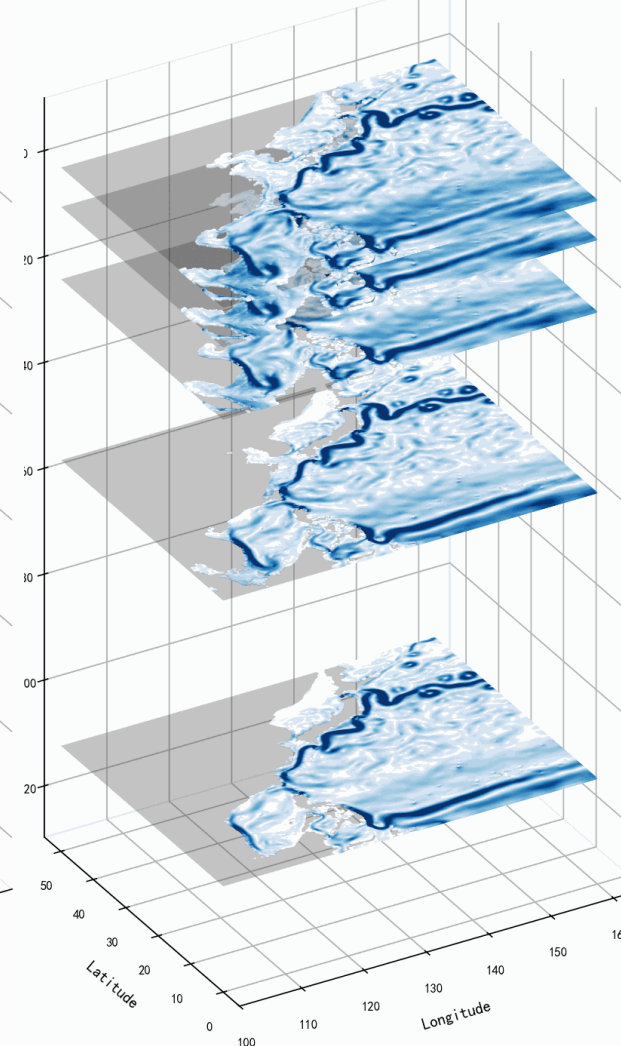
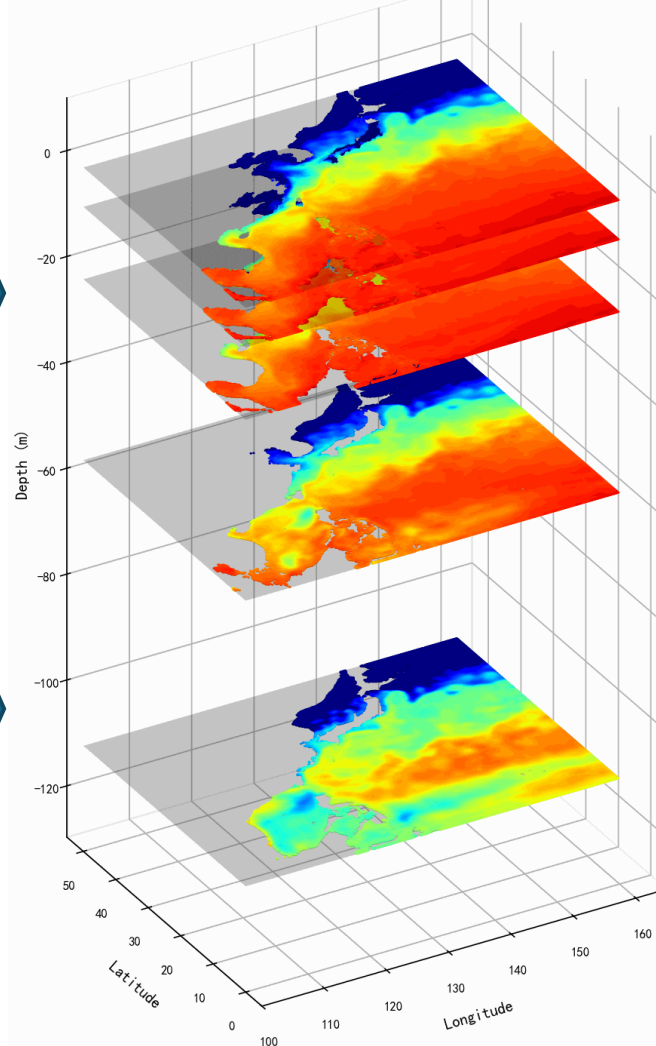
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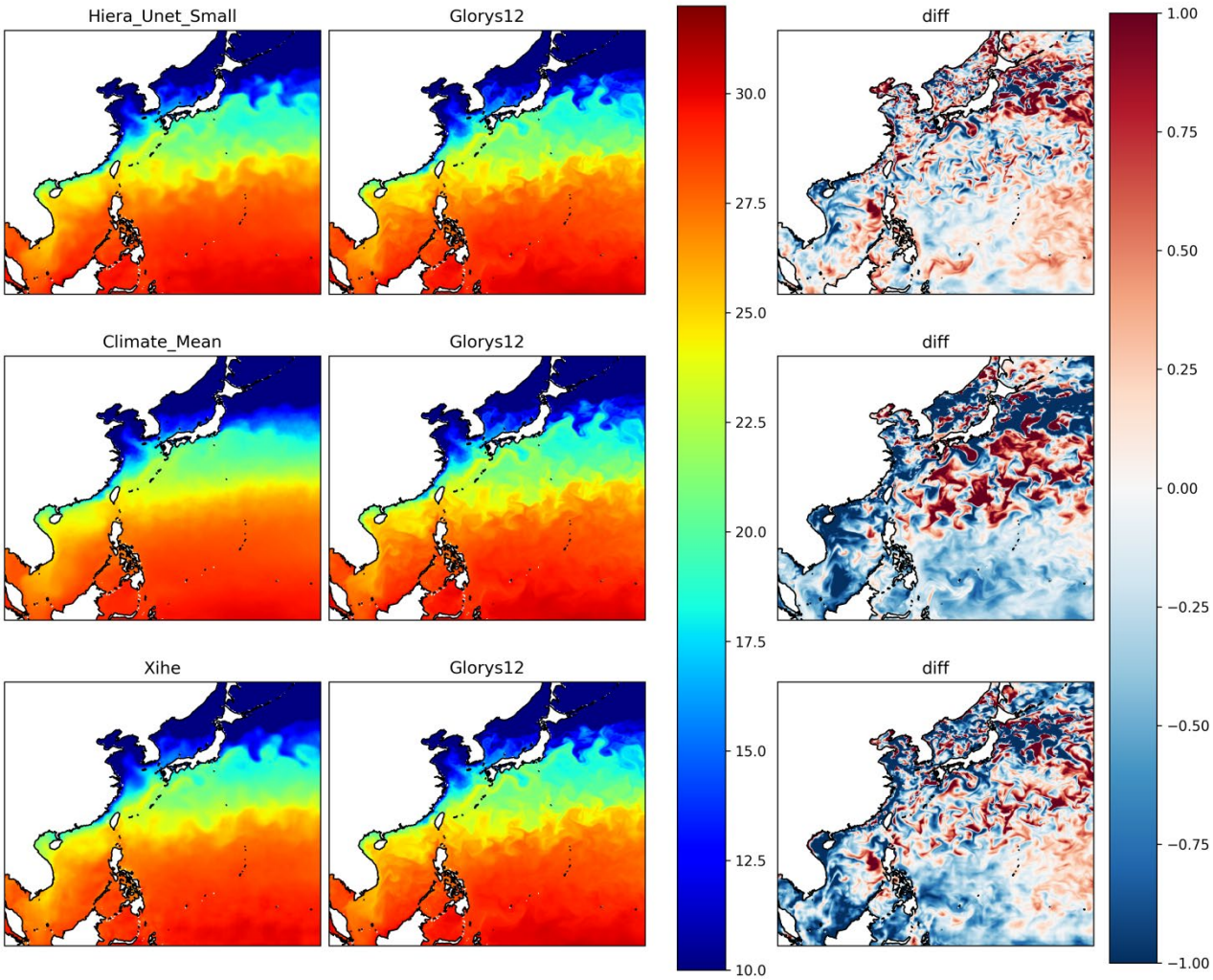


About 20 seconds to complete the prediction of future 10 days 3D ocean parameters

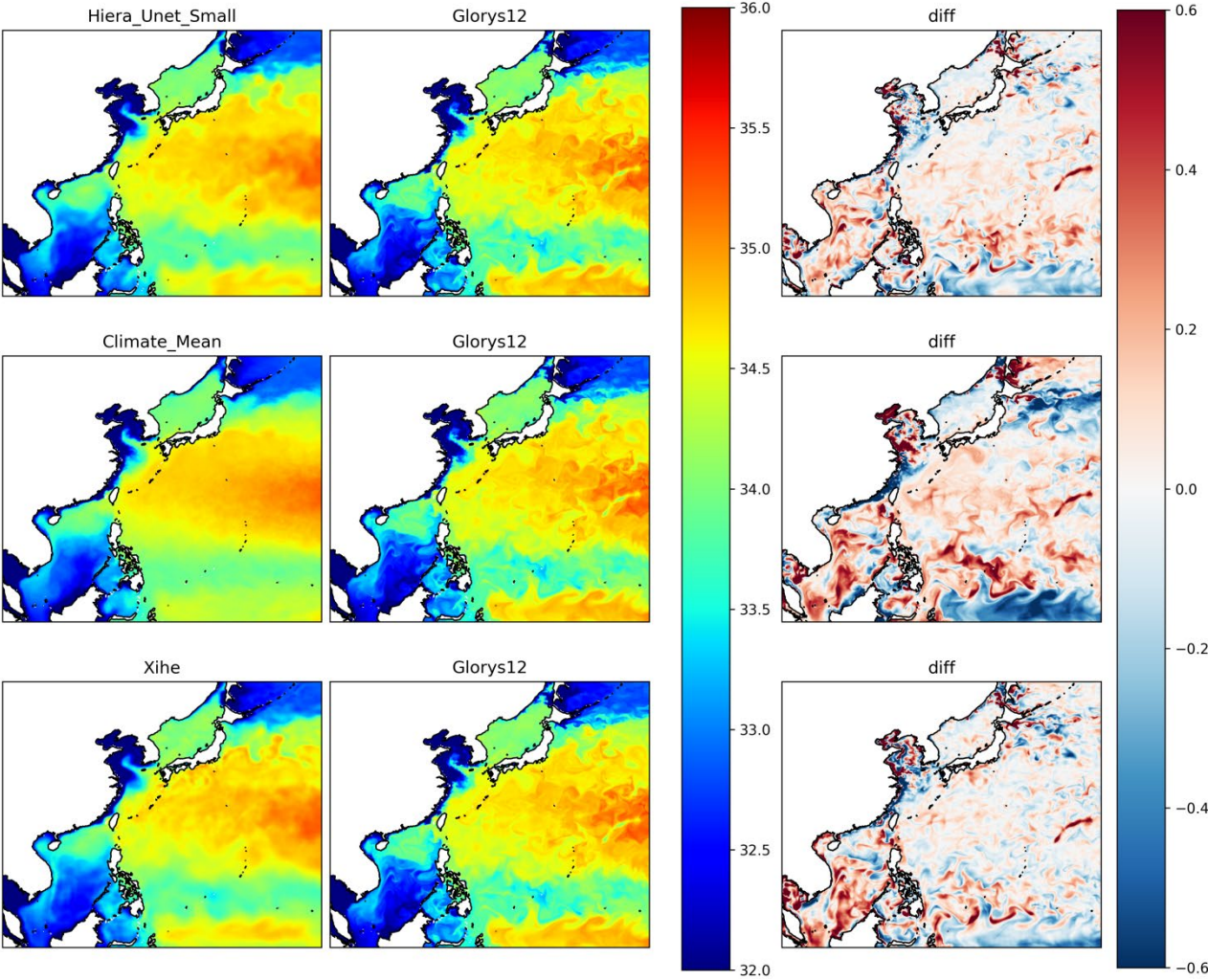




Sea Surface Temperature: lead day 10



Sea Surface Salinity: lead day 10



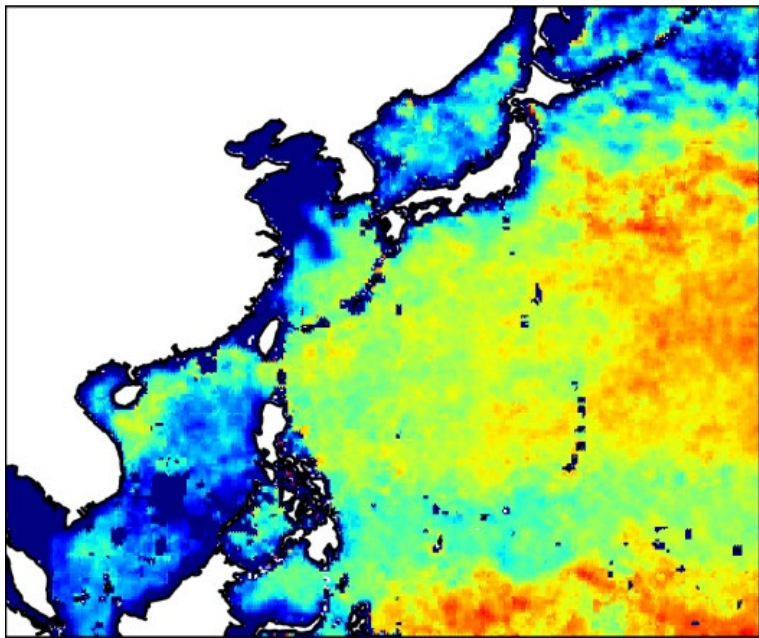
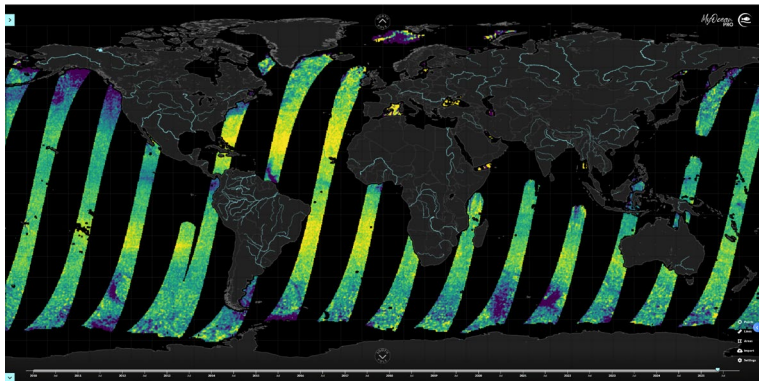
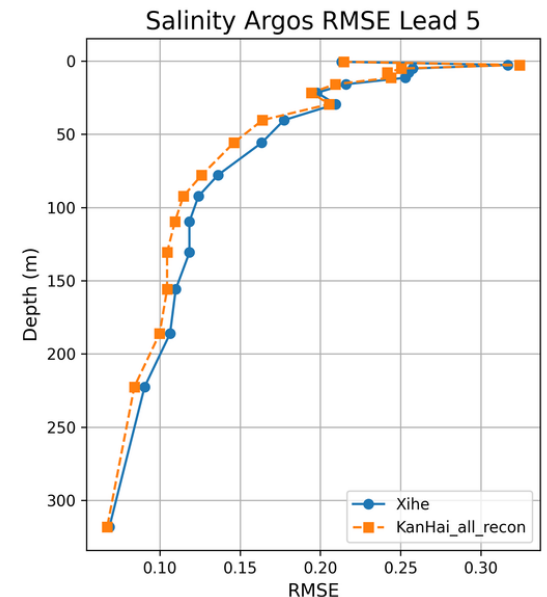
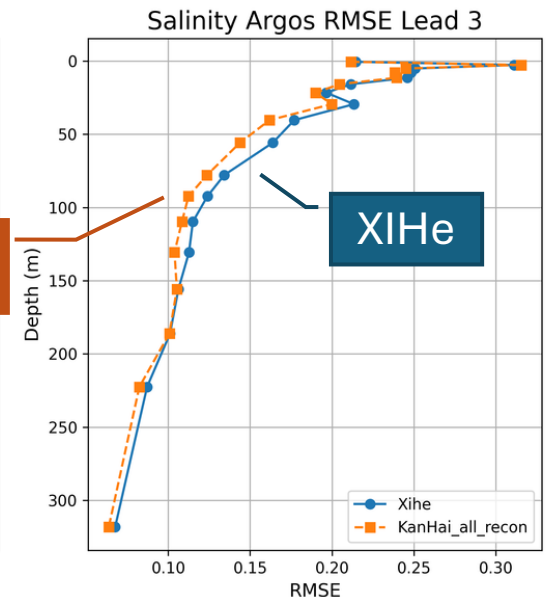
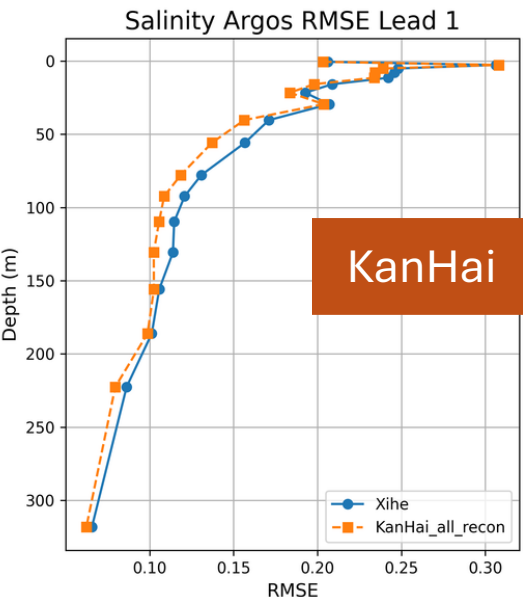
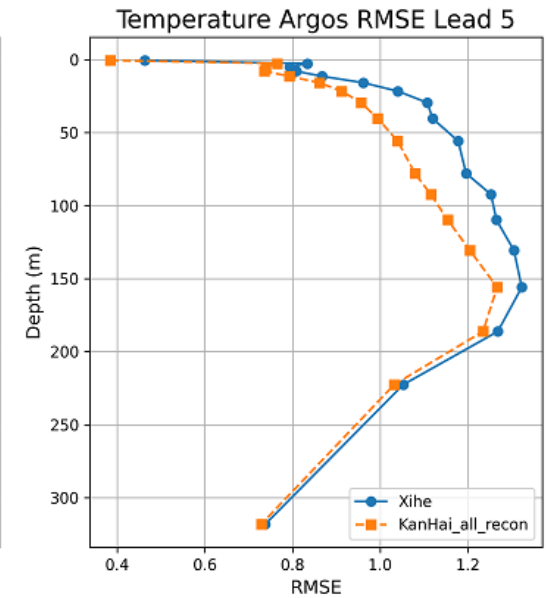
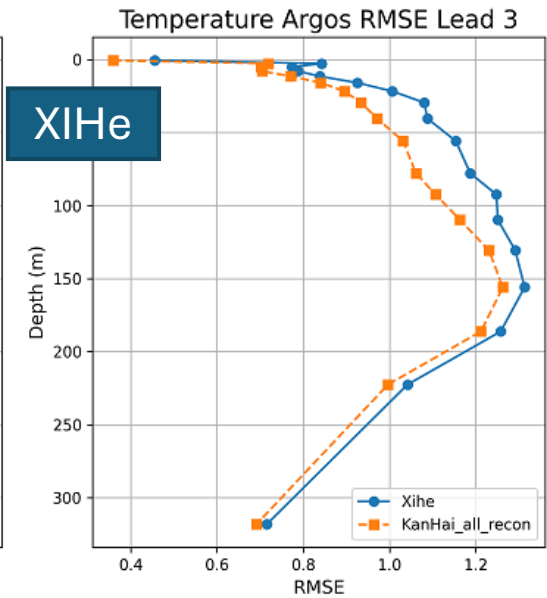
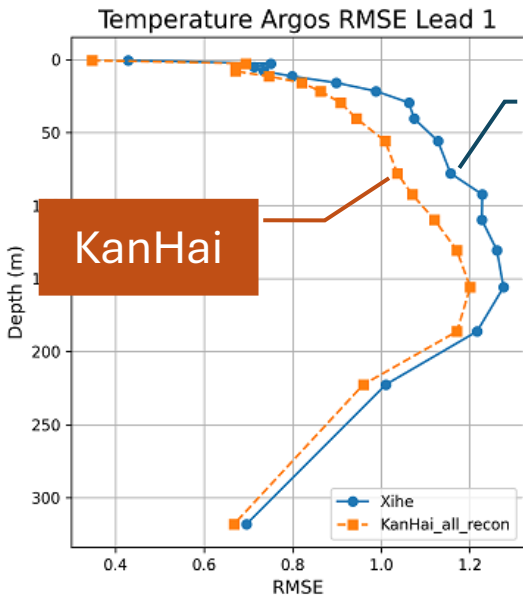
Assessments



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“
End
to
End
”

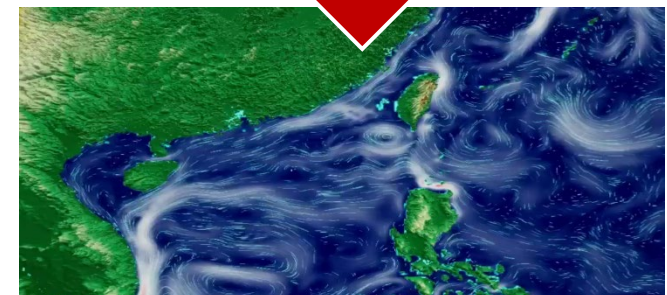
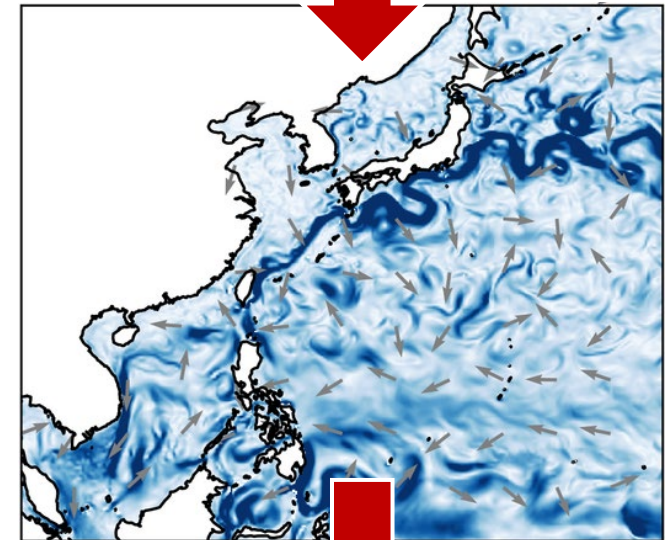
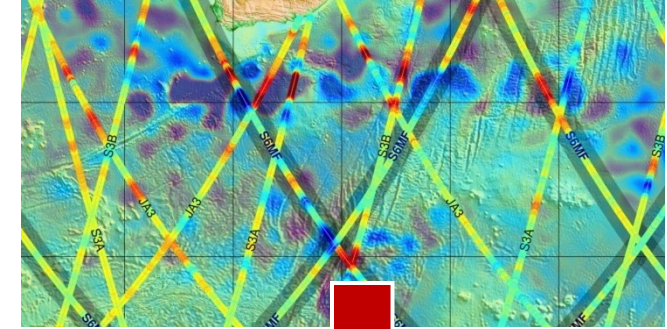
From “**NOW**” to “**Future**” :
Significant extension of remote sensing value

3D Reconstruction - > 3D Prediction

The rapid update of remote sensing forms
a rolling high-frequency forecast

Greatly reduces the cost of forecasting
and forms a lightweight system

Supporting the Ocean Digital Twin





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Thank you very much for listening!

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