Copernicus Marine Service

MERCATOR OCEAN INTERNATIONAL

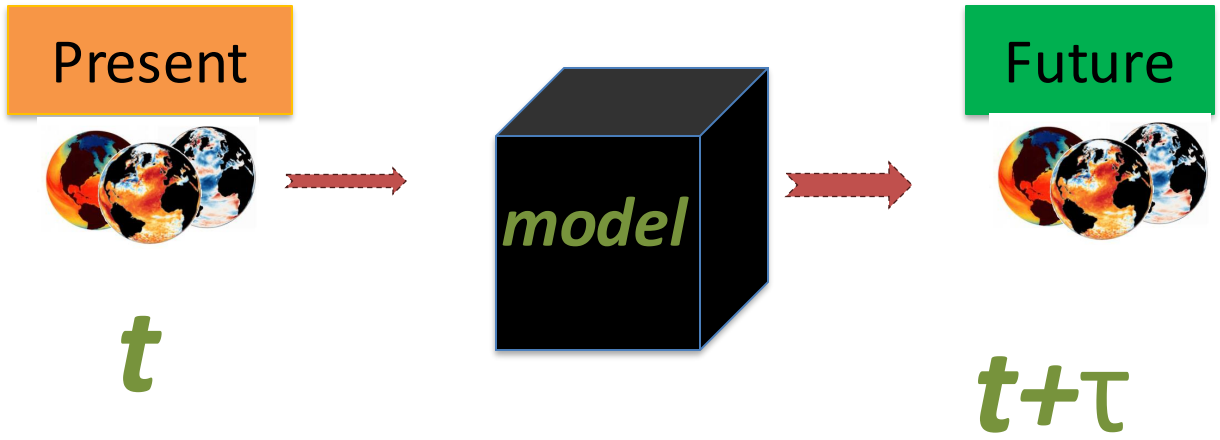
EDITO European Digital Twin Ocean

GLONET: Mercator's end-to-end neural Global Ocean forecasting system

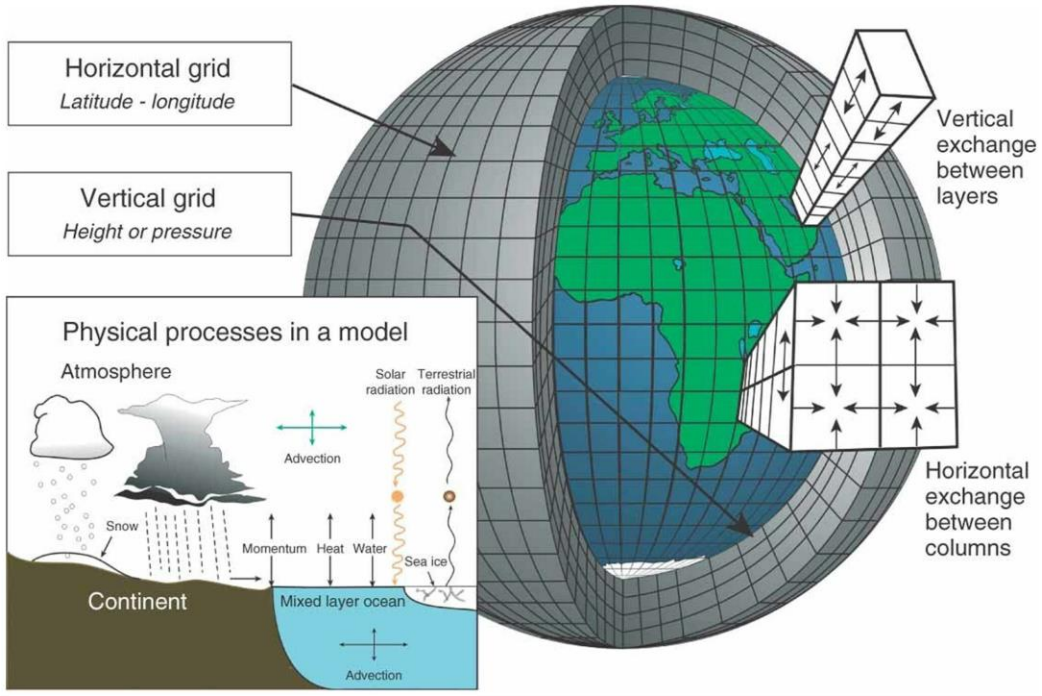
Anass El Aouni

Forecasting system

Forecasting Problem,



Classical Global Ocean models Forecast

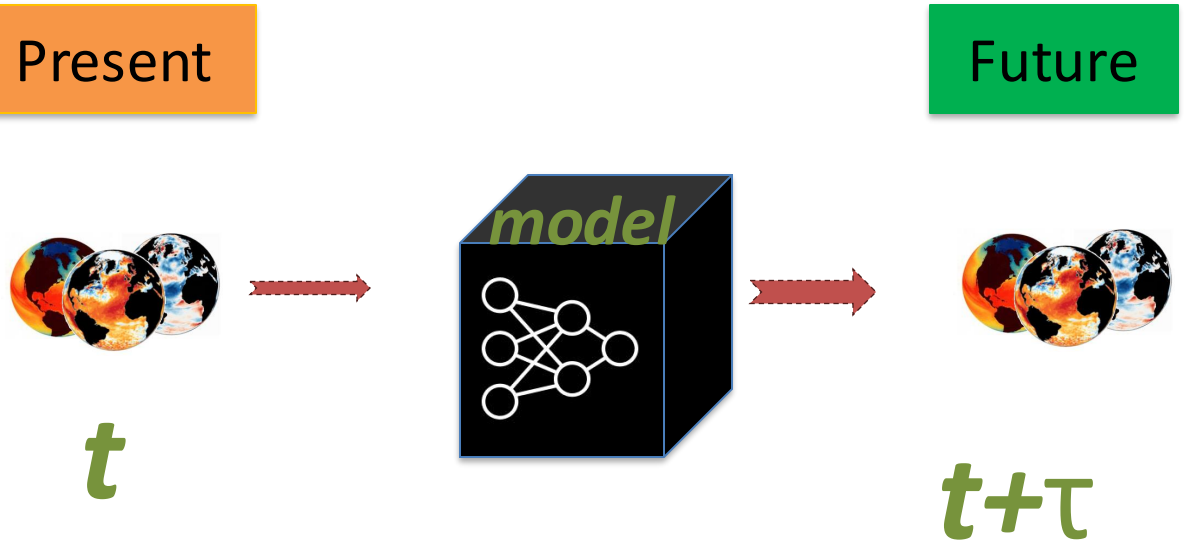


- **Rooted in established physical laws;**
- **Highly interpretable**

- Computationally expensive
- Memory Intensive
- **Difficult to improve given more data**

Forecasting system

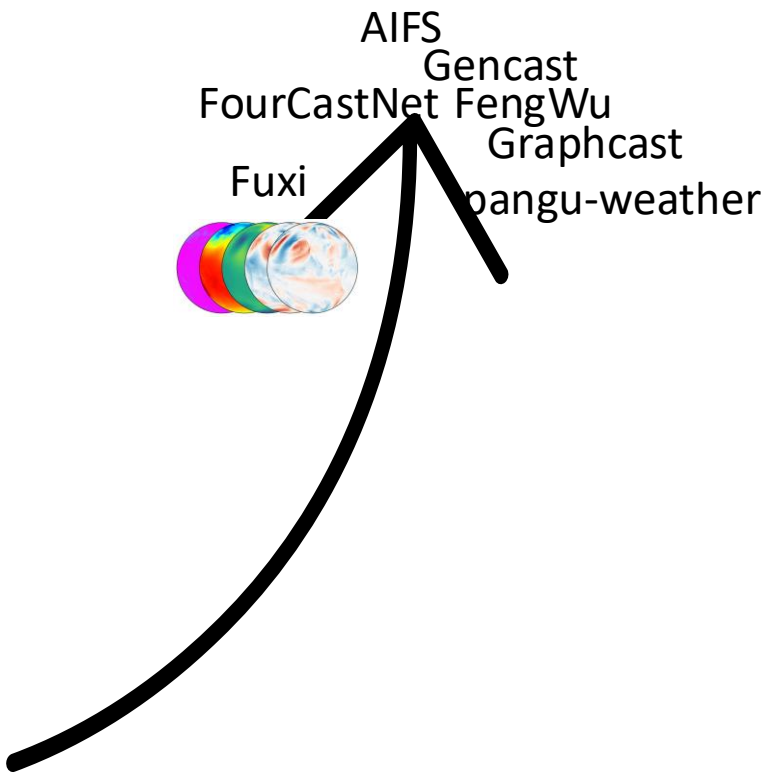
AI-Forecasting model



- Competitive accuracies
- Fast prediction
- Performance improves given more data
- Learn more complex patterns not representable by equations

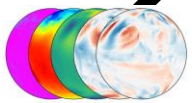
- Lack the versatility of numerical methods

AI-Atmosphere



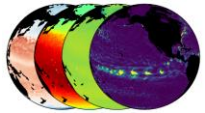
AI-Atmosphere

AIFS
Gencast
FourCastNet FengWu
Graphcast
Fuxi
pangu-weather



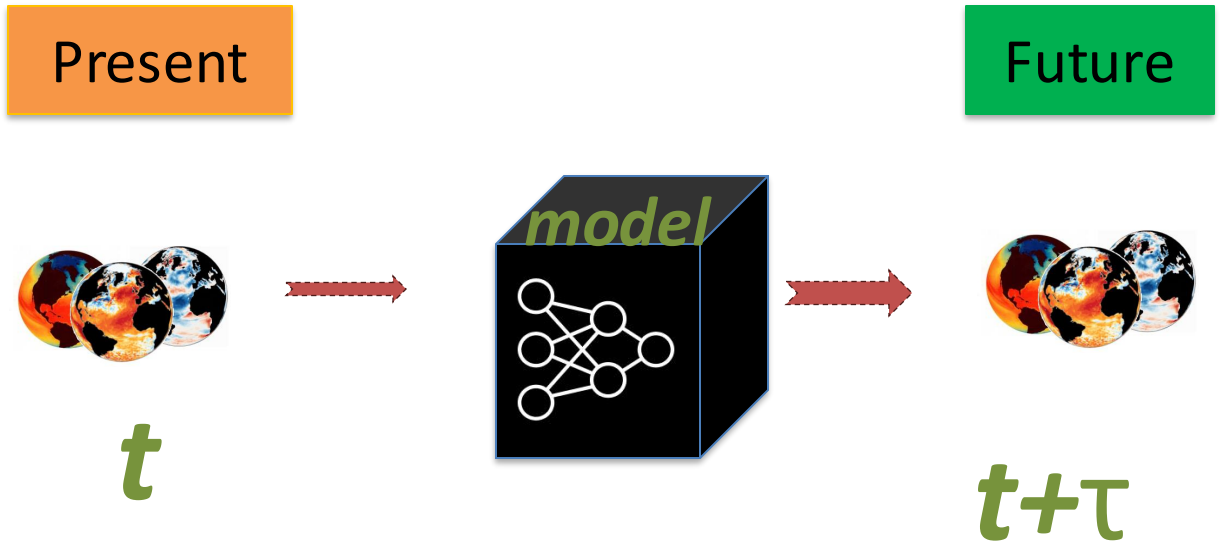
Glonet
Wenhai Xihe

AI-Ocean



Forecasting system

AI-Forecasting model



In Mercator

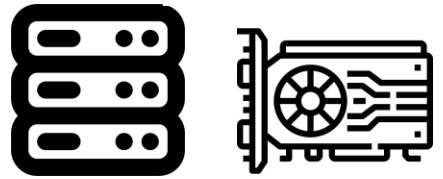
Physics Models

```
Forecast(daily):
Hours, days
```

AI Models

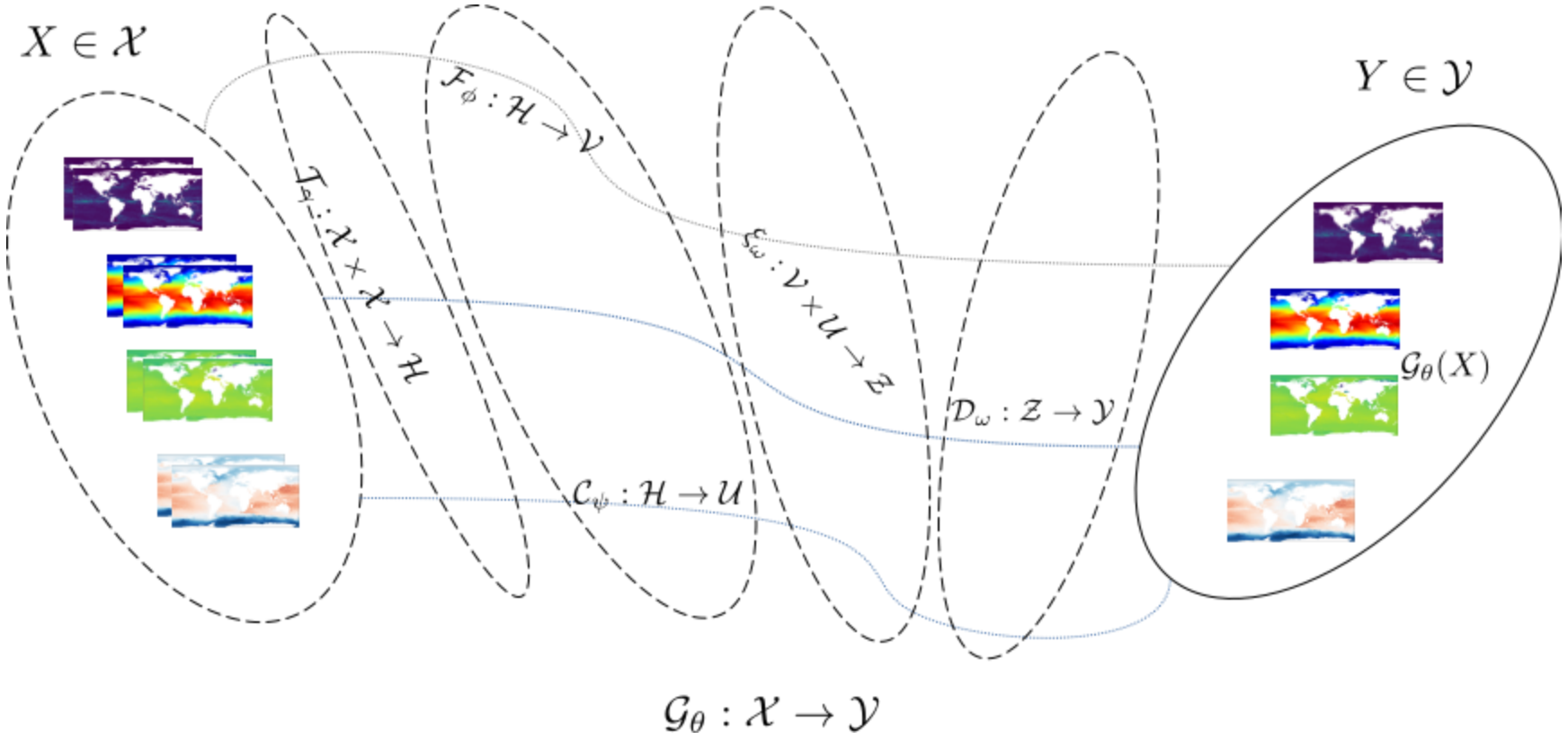
```
Forecast(daily):
-Seconds
-On demand
-Research
-What if..
```

EDITO



Moi's NN-Forecasting system

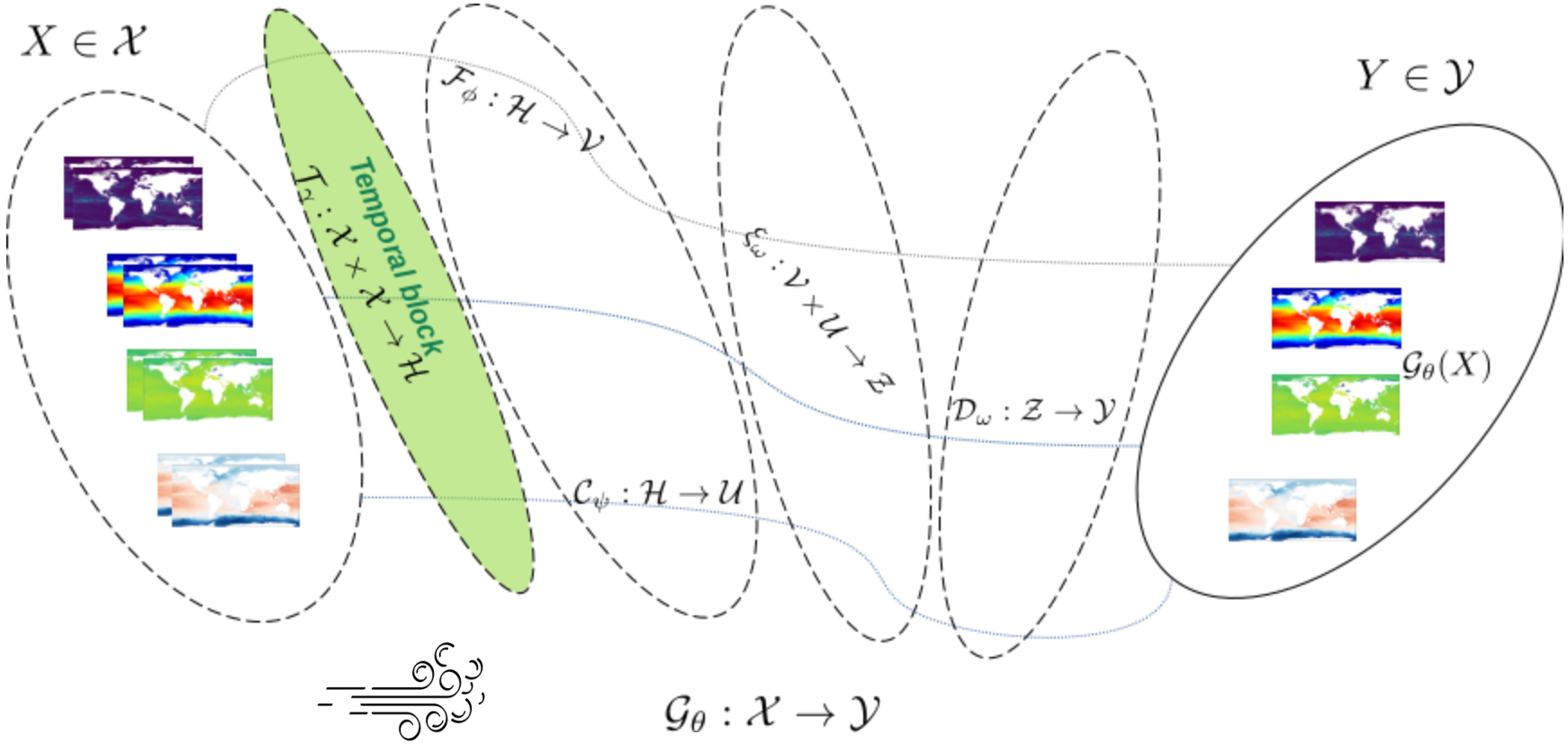
GLONET



(t_i) $(t_{i+\tau})$

Moi's NN-Forecasting system

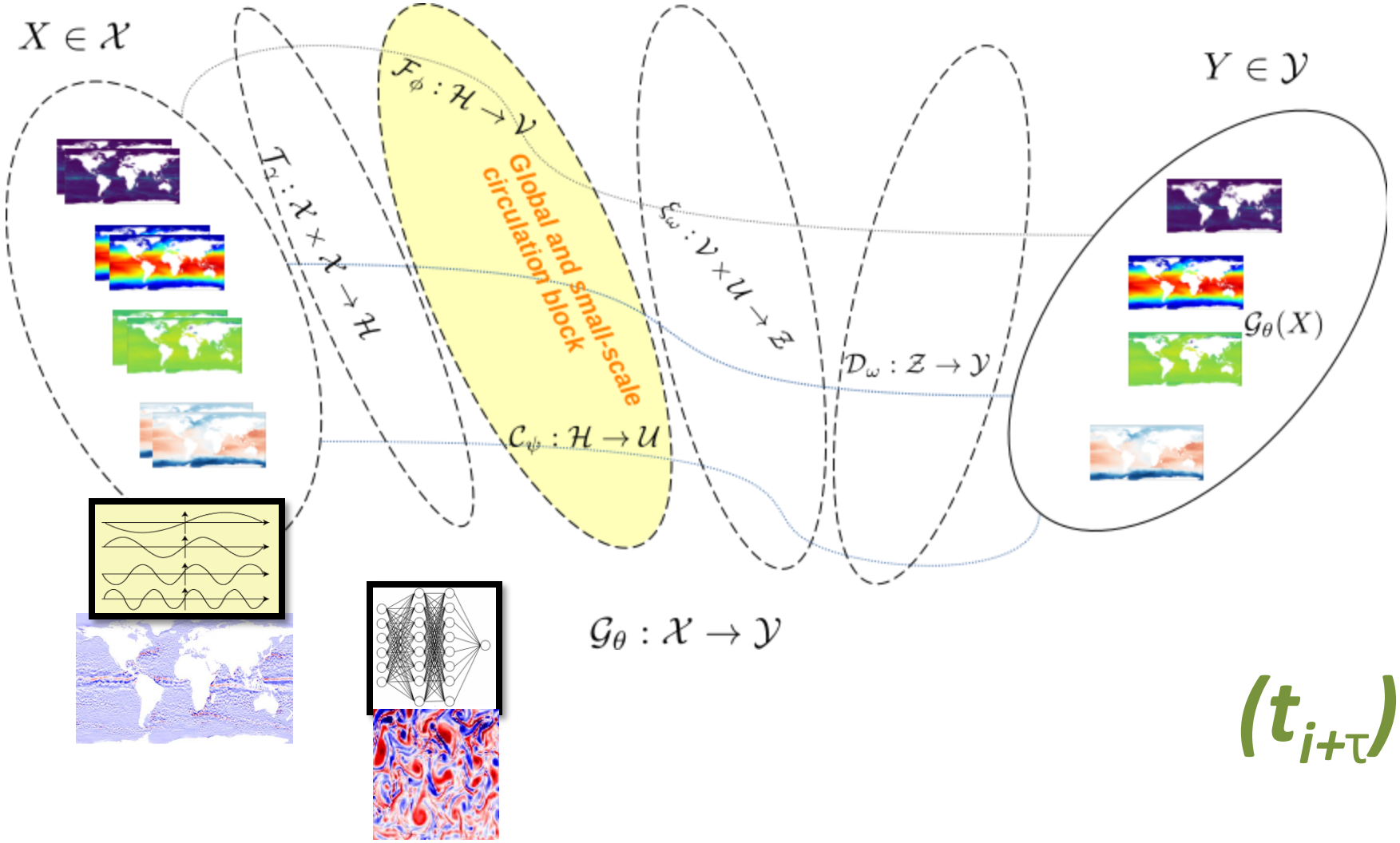
GLONET



(t_i) $(t_{i+\tau})$

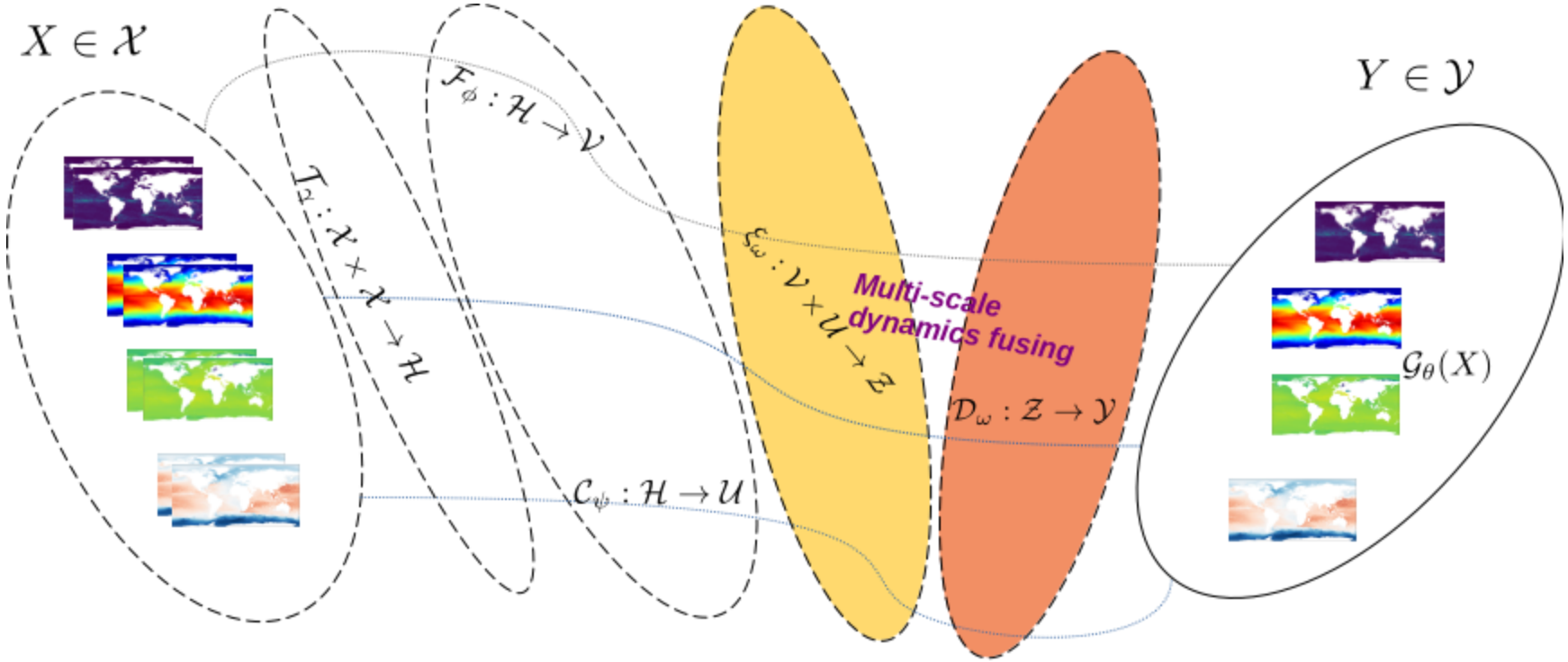
Moi's NN-Forecasting system

GLONET

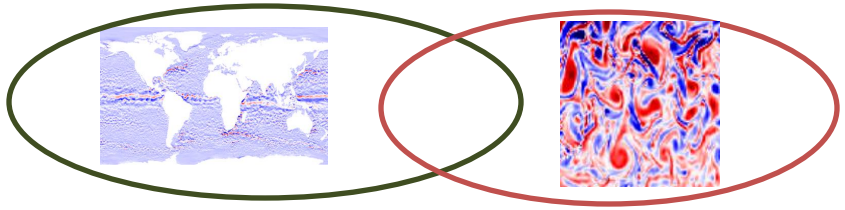


Moi's NN-Forecasting system

GLONET



$\mathcal{G}_\theta : \mathcal{X} \to \mathcal{Y}$

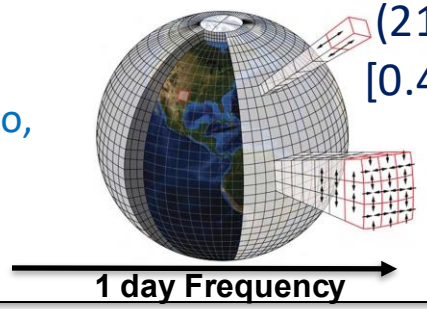


(t_i) $(t_{i+\tau})$

Moi's NN-Forecasting system

- **GLORY12**
  - Training [1993, 2020]
  - Validation [2021]
  - Testing [GLO12]

Vars: zos [thetao, uo,vo, so]

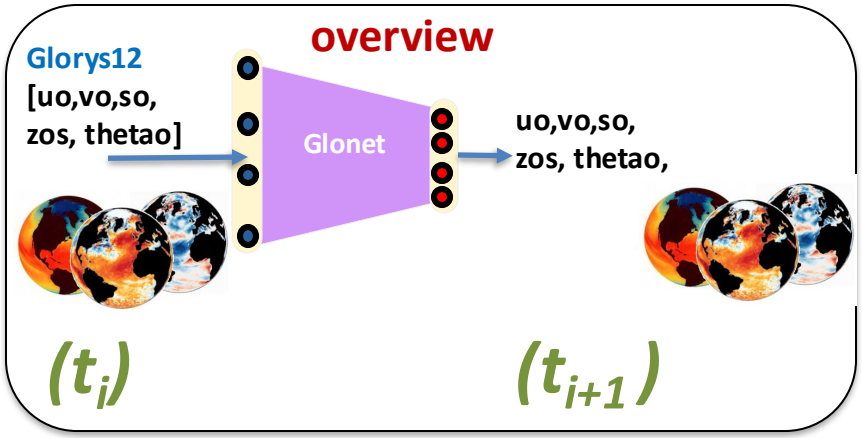


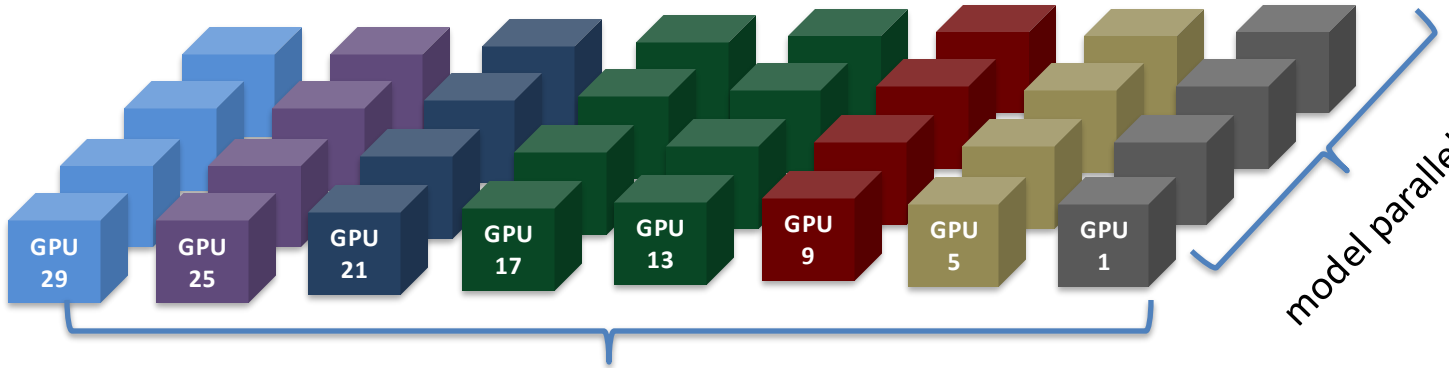
(21layers [0.49--> 5k])

[1/4°]

Glonet [1/4] Configuration

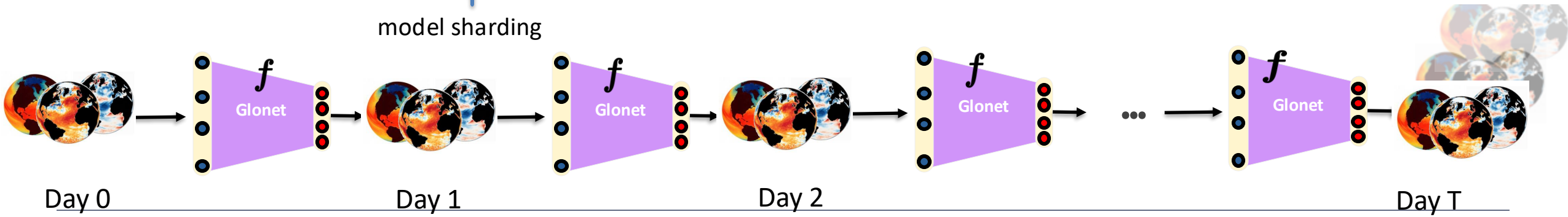
- FSDP, cpu offloading, Mixed precision training, checkpointing





Ressources

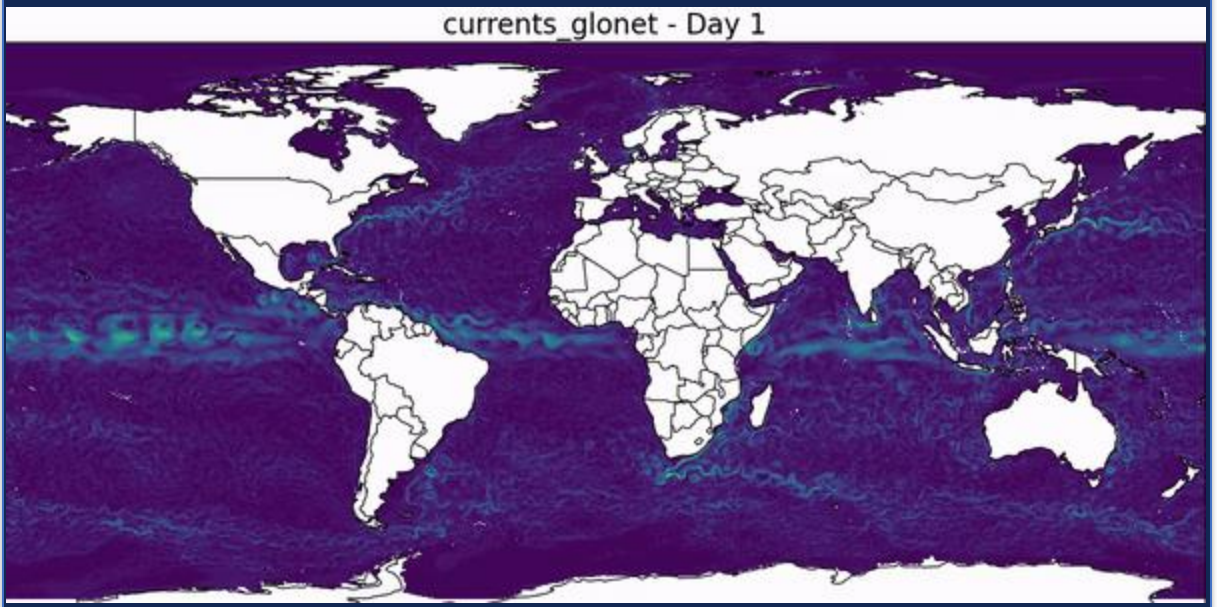
- ECP: 8 nodes, 32xA100 GPUs
- Several days of training



Moi's NN-Forecasting system

GLONET

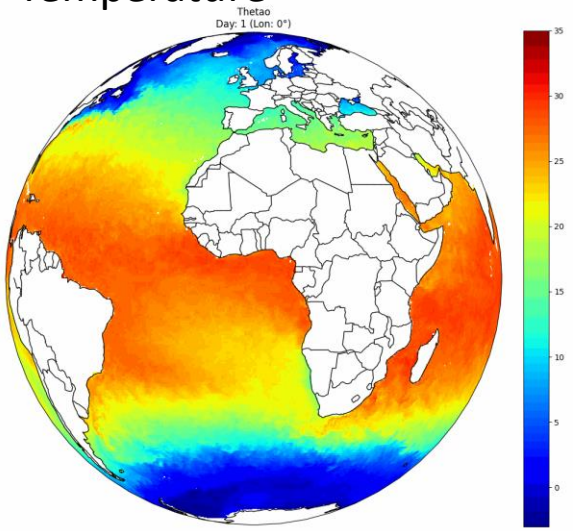
- CPU 16 cores ~ 7min
- 12G VRAM ~ 30 sec (JIT) [Nvidia]
- A100 node ~ 3 sec



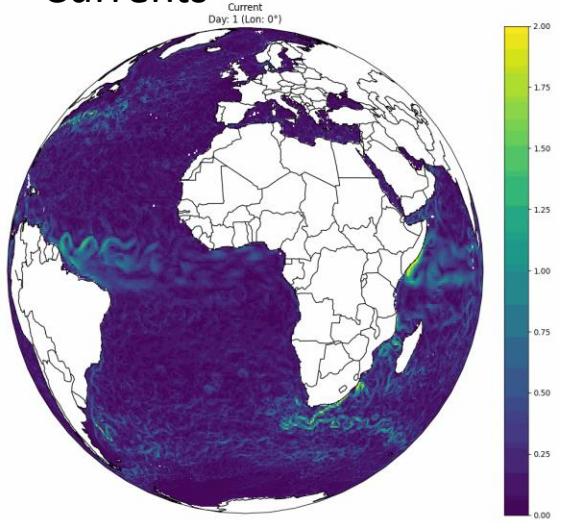
365 days in 3min

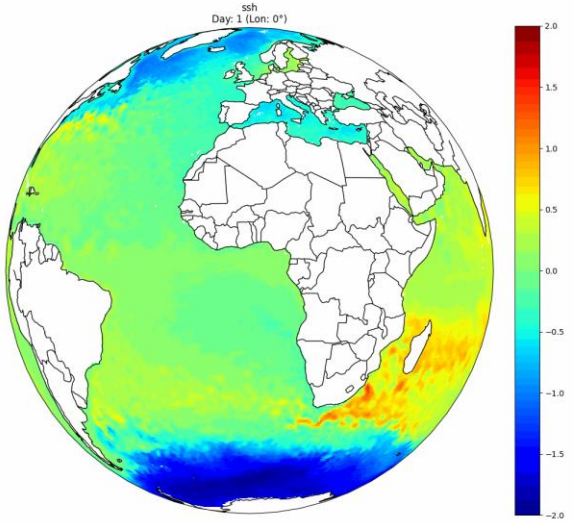
10 days forecast

Temperature

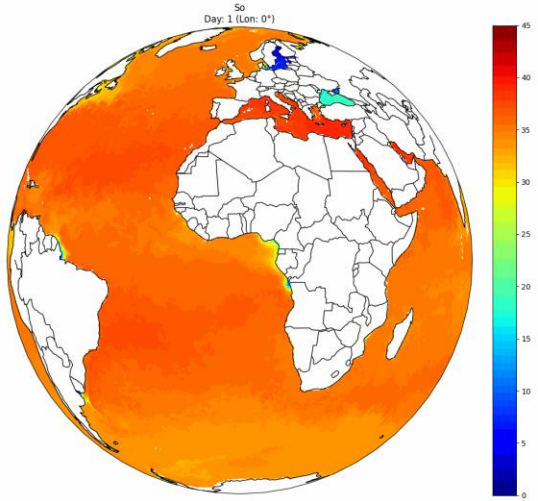


Currents



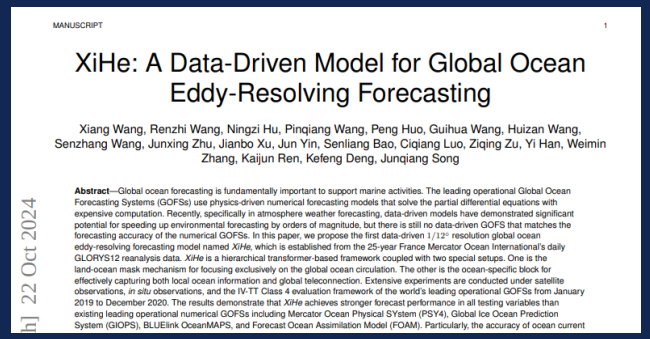


SSH



Salinity

Benchmarking

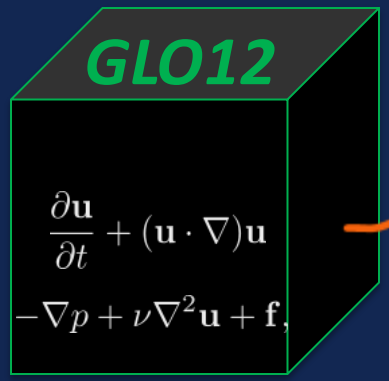


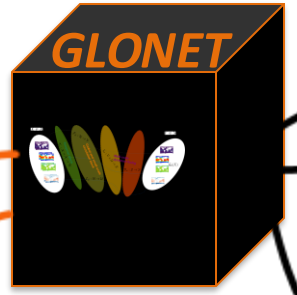
MANUSCRIPT 1

XiHe: A Data-Driven Model for Global Ocean Eddy-Resolving Forecasting

Xiang Wang, Renzhi Wang, Ningzi Hu, Pinqiang Wang, Peng Huo, Guihua Wang, Huizan Wang, Senzhang Wang, Junxing Zhu, Jianbo Xu, Jun Yin, Senliang Bao, Ciqiang Luo, Ziqing Zu, Yi Han, Weimin Zhang, Kaijun Ren, Kefeng Deng, Junqiang Song

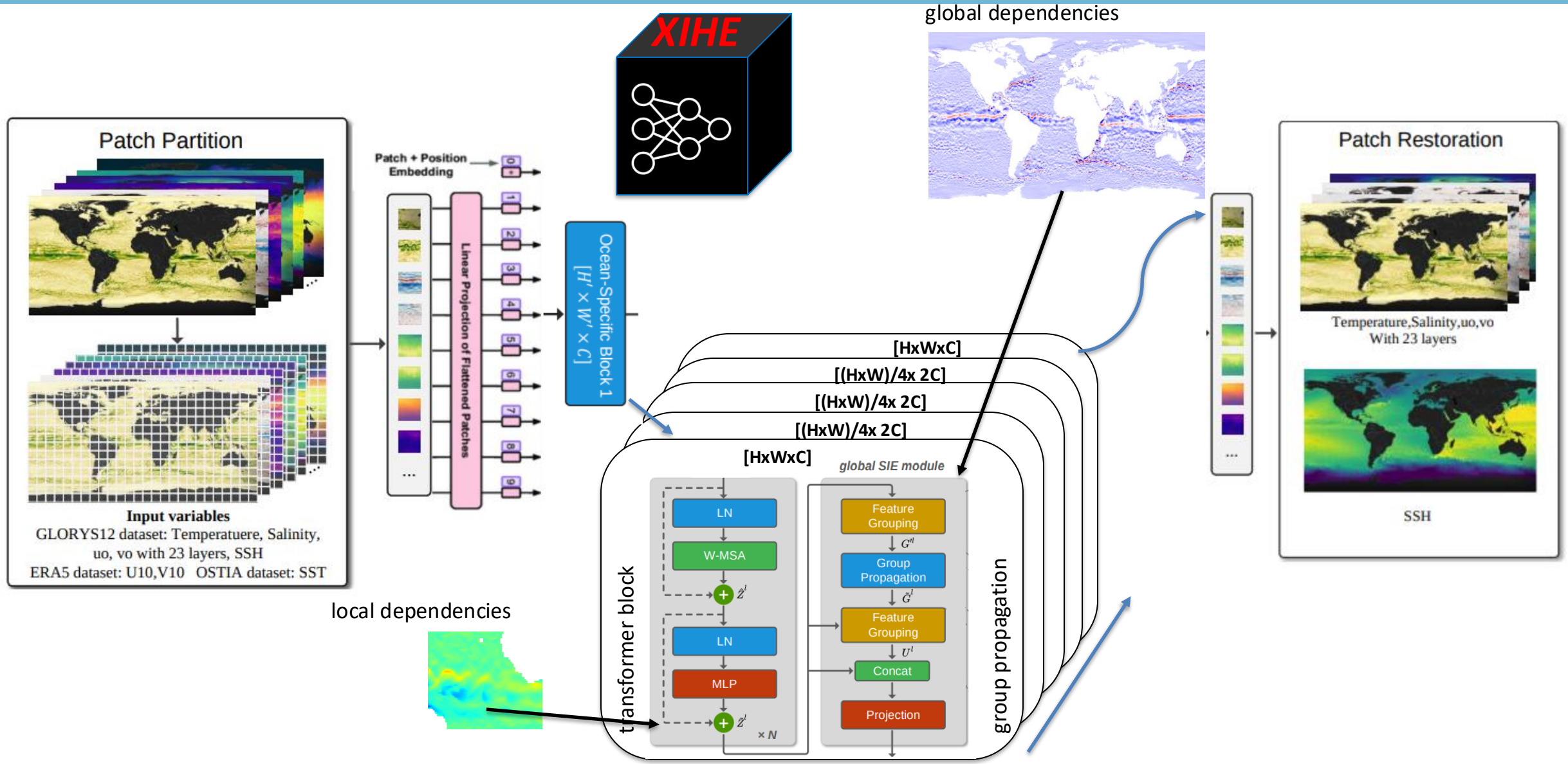
Abstract—Global ocean forecasting is fundamentally important to support marine activities. The leading operational Global Ocean Forecasting Systems (GOFSs) use physics-driven numerical forecasting models that solve the partial differential equations with expensive computation. Recently, specifically in atmosphere weather forecasting, data-driven models have demonstrated significant potential for speeding up environmental forecasting by orders of magnitude, but there is still no data-driven GOFS that matches the forecasting accuracy of the numerical GOFSs. In this paper, we propose the first data-driven $1/12^{\circ}$ resolution global ocean eddy-resolving forecasting model named *XiHe*, which is established from the 25-year France Mercator Ocean International's daily GLORYS12 reanalysis data. *XiHe* is a hierarchical transformer-based framework coupled with two special setups. One is the land-ocean mask mechanism for focusing exclusively on the global ocean circulation. The other is the ocean-specific block for effectively capturing both local ocean information and global teleconnection. Extensive experiments are conducted under satellite observations, *in situ* observations, and the IV-TT Class 4 evaluation framework of the world's leading operational GOFSs from January 2019 to December 2020. The results demonstrate that *XiHe* achieves stronger forecast performance in all testing variables than existing leading operational numerical GOFSs including Mercator Ocean Physical SYstem (PSY4), Global Ice Ocean Prediction System (GIOPS), BLUElink OceanMAPS, and Forecast Ocean Assimilation Model (FOAM). Particularly, the accuracy of ocean current





- Class-IV
- OSSE
- Process

XiHe, AI Global Forecasting system

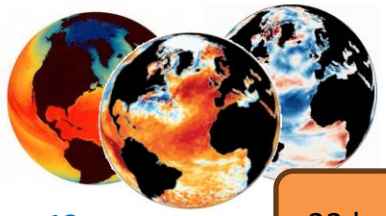


XiHe, AI Global Forecasting system

Dataset

- **GLORY12** [zos][thetao, uo,vo, so]
  (23 layers [0.49--> 643.57m])
  - Training [1993~2017]
  - Validation [2018]
  - Testing [2019~2020]
- **ERA5** (1/4°) ---> (1/12°) [10m wind]
  - Training [1993~2017]
  - Validation [2018]
  - Testing [2019~2020]
- **OSTIA** (1/20°) ---> (1/12°)
  - Training [1993 ~ 2017]

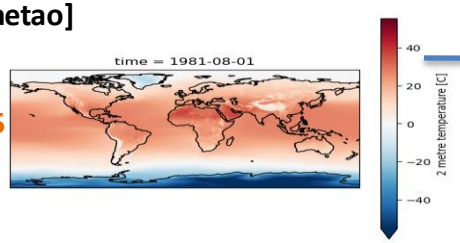
Training Setup



(t_i)

Glorys12
[uo,vo,so,
zos, thetao]

23 levels



ERA5
[u,v]

Configuration

10 Models

t_i t_{i+10}
... ...
t_i t_{i+2}
t_i t_{i+1}

Glorys12
[uo,vo,so,
zos, thetao]

ERA5
[u,v]

XiHe

uo,vo,so,
zos, thetao,
sst

12 levels

10 Models

t_i t_{i+1}

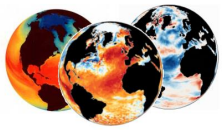
Glorys12
[uo,vo,so,
zos, thetao]

ERA5
[u,v]

XiHe

11 levels

$t_{i+1...}, t_{i+10}$

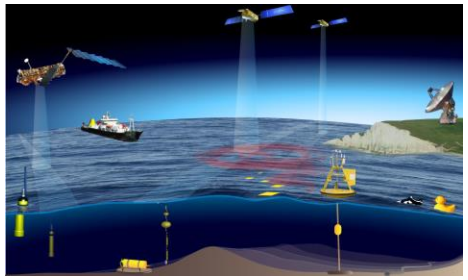


Xihe
[uo,vo,so,
zos, thetao]

Evaluation

Class-IV

Observations



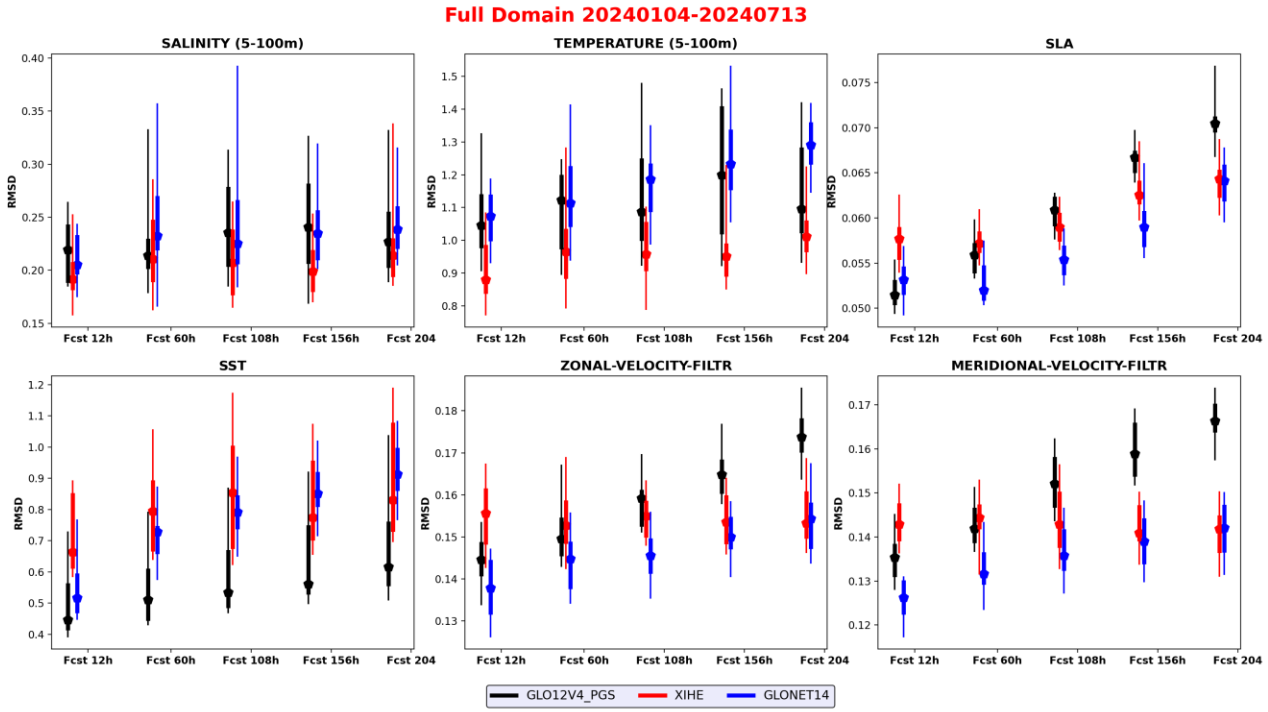
GLO12

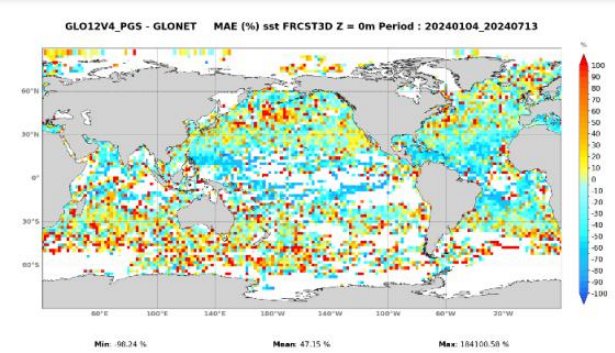
$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u}$$

$$-\nabla p + \nu \nabla^2 \mathbf{u} + \mathbf{f},$$

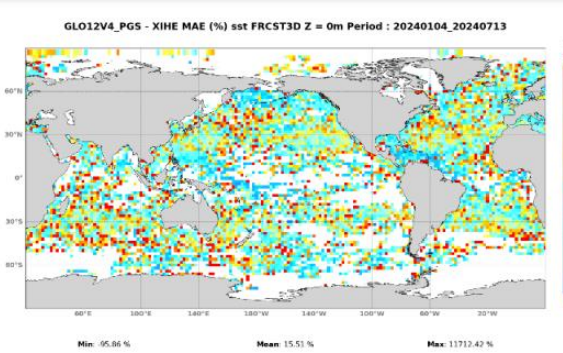
GLONET

XIHE

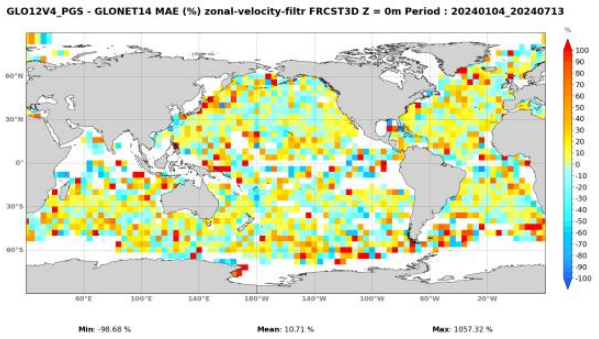




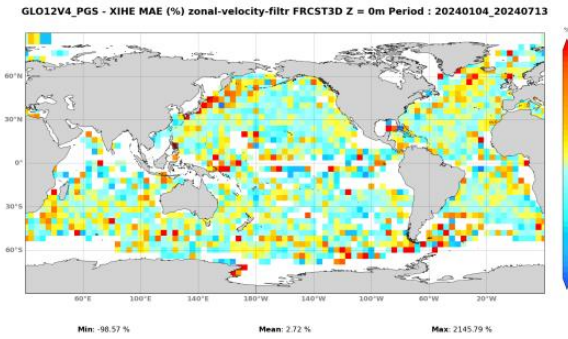
(a) GLO12 vs GLONET in SST



(b) GLO12 vs XIHE in SST



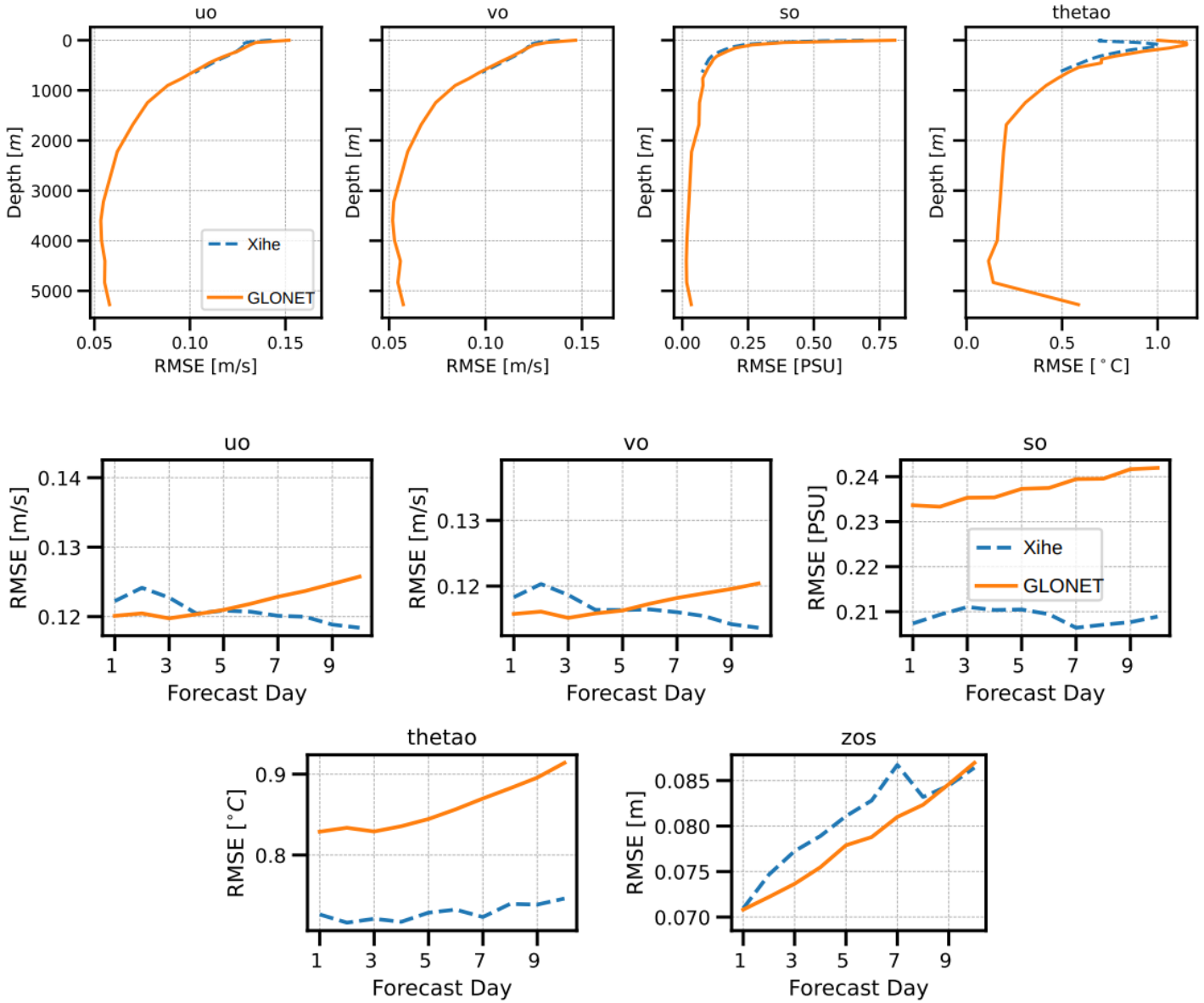
(c) GLO12 vs GLONET in Zonal current



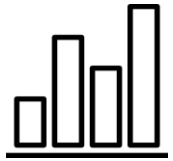
(d) GLO12 vs XIHE in Zonal current

Evaluation

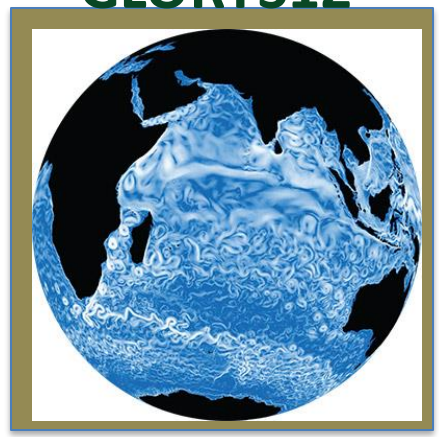
OSSE



Class-IV like with GLORYS12 as a reference



GLORYS12

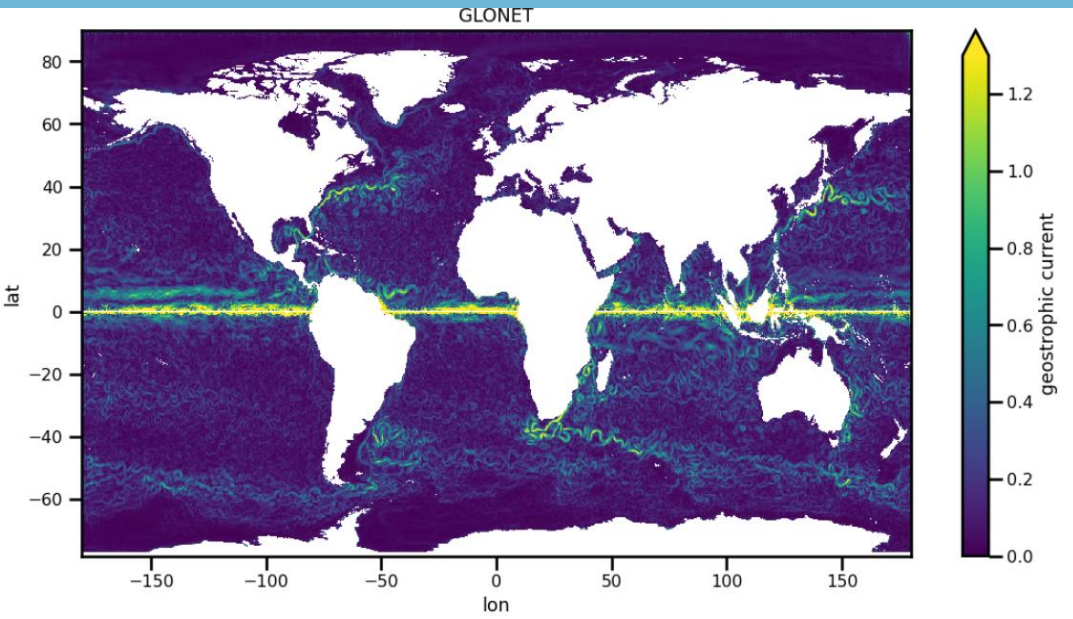


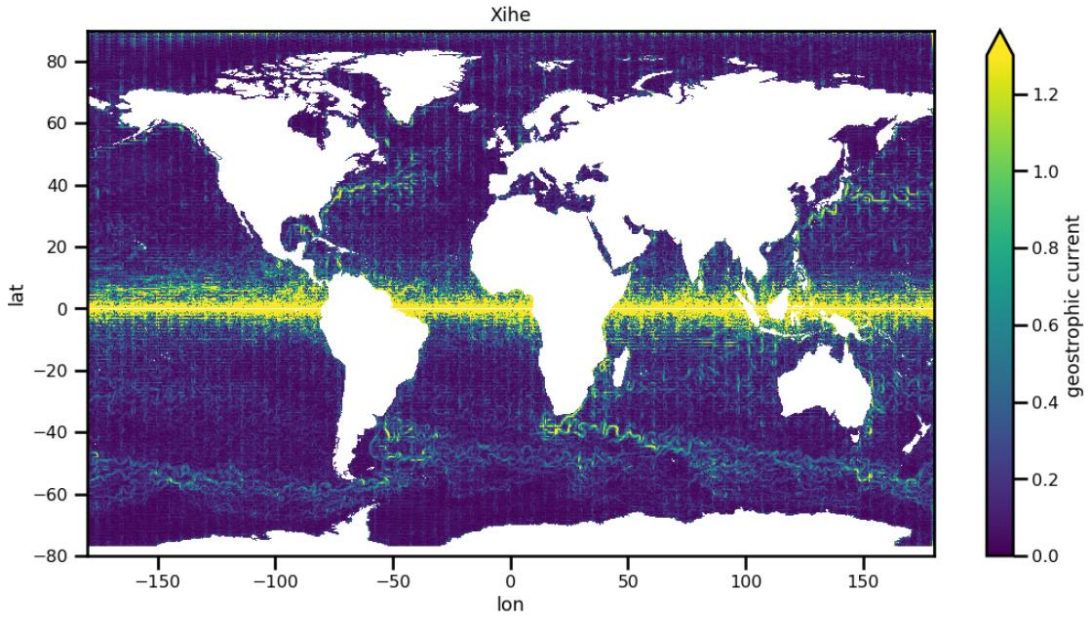
Jan-July 2024

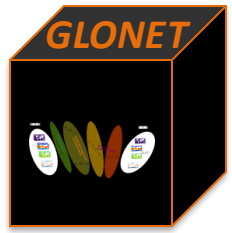
Evaluation

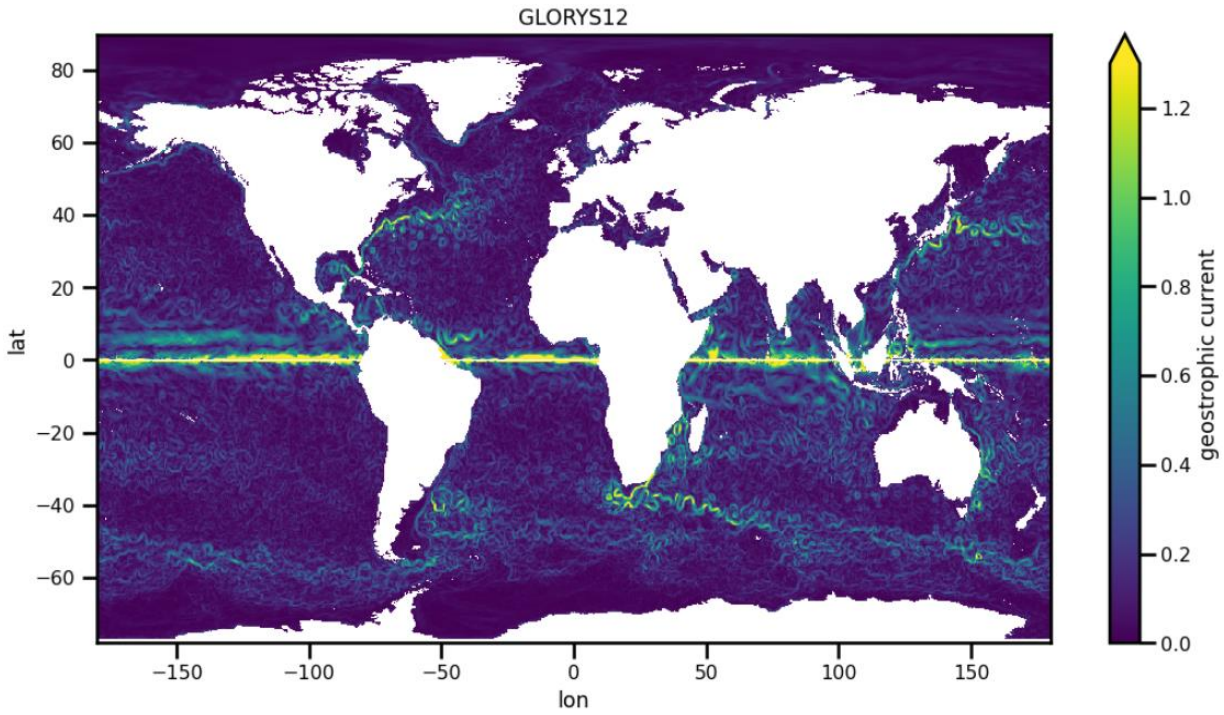
Process-oriented

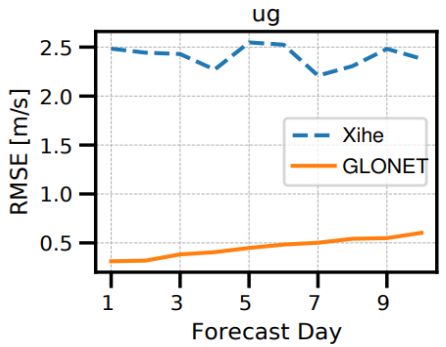
$$\mathbf{v}(\phi,\theta,t) = gf^{-1}\nabla^{\perp}\eta(\phi,\lambda,t)$$

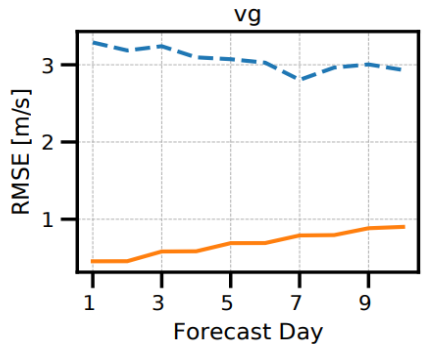










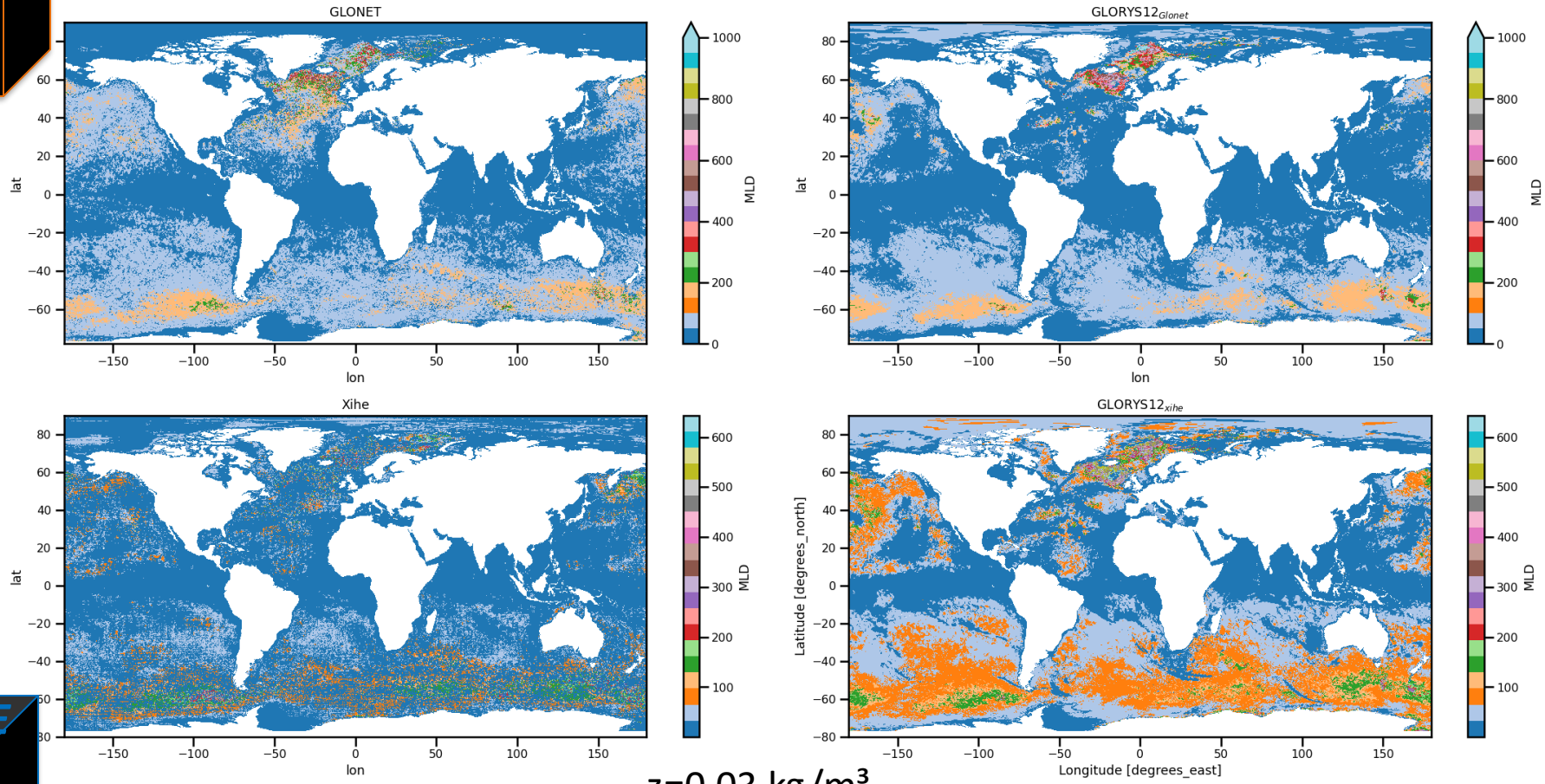


Evaluation

Process-oriented

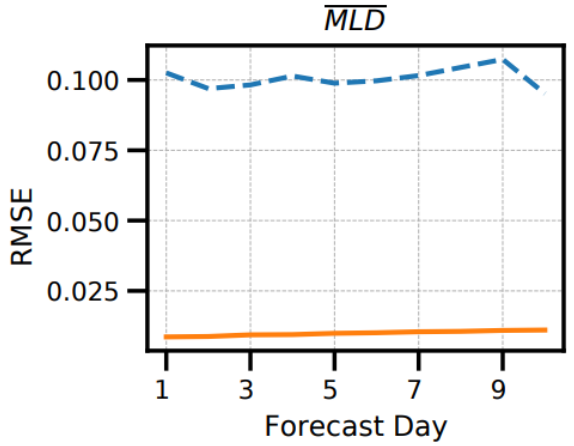
GLONET

$$\mathrm{MLD} = \min\{z \mid \rho(z) - \rho(0) \geq \Delta\rho\}$$



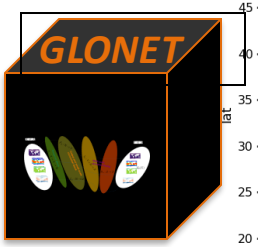
z=0.03 kg/m³

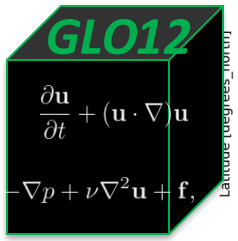
XIHE

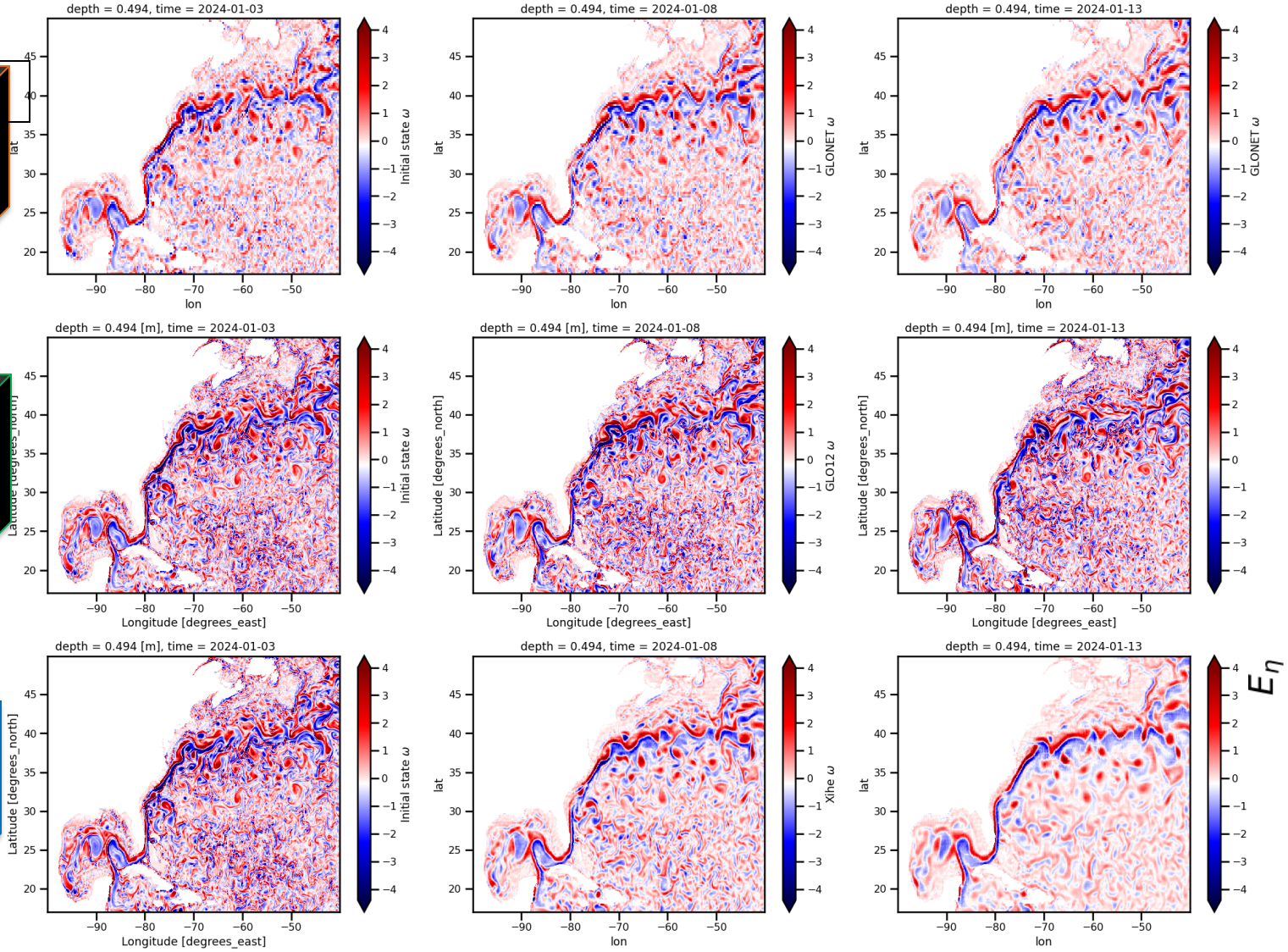


Evaluation

Process-oriented

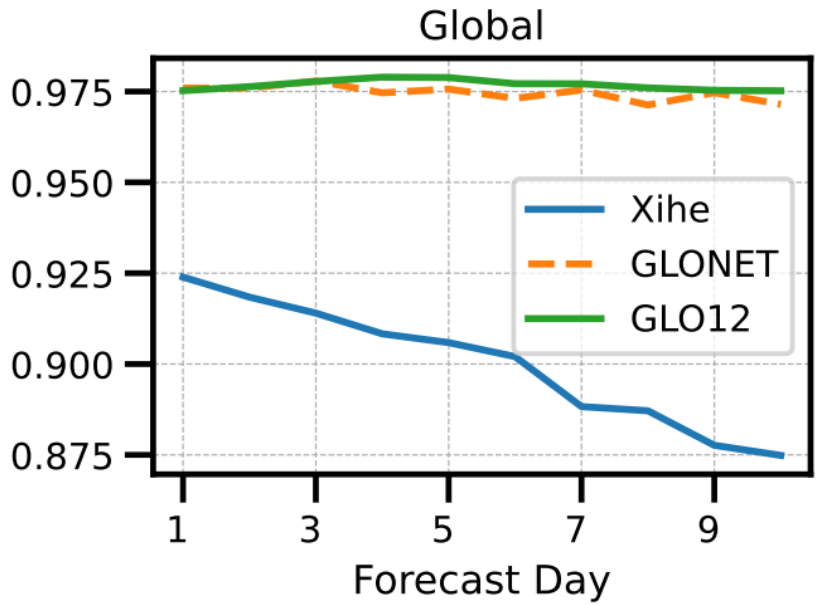






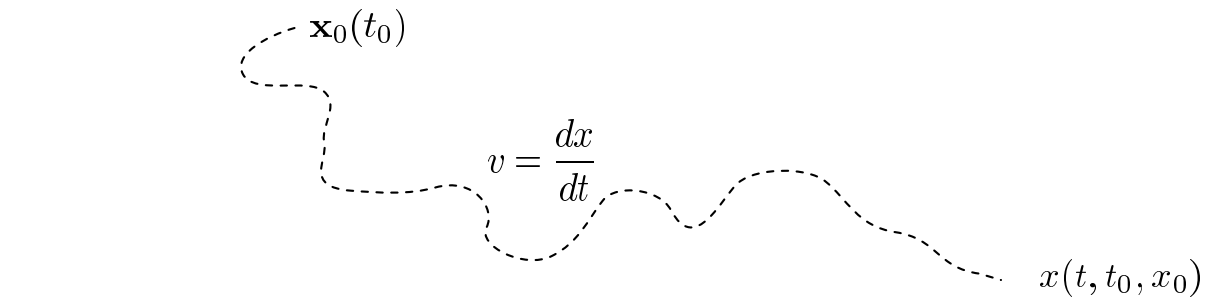
$$\omega = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}, \qquad \hat{\omega}(k_x, k_y)$$

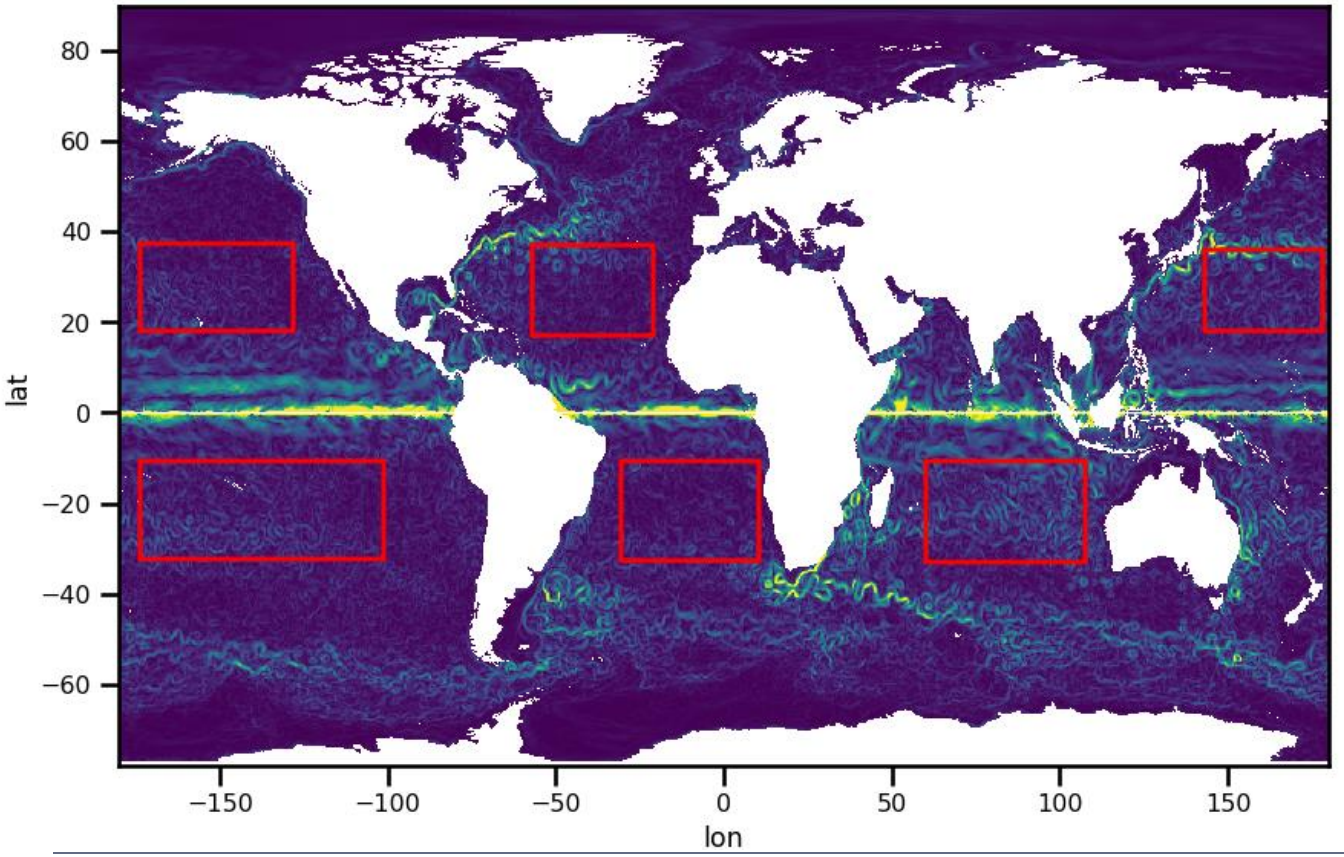
$$E_\eta = \frac{\sum_{k>k_c} E(k)}{\sum_k E(k)}$$



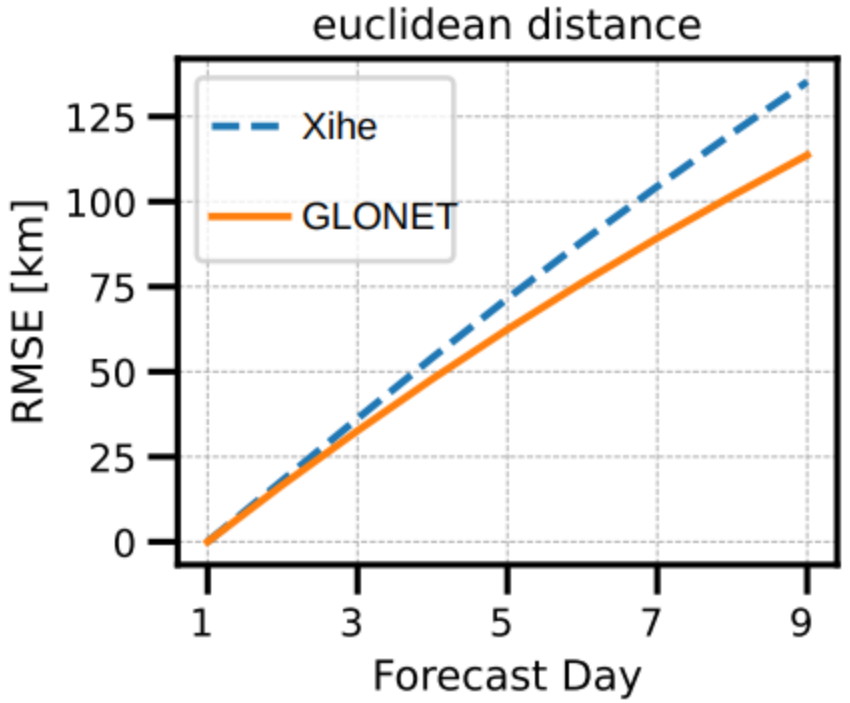
Evaluation

Process-oriented



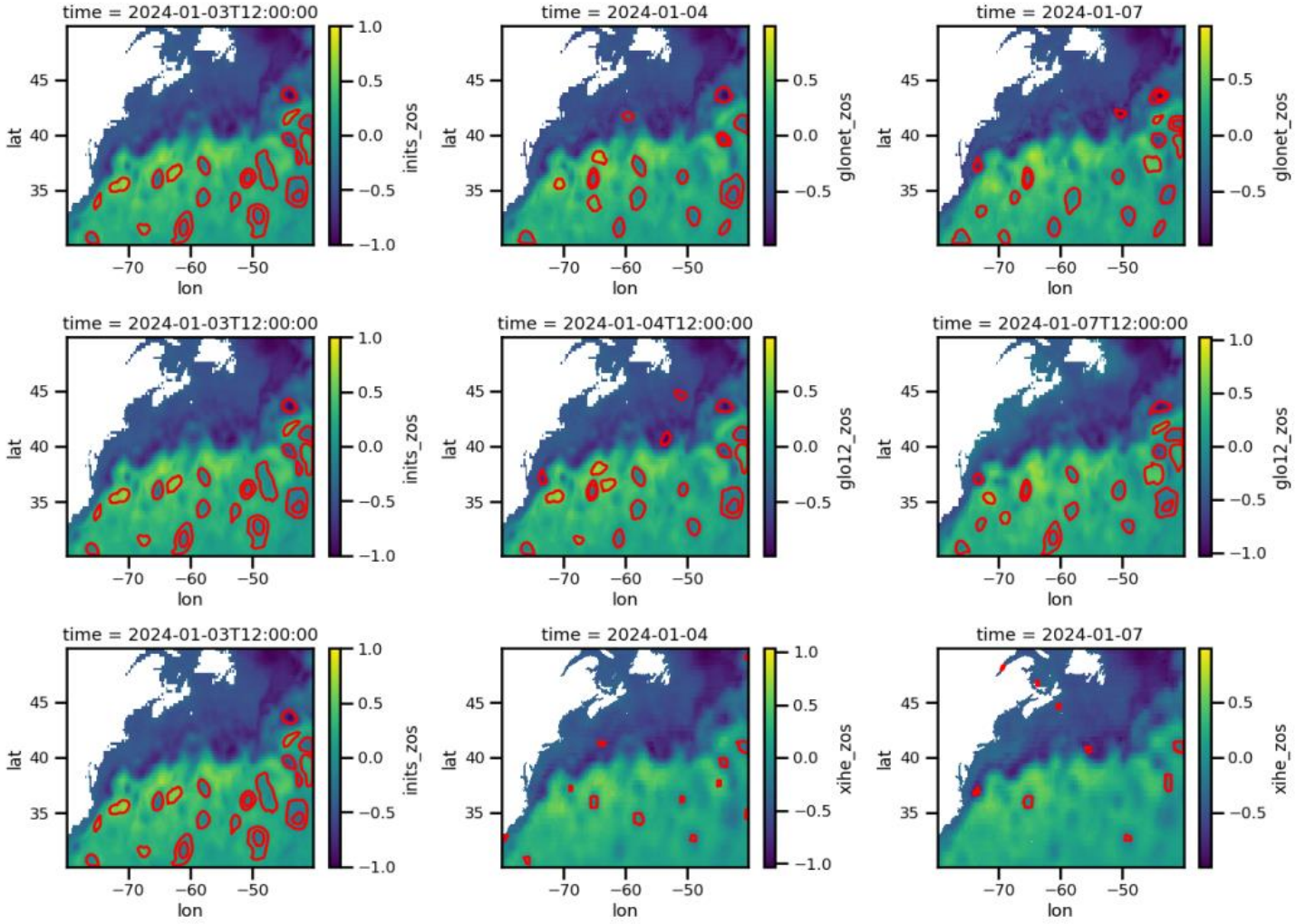


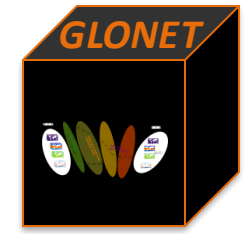
$$\mathbf{x}(t_f, t_0, \mathbf{x}_0) = \mathbf{x}_0 + \int_{t_0}^{t_f} \mathbf{v}(\mathbf{x}(\tau), \tau)\, d\tau$$

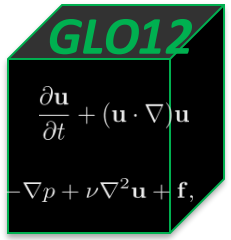


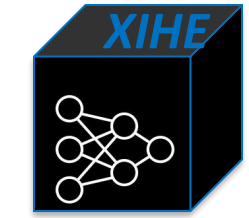
Evaluation

Process-oriented

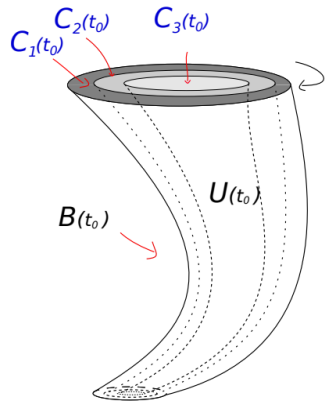


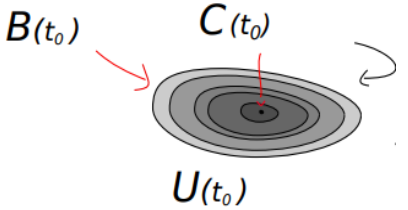






Mesoscale eddies ocean





Eulerian frame

GLONET on EDITO

GLONET's daily forecast pipeline on EDITO.

CPU

10 min

Nowcast process

Copernicus Marine Service

If nowcast ready

GPU [RTXA6000]

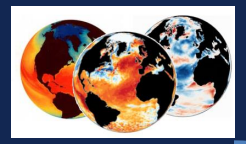
Forecast process

GLONET

Events

Kubernetes namespace's events, it's a real-time feed of kubectl get events

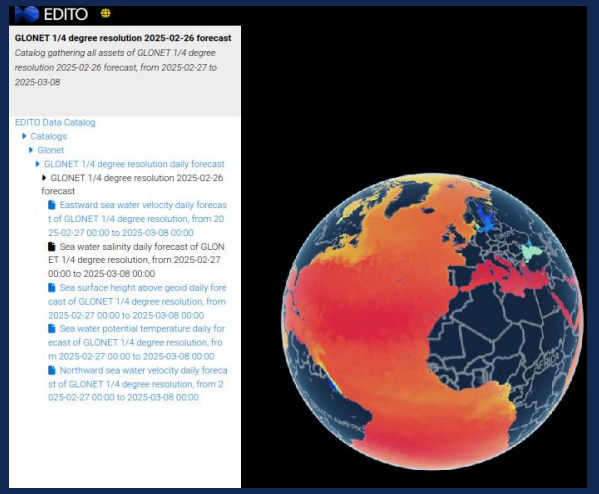
```
50 minutes ago - Pulling image "docker.mercator-ocean.fr/moi-docker/st
11 minutes ago - Successfully assigned project-glonet/glonet-daily-for
11 minutes ago - Created pod: glonet-daily-forecast-data-orchestration
11 minutes ago - Created job glonet-daily-forecast-data-orchestration-
11 minutes ago - Pulling image "docker.mercator-ocean.fr/moi-docker/gl
11 minutes ago - Successfully pulled image "docker.mercator-ocean.fr/m
11 minutes ago - Created container glonet-daily-forecast-orchestration
11 minutes ago - Started container glonet-daily-forecast-orchestration
11 minutes ago - Job completed
```

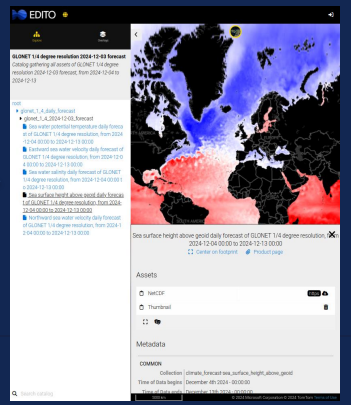


cataloging

S3 bucket

EDITO viewer

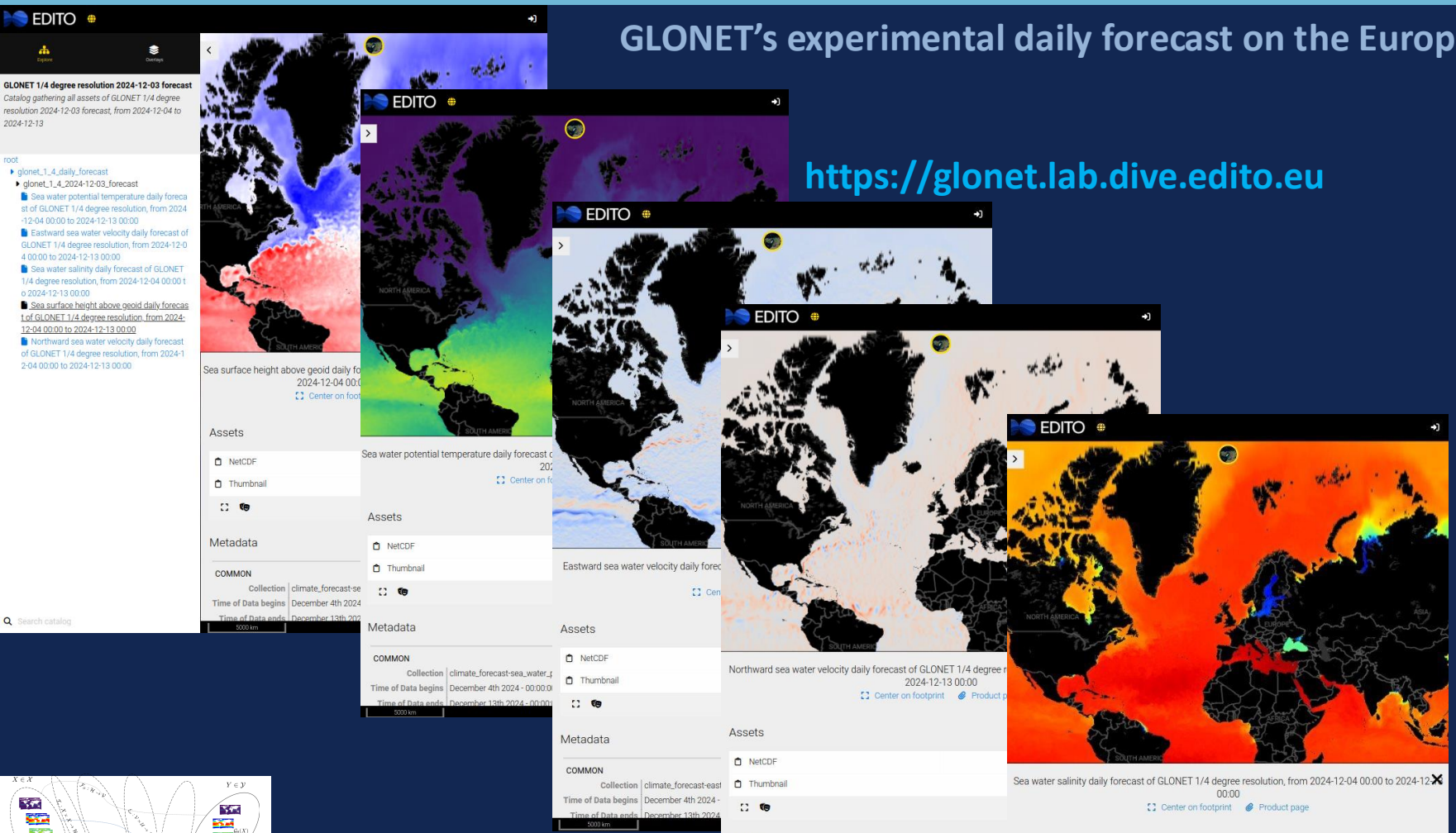




GLONET on EDITO

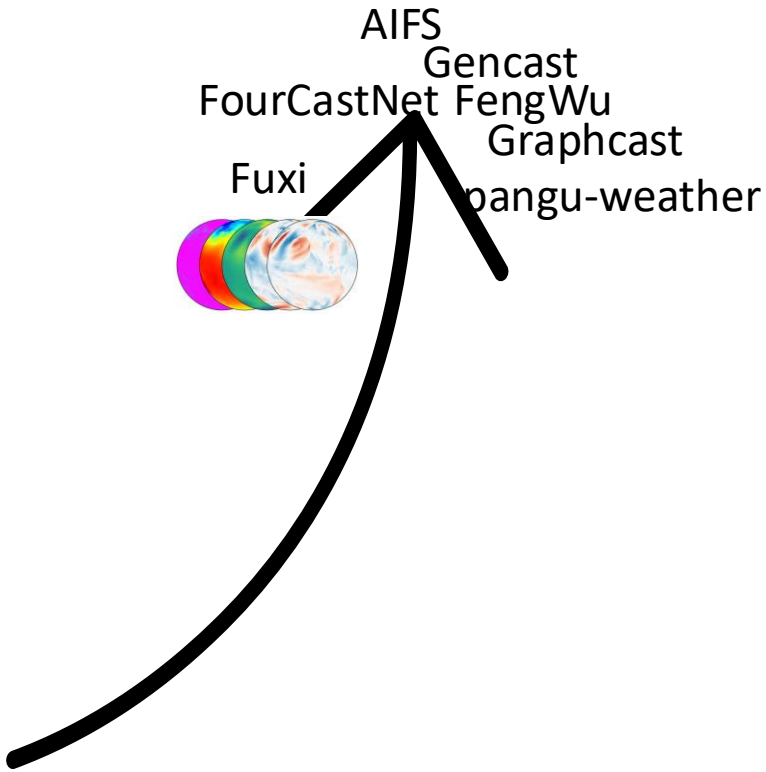
GLONET's experimental daily forecast on the European Digital Twin Ocean platform EDITO.

https://glonet.lab.dive.edito.eu

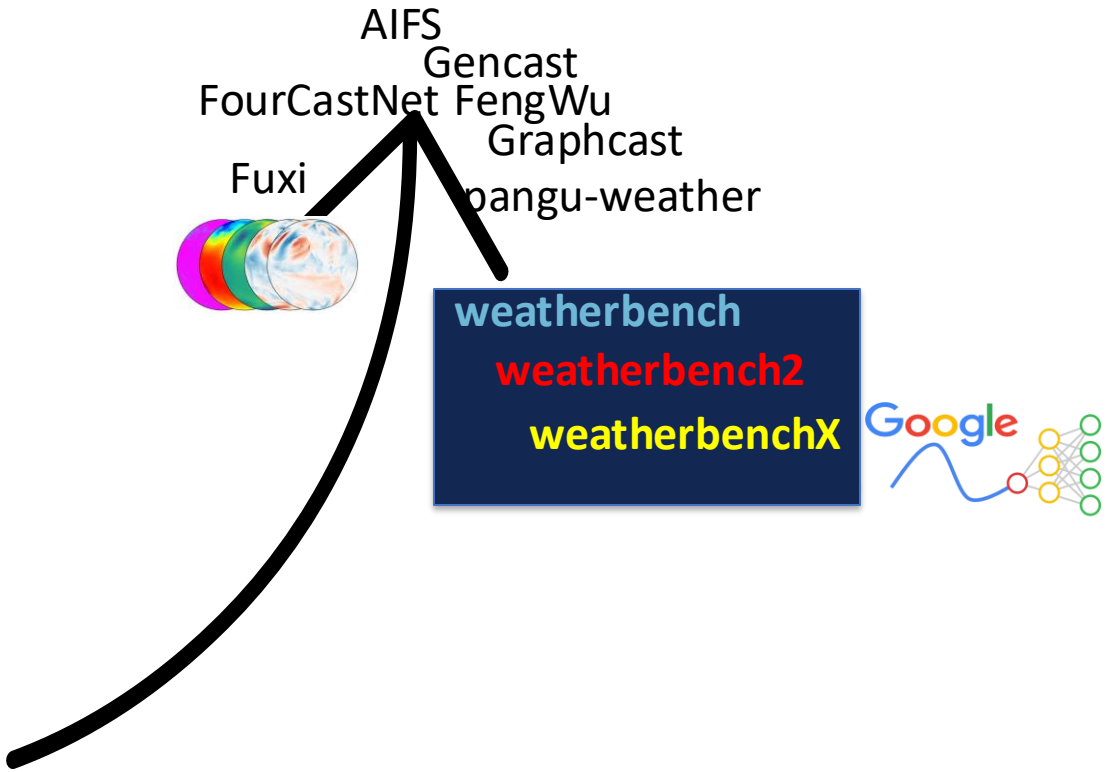


https://doi.org/10.48550/arXiv.2412.05454

AI-Atmosphere



AI-Atmosphere



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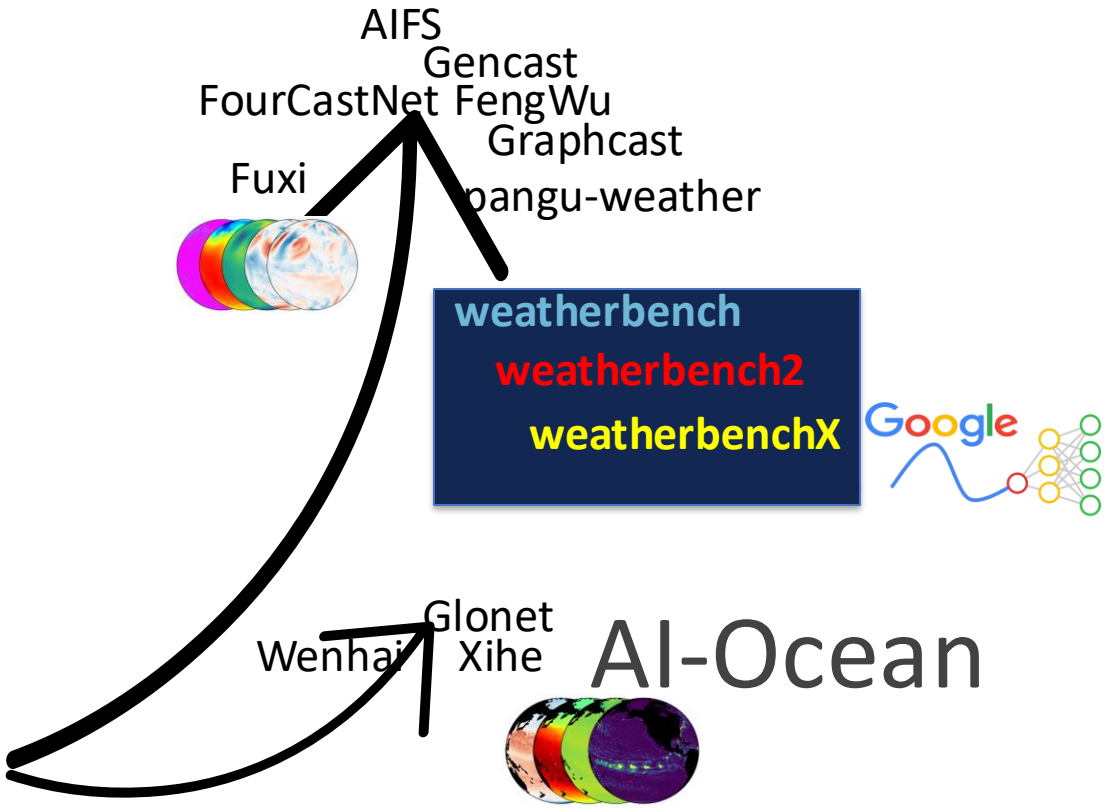

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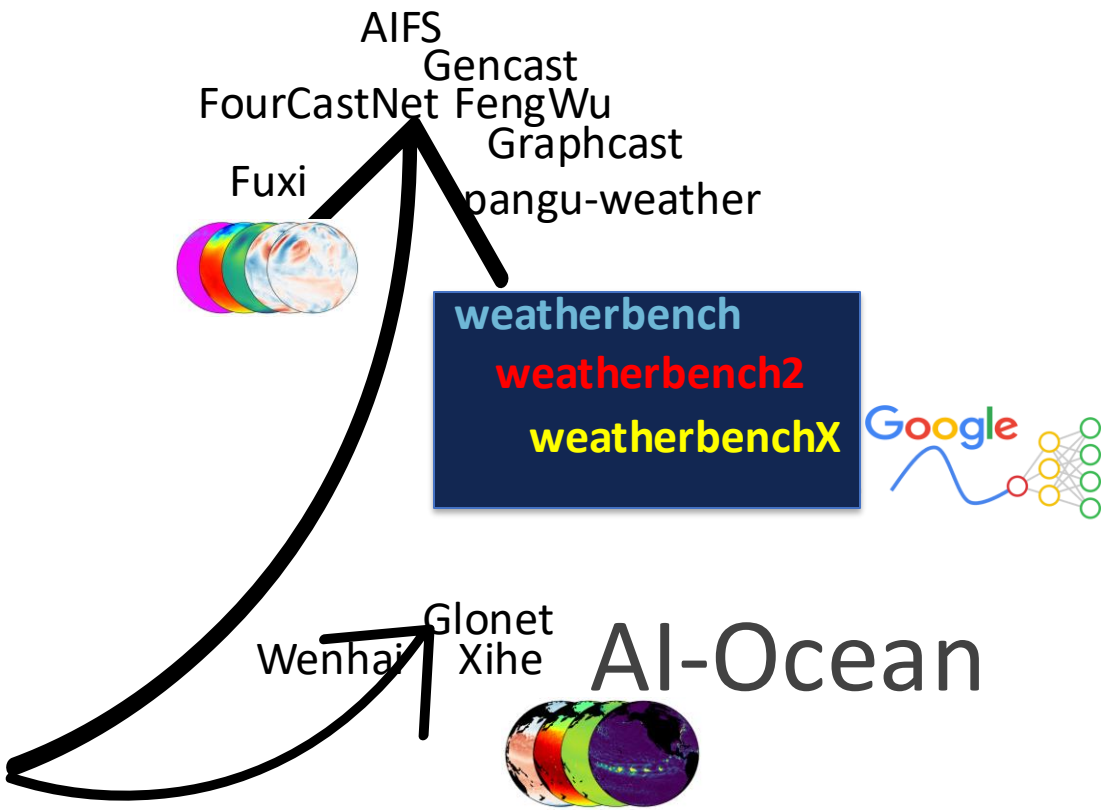

OceanBench

OceanBench: A Benchmark for Data-Driven Global Ocean Forecasting systems

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Charly Regnier[1] Julien Le Sommer[3] Simon Van Gennip[1] Ronan Fablet[4]
Marie Drevillon[1] Yann Drillet[1] Pierre-Yves Le Traon[1]

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neurips 2025

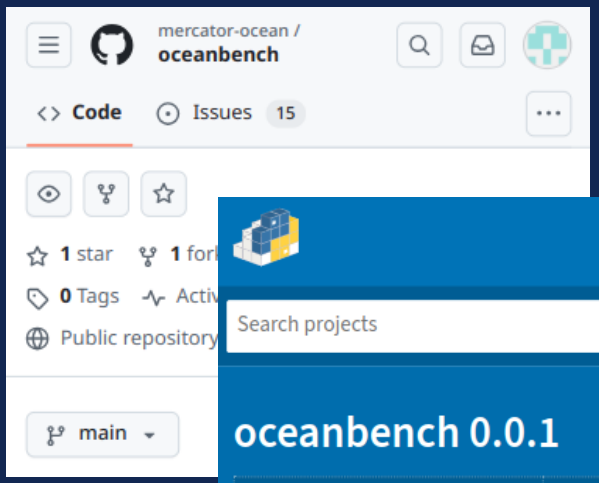
Abstract

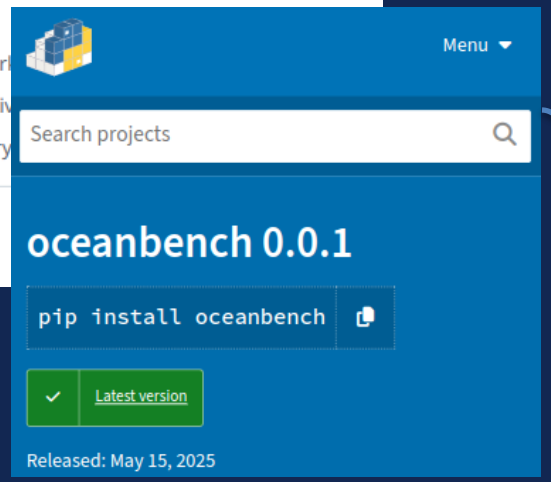
Data-driven approaches, particularly those based on deep learning, are rapidly advancing Earth system modeling. However, their application to ocean forecasting remains limited despite the ocean's pivotal role in climate regulation and marine ecosystems. To address this gap, we present OceanBench, a benchmark designed to evaluate and accelerate global short-range (1–10 days) data-driven ocean fore-

mercator-ocean / oceanbench

OceanBench: A Benchmark for Data-Driven Global Ocean Forecasting systems

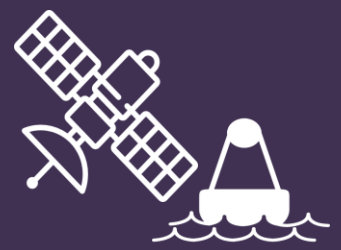
MERCATOR OCEAN INTERNATIONAL

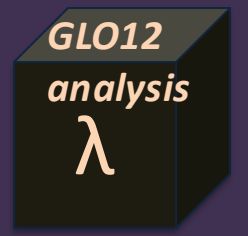


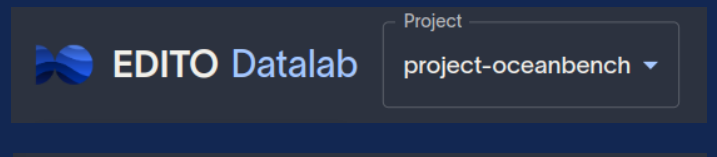


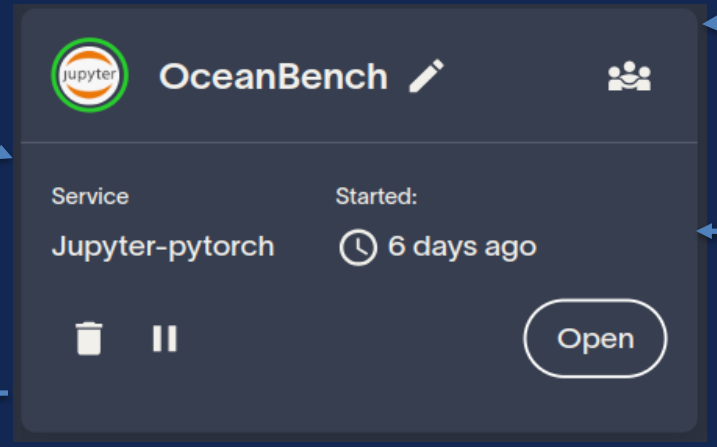
https://oceanbench.lab.dive.edito.eu/

References

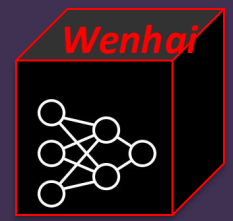


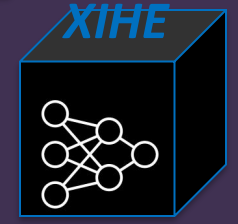






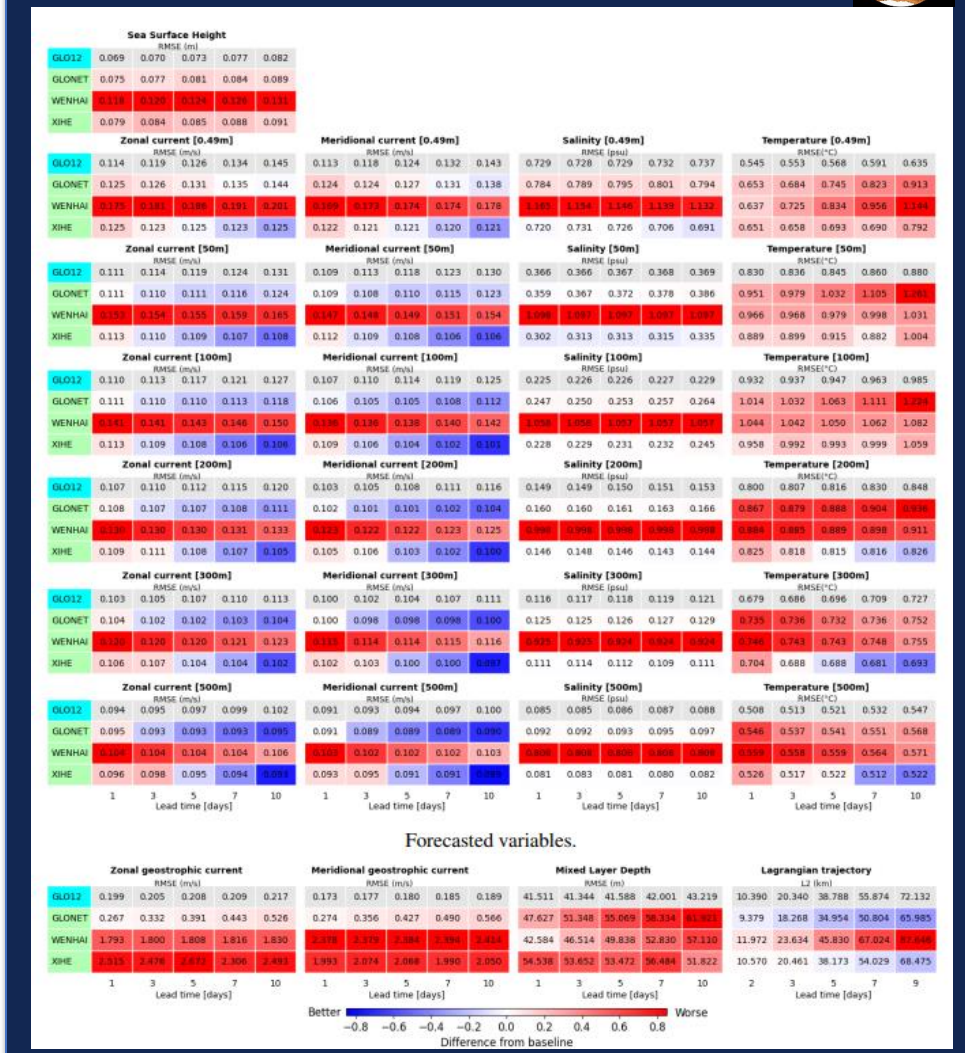
Candidates



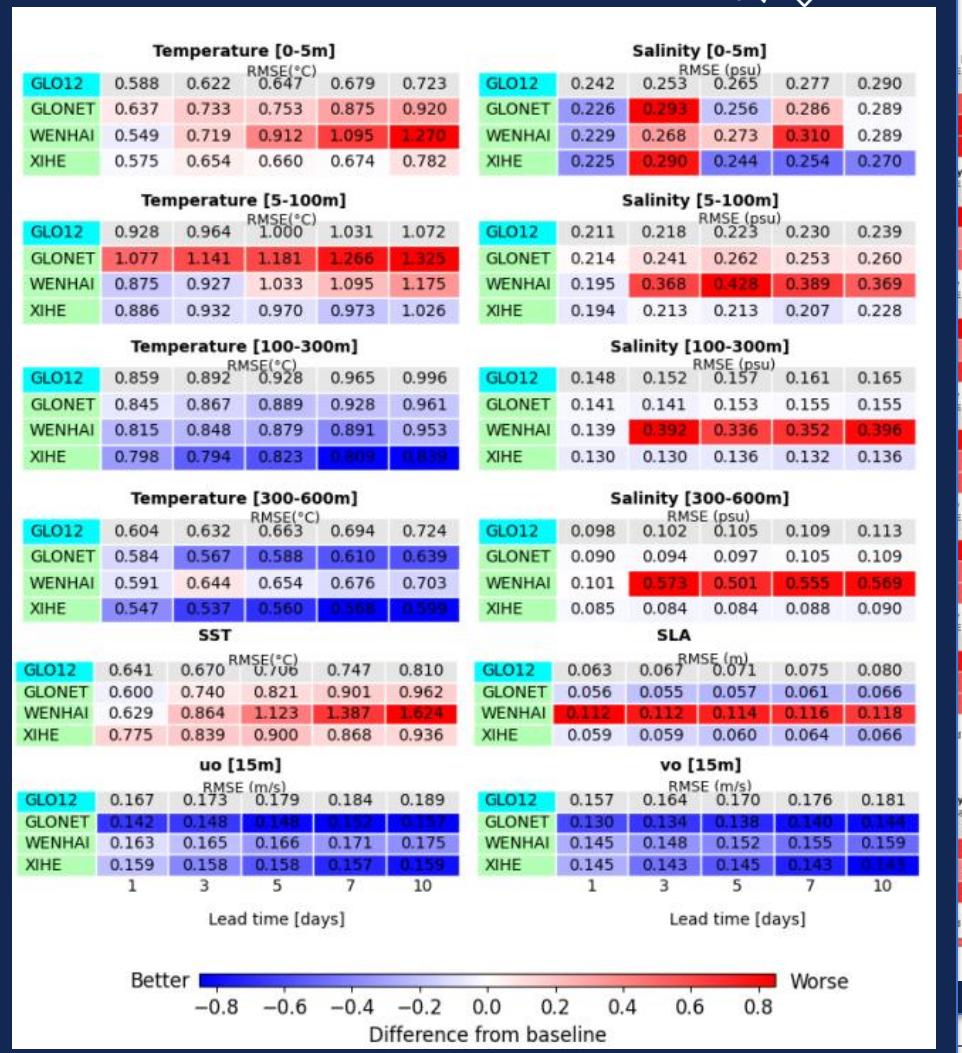


OceanBench: A Benchmark for Data-Driven Global Ocean Forecasting systems

Models-to-Reanalysis



Models-to-Observation



Models-to-Analysis