



**MERCATOR
OCEAN**
INTERNATIONAL

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

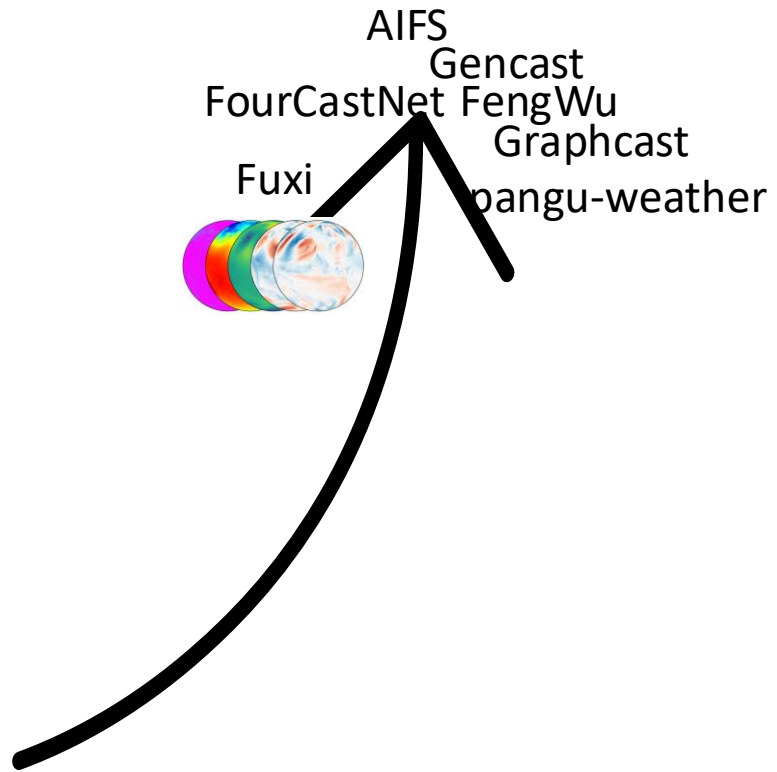
Anass El Aouni, Quentin Gaudel, Yann Drillet,

Marie Drevillon, Simon Van Gennip, Pierre-Yves Le Traon, Alain Arnaud

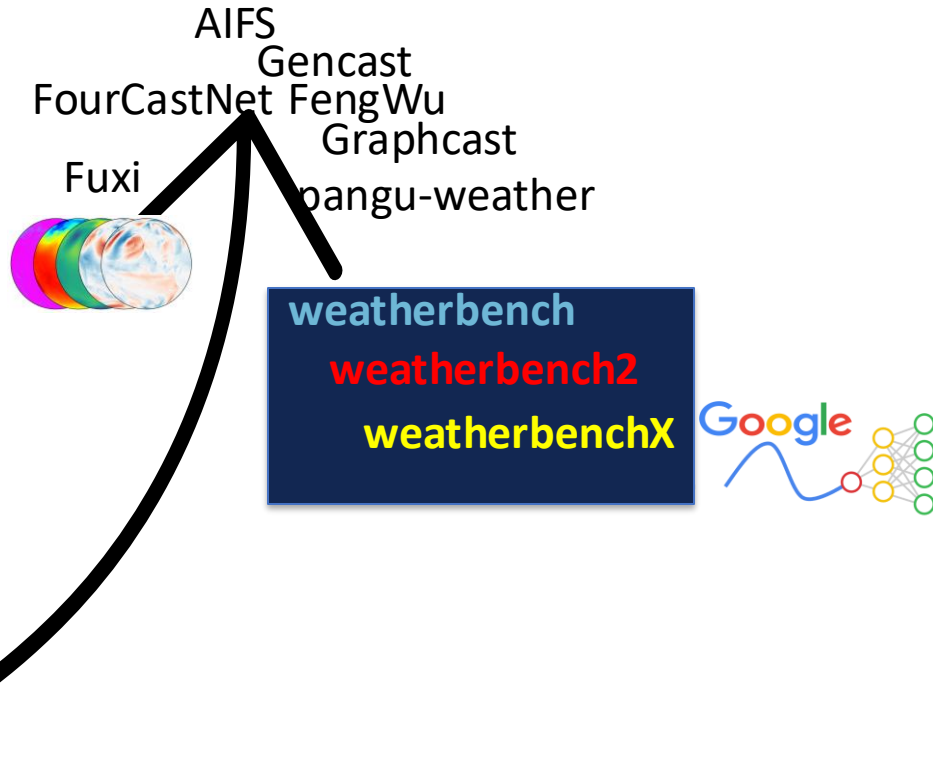
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AI-Atmosphere



AI-Atmosphere



WeatherBench

A benchmark for the next generation of data-driven global weather models

[Paper](#) [Code](#) [Blog](#)

Overview

Weather forecasting using machine learning (ML) has seen [rapid progress](#) in recent years. WeatherBench is an open framework for evaluating ML and physics-based weather

Headline scorecards

There is no single metric for measuring weather forecast performance. For example, one end user might be worried about wind gusts, while another might care more about average temperatures. For this reason, WeatherBench 2 contains a range of metrics, which you can find in the navigation at the top of this page. To provide a concise summary, we defined several key - "headline" - metrics that closely mirror the routine evaluation done by weather agencies and the World Meteorological Organization. It is important to remember that these metrics measure some important but not all aspects of what makes a good forecast.

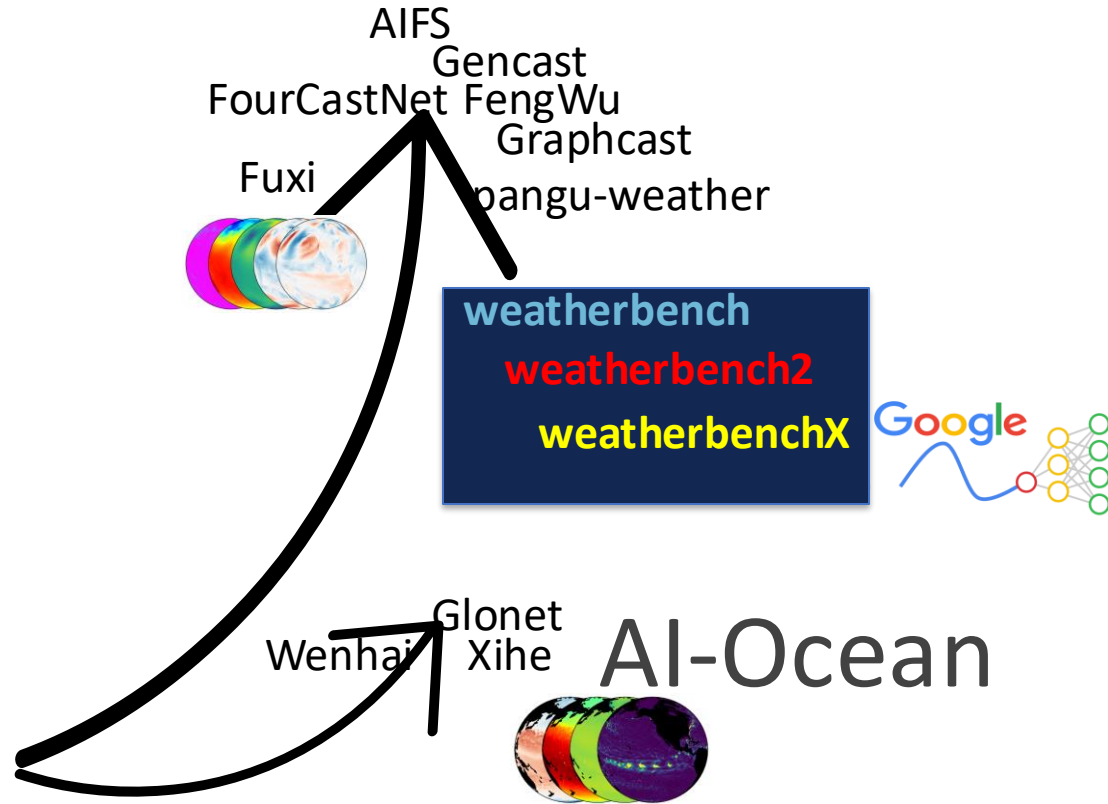
The scorecards below show the skill (measured by the global root mean squared error) of different physical and ML-based methods relative to ECMWF's IFS-HRES, one of the world's best operational weather models, on a number of key variables. For a detailed explanation of the different skill metrics and variables, check out the [FAQ](#).

| Model | Geopotential | | | | Temperature | | | | Humidity | | | | Wind Vector | | | | | | | |
|------------------------|--------------|-----|-----|-----|-------------|------|------|------|----------|------|------|------|-------------|------|------|------|------|------|------|------|
| | 1000 | 925 | 850 | 775 | 2000 | 1500 | 1000 | 500 | 2000 | 1500 | 1000 | 500 | U | V | W | W | | | | |
| IFS HRES | 41 | 136 | 306 | 521 | 809 | 0.83 | 1.19 | 1.84 | 2.42 | 3.82 | 0.53 | 0.96 | 1.28 | 1.55 | 1.84 | 1.60 | 3.23 | 5.15 | 7.07 | 9.13 |
| IFS ENS (mean) | 40 | 132 | 278 | 479 | 755 | 0.82 | 1.09 | 1.66 | 2.21 | 3.55 | 0.50 | 0.82 | 1.05 | 1.28 | 1.54 | 1.57 | 2.92 | 4.40 | 5.75 | 7.56 |
| PanguWeather (oper.) | 45 | 138 | 304 | 517 | 799 | 0.86 | 1.12 | 1.76 | 2.51 | 3.57 | 0.53 | 0.93 | 1.18 | 1.46 | 1.78 | 1.68 | 3.63 | 4.86 | 6.81 | 8.91 |
| GraphCast (oper.) | 38 | 126 | 276 | 489 | 747 | 0.86 | 0.95 | 1.55 | 2.31 | 3.34 | 0.47 | 0.78 | 1.08 | 1.38 | 1.68 | 1.46 | 2.68 | 4.41 | 5.98 | 8.47 |
| GemCast (oper.) (mean) | 39 | 124 | 264 | 431 | 669 | 0.86 | 0.89 | 1.47 | 2.08 | 3.08 | 0.46 | 0.76 | 1.05 | 1.35 | 1.65 | 1.49 | 2.70 | 4.18 | 5.66 | 8.09 |
| Aurora (oper.) | 38 | 119 | 263 | 442 | 668 | 0.86 | 0.95 | 1.50 | 2.15 | 3.21 | 0.47 | 0.77 | 1.03 | 1.27 | 1.47 | 1.81 | 2.83 | 4.21 | 5.58 | 7.91 |
| FCM (oper.) (mean) | 37 | 124 | 271 | 488 | 751 | 0.83 | 0.96 | 1.36 | 1.95 | 2.95 | 0.44 | 0.75 | 1.02 | 1.30 | 1.58 | 1.31 | 2.52 | 3.88 | 5.25 | 7.55 |
| Pangu-Weather | 44 | 134 | 295 | 503 | 789 | 0.82 | 1.05 | 1.71 | 2.51 | 3.56 | 0.53 | 0.90 | 1.18 | 1.45 | 1.76 | 1.65 | 2.96 | 4.60 | 6.15 | 8.05 |
| GraphCast | 39 | 122 | 270 | 489 | 732 | 0.81 | 0.90 | 1.54 | 2.30 | 3.36 | 0.46 | 0.77 | 1.03 | 1.30 | 1.58 | 1.40 | 2.71 | 4.42 | 6.20 | 8.27 |
| Climatology | 47 | 145 | 315 | 535 | 810 | 0.80 | 1.15 | 1.85 | 2.45 | 3.85 | 0.52 | 0.95 | 1.25 | 1.55 | 1.85 | 1.55 | 3.05 | 4.75 | 6.45 | 8.75 |

QUICK LINKS

- [Paper](#)
- [Code](#)
- [Data](#)

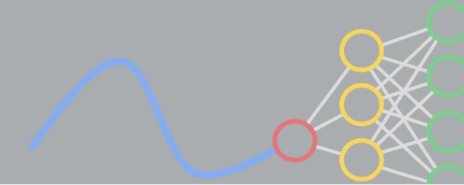
AI-Atmosphere



WeatherBench

A benchmark for the next generation of data-driven global weather models

[Paper](#) [Code](#) [Blog](#)



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QUICK LINKS

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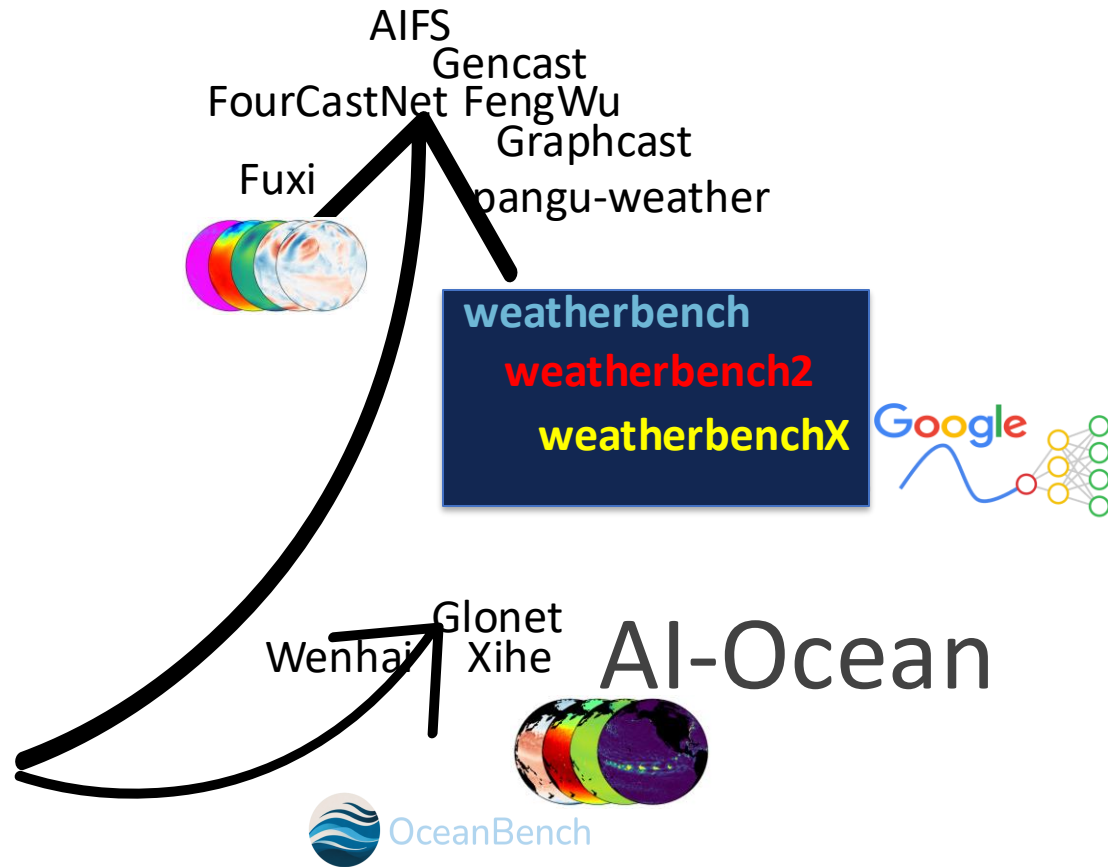
Headline scorecards

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The scorecards below show the skill (measured by the global root mean squared error) of different physical and ML-based methods relative to ECMWF's IFS-HRES, one of the [world's best operational weather models](#), on a number of key variables. For a detailed explanation of the different skill metrics and variables, check out the [FAQ](#).

| All-Weather (lead time) | Geopotential (mean geopotential height [gpm]) | | | | Temperature (mean temperature [K]) | | | | Humidity (mean specific humidity [kg/kg]) | | | | Wind Vector (mean wind speed [m/s]) | | | | | | | |
|-------------------------|---|----------------|-----------------------|-------------------|------------------------------------|----------------|-----------------------|-------------------|---|----------------|-----------------------|-------------------|-------------------------------------|----------------|-----------------------|-------------------|------|------|------|------|
| | IFS HRES | IFS ENS (mean) | Pangu Weather (oper.) | GraphCast (oper.) | IFS HRES | IFS ENS (mean) | Pangu Weather (oper.) | GraphCast (oper.) | IFS HRES | IFS ENS (mean) | Pangu Weather (oper.) | GraphCast (oper.) | IFS HRES | IFS ENS (mean) | Pangu Weather (oper.) | GraphCast (oper.) | | | | |
| 1 | 41 | 136 | 306 | 521 | 809 | 0.83 | 1.19 | 1.84 | 2.42 | 3.82 | 0.53 | 0.96 | 1.28 | 1.55 | 1.84 | 1.60 | 3.23 | 5.15 | 7.07 | 9.13 |
| 3 | 40 | 132 | 278 | 479 | 825 | 0.82 | 1.09 | 1.66 | 2.21 | 3.55 | 0.50 | 0.82 | 1.05 | 1.28 | 1.54 | 1.57 | 2.92 | 4.40 | 5.75 | 8.06 |
| 5 | 38 | 138 | 304 | 517 | 799 | 0.86 | 1.12 | 1.76 | 2.51 | 3.57 | 0.53 | 0.87 | 1.18 | 1.46 | 1.78 | 1.68 | 3.03 | 4.86 | 6.81 | 8.91 |
| 10 | 36 | 126 | 276 | 489 | 747 | 0.86 | 0.95 | 1.55 | 2.31 | 3.34 | 0.47 | 0.76 | 1.08 | 1.38 | 1.68 | 1.46 | 2.68 | 4.41 | 5.98 | 8.47 |
| 15 | 35 | 124 | 264 | 431 | 703 | 0.86 | 0.89 | 1.47 | 2.04 | 2.98 | 0.46 | 0.76 | 1.05 | 1.35 | 1.64 | 1.49 | 2.70 | 4.18 | 5.66 | 8.09 |
| 20 | 36 | 119 | 263 | 442 | 668 | 0.86 | 0.95 | 1.50 | 2.15 | 2.87 | 0.47 | 0.77 | 1.05 | 1.37 | 1.61 | 1.81 | 2.87 | 4.21 | 5.58 | 7.91 |
| 25 | 37 | 124 | 271 | 468 | 621 | 0.85 | 0.96 | 1.50 | 1.95 | 2.76 | 0.46 | 0.76 | 1.05 | 1.30 | 1.58 | 1.71 | 2.70 | 3.98 | 5.25 | 7.58 |
| 30 | 38 | 134 | 295 | 503 | 789 | 0.82 | 1.05 | 1.71 | 2.51 | 3.56 | 0.53 | 0.86 | 1.18 | 1.45 | 1.74 | 1.65 | 2.96 | 4.60 | 6.15 | 8.65 |
| 35 | 39 | 122 | 270 | 499 | 732 | 0.81 | 0.95 | 1.54 | 2.30 | 3.36 | 0.46 | 0.77 | 1.03 | 1.36 | 1.58 | 1.40 | 2.71 | 4.42 | 6.20 | 8.27 |
| 40 | 39 | 122 | 270 | 499 | 732 | 0.81 | 0.95 | 1.54 | 2.30 | 3.36 | 0.46 | 0.77 | 1.03 | 1.36 | 1.58 | 1.40 | 2.71 | 4.42 | 6.20 | 8.27 |
| 45 | 39 | 122 | 270 | 499 | 732 | 0.81 | 0.95 | 1.54 | 2.30 | 3.36 | 0.46 | 0.77 | 1.03 | 1.36 | 1.58 | 1.40 | 2.71 | 4.42 | 6.20 | 8.27 |
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AI-Atmosphere



OceanBench

Neurips 2025:

<https://openreview.net/forum?id=wZGe1Kqs8G>

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

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Quentin Gaudel¹

Juan Emmanuel Johnson²

Charly Regnier¹

Julien Le Sommer³

Simon Van Gennip¹

Ronan Fablet⁴

Marie Drevillon¹

Yann Drillet¹

Pierre-Yves Le Traon¹

¹Mercator Ocean International, Toulouse, France

²International Methane Emissions Observatory, UNEP, Paris, France

³Université Grenoble Alpes, CNRS, Grenoble, France

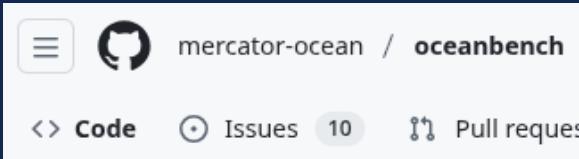
⁴IMT Atlantique, Brest, France

Abstract

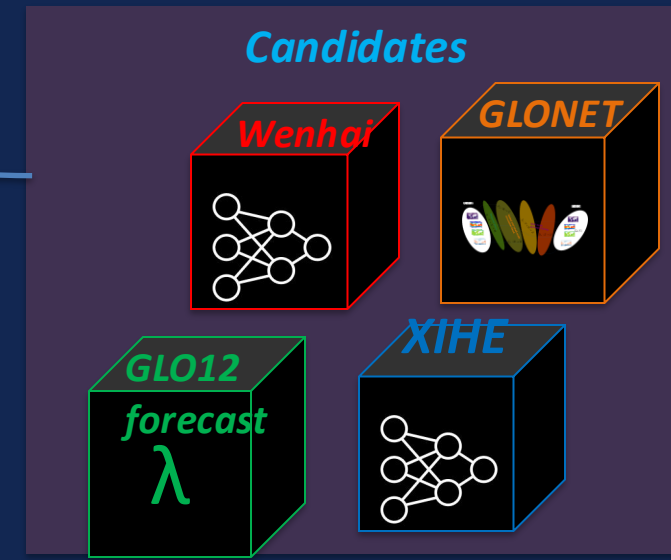
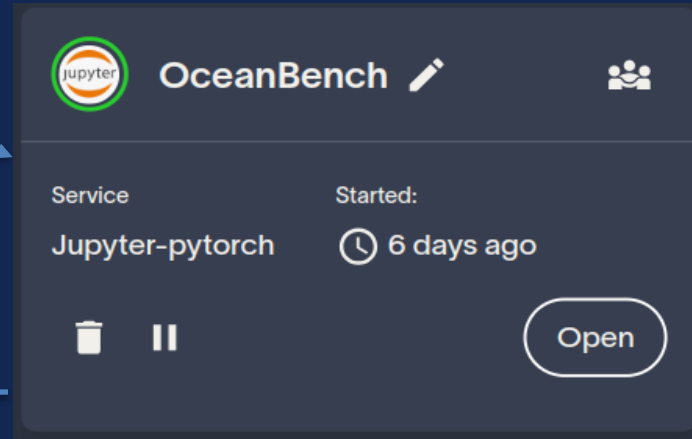
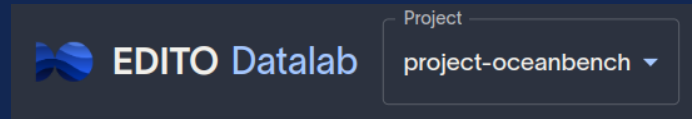
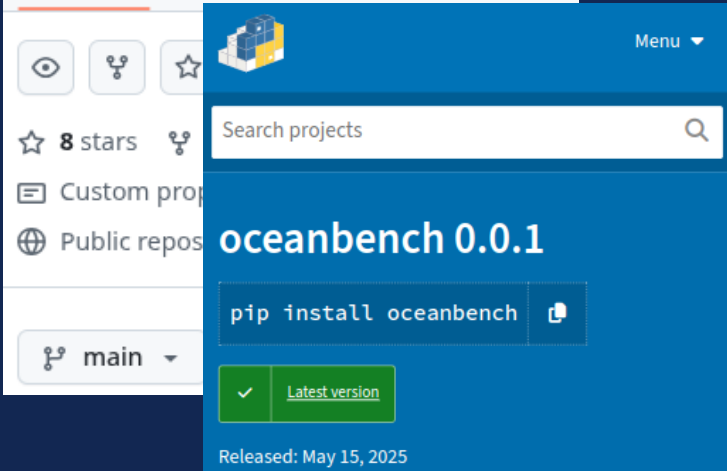
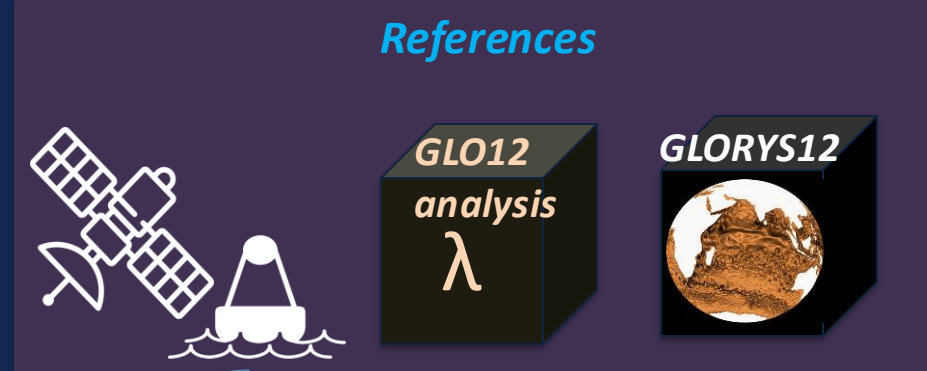
Data-driven approaches, particularly those based on deep learning, are rapidly advancing Earth system modeling. However, their application to ocean forecasting remains limited. In this paper, we introduce OceanBench, a benchmark designed to evaluate (1–10 days) data-driven ocean fore-



mercator-ocean / oceanbench



github.com/mercator-ocean/oceanbench




Forecast variables:

| Variable | Wenhai | GLONET | GLO12 forecast λ | XIHE |
|--------------------|--------|--------|--------------------------|-------|
| Temperature (0-5m) | 0.588 | 0.612 | 0.557 | 0.619 |
| Salinity (0-5m) | 0.637 | 0.733 | 0.753 | 0.875 |
| Sea Level Pressure | 0.549 | 0.719 | 0.692 | 0.695 |
| Surface Current | 0.614 | 0.660 | 0.624 | 0.727 |

Forecast variables:

| Variable | Wenhai | GLONET | GLO12 forecast λ | XIHE |
|--------------------|--------|--------|--------------------------|-------|
| Temperature (0-5m) | 0.247 | 0.247 | 0.255 | 0.255 |
| Salinity (0-5m) | 0.226 | 0.256 | 0.268 | 0.269 |
| Sea Level Pressure | 0.228 | 0.265 | 0.273 | 0.298 |
| Surface Current | 0.248 | 0.254 | 0.262 | 0.292 |

D.S. (Dissimilarity Score) - 0.8 is Worse

Benchmarking

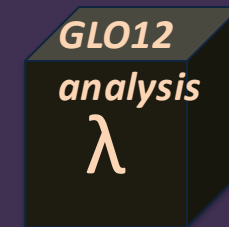
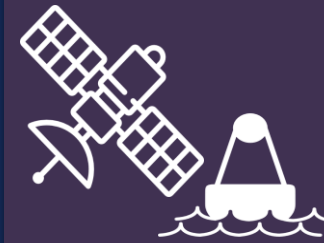
Initialization (EDITO)

- GLO12 hindcast (EDITO)
 - zos, so, thetao, uo, vo...
 - 2024
- IFS
 - u10,v10,t2m, mslp, sp..

References (EDITO)

- GLORYS12 2024
- GLO12 analysis 2024
- Observaration (2024)
 - Satellite and in situ

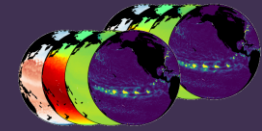
dataset/references



Training (CMC, CAMS..)

- GLORYS12
 - zos, so, thetao, uo, vo
 - 1993~2020
- ERA5/IFS....

Candidates



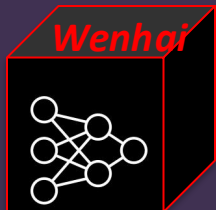
ML-based models



Wang, Xiang, et al.
"Xihe: arXiv:2402.02995 (2024).



El Aouni, Anass, et al. " Journal of Geophysical Research: Machine Learning and Computation 2.3 (2025): e2025JH000686.



Cui, Yingzhe, et al. "Forecasting the eddying ocean with a deep neural network." Nature Communications 16.1 (2025): 2268.

physics-based models

Baseline



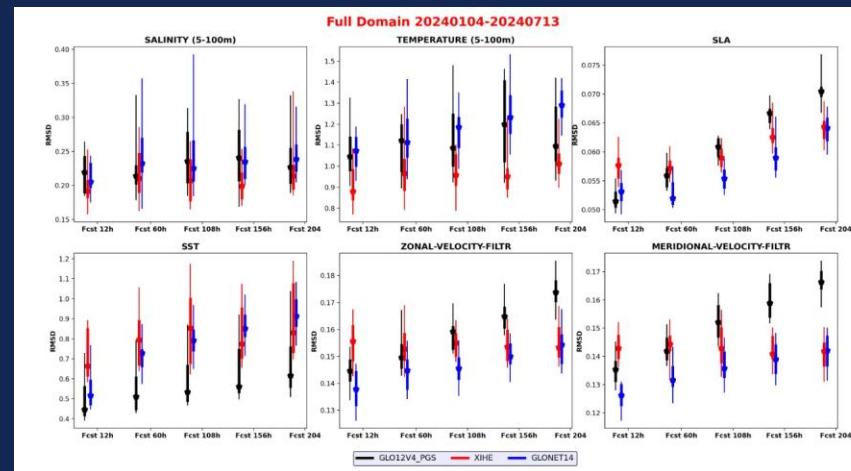
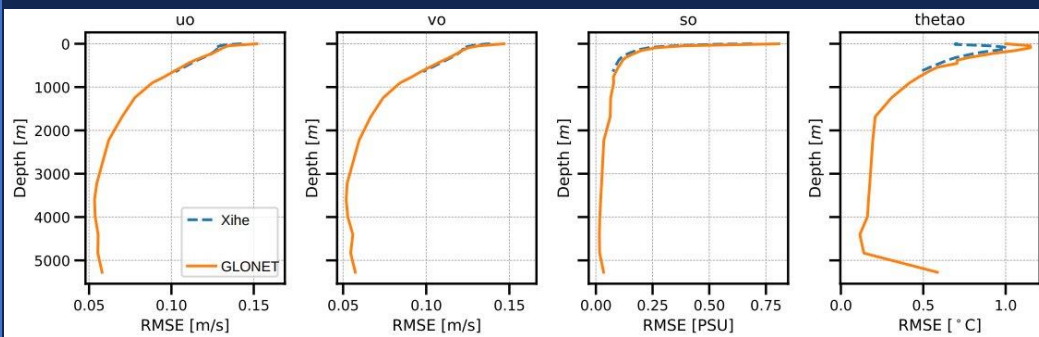
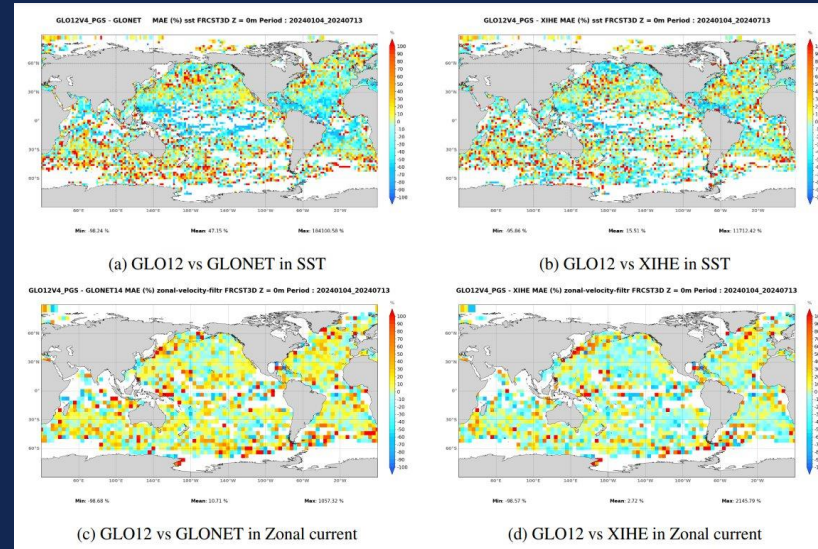
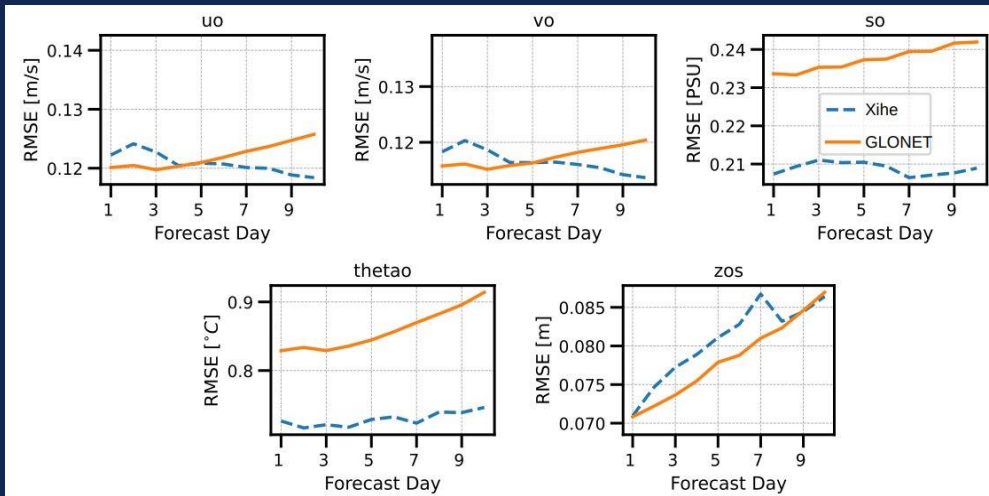
Lellouche, Jean-Michel, et al. "Recent updates to the Copernicus Marine Service global ocean monitoring and forecasting real-time 1/12° high-resolution system." Ocean Science 14.5 (2018): 1093-1126.

Hybrid models

ANY?

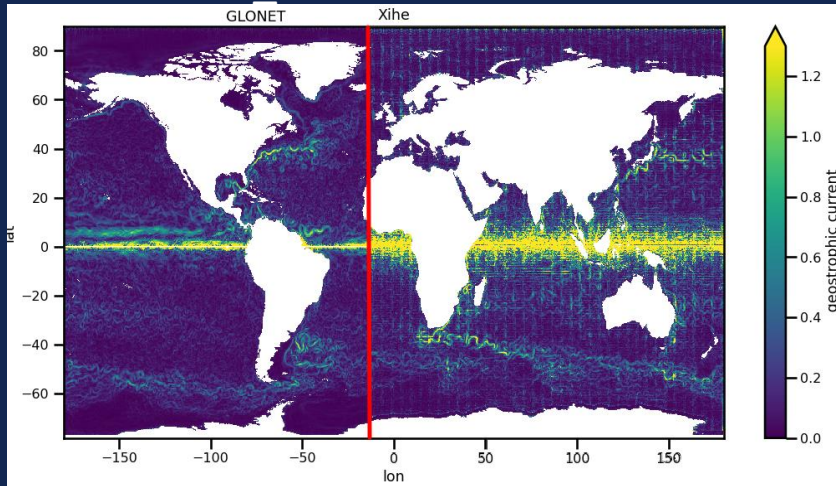
Pointwise

Evaluation metrics

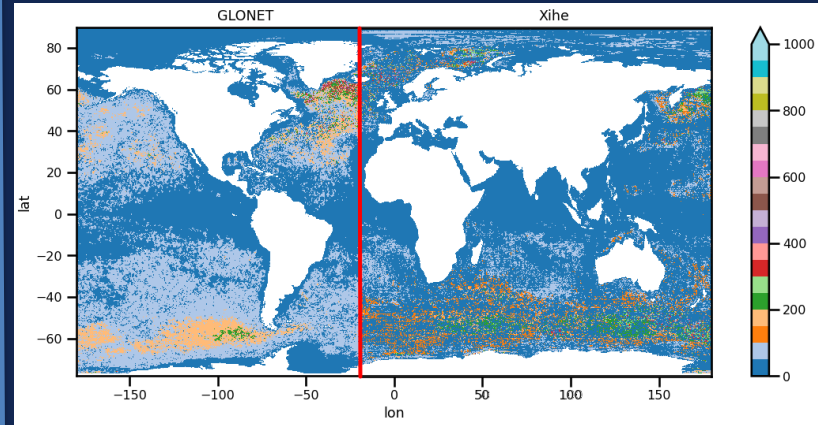


Process-based

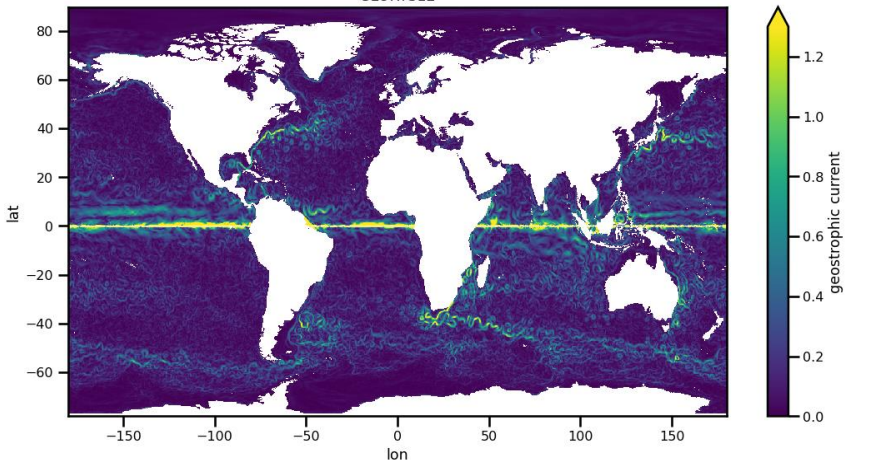
Geo currents



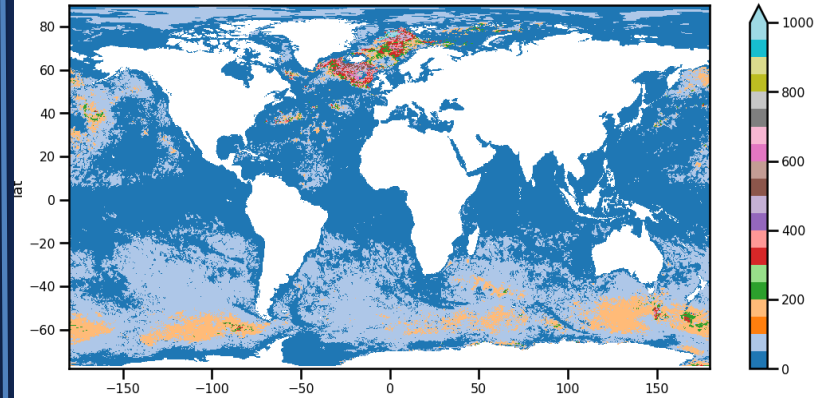
MLD



GLORYS12



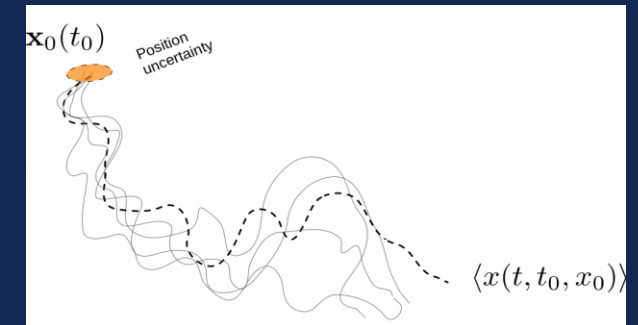
GLORYS12

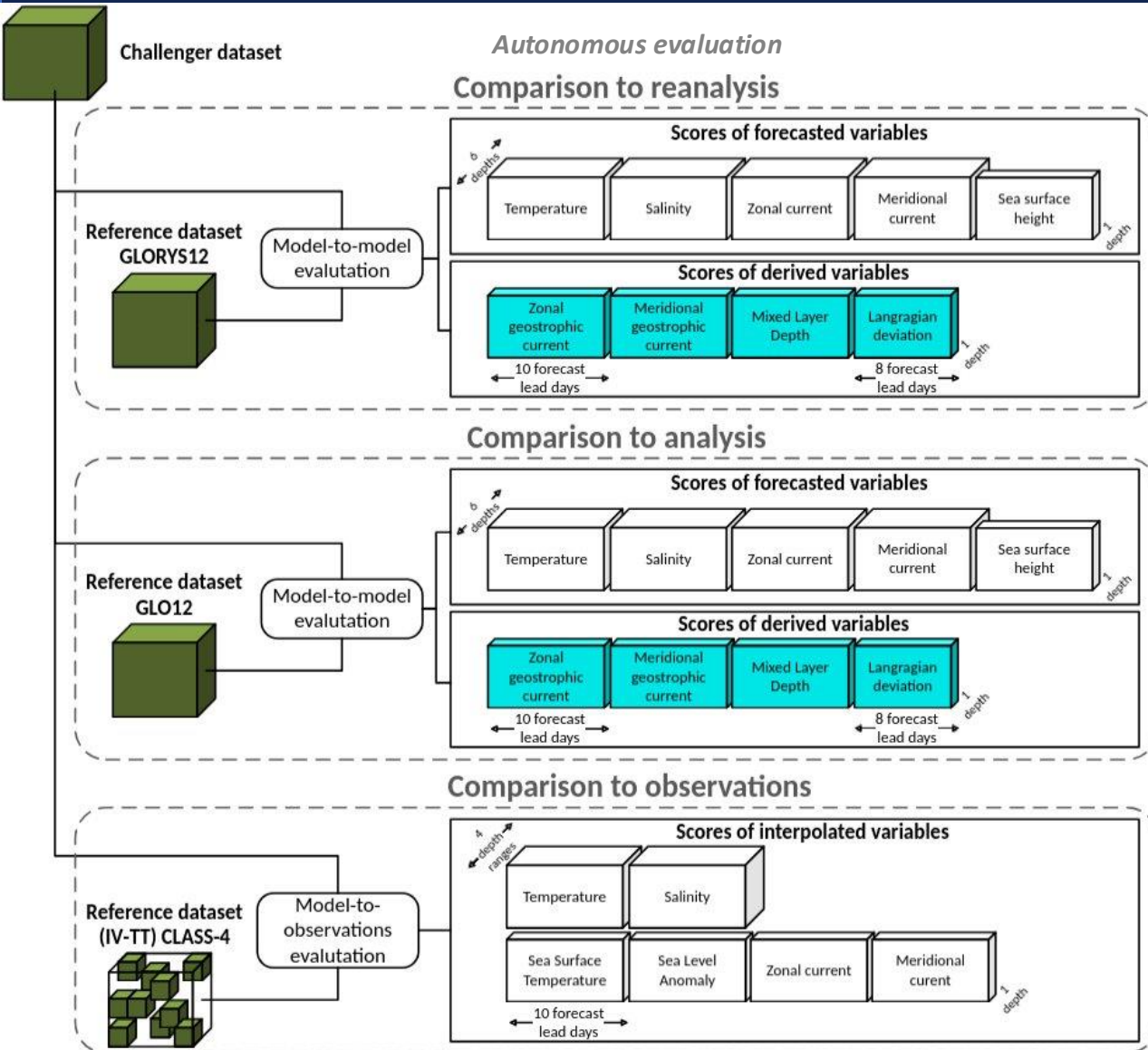


Evaluation metrics

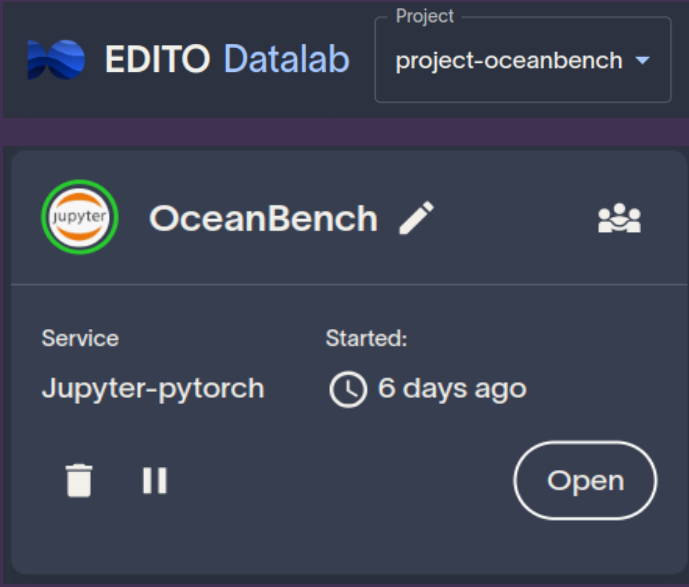


Lagrangian Drift





Evaluation process



EDITO Datalab Project: project-oceanbench

Jupyter OceanBench

Service: Jupyter-pytorch Started: 6 days ago

Open

Code



OceanBench: Evaluating ocean forecasting systems

[pypi v0.0.2](#)
[Powered by EDITO](#)
[python 3.13](#)
[platform linux](#)
[licence EUPL](#)
[REUSE compliant](#)
[docs passing](#)

OceanBench is a benchmarking tool to evaluate ocean forecasting datasets (such as 2024 [GLORYS reanalysis](#) and [GLO12 analysis](#)) as

Score table and system comparison

The official score table is available on the [OceanBench website](#).

Evaluate your system with OceanBench

The evaluation of a system consists in the sequential execution of methods against a set of forecasts (produced by the system), namely [xarray Dataset](#).

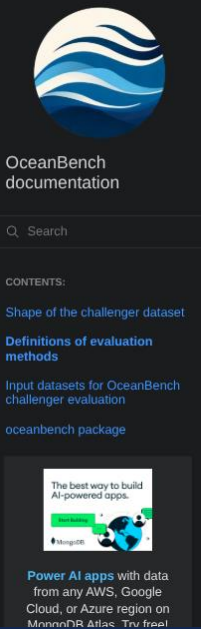
The OceanBench documentation describes [the shape a challenge definitions of the methods used to evaluate systems](#).

Official evaluation

All official challenger notebooks are maintained and re-executable on OceanBench versions (all official challengers are re-evaluated at

To officially submit your system to OceanBench, please open an issue following:

1. The executed notebook resulting from an [interactive](#) or [prog](#)
2. A way to access the system output data in a standard format
3. A way to execute the system code or container along with clear



OceanBench documentation

Q Search

CONTENTS:

- Shape of the challenger dataset
- Definitions of evaluation methods
- Input datasets for OceanBench challenger evaluation
- oceanbench package

The best way to build AI-powered apps.

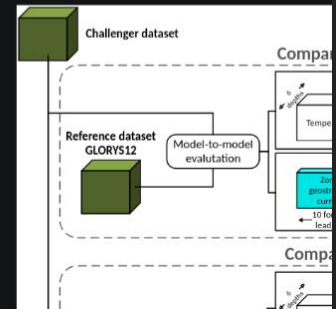
Power AI apps with data from any AWS, Google Cloud, or Azure region on Microsoft Atlas. Try free!

Documentation

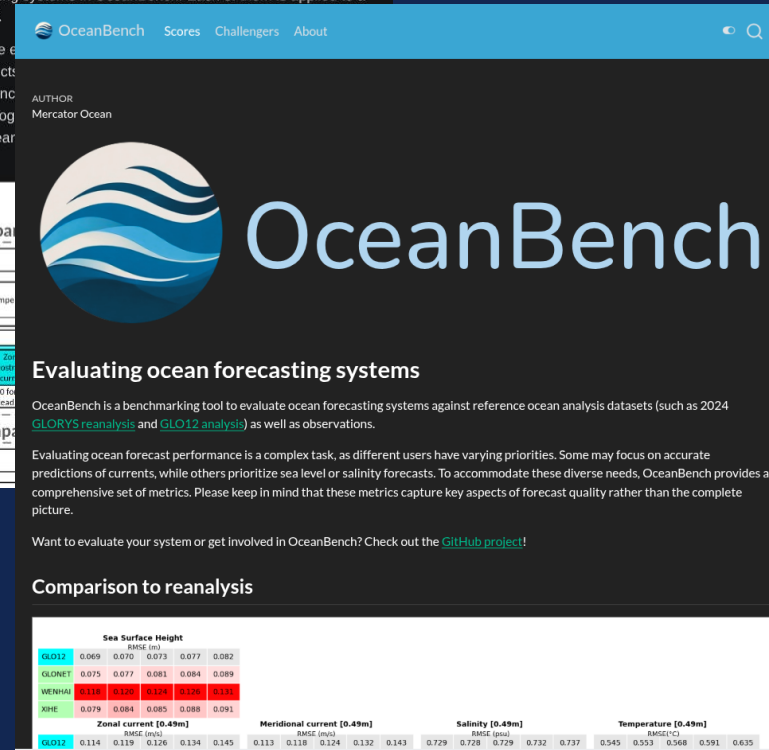
Definitions of evaluation methods

Several methods are used to evaluate forecasting systems in OceanBench. Each of them is applied to a dataset grouping 52 forecasts in the year 2024.

The following figure provides an overview of the evaluation strategy that captures different aspects: (i) based intercomparison, (ii) reference-model benchmark derived from physically meaningful variables. Together, they assess each model's ability to reproduce observed ocean conditions and generalize beyond the training regime.



Website



OceanBench Scores Challengers About

AUTHOR: Mercator Ocean

OceanBench

Evaluating ocean forecasting systems

OceanBench is a benchmarking tool to evaluate ocean forecasting systems against reference ocean analysis datasets (such as 2024 [GLORYS reanalysis](#) and [GLO12 analysis](#)) as well as observations.

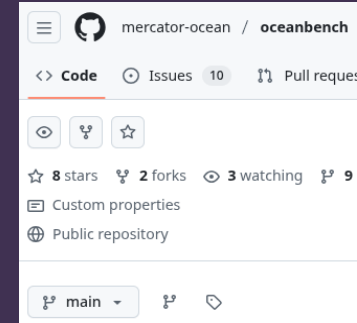
Evaluating ocean forecast performance is a complex task, as different users have varying priorities. Some may focus on accurate predictions of currents, while others prioritize sea level or salinity forecasts. To accommodate these diverse needs, OceanBench provides a comprehensive set of metrics. Please keep in mind that these metrics capture key aspects of forecast quality rather than the complete picture.

Want to evaluate your system or get involved in OceanBench? Check out the [GitHub project!](#)

Comparison to reanalysis

| | Sea Surface Height | | | | Zonal current [0-49m] | | | | Meridional current [0-49m] | | | Salinity [0-49m] | | | Temperature [0-49m] | | | | | | | | | | |
|--------|--------------------|-------|-------|-------|-----------------------|-------|-------|-------|----------------------------|-------|-------|------------------|-------|-------|---------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| | RMSE (m) | | | | RMSE (m/s) | | | | RMSE (m/s) | | | RMSE (psu) | | | RMSE (C) | | | | | | | | | | |
| GLO12 | 0.069 | 0.070 | 0.073 | 0.077 | 0.082 | 0.114 | 0.119 | 0.126 | 0.134 | 0.145 | 0.113 | 0.118 | 0.124 | 0.132 | 0.143 | 0.729 | 0.728 | 0.729 | 0.732 | 0.737 | 0.545 | 0.553 | 0.568 | 0.591 | 0.635 |
| GLONET | 0.075 | 0.077 | 0.081 | 0.084 | 0.089 | | | | | | | | | | | | | | | | | | | | |
| WERRM | 0.134 | 0.129 | 0.124 | 0.119 | 0.117 | | | | | | | | | | | | | | | | | | | | |
| XRHE | 0.079 | 0.084 | 0.085 | 0.089 | 0.091 | | | | | | | | | | | | | | | | | | | | |

Github Project



mercator-ocean / oceanbench

<> Code Issues 10 Pull requests

8 stars 2 forks 3 watching 9 followers

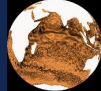
Custom properties

Public repository

main

Models-to-Analysis

Models-to-Reanalysis



| Sea Surface Height | | | | | | | | | | | | |
|--------------------|----------|-------|-------|-------|-------|--|--|--|--|--|--|--|
| | RMSE (m) | | | | | | | | | | | |
| GLO12 | 0.069 | 0.070 | 0.073 | 0.077 | 0.082 | | | | | | | |
| GLONET | 0.075 | 0.077 | 0.081 | 0.084 | 0.089 | | | | | | | |
| WENHAI | 0.114 | 0.126 | 0.134 | 0.136 | 0.131 | | | | | | | |
| XIHE | 0.079 | 0.084 | 0.085 | 0.088 | 0.091 | | | | | | | |

| Zonal current [0-49m] | | | | | Meridional current [0-49m] | | | | | Salinity [0-49m] | | | | | Temperature [0-49m] | | | | | | | | | | | | | | | |
|-----------------------|------------|-------|-------|-------|----------------------------|-------|-------|-------|-------|------------------|------------|-------|-------|-------|---------------------|-------|-------|-------|-------|-------|-----------|-------|-------|-------|-------|--|--|--|--|--|
| | RMSE (m/s) | | | | | | | | | | RMSE (psu) | | | | | | | | | | RMSE (°C) | | | | | | | | | |
| GLO12 | 0.114 | 0.119 | 0.126 | 0.134 | 0.145 | 0.113 | 0.118 | 0.124 | 0.132 | 0.143 | 0.729 | 0.728 | 0.729 | 0.732 | 0.737 | 0.545 | 0.553 | 0.568 | 0.591 | 0.635 | 0.729 | 0.728 | 0.729 | 0.732 | 0.737 | | | | | |

| Zonal current [50m] | | | | | Meridional current [50m] | | | | | Salinity [50m] | | | | | Temperature [50m] | | | | | | | | | | | | | | | |
|---------------------|------------|-------|-------|-------|--------------------------|-------|-------|-------|-------|----------------|------------|-------|-------|-------|-------------------|-------|-------|-------|-------|-------|-----------|-------|-------|-------|-------|--|--|--|--|--|
| | RMSE (m/s) | | | | | | | | | | RMSE (psu) | | | | | | | | | | RMSE (°C) | | | | | | | | | |
| GLO12 | 0.111 | 0.114 | 0.119 | 0.124 | 0.131 | 0.109 | 0.113 | 0.118 | 0.123 | 0.130 | 0.366 | 0.366 | 0.367 | 0.368 | 0.369 | 0.830 | 0.836 | 0.845 | 0.860 | 0.880 | 0.366 | 0.366 | 0.367 | 0.368 | 0.369 | | | | | |

| Zonal current [100m] | | | | | Meridional current [100m] | | | | | Salinity [100m] | | | | | Temperature [100m] | | | | | | | | | | | | | | | |
|----------------------|------------|-------|-------|-------|---------------------------|-------|-------|-------|-------|-----------------|------------|-------|-------|-------|--------------------|-------|-------|-------|-------|-------|-----------|-------|-------|-------|-------|--|--|--|--|--|
| | RMSE (m/s) | | | | | | | | | | RMSE (psu) | | | | | | | | | | RMSE (°C) | | | | | | | | | |
| GLO12 | 0.110 | 0.113 | 0.117 | 0.121 | 0.127 | 0.107 | 0.110 | 0.114 | 0.119 | 0.125 | 0.225 | 0.226 | 0.226 | 0.227 | 0.229 | 0.932 | 0.937 | 0.947 | 0.963 | 0.985 | 0.225 | 0.226 | 0.226 | 0.227 | 0.229 | | | | | |

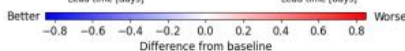
| Zonal current [200m] | | | | | Meridional current [200m] | | | | | Salinity [200m] | | | | | Temperature [200m] | | | | | | | | | | | | | | | |
|----------------------|------------|-------|-------|-------|---------------------------|-------|-------|-------|-------|-----------------|------------|-------|-------|-------|--------------------|-------|-------|-------|-------|-------|-----------|-------|-------|-------|-------|--|--|--|--|--|
| | RMSE (m/s) | | | | | | | | | | RMSE (psu) | | | | | | | | | | RMSE (°C) | | | | | | | | | |
| GLO12 | 0.107 | 0.110 | 0.112 | 0.115 | 0.120 | 0.103 | 0.105 | 0.109 | 0.111 | 0.116 | 0.149 | 0.149 | 0.150 | 0.151 | 0.153 | 0.800 | 0.807 | 0.816 | 0.830 | 0.848 | 0.149 | 0.149 | 0.150 | 0.151 | 0.153 | | | | | |

| Zonal current [300m] | | | | | Meridional current [300m] | | | | | Salinity [300m] | | | | | Temperature [300m] | | | | | | | | | | | | | | | |
|----------------------|------------|-------|-------|-------|---------------------------|-------|-------|-------|-------|-----------------|------------|-------|-------|-------|--------------------|-------|-------|-------|-------|-------|-----------|-------|-------|-------|-------|--|--|--|--|--|
| | RMSE (m/s) | | | | | | | | | | RMSE (psu) | | | | | | | | | | RMSE (°C) | | | | | | | | | |
| GLO12 | 0.103 | 0.105 | 0.107 | 0.110 | 0.113 | 0.100 | 0.102 | 0.104 | 0.107 | 0.111 | 0.110 | 0.117 | 0.118 | 0.119 | 0.121 | 0.679 | 0.686 | 0.696 | 0.709 | 0.727 | 0.110 | 0.110 | 0.111 | 0.112 | 0.113 | | | | | |

| Zonal current [500m] | | | | | Meridional current [500m] | | | | | Salinity [500m] | | | | | Temperature [500m] | | | | | | | | | | | | | | | |
|----------------------|------------|-------|-------|-------|---------------------------|-------|-------|-------|-------|-----------------|------------|-------|-------|-------|--------------------|-------|-------|-------|-------|-------|-----------|-------|-------|-------|-------|--|--|--|--|--|
| | RMSE (m/s) | | | | | | | | | | RMSE (psu) | | | | | | | | | | RMSE (°C) | | | | | | | | | |
| GLO12 | 0.094 | 0.095 | 0.097 | 0.099 | 0.102 | 0.091 | 0.093 | 0.094 | 0.097 | 0.100 | 0.085 | 0.085 | 0.086 | 0.087 | 0.088 | 0.508 | 0.513 | 0.521 | 0.532 | 0.547 | 0.094 | 0.095 | 0.097 | 0.099 | 0.102 | | | | | |

Forecasted variables.

| Zonal geostrophic current | | | | | Meridional geostrophic current | | | | | Mixed Layer Depth | | | | | Lagrangian trajectory | | | | | | | | | | | | | | | |
|---------------------------|------------|-------|-------|-------|--------------------------------|-------|-------|-------|-------|-------------------|----------|--------|--------|--------|-----------------------|--------|--------|--------|--------|--------|---------|-------|-------|-------|-------|--|--|--|--|--|
| | RMSE (m/s) | | | | | | | | | | RMSE (m) | | | | | | | | | | L2 (km) | | | | | | | | | |
| GLO12 | 0.199 | 0.205 | 0.208 | 0.209 | 0.217 | 0.173 | 0.177 | 0.180 | 0.185 | 0.189 | 41.511 | 41.344 | 41.588 | 42.001 | 43.219 | 10.390 | 20.340 | 38.788 | 55.874 | 72.132 | 0.199 | 0.205 | 0.208 | 0.209 | 0.217 | | | | | |



Models-to-Observation



| Temperature [0-5m] | | | | | Salinity [0-5m] | | | | | |
|--------------------|-----------|-------|-------|-------|-----------------|-------|-------|-------|-------|-------|
| | RMSE (°C) | | | | RMSE (psu) | | | | | |
| GLO12 | 0.588 | 0.622 | 0.647 | 0.679 | 0.723 | 0.242 | 0.253 | 0.265 | 0.277 | 0.290 |
| GLONET | 0.637 | 0.733 | 0.753 | 0.875 | 0.920 | 0.226 | 0.293 | 0.256 | 0.286 | 0.289 |
| WENHAI | 0.549 | 0.719 | 0.912 | 1.095 | 1.270 | 0.229 | 0.268 | 0.273 | 0.310 | 0.289 |
| XIHE | 0.575 | 0.654 | 0.660 | 0.674 | 0.782 | 0.225 | 0.290 | 0.244 | 0.254 | 0.270 |

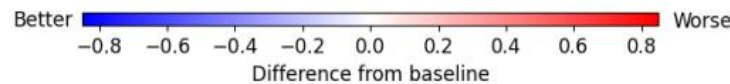
| Temperature [5-100m] | | | | | Salinity [5-100m] | | | | | |
|----------------------|-----------|-------|-------|-------|-------------------|-------|-------|-------|-------|-------|
| | RMSE (°C) | | | | RMSE (psu) | | | | | |
| GLO12 | 0.928 | 0.964 | 1.000 | 1.031 | 1.072 | 0.211 | 0.218 | 0.223 | 0.230 | 0.239 |
| GLONET | 1.077 | 1.141 | 1.181 | 1.266 | 1.325 | 0.214 | 0.241 | 0.262 | 0.253 | 0.260 |
| WENHAI | 0.875 | 0.927 | 1.033 | 1.095 | 1.175 | 0.195 | 0.368 | 0.428 | 0.389 | 0.369 |
| XIHE | 0.886 | 0.932 | 0.970 | 0.973 | 1.026 | 0.194 | 0.213 | 0.213 | 0.207 | 0.228 |

| Temperature [100-300m] | | | | | Salinity [100-300m] | | | | | |
|------------------------|-----------|-------|-------|-------|---------------------|-------|-------|-------|-------|-------|
| | RMSE (°C) | | | | RMSE (psu) | | | | | |
| GLO12 | 0.859 | 0.892 | 0.928 | 0.965 | 0.996 | 0.148 | 0.152 | 0.157 | 0.161 | 0.165 |
| GLONET | 0.845 | 0.867 | 0.889 | 0.928 | 0.961 | 0.141 | 0.141 | 0.153 | 0.155 | 0.155 |
| WENHAI | 0.815 | 0.848 | 0.879 | 0.891 | 0.953 | 0.139 | 0.392 | 0.336 | 0.352 | 0.396 |
| XIHE | 0.798 | 0.794 | 0.823 | 0.803 | 0.839 | 0.130 | 0.130 | 0.136 | 0.132 | 0.136 |

| Temperature [300-600m] | | | | | Salinity [300-600m] | | | | | |
|------------------------|-----------|-------|-------|-------|---------------------|-------|-------|-------|-------|-------|
| | RMSE (°C) | | | | RMSE (psu) | | | | | |
| GLO12 | 0.604 | 0.632 | 0.663 | 0.694 | 0.724 | 0.098 | 0.102 | 0.105 | 0.109 | 0.113 |
| GLONET | 0.584 | 0.567 | 0.588 | 0.610 | 0.639 | 0.090 | 0.094 | 0.097 | 0.105 | 0.109 |
| WENHAI | 0.591 | 0.644 | 0.654 | 0.676 | 0.703 | 0.101 | 0.573 | 0.501 | 0.555 | 0.569 |
| XIHE | 0.547 | 0.537 | 0.560 | 0.568 | 0.599 | 0.085 | 0.084 | 0.084 | 0.088 | 0.090 |

| SST | | | | | SLA | | | | | |
|--------|-----------|-------|-------|-------|----------|-------|-------|-------|-------|-------|
| | RMSE (°C) | | | | RMSE (m) | | | | | |
| GLO12 | 0.641 | 0.670 | 0.706 | 0.747 | 0.810 | 0.063 | 0.067 | 0.071 | 0.075 | 0.080 |
| GLONET | 0.600 | 0.740 | 0.821 | 0.901 | 0.962 | 0.056 | 0.055 | 0.057 | 0.061 | 0.066 |
| WENHAI | 0.629 | 0.864 | 1.123 | 1.387 | 1.624 | 0.112 | 0.112 | 0.114 | 0.116 | 0.118 |
| XIHE | 0.775 | 0.839 | 0.900 | 0.868 | 0.936 | 0.059 | 0.059 | 0.060 | 0.064 | 0.066 |

| uo [15m] | | | | | vo [15m] | | | | | |
|----------|------------|-------|-------|-------|------------|-------|-------|-------|-------|-------|
| | RMSE (m/s) | | | | RMSE (m/s) | | | | | |
| GLO12 | 0.167 | 0.173 | 0.179 | 0.184 | 0.189 | 0.157 | 0.164 | 0.170 | 0.176 | 0.181 |
| GLONET | 0.142 | 0.148 | 0.148 | 0.152 | 0.157 | 0.130 | 0.134 | 0.138 | 0.140 | 0.144 |
| WENHAI | 0.163 | 0.165 | 0.166 | 0.171 | 0.175 | 0.145 | 0.148 | 0.152 | 0.155 | 0.159 |
| XIHE | 0.159 | 0.158 | 0.158 | 0.157 | 0.159 | 0.145 | 0.143 | 0.145 | 0.143 | 0.144 |



| [0.49m] | | | | | Temperature [0.49m] | | | | |
|---------|------------|-------|-------|-------|---------------------|-------|-------|-------|--|
| | RMSE (psu) | | | | RMSE (°C) | | | | |
| GLO12 | 0.122 | 0.168 | 0.223 | 0.107 | 0.167 | 0.255 | 0.352 | 0.472 | |
| GLONET | 0.255 | 0.300 | 0.348 | 0.389 | 0.485 | 0.596 | 0.711 | 0.813 | |
| WENHAI | 0.311 | 0.340 | 0.373 | 0.218 | 0.452 | 0.652 | 0.841 | 0.886 | |
| XIHE | 0.303 | 0.344 | 0.397 | 0.440 | 0.452 | 0.519 | 0.551 | 0.643 | |

| [50m] | | | | | Temperature [50m] | | | | |
|--------|------------|-------|-------|-------|-------------------|-------|-------|-------|--|
| | RMSE (psu) | | | | RMSE (°C) | | | | |
| GLO12 | 0.067 | 0.089 | 0.115 | 0.163 | 0.223 | 0.323 | 0.437 | 0.553 | |
| GLONET | 0.162 | 0.196 | 0.205 | 0.222 | 0.254 | 0.328 | 0.398 | 0.434 | |
| WENHAI | 0.100 | 0.120 | 0.142 | 0.227 | 0.370 | 0.490 | 0.601 | 0.723 | |
| XIHE | 0.120 | 0.129 | 0.132 | 0.503 | 0.530 | 0.603 | 0.626 | 0.736 | |

| [100m] | | | | | Temperature [100m] | | | | |
|--------|------------|-------|-------|-------|--------------------|-------|-------|-------|--|
| | RMSE (psu) | | | | RMSE (°C) | | | | |
| GLO12 | 0.056 | 0.075 | 0.096 | 0.176 | 0.238 | 0.342 | 0.461 | 0.583 | |
| GLONET | 0.121 | 0.137 | 0.151 | 0.523 | 0.598 | 0.706 | 0.820 | 0.896 | |
| WENHAI | 0.084 | 0.101 | 0.119 | 0.229 | 0.363 | 0.485 | 0.597 | 0.725 | |
| XIHE | 0.108 | 0.114 | 0.118 | 0.501 | 0.524 | 0.587 | 0.634 | 0.716 | |

| [200m] | | | | | Temperature [200m] | | | | |
|--------|------------|-------|-------|-------|--------------------|-------|-------|-------|--|
| | RMSE (psu) | | | | RMSE (°C) | | | | |
| GLO12 | 0.044 | 0.059 | 0.076 | 0.130 | 0.182 | 0.268 | 0.369 | 0.473 | |
| GLONET | 0.083 | 0.095 | 0.107 | 0.320 | 0.443 | 0.502 | 0.567 | 0.662 | |
| WENHAI | 0.067 | 0.080 | 0.095 | 0.170 | 0.273 | 0.360 | 0.447 | 0.542 | |
| XIHE | 0.070 | 0.078 | 0.083 | 0.389 | 0.358 | 0.414 | 0.470 | 0.503 | |

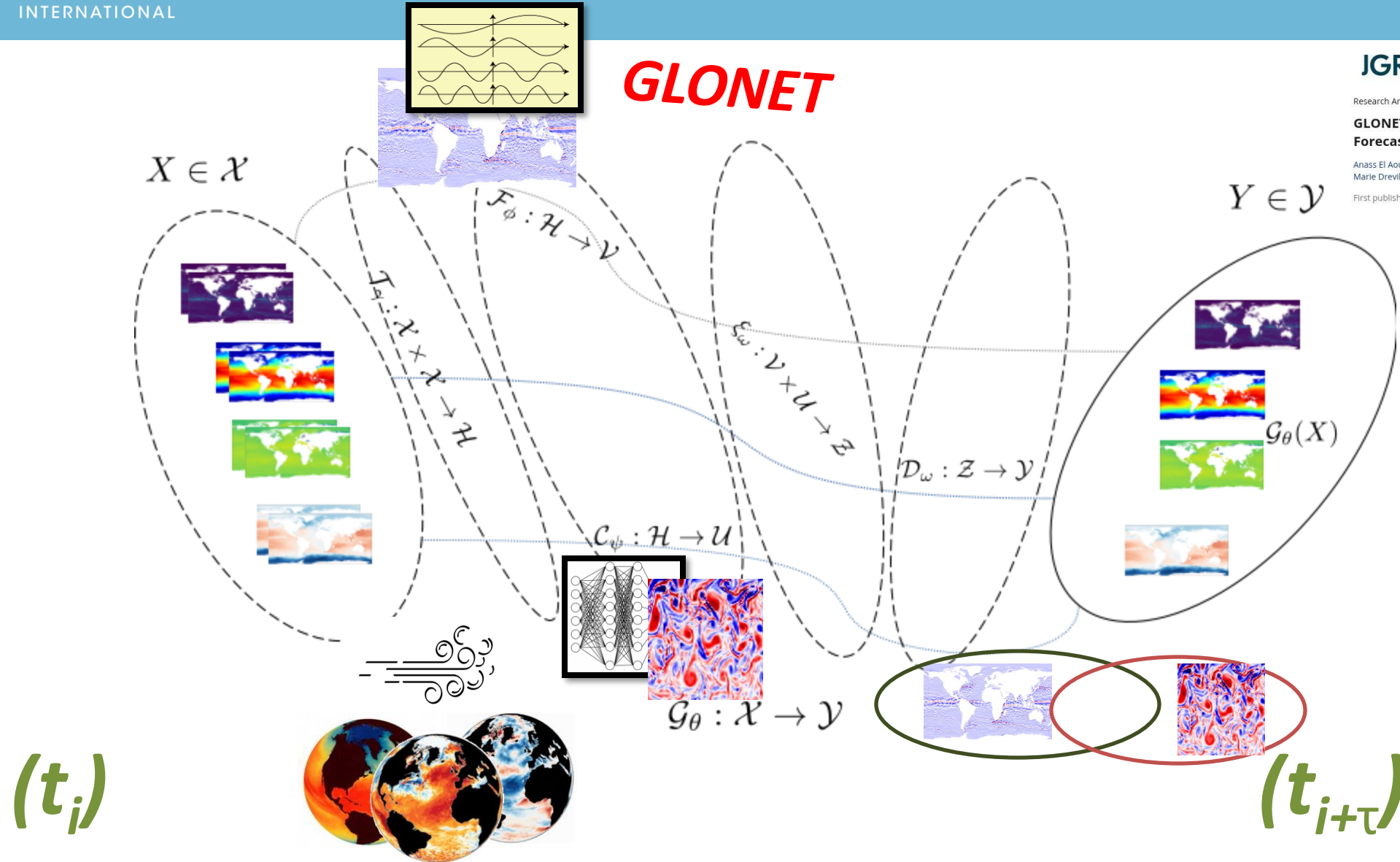
| [300m] | | | | | Temperature [300m] | | | | |
|--------|------------|-------|-------|-------|--------------------|-------|-------|-------|--|
| | RMSE (psu) | | | | RMSE (°C) | | | | |
| GLO12 | 0.037 | 0.050 | 0.065 | 0.108 | 0.155 | 0.232 | 0.321 | 0.415 | |
| GLONET | 0.072 | 0.081 | 0.091 | 0.236 | 0.368 | 0.424 | 0.474 | 0.554 | |
| WENHAI | 0.058 | 0.069 | 0.082 | 0.144 | 0.236 | 0.312 | 0.387 | 0.469 | |
| XIHE | 0.059 | 0.066 | 0.071 | 0.346 | 0.305 | 0.358 | 0.402 | 0.436 | |

| [500m] | | | | | Temperature [500m] | | | | |
|--------|------------|-------|-------|-------|--------------------|-------|-------|-------|--|
| | RMSE (psu) | | | | RMSE (°C) | | | | |
| GLO12 | 0.027 | 0.037 | 0.049 | 0.082 | 0.119 | 0.180 | 0.251 | 0.327 | |
| GLONET | 0.055 | 0.063 | 0.071 | 0.195 | 0.247 | 0.297 | 0.350 | 0.409 | |
| WENHAI | 0.047 | 0.055 | 0.065 | 0.113 | 0.194 | 0.255 | 0.314 | 0.378 | |
| XIHE | 0.046 | 0.051 | 0.054 | 0.288 | 0.238 | 0.282 | 0.309 | 0.332 | |

| Layer Depth | | | | | Lagrangian trajectory | | | | |
|-------------|----------|--------|--------|-------|-----------------------|--------|--------|--------|--|
| | RMSE (m) | | | | L2 (km) | | | | |
| GLO12 | 22.269 | 25.713 | 30.102 | 2.010 | 4.451 | 11.992 | 20.464 | 31.282 | |
| GLONET | 51.121 | 54.864 | 58.712 | 4.220 | 8.244 | 17.205 | 28.660 | 42.114 | |
| WENHAI | 38.536 | 42.753 | 47.984 | 7.605 | 15.685 | 33.070 | 52.283 | 67.850 | |
| XIHE | 52.083 | 57.407 | 60.654 | 5.138 | 10.560 | 21.689 | 33.869 | 46.732 | |



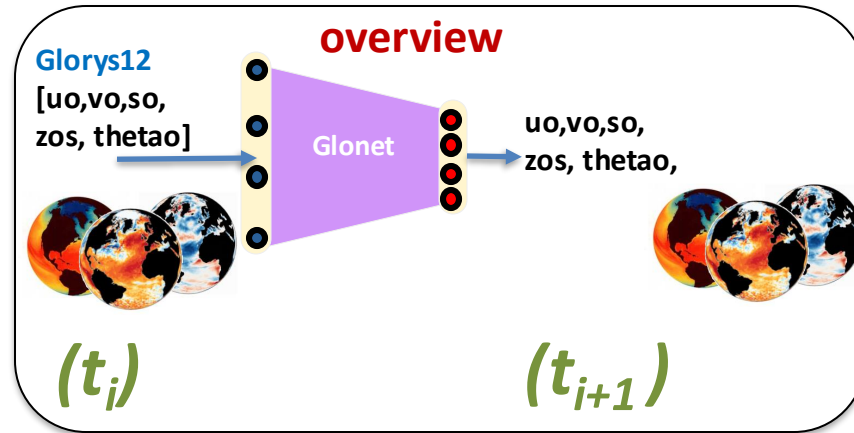
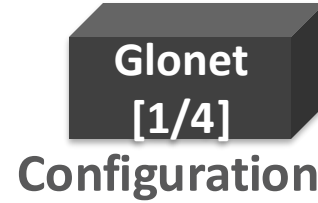
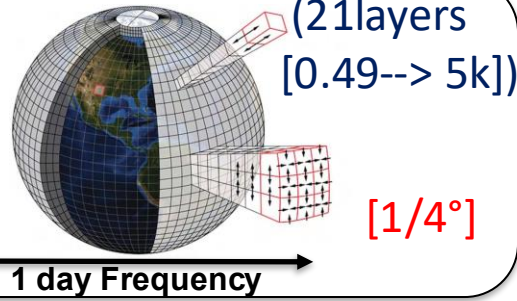
RESULTS



GLORY12

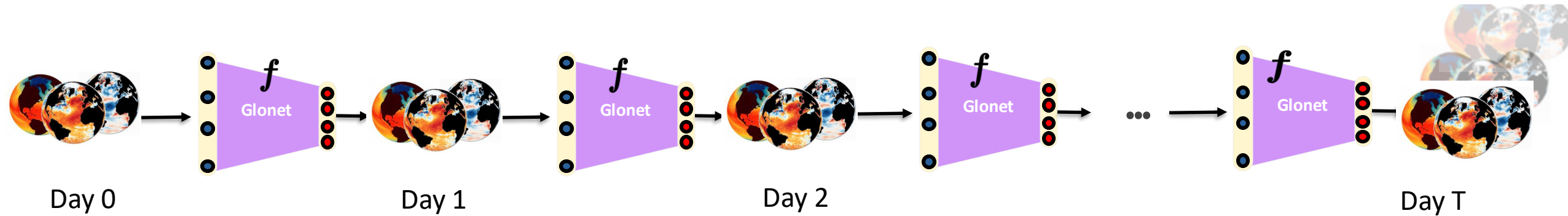
- Training [1993, 2020]
- Validation [2021]
- Testing [GLO12]

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



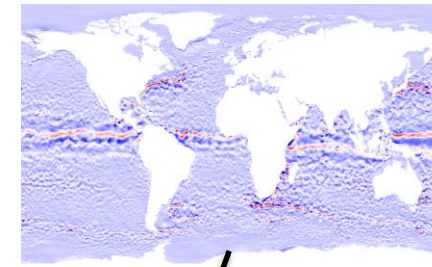
Training

- RMSE over one step
- Finetune over 4 steps rollout (accumulated RMSE)

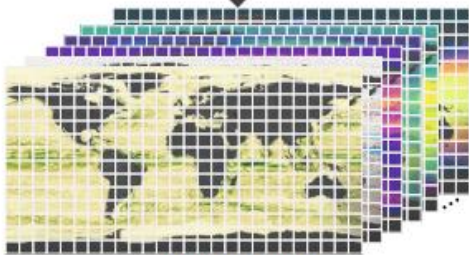
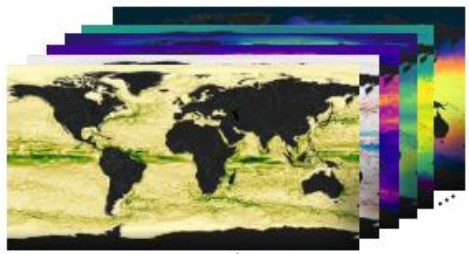




global dependencies

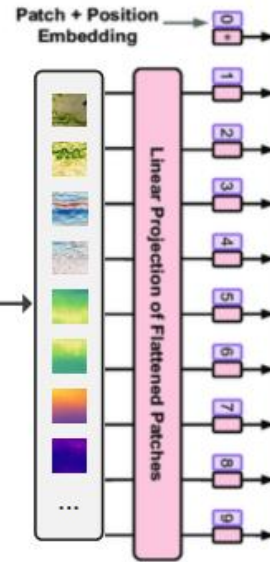


Patch Partition



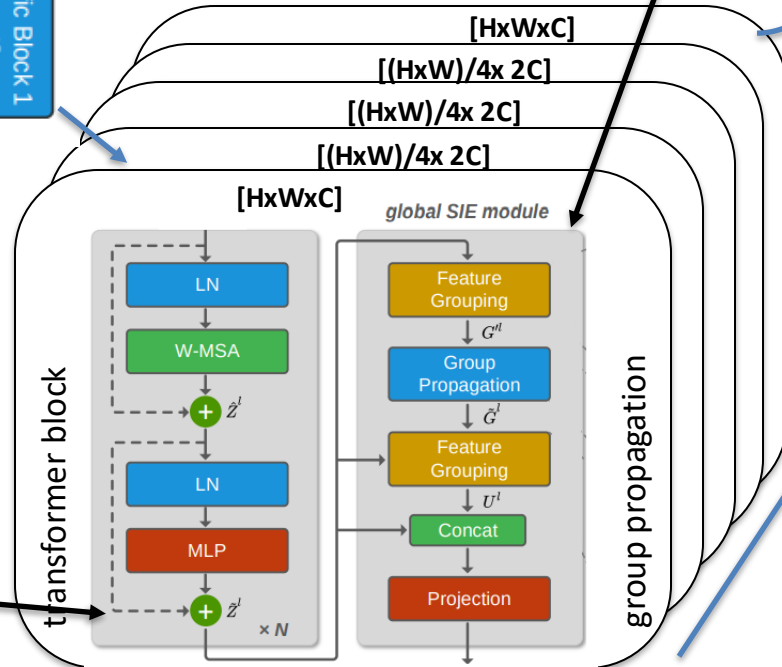
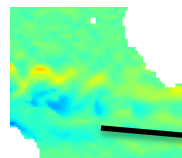
Input variables

GLORYS12 dataset: Temperature, Salinity, uo, vo with 23 layers, SSH
ERA5 dataset: U10, V10 OSTIA dataset: SST



Ocean-Specific Block 1
[H' x W' x C]

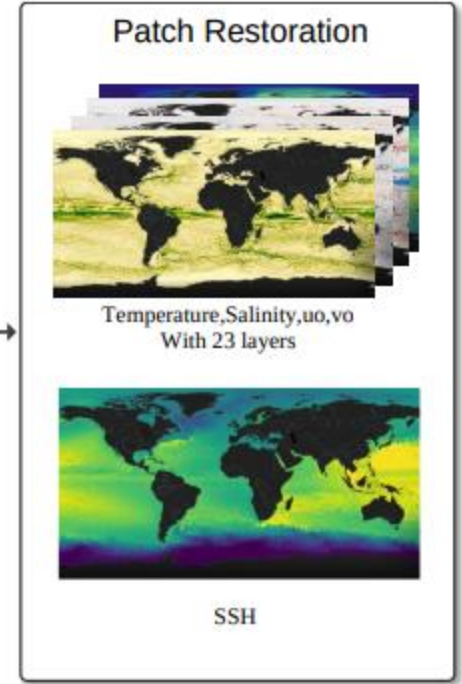
local dependencies



arXiv > physics > arXiv:2402.02995

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

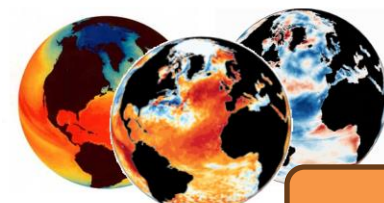
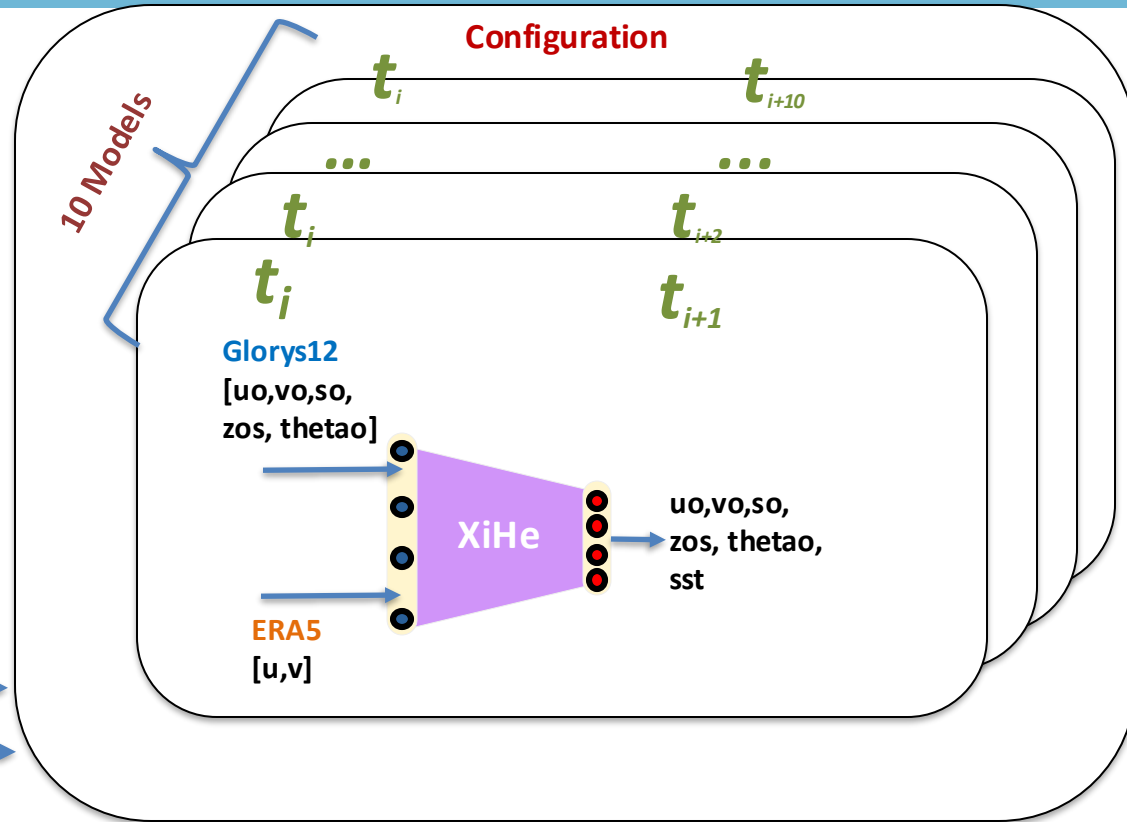
Xiang Wang, Renzhi Wang, Ningzi Hu, Pingqiang Wang, Peng Huo, Guihua Wang, Huizan Wang, Senzhang Wang, Junxing Zhu, Jianbo Xu, Jun Yin, Senliang Bao, Ciqiang Luo, Ziqing Zu, Yi Han, Weimin Zhang, Kaijun Ren, Kefeng Deng, Junqiang Song



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]

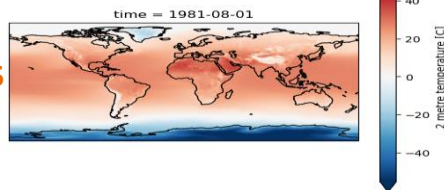
Training Setup



Glory12
[uo,vo,so,
zos, thetAo]

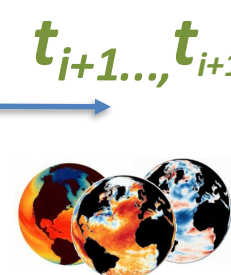
23 levels

ERA5
[u,v]



Training

- RMSE to produce t+1
- Finetune separate checkpoints for t+1, t+2 .. t+10



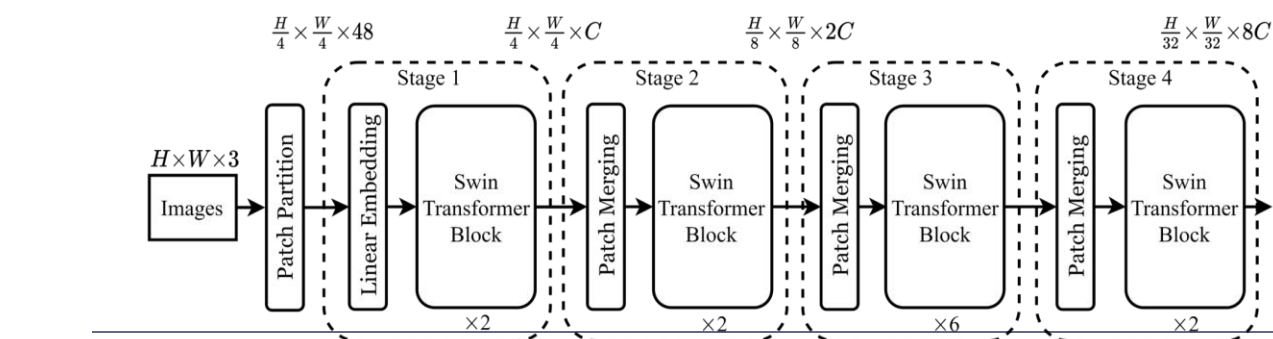
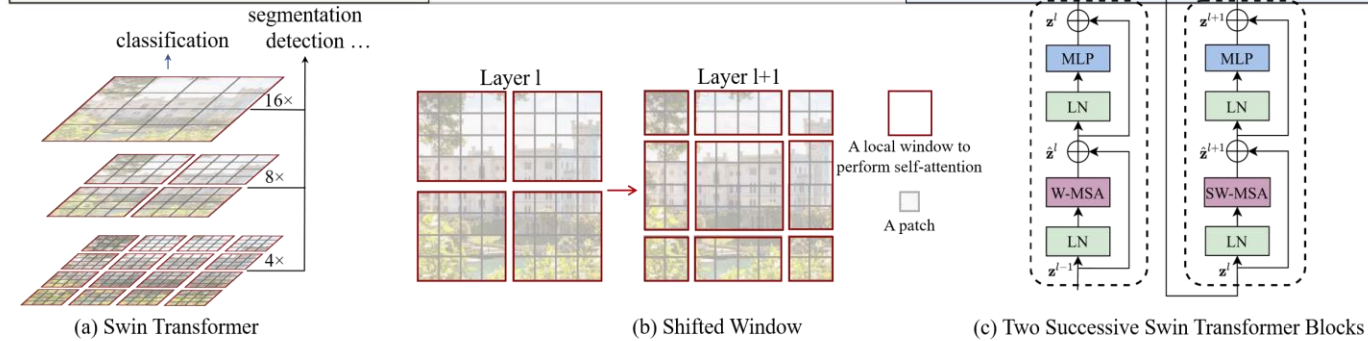
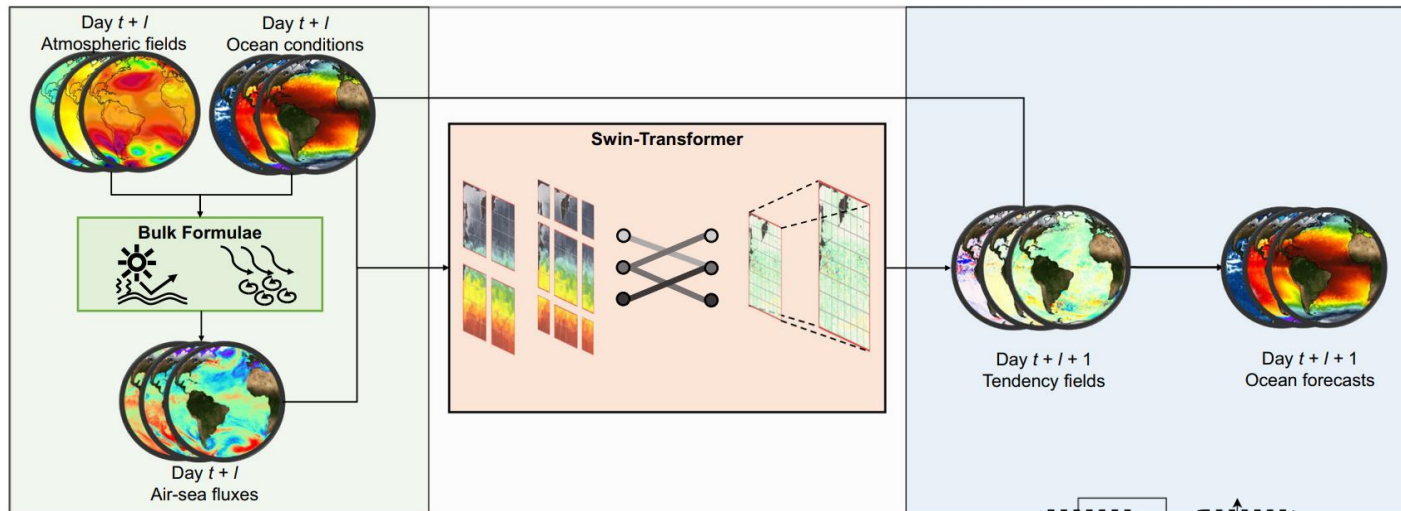
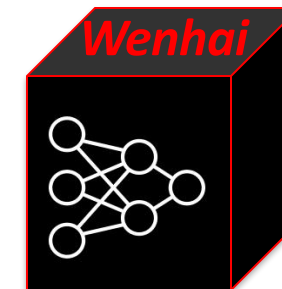
Xihe
[uo,vo,so,
zos, thetAo]

Article | [Open access](#) | Published: 06 March 2025

Forecasting the eddying ocean with a deep neural network

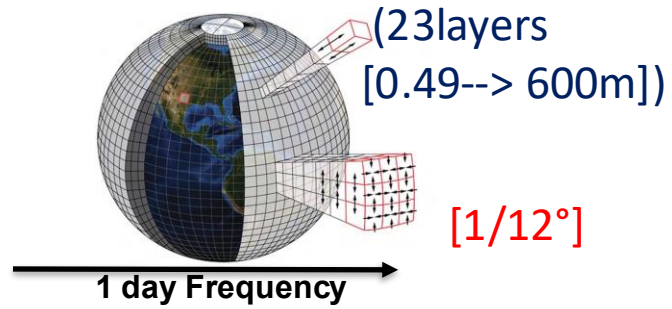
[Yingzhe Cui](#), [Ruohan Wu](#), [Xiang Zhang](#), [Ziqi Zhu](#), [Bo Liu](#), [Jun Shi](#), [Junshi Chen](#), [Hailong Liu](#), [Shenghui Zhou](#), [Liang Su](#), [Zhao Jing](#) ✉, [Hong An](#) ✉ & [Lixin Wu](#) ✉

Nature Communications **16**, Article number: 2268 (2025) | [Cite this article](#)



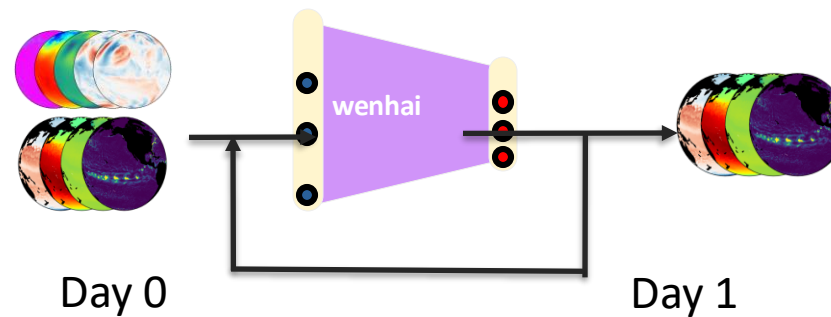
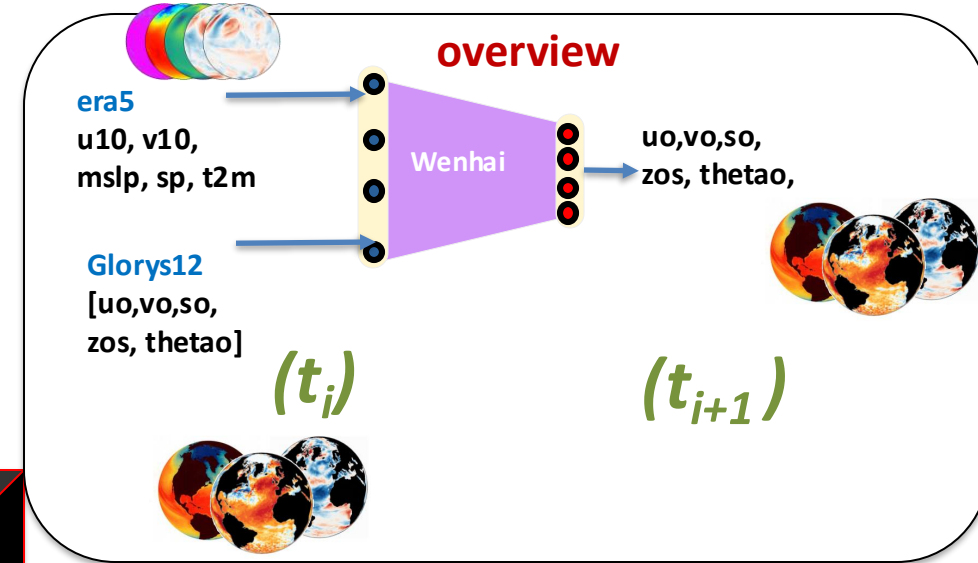
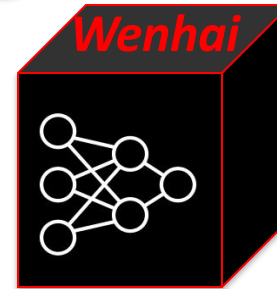
(d) Architecture

- **GLORY12** [zos][thetao, uo,vo, so]
 - Training [1993, 2020]
- ERA5 [u10, v10, mslp, sp, t2m]
 - Training [1993, 2020]

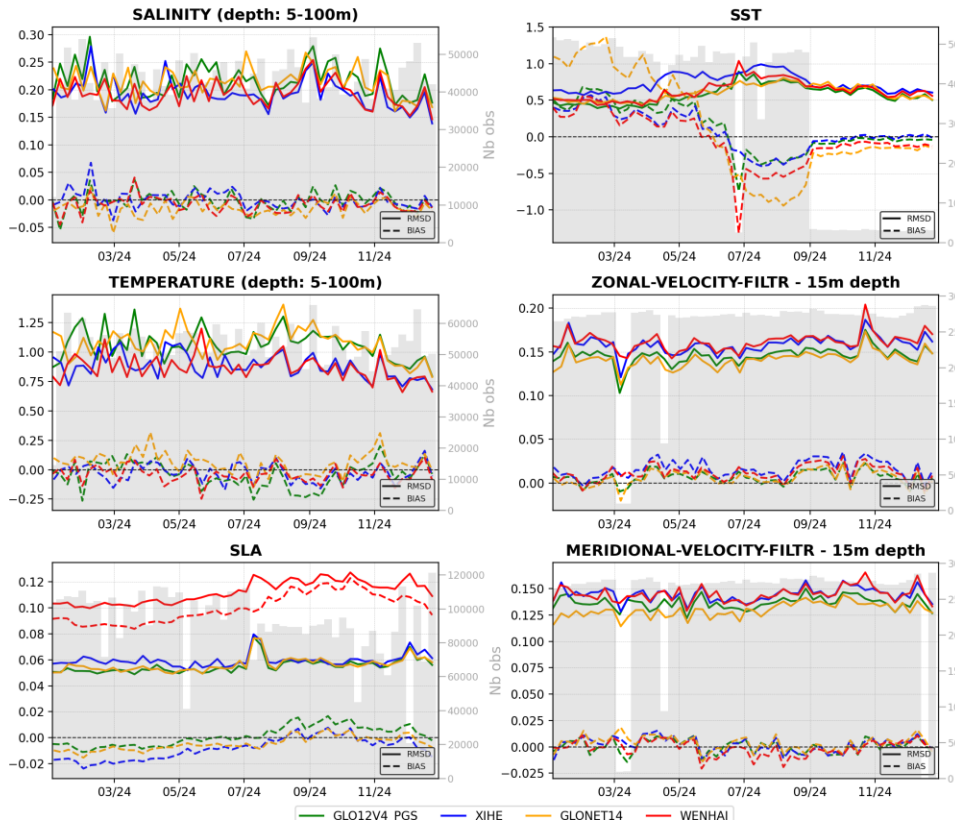


Training

- Weighted MAE over one step
- Finetune over 5 steps rollout (accumulated)



Full Domain - FCST1D



Forecasted variables

| Models | Temperature RMSE (°C) <small>sea_water_potential_temperature</small> | | | | | Salinity RMSE (PSU) <small>sea_water_salinity</small> | | | | | |
|-----------------|--|------|------|------|------|---|------|------|------|------|----|
| | Lead days | 1 | 3 | 5 | 7 | 10 | 1 | 3 | 5 | 7 | 10 |
| 0-5m | | | | | | | | | | | |
| <u>GLO12</u> | 0.59 | 0.62 | 0.65 | 0.68 | 0.72 | 0.24 | 0.25 | 0.27 | 0.28 | 0.29 | |
| <u>GLONET</u> | 0.64 | 0.73 | 0.75 | 0.88 | 0.92 | 0.23 | 0.29 | 0.26 | 0.29 | 0.29 | |
| <u>WenHai</u> | 0.55 | 0.72 | 0.91 | 1.09 | 1.27 | 0.23 | 0.27 | 0.27 | 0.31 | 0.29 | |
| <u>XiHe</u> | 0.57 | 0.65 | 0.66 | 0.67 | 0.78 | 0.23 | 0.29 | 0.24 | 0.25 | 0.27 | |
| 5-100m | | | | | | | | | | | |
| <u>GLO12</u> | 0.93 | 0.96 | 1.00 | 1.03 | 1.07 | 0.21 | 0.22 | 0.22 | 0.23 | 0.24 | |
| <u>GLONET</u> | 1.08 | 1.14 | 1.18 | 1.27 | 1.32 | 0.21 | 0.24 | 0.26 | 0.25 | 0.26 | |
| <u>WenHai</u> | 0.88 | 0.93 | 1.03 | 1.09 | 1.18 | 0.20 | 0.37 | 0.43 | 0.39 | 0.37 | |
| <u>XiHe</u> | 0.89 | 0.93 | 0.97 | 0.97 | 1.03 | 0.19 | 0.21 | 0.21 | 0.21 | 0.23 | |
| 100-300m | | | | | | | | | | | |
| <u>GLO12</u> | 0.86 | 0.89 | 0.93 | 0.96 | 1.00 | 0.15 | 0.15 | 0.16 | 0.16 | 0.17 | |
| <u>GLONET</u> | 0.84 | 0.87 | 0.89 | 0.93 | 0.96 | 0.14 | 0.14 | 0.15 | 0.15 | 0.15 | |
| <u>WenHai</u> | 0.81 | 0.85 | 0.88 | 0.89 | 0.95 | 0.14 | 0.39 | 0.34 | 0.35 | 0.40 | |
| <u>XiHe</u> | 0.80 | 0.79 | 0.82 | 0.81 | 0.84 | 0.13 | 0.13 | 0.14 | 0.13 | 0.14 | |
| 300-600m | | | | | | | | | | | |
| <u>GLO12</u> | 0.60 | 0.63 | 0.66 | 0.69 | 0.72 | 0.10 | 0.10 | 0.10 | 0.11 | 0.11 | |
| <u>GLONET</u> | 0.58 | 0.57 | 0.59 | 0.61 | 0.64 | 0.09 | 0.09 | 0.10 | 0.10 | 0.11 | |
| <u>WenHai</u> | 0.59 | 0.64 | 0.65 | 0.68 | 0.70 | 0.10 | 0.57 | 0.50 | 0.56 | 0.57 | |
| <u>XiHe</u> | 0.55 | 0.54 | 0.56 | 0.57 | 0.60 | 0.09 | 0.08 | 0.08 | 0.09 | 0.09 | |

reference



| Models | Temperature RMSE (°C) <small>sea_surface_temperature</small> | | | | | Sea Surface Height RMSE (m) <small>sea_surface_height_above_geoid</small> | | | | | |
|---------------|--|------|------|------|------|---|------|------|------|------|----|
| | Lead days | 1 | 3 | 5 | 7 | 10 | 1 | 3 | 5 | 7 | 10 |
| <u>GLO12</u> | 0.64 | 0.67 | 0.71 | 0.75 | 0.81 | 0.06 | 0.07 | 0.07 | 0.07 | 0.08 | |
| <u>GLONET</u> | 0.60 | 0.74 | 0.82 | 0.90 | 0.96 | 0.06 | 0.06 | 0.06 | 0.06 | 0.07 | |
| <u>WenHai</u> | 0.63 | 0.86 | 1.12 | 1.39 | 1.62 | 0.11 | 0.11 | 0.11 | 0.12 | 0.12 | |
| <u>XiHe</u> | 0.78 | 0.84 | 0.90 | 0.87 | 0.94 | 0.06 | 0.06 | 0.06 | 0.06 | 0.07 | |

| Models | Zonal Current RMSE (m/s) <small>eastward_sea_water_velocity</small> | | | | | Meridional Current RMSE (m/s) <small>northward_sea_water_velocity</small> | | | | | |
|---------------|---|------|------|------|------|---|------|------|------|------|----|
| | Lead days | 1 | 3 | 5 | 7 | 10 | 1 | 3 | 5 | 7 | 10 |
| <u>GLO12</u> | 0.17 | 0.17 | 0.18 | 0.18 | 0.19 | 0.16 | 0.16 | 0.17 | 0.18 | 0.18 | |
| <u>GLONET</u> | 0.14 | 0.15 | 0.15 | 0.15 | 0.16 | 0.13 | 0.13 | 0.14 | 0.14 | 0.14 | |
| <u>WenHai</u> | 0.16 | 0.17 | 0.17 | 0.17 | 0.17 | 0.14 | 0.15 | 0.15 | 0.15 | 0.16 | |
| <u>XiHe</u> | 0.16 | 0.16 | 0.16 | 0.16 | 0.16 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | |

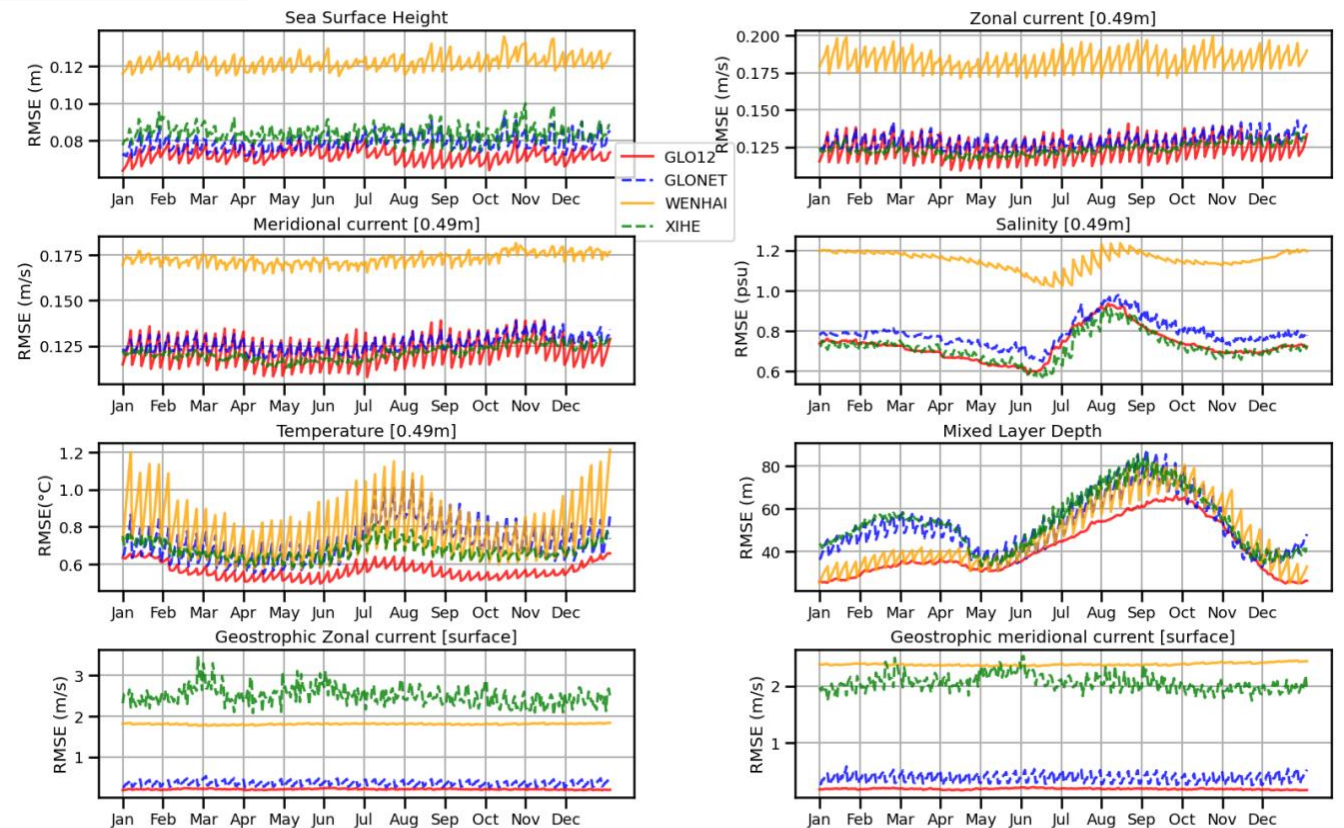
Forecasted variables

| Models | Temperature RMSE (°C) <small>sea_water_potential_temperature</small> | | | | | Salinity RMSE (PSU) <small>sea_water_salinity</small> | | | | | Zonal Current RMSE (m/s) <small>eastward_sea_water_velocity</small> | | | | | Meridional Current RMSE (m/s) <small>northward_sea_water_velocity</small> | | | | | Sea Surface Height RMSE (m) <small>sea_surface_height_above_geoid</small> | | | | |
|------------------------|--|------|------|------|------|---|------|------|------|------|---|------|------|------|------|---|------|------|------|------|---|------|------|------|------|
| | Lead days | 1 | 3 | 5 | 7 | 10 | 1 | 3 | 5 | 7 | 10 | 1 | 3 | 5 | 7 | 10 | 1 | 3 | 5 | 7 | 10 | 1 | 3 | 5 | 7 |
| Surface | | | | | | | | | | | | | | | | | | | | | | | | | |
| GLO12 | 0.55 | 0.55 | 0.57 | 0.59 | 0.64 | 0.73 | 0.73 | 0.73 | 0.73 | 0.74 | 0.11 | 0.12 | 0.13 | 0.13 | 0.14 | 0.11 | 0.12 | 0.12 | 0.13 | 0.14 | 0.07 | 0.07 | 0.07 | 0.08 | 0.08 |
| GLONET | 0.65 | 0.68 | 0.74 | 0.82 | 0.91 | 0.78 | 0.79 | 0.80 | 0.80 | 0.79 | 0.13 | 0.13 | 0.13 | 0.14 | 0.14 | 0.12 | 0.12 | 0.13 | 0.13 | 0.14 | 0.07 | 0.08 | 0.08 | 0.08 | 0.09 |
| WenHai | 0.64 | 0.72 | 0.83 | 0.96 | 1.14 | 1.17 | 1.15 | 1.15 | 1.14 | 1.13 | 0.17 | 0.18 | 0.19 | 0.19 | 0.20 | 0.17 | 0.17 | 0.17 | 0.17 | 0.18 | 0.12 | 0.12 | 0.12 | 0.13 | 0.13 |
| XiHe | 0.65 | 0.66 | 0.69 | 0.69 | 0.79 | 0.72 | 0.73 | 0.73 | 0.71 | 0.69 | 0.13 | 0.12 | 0.13 | 0.12 | 0.13 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.08 | 0.08 | 0.09 | 0.09 | 0.09 |
| 50m | | | | | | | | | | | | | | | | | | | | | | | | | |
| GLO12 | 0.83 | 0.84 | 0.84 | 0.86 | 0.88 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.11 | 0.11 | 0.12 | 0.12 | 0.13 | 0.11 | 0.11 | 0.12 | 0.12 | 0.13 | | | | | |
| GLONET | 0.95 | 0.98 | 1.03 | 1.10 | 1.26 | 0.36 | 0.37 | 0.37 | 0.38 | 0.39 | 0.11 | 0.11 | 0.11 | 0.12 | 0.12 | 0.11 | 0.11 | 0.11 | 0.12 | 0.12 | | | | | |
| WenHai | 0.97 | 0.97 | 0.98 | 1.00 | 1.03 | 1.10 | 1.10 | 1.10 | 1.10 | 1.10 | 0.15 | 0.15 | 0.15 | 0.16 | 0.17 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | | | | | |
| XiHe | 0.89 | 0.90 | 0.92 | 0.88 | 1.00 | 0.30 | 0.31 | 0.31 | 0.32 | 0.34 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | | | | | |
| 100m | | | | | | | | | | | | | | | | | | | | | | | | | |
| GLO12 | 0.93 | 0.94 | 0.95 | 0.96 | 0.98 | 0.23 | 0.23 | 0.23 | 0.23 | 0.23 | 0.11 | 0.11 | 0.12 | 0.12 | 0.13 | 0.11 | 0.11 | 0.11 | 0.12 | 0.13 | | | | | |
| GLONET | 1.01 | 1.03 | 1.06 | 1.11 | 1.22 | 0.25 | 0.25 | 0.25 | 0.26 | 0.26 | 0.11 | 0.11 | 0.11 | 0.11 | 0.12 | 0.11 | 0.10 | 0.10 | 0.11 | 0.11 | | | | | |
| WenHai | 1.04 | 1.04 | 1.05 | 1.06 | 1.08 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 0.14 | 0.14 | 0.14 | 0.15 | 0.15 | 0.14 | 0.14 | 0.14 | 0.14 | 0.14 | | | | | |
| XiHe | 0.96 | 0.99 | 0.99 | 1.00 | 1.06 | 0.23 | 0.23 | 0.23 | 0.23 | 0.24 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.10 | 0.10 | 0.10 | | | | | |
| 200m | | | | | | | | | | | | | | | | | | | | | | | | | |
| GLO12 | 0.80 | 0.81 | 0.82 | 0.83 | 0.85 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.11 | 0.11 | 0.11 | 0.12 | 0.12 | 0.10 | 0.10 | 0.11 | 0.11 | 0.12 | | | | | |
| GLONET | 0.87 | 0.88 | 0.89 | 0.90 | 0.94 | 0.16 | 0.16 | 0.16 | 0.16 | 0.17 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | | | | | |
| WenHai | 0.88 | 0.89 | 0.89 | 0.90 | 0.91 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.12 | 0.12 | 0.12 | 0.12 | 0.13 | | | | | |
| XiHe | 0.82 | 0.82 | 0.81 | 0.82 | 0.83 | 0.15 | 0.15 | 0.15 | 0.14 | 0.14 | 0.11 | 0.11 | 0.11 | 0.11 | 0.10 | 0.10 | 0.11 | 0.10 | 0.10 | 0.10 | | | | | |
| 300m | | | | | | | | | | | | | | | | | | | | | | | | | |
| GLO12 | 0.68 | 0.69 | 0.70 | 0.71 | 0.73 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.10 | 0.10 | 0.11 | 0.11 | 0.11 | 0.10 | 0.10 | 0.10 | 0.11 | 0.11 | | | | | |
| GLONET | 0.73 | 0.74 | 0.73 | 0.74 | 0.75 | 0.13 | 0.13 | 0.13 | 0.13 | 0.13 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | | | | | |
| WenHai | 0.75 | 0.74 | 0.74 | 0.75 | 0.76 | 0.93 | 0.93 | 0.92 | 0.92 | 0.92 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.11 | 0.11 | 0.12 | 0.12 | | | | | |
| XiHe | 0.70 | 0.69 | 0.69 | 0.68 | 0.69 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | | | | | |
| 500m | | | | | | | | | | | | | | | | | | | | | | | | | |
| GLO12 | 0.51 | 0.51 | 0.52 | 0.53 | 0.55 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.10 | 0.10 | 0.10 | 0.10 | 0.09 | 0.09 | 0.09 | 0.10 | 0.10 | | | | | |
| GLONET | 0.55 | 0.54 | 0.54 | 0.55 | 0.57 | 0.09 | 0.09 | 0.09 | 0.10 | 0.10 | 0.10 | 0.09 | 0.09 | 0.09 | 0.10 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | | | | | |
| WenHai | 0.56 | 0.56 | 0.56 | 0.56 | 0.57 | 0.81 | 0.81 | 0.81 | 0.81 | 0.81 | 0.10 | 0.10 | 0.10 | 0.10 | 0.11 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | | | | | |
| XiHe | 0.53 | 0.52 | 0.52 | 0.51 | 0.52 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.10 | 0.10 | 0.10 | 0.10 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | | | | | |

vs GLORYS12

Physically consistent diagnostic variables

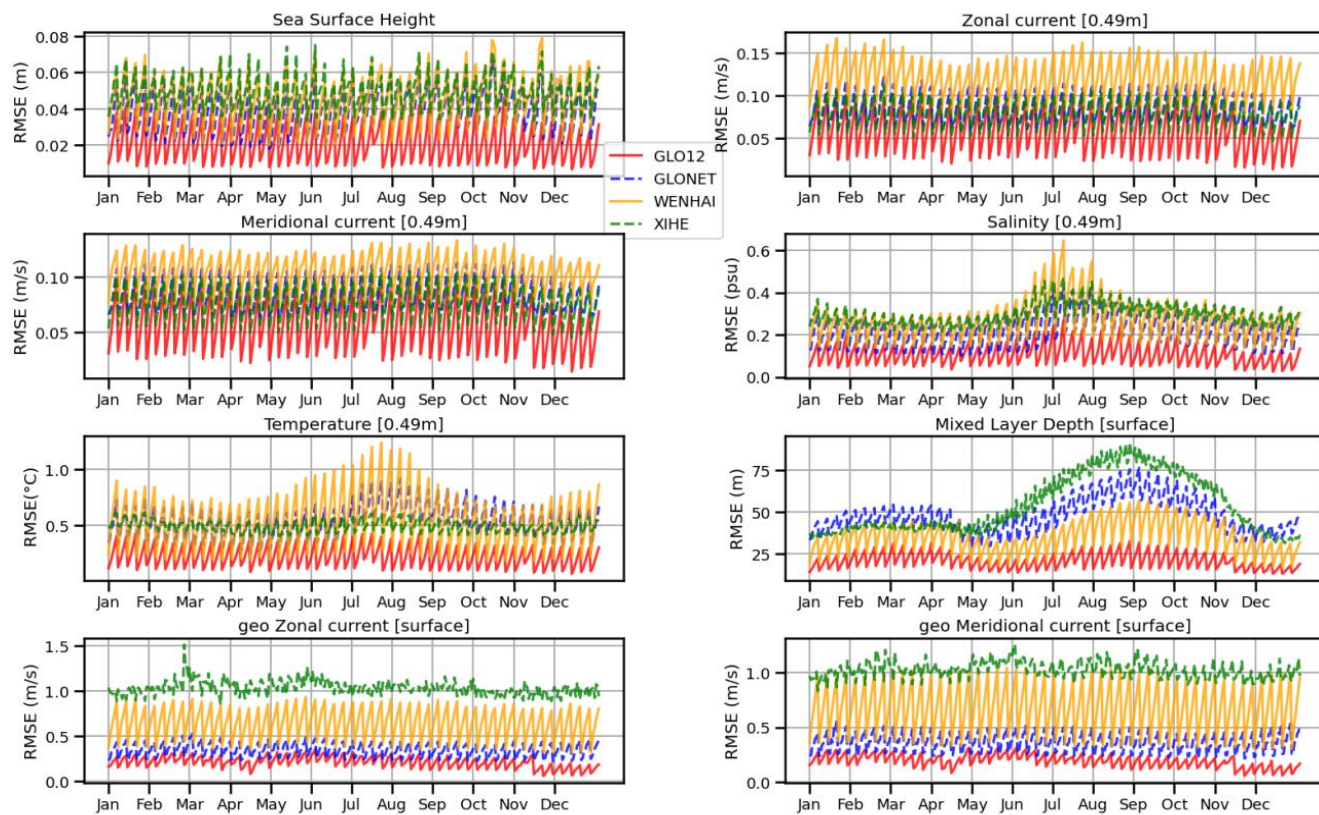
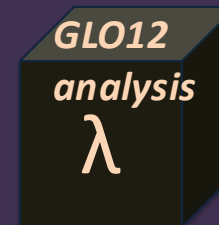
| Models | Mixed Layer Depth RMSE (m) <small>ocean_mixed_layer_thickness</small> | | | | | Meridional Geostrophic Current RMSE (m/s) <small>geostrophic_northward_sea_water_velocity</small> | | | | | Zonal Geostrophic Current RMSE (m/s) <small>geostrophic_eastward_sea_water_velocity</small> | | | | | Surface Lagrangian Trajectory Deviation (km) | | | | |
|------------------------|---|-------|-------|-------|-------|---|------|------|------|------|---|------|------|------|------|---|-------|-------|-------|-------|
| | Lead days | 1 | 3 | 5 | 7 | 10 | 1 | 3 | 5 | 7 | 10 | 1 | 3 | 5 | 7 | 10 | 2 | 3 | 5 | 7 |
| GLO12 | 41.51 | 41.34 | 41.59 | 42.00 | 43.22 | 0.17 | 0.18 | 0.18 | 0.18 | 0.19 | 0.20 | 0.20 | 0.21 | 0.21 | 0.22 | 10.39 | 20.34 | 38.79 | 55.87 | 72.13 |
| GLONET | 47.63 | 51.35 | 55.07 | 58.33 | 61.92 | 0.27 | 0.36 | 0.43 | 0.49 | 0.57 | 0.27 | 0.33 | 0.39 | 0.44 | 0.53 | 9.38 | 18.27 | 34.95 | 50.80 | 65.98 |
| WenHai | 42.58 | 46.51 | 49.84 | 52.83 | 57.11 | 2.38 | 2.38 | 2.38 | 2.39 | 2.41 | 1.79 | 1.80 | 1.81 | 1.82 | 1.83 | 11.97 | 23.63 | 45.83 | 67.02 | 87.65 |
| XiHe | 54.54 | 53.65 | 53.47 | 56.48 | 51.82 | 1.99 | 2.07 | 2.07 | 1.99 | 2.05 | 2.52 | 2.48 | 2.67 | 2.31 | 2.49 | 10.57 | 20.46 | 38.17 | 54.03 | 68.47 |



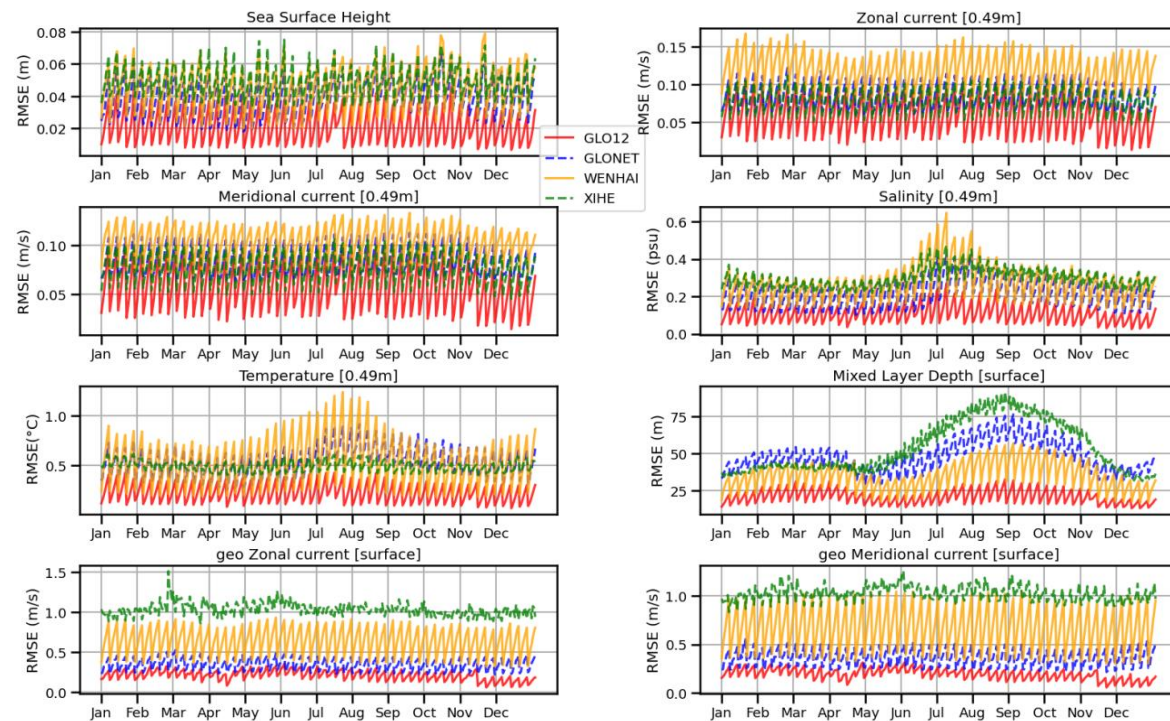
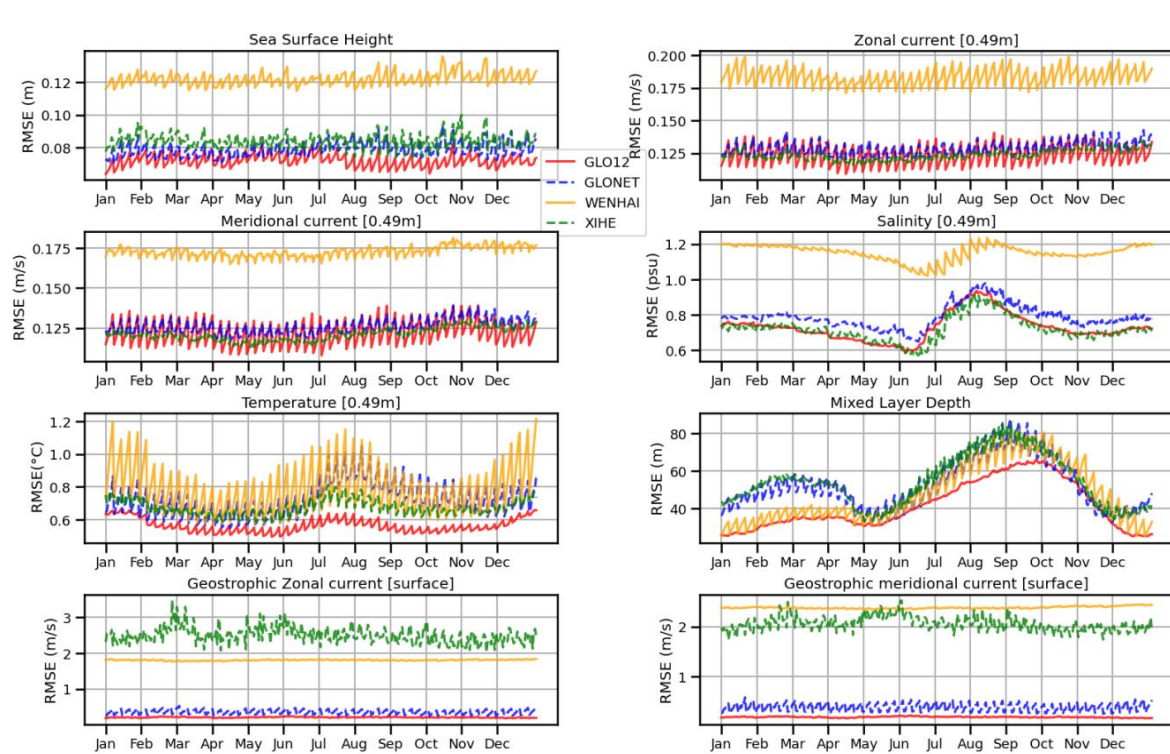
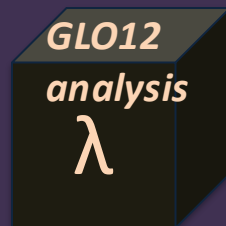
Forecasted variables

| Models | Temperature RMSE (°C) sea_water_potential_temperature | | | | | Salinity RMSE (PSU) sea_water_salinity | | | | | Zonal Current RMSE (m/s) eastward_sea_water_velocity | | | | | Meridional Current RMSE (m/s) northward_sea_water_velocity | | | | | Sea Surface Height RMSE (m) sea_surface_height_above_geoid | | | | |
|------------------------|---|------|------|------|------|--|------|------|------|------|--|------|------|------|------|--|------|------|------|------|--|------|------|------|------|
| | 1 | 3 | 5 | 7 | 10 | 1 | 3 | 5 | 7 | 10 | 1 | 3 | 5 | 7 | 10 | 1 | 3 | 5 | 7 | 10 | 1 | 3 | 5 | 7 | 10 |
| Surface | | | | | | | | | | | | | | | | | | | | | | | | | |
| GLO12 | 0.11 | 0.17 | 0.26 | 0.35 | 0.47 | 0.05 | 0.08 | 0.12 | 0.17 | 0.22 | 0.03 | 0.04 | 0.07 | 0.09 | 0.12 | 0.03 | 0.04 | 0.07 | 0.09 | 0.12 | 0.01 | 0.01 | 0.02 | 0.04 | 0.05 |
| GLONET | 0.39 | 0.48 | 0.60 | 0.71 | 0.83 | 0.14 | 0.20 | 0.26 | 0.30 | 0.35 | 0.07 | 0.07 | 0.09 | 0.11 | 0.13 | 0.07 | 0.07 | 0.09 | 0.11 | 0.13 | 0.03 | 0.03 | 0.05 | 0.05 | 0.07 |
| WenHai | 0.22 | 0.45 | 0.65 | 0.84 | 1.10 | 0.16 | 0.25 | 0.31 | 0.36 | 0.42 | 0.08 | 0.11 | 0.13 | 0.15 | 0.17 | 0.07 | 0.10 | 0.11 | 0.12 | 0.14 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 |
| XiHe | 0.44 | 0.45 | 0.52 | 0.55 | 0.64 | 0.25 | 0.28 | 0.30 | 0.34 | 0.40 | 0.06 | 0.07 | 0.09 | 0.10 | 0.11 | 0.05 | 0.07 | 0.09 | 0.10 | 0.11 | 0.04 | 0.05 | 0.05 | 0.06 | 0.06 |
| 50m | | | | | | | | | | | | | | | | | | | | | | | | | |
| GLO12 | 0.16 | 0.22 | 0.32 | 0.44 | 0.55 | 0.03 | 0.05 | 0.07 | 0.09 | 0.12 | 0.02 | 0.04 | 0.06 | 0.08 | 0.10 | 0.03 | 0.04 | 0.06 | 0.08 | 0.10 | 0.01 | 0.01 | 0.02 | 0.04 | 0.05 |
| GLONET | 0.70 | 0.75 | 0.84 | 0.95 | 1.13 | 0.10 | 0.14 | 0.16 | 0.18 | 0.20 | 0.05 | 0.06 | 0.07 | 0.08 | 0.11 | 0.05 | 0.06 | 0.07 | 0.08 | 0.10 | 0.03 | 0.03 | 0.04 | 0.05 | 0.06 |
| WenHai | 0.23 | 0.37 | 0.49 | 0.60 | 0.72 | 0.05 | 0.08 | 0.10 | 0.12 | 0.14 | 0.04 | 0.06 | 0.08 | 0.10 | 0.12 | 0.04 | 0.06 | 0.07 | 0.09 | 0.11 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 |
| XiHe | 0.50 | 0.53 | 0.60 | 0.63 | 0.74 | 0.11 | 0.11 | 0.12 | 0.13 | 0.13 | 0.04 | 0.05 | 0.07 | 0.08 | 0.09 | 0.04 | 0.05 | 0.07 | 0.08 | 0.09 | 0.04 | 0.05 | 0.05 | 0.06 | 0.06 |
| 100m | | | | | | | | | | | | | | | | | | | | | | | | | |
| GLO12 | 0.18 | 0.24 | 0.34 | 0.46 | 0.58 | 0.03 | 0.04 | 0.06 | 0.07 | 0.10 | 0.02 | 0.03 | 0.05 | 0.07 | 0.09 | 0.02 | 0.03 | 0.05 | 0.07 | 0.09 | 0.01 | 0.01 | 0.02 | 0.04 | 0.05 |
| GLONET | 0.52 | 0.60 | 0.70 | 0.82 | 1.00 | 0.08 | 0.10 | 0.12 | 0.14 | 0.15 | 0.04 | 0.05 | 0.06 | 0.07 | 0.09 | 0.04 | 0.05 | 0.06 | 0.07 | 0.09 | 0.03 | 0.03 | 0.04 | 0.05 | 0.06 |
| WenHai | 0.23 | 0.36 | 0.48 | 0.60 | 0.72 | 0.04 | 0.07 | 0.08 | 0.10 | 0.12 | 0.03 | 0.05 | 0.07 | 0.09 | 0.11 | 0.03 | 0.05 | 0.07 | 0.08 | 0.10 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 |
| XiHe | 0.50 | 0.52 | 0.59 | 0.63 | 0.72 | 0.09 | 0.10 | 0.11 | 0.11 | 0.12 | 0.04 | 0.05 | 0.07 | 0.08 | 0.09 | 0.04 | 0.05 | 0.06 | 0.08 | 0.09 | 0.04 | 0.05 | 0.05 | 0.06 | 0.06 |
| 200m | | | | | | | | | | | | | | | | | | | | | | | | | |
| GLO12 | 0.13 | 0.18 | 0.27 | 0.37 | 0.47 | 0.02 | 0.03 | 0.04 | 0.06 | 0.08 | 0.02 | 0.03 | 0.04 | 0.06 | 0.08 | 0.02 | 0.03 | 0.04 | 0.06 | 0.08 | 0.01 | 0.01 | 0.02 | 0.04 | 0.05 |
| GLONET | 0.39 | 0.45 | 0.50 | 0.57 | 0.66 | 0.05 | 0.07 | 0.08 | 0.10 | 0.11 | 0.03 | 0.04 | 0.05 | 0.06 | 0.08 | 0.03 | 0.04 | 0.05 | 0.06 | 0.08 | 0.03 | 0.03 | 0.04 | 0.05 | 0.06 |
| WenHai | 0.17 | 0.27 | 0.36 | 0.45 | 0.54 | 0.03 | 0.05 | 0.07 | 0.08 | 0.10 | 0.03 | 0.04 | 0.06 | 0.07 | 0.09 | 0.03 | 0.04 | 0.06 | 0.07 | 0.09 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 |
| XiHe | 0.39 | 0.36 | 0.41 | 0.47 | 0.50 | 0.06 | 0.06 | 0.07 | 0.08 | 0.08 | 0.05 | 0.04 | 0.05 | 0.06 | 0.07 | 0.06 | 0.04 | 0.05 | 0.06 | 0.07 | 0.05 | 0.04 | 0.05 | 0.06 | 0.07 |
| 300m | | | | | | | | | | | | | | | | | | | | | | | | | |
| GLO12 | 0.11 | 0.15 | 0.23 | 0.32 | 0.41 | 0.02 | 0.03 | 0.04 | 0.05 | 0.07 | 0.02 | 0.03 | 0.04 | 0.05 | 0.07 | 0.02 | 0.03 | 0.04 | 0.06 | 0.07 | 0.01 | 0.01 | 0.02 | 0.04 | 0.05 |
| GLONET | 0.34 | 0.39 | 0.42 | 0.47 | 0.55 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 | 0.03 | 0.03 | 0.04 | 0.05 | 0.07 | 0.03 | 0.03 | 0.04 | 0.06 | 0.07 | 0.03 | 0.03 | 0.04 | 0.05 | 0.06 |
| WenHai | 0.14 | 0.24 | 0.31 | 0.39 | 0.47 | 0.03 | 0.04 | 0.06 | 0.07 | 0.08 | 0.02 | 0.04 | 0.05 | 0.07 | 0.08 | 0.03 | 0.04 | 0.05 | 0.07 | 0.08 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 |
| XiHe | 0.35 | 0.30 | 0.36 | 0.40 | 0.44 | 0.05 | 0.05 | 0.06 | 0.07 | 0.07 | 0.05 | 0.04 | 0.05 | 0.06 | 0.07 | 0.05 | 0.04 | 0.05 | 0.06 | 0.07 | 0.05 | 0.04 | 0.05 | 0.06 | 0.07 |
| 500m | | | | | | | | | | | | | | | | | | | | | | | | | |
| GLO12 | 0.08 | 0.12 | 0.18 | 0.25 | 0.33 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.01 | 0.02 | 0.03 | 0.04 | 0.06 | 0.01 | 0.02 | 0.03 | 0.05 | 0.06 | 0.01 | 0.01 | 0.02 | 0.04 | 0.05 |
| GLONET | 0.20 | 0.25 | 0.30 | 0.35 | 0.41 | 0.04 | 0.05 | 0.06 | 0.06 | 0.07 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.03 | 0.03 | 0.04 | 0.05 | 0.06 | 0.03 | 0.03 | 0.04 | 0.05 | 0.06 |
| WenHai | 0.11 | 0.19 | 0.26 | 0.31 | 0.38 | 0.02 | 0.04 | 0.05 | 0.06 | 0.07 | 0.02 | 0.04 | 0.05 | 0.06 | 0.07 | 0.02 | 0.04 | 0.05 | 0.06 | 0.07 | 0.02 | 0.04 | 0.05 | 0.06 | 0.07 |
| XiHe | 0.27 | 0.24 | 0.28 | 0.31 | 0.33 | 0.04 | 0.04 | 0.05 | 0.05 | 0.05 | 0.04 | 0.03 | 0.04 | 0.05 | 0.06 | 0.04 | 0.03 | 0.04 | 0.05 | 0.06 | 0.04 | 0.03 | 0.04 | 0.05 | 0.06 |

references



References



References

Extend the evaluation period 2025 & 2023

Challengers

- **Physics based:** *GLOEnS, GLO36*
- **ML-based:** *Langya, FuXi-Ocean, SeaCast, MedFormer..*

Evaluation Tracks

Probabilistic forecast,

Seasonal forecast

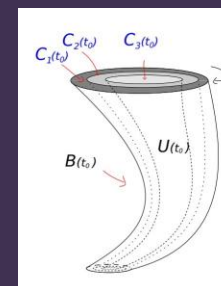
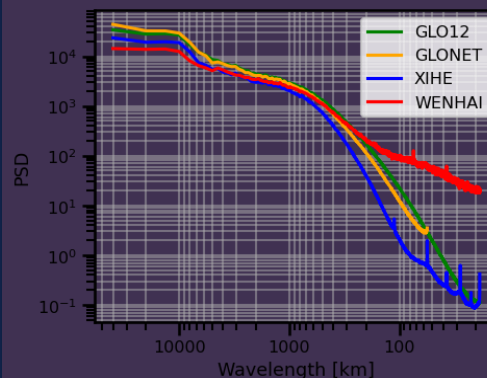
Regional Track,

ICE

1° Track,

BGC

Evaluation metrics



Continuous
Ranked Probability
Score

DEMO