Ocean Predict

SYMPOSIUM OP'24

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Intergovernmental Oceanographic Commission

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

Exploring Ensemble Ocean Forecasting: Foundations and Future Trends

Giovanni Ruggiero

giovanni.ruggiero@mercator-ocean.fr

Geoengineering and operational oceanography

Katja Fennel

katja.fennel@dal.ca

Exploring Ensemble Ocean Forecasting: Foundations and Future Trends

1. Introduction
Why ocean prediction

3. Challenges
Computational costs and model uncertainties

2. Key Concepts
Basics of ensemble and stochastic models

4. Recent Advances
Innovations in stochastic modelling

5. Future Directions
Pathways for improved forecasting

Geoengineering and operational oceanography

1. Current climate and emission trends

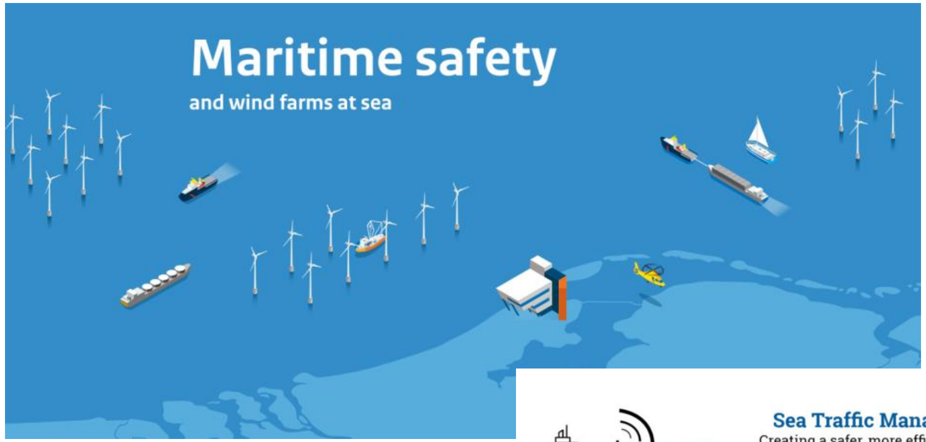
3. Tools needed and available

2. Imperative of research for solutions

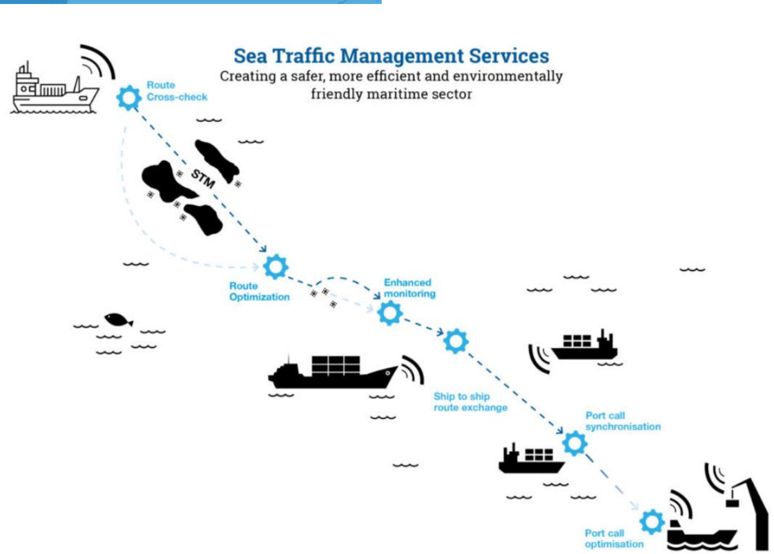
4. Role of operational oceanography

Why Ocean Forecasting Matters

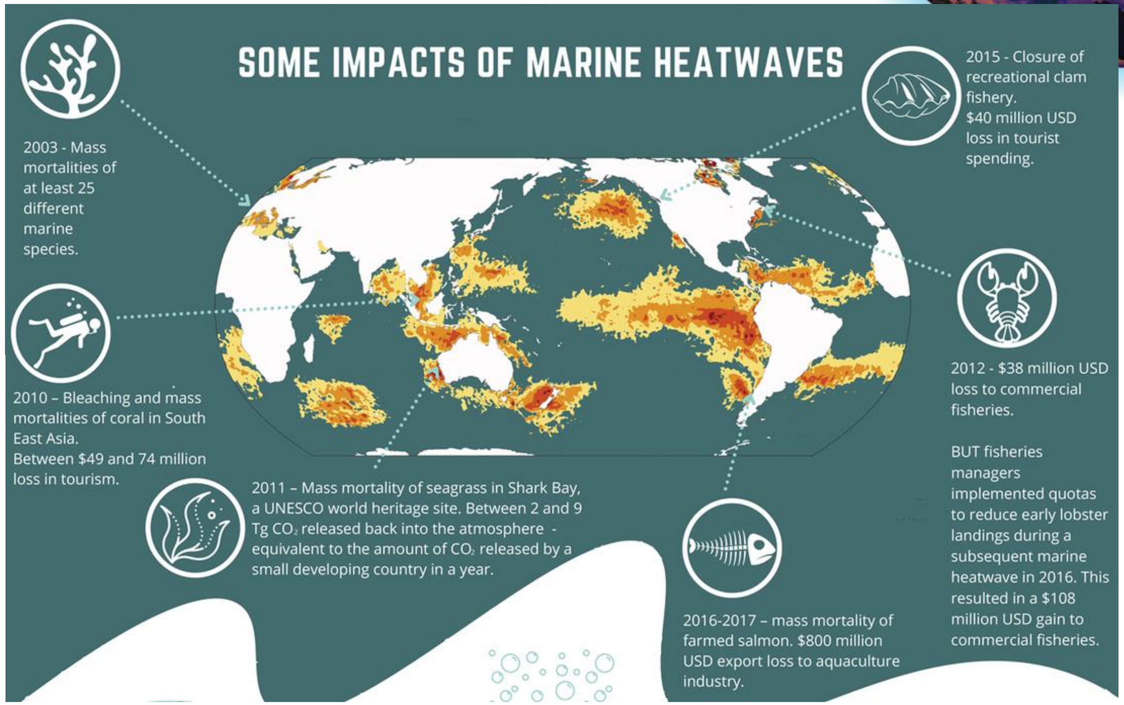
Essential for Climate, Navigation, Ecosystems



From https://www.noordzeeloket.nl/



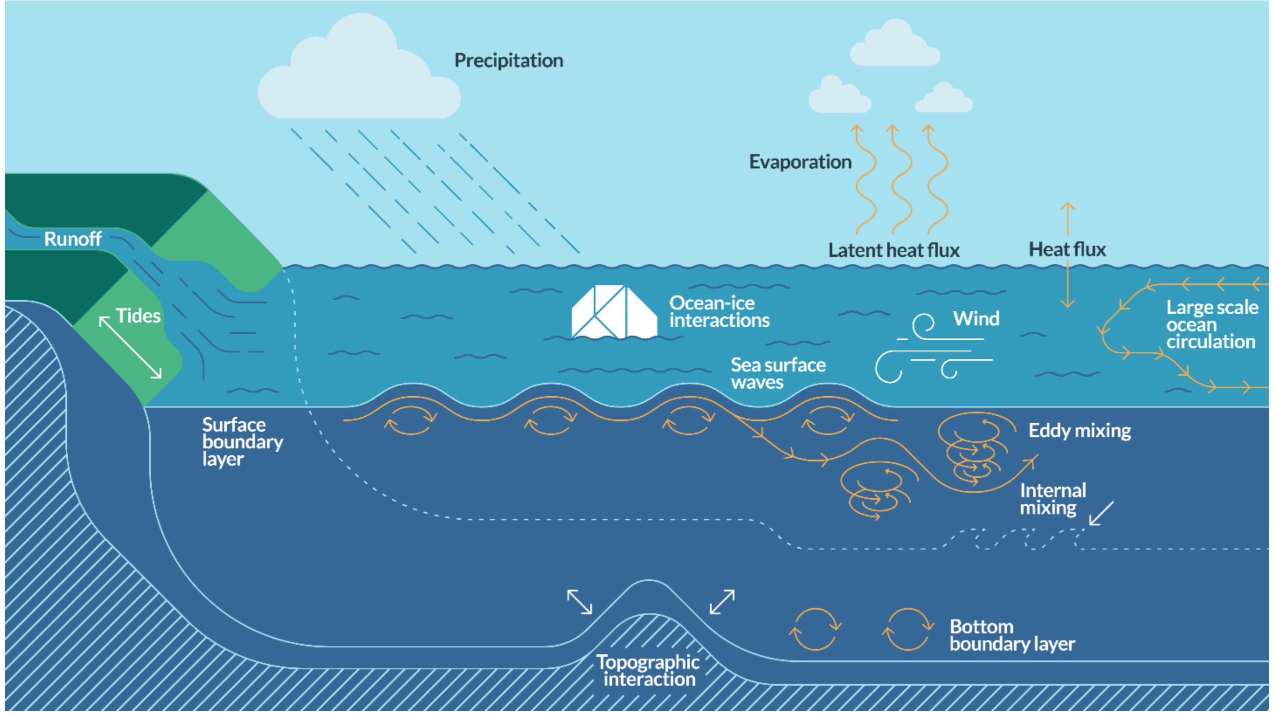
https://www.seatrafficmanagement.info/stm-services/



https://www.marineheatwaves.org/mhw-impacts.html

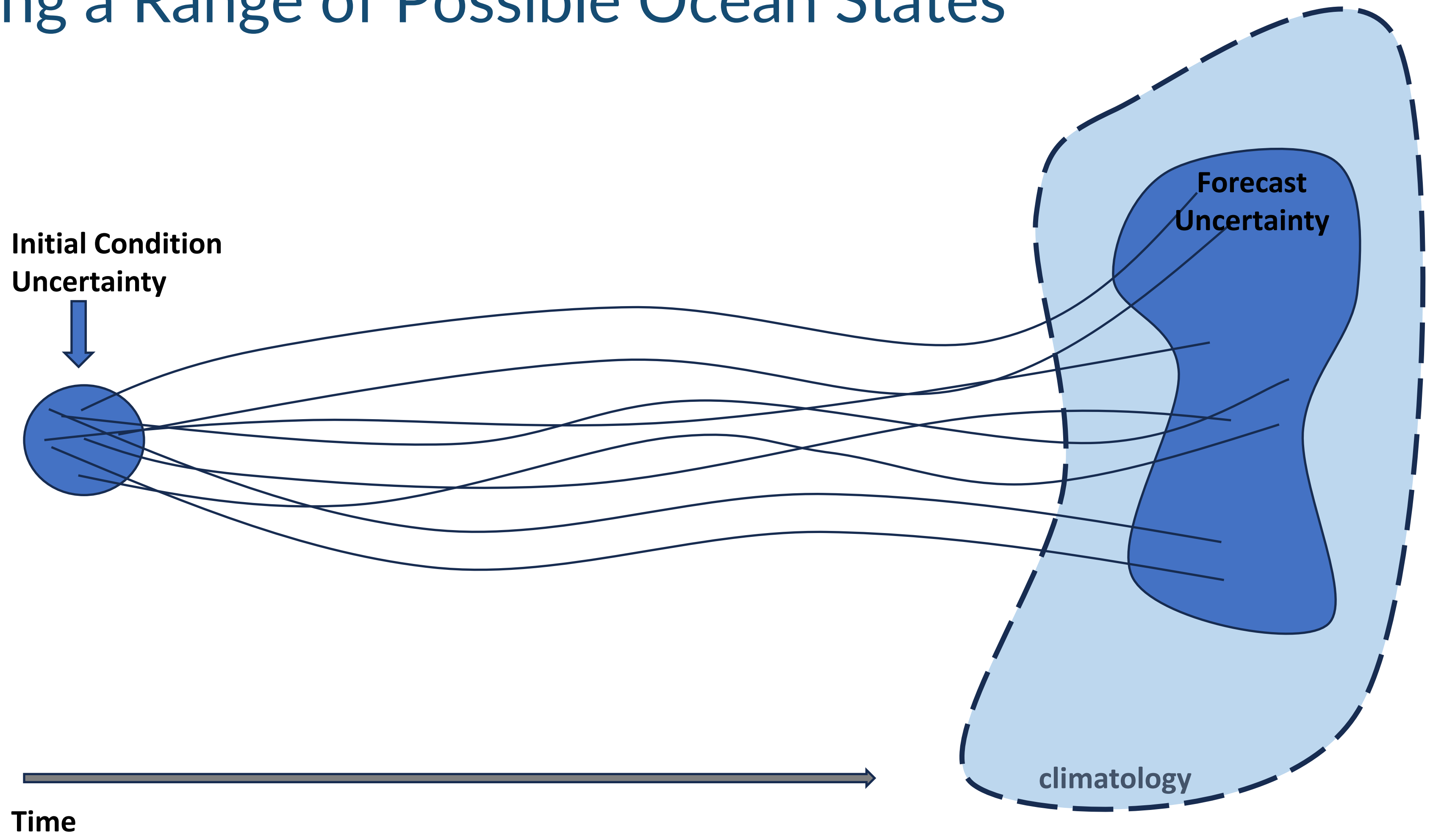
The Challenge: Uncertainty in Ocean Prediction

Chaotic Dynamics and Complex Interactions Drive Forecast Uncertainty



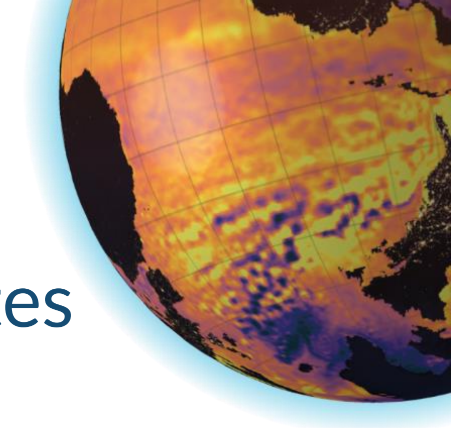
The Ensemble Approach

Capturing a Range of Possible Ocean States

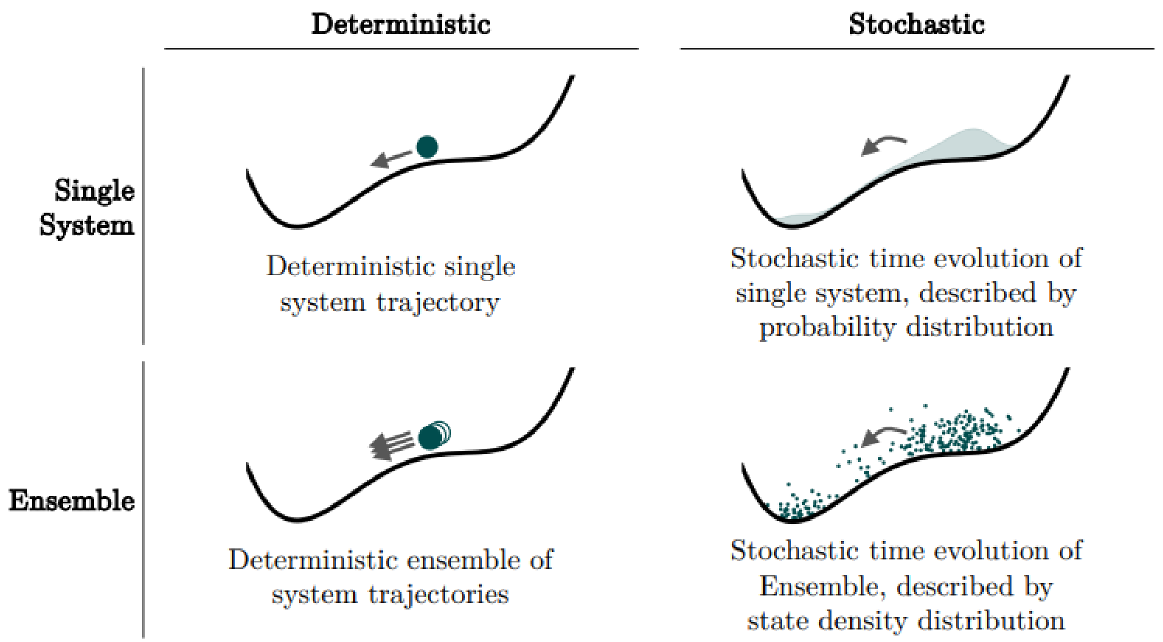


Ensemble Prediction through Stochastic Modeling

Using randomness to represent uncertainties in ocean states



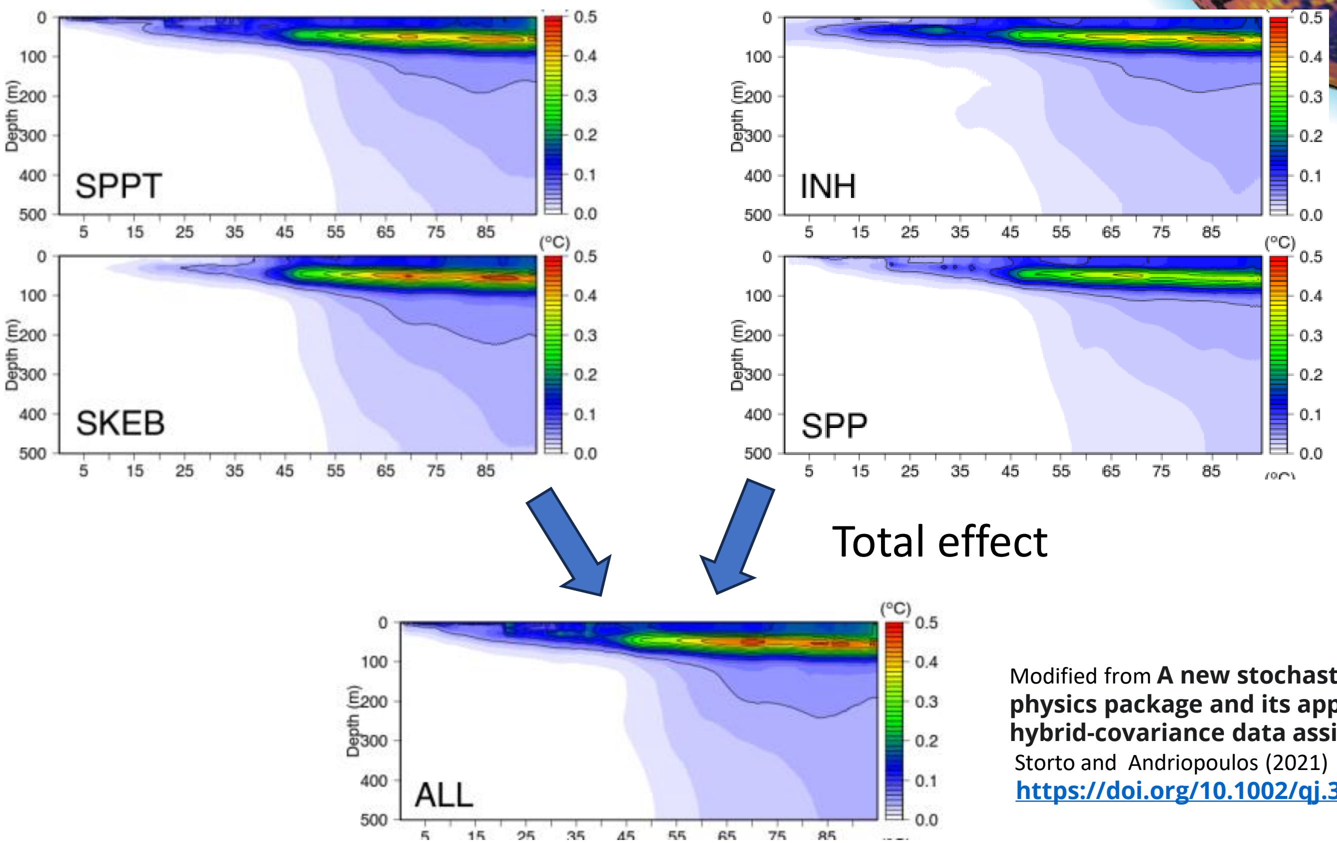
- Simulates a range of possible states
- Models includes random perturbations to inputs or physics
- Governing equations from deterministic to stochastic



From Dechert et. al 2024

Current Stochastic Perturbation Methods in Ocean Forecasting

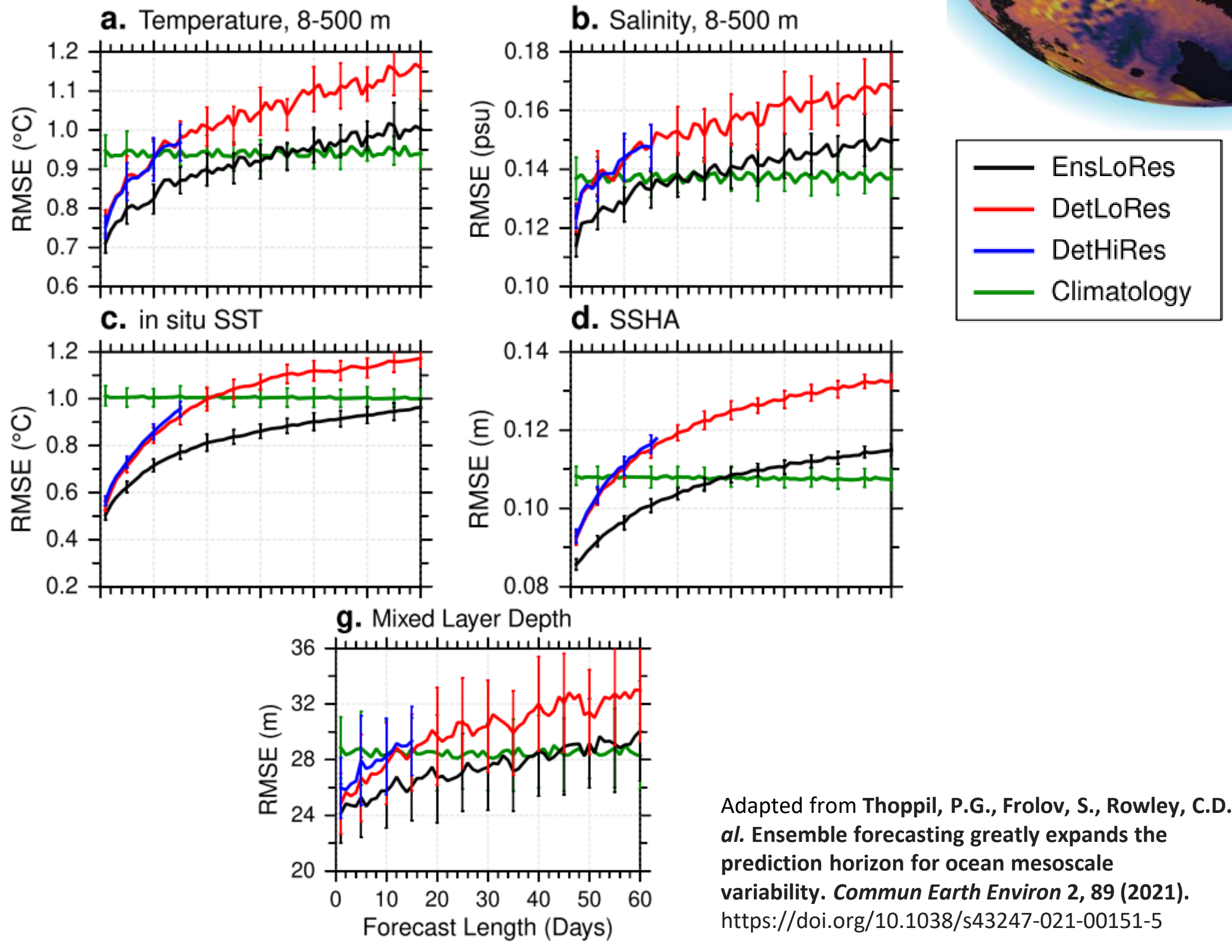
- Autoregressive models with prescribed statistics
- Perturbation of parameters (SPP)
- Effect of non-resolved scales (SKEB)
- Perturbation of model tendencies (SPPT)



Modified from **A new stochastic ocean physics package and its application to hybrid-covariance data assimilation**
Storto and Andriopoulos (2021)
https://doi.org/10.1002/qj.3990

Benefits of Ensemble Ocean Prediction

- Enhence predictive accuracy
- Extend predictability
- Supports risk assessement and planning
- Forecasts probabilitites and provides insight into forecast confidence levels



Adapted from **Thoppil, P.G., Frolov, S., Rowley, C.D.** ***et al.*** **Ensemble forecasting greatly expands the prediction horizon for ocean mesoscale variability.** ***Commun Earth Environ*** **2, 89 (2021).** https://doi.org/10.1038/s43247-021-00151-5

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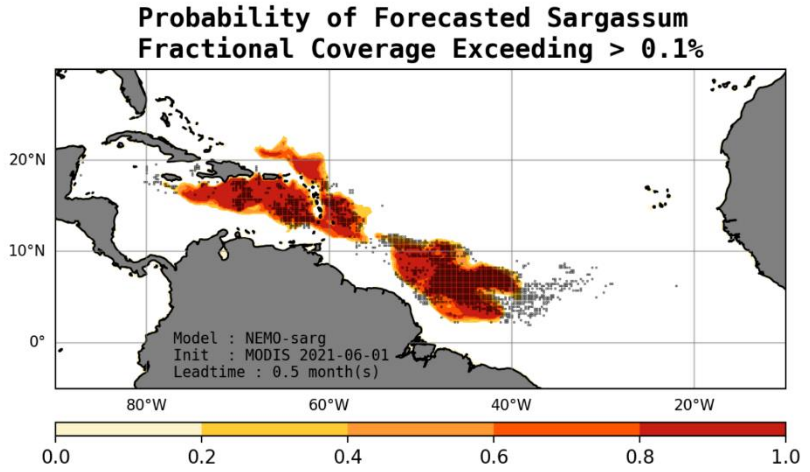

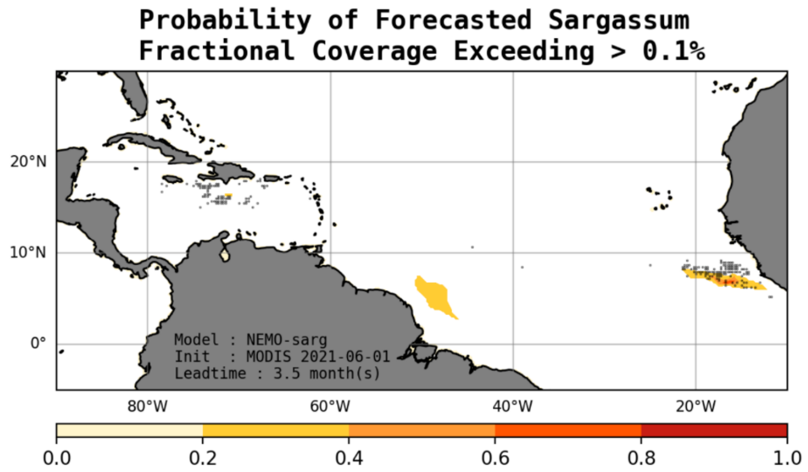

SCO SPACE FOR CLIMATE OBSERVATORY

Many Gaël - SeSAM project – SCO - SeSaM | Space for Climate Observatory

Challenges in Ensemble Prediction

Challanges	Explanation	Impact on Forecasting Quality
Computational Cost	Large ensembles and high-resolution models require substantial computing power and storage.	Limits feasible ensemble size, potentially reducing forecast accuracy.
Model error representation	Incomplete or inaccurate representation of model physics and uncertainties.	May result in biased forecasts, limiting reliability and skill.
Uncertainty Quantification	Difficulty in assessing and representing forecast uncertainties comprehensively.	Incomplete uncertainty information may lead to over- or under-confidence.
Initial Condition Accuracy	Uncertainty in observations affects ensemble spread and evolution.	Higher initial error can increase forecast spread, reducing precision.
Data Assimilation Complexity	Challenges in incorporating diverse data sources (e.g., satellite, in-situ) efficiently.	Impacts the accuracy of initial conditions and forecast update quality.

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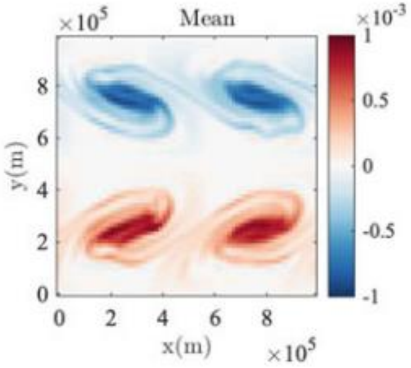
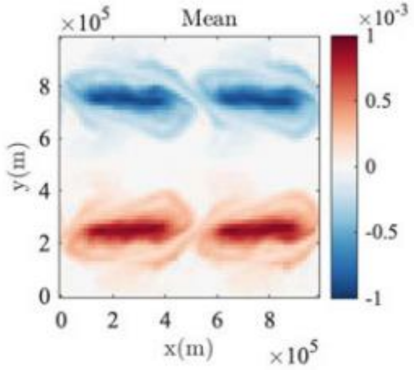
Recent Advances: Stochastic modelling for Ensemble Forecasting

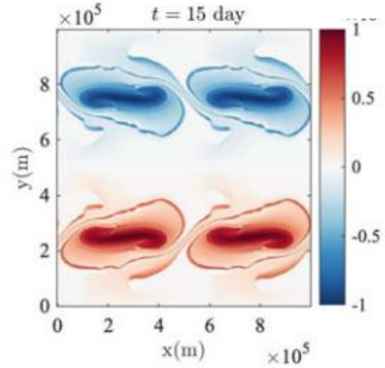
Adaptive Stochastic Parameterization

uncalibrated





calibrated



truth

B. Dufée, E. Mémin, and D. Crisan (2023) Observation-Based Noise Calibration: An Efficient Dynamics for the Ensemble Kalman Filter. In: Stochastic Transport in Upper Ocean Dynamics Annual Workshop, Springer, pp 43–56

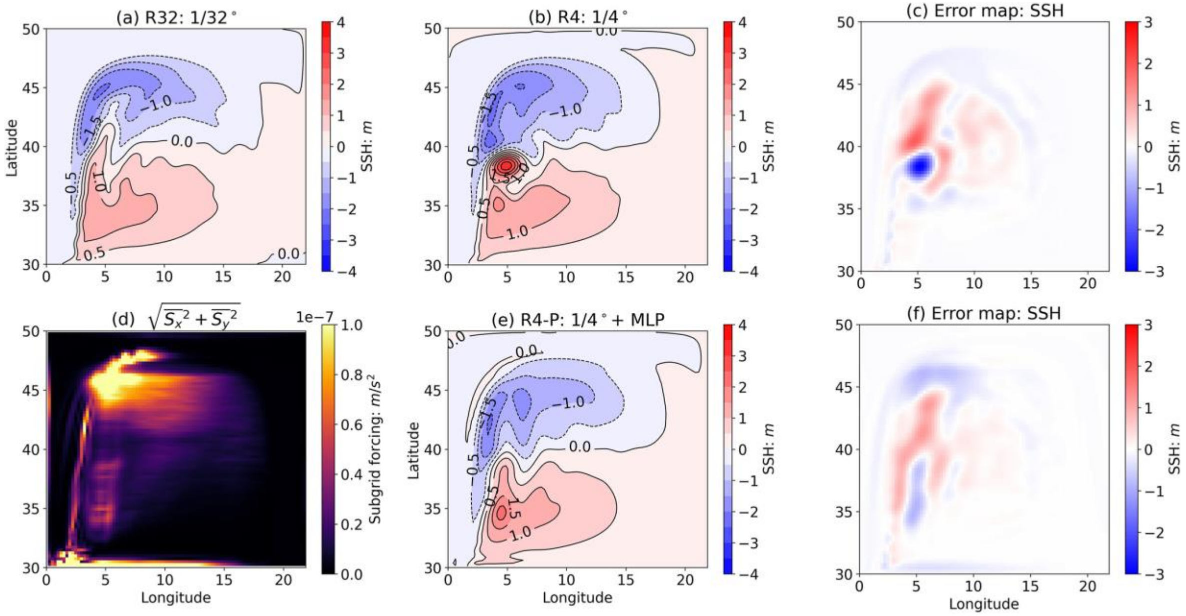
Adjusts model parameters in real-time based on observed data, making forecasts more responsive to changing conditions.
Adaptive parameterization reduces forecast errors by aligning the model more closely with actual ocean states

Recent Advances: Stochastic modelling for Ensemble Forecasting

Machine Learning for Stochastic Modeling

Implementation and Evaluation of a Machine Learned Mesoscale Eddy Parameterization Into a Numerical Ocean Circulation Mode

J Adv Model Earth Syst, Volume: 15, Issue: 10, First published: 10 October 2023, DOI: (10.1029/2023MS003697)



Applies machine learning to emulate complex noise patterns and sub-grid dynamics. By learning from historical data, ML models can generate accurate, efficient representations of uncertainty, capturing small-scale processes without added computational costs.

Challenges in Ensemble Prediction

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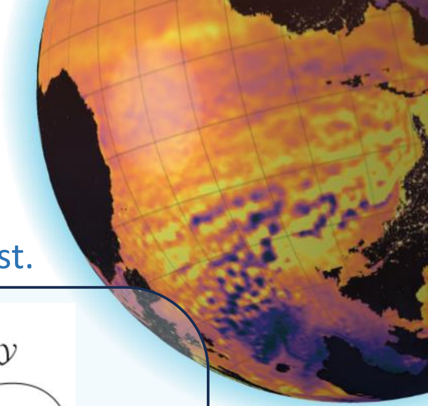
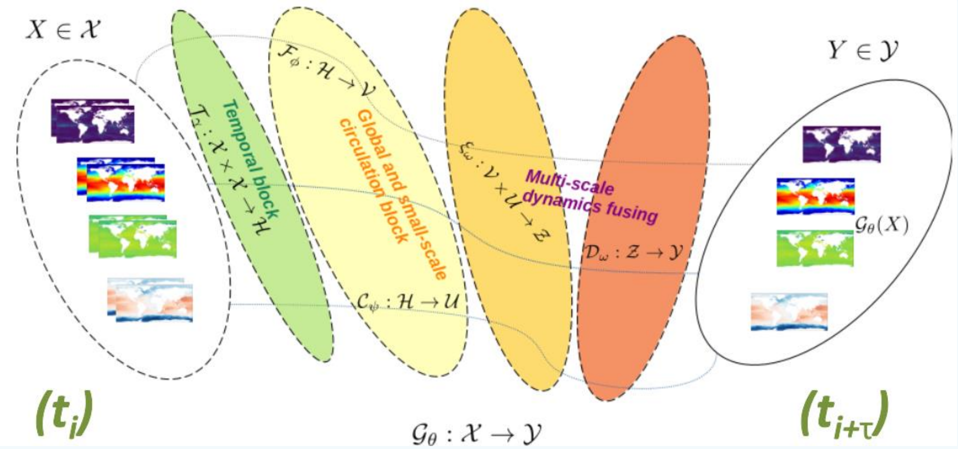
GLOnet: Neural Network-Based Ocean Forecasting

Pure machine learning forecast. Development of a system trained with global reanalysis to produce high resolution physical forecast.



Development of a NN Ocean forecating system

- ¼ ° resolution, Multivariate, 3D (21 layers)
- Trainning takes 3 weeks
- **10-days forecast in 10s (GLORYS12 requires 45 minutes)**

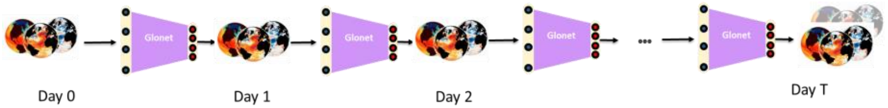


El Aouni, Anass, et al. "Glonet-Mercator's End-to-end Neural Ocean Forecasting System." *AGU24* (2024).

DATASET

Computing ressources [EDITO]

- 8 nodes, 32xA100 GPUs
- 3 To Ram
- 10 To storage

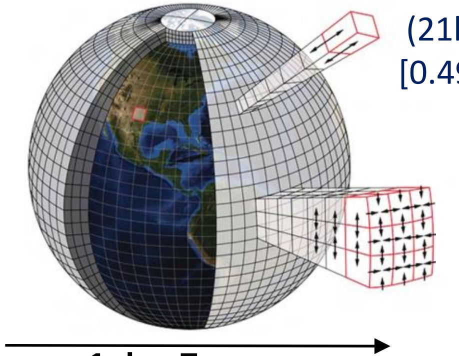


- **GLORYS12**
  - Training [1993~2020]
  - Validation [2021]
  - Testing [GLO12]

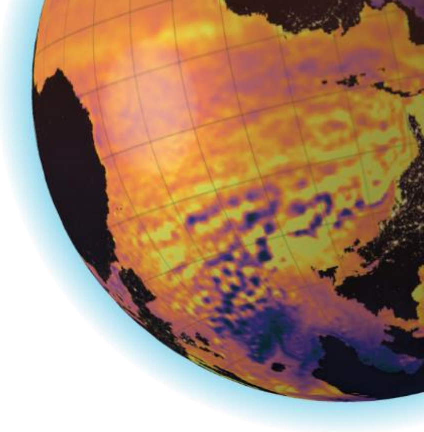
Variables:

1D: zos

3D: [thetao, uo,vo, so]



Future Directions in Ensemble Ocean Forecasting



Key Trends in Ensemble Forecasting:

- Increased Computational Efficiency
- Improved Stochastic Modeling Techniques
- Machine Learning (ML) and AI Integration
- Better Handling of Non-Gaussian Uncertainties
- Incorporation of High-Resolution Observations

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"Forecasts possess no intrinsic value. They acquire value through their ability to influence decisions made by users of the forecasts" (Allan Murphy)

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SYMPOSIUM OP'24

ADVANCING OCEAN PREDICTION SCIENCE FOR SOCIETAL BENEFITS

Thank you!

European Commission

Copernicus Marine Service

EU4OceanObs International Ocean Governance EU Component to Global Ocean Observations

Mercator Ocean International

esa

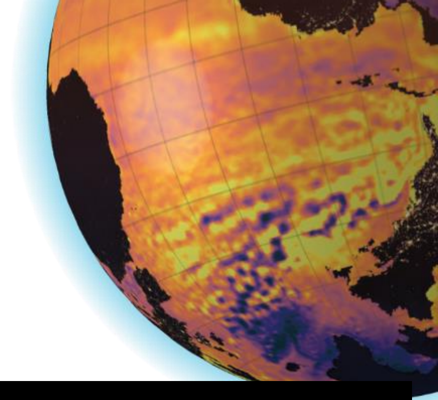
cnes Centre National d'Études Spatiales

Met Office

NERSC

Australian Government Bureau of Meteorology

Canada



Glonet Provides daily Forecasts on Edito platform