Spinup-Evaluation

A Physics-Based Benchmarking Platform for ML-Based Spinup of the NEMO Ocean Model

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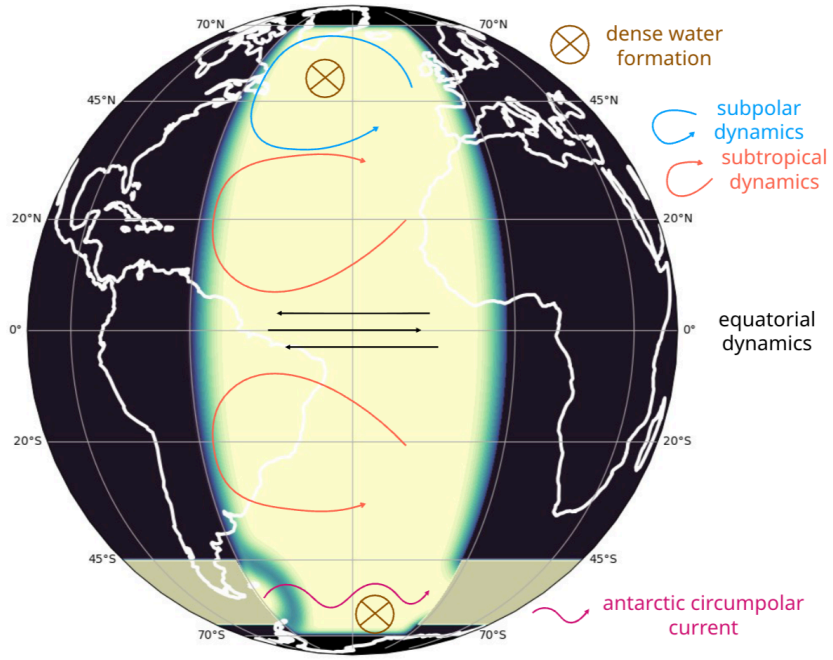
Spinup-evaluation

Accelerating Spinup

- Ocean spinup is `slow`. Upwards of a 1000 simulation years to achieve equilibrium state!
- Many machine learning emulators exist for ocean modelling that are well validated:
  - How do we know if they are correct *physically*?
  - Errors can easily propagate during rollout.
- Our focus is on the physical `evaluation` of ocean models:
  - Including equation resolving, pure AI emulators and hybrid approaches.
- Implement sustainable software that is easy to extend, robust and reusable.
  - Generalised evaluation benchmark for climate.

NEMO/DINO ocean model

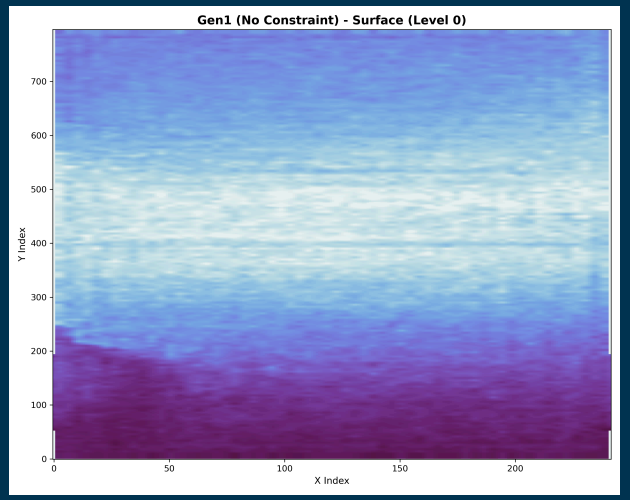
diabatic neverworld : a simplified version of pole-to-pole ocean dynamics

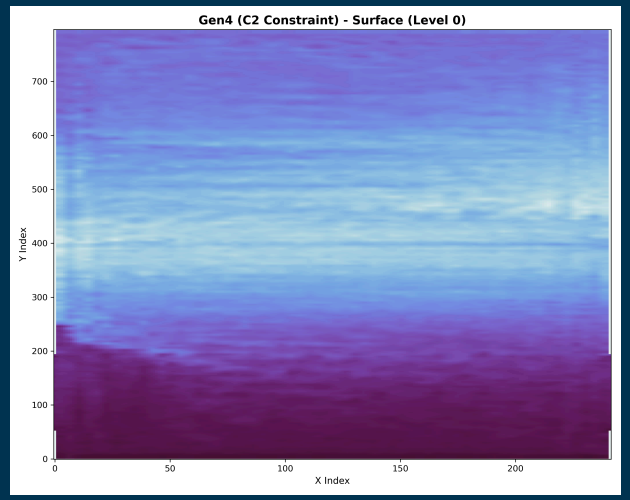


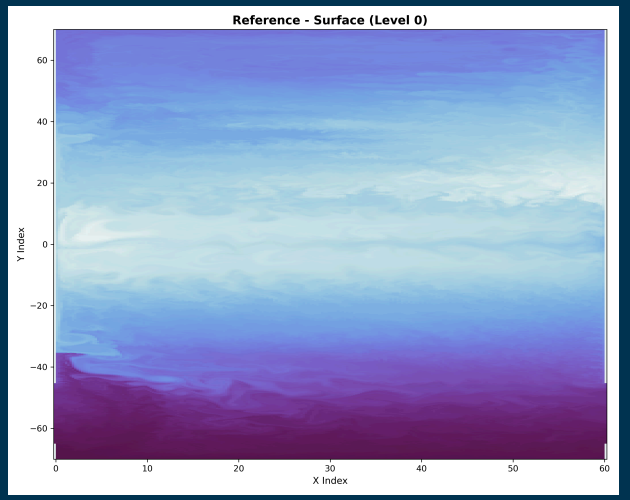
/vopikamm/DINO

We use the DINO configuration (Kamm, Deshayes, and Madec 2025) for development purposes.

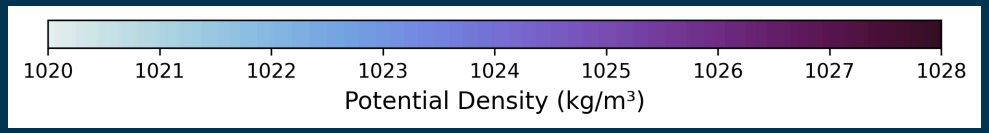
Is RMSE enough?







Unconstrained ✅ Constrained Reference

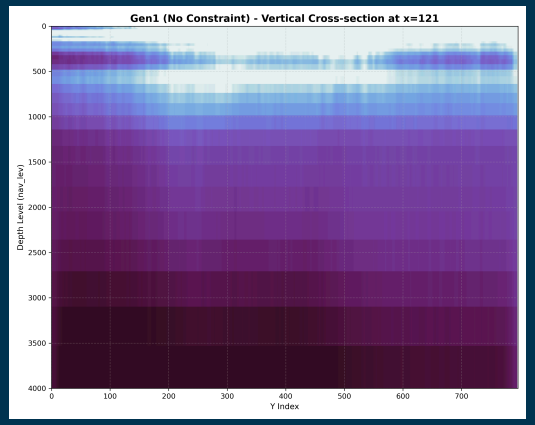


	Unconstrained	*Constrained*	**Reference**
T DW	2.9	**2.6**	2.6
ρ error	26.8	**0.4**	0.4

Evaluate even when resolution changes.

Meunier et al. (2025), Gorce et al. (2025)

Is RMSE enough?



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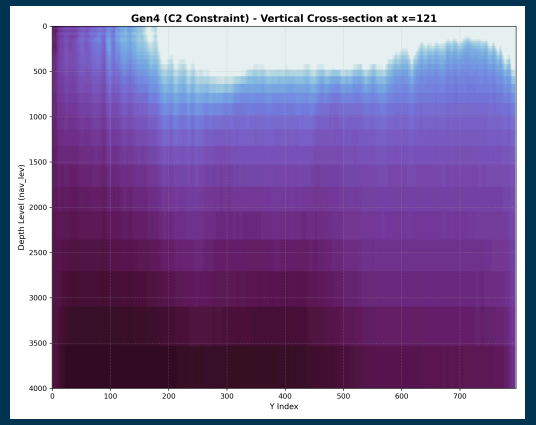

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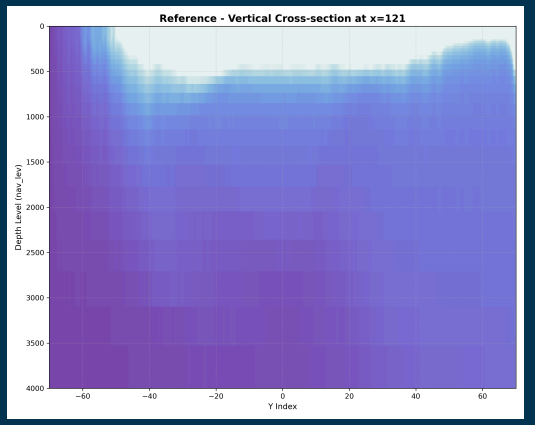

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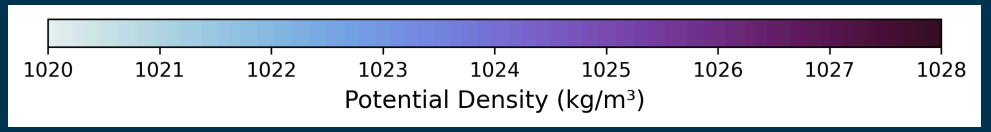

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Physical evaluation

Metrics

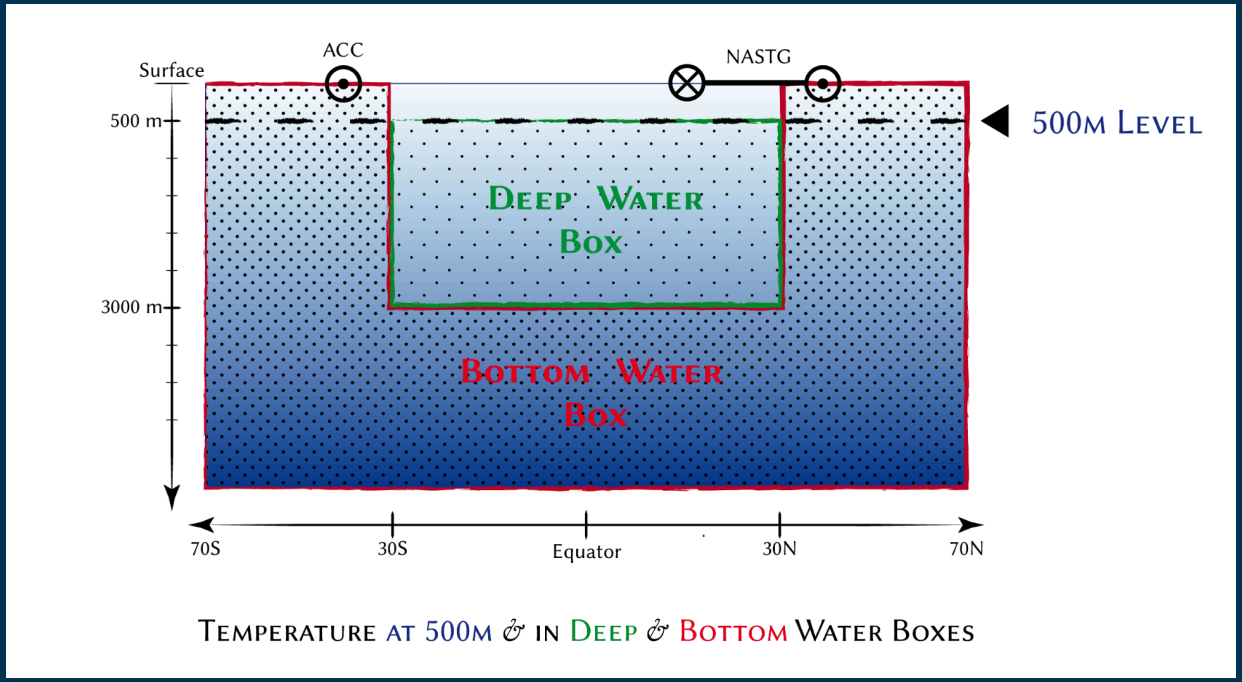


Figure from *Learning to generate physical ocean states. Meunier et al. (2025)*

Bring in physical knowledge of problem

i.e. metrics specific to tracking `equilibrium` progress.

- *No ground truth*

Evaluation-Benchmark

Ocean Model

AI emulator or traditional time integrator of physical quantities.

AI Emulator / Hybrid

/m2lines/nemo-spinup-forecast

Translator Toolbox

- Create `restart` state from AI emulator
- Simple checks
- ‘Glue’ module for future time-stepping

Physical Evaluation

- Physical evaluation of instantaneous and temporal fields [`GridT`, `restart`].nc

Evaluation-Benchmark

- How do we evaluate hybrid ocean emulators?
- PILLAR 1:
  - Compute metrics at `end` time only.
  - Compute during `roll-out`
- PILLAR 2:
  - Feed emulated state back into ocean model to check `stability` and
    - evaluate metrics over time history
- PILLAR 3:
  - Sample from a `distribution` of possible emulated states

/m2lines/spinup-evaluation

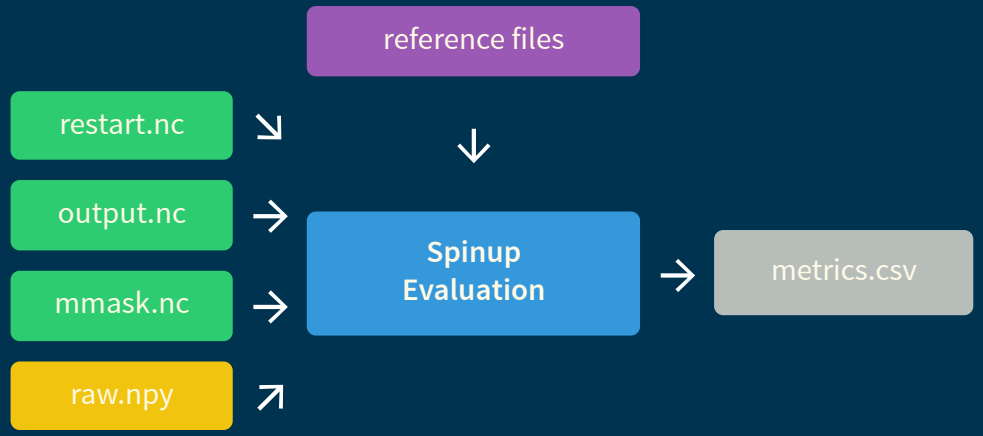
version `0.2`

Pillars 1, 2 and 3 enabled with the use of two software components:

Developer highlights

Spinup-evaluation (1)

- Computes metrics on raw emulator outputs (`.npy`), instantaneous (`restart.nc`) and time averaged (`grid.nc`) output files & **statistical comparisons**
- Strict mapping of ocean variables to `restart`, `grid` (output) and `mesh_data` names
- Provides a framework to easily add **new metrics**
- Implements temporal downsampling – all possible metrics computed even if data output at different cadences.



/m2lines/spinup-evaluation

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Developer highlights

Spinup-restart/translator (2)

- Take an **emulator** state and converts to NEMO compatible `restart.nc` file
- Basic validation gate; does **grid encoding** and **sanity checks** (existence of `NaNs` etc)
- *Regrid*, *upscale*, *downscale* resolution;
- Encode other **physical assumptions** (geostrophic velocities)

Translate between other ocean model restart files - potentially difficult due to grids (in progress..)

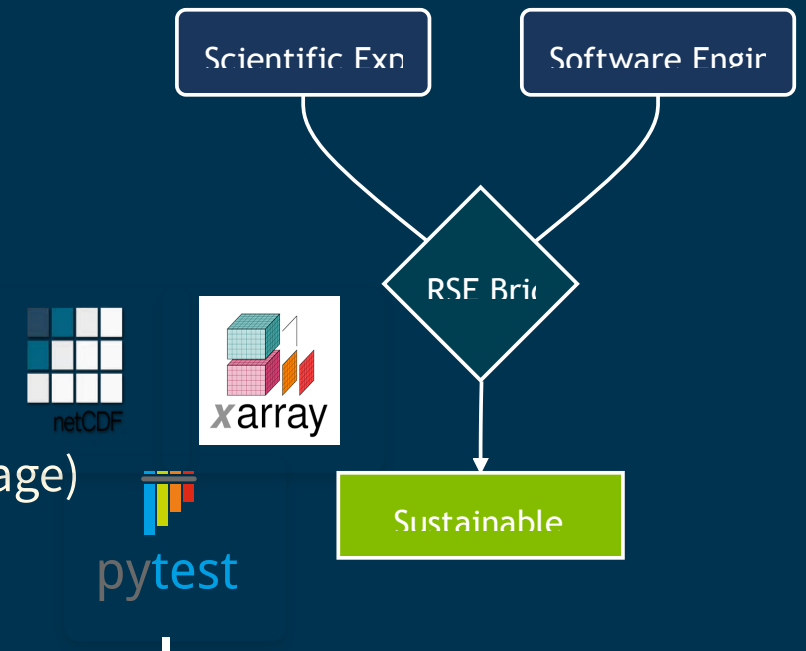
Software engineering

Modular & Generalizable

- Reusable components across domains
- Extensible to new models (e.g., MOM6, *Oceananigans*)

Quality & Standards

- Robust testing (Unit, Integration, Coverage) with CI
- Well documented end-to-end examples (hybrid)
- Data products adhere to **FAIR** (see Wilkinson et al. 2016)
- **Collaborative Design**: Bridging Science & RSE



Eliminating silos through cross-disciplinary partnership.

Conclusions

Key Takeaways

1. **Extend evaluation of ocean models**:
    - Evaluation of AI emulators must go beyond simple RMSE metrics.
    - Enable evaluation in conjunction with equation resolving techniques.

2. **Software enabled research**:
    - Research software engineering is a critical component of research bringing generalisability, extensibility and robustness to software products.

Next Steps

- Extend to other ocean models and AI emulators
- Translation between different ocean checkpoint files

Thanks for Listening

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/ma595/spineval-agu - Slides

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