

Réunion annuelle projet COMPACT, 3 février 2026



EOPHIS library and ML coupling through OASIS3-MCT

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Need and issues with hybrid physics / AI models

Applications of hybrid modeling

Parameterization from hi-fidelity models (LES, km-scale models)

Sane et al. 2023

Zhang et al. 2023

Yuval et al. 2021

Model error correction from reanalysis or DA increments

Gregory et al. 2024

Chapman and Berner. 2023

Acceleration of code components with neural emulators

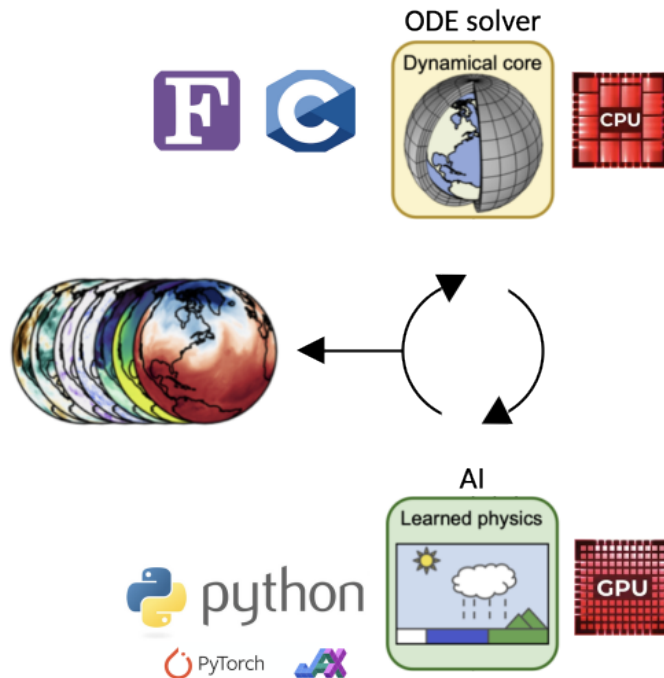
Hogan and Bozzo, 2018

Chantry et al. 2021

Practical questions raised

How to call ML from Fortran

- Computational efficiency
- Reproducibility: sharing weights and biases
- Reproducibility: production environment



Need to explore options and practices for reproducible hybrid modeling

Landscape of existing solutions

Neural Network in Fortran



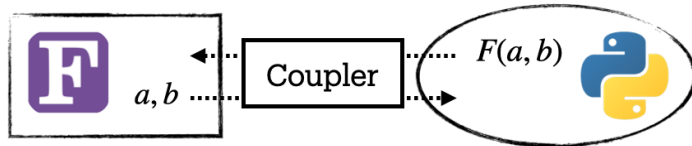
Call Python scripts with Fortran-Python bindings



Fortran wrappers for ML libraries



Earth System Models coupling libraries



Landscape of existing solutions

Neural Network in Fortran



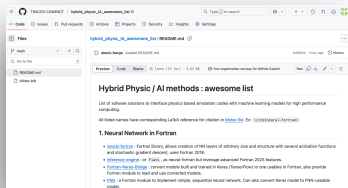
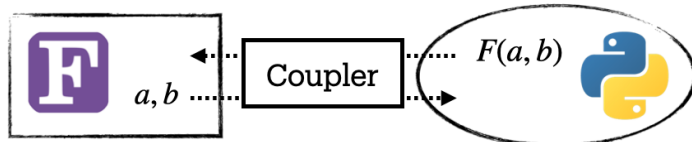
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Fortran wrappers for ML libraries



Earth System Models coupling libraries



NB: Physics / AI methods awesome list

https://github.com/TRACCS-COMPACT/hybrid_physics_AI_awesome_list

Large variety of solutions

Open to contribution

No standard procedures for sharing codes and experiments

EOPHIS: a library for deploying ML models through OASIS3-MCT

Couplers are in codes

OASIS3-MCT : 5 of the 7 European ESMs in CMIP6

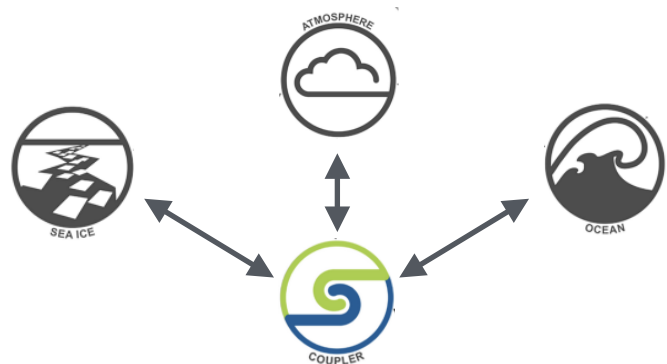
YAC : ICON

CMEPS : NCAR CESM — NOAA UFS

FMS : NOAA GFDL

CPL7/MCT : E3SM

C-COUPLER2 : Chinese institutions models



OASIS3-MCT_5.0

Coupling library between different components

Interpolate and exchange 2D/3D fields

Python, C/C++ and Fortran API

Widely deployed in European models

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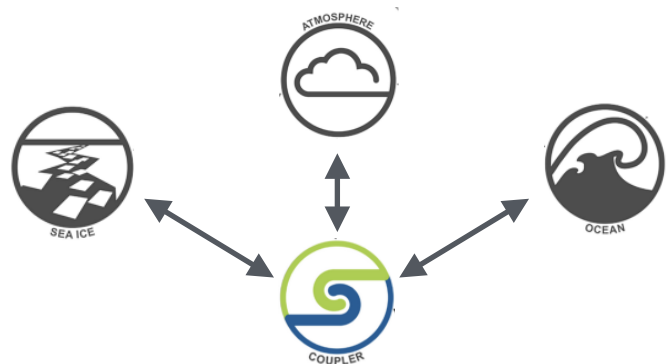
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OASIS3-MCT_5.0

Coupling library between different components

Interpolate and exchange 2D/3D fields

Python, C/C++ and Fortran API

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Required components features

Time stepping procedure

MPI decomposition and internal communication

Autonomy in generating fields and grids

Neural Networks are passive functions awaiting to be fed

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OASIS3-MCT_5.0

Coupling library between different components

Interpolate and exchange 2D/3D fields

Python, C/C++ and Fortran API

Widely deployed in European models

EOPHIS_1.1

Generic OASIS3-MCT Python component

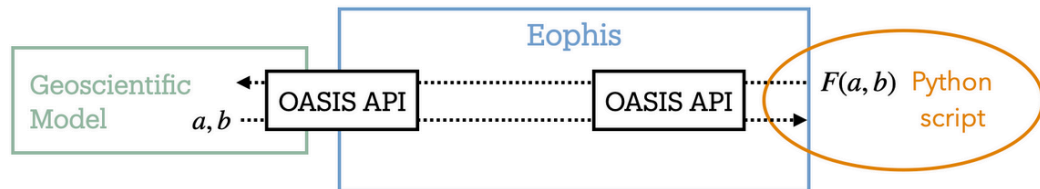
Provide requirements to bridge Python scripts with coupling API

Flexibly configure coupling environment

Assistance for Fortran side configuration

<https://github.com/meom-group/eophis>

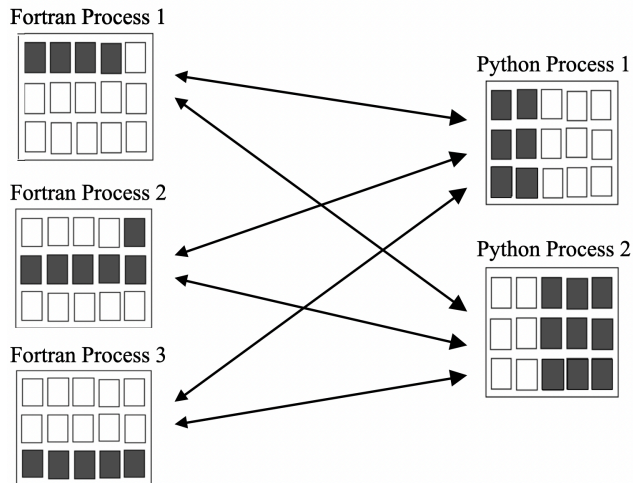
MIT Licensed, Open Source



Benefits of using couplers

Adjustments of resources

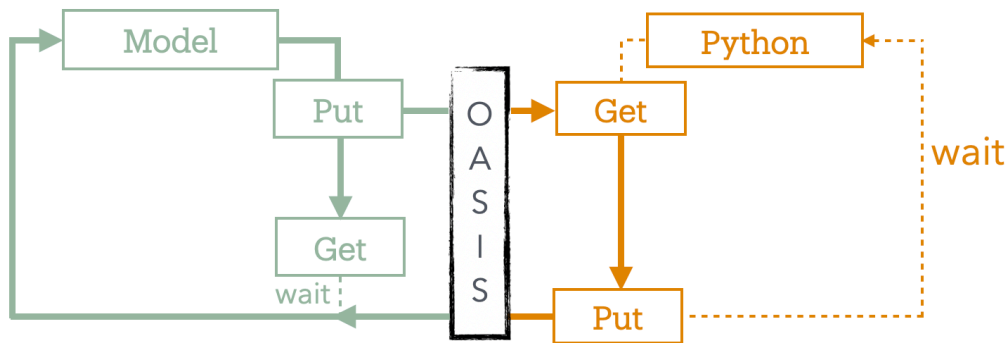
Optimal process number for model and inference
Isolate GPU access to Python processes
Flexibility (fast, smooth, cheap...)



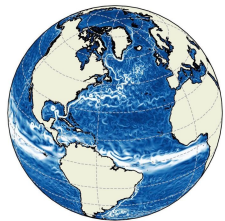
Asynchronicity

Send inputs as soon as possible
Continue computation as far as possible
Wait for Python returns

Time overlap reduces resources overhead



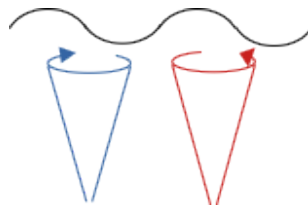
Existing use cases with NEMO and OASIS3-MCT/EOPHIS



Realistic

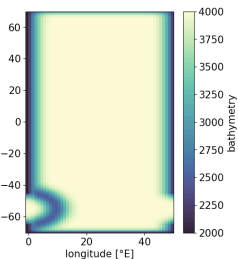
Eddy closures

- Tracer fluxes
- Momentum fluxes



Stanley et al., 2022

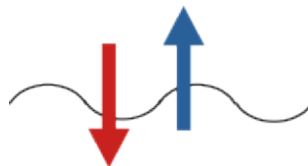
Guillaumin and Zanna, 2021



Idealized

Air-Sea fluxes

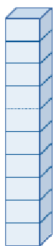
- Correction
- Bulk formulae



Storto et al., 2024

Biri et al., 2021

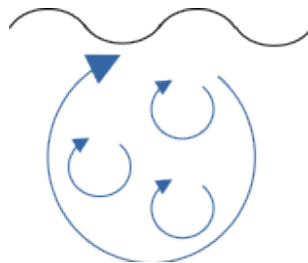
Wu et al., 2025



1D-Column

Parameterizations

- Vertical mixing
- Mixed layer eddies
- Subgrid density fluctuations



Liang et al., 2021

Bodner, Balwada and Zanna 2024

Stanley et al., 2022

OASIS3-MCT performances

Simulation speed

Realistic global 1/4° NEMO config

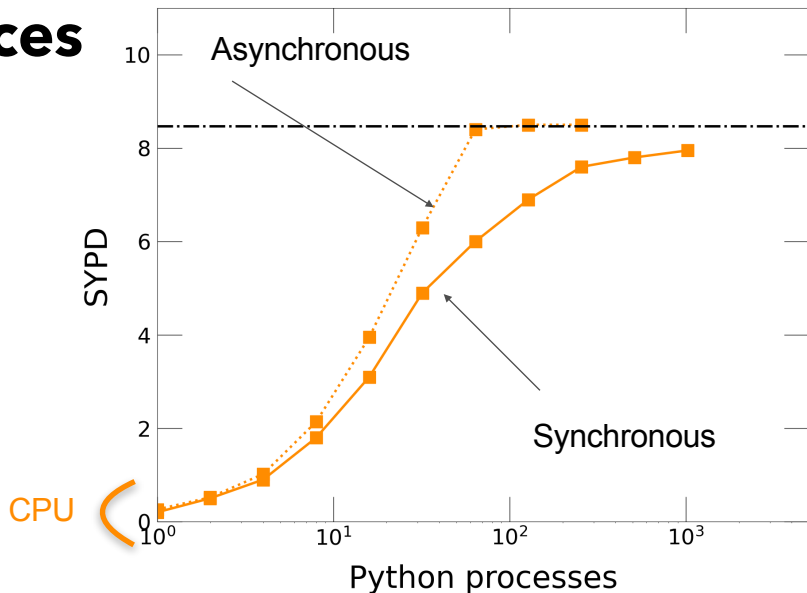
MLE parameterization

2D coupling

NEMO: 999 cpus

Bodner et al. 2024 : <https://arxiv.org/abs/2312.06972>

Work by M. Contreras



Optimal resources overhead	Synchronous	Asynchronous
ML	30 %	4-6%

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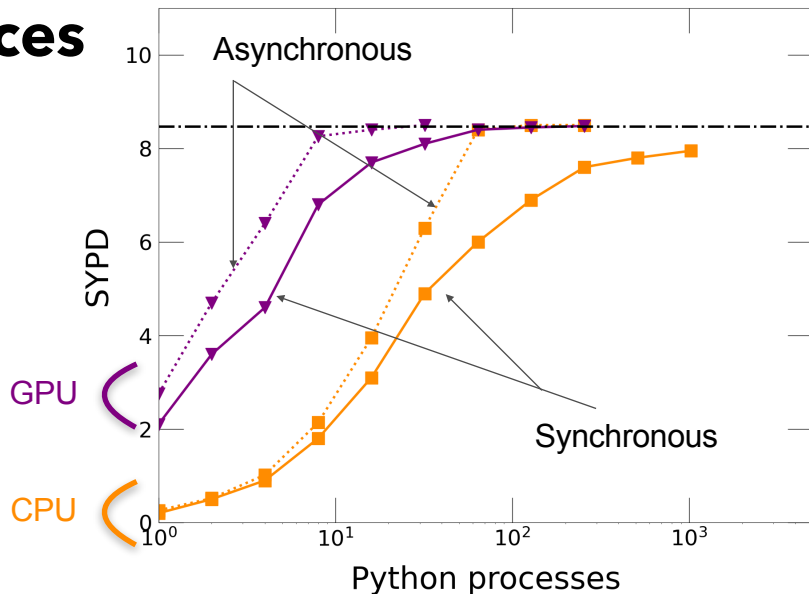
Bodner et al. 2024 : <https://arxiv.org/abs/2312.06972>

Work by M. Contreras

CPU/GPU hybridization

1 GPU per group of 40 Python CPUs

/!\ Machine dependent



<i>Optimal resources overhead</i>	Synchronous	Asynchronous
ML	30 %	4-6%
ML-GPU	2-5%	< 1%

Comparison with other solutions

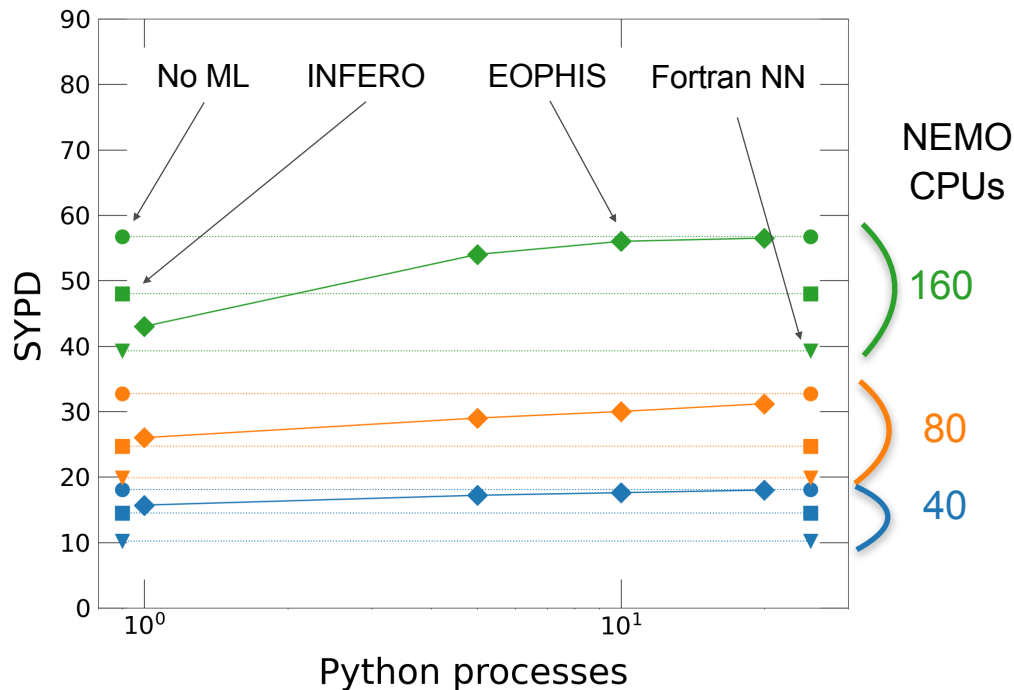
Simulation speed

Realistic global 1° NEMO config
Correction of Air-Sea heat fluxes
2D coupling

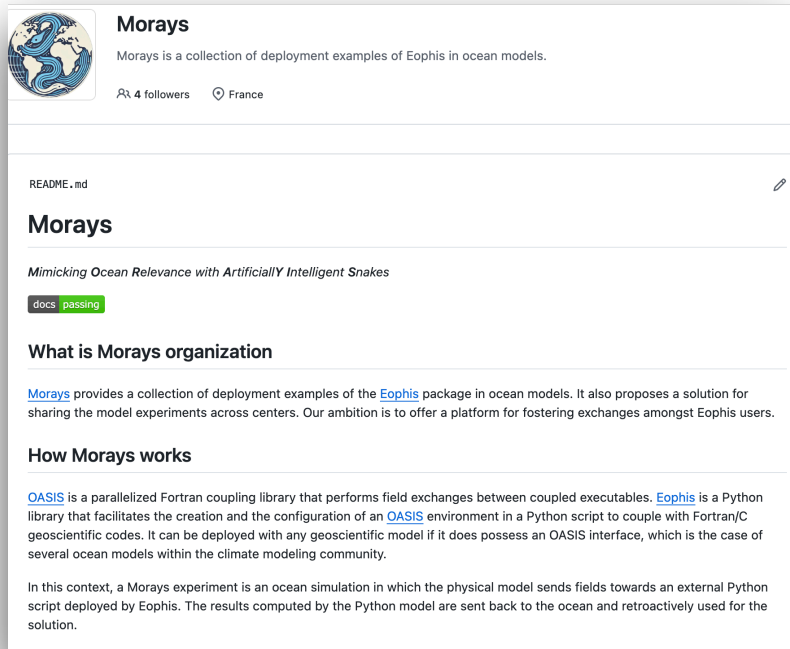
Storto et al. 2024 : [10.5194/gmd-2024-185](#)

Compared methods

Fortran-written NN
TensorFlow Fortran wrapper INFERO
OASIS3-MCT and EOPHIS



Morays-Community: Reproducible hybrid ocean modeling



Morays

Morays is a collection of deployment examples of Eophis in ocean models.

4 followers France

README.md

Morays

Mimicking Ocean Relevance with Artificially Intelligent Snakes

docs passing

What is Morays organization

Morays provides a collection of deployment examples of the Eophis package in ocean models. It also proposes a solution for sharing the model experiments across centers. Our ambition is to offer a platform for fostering exchanges amongst Eophis users.

How Morays works

OASIS is a parallelized Fortran coupling library that performs field exchanges between coupled executables. Eophis is a Python library that facilitates the creation and the configuration of an OASIS environment in a Python script to couple with Fortran/C geoscientific codes. It can be deployed with any geoscientific model if it does possess an OASIS interface, which is the case of several ocean models within the climate modeling community.

In this context, a Morays experiment is an ocean simulation in which the physical model sends fields towards an external Python script deployed by Eophis. The results computed by the Python model are sent back to the ocean and retroactively used for the solution.

GitHub Morays-Community

Use cases of ML closures in ocean models with EOPHIS
Examples deployment and tutorial

<https://github.com/morays-community>

Templates for sharing hybrid experiments
Reproducible environment and codes

Open to contribution
Documentation and tutorial

https://morays-doc.readthedocs.io/en/latest/nemo.getting_started.html

Discussions

- Review of ESMs coupling libraries for hybrid modeling
- Practical aspects and missing features identified
- Feedbacks for next generation of ESMs coupling libraries

Realizations

- EOPHIS** and **Morays**: operational tools to build and share hybrid ocean modeling experiments
- Increasing number of realizations and collaborators
- Paper under submission to GMD

Perspectives

- Couple NEMO with sea-ice emulator developed by C. Durand and P. Rampal
- Extend work to other OASIS3-MCT equipped models
- Support backend to other Python interfaced coupling libraries (YAC, XIOS ?)



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Merci pour votre attention



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