WAVE-EDDY INTERACTIONS IN THE GULF OF LION: BRIDGING OGCMs AND OCEAN PROCESS SIMULATIONS

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1. MOTIVATION

Near-inertial waves (NIWs) play a crucial role in the ocean's energy budget. They provide a direct path to dissipation by transferring wind energy to dissipative scales in the ocean interior where mixing occurs. Quantifying their contribution to ocean mixing remains challenging because of the multiple scales involved and because meso- and submesoscale flows modulate NIW propagation. These interactions are largely unconstrained because:

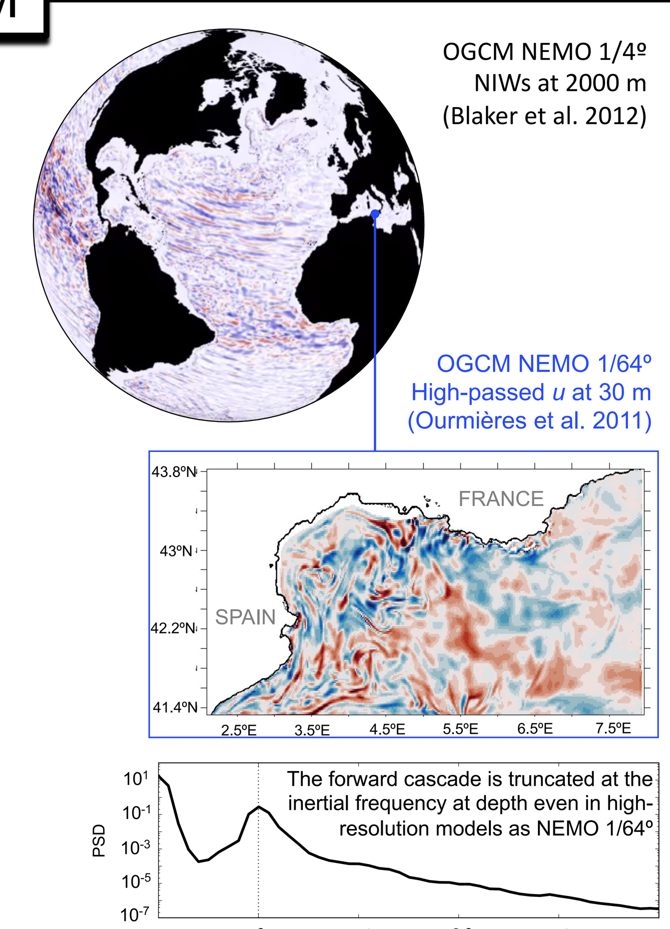
- ❑ Synoptic high-resolution observations of NIWs over large regions remain scarce.
- ❑ Idealized process studies demonstrate the importance of NIW-eddy interactions but do not typically capture both realistic background and eddy fields as well as detailed NIW dynamics.
- ❑ Eddy-permitting Ocean General Circulation Models (OGCMs) excite NIWs at the surface but do not capture NIW propagation to the interior or wave-wave interactions due to the lack of vertical resolution.

We **propose a novel numerical method** that incorporates large-scale forcing from OGCMs into a non-hydrostatic process model at high vertical resolution with the goal of **providing a mechanistic understanding of pathways to mixing driven by NIWs in a realistic oceanographic setting.**

2. THE PROBLEM

Ocean General Circulation Models are attractive tools used to quantify impacts of meso- and/or submesoscale flows over global or regional scales. Computational costs associated with resolving the smallest scales are minimized through various subgrid scale parameterizations. These parameterizations, however, typically fall short in quantifying wave-driven mixing at depth because OGCMs are hydrostatic and their vertical resolution coarsens with depth. These limitations prevent OGCMs from capturing the energy cascade to the small scales where waves are prone to shear instability.

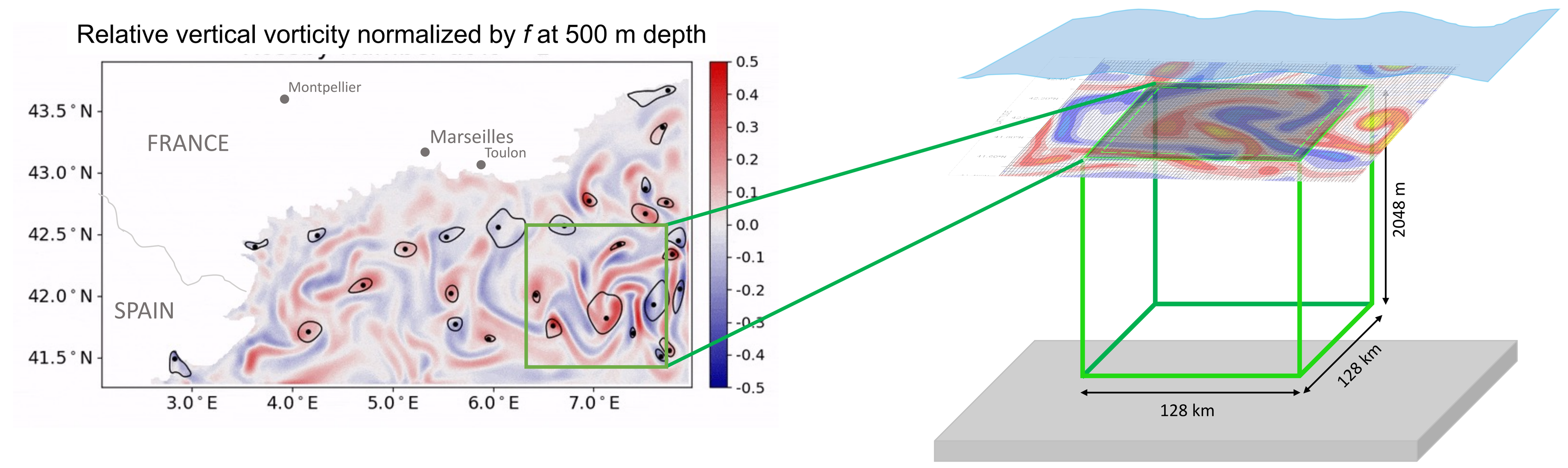
Non-hydrostatic process models, on the other hand, can resolve NIW pathways to turbulence and mixing due to wave-breaking but they are computationally prohibitive when used over domains large enough to capture background flows and eddies.



3. A NOVEL APPROACH

OGCM NEMO-GLazur64 (Ourmières et al. 2011) + **FLOW_SOLVE** (Winters et al., 2022 in prep)

- 1/64° lateral resolution(~1 km) (submesoscale-resolving)
- 130 vertical levels
- 2 years of hourly output
- Finite differences
- Hydrostatic
- Subgrid-scale parameterization
- Forced with observed hourly atmospheric fields -> NIWs excitation



- 500 m horizontal resolution
- 513 vertical levels (dz=4 m)
- Spectral methods
- Non-hydrostatic
- FLOW_SOLVE forced by OGCM NEMO-GLazur64 solutions at Open Boundaries.

THE NUMERICAL PROBLEM AND SOLUTION

Spectral codes are well suited for wave propagation problems, especially in the non-hydrostatic regime. However, they are **ill-suited to handle arbitrary boundary conditions** such as those provided by NEMO-GLazur64 in a nested simulation.

Solution? Discontinuous endpoint derivatives are removed before applying spectral methods using analytically differentiable Bernoulli polynomials.

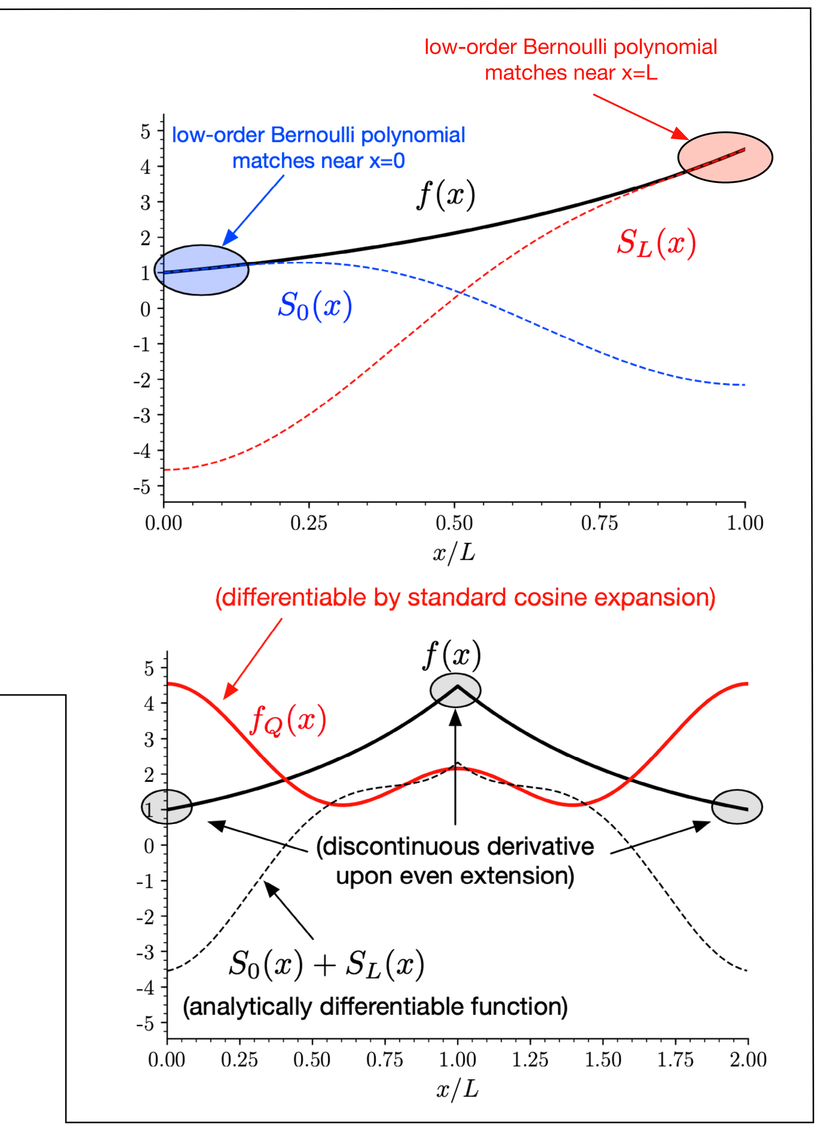
Illustration of the method in 1D

Let f(x) be a simple function defined in domain 0 < x < L that satisfies externally supplied boundary values. To differentiate this function, it is decomposed as:

f(x) = S_0(x) + S_L(x) + S_Q(x),

with

- S_0 (x) and S_L (x) low-order Bernoulli polynomials.
- S_0(x) = f (x) near x = 0 and S'_0(L) = 0.
- S_L(x) = f (x) near x = L and S'_L(0) = 0.
- S_Q(x) = f (x)-s_0(x)-S_L(x) and S'_Q(0) = S'_Q(L) = 0, so S_Q(x) is expandable in a differentiable cosine series.

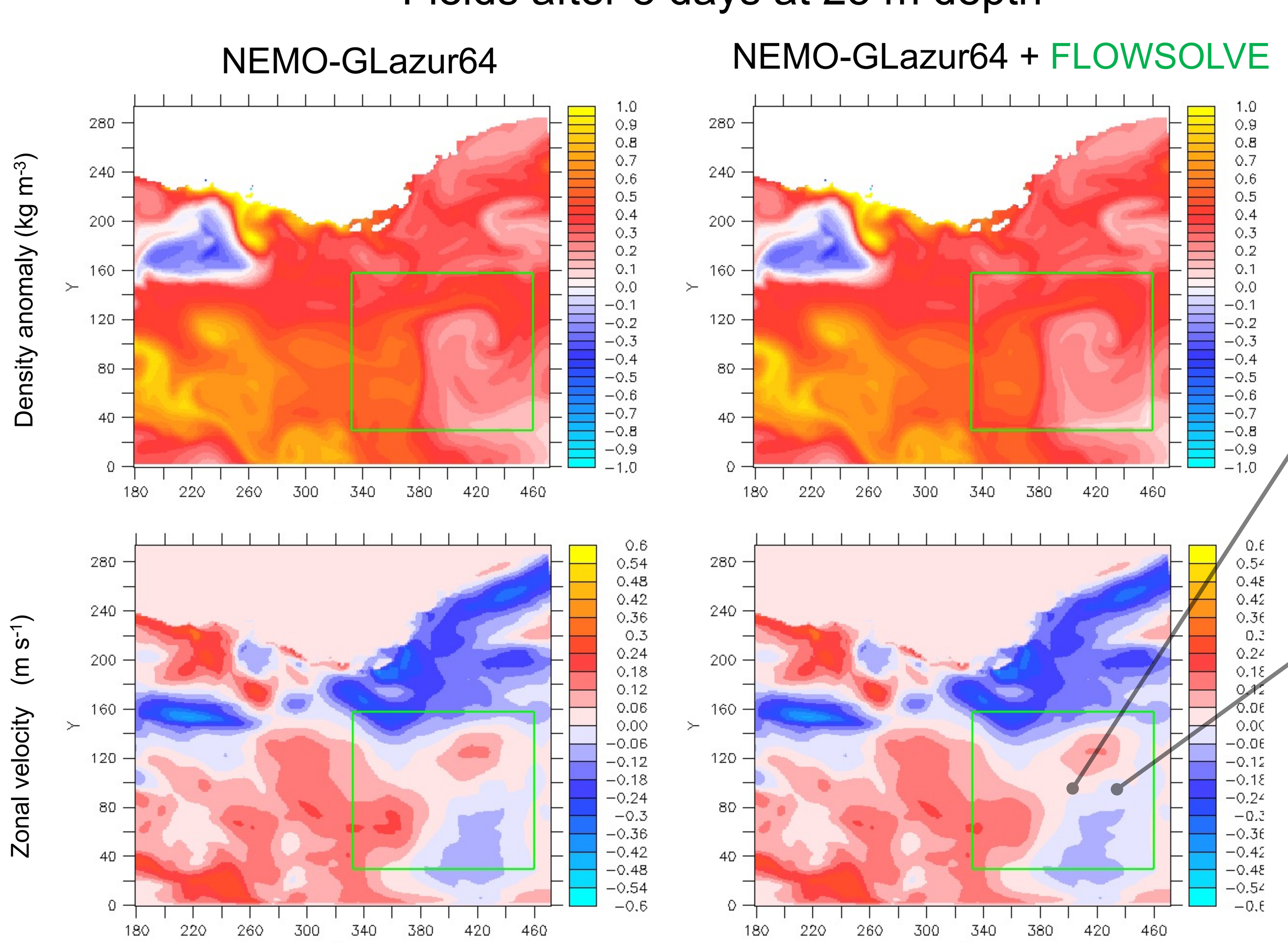


Our approach overcomes OGCMs and process models limitations by performing high-resolution nonhydrostatic simulations in limited domains while retaining the impact of larger scales through boundary forcing with OGCM fields. In contrast to conventional nesting techniques, our approach has the following **advantages**:

- ❑ It retains the accuracy and computational efficiency of traditional spectral methods.
- ❑ Small scales are resolved directly, eliminating the need for subgrid-scale parameterizations.
- ❑ Vertical domains can be limited and need not to span the entire water column.

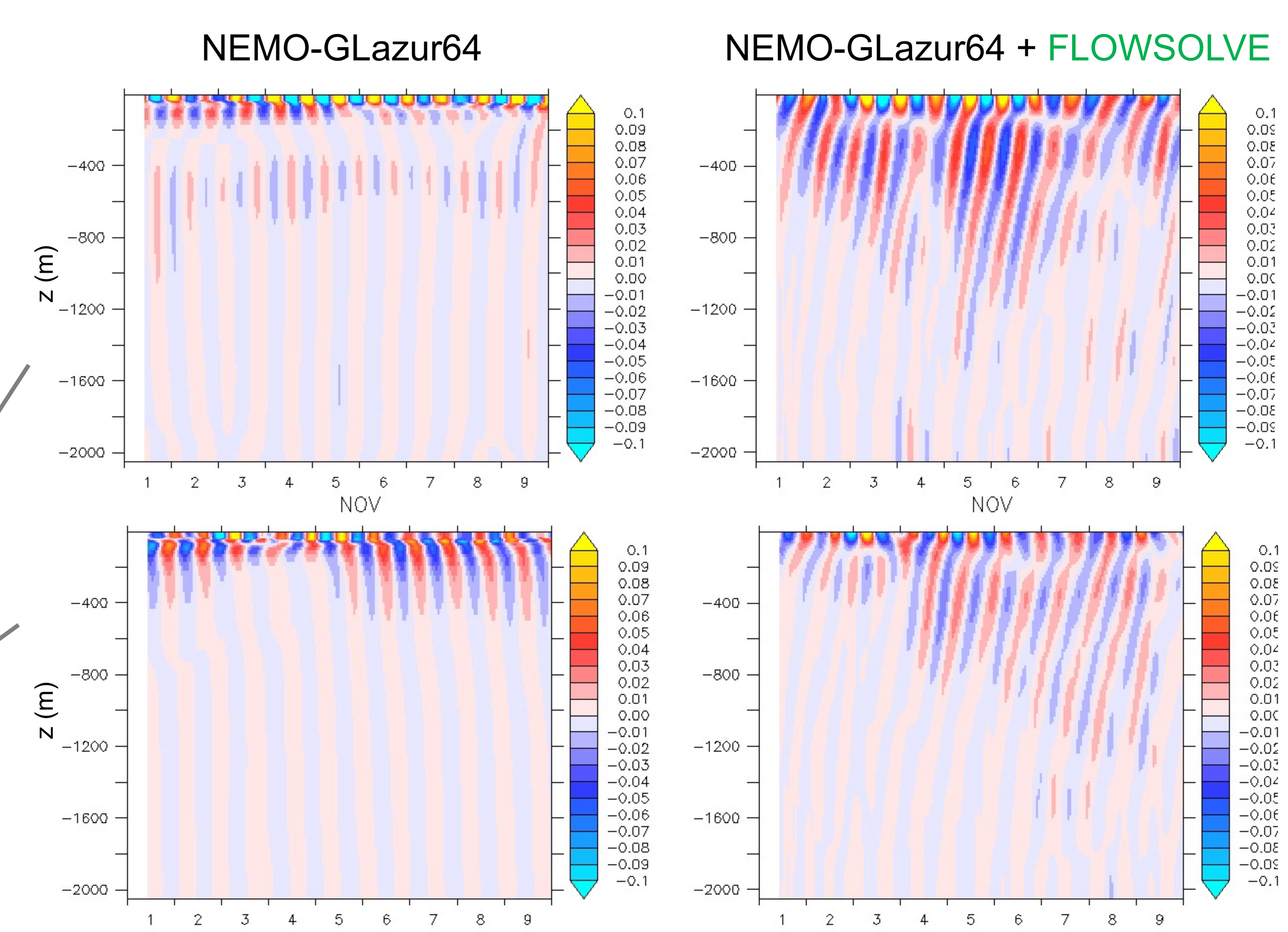
4. RESULTS

Fields after 8 days at 25 m depth



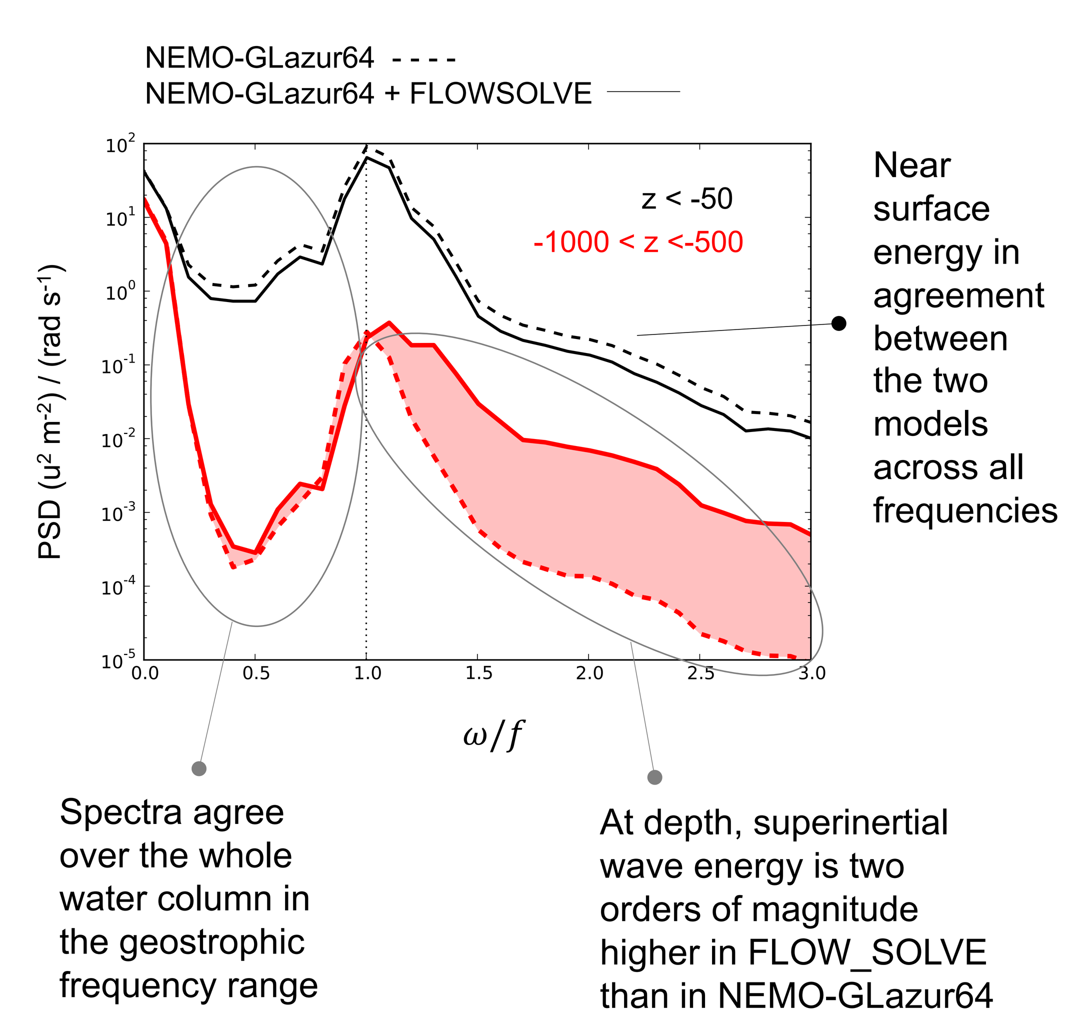
Density and velocity fields from OGCM NEMO-GLazur64 enter smoothly the FLOW_SOLVE domain through open boundaries

Hövmoller diagrams of high-passed zonal velocity (m s^{-1})



NIWs in FLOWSOLVE penetrate deeper than in OGCM NEMO-GLazur64 and show more vertical structure as a result of increased vertical resolution

Domain averaged frequency spectra



Near surface energy in agreement between the two models across all frequencies

Spectra agree over the whole water column in the geostrophic frequency range

At depth, superinertial wave energy is two orders of magnitude higher in FLOW_SOLVE than in NEMO-GLazur64

5. CONCLUSIONS

- ❑ Demonstration of a novel Bernoulli-Cosine numerical technique for modeling flows with arbitrary boundary conditions.
- ❑ Successful nesting of FLOW_SOLVE within an arbitrary embedded domain from an OGCM.
- ❑ Wind-driven NIW energy propagates downward in nested simulation, in contrast to the surface layer confinement of NIWs seen in NEMO-GLazur64.
- ❑ Richer and more energetic wave frequency spectra below the mixed layer suggesting resolution of the energy cascade to higher frequencies.

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