A kilometric scale nested configuration in the Copernicus IBI model: assessment, and impact on oceanic currents

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WOC (World ocean circulation) user consultation meeting 2022

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Abstract

In the framework of the IMMERSE project, the NEMO ocean model has recently undergone a deep rewriting. One of the major expectations was a significant jump in efficiency/accuracy thanks to the reformulation of the vertical coordinate, optimized cache memory access, a new time stepping with an extended stability range and an improvement of the vertical physics and air-sea interactions. As a testbed of the freshly released v4.2 version, we present here a kilometric scale configuration, two-way nested in the existing Copernicus IBI operational system, spanning the Bay of Biscay and the western Mediterranean Sea. With explicit tidal forcing, and the associated ubiquitous presence of large internal waves, this also makes a challenging test for the online block structured refinement procedure.
Based on a 18 month long experiment (January 2017 – June 2018), we perform a standard assessment of our nested configuration against satellite and in-situ data. We focus on the validation of the surface currents and of the sea surface height. Then, we investigate the impact of the high-resolution nest on the ocean currents by comparing the simulation with a twin experiment over the same period but without nest. We show that the high-resolution nest increases the kinetic energy of small-scale, and short lived (less than a month) oceanic structures. In the open ocean, the kinetic energy of internal waves is significantly increased in the nested configuration. We also observe an increase of the oceanic KE in regions where the Rossby radius is small such as the Mediterranean Sea.

Context : Benefits of increasing the resolution of ocean models

- Currently, the highest resolution of Mercator configurations (used for ocean reanalysis or forecasts) is 1/36° (2-3km)(e.g : IBI36, Sotillo et al., 2015).
- Mediterranean sea : mesoscale structures are poorly resolved at a 1/36° (only 2 to 3 points per eddy) (Fig. 1).
- Continental shelf: eddies are not resolved.
- Kilometric resolution :
  - -Mesoscale resolving in the Mediterranean sea, and submesoscale permitting over the shelf
  - -Better representation of ITW spectrum (higher modes).
  - -Better representation of geometric constraints (e.g : Gibraltar strait)

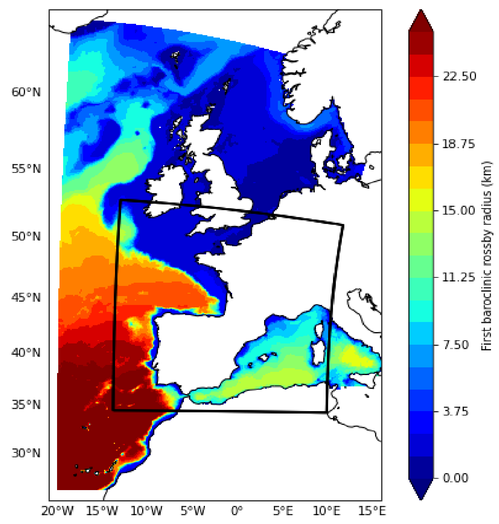

Figure 1 : First baroclinic rossby radius on the eNEATL36 domain. Nest area is indicated in black,. The Galician bank section is indicated in grey

eNEATL36 + BIZoo configuration (Biscay zoom)

- **Parent configuration: eNEATL36 (Figure 1)**
  - -1/36° resolution (~2-3km)
  - -150s time step
- **High resolution nest: BIzoo**
  - -based on AGRIF code (Debreu and Blayo, 2008)
  - -1/108° resolution (~1km)
  - -50s time-step
- **Forcing :**
  - -Atmospheric : IFS operation analysis
  - -Initial & lateral boundary condition : 1/12° CMEMS operational product
  - - Tides : FES2014
- **Bathymetry** : Emodnet 2018
- NEMO 4.2 version (Madec et al. 2022)
- **2 way nesting between the parent and the child configuration**

Simulations : 2017/01 – 2018/06 period

- **NEST:** - eNEATL36 + BIZoo
  - Drag boost x2 (for stability issues) in the bay of Bristol and of the mt saint Michel
- **TWIN:** - eNEATL36 only
  - Same parameterisations / schemes /drag boost as NEST
  - Slightly different topography

Macroscopic validation

- **SLA along satellite tracks (Jason 3, Fig. 2):**
  - SLA = proxy of geostrophic currents
  - Unfiltered from tides
  - Good agreement with satellite SLA for scales >70km (=satellite effective resolution)
  - Model small scales filtered by on-track interpolations : current altimeter resolution is not sufficient to validate models finer scales.

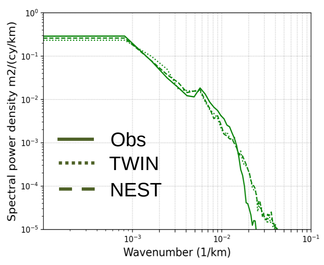

Figure 2: SLA spectrums

- **Tides : Validation with FES2014 (Fig. 3):**
  - NEST : Good agreement with FES (differences < 15cm)
  - Stronger differences in tidal amplitude over the shelf : differences in bathymetry between NEST and TWIN.
  - Continuous tidal solution across the nest boundaries.

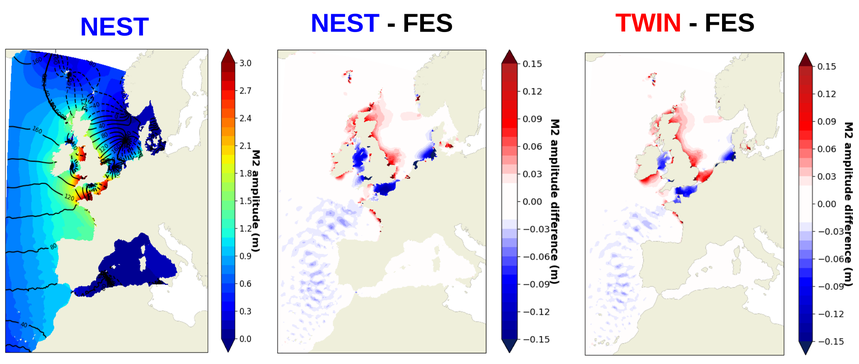

Figure 4: M2 amplitude, comparison with FES2014

Validation of internal tides

- Figure 5: Comparison with MIOST-IT (Ubelmann et al. 2022)
- Model data : harmonic analysis on mode 1 only, computed over two months of data (08-09/2017)
- We apply a correction factor of 0,7 on the model data to take into account the length of the analysis (Buijsman et al., 2020).
- Good agreement of NEST with MIOST

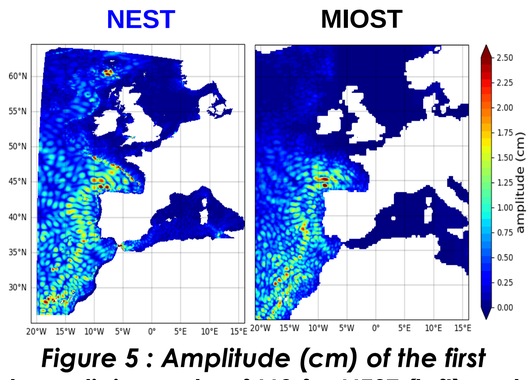

Figure 5 : Amplitude (cm) of the first baroclinic mode of M2 for NEST (left) and MIOST dataset

Resolution impact on kinetic energy temporal scales

- **KE for scales between 1 day and 1 month:**
  - Small Rossby radius of the Mediterranean sea = mesoscale is properly resolved in NEST = Increase of KE
- **Subdaily KE:**
  - Over the shelf : differences in KE due to changes in barotropic tide amplitude.
  - Bay of Biscay: increase of KE in NEST, ITW or balanced motions?
- **KE temporal spectrum in the bay of Biscay (Fig 6.):**
  - Nest : impact the whole KE spectrum for scales < 1 day
- **Energisation in the bay of Biscay:** due to submesoscales structures, or oceanic re-energisation by tides ?

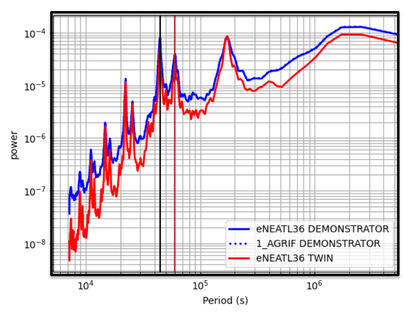

Figure 6 : Temporal KE spectrum over the bay of Biscay (over the dark square in Fig.7)

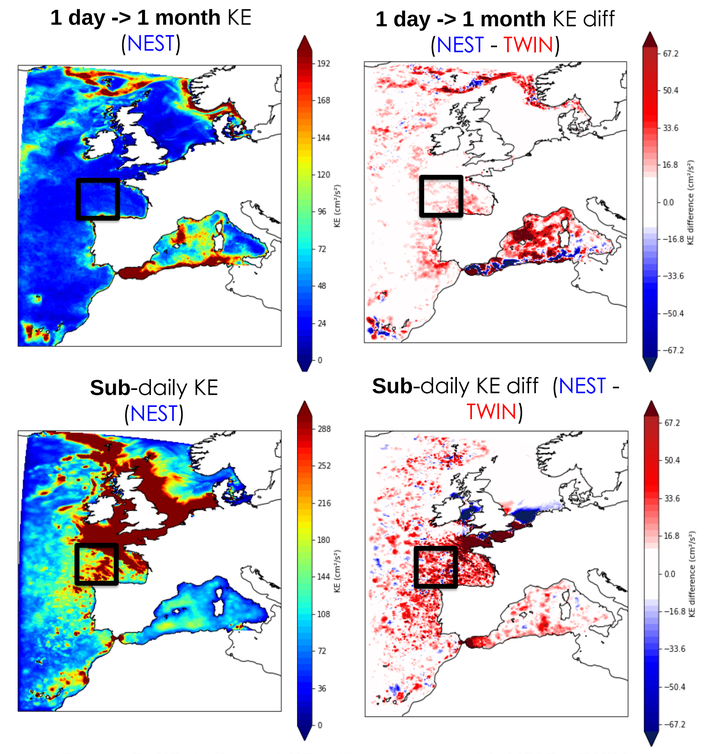

Figure 7: KE (left) and KE differences (right, NEST – TWIN) averaged over 2017. The dark square represent the area over which the KE spectrum in Fig.6 is computed

Impact on internal waves & balanced motions

- **Internal waves :**
  - Modal analysis (Lahaye et al. 2020) over the August / September 2017 period
  - Highly stratified period
  - Increase of KE of high modes with the nest (Fig. 9)
- **Balanced motions :**
  - Much more small scales / submesoscales structures in NEST (Fig 8.)
- **The nest has an impact on both balanced motions and ITW**

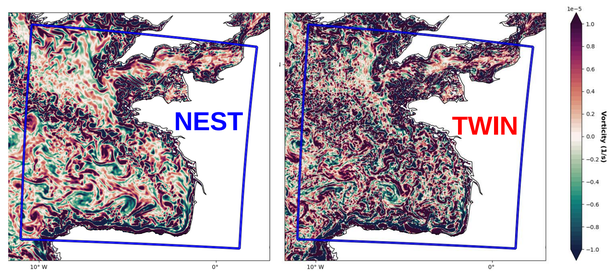

Figure 8 : Snapshot of the vorticity averaged over one day, the 2017/09/01 for NEST (left) and TWIN (right), the area over which we performed the modal analysis is indicated in blue

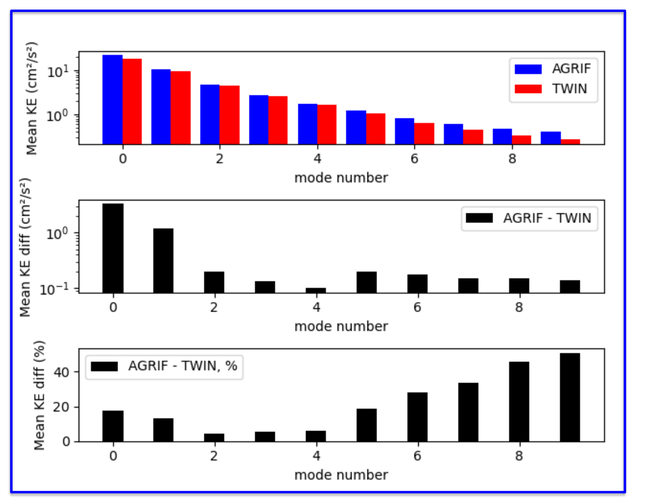

Figure 9 : (top) Mean KE averaged over the nest area (the continental shelf has been masked) and absolute (middle) and relative (bottom) differences in KE (cm²/s²) between NEST and TWIN

Conclusion and perspectives

- The high-resolution nested configuration eNEATL36 + BIZoo (test case for NEMO 4.2 and AGRIF) was successfully implemented in the frame of IMMERSE project.
- The tidal solution is realistic when compared to observation-derived products.
- **Bay of Biscay**: the high-resolution nest has an impact on both internal tides and balanced motions, and over the whole KE spectrum for scales < 1 day.
- **Mediterranean sea:** small Rossby radius, a kilometric-resolution model is able to solve the mesoscale.
- **Perspectives:**
  - Comparison with a non-tidal run
  - Additional tests: Increase of vertical resolution, wetting & drying

Recommendations

- A kilometric resolution is needed to properly represent the mesoscales in the Mediterranean sea, and to improve the representation of internal waves in the bay of Biscay.
- Higher resolution satellite datasets (such as SWOT), and / or access to high resolution surface current estimation would allow to better validate model dynamics at finer scales.