SYMPOSIUM OP'24 — ADVANCING OCEAN PREDICTION SCIENCE FOR SOCIETAL BENEFITS

Theme #5.7 –
Improvements of operational systems

Tides representation in eddy permitting, eddy rich and sub-mesocale permitting global configurations based on NEMO OGCM

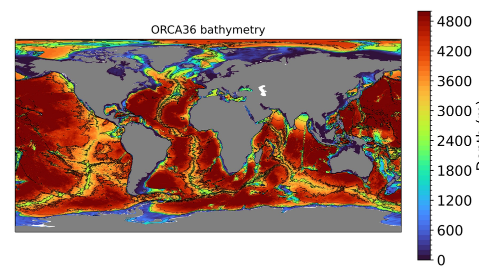
Introduction

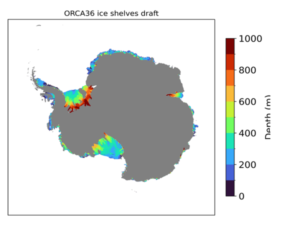
In the framework of the Copernicus Marine Environment Monitoring Service, Mercator Ocean International operates a global high-resolution forecasting system at the resolution of 1/12°. Resolving scales below 100 kilometers, and in particular sub mesoscale processes (1-50 km), appears to be essential to better represent the circulation in the open ocean (Chassignet, 2017), and, to improve the large-scale representations thanks to a more explicit energy transfers between finer and larger scales (Fox-Kemper Baylor, 2019). In particular, mixing plays a significant role in shaping the mean state of the ocean. Global internal tides are one of the sources of this mixing. Increasing resolution appears necessary to improve the barotropic tides solution and the baroclinic tides generation.
Benefiting from the context of the European H2020 IMMERSE project, a new 1/36° global configuration (2 to 3 km resolution), based on the NEMO 4.2 OGCM, has been developed. Thanks to the resolution increase, this model can resolve the Rossby radius in almost all open oceans areas at global scale quite everywhere and to span a large part of the internal wave spectrum.
A hierarchy of multi-year simulations at 1/4°, 1/12° and 1/36° resolution and with/without explicit tide representation has been performed: for each resolution, after a 3-years spin up without tidal forcing, 2 twin 3-years runs have been realized: one without tidal forcing and one forced by the 5 tidal components K1, O1, S2, M2, N2. These models are driven at the surface by the 8km/1hour ECMWF IFS system. Atmospheric pressure forcing have been activated.
We propose an evaluation of the benefits due to the resolution on the barotropic tidal solutions and the internal tides content.

1. Method: Model configurations and parametrizations

Configuration:

Horizontal grid : tripolar ORCA grid (12960 * 10850 points)
Vertical grid: 75 Z-levels, 1 meter at surface
Domain Include Antarctic Ice Shelves (explicit resolution)
Bathymetry: GEBCO 2019 (GEBCO, 2019) and Bedmachine Antarctica 2
Antarctic ice caps: Bedmachine Antarctica 2





Code:
NEMO 4.2 release (including sea-ice SI3 model)

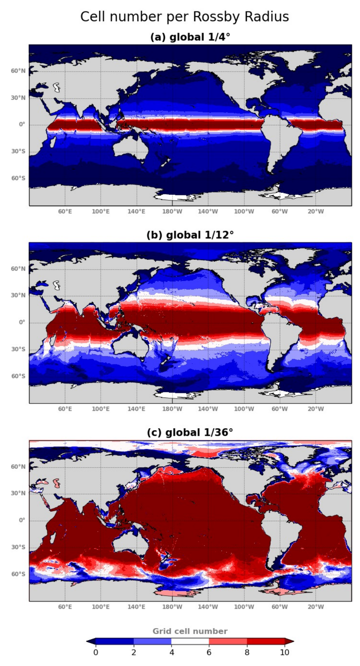
Numerical settings:
Non-linear free surface (Quasi-eulerian Coordinates formulation)
Forcing: ECMWF bulk formulae + Atmospheric pressure gradient.
Tracers transport: FCT advection scheme 4th order on horizontal and vertical + Explicite diffusion with iso-neutral operator
Dynamic: Advection: flux form - 3rd order UBS + No explicit viscosity
Vertical physic: Vertical mixing: k-epsilon vertical mixing (GLS) + adaptive-implicit vertical advection (Shchepetkin 2015)

Impact of resolution on waves resolution:
A minimum of 2 grid cells per Rossby radius to resolve a wave on a discrete grid (Hallberg, 2013)

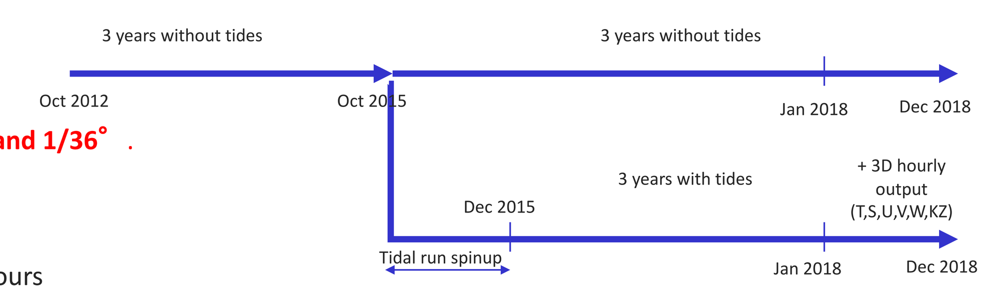
Global ¼° : eddy-permitting
Global 1/12° : eddy-rich
Global 1/36° : eddy resolving
+ able to represent a part of the sub-mesoscale activity: sub-mesoscale permitting.

Configuration	30°S / 30°N	80°S / 30°S and 30°N / 80°N	80°S / 90°S and 80°N / 90°N
ORCA025	2-10	0-1	0
ORCA12	4-10	1-4	0-1
ORCA36	10	6-10	3-6

Number of grid cells to resolve the first Rosby deformation radius



2. Hindcast set up

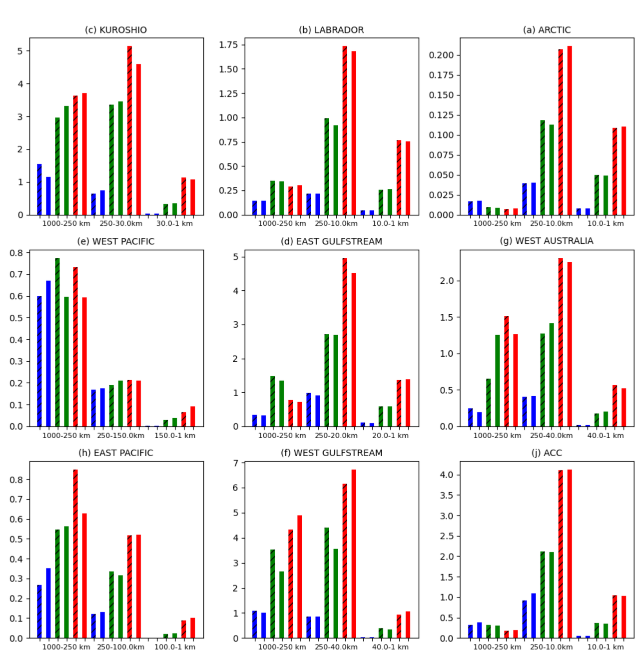


- A portfolio of simulations at **1/4°, 1/12° and 1/36°**. **Without** and **with tidal** forcing

- **Atmospheric forcing**
from ECMWF/IFS real time system at 8 km/1 hours
- **Initial conditions**:
T&S from WOA13 climatology
sea-ice form CMEMS/Mercator ¼° reanalysis GLORYS2V4.
- **Tidal forcing**: O1, K1, M2, S2, N2 + Self Attraction Loading
- **Runoff**: climatology
- **Run on ECMWF/ATOS computer**: 25600 cores for NEMO, 100 XIOS servers (1 per node), 2 months per day
- **Model outputs:** 3D daily average (T, S, U, V, W, KZ, SBC,SI), 2D hourly (T,S,U,V,SSH)

If Tidal model: + 3D 25h average (T, S, U, V)
Last year of each hindcasts: + 3D hourly average (T, S, U, V, W, KZ, sea ice)
MOI Observation operator (NOOBS): SLA, SST, SSS, SIC, INSITU

3. Kinetic Energy representation: spatial decomposition



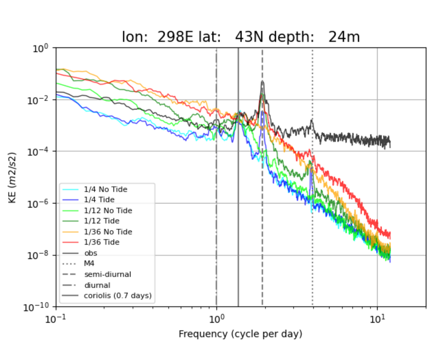
hashed boxes : no tidal forcing
Empty boxes: tidal forcing

3 bands:
the large scales : from 1000 to 250 km
the mesoscales: from 250 km to the local first baroclinic Rossby radius of deformation
the sub-mesoscales: from the first baroclinic Rossby radius of deformation to 1 km

freq < 10−2 cyc/km, ORCA12 and ORCA36 are close and ORCA025 is weaker in most of the boxes.
freq > 10−2 cyc/km, the 3 configurations well differ.
freq > 10−1 cyc/km, only ORCA36 is able to produce SKE.

- ORCA025 is not able to represent all the mesoscale
- ORCA12 can not represent the finest mesoscale processes and can not simulate sub-mesoscale phenomena.
- ORCA36 is able to represent all the mesoscale processes and can simulate the largest sub-mesoscale processes.

4. Kinetic Energy representation: temporal decomposition

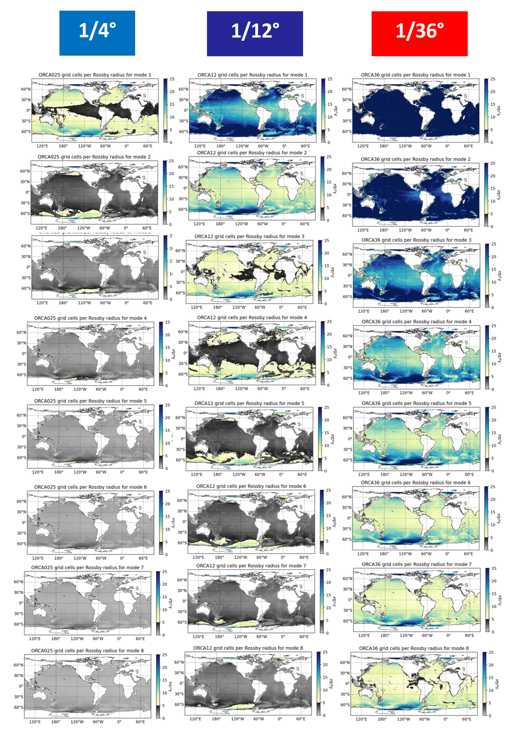


As in Luecke 2020: compare model spectra to observations (GMACMD database)
Non-tidal and tidal solutions at ¼°, 1/12° and 1/36° resolutions are compared to observations.
The KE content increases at all scales with the model resolution.
Models with a higher resolution and tidal forcing are closer to observations.
Impact of tidal forcing at coriolis, semi-diurnal and M4 frequencies:
- Tidal-forced models well reproduce the hint of energy, also present in the observations.
- Impact of tidal forcing at f > 1 cyc/day : no major impact on ORCA025 but changes for ORCA12 and ORCA36
- Impact of tidal forcing at f > M4: more energetic for ORCA36

Conclusions

A multi-year hindcast has been performed, with the twins global ¼° and 1/12° configurations. Without and with tidal forcing.
Increasing resolution leads to an improvement in term of energy.
Improved representation of barotropic tide thanks to resolution (and Antarctic cavities in the domain).
7 baroclinic modes resolved for ORCA36, 2 baroclinic modes resolved for ORCA12.
Specific diagnostics has been designed to highlight benefices of resolutions and tidal forcing.

5. Vertical modes decomposition and harmonics extraction



5.1 Modes decomposition:

Based on the theory for linear internal waves.
Assuming that vertical and horizontal motions can be decoupled.
Leads to resolving the Sturm-Liouville problem.
Need to 3D hourly outputs to compute pressure at hourly frequency.

Mode n = 0 : barotropic mode
Modes n ≥ 1 : baroclinic modes

To determine the number of modes that can be resolved, comparison between:
- the size of the horizontal resolution: $\Delta x = \max(dx, dy)$
- the M2 wavelength of the mode: $\lambda_n = \frac{2\pi c_n}{\sqrt{\omega^2 - f^2}}$

We consider that the mode is resolved if $\lambda_n/\Delta x > 5$.

Grey/black. : $\lambda_n/\Delta x < 5$. => mode not resolved
Yellow/green/blue: $\lambda_n/\Delta x > 5$ => mode resolved

ORCA025 does not fully resolve any modes
ORCA12 resolves 2 baroclinic modes
ORCA36 resolves 7 baroclinic modes.

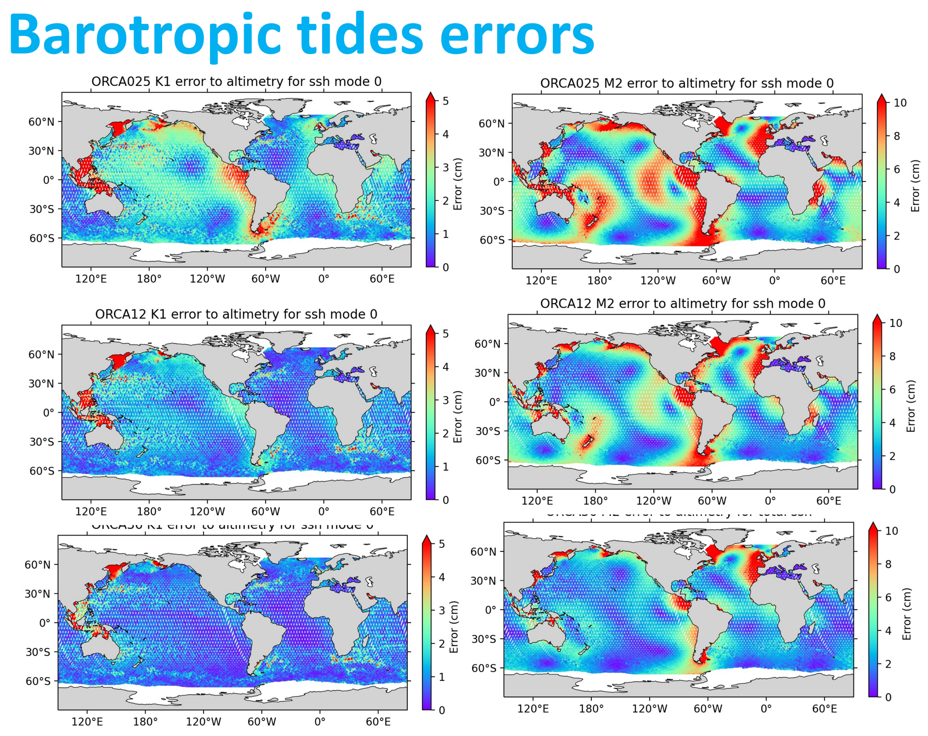
Ref: N. Lahaye, GitHub - NoeLahaye/ITideNATL: ongoing work for internal tide analyis in eNATL NEMO simulations

5.2 Harmonics extraction:

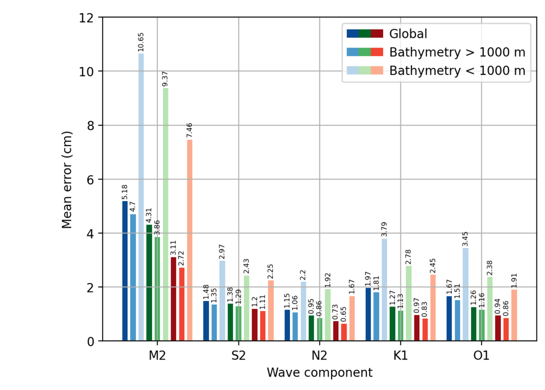
2 ways to extract harmonics:
filtering around harmonics frequencies => coherent and incoherent signals
Harmonic analysis => coherent signals

Here we perform harmonic analysis, over a 3 months period (January to March 2018).

6. Barotropic tides errors



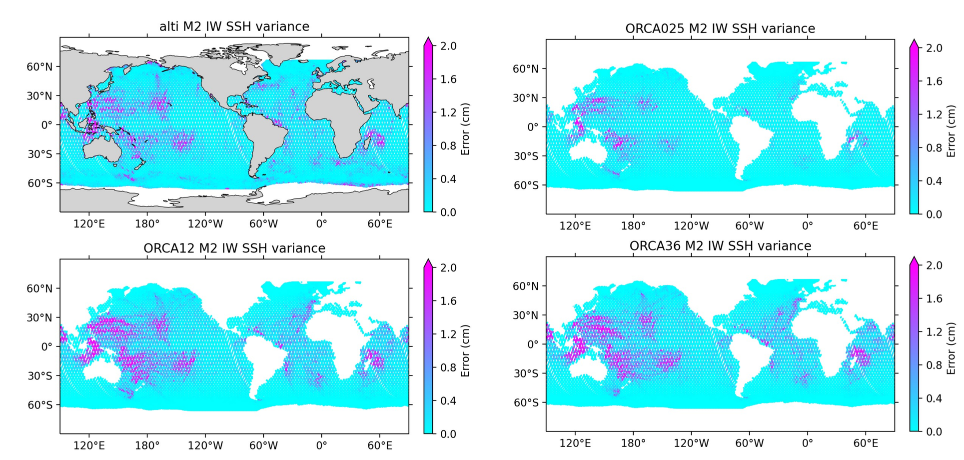
K1 (left) and M2 (right) errors to altimetry for ORCA025 (top), ORCA12 (middle) and ORCA36 (bottom) for a 3-months harmonical analysis. SSH mode-0 have been used for models analysis



Errors to altimetry for a 3-months harmonical analysis. SSH mode-0 have been used for models analysis
Blue: ORCA025, green: ORCA12, red: ORCA36

- The harmonical analysis is performed on a 3-months period with SSH mode-0.
- Increasing resolution reduces model errors to altimetry and improve barotropic tides representation.

7. Baroclinic tides SSH variances



M2 internal tides variances for altimetry (top left), ORCA025 (top right), ORCA12 (bottom left) and ORCA36 (bottom right).

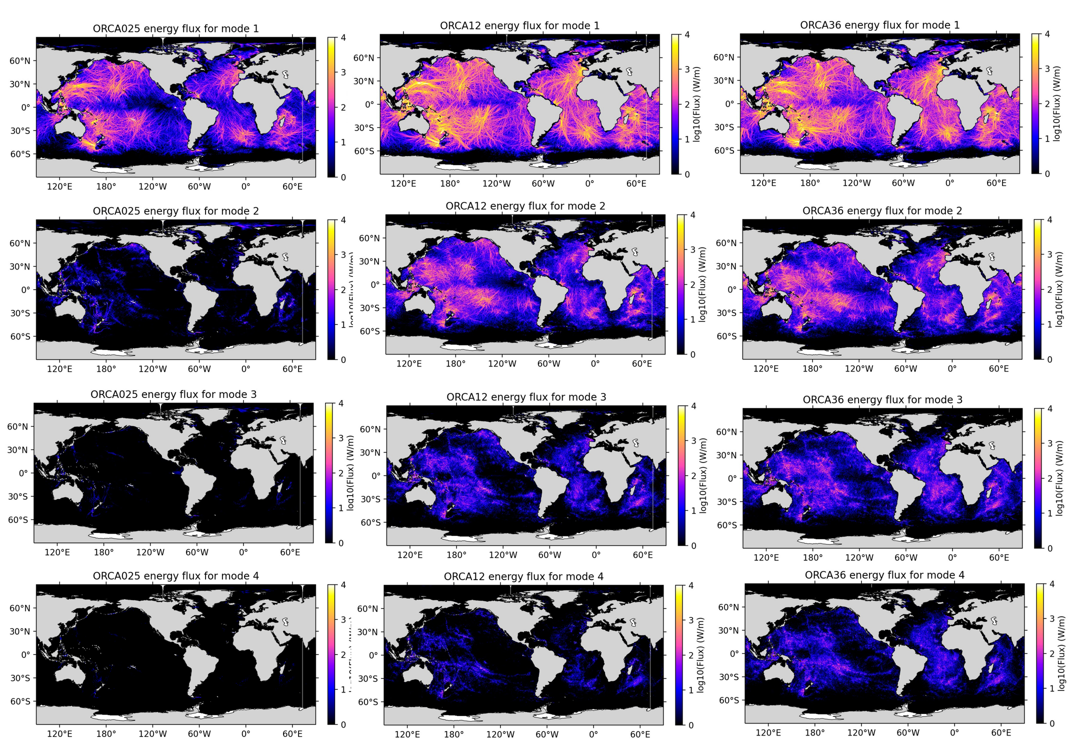
- Internal tides extraction:

Altimetry:
FES (barotropic) amplitude are removed from altimetry, then a 50-400 km band-pass filtering is applied

Model:
sum of modes 1 and 2

- Large increase of variance with resolution
- ORCA12 and ORCA36 have more variance than altimetry

8. M2 baroclinic energy fluxes



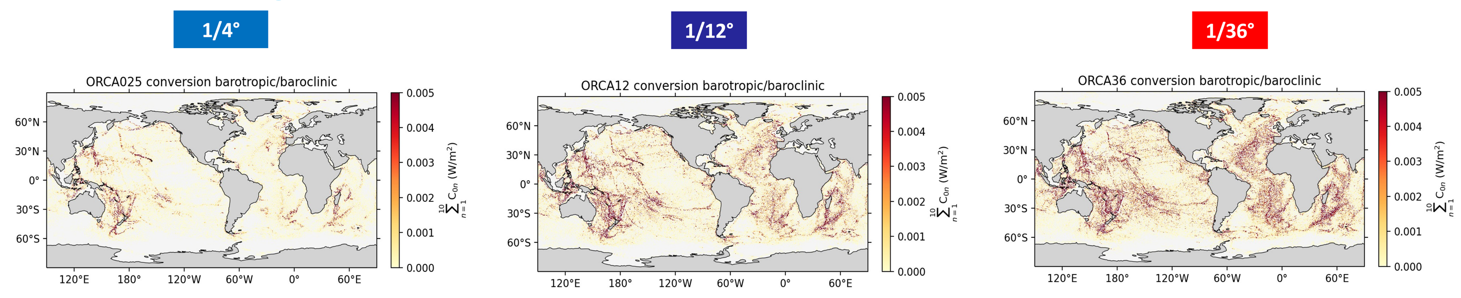
- We present M2 baroclinic energy fluxes for mode 1 to 5

Lower modes: the energy propagates over thousands of km

Higher modes: quickly dissipated

- ORCA025 energy fluxes are weak for modes greater than 2
- ORCA12 energy fluxes are weak for modes greater than 4
- ORCA36 energy fluxes are for modes greater than 5

9. Barotropic mode to baroclinic modes conversion



M2 barotropic to baroclinic conversion

resolution	M2	K1	O1	N2	Q1	S2	Total
1/36°	633	66	40	26	0	97	862
1/12°	421	57	35	17	0	64	594
1/4°	74	33	25	3	0	11	146

barotropic to baroclinic conversion rates (GW)

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