ROMS online nesting: An application to the Texas-Louisiana shelf

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August 12, 2023

1 Summary

This report describes ROMS online nesting and its applications to the Texas-Louisiana shelf undertaken for the NSF project entitled "Energy transfer between submesoscale vortices and resonantly-forced inertial motions in the northern Gulf of Mexico". The online nesting capability of ROMS is available for a recent version of ROMS (version 3.7 or later: `http://www.myroms.org`). The model result demonstrated ROMS's capability on online nesting and its drawbacks. This report is by no means detailed, but a brief description of ROMS online nesting and its application. A detailed description of ROMS online nesting and its examples is available at `https://www.myroms.org/wiki/Nested_Grids`.

2 TXLA shelf model (Parent model)

The model configured for the parent model covers the entire Texas-Louisiana shelf and its slopes (Figure 1). The model uses a curvilinear grid stretching along the coastline of Texas and Louisiana horizontally and terrain-following stretching coordinate (s-coordinate) vertically. The finest horizontal resolution is approximately 650 m and the coarsest resolution is approximately 3.7 km. The number of vertical layers (N) is 30 and more layers are concentrated near the surface and bottom to ensure the adequate number of layers in the surface and bottom boundary layers. As with the previous incarnations of this model configuration [e.g. Hetland and DiMarco, 2012, Zhang et al., 2012], tides are not included as they are very weak over the TXLA shelf [DiMarco and Reid, 1998]. The shelf model is nested into global general ocean circulation models (OGCMs), Global Mercator (`http://marine.copernicus.eu/`), which has the spatial resolution of approximately 9 km. Surface forcing and fluxes are obtained from ERA interim [Dee et al., 2011] (`https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-interim`). A total of nine rivers, namely Sabine, San Antonio, Trinity, Brazos, Calcasieu, Lavaca, Nueces as well as the Mississippi and Atchafalaya rivers, two major rivers connected to the shelf, are included. The streamflow data are obtained from U.S. Army Corps of Engineers (`https://www.mvn.usace.army.mil/`) and U.S. Geological Survey (`https://waterdata.usgs.gov/nwis`). Salinity of the rivers is set to zeros and streamflow temperature is estimated from air temperature using a bulk formulae based on Stefan and Preud'homme [1993]. The model uses third-order upwind scheme (horizontal) and 4^{th}-order centered scheme (vertical) for momentum advection and MPDATA (Multidimensional Positive Definite Advection Transport Algorithm) for tracer advection [Smolarkiewicz, 2006]. Vertical mixing is k-ω [Warner et al., 2005] and horizontal mixing is a constant value of 5.0 $m^2 \cdot s^{-1}$ for momentum and 1.0 $m^2 \cdot s^{-1}$ for tracers, both of which are scaled with grid size.

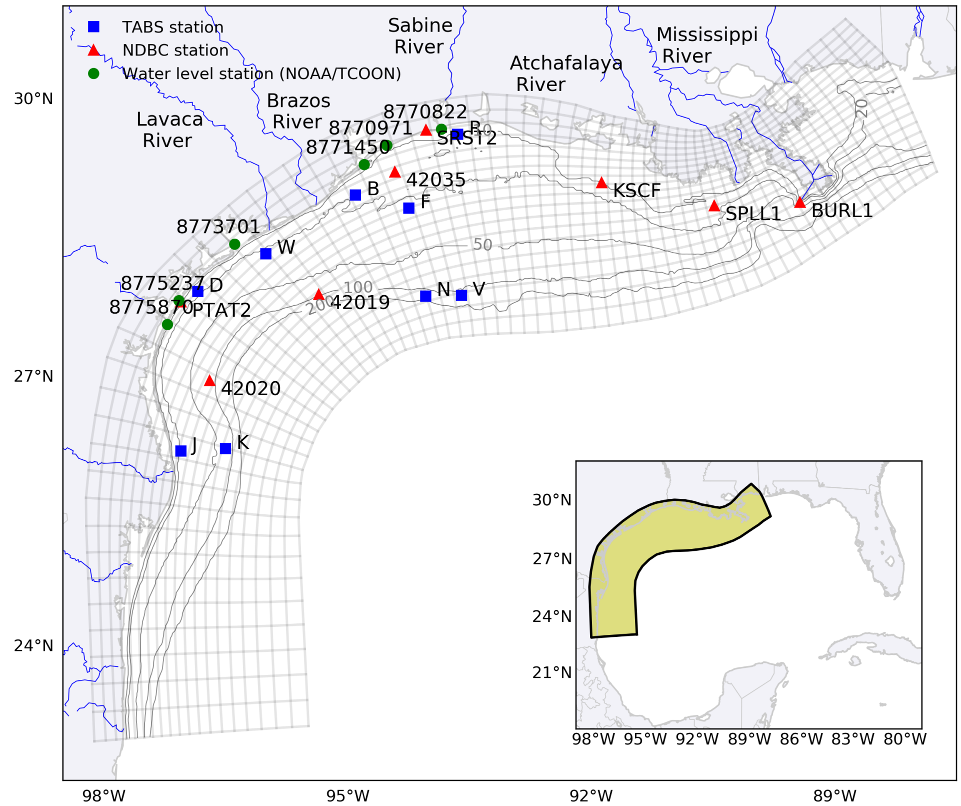

Figure 1: TXLA shelf model domain

3 ROMS online nesting

The developers of ROMS has developed a two-way nesting algorithm to exchange variables between the parent and child grids for different nesting scenarios. Users can do two-way nesting with composite grids (which allow overlap regions of aligned and non-aligned grids) and refinement grids (which increase resolution of child grids with ratios e.g. 3:1, 5:1) in a specific region. Our nested model uses refinement grid which is five times the resolution of the parent grid.

3.1 How the nesting works

ROMS has a nested design structure for coupling between parent and child grids (ROMS developers mention parent grid as "donor" grid and the child grid as "receiver" grid). All the state variables (e.g. sea surface height, current velocity, temperature, salinity etc.) are dynamically allocated and passed as arguments using F90 pointer structures. ROMS has three types of nesting capabilities: Mosaics Grids, Composite Grids, and Refinement Grids. **Mosaic grids** connects several grids along their edges, **Composite Grids** allow overlap regions of aligned and non-aligned grids, and **Refinement Grids** provide increased resolution (e.g. 3:1 or 5:1 aka refinement factor) in a specific region. The refinement factor (i.e. the ratio of the parent and child grid resolution) in C-grids needs to have an integer value given by an odd number (2 * n + 1 where n=1,2,3...) to always guarantee a ρ-point at the centre of the grid cell.

ROMS uses contact points for nested modeling. The contact region is an extended section of the grid that overlays an adjacent grid, which allows us to compute full horizontal operator at the contact points between the parent and child grids (Figure 2). A contact point is a grid cell inside the contact region. Each contact region has a receiver (child) grid and donor (parent) grid. If parent and child grids share the same contact points, the parent and child grids occupy the same position and uses the donor data. Otherwise, the child grid data is linearly interpolated from the parent grid cell containing the contact point. In nesting applications, the values at the lateral boundary conditions are

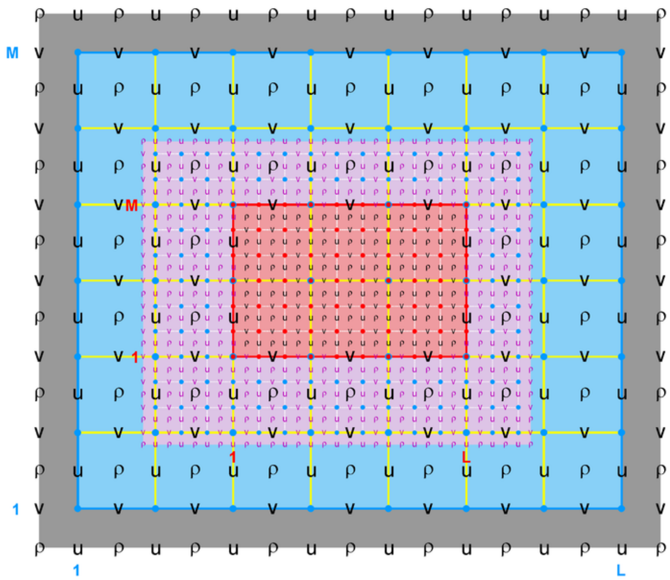

Figure 2: Schematic illustration of refinement grids used in ROMS. The parent grids are shown in Blue and the child grids in red and the contact points in purple

computed directly in the contact region by the numerical kernel. In the refinement applications, the information is exchanged at the beginning of the full time step; whereas, in composite grid applications, the information is exchanged between each sub-time step call. That is, the composite parent and child grids need to sub-time step in the 2D momentum equations before any of them start solving and coupling the 3D momentum equations. Therefore, the governing equations are solved and nested in a synchronous fashion. ROMS nesting algorithm allows us to mix composite grids and refinement grids by requiring at least two nesting layers. In the first layer, 1) composite grids 1 and 2 are synchronously sub-time stepped for each governing equation term. Then, in the second and the last nesting layer, the refinement grid 3 is time stepped and the information between the parent and child refinement grids are exchange at the beginning of the time step for both contact regions: coarse-to-fine and vice versa. Thus, the exchange between grids is two-way.

ROMS nesting capability can be activated by defining TWO_WAY in cppdef.h. ROMS is also capable of doing one-way nesting by defining ONE_WAY in cppdef.h. In this case, ROMS only exchanges variables from the parent to child grids, but not the other way. In order to run the nested model, users will need the child grid bathymetry and contact file as well as the forcing and initial conditions files.

3.2 TXLA nesting application

A nested model was developed for the Texas-Louisiana shelf. The model domain was selected for the region of active submesoscale currents [e.g Kobashi and Hetland, 2020] (Figure 3). The nested model exchanges variables along the boundaries between the parent and child models and thus, the exchange between grids is two-way. The child domain was created from the parent domain and therefore, the bathymetry and s-grid parameters of the child grid including the number of vertical sigma layers (N=30) is the same as the parent's. The bathymetry of the child domain was obtained by linearly interpolating the bathymetry of the parent domain. The ratio of the nesting is 5 to 1. The surface fluxes, open boundaries and initial conditions were also obtained from the parent model by interpolating the parent model outputs to the child grid. By doing so, the models can avoid initial shocks typically seen at the beginning of the simulation.

The nested model was run for three different periods: summer 2010, summer 2021, and summer 2022. Details are described below.

3.2.1 Summer 2010

and the grid resolution of the child grid is roughly 300 meters. The surface fluxes, open boundaries and initial conditions were also obtained from the parent model by interpolating the parent model outputs to the child grid. By doing so, the models can avoid initial shocks typically seen at the beginning of the simulation. The parent and child models was run for the period from June 1 to July 26, 2010 (roughly 6 weeks). The output frequency is 1 hour.

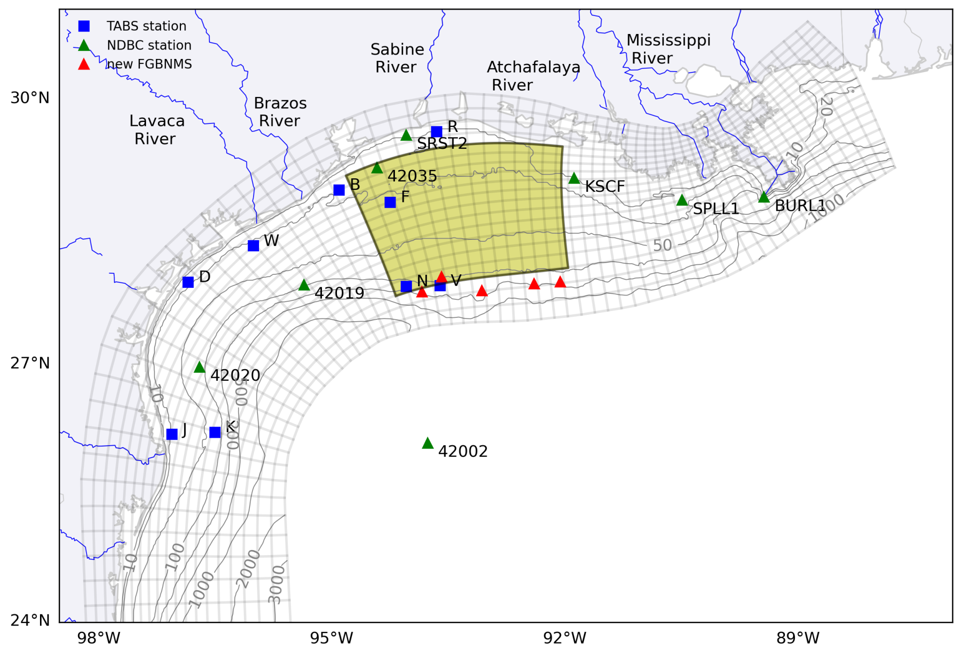

Figure 3: TXLA shelf model and nested domain

The model output showed a rich feature of submesoscale instabilities along the plume fronts (Figure 4). Also, the comparison between the parent and child grids along the open boundaries (i.e. contact points) demonstrates that the fluxes in and out of the boundaries seem to be conserved.

One thing to note is that the computational cost of the nesting applications is very high (as of August, 2021). The runtime of the TXLA nesting application for XX day simulation is about 8.5 days with 120 CPU cores compared to roughly 2 days for 1-year simulation of the TXLA parent model. Surprisingly, increasing the number of CPU cores to 200 did not reduce the computational time, but rather increased it. A possible reason for that might be because increasing the CPU cores spreads computational nodes, which requires more communication between nodes and thus, increase the computational time. Users who wish to reduce the runtime may want to reduce the number of contact points by choosing a smaller child domain, by decreasing the ratio (e.g. from 5:1 to 3:1) and/or by doing one-way nesting instead of two-way. Given the long runtime, the ROMS online nesting is not necessarily suitable for long-term simulation (> 1 year) at least for now. Rather, it will be more suitable for short-term event-driven simulation (< 1 month).

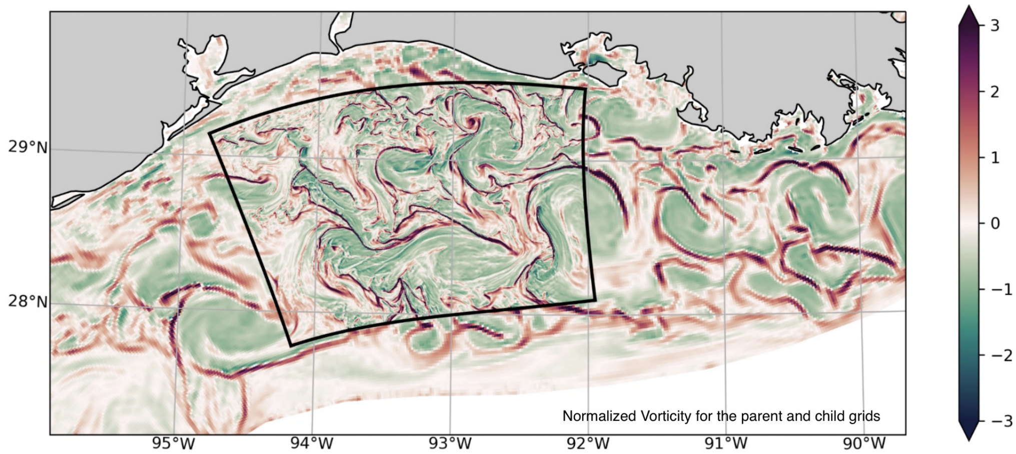

Figure 4: Normalized vorticity for the parent and child grids. The black frame is the boundary between the parent and child domain

3.2.2 Summer 2021

3.2.3 Summer 2022

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