

Numerical Modelling

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the anatomy of an ocean model

- **Lesson 1 : [D109]**
 - Introduction
 - Equations of motions
 - *Activity 1 [run an ocean model]*
- **Lesson 2 : [D109]**
 - Horizontal Discretization
 - *Activity 2 [Dynamics of an ocean gyre]*
- **Lesson 3 : [D109]**
 - *Activity 2 [Dynamics of an ocean gyre]*
- **Lesson 4 : [D109]**
 - Numerical schemes
 - *Activity 3 [Impacts of numerics]*
- **Lesson 5 : [D109]**
 - Vertical coordinates
 - *Activity 3 [Impacts of numerics]*
 - *Activity 4 [Impact of topography]*
- **Lesson 6 : [D109]**
 - Dynamics of the ocean gyre
 - *Activity 4 [Impact of topography]*
- **Lesson 7 : [D109]**
 - *Boundary Forcings*
 - Presentation of the model CROCO
 - *Activity 5 [Design a realistic simulation]*
- **Lesson 8 : [D109]**
 - Diagnostics and validation
 - *Activity 6 [Analyze a realistic simulation]*

Presentations and material
will be available at :

jgula.fr/ModNum/

#6

Setting up a realistic configuration with CROCO

CROCO ocean model

To perform a CROCO simulation, we need :

- Horizontal grid
- Bottom topography
- Land mask
- Atmospheric surface boundary forcing
- Initial oceanic conditions
- Lateral oceanic boundary conditions



Datasets
(observations
and/or models)
+
Tools for
interpolation/
smoothing
(CROCOTOOLS)

Bottom topography + Land Mask

Satellite geodesy data + soundings

Available Datasets:

- SRTM30 (http://topex.ucsd.edu/WWW_html/srtm30_plus.html)

Smith, W. H. F., and D. T. Sandwell, Global seafloor topography from satellite altimetry and ship depth soundings, *Science*, v. 277, p. 1957-1962, 26 Sept., 1997.

- Etopo1 (<https://www.ngdc.noaa.gov/mgg/global/global.html>)

Amante, C. and B.W. Eakins, 2009. ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. NOAA Technical Memorandum NESDIS NGDC-24. National Geophysical Data Center, NOAA. doi:10.7289/V5C8276M.

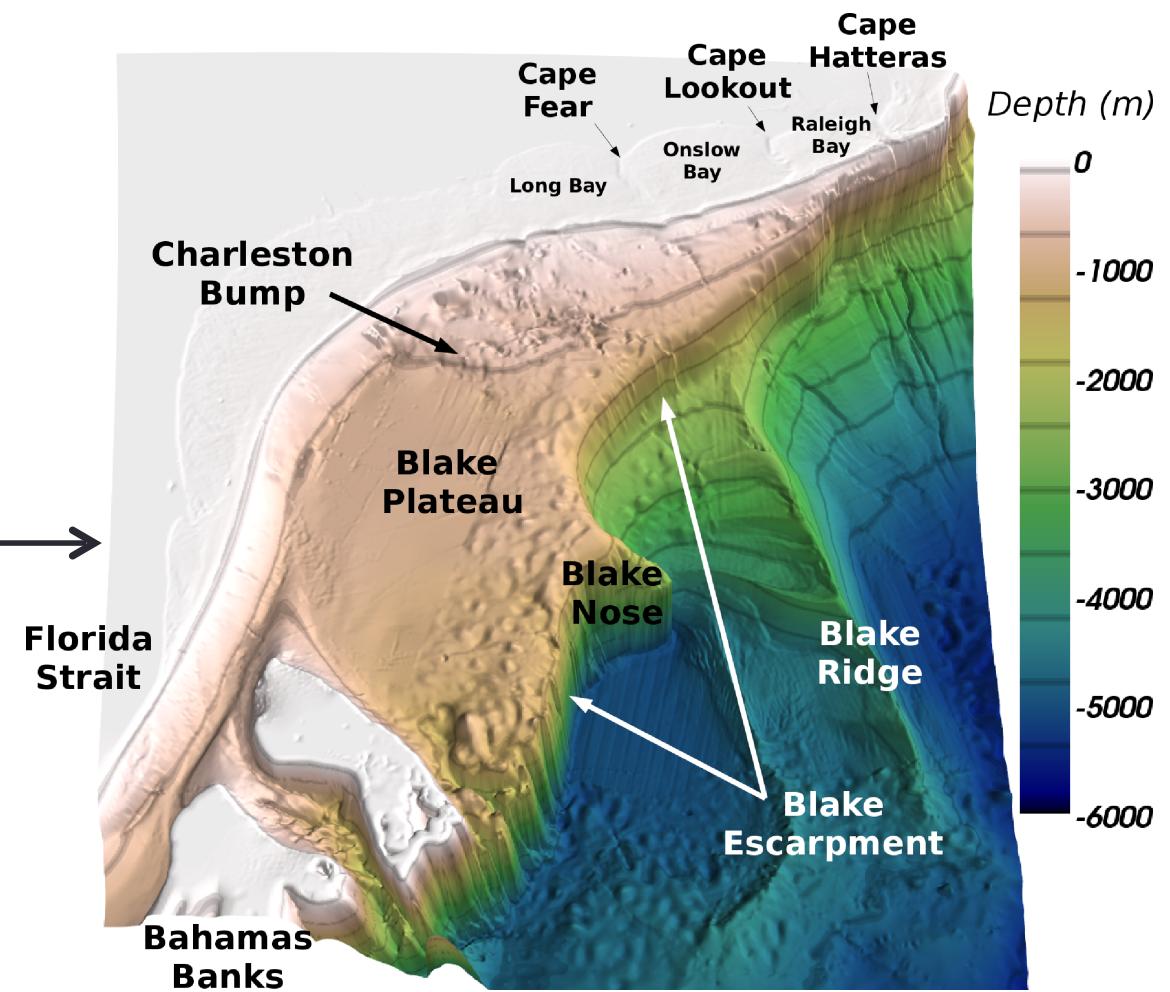
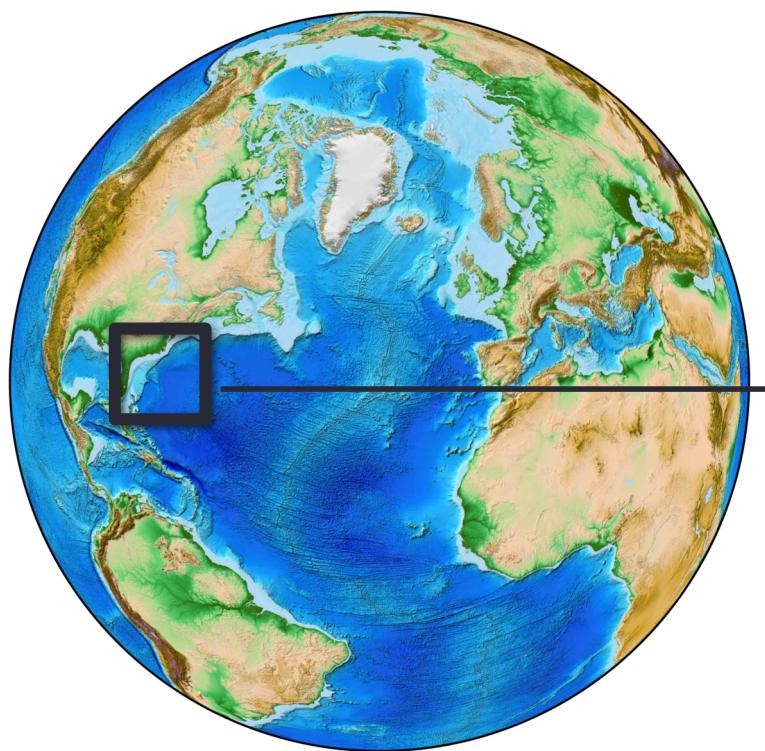
- Gebco30 (http://www.gebco.net/data_and_products/gridded_bathymetry_data/)

British Oceanographic Data Centre (BODC), 2008, The GEBCO_08 Grid, version 20091120, General Bathymetric Chart of the Oceans (GEBCO)



Bottom topography + Land Mask

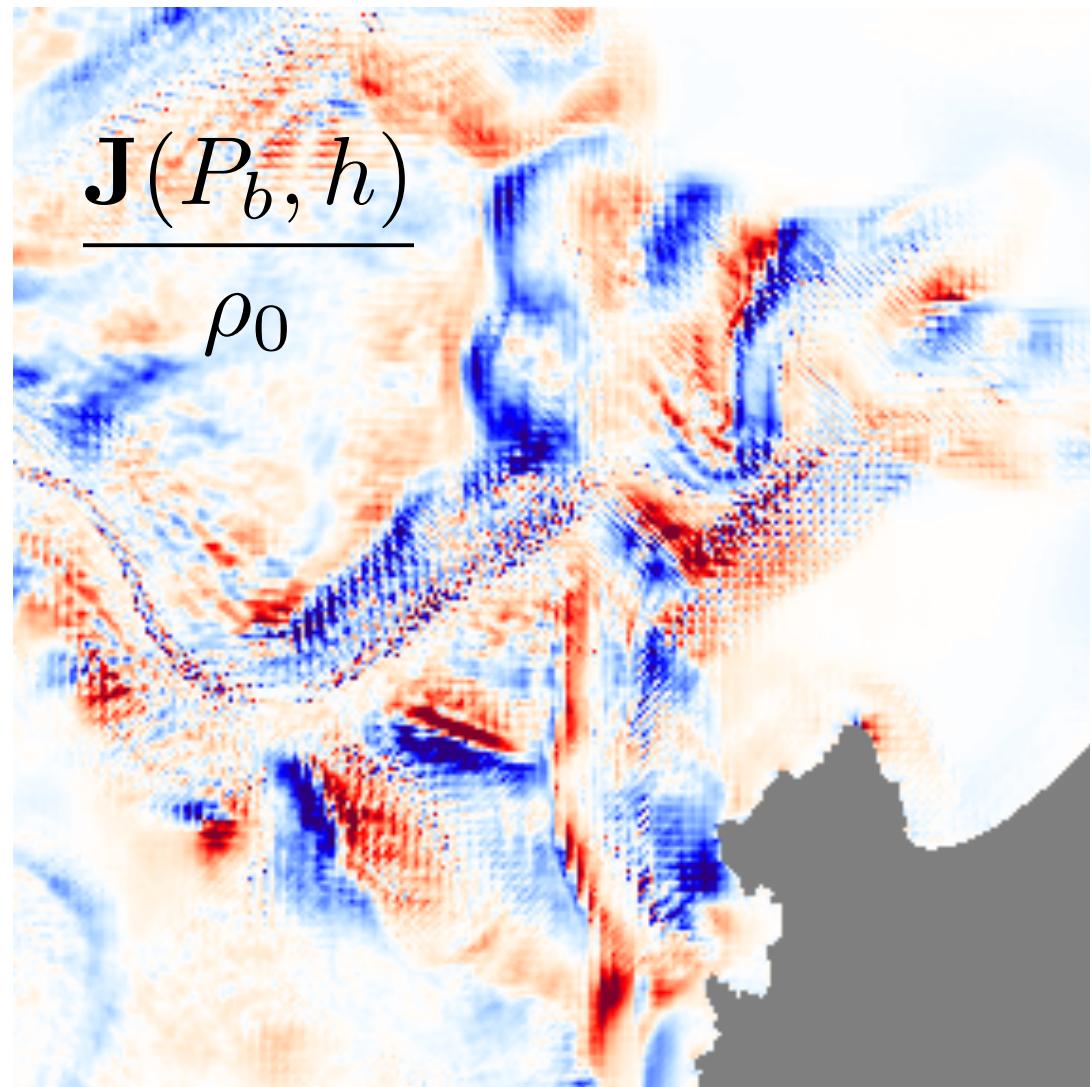
Topography and masked created by smoothing or interpolating on the model's grid using CROCOTOOLS:



Bottom topography + Land Mask

- Avoid linear interpolation when interpolating your topography.

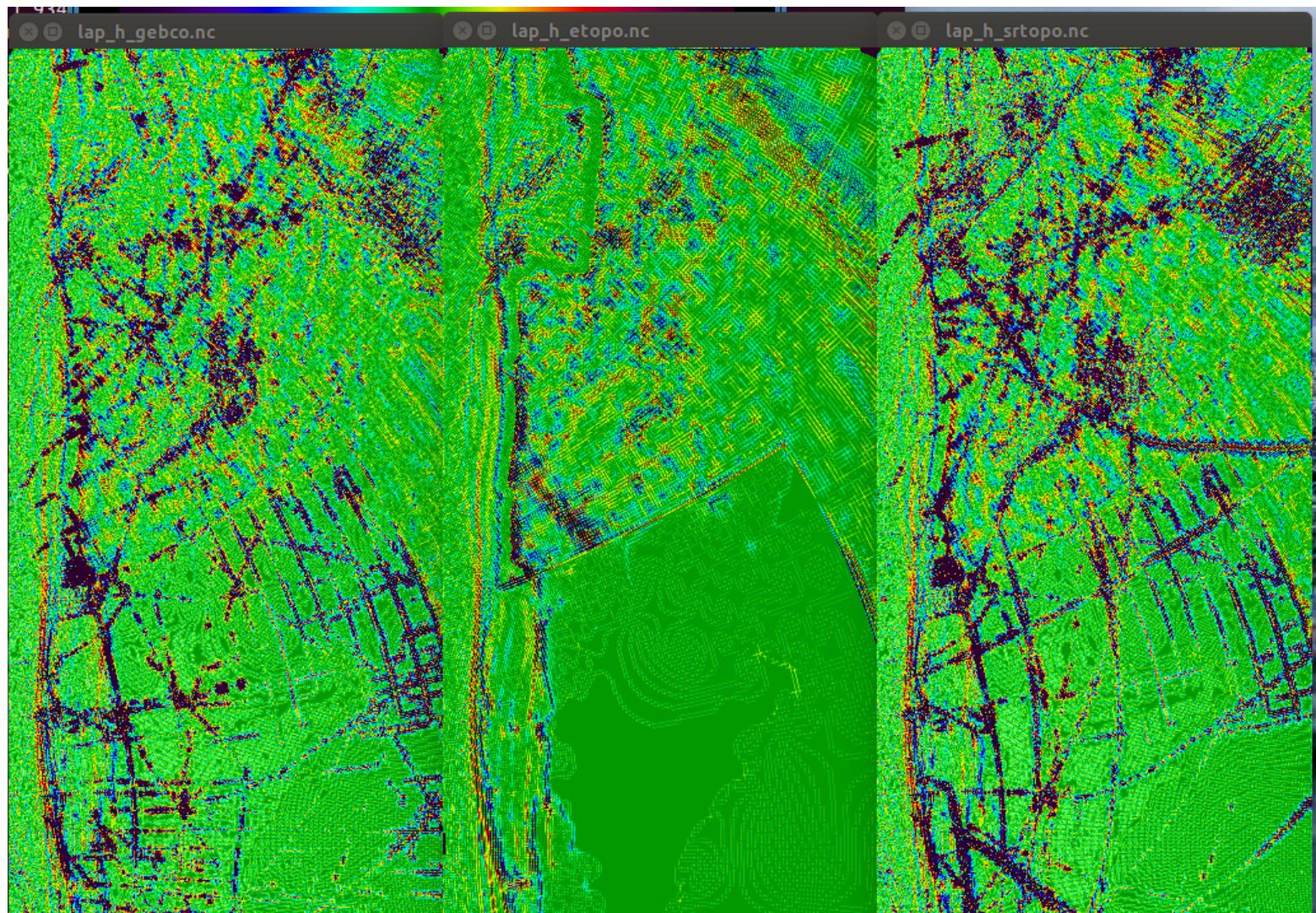
$$\frac{\mathbf{J}(P_b, h)}{\rho_0}$$



Ex: California Current simulation at 150m resolution with linearly interpolated topography

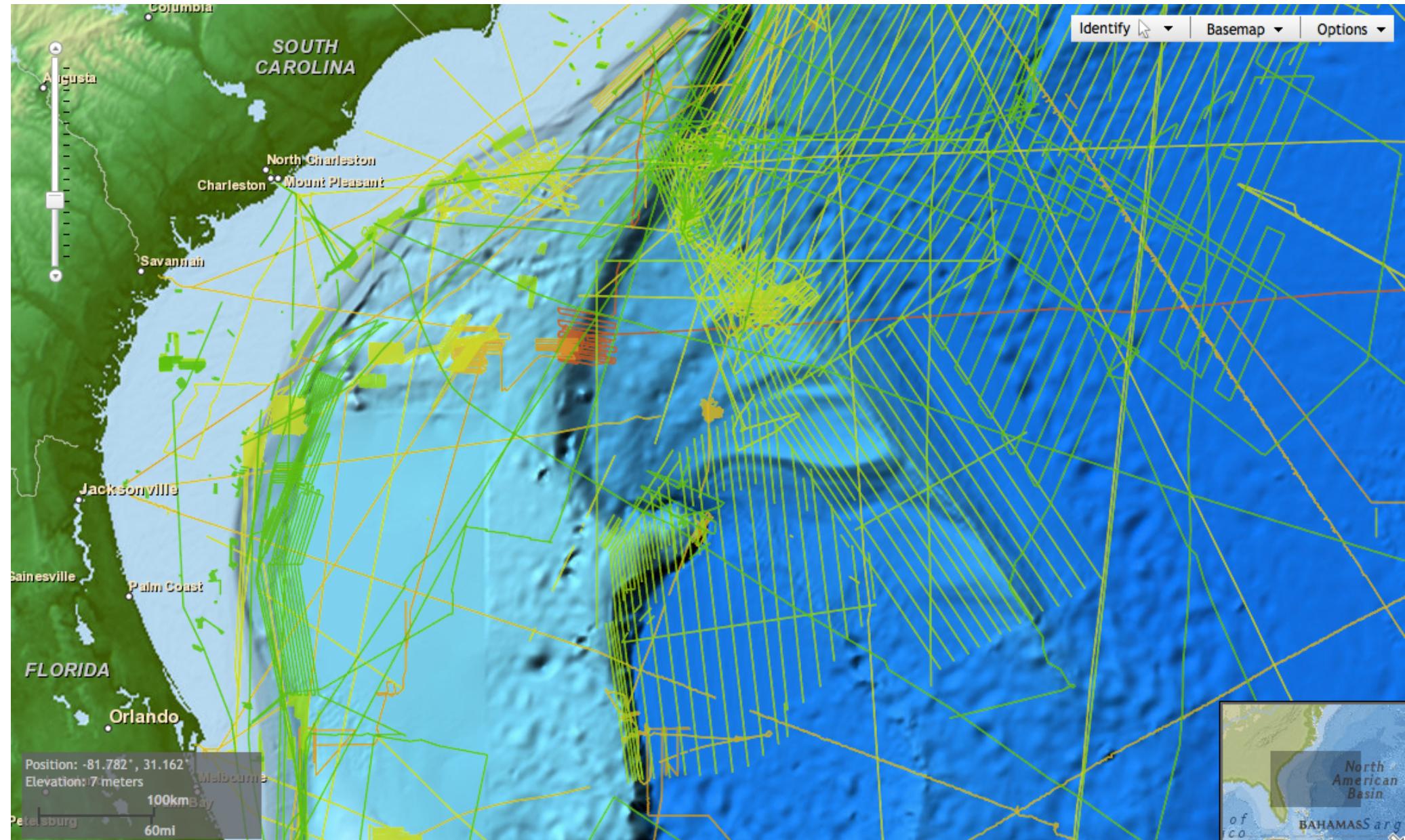
Bottom topography + Land Mask

- Topography Datasets also have number of issues



Bottom topography + Land Mask

<https://www.ncei.noaa.gov/maps/bathymetry/>



Atmospheric surface boundary forcing

- Surface boundary conditions ($z=\eta$):

$$\begin{aligned}\frac{\partial \eta}{\partial t} &= w \\ K_M v \frac{\partial u}{\partial z} &= \frac{\tau_x}{\rho_0} \\ K_M v \frac{\partial v}{\partial z} &= \frac{\tau_y}{\rho_0} \\ K_T v \frac{\partial T}{\partial z} &= \frac{Q}{\rho_0 C_p} \\ K_{Sv} \frac{\partial S}{\partial z} &= \frac{S(E - P)}{\rho_0}\end{aligned}\quad \begin{aligned}&\text{Wind stress} \\ &\text{Heat flux} \\ &\text{Salt flux :} \\ &\text{evap -} \\ &\text{rain}\end{aligned}$$

Atmospheric surface boundary forcing

Heat fluxes & Freshwater fluxes:

- Directly read the forcing files
- Or use of a bulk formulae :
 - Heat flux : compute total heat flux from latent, sensible, solar and longwave fluxes and model SST
 - Freshwater flux : compute from evap, prate and model SSS



bulk_flux.F

Wind stress:

- Directly read the forcing files
- Or compute the windstress from the Cd drag coefficient, model SST and wind (use of bulk formulae)



bulk_flux.F

+ Rivers runoff

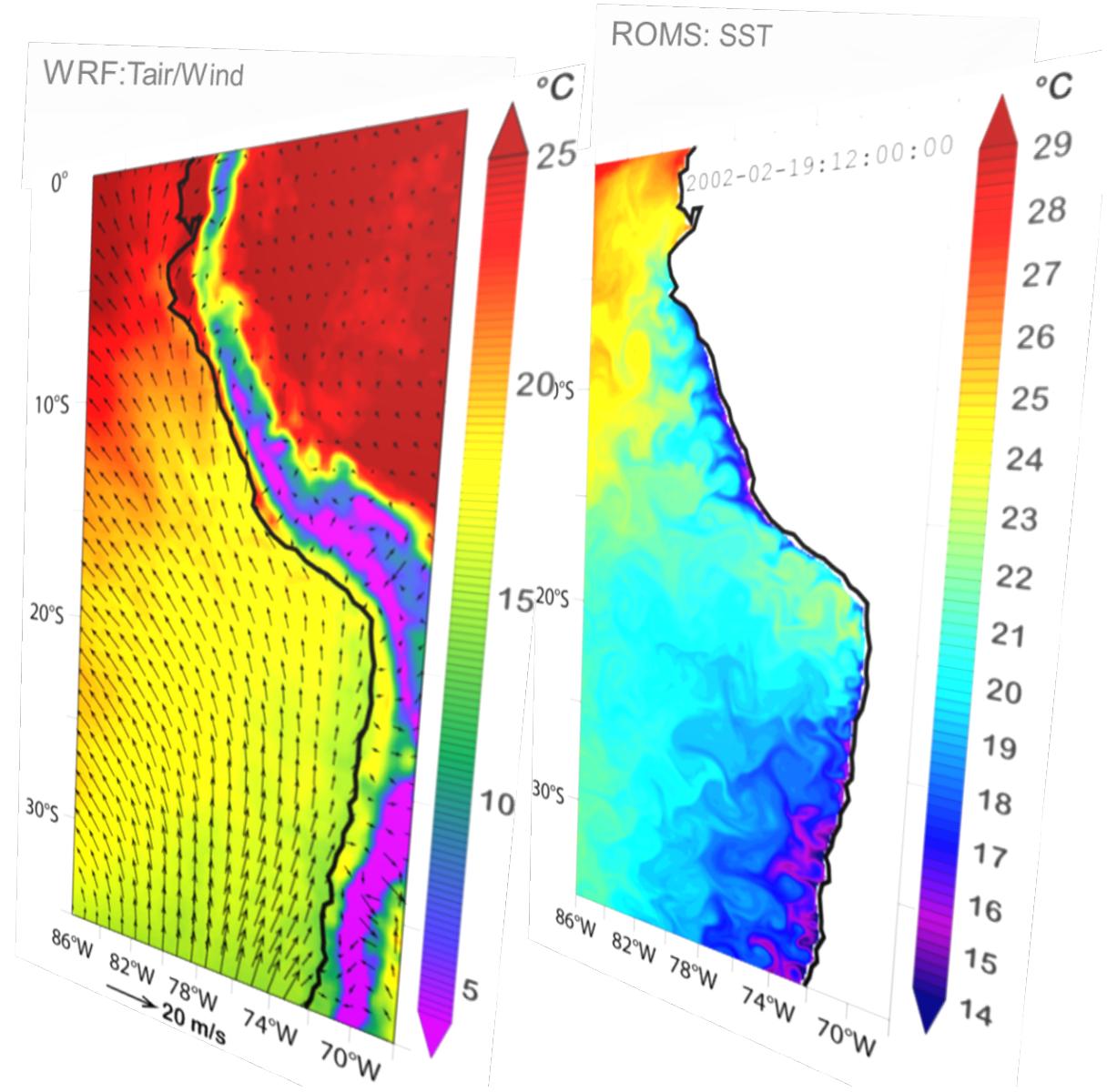
Atmospheric surface boundary forcing

Available Datasets:

- Heat and freshwater fluxes : COADS, ...
- Wind Stress: QuickScat, SCOW, ...
- Reanalysis (Model +obs.) : CFSR, ERA interim, ERA5, etc.

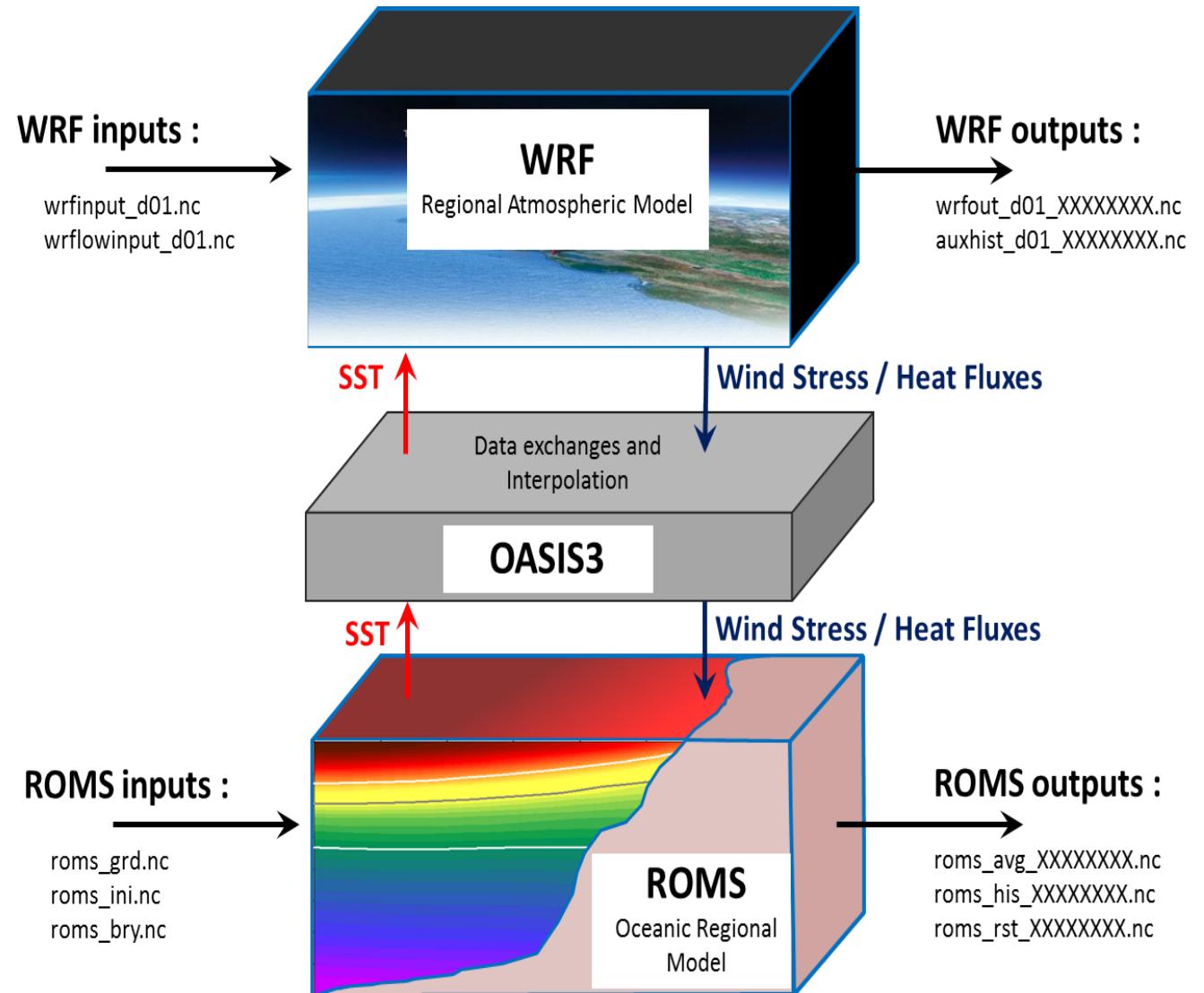
Ocean-Atmosphere coupling

- Interactive coupling with an atmospheric model:



Ocean-Atmosphere coupling

e.g. OASIS3-MCT implementation in CROCO:

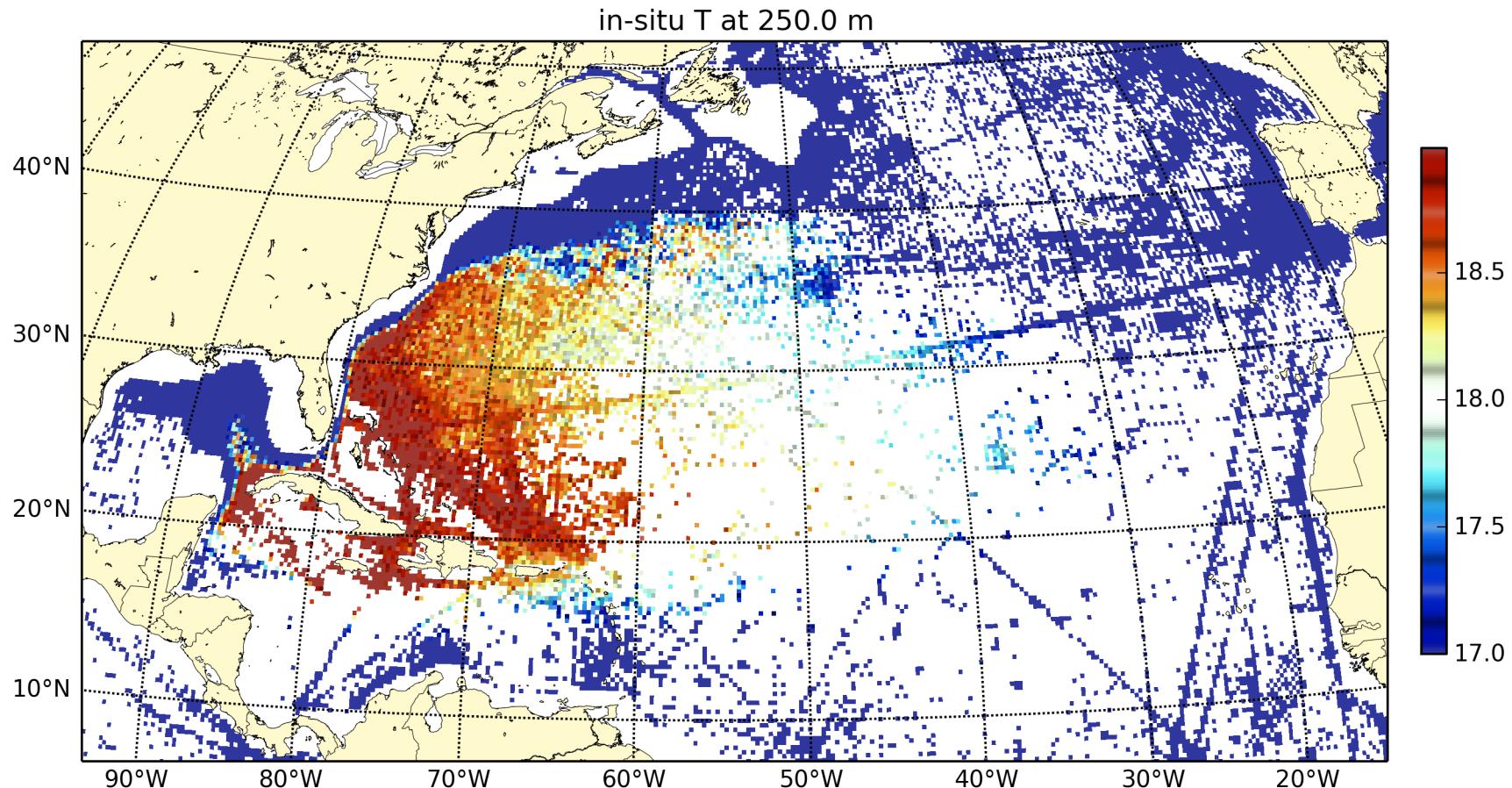


Initial + boundary conditions

- Observations (World Ocean Atlas, CARS)
- Reanalysis (SODA, ECCO, GLORYS, etc.)
- Lower resolution model outputs (= nesting)

Initial + boundary conditions

- Observations are limited -> **Climatological runs only**
 - Ex: Temperature at 250m from WOA
(all data from 1955 to 2012 binned to $\frac{1}{4}$ deg grid)



Initial + boundary conditions

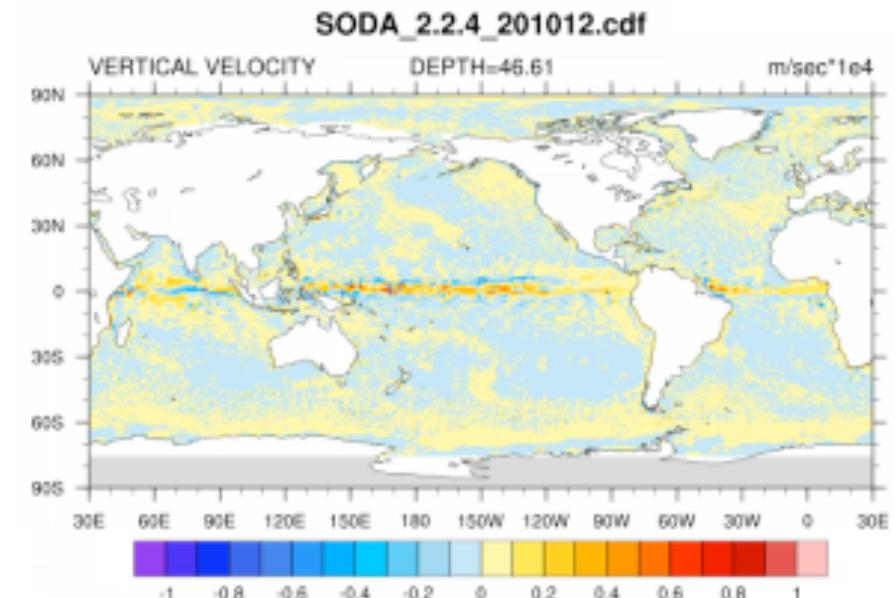
Interannual forcing:

- Reanalysis (SODA, ECCO, ECMWF, etc.)

<https://reanalyses.org/ocean/overview-current-reanalyses>

= Model + data assimilation

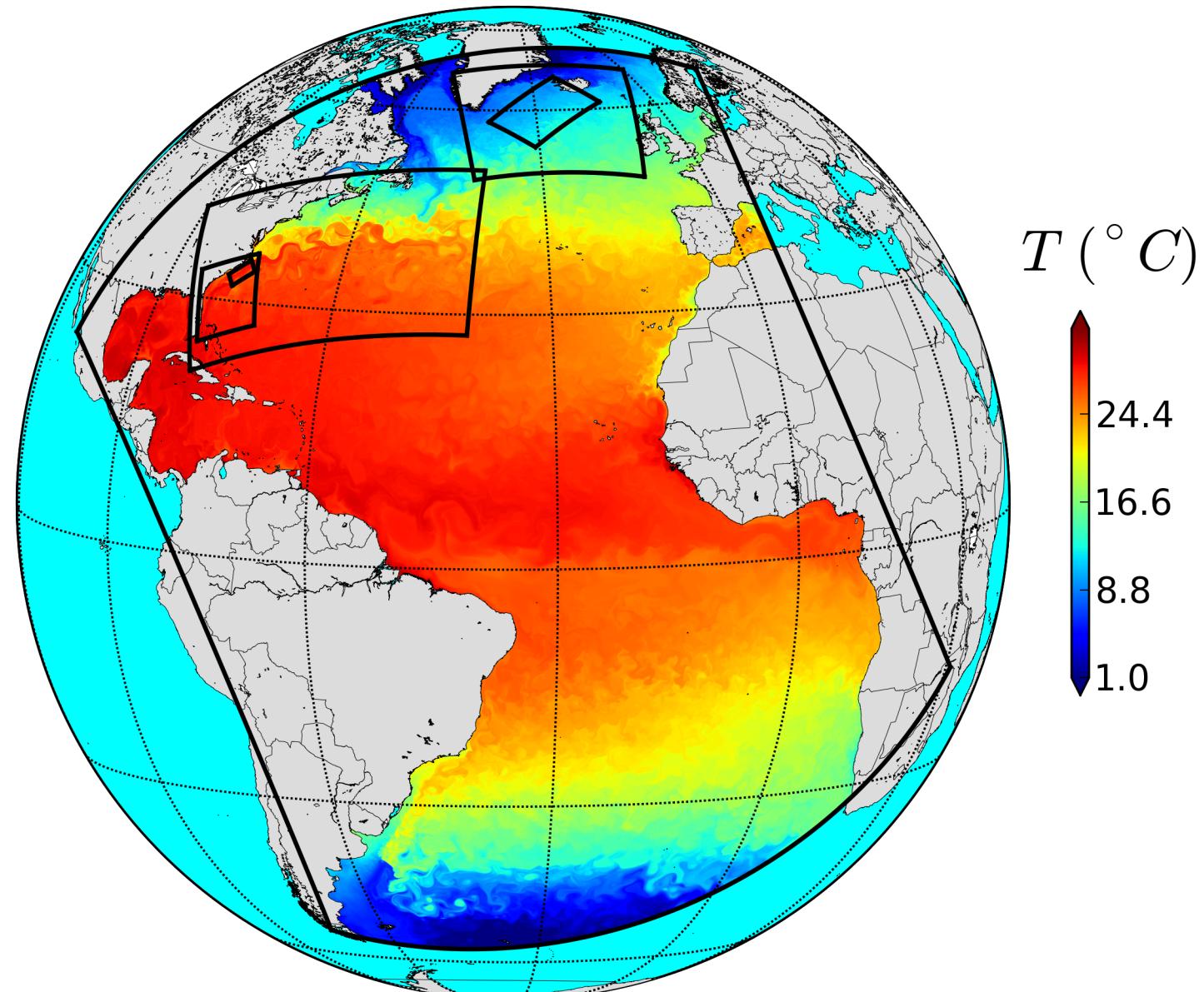
- Model outputs (OGCM)
(e.g. for IPCC runs)



Offline Nesting

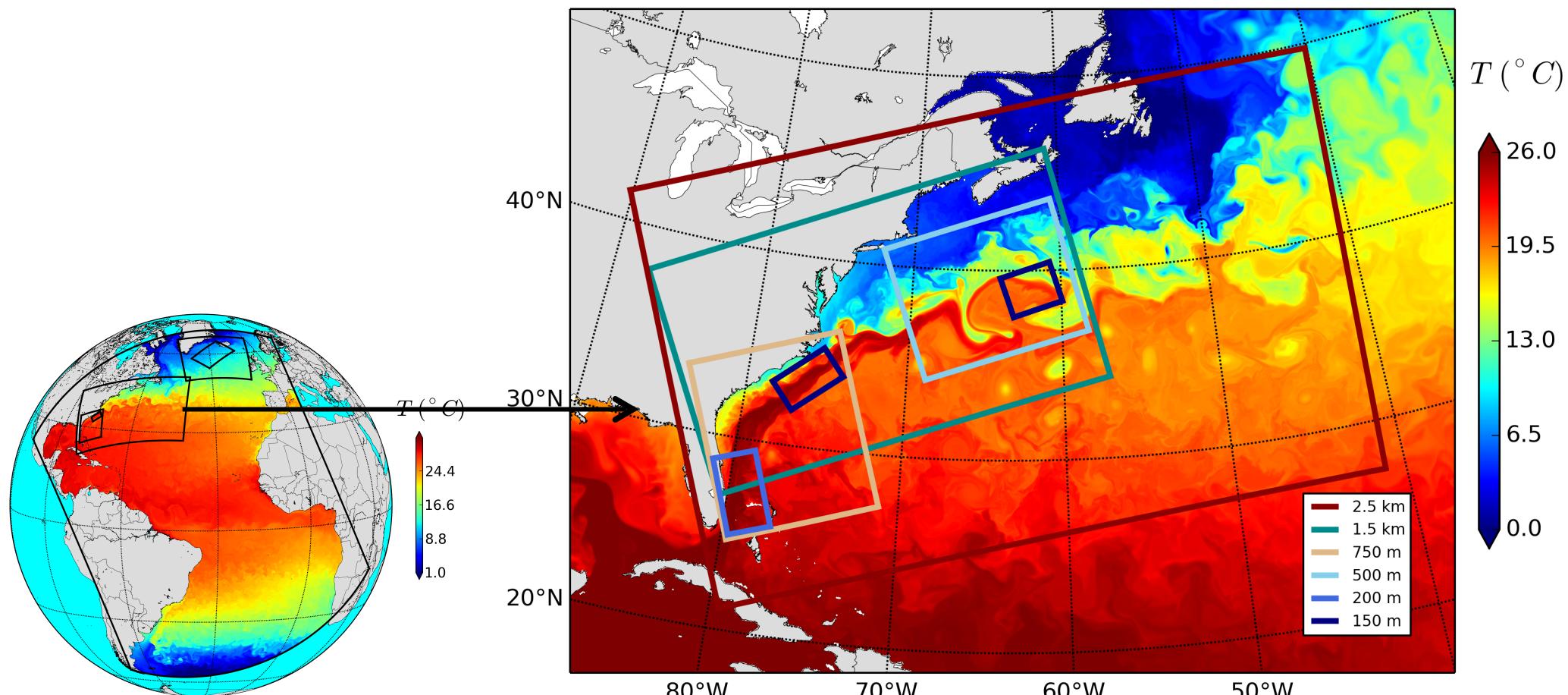
✓ “Offline” nesting
Roms2Roms (*Mason et al, 2010, Ocean Modeling*):

- Processing of croco OBC using the output of a larger croco simulation.
- Enable offline oceanic downscaling



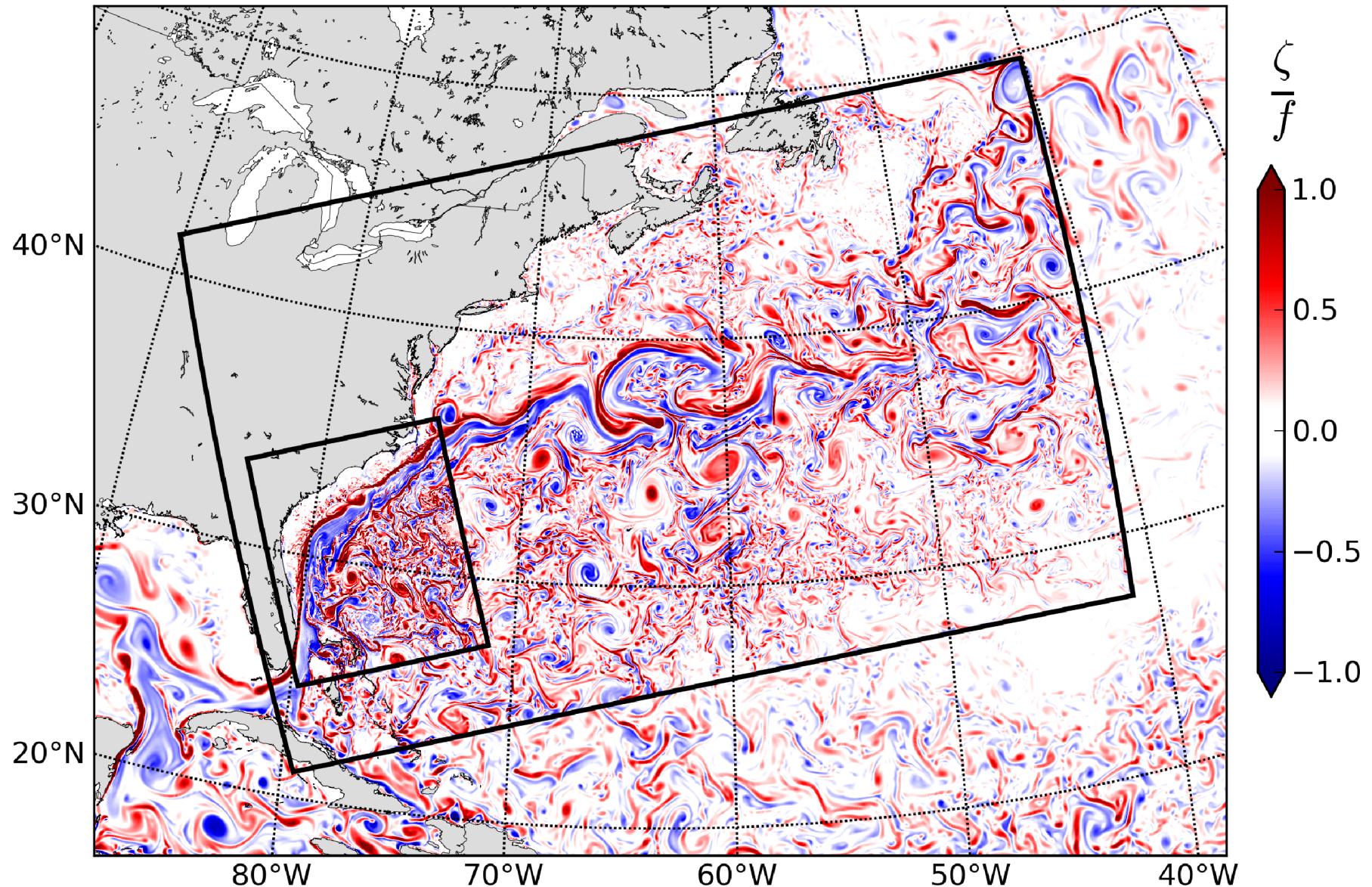
Offline Nesting

$$\Delta x = 6 \rightarrow 0.15 \text{ km}$$



A portion of the Atlantic domain showing mean SST and several (1-way) nested grids:
Forced by repeating “typical” year with QuikSCAT and SODA at open boundaries.

Offline Nesting



Open boundary conditions I (OBC type)

Adaptative mixed radiations/nudging open boundary conditions
[Marchesiello et al, Ocean Modelling, 2001].

$$\frac{\partial \phi}{\partial t} + c_x \frac{\partial \phi}{\partial x} + c_y \frac{\partial \phi}{\partial y} = -\frac{1}{\tau} (\phi - \phi_{ext})$$

Radiation, (Orlanski, 1982)

- Possibility to use “Flather” OBC conditions for barotropic mode :
Specially designed for tidal applications

Adaptative nudging term :

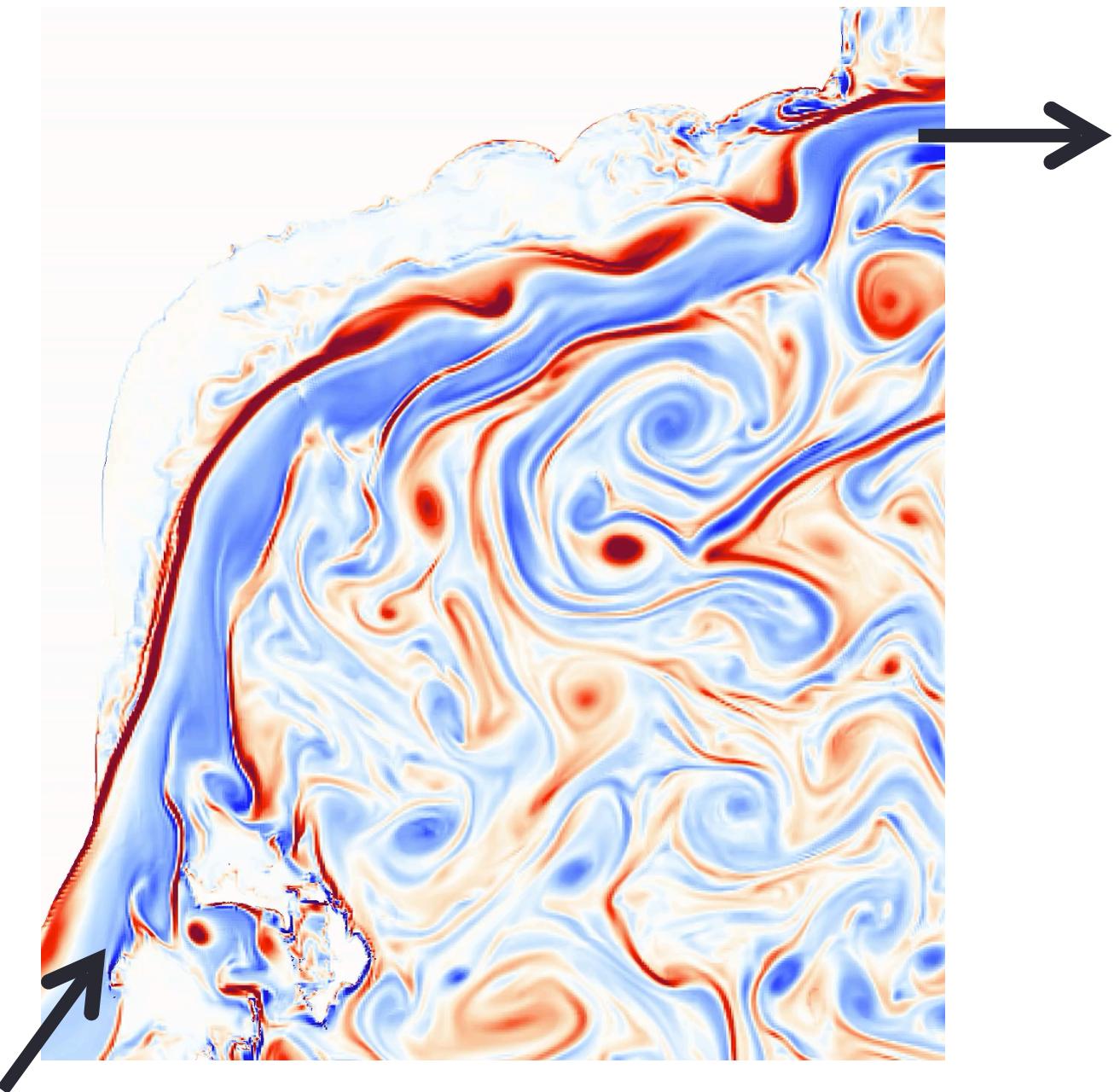
Adaptativity

- Ingoing signal ($C_x > 0$) : strong nudging toward external data using $\tau = \tau_{in}$
- Outgoing signal ($C_x < 0$) : weak nudging toward ext. Data $\tau = \tau_{out}$

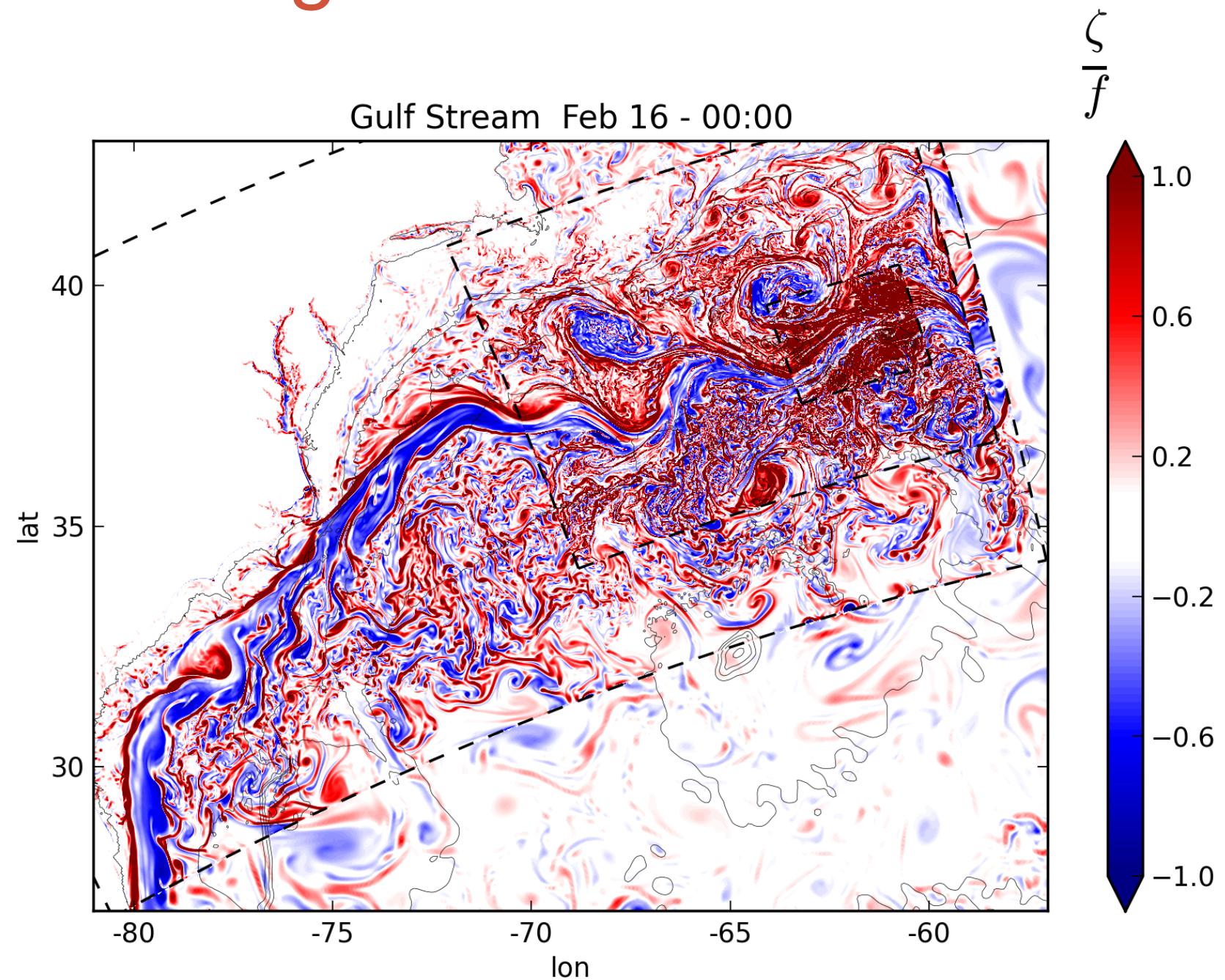
$$\left. \begin{array}{l} \tau_{out} \approx 180 \text{ days} \\ \tau_{in} \approx 1 \text{ days} \end{array} \right]$$

$\tau_{M_in}, \tau_{M_out}$: momentum
 $\tau_{T_in}, \tau_{T_out}$: tracer

Open boundary conditions I (OBC type)

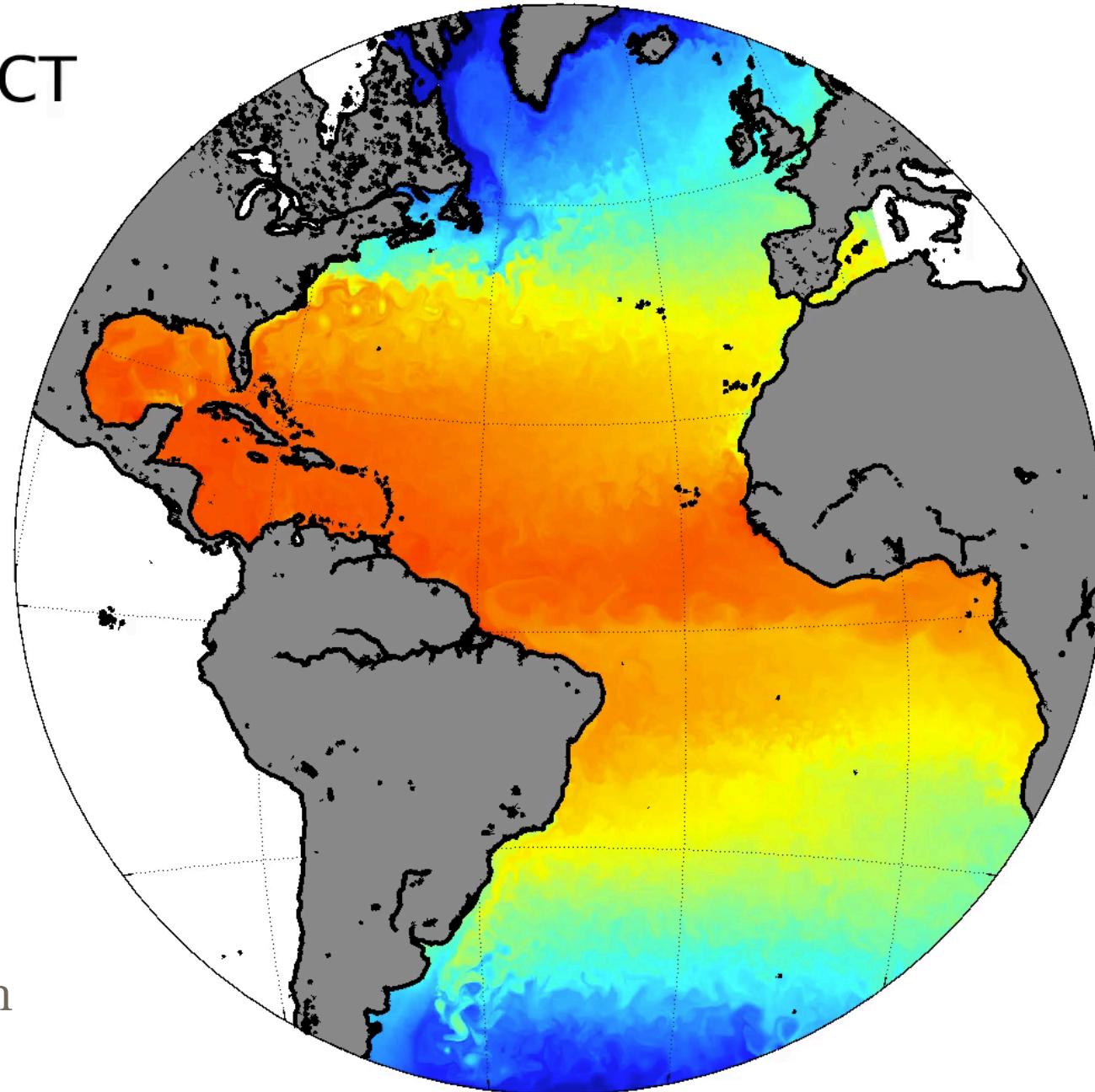


Offline Nesting



OCT

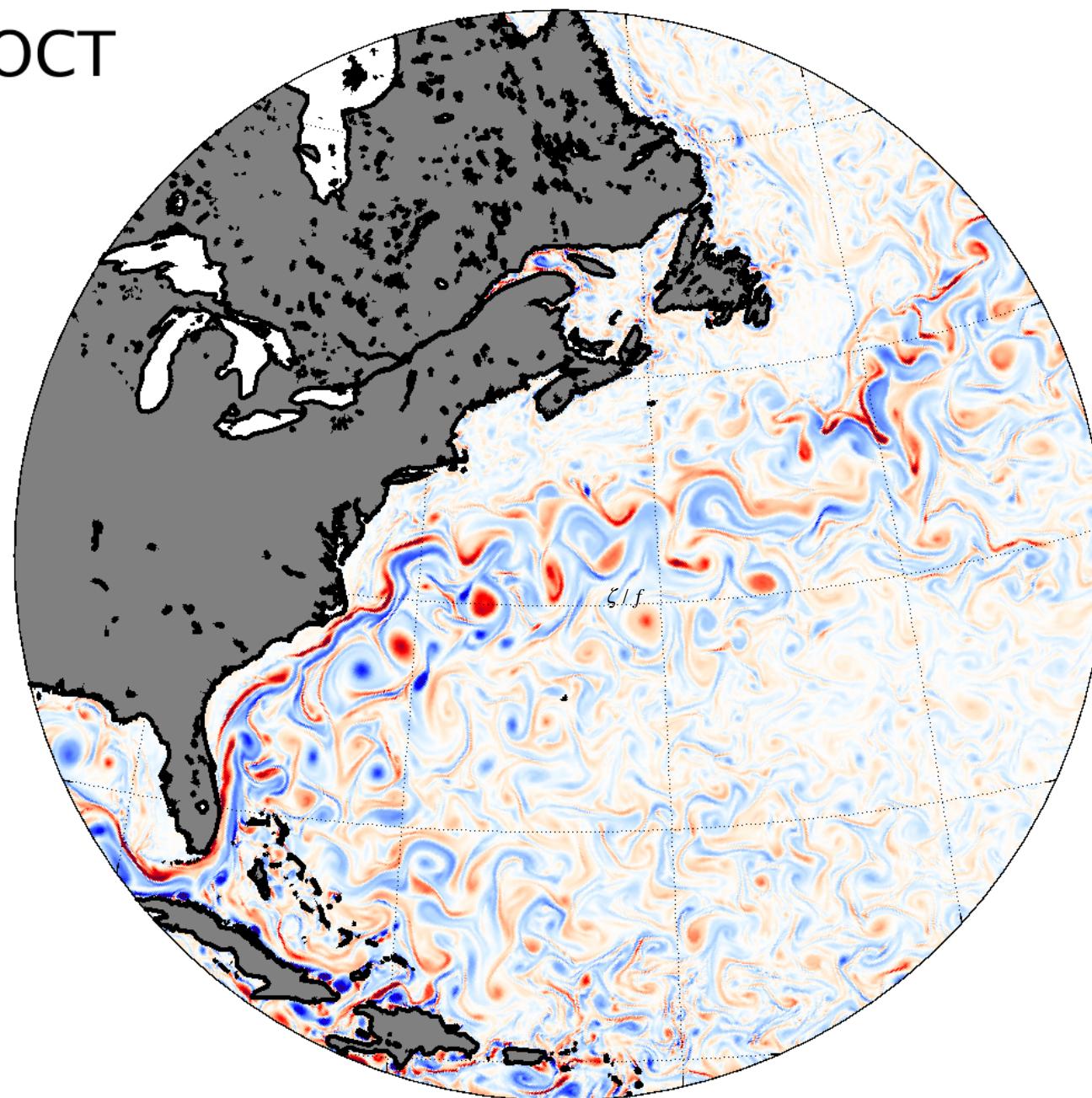
$dx = 5-7 \text{ km}$



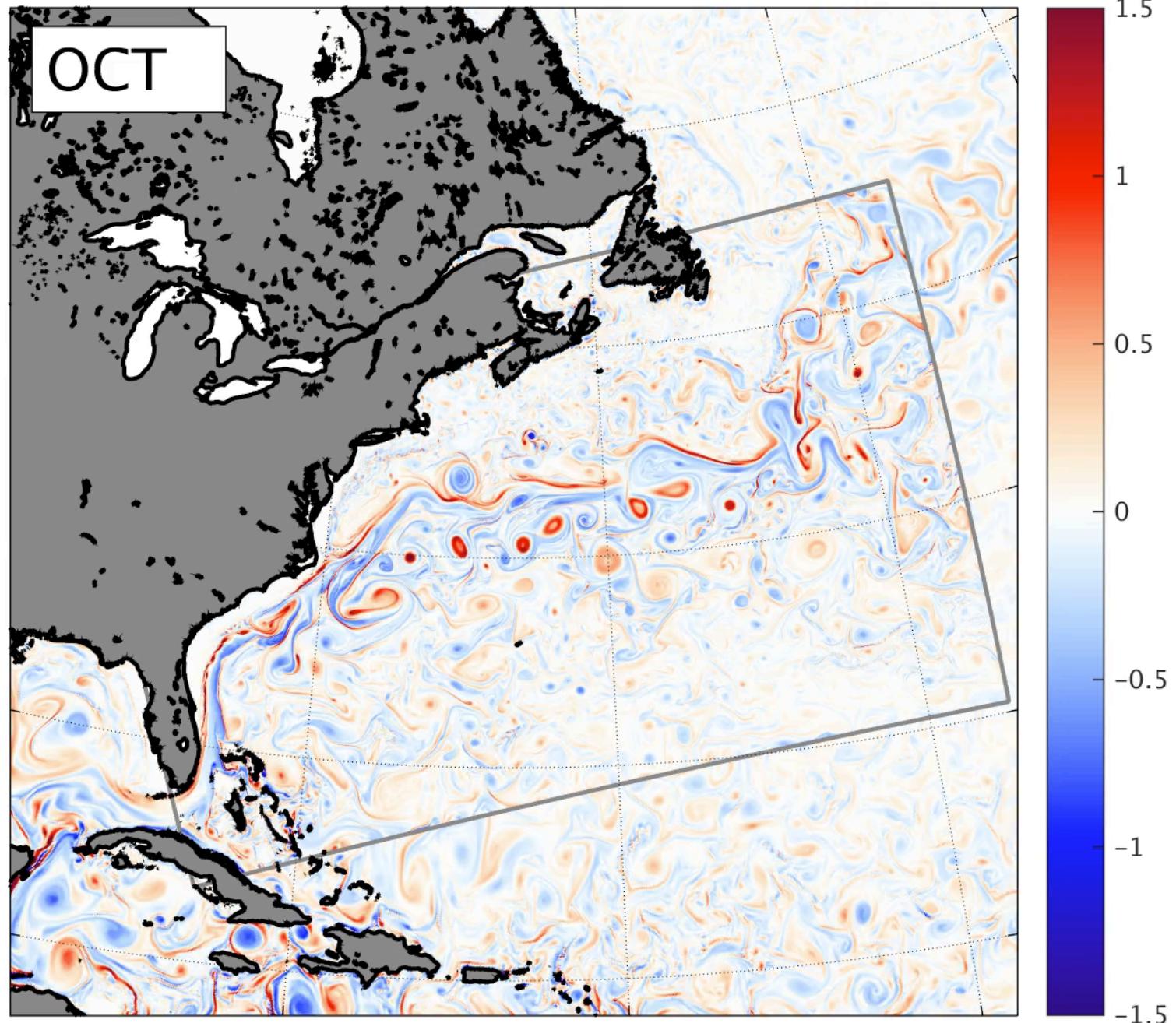
SST

Simulations using ROMS: Regional is a relative concept

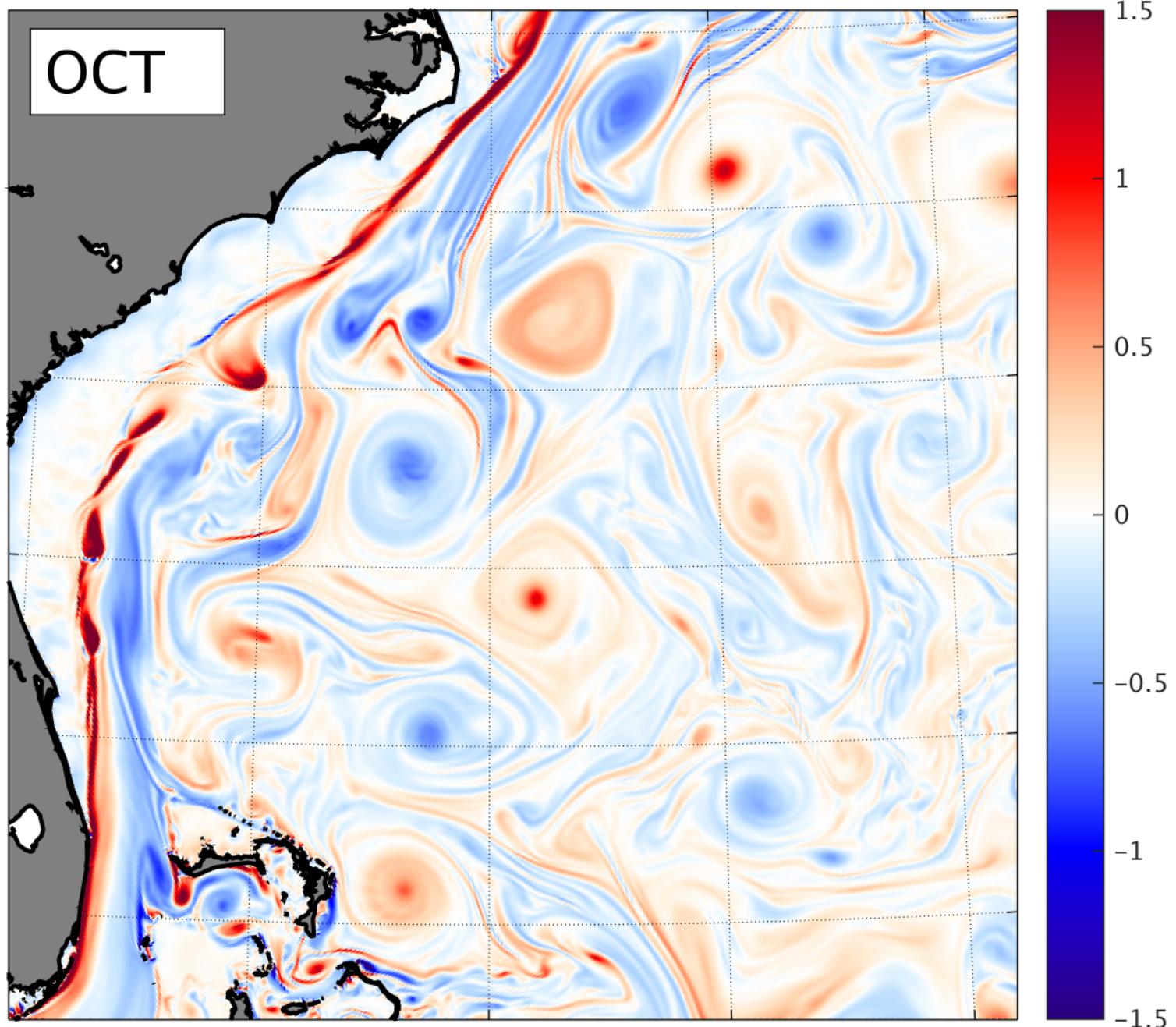
OCT

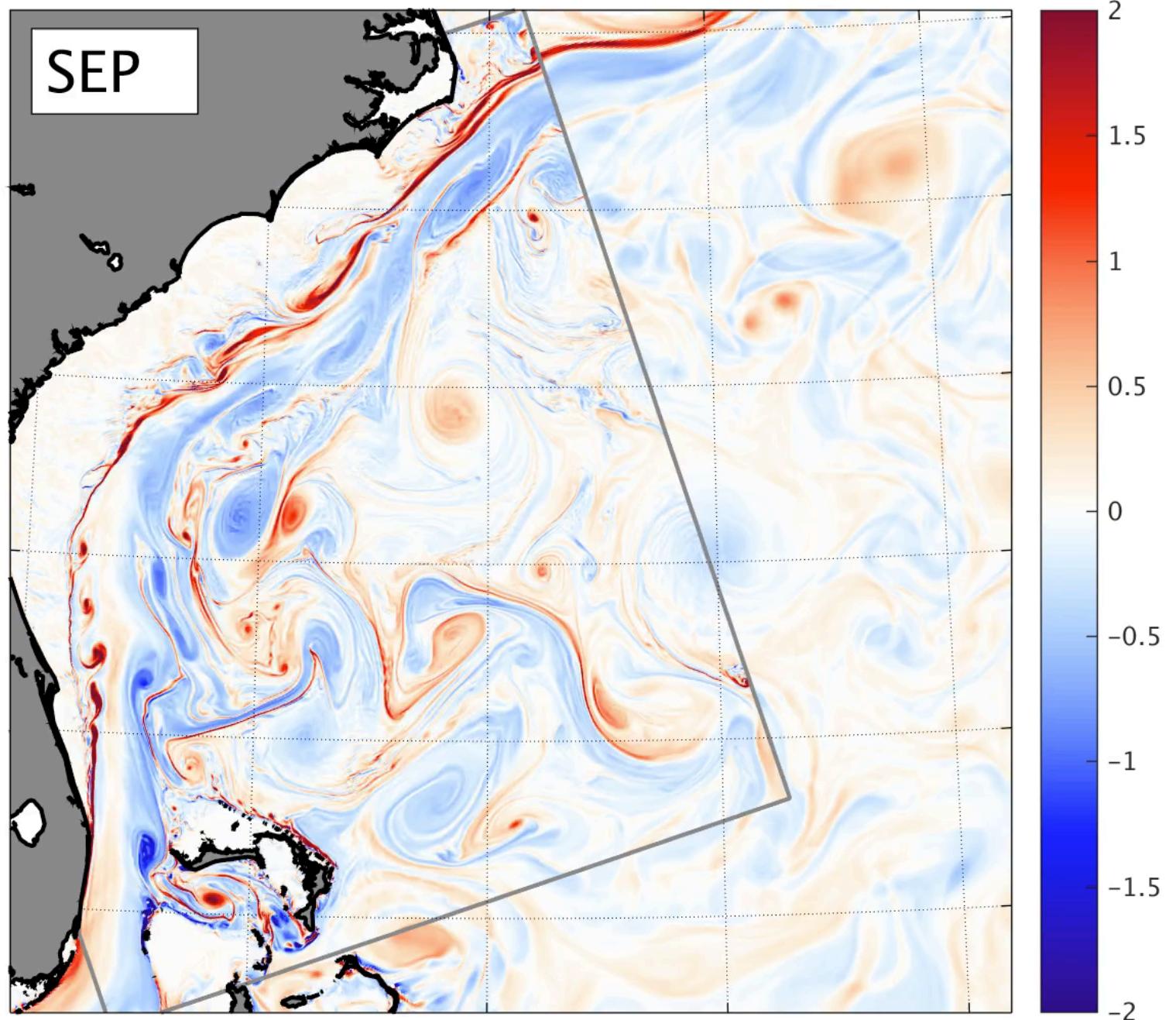


Normalized relative vorticity, or $Ro = \zeta / f$

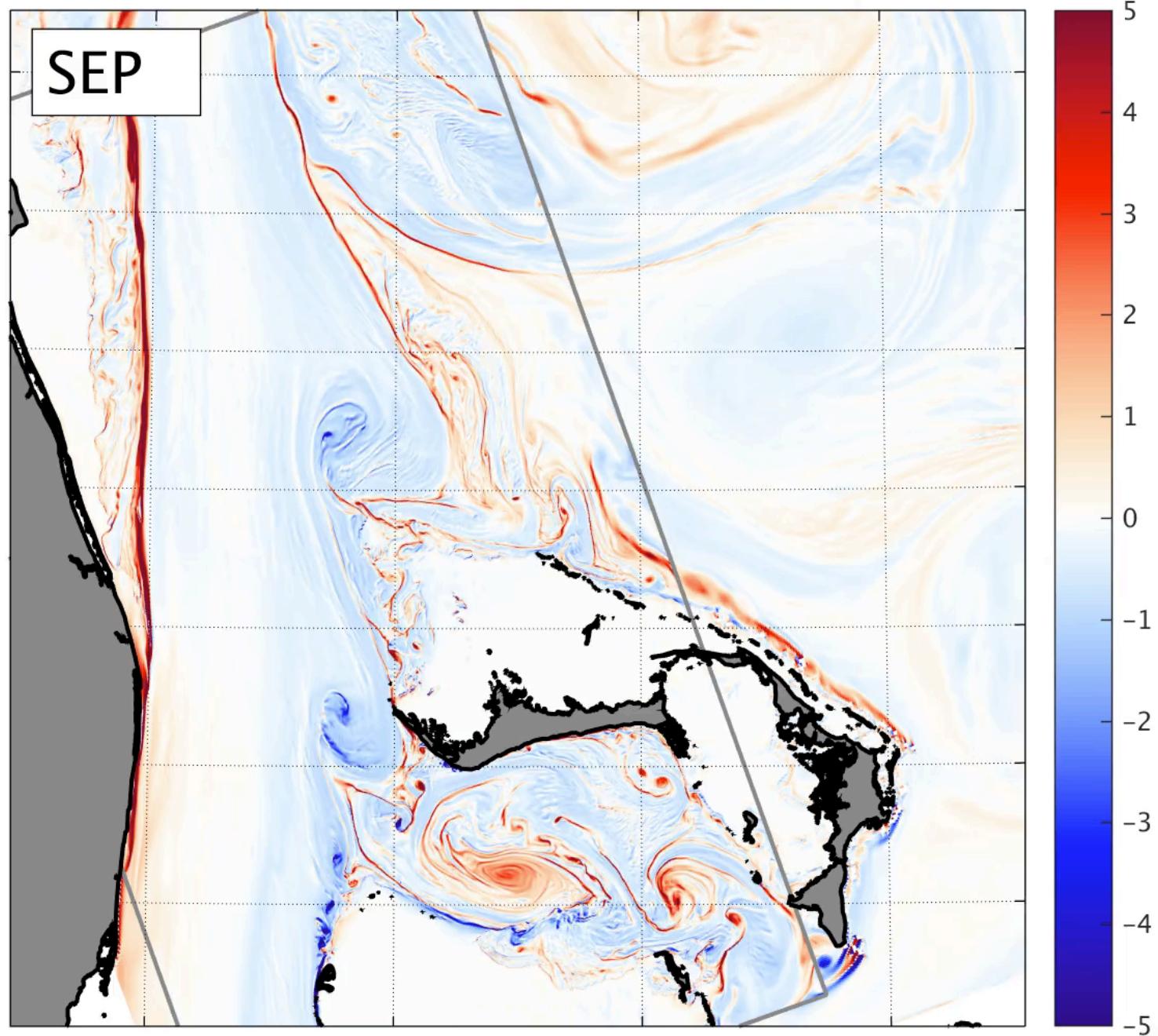
ζ / f 

Nested domain with open boundaries with $dx = 2.5 \text{ km}$

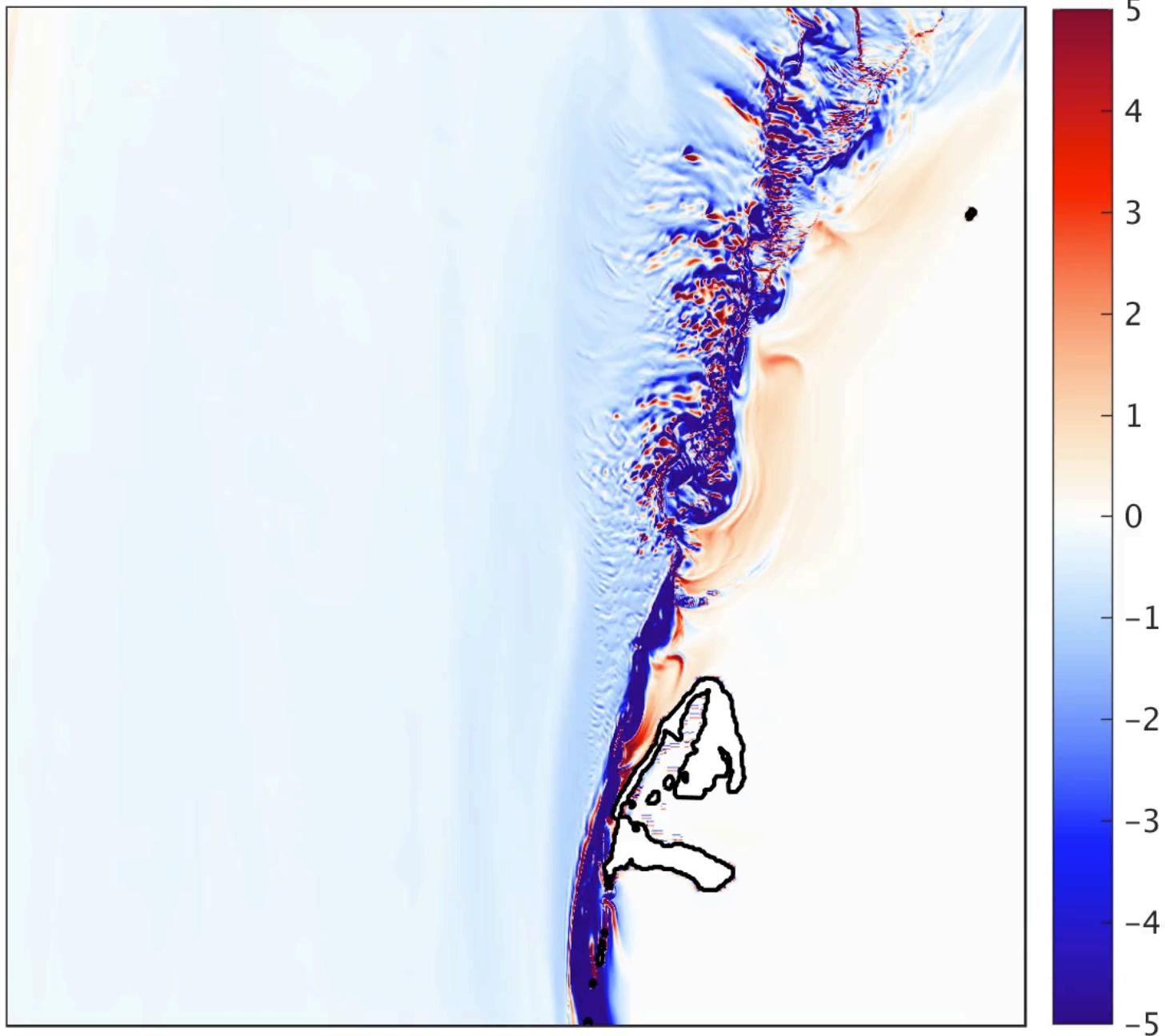
ζ / f 



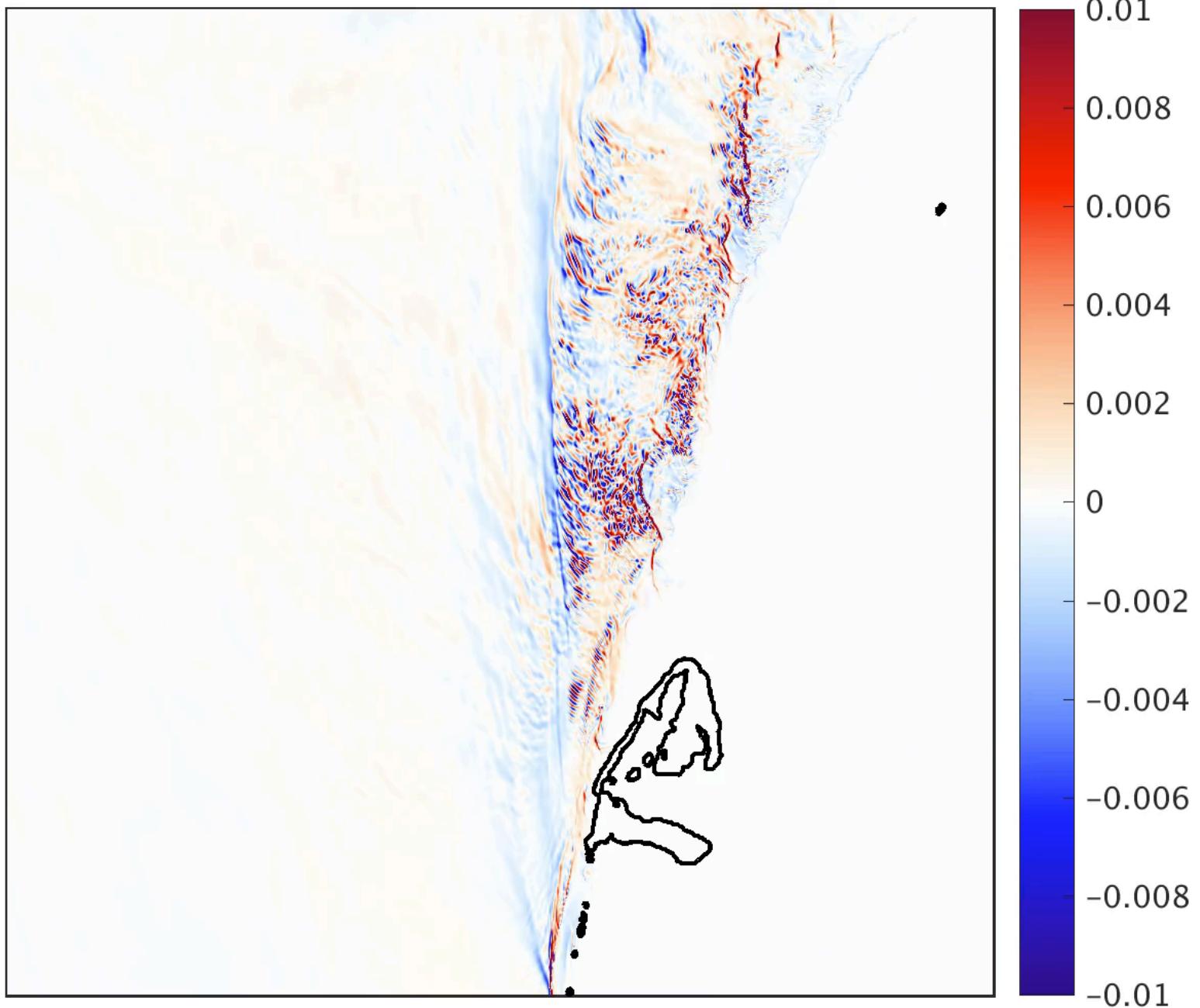
$\text{dx} = 700 \text{ m}$



$\text{dx} = 200 \text{ m}$

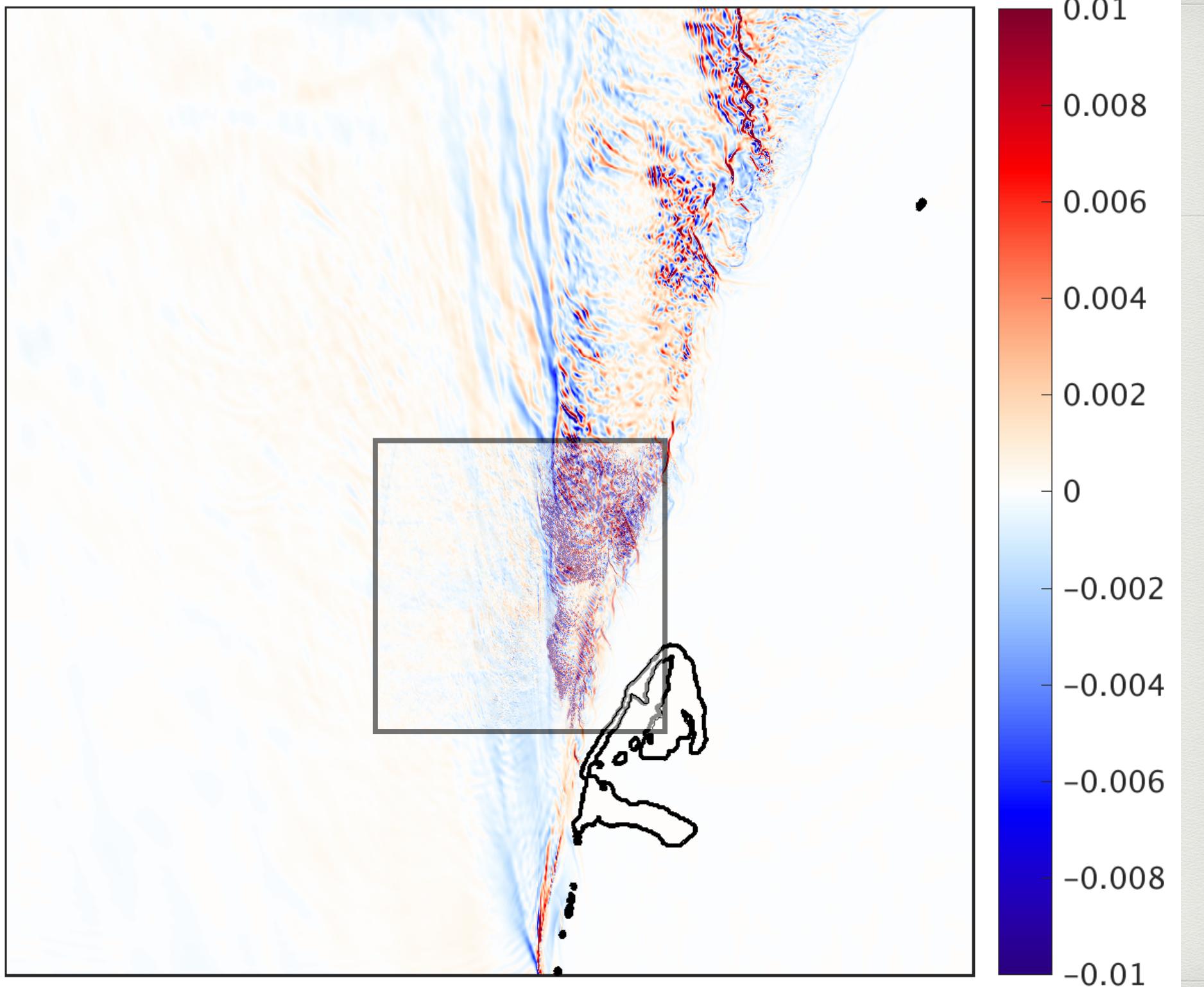


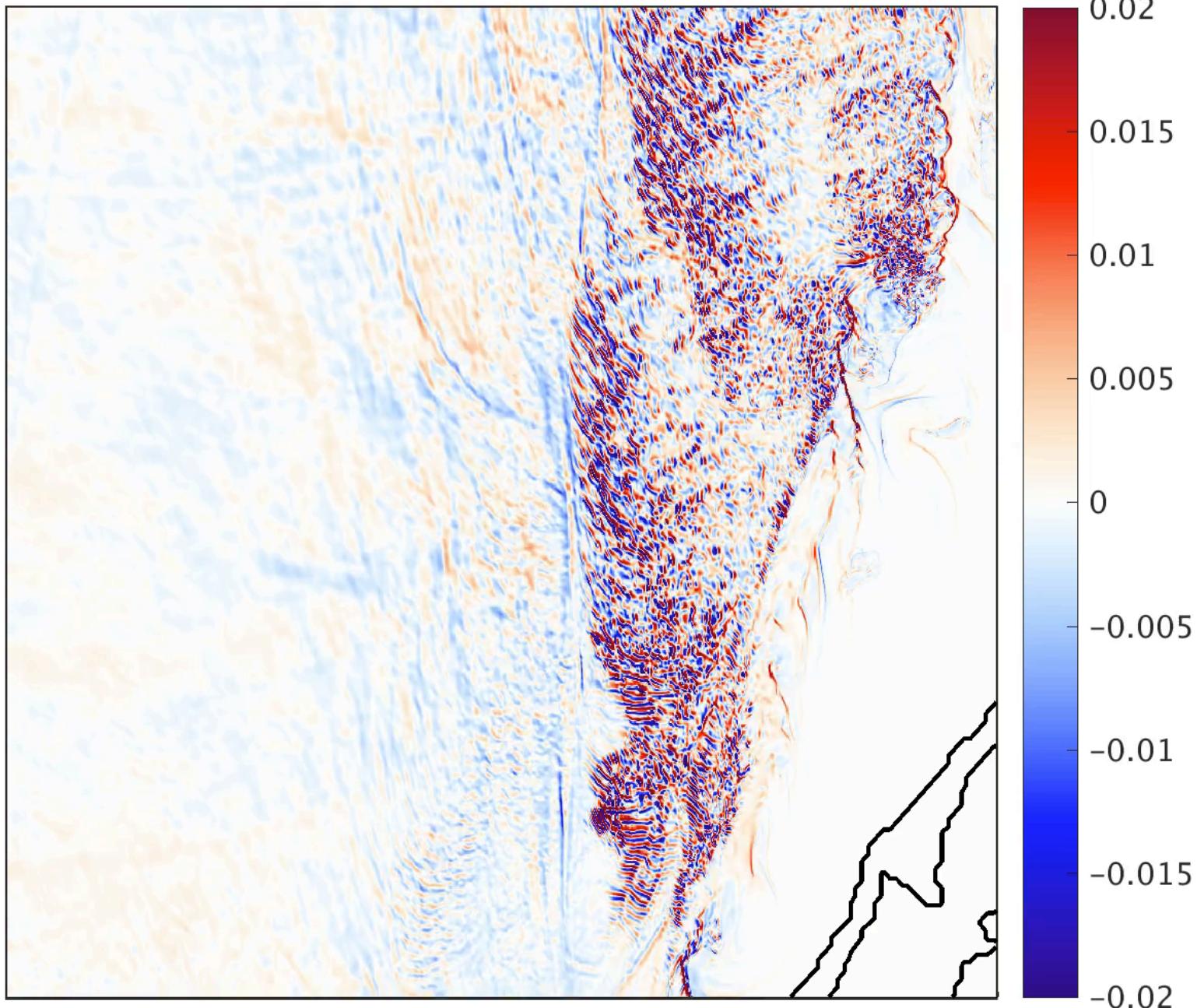
$\text{dx} = 50 \text{ m}$, non-hydrostatic



$\text{dx} = 50 \text{ m}$, non-hydrostatic

Surface layer vertical velocity





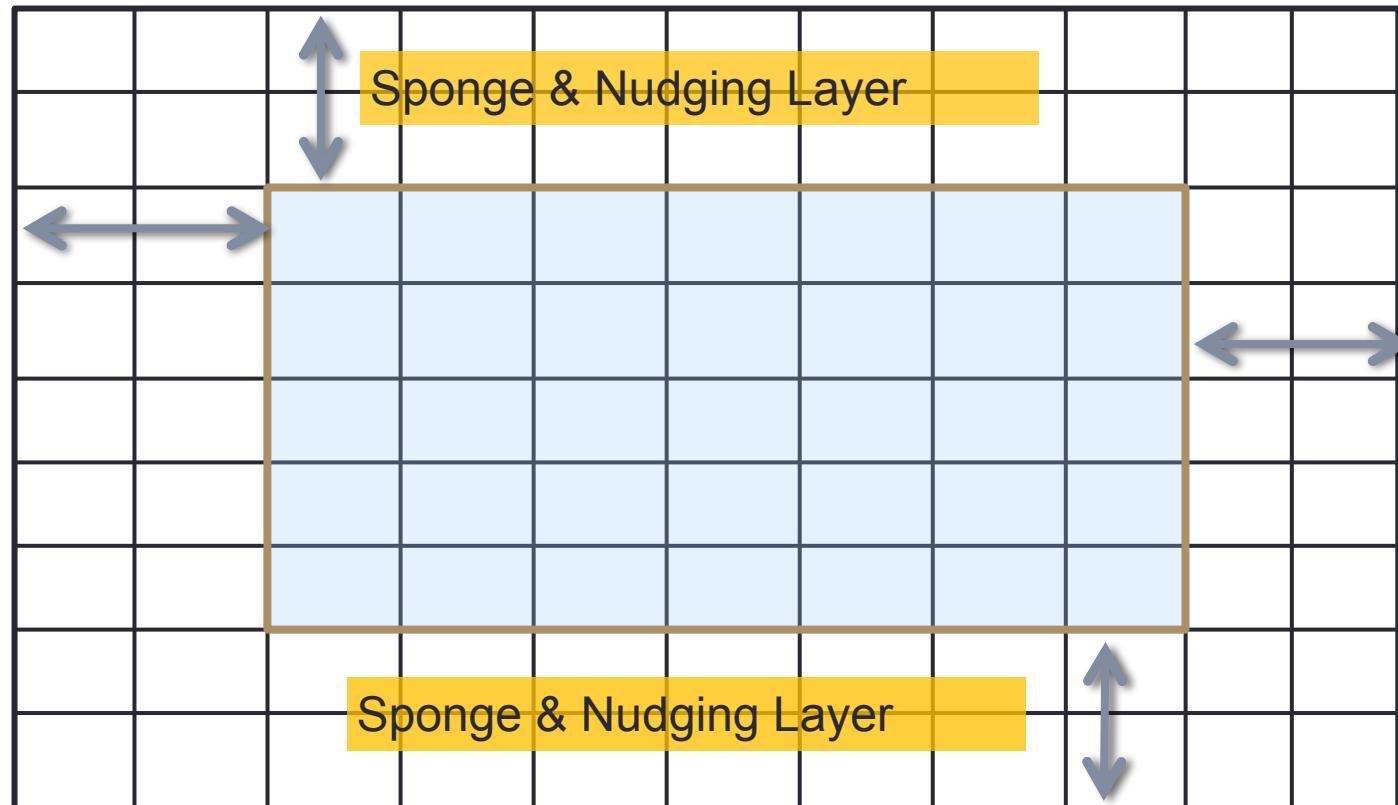
$dx = 15 \text{ m (NH)}$

Surface layer vertical velocity



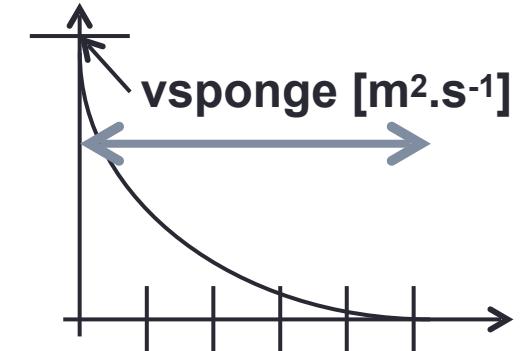
Visible light, (credit NASA)

Sponge/Nudging Layer

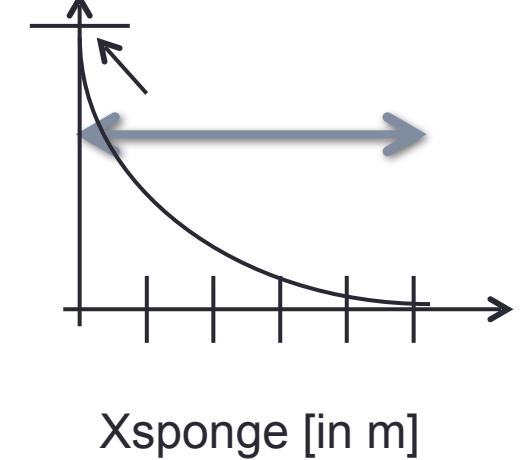


- Sponge : Additional viscosity/diffusivity
- Nudging : Add a weak nudging, $\tau = 0 \rightarrow \tau_{out}$, toward climatology, if available (see after)

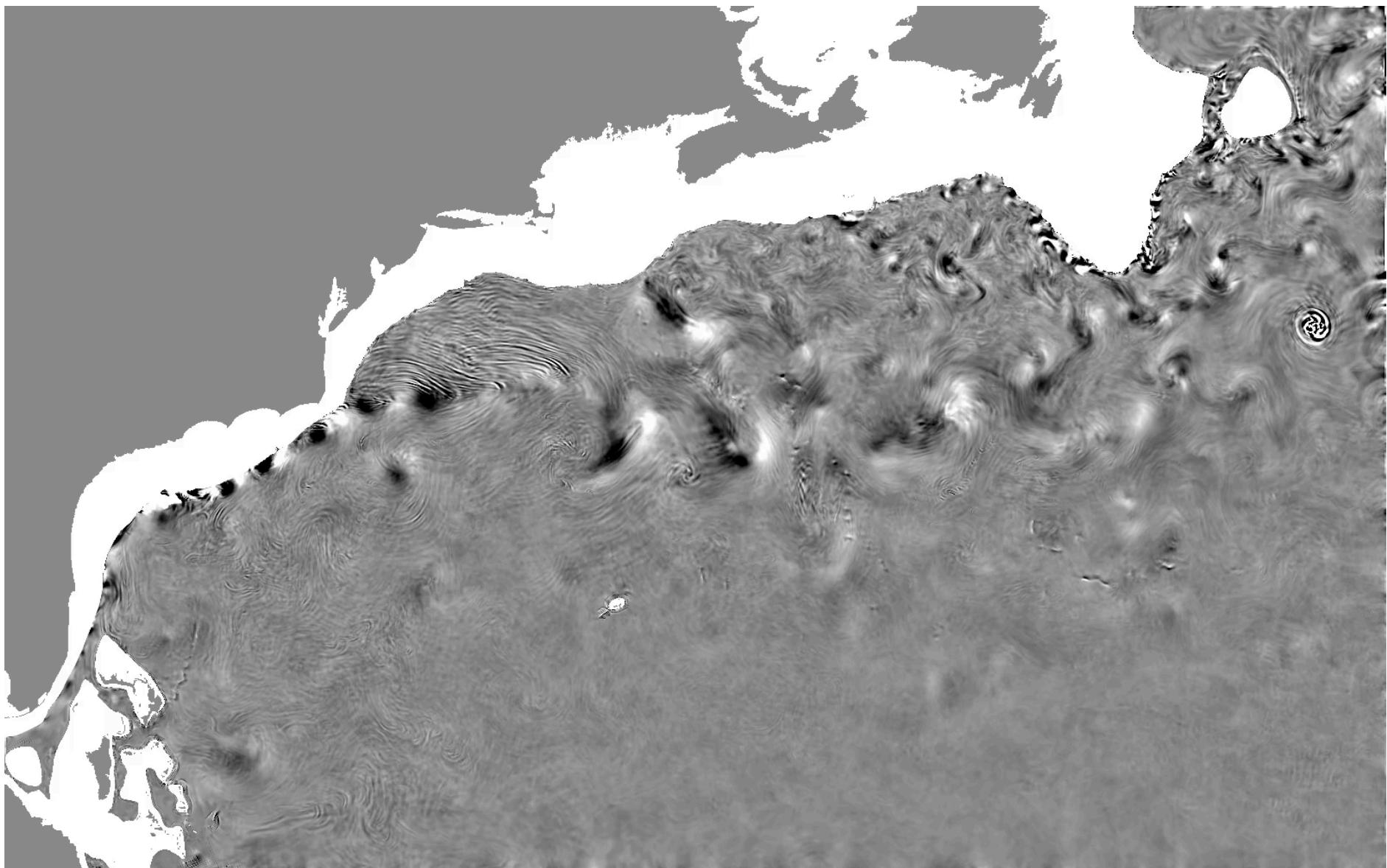
KTh, K^{mh} profil across sponge layer



τ_{out} profil cross nudging layer



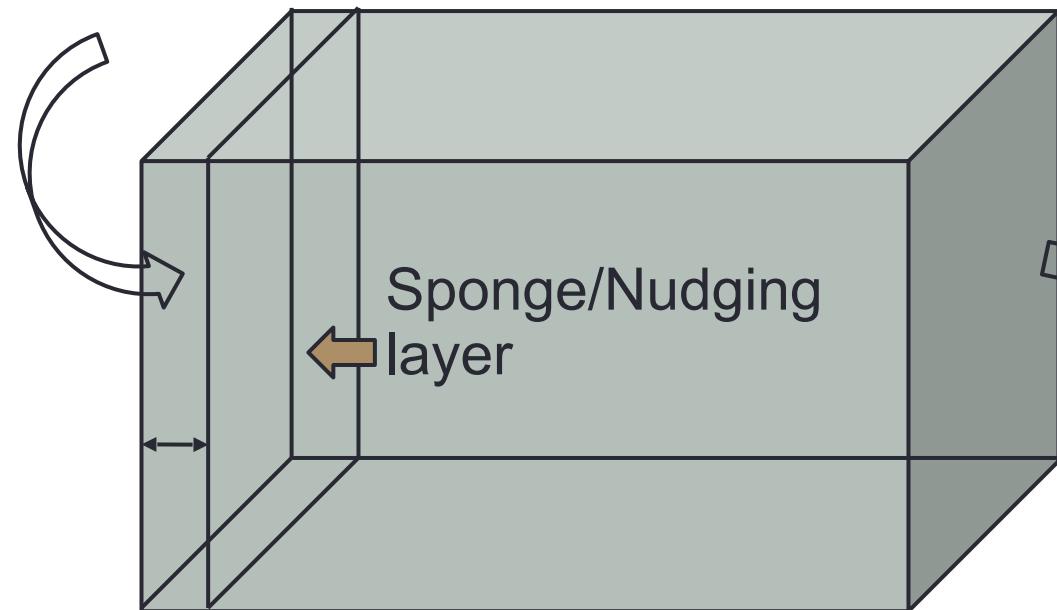
Sponge/Nudging Layer



Open boundary forcing (Clim or Bry)

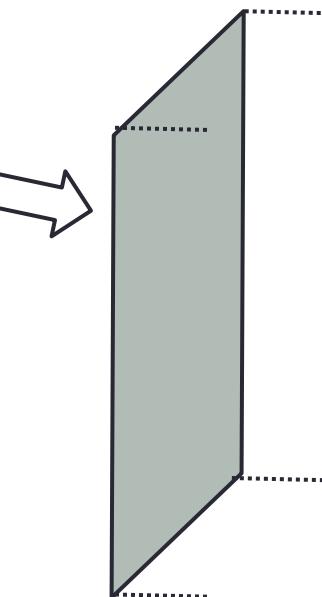
CLIM : ‘3D+time’ files (x,y,z,t) only used at boundaries point + sponge/nudging layer : large amount of data unused.

Data used here only



BRY: ‘2D+time’ file (x,z,t) only used at boundaries point : much less data needed !! **but no nudging layer**

Data used here only

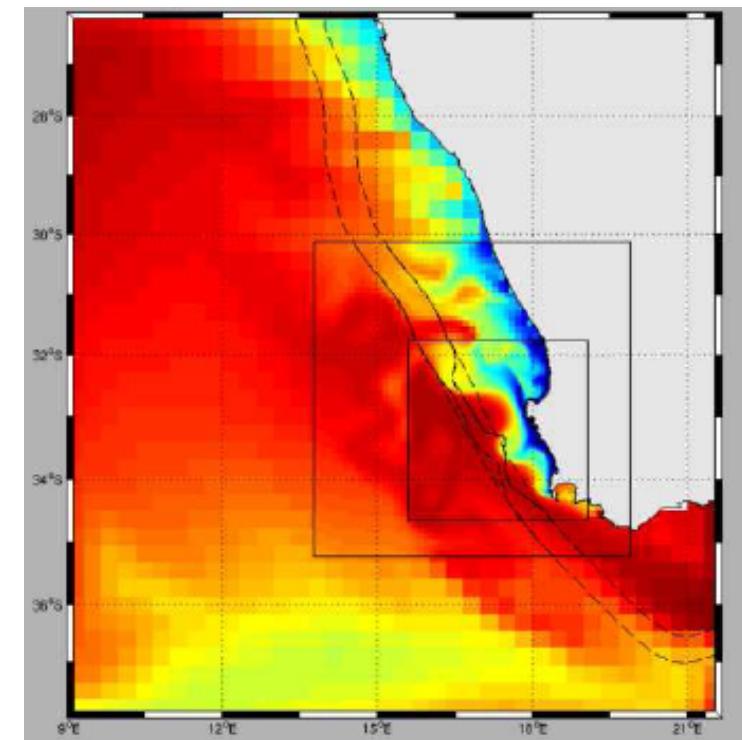


These type of file 3D (x,y,z) are used for initialization

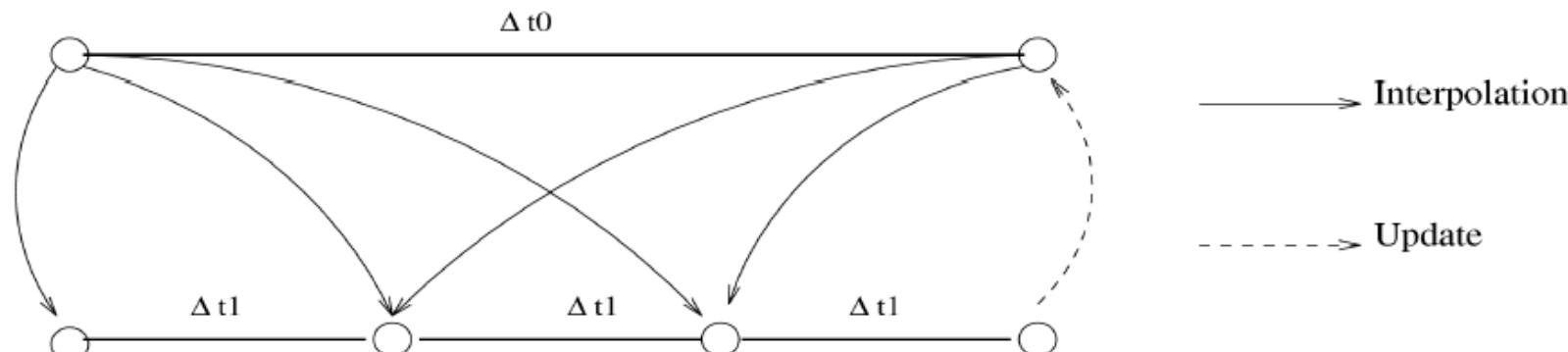
AGRIF Nesting

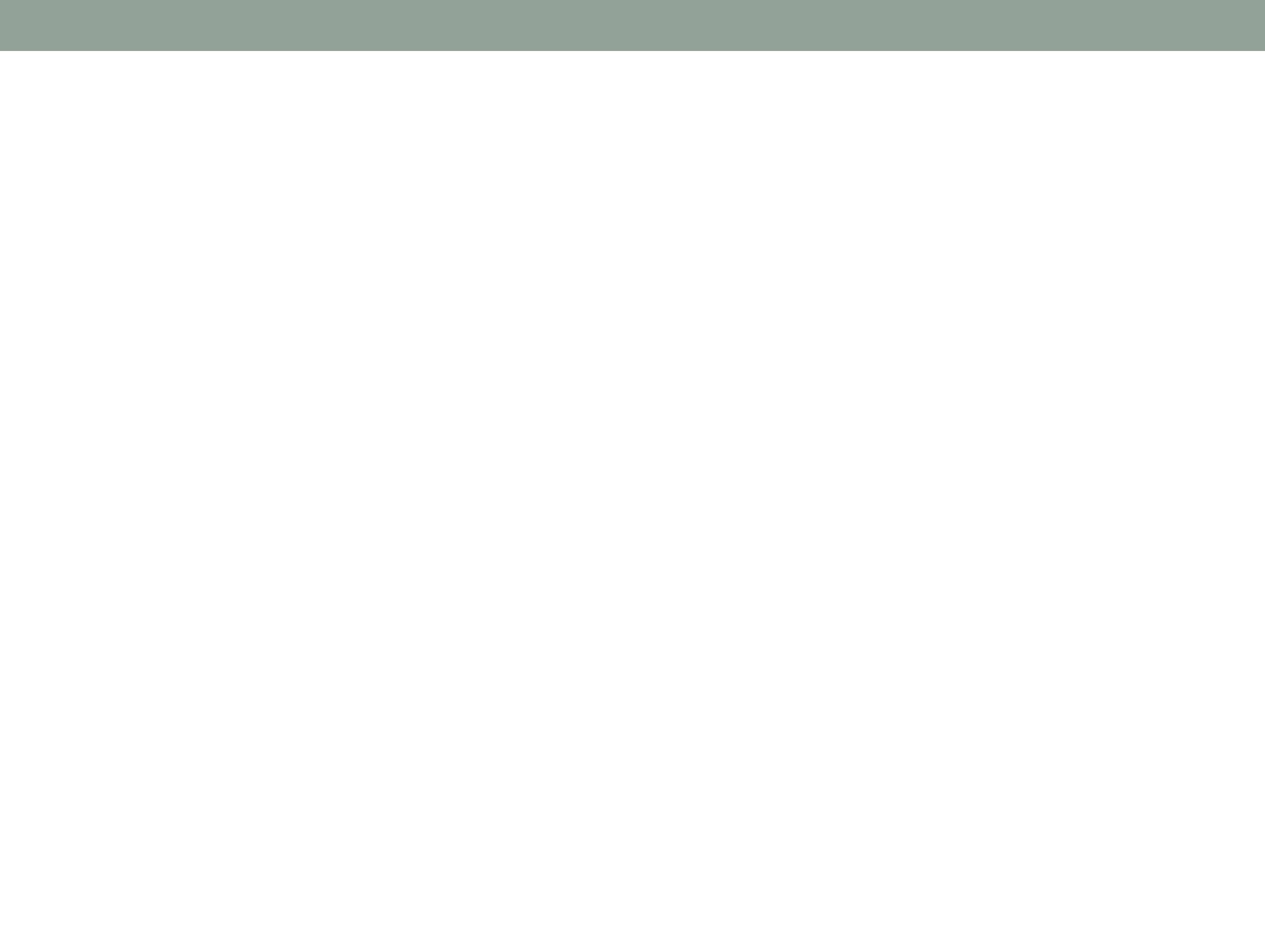
Nesting capability of CROCO:
CROCO_AGRIF

- Manage arbitrary number of fixed grid and embedded levels
- AGRIF : Adaptative Mesh Refinement (<http://www.ljk.imag.fr/MOISE/AGRIF/>)
- 1-way and 2 way nesting capability:
 - ✓ 1 way coarse grid feed fine grid
 - ✓ 2 way nesting : feed back of the fine grid on the coarse grid



Temporal coupling between a parent and a child grid for a refinement factor of 3 :





Activity :

- See Activity5.pdf

Activity :

2. Define Parameters of the simulation

- Edit general parameters in crocotools_param.m file

Activity : 3. Prepare files

Launch matlab –nodesktop

>> start : *Add all the needed matlab path of the system*

>> make_grid ⇒ CROCO_FILES/croco_grd.nc

Horizontal grid : position of the grid points, size of the grid cells

Bottom topography + Land mask

>> make_bulk : CROCO_FILES/croco_blk.nc

Surface forcing : wind stress, surface heat flux, surface freshwater flux

>> make_clm : ⇒ /CROCO_FILES/croco_ini.nc

initial conditions : T, S, currents , SSH

>> make_bry ⇒ /CROCO_FILES/croco_bry.nc

Lateral oceanic boundary conditions : T, S, currents , SSH

Activity : 4. Set up the model

Edit the param.h and cppdefs.h file to set-up the model

param.h defines the size of the arrays in ROMS:

```
...
#elsif defined REGIONAL
# if defined BENGUELA
  parameter (LLm0=23, MMm0=31, N=32) <---- Southern Benguela test Model
# else
  parameter (LLm0=??, MMm0=??, N=??)
# endif
...
```

Given by running make_grid

Southern Benguela test Model

Defined in romstools_param.m

cppdefs.h:

- Basic options
- More advanced options

- Define CPP keys used by the C-preprocessor when compiling the model.
- Reduce the code to its minimal size: fast compilation.
- Avoid FORTRAN logical statements: efficient coding.

Activity : 4. Set up the model

View
cppdef.h
file



```
!-----  
!      BASIC OPTIONS  
!  
*/  
/*          Configuration Name */  
# define BENGUELA  
/*          Parallelization */  
# undef OPENMP  
# undef MPI  
/*          Embedding */  
# undef AGRIF  
/*          Open Boundary Conditions */  
# undef TIDES  
# define OBC_EAST  
# undef OBC_WEST  
# define OBC_NORTH  
# define OBC_SOUTH  
/*          Embedding conditions */  
# ifdef AGRIF  
# undef AGRIF_OBC_EAST  
# define AGRIF_OBC_WEST  
# define AGRIF_OBC_NORTH  
# define AGRIF_OBC_SOUTH  
# endif  
/*          Applications */  
# undef BIOLOGY  
# undef FLOATS  
# undef STATIONS  
# undef PASSIVE_TRACER  
# undef SEDIMENTS  
# undef BBL  
  
!-----  
!      MORE ADVANCED OPTIONS  
!  
*/  
/*          Model dynamics */  
# define SOLVE3D  
# define UV_COR  
# define UV_ADV  
# ifdef TIDES  
# define SSH_TIDES  
# define UV_TIDES  
# define TIDERAMP  
# endif  
/*          Grid configuration */  
# define CURVGRID  
# define SPHERICAL  
# define MASKING  
/*          Input/Output & Diagnostics */  
# define AVERAGES  
# define AVERAGES_K  
# define DIAGNOSTICS_TS  
# define DIAGNOSTICS_UV  
/*          Equation of State */ ...  
/*          Surface Forcing */ ...  
/*          Lateral Forcing */ ...  
/*          Input/Output & Diagnostics */ ...  
/*          Bottom Forcing */ ...  
/*          Point Sources - Rivers */ ...  
/*          Lateral Mixing */ ...  
/*          Vertical Mixing */ ...  
/*          Open Boundary Conditions */ ...  
/*          Embedding conditions */ ...
```

Activity : 4. Set up the model

The namelist croco.in

roms.in provides the run time parameters for ROMS:

title:
Southern Benguela
time_stepping: NTIMES dt[sec] NDTFAST NINFO
480 5400 60 1
S-coord: THETA_S, THETA_B, Hc (m)
6.0d0 0.0d0 10.0d0

grid: filename
ROMS_FILES/roms_grd.nc

forcing: filename
ROMS_FILES/roms_frc.nc

bulk_forcing: filename
ROMS_FILES/roms_blk.nc

climatology: filename
ROMS_FILES/roms_clm.nc

boundary: filename
ROMS_FILES/roms_bry.nc

initial: NRREC filename
1
ROMS_FILES/roms_ini.nc

restart: NRST, NRPFRST / filename
480 -1
ROMS_FILES/roms_RST.nc

Warning ! These
should be identical to
the ones in
romstools_param.m

history: LDEFHIS, NWRT, NRPFHIS / filename
T 480 0
ROMS_FILES/roms_his.nc
averages: NTSAVG, NAVG, NRPFAVG / filename
1 48 0
ROMS_FILES/roms_avg.nc

primary_history_fields: zeta UBAR VBAR U V wrtT(1:NT)
T F F F F 10*T
auxiliary_history_fields: rho Omega W Akv Akt Aks HBL Bostr
F F F F F F F F F
primary_averages: zeta UBAR VBAR U V wrtT(1:NT)
T T T T T 10*T
auxiliary_averages: rho Omega W Akv Akt Aks HBL Bostr
F T T F T F T T
rho0:
1025.d0
lateral_visc: VISC2, VISC4 [m^2/sec for all]
0. 0.
tracer_diff2: TNU2(1:NT) [m^2/sec for all]
10*0.d0
bottom_drag: RDRG [m/s], RDRG2, Zob [m], Cdb_min, Cdb_max
0.0d-04 0.d-3 1.d-2 1.d-4 1.d-1
gamma2:
1.d0
sponge: X_SPONGE [m], V_SPONGE [m^2/sec]
100.e3 800.

nudg_cof: TauT_in, TauT_out, TauM_in, TauM_out [days for all]
1. 360. 10. 360.

Activity : 5. Compile the model and Run

- Compile: `./jobcomp`
- Run: `./croco croco.in`

Other CROCOTOOLS processing tools ...

- ✓ Process the tides forcings : `make_tides.m`
- ✓ Process the biological forcing : `make_biol.m`, `make_bgc.m`,
`make_pisces.m`
- ✓ Process interannual forcing (atmopsheric and oceanic) using Opendap connection : `make_ncep.m`, `make_OGCM.m`
- ✓ Diagnostics tools
- ✓ Script to run long simulation (→ `croco_YxxMxx.nc`) :
 - ✓ Climatological runs : `run_croco.csh`
 - ✓ Interannual run : `run_croco_inter.csh`
- ✓ Forecast system using Mercator and NCEP data: `make_forecast.m`
- ✓ ...

Vizualization

In ~/Roms_tools/Run

\$ matlab

>> croco_gui

