Numerical Modelling

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the anatomy of an ocean model

Outline

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

Presentations and material will be available at :

jgula.fr/ModNum/

#7
Setting up a realistic configuration with CROCO

Master's degree 2nd year Marine Physics

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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*)

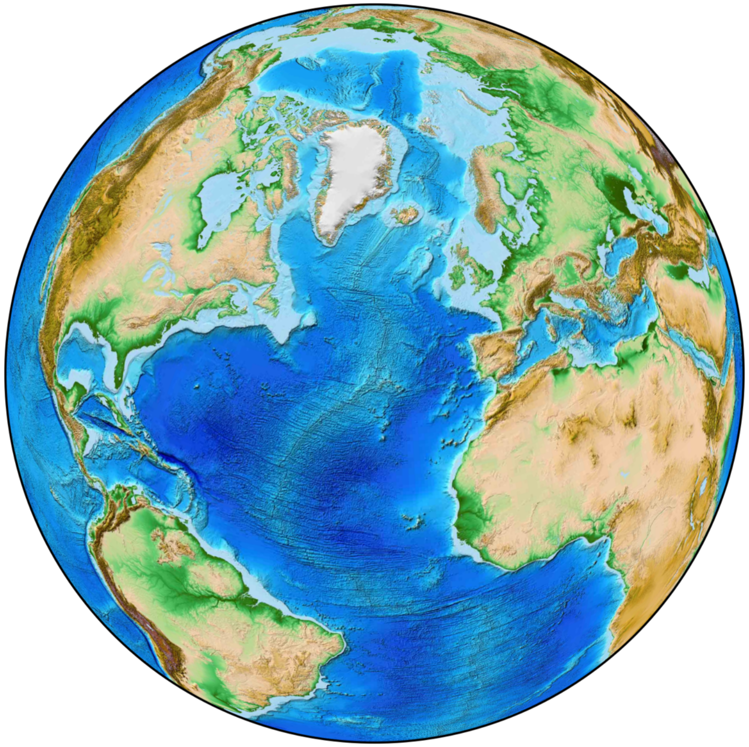
  Smith, W. H. F., and D. T. Sandwell, Global seafloor topography from satellite altimetry and ship depth soundings, Science, v. 277, p. 1957-1962, 26 Sept., 1997.

- 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.

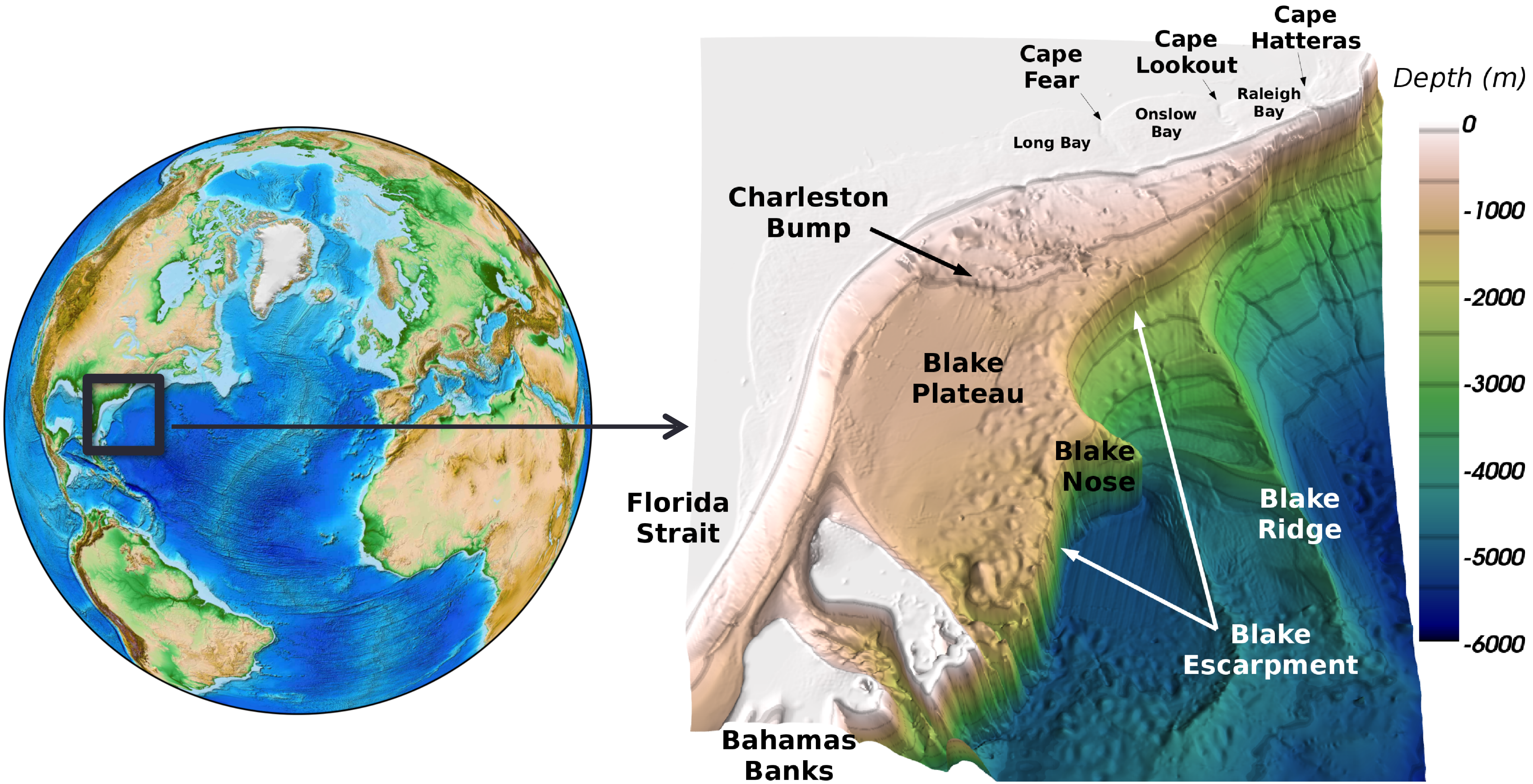
- Gebco30 (*http://www.gebco.net/data_and_products/gridded_bathymetry_data/*)

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



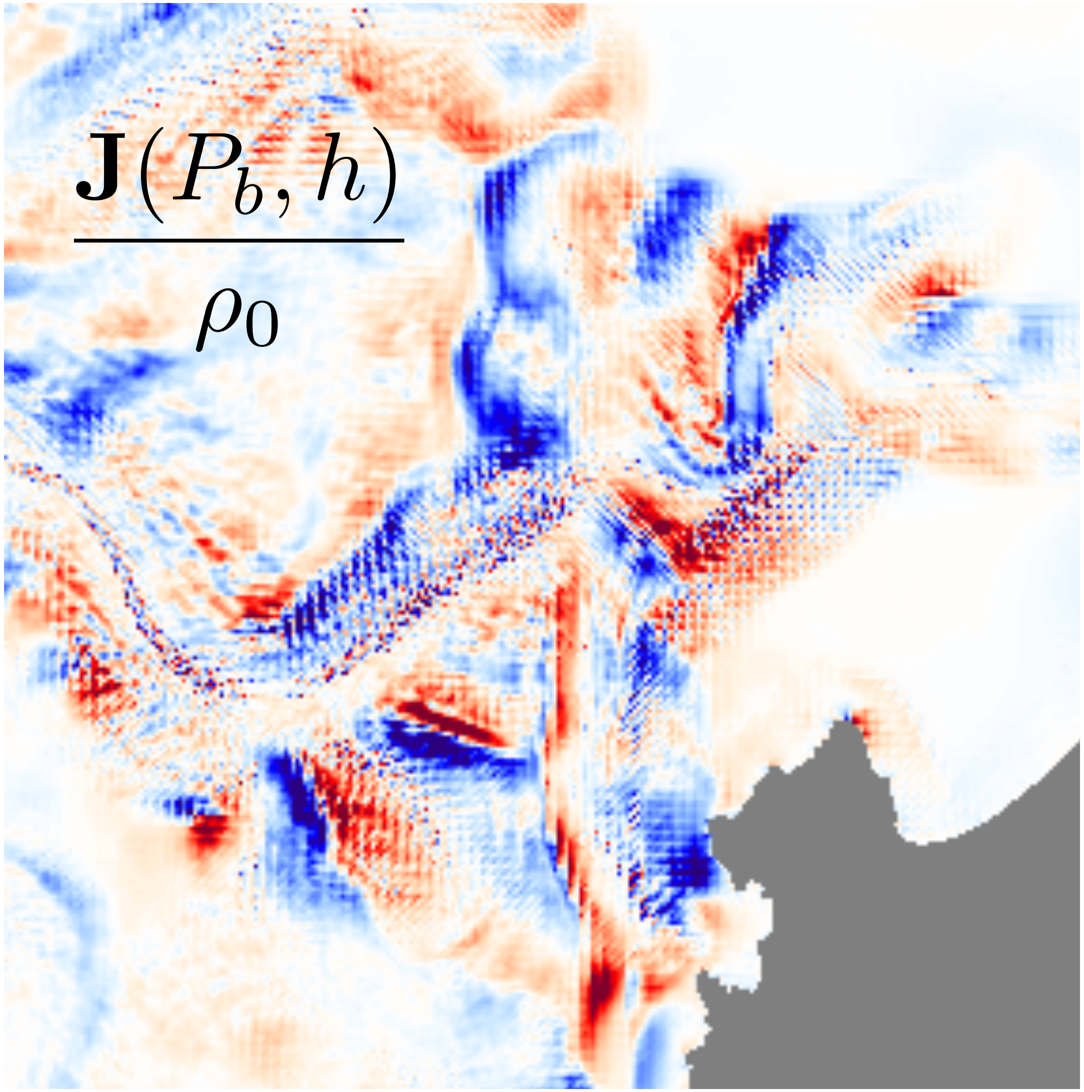
Bottom topography + Land Mask

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



Bottom topography + Land Mask

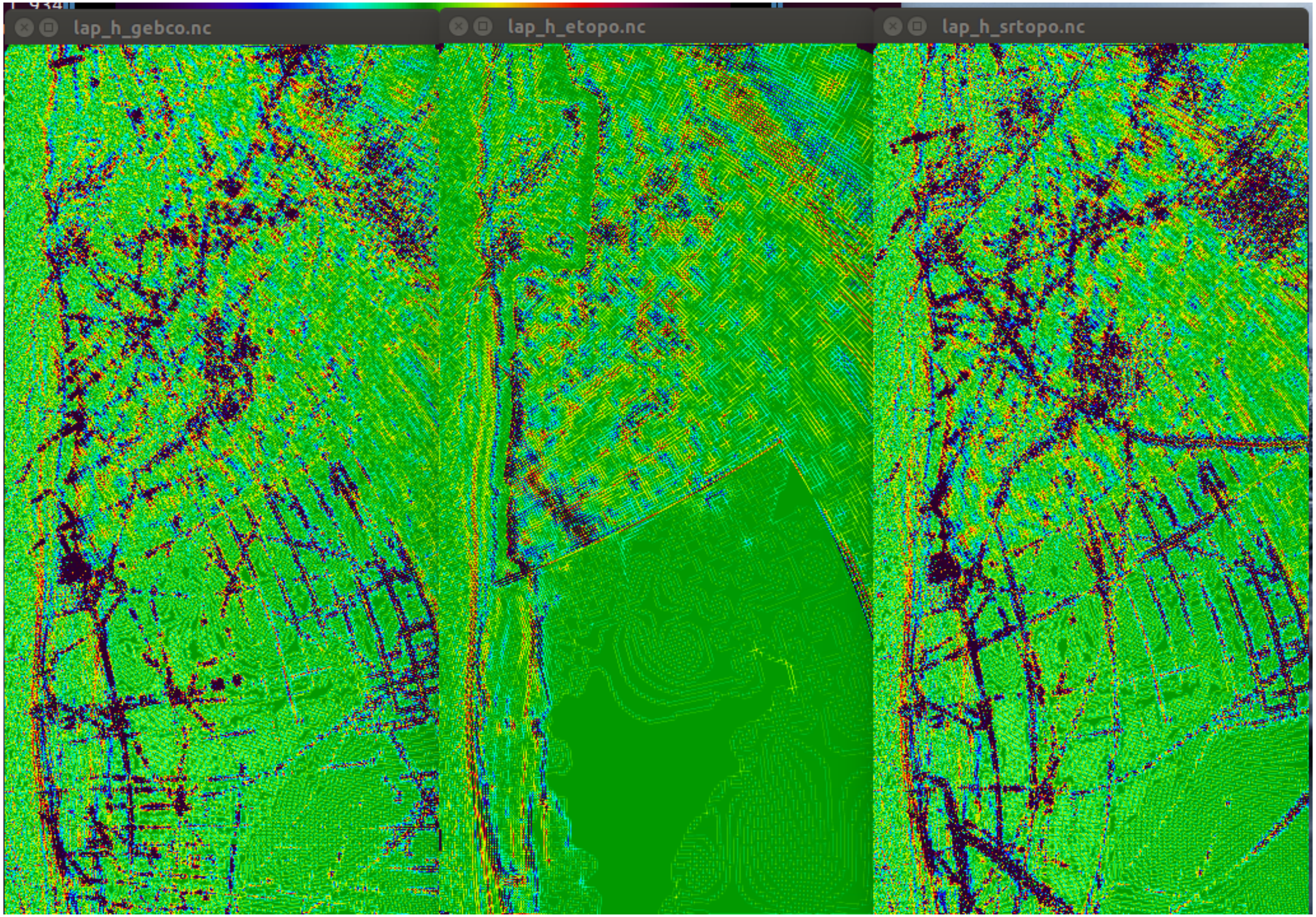
- Avoid linear interpolation when interpolating your topography.



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

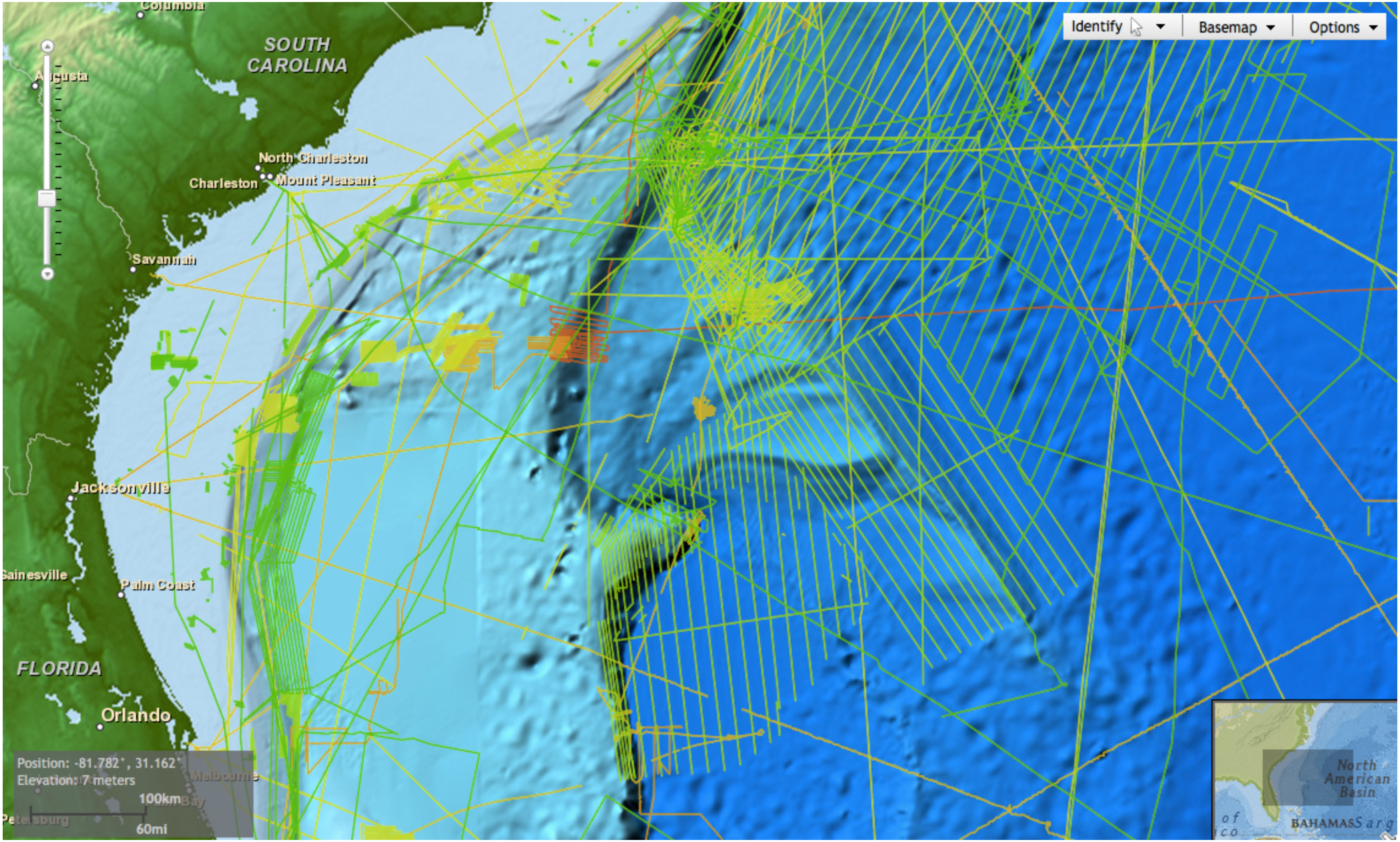
Bottom topography + Land Mask

- 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=η):**

$$\frac{\partial \eta}{\partial t} = w$$

$$\left.\begin{aligned} K_{Mv}\frac{\partial u}{\partial z} &= \frac{\tau_x}{\rho_0} \\ K_{Mv}\frac{\partial v}{\partial z} &= \frac{\tau_y}{\rho_0} \end{aligned}\right\} \text{Wind stress}$$

$$K_{Tv}\frac{\partial T}{\partial z} = \frac{Q}{\rho_0 C_p} \qquad \text{Heat flux}$$

$$K_{Sv}\frac{\partial S}{\partial z} = \frac{S(E-P)}{\rho_0} \qquad \text{Salt flux : evap - rain}$$

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

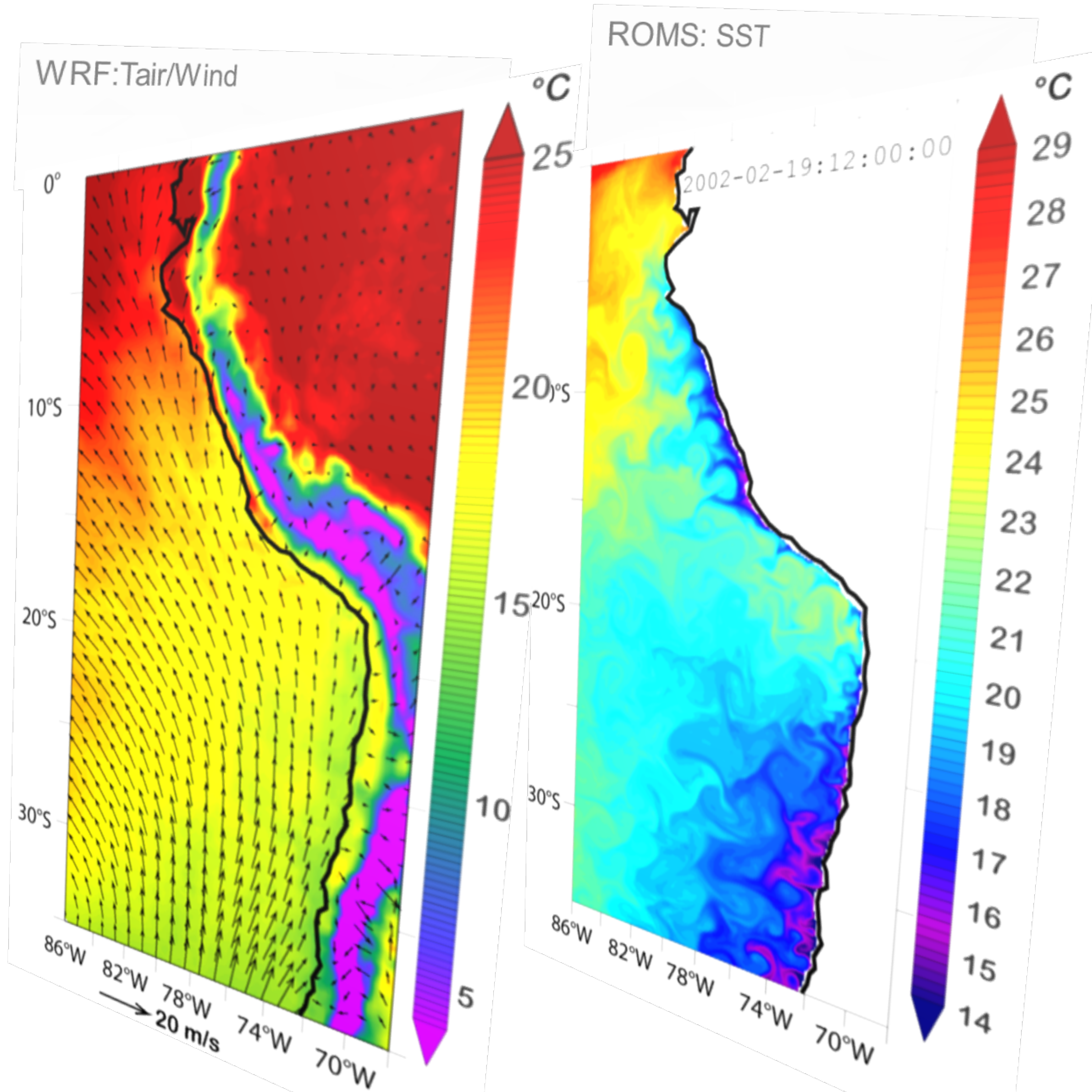
Available Datasets:

- Heat and freshwater fluxes : COADS, …
- Wind Stress: QuickScat, SCOW, …

- Reanalysis (Model +obs.) : CFSR, ERA interim, ERA5, etc.

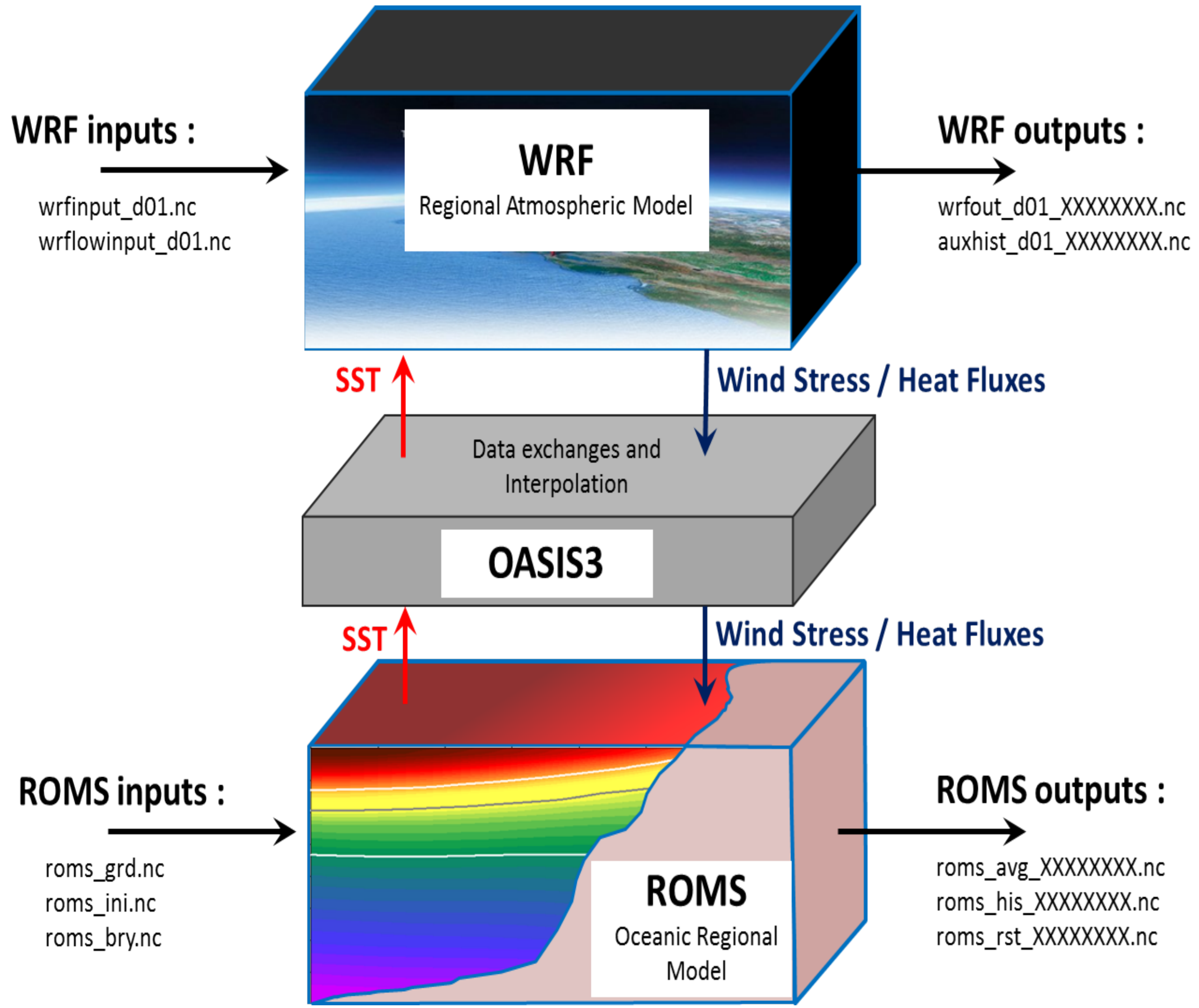
Ocean-Atmosphere coupling

- Interactive coupling with an atmospheric model:



Ocean-Atmosphere coupling

e.g. OASIS3-MCT implementation in CROCO:



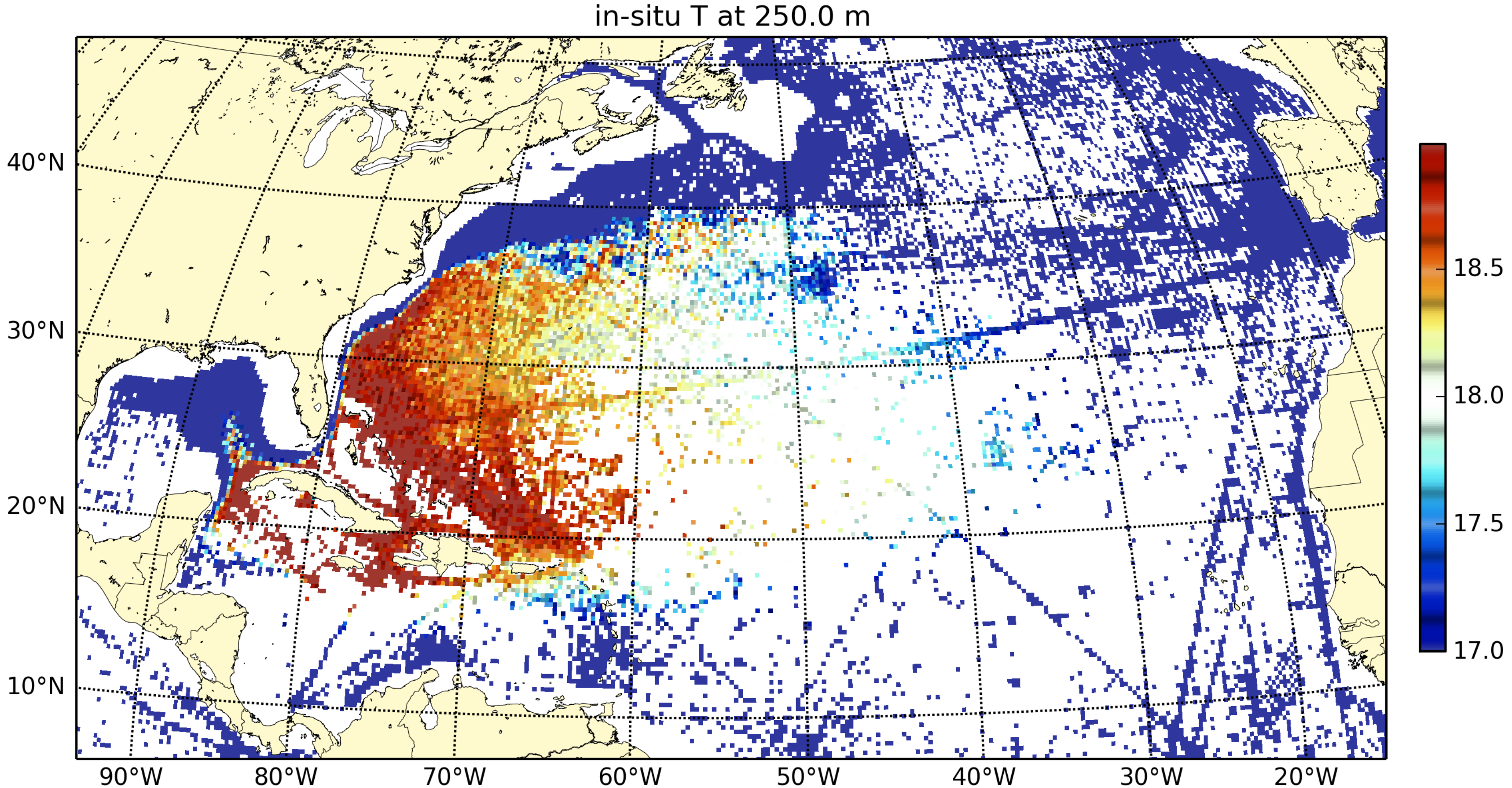
Initial + boundary conditions

- 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 ¼ deg grid)



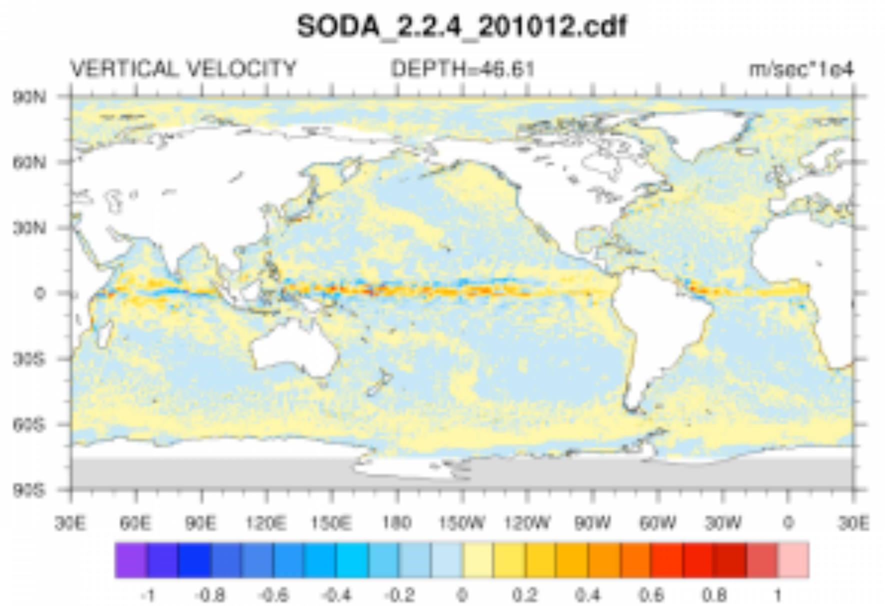
Initial + boundary conditions

Interannual forcing:

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

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

= Model + data assimilation



- Model outputs (OGCM)

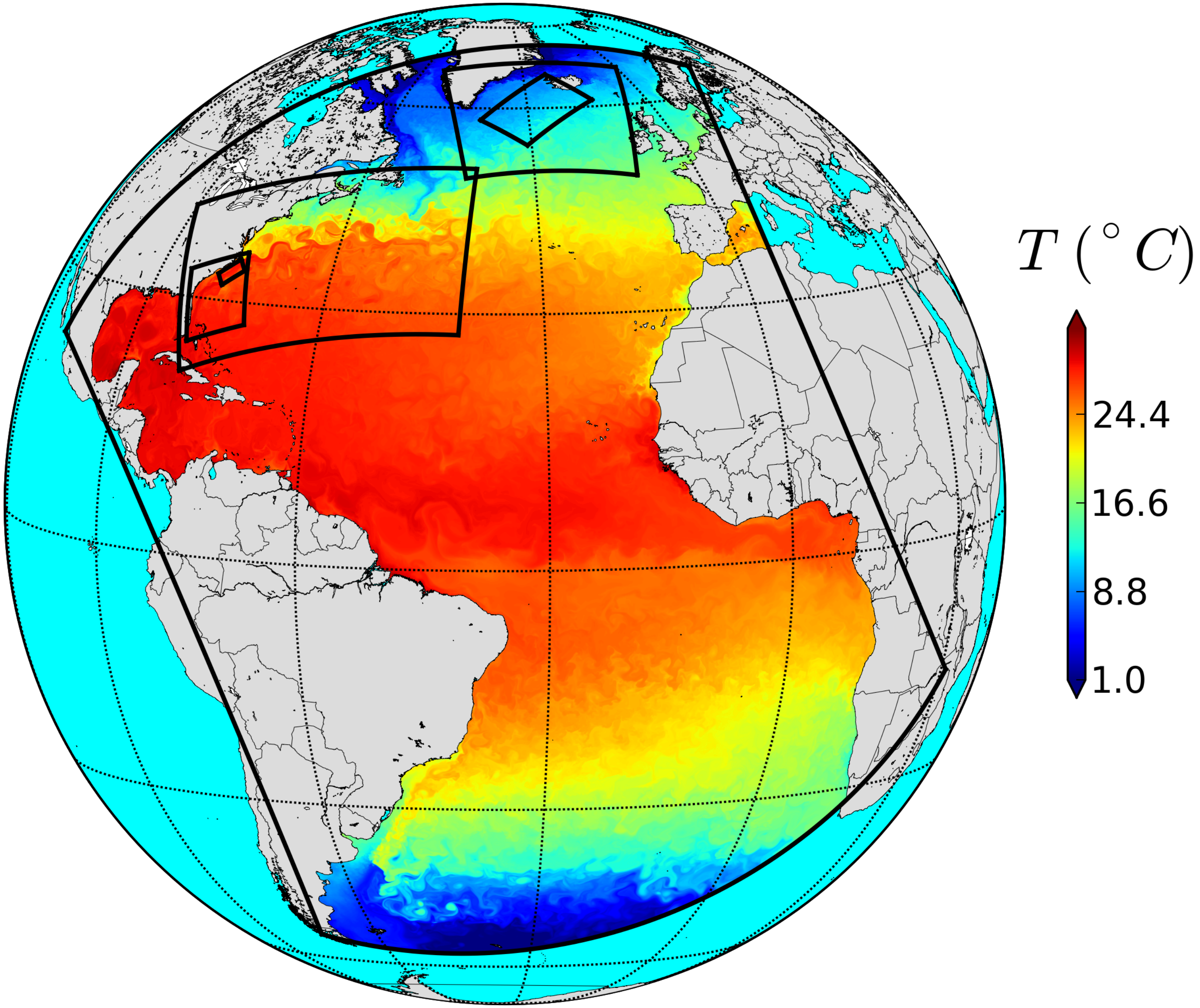
  (e.g. for IPCC runs)

Offline Nesting

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

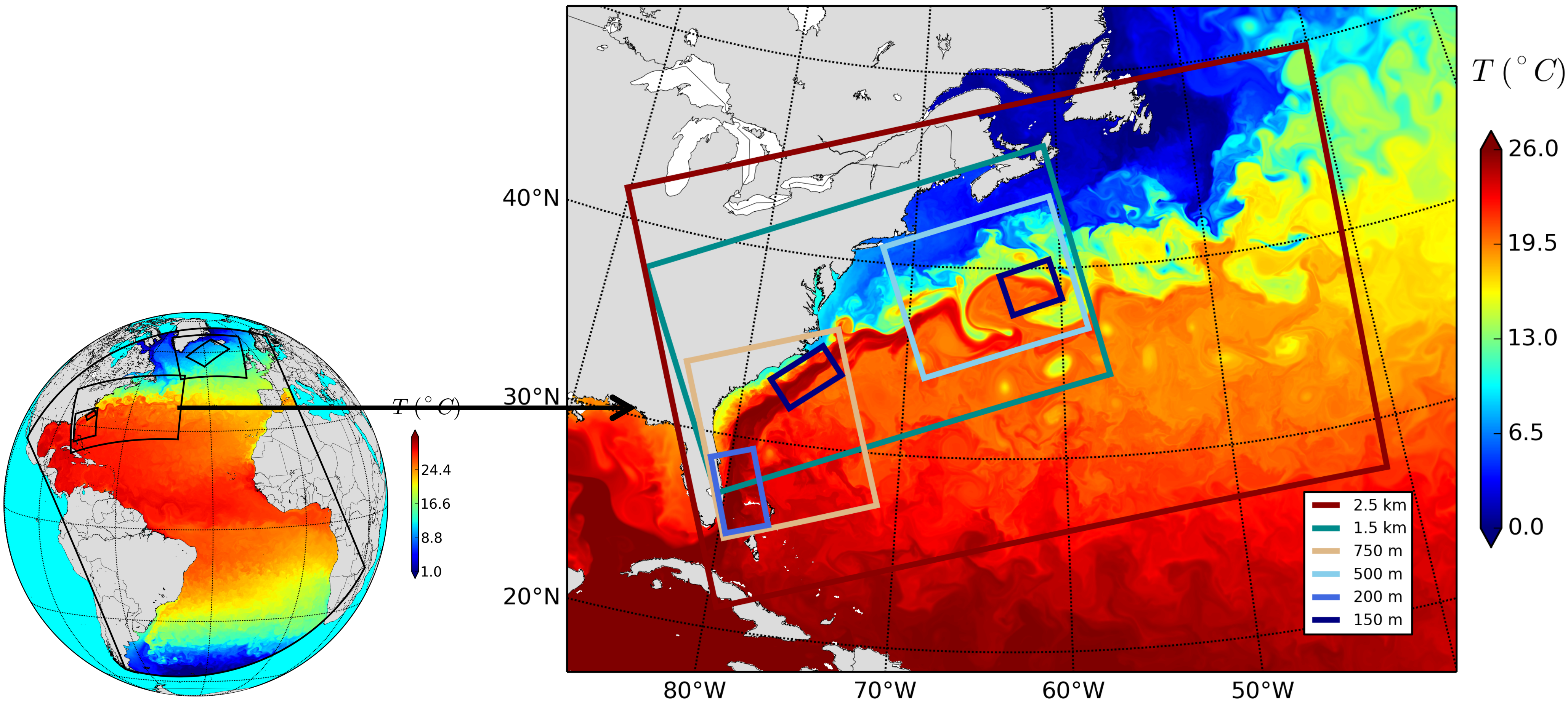
- Processing of croco OBC using the output of a larger croco simulation.

- Enable offline oceanic downscalling



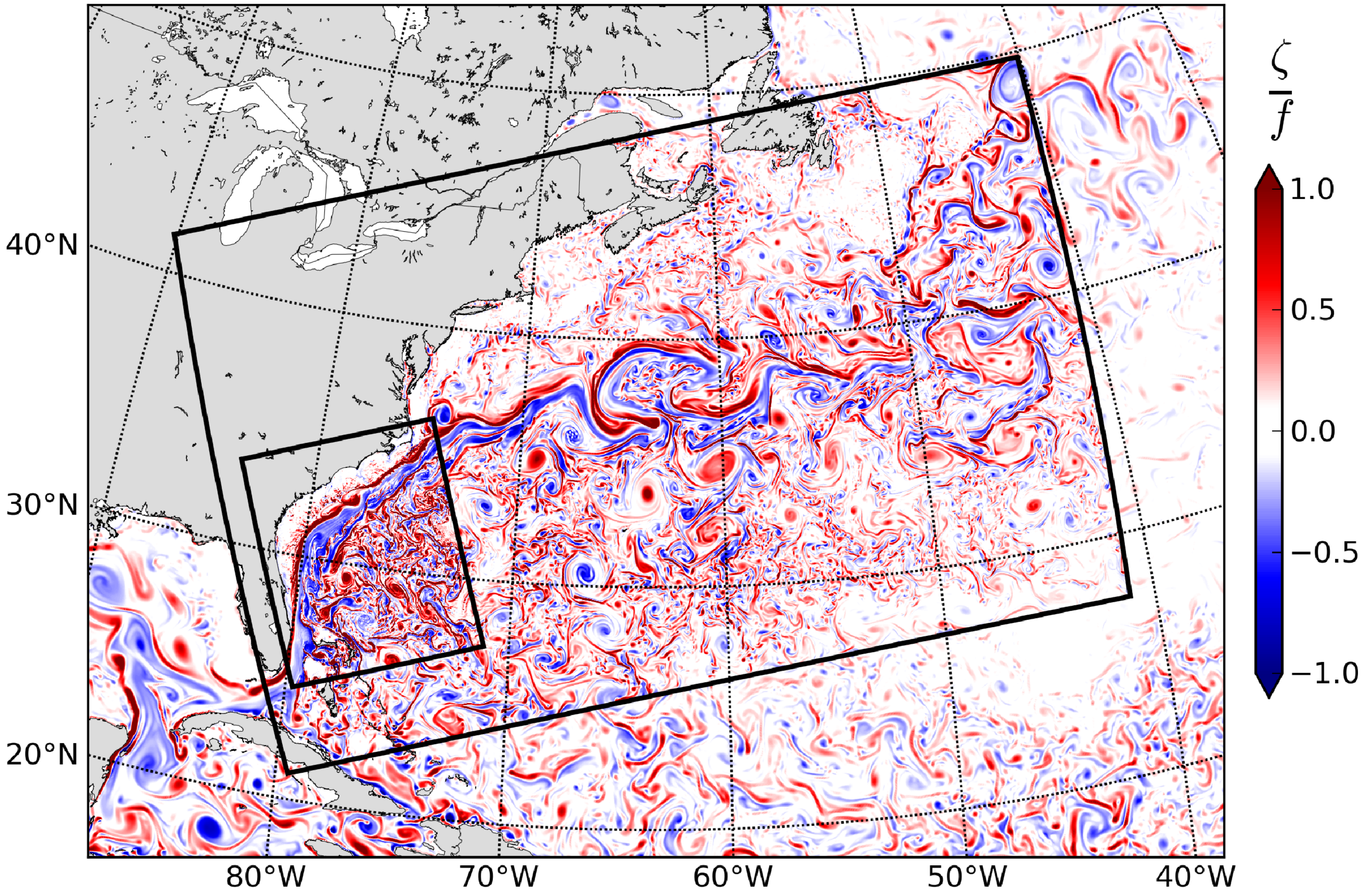
Offline Nesting

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



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].

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

Radiation, (Orlanski, 1982)

- Possibility to **use "Flather" OBC conditions for barotropic mode :** Specially designed for tidal applications

Adaptative nudging term :

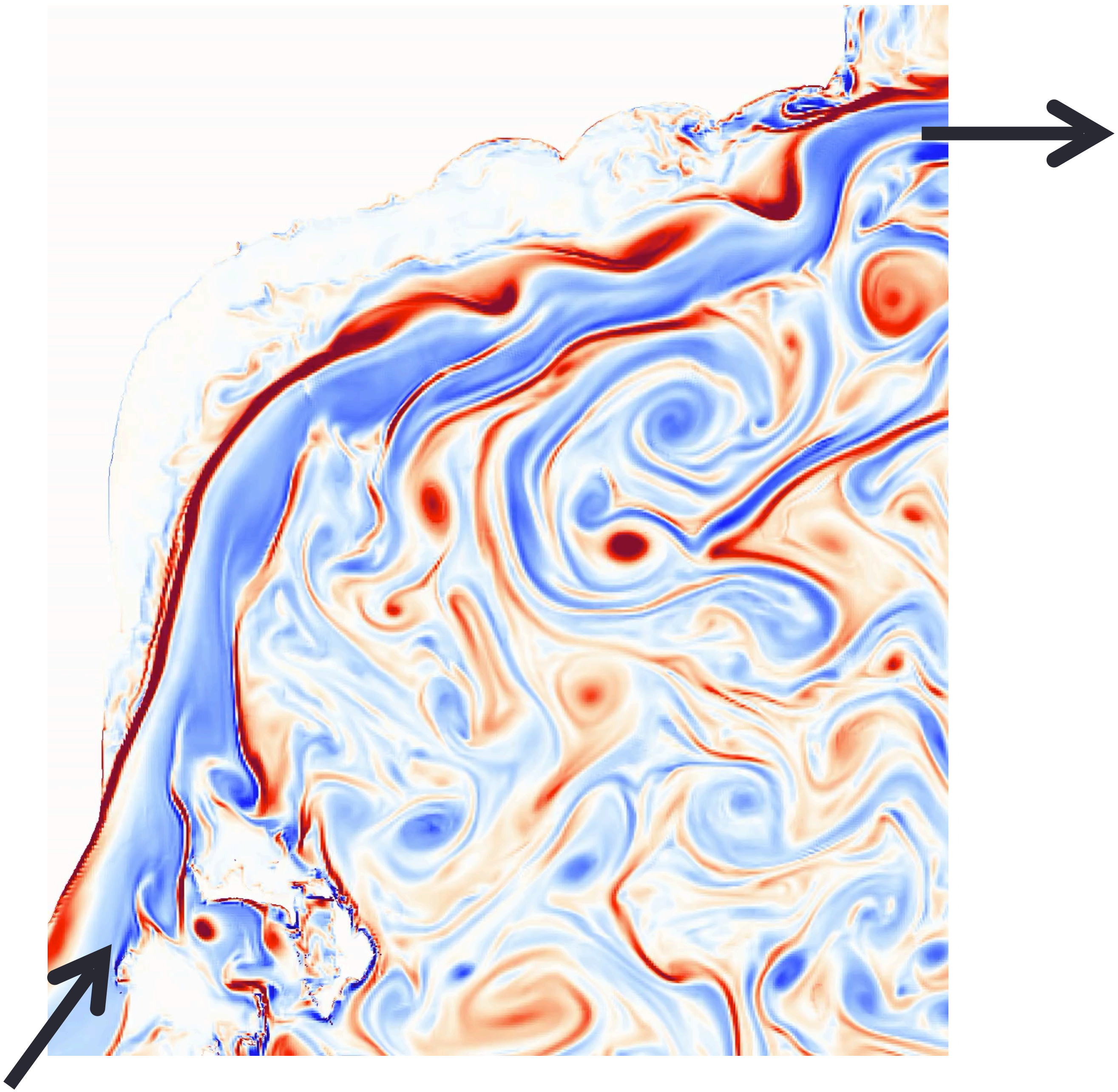
Adaptativity

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

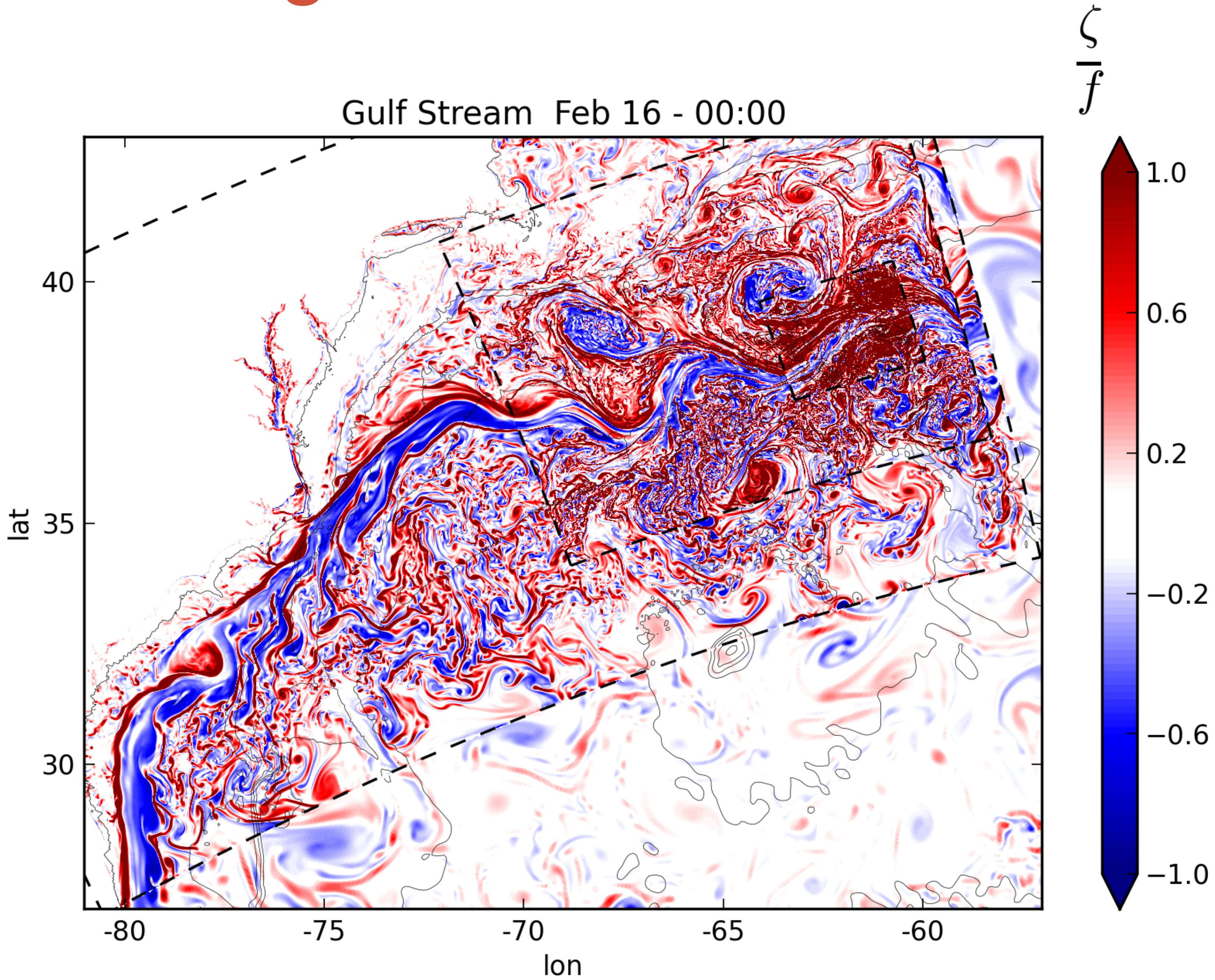
$$\left.\begin{aligned} \tau_{out} &\approx 180 \text{ days} \\ \tau_{in} &\approx 1 \text{ days} \end{aligned}\right]$$

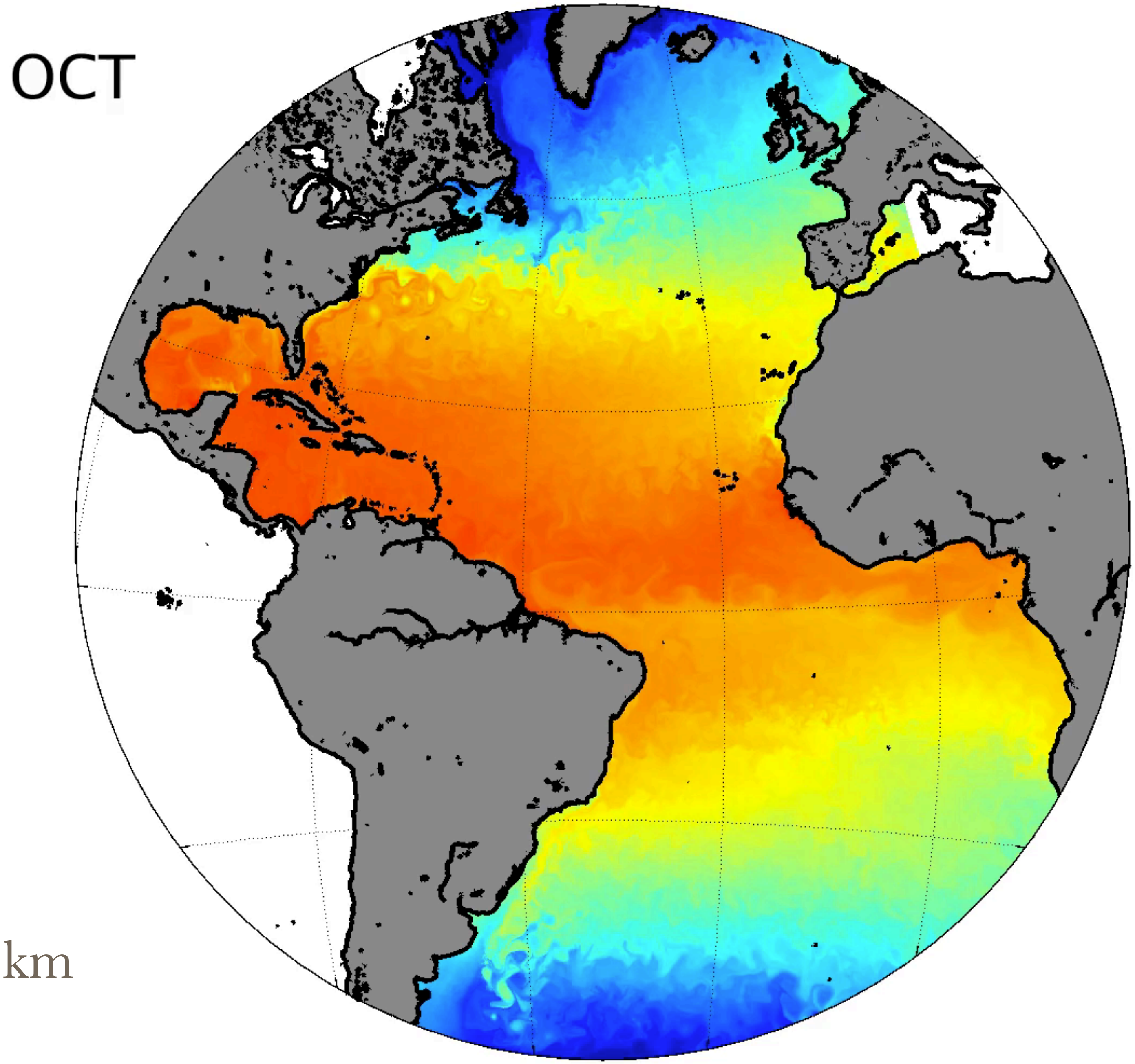
τ_{M_in} , τ_{M_out} : momentum
τ_{T_in} , τ_{T_out} : tracer

Open boundary conditions I (OBC type)



Offline Nesting

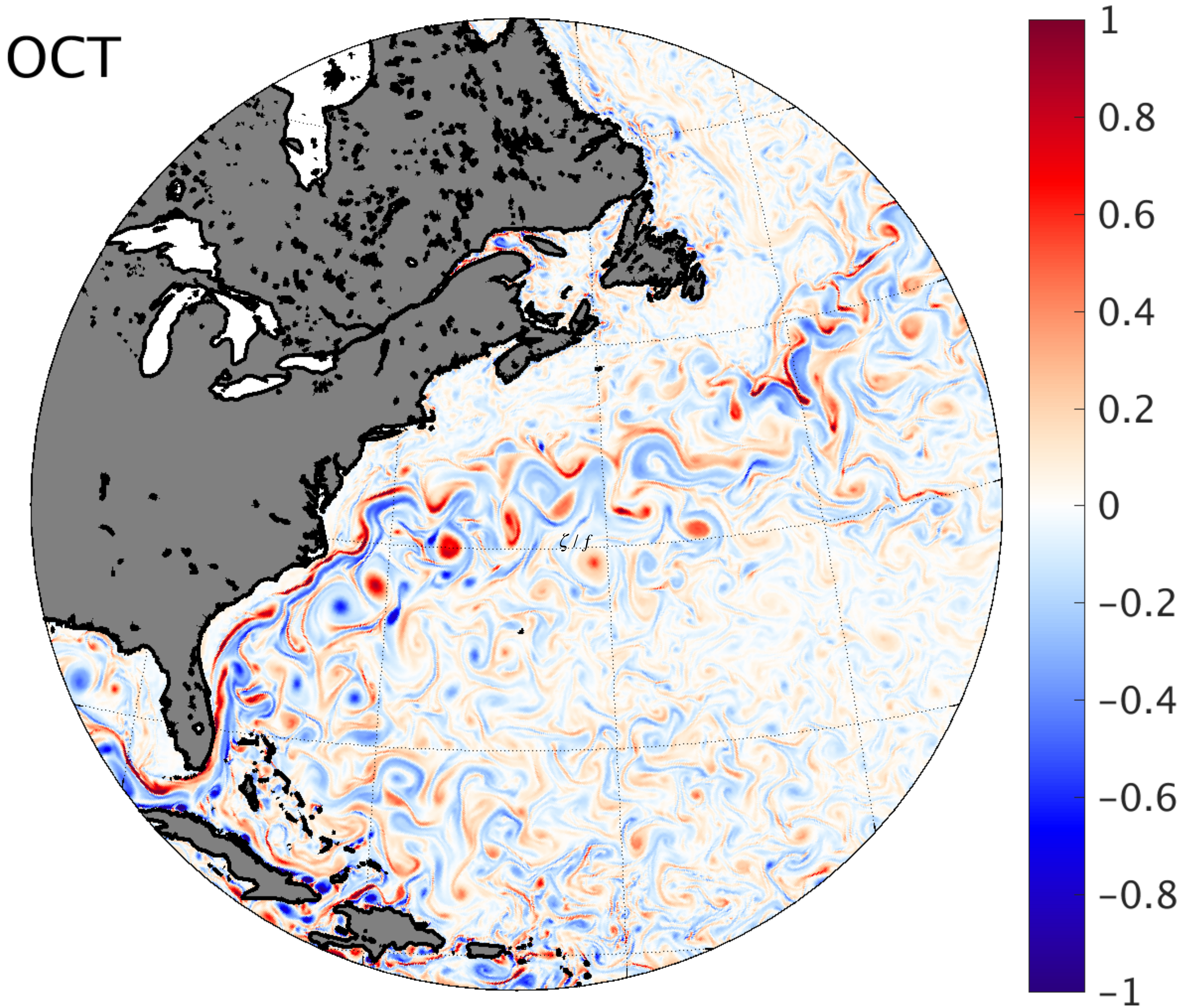




dx = 5-7 km

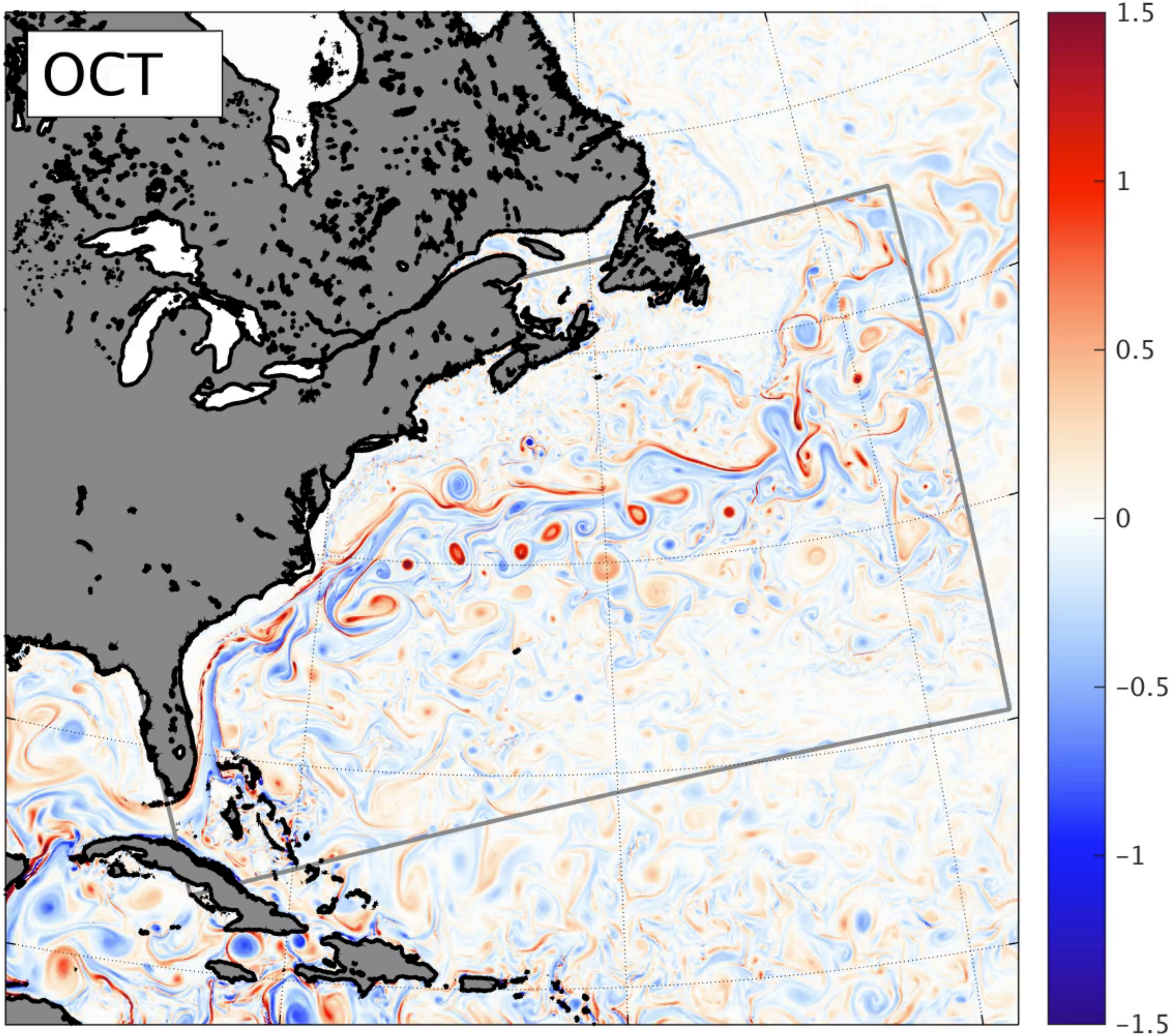
SST

Simulations using ROMS: Regional is a relative concept

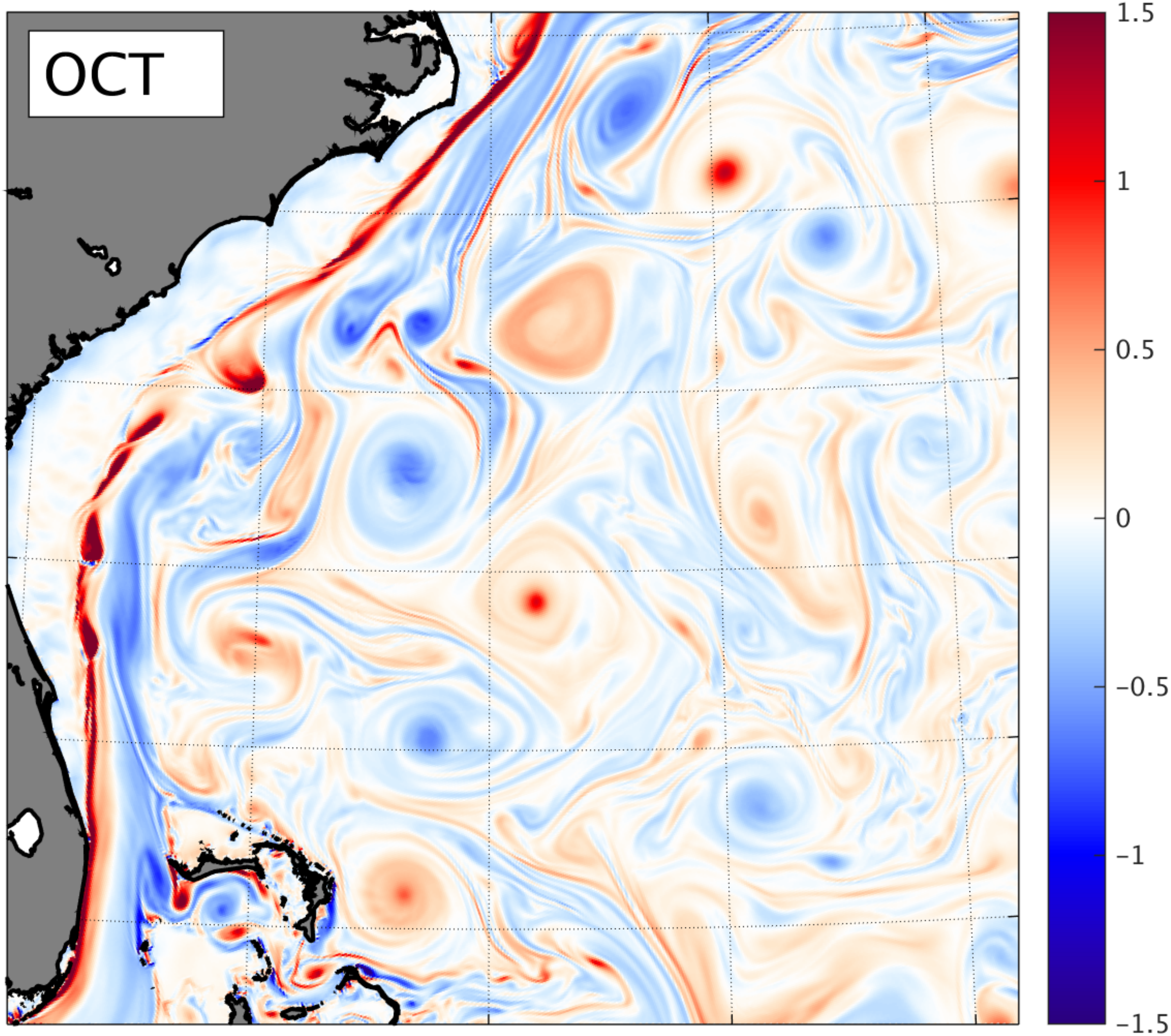


Normalized relative vorticity, or $Ro = \zeta / f$

ζ / f

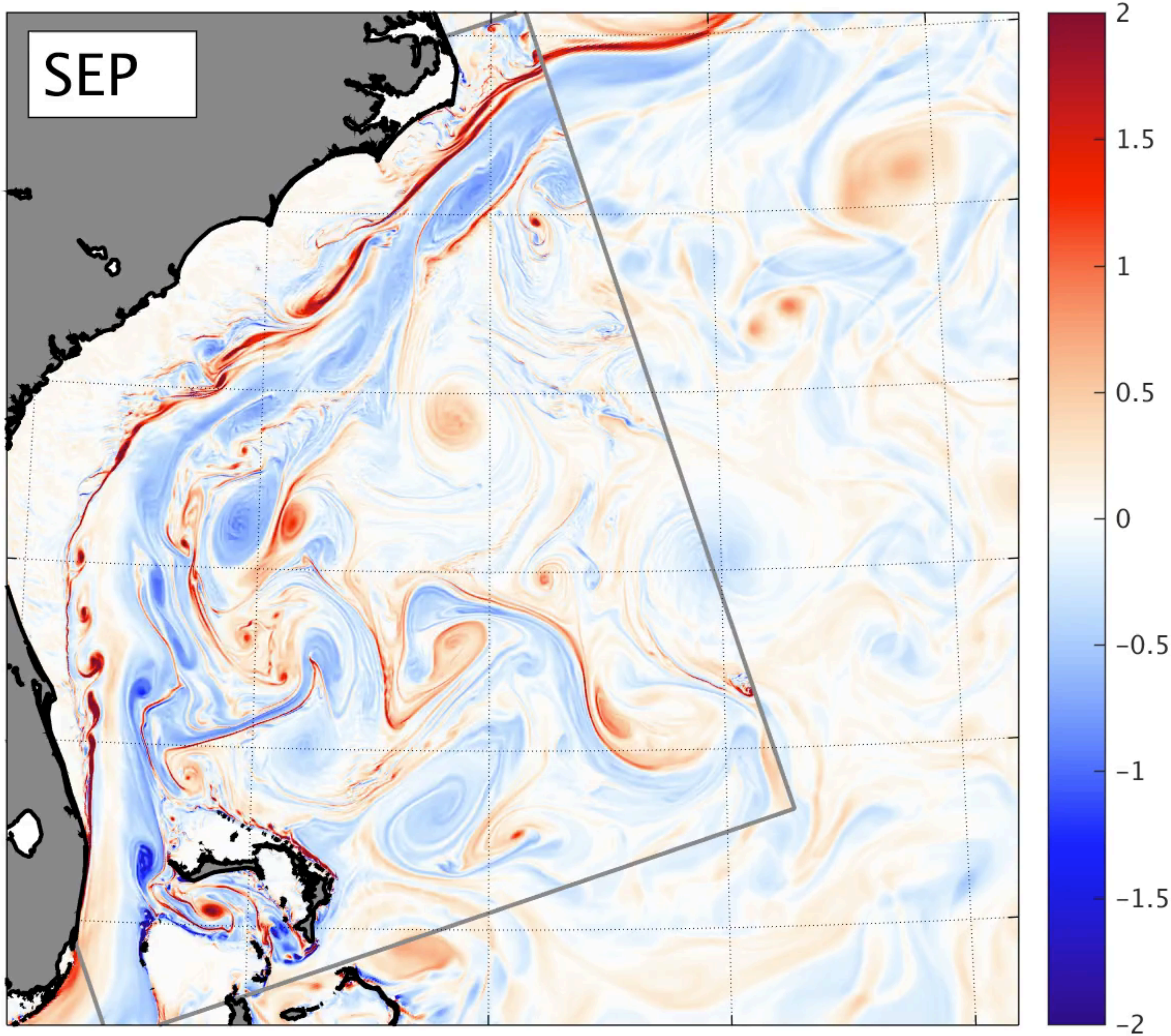


Nested domain with open boundaries with dx = 2.5 km

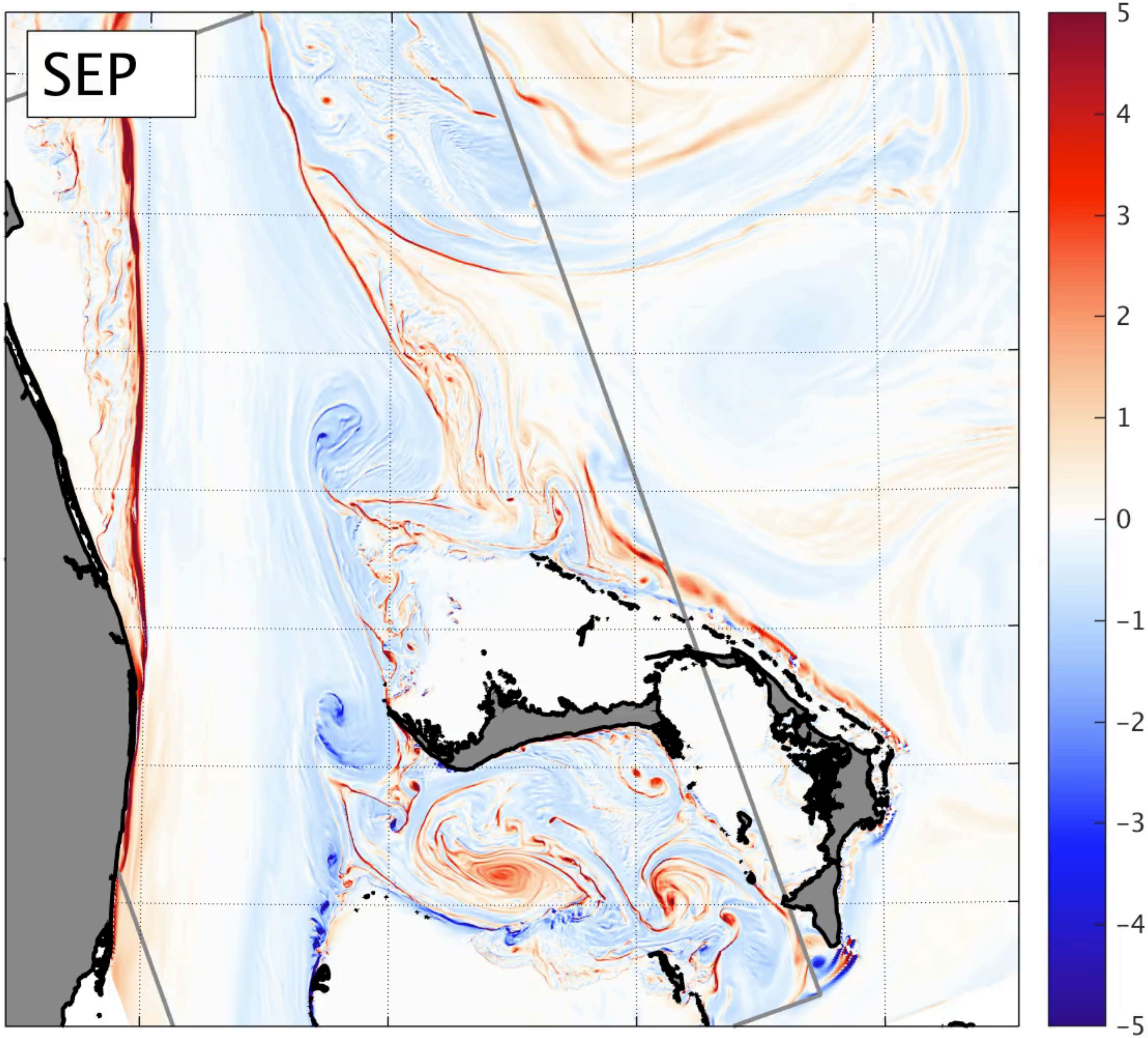


ζ / f

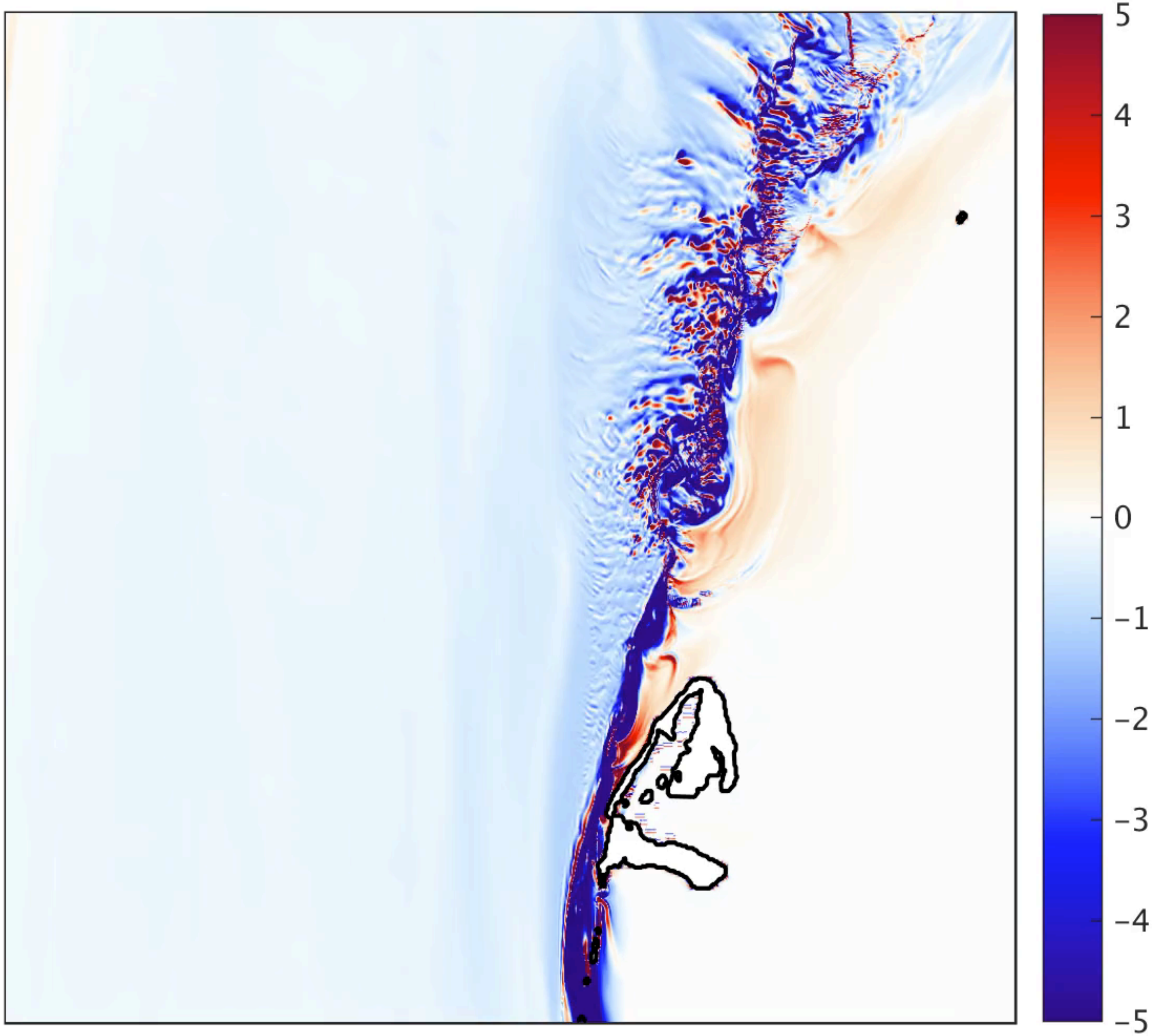
dx = 2.5 km



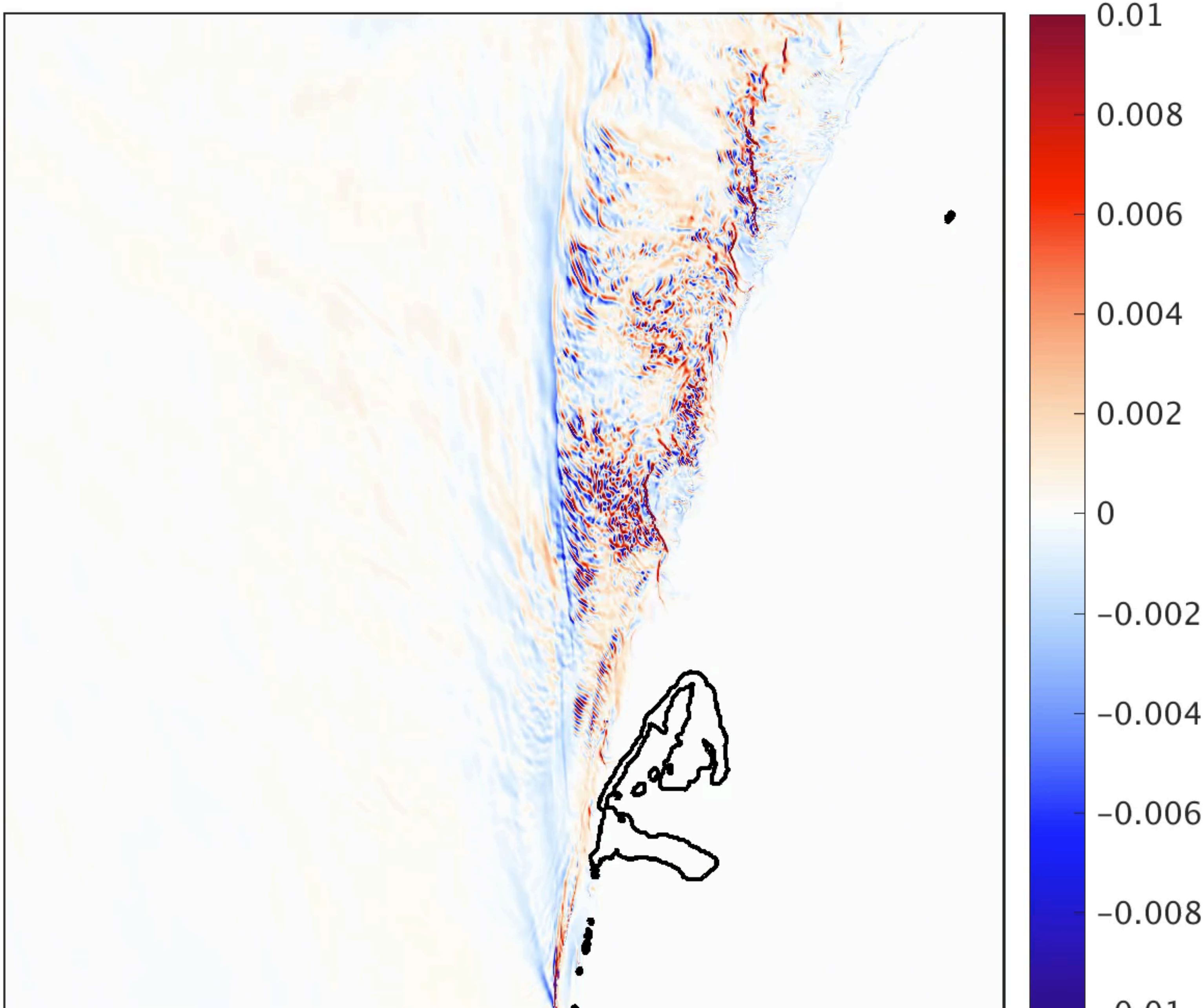
dx = 700 m



dx = 200 m

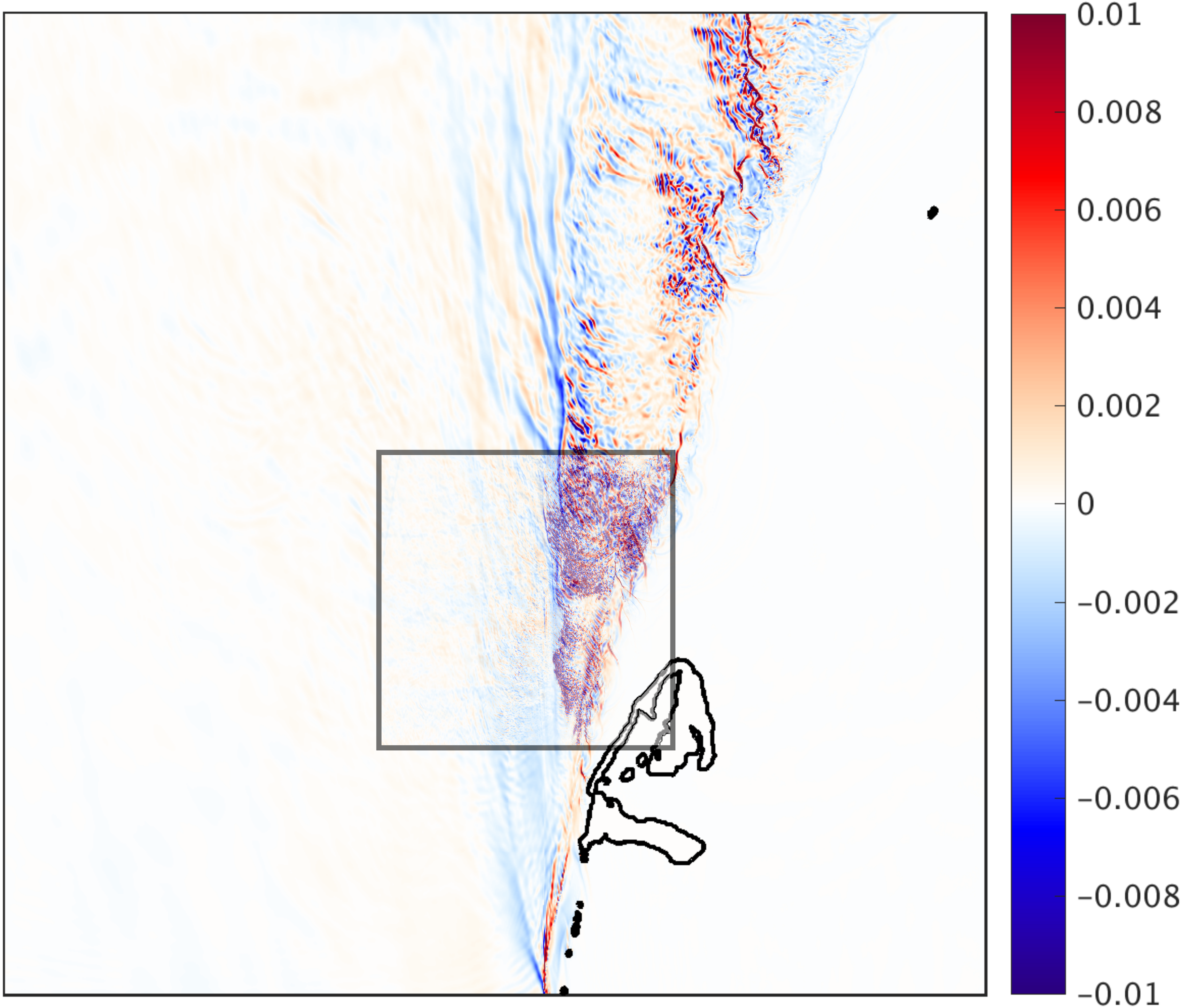


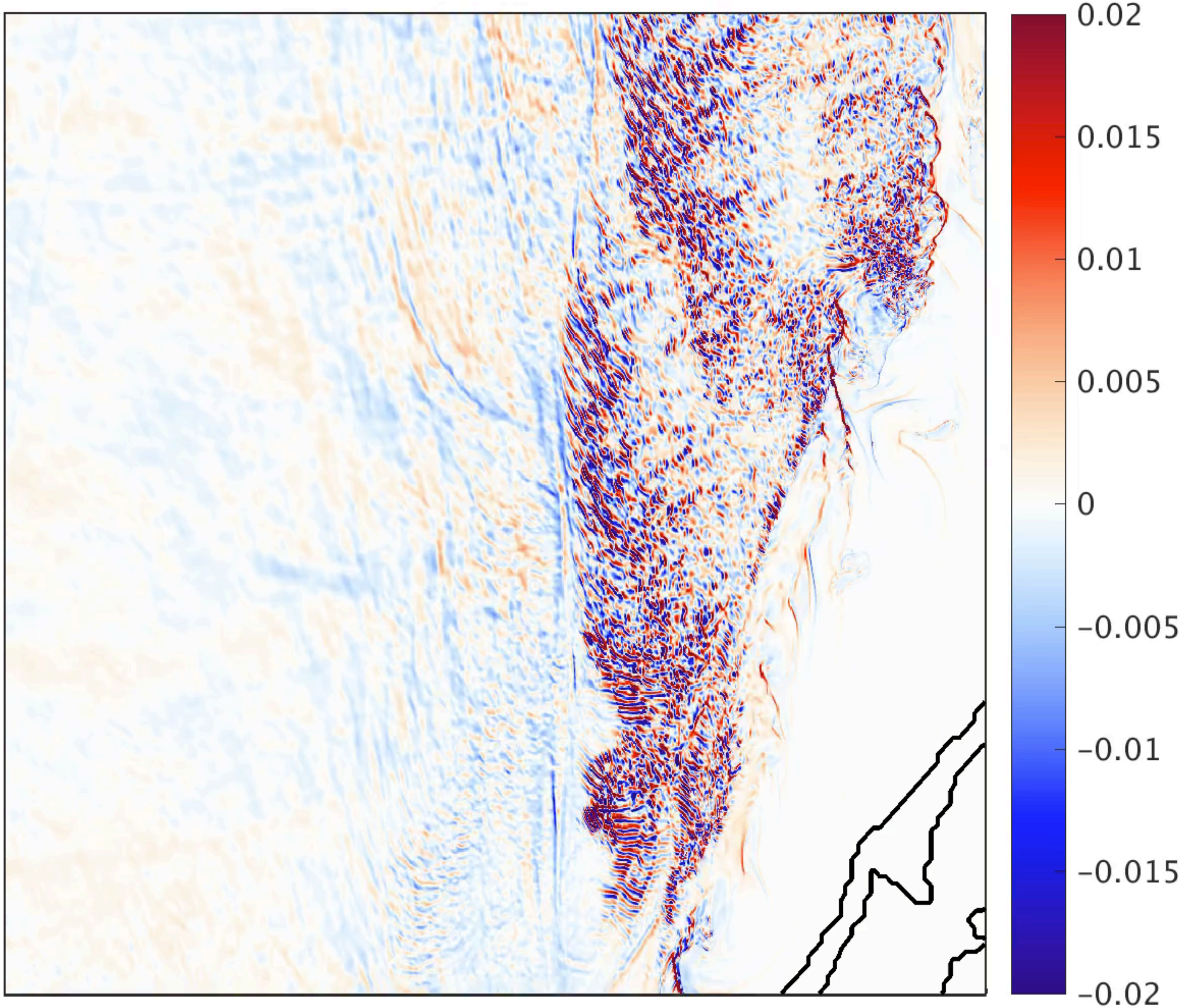
dx = 50 m, non-hydrostatic



dx = 50 m, non-hydrostatic

Surface layer vertical velocity


0.01
0.008
0.006
0.004
0.002
0
−0.002
−0.004
−0.006
−0.008
−0.01

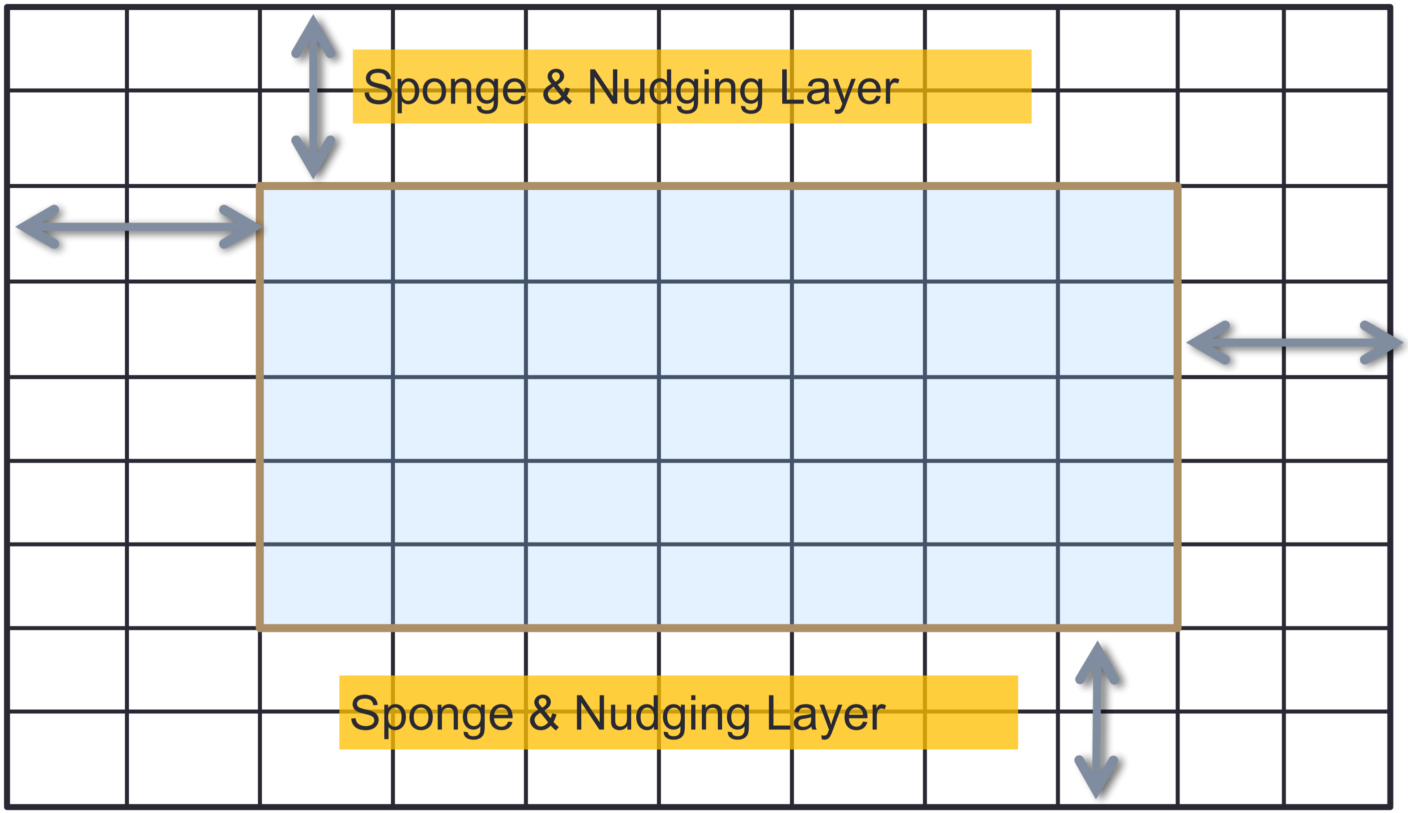


dx = 15 m (NH)

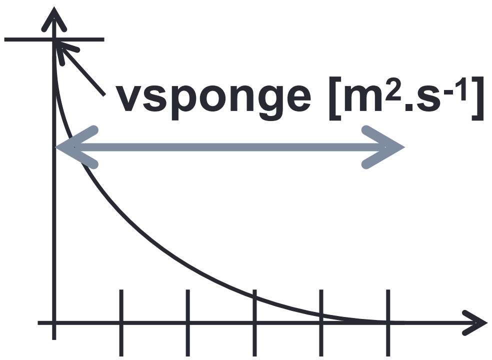
Surface layer vertical velocity


Visible light, (credit NASA)

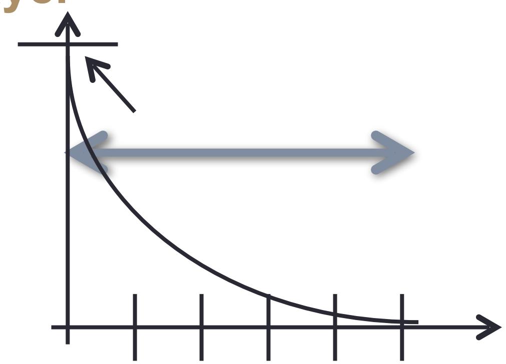
Sponge/Nudging Layer



$K^T h$, $K^m h$ profil across sponge layer

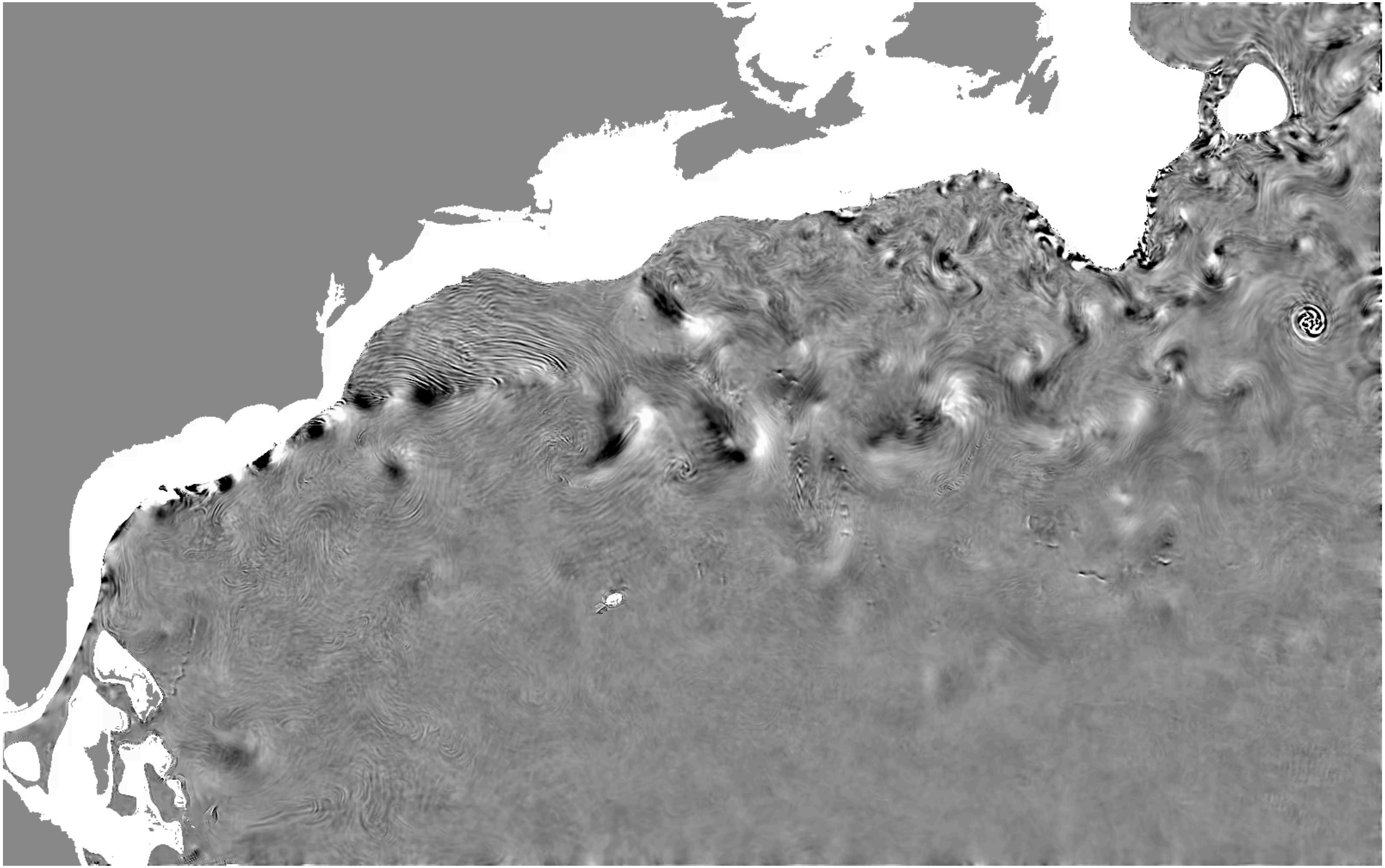


τ_{out} profil cross nudging layer



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

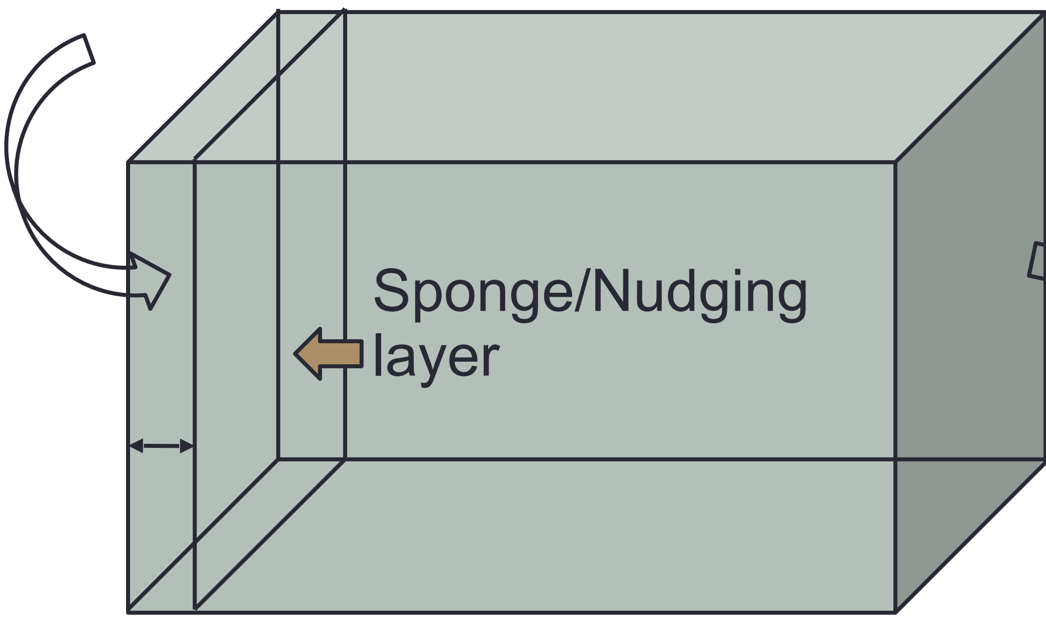
Sponge/Nudging Layer



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.

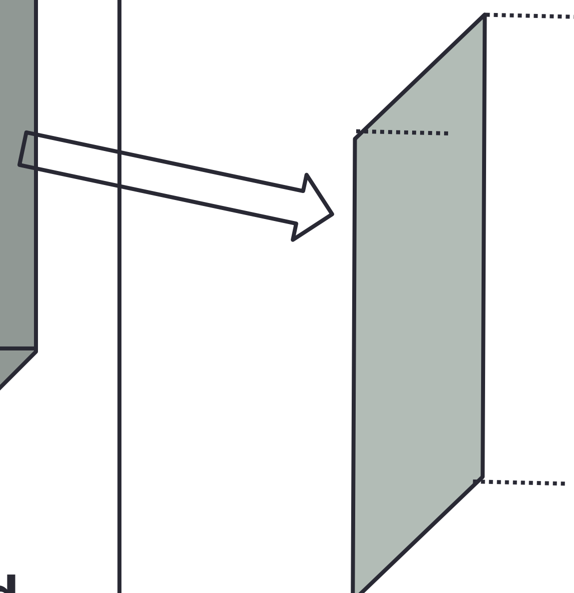
Data used here only



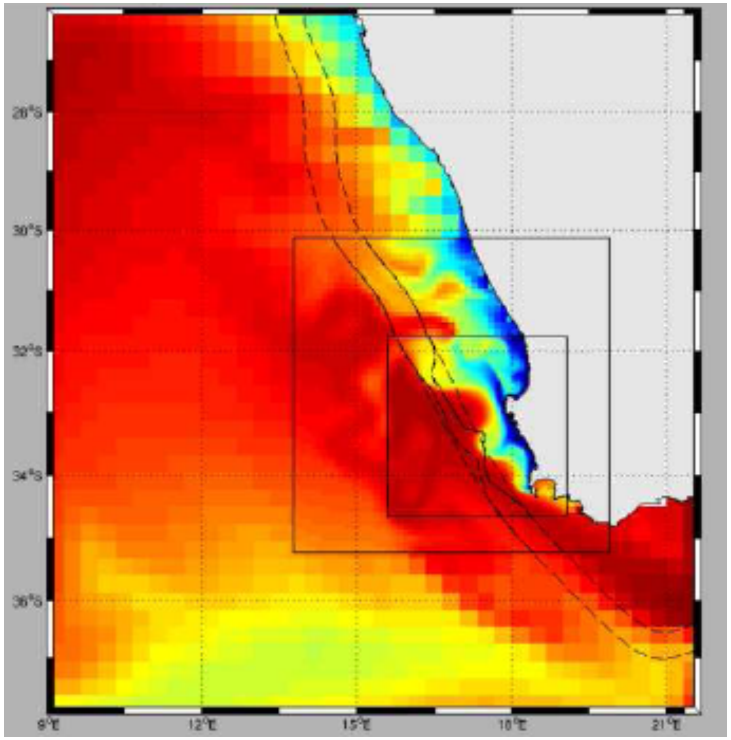
These type of file 3D (x,y,z) are used for initialization

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

Data used here only



AGRIF Nesting

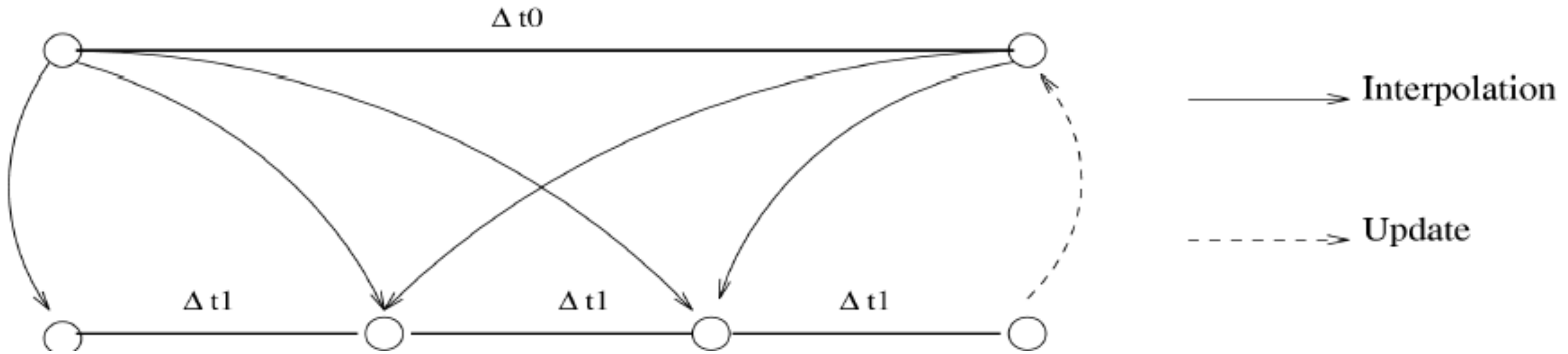


Nesting capability of CROCO: CROCO_AGRIF

- 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 https://www.jgula.fr/ModNum/Activity4.html
-

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:

```
...
#elif 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

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*F
auxiliary_history_fields:   rho Omega  W  Akv  Akt  Aks  HBL  Bostr
                   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 interanual 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