CROCO forcing

CROCO
Coastal and Regional Ocean COmmunity model

Momentum conservation

$$\frac{\partial u}{\partial t} + \vec{u}.\nabla u - fv = -\frac{1}{\rho_0}\frac{\partial P}{\partial x} + \nabla_h\left(K_{Mh}.\nabla_h u\right) + \frac{\partial}{\partial z}\left(K_{Mv}\frac{\partial u}{\partial z}\right)$$

$$\frac{\partial v}{\partial t} + \vec{u}.\nabla v + fu = -\frac{1}{\rho_0}\frac{\partial P}{\partial y} + \nabla_h\left(K_{Mh}.\nabla_h v\right) + \frac{\partial}{\partial z}\left(K_{Mv}\frac{\partial v}{\partial z}\right)$$

advection   Coriolis   Pressure gradient   Horizontal diffusion   Vertical diffusion

Hydrostatic

$$0 = -\frac{\partial P}{\partial z} - \rho g$$

Continuity

$$0 = \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z}$$

Tracer conservation

$$\frac{\partial T}{\partial t} + \vec{u}.\nabla T = \nabla_h\left(K_{Th}.\nabla_h T\right) + \frac{\partial}{\partial z}\left(K_{Tv}\frac{\partial T}{\partial z}\right)$$

$$\frac{\partial S}{\partial t} + \vec{u}.\nabla S = \nabla_h\left(K_{Sh}.\nabla_h S\right) + \frac{\partial}{\partial z}\left(K_{Sv}\frac{\partial S}{\partial z}\right)$$

Equation of state

$$\rho = \rho(S, T, p)$$

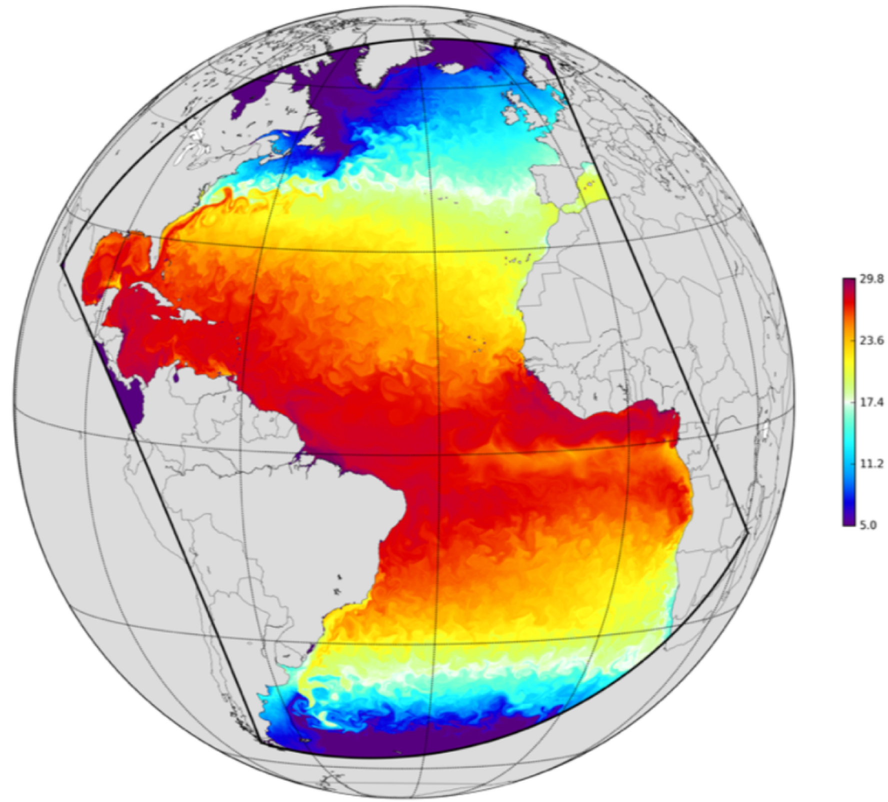
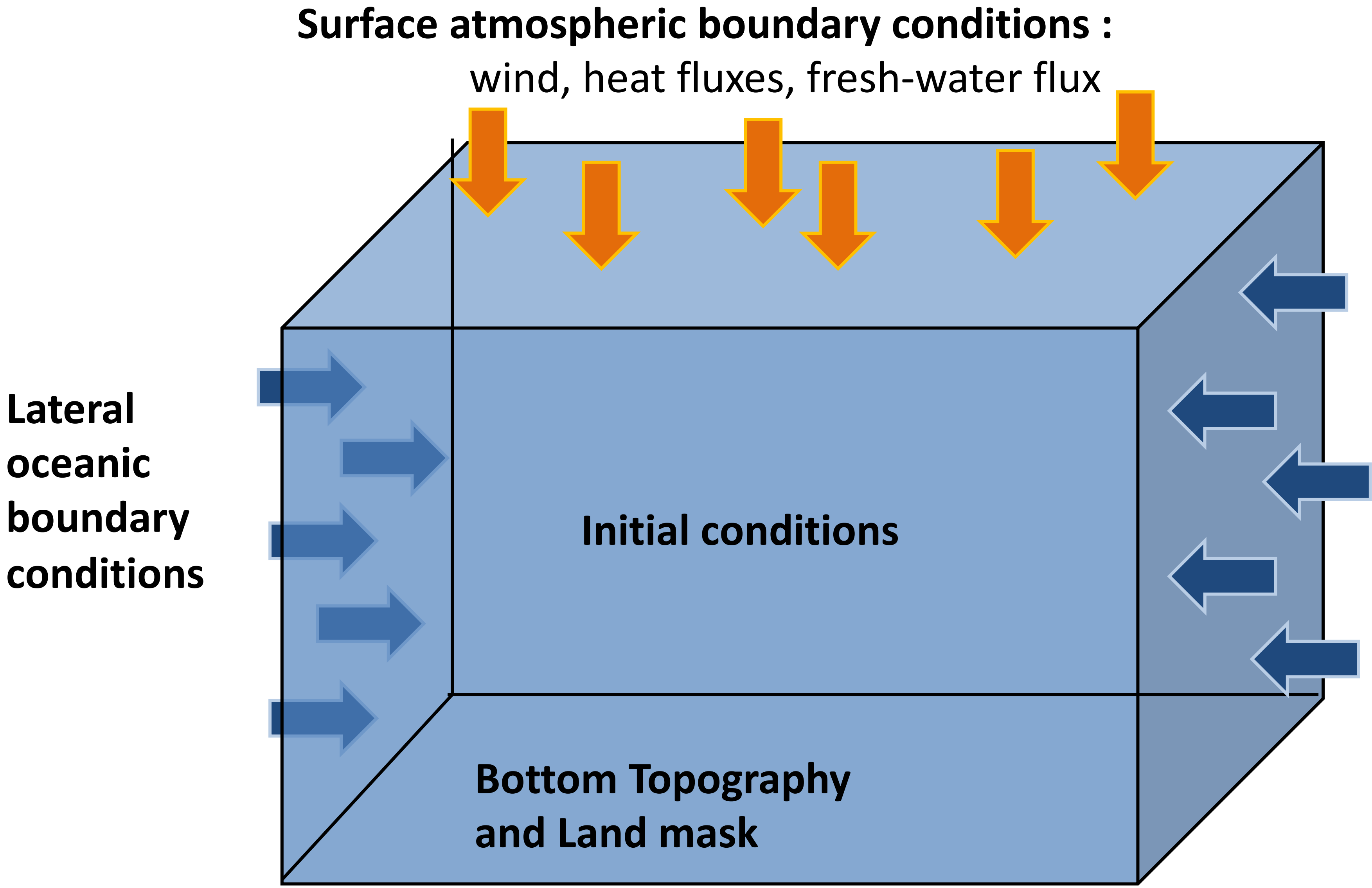


Figure 4: Snapshot of SST for the Atlantic simulation domain from a 6 km CROCO simulation.

Courtesy of J. Gula

Matthieu Caillaud
Gildas Cambon

Generalities



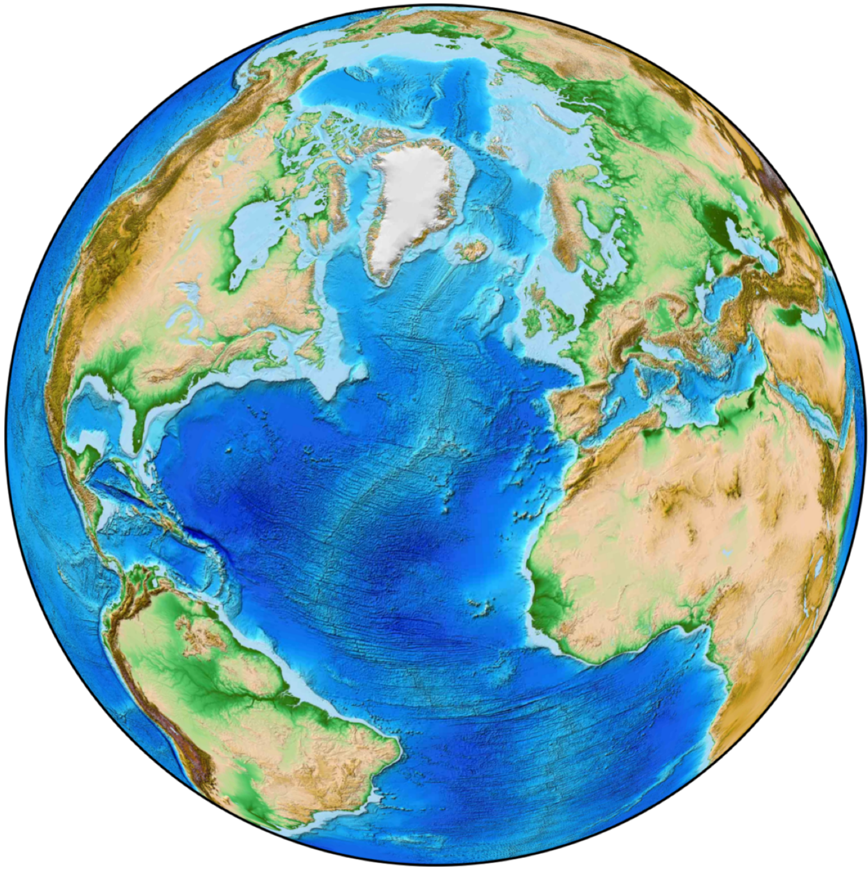
Bottom topography + Land Mask

Satellite geodesy data + soundings

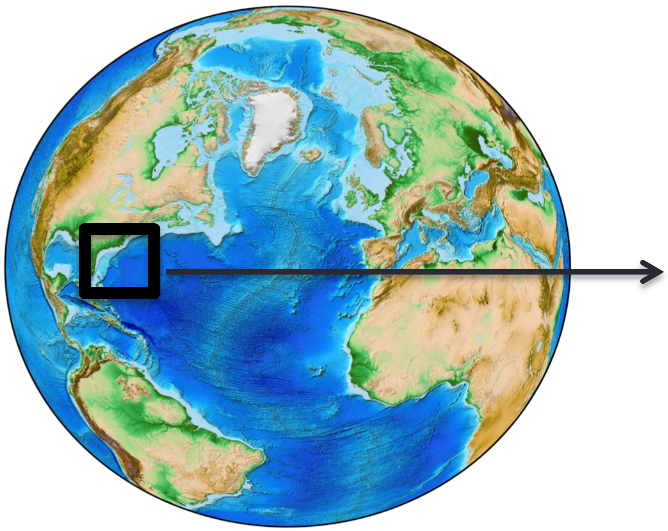
Available Global Datasets:

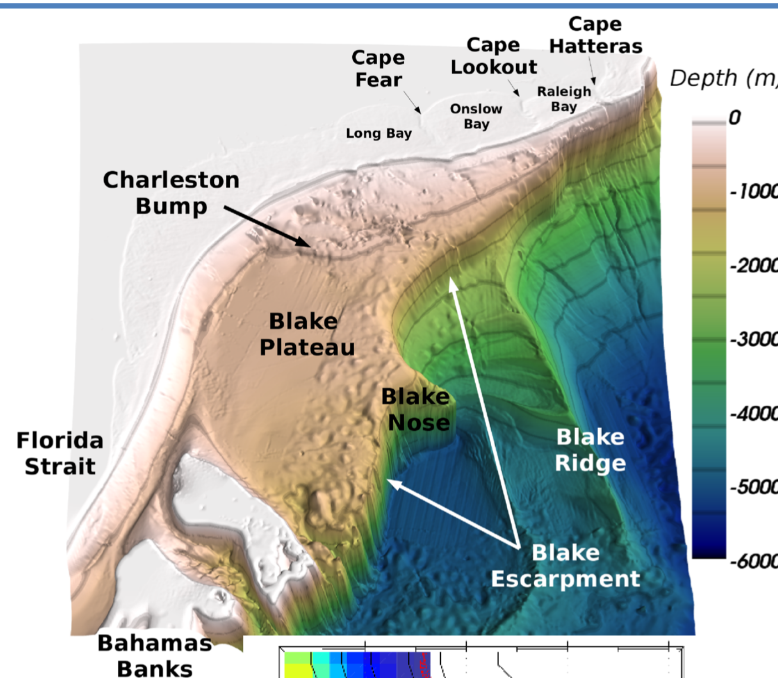
- SRTM30 (http://topex.ucsd.edu/WWW_html/srtm30_plus.html)
- Etopo1 (https://www.ngdc.noaa.gov/mgg/global/global.html)
- Gebco30 (http://www.gebco.net/data_and_products/gridded_bathymetry_data/)

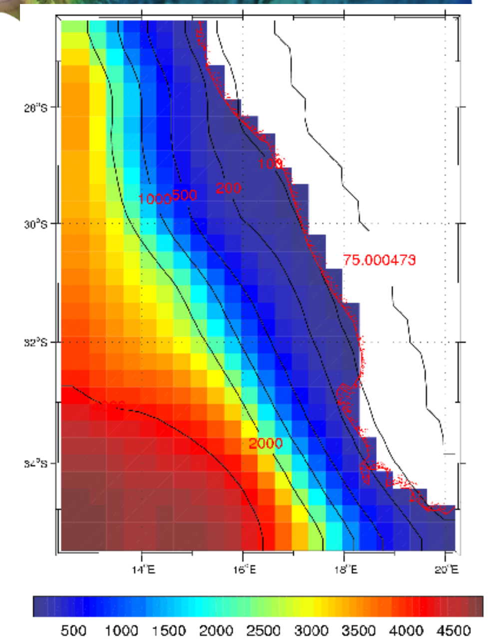
High resolution datasets from national Hydrographic services (ex: SHOM in France)



Bottom topography + Land Mask



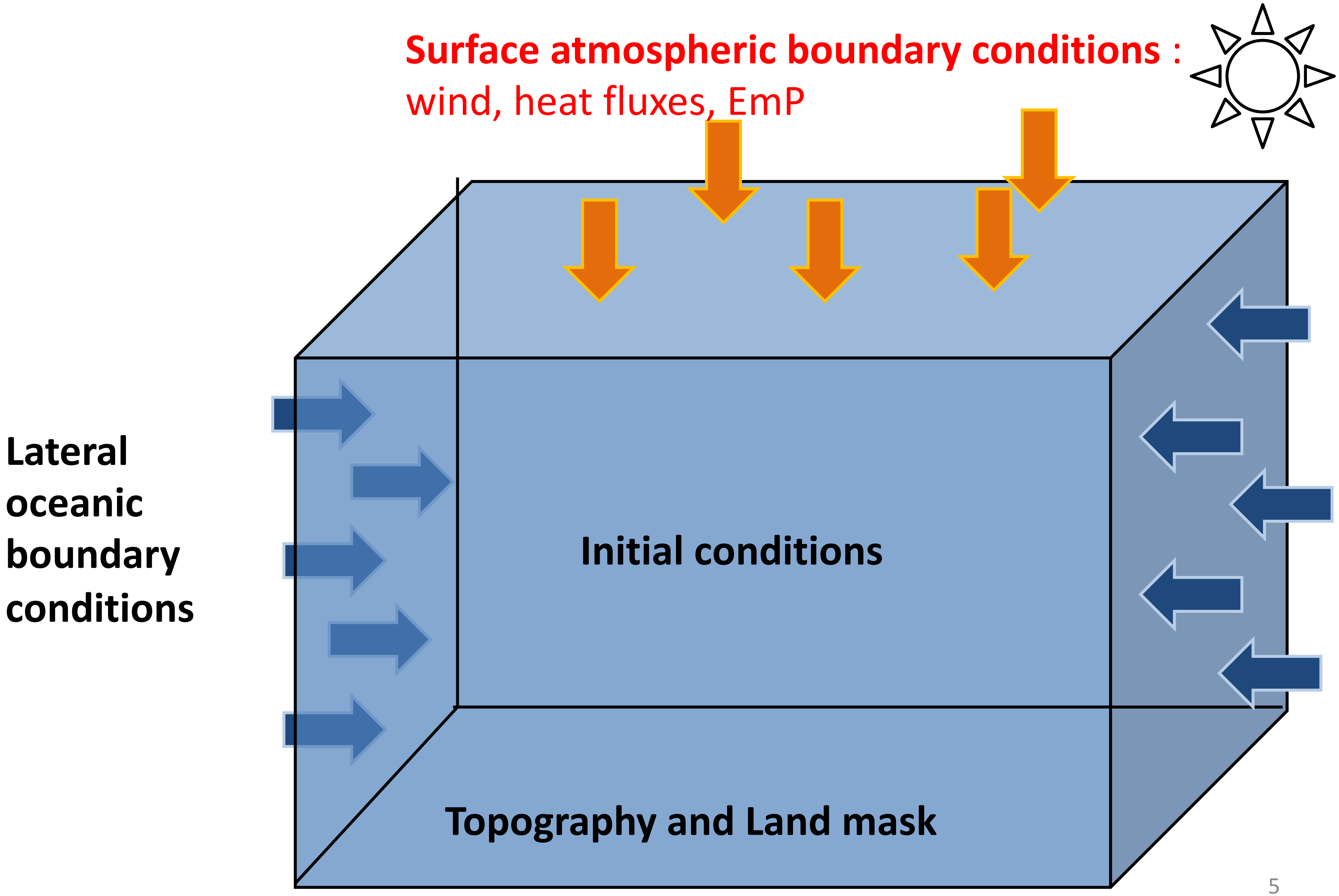




- Topography and mask extraction
- Smoothing of the topography
- Interpolating on the model's grid using

  => Tools provided by CROCOTOOLS

Atmospheric forcing



Surface atmospheric boundary conditions

- **Surface boundary conditions (z=η):**

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

$$K_{Mv}\frac{\partial u}{\partial z} = \frac{\tau_x}{\rho_0}$$

$$K_{Mv}\frac{\partial v}{\partial z} = \frac{\tau_y}{\rho_0}$$

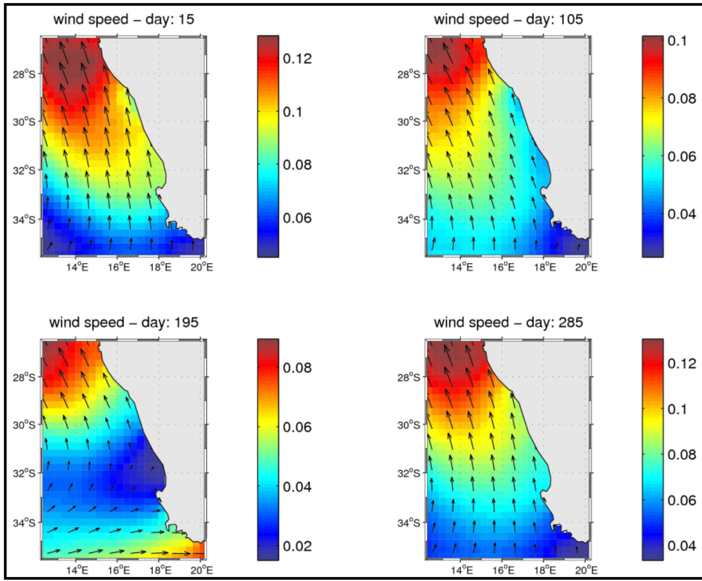
Wind stress

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

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

- Datasets (observations and/or models)
  - Heat and freshwater fluxes : COADS, …
  - Wind Stress: QuikScat, SCOW, …
  - Reanalysis (Model +obs.) : CFSR, ERA interim, etc.
  - Hindcast from national services (Metoffice, MeteoFrance , etc)

- Tools for interpolation on the croco grid => CROCOTOOLS



Surface atmospheric boundary conditions

Heat fluxes & Freshwater fluxes:

- Directly read the forcing files

- OR use of a bulk formulae to compute
  - Heat flux : compute total heat flux from latent, sensible, solar and long-wave fluxes and model SST
  - Fresh-water flux : compute from evap, prate and model SSS

Wind stress:

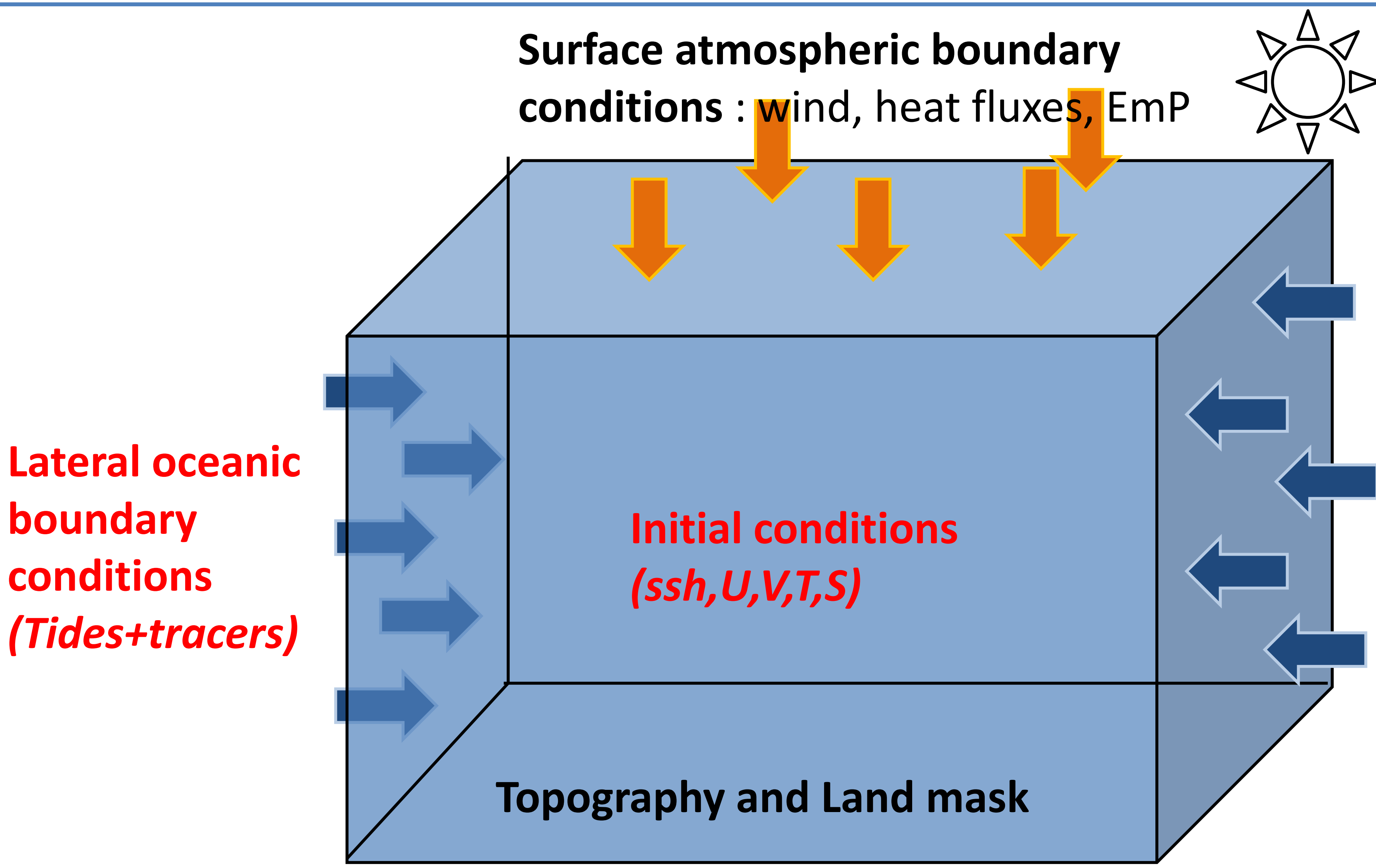
- Directly read the wind stress files

- Or use of bulk formulae to compute the wind stress from the Cd drag coefficient, model SST and wind

cppdefs.h

```
                                   /* Vertical Mixing */
# undef  BODYFORCE
# undef  BVF_MIXING
# define LMD_MIXING
# undef  GLS_MIXING
# ifdef LMD_MIXING
#  define LMD_SKPP
#  define LMD_BKPP
#  define LMD_RIMIX
#  define LMD_CONVEC
#  undef  LMD_DDMIX
#  define LMD_NONLOCAL
#  undef  MLCONVEC
# endif
                                   /* Surface Forcing */
# undef BULK_FLUX
# ifdef BULK_FLUX
#  define BULK_FAIRALL
#  define BULK_LW
#  define BULK_EP
#  define BULK_SMFLUX
#  undef  SST_SKIN
#  undef  ANA_DIURNAL_SW
#  undef  ONLINE
#  ifdef ONLINE
#   undef  AROME
#   undef  ERA_ECMWF
#  endif
#  undef READ_PATM
#  ifdef READ_PATM
#   define OBC_PATM
#  endif
# else
#  define QCORRECTION
#  define SFLX_CORR
#  undef  SFLX_CORR_COEF
#  define ANA_DIURNAL_SW
# endif
# undef SMFLUX_CFB
# undef  SEA_ICE_NOFLUX
                                   /* Wave-current interactions */
# ifdef OW_COUPLING
#  define MRL_WCI
#  define BBL
# endif
# ifdef MRL_WCI
#  ifndef OW_COUPLING
#   define WAVE_OFFLINE
```

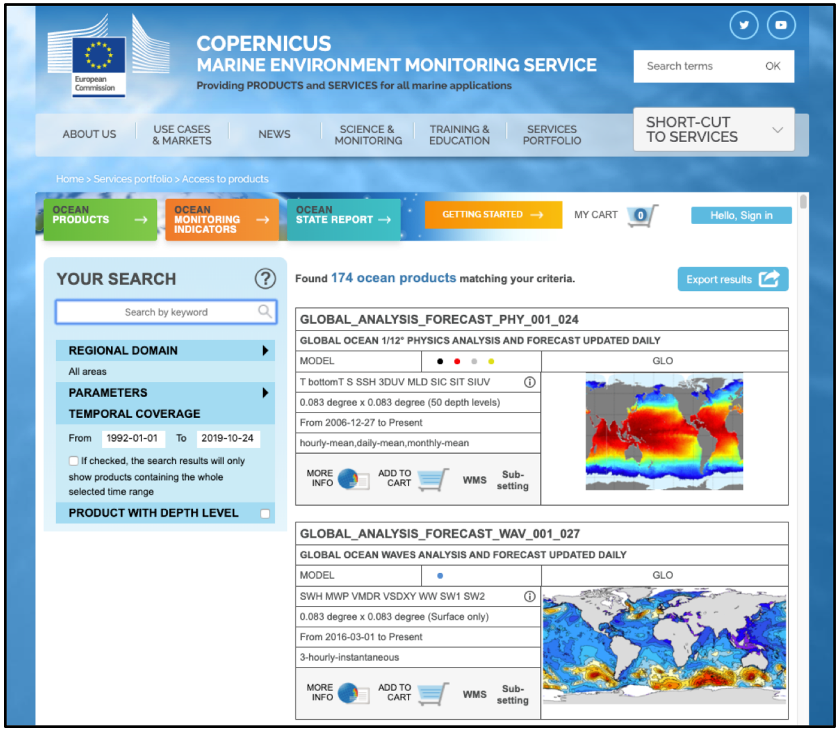
Initial and lateral oceanic boundary conditions

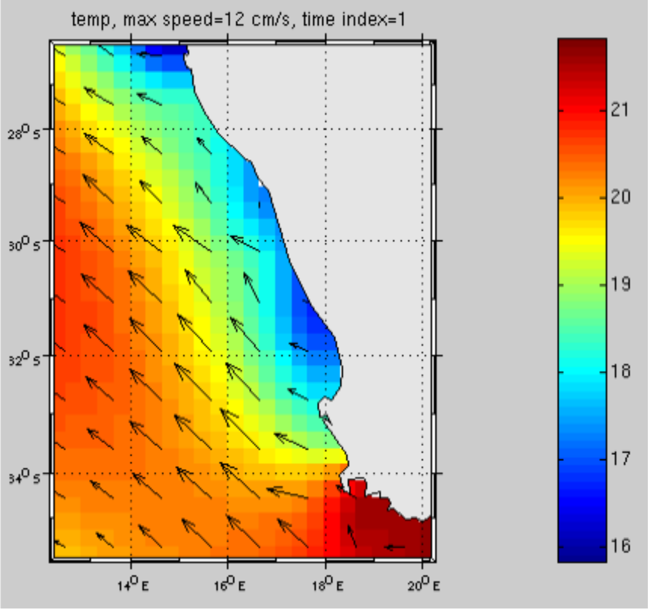


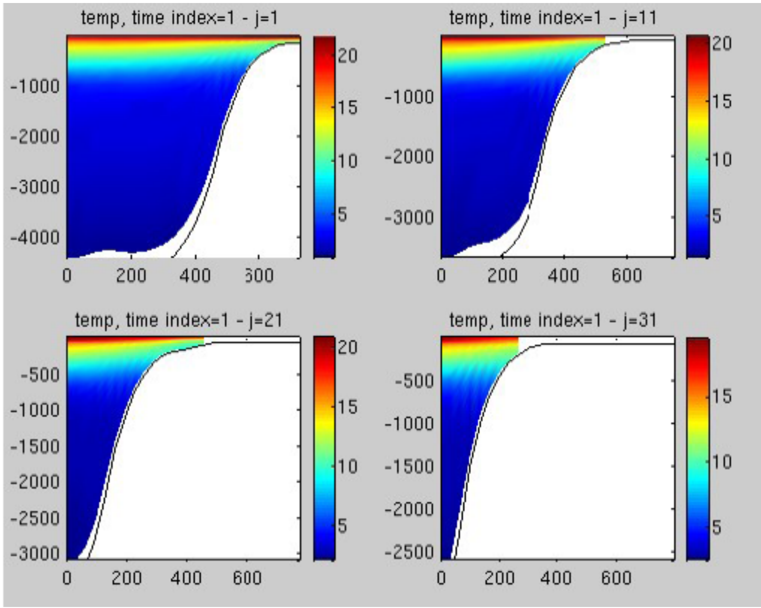
Initial and lateral oceanic boundary conditions

- Datasets (observations and/or models)
  - Observations (World Ocean Atlas, CARS)
  - Reanalysis (SODA, ECCO, etc.)
  - Lower resolution model outputs (CMEMS products)

- Tools for interpolation on the croco grid => CROCOTOOLS







Initial and lateral oceanic boundary conditions

```
#if defined REGIONAL
/*
!====================================================================
!               REGIONAL (realistic) Configurations
!====================================================================
!
!----------------------
! BASIC OPTIONS
!----------------------
!
*/
                      /* Configuration Name */
# define BENGUELA_LR
                      /* Parallelization */
# undef  OPENMP
# undef  MPI
# undef  MPI_NOLAND
                      /* I/O server */
# undef  XIOS
                      /* Non-hydrostatic option */
# undef  NBQ
                      /* Nesting */
# undef  AGRIF
# undef  AGRIF_2WAY
                      /* OA and OW Coupling via OASIS (MPI) */
# undef  OA_COUPLING
# undef  OW_COUPLING
                      /* Wave-current interactions */
# undef  MRL_WCI
                      /* Open Boundary Conditions */
# undef  TIDES
# define OBC_EAST
# define OBC_WEST
# define OBC_NORTH
# define OBC_SOUTH
                      /* Applications */
# undef  BIOLOGY
# undef  FLOATS
# undef  STATIONS
# undef  PASSIVE_TRACER
```

How to activate OBC ?

Use open boundary conditions

If undef then the domain is closed (see e.g. basin) or periodic.

Open boundary conditions (OBC type)

Adaptative mixed radiations/nudging open boundary conditions (*Marchesiello et al, 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) for tracers
- Possibility to **use "Characteristic method" 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 $\tau = \tau_{out}$

$\tau_{out} \approx 180$ days
$\tau_{in} \approx 1$ days

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

```
# define OBC_M2CHARACT
# undef  OBC_M2ORLANSKI
# define OBC_M3ORLANSKI
# define OBC_TORLANSKI
# undef  OBC_M2SPECIFIED
# undef  OBC_M3SPECIFIED
# undef  OBC_TSPECIFIED
```

3D Open boundary forcing (Clim or Bry)

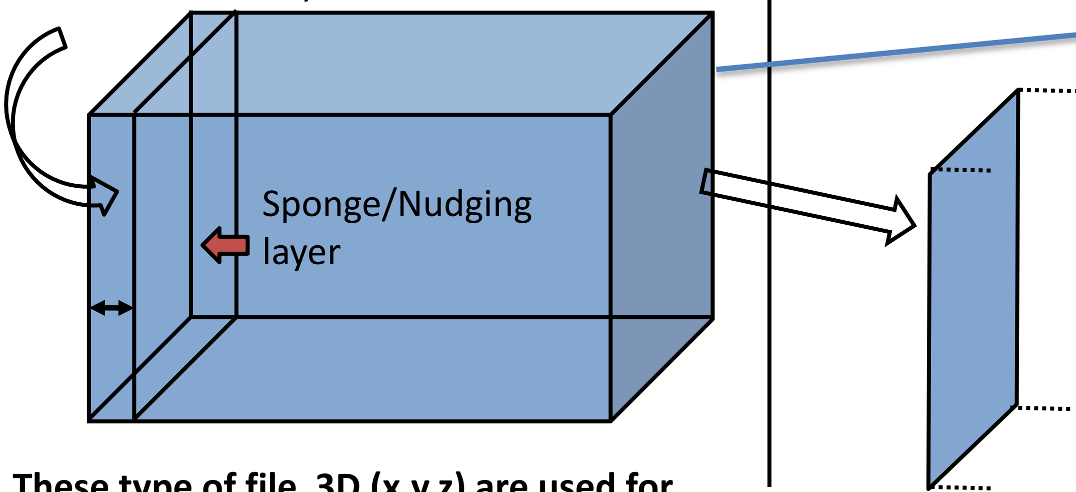
Different ways to impose OBC

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** (for the moment)

Data used here only



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

CLIM or BRY = Datasets+
Interpolation from crocotools

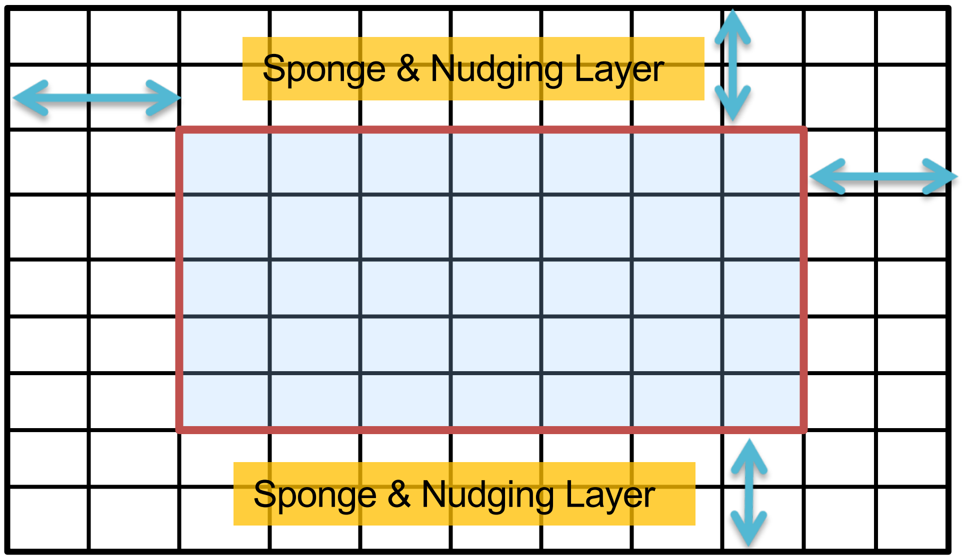
cppdefs.h

```
/* Lateral Forcing
# define CLIMATOLOGY
# ifdef CLIMATOLOGY
#  define ZCLIMATOLOGY
#  define M2CLIMATOLOGY
#  define M3CLIMATOLOGY
#  define TCLIMATOLOGY

#  define ZNUDGING
#  define M2NUDGING
#  define M3NUDGING
#  define TNUDGING
#  undef  ROBUST_DIAG
# endif
```

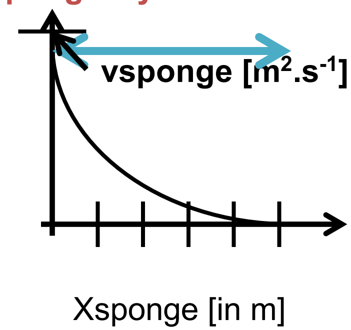
```
# undef  FRC_BRY
# ifdef FRC_BRY
#  define Z_FRC_BRY
#  define M2_FRC_BRY
#  define M3_FRC_BRY
#  define T_FRC_BRY
# endif
```

Sponge/Nudging Layer

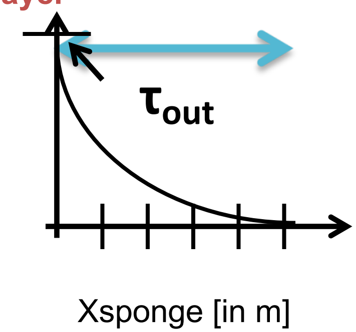


- Sponge : Additional viscosity/diffusivity
- Nudging : Add a weak nudging, $\tau = 0 \rightarrow \tau_{out}$, toward climatology, if available

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



τ_{out} profil cross nudging layer



Activate areas of enhanced viscosity and diffusivity near lateral open boundaries.

Tides

• The tides are imposed at open boundaries, using the Characteristic OBC. (**OBC_M2CHARACT** cppkeys)

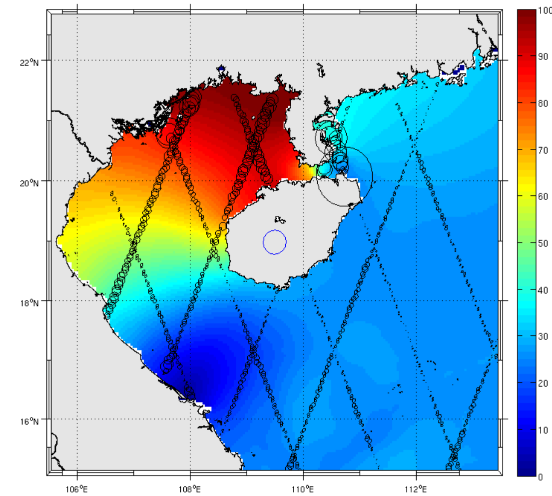
ζ_{tides}, $\bar{u}_{tides}$ et $\bar{v}_{tides}$ (ssh and depth averaged zonal and meridian currents) are added at the open ζ_{clim}, $\bar{u}_{clim}$ et $\bar{v}_{clim}$. ζ_{tides}, $\bar{u}_{tides}$ et $\bar{v}_{tides}$ are computed from the tidal harmonics given by some tidal model, in our case TPXO7 (0.25° resolution, 10 tidal components : M2, N2, S2, K2, K1, O1, P1,Q1,Ln, Mm)

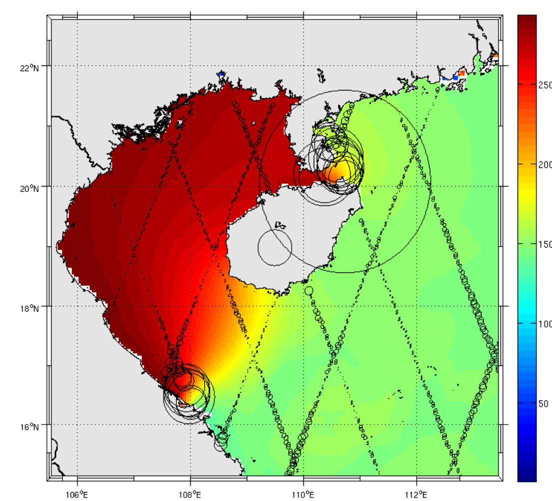
• The global tidal model gives harmonics constants for all the principal tidal waves. These constants permits to compute at every time ζ^{N}_{tides} $\bar{u}^{N}_{tides}$ $\bar{v}^{N}_{tides}$ of the tidal wave component N .

• You need :

  • Choose the number of tidal wave component you want.
  • Interpolate on the grid the different harmonic constant

```
                 /* Open Boundary Conditions */
# ifdef TIDES
#  define SSH_TIDES
#  define UV_TIDES
#  define POT_TIDES
#  undef  TIDES_MAS
#  ifndef UV_TIDES
#   define OBC_REDUCED_PHYSICS
#  endif
#  define TIDERAMP
# endif
# define OBC_M2CHARACT
```





PhD thesis of Nguyen Nguyet Minh, May 2013

Rivers/Source points

Source points are applied on U,V points on C-grid:

- Outflow is converted as velocity which is added to the *momentum* term in the equations
- Possibility to inject a tracer concentration associated to the source

cppdefs.h

```
# define ANA_BTFLUX
                                          /* Point
# undef PSOURCE
# undef PSOURCE_NCFILE
# ifdef PSOURCE_NCFILE
#  undef PSOURCE_NCFILE_TS
# endif
```

croco.in

- Constant in time values (outflow + tracer) : ***#define PSOURCE***

```
     psource:    Nsrc  Isrc  Jsrc  Dsrc  Qbar [m3/s]    Lsrc       Tsrc
                   2
                          3    54     1    200.           T T      5. 0.
                          3    40     0    200.           T T      5. 0.
```

OR

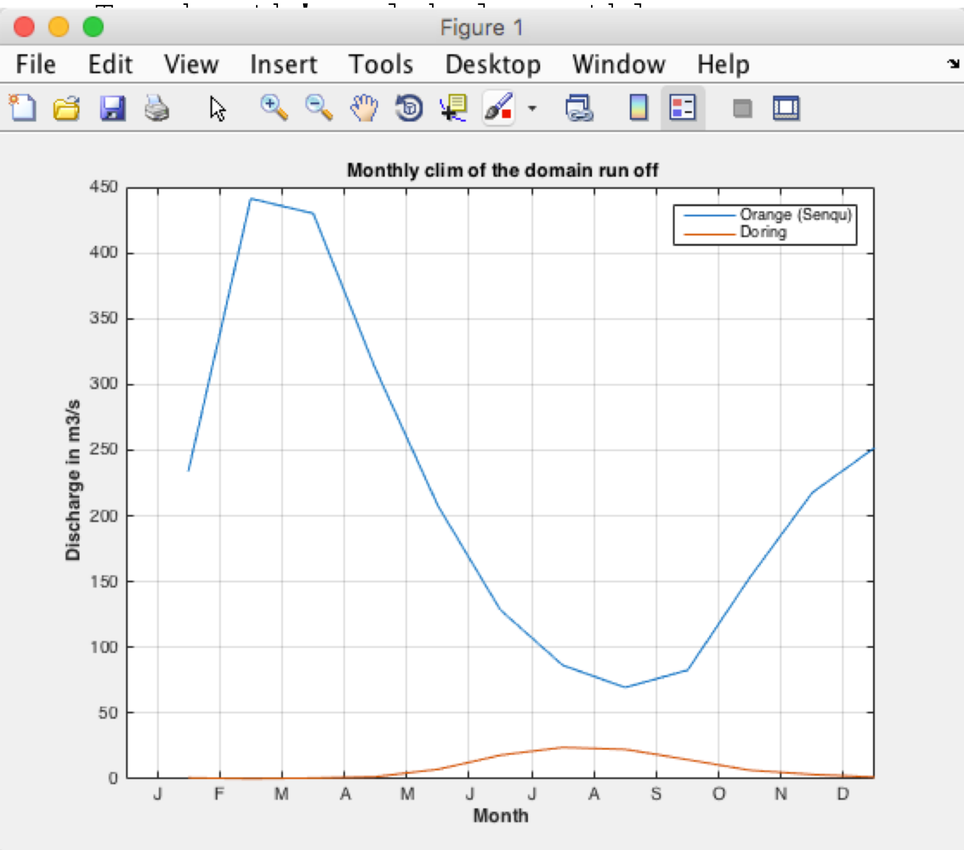
- Variable in time read netcdf file
  - ***#define PSOURCE_NCFILE*** *:* only for outflows and constant tracer concentration
  - ***#define PSOURCE_NCFILE_TS :*** both outflow rate and tracers concentration

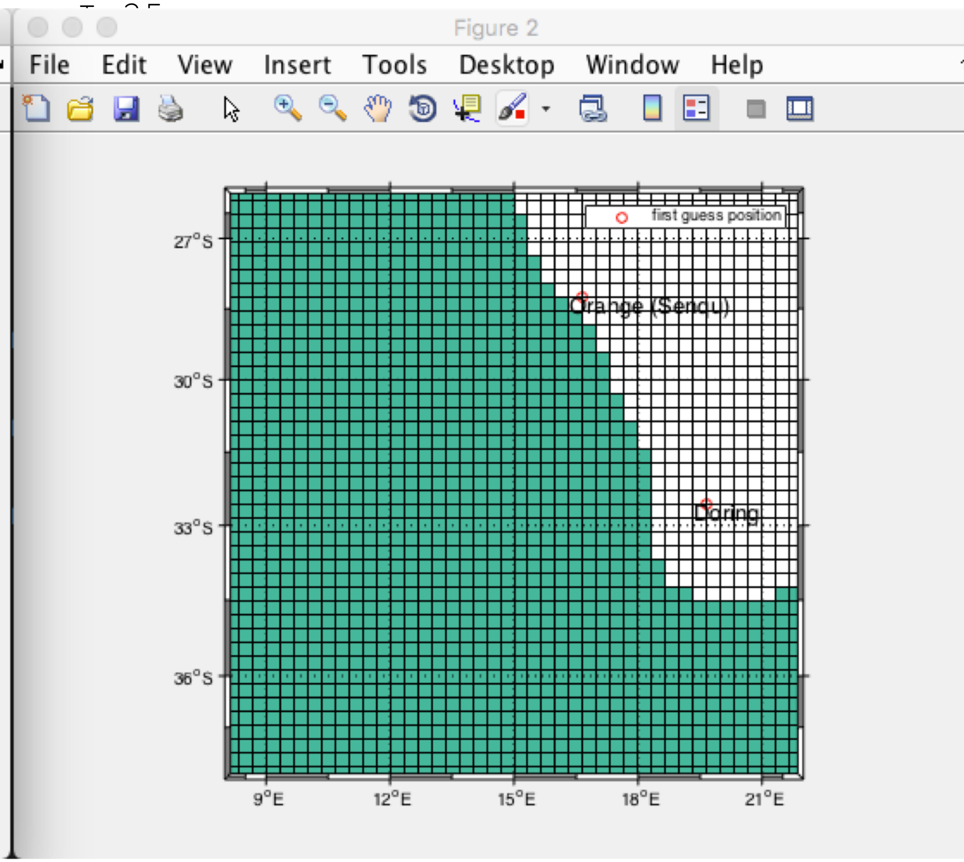
```
psource_ncfile:   Nsrc  Isrc  Jsrc  Dsrc qbardir  Lsrc  Tsrc   runoff file name
   CROCO_FILES/croco_runoff.nc
                 2
                        24   35   0   -1    30*T    5.0   0.0
                        35   13   1   -1    30*T    5.0   0.0
```

Rivers/Source points

- > In make_runoff (line 29)
- mkdir: /Users/gcambon/DATA/for_asi18_sess2/CONFIGS/BENGUELA_LR/CROCO_FILES/: File exists
- Create runoff forcing from Dai and

- Position is approximetly J=35 and I=26
- lon src in grid (rho point) ~16.3333
- lat src in grid (rho point) ~-28.5604
- - Process river #2: Doring
- Position is approximetly J=20 and





Animation from GIGATL simulation, 3KM

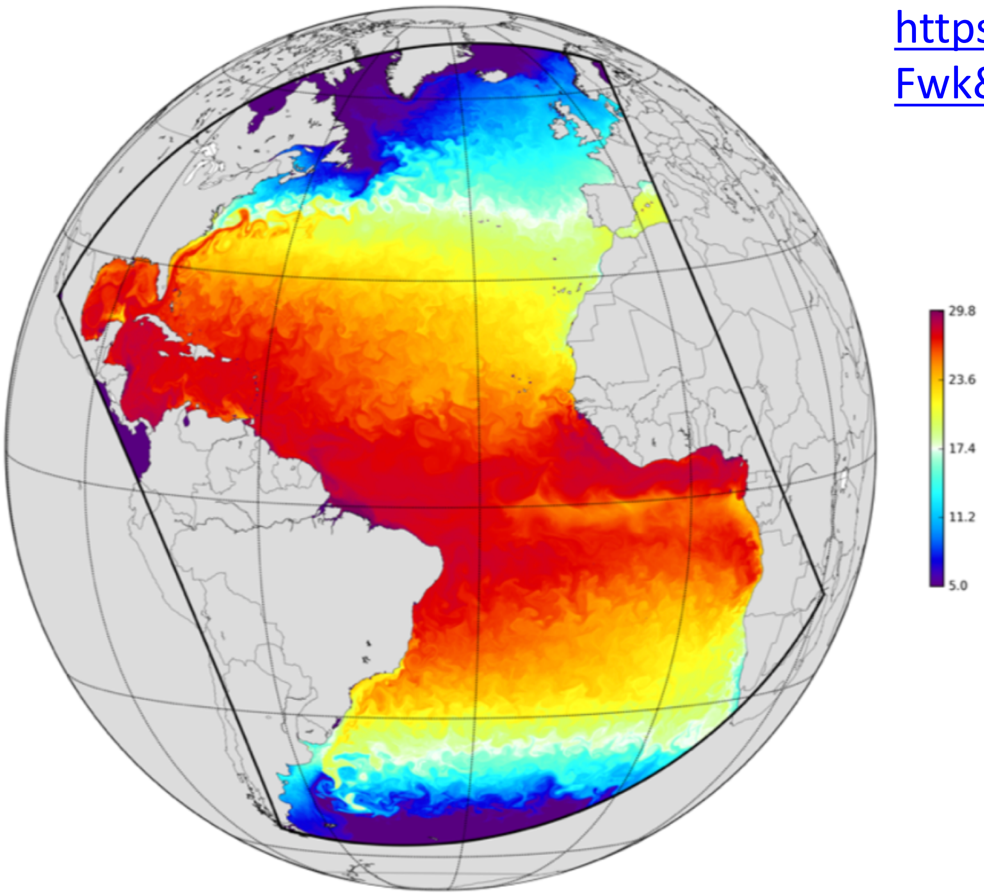


Figure 4: Snapshot of SST for the Atlantic simulation domain from a 6 km CROCO simulation.

https://www.youtube.com/watch?v=YzF2Di9AFwk&feature=youtu.be