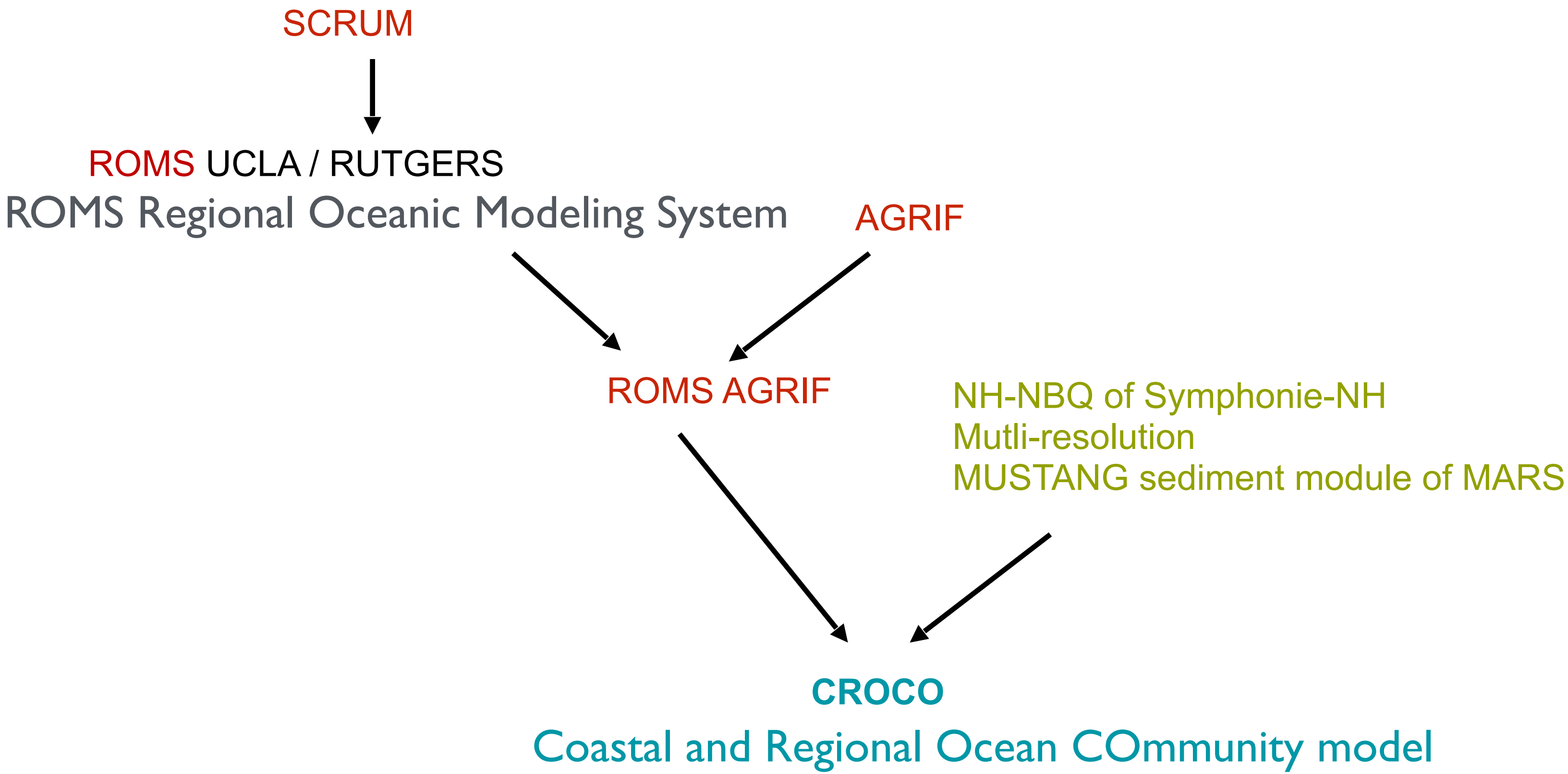
CROCO

Introduction to CROCO model

CROCO

Coastal and Regional Ocean COmmunity model

CROCO history



CROCO philosophy

Community development

Continuous development

Open Source

Stable releases: every 1 / 1.5 year

Help/support through a forum

Tools for an easy built of regional and coastal configurations

Adapted to IRD

High-level numerical schemes

HPC

Realistic complex modelling

Circulation forced by waves

Coupling with atmosphere and waves

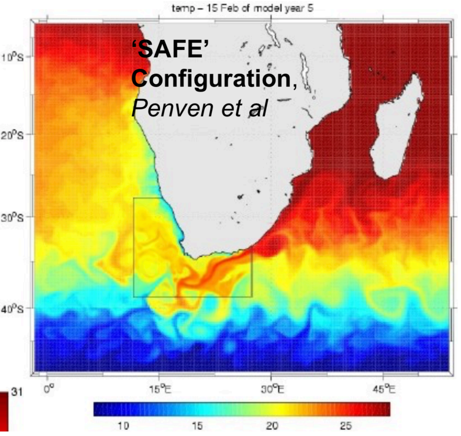
Coupling with biogeochemistry and ecology

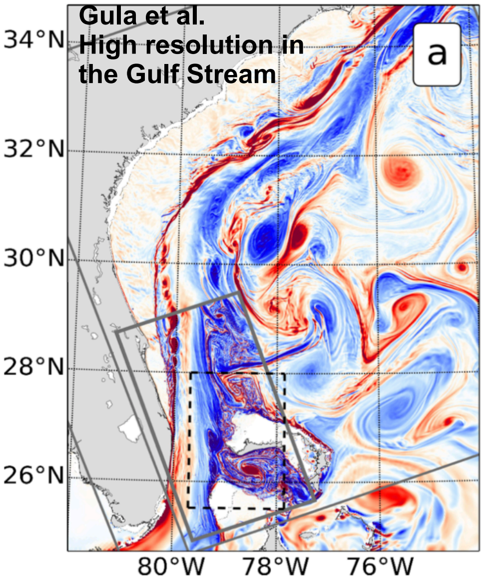
LES / DNS

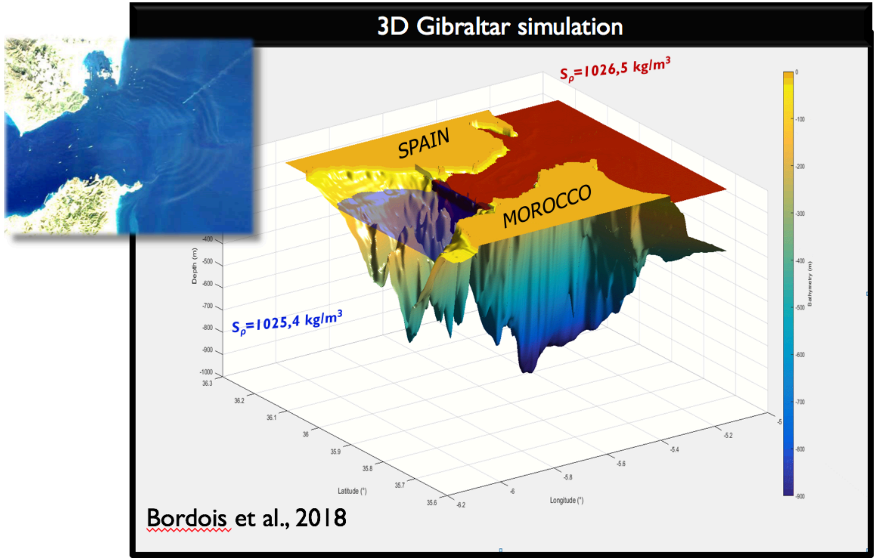
CROCO examples

CROCO
Coastal and Regional Ocean COmmunity model

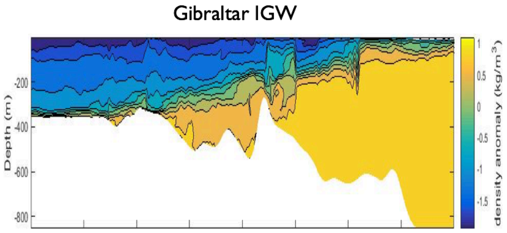
For starting, here are a few examples of use of CROCO







NBQ mode

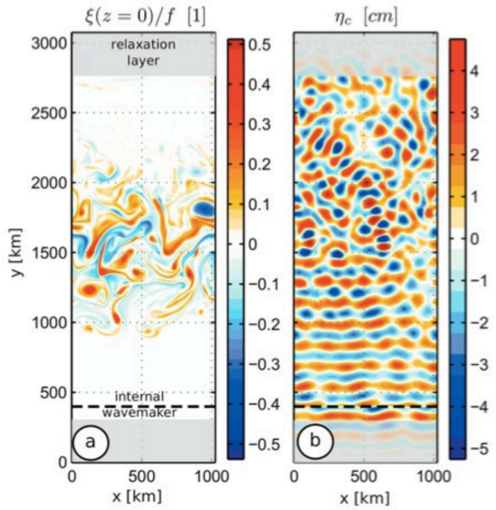


CROCO examples

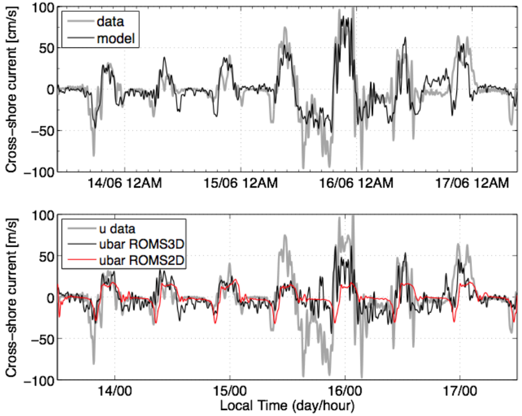
Coastal and Regional Ocean COmmunity model

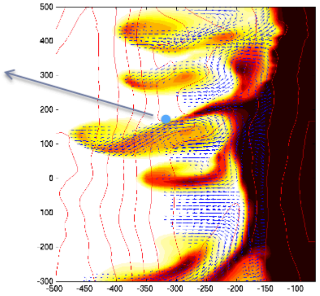
For starting, here are a few examples of use of CROCO

Ponte & Klein, 2015,, internal tides and eddies

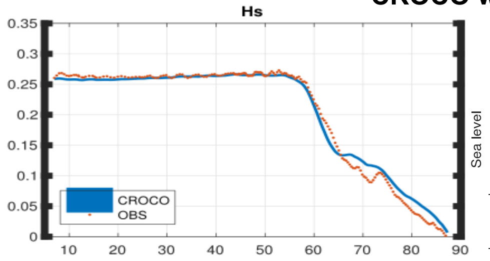


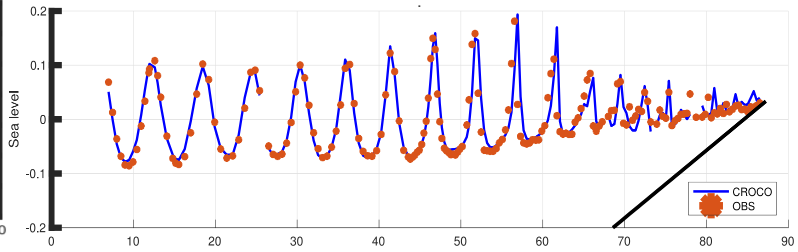
Marchesiello,Benshila. 2015, Rip current





CROCO wave-to-wave (Marchesiello, Benshila)





CROCO numerics

CROCO
Coastal and Regional Ocean COmmunity model

- Solves the Primitive Equations in an Earth-centered rotating environment:

  * momentum conservation
  * continuity
  * tracer conservation
  * equation of state

Momentum conservation

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

advection Coriolis Pressure gradient Horizontal diffusion Vertical diffusion

Continuity

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

Equation of state

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

Tracer conservation

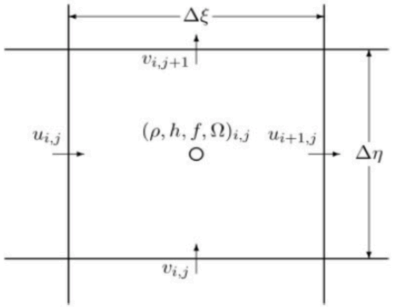
$$\frac{\partial T}{\partial t} + \vec{u}.\nabla T = \nabla_h (K_{Th}.\nabla_h T) + \frac{\partial}{\partial z}\left(K_{Tv}\frac{\partial T}{\partial z}\right)$$
$$\frac{\partial S}{\partial t} + \vec{u}.\nabla S = \nabla_h (K_{Sh}.\nabla_h S) + \frac{\partial}{\partial z}\left(K_{Sv}\frac{\partial S}{\partial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

- Boussinesq hystrostatic mode, and non-hydrostatic, non-Boussinesq mode (NBQ) available

- Split-explicit time-stepping: → see dedicated course

  * **short time steps** are used to advance the surface elevation and **barotropic** momentum
  * much **larger time step** used for temperature, salinity, and **baroclinic** momentum
  * for **NBQ** mode: barotropic mode solver is replaced by a fully 3D fast mode solver,
resolving all waves down to **acoustic waves** (with sound speed that can be decreased to the maximum wave velocity one wants to solve)

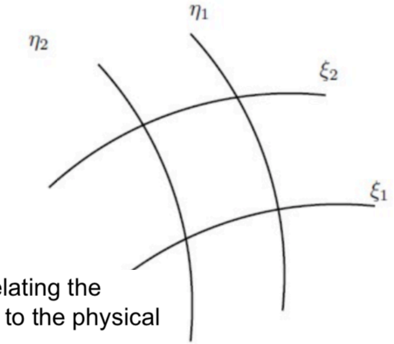
CROCO grid is discretized in coastline- and terrain-following curvilinear coordinates with free-surface, on an Arakawa-C grid



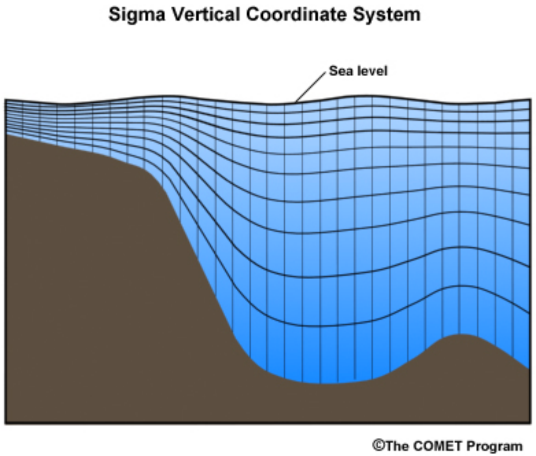
(a) Grille C d'Arakawa

$$(ds)_\xi = \left(\frac{1}{m}\right) d\xi$$

$$(ds)_\eta = \left(\frac{1}{n}\right) d\eta$$



m, *n*: scale factors relating the differential distances to the physical arc lengths



free-surface — vertical stretching coord. — Water column thickness (changed in sediment applications with erosion/deposition)

$$z(x, y, \sigma, t) = \zeta.(1+\sigma) + h_c.\sigma + (h - h_c).C(\sigma)$$

parameter controlling stretching between surface and bottom levels

Stretching function C=*f*(θs θ*b*)

CROCO numerics

Coastal and Regional Ocean COmmunity model

High-order numerics

High-order numerical schemes: 3rd and 5th-order advection schemes

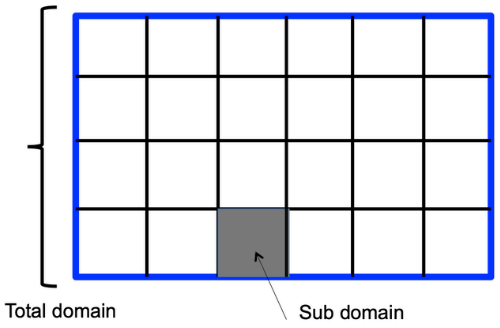
Rotated tensors to reduce diapycnal mixing

KPP and GLS mixing parameterizations

see dedicated courses

Optimization

Parallelization by two-dimensional subdomain partitioning
OPEN-MP and MPI



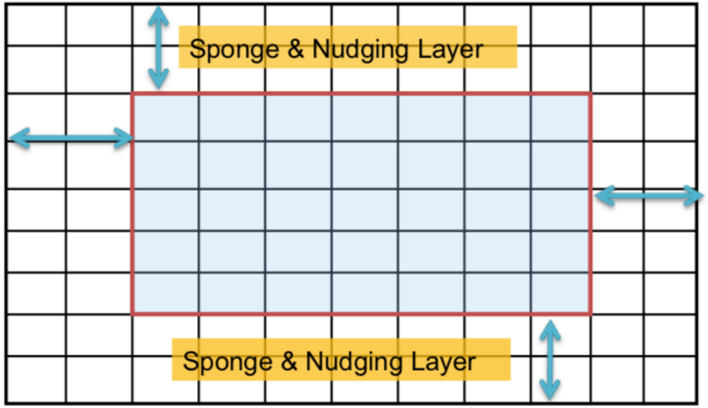
CROCO configurations

Idealized conditions

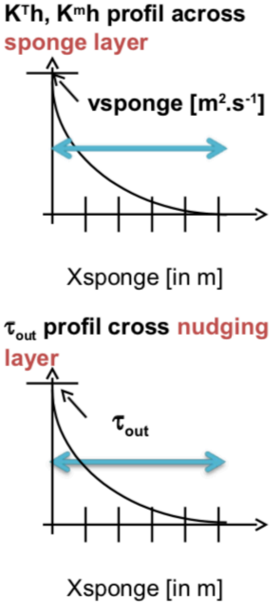
- Several idealized test cases are provided
- Analytical forcing and boundary conditions can be set

Regional configurations

- Open boundaries: active, implicit, upstream-biased radiation conditions
- Climatological or interannual surface and boundary conditions
- Bulk formulations for atmospheric forcing
- Rivers, and tidal forcing available



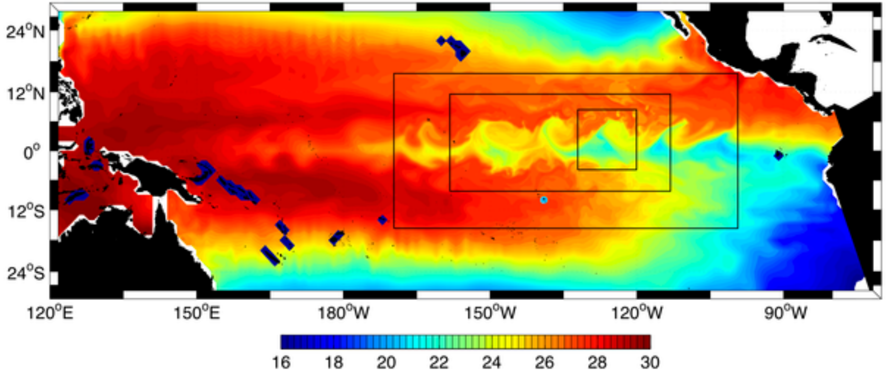
▪Sponge : Additional viscosity/diffusivity
▪Nudging : Add a weak nudging, $\tau = 0 \rightarrow \tau_{out}$, toward climatology, if available (see after)



CROCO nesting

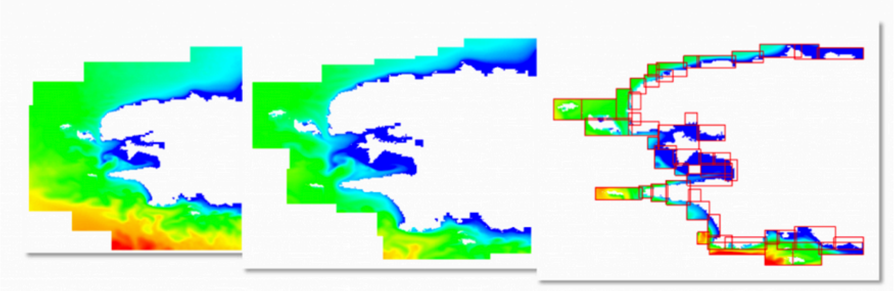
Nesting with AGRIF

- Grid refinement with the AGRIF library (developed at Inria)
- 1-way (coarse grid force the finer grid) and 2-way (feedback of the finer grid to the coarse grid) nesting capabilities



Towards multi-grid / multi-resolution (in dev.)

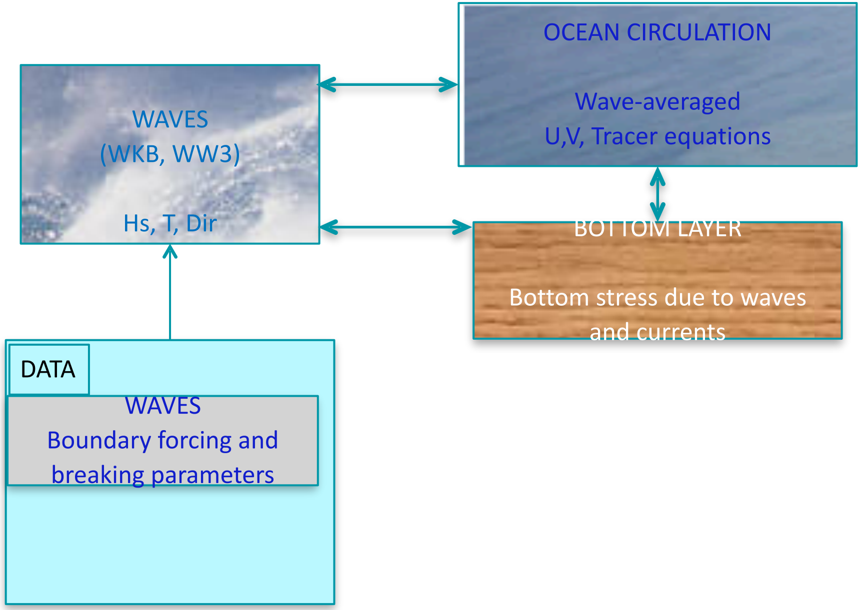
- Exchanges between grids of the same level
- Refinement criteria
- Good CPU load balance
- Management of numerous grid outputs



CROCO modules and coupling

Wave-current interactions

- Based on the vortex force formalism (Uchiyama et al. 2010):
  - Impact of evolving water level on waves
  - Impact of current on waves evolution (refraction, etc)
  - Wave-induced circulation (stokes drift and transport, acceleration by breaking)
  - Enhanced mixing due to wave breaking
  - Surface and bottom streaming (wave-induced thin viscous boundary layer)
  - Mass flux due to wave rollers
  - Wave-induced pressure effects
  - Wave-induced additional diffusivity
  - Wave-induced setup
- WKB module
- Coupling with a wave model through OASIS3-MCT library (developed at CERFACS)



CROCO modules and coupling

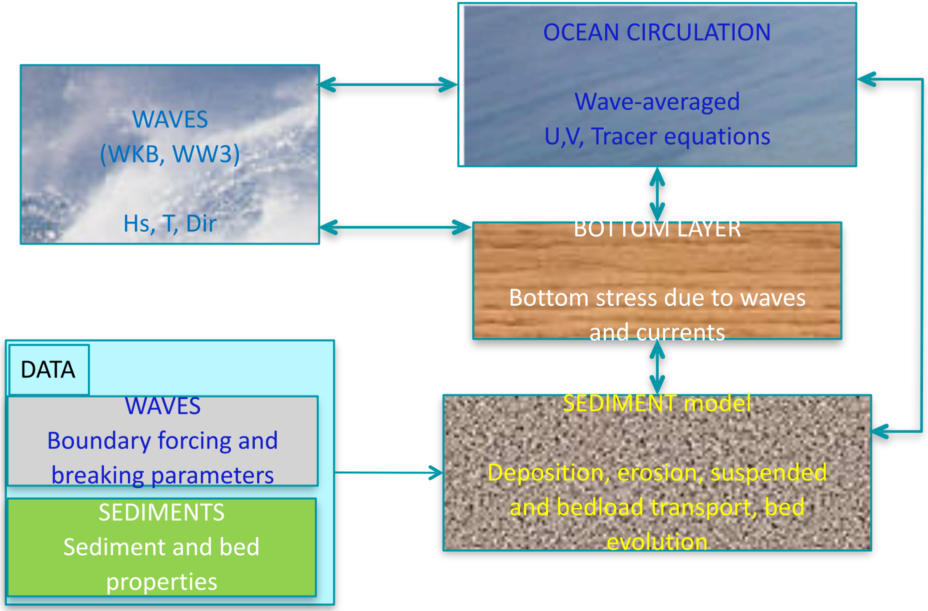
Sediment modules

- USGS Sediment model (Blaas et al. (2007); Warner et al. (2008))
    - Wave input (specified, WKB, or WW3)
    - Wave-current combined bottom stress (Soulsby, 1995)
    - Erosion (armoring), deposition, suspended transport
    - Bedload transport and flux divergence
    - Bed model (sand, mud, or mixed)
    - Morphological evolution (with acceleration factor)
    - Wetting and drying
    - Positive-definite advection schemes (WENO,TVD)
    - Sediment influence on density
- MUSTANG (Mud and Sand Transport Modeling, Le Hir et al., 2011, in dev. by Ifremer/DHYSED)

Morphodynamics

Currents-sediment coupling (Warner et al. 2008):

- Volume and constancy preserving scheme
- Speed-up equilibration: morpho. factor (Roelvink, 2006)

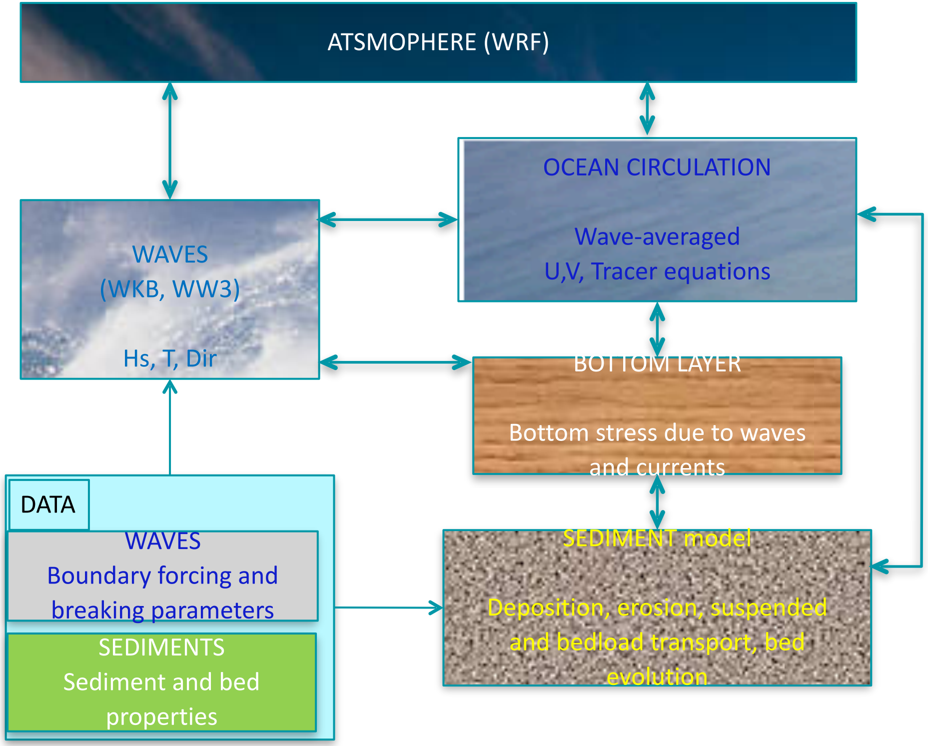


CROCO modules and coupling

Ocean-wave-atmosphere coupling

- Current feedback (CFB) option available
- Coupling with an atmospheric model through **OASIS3-MCT library** (developed at CERFACS)

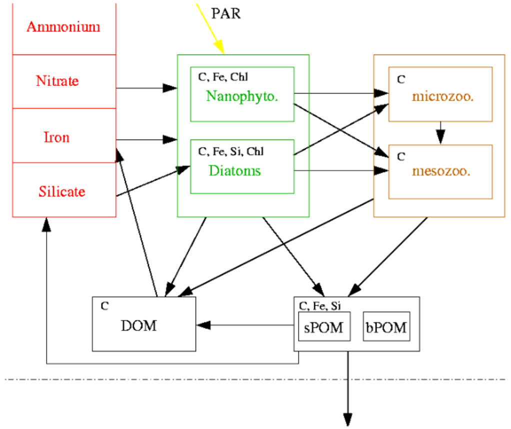
⇒ Need to download and compile OASIS and coupled models



CROCO modules and coupling

Coastal and Regional Ocean COmmunity model

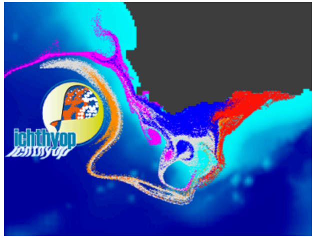
Biogeochemistry

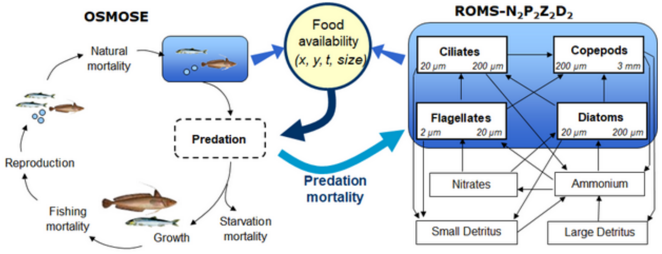


- PISCES module (Aumont and Bopp, 2006)
- BioEBUS module (Gutknecht et al., 2013)
- NPZD
- MEDUSA (in dev)

Coupling with lagrangian and ecosystemic models

- ARIANE
- ICHTYOP
- OSMOSE
- APECOSM





CROCO tools and facilities

CROCO
Coastal and Regional Ocean COmmunity model

Matlab CROCO_TOOLS

- Climatological pre-processing
- Interannual pre-processing
- Visualization

Python CROCO_TOOLS

- Pre-processing: in dev.
- Visualization

Online diagnostics

- Online temperature / vorticity / energy balance

XIOS (dev. at ISPL)

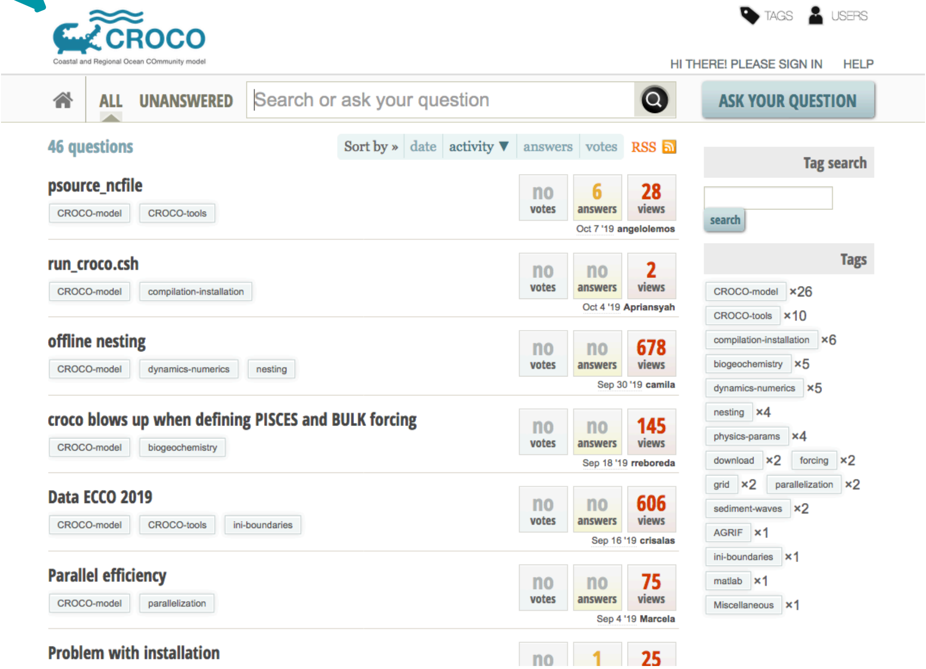
- Outputs facilities
- Diagnostics facilities

⇒ Need to download and compile XIOS

CROCO help

DOCUMENTATION

FORUM



CROCO team and contributors

CROCO
Coastal and Regional Ocean COmmunity model

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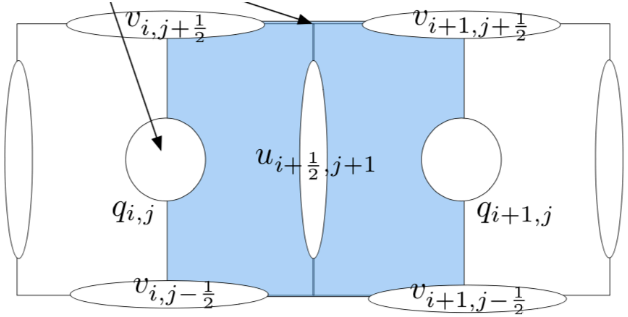
https://www.croco-ocean.org

https://croco-ocean.gitlabpages.inria.fr/croco_doc

APPENDICES

CROCO numerics

CROCO grid is discretized in coastline- and terrain-following curvilinear coordinates, on an Arakawa-C grid, with free-surface



CROCO numerics

Coastal and Regional Ocean COmmunity model

$$z(x,y,\sigma,t) = \zeta(x,y,t) + [\zeta(x,y,t) + h(x,y)]\, S(x,y,\sigma),$$

$$S(x,y,\sigma) = \frac{h_c\,\sigma + h(x,y)\,C(\sigma)}{h_c + h(x,y)}$$

$$z(x,y,\sigma,t) = S(x,y,\sigma) + \zeta(x,y,t)\left[1 + \frac{S(x,y,\sigma)}{h(x,y)}\right],$$

$$S(x,y,\sigma) = h_c\,\sigma + [h(x,y) - h_c]\,C(\sigma)$$

$$z = \zeta(1+s) + h_c s + (h - h_c)C(s)$$

$$C(s) = (1-b)\frac{\sinh[\theta s]}{\sinh\theta} + b\frac{\tanh[\theta(s+\frac{1}{2})] - \tanh[\frac{1}{2}\theta]}{2\tanh[\frac{1}{2}\theta]}$$

where

ζ(x, y, t) is the time-varying free-surface,

h(x, y) is the unperturbed water column thickness

S(x, y, σ) is a nonlinear vertical transformation functional,

σ is a fractional vertical stretching coordinate ranging from $-1 \leq \sigma \leq 0$

C(σ) is a nondimensional, monotonic, vertical stretching function ranging from $-1 \leq C(\sigma) \leq 0$,

h_c is a positive thickness controlling the stretching.

Note: in sediment applications, h = h (x, y, t) is changed at every time-step since it is affected by erosion and deposition processes.