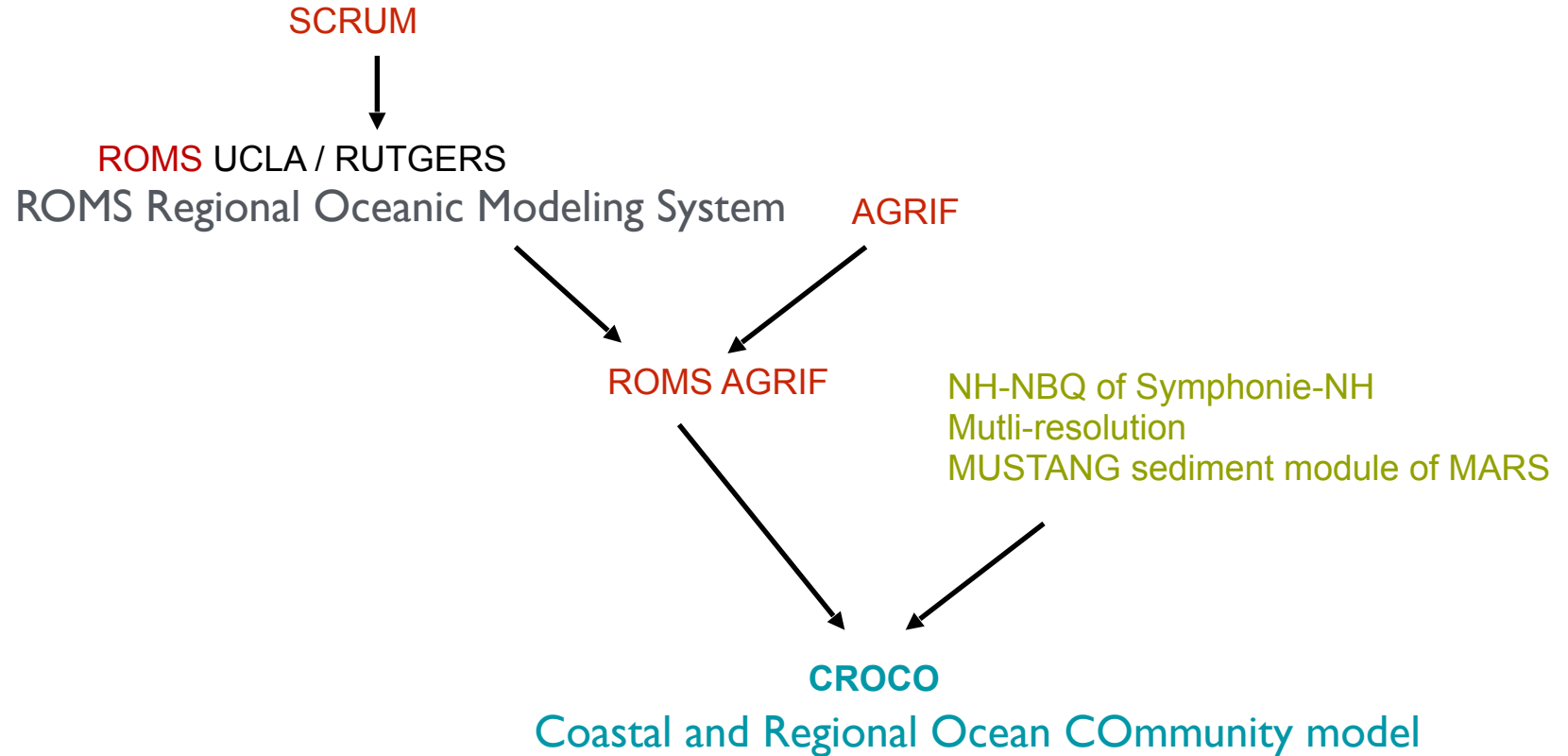


CROCO

Introduction to CROCO model





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

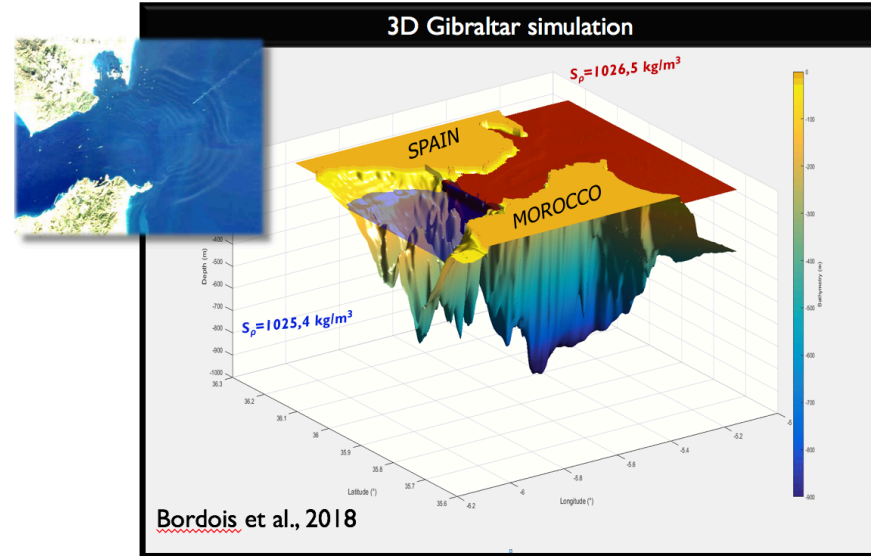
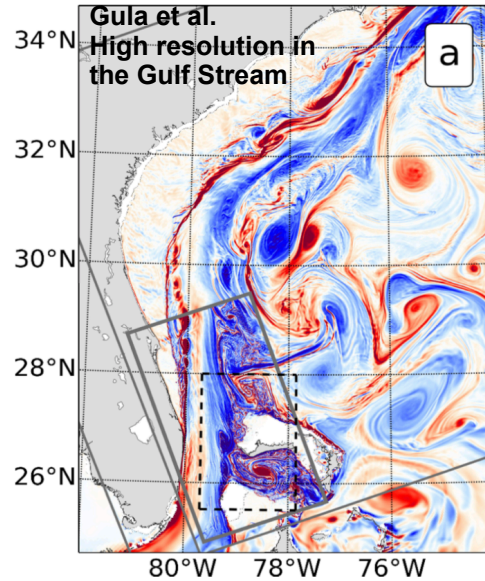
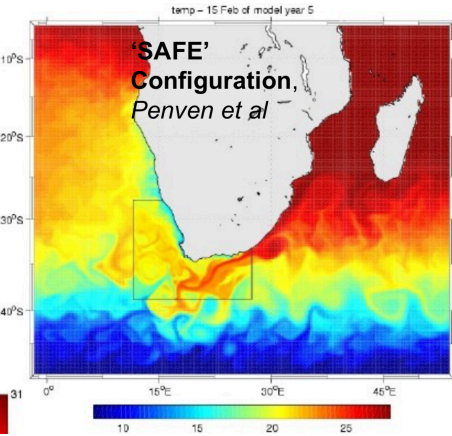
Coupling with atmosphere and
waves

Coupling with biogeochemistry
and ecology

LES / DNS

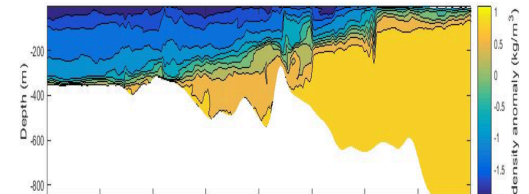
CROCO examples

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



NBQ mode

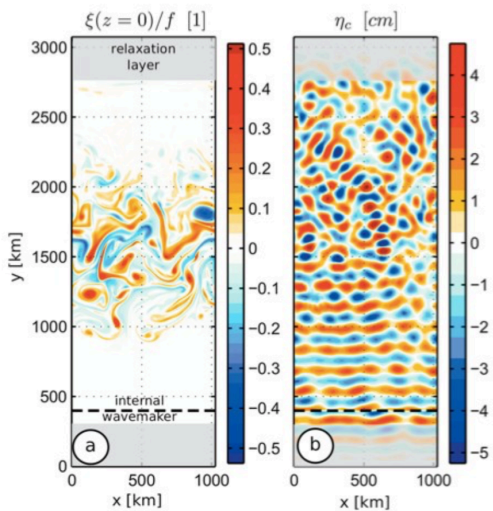
Gibraltar IGW



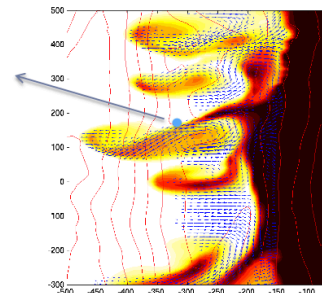
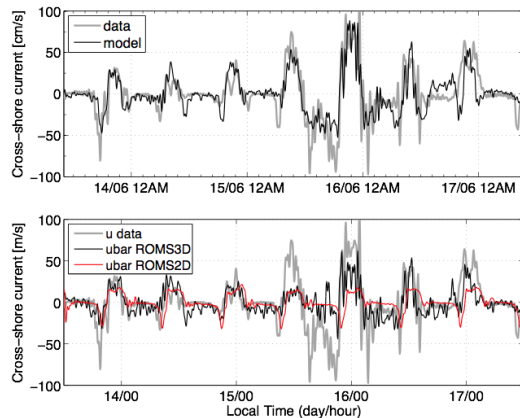
CROCO examples

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

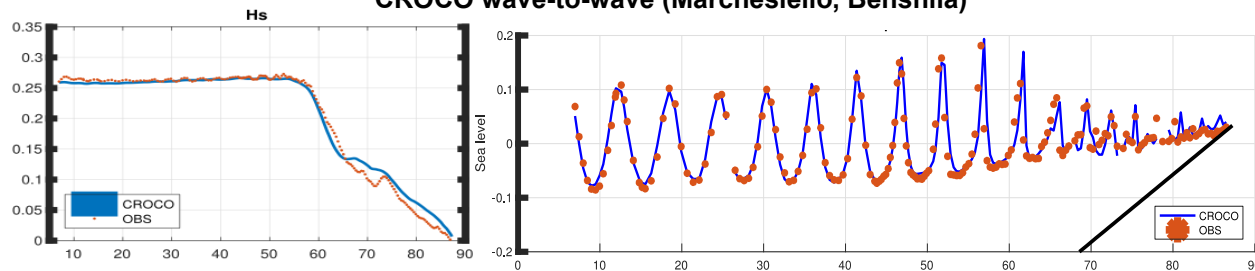
Ponte & Klein, 2015,, internal tides and eddies



Marchesiello, Benschila. 2015, Rip current



CROCO wave-to-wave (Marchesiello, Benschila)



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

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

Momentum conservation

$$\begin{aligned} \frac{\partial u}{\partial t} + \vec{u} \cdot \nabla u - f v &= -\frac{1}{\rho_0} \frac{\partial P}{\partial x} + \nabla_h (K_{Mh} \cdot \nabla_h u) + \frac{\partial}{\partial z} \left(K_{Mv} \frac{\partial u}{\partial z} \right) \\ \frac{\partial v}{\partial t} + \vec{u} \cdot \nabla v + f u &= -\frac{1}{\rho_0} \frac{\partial P}{\partial y} + \nabla_h (K_{Mh} \cdot \nabla_h v) + \frac{\partial}{\partial z} \left(K_{Mv} \frac{\partial v}{\partial z} \right) \end{aligned}$$

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

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

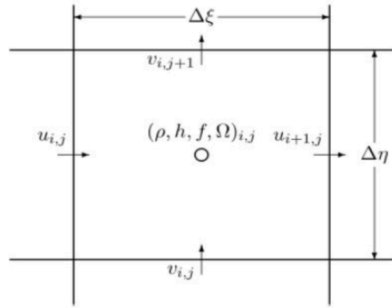
Tracer conservation

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

- 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

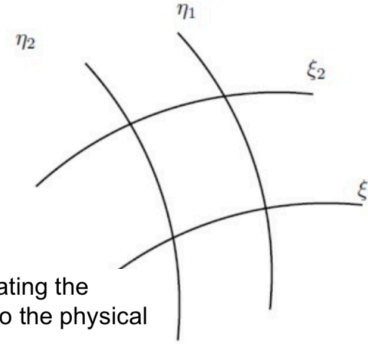


(a) Grille C d'Arakawa

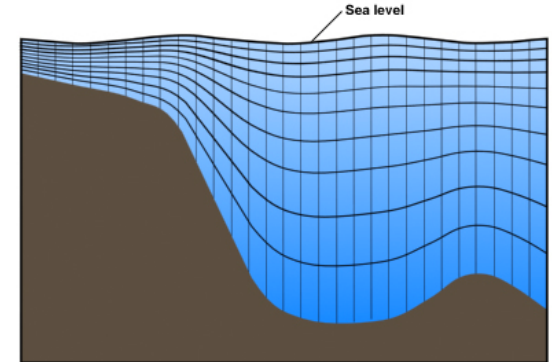
$$(ds)_\xi = \left(\frac{1}{m}\right) d\xi$$

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

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



Sigma Vertical Coordinate System



free-surface

vertical stretching coord.

Water column thickness

(changed in sediment applications with erosion/deposition)

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

parameter controlling stretching between surface and bottom levels

Stretching function $C=f(\theta_s \theta_b)$

High-order numerics

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

Rotated tensors to reduce diapycnal mixing

KPP and GLS mixing parameterizations

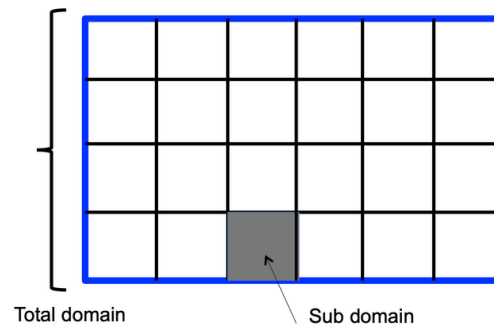


see dedicated
courses

Optimization

Parallelization by two-dimensional subdomain partitioning

OPEN-MP and MPI

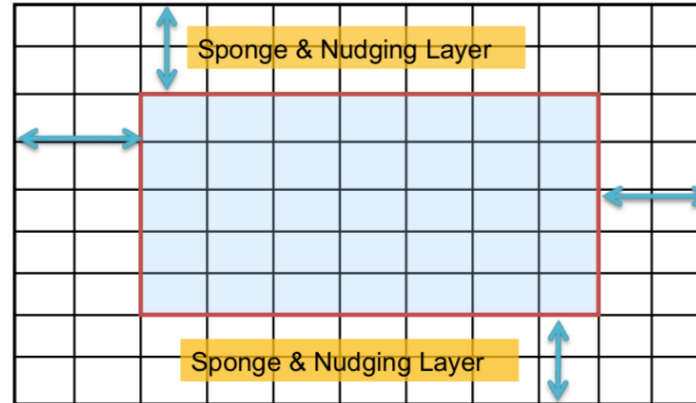


Idealized conditions

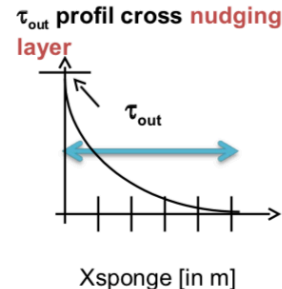
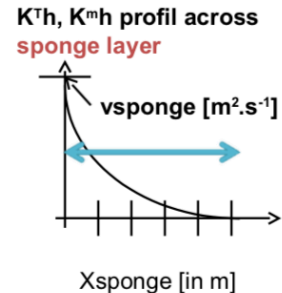
- Several idealized test cases are provided
- Analytical forcing and boundary conditions can be set

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

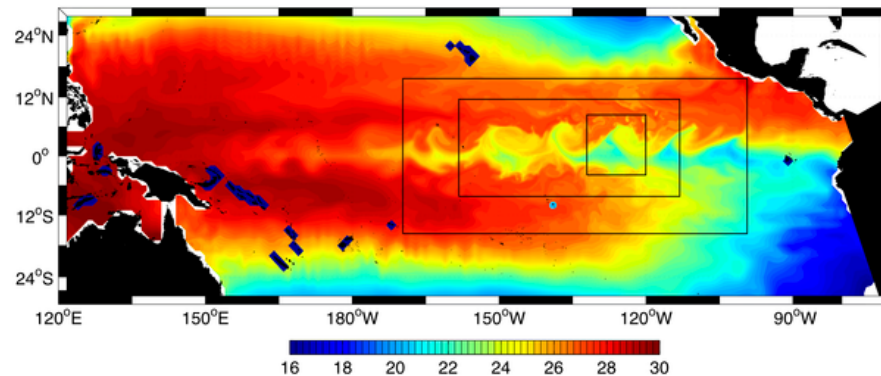


- Sponge : Additional viscosity/diffusivity
- Nudging : Add a **weak nudging**, $\tau=0 \rightarrow \tau_{out}$, toward climatology, if available (see after)



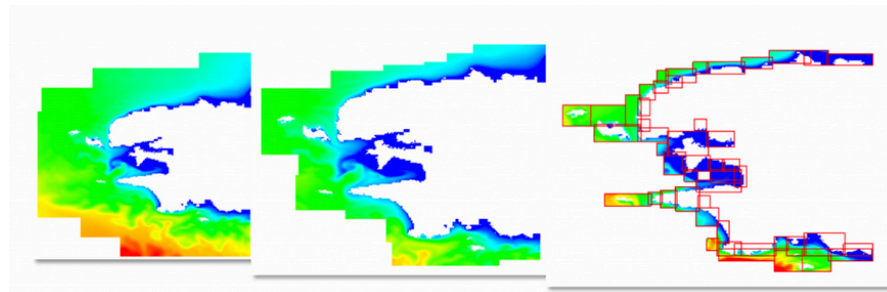
Nesting with AGRIF

- 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



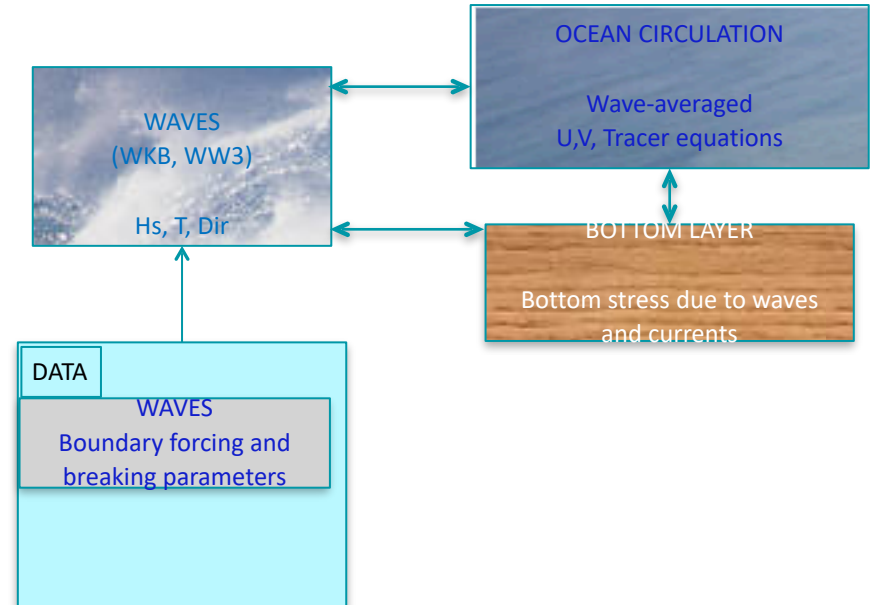
Towards multi-grid / multi-resolution (in dev.)

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



Wave-current interactions

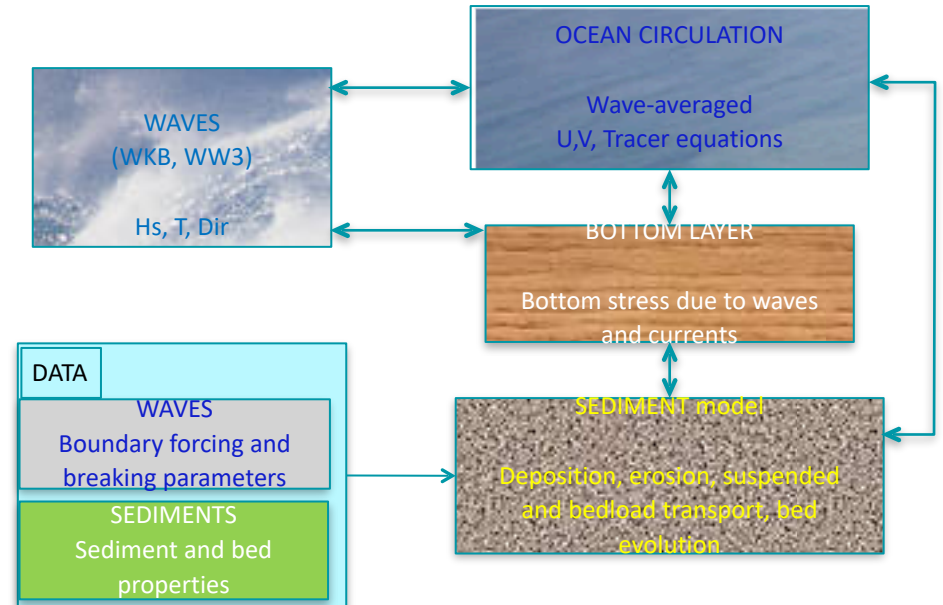
- Based on the vortex force formalism (Uchiyama et al. 2010):
 - Impact of evolving water level on waves
 - Impact of current on waves evolution (refraction, etc)
 - Wave-induced circulation (stokes drift and transport, acceleration by breaking)
 - Enhanced mixing due to wave breaking
 - Surface and 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

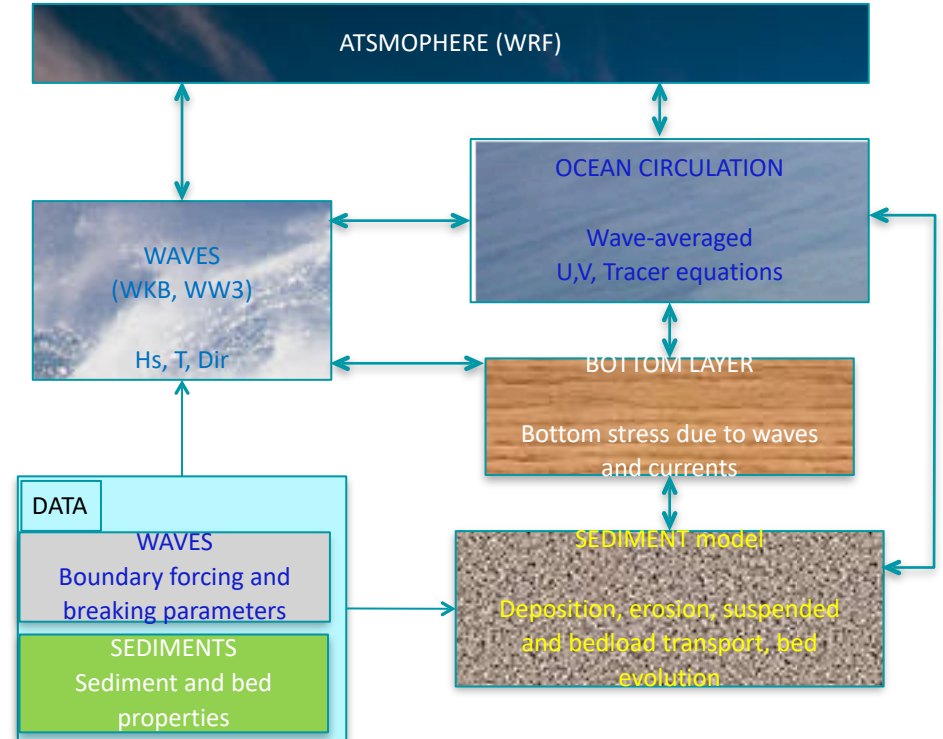
- USGS Sediment model (Blaas et al. (2007); Warner et al. (2008))
 - Wave input (specified, WKB, or WW3)
 - Wave-current combined bottom stress (Soulsby, 1995)
 - Erosion (armoring), deposition, suspended transport
 - Bedload transport and flux divergence
 - Bed model (sand, mud, or mixed)
 - Morphological 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)



Ocean-wave-atmosphere coupling

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

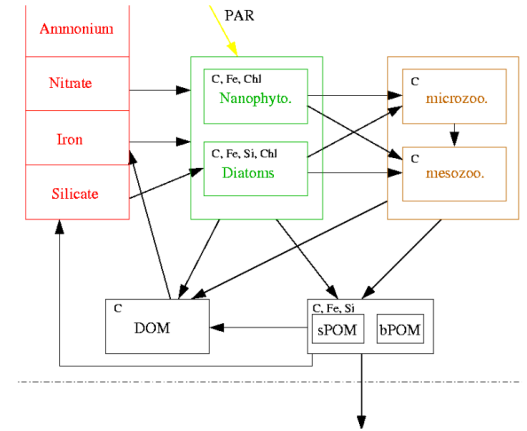
⇒ Need to download and compile OASIS and coupled models



CROCO modules and coupling

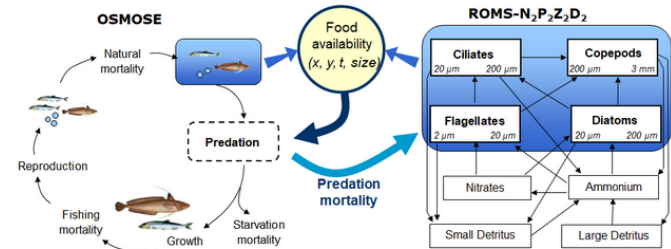
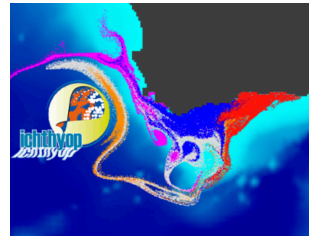
Biogeochemistry

- 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



Matlab CROCO_TOOLS

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

Online diagnostics

- Online temperature / vorticity / energy balance

Python CROCO_TOOLS

- Pre-processing: in dev.
- Visualization

XIOS (dev. at ISPL)

- Outputs facilities
- Diagnostics facilities
- ⇒ Need to download and compile XIOS

CROCO help



CROCO, Coastal and Regional Ocean Community model

CROCO is a new oceanic modeling system built upon ROMS_AGRIF and the non-hydrostatic kernel of SNH (under testing), gradually including algorithms from MARS3D (sediments) and HYCOM (vertical coordinates). An important objective for CROCO is to resolve very fine scales (especially in the coastal area), and their interactions with larger scales. It is the oceanic component of a complex coupled system including various components, e.g., atmosphere, surface waves, marine sediments, biogeochemistry and ecosystems.

CROCO Version 1.0 official release is now available in the Download section. It includes new capabilities as non-hydrostatic kernel, ocean-wave-atmosphere coupling, sediment transport, new high-order numerical schemes for advection and mixing, and a dedicated I/O server (XIOS). A new version of CROCO_TOOLS accompany this release. CROCO will keep evolving and integrating new capabilities in the following years.

[CROCO project](#): version 1.0

Releases

Official release [CROCO v1.0](#) now available
New release of [croco_tools](#) with new tools in python ([croco_pytools](#)) and new tools for coupling ([Coupling_tools](#))

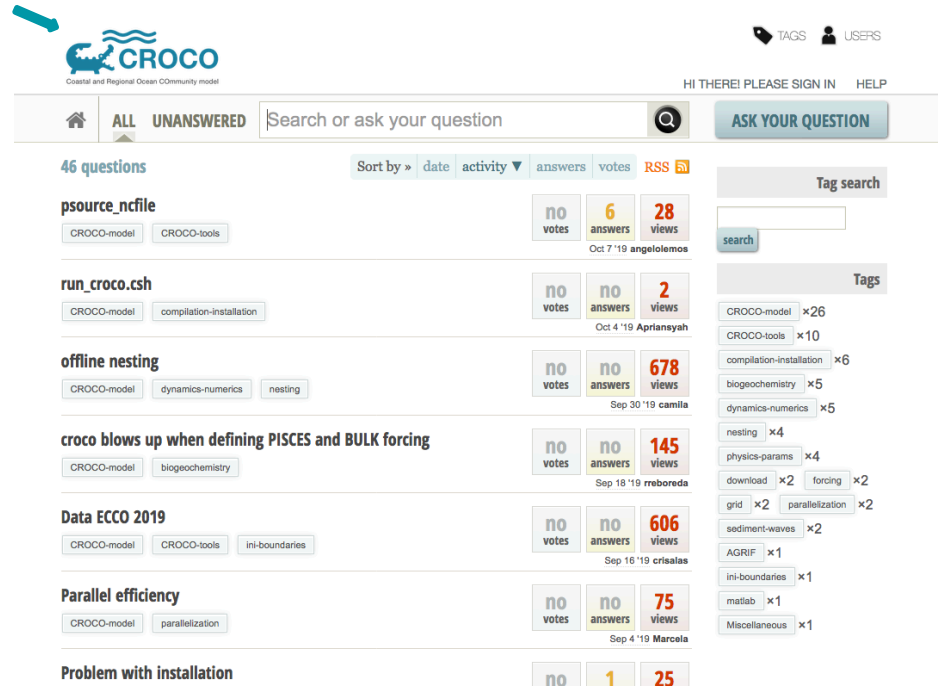
Mailing list & Forum

We strongly encourage all users to join our mailing list (low traffic; announcements, updates, bug fixes):

croco-users@lists.gforge.inria.fr

To **subscribe**, simply send an email to croco-users-join@lists.gforge.inria.fr

To **unsubscribe**, simply send an email to croco-users-leave@lists.gforge.inria.fr



































The image shows the CROCO forum page. At the top, there is a search bar and a navigation menu. The main content area displays a list of questions with their respective statistics (votes, answers, views) and tags. The sidebar on the right contains a tag search box and a list of tags.

Question	Answers	Views
psource_nfile	6	28
run_croco.csh	0	2
offline nesting	0	678
croco blows up when defining PISCES and BULK forcing	0	145
Data ECCO 2019	0	606
Parallel efficiency	0	75
Problem with installation	1	25

Tags: CROCO-model, CROCO-tools, compilation-installation, dynamics-numerics, nesting, biogeochemistry, ini-boundaries, parallelization, physics-params, download, forcing, grid, parallelization, sediment-waves, AGRIF, ini-boundaries, matlab, Miscellaneous.

CROCO team and contributors



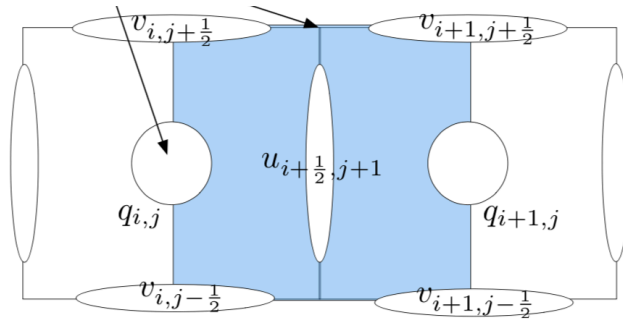
 BENSHILA Rachid LEGOS, CNRS, Toulouse, France	 MARCHESIELLO Patrick LEGOS, IRD, Toulouse, France	 AUCLAIR Francis LA, Toulouse, France	 CAMBON Gildas LOPS, IRD, Brest, France	 JULLIEN Swen LOPS, Ifremer, Brest, France	 LEMARIÉ Florian IJK, Inria, Grenoble, France	 CAILLAUD Matthieu DHYSED, Ifremer, Brest, France
 DUMAS Franck SHOM, Brest, France	 DEBREU Laurent IJK, Inria, Grenoble, France	 PENVEN Pierrick LOPS, IRD, Brest, France	 NGUYEN Cyril LA, Toulouse, France	 ETHÉ Christian LOCEAN, IPSL, Paris, France	 ROBLOU Laurent LA, Toulouse, France	 CAPET Xavier LOCEAN, CNRS, Paris, France
 THEETTEN Sébastien LOPS, Ifremer, Brest, France	 GULA Jonathan LOPS, UBO, Brest, France	 BORDOIS Lucie SHOM, Toulouse, France	 LE GENTIL Sylvie LOPS, Ifremer, Brest, France	 BRÉMOND Maurice INRIA, AIRSEA, Grenoble, France	 RENAULT Lionel LEGOS, IRD, Toulouse, France	 PIANEZZE Joris LAERO, Toulouse, France
 LE GAC Solène DHYSED, Ifremer, Brest, France	 LE CORRE Mathieu	 BOUTET Martial M2C, CNRS, Caen, France	 ILLIG Serena IRD, LEGOS, Toulouse, France	 SEPULVEDA Andres Université de Concepcion, Chili	 POUS Stéphane LOCEAN, Paris, France	 PERSON Renaud LOCEAN, Paris, France
 HOURDIN Christophe LOCEAN, Paris, France	 DUFOIS François DHYSED, Ifremer, Brest, France	 MAZOYER Camille MIO, Marseille, France	 MORVAN Guillaume LEGOS, Toulouse, France			

<https://www.croco-ocean.org>

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

APPENDICES

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



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

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

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

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

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

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

where

$\zeta(x, y, t)$ is the time-varying free-surface,

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

$S(x, y, \sigma)$ is a nonlinear vertical transformation functional,

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

$C(\sigma)$ 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.