Introduction

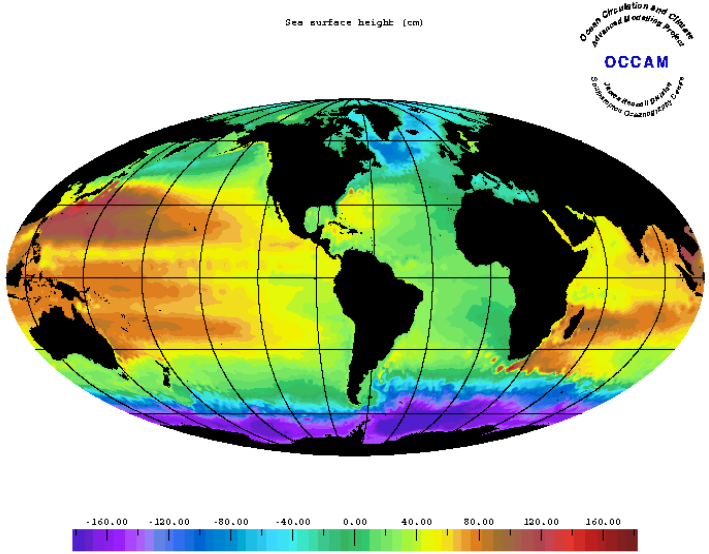
CROCO
Coastal and Regional Ocean COmmunity model

Why ocean modelling ?

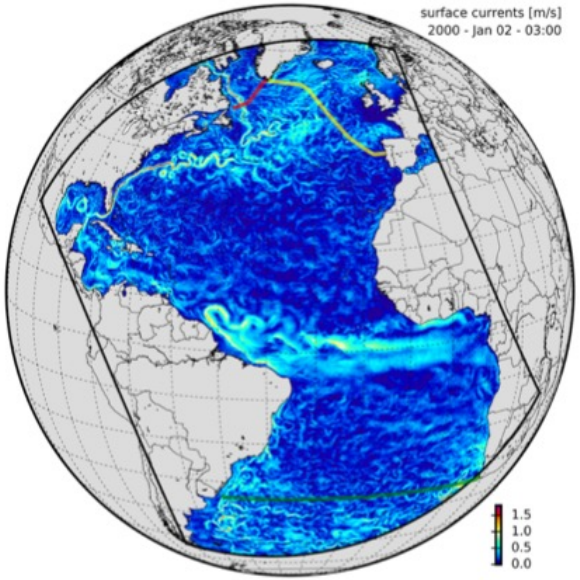
- **Fundamental research** : understand ocean functioning
- **Applied research and Operational oceanography** : ocean forecast, pollution, water quality, halieutic resources, …
- **Climate modeling**
- **…**

Advantages :

- Cost effective
- Synoptic 4D view
- Equilibrium diagnostics
- Test hypothesis
- Hindcast and forecast
- Coupling with different models
- …



Global model SSH

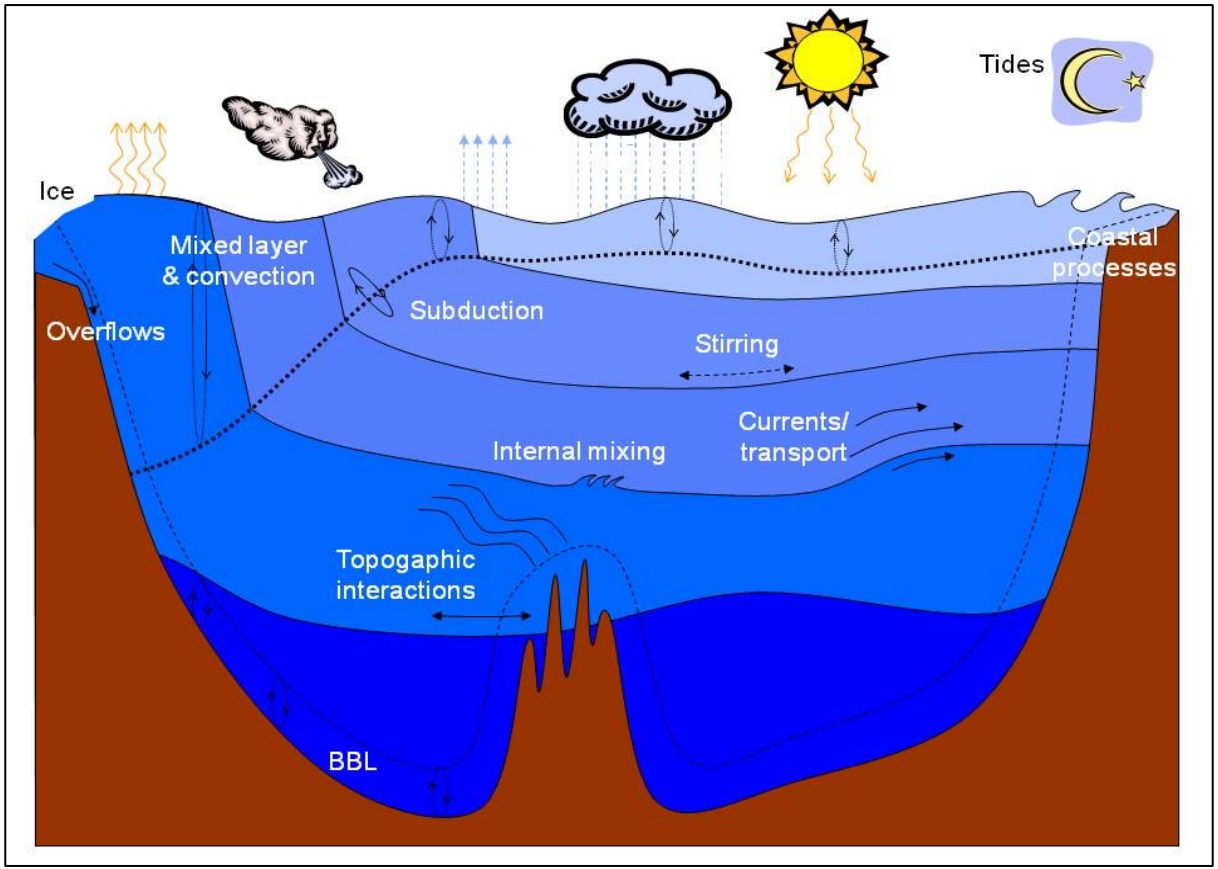


Croco 3km resolution

regional model SST (Gula et al)

Many ocean process to model

CROCO
Coastal and Regional Ocean COmmunity model



Source http://www.gfdl.noaa.gov/ocean-models-at-gfdl

Many ocean process to model

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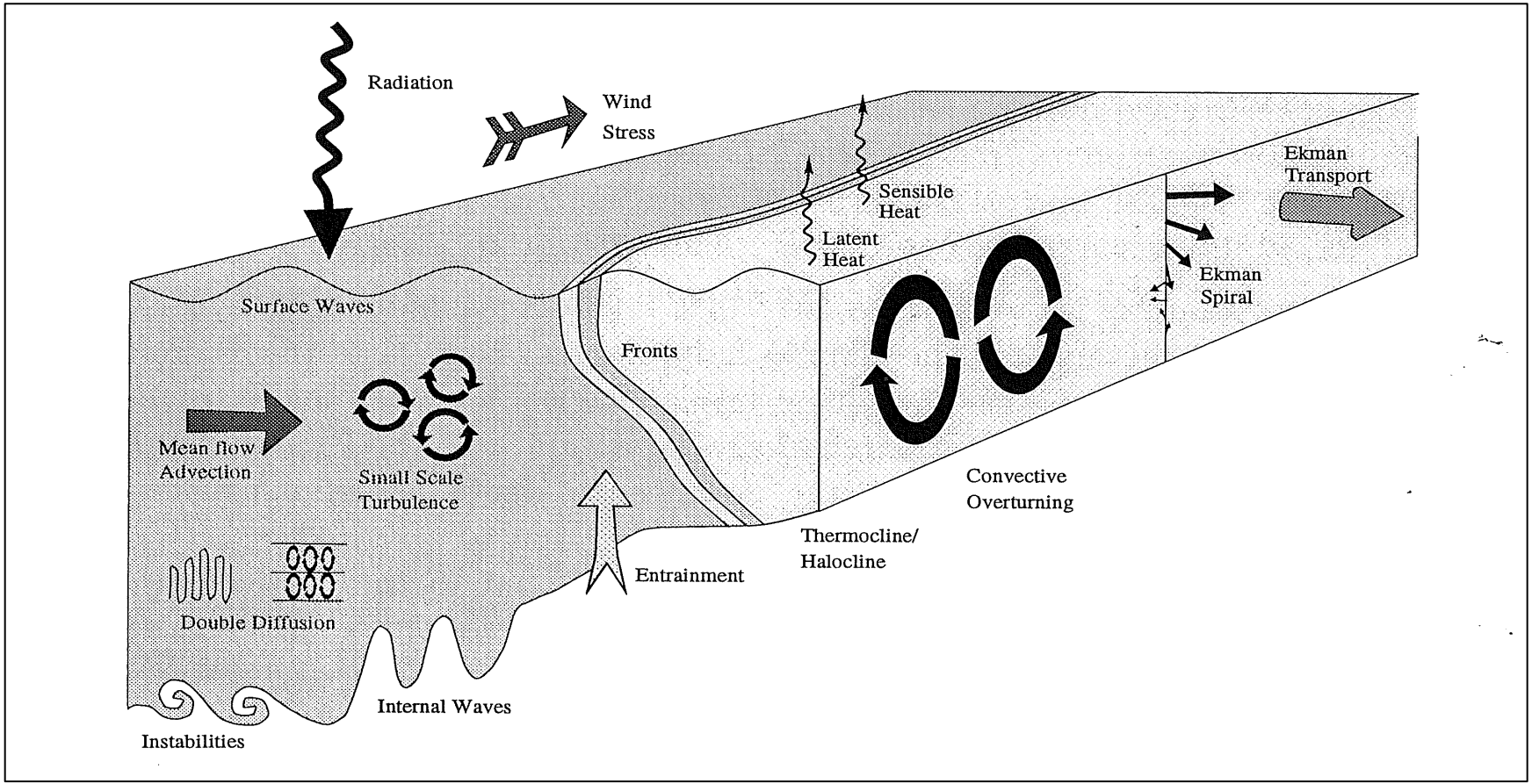

About ocean processes and model resolution

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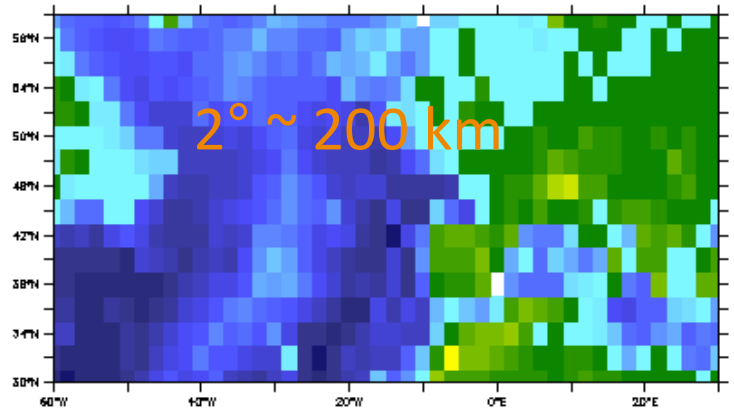
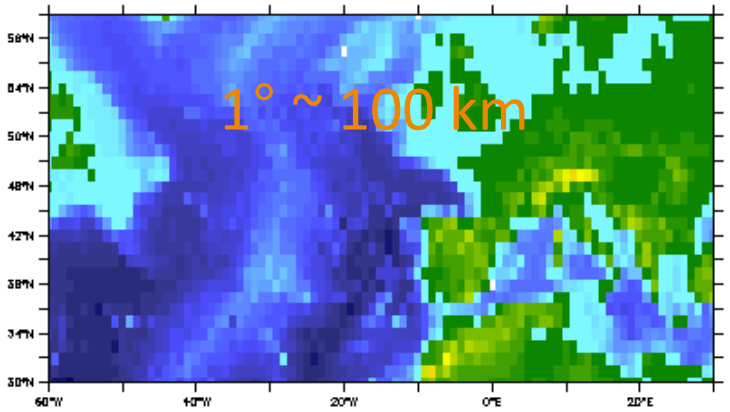
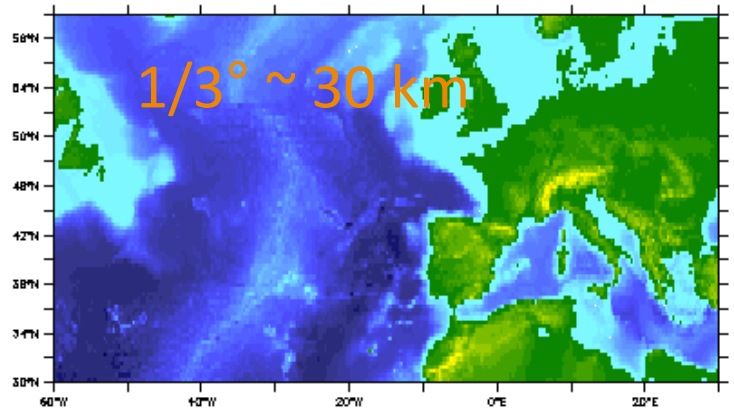
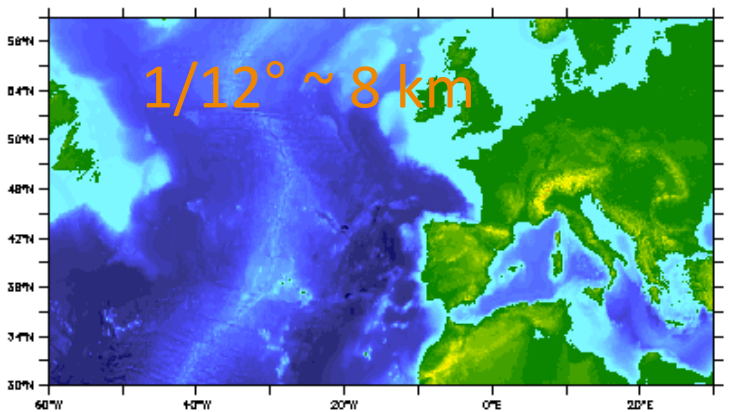
Coastal and Regional Ocean COmmunity model









Adapted from Biastoch, 2011

About ocean processes and model resolution

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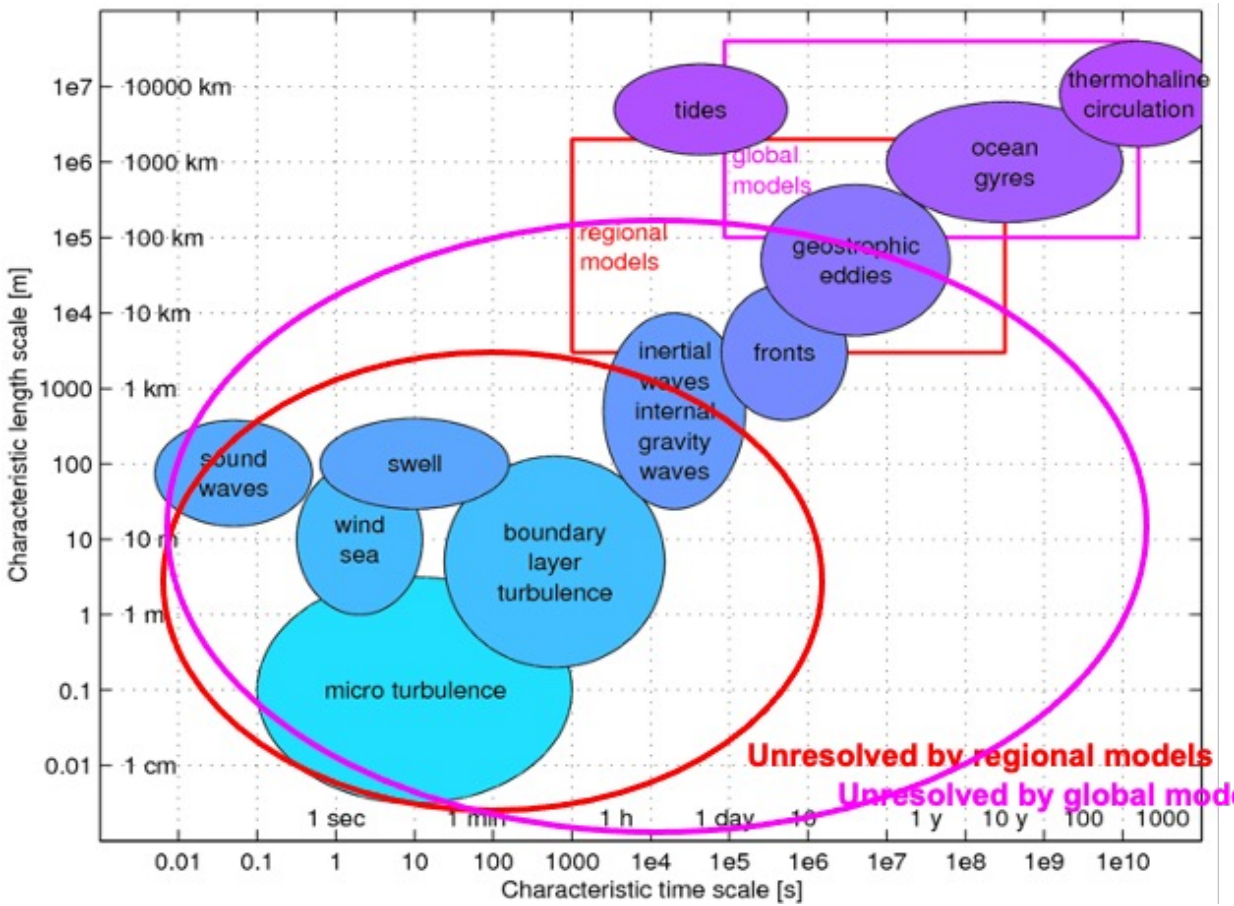

Various type of ocean model depending on space discretization techniques

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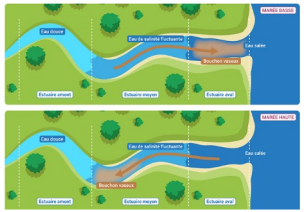
Coastal and Regional Ocean COmmunity model



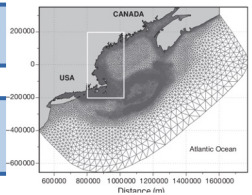
Beach, lagoon, estuary

Coast, continental shelf, regional

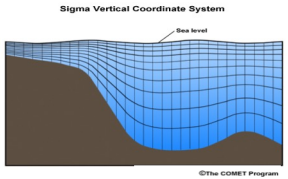
Offshore, ocean

Finite elements **Coherens, Telemac …**

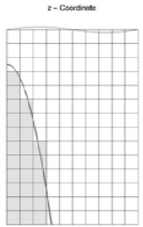
Finite Volumes **FVCOM, MIKE3, MOHID…**



Finite Differences



Sigmas coordinates
MARS3D, CROCO, …



Finite Differences

Z coordinates

NEMO, MITgcm, …

Isopycnal or hybrid coordinates **HYCOM**

Choice of an ocean model

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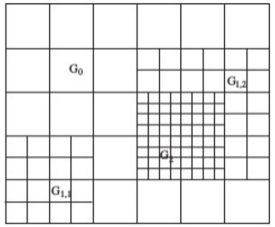
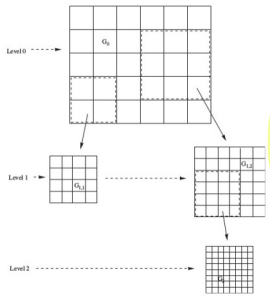




Zoom?
(Agrif : Adaptative Grid Refinement In Fortran)

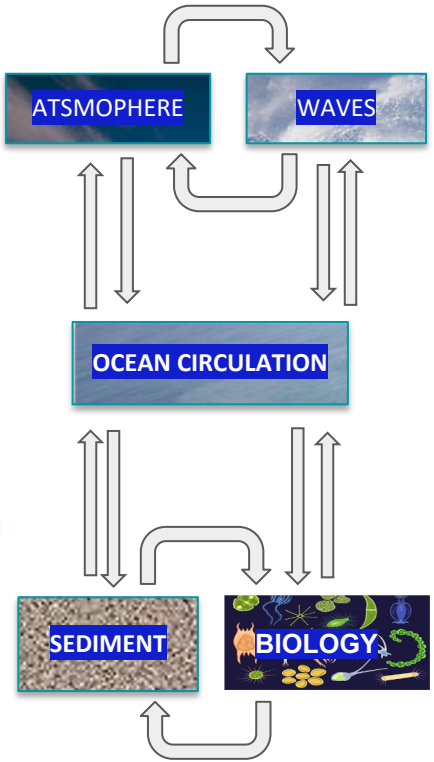
Modules?
(Biology, Sediments, …)

Interest

Community
(France, USA, …)

Coupling available?
(atmosphere, waves, …)

Available computing resources



How does it work?

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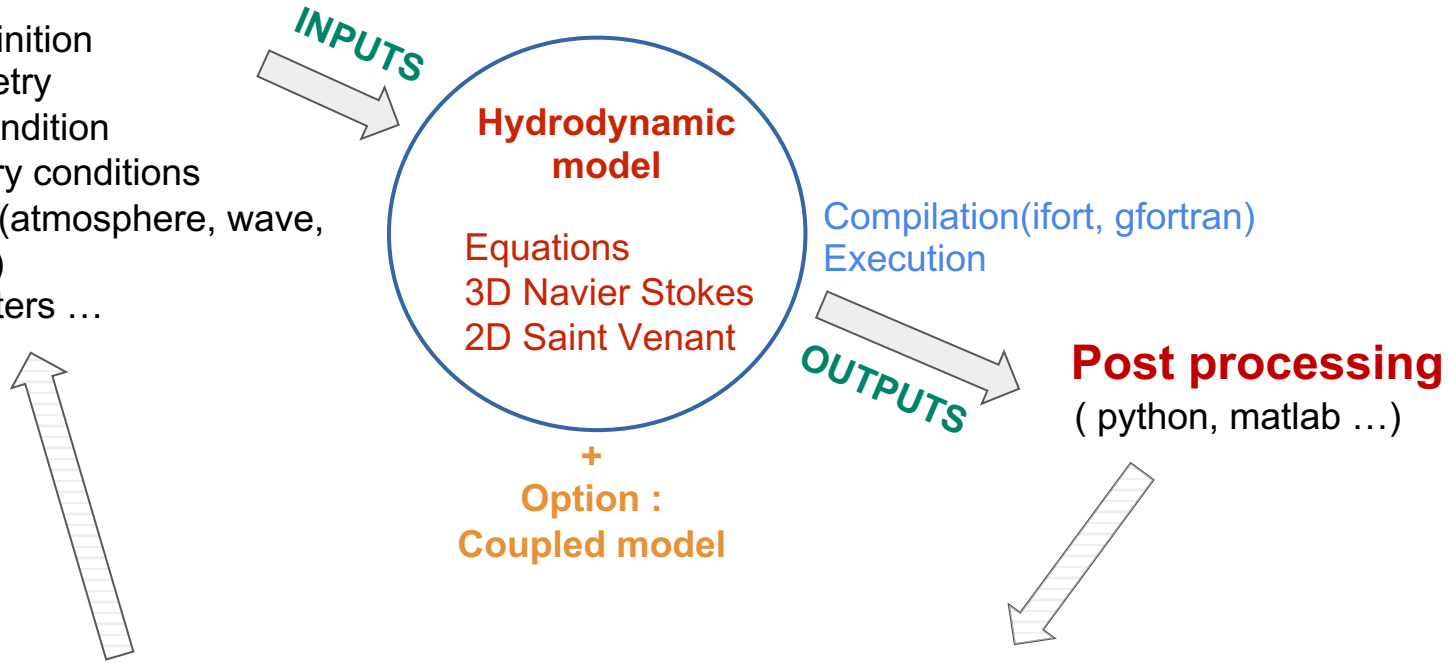
Préprocessing

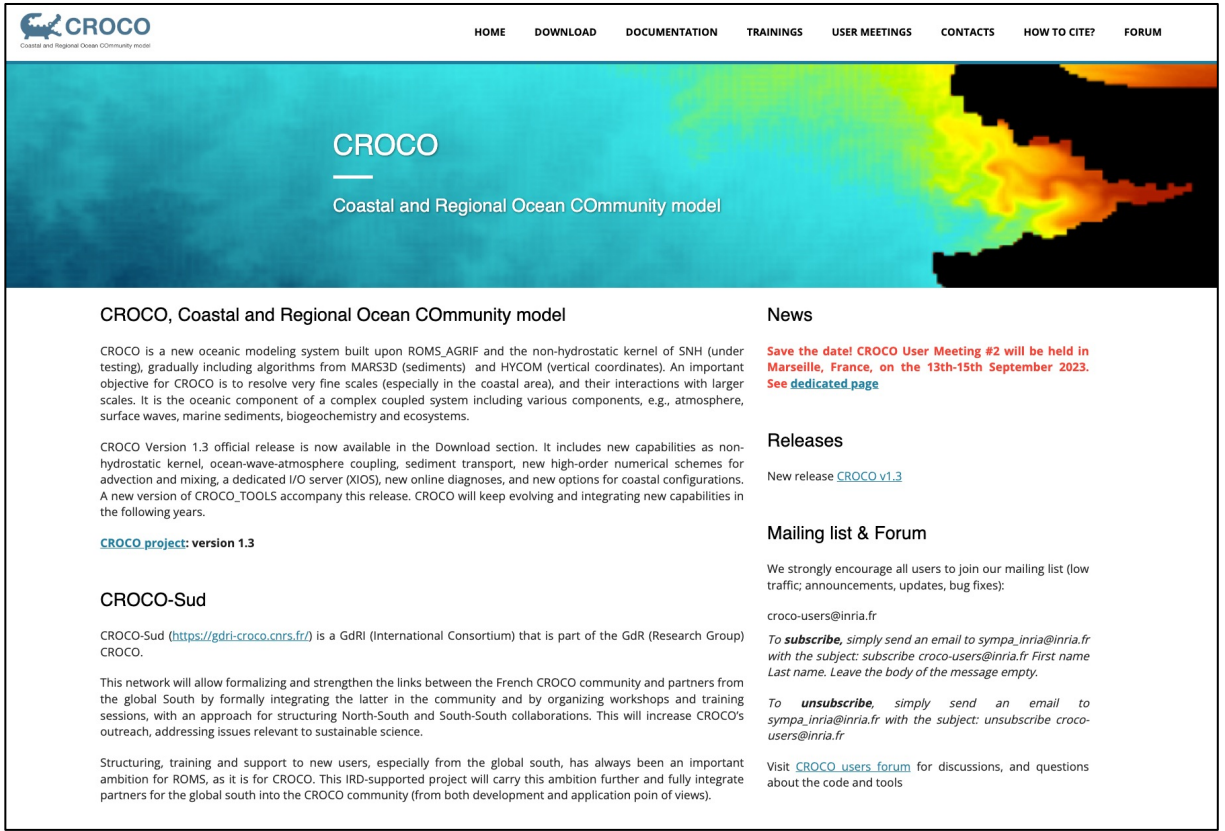
- Grid definition
- Bathymetry
- Initial condition
- Boundary conditions
- Forcing (atmosphere, wave, rivers…)
- Parameters …



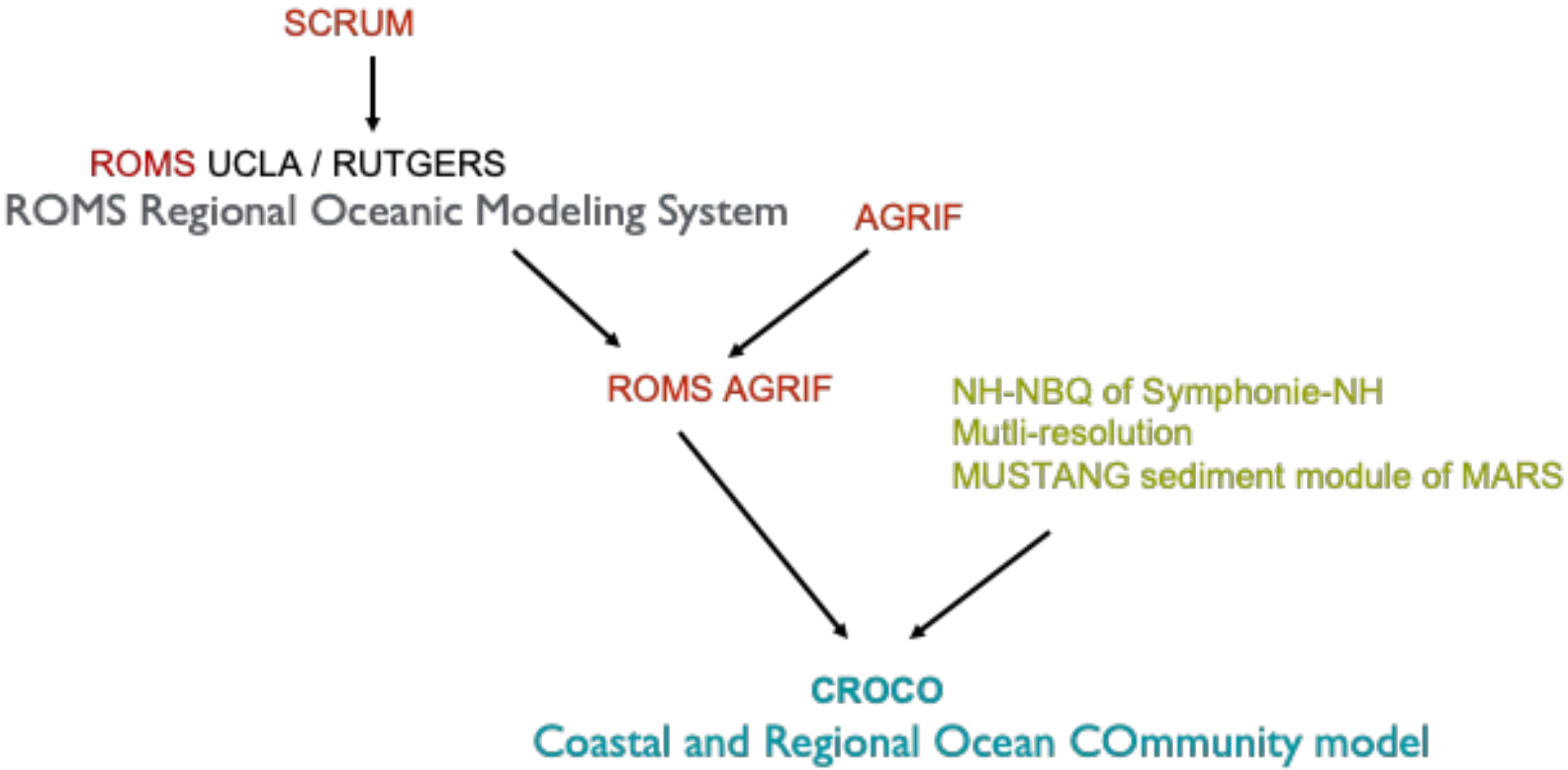
About CROCO ocean model

CROCO
Coastal and Regional Ocean COmmunity model

croco-ocean.org



CROCO history



CROCO philosophy

Community development

Continuous development

Stable releases: every 1 / 1.5 year

Help/support through a forum

High-level numerical schemes

Tools for an easy built of regional and coastal configurations

Adapted to IRD

Realistic complex modelling

Circulation forced by waves

Coupling with atmosphere and waves

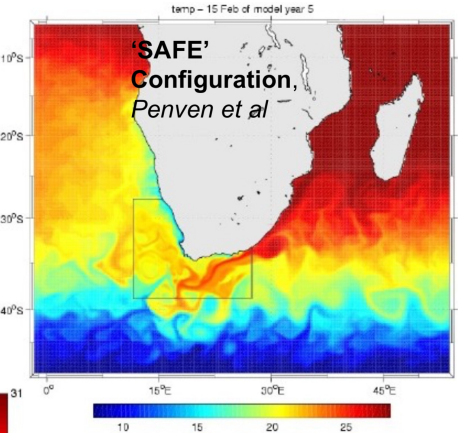
Coupling with biogeochemistry and ecology

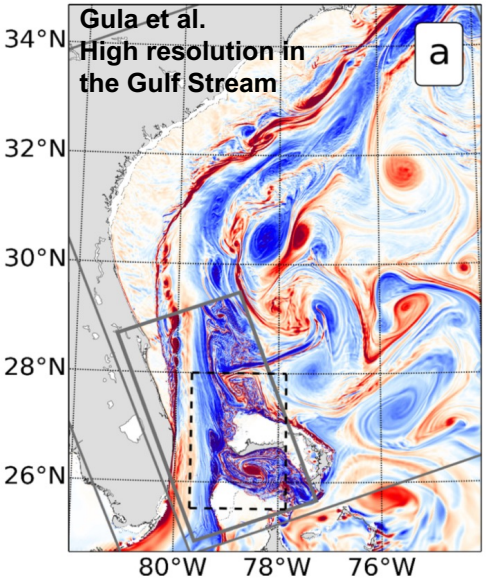
LES / DNS

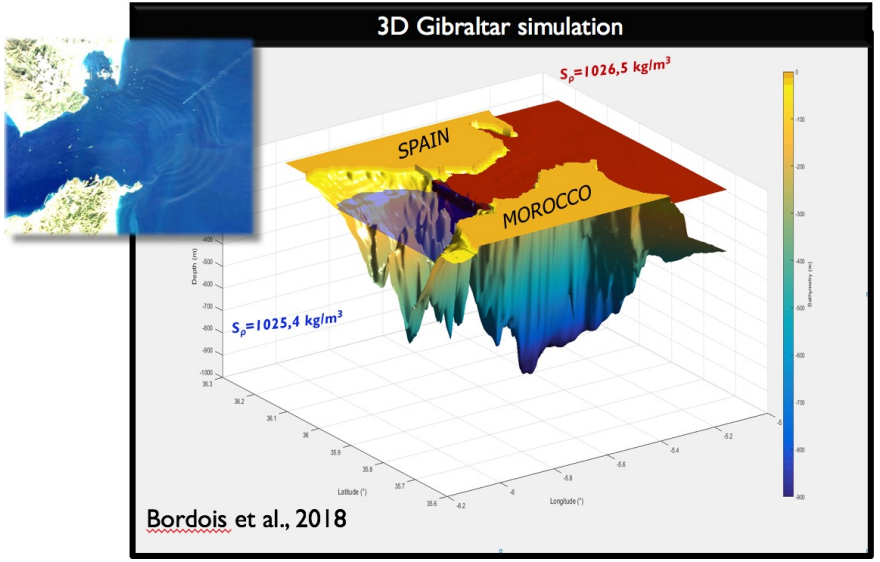
CROCO examples

Coastal and Regional Ocean COmmunity model

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

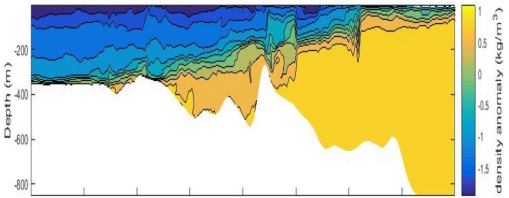






NBQ mode

Gibraltar IGW

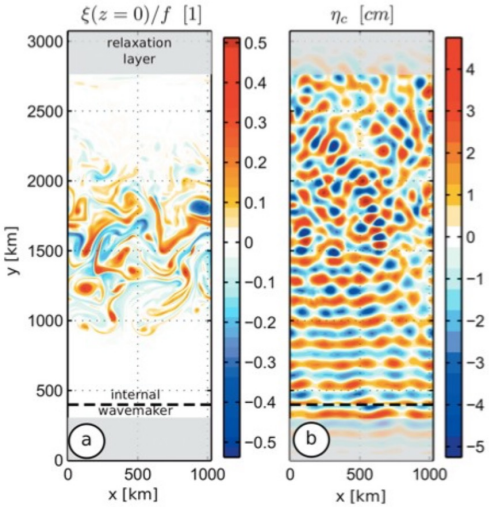


CROCO examples

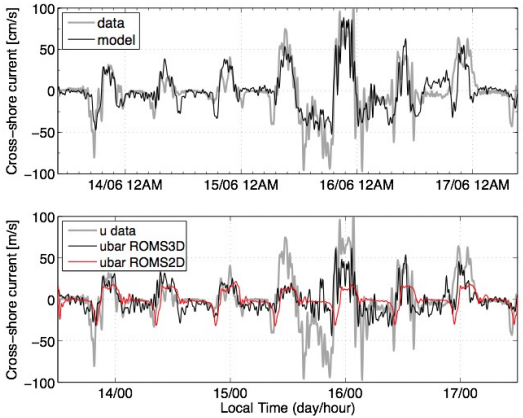
Coastal and Regional Ocean COmmunity model

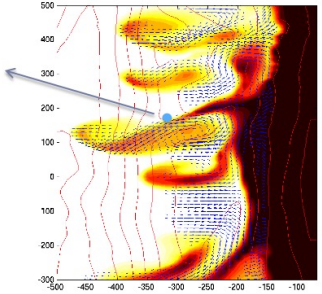
For starting, here are a few examples of use of CROCO

Ponte & Klein, 2015,, internal tides and eddies

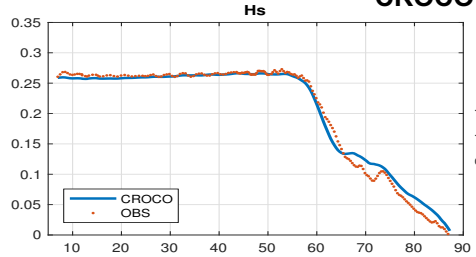


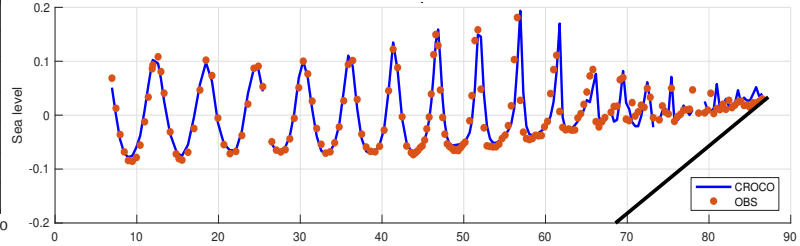
Marchesiello et al. 2015, Rip current





CROCO wave-to-wave (Marchesiello, Benshila)





CROCO numerics

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

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

Momentum conservation

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

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

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

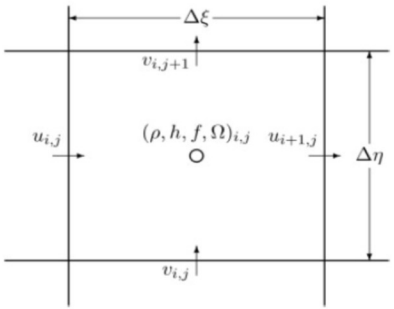
- Boussinesq hystrostatic mode, and non-hydrostatic, non-Boussinesq mode (NBQ) available

- 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 numerics

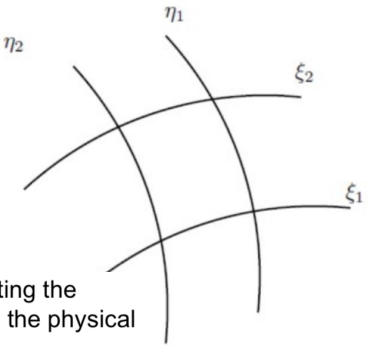
CROCO grid is discretized in coastline- and terrain-following curvilinear coordinates with free-surface, on an Arakawa-C grid



(a) Grille C d'Arakawa

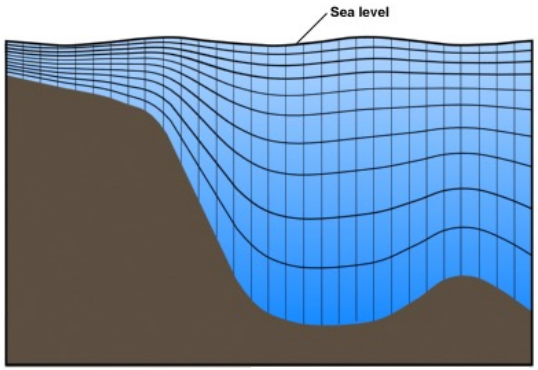
$$(ds)_\xi = \left(\frac{1}{m}\right) d\xi$$

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



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)

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

parameter controlling stretching between surface and bottom levels — Stretching function $C=f(\theta s\ \theta b)$

CROCO numerics

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Coastal and Regional Ocean COmmunity model

High-order numerics

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

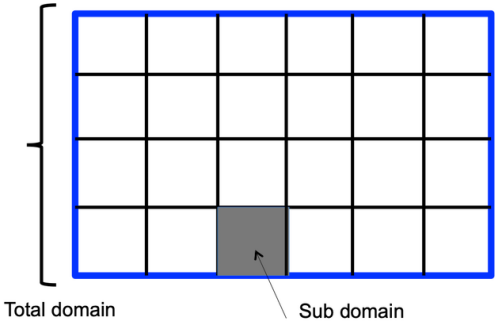
Rotated tensors to reduce diapycnal mixing

KPP and GLS mixing parameterizations

see dedicated courses

Optimization

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



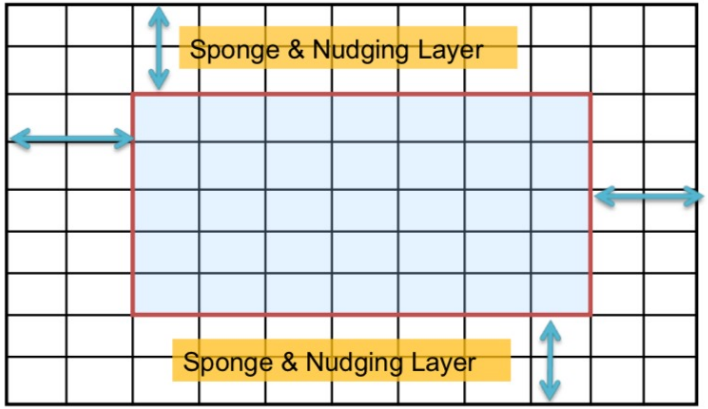
CROCO numerics

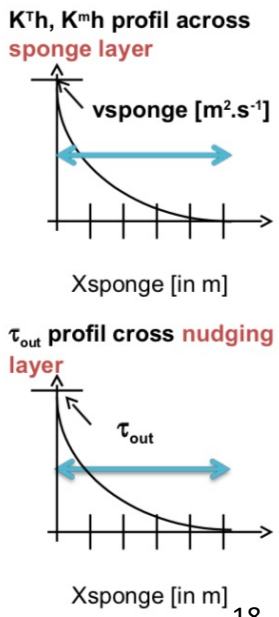
Idealized conditions

- 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





CROCO nesting

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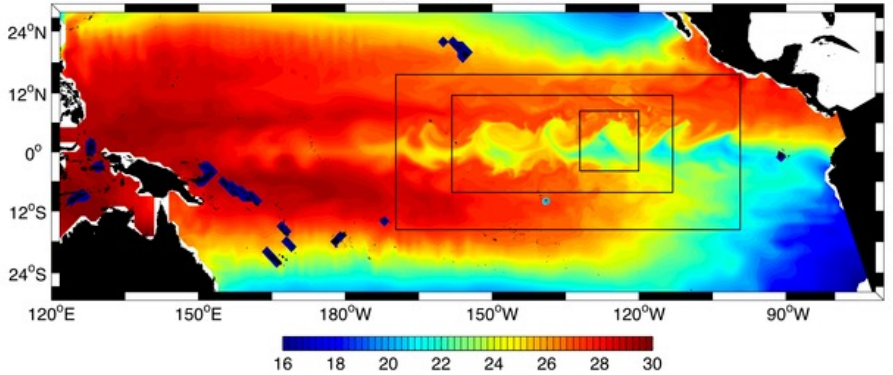
Coastal and Regional Ocean COmmunity model

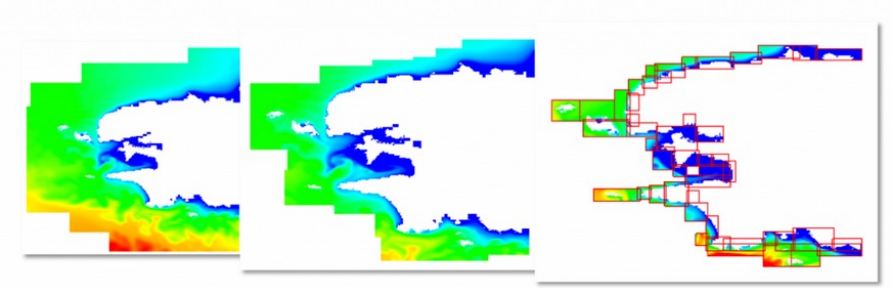
Nesting with AGRIF

- 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

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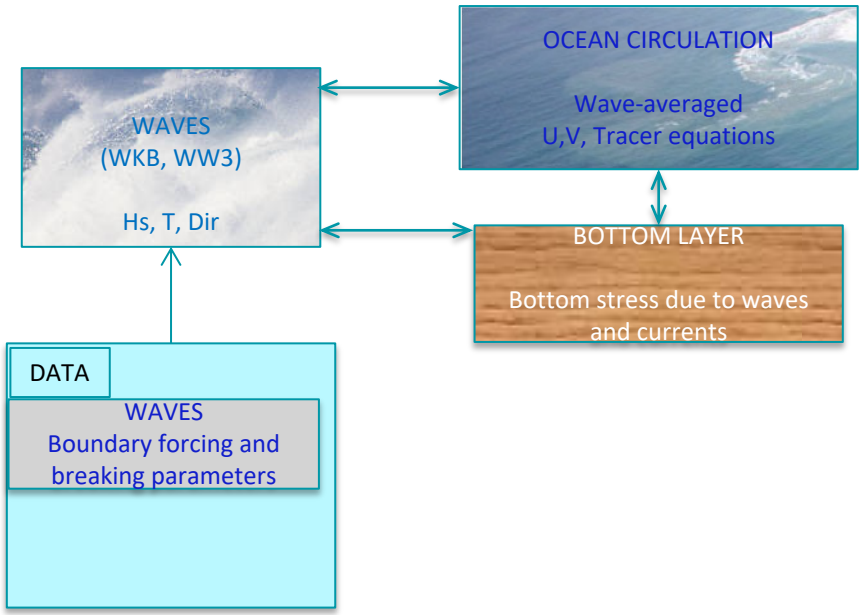
Coastal and Regional Ocean COmmunity model

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

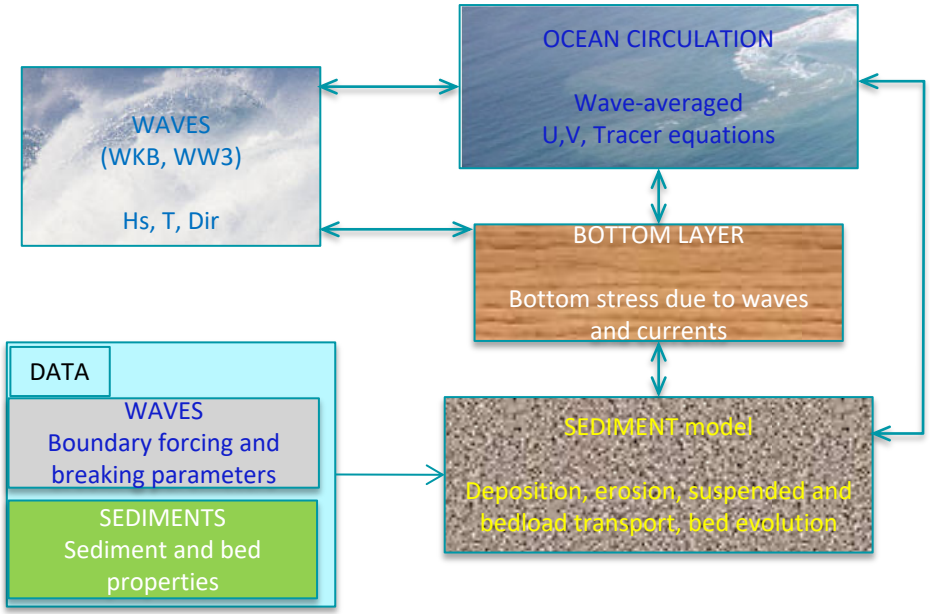
Sediment modules

- 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

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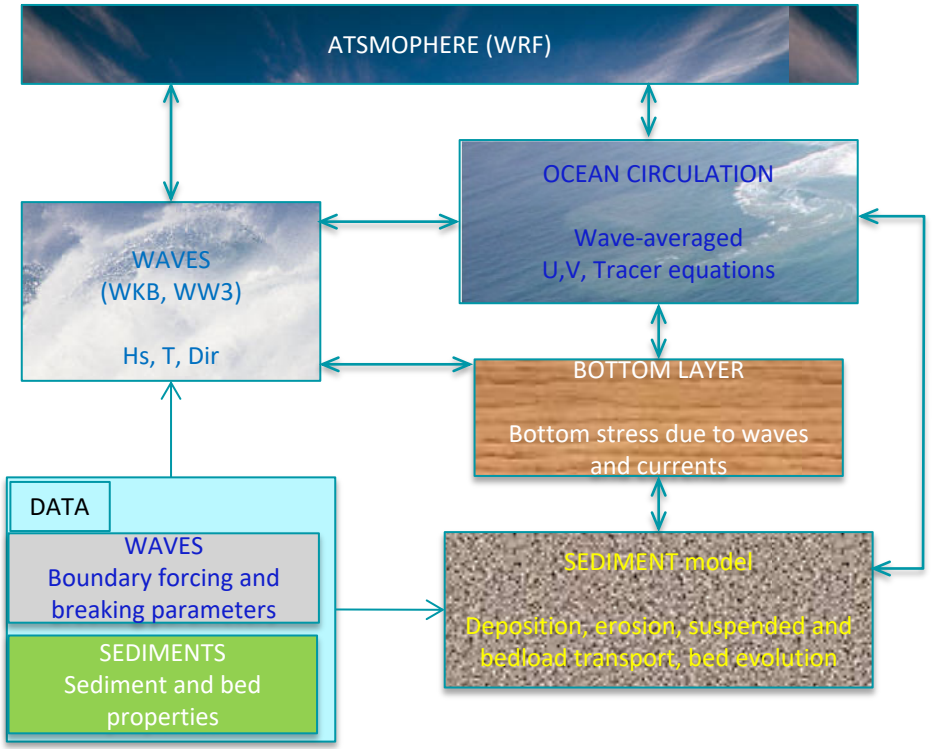
Ocean-wave-atmosphere coupling

- 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

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Coastal and Regional Ocean COmmunity model

Biogeochemistry

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

Coupling with lagrangian and ecosystemic models

- ARIANE
- ICHTYOP
- OSMOSE
- APECOSM

CROCO tools and facilities

Matlab CROCO_TOOLS

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

Python CROCO_TOOLS (in dev)

- Pre-processing
- Visualization

XIOS (dev. at ISPL)

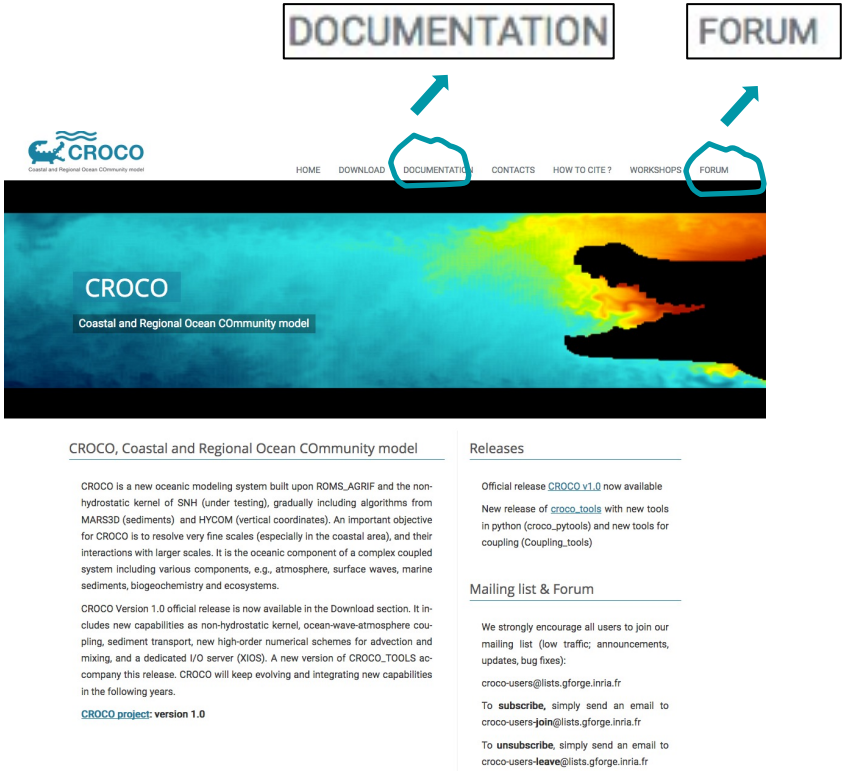
- Outputs facilities
- Diagnostics facilities

⇒ Need to download and compile XIOS

Online diagnostics

- Online temperature / vorticity / energy balance

CROCO help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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
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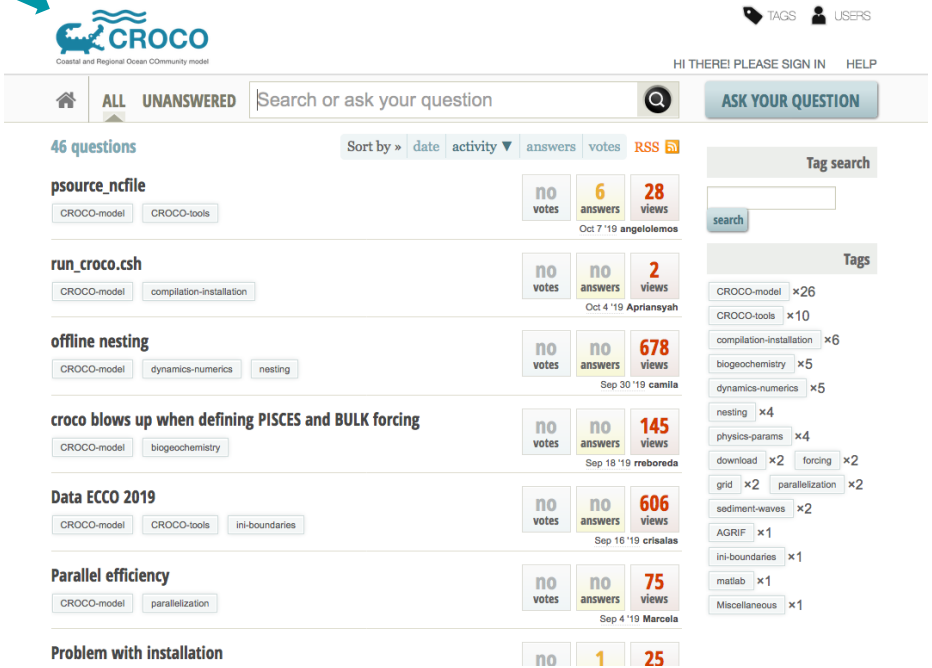
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