

CROCO – training 2024

Introduction to CROCO model



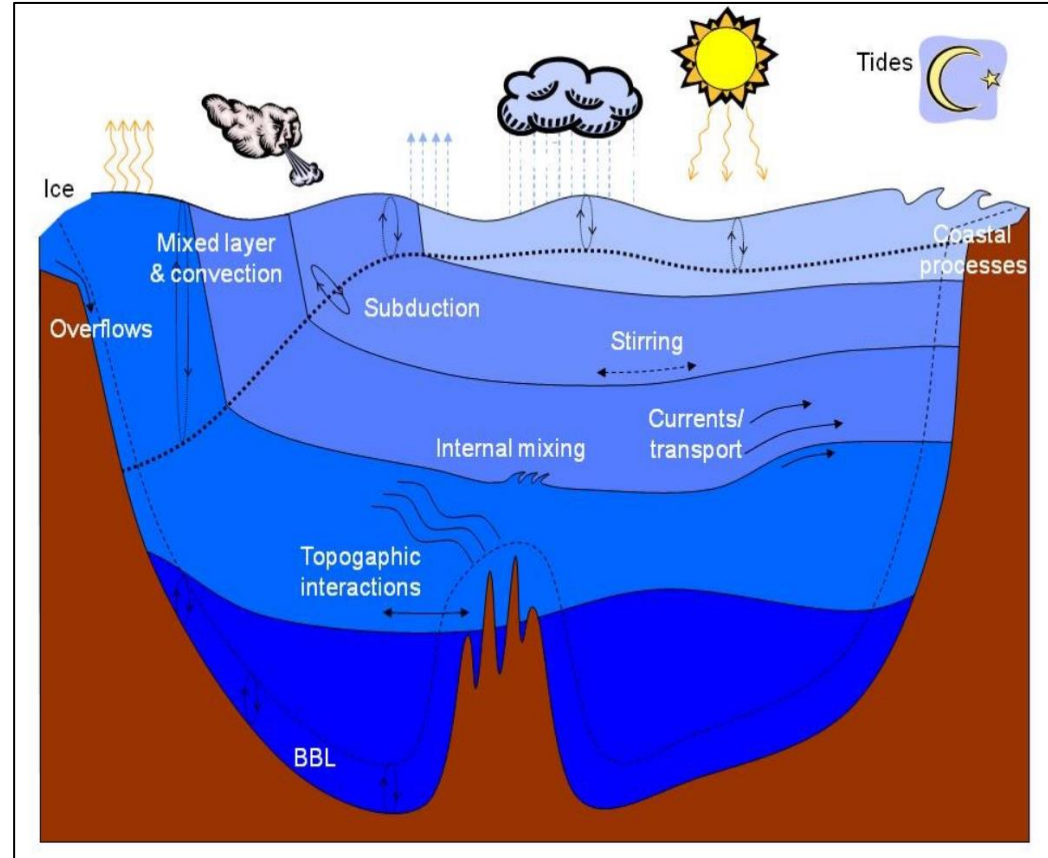
- Ocean processes: brief outline
- Ocean Modelling Principle
- CROCO model equations
- CROCO performances (nesting, coupling...)

Sea level variability causes

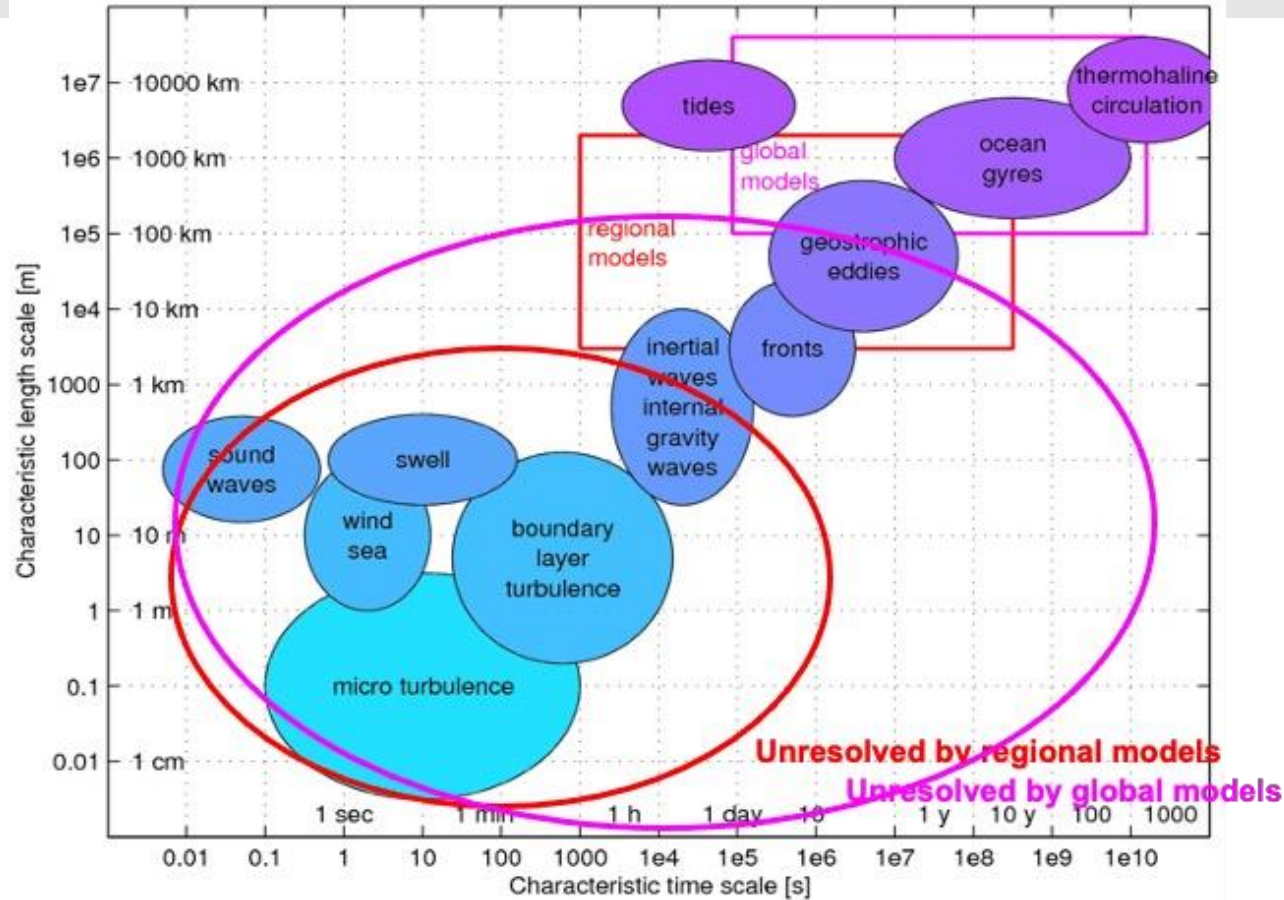
The fluctuations in sea level reflect a variety of phenomena related to ocean dynamics .

These fluctuations can be due to:

- Wind action
- Atmospheric pressure
- Heat flux
- Tidal forces



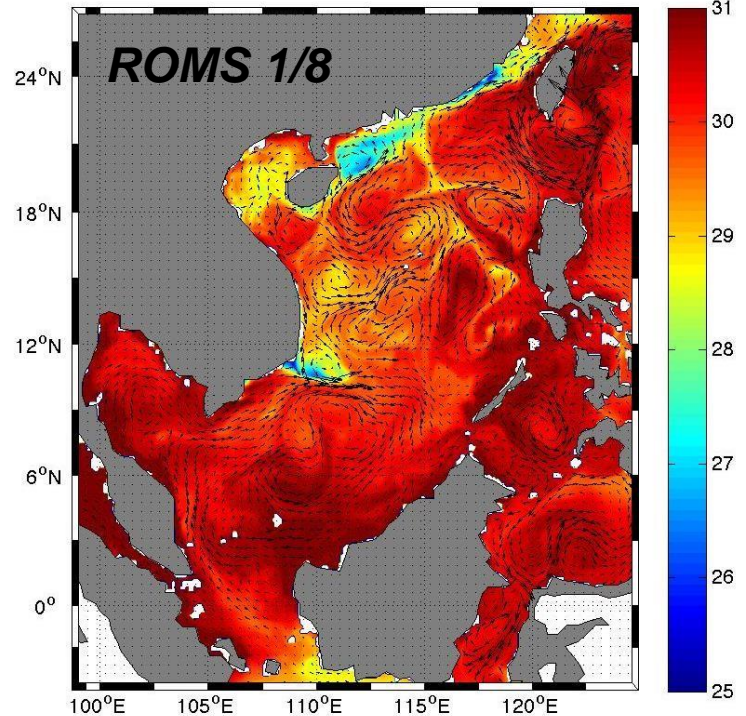
Spatial and time scale for different ocean process



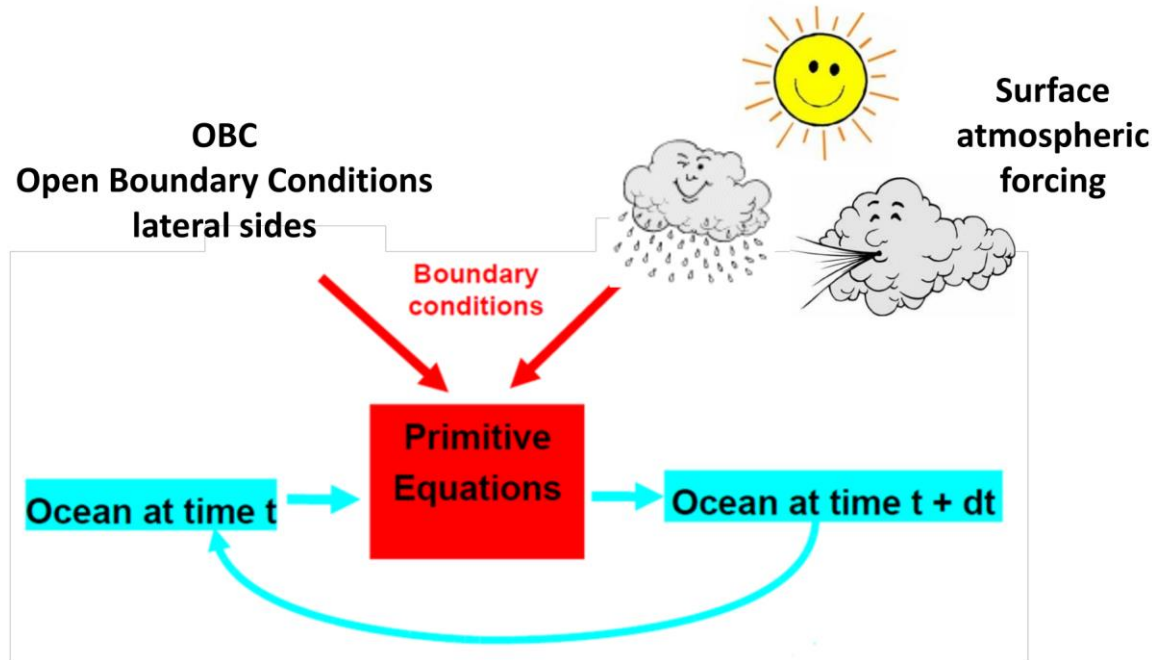
Why modelling ?

Advantages:

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



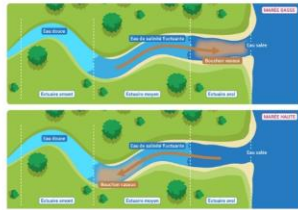
Sea Surface Temperature (SST) and surface current on 24/07/1992



If we know: The **ocean state at time t** : u,v,T,S ..we can **compute the ocean state at time $t+dt$** using numerical approximations of Navier-Stokes Equations.

=> **discretization** of the equations in **time** and **space**

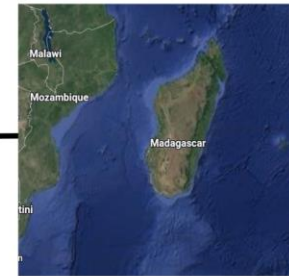
Various type of ocean model depending on space discretization techniques



Beach, lagoon, estuary



Coast, continental shelf, regional



Offshore, ocean

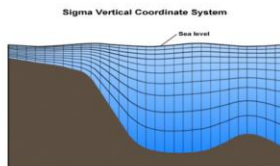
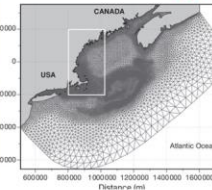
Finite elements

Coherens, Telemac ...

Finite Volumes

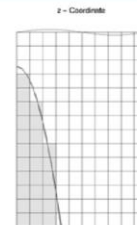
FVCOM, MIKE3, MOHID...

Finite Differences



Sigmas coordinates
MARS3D, CROCO, ...

ROMS



Z coordinates

NEMO, MITgcm, ...

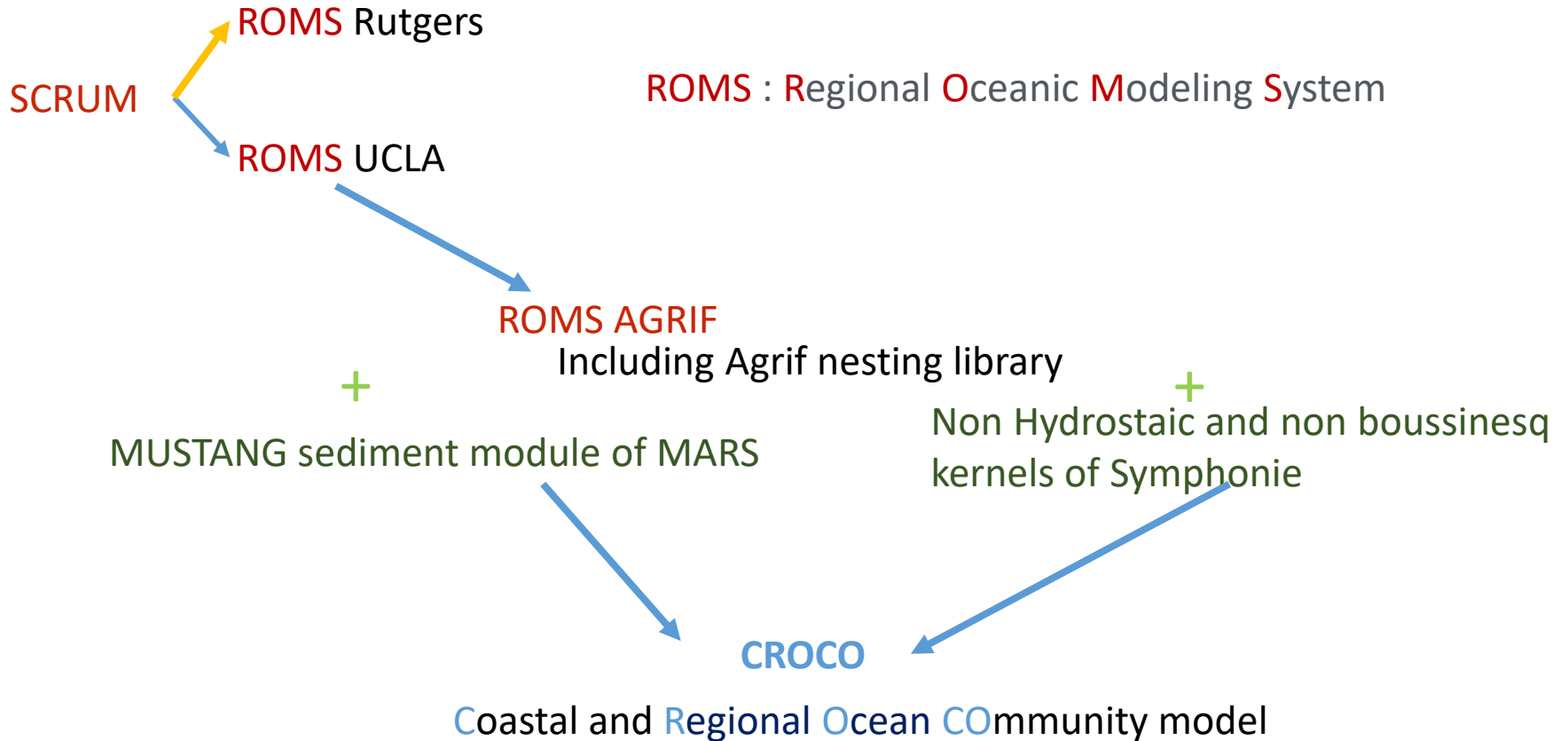
Finite Differences

Isopycnal or hybrid coordinates

HYCOM

CROCO MODEL

CROCO brief history



Open-source Community

- CROCO is open-source and developed by an active community of users and developers. Contributions are managed through a Git repository, ensuring continuous updates and improvements.
- Stable versions of the model are released every 1 to 1.5 years.
- A community forum is available for discussions, troubleshooting...

Pre- and Post-processing Tools

- Tools are provided to simplify the configuration of the model and visualize output data

CROCO Model equations

Momentum conservation

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

advection Coriolis Pressure gradient Horizontal diffusion Vertical diffusion

Continuity

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

Tracer conservation

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

Equation of state

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

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

CROCO boundary conditions

- At the surface ($z = \xi$)

$$K_{Mv} \frac{\partial u}{\partial z} = \frac{\tau_s^x}{\rho_0}(x, y, t)$$

$$K_{Mv} \frac{\partial v}{\partial z} = \frac{\tau_s^y}{\rho_0}(x, y, t)$$

$$\kappa_{Tv} \frac{\partial T}{\partial z} = \frac{Q_T}{\rho_0 C_p} + \frac{1}{\rho_0 C_p} \frac{dQ_T}{dT} (T - T_{ref})$$

$$\kappa_{Sv} \frac{\partial S}{\partial z} = \frac{(E - P)S}{\rho_0} \quad ; w = \frac{\partial \xi}{\partial t}$$

- At the bottom ($z = -H$)

$$K_{Mv} \frac{\partial u}{\partial z} = \tau_b^x(x, y, t)$$

$$K_{Mv} \frac{\partial v}{\partial z} = \tau_b^y(x, y, t)$$

$$\kappa_T \frac{\partial T}{\partial z} = 0$$

$$\kappa_S \frac{\partial S}{\partial z} = 0$$

$$-w + \vec{v} \vec{\nabla} h = 0$$

Variables	Description
τ_s^x, τ_s^y	Wind stress
Q_T	Net heat flux
$E - P$	Evaporation minus rain
τ_b^x, τ_b^y	Bottom stress
T_{ref}	Reference Temperature

CROCO Model equations

Momentum conservation

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

advection Coriolis Pressure gradient Horizontal diffusion Vertical diffusion

depends on turbulent closure scheme used (KPP , GLS scheme...)

Tracer conservation

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

Turbulent mixing schemes

Two types of mixing schemes

- **Pronostic type like GLS** : based on two differential equations: one governing TKE (Turbulent Kinetic Energy) and the other describing the turbulence length scale

$$\frac{\partial q^2}{\partial t} + \vec{u} \cdot \vec{\nabla} q^2 = \underbrace{2K_{Mv} \left[\left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial z} \right)^2 \right]}_{\text{TKE production}} + \underbrace{K_{Tv} \frac{2g}{\rho_0} \frac{\partial \rho_\theta}{\partial z}}_{\text{flottability}} + \underbrace{\frac{\partial}{\partial z} \left[K_q \frac{\partial q^2}{\partial z} \right]}_{\text{TKE diffusion}} - \underbrace{\frac{2q^3}{B_1 \ell}}_{\text{TKE dissipation}}$$

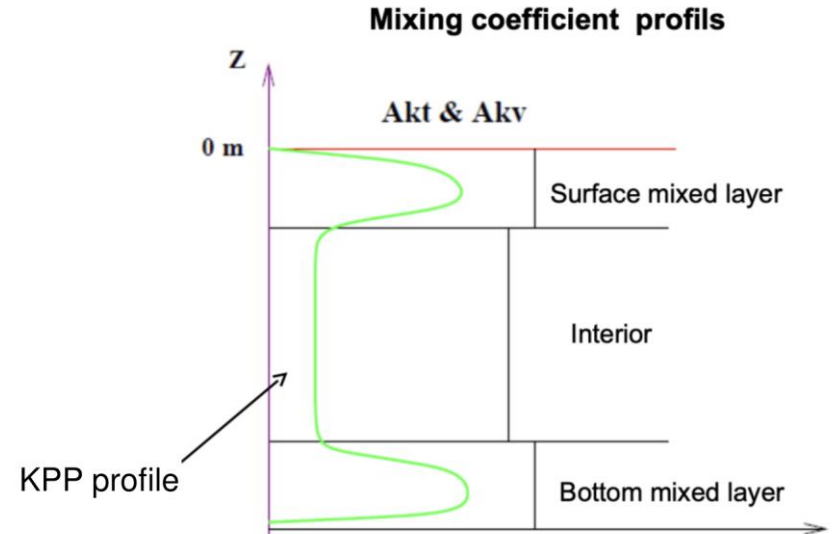
$$\frac{\partial \ell q^2}{\partial t} + \vec{u} \cdot \vec{\nabla} \ell q^2 = E_1 \ell \left\{ K_{Mv} \left[\left(\frac{\partial u}{\partial z} \right)^2 + \left(\frac{\partial v}{\partial z} \right)^2 + K_{Tv} \frac{g}{\rho_0} \frac{\partial \rho_\theta}{\partial z} \right] \right\} - \frac{q^3 W}{B_1} + \frac{\partial}{\partial z} \left[K_q \frac{\partial \ell q^2}{\partial z} \right]$$

ℓ : turbulent length scale $q^2=2*\text{TKE}$

Turbulent mixing schemes

- **Non Pronostic type KPP:** The vertical mixing in the ocean's surface layer can be described by a vertical diffusion profile. It relates turbulence to the density gradient, allowing diffusion coefficients to be calculated f

- KPP assumes that turbulence in the boundary layer is in equilibrium with surface and bottom fluxes => true for large scale models,
- for coastal applications, the scheme should : respond to local forcing, respond rapidly to surface and bottom fluxes => GLS-type scheme preferred



Open boundary conditions

CROCO Model integrates several OBC Schemes notably:

External mode

*Oranski radiation condition
for 2D momentum...*

$$\frac{\partial \phi}{\partial t} + c_x \frac{\partial \phi}{\partial x} + c_y \frac{\partial \phi}{\partial y} = 0$$

Pronostic variable ϕ (ϕ can be T, S or \vec{v} or 2D momentum speed)

Internal mode

Radiation, Orlandsky (1976), Kuo (1984).

$$\frac{\partial \phi}{\partial t} + c_x \frac{\partial \phi}{\partial x} + c_y \frac{\partial \phi}{\partial y} = 0$$

*Adaptative mixed radiations/nudging
open boundary conditions (Marchesiello
et al, 2001).*

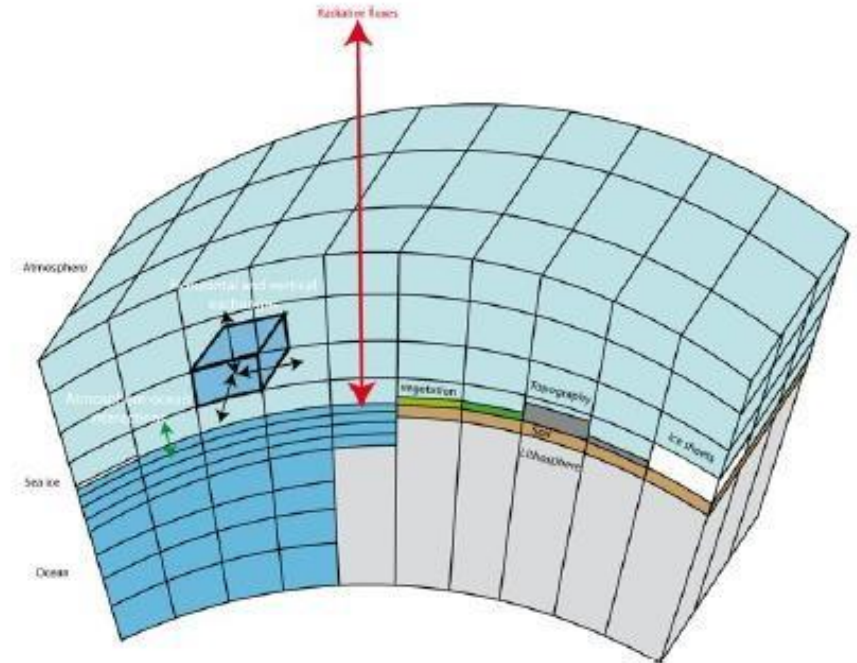
$$\frac{\partial \phi}{\partial t} + c_x \frac{\partial \phi}{\partial x} + c_y \frac{\partial \phi}{\partial y} = -\frac{1}{\tau} (\phi - \phi_{ext})$$

$\vec{c}(c_x, c_y)$: phase speed

$$c_x = -\frac{\frac{\partial \phi}{\partial t} \frac{\frac{\partial \phi}{\partial x}}{\left(\frac{\partial \phi}{\partial x}\right)^2 + \left(\frac{\partial \phi}{\partial y}\right)^2}}{\frac{\partial \phi}{\partial t} \frac{\frac{\partial \phi}{\partial y}}{\left(\frac{\partial \phi}{\partial x}\right)^2 + \left(\frac{\partial \phi}{\partial y}\right)^2}}$$
$$c_y = -\frac{\frac{\partial \phi}{\partial t} \frac{\frac{\partial \phi}{\partial y}}{\left(\frac{\partial \phi}{\partial x}\right)^2 + \left(\frac{\partial \phi}{\partial y}\right)^2}}{\frac{\partial \phi}{\partial t} \frac{\frac{\partial \phi}{\partial x}}{\left(\frac{\partial \phi}{\partial x}\right)^2 + \left(\frac{\partial \phi}{\partial y}\right)^2}}$$

Spatial discretization

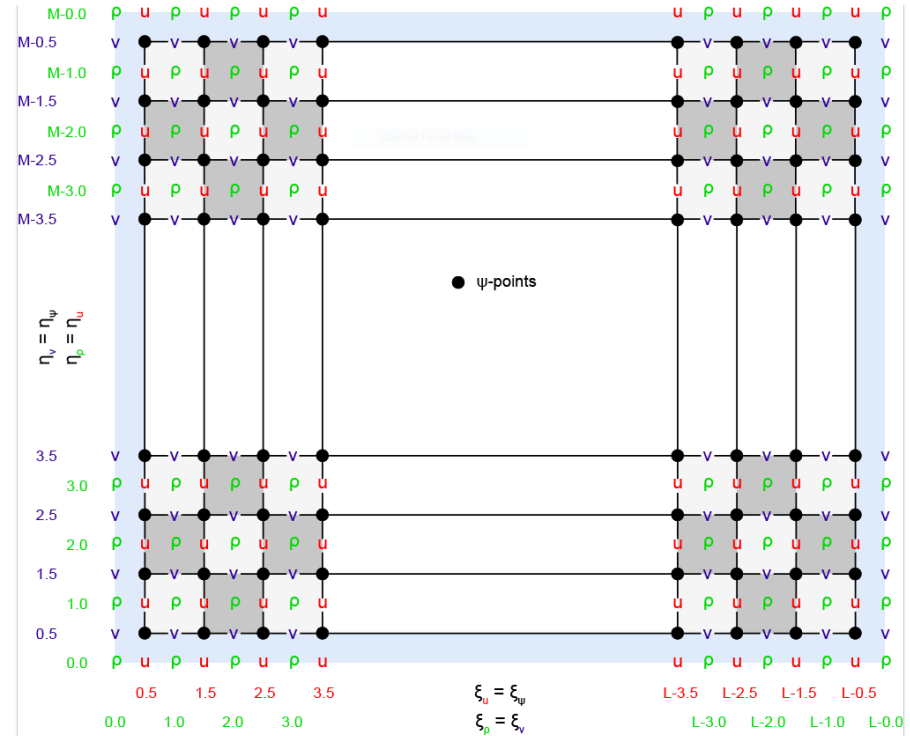
The model domain is divided into « small » boxes.



Example of a finite difference grid

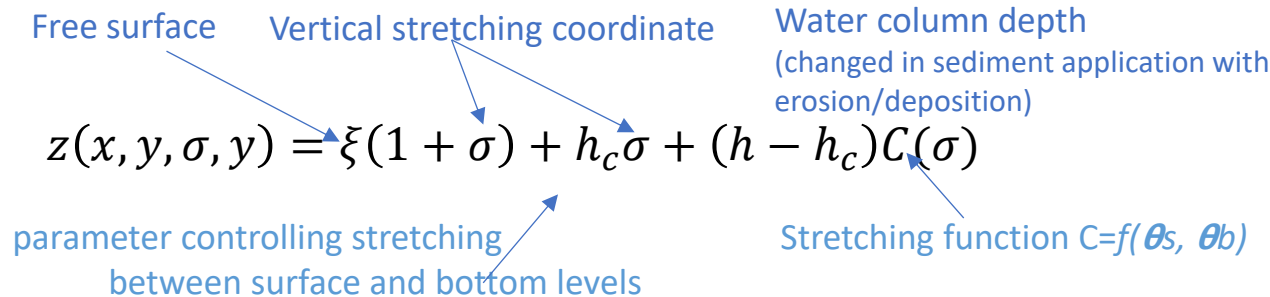
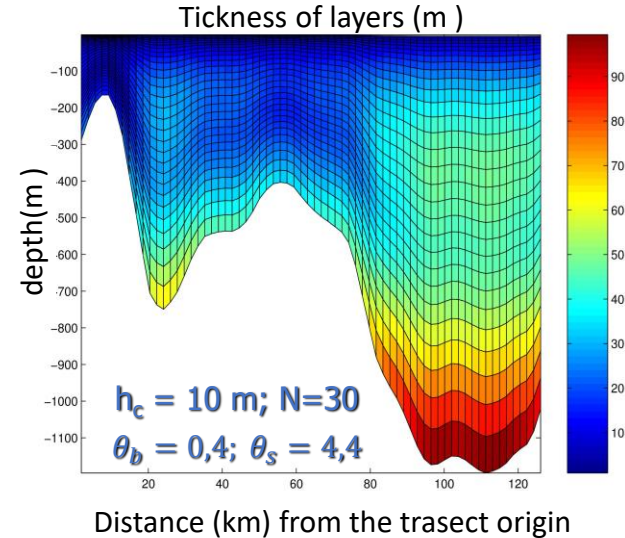
CROCO Horizontal discretization

Horizontally: CROCO grid is discretized in curvilinear coordinates that follow the coastline and terrain, with a free surface. It uses an **Arakawa-C grid**, where variables are arranged in a specific way to improve the accuracy of fluid dynamics calculations



CROCO vertical descretisation

Vertically, CROCO uses sigma coordinates, allowing for stretched bathymetry and specific resolution at the surface or the bottom, depending on the application



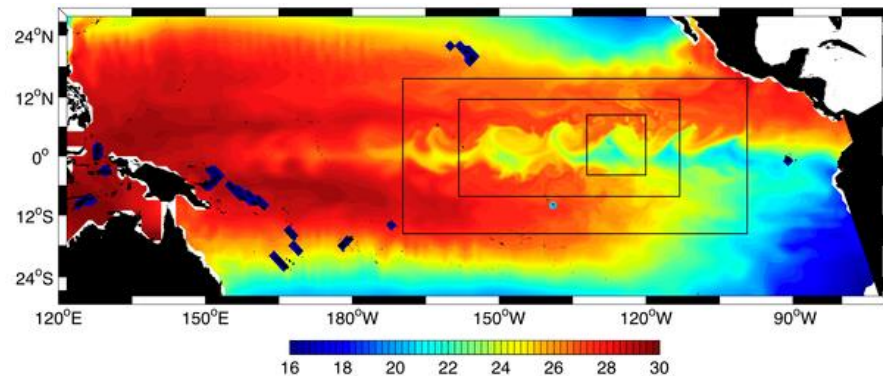
CROCO is a free surface model that :

- resolves the dynamics associated with fast scales, which directly affect the free surface,
 - resolves slow scales, related to the ocean's interior dynamics.
- ⇒ To handle these contrasting dynamics, CROCO adopts a time-splitting strategy.
- In Boussinesq mode the equations associated with fast scales (barotropic mode) are separated from the complete equations and integrated over time using an efficient time-stepping scheme, with a time step that is a sub-multiple of the main time step (baroclinic time step).
 - For **Non-Boussinesq (NBQ) mode**, the barotropic mode solver is replaced by a fully 3D fast mode solver, which resolves all waves, including acoustic waves.

CROCO PERFORMANCES

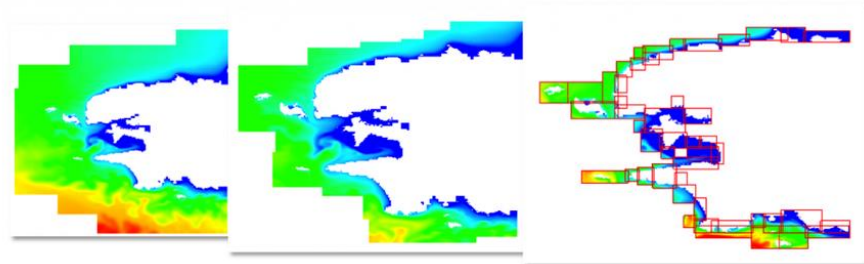
Nesting with AGRIF

- 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



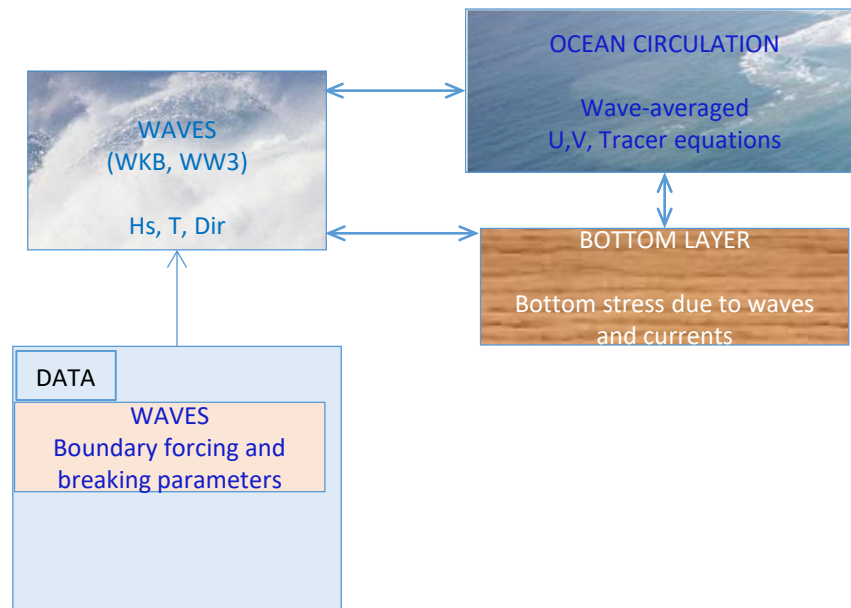
Towards multi-grid / multi-resolution (in dev.)

- 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

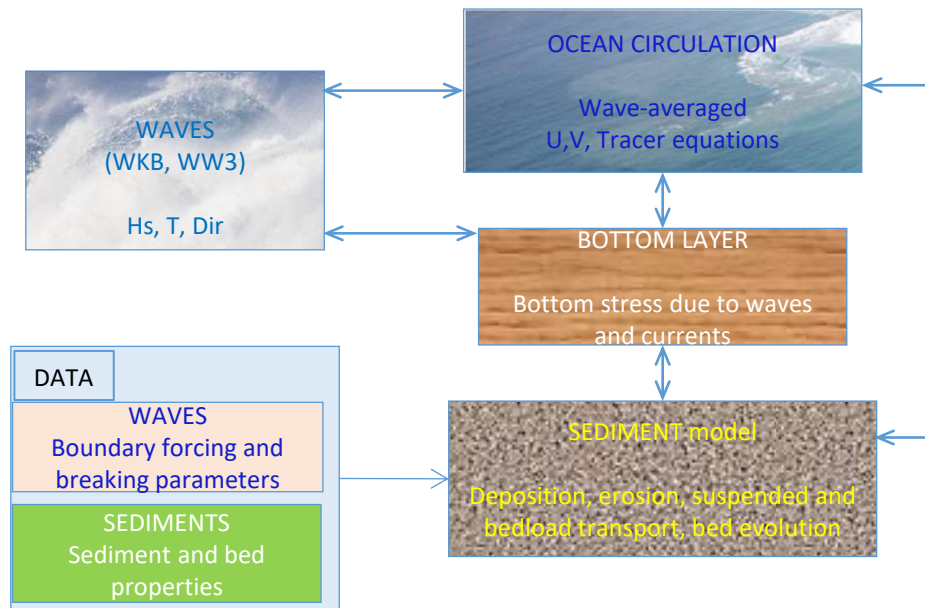
Sediment modules

- 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 by Ifremer/DHYSED)

Morphodynamics

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

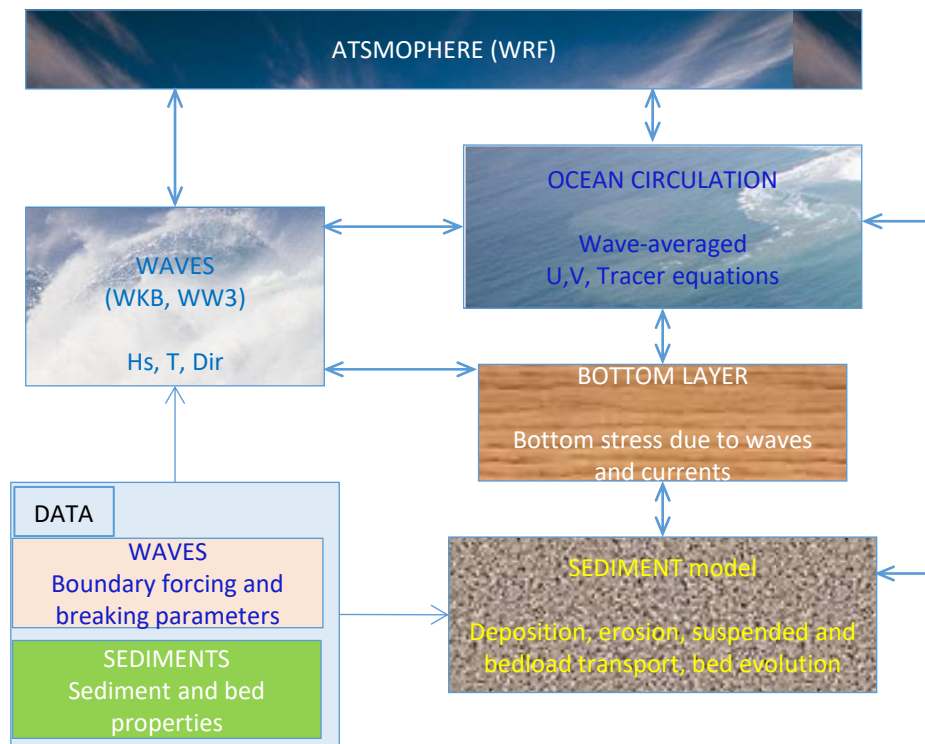
- Volume and constancy preserving scheme
- Speed-up equilibration: morpho. factor (Roelvink, 2006)



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

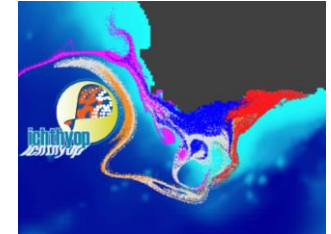


Biogeochemistry

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

Coupling with lagrangian and ecosystemic models

- ARIANE
- Tracmass
- ICHTYOP
- Ltrans
- 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

Modeling package

CROCO_TOOLS

- Aforc_NCEP
 - Aforc_QuikSCAT
 - Diagnostic_tools
 - Nesting_tools
 - Opendap_tools
 - Opendap_tools_no_loaddap
 - RUNOFF_DAI
 - Tides
 - Town
 - **UTILITIES**
 - Visualization_tools
 - croco_pytools
 - croco_pyvisu
 - start.m
 - Oforc_OGCM
 - Aforc_CFSR
 - Aforc_ECMWF
- Coupling_tools
 - Rivers
 - crocotools_param.m
 - Preprocessing_tools
 - readme_crocotools.txt,
 - Forecast_tools
- air_sea
 - export_fig
 - m_map1.4h
 - mask
 - mex60
 - mexcdf
 - netcdf_matlab_60
 - netcdf_x86_64

CROCO : Fortran source code

- AGRIF
- CVTK
- OCEAN
- PISCES
- Run
- XIOS
- create_config.bash

DATA_SETS : Global datasets to build the regional forcing

CARS2009, COADS05, GOT99.2, m_map1.4f, QuikSCAT_clim, RUNOFF_DAI, SeaWifs, SST_pathfinder, Topo, TPX06, TPX07, WOA2009, WOAPISCES

OS: LINUX or UNIX

CROCO : fortran program ~ (55000 lines of FORTRAN code)

CROCOTOOLS : Matlab (Octave) scripts + datasets (18 Gb)

PC configuration:

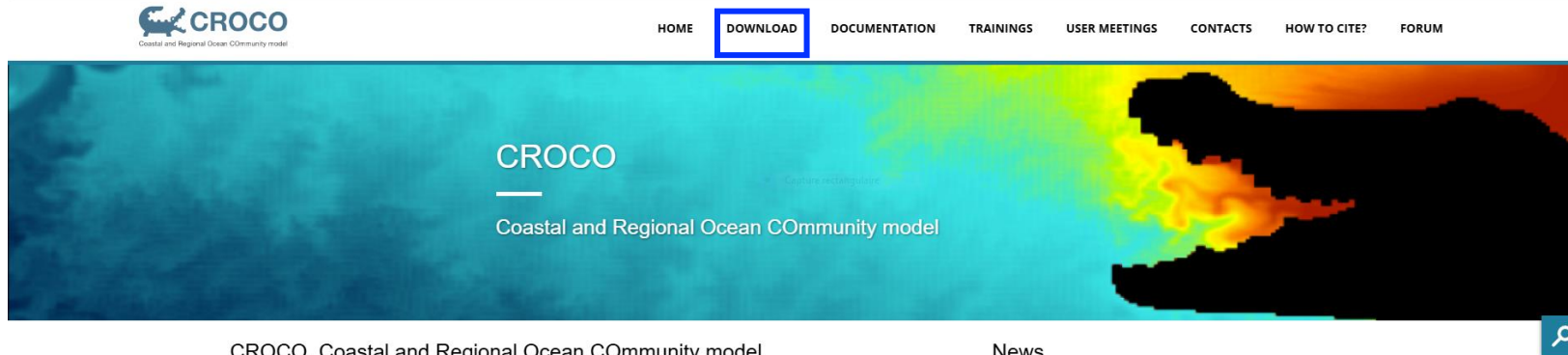
- Fortran Compiler : gfortran, Intel Fortran Compiler
- NetCDF : <http://www.unidata.ucar.edu>
- OpenMPI : <http://www.open-mpi.org>
- Matlab (or Octave)

Additional software

- Ncview, NCO, Ferret, Octave-3.6.1 + netcdf ...

HOW TO GET CROCO AND CROCO TOOLS

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



CROCO, Coastal and Regional Ocean COmmunity model

CROCO is a modeling platform to study the regional, coastal and nearshore ocean (ocean dynamics, sedimentary dynamics, biogeochemistry) on time scales ranging from event to multi-decadal, and spatial scales ranging from kilometric to metric resolutions. CROCO's flexible equation system, including non-hydrostatic capabilities, and its computational efficiency enable it to simulate very fine scales (especially in the coastal area up to individual waves), 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 is also dedicated to carrying out academic simulations (simple geometry, well-targeted processes to digitally mimic controlled experiments) for more fundamental research in geophysical fluid mechanics with LES (Large Eddy Simulation) or even DNS (Direct Numerical Simulation) simulation capabilities, that can be used in the context of creating digital twin experiments, study complex dynamic regimes or sub-grid scale parameterizations. CROCO comes with pre- and post-processing tools that make it easy and efficient to set up and analyze model configurations, even for complex geometries and coupled models.

News

Releases

New release [CROCO v2.0.1](#)

Mailing list & Forum

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

croco-users@inria.fr

To **subscribe**, simply send an email to sympa_inria@inria.fr with the subject: `subscribe croco-users@inria.fr` First name Last name. Leave the body of the message empty.

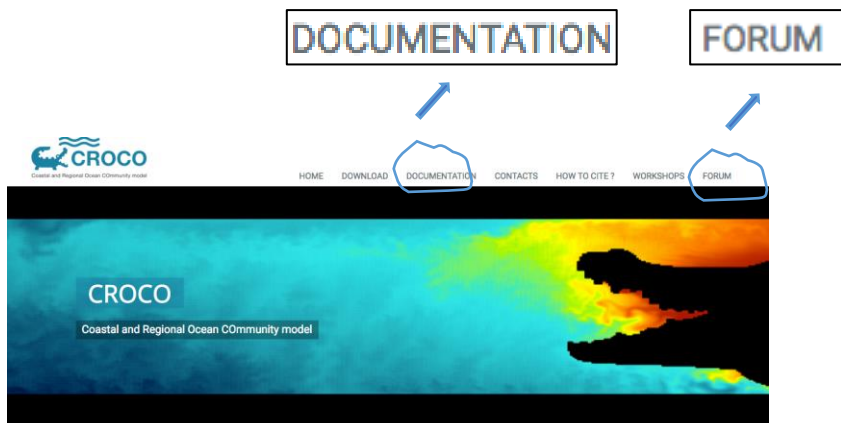
To **unsubscribe**, simply send an email to sympa_inria@inria.fr with the subject: `unsubscribe croco-users@inria.fr`

Visit [CROCO users forum](#) for discussions, and questions about the code and tools

In the download section

- **CROCO** : Fortran source code
- **CROCO_TOOLS** : Pre- and post processing toolbox (Matlab)
- **DATASETS [18 Gb]** : the global datasets needed by the CROCO_TOOLS
- **UTILITIES** : netCDF library, mapping toolbox etc ...

CROCO help



CROCO, Coastal and Regional Ocean Community model

CROCO is a new oceanic modeling system built upon ROMS, AGRIFF 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](#))

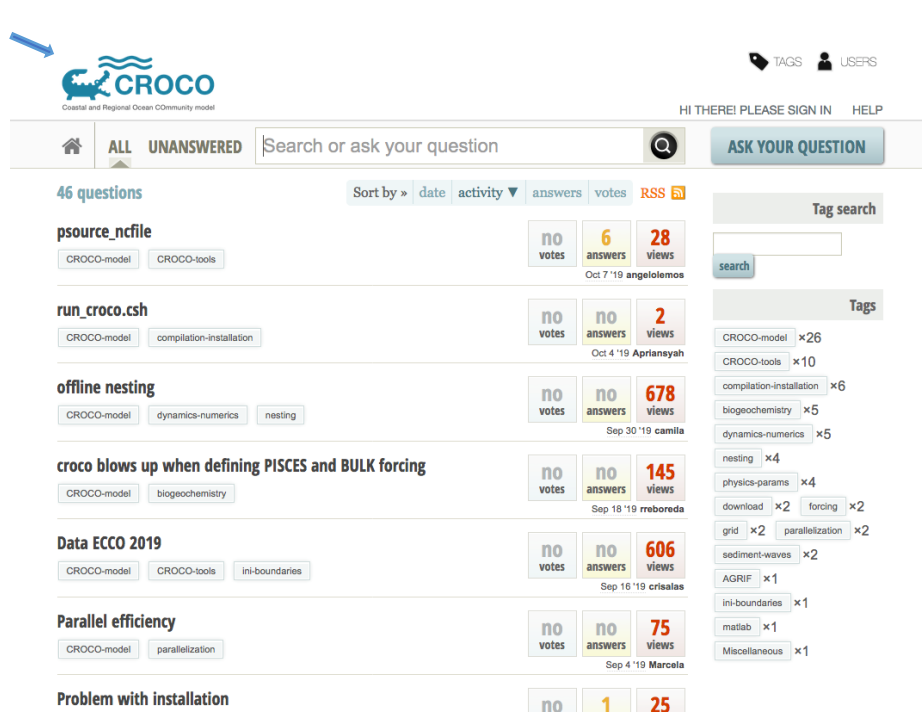
Mailing list & Forum

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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 bar with 'ALL UNANSWERED' and 'ASK YOUR QUESTION' buttons. Below the search bar, there is a list of 46 questions. Each question entry includes the title, tags, and statistics (votes, answers, views). The questions listed are:
































- psource_nfile**: 0 votes, 6 answers, 28 views. Tags: CROCO-model, CROCO-tools. Author: angelolemos (Oct 7 '19).
- run_croco.csh**: 0 votes, 0 answers, 2 views. Tags: CROCO-model, compilation-installation. Author: Apriansyah (Oct 4 '19).
- offline nesting**: 0 votes, 0 answers, 678 views. Tags: CROCO-model, dynamics-numerics, nesting. Author: camila (Sep 30 '19).
- croco blows up when defining PISCES and BULK forcing**: 0 votes, 0 answers, 145 views. Tags: CROCO-model, biogeochemistry. Author: mreborada (Sep 18 '19).
- Data ECCO 2019**: 0 votes, 0 answers, 606 views. Tags: CROCO-model, CROCO-tools, ini-boundaries. Author: crisalaa (Sep 16 '19).
- Parallel efficiency**: 0 votes, 0 answers, 75 views. Tags: CROCO-model, parallelization. Author: Marcola (Sep 4 '19).
- Problem with installation**: 0 votes, 1 answer, 25 views.

On the right side, there is a 'Tag search' section with a search input field and a list of tags with their counts:

- CROCO-model: x26
- CROCO-tools: x10
- compilation-installation: x6
- biogeochemistry: x5
- dynamics-numerics: x5
- nesting: x4
- physics-params: x4
- download: x2
- forcing: x2
- grid: x2
- parallelization: x2
- sediment-waves: x2
- AGRIFF: x1
- ini-boundaries: x1
- matlab: x1
- Miscellaneous: x1

CROCO DEVELOPMENT

CROCO team

 <p>BENSHILA Rachid LEGOS, CNRS, Toulouse, France</p>	 <p>MARCHESIELLO Patrick LEGOS, IRD, Toulouse, France</p>	 <p>AUCLAIR Francis LAERO, Toulouse, France</p>	 <p>CAMBON Gildas LOPS, IRD, Brest, France</p>	 <p>JULLIEN Swen LOPS, Ifremer, Brest, France</p>
 <p>LEMARIÉ Florian LJK, Inria, Grenoble, France</p>	 <p>CAILLAUD Matthieu DHYSED, Ifremer, Brest, France</p>	 <p>DUMAS Franck SHOM, Brest, France</p>	 <p>DEBREU Laurent LJK, Inria, Grenoble, France</p>	 <p>PENVEN Pierrick LOPS, IRD, Brest, France</p>
 <p>NGUYEN Cyril LAERO, CNRS, Toulouse, France</p>	 <p>ETHÉ Christian LOCEAN, IPSL, Paris, France</p>	 <p>ROBLOU Laurent LAERO, CNRS, Toulouse, France</p>	 <p>LE GENTIL Sylvie LOPS, Ifremer, Brest, France</p>	 <p>BRÉMOND Maurice Inria, Grenoble, France</p>
 <p>RENAULT Lionel LEGOS, IRD, Toulouse, France</p>	 <p>PIANEZZE Joris LAERO, Toulouse, France</p>	 <p>LE GAC Solène DHYSED, Ifremer, Brest, France</p>	 <p>LE CORRE Mathieu SHOM, Brest, France</p>	 <p>BOUTET Martial LOPS, CNRS, Brest, France</p>
 <p>ILLIG Serena LEGOS, IRD, Toulouse, France</p>	 <p>SEPULVEDA Andres Université de Concepcion, Chili</p>	 <p>PERSON Renaud LOCEAN, IRD, Paris, France</p>	 <p>HOURDIN Christophe LOCEAN, CNRS, Paris, France</p>	 <p>DUFOIS François Ifremer, Toulon, France</p>
 <p>MAZOYER Camille MIO, IRD, Marseille, France</p>	 <p>MORVAN Guillaume LEGOS, IRD, Toulouse, France</p>	 <p>DUCOUSSOU Nicolas SHOM, Brest, France</p>	 <p>GANTHY Florian Ifremer, Arcachon, France</p>	 <p>PLUS Martin Ifremer, Brest, France</p>
 <p>RAYNAUD Stéphane SHOM, Brest, France</p>				