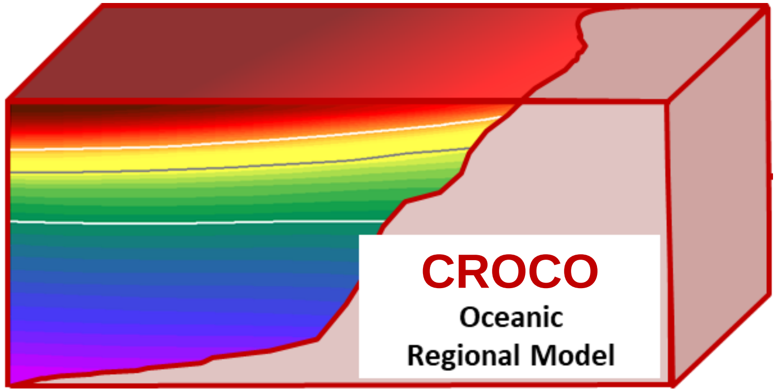
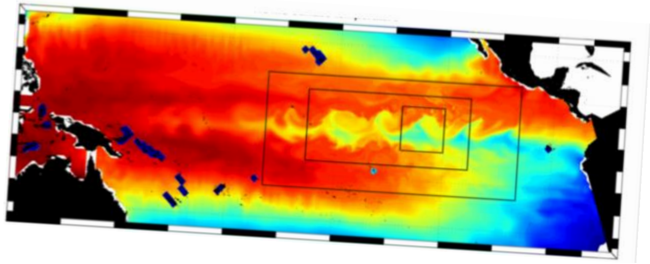


Introduction To Ocean modeling Using CROCO And The CROCO_TOOLS



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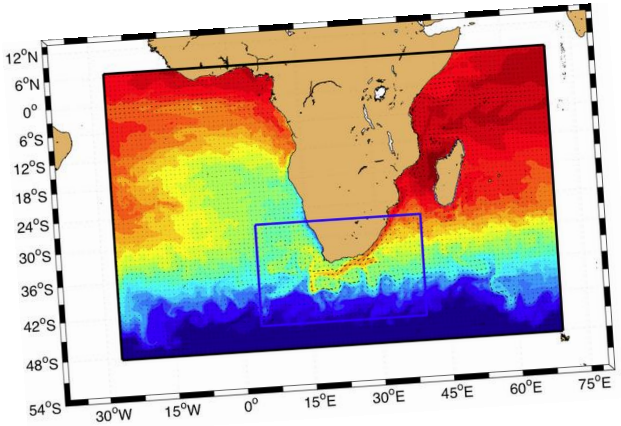
© http://doi.org/10.5281/zenodo.17091356



OBJECTIVES

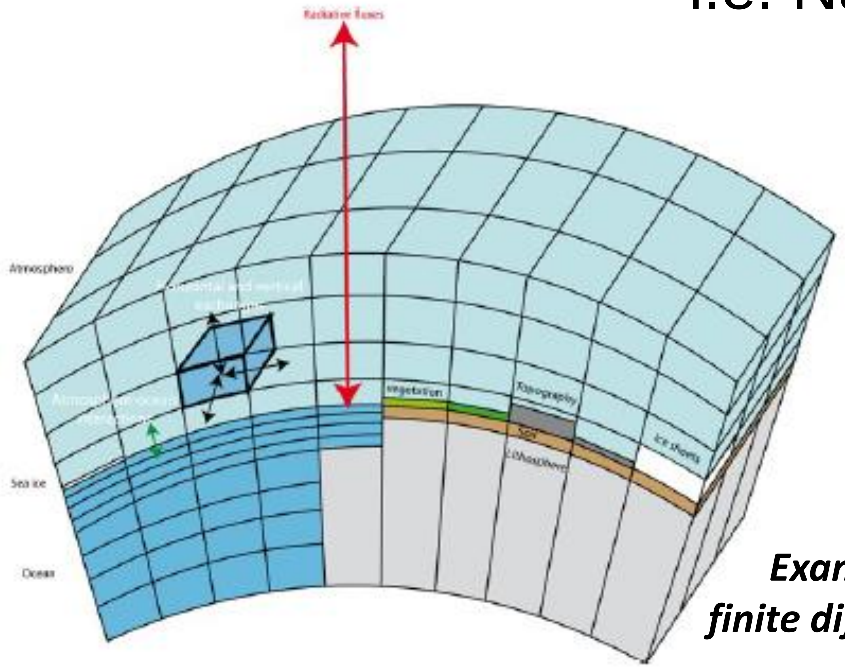
- Ocean Modelling Principle
- Ocean Modelling Advantages
- Methodology and primitive equations
- The CROCO model
- Program of basic week CROCO summer school

Introduction: Ocean modelling principle (0/3)

Introduction: Ocean modelling principle (1/3)

- Ocean model = simplified representation of physical processes that take place in the ocean.

- Ocean model = uses law of physics i.e. Navier Stokes equations



Example of a finite difference grid

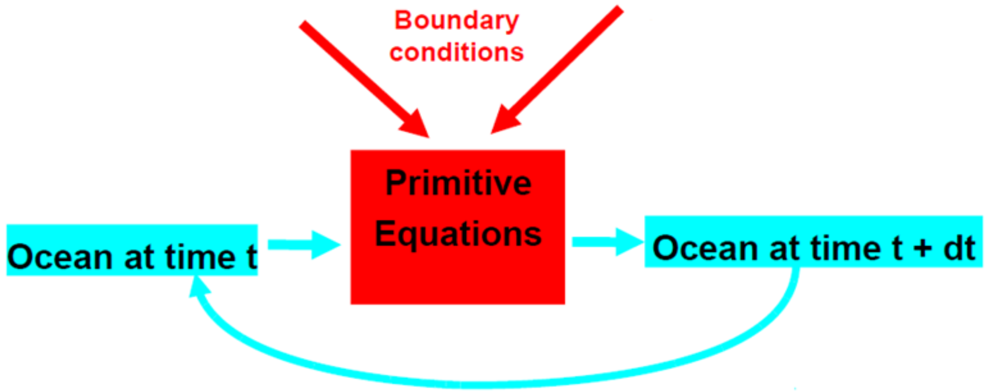
- To do this, the ocean is divided into « small» boxes.
  ↳ **Discretization**

Introduction: Ocean modeling principle (2/3)

➢ If we know:

- The **ocean state at time *t* :**
u, v, T, S, …

- **Boundary conditions** :
surface, bottom, lateral sides



➢ We can **compute the ocean state at time *t+dt*** using **numerical approximations of Navier-Stokes Equations**

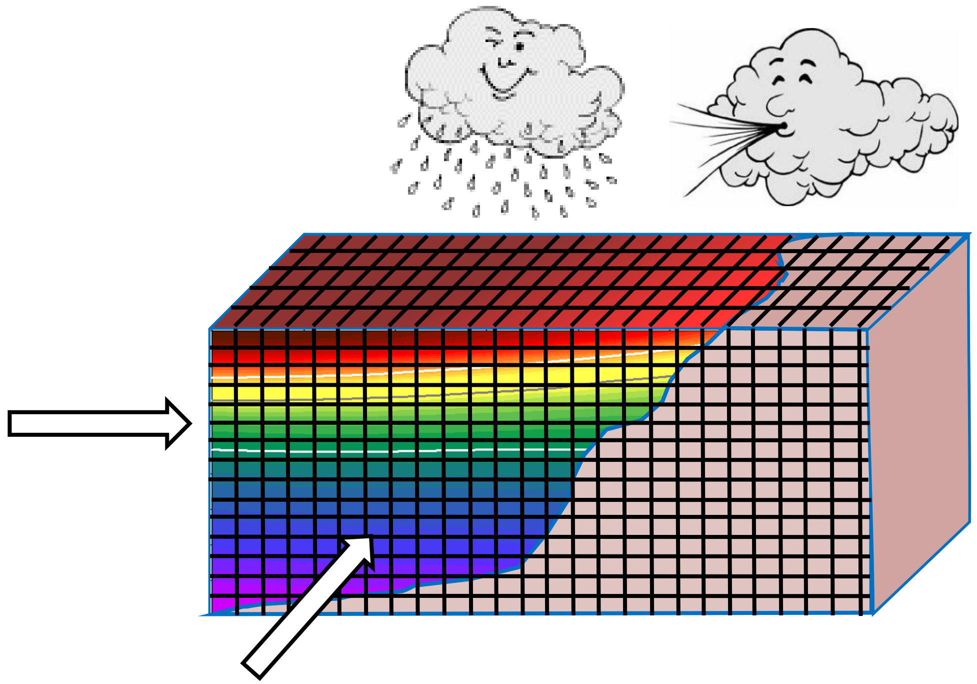
↳ For that we need to proceed to the **discretization** of the equations in **time** and **space**

Introduction: Ocean modelling principle (3/3)

- Let's compare the ocean model as a giant rectangular swimingpool

  - We know **ocean state at time *t***
  -> Filling the swimingpool

  - •• **Boundary conditions** :
  -> surface
  •**->** Bottom
  •**->** lateral sides



- We can **compute the ocean state at time *t+dt*** using **numerical approximations of Navier-Stokes Equations**

↳ For that we need to proceed to the **discretization** of the equations in time and space

Introduction: Ocean modeling, Objectives and Advantages

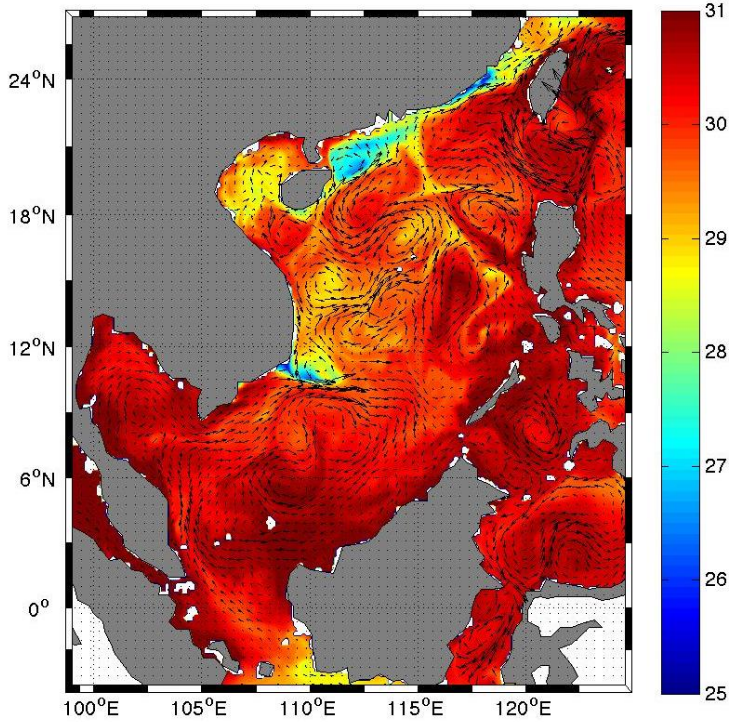
➢ Objectives:

- **Fundamental research** : understand ocean functioning
- **Applied research, operational oceanograpy** : ocean forecast, pollution, water quality …

➢ Advantages:

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

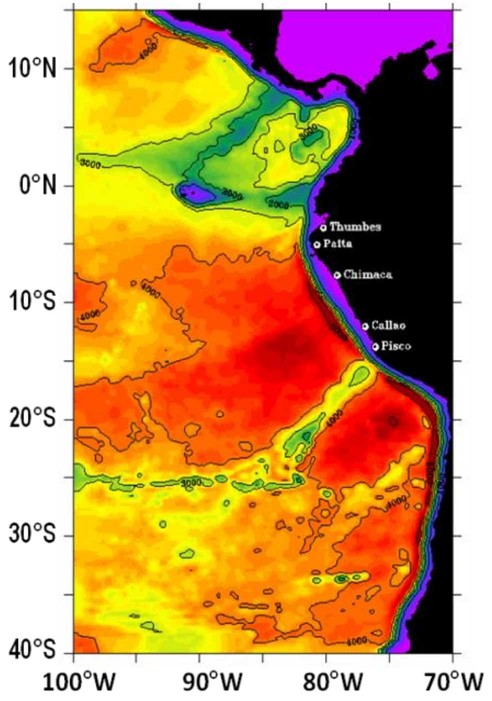
Sea Surface Temperature (SST) and surface current on 24/07/1992 ROMS 1/8°



Introduction: Ocean modeling, Objectives and Advantages

What are the forcing mechanisms of the intraseasonal SST variability off Peru ?

- *Remote – Connection with the equatorial variability ?*
- *Locally forced – Wind stress, Heat Fluxes ?*

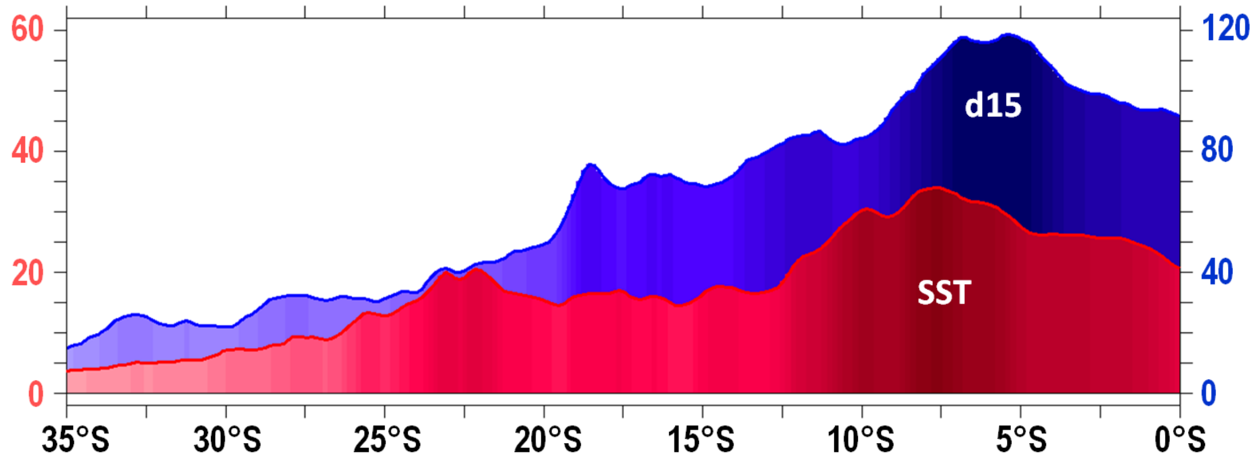


- **Sensitivity experiments:**

EXP-Name	SODA OBC (E)	QS Wind Stress (W)	HF Bulk fields (Q)
ROMS^{CR}	Total	Total	Total
ROMS^{E}	Total	Climatology	Climatology
ROMS^{WQ}	Climatology	Total	Total

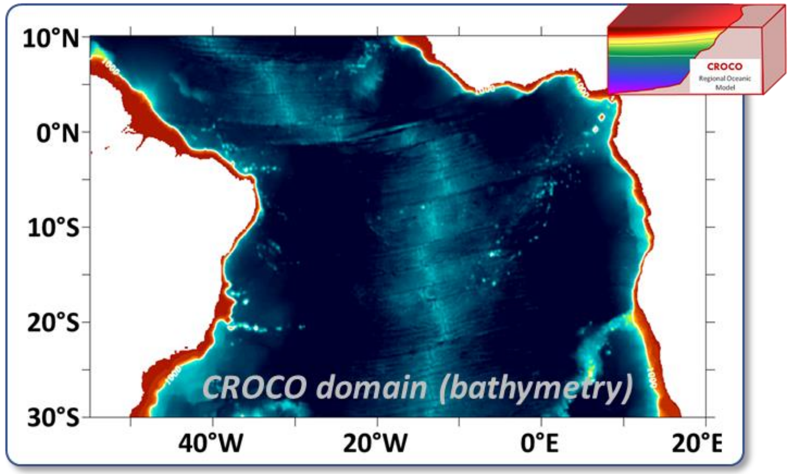
➡ *Connection with the remote equatorial variability represents only ~20% of the intraseasonal SST variability off Central Peru in 2000-2008 !*

IEKW contribution to coastal variability (%)

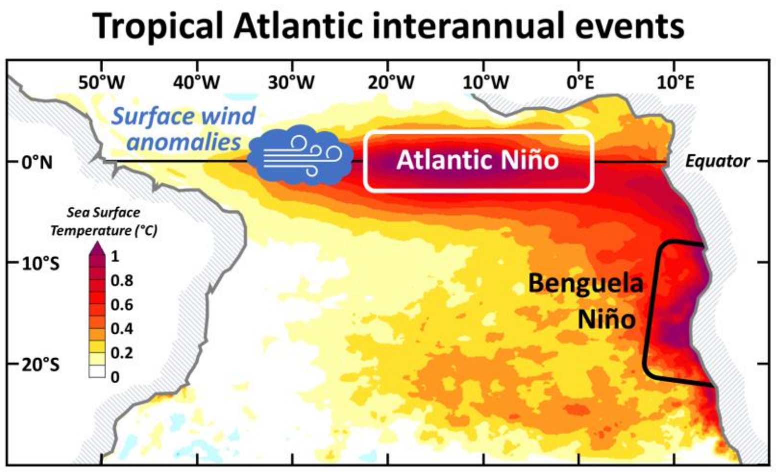


Introduction: Ocean modeling, Objectives and Advantages

Why does the Benguela Niño events precede the Atlantic Niños?

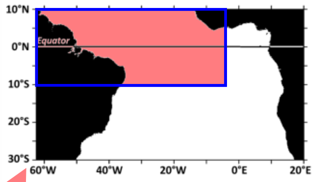


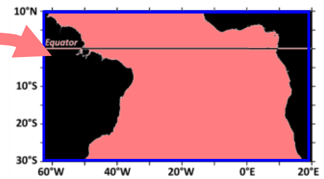
Benguela Niños stop earlier due to the development of coastal wind anomalies associated with a **convergent anomalous circulation located on the warm Atlantic Niño event**.



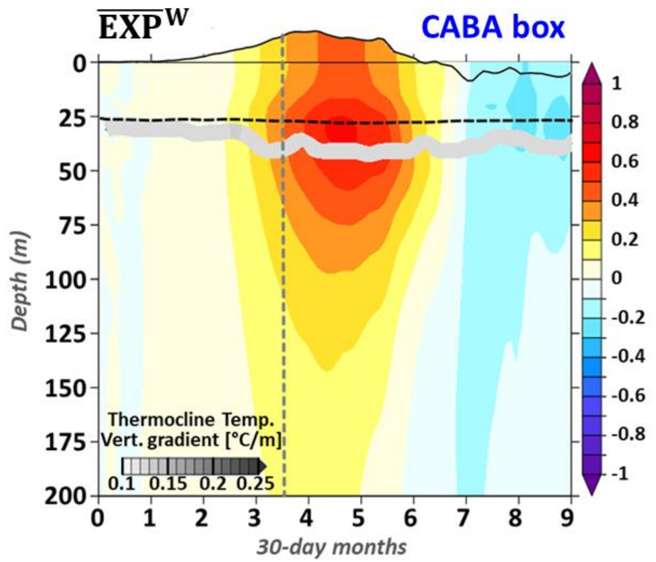
- **Sensitivity experiments:**

EXP-Name	Wind stress Perturbation
$\overline{EXP}$	×
$\overline{EXP}^W$	Restritect to the West
$\overline{EXP}^A$	Everywhere



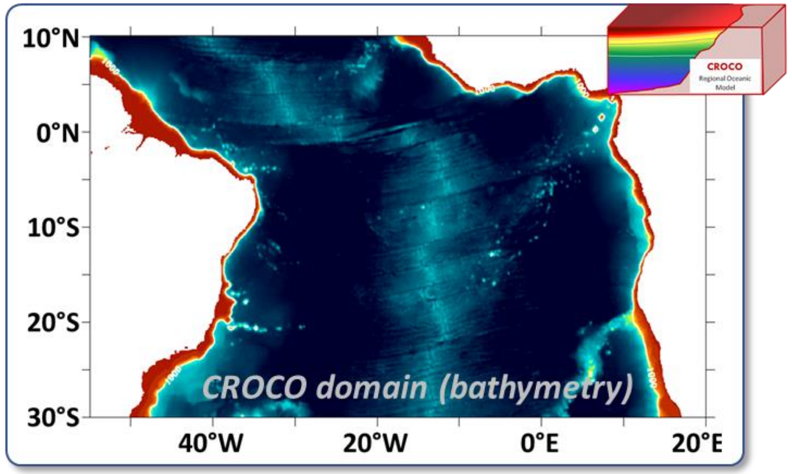


COASTAL WIND-STRESS SWITCHED OFF



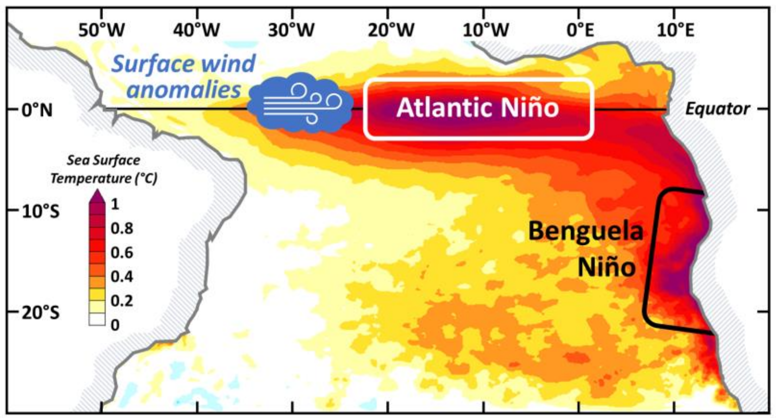
Introduction: Ocean modeling, Objectives and Advantages

Why does the Benguela Niño events precede the Atlantic Niños?



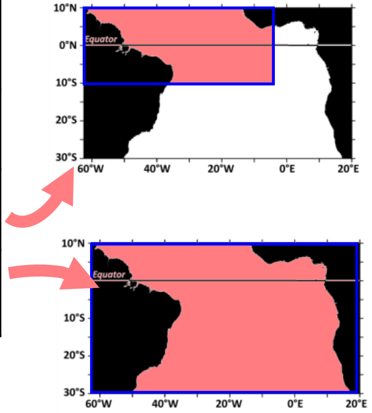
Benguela Niños stop earlier due to the development of coastal wind anomalies associated with a **convergent anomalous circulation located on the warm Atlantic Niño event**.

Tropical Atlantic interannual events

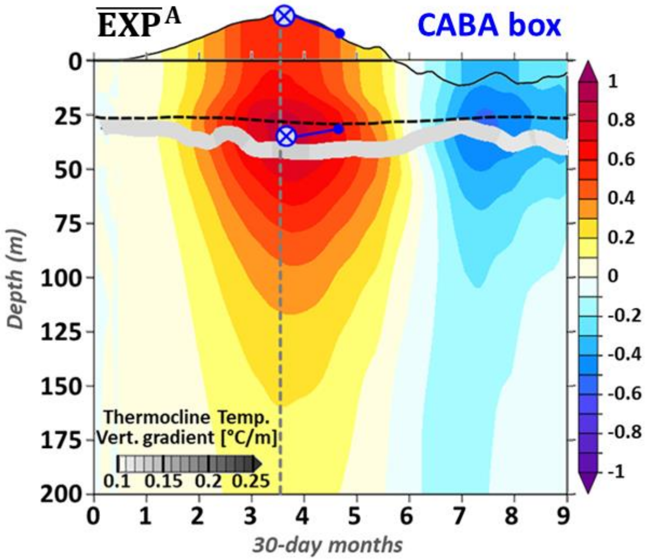


- **Sensitivity experiments:**

EXP-Name	Wind stress Perturbation
$\overline{EXP}$	×
$\overline{EXP}^{W}$	Restritect to the West
$\overline{EXP}^{A}$	Everywhere



COASTAL WIND-STRESS SWITCHED ON



Introduction: Methodology

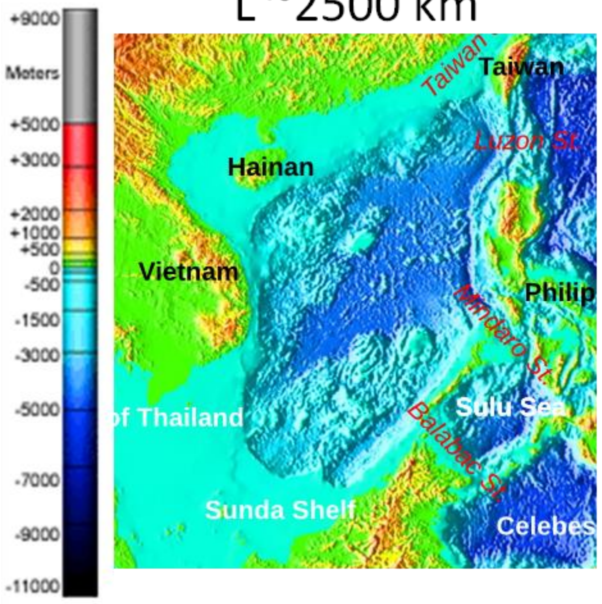
- Equations to solve: **Navier-Stokes equations**

The **Millennium Prize Problems** are seven problems in mathematics that were stated by the Clay Mathematics Institute in 2000. As of October 2014, six of the problems remain unsolved. A correct solution to any of the problems results in a US $1,000,000 prize (sometimes called a *Millennium Prize*) being awarded by the institute. The Poincaré conjecture was solved by Grigori Perelman, but he declined the award in 2010.

We make some **approximations** !

H ~3000 m

L ~2500 km



- Hypothesis:
  - ✓ Hydrostatic : H/L <<1 (aspect ratio low)
    - neglect vertical acceleration
    - neglect Coriolis term associated to vertical velocities
  - ✓ Incompressibility
  - ✓ Boussinesq : $\rho=\rho_o$=cste for horizontal gradient pressure

→ **Primitive equations**

Primitive Equations (1/3)

Momentum conservation equation

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

advection *Coriolis* *Pressure gradient* *Horizontal diffusion* *Vertical diffusion*

Hydrostatic equation

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

Continuity equation

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

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

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

Primitive Equations (2/3)

- **Initial 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

- **Bottom boundary conditions (z=-H):**

$$\vec{u}.\nabla(-H) = w$$ Kinematic

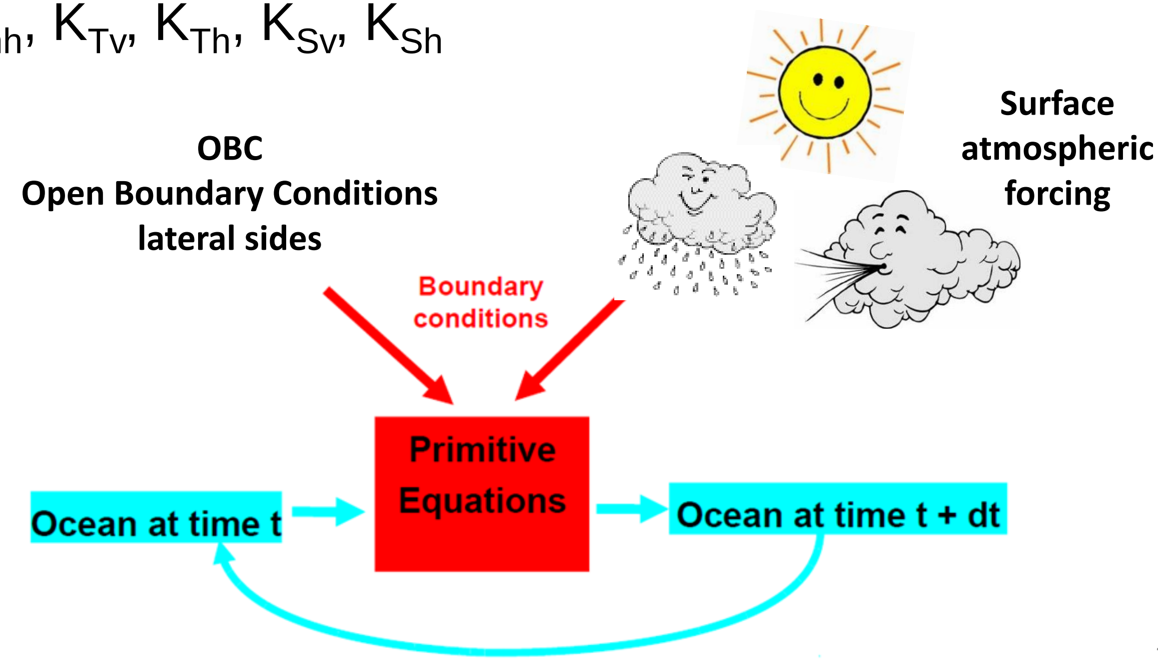
$$K_{Mv}\frac{\partial u}{\partial z} = \frac{-C_d|\vec{u}|u}{\rho_0}$$
$$K_{Mv}\frac{\partial v}{\partial z} = \frac{-C_d|\vec{u}|v}{\rho_0}$$
Bottom friction

$$K_{Tv}\frac{\partial T}{\partial z} = 0$$
$$K_{Sv}\frac{\partial S}{\partial z} = 0$$
Bottom-flux

Primitive Equations (3/3)

- Solving the primitive equations
  + the boundary conditions on a discretised grid
- Unknowns : **Prognostic variables** at **time t+dt** : u, v, T, S, η
  We then compute the **diagnostic variables** : w, P, ρ
- Knowns :
  - Pronostic variable at time t
  - Boundary conditions
  - Model parameters : K_{mv}, K_{mh}, K_{Tv}, K_{Th}, K_{Sv}, K_{Sh}

⇨



CROCO model (1/5): History

SCRUM

ROMS UCLA / RUTGERS

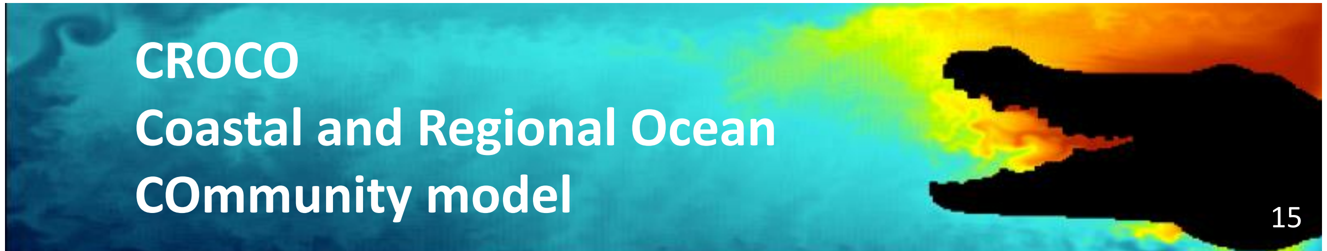
ROMS Regional Oceanic Modeling System

AGRIF

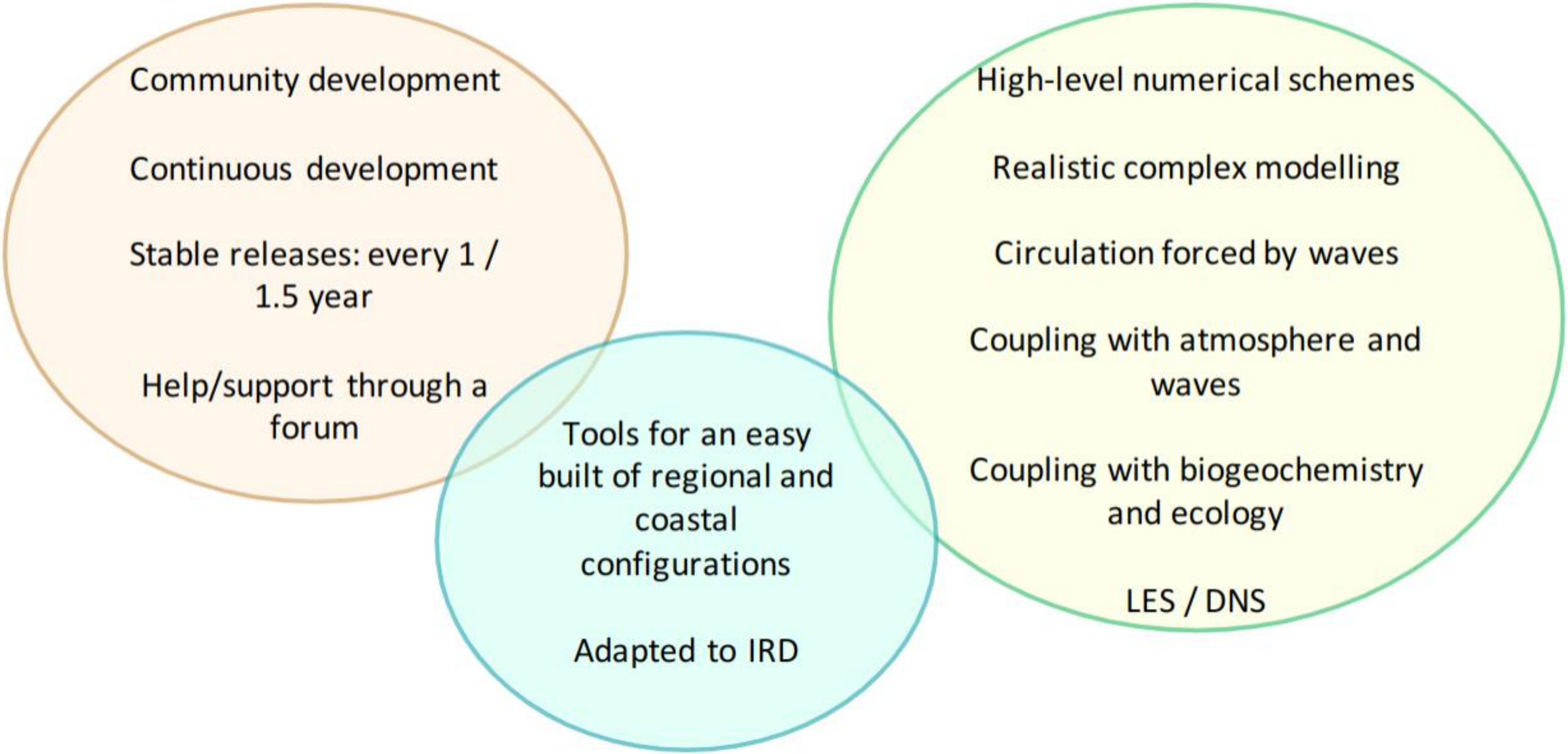
ROMS AGRIF

NH-NBQ of Symphonie-NH
Mutli-resolution
MUSTANG sediment module of MARS

Coastal and Regional Ocean COmmunity model

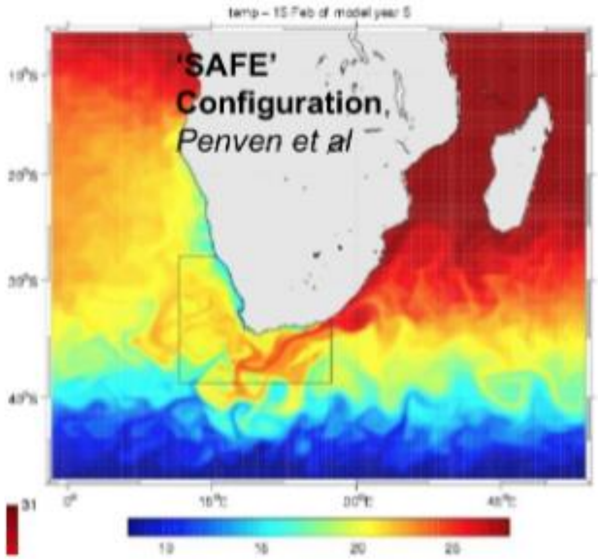


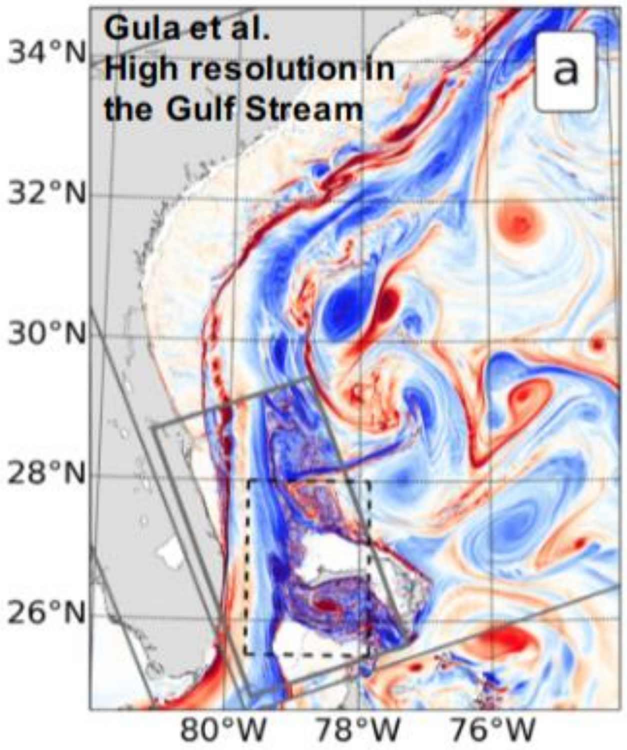
CROCO model (2/5): Philosophy

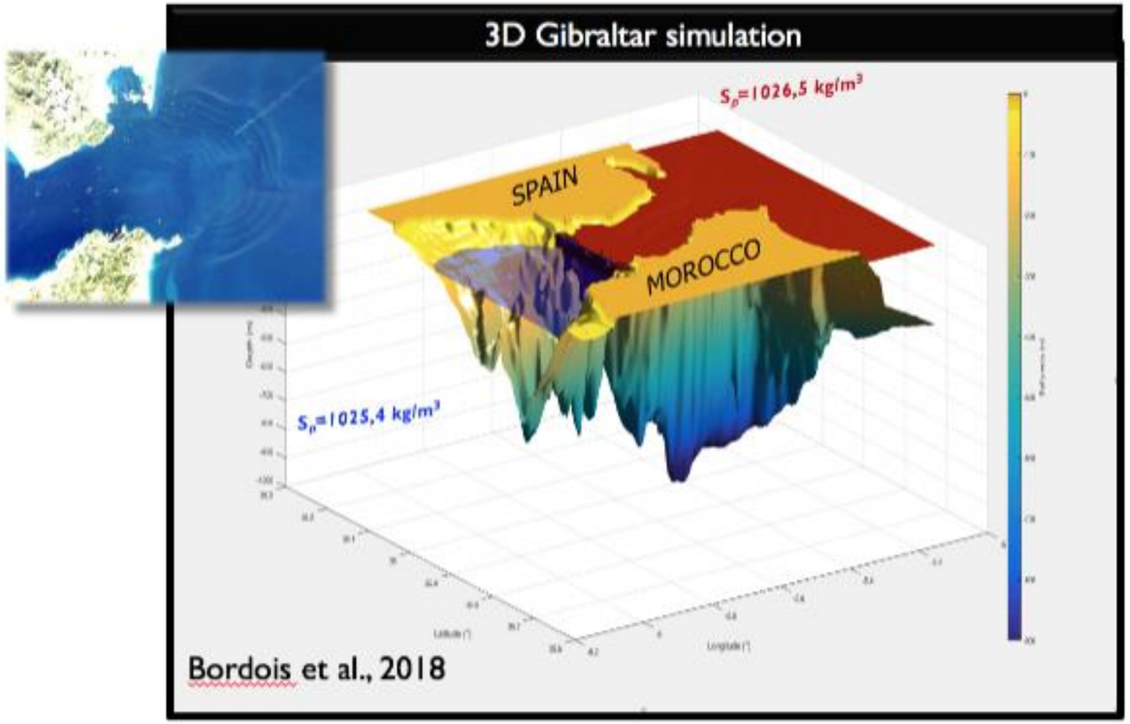


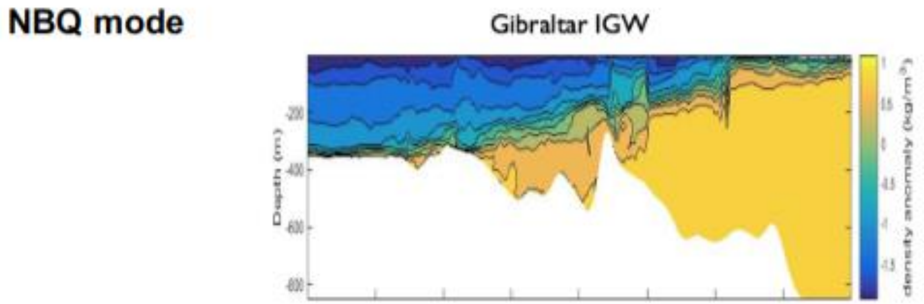
CROCO model (3/5): Examples

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





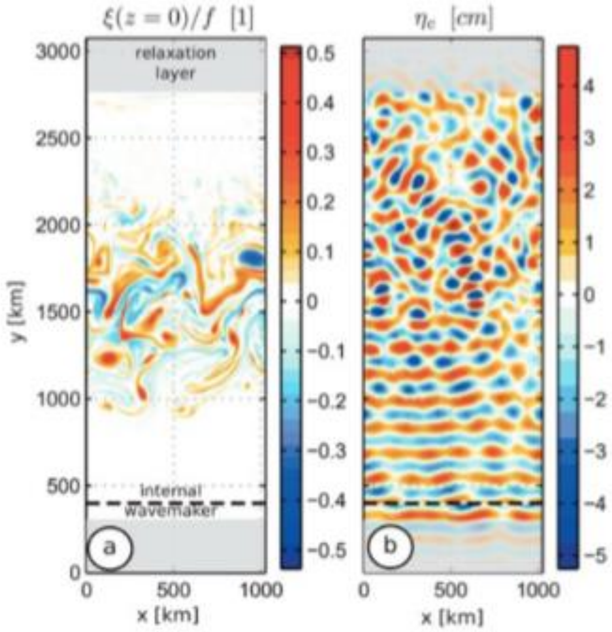




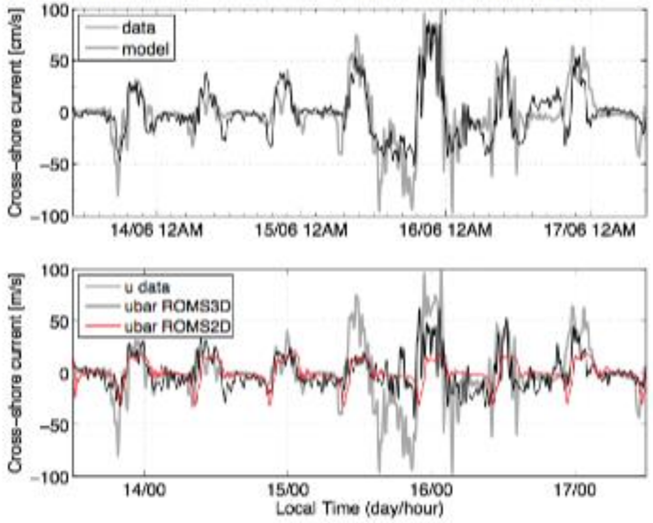
CROCO model (4/5): Examples

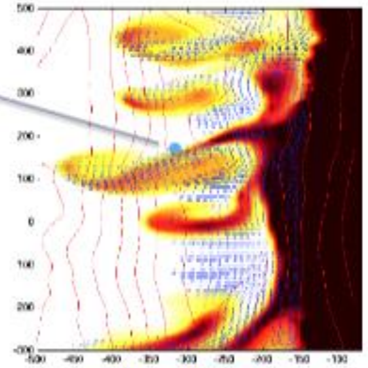
For starting, here are a few examples of use of CROCO

Ponte & Klein, 2015,, internal tides and eddies

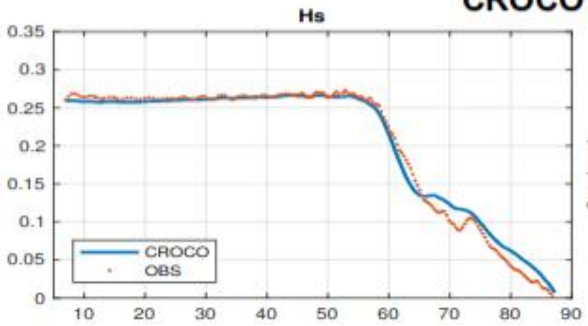


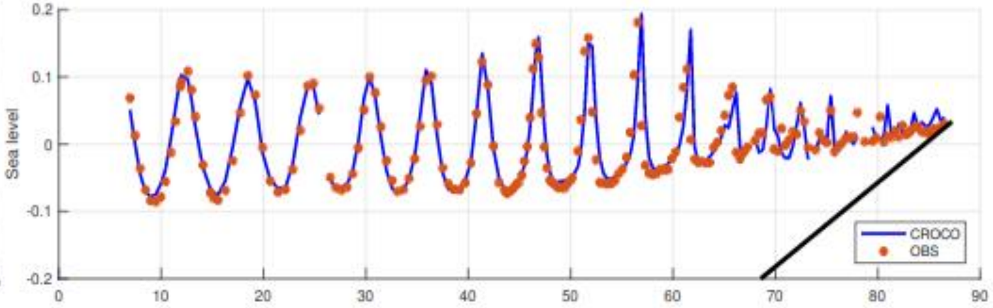
Marchesiello et al. 2015, Rip current





CROCO wave-to-wave (Marchesiello, Benshila)

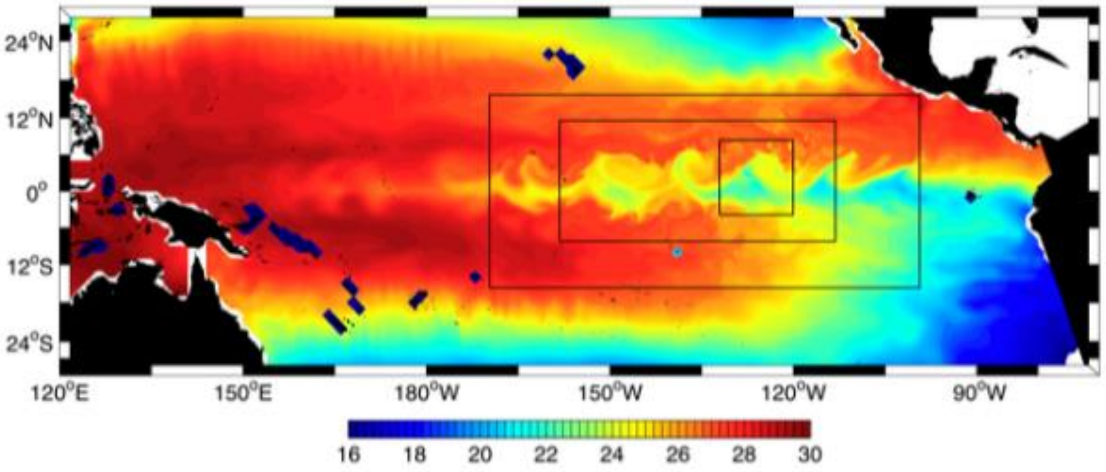




CROCO and more (1/2)

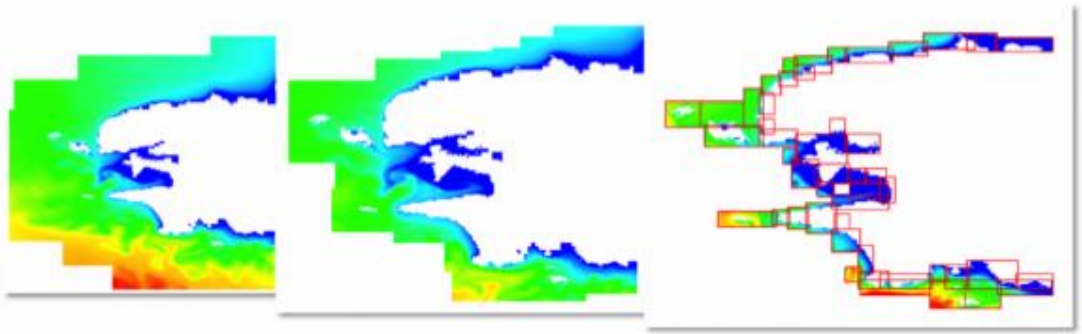
Nesting with AGRIF

- 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 and more (2/2)

- Rivers inputs and passive tracer evolution
- Wave-current interactions (WKB module, coupling with WW3)
- Current sediment interactions/Morphodynamics (USGS/MUSTANG modules)
- Ocean/Wave/Atmosphere coupling (using the OASIS-MCT coupler)
- Biogeochemistry (PISCES/BIOEBUS/NPZD modules)
- Coupling with Lagrangian and ecosystem modules.

CROCO tools and facilities

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

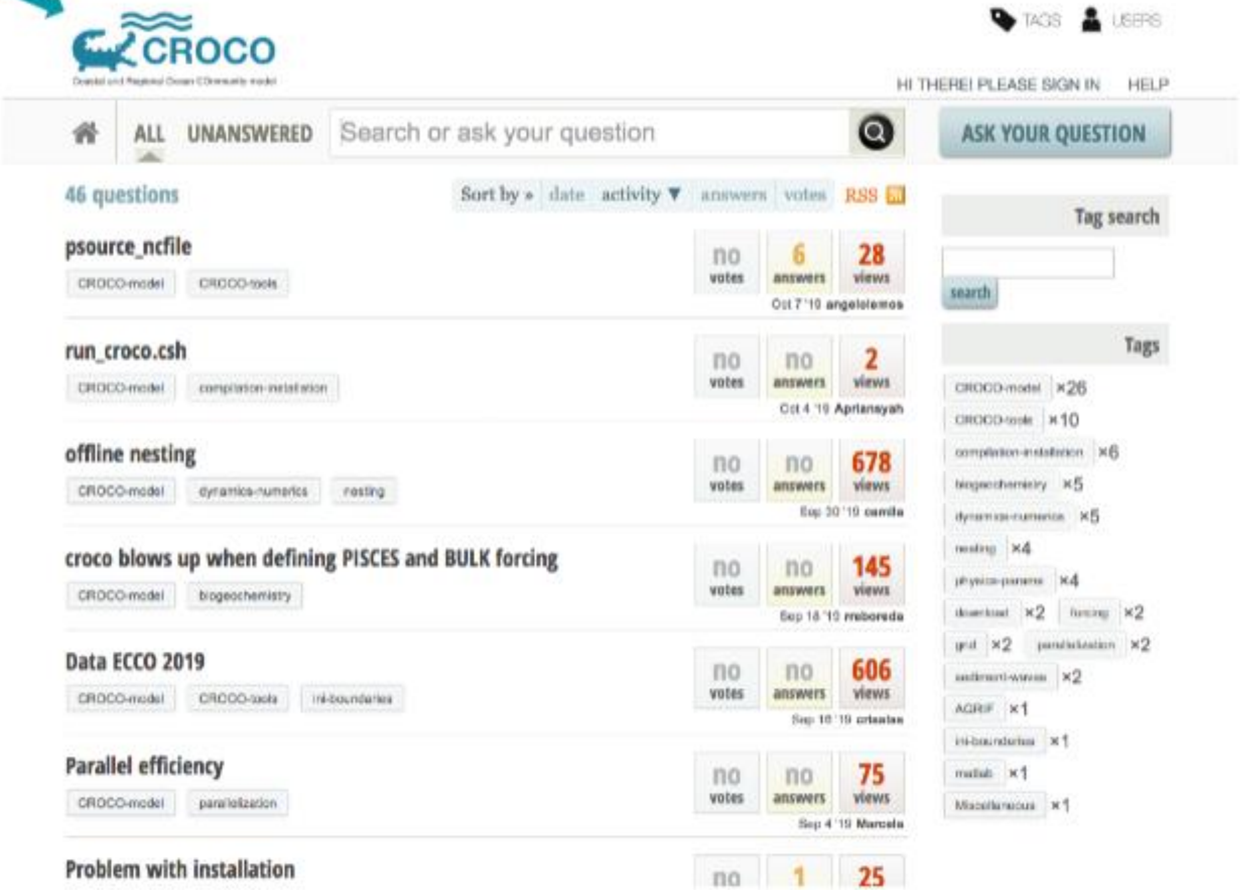
XIOS (dev. at ISPL)
- Outputs facilities
- Diagnostics facilities

⇒ Need to download and compile XIOS

CROCO help

DOCUMENTATION

FORUM



Day 1 : Monday November 25th

MORNING

Forewords by Jennifer Veitch

Class: "Introduction to regional ocean modeling",
followed by a round-table discussion during which attendees will present their scientific objectives and their expectations for this class

Hands-on session : First connection on the Lengau cluster, and test Matlab

AFTERNOON

Class: Let's make our first CROCO grid

Hands-on session :
- Presentation of CROCO and CROCO_tools environment.
- Quick Linux and NetCDF recaps
- First preprocessing steps: model grid and work on the vertical sigma parameters

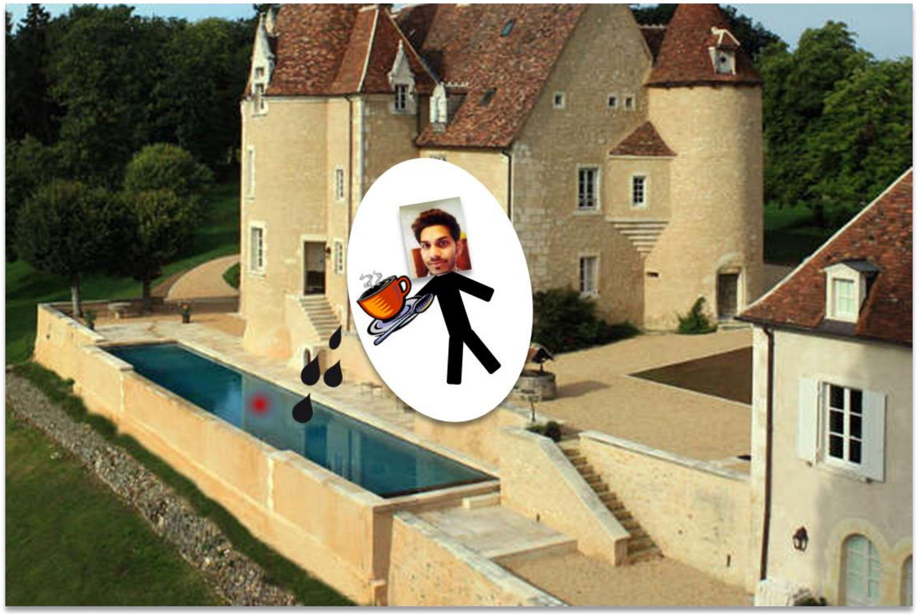
Day 2 : Tuesday November 26th

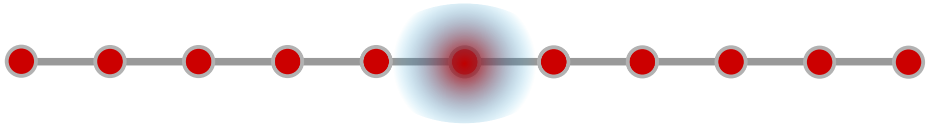
MORNING

Talk by Jenny Veitch: ‘Modelling the Benguela upwelling System and Fun with boundary conditions”
Class: "Numerical aspects I "Finite differences: Spatial and temporal discretization
Hands-on session : Finite differences - Solving a simple case, the 1-D Diffusion equation

AFTERNOON

Class: Forcing and Open Lateral Boundary conditions
Hands-on session:
- Creation of all CROCO forcing inputs (climatological forcing)
- Launch of the model (climatological configuration)



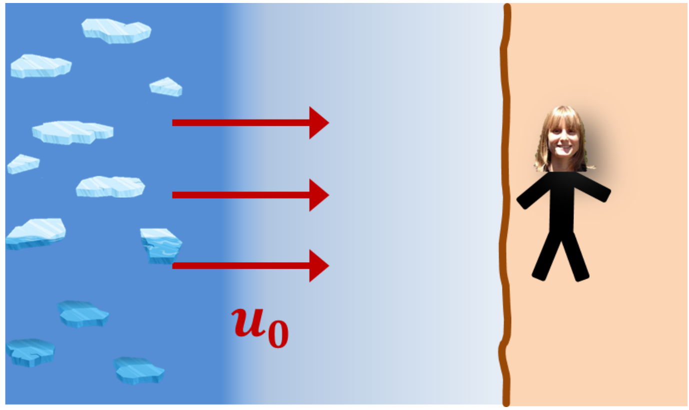


Day 3 : Wednesday November 27th

MORNING

Class: "Numerical aspects II " • Consistency and stability of a numerical scheme
• Introduction to CFL condition
• Quick overview of Sigma coordinates and truncation error

Hands-on session : • Model outputs analysis with CROCO_gui



AFTERNOON

Class: Introduction to the online nesting with AGRIF

Hands-on session : • Creation of all CROCO Forcings inputs (climatological forcing) for a zoom (with nestgui)
• Launch of the model (climatological configuration) with a zoom

Day 4 : Thursday November 28th

MORNING

Role game in order to give a complete understanding of the model input files, with an emphasis on how the model handles the time“

Hands-on session : • Model outputs analysis with CROCO_gui

AFTERNOON

Talk by Moagabo Ragoasha: title TBC

Class: Running an inter-annual simulation (Guillaume)

Hands-on session: • Preparation of an inter-annual simulation input files
• Launch of the inter-annual simulation
• Notions of optimization of the I/O

Day 5 : Friday November 29th

MORNING

Talk by Pierrick Penven: “Modeling around Africa, demo, tips, and advices”
Class: Parallelization (Rachid Benshila)
Demonstration: Let’s put river in one of your configurations
Discussion: Notion of model validation.

AFTERNOON

Hands-on session: Model outputs analysis
Student presentations to get their certificates