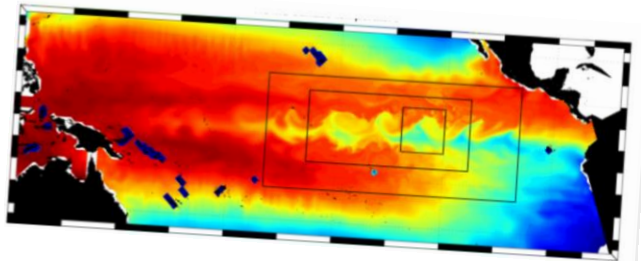
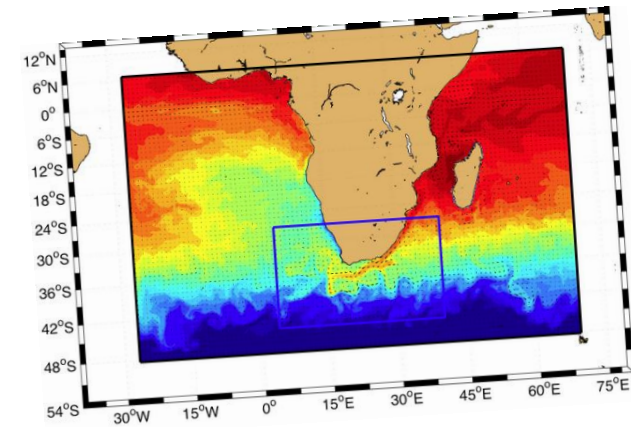


INTRODUCTION TO OCEAN MODELING USING CROCO AND THE CROCO_TOOLS



<http://sillig.free.fr>

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



OBJECTIVES

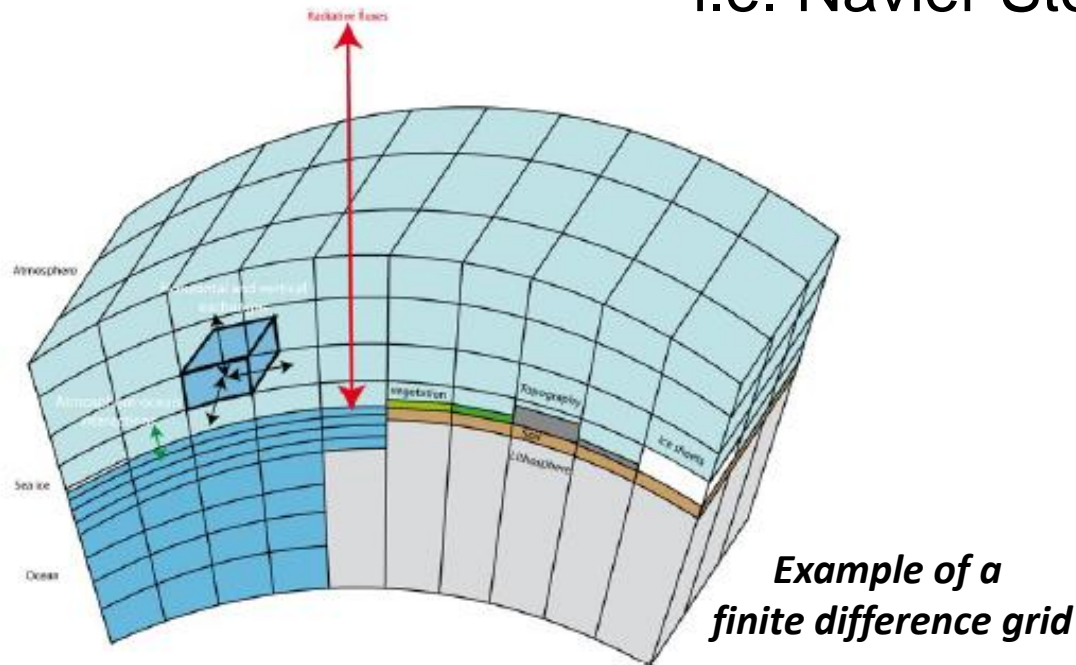
- Ocean Modelling Principle
- Ocean Modelling Advantages
- Methodology and primitive equations
- The CROCO model
- Program of basic week CROCO summer school

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



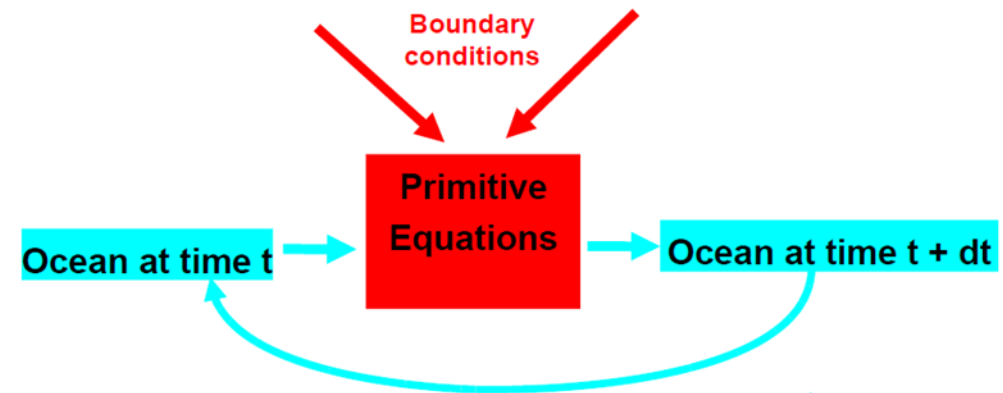
- To do this, the ocean is divided into « small » boxes.

↪ **Discretization**

Introduction: Ocean modeling principle (2/3)

➤ If we know:

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

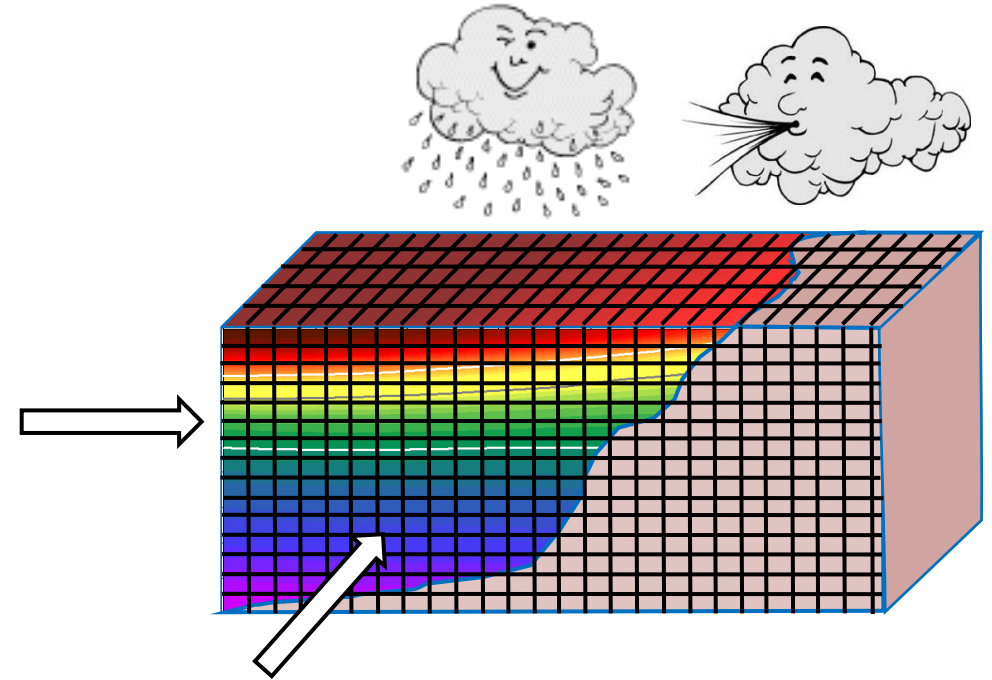
Introduction: Ocean modelling principle (3/3)

➤ Let's compare the ocean model as a giant rectangular swimmingpool

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

- **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

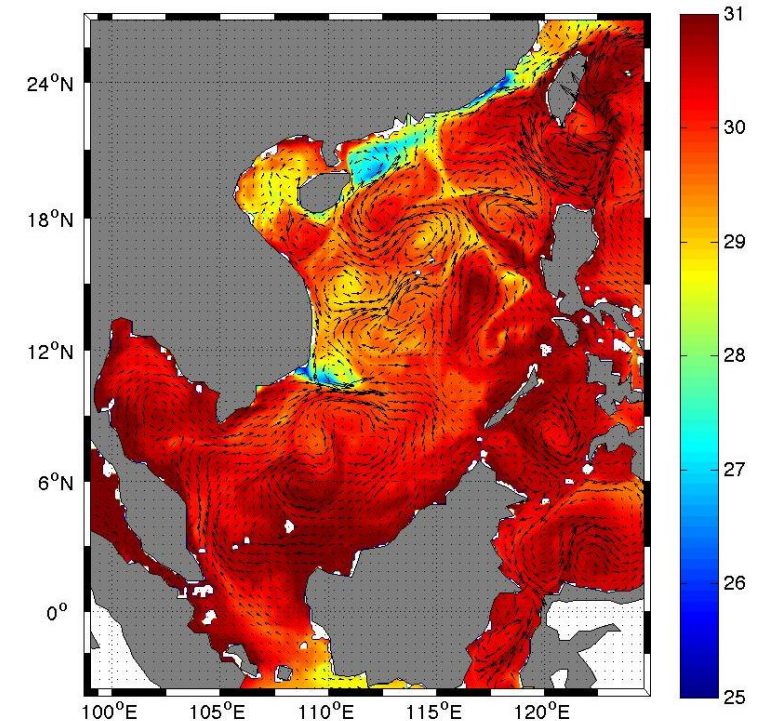
➤ Objectives:

- **Fundamental research** : understand ocean functioning
- **Applied research, operational oceanography** : 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°*



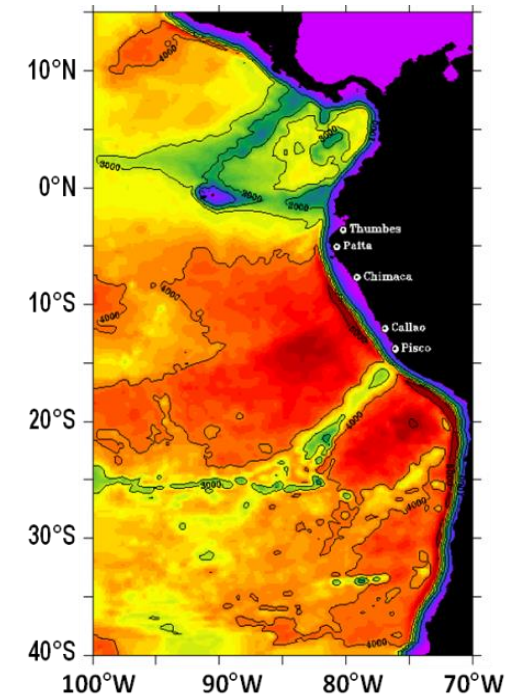
Introduction: Ocean modeling, Objectives and Advantages

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

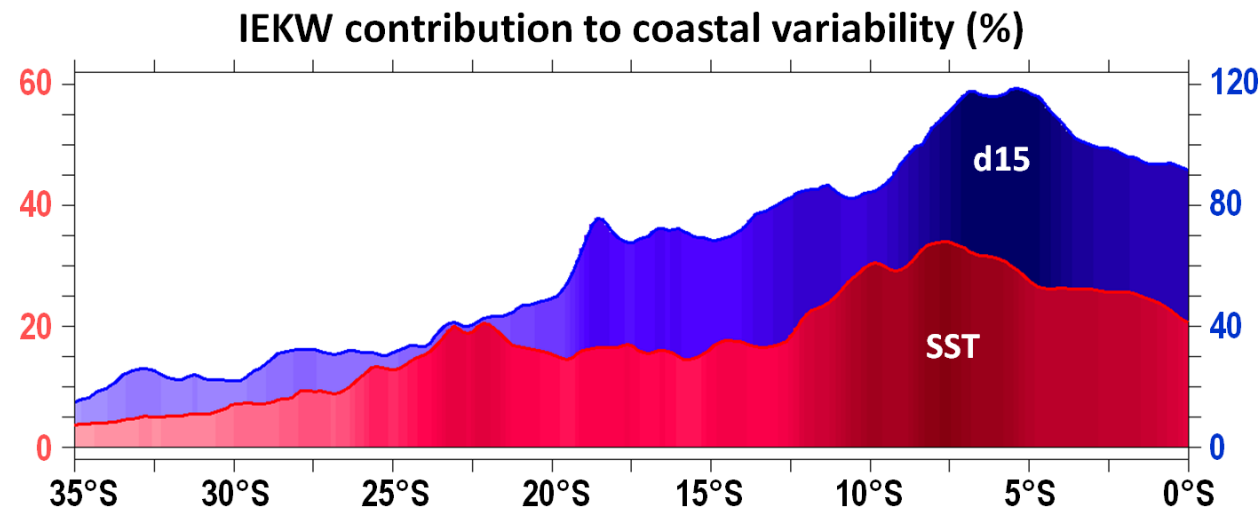
- *Remote - Connection with the equatorial variability ?*
- *Locally forced - Wind stress, Heat Fluxes ?*

• 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

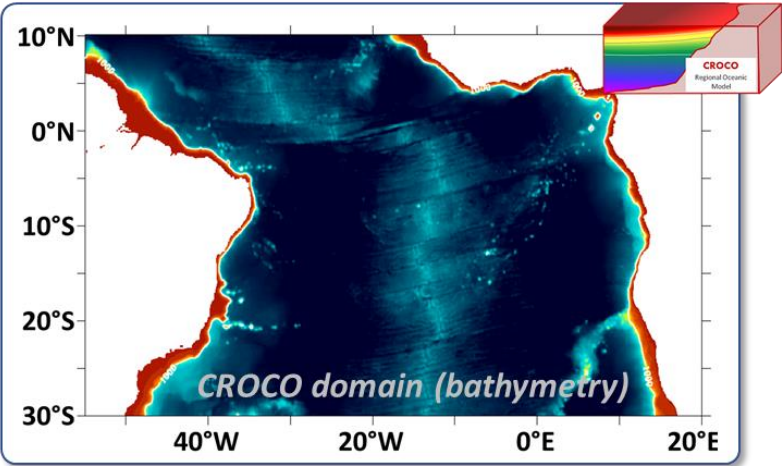


➡ *Connection with the remote equatorial variability represents only ~20% of the intraseasonal SST variability off Central Peru in 2000-2008 !*

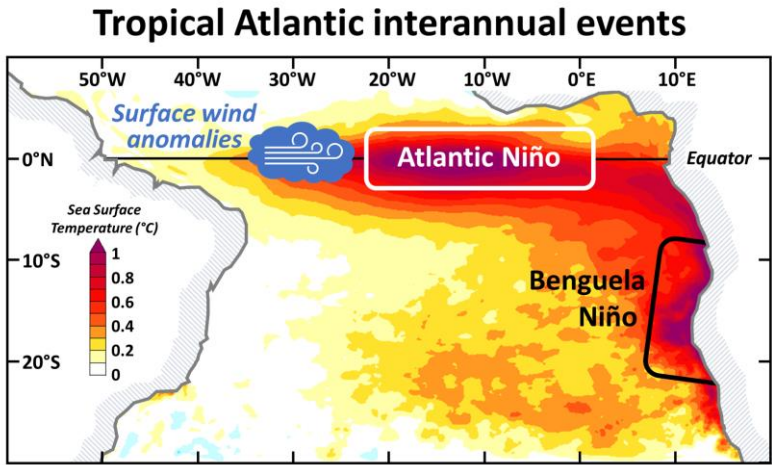


Introduction: Ocean modeling, Objectives and Advantages

Why does the Benguela Niño events precede the Atlantic Niños?

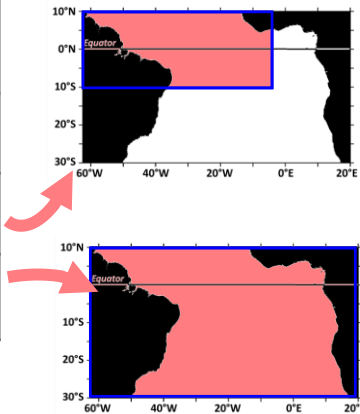


Benguela Niños stop earlier due to the development of coastal wind anomalies associated with a convergent anomalous circulation located on the warm Atlantic Niño event.

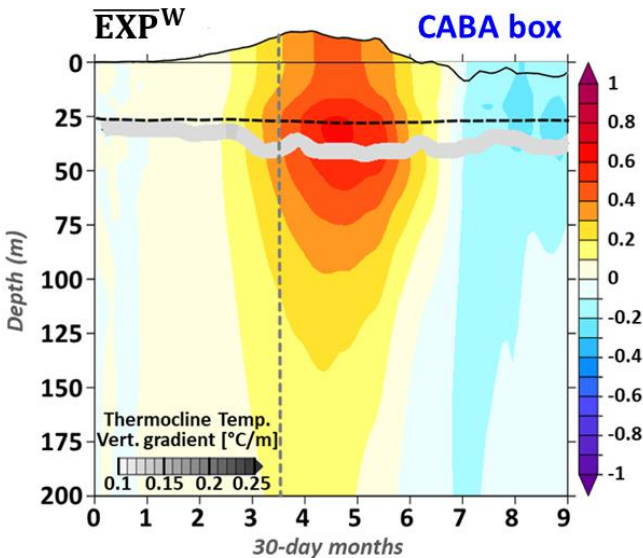


• Sensitivity experiments:

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

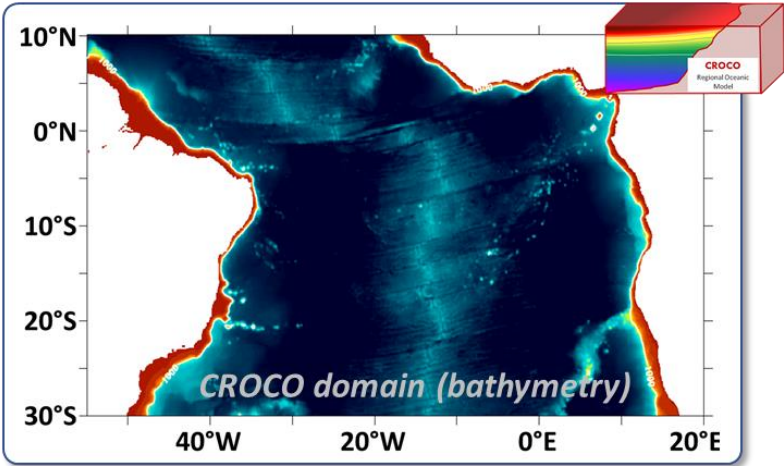


COASTAL WIND-STRESS SWITCHED OFF

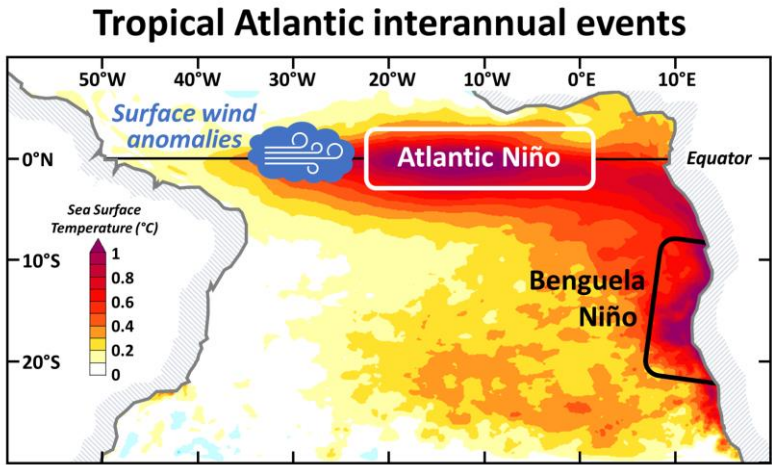


Introduction: Ocean modeling, Objectives and Advantages

Why does the Benguela Niño events precede the Atlantic Niños?

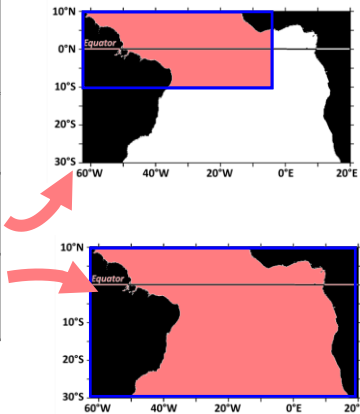


Benguela Niños stop earlier due to the development of coastal wind anomalies associated with a convergent anomalous circulation located on the warm Atlantic Niño event.

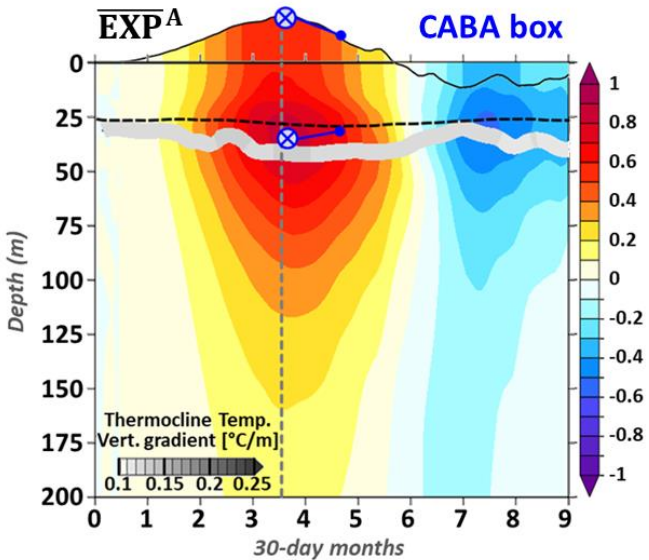


• Sensitivity experiments:

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



COASTAL WIND-STRESS SWITCHED ON



Introduction: Methodology

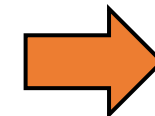
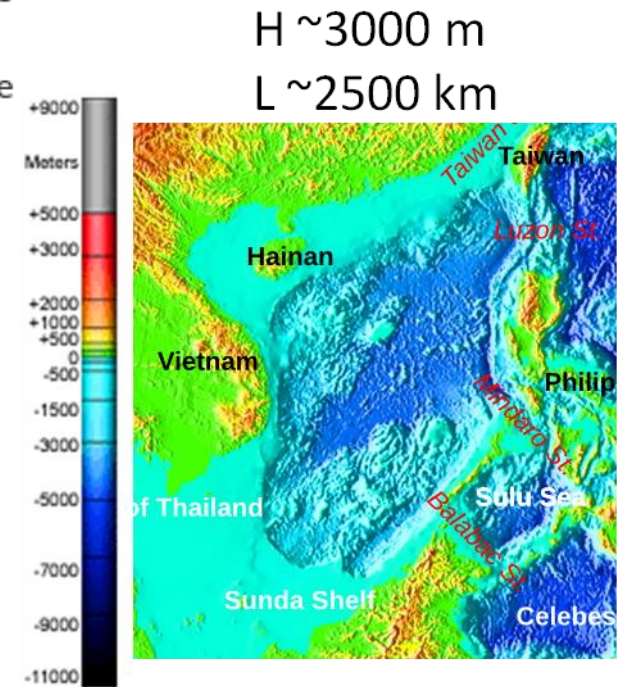
➤ Equations to solve: Navier-Stokes equations

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** !

➤ Hypothesis:

- ✓ Hydrostatic : $H/L \ll 1$ (aspect ratio low)
 - neglect vertical acceleration
 - neglect Coriolis term associated to vertical velocities
- ✓ Incompressibility
- ✓ Boussinesq : $\rho = \rho_0 = \text{cste}$ for horizontal gradient pressure



**Primitive
equations**

Primitive Equations (1/3)

Momentum conservation equation

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

advection Coriolis Pressure gradient Horizontal diffusion Vertical diffusion

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

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

Equation of state

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

Primitive Equations (2/3)

- Initial conditions

- Surface boundary conditions ($z=\eta$):

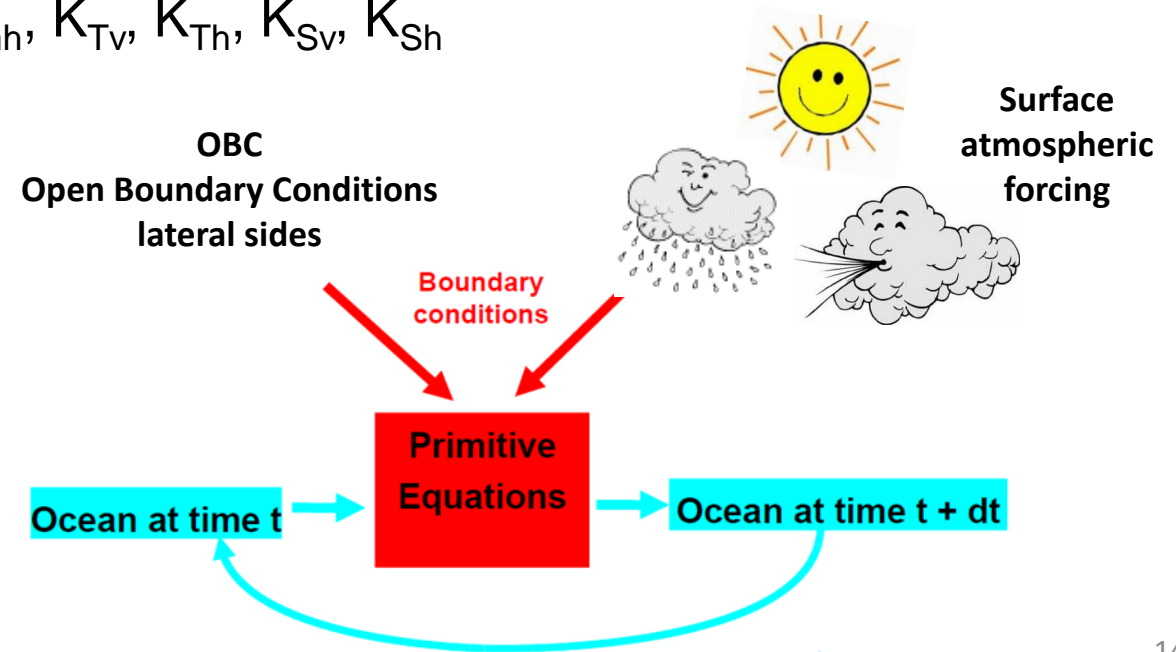
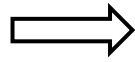
$$\begin{aligned}
 \frac{\partial \eta}{\partial t} &= w && \text{Kinematic} \\
 K_{Mv} \frac{\partial u}{\partial z} &= \frac{\tau_x}{\rho_0} \\
 K_{Mv} \frac{\partial v}{\partial z} &= \frac{\tau_y}{\rho_0} && \left. \begin{array}{l} \\ \\ \end{array} \right\} \text{Wind stress} \\
 K_{Tv} \frac{\partial T}{\partial z} &= \frac{Q}{\rho_0 C_p} && \text{Heat flux} \\
 K_{Sv} \frac{\partial S}{\partial z} &= \frac{S(E - P)}{\rho_0} && \text{Salt flux : evap - rain}
 \end{aligned}$$

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

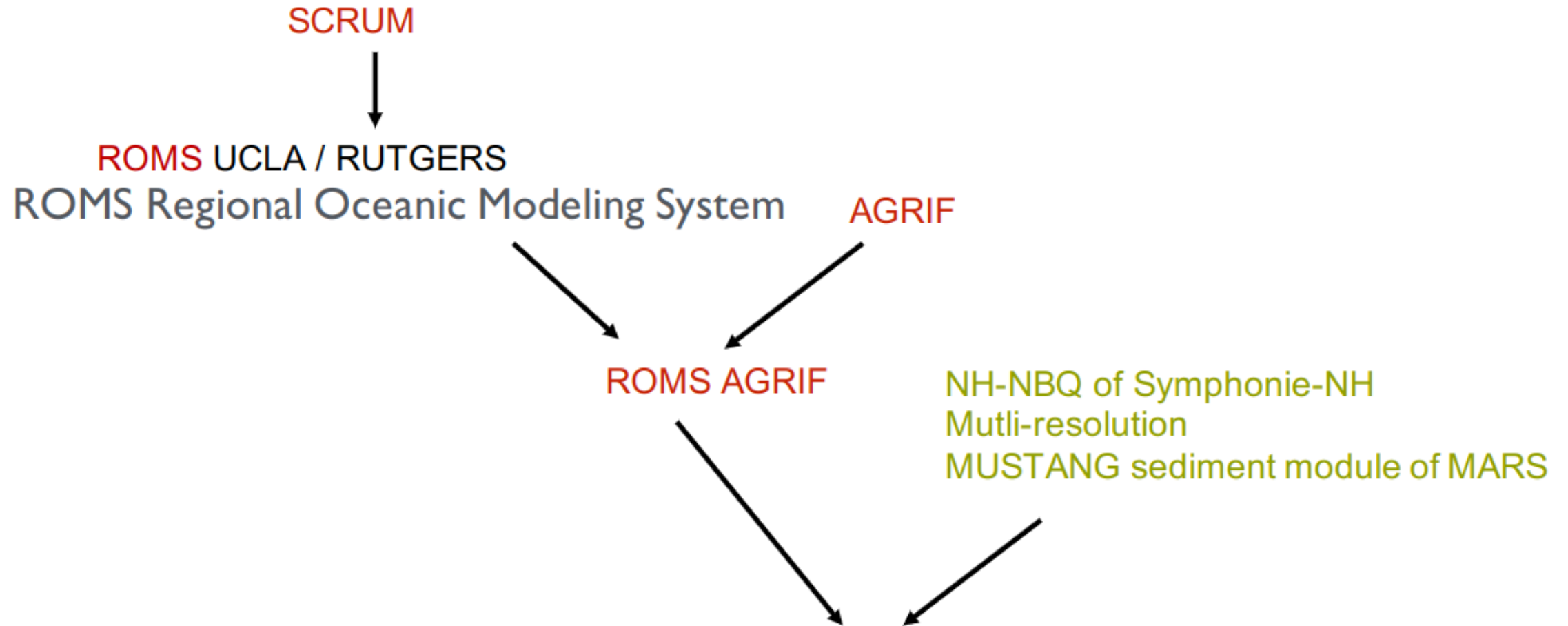
$$\begin{aligned}
 \vec{u} \cdot \nabla(-H) &= w && \text{Kinematic} \\
 K_{Mv} \frac{\partial u}{\partial z} &= \frac{-C_d |\vec{u}| u}{\rho_0} \\
 K_{Mv} \frac{\partial v}{\partial z} &= \frac{-C_d |\vec{u}| v}{\rho_0} && \left. \begin{array}{l} \\ \\ \end{array} \right\} \text{Bottom friction} \\
 K_{Tv} \frac{\partial T}{\partial z} &= 0 \\
 K_{Sv} \frac{\partial S}{\partial z} &= 0 && \left. \begin{array}{l} \\ \\ \end{array} \right\} \text{Bottom-flux}
 \end{aligned}$$

Primitive Equations (3/3)

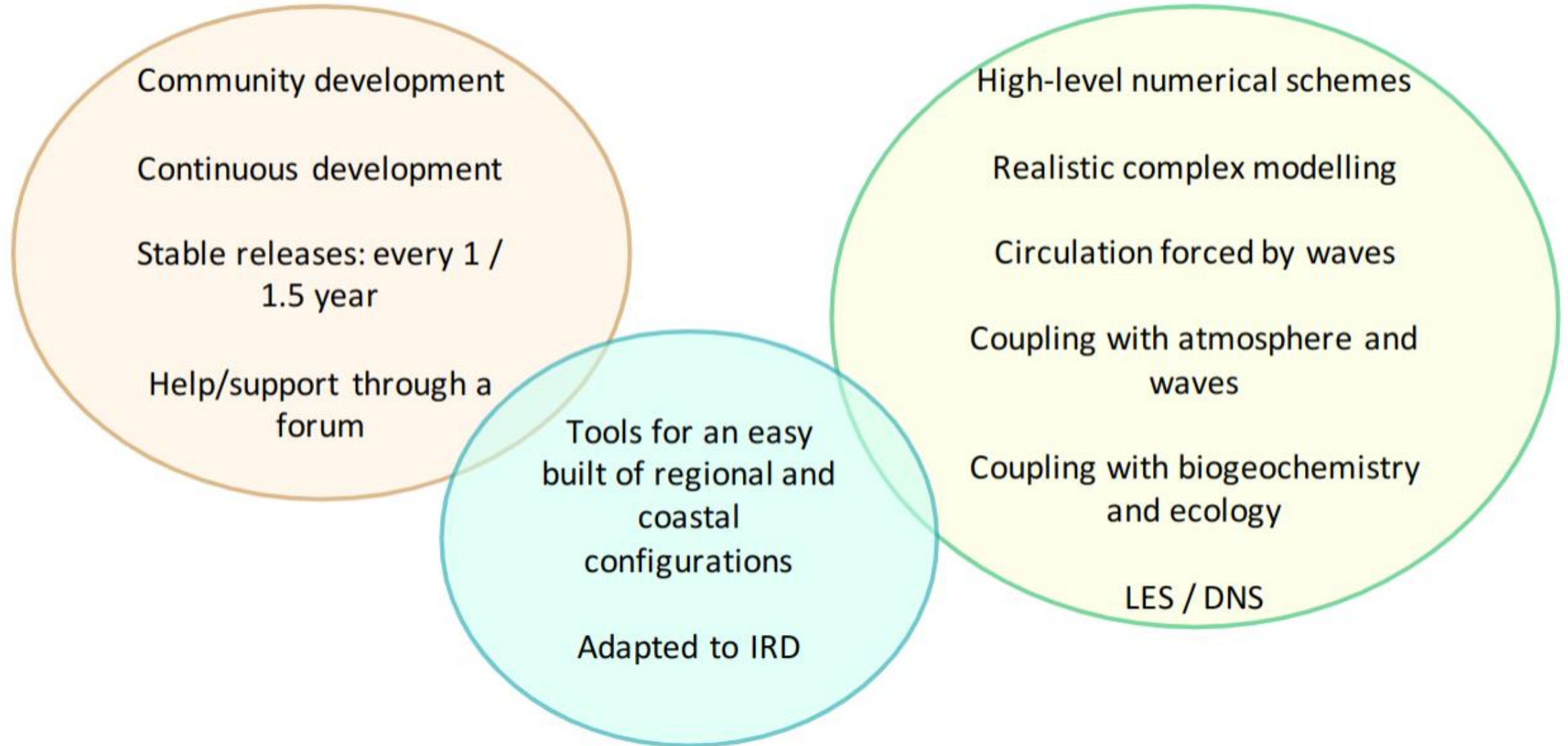
- Solving the primitive equations
+ the boundary conditions on a discretised grid
- Unknowns : **Prognostic variables** at **time $t+dt$** : u, v, T, S, η
We then compute the **diagnostic variables** : w, P, ρ
- Knowns :
 - Prognostic variable at time t
 - Boundary conditions
 - Model parameters : $K_{mv},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



CROCO model (1/5): History

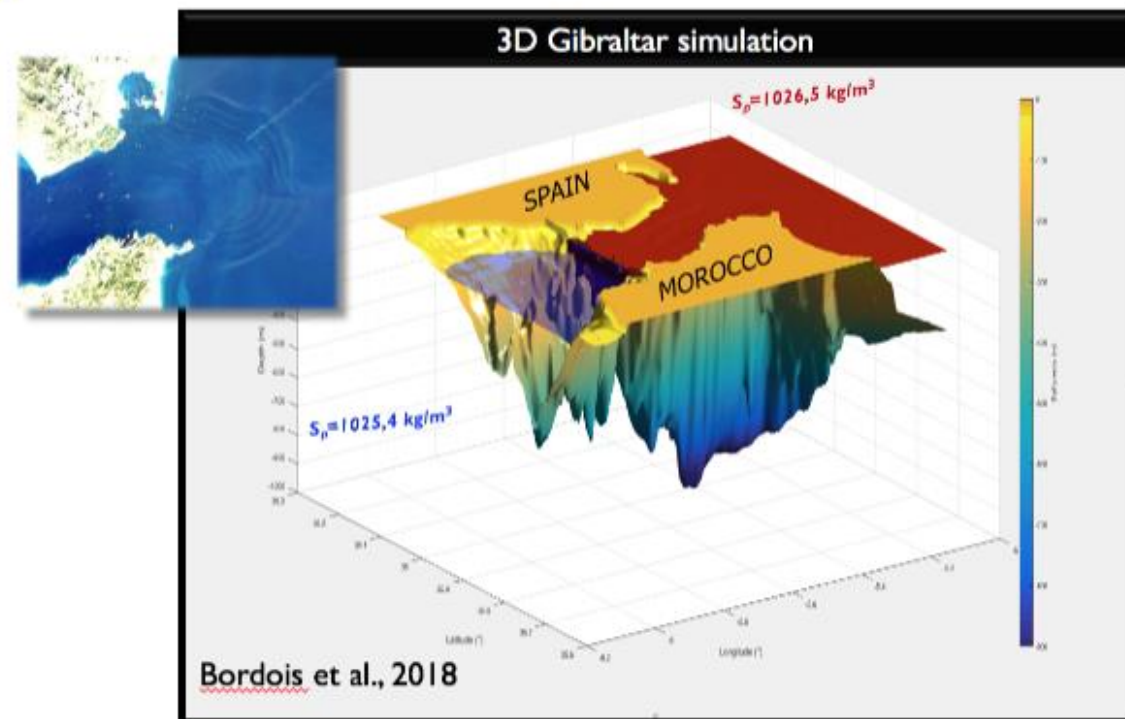
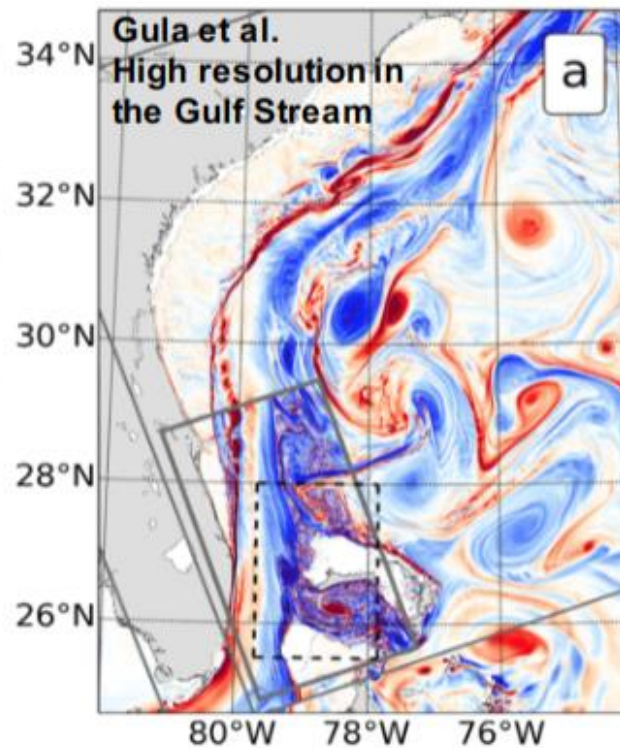
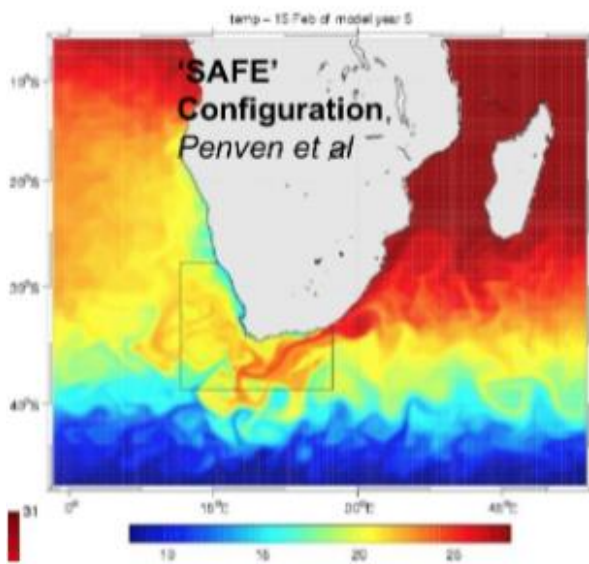


CROCO model (2/5): Philosophy



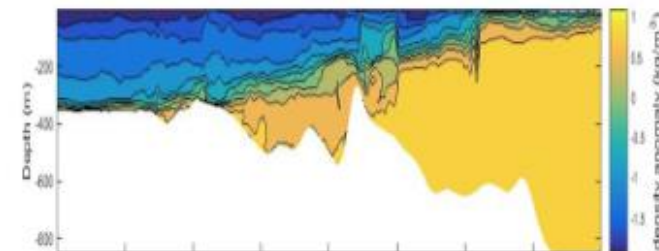
CROCO model (3/5): Examples

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



NBQ mode

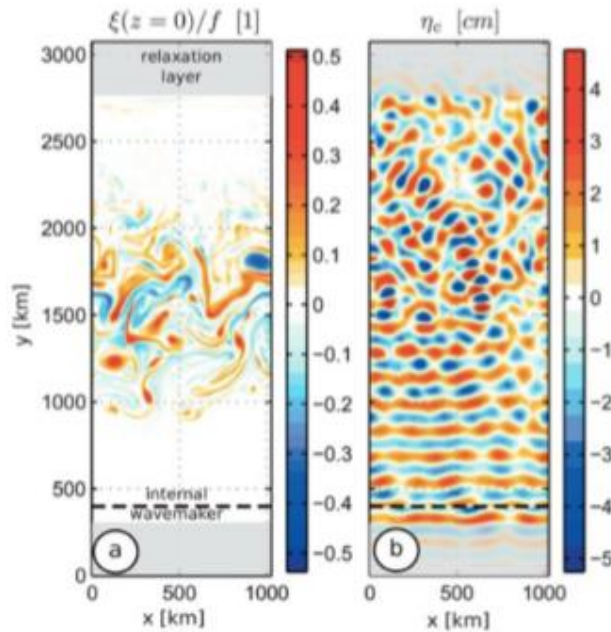
Gibraltar IGW



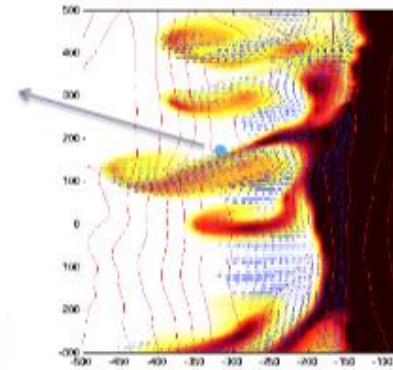
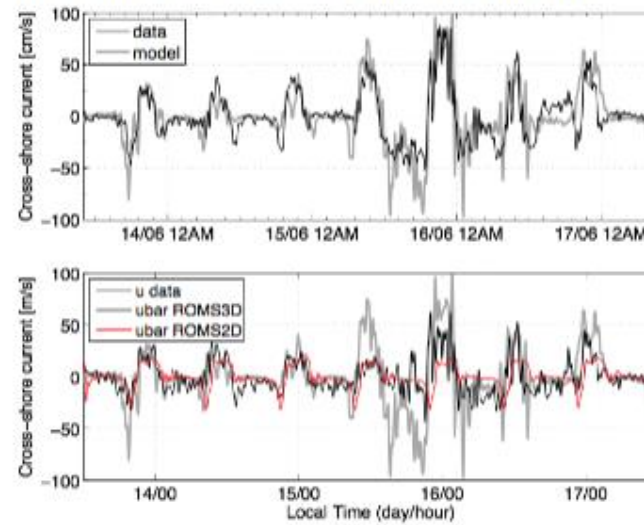
CROCO model (4/5): Examples

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

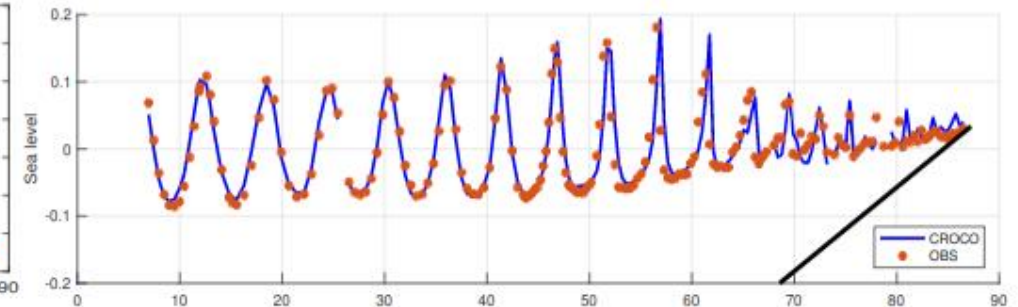
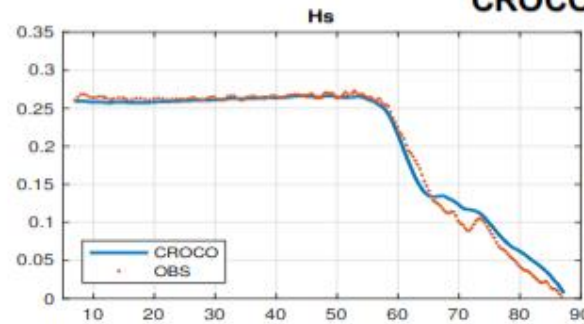
Ponte & Klein, 2015,, internal tides and eddies



Marchesiello et al. 2015, Rip current



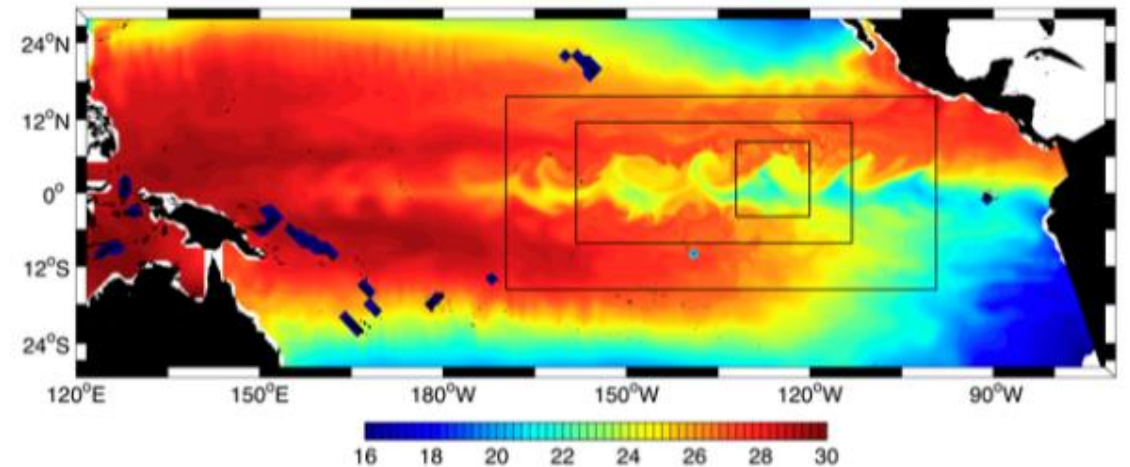
CROCO wave-to-wave (Marchesiello, Benshila)



CROCO and more (1/2)

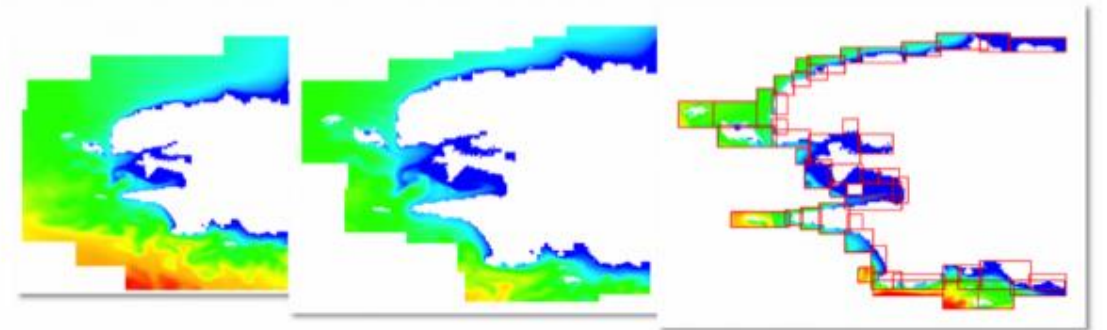
Nesting with AGRIF

- 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

Online diagnostics

- Online temperature / vorticity / energy balance

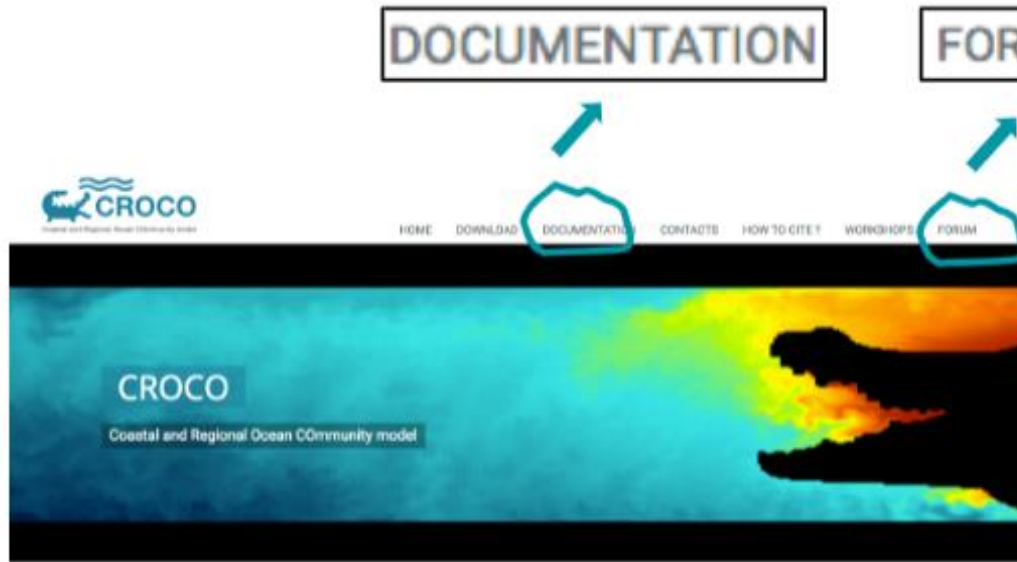
Python CROCO TOOLS

- 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 screenshot shows the CROCO forum page. At the top, there is a navigation bar with links: ALL, UNANSWERED, and a search bar. The 'ALL' link is selected. The main content area displays a list of questions. Each question entry includes the question title, a list of tags, and statistics for votes, answers, and views. The questions listed are: 'psource_nfile', 'run_croco.csh', 'offline nesting', 'croco blows up when defining PISCES and BULK forcing', 'Data ECCO 2019', 'Parallel efficiency', and 'Problem with installation'. On the right side, there is a 'Tag search' section and a 'Tags' section listing various tags with their respective counts.

Question Title	Tags	Votes	Answers	Views	Author	Date
psource_nfile	CROCO-model, CROCO-tools	no votes	6 answers	28 views	angelelemon	Oct 7 '10
run_croco.csh	CROCO-model, compilation-installation	no votes	no answers	2 views	Aplariyah	Oct 4 '10
offline nesting	CROCO-model, dynamics-numerics, nesting	no votes	no answers	678 views	camila	Sep 30 '10
croco blows up when defining PISCES and BULK forcing	CROCO-model, biogeochemistry	no votes	no answers	145 views	reboreda	Sep 18 '10
Data ECCO 2019	CROCO-model, CROCO-tools, ini-boundaries	no votes	no answers	606 views	crutken	Sep 16 '10
Parallel efficiency	CROCO-model, parallelization	no votes	no answers	75 views	Marcota	Sep 4 '10
Problem with installation		no votes	1 answer	25 views		

Tag search

Tags

- CROCO-model x26
- CROCO-tools x10
- compilation-installation x6
- biogeochemistry x5
- dynamics-numerics x5
- nesting x4
- physics-param x4
- download x2
- forcing x2
- grid x2
- parallelization x2
- sediment-wave x2
- AGRIF x1
- ini-boundaries x1
- model x1
- Macellaneux x1

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

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

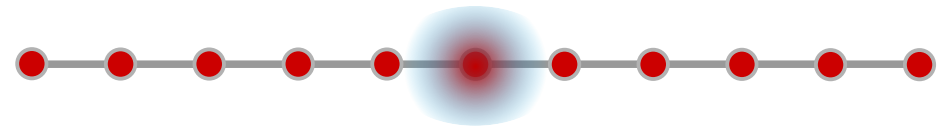
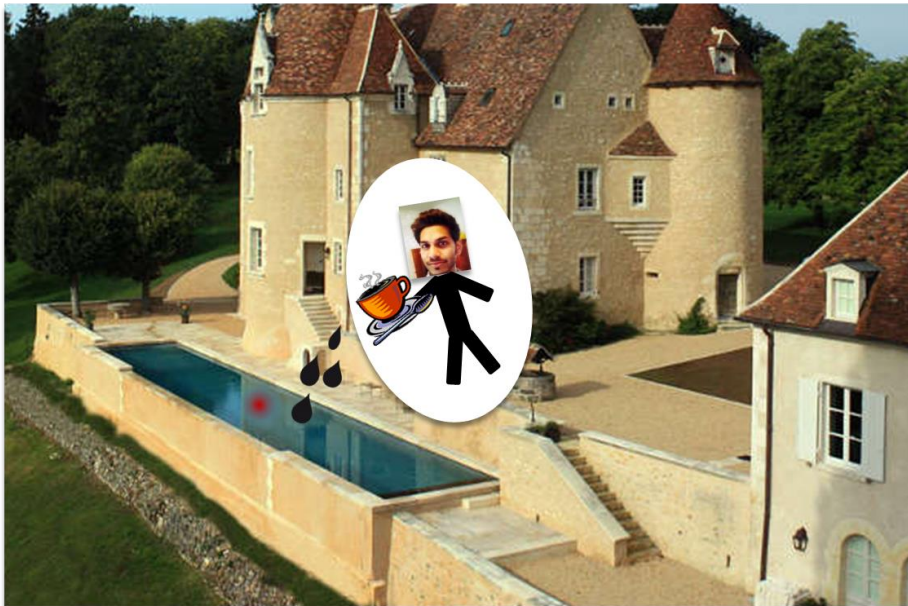
Hands-on session : Finite differences - Solving a simple case, the 1-D Diffusion equation

AFTERNOON

Class: Forcing and Open Lateral Boundary conditions

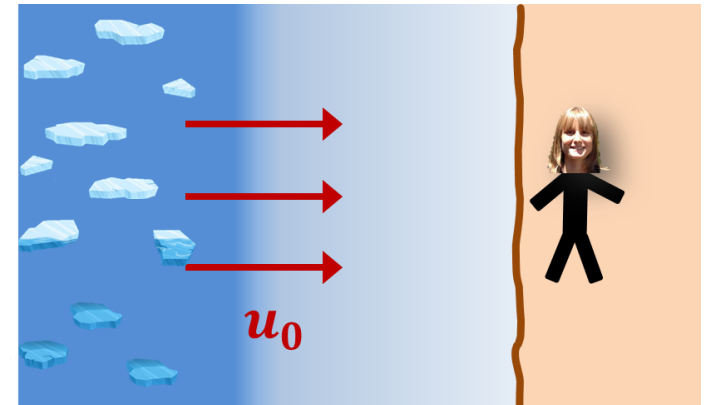
Hands-on session:

- Creation of all CROCO forcing inputs (climatological forcing)
- Launch of the model (climatological configuration)



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

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





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