A wide-angle photograph of a sunset over the ocean. The sky is filled with horizontal clouds, transitioning from deep orange and red near the horizon to a darker blue at the top. A small white boat is visible on the horizon. The ocean surface has gentle ripples.

JuliaEO 2024 Terceira Azores Portugal

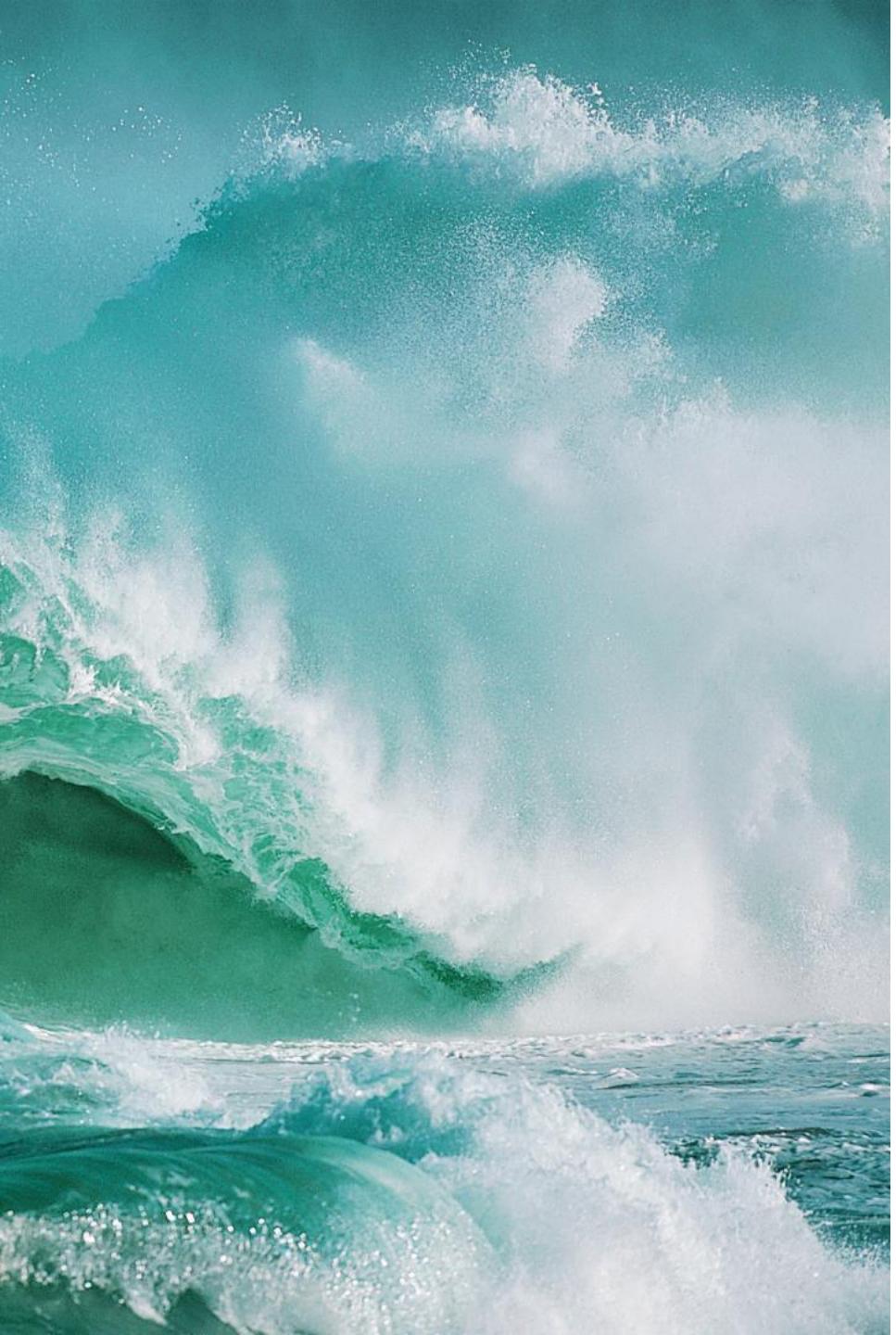
Ocean Modelling with MOHID for Operations



Francisco Campuzano

francisco.campuzano@colabatlantic.com

[in](#) [Twitter](#) @colabatlantic

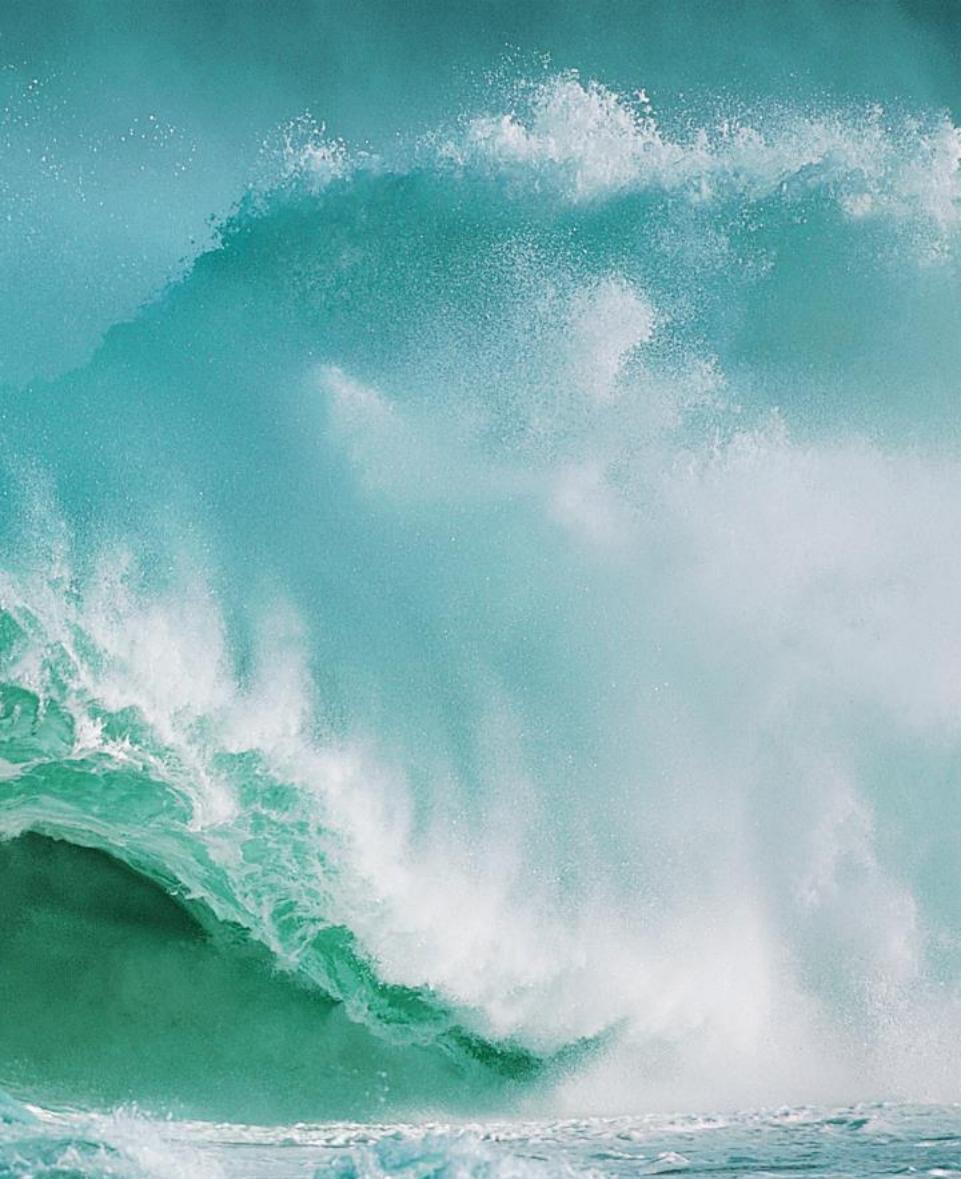


- Intro +ATLANTIC
- Numerical modelling
- Operational modelling
- Common graphs and data management
- The JULIA Challenge

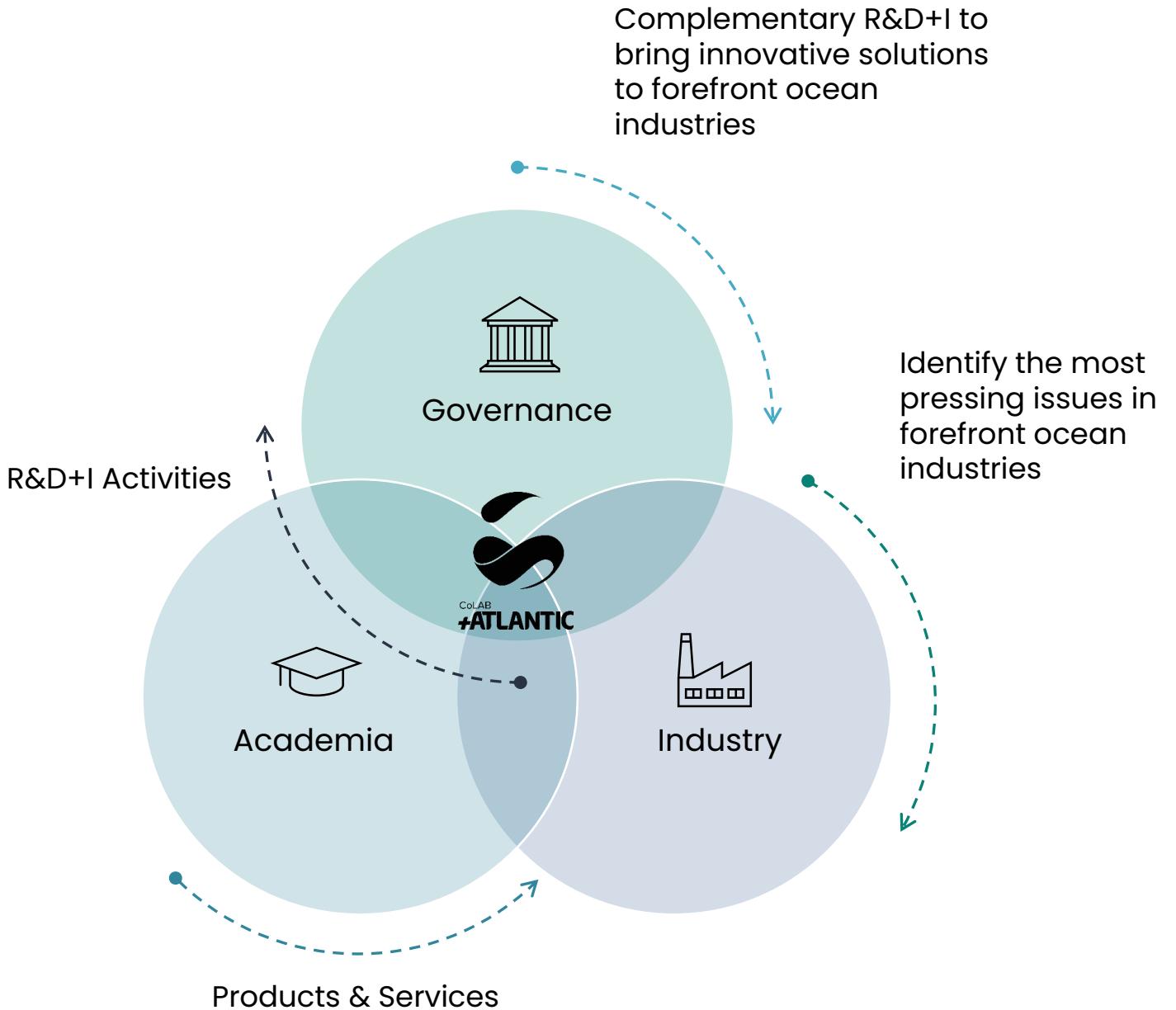
Intro

WHO? & WHAT?





Associates



Product Lines

Support to Ocean-based Economic Activities



AQUACULTURE & FISHERIES

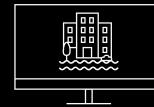
Software modules

- Dead fish monitoring
- Biometric parameters
- Physical conditions monitoring
- Feed optimisation

TAILOR-MADE SOFTWARE



Coastal and Transitional Areas



LISBON BAY DIGITAL TWIN

Operational Information as a service for climate

- Ocean and estuaries
- Coastal risks assessment and monitoring
- Climate and land
- Blue carbon capture and neutrality

OPERATIONAL DATA SERVICES

Ocean Stewardship

BLUE ECONOMY CONSULTANCY

Studies and services

- User consultation and requirements
- Stakeholder engagement and communication
- Regulatory support
- Ocean literacy

TAILOR-MADE SERVICES

Who?

The Team



Ana Luisa Almeida
COO



Ana Oliveira
CTO Space



André Oliveira



Andreia Silva



Artur Vieira Costa
CTO Ocean



Caio Fontes



Catarina Cecilio



Cintia Bonanad



Francisco Campuzano



Inês Girão



Inês de Sousa Magusteiro



Luis Pedro Almeida



Luís Figueiredo



Luísa Barros



Manvel Khudinyan



Maria Castro



Nuno Lourenço
CEO



Paula Salge



Renato Mendes



Rita Cunha



Rui Lopes Baeta



Sara Freitas



Sofia Aguiar



Soraia Romão



Tiago Garcia

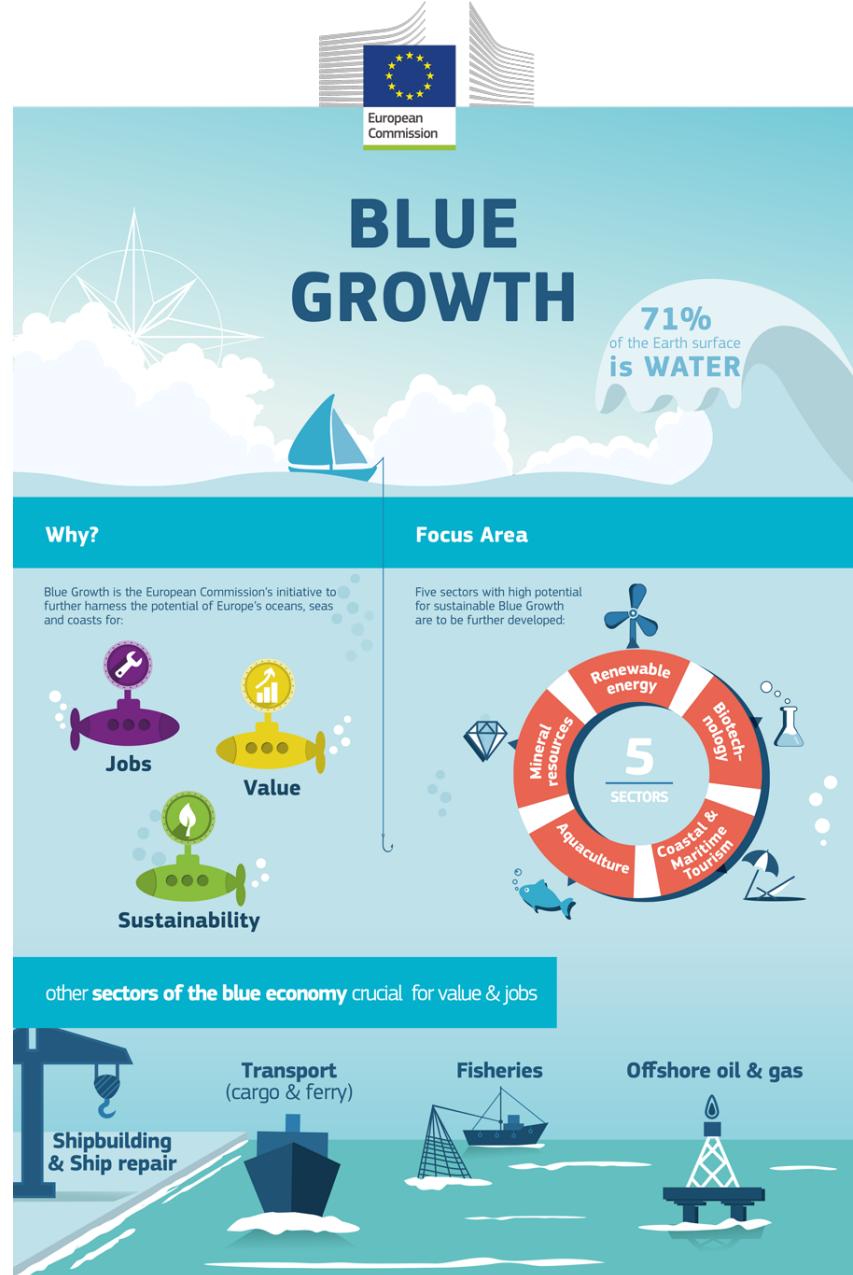
Intro

WHY?

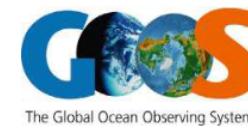


Blue economy

- Many **economic activities** take place in the **near ocean** i.e., marine renewable energy production, fisheries and aquaculture, coastal and maritime tourism, ship transport, oil and gas exploration, etc.
- These activities are subjected to **risks** and need to be sustainable. Numerical operational models are capable to analyse and forecast the **environmental suitability** of those activities.
- Other **services** such as oil spill forecast, HABs propagation and **search and rescue operations** may also rely in the **accuracy** of numerical models **forecasts** near the coastal area.



Meteocean prediction systems in our ocean



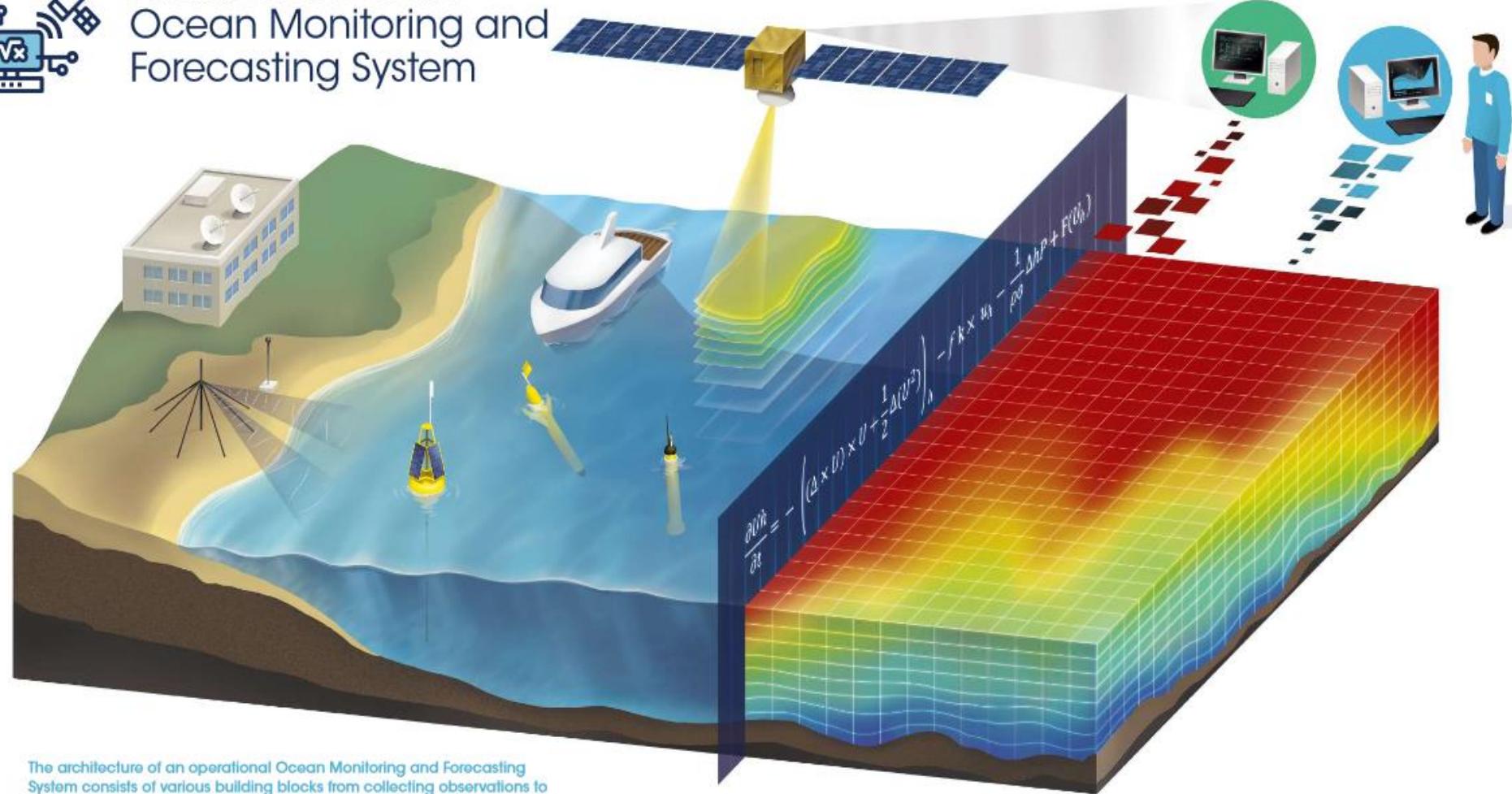
Numerical ocean modelling to know current sea state and **predict** near future events.

Modelling products tailored to **users' needs** anywhere in the planet.

Requires knowledge of several scientific and technological fields: i.e. meteo-oceanography, engineering, IT, data science...

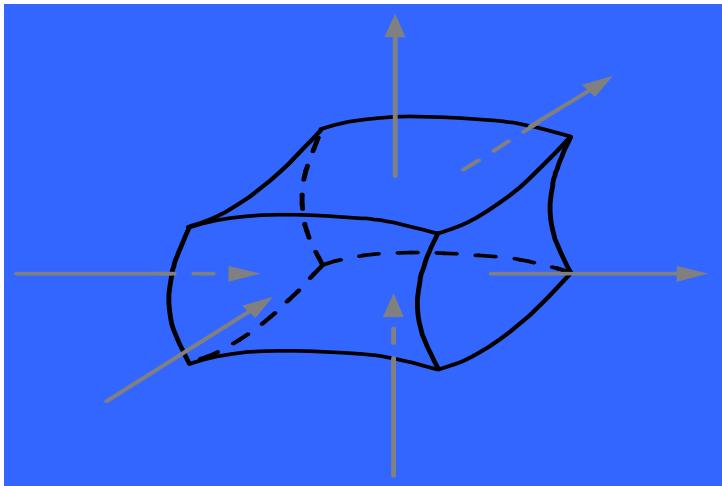


Architecture of an Ocean Monitoring and Forecasting System



The architecture of an operational Ocean Monitoring and Forecasting System consists of various building blocks from collecting observations to modeling and forecasting the ocean state.

The models

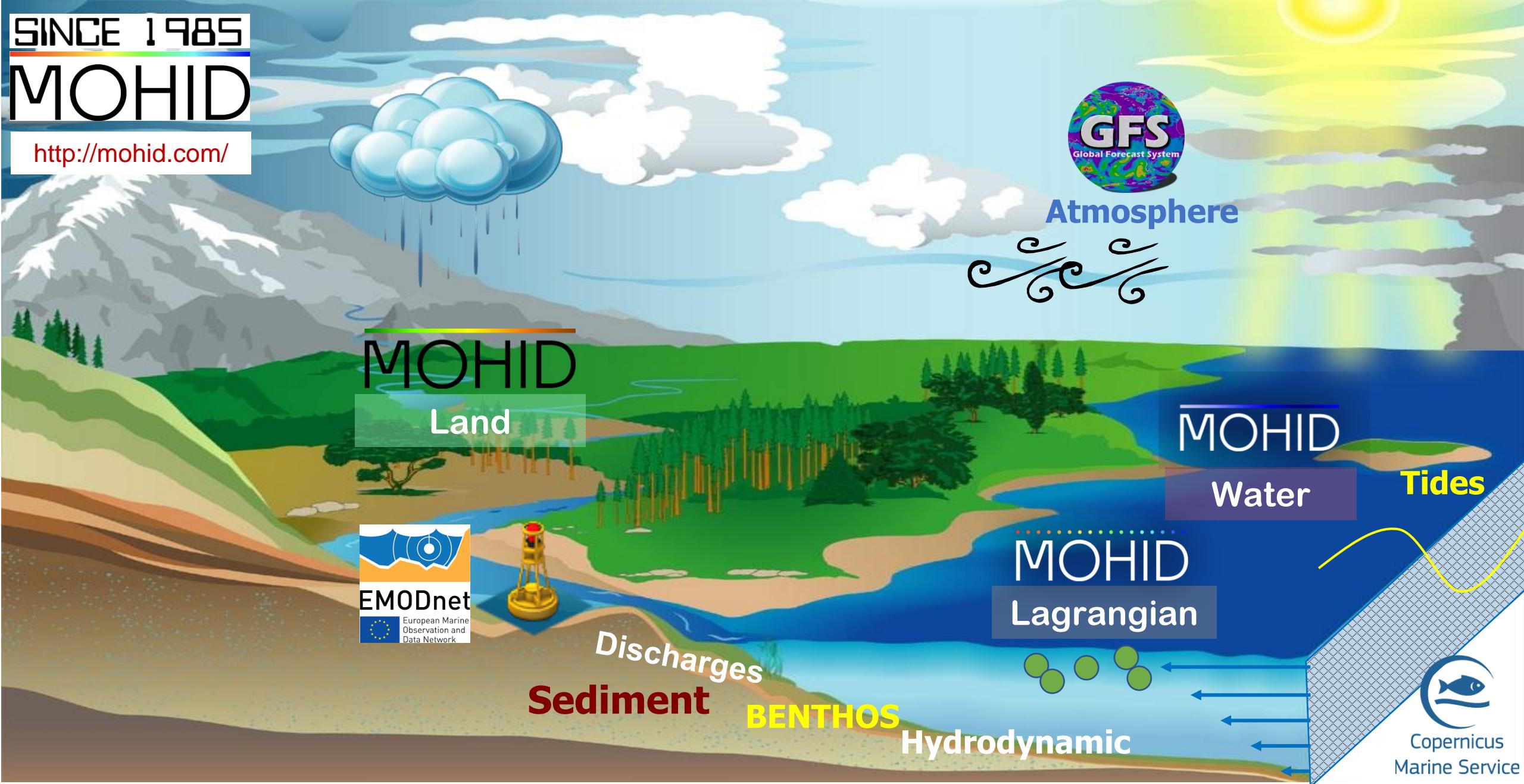


$$\frac{\partial}{\partial t} \iiint_{CV} \beta dV = - \iint_{surface} (\beta \vec{v} \cdot \vec{n} - A(\vec{\nabla} \beta) \cdot \vec{n}) dA + \\ + (S_o - S_i)$$

Mathematical models improve with age.....

SINCE 1985
MOHID

<http://mohid.com/>

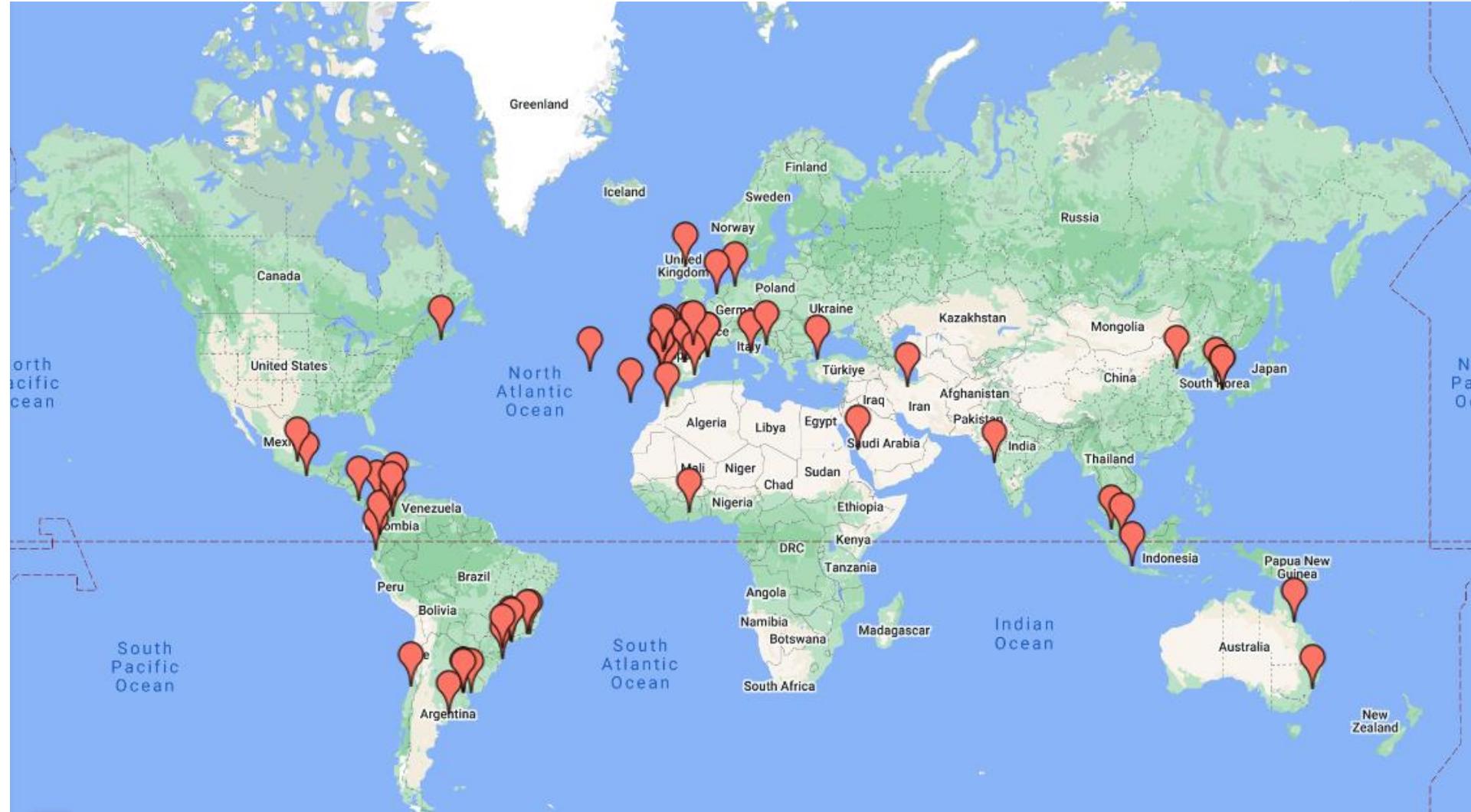


Main Contributors:



MOHID

- Designed and maintained by a global community **since 1985**
- Open-source code at GitHub:
<https://github.com/Mohid-Water-Modelling-System>



Institutions used MOHID

MOHID

- 3D hydrodynamics and biogeochemistry
- Cartesian, sigma and hybrid vertical grids

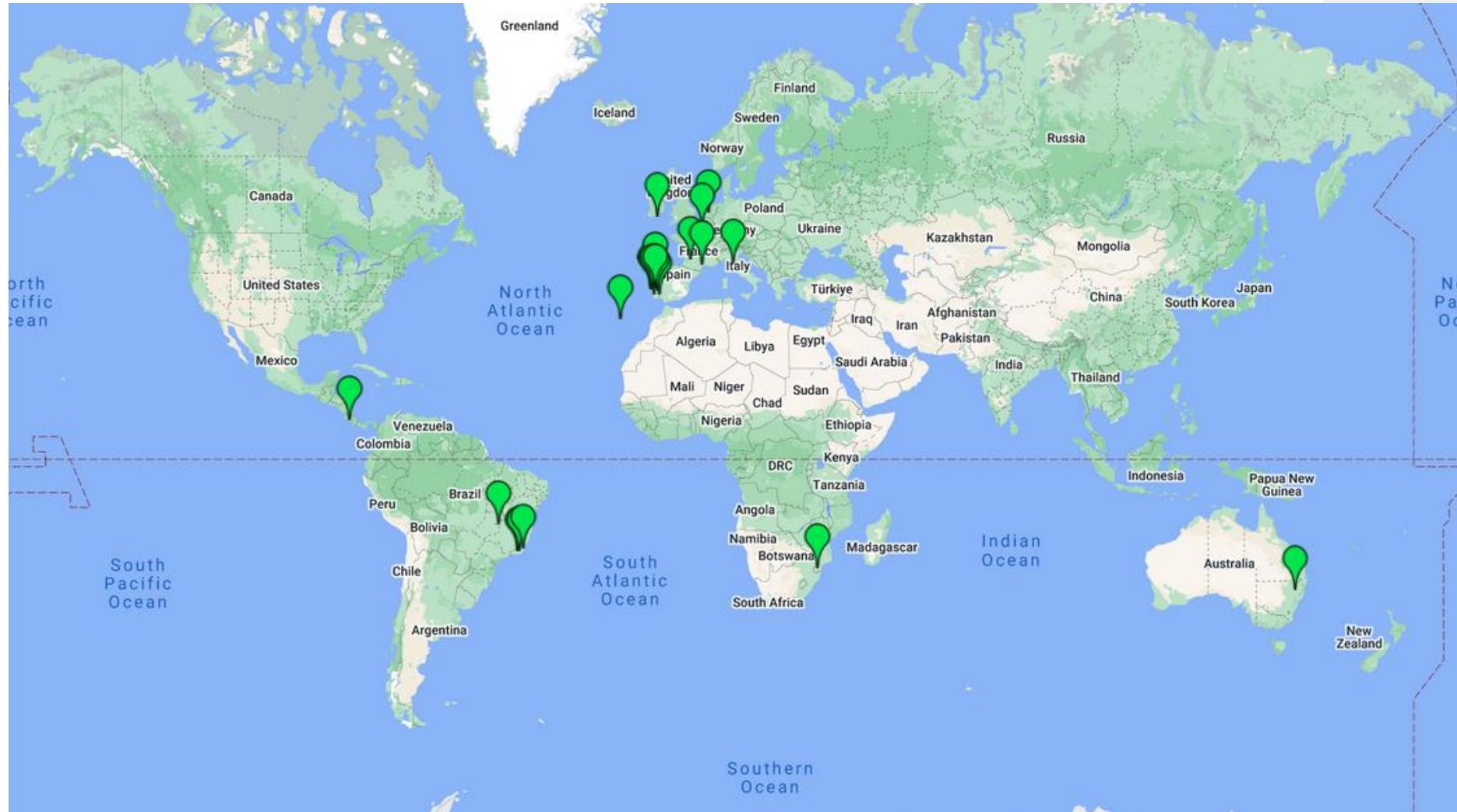
MOHID

- Online and offline coupling with circulation models



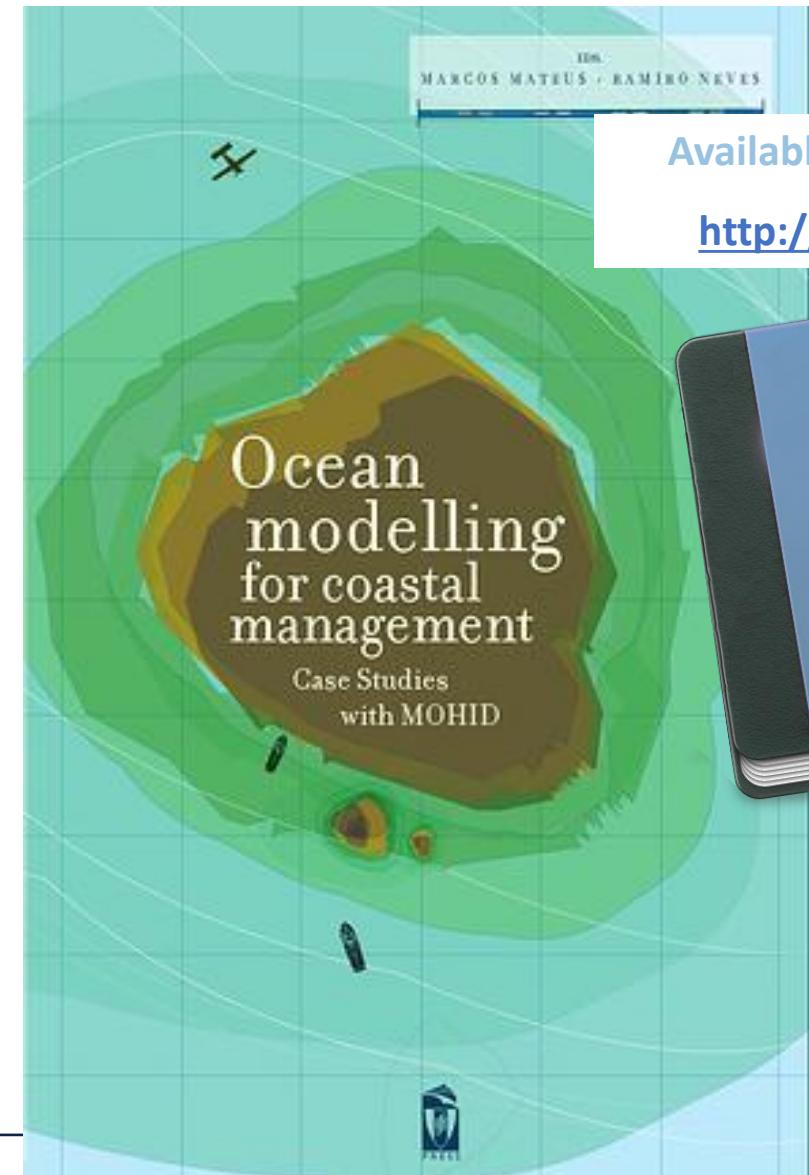
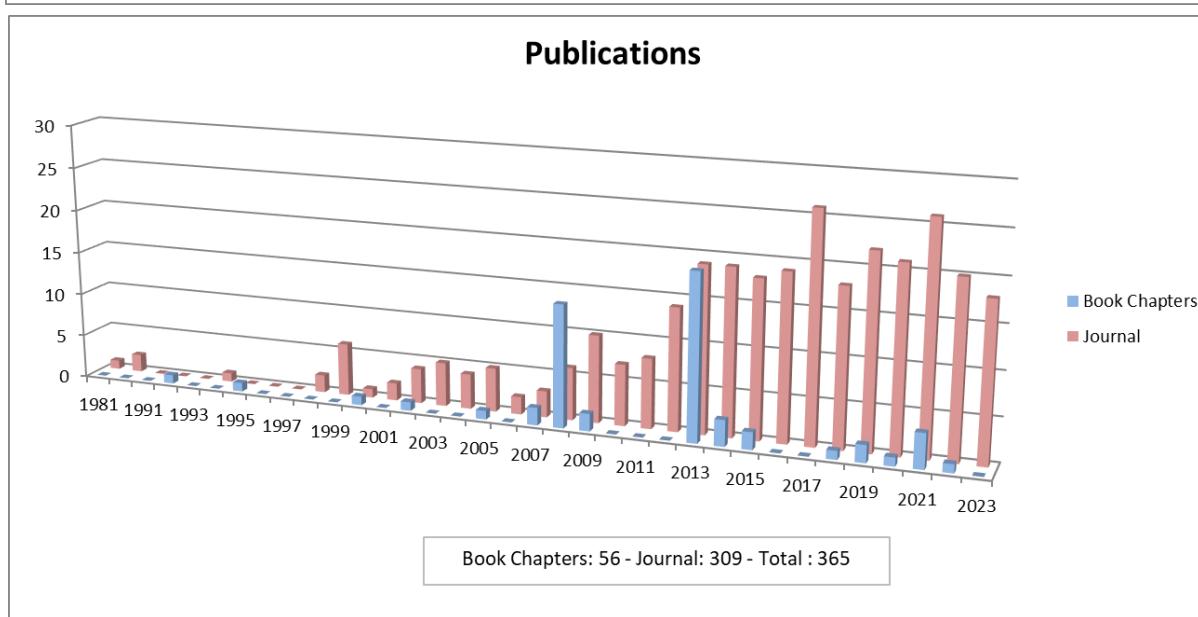
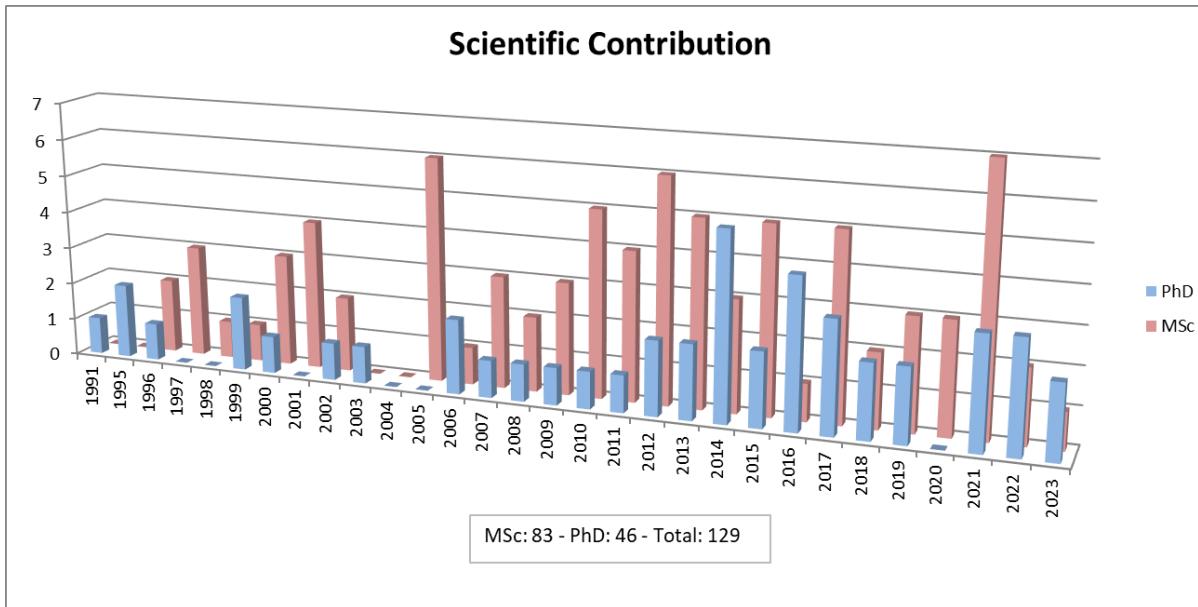
MOHID

- Physical-oriented model
- 1D river network, 2D surface and 3D groundwater processes
- Plant dynamics



MOHID Land applications

Scientific background of MOHID



Available for download at:
<http://wiki.mohid.com>

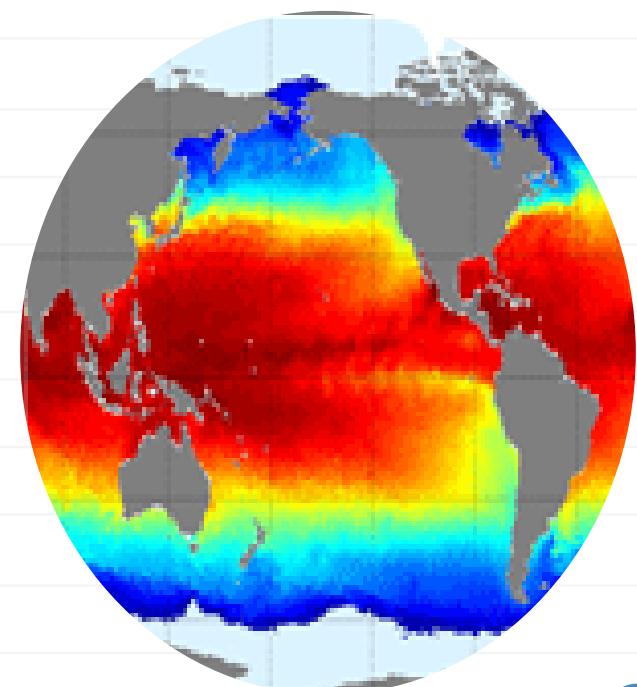




Global circulation models

Provide 3D daily and hourly surface fields for velocity, water level, temperature and salinity

- Full name: Global Ocean 1/12° Physics Analysis and Forecast updated Daily
- Product ID: GLOBAL_ANALYSISFORECAST_PHY_001_024
- Copernicus Marine Catalogue link:
[https://data.marine.copernicus.eu/product/GLOBAL ANALYSISFORECAST PHY 001 024/description](https://data.marine.copernicus.eu/product/GLOBAL_ANALYSISFORECAST_PHY_001_024/description)





<https://marine.copernicus.eu/>

https://data.marine.copernicus.eu/products

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Services Opportunities Access Data Use Cases User Corner About

Copernicus Marine Data Store



Home > Marine Data Store

Filters

FREE-TEXT SEARCH

Free text

FAVOURITES ★ 0

TIME RANGE ▾

mm / dd / yyyy mm / dd / yyyy

Covering full interval

WITH DEPTH 39

DEPTH RANGE ▾

UNIVERSE ▾

Blue Ocean 189

White Ocean 39

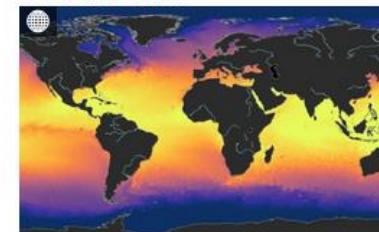
Green Ocean 78

MAIN VARIABLES ▾

Carbonate system 19

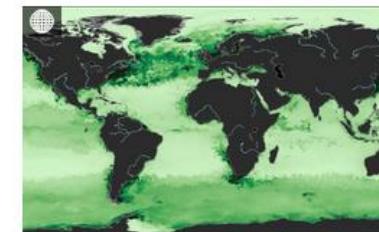
Products 275

MOST POPULAR



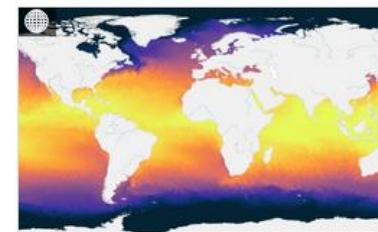
Global Ocean Physics Analysis
and Forecast

GLOBAL_ANALYSISFORECAST_P... 001_024
Models
Global, $0.083^\circ \times 0.083^\circ \times 50$ levels
31 Oct 2020 to 21 Jul 2023, hourly, daily,...
Mixed layer thickness, salinity, sea ice, sea
surface height, temperature, velocity, wave...



Global Ocean Biogeochemistry
Analysis and Forecast

GLOBAL_ANALYSIS_FORECAST_B... 001_028
Models
Global, $0.25^\circ \times 0.25^\circ \times 50$ levels
31 Oct 2020 to 14 Jul 2023, daily, monthly
Carbonate system, nutrients, oxygen,
plankton



Global Ocean Physics Reanalysis

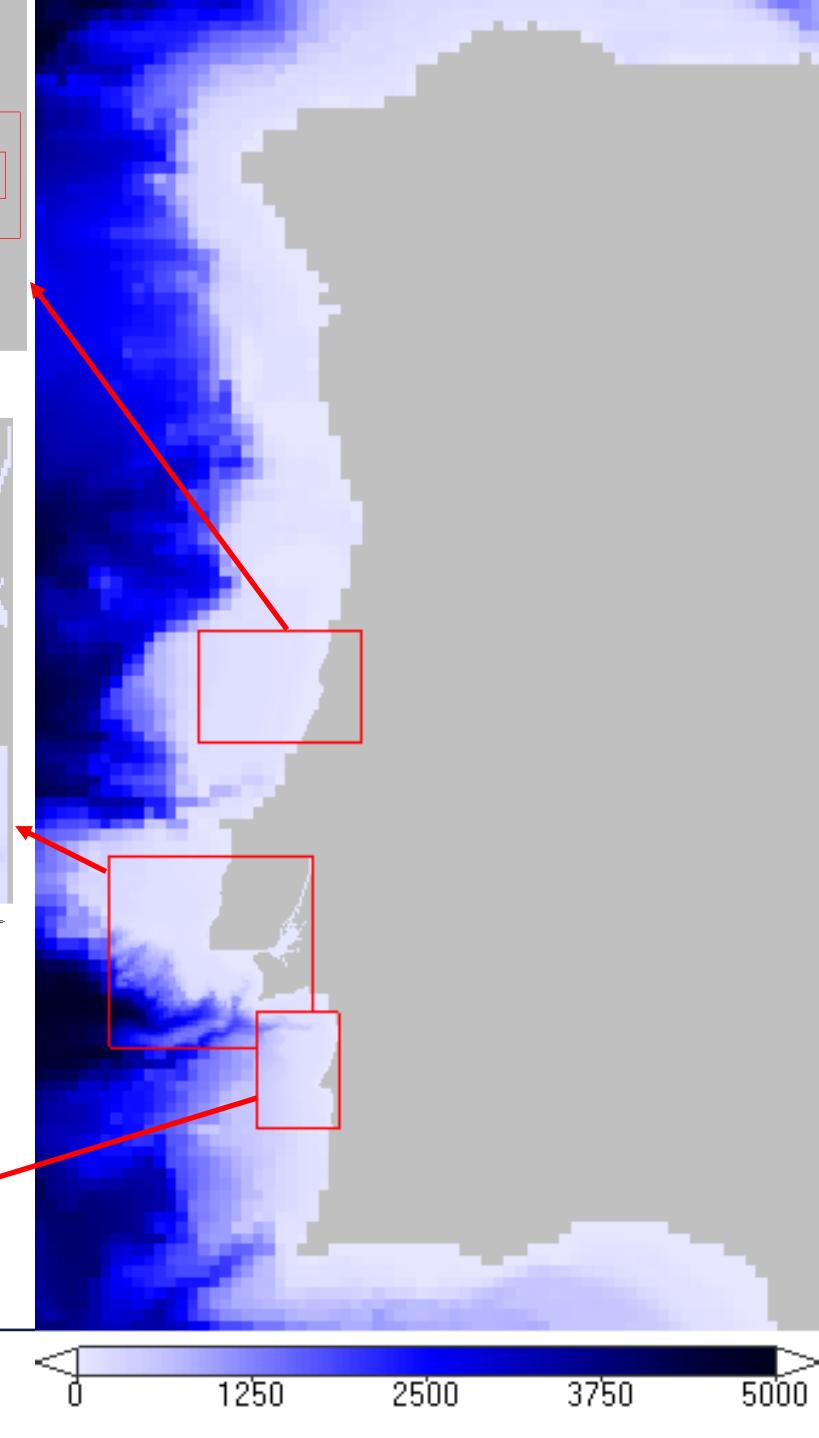
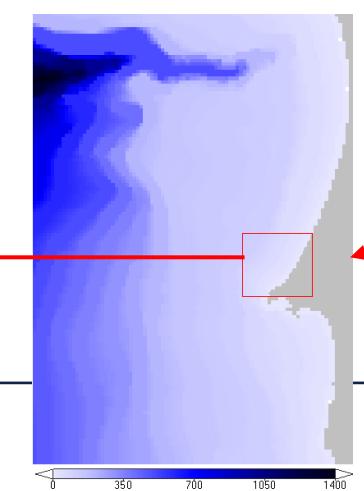
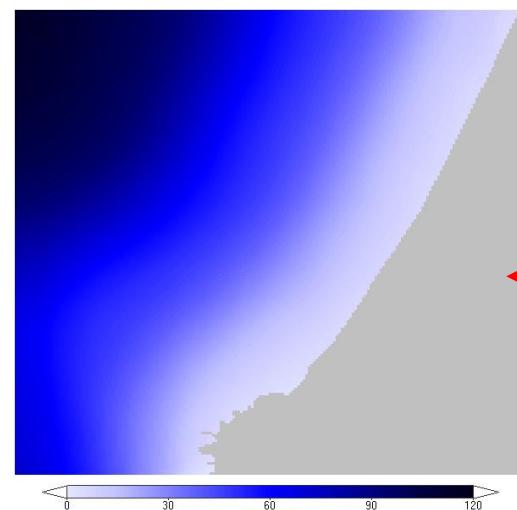
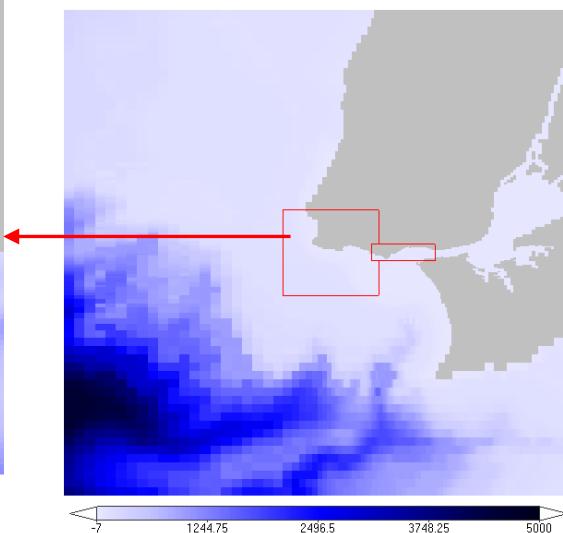
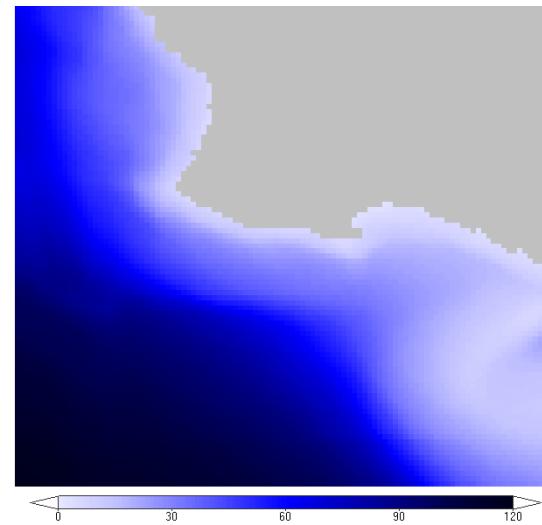
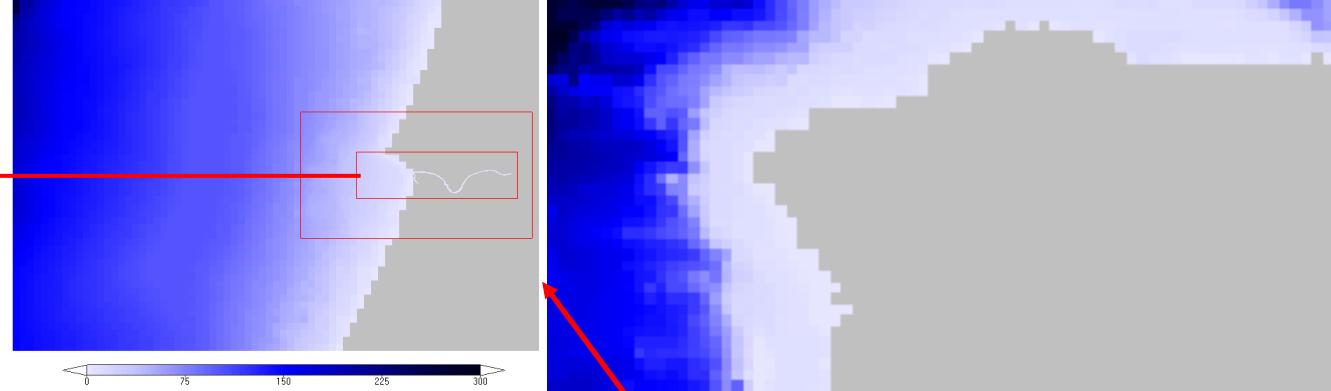
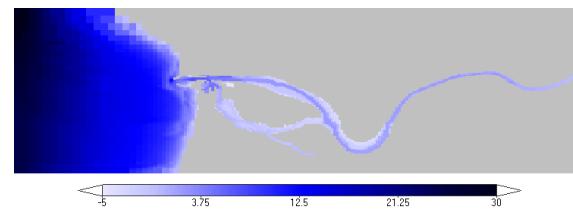
GLOBAL_MULTIYEAR_PHY_001_030
Models
Global, $0.083^\circ \times 0.083^\circ \times 50$ levels
1 Jan 1993 to 30 Dec 2020, daily, monthly
Mixed layer thickness, salinity, sea ice, sea
surface height, temperature, velocity



Global Ocean Surface H...

SEALEVEL_I
Satellite (L4)
Global, 0.25°
1 Jan 1993
Sea surface

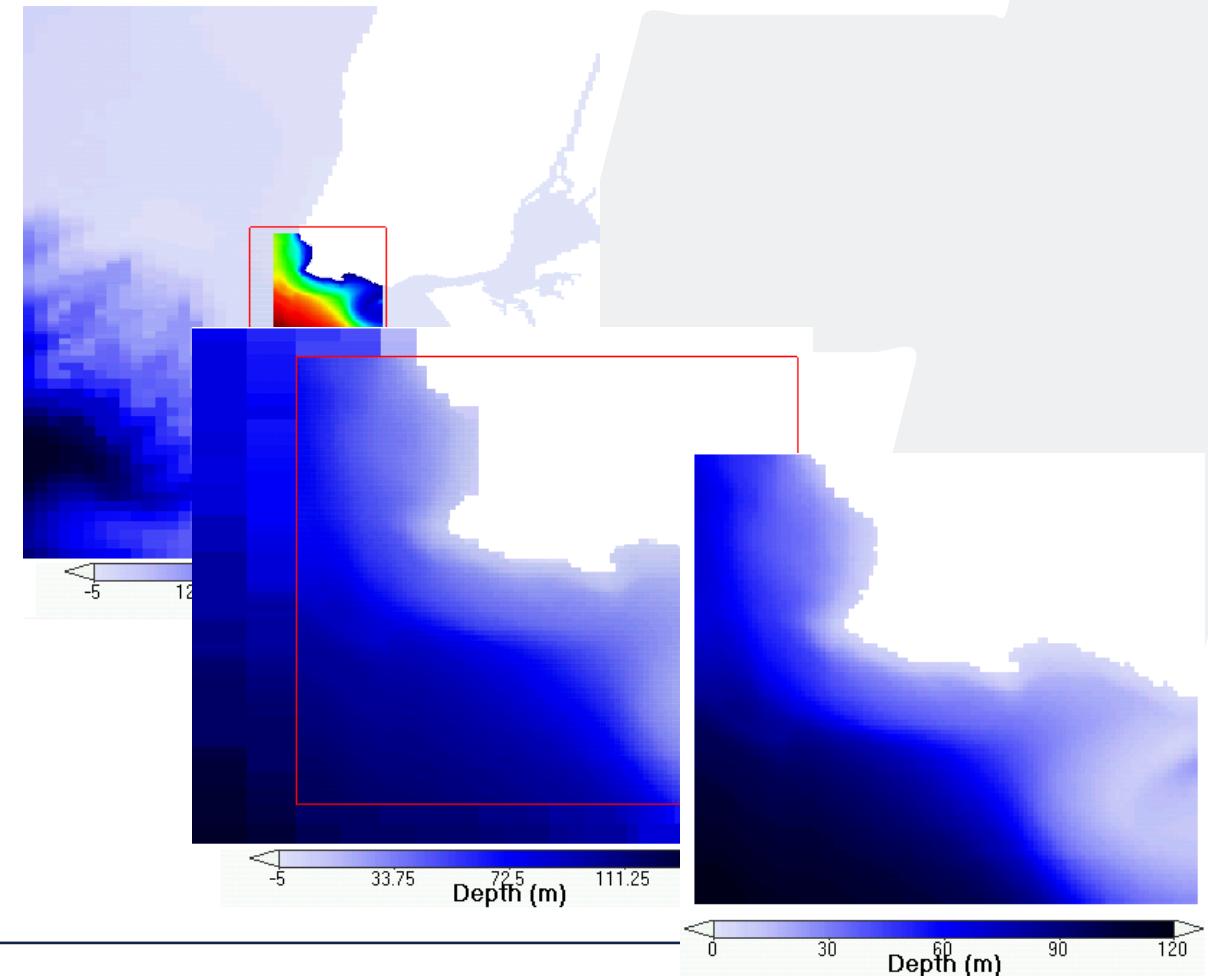
Downscaling



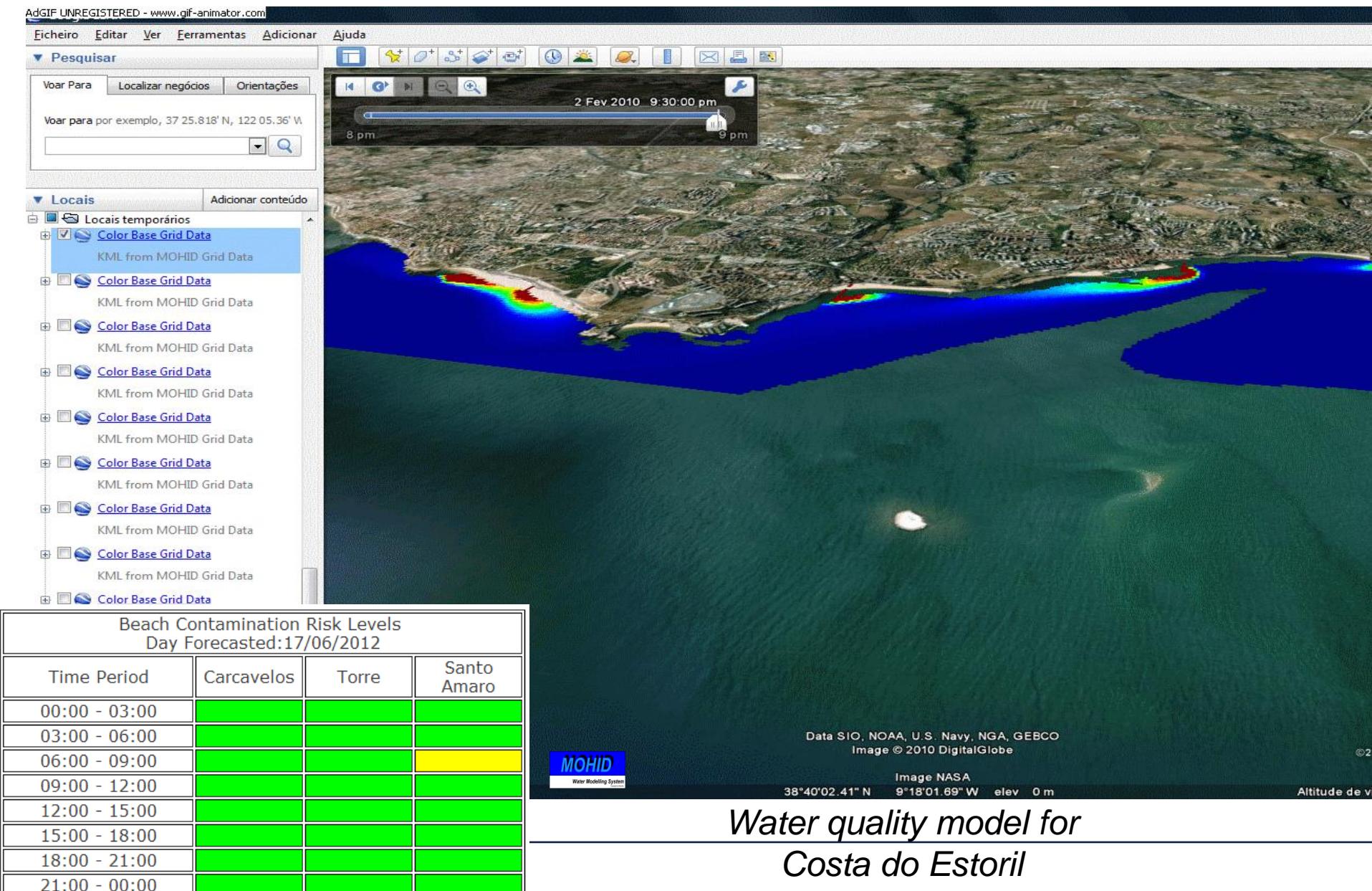
"Any procedure to infer high-resolution information from low-resolution variables. The term downscaling usually refers to an increase in spatial resolution"(Wikipedia)

The Window Downscaling Technique

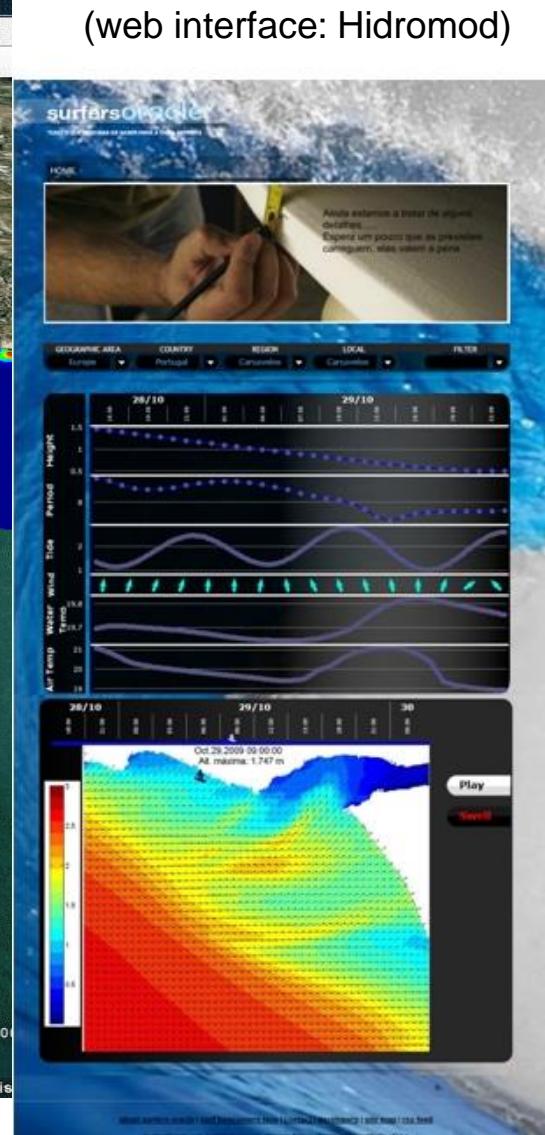
- Is a delayed mode (offline) technique.
- Consists in saving a window of model results from the upstream model with a high temporal resolution able to represent the main processes coming from the open ocean (i.e. the tide signal). Some advantages are:
 - Allows the local model to run independently
 - Does not increase the running time of the upstream models
 - Allows running several downstream models at the same time
 - Allows integrating ecological processes with greater time scales



Local Scale ($dx=35m$)

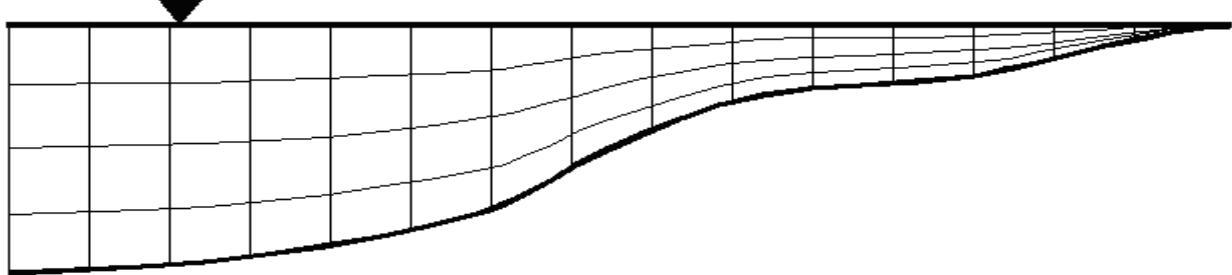


Water quality model for Costa do Estoril

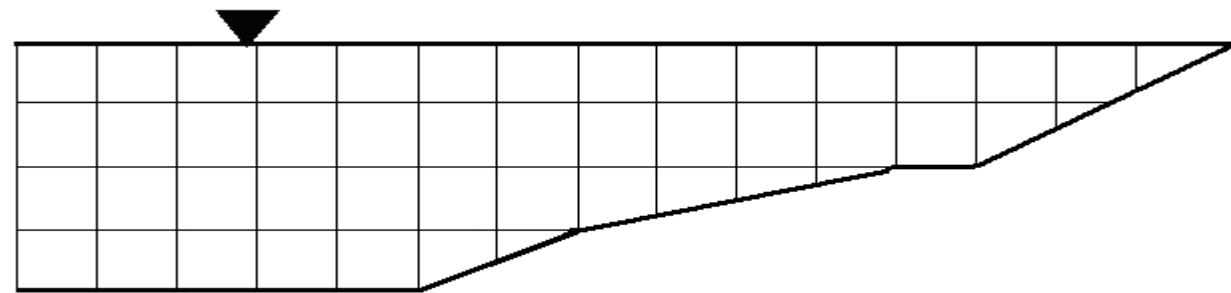


Vertical Discretisation – type of layer

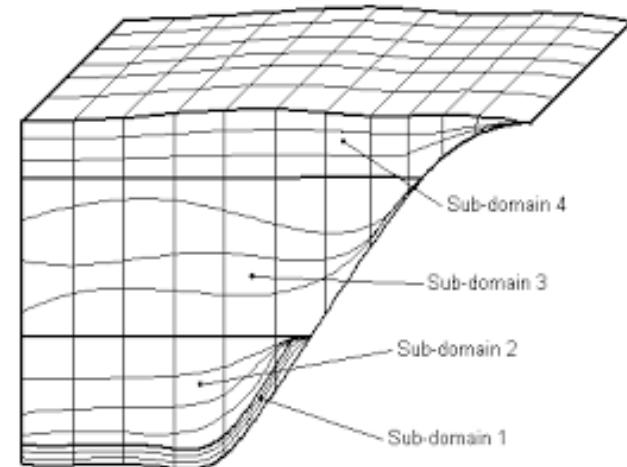
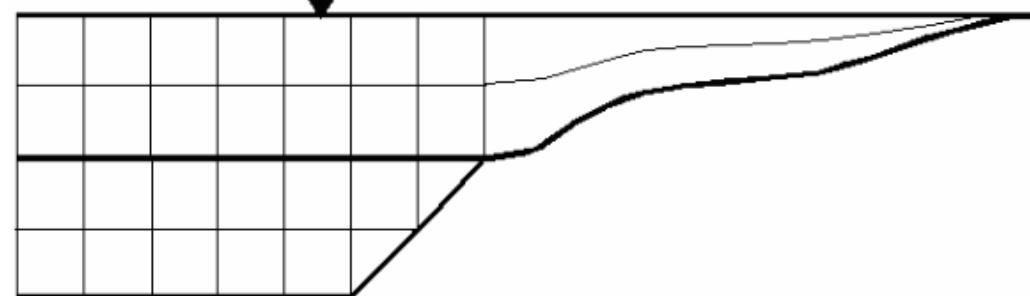
Sigma



Cartesian or z-layer



Hybrid



Level 1

Level 2

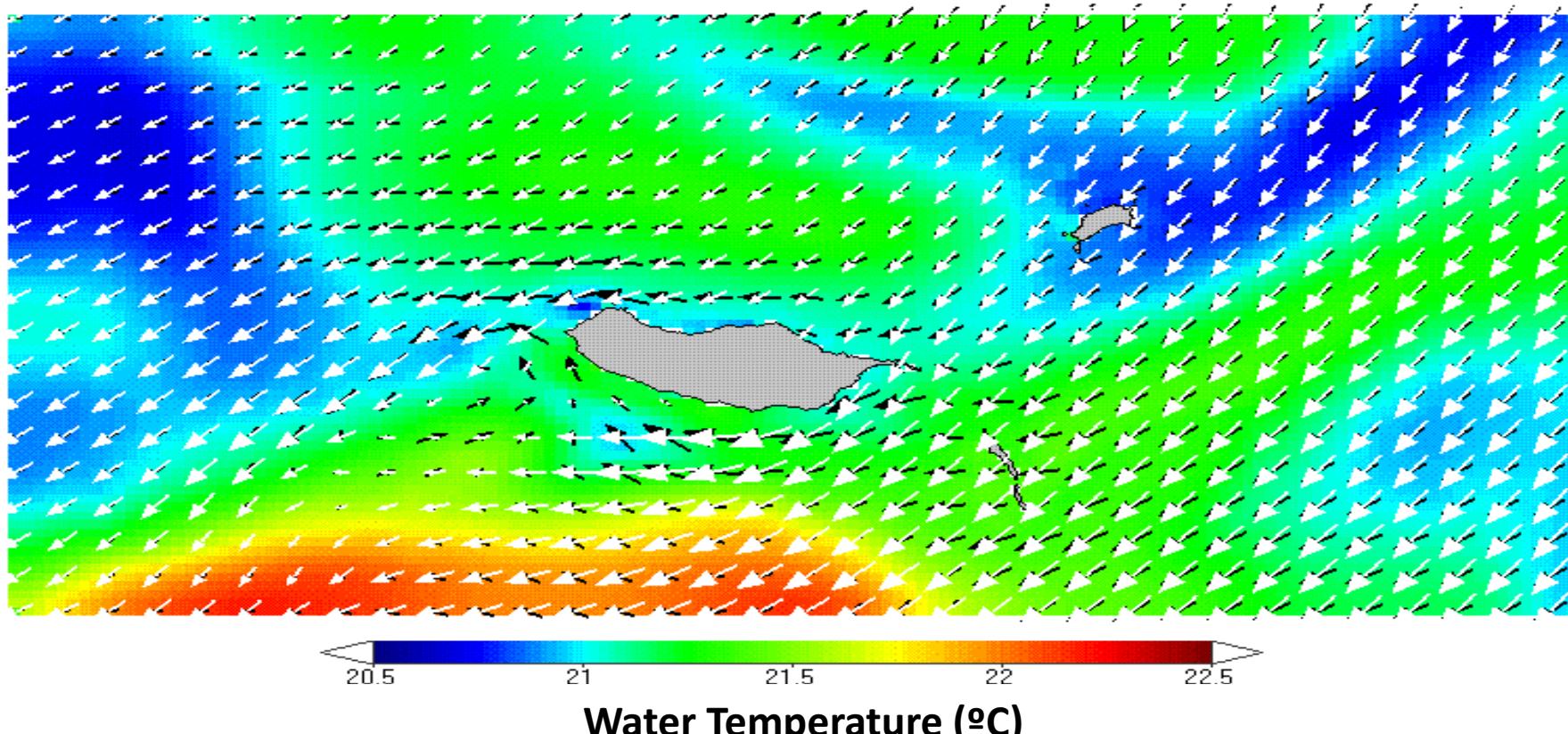
Level 3

Level 4

Level 5



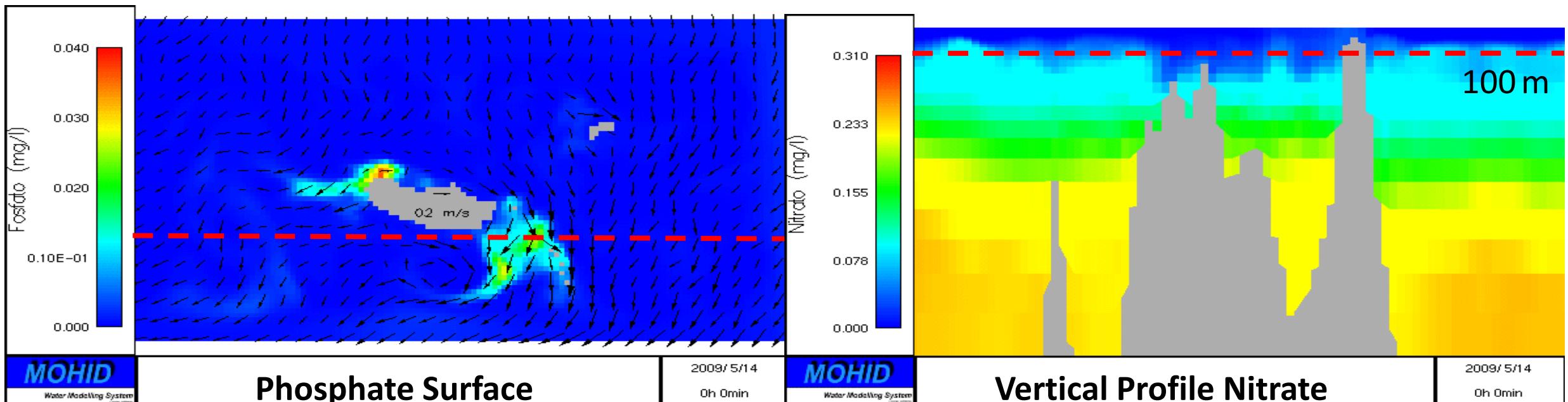
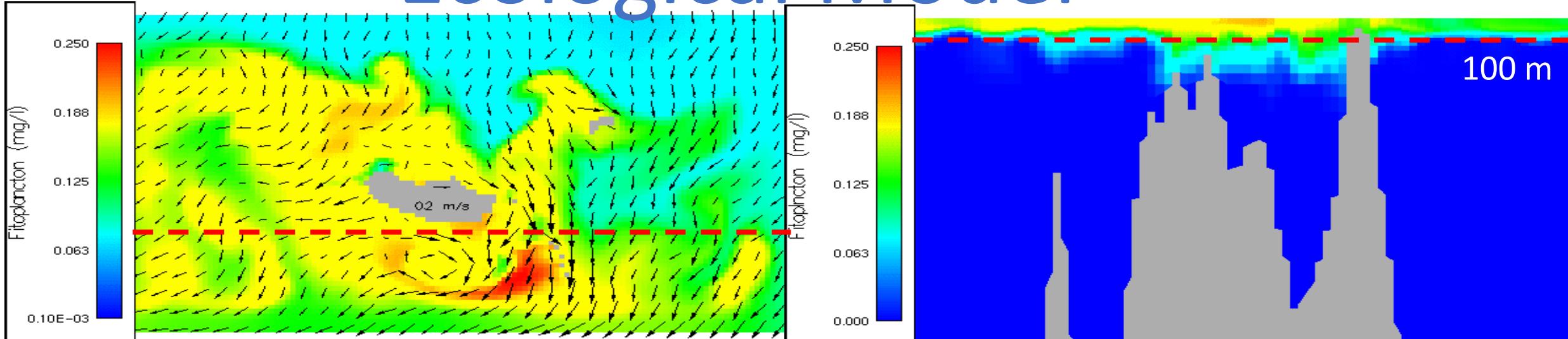
Coupled Models



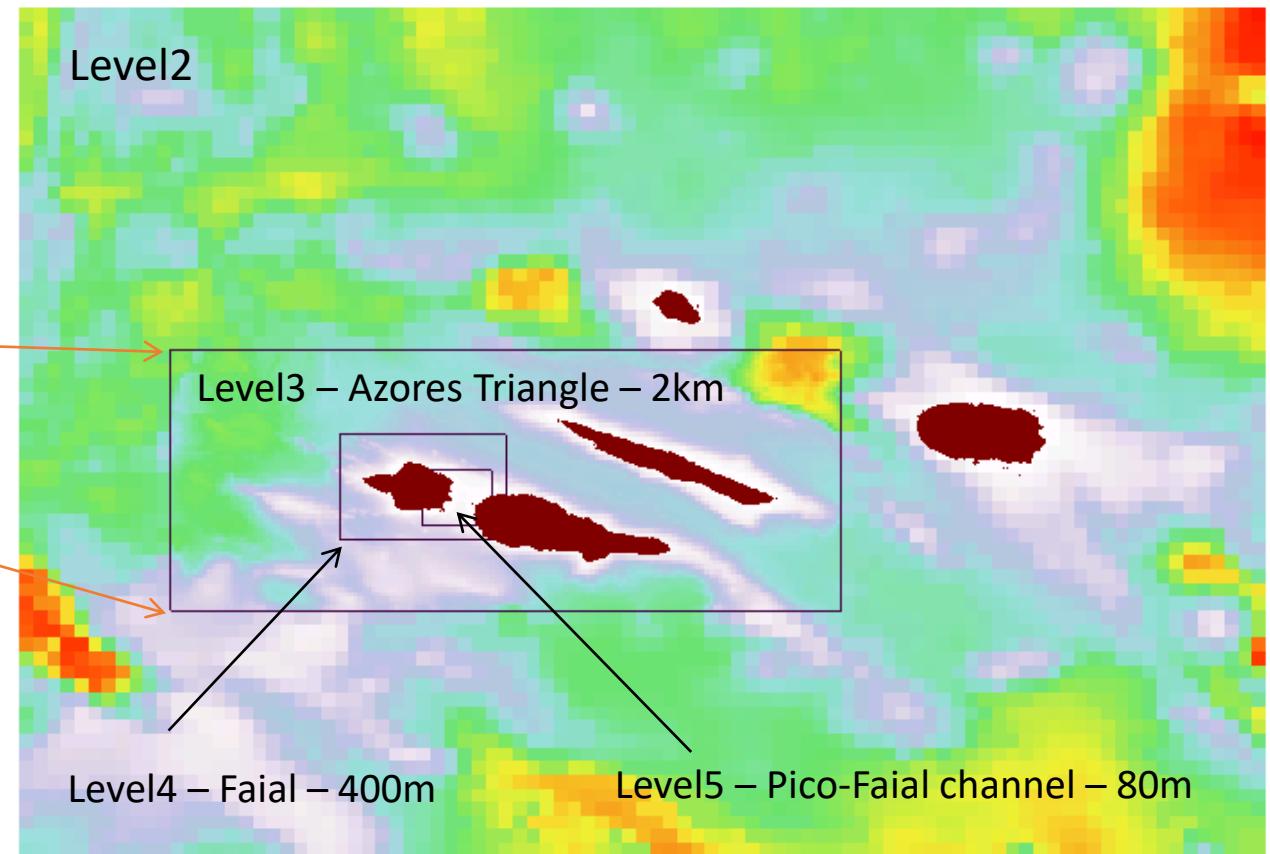
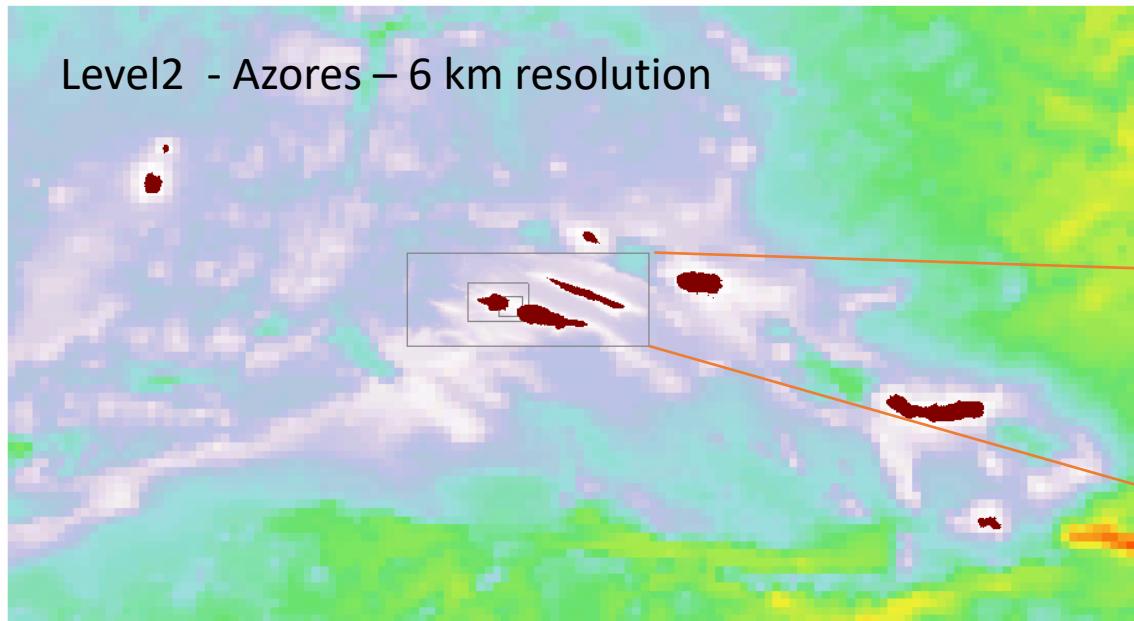
Surface Temperature in the Madeira Archipelago
White arrows (Wind) Black Arrows (Surface velocity)

07-11-2008
16:00

Ecological Model

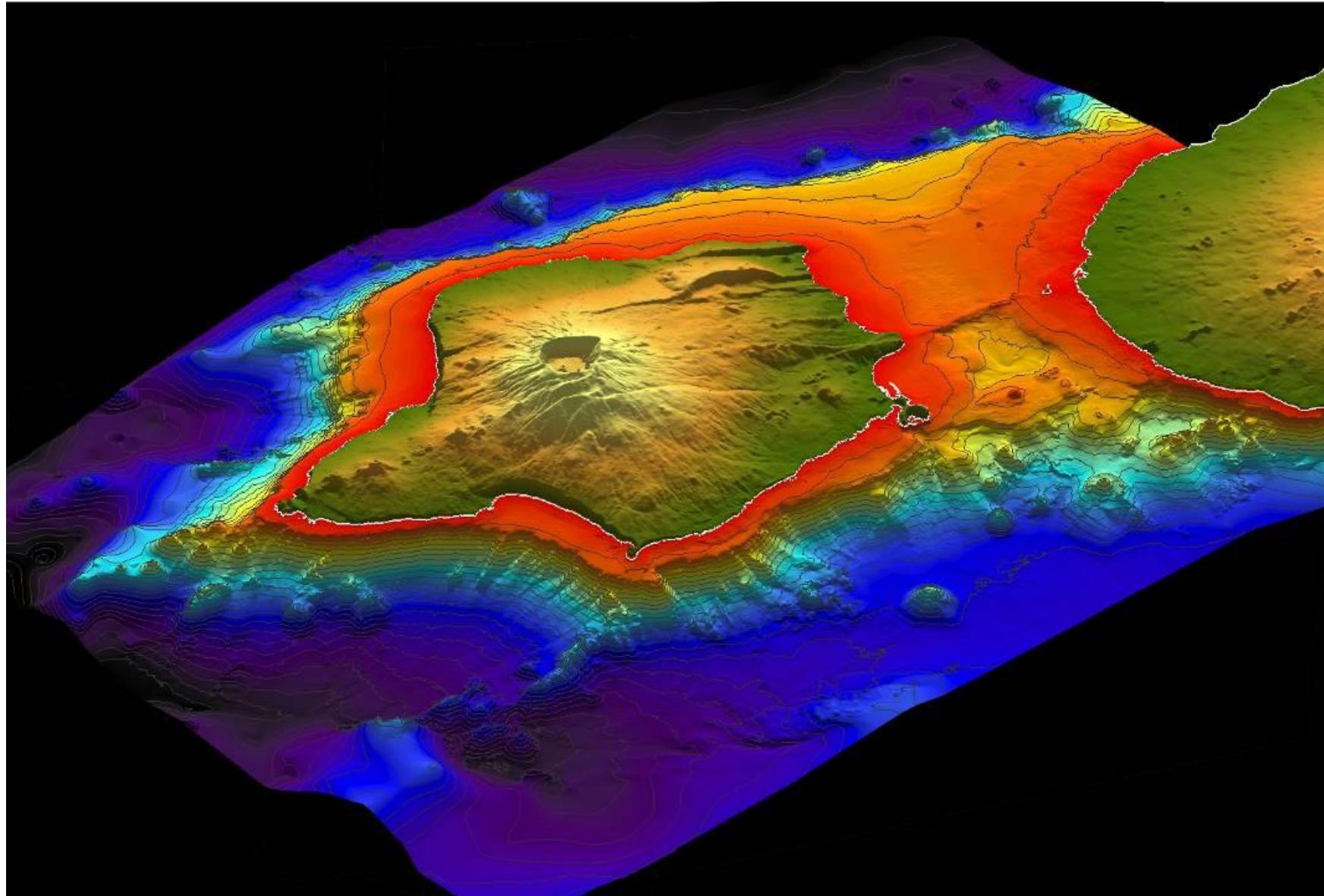


Azores Modeling domains



UAc
UNIVERSIDADE
DOS AÇORES

Azores - Pico-Faial channel



Credits: Fernando Tempera



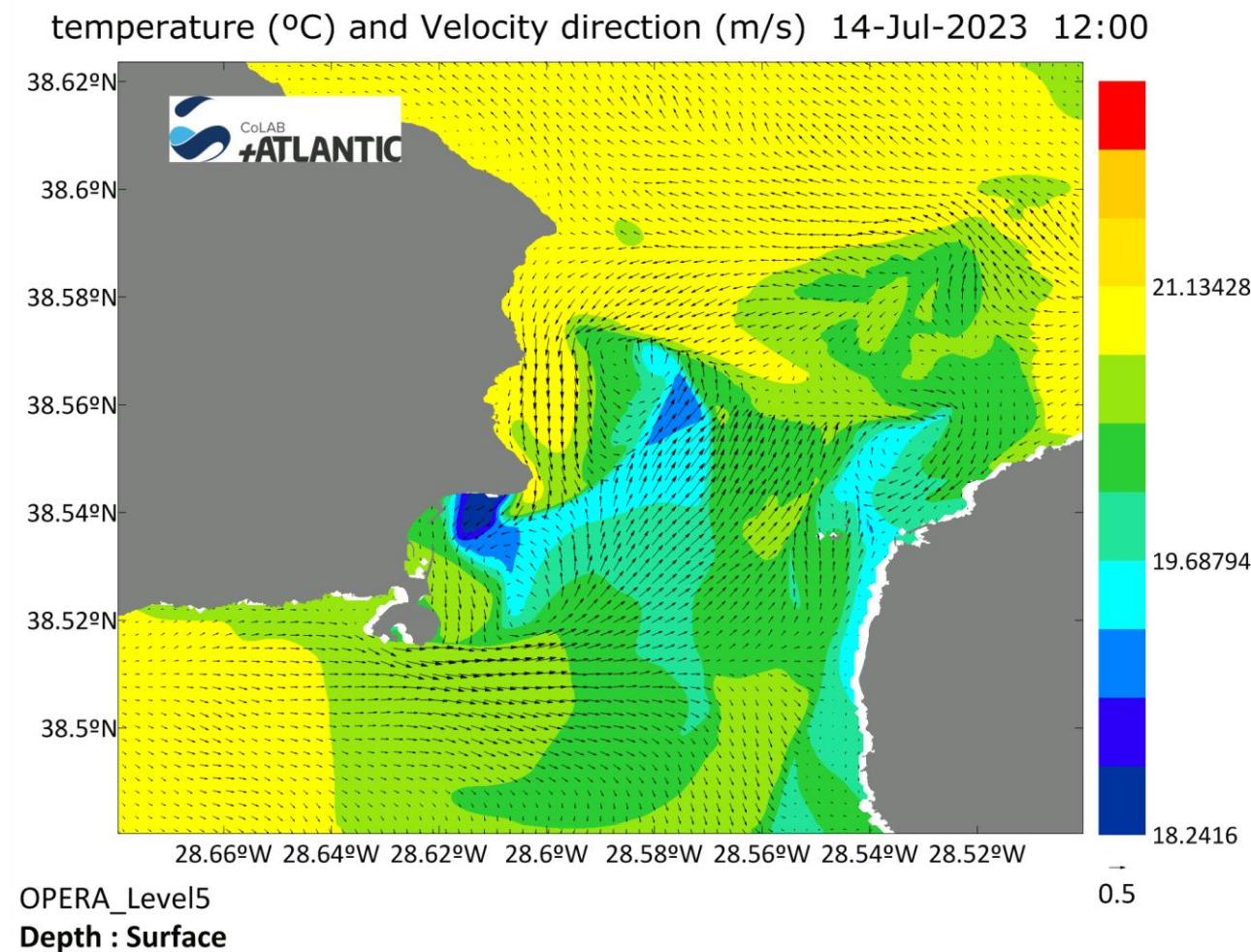
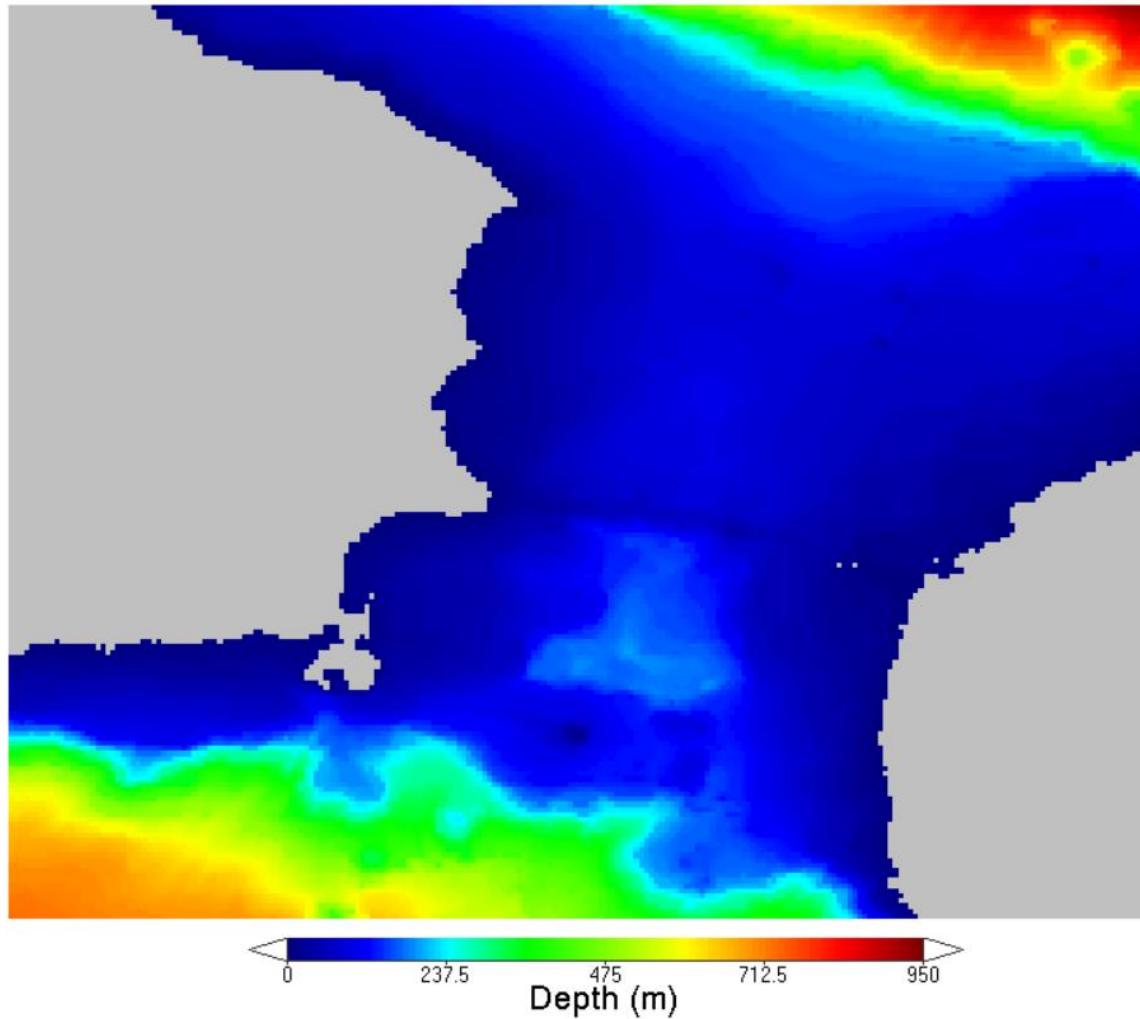
UAc
UNIVERSIDADE
DOS AÇORES



<https://marine.copernicus.eu/>

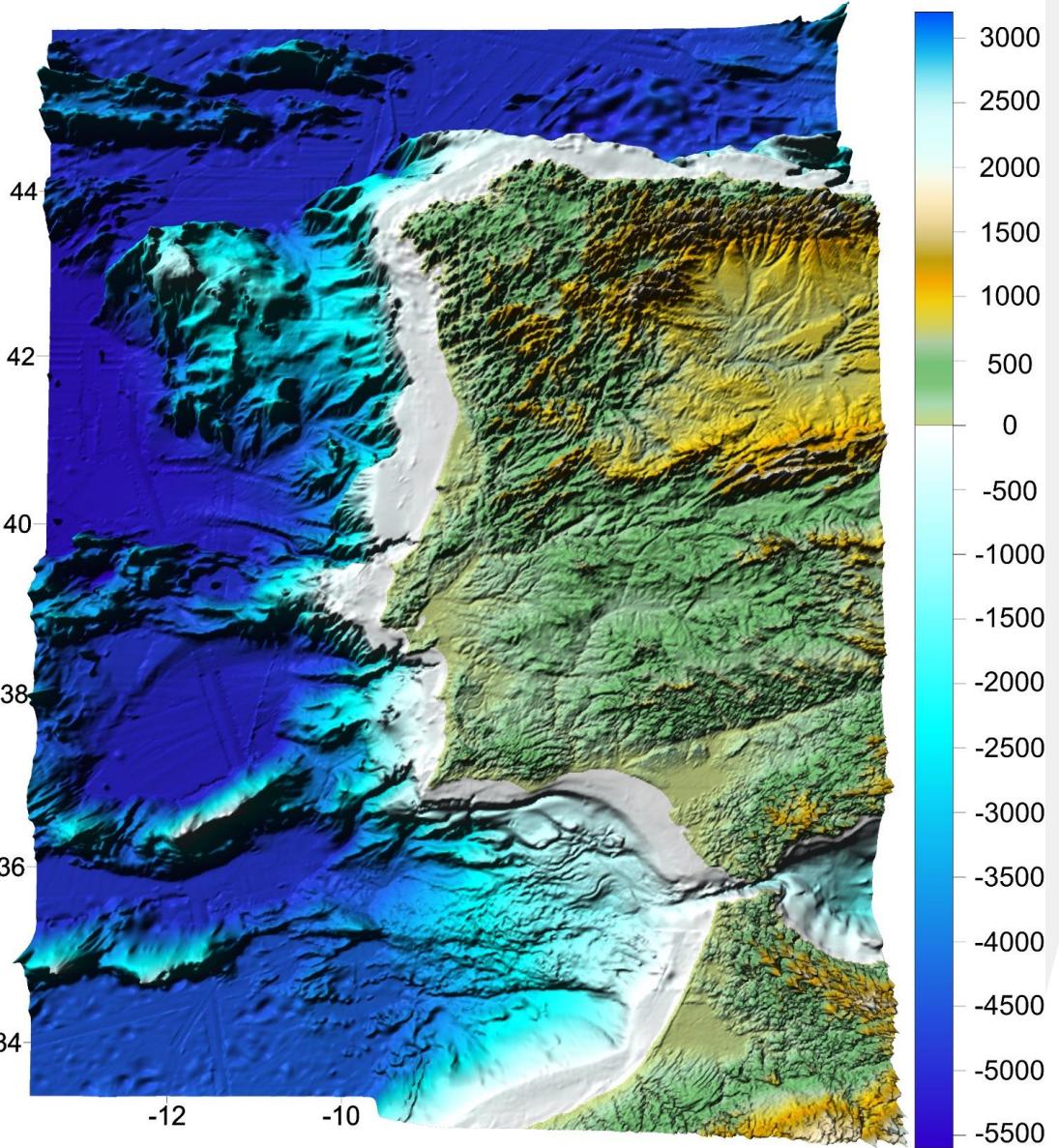
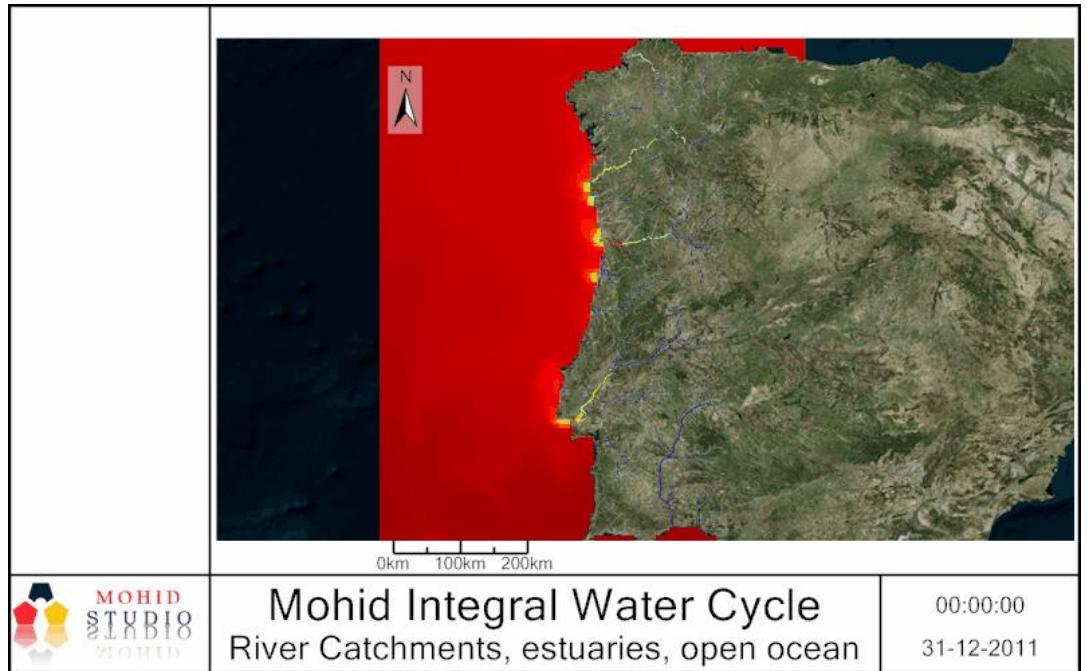


Azores Modelling Domains - Pico-Faial channel Level 5 – Pico – Faial channel – 80 m hor. resolution



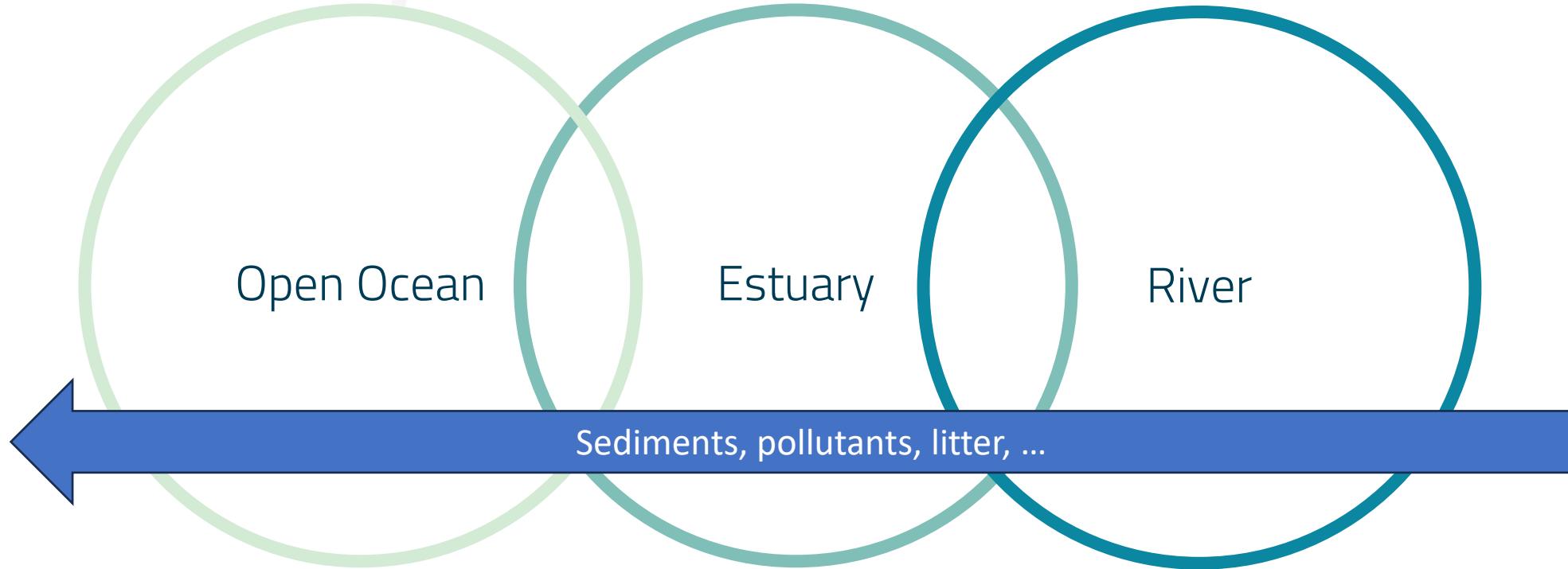
A paradigm shift: Integrated water cycle approach

Current research trends include to **improve** the coastal circulation in regional ocean model applications by a better characterisation of the **land-ocean boundary conditions**. Towards a holistic view of the coastal area.



Integrated water cycle approach/Water Continuum

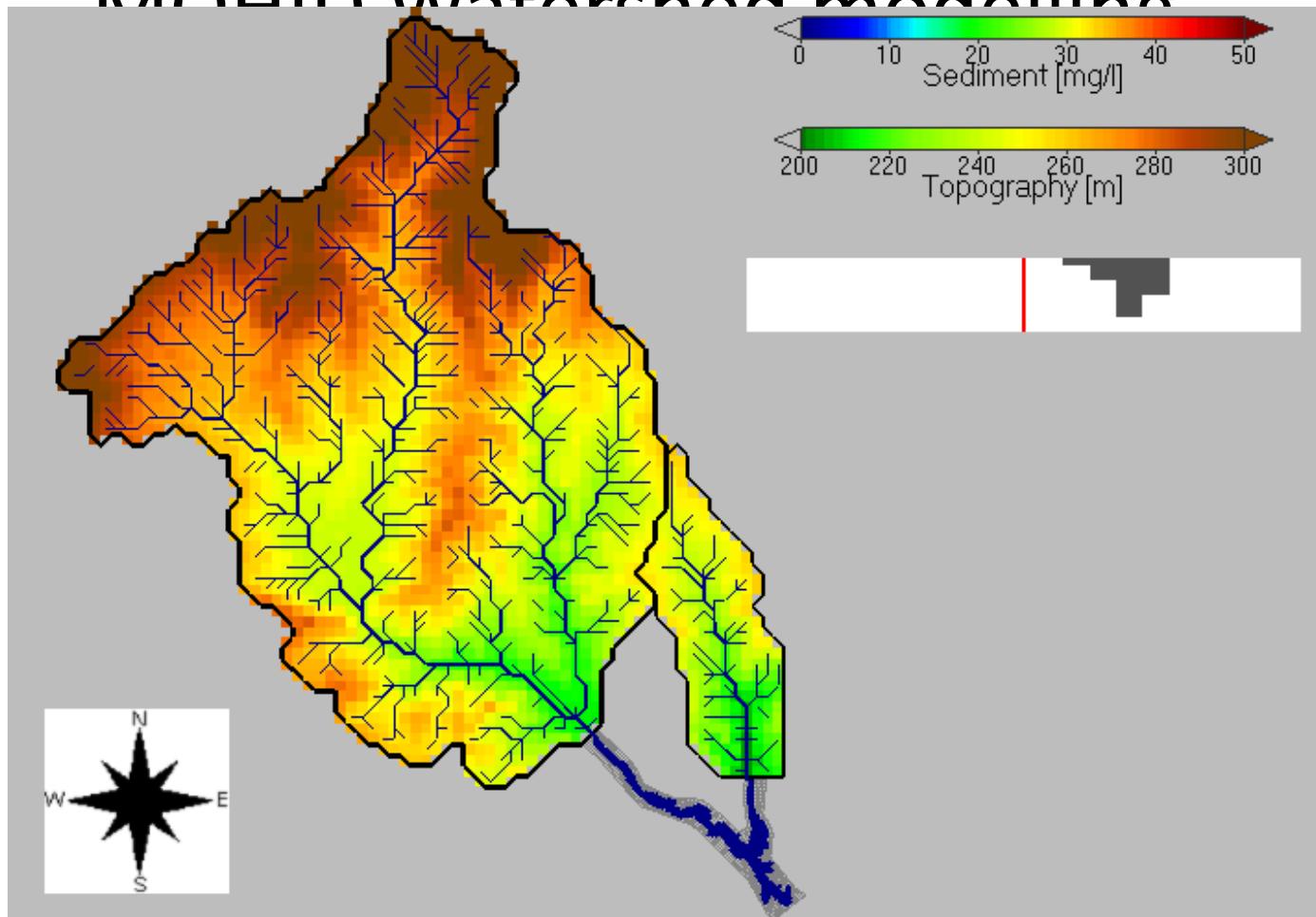
- Coastal water are deeply influenced by river outflow



Complete description at:

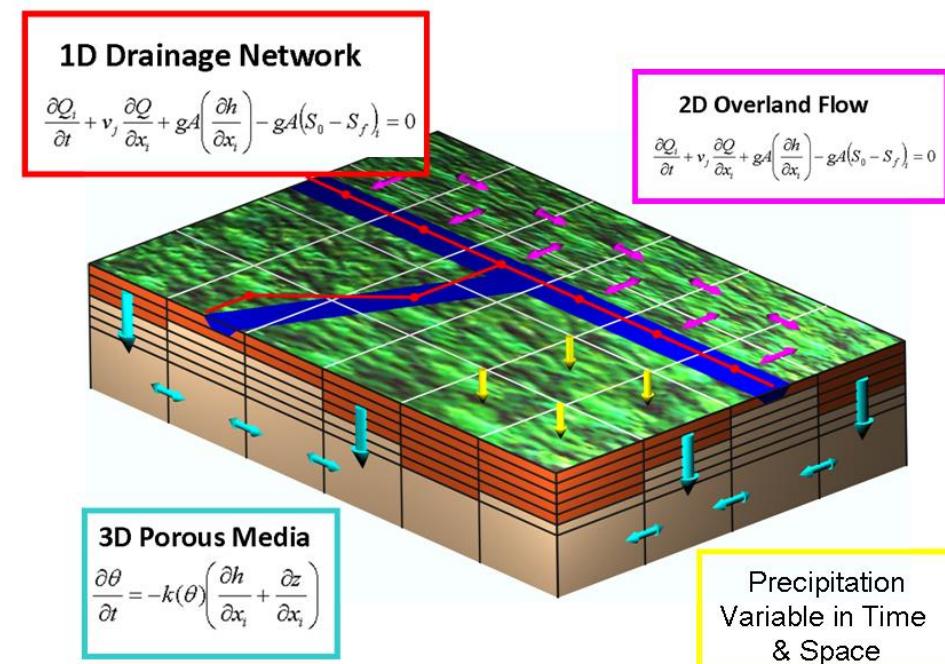
Campuzano F (2018). Coupling watersheds, estuaries and regional seas through numerical modelling for Western Iberia. PhD Thesis, Instituto Superior Técnico, Universidade de Lisboa, Portugal.

MOHID Watershed modelling



Integrated Catchment Modelling
Coupled Watershed / Reservoir Model

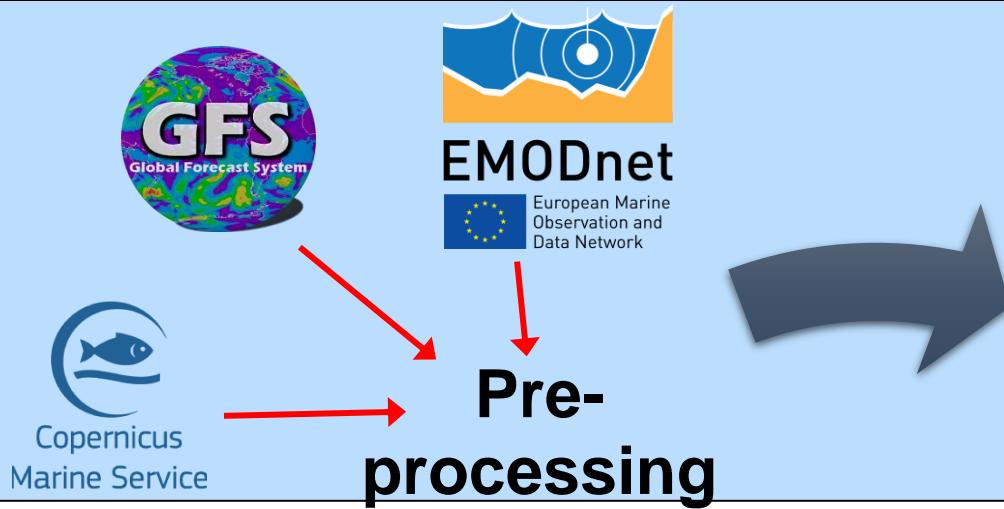
1/10/2002
12:00 AM



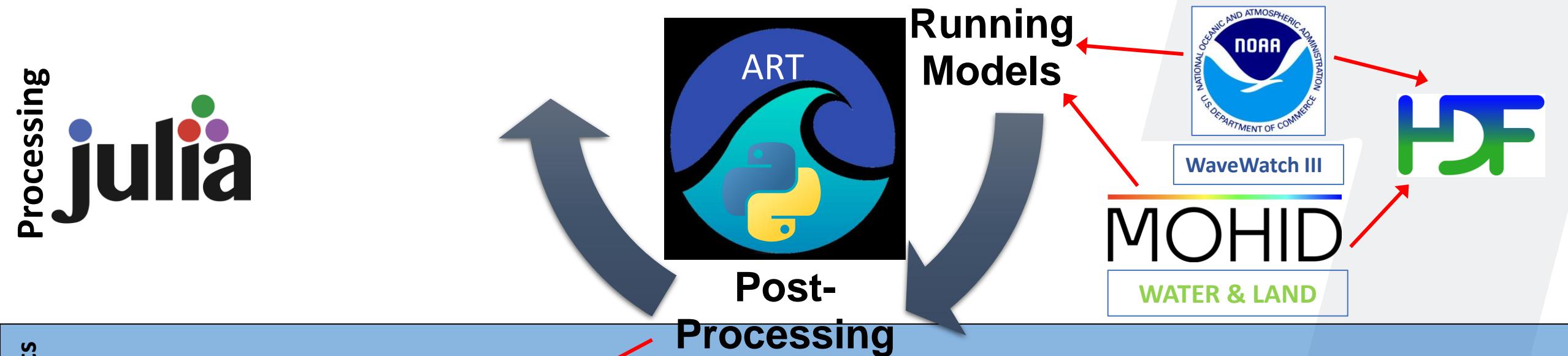
Integrated ocean-watersheds in Madeira island



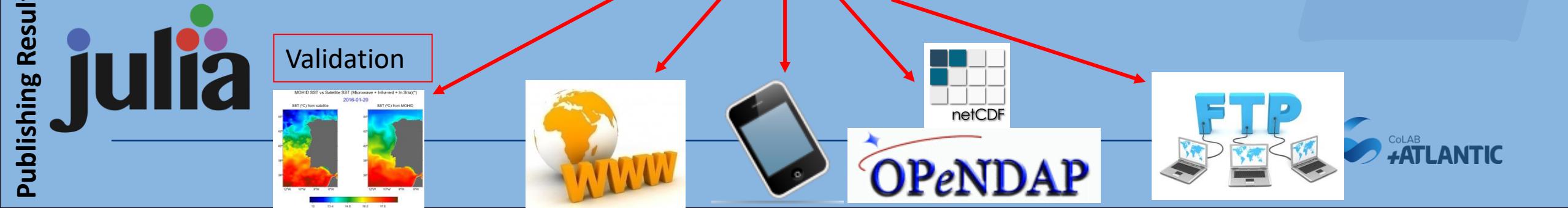
Data Sources



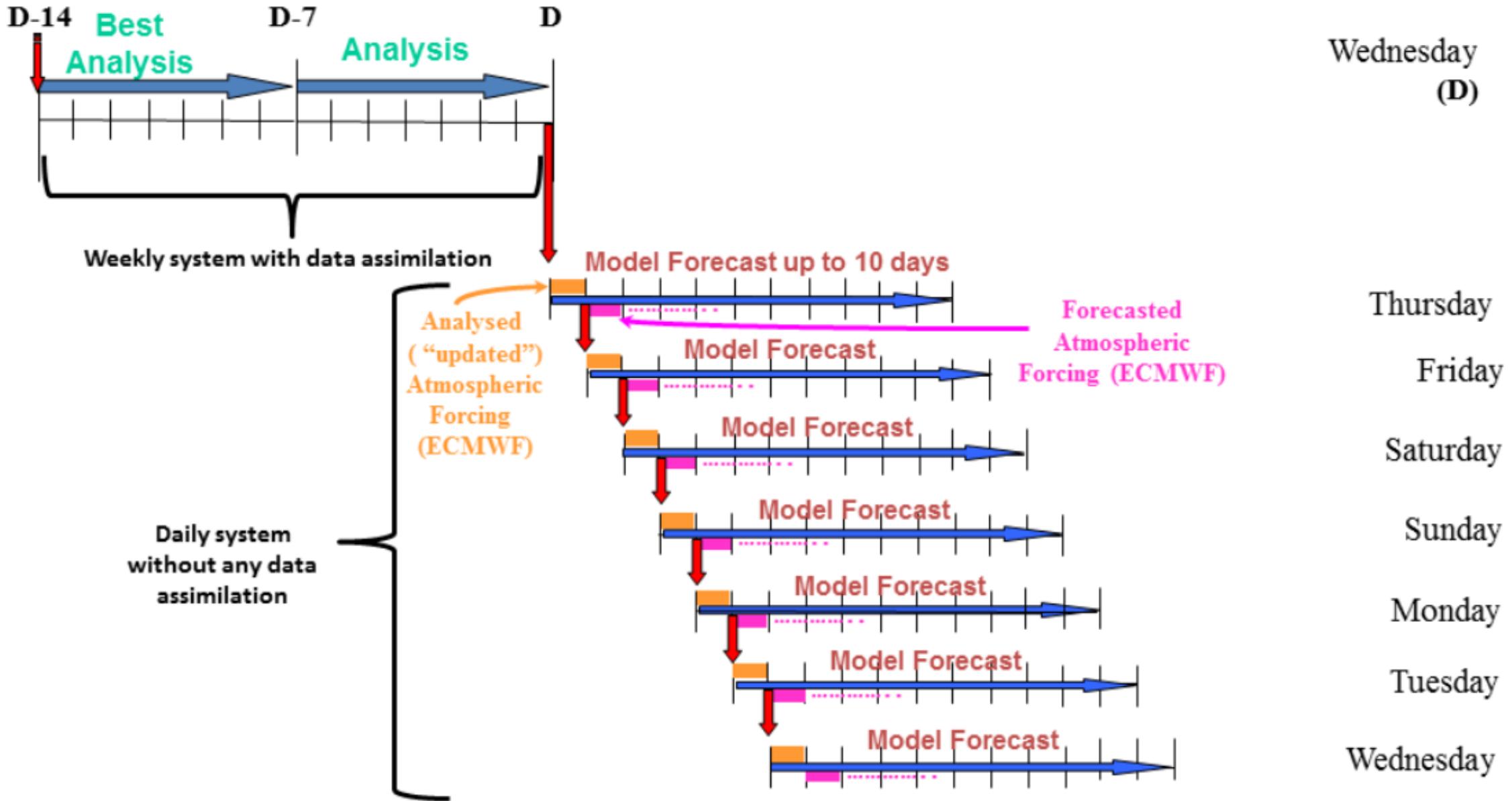
Processing

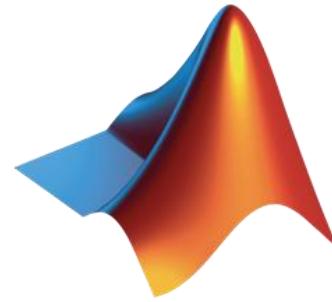
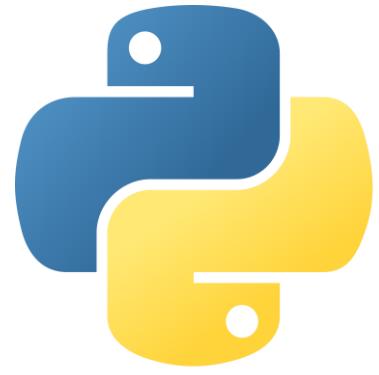


Publishing Results



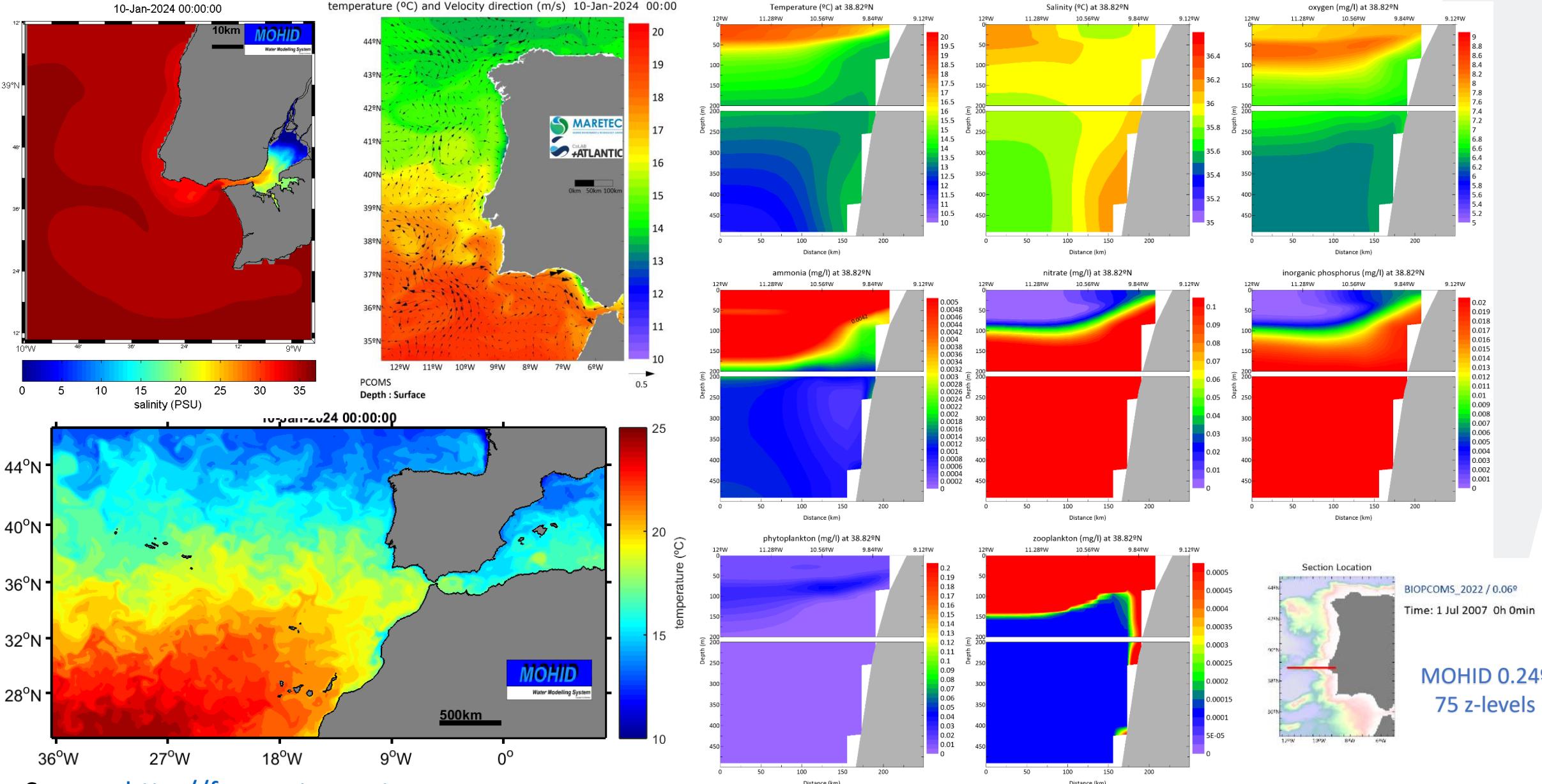
The product is updated as follows:

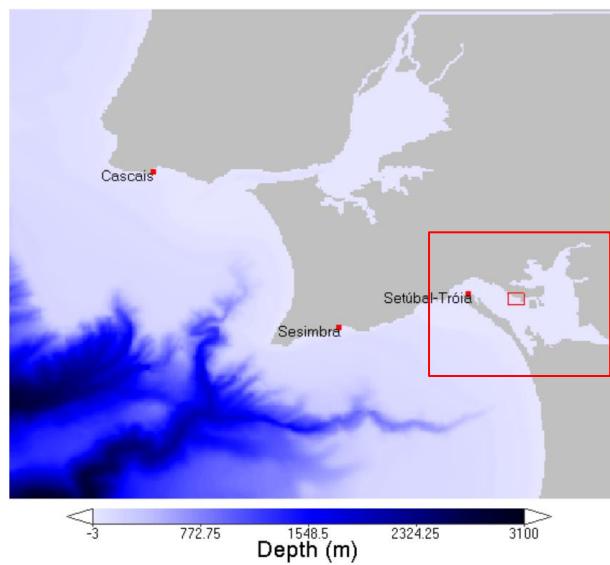




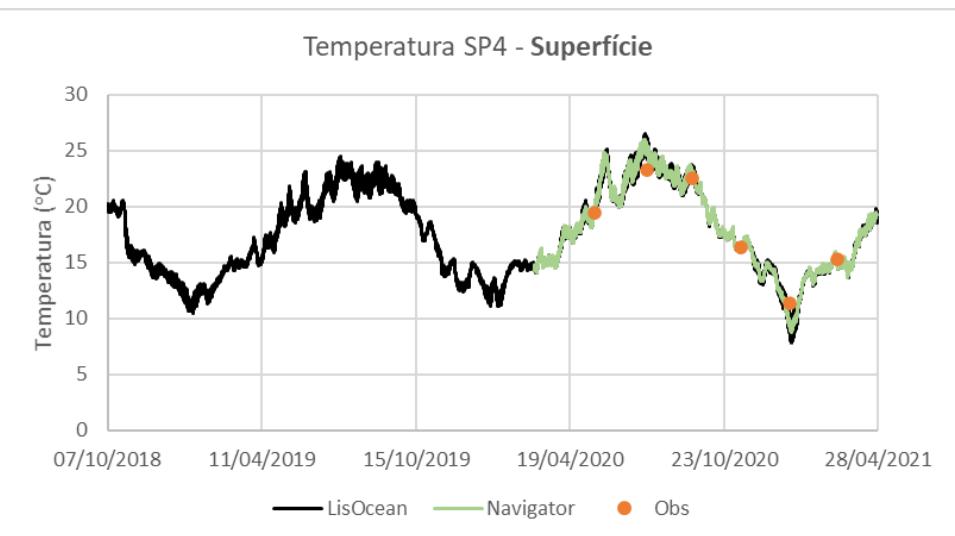
Previously used software

Instantaneous results for website



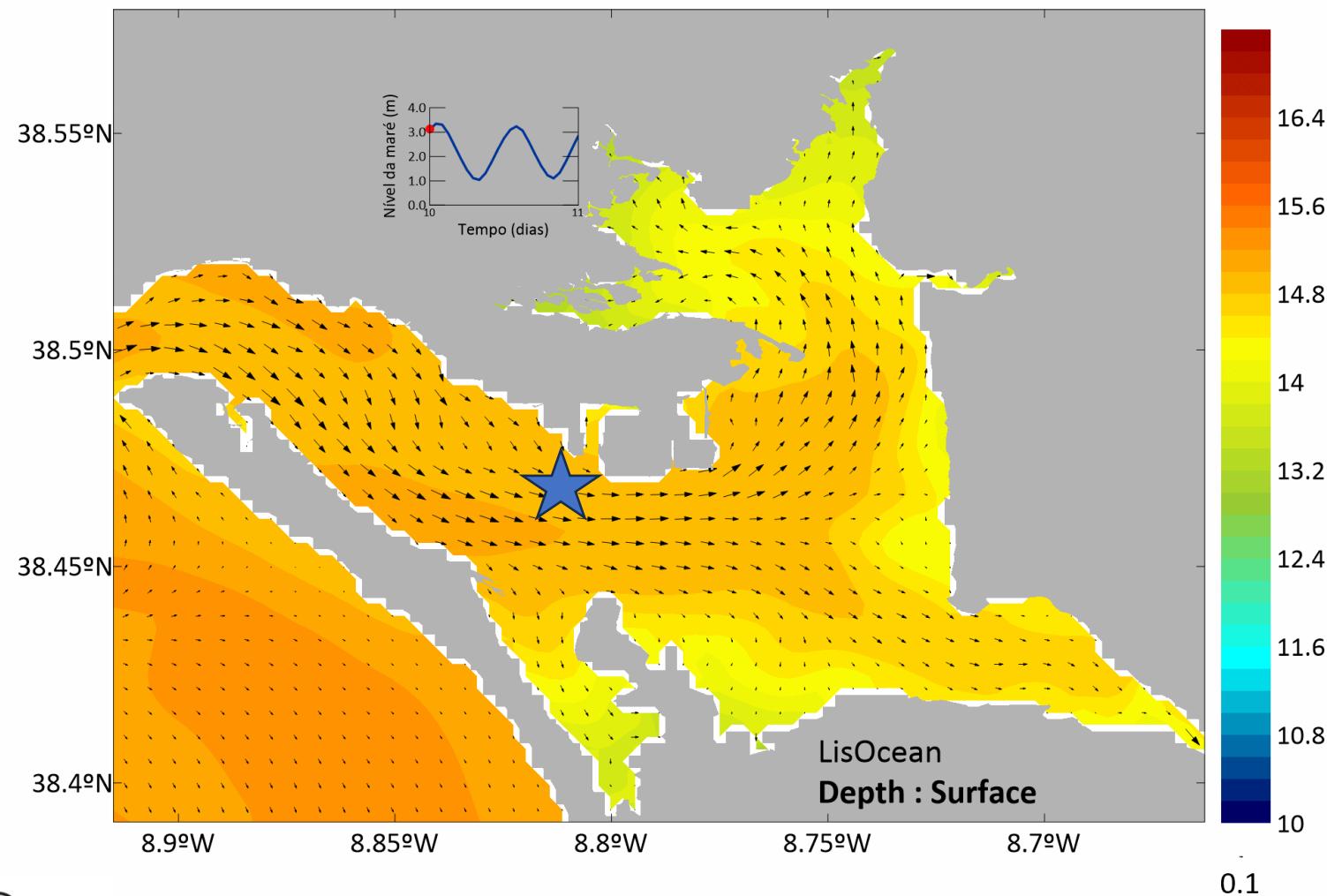


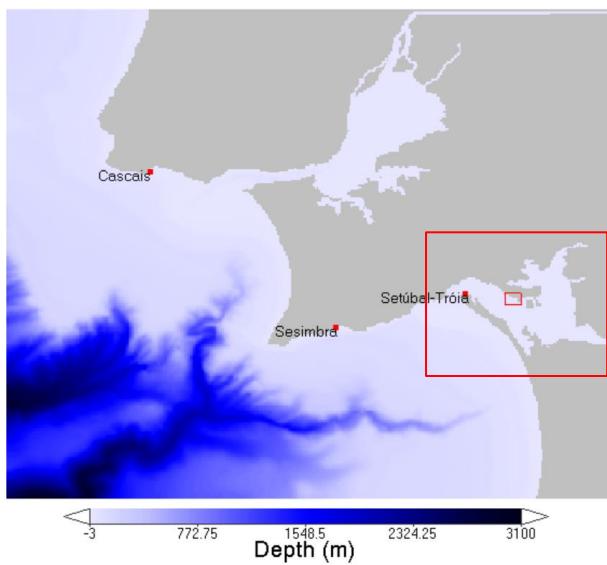
The model shows the spatial variability of surface temperature in the estuary and correctly simulates observations from monitoring campaigns



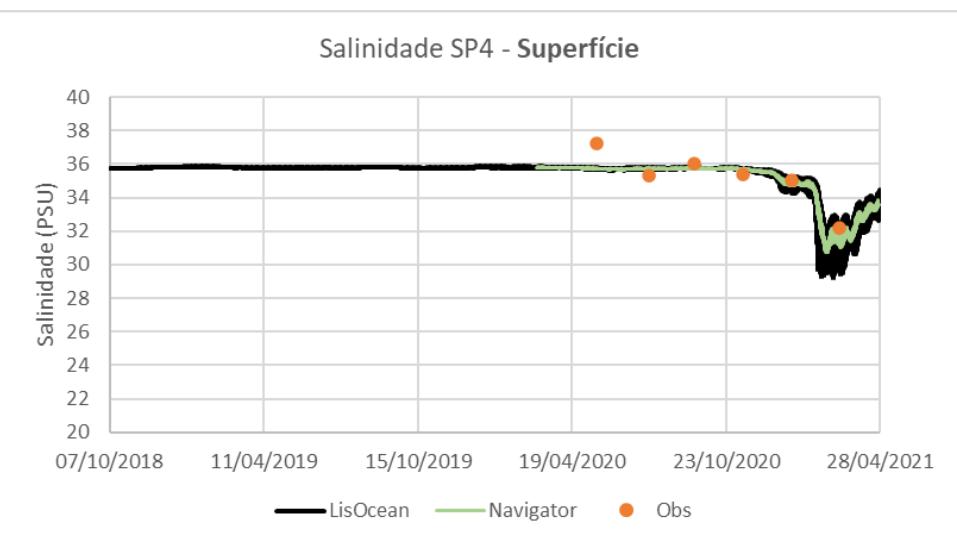
Surface Temperature - Sado

temperature (°C) and Velocity direction (m/s) 10-Mar-2021 00:00



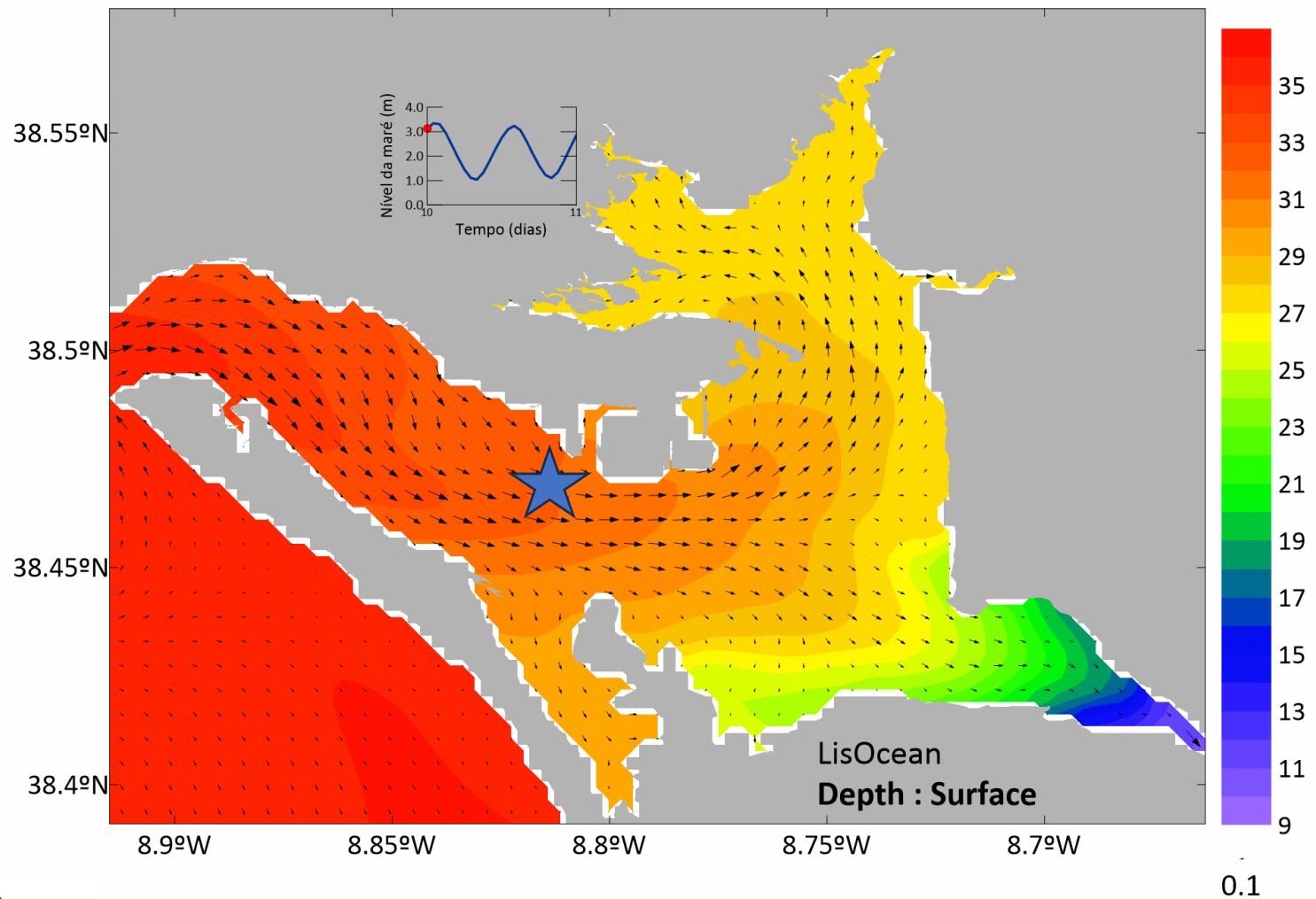


The model accurately reproduces the general conditions of the estuary and the heavy rainfall event.



Surface Salinity - Sado

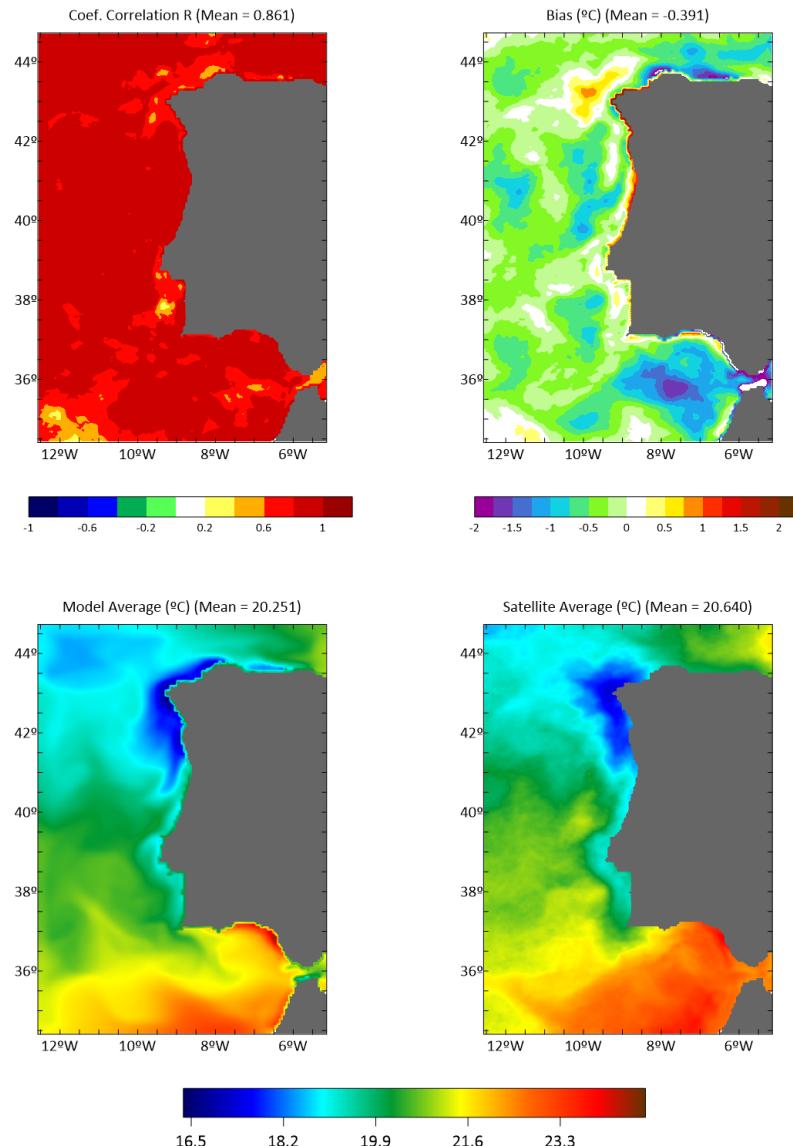
salinity (PSU) and Velocity direction (m/s) 10-Mar-2021 00:00



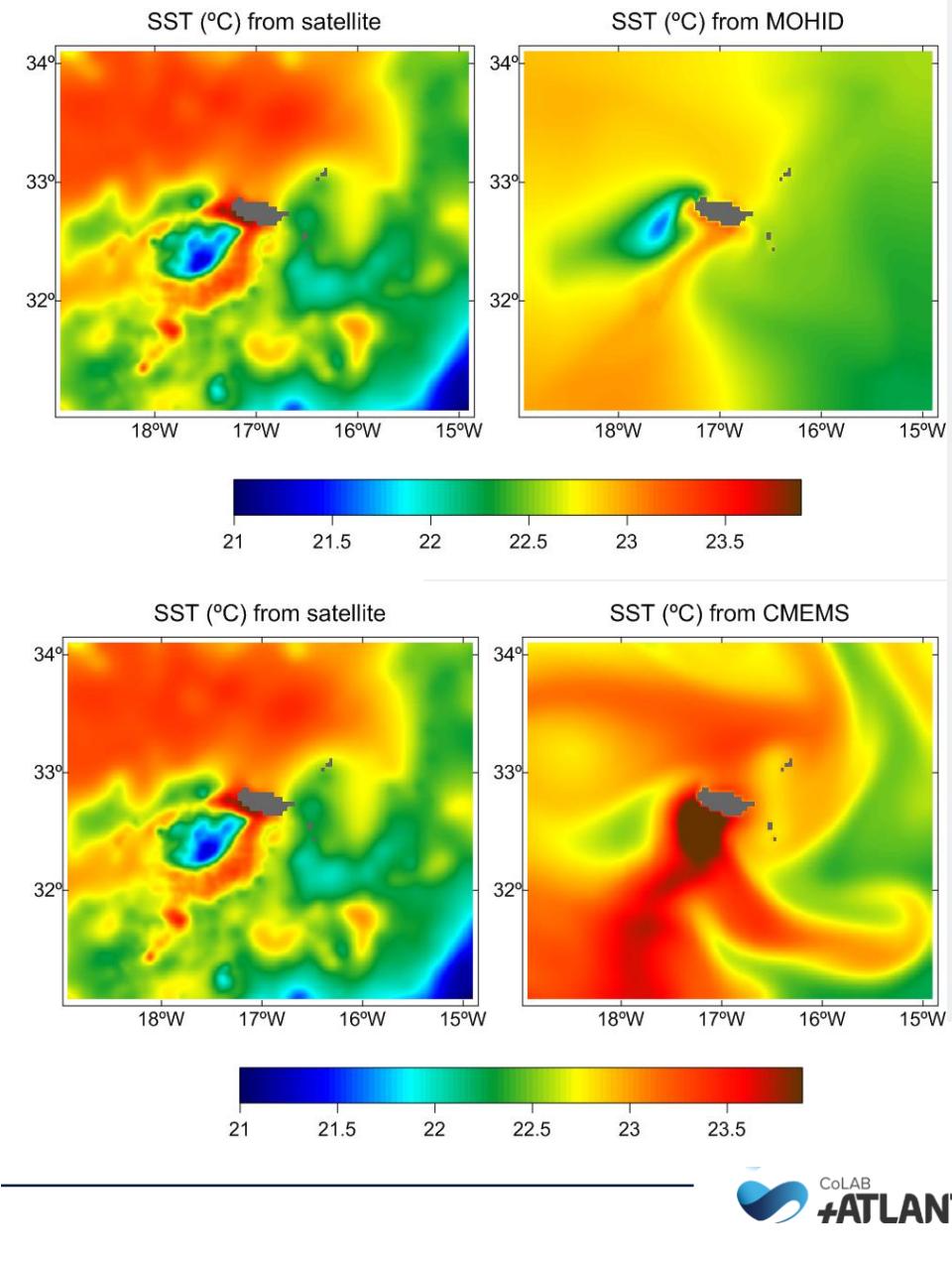
Validation – Remote sensing

20180807

MOHID SST vs Satellite SST (Microwave + Infra-red + In Situ)(*)

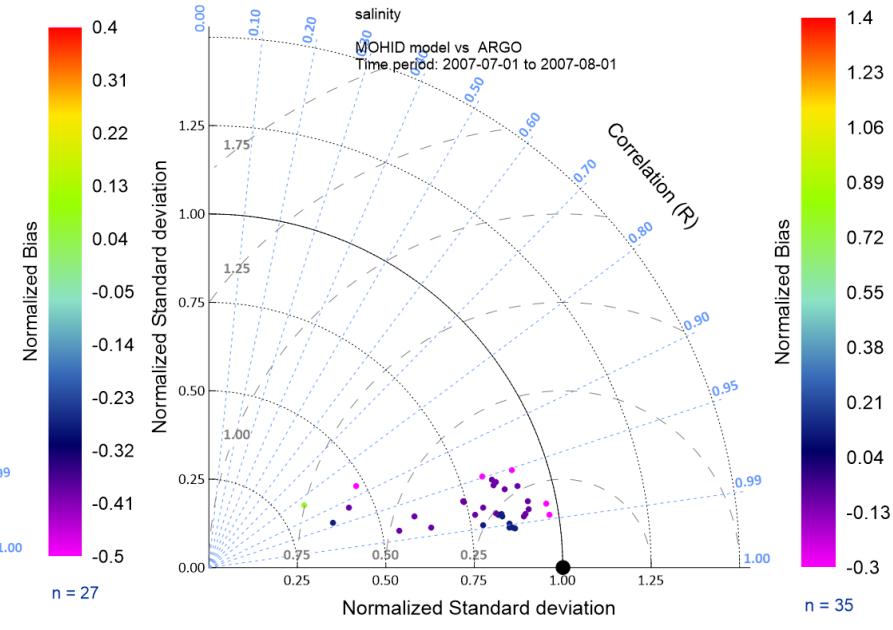
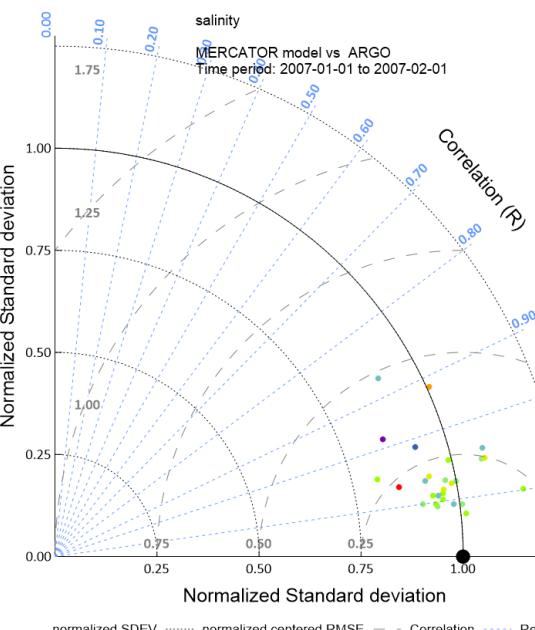
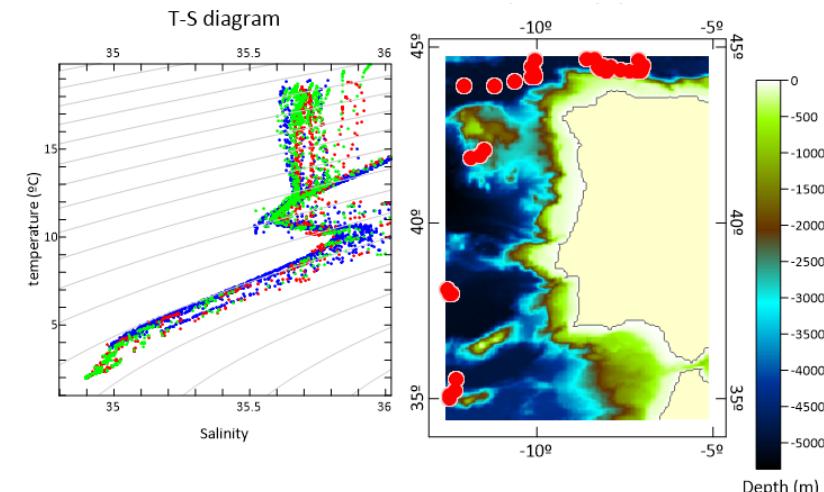
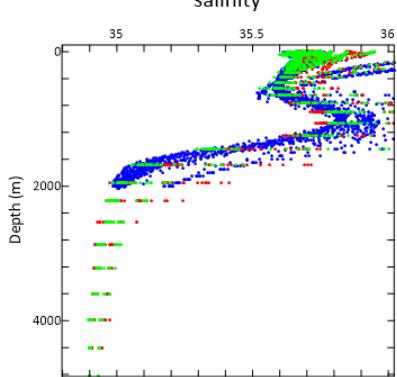
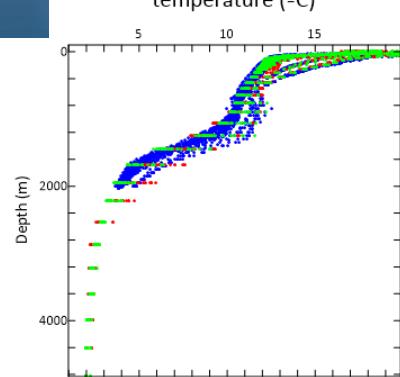
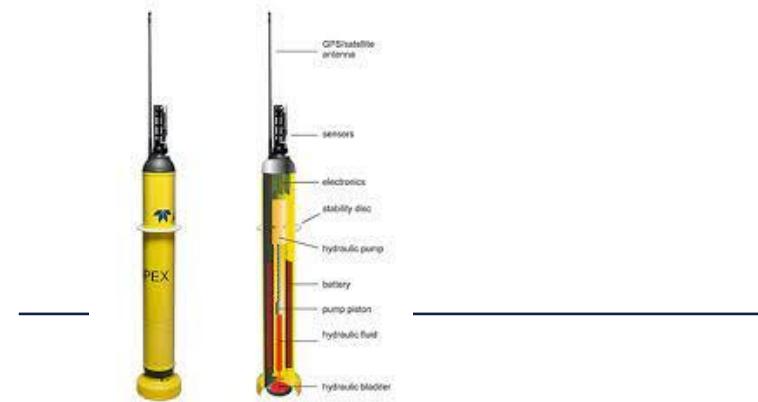
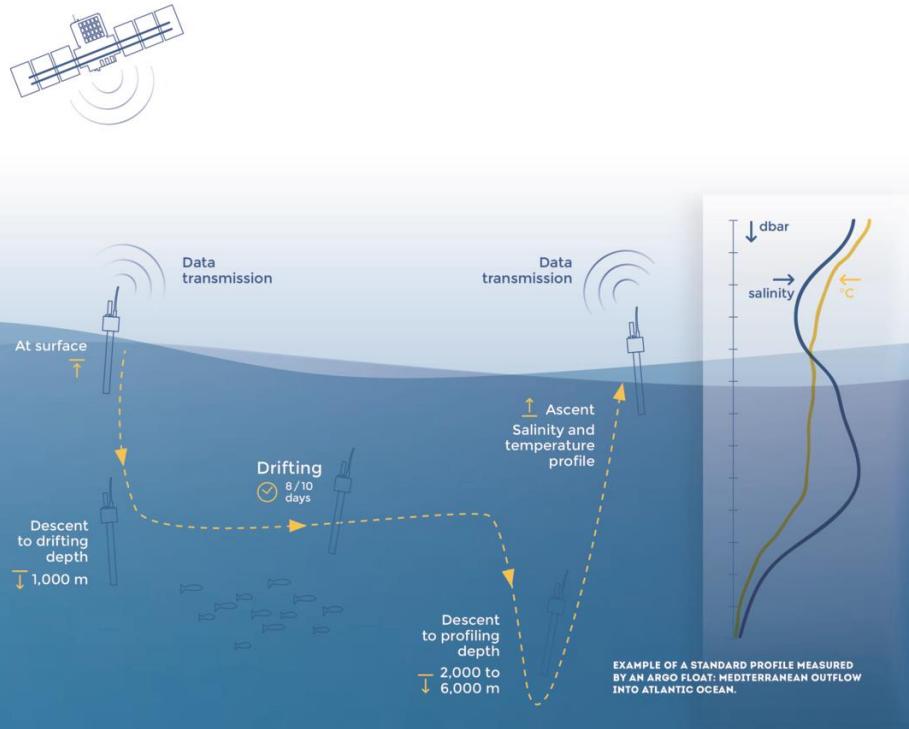


SST MUR



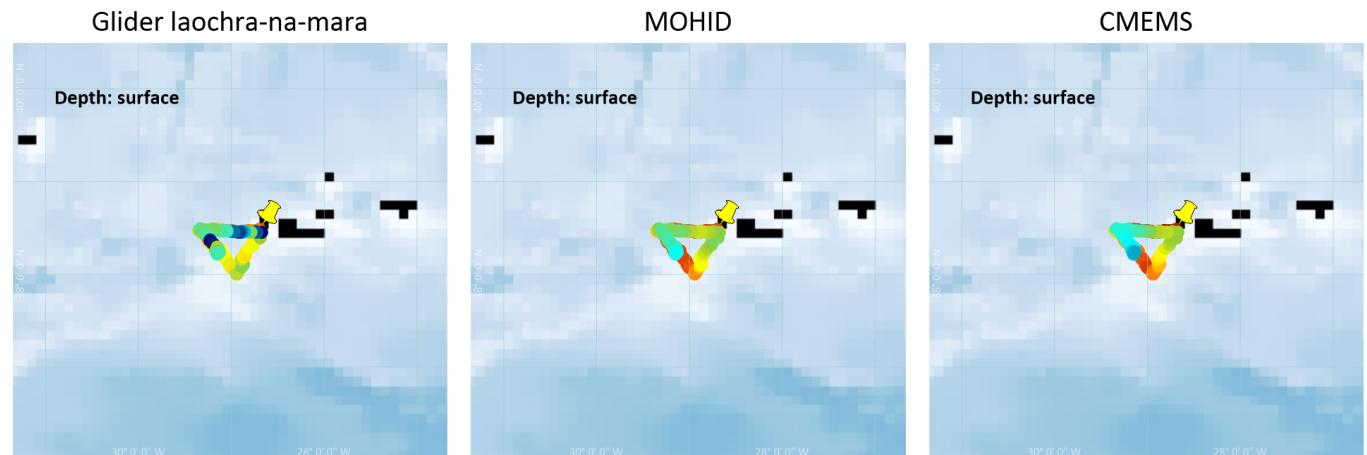
Validation – Vertical profiles (Argo floats)

July 2007 - Reanalysis

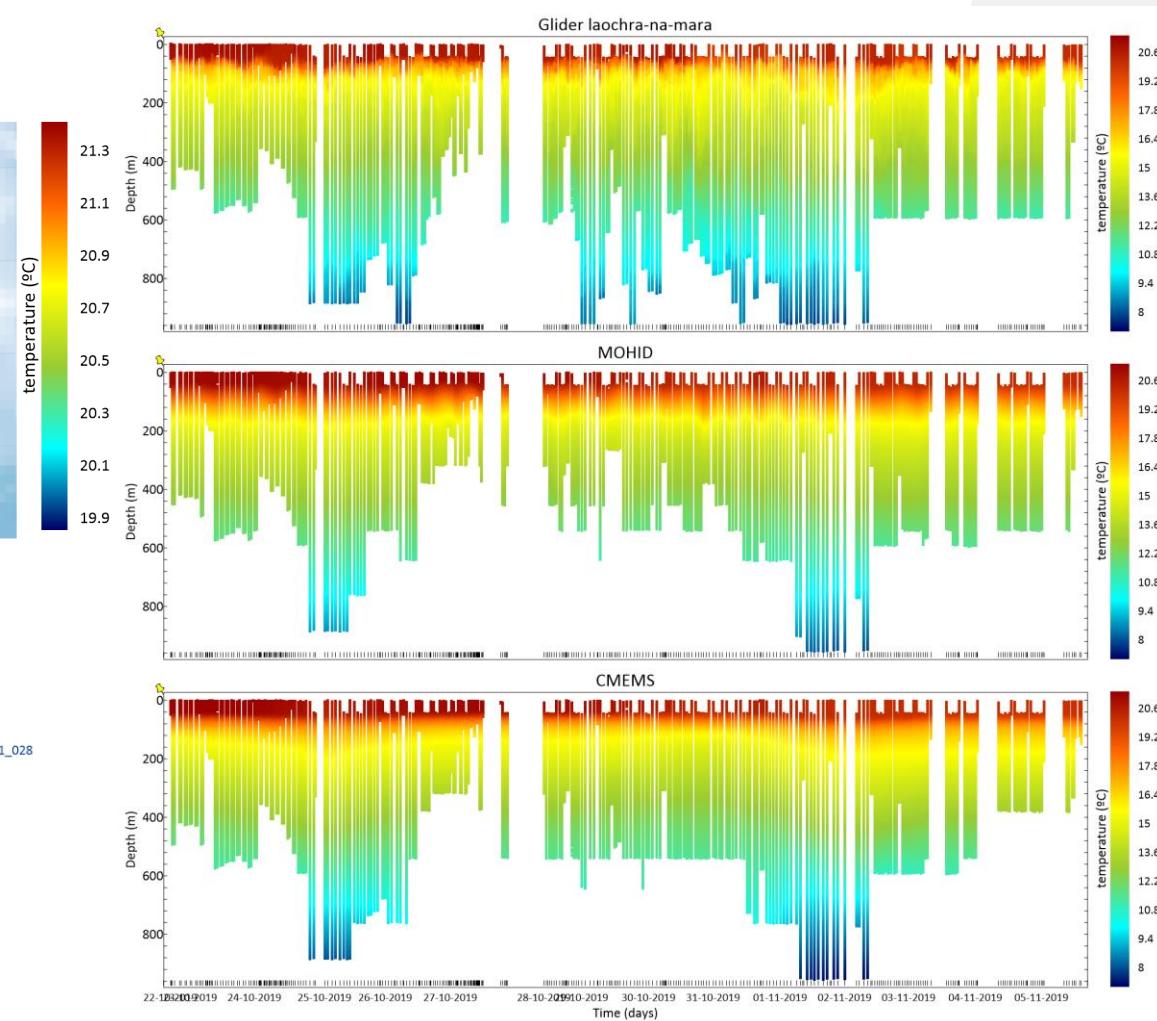


Validation – Moving profiles (gliders)

Time: 22-Oct-2019 to 05-Nov-2019



CMEMS product:
GLOBAL_ANALYSIS_FORECAST_BIO_001_028



CMEMS product:
GLOBAL_ANALYSIS_FORECAST_BIO_001_028

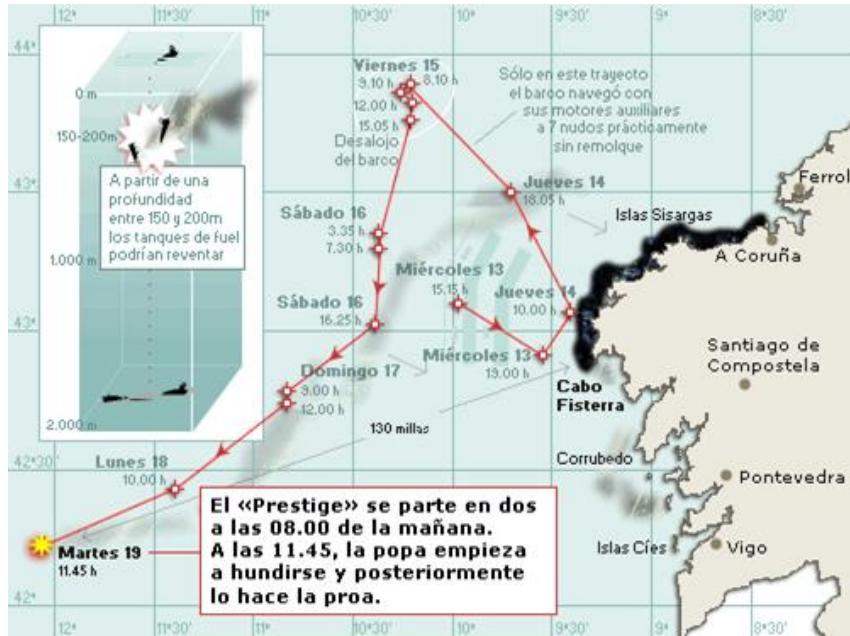
MOHID Lagrangian

- Small objects:
 - Drifting buoys
 - Search-and-rescue
 - Small ships
- Large Objects:
 - Floating containers
 - Vessels or ships

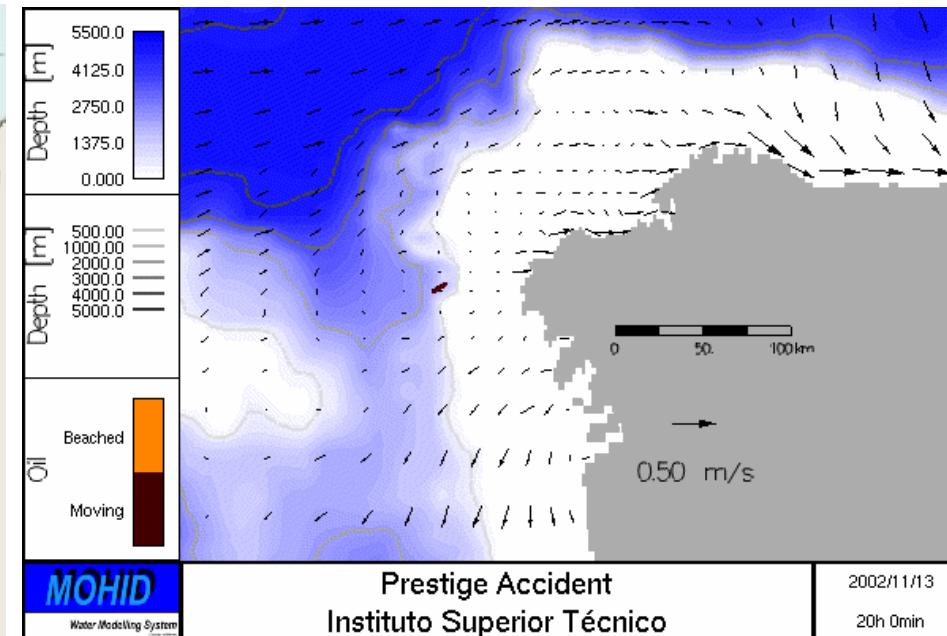


The Prestige Accident (2002)

Ship Trajectory



MOHID – Oil Spilt along ship trajectory

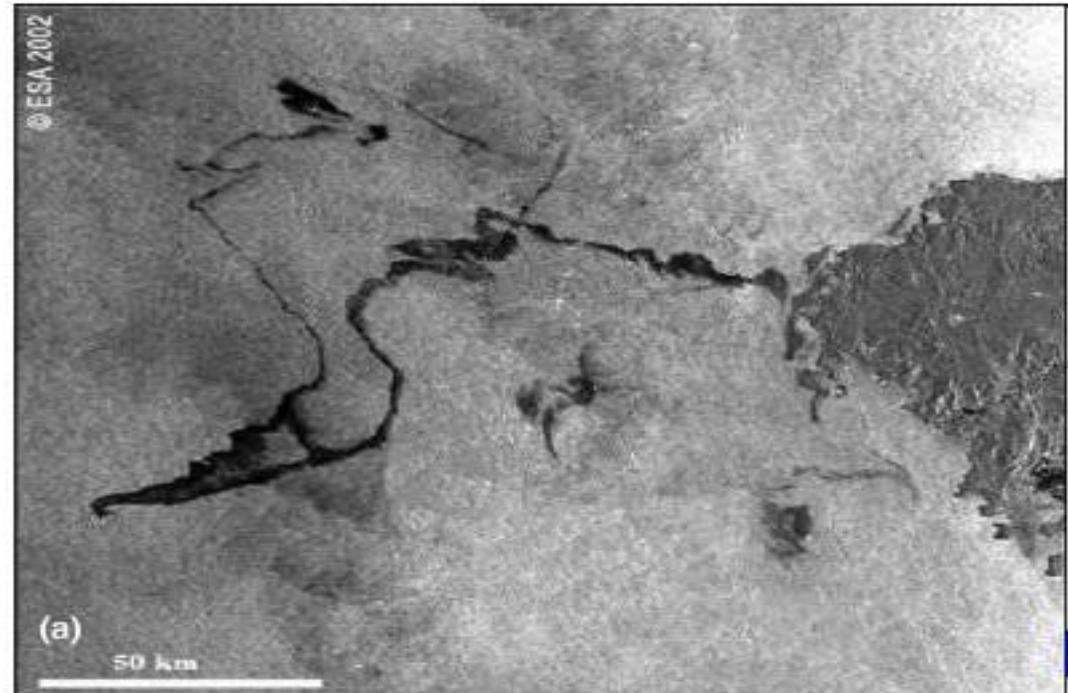


Forcing conditions:

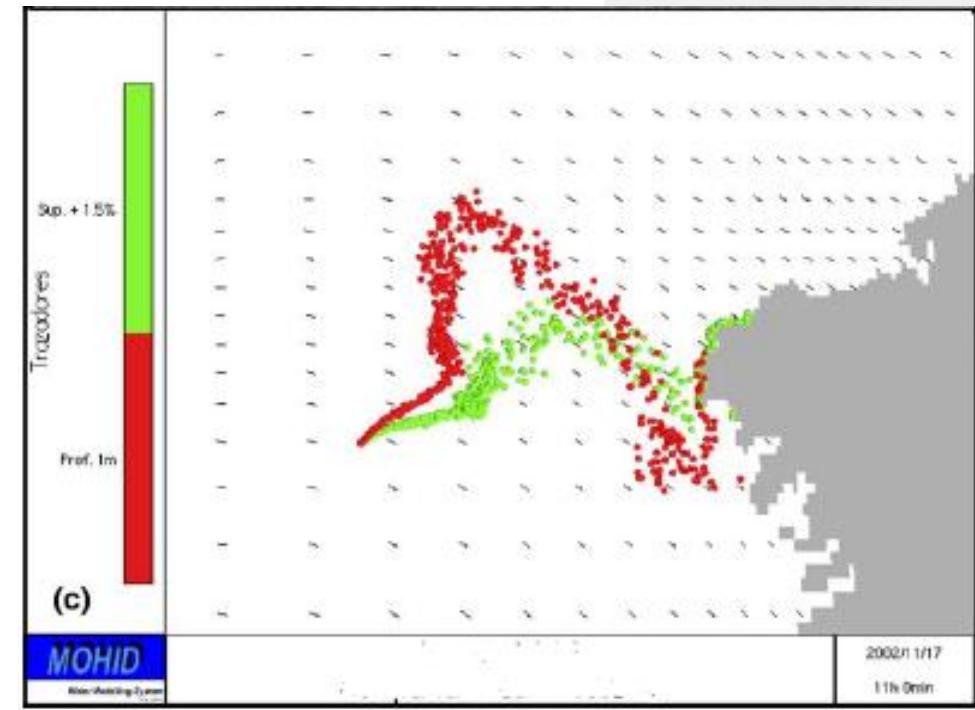
- Space and time Variable wind fields: predictions using ARPS model (MeteoGalicia);
- hydrodynamics: 20 layers (surface layer = 10cm) variable density (climatological density) + slope current;
- Vertical turbulence (GOTM Model);
- 2 Km minimum spatial step.

Model comparison

ENVISAT satellite image taken on
17th November 2002



MOHID simulation, with tracers at different depths: surface tracers (green) + 1m depth tracers (red)



Atlantic Scenarios Action 4 Modelling influence of river and land-based sources of marine litter

61 European Rivers
(daily average)



Interreg
Atlantic Area
European Regional Development Fund



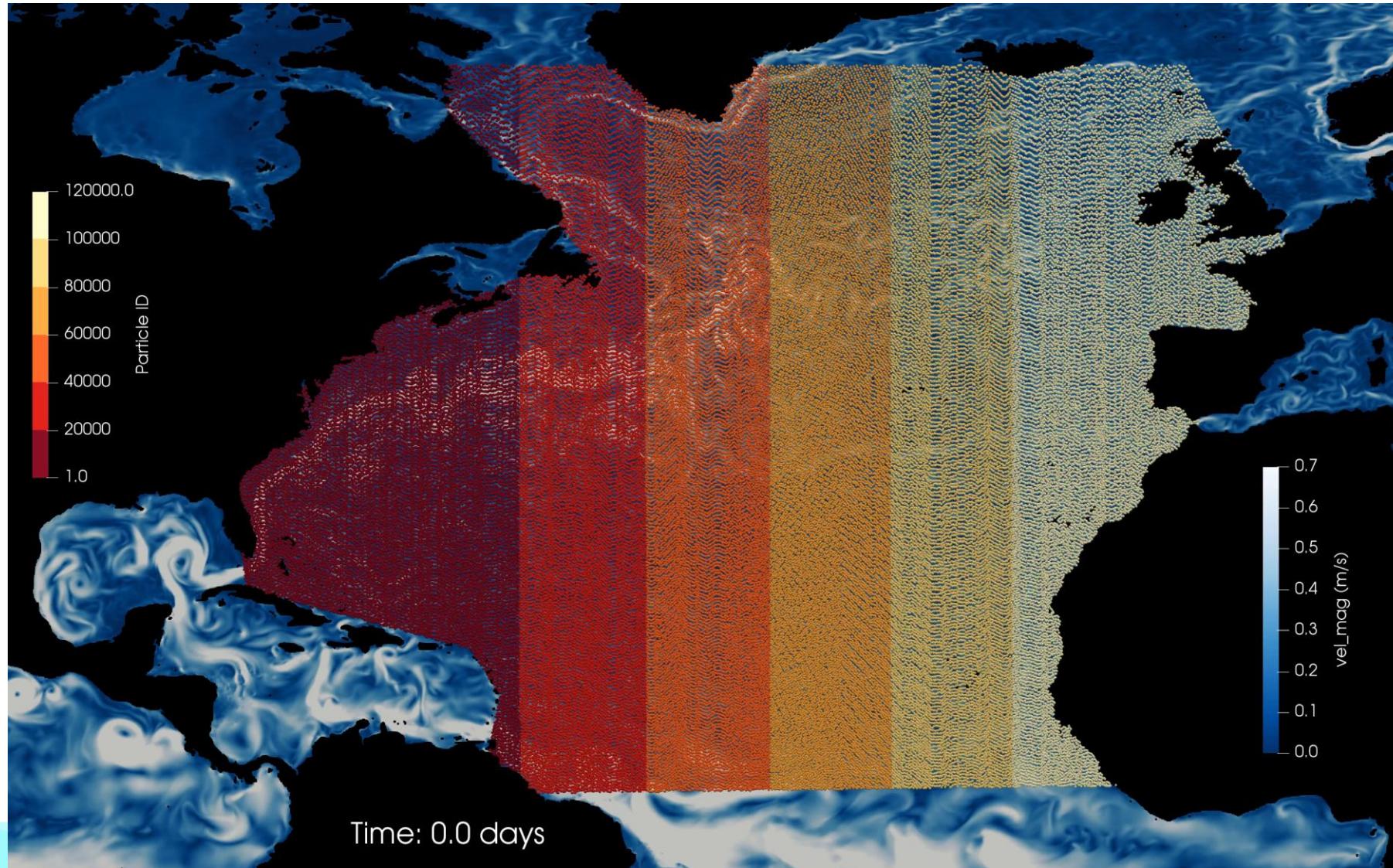
Clean
Atlantic

- Hydrodynamic

CMEMS
No waves
No tide
No rivers
- Lagrangian

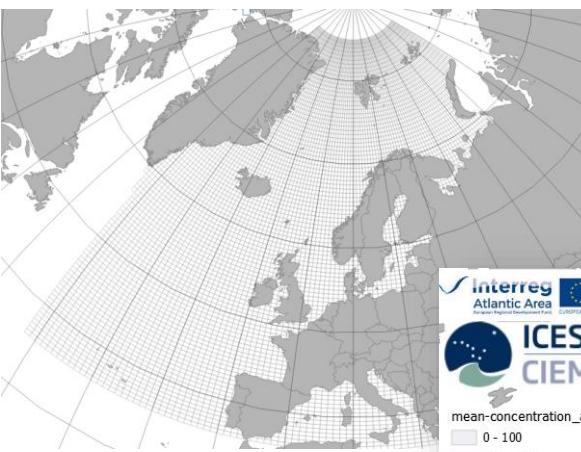
Lagrangian tool
Conservative particles (=water)
61 Rivers
Surface
1 500 000 particles
- Simulation time = 4 years

Atlantic Scenarios Action 4 Modelling influence of river and land-based sources of marine litter



- **Hydrodynamic**
CMEMS 2D surface velocity field data
No waves
No tide
No rivers
- **Lagrangian**
neutrally buoyant particles
270 days
1 500 000 particles
- **Simulation time = 270 days**

Reduction Scenarios: Maps with ICES rectangles: emission from Atlantic rivers



Domain: Atlantic

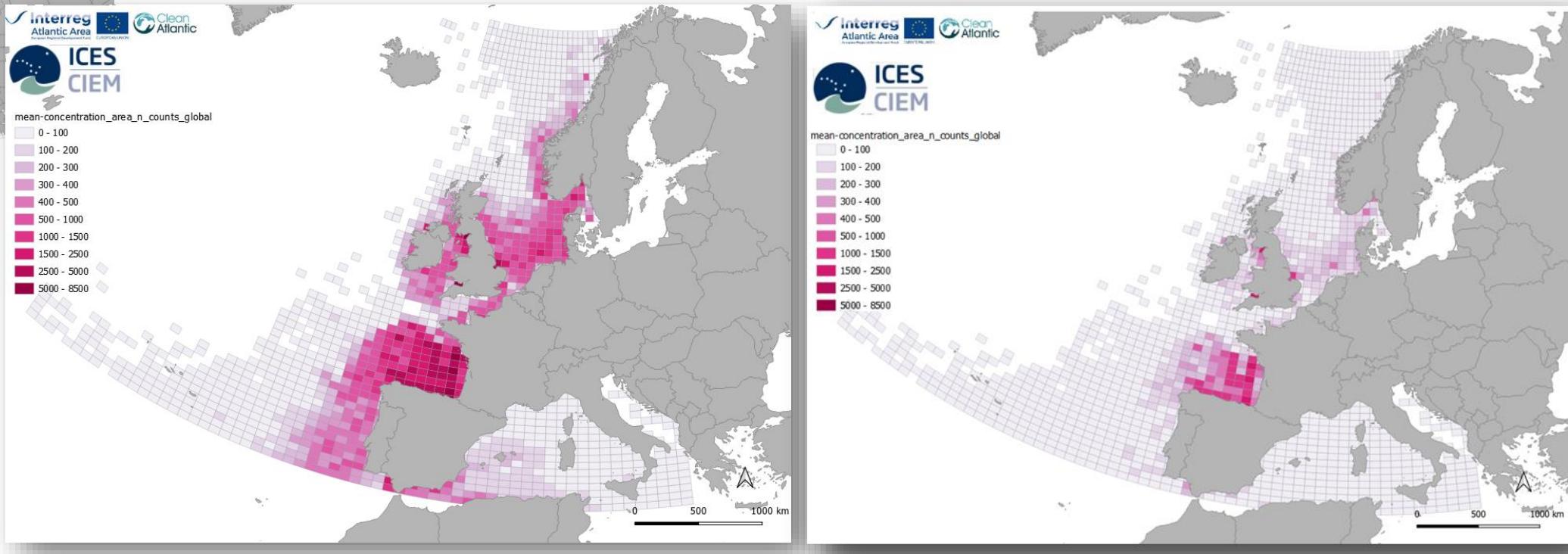
Simulation:
2D (surface)

Time: 4years (2016-2020)

InputData: currents, wind, waves

Source: 68 rivers
Emission rate:
constant (left) variable(right)

Particles type: lagrangian
Nºtotal: ~320 000 particles

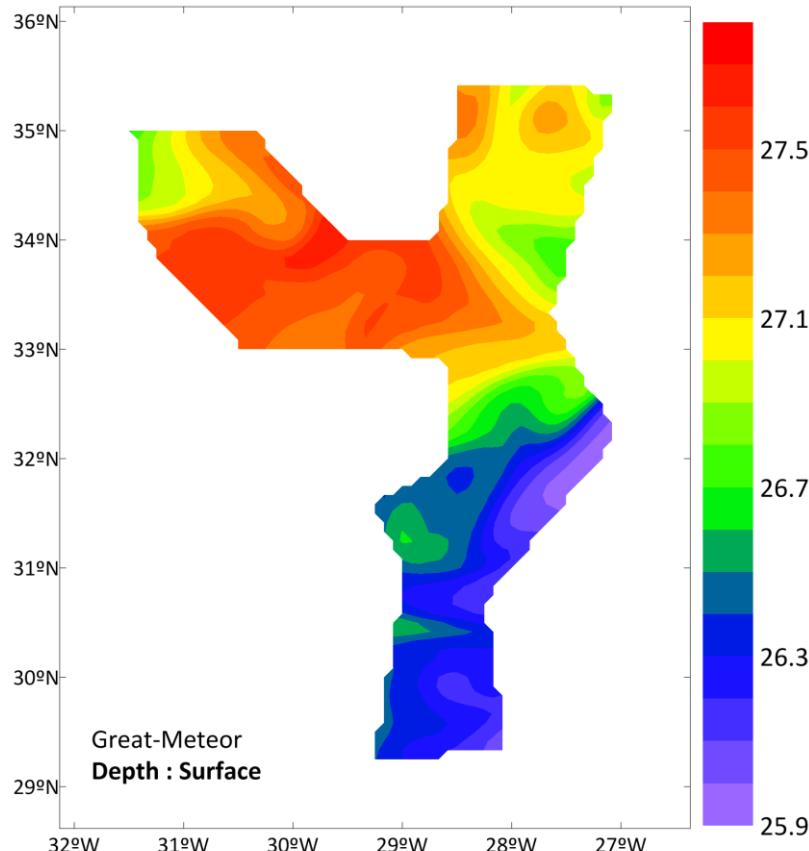
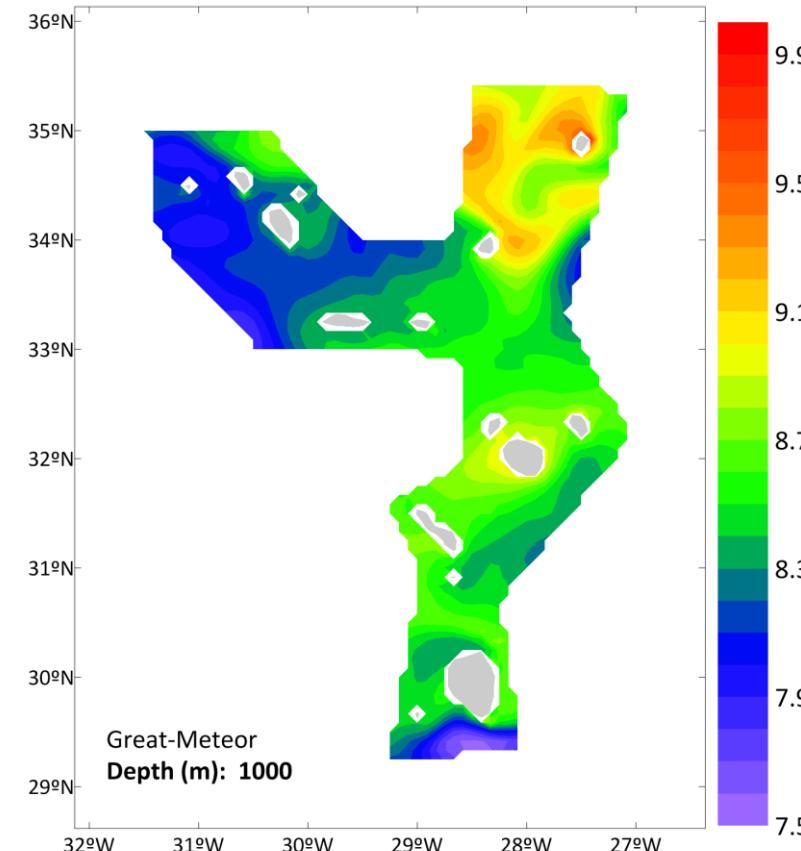
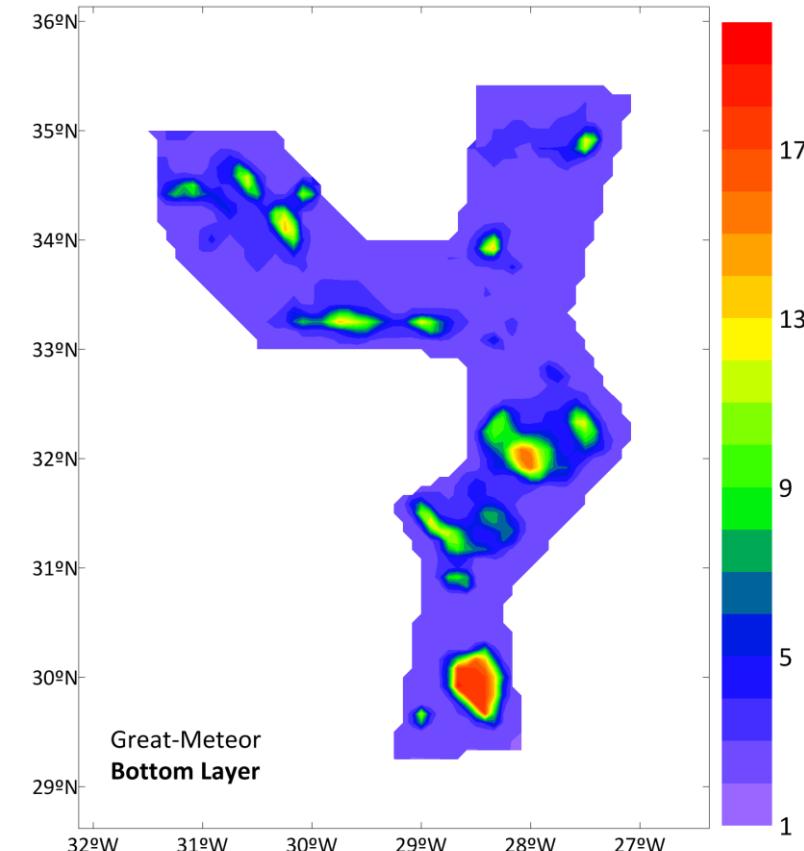


Scenario 2: Emission rate: **variable**

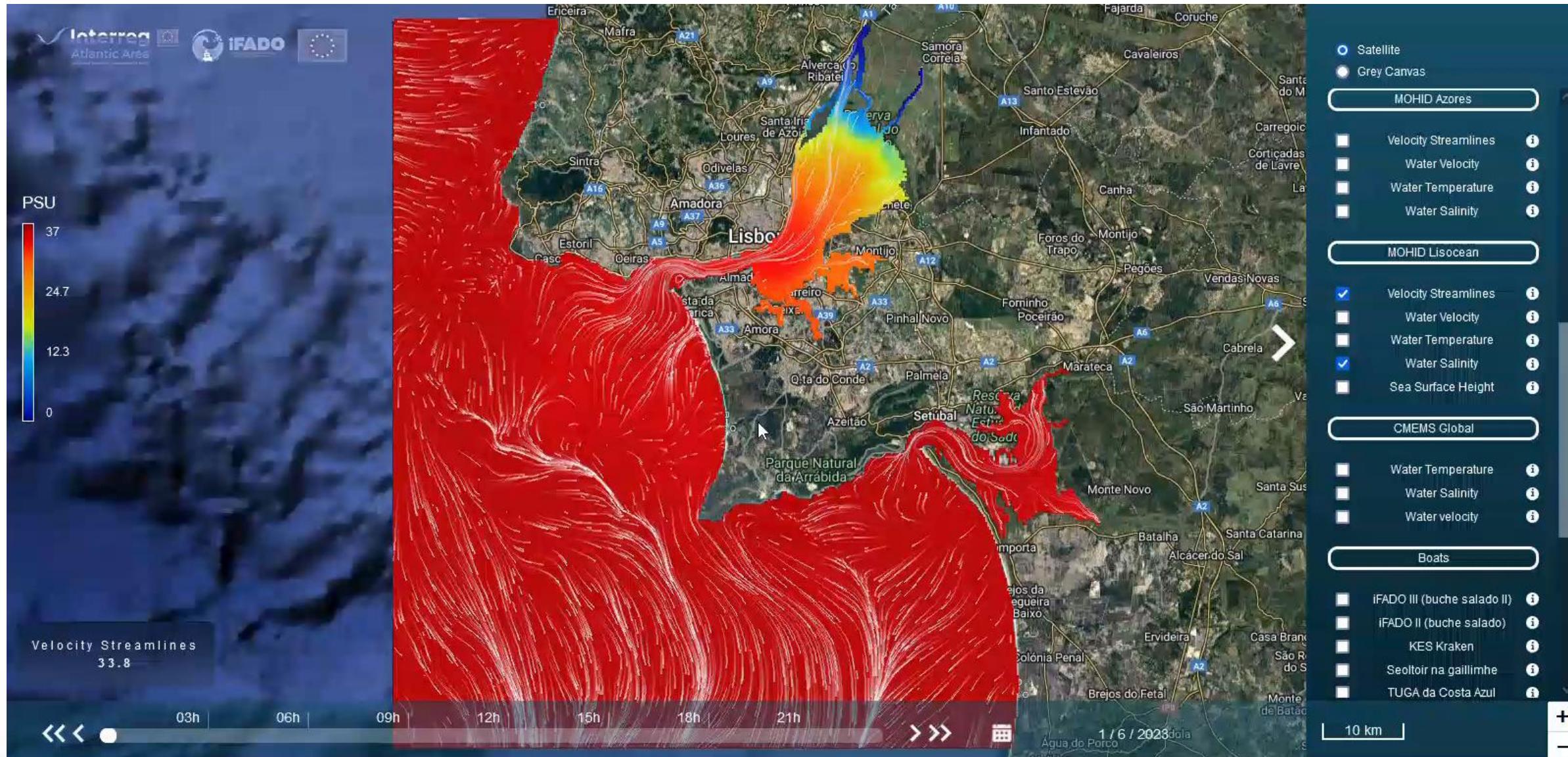
(rivers emit particles depending on their daily flow)

mean particle concentration (part / km²) in each rectangle

50% reduction - same distribution pattern
(conservative particles) - concentration halved

temperature ($^{\circ}\text{C}$) Average period: 20190831_20190831temperature ($^{\circ}\text{C}$) Average period: 20190831_20190831temperature ($^{\circ}\text{C}$) Average period: 20190831_20190831

Numerical Model Fields & Streamlines



+ CONTROL ROOM

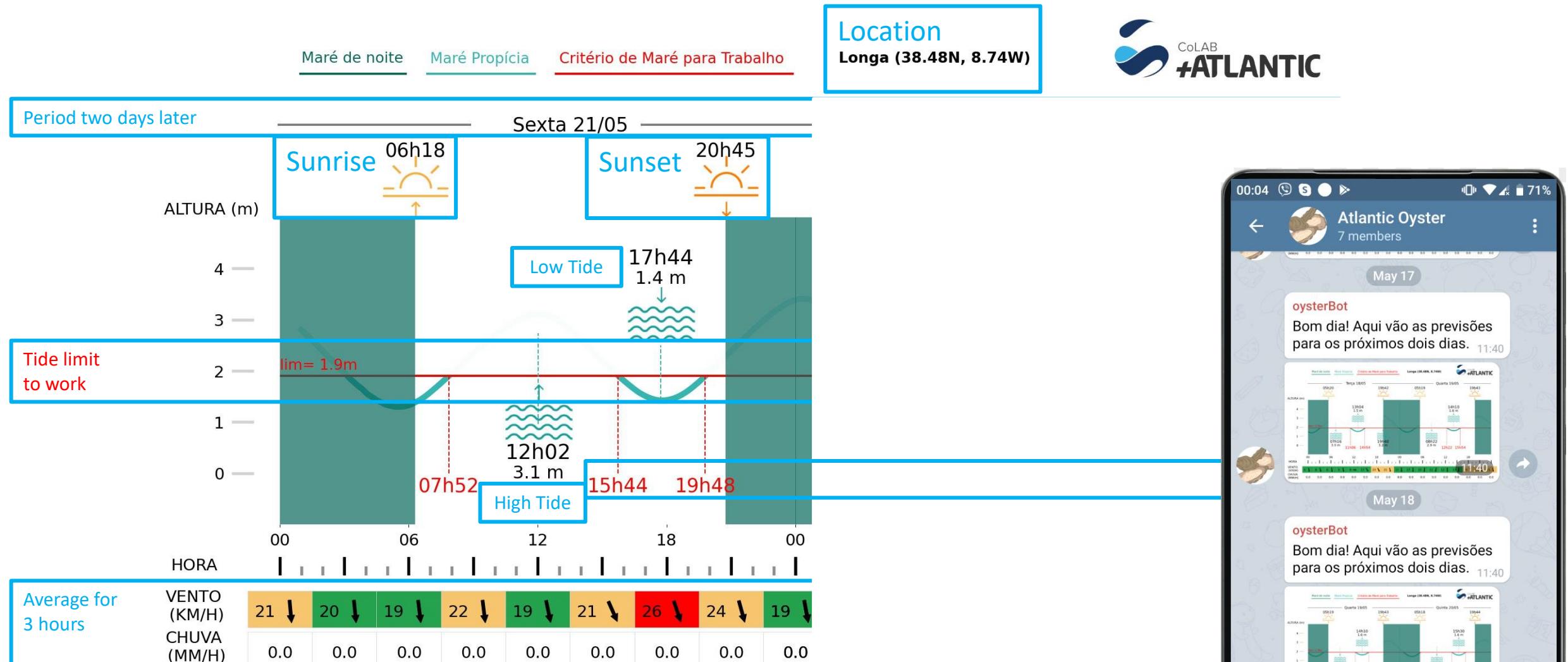


+ AQUACULTURE OFFICE



+ DAILY MESSAGE

Y T I D E



Questionário <http://tiny.cc/ytide>



Julia 2024

The Challenge!

julia

Numerical models improve with age but support tools get older



Requirements are clear

Not wasting time on user/developer feedback

User satisfaction guaranteed

Access to end-users community

Tool can be distributed along the numerical model



Gaining more Julia users

Jackpot!



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m

