

JuliaEO 2024 Terceira Azores Portugal

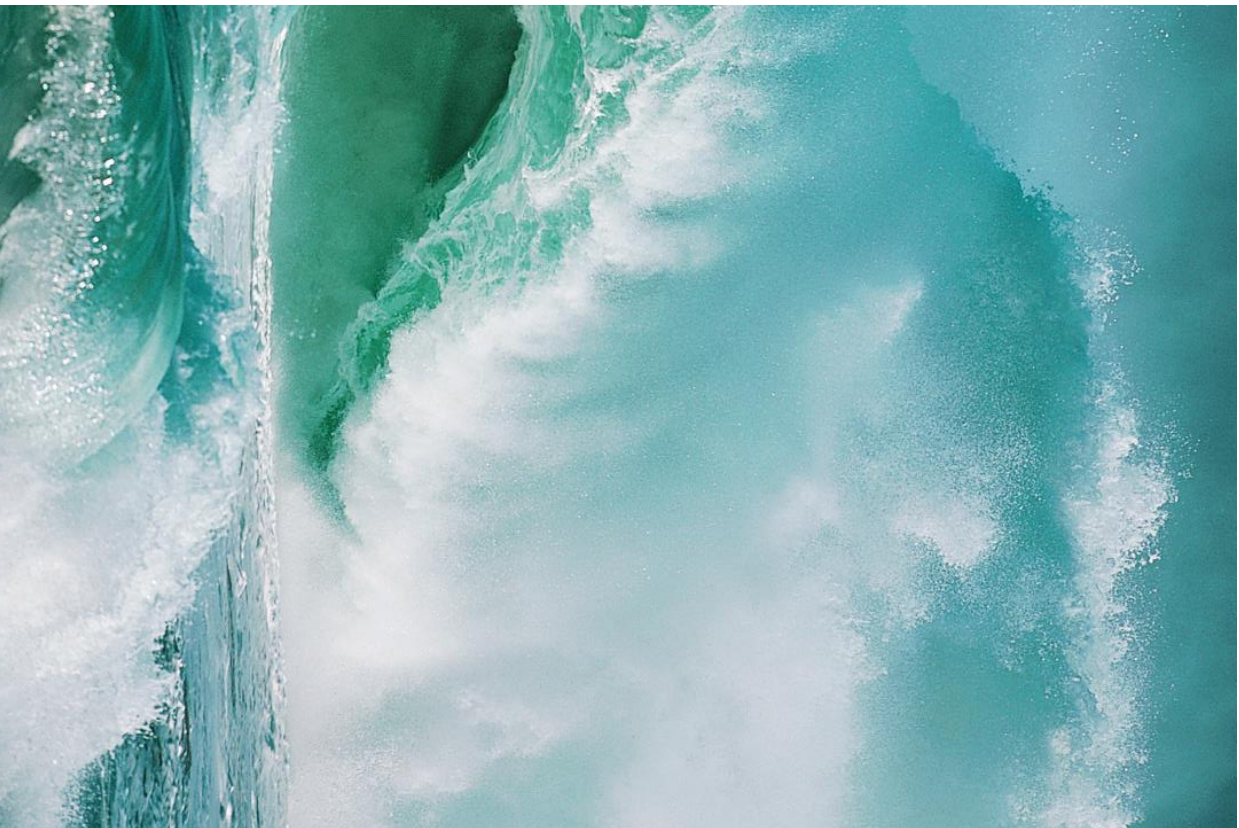
Ocean Modelling with MOHID for Operations



Francisco Campuzano

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[in](#) [🐦](#) [@colabatlantic](#)



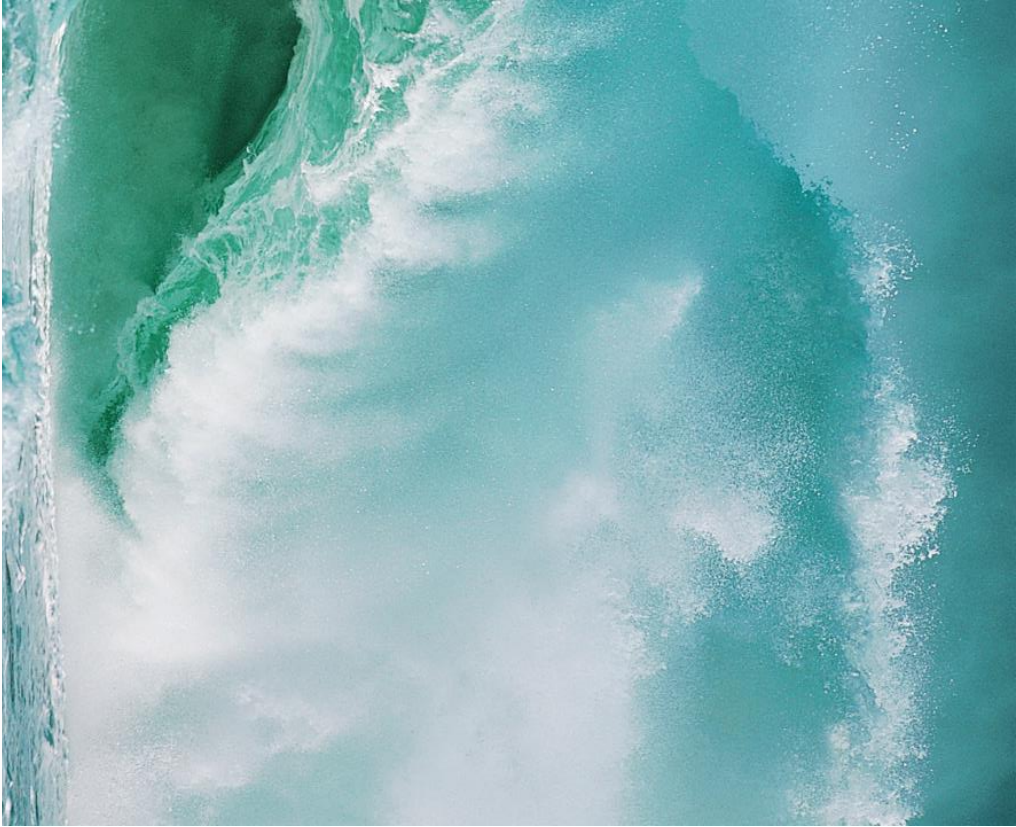
- **Intro + ATLANTIC**
- **Numerical modelling**
- **Operational modelling**
- **Common graphs and data management**
- **The JULIA Challenge**

I

Intro

WHOP? & WHAT?

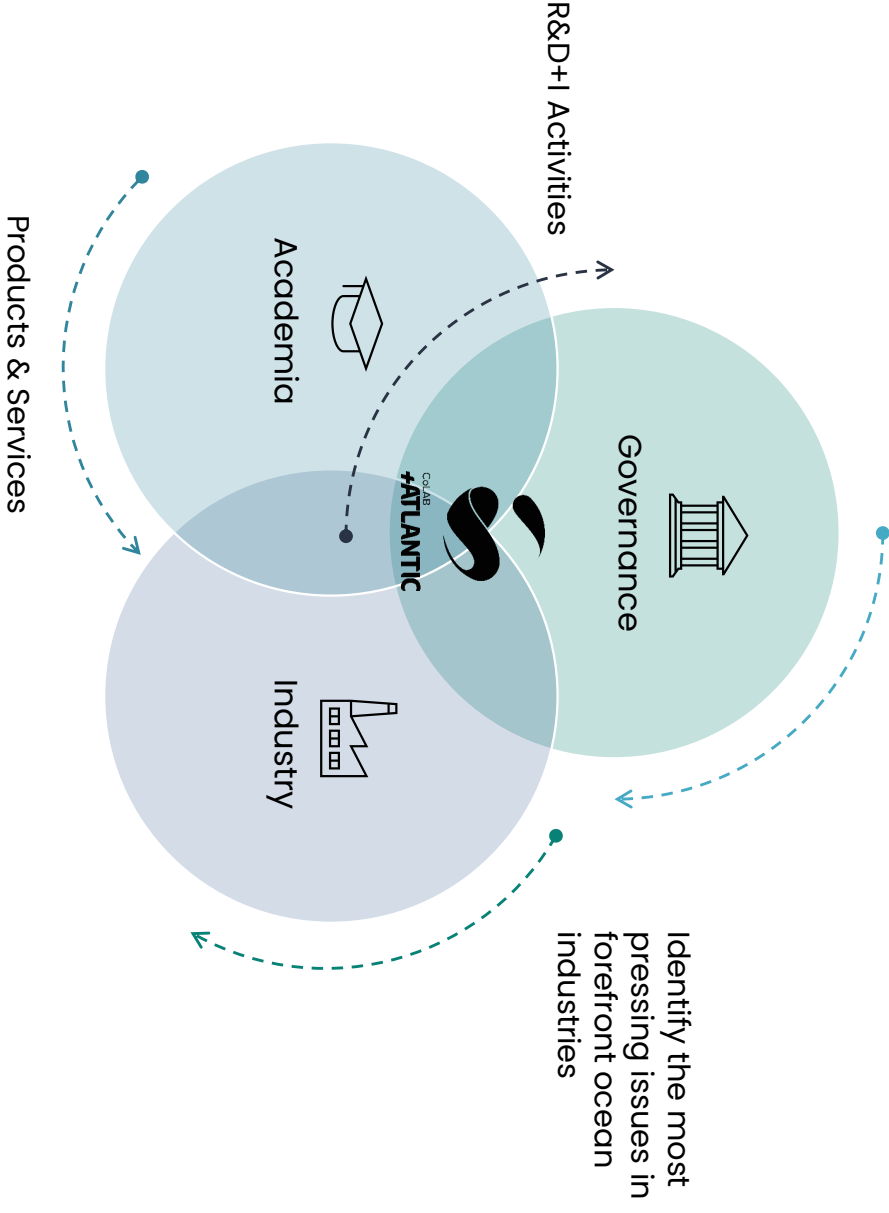




Associados

- CEIA
- delimos
- EQUISOFT
- FEUP PORTO
- gmv
- HIDROMOD
- INTELLIGENCE
- IPMA
- ISO
- TECNICO
- PREDEFIN
- TEKEVER
- MOVEC
- PULPERINA

Complementary R&D+I to bring innovative solutions to forefront ocean industries



WHAT?

Product Lines

Support to Ocean-based Economic Activities



AQUACULTURE & FISHERIES

Software modules

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

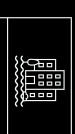
TAILOR-MADE SOFTWARE



ColAB

#ATLANTIC

Ocean Stewardship



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



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 Fonteles



Catarina Cecílio



Cintia Bonanad



Francisco Campuzano



Inês Girão



Inês de Sousa Magusseiro



Luis Pedro Almeida



Luis Figueiredo



Luisa Barros



Manuel Khudnyan



Maria Castro



Nuno Lourenço
CEO



Paula Salge



Renato Mendes



Rita Cunha



Rui Lopes Baeta



Sara Freitas



Sofia Aguiar



Soraia Romão



Tiago Garcia

|

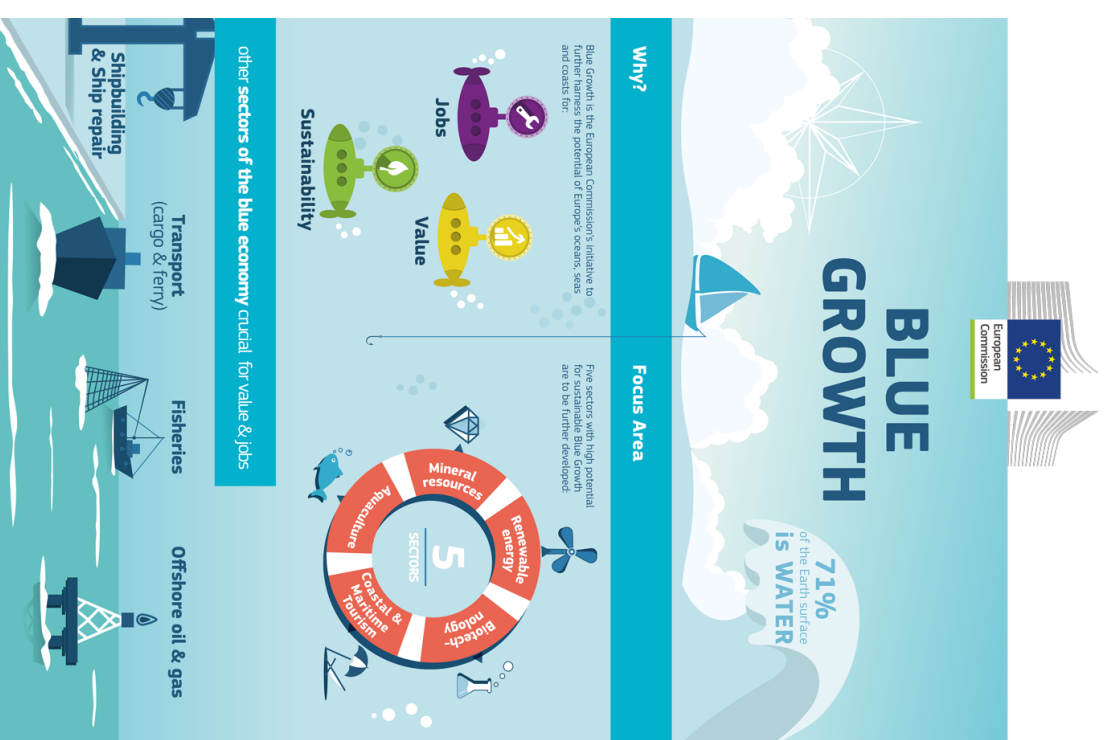
Intro

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

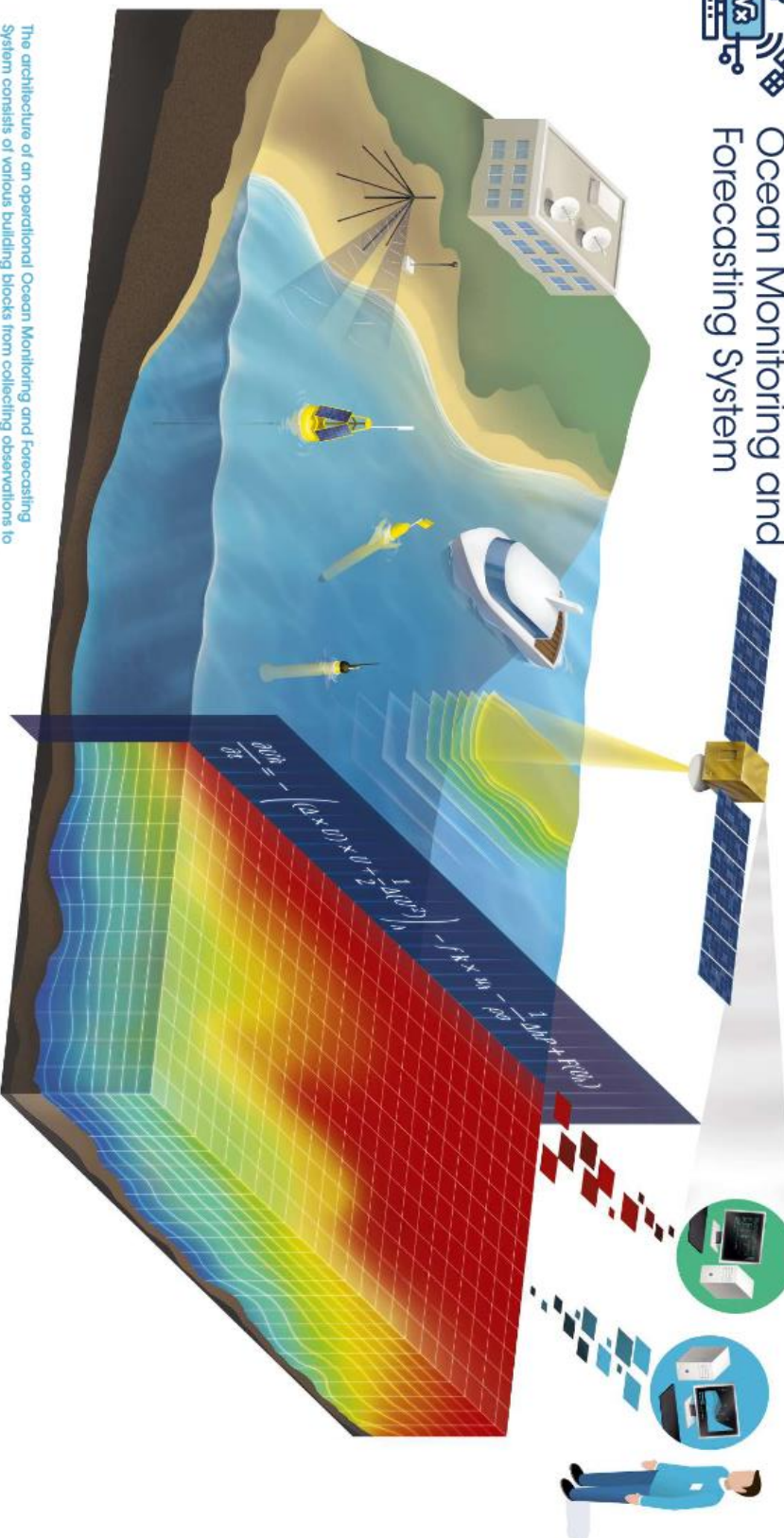
Numerical ocean modelling to know current sea state and **predict** near future events.

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...



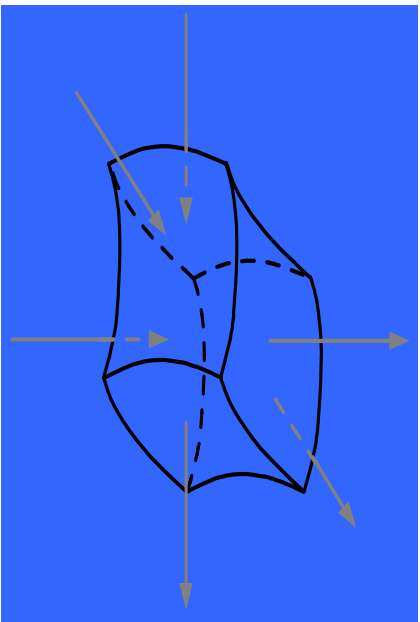
Architecture of an Ocean Monitoring and Forecasting System



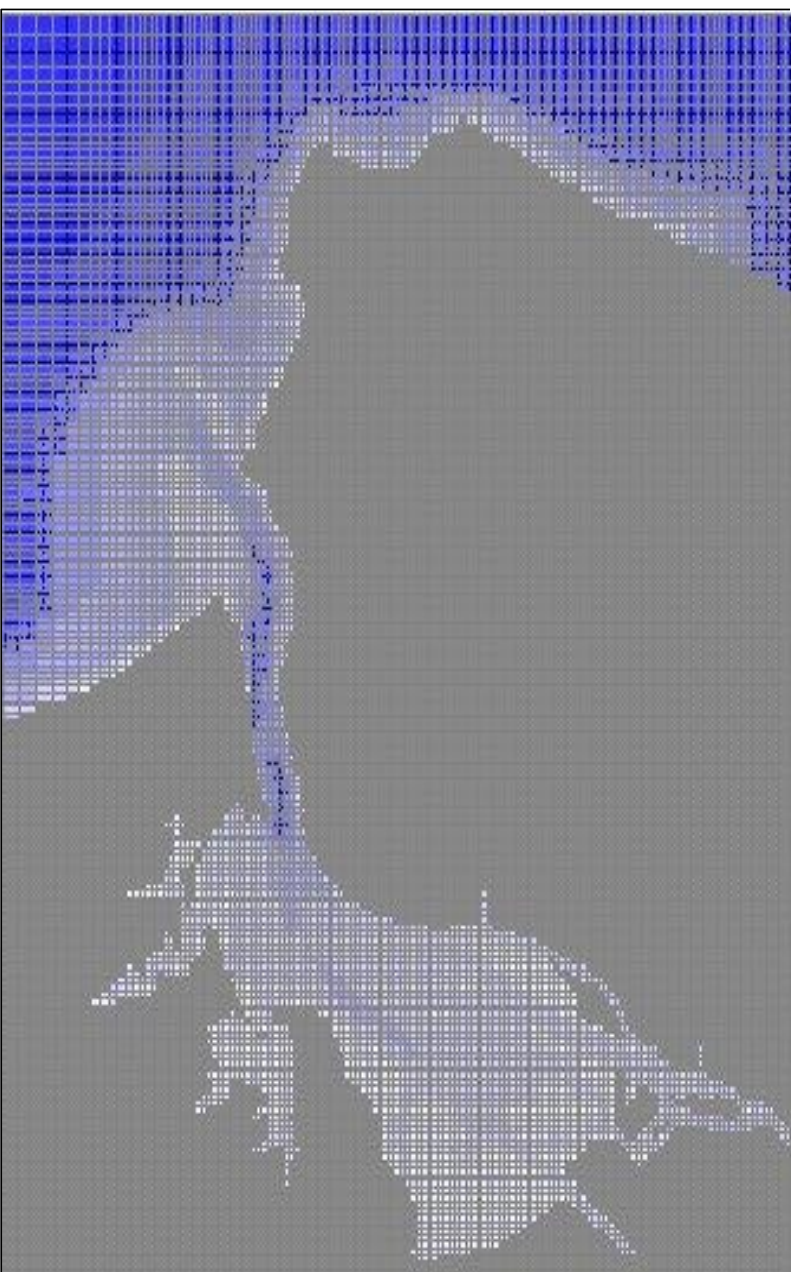
The architecture of an operational Ocean Monitoring and Forecasting System consists of various building blocks from collecting observations to modelling and forecasting the ocean state.



The models



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

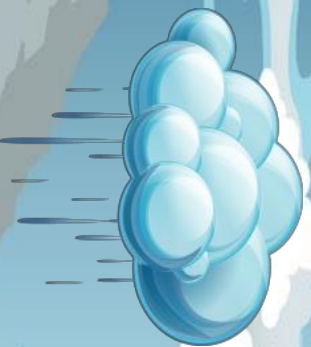


Mathematical models improve with age.....

SINCE 1985

MOHID

<http://mohid.com/>



Atmosphere



MOHID

Land



Discharges

Sediment

BENTHOS

Hydrodynamic

MOHID

Lagrangian

MOHID

Water

Tides



Copernicus
Marine Service

Main Contributors:



TÉCNICO
LISBOA



MARETEC
MARINE ENVIRONMENT & TECHNOLOGY CENTER

Bentley®
Advancing Infrastructure



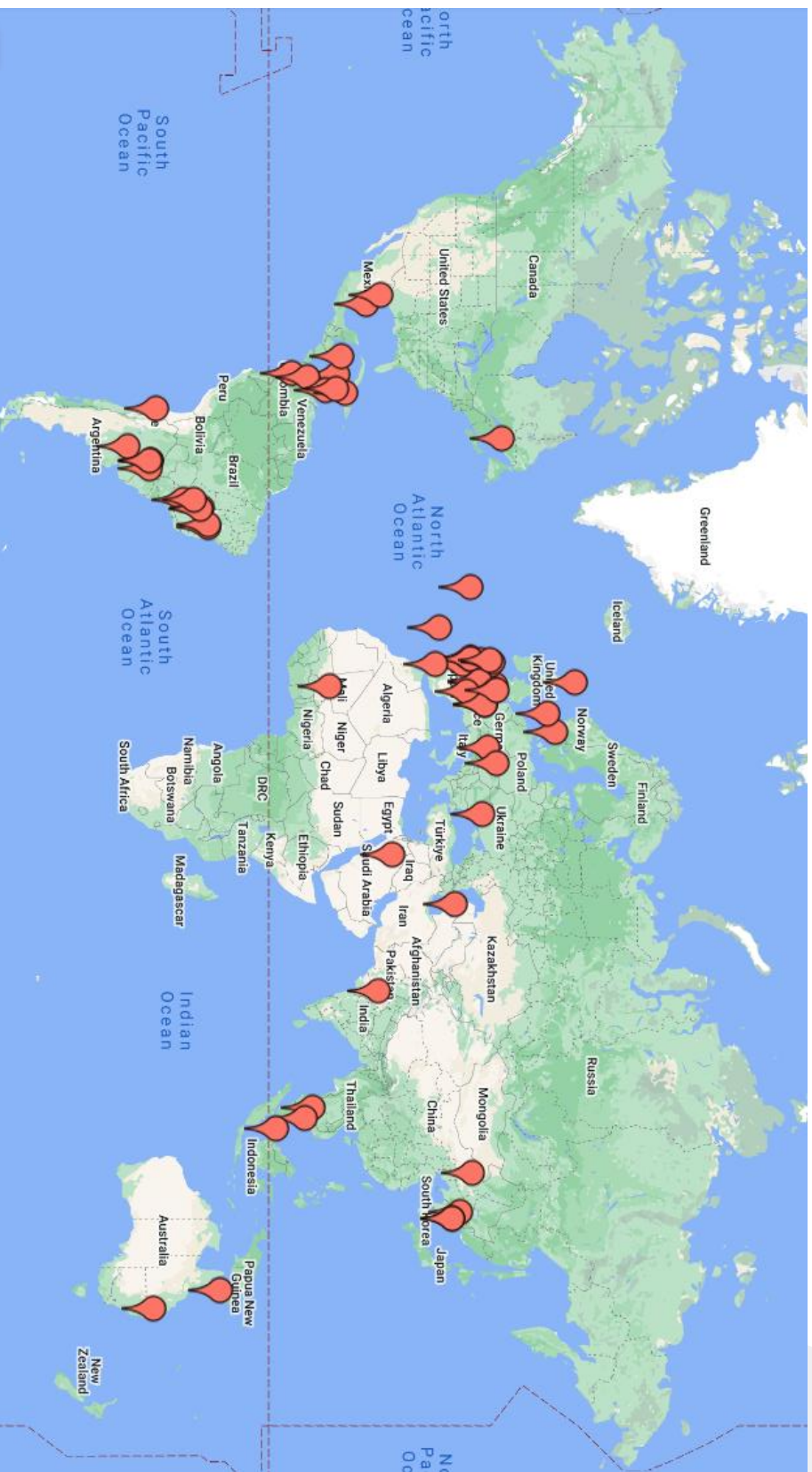
COLAB
ATLANTIC

+ MOHID: a global community model

<http://mohid.com/>

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

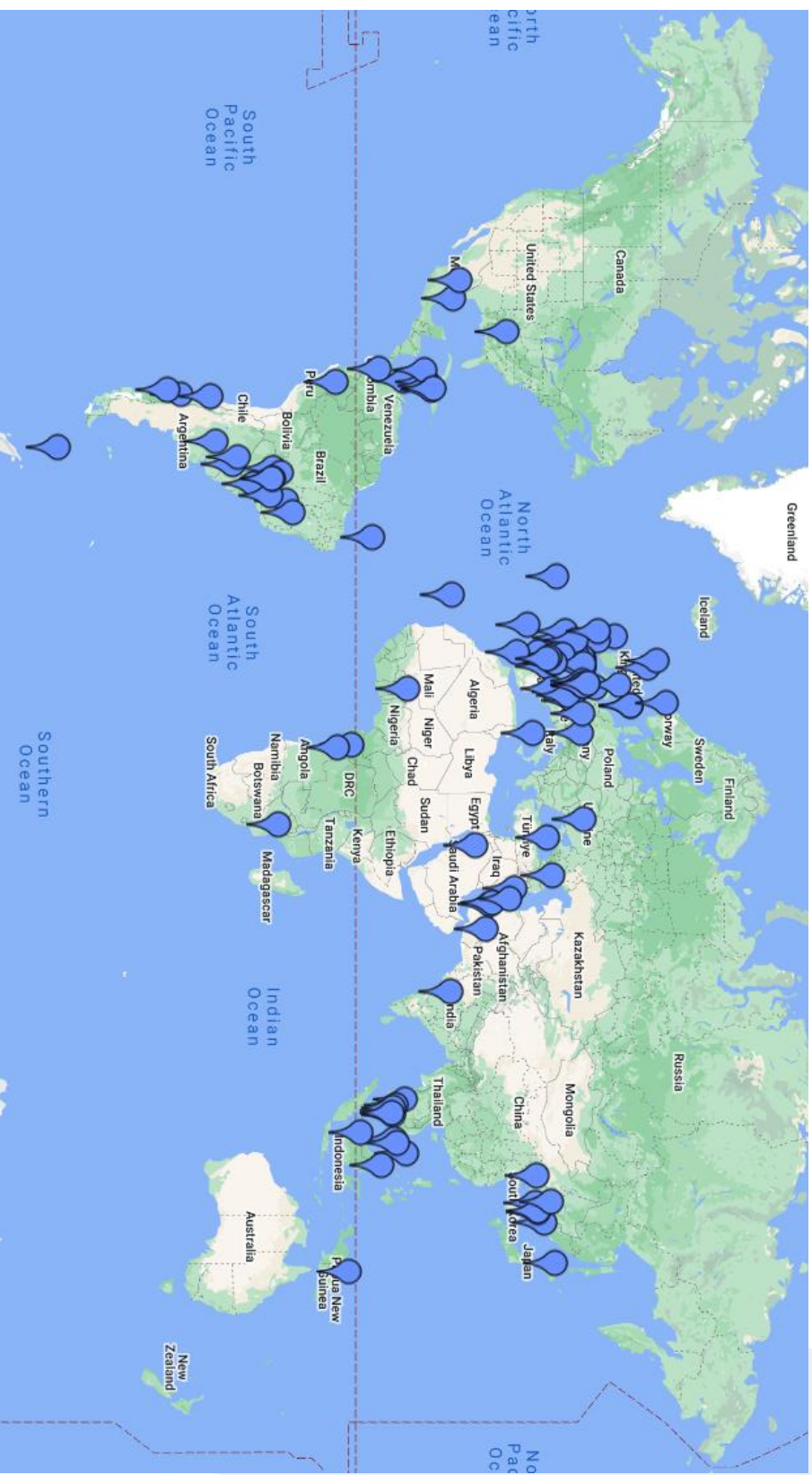
+ MOHID and its applications – a global community

<http://mohid.com/>

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

MOHID

- Online and offline coupling with circulation models



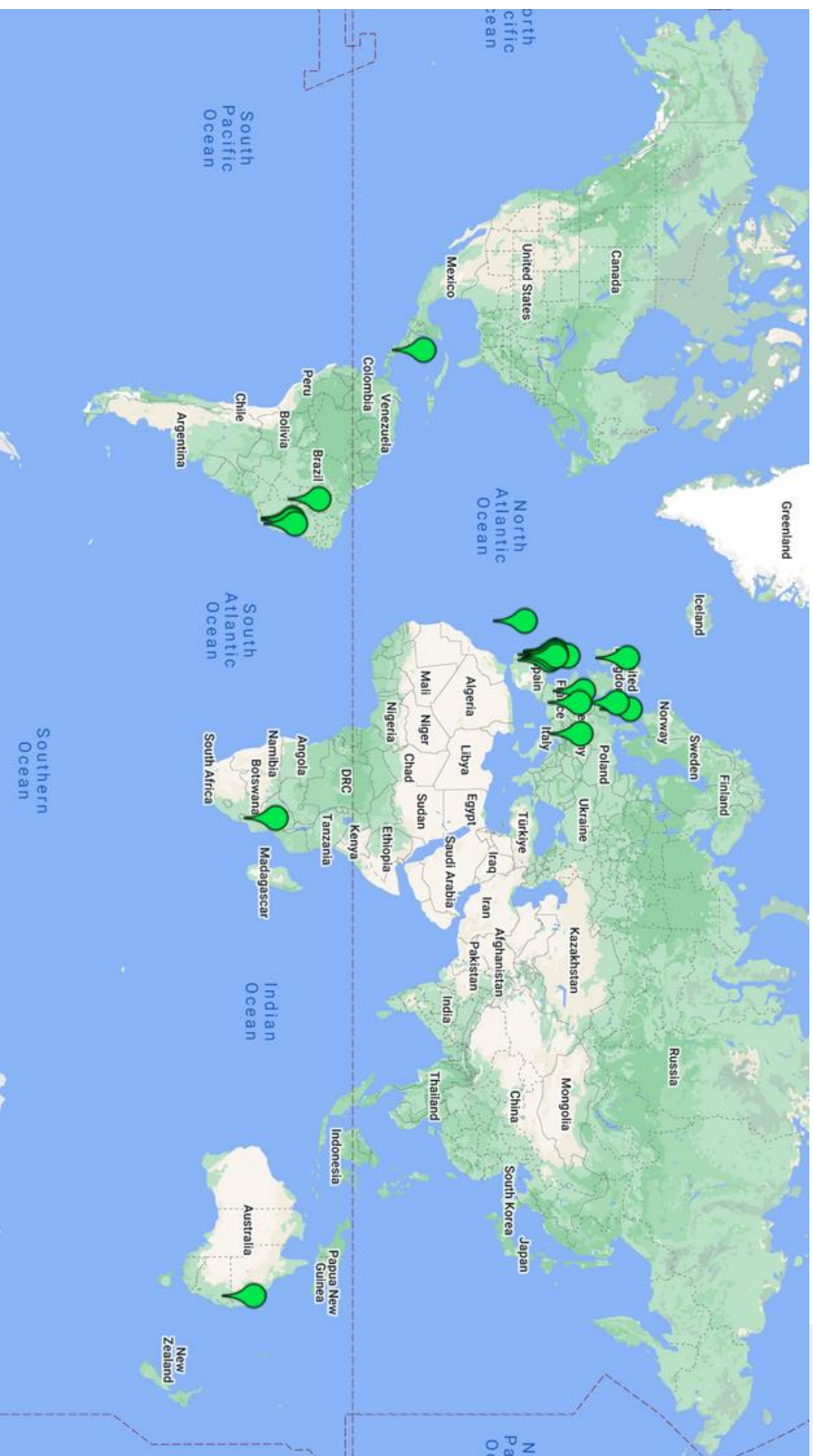
 MOHID Water applications

+ MOHID model and its applications – a global community

<http://mohid.com/>

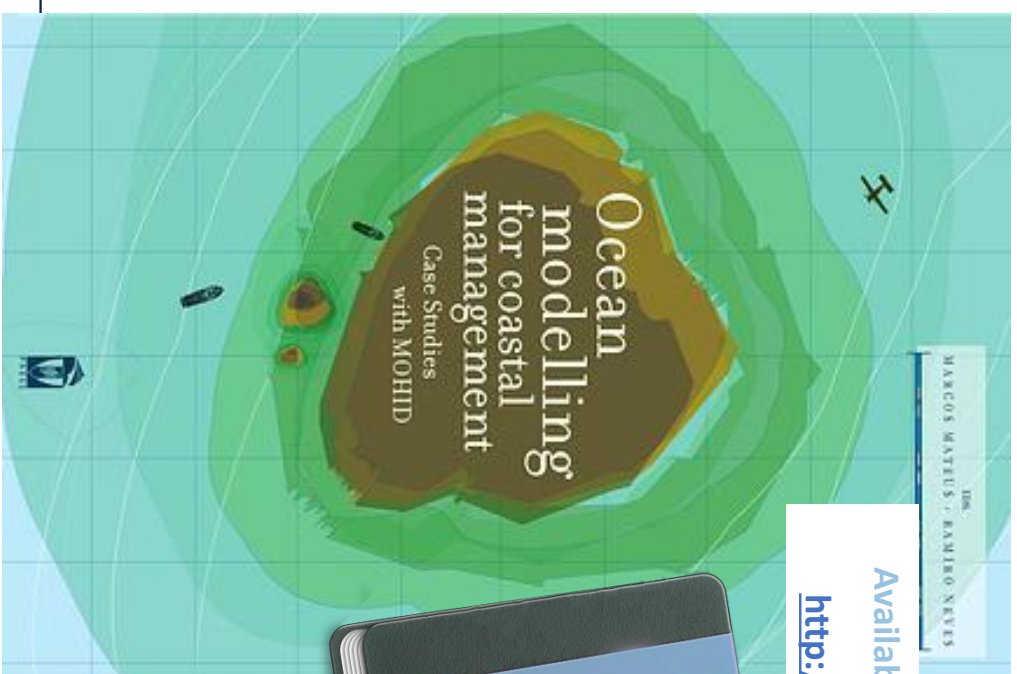
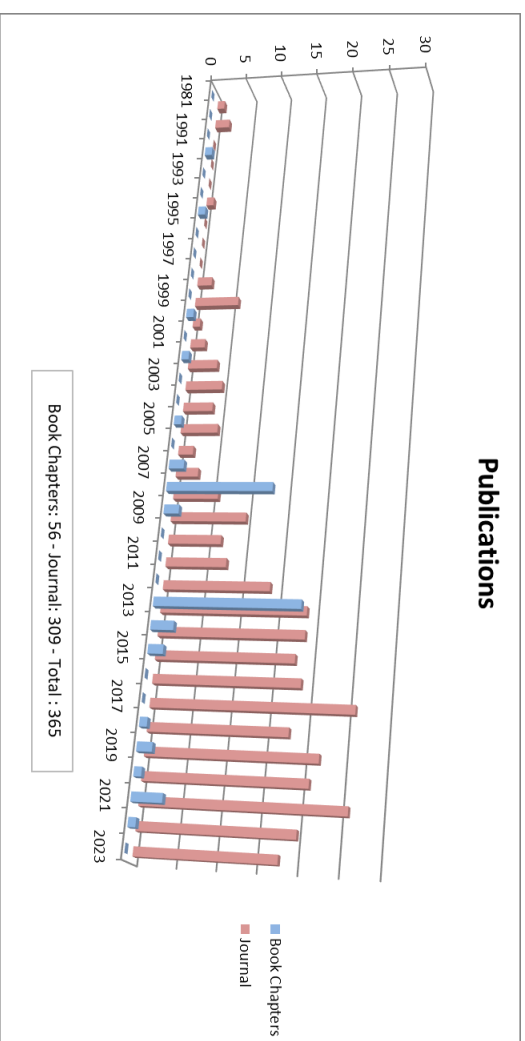
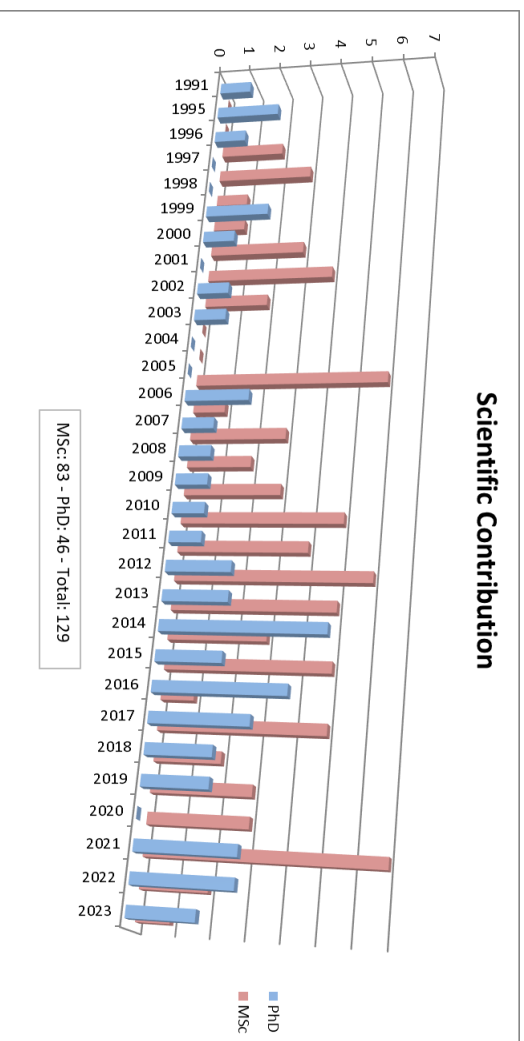
MOHID

- 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>

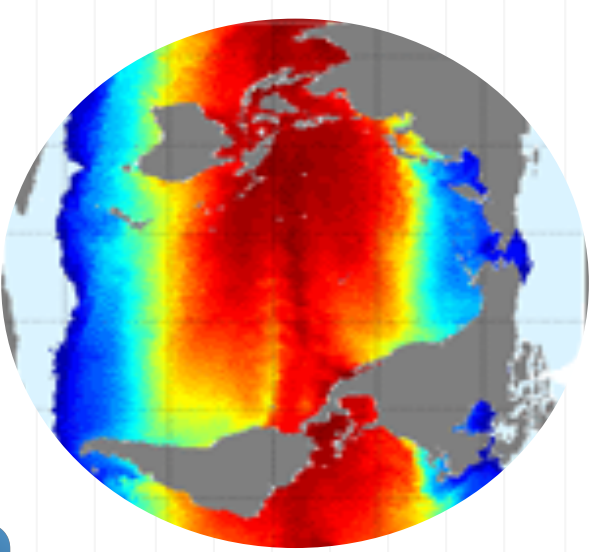




Global circulation models

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://marine.copernicus.eu/>

https://datamarine.copernicus.eu/products



Copernicus
Europe's system for Earth



Copernicus
Marine Service

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

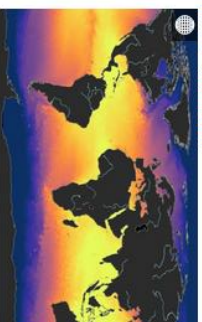
DEPTH RANGE
↓ ↑

UNIVERSE
Blue Ocean 189
White Ocean 39
Green Ocean 78

MAIN VARIABLES
Carbonate system 19

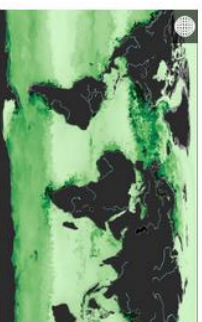
Products 275

MOST POPULAR



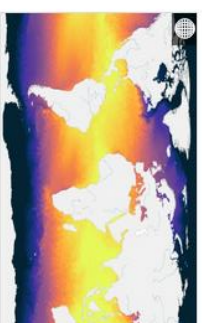
Global Ocean Physics Analysis and Forecast

GLOBAL_ANALYSISFORECAST_P..._001_024
Models
Global, 0.083° x 0.083° x 50 levels
31 Oct 2020 to 21 Jul 2023, hourly, daily,...



Global Ocean Biogeochemistry Analysis and Forecast

GLOBAL_ANALYSIS_FORECAST_R..._001_028
Models
Global, 0.25° x 0.25° x 50 levels
31 Oct 2020 to 14 Jul 2023, daily, monthly
Carbonate system, nutrients, oxygen,
plankton



Global Ocean Physics Reanalysis

GLOBAL_MULTYEAR_PHY_001_030
Models
Global, 0.083° x 0.083° x 50 levels
1 Jan 1993 to 30 Dec 2020, daily, monthly
Mixed layer thickness, salinity, sea ice, sea
surface height, temperature, velocity

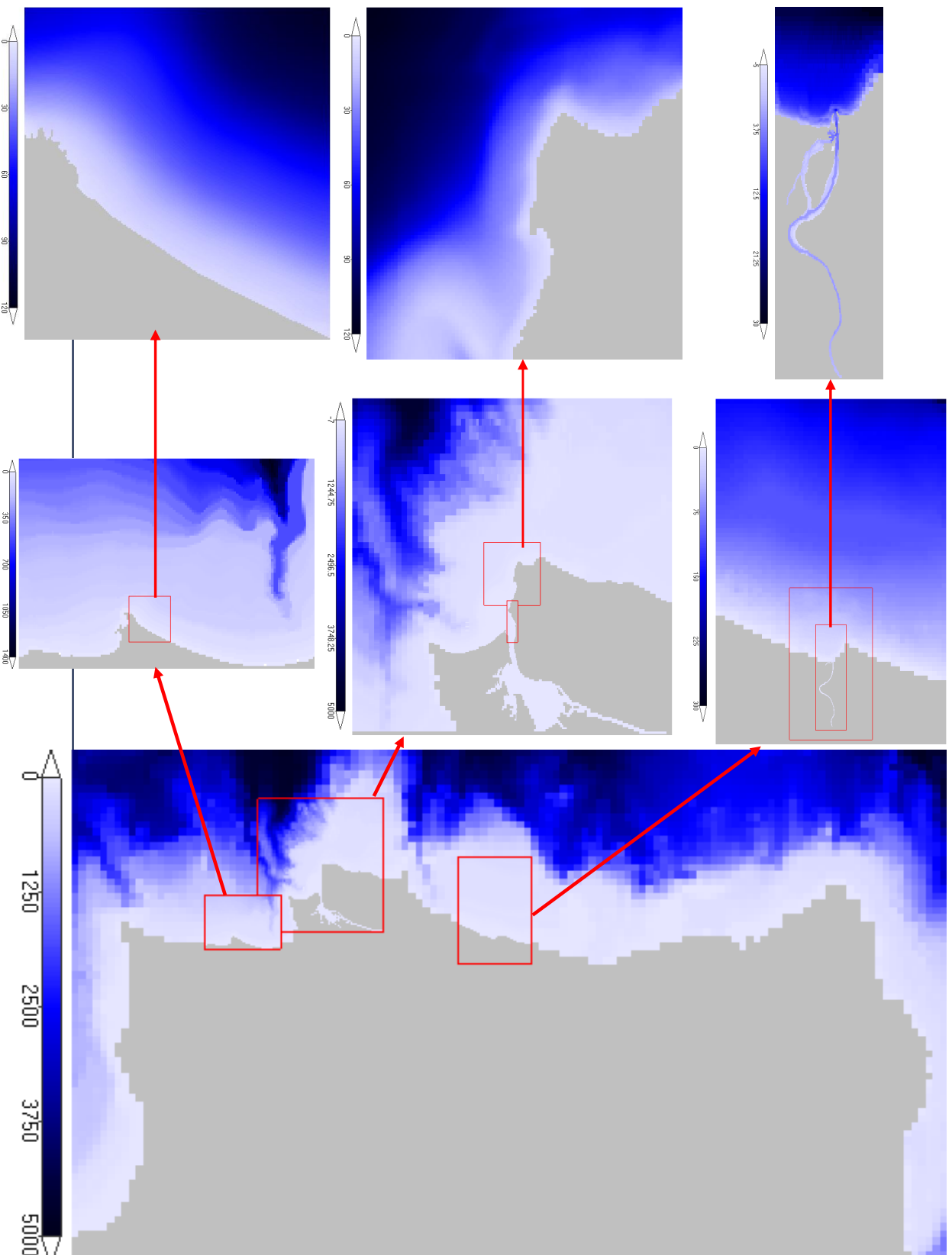


Global Ocean Surface Fluxes

SEALEVEL_Satellite (L4)
Global, 0.25° x 0.25° x 50 levels
1 Jan 1993 to 30 Dec 2020, daily, monthly
Sea surface

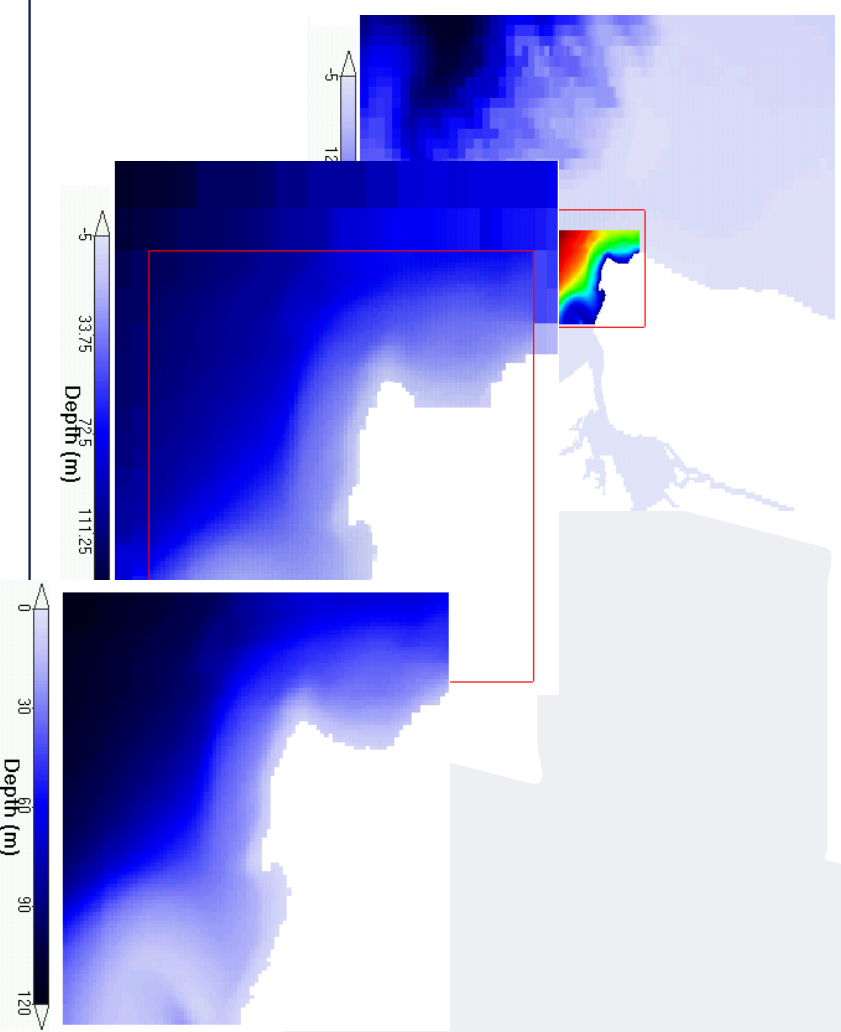
Downscaling

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

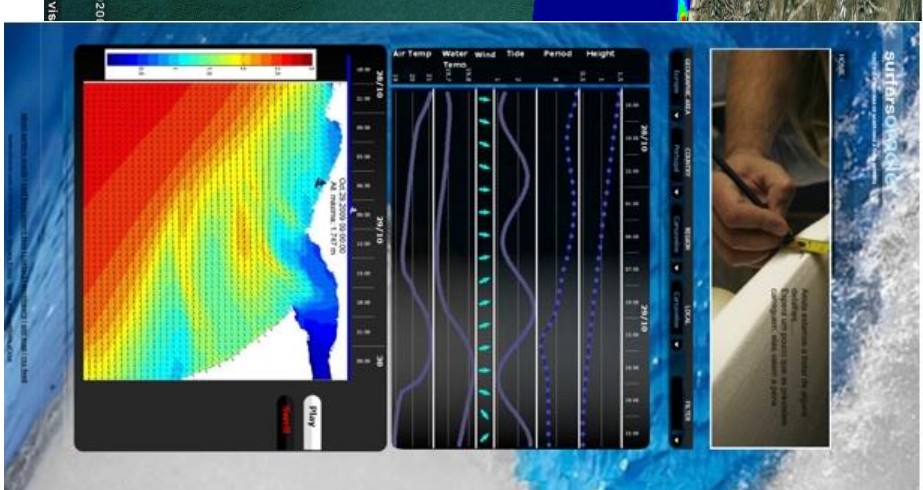
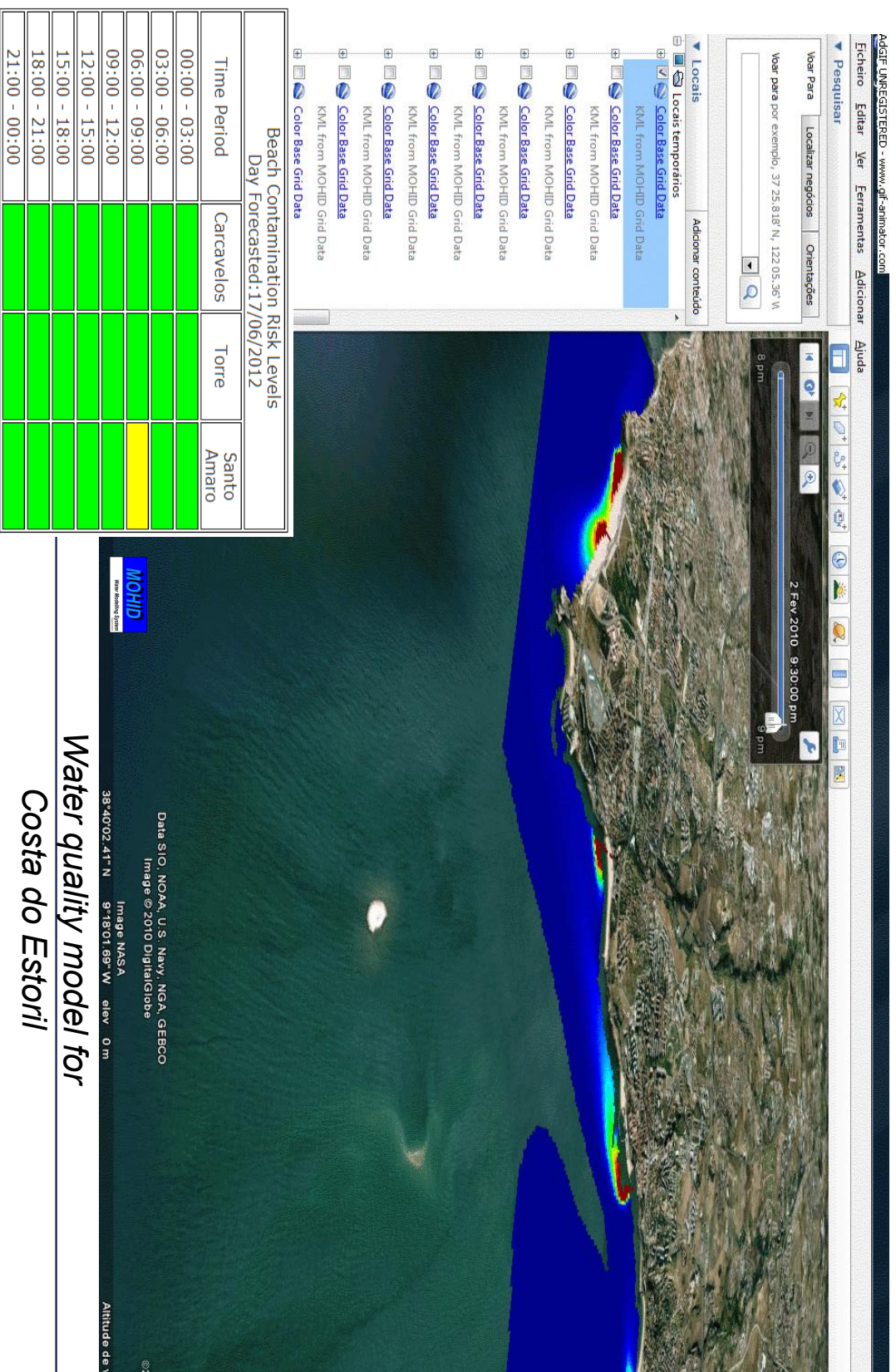


The Window Downscaling Technique

- 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)

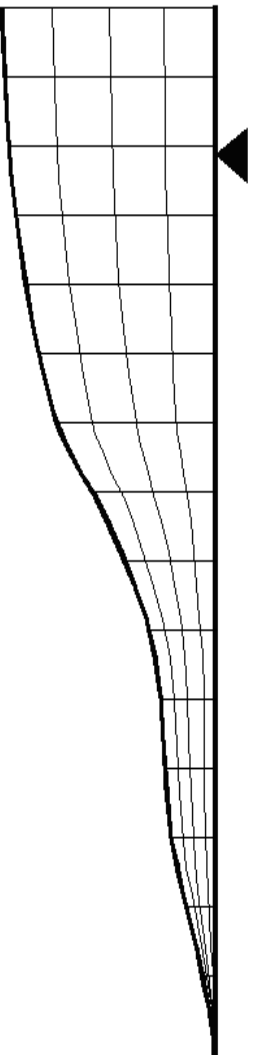


Water quality model for

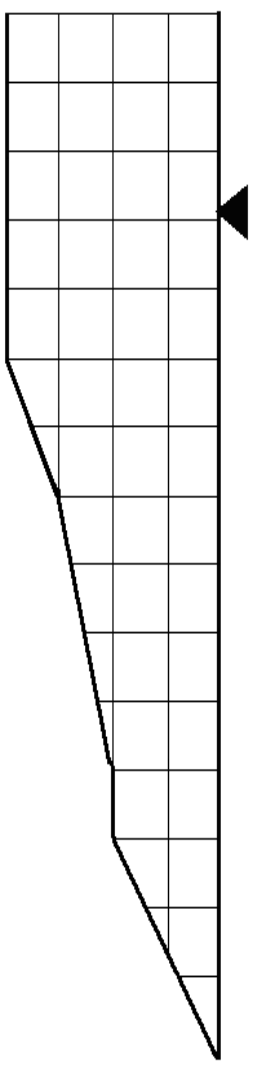
Costa do Estoril

Vertical Discretisation – type of layer

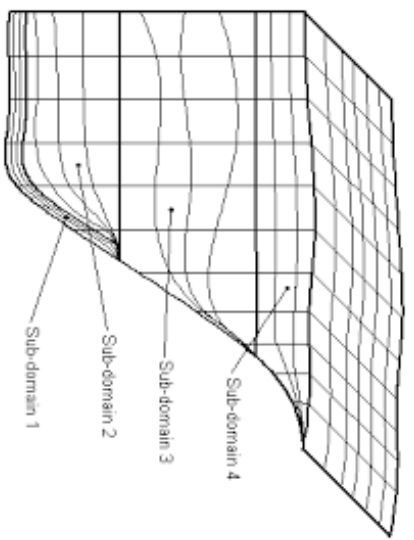
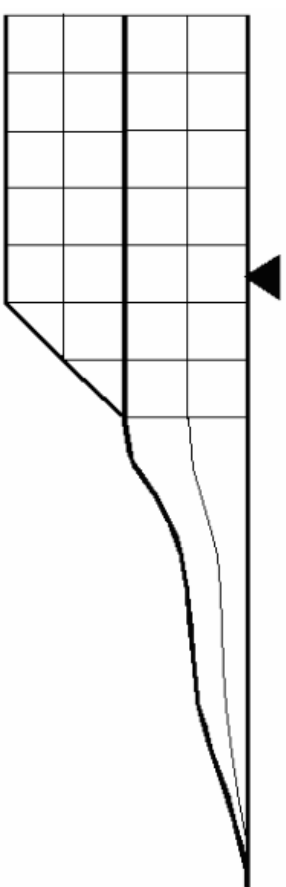
Sigma



Cartesian or z-layer



Hybrid



Level 1

Level 2

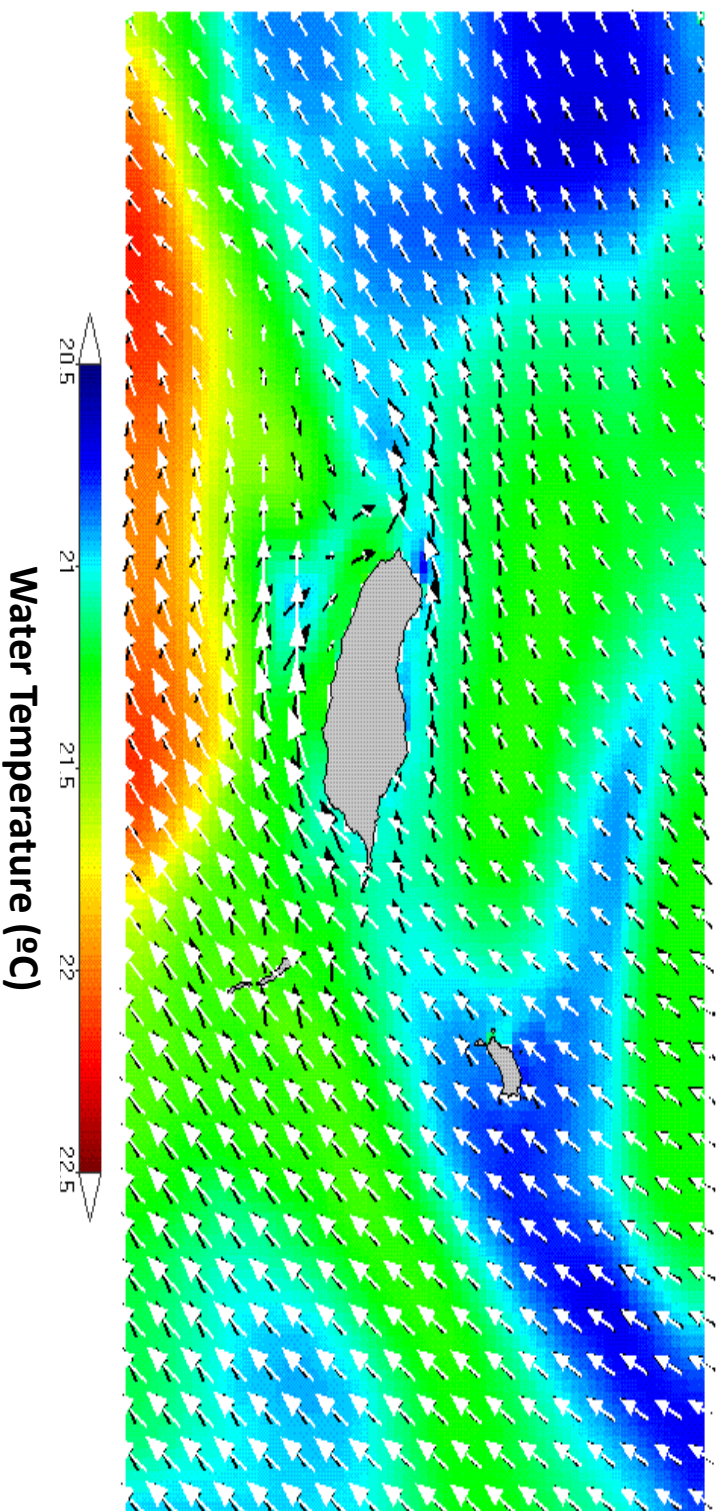
Level 3

Level 5

Level 4



Coupled Models



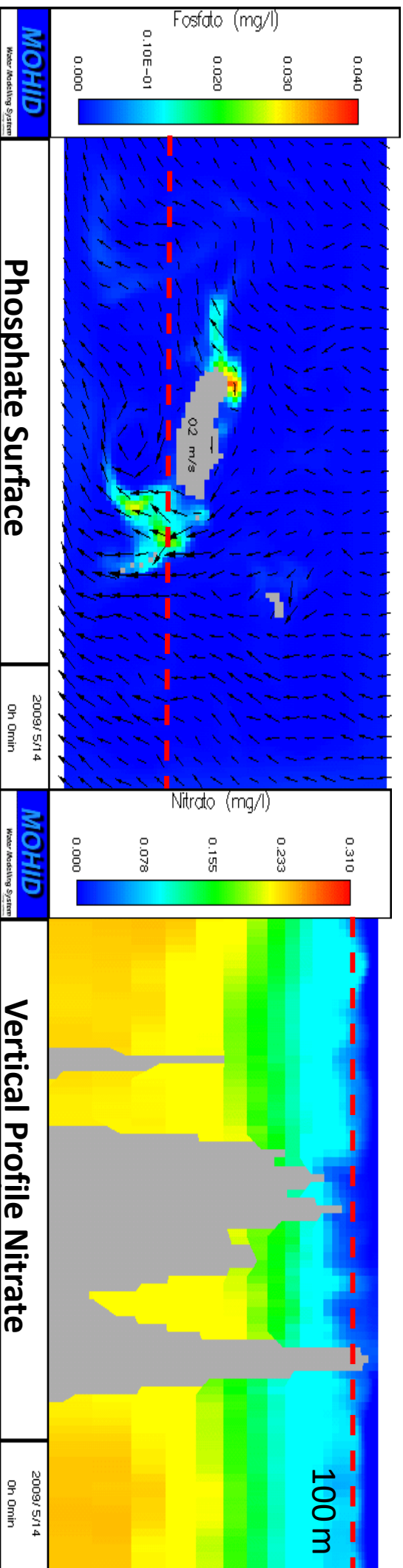
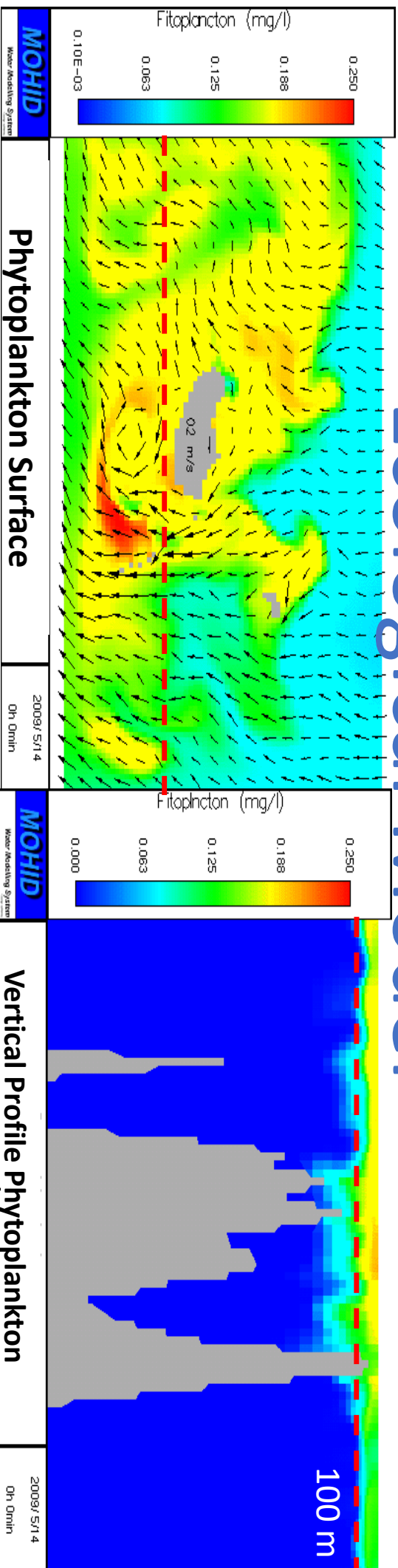
Surface Temperature in the Madeira Archipelago

White arrows (Wind) Black Arrows (Surface velocity)

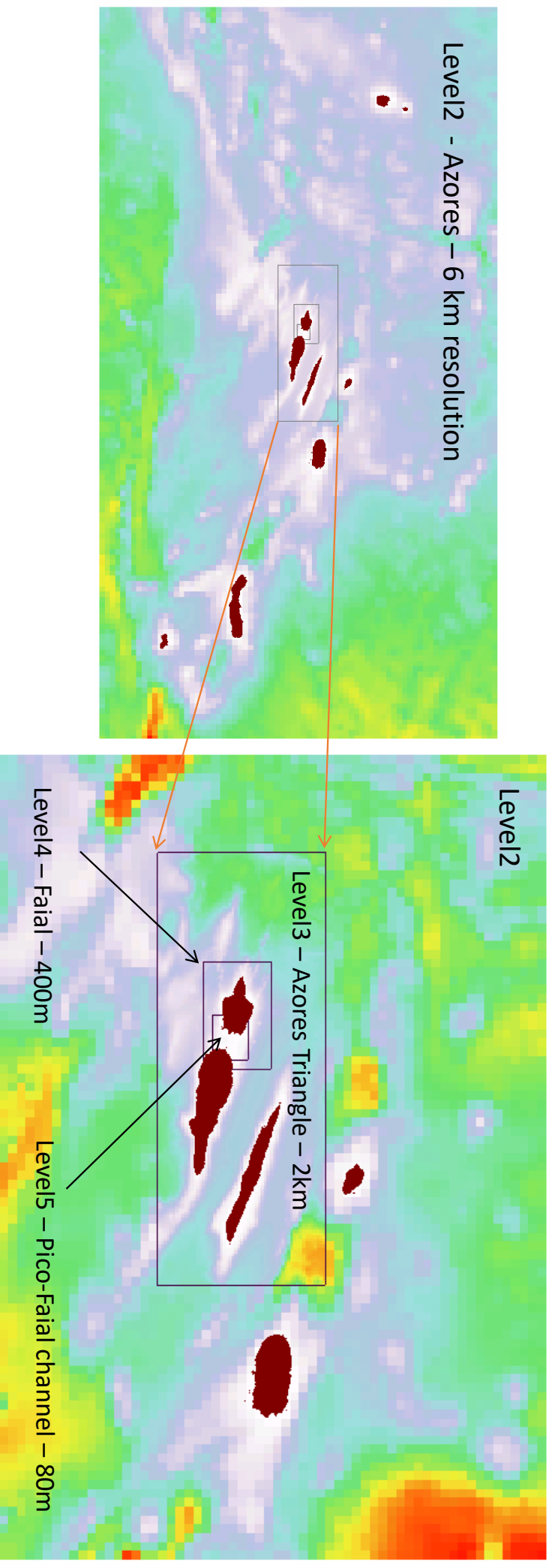
07-11-2008

16:00

Ecological Model

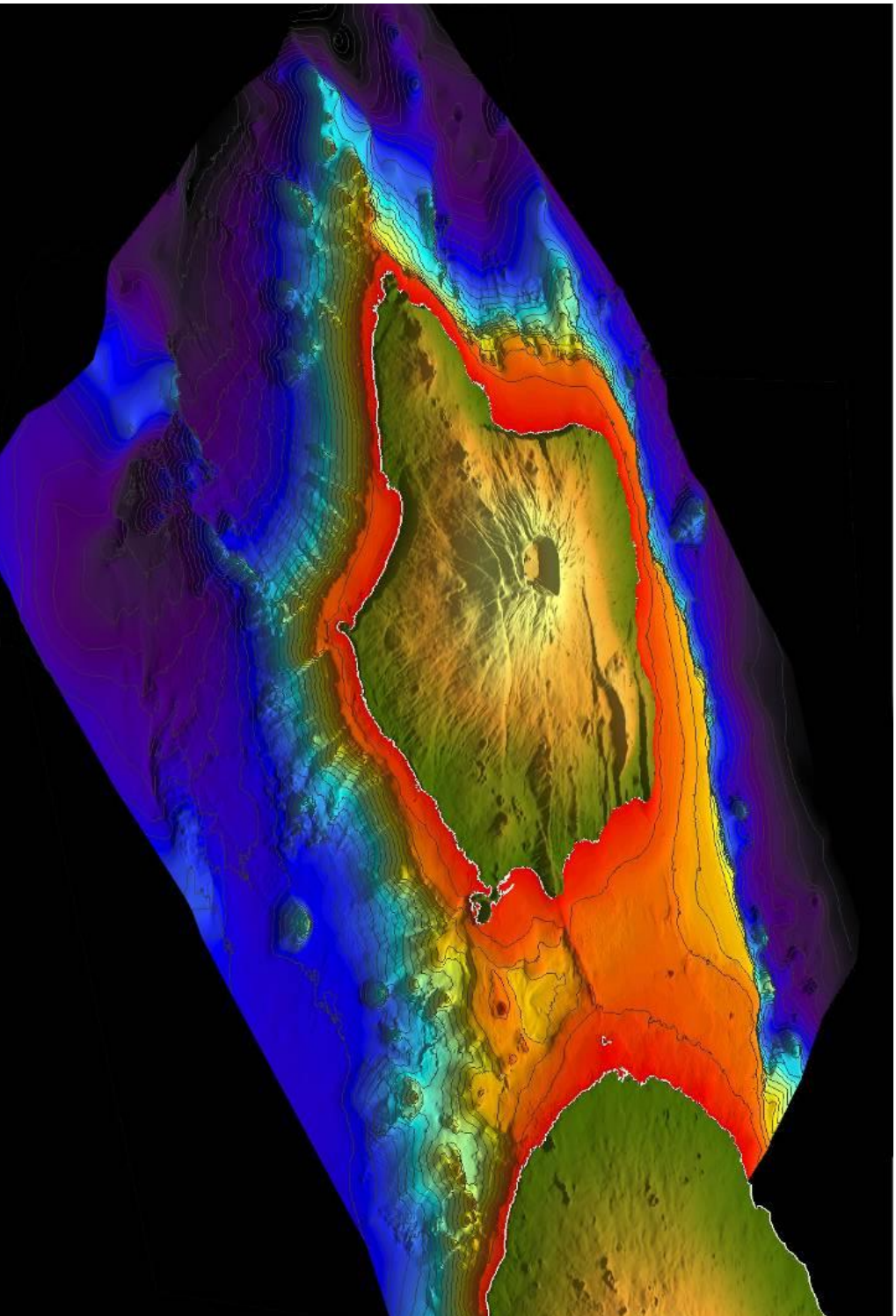


Azores Modeling domains



UAc
UNIVERSIDADE
DOS AÇORES

Azores - Pico-Faial channel



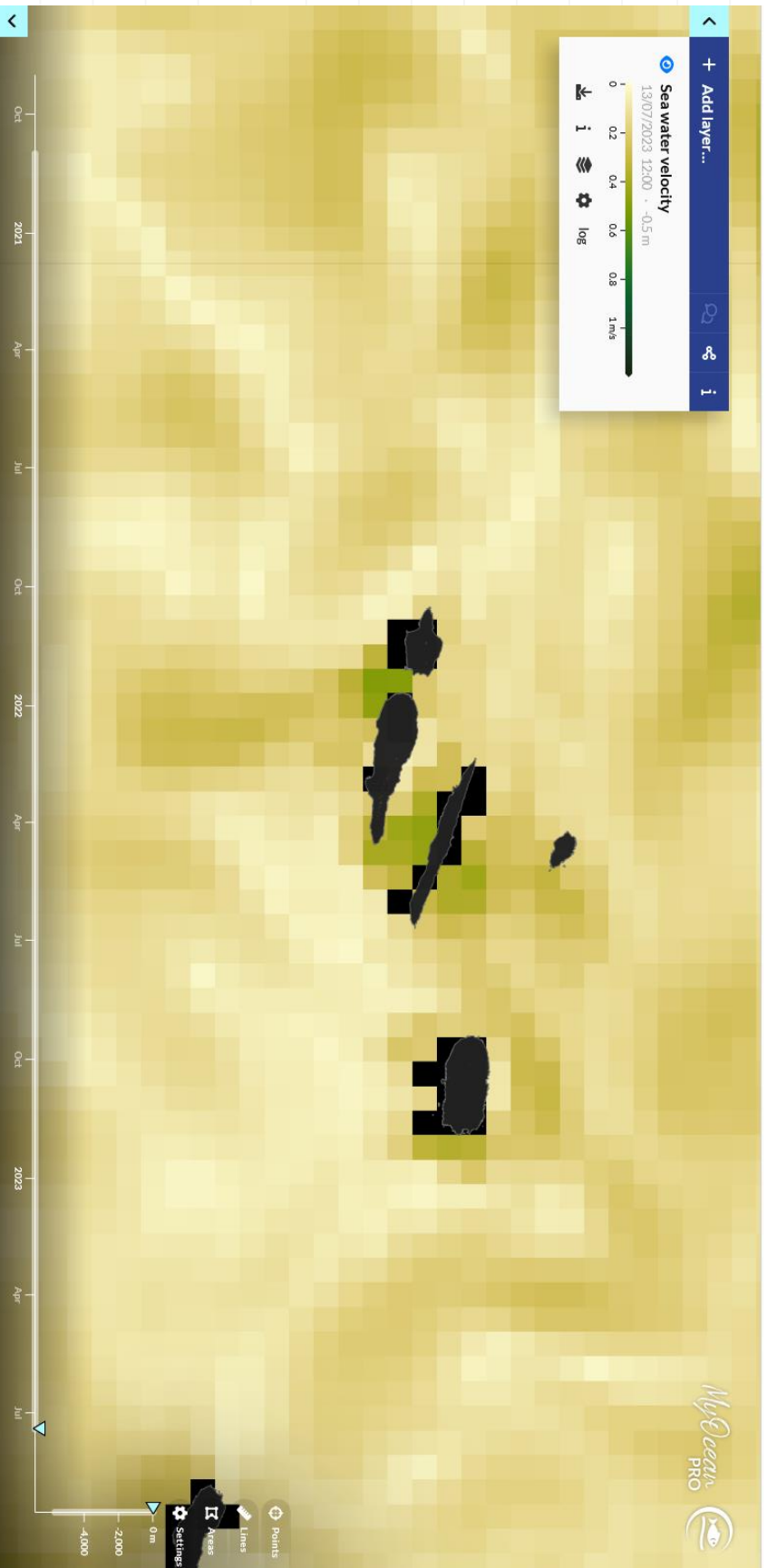
Credits: Fernando Tempera



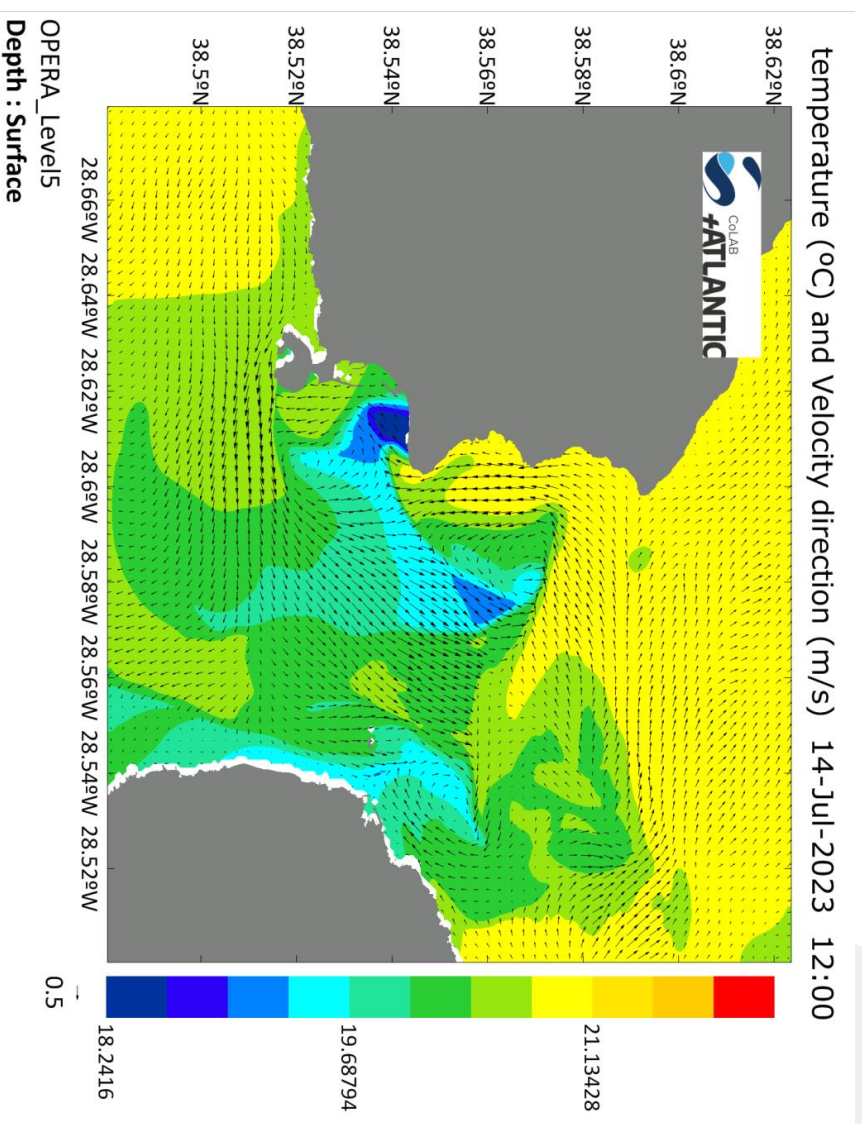
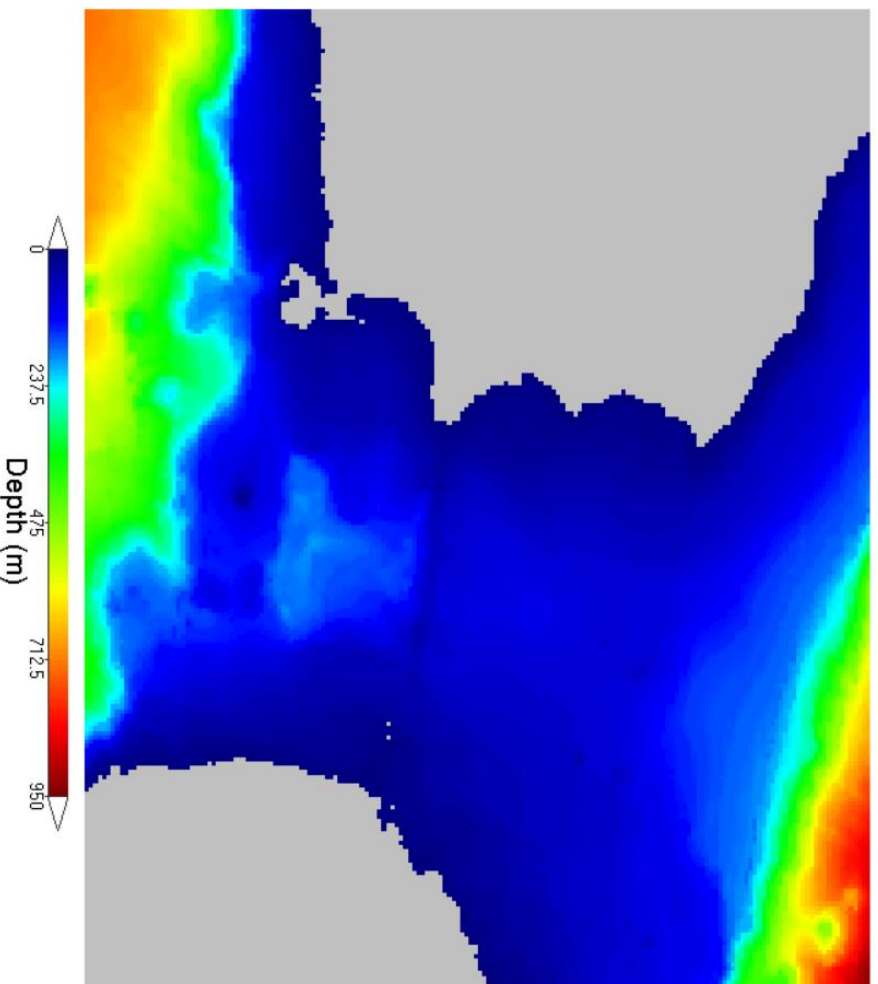
UAc
UNIVERSIDADE
DOS AÇORES



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

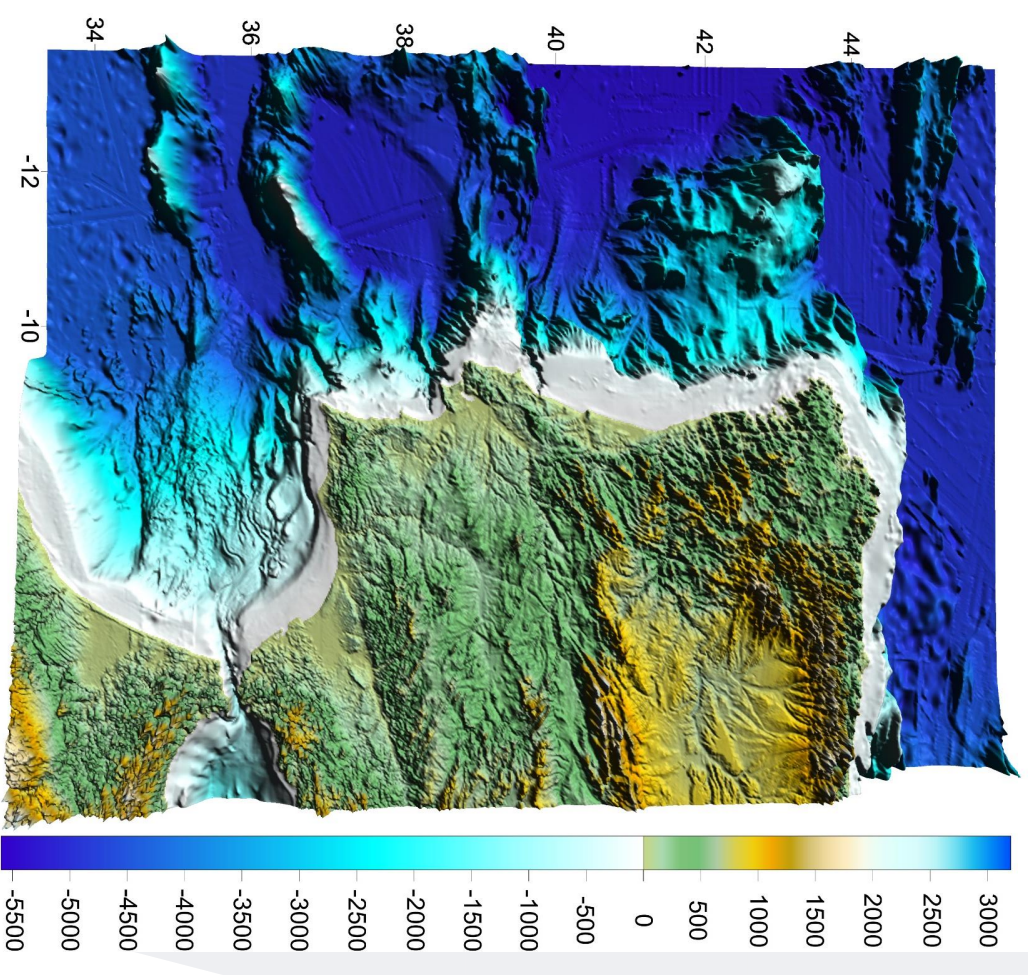
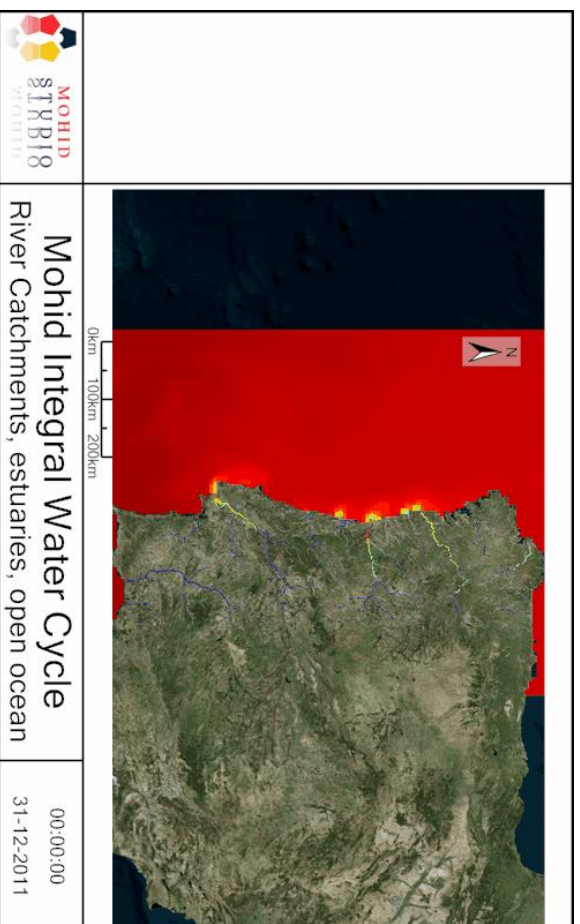


Azores Modelling Domains - Pico-Faial channel **Level 5** – Pico – Faial channel – 80 m hor. resolution



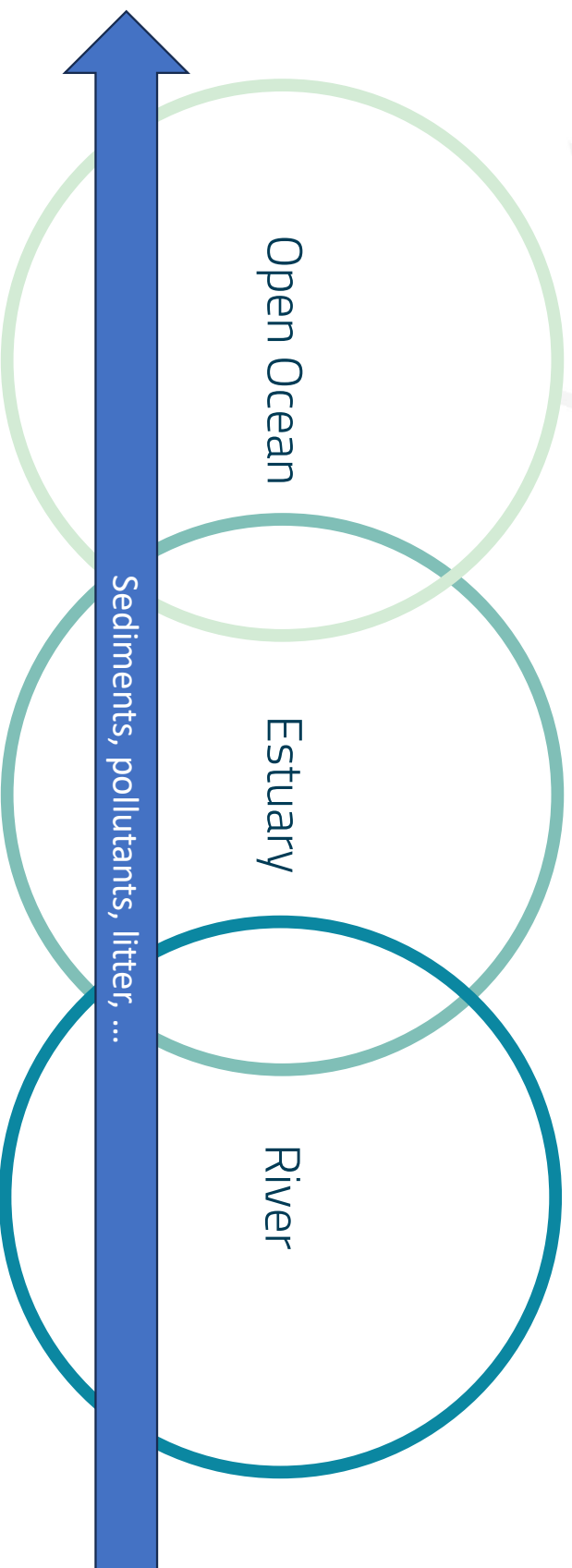
A paradigm shift: Integrated water cycle approach

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

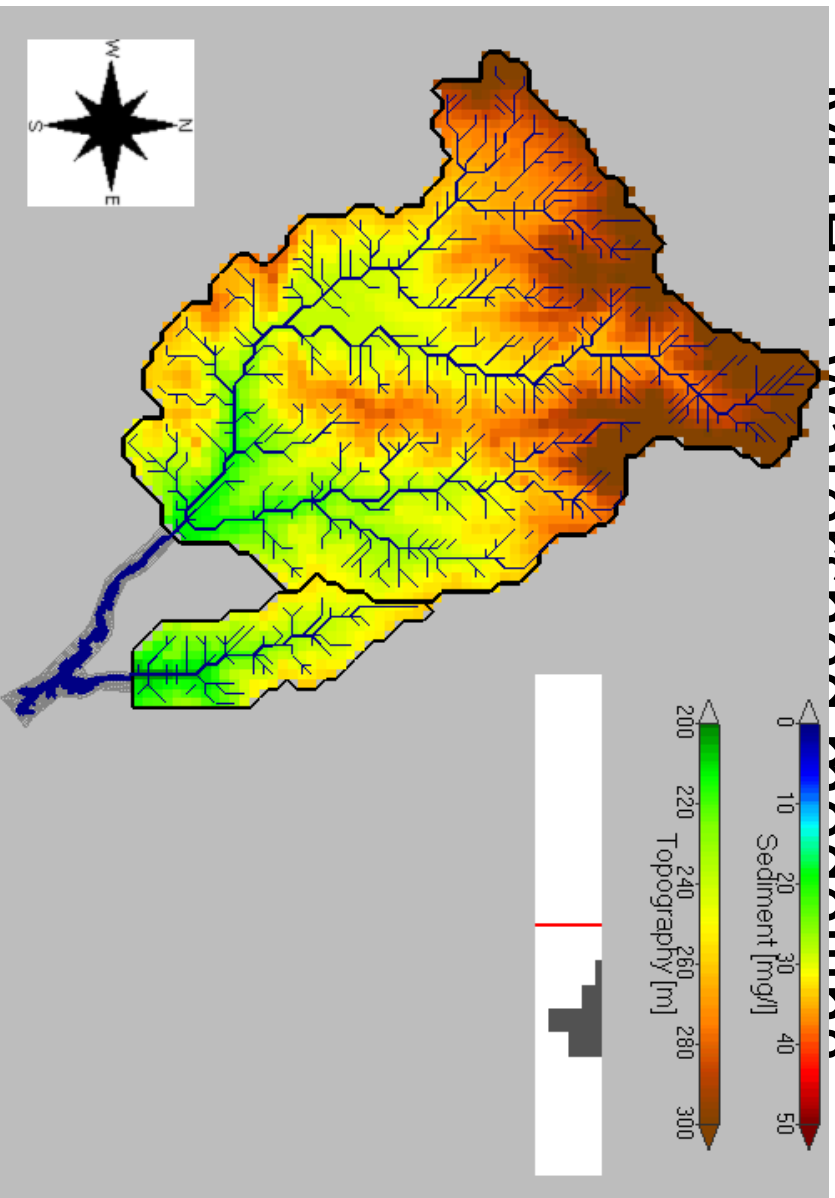
- Coastal water are deeply influenced by river outflow



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



1D Drainage Network

$$\frac{\partial Q}{\partial t} + v_i \frac{\partial Q}{\partial x_i} + gA \left(\frac{\partial h}{\partial x_i} \right) - gA(S_0 - S_{f,i}) = 0$$

2D Overland Flow

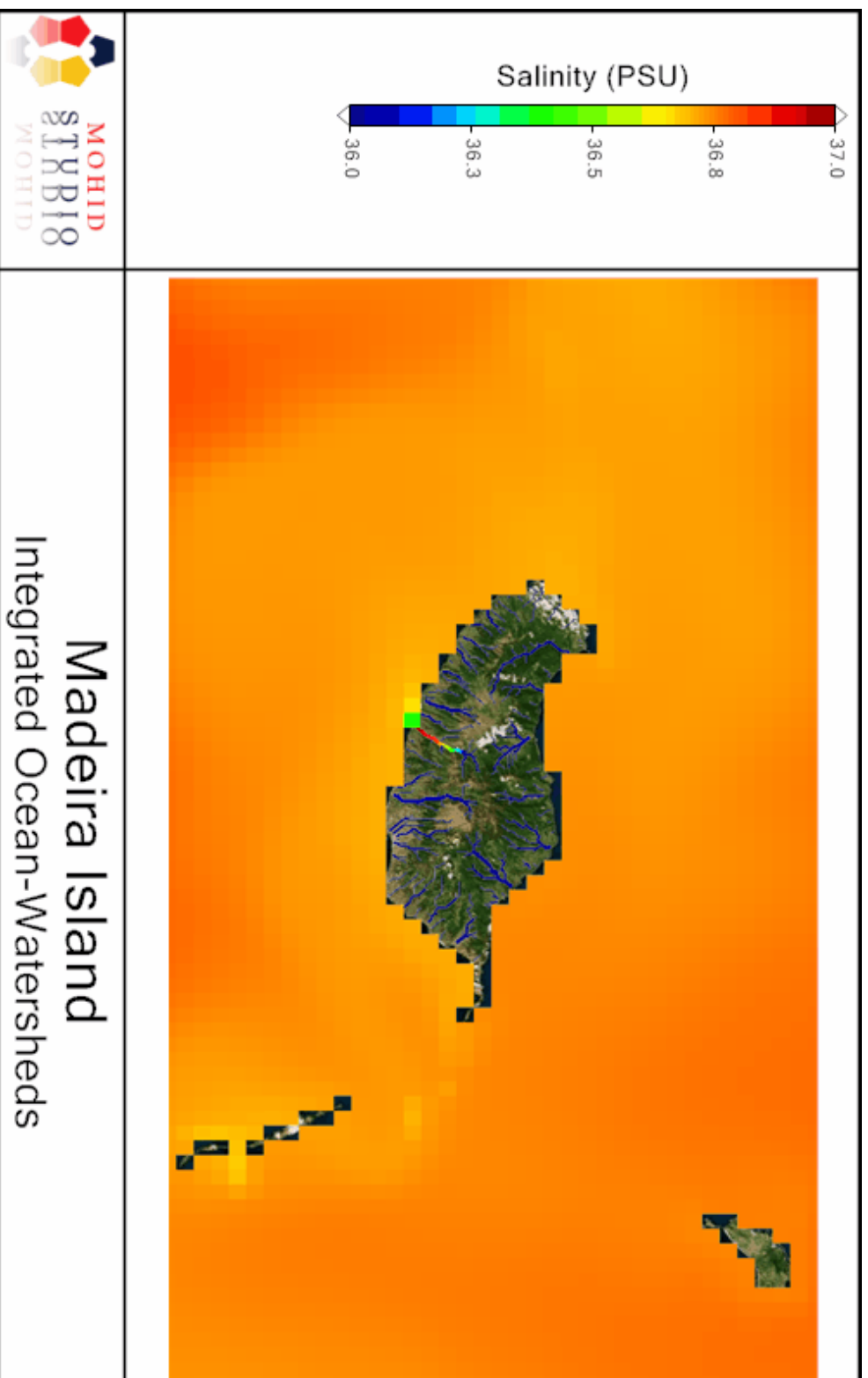
$$\frac{\partial Q}{\partial t} + v_i \frac{\partial Q}{\partial x_i} + gA \left(\frac{\partial h}{\partial x_i} \right) - gA(S_0 - S_{f,i}) = 0$$

3D Porous Media

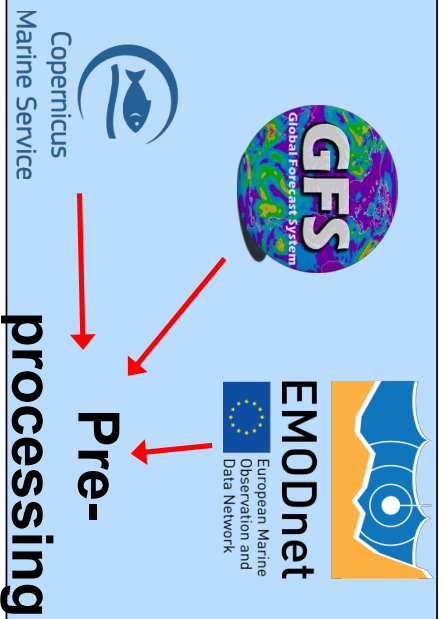
$$\frac{\partial \theta}{\partial t} = -k(\theta) \left(\frac{\partial h}{\partial x_i} + \frac{\partial z}{\partial x_i} \right)$$

Precipitation
Variable in Time
& Space

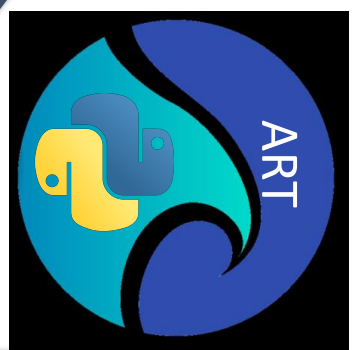
Integrated ocean-watersheds in Madeira island



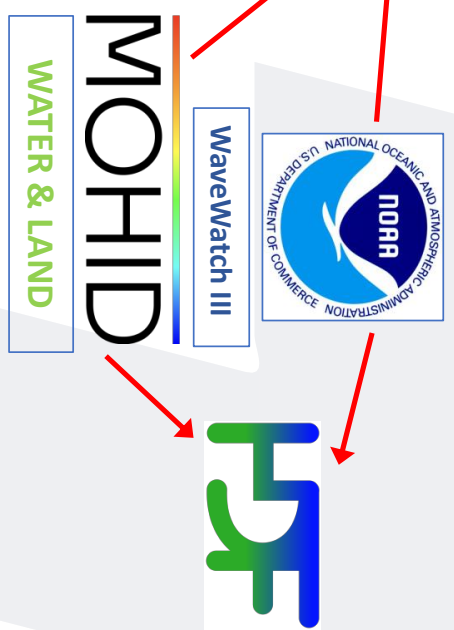
Data Sources



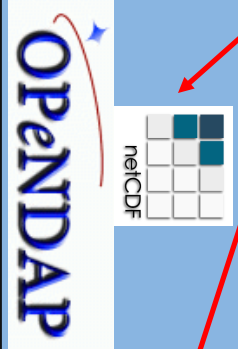
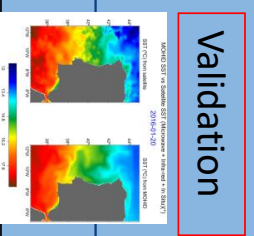
Processing



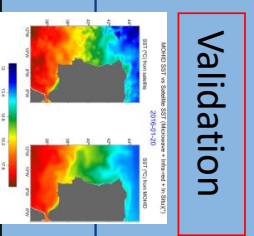
Running Models



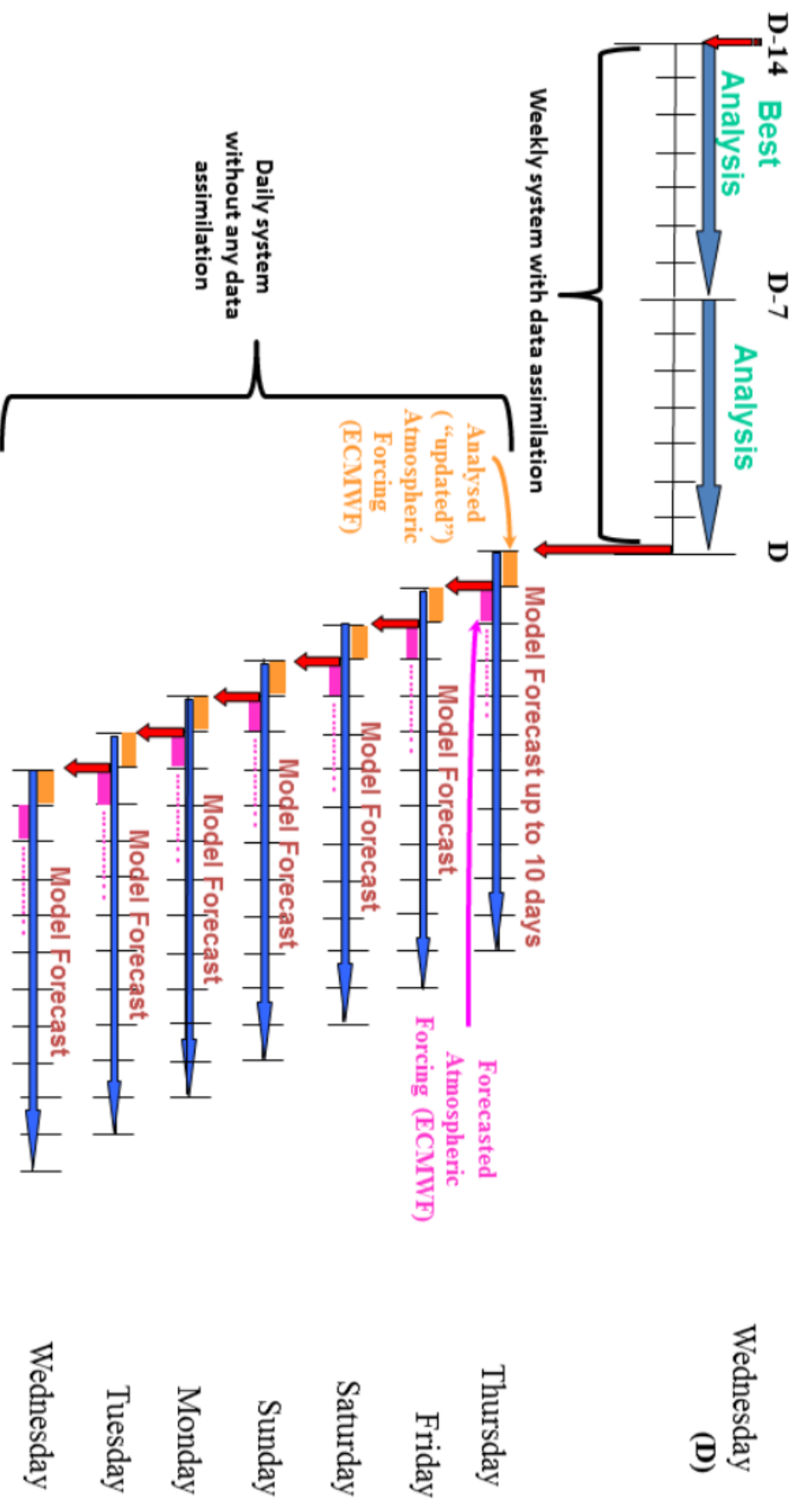
Post-Processing

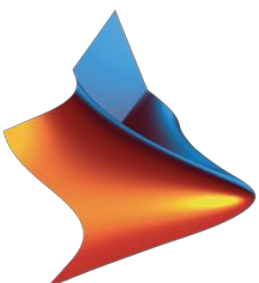


Publishing Results



The product is updated as follows:



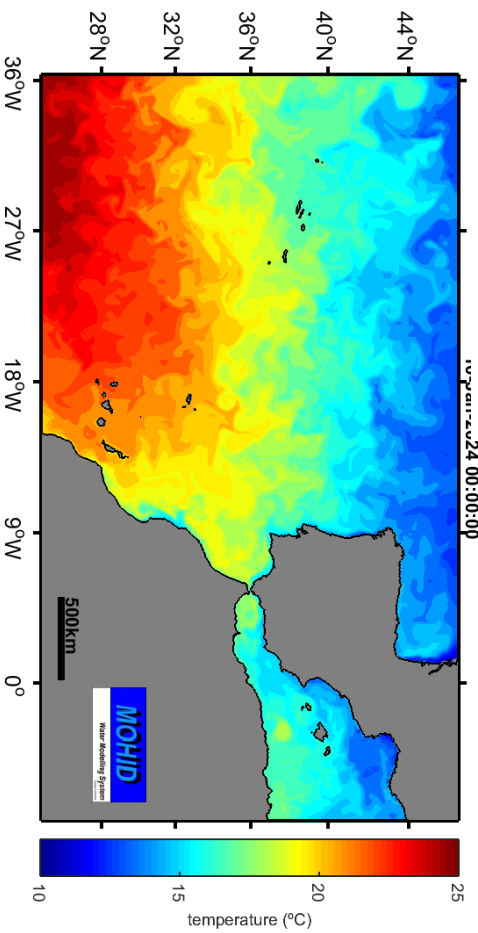
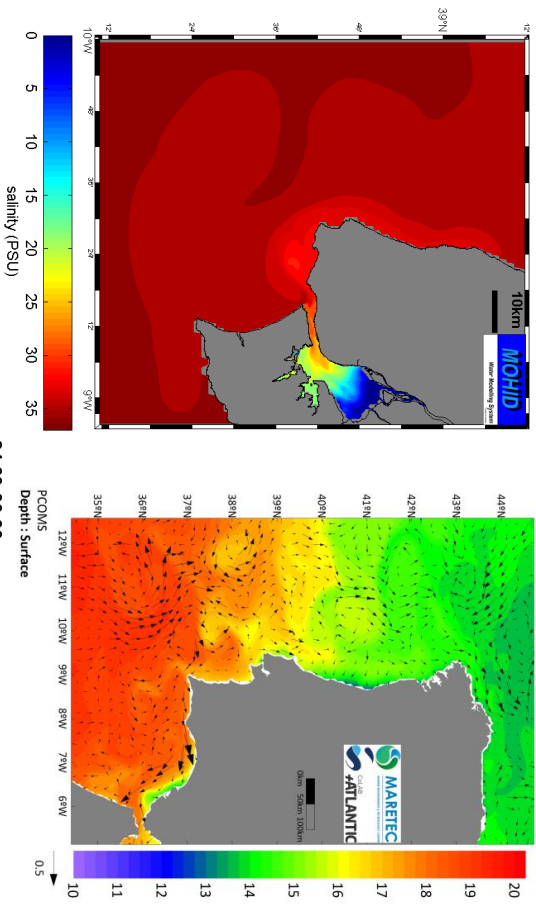


Previously used software

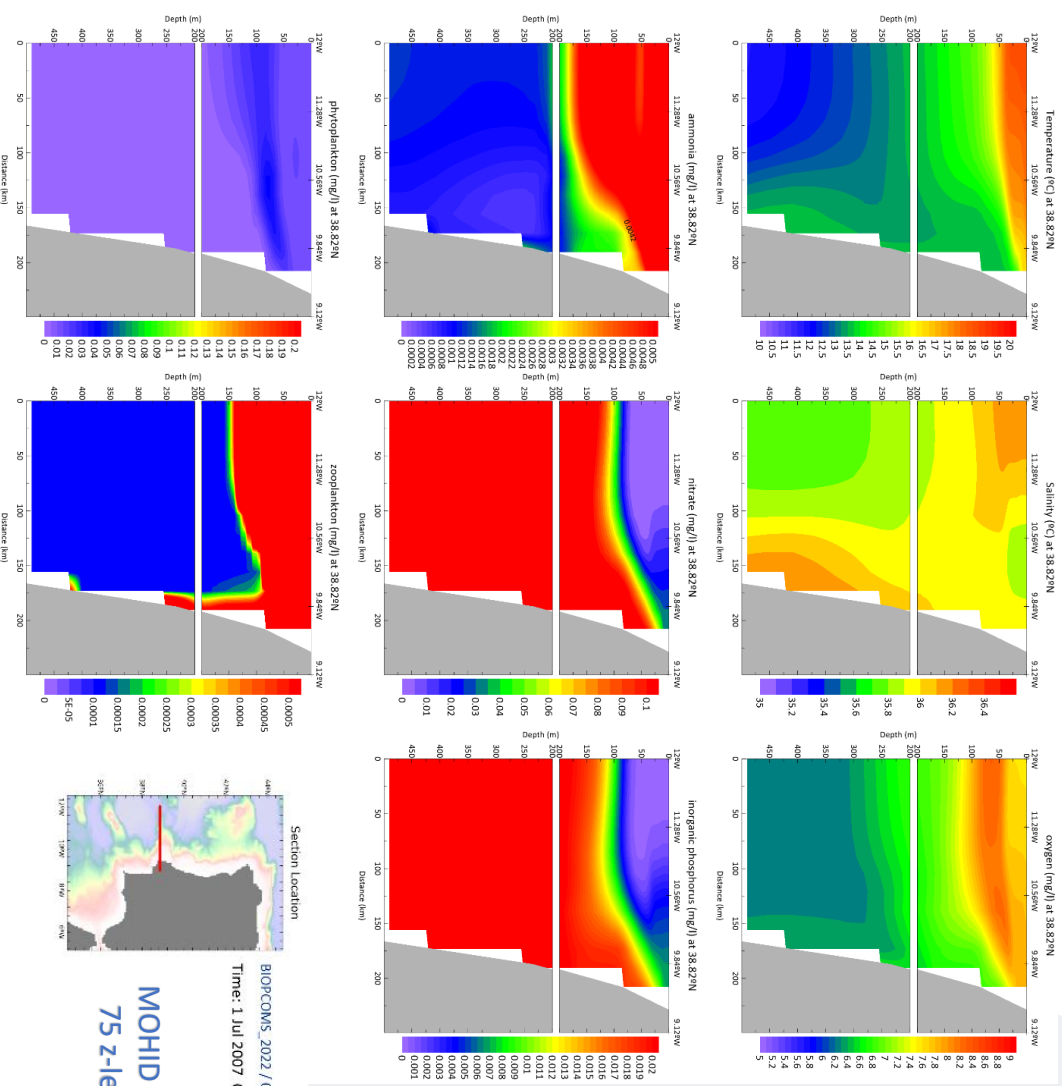
Instantaneous results for website

10-Jan-2024 00:00:00

Temperature (°C) and Velocity direction (m/s) 10-Jan-2024 00:00:00



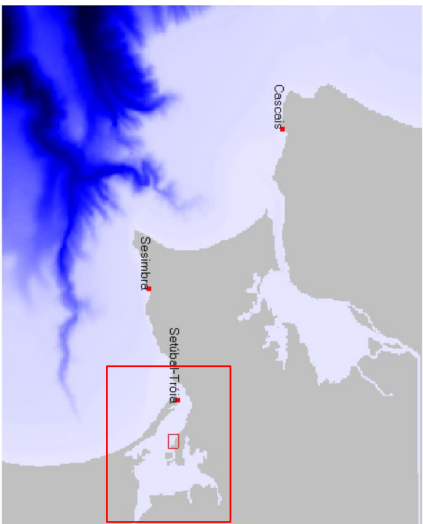
Source: <http://forecast.maretec.org>



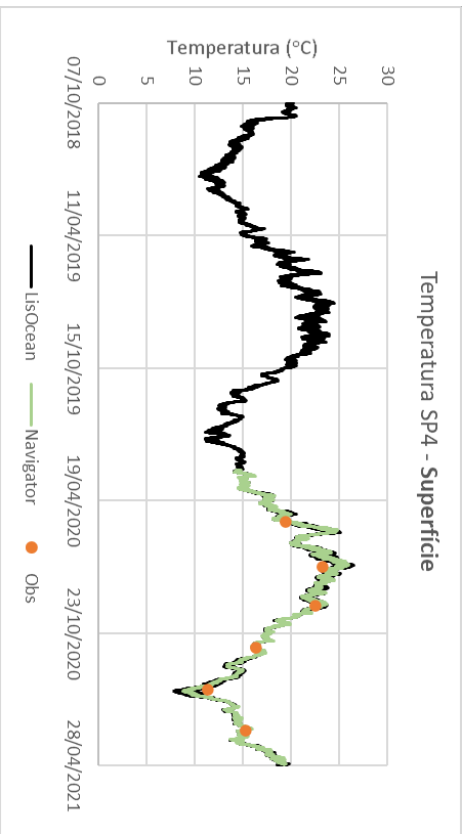
MOHID 0.24e
75 z-levels

Time: 1 Jul 2007 0h 0min

BIOPCOMS_2022 / 0.06°

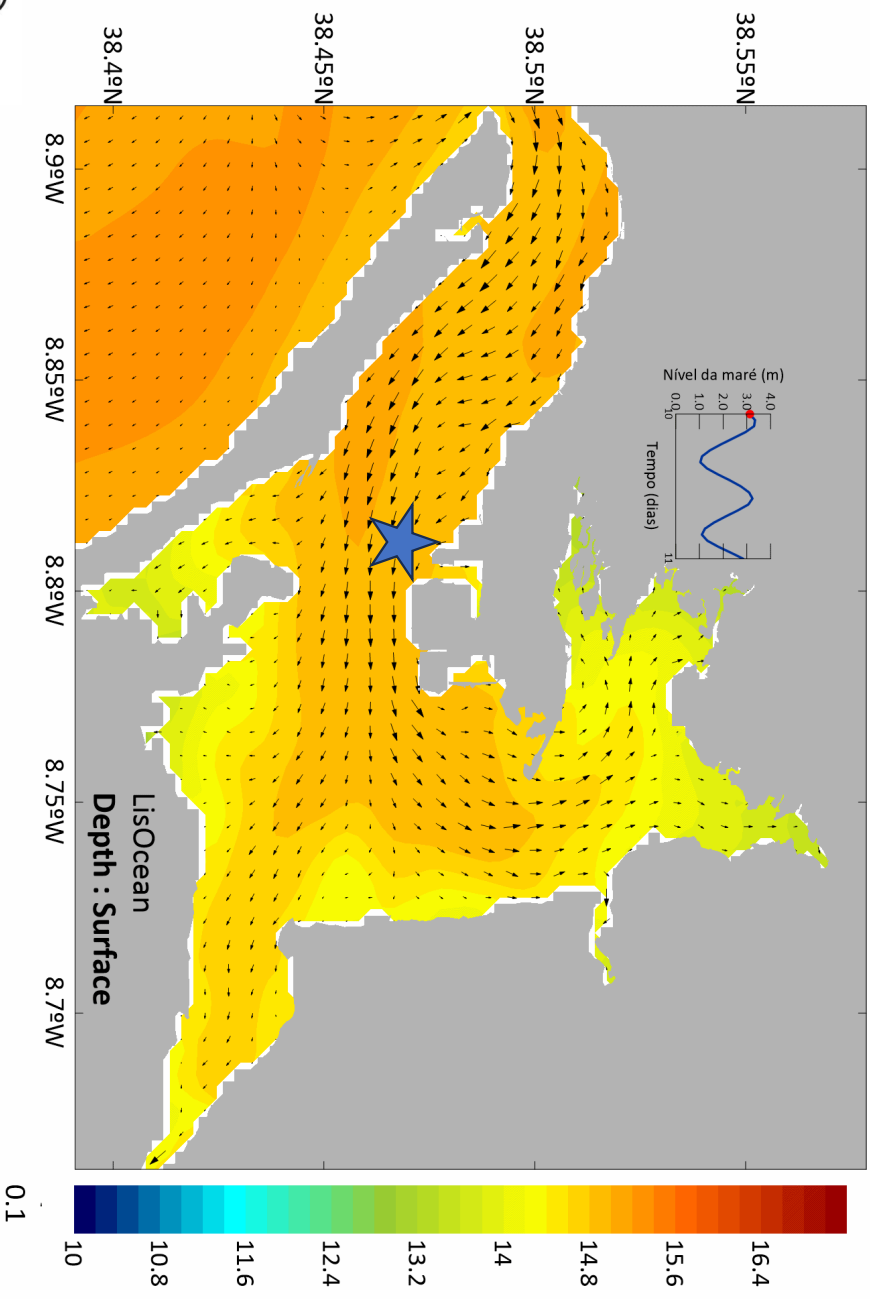


The model shows the spatial variability of surface temperature in the estuary and correctly simulates observations from monitoring campaigns



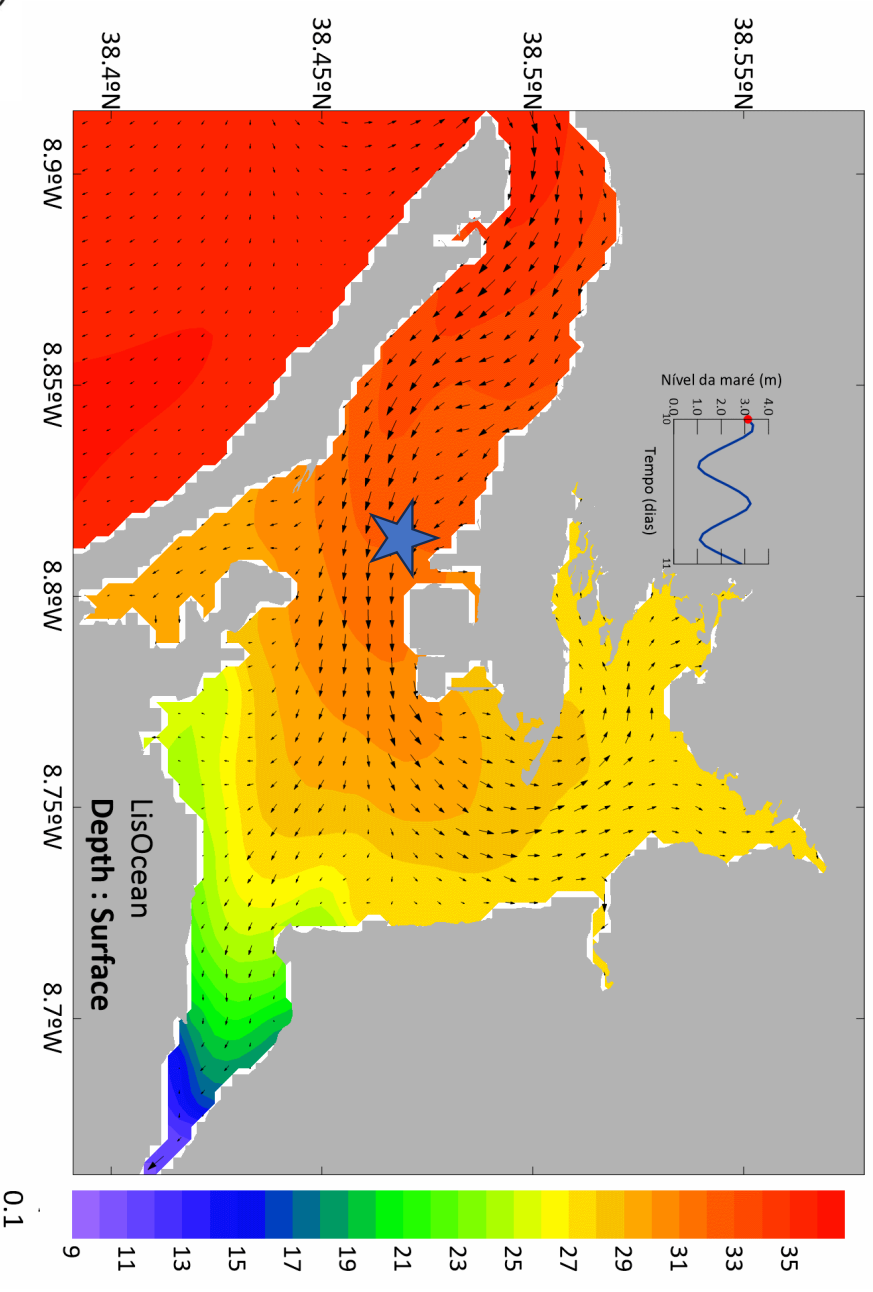
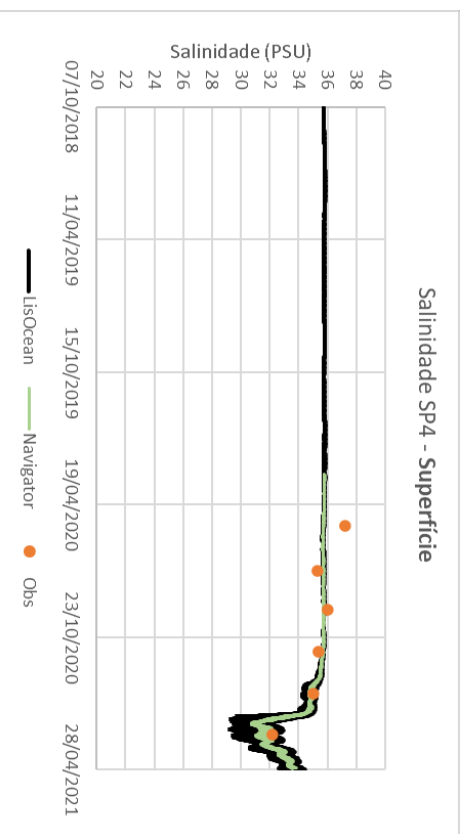
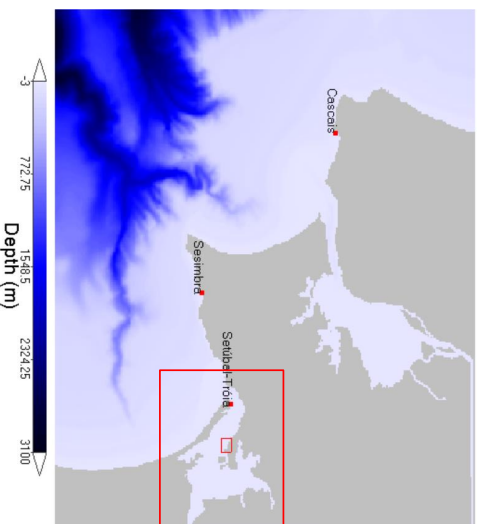
Surface Temperature - Sado

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



Surface Salinity - Sado

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

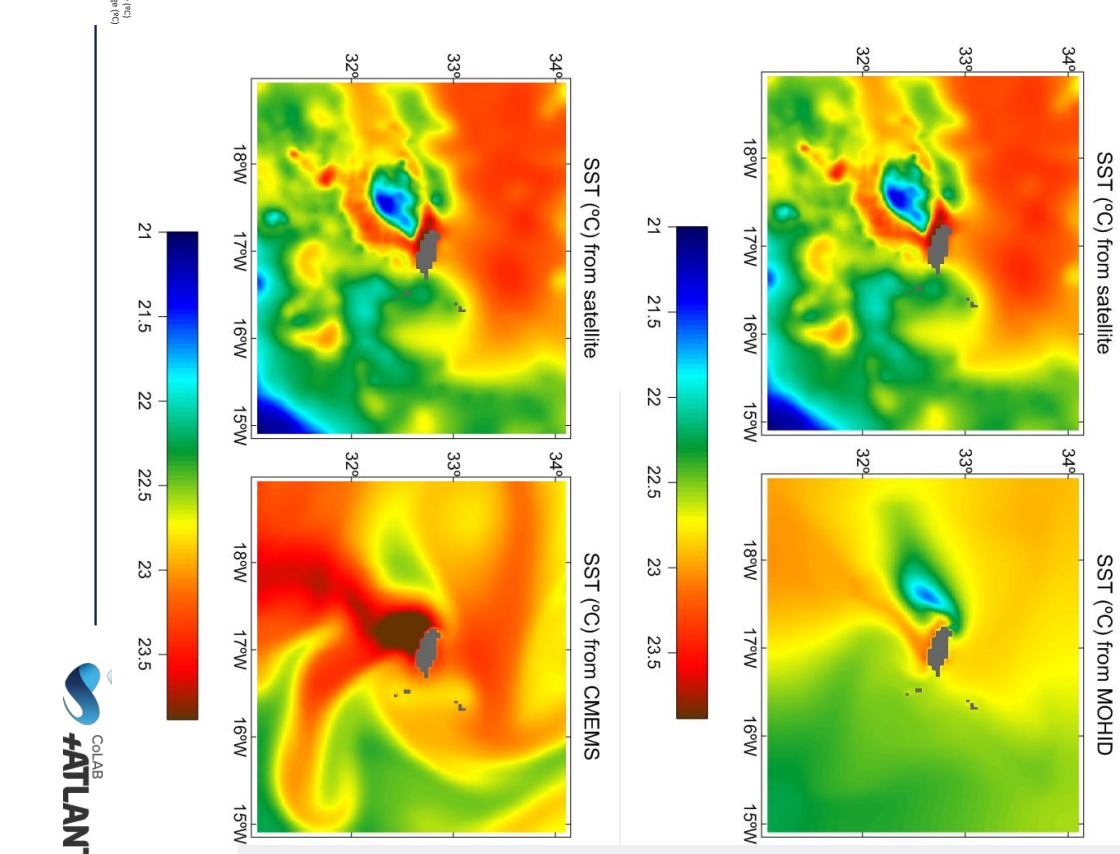
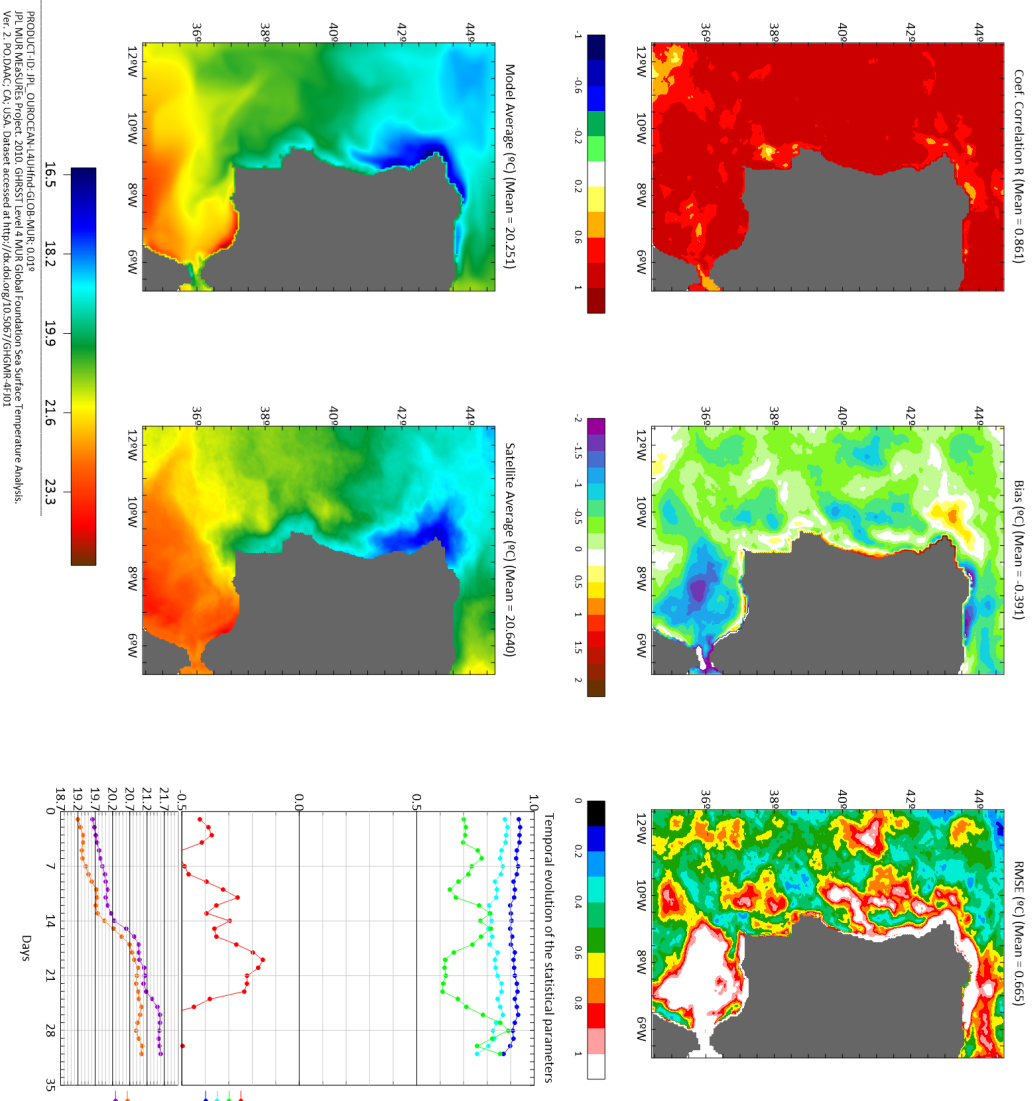


Validation – Remote sensing

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

SST MUR

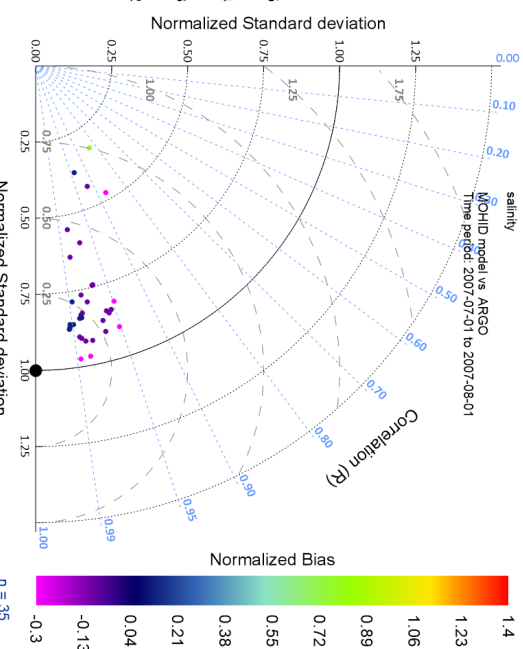
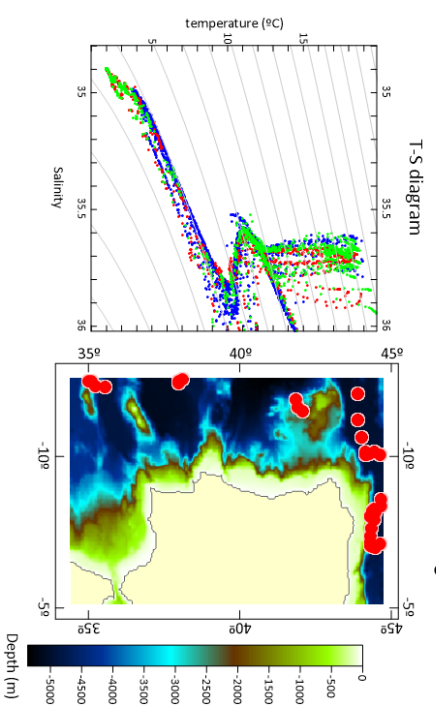
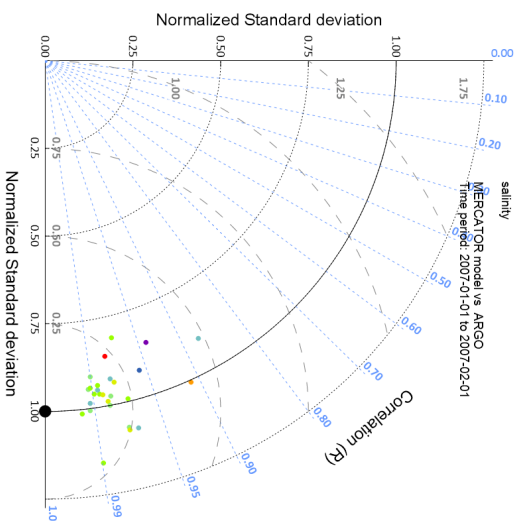
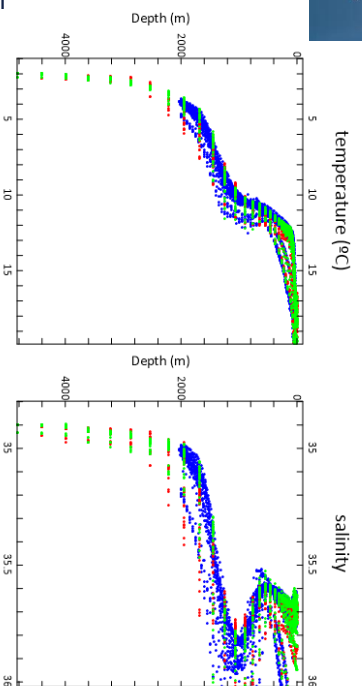
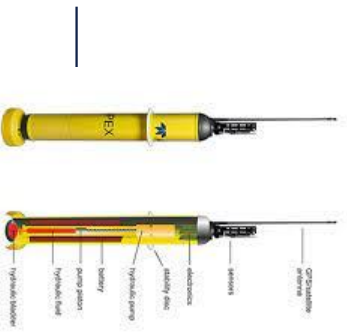
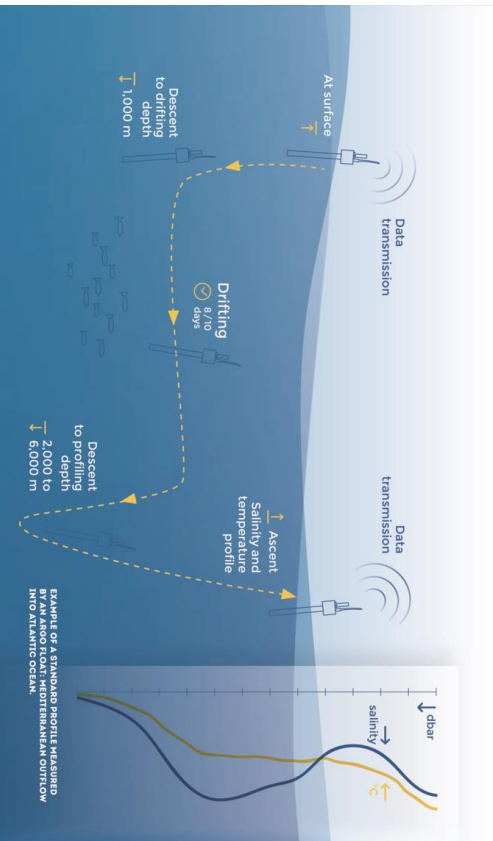
20180807



PRODUCT ID: JPL_CUMRGENA1401HRSGL08.MUR_0303 Global Foundation Sea Surface Temperature Analysis
 PROJECT ID: JPL_CUMRGENA1401HRSGL08.MUR_0303 Global Foundation Sea Surface Temperature Analysis
 Ver. 2. POC: DAC, CA, USA. Dataset accessed at <http://dx.doi.org/10.5877/5HQHMR-4F101>

Validation – Vertical profiles (Argo floats)

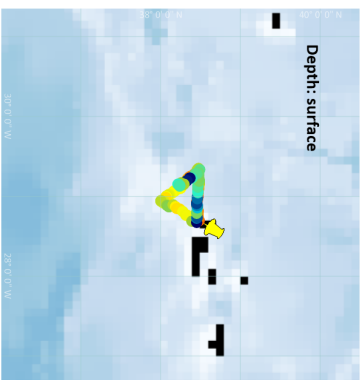
July 2007 - Reanalysis



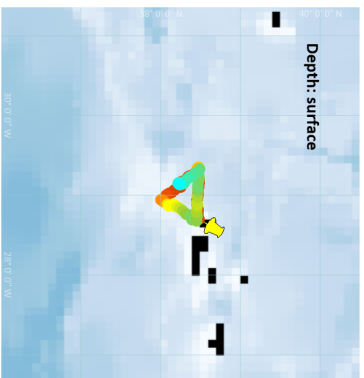
Validation – Moving profiles (gliders)

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

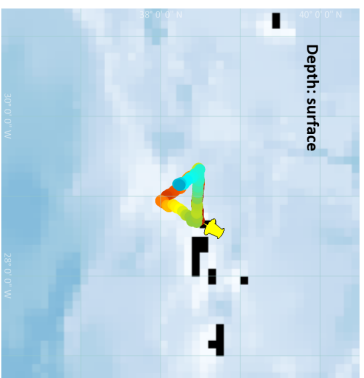
Glider laochra-na-mara



MOHID



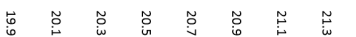
CMEMS



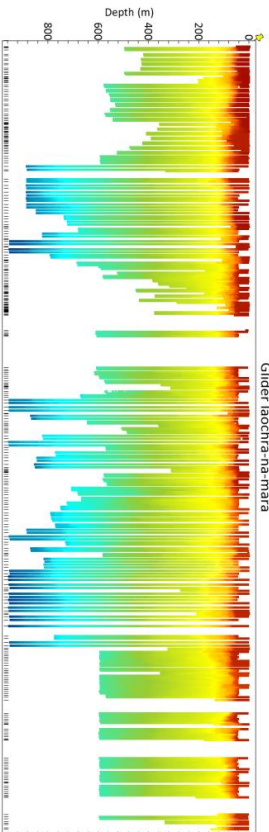
CMEMS product:
GLOBAL_ANALYSIS_FORECAST_BIO_001_028

CMEMS product:
GLOBAL_ANALYSIS_FORECAST_BIO_001_028

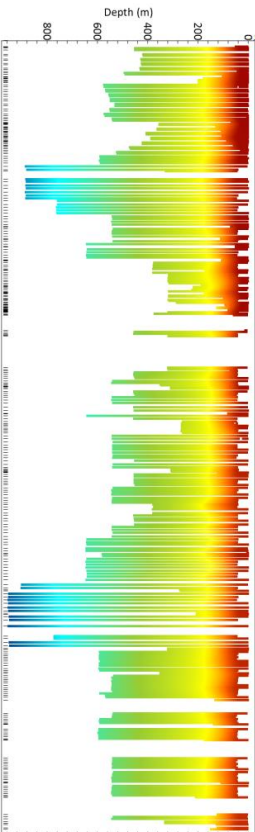
temperature (°C)



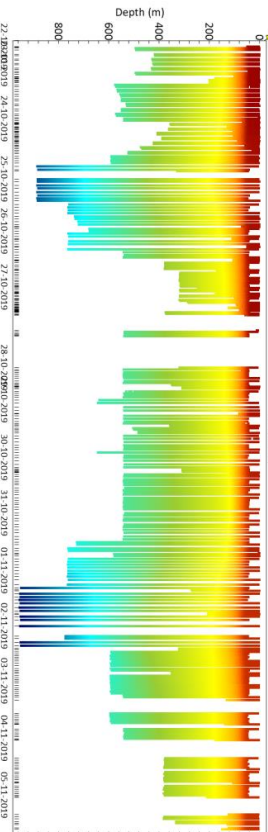
Glider laochra-na-mara



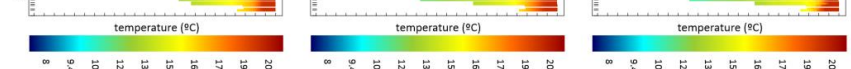
MOHID



CMEMS



CMEMS



MOHID Lagrangian

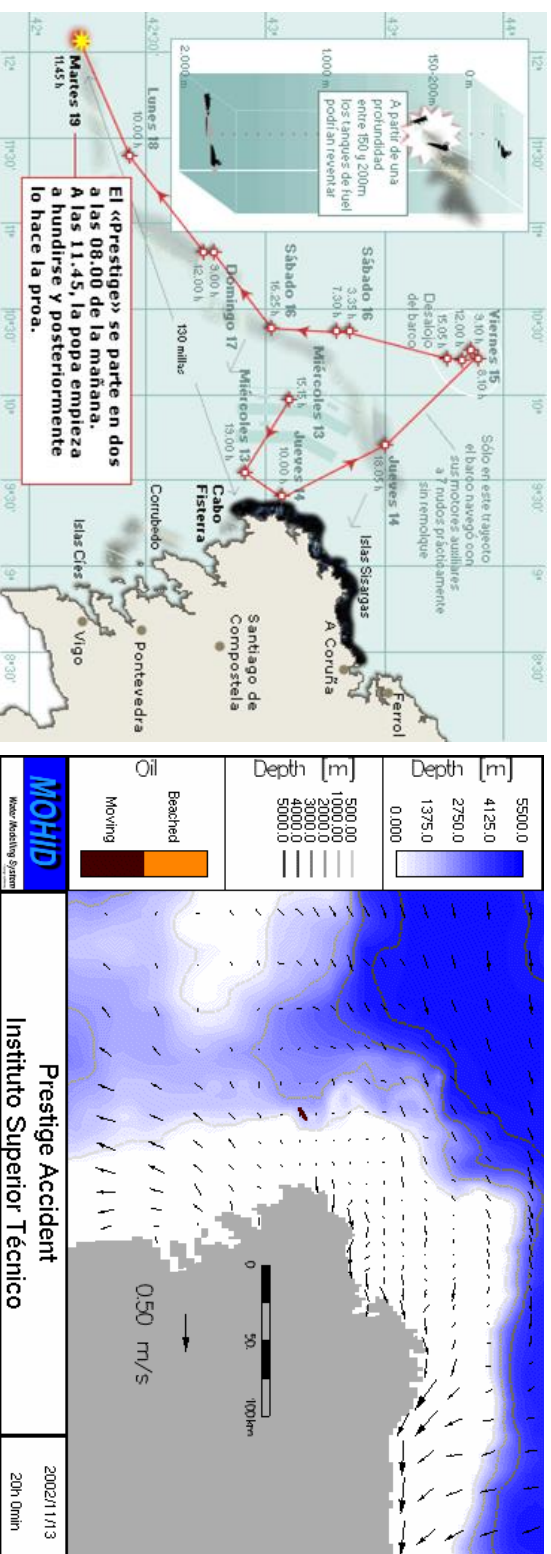
- Small objects:
 - Drifting buoys
 - Search-and-rescue
 - Small ships
- Large Objects:
 - Floating containers
 - Vessels or ships



The Prestige Accident (2002)

Ship Trajectory

MOHID – Oil Spilt along ship trajectory

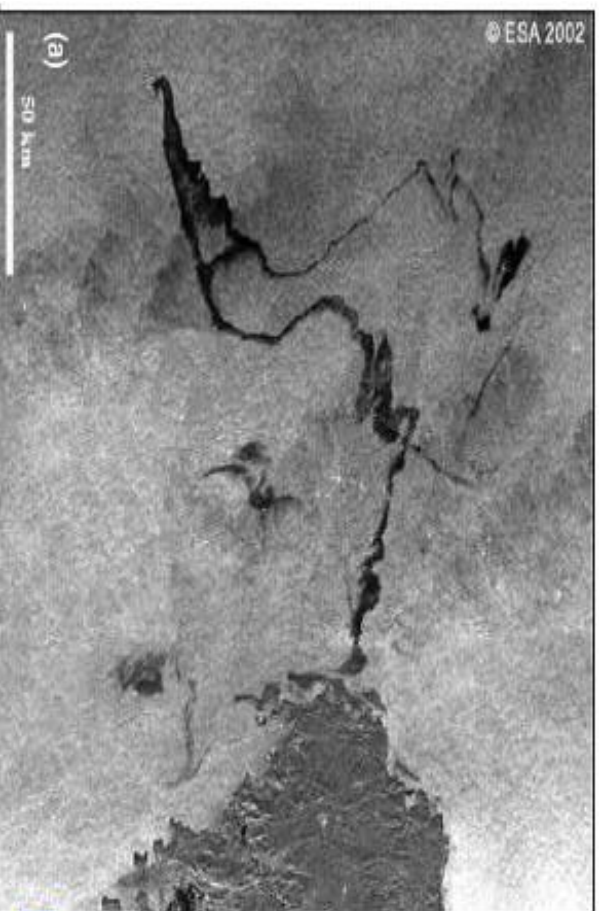


Forcing conditions:

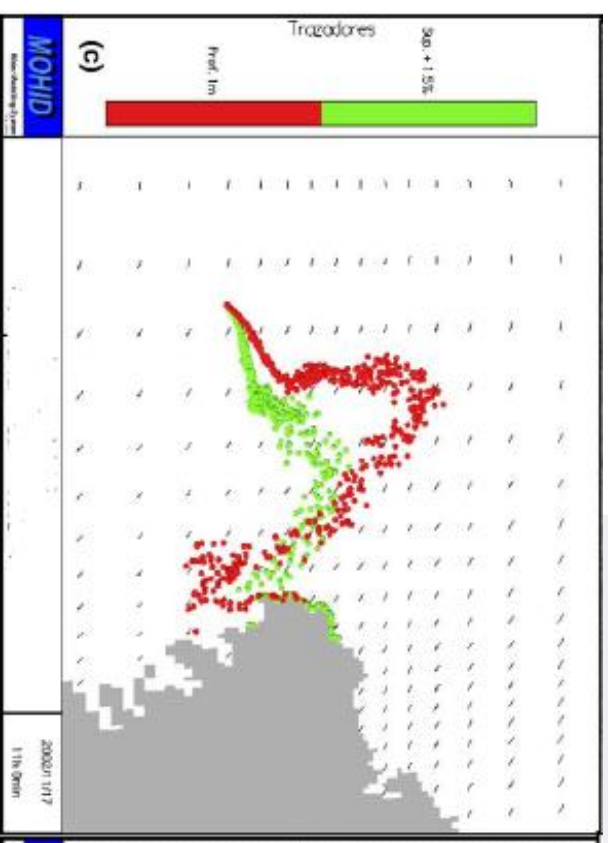
- Space and time Variable wind fields: predictions using ARPS model (MeteoGalicia);
- hydrodynamics: 20 layers (surface layer = 10cm) variable density (climatological density) + slope current;
- Vertical turbulence (GOTM Model);
- 2 Km minimum spatial step.

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)



U.S.C. | IBERO | MARITIC
ATLANTIC Rivers
2016-02-01 12:00:00

- 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


Interreg
Atlantic Area

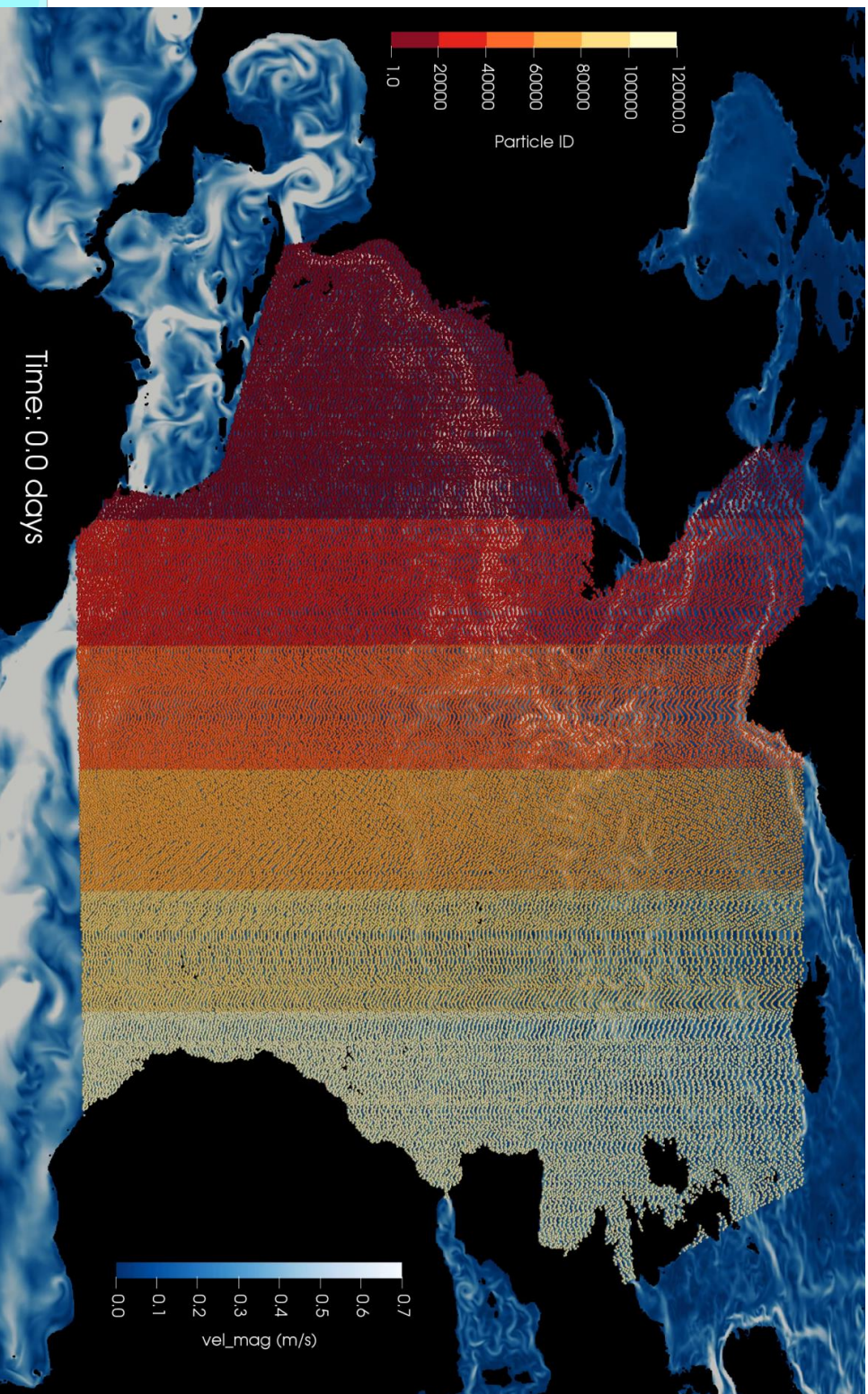
European Regional Development Fund



EUROPEAN UNION


Clean Atlantic

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

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



Domain: Atlantic

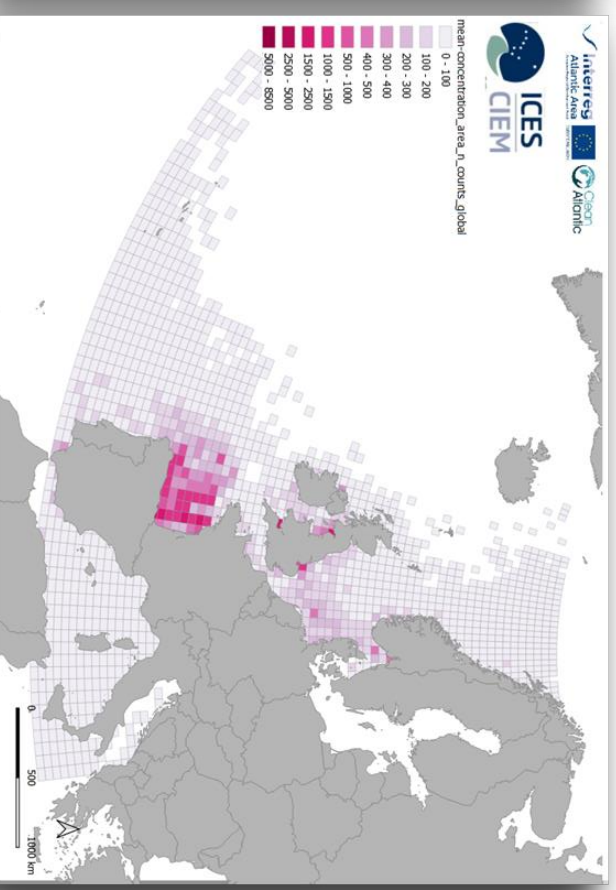
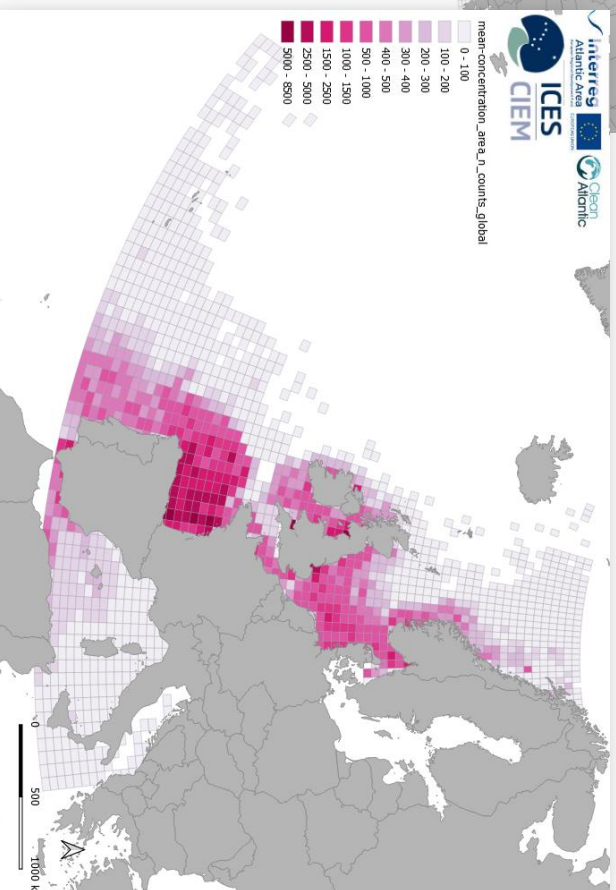
Simulation:
2D (surface)

Time: 4years (2016-2020)

InputData: currents, wind, waves

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

Particles type: lagrangian
Ntotal: ~320 000 particles





iFADO

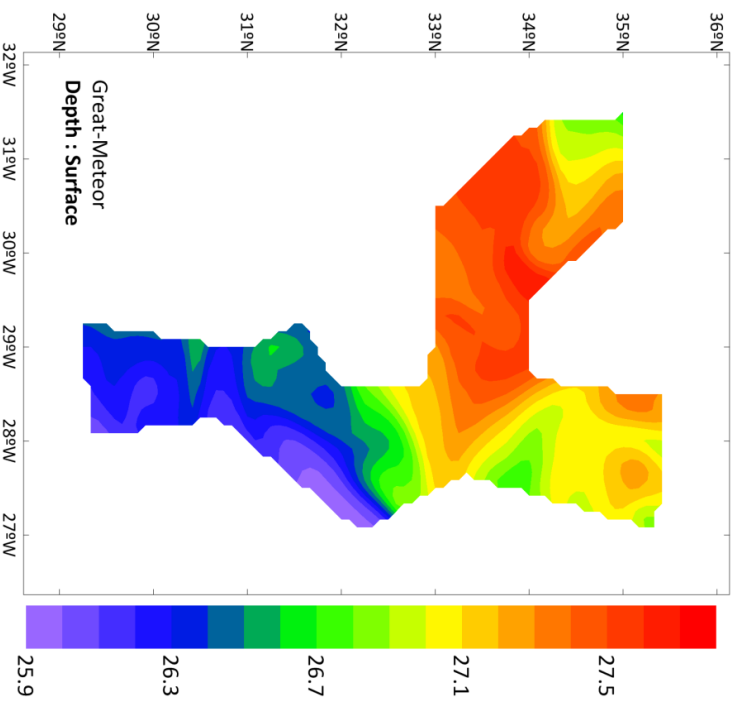
Modelling outputs - Azores



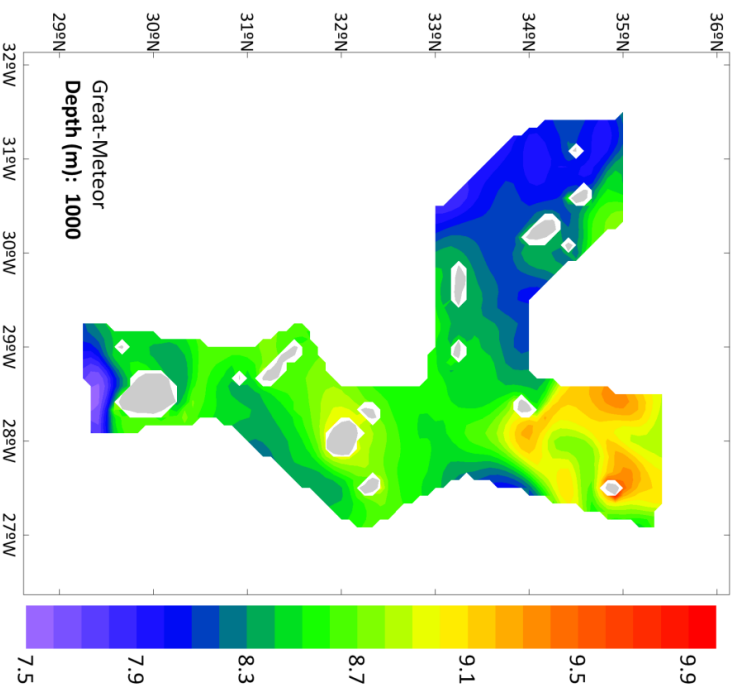
Interreg
Atlantic Area
European Regional Development Fund



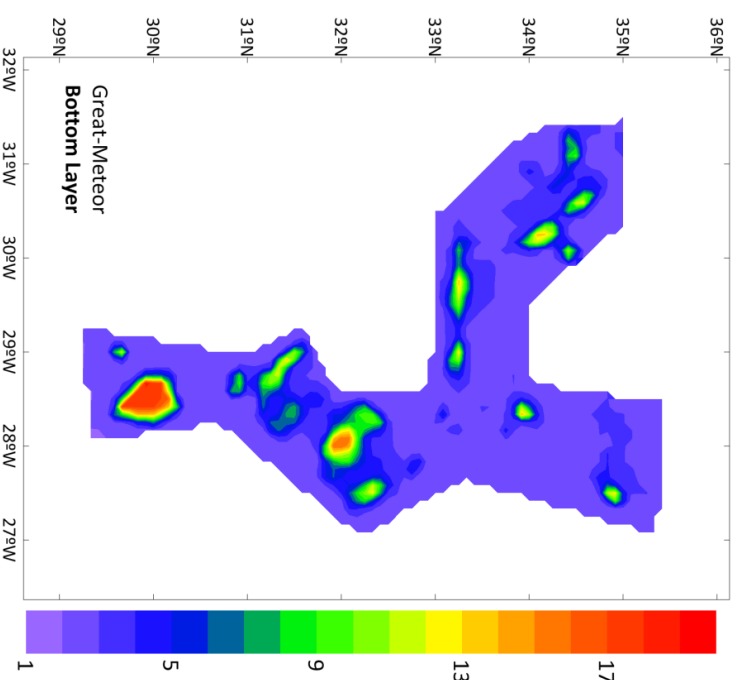
temperature (°C) Average period: 20190831_20190831



temperature (°C) Average period: 20190831_20190831



temperature (°C) Average period: 20190831_20190831



+ CONTROL ROOM



+ AQUACULTURE OFFICE



+ DAILY MESSAGE



Maré de noite

Maré Propícia

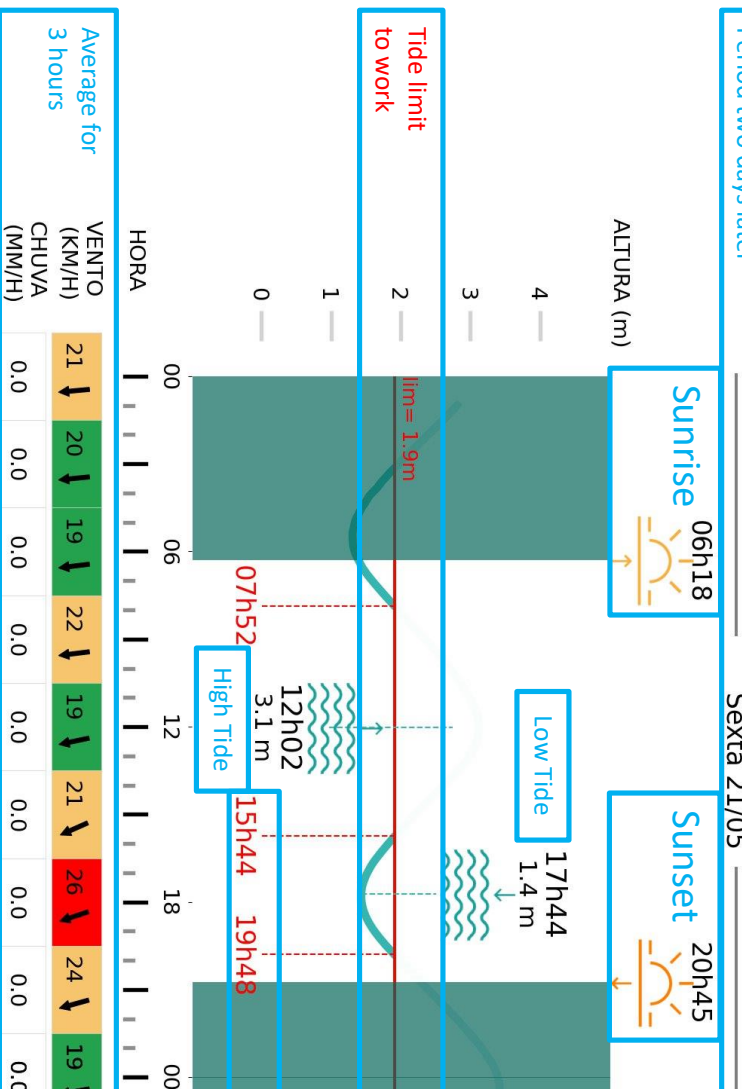
Critério de Maré para Trabalho

Location
Longa (38.48N, 8.74W)



Period two days later

Sexta 21/05



Questionário <http://tiny.cc/ytide>





Julia 2024

The Challenge!



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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