Can ocean-atmosphere climate change (studies) at the coastal scale be achieved? the example of the Adriatic Sea

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ADIOS project
IP-2016-06-1955

Hrzz Hrvatska zaklada za znanost

Med CORDEX

ECMWF

Copernicus Europe's eyes on Earth

WCRP CORDEX

14-18 OCTOBER 2019 BEIJING, CHINA

ICRC-CORDEX 2019

International Conference On Regional Climate

The Adriatic Sea

- ✓ northernmost area of the Mediterranean Sea, extending from the Strait of Otranto (where it connects to the Ionian Sea) to the northwest and the Po Valley
- ✓ over 1300 islands, mostly located along the Croatian coastline
- ✓ shallow northern shelf of about 50m depth and deep southern part reaching up to 1233m
- ✓ surrounded by mountains: Alps in the north, Apennines in the west and Dinaric Alps in the east
- ✓ collects a third of the fresh water flowing into the Mediterranean Sea

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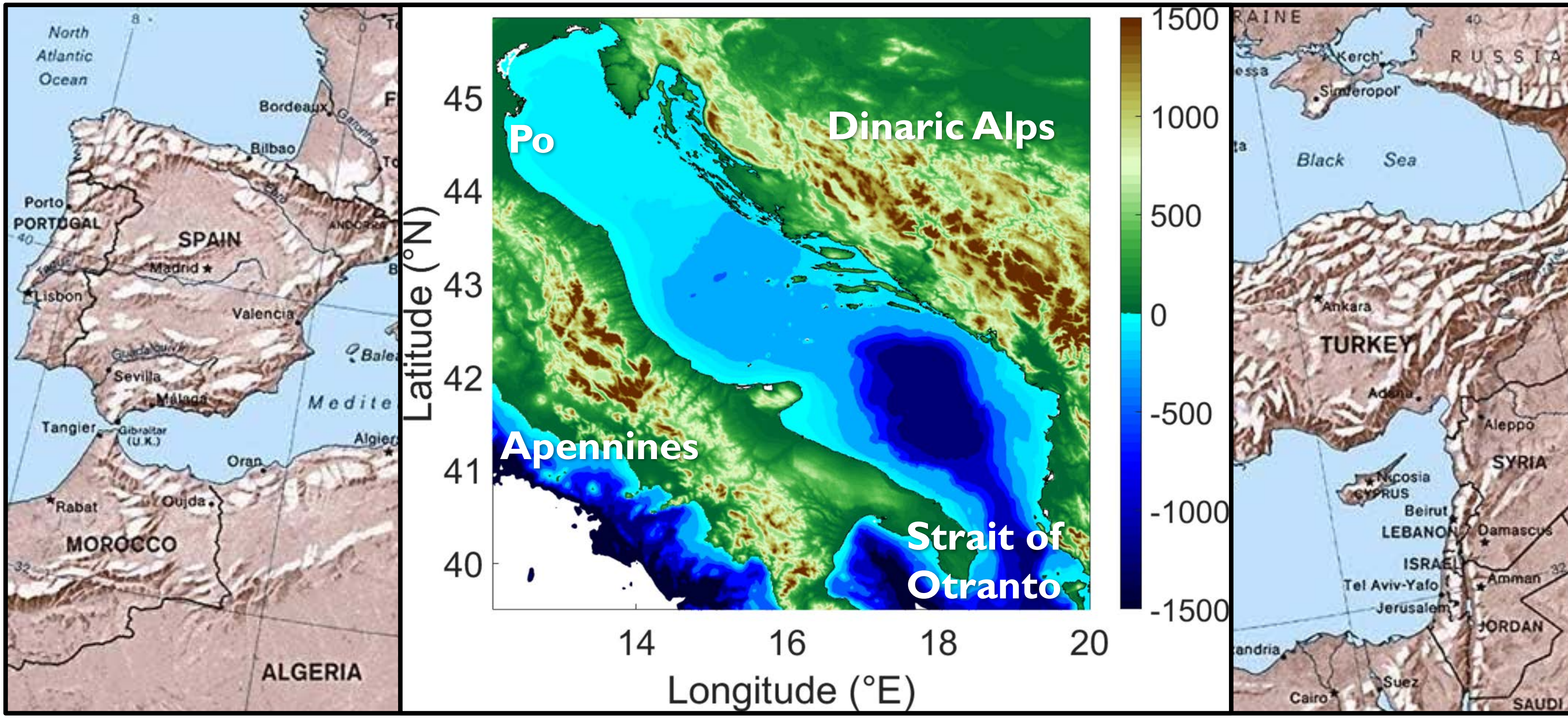


Introduction

Aims & Challenges of the Study

Present & Future of:

Ionian-Adriatic exchanges

upwelling/downwelling

larvae transport

wind driven circulation

dense water formation

bivalve habitat

Ekman pumping

boulder motion

meteotsunamis

coastal hazard

extreme sea-levels

wind waves

pollutants & sediment transport

nearshore circulation

land-sea breeze

Challenge #1 – Suitable Numerical Framework

- ✓ extremely complex orography and bathymetry (including many islands) ⇒ convection permitted atmospheric and ocean models at ultra high resolution (below 3km) necessary
- ✓ varying time and spatial scales depending on the studied processes: extreme events vs. Ionian-Adriatic circulation

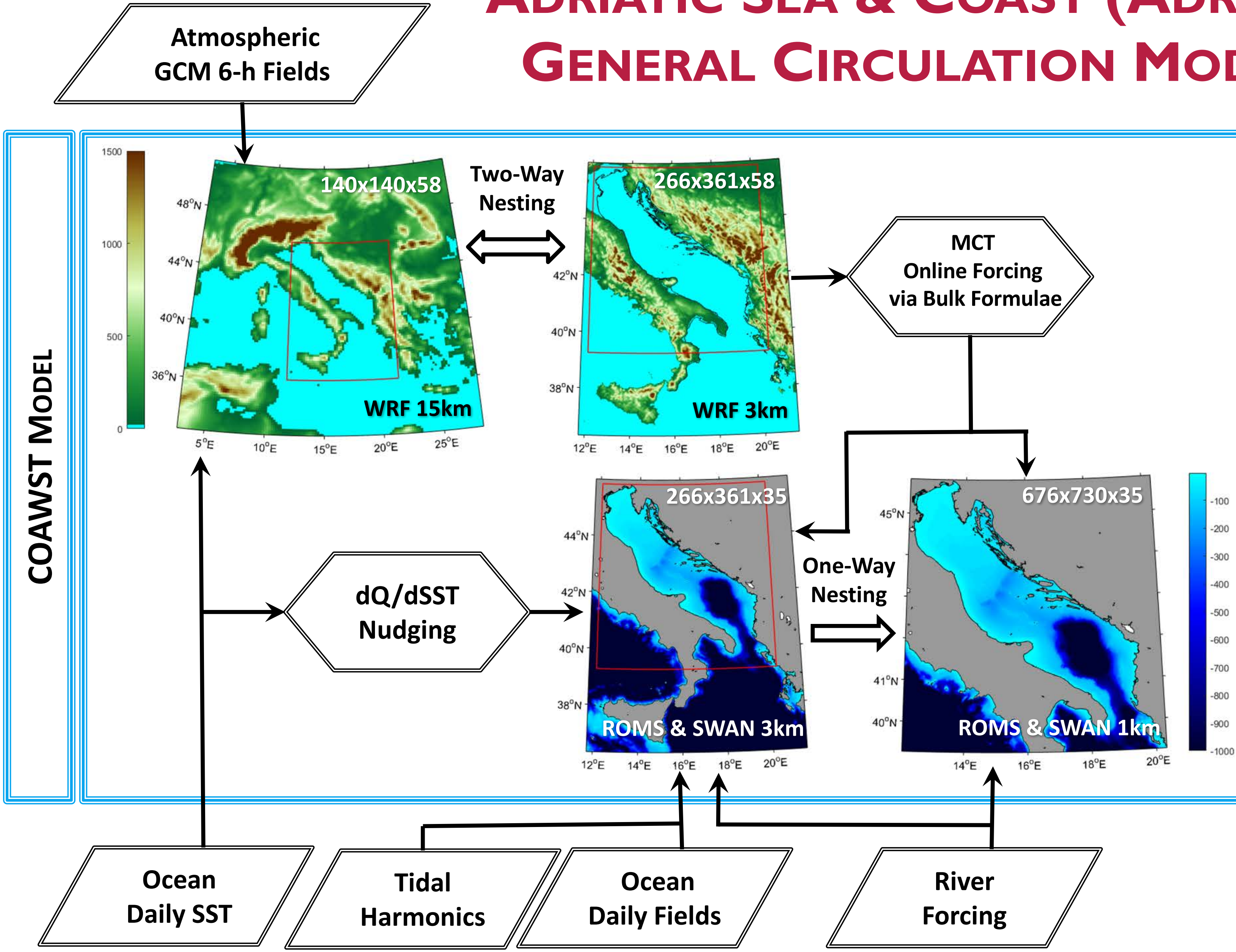
Challenge #2 – Future Simulation Forcing

- ✓ low temporal and spatial resolution of the Regional Climate Models (e.g. Med-CORDEX) & slow calculation of ultra high resolution models ⇒ classical climate approach with evaluation + historical + rcp scenarios impossible

Challenge #3 – Numerical Resources

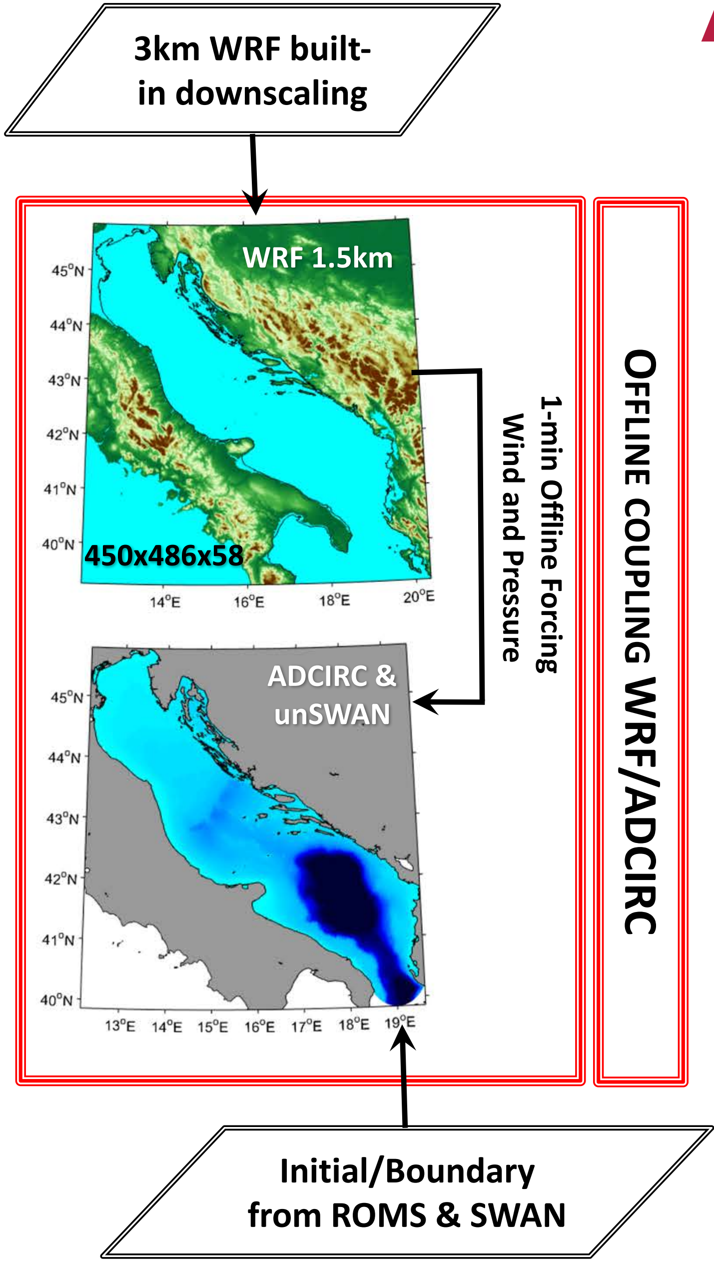
- ✓ extreme computational costs of running ultra high resolution coupled models

Adriatic Sea & Coast (AdriSC) General Circulation Module



Challenge #1 – Suitable Numerical Framework

Adriatic Sea & Coast (AdriSC) Extreme Event Module



Nearshore Circulation

✓ Downscale results of the General Circulation Module to better represent extreme events in the Adriatic Sea and more particularly in Croatia

WRF 1.5km

✓ Downscale the results of WRF Inner Grid

✓ Generates Wind & Pressure fields for ADCIRC

ADCIRC & unSWAN up to 10m

✓ Initial and boundary conditions from ROMS 1km

Advantages of the Modular Approach

(1) Modules can be run either separately or together

(2) Each module is adapted to simulate processes at certain time and spatial scales

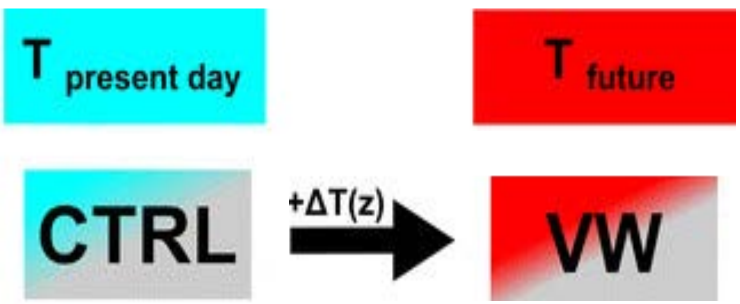
(3) The nearshore module can be run for short time periods when extreme events are detected on longer runs of the general circulation module

Challenge #1 – Suitable Numerical Framework

Pseudo Global Warning (PGW) Method

Basic idea (for the atmosphere):

- ✓ apply large-scale changes of temperature, relative humidity, wind, etc. to the lateral boundary conditions of a present-day reference simulation of a regional climate model (RCM)
- ✓ the mean perturbation is taken from a mean climate change signal of the driving GCM run. The resulting pseudo global warning follows the large-scale circulation of the reference period (variability is unchanged) but with a warmer climate for example (mean is shifted).



Adapted from Kröner et al., 2016.
DOI 10.1007/s00382-016-3276-3

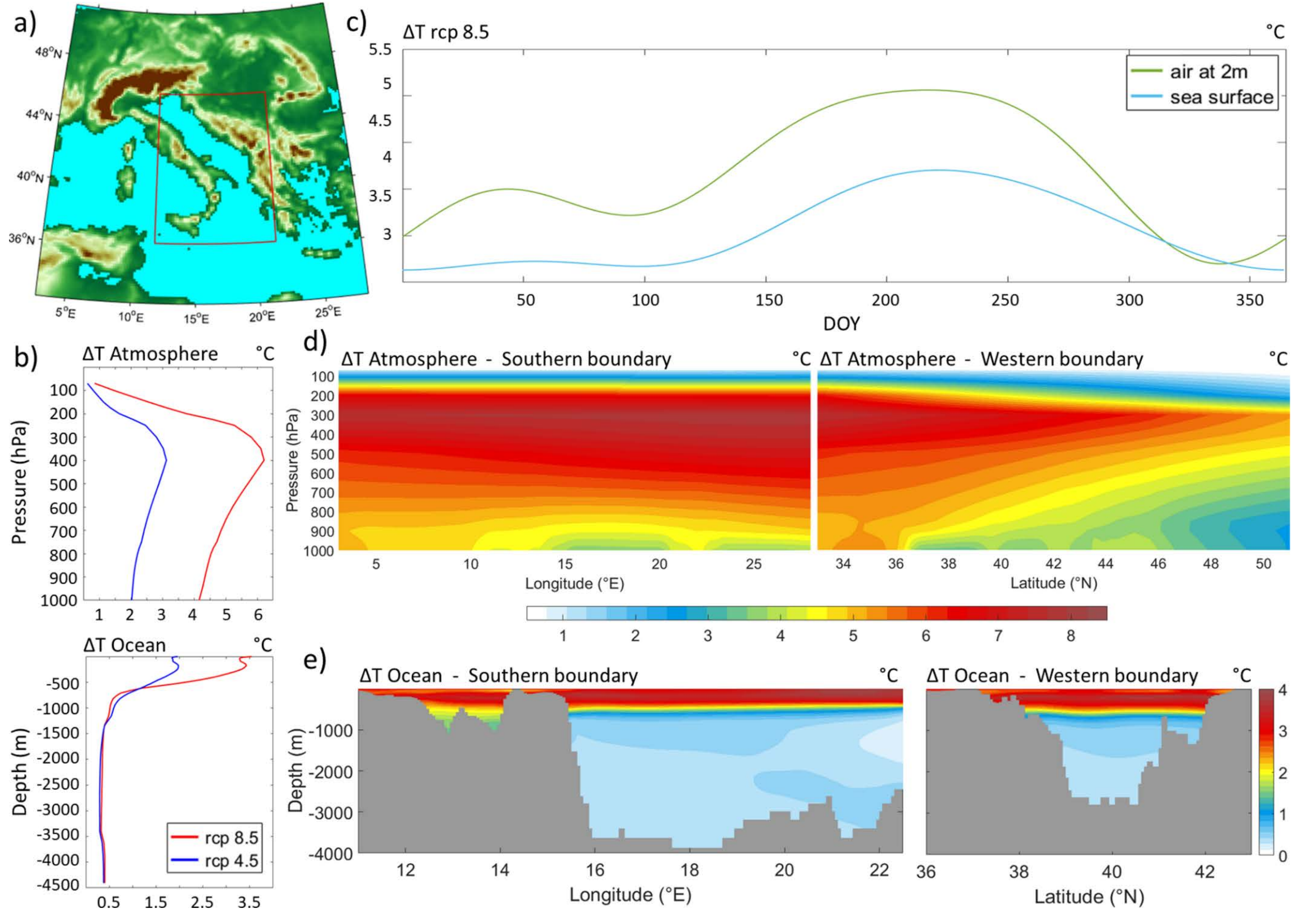
Extension of the Method to the Ocean:

(1) Modified variables: salinity, temperature, currents and sea surface height
(2) Stability of the forcing imposed to be ≥ 0
(3) Wave forcing not modified as not enough high resolution information was available
(4) River flow discharges modified with monthly percentage changes

PGW Forcing:

- ✓ Initial and boundary conditions modified with historical + rcp 4.5 + rcp 8.5 daily/monthly results extracted from the Med-CORDEX coupled ocean-atmosphere RCM: LMDZ4-NEMOMED8
- ✓ River flow discharges modified following Macias et al. (2018)

Challenge #2 – Future Simulation Forcing



Challenge #2 – Future Simulation Forcing

SUPERCOMPUTER ACCESS

PERFORMANCE OF THE ADRISC MODELLING SUITE:

- ✓ **general circulation module** alone: 260 CPUs to produce 1 month of run in 24h
- ✓ **general + extreme event modules**: ~230 CPUs to produce 3 days of run in 20h

FUNDED PROJECTS:

- ✓ **ADIOS project** (**IP-2016-06-1955**) funded by HrZZ: present and future of the Ionian-Adriatic exchanges
- ✓ **MESSI project** (**UKF Grant 25/15**): early warning system for meteotsunamis
- ✓ **Other projects**: CHANGE WE CARE Interreg Croatia-Italy

AVAILABLE NUMERICAL RESOURCES:

- ✓ **no local Croatian** resources available
- ✓ access to **ECMWF national quotas** to run the operational model within the MESSI project
- ✓ **ECMWF special project** with dedicated quotas to run the simulations needed for the ADIOS project

MAJOR LIMITATIONS:

(1) Slowness of the AdriSC modelling suite
(2) Numerical cost of the simulations

Optimization of simulations & resources needed!

EXPERIMENT #1 – EXTREME WAVES

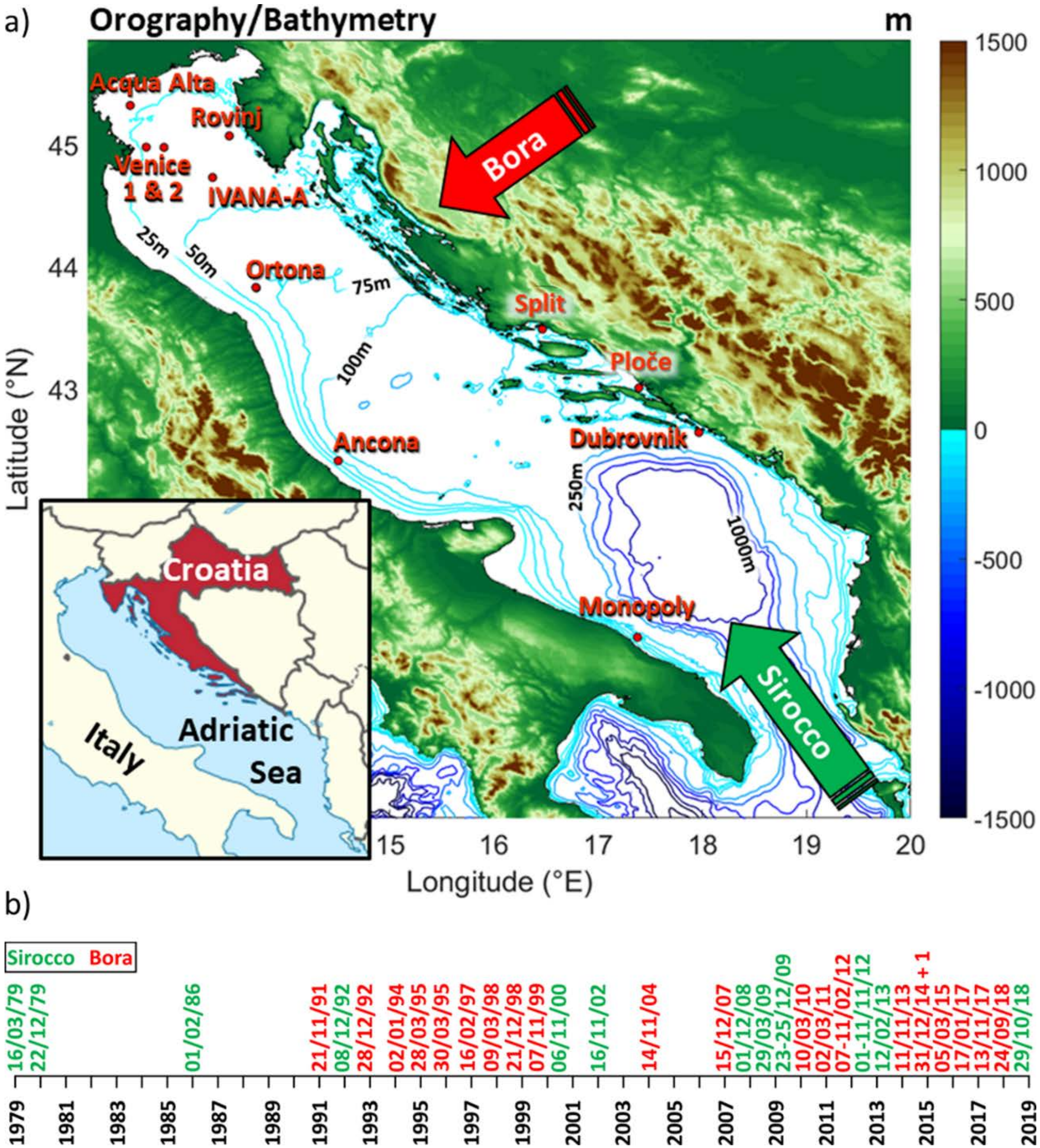
- ✓ limited to a certain number of storms but for evaluation + rcp 4.5 + rcp 8.5 scenarios

EXPERIMENT #2 – GENERAL CIRCULATION

- ✓ continuous 31 year evaluation run (1987-2018) + continuous 31 year rcp 8.5 future run (2070-2100)

Challenge #3 – Numerical Resources

Simulation Set-Up



First Test of the coupled PGW method

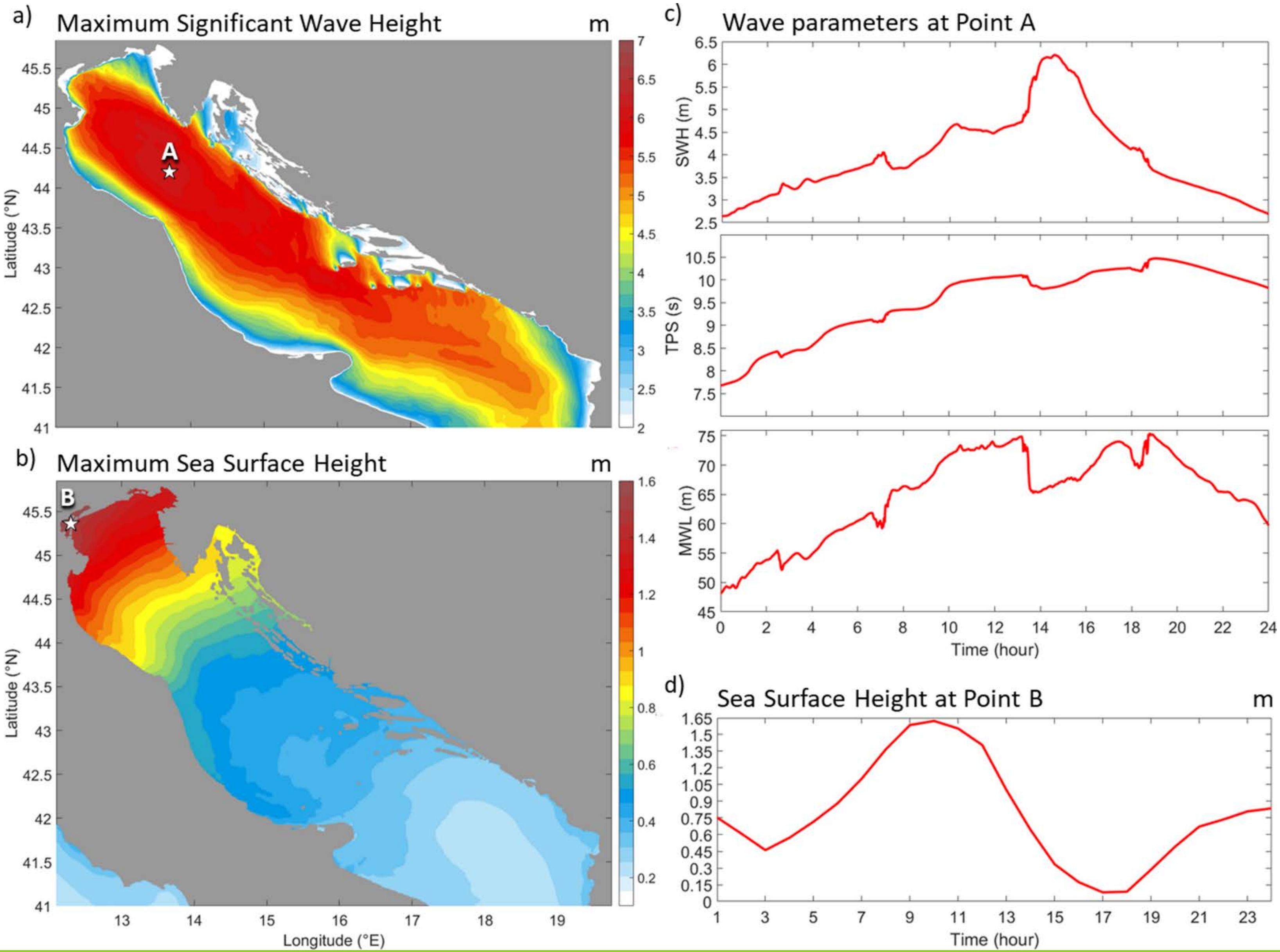
- ✓ AdriSC general circulation & extreme event modules used with waves
- ✓ 36 wave storms selected in the Adriatic between 1979-2019: 14 Sirocco events & 22 Bora events
- ✓ Evaluation mode forced with 6-hourly ERA-I fields in the atmosphere, daily MEDSEA reanalysis for the ocean and either 6-hourly ERA-I waves (before 2006) or hourly MEDSEA waves
- ✓ rcp 4.5 & rcp 8.5 PGW corrections used to re-run the 36 storms in a climate warning context

Evaluation of the extreme event module

- ✓ Evaluation of the unSWAN wave model coupled to ADCIRC
- ✓ 6 wave buoys along the Italian coastline between 1979 & 2018
- ✓ 5 wave buoys along the Croatian coastline between 2007 & 2019

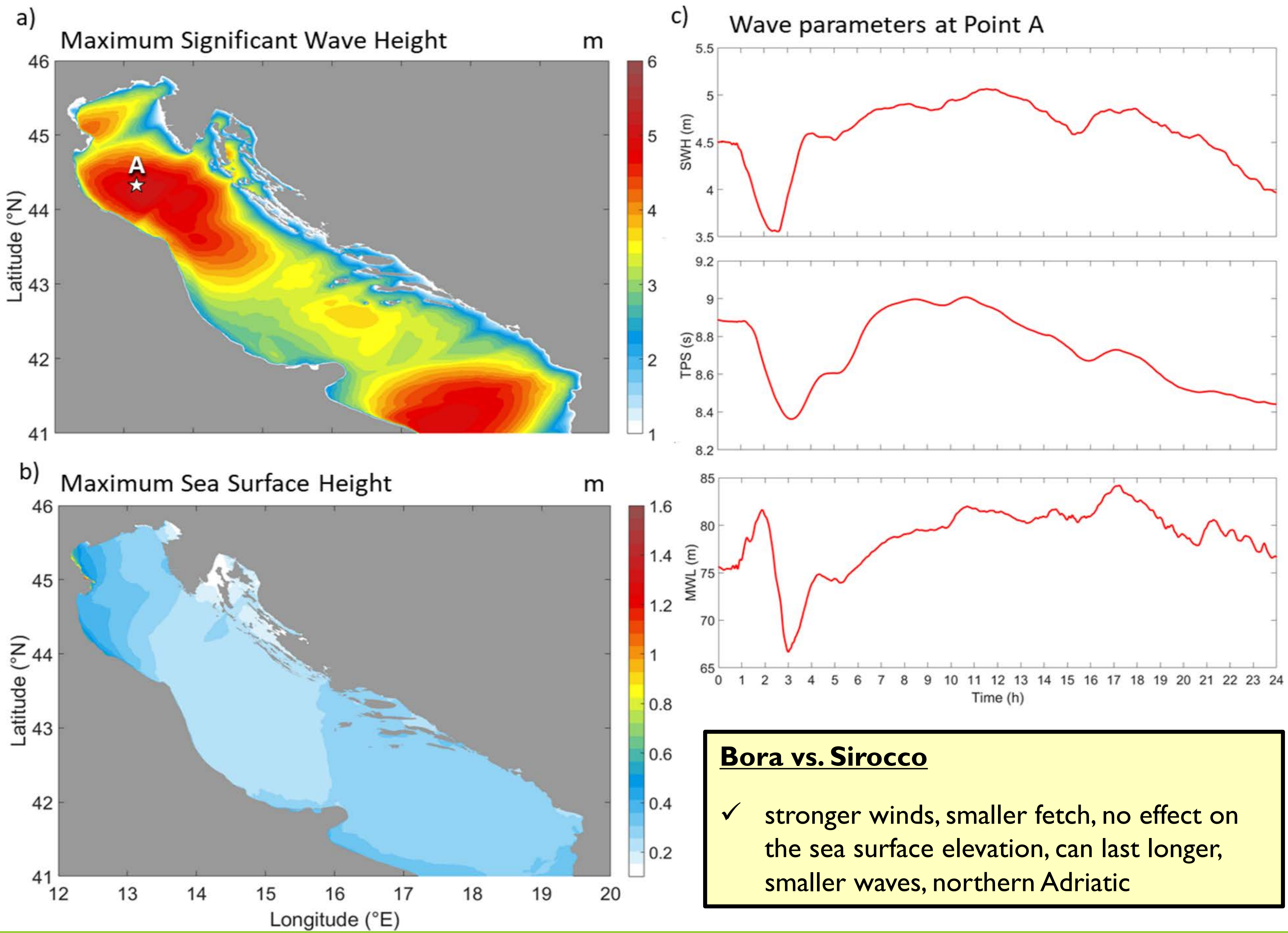
Experiment #1 – Extreme Wave Events

Sirocco Event of 22/12/1979



Experiment #1 – Extreme Wave Events

Bora Event of 07/02/2012

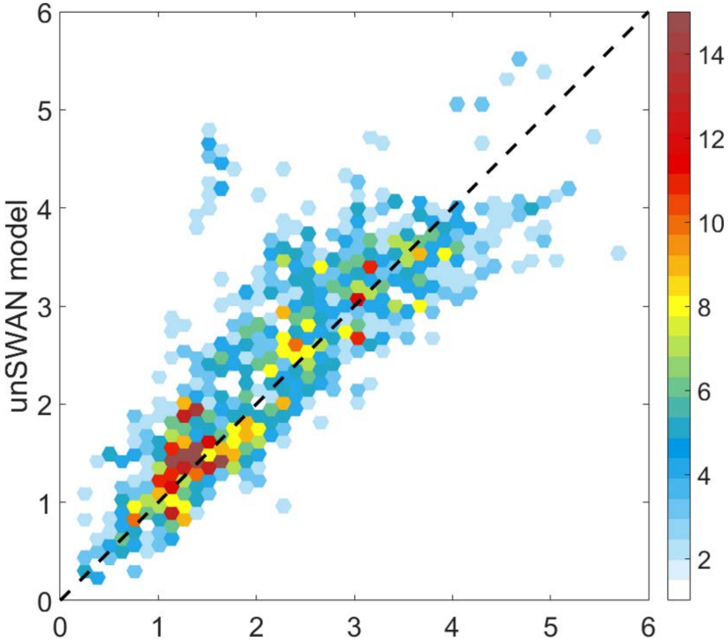


Bora vs. Sirocco

✓ stronger winds, smaller fetch, no effect on the sea surface elevation, can last longer, smaller waves, northern Adriatic

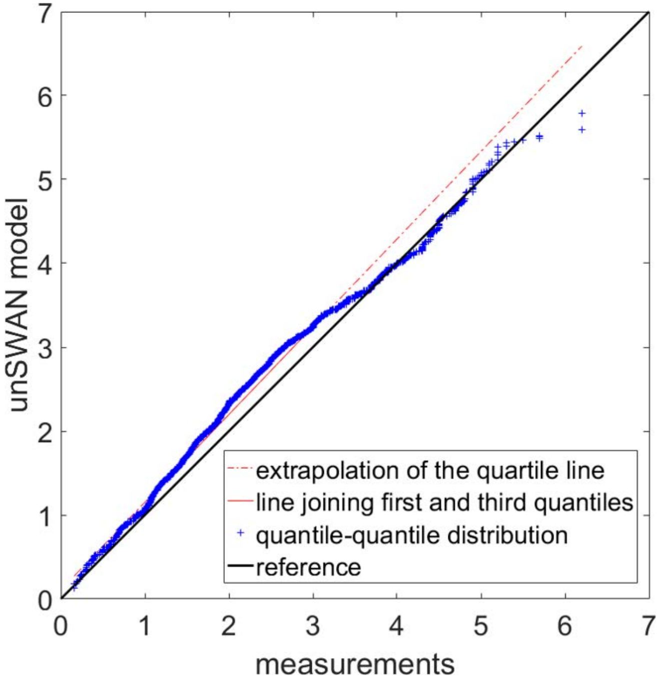
Experiment #1 – Extreme Wave Events

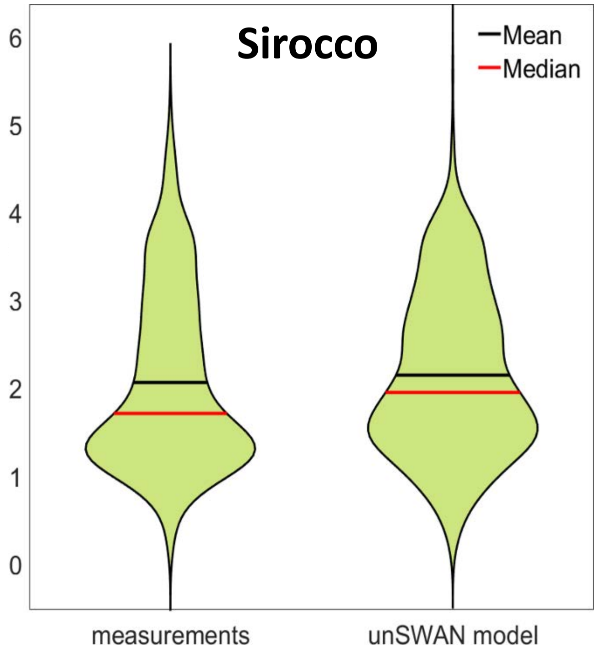
Evaluation

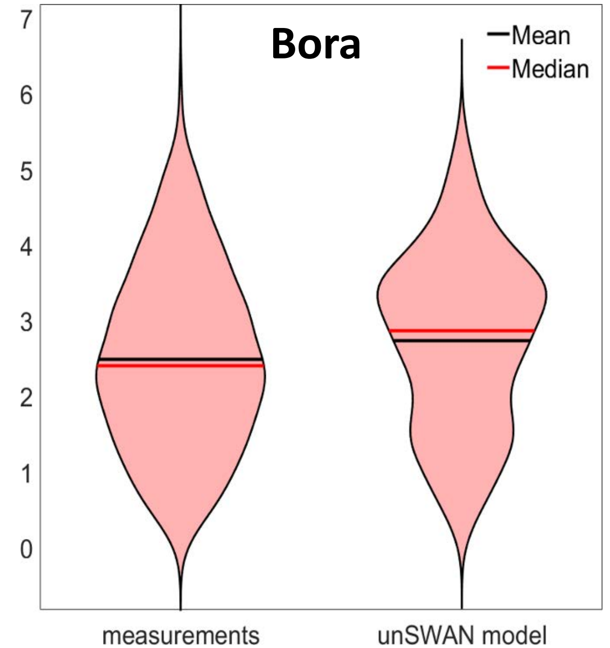


Significant Wave Height (Hs)

- ✓ **scatter plot:** 36 storms (bora & sirocco) overall well represented by the unSWAN model but maybe some timing issues
- ✓ **qqplot**: the quantile-quantile is as expected near perfect for the 36 storms
- ✓ **violin plots (bora & sirocco separately)**: distribution of the unSWAN model Hs slightly different from the measurements in particular for 2.5m < Hs < 4m but good mean and median.



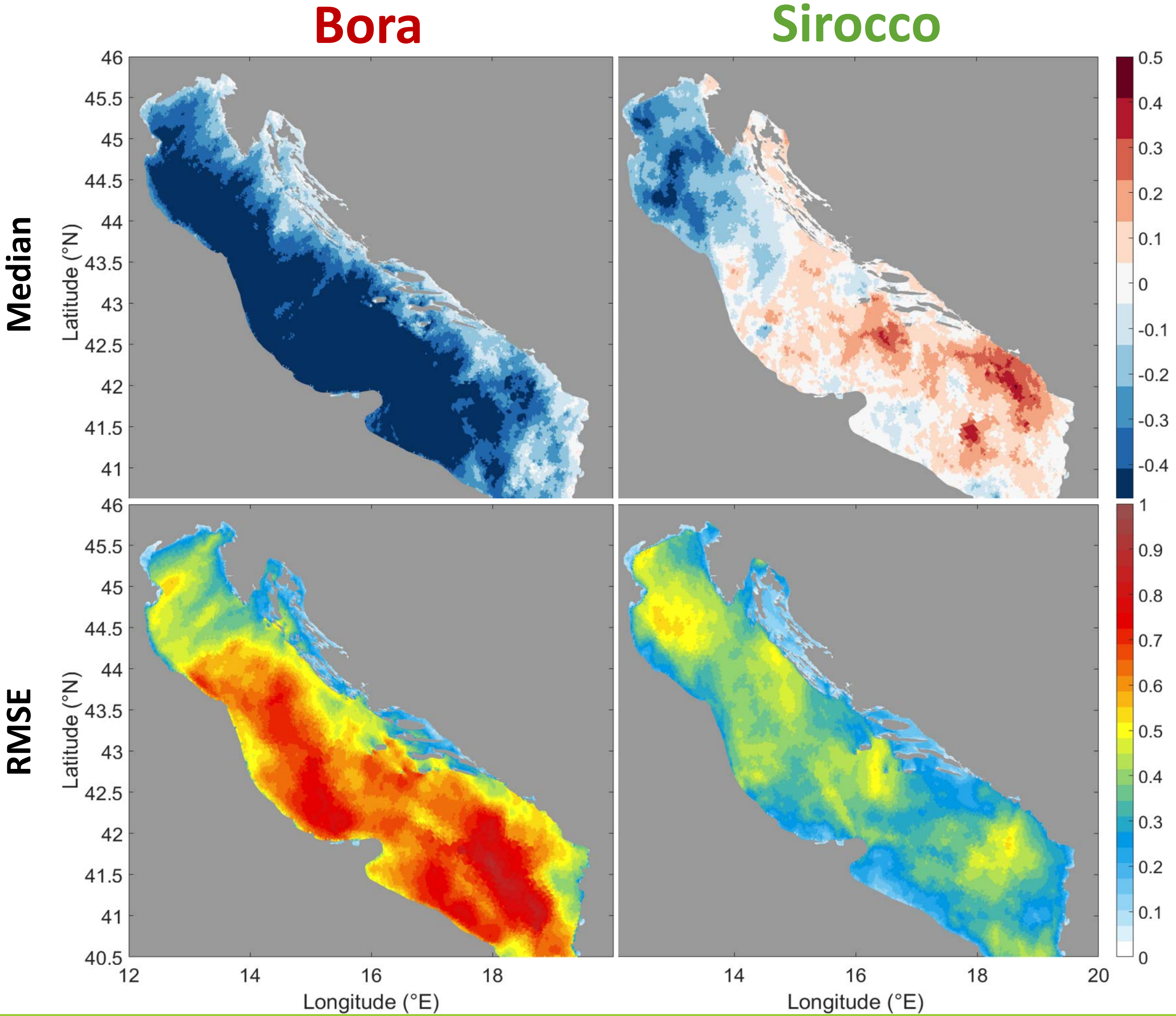




Experiment #1 – Extreme Wave Events

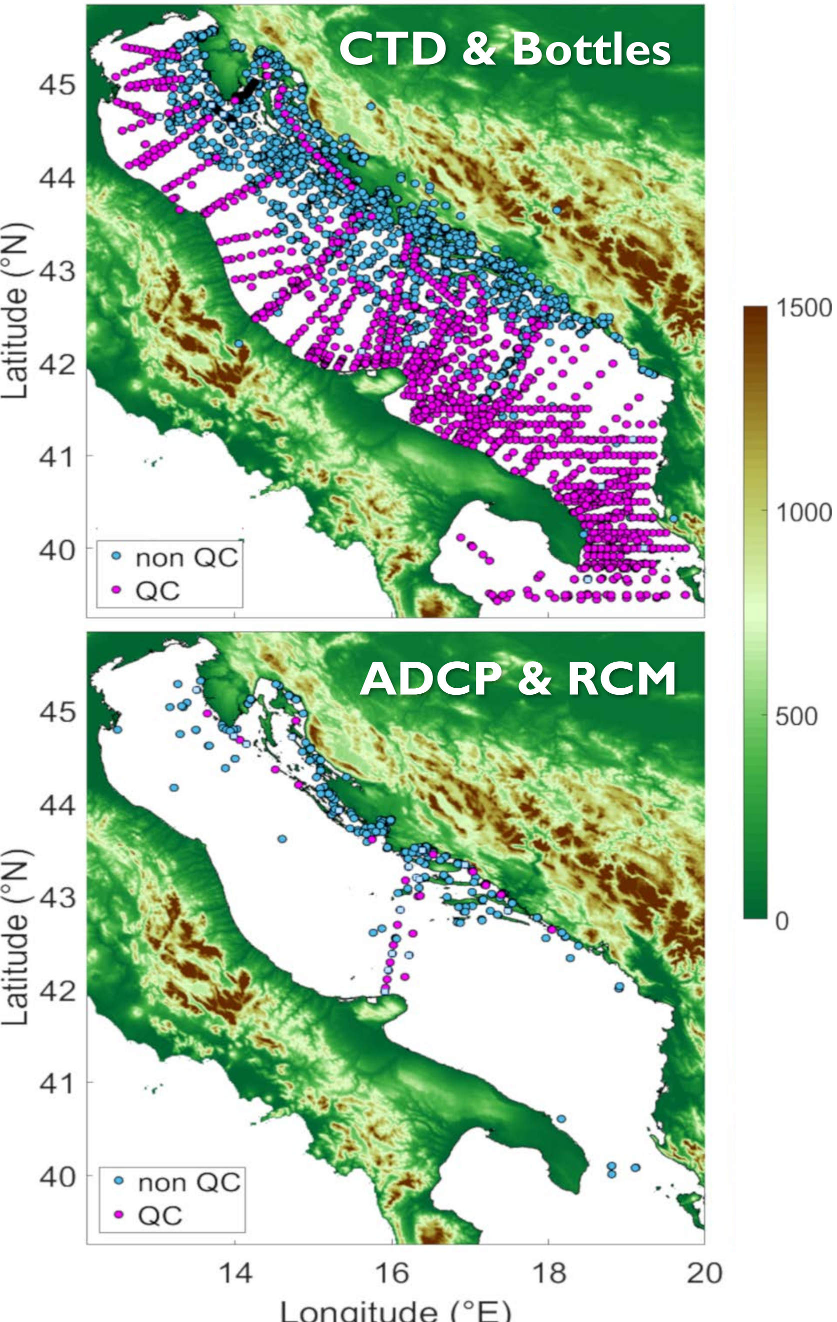
Bias of Maximum Significant Wave Height

RCP 8.5 - Evaluation



Experiment #1 – Extreme Wave Events

Simulation Set-Up



Evaluation run

- ✓ AdriSC general circulation module used without waves
- ✓ 31-year continuous long term evaluation simulation between 1987 & 2018
- ✓ Evaluation run forced with 6-hourly ERA-I fields in the atmosphere and daily MEDSEA reanalysis for the ocean

Climate change projection

- ✓ 31-year continuous long term future rcp 8.5 projection between 2070 & 2100 forced with PGW method

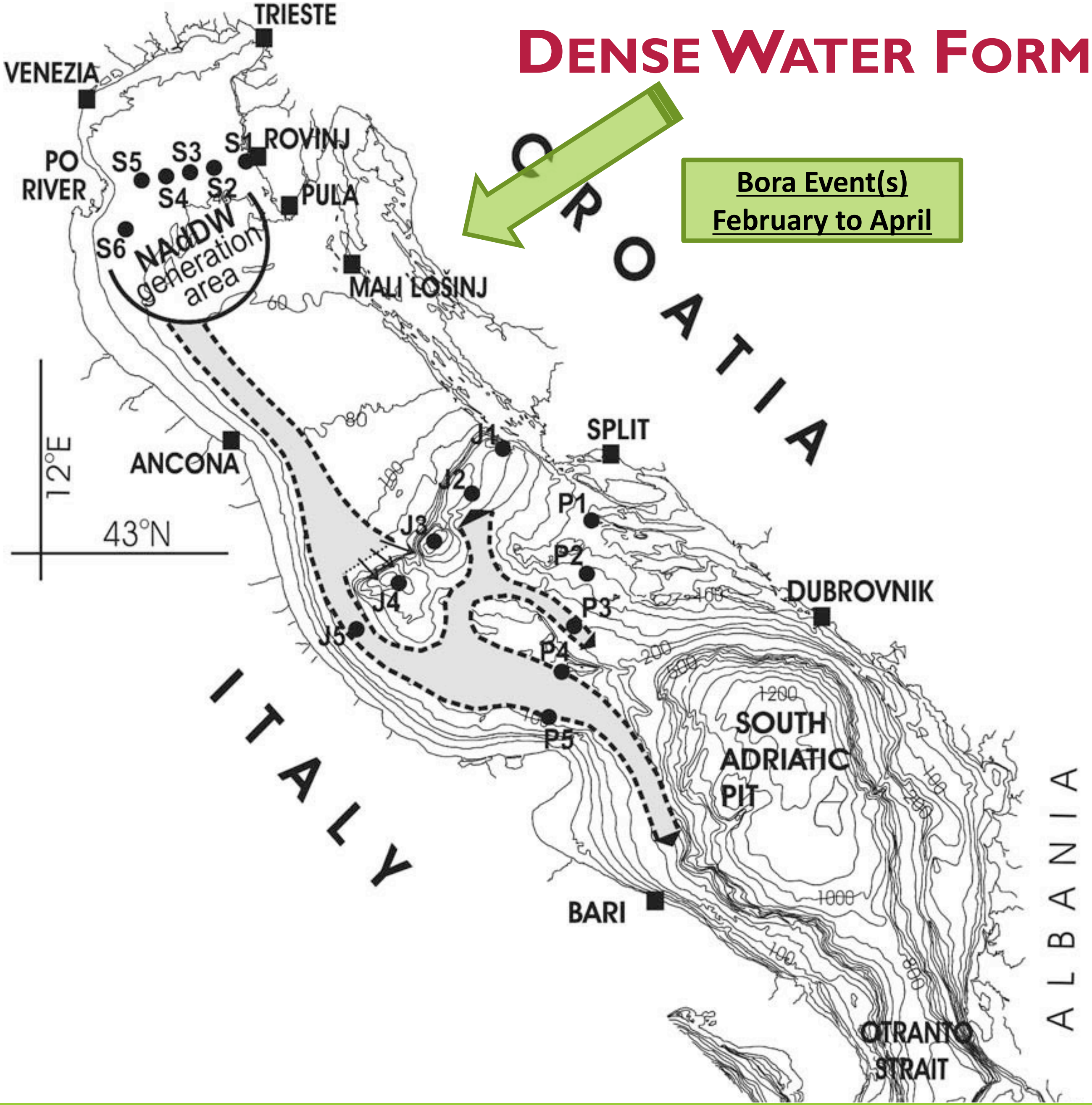
Evaluation of the general circulation module

1) For the atmosphere: E-OBS 0.1°gridded dataset
2) For the ocean: compilation of measurements including CTD, RCM and ADCP measurements either moored for several months or along some boat transects.
3) Quality check of the ocean data in progress …

Experiment #2 – Adriatic Circulation

Dense Water Formation

Bora Event(s)
February to April



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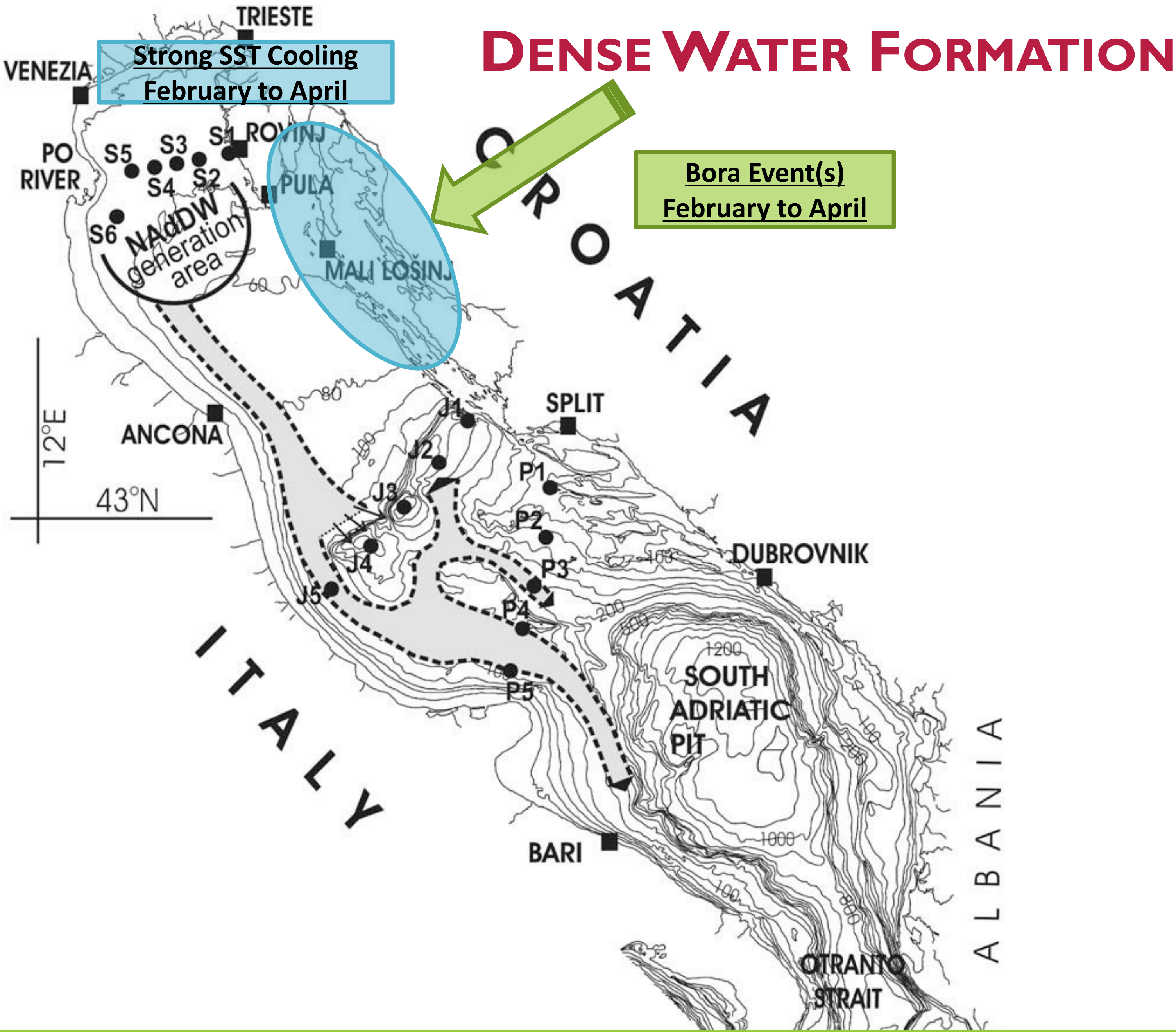

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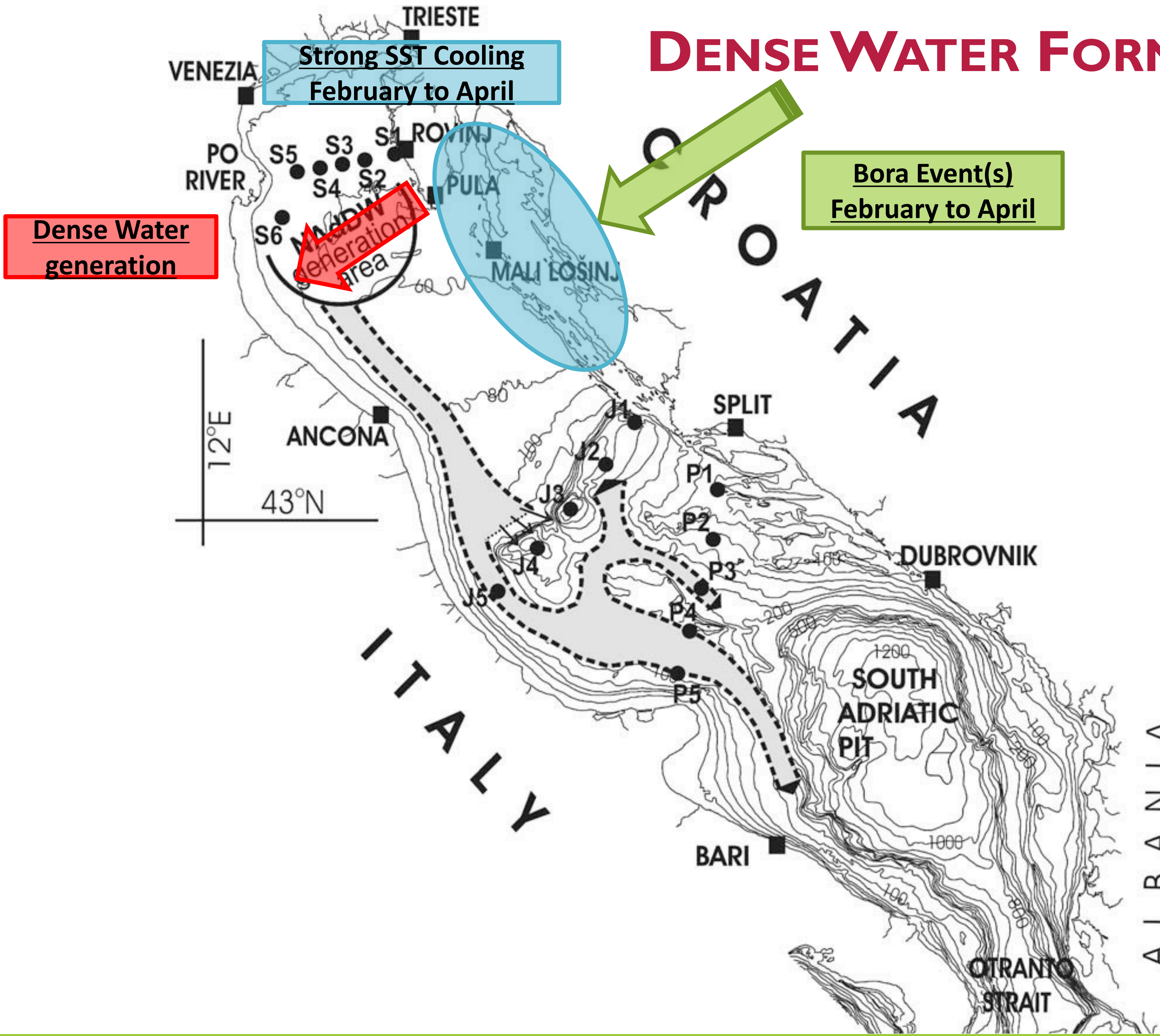

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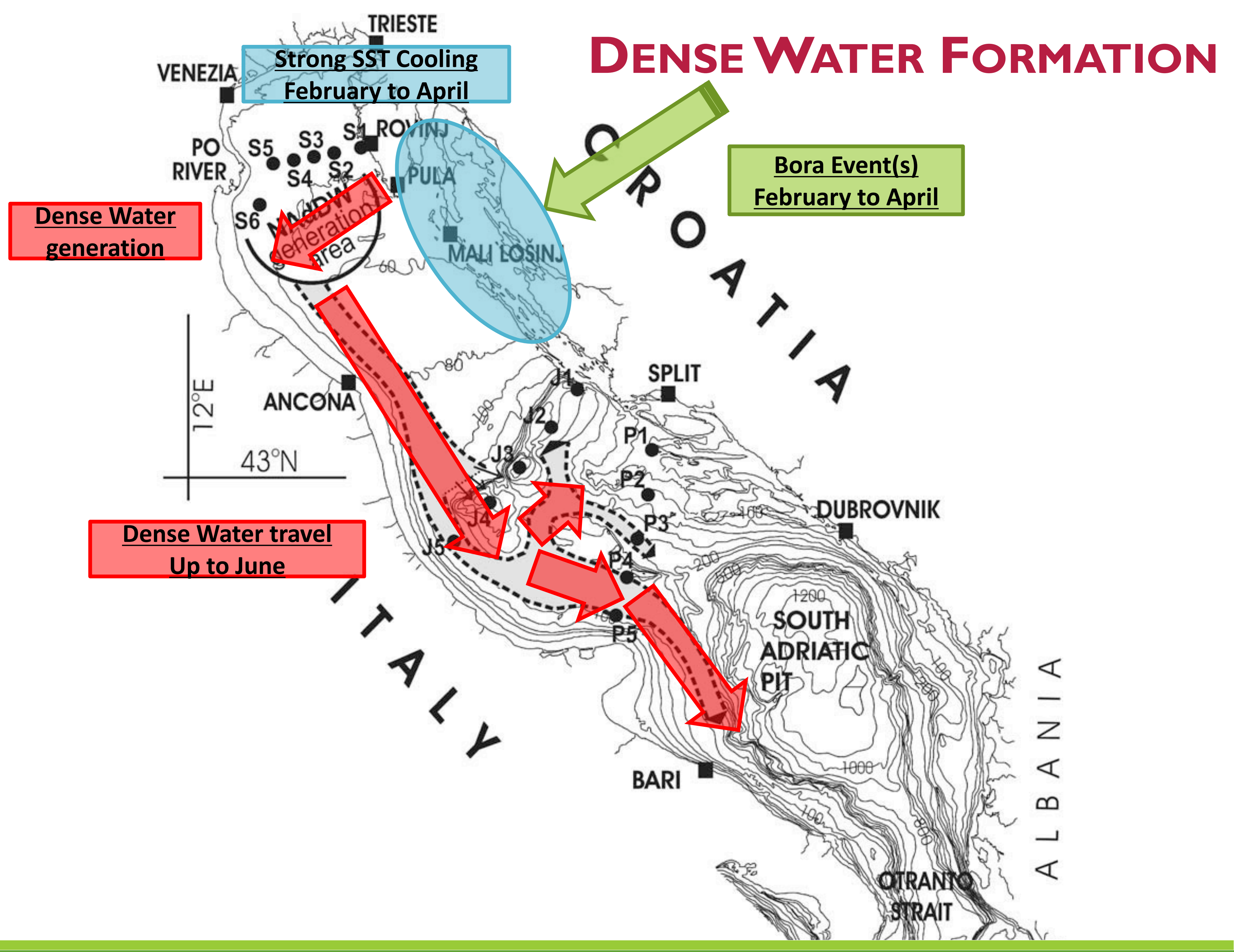

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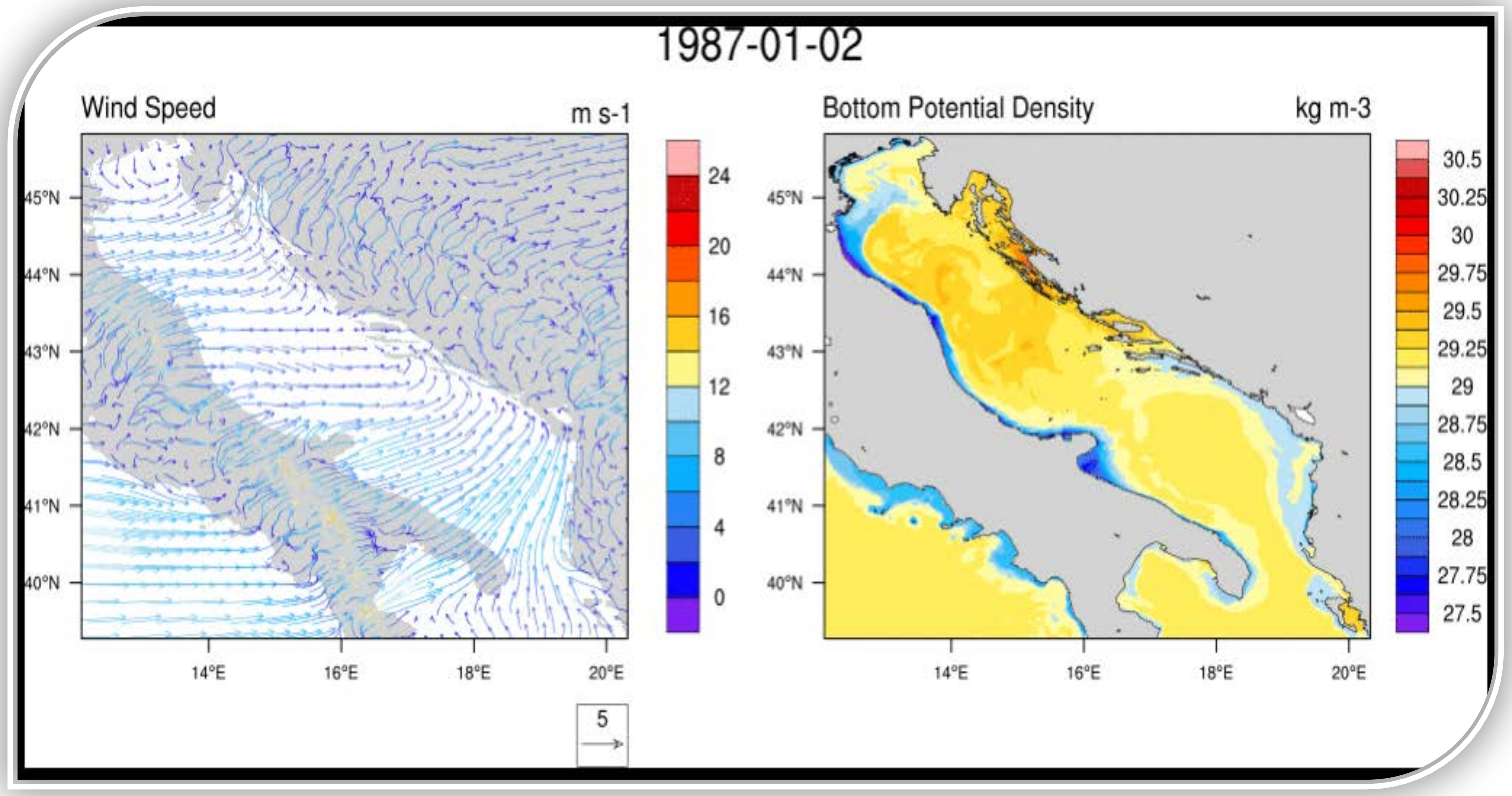


Experiment #2 – Adriatic Circulation

CONCLUSIONS

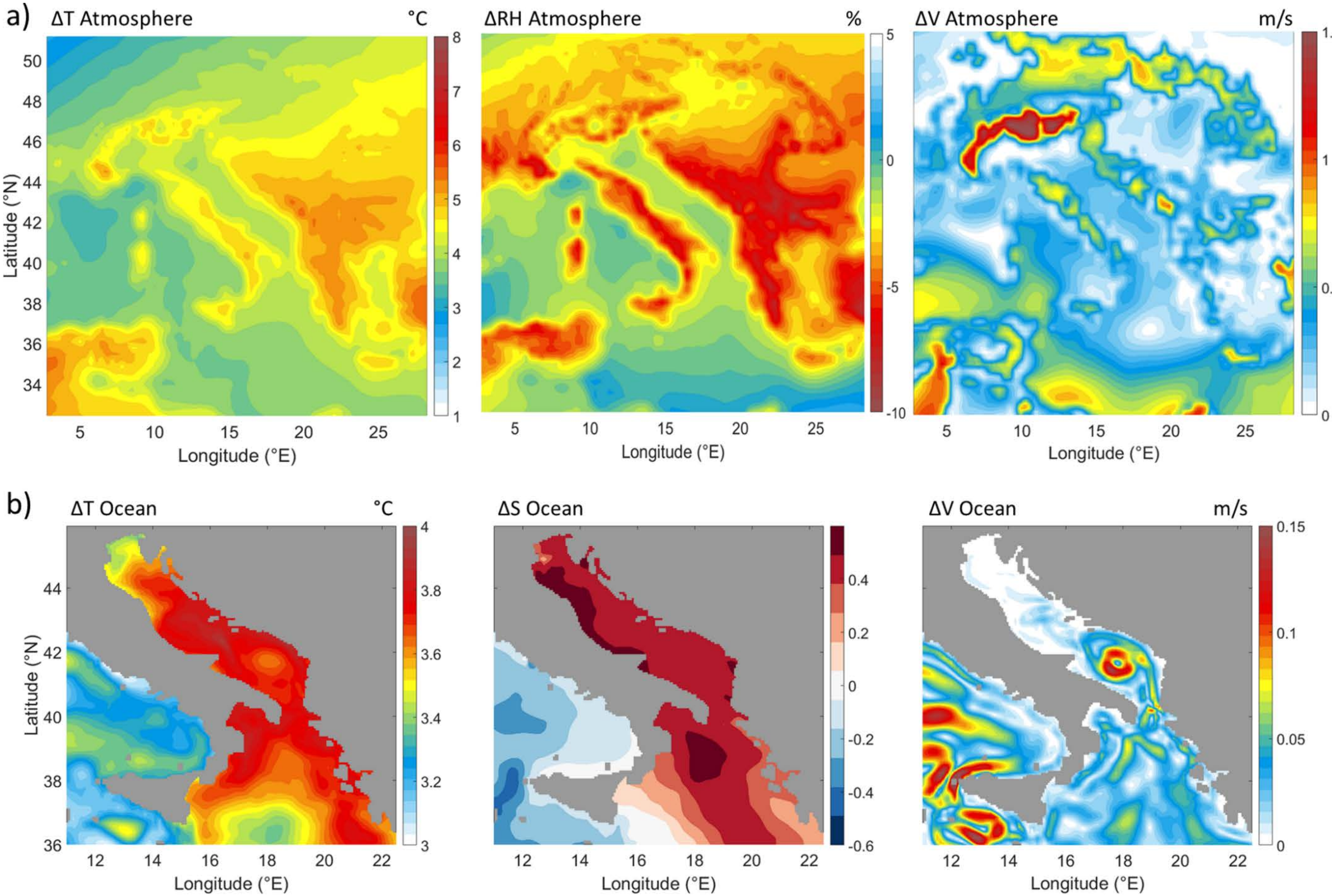
CHALLENGES:

- ✓ High resolution modelling vs. Computational resources
- ✓ Choice of the “best” available forcing fields
- ✓ Development of the PGW methodology for the ocean
- ✓ Available datasets for validation of the modelling system
- ✓ Projection of the river input depending on RCP scenarios

PRINCIPAL GOAL:

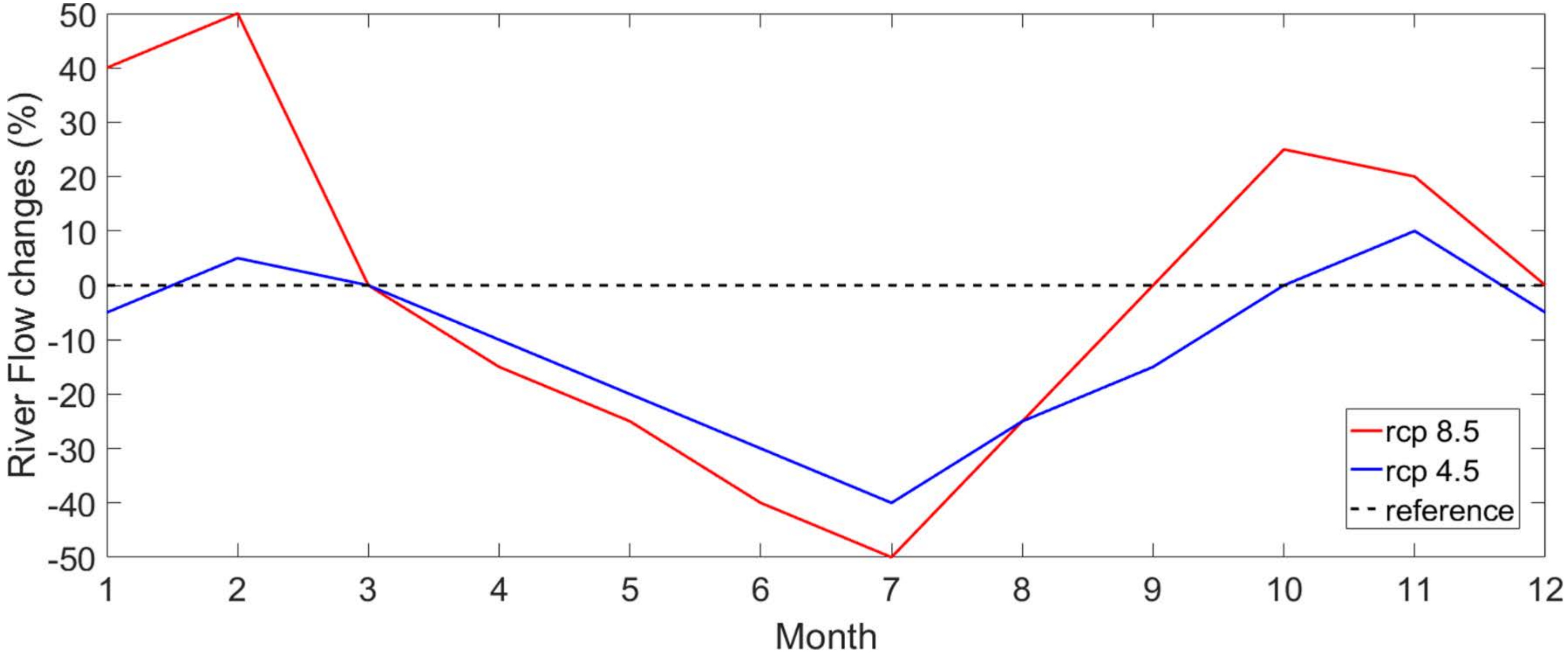
Making sure that generated model datasets can be used for the research purposes of ADIOS project as well as by the entire scientific community – quality is a priority!

Thank You!



Challenge #2 – Future Simulation Forcing

Atmospheric gas volume mixing ratios	carbon dioxide CO_2 (ppmv)	methane CH_4 (ppbv)	nitrous oxide N_2O (ppbv)	chlorofluorocarbon	
				CFC-11 (ppt)	CFC-12 (ppt)
Historical	379	1774	319	251	538
RCP 4.5	532	1648	367	95	226
RCP 8.5	803	3558	414	88	213



Wave Forcing is kept unchanged as the LMDZ4-NEMOMED8 model was not coupled with waves!

Challenge #2 – Future Simulation Forcing