Climate variability and change in the Mediterranean Sea

Nadia Pinardi, *P. Oddo, L. Mentaschi*

Department of Physics and Astronomy

Decade Collaborative Center for Coastal Resilience

University of Bologna

and

Centro EuroMediterraneo sui Cambiamenti Climatici

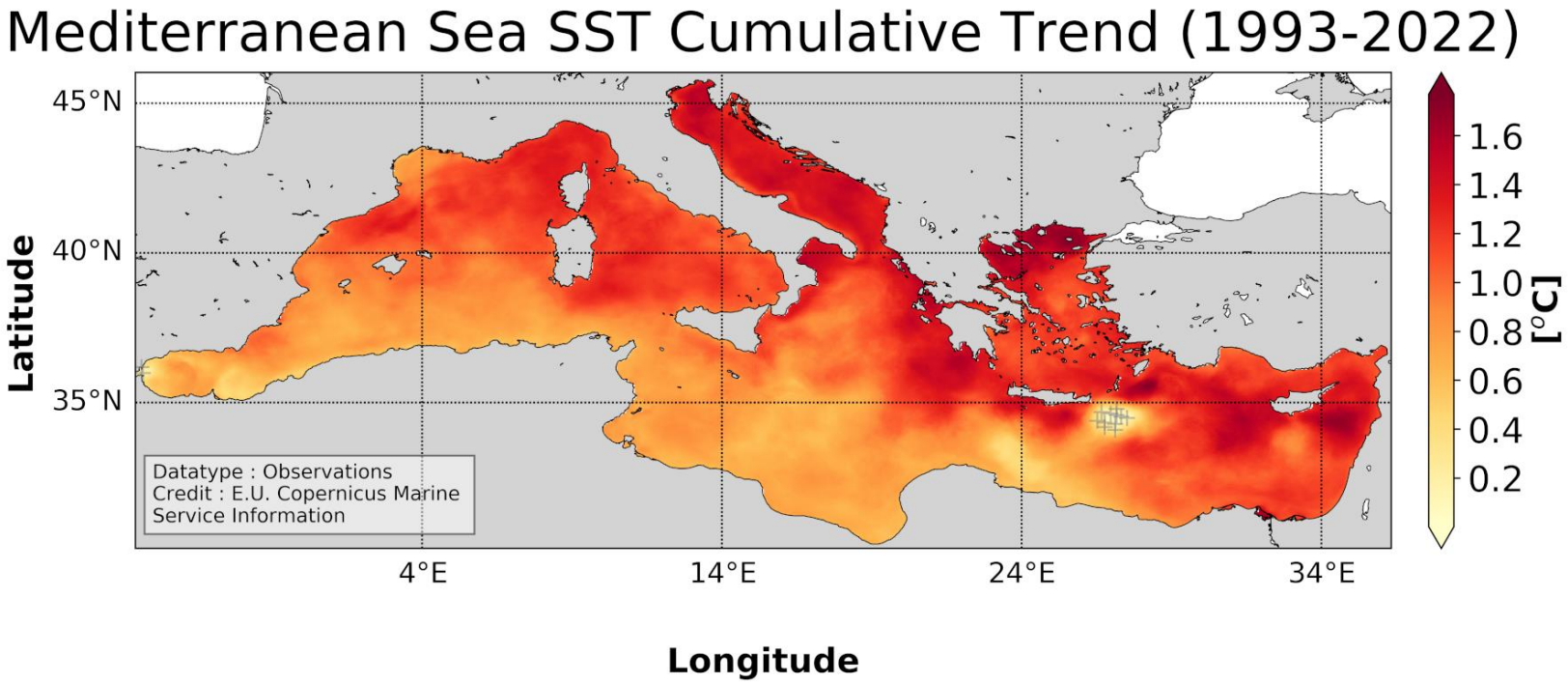
with the contribution of:

G.Coppini, S.Masina, E.Clementi, I.Federico, G.Verri, F. Maicu, F.Borile, P.Cessi, S.Ciliberti, A.Aydogdu, M.Drudi, J.Pistoia, A. Goglio, A.Grandi, E.Jansen, V. Lyubartsev, R.Lecci, G.Liguori, M.H. Ghani, L.Aragao, B. McDonagh

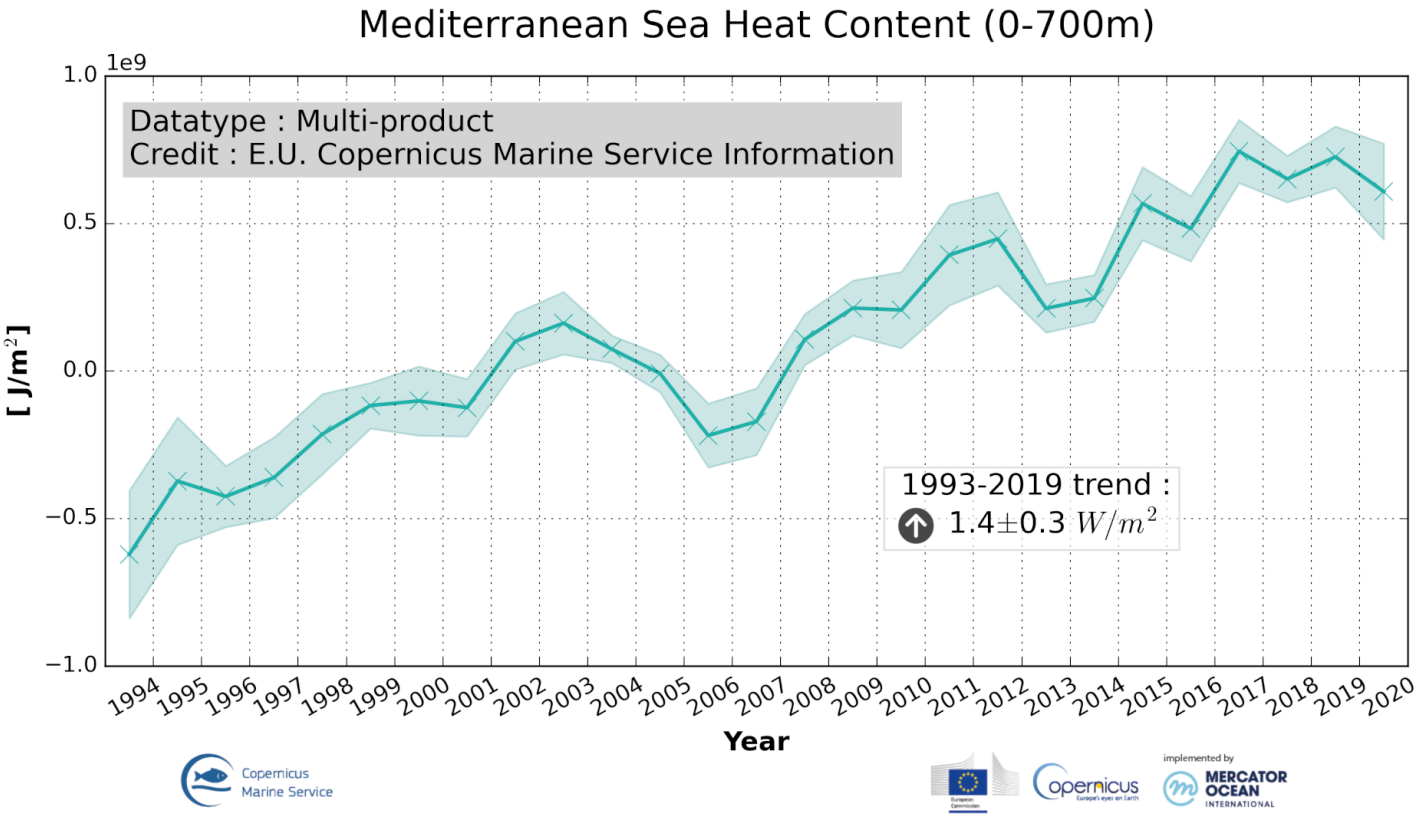
Outline

- Climate change in the Mediterranean Sea
- The new information to study ocean variability and change: open and free data at 1-5 km scale
- The Mediterranean Sea climate signals: circulation structures, overturning, sea level rise and changes in the carbon cycling

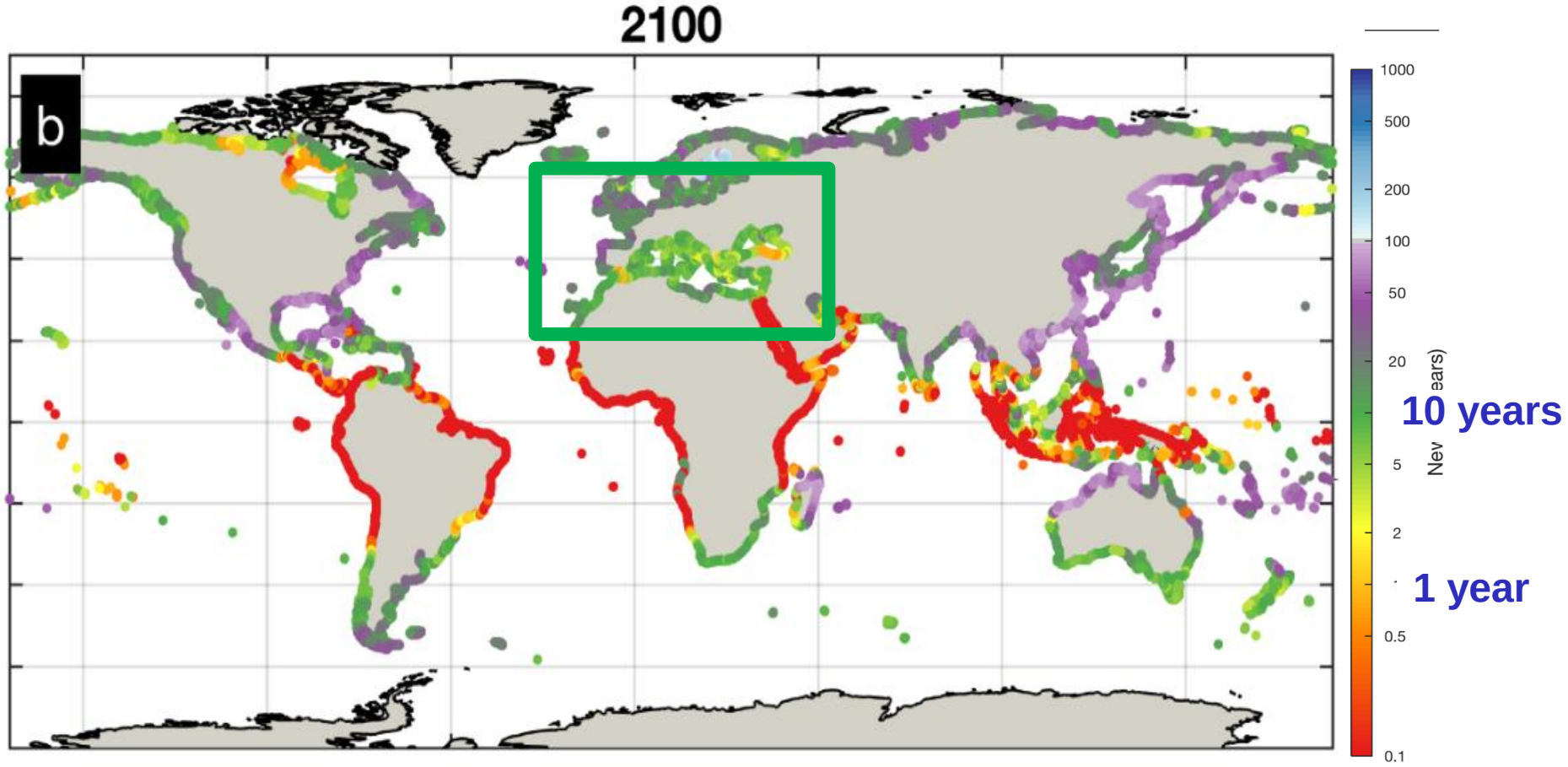
Climate Change in the Mediterranean Sea: Temperature



Climate Change in the Mediterranean Sea: 0-700 m heat content

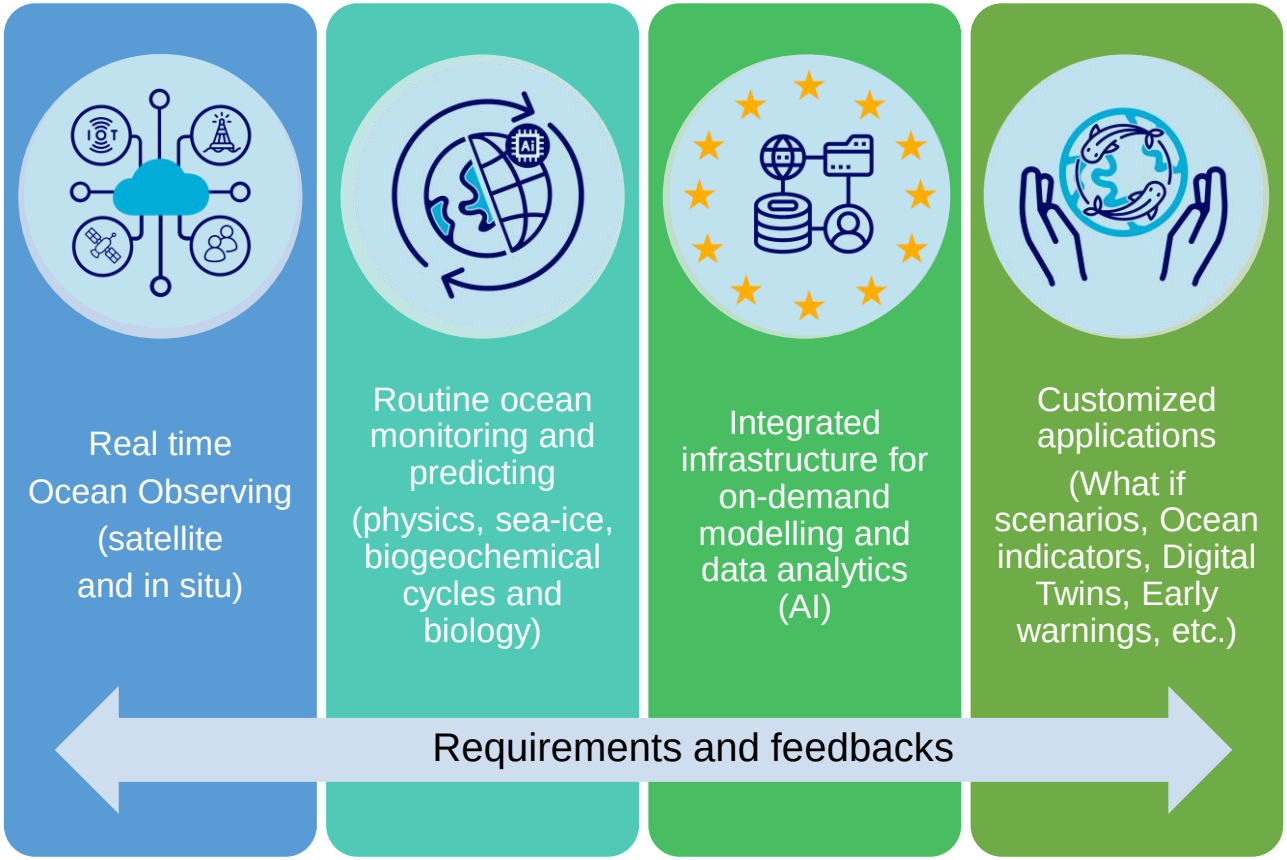


Frequency of the 100 year storm surge event in 2100



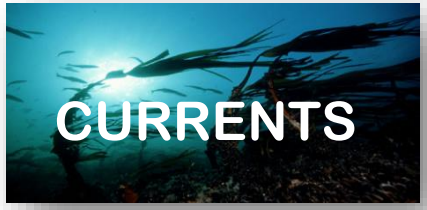
From: Vousdoukas et al., Nature communication, 2018

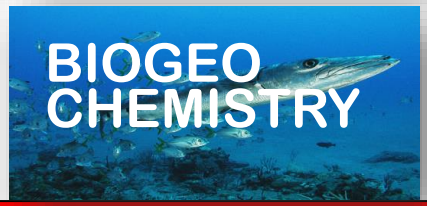
The ocean value chain



Systemic science: monitoring and predicting (1-5 km scales, hours and days)

QC OBSERVATIONS in real time and 10-20 years t.s. → **ANALYSES** Daily/weekly → **FORECASTS** 2 to 10 days → **REANALYSES** 10 to 45 years





DISCOVER

VIEW

DOWNLOAD

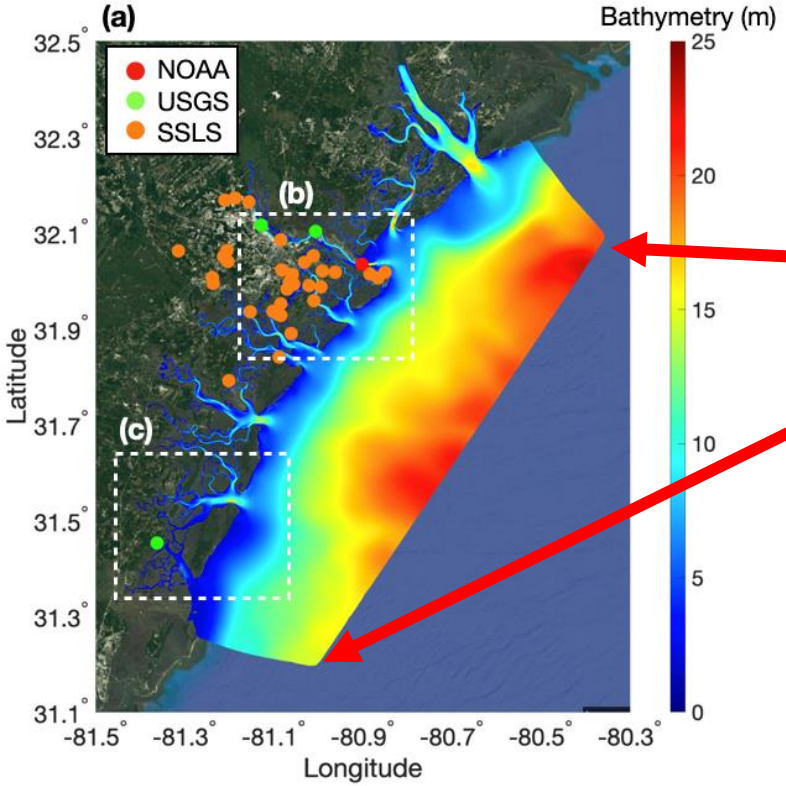
Open & Free

copernicus
The European Earth Observation Programme

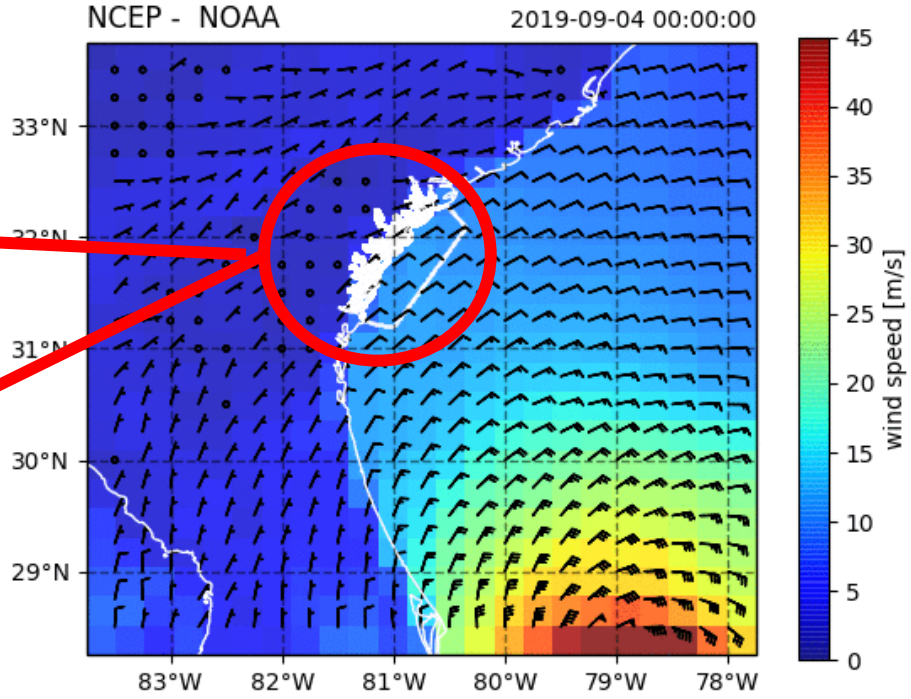
http://marine.copernicus.eu/

Why from large to coastal scales?

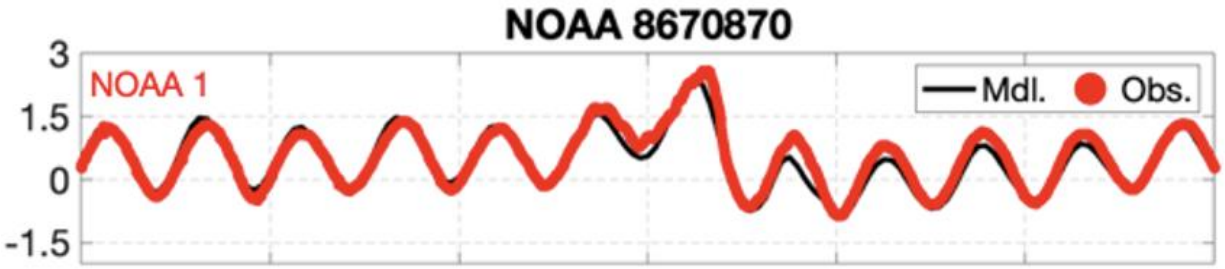
Limited area model for the Georgia (USA) coasts



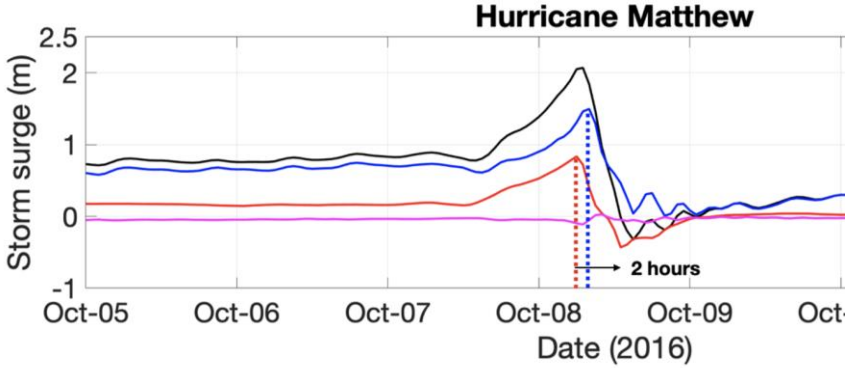
A Hurricane induced storm surge: Can we forecast it?



Why from large to coastal scales?



Model vs observations



Black: total surge

Blue: sea level from offshore

Red: Local hurricane winds

Park et al, Coastal Engineering, 2022

The systemic approach applied in the Mediterranean Sea

Currents (with tidal forcing)

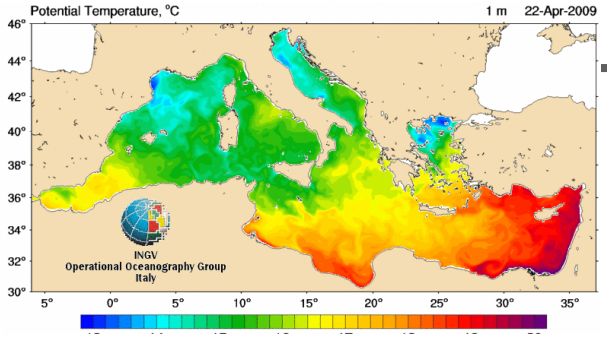
(1/24 x 1/24 x 140)

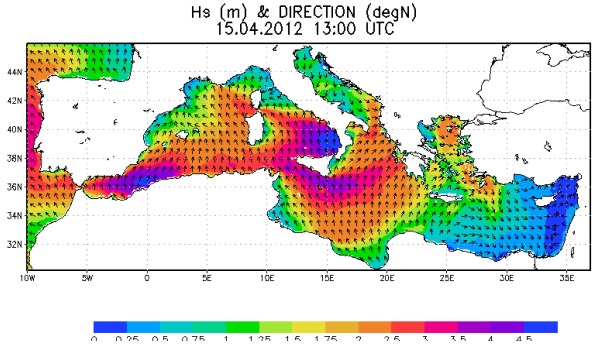
Waves

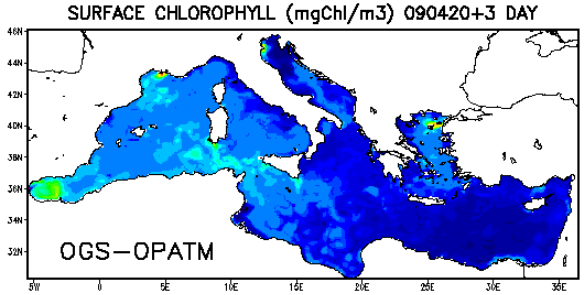
(1/24 x 1/24 x 140)

Pelagic biogeochemistry

(1/24 x 1/24 x 140)



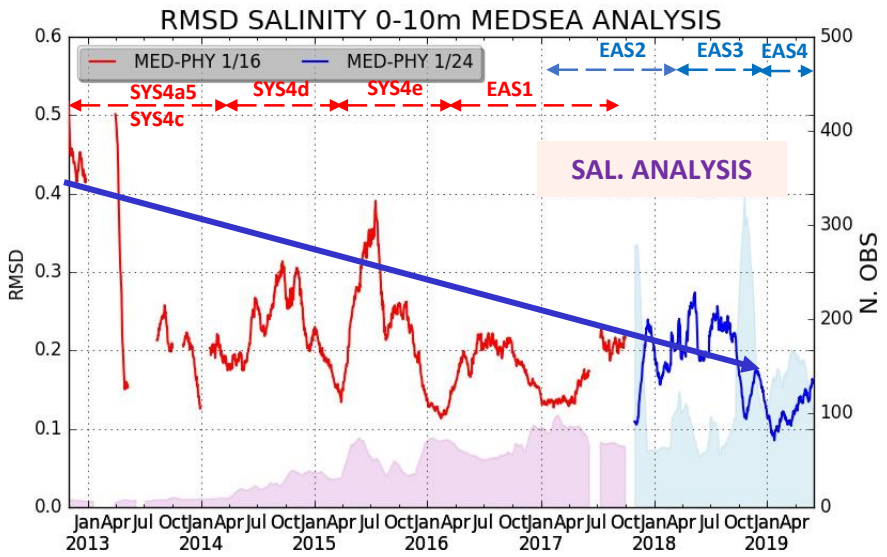


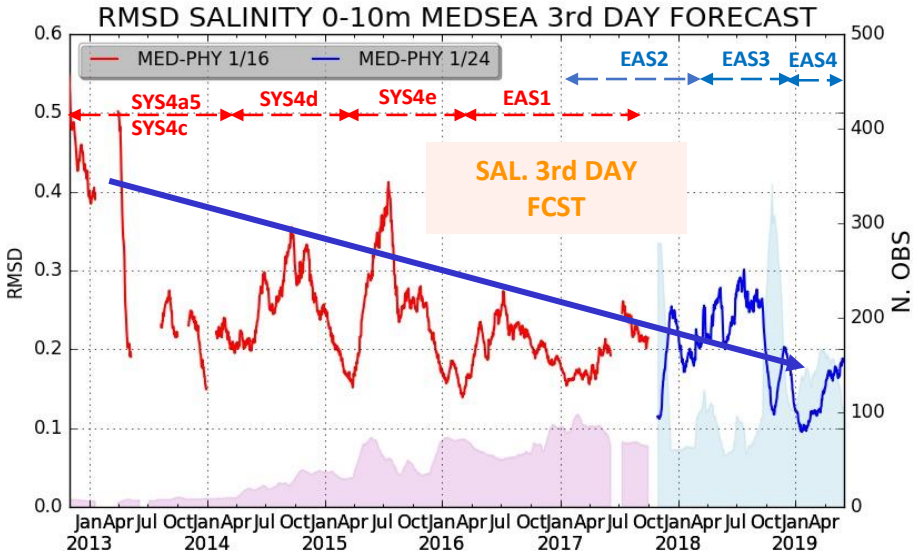


coupled

The systemic approach allows to decrease the errors with time

Date	NAME	SYSTEM changes
2013	SYS4c	Resolution: 1/16, 72 z vert levels, 7 rivers, coupled NEMO-WW3
2017	EAS2	Resolution: 1/24º, 141 z*vert level, new bathymetry from GEBCO, 39 rivers, coupled NEMO-WW3
2019	EAS4	Open Lateral Boundary conditions at Dardanelles strait + improvement in SST nudging

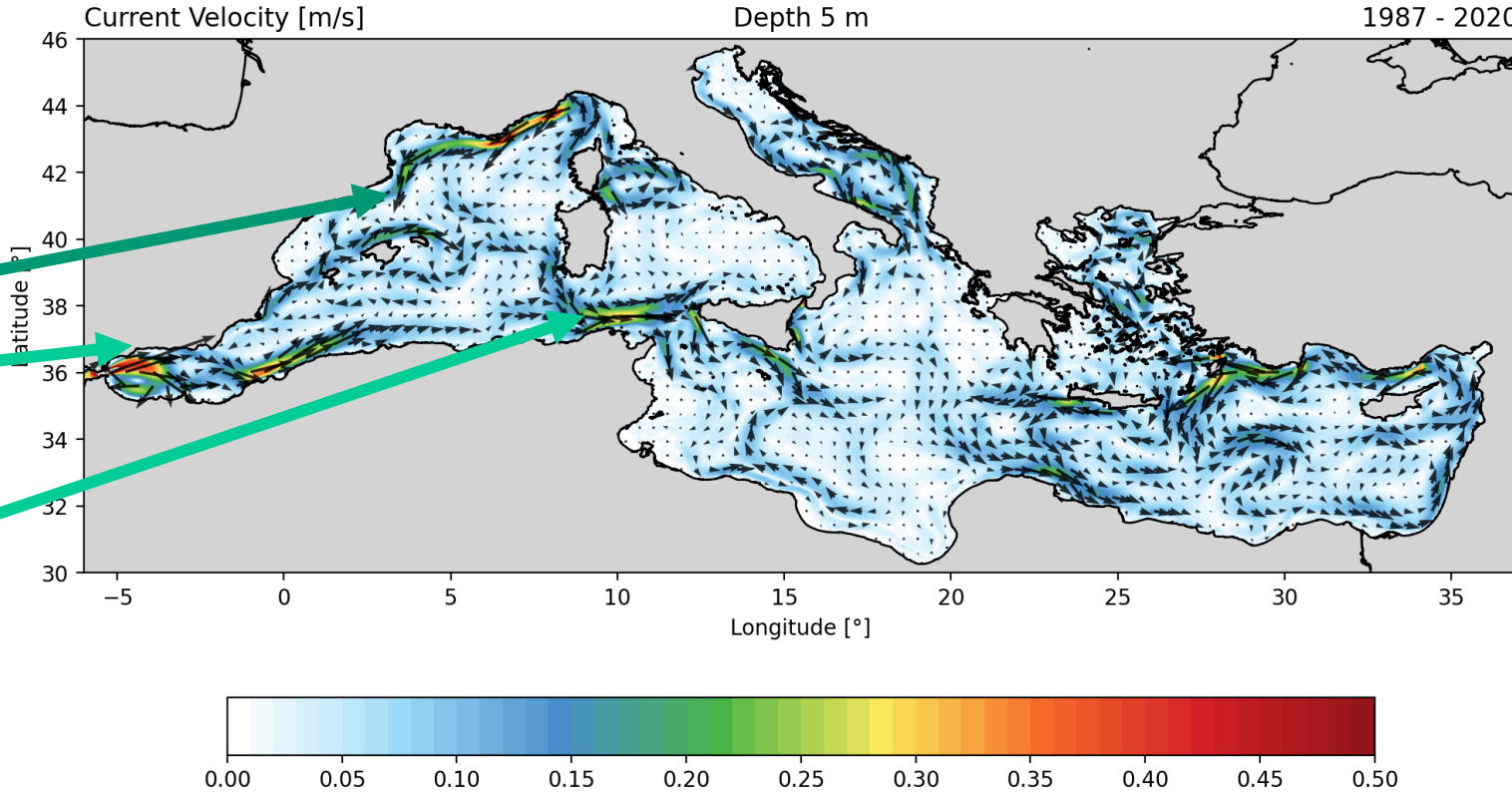




Clementi et al., 2019

The Mediterranean long term mean (34 years) climate circulation from reanalysis

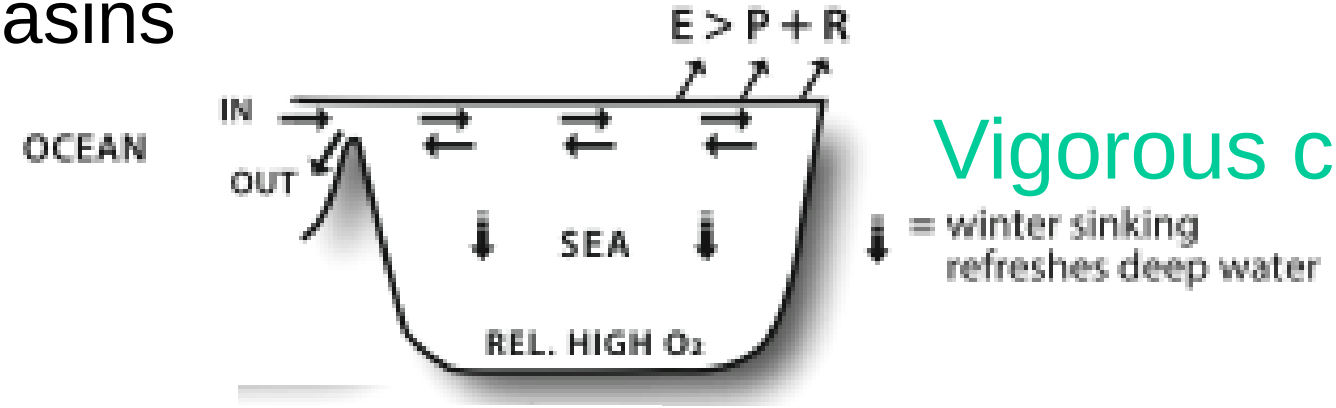
The large scale circulation is composed of jets and intesified currents



New understanding of the Med Sea circulation

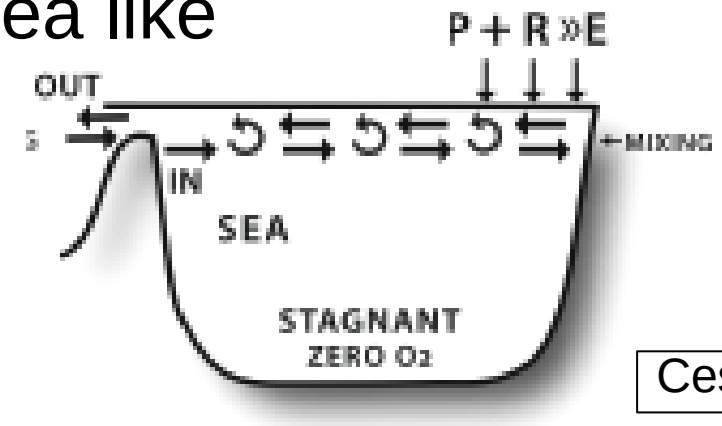
The marine health status is connected to basin **vertical** circulation

Mediterranean like basins



Vigorous circulation

Black Sea like



Stagnant circulation

Cessi, Pinardi and Lyubartsev, 2014

Why is the Mediterranean Sea healthier than the Black Sea one?

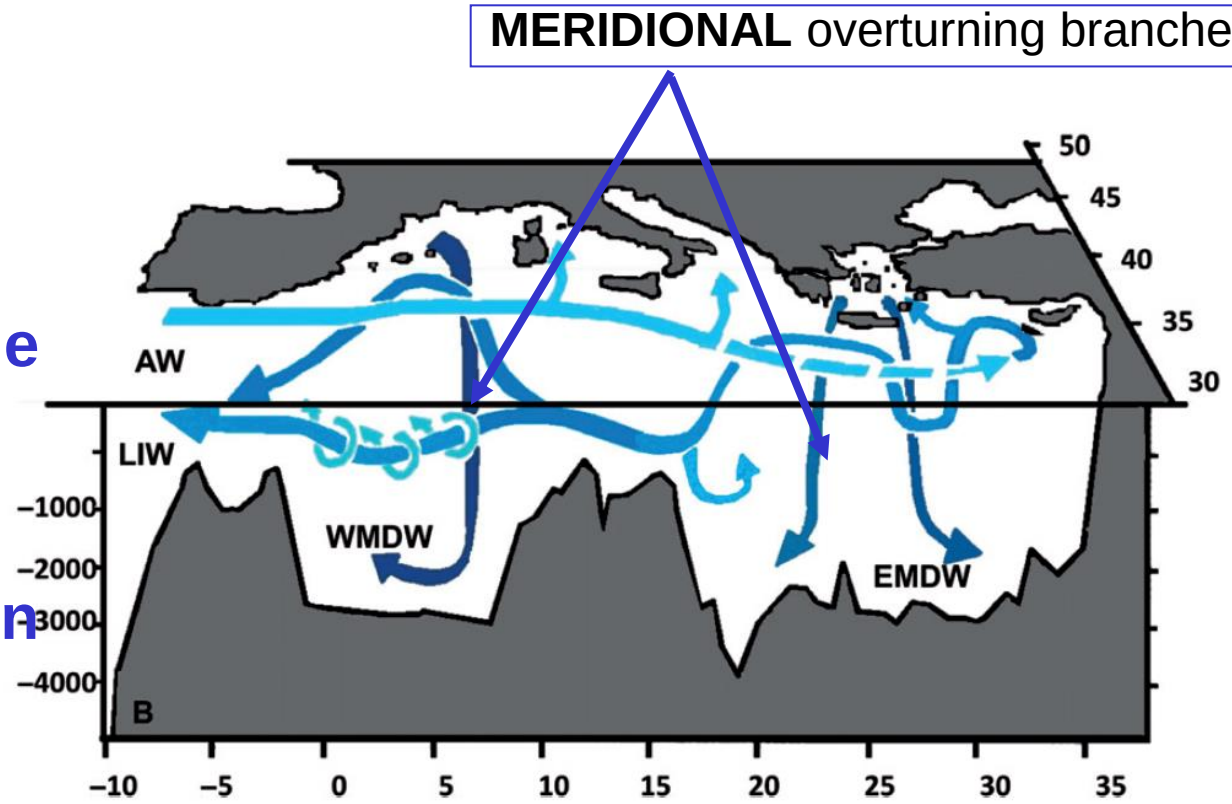
Total energy of the circulation = **Energy inserted by winds** + **Energy inserted by heat and water fluxes**

	Winds	Heat and water fluxes
Mediterranean Sea	+0.8	+1.1
Black Sea	-3	+3

In the Mediterranean both winds, heat and water fluxes power the circulation, in the Black Sea they cancel each other

The Mediterranean overturning circulation structure

A climate index can be extracted from the strength of the overturning circulation that brings oxygen to the deep basin layers

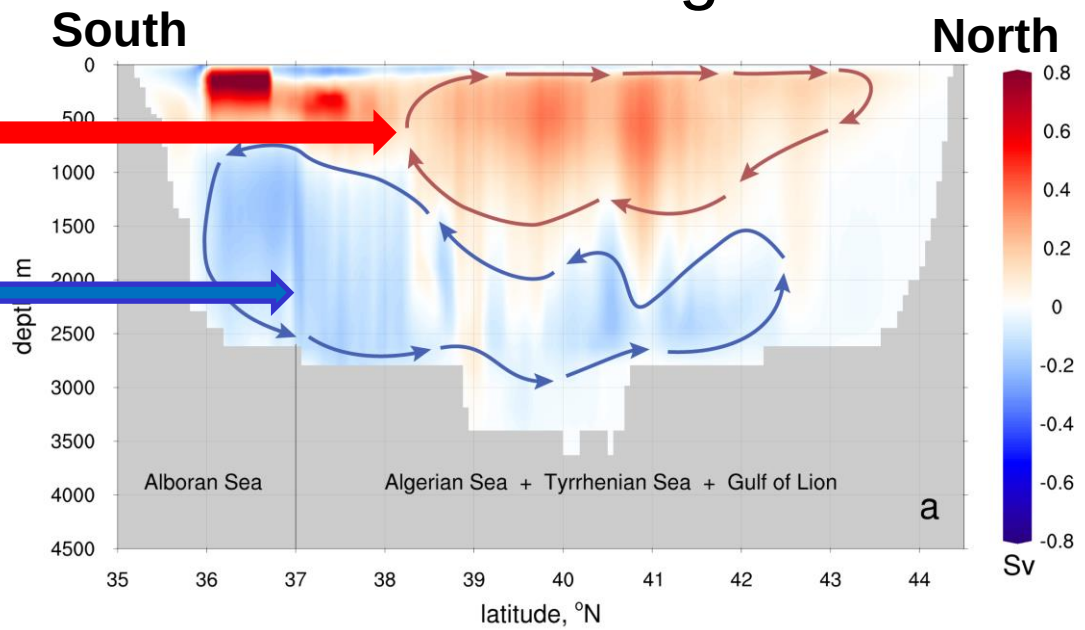


The climate index of the Mediterranean Sea overturning: a proxy for oxygen supply

Mid-depth clockwise cell connected to deep water formation in the Northern regions

Deep anticlockwise cell connected to deep ocean eddy processes

Overturning cells

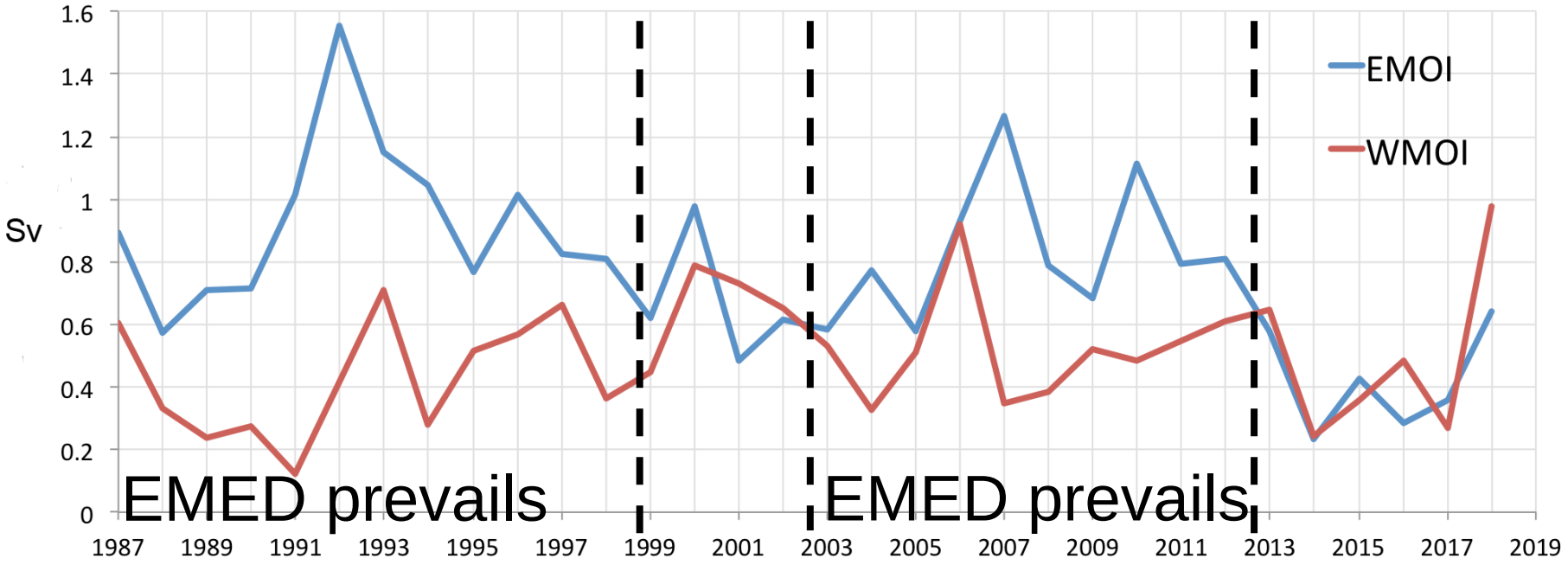


Climate Index: strength of the upper overturning clockwise cell

Pinardi et al., 2019, Journal of Physical Oceanography

The climate index of the Mediterranean Sea: a proxy for oxygen supply

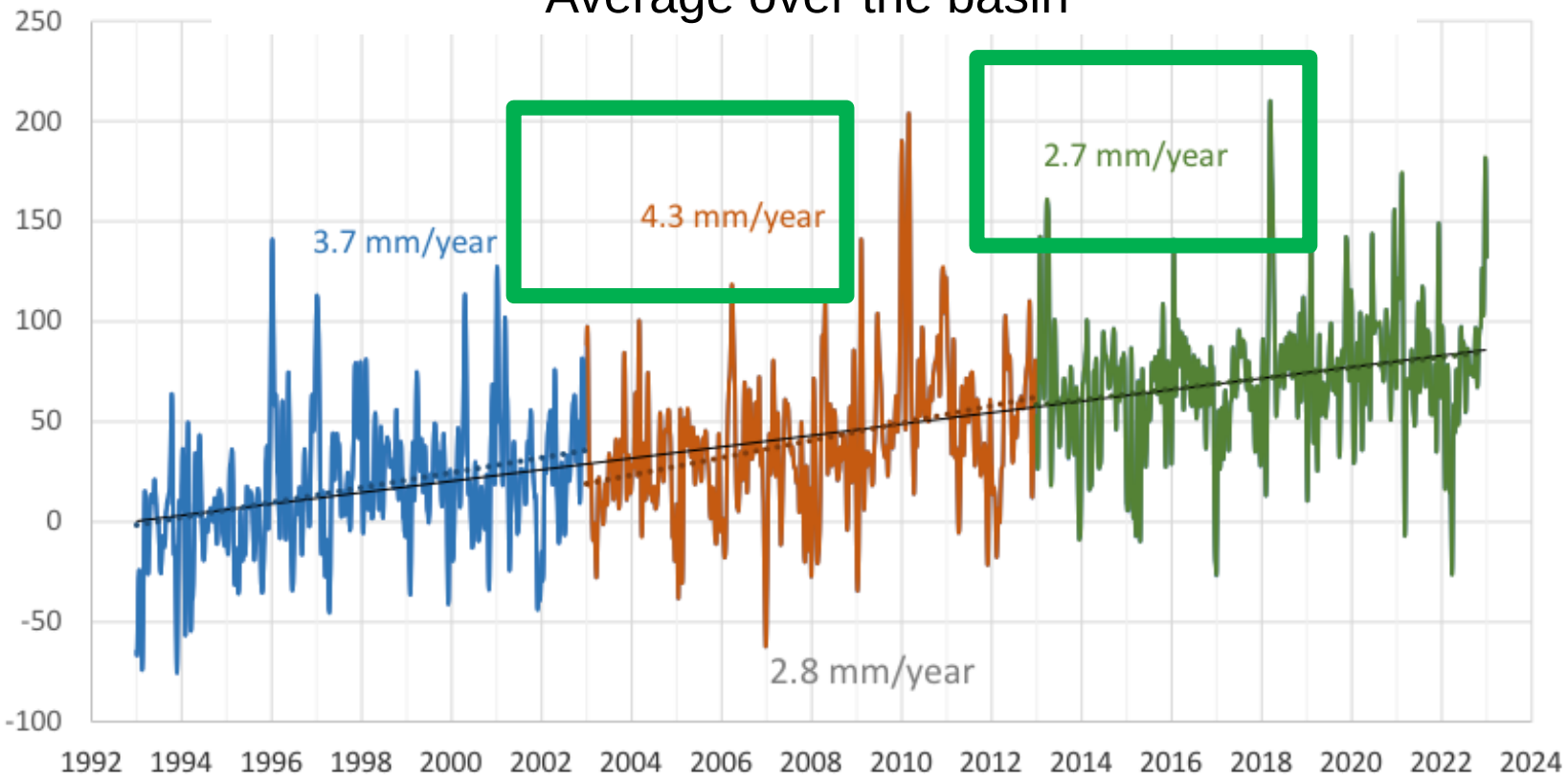
WMOI: maximum of the anticyclonic cell in the Western Mediterranean
EMOI: maximum of the anticyclonic cell in the Eastern Mediterranean



Lybartsev et al., 2021, Ocean State Report

Climate Change in the Mediterranean Sea: sea level rise

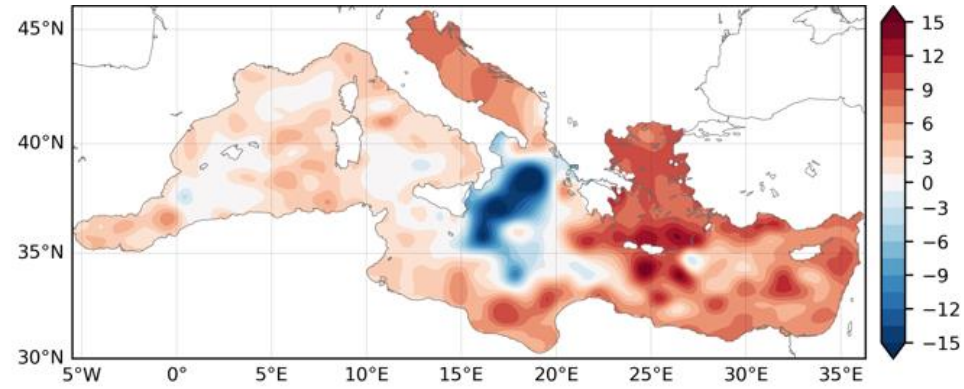
Satellite altimetry Copernicus gridded product [mm]
Average over the basin



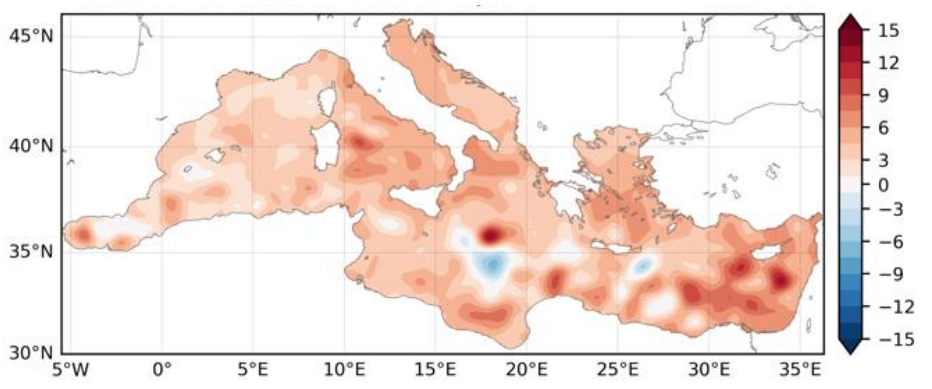
The mean sea level rise in the past 30 years has slowed down

Climate Change in the Mediterranean Sea: sea level rise

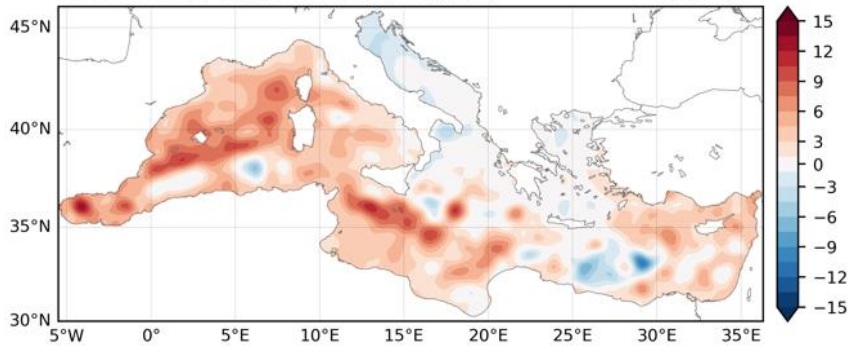
SEA LEVEL TREND in mm/yr (1993-2002)



SEA LEVEL TREND in mm/yr (2003-2012)



SEA LEVEL TREND in mm/yr (2013-2022)



Changes in sea level rise are local and decadal

Why is sea level slowing down in the Mediterranean Sea?

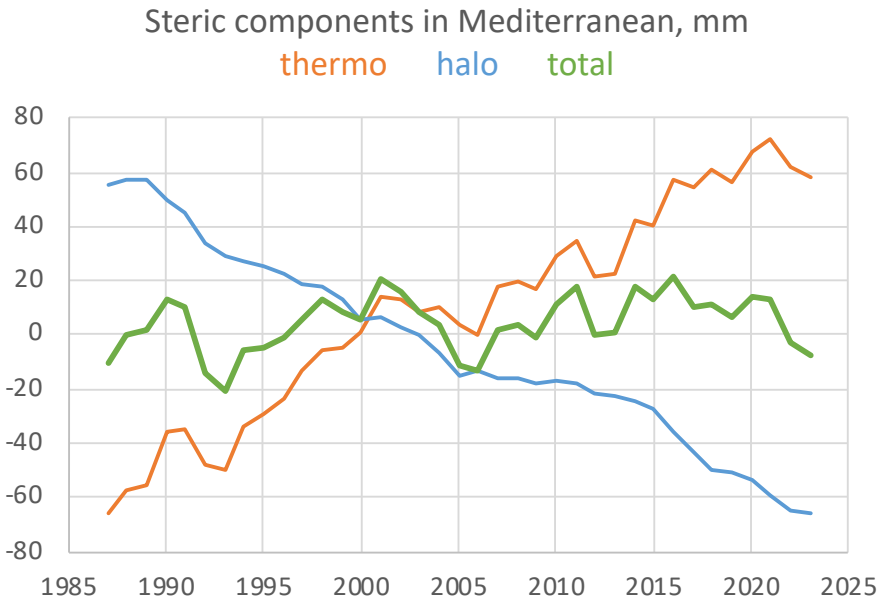
Gibraltar Water Halo Thermo

$$\frac{d\langle\eta\rangle}{dt} = -\frac{T_r}{\Omega} - \langle q_w\rangle - \frac{\rho_f}{\rho_0}\langle\beta S_0 q_w\rangle + \frac{1}{\rho_0}\langle\alpha_T\frac{Q}{C_w}\rangle - F_\rho$$

$$= \quad (1) \quad (2) \quad (3) \quad (4) \quad (5)$$

Pinardi et al, 2014

Salinity increase compensate the large heat storage increase



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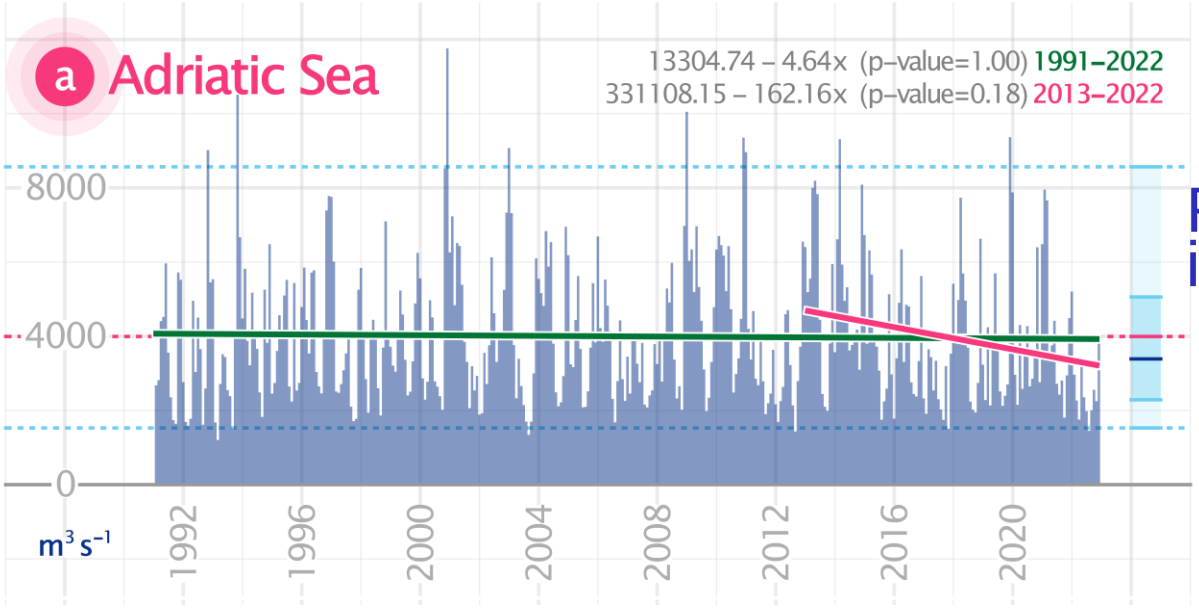
Pinardi et al, 2014



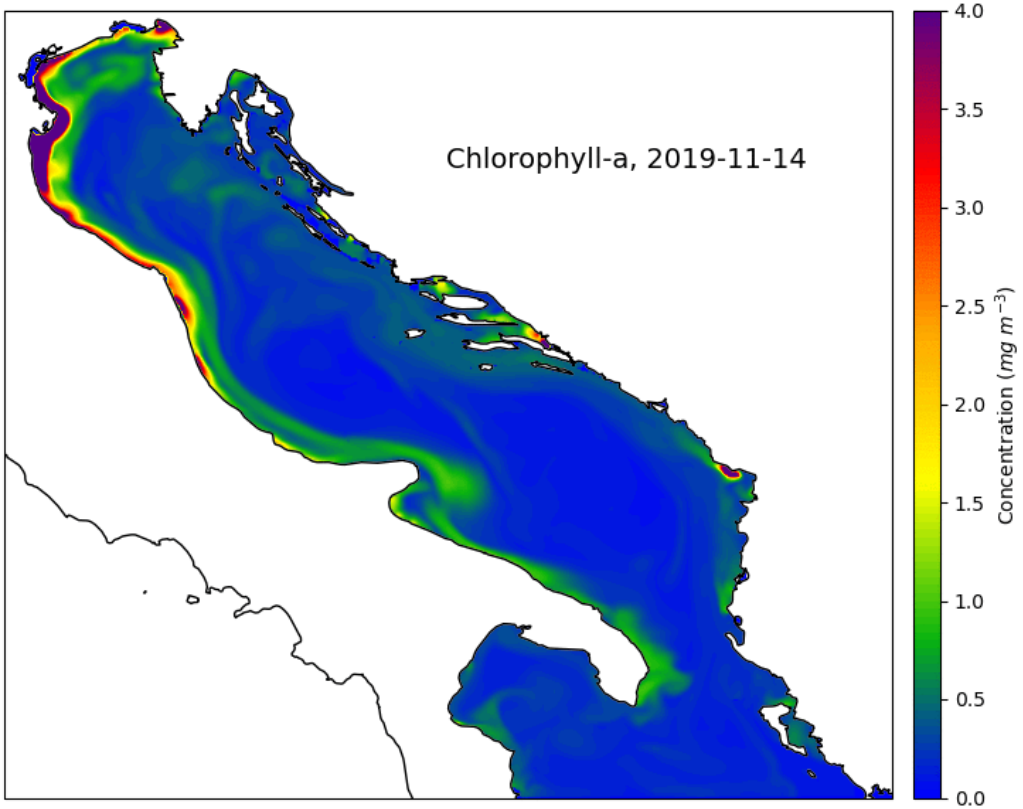
River discharge is decreasing

Aragao et al., 2024

Climate downscaling to the coastal areas: the Adriatic Sea case

Present climate simulation

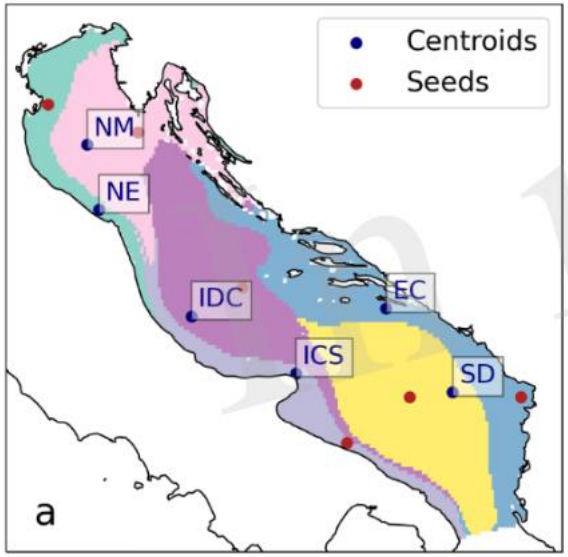
The Adriatic Sea: a high contrast Chlorophyll area



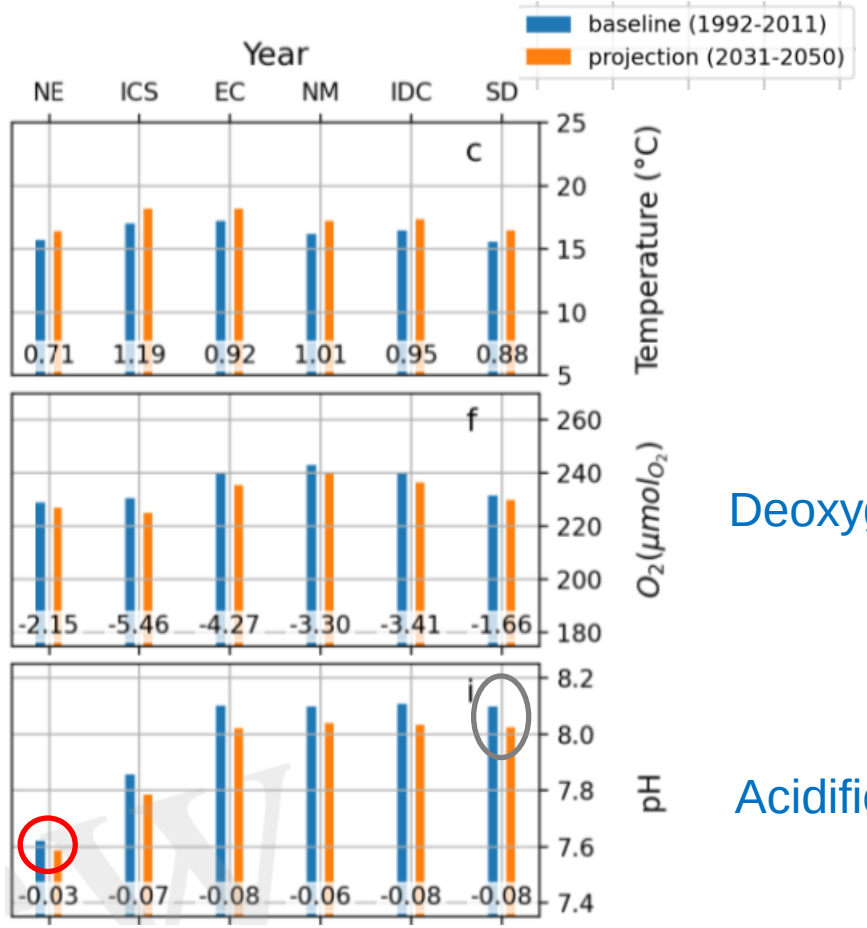
Mentaschi et al., 2024

How is the oxygen and the acidity in the future Adriatic?

Mentaschi et al., 2024



NE: Northern Estuarine
ICS: Italy Center-South
EC: Eastern Coastal
NM: Northern Mesotrophic
IDC: Itermediate-Depth Center
SD: Southern Deep



Deoxygenation

Acidification

Final considerations

- The Mediterranean Sea climate can now be properly studied with new reanalysis products at high resolution for the Med Sea. The circulation is boundary and free jets intensified
- The Mediterranean Sea health status depends on its overturning circulation: Eastern Mediterranean plays a crucial role in the oxygenation of the basin
- Sea Level Rise in the Mediterranean is decadal, slow down detected for the first time
- Advanced climate downscaling in the Adriatic Sea for biogeochemistry shows that oxygen will decrease and acidity will increase with important subregional differences