Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile

FONDAZIONE ROMA SAPIENZA

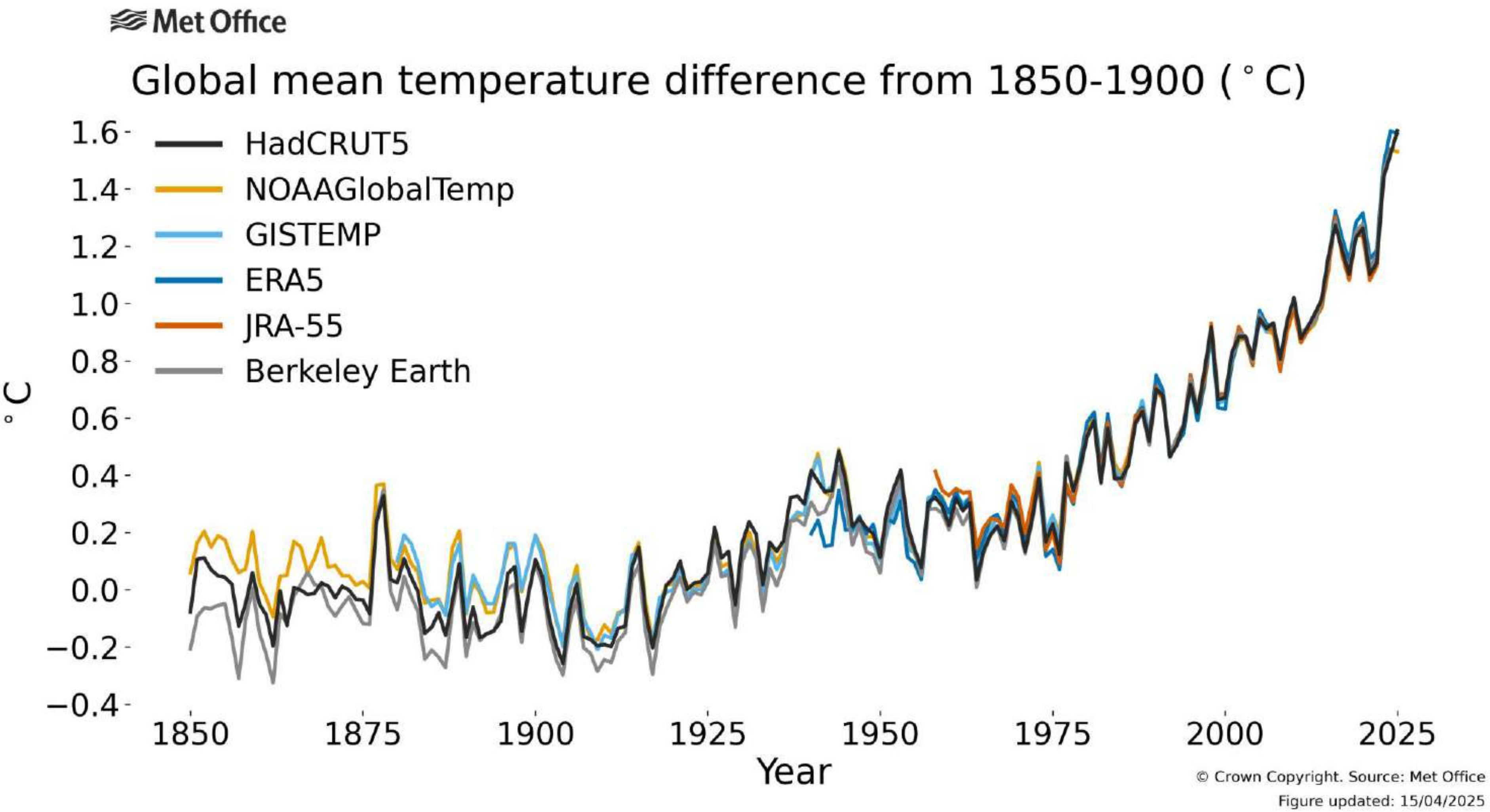
Le sfide del XXI secolo: il Clima

Cambiamento climatico: stato attuale, tendenze future e impatti in area mediterranea

Roma – 8 giugno 2025

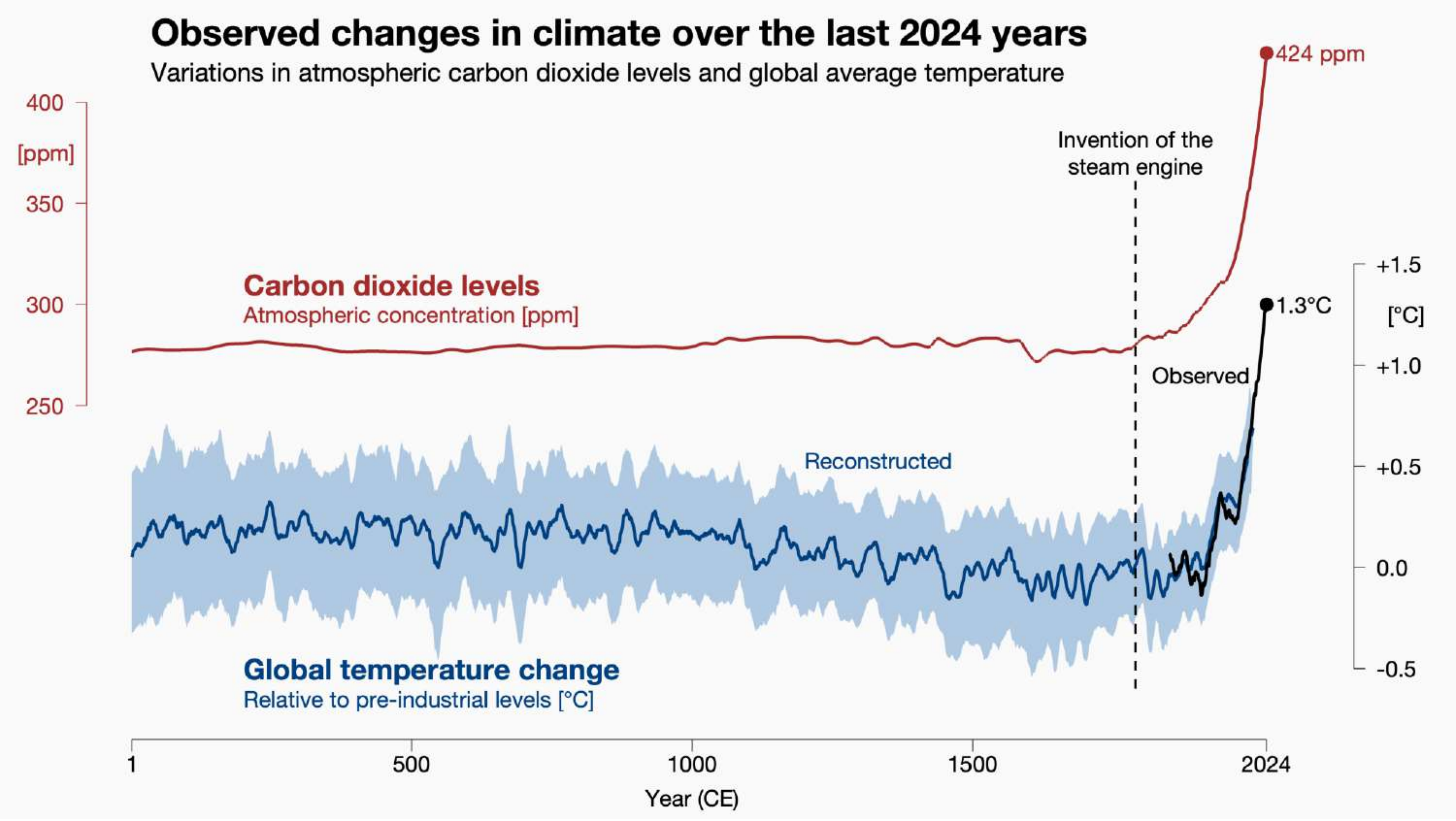
G. Sannino: Divisione Modelli, Osservazioni e Scenari per il Cambiamento Climatico e la Qualità dell'Aria

State of Cimate: Global Surface Temperature



Annual global mean temperatures expressed as a difference from pre-industrial conditions. Four different data sets are shown - HadCRUT, NOAAGlobalTemp, GISTEMP, and Berkeley Earth - as well as two reanalyses - ERA5 and JRA-55. There is good agreement on the overall evolution of global temperatures and year-to-year variability. Dataset anomalies are calculated relative to a **1981 to 2010 baseline** and offset by 0.69° C, which is the best estimate difference for that period from the 1850-1900 average given in the IPCC sixth assessment report.

State of Cimate: Global Surface Temperature & CO2

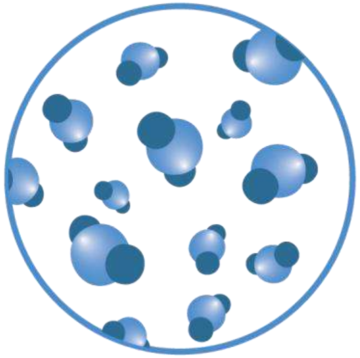


Climate Visuals by
(National Centre for Atmospheric Science, University of Reading)

Changes at global scale

INTERGOVERNMENTAL PANEL ON climate change ipcc WMO UNEP

CO_2
concentration



Highest

in at least

2 million years

Sea level
rise

Fastest rates

in at least

3000 years

Arctic sea ice
area

Lowest level

in at least

1000 years

Glaciers
retreat

Unprecedented

in at least

2000 years

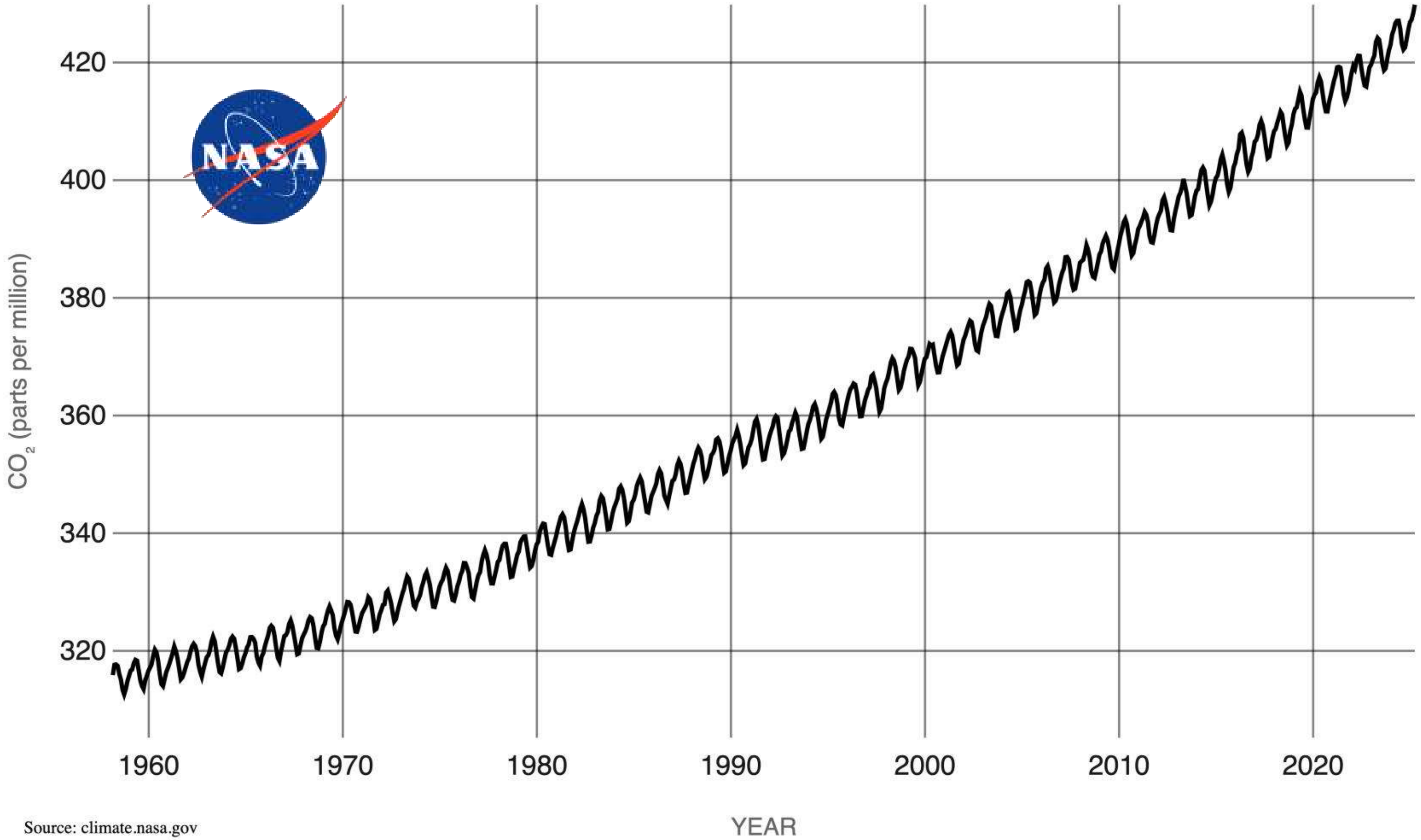
Cimate status: Carbon Dioxide in Atmosphere

LATEST MEASUREMENT: April 2025

430 ppm

The global CO_2 concentration increased from

~277 ppm in 1750 to **422.5 ppm** in 2024 (up 52%)



Source: climate.nasa.gov

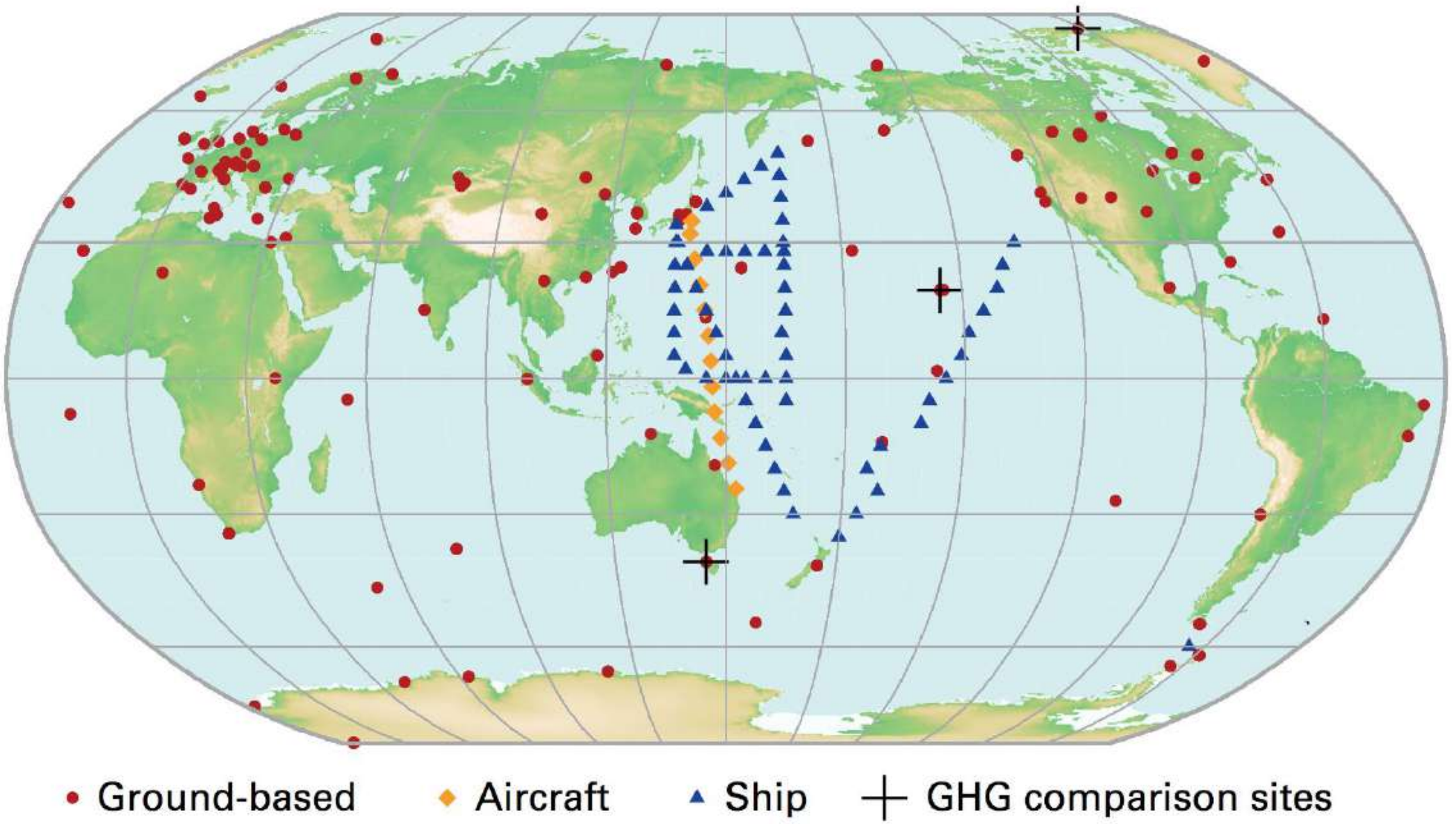
Cimate status: Carbon Dioxide in Atmosphere

WORLD METEOROLOGICAL ORGANIZATION

The Global Atmosphere Watch (GAW) global network for carbon dioxide in the last decade. The network for methane is similar.

CO2	129
CH4	126
N2O	96
CFC-11	23
CFC-12	25
CFC-113	21
CCl4	21
CH3CCl3	24
HCFC-141b	9
HCFC-142b	14
HCFC-22	13
HFC-134a	10
HFC-152a	9
SF6	85

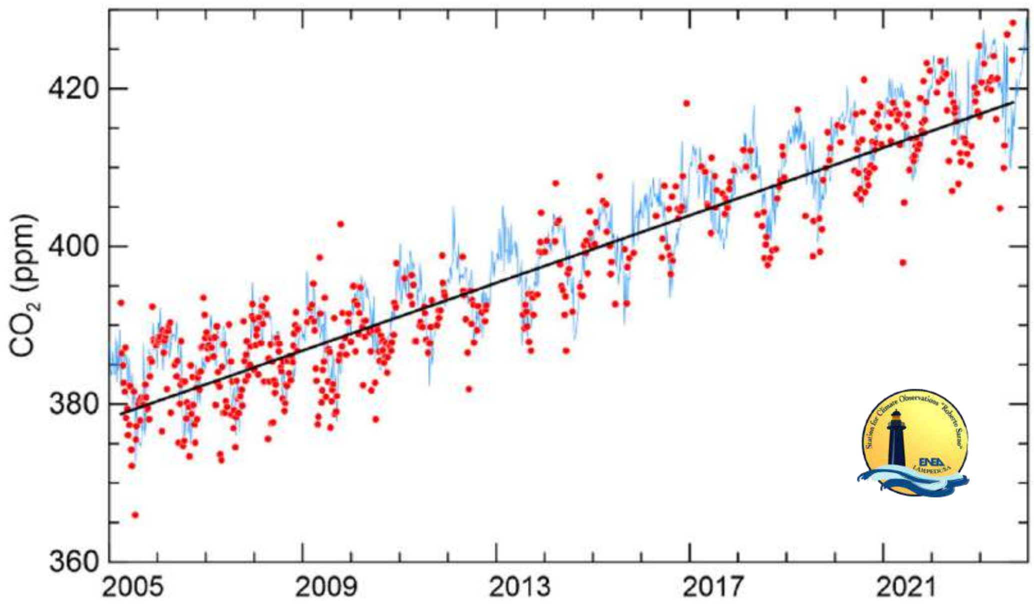
Number of stations used for the calculation of the global averages



ENEA

Cimate status: ENEA Contribution (GHG Measurement)

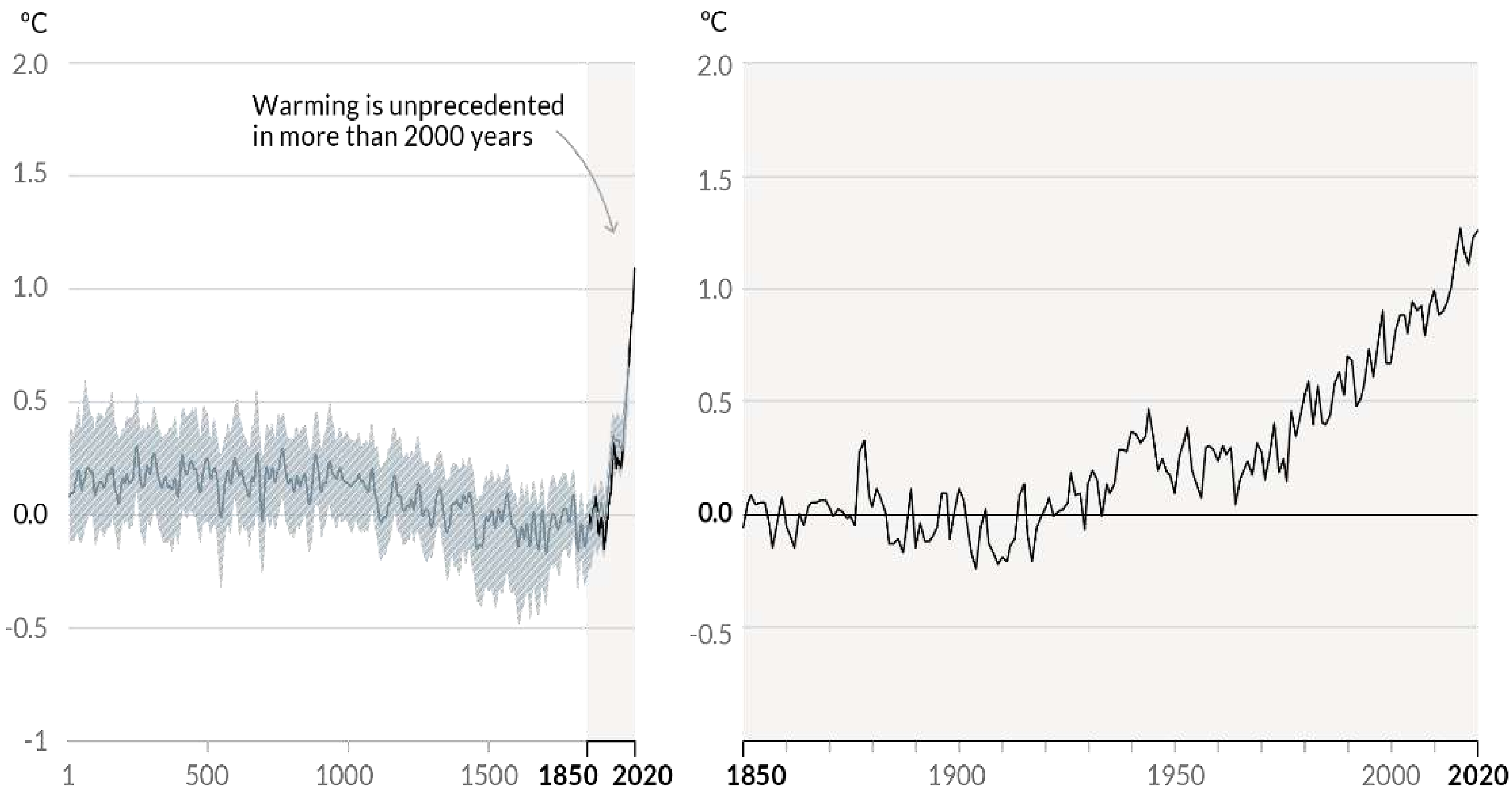
The **ENEA** Station for Climate Observations (Roberto Sarao) on the island of **Lampedusa** is a research facility in the Mediterranean dedicated to the measurement of climatic parameters.
Lampedusa is an excellent site for studies on the atmospheric composition and structure, on the transfer of solar and infrared radiation, and for oceanographic investigations.



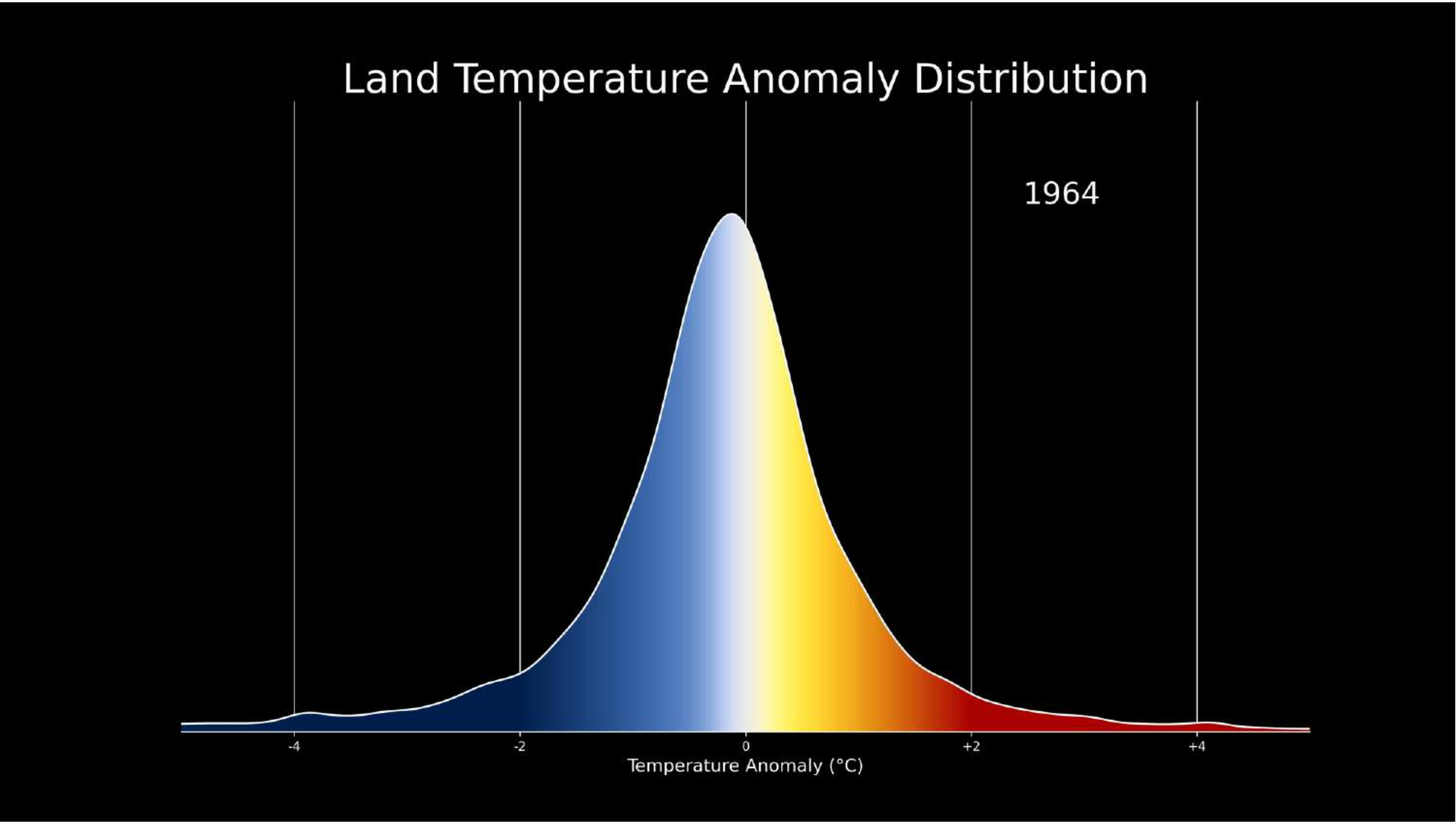
Comparison of the evolution of atmospheric CO2 concentration at **Madonie-Piano Battaglia** since 2005 (red dots) and at Lampedusa (blue curve)

Surface temperature relative to 1850-1900

Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years.

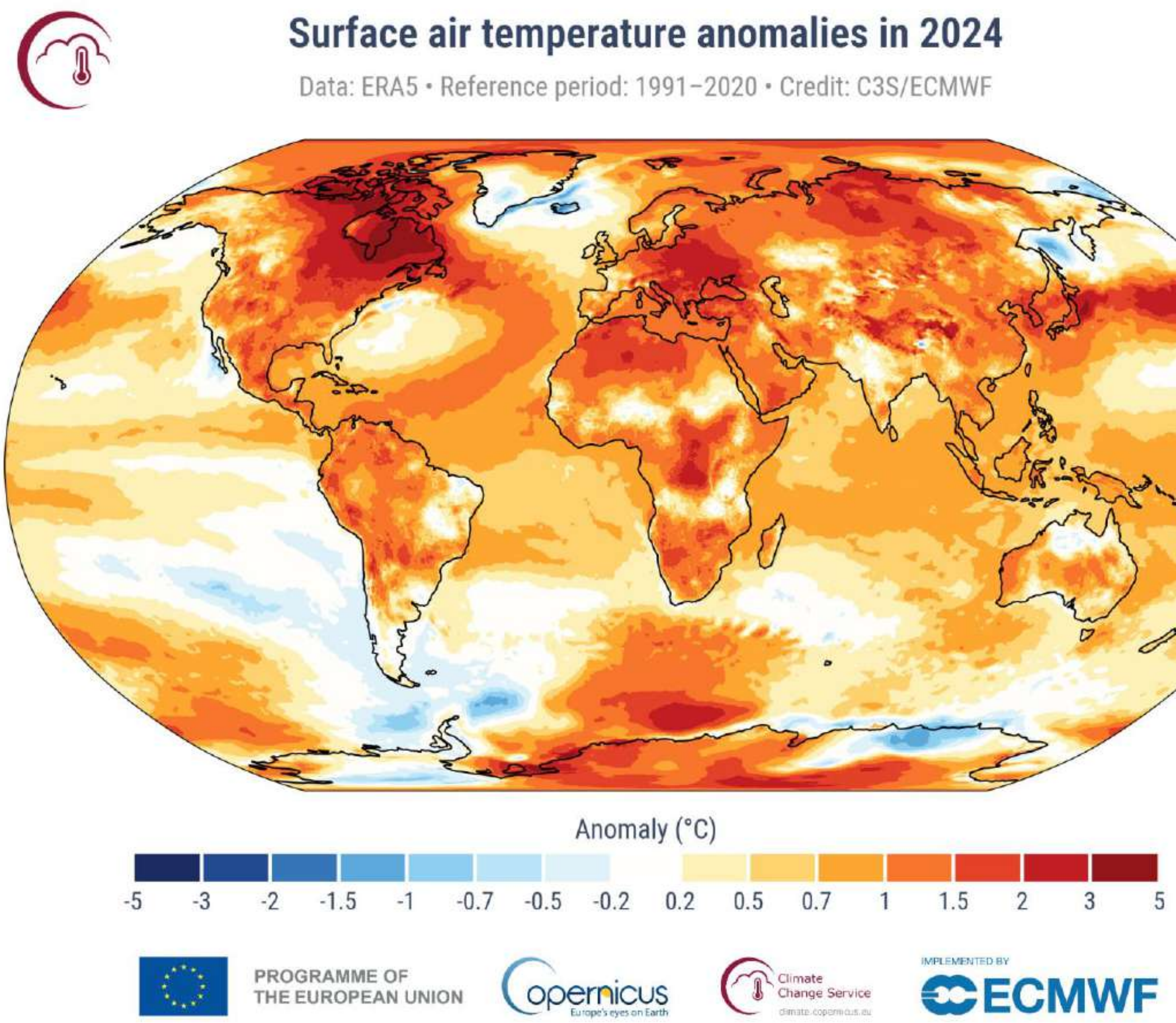


Shifting Distribution of Land Temperature Anomalies, 1964-2024



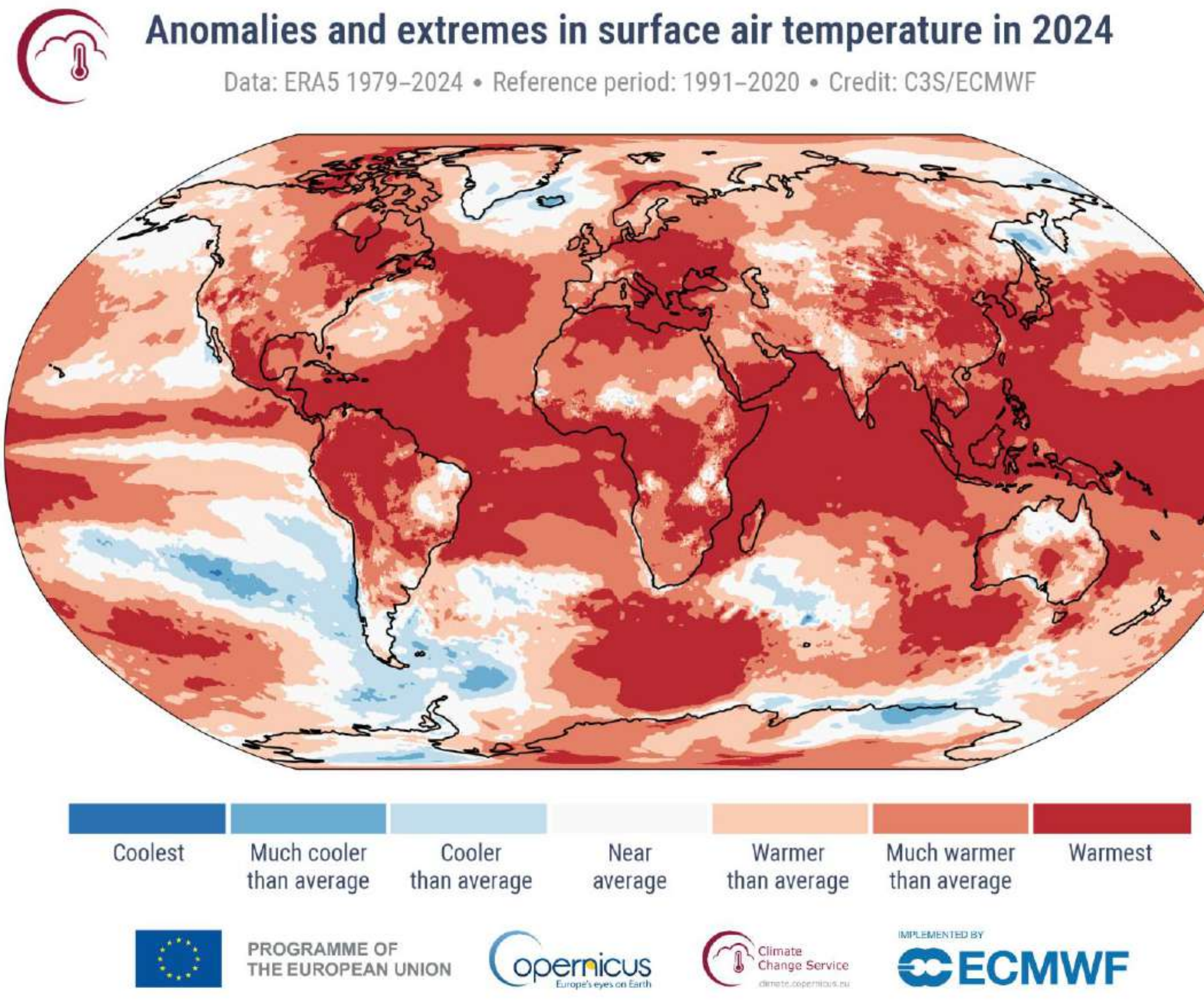
Climate Visuals by
(National Centre for Atmospheric Science, University of Reading)

State of Cimate: Global Surface Temperature



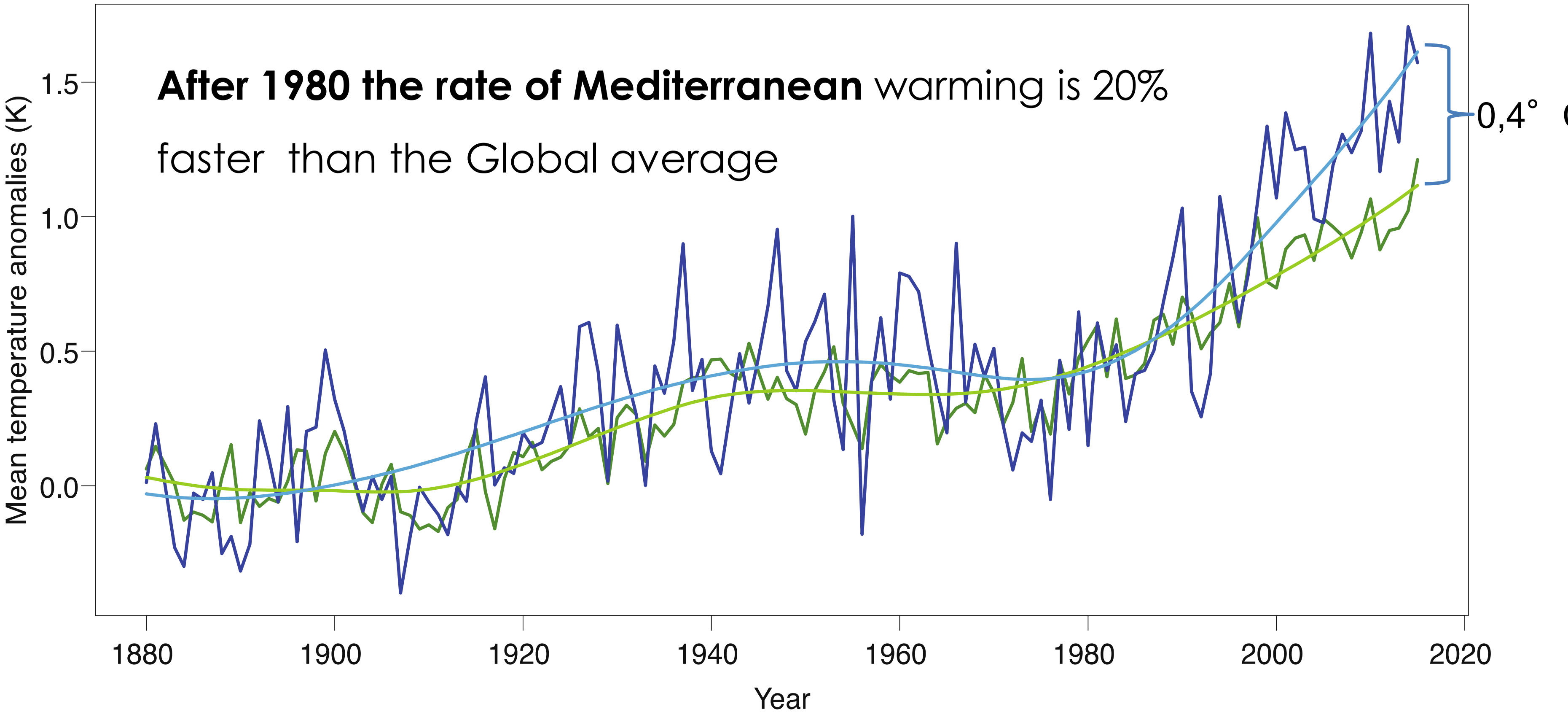
Surface air temperature anomalies in 2024, relative to the average for the 1991–2020 reference period. A non-linear colour scale is used to enhance the visibility of smaller anomalies and distinguish larger deviations. Data source: ERA5. Credit: C3S/ECMWF.

State of Cimate: Global Surface Temperature



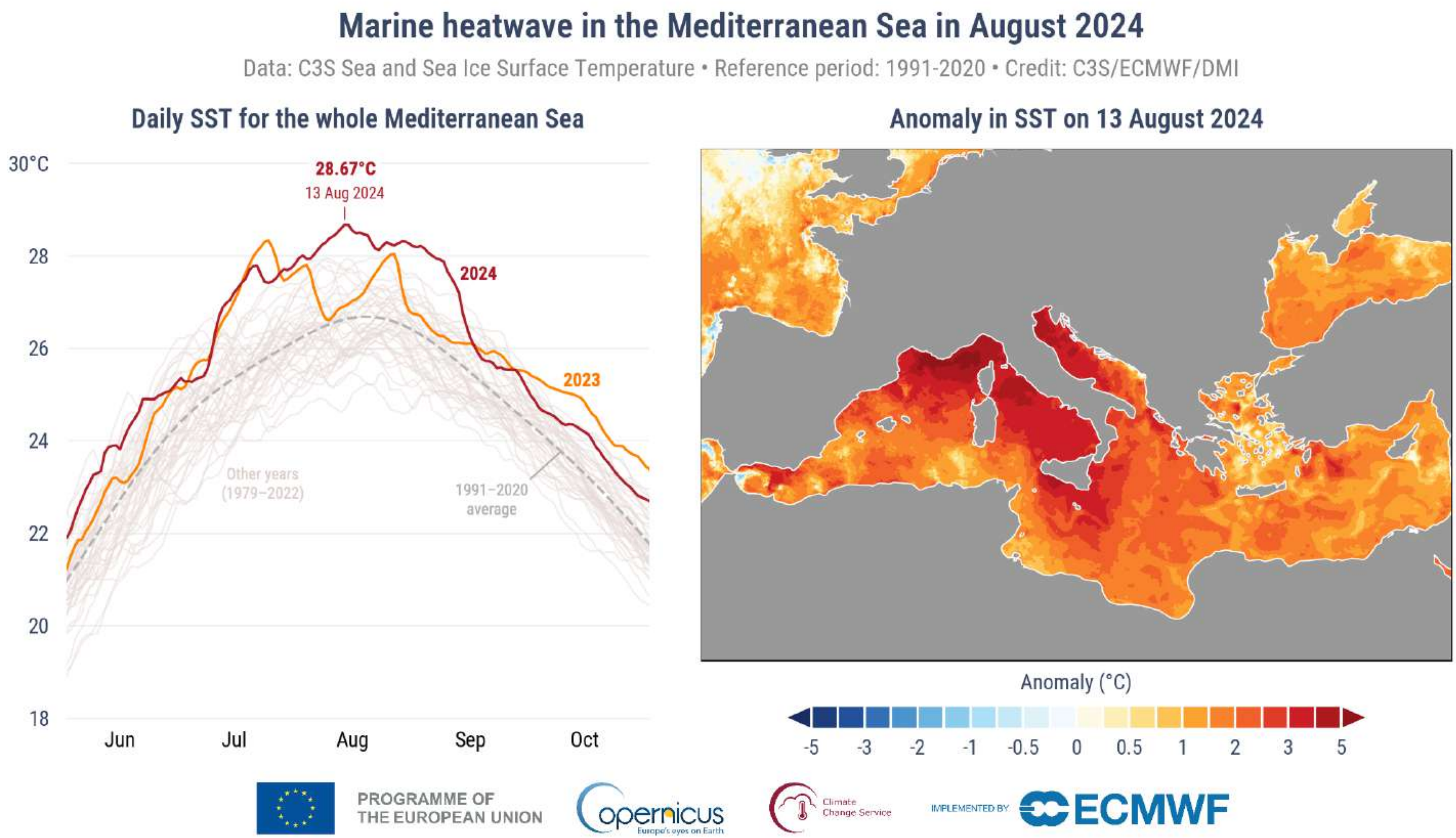
Surface air temperature anomalies in 2024, relative to the average for the 1991–2020 reference period. A non-linear colour scale is used to enhance the visibility of smaller anomalies and distinguish larger deviations. Data source: ERA5. Credit: C3S/ECMWF.

Changes in global vs Mediterranean surface temperature



Historic warming of the atmosphere at Global and Mediterranean scale. Annual mean air temperature anomalies are shown with respect to the preindustrial period **(1880–1899).** Adapted by Cramer et al. 2018 (NCC)

State of Cimate: Mediterranean Sea



Daily sea surface temperatures (° C) for the Mediterranean Sea as a whole during 2023 (orange) and 2024 (red), and previous years since 1982 (grey). (Right) Daily sea surface temperature anomalies (° C) on 13 August 2024, the day of the highest SST across the Mediterranean Basin, relative to the average for the 1991–2020 reference period. Data: C3S Sea and Sea Ice Surface Temperature v1.0. Credit: C3S/ECMWF/DMI.

2022-2023: Extreme sea surface temperature

IOP Publishing   *Environ. Res. Lett.* **18** (2023) 114041   https://doi.org/10.1088/1748-9326/ad02ae

ENVIRONMENTAL RESEARCH
LETTERS

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LETTER

Record-breaking persistence of the 2022/23 marine heatwave in the Mediterranean Sea

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Keywords: marine heatwave, Mediterranean Sea, sea surface temperatures

Supplementary material for this article is available online

Abstract

Since May 2022, the Mediterranean Sea has been experiencing an exceptionally long marine heatwave event. Warm anomalies, mainly occurring in the Western basin, have persisted until boreal spring 2023, making this event the longest Mediterranean marine heat wave of the last four decades. In this work, the 2022/2023 anomaly is characterized, using *in-situ* and satellite measurements, together with state of the art reanalysis products. The role of atmospheric forcing is also investigated; the onset and growth of sea surface temperature anomalies is found to be related to the prevalence of anticyclonic conditions in the atmosphere, which have also caused severe droughts in the Mediterranean region over the same period. Analysis of *in-situ* observations from the Lampedusa station and of ocean reanalyzes reveals that wind-driven vertical mixing led to the penetration of the warm anomalies below the sea surface, where they have persisted for several months, particularly in the central part of the basin. The evolution of the 2022/23 event is compared with the severe 2003 event, to put recent conditions in the context of climate change.

ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES, ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT

CNR ISMAR
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2022-2023: Extreme sea surface temperature

Environ. Res. Lett. **18** (2023) 114041

ITALIAN NATIONAL AGENCY FOR NEW TECHNOLOGIES, ENERGY AND SUSTAINABLE ECONOMIC DEVELOPMENT

CNR ISMAR ISTITUTO DI SCIENZE MARINE

S Marullo *et al*

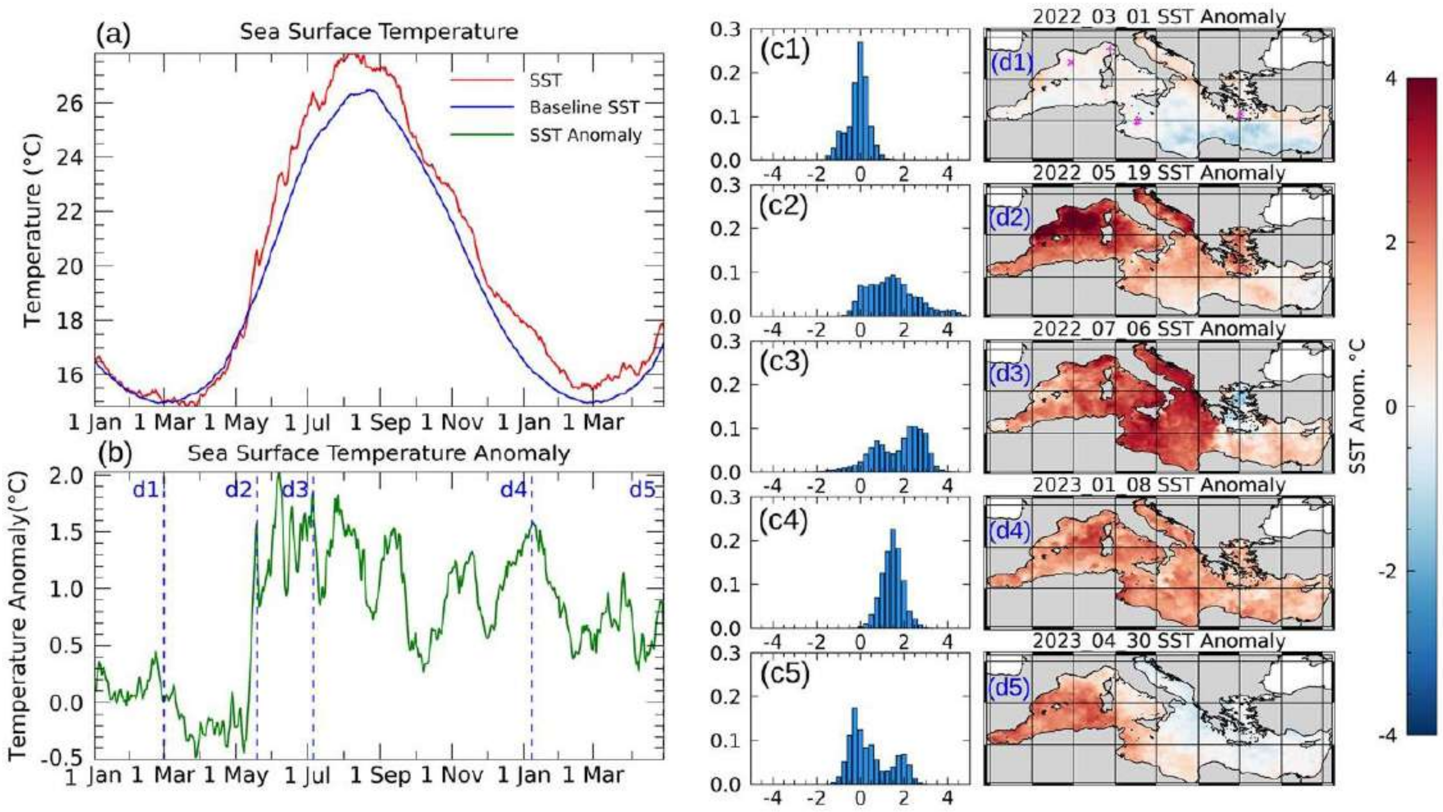
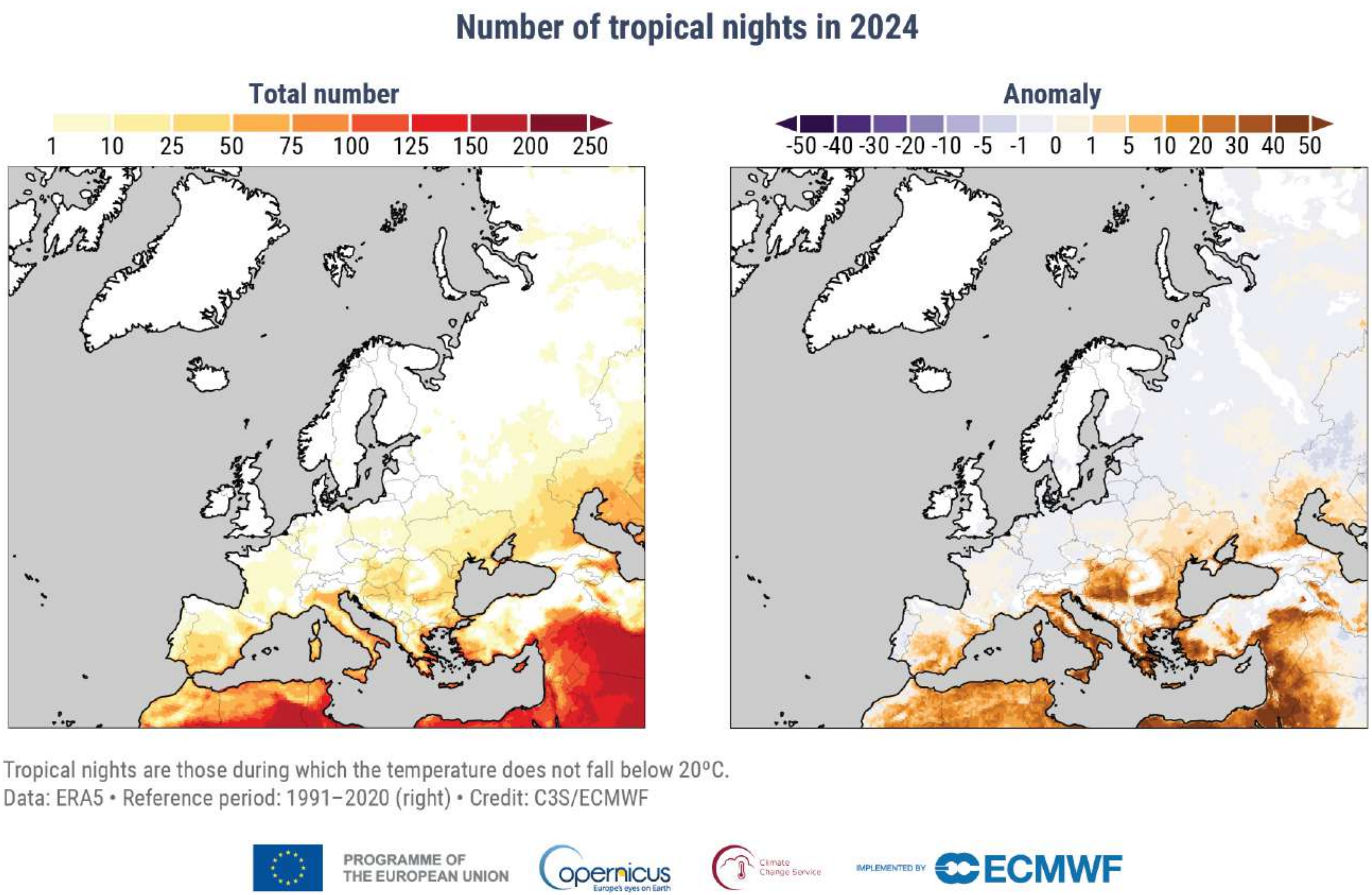


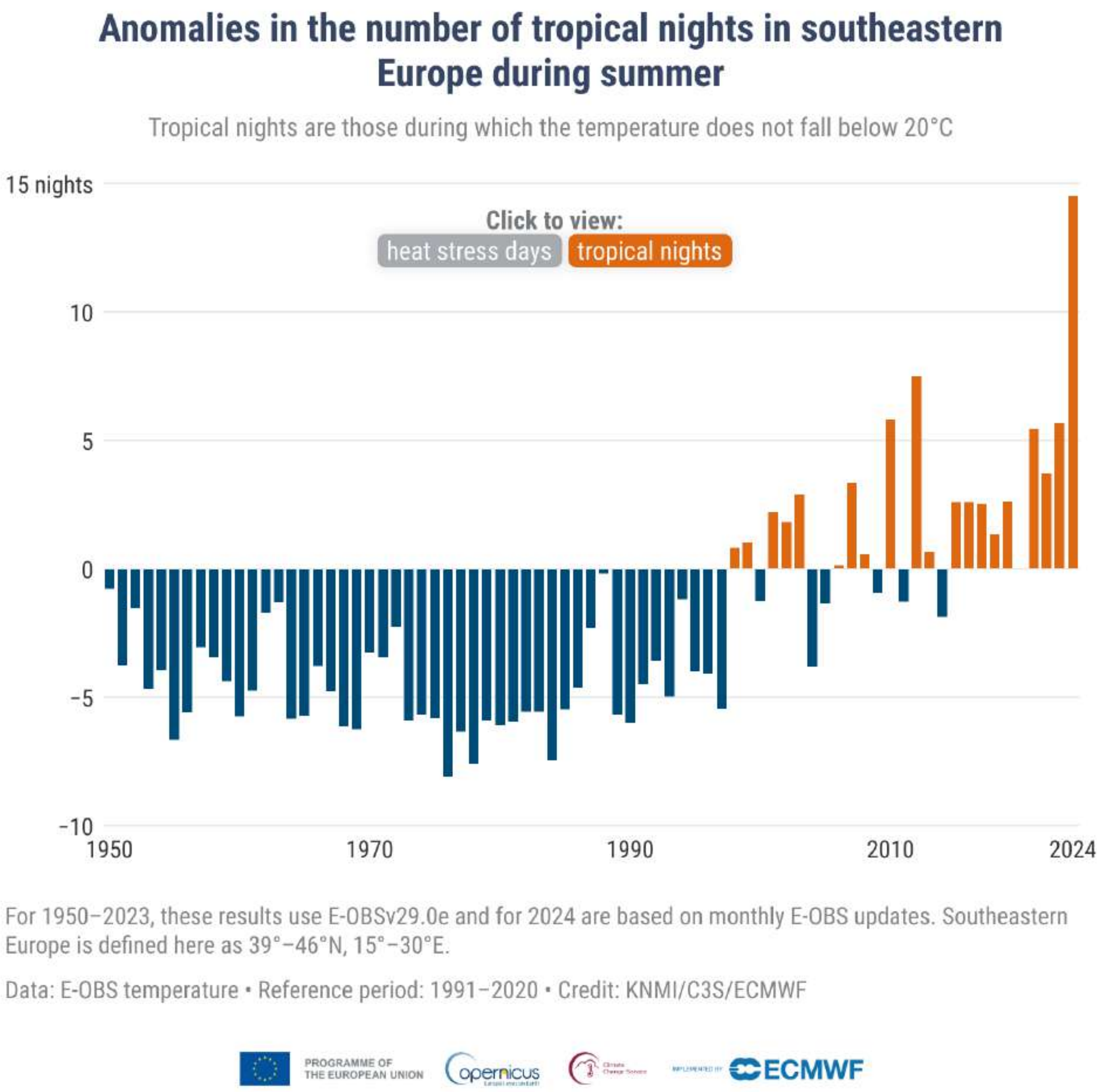
Figure 1. Overview of Mediterranean SST conditions in 2022/23 based on satellite data. (a) Daily mean Mediterranean basin SST time series (red line) and corresponding baseline 1991–2020 (blue line); (b) basin scale SST anomalies over the same period. Five dates (indicated as d1–5) are selected to represent pre-MHW conditions, the MHW onset, one of its summer peaks, the January peak and spring 2023. For each date, anomaly maps (panels (d1)–(d5)) and corresponding frequency histograms (panels (c1)–(c5)) are shown. The locations of mooring stations are indicated with pink markers ($\times$ for LION, $+$ for ODAS, # for LMP, and $*$ for E1M3A) in (d1).

State of Cimate: Mediterranean Sea



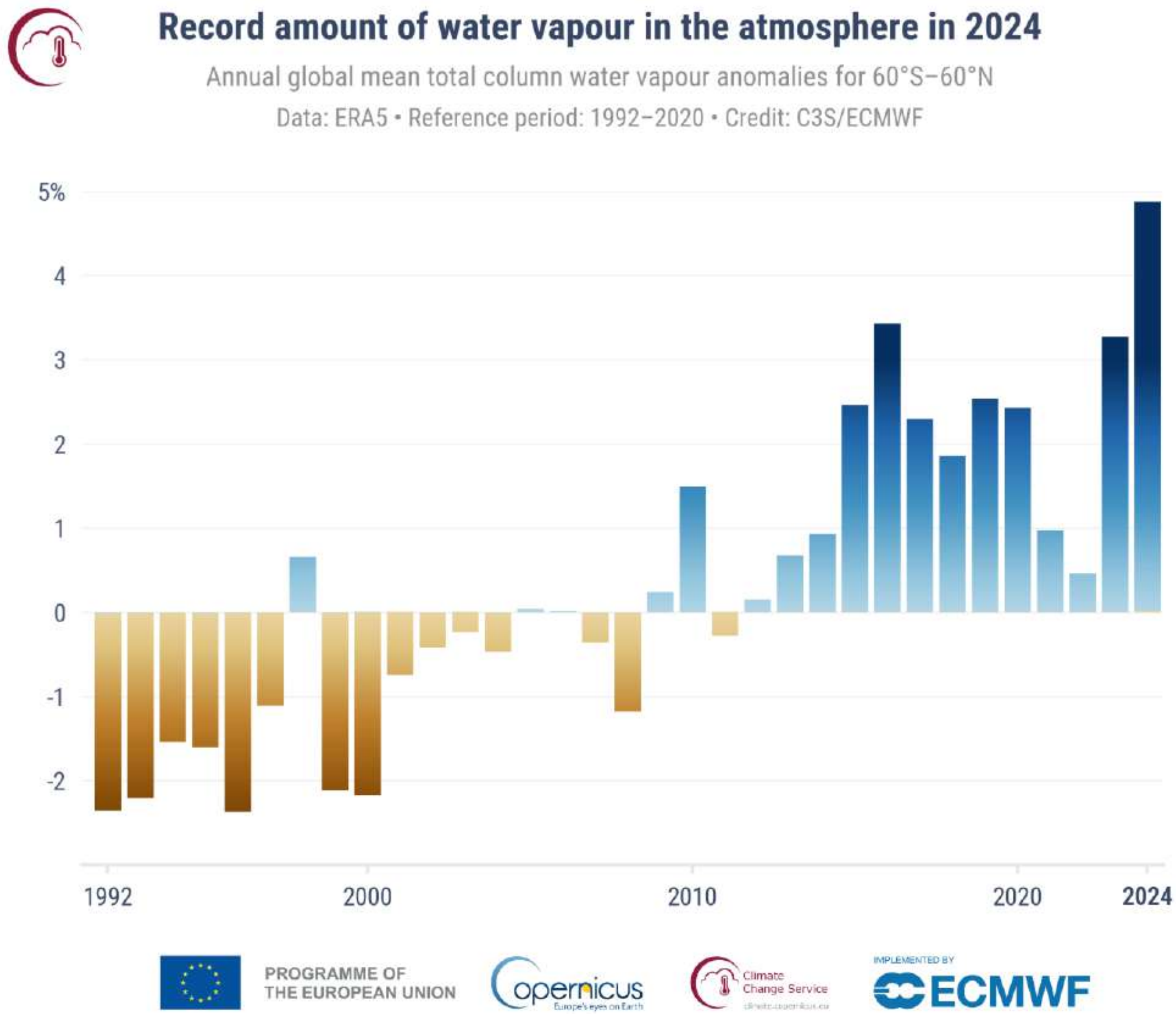
Number of tropical nights in 2024 and associated anomalies relative to the average for the 1991–2020 reference period. Tropical nights are those during which the temperature does not fall below 20° C. Data: ERA5. Credit: C3S/ECMWF.

State of Cimate: Mediterranean Sea



Anomalies in the number of tropical nights in southeastern Europe, for each summer for the period 1950–2024. Southeastern Europe is defined here as 39° –46° N, 15° –30° E. For 1950–2023, the indices based on E-OBSv29.0e are used and for 2024 the indices based on the monthly E-OBS updates. Data: ERA5-HEAT, E-OBS. Credit: C3S/ECMWF/KNMI.

State of Cimate: water vapour in the atmosphere

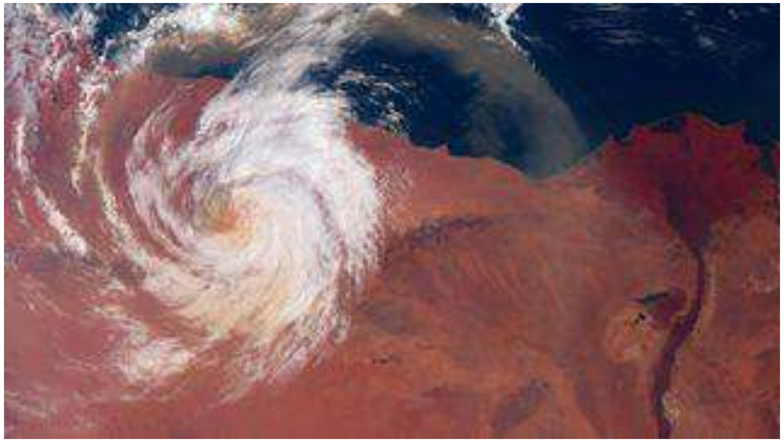


Annual anomalies in the average amount of total column water vapour over the 60° S–60° N domain relative to the average for the 1992–2020 reference period. The anomalies are expressed as a percentage of the 1992–2020 average. Data: ERA5. Credit: C3S/ECMWF.

2023: Medicane (Mediterranean Hurricane) Daniel

Storm Daniel, also known as **Cyclone Daniel**, was the deadliest in recorded history, as well as one of the costliest tropical cyclones on record outside of the north .

Storm Daniel formed over the Mediterranean Sea in **early September 2023** and caused significant flooding and damage in multiple countries, including **Greece**, **Turkey**, **Bulgaria**, and **Libya**. As it moved across the Mediterranean, it gained strength from the **unusually warm sea surface** temperatures, which is typical for medicanes.



These storms, while infrequent, are becoming more intense due to climate change, which increases the amount of moisture they can carry and the energy they derive from warmer waters.

Medicane Daniel was particularly devastating in Libya, where it led to catastrophic flooding and significant loss of life, especially in the city of Derna, due to the collapse of dams under the heavy rainfall brought by the storm

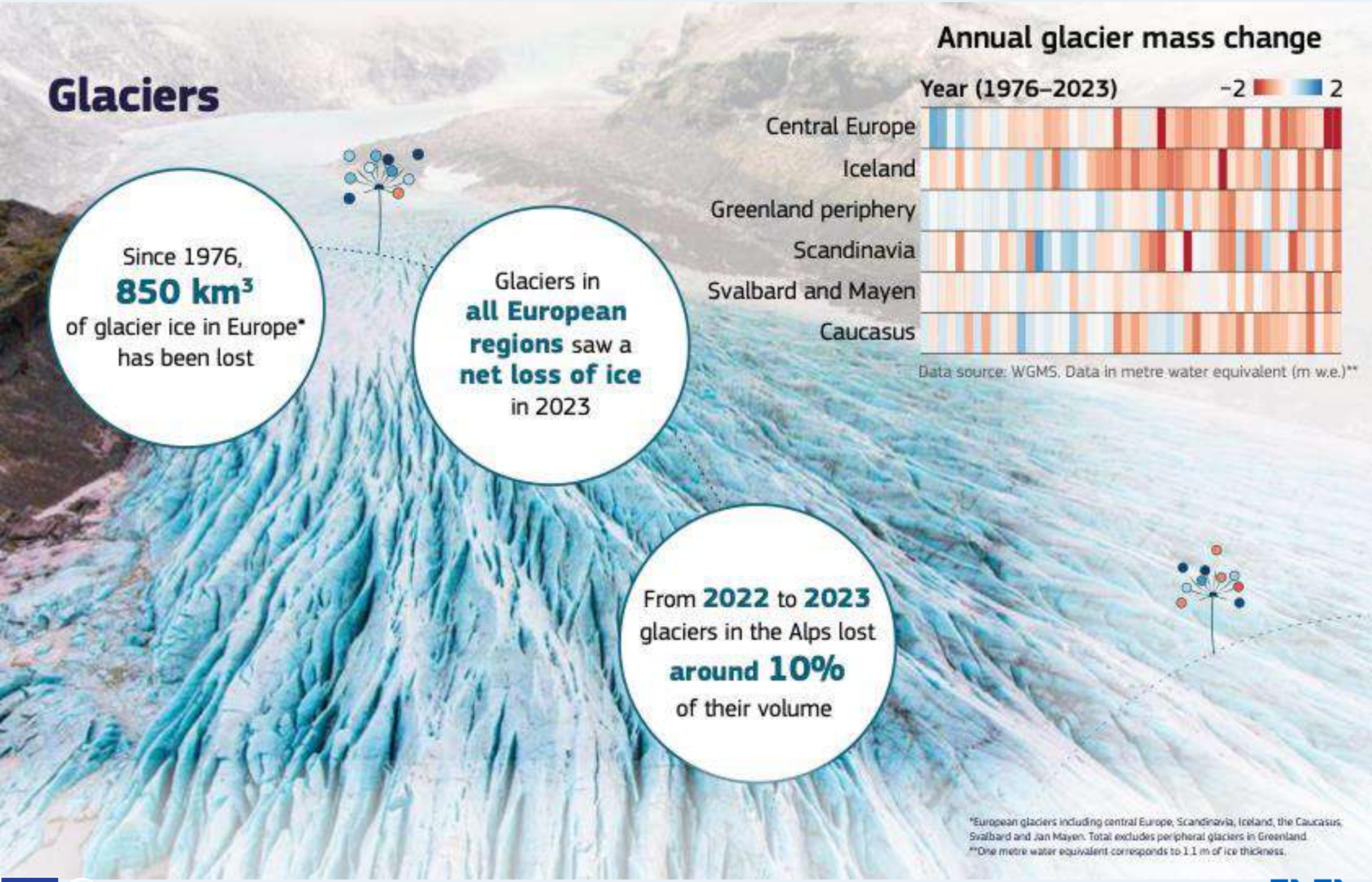
2023: Medicane (Mediterranean Hurricane) Daniel

Map animation tracking Storm Daniel as it unleashed record rainfall across the Eastern Mediterranean

2023: Medicane (Mediterranean Hurricane) Daniel

At least 4700 confirmed deaths in Libya have been attributed to the flooding following Storm Daniel, with 8000 still missing.

State of Cimate: Glaciers in Europe



Changes at global scale

ipcc INTERGOVERNMENTAL PANEL ON climate change WMO UNEP

CO_2
concentration

Highest
in at least
2 million years

Sea level
rise

Fastest rates
in at least
3000 years

Arctic sea ice
area

Lowest level
in at least
1000 years

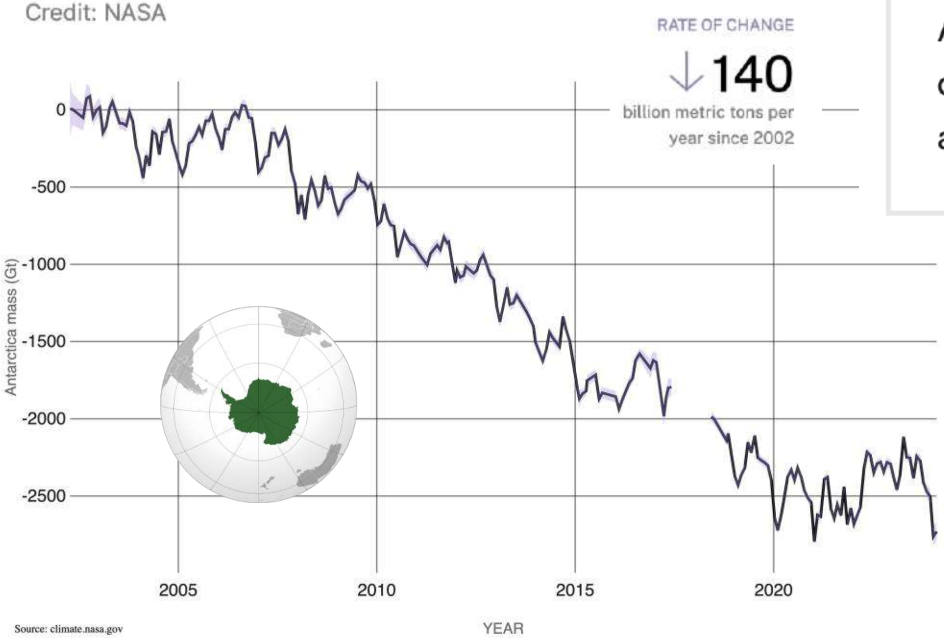
Glaciers
retreat

Unprecedented
in at least
2000 years

Climate Status: Ice Sheets

ANTARCTICA MASS VARIATION SINCE 2002

Data source: Ice mass measurement by NASA's GRACE satellites. **Gap represents time between missions.**
Credit: NASA

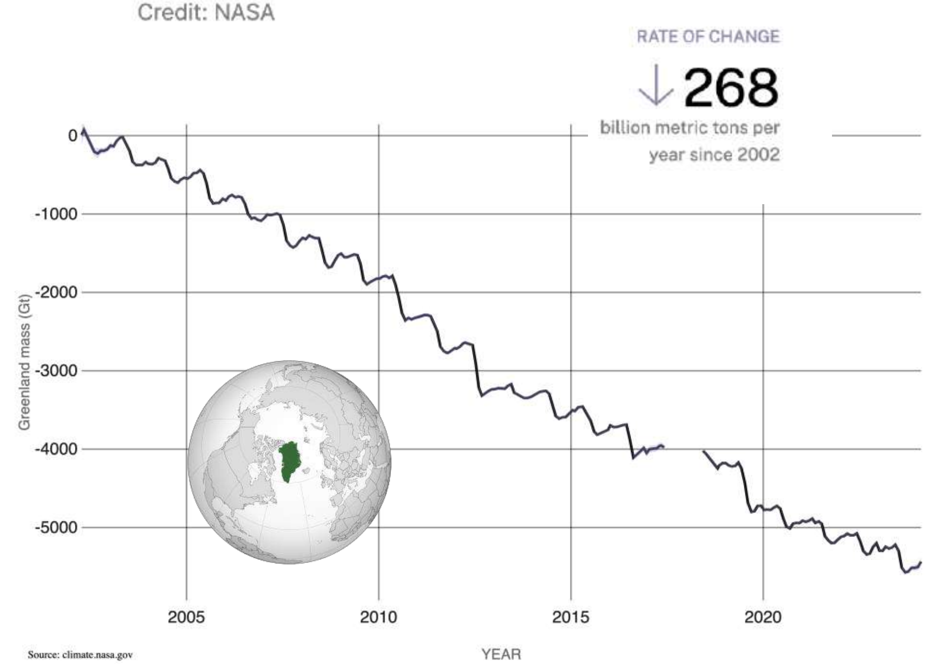


Key Takeaway:

Antarctica is losing ice mass (melting) at an average rate of about 150 billion tons per year, and Greenland is losing about 270 billion tons per year, adding to sea level rise.

GREENLAND MASS VARIATION SINCE 2002

Data source: Ice mass measurement by NASA's GRACE satellites. **Gap represents time between missions.**
Credit: NASA



GLOBAL CLIMATE CHANGE
Vital Signs of the Planet

Changes at global scale

CO_2
concentration

Highest

in at least

2 million years

Sea level
rise

Fastest rates

in at least

3000 years

Arctic sea ice
area

Lowest level

in at least

1000 years

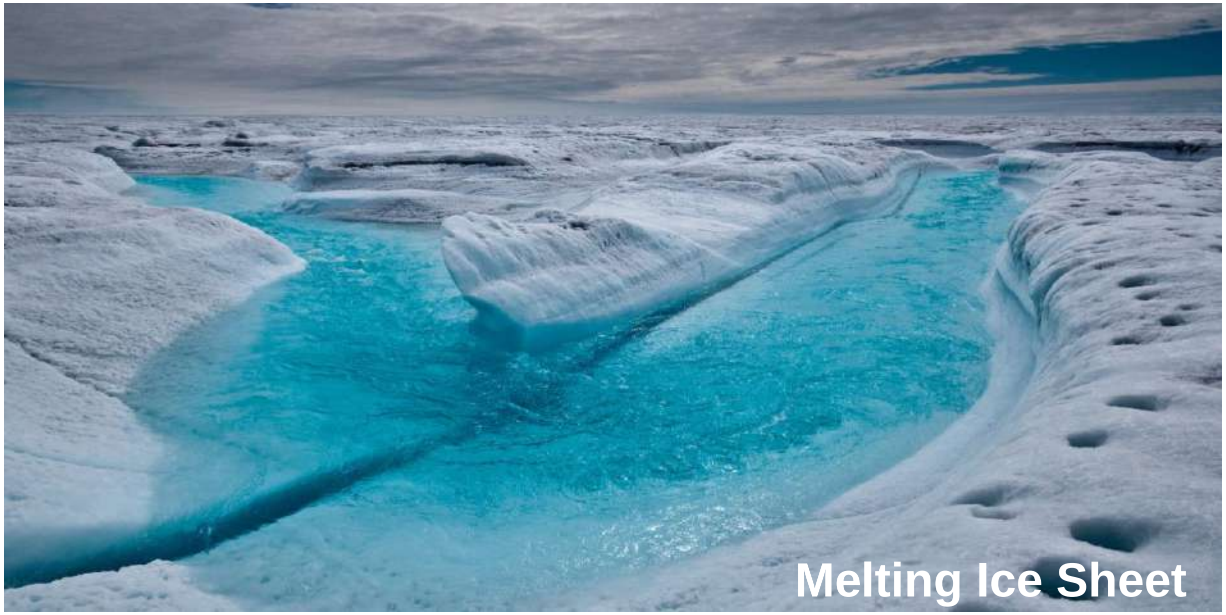
Glaciers
retreat

Unprecedented

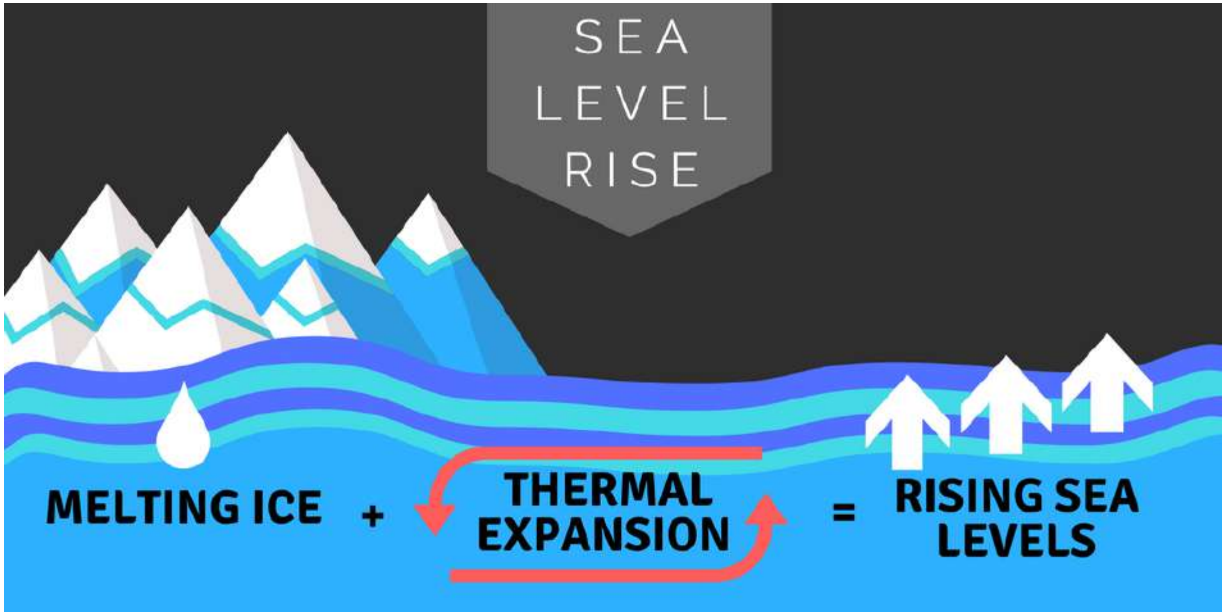
in at least

2000 years

Two main causes for sea-level rise



60%



40%

Climate status: Ocean Warming

LATEST MEASUREMENT: December 2023

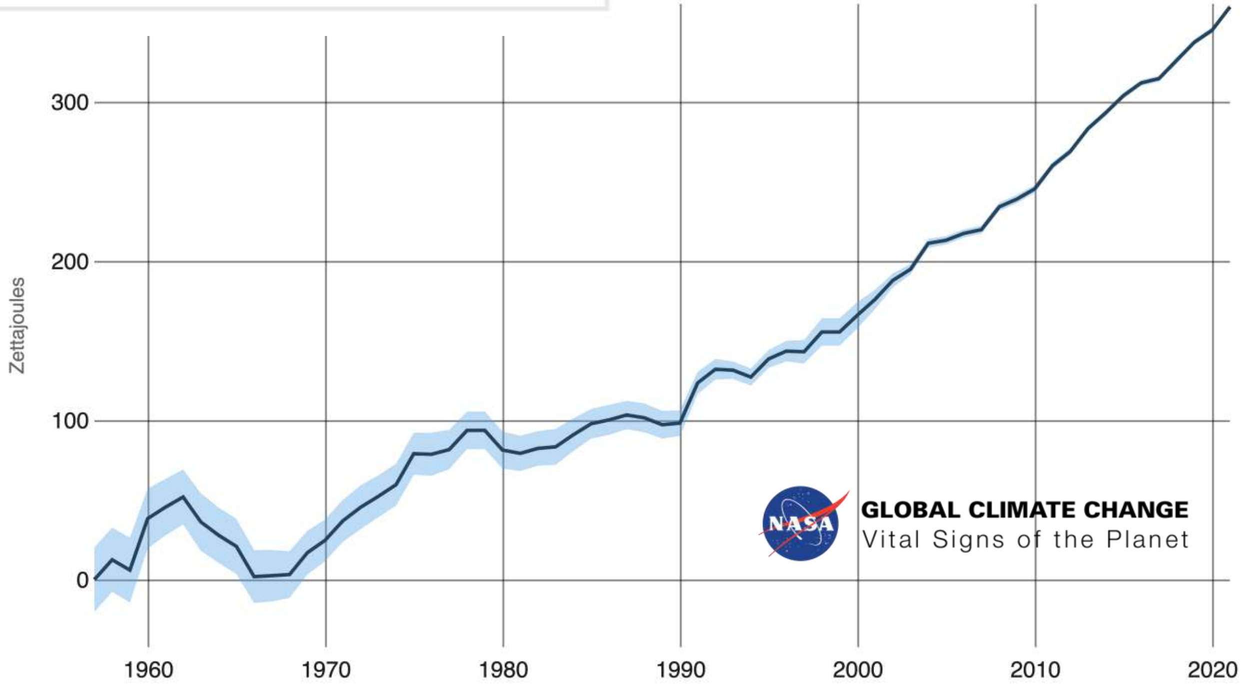
360 (± 2) zettajoules

Key Takeaway:

About ninety percent of global warming is occurring in the ocean.

OCEAN HEAT CONTENT CHANGES SINCE 1955 (NOAA)

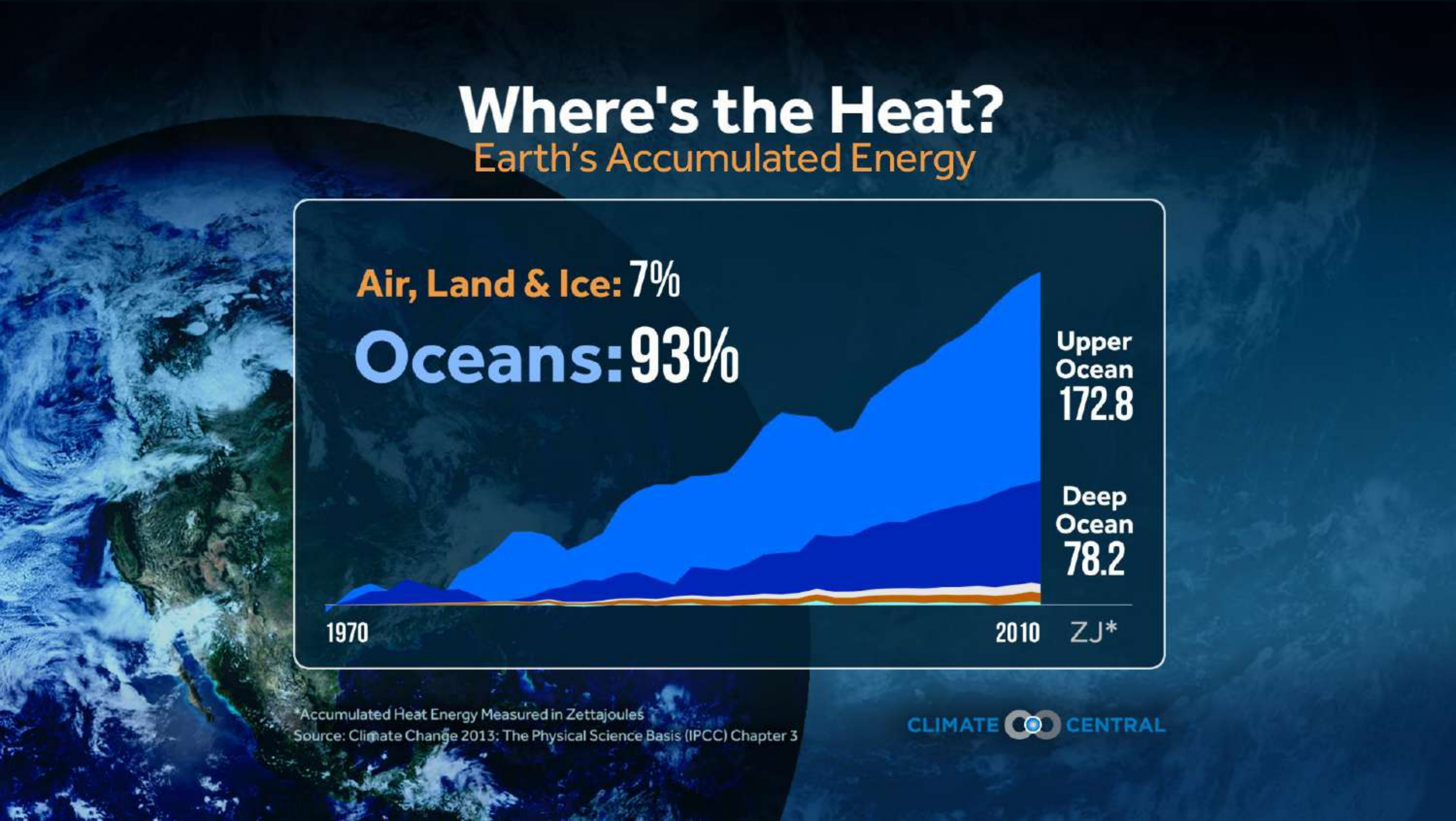
Data source: Observations from various ocean measurement devices, including conductivity-temperature-depth instruments (CTDs), Argo profiling floats, and eXpendable BathyThermographs (XBTs). Credit: NOAA/NCEI World Ocean Database



Source: climate.nasa.gov

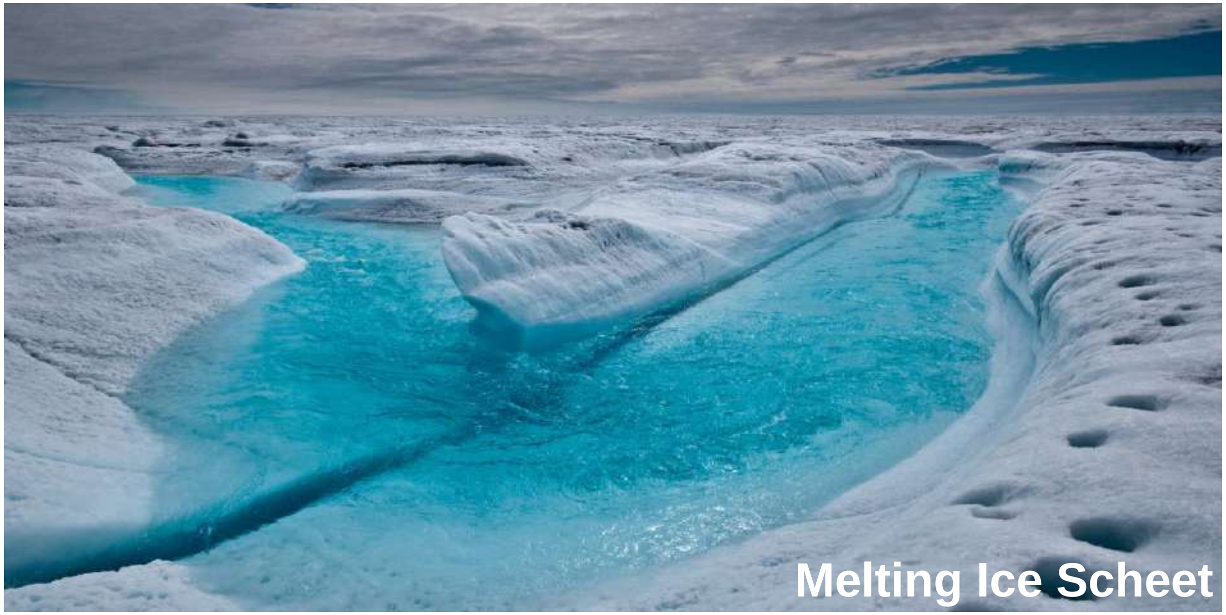
1 **zettajoule** = 10^{21} **joule**

360 zettajoule are equivalent to 5.736.138 atomic bomb, 15 megatons each (Hiroshima)

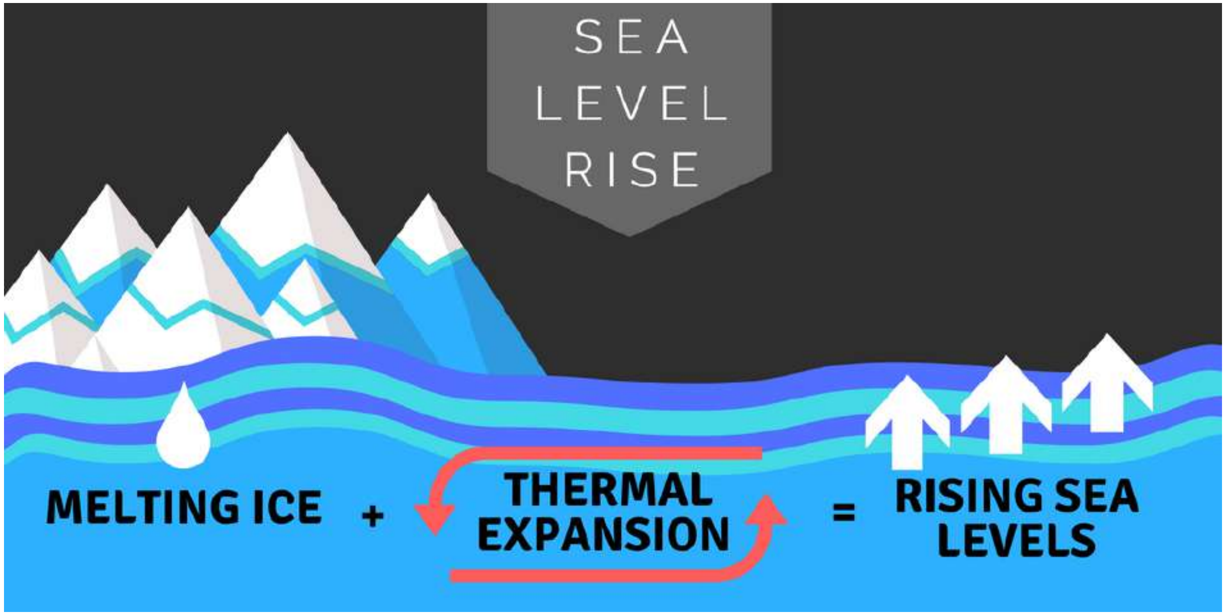


Where's the Heat?
Earth's Accumulated Energy
Air, Land & Ice: 7%
Oceans: 93%
Upper Ocean 172.8
Deep Ocean 78.2
1970
2010
ZJ*
*Accumulated Heat Energy Measured in Zettajoules
Source: Climate Change 2013: The Physical Science Basis (IPCC) Chapter 3
CLIMATE CENTRAL

Two main causes for sea-level rise



60%

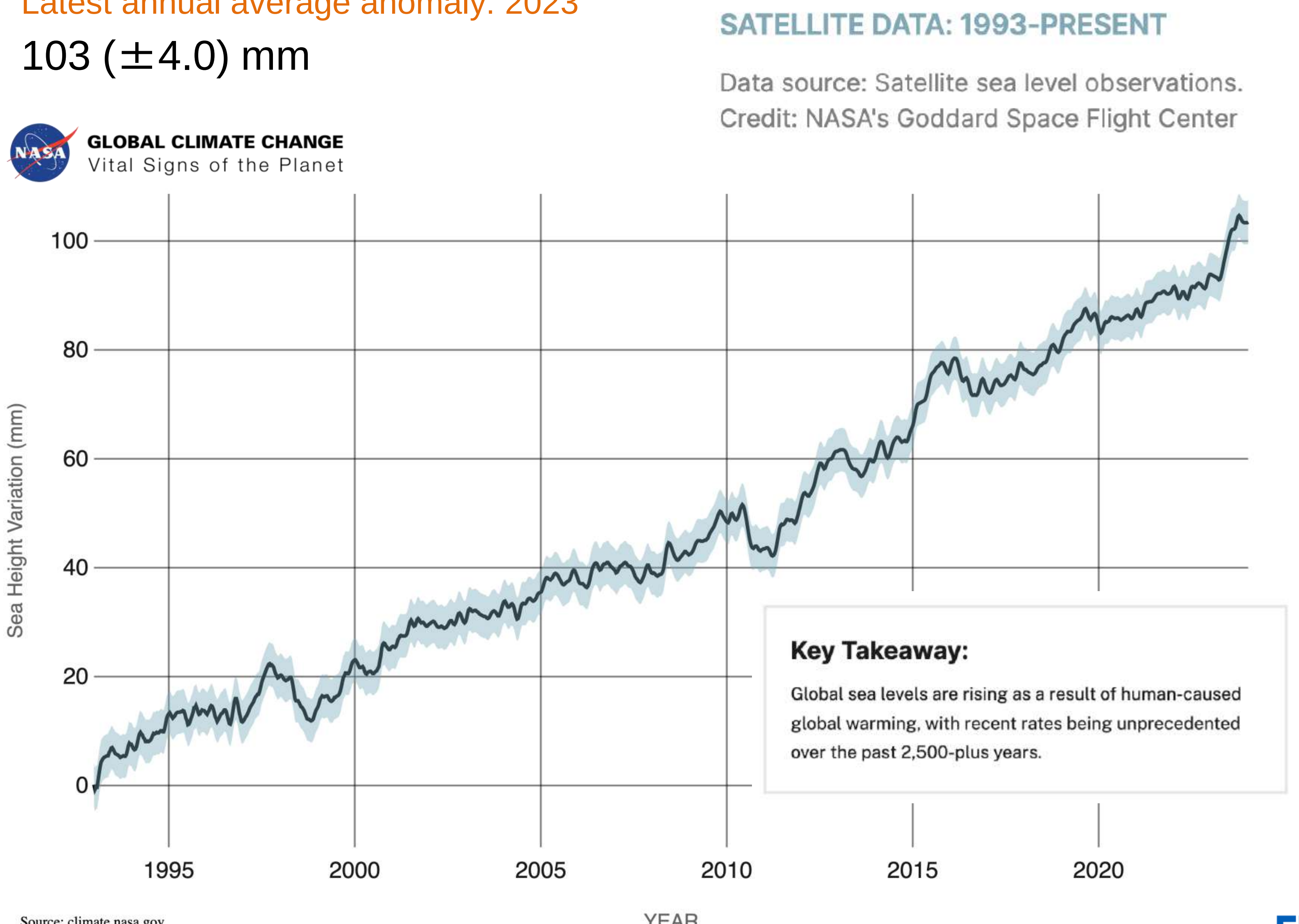


40%

Climate status: Sea Level since 1993

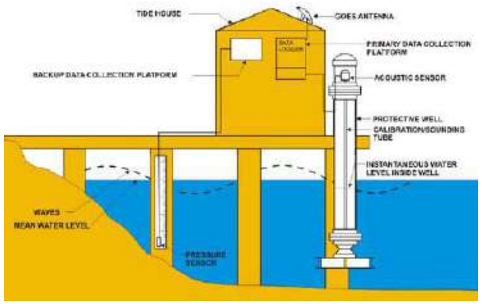
Latest annual average anomaly: 2023

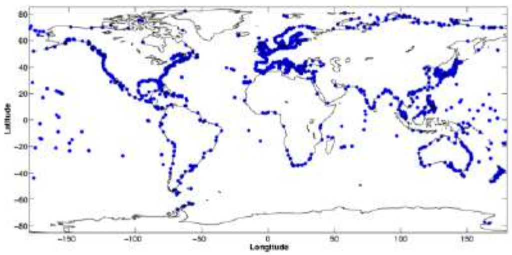
103 (±4.0) mm



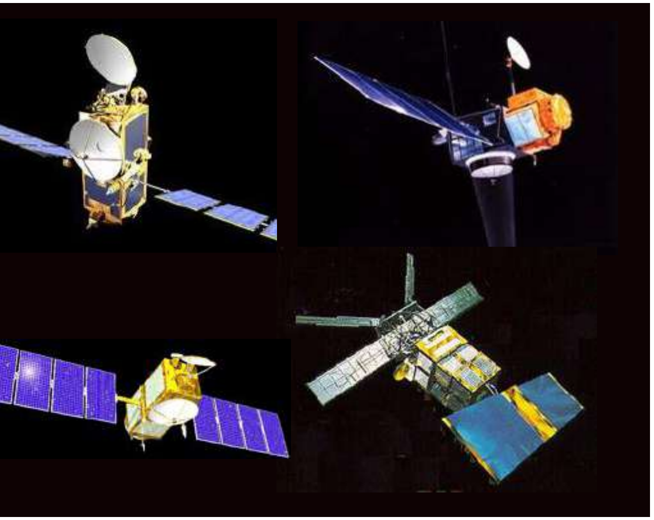
Source: climate.nasa.gov

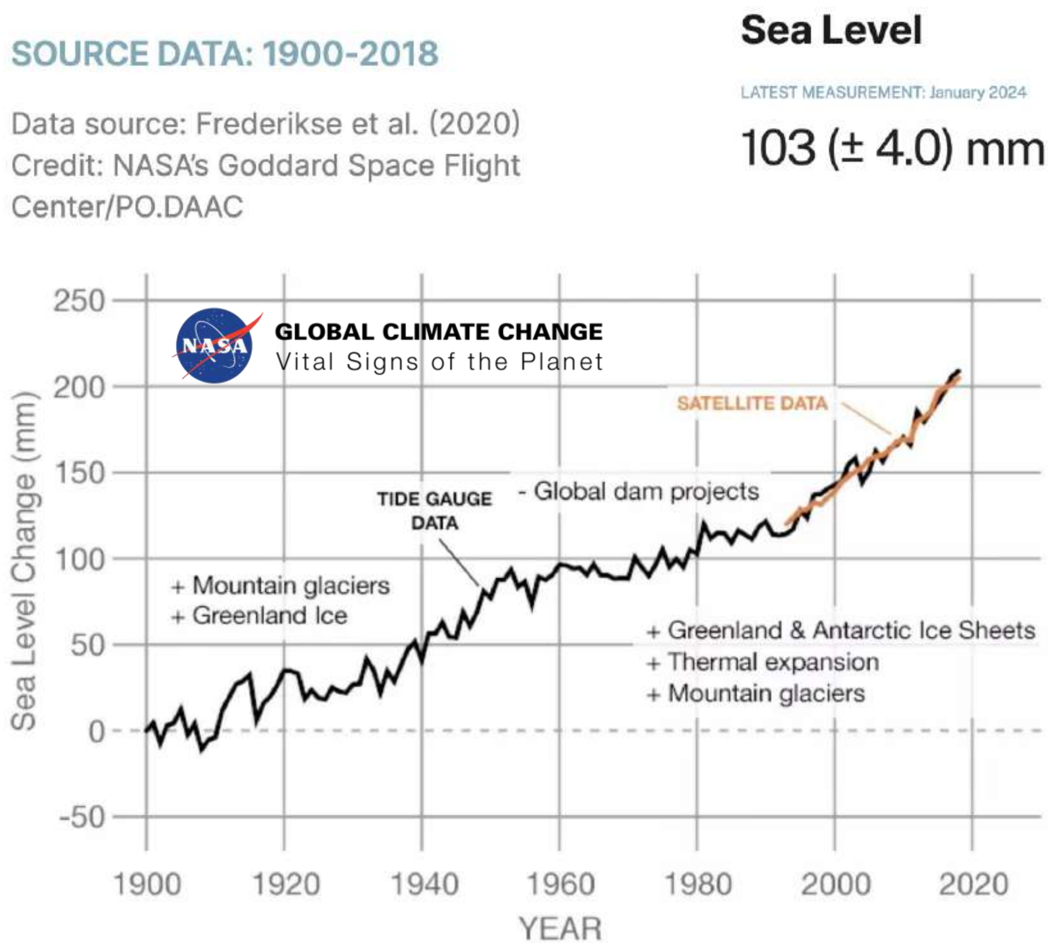
Change in sea level since 1900





Spatial distribution of the **1420** tide gauges

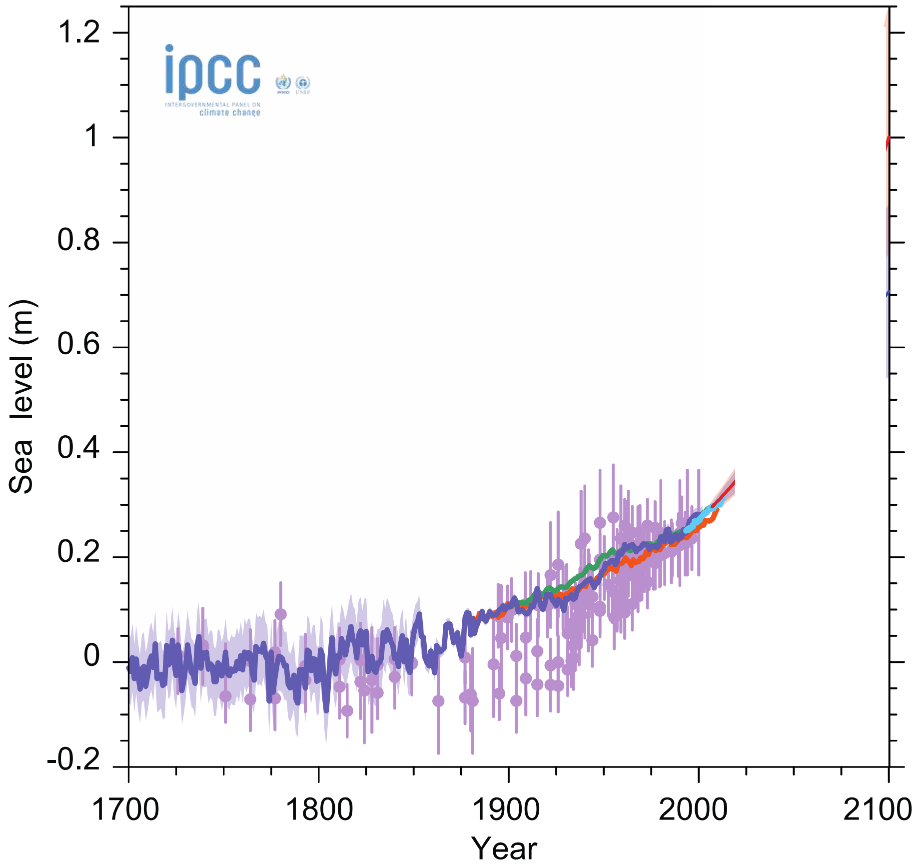




About **+21 cm from 1900**

Change in sea level since 1900 as observed by coastal tide gauge and satellite

Climate status: Sea Level since 1700



Rate during 1901-1990 was 1.50 ± 0.2 mm yr^{-1}

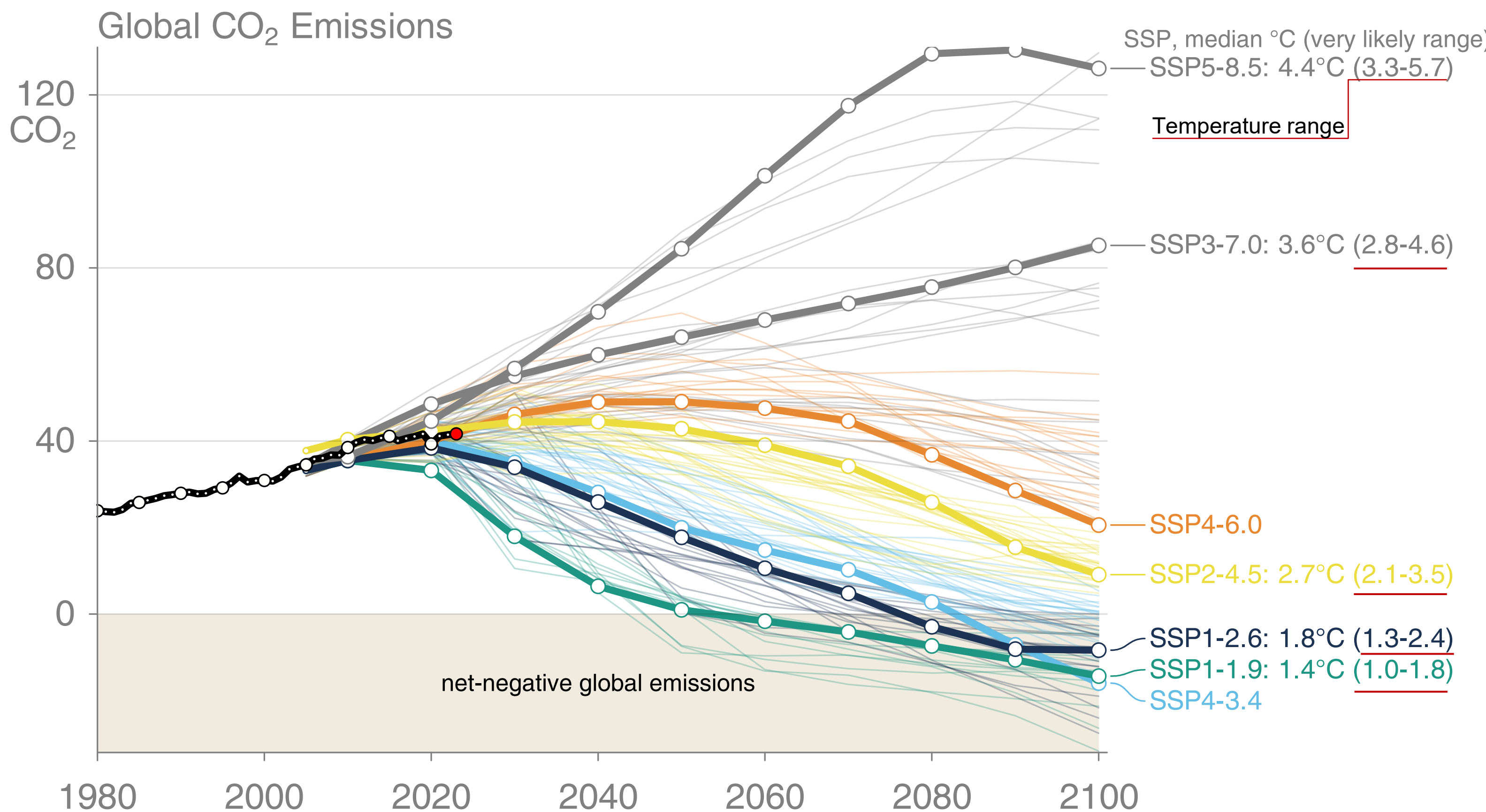
Rate during 1993-2010 was 3.07± 0.37 mm yr^{-1}

Rate during 2005-2017 was **3.50± 0.2 mm yr^{-1}**

Compilation of paleo sea level data, tide gauge data, altimeter data.

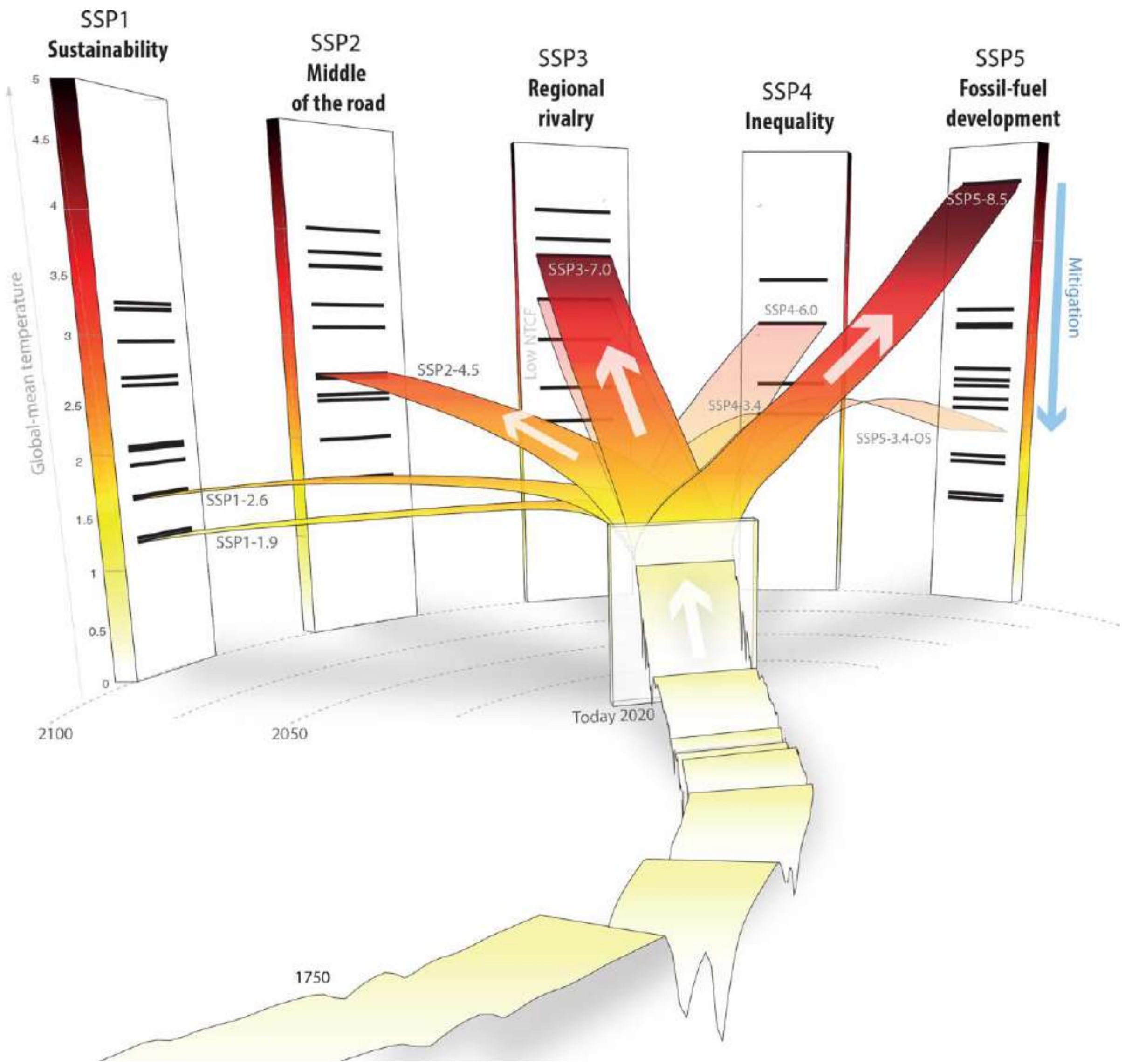
State of Cimate: Carbon Dioxide emissions

The SSPs were designed to span the range of potential outcomes. Total CO_2 emissions are currently tracking in the middle of the range. The temperature outcomes are based on assessed scenarios in IPCC AR6 Working Group I.



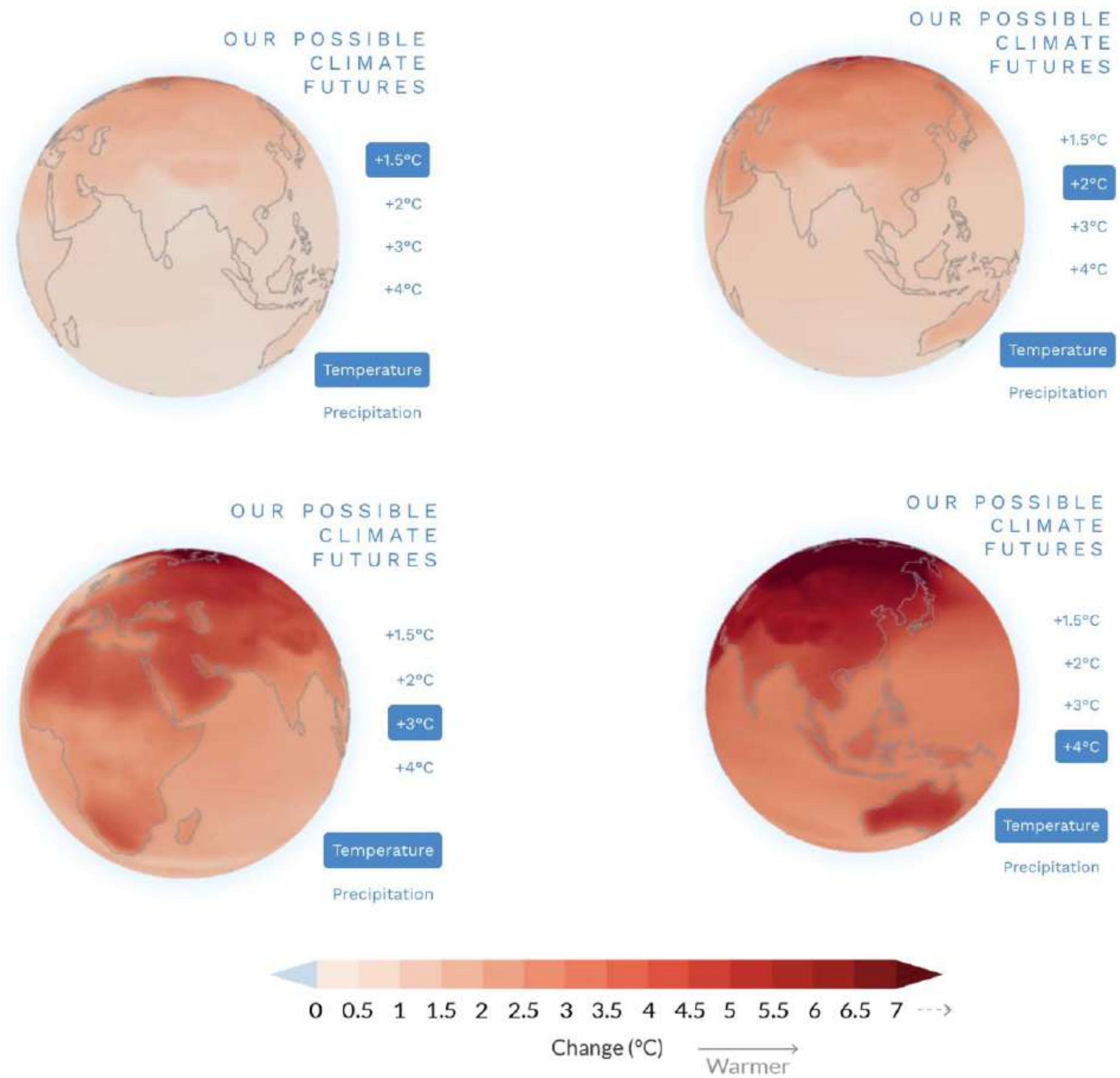
 • Data: Riahi et al (2017), Rogelj et al (2018), SSP Database (version 2)

Shared Socioeconomic Pathways & Temperature

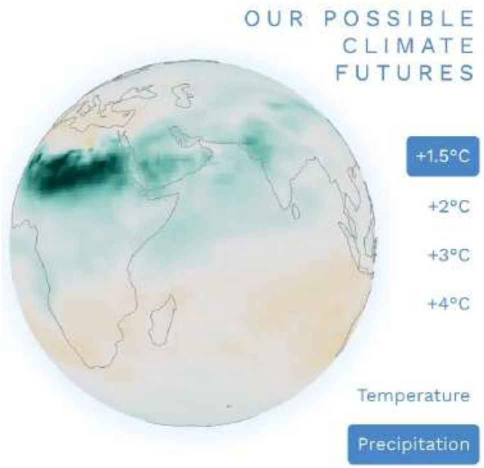


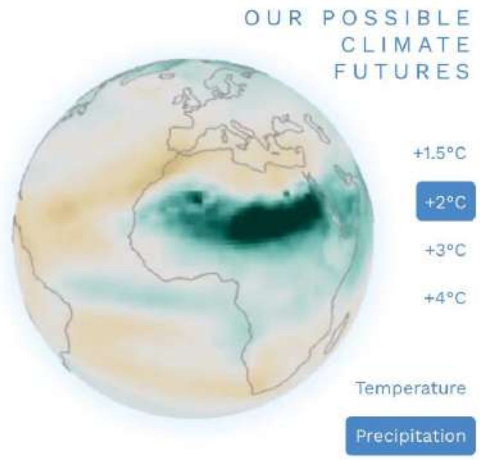
Meinshausen et al, GMD 2020

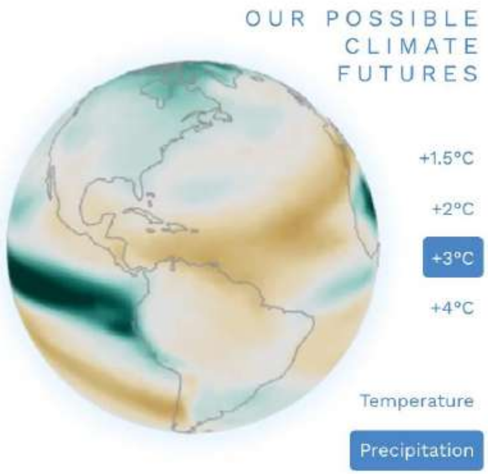
Future climate scenario

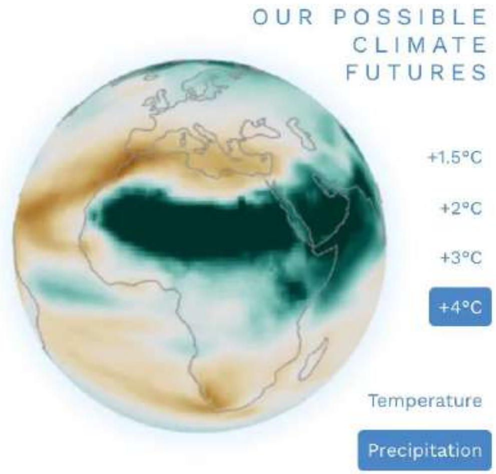


Future climate scenario

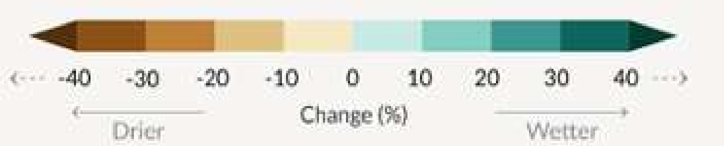




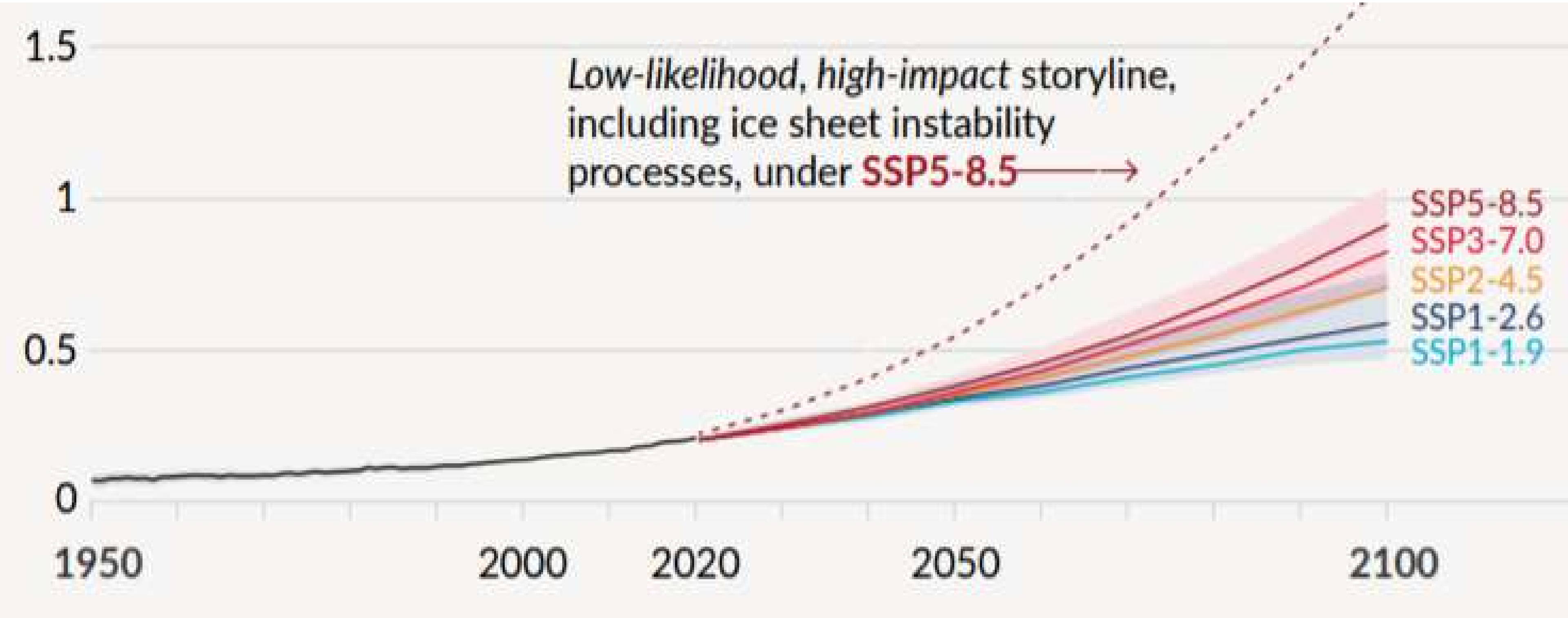




Extreme rainfall intensifies by 7% for each additional 1°C



Future Scenarios global sea level



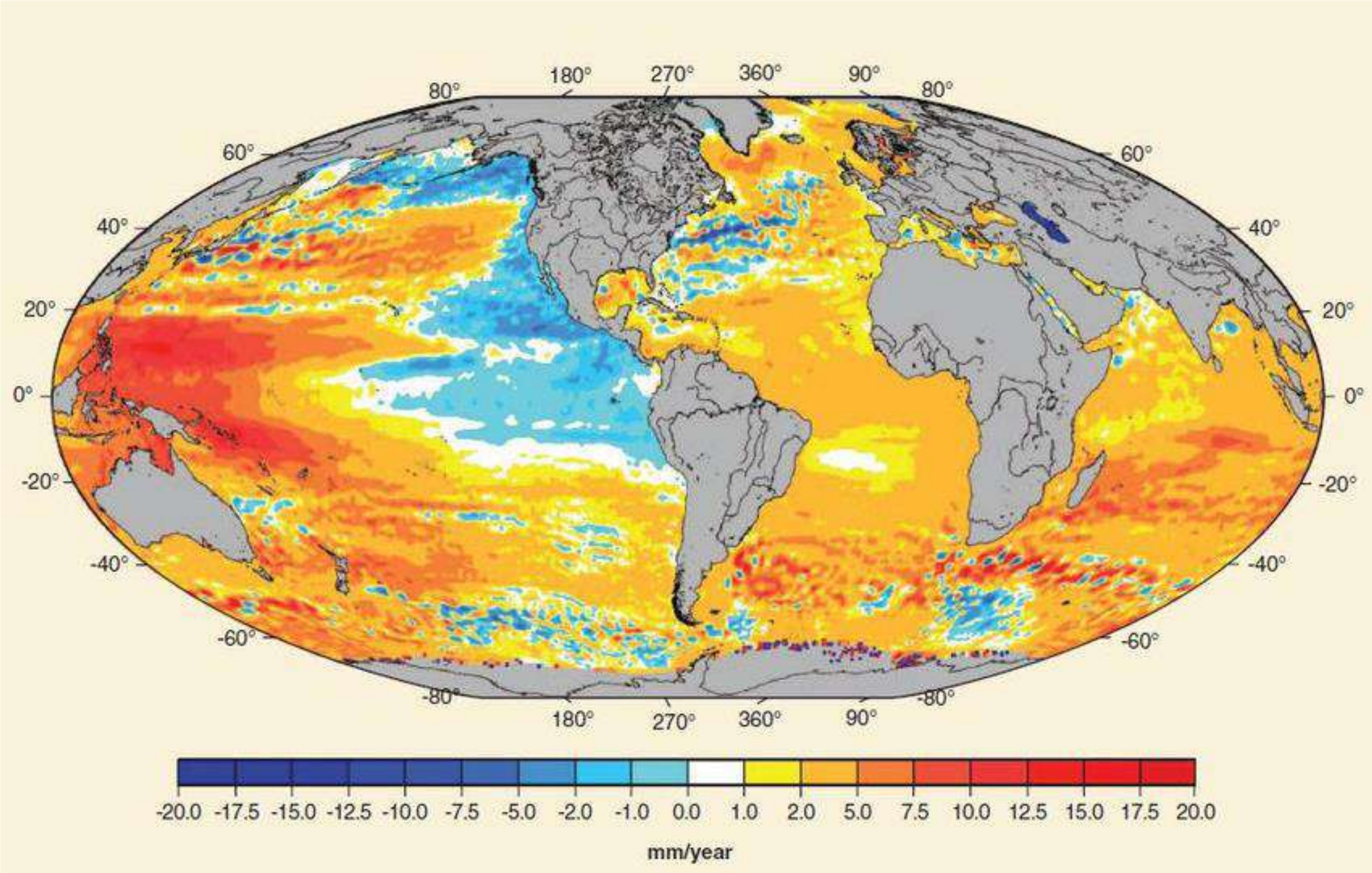
AR6 ipcc

INTERGOVERNMENTAL PANEL ON climate change

WMO UNEP

ENEA

Regional Sea Level



Regional sea-level trends from satellite altimetry for the period: **October 1992 to July 2009**

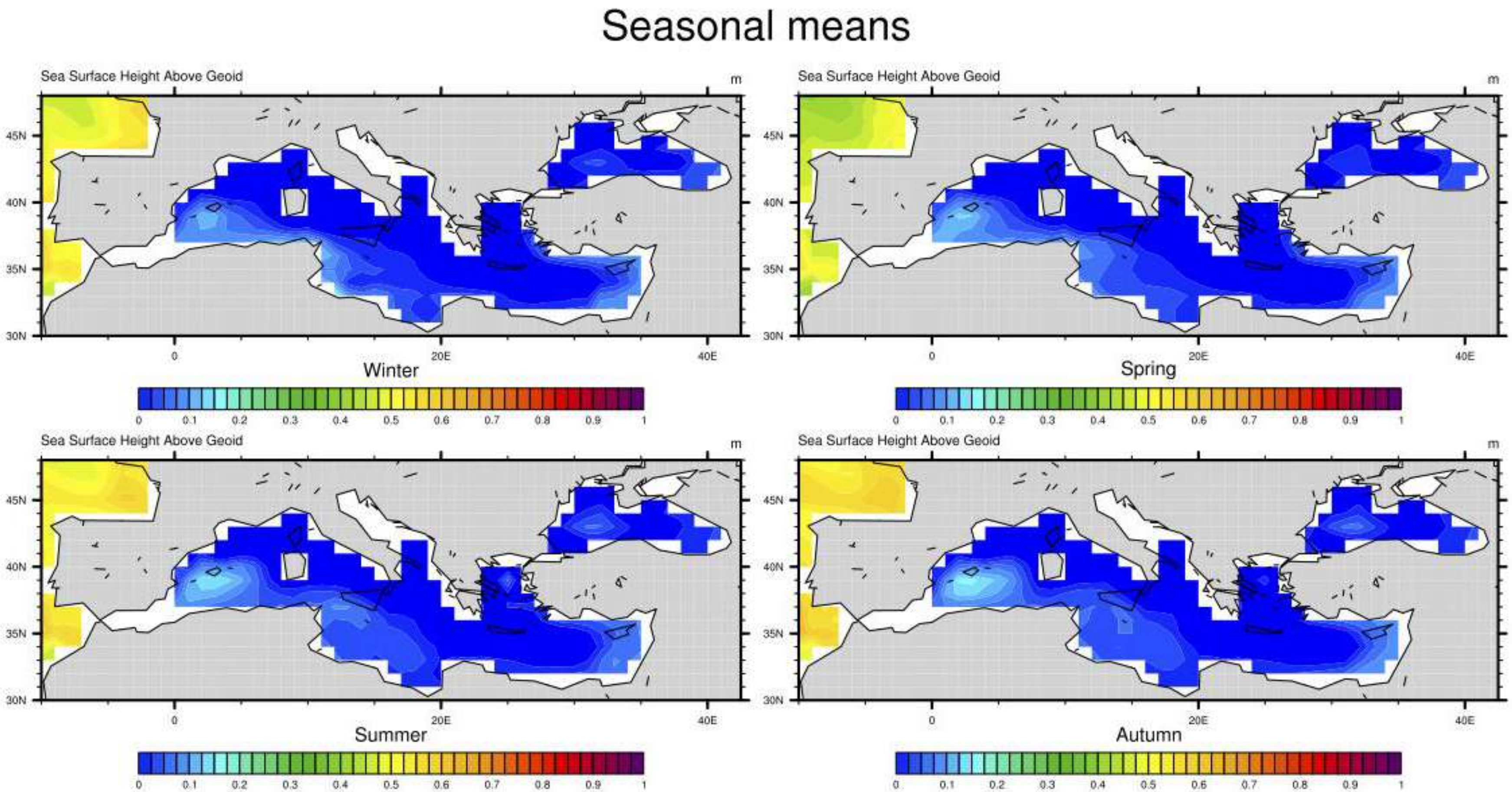
Spatial differences are due to the steric effect. Nicholls & Cazenave, 2010

SROCC & IPCC AR6 – WGI Chapter 9

The ***SROCC*** *estimated regional sea-level changes from combinations of the various contributions to sea-level change from* ***CMIP5*** *climate model outputs, allowing comparison with satellite altimeter and tide-gauge observations. Closure of the regional sea-level budget is complicated by the fact that* ***regional sea-level variability is larger than GMSL variability*** *and there are more processes that need to be considered, such as vertical land movement and ocean dynamical changes.*

Since ***CMIP6*** *models are of fairly coarse (typically ~100km) resolution, and even the models participating in HighResMIP (near 10km resolution) do not capture all the phenomena that contribute to coastal ocean dynamic sea-level change, there is low confidence in the details of ocean dynamic sea-level change along the coast and in semi-enclosed basins,* ***like the Mediterranean****, where* ***coarse models can misrepresent key dynamic processes****.*

Global climate models: present climate seasonal means

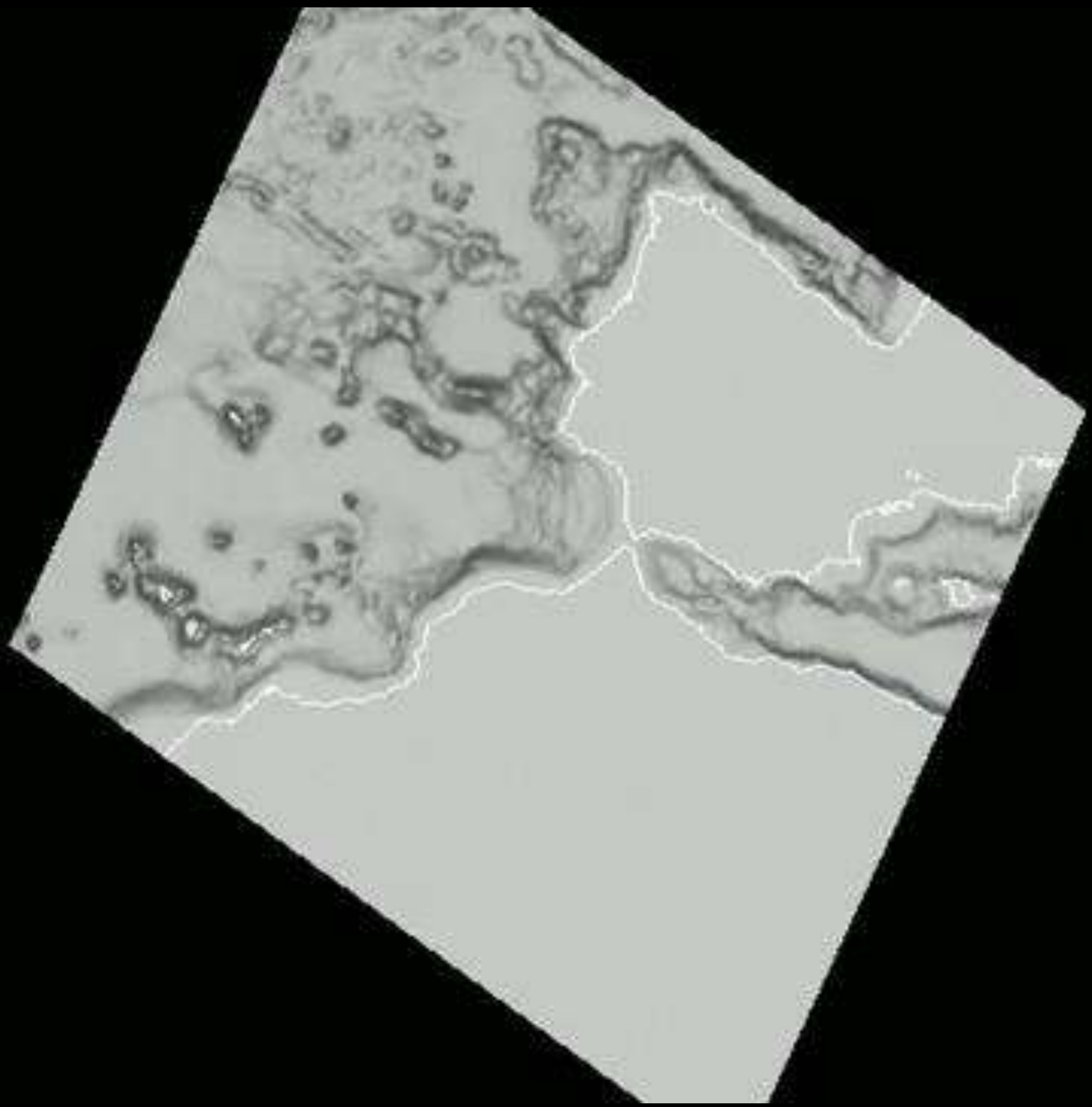


Mediterranean sea level reproduced by CMIP5* global models (present climate)

*Coupled Model Intercomparison Project - https://cmip.llnl.gov/cmip5/

Background geography

Strait of Gibraltar Background: 3D Bathymetry



Strait of Gibraltar Background

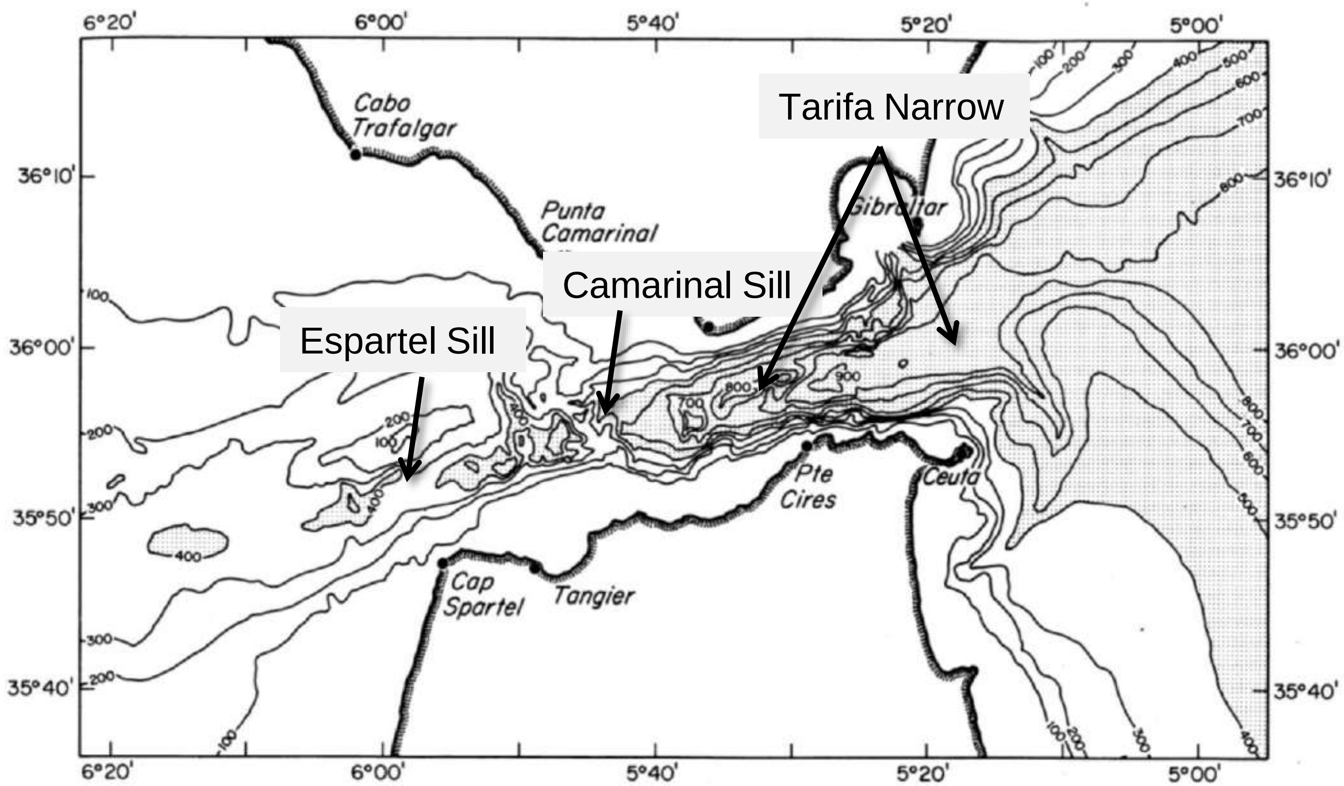


Chart of the Strait of Gibraltar, adapted from Armi & Farmer (1988), showing the principal geographic features referred to in the text.

Areas deeper than 400 m are shaded

Strait of Gibraltar Background: Physics

Strong mixing and entrainment mainly driven by the very intense tides.

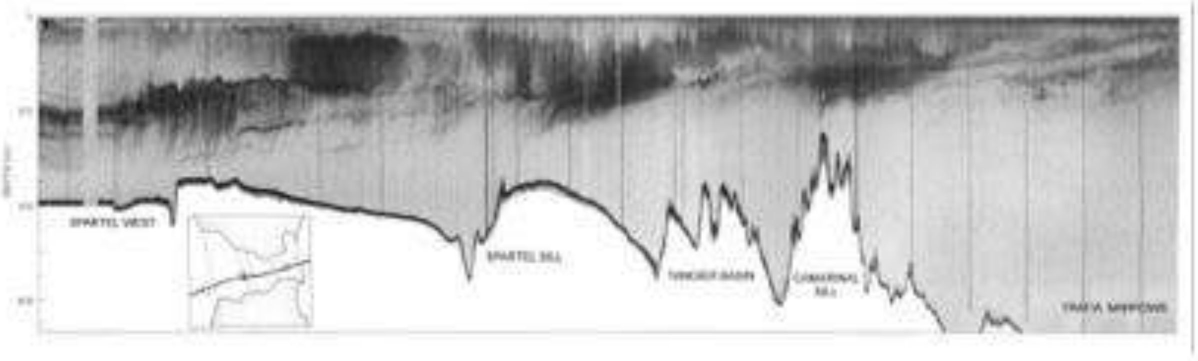


Figure 2. Transect of the Strait [From Armi and Farmer, Farmer and Armi 1988]

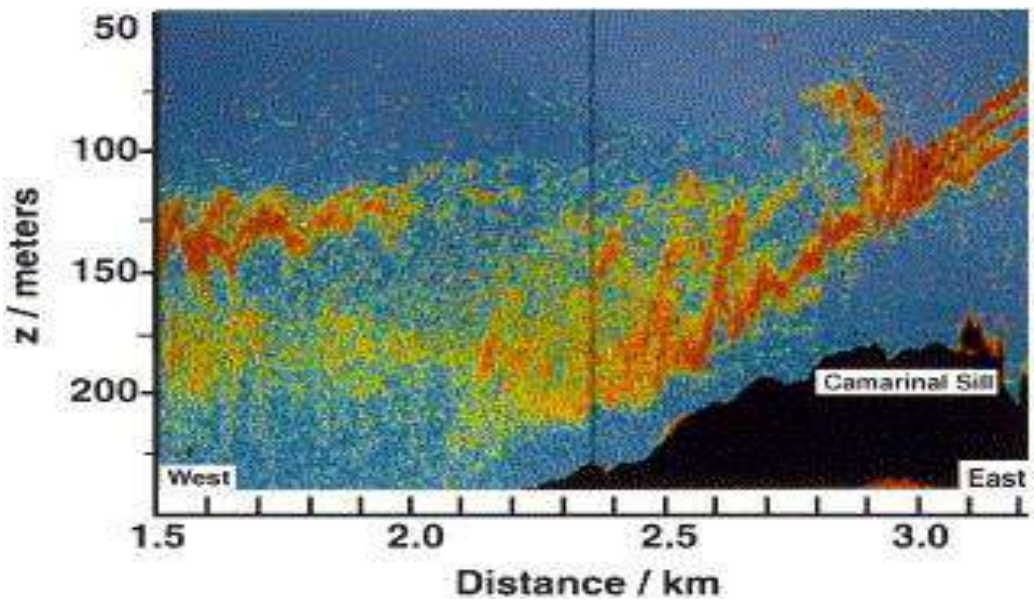
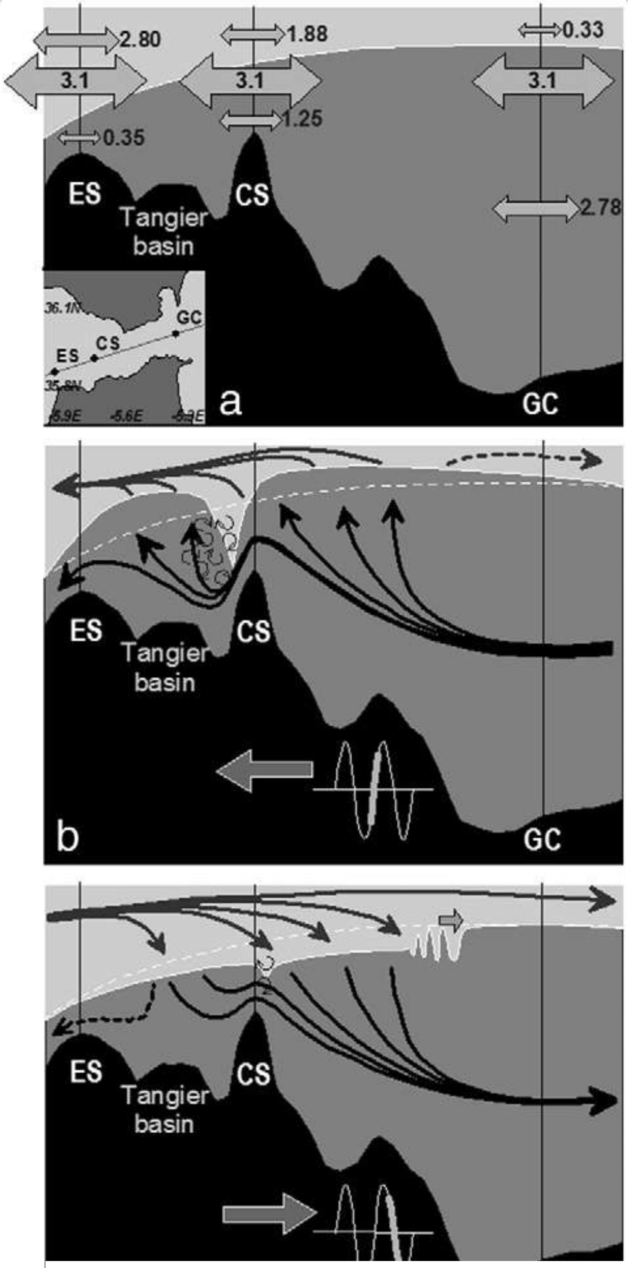
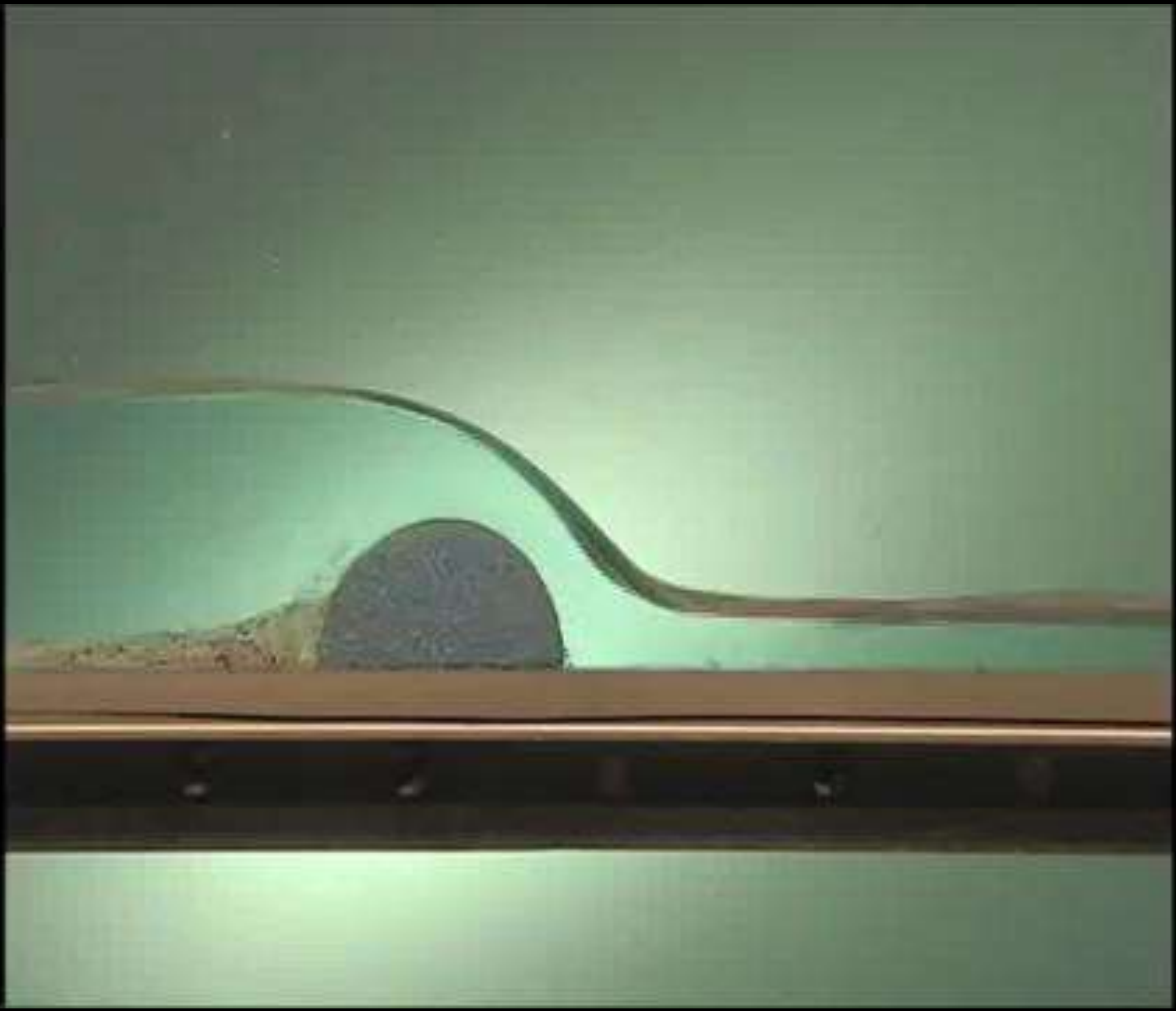


Image of acoustic backscatter during ebb tide over Camarinal Sill in the Strait of Gibraltar (Wesson and Gregg, 1994)

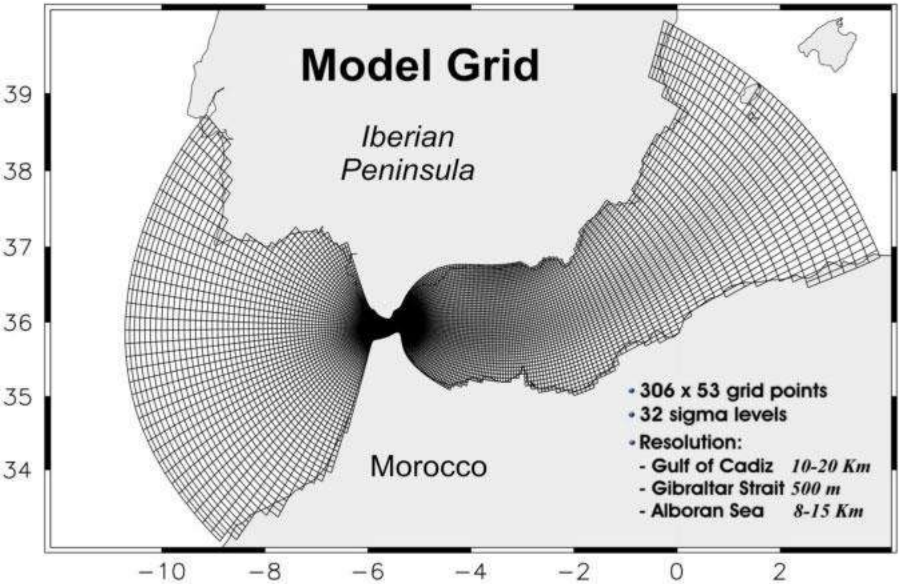


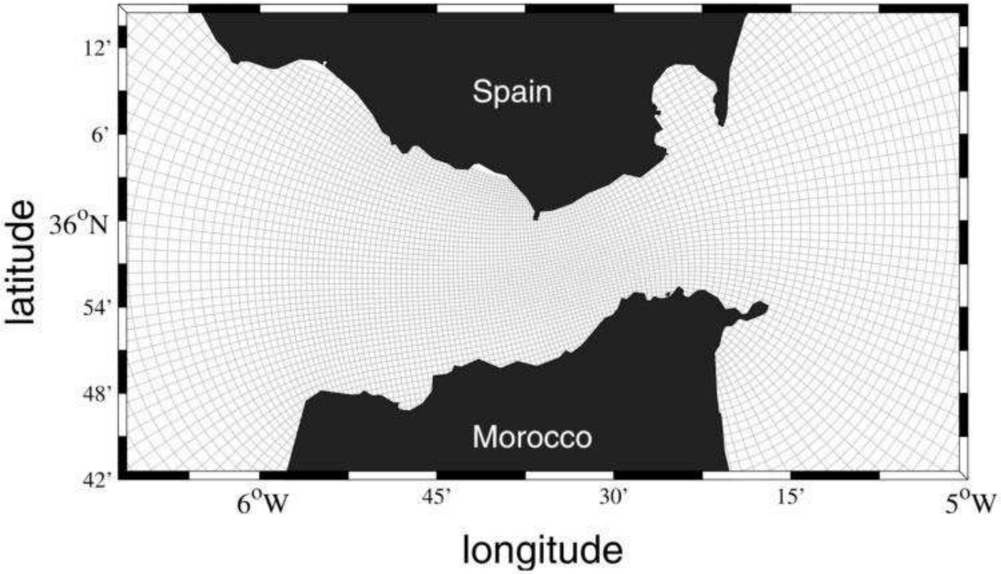
A. Sánchez-Román et al, JGR 2012

Hydraulics jump: an example



Sub-basin Model (POM): Cadiz – Gibraltar - Alboran





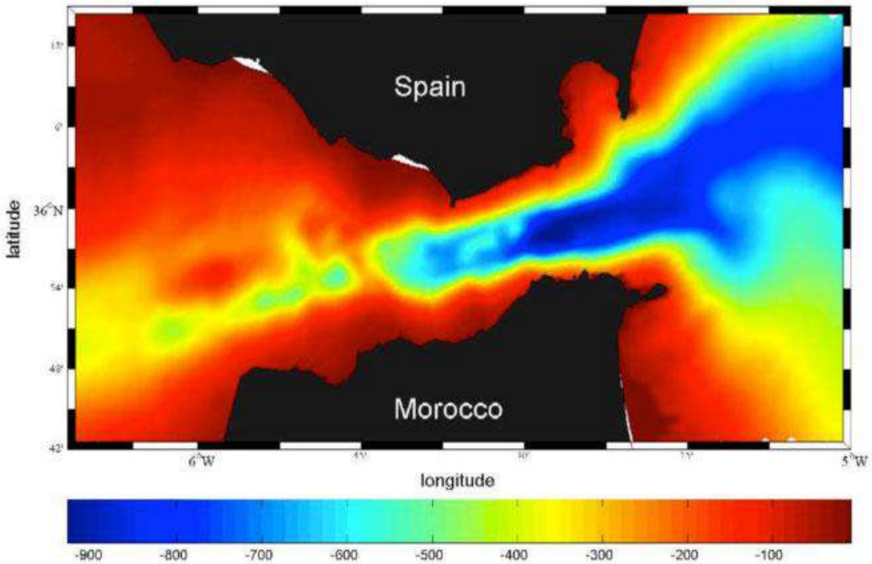
Modified POM

Minimal Hor. Resolution: < 500 m

External Time-Step: 0.1 sec

O_1 K_1 diurnal tidal component

M_2 S_2 diurnal tidal component



•Sannino et al, JGR-Book, 2013

•Sannino et al, JPO, 2009

•Sanchez et al, JGR, 2009

•Garrido et al, JGR, 2008

•Garcia-Lafuente et al, JGR, 2007

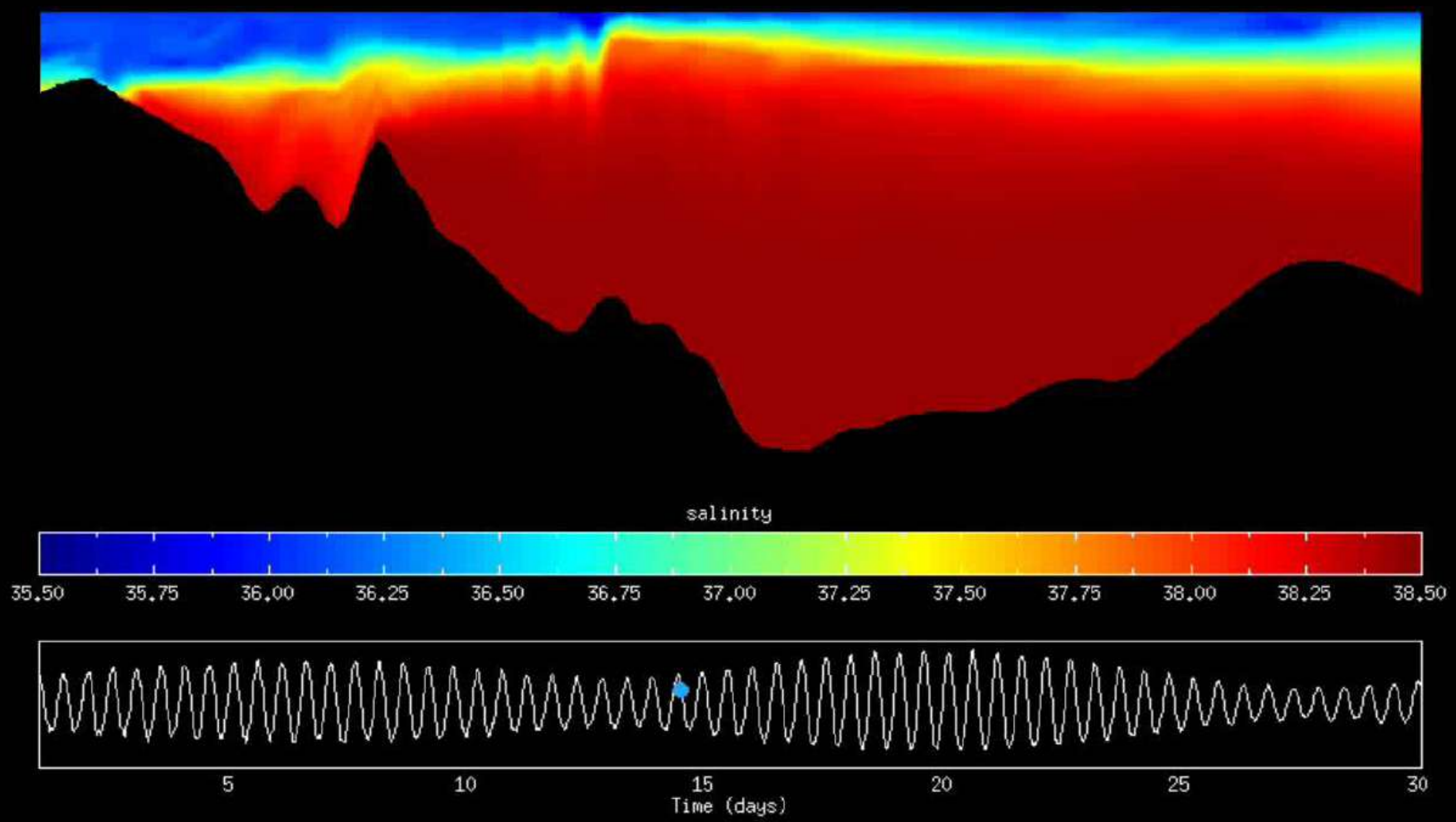
•Sannino et al, JGR, 2007

•Sannino et al , NC, 2005

•Sannino et al, JGR, 2004

•Sannino et al, JGR, 2002

Sub-basin Model (POM): Cadiz – Gibraltar - Alboran



salinity along-strait section

Sub-basin Model (POM): Cadiz – Gibraltar - Alboran

Tidal Components comparison
Surface elevation

TABLE 1. Comparison between Observed and Predicted Amplitudes A and Phases P of M_2 tidal elevation.

			Observed M_2		Predicted M_2		Predicted - Observed		
Location	Latitude	Longitude	A,cm	P,deg	A,cm	P,deg	A,cm	A,%	P,deg
			Tsimplis et al. (1995)						
Gibraltar	36°08′	05°21′	29.8	46.0	29.5	46.0	-0.3	1.0	+0.0[a]
			García-Lafuente (1986)						
Pta. Gracia	36°05.4′	05°48.6′	64.9 ± 0.2	49.0 ± 0.5	67.6	53.8	+2.7	4.1	+4.5
Tarifa	36°00.2′	05°36.4′	41.5 ± 0.2	57.0 ± 0.5	43.5	49.7	+2.0	4.8	-7.3
Pta. Cires	35°54.7′	05°28.8′	36.4 ± 0.2	46.5 ± 0.5	35.0	54.9	-1.4	3.8	+8.4
Pta. Carnero	36°04.3′	05°25.7′	31.1 ± 0.2	47.5 ± 0.5	30.8	47.4	-0.3	0.9	-0.1
			Candela et al. (1990)						
DN	35°58′	05°46′	60.1	51.8	58.2	57.8	-1.9	3.1	+6.0
DS	35°54′	05°44′	54.0	61.8	54.1	64.1	+0.1	0.2	+2.3
SN	36°03′	05°43′	52.3	47.6	52.3	52.9	0.0	0.0	+5.3
SS	35°50′	05°43′	57.1	66.8	56.8	67.4	-0.3	0.5	+0.6
DW	35°53′	05°58′	78.5	56.1	76.6	62.7	-1.9	2.4	+6.6
TA	36°01′	05°36′	41.2	41.2	43.5	49.7	+2.3	5.5	+8.5
AL	36°08′	05°26′	31.0	48.0	30.0	49.7	-1.0	3.2	+1.7
CE	35°53′	05°18′	29.7	50.3	29.5	51.5	-0.2	0.6	+1.2
DP5	36°00′	05°34′	44.4	47.6	42.1	47.6	-2.3	5.1	+0.0

[a]Calibration.

Max Differences:
Amp: 3.6 cm
Pha: 11°

Sannino et al.,JPO, 2009

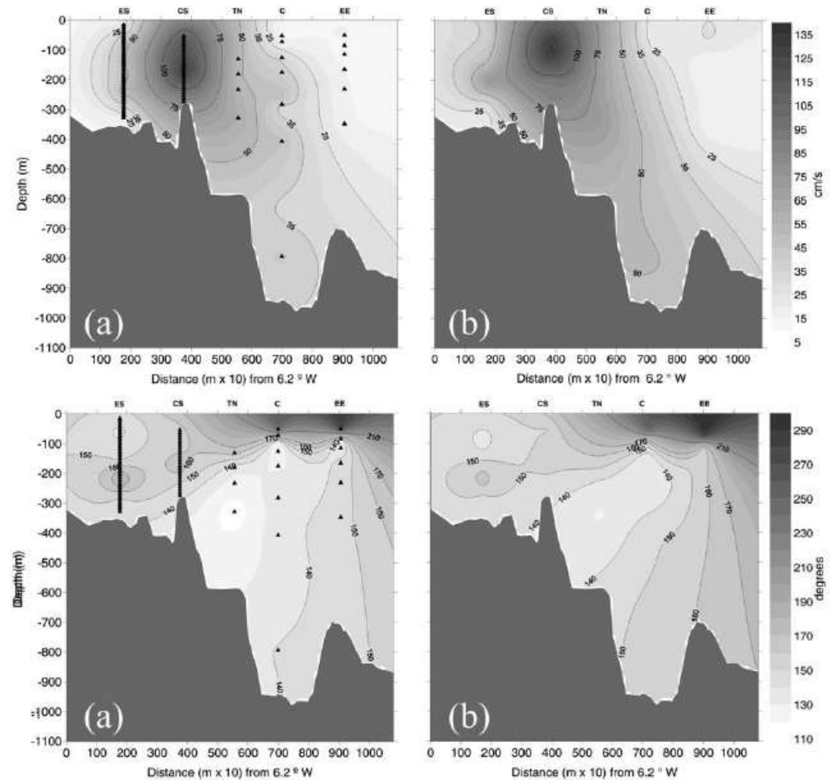
Tidal Components comparison
Along-strait velocity

(a) Data

(b) Model

(a) Data

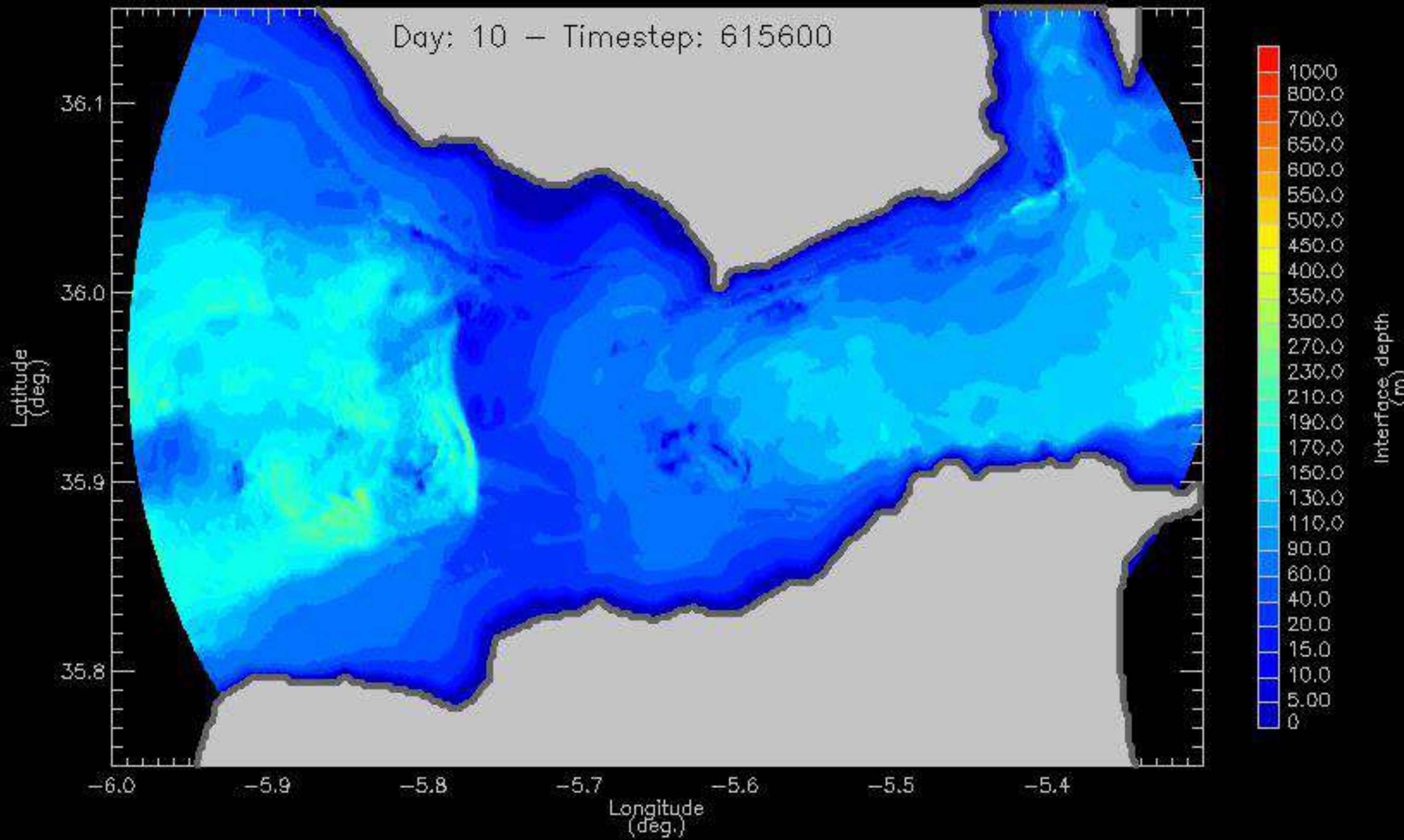
(b) Model



Max Differences:
Amp: 10 cm s^{-1}
Pha: 20°

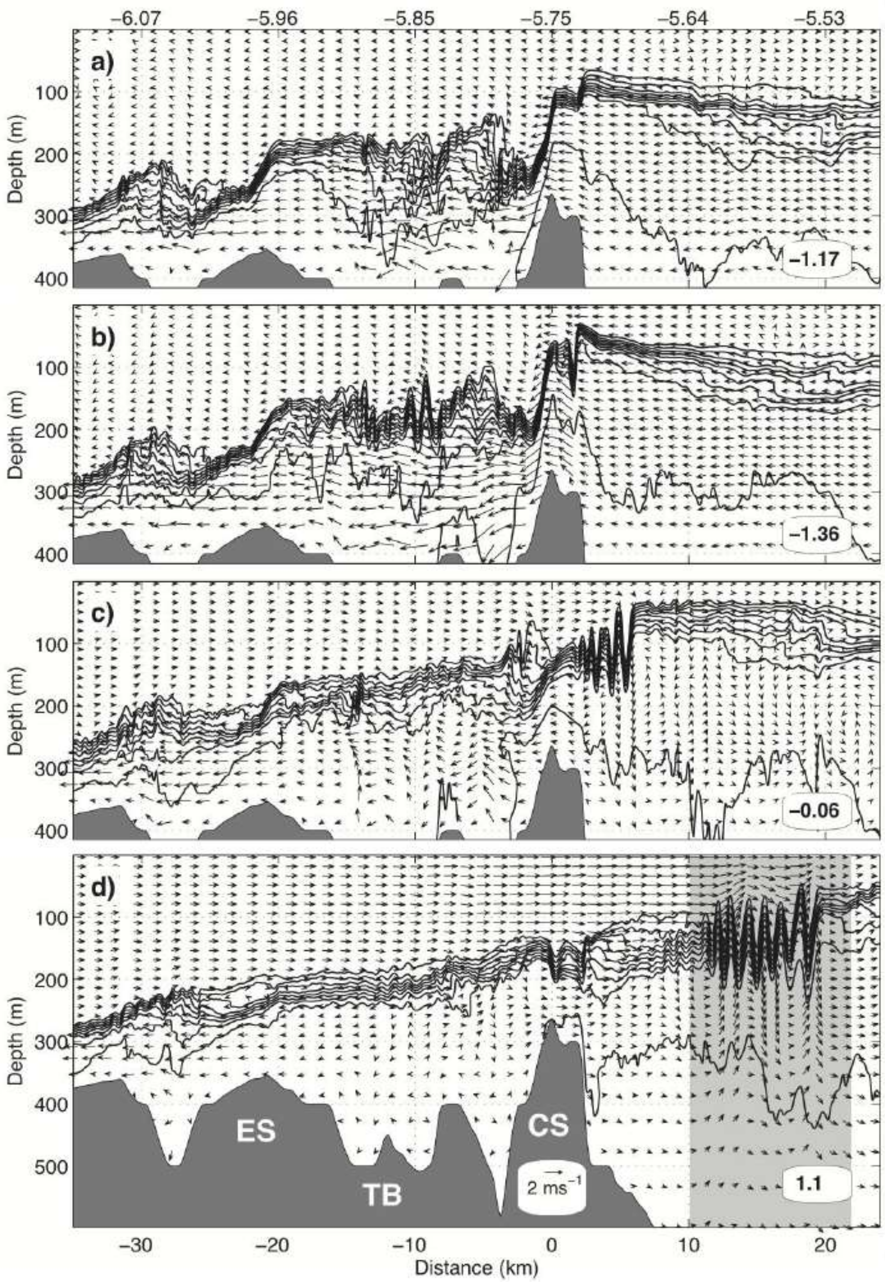
Sánchez-Román et al., JGR, 2009

MITgcm model simulation



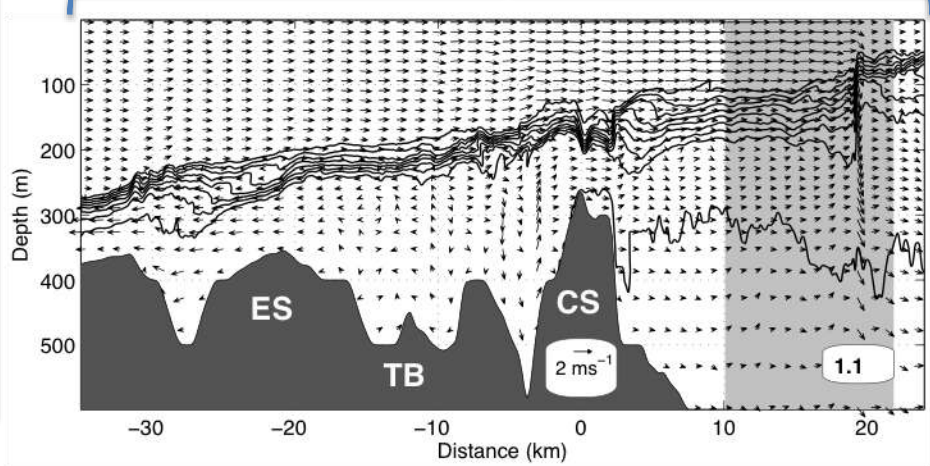
Interface depth evolution

MITgcm sensitivity to non-hydrostaticity



MITgcm NON Hydrostatic

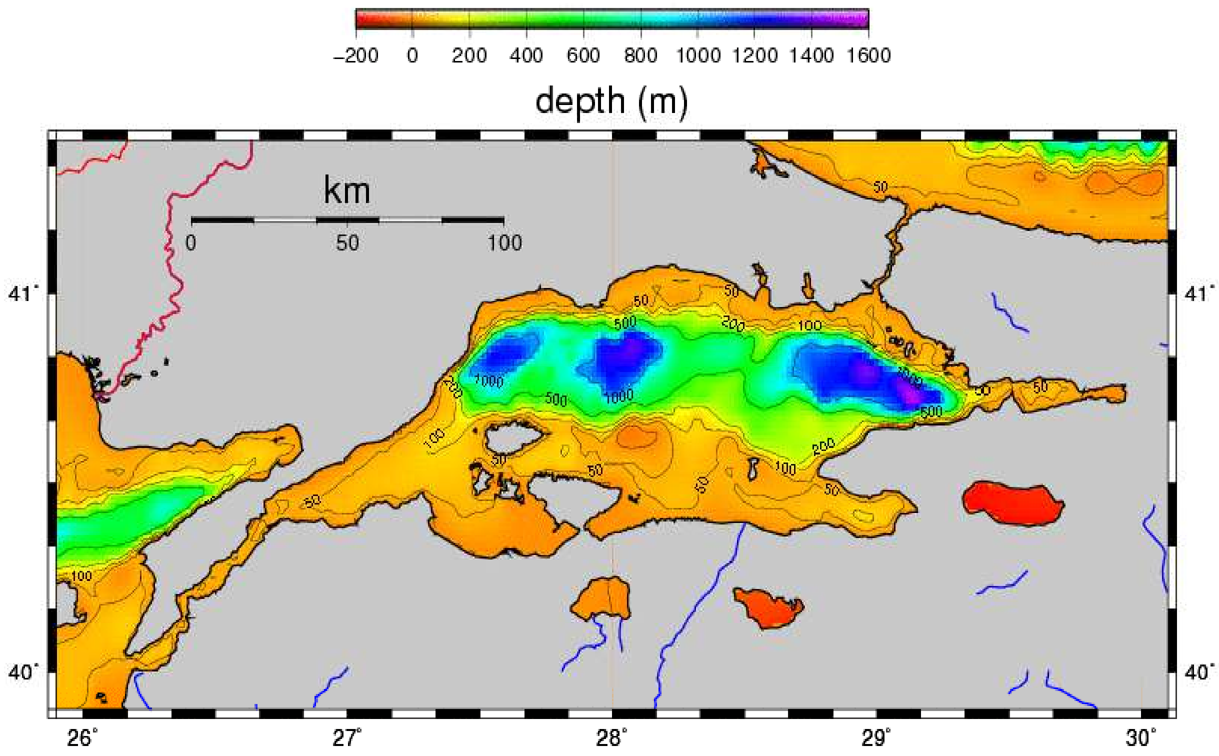
MITgcm Hydrostatic



Turkish Strait System Background: Previous modelling works

The Turkish straits system is a complex environment characterized by highly contrasting properties in a region of high climatic variability.

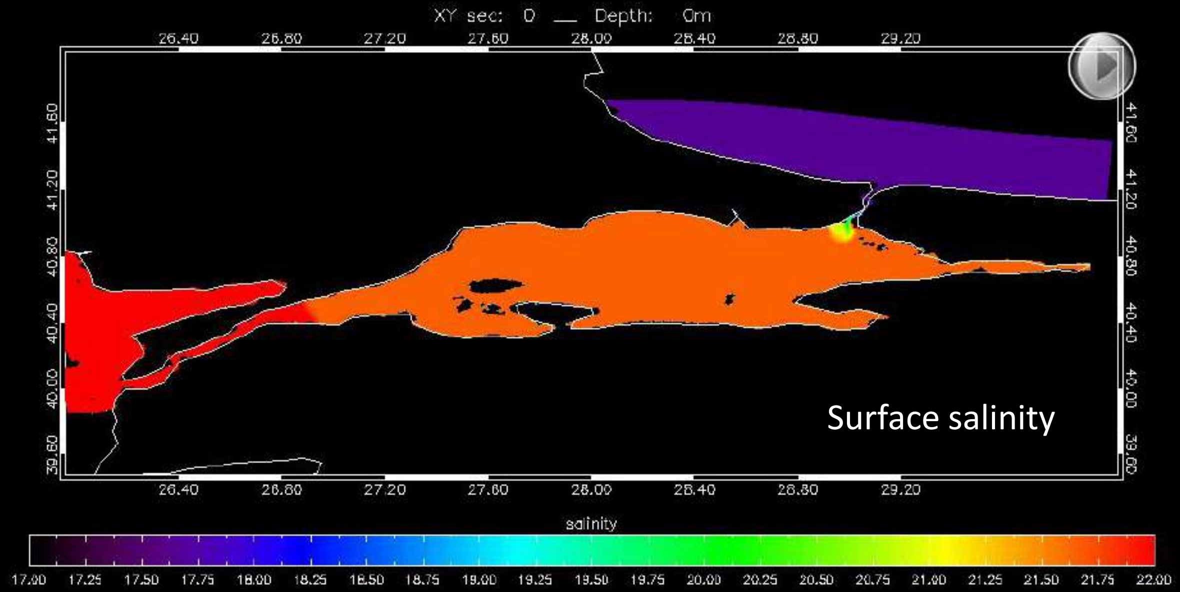
An all time challenge is the modeling of the entire system: Dardanelles – Maramara Sea – Bosphorous.



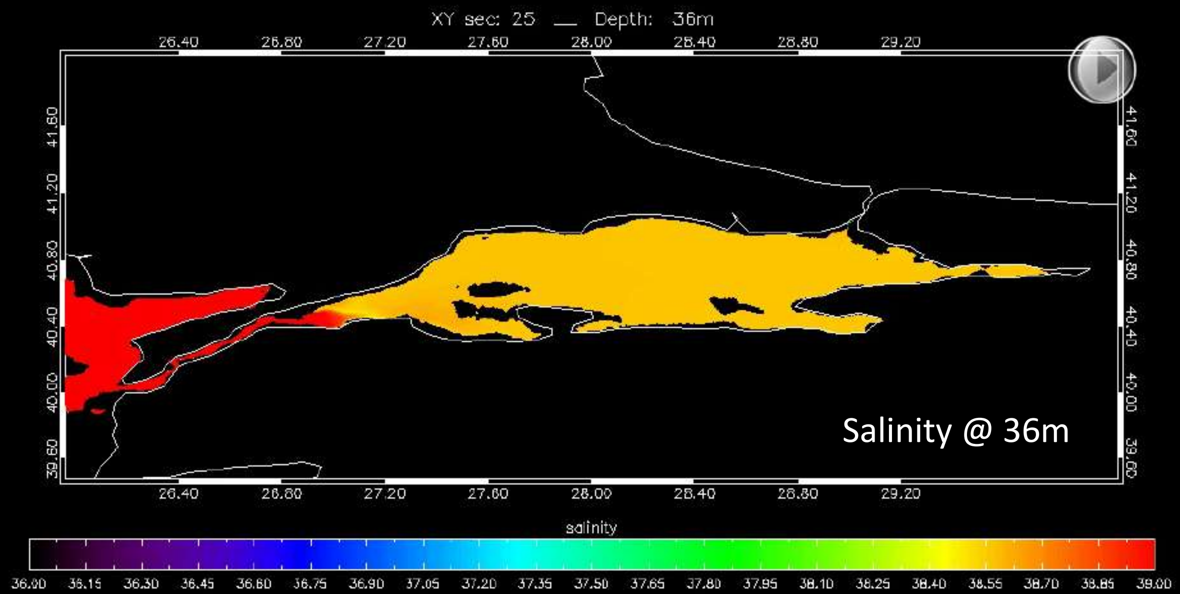
Question:

can we use state-of-art finite difference model to reproduce correctly the TSS circulation?

Sannino et al.
ODY 2017



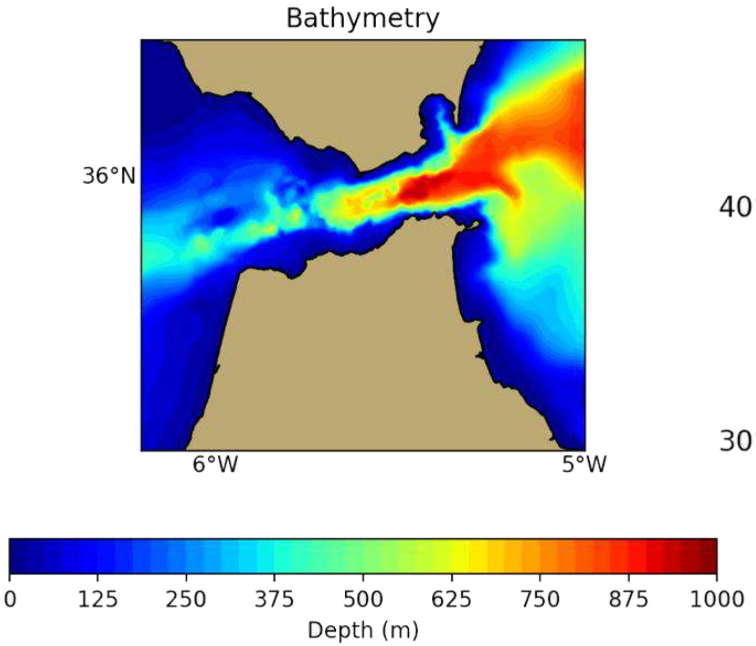
Forced net barotropic flow 18000 m³/sec experiment

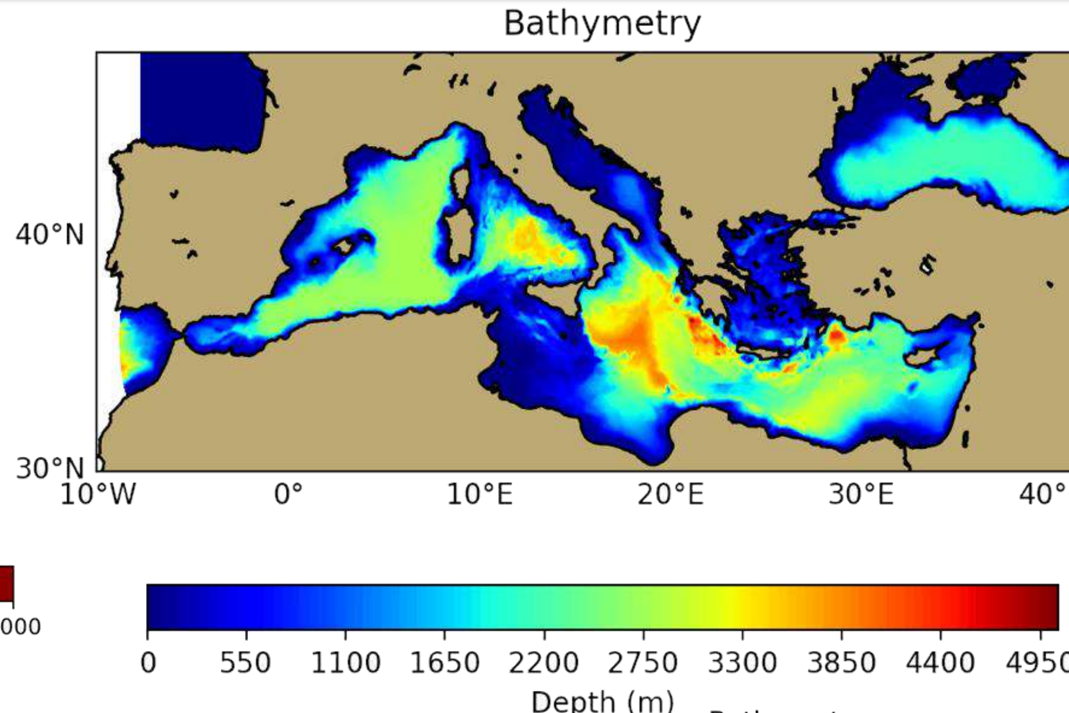


Sannino et al. ODY 2017

Three experiments were conducted to study the sensitivity of the circulation to different net barotropic flows: **5600, 9600, 18000, and 50000** m^3/sec

Toward a new climate Mediterranean Black Sea model



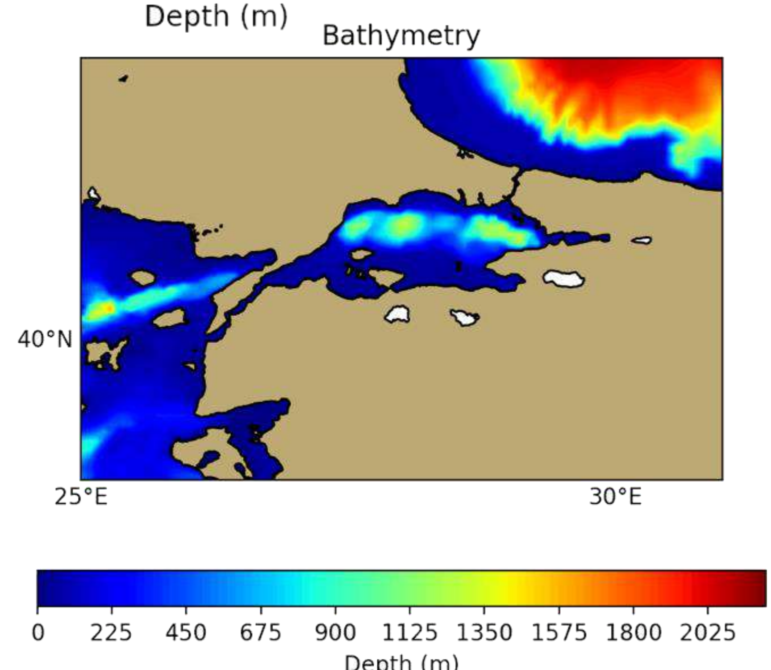


MITgcm – Explicit Tides (M2,S2, K1, O1) – Lateral Tide + Tidal Potential

Average resolution 1/16° (2.3 Km)

Minimum resolution 230m (Gibraltar and Turkish Straits)

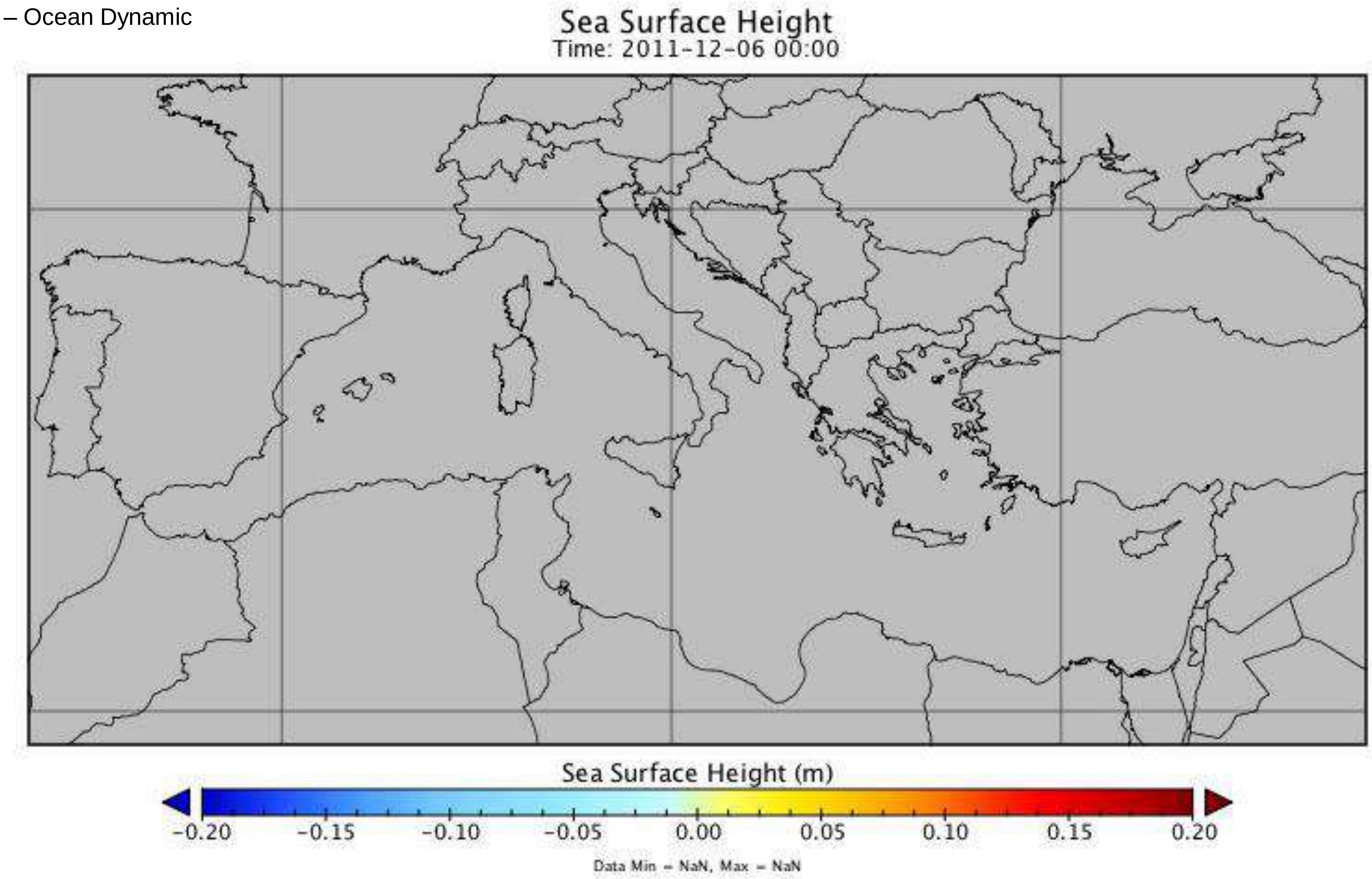
100 Vertical Levels



Sannino et al.
Clim Dyn 2012

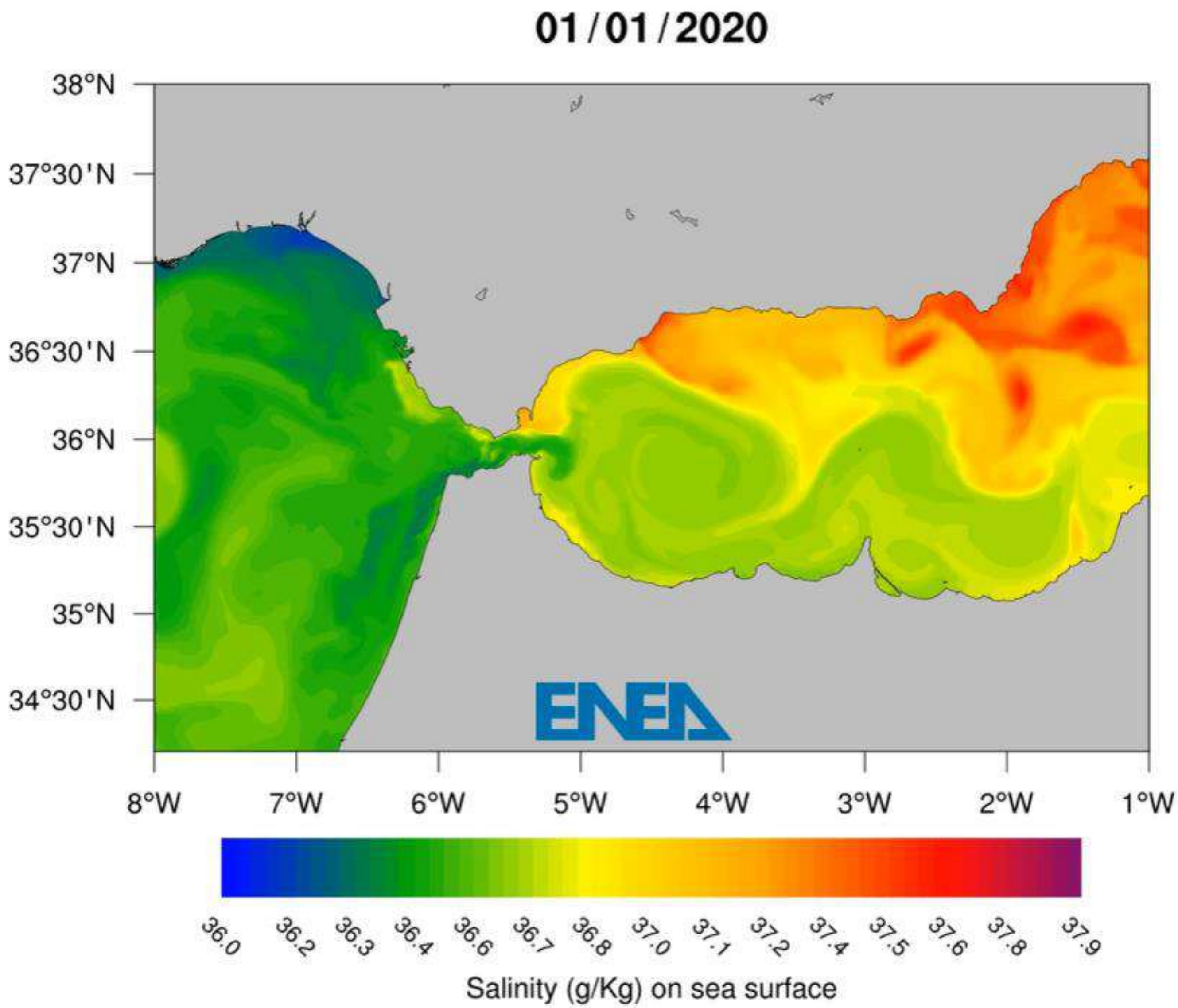
ENEA Hi-resolution Mediterranean Climate Model

Palma et al 2019 – Ocean Dynamic



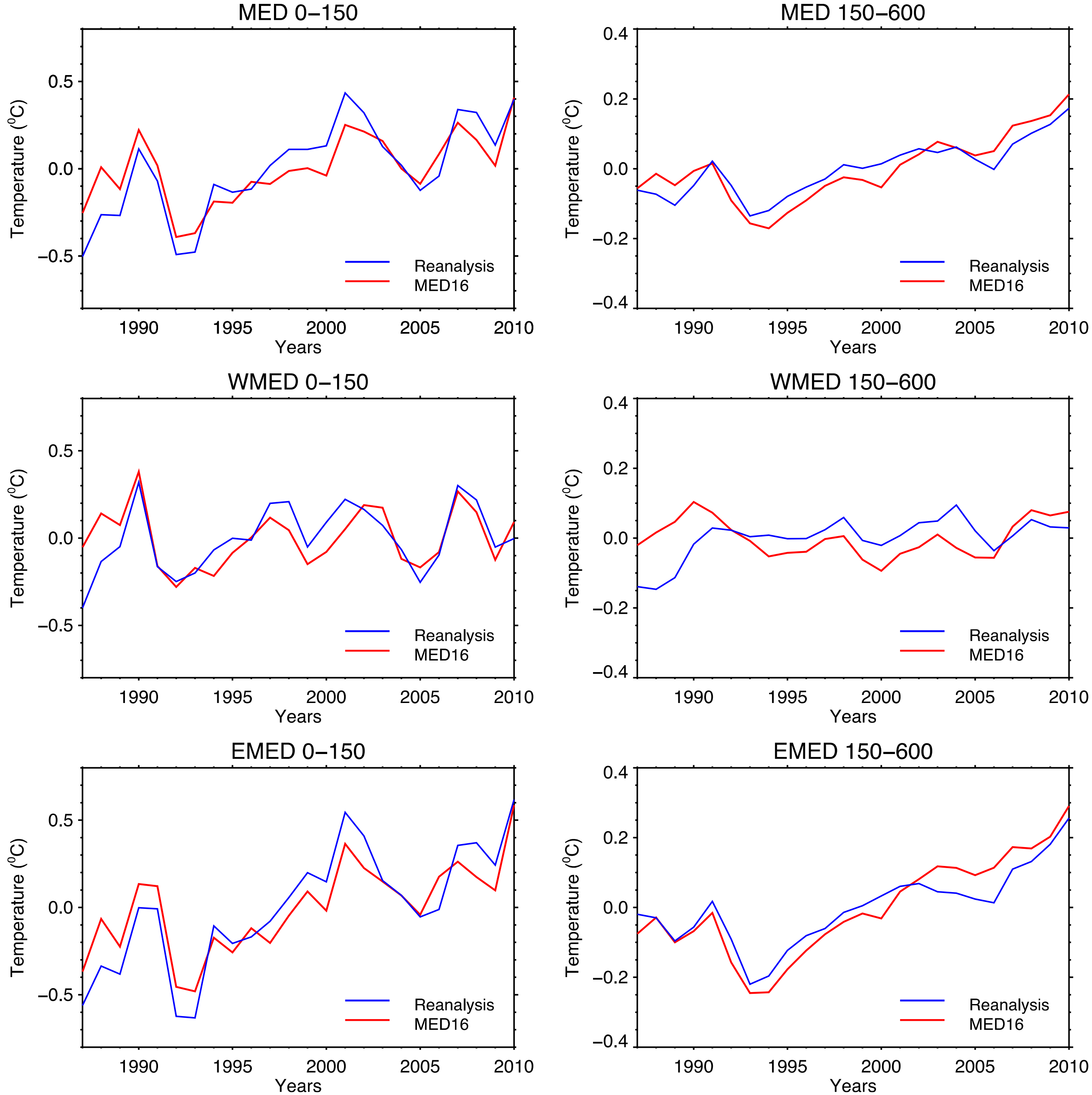
MITgcm – Explicit Tides (M2,S2, K1, O1) – Lateral Tide + Tidal Potential
Average resolution 1/16˚ (7 Km)
Minimum resolution at Gibraltar (230m) and Turkish Straits (90m)
100 Vertical Levels

ENEA Hi-resolution Mediterranean Climate Model



Hi-resolution Mediterranean Climate Model

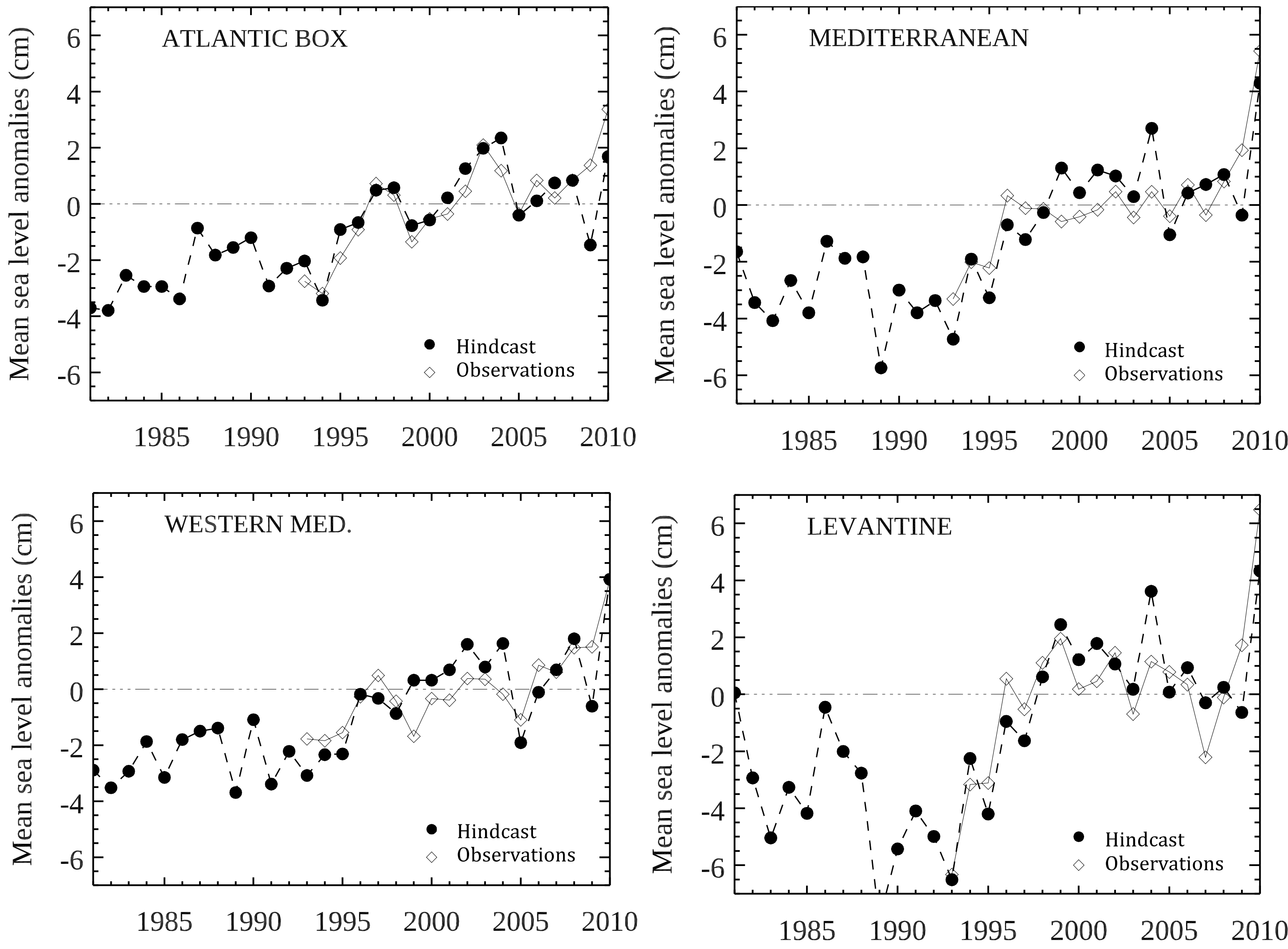
Reanalysis (blue) and **hindcast** (red) time series of temperature anomalies ($^{\circ}C$; annual values) for the upper (0-150 m) and intermediate (150-600 m) layers, for the Mediterranean Sea, and the western and eastern sub-basins



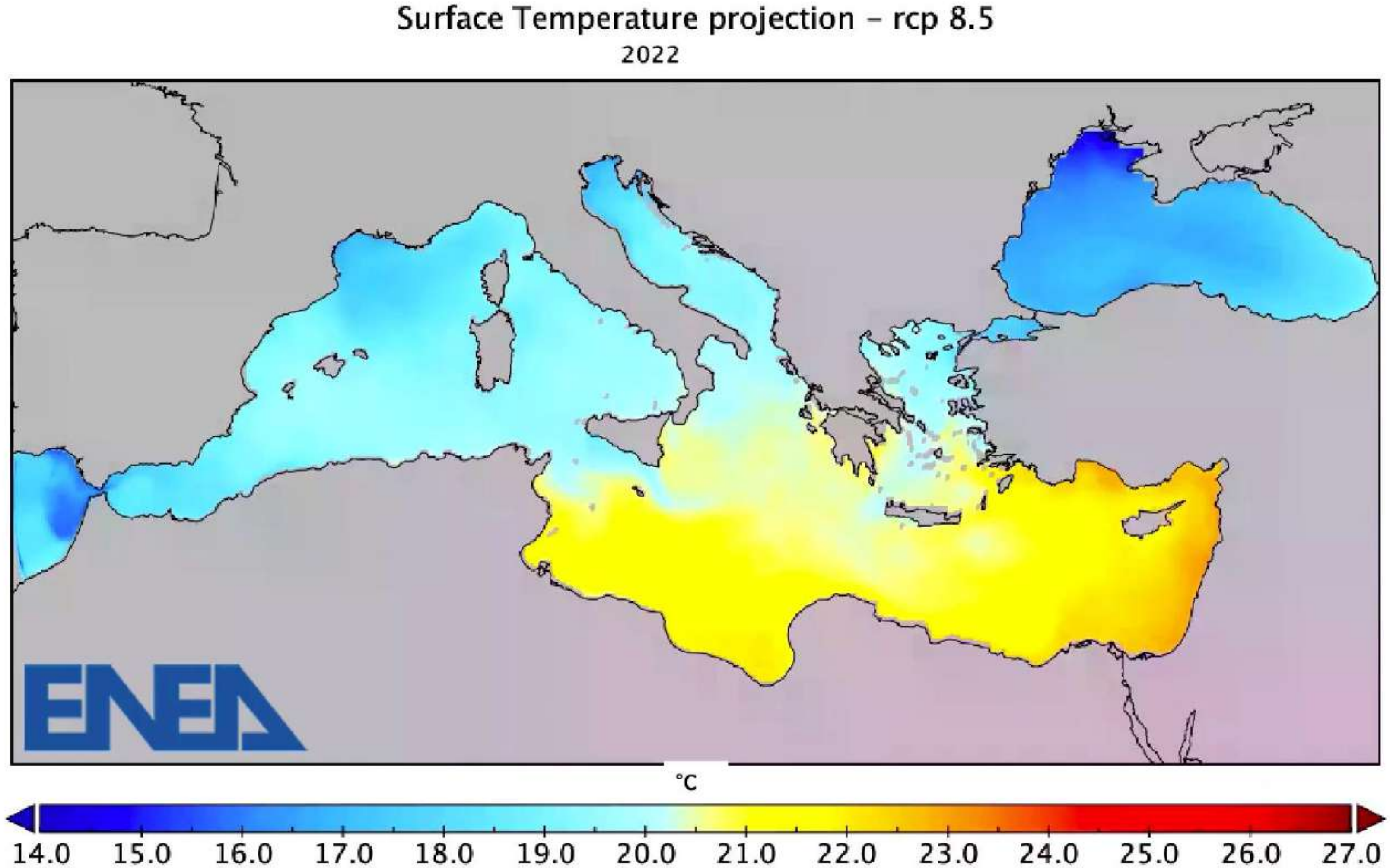
ENEA

Hindcast Mediterranean Sea Level

Interannual variability of the sea-level anomaly in different basins: whole Mediterranean (panel a), western and eastern sub-basins (panels b-c). Black dots denote values computed from the hindcast simulation, and diamonds those from the observations

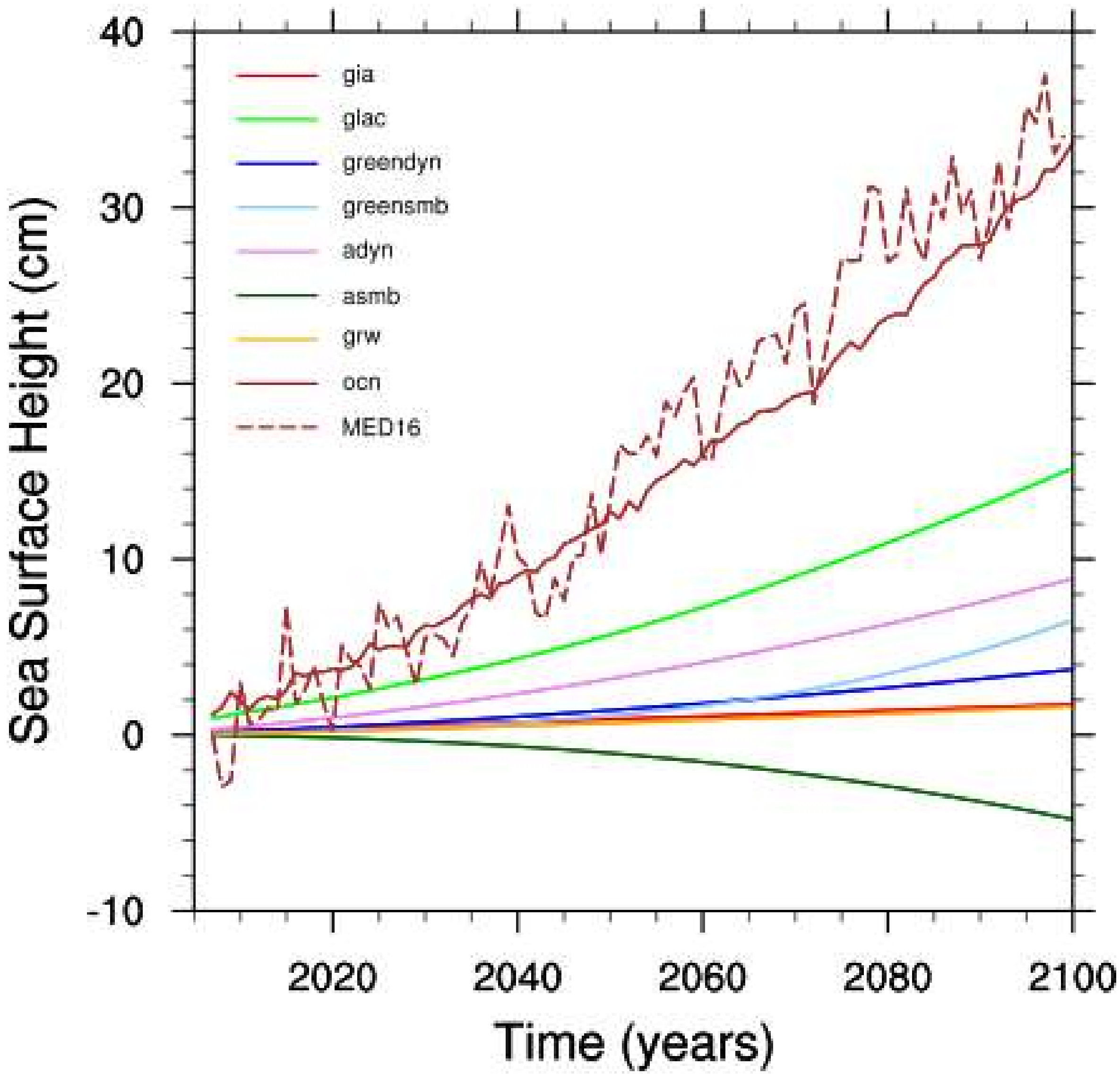


Future (2100) Mediterranean SST (rcp 8.5)

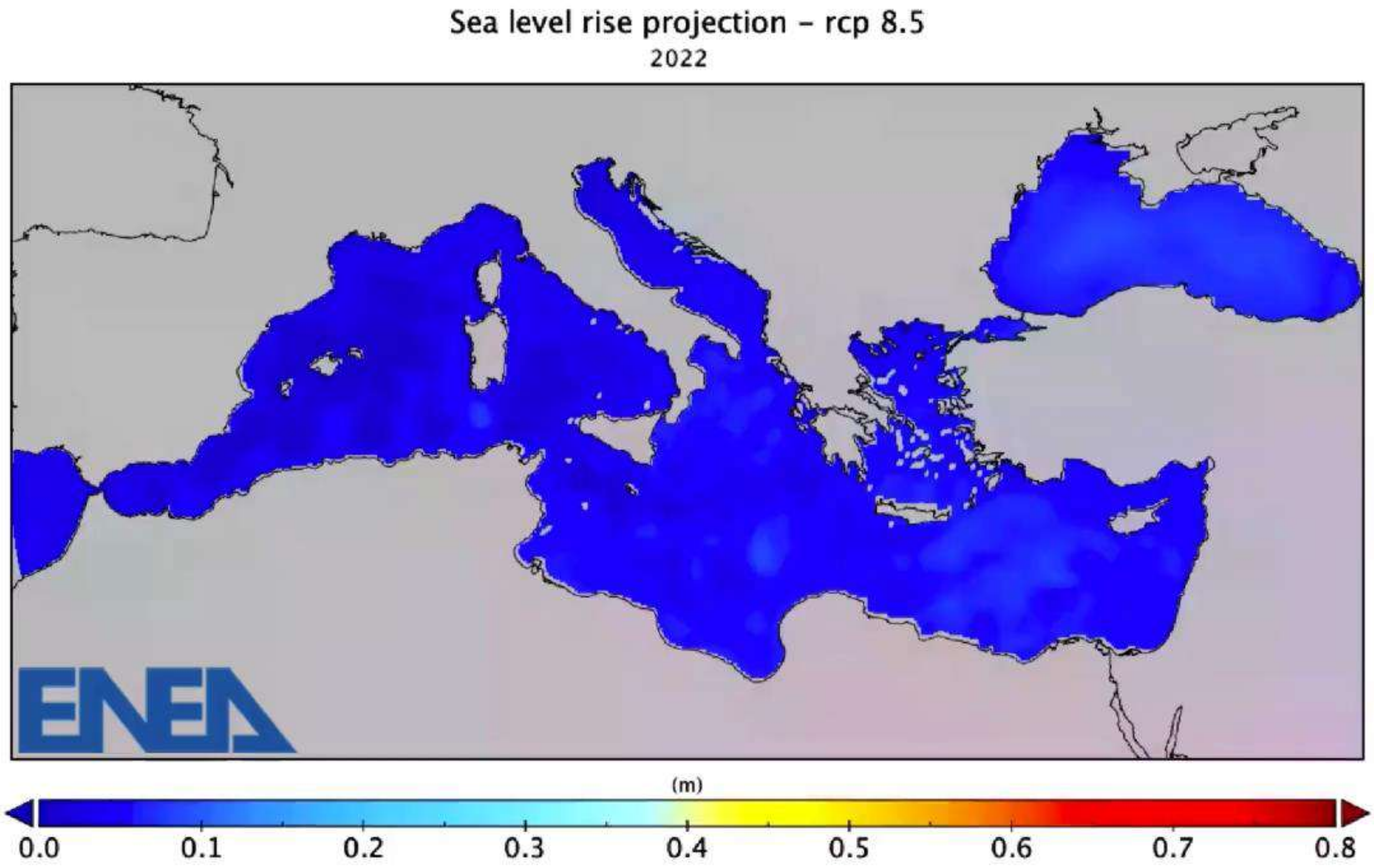


Future (2100) Mediterranean Sea Level (rcp 8.5)

Time evolution of the components contributing to the projected mean sea level in the Mediterranean under the RCP8.5. Solid lines represent the central estimate over available models



Future (2100) Mediterranean Sea Level (rcp 8.5)

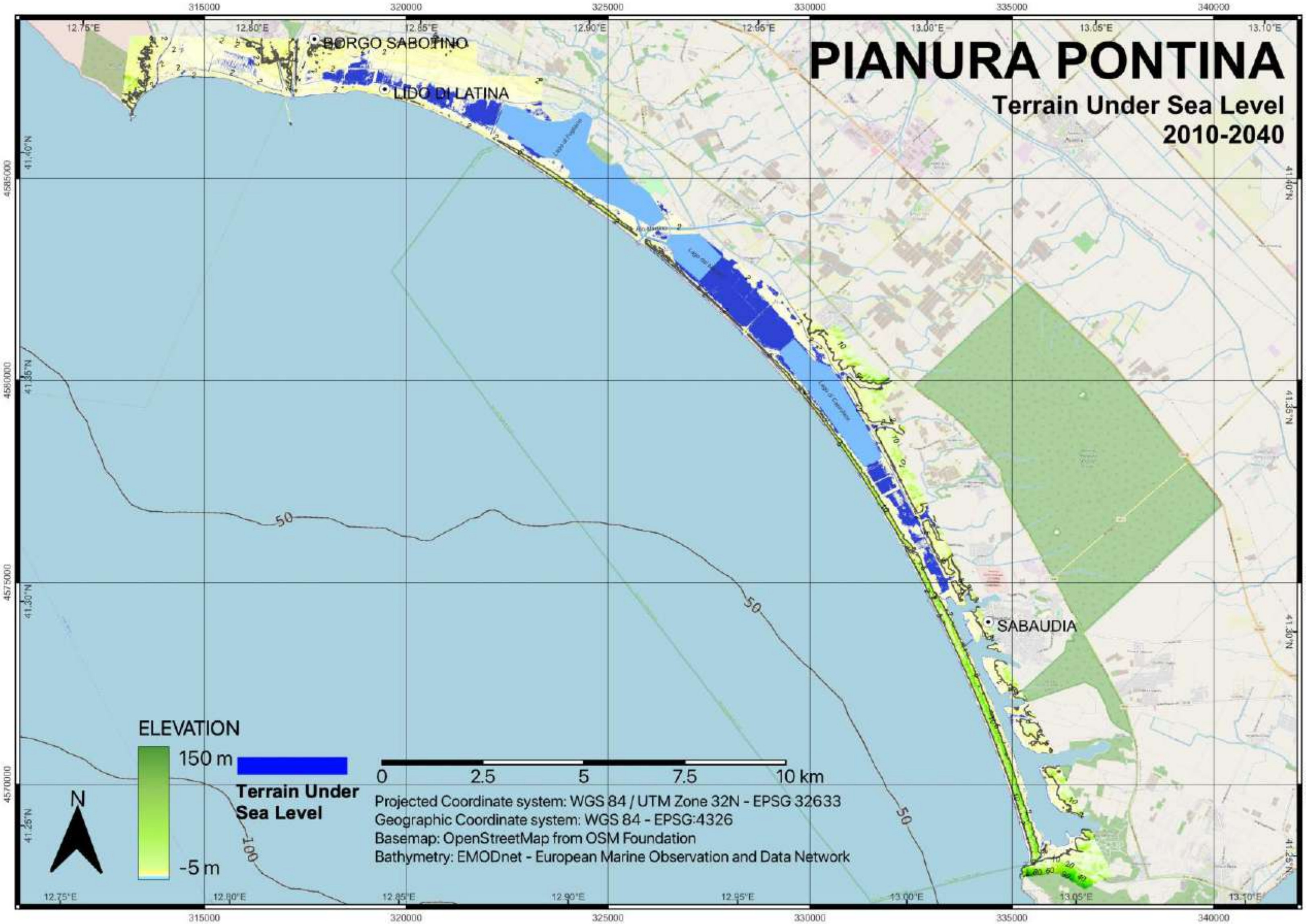


Causes of R-SLR at Gobal, Regional and Local scale

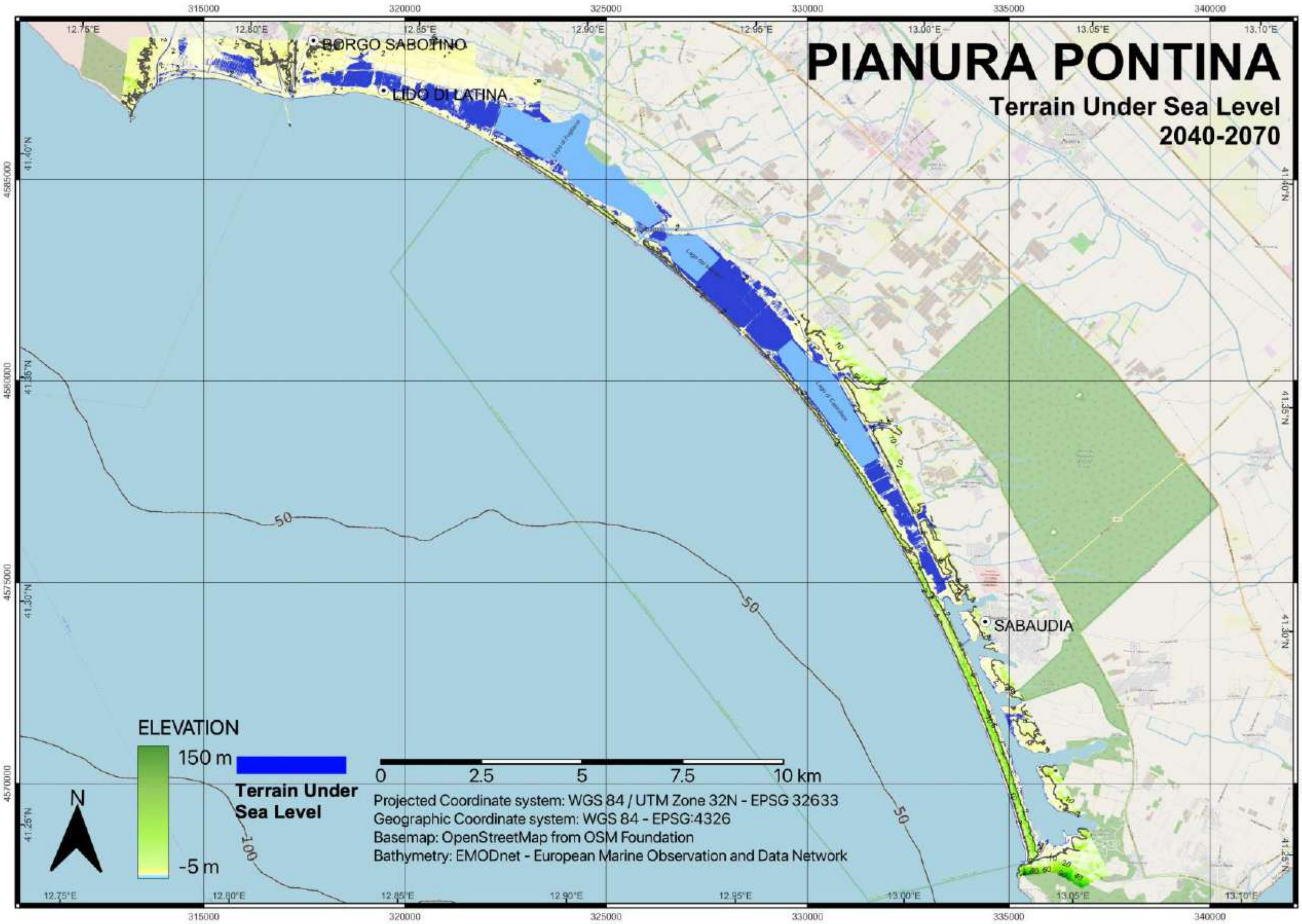
	G	R	L
Melting Greenland and Antarctica	●	●	○
Melting Glaciers and ice caps	●	●	○
Ocean Thermal expansion	●	●	○
Ocean Circulation	●	●	○
Postglacial rebound, self-attraction and loading	○	●	●
Land Hydrology	○	○	●
Tides, Storm surge, Subsidence	○	○	●

ENEA

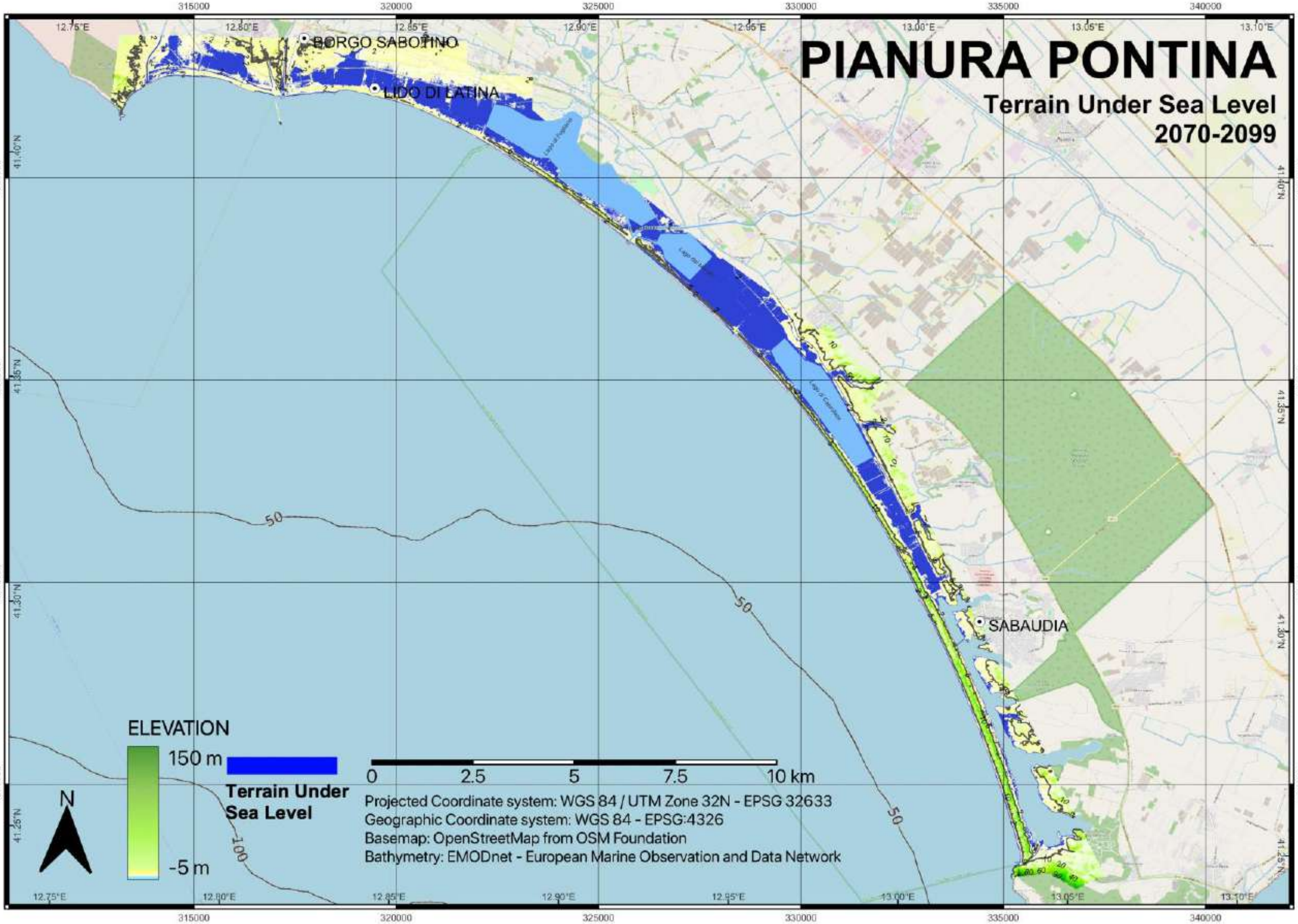
Future (2100) Mediterranean Sea Level



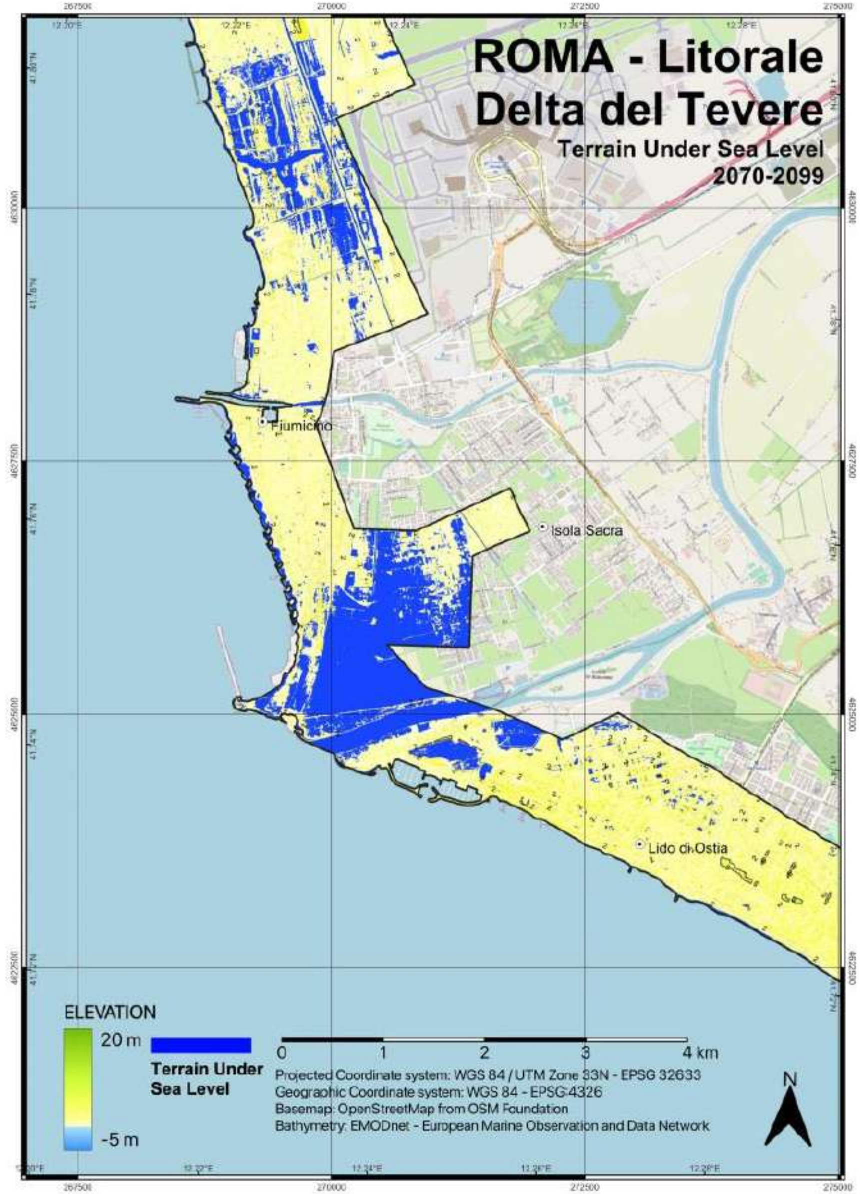
Future (2100) Mediterranean Sea Level



Future (2100) Mediterranean Sea Level

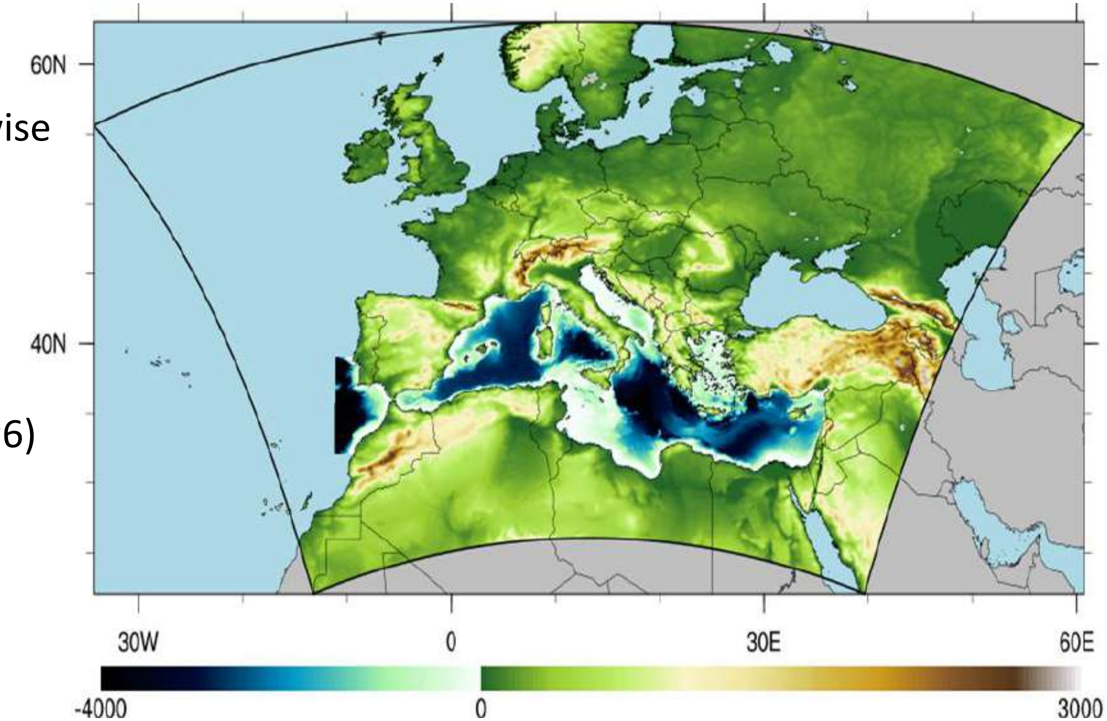


Modello climatico ENEA: mappe allagamento



Regional Earth System Model: ENEA-REG

- **ATM Model**
  - **WRF** (12 km), **51 vertical levels** (up to 10 hPa)
- **Ocean model**
  - **MITgcm** (1/12°) over Med, GCM otherwise
- **River routing model**
  - **HD** (0.5°)
- **Driving models**
  - **ERA5** (reanalysis), **MPI-ESM1-2-HR** (CMIP6)
- **Emission Scenario**
  - **Historical, SSP126, SSP245 and SSP585**
- **Temporal period**
  - **Historical**: 1980-2014
  - **Scenario**: 2015-2100

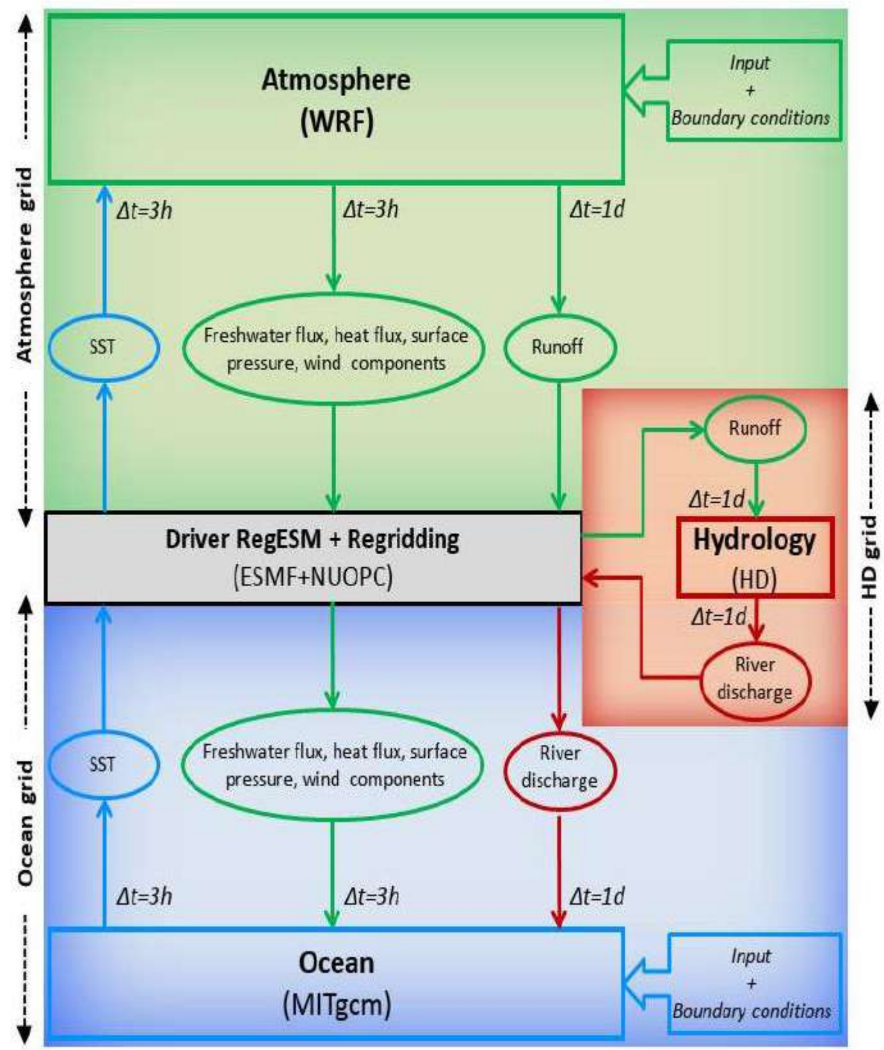


WCRP CMIP6
World Climate Research Programme

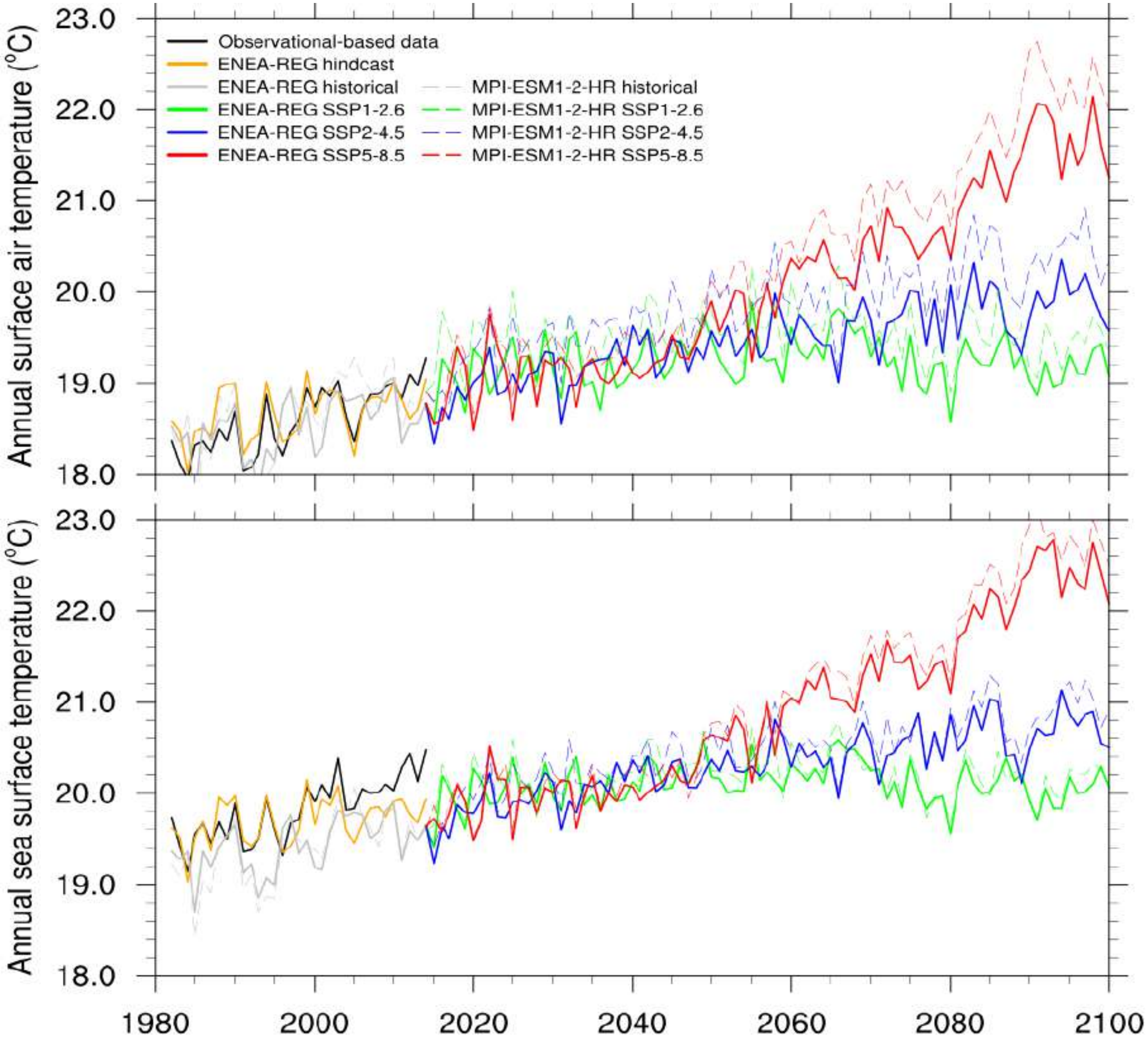
ENEA Regional Earth System Model

- Atmospheric Component: WRF (v4.2.2)
- Land surface: NOAH-MP
- Ocean model: MITgcm (z67)
- River Routing: HD
- Coupler: RegESM

Anav et al., 2021, GMD

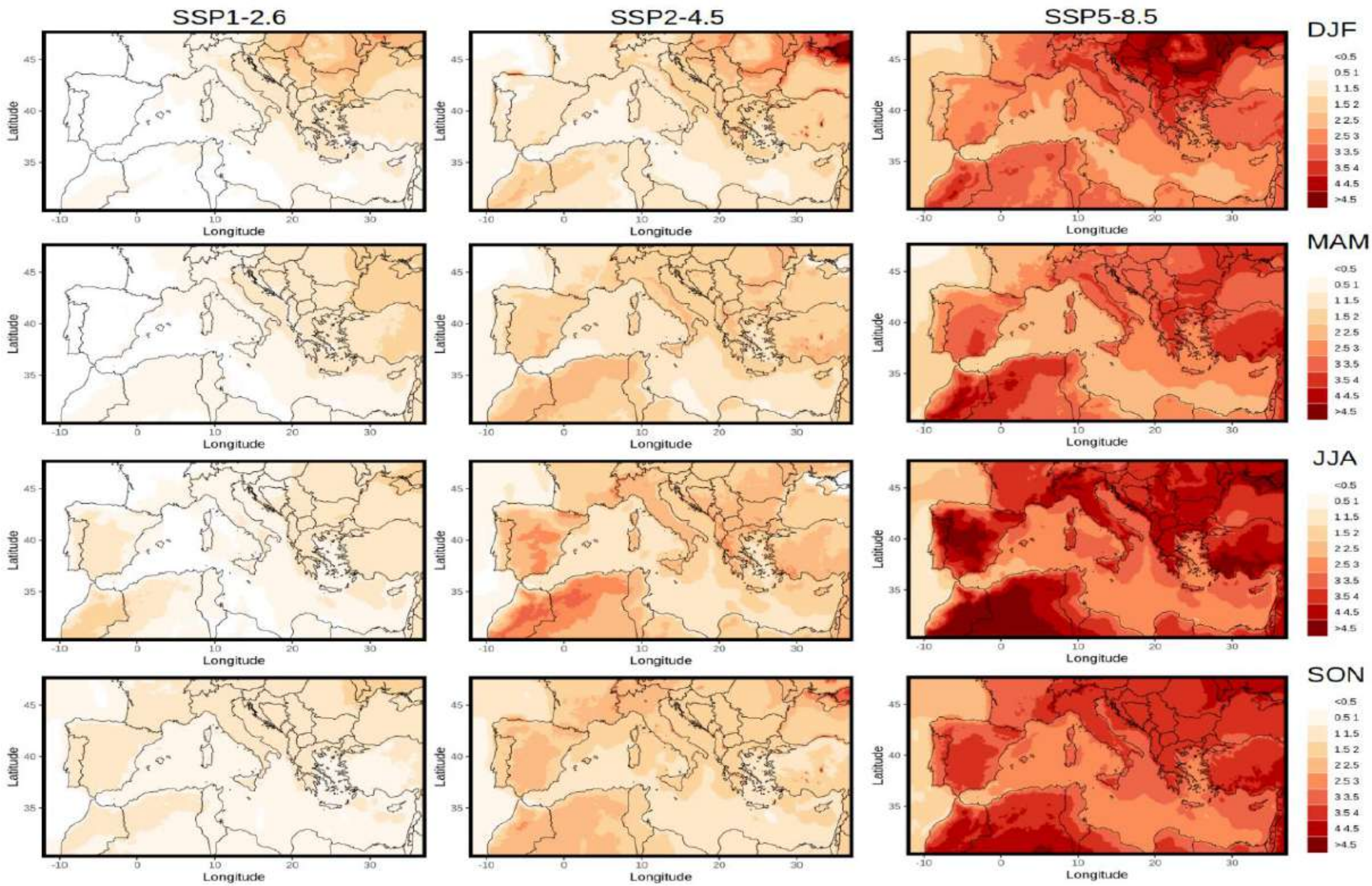


Future (2100) Mediterranean SST(CMIP6)



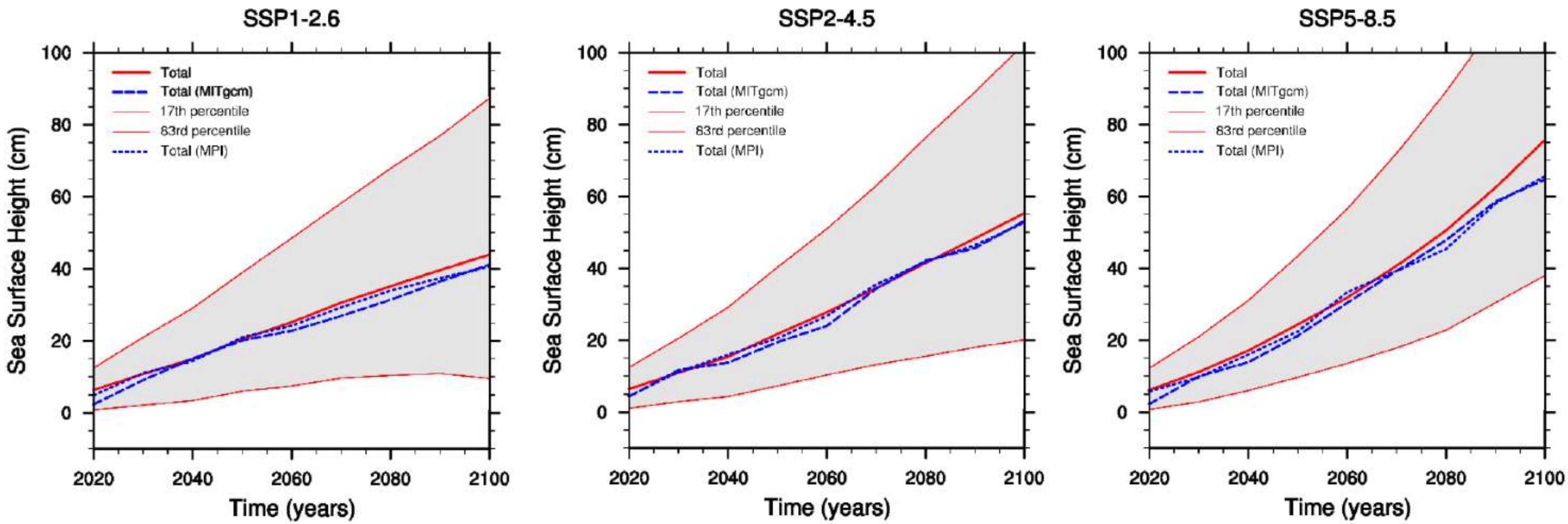
Results indicate that temperature trends strictly follow the large-scale driving models and the coupling or downscaling are able to modulate the magnitude of interannual variability

Future (2100) Mediterranean T2m



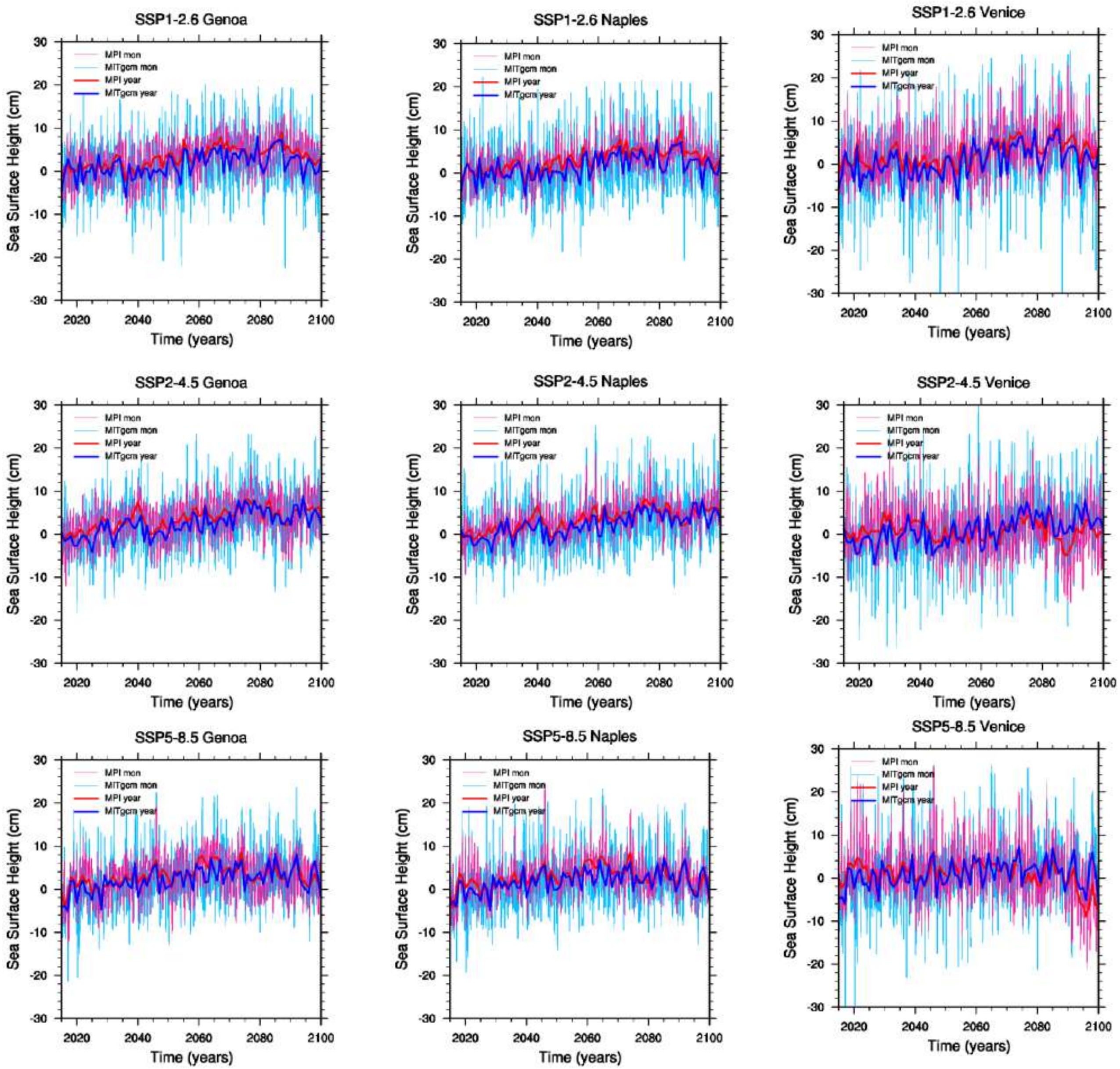
Projected climate change (2071-2100 minus 1985-2014)

Future (2100) Mediterranean Sea Level (CMIP6)



Total Sea level change averaged over the Mediterranean basin for the three SSP scenarios. Median over the AR6 models (red line) and 17th-83rd percentile range (shaded area). Projections are relative to a 1995-2014 baseline. Total using for the oceanic components MPI and MITgcm models are plotted in blue.

Future (2100) Mediterranean Sea Level (CMIP6)



Comparison of the MPI global model and MITgcm sea surface height for model points near to **Genoa**, **Naples** and **Venice**. From the left to the right column, scenario **SSP1-2.6**, **SSP2-4.5** and **SSP5-8.5**. Monthly values and yearly means are shown.

"What's the use of having developed a science well enough to make predictions if, in the end, all we're willing to do is stand around and wait for them to come true?"

— F. Sherwood Rowland (Nobel laureate)

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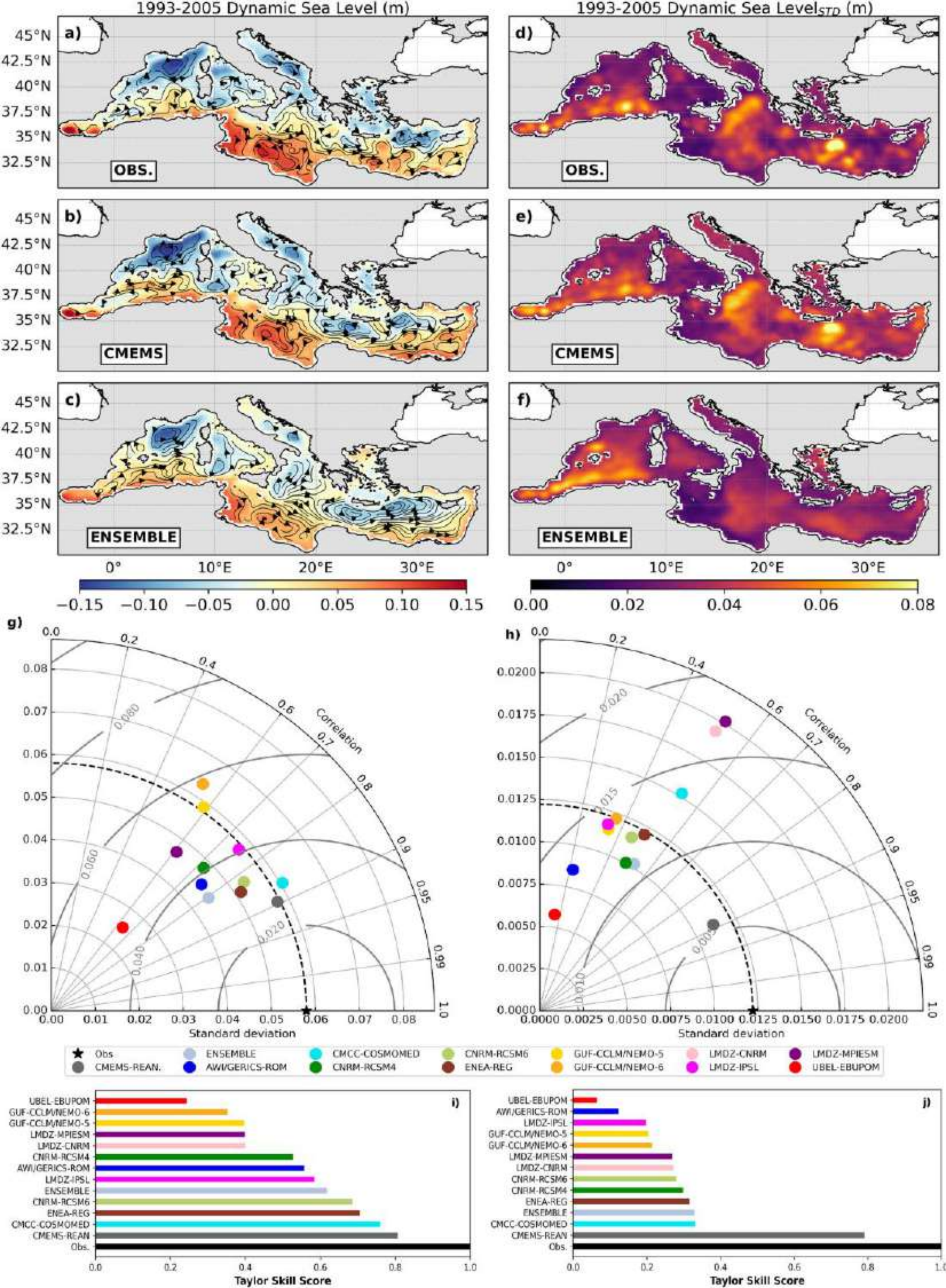

(a–c) 1993–2005 mean dynamic sea level (DSL, m) and geostrophic velocities (contours) from satellite measurements (OBS), the CMEMS reanalysis and ensemble mean. (d–f) 1993–2005 mean DSL (m) monthly variability from satellite measurements (OBS), the CMEMS reanalysis and ensemble mean. (g, h) Taylor diagram for Mediterranean (g) mean DSL and (h) DSL monthly variability during the 1993–2005 period. The diagram summarizes the relationship between standard deviation (m), spatial correlation (r) and RMSE (gray lines, m) for all datasets. (i, j) Taylor Skill Score (Taylor, **2001**) of (i) DSL and (j) DSL monthly variability between satellite observations and each individual model.