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

Il Mediterraneo: Hot-Spot Climatico

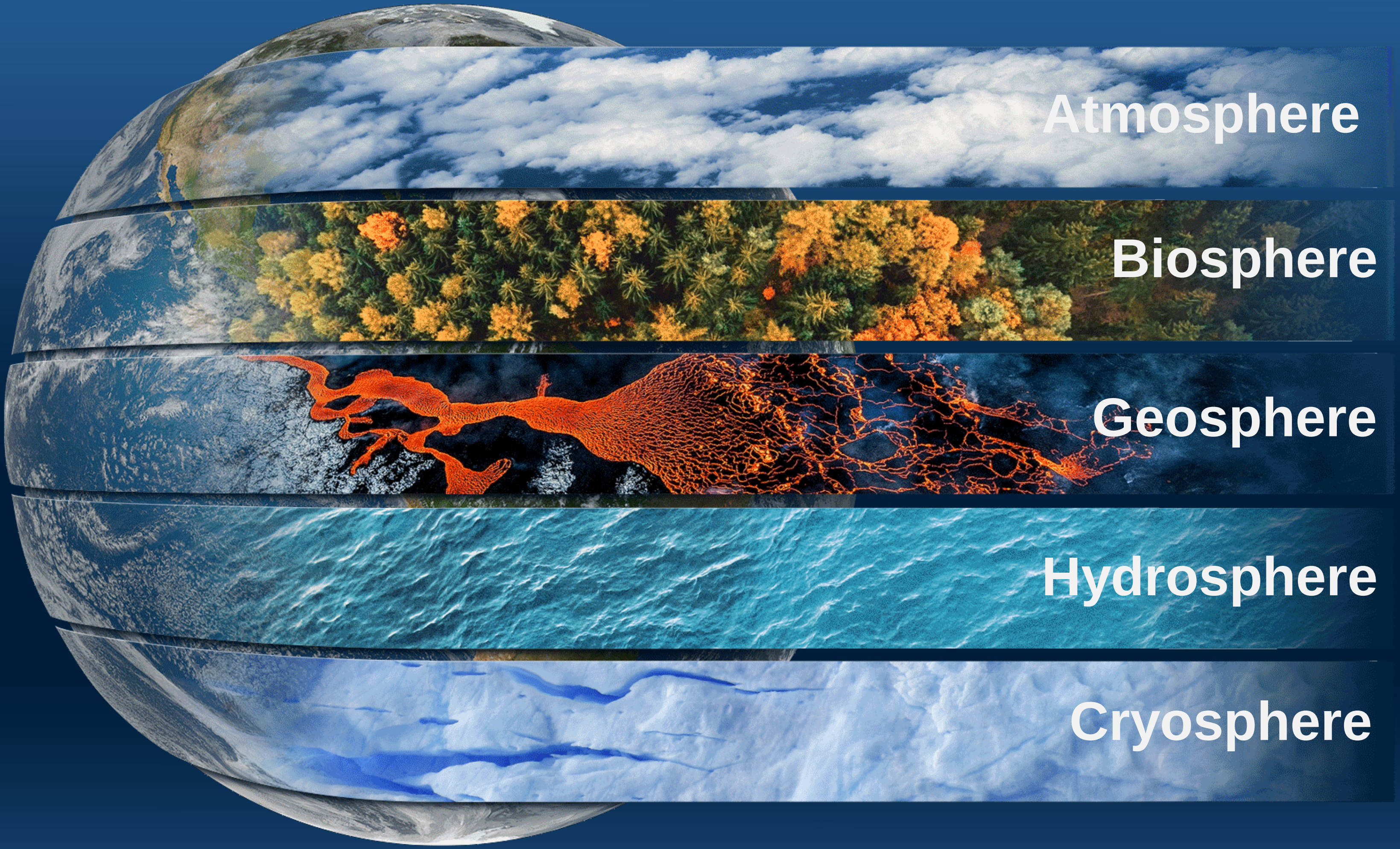
Dati Attuali e Proiezioni Future

Gianmaria Sannino

Models, Observations, and Scenarios for Climate Change and Air Quality Division

Background: The Climate System

Five components that interact among them through different overlapping and complex processes.

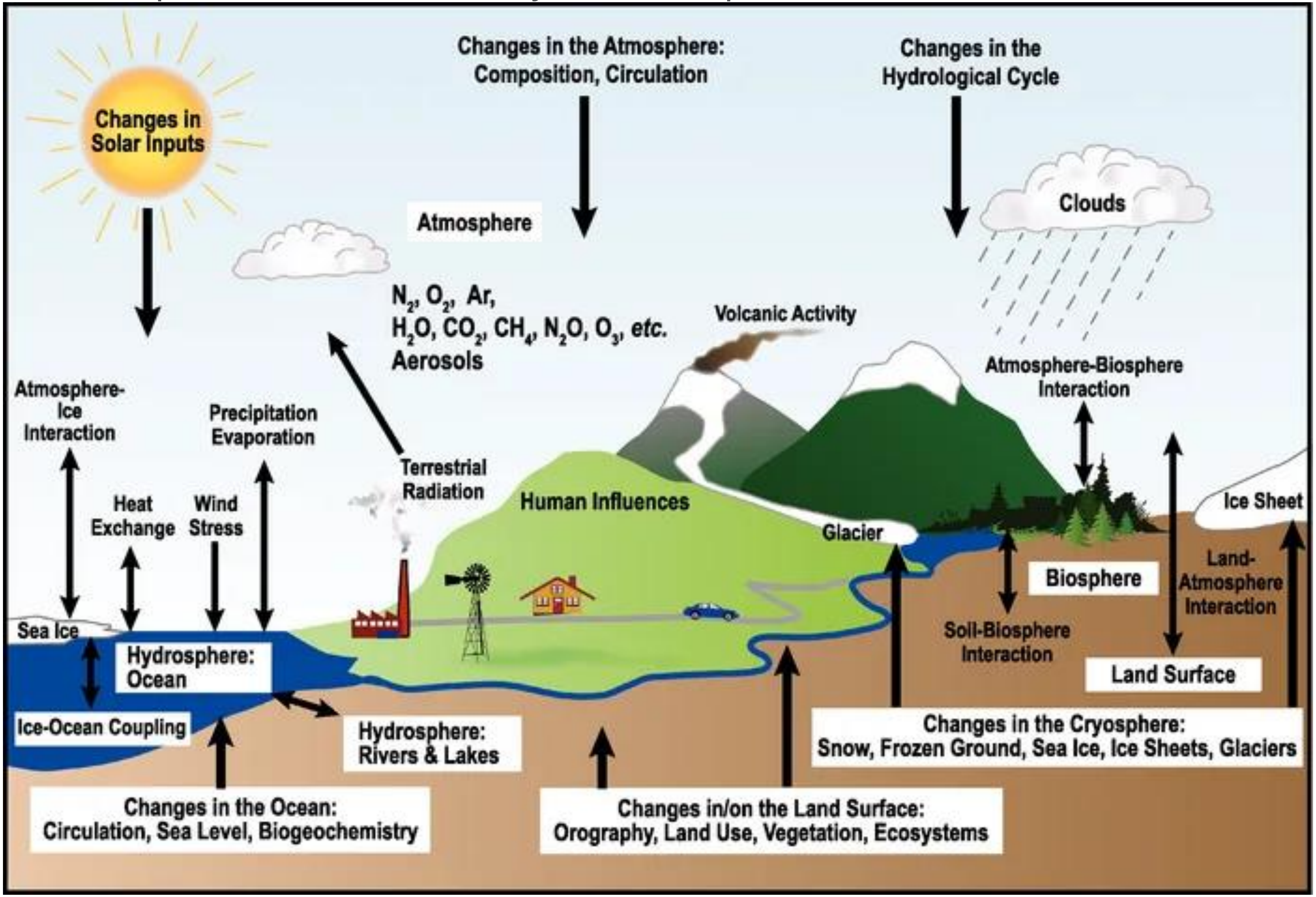


These five components are interconnected through various biogeochemical cycles (like the water cycle and carbon cycle) and feedback loops. They influence each other on **different spatial and temporal scales**, leading to the complex and dynamic nature of our planet.

Cresdit: https://mynasadata.larc.nasa.gov/

Background: The Climate System

The components of the climate system, their processes, and interactions.



Background: The Climate System

The **Sun** is the major source of energy for Earth's oceans, atmosphere, land, and biosphere. Averaged over an entire year, approximately **342 watts** of solar energy fall upon **every square meter** of Earth. This is a tremendous amount of energy — **44 quadrillion** (4.4×10^{16}) watts of power to be exact.

ENEA

Background: Sun & Climate System

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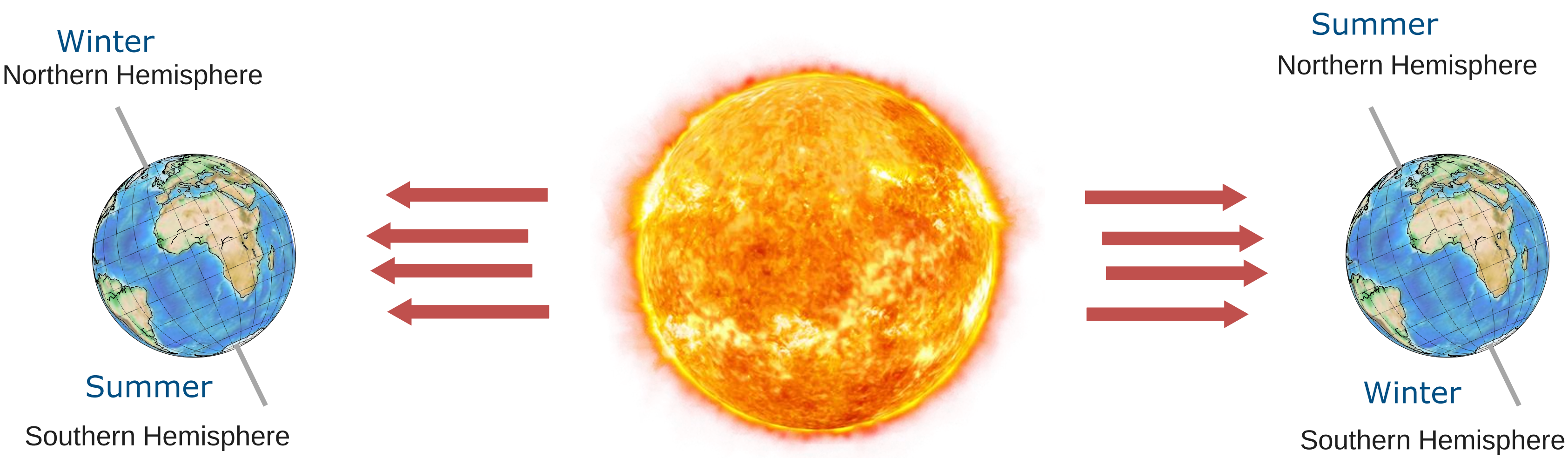
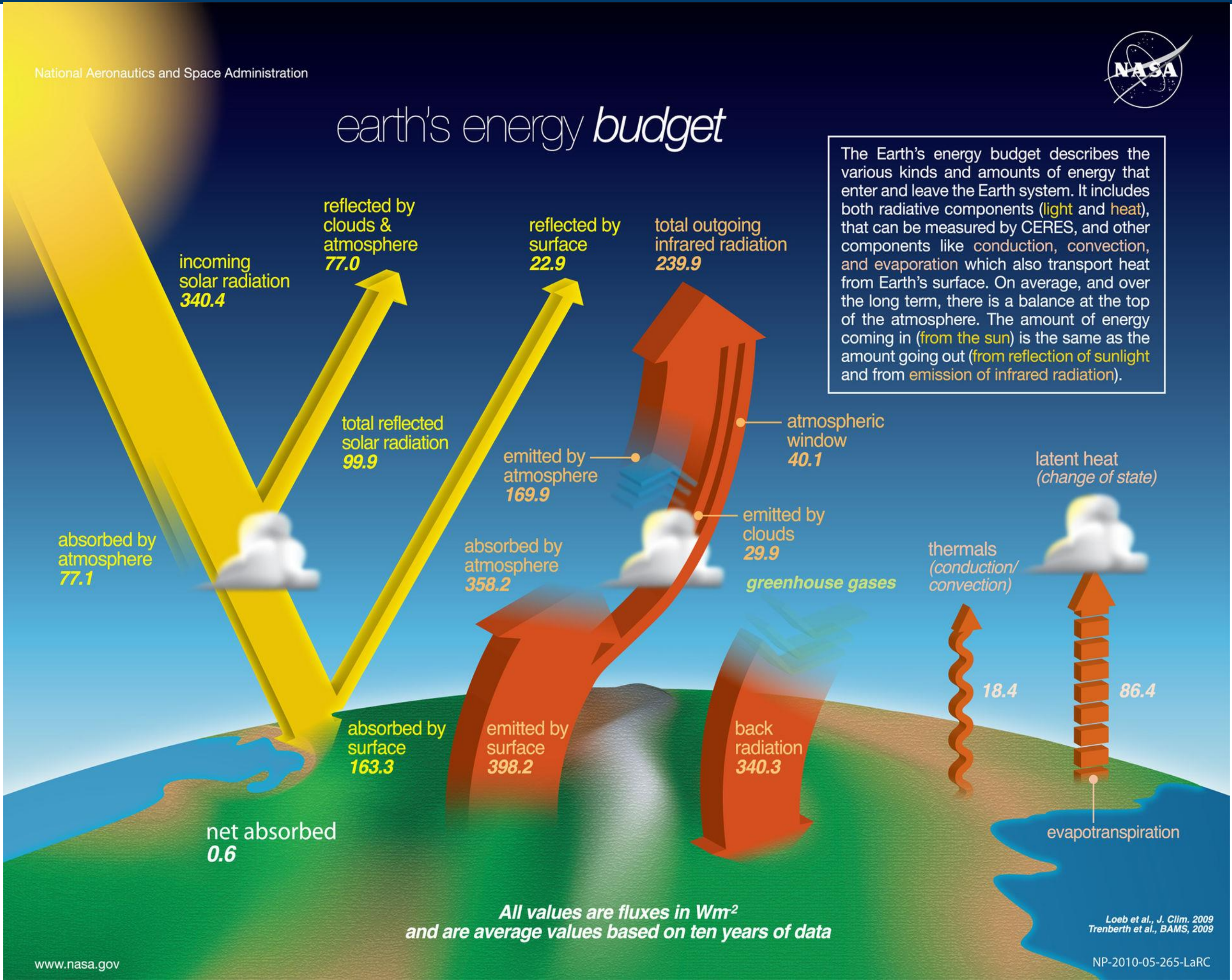


44 quadrillion watts = 5.5 million of the most powerful nuclear power plant

Kashiwazaki-Kariwa Nuclear Power Plant (capacity 8 GW)

Background: The Climate System

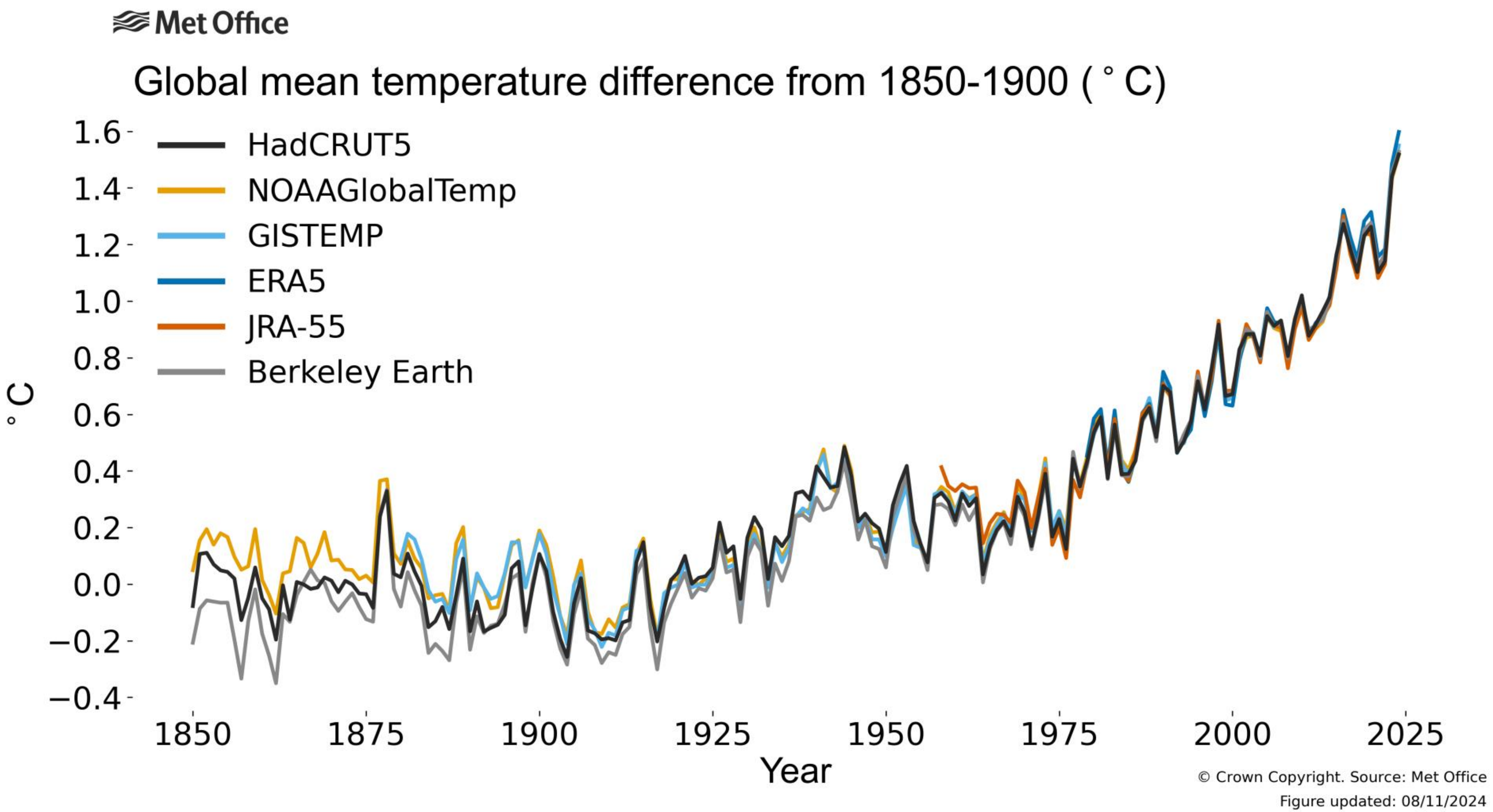


Background: The Climate System

The most basic way to characterize the **climate system** is describing it as a **nonequilibrium thermodynamic system**, generating entropy by irreversible processes and – if time-dependent forcings can be neglected – keeping a steady state by **balancing the input and output of energy** and entropy with the surrounding environment.

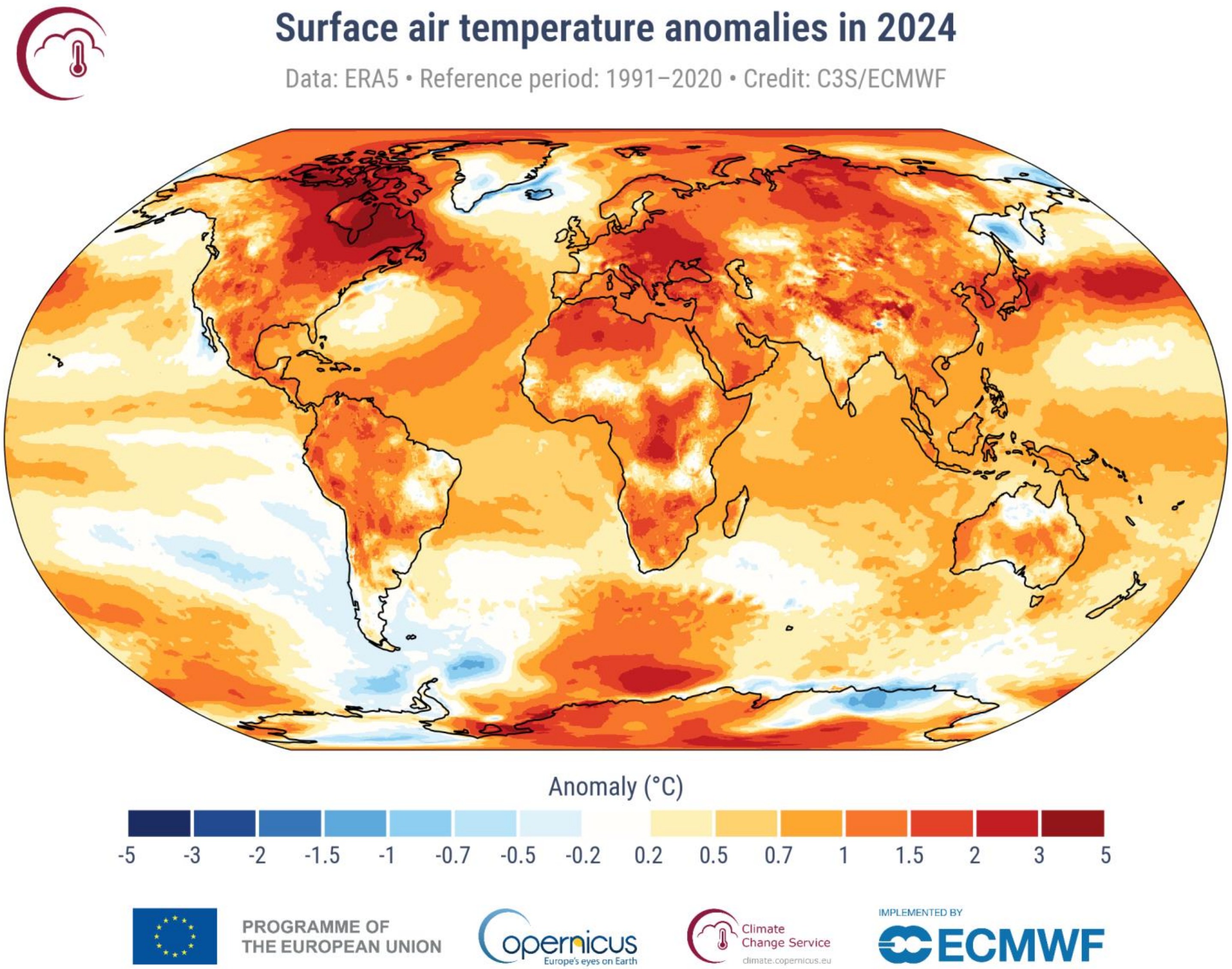
Schneider and Bony, Nature Geo. 2014

State of Cimate: Global Surface Temperature



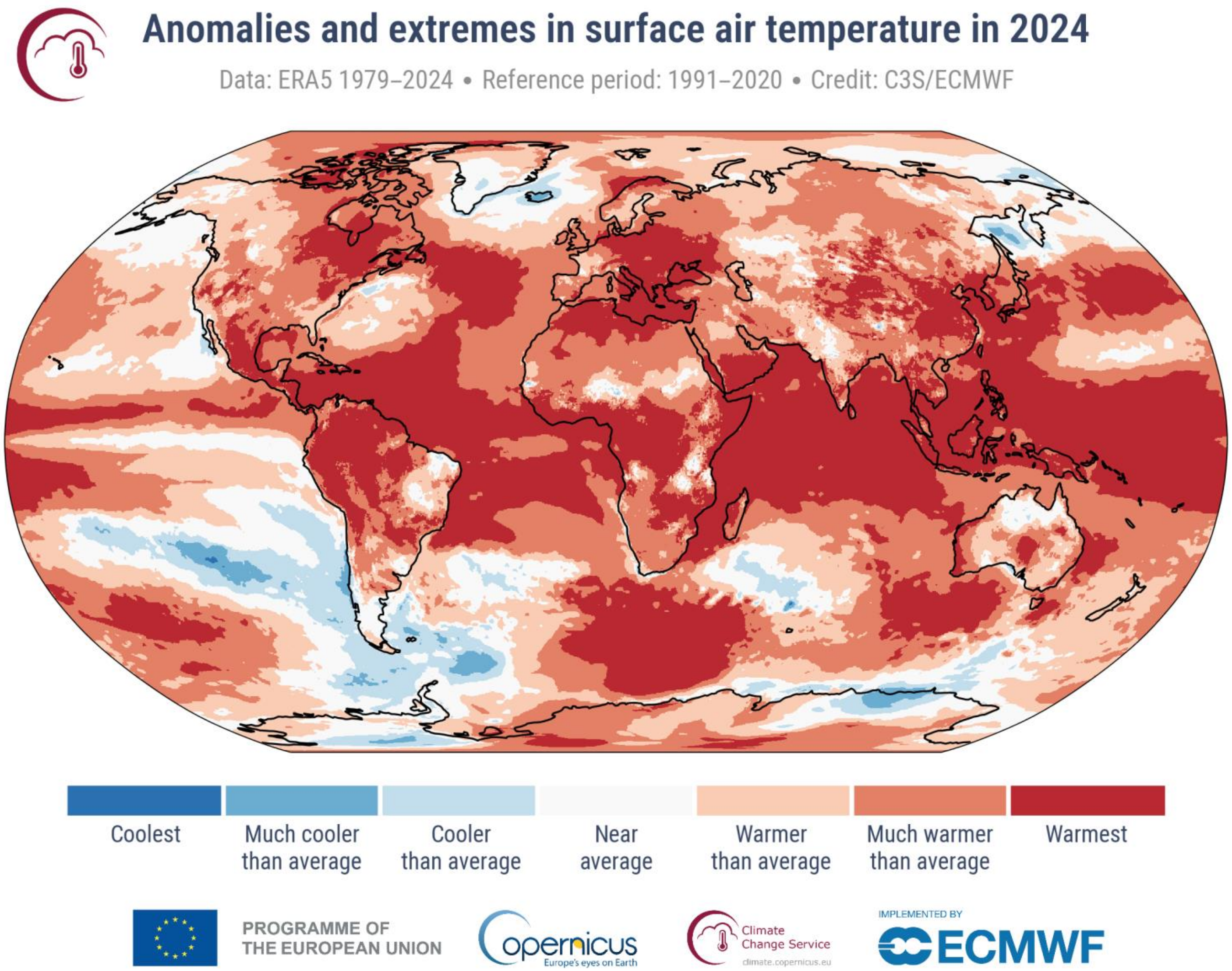
Annual global mean temperatures expressed as a difference from pre-industrial conditions. Four different data sets are shown - HadCRUT, NOAAGlobalTemp, GISTEMP, and Berkeley Earth - as well as two reanalyses - ERA5 and JRA-55. Dataset anomalies are calculated relative to a 1981 to 2010 baseline and offset 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



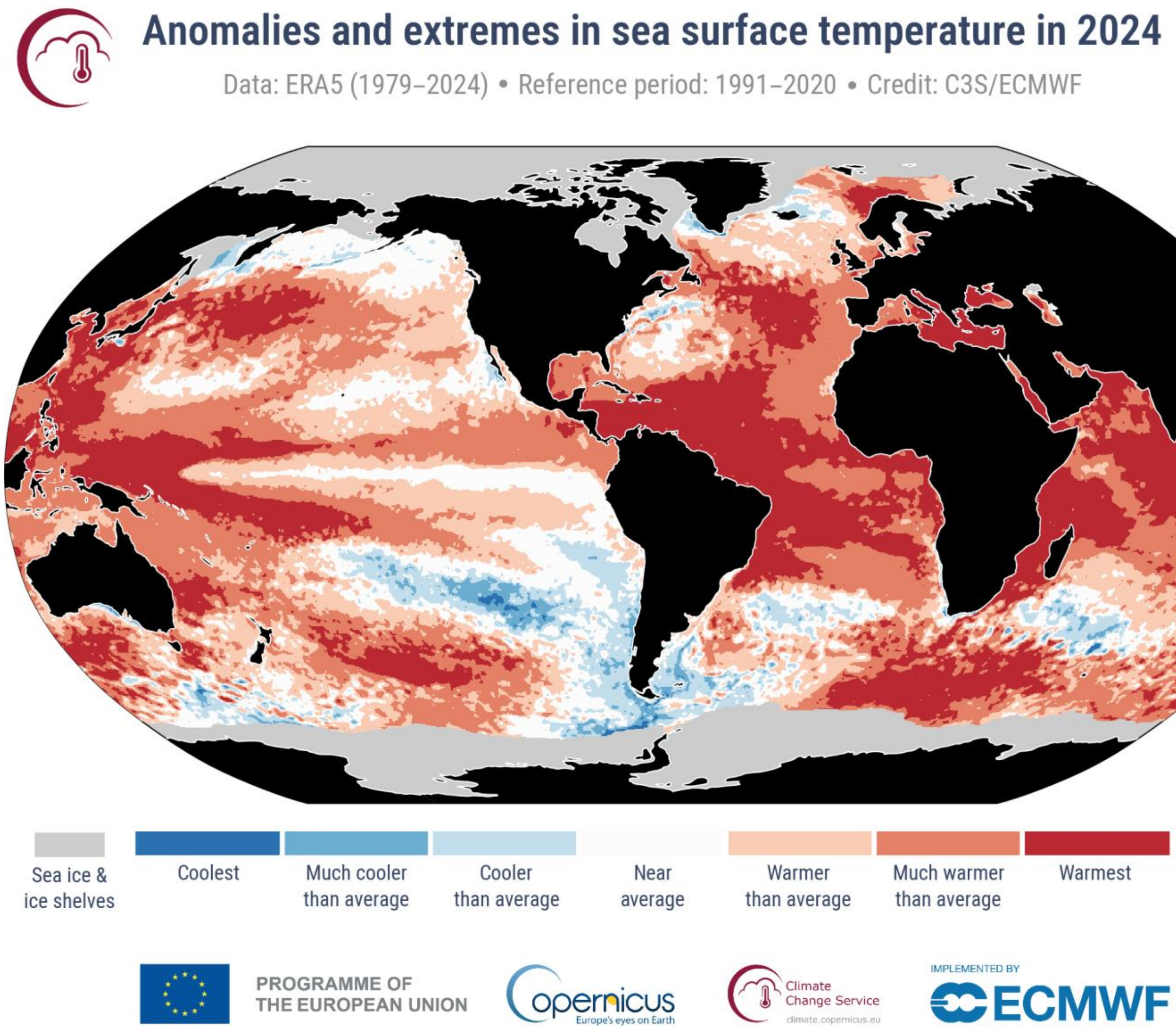
Surface air temperature anomalies in 2024, relative to the average for the 1991–2020 reference period. A non-linear colour scale is used to enhance the visibility of smaller anomalies and distinguish larger deviations. Data source: ERA5. Credit: C3S/ECMWF.

State of Cimate: Global Surface Temperature



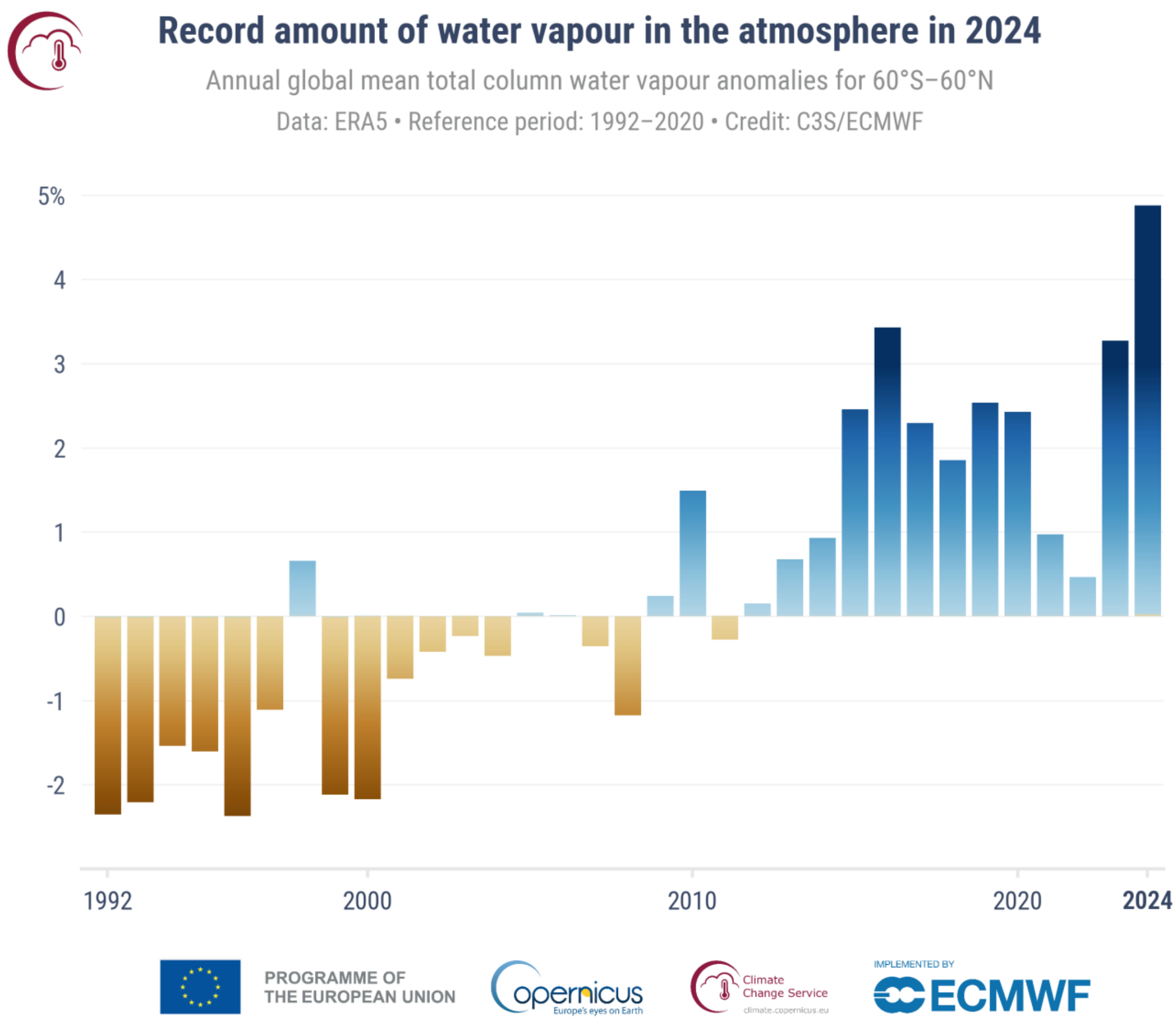
Surface air temperature anomalies in 2024, relative to the average for the 1991–2020 reference period. A non-linear colour scale is used to enhance the visibility of smaller anomalies and distinguish larger deviations. Data source: ERA5. Credit: C3S/ECMWF.

State of Cimate: Global Surface Temperature



Anomalies and extremes in sea surface temperature for 2024. Colour categories refer to the percentiles of the temperature distributions for the 1991–2020 reference period. The extreme ('coolest' and 'warmest') categories are based on rankings for the period 1979–2024. Values are calculated only for the ice-free oceans. Data source: ERA5. Credit: C3S/ECMWF.

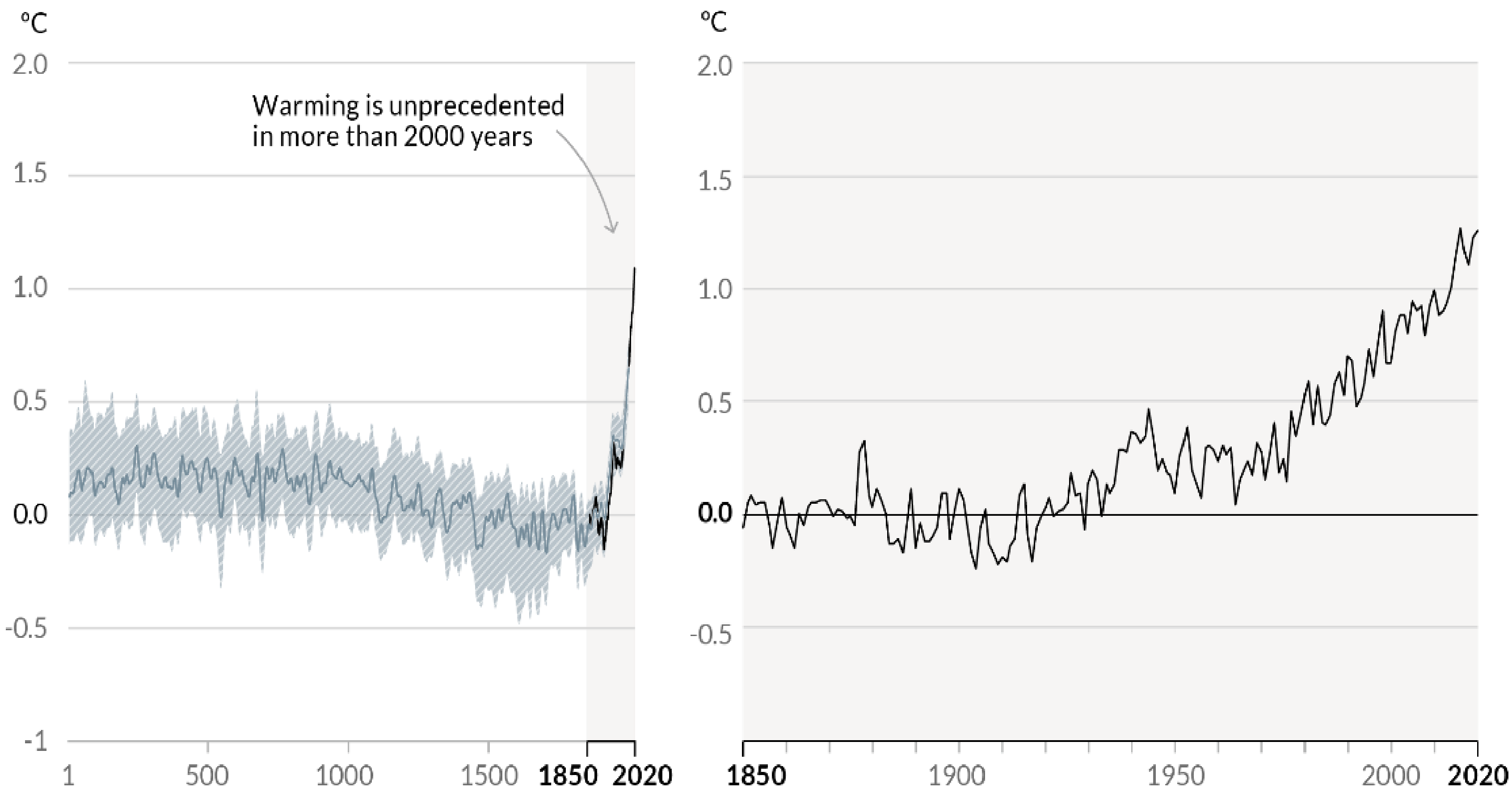
State of Cimate: water vapour in the atmosphere



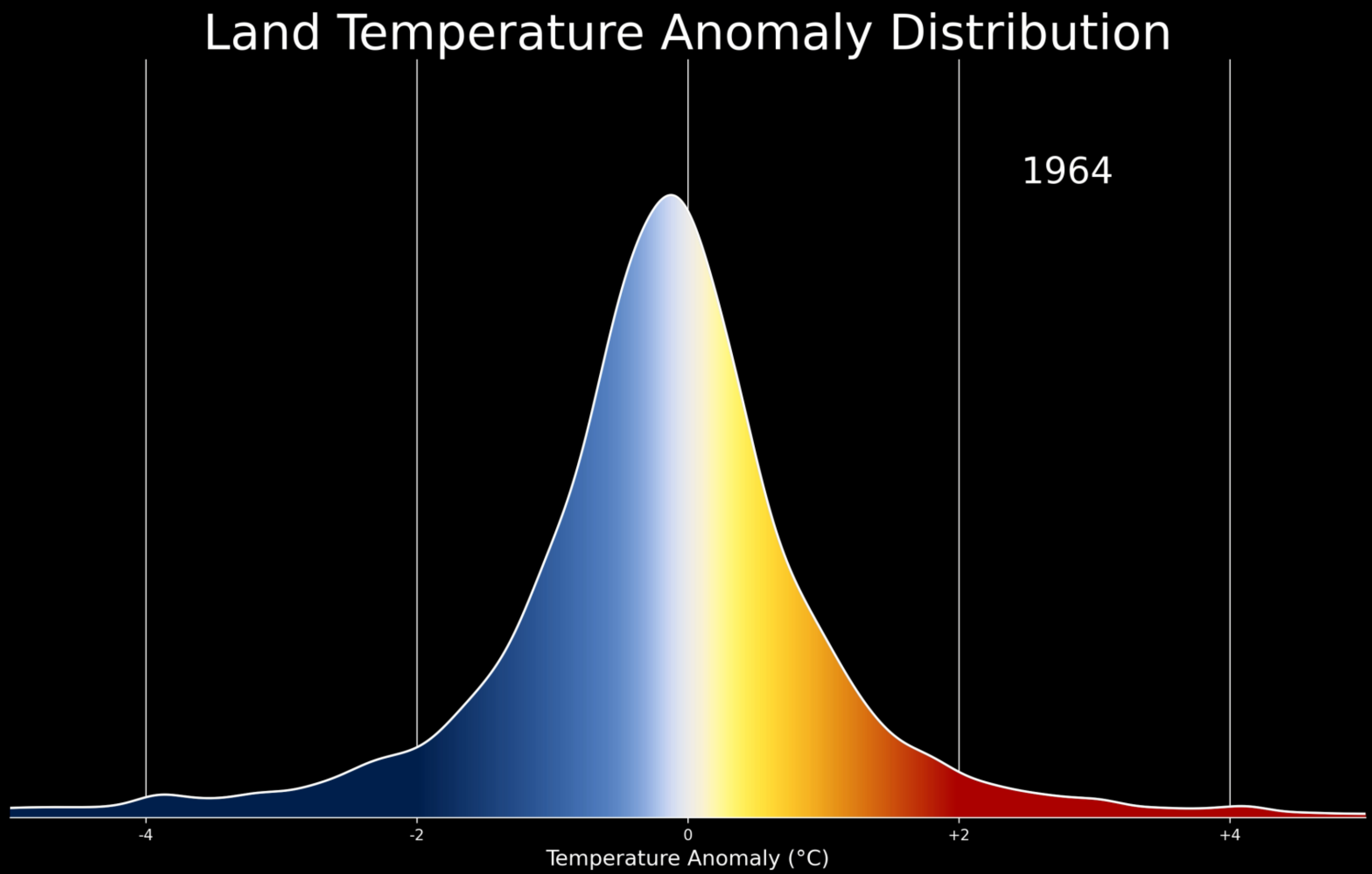
Annual anomalies in the average amount of total column water vapour over the 60 ° S–60 ° N domain relative to the average for the 1992–2020 reference period. The anomalies are expressed as a percentage of the 1992–2020 average. Data: ERA5. Credit: C3S/ECMWF.

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.

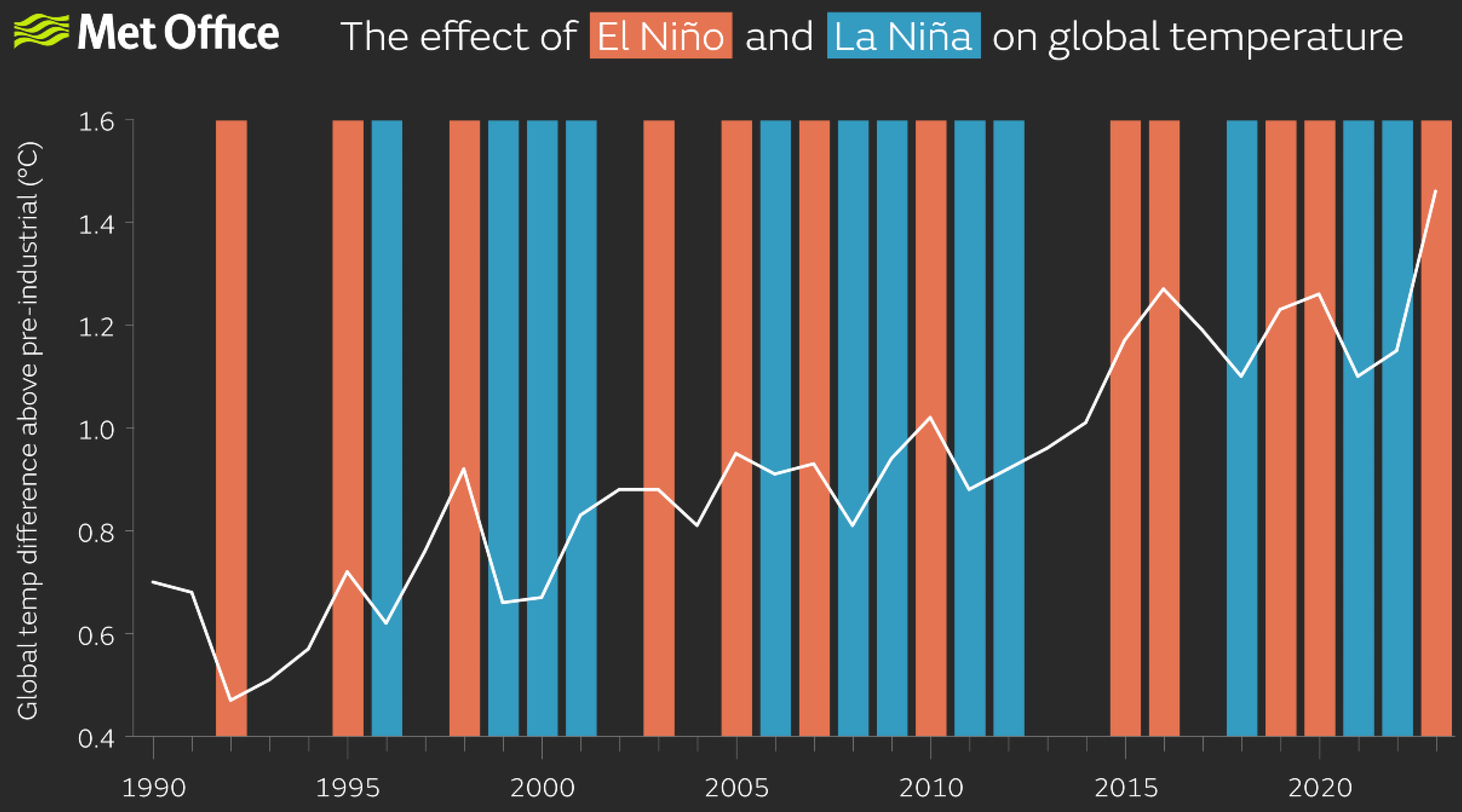


Shifting Distribution of Land Temperature Anomalies, 1964-2024



The data visualization above shows how air temperatures between 1964 and 2024 departed from the average for 1951-1980.) The darker shades of blue represent times when temperatures were significantly cooler than the norm and the orange and red represent times when temperature was hotter than the norm.

State of Cimate: Global Surface Temperature

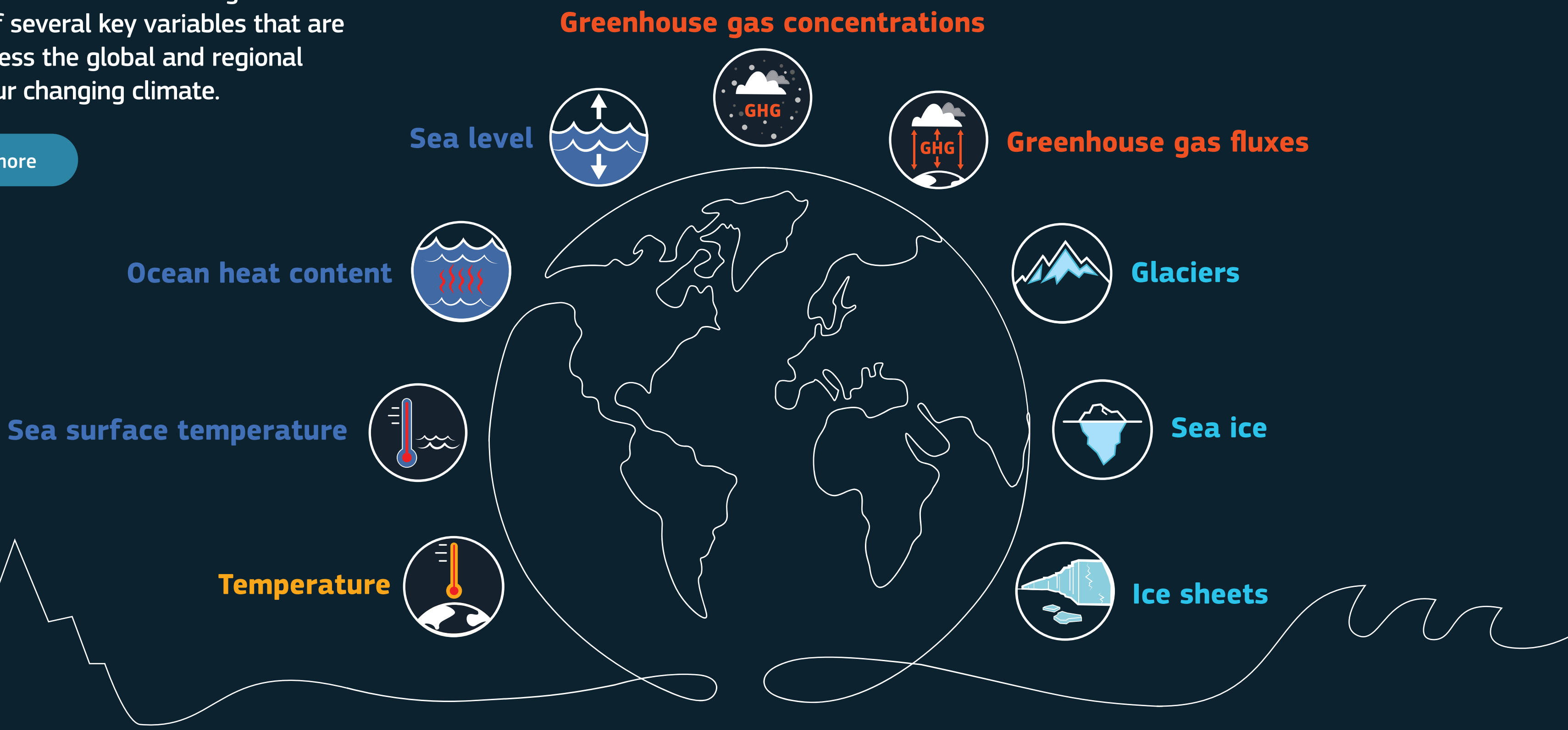


State of climate: Not only Temperature

Trends in **Climate Indicators**

Climate Indicators show the long-term evolution of several key variables that are used to assess the global and regional trends of our changing climate.

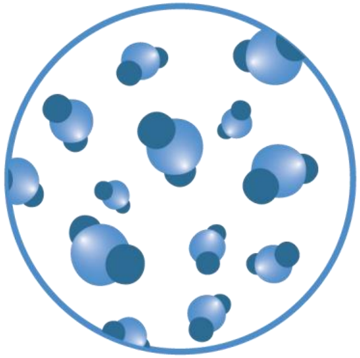
Find out more



Copernicus
Europe's eyes on Earth

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

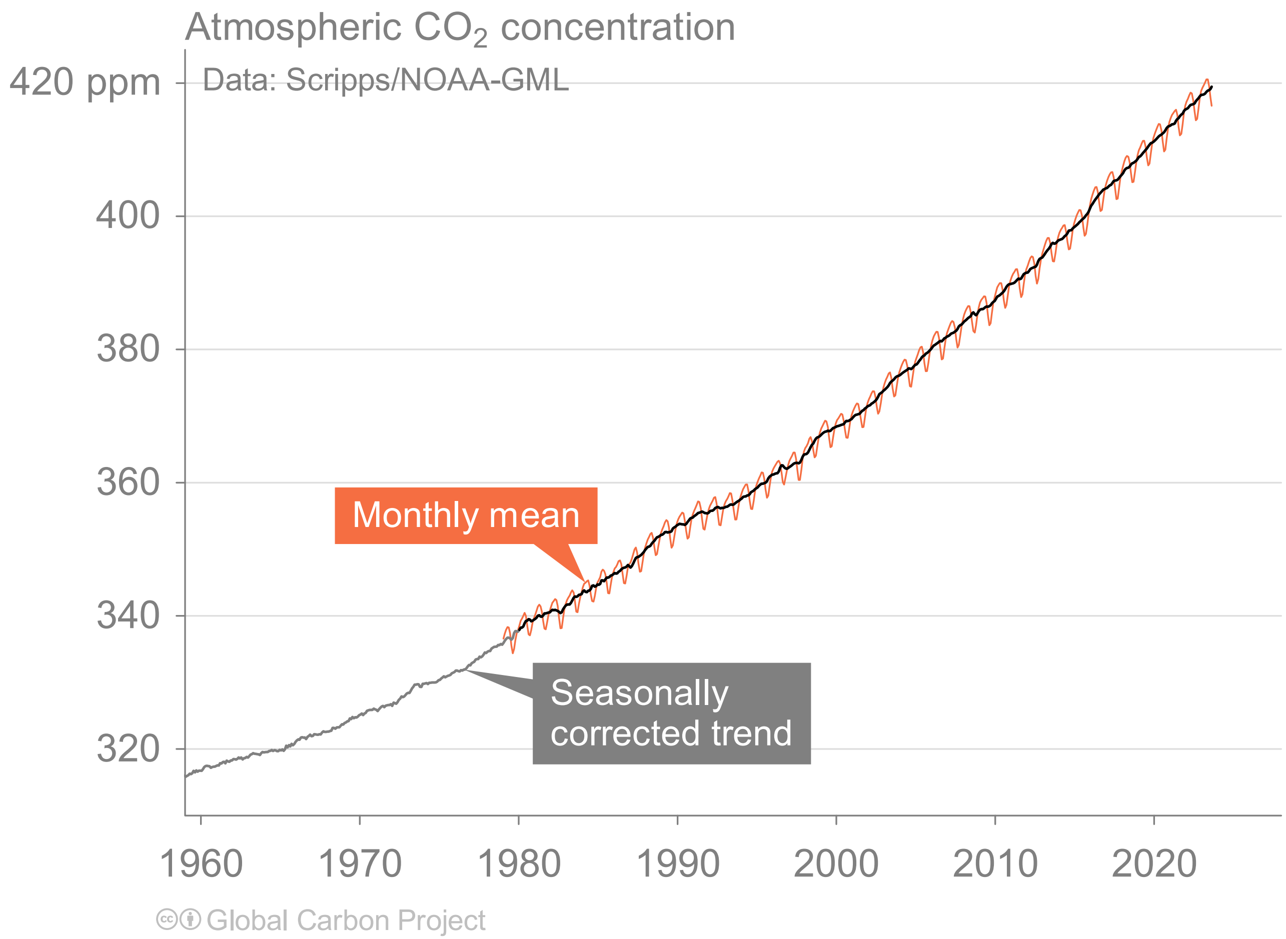
2000 years

Cimate status: Carbon Dioxide in Atmosphere

Latest Measurement: April 2024

427 ppm

The global CO_2 concentration increased from ~277 ppm in 1750 to **419.3 ppm** in 2023 (up 51%)



[Credit: Yoda Adaman | Unsplash]

"It is indisputable that human activities are causing climate change, making extreme climate events, including heat waves, heavy rainfall, and droughts, more frequent and severe.

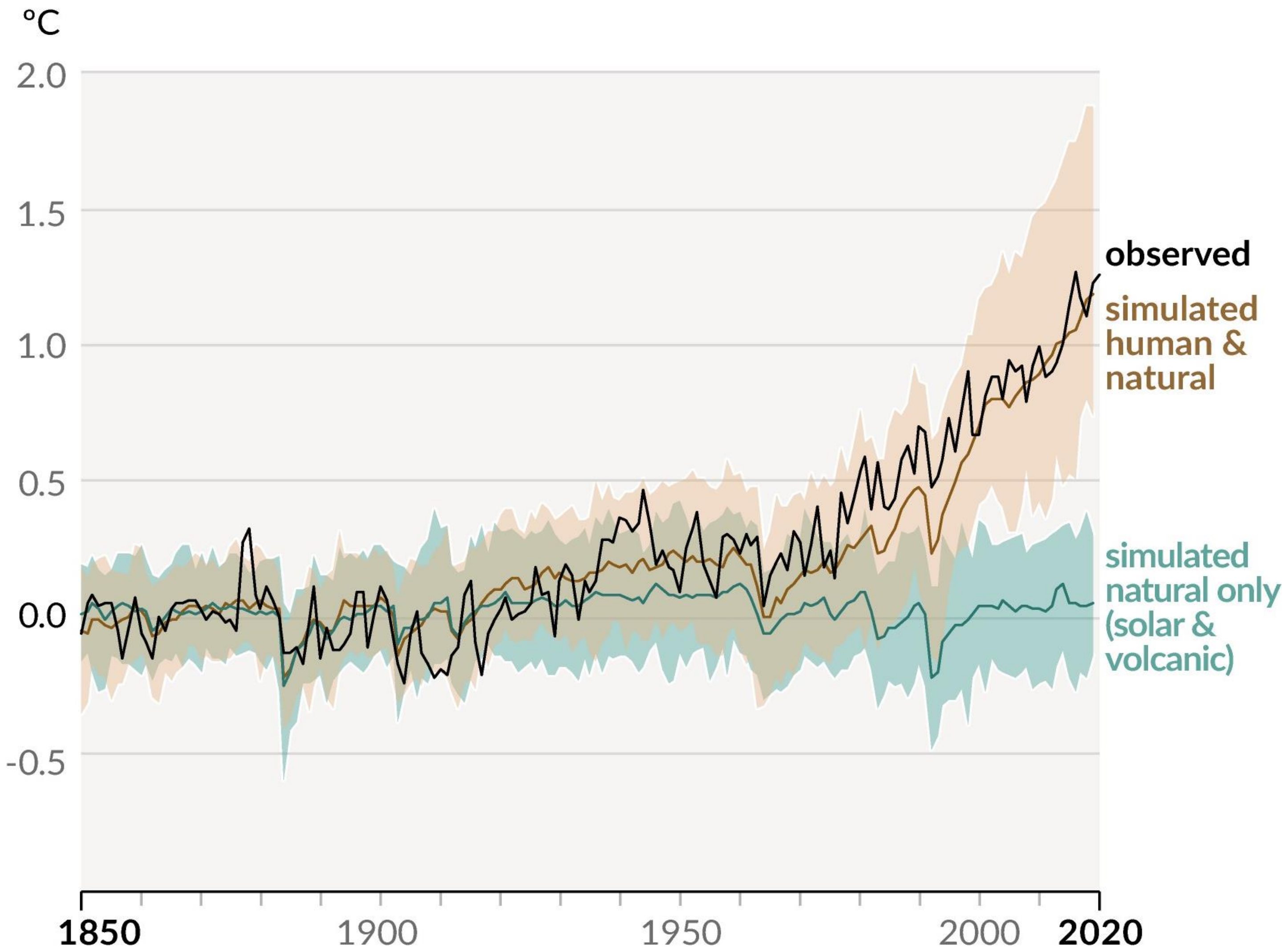
INTERGOVERNMENTAL PANEL ON climate change

ipcc

WMO UNEP

Human influence on climate change

b) Change in global surface temperature (annual average) as **observed** and simulated using **human & natural** and **only natural** factors (both 1850-2020)



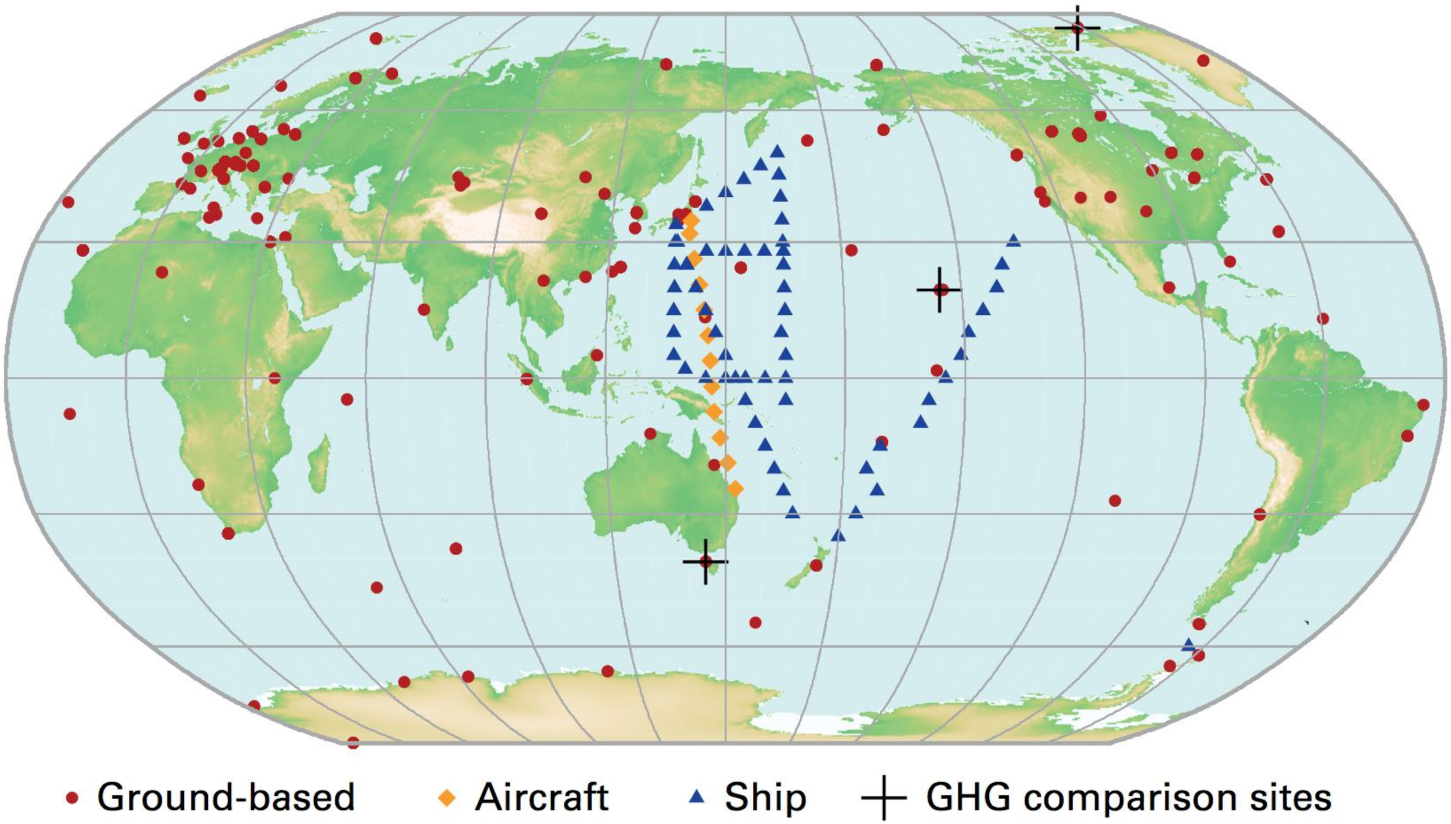
Cimate status: Carbon Dioxide in Atmosphere

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

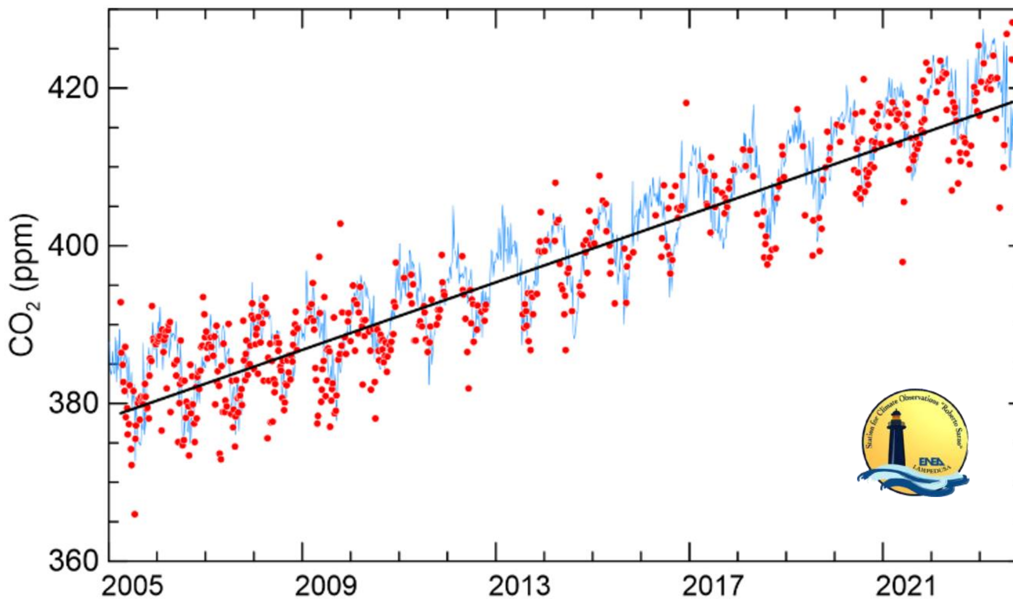


ENEA

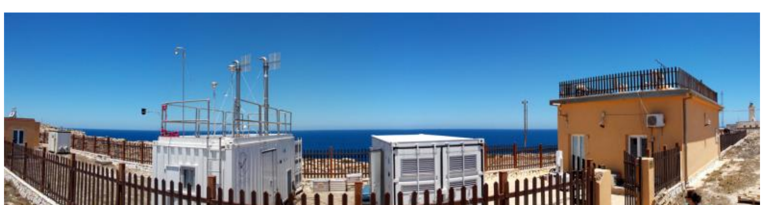
Cimate status: ENEA Contribution (GHG Measurement)

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)



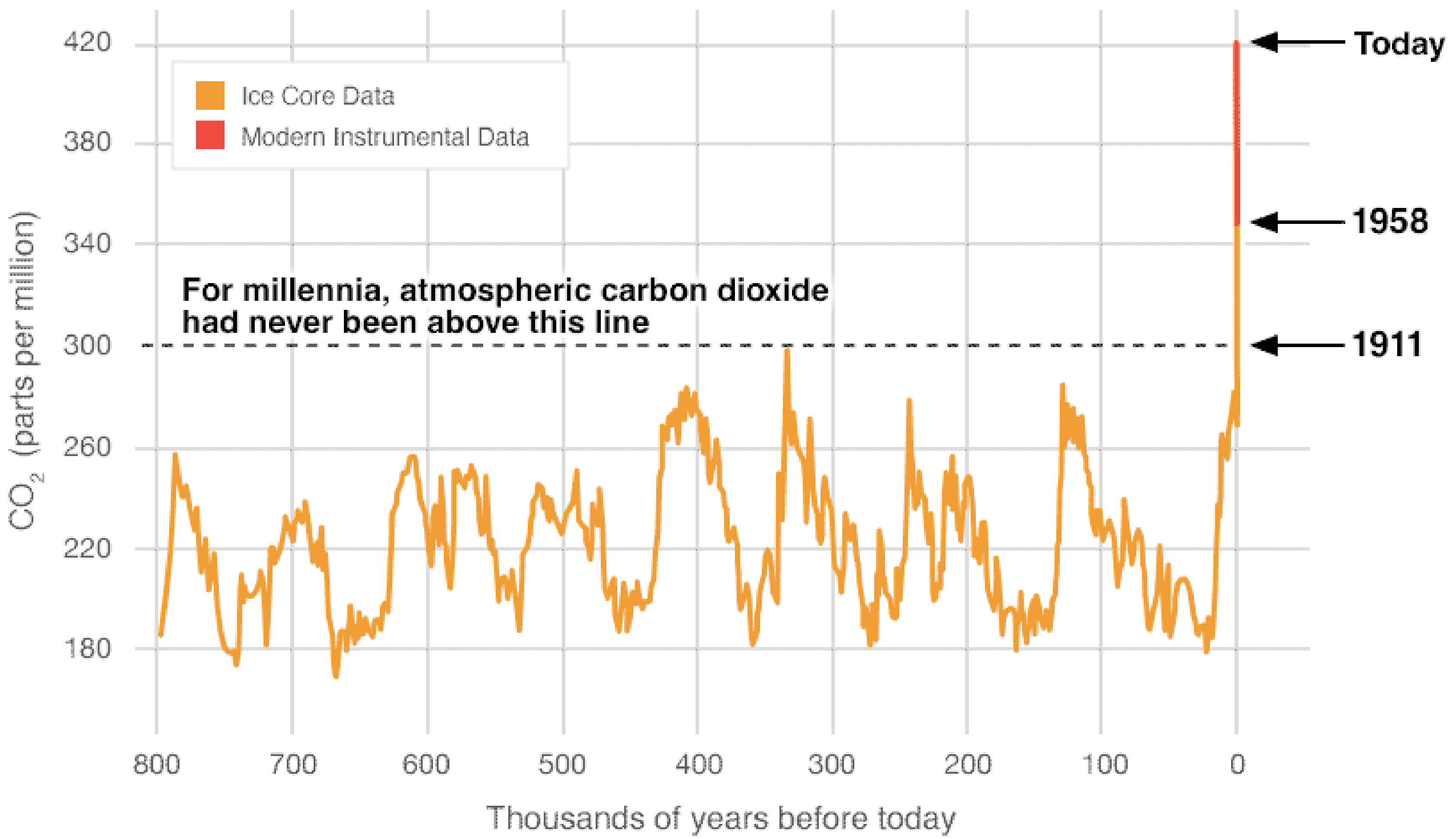
Cimate status: Carbon Dioxide

PROXY (INDIRECT) MEASUREMENTS

Data source: Reconstruction from ice cores.
Credit: NOAA

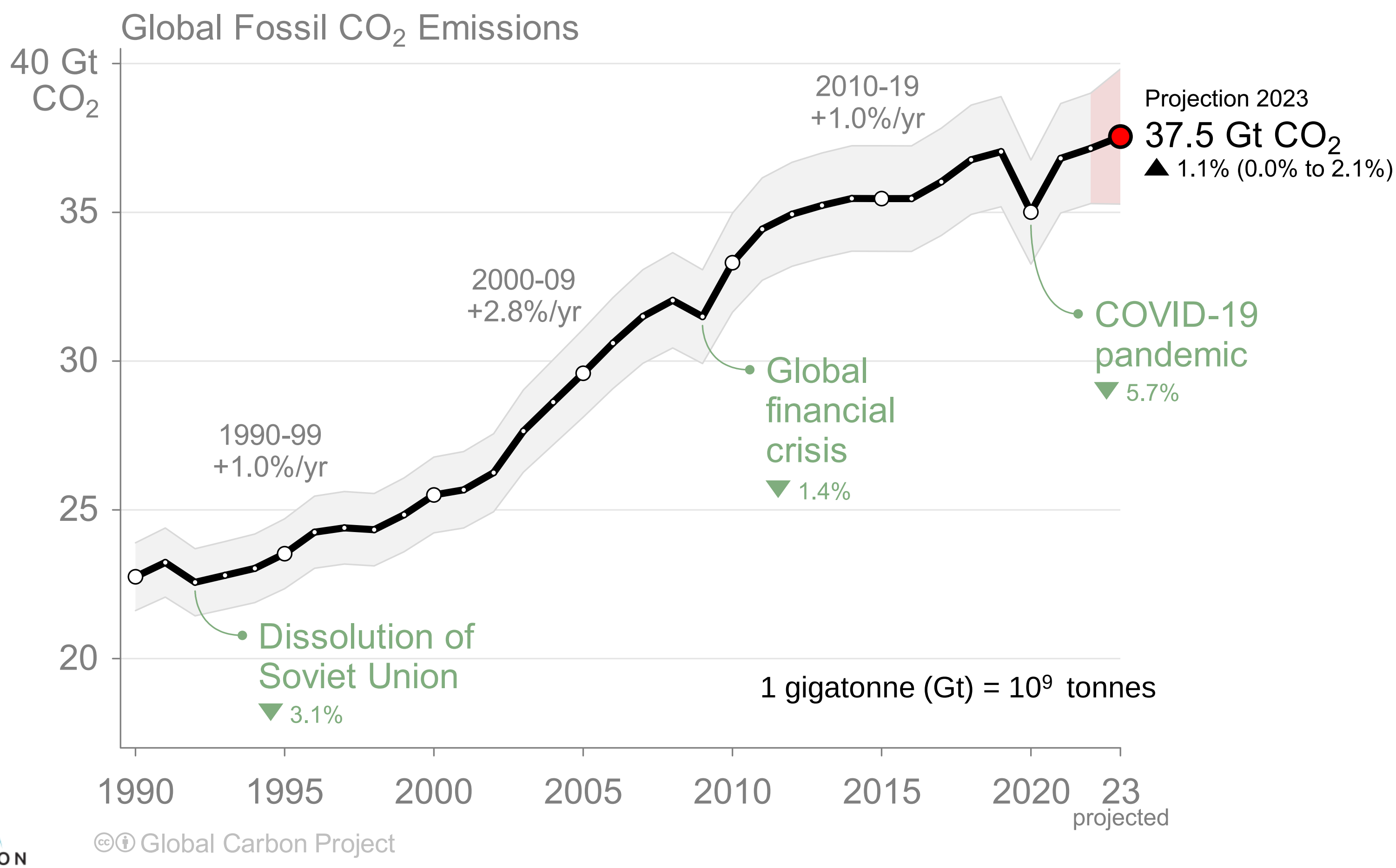
Latest Measurement: April 2024

427 ppm



Cimate status: Carbon Dioxide emissions

Global carbon emissions in 2023 remain at record levels – with no sign of the decrease that is urgently needed to limit warming to 1.5° C, according to the Global Carbon Project science team.



GLOBAL CARBON project

ENEA

Cimate status: Carbon Dioxide emissions

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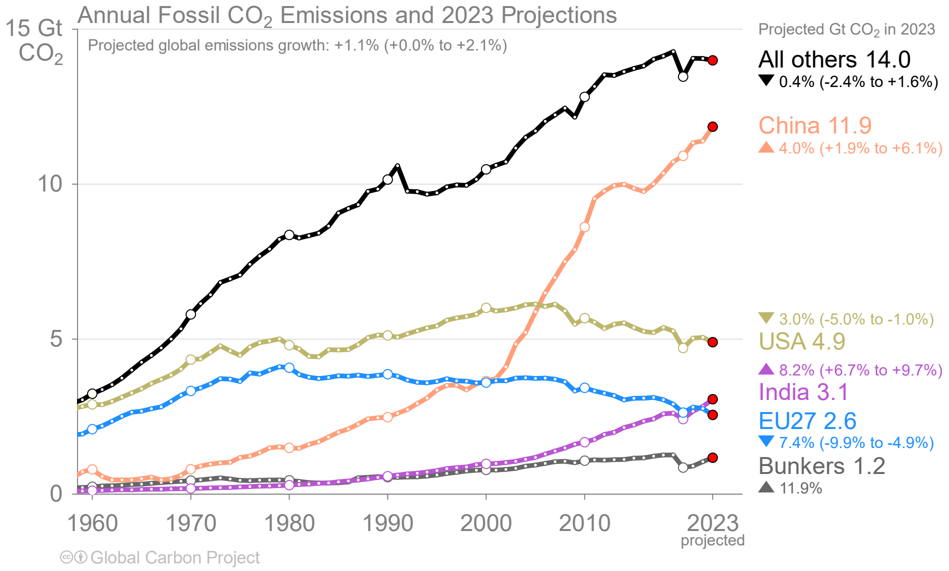

1 gigatonne (Gt) = 10^9 tonnes

Cimate status: Carbon Dioxide emissions

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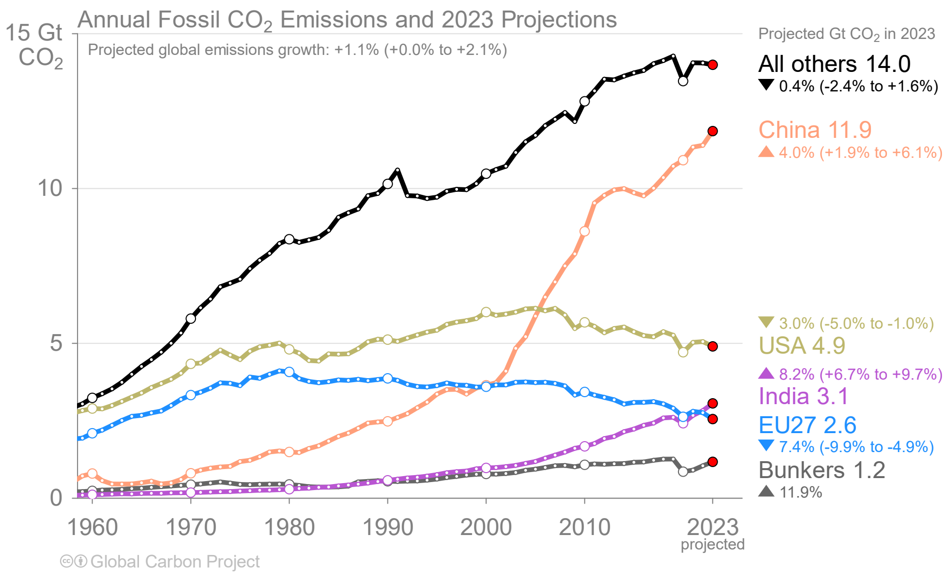
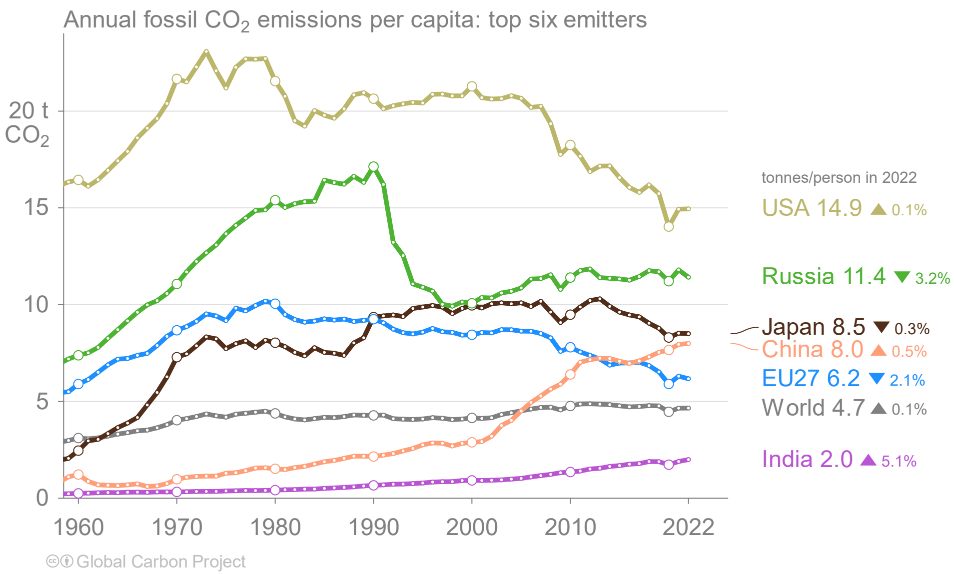
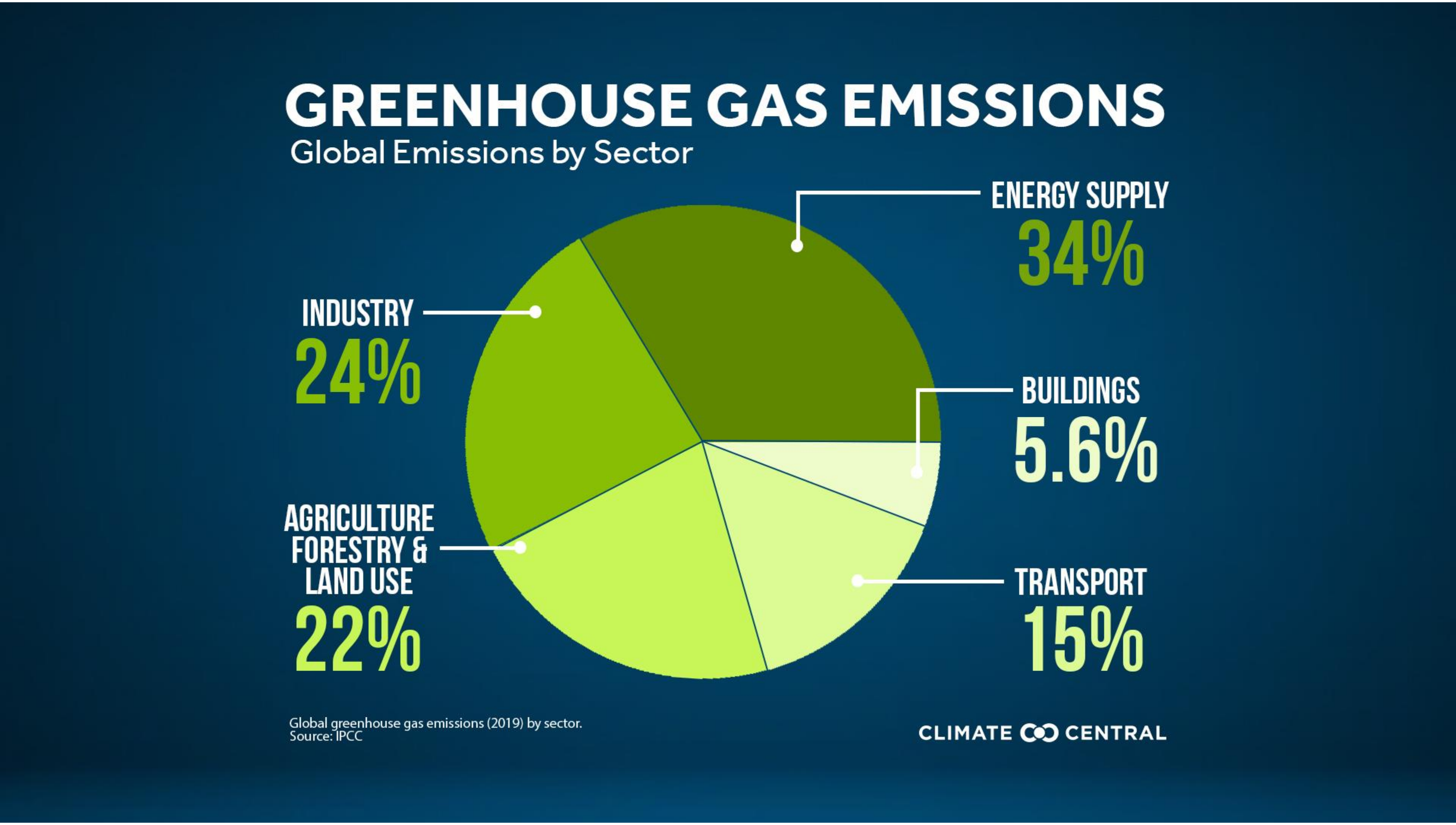




1 gigatonne (Gt) = 10^9 tonnes

Countries have a broad range of per capita emissions reflecting their national circumstances

Cimate status: Carbon Dioxide emissions by sector



Changes at global scale

INTERGOVERNMENTAL PANEL ON climate change

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

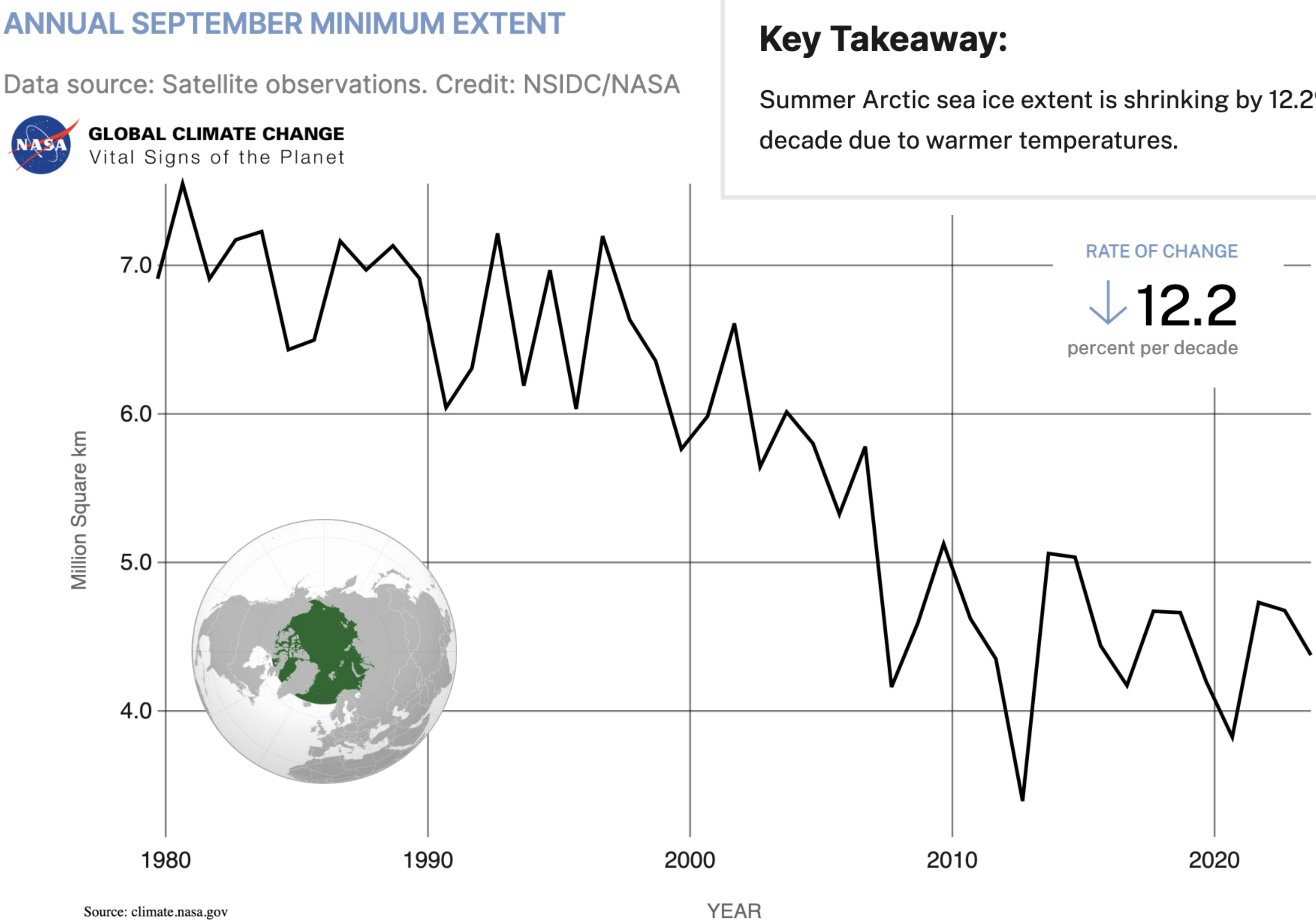
Glaciers retreat

Unprecedented

in at least

2000 years

Cimate status: Arctic Sea Ice Minimum Extent



Key Takeaway:

Summer Arctic sea ice extent is shrinking by 12.2% per decade due to warmer temperatures.

Source: climate.nasa.gov

Changes at global scale

ipcc INTERGOVERNMENTAL PANEL ON climate change

WMO UNEP

CO_2
concentration

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area

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1000 years

Glaciers
retreat

Unprecedented

in at least

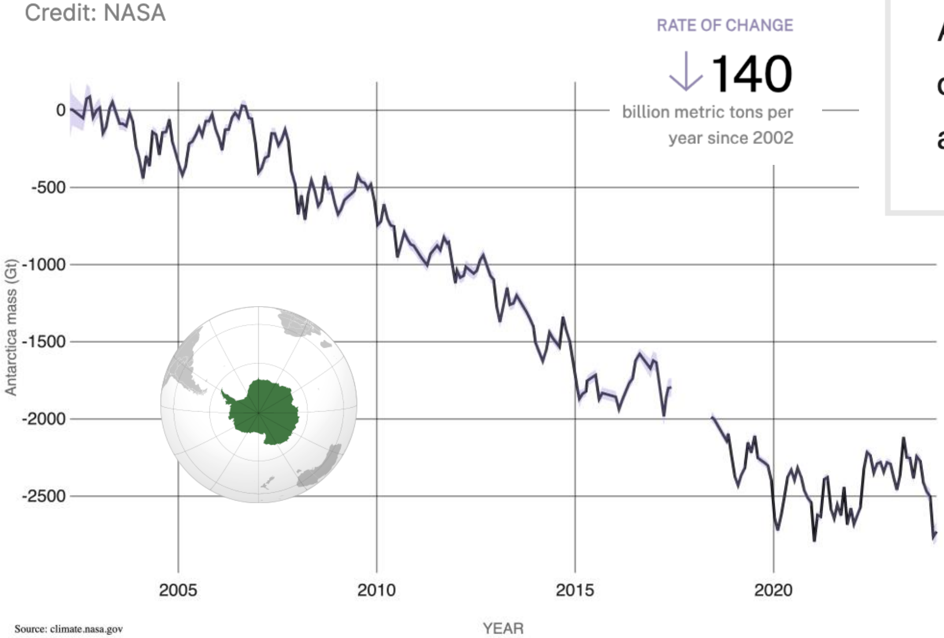
2000 years

ENEA

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

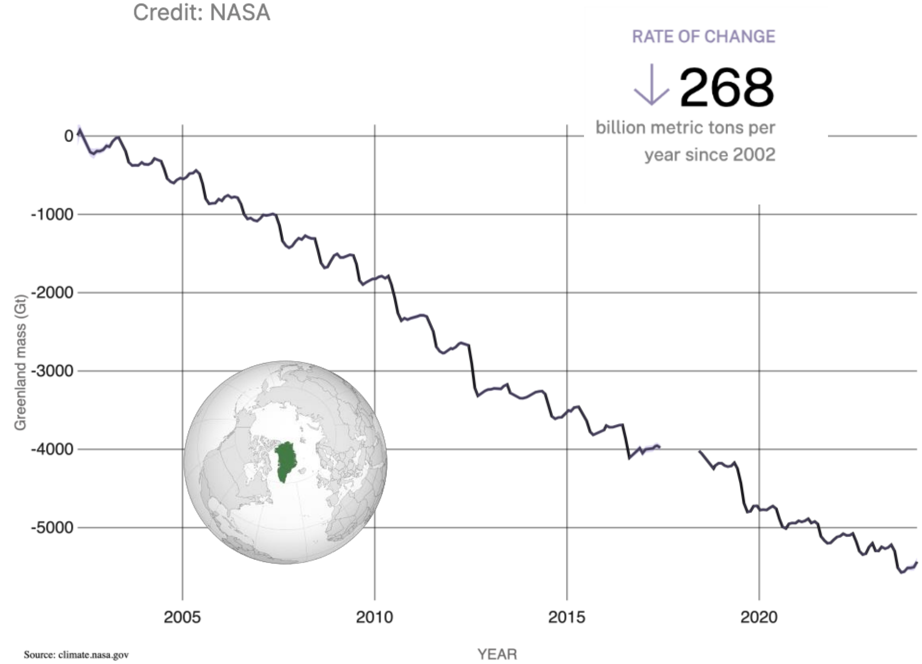


Key Takeaway:

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

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Sea level rise

Fastest rates

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Arctic sea ice area

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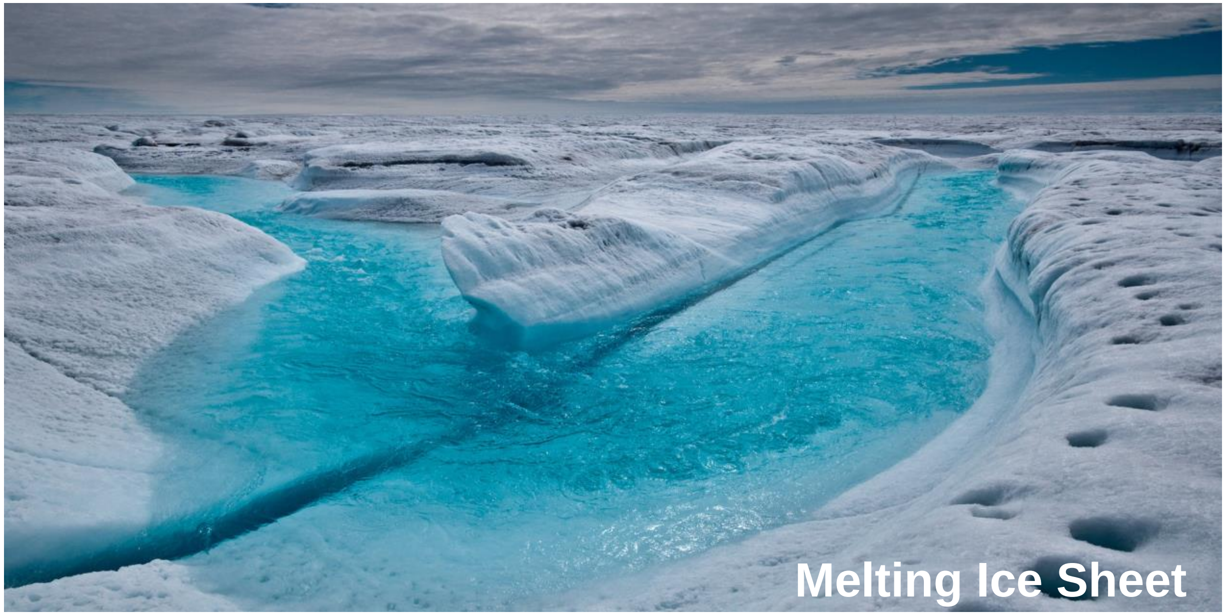
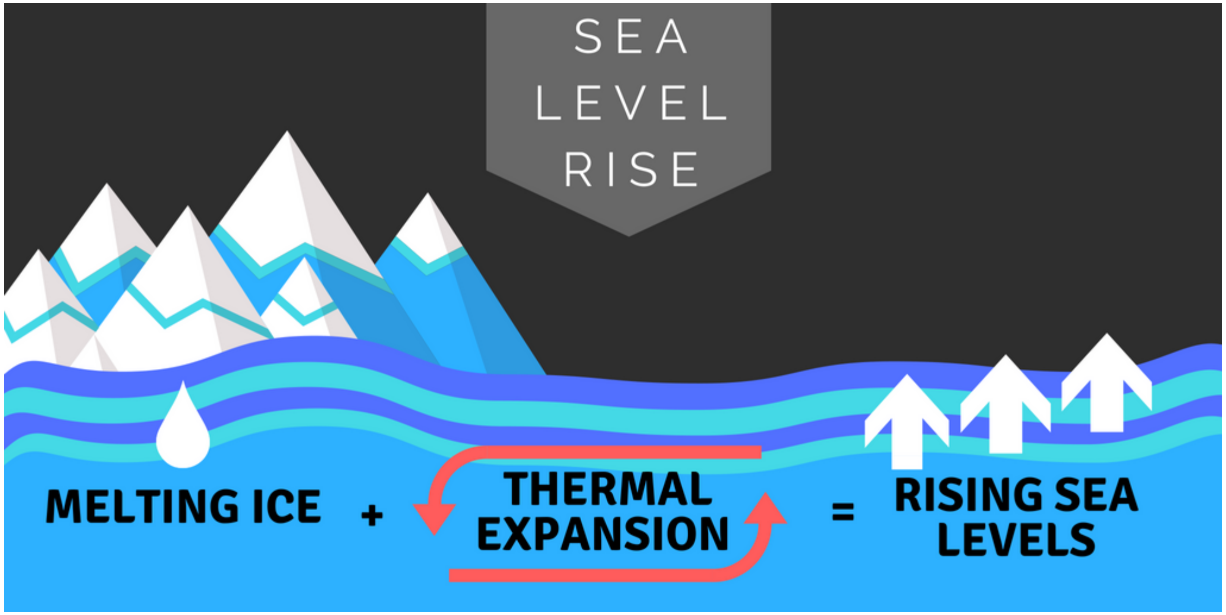
Two main causes for sea-level rise



60%



40%

Climate status: Ocean Warming

LATEST MEASUREMENT: December 2023

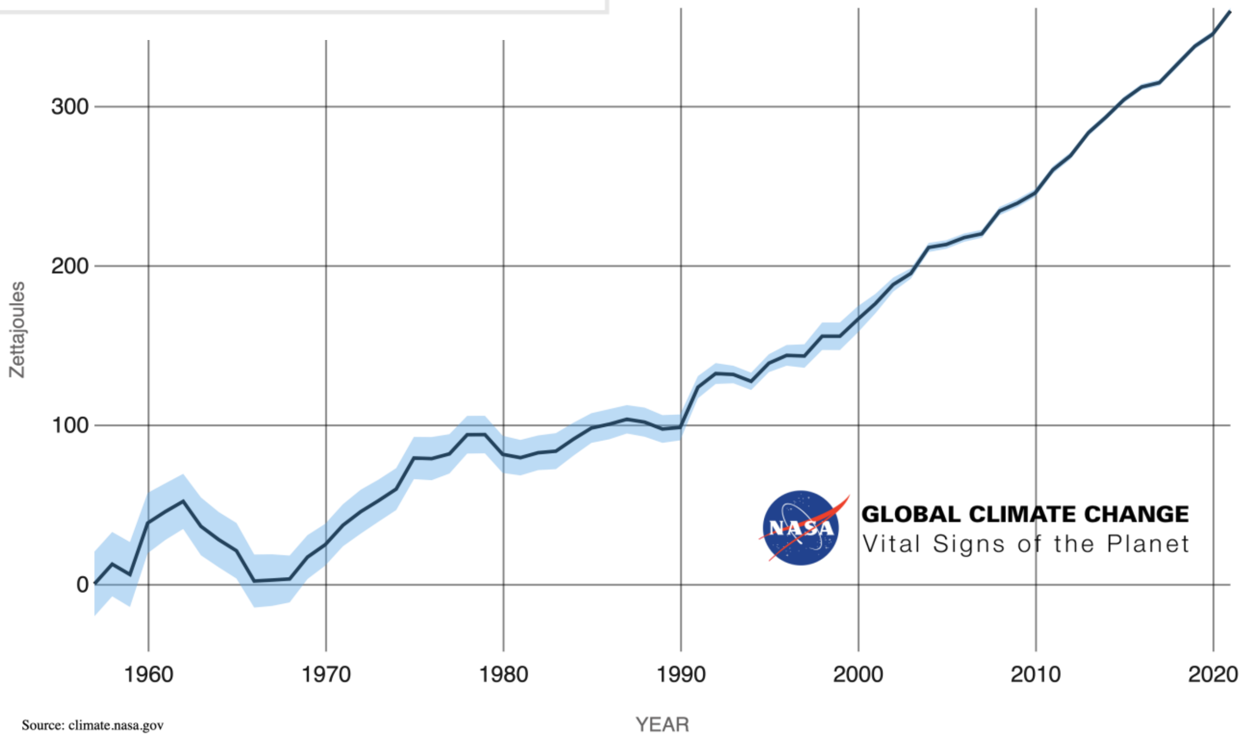
360 (± 2) zettajoules

Key Takeaway:

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

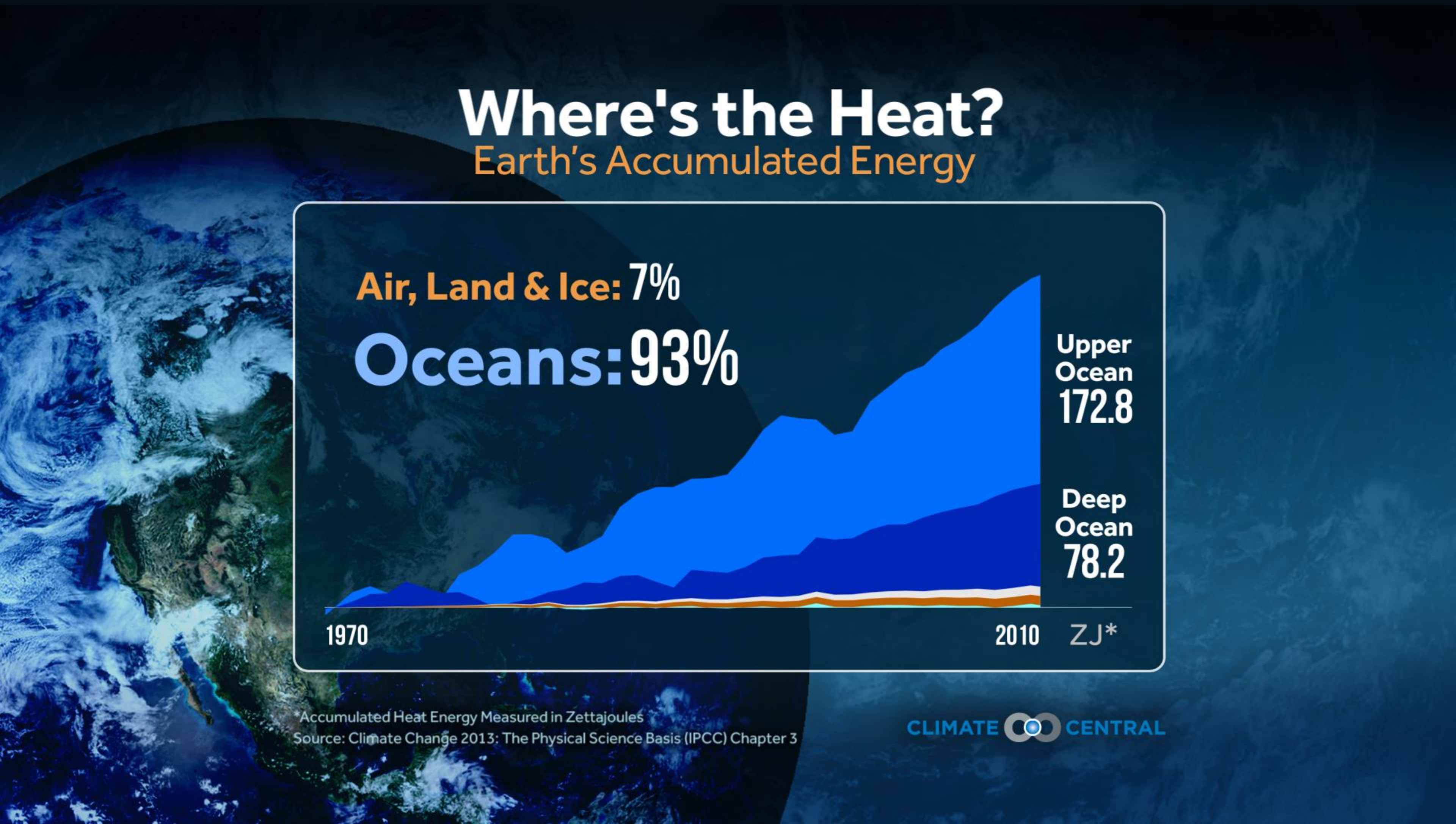
OCEAN HEAT CONTENT CHANGES SINCE 1955 (NOAA)

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

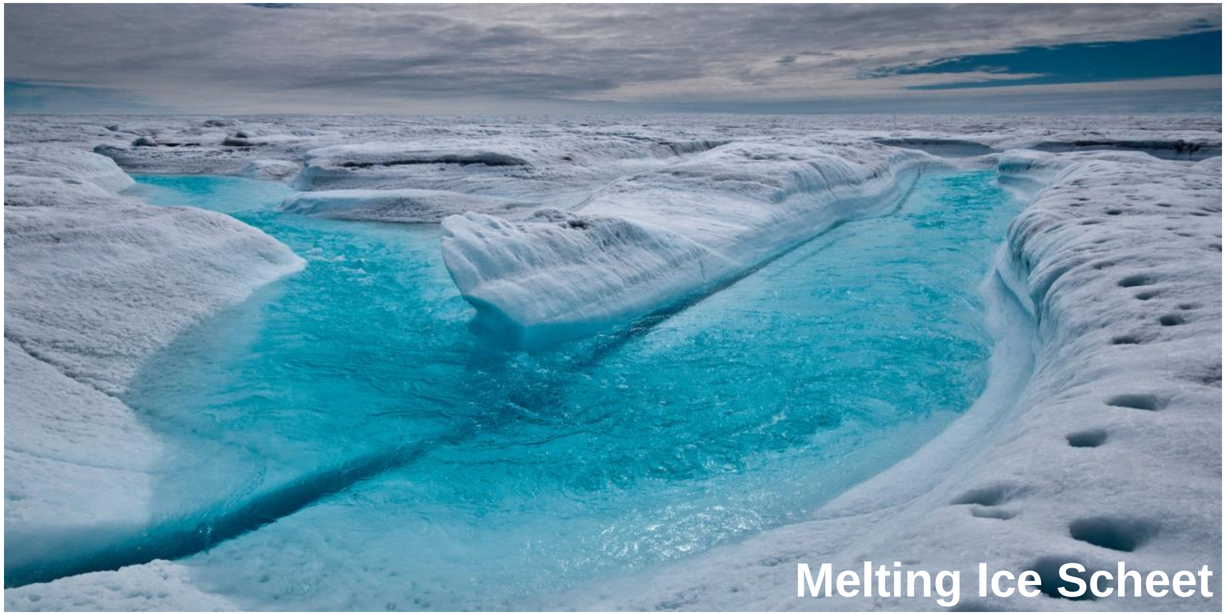


1 **zettajoule** = 10^{21} **joule**

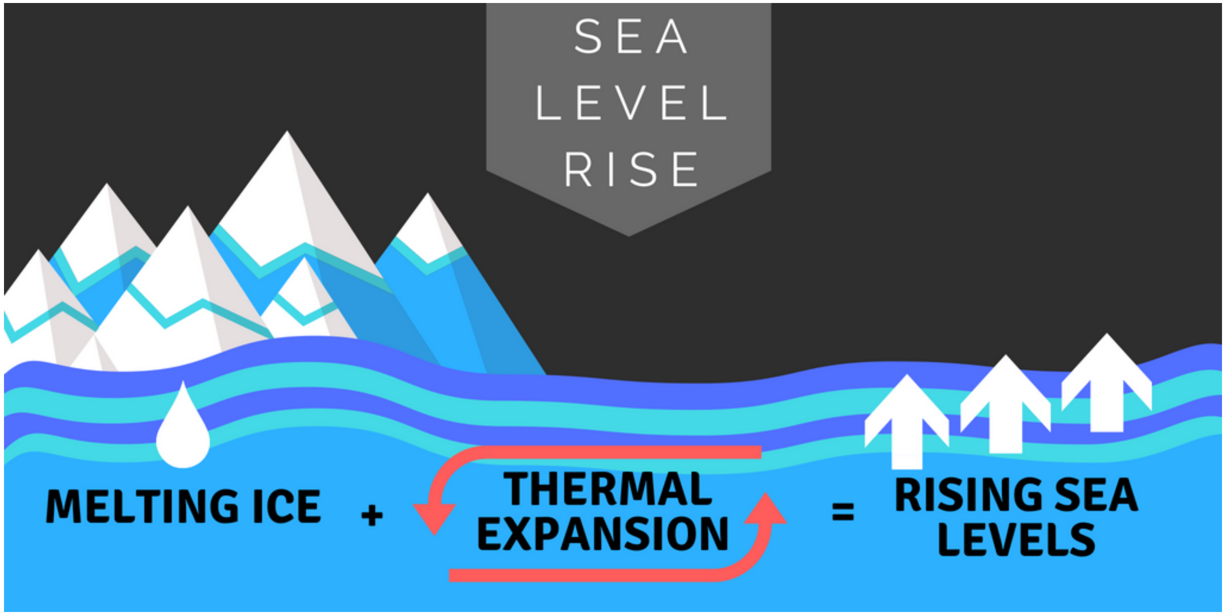
360 zettajoule are equivalent to 5.736.138 atomic bomb, 15 megatons each (Hiroshima)


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%

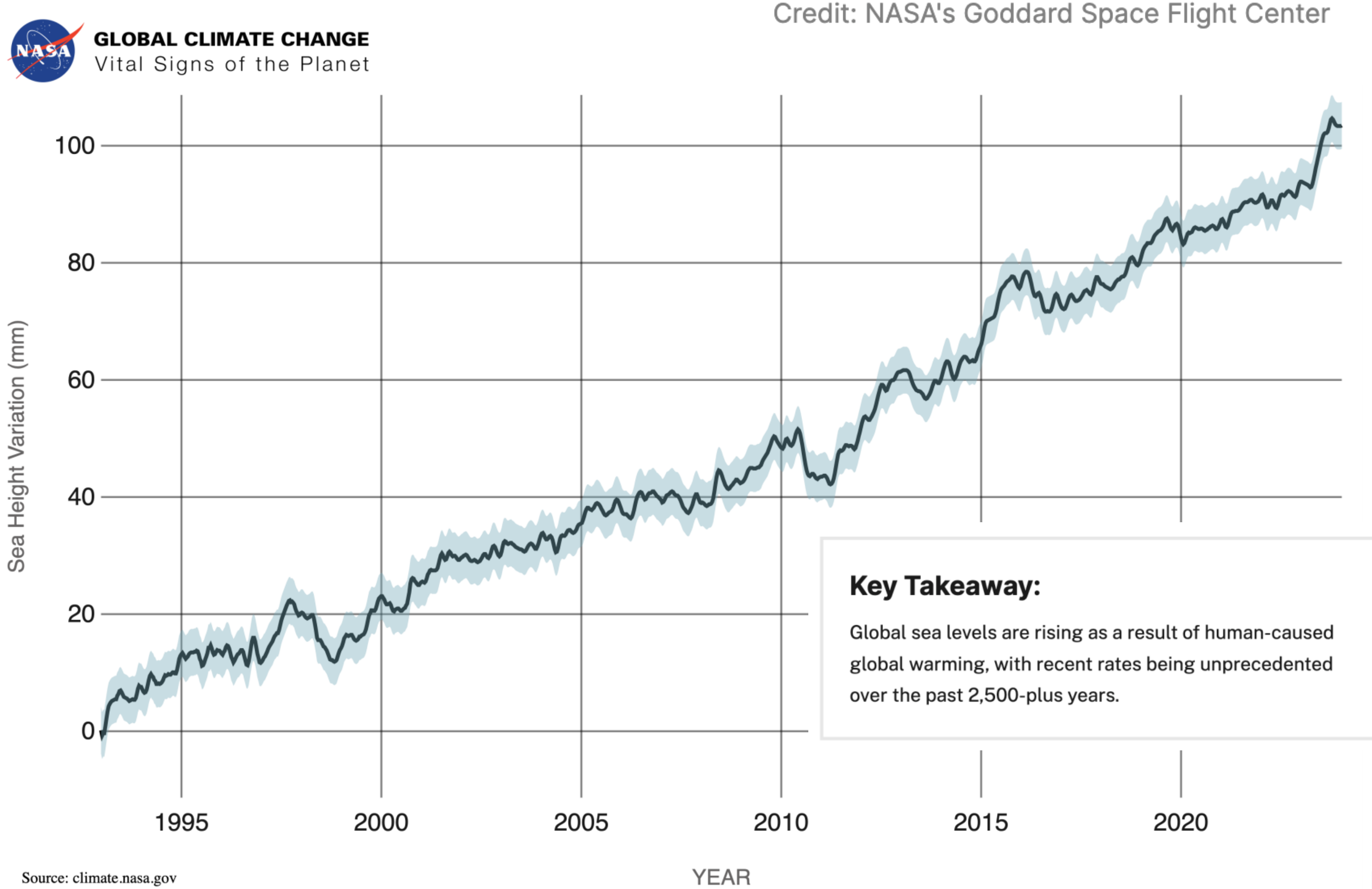
Climate status: Sea Level since 1993

Latest annual average anomaly: 2023

103 (±4.0) mm

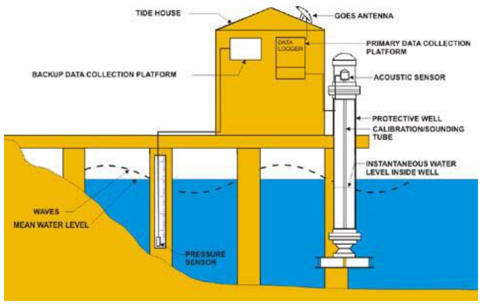
SATELLITE DATA: 1993-PRESENT

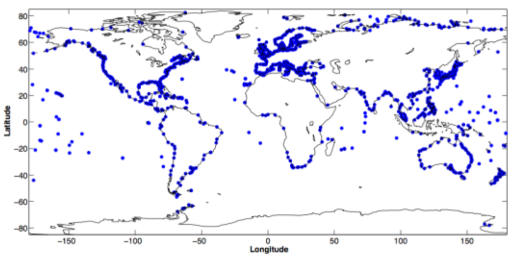
Data source: Satellite sea level observations.
Credit: NASA's Goddard Space Flight Center



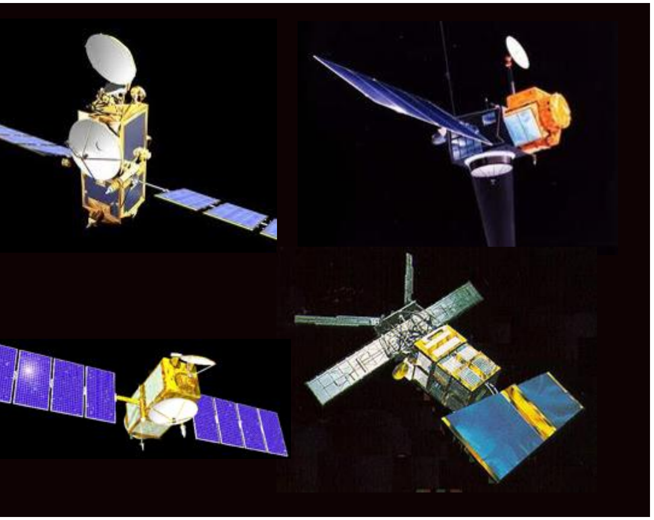
Source: climate.nasa.gov

Change in sea level since 1900





Spatial distribution of the **1420** tide gauges



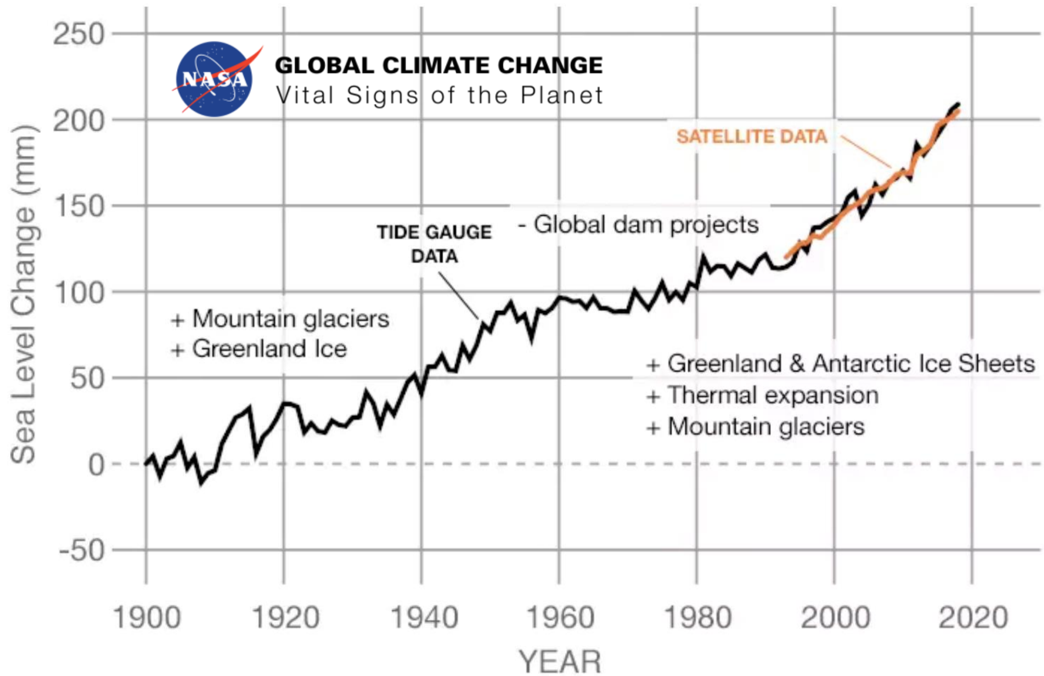
SOURCE DATA: 1900-2018

Data source: Frederikse et al. (2020)
Credit: NASA's Goddard Space Flight Center/PO.DAAC

Sea Level

LATEST MEASUREMENT: January 2024

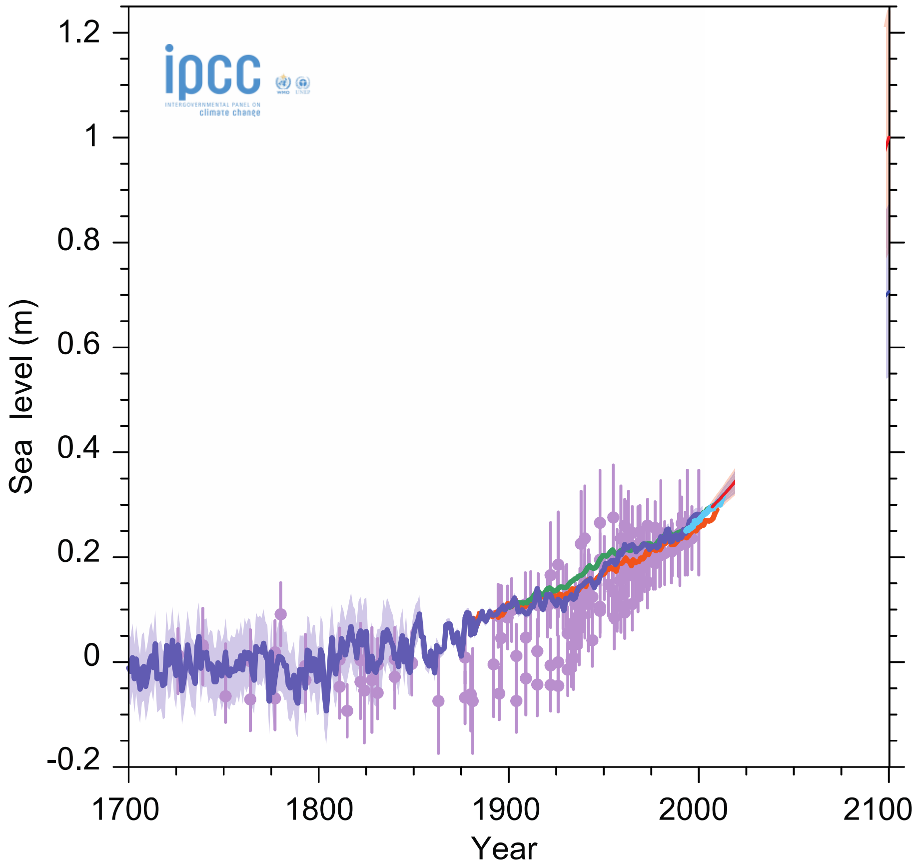
103 (± 4.0) mm



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.

Climate related impacts

Extreme heat

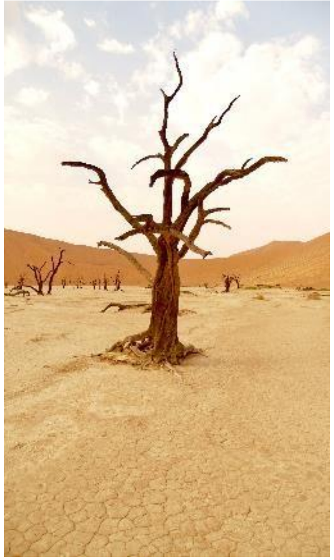
More frequent

More intense

Heavy rainfall

More frequent

More intense



Drought

Increase in some regions

Wildfire Fire

More frequent

More intense

Ocean

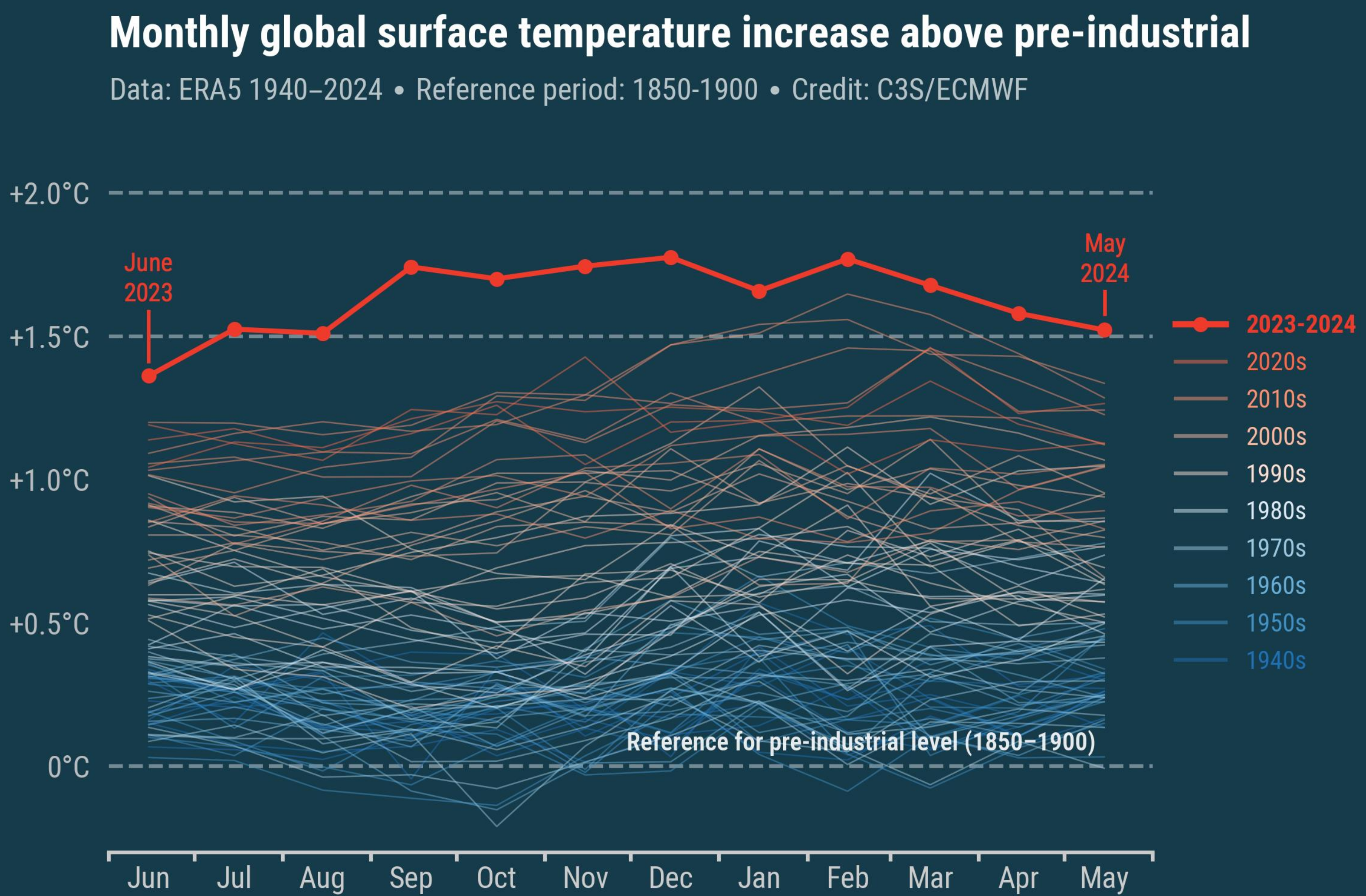
Warming

Acidifying

Losing oxygen

Photo Credits from left: 1. Luiz Guimaraes 2. Jonathan Ford 3. Peter Burdon 4. Ben Kuo 5. NOAA

2023 as the ‘climate stress-test’



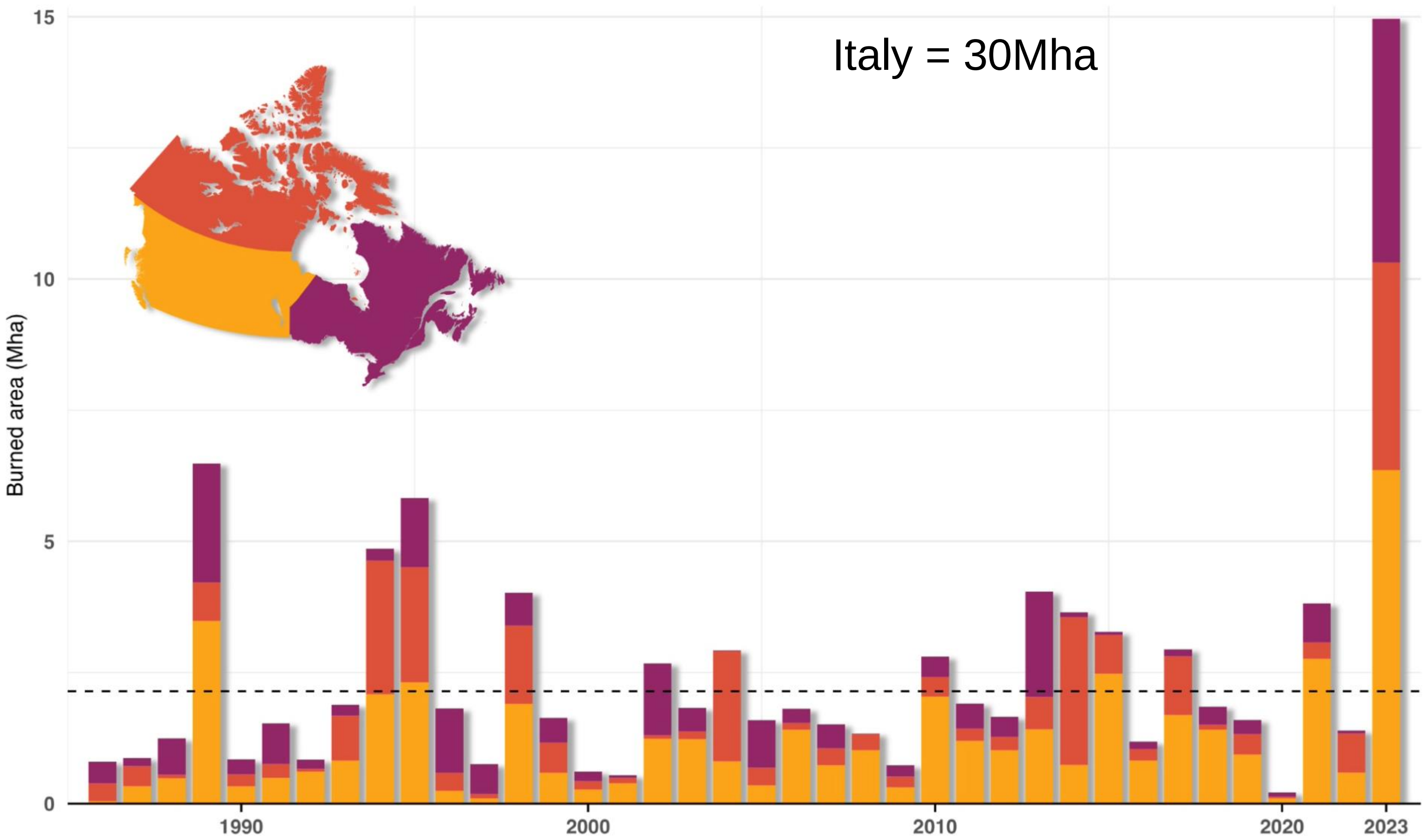
PROGRAMME OF THE EUROPEAN UNION

Copernicus Europe's eyes on Earth

IMPLEMENTED BY ECMWF

Climate Change Service climate.copernicus.eu

2023: Escalation of Global Extreme Heat



Annual area burned for Canada from the National Burned Area Composite (NBAC; 1986–2022) and NBAC-M3 (Natural Resources Canada, 2023b) datasets. During 2023, **15 Mha burned**, compared to the **annual mean of 2.1 Mha (1986–2022, dashed line)**. The next largest annual area burned occurred in 1989 with 6.7 Mha.

Jain et al. 2024

2023: Escalation of Global Extreme Heat

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The year **2023 was the hottest year** on record. **July 2023 was the hottest month ever** recorded and **July 6, 2023 was the hottest day ever**. Since then, each one of the last 12 months have broken their previous monthly record for highest average temperature

- Using World Weather Attribution criteria, the study identified **76 extreme heat waves** that **span 90 different countries**. These events put billions of people at risk, including in densely populated areas of South and East Asia, the Sahel, and South America.

- Over the 12-month period, **6.3 billion people (about 78% of the global population)** experienced at least 31 days of extreme heat (hotter than 90% of temperatures observed in their local area over the 1991-2020 period) that was made at least two times more likely due to human-caused climate change.

- Over the last 12 months, human-caused climate change **added an average of 26 days of extreme heat** (on average, across all places in the world) than there would have been without a warmed planet.

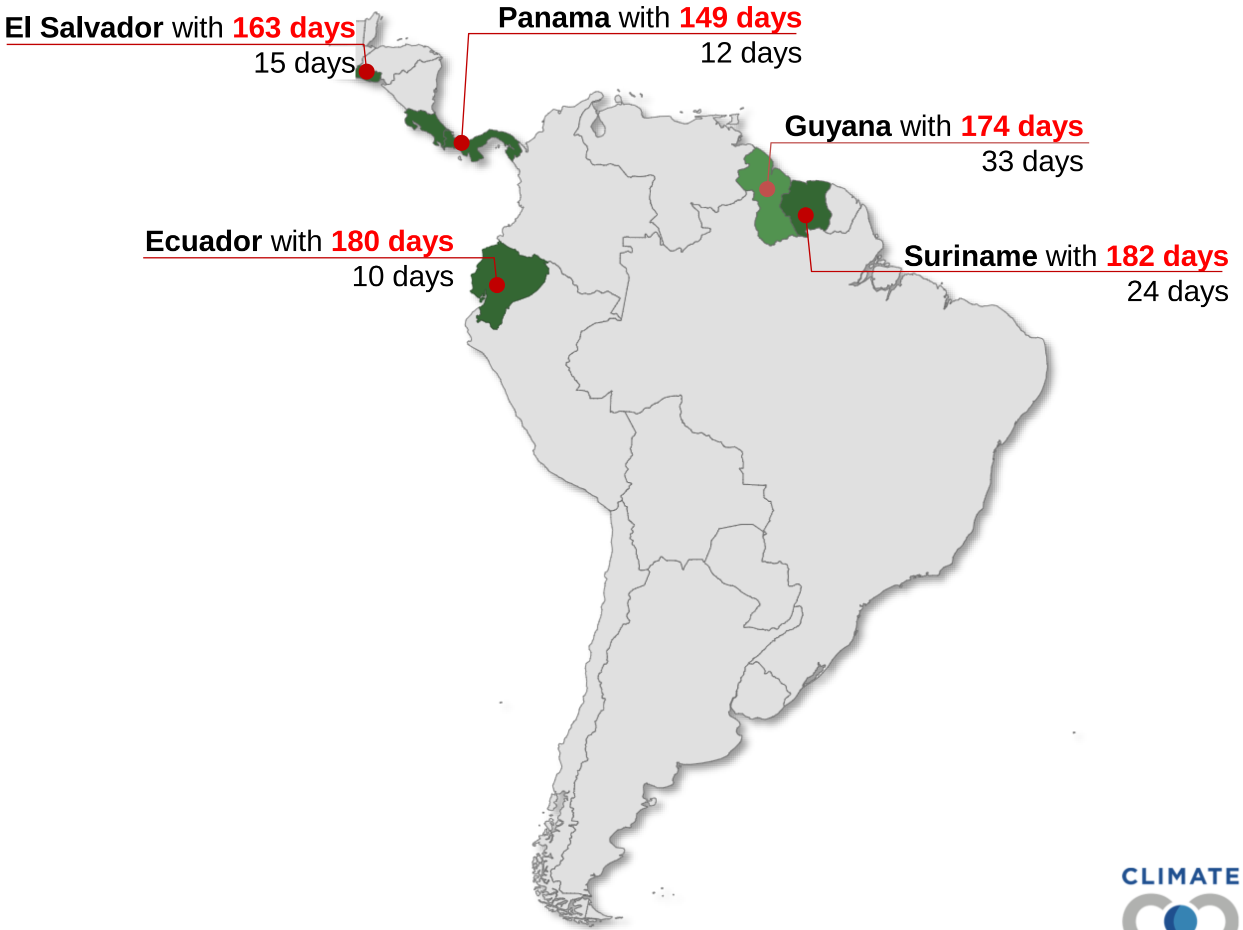
CLIMATE CENTRAL

Climate Centre

World Weather Attribution

2023: Escalation of Extreme Heat in South America

Using World Weather Attribution criteria, the study identified 76 extreme heat waves that **span 90 different countries**. These events put billions of people at risk, including in densely populated areas of South and East Asia, the Sahel, and **South America**.



The five countries where the average person experienced the most days with extreme heat above their local heat level were **Suriname** with 182 days, **Ecuador** with 180 days, **Guyana** with 174 days, **El Salvador** with 163 days, and Panama with 149 days.

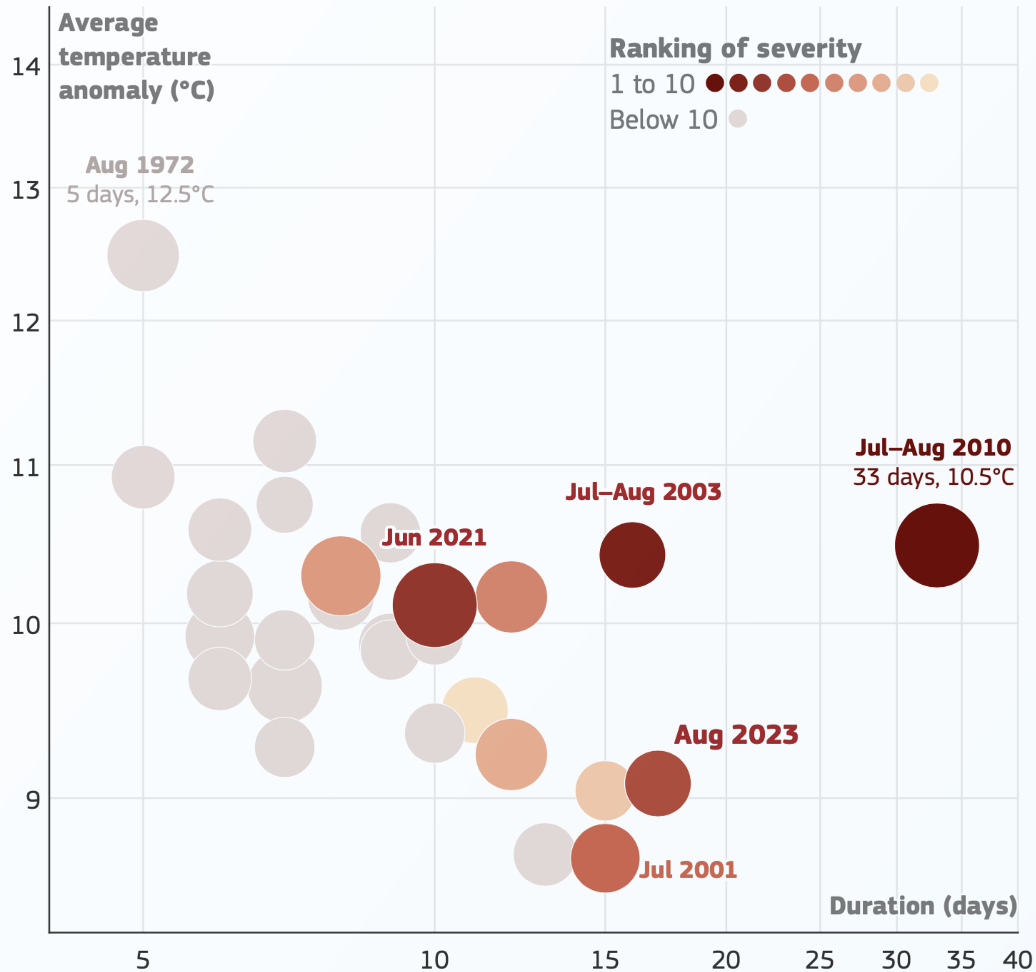
Without human-induced climate change, the average person in Suriname would have experienced 24 such days. That number was 10 days for Ecuador, 33 days for Guyana, 15 days for El Salvador, and 12 days for Panama.

CLIMATE CENTRAL | Climate Centre | World Weather Attribution

Extreme weather and climate events on human health

Heat-related deaths have increased in 94% of European regions

- Since 1970, extreme heat has been the leading cause of weather- and climate-related deaths in Europe.
- **23 of the 30 most severe heatwaves** have occurred since 2000, and five in the last three years.
- Between **55,000** and **72,000 deaths** due to heatwaves were estimated in each summer of **2003**, **2010** and **2021**. An estimate for 2023 is not yet available.
- In the World Health Organization's European Region, **heat-related mortality has increased by around 30% in the past 20 years**. The effect of heat on human health is more pronounced in cities.

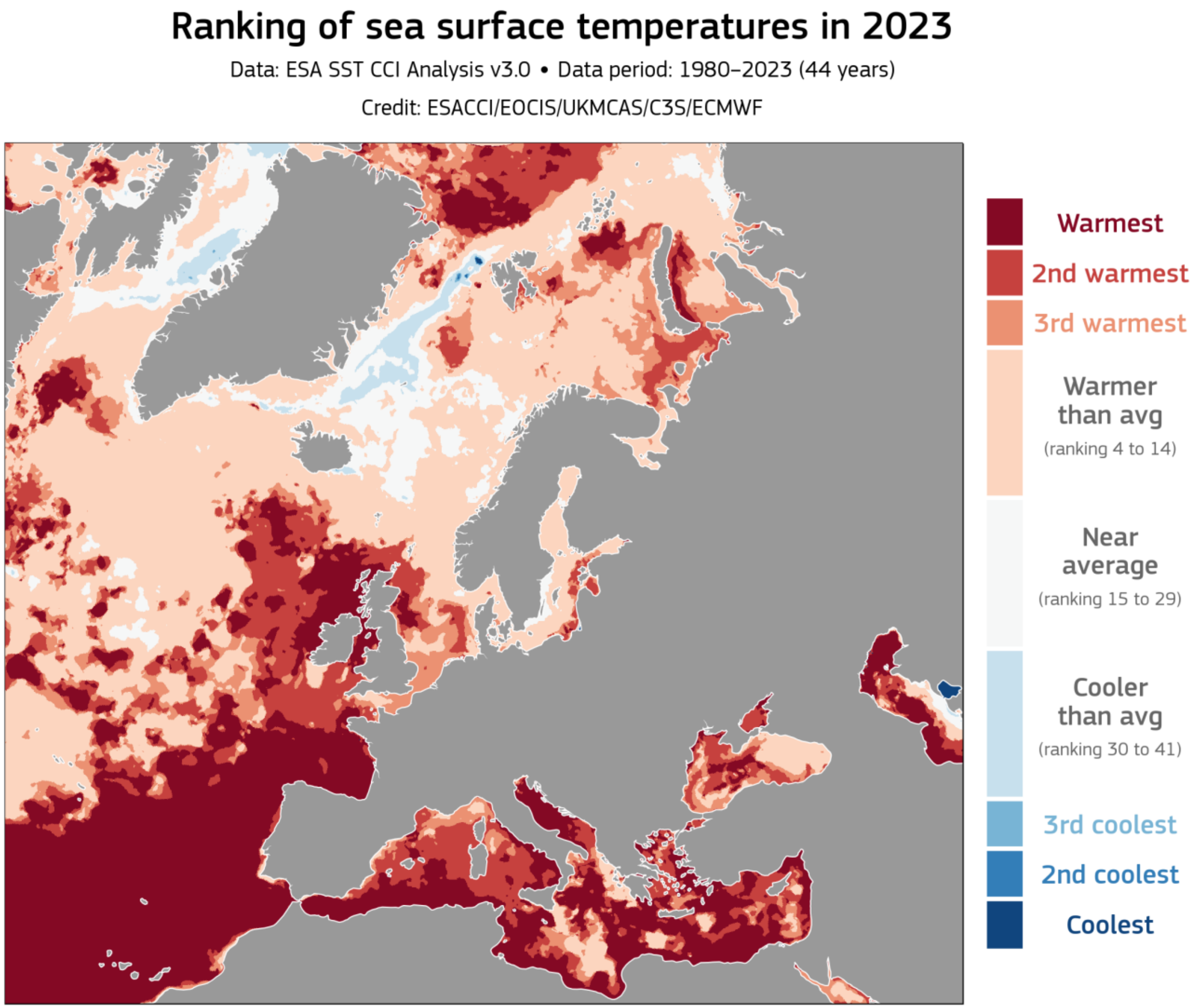


Top 30 most severe heatwaves in Europe (1950–2023)

The size of a circle is proportional to the area affected

Data source: DWD • Credit: DWD/C3S/ECMWF

2023: Extreme sea surface temperature



In **2023**, the average **sea surface temperature** (SST) for the ocean across Europe was the **warmest on record**. Parts of the Mediterranean Sea and the northeastern Atlantic Ocean saw their warmest annual average SST on record.

In June, the Atlantic Ocean west of Ireland and around the United Kingdom was impacted by a marine heatwave that was classified as 'extreme' and in some areas 'beyond extreme', with sea surface temperatures as much as 5° C above average.

2022-2023: Extreme sea surface temperature

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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.

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2022-2023: Extreme sea surface temperature

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

S Marullo *et al*

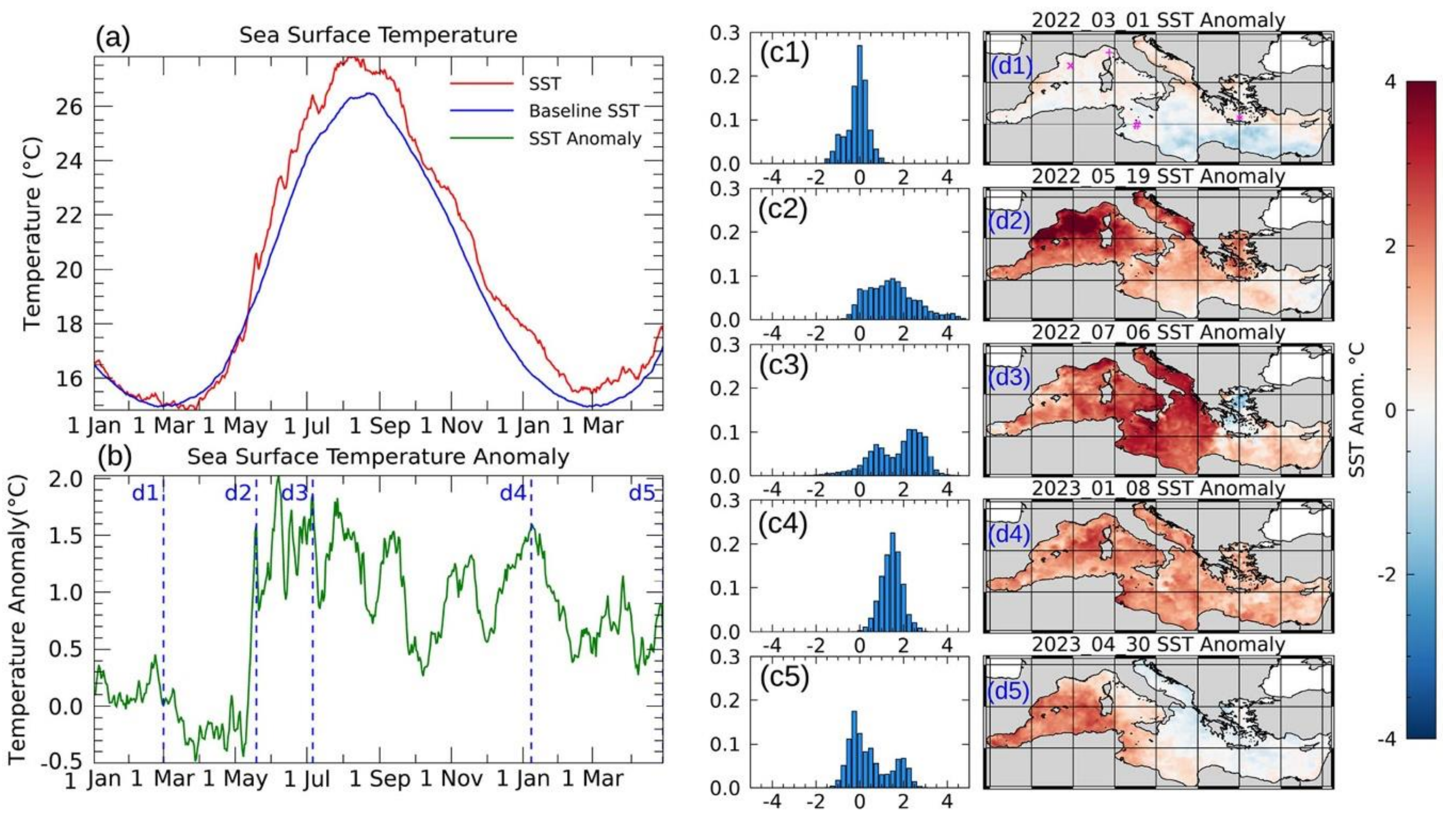
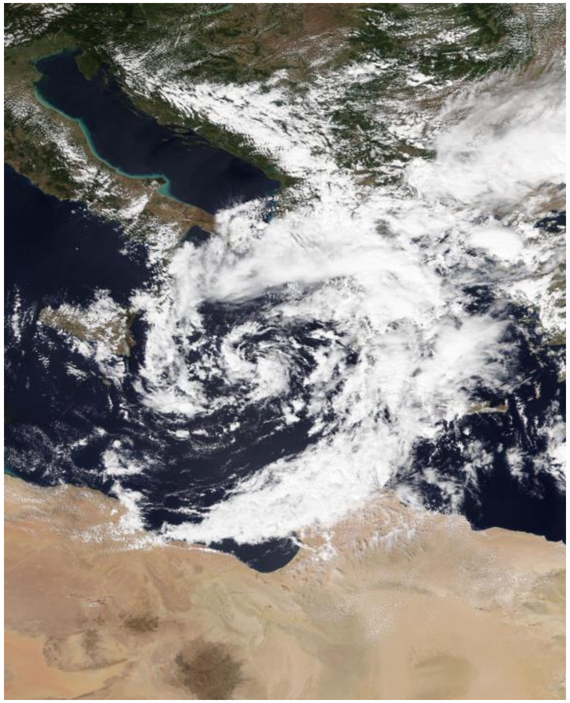


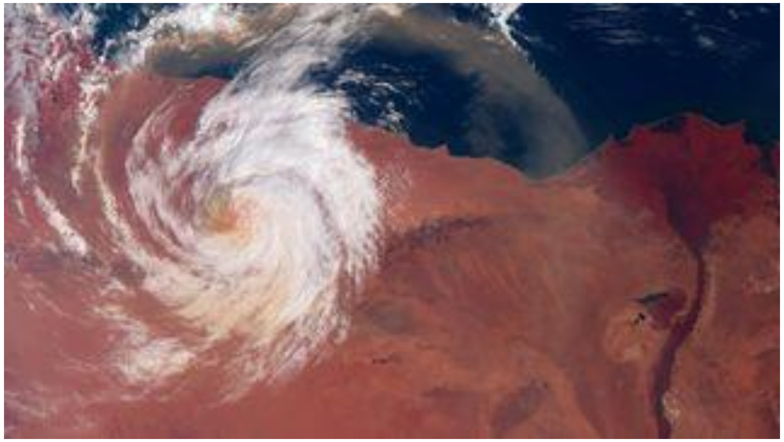
Figure 1. Overview of Mediterranean SST conditions in 2022/23 based on satellite data. (a) Daily mean Mediterranean basin SST time series (red line) and corresponding baseline 1991–2020 (blue line); (b) basin scale SST anomalies over the same period. Five dates (indicated as d1–5) are selected to represent 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 (× for LION, + for ODAS, # for LMP, and ∗ for E1M3A) in (d1).

2023: Medicane (Mediterranean Hurricane) Daniel



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

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.



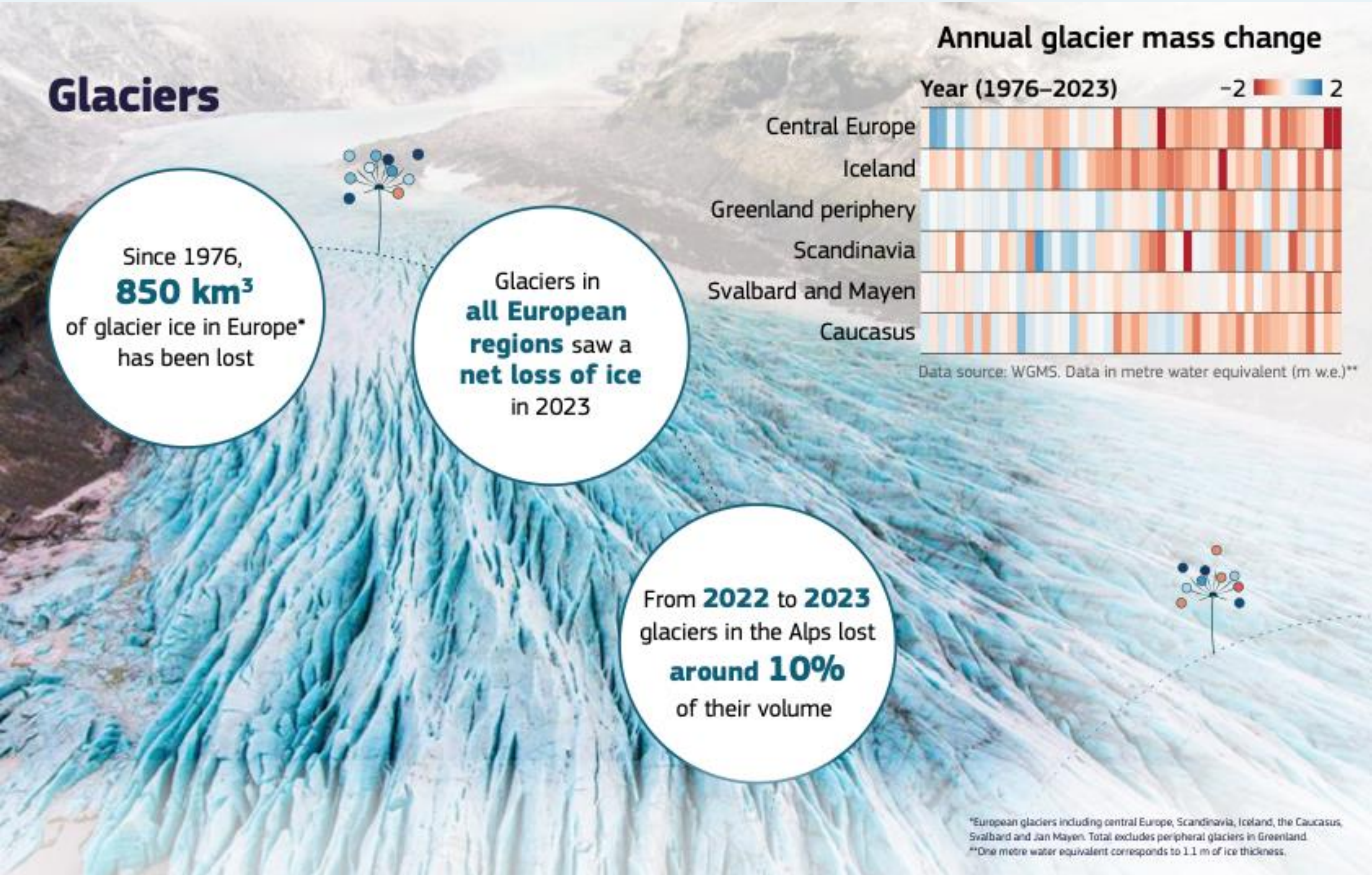
These storms, while infrequent, are becoming more intense due to climate change, which increases the amount of moisture they can carry and the energy they derive from warmer waters.
Medicane Daniel was particularly devastating in Libya, where it led to catastrophic flooding and significant loss of life, 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

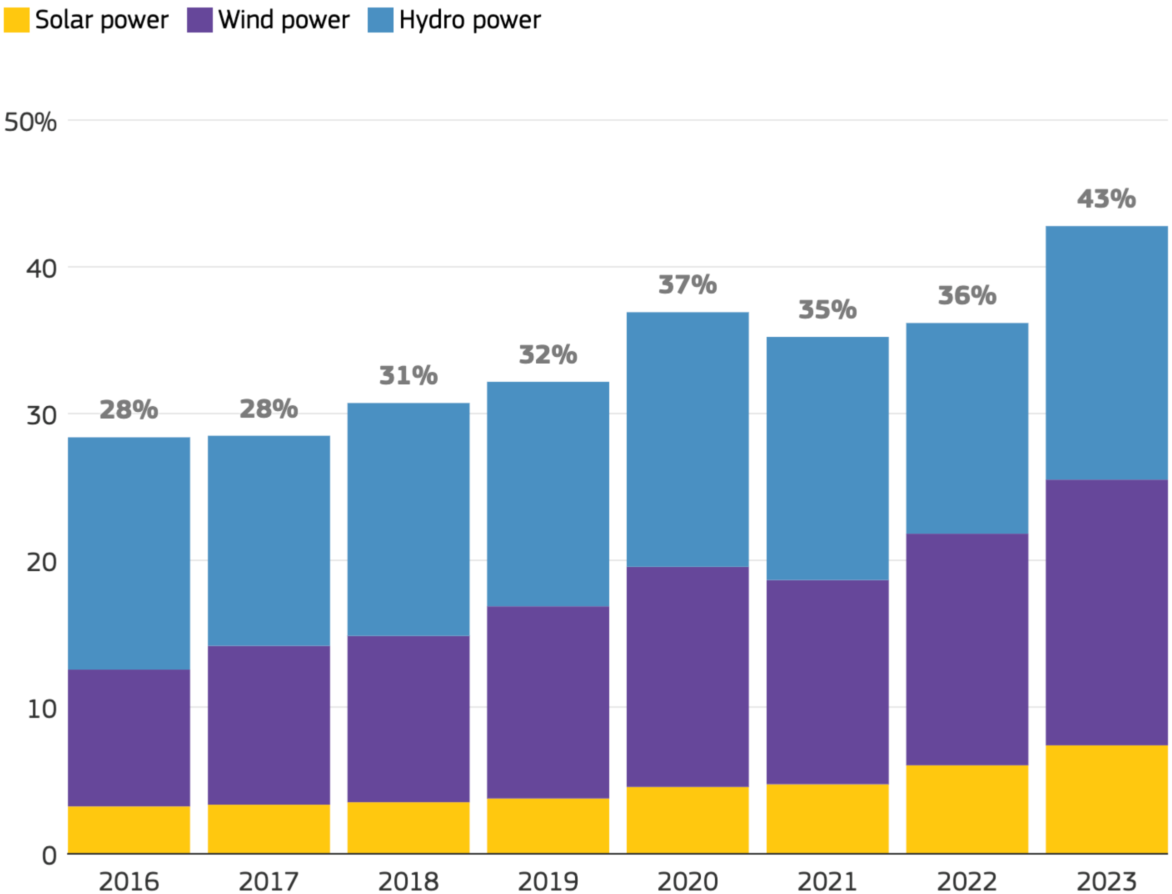
2023: Medicane (Mediterranean Hurricane) Daniel

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


Glaciers
Since 1976, 850 km³ of glacier ice in Europe* has been lost
Glaciers in all European regions saw a net loss of ice in 2023
From 2022 to 2023 glaciers in the Alps lost around 10% of their volume
Annual glacier mass change
Year (1976–2023)
-2
2
Central Europe
Iceland
Greenland periphery
Scandinavia
Svalbard and Mayen
Caucasus
Data source: WGMS. Data in metre water equivalent (m w.e.)**
*European glaciers including central Europe, Scandinavia, Iceland, the Caucasus, Svalbard and Jan Mayen. Total excludes peripheral glaciers in Greenland.
**One metre water equivalent corresponds to 1.1 m of ice thickness.

Renewable energy resources

Percentage of the total annual actual electricity generation for Europe from different sources



Data: ENTSO-E and Elexon • Credit: C3S/ECMWF

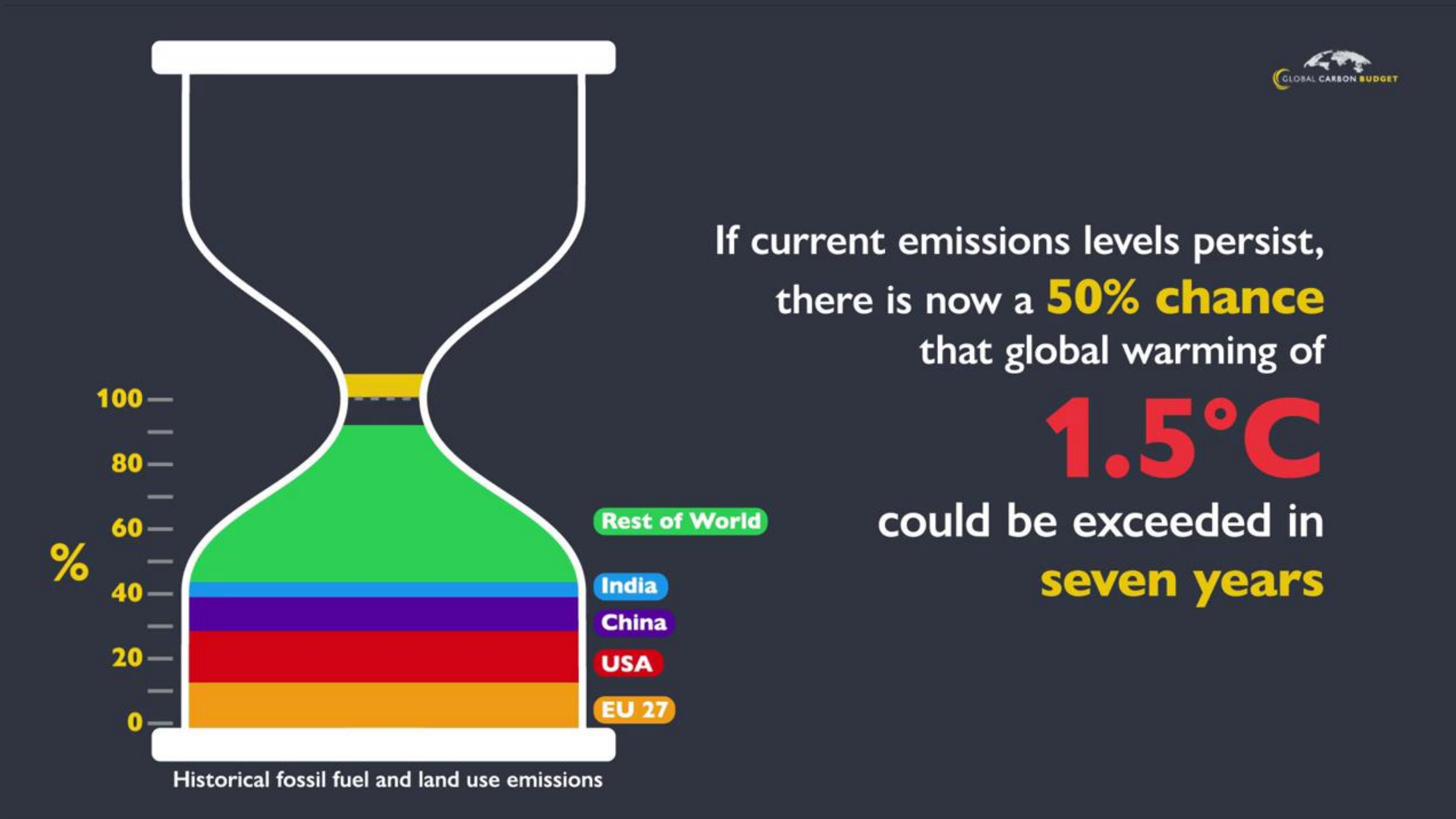
Copernicus Climate Change Service
European State of the Climate | 2023
PROGRAMME OF THE EUROPEAN UNION
IMPLEMENTED BY ECMWF

- **2003 saw a record proportion of actual electricity generation by renewables in Europe, at 43%.**

- Climate-driven electricity demand was above average in southern Europe, due to cooling required during exceptional summer temperatures, and in Scandinavia, where cooler-than-average temperatures in several months led to increased demand for heating.

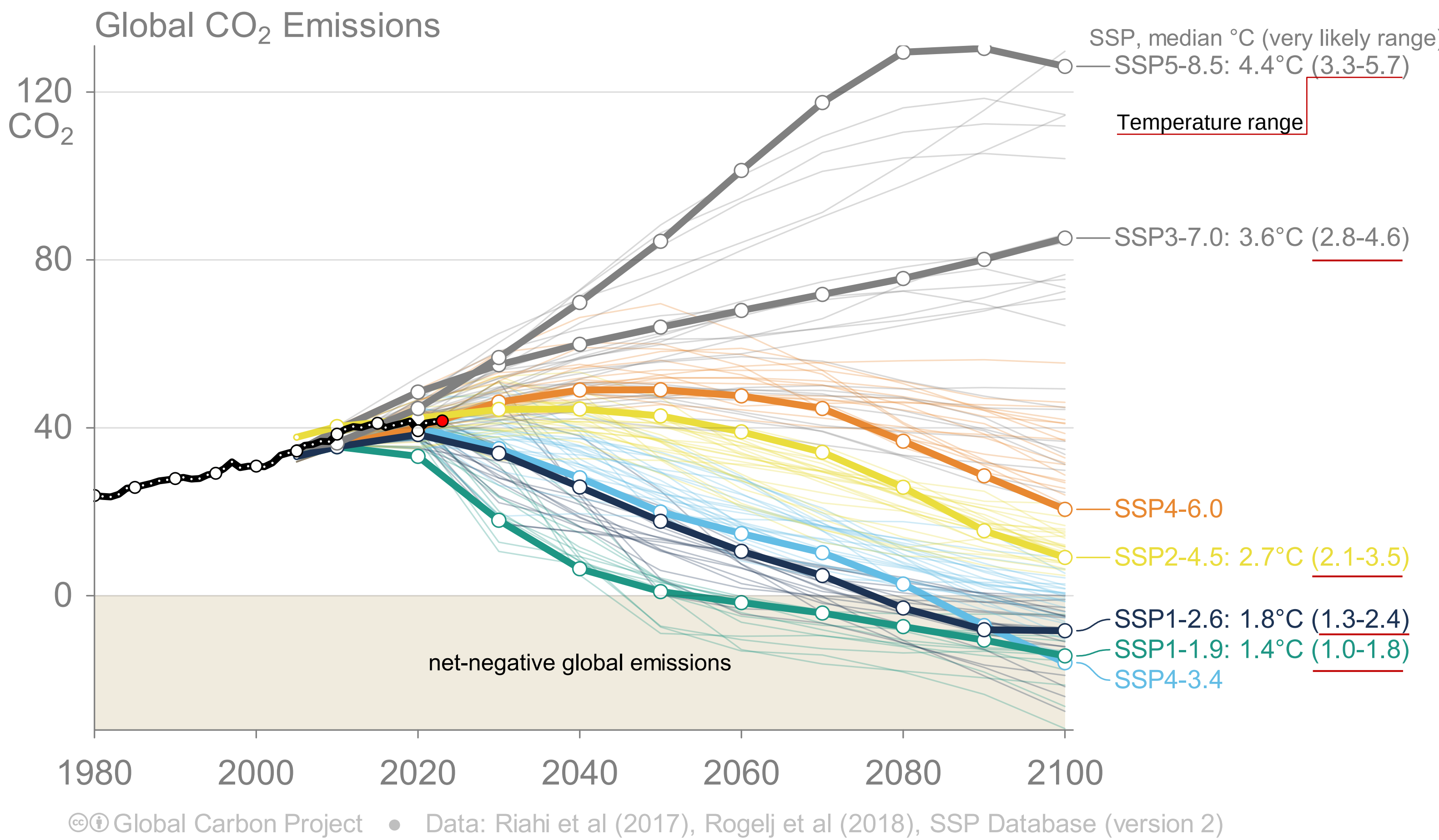
- Increased storm activity through October to December resulted in above-average potential for wind power production.

- For the year as a whole, potential for solar photovoltaic power generation was below average in northwestern and central parts of Europe, and above average in southwestern and southern Europe, and Fennoscandia.


GLOBAL CARBON BUDGET
100
80
60
%
40
20
0
Rest of World
India
China
USA
EU 27
Historical fossil fuel and land use emissions
If current emissions levels persist,
there is now a 50% chance
that global warming of
1.5°C
could be exceeded in
seven years

State of Cimate: Carbon Dioxide emissions

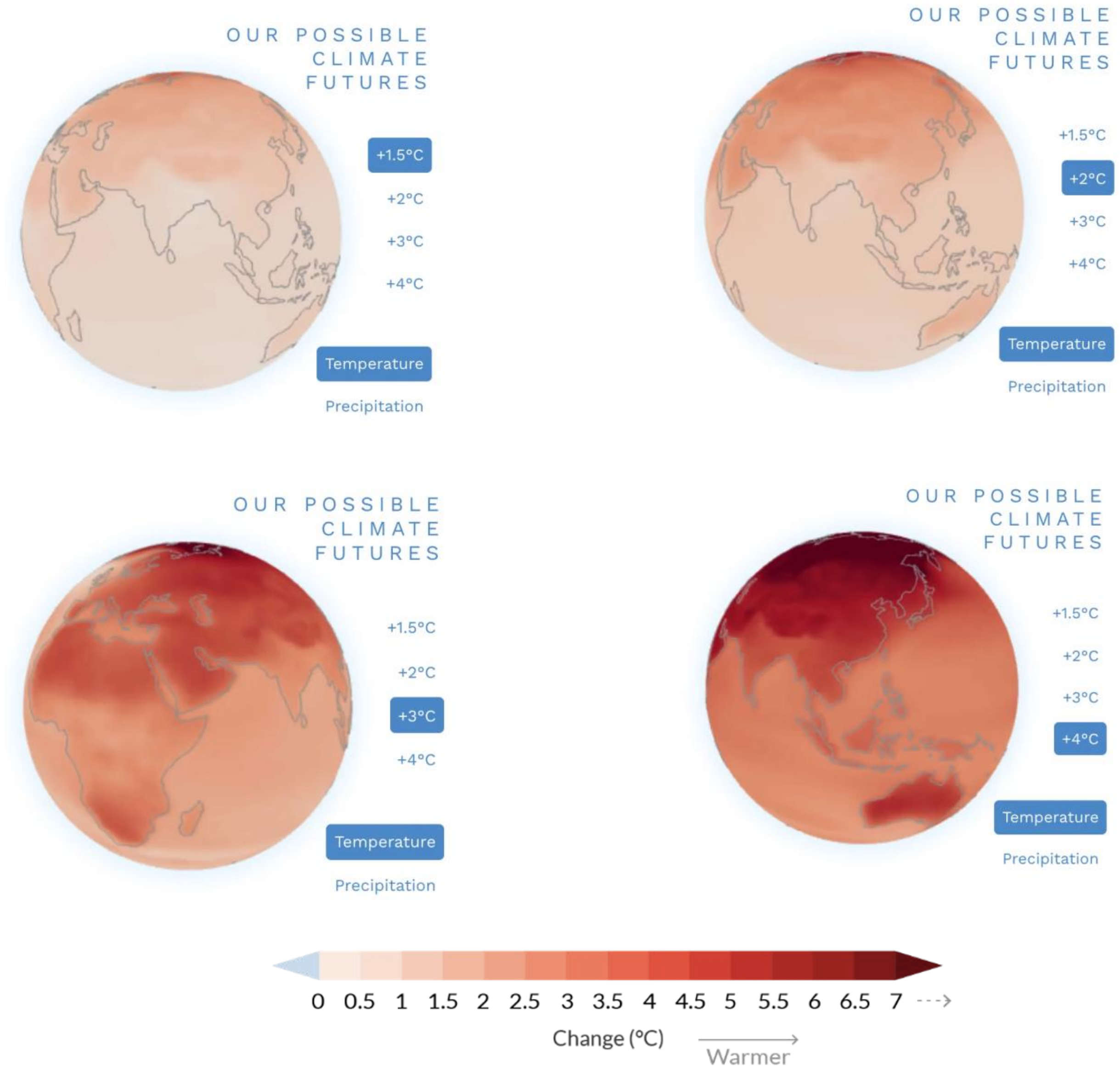
The SSPs were designed to span the range of potential outcomes. Total CO_2 emissions are currently tracking in the middle of the range. The temperature outcomes are based on assessed scenarios in IPCC AR6 Working Group I.



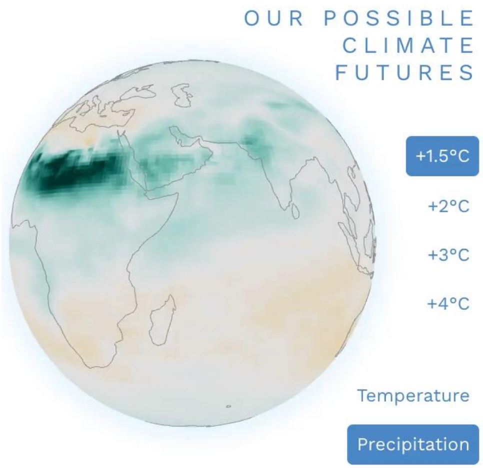
GLOBAL CARBON project

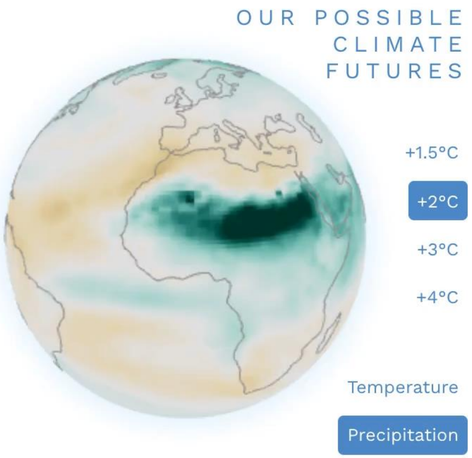
ENEA

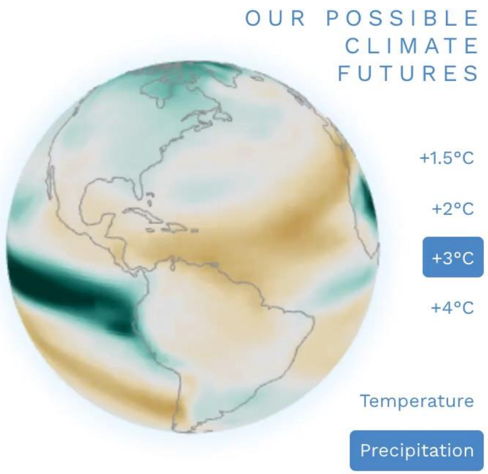
Future climate scenario

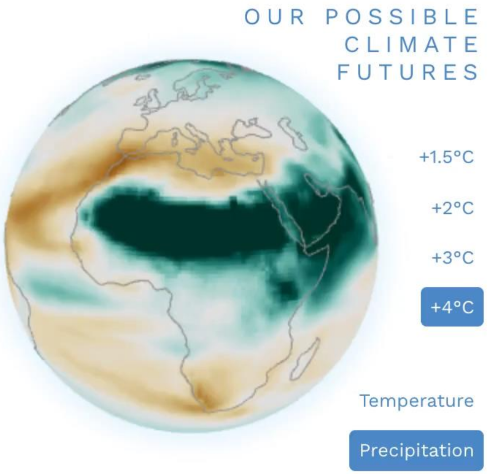


Future climate scenario

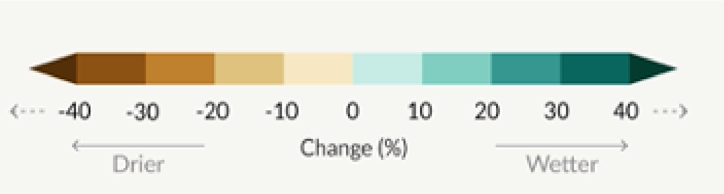








Extreme rainfall intensifies by 7% for each additional 1°C

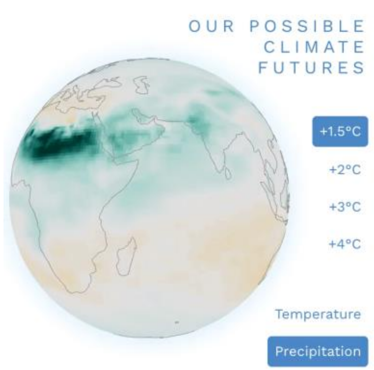


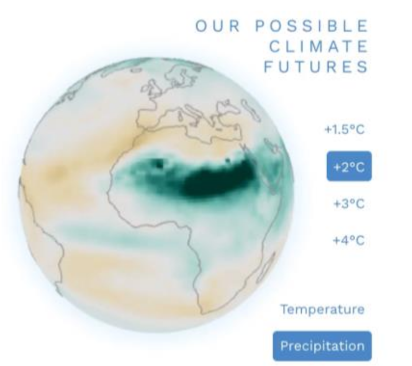
How climate change is disrupting the water cycle

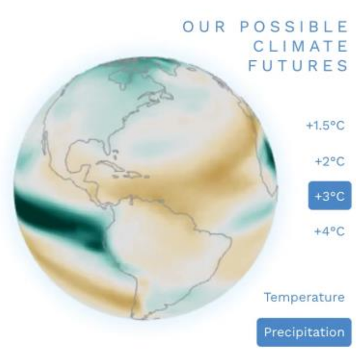
A warmer climate increases moisture transport into weather systems, which, on average, makes wet seasons and events wetter

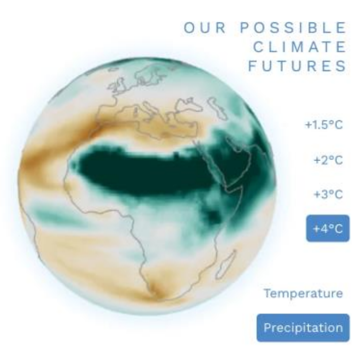
The Clausius–Clapeyron equation determines that low-altitude specific humidity increases by about 7% $°C^{-1}$ of warming, assuming that relative humidity remains constant, which is approximately true at a global scale but not necessarily valid regionally.

Warmer temperatures are heating the lower atmosphere and increasing evaporation, adding more water vapor to the air. More water in the air means a greater chance of precipitation, often in the form of intense, unpredictable storms. Conversely, increased evaporation can also intensify dry conditions in areas prone to drought, with water escaping into the atmosphere rather than staying on the ground where it's needed.

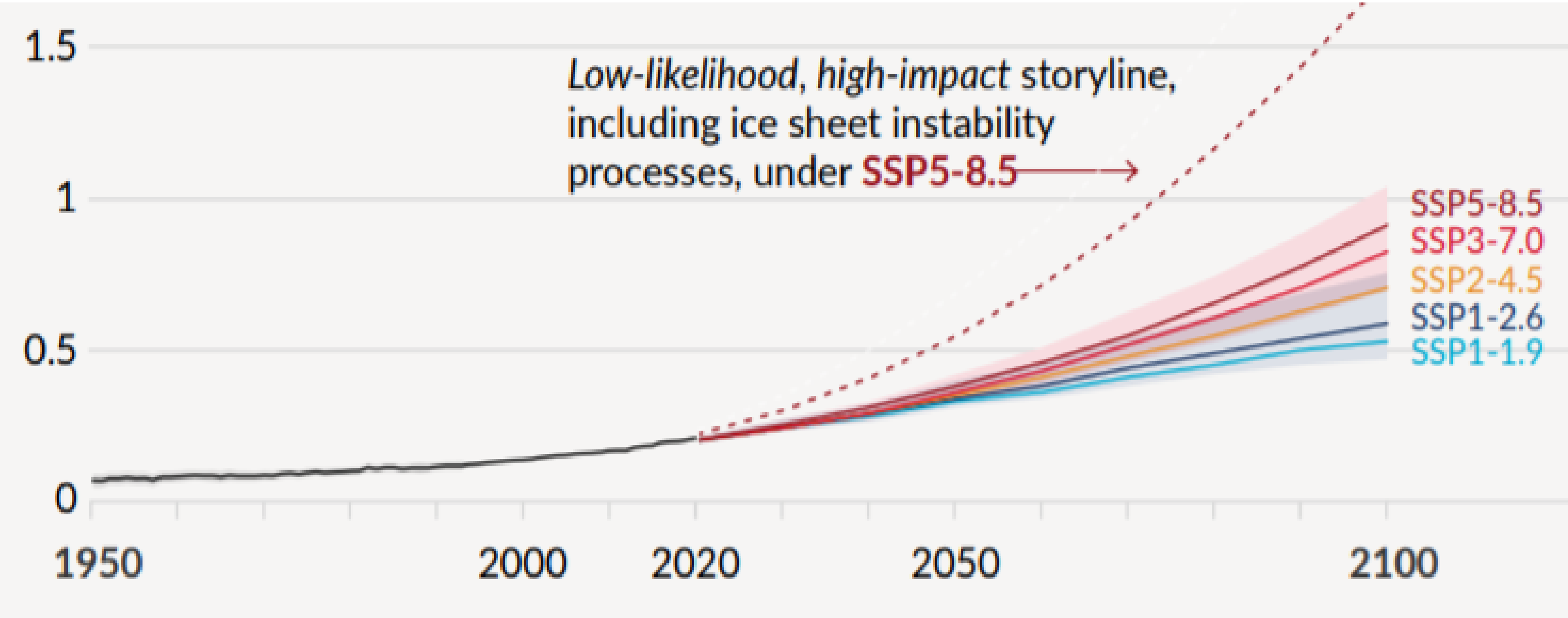








Future Scenarios global sea level



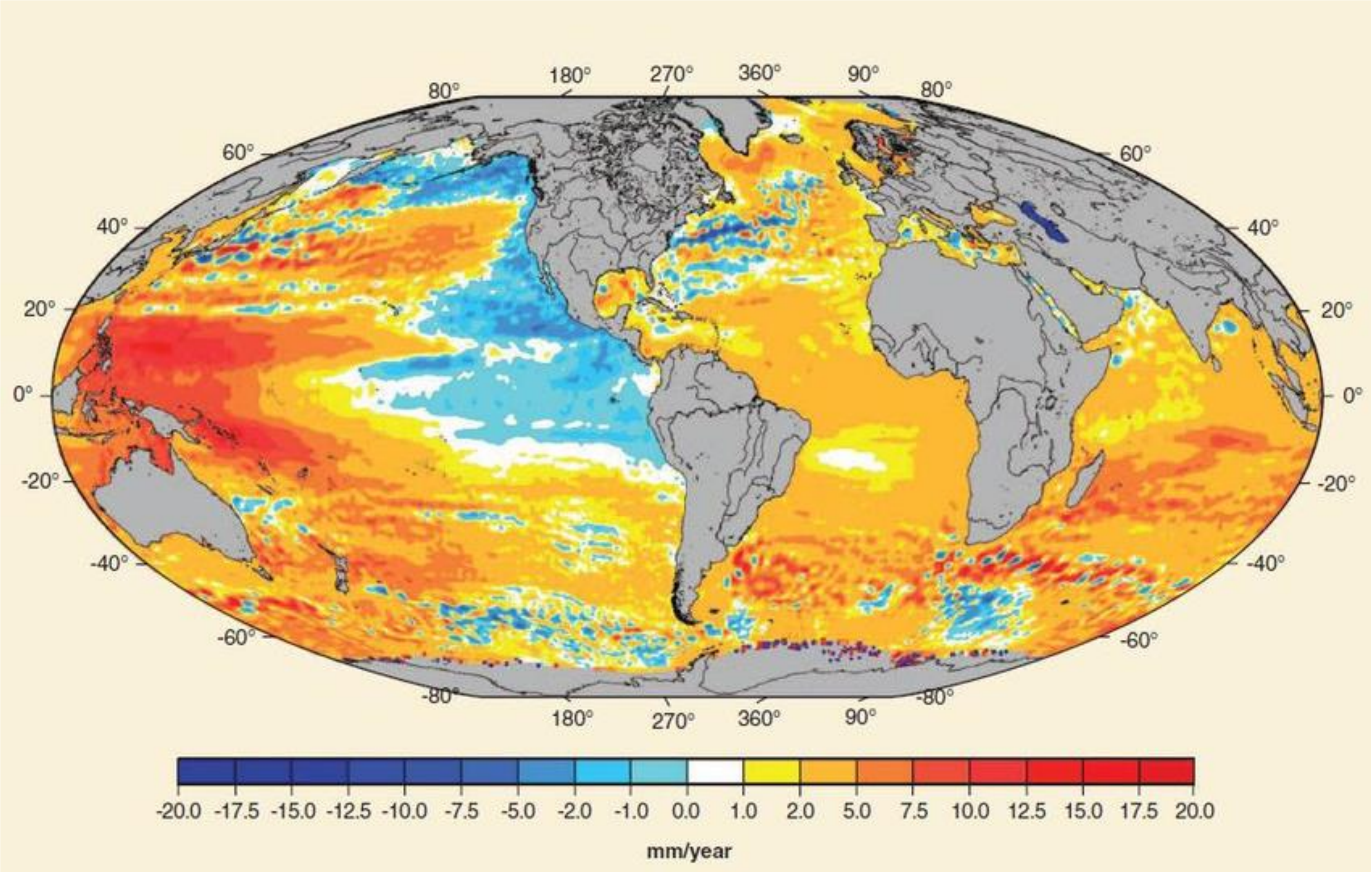
AR6 IPCC

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**

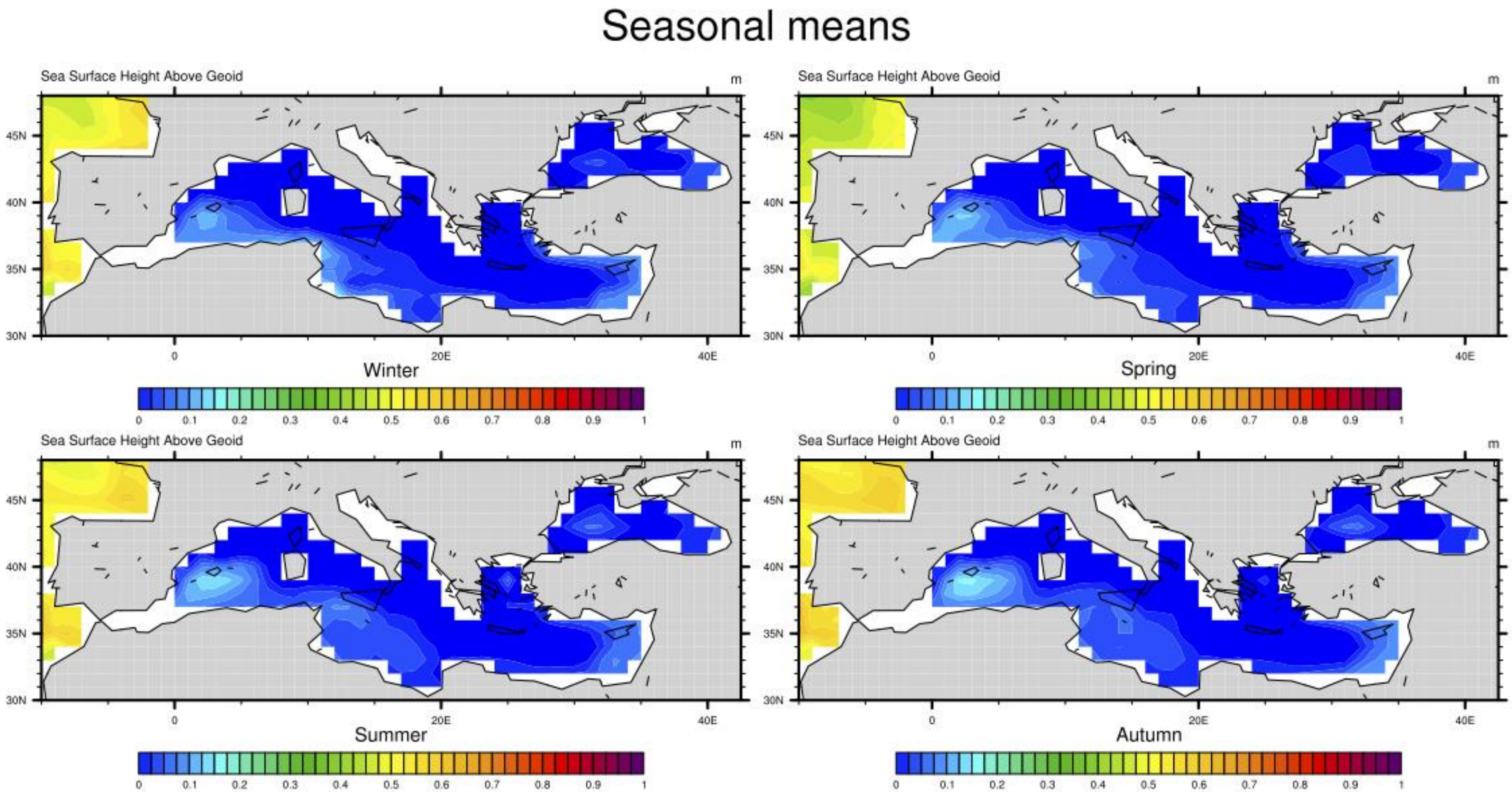
Spatial differences are due to the steric effect. Nicholls & Cazenave, 2010

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



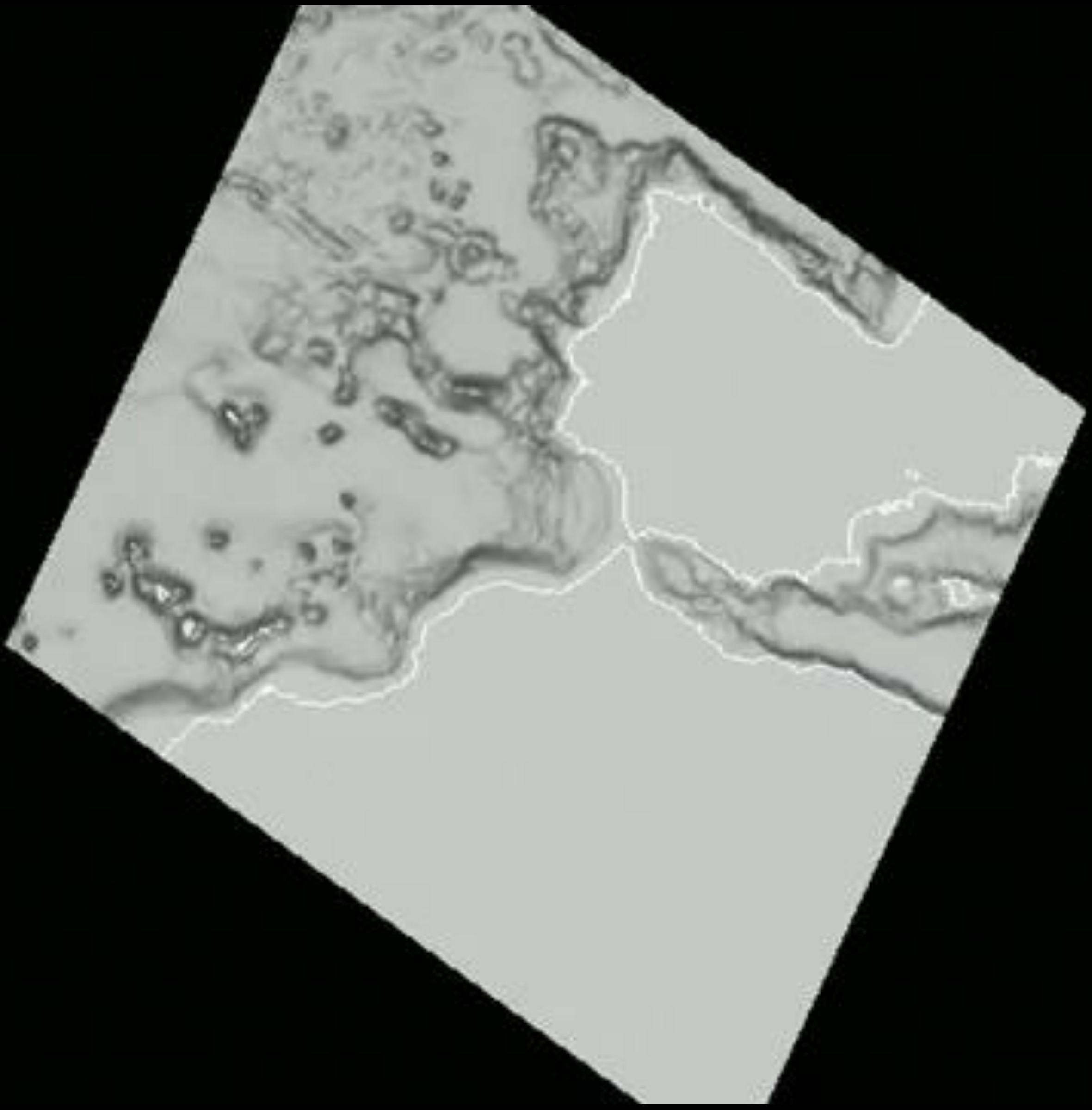
Mediterranean sea level reproduced by CMIP5* global models (present climate)

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

Background geography

ENEA

Strait of Gibraltar Background: 3D Bathymetry



Strait of Gibraltar Background

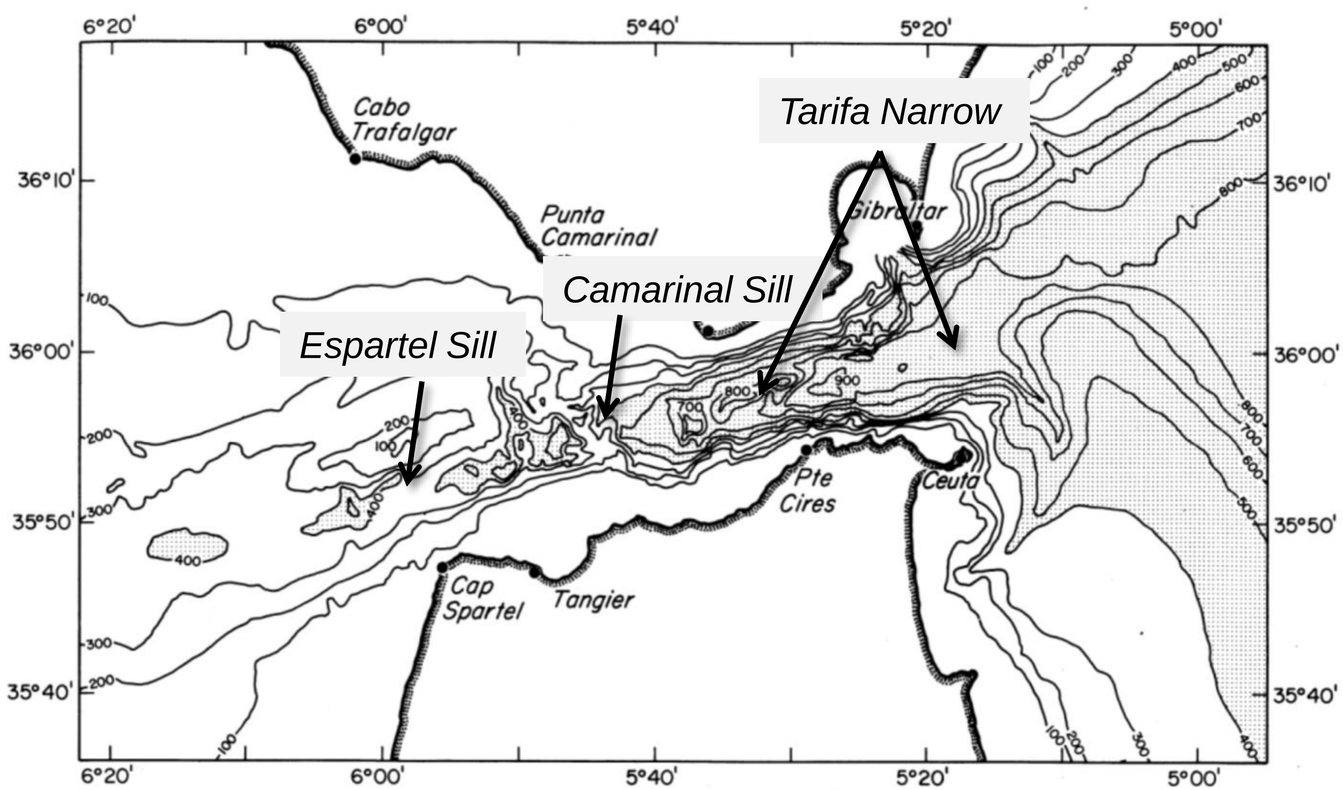


Chart of the Strait of Gibraltar, adapted from Armi & Farmer (1988), showing the principal geographic features referred to in the text.

Areas deeper than 400 m are shaded

Strait of Gibraltar Background: Physics

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

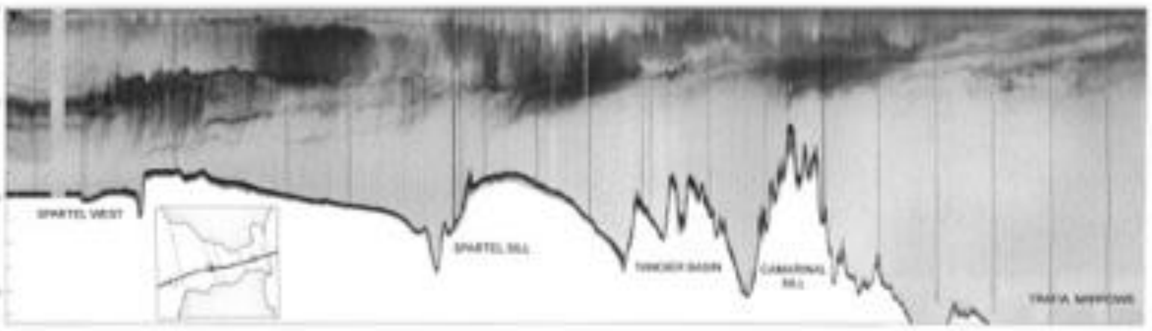


Figure 2. Transect of the Strait [From Armi and Farmer, Farmer and Armi.1988]

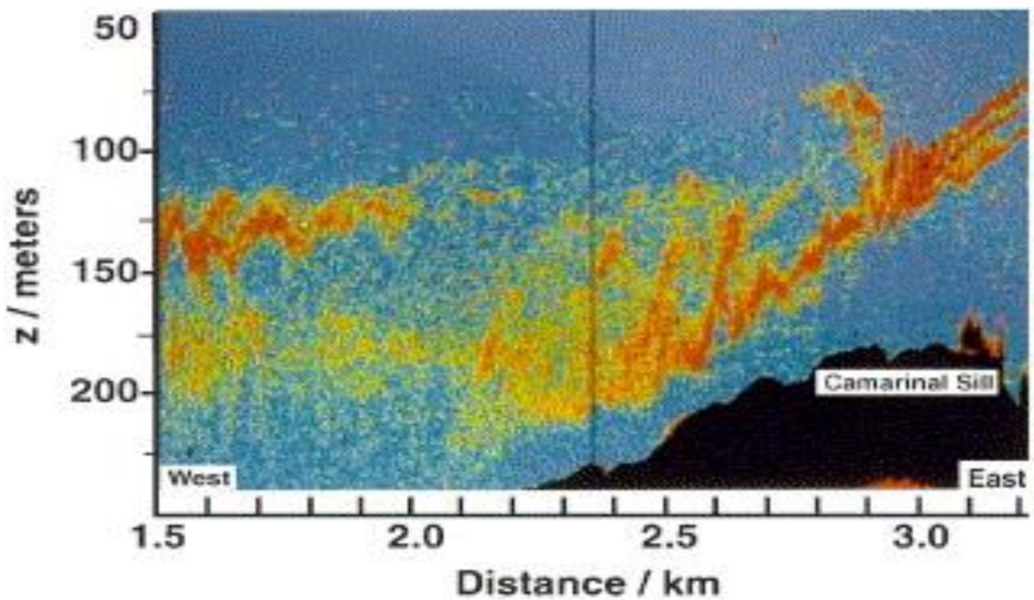
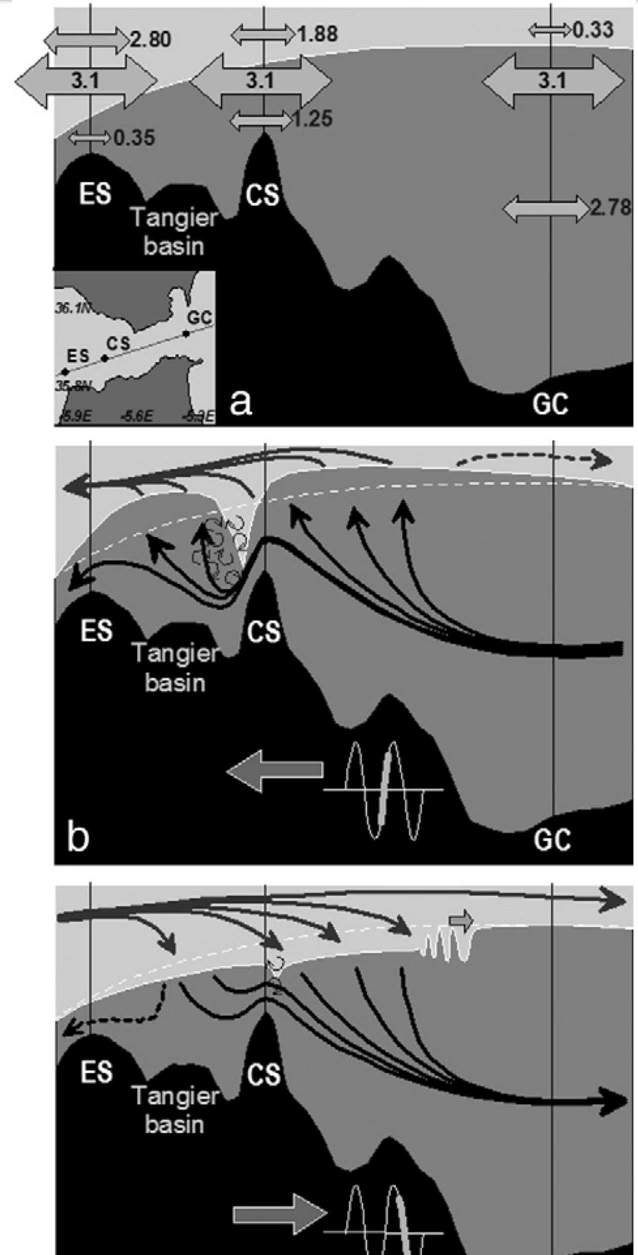
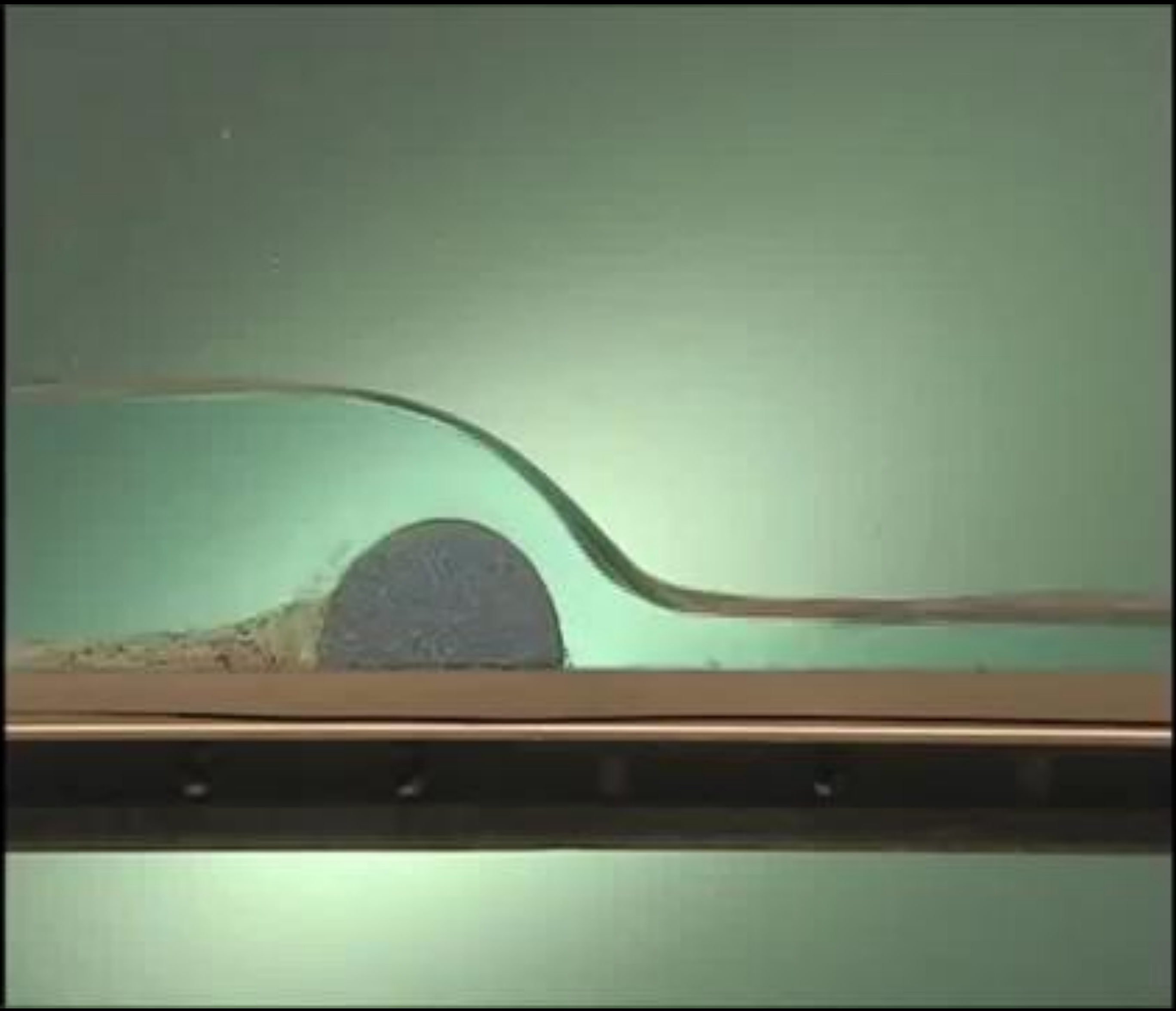


Image of acoustic backscatter during ebb tide over Camarinal Sill in the Strait of Gibraltar (Wesson and Gregg, 1994)

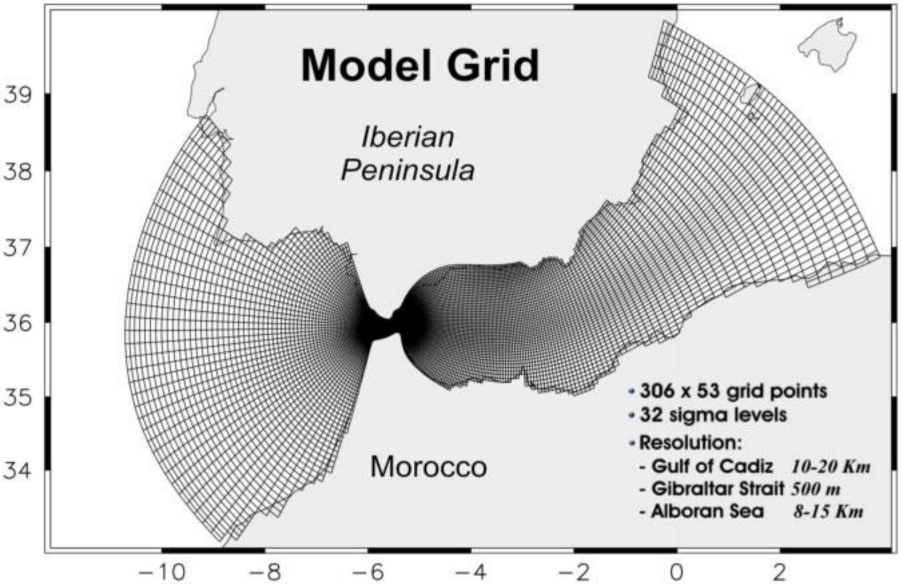


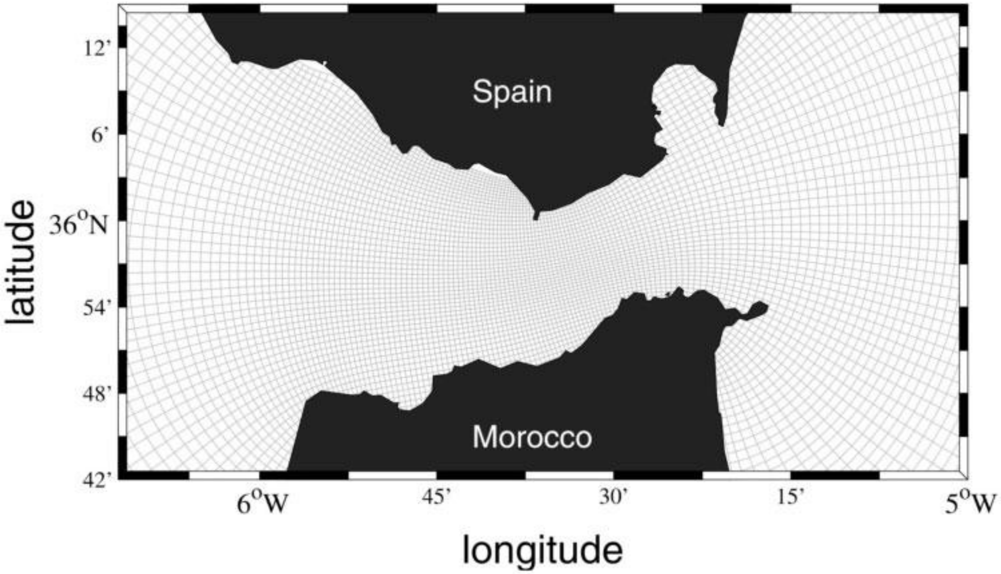
A. Sánchez-Román et al, JGR 2012

Hydraulics jump: an example



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





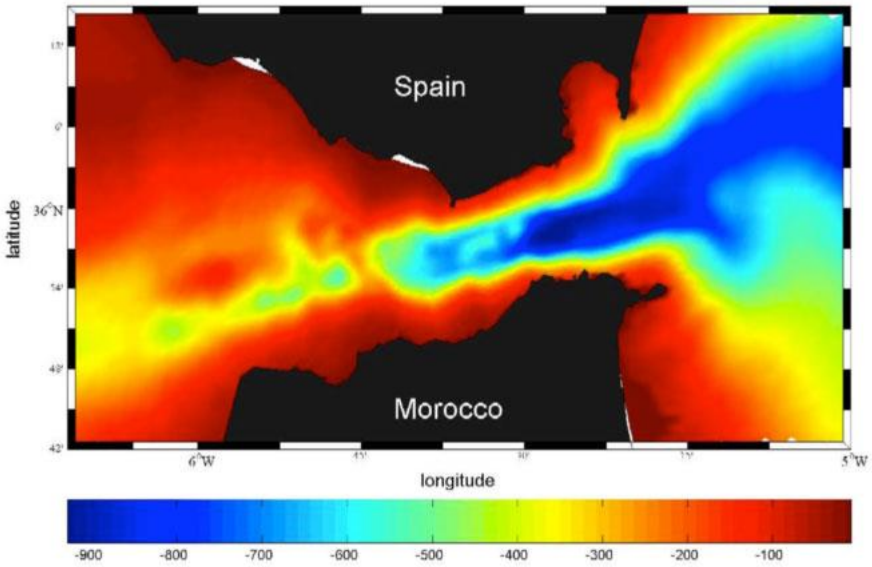
Modified POM

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

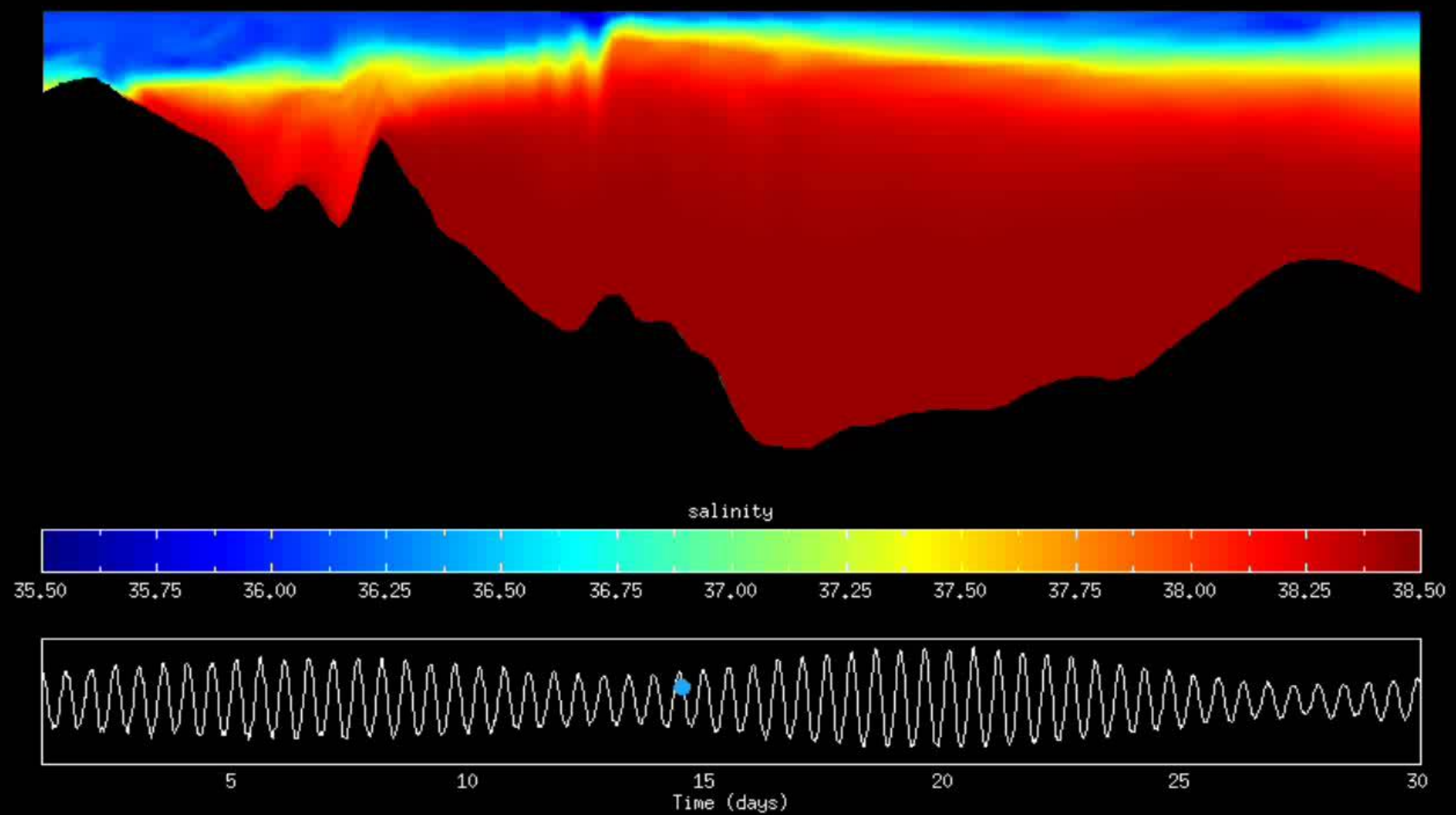
•Sannino et al, JGR, 2007

•Sannino et al , NC, 2005

•Sannino et al, JGR, 2004

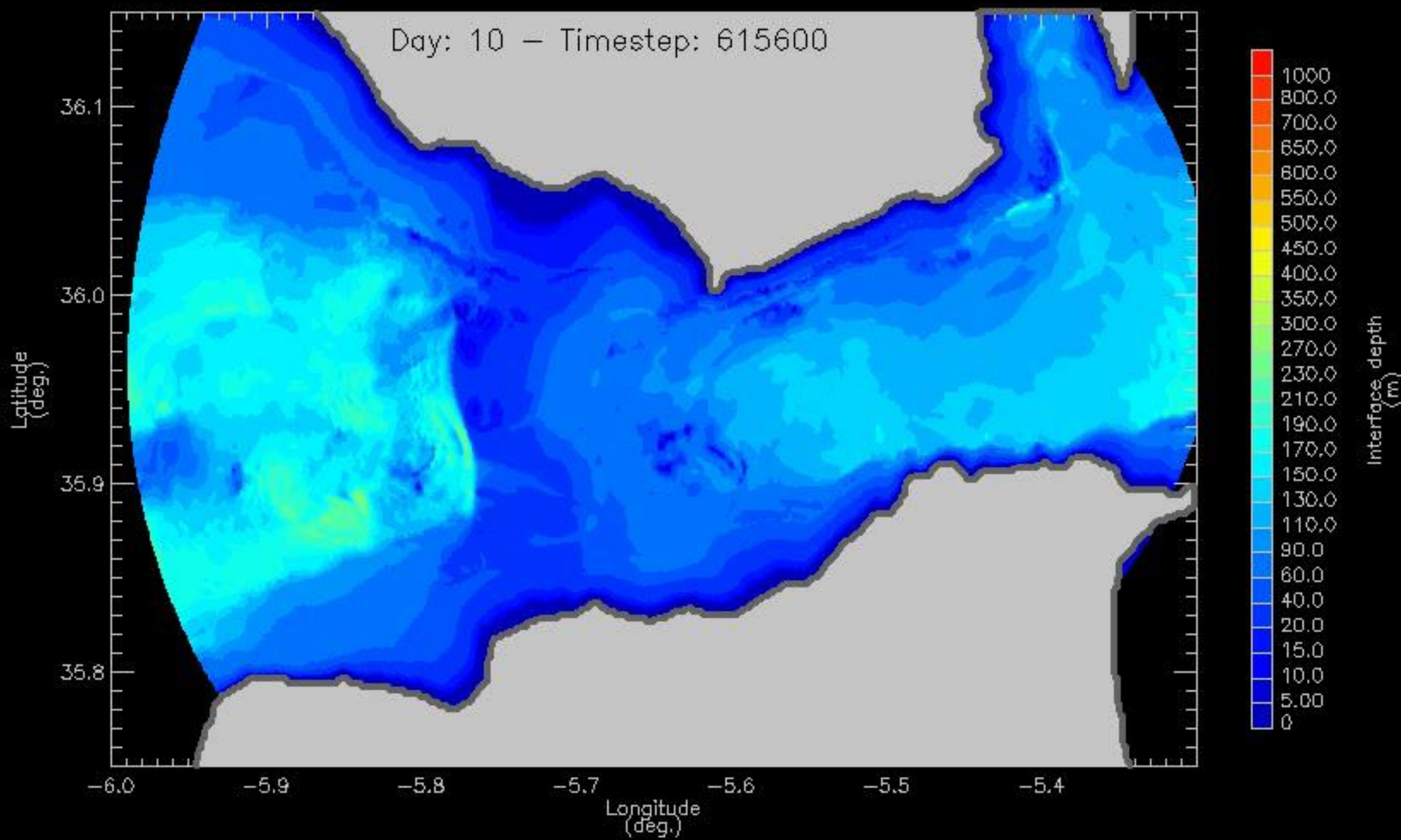
•Sannino et al, JGR, 2002

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



salinity along-strait section

MITgcm model simulation

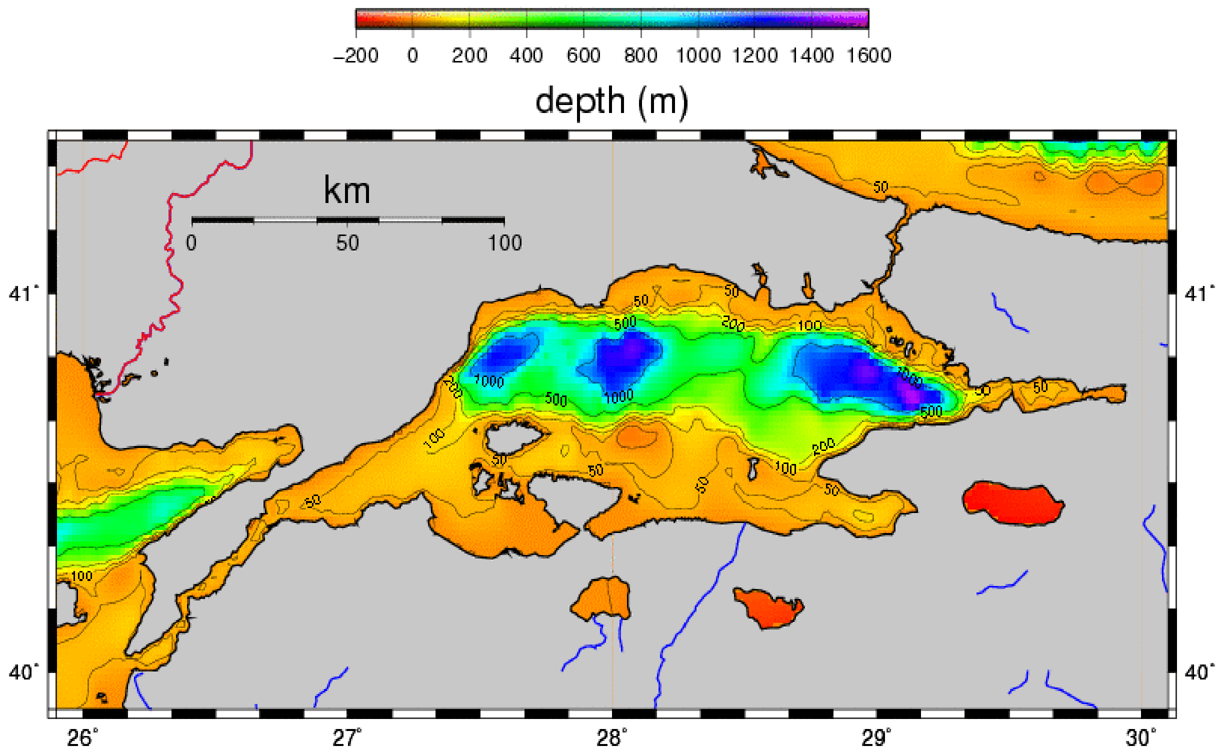


Interface depth evolution

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.

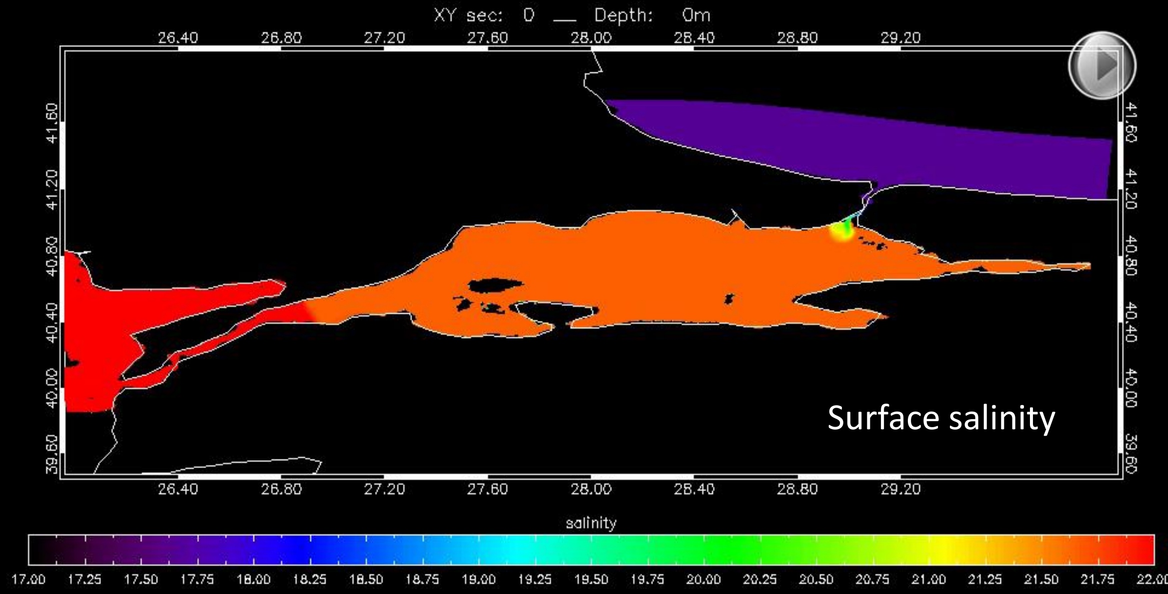
An all time challenge is the modeling of the entire system: Dardanelles – Maramara Sea – Bosphorous.



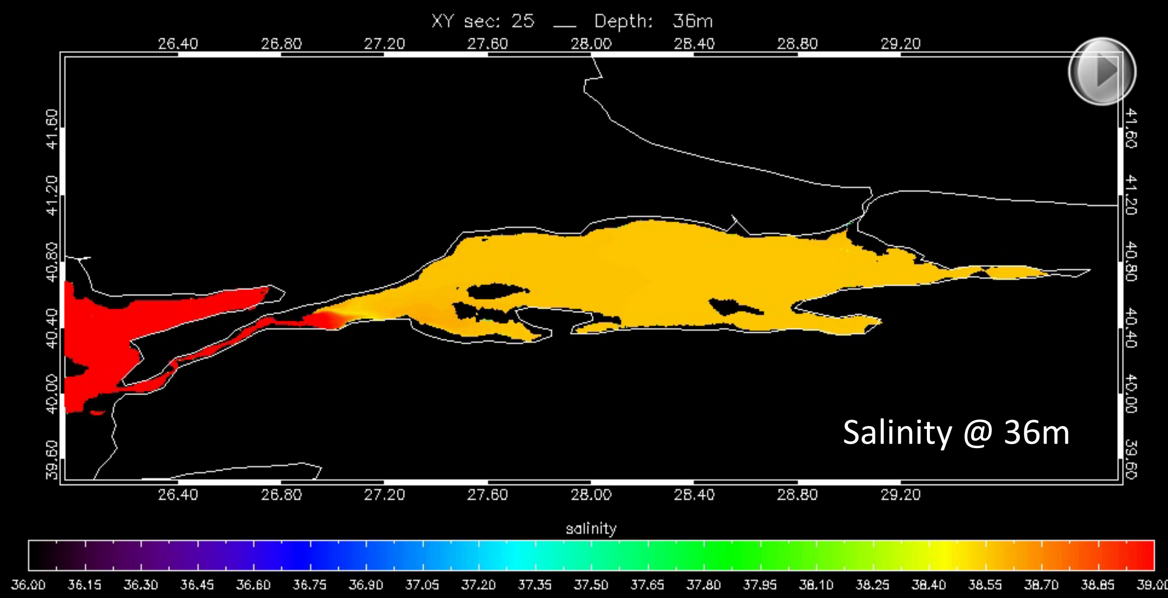
<u>Question</u>:

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

Sannino et al.
ODY 2017



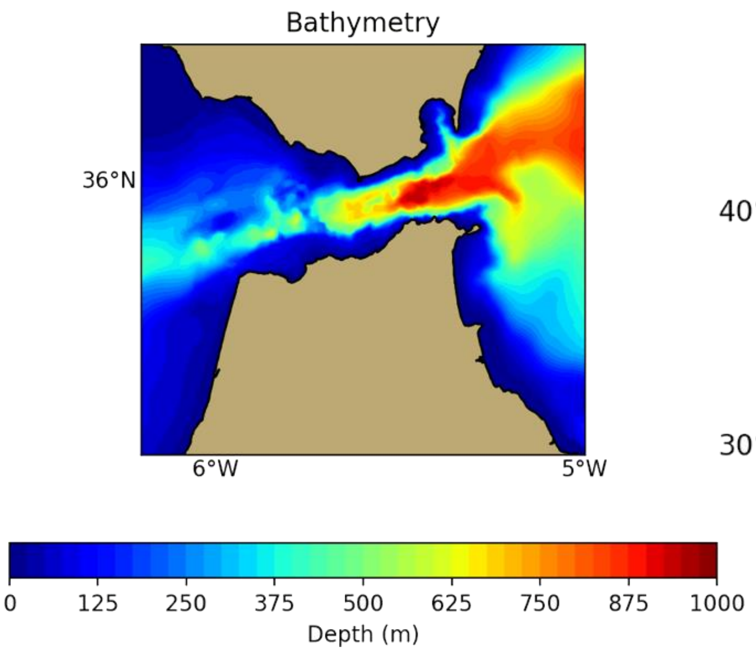
Forced net barotropic flow 18000 m^3/sec experiment

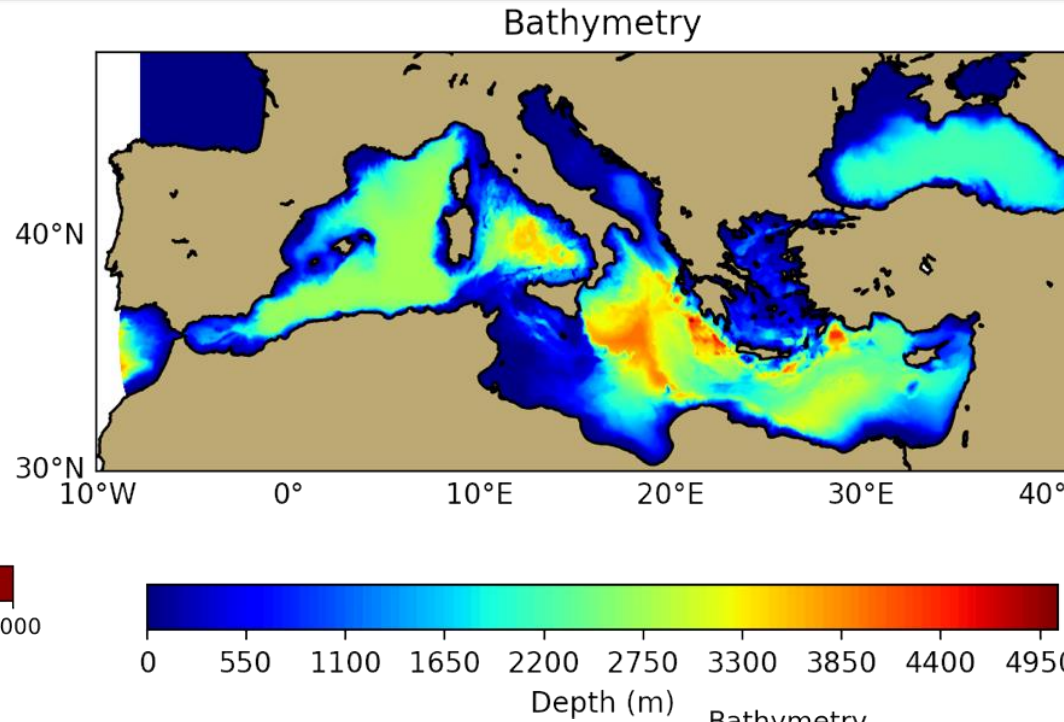


Sannino et al.
ODY 2017

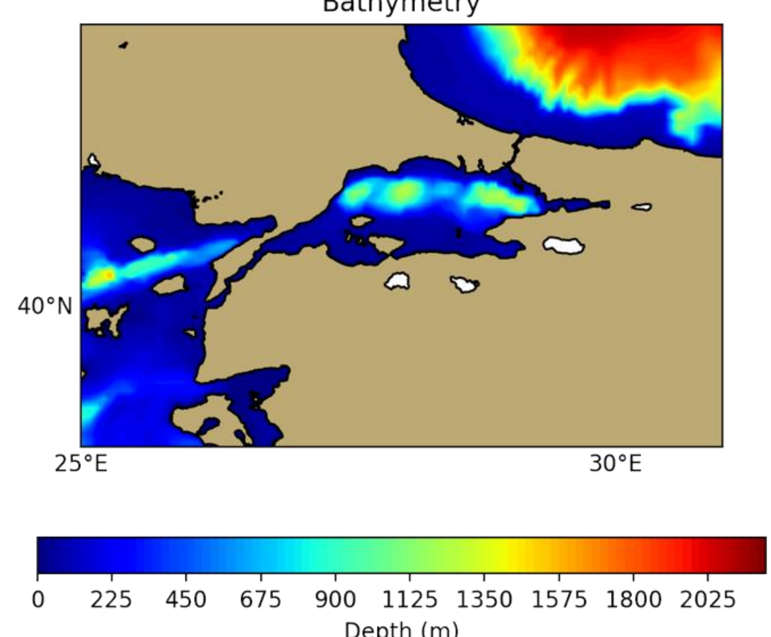
Three experiments were conducted to study the sensitivity of the circulation to different net barotropic flows: **5600, 9600, 18000, and 50000** m^3/sec

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

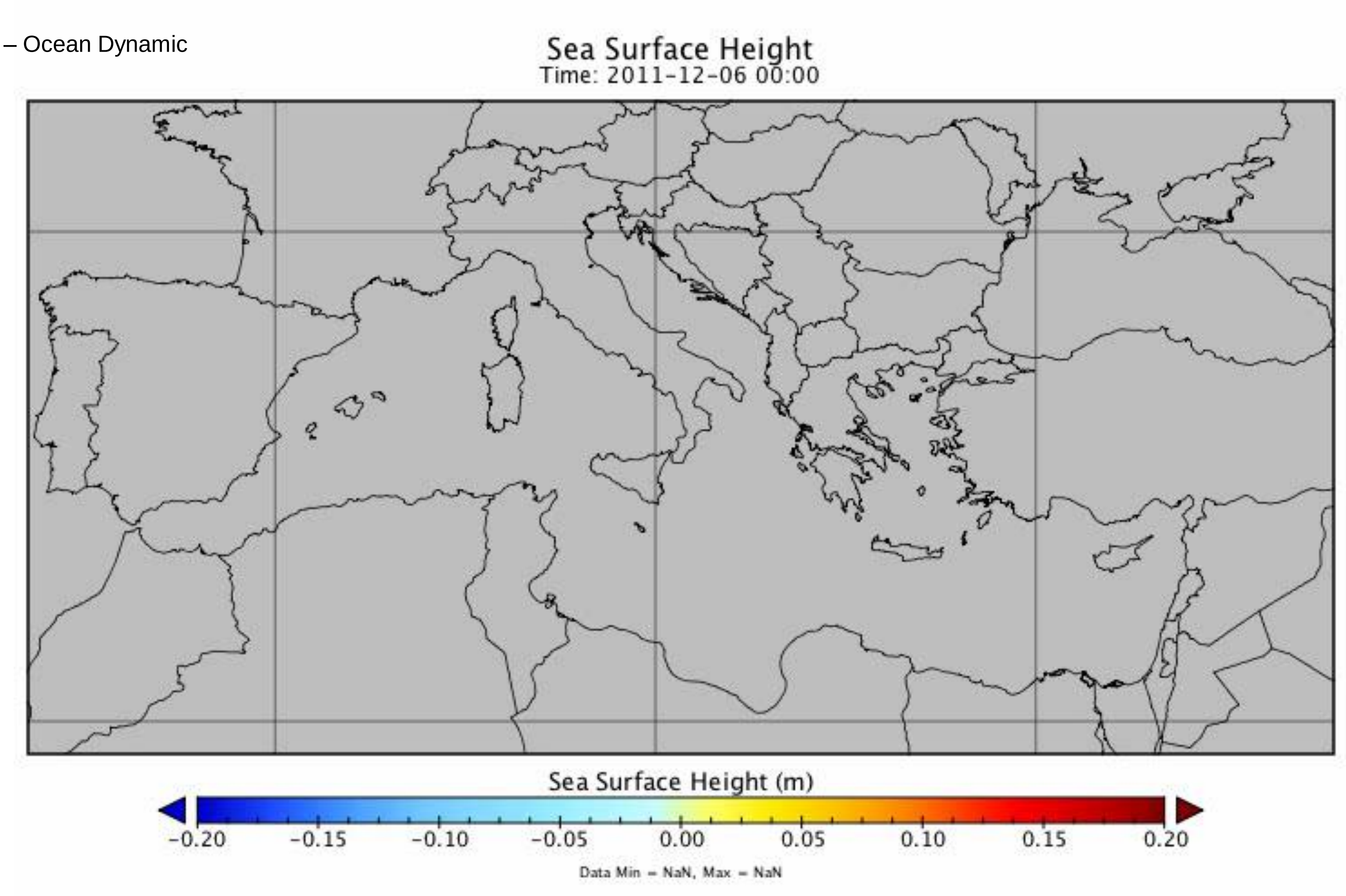


Sannino et al.
Clim Dyn 2012

ENEA

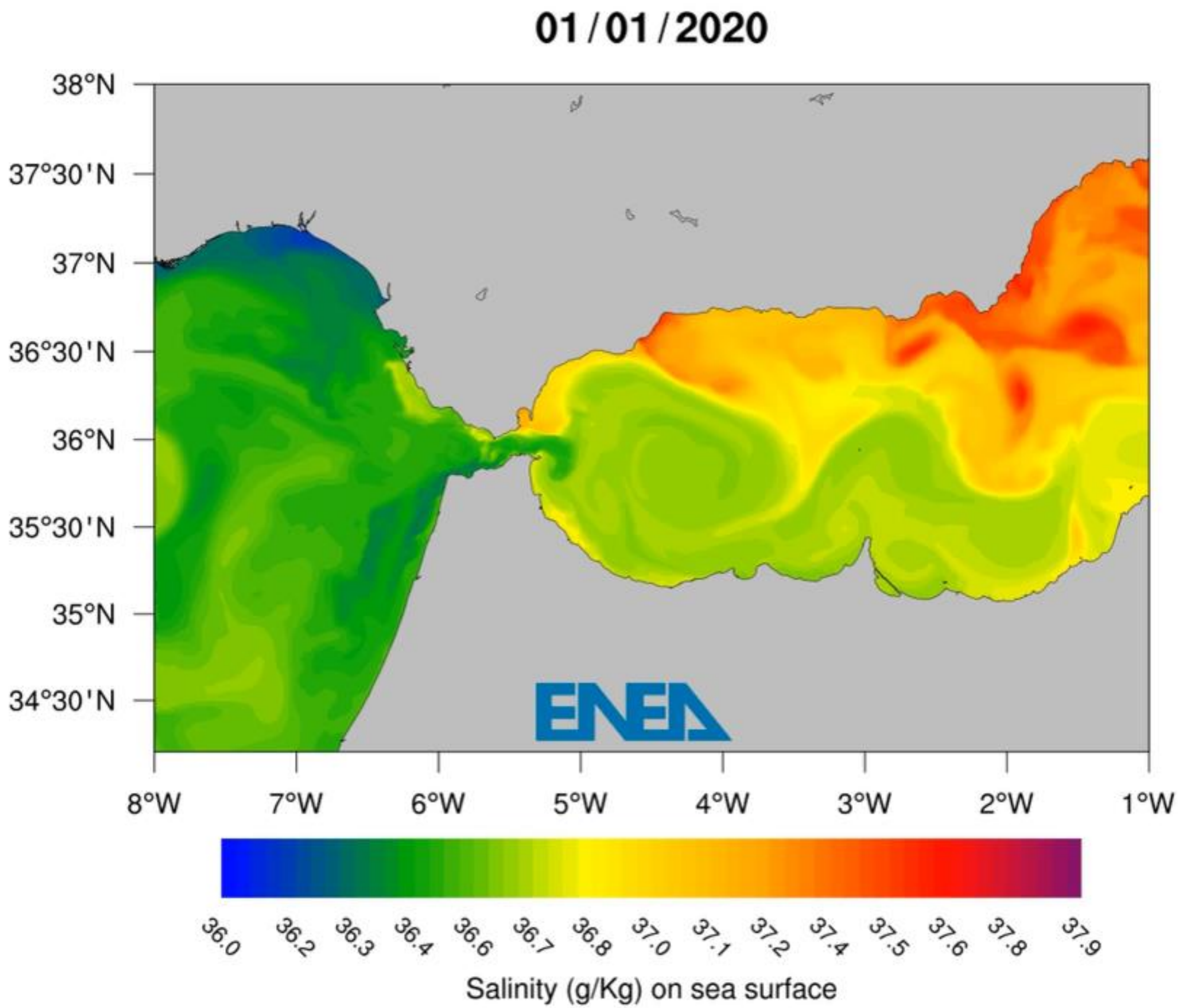
ENEA Hi-resolution Mediterranean Climate Model

Palma et al 2019 – Ocean Dynamic



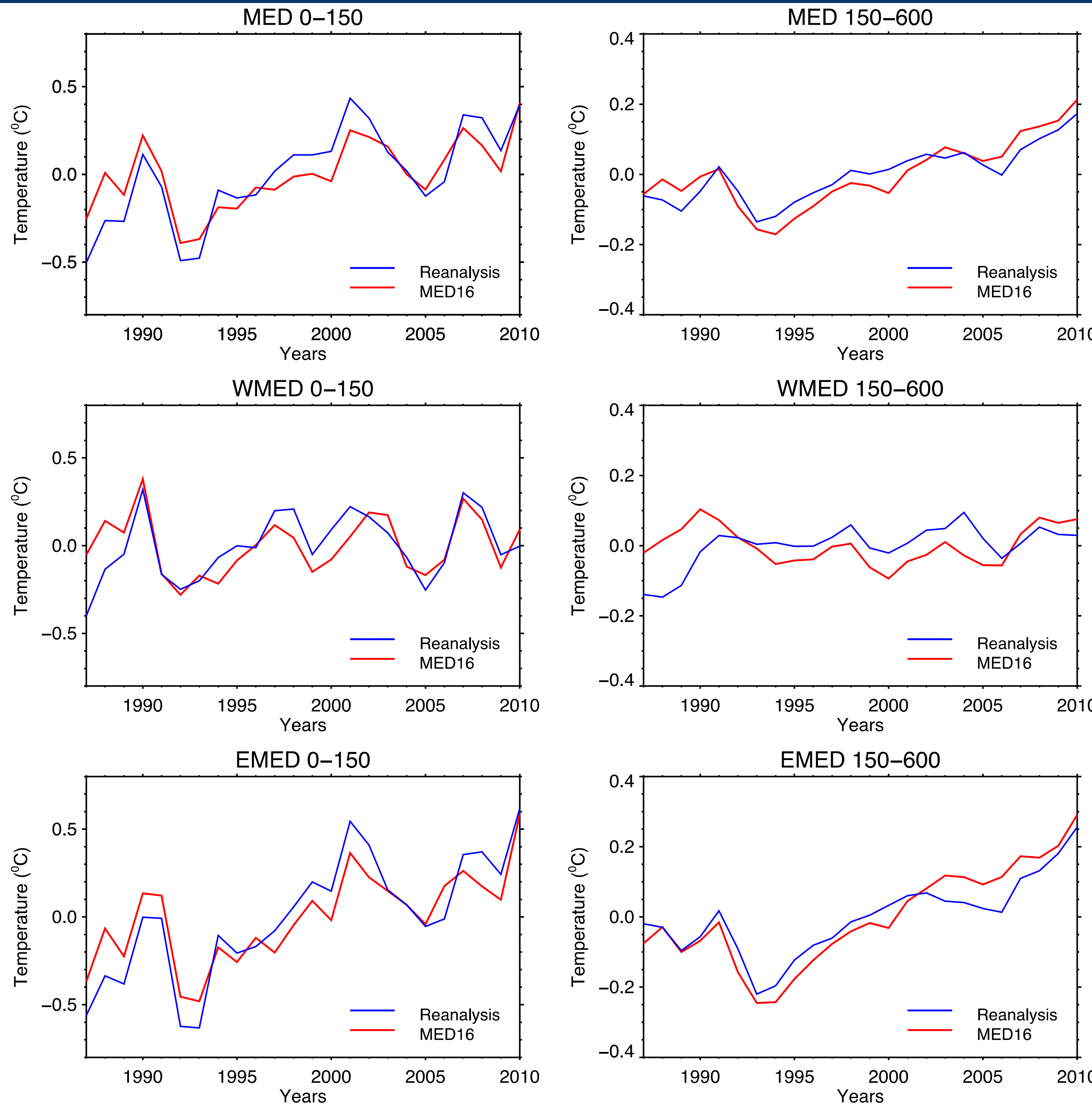
MITgcm – Explicit Tides (M2,S2, K1, O1) – Lateral Tide + Tidal Potential
Average resolution 1/16˚ (7 Km)
Minimum resolution at Gibraltar (230m) and Turkish Straits (90m)
100 Vertical Levels

ENEA Hi-resolution Mediterranean Climate Model



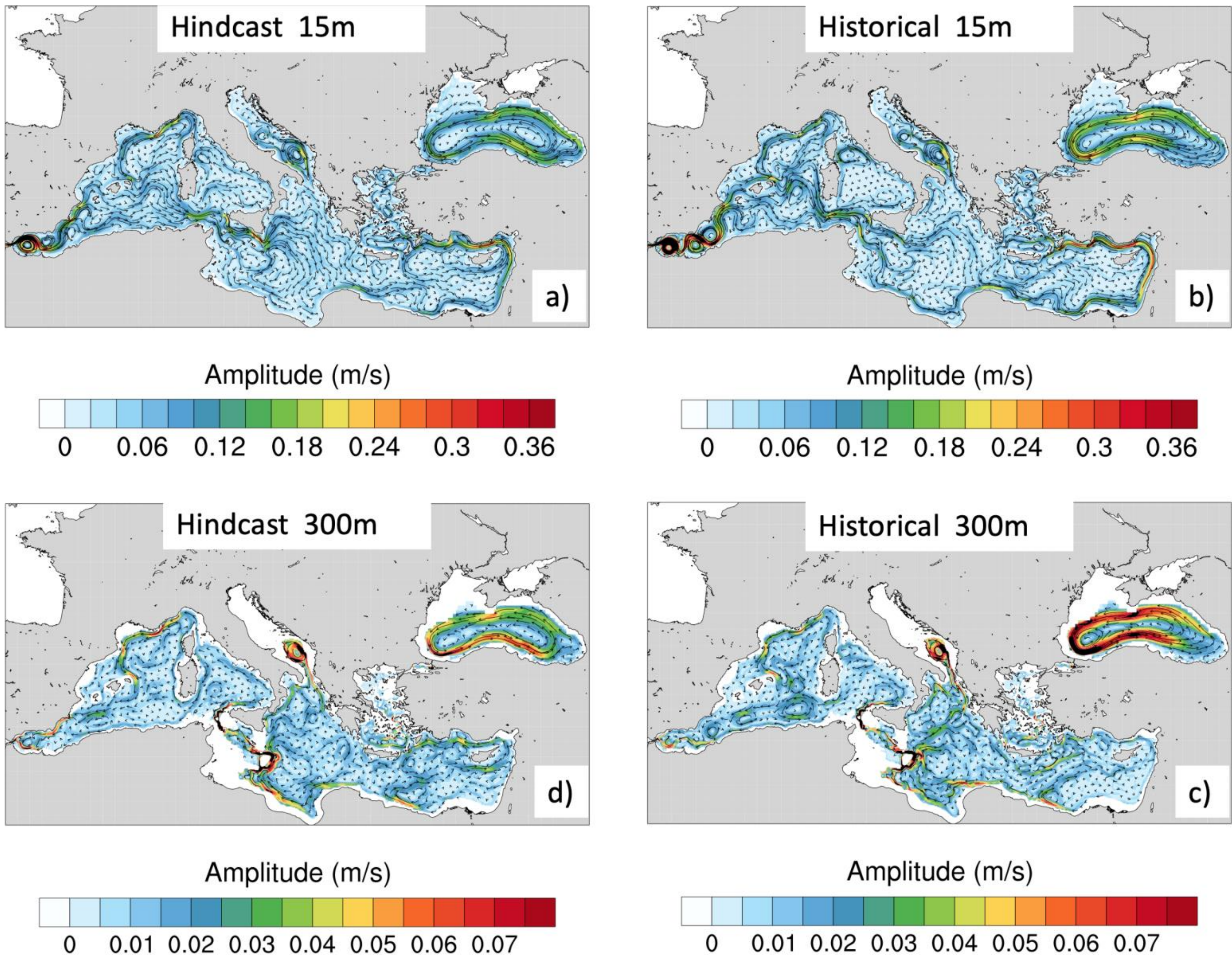
Hi-resolution Mediterranean Climate Model

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



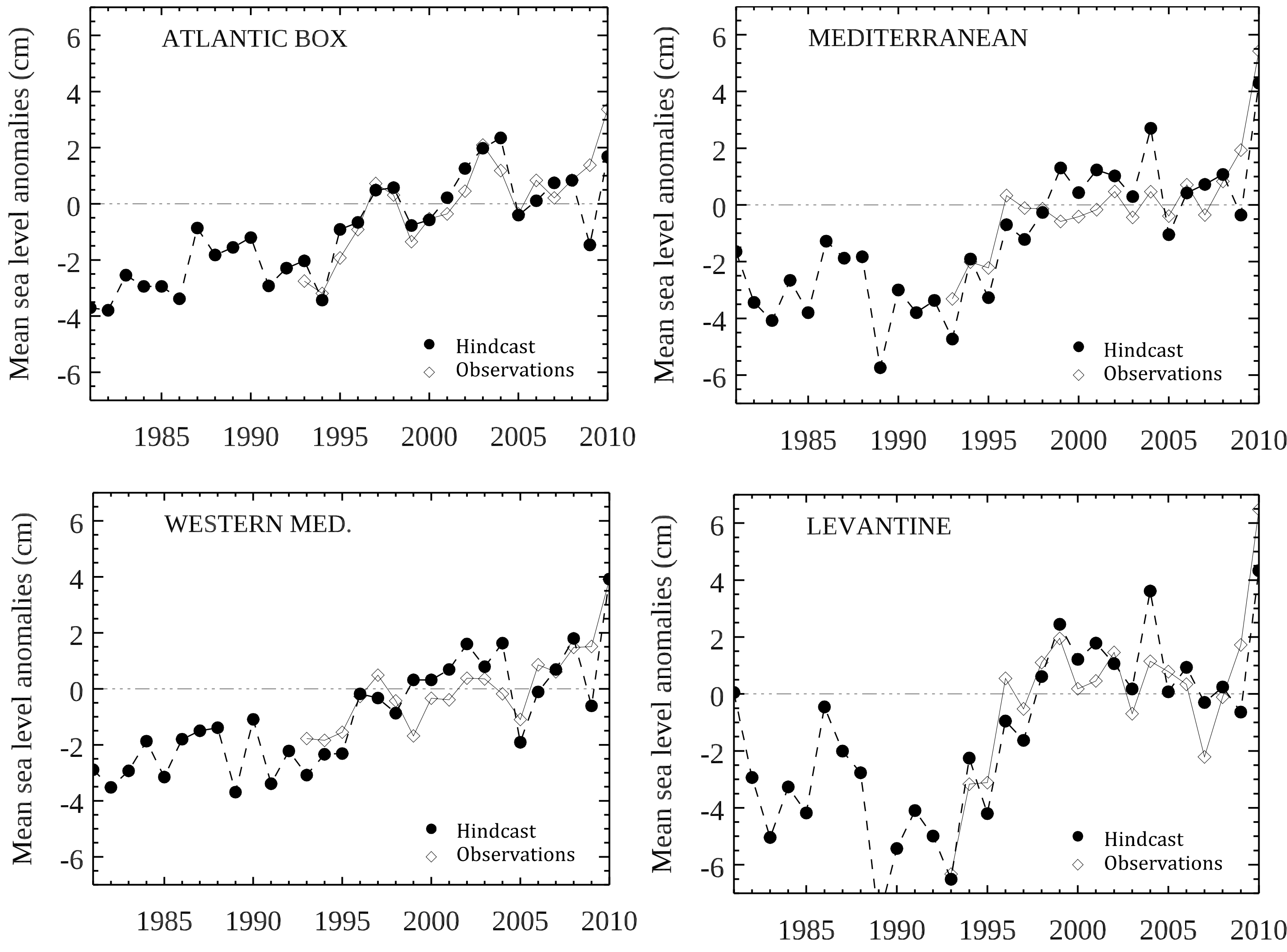
Hi-resolution Mediterranean Climate Model

Surface (15 m of depth) and intermediate (300 m of depth) circulation, averaged over the simulation periods of the hindcast (left panel) and of the historical (right panel) experiments



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



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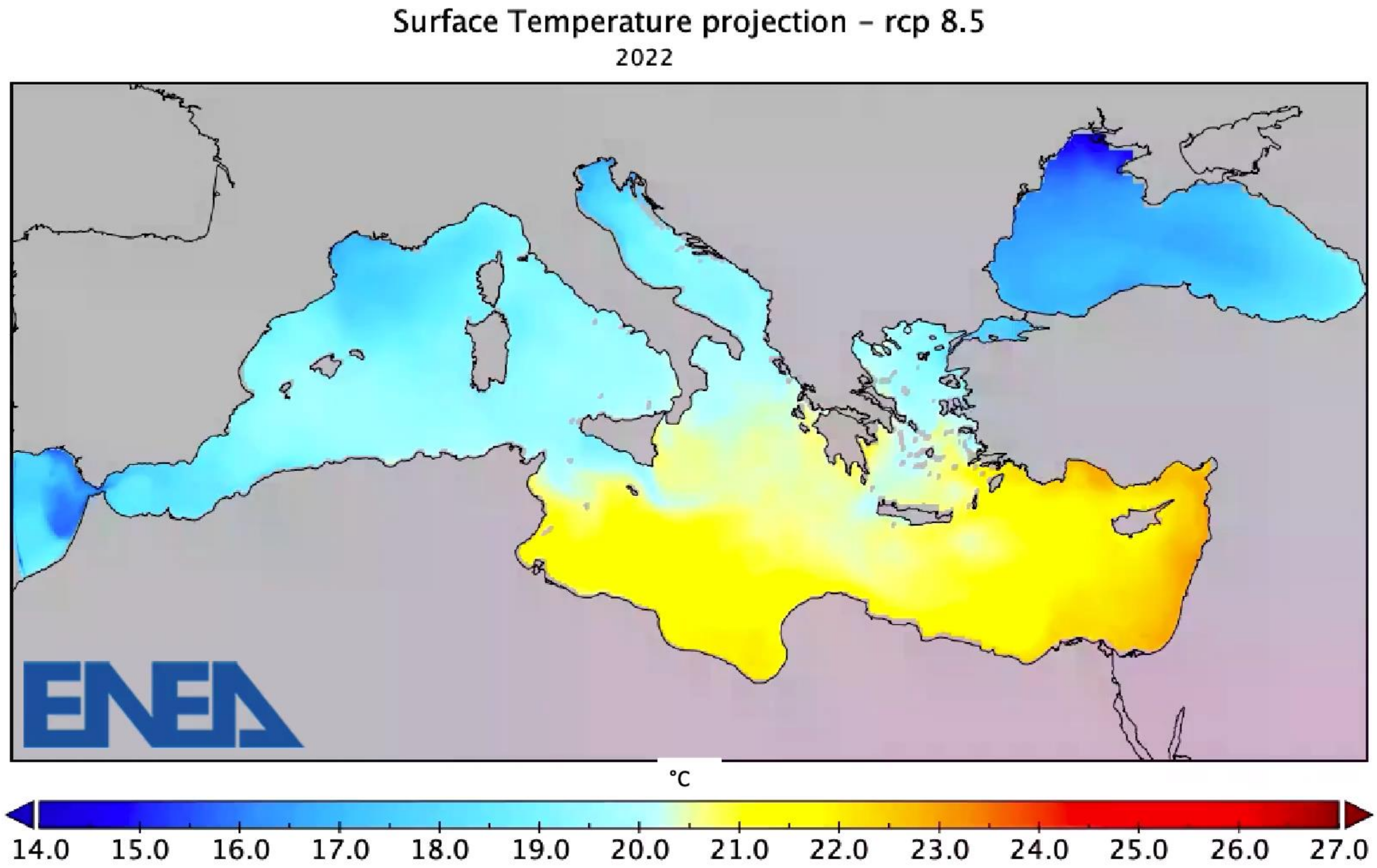
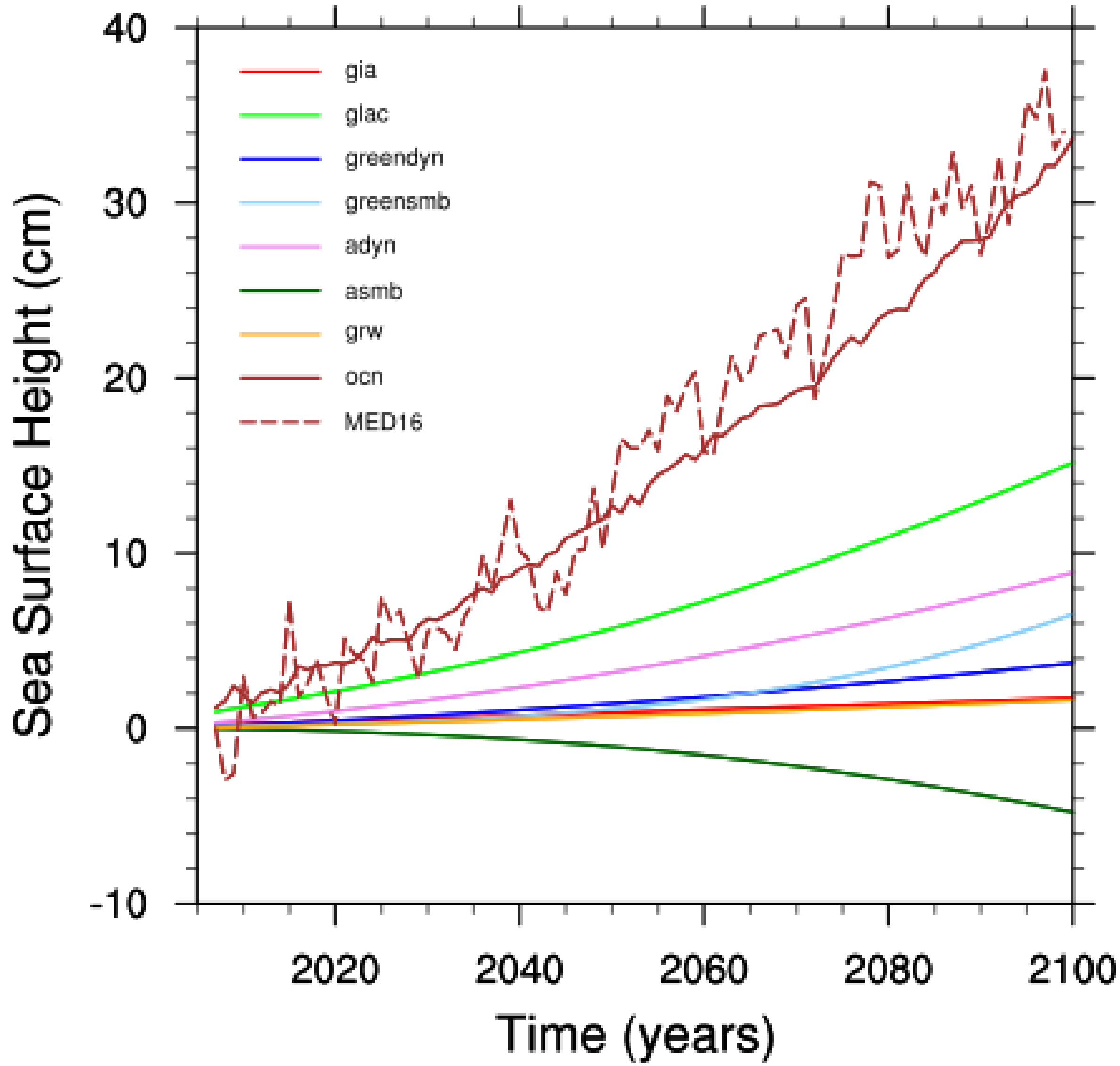
Future (2100) Mediterranean SST (rcp 8.5)

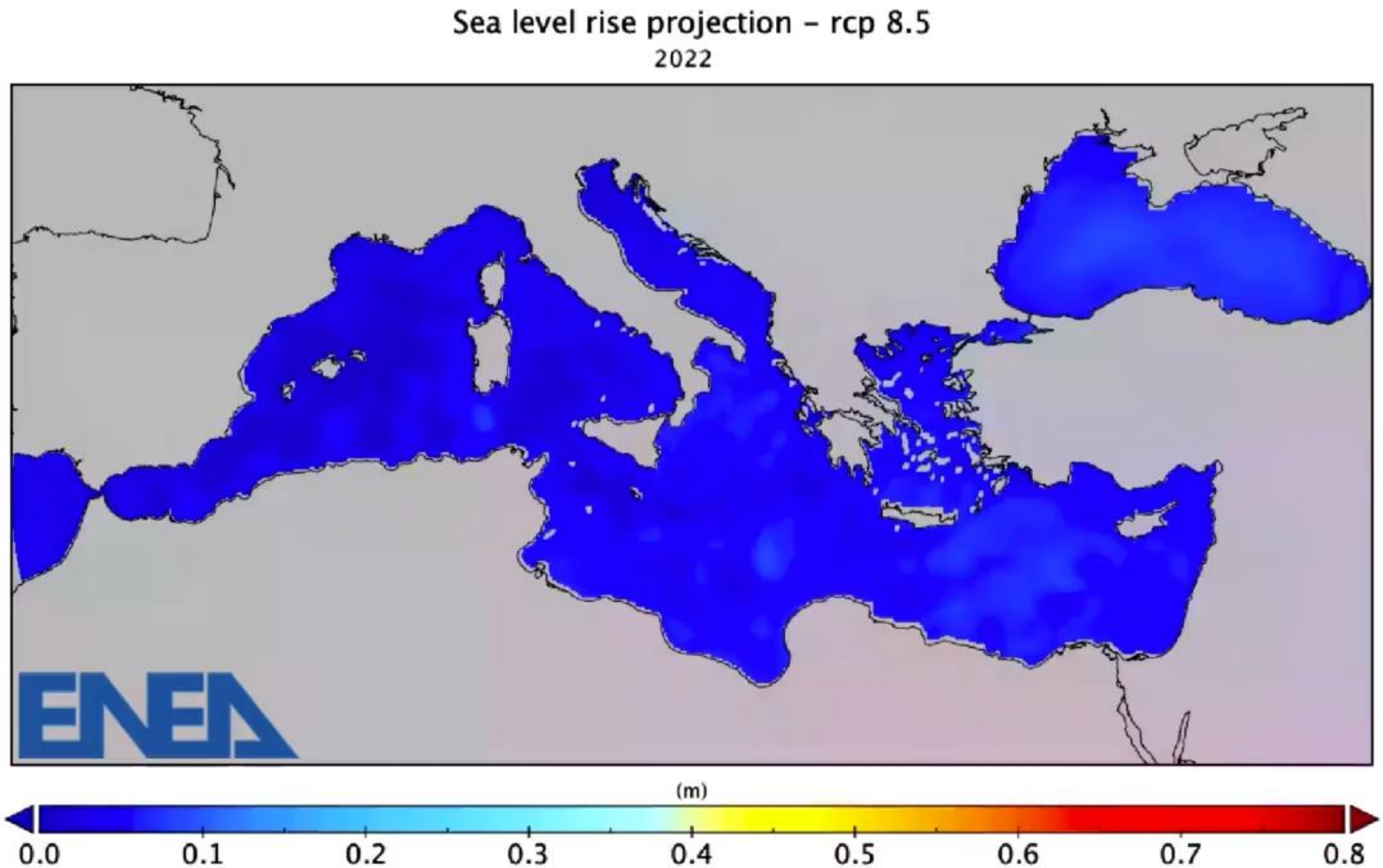


Future (2100) Mediterranean Sea Level (rcp 8.5)

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



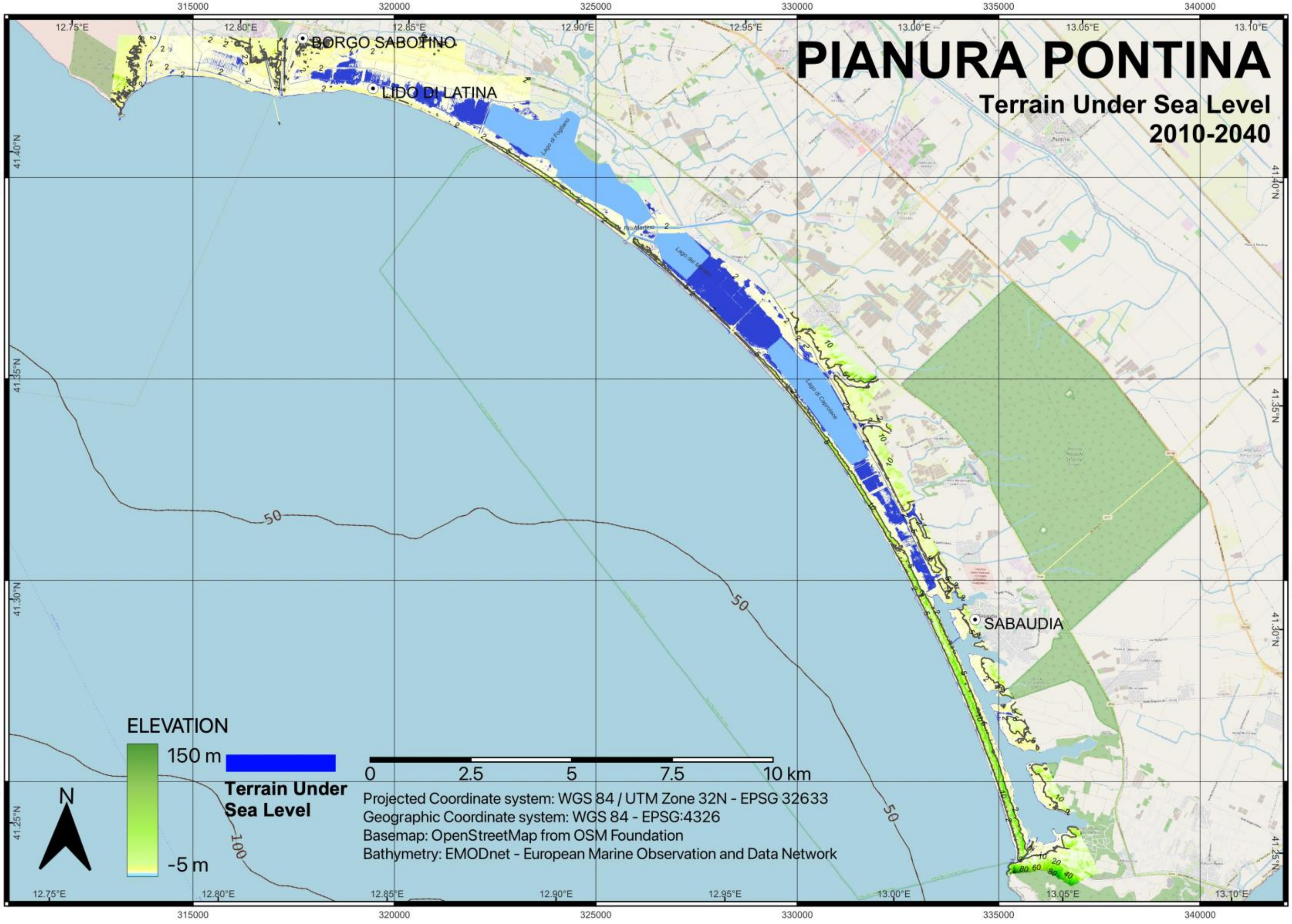
Future (2100) Mediterranean Sea Level (rcp 8.5)



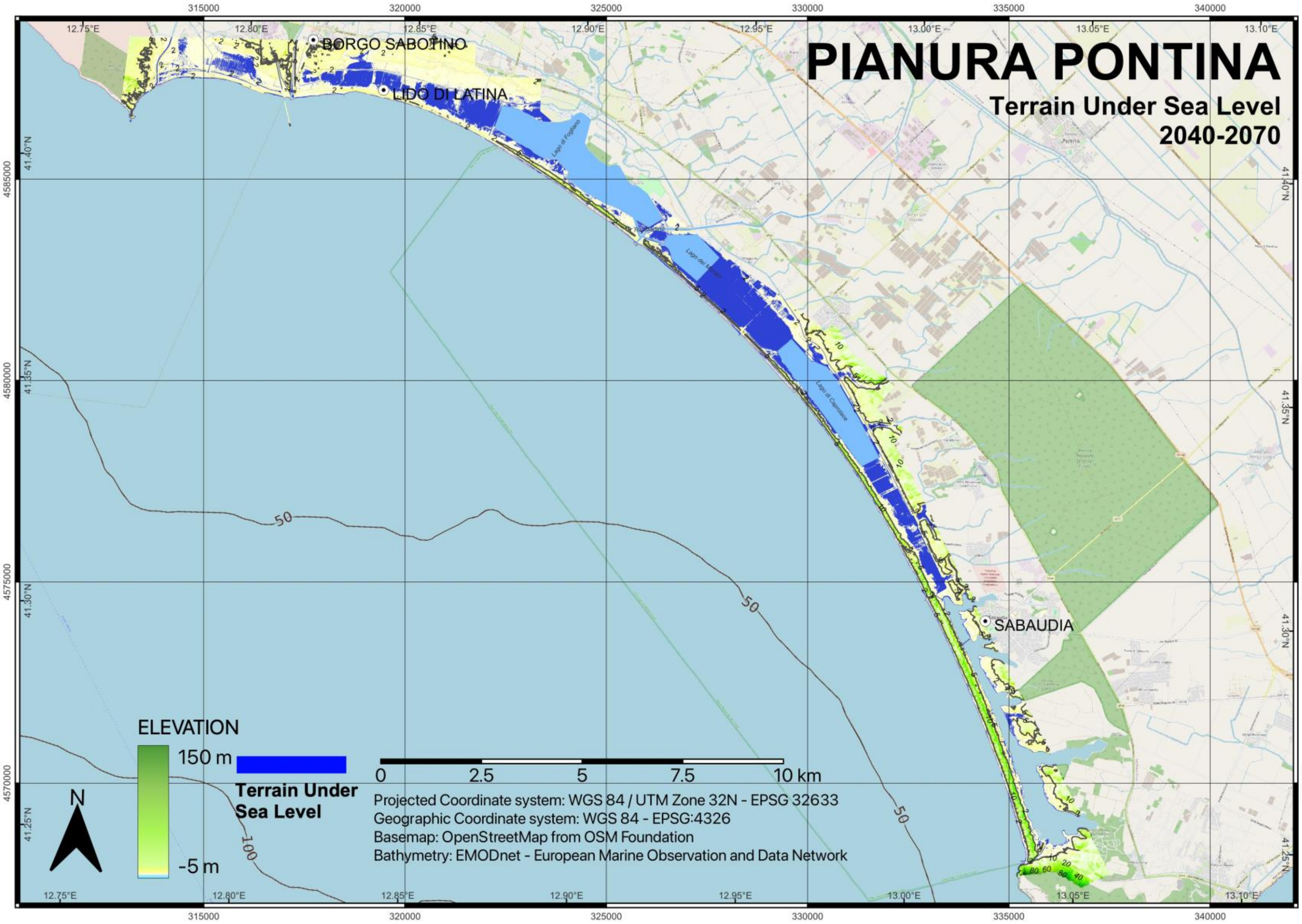
Causes of R-SLR at Gobal, Regional and Local scale

	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	○	○	●

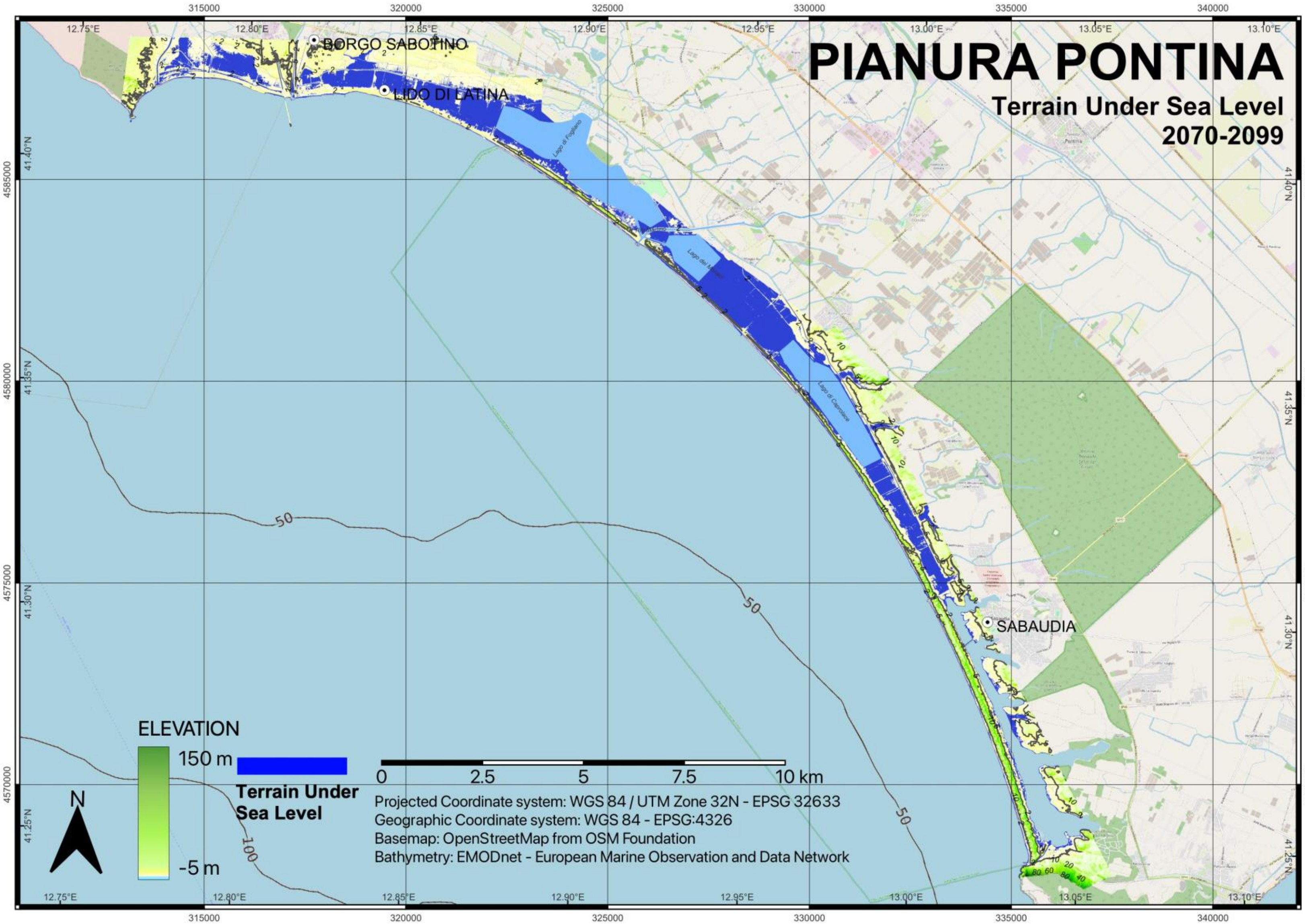
Future (2100) Mediterranean Sea Level



Future (2100) Mediterranean Sea Level

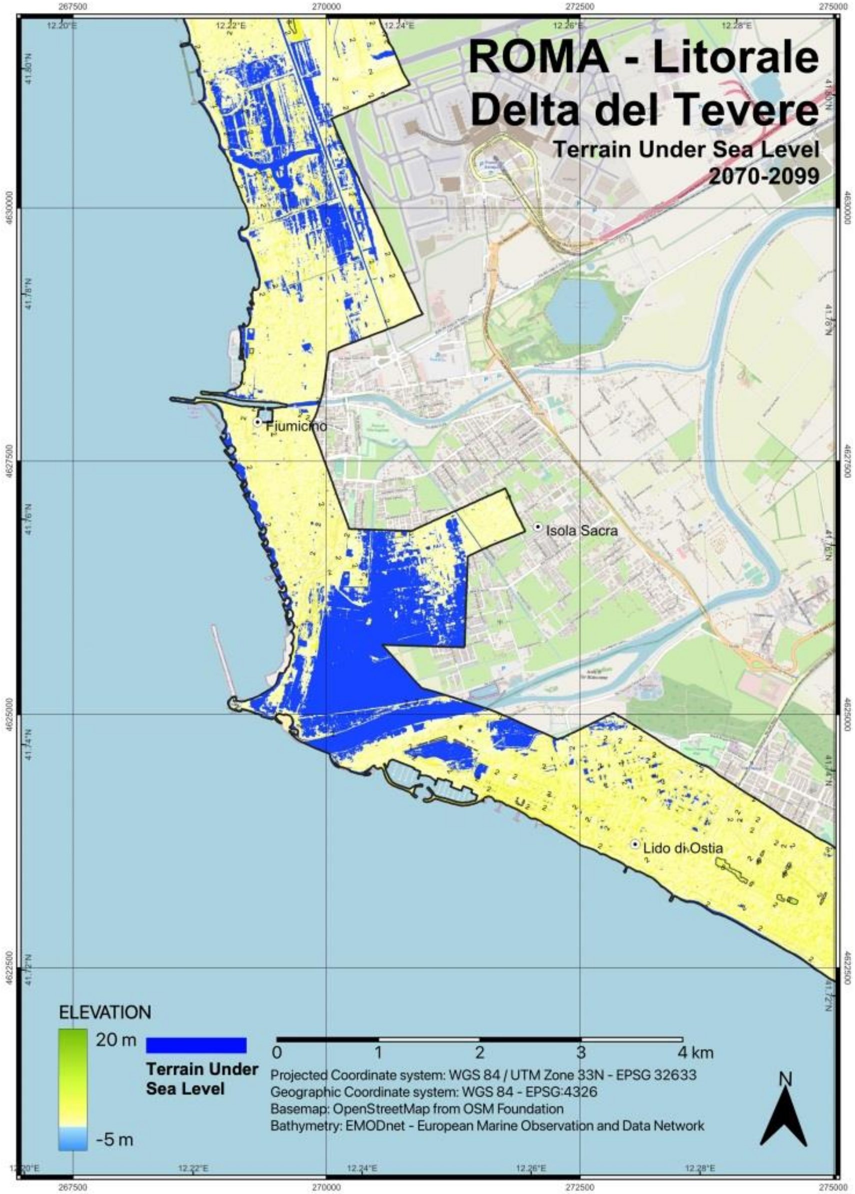


Future (2100) Mediterranean Sea Level



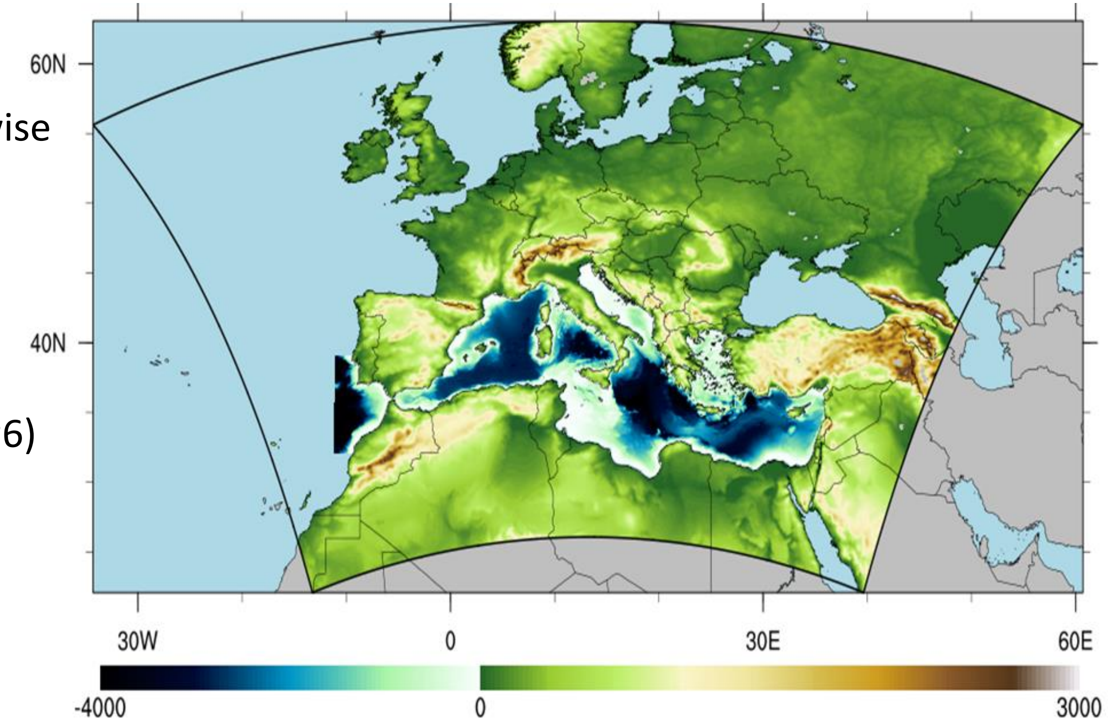
ENEA

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

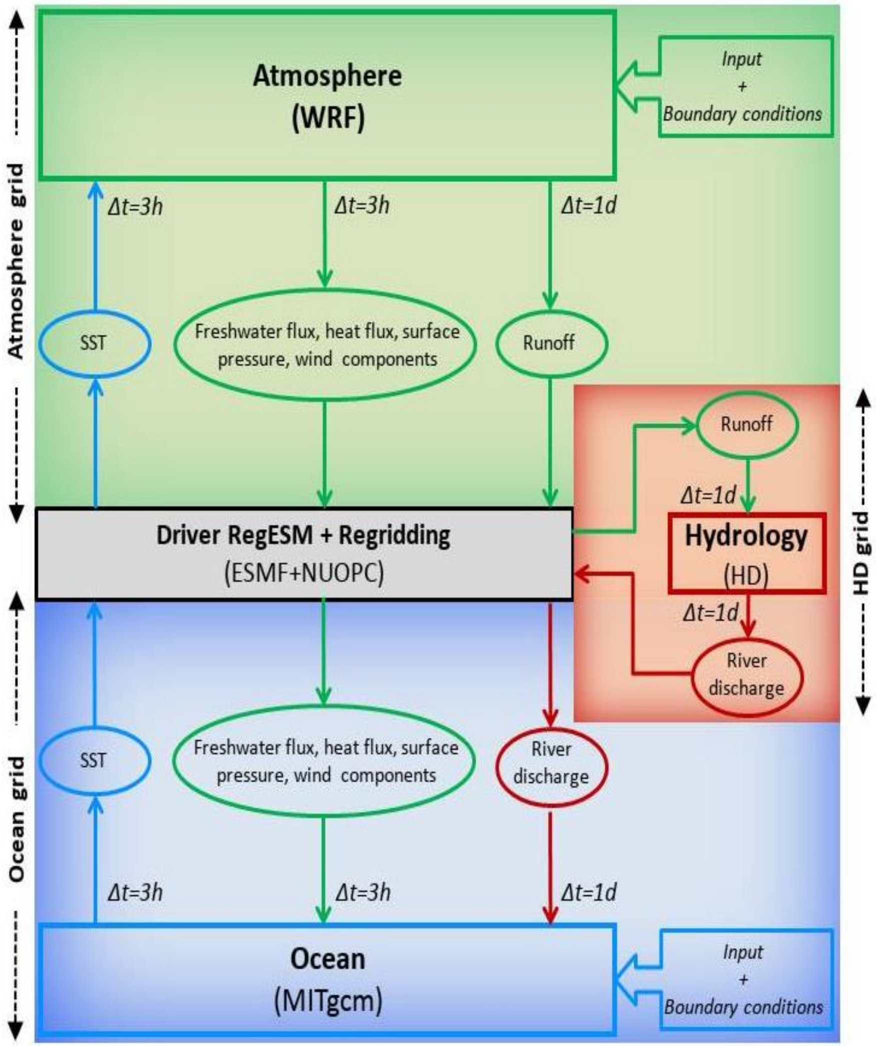


World Climate Research Programme

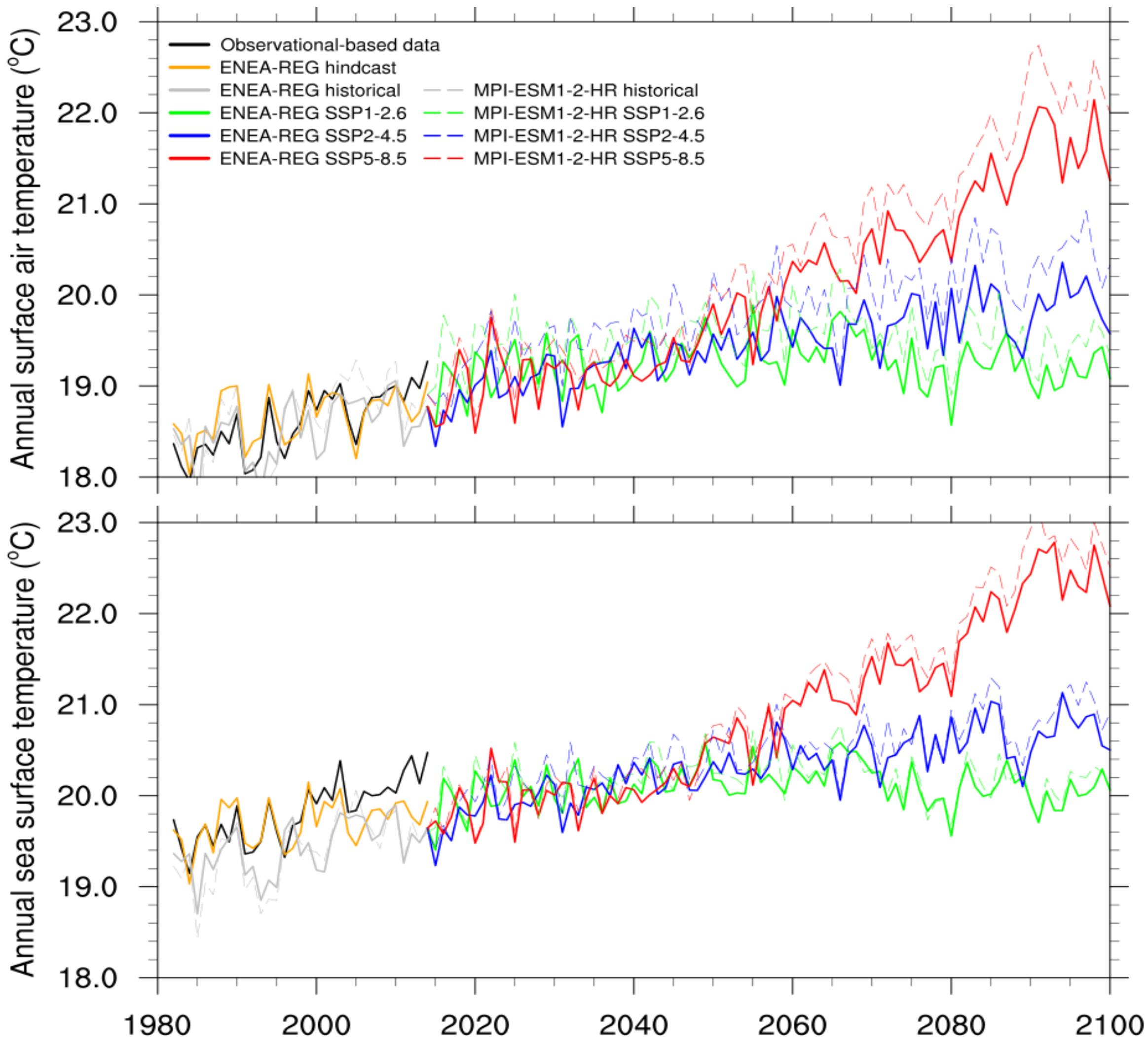
ENEA Regional Earth System Model

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

Anav et al., 2021, GMD

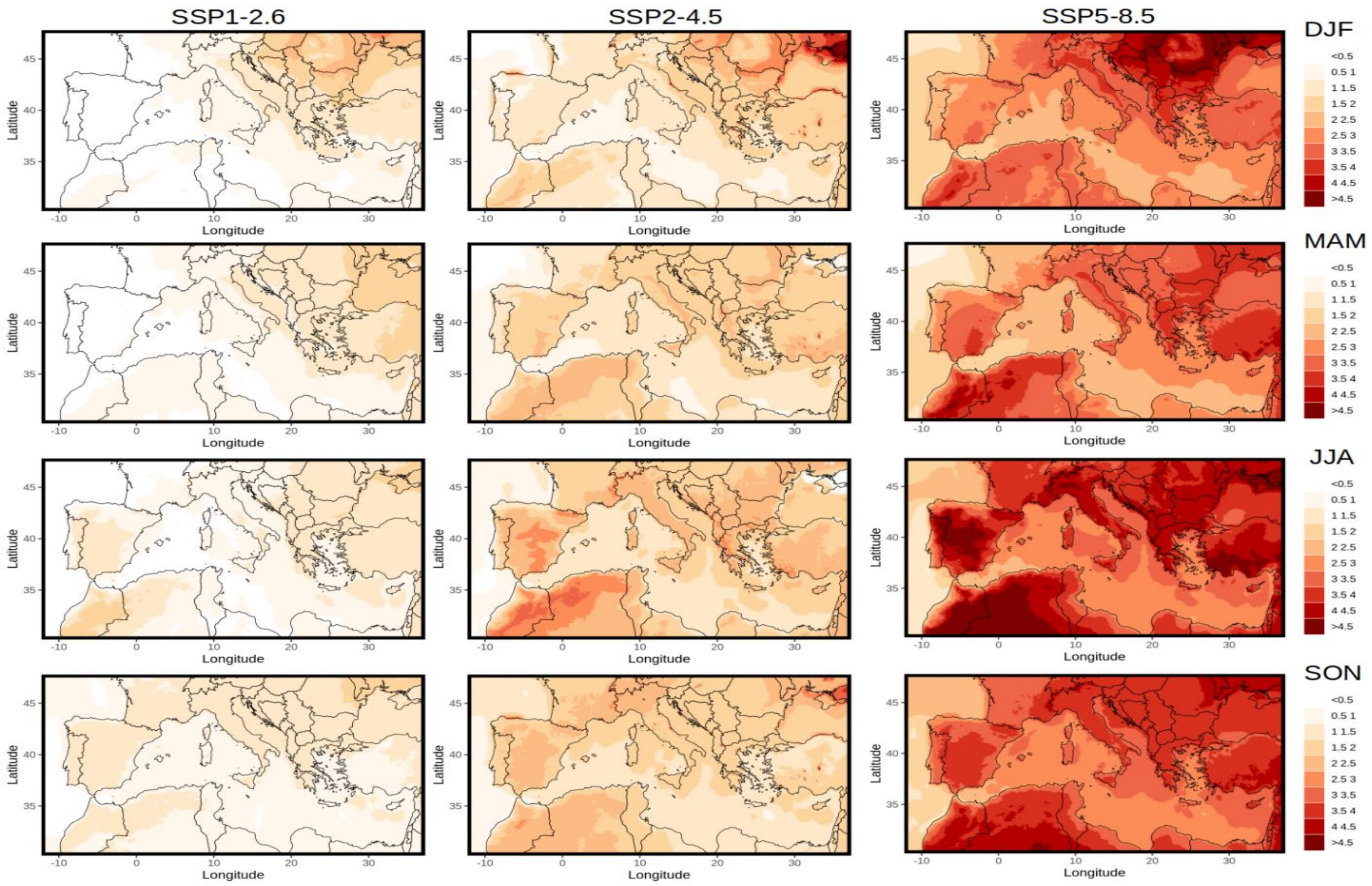


Future (2100) Mediterranean SST(CMIP6)



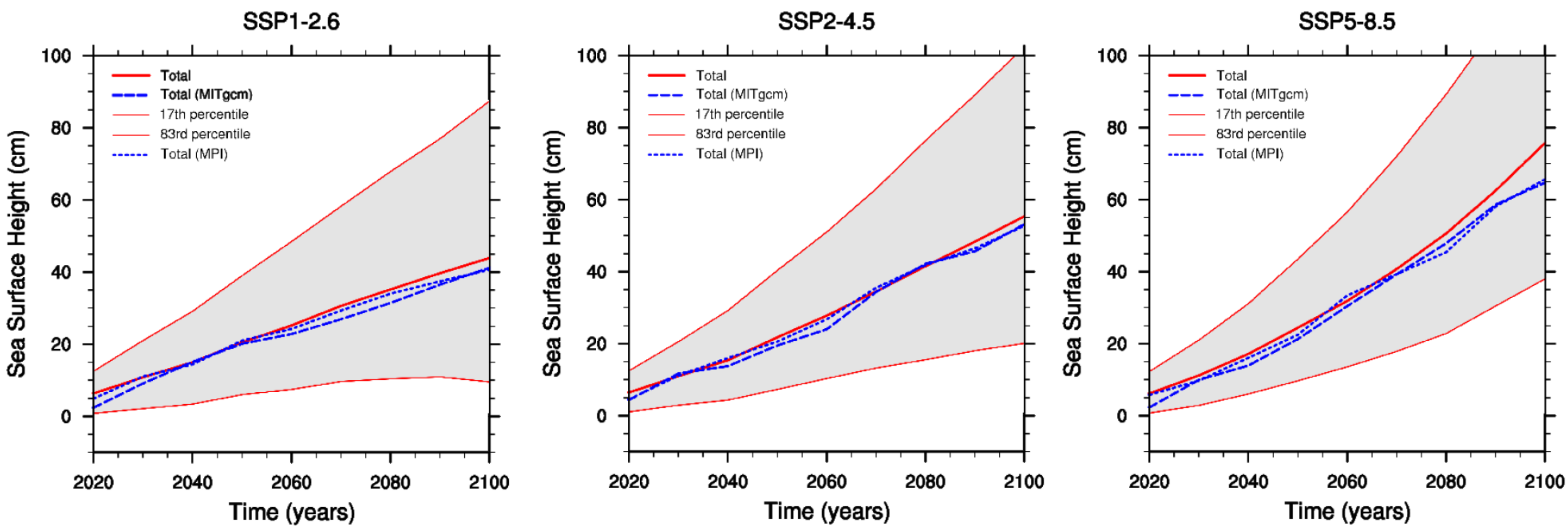
Results indicate that temperature trends strictly follow the large-scale driving models and the coupling or downscaling are able to modulate the magnitude of interannual variability

Future (2100) Mediterranean T2m



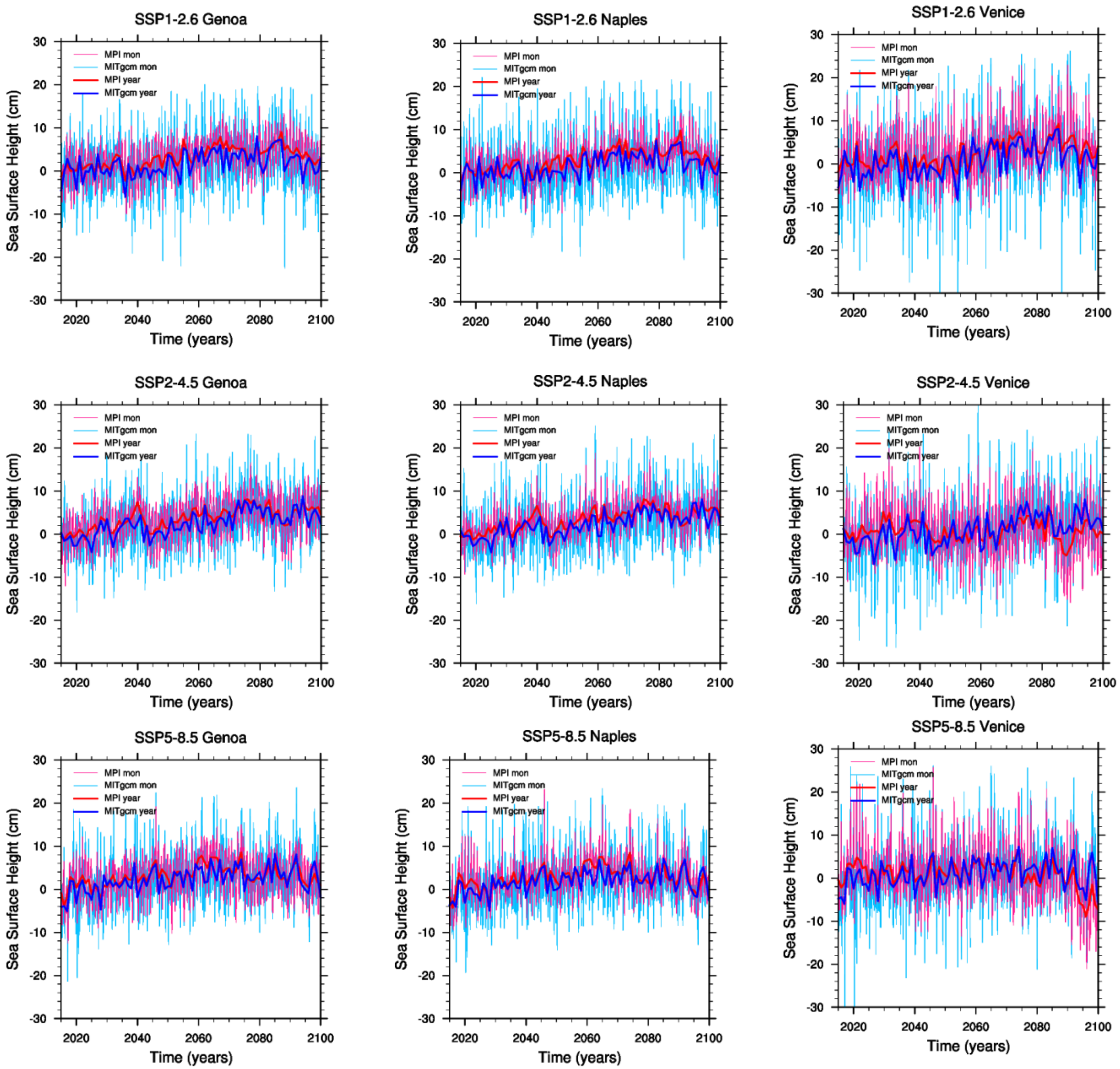
Projected climate change (2071-2100 minus 1985-2014)

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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