# The Ocean and Climate

# The Climate System

**Atmosphere**

**Solar Radiation**

Rain

Evaporation

BIOSPHERE

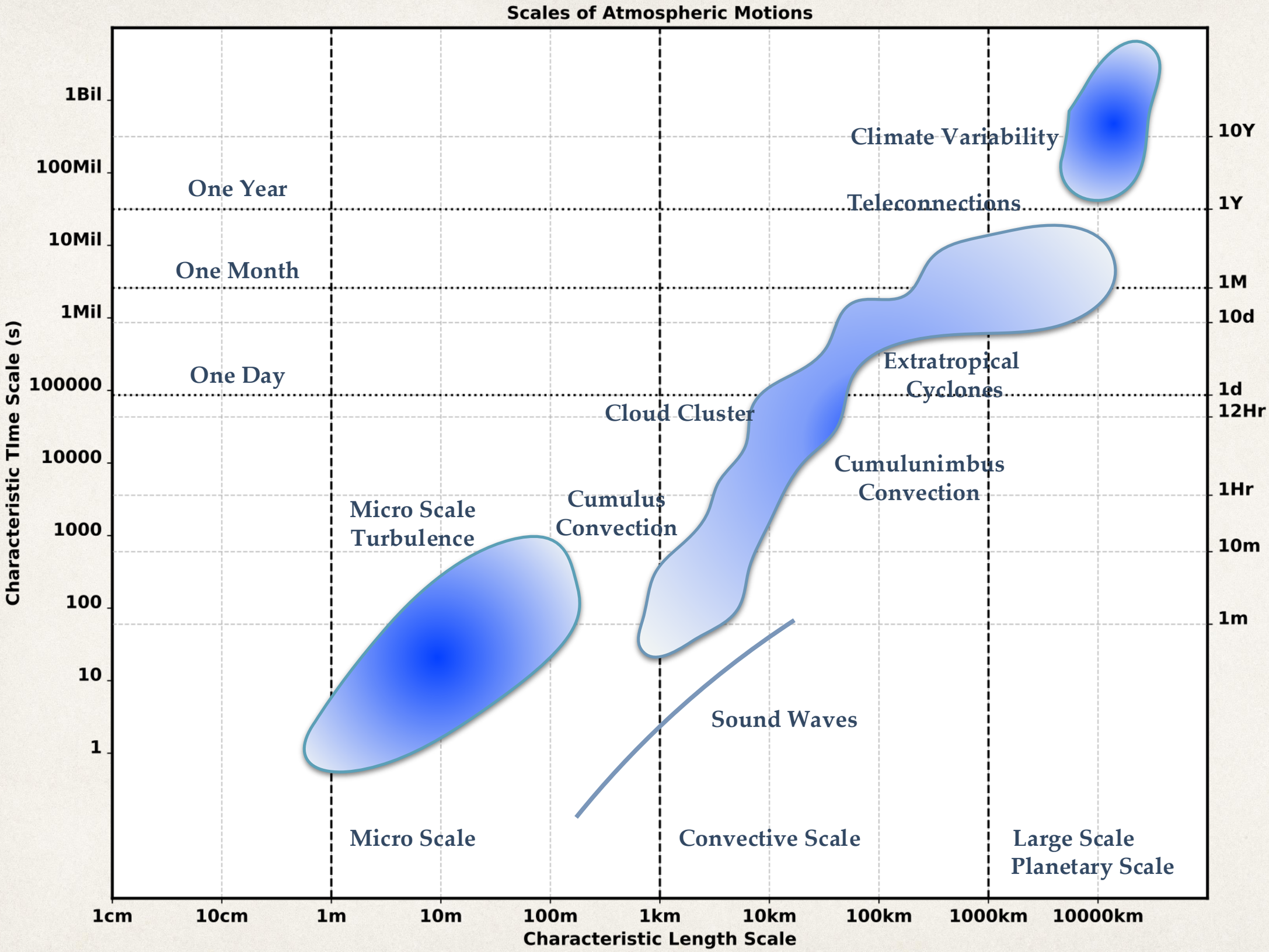
**Soil**

Run-off

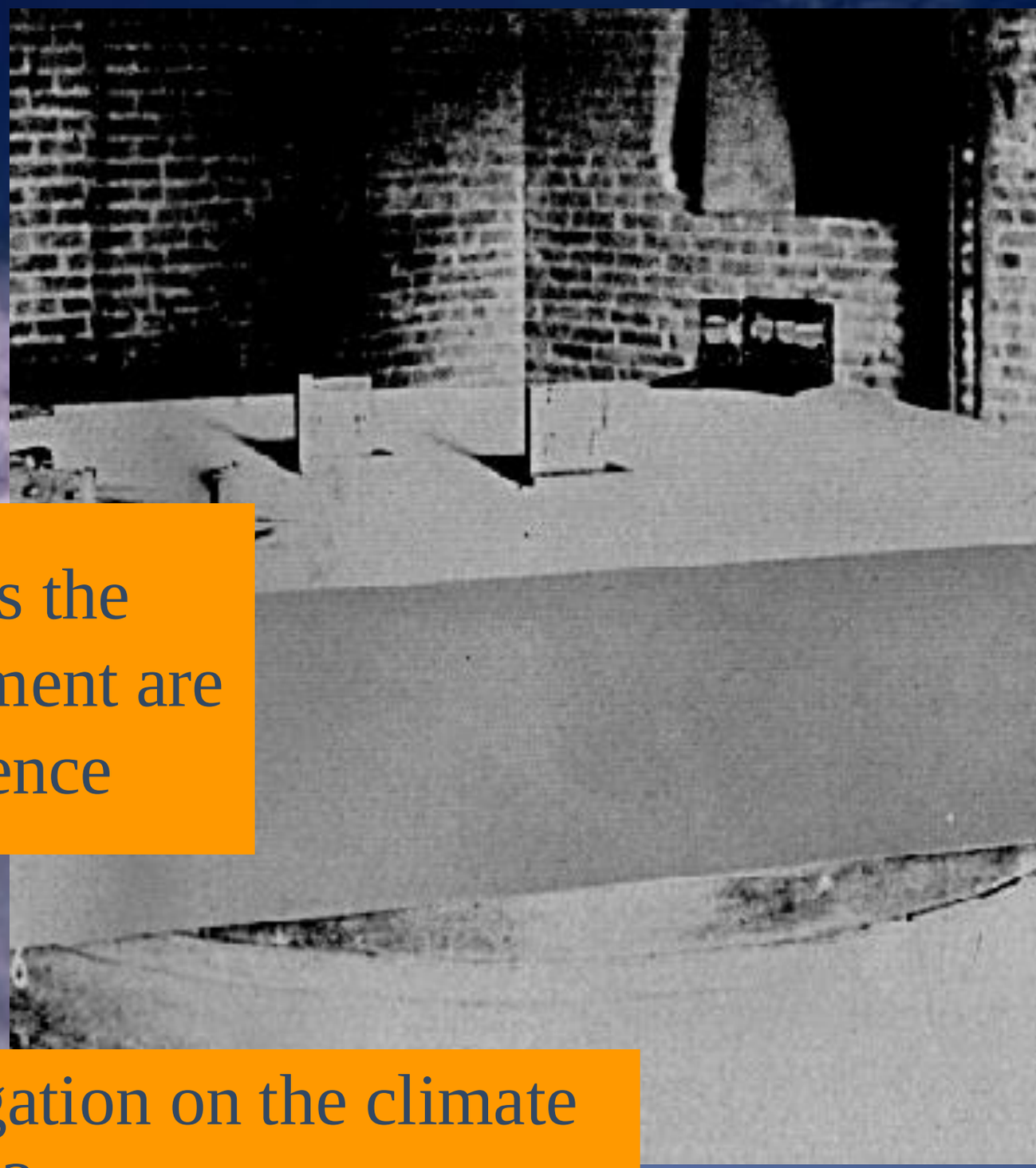
**Sea-ice**

MARINE ECOSYSTEMS

**Oceans**


Scales of Atmospheric Motions
Characteristic Time Scale (s)
1Bil
100Mil
10Mil
1Mil
100000
10000
1000
100
10
1
10Y
1Y
1M
10d
1d
12Hr
1Hr
10m
1m
One Year
One Month
One Day
Climate Variability
Teleconnections
Extratropical Cyclones
Cloud Cluster
Cumulunimbus Convection
Micro Scale Turbulence
Cumulus Convection
Sound Waves
Micro Scale
Convective Scale
Large Scale Planetary Scale
1cm
10cm
1m
10m
100m
1km
10km
100km
1000km
10000km
Characteristic Length Scale

# A scientific consideration of climate (I)



Crucial experiments such as the Michelson and Morley experiment are not possible in climate science

How is a scientific investigation on the climate possible?

# A scientific consideration of climate (II)

We can make experiments if we represent the climate system through a set of mathematical relationships: the climate equations.

The climate equations are very difficult, but they can be solved by numerical methods.

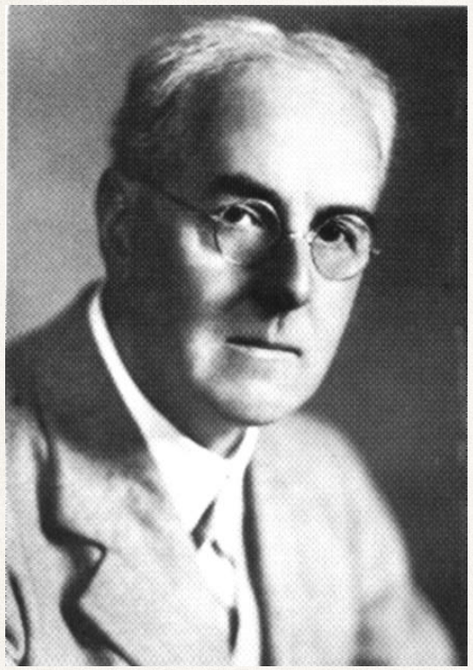
We can therefore deal with very complex mathematical equations, paying the price of a huge number of elementary operations.

# Climate as a physical System

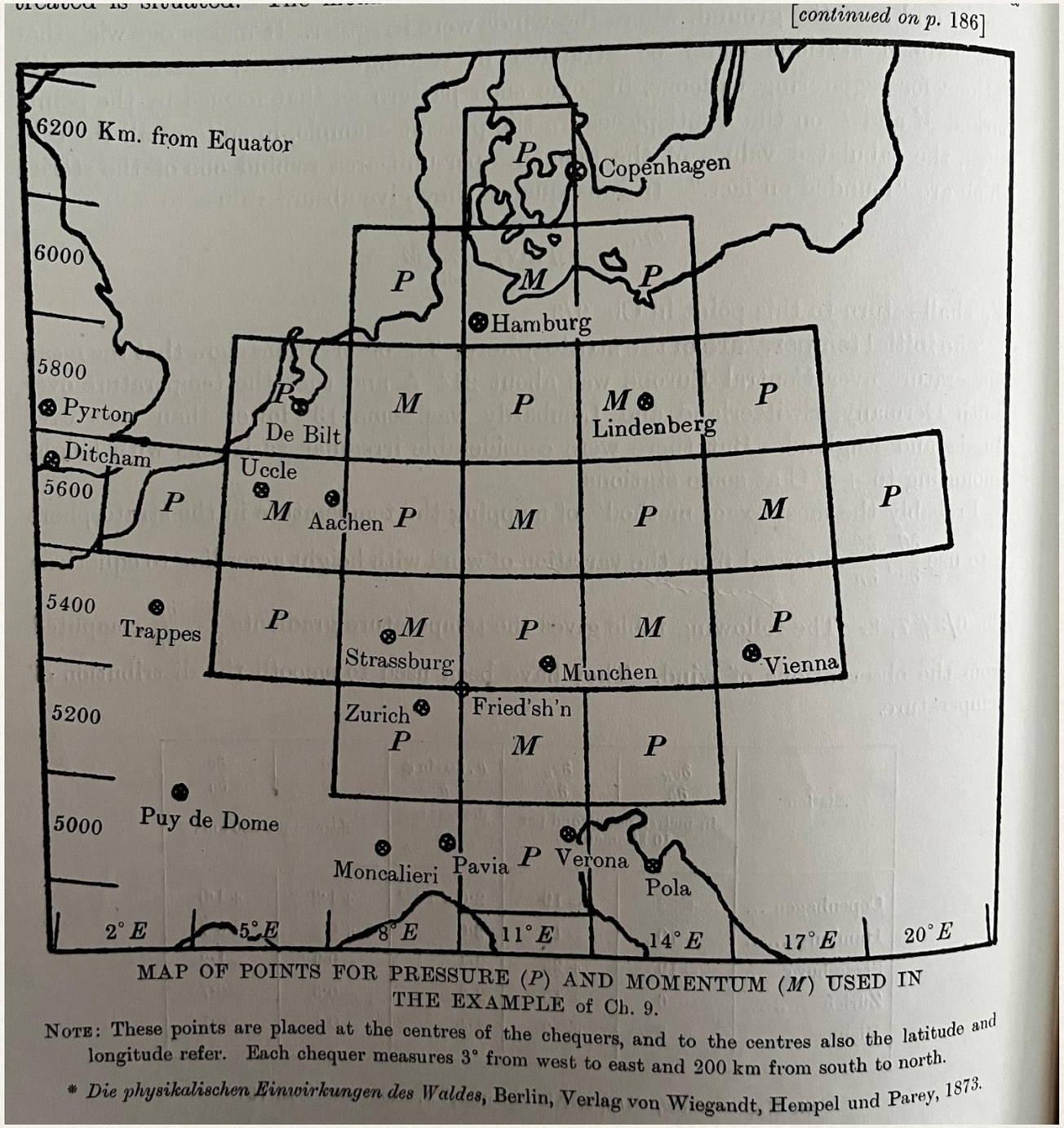
- Development of fluid mechanics in the XIX century
- Development of thermodynamic
- Discovery of the effect of rotation

*Vilhelm Bjerknes, 1862-1951*

# Numerical Models



Lewis Fry Richardson




MAP OF POINTS FOR PRESSURE (*P*) AND MOMENTUM (*M*) USED IN THE EXAMPLE of Ch. 9.

NOTE: These points are placed at the centres of the chequers, and to the centres also the latitude and longitude refer. Each chequer measures 3° from west to east and 200 km from south to north.

* *Die physikalischen Einwirkungen des Waldes*, Berlin, Verlag von Wiegandt, Hempel und Parey, 1873.

# Richardson's (Fantasy) Forecast Factory

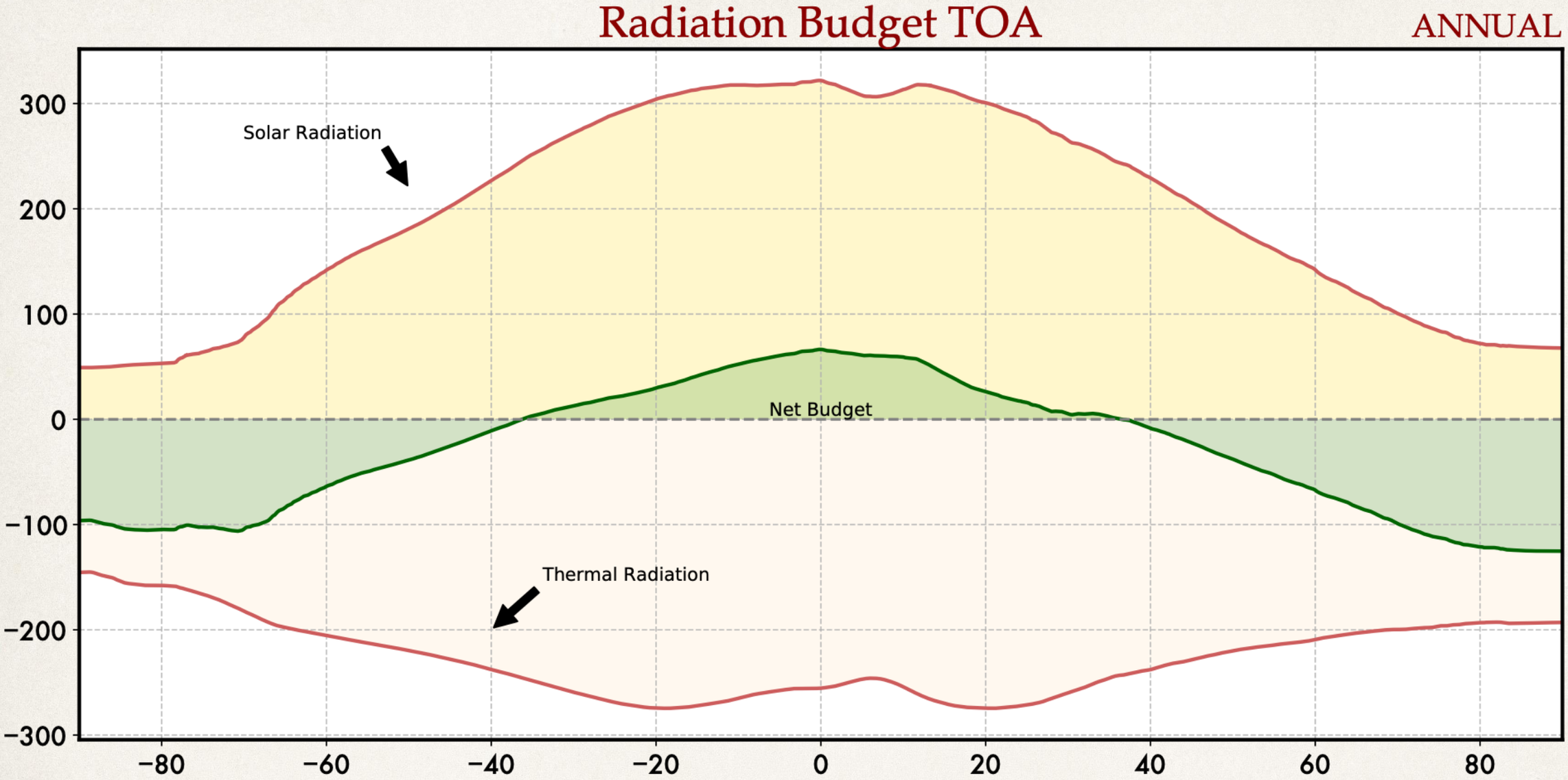
64,000 human "computers" each calculate how the weather in his/her grid box should be updated, based on the calculations of the neighboring grid boxes, synchronized by a director on the central pedestal who shines spotlights to indicate which part of the globe is being calculated at a given time.

# The Princeton Project

Left to right: Harry Wexler, John von Neumann, M. H. Frankel, Jerome Namias, John Freeman, Ragnar Fjortoft, Francis Reichelderfer and Jule Charney

Back row: Fjortoft, Charney, Freeman, Joe Smagorinsky
Front: unidentifed ENIAC programmers

# The Radiation Balance

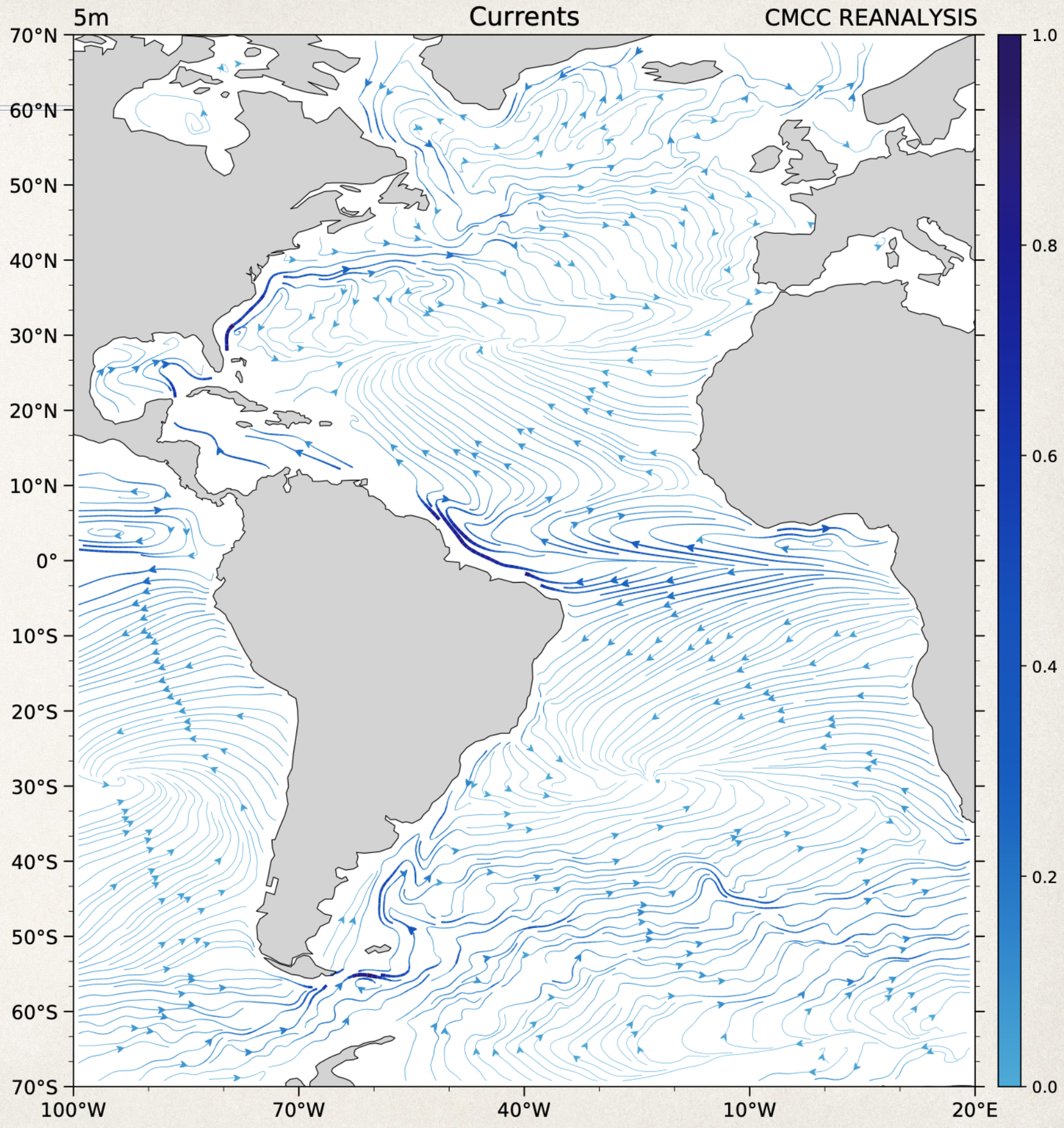



The radiation budget at the top of the atmosphere, between the Net Solar Radiation, the Net Thermal (Earth) Radiation and the resulting balance.

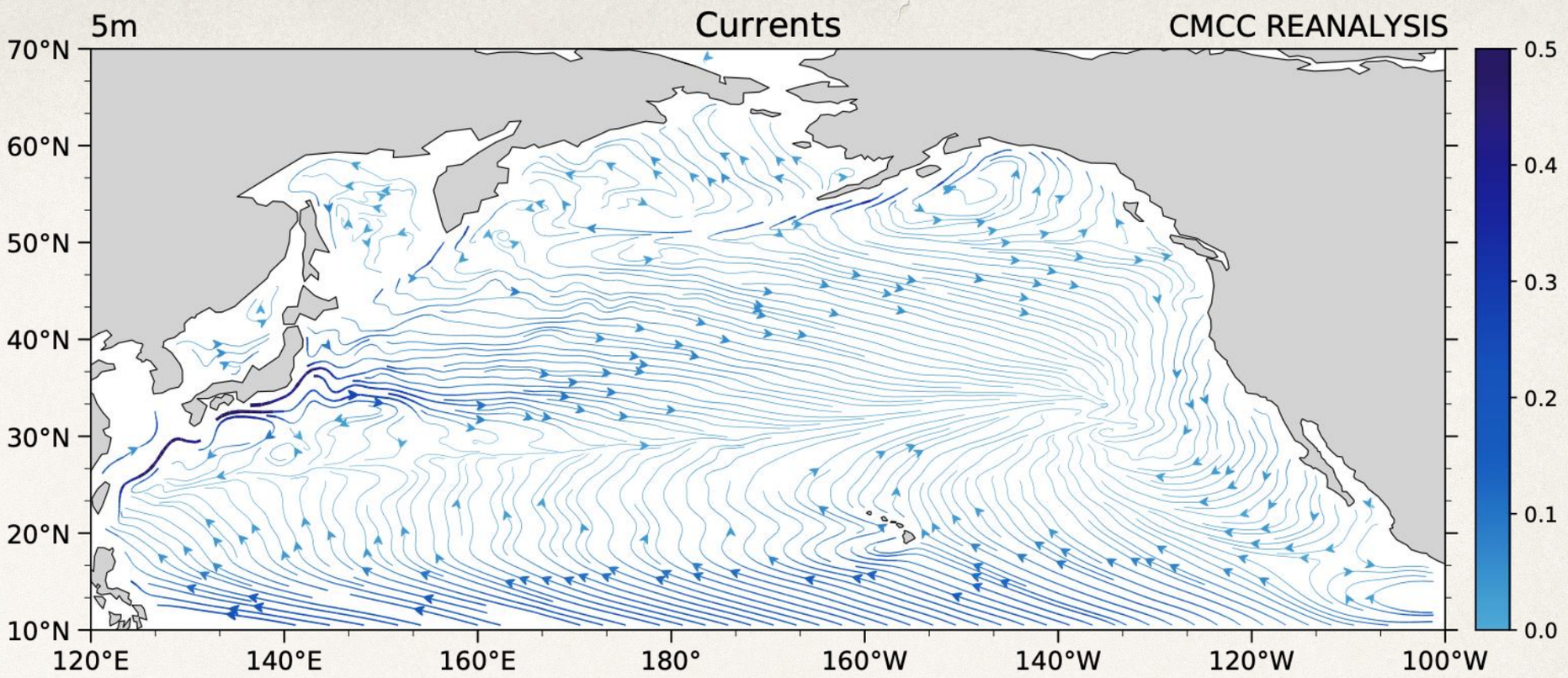
*ERA5, Monthly means data*

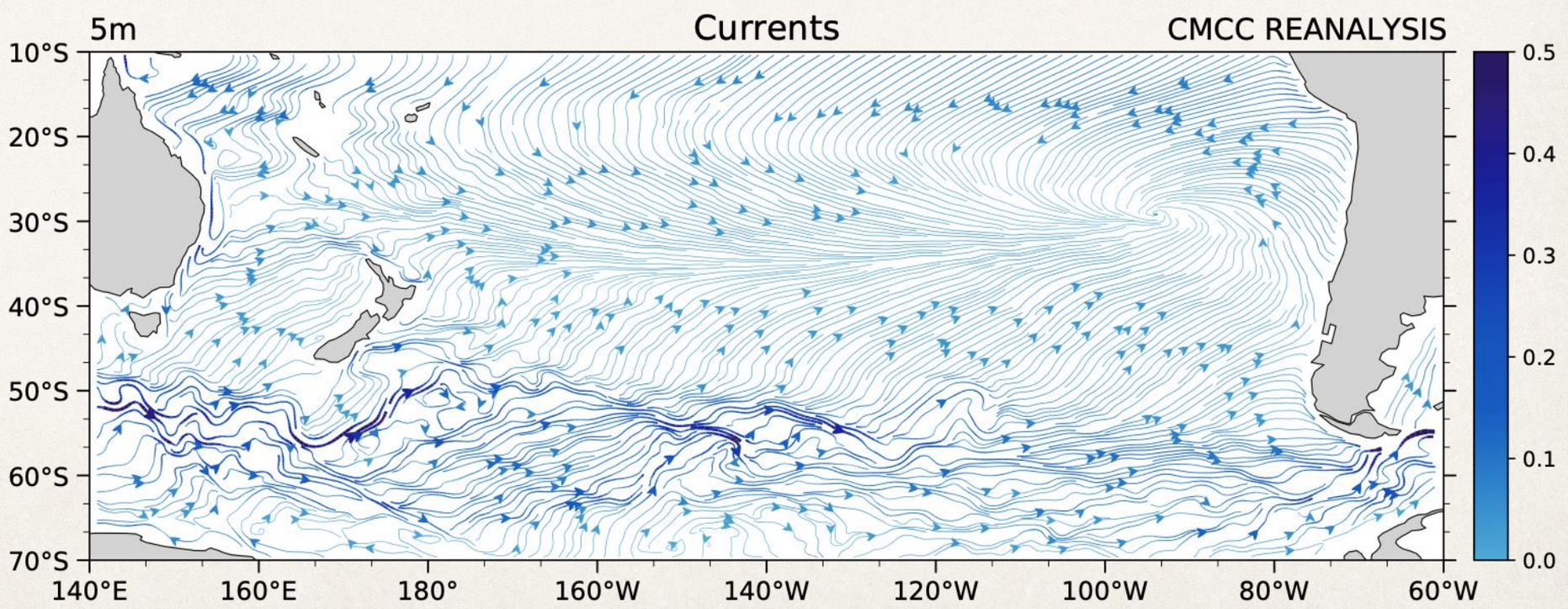
# Atlantic

The climatological distribution of the geopotential from ERA5 reanalyses 1950-2019.



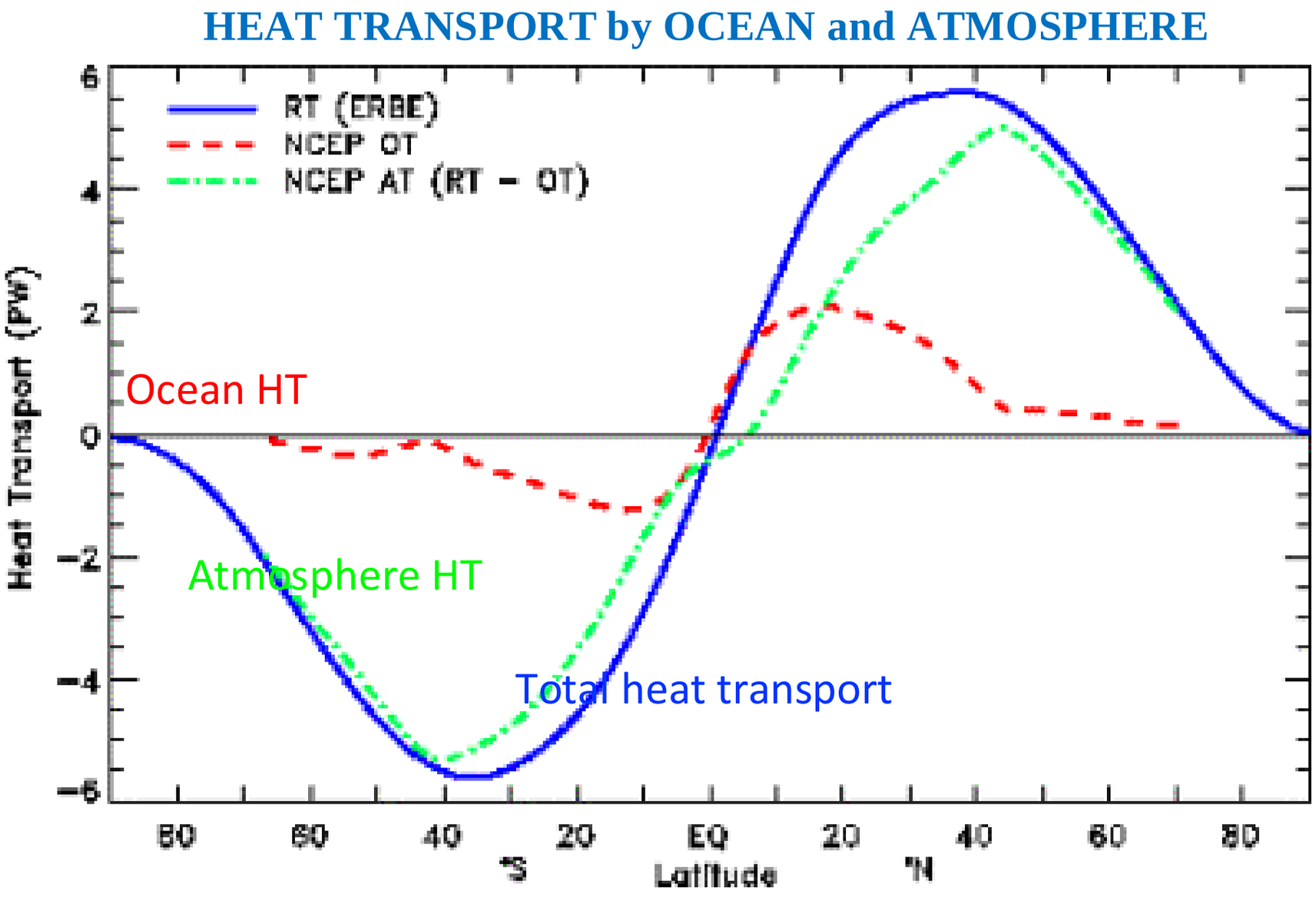
# Pacific


5m
Currents
CMCC REANALYSIS
70°N
60°N
50°N
40°N
30°N
20°N
10°N
120°E
140°E
160°E
180°
160°W
140°W
120°W
100°W
0.5
0.4
0.3
0.2
0.1
0.0


5m
Currents
CMCC REANALYSIS
10°S
20°S
30°S
40°S
50°S
60°S
70°S
140°E
160°E
180°
160°W
140°W
120°W
100°W
80°W
60°W
0.5
0.4
0.3
0.2
0.1
0.0

# OCEANS IN THE CLIMATE SYSTEM

A positive value of the transport on the y-axis corresponds to a northward transport

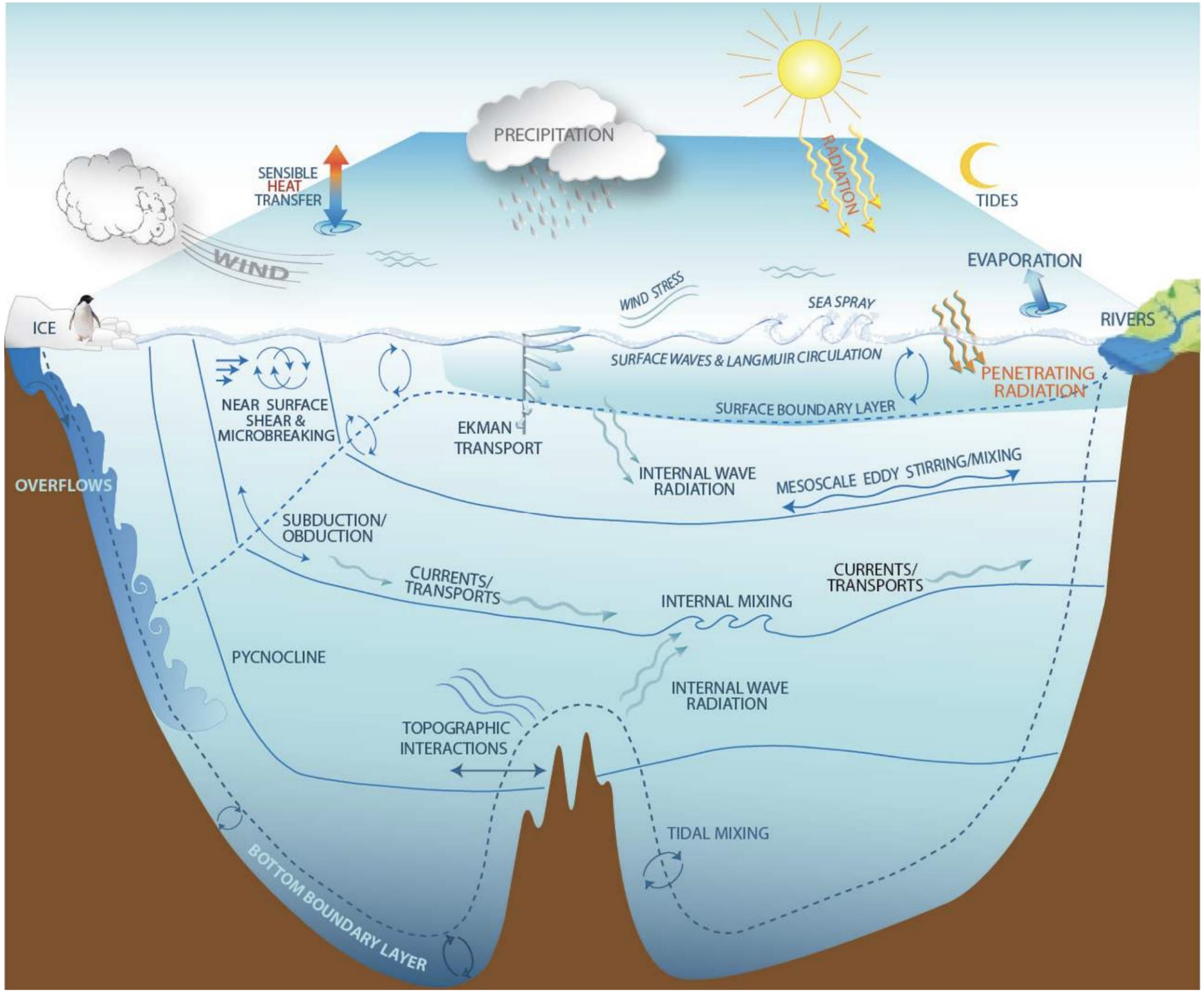



Poleward heat transport reduces pole-to-equator contrast.

There is more ocean in Southern Hemisphere, yet transport is largest in Northern Hemisphere

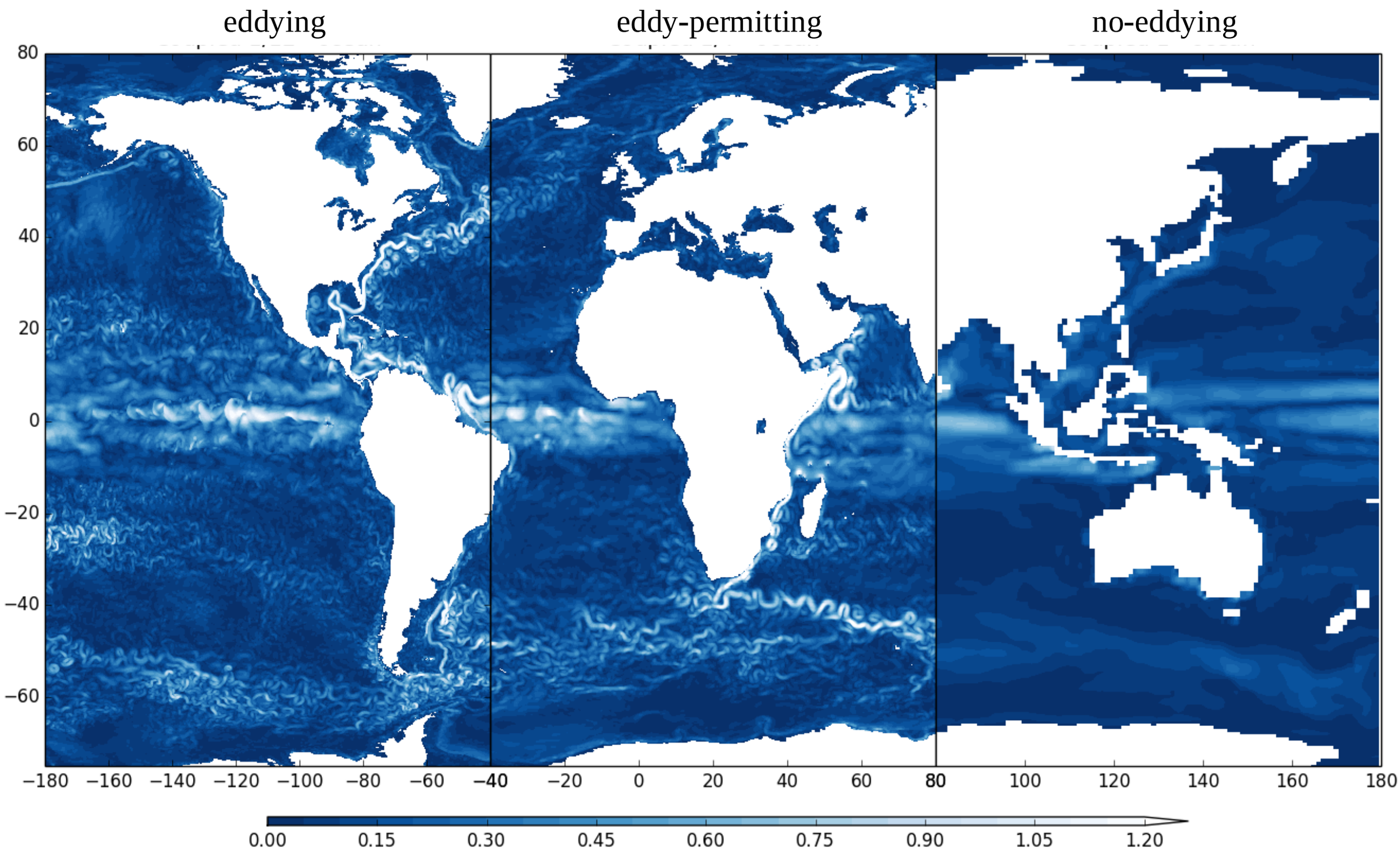
# A ZOO OF PHYSICAL OCEAN PROCESSES

- Strong coupling between processes ⇔ no spectral gap
- Coupling means it is generally better to resolve than parameterize
- Yet we cannot resolve everything ⇒ a practical need for parameterizations

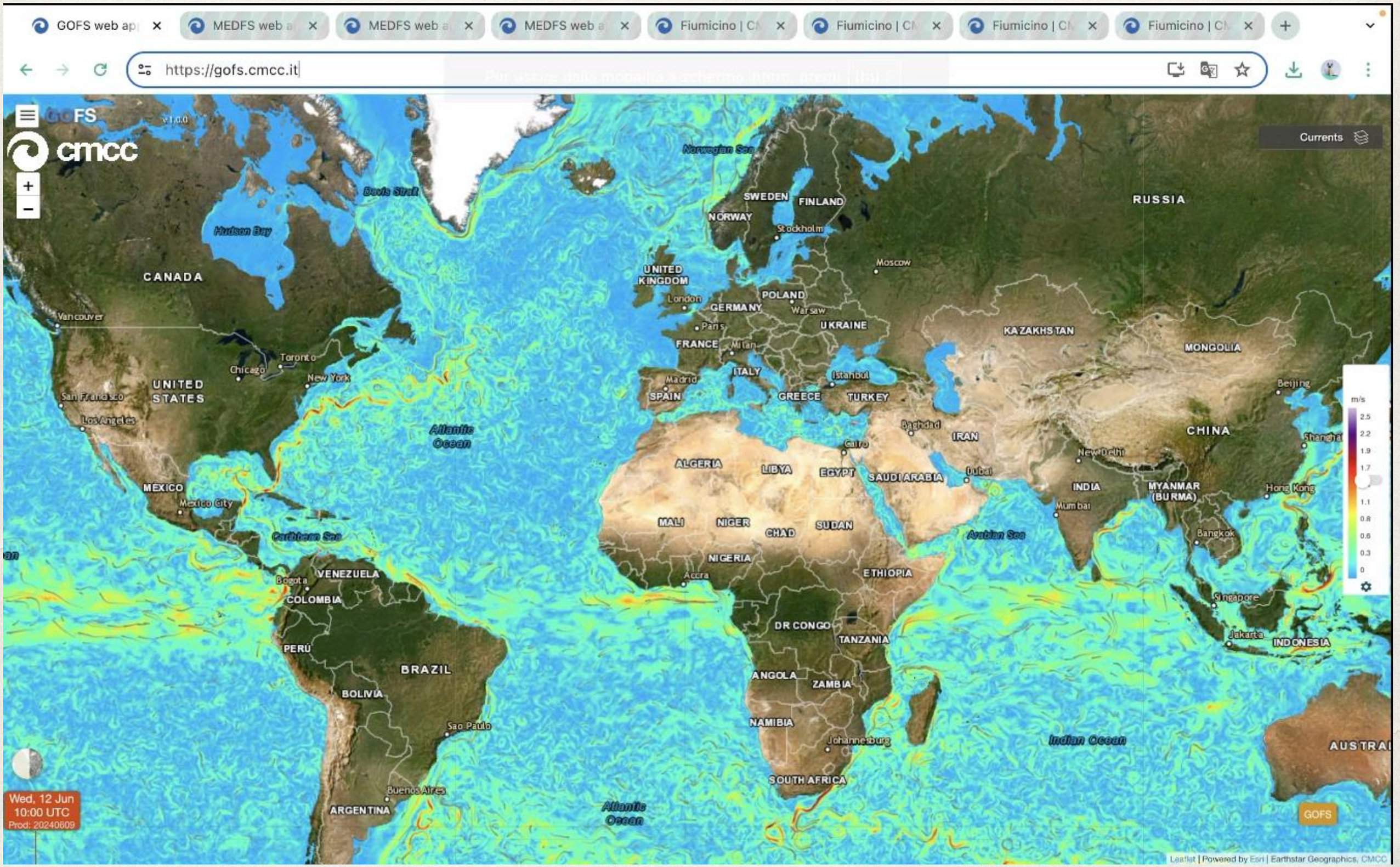



Schematic of ocean physical processes that participate in the cascade of mechanical energy from the forcing scales to the dissipation scales

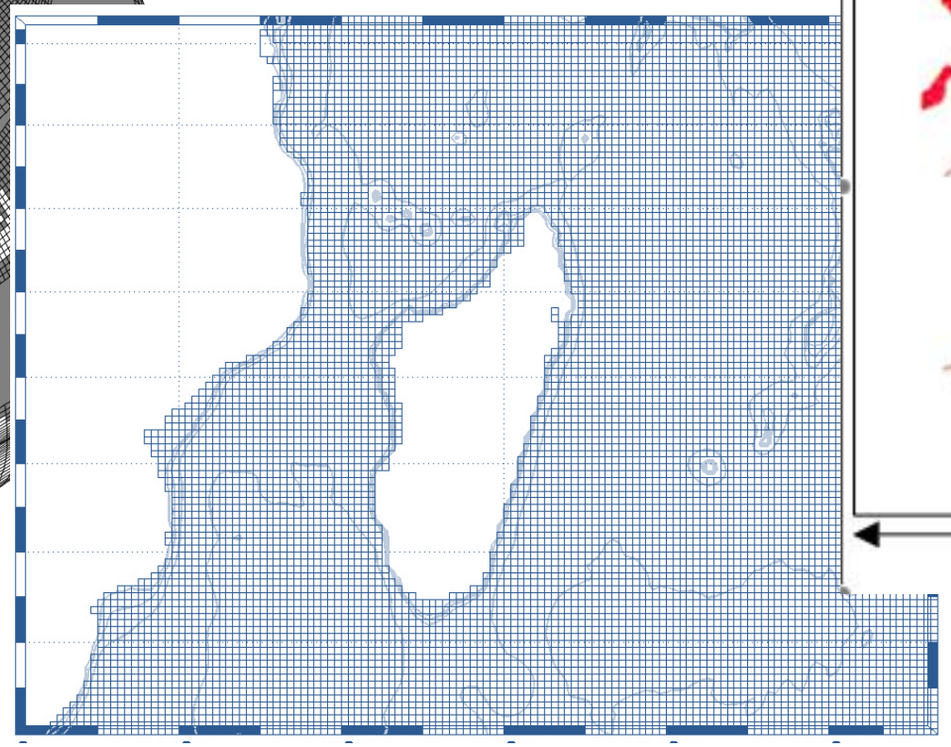
# PARTITIONING THE HORIZONTAL (RESOLUTION)

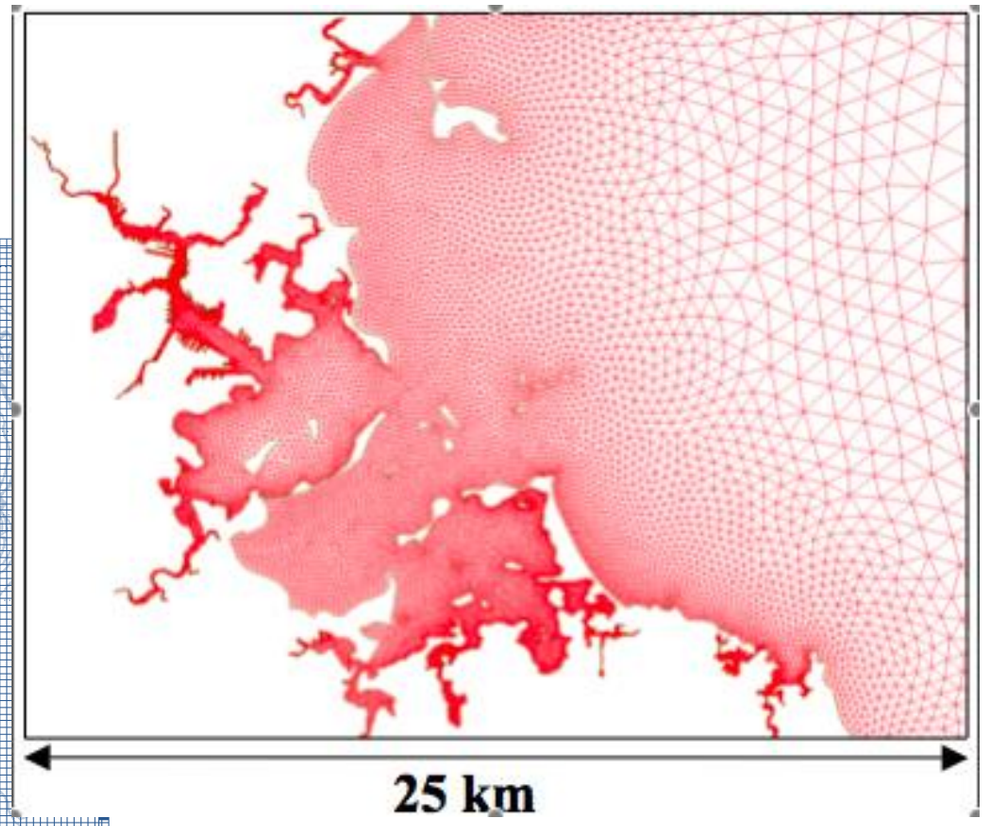


# The digital ocean



# DISCRETIZATION






Gobal models
$\Delta x=\Delta y$ = 25-200 km
$\Delta t$ = 30'-1h30'

simulation : 50-200 years

Regional models
$\Delta x=\Delta y$ = 3-25 km
$\Delta t$ = 5'-30'

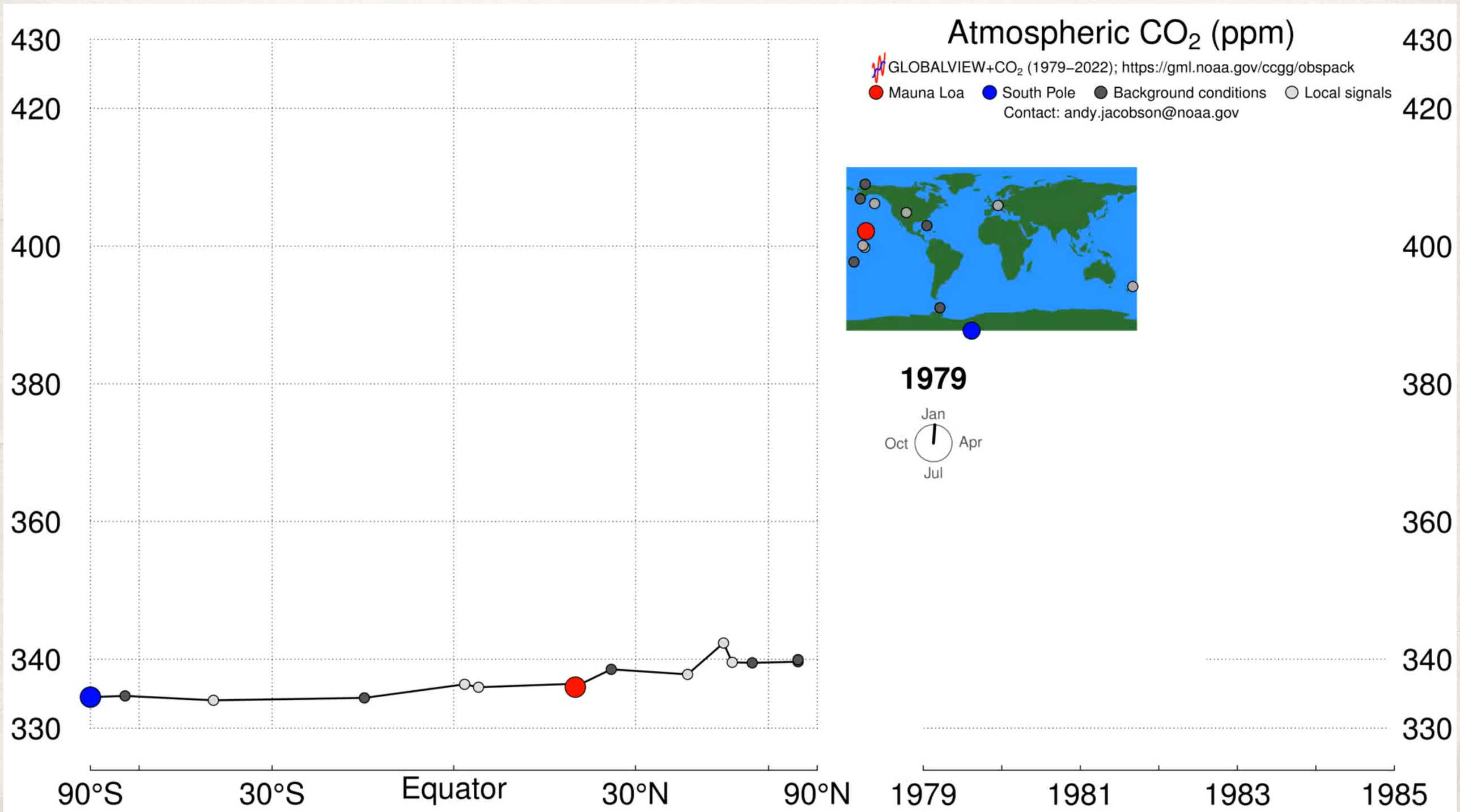
simulation : 1-50 years

Coastal models
$\Delta x=\Delta y$ = 30m-5 km
$\Delta t$ = 10'' – 30'

simulation :days -years

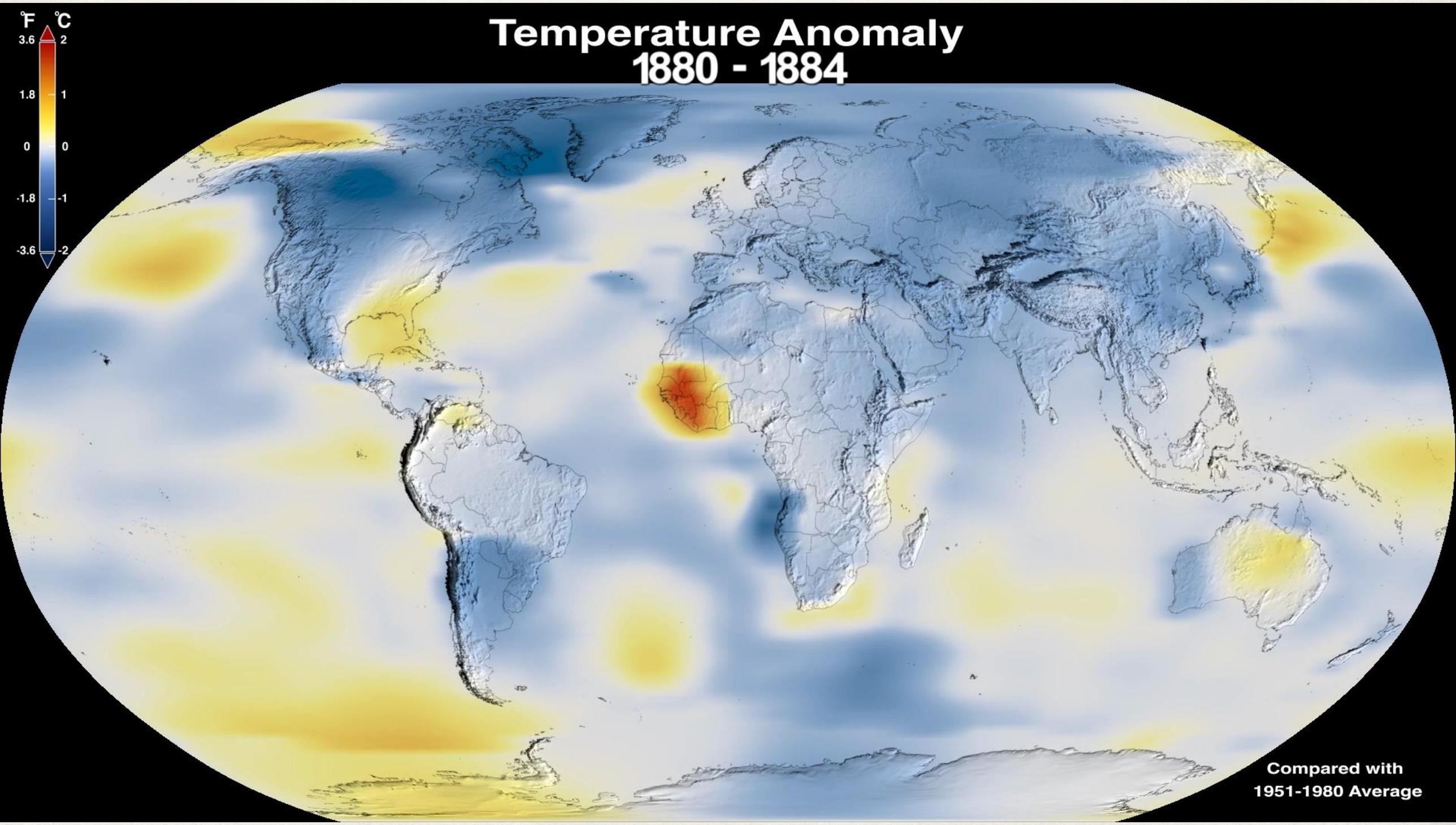
# CO2 in perspective

From: https://gml.noaa.gov/ccgg/trends/history.html



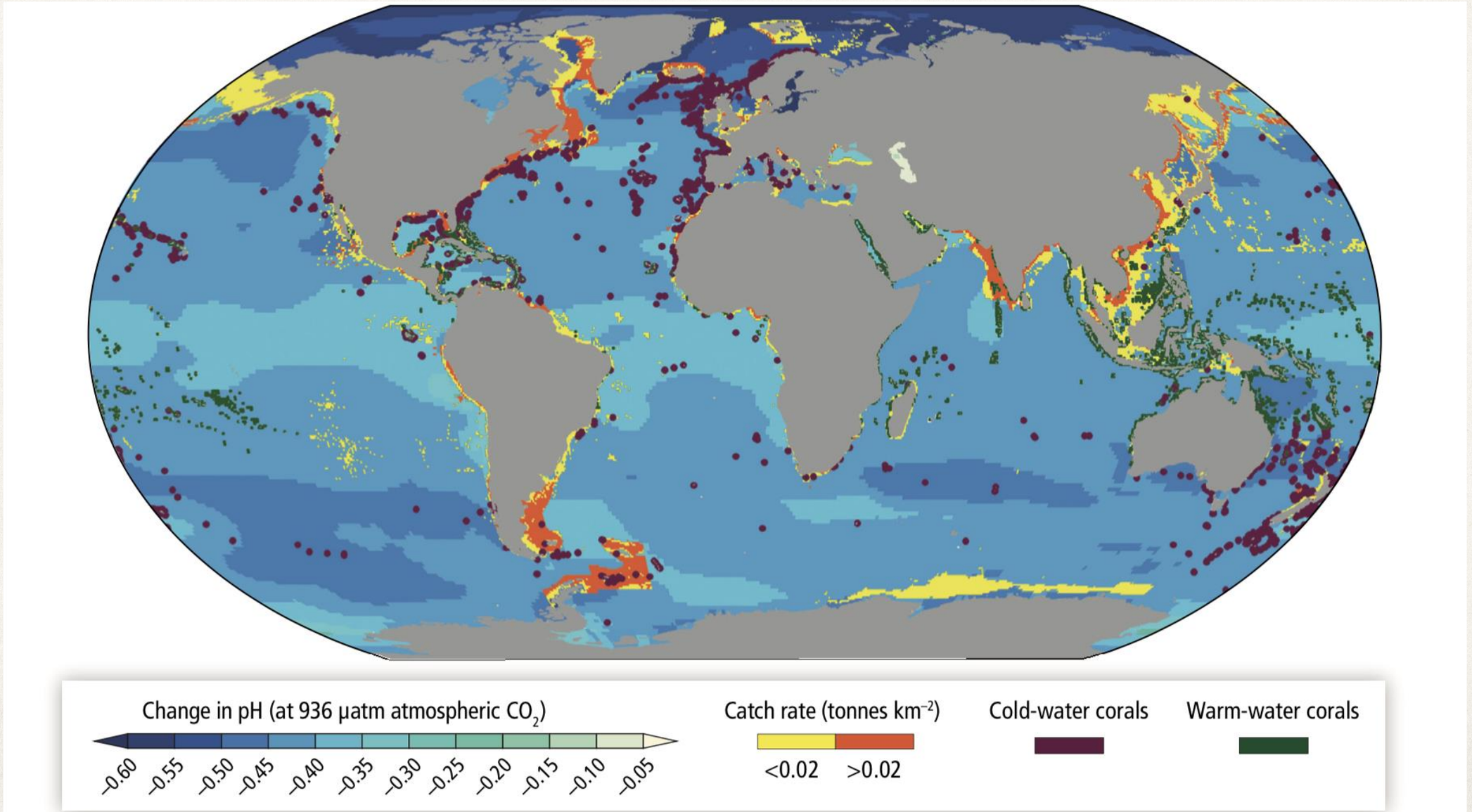
# Marine temperature

From: https://data.giss.nasa.gov/gistemp/animations/

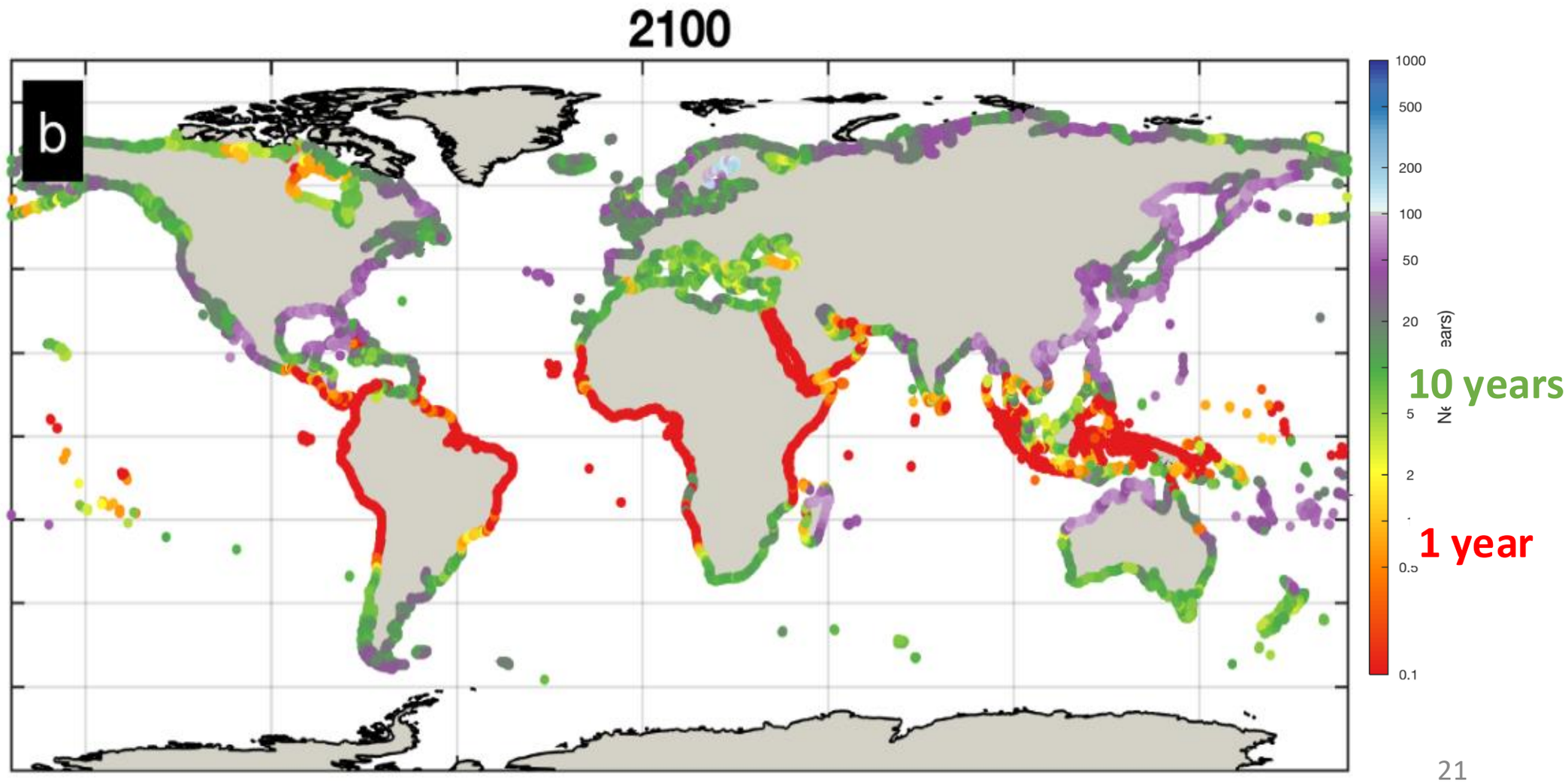


# Ocean acidification

- Increased levels of atmospheric CO2 lead to increased uptake of CO2 in seawater
- CO2 increase in the seawater causes increase in oceanic pH following the processes above



# Storm Surges

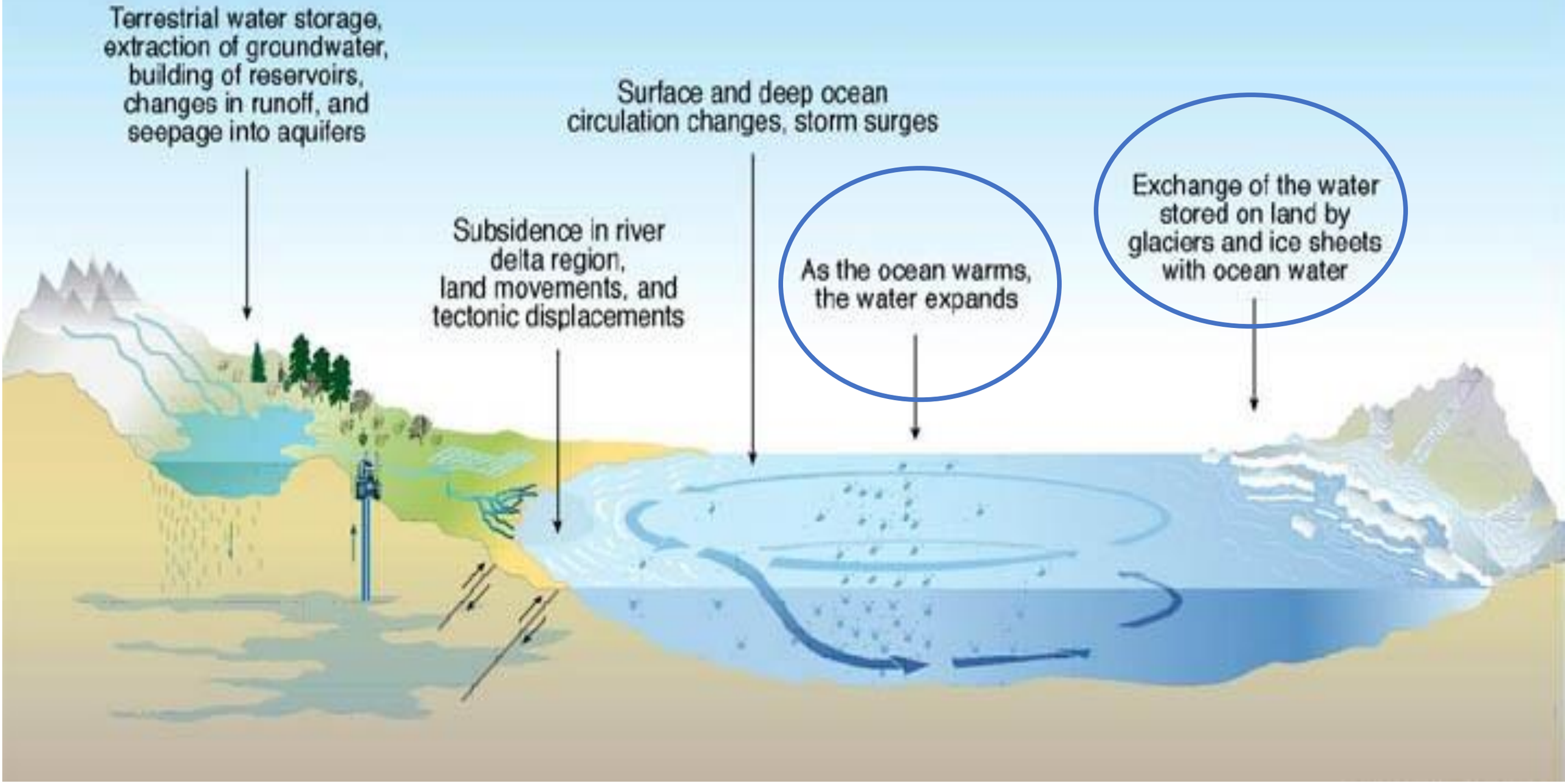





Frequency of the 100 year storm surge event in 2100

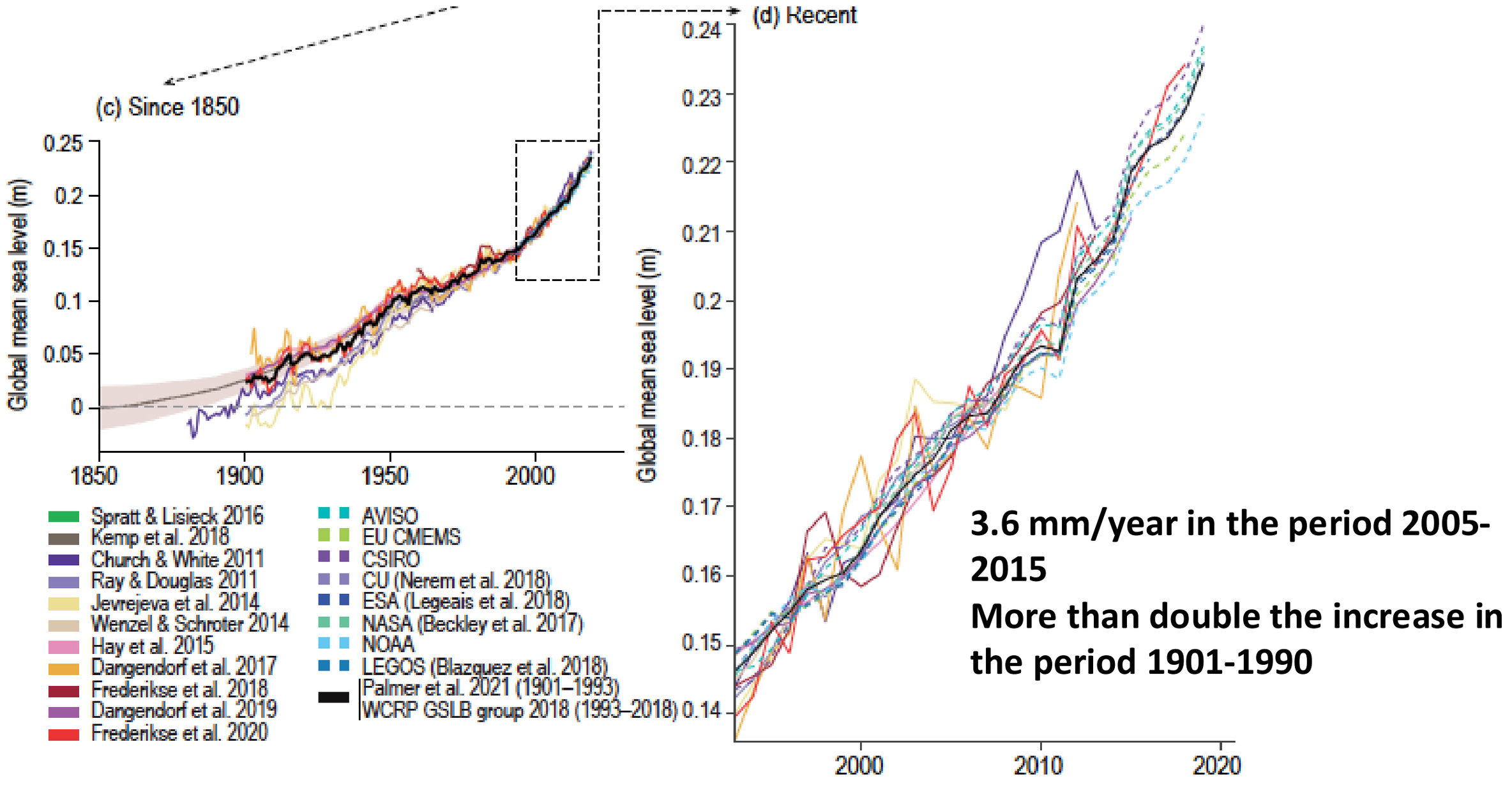
From: Vousdoukas et al., Nature communication, 2018

# What causes the sea level to change?



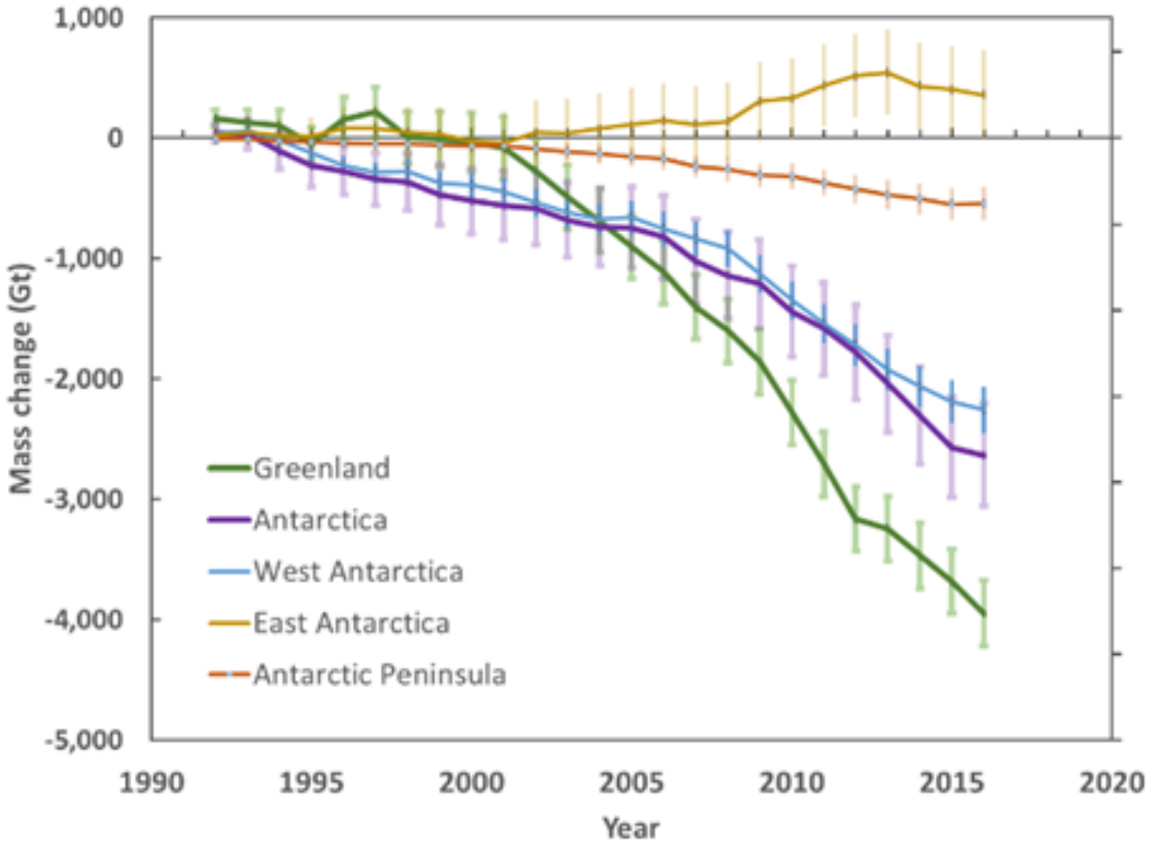

Source: https://climate.nasa.gov/explore/ask-nasa-climate/3002/sea-level-101-part-two-all-sea-level-is-

# Global Sea-Level rise




Fonte: IPCC Assessment Report 6

# Loss of continental ice

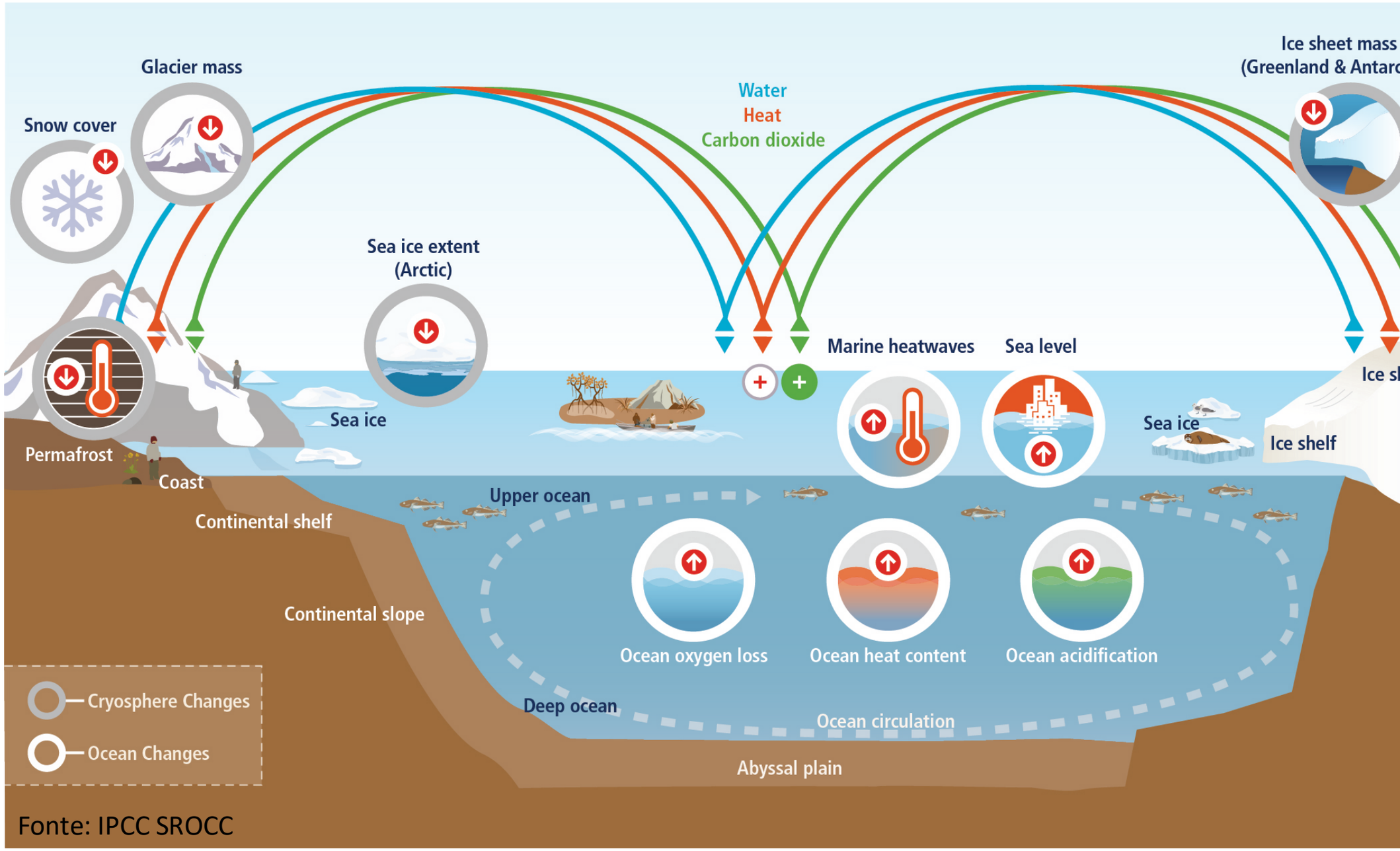



**Change in continental ice mass from 1992 to 2016 (Bamber et al., 2018)**

**Continental ice and glaciers have lost mass. From 2006 to 2015:**

- **Greenland lost 278 ± 11 Gt yr–1 (equivalent to 0.77 ± 0.03 mm yr–1 of sea level increase)**
- **Antarctica lost 155 ± 19 Gt yr–1 (0.43 ± 0.05 mm yr–1)**
- **Glaciers lost 220 ± 30 Gt yr–1 (0.61 ± 0.08 mm yr–1)**

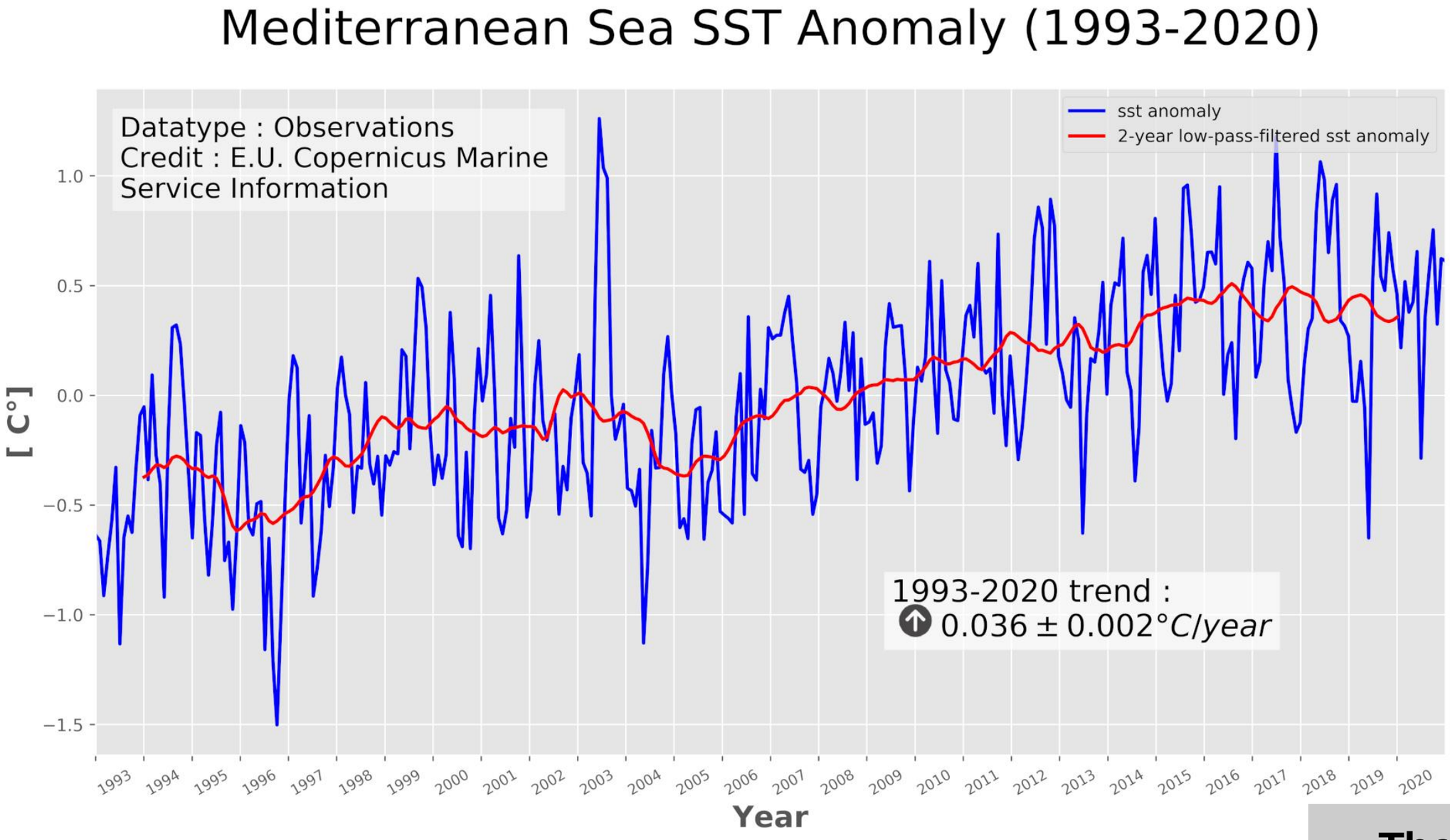
# Key Points




Fonte: IPCC SROCC

- Today, the ocean has absorbed over 90% of the excess heat in the climate system. By 2100, the ocean will absorb 2 to 4 times more heat if global warming is limited to 2°C
- Ocean warming reduces the mixing between the layers of water and therefore the supply of oxygen and nutrients for marine life
- Sea heat waves are becoming more frequent and severe, damaging corals, algae forests and the marine ecosystem
- The ocean absorbs human-induced carbon emissions. This increases acidity. The ocean has absorbed 20 to 30% of these emissions.

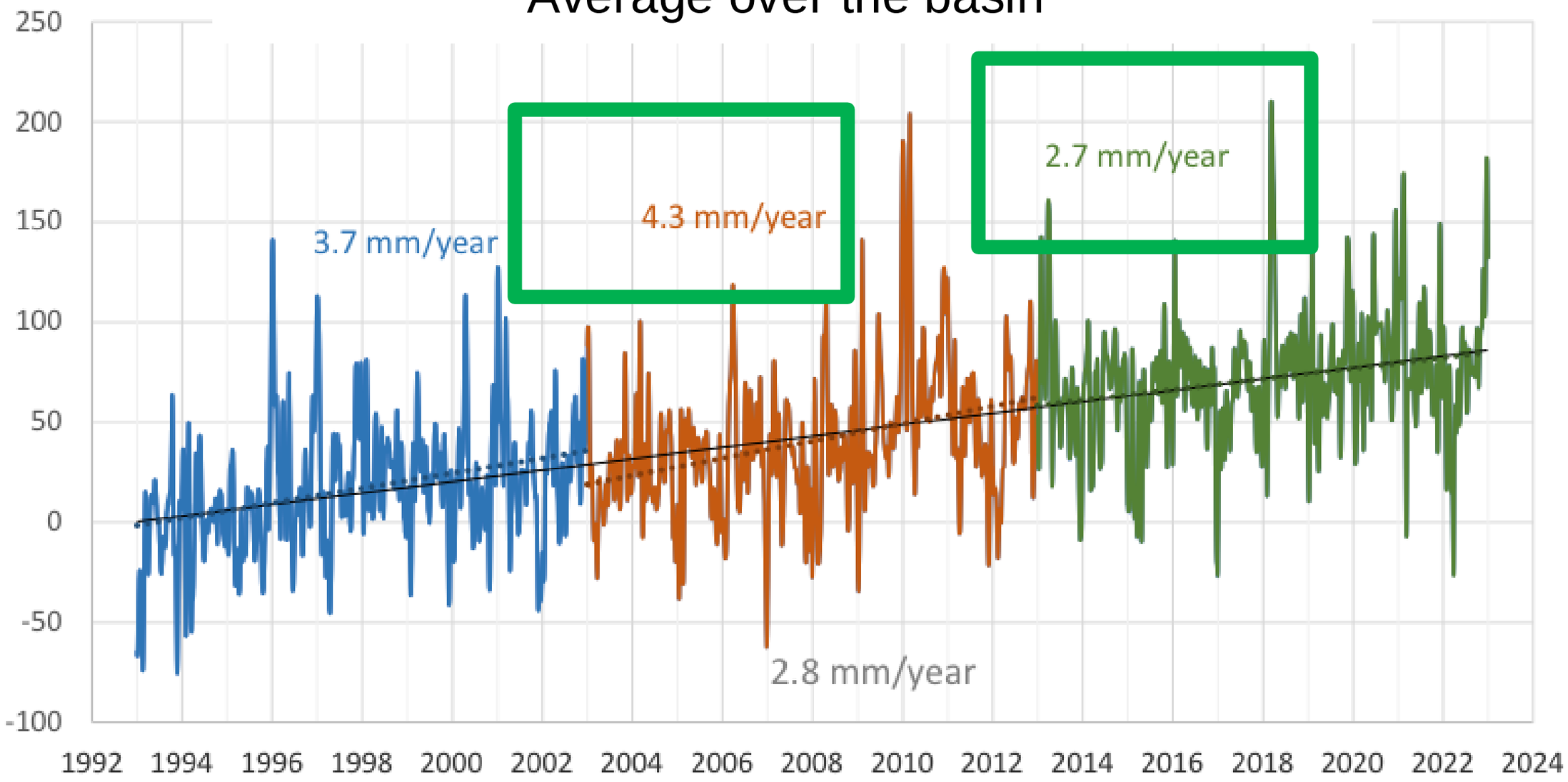
# Mediterranean Region




- **The surface temperature of the Mediterranean has increased by about 1 Celsius from 1993 to 2020.**

# Climate Change in the Mediterranean Sea: sea level rise

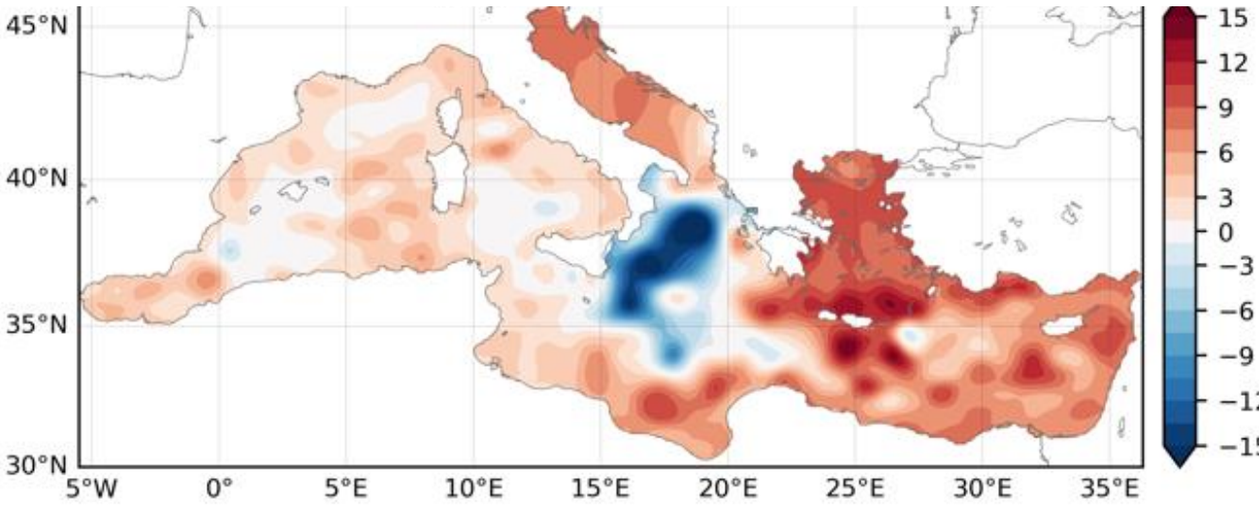
Satellite altimetry Copernicus gridded product [mm]
Average over the basin



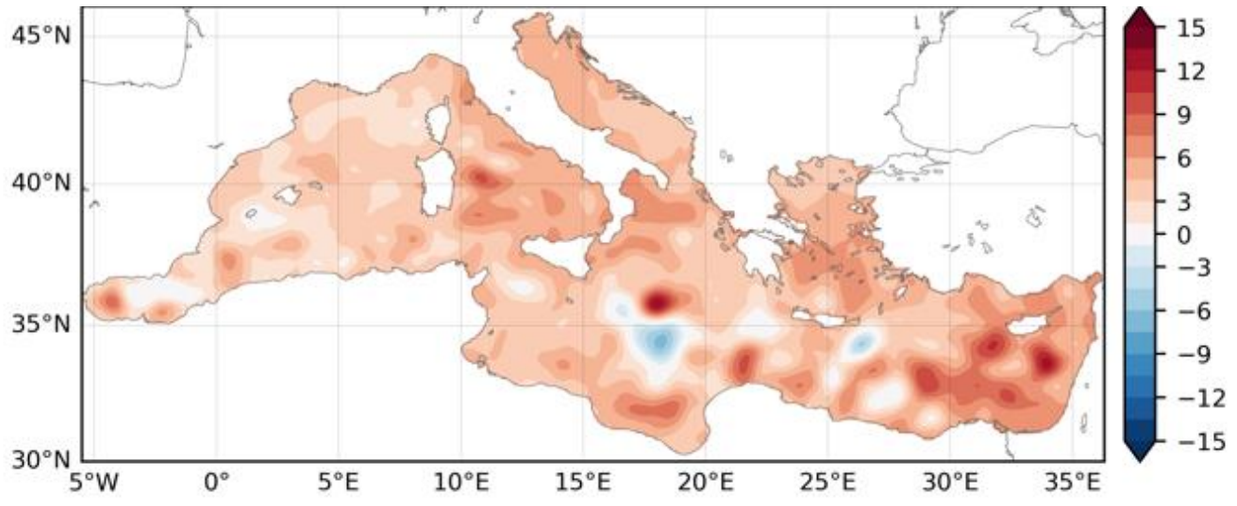

The mean sea level rise in the past 30 years has slowed down

# Climate Change in the Mediterranean Sea: sea level rise

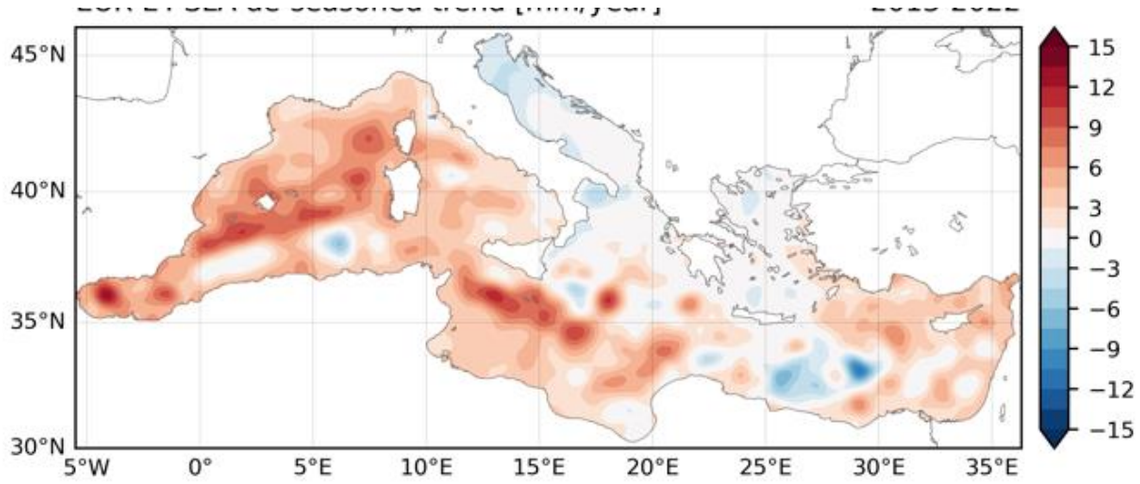
SEA LEVEL TREND in mm/yr (1993-2002)




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

www.cmcc.it