Sea level & Consequences

Anastasiia Babenko
Mirosław Banach
Rujan Shakya
Sofia Delgado

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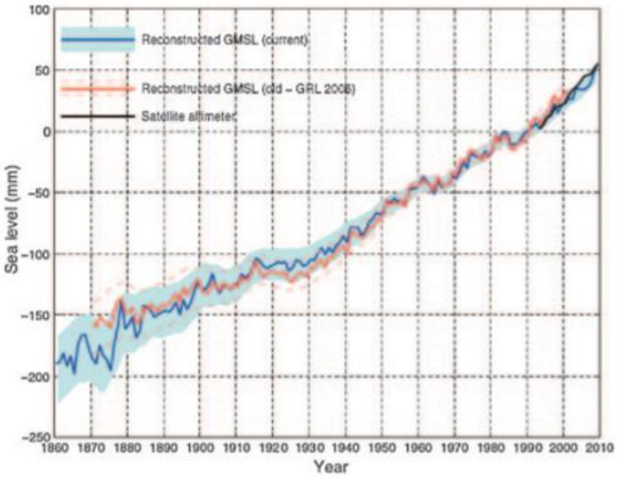
INTRODUCTION

To what extent did climate change contribute to sea-level rise in the past?
How much will global mean sea level increase in the future?
How serious are the impacts?

Agenda

- Sea-level fluctuation in the past;
- General causes of the sea level rise;
- High Mountain and Polar regions;
- Coast and Ocean regions;
- Extremes and abrupt or irreversible changes in the ocean and cryosphere in a changing climate

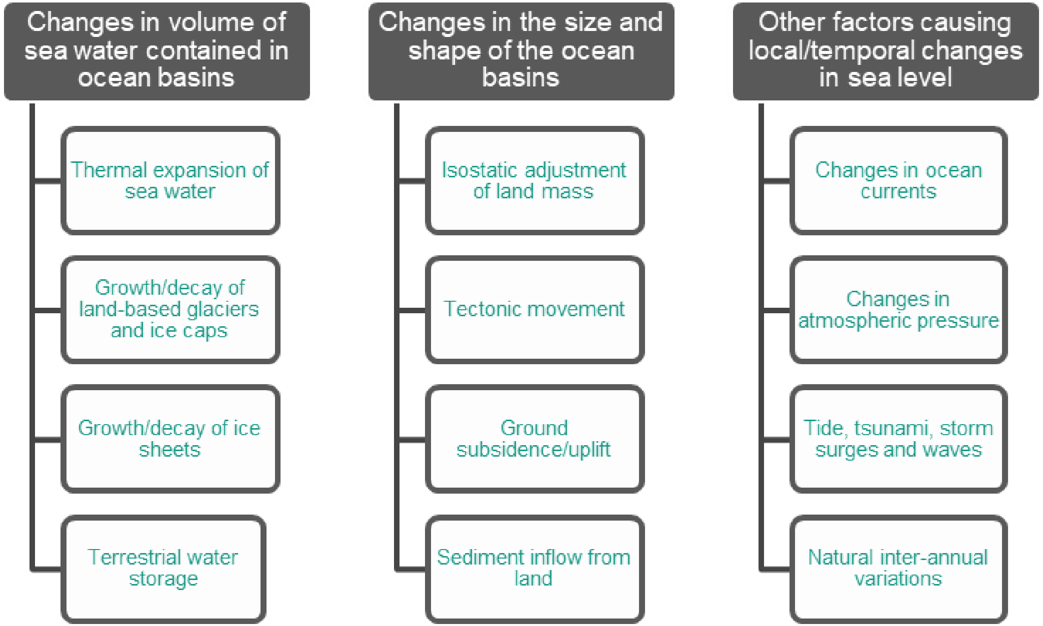
Sea-level rise since the end of 19th century



Global mean sea level from 1860 to 2009

Mimura, 2013

Factors causing changes in sea level



Mimura, 2013

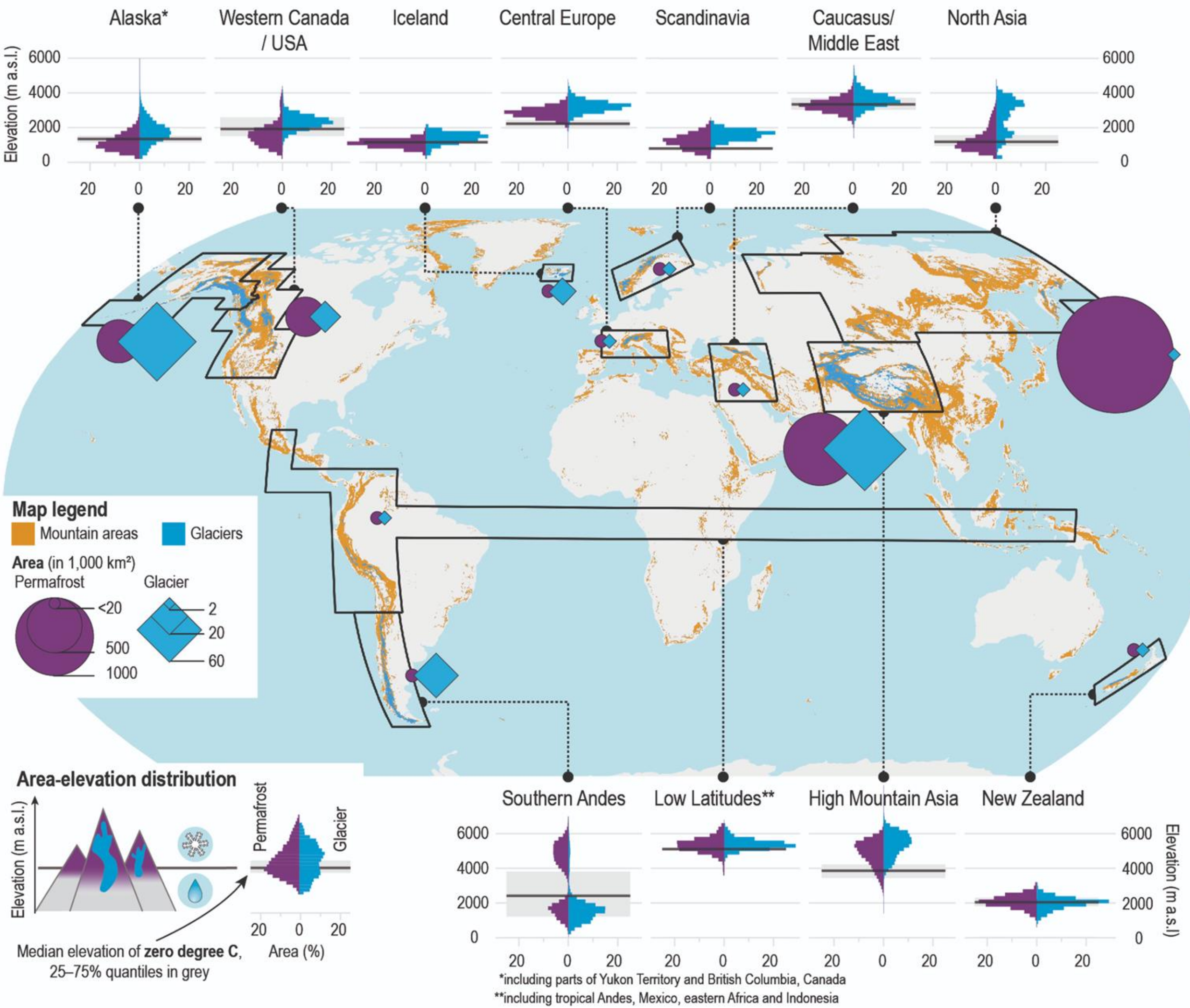

HIGH
MOUNTAINS
&
POLAR REGIONS

Mountains & Glaciers

<u>cryosphere</u> (snow, glaciers, permafrost, lake and river ice)

<u>High mountain regions:</u> rugged terrain, low-temperature climate regime, steep slopes, institutional and spatial remoteness.

roughly 10% of global population.



Observations

general warming (European Alps, Scandinavia, Mongolia, the Tien Shan and the Tibetan Plateau)

permafrost degradation (Tibetan Plateau)

Table 2.1 | Observed changes in permafrost mean annual ground temperature (MAGT) in mountain regions. Values are based on individual boreholes or ensembles of several boreholes. The MAGT refers to the last year in a period and is taken from a depth of 10–20 m unless the borehole is shallower. Region names refer to Figure 2.1. Numbers in brackets indicate how many sites are summarised for a particular surface type and area; the underscored value is an average. Elevation is metres above sea level (m a.s.l.).

Region	Elevation [m a.s.l.]	Surface Type	Period	MAGT [ºC]	MAGT trend [ºC per decade]	Reference
Global	>1,000	various (28)	2006–2017	not specified	0.2 ± 0.05	Biskaborn et al. (2019)
European Alps	2,500–3,000	debris or coarse blocks (>10)	1987–2005 2006–2017	>-3 >-3	0.0–0.2 0.0–0.6	PERMOS (2016) Noetzli et al. (2018)
	3,500–4,000	bedrock (4)	2008–2017	>-5.5	0.0–1.0	Pogliotti et al. (2015) Magnin et al. (2015) Noetzli et al. (2018)
Scandinavia	1,402–1,505	moraine (3)	1999–2009	0 to – 0.5	0.0–0.2	Isaksen et al. (2011)
	1,500–1,894	bedrock (2)	1999–2009	-2.7	0.5	Christiansen et al. (2010)
High Mountain Asia (Tien Shan)	~3,330	bare soil (2)	1974–2009	-0.5 to – 0.1	0.3–0.6	Zhao et al. (2010)
	3,500	meadow (1)	1992–2011	-1.1	0.4	Liu et al. (2017)
High Mountain Asia (Tibetan Plateau)	~4,650	meadow (6)	2002–2012	-1.52 to – 0.41	0.08–0.24	Wu et al. (2015)
	~4,650	steppe (3)	2002–2012	-0.79 to – 0.17		Wu et al. (2015)
	~4,650	bare soil (1)	2003–2012	-0.22	0.15	Wu et al. (2015)
	4,500–5,000	unknown (6)	2002–2011	-1.5 to – 0.16	0.08–0.24	Peng et al. (2015)
North Asia (Mongolia)	1,350–2,050	steppe (6)	2000–2009	-0.06 to – 1.54	0.2–0.3	Zhao et al. (2010)

Table 2.2 | Observed changes of active-layer thickness (ALT) in mountain regions. Numbers in brackets indicate how many sites are summarised for a particular surface type and area. Region names refer to Figure 2.1. Elevation is metres above sea level (m a.s.l.).

Region	Elevation [m a.s.l.]	Surface Type	Period	ALT in last year [m]	ALT trend [cm per decade]	Reference
Scandinavia	353–507	peatland (9)	1978–2006 1997–2006	~0.65–0.85	7–13 13–20	Åkerman and Johansson (2008)
European Alps	2,500–2,910	bedrock (4)	2000–2014	4.2–5.2	10–100	PERMOS (2016)
High Mountain Asia (Tien Shan)	3,500	meadow (1)	1992–2011	1.70	19	Liu et al. (2017)
High Mountain Asia (Tibetan Plateau)	4,629–4,665	meadow (6)	2002–2012	2.11–2.3	34.8–45.7	Wu et al. (2015
	4,638–4,645	steppe (3)	2002–2012	2.54–3.03	39.6–67.2	Wu et al. (2015)
	4,635	bare soil (1)	2002–2012	3.38	18.9	Wu et al. (2015)
	4,848	meadow	2006–2014	1.92–2.72	15.2–54	Lin et al. (2016)

1. Mean Annual Ground Temp (MAGT)
2.Active Layer Thickness (ALT)

Impacts | Risks

- Changes in river runoff
- Water quality

Key impacts and Vulnerability:

- Hydropower
- Agriculture
- Drinking water supply

- Unstable slopes, landslides and glacier instabilities
- Snow avalanches
- Floods
- Other Combined hazards and cascading events

Challenges to Farmers and local Population, Ecosystems, Cultural values and Human well-being

Polar Regions, People and the Planet

<u>Atmospheric feedbacks</u>: connect polar cryosphere and ocean change to the global climate system

<u>Snow frozen ground</u>: affect landscapes, people, their culture(Arctic) and climate

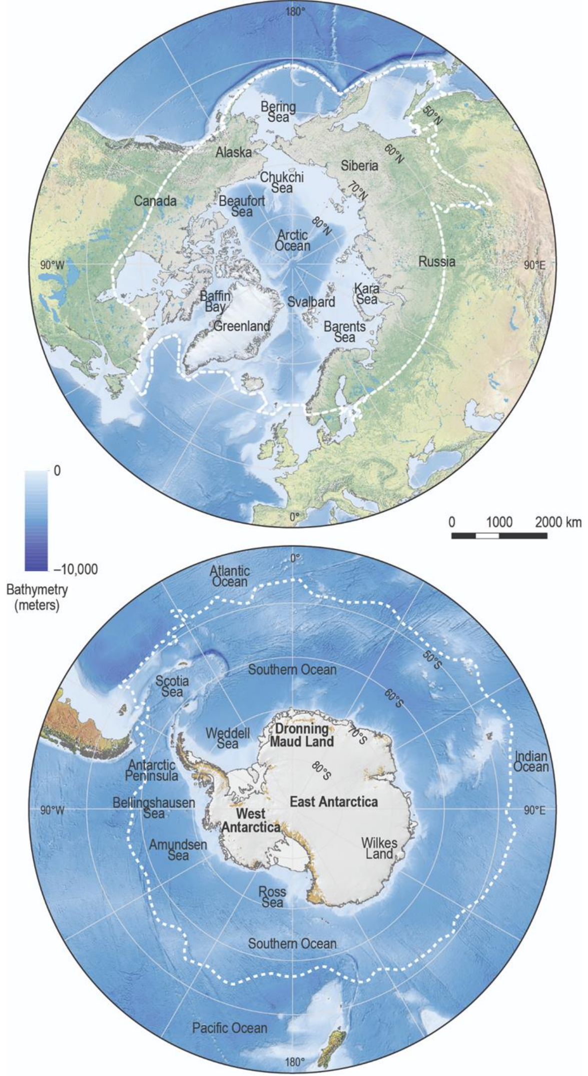
<u>Ocean circulation</u>: influenced globally by polar processes and affects drawdown of atmospheric heat and carbon

<u>Ice sheets and glaciers</u>: discharge freshwater that influences ocean circulation, ecosystems and sea level

<u>Sea ice</u>: influence climate weather, marine ecosystems and humans activities

<u>Marine ecosystems</u>: vulnerable to climate change

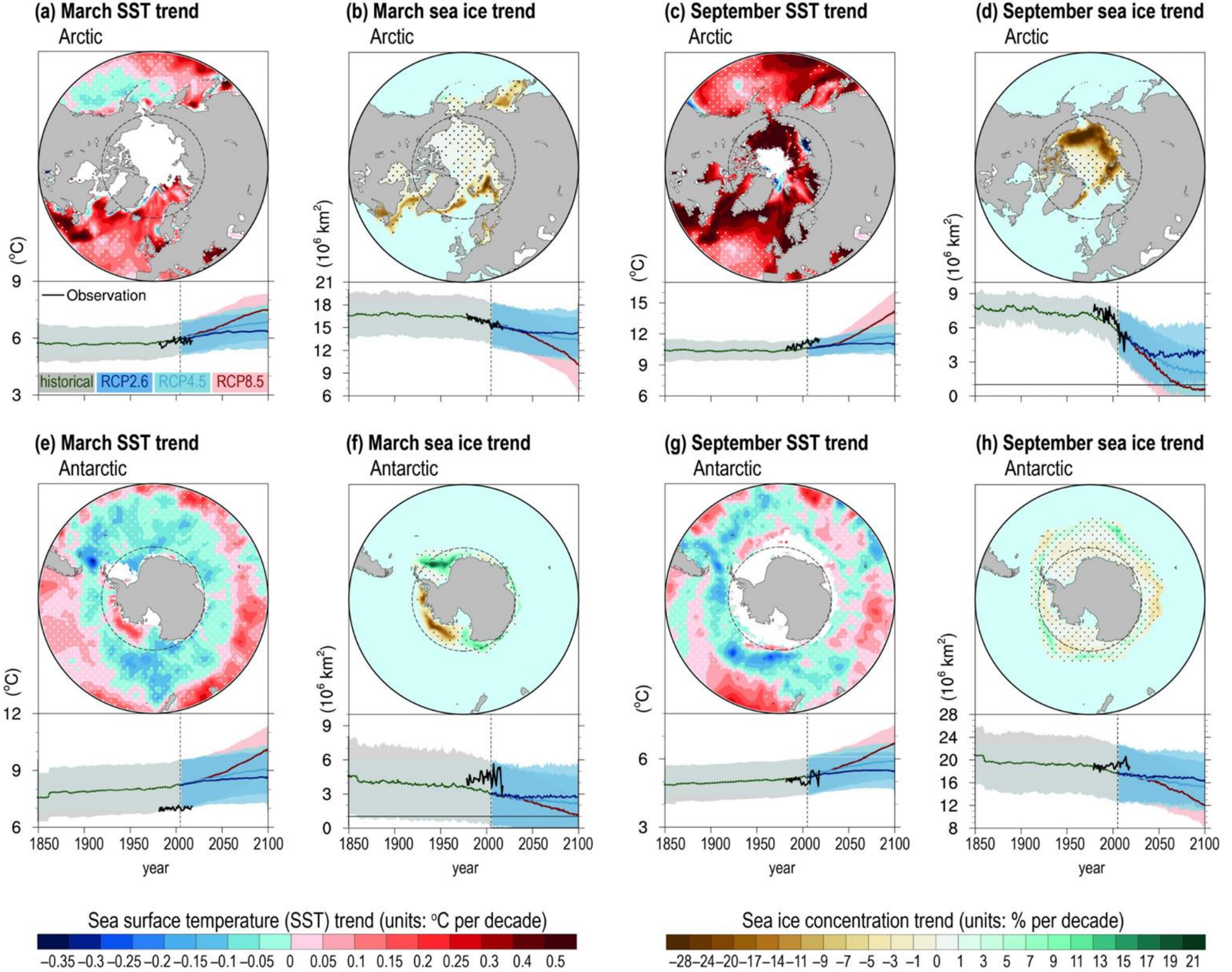
<u>Terrestrial ecosystems</u>: provide for people and contain unique biodiversity affected by climate change



changes are largest in summer and smallest in winter, with the strongest trends in September.

warming trends
have continued: August trends for 1982–2017 reveal summer mixed
layer temperatures increasing at about 0.5°C per decade over large
sectors of the Arctic basin that are ice-free in summer

the ensemble
mean across multiple models show a decrease in total Antarctic
sea ice extent during the satellite era, in contrast to the lack of
any observed trend



Coast & Ocean Regions

Projected impacts

Coastal cities and megacities

-New York City, Tokyo, Jakarta, Mumbai, Shanghai, Lagos and Cairo

Risks:

-Economic (monetary value)
-Urban
-Social

https://economipedia.com/wp-content/uploads/Buque-de-carga.jpg

Small islands

Tuvalu (Oceania)

Loss and damage of territory:
-Ocean acidification
-Storms
-Floods
-Hurricanes

-Uninhabitable before the middle of the 21st century

-Near future problems: land, soils and freshwater availability
-Tourism and recreation

https://bi.im-g.pl/im/2/7990/z7990462V,Atol-Funafuti-i-stolica-Tuvalu---Vaiaku.jpg

Arctic coasts

Norway's Lofoten archipelago

Impacts:
-Economy
-Local cultural identity, self-sufficiency of the land (fish and seabird population)
-Decrease in seasonal sea ice extent = reduction of protection of the land

-'Indigenous peoples (…) have been pushed into marginalised territories that are more sensitive to climate impacts' (Ford et al., 2016: 350)

https://assets.simpleviewcms.com/simpleview/image/upload/c_limit,h_1200,q_75,w_1200/v1/clients/norway/2000_1000Henningsv_r_Bryggehotell_Classic_Norway_Christer_Olsen_Photo_82a94e68-bf34-4571-b14a-ee781eb41eea.jpg

Subsidence caused by human activities

Jakarta, Indonesia

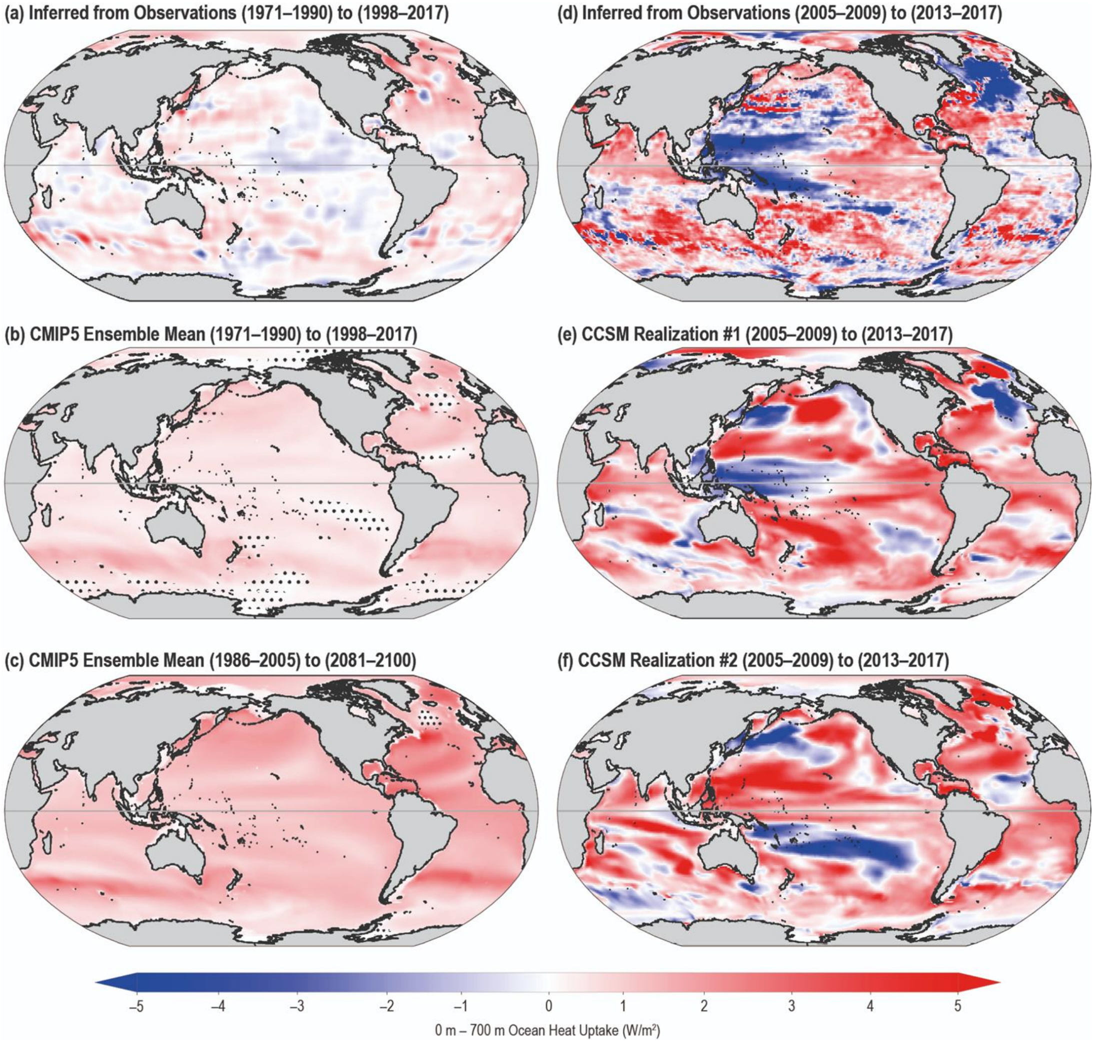
Jakarta is sinking up to 6.7 inches per year due to excessive groundwater pumping

Much of the city could be underwater by 2050

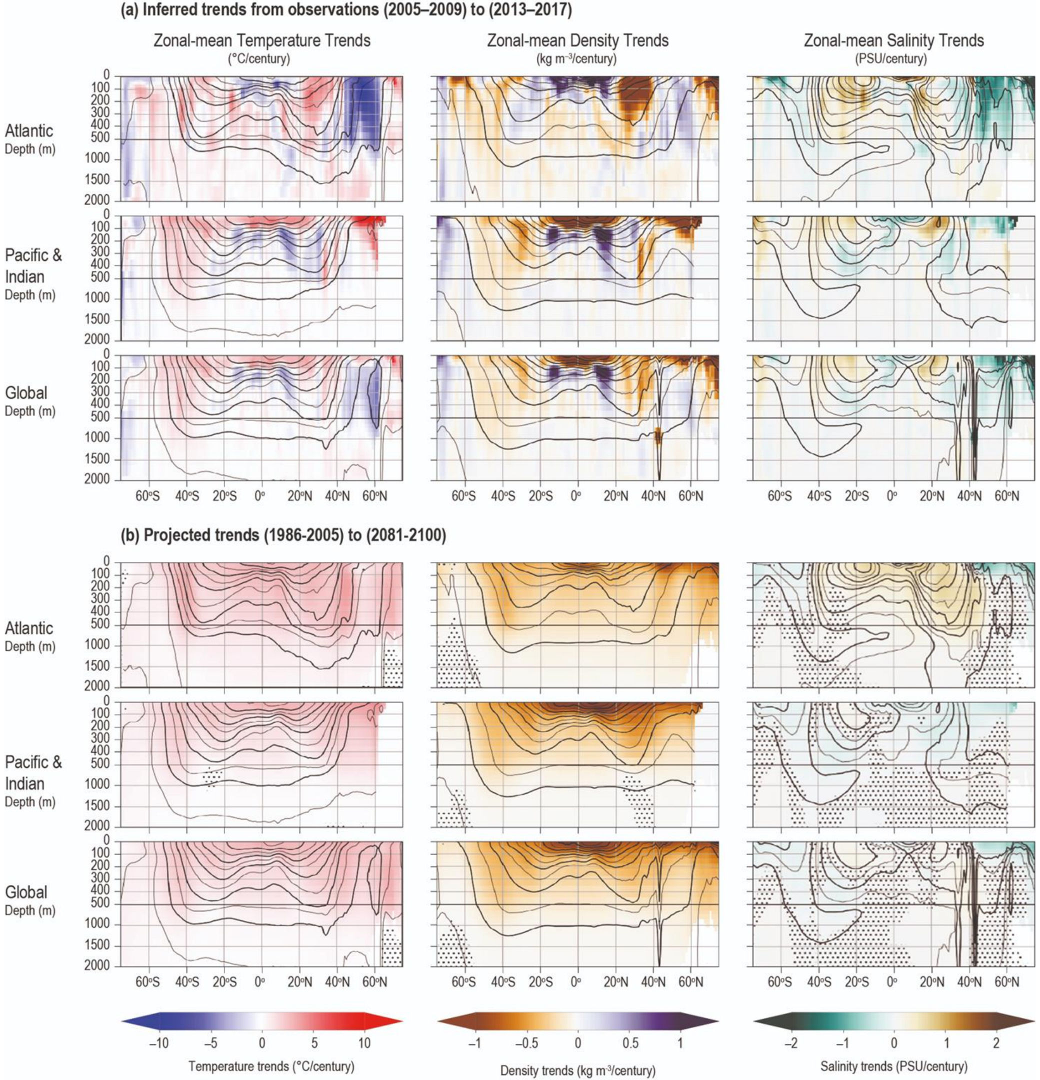
https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.globaltimes.cn%2Fpage%2F202111%2F1238590.shtml&psig=AOvVaw3GJ9MqBKwXSBFDpaKXQ1n6&ust=1641868157606000&source=images&cd=vfe&ved=0CAsQjRxqFwoTCIDI0tSRpvUCFQAAAAAdAAAAABAI

Changing ocean and biodiversity

Heat

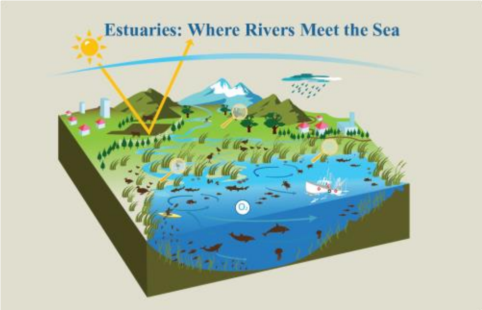


Temperature, Salinity and Density.



Changing coastal ecosystems and biodiversity

Salinisation - Estuaries and vegetated wetlands (Blue carbon)



2.

1.

3.

1. Salt marshals
2. Mangrove forests
3. Subtidal seagrass meadows

Globally, between 20–90% of existing coastal wetland area is projected to be lost by 2100

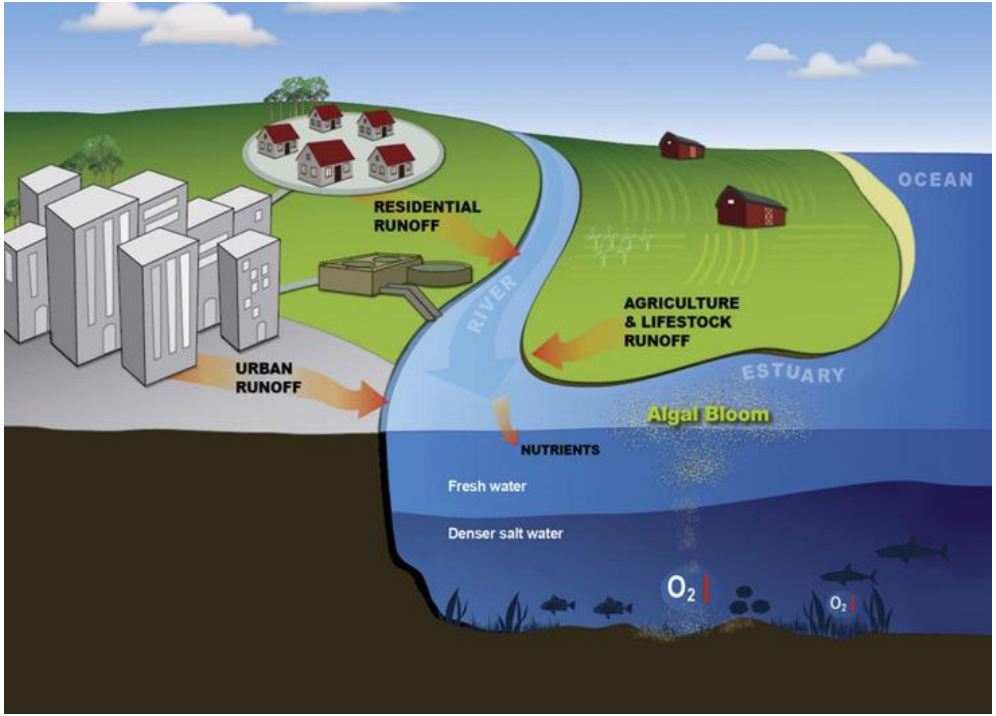
https://coast.noaa.gov/data/estuaries/img/curriculum-climate-extension-slide-1-1168.png

https://www.nature.scot/sites/default/files/styles/max_1300x1300/public/2017-07/Northton-D11065.jpg?itok=xYJGm0lJ

http://site-547756.mozfiles.com/files/547756/medium/Mangrove_Swamp_Wetlands-1.jpg

https://upload.wikimedia.org/wikipedia/commons/4/45/Sanc0209_-_Flickr_-_NOAA_Photo_Library.jpg

Oxygen-depleted dead zones



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Ecosystems at high risks

Coral reefs and rocky shores

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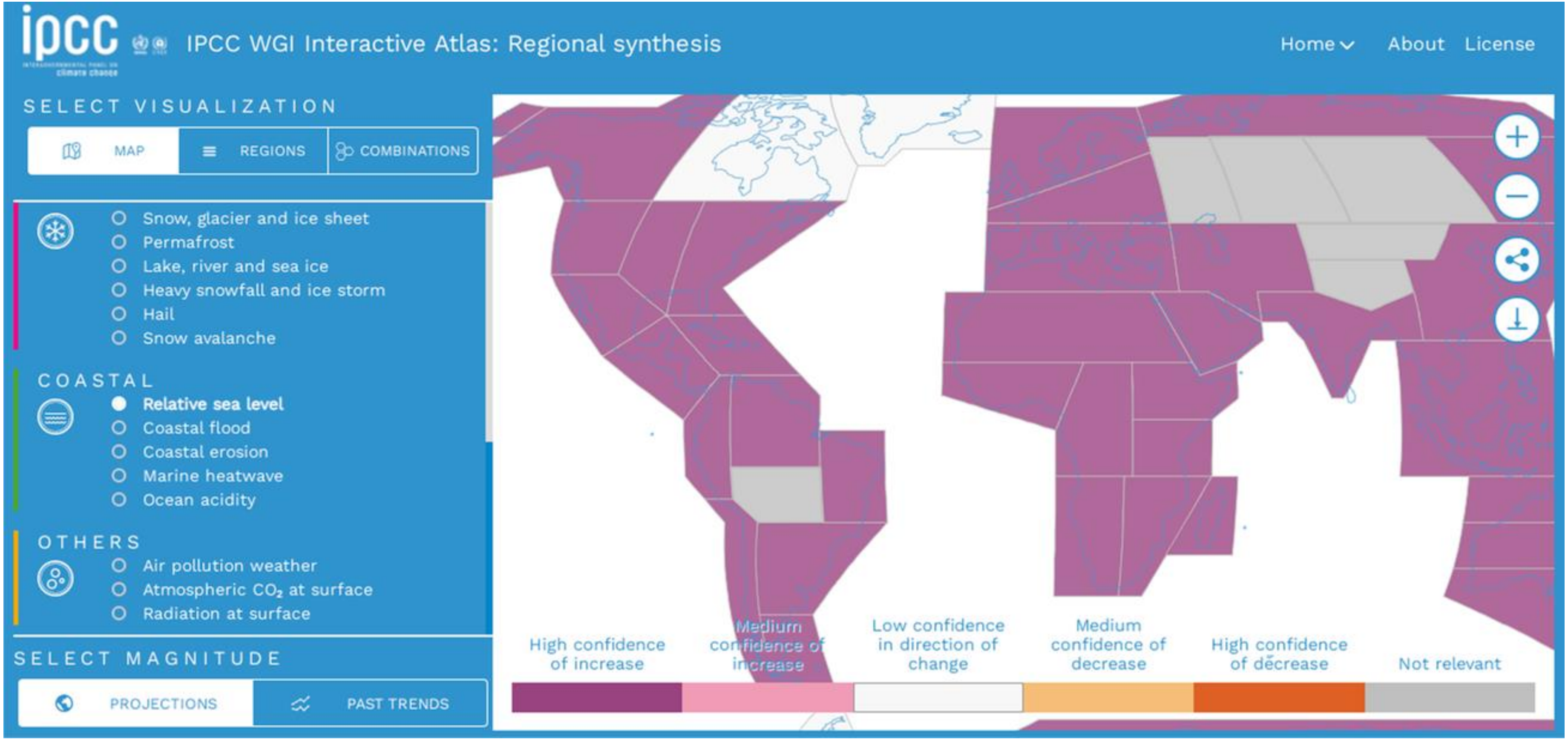
https://teara.govt.nz/files/p2655enz.jpg



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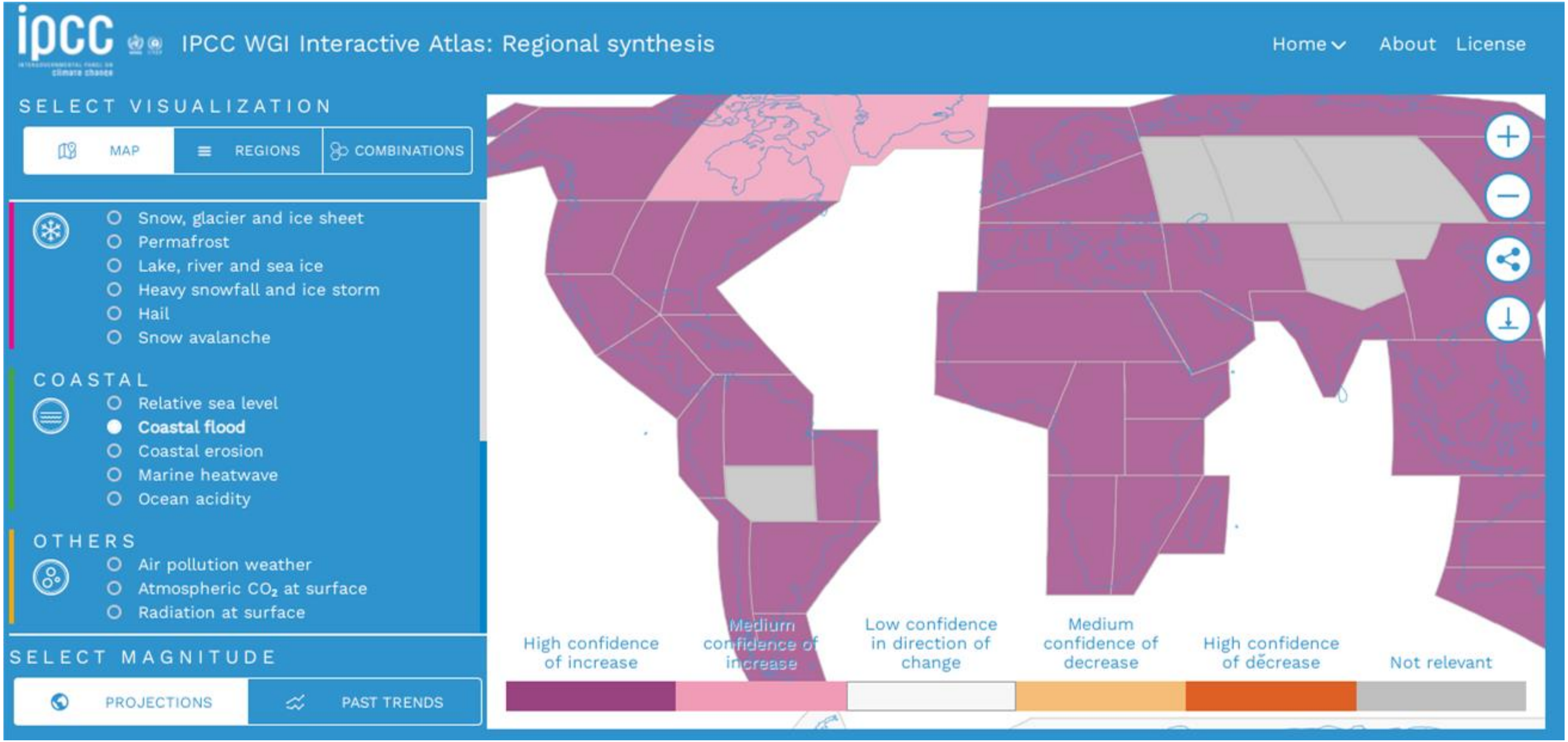

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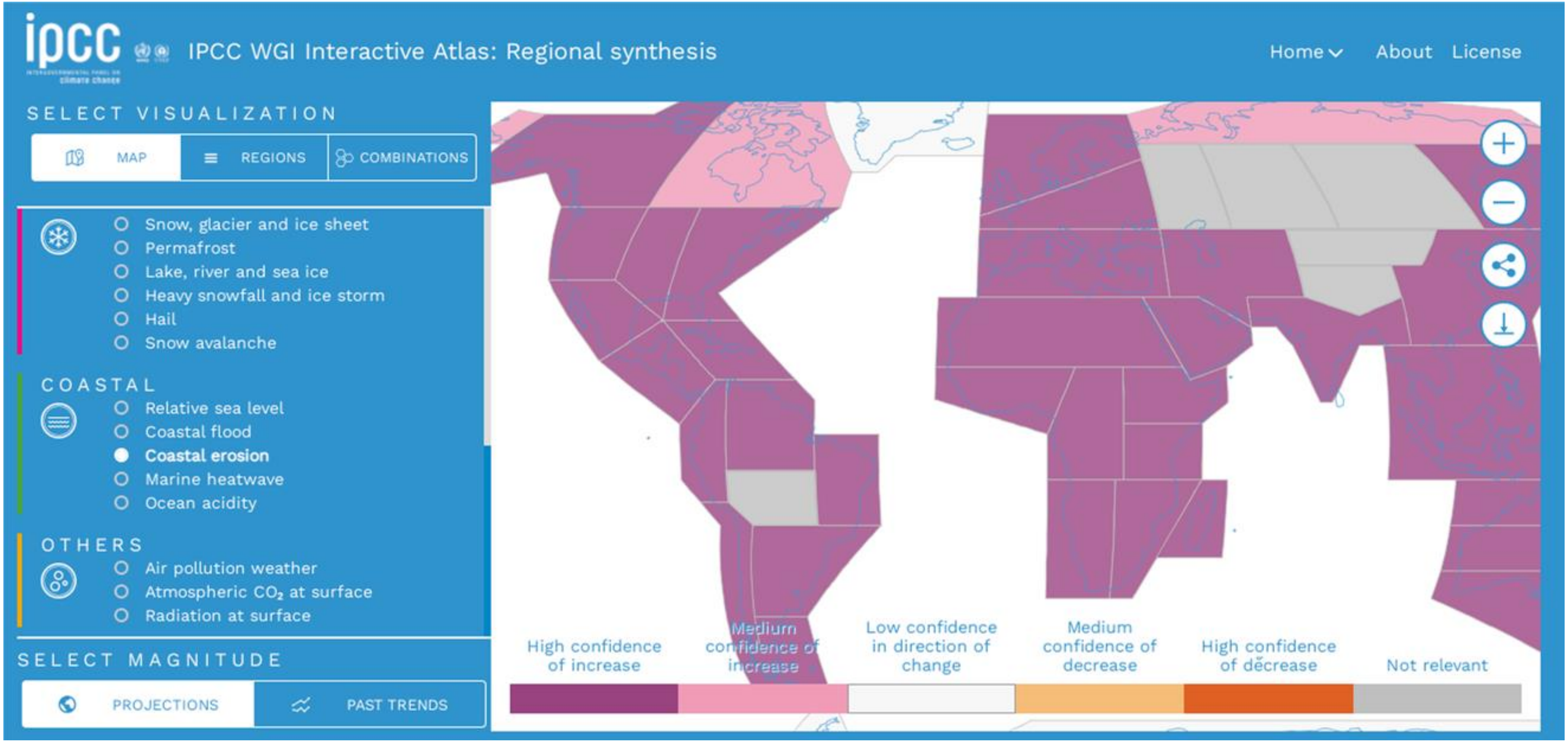

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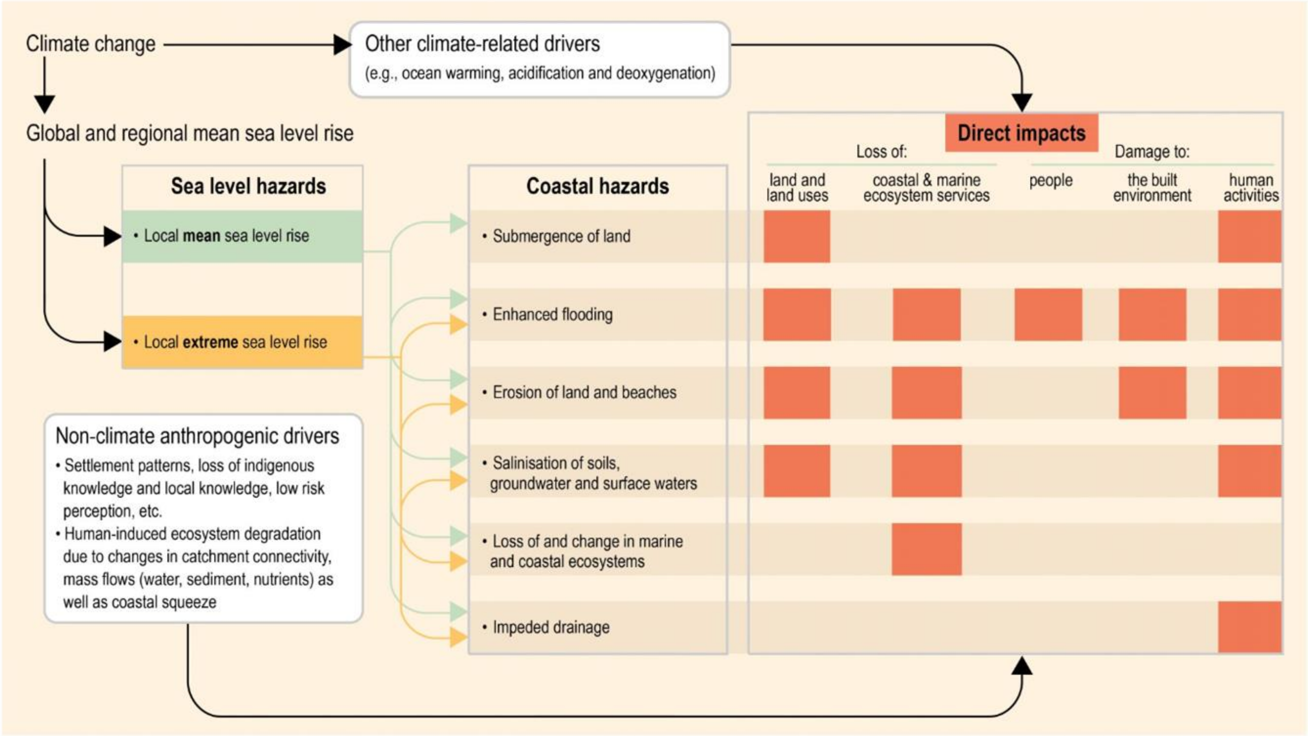
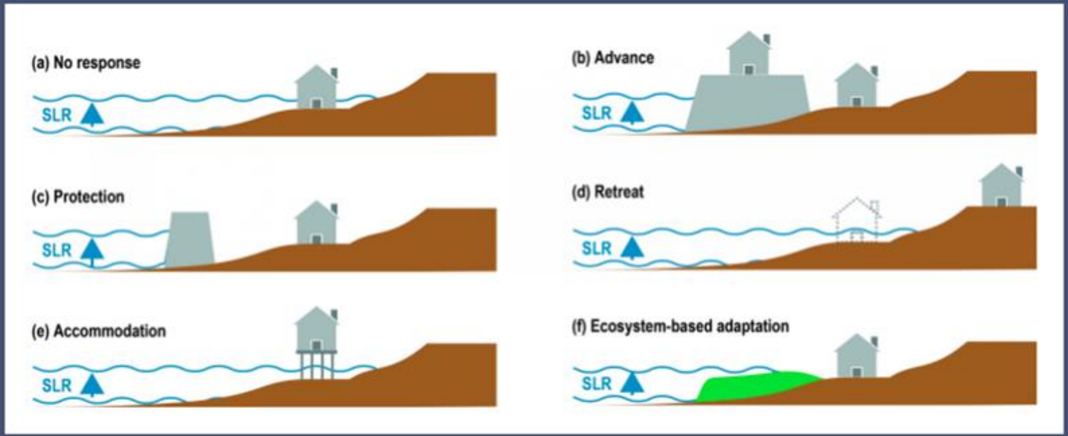
Figure 4.13 | Overview of the main cascading effects of sea level rise (SLR). Styles and colours of lines (left hand side: light/dark blue; right hand side: dotted/undotted and orange/green/dark yellow/purple/turquoise) and boxes are used only for the readability of the figure.



https://www.ipcc.ch/site/assets/uploads/sites/3/2019/10/IPCC-SROCC-CH_4_13-2318x3000.jpg

Progress and adaptation

- Advance
- Protection
- Retreat
- Accommodation
- Ecosystem-based adaptation (EbA)



Box 4.8, Figure 1 | Different types of responses to coastal risk and sea level rise (SLR).

https://www.ipcc.ch/srocc/chapter/chapter-4-sea-level-rise-and-implications-for-low-lying-islands-coasts-and-communities/

Preventing floods

Chulalongkorn University Centenary Park

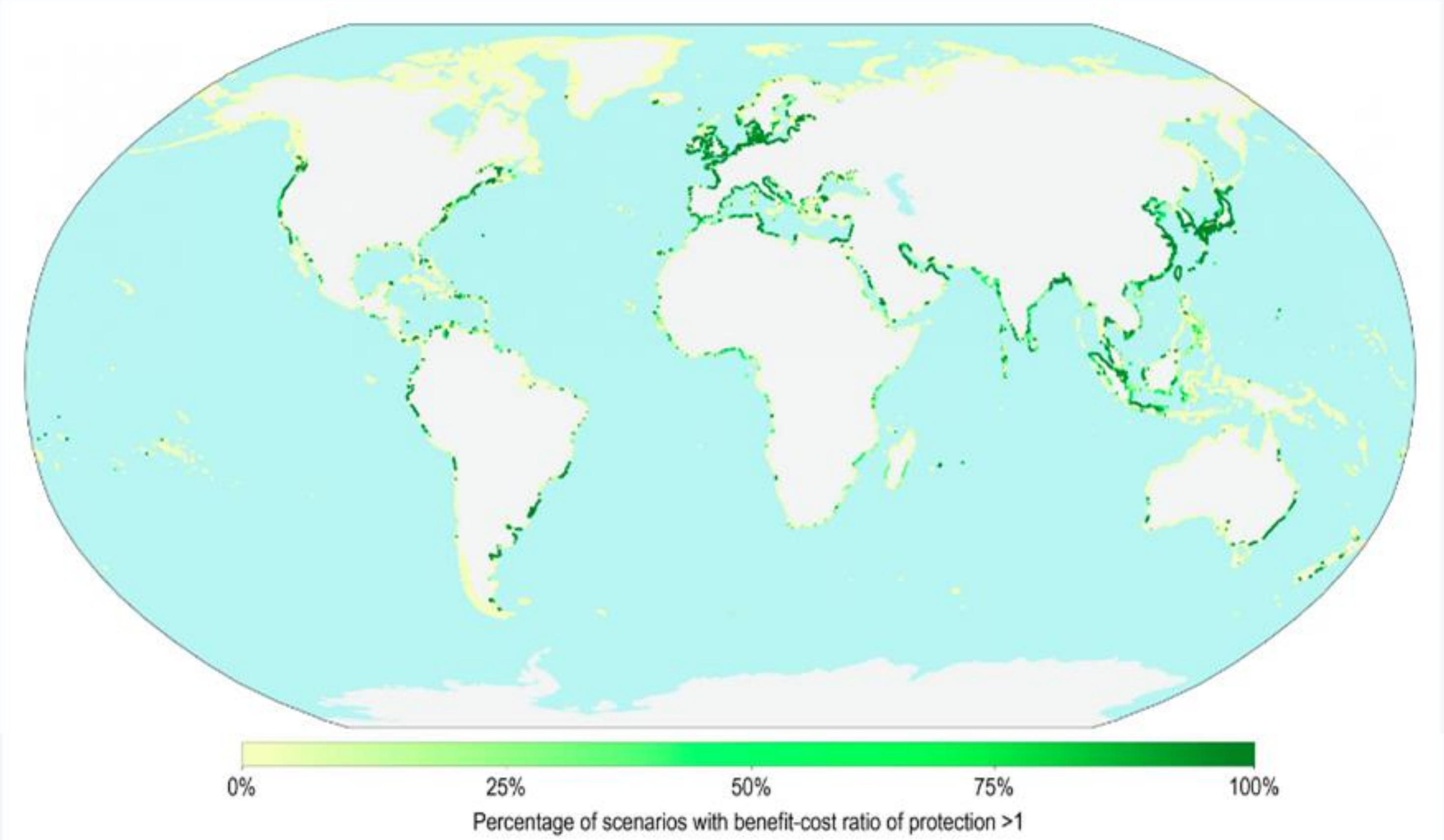
Bangkok, Thailand

Bangkok is sinking at a rate of more than 1 centimeter a year
Estimated below sea level by 2030, according to The Guardian

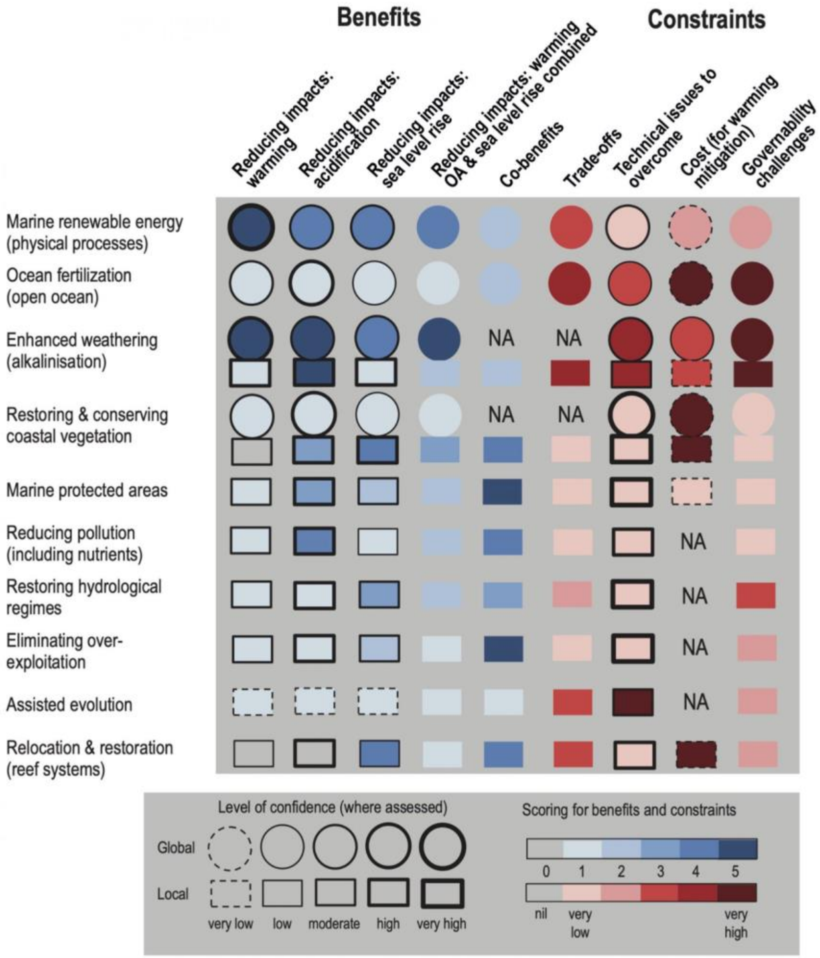
To help prevent flooding, especially during rainy season,
an architecture firm built an 11-acre park that can hold up
to 1 million gallons of rainwater

https://worldlandscapearchitect.com/chulalongkorn-centenary-park-green-infrastructure-for-the-city-of-bangkok/#.YdubB9VKjIV

Figure 4.14 | Economic robustness of coastal protection under sea level rise (SLR) scenarios from 0.3–2.0 m, the five Shared Socioeconomic Pathways (SSPs) and discount rates of up to 6%. Coastlines are coloured according to the percentage of scenarios under which the benefit-cost ratio of protection (reduced flood risk divided by the cost of protection) [...]



Potential benefits and constraints of ocean-based risk-reduction options using natural processes, from literature-based expert assessments by Gattuso et al. (2018). Mitigation effectiveness was quantified relative to Representative Concentration Pathway (RCP)8.5



https://www.ipcc.ch/site/assets/uploads/sites/3/2019/11/SROCC_Ch05_Figure5.23-scaled.jpg

Overview

“Climate-change induced GMSL (global mean sea level) rise is caused by thermal expansion of ocean water and ocean mass gain, the latter primarily due to a decrease in land-ice mass”

“The combination of gradual change of mean sea level with ESL (extreme sea level) events such as tides, surges and waves causes coastal impacts”

Preparing for future SLR:

- Manage and reduce anthropogenic subsidence.

-Improve observational systems (tide gauges, wave buoys and remote sensing techniques), because in many places around the world current frequencies and intensities of ESL events are not well understood due to a lack of observational data.

-Ecosystem-based adaptation

-Accommodation to reduce vulnerability of coastal residents, human activities, ecosystems and the built environment

Nevertheless

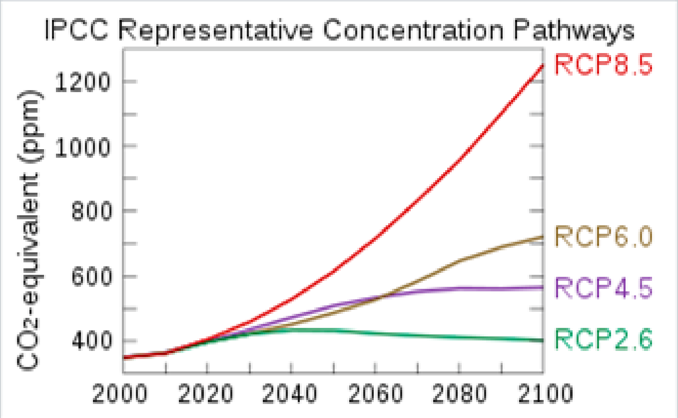
RCP: Representative Concentration Pathways

Up to 2050, uncertainty in climate change-driven future sea level is relatively small, which provides a robust basis for short-term (≤30 years) adaptation planning. GMSL will rise between 0.24 m under RCP2.6 and 0.32 m under RCP8.5

References: https://www.ipcc.ch/srocc/chapter/chapter-4-sea-level-rise-and-implications-for-low-lying-islands-coasts-and-communities/

https://www.ipcc.ch/srocc/chapter/chapter-5/

https://www.weforum.org/agenda/2019/09/11-sinking-cities-that-could-soon-be-underwater/



All forcing agents' atmospheric CO_2-equivalent concentrations (in parts-per-million-by-volume (ppmv)) according to the four RCPs used by the fifth IPCC Assessment Report to make predictions.

EXTREMES AND ABRUPT OR IRREVERSIBLE CHANGES IN THE OCEAN AND CRYOSPHERE IN A CHANGING CLIMATE

Extreme weather/climate event:
An event that is rare at a particular place and time of year. Definitions of 'rare' vary, but an extreme event would normally be as rare as or rarer than the 10th percentile of a probability function estimated from observations.

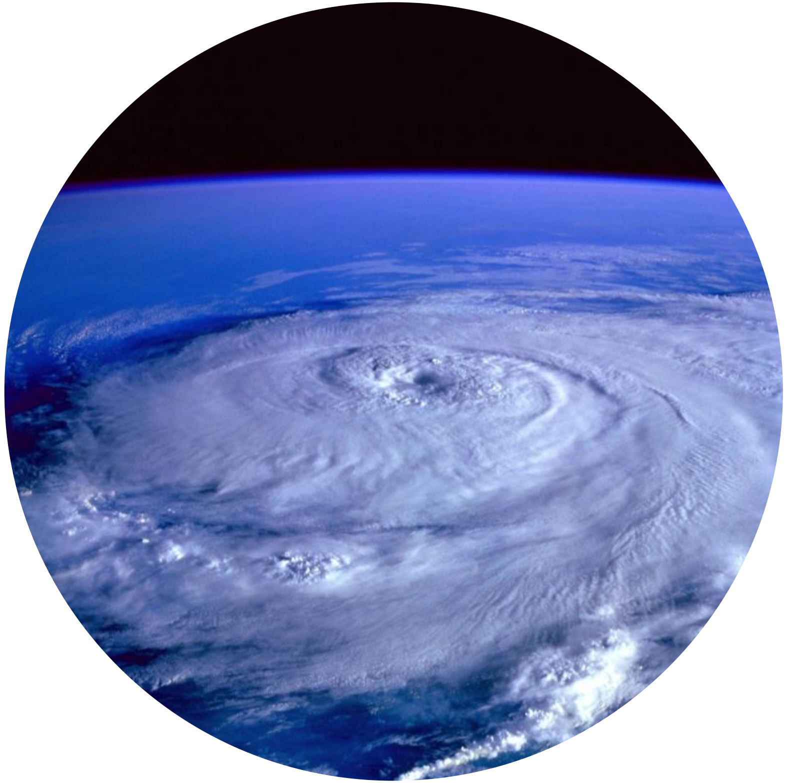
Abrupt climate change:
A large-scale change in the climate system that takes place over a few decades or less, persists (or is anticipated to persist) for at least a few decades, and causes substantial disruptions in human and natural systems.

Irreversibility:

A perturbed state of a dynamical system is defined as irreversible on a given timescale, if the recovery timescale from this state due to natural processes is significantly longer than the time it takes for the system to reach this perturbed state.

In the context of IPCC report and the Climate Change, the recovery time scale is hundreds to thousands of years.

Tipping point:
A level of change in system properties beyond which a system reorganizes and does not return to the initial state even if the drivers of the change are abated.



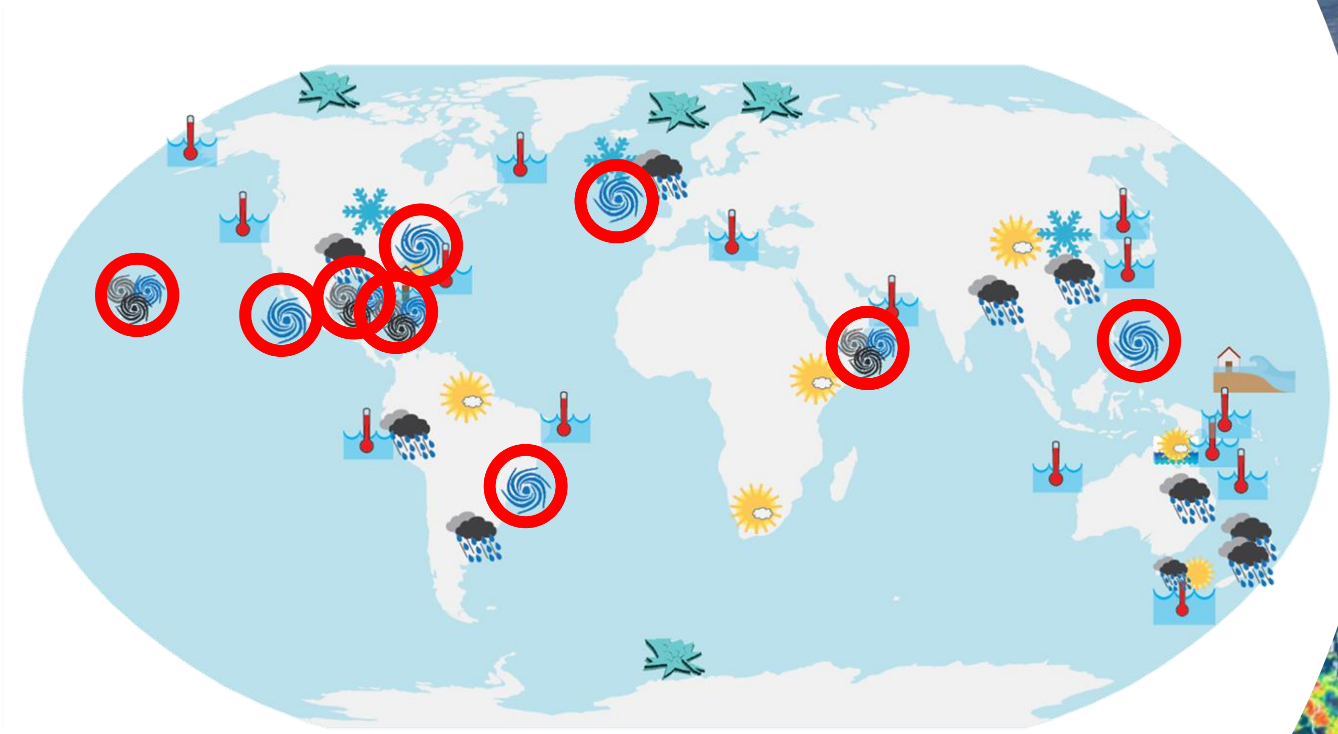
Compound events
refer to the combination of multiple drivers and/or hazards that contribute to societal or environmental risks.

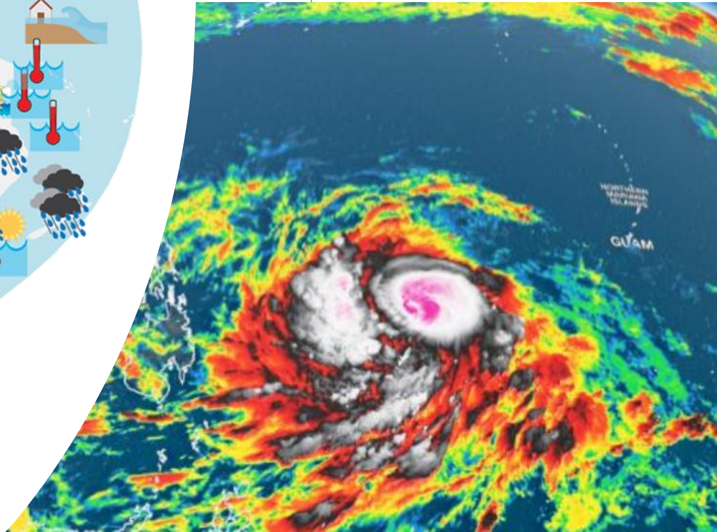
Cascading impacts
from extreme weather/climate events occur when an extreme hazard generates a sequence of secondary events in natural and human systems that result in physical, natural, social or economic disruption, whereby the resulting impact is significantly larger than the initial impact.

EXTREMES AND ABRUPT
OR IRREVERSIBLE CHANGES
IN THE OCEAN
AND CRYOSPHERE
IN A CHANGING CLIMATE

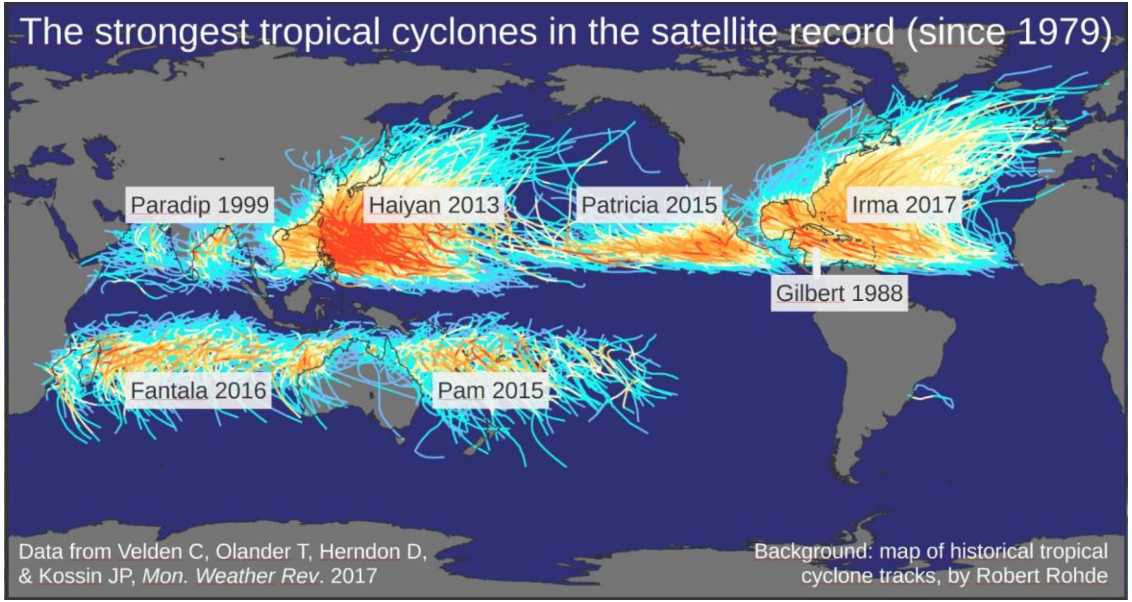
WHAT WE CAN SEE?

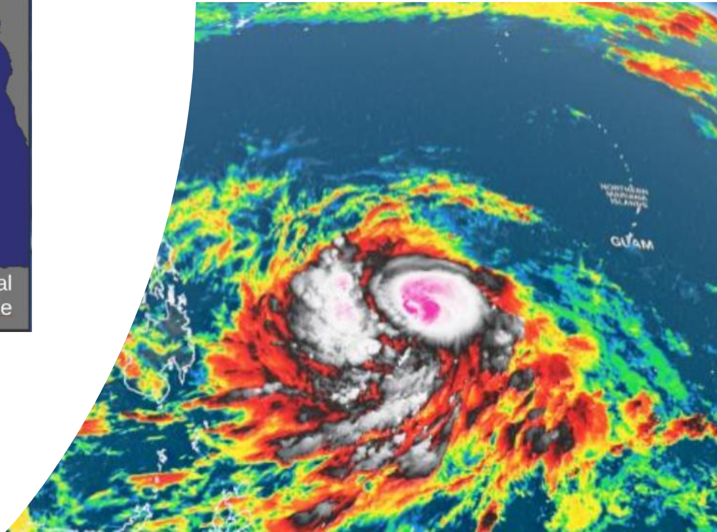
TROPICAL CYCLONES





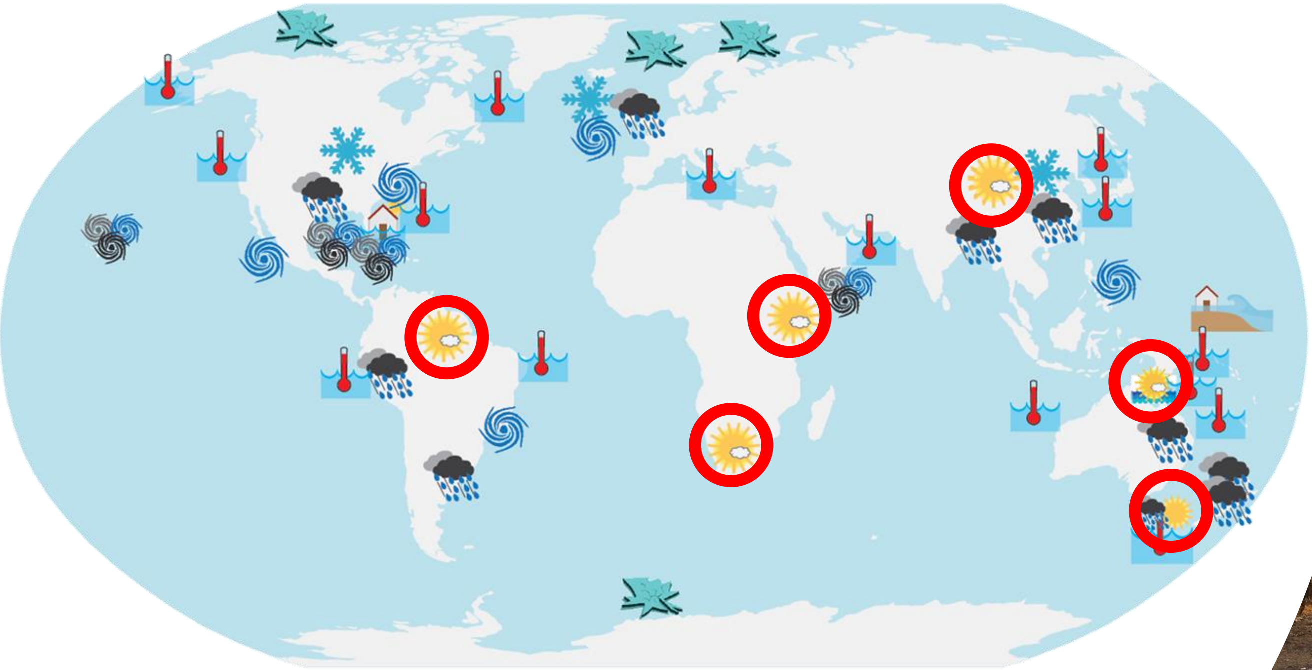
TROPICAL CYCLONES



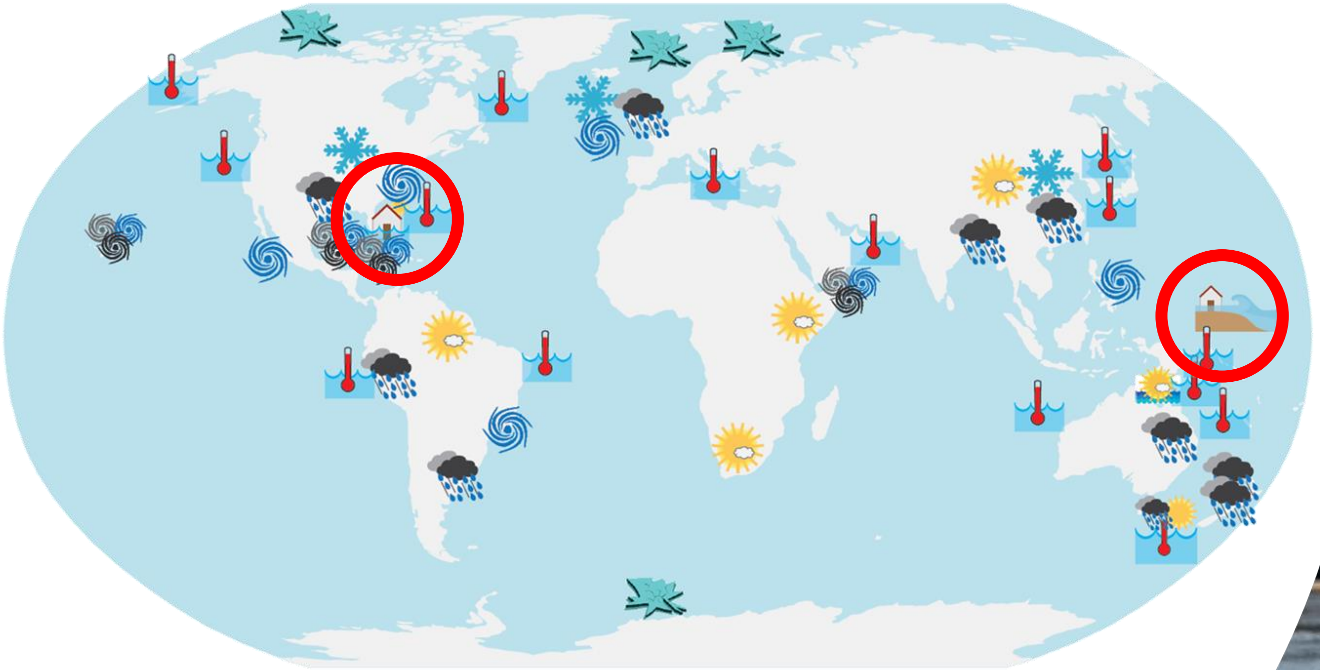


EXTREME RAINFALL

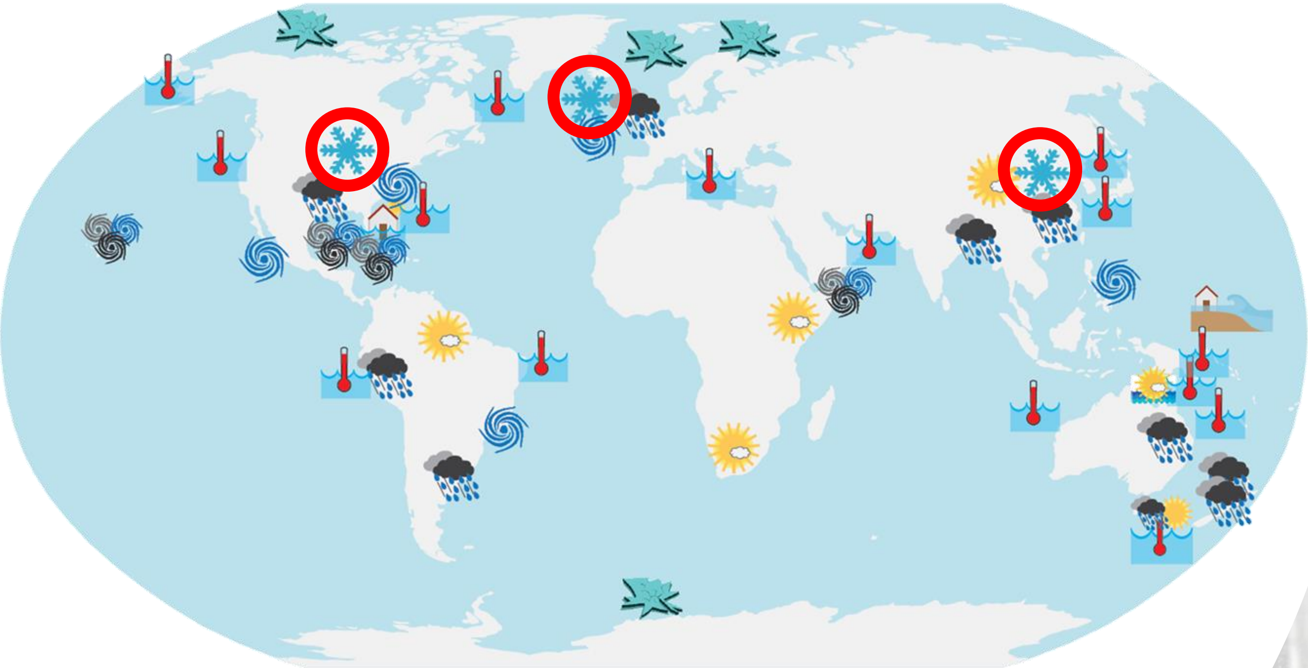
EXTREME DROUGHTS



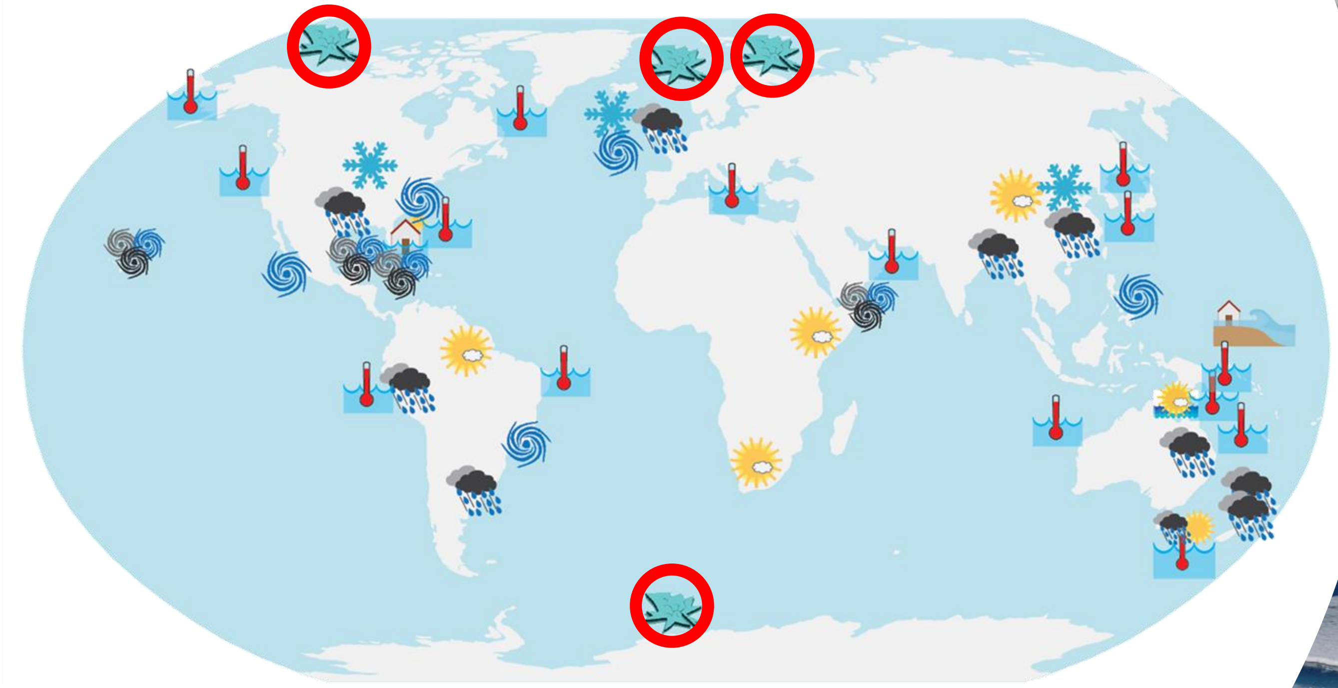
EXTREME TIDAL FLOODING
EXTREME WAVE INDUCED FLOODING



EXTREME COLD OR SNOW STORM



SEA ICE MELTING



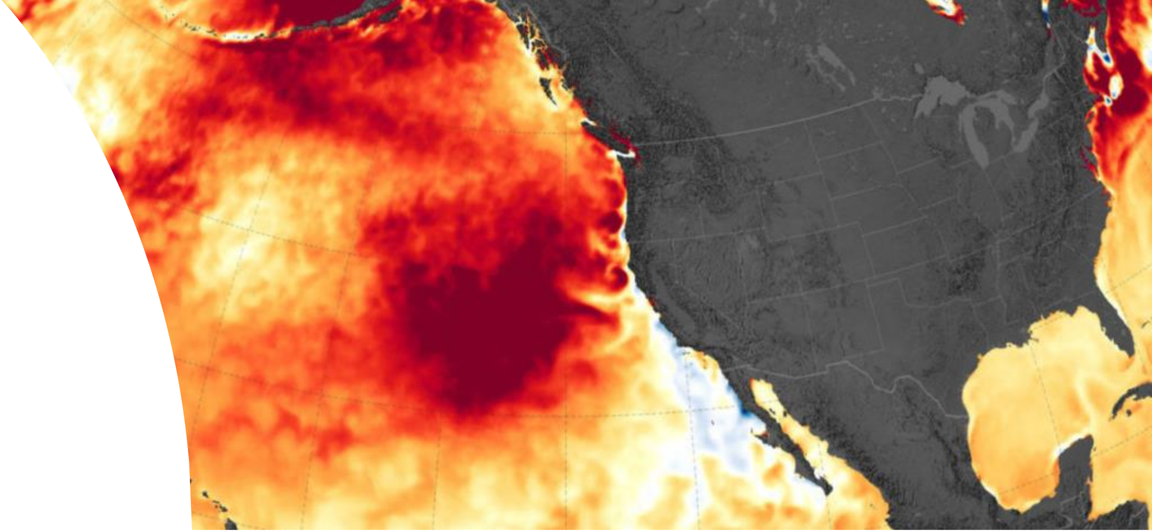
EXTREMES AND ABRUPT OR IRREVERSIBLE CHANGES IN THE OCEAN AND CRYOSPHERE IN A CHANGING CLIMATE

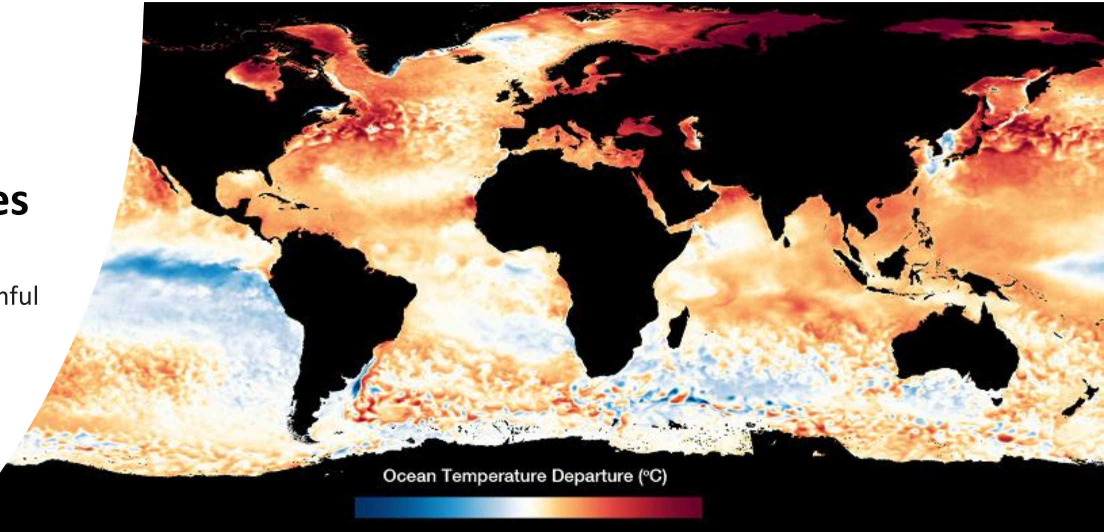
WHAT WE CAN NOT SEE BUT SHALL BE WORRIED ABOUT?

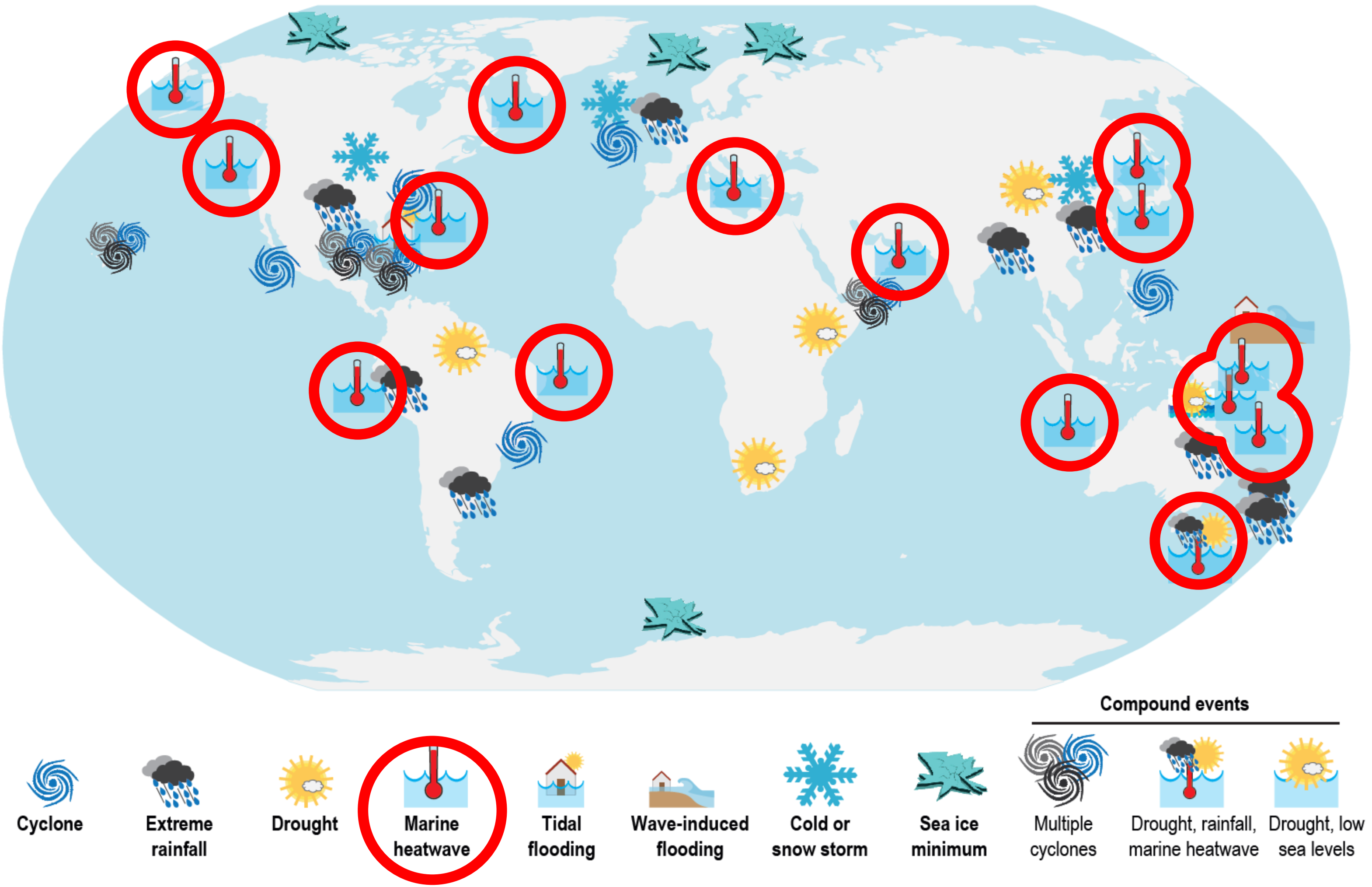
MARINE HEATWAVES INCREASE

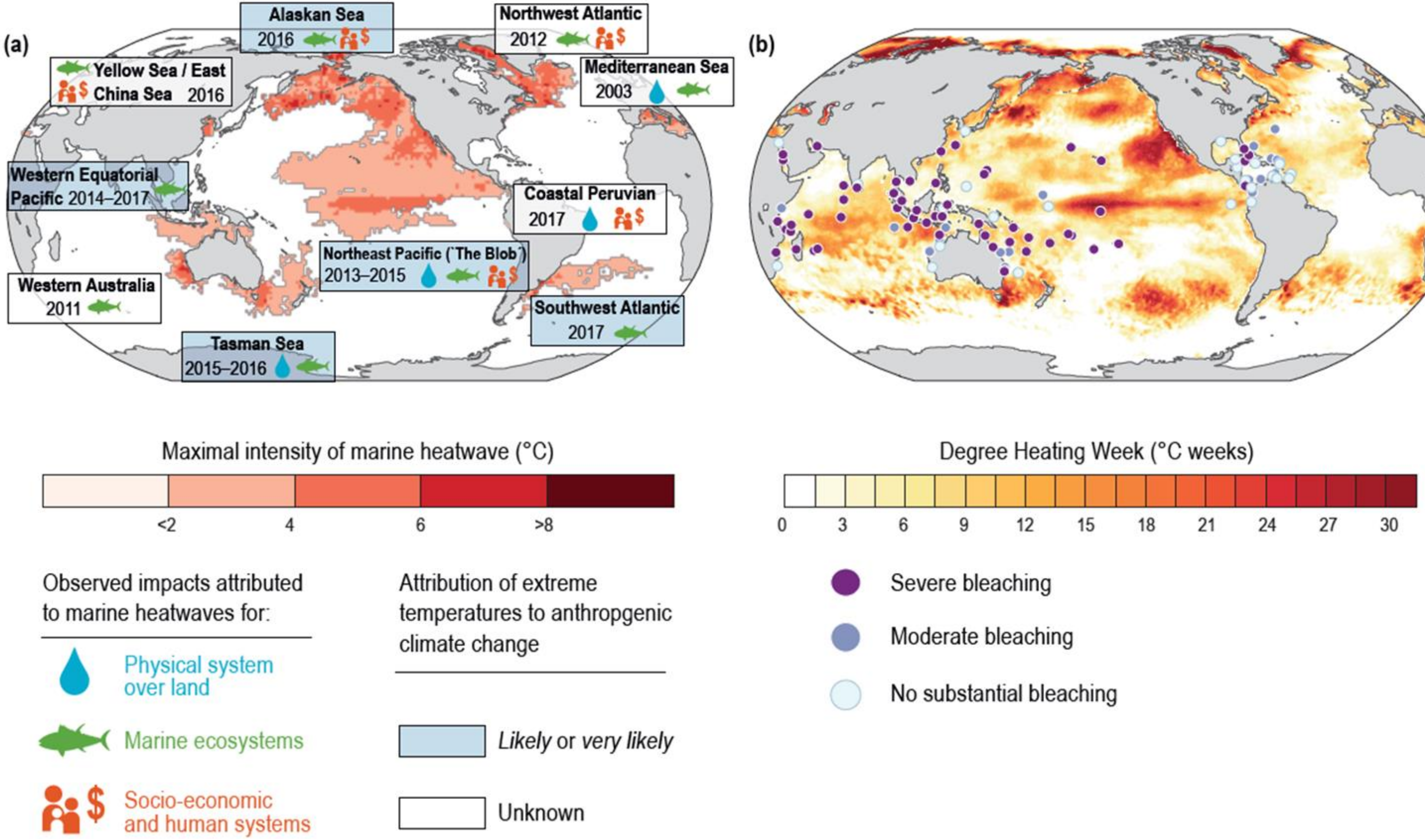
Reversible within decades to centuries

IMPACT:
Coral bleaching, loss of biodiversity and ecosystem services, harmful algal blooms, species redistribution

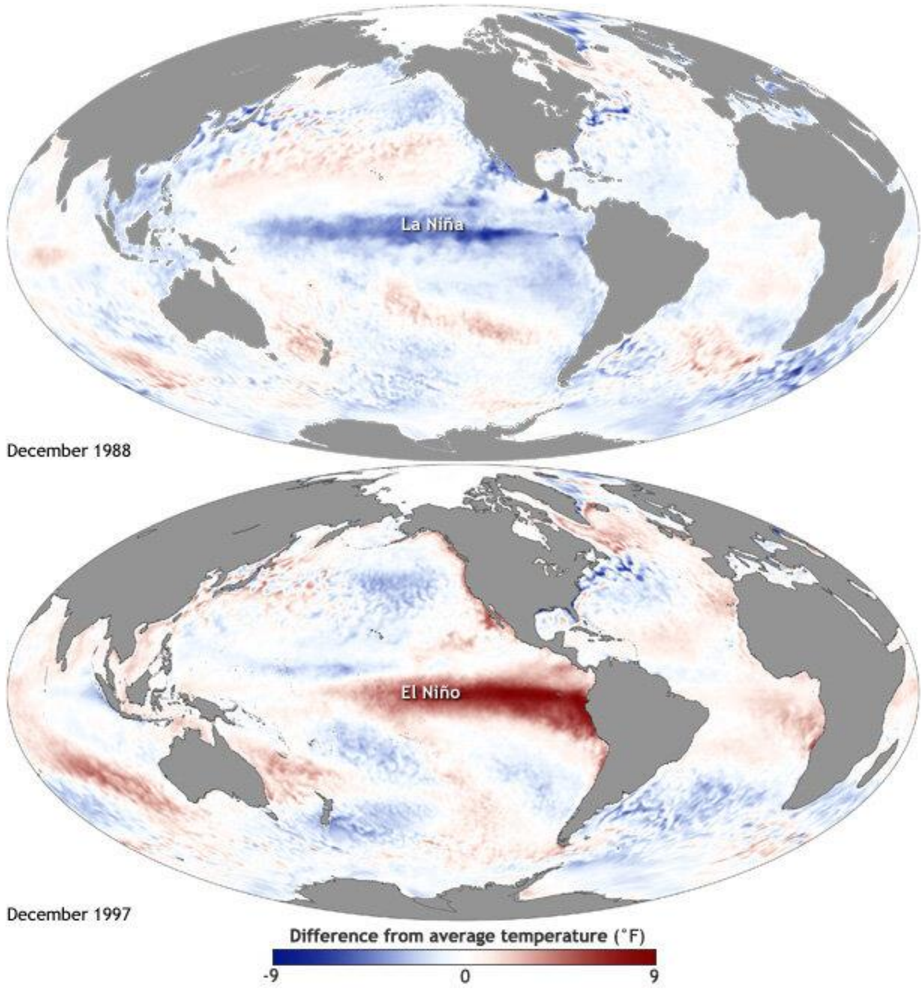





Compound events
Cyclone
Extreme rainfall
Drought
Marine heatwave
Tidal flooding
Wave-induced flooding
Cold or snow storm
Sea ice minimum
Multiple cyclones
Drought, rainfall, marine heatwave
Drought, low sea levels

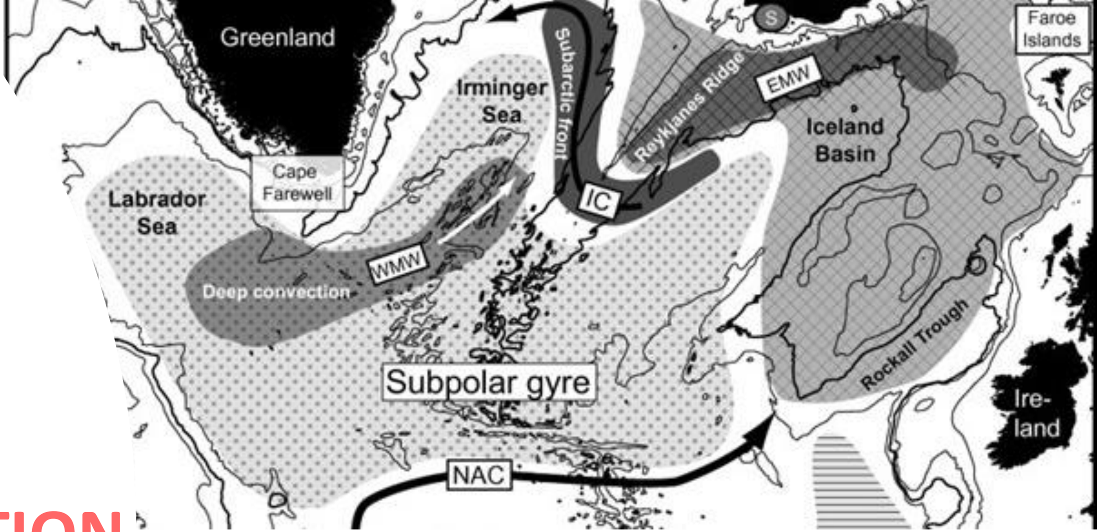

(a)
Alaskan Sea
2016
Northwest Atlantic
2012
Yellow Sea / East China Sea 2016
Mediterranean Sea
2003
Western Equatorial Pacific 2014–2017
Coastal Peruvian
2017
Northeast Pacific (`The Blob`)
2013–2015
Western Australia
2011
Southwest Atlantic
2017
Tasman Sea
2015–2016
(b)
Maximal intensity of marine heatwave (°C)
<2
4
6
>8
Degree Heating Week (°C weeks)
0
3
6
9
12
15
18
21
24
27
30
Observed impacts attributed to marine heatwaves for:
Physical system over land
Marine ecosystems
Socio-economic and human systems
Attribution of extreme temperatures to anthropogenic climate change
Likely or very likely
Unknown
Severe bleaching
Moderate bleaching
No substantial bleaching

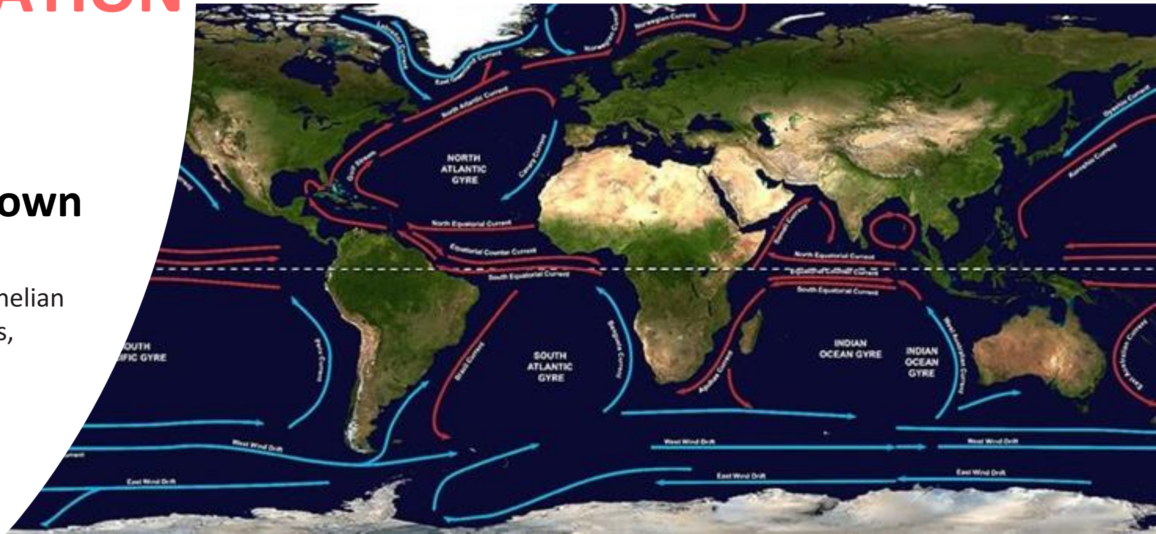
EXTREME
EL NIŃO AND LA NIŃA



SUBPOLAR GYRE COOLING

ATLANTIC MERIDIONAL OVERTURNING CIRCULATION (AMOC) COLLAPSE

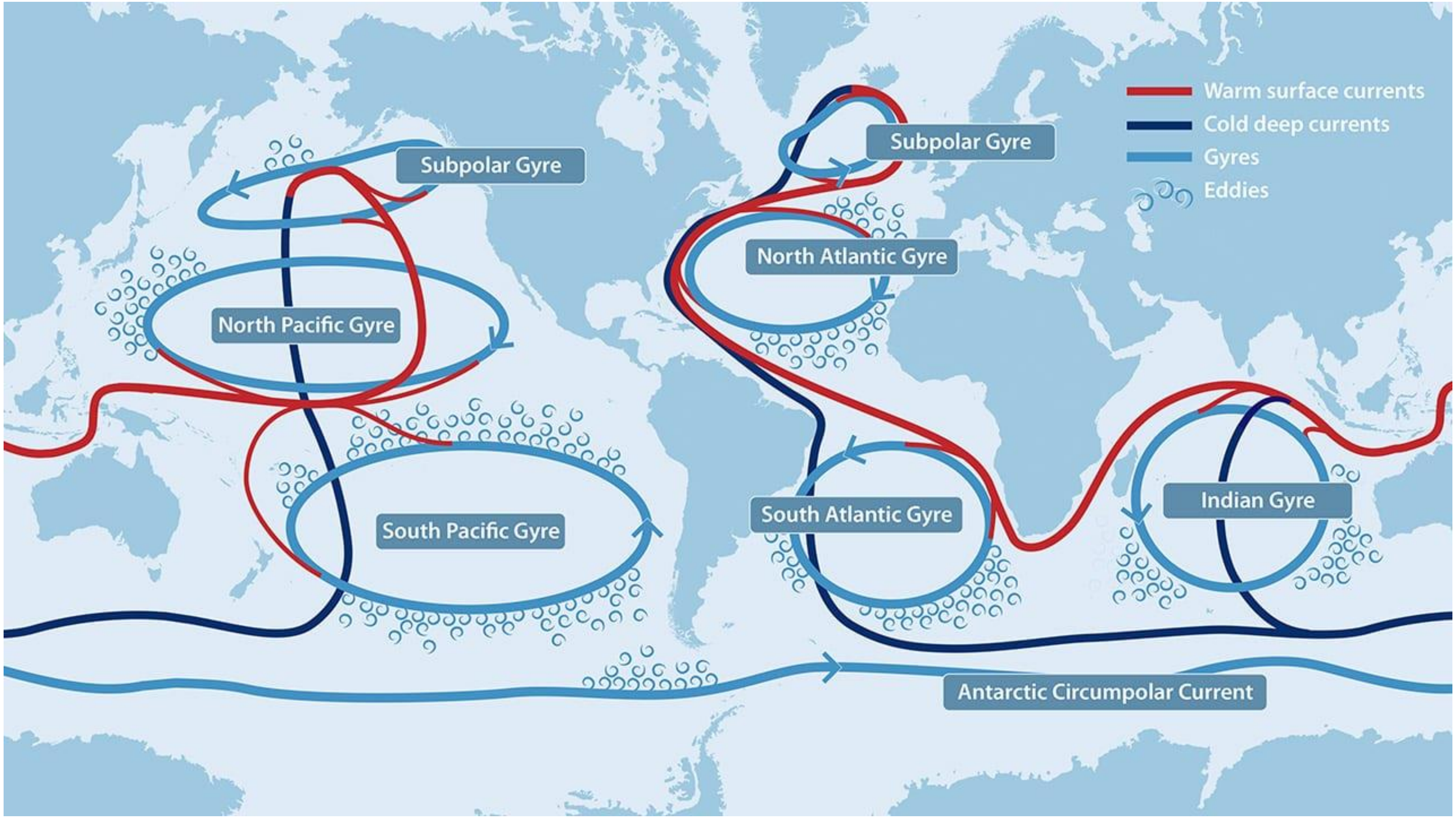


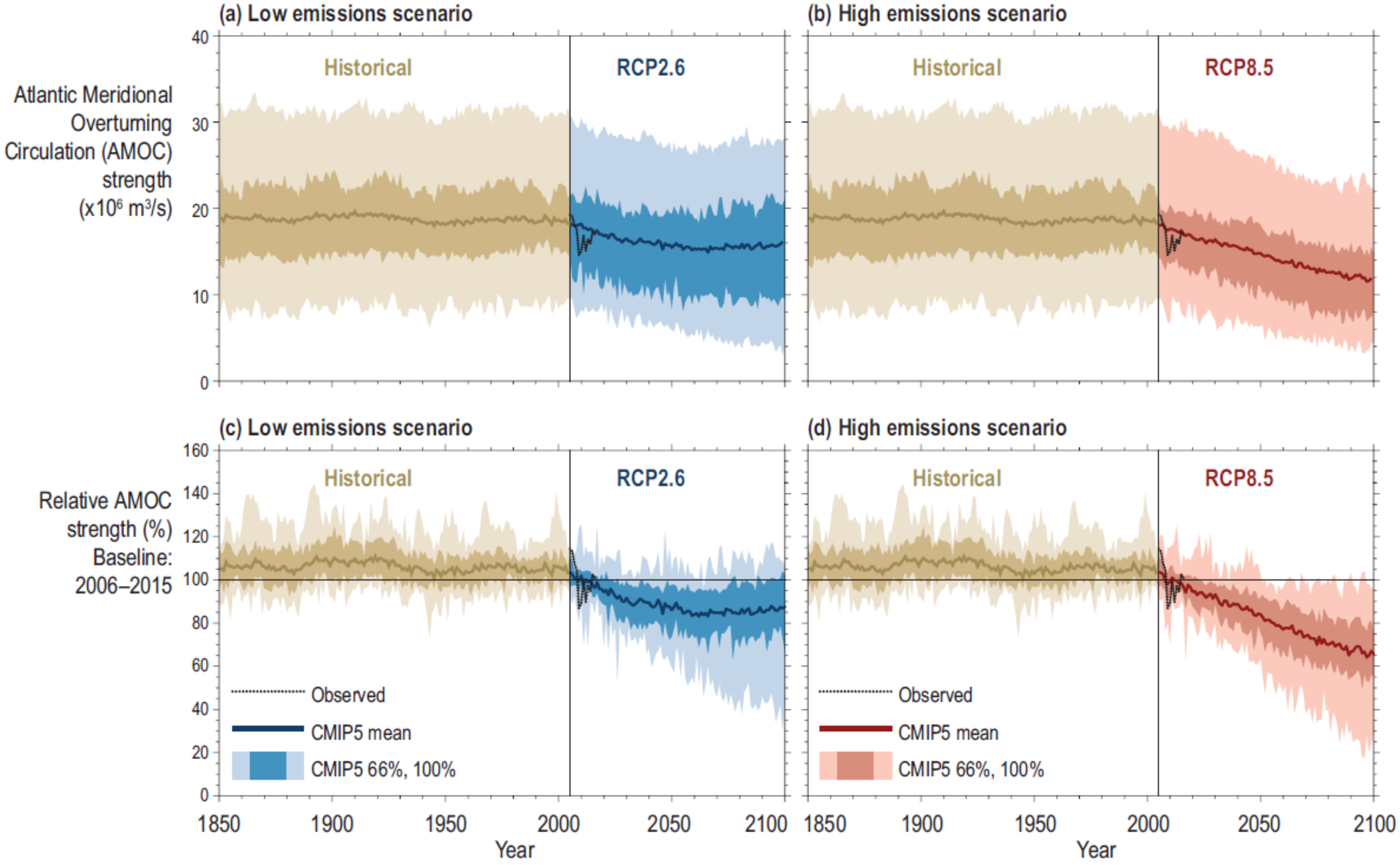


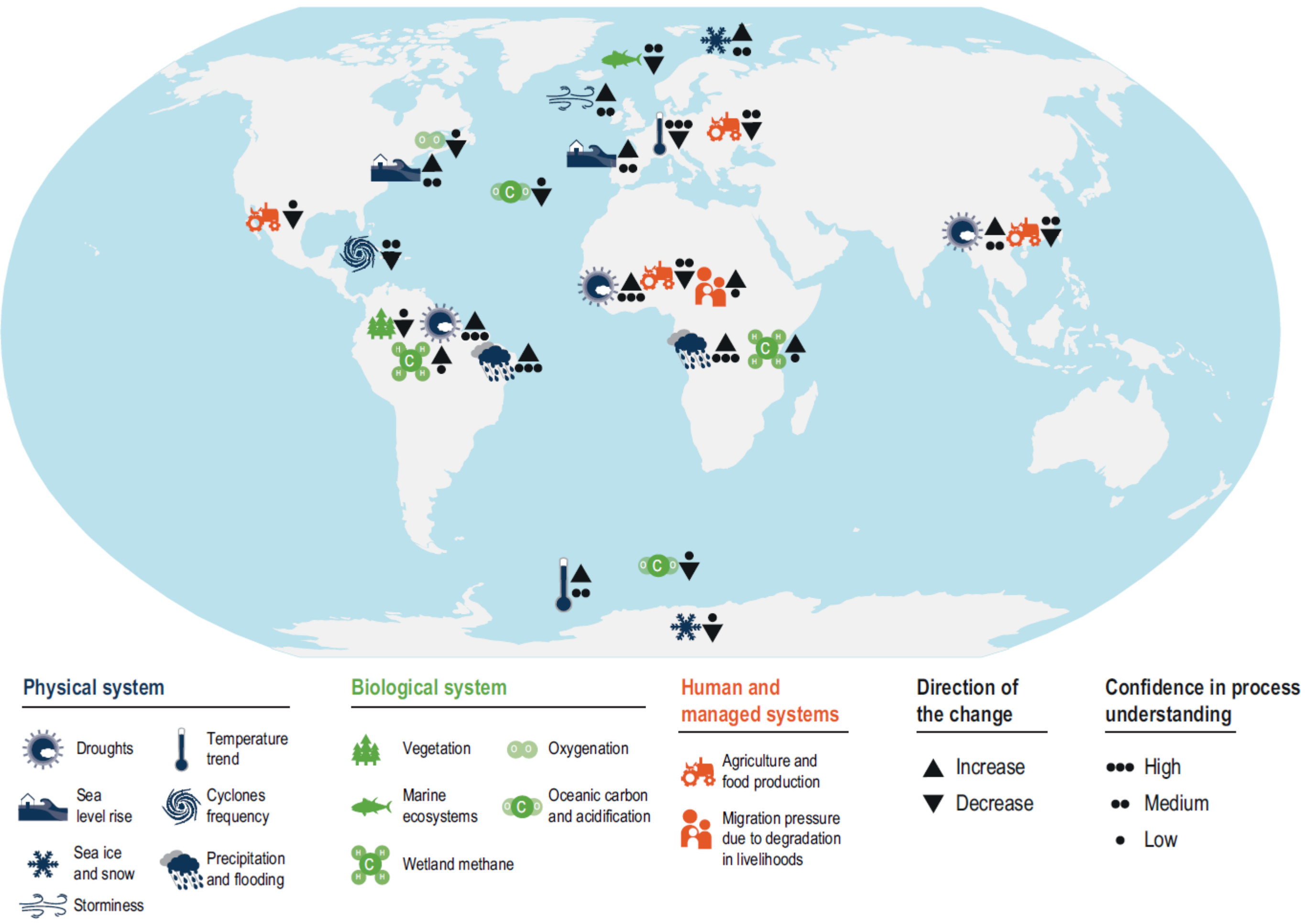
Irreversible within decades / unknown

IMPACT:

Widespread; increased winter storms in Europe, reduced Sahelian rainfall and agricultural capacity, variations in tropical storms, increased sea levels on Atlantic coasts


Warm surface currents
Cold deep currents
Gyres
Eddies
Subpolar Gyre
North Pacific Gyre
South Pacific Gyre
Subpolar Gyre
North Atlantic Gyre
South Atlantic Gyre
Indian Gyre
Antarctic Circumpolar Current


(a) Low emissions scenario
(b) High emissions scenario
Historical
RCP2.6
RCP8.5
Atlantic Meridional Overturning Circulation (AMOC) strength (x10⁶ m³/s)
0
10
20
30
40
(c) Low emissions scenario
(d) High emissions scenario
Relative AMOC strength (%) Baseline: 2006–2015
0
20
40
60
80
100
120
140
160
Observed
CMIP5 mean
CMIP5 66%, 100%
1850
1900
1950
2000
2050
2100
Year


Physical system
Droughts
Temperature trend
Sea level rise
Cyclones frequency
Sea ice and snow
Precipitation and flooding
Storminess
Biological system
Vegetation
Oxygenation
Marine ecosystems
Oceanic carbon and acidification
Wetland methane
Human and managed systems
Agriculture and food production
Migration pressure due to degradation in livelihoods
Direction of the change
Increase
Decrease
Confidence in process understanding
High
Medium
Low

CONCLUSIONS?

The likelihood of rare, extreme weather events **is increasing with each kilogram of CO_2 emitted into the atmosphere!**

Prof. Szymon Malinowski

Thank you.