Sea Level Rise and Consequences

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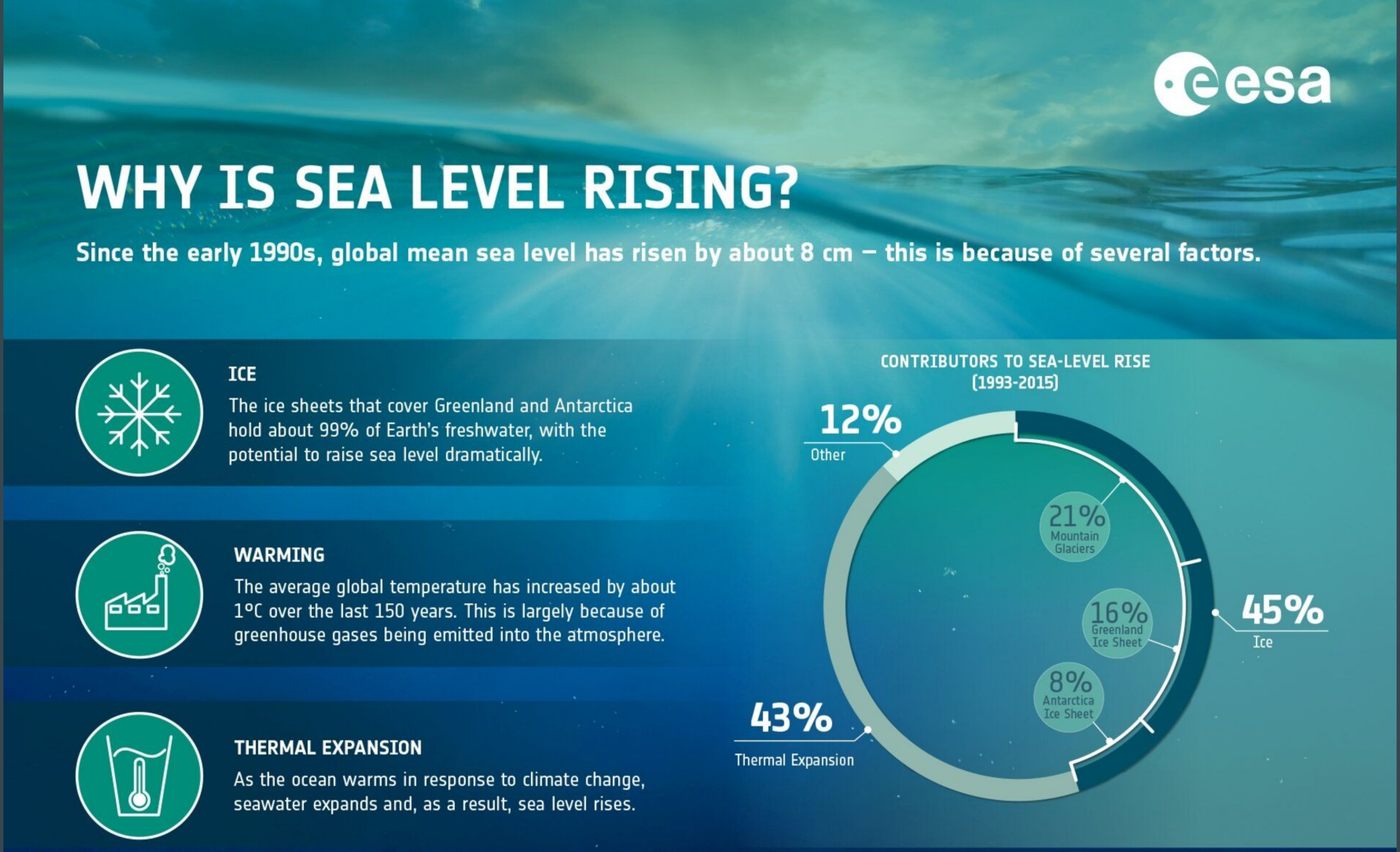
Outline

- Introduction to Sea Level Rise
- Introduction to Presentation and Framing
- High Mountain Areas
- Polar Regions
- Implications for Low-lying Islands, Coasts and Communities
- Changing Ocean, Marine Ecosystems and Dependent Communities
- Extremes, Abrupt Changes and Managing Risks
- Shared Socioeconomic Pathways and Conclusions

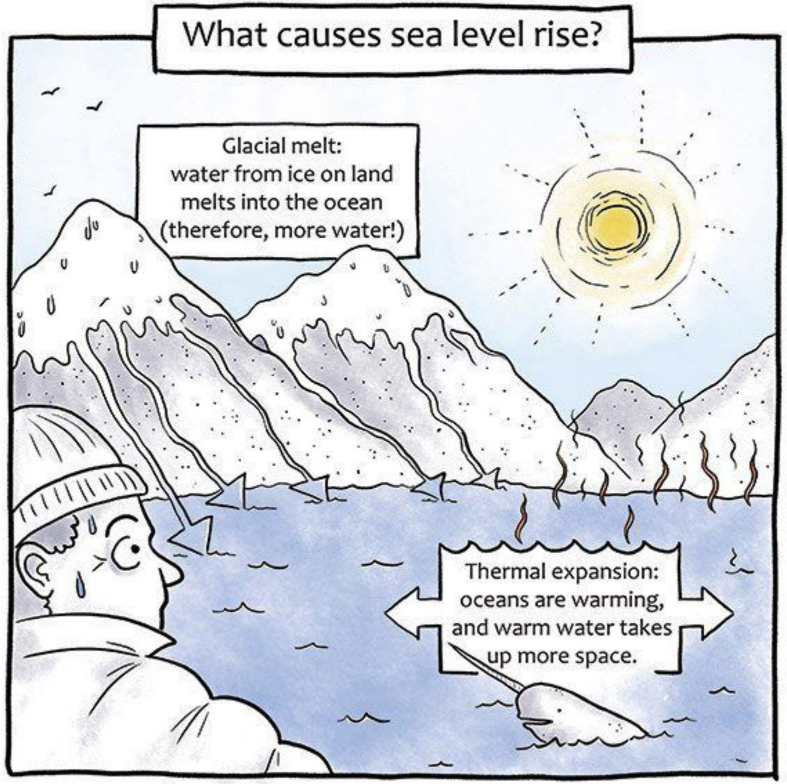

Introduction to Sea Level Rise



https://www.esa.int/ESA_Multimedia/Images/2020/09/Causes_of_sea-level_rise

2 main causes of sea level rise:

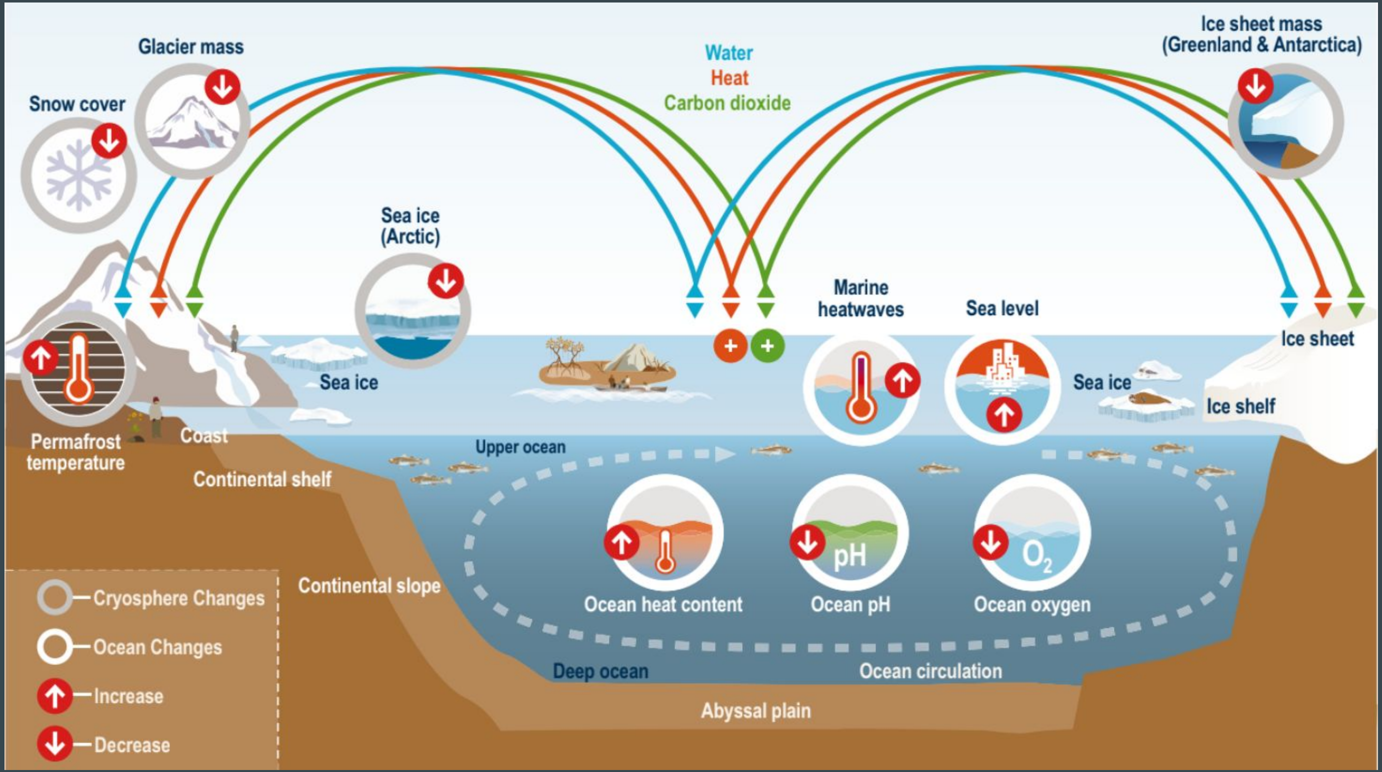
- Glacial melt
- Thermal expansion



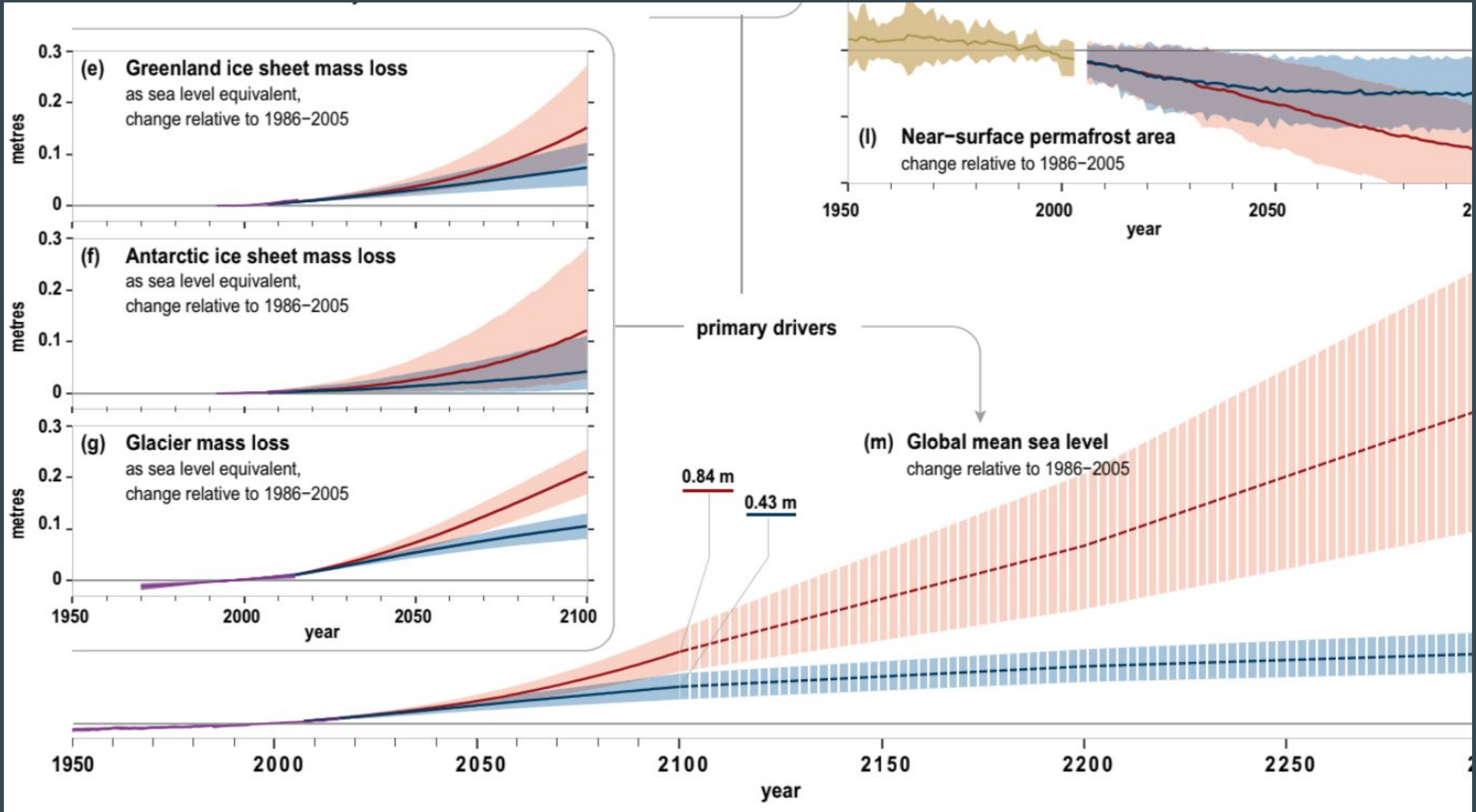
https://vancouver.ca/green-vancouver/sea-level-rise.aspx

Introduction to Presentation and Framing

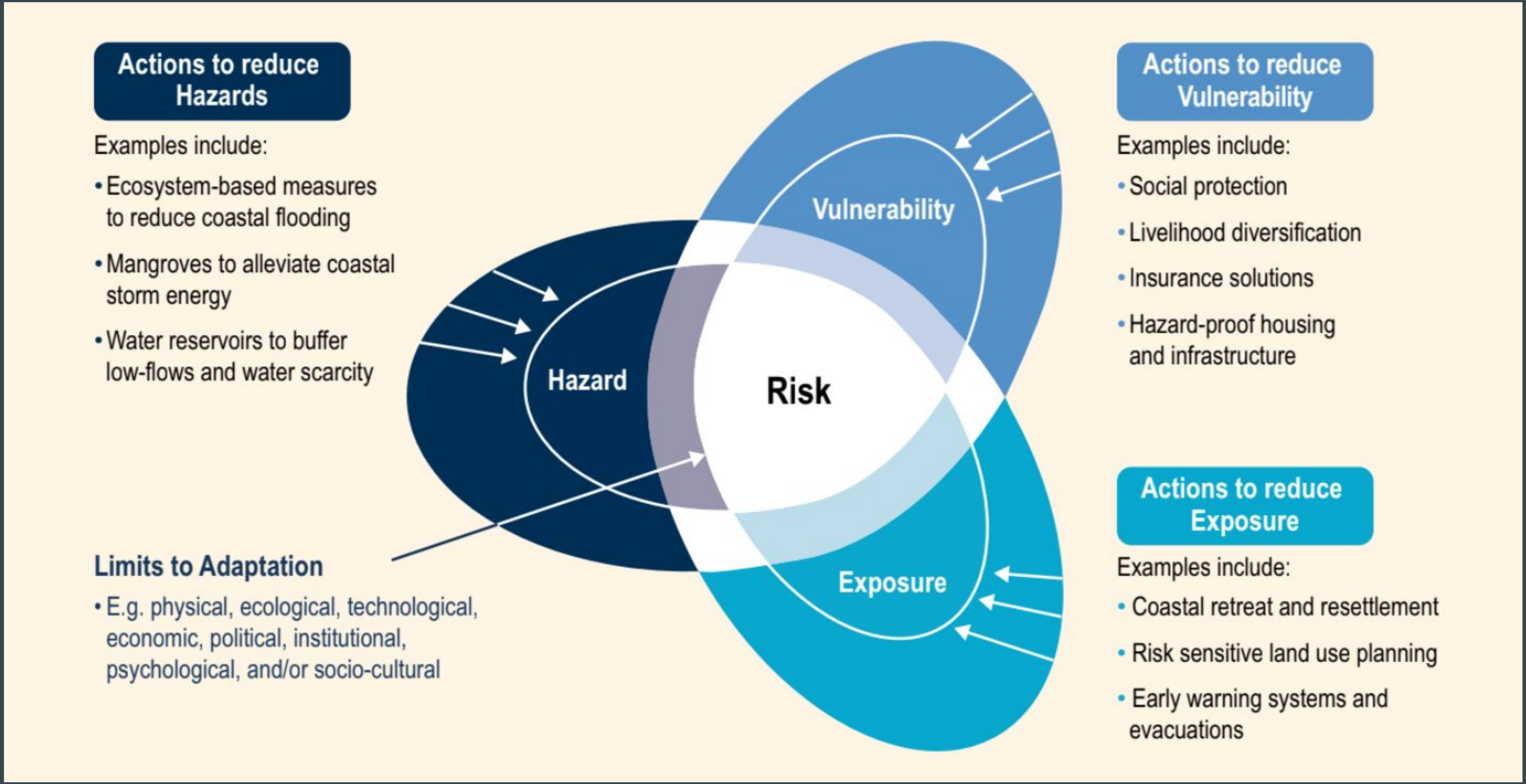
Cryosphere - why is it important



Current trends



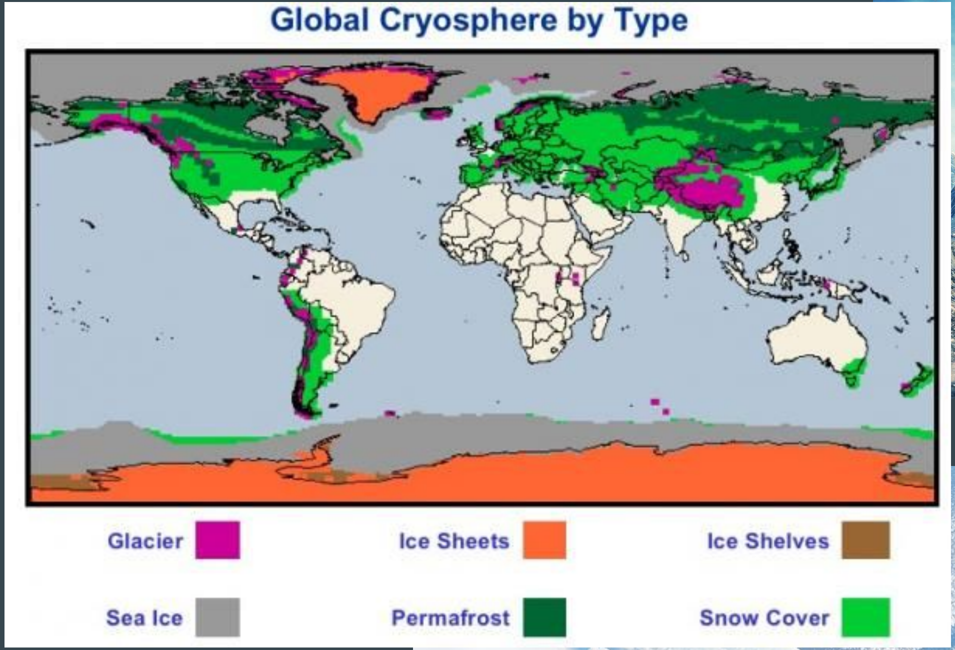
Ways of mitigation



High Mountain Areas

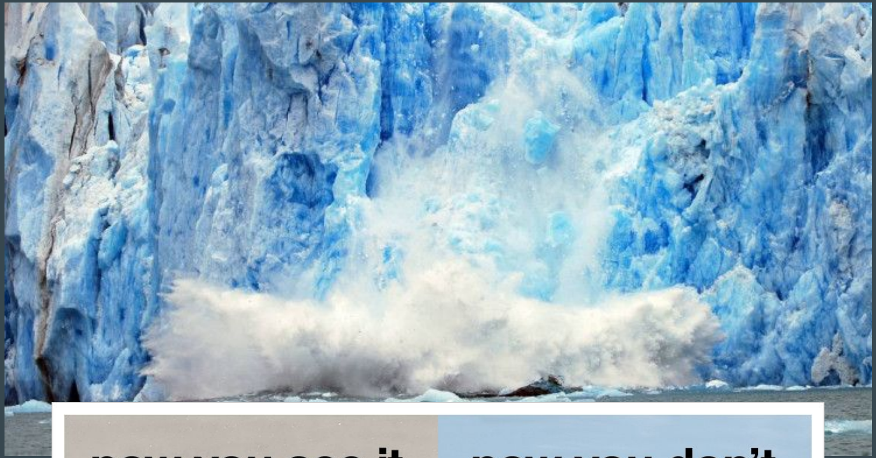
https://public.wmo.int/en/our-mandate/focus-areas/cryosphere

The cryosphere



Observations of cryospheri changes

https://interestingengineering.com/scary-video-shows-greenland-melting-glaciers-turned-into-a-charging-river



Further about observations

https://www.backpacker.com/gear/the-essential-mountaineering-gear-kit

Future projections of cryospheric changes

https://www.scientificamerican.com/article/why-are-glaciers-melting-from-the-bottom-its-complicated/

Further about changes

https://www.mvestnik.ru/newslent/razliv-reki-mozhet-podtopit-doma-v-belokamenke/

Enablers and response options

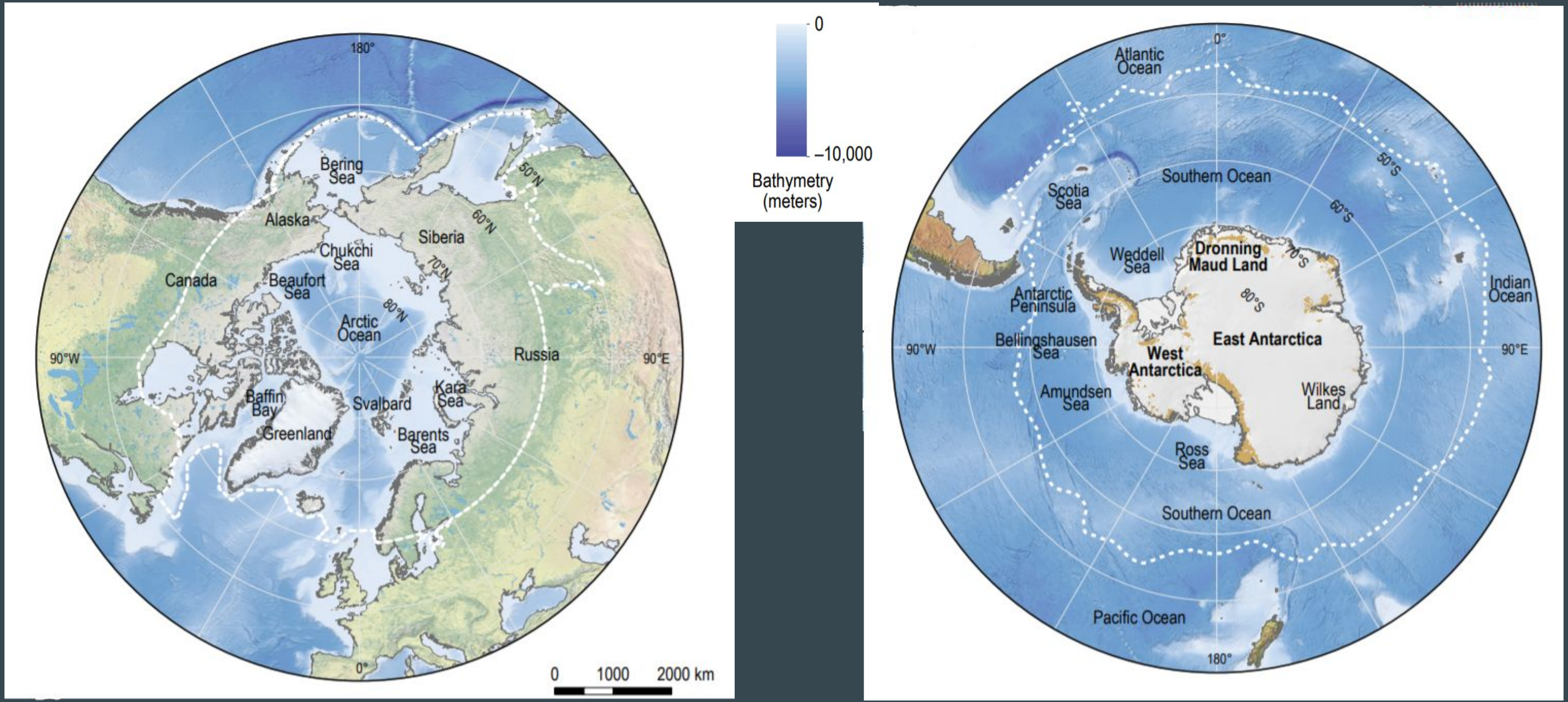
International cooperation

Effective hazards management and governance

Integrated water resources management

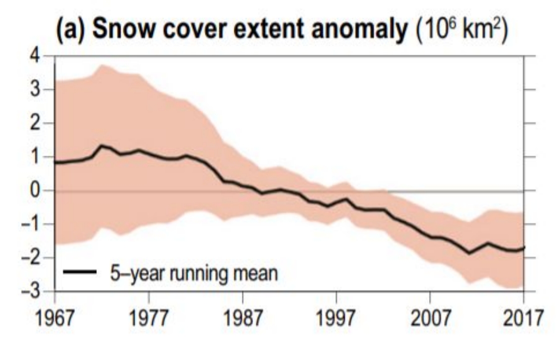
IWRM
Integrated Water Resources Management Research Group
Universiti Kebangsaan Malaysia

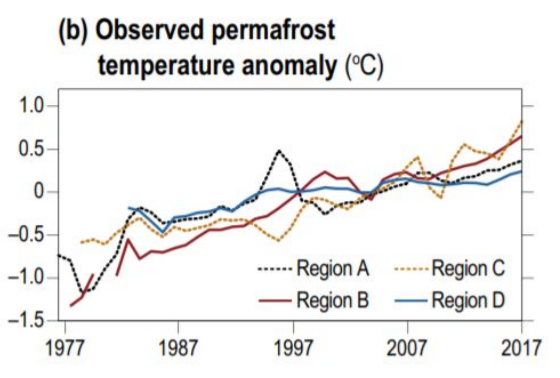
Polar Regions

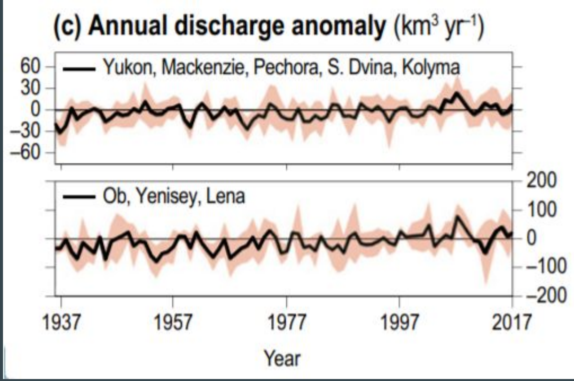


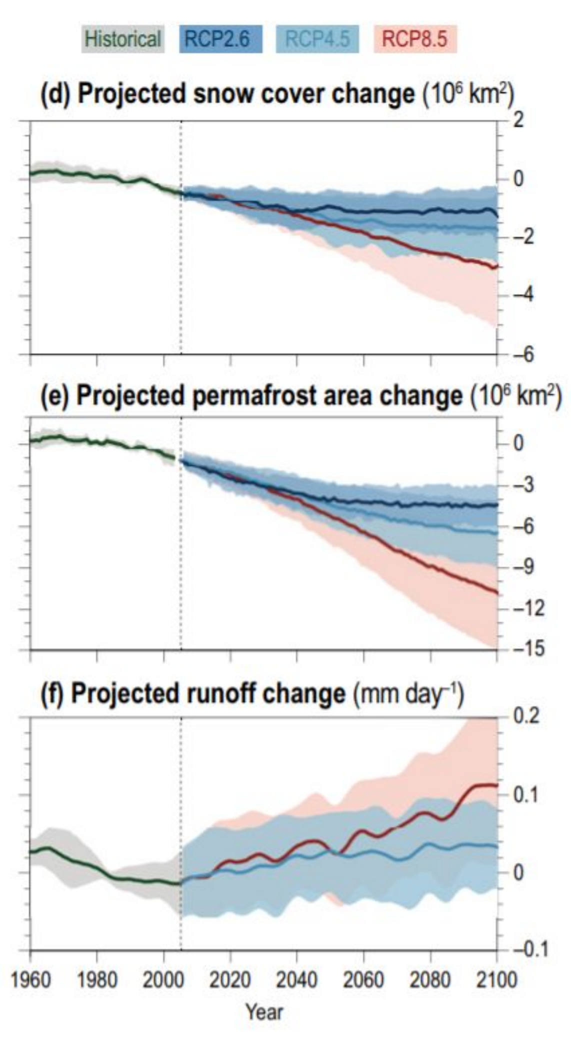
1. a vast share of the world's **ocean** and **cryosphere**
2. 20% of the **"global ocean"**
3. more than 90% of the world's continuous and discontinuous **"permafrost"** area
4. 69% of the world's **"glacier"** area including **"ice sheets"**, **"sea ice"**, and land areas with the most persistent winter "**snow cover"**

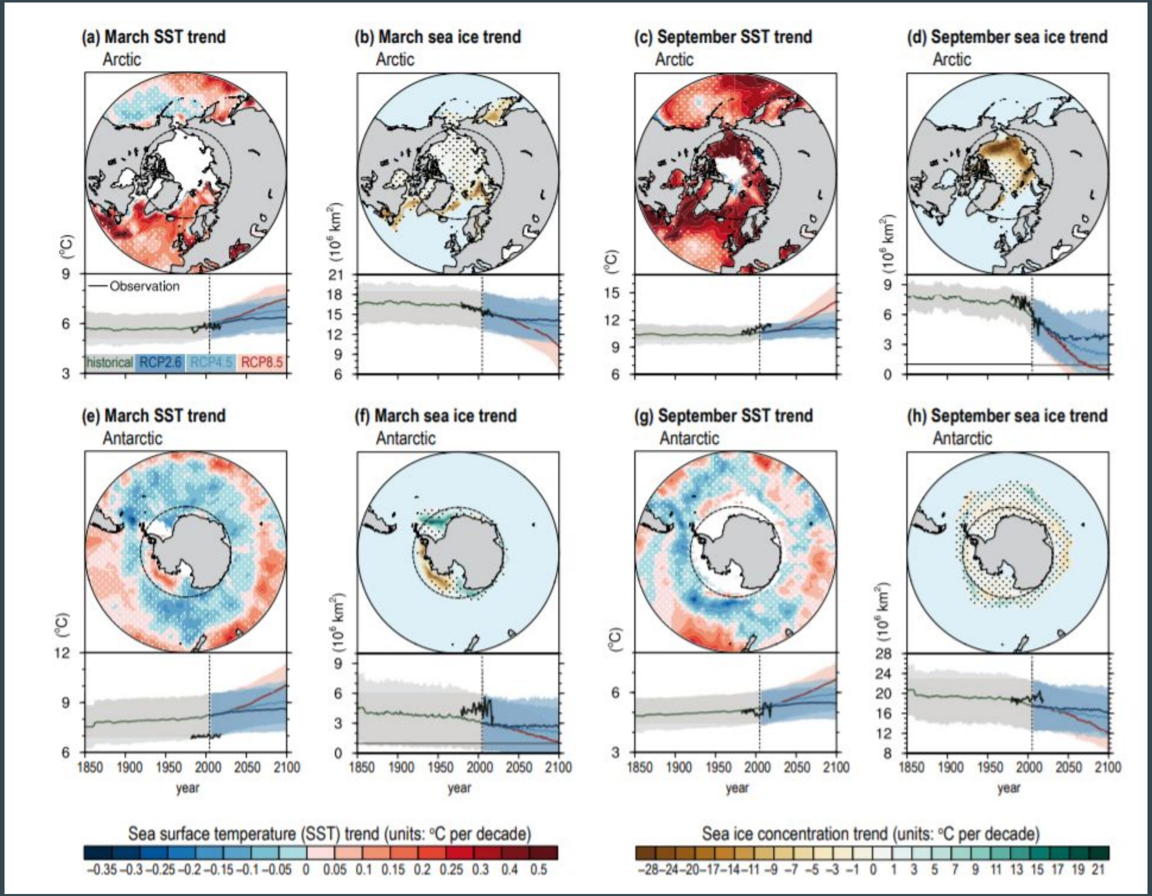
Physical Changes and Projections











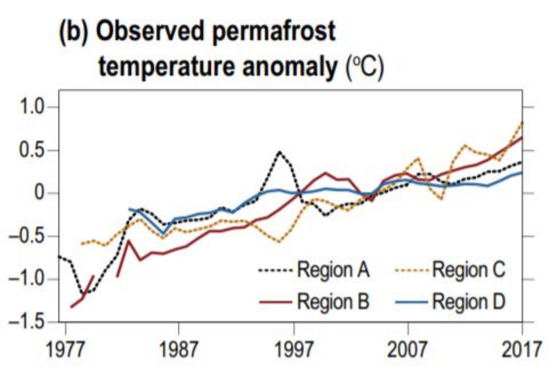
Arctic sea ice → declines **all months**; (very high confidence)

Mostly → in **September**

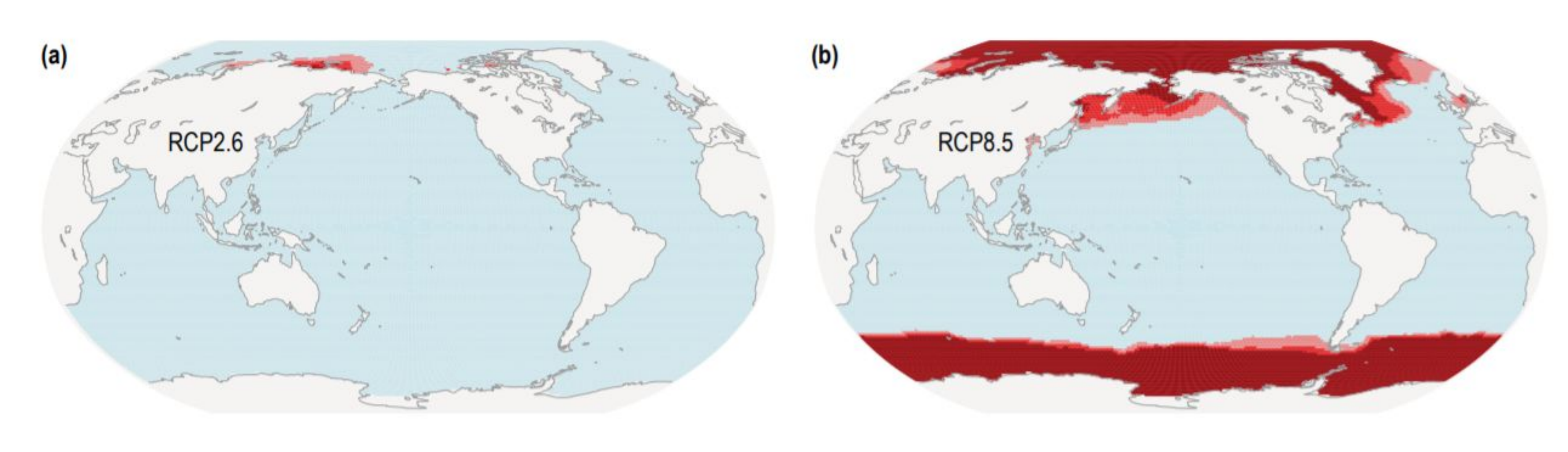
(very likely **–12.8 ± 2.3% per decade**; 1979–2018) are unprecedented in at least 1000 years (medium confidence)

SST: Sea Surface Temperature

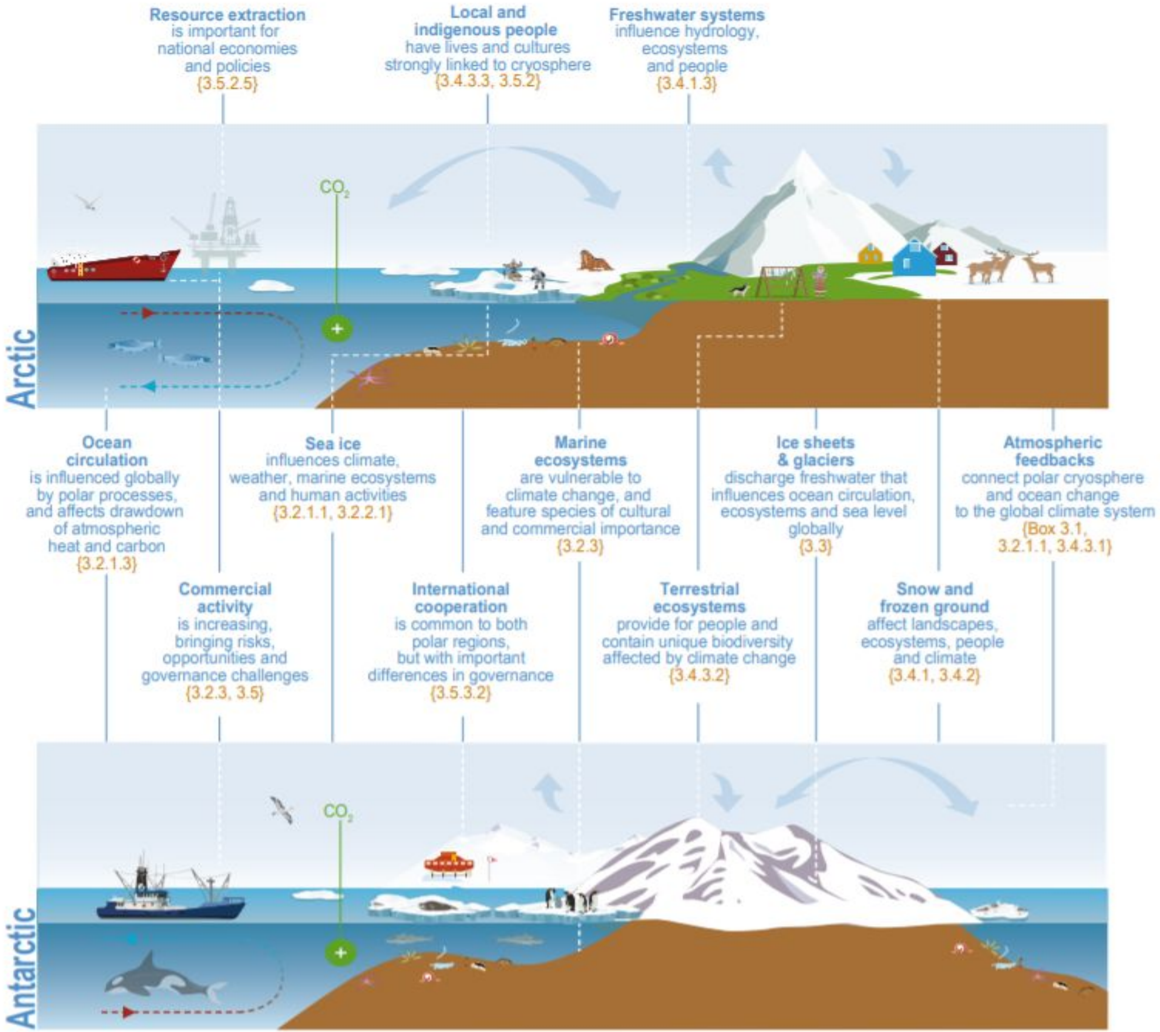
Permafrost



- Permafrost temperature increase
- Disappearance of Arctic near-surface permafrost
- Effects of permafrost on vegetation, human infrastructure and ecology

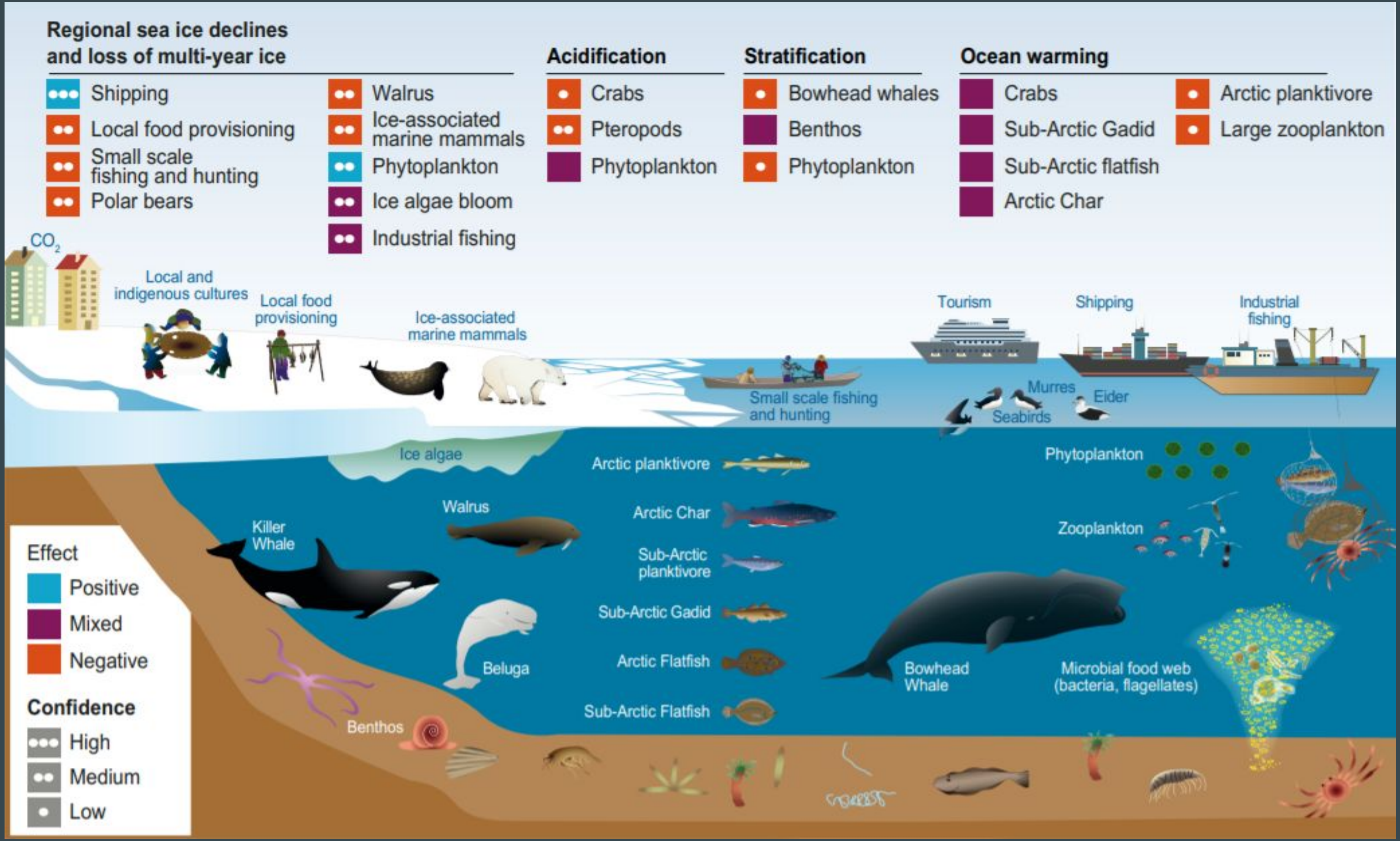


The upper ocean (0–10 m) at end of this century (2081–2100), characterised by year-round **undersaturated conditions for aragonite** for the Representative Concentration Pathway (RCP)8.5 (a) and RCP2.6 (b) scenarios in the Coupled Model Intercomparison Project Phase 5 (CMIP5)

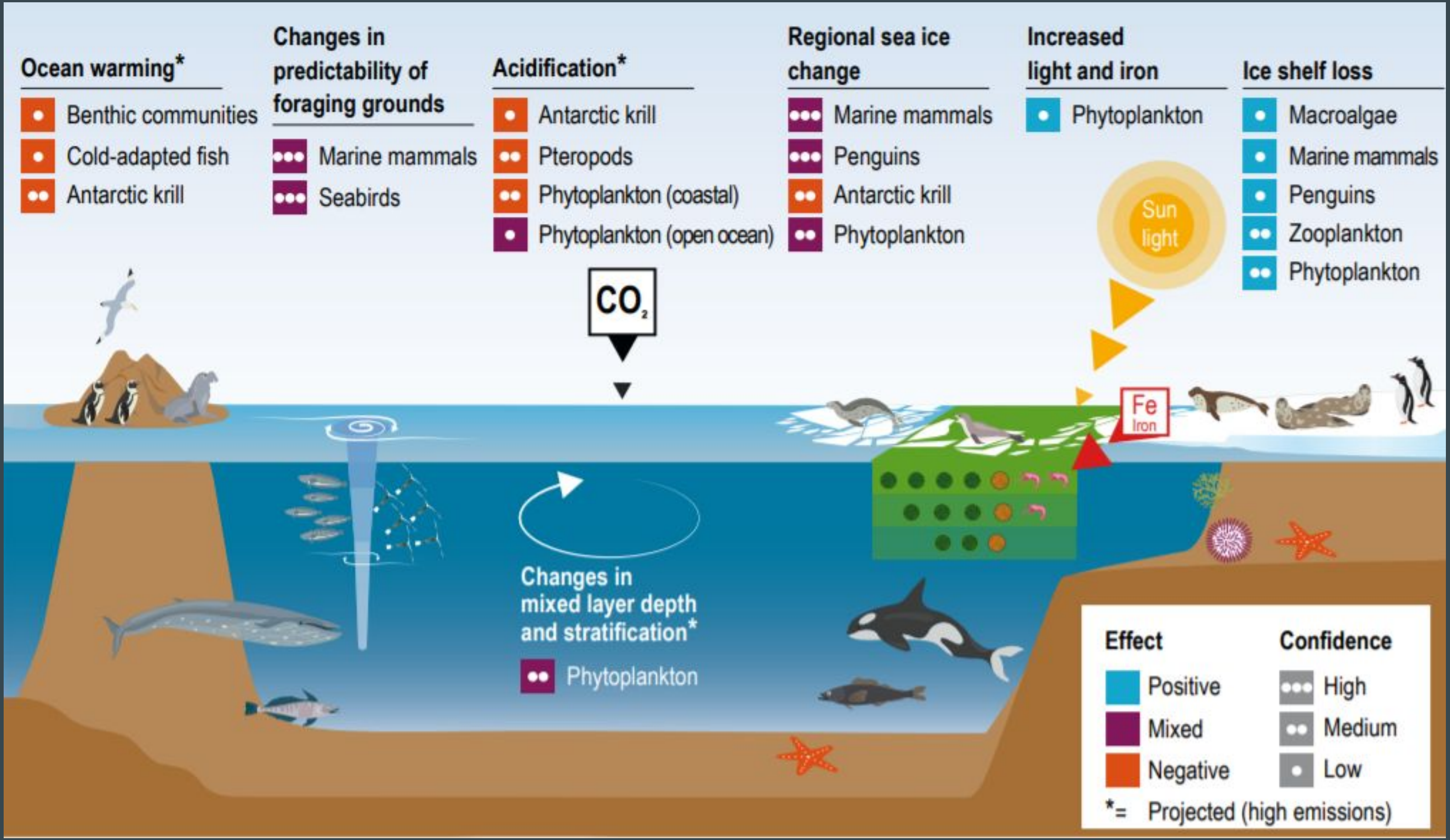


Resource extraction is important for national economies and policies {3.5.2.5}
Local and indigenous people have lives and cultures strongly linked to cryosphere {3.4.3.3, 3.5.2}
Freshwater systems influence hydrology, ecosystems and people {3.4.1.3}
CO2
Arctic
Ocean circulation is influenced globally by polar processes, and affects drawdown of atmospheric heat and carbon {3.2.1.3}
Sea ice influences climate, weather, marine ecosystems and human activities {3.2.1.1, 3.2.2.1}
Marine ecosystems are vulnerable to climate change, and feature species of cultural and commercial importance {3.2.3}
Ice sheets & glaciers discharge freshwater that influences ocean circulation, ecosystems and sea level globally {3.3}
Atmospheric feedbacks connect polar cryosphere and ocean change to the global climate system {Box 3.1, 3.2.1.1, 3.4.3.1}
Commercial activity is increasing, bringing risks, opportunities and governance challenges {3.2.3, 3.5}
International cooperation is common to both polar regions, but with important differences in governance {3.5.3.2}
Terrestrial ecosystems provide for people and contain unique biodiversity affected by climate change {3.4.3.2}
Snow and frozen ground affect landscapes, ecosystems, people and climate {3.4.1, 3.4.2}
CO2
Antarctic

Schematic summary of key drivers that are causing, or are projected to cause, direct effects on Arctic marine ecosystems



Schematic summary of key drivers that are causing or are projected to cause direct effects on Southern Ocean marine ecosystems

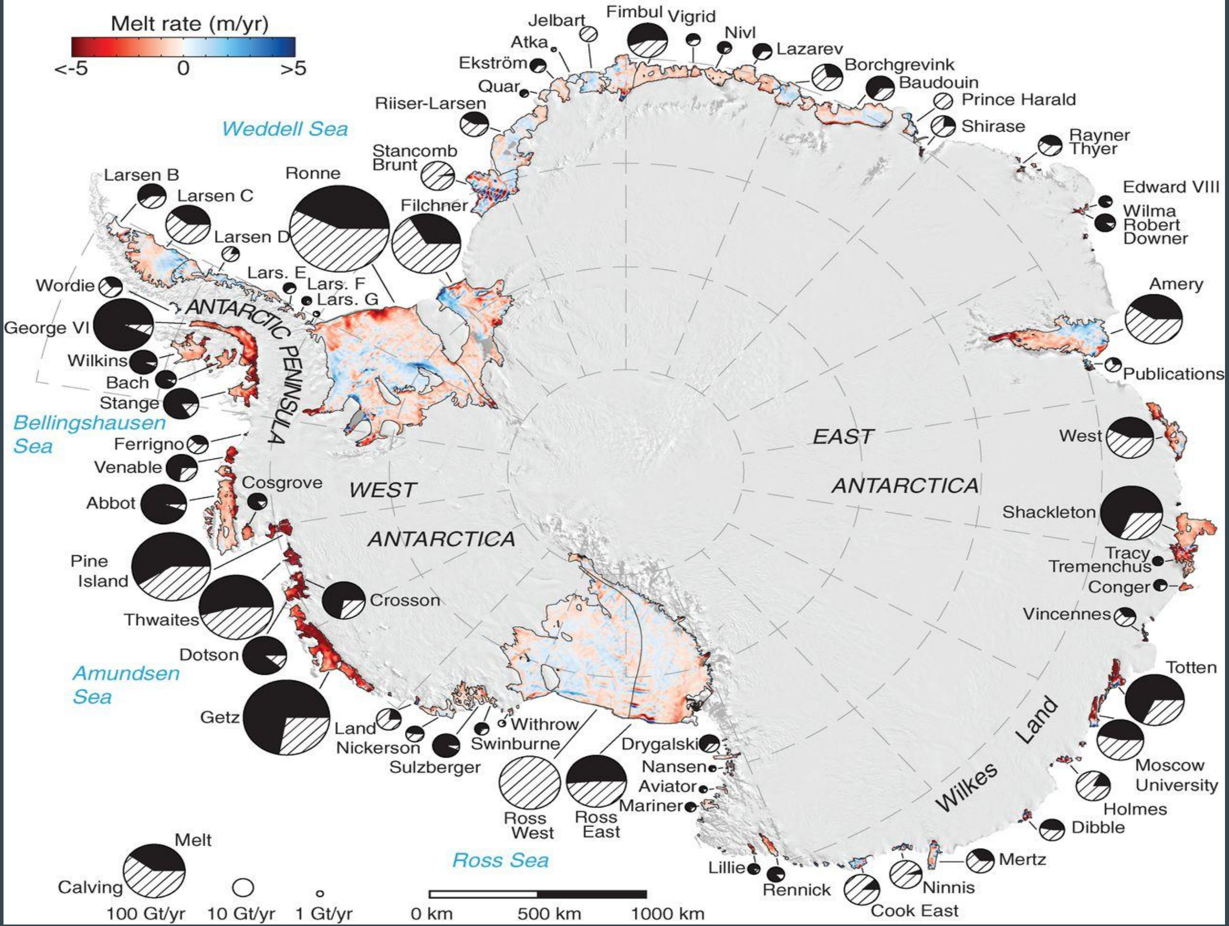


Type of resilience-building activity	Practices, tool, or strategy	Potential extent of contribution to resilience building (Large / Moderate / Limited) and Areas of potential contributions to resilience: DIV = Maintain diversity & redundancy; CON = Manage connectivity; PAR = Broaden participation; LEA = Encourage learning & experimentation; SYS = Foster complex system understanding; GOV = Enhance polycentric governance; SLO = Manage slow variables and feedbacks. Confidence regarding potential contribution to resilience building: ●●● = high ●● = medium ● = low	Current level of application in polar regions (High / Medium / Low) and Key conditions facilitating implementation: F = Financial support; I = Institutional support; T&S = Technical and science support; L&I = Local & indigenous capacity and knowledge; C = Interdisciplinary and/or cross-cultural cooperation
Knowledge Co-Production and Integration	**Community-based monitoring**	(Moderate) DIV, PAR, SYS ●●	(Medium) F, I, T&S, L&I, C
	Understanding regime shifts	(Large) LEA, SYS, SLO ●●●	(Low) I, T&S, C
	Indicators of resilience and adaptive capacity	(Moderate) PAR, LEA, SYS, SLO ●●	(Low) F, L&I, T&S
Linking Knowledge with Decision Making	**Participatory scenario analysis and planning**	(Limited) PAR, LEA, SYS ●●	(High) T&S, L&I, C
	Structured decision making	(Limited) PAR, LEA, SYS ●	(Low) I, T&S, C
Resilience-based Ecosystem Stewardship	**Adaptive ecosystem governance**	(Large) DIV, PAR, LEA, SYS, GOV, SLO ●●●	(Medium) I, T&S, L&I, C
	Spatial planning for biodiversity	(Moderate) DIV, CON, GOV, SLO ●●	(Low) I, T&S, L&I, C
	Linking ecosystem services with human livelihoods	(Large) DIV, PAR, SYS, GOV, SLO ●●●	(Low) I, T&S, L&I, C

Implications for Low-lying Islands, Coasts and Communities

Processes of Sea Level Change

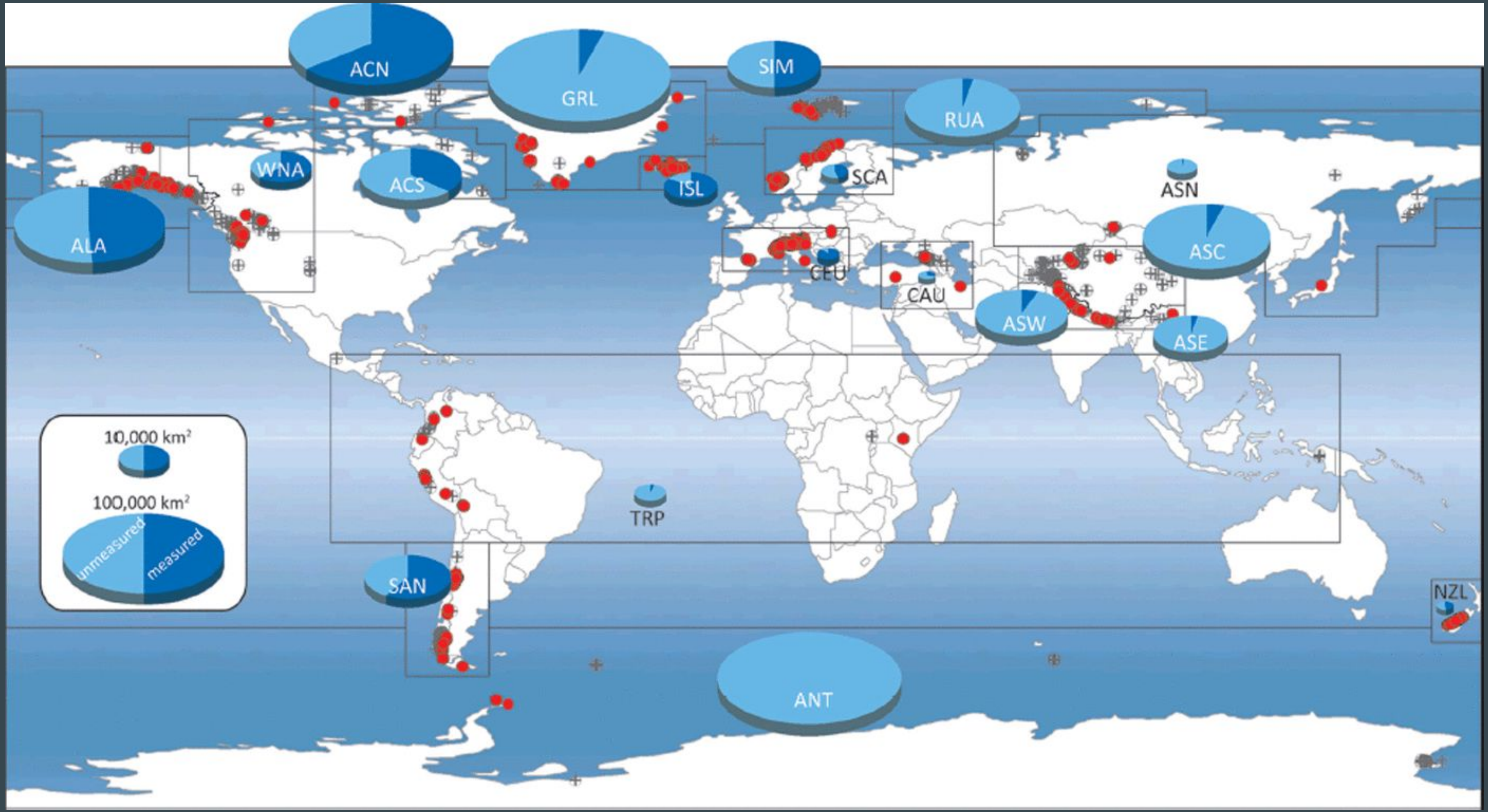
1. Ice Sheets and Ice Shelves



Basal melt rates of Antarctic ice shelves

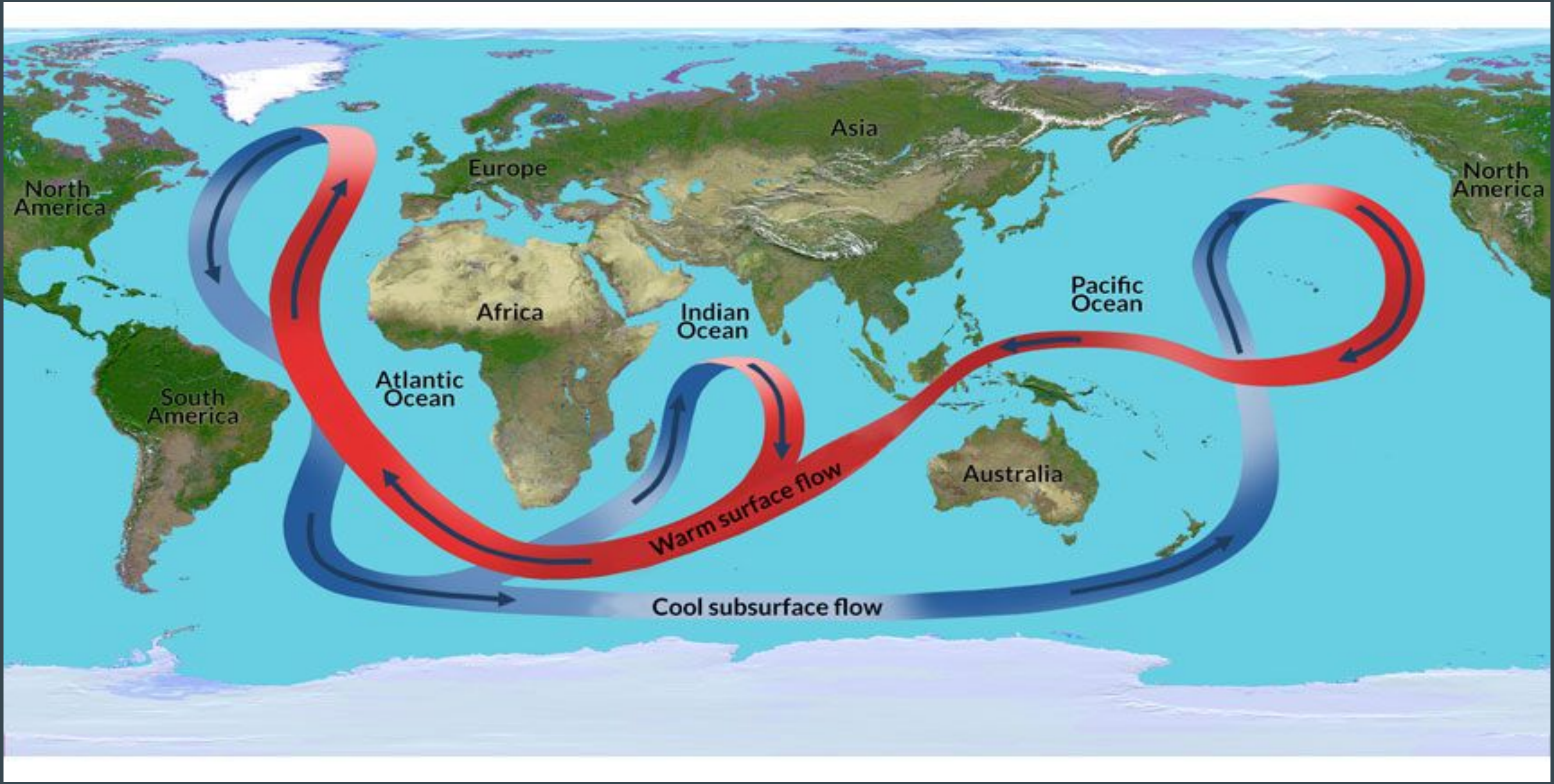
Rignot, E. & Jacobs, S. & Mouginot, Jeremie & Scheuchl, B. (2013). Ice-Shelf Melting Around Antarctica. Science (New York, N.Y.). 341. 10.1126/science.1235798

2. Glaciers



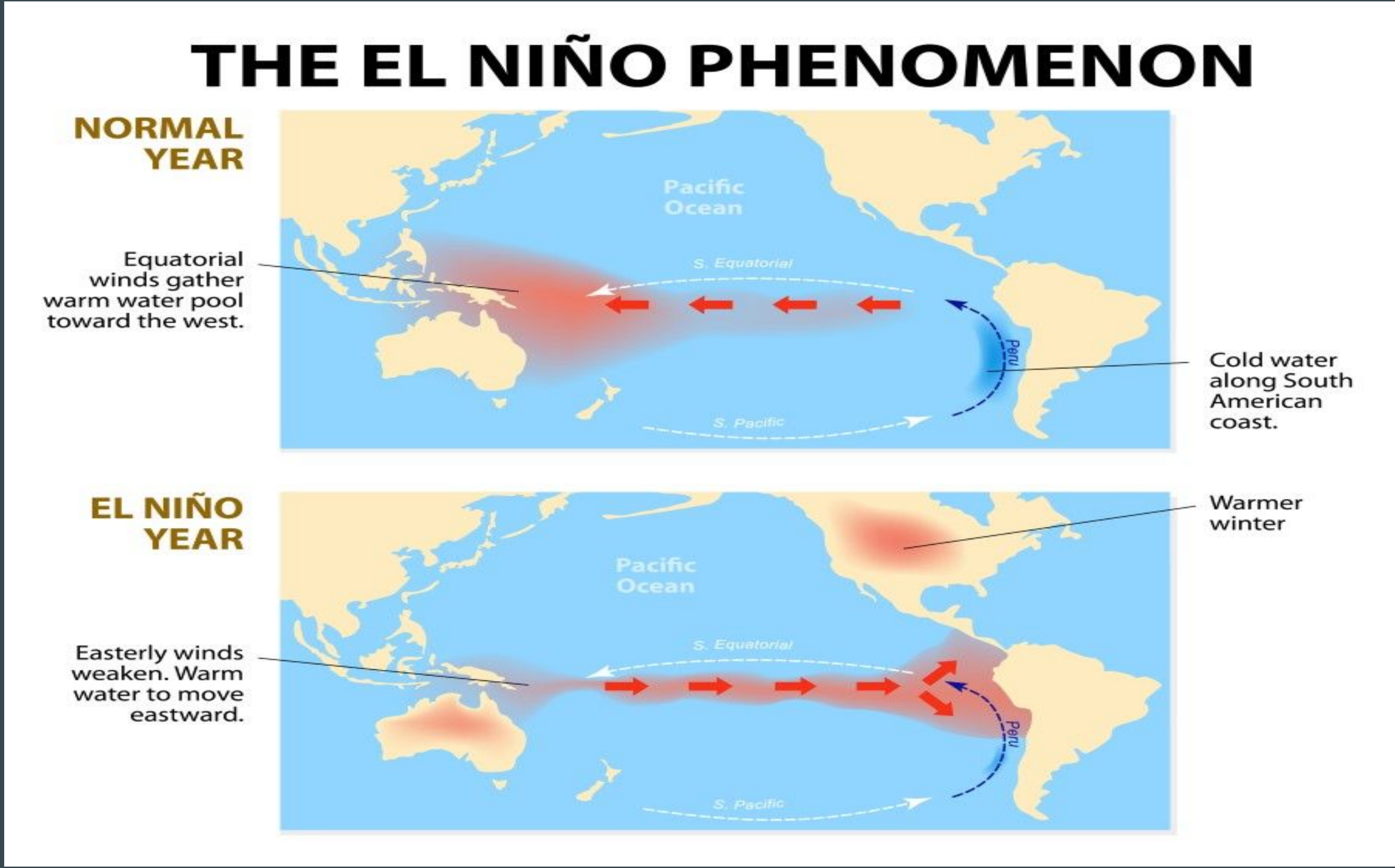
Zemp, M. & Frey, Holger & Gärtner-Roer, Isabelle & Nussbaumer, Samuel & Hoelzle, Martin & Paul, Frank & Haeberli, Wilfried & Denzinger, Florian & m, Andreas & Anderson, Brian & Bajracharya, Samjwal & Baroni, Carlo & Braun, Ludwig & Cáceres, Bolívar & Casassa, Gino & Cobos, Guillermo & Davila, Luzmila & Delgado Granados, Hugo & Demuth, Michael & Vincent, Christian. (2015). Historically unprecedented global glacier decline in the early 21st century. Journal of Glaciology. 61. 745-762. 10.3189/2015JoG15J017.

3. Ocean Processes



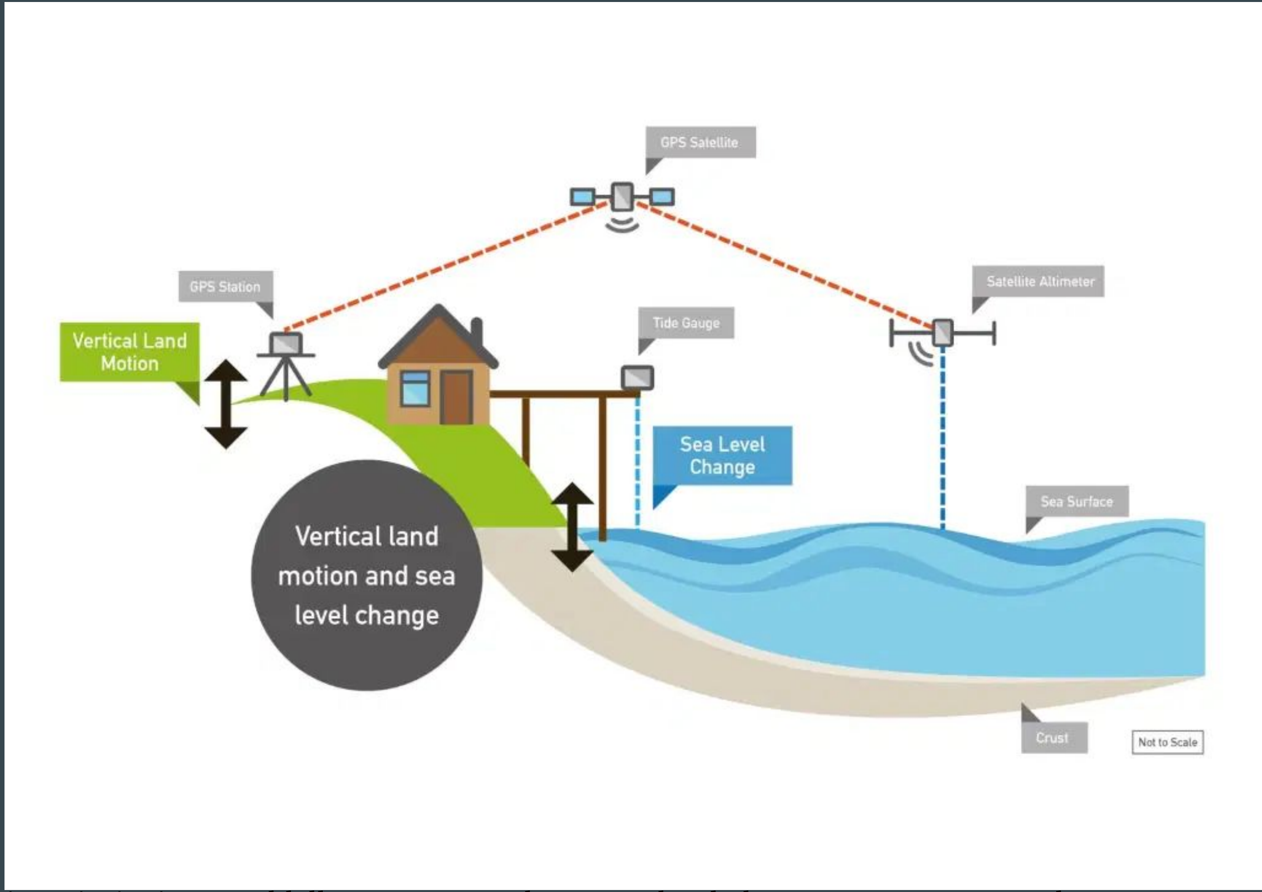
Ocean currents ferry warm and cool water around the globe. The Atlantic Ocean current boosts temperatures in northwestern Europe. But rising levels of carbon dioxide in the atmosphere could shut these warming currents down.

4. Terrestrial Reservoirs



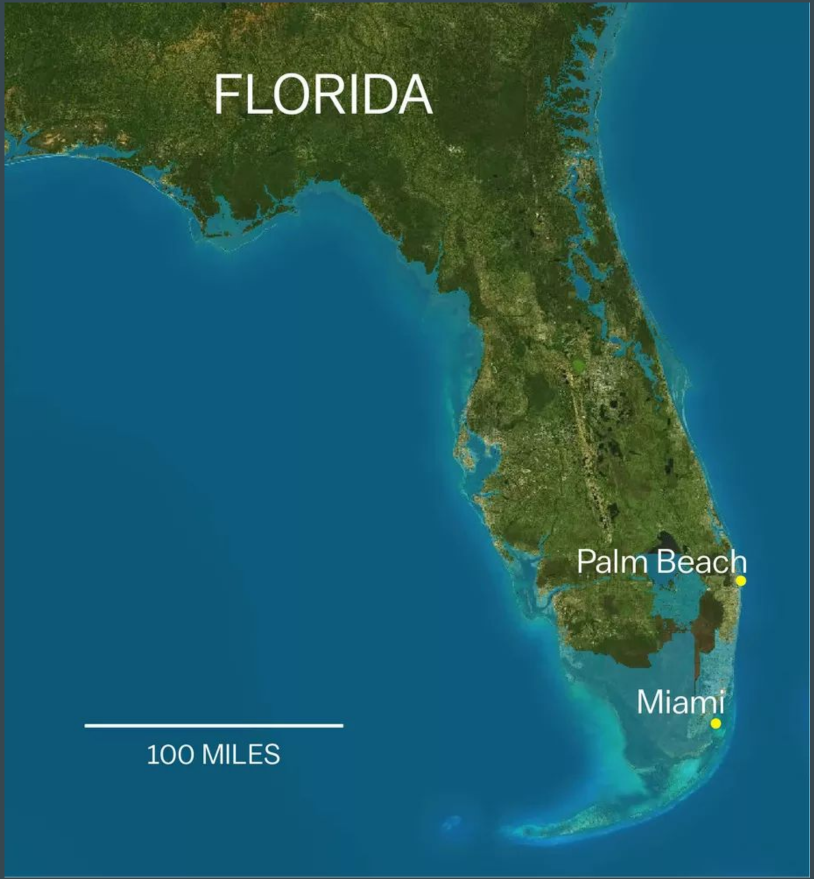
https://www.wonderopolis.org/wonder/what-is-el-nino

5. Geodynamic Processes

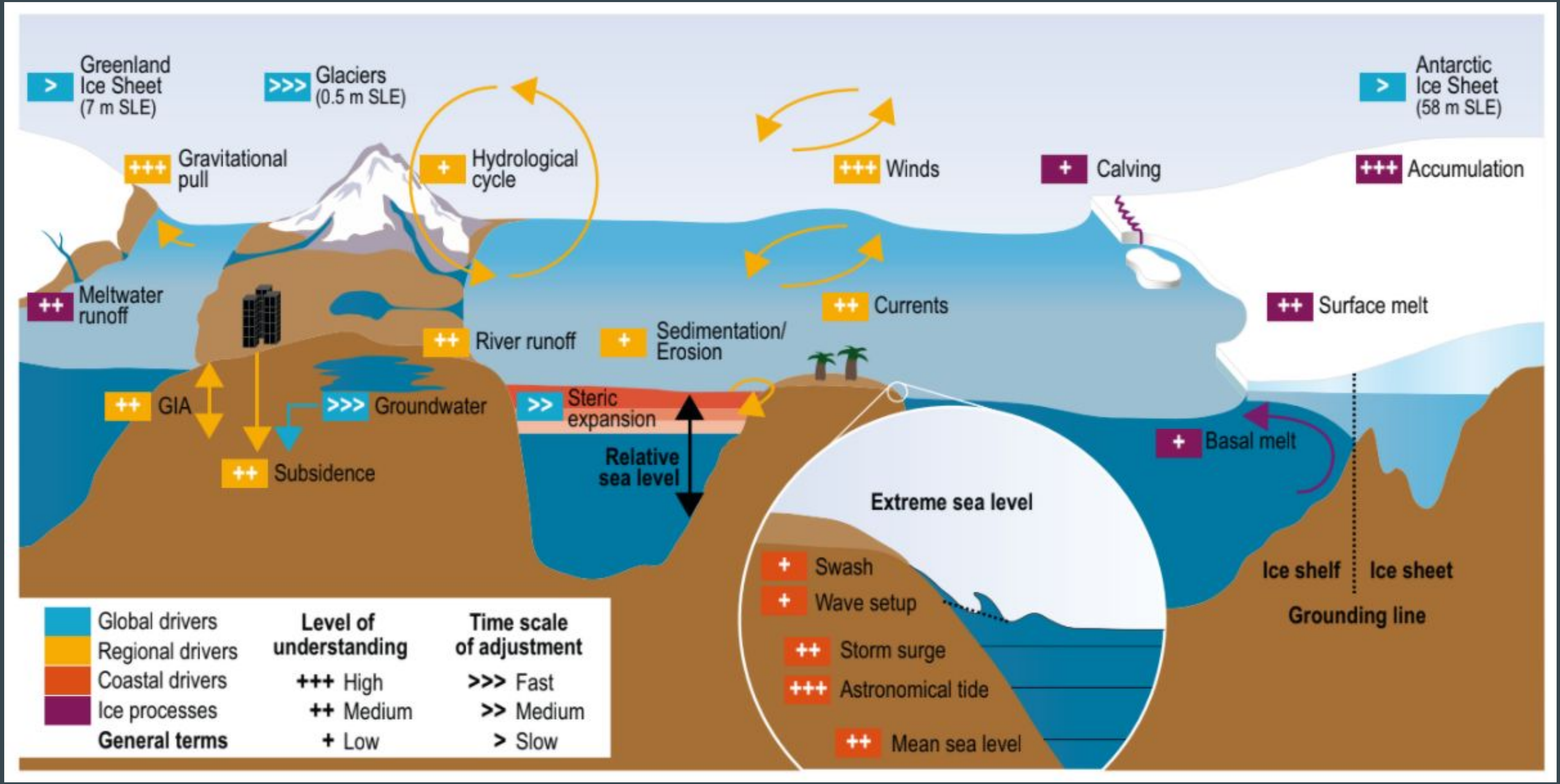


https://geohipster.com/2018/01/29/anna-riddell-monitoring-relative-sea-level-change-accounting-wiggle-centre-e
arth/

6. Extreme Sea Level Events



Florida, USA by 2100

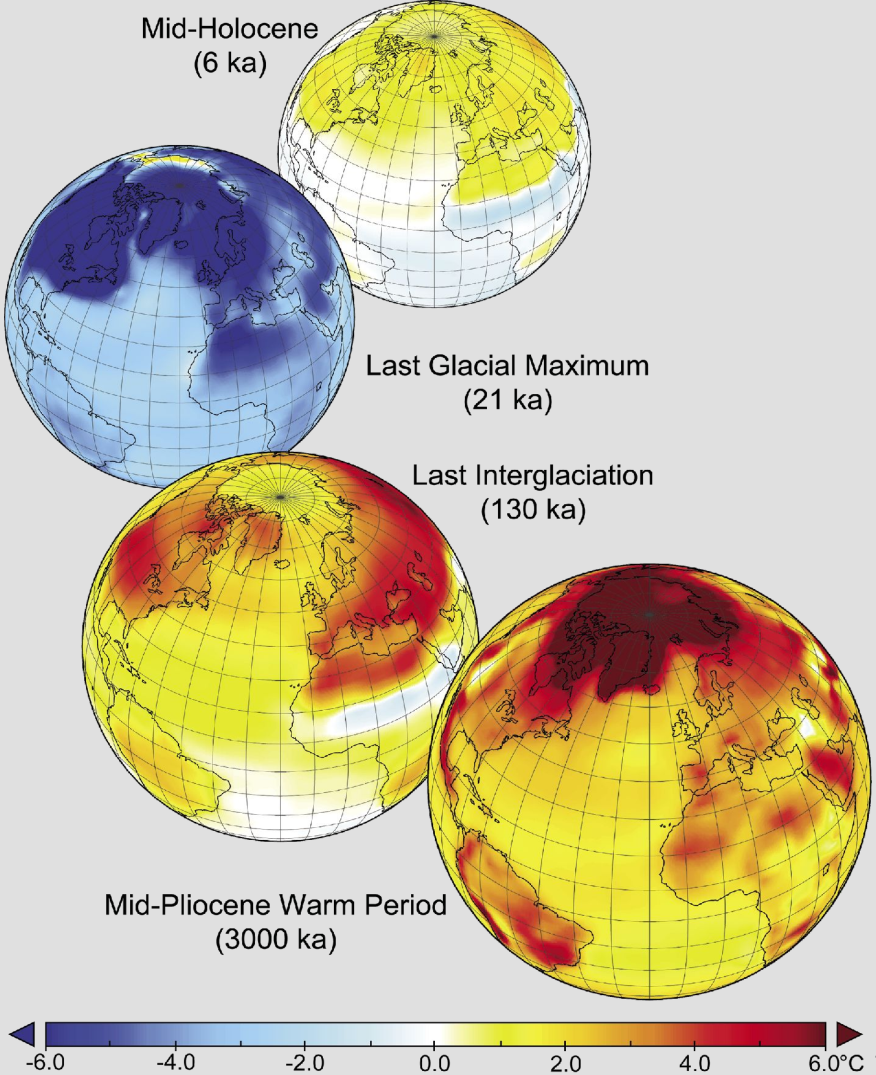


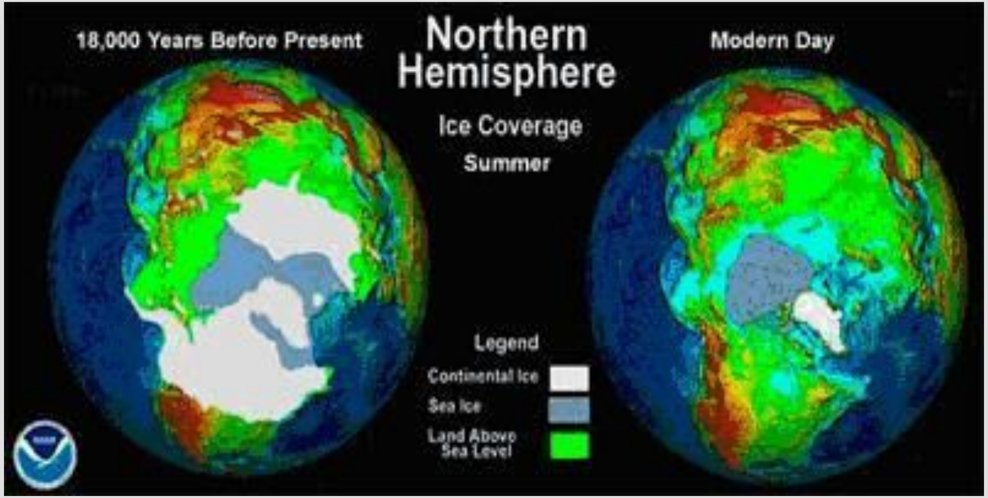
A schematic illustration of the climate and non-climate driven processes that can influence global, regional , relative and extreme sea level (ESL) events along coasts.

OBSERVATIONS

Source	1901–1990	1970–2015	1993–2015	2006–2015
Observed contribution to GMSL rise				
Thermal expansion		0.89 (0.84–0.94) [a]	1.36 (0.96–1.76) [a]	1.40 (1.08–1.72)[a]
Glaciers except in Greenland and Antarctica	0.49 (0.34–0.64)[b]	0.46 (0.21–0.72)[o]	0.56 (0.34–0.78) [p]	0.61 (0.53–0.69)[n]
GIS including peripheral glaciers	0.40 (0.23–0.57)[c]		0.46 (0.21–0.71)[d]	0.77 (0.72–0.82)[d]
Antarctica ice sheet including peripheral glaciers			0.29 (0.11–0.47)[e]	0.43 (0.34–0.52)[e]
Land water storage	–0.12[f]	–0.07[f]	0.09[f]	–0.21 (–0.36–0.06)[g]
Ocean mass				2.23 (2.07–2.39)[h]
Total contributions			**2.76 (2.21–3.31)**[i]	**3.00 (2.62–3.38)**[i]
Observed GMSL rise from tide gauges and altimetry	**1.38 (0.81–1.95)**	**2.06 (1.77–2.34)**[j]	**3.16 (2.79–3.53)**[k]	**3.58 (3.10–4.06)**[k]
Modelled contributions to GMSL rise				
Thermal expansion	0.32 (0.04–0.60)	0.97 (0.45–1.48)	1.48 (0.86–2.11)	1.52 (0.96–2.09)
Glaciers	0.53 (0.38–0.68)	0.73 (0.50–0.95)	0.99 (0.60–1.38)	1.10 (0.64–1.56)
Greenland SMB	–0.02 (–0.05–0.02)	0.03 (–0.01–0.07)	0.08 (–0.01–0.16)	0.12 (–0.02–0.26)
Total including land water storage and ice discharge [l]	0.71 (0.39–1.03)	1.88 (1.31–2.45)	3.13 (2.38–3.88)	3.54 (2.79–4.29)
Residual with respect to observed GMSL rise[m]	**0.67 (0.02–1.32)**	**0.18 (–0.46–0.82)**	**0.03 (–0.81–0.87)**	**0.04 (–0.85–0.93)**

Global mean sea level (GMSL) budget over different periods from observations and from climate model base contributions. All values are in mm yr–1.





Multi-model mean summer (JJA) warming in the main Paleoclimate Model Intercomparison Project (PMIP3) equilibrium time periods, mid-Holocene, Last Glacial Maximum (Braconnot et al. 2012), Last Interglacial (Lunt et al. 2012) and the mid-Pliocene Warm period (Haywood et al. 2012).

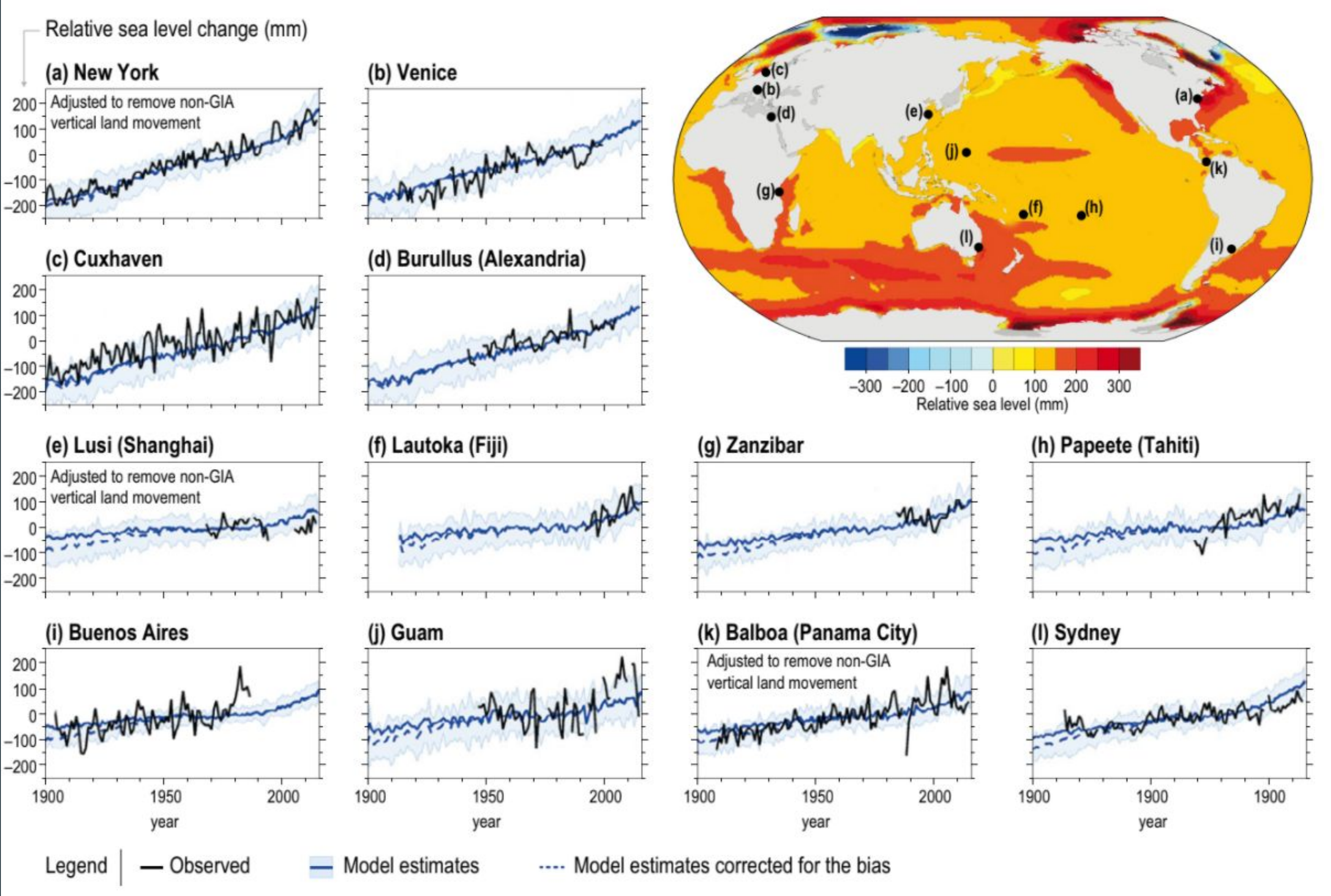
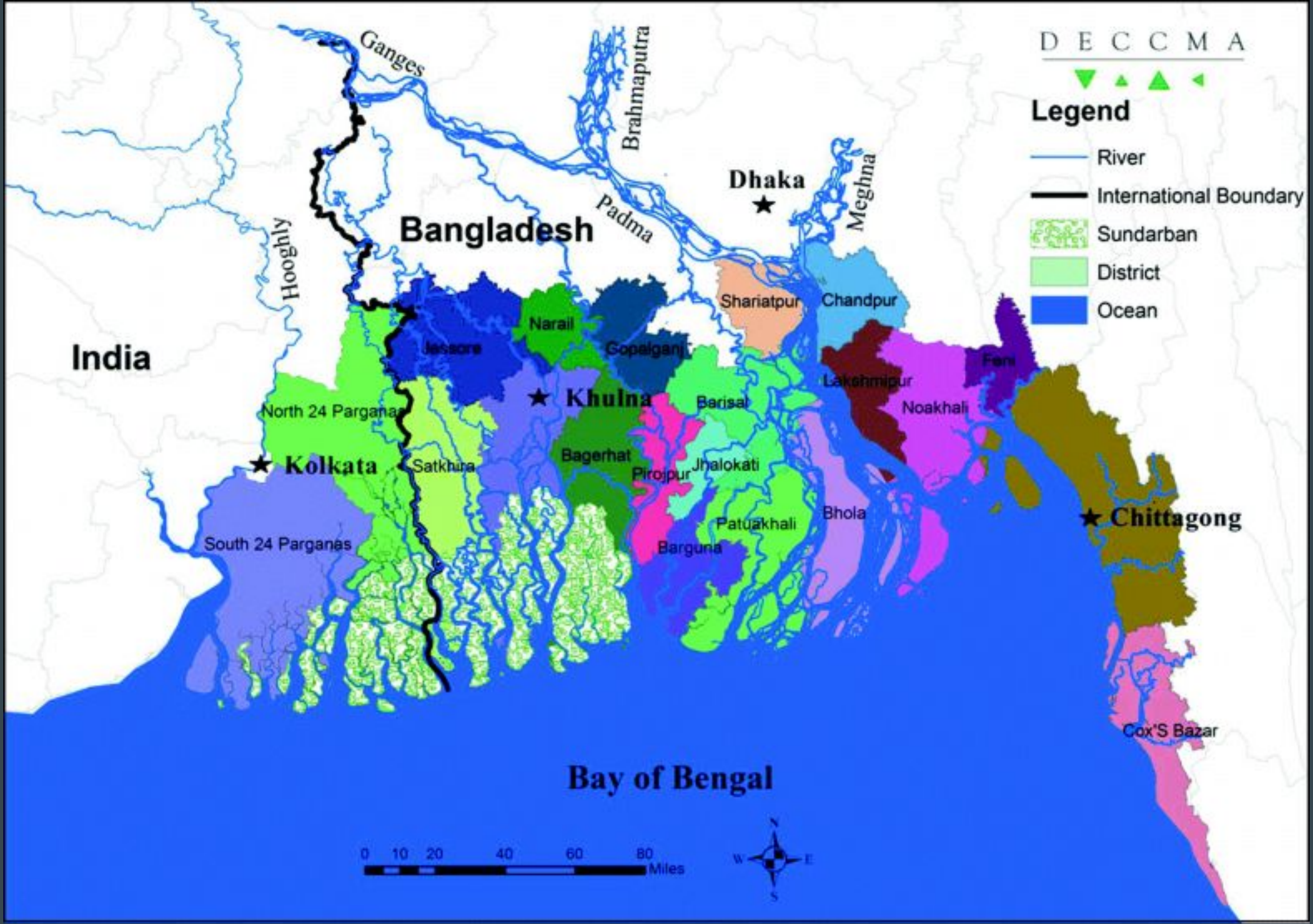
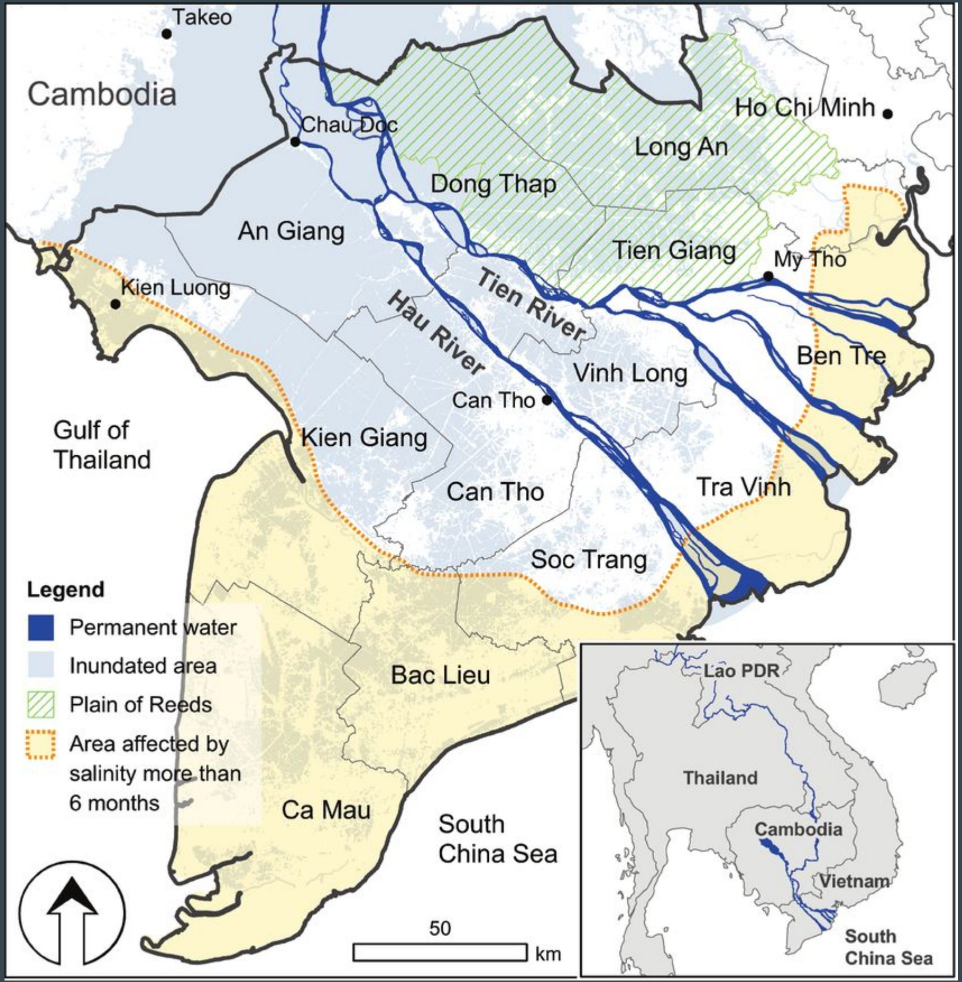


Fig. 20th century simulated regional sea level changes by coupled climate models and comparison with a selection of local tide gauge time series.



Ganges-Brahmaputra-Meghna Delta

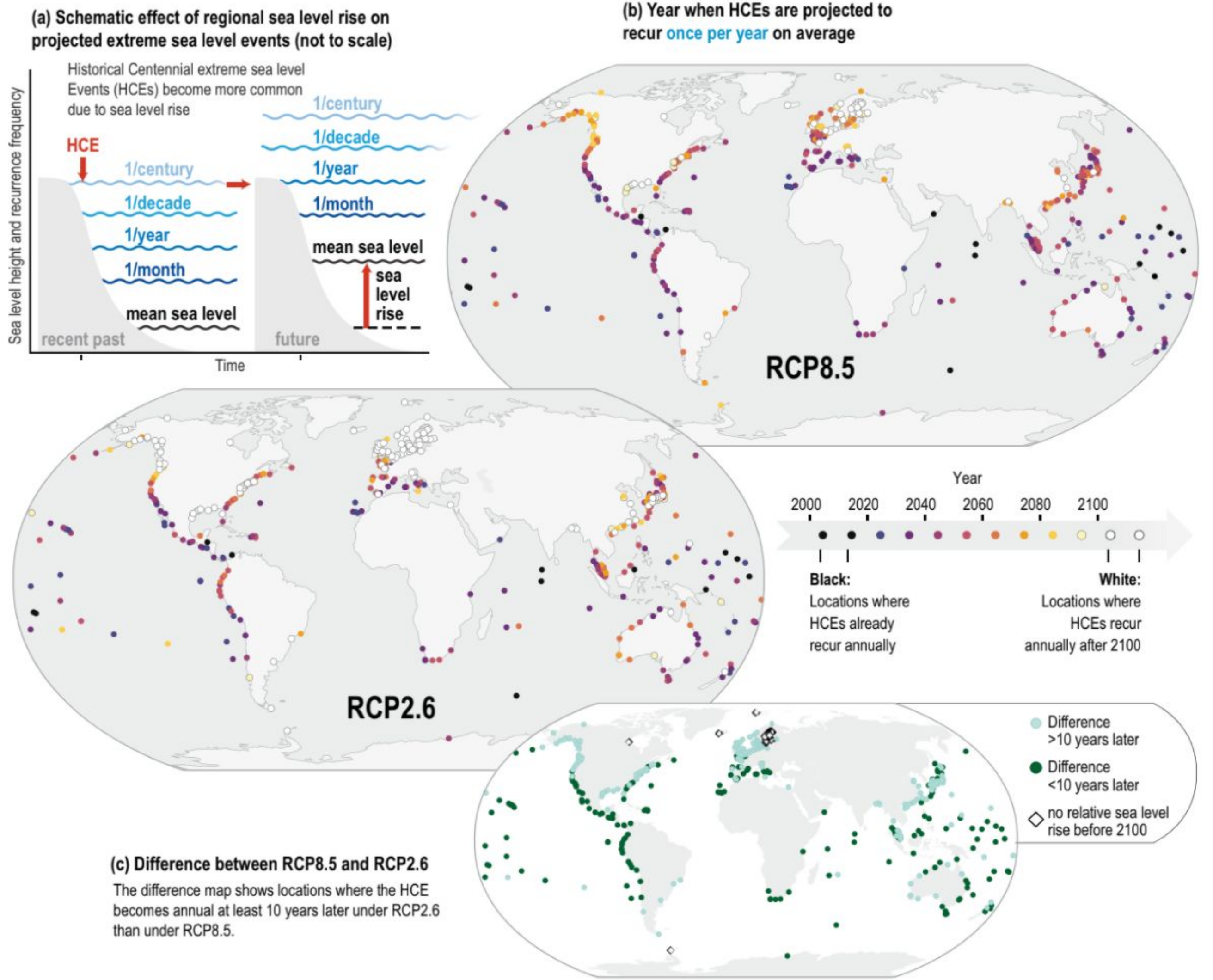


Mekong Delta

PROJECTIONS

	RCP2.6	RCP4.5	RCP8.5	Comments
Thermal expansion	0.14 (0.10–0.18)	0.19 (0.14–0.23)	0.27 (0.21–0.33)	AR5
Glaciers	0.10 (0.04–0.16)	0.12 (0.06–0.18)	0.16 (0.09–0.23)	AR5
Greenland SMB	0.03 (0.01–0.07)	0.04 (0.02–0.09)	0.07 (0.03–0.17)	AR5
Greenland DYN	0.04 (0.01–0.06)	0.04 (0.01–0.06)	0.05 (0.02–0.07)	AR5
LWS	0.04 (–0.01–0.09)	0.04 (–0.01–0.09)	0.04 (–0.01–0.09)	AR5
Total AR5 – Antarctica AR5*; 2081–2100	0.35 (0.23–0.48)	0.43 (0.30–0.57)	0.60 (0.43–0.78)	SROCC implicit in AR5
Total AR5 – Antarctica AR5; 2046–2065	0.22 (0.15–0.29)	0.24 (0.17–0.31)	0.28 (0.20–0.36)	SROCC implicit in AR5
Antarctica 2031–2050	0.01 (0.00–0.03)	0.01 (0.00–0.03)	0.02 (0.00–0.05)	SROCC
Antarctica 2046–2065	0.02 (0.00–0.05)	0.02 (0.01–0.05)	0.03 (0.00–0.08)	SROCC
Antarctica 2081–2100	0.04 (0.01–0.10)	0.05 (0.01–0.13)	0.10 (0.02–0.23)	SROCC
Antarctica 2100	0.04 (0.01–0.11)	0.06 (0.01–0.15)	0.12 (0.03–0.28)	SROCC
GMSL 2031–2050	0.17 (0.12–0.22)	0.18 (0.13–0.23)	0.20 (0.15–0.26)	SROCC
GMSL 2046–2065	0.24 (0.17–0.32)	0.26 (0.19–0.34)	0.32 (0.23–0.40)	SROCC
GMSL 2081–2100	0.39 (0.26–0.53)	0.49 (0.34–0.64)	0.71 (0.51–0.92)	SROCC
GMSL in 2100	0.43 (0.29–0.59)	0.55 (0.39–0.72)	0.84 (0.61–1.10)	SROCC
Rate (mm yr^{-1})	4(2–6)	7(4–9)	15(10–20)	SROCC

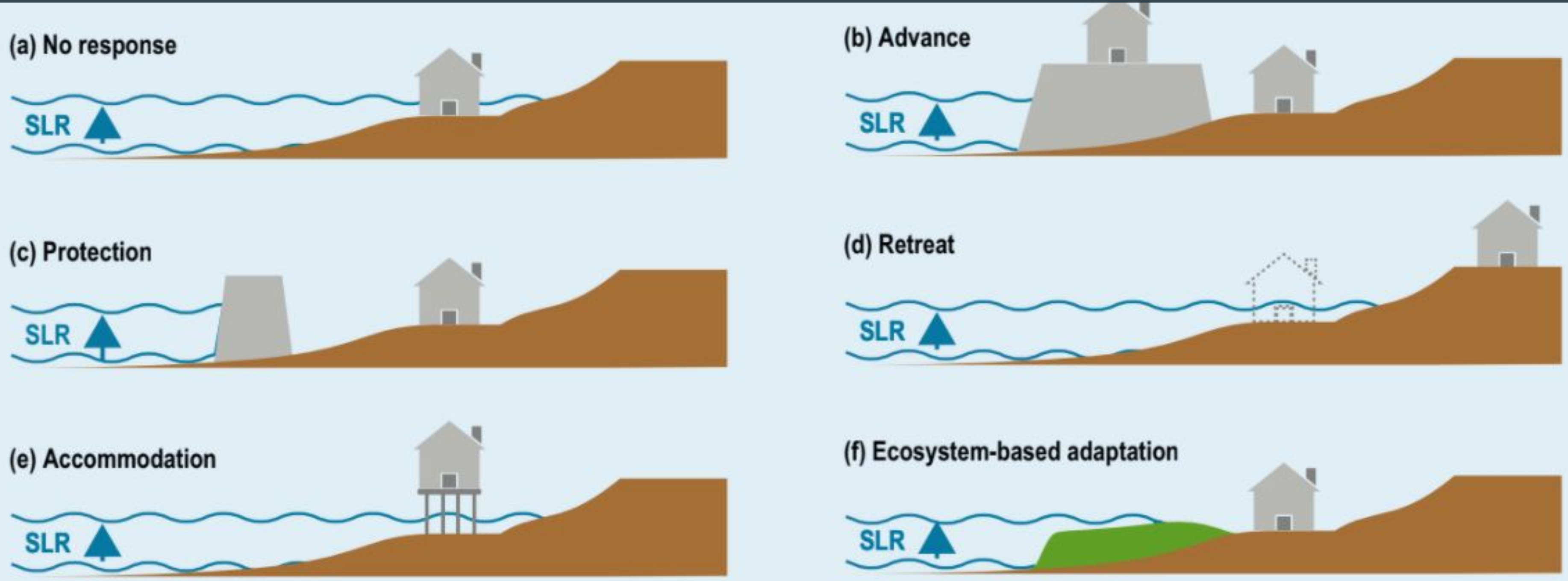
Fig. Median values and likely ranges for projections of global mean sea level (GMSL) rise in metres in 2081–2100 relative to 1986–2005 for three scenarios.



(a) Schematic effect of regional sea level rise on projected extreme sea level events (not to scale)
Historical Centennial extreme sea level Events (HCEs) become more common due to sea level rise
HCE
1/century
1/decade
1/year
1/month
mean sea level
sea level rise
recent past
future
Time
Sea level height and recurrence frequency
(b) Year when HCEs are projected to recur once per year on average
RCP8.5
RCP2.6
Year
2000
2020
2040
2060
2080
2100
Black:
Locations where HCEs already recur annually
White:
Locations where HCEs recur annually after 2100
Difference >10 years later
Difference <10 years later
no relative sea level rise before 2100
(c) Difference between RCP8.5 and RCP2.6
The difference map shows locations where the HCE becomes annual at least 10 years later under RCP2.6 than under RCP8.5.


テレトラック
MIYAKO

RESPONSES



Box 4.3, Figure 1 | Different types of responses to coastal risk and sea level rise (SLR).

DECISIONS

Changing Ocean, Marine Ecosystems and Dependent Communities

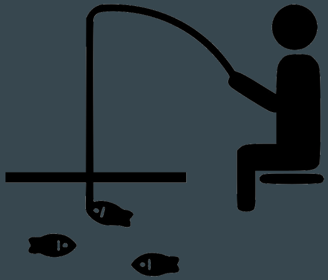
Observations

Carbon emissions from human activities

causing

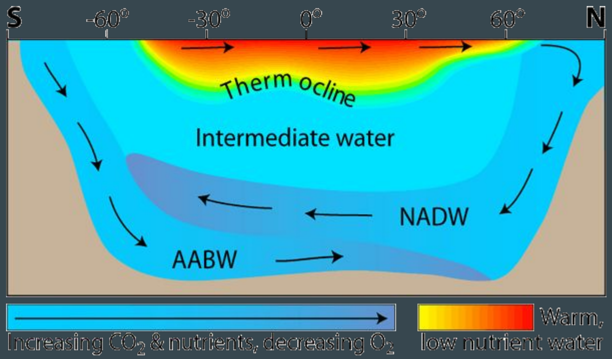
- Ocean warming
- Acidification
- Oxygen loss

- Affecting marine organisms
- Impacting fisheries



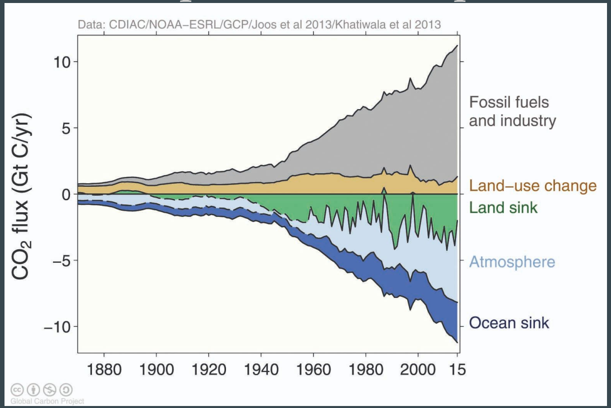
Consequences of ocean warming

Stratification



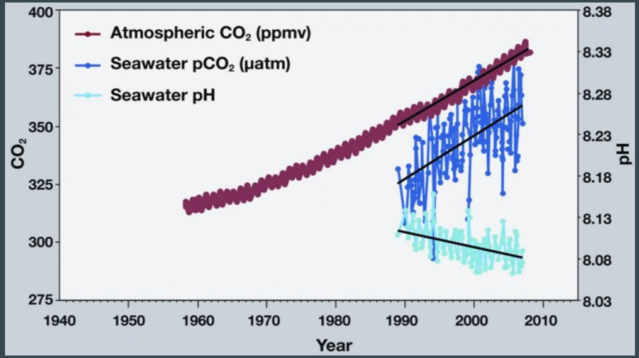
https://blogs.egu.eu/geolog/2013/09/20/momentous-discoveries-in-oceanography/

Atmospheric CO2 uptake



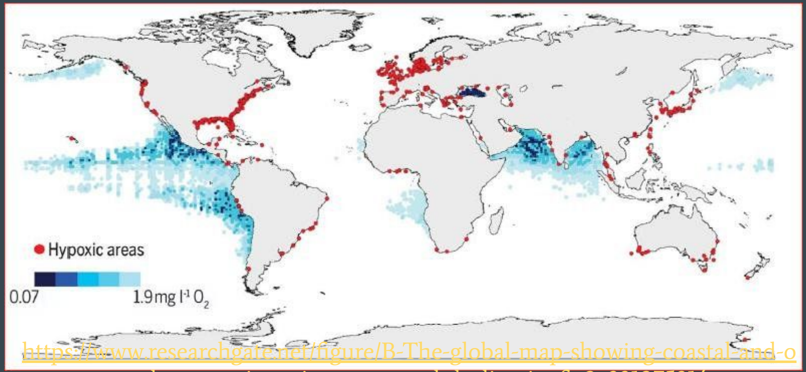
https://public.wmo.int/en/resources/bulletin/annual-global-carbon-budget

Acidification



https://ocean.si.edu/conservation/acidification/ocean-acidification-graph

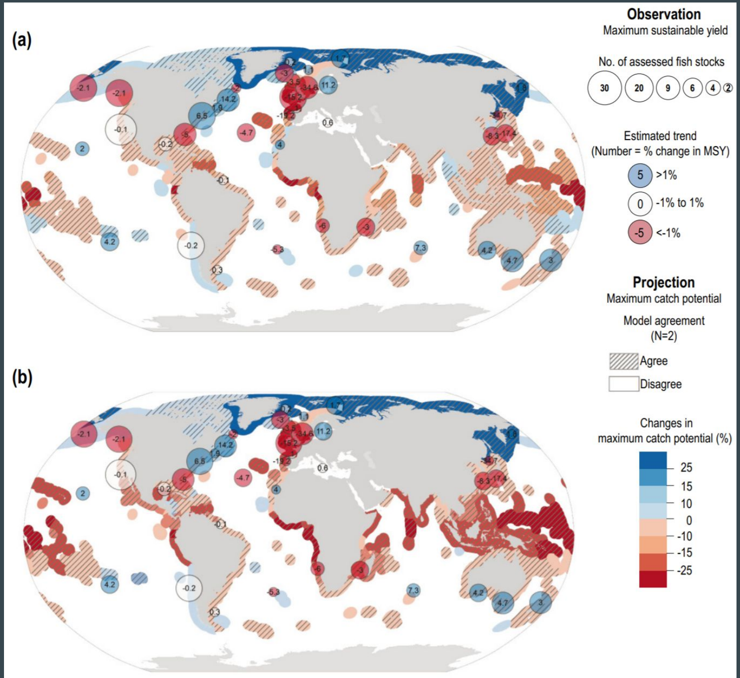
Oxygen loss



https://www.researchgate.net/figure/B-The-global-map-showing-coastal-and-open-ocean-where-nutrients-inputs-caused-decline-in_fig2_331275314

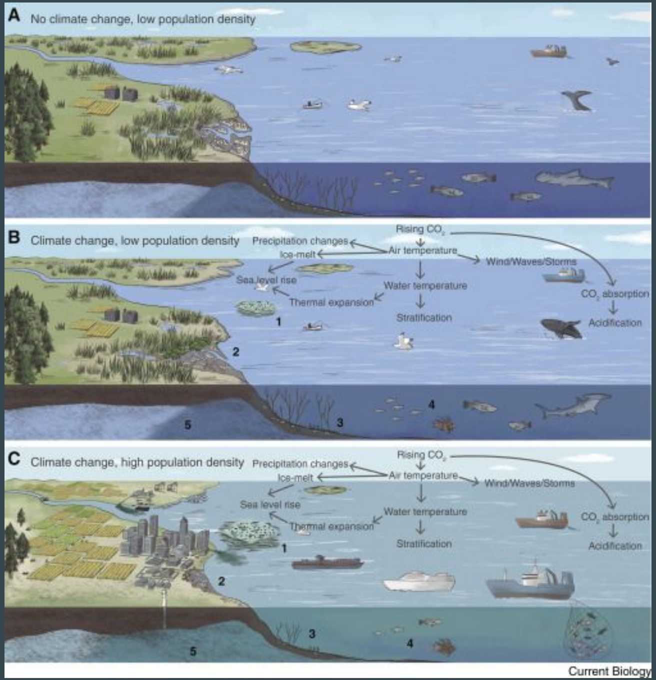
Effects on Communities

Fisheries



MSY comparison between (a) RCP2.6 and (b) RCP8.5

Human Activities



https://www.sciencedirect.com/science/article/pii/S0960982219310929

Projections: Scenarios and Time Horizons

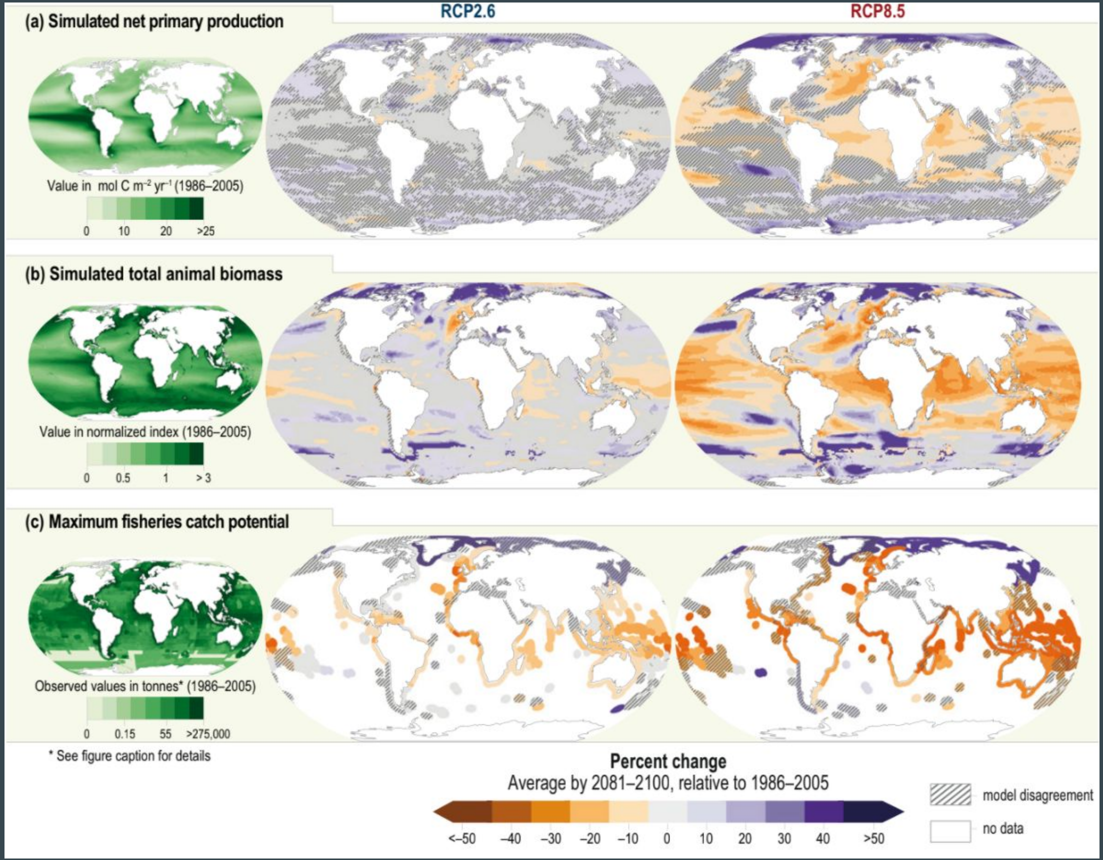
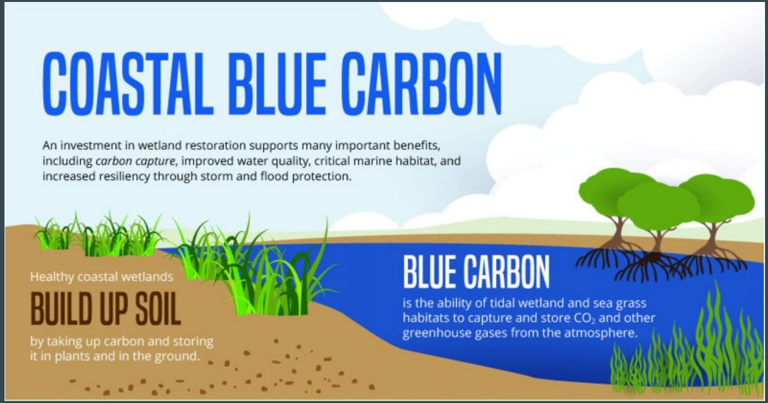


Fig: comparison of RCP2.6 and RCP8.5 scenarios over 3 occasions

Response Options to Enhance Resilience

Blue Carbon Ecosystems



https://www.earthcorps.org/our-story/key-initiatives/blue-carbon/

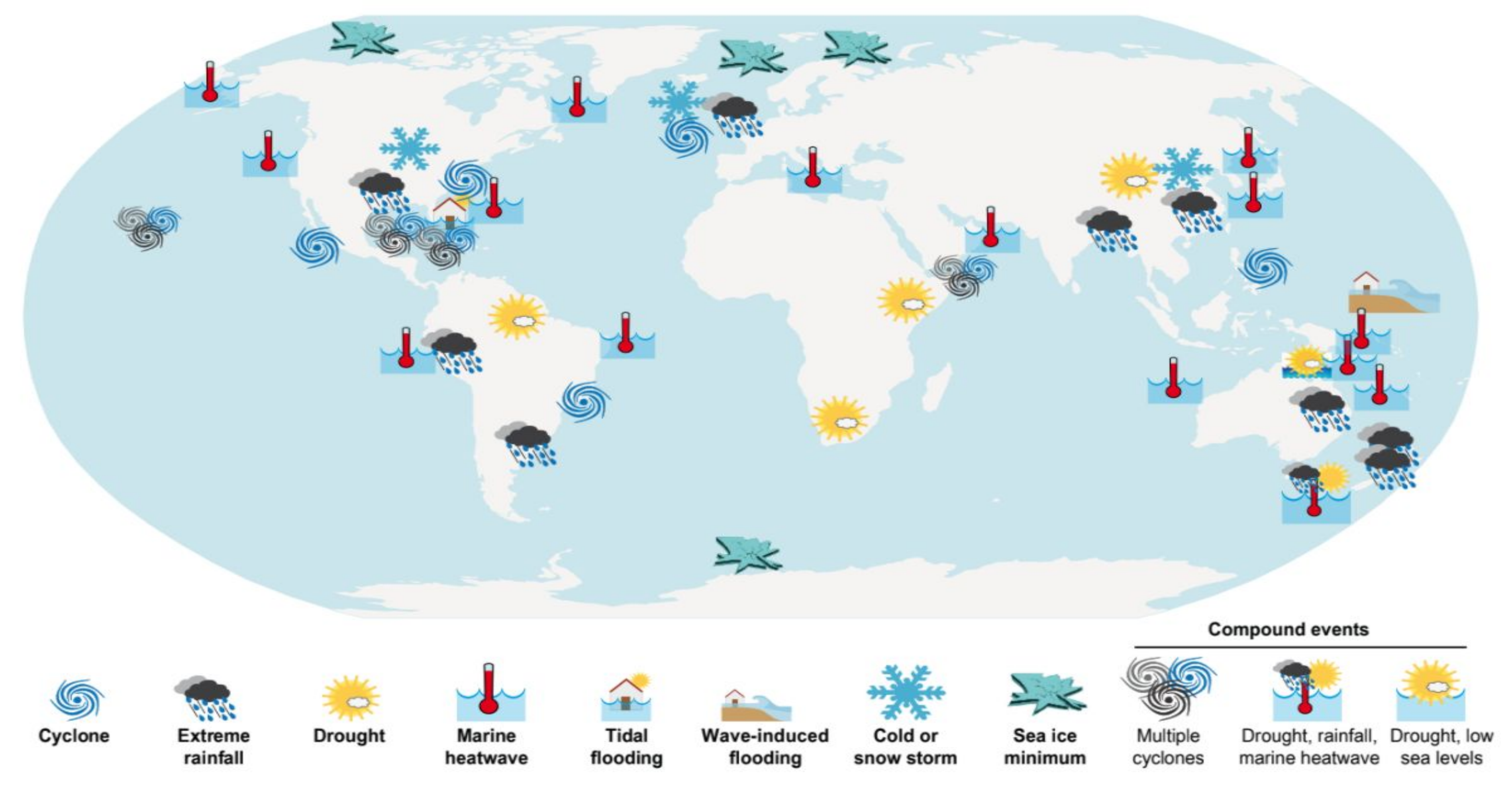
Ecosystem Based Adaptation (EbA)

https://www.iucn.org/resources/issues-briefs/ecosystem-based-adaptation

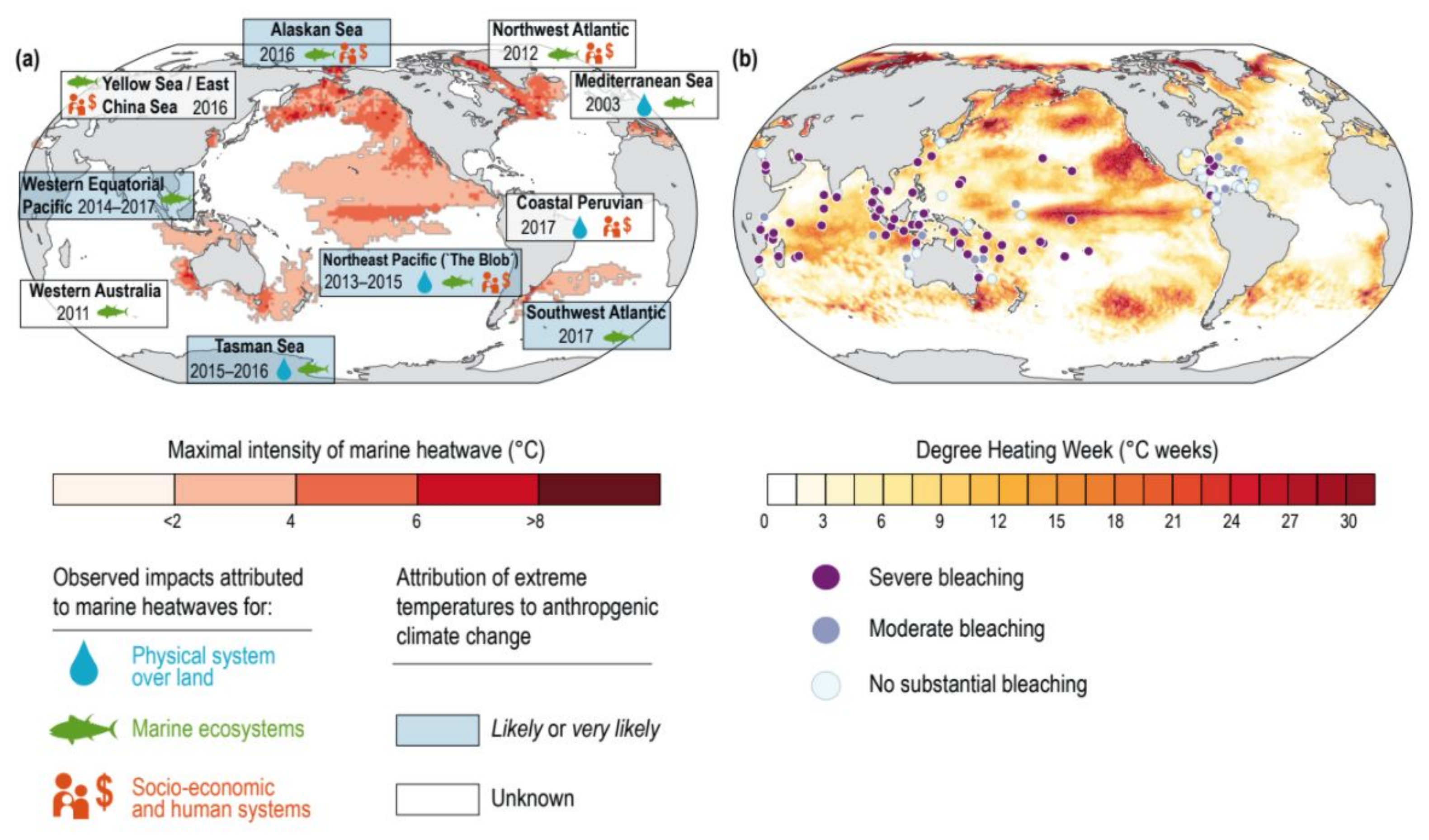
Extremes, Abrupt Changes and Managing Risks

Ongoing and Emerging Changes in the Ocean and Cryosphere, and their Impacts on Ecosystems and Human Societies

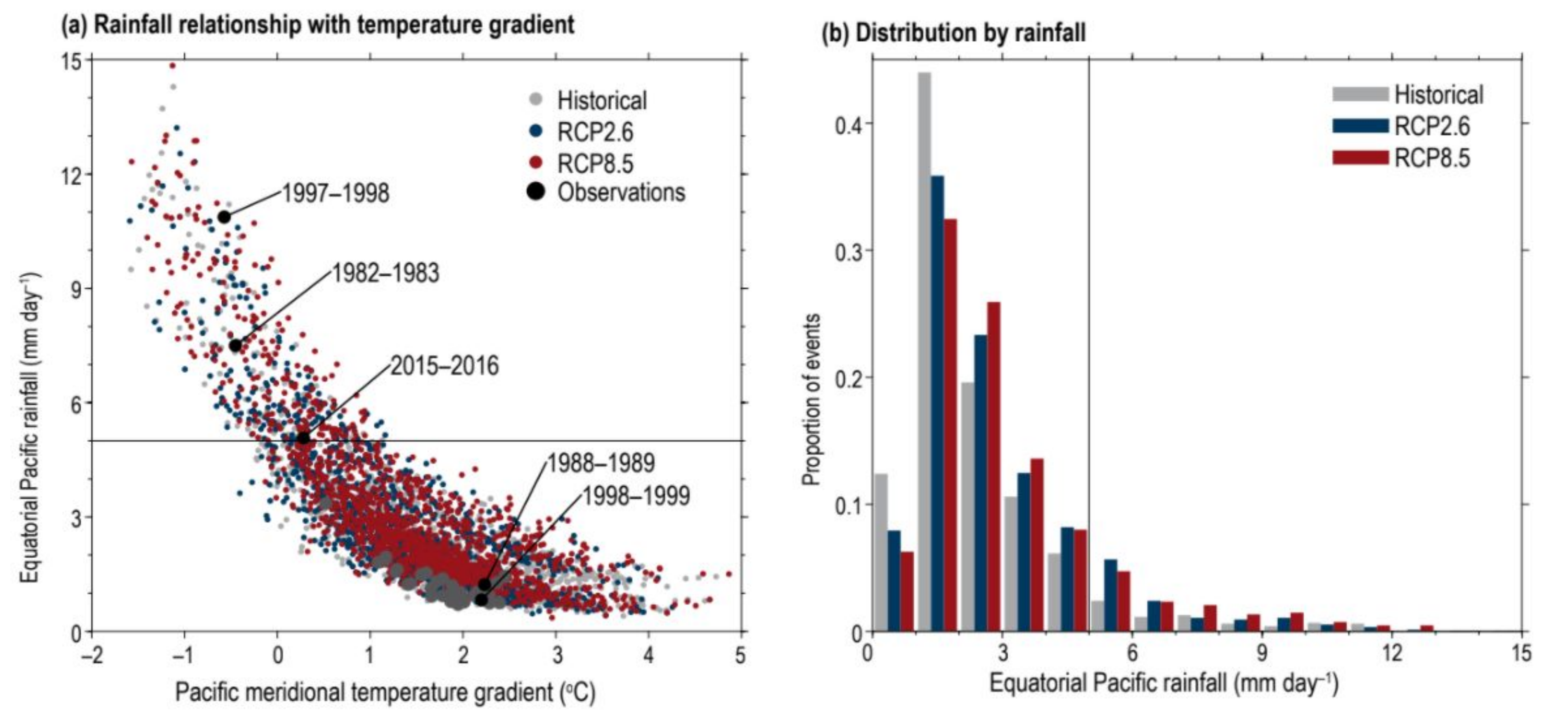
Extreme risk areas



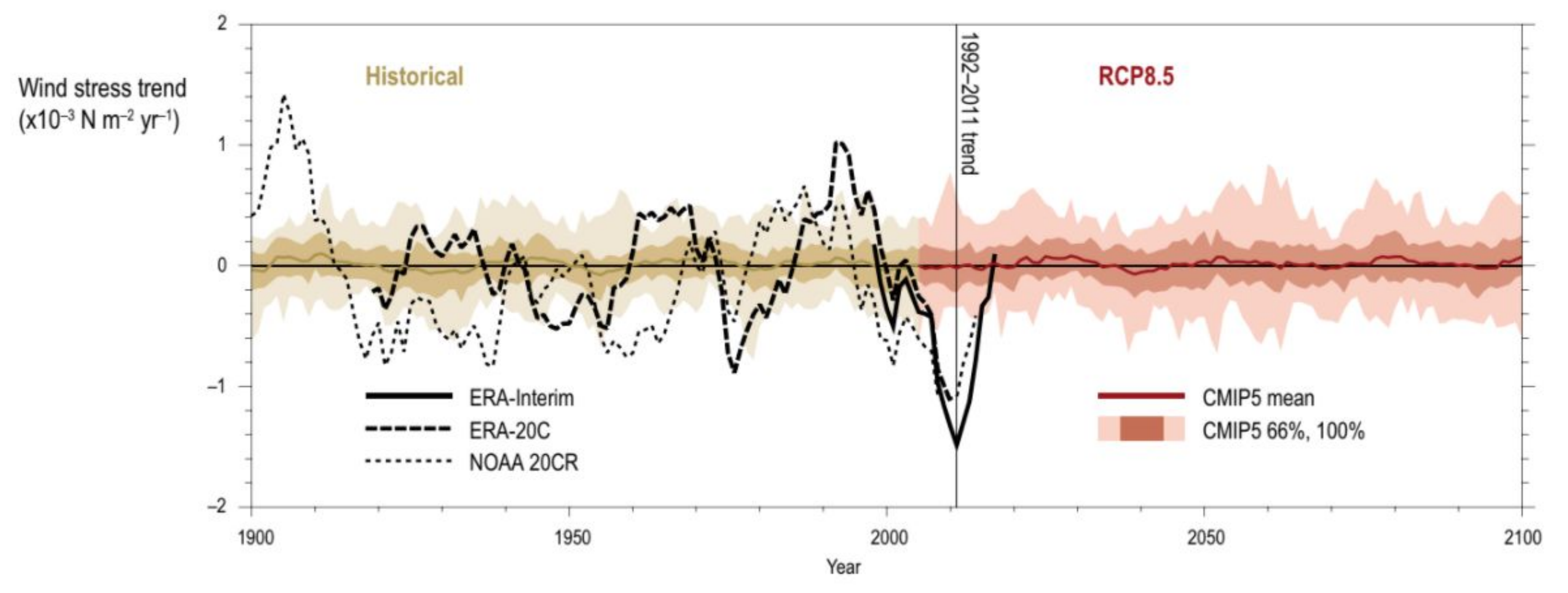
Marine heatwaves



Strongest El Niño and La Niña events

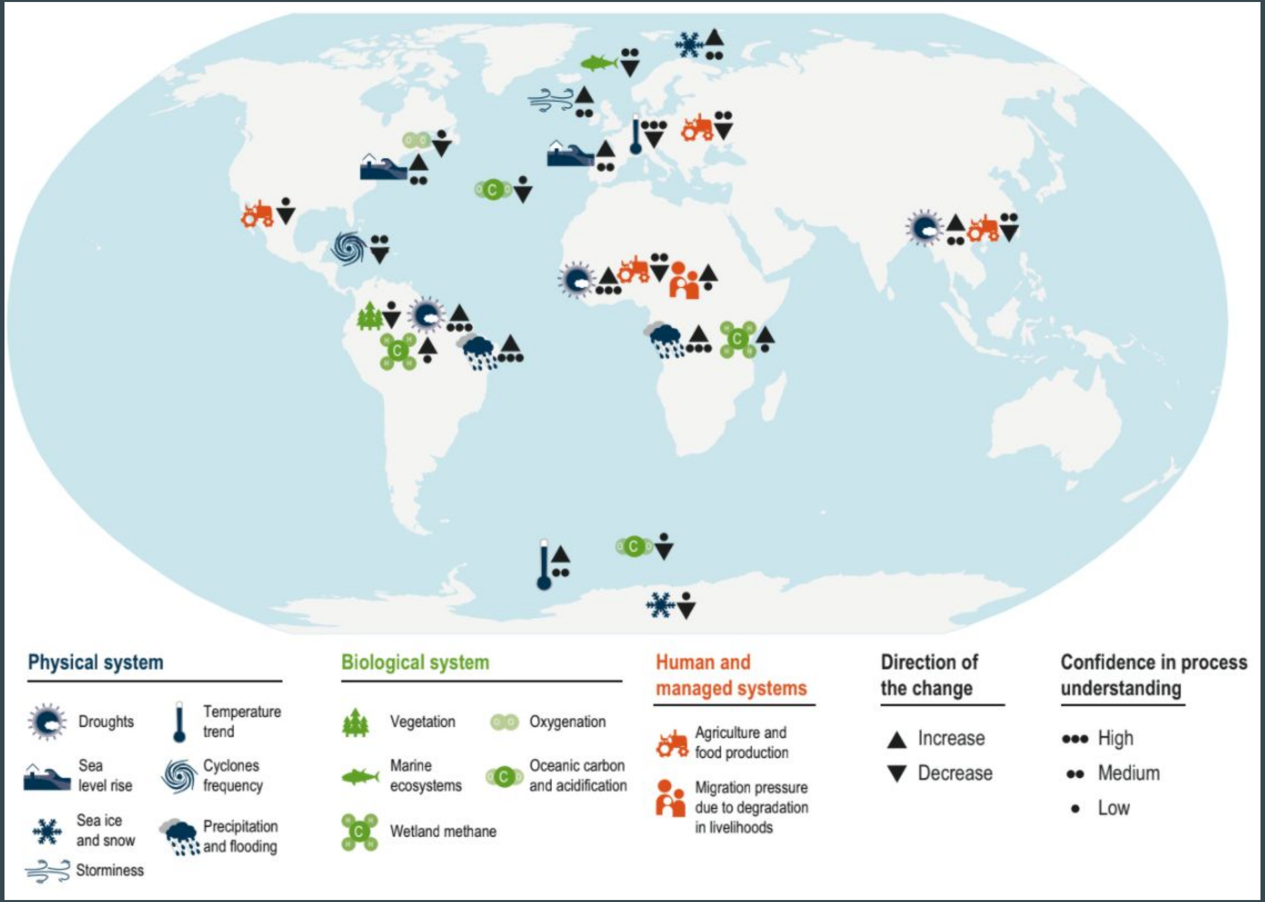


Wind stress



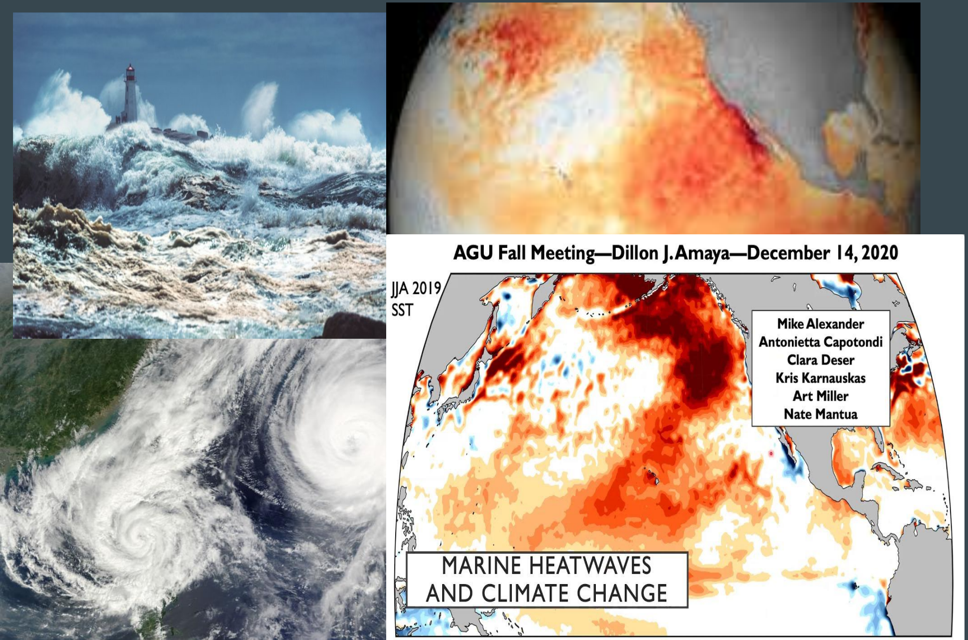
Wind stress trend
(x10−3 N m−2 yr−1)
Historical
RCP8.5
1992–2011 trend
ERA-Interim
ERA-20C
NOAA 20CR
CMIP5 mean
CMIP5 66%, 100%
2
1
0
−1
−2
1900
1950
2000
2050
2100
Year

Infographic on teleconnections and impacts due to Atlantic Meridional Overturning Circulation (AMOC).



Projections of Ocean and Cryosphere Change and Hazards to Ecosystems and Human Society Under Low and High Emission Futures.

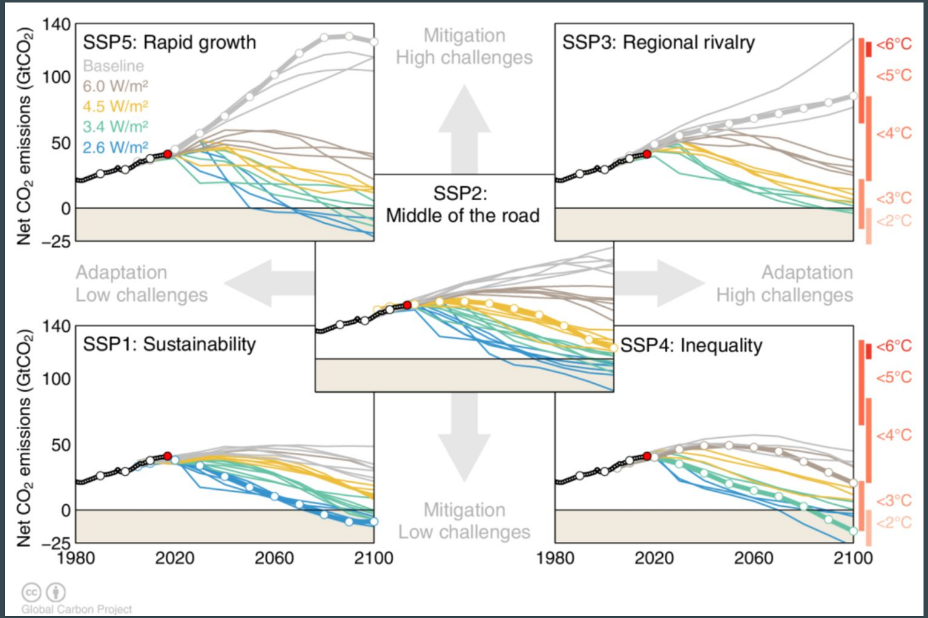
- Tropical cyclones
- Wave heights
- Marine heatwaves
- Extreme El Niño and La Niña



Strengthening the Global Responses in the Context of Sustainable Development Goals (SDGs) and Charting Climate Resilient Development Pathways for Oceans and Cryosphere

Shared Socioeconomic Pathways and Conclusions

Scenario Analysis



Thank you