Vulnerability to climate change

impacts to natural systems

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References:
https://www.ipcc.ch/report/sixth-assessment-report-working-group-ii/
https://www.ipcc.ch/report/ar6/syr/

Understanding Vulnerability

- IPCC definition: propensity or predisposition to be adversely affected and encompasses a variety of concepts and elements, including sensitivity or susceptibility to harm and lack of capacity to cope and adapt
- vulnerability = sensitivity to change + capacity to adapt

Drivers of vulnerability

- rapid warming
- habitat degradation
- pollution
- overexploitation
- invasive species
- ocean acidification

Human pressures amplify climate-related vulnerability

Projected Impacts and Increasing Risks

What Do We Mean by “Projected Impacts”

- IPCC projects risks under warming levels of **1.5°C, 2°C, 3°C, 4°C+**
- Risks rise with **every increment of warming**
- Impacts depend on **hazards + exposure + vulnerability**

The IPCC framework says risk isn’t only about climate hazards, it’s how those hazards interact with societal vulnerability.

Forest Ecosystems

At +1.5 to 2°C:

- Rising *tree mortality* and declining forest health (high confidence)
- More frequent *wildfires*, drought stress
- Boreal forests: shifting ranges northward

At +3°C+:

- High risk of large-scale *forest loss* and biome shifts
- Some losses become *irreversible* (medium confidence)

Arctic Systems

At +1.5°C:

- Very high risks for Arctic sea-ice ecosystems
- Permafrost thaw → irreversible carbon release (high confidence)

At +2–3°C:

- Severe biodiversity loss
- Collapse of ice-dependent ecosystems (polar bears, seals)

At +4°C:

- Arctic becomes *ice-free in summer* in some years

Coral Reefs

Warm-water coral reefs:

- Already at *very high* risk at 1.5°C
- At 1.5°C: **70–90%** decline in live coral cover
- At 2°C: **>99%** loss (near-total collapse)

This is one of the clearest examples of *irreversible ecosystem loss* in the IPCC.

Freshwater Systems

At +1.5–2°C:

- Increased water scarcity for billions of people
- Higher risks of droughts and water quality decline
- Glacier-fed river systems lose seasonal reliability

At +3°C+:

- Permanent glacier loss in many regions (irreversible)
- Collapse of high-mountain ecosystems (high confidence)

Compound & Cascading Risks

Definition:
Multiple climate hazards occurring *simultaneously* or *interacting*, amplifying damage.

Examples (from SPM):

- Heatwaves + drought → massive wildfire risk
- Flooding + infrastructure failure → health crises
- Crop failures + supply chain shocks → food insecurity
- Sea-level rise + storms → coastal collapse

Why this matters:
Risks “cascade” across systems — from ecosystems → economies → society.

What Are “Limits to Adaptation”?

Soft limits:
Adaptation *could* work but is not feasible today (e.g., lack of money, governance).

Hard limits:
Adaptation **cannot** prevent intolerable risk — even with infinite resources.

Examples of hard limits (IPCC):

- *Warm-water coral reefs* — cannot adapt to >1.5–2°C
- *Some coastal ecosystems* — submerged by sea-level rise
- *Arctic permafrost thaw* — irreversible once triggered

Human Systems: Reaching Limits Too

Examples of approaching limits:

- Heat stress: outdoor labor becomes impossible in tropics
- Coastal settlements: long-term uninhabitable zones
- Food security: crop yield drops at 2–3°C in key regions
- Water scarcity: up to **3.6 billion people** highly vulnerable

IPCC note:
Human vulnerability + climate hazards = regions where adaptation is already failing.

Takeaways

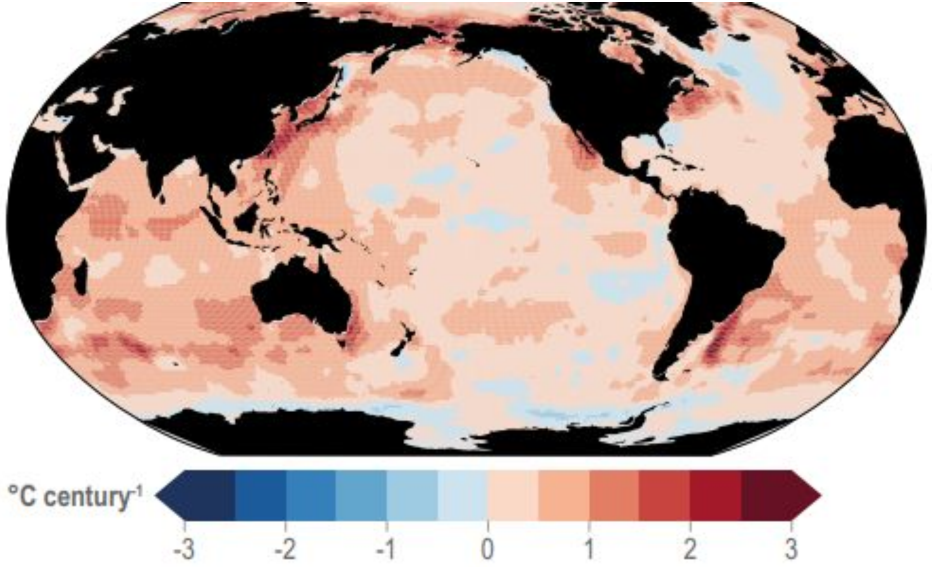
1. **Risks escalate with every tenth of a degree** of warming
2. Many crucial ecosystems hit **high/very high risk** already at **1.5°C**
3. *Compound risks* mean crises won’t happen one at a time
4. Some systems face **hard limits** → irreversible loss
5. Near-term action *cannot eliminate all losses* but drastically reduces them

Human influence on the climate is a **fact**. The scale of change in recent years has been unprecedented, **drastically affecting ecosystems**.

Human activity has led to irreversible negative changes in **all types of ecosystems** - from terrestrial to marine.

Observed climate change impact on ecosytems

ECOSYSTEMS		Global	Africa	Asia	Australasia	Central & South America	Europe	North America	Small Islands
Changes in ecosystem structure	Terrestrial	•••	•••	•••	•••	•••	•••	•••	•••
	Freshwater	•••	•••	••	–	•••	•••	•••	•••
	Ocean	•••	•••	•••	•••	•••	•••	•••	•••
Species range shifts	Terrestrial	•••	•••	•	•••	•••	•••	•••	•••
	Freshwater	•••	–	••	–	•••	•••	•••	•••
	Ocean	•••	•••	–	•••	•••	•••	•••	•••
Changes in seasonal timing (phenology)	Terrestrial	•••	–	•	•••	–	•••	•••	•••
	Freshwater	•••	•	•	–	–	•••	•••	–
	Ocean	•••	•	••	•	•	•••	•••	••



The global average sea level rose by approximately **0.20 m** between 1901 and 2018. Growth is getting faster and faster.

Most coastal ecosystems (mangroves, seagrasses, salt marshes, shallow coral reefs, rocky shores and sandy beaches) are affected by changes in the sea level.

The average temperature of the global ocean has increased by about **0.9 °C** since the beginning of the XX century, which is very important because ocean warming accounts for **91%** of the heating in the climate system.

Coral reefs are one of the most vulnerable marine ecosystems. They are threatened by climate-induced drivers, especially ocean warming, ocean acidification, tropical cyclones, fisheries/overharvesting, land-based pollution, disease spread and destructive shoreline practices.

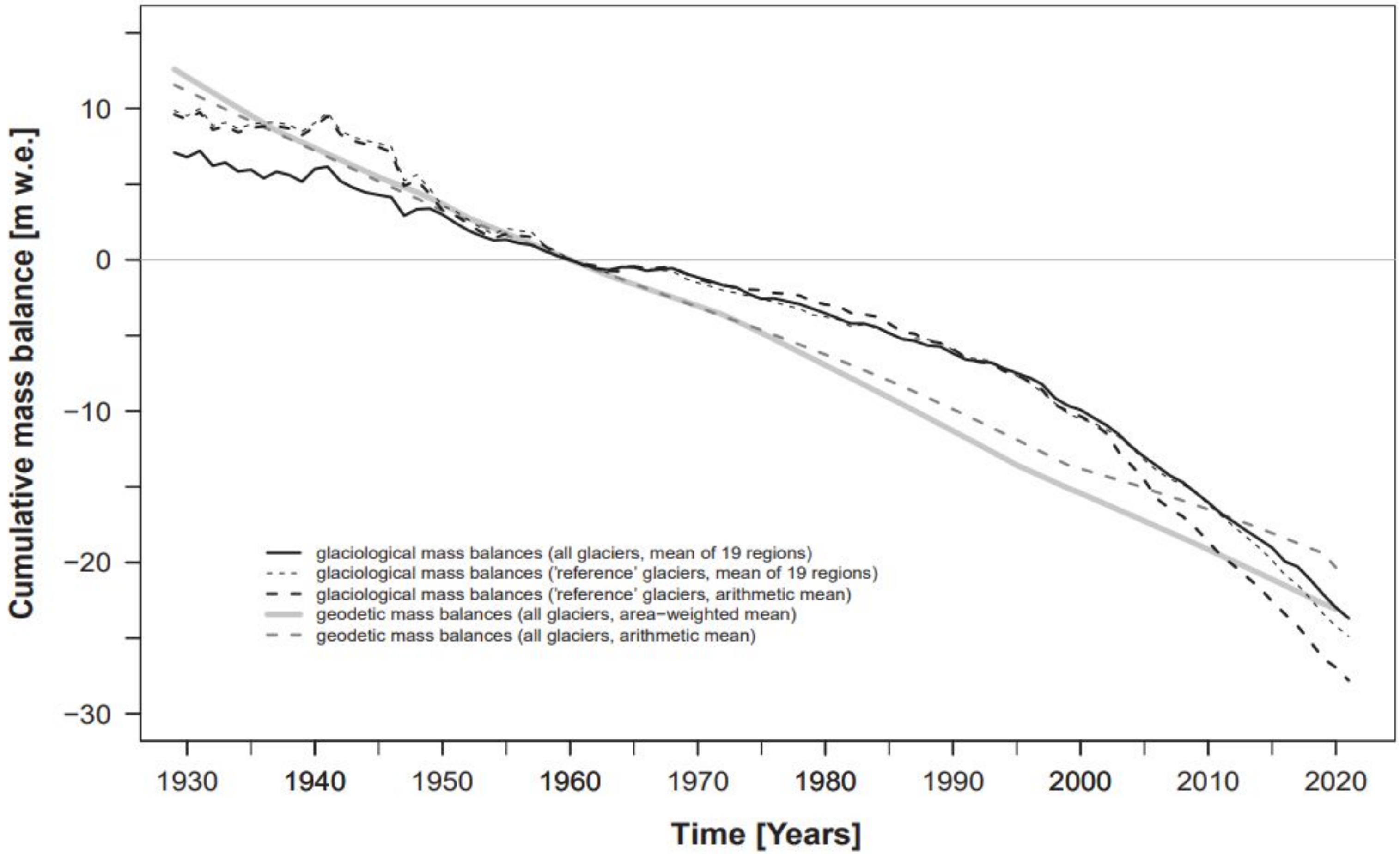
Mass coral bleaching and disease outbreaks have increased due to more frequent and severe heat stress associated with ocean warming.

Ocean acidification reduces biodiversity and the calcification rate of corals while at the same time increasing the rate of dissolution of the reef framework.

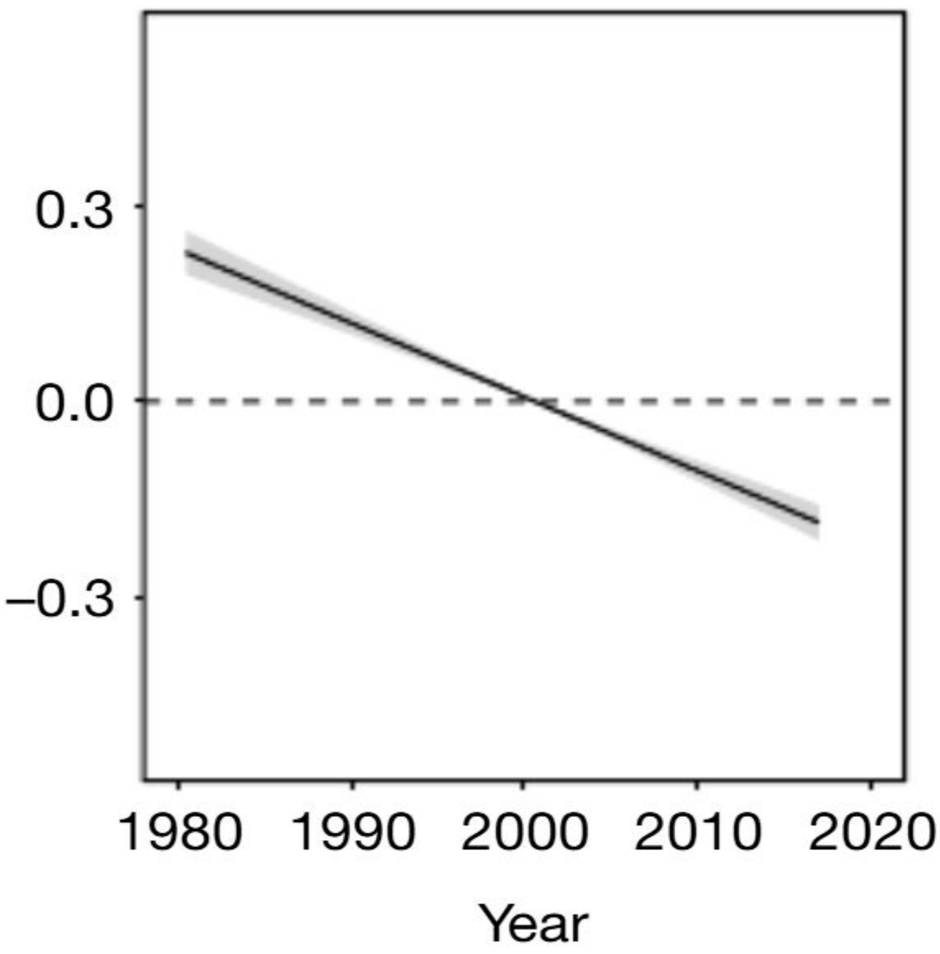
← High diversity colar reef

Degraded colar reef →

Global glacier mass loss rate (0.5-meter water equivalent/year)



WGMS, 2017: Global Glacier Change Bulletin no. 5

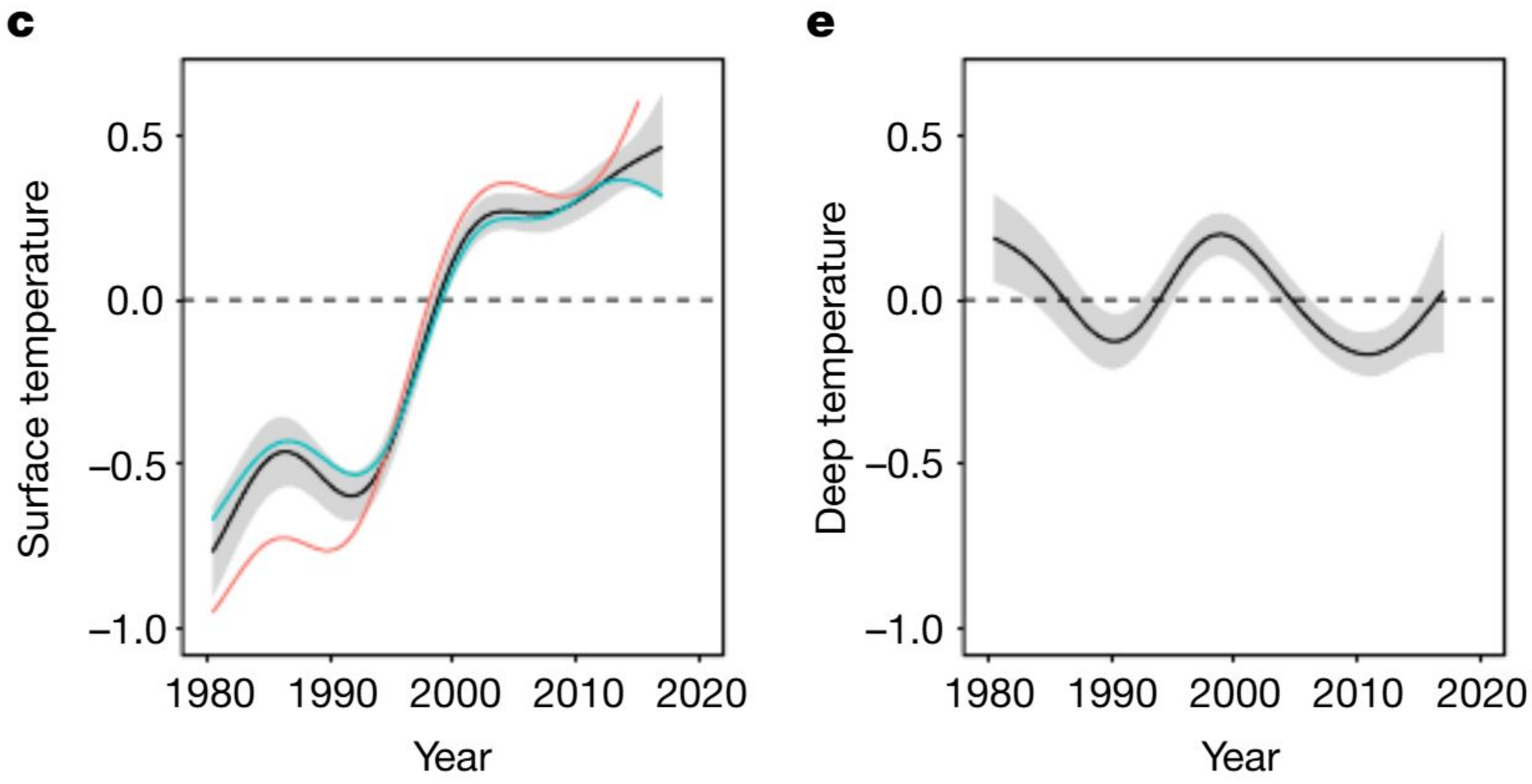


Increased water temperature and reduced mixing cause a decrease in dissolved oxygen.

In 400 studied lakes, dissolved oxygen in deep waters declined by 16.8%, between 1980 and 2017.

Reduced mixing of water results from greater warming of surface temperatures relative to deep-water temperature.

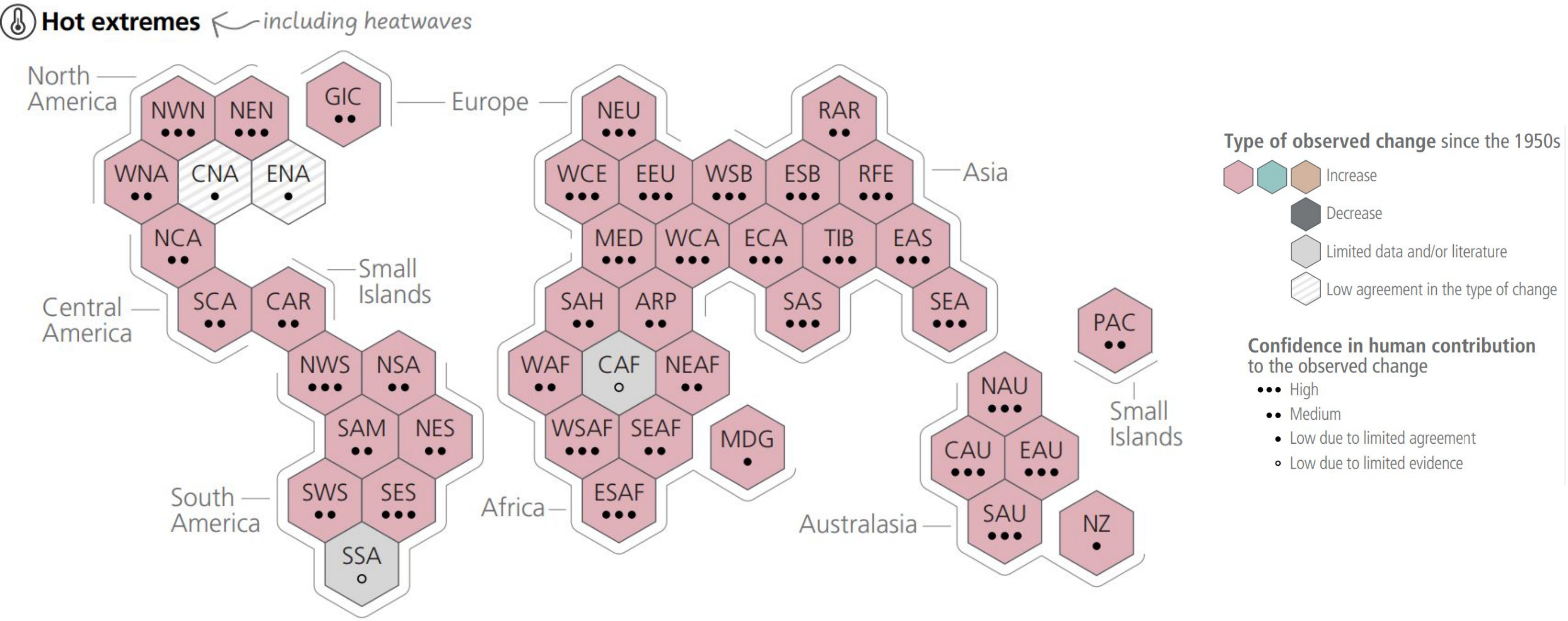
Jane, S. F. et al., 2021: Widespread deoxygenation of temperate lakes. Nature, 594(7861)



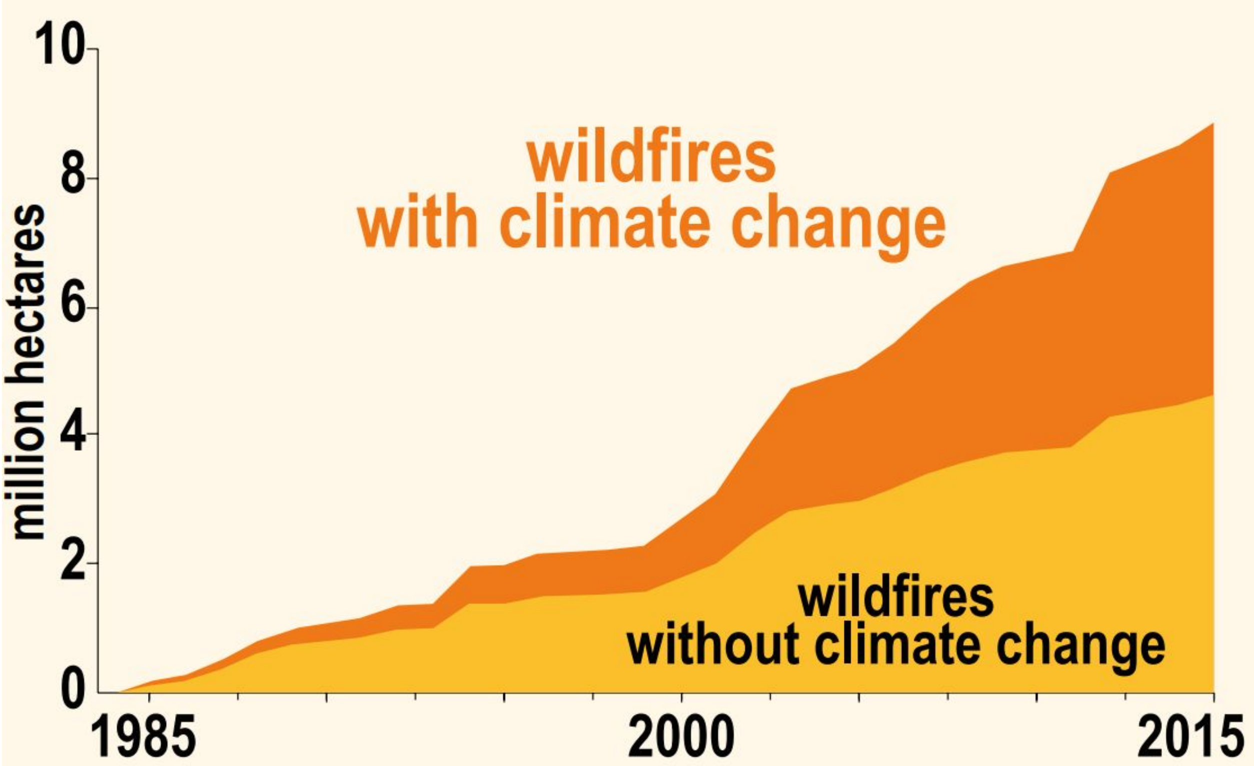
c
e
Surface temperature
Deep temperature
0.5
0.0
−0.5
−1.0
1980
1990
2000
2010
2020
Year

Hot extremes (including heatwaves) have become more frequent and more intense across most land regions in the world since the 1950s.

On the other hand cold extremes (including cold waves) have become less frequent and less severe.

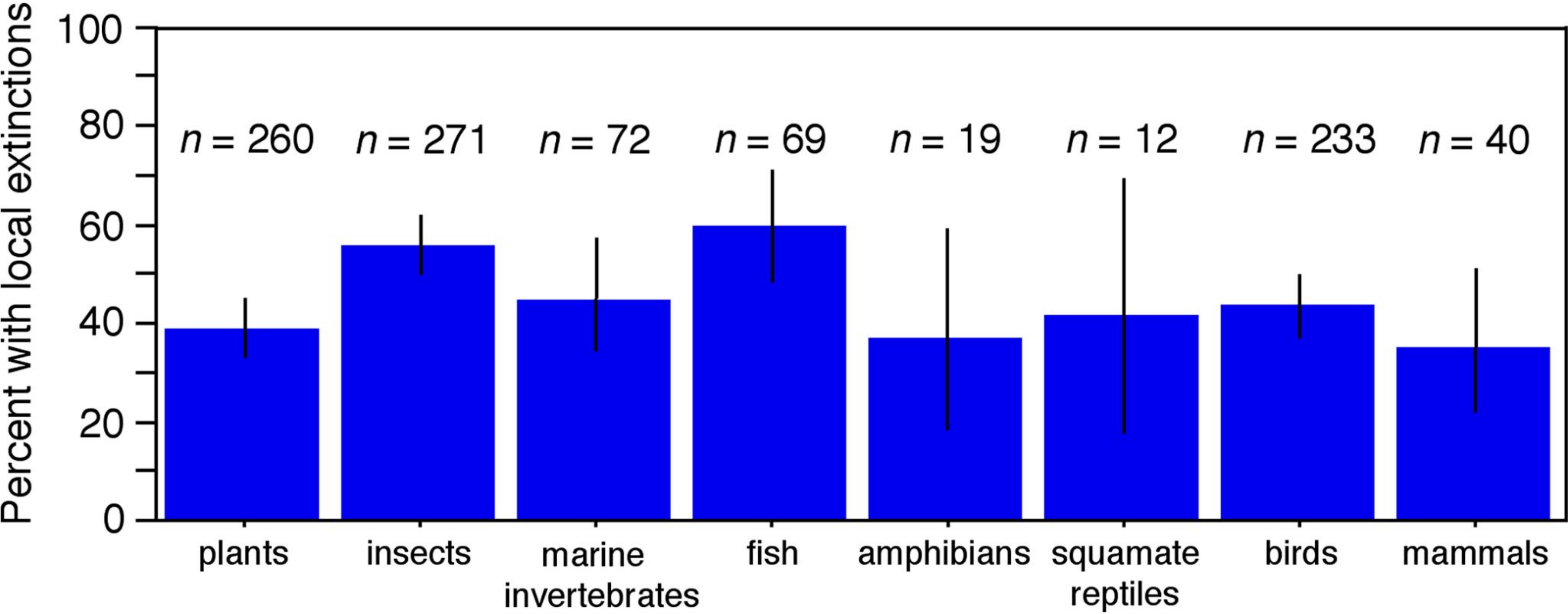


In the Amazon, Australia, North America, Siberia and other regions, wildfires are burning wider areas than in the past. Human-caused climate change increases wildfire by intensifying heat which is the main wildfire factor and dries out vegetation and accelerates burning.



On the other hand, despite the increase in the number and area of fires in some regions, in other parts of the world these values are decreasing due to the regulation of even natural fires by humans.

Many species are becoming extinct locally due to climate change. Many researchers consider global warming to be the main cause of biodiversity loss.

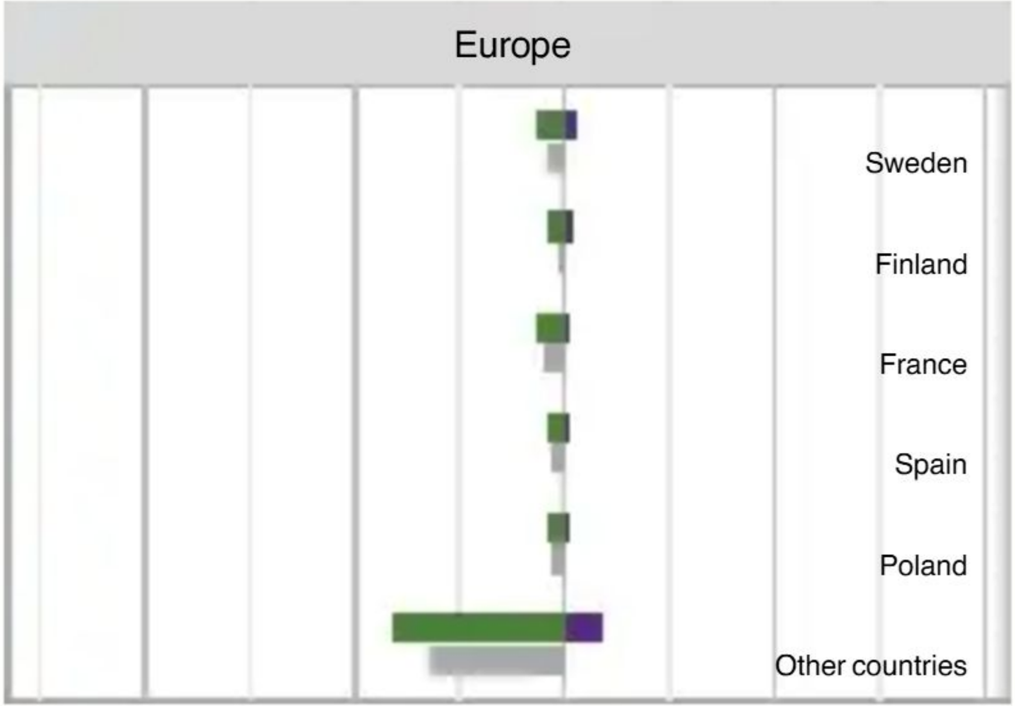


Wiens, J., 2016: Climate-Related Local Extinctions Are Already Widespread among Plant and Animal Species. PLoS Biology, 14(12).

Global terrestrial gross primary production increased by 2% from 1951 to 2010 and continued increasing in the next years, mainly due to higher CO2 concentration and stronger solar radiation.

Global forest area increased by 7% from 1982 to 2016, mainly thanks to forest plantations and temperate forests in Asia and Europe. These forests generated a net removal of 7.7 Gt/year CO2 from the atmosphere from 2001 to 2019.

However, the relative increase in GPP per unit of increased atmospheric CO2 declined from 1982 to 2015.

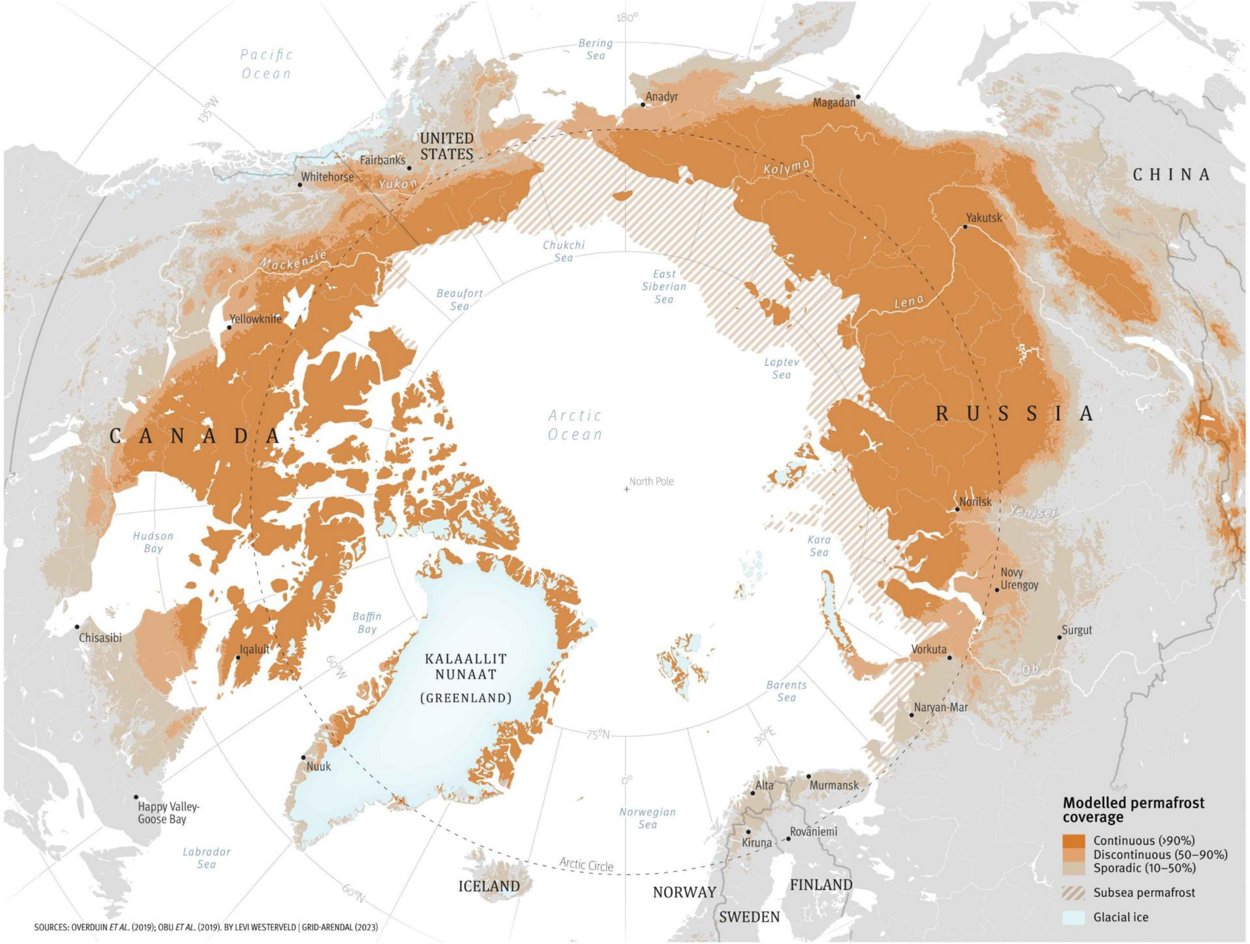


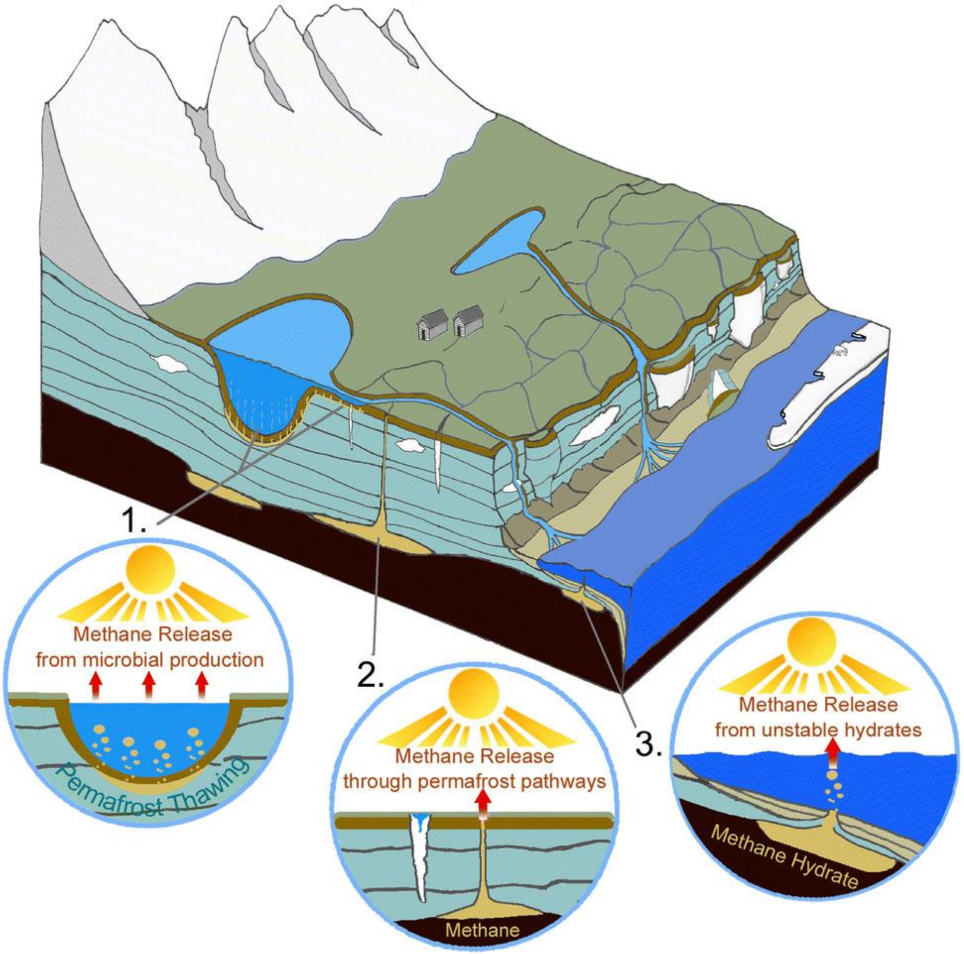
Harris, N. L. et al., 2021: Global maps of twenty-first century forest carbon fluxes. Nature Climate Change, 11(3), 22

Case Studies: Permafrost decline

Def.: Permafrost is any ground that remains completely frozen (0°C>) for a least two years straight.

Actual land area underlain by permafrost occupies between 12 and 17 million km² (Brown et al., 1997; Zhang et al., 2000)

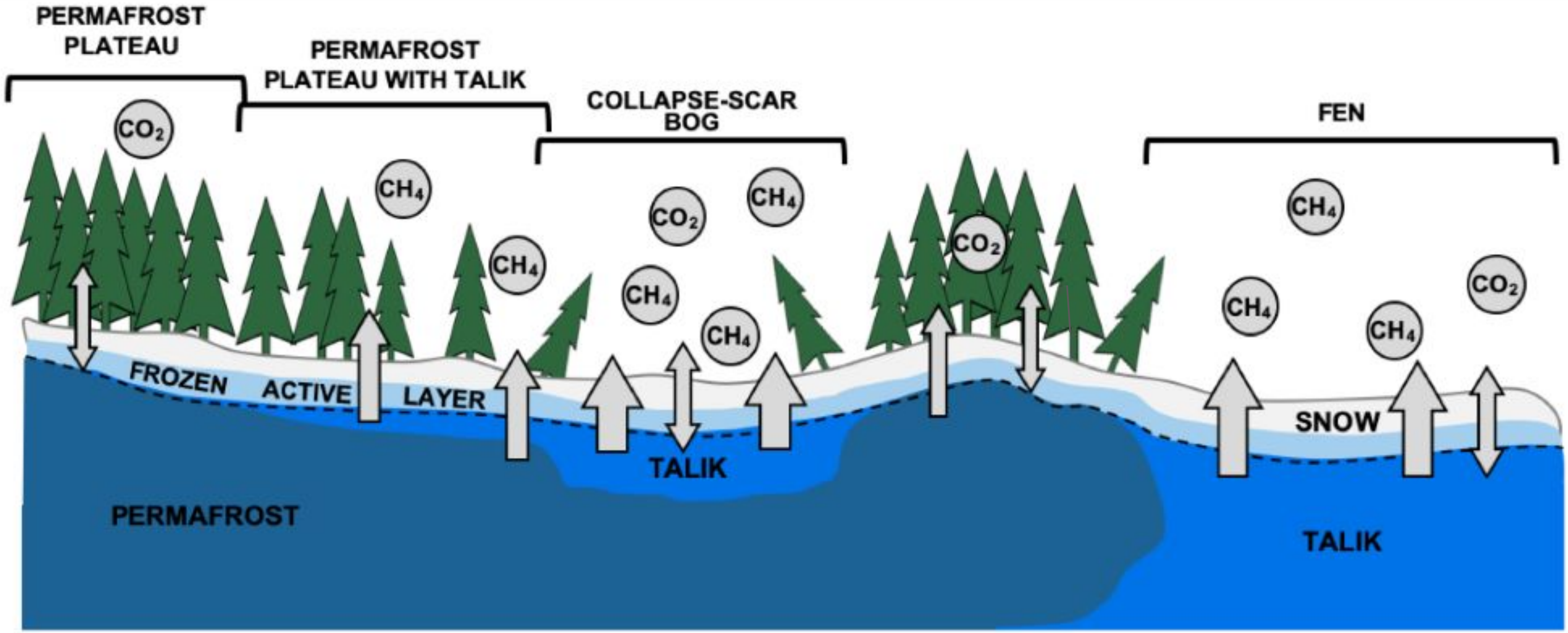




Why permafrost release methane?

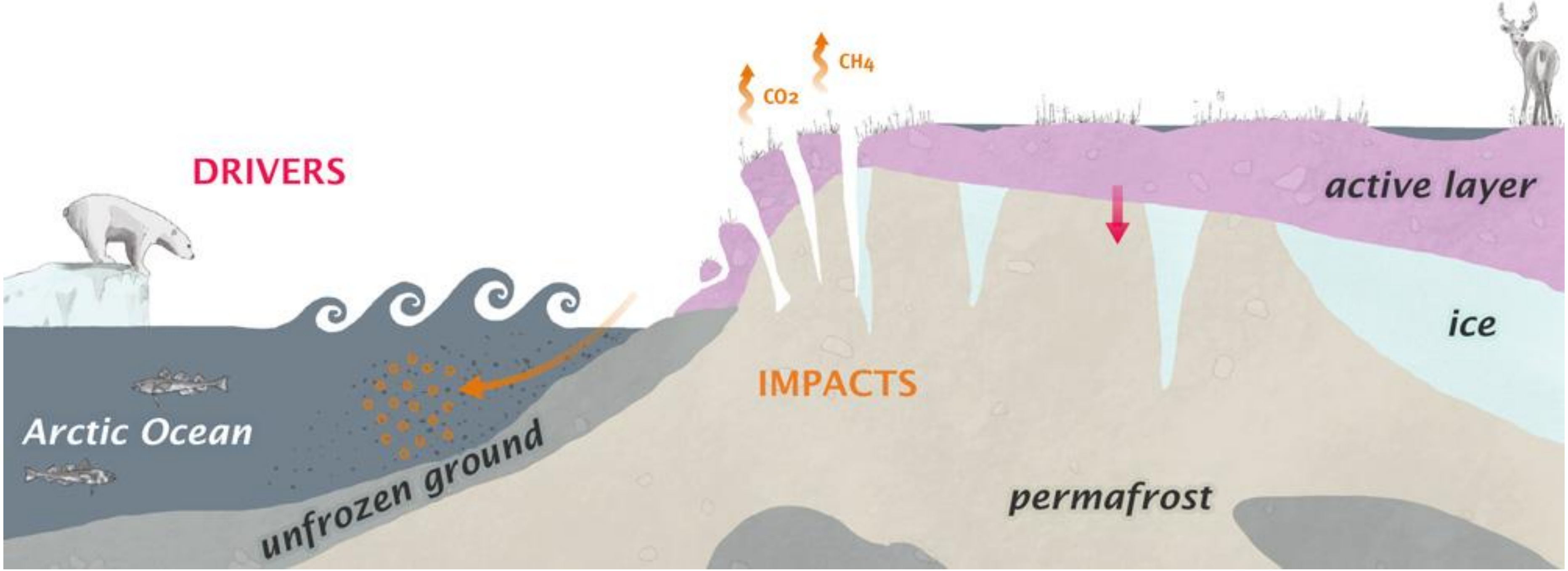
Most of today's permafrost was formed during or since the last ice age 100 ka to 11 ka ago.

Why permafrost release methane?

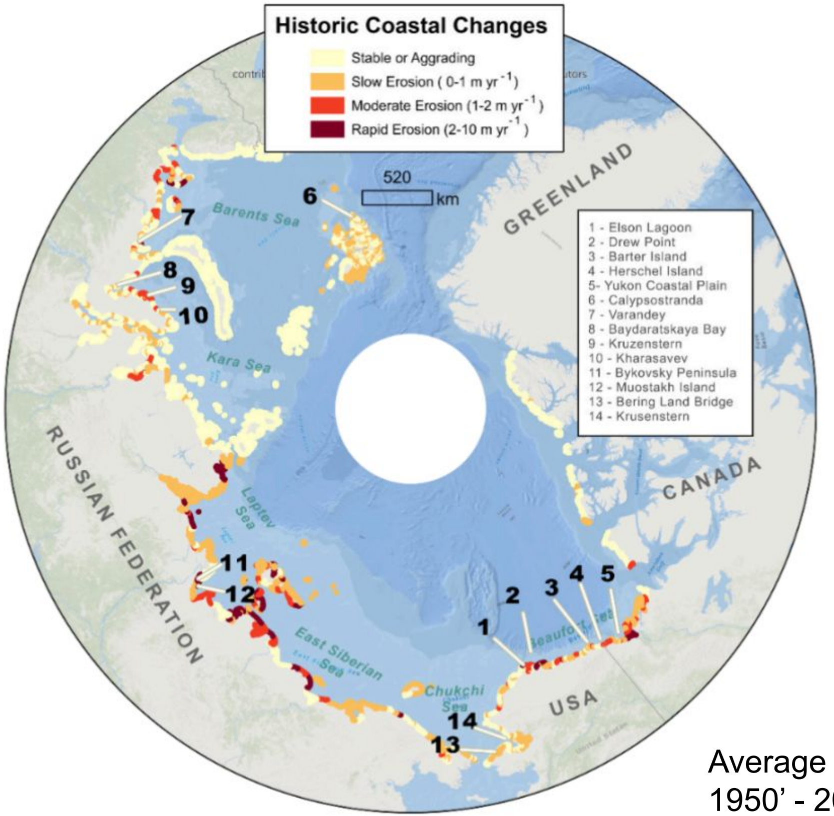


talik - a layer or body of unfrozen ground occurring in a permafrost area due to a local anomaly in thermal, hydrological, hydrogeological, or hydrochemical conditions.

Global warming - impact to coastal area

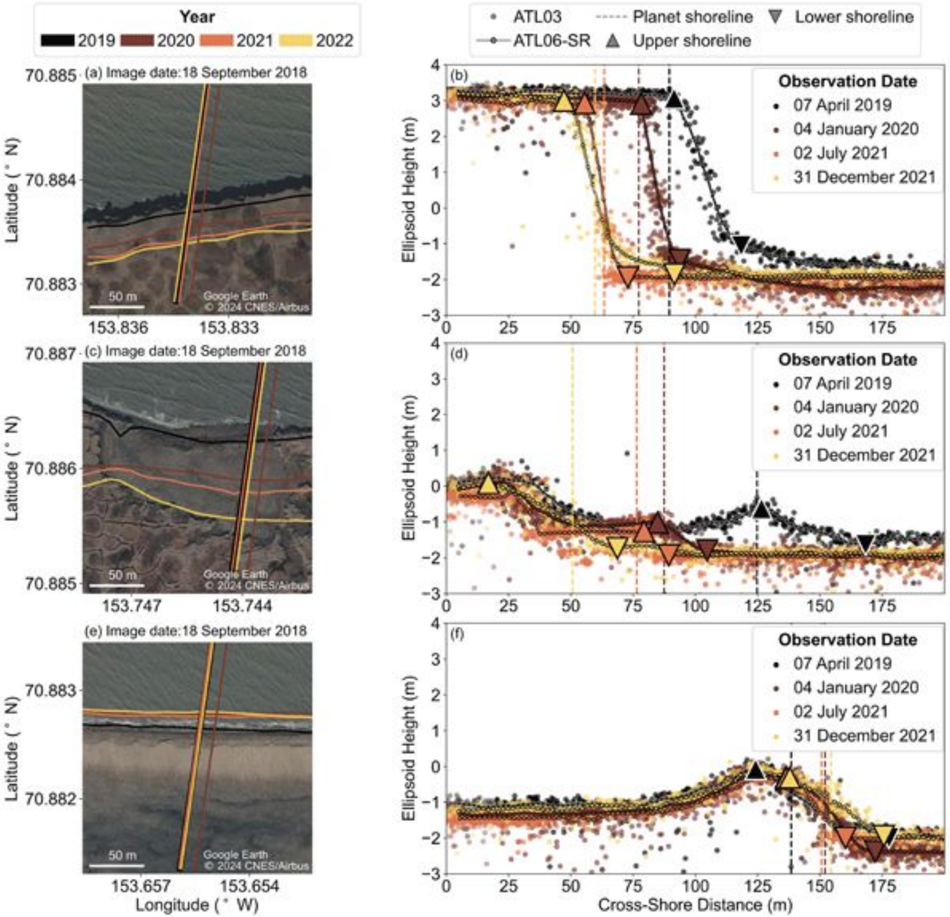


NOAA Arctic Report Card 2020



Average erosion
1950’ - 2000’

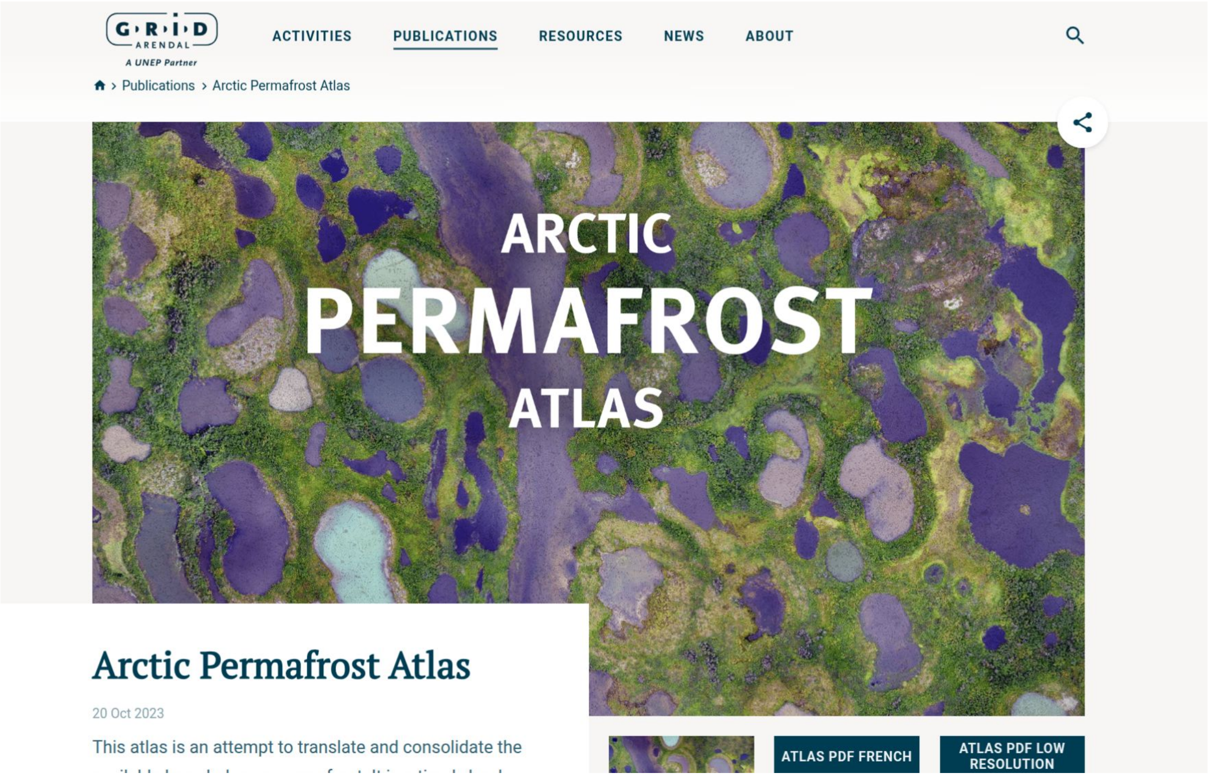
Jones B. et al. (2020): Coastal Permafrost Erosion. 2020 Arctic Report Card. National Oceanic and Atmospheric Administration (NOAA). DOI: https://doi.org/10.25923/e47w-dw52



Multiple modes of shoreline change along the Alaskan Beaufort Sea observed using ICESat-2 altimetry and satellite imagery. The Cryosphere, 19, 1825–1847. https://doi.org/10.5194/tc-19-1825-2025

U.S. Geological Survey. Alaska North Coastline

Yedoma cliff, Lena Delta, Russia



For those who want to know more…

https://gridarendal-website-live.s3.amazonaws.com/production/documents/:s_document/1041/original/PermafrostAtlas_dec2023.pdf?1704717115

Successful Adaptation Responses

- Ecosystem Restoration & Conservation
- Infrastructure & Planning Measures

Ecosystem Restoration & Conservation

Restoration of wetlands, mangroves, coral reefs, and forests

- Wetlands - removing drainage canals, reconnecting rivers to floodplains, re-establishing native plants
- Mangroves - giving local communities rights to co-manage, preventing shrimp farming and logging, planting in degraded coastal zones
- Coastal Reefs - reducing overfishing, establishing marine protected areas
- Forests - preventing logging, removing invasive species

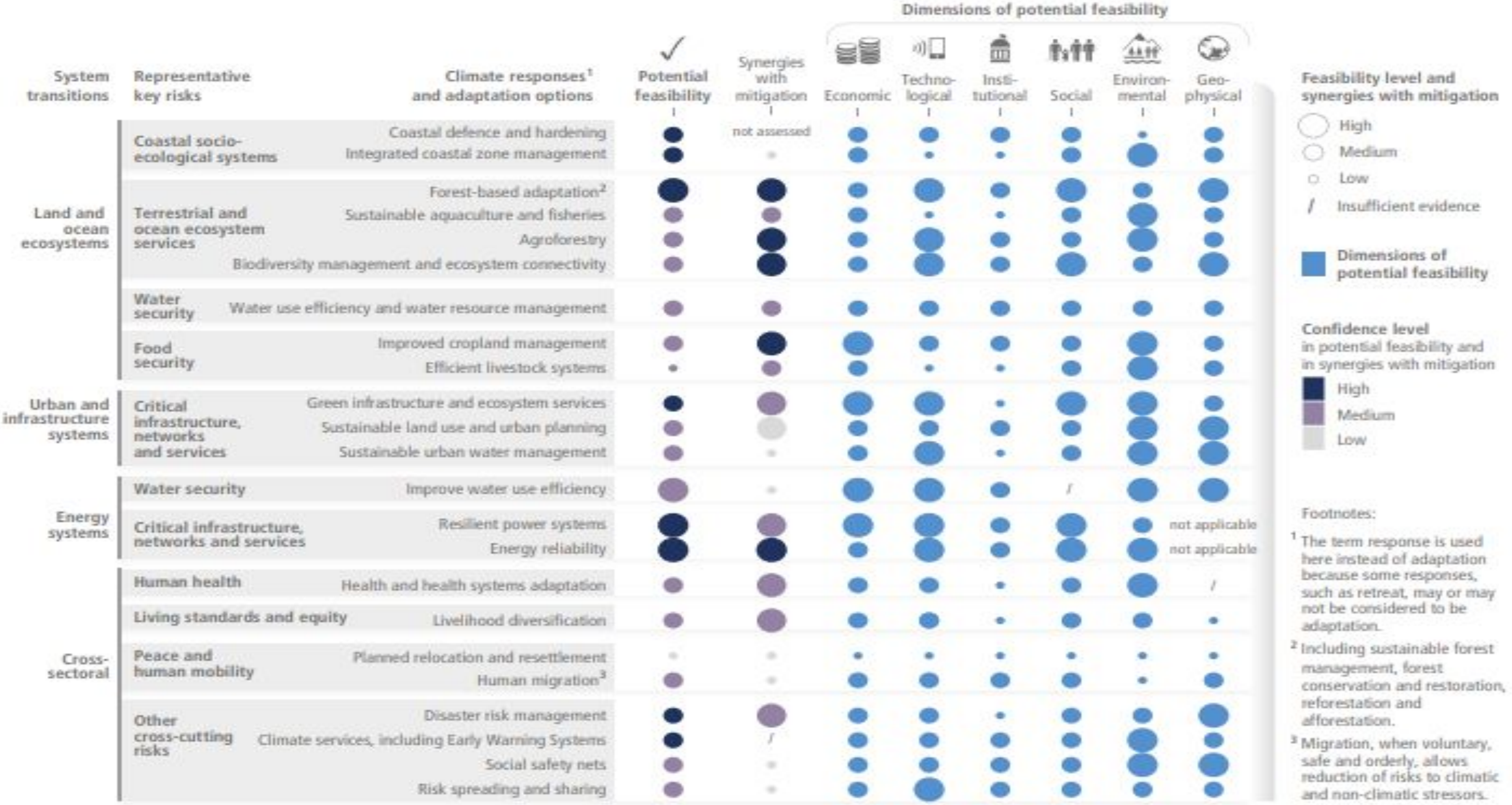
+ reduces floods, storm surges, and erosion
+ carbon sequestration

Infrastructure & Planning Measures

- Improved water management - reservoirs, recycling, irrigation technologies
- Coastal protection - seawalls, tidal barriers
- Sustainable food production system - agroforestry, crops diversification

(a) Diverse feasible climate responses and adaptation options exist to respond to Representative Key Risks of climate change, with varying synergies with mitigation

Multidimensional feasibility and synergies with mitigation of climate responses and adaptation options relevant in the near-term, at global scale and up to 1.5°C of global warming



What is needed for effective adaptation?

- Policy and Institutional Support - across sectors, long-term, on all levels
- Finance (Public & Private) - climate funds, grant-based, climate bonds
- Equity and Justice - uneven vulnerability
- Local and Indigenous knowledge - early warning system, local monitoring
- International Cooperation - shared water basins and marine ecosystems
- Innovation and Technology - climate resilient crops, water management tools, nature-based engineering