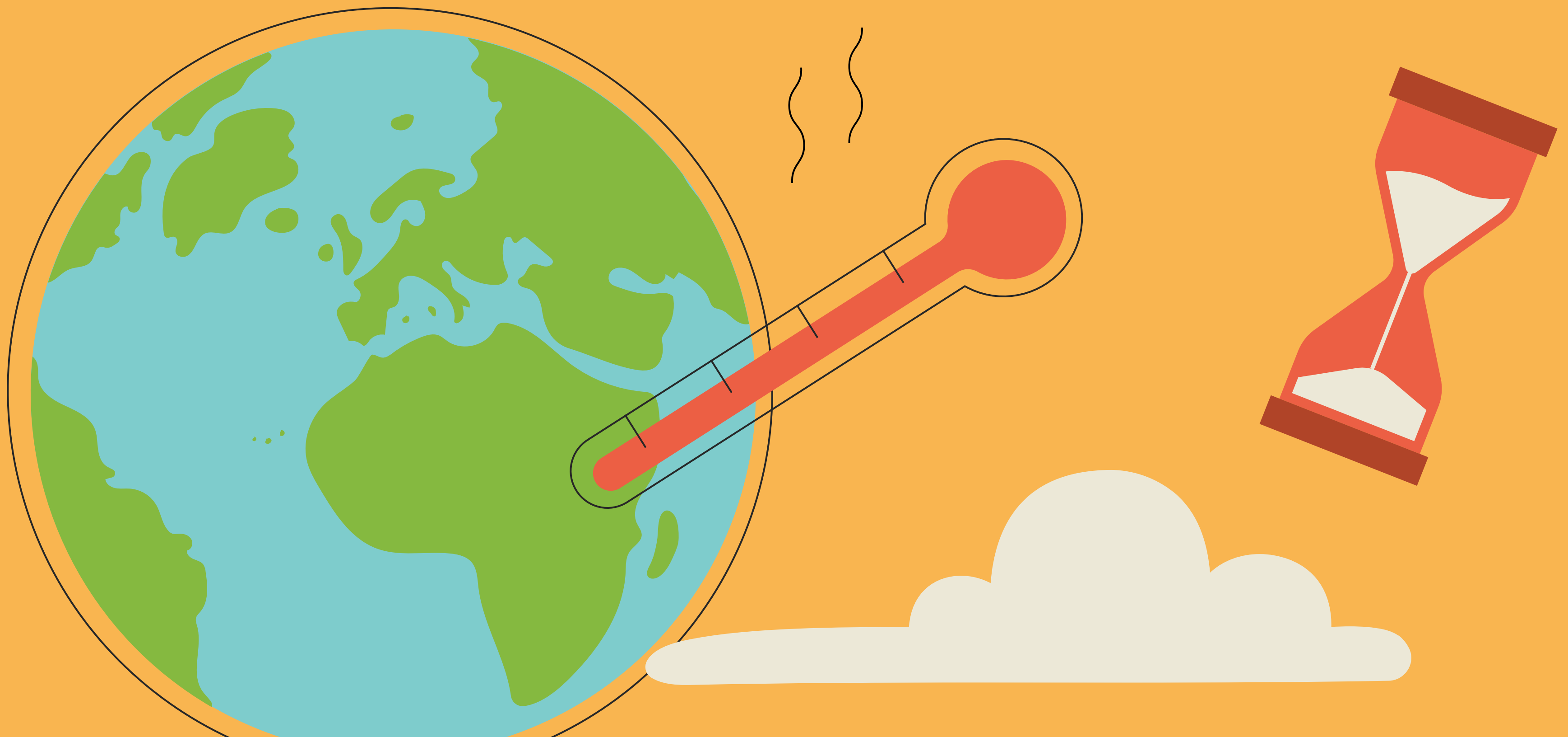
EMISSION SCENARIOS & FUTURE CLIMATES

By Pengfei Ao, Aitana Cortés, Julita Pietroń and Tisha Sitoe



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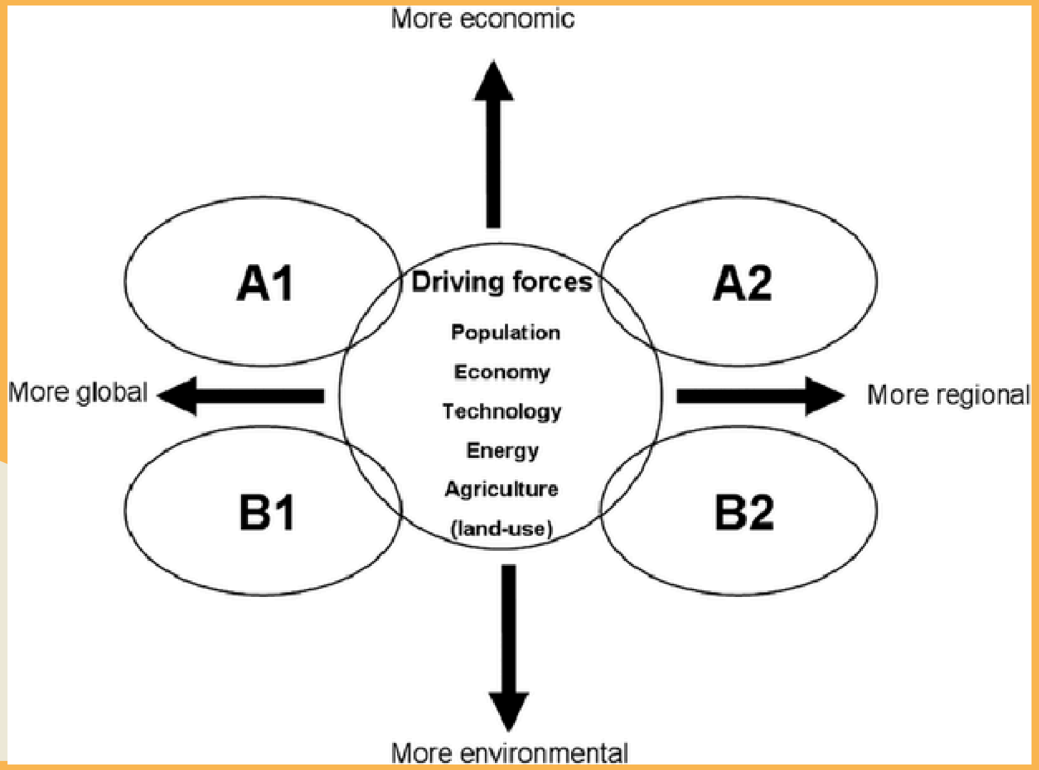
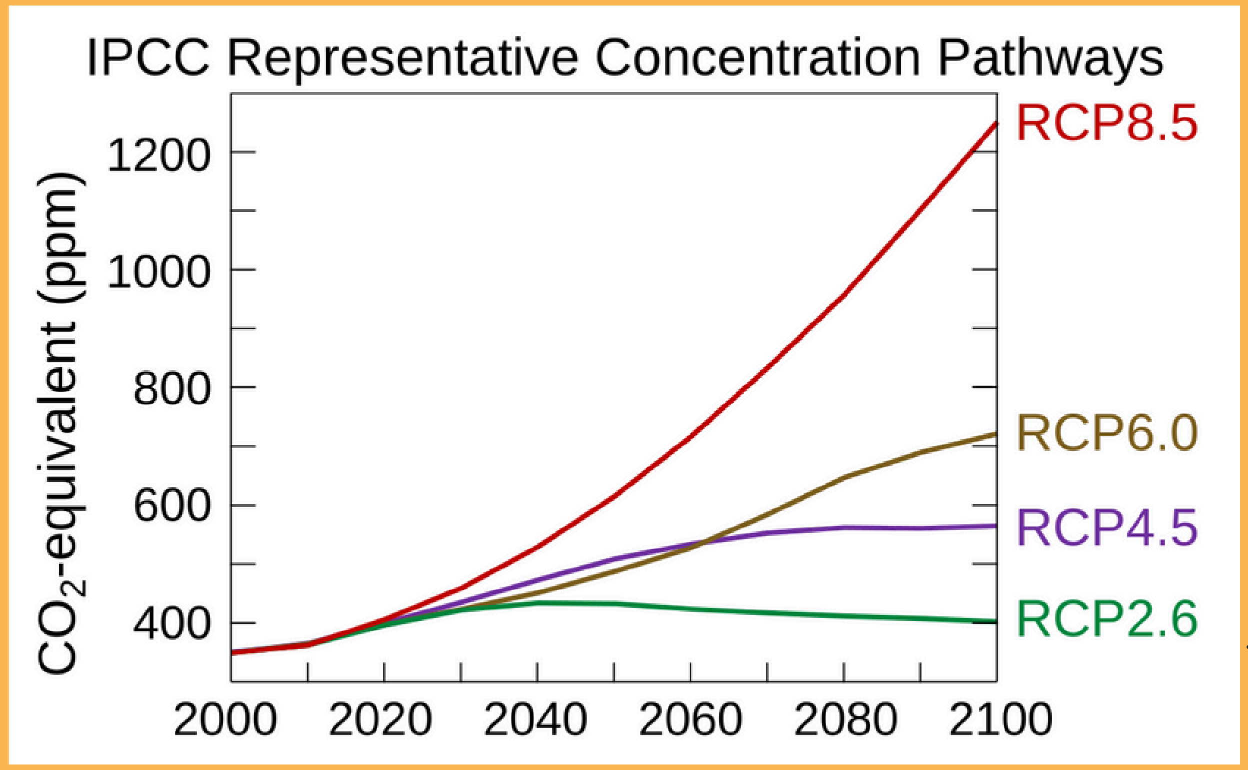
01

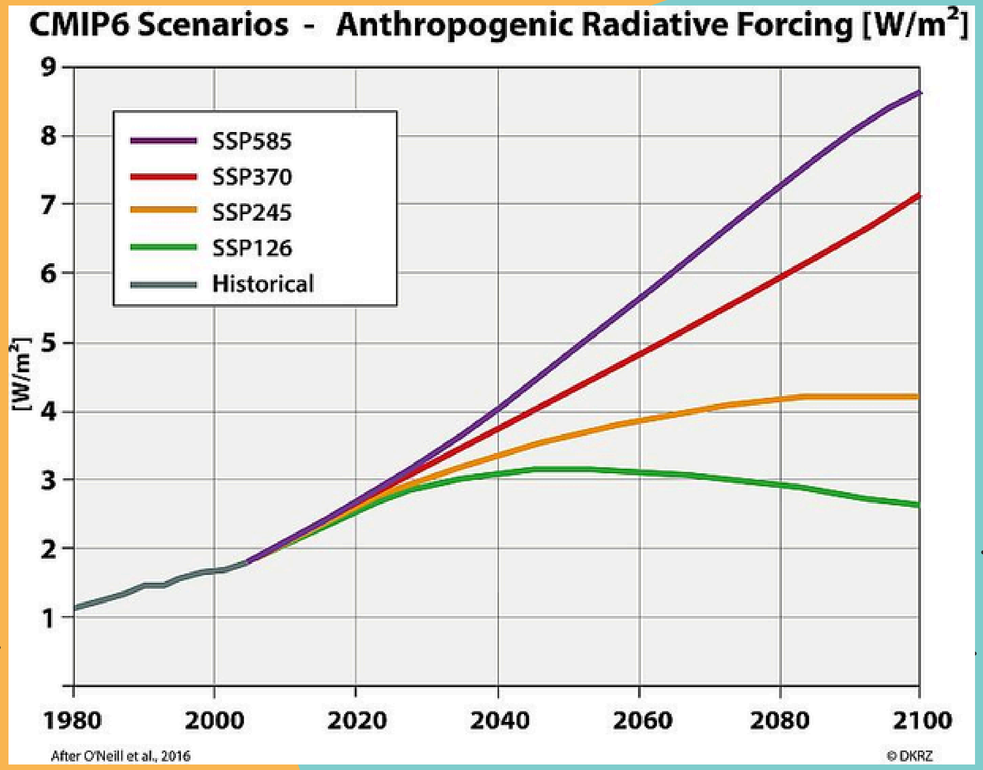
Introduction: scenarios and methodology

A climate scenario is a coherent, internally consistent description of a possible future climate, constructed for explicit use in investigating potential impacts of anthropogenic climate change and for exploring adaptation and mitigation strategies.

Projections used to simulate future climate:

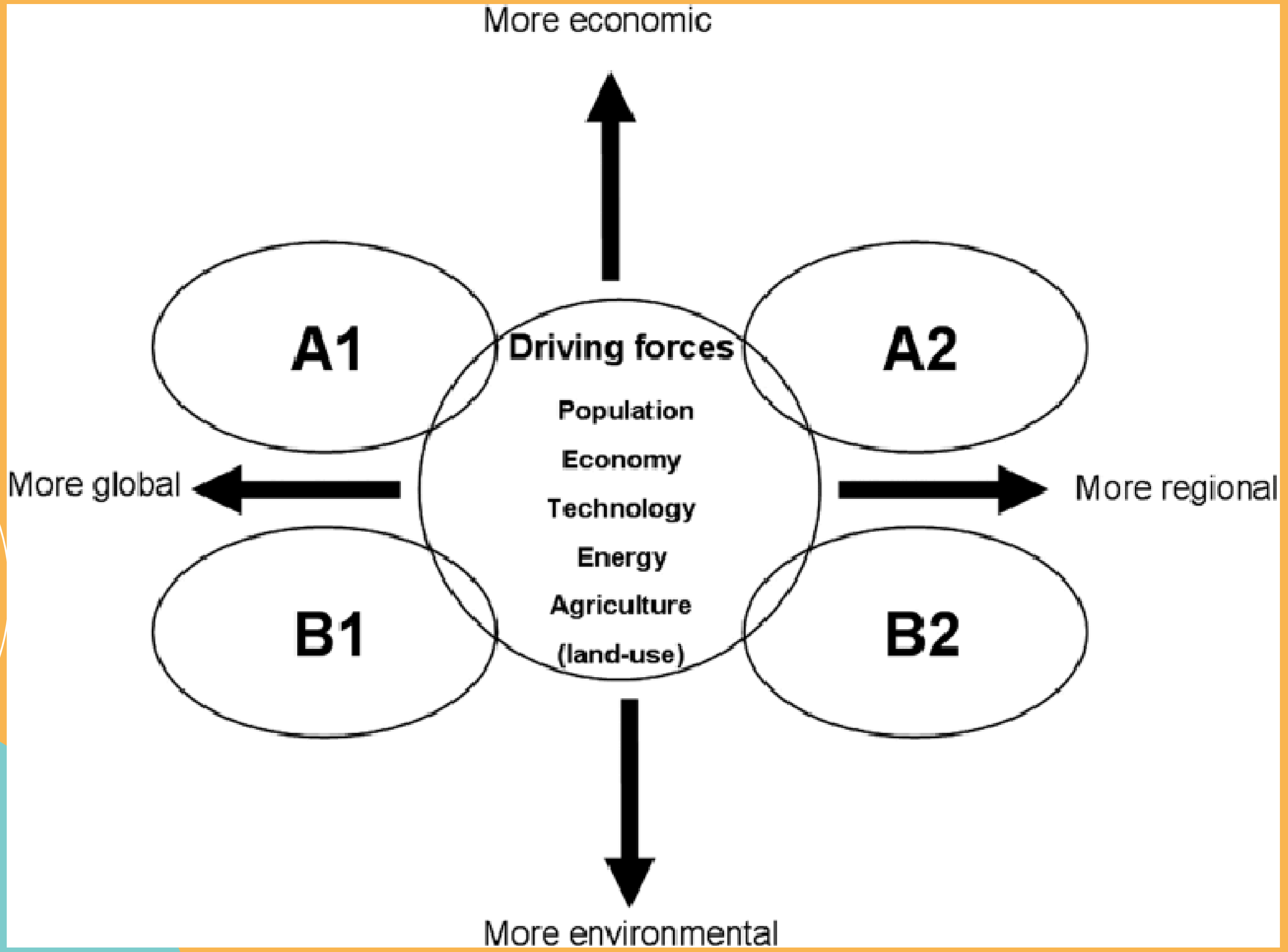






SRES

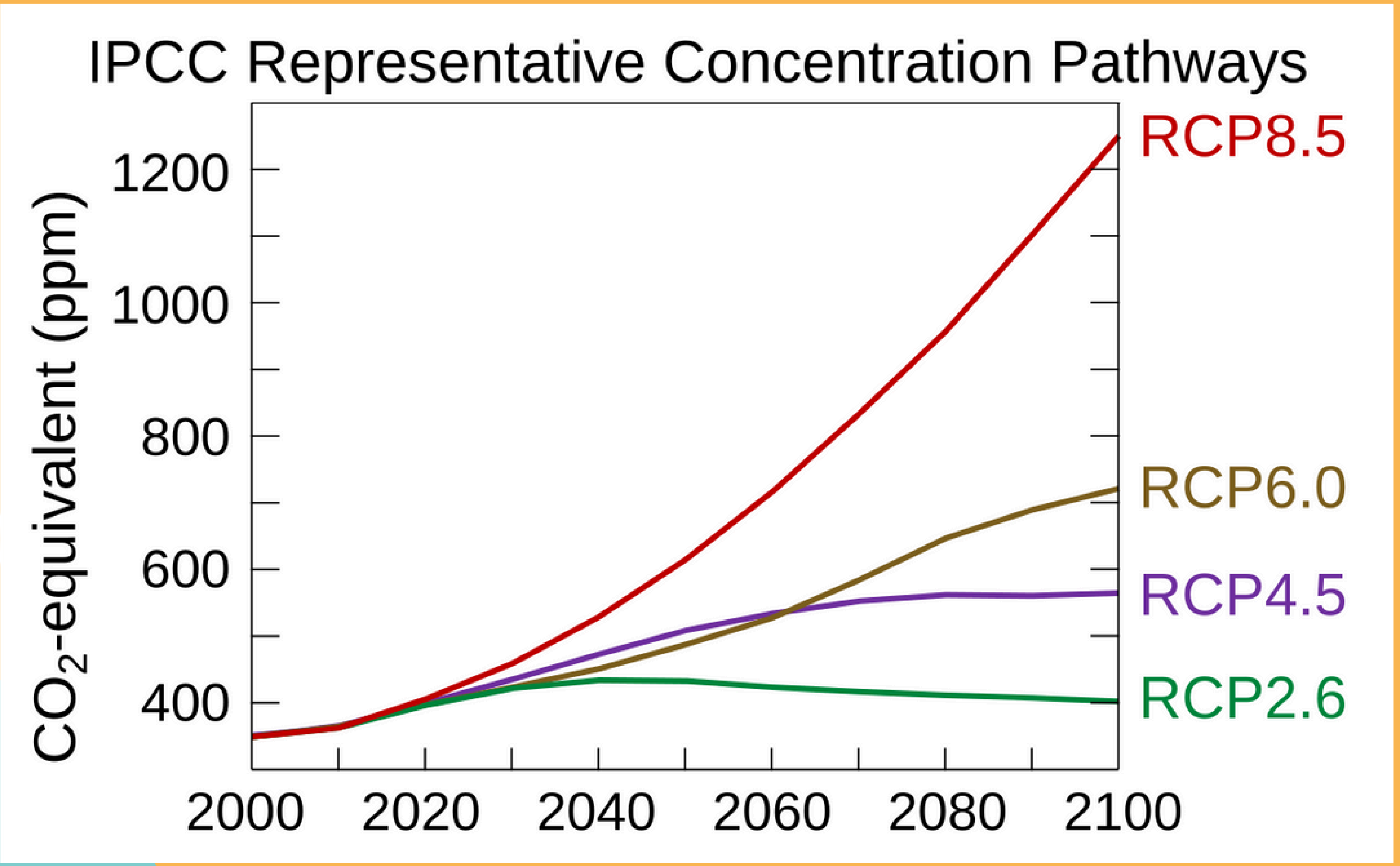
IPCC SPECIAL REPORT EMISSIONS SCENARIOS



- AR4 (2007)
- CMIP3 models
- A1: Rapid economic growth, globalized world, technological innovation (high emissions initially, may drop later).
- A2: Regionally oriented, high population growth, slower economic development (high emissions).
- B1: Global sustainability, cleaner technologies, reduced emissions.
- B2: Local solutions to sustainability, moderate emissions.

RCP

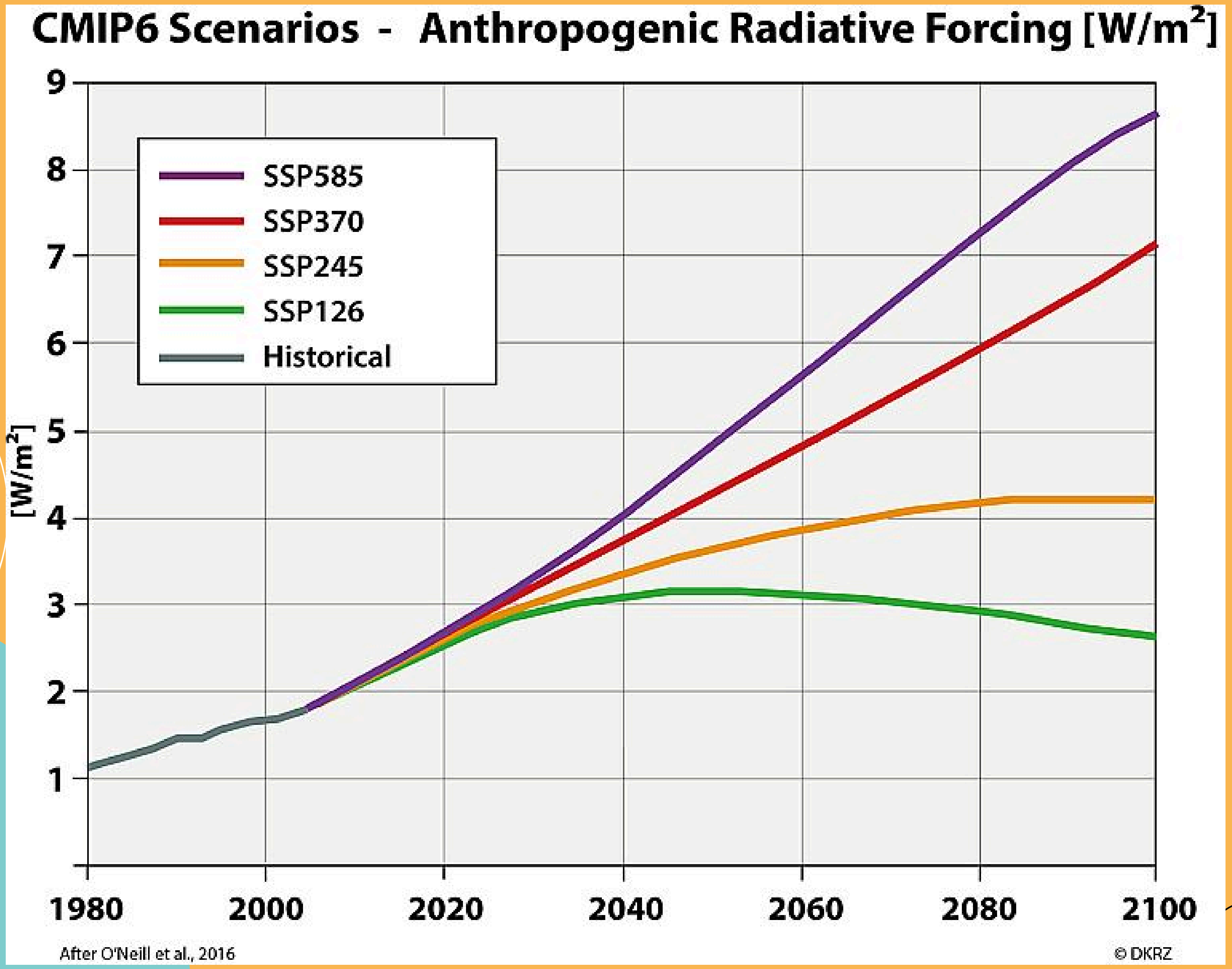
IPCC Representative Concentration Pathways



- CMIP5 models
- time series of emissions and concentrations of the full suite of greenhouse gases, aerosols and chemically active gases
- labelled after possible radiative forcing values in 2100
- four pathways describing different climate futures

SSP

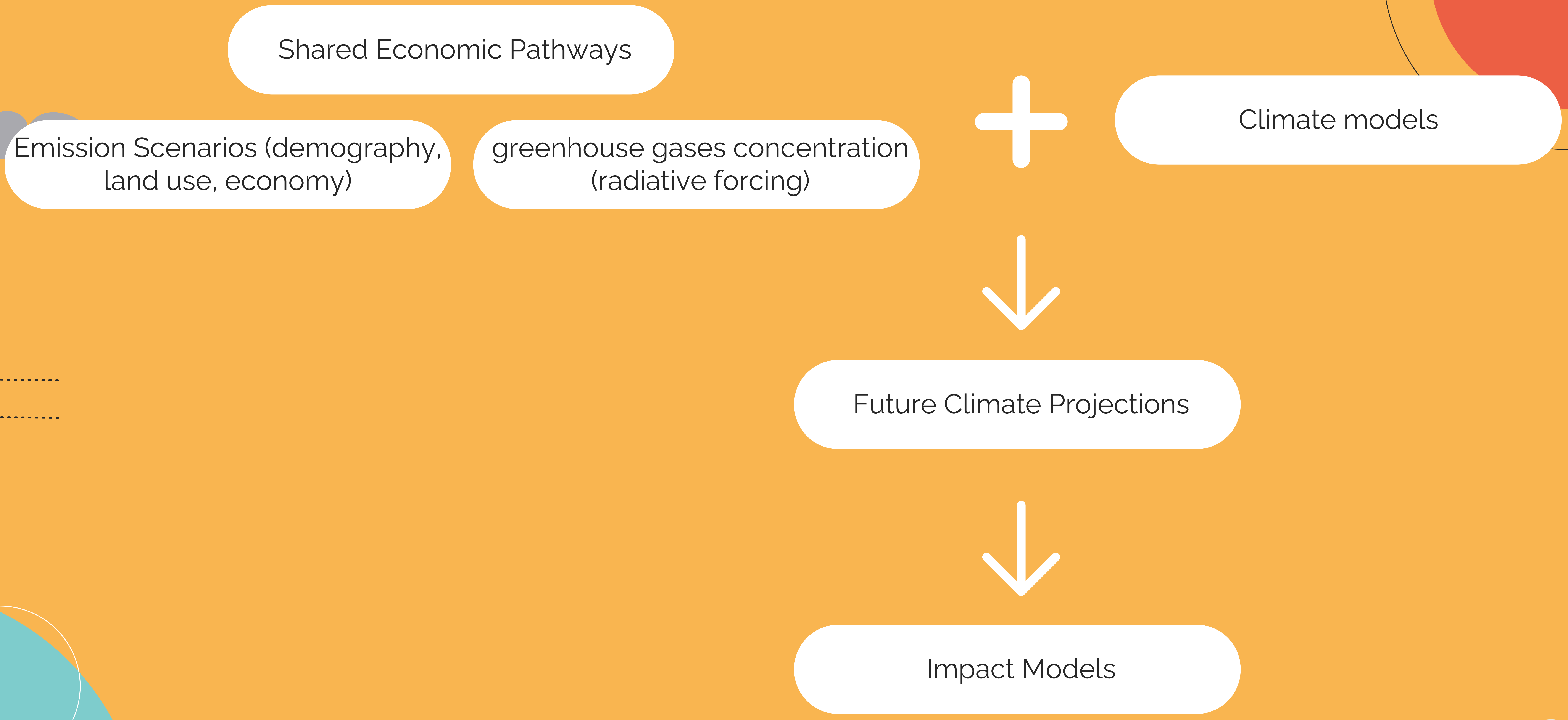
IPCC Shared Socioeconomic Pathways



Not only considers emissions but also socioeconomic factors like population, economic growth, technological development, and governance.

The five scenarios are:

- SSP1: Sustainability ("Taking the Green Road")
- SSP2: "Middle of the Road"
- SSP3: Regional Rivalry ("A Rocky Road")
- SSP4: Inequality ("A Road Divided")
- SSP5: Fossil-fueled Development ("Taking the Highway")


Shared Economic Pathways
Emission Scenarios (demography, land use, economy)
greenhouse gases concentration (radiative forcing)
Climate models
Future Climate Projections
Impact Models

Climate Scenario/Projections

What they are:

✓ Tools to explore possible futures
✓ Conditional, exploratory
✓ Often model- or evidence-based
✓ Plausible futures
✓ Inform thinking and planning

What they are not:

✗ Predictions of what will happen
✗ Certain, definitive
✗ Pure speculation or opinion
✗ Guaranteed outcomes
✗ Replace decision-making

A SIMPLIFIED REPRESENTATION OF THE POSSIBLE FUTURE CLIMATE!

02

Projected changes in the 21st century

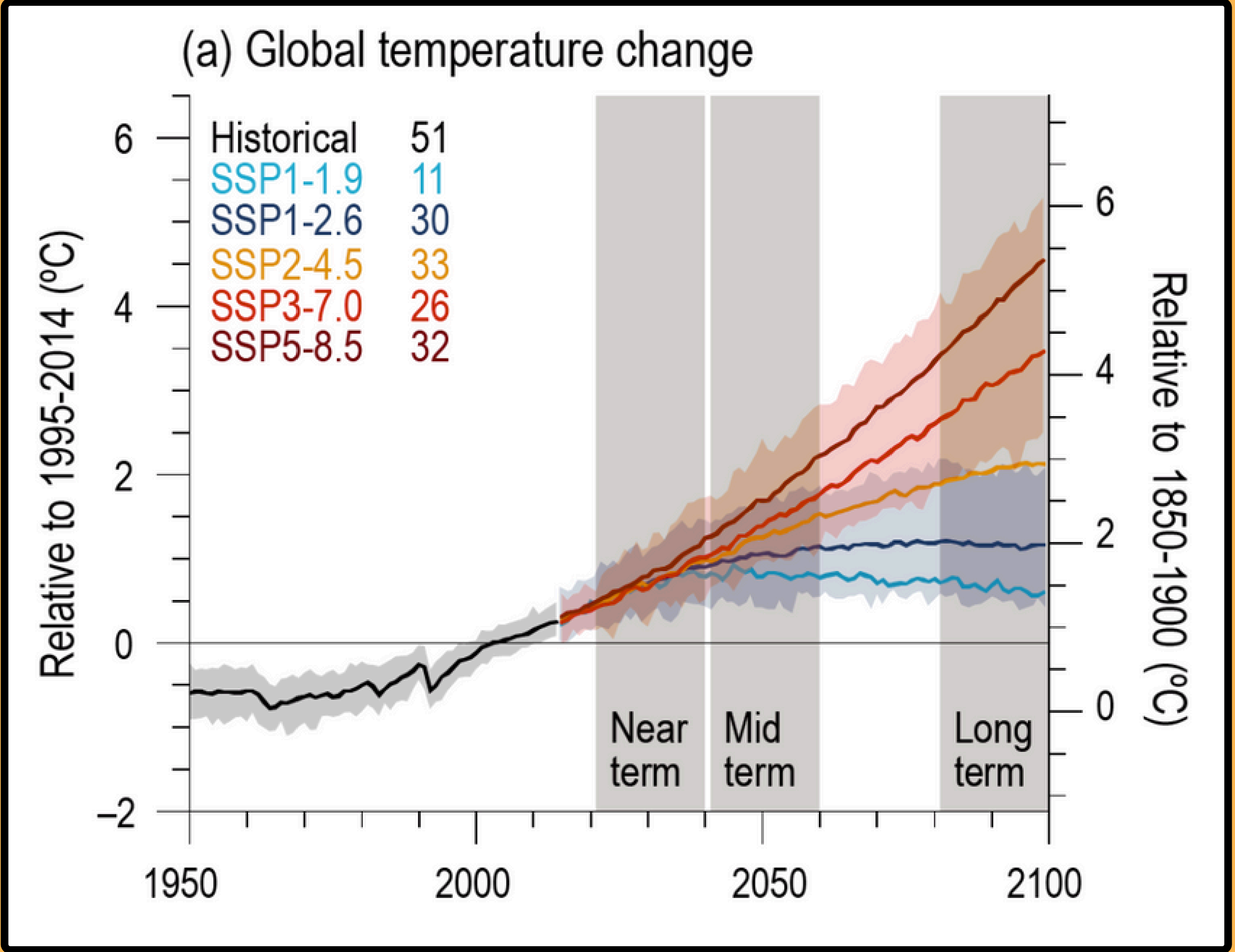
In the atmospheric and the cryospheric, oceanic and biospheric realms

ATMOSPHERE: GLOBAL SURFACE AIR TEMPERATURE

GSAT is the global average of near-surface air temperatures over land, oceans and sea ice.

The main forcing of the planet's warming is the **radiative forcing**

- Human-caused radiative forcing: 2.72 W/m^2 (2019)
  - GHG concentrations
  - Partially reduced by aerosol concentrations



TIME PERIOD	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
2021-2040	1.1-2.2 °C	1.1-2.2°C	1.0-2.3°C	1.0-2.4°C	1.2-2.4°C
2041-2060	1.1-2.4°C	1.2-2.7°C	1.5-3.0°C	1.6-3.2°C	1.8-3.4°C
2061-2100	1.0-2.2°C	1.3-2.8°C	2.1-4.0°C	2.8-5.5°C	3.6-6.5°C

Changes in temperature relative to 1850-1900

ATMOSPHERE: GLOBAL WARMING LEVEL

GWLs are defined as a global surface temperature increase of 1.5˚C, 2˚C, 3°C or 4°C relative to the mean of 1850–1900.

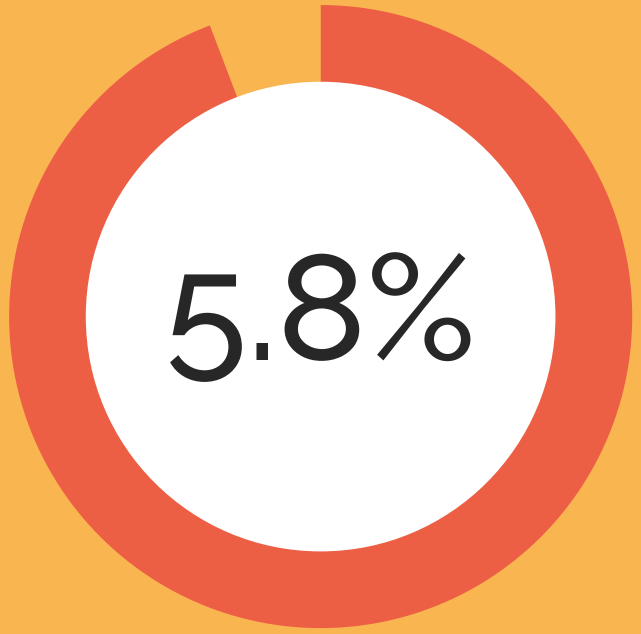
- An useful way to estimate the geographical patterns of changes independently of the details of the emissions pathways
- A near-linear relationship between cumulative CO2 emissions and the resulting increase in global surface temperature

GWL	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
1.5°C	2025-2044	2023-2042	2021-2040	2021-2040	2018-2037
2°C	n.c.	n.c.	2043-2062	2037-2056	2032-2051
3°C	n.c.	n.c.	n.c.	2066-2085	2055-2074
4°C	n.c.	n.c.	n.c.	n.c	2075-2094

The first 20-year period during which the GWL is reached

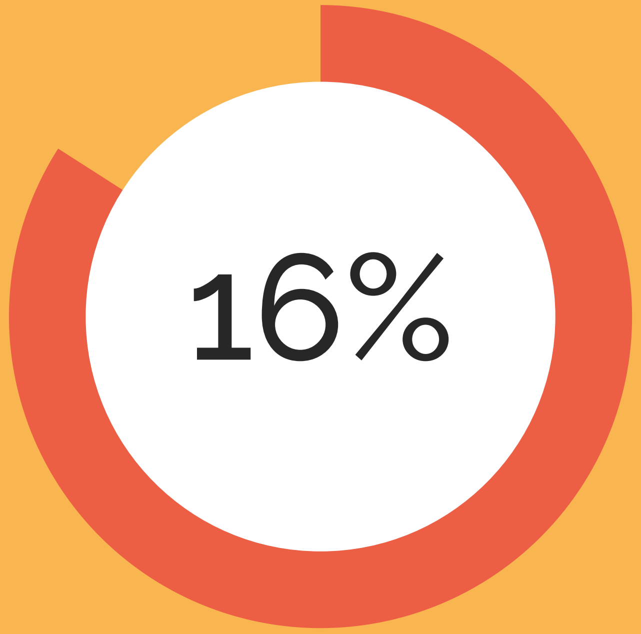
ATMOSPHERE: GLOBAL CARBON BUDGET

The carbon budget is the upper limit of total CO_2 emissions associated with staying below a specified global average temperature.



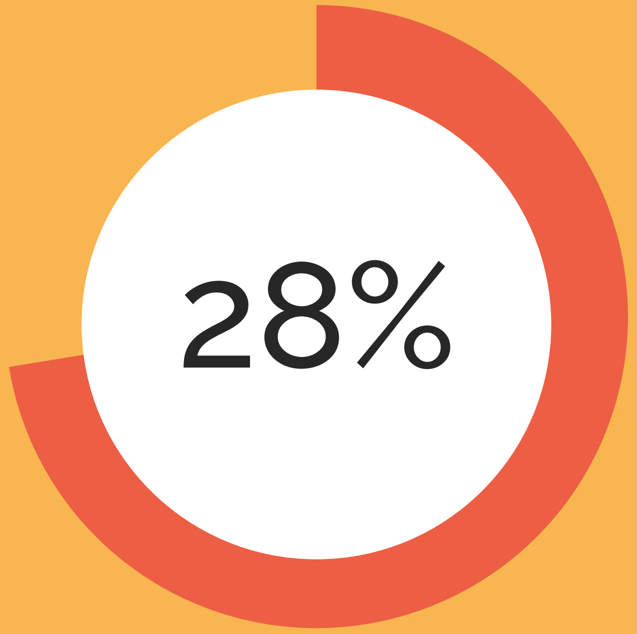
1.5°C

170 Gt CO_2 left
4 years from 2026



1.7°C

525 Gt CO_2 left
12 years from 2026



2.0°C

1055 Gt CO_2 left
25 years from 2026

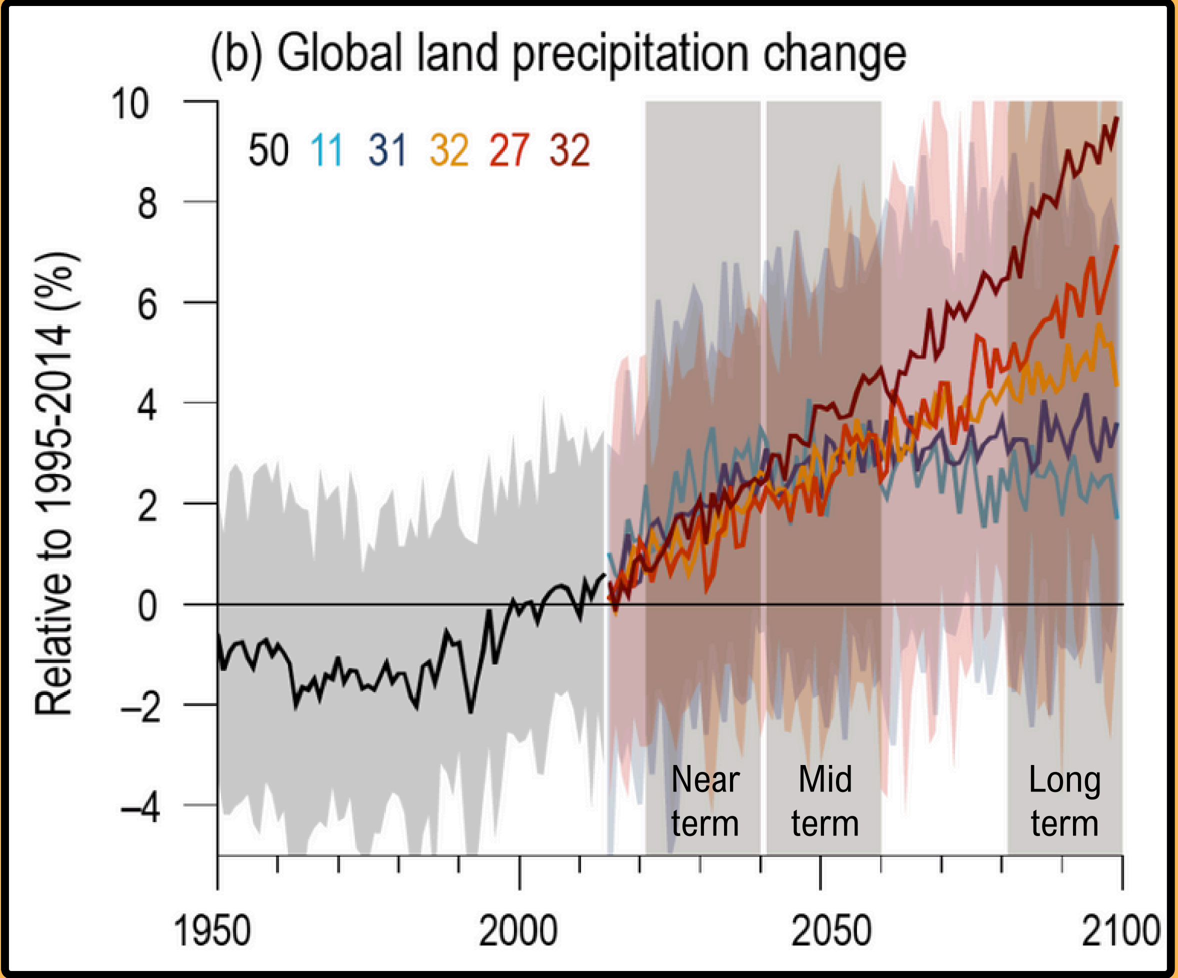
ATMOSPHERE: PRECIPITATION

Focus on **global land precipitation** (more societal relevance)

Global mean precipitation changes constrained by the energy balance:

- Warming enhances the cooling rate (+ precipitation)
- Increase of CO_2 → decrease in efficiency of radiative cooling (- precipitation)

Extreme precipitation is constrained by the atmospheric moisture content.



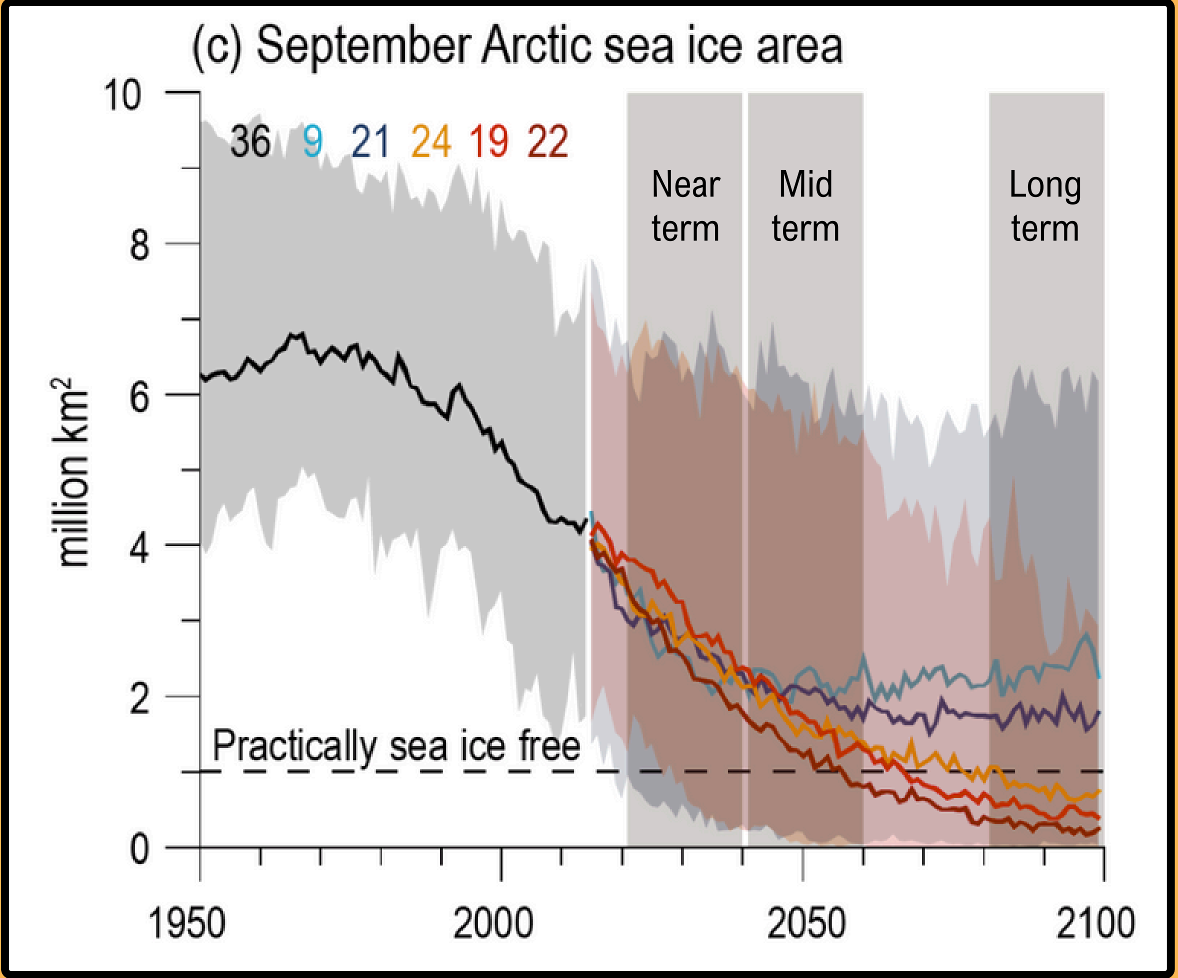
TIME PERIOD	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
2021-2040	0.7 - 4.1%	-0.6 - 3.6%	-0.4 - 3.6%	-1.0 - 3.4%	-0.1 - 4.1%
2041-2060	0.6 - 5.0%	-0.4 - 5.2%	0.3 - 5.2%	-0.8 - 5.1%	-0.1 - 6.9%
2061-2100	-0.2 - 4.7%	0.0 - 6.6%	1.5 - 8.3%	0.5 - 9.6%	0.9 - 12.9%

Precipitation anomalies (%) relative to averages over 1995-2014 (5th-95th percentile)

ARCTIC SEA ICE COVERAGE

Sea ice **extent** is defined as the area with at least 15% of sea covered with ice.
Ice accumulates as seawater freezes during colder months and melts away during the warmer months.

- On average the Arctic will become practically ice-free in September by the end of the 21st century under SSP2-4.5, SSP3-7.0, and SSP5-8.5
- Much-reduced likelihood of a practically ice-free Arctic Ocean during summer for global warming of 1.5˚C than for 2.0˚C.



TIME PERIOD	SSP1-1.9	SSP1-2.6	SSP2-4.5	SSP3-7.0	SSP5-8.5
2021-2040	14.0 - 2.6	14.9 - 2.7	14.9 - 2.8	15.0 - 3.1	14.9 - 2.5
2041-2060	13.8 - 2.2	14.5 - 2.0	14.3 - 1.7	14.2 - 1.7	13.9 - 1.2
2061-2100	13.7 - 2.4	14.2 - 1.7	13.1 - 0.8	11.8 - 0.5	9.7 - 0.3

Arctic sea ice area for March - September (in 10^6 km^2)

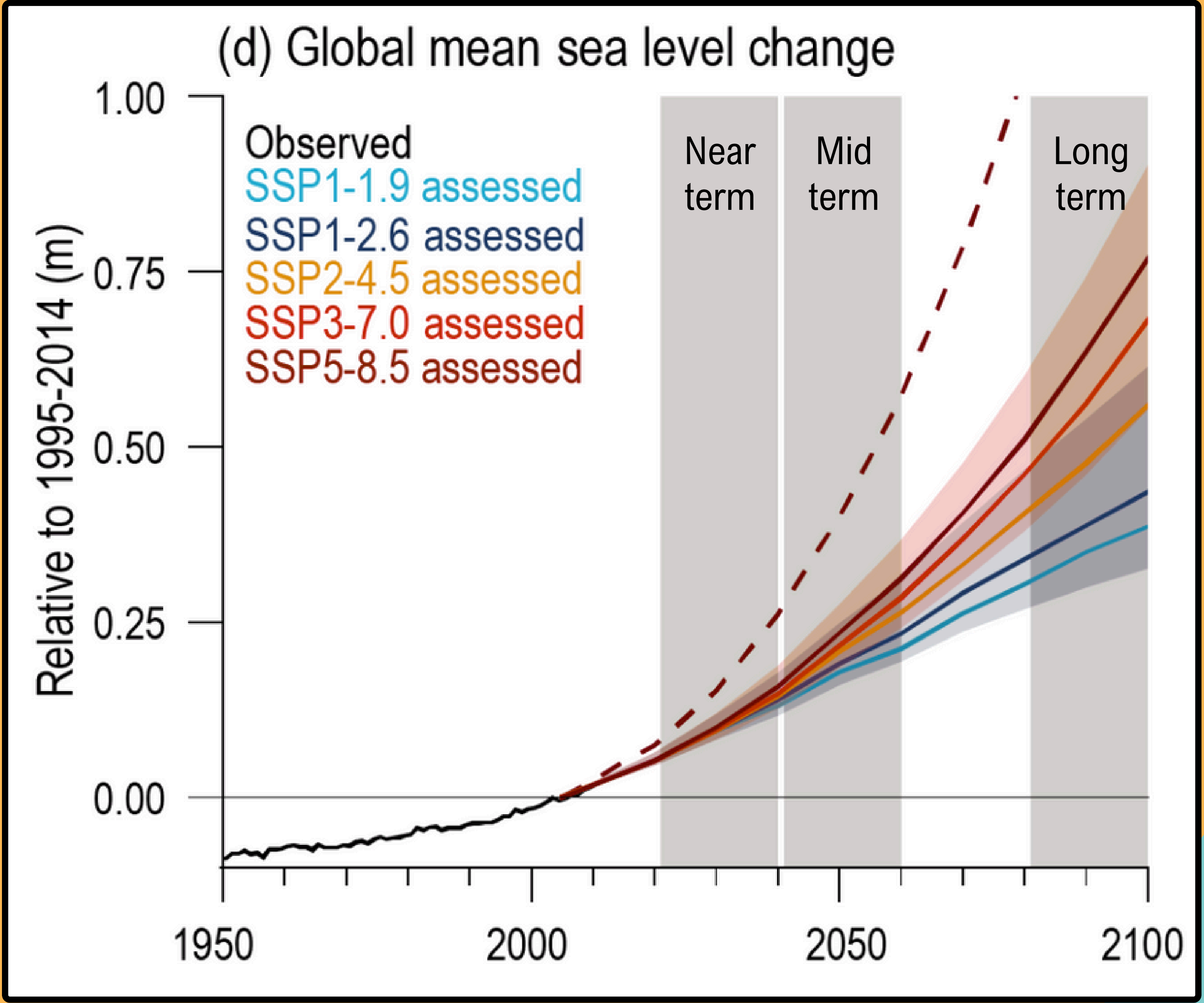
GLOBAL MEAN SEA LEVEL

GMSL is the average height of the entire ocean surface. It's caused primarily by 2 factors:

44%
Melting ice sheets and glaciers

42%
Thermal expansion of water

Sea level rise lags behind changes in the Earth's temperature by decades, and sea level rise will therefore continue to accelerate between now and 2050 in response to warming that has already happened.



OCEAN AND LAND CARBON UPTAKE

A **carbon sink** is a carbon sequestration process that has the capability to take up more carbon from the atmosphere than it releases. The main carbon sinks in the Earth are:

Land sink

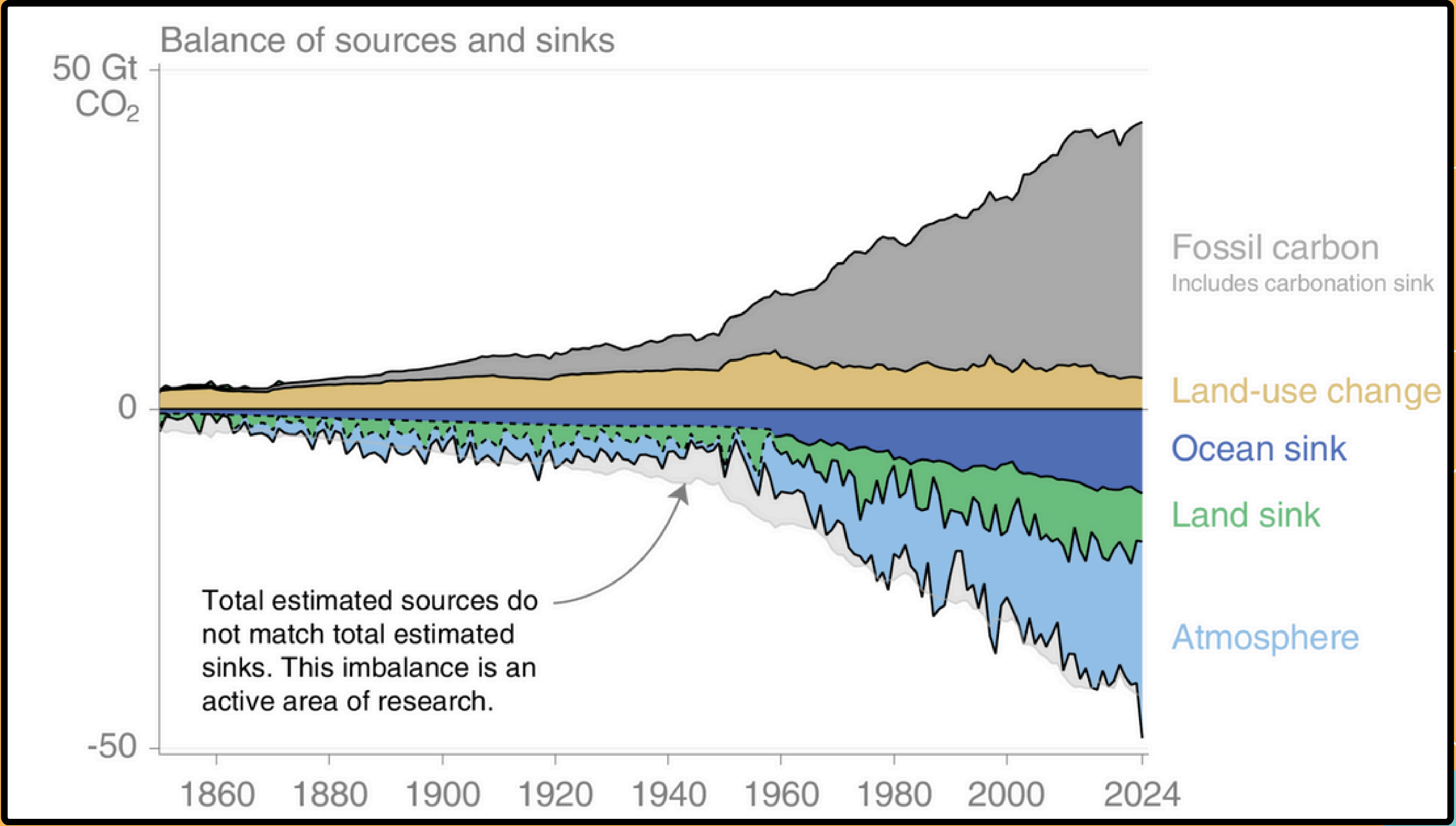
Plants absorb CO_2 through photosynthesis

- Deforestation and land degradation reduce its effectivennes

Ocean sink

Absorption of CO_2 through:

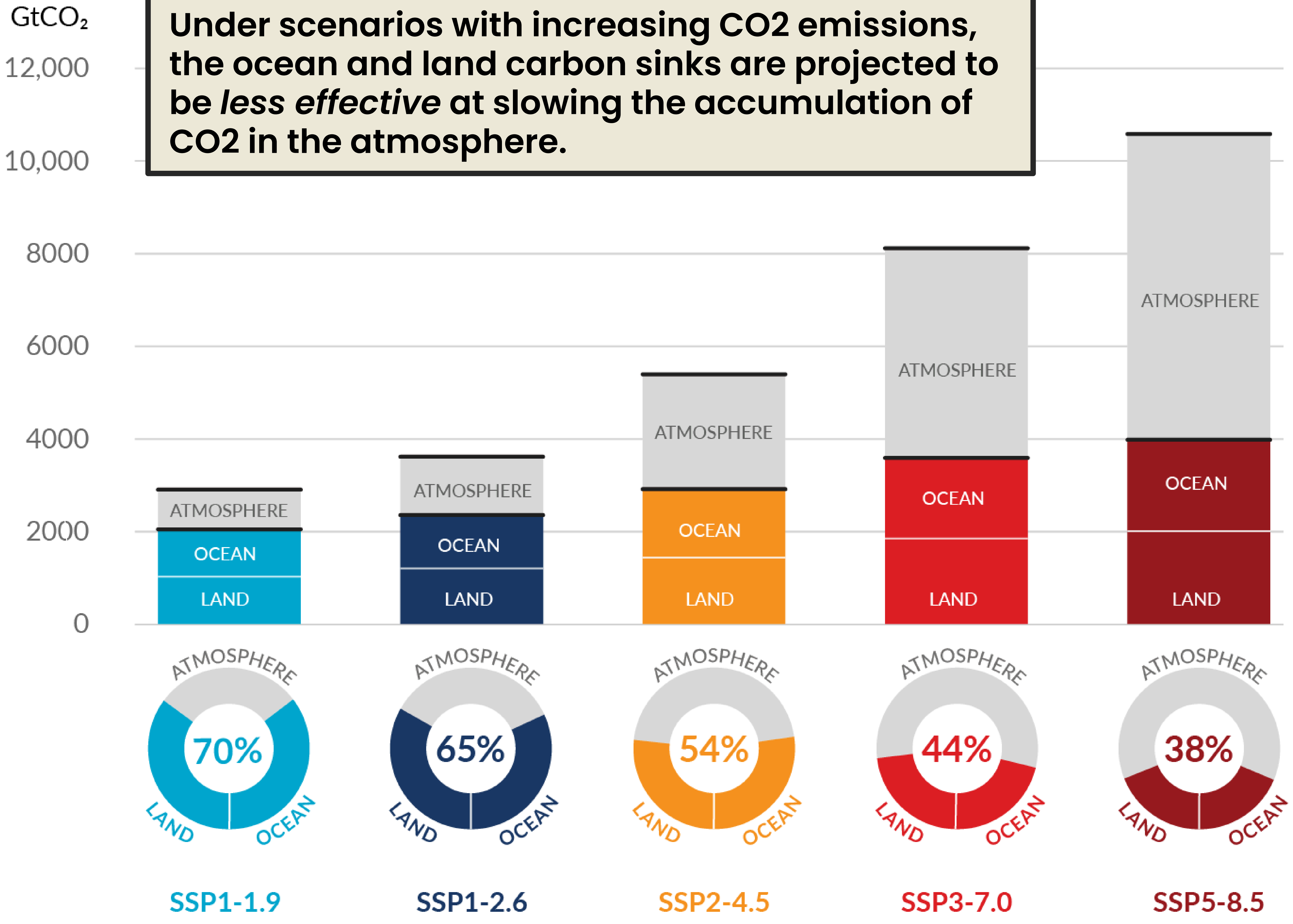
- Dissolution in the surface water (more soluble with cold temperatures)
- Photosynthesis from the phytoplankton



While natural land and ocean carbon sinks are projected to take up, in absolute terms, a progressively larger amount of CO2 under higher emissions scenarios, they become less effective

Total cumulative CO_2 emissions **taken up by land and ocean** (colours) and remaining in the atmosphere (grey) under the five illustrative scenarios from 1850 to 2100

Under scenarios with increasing CO2 emissions, the ocean and land carbon sinks are projected to be *less effective* at slowing the accumulation of CO2 in the atmosphere.



For scenarios with **higher** cumulative CO_2 emissions…

…the amount of CO_2 emissions taken up by land and ocean carbon sinks is **larger**, but more of the emitted CO_2 remains in the atmosphere…

…meaning that the proportion of CO_2 emissions taken up by land and ocean carbon sinks from the atmosphere is **smaller** in scenarios with higher CO_2 emissions.

GLOBAL SURFACE OCEAN pH

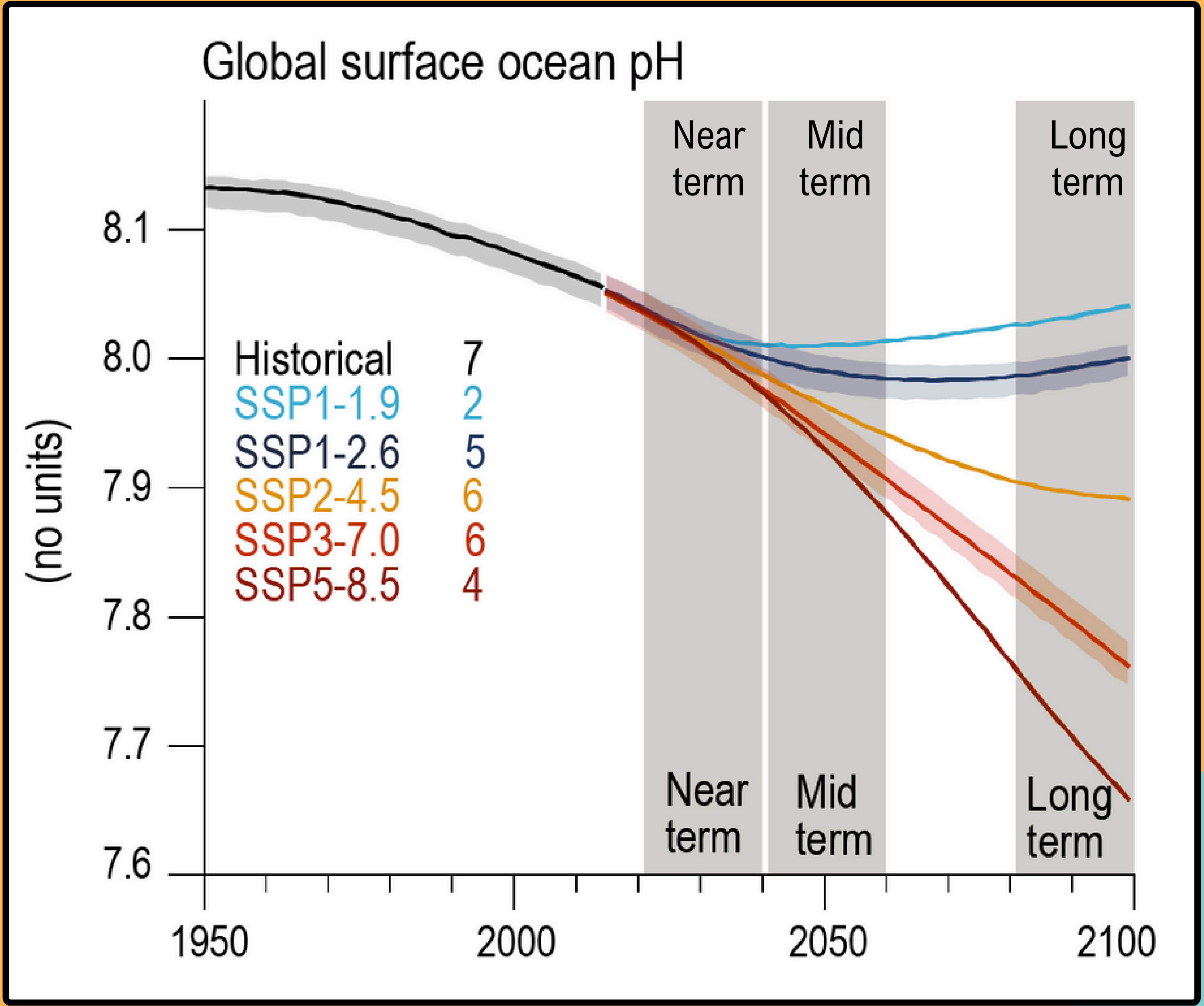
When CO_2 is dissolved in water, a part of it reacts with water to become carbonic acid. It is the hydrogen ions present in carbonic acid that make water acidic, lowering the pH.

30% Increase in ocean acidity during the 20th century (a pH decrease of 0.1)

The rate of change in ocean acidification is much higher than in the geological past.

- Prevents organisms from gradually adapting
- Prevents climate cycle feedbacks from kicking in to mitigate ocean acidification

Ocean acidification is now on a path to reach lower pH levels than at any other point in the last 300 million years.



03

Near-term changes regionally

This section assesses changes in large-scale climate over the period 2021–2040 and includes information from both projections and initialized decadal predictions.

the assessment assumes that there will be no major volcanic eruption in the near term

Atmosphere

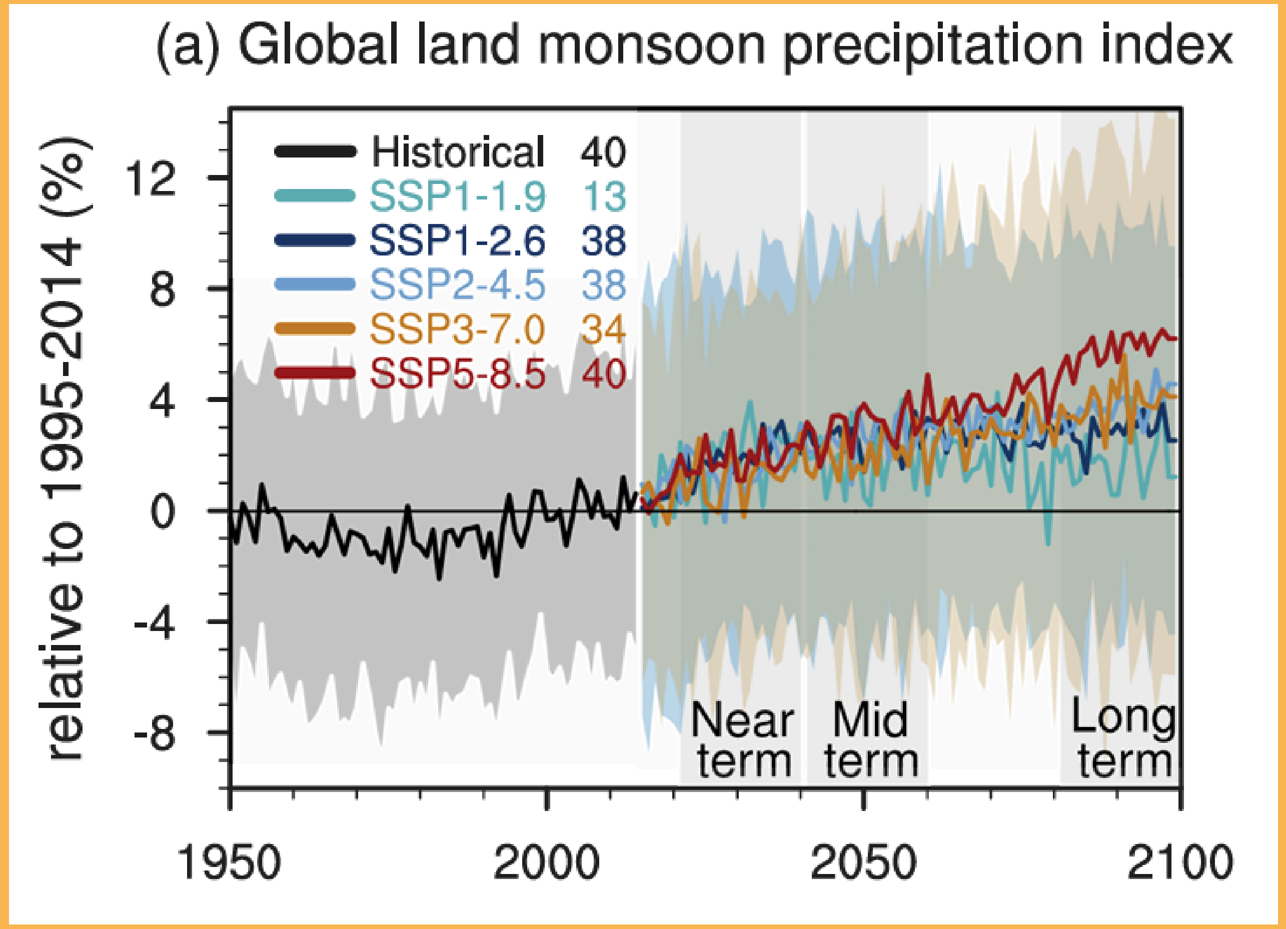
Cryosphere, Ocean and Biosphere

Modes of Variability

Response to Short-lived Climate Forcers and Volcanic Eruptions

The Climate Effects of Volcanic Eruption

Atmosphere



Average Global Surface Air Temperature

By 2030, GSAT in any individual year could exceed 1.5˚C relative to 1850–1900 with a likelihood between 40 and 60 percent, across the five SSP scenarios

Spatial Patterns of Surface Warming

the largest warming occurs at high latitudes, particularly in boreal winter in the Arctic , and larger warming over land than over the ocean. regions that do not show robust warming in the near-term include the northern North Atlantic, parts of India, parts of North America and Eurasia in winter, and the subtropical eastern Pacific in the Southern Hemisphere.

Precipitation

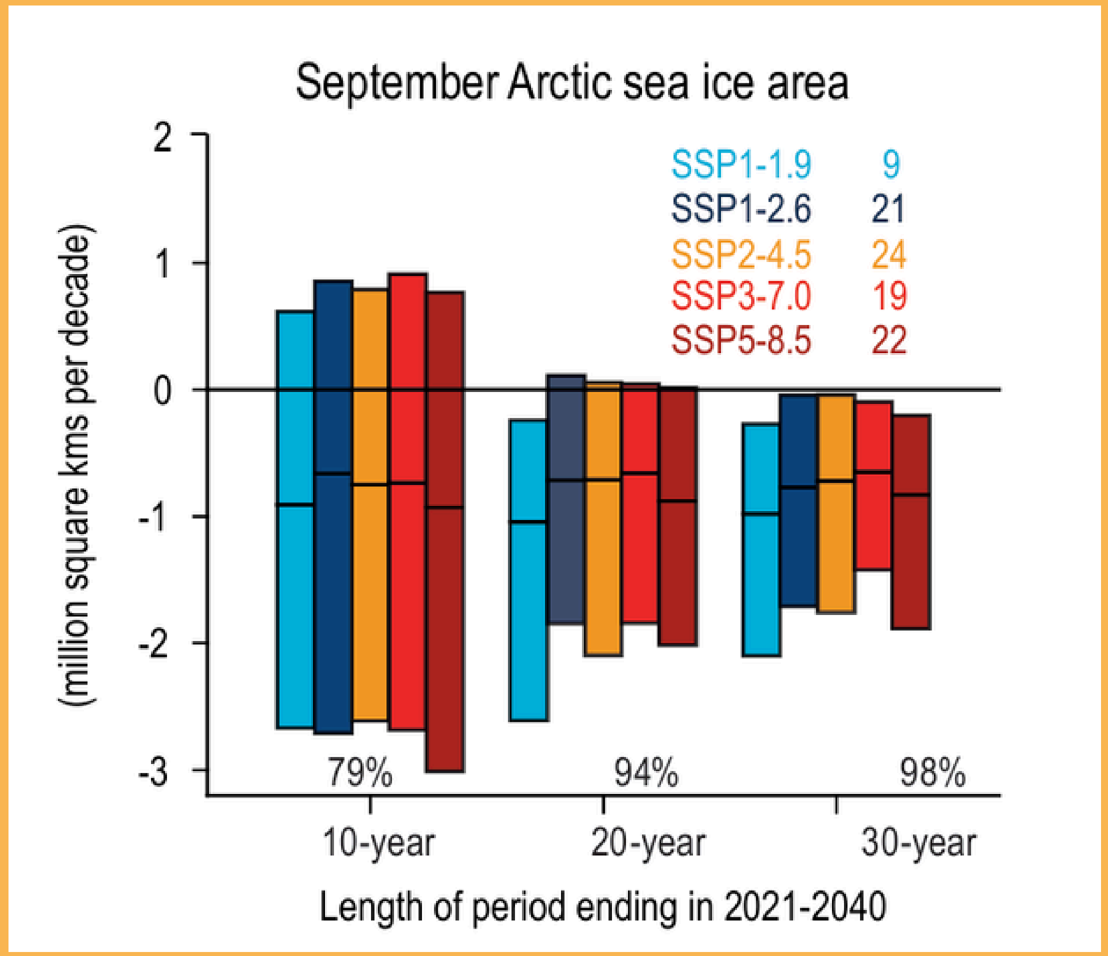
increasing at high latitudes, over oceanic regions, and in wet regions over the tropics; and decreasing in dry regions including large parts of the subtropics.The large uncertainties in near-term regional precipitation projections arise due to the interplay between internal variability and anthropogenic external forcing

Global Monsoon Precipitation and Circulation

The global land monsoon precipitation index, defined as the area weighted precipitation rate in the global land monsoon domain, tends to increase in the near term under all five core SSPs

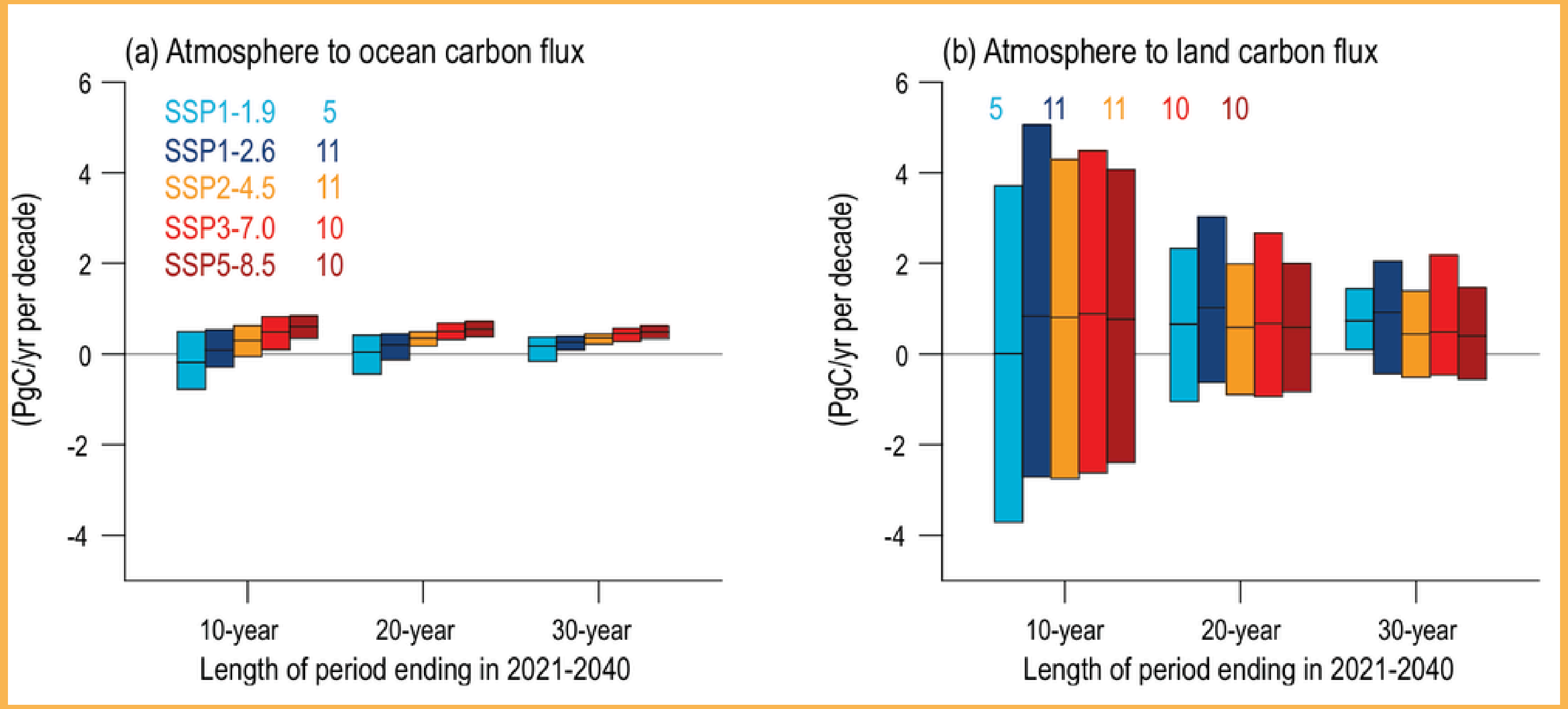
Cryosphere, Ocean and Biosphere

Arctic Sea Ice



Based on results from CMIP6 models, we conclude that Arctic SIA will decrease in September in the near term. Arctic sea ice coverage in September will drop below 1 million km2, or become practically ice-free, at some point between 2040 and 2060

Ocean and Land Carbon Flux



it is likely that ocean carbon flux will increase in the near term under the higher emissions scenarios, while a large component of terrestrial variability makes it is unlikely that an increase in land carbon flux will be detected over this period.

Modes of Variability

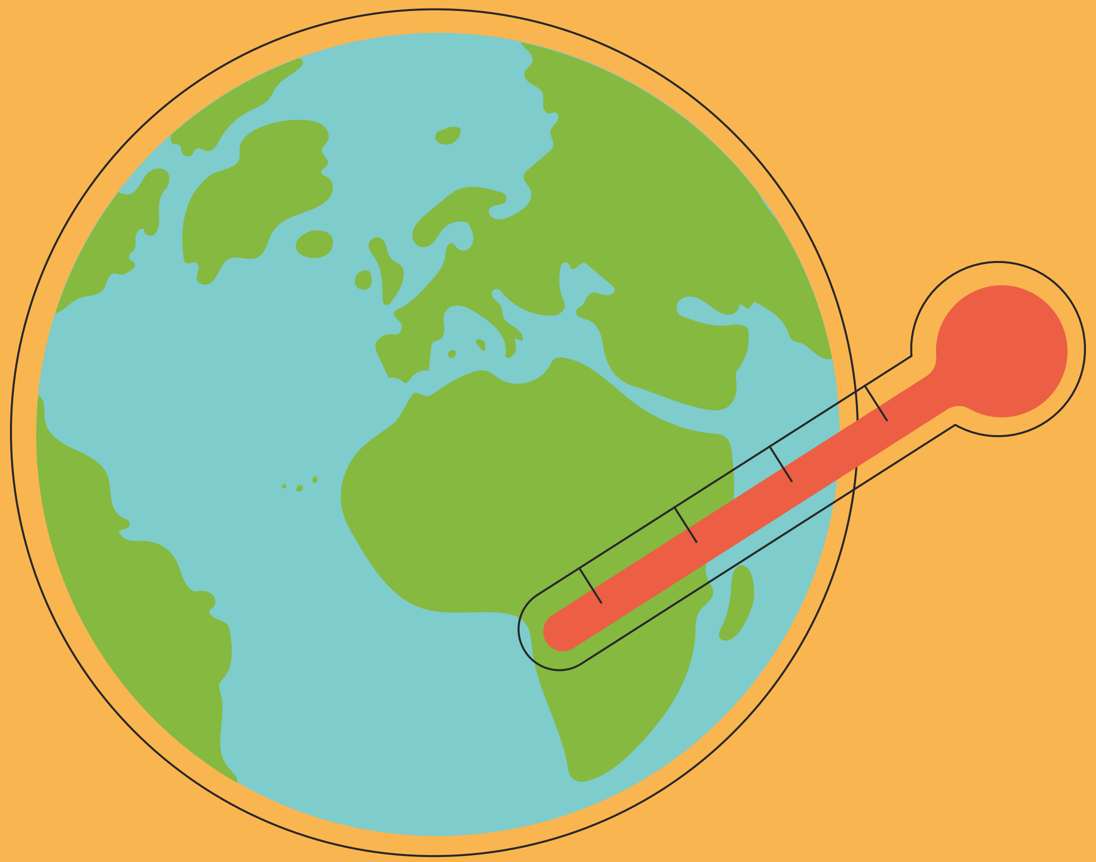
Northern and Southern Annular Modes

the projected near term multi-model mean change in the NAM is small

in the near-term under all assessed SSP scenarios the SAM index would become more positive than in present-day in austral autumn, winter and spring.

Pacific Decadal Variability

Because PDV represents not one, but many dynamical processes, it represents a challenge as a target for near-term climate predictions and projections.



El Niño–Southern Oscillation

using CMIP6 models, shows no robust change in ENSO SST variability in the near term.

no robust change in amplitude of ENSO SST and rainfall variability is expected in the near term

Response to Short-lived Climate Forcers and Volcanic Eruptions

Short-lived Climate Forcers

Table 4.6 | The net effect of SLCFs on GSAT change. Changes in 20-year averaged GSAT relative to 1995–2014 for 2021–2040, 2041–2060, and 2081–2100 for the five marker SSP scenarios. Values give the median and, in parentheses, the 5–95% range calculated from a 2237-member ensemble of the two-layer emulator that is driven with the ERF projections, including uncertainties, described in Chapter 7 Supplementary Material 7.SM.1.4. The ensemble is constrained to assessed ranges of ECS, TCR, ocean heat content change, GSAT response, and carbon cycle metrics (Section 7.3.5; Chapter 7 Supplementary Material 7.SM.2.2). The GSAT contribution of individual forcer responses use the difference between parallel runs of the constrained two-layer model with all anthropogenic forcing and all anthropogenic forcing with the component of interest (e.g., methane) removed (Chapter 7 Supplementary Material 7.SM.2.3). Values are given to one decimal place.

Time Period	SSP1-1.9 (°C)	SSP1-2.6 (°C)	SSP2-4.5 (°C)	SSP3-7.0 (°C)	SSP5-8.5 (°C)
Near Term (2021–2040)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)	0.2 (0.1, 0.3)	0.3 (0.2, 0.4)
Mid-Term (2041–2060)	0.2 (0.0, 0.4)	0.2 (0.0, 0.4)	0.3 (0.2, 0.4)	0.3 (0.2, 0.4)	0.5 (0.3, 0.7)
Long Term (2081–2100)	0.1 (-0.1, 0.4)	0.2 (0.0, 0.4)	0.3 (0.1, 0.6)	0.5 (0.4, 0.8)	0.7 (0.4, 1.0)

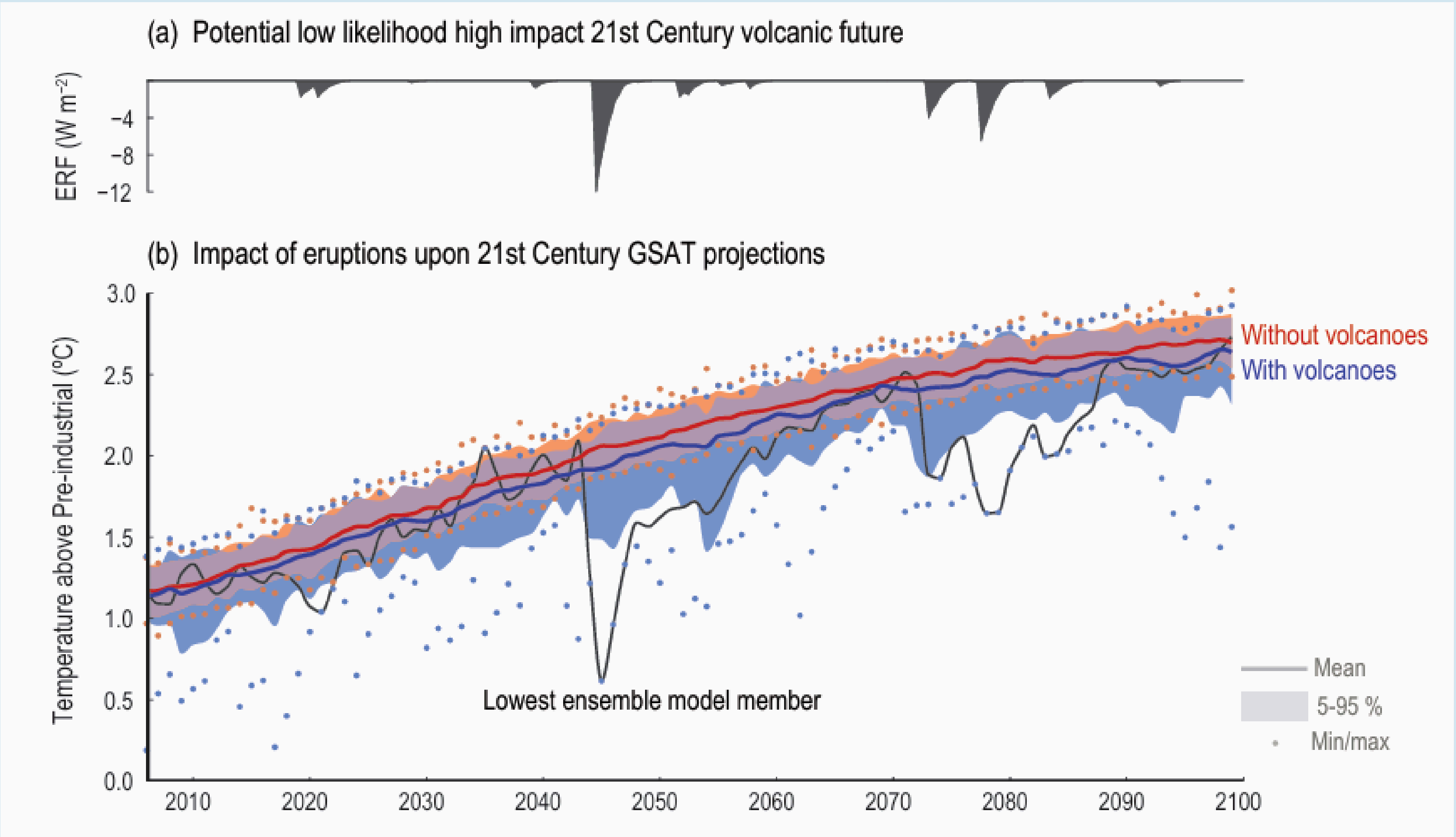
it is very likely that changes in SLCFs contribute to an overall warmer GSAT over the near, mid- and long term in the five SSP scenarios considered

Volcanic Eruptions

Another factor that could substantially alter projections in the near-term would be the occurrence of a large explosive volcanic eruption, or even a decadal to multi-decadal sequence of small-to moderate volcanic eruptions as witnessed over the early 21st century

Volcanic eruptions generally result in decreased global precipitation for up to a few years following the eruption. with climatologically wet regions drying and climatologically dry regions wetting

The Climate Effects of Volcanic Eruption



Cross-Chapter Box 4.1, Figure 1 | Potential impact of volcanic eruption on future global temperature change. CMIP5 projections of possible 21st-century futures under RCP4.5 after a 1257 Samalas magnitude volcanic eruption in 2044, from Bethke et al. (2017). **(a)** Volcanic ERF of the most volcanically active ensemble member, estimated from SAOD. **(b)** Annual mean global surface air temperature. Ensemble mean (solid) of future projections including volcanoes (blue) and excluding volcanoes (red) with 5–95% range (shading) and ensemble minima/maxima (dots); evolution of the most volcanically active member (black). Data created using a SMILE approach with NorESM1 in its CMIP5 configuration. See Sections 2.2.2 and 4.4.4 for more details. Further details on data sources and processing are available in the chapter data table (Table 4.SM.1).

Before the industrial period, explosive volcanic eruptions were the largest source of forced climate variability globally on interannual to centennial time scales

Major eruptions drive a range of climate system responses for several years depending upon whether the eruption occurs in the tropics or the extratropics

Due to the direct radiative effect of volcanic stratospheric aerosols, large volcanic eruptions lead to an overall decrease of GSAT, which can extend to multi-decadal or century time scales in the case of clustered volcanism

It is likely that at least one large eruption will occur during the 21st century. Such an eruption would reduce GSAT for several years, decrease global mean land precipitation, alter monsoon circulation, modify extreme precipitation, and change the profile of many regional climatic impact-drivers. A low-likelihood, high-impact outcome would be several large eruptions that would greatly alter the 21st century climate trajectory compared to SSP-based ESM projections.

04

Consequences and conclusion

CONSEQUENCES

There are several areas that in all projected scenarios will behave similarly. The consequences of global changes are as follows.

TEMPERATURE RISE

PRECIPITATION CHANGES

CIRCULATION CHANGES AND CLIMATE VARIABILITY

SEA LEVEL RISE

TIPPING POINTS

TEMPERATURE RISE AND PRECIPITATION CHANGES

TEMPERATURE

1. By 2030 = very likely 1.5;
2. Land 1.5x higher than ocean;
3. Arctic amplification.

PRECIPITATION

1. Rise in global sum;
2. Regional variation;
3. Interannual amplification.

CIRCULATION CHANGES AND CLIMATE VARIABILITY

- AMOC → weakened in all scenarios
- ENSO → remains dominant mode of interannual variability

Other are projected to shift, altering regional patterns.

SEA LEVEL AND TIPPING POINTS

Low emission scenario: ~0.3 - 0.5 m
High emission scenario: ~0.5 - 0.8 m

Unavoidable in all projections by the year 2100.

Critical thresholds cross = irreversable changes

increased global warming = high-impact + low probability

CARBON EMISSION REDUCTION

CDR according to all reports is necessary.
The visibility of benefits of that, however, is delayed due to:

- natural variability;
- variation between indicators.

IPCC Chapter 4 Takeaways

Future climate depends on present-day choices;

Strong mitigation keeps impacts manageable;

Without it, the risks escalate sharply.

The 21st century climate is still shapeable.

Bibliography

https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-4/

Thank you