SIXTH ASSESSMENT REPORT
Working Group I – The Physical Science Basis

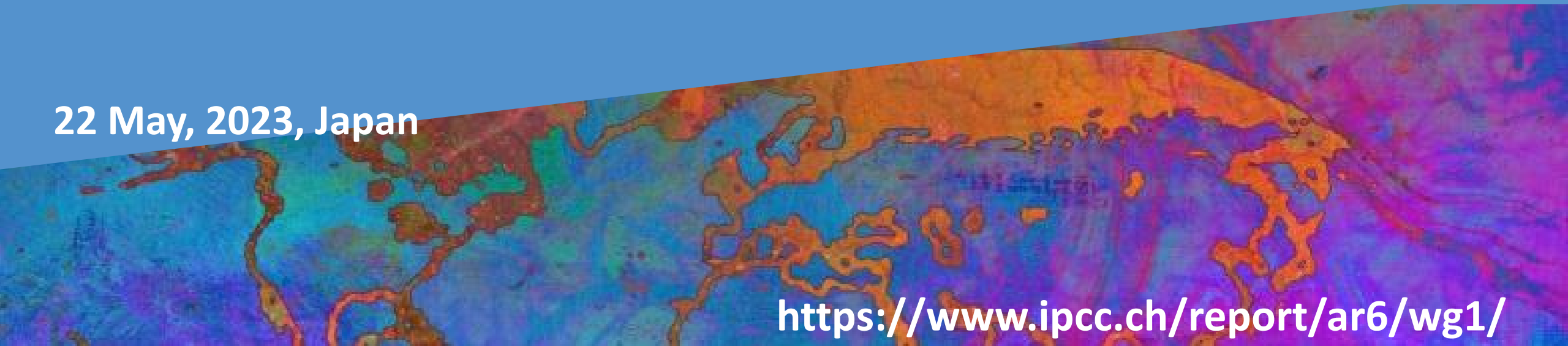
ipcc
INTERGOVERNMENTAL PANEL ON climate change

WMO UNEP

New Understandings in the Physical Climate Change Sciences

Panmao ZHAI
IPCC WGI Co-chair

22 May, 2023, Japan

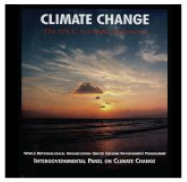


https://www.ipcc.ch/report/ar6/wg1/

FAQ 1.1: **Do we understand climate change better than when the IPCC started?**

Yes. Between 1990 and 2021, observations, models and climate understanding improved, while the dominant role of human influence in global warming was confirmed.

1990 IPCC First Assessment



2021 IPCC Sixth Assessment

Understanding

Human influence on climate	? Suspected	Established fact ✓
Energy budget	Open (inconsistent estimates)	Closed (inputs = outputs + retained energy)
Sea level budget	Open (inconsistent estimates)	Closed (sum of contributions = observed sea level rise)

Observations

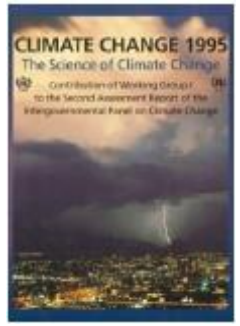
Global warming since late 1800s	0.3–0.6°C	0.95–1.20°C
Land surface temperature	1887 stations (1861–1990)	Up to 40,000 stations (1750–2020)
Geological records	5 million years (temperature) 5 million years (sea level) 160,000 years (CO_2)	65 million years (temperature) 50 million years (sea level) 450 milion years (CO_2)
Global ocean heat content	1955–1981 (two regions)	1871–2018 (global)
Satellite remote sensing	Temperature, snow cover, Earth radiation budget	Temperature, cryosphere, Earth radiation budget, CO_2, sea level, clouds, aerosols, land cover, many others

Climate models

	Global	Global	Regional
State of the art	General circulation models	Earth system models	High-resolution models
Typical model resolution	500 km	100 km	25–50 km
Major elements	Circulating atmosphere and ocean	Circulating atmosphere and ocean	
	Radiative transfer	Radiative transfer	
	Land physics	Land physics	
	Sea ice	Sea ice	
		Atmospheric chemistry	
		Land use/cover	
		Land and ocean biogeochemistry	
		Aerosol and cloud interations	

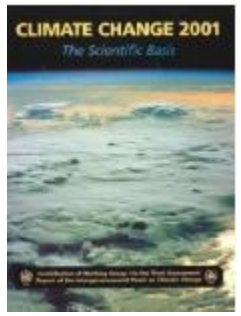
1990

Gave a broad overview of climate change science, discussion of uncertainties and evidence of warming



1995

"The balance of evidence suggests a **discernible** human influence on global climate"



2001

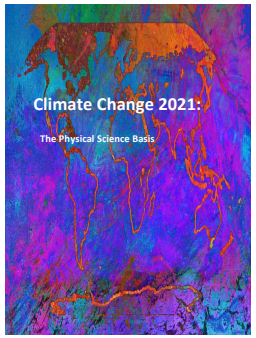
"There is new and **stronger evidence** that most of the warming observed over the last 50 years is attributable to human activities"

2007

"Warming of the climate system is **unequivocal**…"

2013

"Human influence on the climate system is **clear**."



2021

"It is **unequivocal** that human influence has warmed the atmosphere, ocean and land".

Improvements:

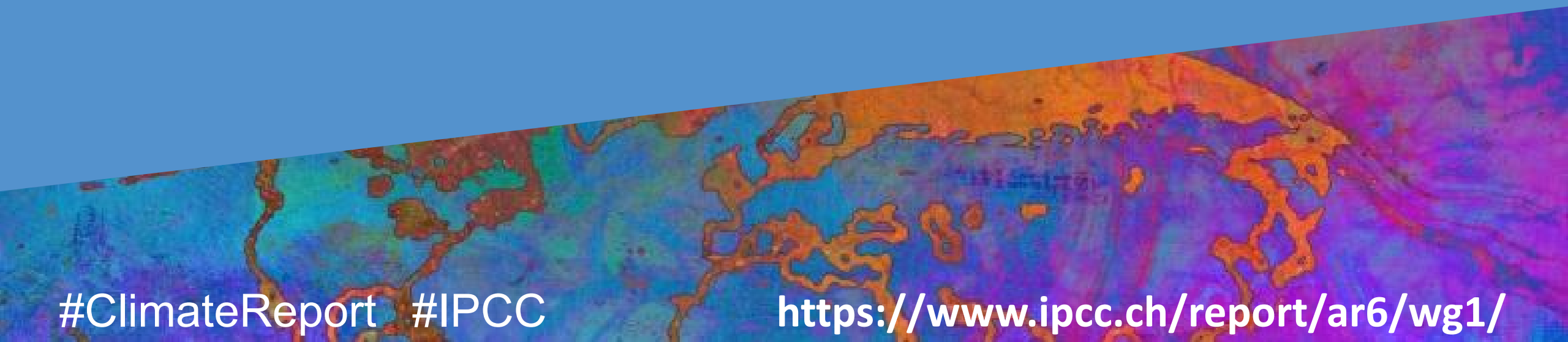
UNEP

SIXTH ASSESSMENT REPORT
Working Group I – The Physical Science Basis

ipcc
INTERGOVERNMENTAL PANEL ON Climate change

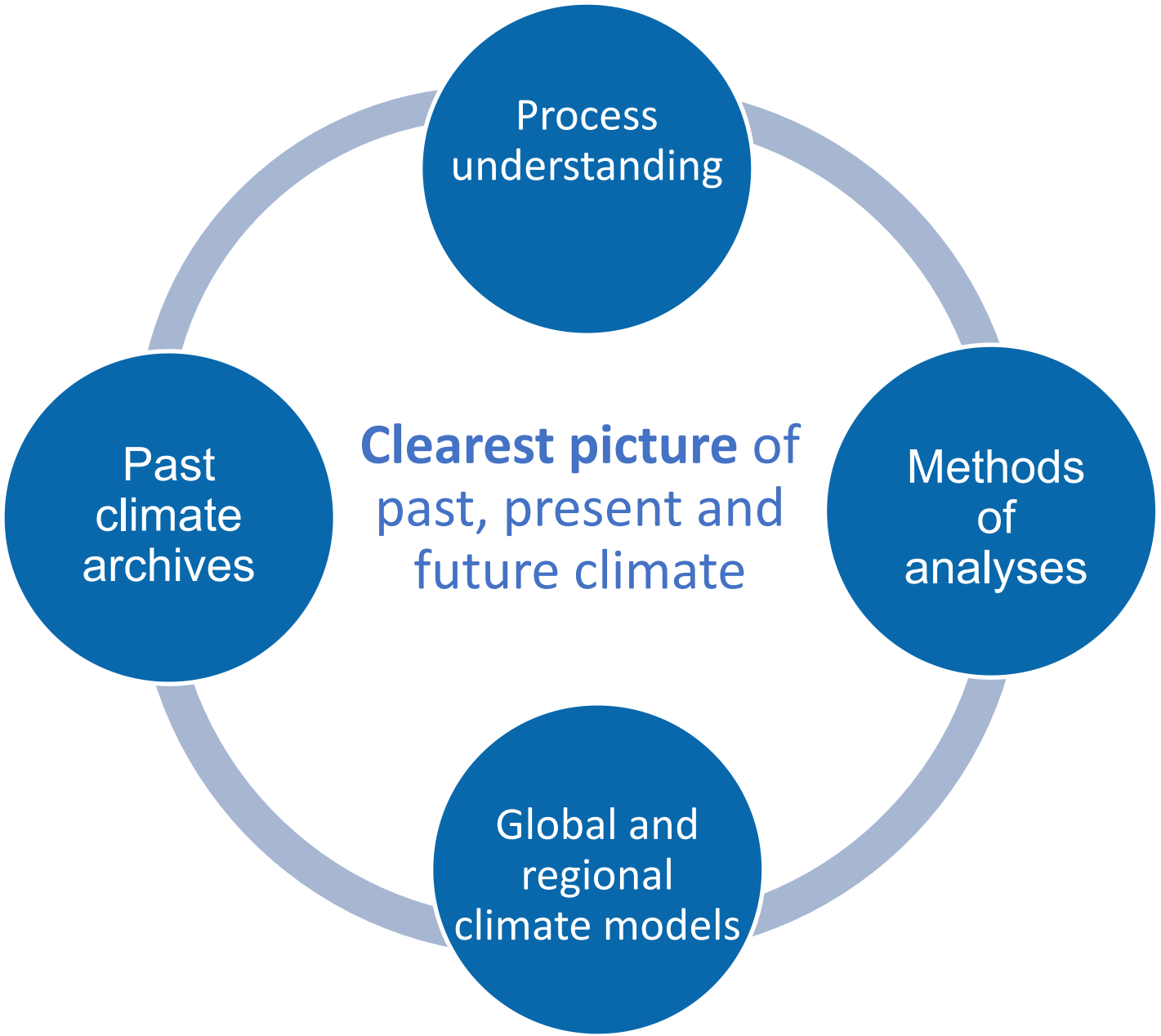
WMO UNEP

Observed Climate change



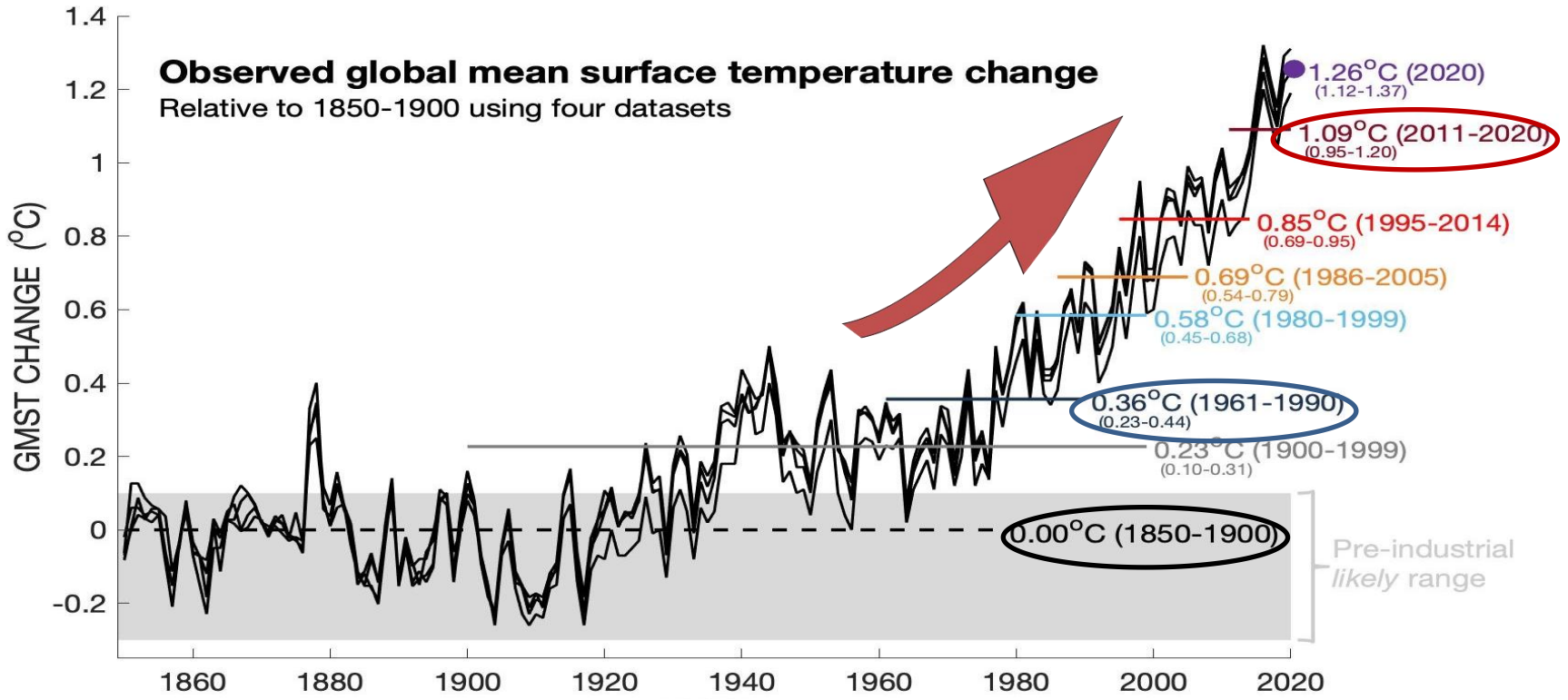
#ClimateReport #IPCC

https://www.ipcc.ch/report/ar6/wg1/



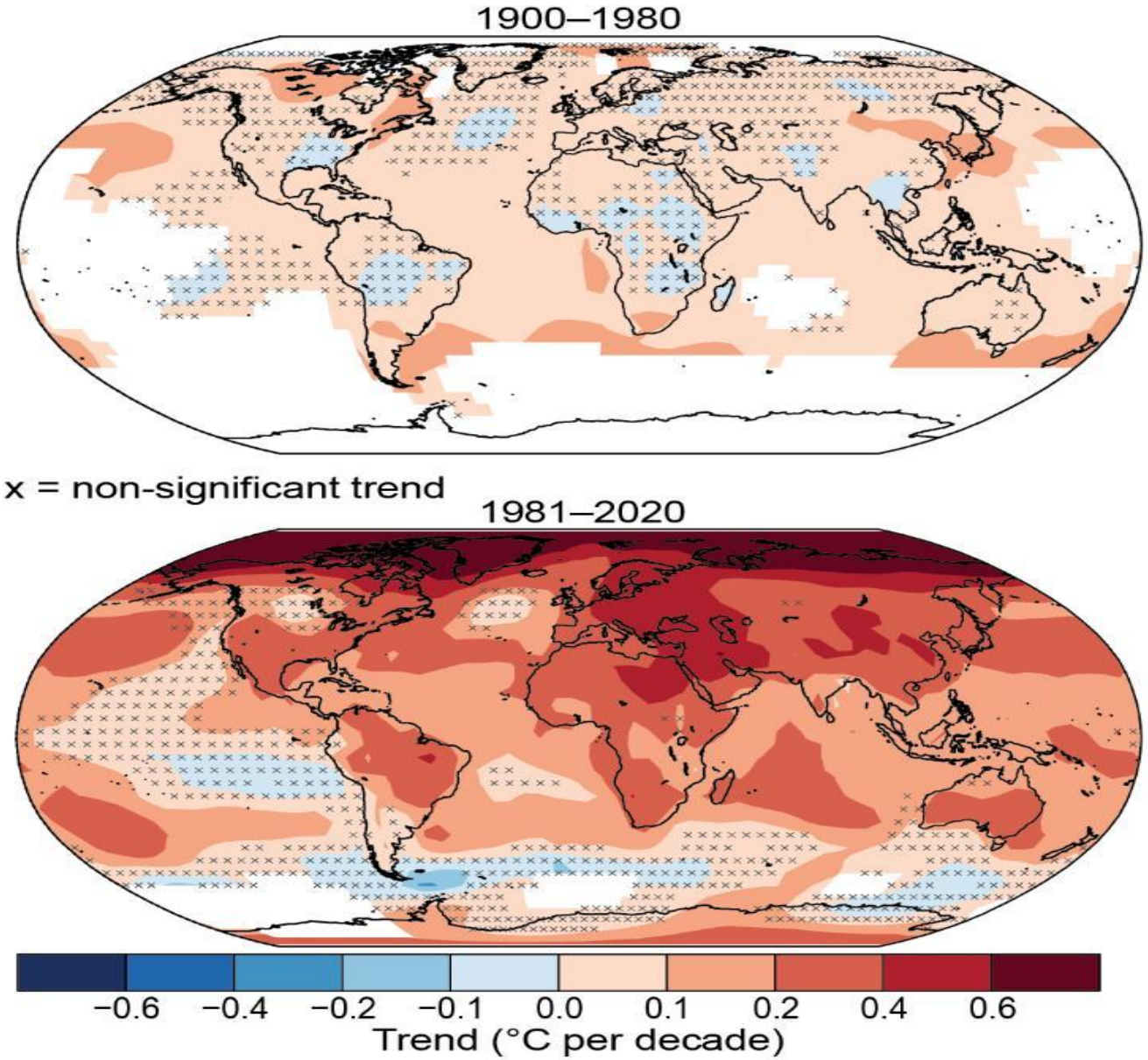
evidence from over **14,000 publications** assessed in the report

Since the 20th century, the global surface temperature has increased rapidly. Global surface temperature was 1.09°C higher in the last decade than 1850–1900.

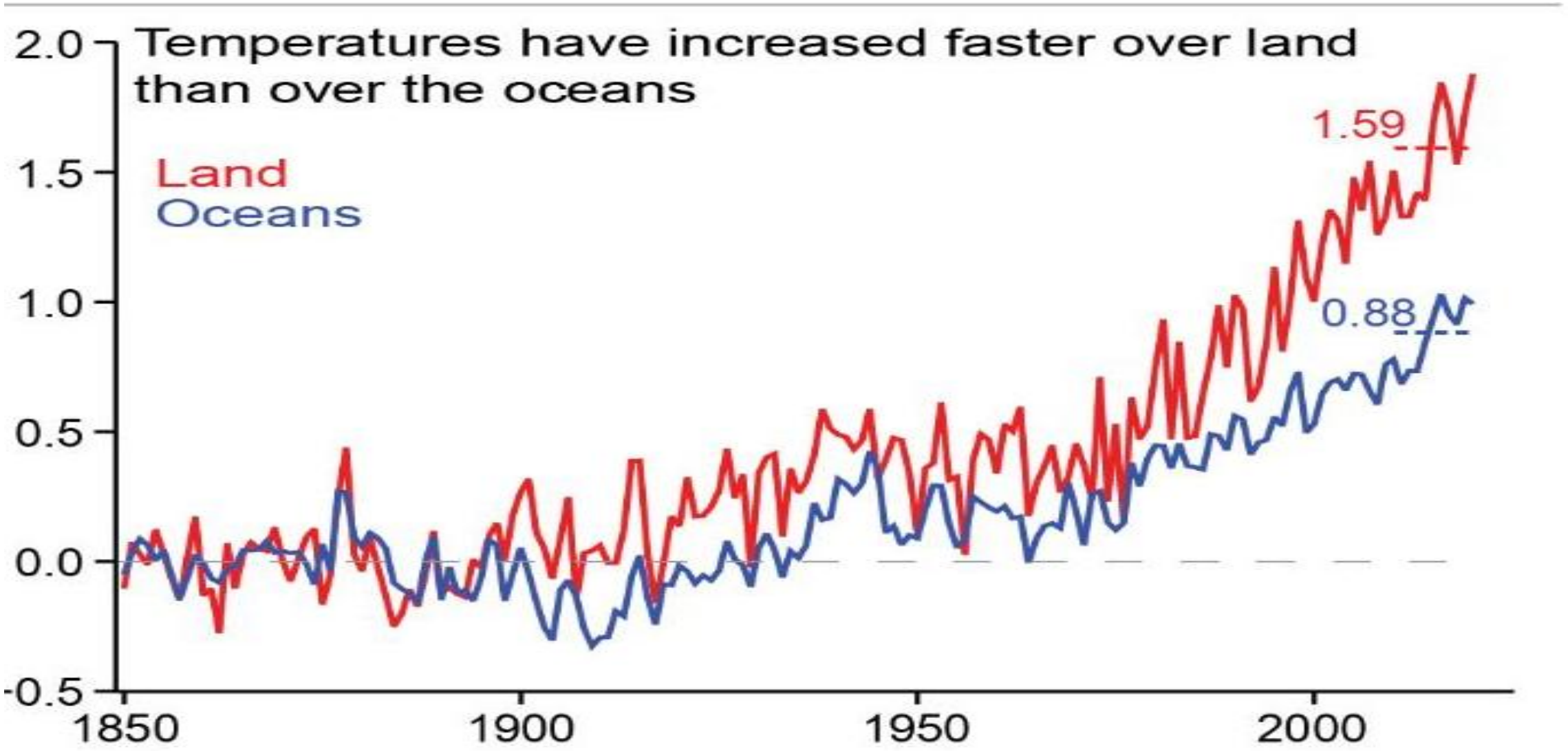


2001-2020 warming 0.99°C；2011-2020 warming 1.09°C

(b) Warming accelerated after the 1970s, but not all regions are warming equally

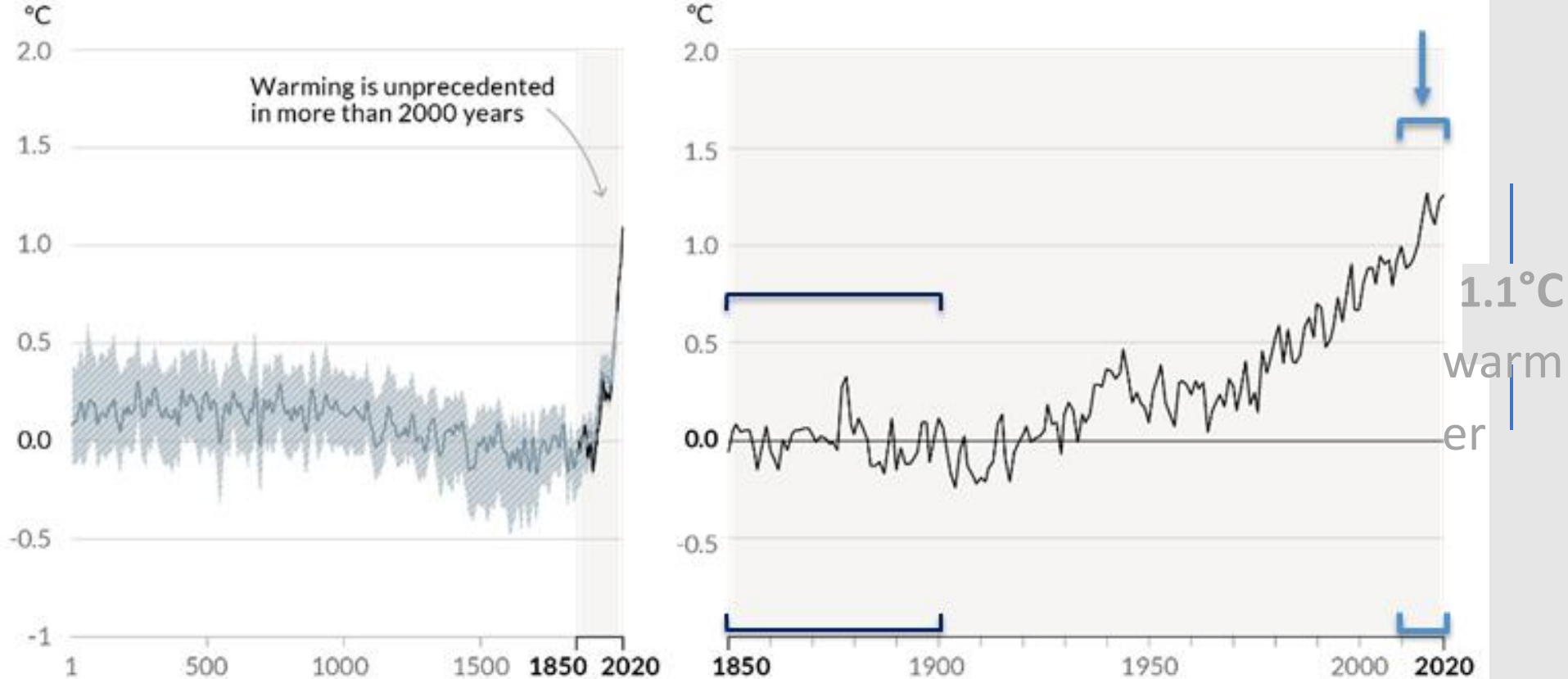


Motivation and Background



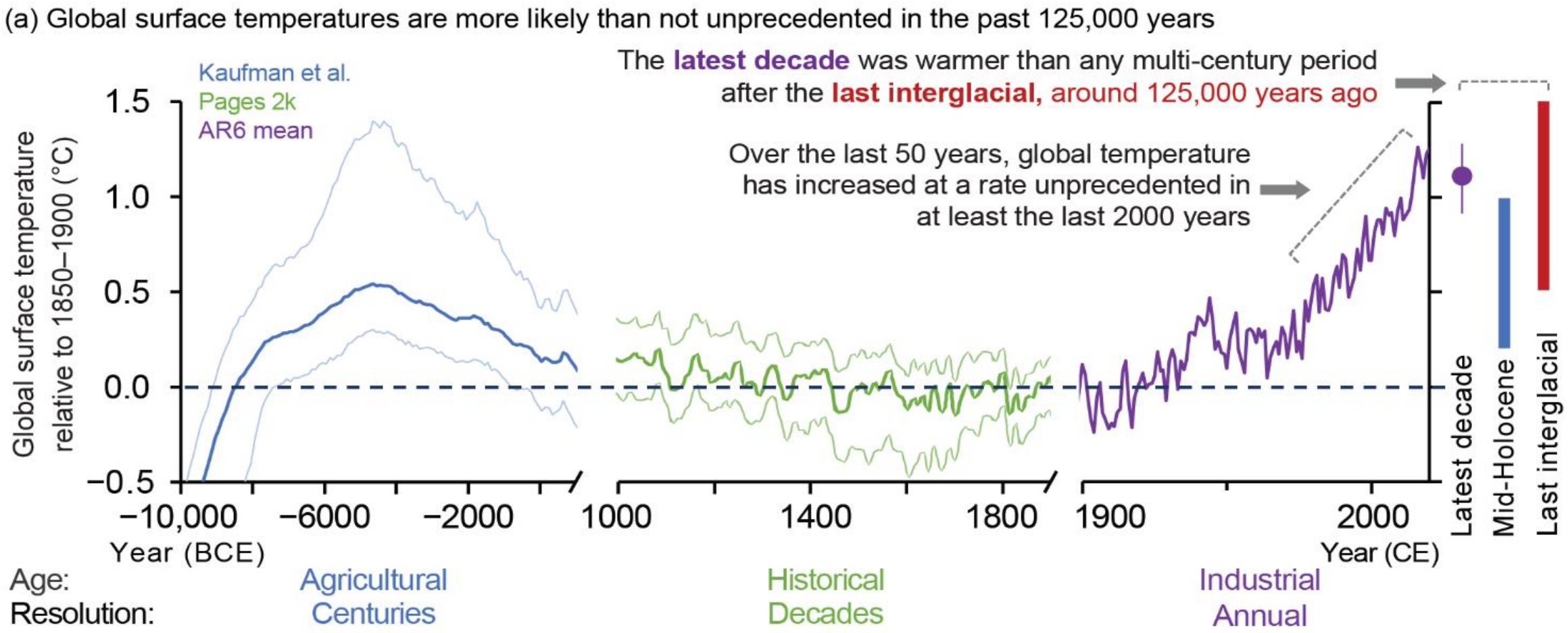
The Earth has warmed by 1.1℃
Warming is unprecedented in more than 2000 years

Changes in global surface temperature relative to 1850-1900

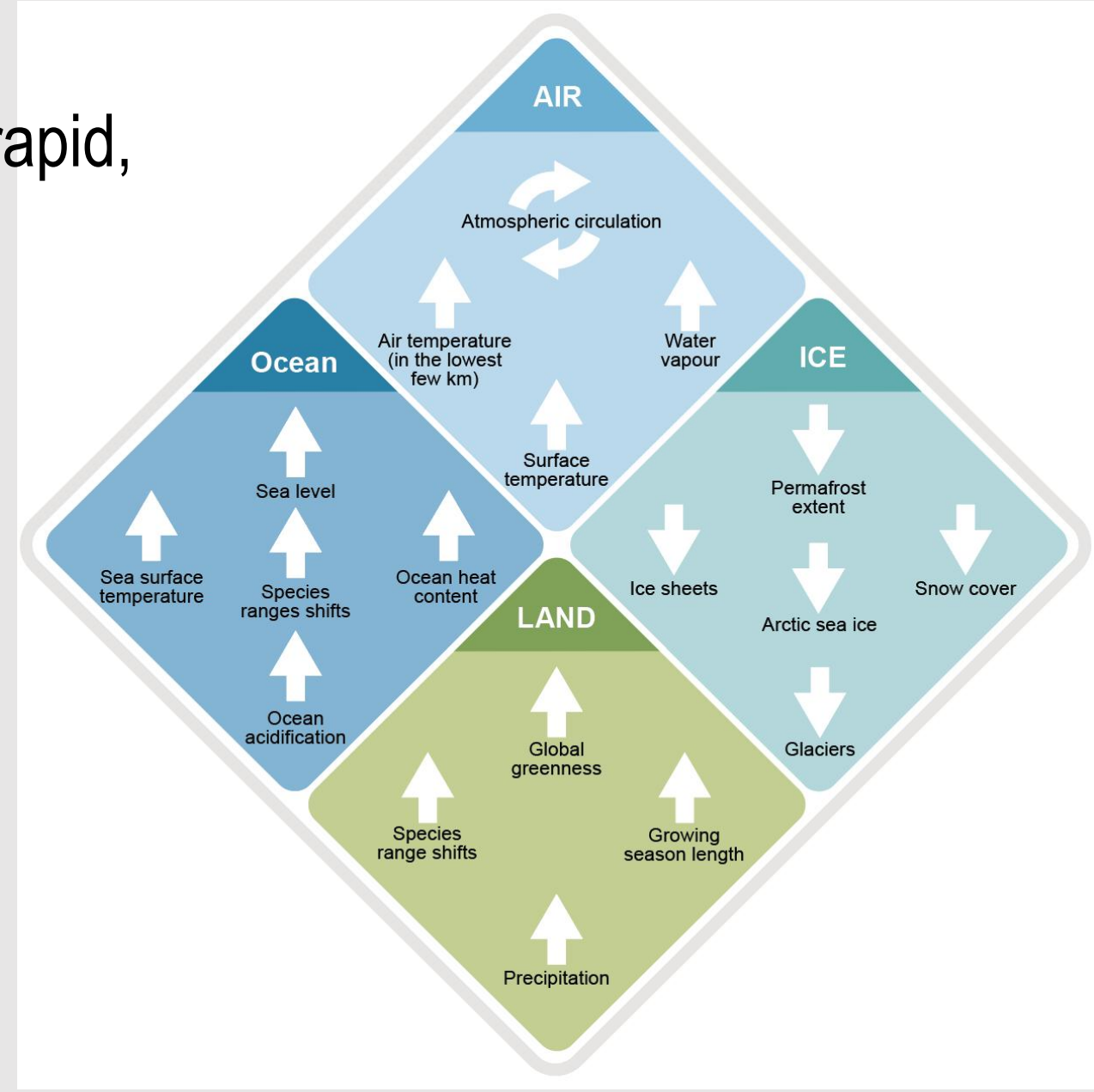


Adapted from Figure SPM.1

目前的气候可能是10万年来最暖的；过去2百万年地球气候在冰期与间冰期冷暖变化的波动；末次冰期向间冰期过渡期间最大的增暖速率为1.5℃/千年；19世纪后期以来全球地表温升已经超过了1.1℃，逆转了6千多年以来长期缓慢的变冷趋势，表现为快速的温升趋势！



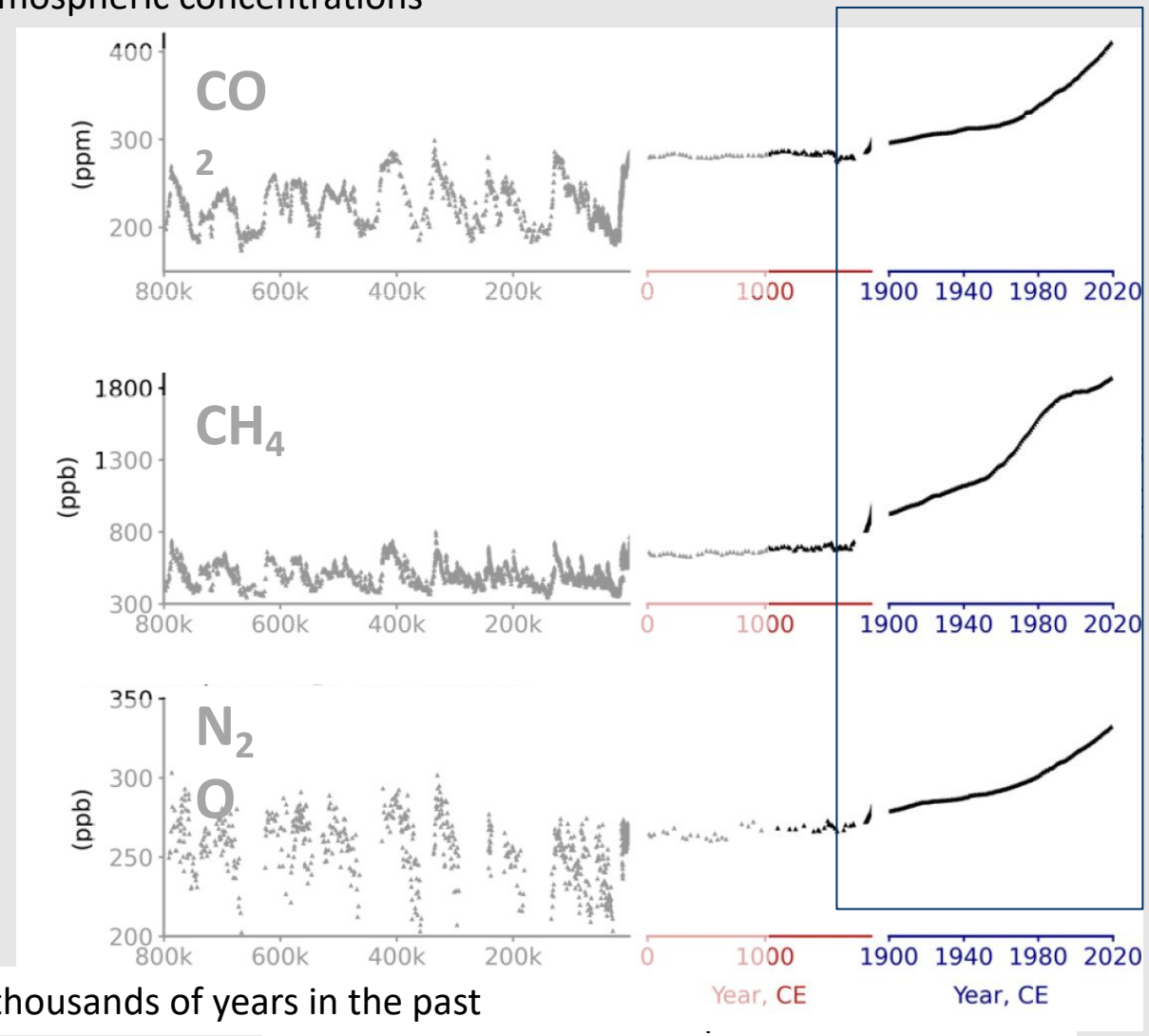
Changes are widespread, rapid, and intensifying



Figure

Human influence on climate is unequivocal

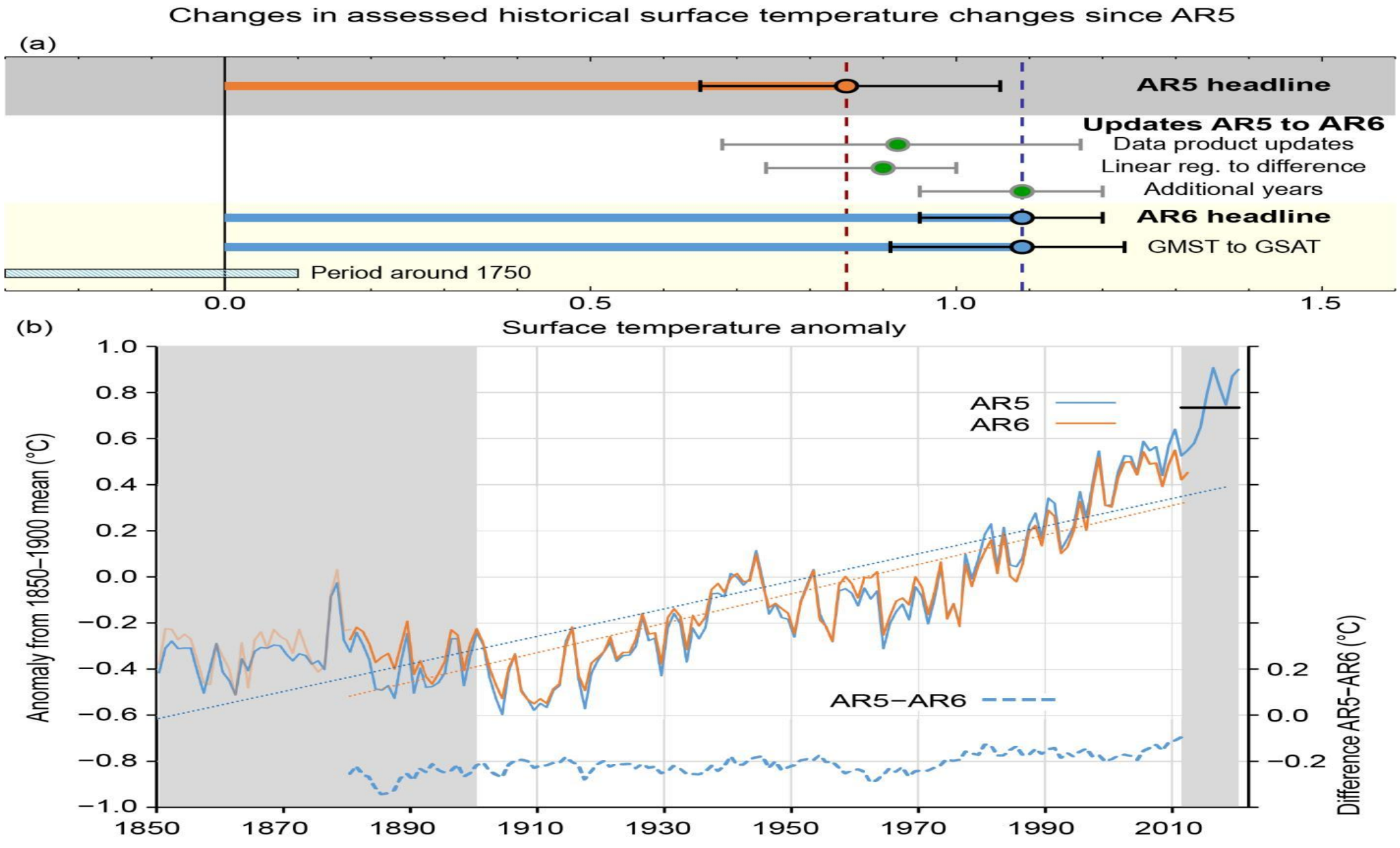
Atmospheric concentrations



Observed increases in well-mixed **greenhouse gas (GHG)** concentrations since ~1750 are unequivocally caused by **human activities**

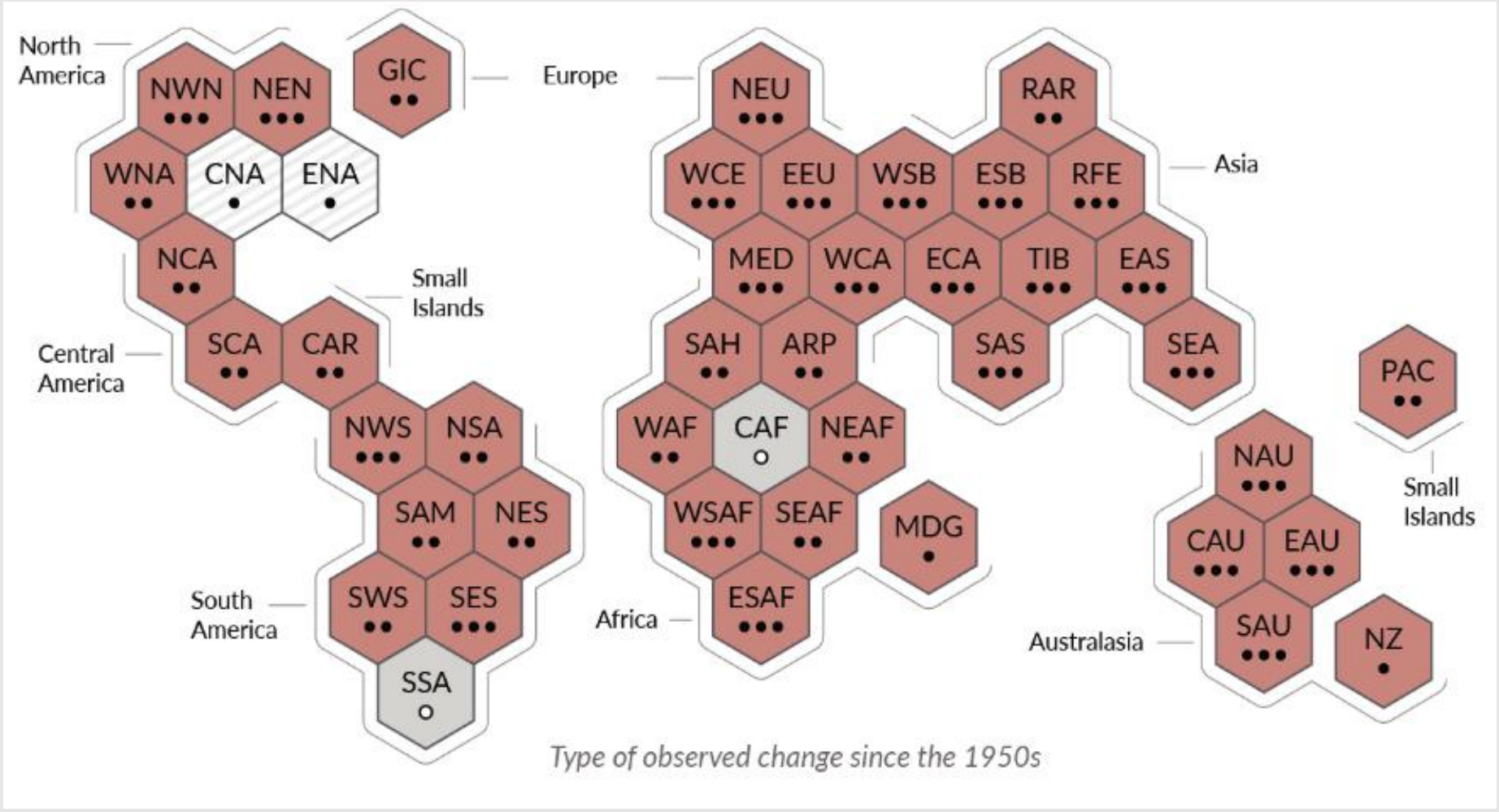
Emissions in the last decade reached the highest levels in human history

Figure 5.4


Changes in assessed historical surface temperature changes since AR5
(a)
AR5 headline
Updates AR5 to AR6
Data product updates
Linear reg. to difference
Additional years
AR6 headline
GMST to GSAT
Period around 1750
0.0
0.5
1.0
1.5
(b)
Surface temperature anomaly
Anomaly from 1850–1900 mean (°C)
AR5
AR6
AR5–AR6
Difference AR5–AR6 (°C)
1850
1870
1890
1910
1930
1950
1970
1990
2010

Climate change is already affecting every region on Earth

Hot extremes



Type of observed change

Colour = Increase/decrease

Low agreement in the type of change

Limited data and/or literature

Confidence in human contribution to the observed change

●●● High

●● Medium

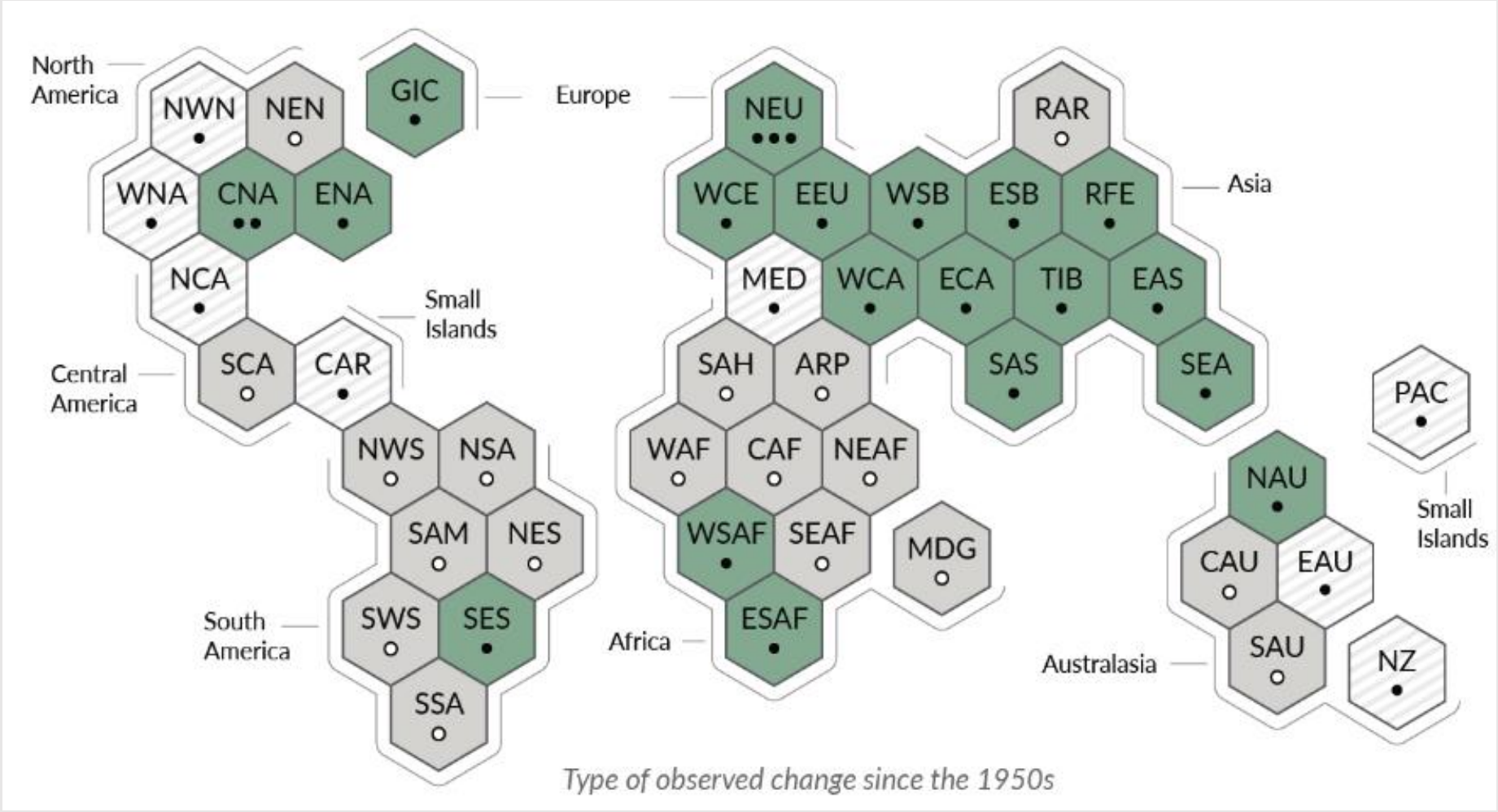
● Low due to limited agreement

○ Low due to limited evidence

Figure SPM.3

Climate change is already affecting every region on Earth

Heavy precipitation



Type of observed change

Colour = Increase/decrease

Low agreement in the type of change

Limited data and/or literature

Confidence in human contribution to the observed change

●●● High

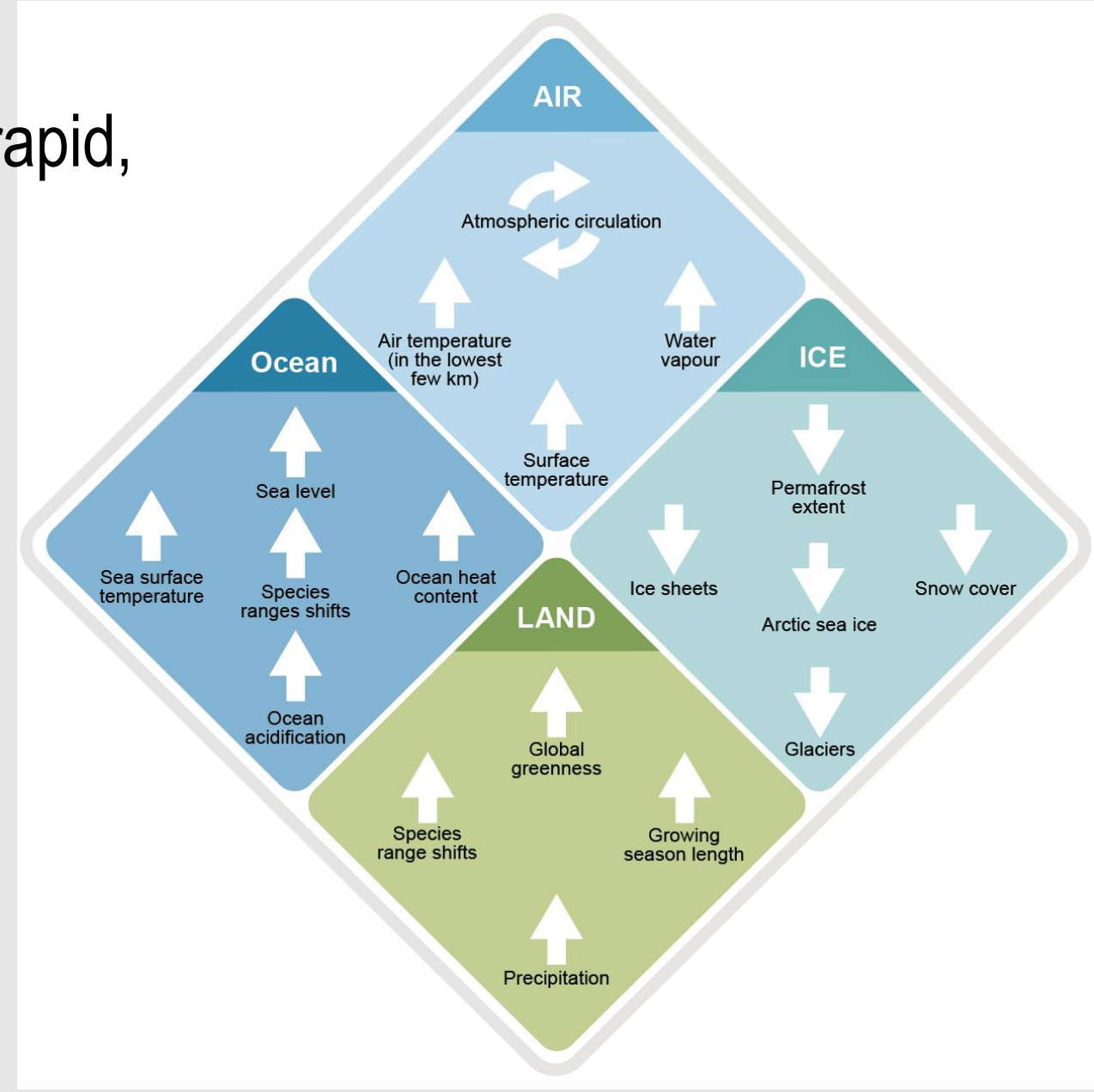
●● Medium

● Low due to limited agreement

○ Low due to limited evidence

Figure SPM.3

Changes are widespread, rapid, and intensifying



Figure

These changes are unprecedented

Fastest sea level rates in at least **3000 years**

Fastest sea surface temperature warming in at least **11,000 years**

Ocean acidification **unusual** in at least **2 million years**

Ocean heat content **unprecedented** in at least **18,000 years**

Lowest Arctic sea ice level in at least **1000 years**

Unprecedented glacier melt in at least **2000 years**

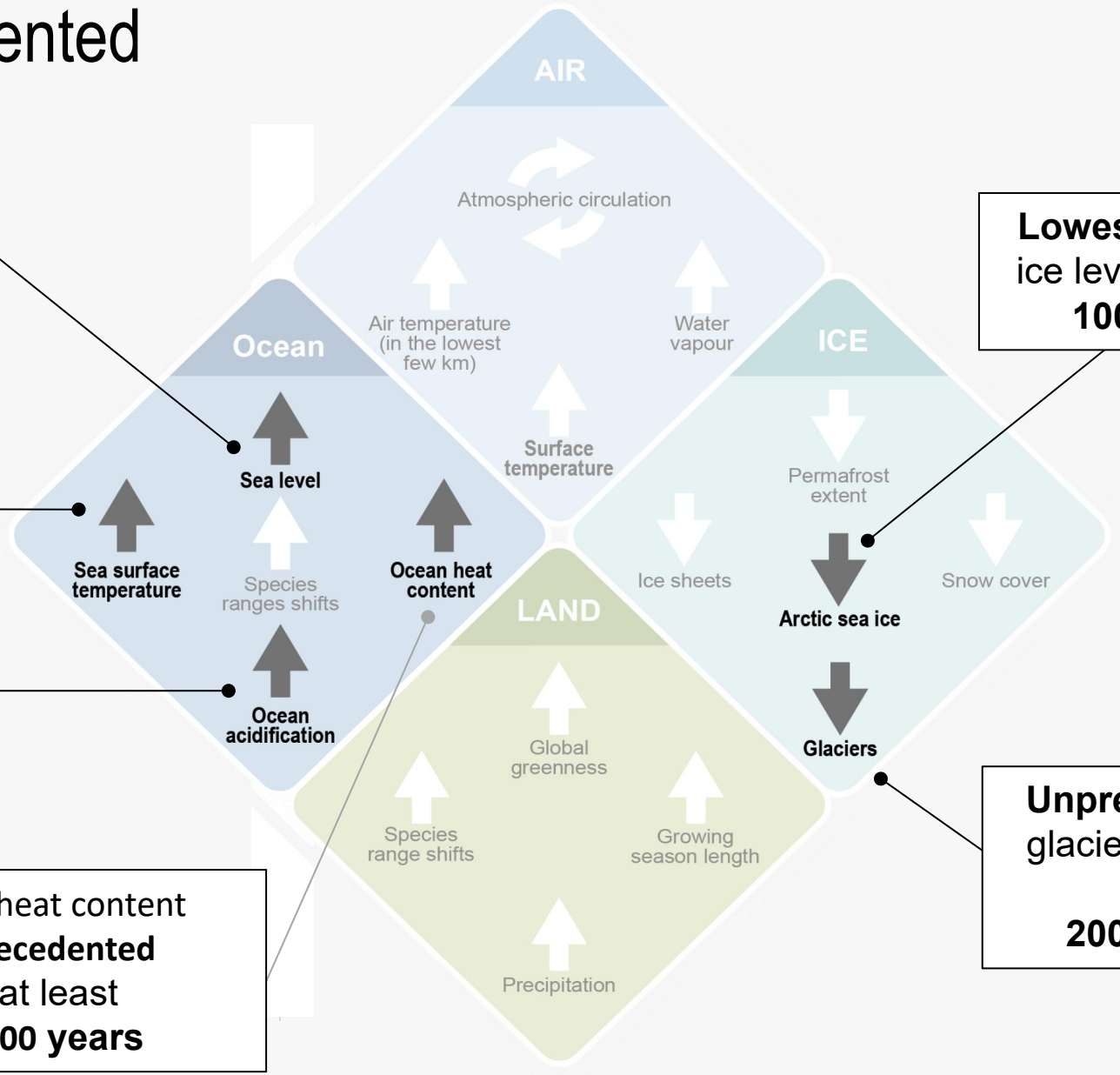
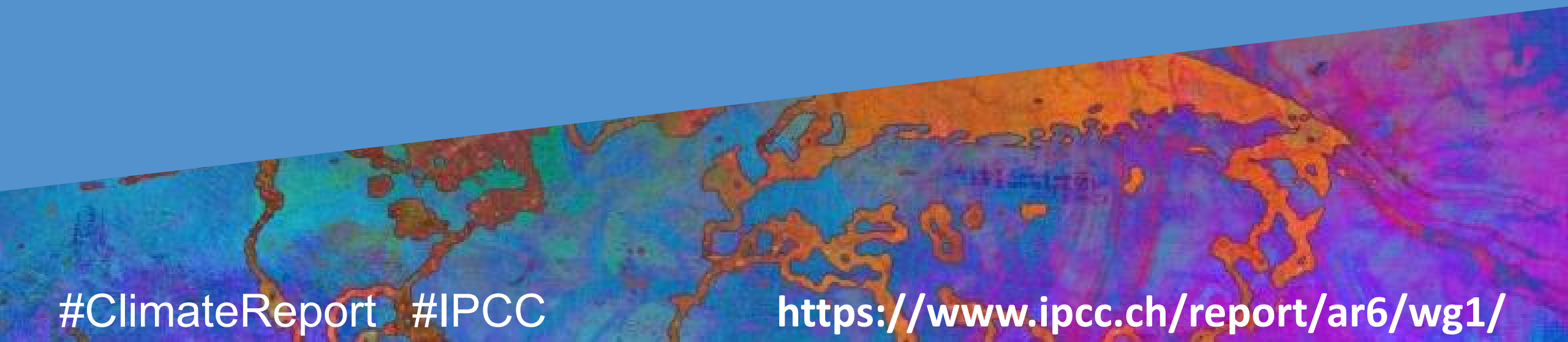


Figure FAQ2.2

ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP

Human influecnes on climate change

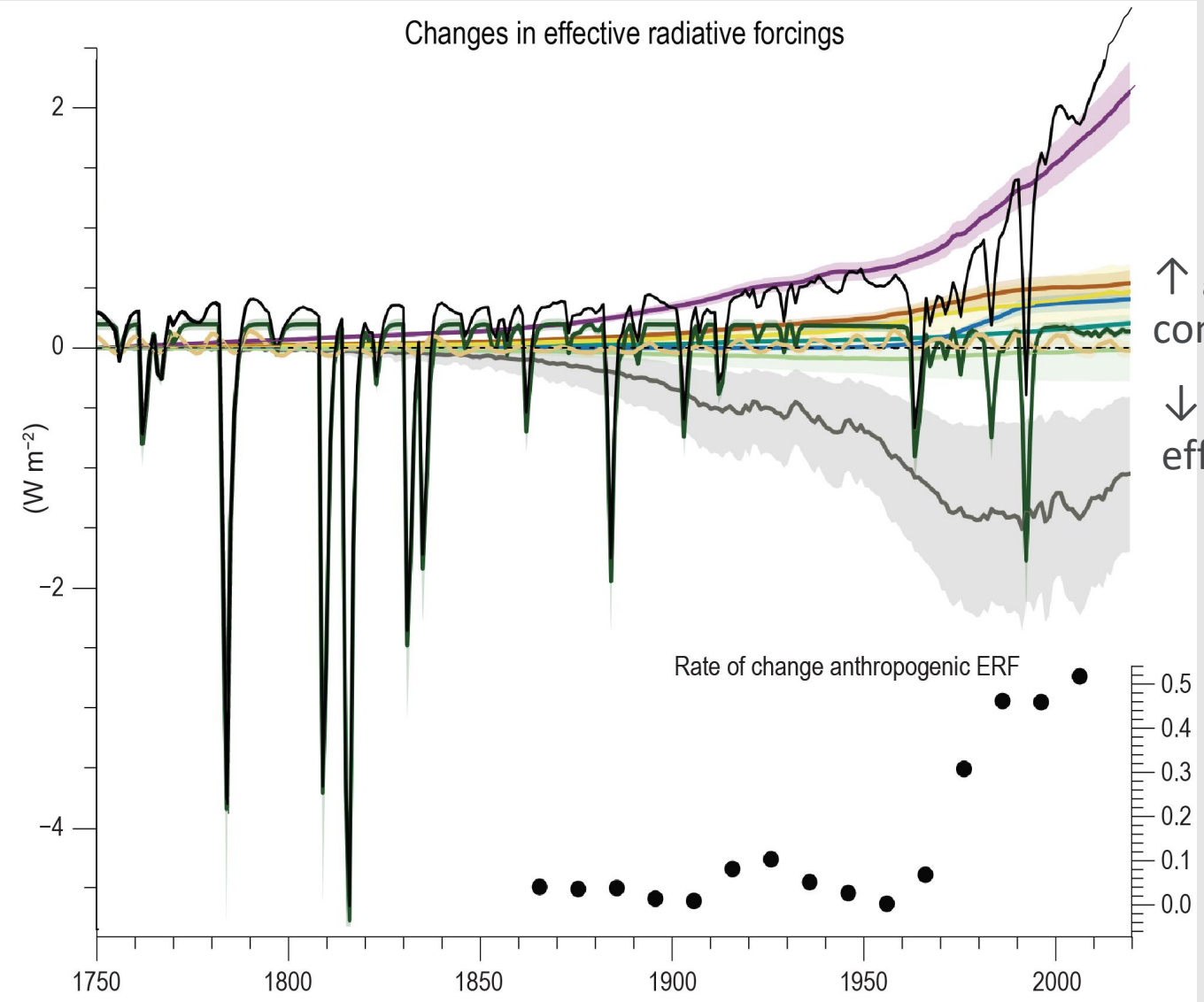


#ClimateReport #IPCC

https://www.ipcc.ch/report/ar6/wg1/

Human-caused radiative forcing is increasing

Carbon dioxide (CO_2)
Methane (CH_4)
Nitrous oxide (N_2O)
Ozone (O_3)
Halogenated gases
Tropospheric Aerosol
Other anthropogenic
Volcanic
Solar
Total



↑ greenhouse gas concentrations

↓ global cooling effect of aerosols

Change in effective radiative forcings (W/m^2)

Rate (W/m^2 per decade)

Figure 2.10

Human influence causes heating of the climate system

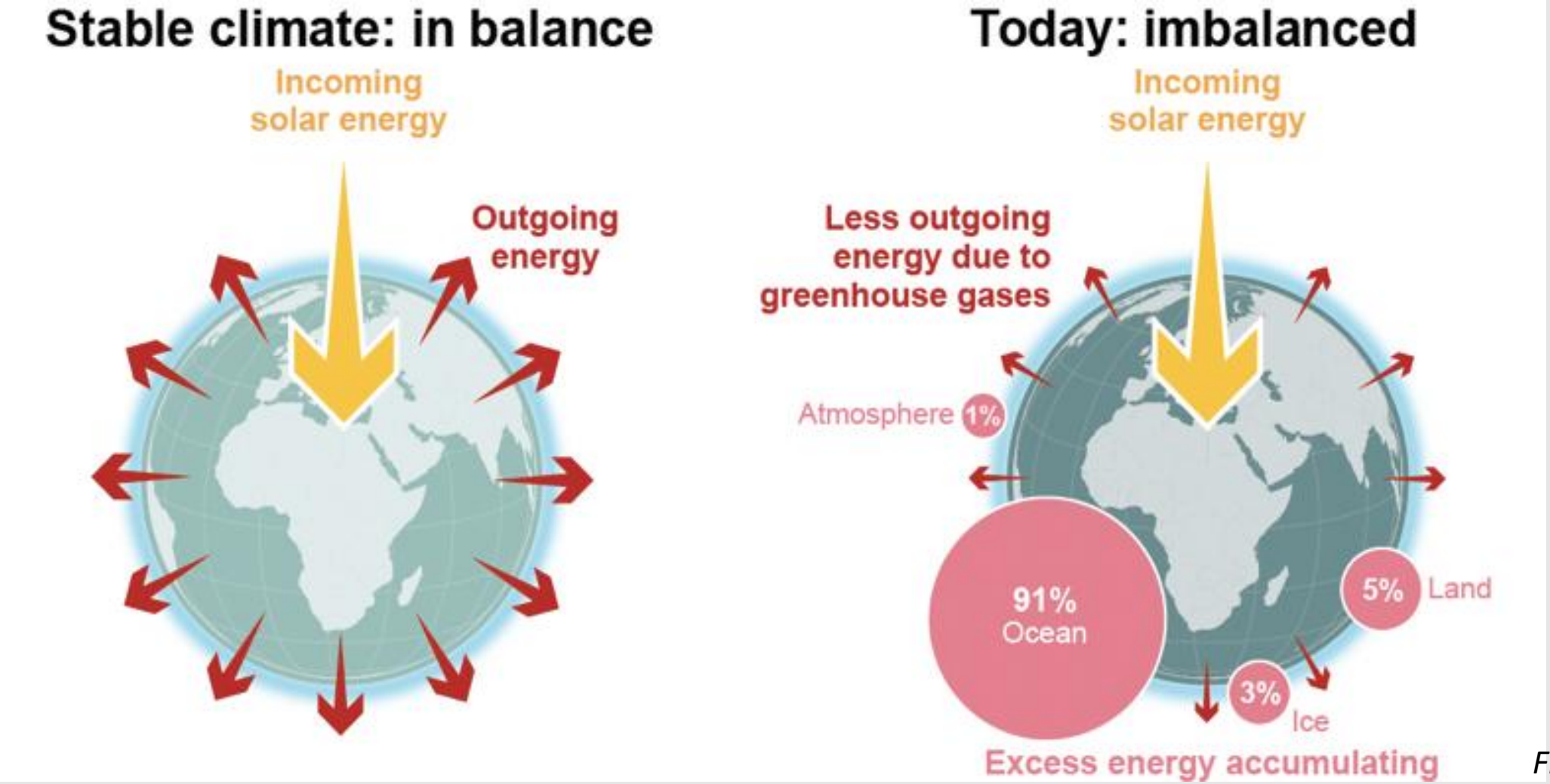
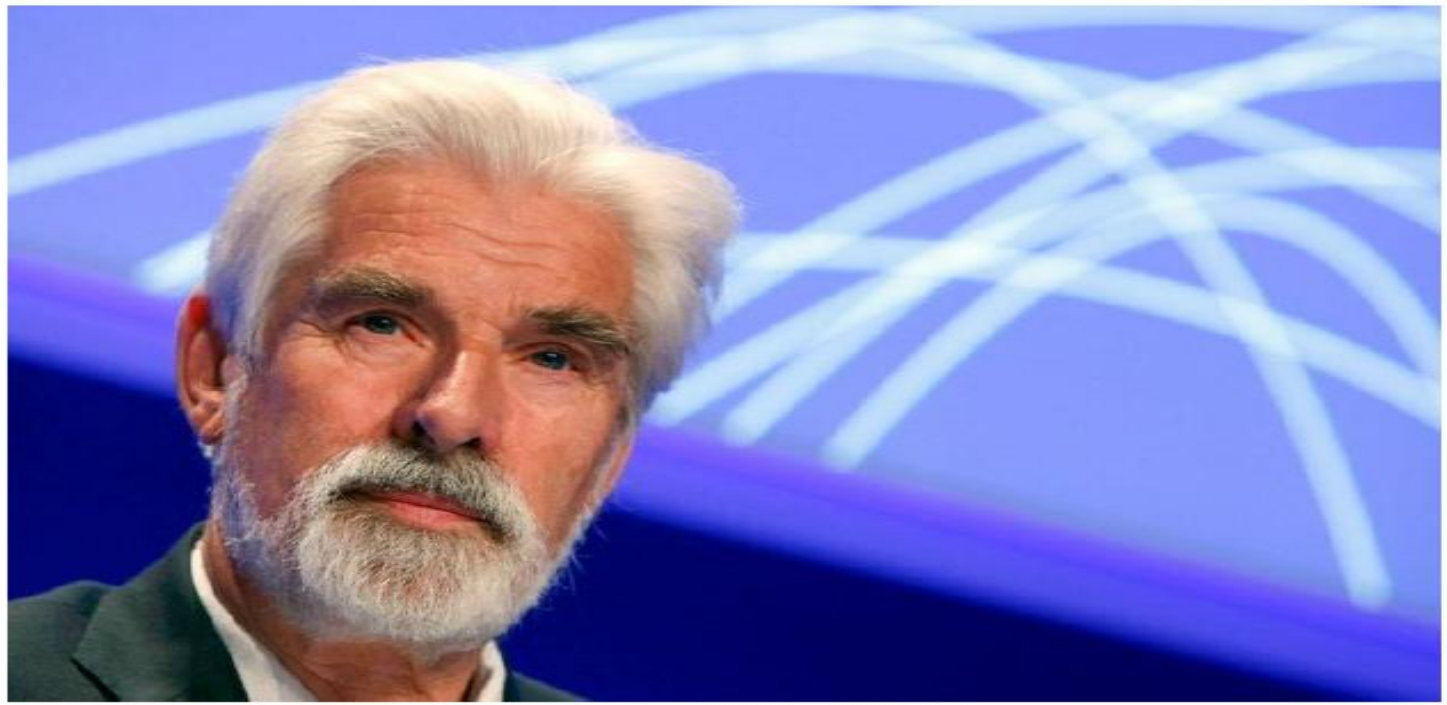


Figure FAQ7.1



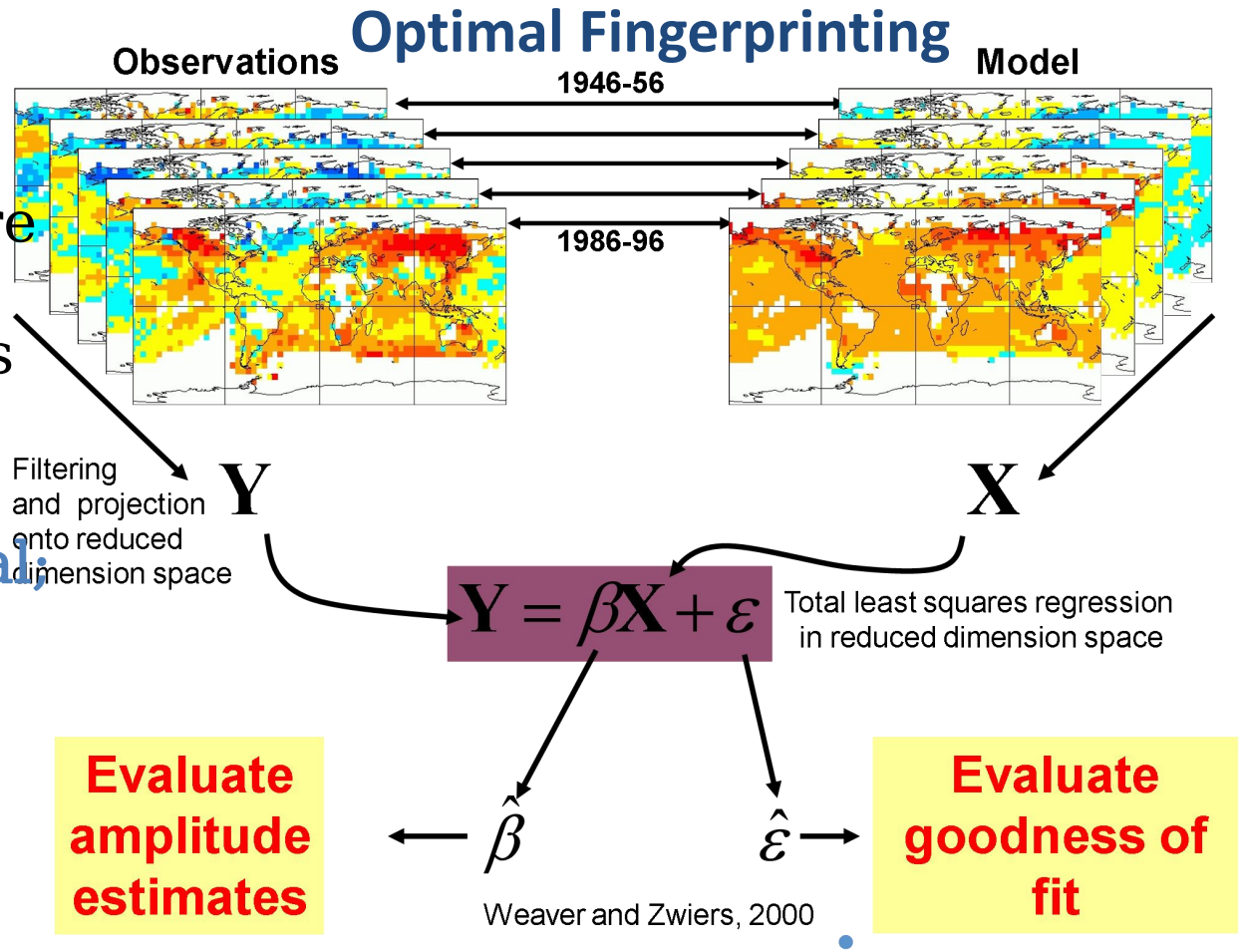
Klaus Hasselmann: 2021 Nobel Prize in Physics

The pioneer of Optimal Fingerprinting Approach

The scaling factor β gives a measure of how well X simulates the magnitude of climate change signals in Y:

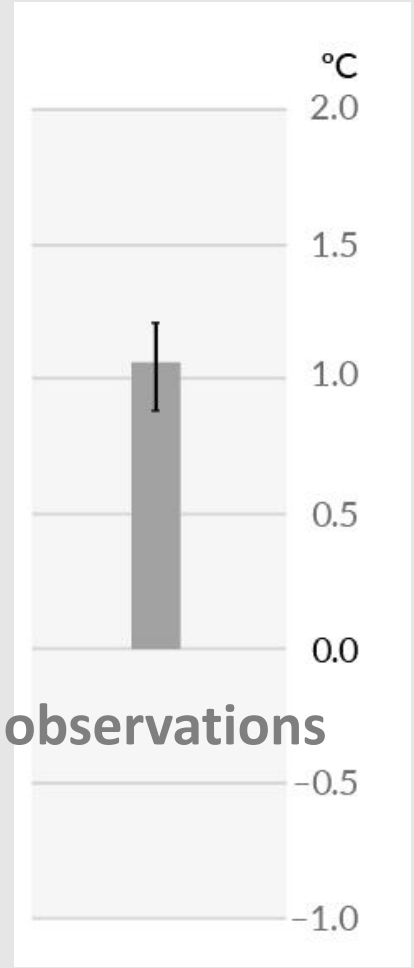
if β is < 1, X overestimates the signal;
if β is > 1, X underestimates the signal

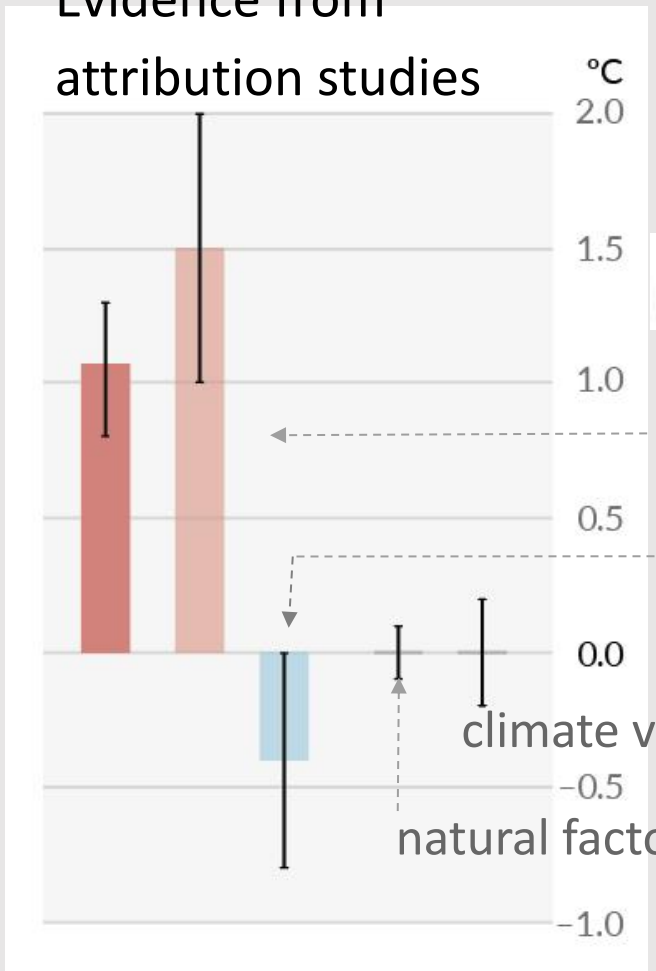
β can be used to 'constrain' model projection



Hasselmann 1993,1997; Allen and Tett 1999; Hegerl and Zwiers 2011;

Observed warming is driven by emissions from **human activities**, with **greenhouse gas** warming partly masked by **aerosol cooling**





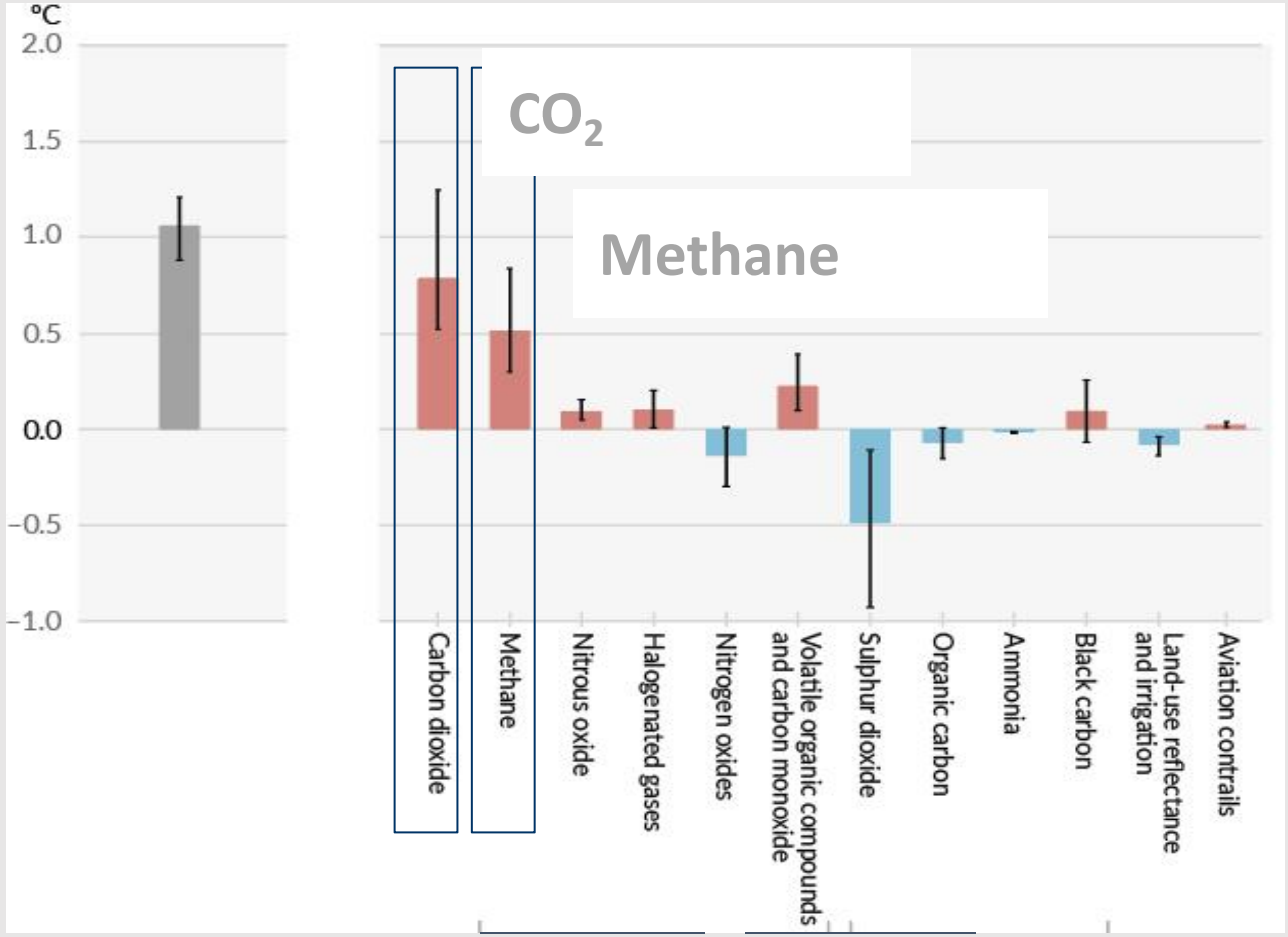
human influence

greenhouse gas warming

aerosol cooling

Adapted from Figure SPM.2

Improved understanding of the role of each individual component of human influence



Evidence from radiative forcing and climate sensitivity studies

Mainly contribute to changes in **non-CO_2 greenhouse gases**

Mainly contribute to changes in **anthropogenic aerosols**

Adapted from Figure SPM.2

Human-induced changes are increasingly apparent at regional and local scales

Change in surface air temperature
human-caused & natural
natural only

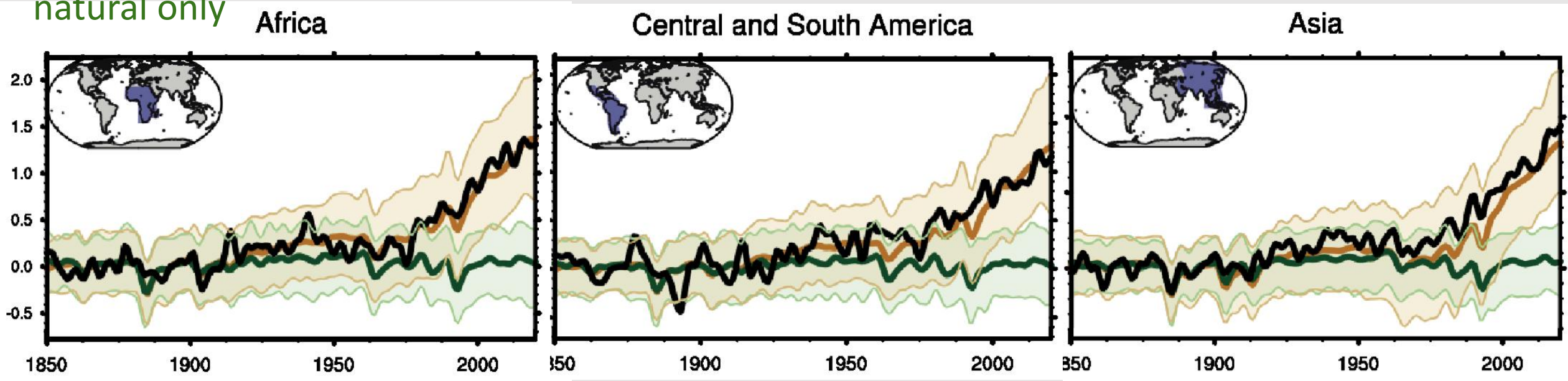
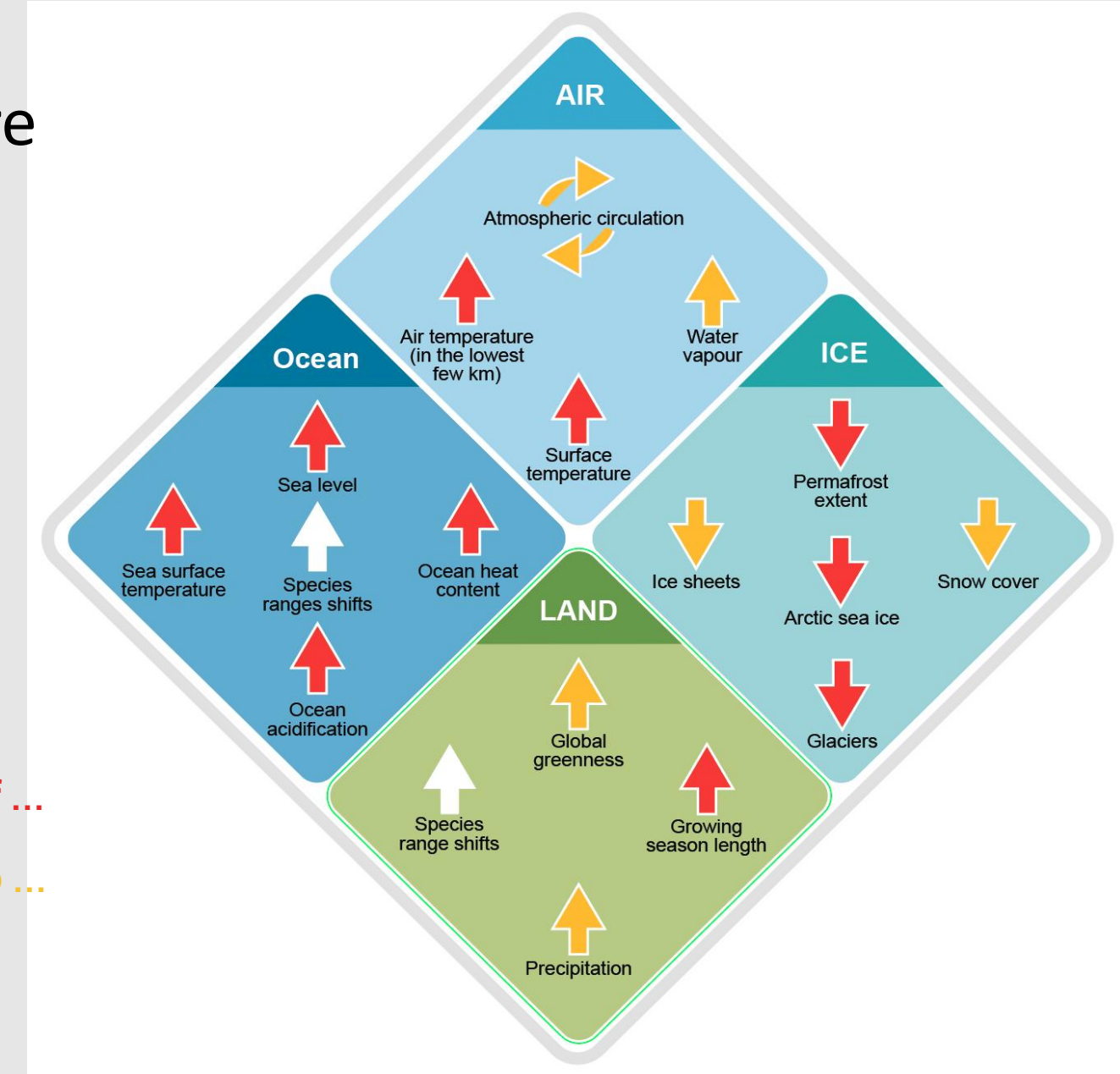


Figure TS.7

Widespread changes are attributed to human influence



Main driver of …

Contributes to …

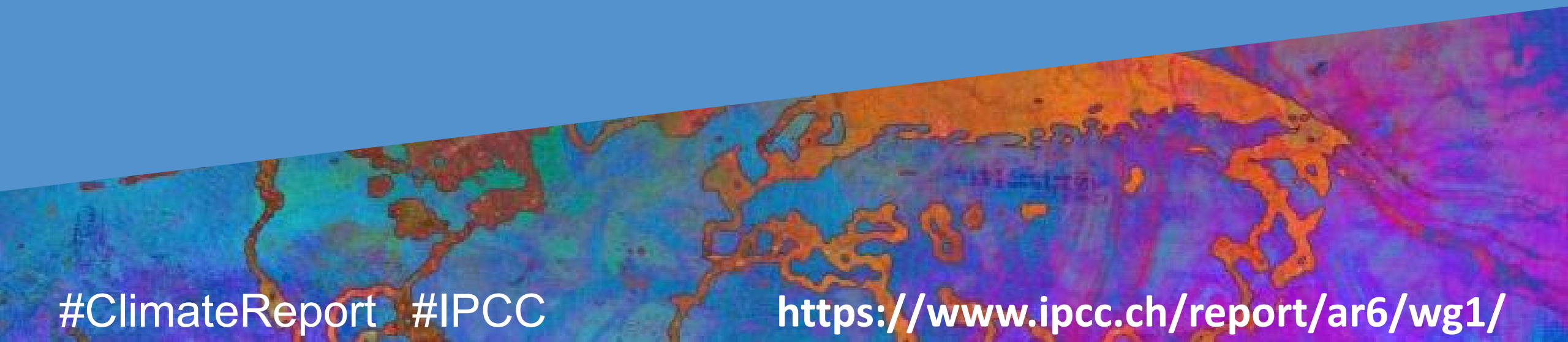
…om Figure FAQ2.2

Confidence has increased in human influence on many aspects of climate system

Variables	AR5 (2013)	AR6 (2021) Confidences
GST	*Extremely high*	Unequivical
Large sclae precipitation	*Midum*	*Likely*
Extreme temperature	*Extremely high*	*Virtually certain*
Extreme Precipitation	*Midium*	*Likely*
Drought	*Low*	*Midium*
Occurance of compound extremes	/	*likely*
Spring snow cover decline over NH	*likely (since 1970)*	*Very likely (sicne 1950)*
Reduction in glacials	*Likely*	*Very likely*
Mass loss in Green land ice sheet	*Likely*	*Very likely*
Ocean acidification	*Very likely*	*Virtually certain*
Heat content increase in upper ocean	*Likely*	*Extremely likely*

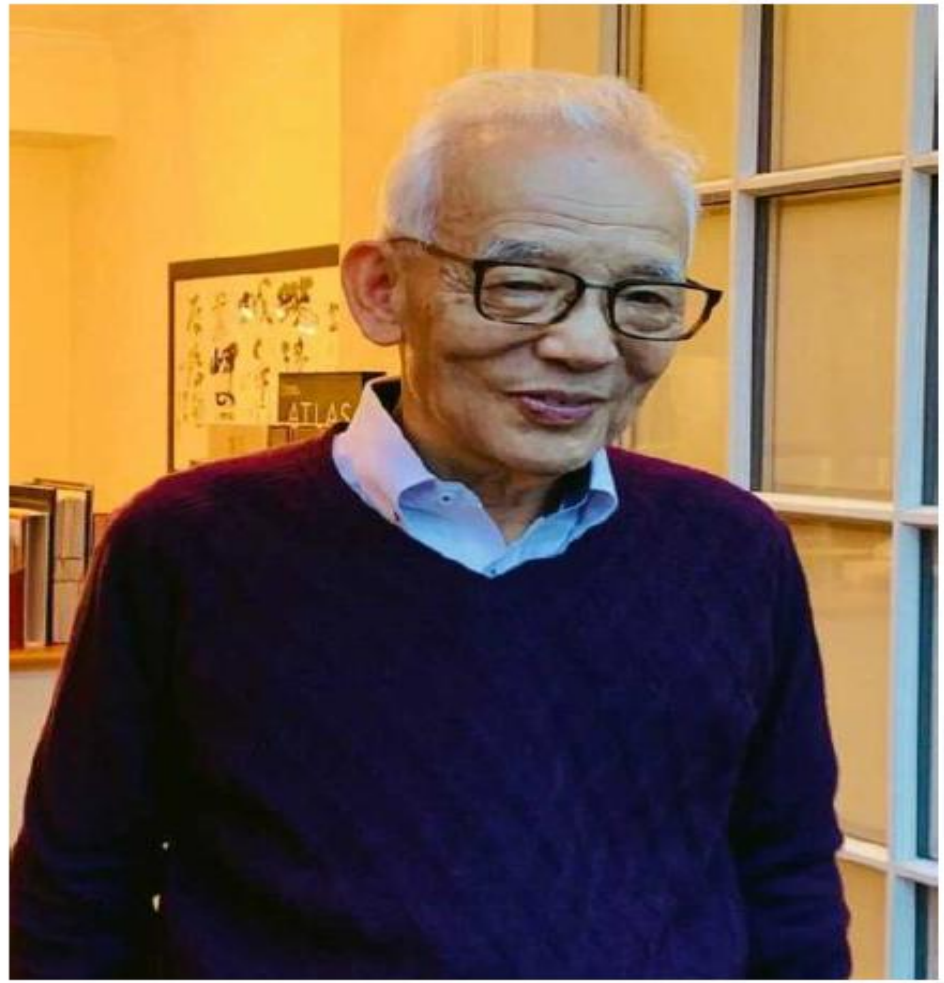
ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP

Possible climate futures



#ClimateReport #IPCC

https://www.ipcc.ch/report/ar6/wg1/



Syukuro Manabe: 2021 Nobel Prize in Physics

“The father of the first general circulation climate model”

SSP-RCP Senario Framework

- CMIP5 used RCPs
- CIMP6 used SSPs

***SSPX-Y:** 5 set of illustraive senarios:

SSP1-1.9 Very low GHG emission
SSP1-2.6 Low
SSP2-4.5 Medium
SSP3-7.0 High
SSP5-8.5 Very high GHG emission

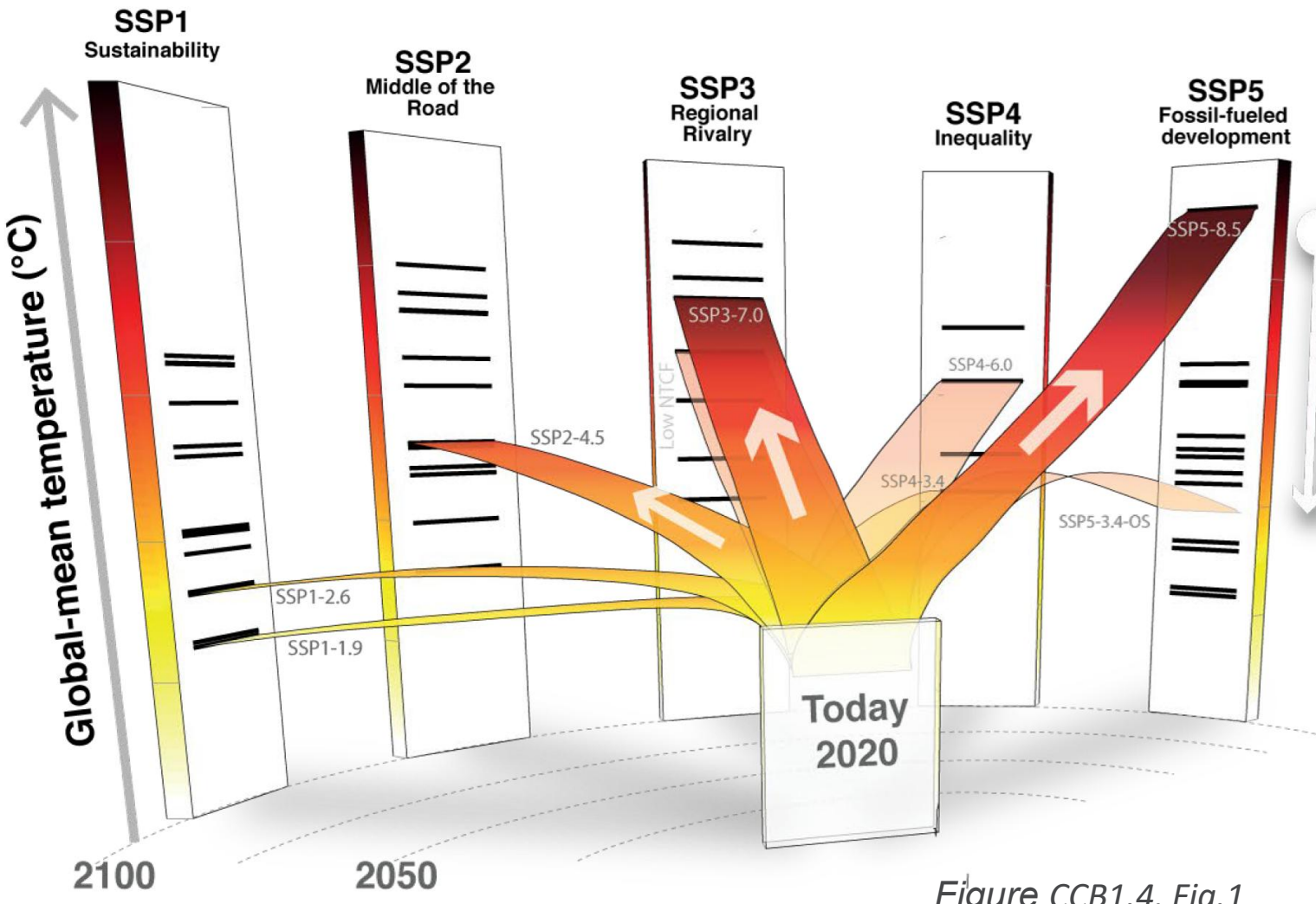
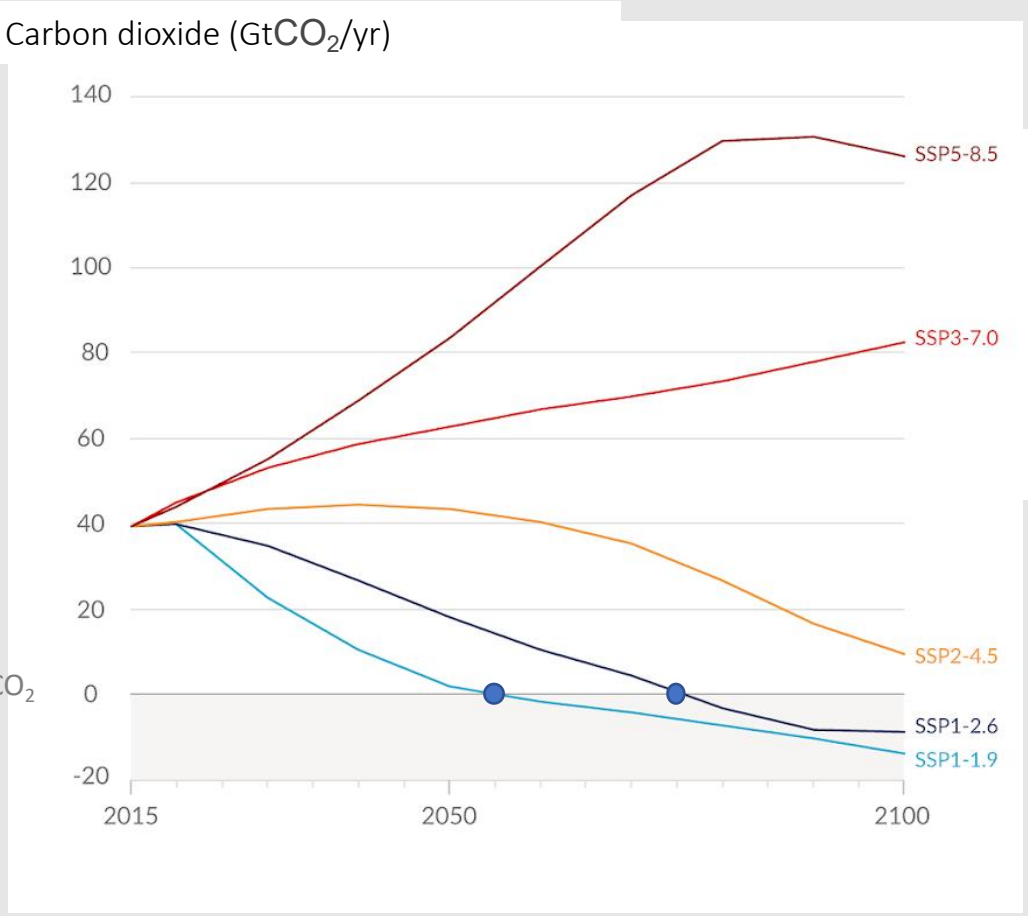


Figure CCB1.4, Fig.1

The illustrative set of five SSP scenarios span a broader range of greenhouse gas and air pollutant futures than assessed in earlier WGI reports

Shared Socioeconomic Pathway (SSP) Scenarios



Very high

High

CO_2 emission pathways without any climate change mitigation

Intermediate

CO_2 emission pathway

Low

Very low

CO_2 emission pathways in which CO_2 emissions decline to net zero around or after 2050

Box SPM.1, Figure SPM.4

Broad agreement across multiple lines of evidence, supporting a best estimate of equilibrium climate sensitivity of 3°C, with a *likely* range of 2.5°C to 4°C

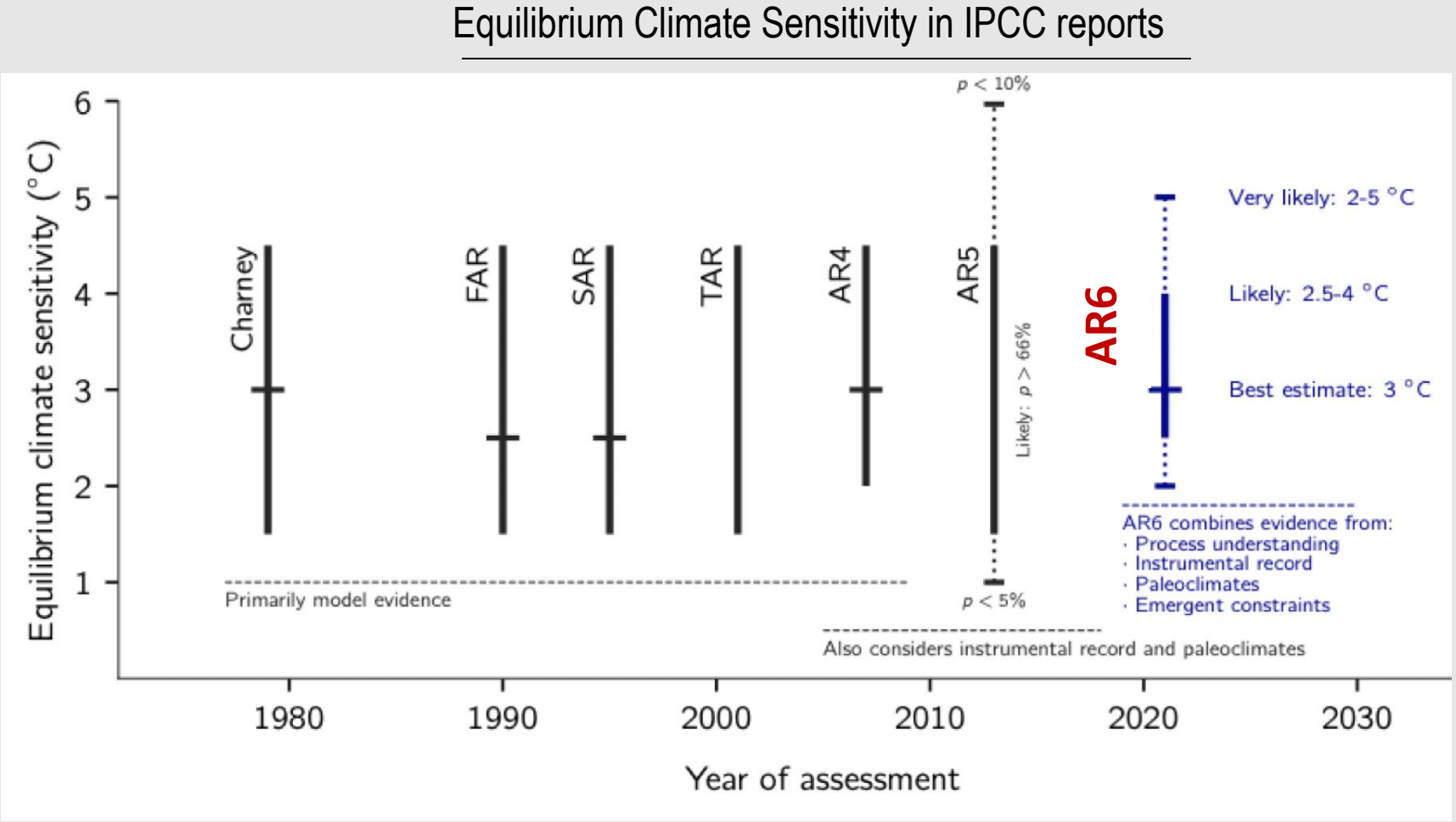


Figure TS.16

Broad agreement across multiple lines of evidence, supporting a best estimate of equilibrium climate sensitivity of 3°C, with a *likely* range of 2.5°C to 4°C

Multiple **lines of evidence** are used to better constrain climate sensitivity

The AR6 **best estimate of ECS** is 3°C, the *likely* range is 2.5 to 4°C and the *very likely* range is 2 to 5°C.

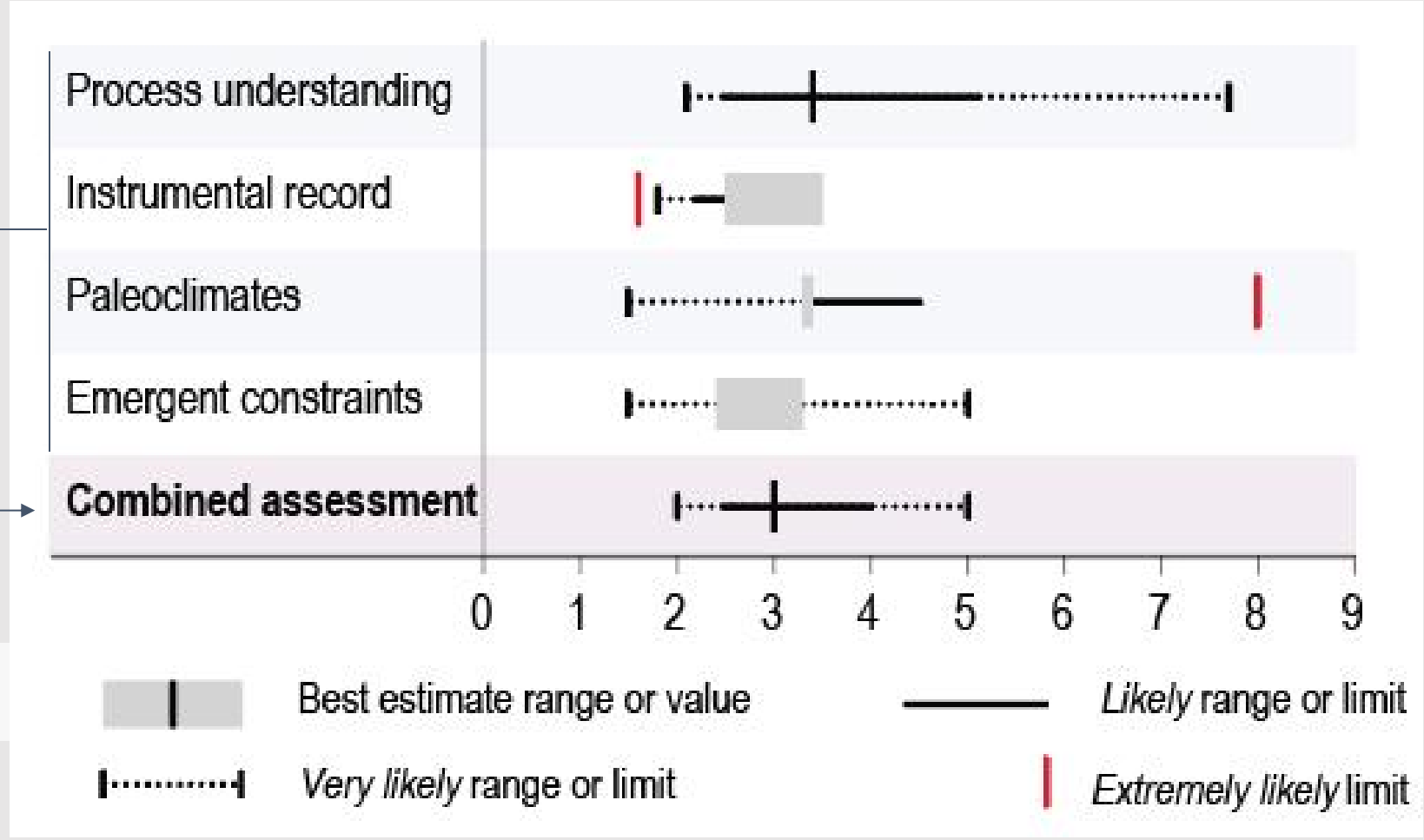
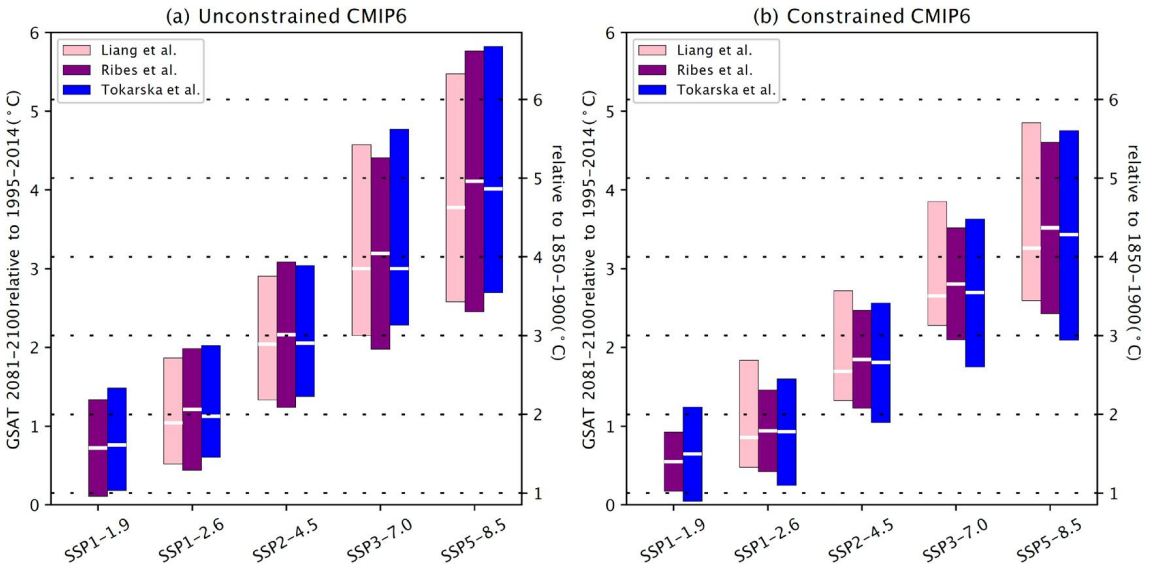
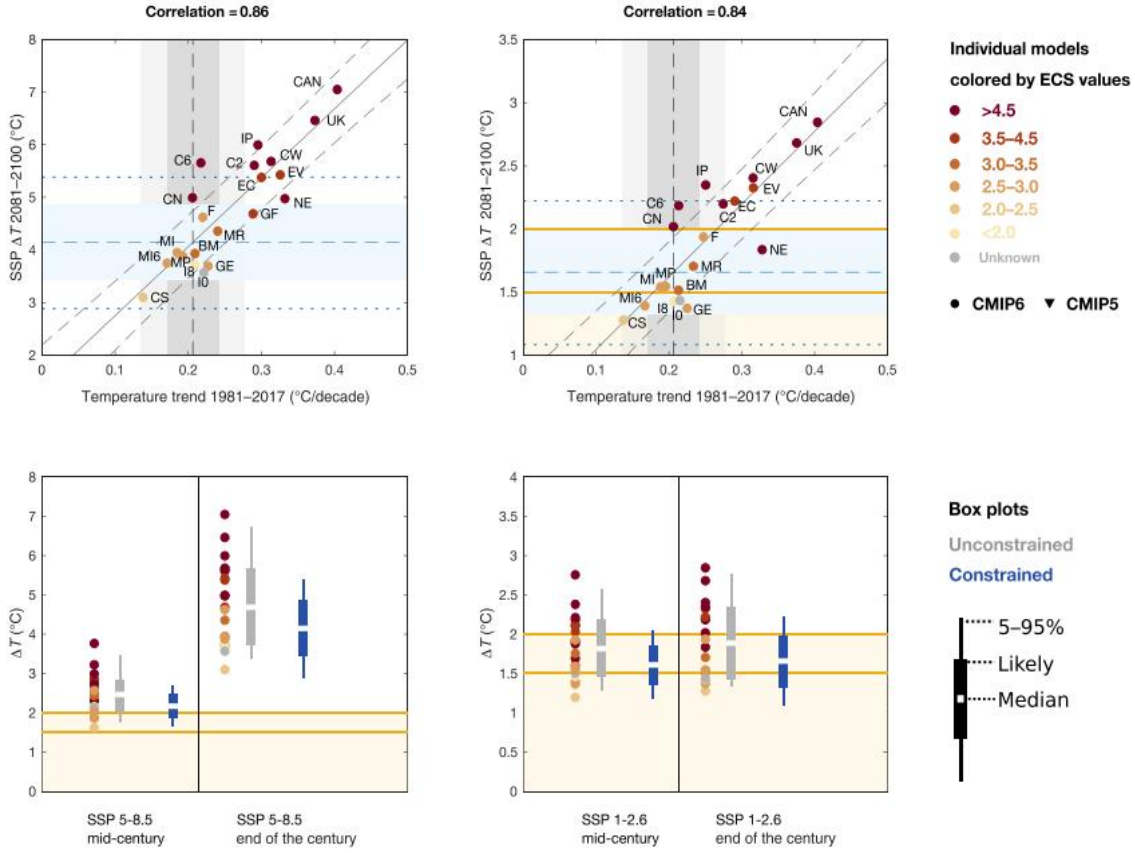


Figure TS.16

AR6 Constrant projections for GST changes



Tokarska et al., 2020



Global warming of 1.5°C and 2°C will be exceeded unless deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades

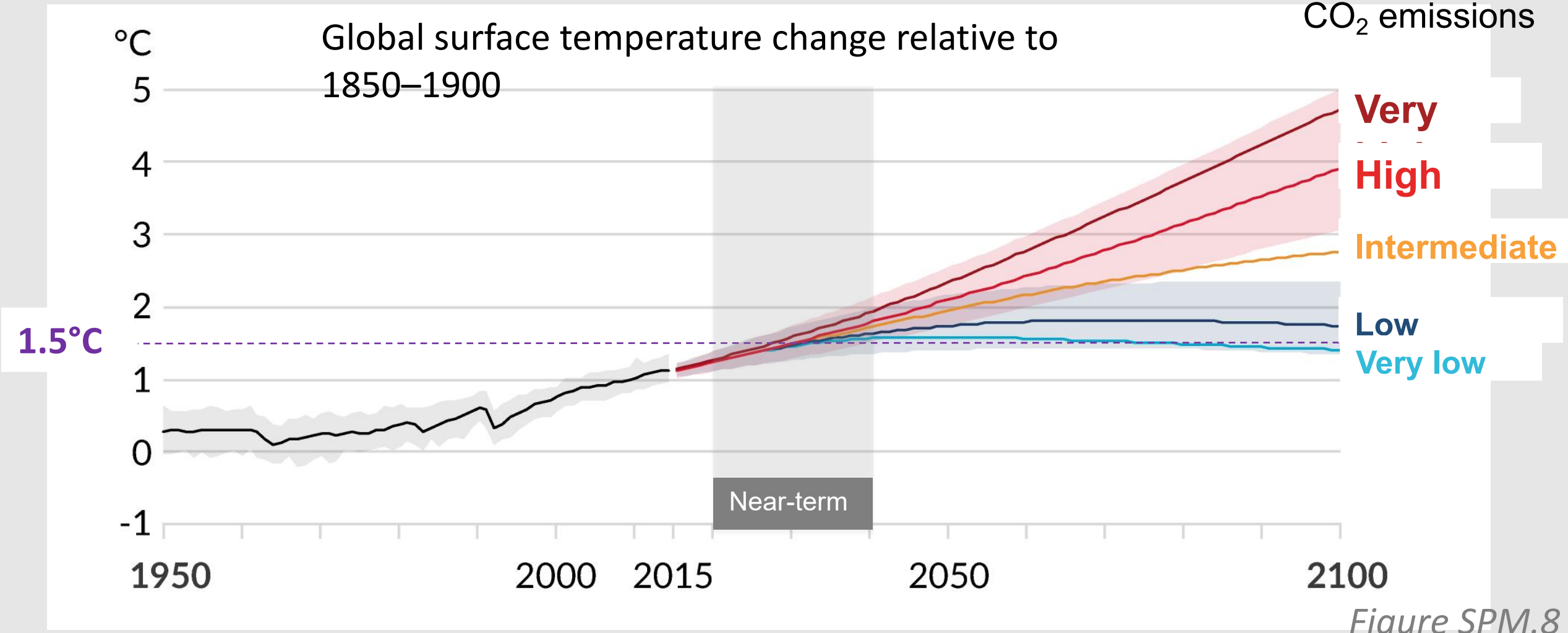


Figure SPM.8

Global warming of 1.5°C and 2°C will be exceeded unless deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades

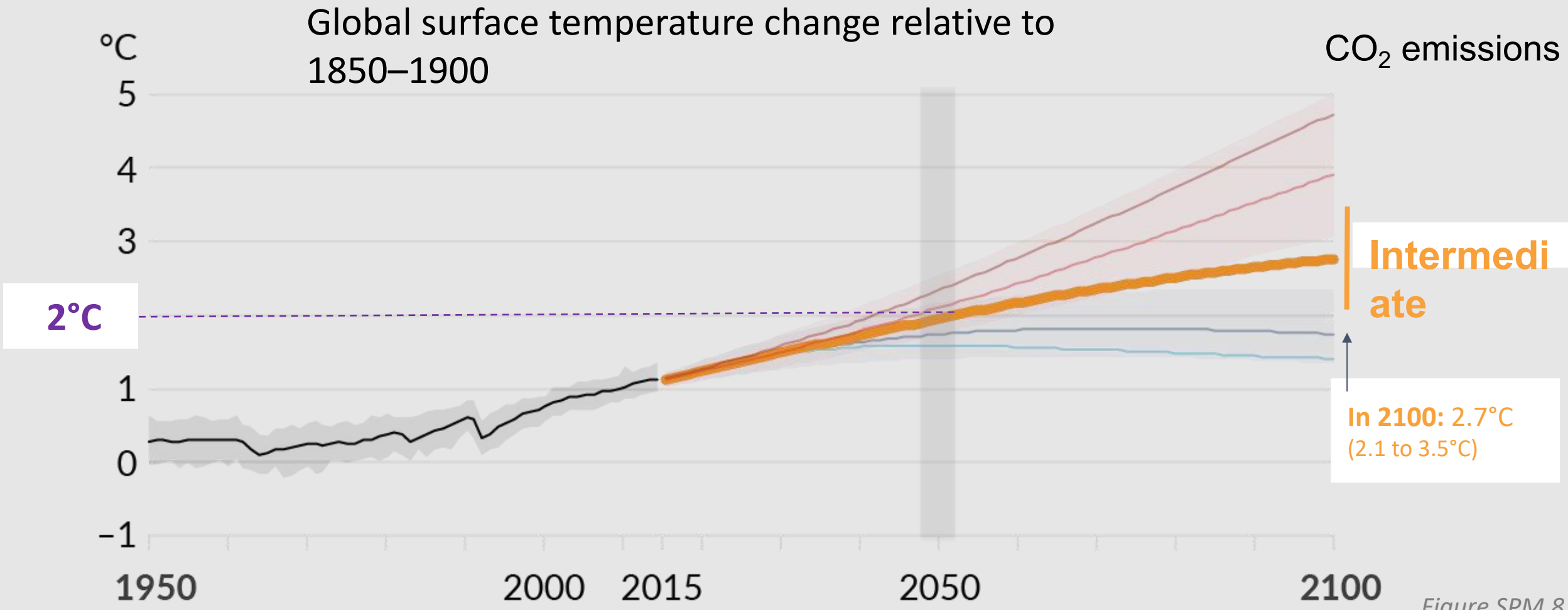


Figure SPM.8

Projections in the context of the Earth's climate history

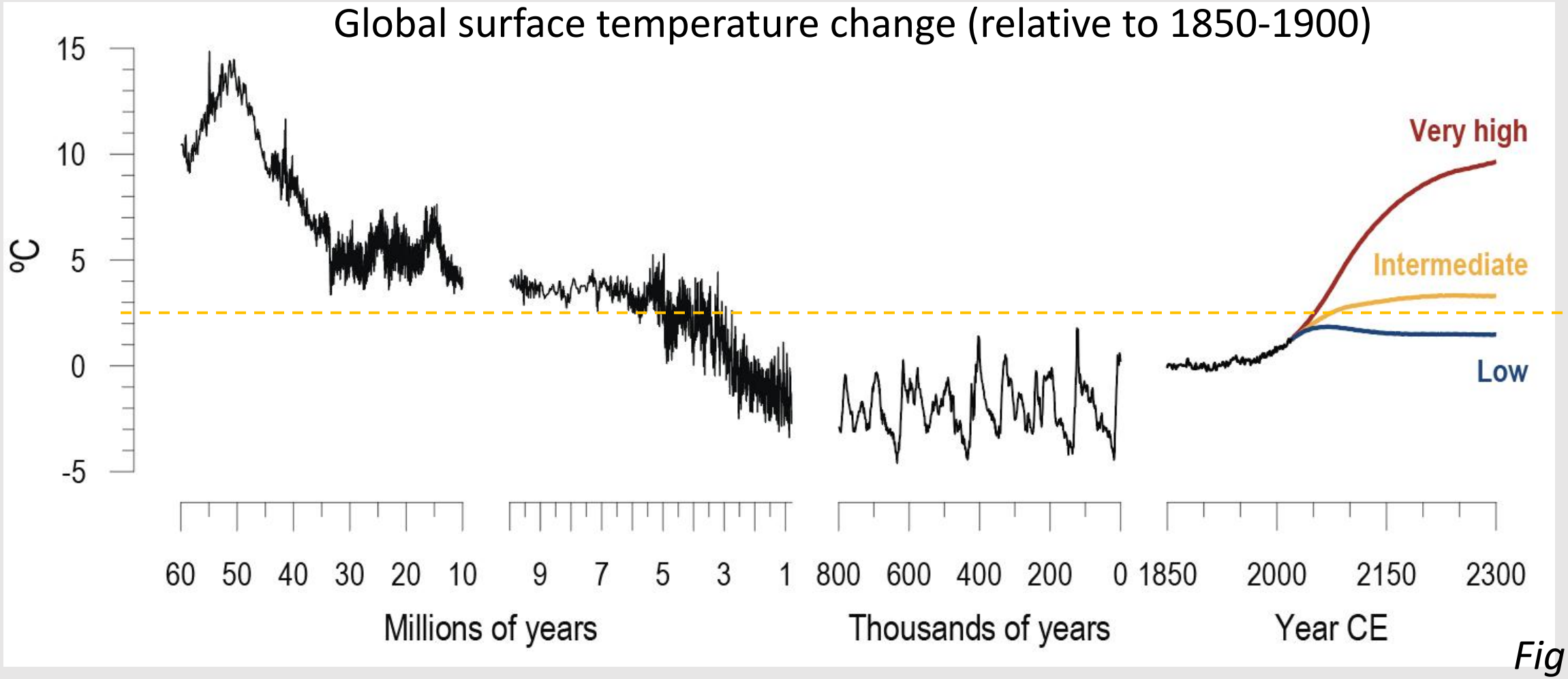
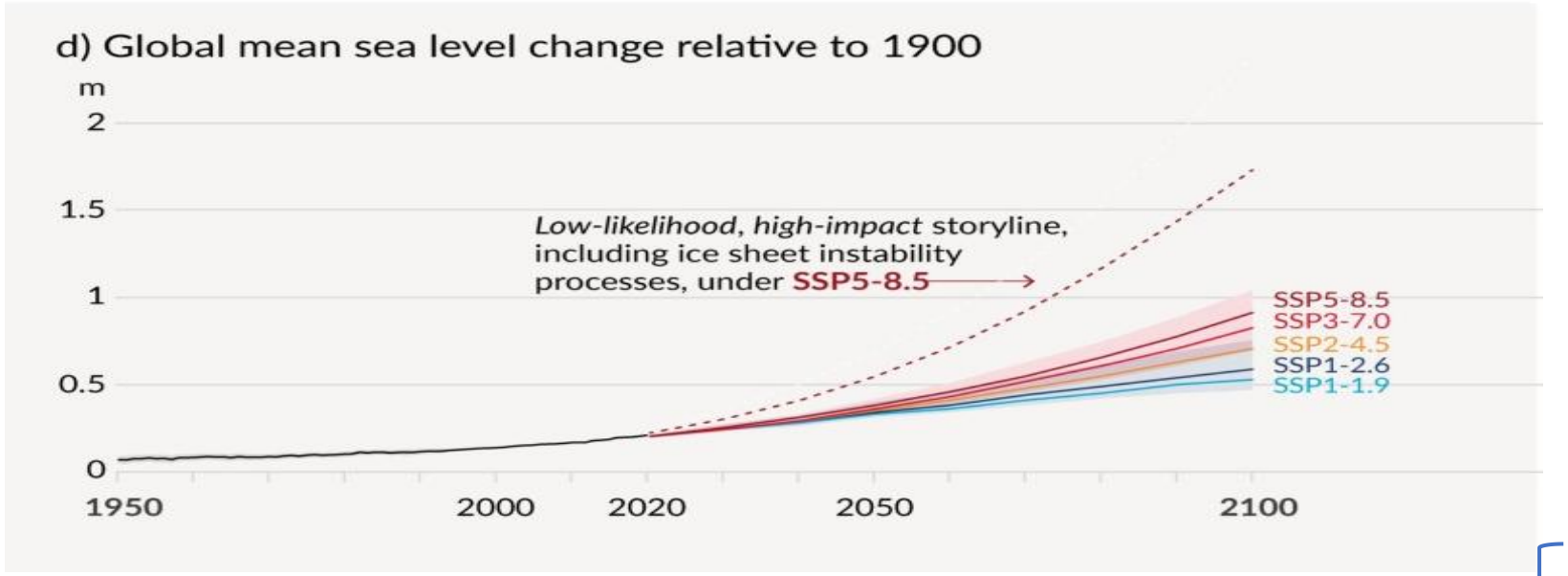
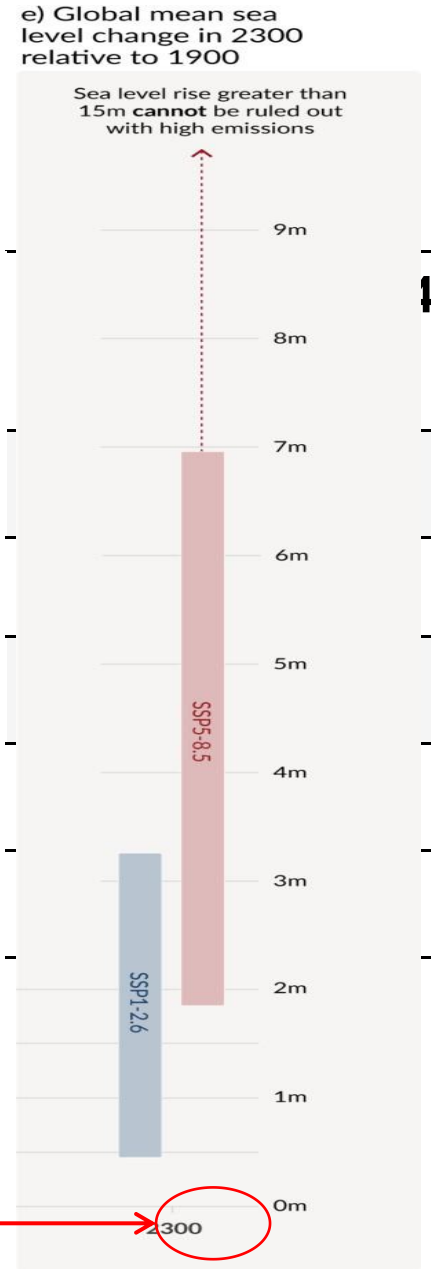


Figure TS.1

Projected change in Global mean sea level rise





over 15m

2100

0.38 m

0.44m

0.56m

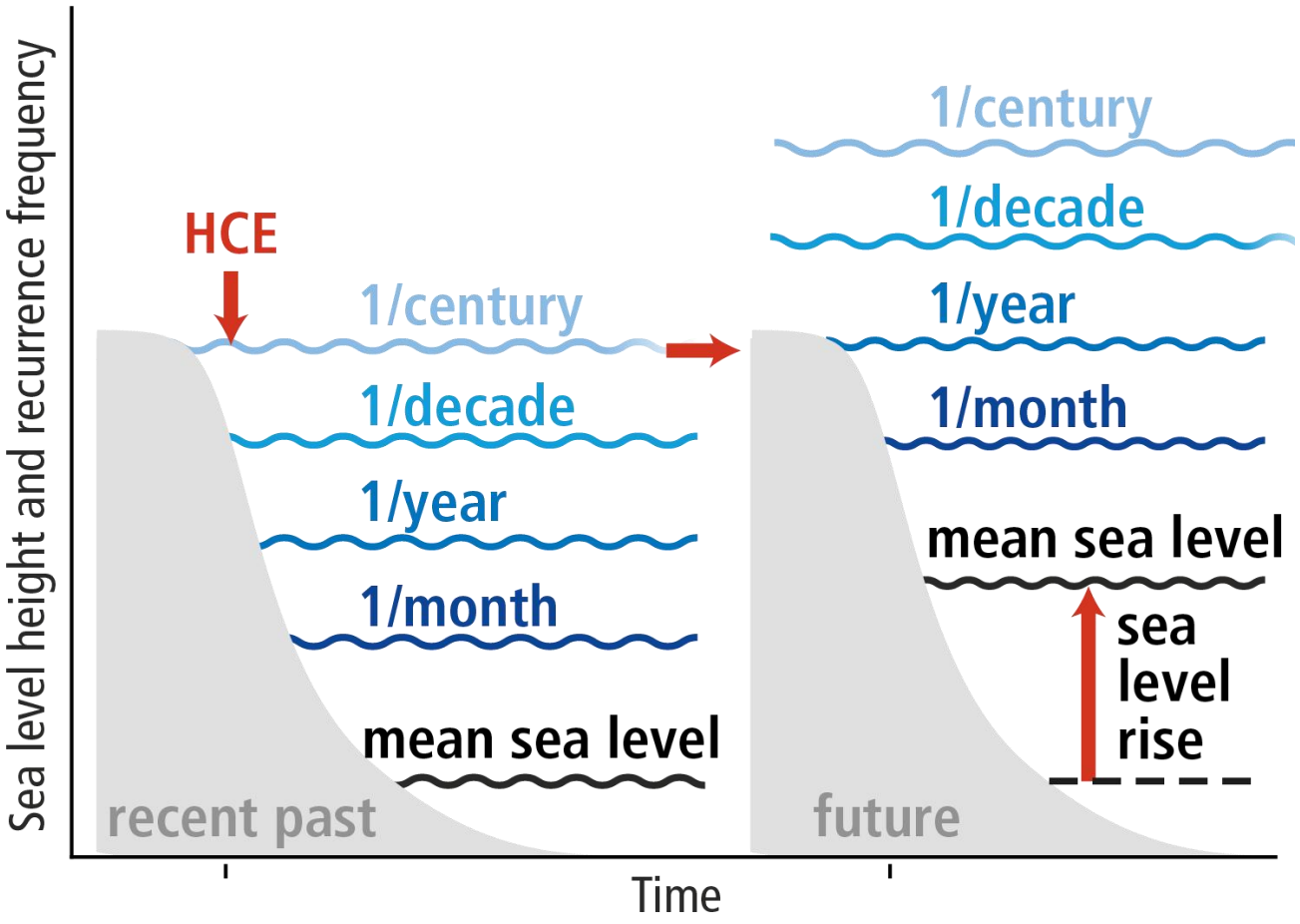
SSP5-8.5

0.68m

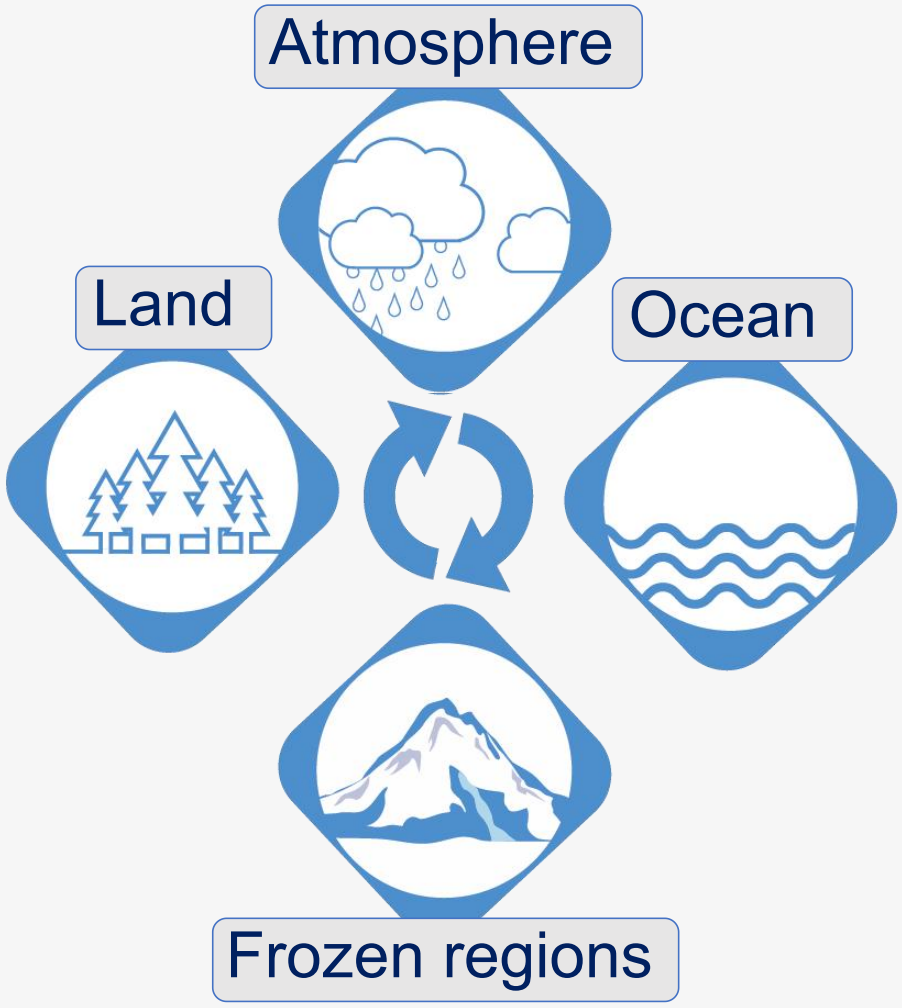
0.77m

SSP1-2.6

Extreme sea level events will increase as GSL rise



Continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation and the severity of wet and dry events



Many changes in the climate system become larger in direct relation to increasing global warming

↑ frequency and intensity
- hot extremes and marine heatwaves
- heavy precipitation **(+7% per °C)**
- drought in some regions

↑ proportion of intense tropical cyclones

Figure FAQ11.2

全球变暖背景下温升的未来预估

Table SPM.1

SSP1-1.9(极低排放情景) :
2041-2060为1.6°C
2081-2100为1.4°C

	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
Scenario	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

全球变暖背景下温升的未来预估

Table SPM.1. See more in Table 4.5 and Fig 4.11

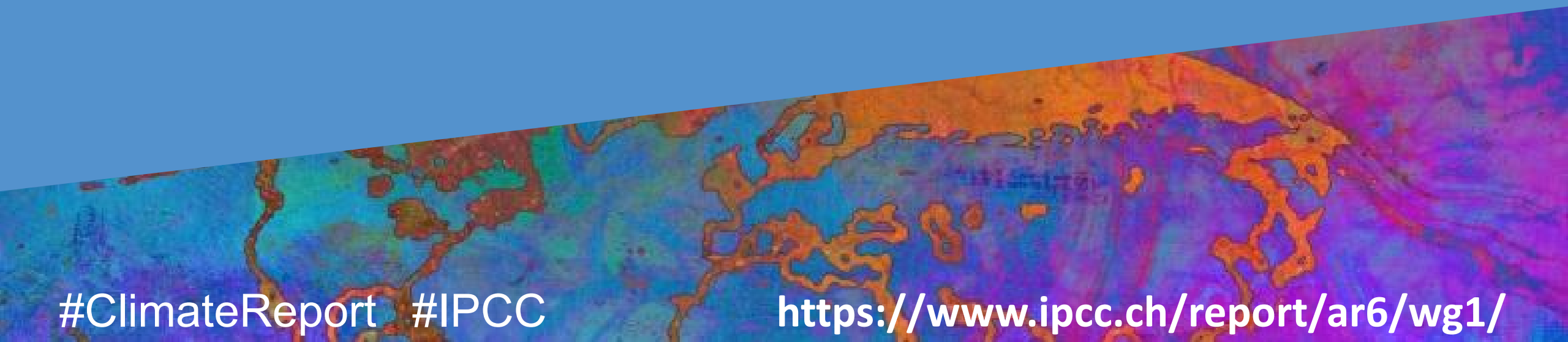
	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
Scenario	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

SIXTH ASSESSMENT REPORT
Working Group I – The Physical Science Basis

ipcc
INTERGOVERNMENTAL PANEL ON Climate change

WMO UNEP

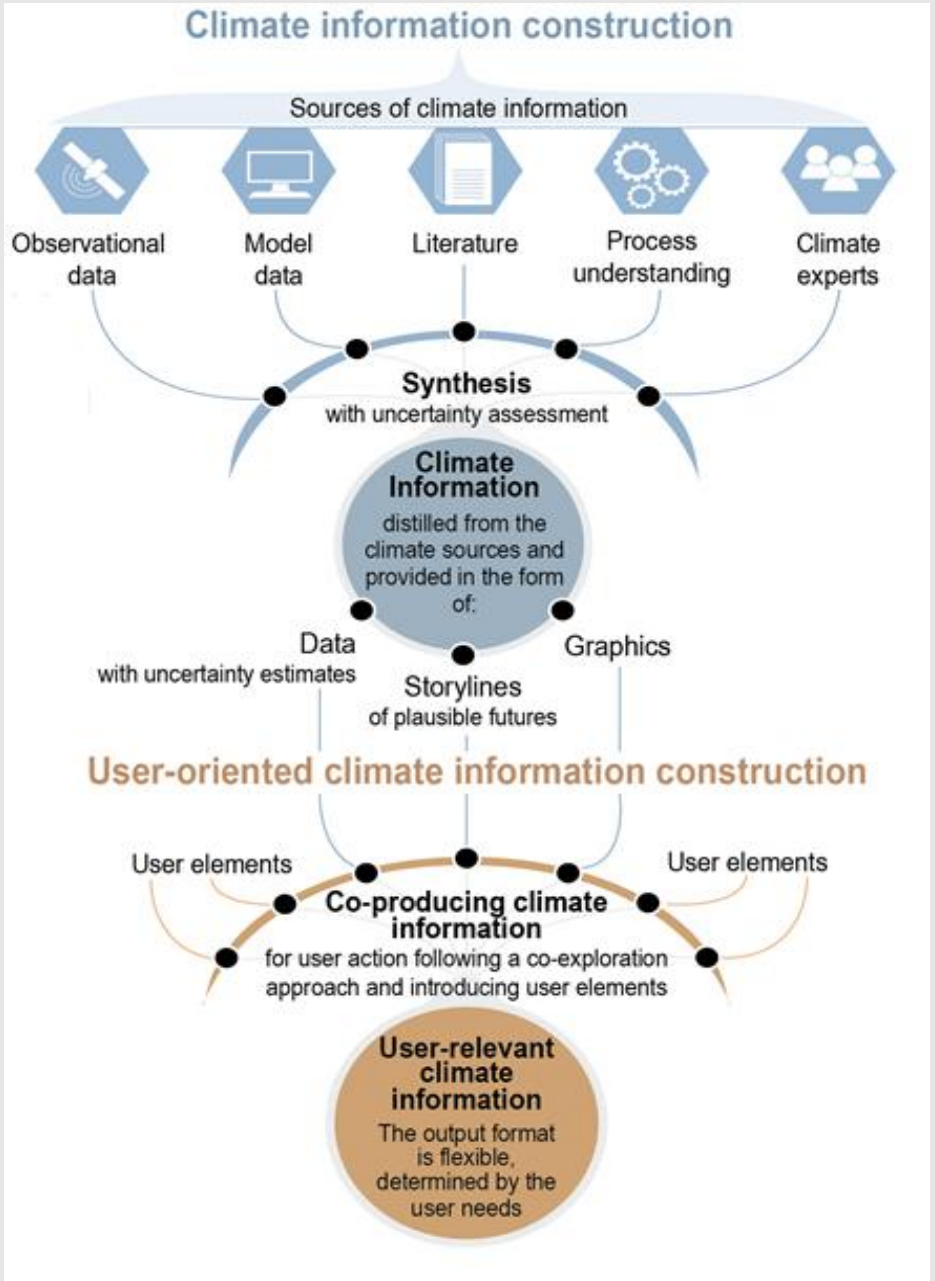
Climate information for adaptation and mitigation



#ClimateReport #IPCC

https://www.ipcc.ch/report/ar6/wg1/

Multiple lines of evidence are distilled for the co-production of user-relevant regional climate information framed by context and values



Chapter 10, Figure 10.1

Natural variability can enhance or reduce near term climate changes, particularly on regional scales

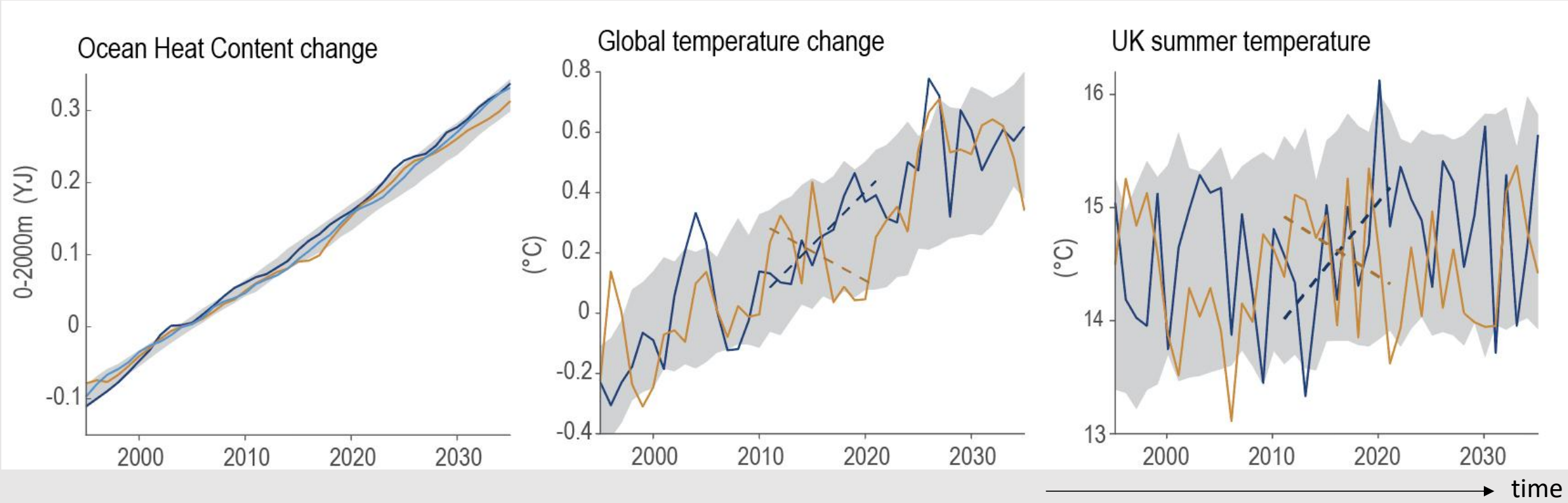
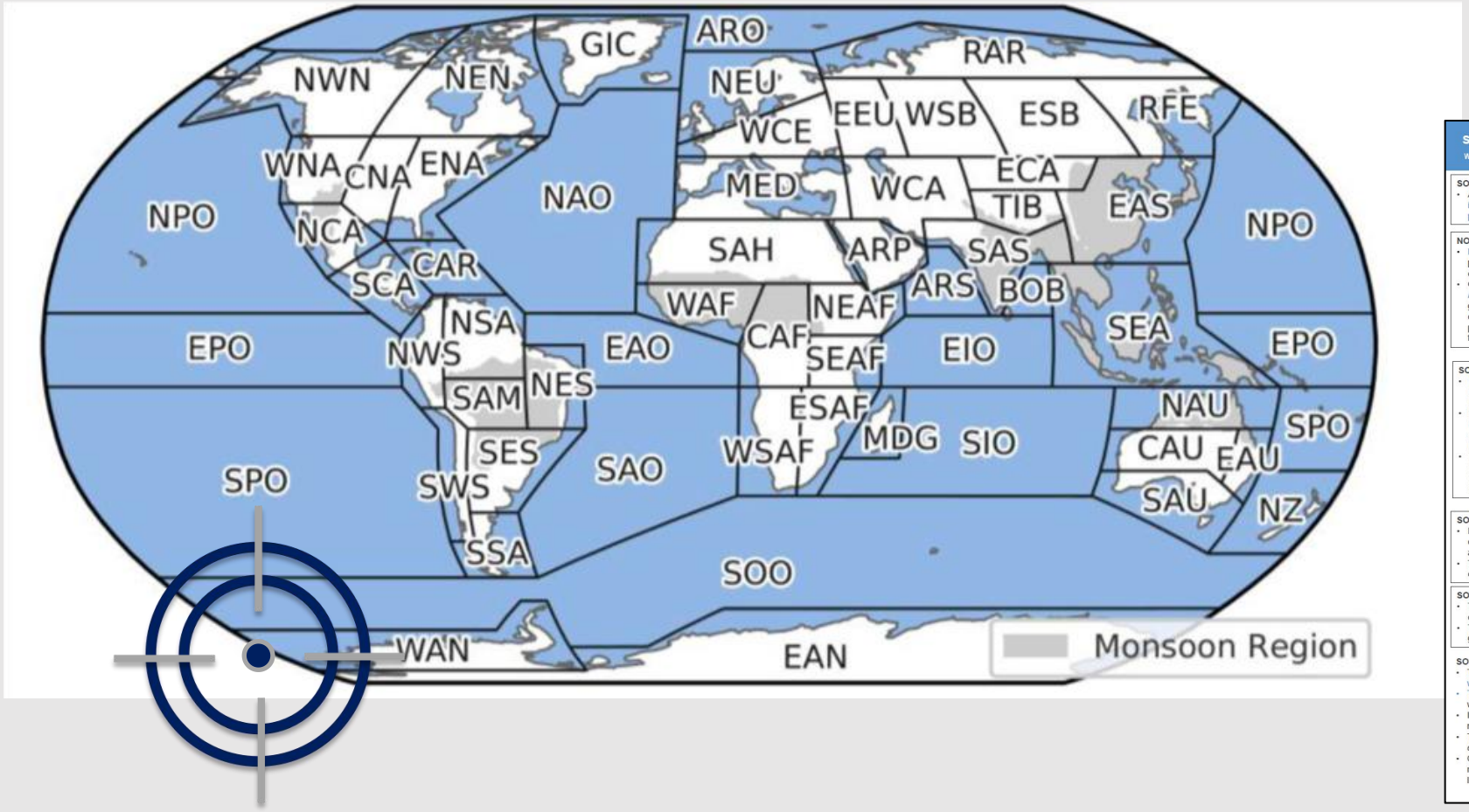
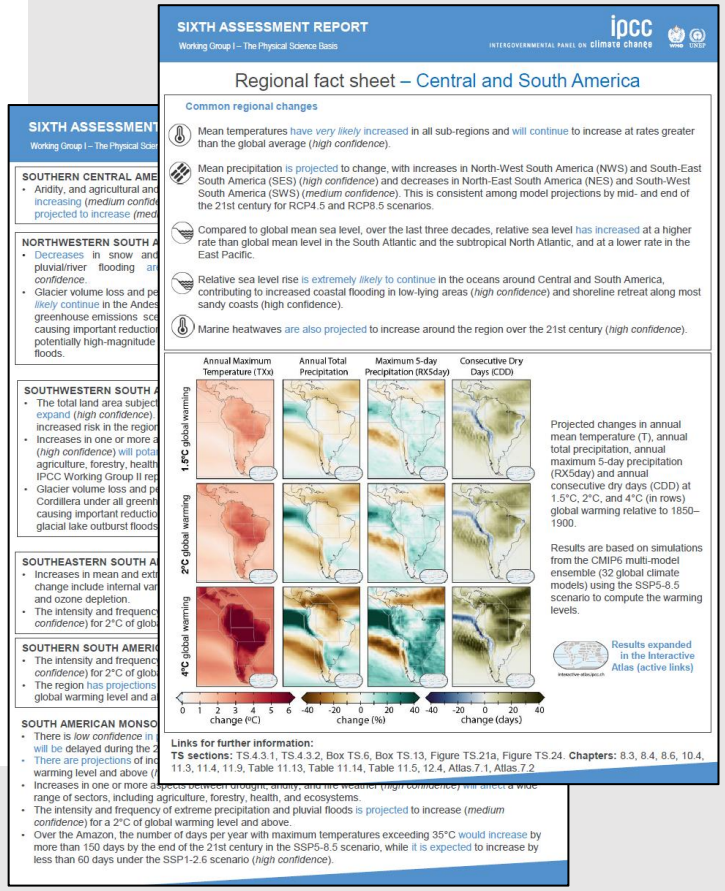


Figure 1.13

Regional climate assessment





SIXTH ASSESSMENT REPORT

Working Group I – The Physical Science Basis

ipcc

INTERGOVERNMENTAL PANEL ON climate change

Regional fact sheet – Central and South America

Common regional changes

Mean temperatures have *very likely* increased in all sub-regions and will continue to increase at rates greater than the global average (*high confidence*).

Mean precipitation is projected to change, with increases in North-West South America (NWS) and South-East South America (SES) (*high confidence*) and decreases in North-East South America (NES) and South-West South America (SWS) (*medium confidence*). This is consistent among model projections by mid- and end of the 21st century for RCP4.5 and RCP8.5 scenarios.

Compared to global mean sea level, over the last three decades, relative sea level has increased at a higher rate than global mean level in the South Atlantic and the subtropical North Atlantic, and at a lower rate in the East Pacific.

Relative sea level rise is extremely *likely* to continue in the oceans around Central and South America, contributing to increased coastal flooding in low-lying areas (*high confidence*) and shoreline retreat along most sandy coasts (high confidence).

Marine heatwaves are also projected to increase around the region over the 21st century (*high confidence*).

Annual Maximum Temperature (TXx) | Annual Total Precipitation | Maximum 5-day Precipitation (RX5day) | Consecutive Dry Days (CDD)

1.5°C global warming

2°C global warming

4°C global warming

change (°C) | change (%) | change (days)

Projected changes in annual mean temperature (T), annual total precipitation, annual maximum 5-day precipitation (RX5day) and annual consecutive dry days (CDD) at 1.5°C, 2°C, and 4°C (in rows) global warming relative to 1850–1900.

Results are based on simulations from the CMIP6 multi-model ensemble (32 global climate models) using the SSP5-8.5 scenario to compute the warming levels.

Results expanded in the Interactive Atlas (active links)

Links for further information:

TS sections: TS.4.3.1, TS.4.3.2, Box TS.6, Box TS.13, Figure TS.21a, Figure TS.24. **Chapters:** 8.3, 8.4, 8.6, 10.4, 11.3, 11.4, 11.9, Table 11.13, Table 11.14, Table 11.5, 12.4, Atlas.7.1, Atlas.7.2

Multiple climatic impact-drivers will change in all regions of the world

Heat & cold

Rain & drought

Snow & ice

Wind

Coastal & oceanic

Other

Open ocean

A **climatic impact-driver is a** physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems

Worldwide changes in heat, cold, snow and ice, coastal, oceanic climatic impact-drivers will continue over the 21st century

Changes of CIDs related to the water cycle have a more region specific distribution

- All regions are projected to experience changes in at least 5 CIDs.
- 96% of regions are projected to experience changes in at least 10 CIDs.
- 50% of regions are projected to experience changes in at least 15 CIDs.

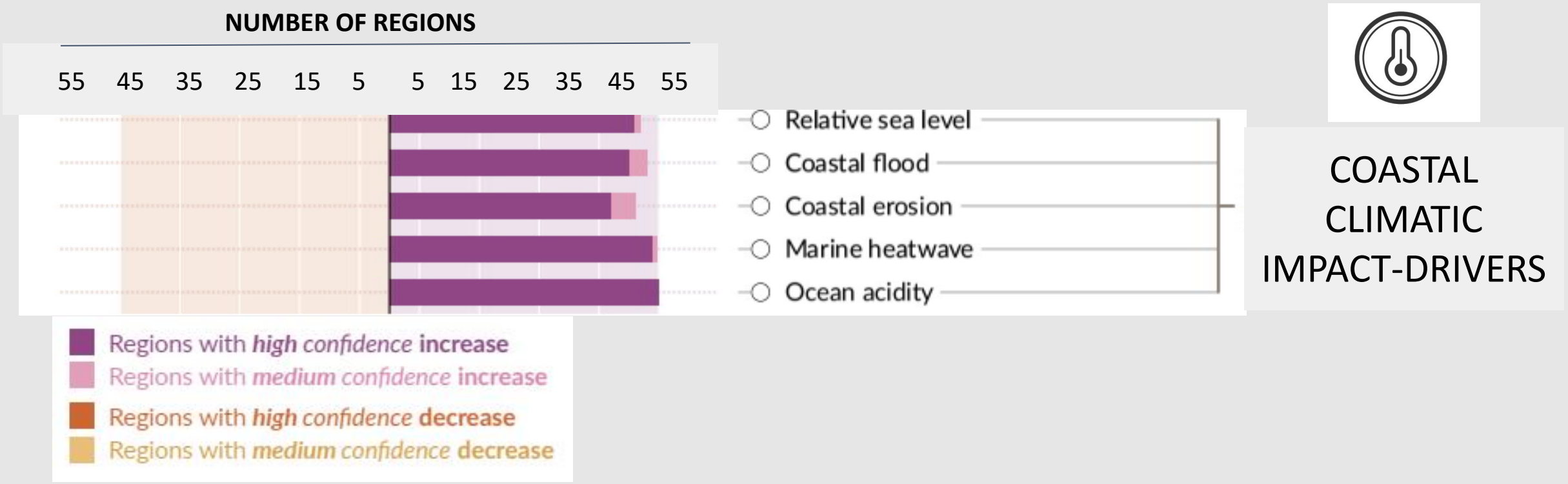
Regional sea level rise contributes to increases in the frequency and severity of coastal flooding in low-lying areas and to coastal erosion along most sandy coasts

Extreme sea levels that occurred once per century in the recent past will occur

- by 2050: 20 to 30 times more frequently
  annually or more frequently at about 19–31% of tide gauges

- by 2100 : at least 160 times more frequently,
  annually or more frequently at 60% (<2°C) to 80% (4°C) of tide gauges

Regional sea level rise contributes to increases in the frequency and severity of coastal flooding in low-lying areas and to coastal erosion along most sandy coasts

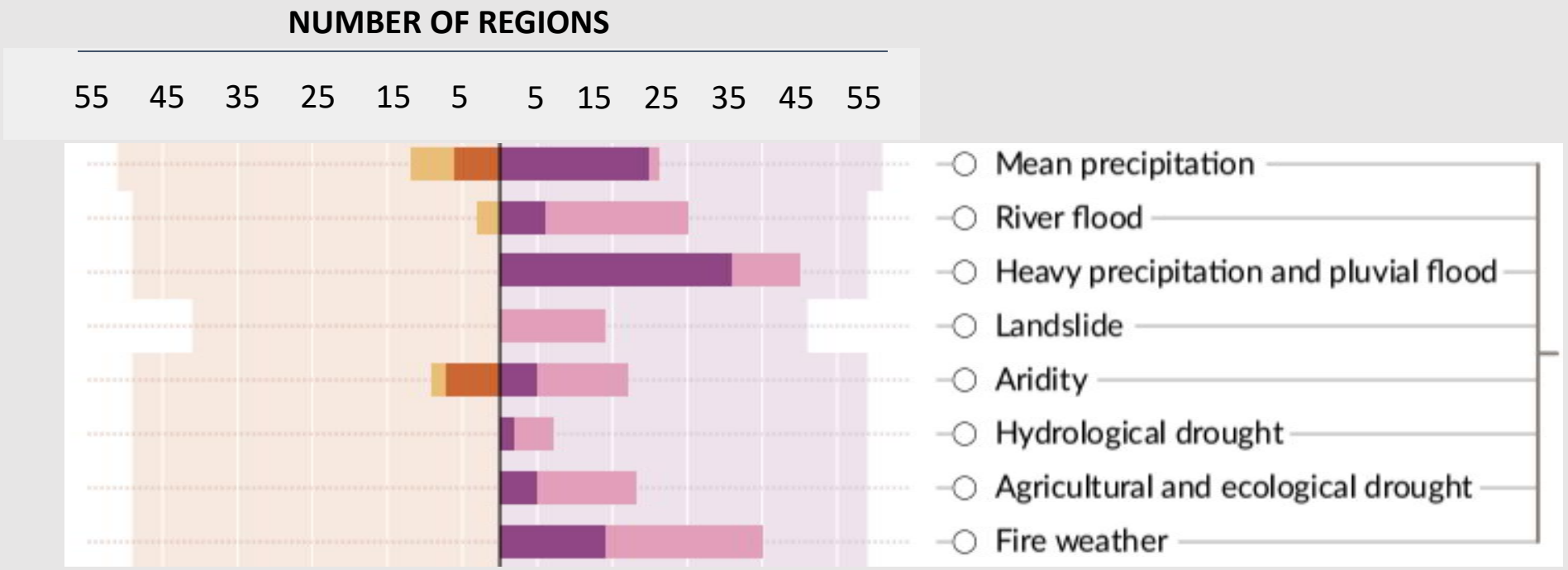


COASTAL CLIMATIC IMPACT-DRIVERS

by 2050 compared to 1960-2014 (2°C global warming)

Figure SPM.9

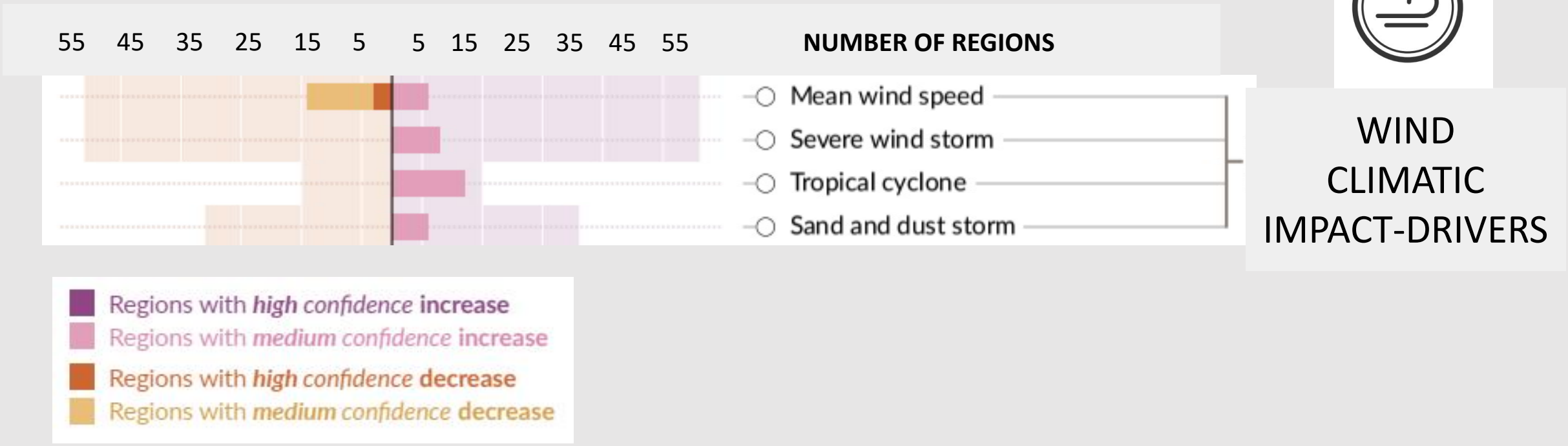
At 2°C global warming and above, the magnitude of changes increases for droughts, heavy precipitation and associated flooding events, and for mean precipitation compared to those at 1.5°C



WET & DRY CLIMATIC IMPACT-DRIVERS

Figure SPM.9

Region-specific changes include intensification of tropical cyclones and/or extratropical storms

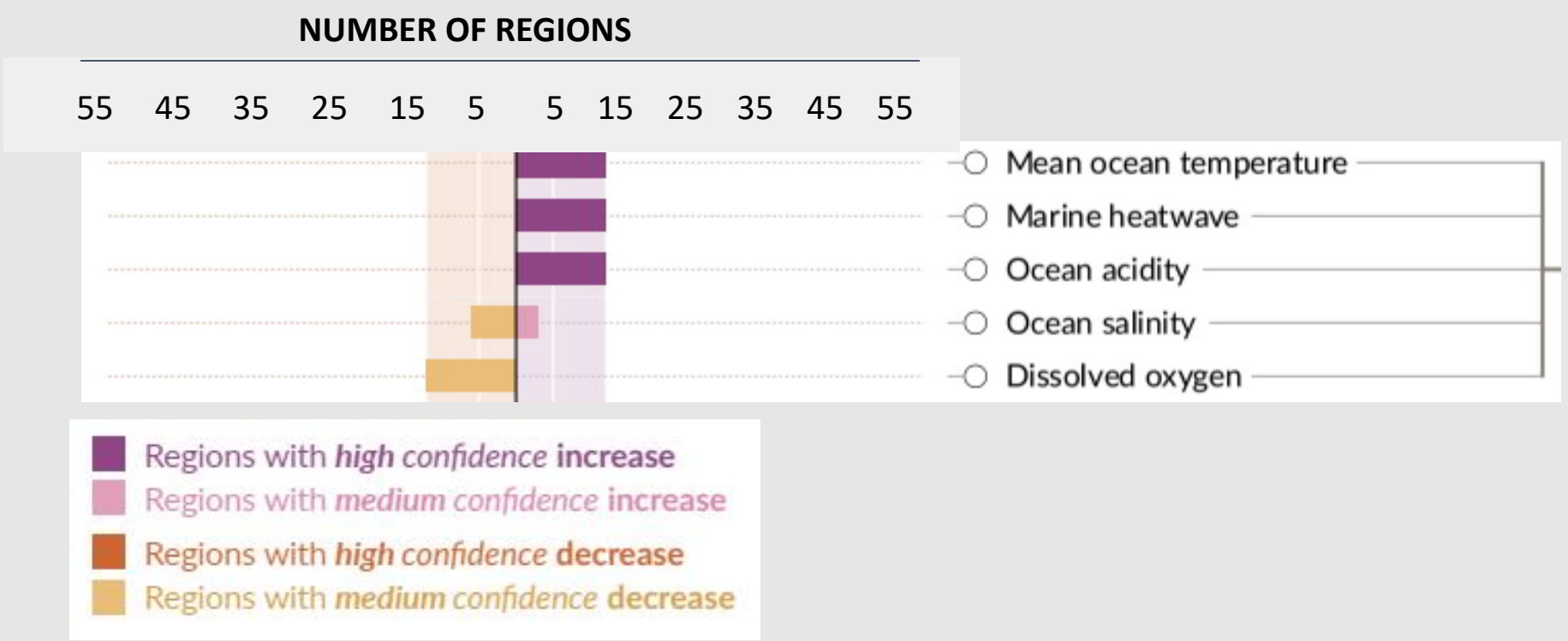


WIND CLIMATIC IMPACT-DRIVERS

by 2050 compared to 1960-2014 (2°C global warming)

Figure SPM.9

The open ocean regions are projected to experience widespread warming, increased marine heatwaves, loss of oxygen and increased surface salinity contrasts due to the intensified water cycle



OPEN OCEAN CLIMATIC IMPACT-DRIVERS

by 2050 compared to 1960-2014 (2°C global warming)

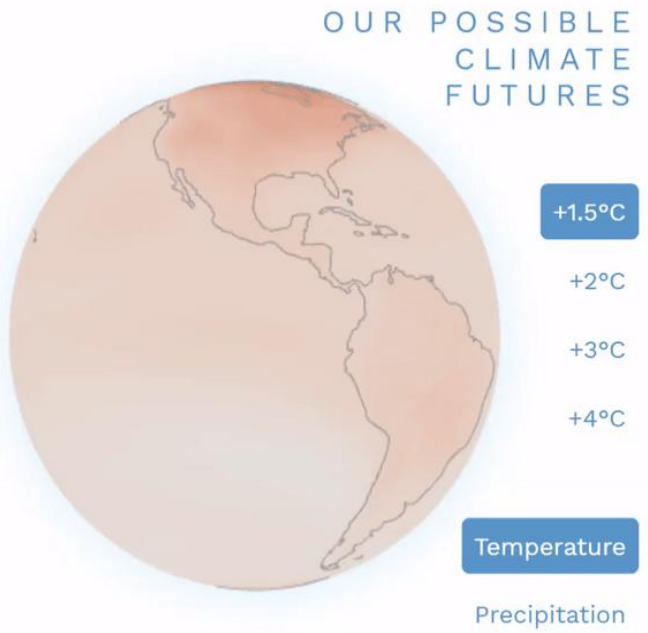
Figure SPM.9

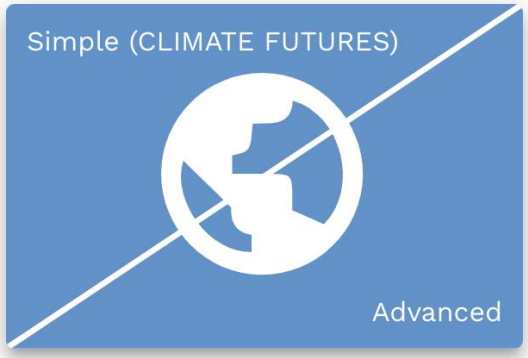
IPCC WGI Interactive Atlas

A novel tool for flexible spatial and temporal analyses of much of the observed and projected climate change information underpinning the Working Group I contribution to the Sixth Assessment Report, including regional synthesis for Climatic Impact-Drivers (CIDs).

Participate in the user testing survey

Errata and problem reporting





REGIONAL INFORMATION

REGIONAL SYNTHESIS

DOCUMENTATION

Low Likelihood High Impact events

- The probability of occurrence is low but potential impacts on society and ecosystems could be high
- Their chance of occurrence increases with higher global warming
- They can occur at the global and regional scale

See Table 4.1

二氧化碳累计排放增加会加剧全球变暖（~每年排放40GT）

Every tonne of CO_2 emissions adds to global warming

Global surface temperature increase since 1850-1900 (°C) as a function of cumulative CO_2 emissions ($GtCO_2$)

Figure SPM.10

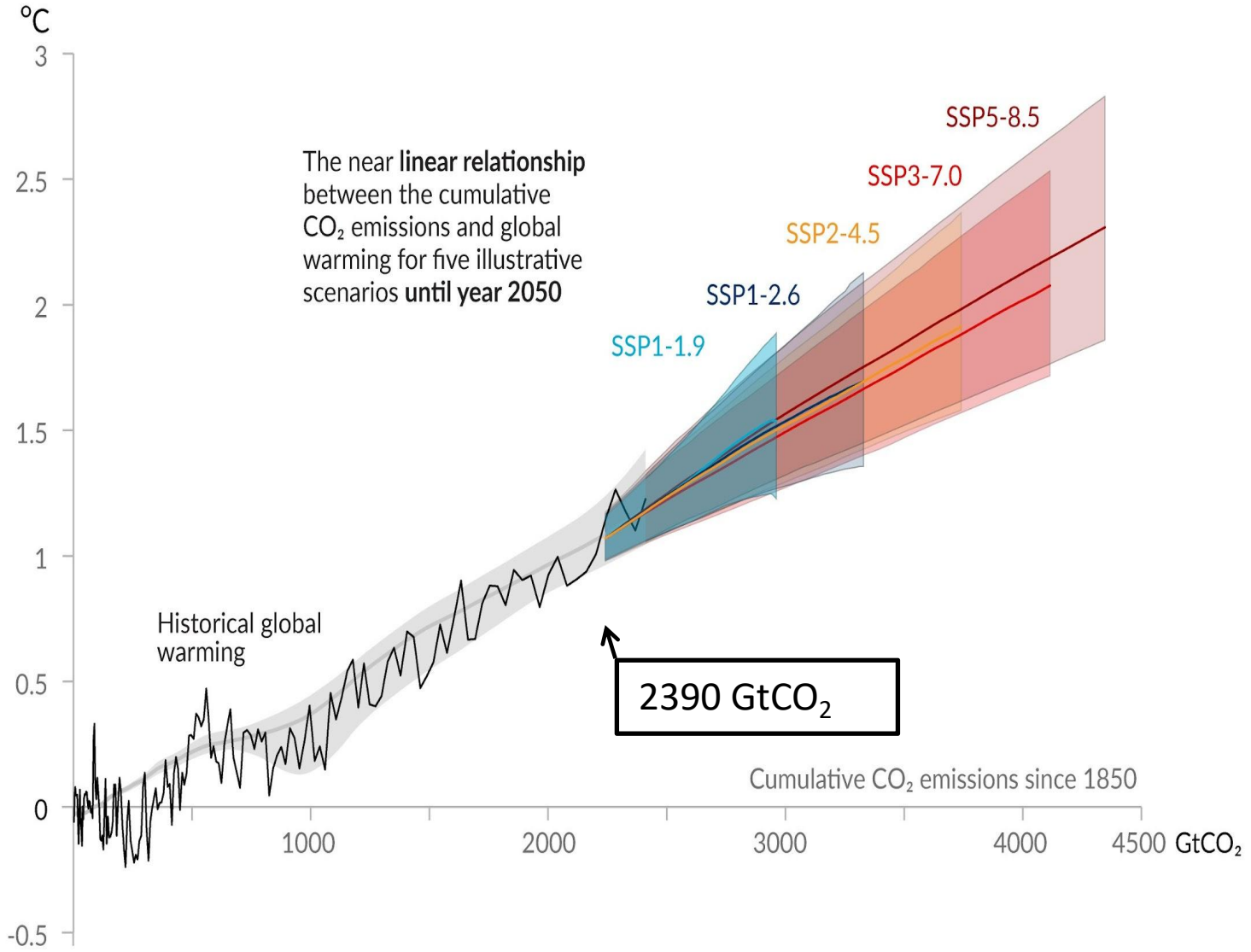


Table SPM.2

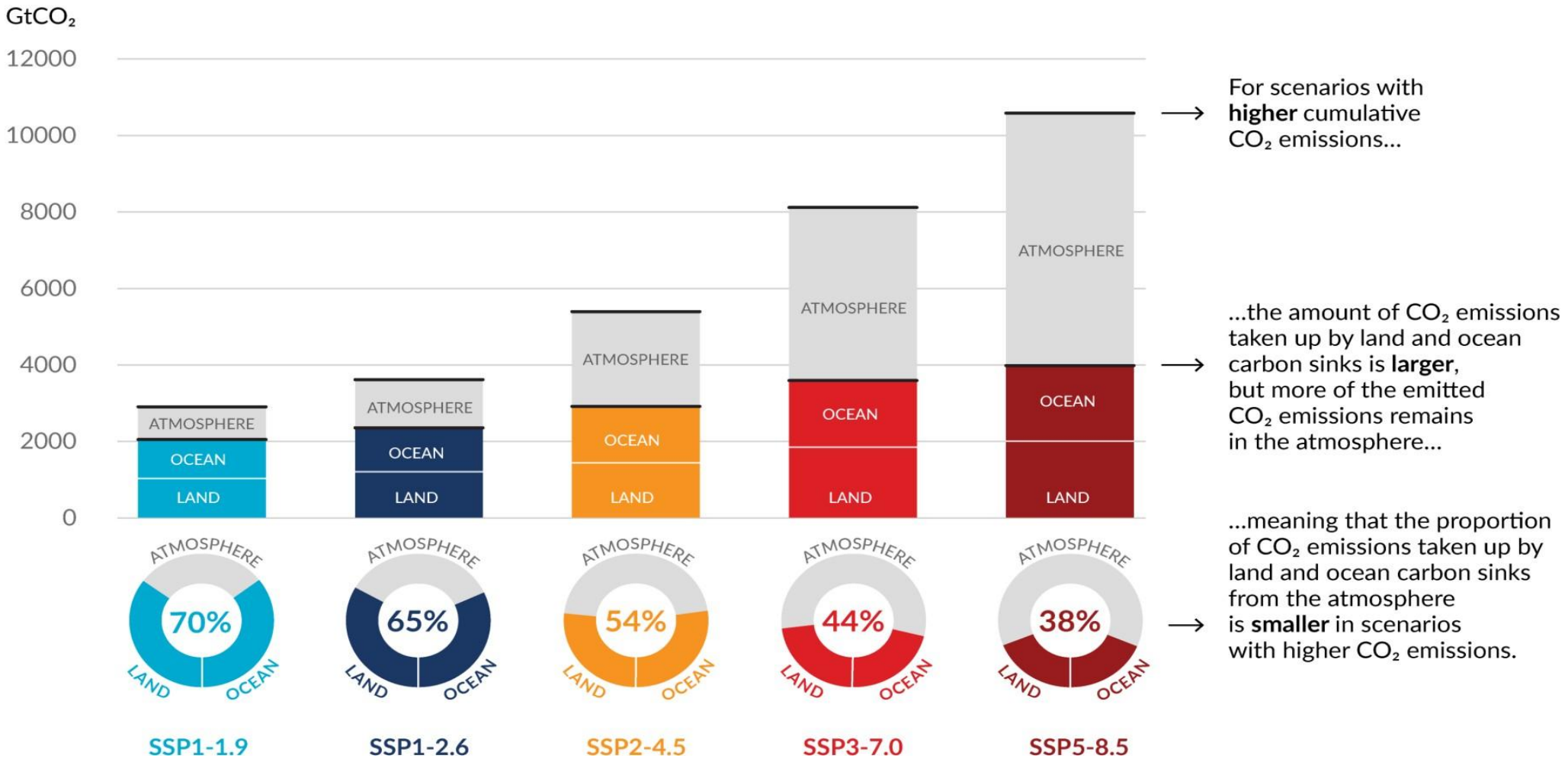
剩余碳收支
Remaining carbon budgets

Approximate global warming relative to 1850–1900 until temperature limit *(°C)**(1)	Additional global warming relative to 2010–2019 until temperature limit *(°C)*	Estimated remaining carbon budgets from the beginning of 2020 *($GtCO_2$)* — *Likelihood of limiting global warming to temperature limit*(2)*					Variations in reductions in non-CO_2 emissions*(3)
		17%	*33%*	*50%*	*67%*	*83%*	
1.5	0.43	900	650	500	400	300	Higher or lower reductions in accompanying non-CO_2 emissions can increase or decrease the values on the left by 220 $GtCO_2$ or more
1.7	0.63	1450	1050	850	700	550	
2.0	0.93	2300	1700	1350	1150	900	

CO_2累积排放量高的情景下，陆地和海洋碳汇占比迅速减少！

Figure SPM.7

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



Summery:

- Recent climate changes are widespread, rapid, and intensifying, and unprecedented in thousands of years.
- Human activities are causing climate change, making extreme climate events, including heat waves, heavy rainfall, and droughts, more frequent and severe.
- Climate change is already affecting every region on Earth, in multiple ways. The changes we experience will increase with further warming.
- There’s no going back from some changes in the climate system. However, some changes could be slowed and others could be stopped by limiting warming.
- Unless there are immediate, rapid, and large-scale reductions in greenhouse gas emissions, limiting warming to 1.5°C and even 2°C will be beyond reach.


Forty-Eighth Session of the IPCC and
First Joint Session of Working Groups I, II and III
1-5 October 2018 I Incheon, Republic of Korea
ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP
Korea Meteorological Administration
Incheon Metropolitan City
Valérie Masson-Delmotte
Co-Chair WG I
Panmao Zhai
Co-Chair WG I
Abdalah Mokssit
Secretary IPCC
Hoesung Lee
Chair IPCC
Jim Skea
Co-Chair WG III
Priyadarshi R. Shukla
Co-Chair WG III
Hans-Otto Pörtner
Co-Chair WG II
Debra Roberts
Co-Chair WG II

Thank you.

More Information:

IPCC: www.ipcc.ch
Interactive Atlas: interactive-atlas.ipcc.ch

IPCC Working Group I TSU:

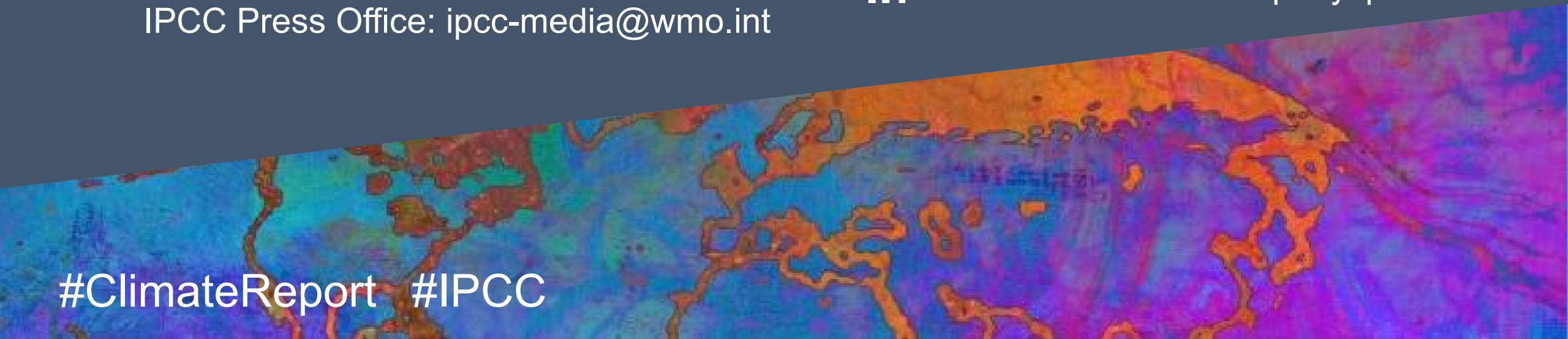
IPCC Press Office: ipcc-media@wmo.int

Follow Us:

@IPCC

@IPCC_CH

linkedin.com/company/ipcc



#ClimateReport #IPCC