Extreme Weather and Climate Events in a Changing Climate

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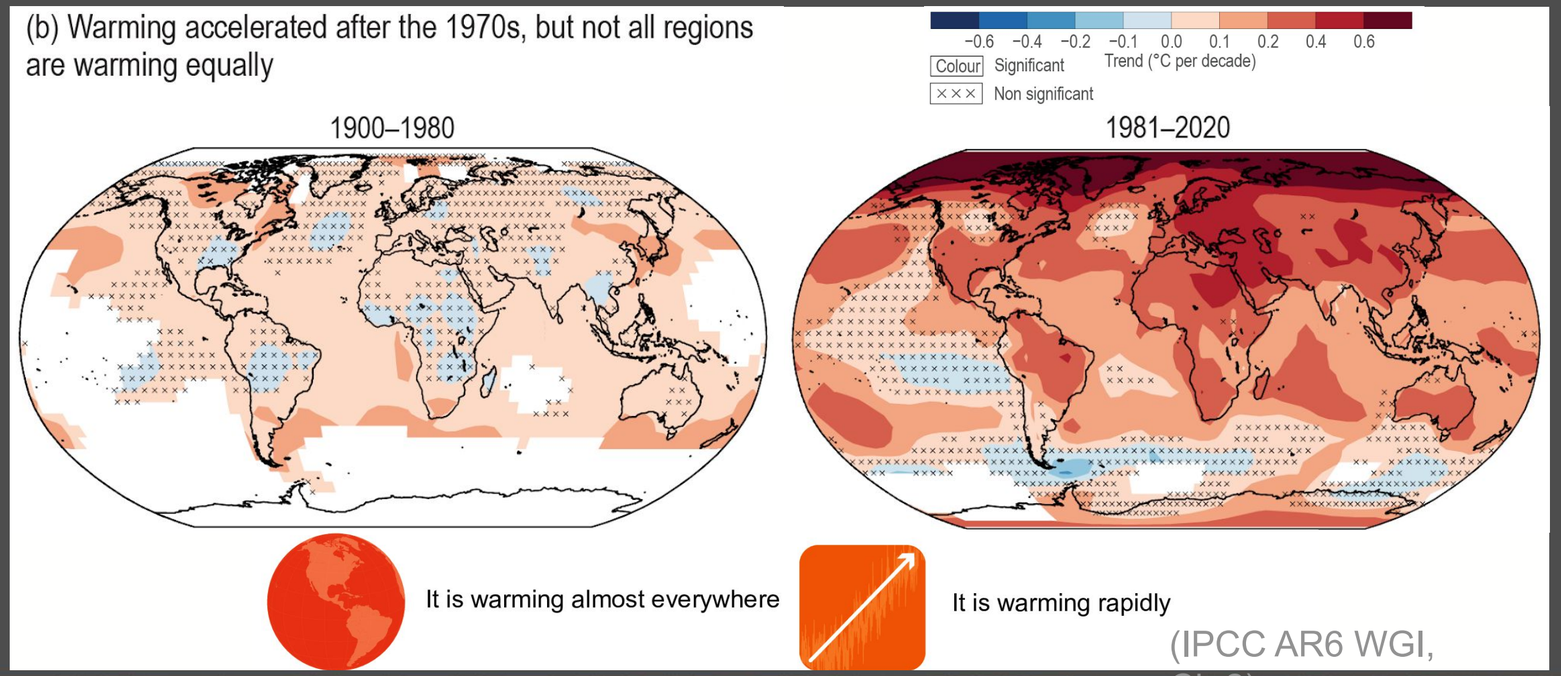
June 4, 2025 @ Asia Clean Energy Forum 2025, Manila

ASIA CLEAN ENERGY FORUM 2025
Empowering the Future: Clean Energy Innovations,
Regional Cooperation and Integration, and Financing Solutions
2–6 June | ADB Headquarters, Manila

National Institute for Environmental Studies, Japan

Global warming in observations

National Institute for Environmental Studies, Japan



(IPCC AR6 WGI, Ch.2)

1850

2024

(#ShowYourStripes

Human-induced global warming

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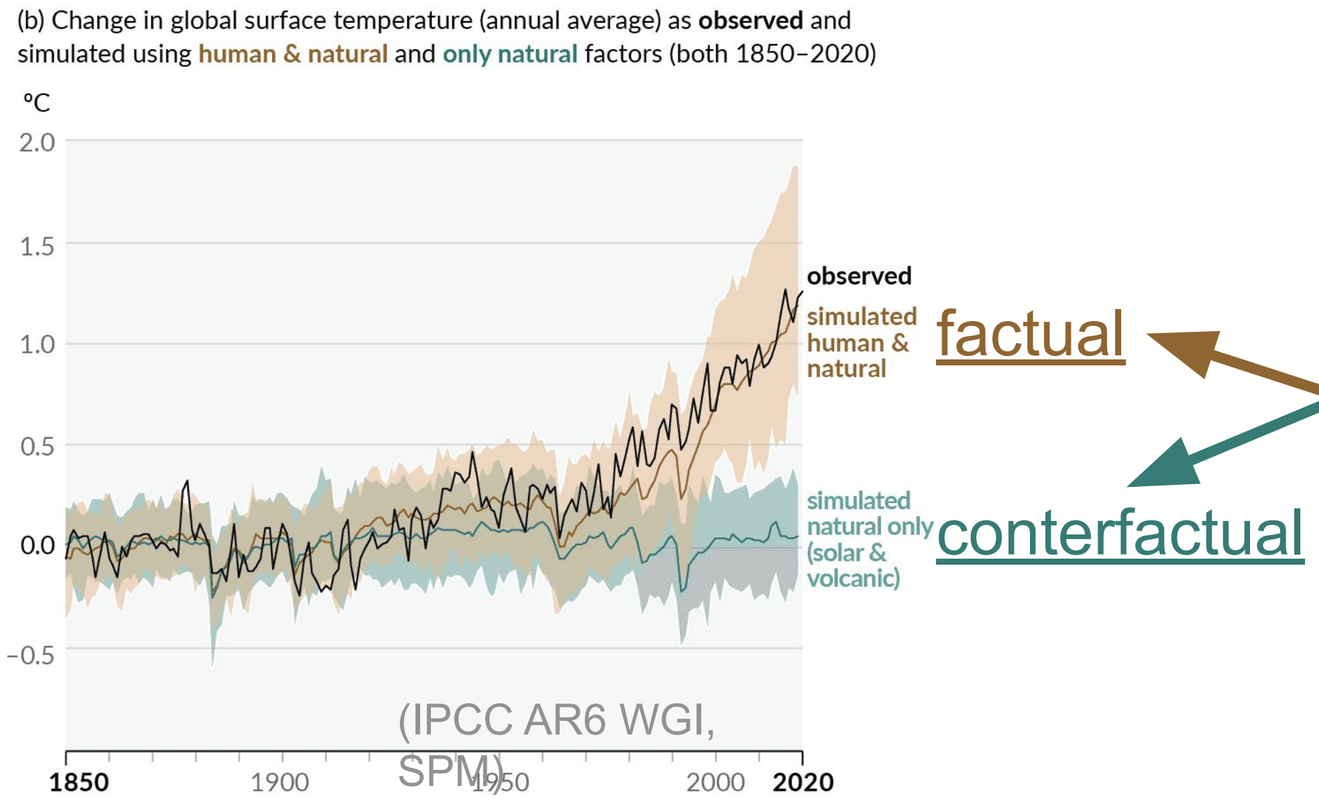
"It is **unequivocal that human influence has warmed the atmosphere, ocean and land**." (IPCC AR6 WGI, SPM Headline Statements)

"Human-induced climate change is **already affecting many weather and climate extremes** in every region across the globe." (IPCC AR6 WGI, SPM Headline Statements)

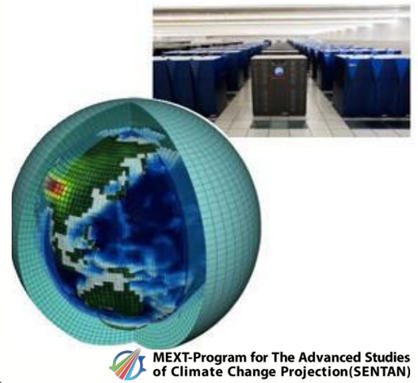


(IPCC AR6 WGI, SPM)

factual

conterfactual

Climate models



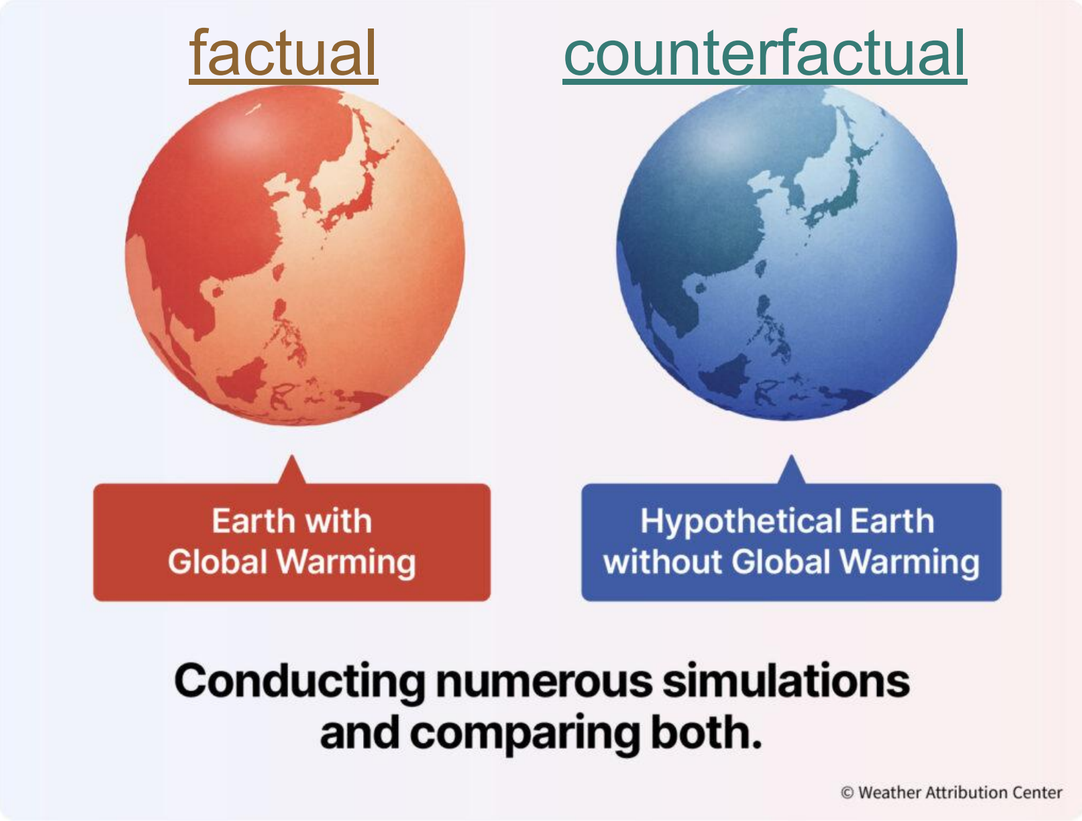
MEXT-Program for The Advanced Studies of Climate Change Projection(SENTAN)

Attribution of extreme weather events

National Institute for Environmental Studies, Japan

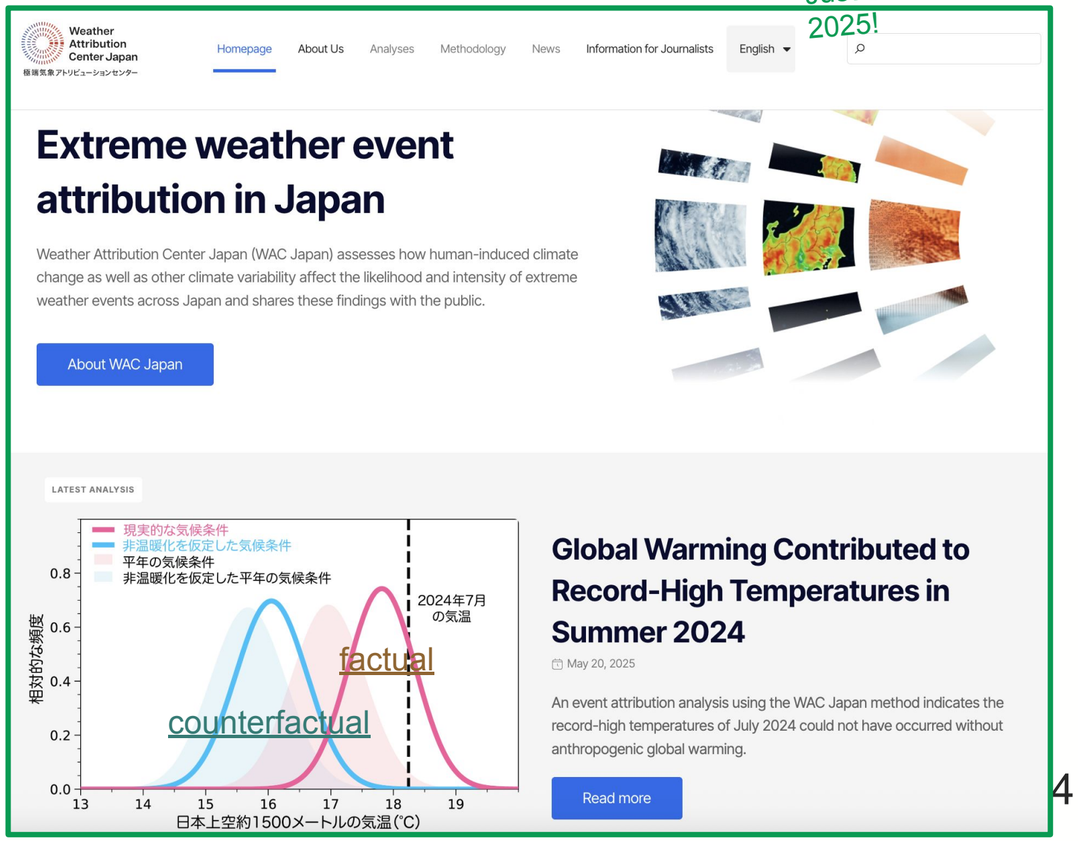
Event attribution in Japan

Event attribution is a scientific methodology for quantitatively assessing the extent to which **human-induced global warming** and **other climate variability** have contributed to **extreme weather events**.



Weather Attribution Center Japan
極端気象アトリビューションセンター

Just established in May 2025!



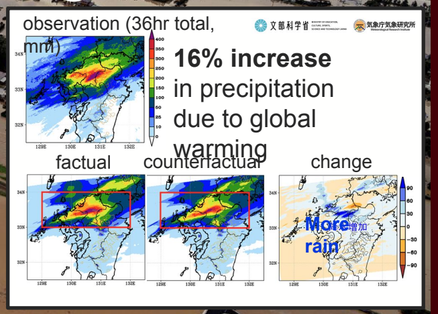
https://weatherattributioncenter.jp/en/

“I think we can very confidently say that **every heatwave occurring has been made more intense and more likely because of climate change**” Dr Friederike Otto

July 2022

In France, Portugal, Spain, Greece and Croatia (euronews.)

“The increasing intensity of heavy rainfall events and associated flooding is **an expected consequence of a warming climate due to our emissions of greenhouse gases**” Richard Allan



July 2023

In Fukuoka, Japan (CNN World)

The monsoon season in South Asia caused severe flooding in Bangladesh, India, Thailand, Nepal and Pakistan

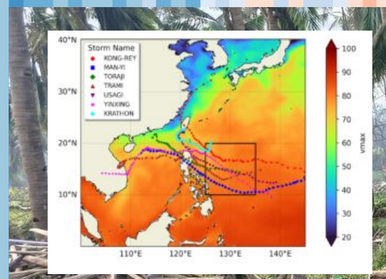
May to September 2024

In South Asia (CDP)

Northern Hemisphere’s extreme summer drought **‘virtually impossible’ without human-made climate change**

July 2022

In Nevada, US (CNN World)



Climate change supercharged late typhoon season in the Philippines

Sep to Nov 2024

Changes in climate averages and extremes

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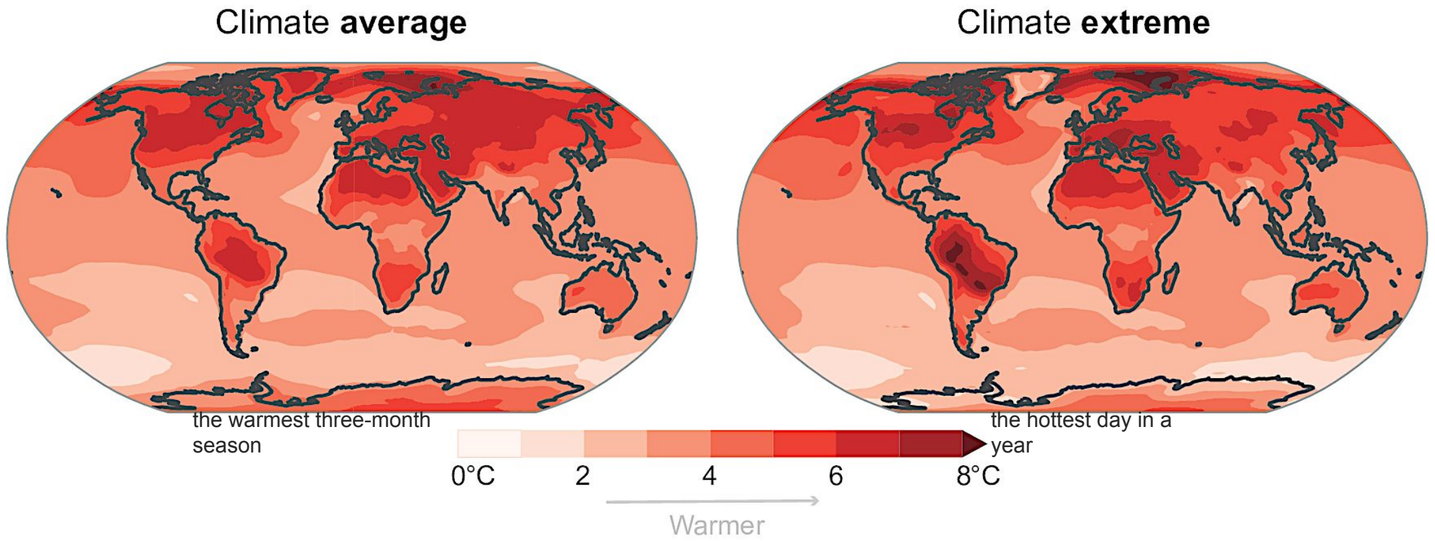
FAQ 11.1: **How will changes in climate extremes compare with changes in climate averages?**

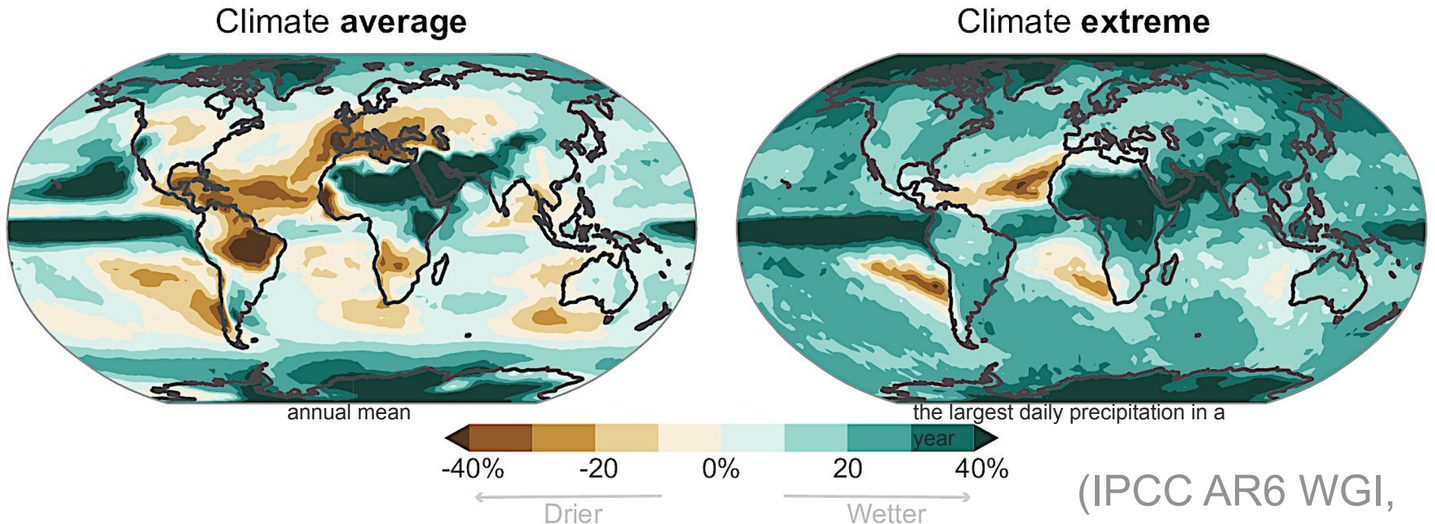
The direction and magnitude of future changes in climate extremes and averages depend on the variable considered.

4°C warming

Future **changes in temperature** averages and extremes will be **similar**



Future **changes in precipitation** averages and extremes can be **very different**



(IPCC AR6 WGI,

Extreme weather events have increased

National Institute for Environmental Studies, Japan

Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes

(a) Synthesis of assessment of observed change in **hot extremes** and confidence in human contribution to the observed changes in the world's regions

Type of observed change
in hot extremes

- Increase (41)
- Decrease (0)
- Low agreement in the type of change (2)
- Limited data and/or literature (2)

Confidence in human contribution
to the observed change

- ●●● High
- ●● Medium
- ● Low due to limited agreement
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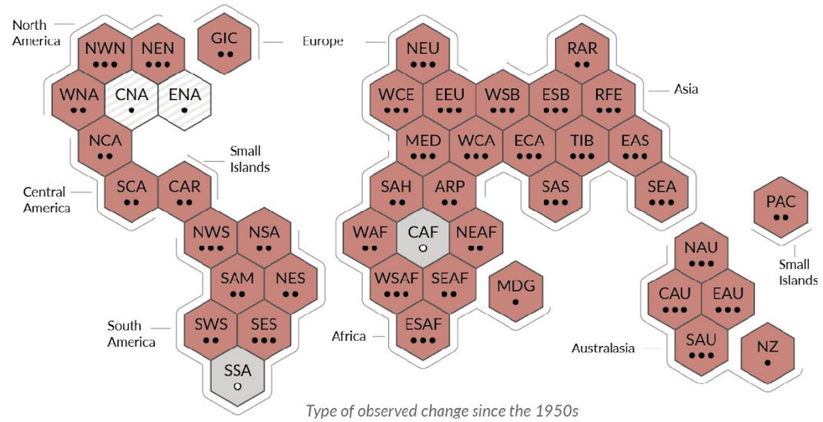

Type of observed change since the 1950s

Each hexagon corresponds to one of the IPCC AR6 WGI reference regions

NWN *North-Western North America*

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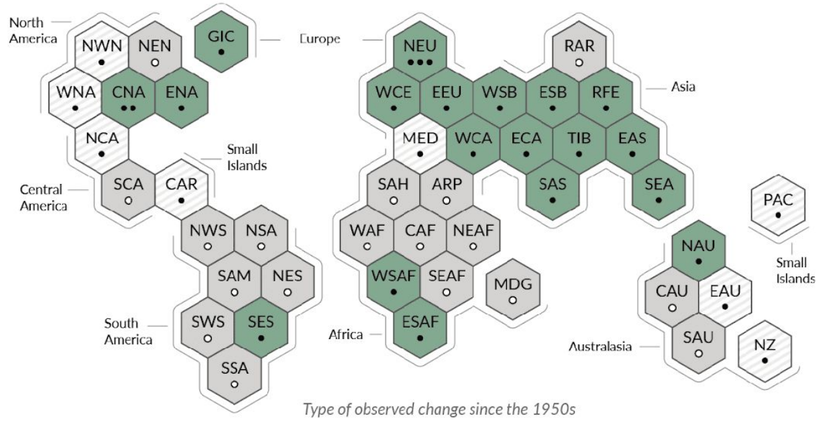
(b) Synthesis of assessment of observed change in **heavy precipitation** and confidence in human contribution to the observed changes in the world's regions



Type of observed change since the 1950s

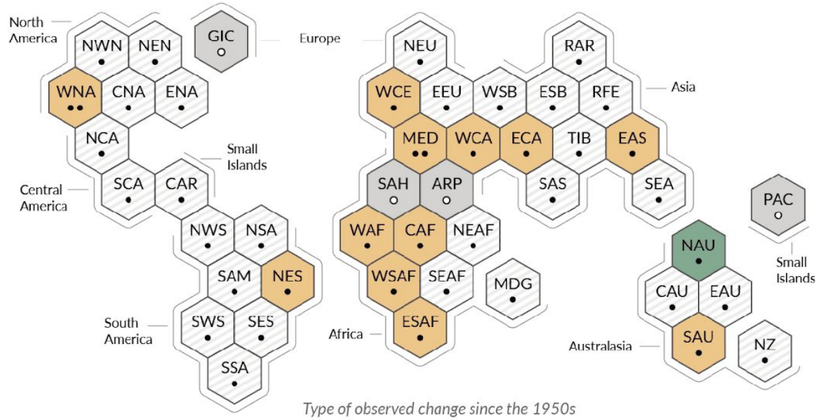
Type of observed change
in agricultural and ecological drought

- Increase (12)
- Decrease (1)
- Low agreement in the type of change (28)
- Limited data and/or literature (4)

Confidence in human contribution
to the observed change

- ●●● High
- ●● Medium
- ● Low due to limited agreement
- ○ Low due to limited evidence

(c) Synthesis of assessment of observed change in **agricultural and ecological drought** and confidence in human contribution to the observed changes in the world's regions



Type of observed change since the 1950s

(IPCC AR6 WGI,

Fluctuations along the long-term warming

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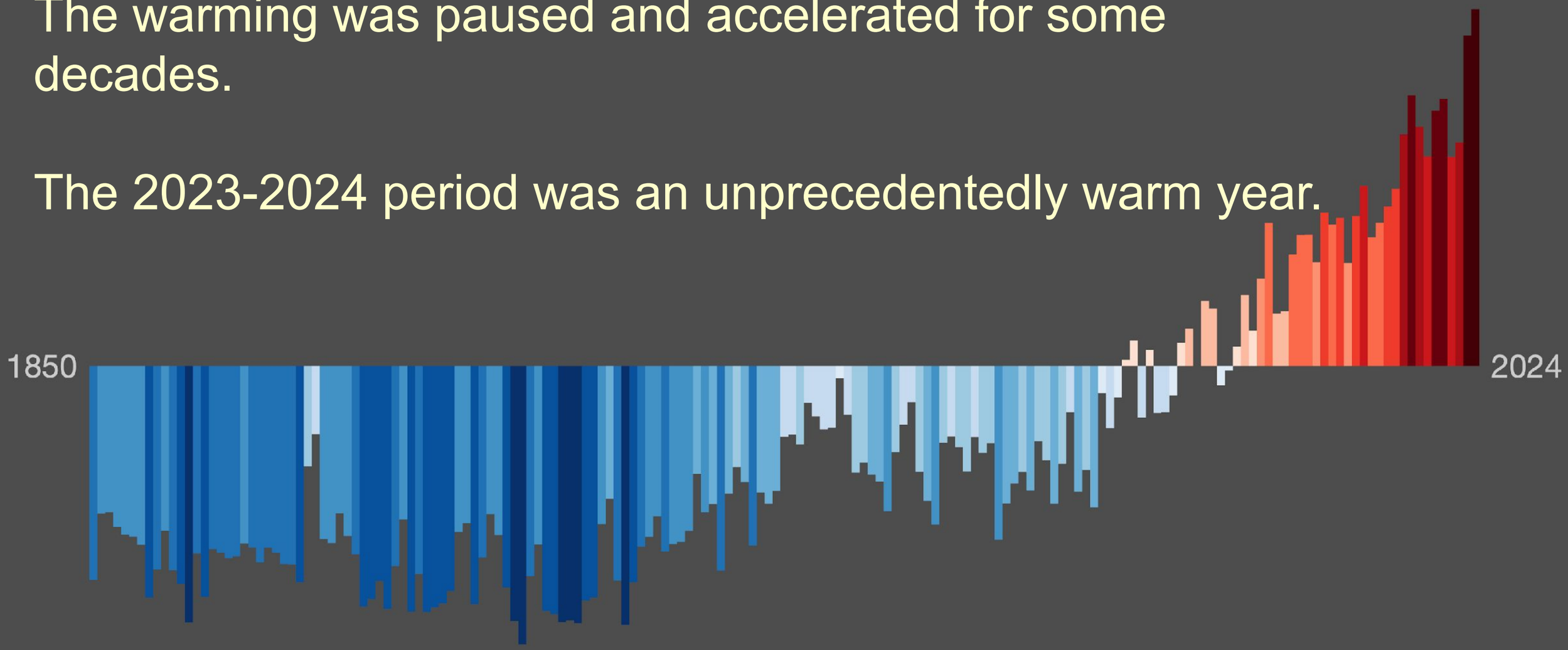
The warming was paused and accelerated for some decades.

The 2023-2024 period was an unprecedentedly warm year.



(#ShowYourStripes

Natural climate variability is a matter

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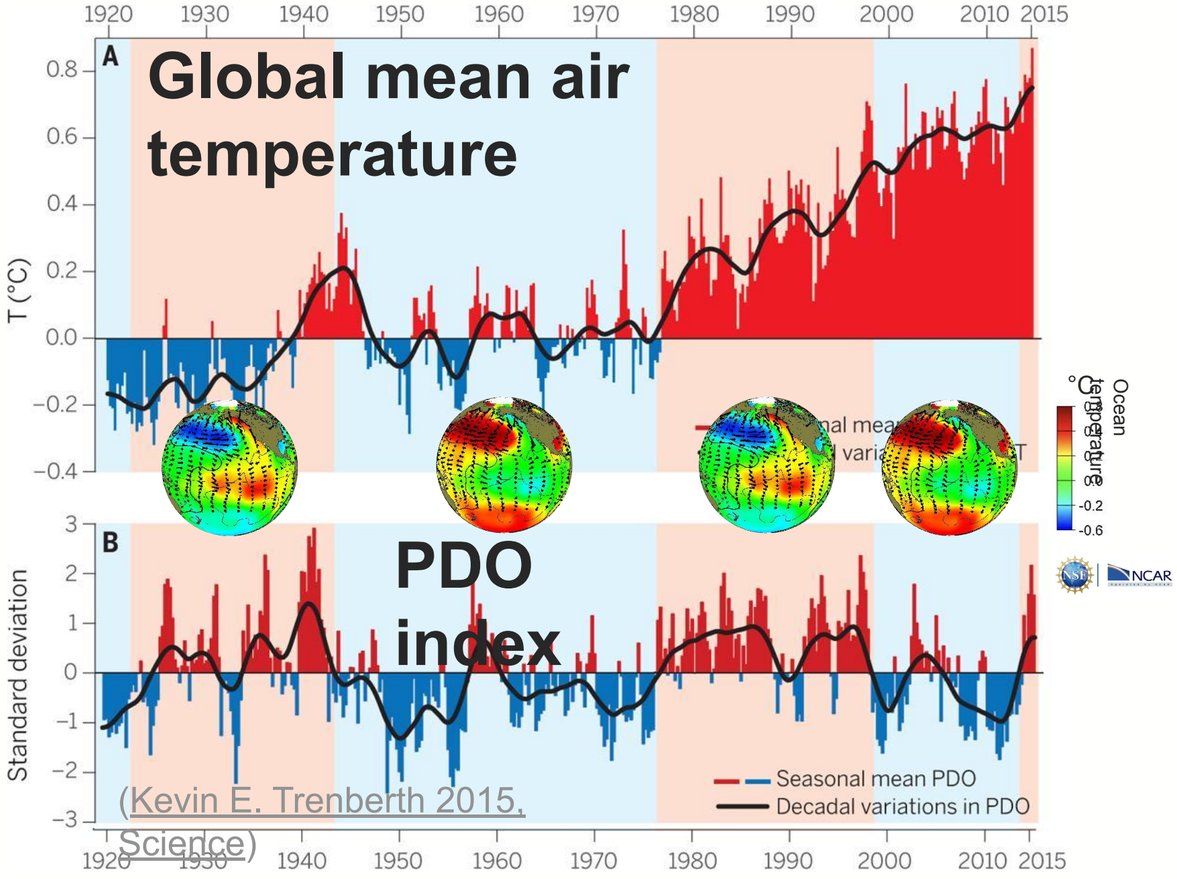
Pacific Decadal Oscillation (PDO; IPO)

– **(more than) 10-year scale natural variability**

– *"Natural fluctuations are big enough to overwhelm the steady background warming at any point in time,"* K. Trenberth (2015, Science)

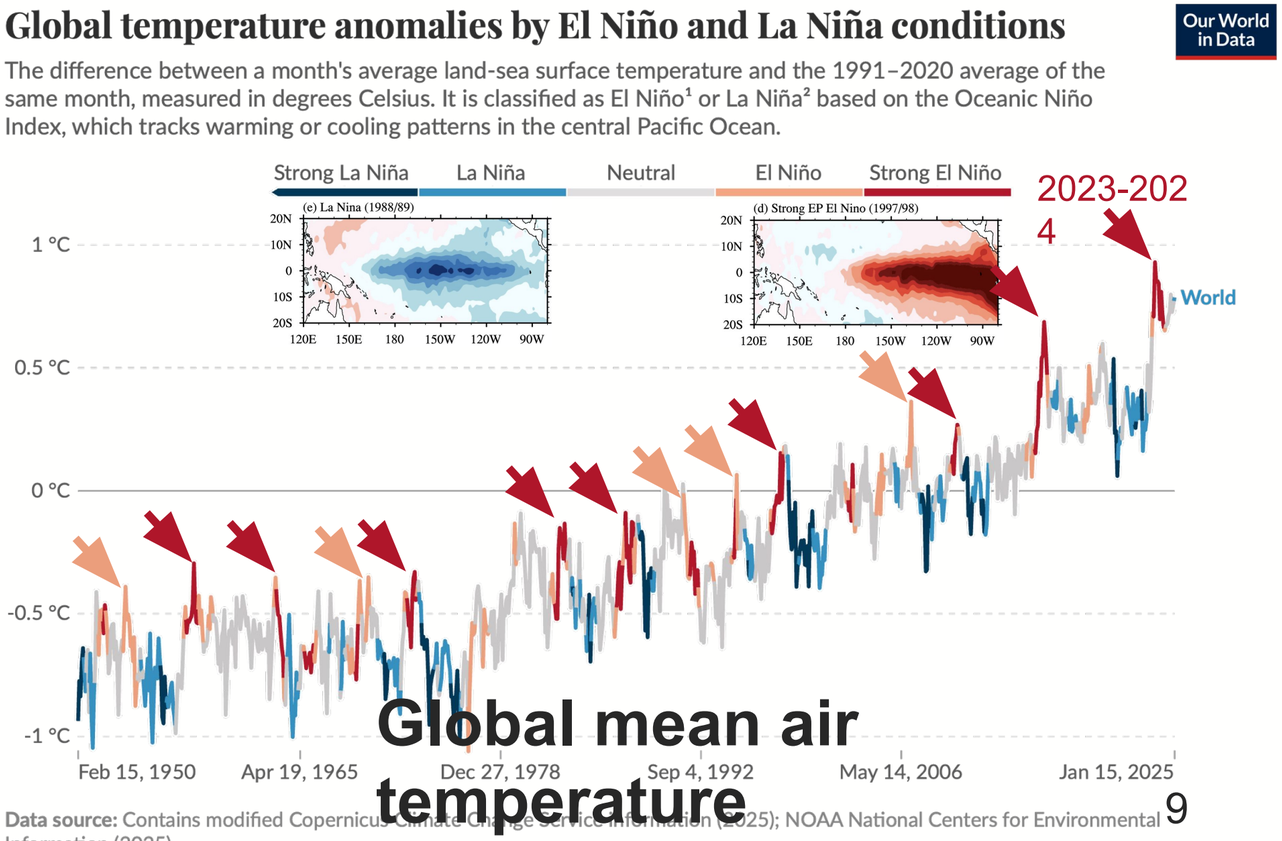


(Kevin E. Trenberth 2015, Science)

El Niño-Southern Oscillation (ENSO)

– **3- to 7-year scale natural variability**

– *"El Niño-induced warming is efficiently communicated throughout the tropical troposphere,"* S.-P. Xie et al. (2024, Nature)



(Our World in Data, accessed on 20 May

ENSO has been changed & will change

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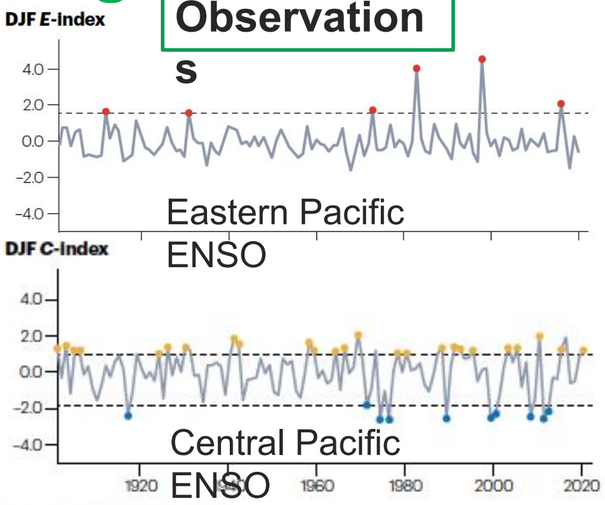
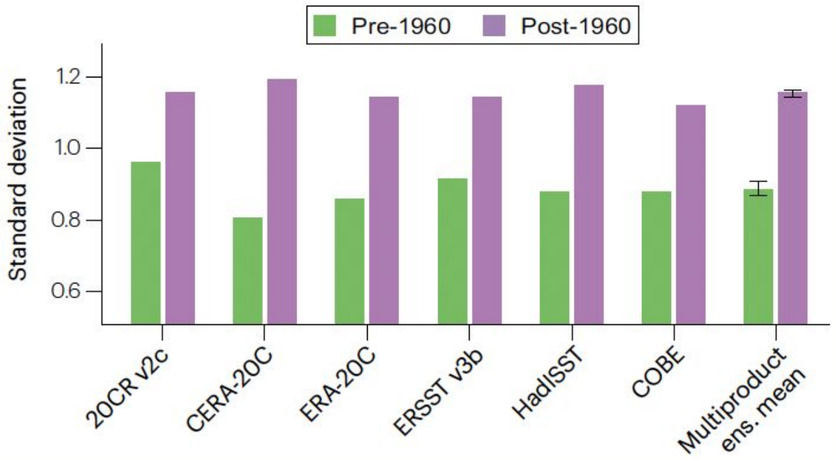
ENSO amplitude changes

Observations



Reanalysis *E*-index variability



ENSO sea surface temperature variability increased after 1960, influenced by more frequent strong El Niño and La Niña events.

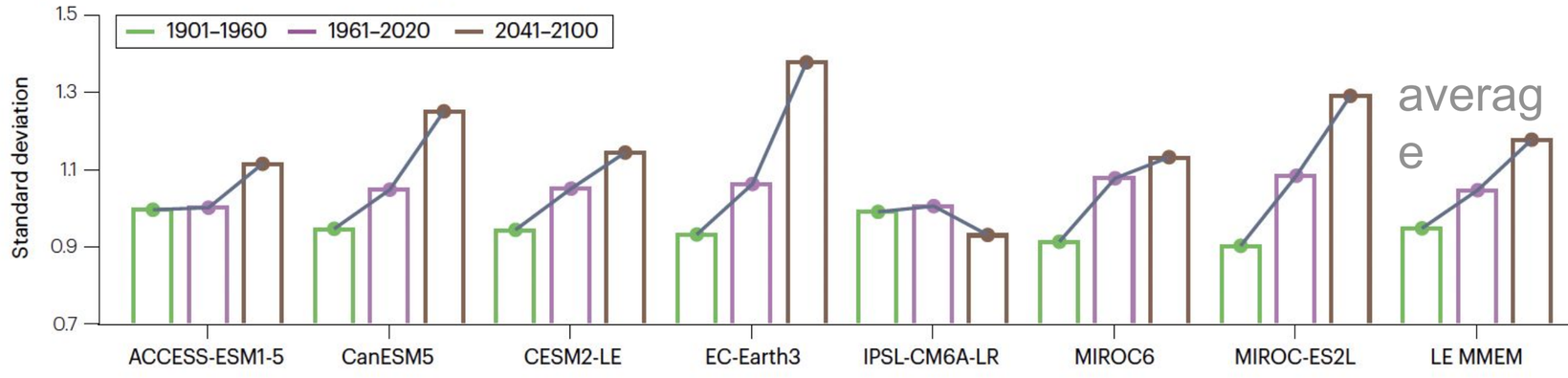
- **Anthropogenic greenhouse gas forcing** might have already contributed to an increase in ENSO variability

Six out of seven climate model large ensemble means exhibit **a continuous increase in E-index**

- The continuous increase reinforces that **the post-1960 ENSO enhancement is likely a part of the long-term change**.

Climate model large ensembles

Past, present and future *E*-index variability



(Cai et al. 2023, Nature Rev Earth

What enhances the ENSO variability?

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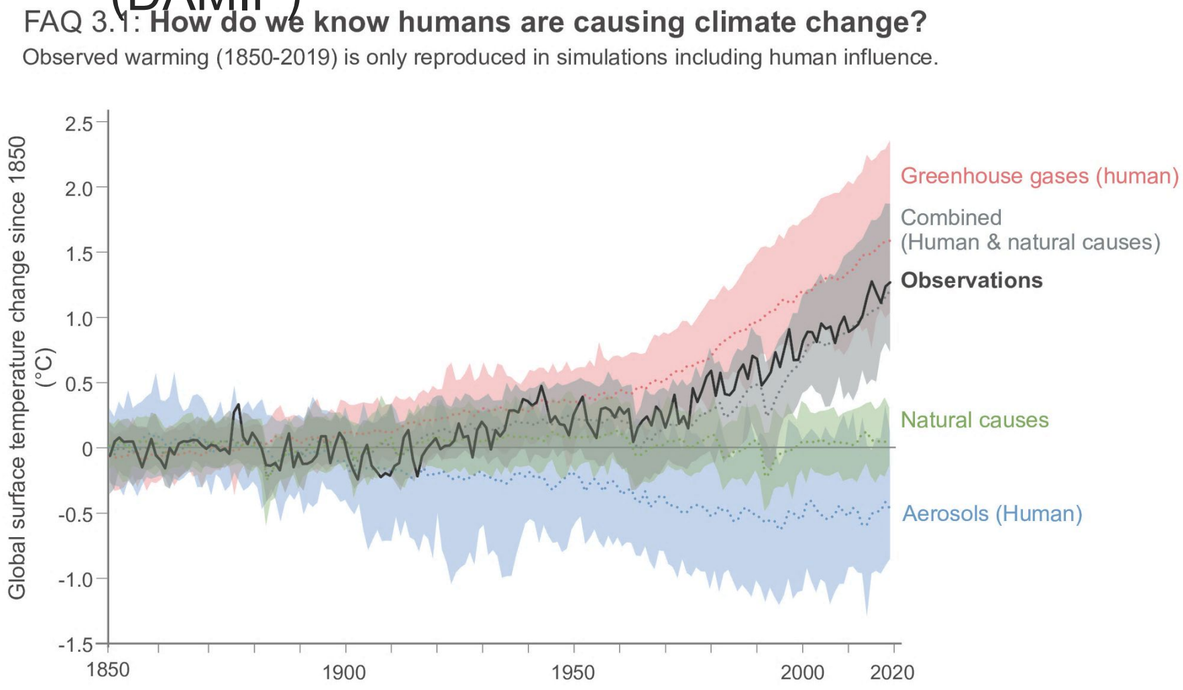
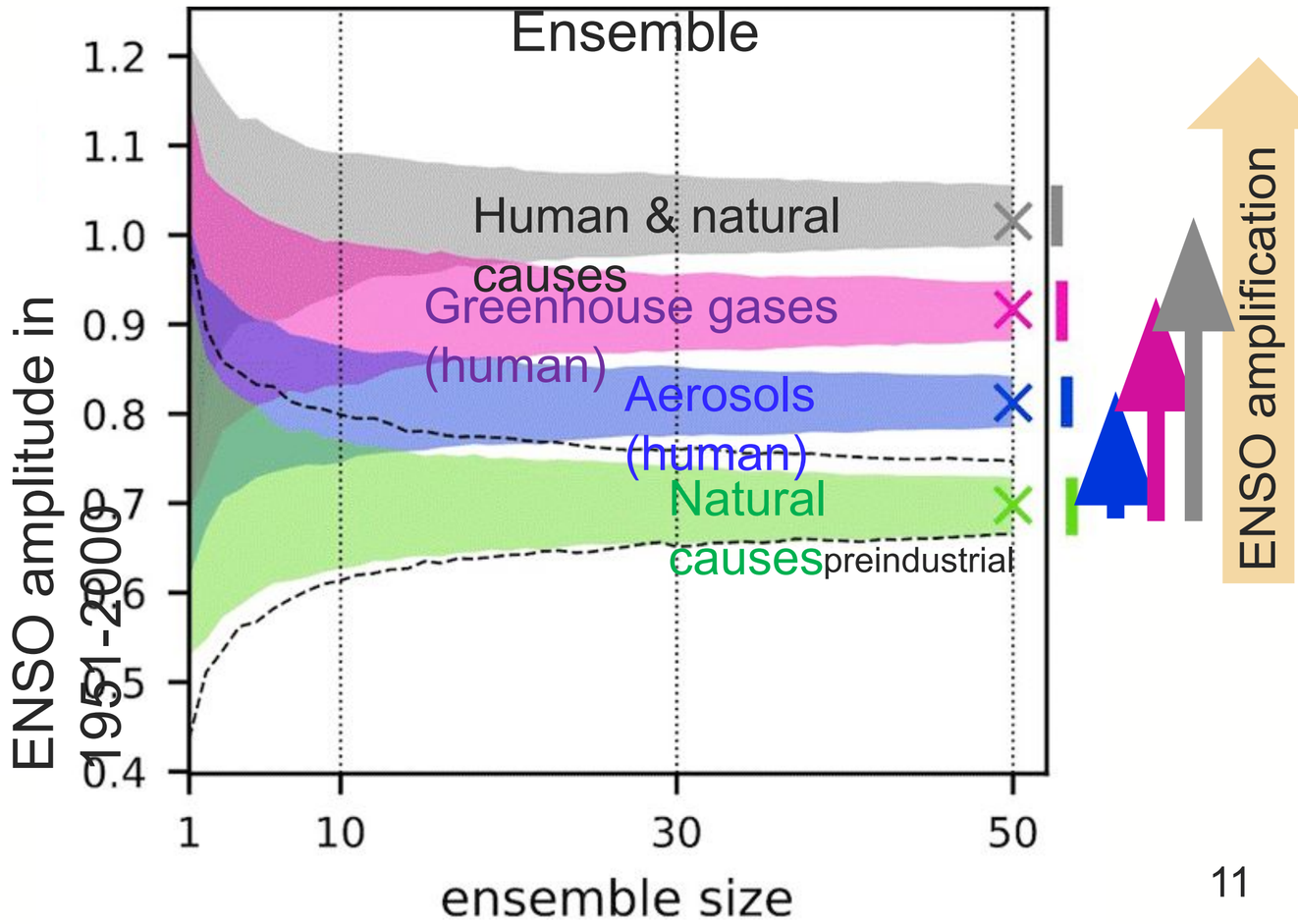
Both the increased greenhouse gases and aerosol emissions may enhance ENSO

Detection & Attribution Model Intercomparison Project (DAMIP)



(IPCC AR6 WGI,

In MIROC6 Large Ensemble



(Shiogama, Tatebel, Hayashi, et al. 2023, Earth System

Amplified ENSO damages the economy

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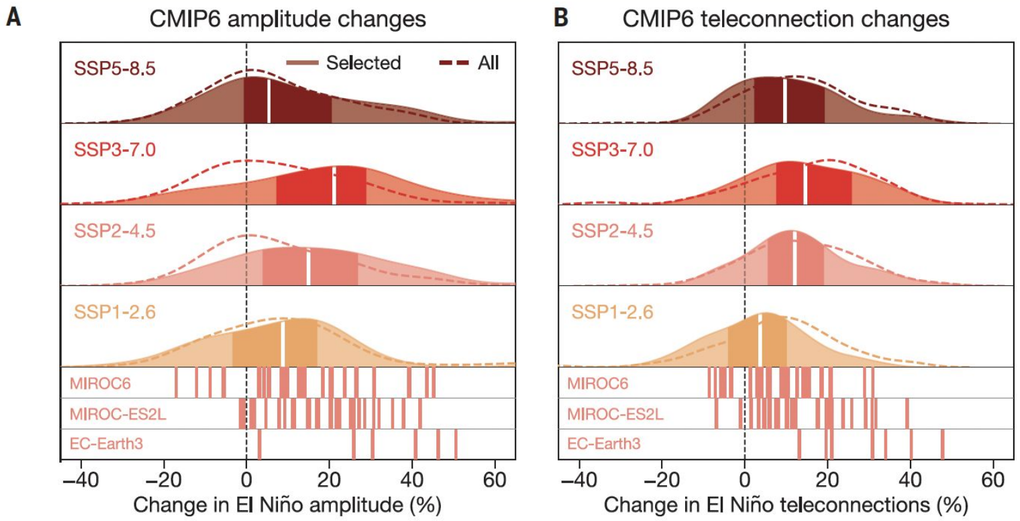
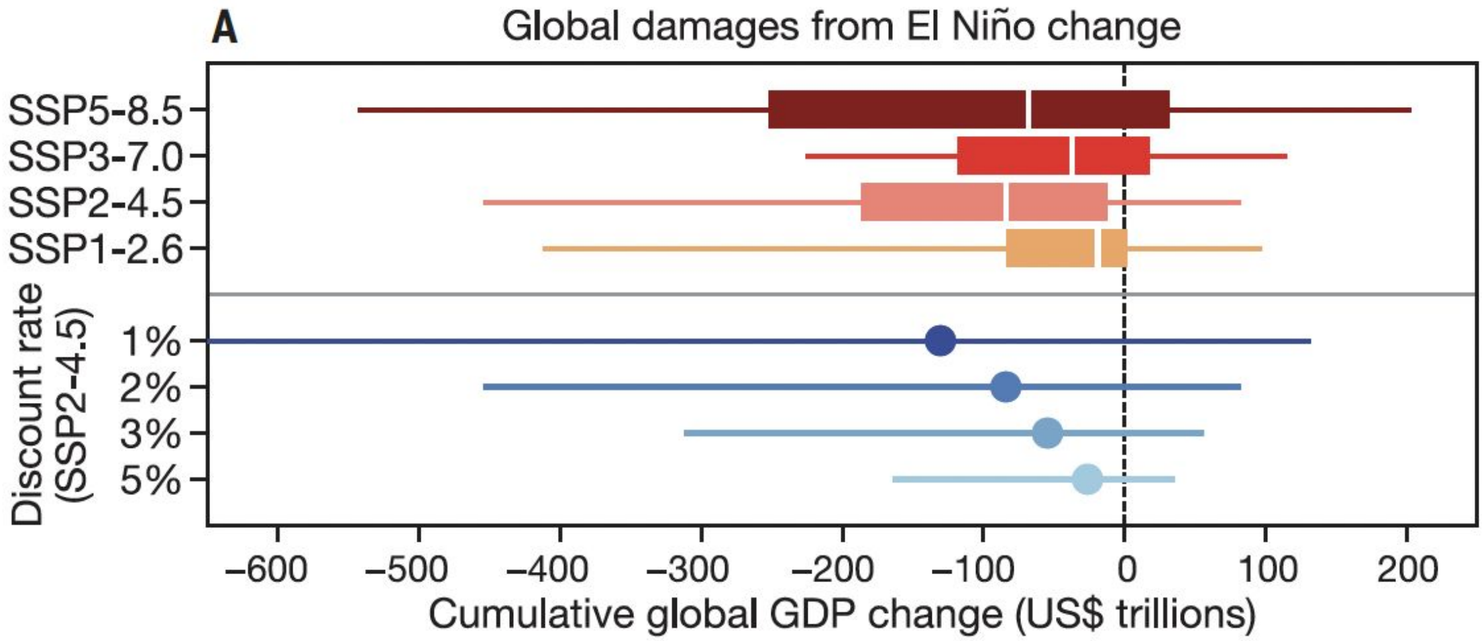
*"In an emissions scenario consistent with current mitigation pledges [SSP2-4.5], **increased ENSO amplitude and teleconnections** from warming are projected to cause **$84 trillion in 21st-century economic losses**,"* Callahan and Mankin (2023, Science)

Increased amplitude enhanced teleconnections





(Callahan and Mankin 2023, Science)

Takehome messages

National Institute for Environmental Studies, Japan

Extreme weather events have been changed by human-induced warming

Observed increases in hot extremes, heavy precipitation, & drought are attributable to global warming.

Changes in natural climate variability need to be paid attention to

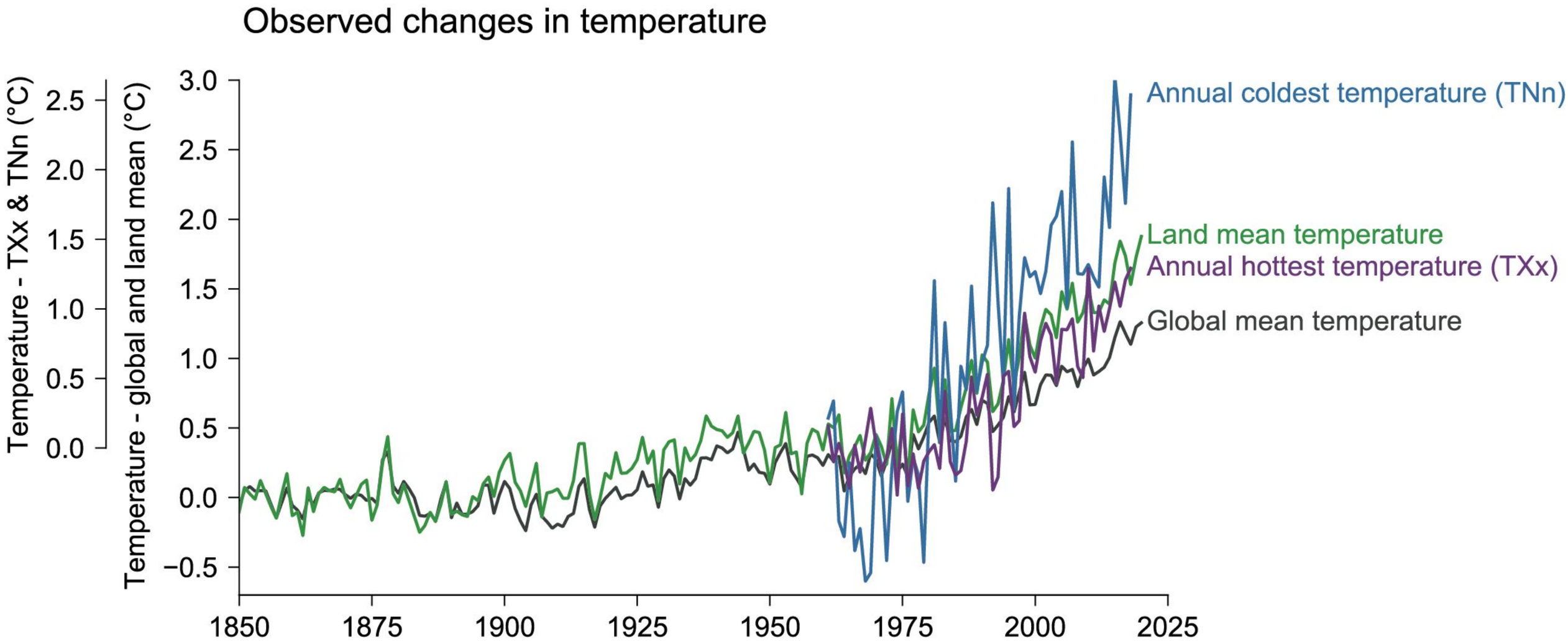
ENSO may be enhanced under global warming, increasing the damage to global economic growth.

We need to prepare for both global warming & climate variability changes

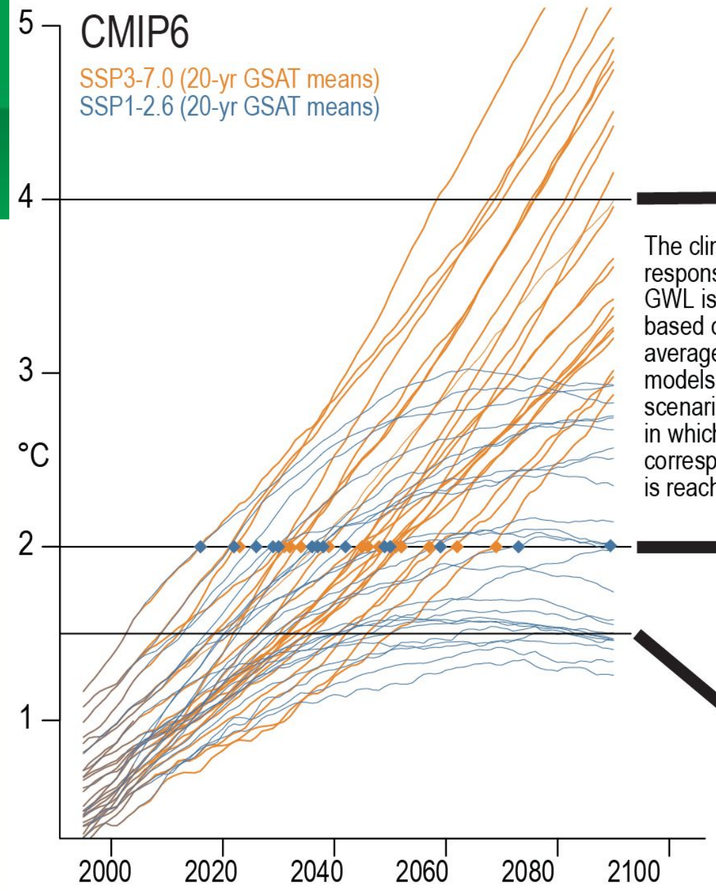
Thank you for your attention!

Contact:
hayashi.michiya@nies.go.jp

The ADB supported my participation in ACEF 2025.
A part of the studies presented today was supported by the Ministry of Education, Culture, Sports, Science and Technology of Japan (grant numbers JPMXD0722680395 & JP21K13993).

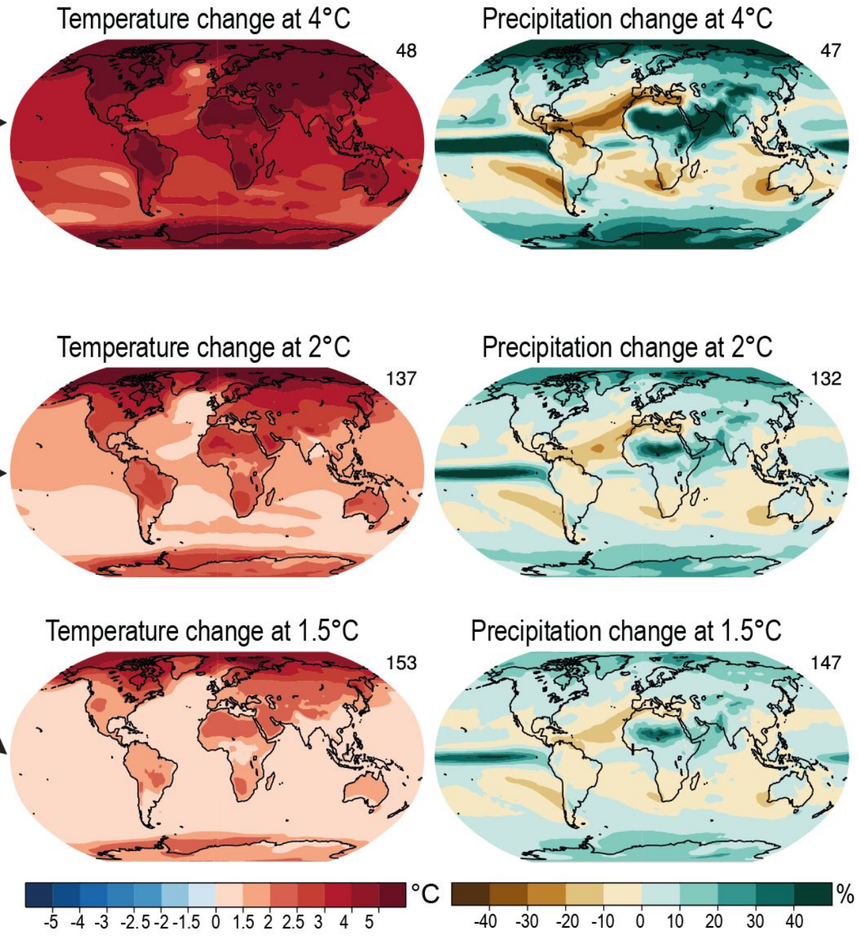

Observed changes in temperature
Temperature - TXx & TNn (°C)
Temperature - global and land mean (°C)
2.5
2.0
1.5
1.0
0.5
0.0
3.0
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
1850
1875
1900
1925
1950
1975
2000
2025
Annual coldest temperature (TNn)
Land mean temperature
Annual hottest temperature (TXx)
Global mean temperature

(IPCC AR6 WG1,



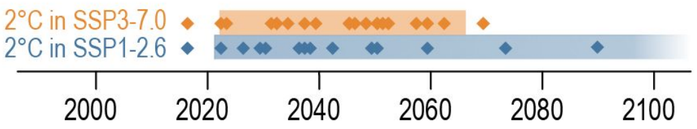
The climate response at a given GWL is estimated based on an average across all models and all SSP scenarios in CMIP6 in which the corresponding GWL is reached.

Response at global warming level (GWL)



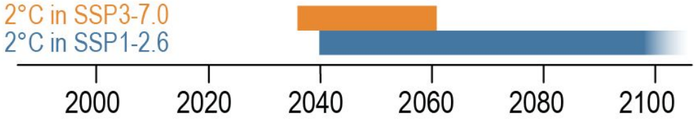
Timing of GWL

CMIP6 range (table 4.2 and Hauser et al. 2021)



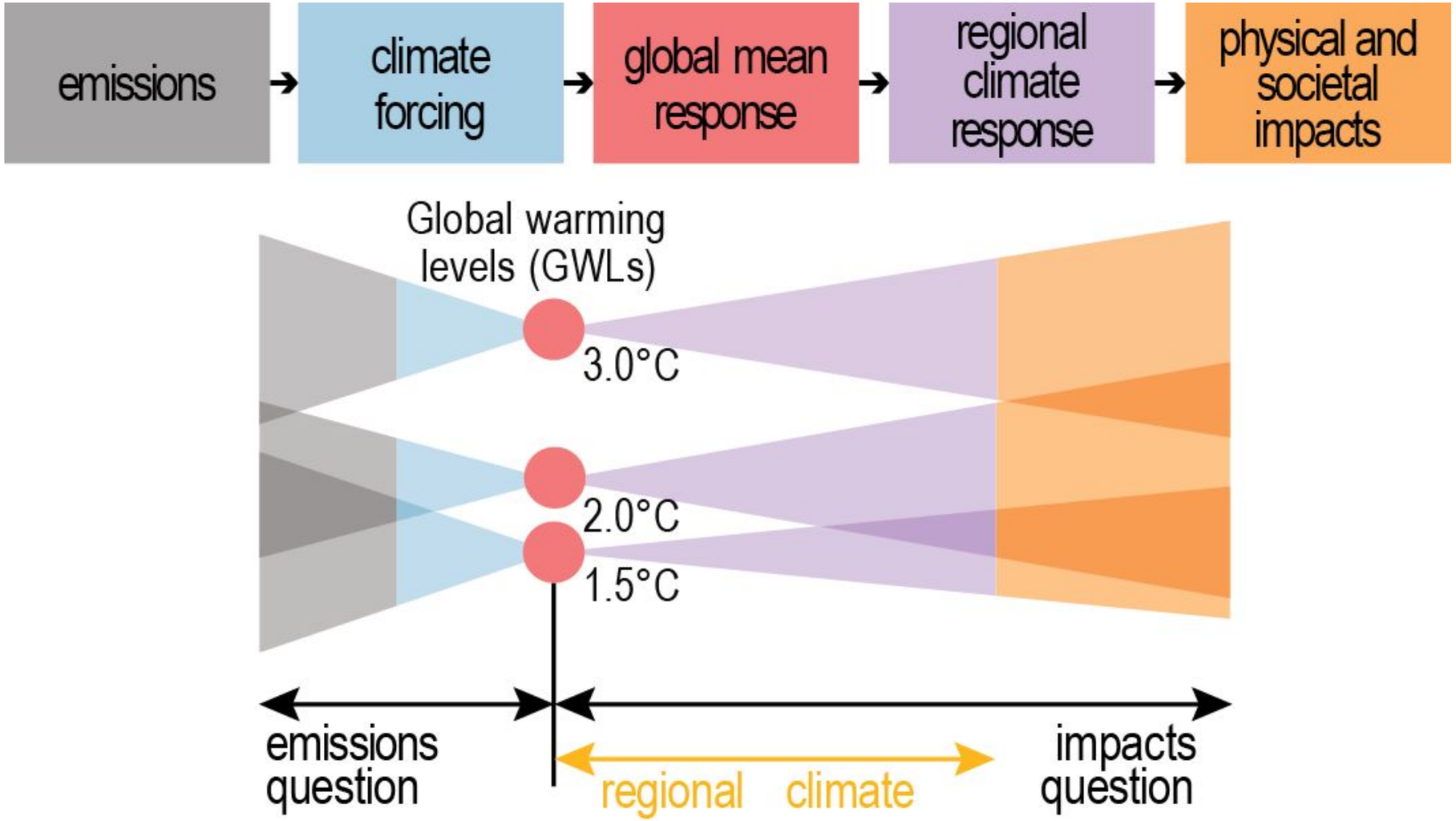
The best estimate and likely range when a GWL is crossed is not based on CMIP6 only but on the GSAT assessment in section 4.3.4.

Assessed GSAT range (table 4.5 and section 4.3.4)



Timing 2°C	Best estimate	Very likely range
SSP1-1.9	NA	NA
SSP1-2.6	NA	(2031–50 to NA)
SSP2-4.5	2043-62	(2028–47 to 2075–94)
SSP3-7.0	2037–56	(2026–45 to 2053–72)
SSP5-8.5	2032–51	(2023–42 to 2044–63)

Uncertainty



FAQ 11.2: **Will climate change cause unprecedented extremes?**

Yes, in a changing climate, extreme events may be unprecedented when they occur with...

Larger magnitude

Increased frequency

New locations

Different timing

New combinations (compound)

https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-11/

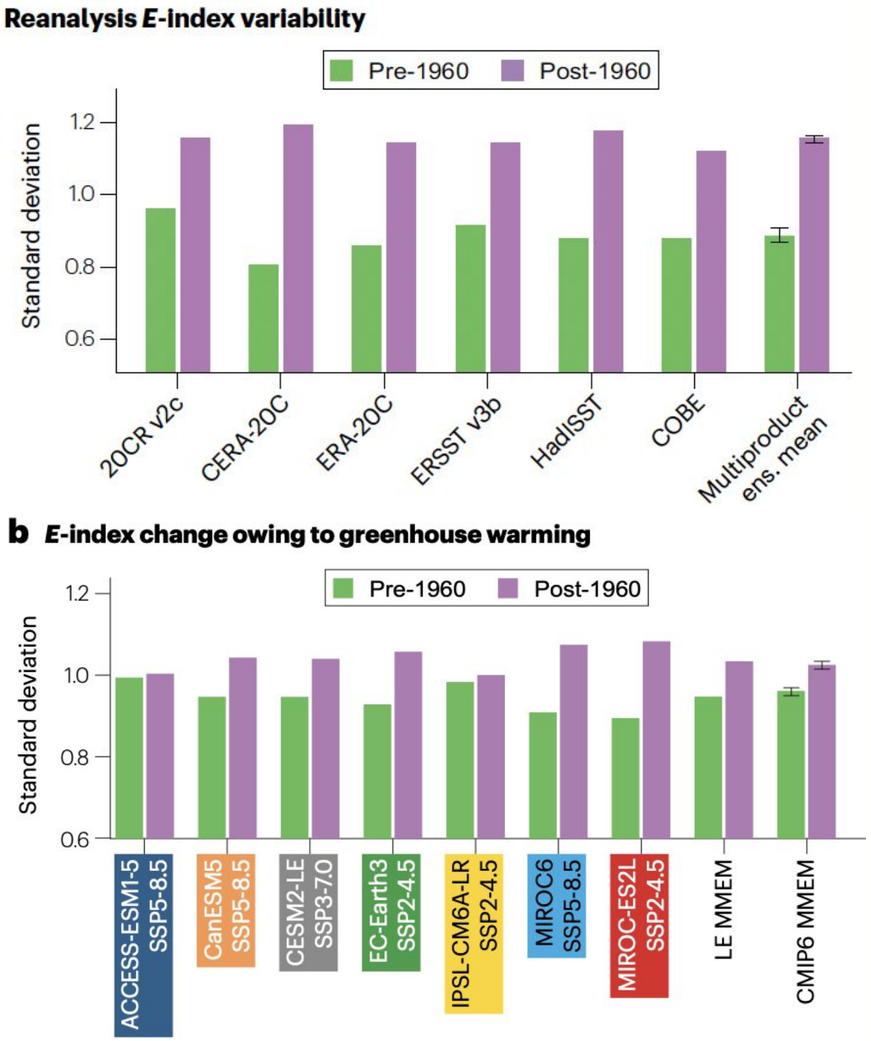
ENSO has been changed & will change

National Institute for Environmental Studies, Japan

ENSO amplified from pre- to post-1

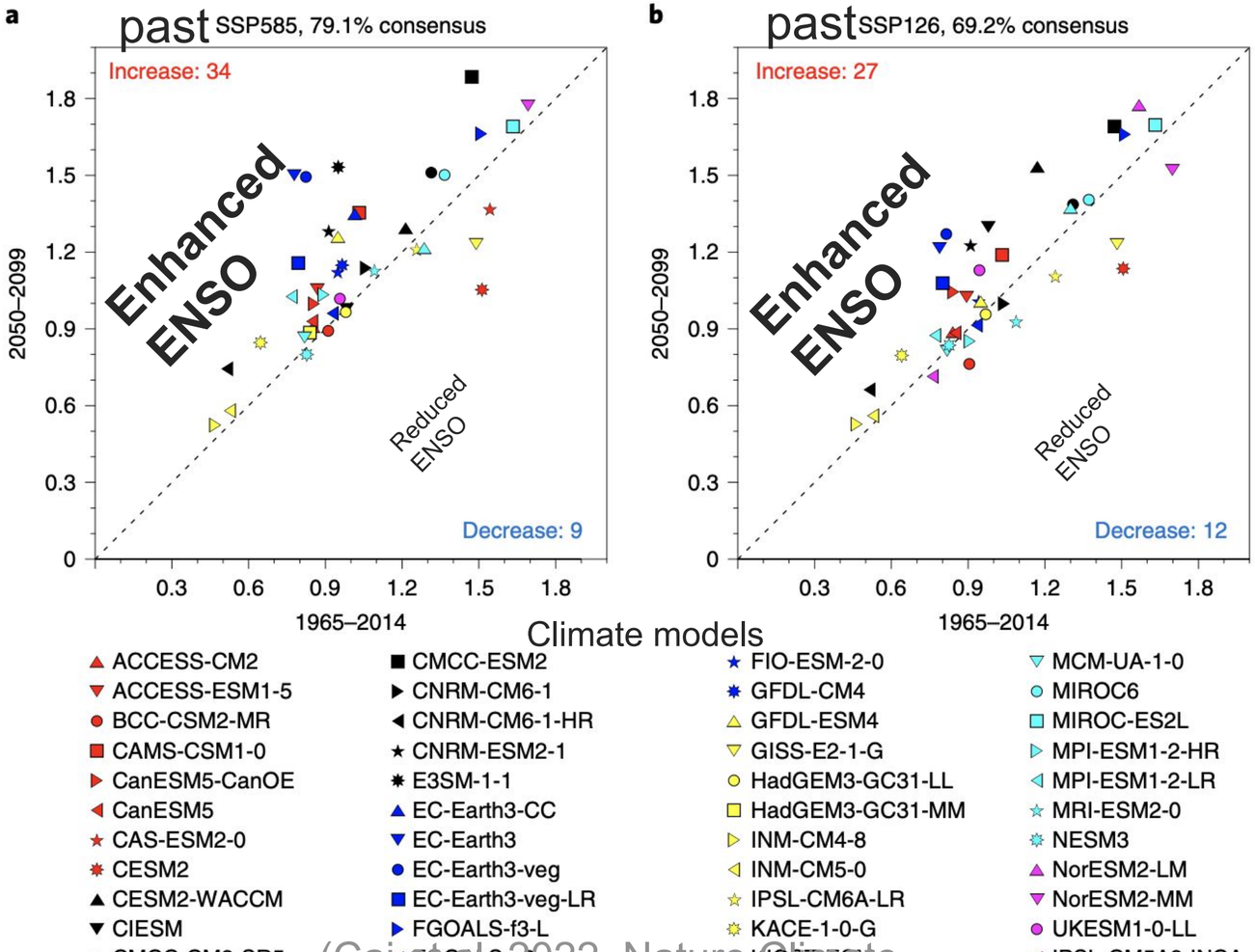
observations

Climate models



(Cai et al. 2023, Nature Rev Earth

ENSO amplitude in the future scenarios



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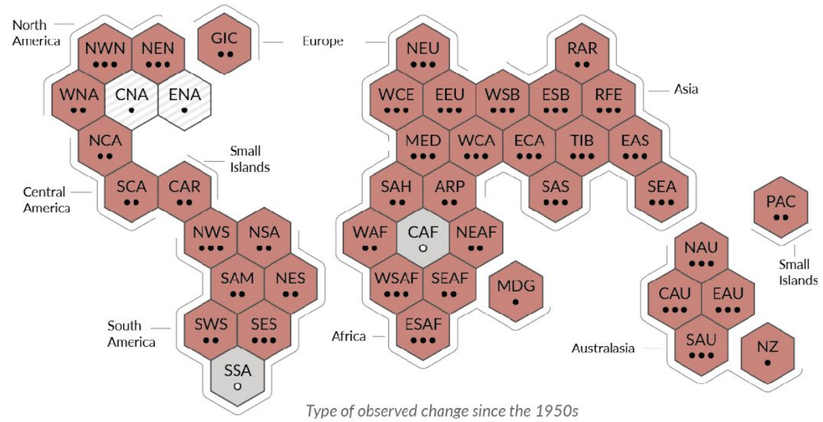

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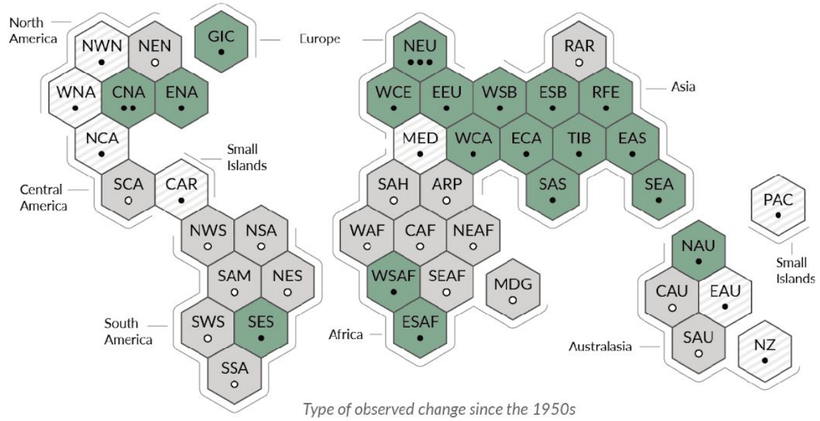

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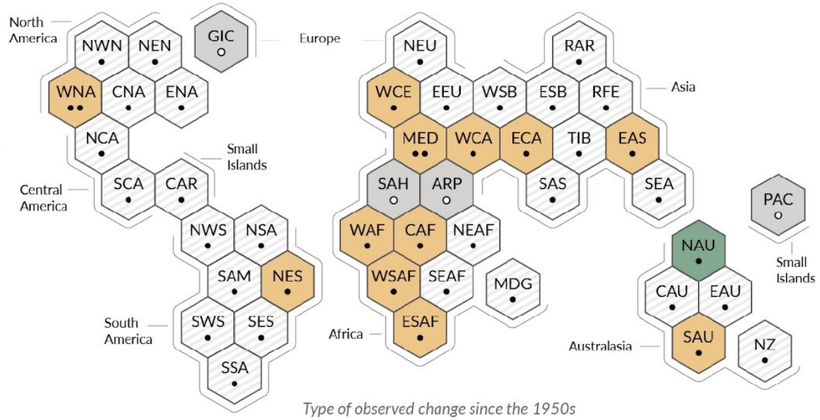
- Decrease (1)
- Low agreement in the type of change (28)
- Limited data and/or literature (4)

Confidence in human contribution
to the observed change

- ●●● High
- ●● Medium
- ● Low due to limited agreement
- ○ Low due to limited evidence

(c) Synthesis of assessment of observed change in **agricultural and ecological drought** and confidence in human contribution to the observed changes in the world's regions



Type of observed change since the 1950s

(IPCC AR6 WGI,