Department of Meteorology

University of Reading

OBSERVING EARTH TO MONITOR, UNDERSTAND & PREDICT CLIMATE CHANGE

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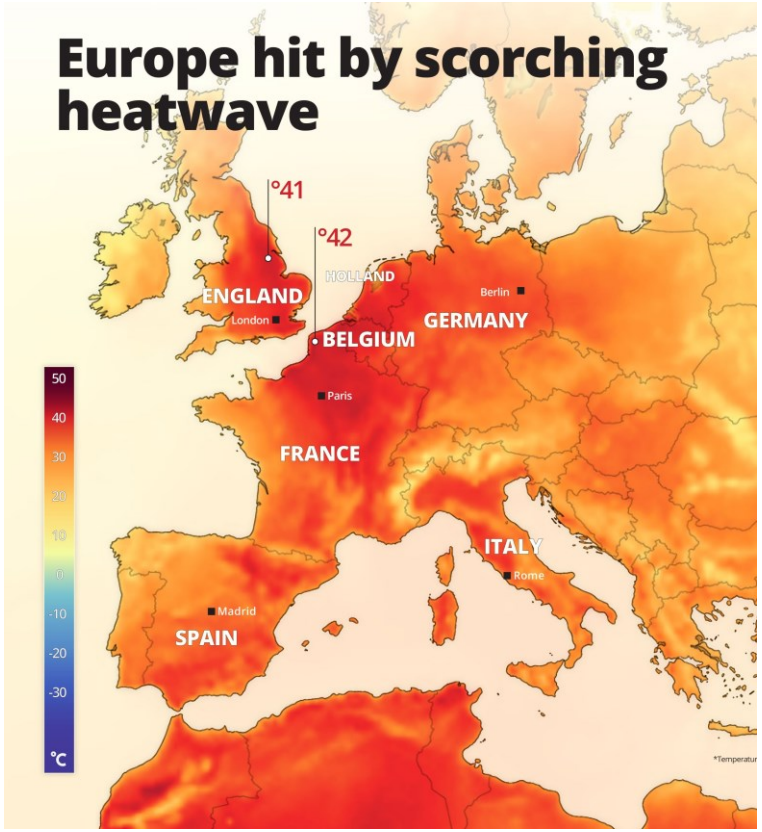
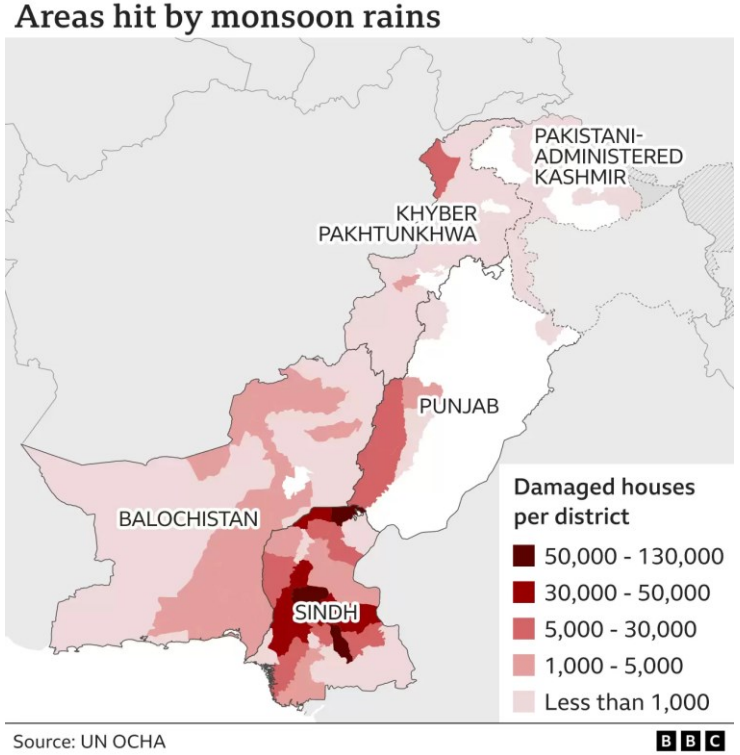
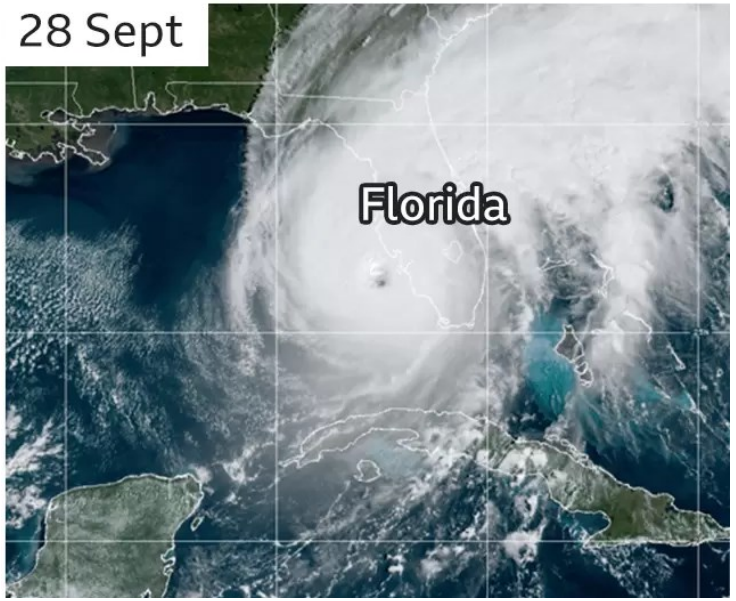
Belgian contributions to Earth Sciences in a Changing World study day, 4th November 2022

National Centre for Earth Observation
NATURAL ENVIRONMENT RESEARCH COUNCIL

ONGOING CLIMATE CHANGE

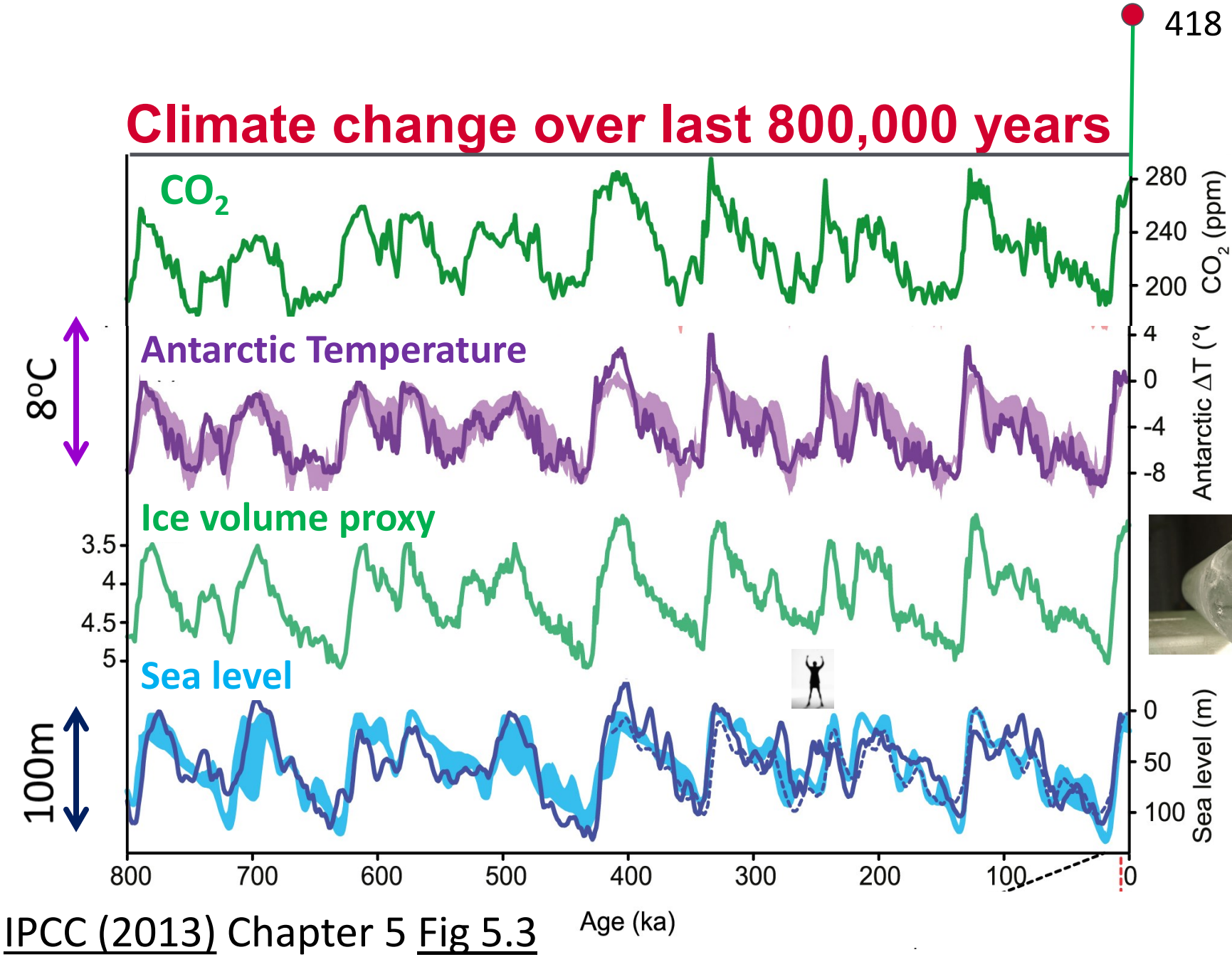






www.met.reading.ac.uk/~sgs02rpa/extreme.html

Climate change over last 800,000 years



IPCC (2013) Chapter 5 Fig 5.3

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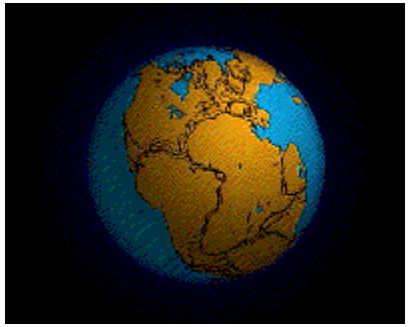
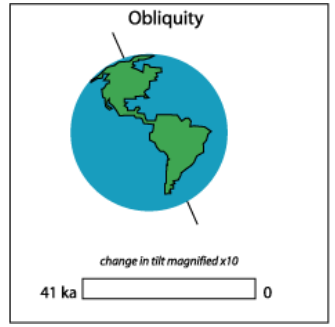
- Paleoclimate insights into Earth systems & climate





Natural & human-influenced carbon cycle

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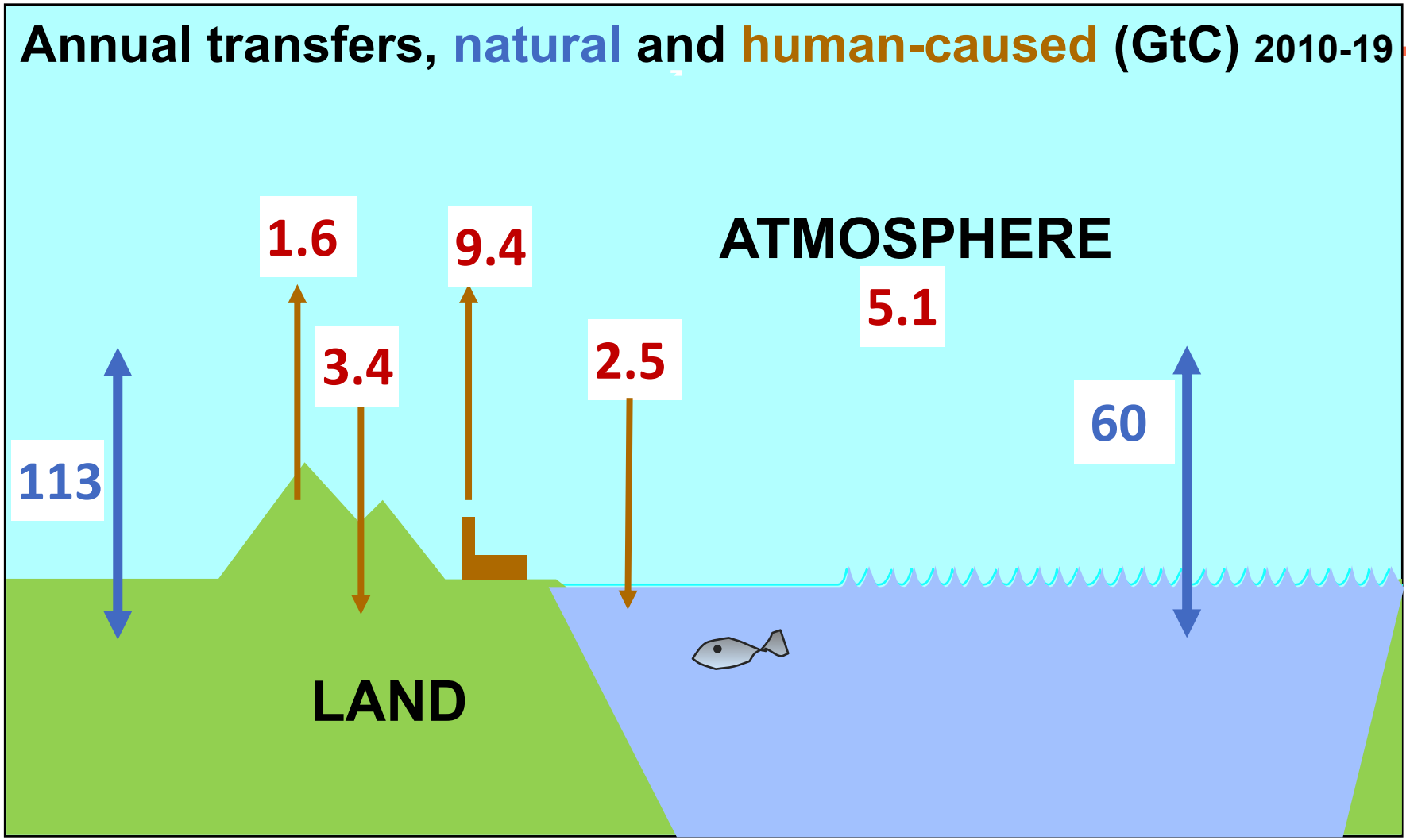

- Human activities have tipped the natural carbon cycle out of balance
- This is driving increases in atmospheric CO_2 concentrations
- CO_2 concentrations highest in at least 2 million years

Values in billions of tonnes of Carbon per year from IPCC (2021) Ch5

It is indisputable that human activities are causing climate change

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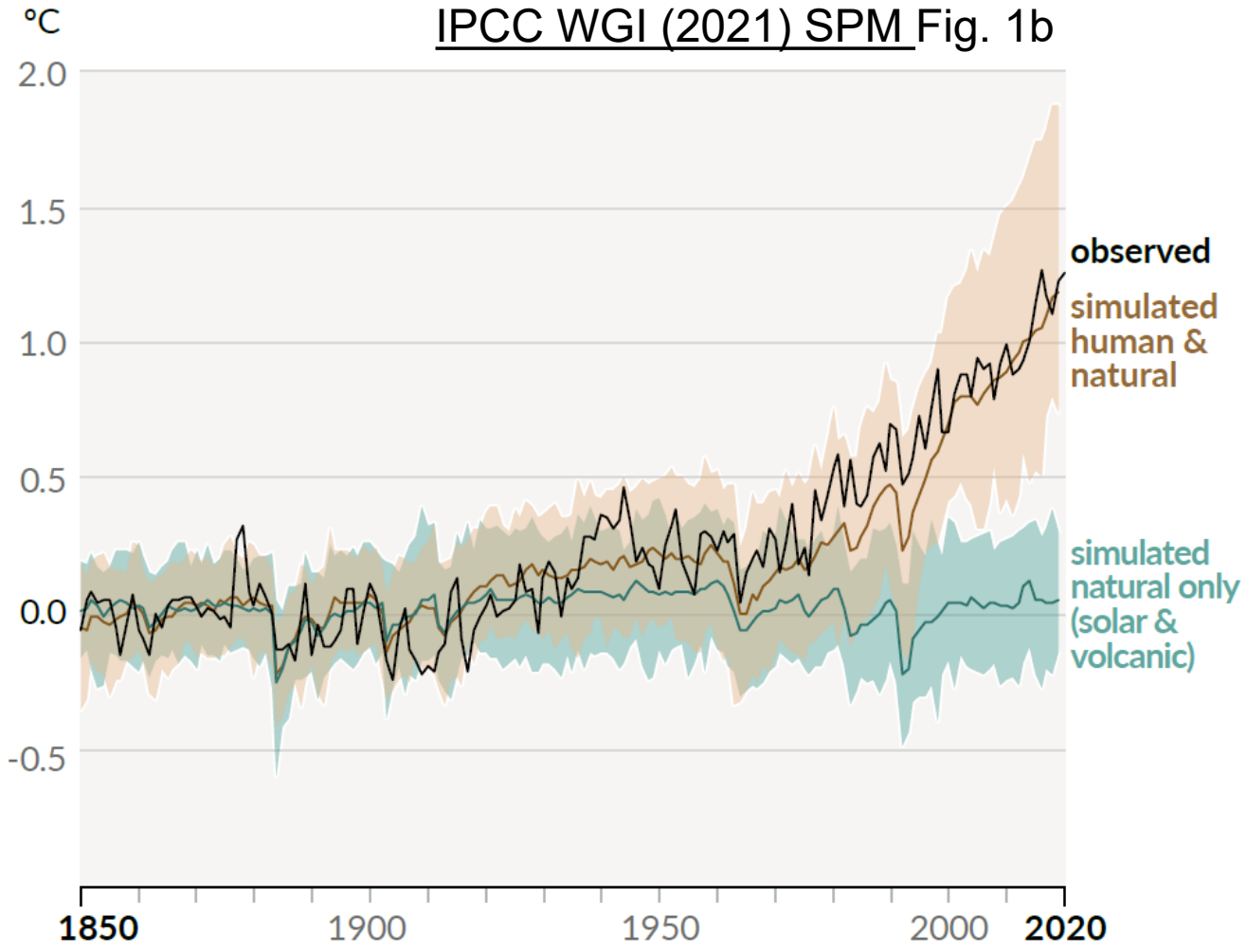
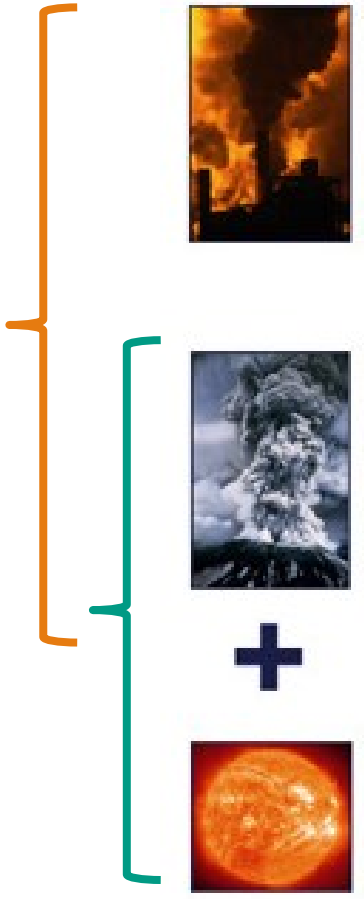




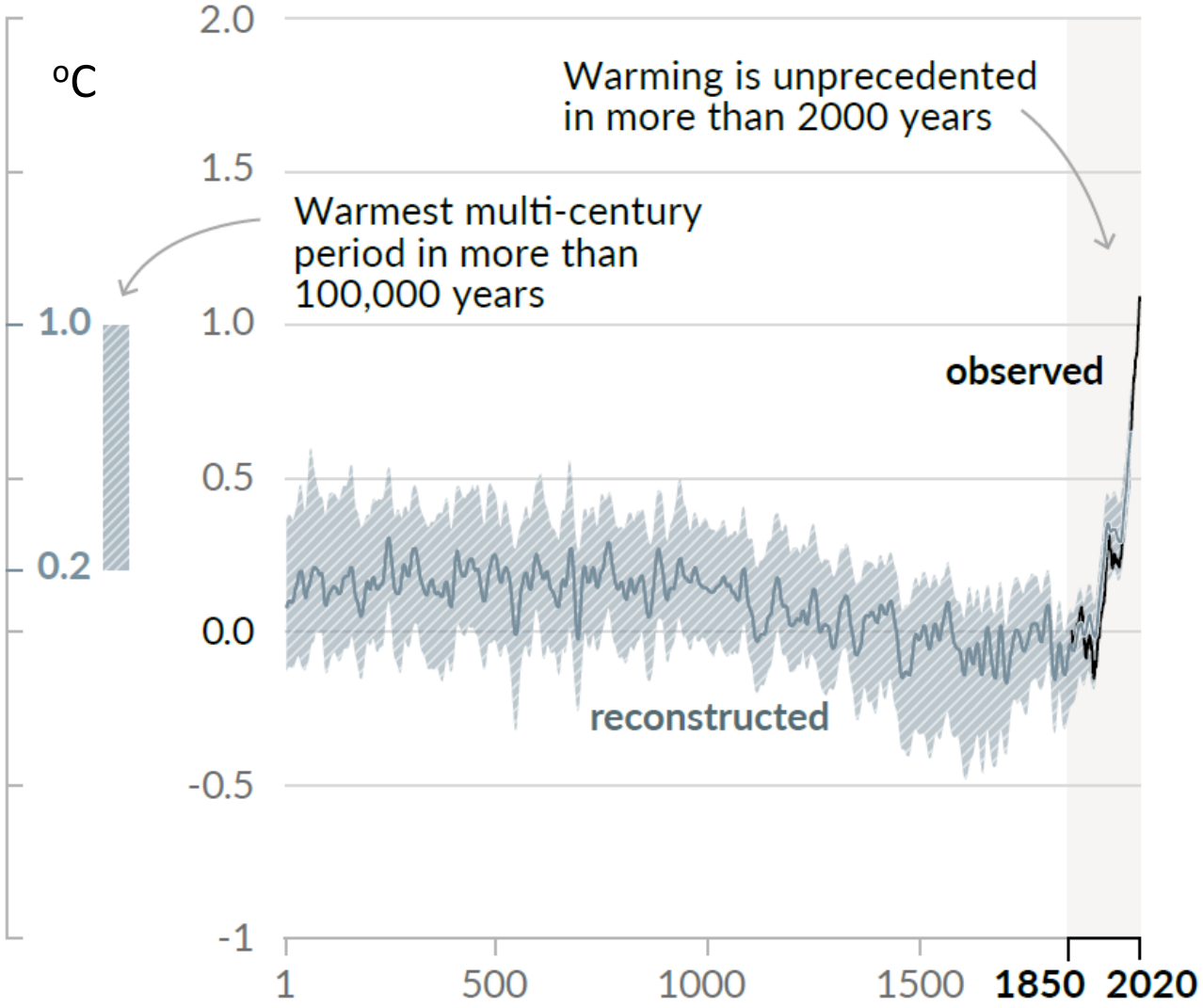
► Observed warming is driven by emissions from human activities

► Natural factors do not contribute to rapid warming over past 5 decades

► Greenhouse gas warming has been partly masked by aerosol cooling

► Warming is amplified by feedback loops involving water vapour, ice & clouds

Recent changes in the climate are widespread, rapid and unprecedented in thousands of years



- Global mean surface temperature increased faster since 1970 than in any other 50 year period over at least the last 2000 years
- Warmth of past decade comparable to last interglacial 125,000 years ago *[when peak sea level was 5-10m higher than today]*

[IPCC WGI 2021 SPM]

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

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Figure SPM.3

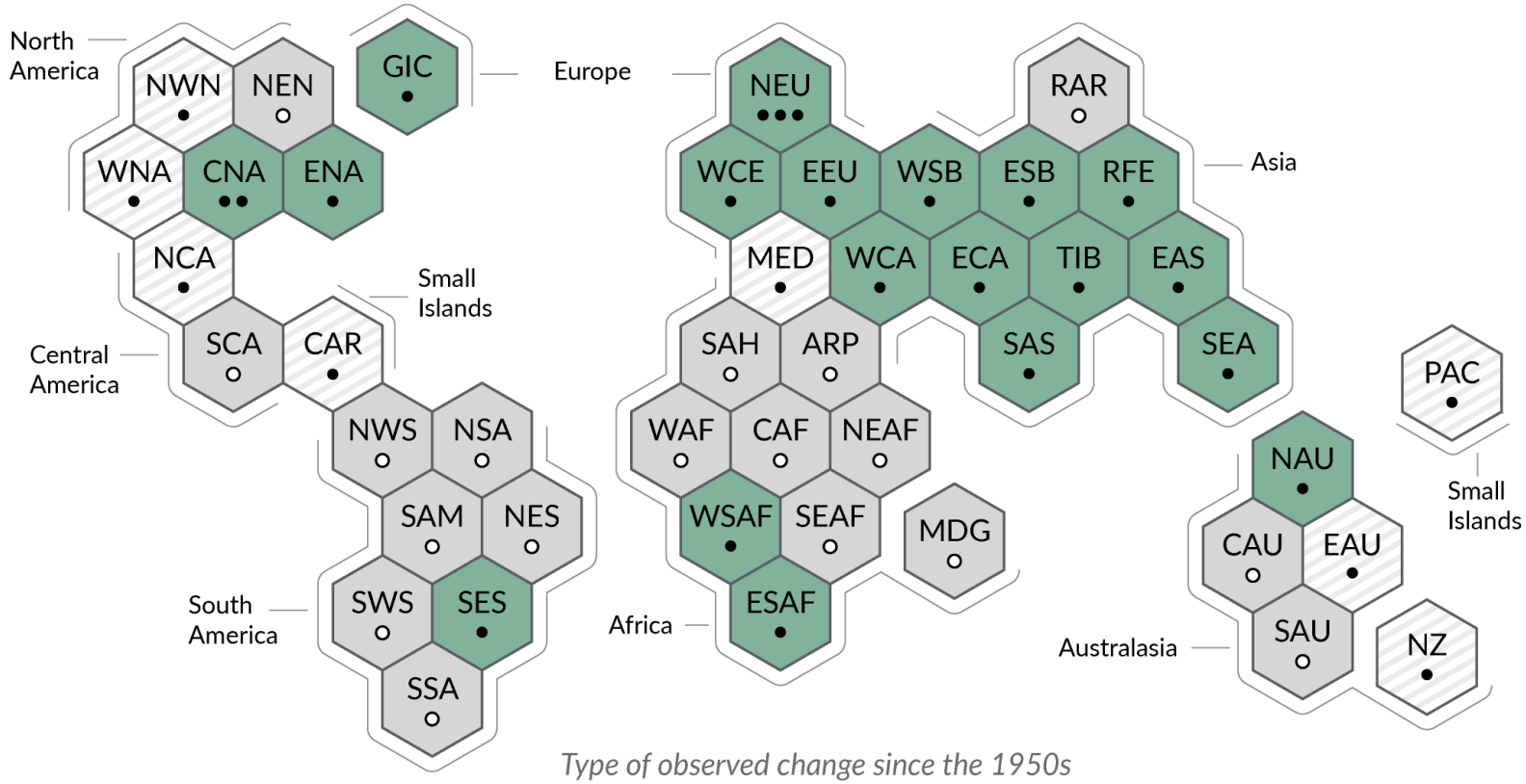
b) Synthesis of assessment of observed change in **heavy precipitation** and confidence in human contribution to the observed changes in the world's regions

Type of observed change
in heavy precipitation

- Increase (19)
- Decrease (0)
- Low agreement in the type of change (8)
- Limited data and/or literature (18)

Confidence in human contribution
to the observed change

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



Type of observed change since the 1950s

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

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Figure SPM.3

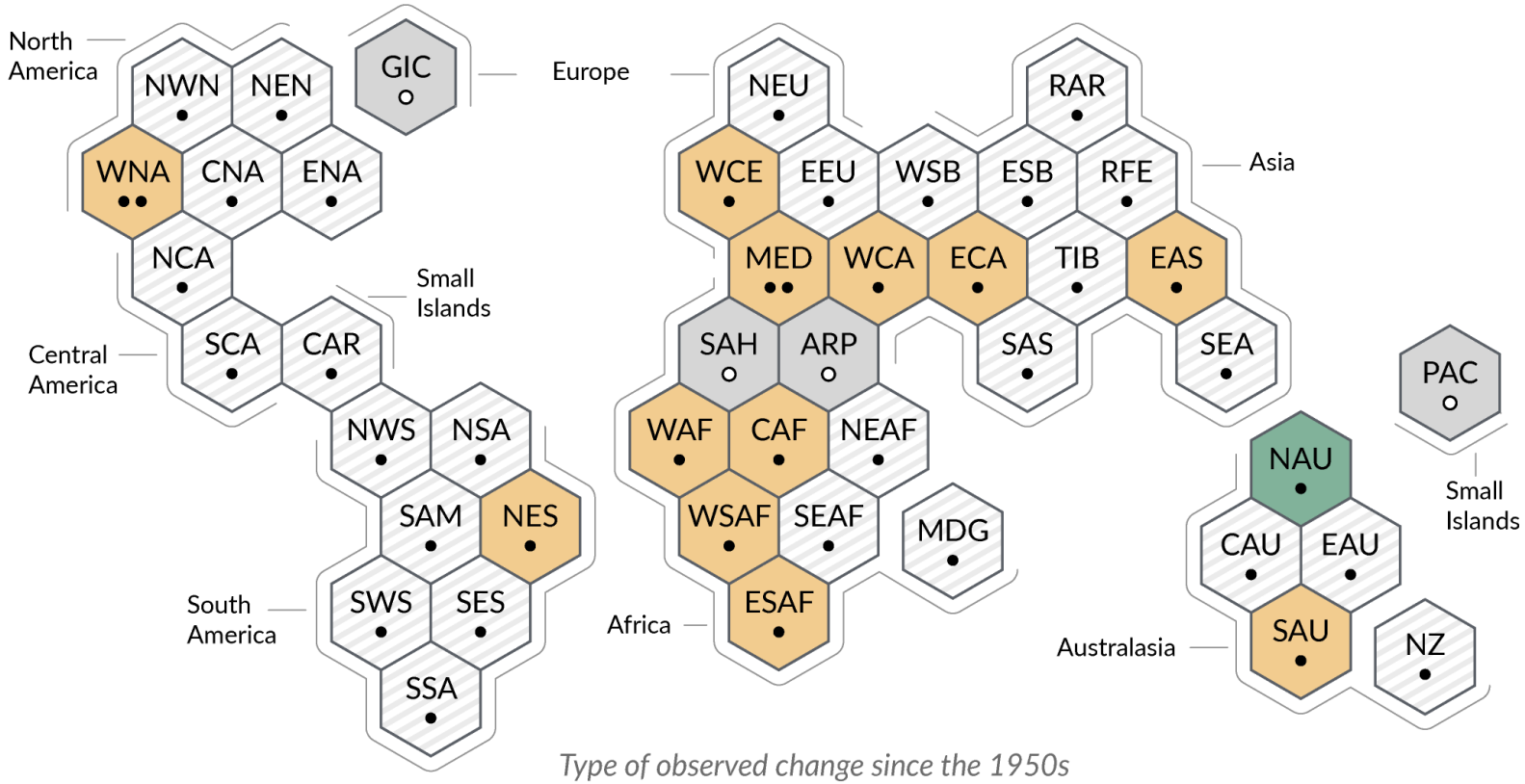
c) Synthesis of assessment of observed change in **agricultural and ecological drought** and confidence in human contribution to the observed changes in the world's regions

Type of observed change
in agricultural and ecological drought

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

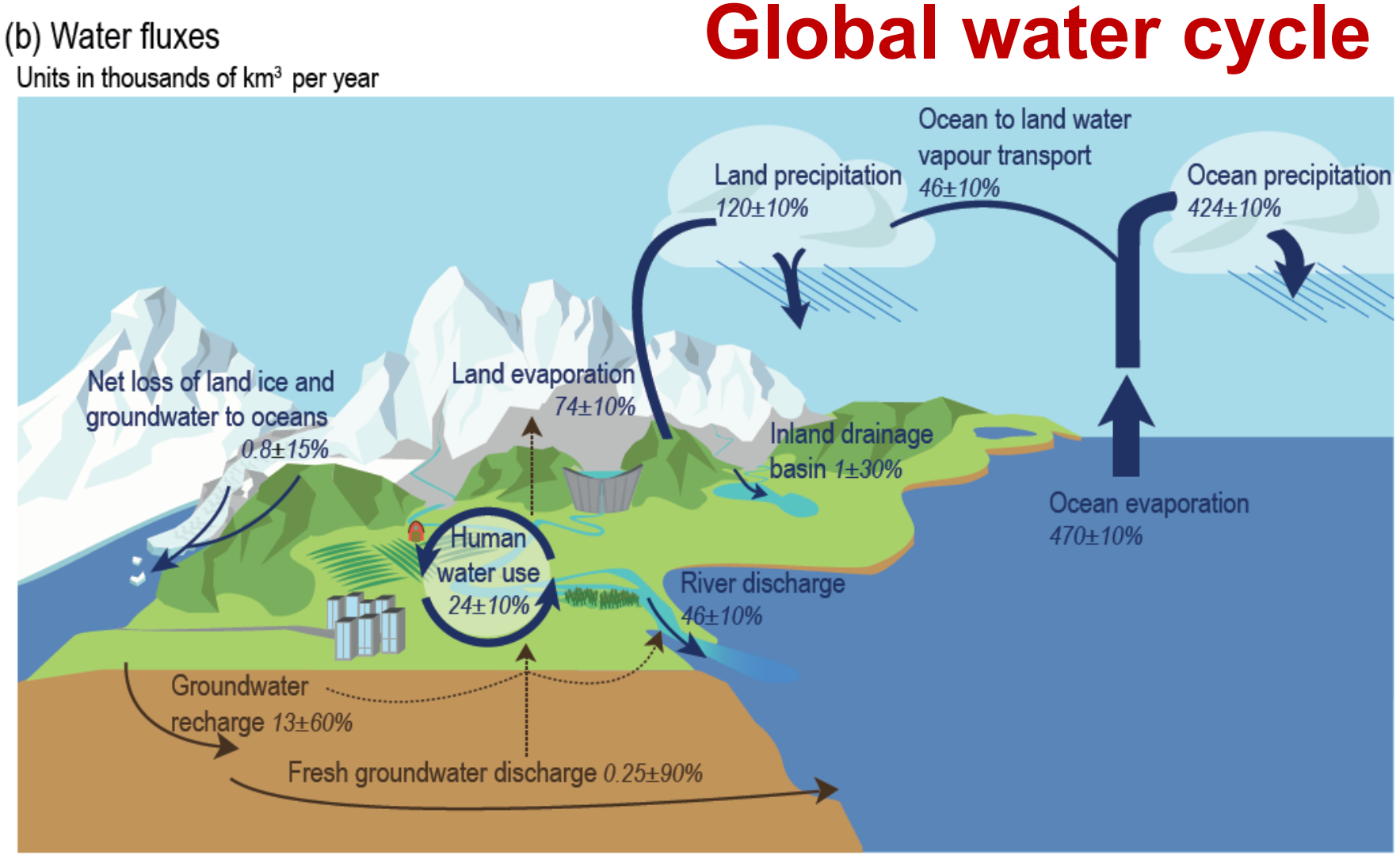
Confidence in human contribution
to the observed change

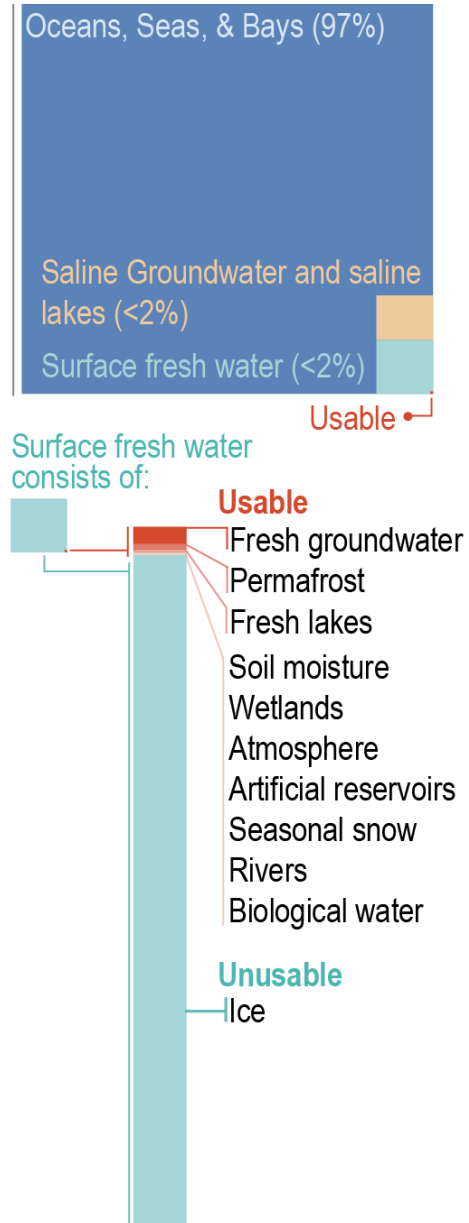
- ●●● High
- ●● Medium
- ● Low due to limited agreement
- ○ Low due to limited evidence



Type of observed change since the 1950s

Global water cycle





Douville et al. (2021) IPCC, Ch 8 (Fig. 8.1).

See also Allan et al. (2020) NYAS; Abbott et al. (2018) Nature Geosci

> 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.

Water cycle changes at 4°C warming…

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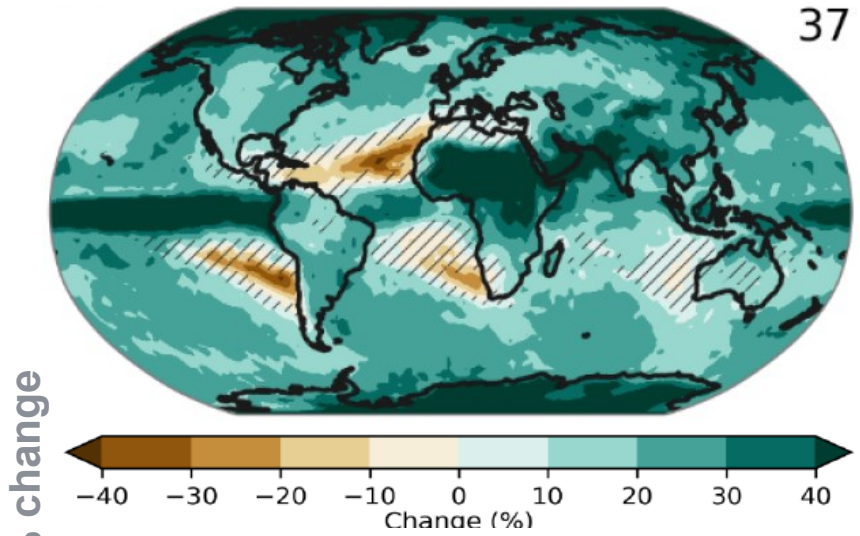
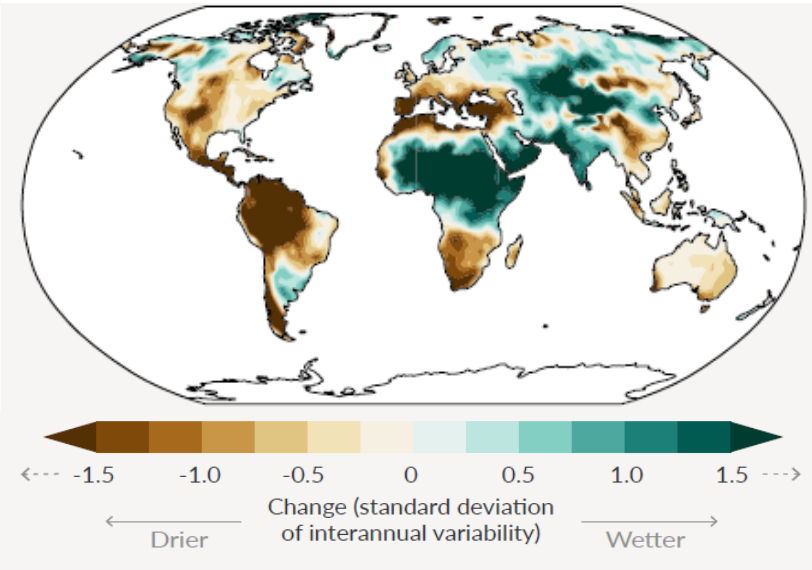
Precipitation intensity (Rx1day)

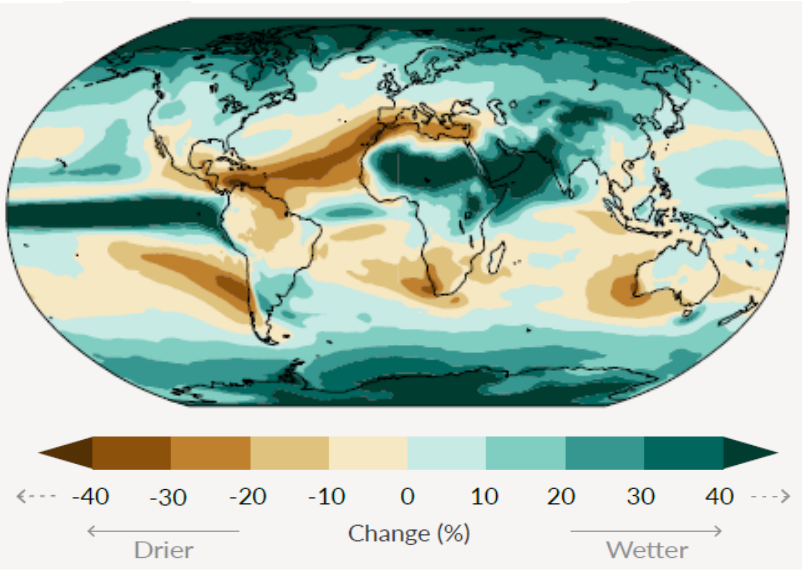


- More intense rainfall
- More severe droughts (and hot/dry extremes)
- Wet events wetter, dry events drier
- Increased variability (day to day, year to year)

Total Column Soil Moisture



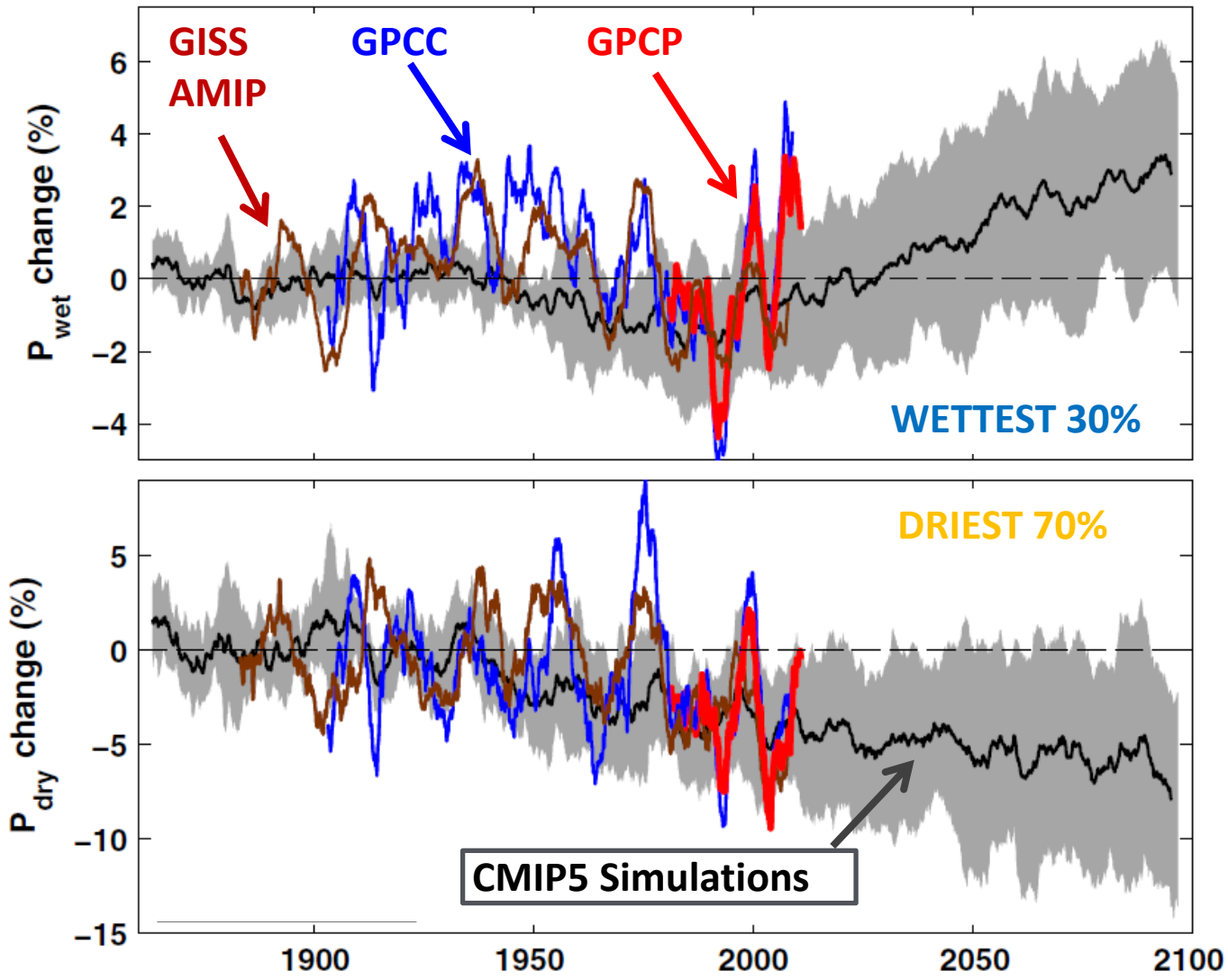
Mean Precipitation



- But large effect of circulation change on regional water cycle

IPCC WG1 (2021) Chapters 11, 4, 8 and SPM; see also Technical Summary BoxTS.6

Larger seasonal & interannual contrasts in tropics

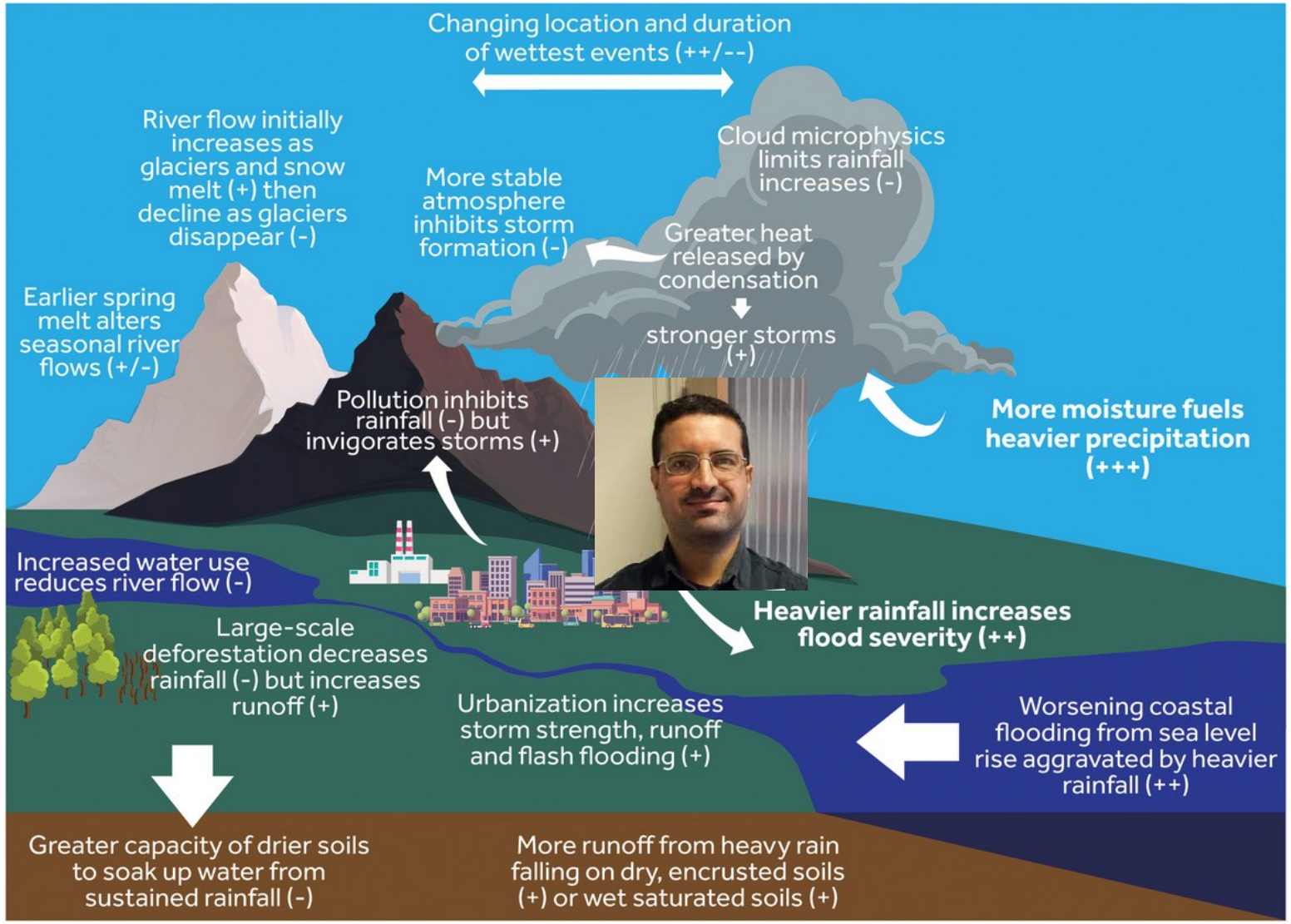


- Dynamically track wettest 30%, driest 70% regions each month
- Tropical land precipitation increases in wet regime, decreases in dry regime
- Observed decadal variability explained by internal variability

See also **Schurer et al. (2020) ERL**; **Kumar et al. (2015) GRL**

Liu & Allan (2013) ERL update in *Tropical Extremes: Natural Variability & Trends*

Intensification of heavy precipitation & flood hazard



- Intensification of extreme precipitation with increasing moisture (~7% per °C)
  - ➢ Flooding more complex
  - ➢ Direct human influences including Urbanization
  - ➢ Compounding effects of sea level rise/heavy rain

See IPCC 2021 Chapter 11 & SPM

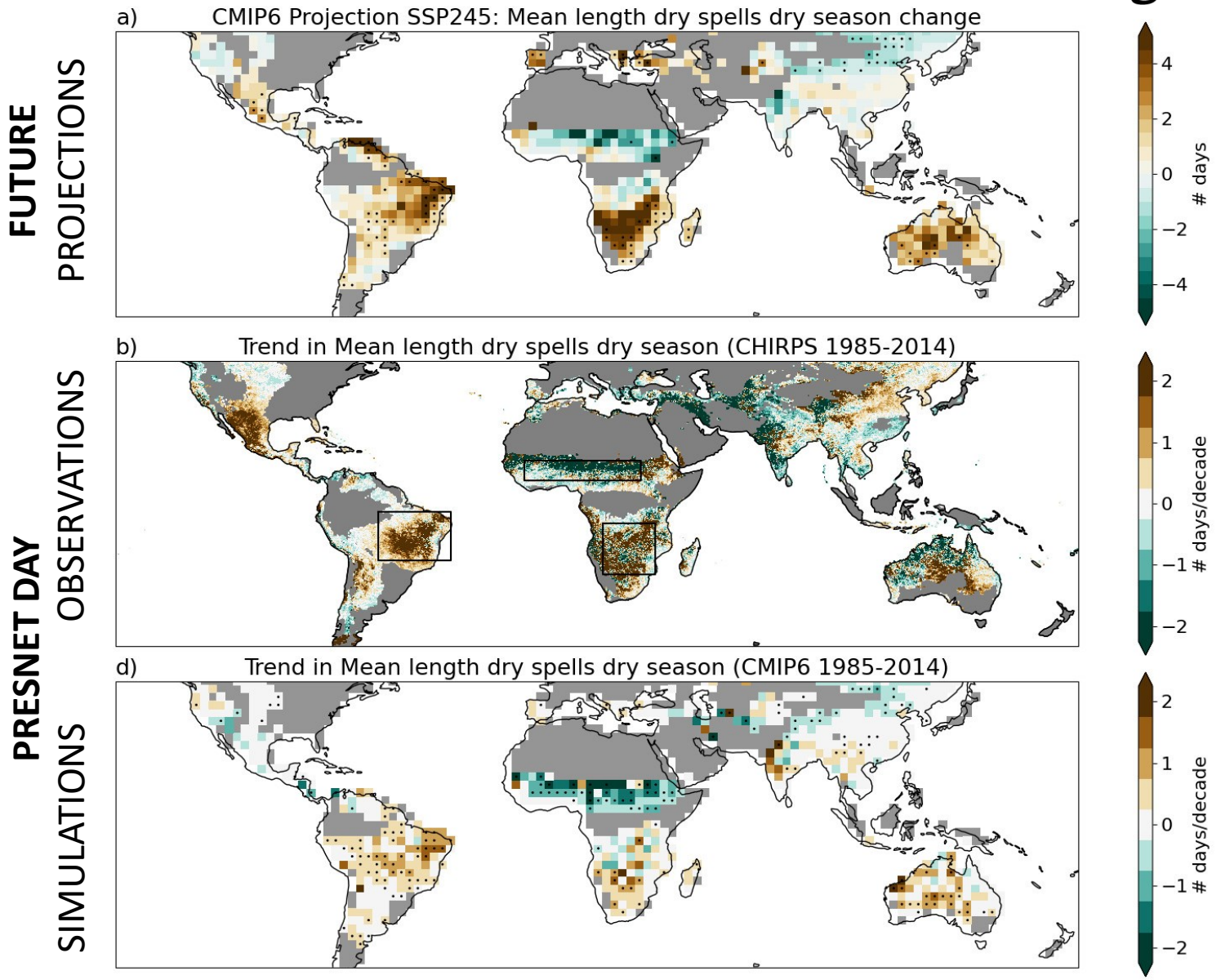
Allan et al. (2020) NYAS; see also Fowler et al. (2021) Nature Rev.

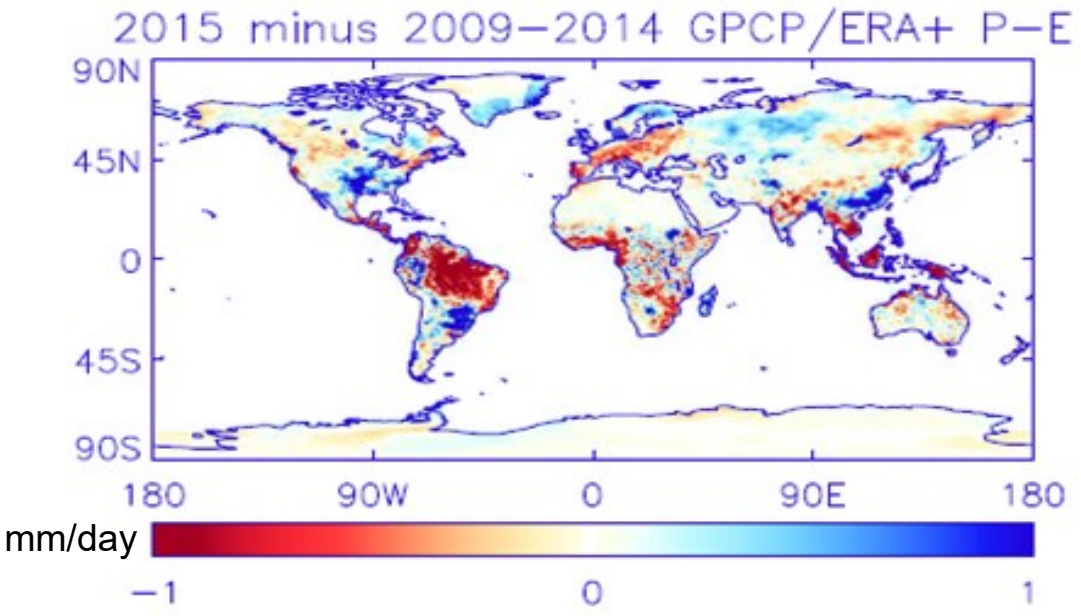
Emerging signals of climate change

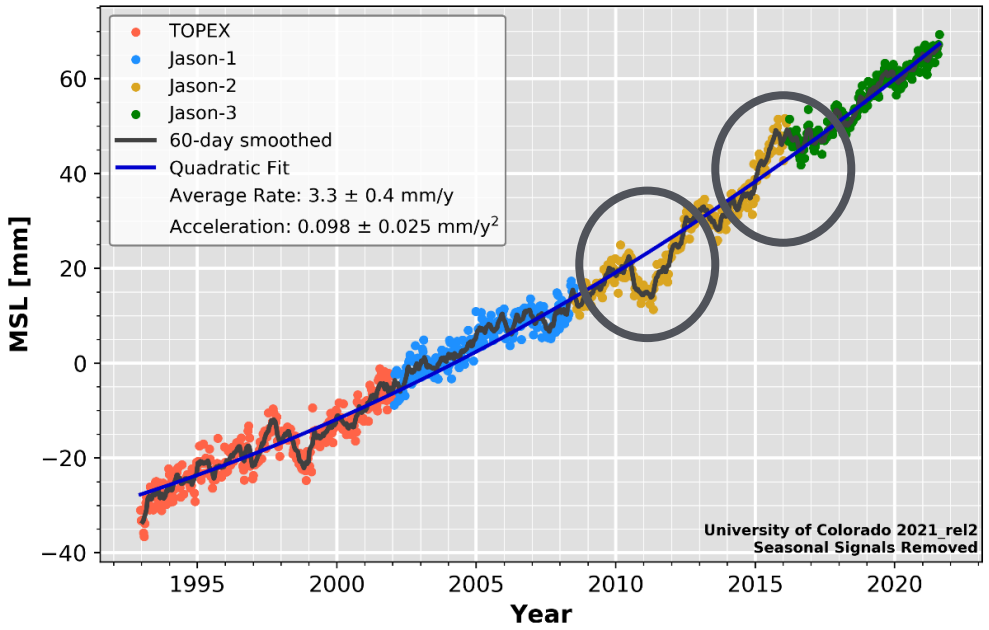
- Intensification of dry seasons
  - ➢ Dry season severity e.g. Wainwright et al. (2022) GRL →
  - ➢ Intensity/timing change impacts

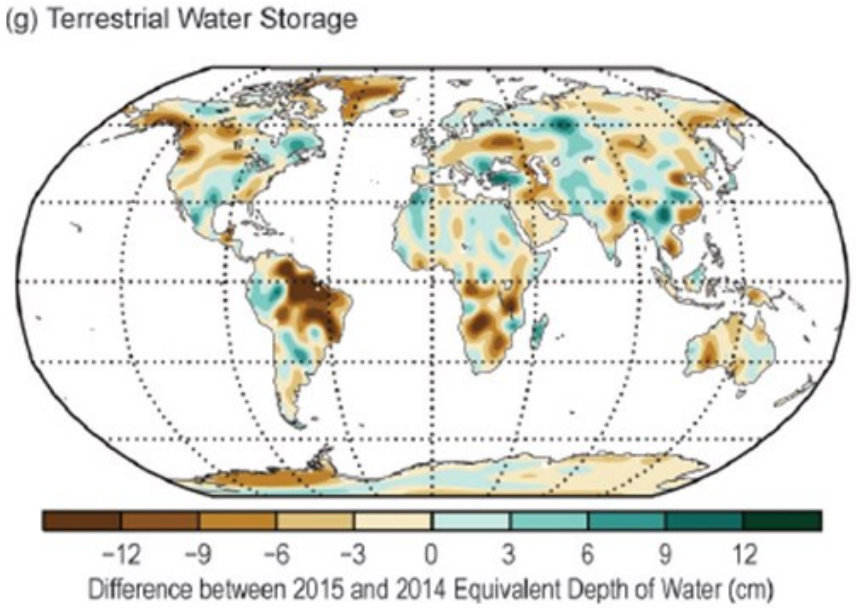
Alarm bells?

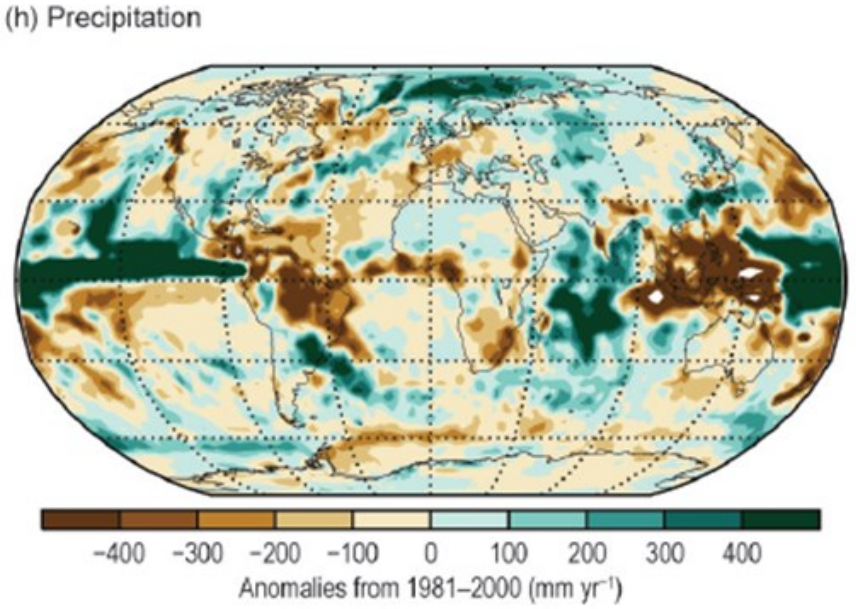
- ➢ Amazon dieback Boulton et al. 2022 Nature Clim
- ➢ Wetland methane emissions Feng et al. (2022) Nature Comm.
- ➢ Atlantic Meridional Overturning ocean Circulation collapse? Boers 2021 Nature Clim …











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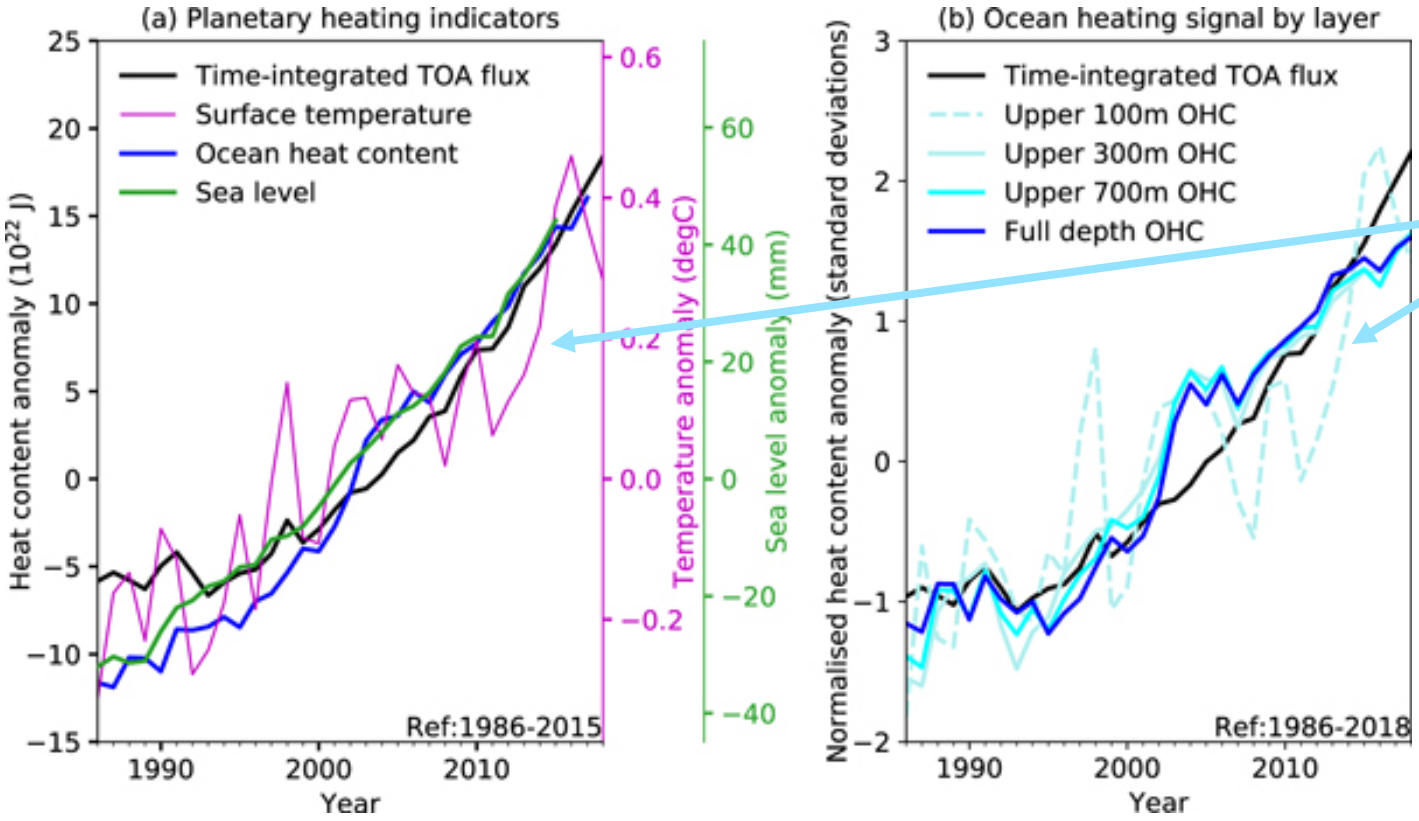
Chasing water through 2015/16 El Niño

Boening et al. (2012) GRL: The 2011 La Niña so strong, the oceans fell

Planetary heating and sea level rise



Allison et al. (2020) ERC

See also Cheng et al. 2017 Sci. Adv.

See also climate.gov blog

Surface temperature determined by upper mixed layer ocean heat

e.g. Allan (2018) Nature Clim.

Planetary Heating:

- 1985-1999: **0.10 ± 0.61 W m^{-2}**
- 2000–2016: **0.62 ± 0.1 W m^{-2}**

Liu et al. 2020 Clim. Dyn

Can we measure acceleration in heating of climate?

von Shuckmann et al. 2022 ESSD

Monitoring global energy & water cycle changes

- Climate change in steps?
- Water vapour increasing (1%/10yr for microwave satellite data/models) e.g. Allan et al. 2022 JGR
- Reanalyses cannot yet represent global energy/water cycle change
- Increasing net planetary heating
  - low cloud changes important? Loeb et al. 2020 GRL
- Monitoring of energy budget changes at risk…

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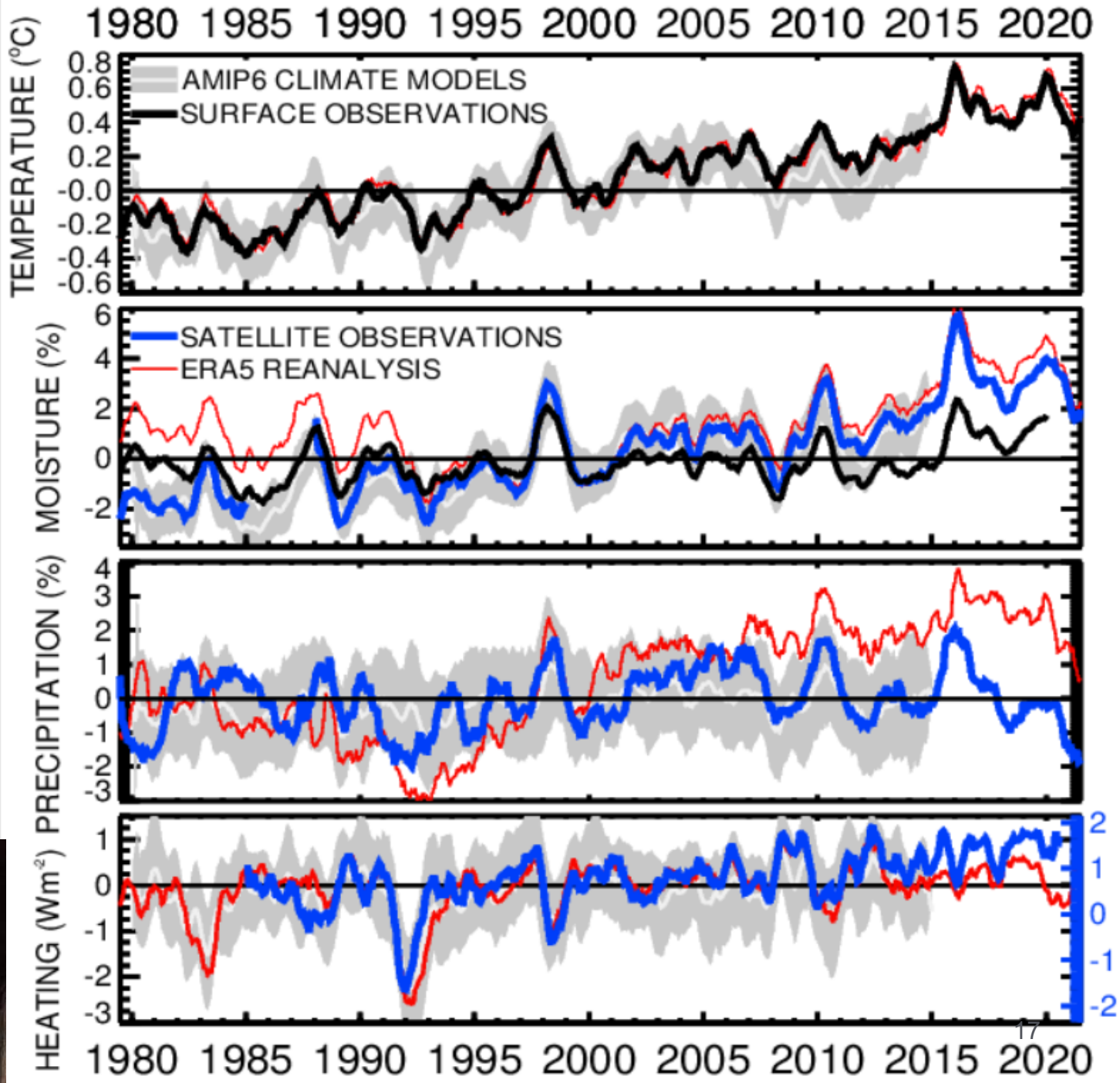

Gauging Variable Climate Sensitivity

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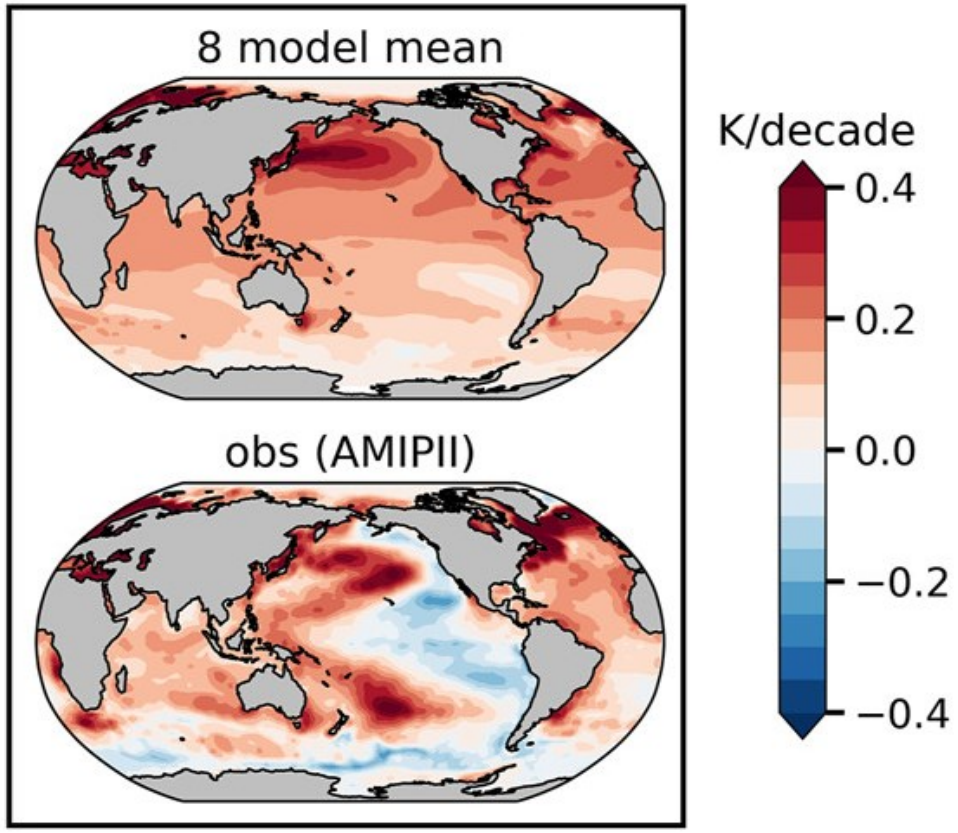
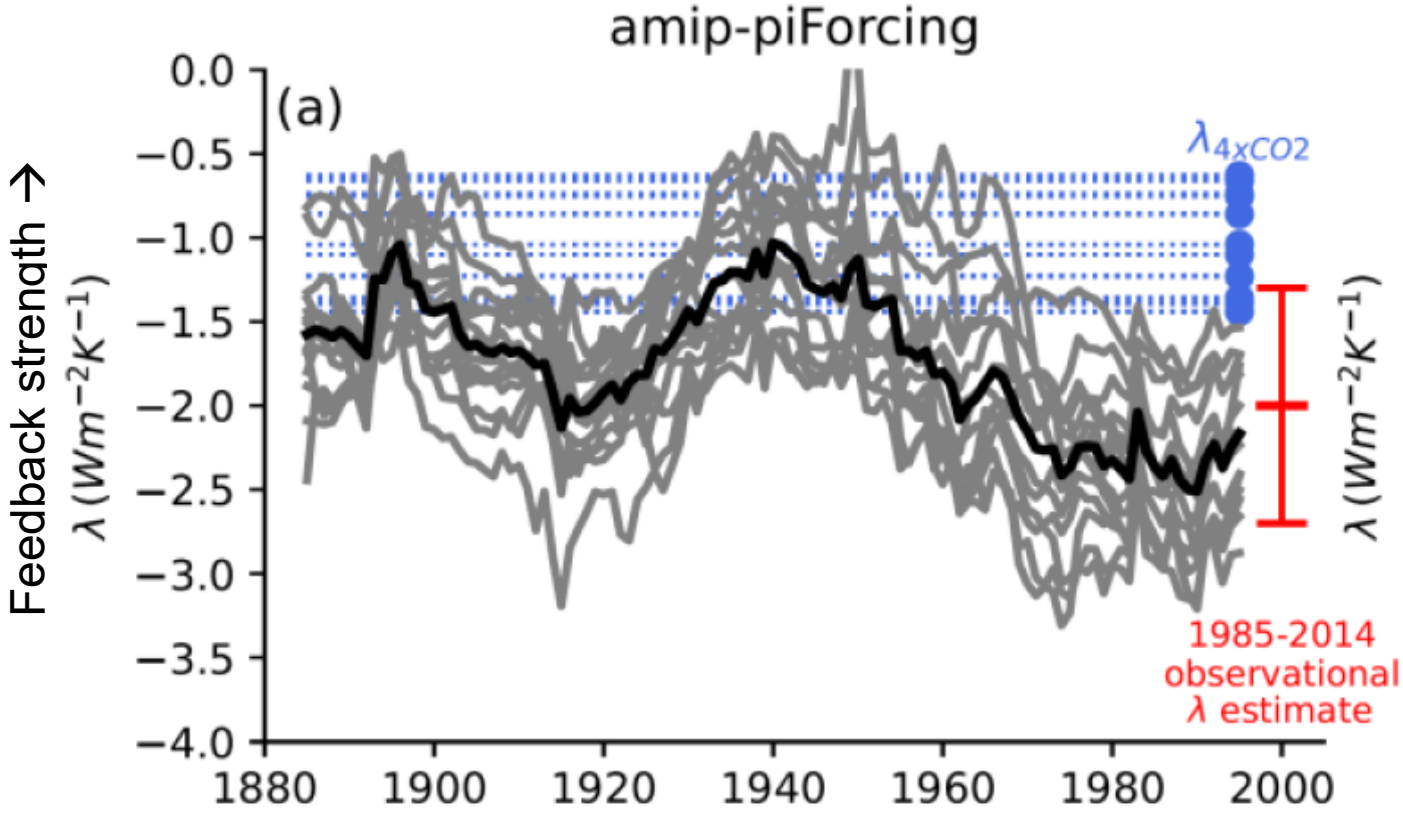
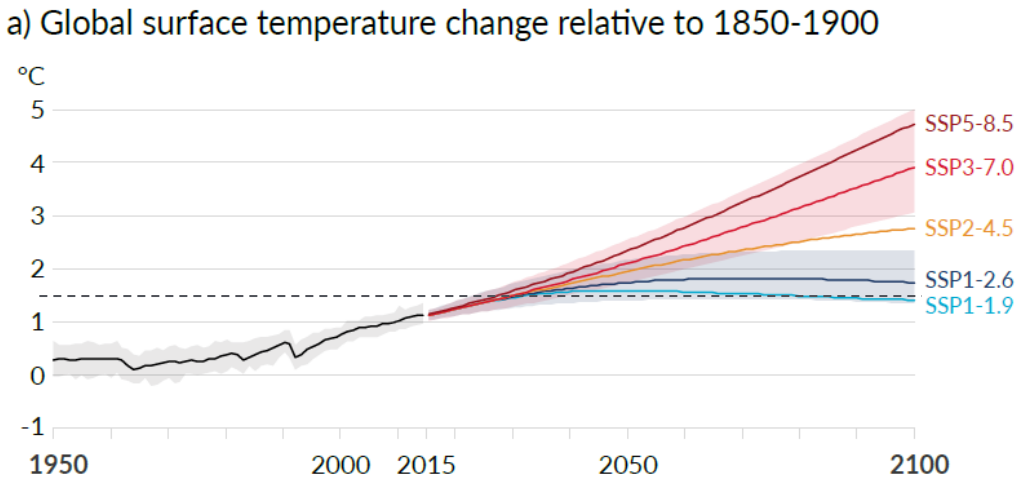




Pattern of observed warming (1979-2014) is unexpected!
Dong et al. (2021) GRL

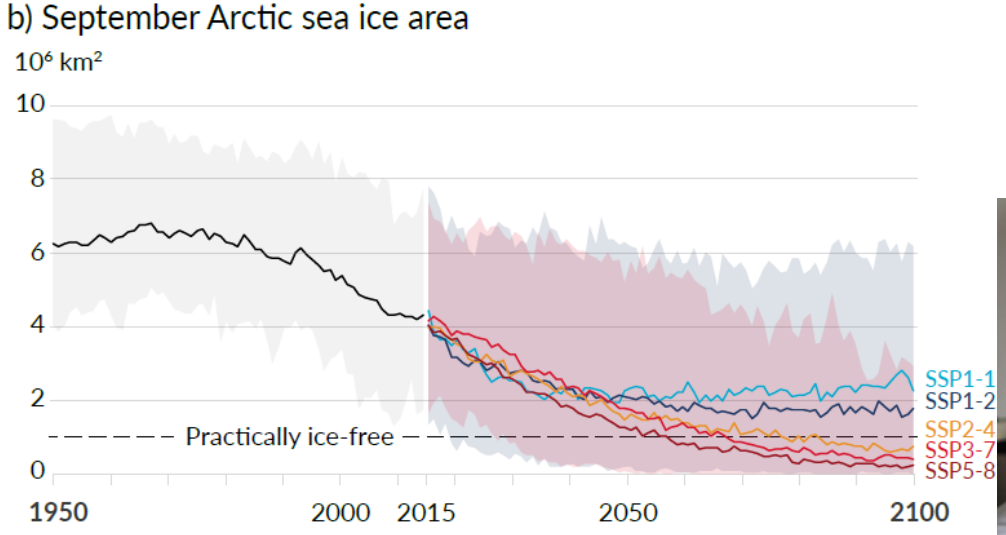
Observed pattern of global warming has weakened climate feedbacks relative to coupled models
(Andrews et al. 2022 JGR)

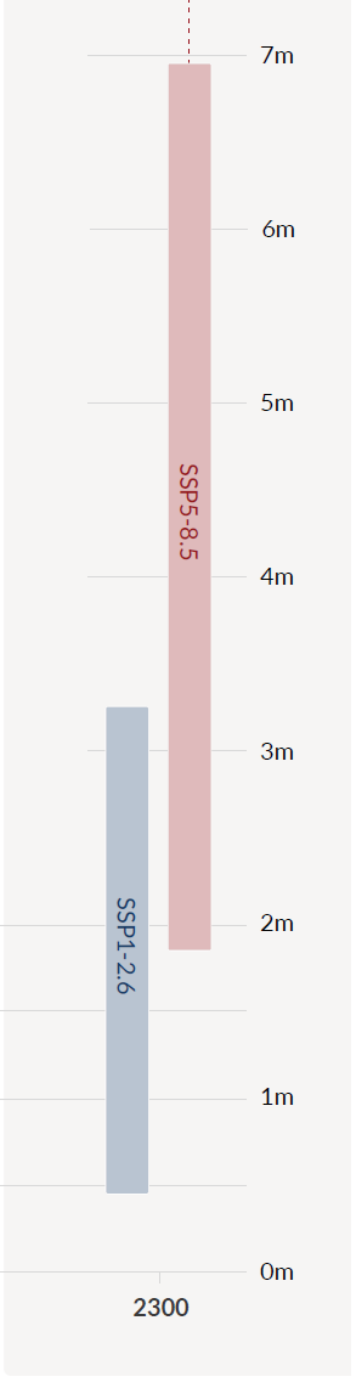
Some changes in the climate system are irreversible but many changes can be slowed or stopped by limiting warming



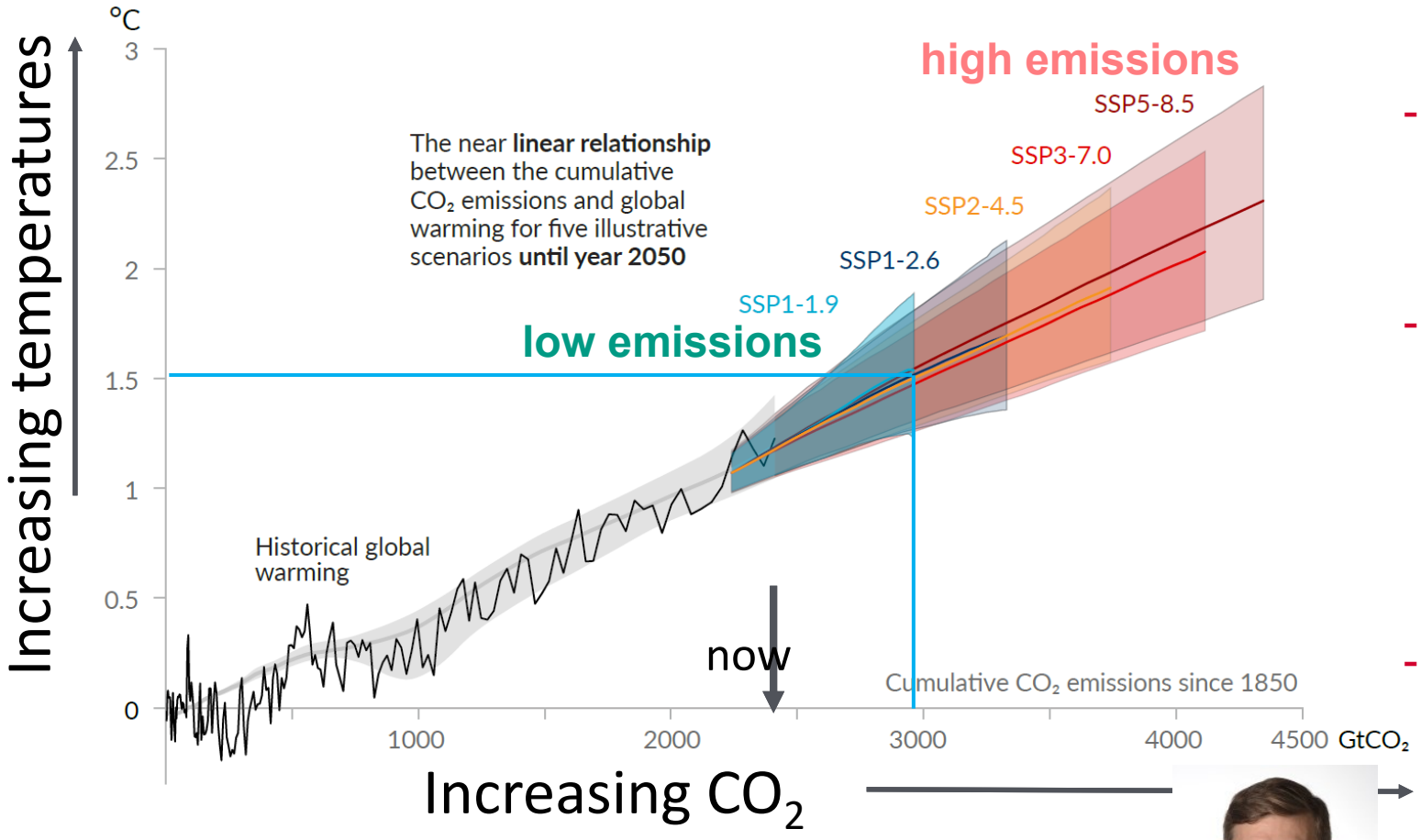
Global warming of 1.5°C and 2°C will be exceeded during the 21st century unless deep reductions in CO_2 and other greenhouse gas emissions occur in the coming decades
[IPCC (2021) WG1 SPM]

High emissions
Low emissions





Limit Carbon Emissions to Avoid Dangerous Climate Change



[IPCC WGI 2021 SPM]

- Act now

  To keep future options open

- Act everywhere

  Efforts in all sectors are needed to reach global zero CO_2 emissions

- Act thoughtfully

  Develop strategies maximising synergies and taking into account the local context, use a wide array of measures and actions

- Act jointly

  Collaboratively and including national and sub-national authorities, civil society, the private sector and local communities

Joeri Rogelj (IPCC AR6 & SR1.5 author)

Glimmers of good news!

- Warming effectively stops after net zero CO_2 emissions are reached
- Still physically possible to limit global warming to 1.5°C
- Amplifying carbon cycle feedbacks small? (so far…)
- More certain on climate sensitivity 3°C (2.5 to 4°C)
- Reducing Methane emissions limits warming & improves air quality

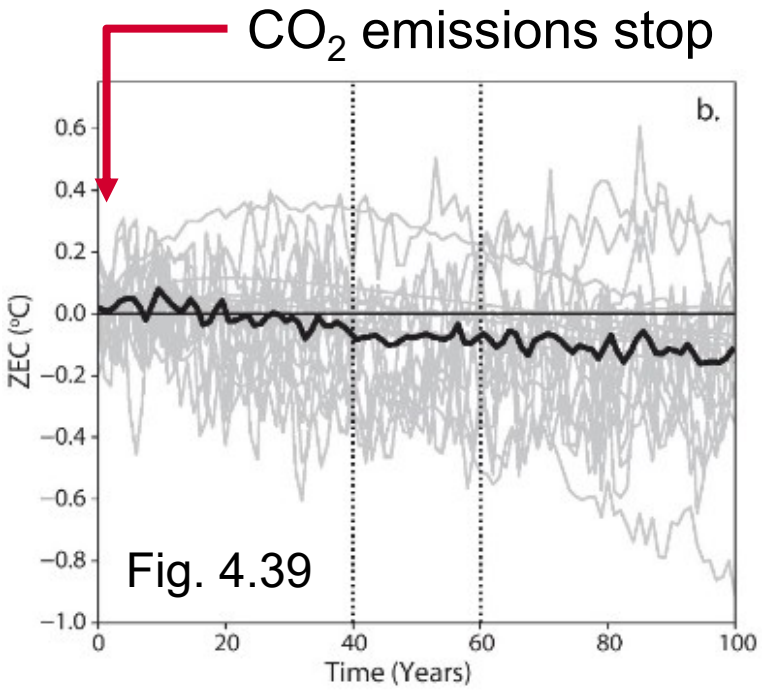


Fig. 4.39

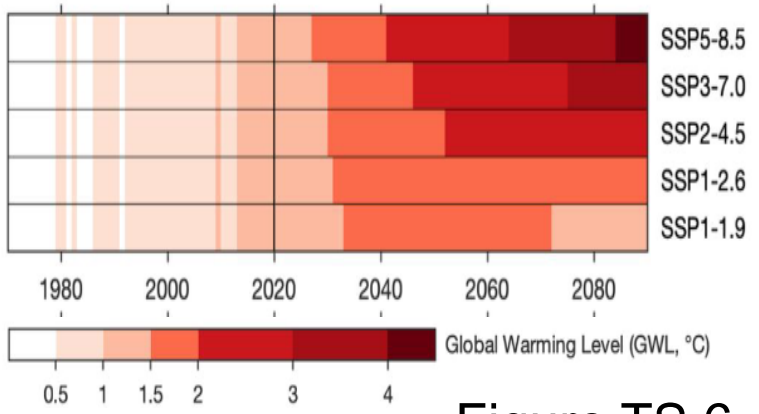
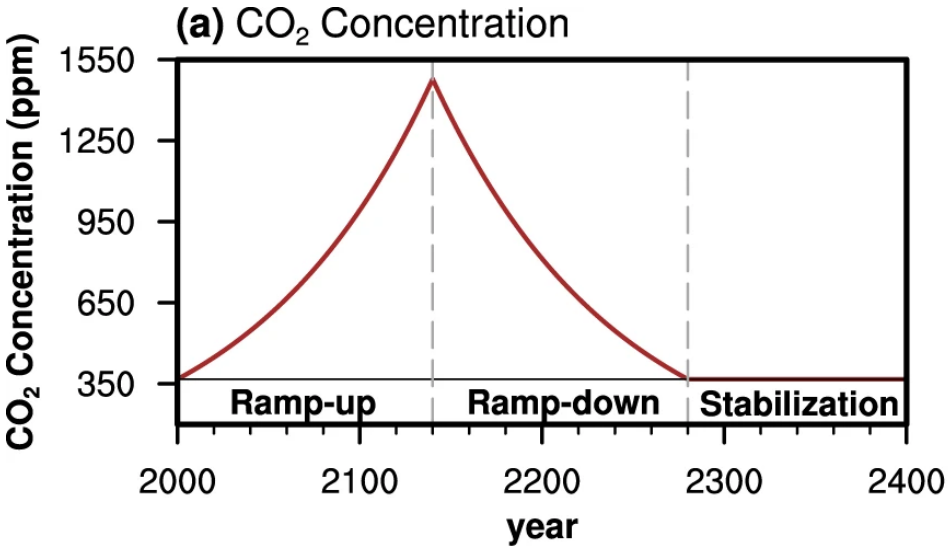
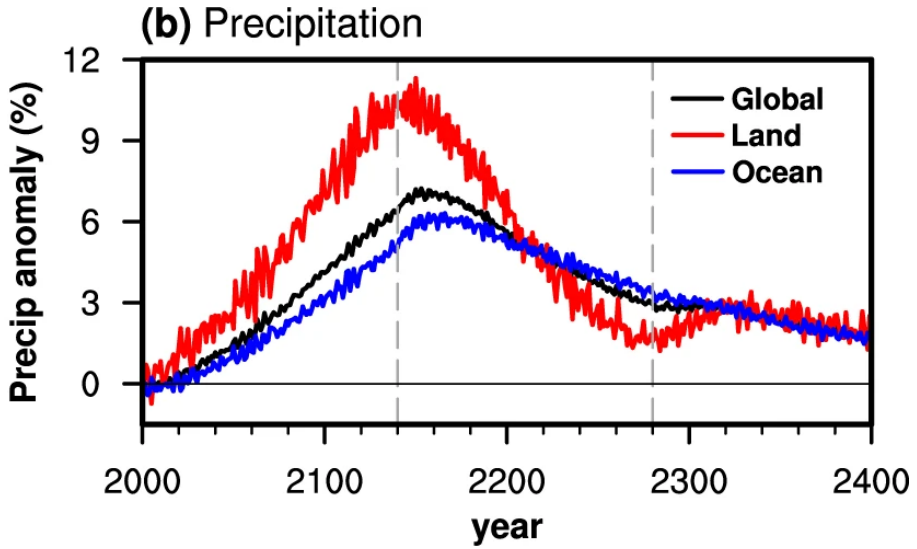


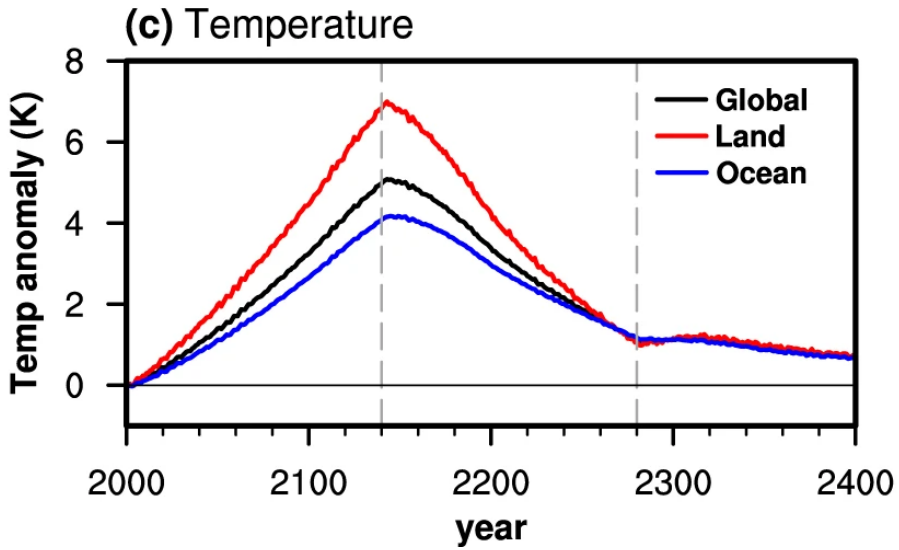
Figure TS.6

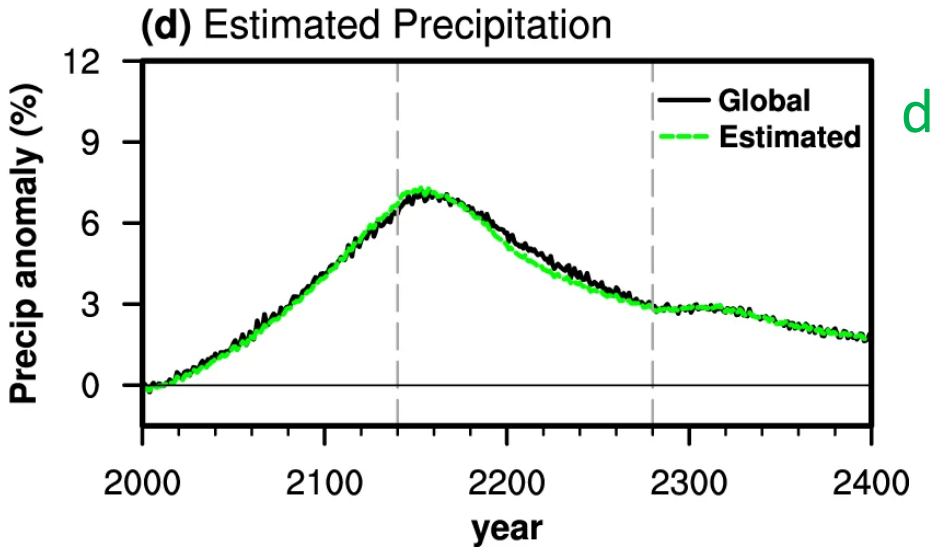
What will a post net zero world look like?

e.g. see King et al. (2022) Nature Climate Change







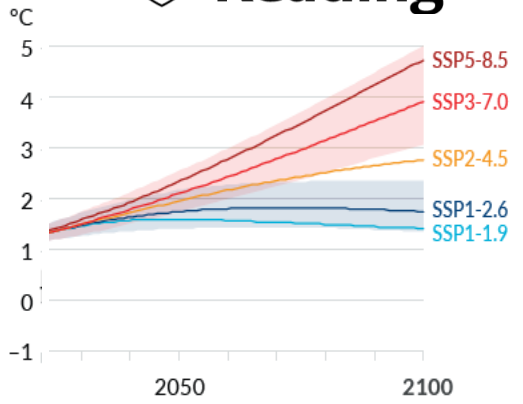


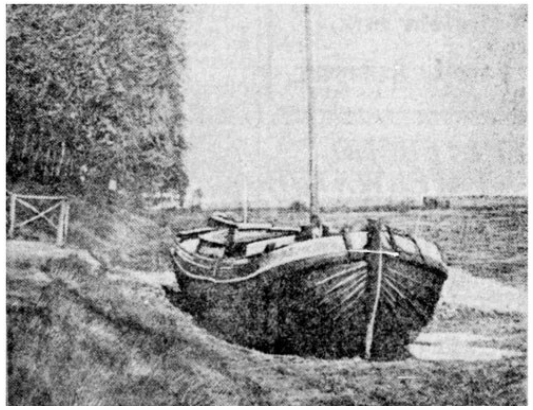
$dP = \eta\Delta T - \Sigma f_F.\Delta F$

Yeh et al. (2021) npj Clim Atmos Sci

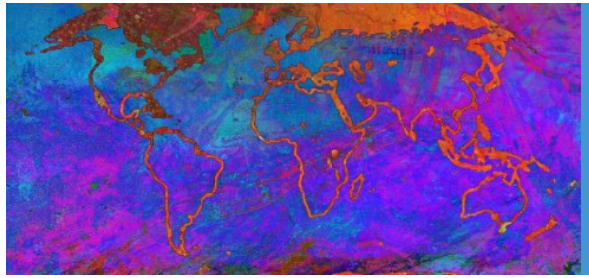
Future storylines

- Plausible set of distinct, policy-relevant regional outcomes from multiple realisations of future scenarios
- Unlikely but possible high impact climate events (e.g. AMOC shut down, Amazon die back, monsoon failure, huge or clustered volcanoes, etc)
- Sustainability, Regional Rivalry, Inequality?
- What if 1921 European drought (e.g. van der Schrier et al. 2021 Clim. Past.) conditions occur at 2°C warming?
- What if record breaking wet season or stalling tropical cyclone or intense convective event occurred in 3°C warmer world?





Key Messages (Abridged)



IPCC
INTERGOVERNMENTAL PANEL ON climate change

Climate Change 2021
The Physical Science Basis

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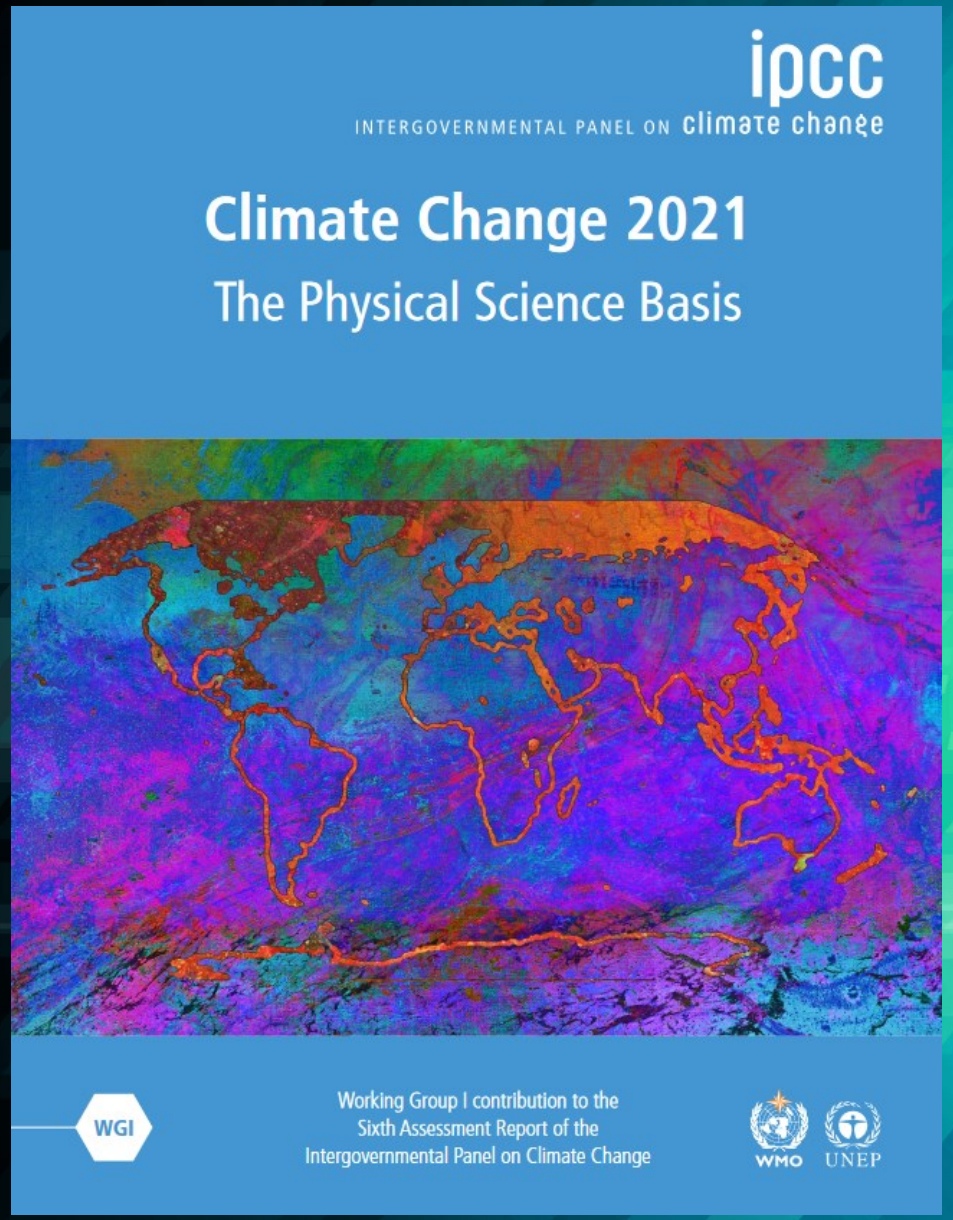
- Earth's climate has always varied but it is an established fact that human activities are now driving climate change
- Recent changes in climate are widespread, rapid and unprecedented in thousands of years.
- Human activities are intensifying extreme climate events, including heat waves, heavy rainfall, and droughts
- Every bit of global warming increases the magnitude of climate change including the severity of climate extremes
- Limiting warming to 1.5°C requires immediate, rapid, and large-scale reductions in greenhouse gas emissions



www.ipcc.ch/report/ar6/wg1