

Sources of uncertainty in global warming projections

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Outline

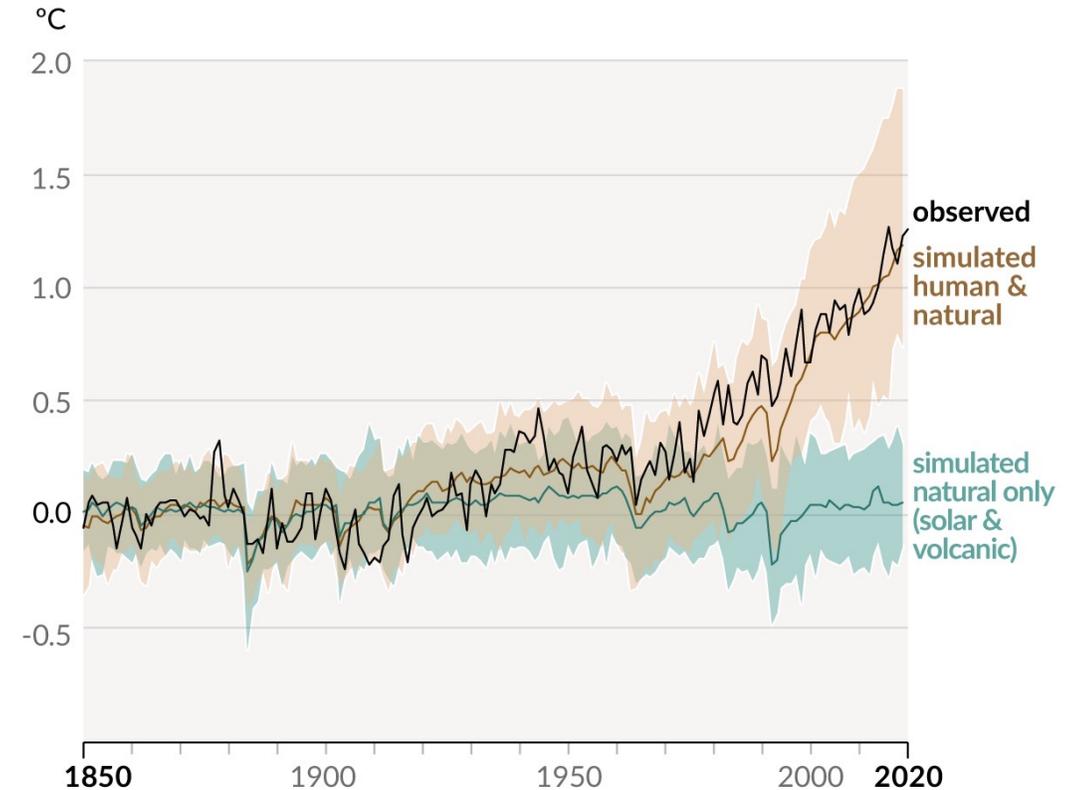
- A look at the recent past
- What climate models tell us about the future
- Sources of uncertainty in climate projections: the role of clouds

About me

- Lecturer in Climate Science, Grantham Institute & Department of Physics, Imperial College London (since 2018)
- I study the physical aspects of climate change
- Research focus on climate feedback processes, particularly by clouds

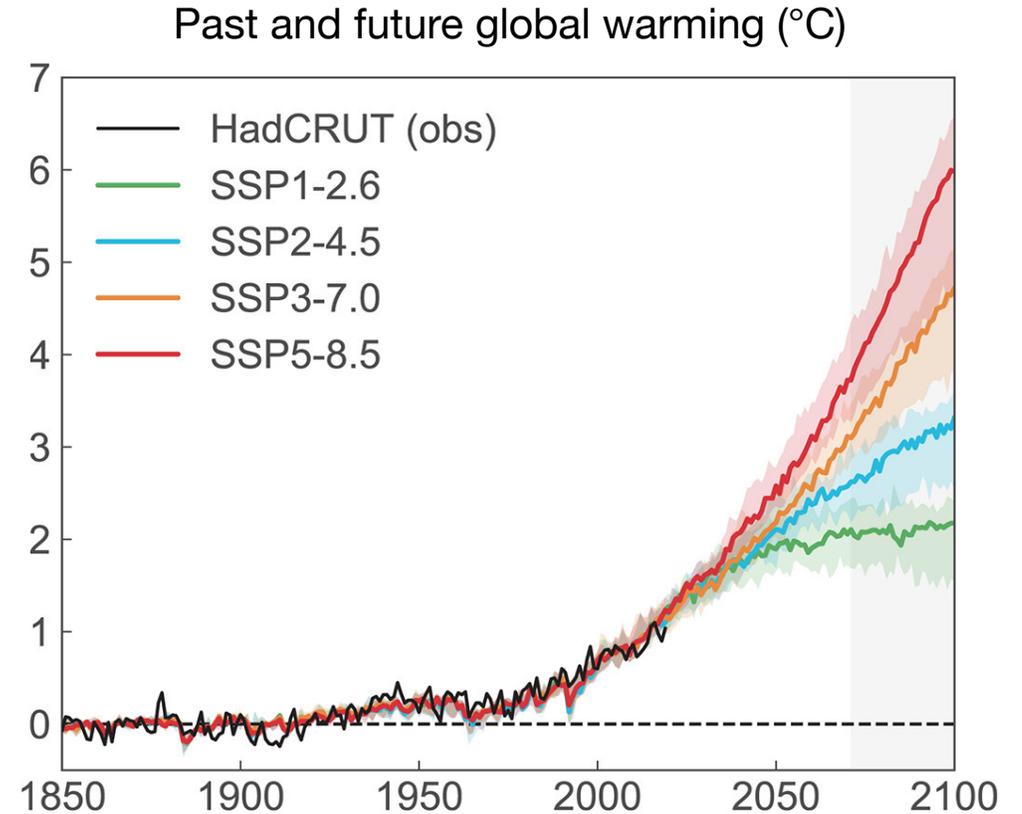
A look at the recent past

- More than 1°C of global warming since 1850 (“pre-industrial era”)
- Climate models can simulate this warming only if **human forcings** are accounted for
- Main human forcing = greenhouse gas emissions (CO₂, methane, nitrous oxide...)
- Partly offset by human emissions of dimming aerosols (essentially air pollution: soot, sulphate, etc)



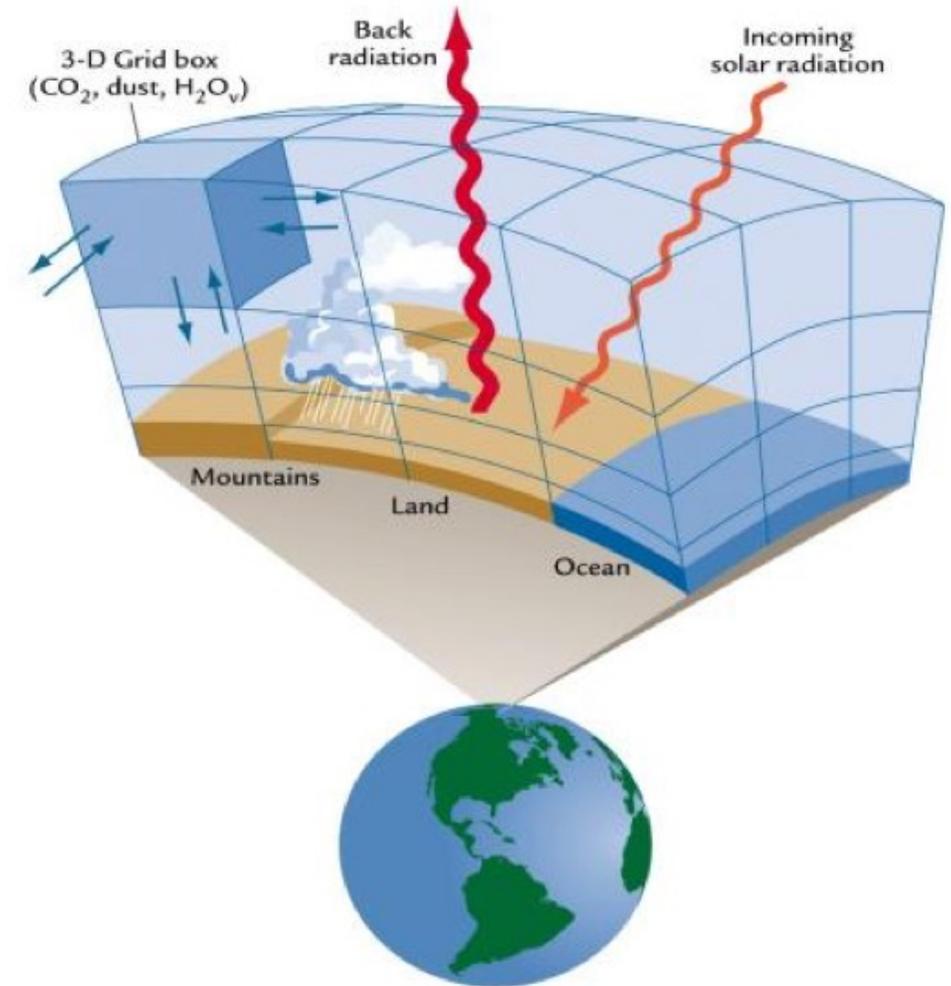
Future projections

- Future climate change depends on **emissions scenario**
 - Human behaviour, socioeconomic development
- IPCC AR6 projections based on **Shared Socioeconomic Pathways (SSPs)**
- Global climate models simulate climate change according to each scenario
- But: even for a given scenario, substantial uncertainty in global warming (and regional climate change)



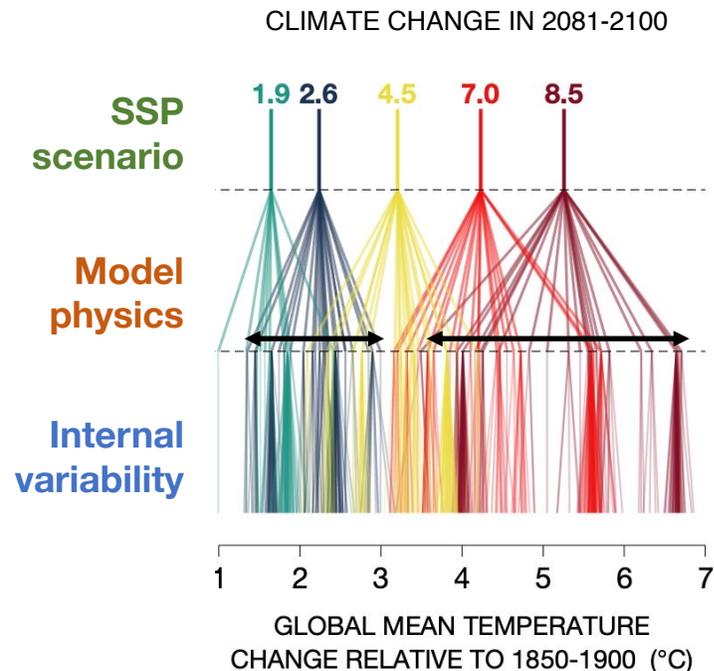
Climate modelling

- What are climate models, and how do we use them to project climate change?
- Climate models are computer models of the atmosphere, ocean, land
- Use laws of physics to simulate fluxes of radiation (= visible light, infrared energy), temperature, humidity, wind, etc
- Accuracy depends on correct simulation of complex processes, some of which happen on very small scales (e.g. clouds)
- No model is perfect → important to compare different models!



Three types of projection uncertainty

- **Scenario**: how much radiative forcing in the future?
- **Model physics**: uncertainty about physical processes → mainly *climate feedbacks*
- **Internal variability**: climate varies naturally from year to year, decade to decade

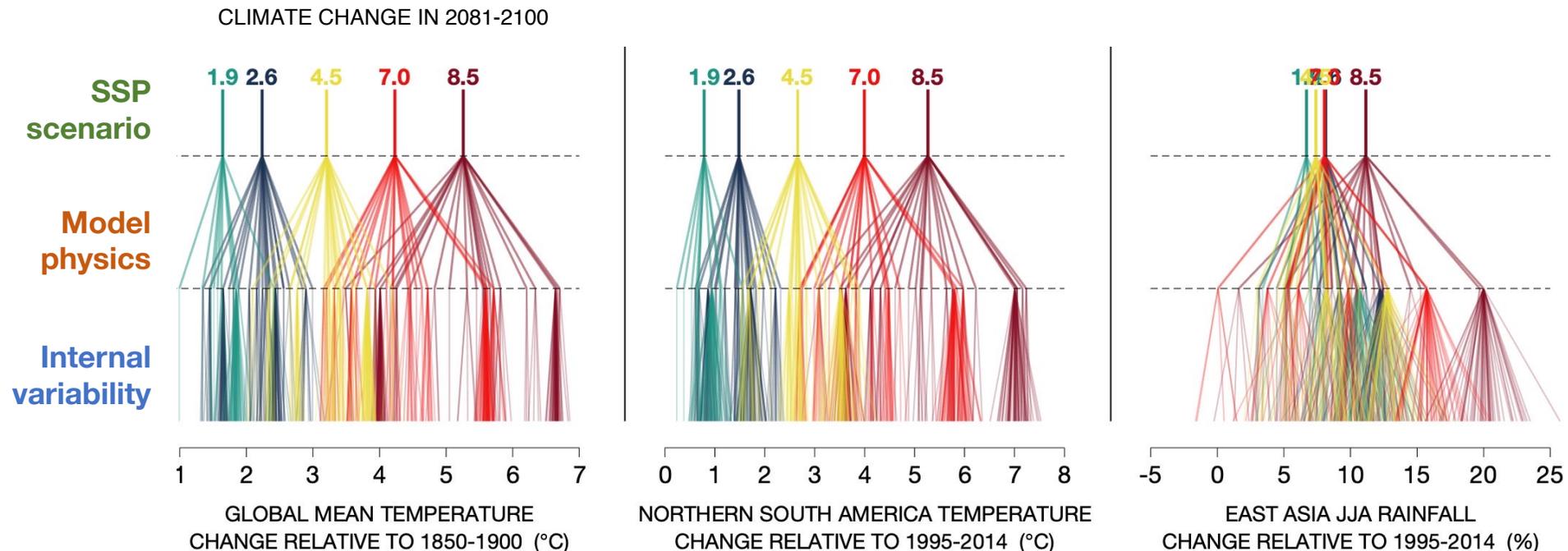


For a *given scenario*, projected global warming varies by a factor of ~2 among global climate models!

Three types of projection uncertainty

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The relative importance of these uncertainties depends on the variable, and on spatial/temporal scale

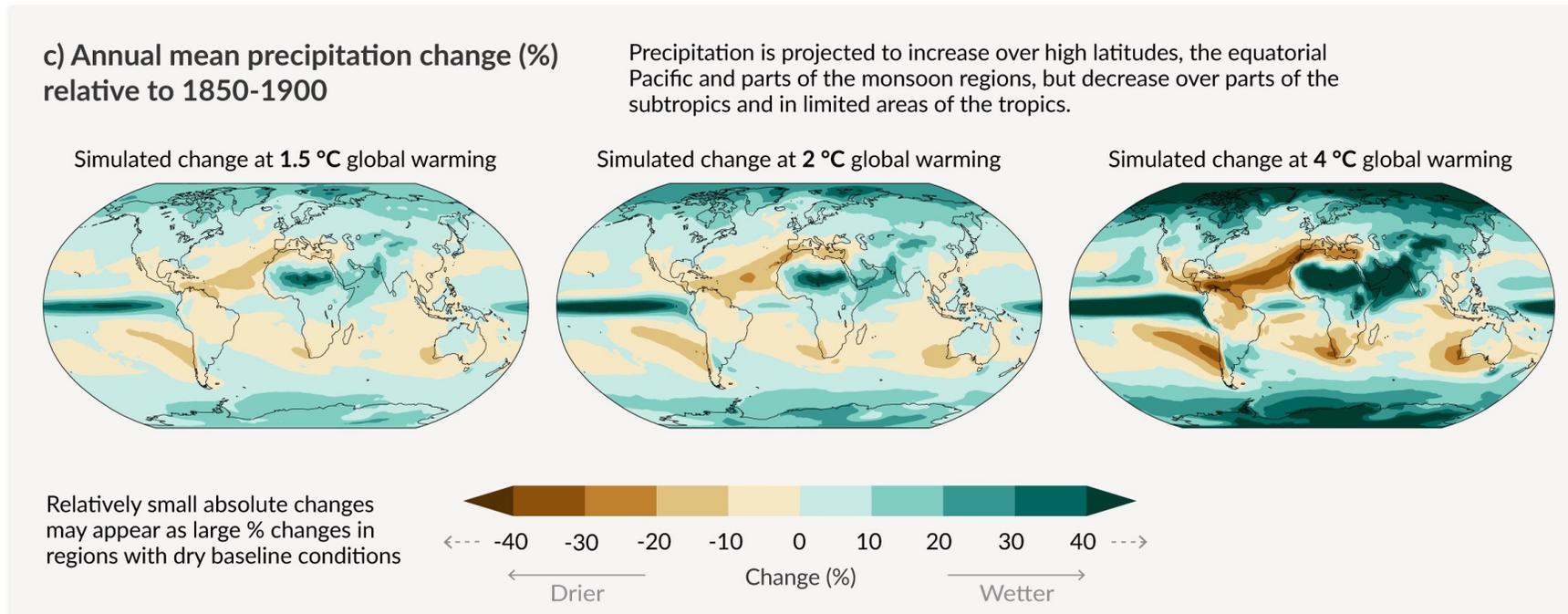


Climate sensitivity

- Science question: For a given amount of greenhouse gas emissions, **how much global warming?**
- This is quantified by the **climate sensitivity**
 - Defined as **the amount of global surface warming, at equilibrium, following a doubling of atmospheric CO₂**
- Best estimate ~3°C, but somewhat uncertain
 - Depends mainly on uncertain **climate feedback** processes that can amplify or dampen global warming

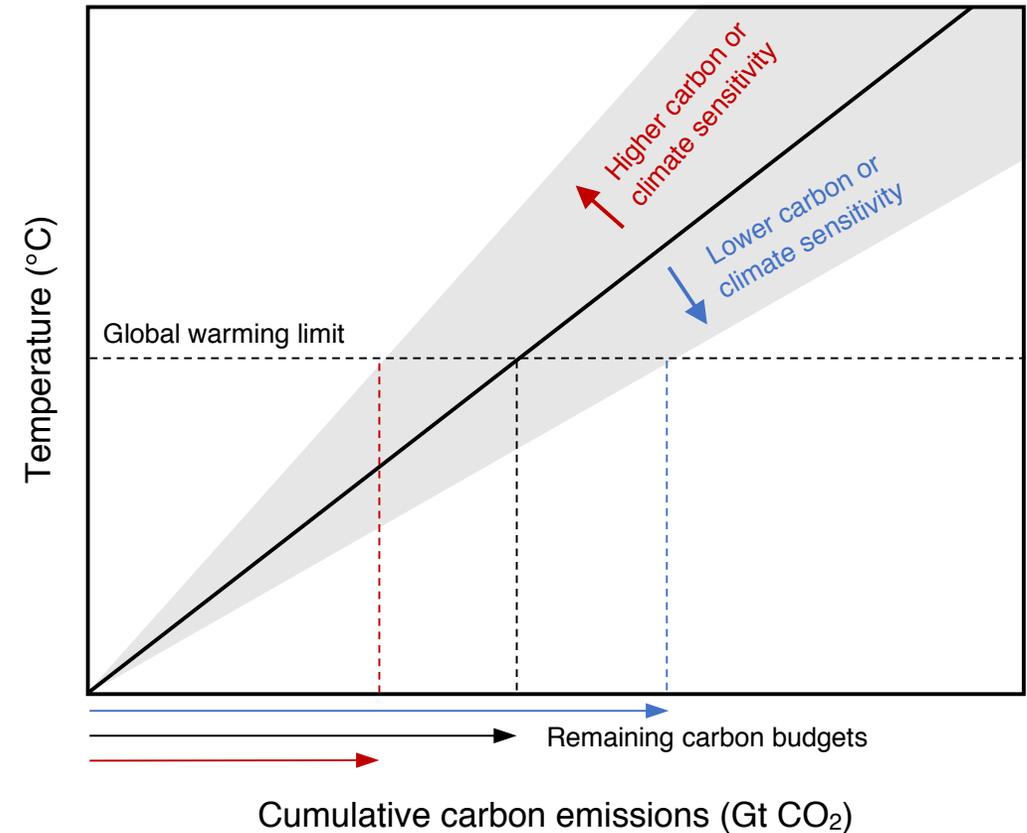
Climate sensitivity and regional climate change

- Many of the *regional* impacts of climate change scale with global warming
 - E.g. heatwaves, rainfall, droughts
- So the climate sensitivity tells us something about the severity of future climate change, given the emissions level



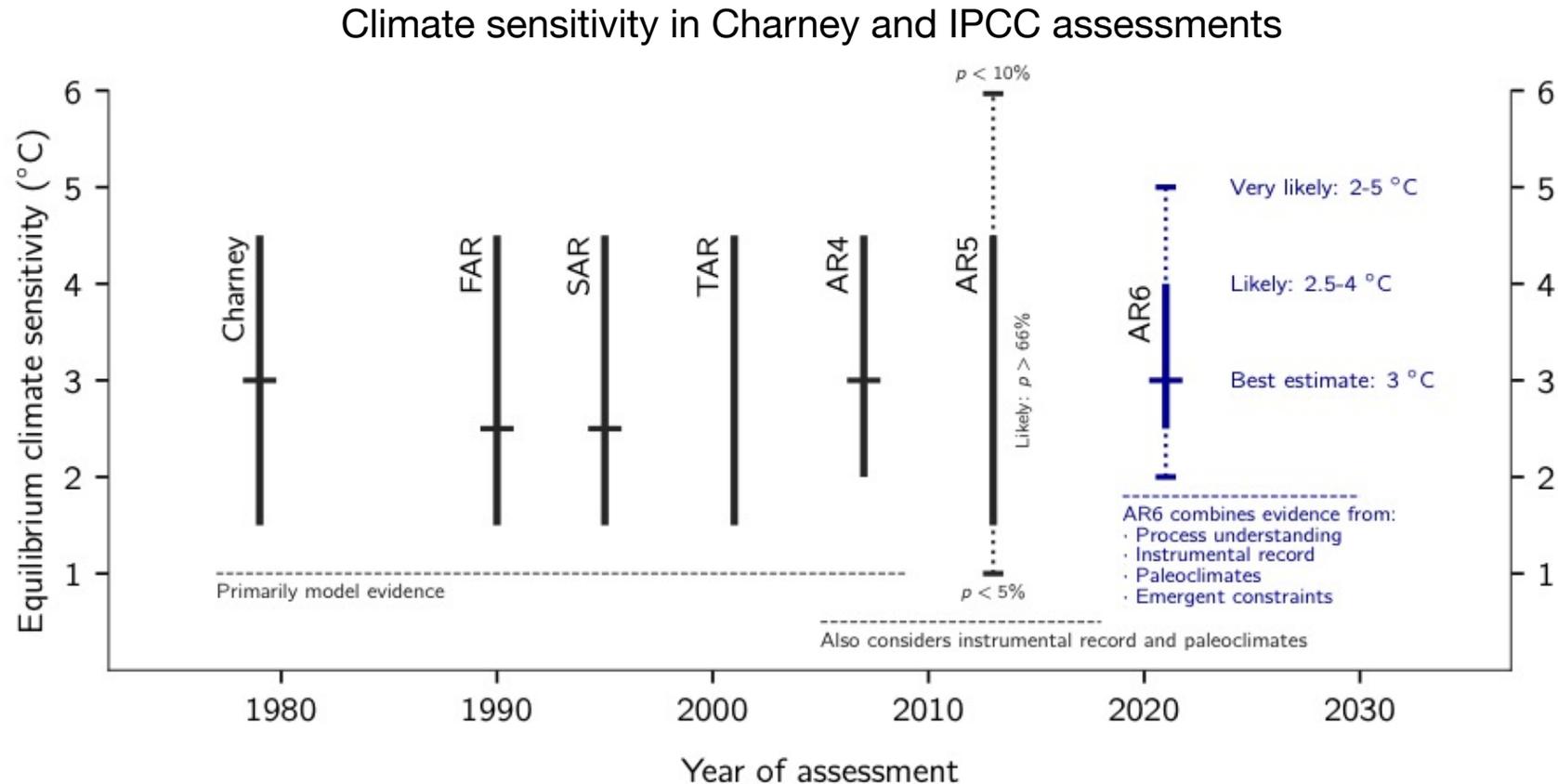
Climate sensitivity and carbon budgets

- Climate sensitivity also important for uncertainty in remaining **carbon budgets**
- Because higher sensitivity means more warming for a given amount of emissions (and vice versa)
- Hence, higher sensitivity = smaller carbon budget for a given warming limit



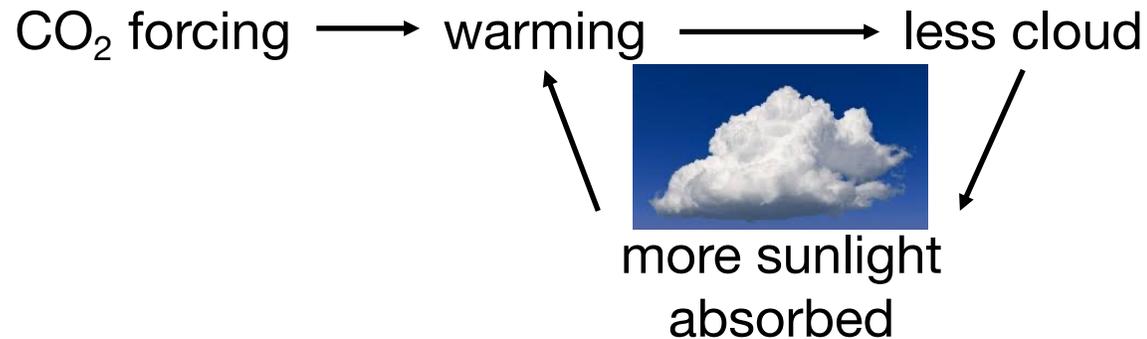
Uncertainty in climate sensitivity

- Current best estimate for climate sensitivity $\sim 3^\circ\text{C}$; “likely” $2.5\text{--}4^\circ\text{C}$ (IPCC AR6)
- Reducing the uncertainty in this number has proven remarkably difficult!



Cloud feedback

- Most of the uncertainty in climate sensitivity comes from **cloud feedback**
- Example: amplifying cloud amount feedback



- Apart from amount, cloud altitude also matters (greenhouse effect)
- Climate models strongly differ in their simulation of cloud feedback
- Predicting how clouds will change with warming is a key challenge of climate science

Recent research on cloud feedback

PNAS

Proceedings of the
National Academy of Sciences
of the United States of America

Observational evidence that cloud feedback amplifies global warming

Paulo Ceppi^{a,b,1,2}  and Peer Nowack^{a,b,c,d,1} 

[PNAS](#), July 2021

See also the Carbon Brief explainer:

[Clouds study finds that low climate sensitivity is ‘extremely unlikely’](#)

IPCC AR6 (2021): cloud feedback will amplify global warming (>90% likelihood)

Summary

- Future climate projections are uncertain for a number of reasons: scenario, model physics, internal variability
- Model physics reflects uncertainty in how much warming will occur for a given increase in CO₂ level (= the climate sensitivity)
- This uncertainty is mainly caused by clouds, and how they will feed back on global warming
 - Recent research advances suggest an amplifying feedback; still more work needed to reduce the uncertainty
- Important to remember: there is scientific consensus that CO₂ causes global warming!