

Climate Sensitivity:

How much warming results from increases in atmospheric carbon dioxide (CO₂)?

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The amount of warming which would accompany increases in atmospheric carbon dioxide (CO₂) – or ‘climate sensitivity’ – is at the heart of the scientific debate on anthropogenic climate change, and also the public debate on the appropriate policy response to increasing carbon dioxide in the atmosphere. Climate sensitivity and its range of possible values are a key input into the economic models that drive cost-benefit analyses and estimates of the social cost of carbon.

Climate sensitivity is often expressed as the temperature change in °C associated with a doubling of the concentration of CO₂ in atmosphere. Two types, appropriate for different situations, are:

1. Equilibrium climate sensitivity (ECS) is an estimate of the increase in global surface temperatures after the climate system has fully adjusted to a doubling of CO₂ concentrations — a process assumed to take centuries or longer due to slow heat uptake by the oceans.
2. Transient climate response (TCR) is the estimated increase in global surface temperatures at the time when CO₂ doubling is reached during an increase of 1% per year. At this rate, doubling the CO₂ levels takes 70 years.

Estimates of both types of climate sensitivity are generally presented as a range due to incomplete knowledge of the behaviour of some aspects of the climate system. ECS is larger than TCR because of the longer timescales for adjustment.

ECS is a key variable in climate model predictions of eventual global warming many centuries after greenhouse gas concentrations have stabilized. In the fifth assessment report (AR5) of the IPCC (Intergovernmental Panel on Climate Change) the different lines of evidence were combined to conclude that the ECS is *likely*¹ in the range from 1.5°C to 4.5°C. A ‘best estimate’ was not given in AR5 because of “a lack of agreement on values across assessed lines of evidence”. However, the IPCC AR5 had high confidence that ECS is *extremely likely*¹ larger than 1°C, but with less confidence on the upper limit. The range of estimates has been broadly consistent over the last three IPCC assessments, and confidence has increased because of the availability of more lines of evidence.

In many respects TCR is more policy relevant than ECS as it is a benchmark for the rate of change of temperature over the coming century. The recent IPCC AR5 report gave a *likely*¹ range of 1°C to 2.5°C with TCR *extremely unlikely*¹ to exceed 3°C.

Neither measure of climate sensitivity can be observed directly, but both can be estimated using climate models, or a combination of climate models and observations from recent or past climates. Studies based on observations from the instrumental period (1850-2014) combined with relatively simple models of the climate system generally arrive at moderate values for ECS and TCR. Estimates using more complex climate models generally result in higher estimates for ECS. The ranges of TCR estimated from past observed warming and from climate models agree better than for ECS, giving more confidence in projections of future temperature change over the 21st century than for longer term climate change.

Confidence in model estimates is limited by our ability to represent some key relevant climate processes. The usefulness of observations is limited because we do not know accurately all the factors that have influenced the observed climate, or to what extent their effect may differ from that of increasing carbon dioxide. In particular, it is difficult to quantify the proportion of climate change which is due to natural variability, independent of changes due to human activity.

Notes, further reading and references:

IPCC AR5 Working Group I, Summary for Policymakers: www.ipcc.ch/pdf/assessment-report/ar5/wg1/WGIAR5_SPM_brochure_en.pdf
IPCC AR4 Working Group I, Chapter 8: www.ipcc.ch/publications_and_data/ar4/wg1/en/ch8s8-6-2-3.html

¹ In the language of the IPCC, ‘likely’ refers to >66% probability, ‘extremely likely’ refers to >95% probability, ‘extremely unlikely’ refers to <5% probability.