# Using ensembles to investigate climate sensitivity and feedbacks

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Climate sensitivity represents the amount of warming that would be experienced for a standard increase (doubling) of atmospheric CO2. It is closely linked to the actual warming that is seen globally and over Australia, and therefore is central to the magnitude of projected climate change. Consequently, the climate science community has put large, repeated, and ongoing efforts into estimating climate sensitivity. For example, each subsequent Intergovernmental Panel on Climate Change (IPCC) Assessment report has made formal climate sensitivity estimates, which typically feature as 'headline' statements of the reports. However, over roughly four decades the evaluated 'likely' range of this parameter has not contracted. The recent IPCC AR5 (2013) concluded that this range is 1.5 to 4K, identical to the 'Charney Report' from 1979 (National Research Council, 1979). Why is this range so large, how is it estimated, and what role do ensembles play in its estimation?

The evaluation of climate sensitivity can be considered the *poster child* of the use of ensembles in climate change science, as it represents one of the most important single quantities in climate science, and because it is based on an *ensemble of ensembles*. In the AR5 (see Fig. 1) the final evaluation was based on a meta-ensemble of estimates from (i) the instrumental record, (ii) climatological constraints, (iii) raw model ranges and (iv) paleoclimate estimates. In turn most of these were ensemble based. For example, the climate model ranges came from the large CMIP3 and CMIP5 multi-GCM ensembles, along with perturbed physics ensembles based on several individual models. The amalgamation of these ensembles into a meta-ensemble, along with 'expert judgement', formed the basis of the final assessment.

This paper will discuss the different methodologies used in these ensembles and give some indication of their strengths and weaknesses. It will also discuss how the use of ensembles not only provides an estimated range but can cast light on critical aspects of sensitivity and the underlying climate radiative feedbacks that are responsible for the range. For example, ensembles show inter-relationships between different feedbacks, clarify the sources of confidence/uncertainty and suggest potential observational constraints. One such example that will be discussed is how ensembles can explore relationships between critical feedback processes operating under climate change, and similar processes operating under interannual and decadal variability (Colman and Power, 2018). These in turn hold out the hope for constraining climate sensitivity from past or future measurements of variability.

Finally, look to the future, and explain how ensembles in the upcoming CMIP6 are designed to help narrow uncertainties in feedbacks and climate sensitivity, and therefore the magnitude of expected future climate change.

 **References**

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**Figure 1**: Probability density functions, distributions and ranges for equilibrium climate sensitivity, plus climatological constraints shown in IPCC AR4, and results from CMIP5. The grey shaded range marks the likely 1.5°C to 4.5°C range, and the grey solid line the extremely unlikely less than 1°C, the grey dashed line the very unlikely greater than 6°C. Source: IPCC AR5 (2013) Box 12.2, Figure 1.