Probabilistic Future Global-mean Temperature Changes from a Simple Earth System Model

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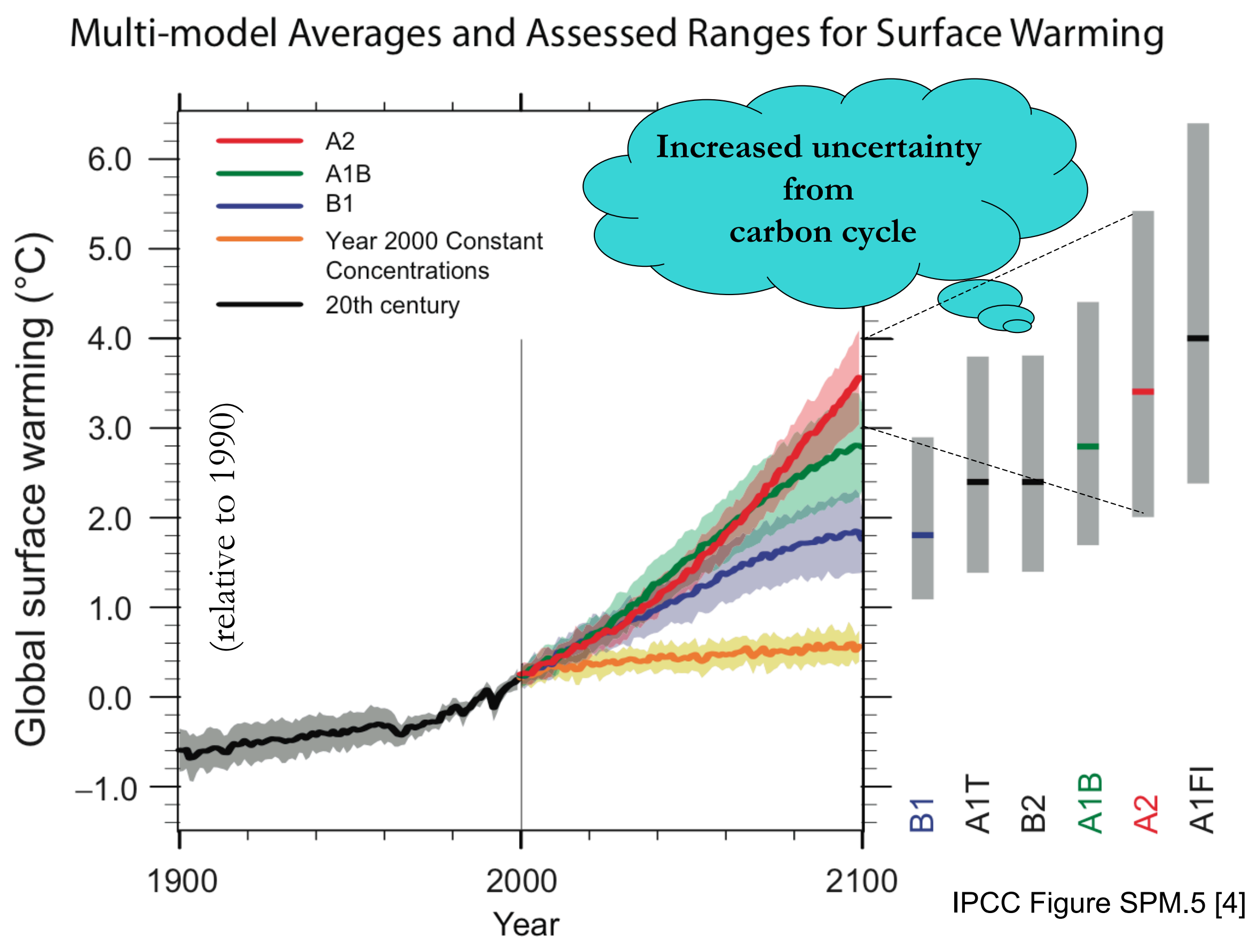
Investigating Uncertainty

❖ IPCC likely range 1.1 - 6.4°C [4]: why so wide a range?

❖ Investigated using a reduced complexity Earth System Model (ESM), MAGICC (Model for the Assessment of Greenhouse-gas Induced Climate Change) [1].

❖ Assessed relative contributions to uncertainties in projected temperature changes due to the climate system and carbon cycle.


Multi-model Averages and Assessed Ranges for Surface Warming

IPCC Figure SPM.5 [4]

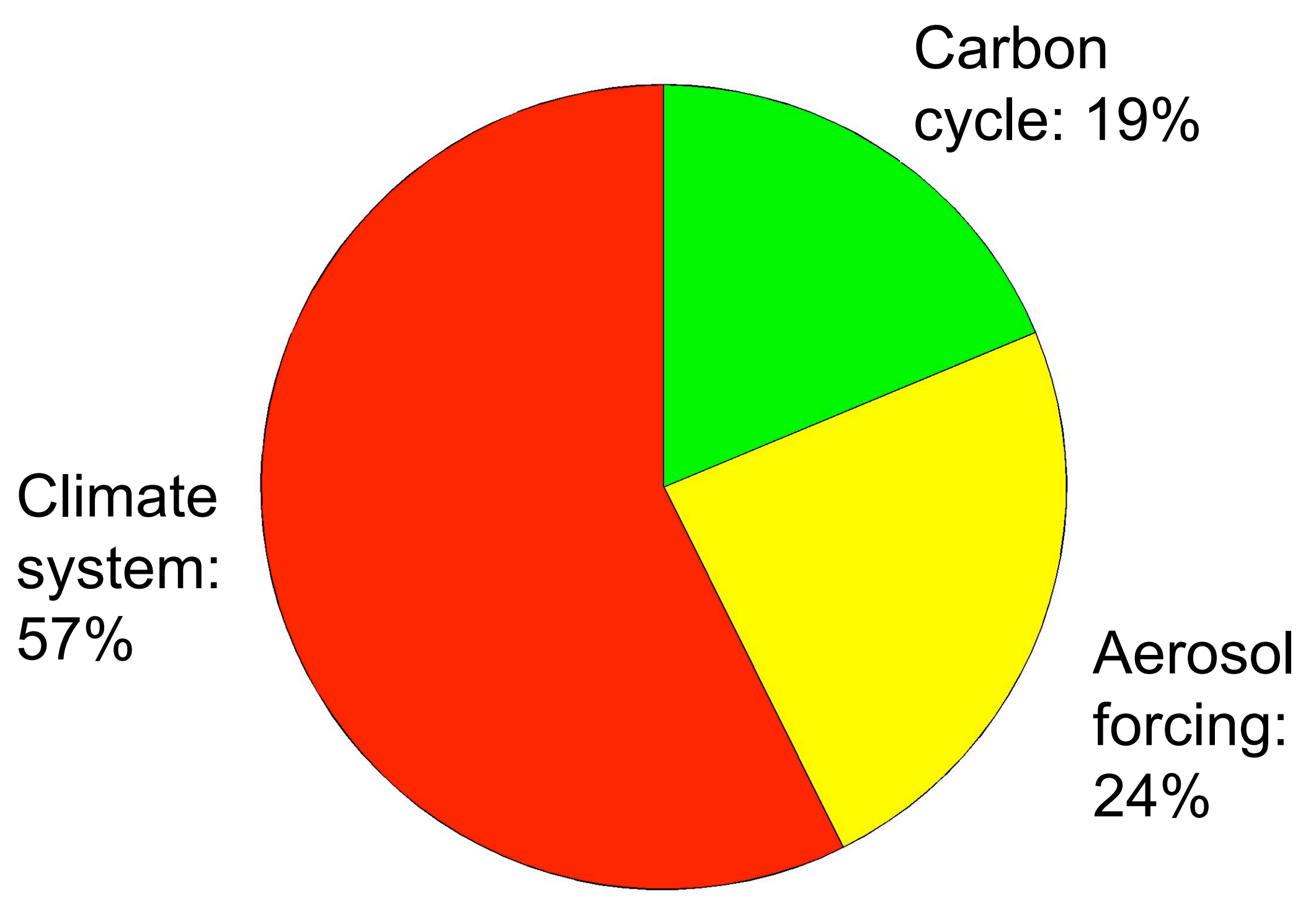
Uncertainty Analysis

❖ An uncertainty analysis technique ascertained which of the model parameters contribute most to the uncertainty in future global-mean temperatures.

❖ MAGICC was run using an initial set of parameter values to establish a reference temperature change result, then re-run in turn for 30 individual parameters, with each parameter value changed by 1% of its nominated standard deviation. The difference in the model results then provides a measure of the sensitivity of the model outputs to the input parameters [5].

❖ From this it was determined that 4 climate system, 1 combined aerosol forcing and 6 carbon cycle parameters accounted for 97% of the uncertainty in temperature change in 2100.

Contributions to uncertainty in temperature change in 2100



Observational data (decadal averages)

Climate System:

Global-mean surface temperature, Land-ocean temp. diff., and North-South hemispheric temp. diff., 1911-2010 (HadCRU);

Ocean temp. change profile, 1960-2008 (S. Wijffels);

Ocean heat content, 1950-2003 (C. Domingues).

Carbon cycle:

CO_2 concentration, 1959-2010 (Mauna Loa);

Ocean CO_2 flux and Land CO_2 flux, 1959-2010 (Global Carbon Project).

Monte Carlo Markov Chain (MCMC)

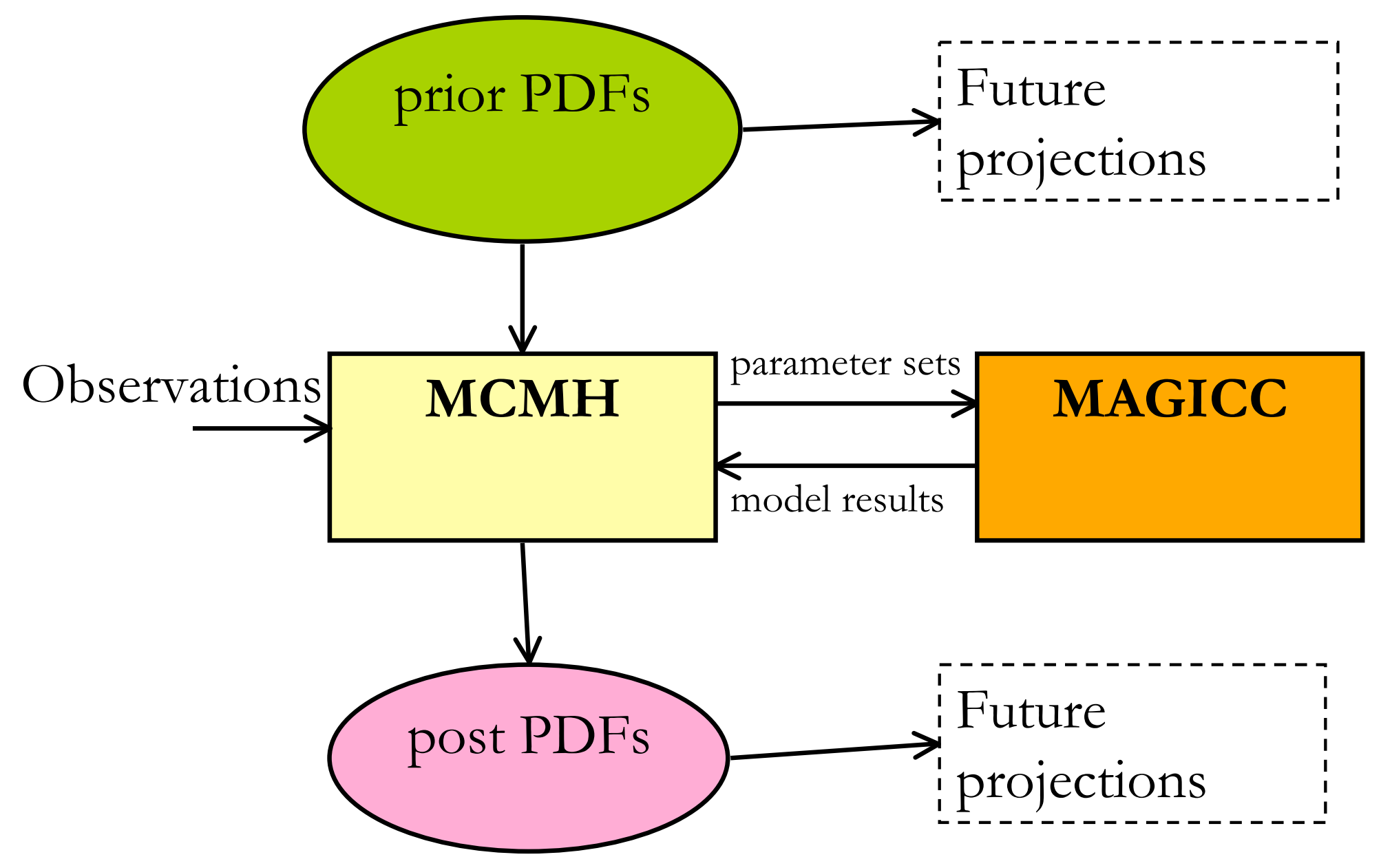
❖ Nominal or 'expert' prior probability density functions (pdfs) assigned to these 11 parameters.

❖ The MCMC with Metropolis-Hastings algorithm (MCMH) samples prior pdfs to generate random parameter sets, which the ESM uses to produce 20th-century model results [2, 3] .

❖ The MCMH compares these to historical observations, accepting the parameter sets based on the fit to observations.

❖ Outcome is a series of accepted parameter sets, the new posterior pdfs.

Monte Carlo Metropolis-Hastings algorithm



Posterior PDFs

❖ MCMH derived PDFs used 8 sets of historical data for the climate and carbon cycle. Examples of prior and posterior pdfs for 6 out of 11 parameters illustrated here.

❖ Climate sensitivity distribution tabled below.

❖ MAGICC's carbon cycle parameters constrained by observations for the first time.

The new pdfs can then be used for probabilistic temperature change projections.

Climate sensitivity, ΔT_{2x}

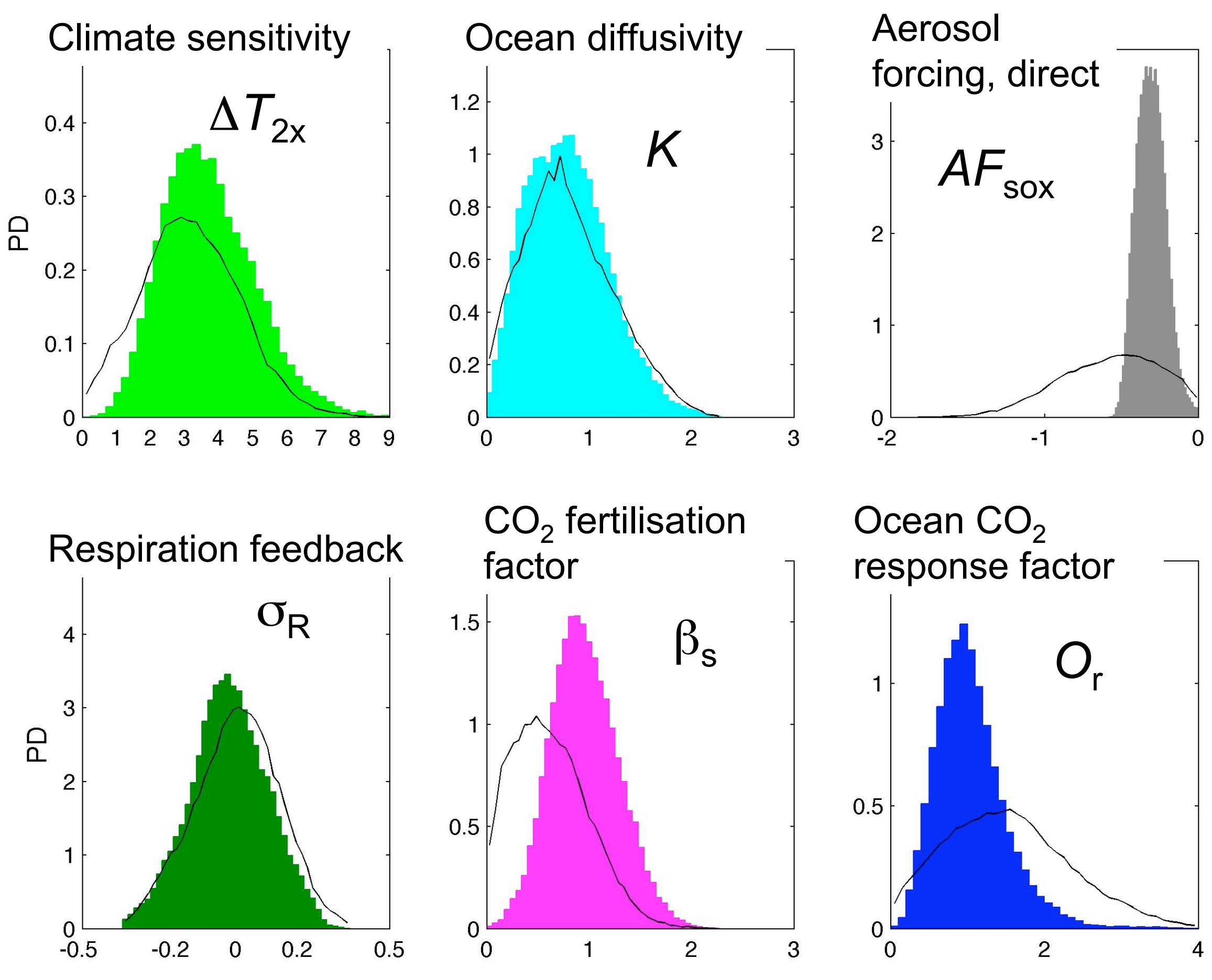
Prior mean	Post mean	Prior σ	Post σ
3.00	3.24	1.50	1.10

Posterior likely range 2.17 - 4.33, mode 2.9°C

Ocean diffusivity, *K*

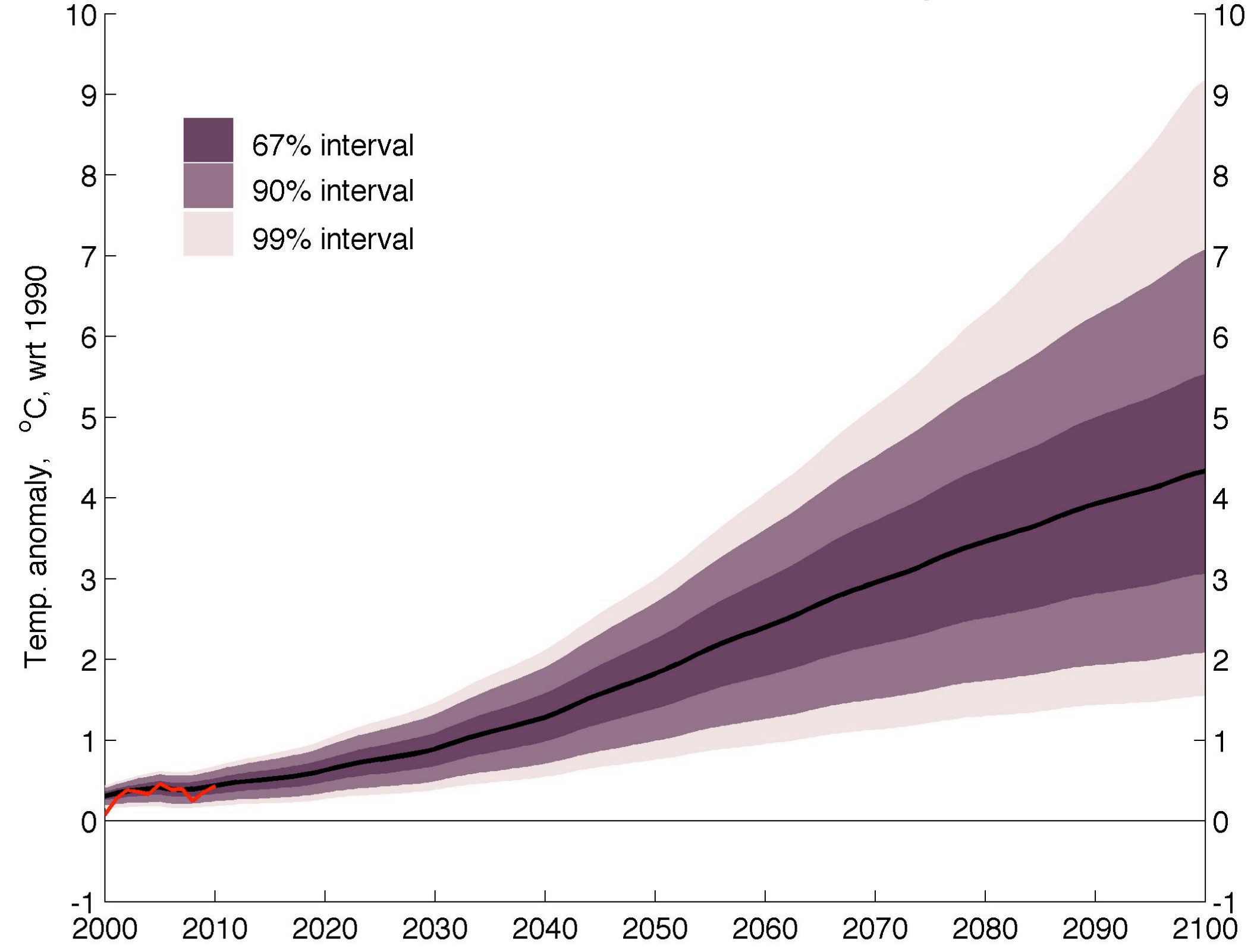
Prior mean	Post mean	Prior σ	Post σ
0.70	0.71	0.50	0.35

Posterior likely range, 0.35 - 1.06, mode 0.7 cm^2s^{-1}



Black outline, prior pdfs; Coloured region, posterior pdfs.

A1FI temperature change

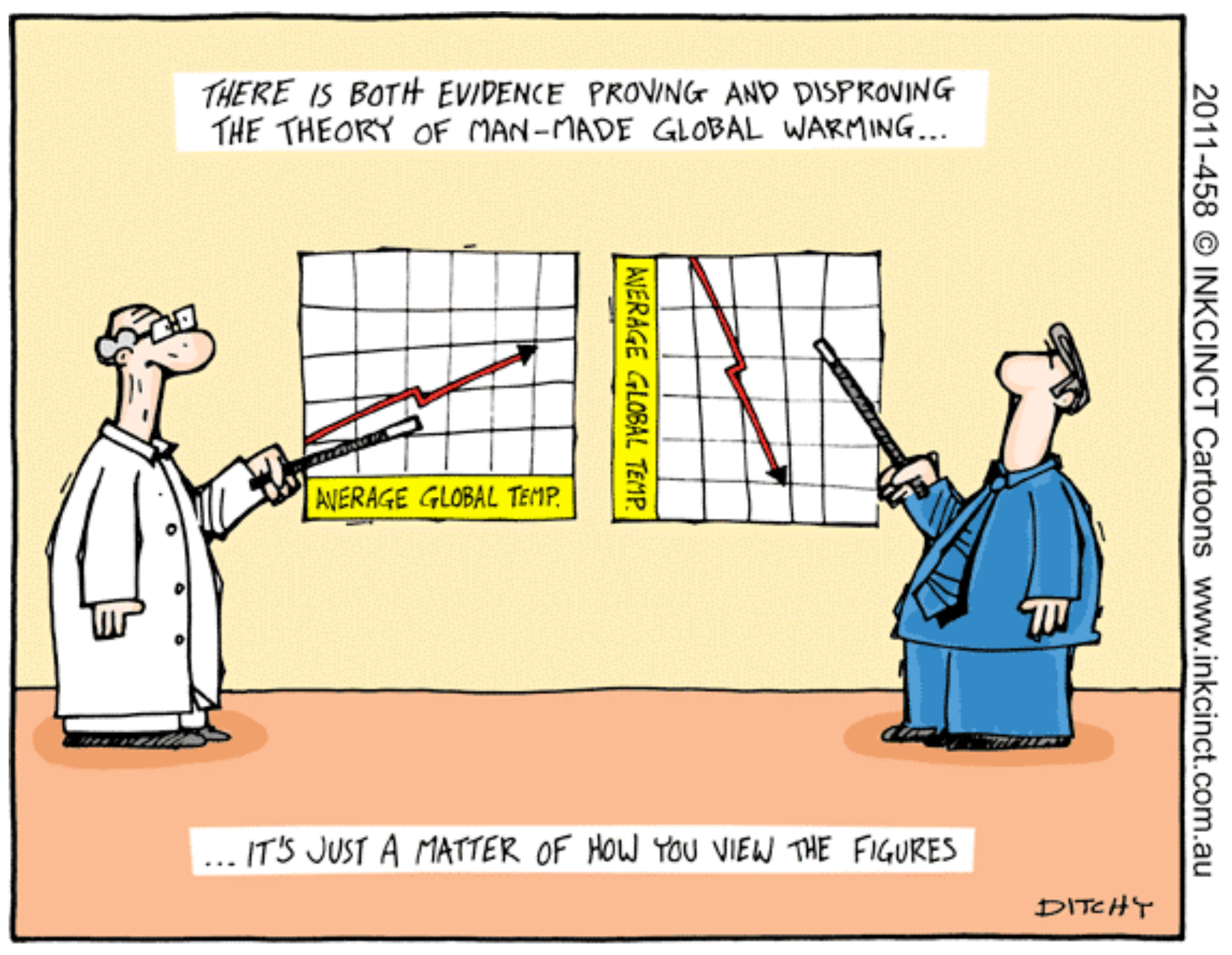


Projected temperature change distribution for the SRES A1FI emission scenario from 36,000 parameter sets using the posterior parameter distribution pdfs, constrained by observations. Solid red line HadCRU observations; solid black line, model mean; dark purple 67%, medium purple 90% and light purple 99% of the distribution.

SRES projections compared:

Temperature change in 2100, °C (wrt 1990)

Name	A1FI	A2	B1
MAGICC			
mean	4.5	3.1	1.8
mode	4.1	3.0	1.7
likely	3.1 - 5.8	2.2 - 4.0	1.1 - 2.5
IPCC			
best	4.0	3.4	1.8
likely	2.4 - 6.4	2.0 - 5.4	1.1 - 2.9



Summary

❖ Key model parameters identified and contributions to uncertainty assessed - roughly 30% to 50% of future uncertainty is from emission choice, the rest from climate system response.

❖ MAGICC model parameters estimated using MCMH approach to derive posterior pdfs using historical observations, including, for the first time, the carbon cycle.

❖ Uncertainty reduced for the key parameters, with a reduced likely range for climate sensitivity of 2.2 to 4.3, with a best estimate (mode) of 2.9°C.

❖ The SRES emission scenarios used to illustrate probabilistic projected temperature change. The results shows a reduced *likely* range as compared to the IPCC Fourth Assessment Report, but with an increased lower bound.

References

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[2] K. Mosegaard and M. Sambridge (2002). Monte Carlo analysis of inverse problems. *Inverse Problems* **18** R29-R54.

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