# How much $CO_2$ at 1.5°C and 2°C? – Supplementary Information

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The Transient Climate Response (TCR) was originally defined as the warming at the time (approx. 70 years) of $CO_2$ doubling in a $1\%^{-y}$ increasing $CO_2$ climate model experiment. More recently, (Frame *et al.* 2006, Gregory & Forster, 2008, Held *et al.* 2010, Otto *et al.* 2013, Richardson *et al.* (2016).I) it is defined as the temperature response of the Earth system ($\Delta T$) to any gradual increase in forcing ($\Delta F$), normalised by the ratio of the forcing change to the forcing due to the doubling of $CO_2$ ($\Delta F_{2\times CO_2}$).

$$TCR = \frac{\Delta T}{\Delta F}\Delta F_{2\times CO_2} \quad \text{(Eq. 1)}$$

Rearranging

$$\Delta F = \frac{\Delta T}{TCR}\Delta F_{2\times CO_2}$$

And we assume a log-linear form for the forcing due to $CO_2$

$$\Delta F = 5.35\times ln(\frac{C}{C_0}) \quad \text{(Eq.2)}$$

We substitute $\Delta F$ and rearrange to obtain $C$, the carbon dioxide concentration at a particular temperature change and TCR.

$$C = C_0\times exp\left(\frac{\Delta T\Delta F_{2\times CO_2}}{5.35\times TCR}\right) \quad \text{(Eq. 3)}$$

Estimates for the various parameters are as follows:

$\Delta F_{2\times CO_2}$ is estimated as 3.44 W/m2 by Forster *et al.* (2013), with a 5-95% confidence interval of +- 10%. We use the central value only. This is the value used by Richardson *et al.* (2016). A higher value of 3.7 $Wm^{-2}$ Vial *et al.* (2013).

$C_0$ is as pre-industrial carbon dioxide concentration of 280 ppm.

$\Delta T$ is a temperature change corresponding to a specific global warming level (GWL) of either 1.5 or 2 degrees above pre-industrial.

We use equation 3 to create a transfer function, that maps a particular value of TCR and temperature change to a carbon dioxide concentration (figure 1).

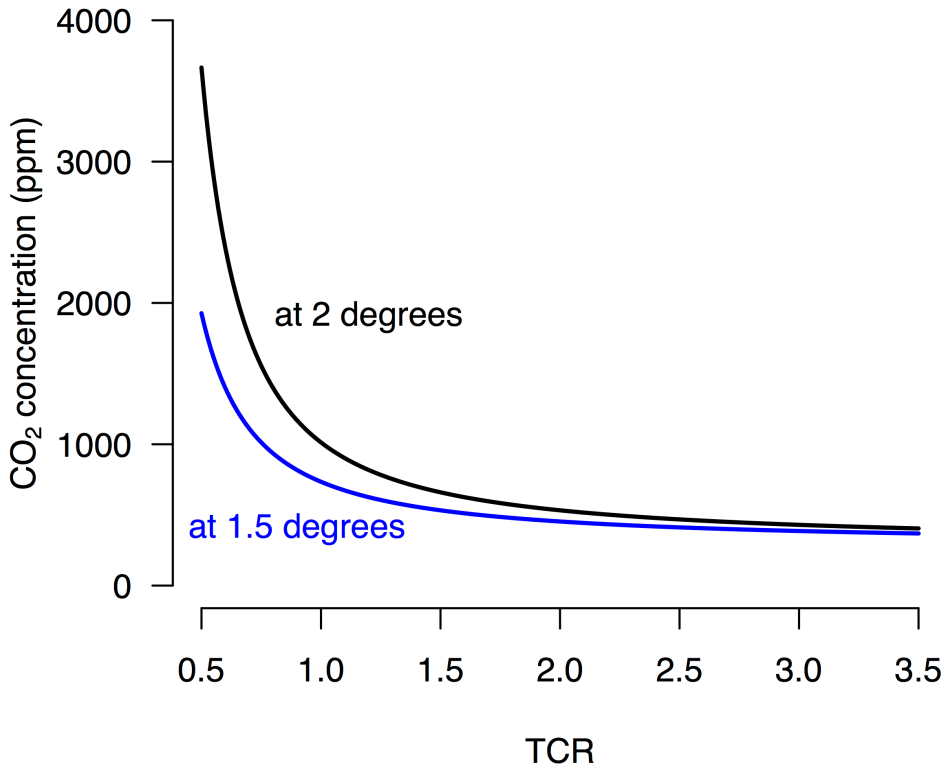


**Figure 1.**

We use a Monte Carlo technique to take $10^6$ samples from a probability distribution of TCR and calculate the corresponding value of $CO_2$ concentration using the transfer function. This results in a distribution of $CO_2$ concentration for the given temperature change of 1.5 or 2K (figure 2, and figure 1 of the main paper).

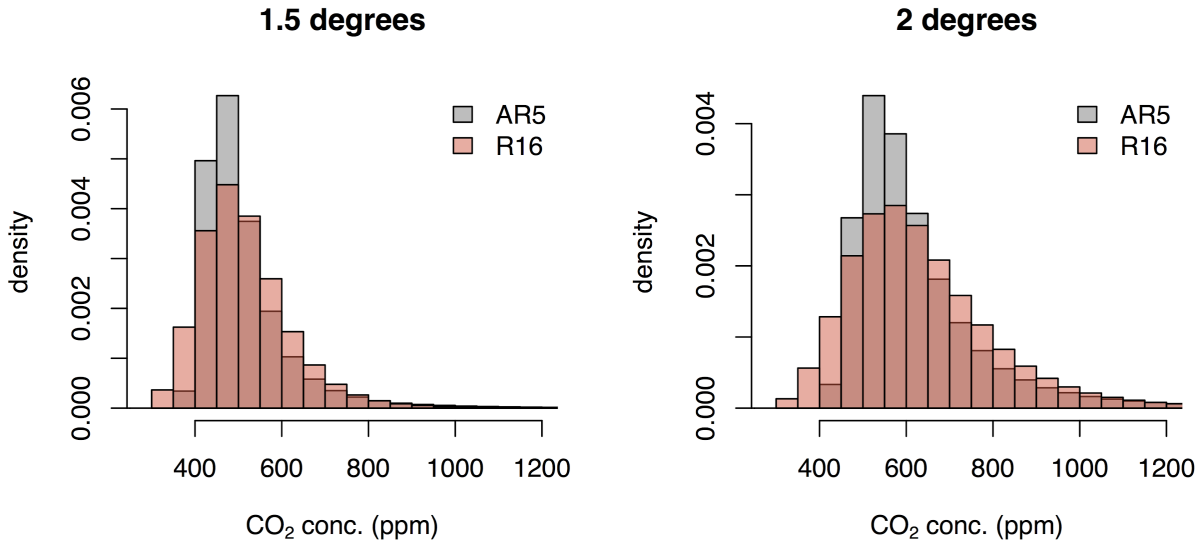


**Figure 2**

We initially use two distributions of TCR: 1) A Gaussian distribution, fitted to have very similar 5th and 95th percentiles as the IPCC AR5 estimate (1.0 and 2.5 k) [i.e. TCR ~N(1.75, $0.45^2$)]. 2) The calculated distribution from Richardson *et al.* (2016), with 5th and 95th percentiles of 1 and 3.3K, and a median of 1.66K (figure 3).

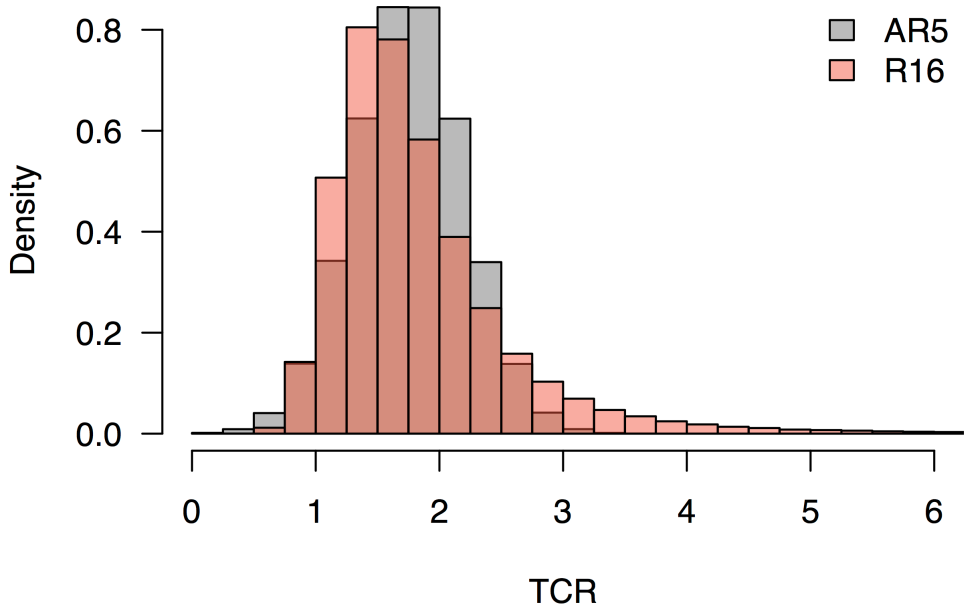


**Figure 3.**

5th, 50th and 95th percentiles for the distributions are as follows:

"AR5 2 degrees"

| 5% | 50% | 95% |
|---|---|---|
| 469.3967 | 584.0162 | 1001.7613 |

"AR5 1.5 degrees"

| 5% | 50% | 95% |
|---|---|---|
| 412.5196 | 485.9686 | 728.3879 |

"R16 2 degrees"

| 5% | 50% | 95% |
|---|---|---|
| 415.6429 | 606.1163 | 969.7779 |

"R16 1.5 degrees"

| 5% | 50% | 95% |
|---|---|---|
| 376.5562 | 499.6967 | 710.8758 |