

Grantham Briefing Note 2 – September 2013

Climate sensitivity

DR FLORA MACTAVISH AND DR SIMON BUCKLE

Overview

- Climate sensitivity is the increase in surface temperature associated with a doubling of CO₂. The Transient Climate Response is the temperature change at the time of the doubling in CO₂ after a one percent increase per year (i.e. after about 70 years). The Equilibrium Climate Sensitivity is the longer term response over centuries.
- The Equilibrium Climate Sensitivity is likely to be in the range 1.5 - 4.5°C with high confidence, extremely unlikely to be less than 1°C and very unlikely to be greater than 6°C. The Transient Climate Response is likely to be 1.0 - 2.5°C and is extremely unlikely to be greater than 3°C.
- Limiting global warming to less than 2°C relative to pre-industrial temperatures is a widely-discussed policy goal. Considering just carbon dioxide emissions, this would require cumulative emissions over the entire industrial period to be less than about one trillion tonnes of carbon (3.67x10¹² tonnes of carbon dioxide) for a 66 percent chance of limiting the global mean temperature increase to less than 2°C relative to the period 1861-1880.
- About half of the emissions consistent with this had already been emitted by 2011, leaving only about 40 years of carbon dioxide emissions at current rates, excluding the significant additional warming effects of other greenhouse gases and aerosols. Other probabilities and temperature targets could be translated into cumulative emissions budgets in the same way.

What is climate sensitivity?

Climate sensitivity is a measure of how responsive the climate system is to a change in the net energy imbalance between incoming solar radiation and outgoing long-wave radiation at the top of the atmosphere. Climate sensitivity is usually expressed as the increase in global mean surface temperature associated with the change in radiative forcing due to a doubling of atmospheric carbon dioxide levels.

In principle, climate sensitivity captures the effects of all feedbacks within the climate system such as increased water vapour, melting of snow and ice, and clouds. So it is a summary measure of how significant a change we are making to the Earth's climate through emitting carbon dioxide, though it cannot capture the full range of changes that would happen in the climate system, such as changes in precipitation, regional climate, and weather extremes.

The climate sensitivity is not specified in advance in the most complex climate models, such as those used in AR5. Rather it is something that is estimated from the model simulations and depends on the how the different components of the climate system are modelled and interact. In some simpler models, climate sensitivity may be specified.

The IPCC uses two main measures of the climate sensitivity of the AR5 models:

- The **equilibrium climate sensitivity (ECS)** is defined as the change in global annual mean surface air temperature due to a doubling of atmospheric carbon dioxide and measured after an extended period of time (typically several centuries) when climate feedbacks have had their effect and the climate system has returned to equilibrium. In practice, very long timescale feedbacks (e.g. ice-sheets and permafrost melting) are not generally included in estimates. The ECS is not useful for indicating near term changes in mean temperature. Moreover, Equilibrium Climate Sensitivity may depend on the state of the climate system, meaning that its value now could be different from the value in the distant past or in a future warmer world.
- The **transient climate response (TCR)** is the change in global annual mean surface air temperature at the time when carbon dioxide levels double following a 1 percent increase each year. This doubling period is about 70 years but it takes a long time for the Earth to reach full equilibrium due largely to the thermal inertia (and vertical temperature gradients) of the oceans. The temperature response on this shorter timescale, and therefore the TCR, will therefore be smaller than the full equilibrium response and ECS. When compared to the ECS, the TCR reflects the degree of thermal inertia within the system. Estimating TCR is subject to fewer difficulties than ECS due to time-dependent feedbacks.

In addition to the two parameters above, AR5 also uses the near linear relationship between cumulative carbon dioxide emissions over time and global mean temperature change to define the **Transient Climate Response to Cumulative Carbon Emissions (TCRE)**. TCRE provides a measure of transient global mean surface temperature change for a fixed level of cumulative human carbon dioxide emissions, usually 1000 PgC or one trillion (10^{12}) metric tons of carbon (equivalent to 3.67×10^{12} tons of carbon dioxide). This can be used to formulate a carbon budget corresponding to different climate policy targets, e.g. to limit warming to a chosen threshold such as 2°C.

The recent slowdown in the warming of global annual mean surface air temperatures has led to suggestions that climate sensitivity is lower than previously thought, with potential implications for the pace and scale of responses to climate change.

What does the IPCC Fifth Assessment Report (AR5) say about climate sensitivity?

AR5 reports that, based on multiple lines of observational and model evidence:

- **The ECS is likely to be in the range 1.5 - 4.5°C with high confidence**, extremely unlikely to be less than 1°C and very unlikely to be greater than 6°C. The lower end of the “likely” range is lower than at the time of the last Assessment Report, AR4, which estimated ECS as between 2.0 - 4.5°C. At the time of the IPCC Fourth Assessment Report (AR4), values above 6°C could not be ruled out.

- The TCR is a more informative indicator of future climate change in coming the decades than the ECS. **The likely range of the TCR is 1.0 - 2.5°C** and is extremely unlikely to be greater than 3°C.
- **Grantham Institute Comment:** *As with the ECS, this is an expert-assessed range supported by several different and partly independent lines of evidence each based on multiple studies, models and datasets. Unlike for the ECS, the ranges for TCR estimated from the observed warming and from the AR5 models agree well. The observed temperature record lies within the range of model projections, but at the lower end of the uncertainty range due to the combined effects of scenario and natural variability. There is also an uncertainty associated with the observations themselves.*
- **The TCRC is likely to be between 0.8 - 2.5°C for every trillion tonnes of carbon (1000PgC) emitted, for emissions less than about 2000PgC until the time at which temperature peaks.** Limiting the warming caused by human emissions of carbon dioxide alone with a probability of more than 33 percent, more than 50 percent and more than 66 percent to less than 2°C since the period 1861-1880, will require cumulative CO₂ emissions from all human sources to stay below about 1560 PgC, about 1210 PgC and about 1000 PgC respectively. About 531 [446 to 616] PgC had been emitted by 2011.
- **Grantham Institute comment:** *This considers just human carbon dioxide emissions and does not include any of the (significant) radiative forcing effects of other greenhouse gases and aerosols. If we considered the 66 percent figure to be a target, since about half of this cumulative amount of CO₂ has already been emitted, we would only have about 40 years of emissions at current rates. The same concept could be applied to any desired temperature target, with different levels of probability or a higher or lower carbon budget for higher or lower levels of desired maximum global mean surface temperature change.*

References

Intergovernmental Panel on Climate Change, Assessment Report 5, Summary for Policy Makers (2013)

Neelin, J David (2011). Climate Change and Climate Modelling, Cambridge University Press (2011)

Knutti, R. and Hegerl, G.C. (2008). The equilibrium sensitivity of the Earth's temperature to radiation changes, Nature Geosciences, pp 735-743.