Climate Sensitivity Expectations
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http://ccdatacenter.org/documents/ClimateSensitivityExpectations.pdf

- Climate sensitivity which includes "long term" feedbacks (Earth System Sensitivity - ESS) is likely between 4–6° C [1]
- The rate of change in energy forcing is now so great that "long-term" feedbacks have already begun to operate within short time frames[2]
- Recently it has been demonstrated that the models that best capture current conditions have a mean value of 3.7°C compared to 3.1°C by the raw model projections[3]
- The authors conclude that in warmer periods climate sensitivity averages around 4.88°C[2]
- It is important to use high-end climate sensitivity because some studies have suggested that climate models have underestimated three major positive climate feedbacks[2,4,5]

1	(Footnote #63 in **What Lies Beneath** (download PDF from https://www.breakthroughonline.org.au/) The Geological Society 2013, An addendum to the Statement on Climate Change: Evidence from the geological record, The Geological Society, London, December 2013; Hansen, J, Sato, M, Russell, G & Kharecha, P 2013, 'Climate sensitivity, sea level and atmospheric carbon dioxide', Philosophical Transactions of the Royal Society A, vol. 371, no. 2001, 20120294.
2	**What Lies Beneath** (download PDF from https://www.breakthroughonline.org.au/) Climate Sensitivity (Pages 22-23) The question of climate sensitivity is a vexed one. Climate sensitivity is the amount by which the global average temperature will rise due to a doubling of the atmospheric greenhouse gas level, at equilibrium. (Equilibrium refers to the state of a system when all the perturbations have been resolved and the system is in balance.) IPCC reports have focused on what is generally called Equilibrium Climate Sensitivity (ECS). The 2007 IPCC report gives a best estimate of climate sensitivity of 3°C and says it "is likely to be in the range 2°C to 4.5°C". The 2014 report says that "no best estimate for equilibrium climate sensitivity can now be given because of a lack of agreement on values across assessed lines of evidence and studies" and only gives a range of 1.5°C to 4.5°C. This was a backward step.62 What the IPCC reports fail to make clear is that the ECS measure omits key "long-term" feedbacks that a rise in the planet's temperature can trigger. These include the permafrost feedback and other changes in the terrestrial carbon cycle, a decrease in the ocean's carbon-sink efficiency, and the melting of polar ice sheets creating a cold ocean-surface layer underneath that accelerates the melting of ice shelves and hastens the rate of ice-mass loss. Climate sensitivity which includes these feedbacks — known as Earth System Sensitivity (ESS) — does not appear to be acknowledged in the 2014 IPCC reports at all. Yet, there is a wide range of literature which suggest an ESS of 4–6°C.63 It is conventionally considered that these "longterm" feedbacks — such as changes in the polar carbon stores and the polar ice sheets — operate on millennial timescales. Yet the rate at which human activity is changing the Earth's energy balance is without precedent in the last 66 million

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<tr><td></td><td>years, and about ten times faster than during the Paleocene–Eocene Thermal Maximum 55 million years ago, a period with one of the largest extinction events on record.

The rate of change in energy forcing is now so great that these “long-term” feedbacks have already begun to operate within short time frames. The IPCC is not forthcoming on this issue. Instead it sidesteps with statements (from 2007) such as this: “Models used to date do not include uncertainties in climate–carbon cycle feedback... because a basis in published literature is lacking... Climate–carbon cycle coupling is expected to add CO2 to the atmosphere as the climate system warms, but the magnitude of this feedback is uncertain.” This is the type of indefinite language that politicians and the media are likely to gloss over, in favour of a headline number.

It should be noted that carbon budgets — the amount of carbon that could be emitted before a temperature target is exceeded — are generally based on a climate sensitivity mid-range value around 3°C. Yet this figure may be too low. Fasullo and Trenberth found that the climate models that most accurately capture observed relative humidity in the tropics and subtropics and associated clouds were among those with a higher sensitivity of around 4°C.64 Sherwood et al. also found a sensitivity figure of greater than 3°C.65 Zhai et al. found that climate models that are consistent with the observed seasonal variation of low-altitude marine clouds have an average sensitivity of 3.9°C. 66 Recently it has been demonstrated the models that best capture current conditions have a mean value of 3.7°C compared to 3.1°C by the raw model projections.67

The work on existential climate risks by Xu and Ramanathan, cited above, is also important in assessing what is an appropriate climate sensitivity for risk-management purposes, for three reasons.
They say that:
1. Taking into account the biogeochemical feedbacks (such as less efficient land/ocean sinks, including permafrost loss) effectively increases carbon emissions to 2100 by about 20% and can enhance warming by up to 0.5°C, compared to a baseline scenario.
2. Warming has been projected to increase methane emissions from wetlands by 0–100% compared with present-day wetland methane emissions. A 50% increase in wetland methane emissions by 2100 in response to high-end warming of 4.1–5°C could add at least another 0.5°C.
3. It is important to use high-end climate sensitivity because some studies have suggested that climate models have underestimated three major positive climate feedbacks: positive ice albedo feedback from the retreat of Arctic sea ice; positive cloud albedo feedback from retreating storm track clouds in mid-latitudes; and positive albedo feedback by the mixed-phase (water and ice) clouds. When these are taken into account, the ECS is more than 40% higher than the IPCC mid-figure, at 4.5-4.7°C, before adding up to another 1°C of warming as described in 1. and 2. above.68

In research published in 2016, Friedrich et al. show that climate models may be underestimating climate sensitivity because it is not uniform across different circumstances, but in fact higher in warmer, interglacial periods (such as the present) and lower in colder, glacial periods.69 Based on a study of glacial cycles and temperatures over the last 800,000 years, the authors conclude that in warmer periods climate sensitivity averages around 4.88°C. The higher figure would mean warming for 450 parts per million (ppm) of atmospheric CO2 (a figure on current trends we will reach within 25 years) would be around 3°C, rather than the 2°C bandied around in policy making circles. Professor Michael Mann, of Penn State University, says the paper appears “sound and the conclusions quite defensible”</td></tr>
<tr><td>3</td><td>(Footnote #68 in What Lies Beneath (download PDF from https://www.breakthroughonline.org.au/)
Xu, Y & Ramanathan, V 2017, ‘Well below 2 °C: Mitigation strategies for avoiding dangerous to catastrophic climate changes’, Proceedings of the National Academy of Sciences, vol. 114, pp. 10315-10323.</td></tr>
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4	**What we learned about the climate system in 2017 that should send shivers down the spines of policy makers** http://www.climatecodered.org/2018/01/what-we-learned-about-climate-system-in.html 1/15/2018 They also find that the observationally-informed ECS prediction has a mean value of 3.7°C (for a doubling of the atmospheric greenhouse gas level), compared to 3.1°C used in raw models, and in the carbon budget analyses widely used by the IPCC, the UN and at climate policy conferences. In **"Well below 2C: Mitigation strategies for avoiding dangerous to catastrophic climate changes"**, published in September 2017, Xu and Ramanathan look at what are called the "fat tail" risks. These are the low-probability, high-impact (LPHI) consequences ("fat tails") of future emission scenarios; that is, events with a 5% probability at the top end of the range of possible outcomes. These "top end" risks are more likely to occur than we think, so "it is important to use high-end climate sensitivity because some studies have suggested that 3D climate models have underestimated three major positive climate feedbacks: positive ice albedo feedback from the retreat of Arctic sea ice, positive cloud albedo feedback from retreating storm track clouds in mid-latitudes, and positive albedo feedback by the mixed-phase (water and ice) clouds." When these are taken into account, the researchers find that the ECS is more than 40% higher than the IPCC mid-figure, at 4.5-4.7°C. And this is without taking into account carbon cycle feedbacks (such as melting permafrost and the declining efficiency of forests carbon sinks), and increase methane emissions from wetlands, which together could add another 1°C to warming be 2100. This work compliments other recent work which also suggests a higher climate sensitivity: ▪ **Fasullo and Trenberth** found that the climate models that most accurately capture observed relative humidity in the tropics and subtropics and associated clouds were among those with a higher sensitivity of around 4°C. ▪ **Zhai et al.** found that seven models that are consistent with the observed seasonal variation of low-altitude marine clouds yield an ensemble-mean sensitivity of 3.9°C. ▪ **Friedrich et al.** show that climate models may be underestimating climate sensitivity because it is not uniform across different circumstances, but in fact higher in warmer, inter-glacial periods (such as the present) and lower in colder, glacial periods. Based on a study of glacial cycles and temperatures over the last 800,000 years, the authors conclude that in warmer periods climate sensitivity averages around 4.88°C. Professor Michael Mann, of Penn State University, **says** the paper appears "sound and the

	conclusions quite defensible". ▪ **Lauer et al.** found that climate models that most accurately simulate recent cloud cover changes in the east Pacific point to an amplifying effect on global warming and thus a more sensitive climate. And the bottom line? If this work is correct, then the pledges made under the Paris Accord would not produce warming of around 3°C as is widely discussed, but a figure closer to and even above 4°C. And the total carbon budget would a quarter smaller than is generally accepted, or even less.
5	"Young People's Burden: Requirement of Negative CO2 Emissions" Page 10 An important matter to bear in mind is that the sensitivity 3°C for 2×CO2 (0.75°C per W/m2) is the "fast-feedback" climate sensitivity, i.e., it does not include "slow" climate feedbacks that will occur if global temperature long remains above the Holocene level (Hansen et al 2008; Rohling et al 2012a). Slow feedbacks include large-scale shrinking of ice sheets as Earth warms and the enhanced release of GHGs as the ocean, soil, and continental shelves warm. These slow feedbacks are strongly amplifying, indeed, they are the reason that natural long-term climate oscillations are so large in response to even small long-term global-average forcings (Rohling et al 2012b; Masson-Delmotte et al 2013). The fast-feedback climate sensitivity is the appropriate sensitivity to use in interpretation of recent climate change, because we use observed change of GHGs and because ice sheet change so far is small. However, the need to avoid the emergence of slow feedbacks motivates the criterion that energy balance should be restored at a global temperature close to and eventually within the Holocene range (Hansen et al. 2008, 2013). Earth's present energy imbalance is causing heat to accumulate in the ocean, where it contributes to melting of ice shelves (Rignot et al 2013). Rising temperatures also increase the risk of CO2 and CH4 release from drying soils, thawing permafrost (Schadel et al 2016; Schuur et al 2015) and warming continental shelves (Kvenvolden 1993, Judd et al 2002). Time scales for the slow feedbacks are not well established, but recent modeling and empirical evidence suggest that substantial ice sheet and sea level changes could occur within periods as short as several decades (Rohling et al 2013; Pollard et al 2015; Hansen et al 2016). If large planetary energy imbalance continues, there is a danger that the warming driving slow feedbacks will be so far advanced that consequences such as large sea level rise proceed out of humanity's control. Quantification of requirements for stabilizing climate depends on knowledge of ongoing changes of the two largest GHG forcings, CO2 and CH4. It is also necessary to understand how we are changing GHG emissions directly through industrial and agricultural activities (designated 'anthropogenic emissions' and included in the SRES and RCP scenarios) and indirectly through climate change (the slow feedbacks noted above, designated somewhat paradoxically 'natural emissions' changes, and not included in the SRES and RCP scenarios).