100 Months

Technical note

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Summary

We calculate that 100 months from 1 August 2008, atmospheric concentrations of greenhouse gases will begin to exceed a point whereby it is no longer *likely* we will be able to avert potentially irreversible climate change. 'Likely' in this context refers to the definition of risk used by the Intergovernmental Panel on Climate Change (IPCC) to mean that, at that particular level of greenhouse gas concentration, there is only a 66 - 90 per cent chance of global average surface temperatures stabilising at 2º Celsius above pre-industrial levels.[1] Once this concentration is exceeded, it becomes more and more likely that we will overshoot a 2º C level of warming. This is the maximum acceptable level of temperature rise agreed by the European Union and others as necessary to retain reasonable confidence of preventing uncontrollable and ultimately catastrophic warming. We also believe this calculation to be conservative. The reasons why and the assumptions behind our conclusion are detailed below.

Context: human-driven climate change

Present concentrations of carbon dioxide, the most prevalent greenhouse gas, are the highest they have been for the past 650,000 years. In the space of 250 years, the fossil fuel backed Industrial Revolution, and accompanying land-use changes, such as urbanisation and deforestation means we have released, cumulatively more than 1,800 billion tonnes of CO_2 into the atmosphere.[2] Currently, approximately 1,000 tonnes of carbon dioxide (CO_2) are released into the Earths' atmosphere every second due to human (or 'anthropogenic') activity.[3]

Greenhouse gases trap incoming solar radiation. If there are more of these gases in the atmosphere, more heat is trapped causing the planet to warm. Once a certain atmospheric concentration of greenhouse gases is passed (often termed a 'tipping point'), global warming could accelerate. A number of positive feedback loops amplify the warming effect by a physical process triggered by the initial warming itself or the increase in greenhouse gasses. One example is the melting of ice cover which reduces the reflective ability of the Earth's surface and, by revealing a darker land surface, increases heat absorption. Other processes, such as a decreasing ability of oceans to absorb CO_2 due to increasing wind strengths linked to climate change, have already been observed in the Southern and North Atlantic oceans.[4] This increases the amount of CO_2 in the atmosphere, causing further climate change.

Because of such self-reinforcing feedbacks, once a critical greenhouse concentration threshold is passed, even if human beings stop releasing additional greenhouse gases into the atmosphere, global warming is likely to continue. The Earth's climate may shift into a different state (i.e. different ocean circulation, wind and rainfall patterns) with potentially catastrophic implications for life on Earth. Such a change in the state of the climate system is often referred to as irreversible climate change.

100 months from August 2008

By using the best estimates of current greenhouse gas concentrations, emission growth rates, conservative estimates for the potentially damaging environmental feedbacks that accelerate global warming, and the maximum concentration of greenhouse gases that might prevent irreversible climate change, it is possible to estimate the length of time until this threshold is passed.

CO_2 is, of course, not the only gas that affects the climate. For this reason atmospheric concentration figures are often quoted to take account of other factors, including other greenhouse gasses. This is the figure given as the carbon dioxide equivalent or, CO_2e. Two different figures for CO_2e are commonly given depending on whether it is expressing just those gases covered by the Kyoto Protocol, which is not comprehensive, or all radiative forcings[5] that affect the amount of energy received by the climate system and hence its warming or cooling.

Carbon dioxide equivalent (CO_2e) is the amount of carbon dioxide that would be required to give the same global average radiative forcing as the sum of all other forcings. Most commonly, the six greenhouse gasses covered by the Kyoto Protocol have been used to calculate CO_2e.[6] However, if all anthropogenic driven radiative forcings are grouped together *viz*. not just those covered by the Kyoto Protocol, a more accurate estimate of the radiative forcings can be calculated.[7] We have used the most up to date estimate from the latest Intergovernmental Panel on Climate Change report from Working Group One[8] on total anthropogenic radiative forcings to calculate the current CO_2e. This approximation also includes some negative radiative forcings (forcings that result in cooling rather than warming, but which may be shorter-term in effect).[9]

In our calculation, we have taken the concentration threshold to be 400 parts per million volume (ppm) expressed as the more complete measure of carbon dioxide equivalent.[10] Only by stabilising emissions at this concentration is it 'likely' that the global average temperature change will stabilise at 2º C above pre-industrial levels. In December 2007, the likely CO_2e concentration is estimated to be just under 377 ppm, based on a CO_2 concentration of 383ppm - this seemingly counter-intuitive measure is explained by the proper inclusion in the CO_2e figure of all emissions effecting radiative forcing - in other words both those with cooling and warming effects.

In our analysis, we have assumed a 3.3 per cent annual growth rate of emissions. This is based on the average growth rate of carbon dioxide emissions over the period 2000 through to 2006.[11] We have assumed that the other radiative forcings remain constant.

The 3.3 per cent growth rate includes carbon-cycle feedbacks (decrease in the effectiveness of the land and ocean sinks in removing anthropogenic CO_2) as well as *direct* anthropogenic emissions. Of the 3.3 per cent increase, 18 ± 15% of the annual growth rate is due to carbon-cycle feedbacks, while 17 ± 6% is due to the increasing carbon intensity of the global economy (ratio of carbon per unit of economic activity – i.e. GDP). The remaining 65% ± 16% is due to the increase in the global economic activity.[12]

As the atmospheric concentration of CO_2e increases, so will the strength of carbon-cycle feedbacks. Given this we have also included the conservative, lower bound estimate for acceleration of carbon-cycle feedbacks.[13]

Our analysis shows that, assuming that other anthropogenic driven radiative forcings remain constant and the growth rate of carbon dioxide emissions (due to economic growth and increasing carbon intensity of the economy) remains stable – by the end of December 2016 we will exceed an atmospheric CO_2e concentration of 400ppmv.

Our estimate is cautious. We have used the lowest estimate of carbon-cycle feedbacks. Furthermore, historically, an increase in the Earth's global average surface temperatures of just below 2^oC has been considered a 'safe'[14] level of warming. But, with the advancement of global climate models to three-dimensional coupled entities, with ever increasing spatial resolutions, it is now known that the impacts of climate change will manifest in more extreme local changes in temperature. For example, collapse of the Greenland Ice Sheet is more than likely to be triggered by a local warming of 2.7 degrees, which could correspond to a global mean temperature increase of 2 degrees or less.[15] The disintegration of the Greenland Ice Sheet could correspond to a sea level rise of up to 7 metres.

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Endnotes

[1] Hence, even at this level, there is still a one-third chance of exceeding the 2 degree C threshold.

[2] A total of 488 billion tonnes of carbon has been emitted since the beginning of the Industrial Revolution. This has been converted to carbon dioxide multiplying the units of carbon by 44 and dividing by 12 [Canadell J, Le Quéré C, Raupach M, Field C, Buitenhuis E, Ciais P, Conway T, Gillett N, Houghton R, Marland G (2007) 'Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks' *Proceedings of the National Academy of Sciences* **104** (47) 18866-18870.]

[3] Approximately 8 Gigatonnes of carbon are emitted each year. This has been converted to carbon dioxide by using the standard conversion of multiplying the units of carbon by 44 and dividing by 12.

[4] See for example Le Quéré C, Rödenbeck C, Buitenhuis E, Conway T, Langenfelds R, Gomez A, Labuschagne C, Ramonet M, Nakazawa T, Metzl N, Gillett N and Heimann M (2007) ' Saturation of the Southern ocean CO_2 sink due to recent climate change' *Science* **316** (5832): 1735-1738**.**

[5] *Radiative forcing* is defined by the IPCC as a radiative flux (flow of energy) change evaluated at the tropopause. The tropopause is the discontinuity between the troposphere (the portion of the atmosphere that reaches from the surface to a height of between 10 and 20km where most of the weather occurs) and the stratosphere (the layer of the atmosphere that extends from the tropopause to a height of approximately 50km and absorbs most of the harmful ultraviolet radiation from the Sun). Positive radiative forcings lead to a global mean surface warming and negative radiative forcings lead to a global mean surface cooling.

[6] **CO_2** – Carbon Dioxide, **CH_4** – Methane, **N_2O** – Nitrous Oxide, **SF_6** – Sulphur Hexafluoride, **HFCs** – Hydrofluorocarbons and **PFCs** – Perfluorocarbons.

[7] For example ozone, sulphate aerosols, and black carbon.

[8] IPCC (2007) *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* Cambridge: Cambridge University Press.

[9] An important caveat is that particulate emissions which often have a net negative radiative forcing, such as the smogs over industrialising Asia, have a much shorter atmospheric lifetime than the dominant greenhouse gas, CO_2 (which has a lifetime of 100 years or more) .This means that the real extent of the warming is being masked. [See for example, Andreae M, Jones C and Cox P (2005) 'Strong present-day aerosol cooling implies hot future' *Nature* **435**: 1187-1190.]

[10] In 2006, an analysis by Malte Meinhausen suggested that stabilisation of greenhouse gas concentrations (defined as CO_2e) at 550ppm is accompanied by the 68-99% risk of overshooting a warming of 2 degrees. According to the IPCC, this is defined as "likely" to "very likely". His analysis also showed that only by stabilising emissions at 400ppm is it "likely" that global average temperature change will stabilise at 2 degrees. [Meinhausen, M. (2006*), What does a 2°C target mean for greenhouse gas concentrations? A brief analysis based on multi-gas emission pathways and several climate sensitivity uncertainty estimates* (Avoiding dangerous climate change, in H.J. Schellnhuber et al. (eds.), Cambridge, Cambridge University Press, pp.265 – 280)]. This assessment has been supported by findings from two further analyses; an analysis by Baer P and Mastrandrea M (2006) [*High Stakes: Designing emissions pathways to reduce the risk of dangerous climate change* London: Institute for Public Policy Research]. However, top NASA scientist James Hansen and his colleagues form Columbia University in New York published a paper in early 2008 http://www.citebase.org/abstract?id=oai:arXiv.org:0804.1126 to say that, rather than deciding on a future, higher level at which to stabilise the amount of CO_2 in the atmosphere, we need to reduce CO_2 concentrations to 350ppm – the level they were in 1988.

[11] Canadell J, Le Quéré C, Raupach M, Field C, Buitenhuis E, Ciais P, Conway T, Gillett N, Houghton R, Marland G (2007) 'Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks' *Proceedings of the National Academy of Sciences* **104** (47) 18866-18870.

[12] Ibid.

[13] Friedlingstein P, Cox P, Betts R, Bopp L, von Bloh W, Brovkin V, Cadule P, Doney S, Eby M, Fung I, Bala G, John J, Jones C, Joos F, Kato T, Kawamiya M, Knorr W, Lindsay H, Matthews H, Raddatz T, Rayer P, Reick C, Roeckner E, Schnitzler K-G, Schnur R, Strassman K, Weaver A, Yoshikawa C and Zeng N (2006) 'Climate-Carbon Cycle Feedback Analysis: Results from the C^4MIP Model Intercomparison' *Journal of Climate*, **19**:3337-3353.

Friedlingstein et al (2006) analysed the output of eleven climate-carbon cycle models (climate models linked to the biological and geophysical carbon cycle) over the period 1850-2100. The models calculate the Airborne Fraction (AF), the ratio of atmospheric CO_2 increase in a given year to that year's total emissions from fossil fuels and land-use change. AF is a function of the biological and physical processes governing land-atmosphere and ocean- atmosphere CO_2 exchanges. It has a large interannual variability, and is linked to large ocean-atmosphere regimes such as ENSO (El Nino Southern Oscillation). This ratio has been around 0.45 over the period 2000 through 2006; however, the efficiency of the natural sinks in recent years has started to fall. The intercomparison analysis suggested a total increase of additional CO_2 emitted due to carbon-cycle feedbacks could lie in the range 19 and 220ppm by the end of the 21^{st} century. While the majority of the eleven models analysed suggest the increase will lie between 50 and 150ppm, we have used the output of *the most conservative* climate-carbon cycle model output in our calculation – i.e. 19ppm additional CO_2 by the end of the 21^{st} century. We have used their time series of data for our calculation.

[14] A 'safe' level of warming although appears to be a technical quantity, in fact, this is a highly political figure due to the asymmetries of the potential impacts of climate change.

[15] For example, P. Huybrechts et al. (1991) 'The Greenland Ice-Sheet and Greenhouse Warming', *Global and Planetary Change* **89,** 399–412, and J. Gregory et al., 2004, 'Climatology: Threatened loss of the Greenland ice-sheet', *Nature* **428,** 616.