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PERSPECTIVE

More frequent moments in the climate change debate as emissions continue

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Abstract

Recent years have witnessed unprecedented interest in how the burning of fossil fuels may impact on the global climate system. Such visibility of this issue is in part due to the increasing frequency of key international summits to debate emissions levels, including the 2015 21st Conference of Parties meeting in Paris. In this perspective we plot a timeline of significant climate meetings and reports, and against metrics of atmospheric greenhouse gas changes and global temperature. One powerful metric is cumulative CO_2 emissions that can be related to past and future warming levels. That quantity is analysed in detail through a set of papers in this ERL focus issue. We suggest it is an open question as to whether our timeline implies a lack of progress in constraining climate change despite multiple recent keynote meetings—or alternatively—that the increasing level of debate is encouragement that solutions will be found to prevent any dangerous warming levels?

The United Nations (UN) 2015 Paris Meeting (Conference of Parties, COP 21) will focus on action to lower risks of dangerous climate change as a consequence of greenhouse gas (GHG) emissions. This is one of a series of major reports and meetings, marked bottom of figure 1, which can be compared (panel a) to emissions timeline of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Plotted are total annual CO_2 emissions from fossil fuel burning and cement production (Boden *et al* 2010) updated to 2013, and also including land use change (Houghton *et al* 2012). Emissions of CH_4 and N_2O are those estimated to match concentration changes, from pre-industrial to year 2005 (Lamarque *et al* 2011, Meinshausen *et al* 2011). Panel b shows atmospheric CO_2 concentrations (IPCC 2013a), extended to 2014 by NOAA/ESRL (www.esrl.noaa.gov/gmd/ccgg/trends/global.html), and is currently just below 400 ppm. When the 1st IPCC report was published in 1990, atmospheric CO_2 had a value of approximately 354 ppm.

Warming is presented (panel c) as globally averaged surface temperature anomalies relative to the 1960–1990 baseline (Morice *et al* 2012). Comparing the increases in greenhouse gas emissions and global temperature rise does not imply direct causality. However, based on assessment by multiple climate research centres of temperature variations that might be expected for an unperturbed atmosphere, the five IPCC reports have made increasingly strong statements that an anthropogenic influence is detectable on such observed warming. These are represented by IPCC report quotations, top of figure (for detailed timeline specific to activities of United Nations Framework Convention on Climate Change, see http://unfccc.int/timeline/). Continued warming from 'business-as-usual' emissions could increase sea levels significantly (IPCC 2013b, Rahmstorf 2007) leading to major inundation to low-lying regions. Intensification of the hydrological cycle is also expected. This could cause more frequent extreme rain and flood events. However that signal is presently offset by raised counteracting cooling atmospheric aerosol concentrations (Wu *et al* 2013); these may fall through clean-air acts. Furthermore oceans are currently absorbing much thermal energy and so contemporary transient warming may be up to 50% lower than equilibrium 'committed' warming for present-day GHG concentration levels (e.g. Schlesinger 1986). Against this backdrop of potential dangerous change, stabilisation at (or below) two-degrees temperature rise since pre-industrial times is often presented as a maximum acceptable

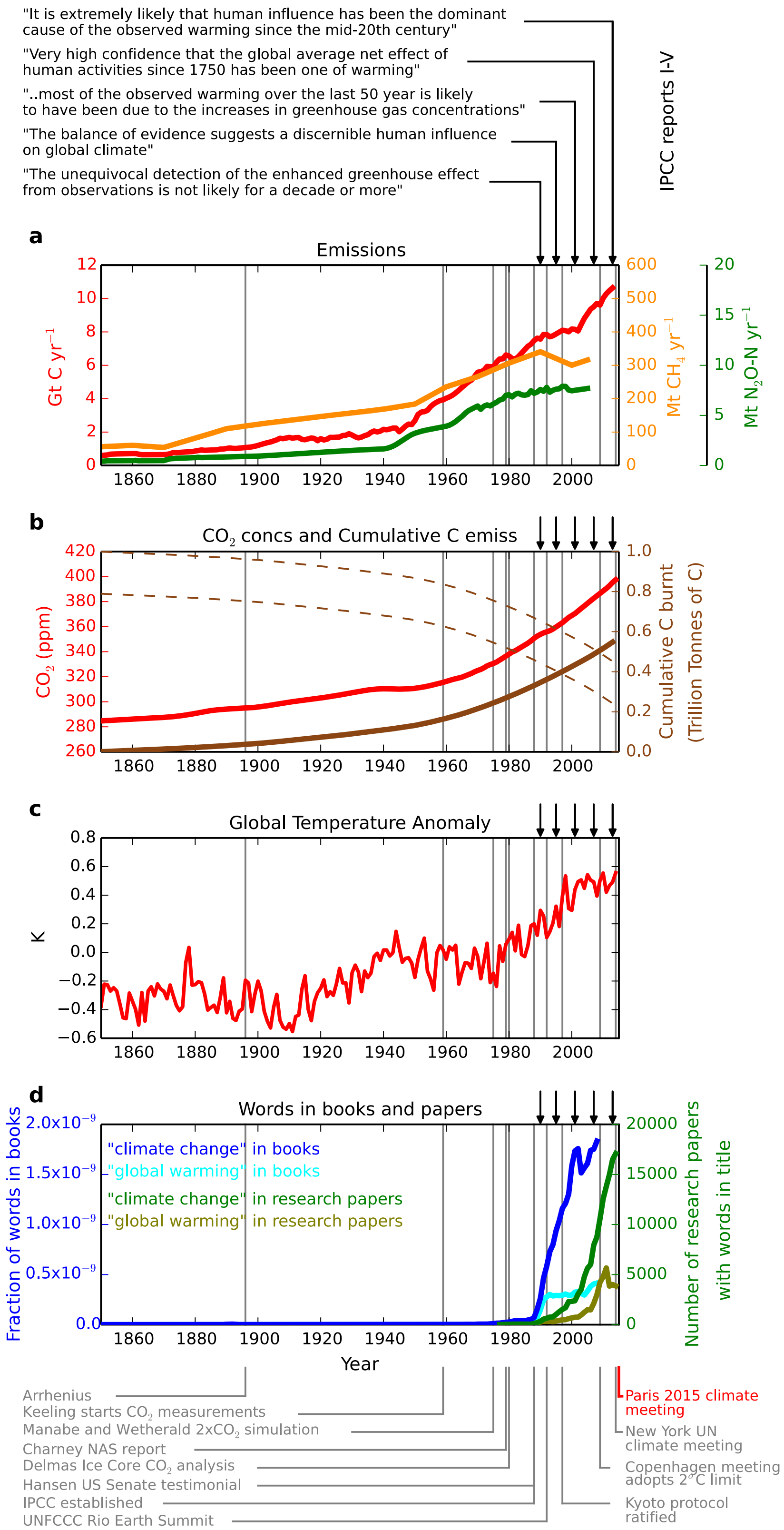

Figure 1. (**a**) Annual historical emissions of carbon dioxide (red), methane (orange) and nitrous oxide (green). (**b**) Atmospheric CO_2 concentrations (red) and cumulative C emissions (brown). Two brown dashed lines, 1.0 TtC and 0.79 TtC minus cumulative emissions (see text). (**c**) Global temperature record anomalies. (**d**) Fractional occurrence of words 'climate change' or 'global warming' anywhere in books and number of occurrences in research paper titles. Dates of five IPCC reports as arrows above panels, with quotations of significant statements made in them. Other major research findings and climate-related meetings at base.

warming threshold. This would need major emissions reductions starting soon, with delays imposing even higher reductions on future generations (e.g. Huntingford *et al* 2012). However the long atmospheric lifetime of carbon dioxide, together with the high inertia of the climate response largely driven by the rate of ocean heat uptake, allows a simple characterisation of such generational exchanges. This is because peak warming can be simply related to the single quantity of cumulative CO_2 emissions (Allen *et al* 2009, Matthews *et al* 2009).

Cumulative historical carbon (C) emissions are also shown in panel b (units of Trillion tonnes of C). The 5th IPCC report (IPCC 2013b) estimates that if CO_2 was the only GHG perturbed, then burning 1000 GtC i.e. one Trillion tonnes of C (Allen *et al* 2009) would likely (66% probability) limit surface warming to 2 °C relative to pre-industrial. Upper dash curve (figure 1(b)) shows remaining 'allowed' emissions, if a trillion tonnes was accepted as an upper limit on total C usage. If the ratio of C emissions to non-CO_2 gas emissions is kept similar to the ratio implicit in RCP8.5, then to stay below two degrees—again with 66% probability but accounting for these additional GHGs—then total 'allowed' C emissions becomes 790GtC (IPCC 2013b). Lower brown dashed line is remaining emissions on that basis, highlighting that we have already emitted roughly two thirds of that overall quota, and at current emissions levels the remaining budget would be exhausted in about 25 years. Against that backdrop, this special issue 'Focus on Cumulative Emissions, Global Carbon Budgets and the Implications for Climate Mitigation Targets' refines and investigates in depth the relationship between anthropogenic emissions and climate target. This considers Earth System models' responses to cumulative emissions (Frölicher and Paynter 2015, LoPresti *et al* 2015, Nohara *et al* 2015); role of non-CO_2 forcing in modulating the relationship between cumulative CO_2 emissions and climate response (Rogelj *et al* 2015a); historical and future contribution from major emitters, in the context of pledges i.e. Intended Nationally Determined Contributions (INDCs) (Gignac and Matthews 2015, Peters *et al* 2015); and implications of emissions mitigations on the global economy (Rogelj *et al* 2015b, Rozenberg *et al* 2015).

To provide historical context to the current climate debate, we mark on figure 1 past key events. The potential for raised CO_2 concentrations to cause surface level temperature warming was first identified in 1896 (Arrhenius 1896). The first full year of direct atmospheric CO_2 measurements started at Mauna Loa, Hawaii, in 1959 (Keeling *et al* 1976), whilst the initial climate model simulation to assess thermal effects of doubling of atmospheric CO_2 occurred sixteen years later (Manabe and Wetherald 1975). Shortly following, ice-core records confirmed CO_2 is rising far beyond levels of recent geological times (Delmas *et al* 1980). In 1988 the UN IPCC was established, and has reported five times, and in 1992 over one hundred heads-of-state attended the Rio Earth Summit. In 1988, James Hansen told the US Senate that there is compelling scientific evidence for global warming; the 1979 Charney *et al* report to US National Academy of Sciences (Charney *et al* 1979) similarly alerts to potential climate change, highlighting temporary inertia due to oceanic thermal sink. In 2009 the Copenhagen Accord agreed the maximum two-degrees warming threshold. As a precursor to COP21, the UN 2014 meeting in New York discussed a future low-carbon world, the first attempt to commit countries to emissions reductions in the 1997 Kyoto protocol. The increasing recent interest in climate change is reflected in the rapid growth of mentions in books (source: Google books analysis) and research paper titles (source: Scopus database) of words 'global warming' or 'climate change' (figure 1(d)).

Timeline illustrated in figure 1 could suggest societal failure so far, as despite recent frequent meetings and reports stating an attributable link between climate change and anthropogenic emissions, the burning of fossil fuels has caused concentrations of GHGs to continue to rise. Yet this rather negative assessment should not suggest that the problem is intractable, which could lead to little incentive at individual level to consider changes to low carbon energy use. The Paris COP21 meeting will strongly set the tone for the next stages in debating GHG emissions, especially with each country presenting their INDCs. That is, their aspiration to mitigate GHG emissions over the next decades. All countries will need to contribute to reduce their GHG emissions, hopefully without causing any economic damage, as the cumulative budget approach tells us that stabilisation of climate ultimately requires net zero emissions. Should similar timeline diagrams be plotted in the decades ahead, then looking back it may well be that the year 2015 Paris meeting becomes the defining marker after which emissions reductions start.

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