From: **Myles Allen** myles.allen@ouce.ox.ac.uk
Subject: Non-CO2 forcing in carbon budgets
Date: 30 January 2019 at 09:58
To: Pierre Friedlingstein P.Friedlingstein@exeter.ac.uk, Keith Shine k.p.shine@reading.ac.uk, Jan Sigurd Fuglestvedt j.s.fuglestvedt@cicero.oslo.no
Cc: Stuart Jenkins stuart.a.jenkins@gmail.com

MA

Dear Pierre, Keith and Jan,

A while ago you pointed out, Keith, that our 2016 NCC paper was really about reconciling metrics with the cumulative carbon story, which is of course true (although I hadn't thought of it that way). But while I think we may have made some impact on metrics discussions, this seems to have gone largely unnoticed in carbon budget discussions — understandably, because apart from a few throwaway asides, we haven't really addressed the implications for carbon budgets in any of these papers and most people concerned about carbon budgets wouldn't think to read technical papers about metrics.

So I am thinking that a short paper with a title along the lines of "Accounting for non-CO2 forcing in outstanding carbon budgets" would be helpful, making the point that remaining warming is, for an ambitious mitigation scenario in which temperatures peak well before 2100 and non-CO2 forcing increases or declines smoothly between now and the time of peak warming, well approximated by:

DeltaT = TCRE x G + TCR x (F1 – F0) / F2x + [(ECS–TCR)/d2] x deltat x F0 / F2x

where G is the cumulative remaining carbon budget to peak warming, F0 is the mean global effective non-CO2 forcing over the past 10-20 years and F1 the mean non-CO2 ERF over the 10-20 years prior to peak warming, F2x is the forcing due to doubled CO2, d2 is the long thermal response-time of the climate system (100-400 years in AR5) and deltat is the time between now and peak warming. The first terms is just the cumulative carbon temperature relationship, the second is the Gregory&Forster proportionality between forcing and temperature changes, and the third term is the centennial adjustment to a stable forcing. This third term is, I expect, relatively small at a global level, because F0 is currently comparable to F1-F0 and deltat << d2 in most scenarios, but it could be important if we break DeltaT down into components contributed by different regions or sectors (and is evidently very important to Andy Reisinger).

Using the relationship TCR = F2x x TCRE x H / AGWP_H noted in our npj paper (and I'm sure noted somewhere else earlier), we can also write this as

DeltaT = TCRE x [G + H x (F1 – F0 + epsilon x deltat x F0) / AGWP_H]

where AGWP_H is the AGWP of CO2 for time-horizon H and epsilon = (ECS–TCR)/(TCR x d2) is the fractional rate of forcing decline required to maintain stable temperatures (around 0.3% per year). So the remaining carbon budget to limit warming to a further DeltaT degrees is

G = DeltaT/TCRE – H x (F1 – F0 + epsilon x deltat x F0) / AGWP_H

This makes it nice and clear how non-CO2 forcing translates into CO2-forcing-equivalent emissions (and hence how individual components could also be expressed in this way, relating this to GWP*, although I wouldn't want to make that the main point of this paper). The reason I think this is important is that all of these quantities (ECS, TCR, d2, AGWP_H, TCRE) are going to be assessed in AR6, and it will therefore be straightforward for anyone to assess whether they are consistent with estimated remaining carbon budgets. If these budgets are estimated from CMIP6, or using MAGICC or FaIR, then there would be no guarantee that they would be consistent, and we would want to avoid the rush we had the last time when it emerged that new forcing estimates weren't consistent with the observed energy budget and estimates of ECS.

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As well as explaining all this (which wouldn't require much more than a moderately expanded version of this email), a short paper could check this claim against diagnosed carbon budgets using CO2 emissions, net non-CO2 ERF and FaIR-derived temperature changes in the SR1.5 ambitious mitigation scenarios. It would be nice to include MAGICC-derived temperature changes as well, but the actual time-series of total non-CO2 ERF prior to the present in those MAGICC runs remains a bit of a mystery. If we wanted an independent model, perhaps we could use the CICERO EBM?

I was going to suggest, if you were all interested and weren't doing this already, that Stuart Jenkins (a doctoral student here working on policy-relevant applications of estimates of total anthropogenic forcing, who led a GRL on CO2-fe emissions last year) could start work on this (and we could badge it as something to do with our first CCiCC deliverable, please).

Looking forward to your thoughts (and apologies for a long email — I hope I haven't made any typos in the inline maths),

Myles

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