Millar et al. reply - Our paper aimed to remain as consistent as possible with the IPCC-AR5 definitions that have informed the UNFCCC negotiations. The definition of global average temperature in the Paris Agreement is undoubtedly important, and different definitions are possible, as acknowledged in our paper. However, the Paris Agreement built on the Working Group I and Working Group II reports[1,2] of the 5th Assessment (AR5) issued by the Intergovernmental Panel on Climate Change (IPCC). In these reports, global temperature change was explicitly defined using the observations in the period 1850-1900 as "an approximation of pre-industrial levels" (Assessment Box SPM.1 Figure 1 of ref 2). Climate model projections were assessed relative to 1986-2005 and then expressed relative to 1850-1900 using observed warming between these periods in the HadCRUT4 dataset[3] (+0.61°C). Based on the IPCC-AR5[4] assessed near-term projections of a warming of 0.3 to 0.7°C for the period 2016-2035 compared to 1986-2005, warming in the decade 2010-2019 is expected to be centred on 0.93°C above 1850-1900, given forcing consistent with the RCPs and no large volcanic eruptions. Such a level of warming is consistent with the "increase of 0.85°C [to 2012] since 1880, a good approximation for pre-industrial levels" reported in the United Nations Framework Convention on Climate Change (UNFCCC) Structured Expert Dialogue (SED – horizontal blue line in Schurer et al)[5], and with the independent estimate for 2015 human-induced warming used in our paper. Alternative definitions of global average temperature or pre-industrial conditions may not be consistent with "observed impacts of climate change **at 0.85°C of warming**"[5] (original emphasis) in the context of which the UNFCCC long-term temperature goal was agreed[1].

We aimed to remain as consistent as possible with the IPCC-AR5 definitions that have informed the UNFCCC negotiations. We therefore proposed 0.6°C warming above the average of the present decade as "a possible interpretation of 'pursuing efforts to limit the temperature increase to 1.5°C' in light of estimated human-induced warming to date", while also providing tables with data for 0.3°C to 1.1°C additional warming to highlight the potential effects of different temperature definitions and pre-industrial reference periods for estimates of remaining budgets (references 17 and 18 in Millar et al.).

The difference between model-based globally-complete surface air temperature (SAT) and globally-incomplete combinations of blended air and sea surface temperature observations is important for quantifying climate impacts at low temperature thresholds. This difference is larger over the historical period than in projected future changes under ambitious mitigation. Studies of impacts of 1.5°C of warming should indeed acknowledge this difference, but it is relatively small for ambitious mitigation scenarios expressed relative to the present decade (less than 0.05°C – difference between blue and purple lines in Figure 2 of this correspondence – ref 7). Schurer et al (2017)[6] state that "blended observational data sets … will probably be those used to determine whether a temperature threshold has been reached". Our use of global SAT projections (figure 1 and tables) means that budget estimates for

[1] Over the period 2006-2015 warming (relative to 1850-1900) in datasets that stretch back to 1850 are: 0.84°C (HadCRUT4), 0.92°C (HadCRUT4- Cowtan and Way) and 1.00°C (Berkeley Earth).

thresholds of warming beyond the present decade are actually slightly underestimated relative to budgets under a blended metric, with the same being true for the AR5 budget estimates.

It is important to understand differences in the definitions of global average temperature in mitigation and climate impact studies. However, the definition of warming in the context of the Paris Agreement is not informed solely by physical geoscience considerations[8,9] Our paper estimated the outstanding carbon budget consistent with limiting the increase in global average temperature above pre-industrial levels to 1.5°C, using a definition of present-day warming consistent with government-approved assessments that directly informed the Paris Agreement, whilst acknowledging that other definitions were possible. We therefore stand by the central definition of warming used in our paper and its estimate of the remaining carbon budget.

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