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Mechanisms controlling the dependence of surface warming on cumulative carbon emissions over the next century in a suite of Earth system models

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Insight into how to avoid dangerous climate may be obtained from Earth system model projections, which reveal a near-linear dependence of global-mean surface warming on cumulative carbon emissions. This dependence of surface warming on carbon emissions is interpreted in terms of a product of three terms: the dependence of surface warming on radiative forcing, the fractional radiative forcing contribution from atmospheric CO_2 and the dependence of radiative forcing from atmospheric CO_2 on cumulative carbon emissions. Mechanistically each of these dependences varies, respectively, with ocean heat uptake, the CO_2 and non-CO_2 radiative forcing, and the ocean and terrestrial uptake of carbon. An ensemble of 9 Earth System models forced by up to 4 Representative Concentration Pathways are diagnosed. In all cases, the dependence of surface warming on carbon emissions evolves primarily due to competing effects of heat and carbon uptake over the upper ocean: there is a reduced effect of radiative forcing from CO_2 due to ocean carbon uptake, which is partly compensated by enhanced surface warming due to a reduced effect of ocean heat uptake. There is a wide spread in the dependence of surface warming on carbon emissions, undermining the ability to identify the maximum permitted carbon emission to avoid dangerous climate. Our framework reveals how uncertainty in the future warming trend is high over the next few decades due to relatively high uncertainties in ocean heat uptake, non-CO_2 radiative forcing and the undersaturation of carbon in the ocean.