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A mechanistic view of why global warming is proportional to cumulative carbon emissions

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Climate model experiments reveal that transient global warming from radiative forcing is nearly proportional to cumulative carbon emissions on multi-decadal to millennial timescales. However, it is not quantitatively understood how this near linear dependence between warming and cumulative carbon emissions arises in transient climate simulations, nor why the proportionality of warming is largely independent of emission scenario. Here, we present the first theoretical equation for how global warming depends on cumulative carbon emissions over time for an atmosphere-ocean system. For the present, our theory identifies a sensitivity of surface warming to emissions of 1.5±0.7 K for every 1000 Pg of carbon emitted, reducing by only 10 to 20% by the end of the century and beyond. The sensitivity remaining nearly constant over time is due to partially-opposing thermal and carbon responses in a coupled atmosphere-ocean, where ocean drawdown of heat and carbon alter the surface warming and radiative forcing in opposing ways. Incorporating estimates of terrestrial carbon uptake into our analysis reduces the sensitivity of surface warming to 1.1±0.5 K for every 1000 Pg of carbon emitted, but does not significantly alter the percentage reduction in warming sensitivity over the 21st century. Our theory provides an analytical framework to understand the controlling mechanisms and interpret why there are different model projections of global warming.