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The scaling law of climate change and its relevance to assessing (palaeo)biological responses

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It is often argued that current rates of climate change are unprecedented in the geological past. At the same time, the magnitudes of change were often much greater in deep time than they are in history. The most severe global warming in the Phanerozoic, with dramatic consequences for life, probably occurred across the Permian-Triassic (P-T) boundary when an increase of tropical water temperatures of 15˚C has been observed to occur over a timespan 0.8 myr (Sun et al. 2012), whereas global ocean warming over the last 50 years was 0.35˚C (Burrows et al. 2011). When transforming these data into rates of change the P-T rate was roughly 370 times smaller than the current rate. We argue that the smaller rates of change inferred from geological proxy records are due to a scaling effect, that is, rates of climate change generally decrease with timespan of observation.

We compiled from the published literature data on measured or inferred temperature changes and the timespans over which these changes were assessed. Our compilation currently comprises 120 values and covers timespans from 20 to 10^7 years. A log-log plot of timespan versus rate of temperature change depicts a highly significant correlation (r^2 = 0.95) of a power-law relationship with an exponent of -0.87. Warming trends show a slightly lower exponent (-0.84) than cooling trends (-0.89) but the explained variance is better for the scaling of warming trends. Importantly, the scaled warming trend across the P-T boundary is higher than the current rates of warming.

Similar scaling effects are well explored for sediment accumulation rates (Sadler 1981) and evolutionary rates (Gingerich 1993). These have been interpreted as being due to breaks in sedimentation and periods of stasis or transient reversals, respectively. In case of climate change, transient reversals in general trends are the most likely explanation for the scaling relationship. Even relatively rapid intervals of warming, such as the Pleistocene interglacials, are not monotonic, but punctuated by short-term cooling intervals.

The fossil record tells us that biodiversity responded dramatically to ancient intervals of climate warming. We can now see that the apparently slower rates of change in some mass extinctions (Permian-Triassic, Triassic-Jurassic) were greater than today when the scaling law is considered. This reassures us that studying deep time patterns of organismic response to climate change is a worthwhile endeavor that is relevant for predicting the future.

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