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The Power, Pitfalls and Potential for Using Palaeoenvironmental Observations to Understand Climate Dynamics

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There is a wealth of observations of the environmental response to climate changes on different timescales, ranging from seasonal to multi-millennial. These primary observations are increasingly available as continental or global syntheses, allowing us to address questions about large-scale dynamics.

Palaeodata provide information about climate changes much larger and much faster than has occurred in the recent past. Thus, we have the *potential* to explore the dynamics of climate under radically different boundary conditions and to perform out-of-sample tests of our understanding of these dynamics as encapsulated in state-of-the-art models. Palaeoclimate assessment has, for example, unequivocally demonstrated that changes in large-scale features of climate that are governed by the energy and water balance show consistent responses to changes in forcing in different climate states, and these consistent responses are reproduced by climate models. This is a *powerful* demonstration that features seen in twenty-first-century projections, including enhanced land–sea temperature contrast, latitudinal amplification, and scaling of precipitation with temperature, are likely to be realistic. However, palaeoclimate assessment has also revealed the shortcomings of our modelling at regional scales. Classic examples are the persistent failure to capture monsoon dynamics through time, the overestimation of mid-continental drying during peak interglacial conditions, and the inability to simulate mid-latitude changes in rainfall seasonality. Process evaluation implicates poor representation of atmospheric circulation in these failures, in some cases exacerbated by poor representation of land-atmosphere coupling.

Nevertheless, there are *pitfalls* in the interpretation of environmental evidence in terms of climate. Traditional approaches, reliant on statistical relationships with specific climate drivers under modern conditions, do not take account of interactions between climate drivers, the potential non-stationarity of single-variable relationships, or the role of non-climatic factors on the dynamics of the recording systems. Changes in [CO_2], for example, have a direct impact on the growth and water-use efficiency of terrestrial plants and this needs to be taken into account e.g. in interpreting tree-ring records and changes in vegetation distribution through time in terms of climate. The ability of marine organisms to move, both in space and time, to secure optimal living conditions provides another example of the difficulties inherent in basing climate reconstructions on modern statistical relationships. New approaches, drawing on knowledge of the physiology and ecology of terrestrial and marine organisms, are however providing new tools to explain past observations. The development of process-based models of biological indicators means we can exploit the *power* of the palaeoenvironmental record more fully to provide evidence for, and explanations of, past climate changes.