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Responses of gravel-bed rivers to periodic climate change

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Periodic variation in Earth's orbit leads to variation in temperature and precipitation at its surface that are expected to exert a profound influence on landscape evolution. Indeed, cyclical fluctuations in sediment yield and grain size are a ubiquitous feature of the geological record, and recurrence times of geomorphological features such as fluvial terraces and alluvial fans often appear to reflect orbital periodicities. However, making quantitative interpretations of these records requires a detailed understanding of the ways in which sediment is transported from mountainous source regions along alluvial channels to depositional sinks. Sediment transport processes may dampen (i.e. buffer, 'shred') or amplify climate signals, such as changes in channel elevation or sediment flux, and may introduce a lag between them and the responsible external forcing. Recent modelling studies, mostly focused on the potential transmission of climatic signals to sedimentary archives, have predicted a wide range of behaviour and have proven challenging to test in the field. Here, we aim to clarify this discussion and also consider the potential preservation of climatic signals by fluvial terraces along alluvial channels. Our starting point is a recently developed model describing the long-profile evolution of gravel-bed rivers. This model is the first of its kind to be derived from first principles using physical relationships that have been extensively tested in laboratory settings, and takes a non-linear diffusive form. We employ perturbation theory to obtain approximate analytical solutions to the relevant equations that describe how channel elevation and sediment flux vary in response to periodic fluctuations in discharge and sediment supply. Our solutions contain expressions for response amplitudes and lag times as functions of downstream distance, system 'diffusivity' and forcing frequency. Lag times can be a significant fraction of the forcing period, implying that care is required when interpreting the timings of terrace formation in terms of changes in discharge or sediment supply. We also show that at the onset of periodic forcing, or a change in the dominant forcing period, alluvial channels undergo a transient response as they adjust to a new quasi-steady state. Importantly, this result implies that suites of fluvial terraces can be preserved without the need for significant local base-level fall. Since the expressions presented here are defined in terms of fundamental properties of alluvial channels, they should be readily applicable to real settings.