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Non-local flow effects on bedform dynamics

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Bedform patterns are sensitive recorders of feedbacks among bed topography, fluid flow, and sediment transport. Some of the most important feedbacks are local. For example, evolution models based on simple flow parameterizations that only incorporate local bed height can reproduce some of the essential features of bedform evolution, including bedform growth and migration. However, non-local effects can also be critically important. For example, field and laboratory measurements have shown that the spacing of most sand ripples generated by wave-driven oscillatory flows is linearly proportional to the amplitude of the flow oscillation, implying that fluid stress and sediment transport at a given location depend on upstream features that perturb the flow. A model that fully captures the coupling of flow and bedform evolution must include such effects, but it is not clear how detailed the description of the flow must be to reproduce the most important aspects of bedform evolution. To account for the most significant non-local flow effects without resorting to a coupled hydrodynamic model, we propose an approximation in which the bed shear stress is expressed as a convolution of the bed topography with a kernel that includes both local effects, such as acceleration over bumps, and non-local effects, such as flow separation and re-attachment. Two-dimensional flow simulations demonstrate that a single, generic kernel gives a good approximation of shear stress over a wide range of bed profiles under oscillatory and some combined flows. Incorporating this approximation into a simple bedform evolution model, we show that non-local effects are required to reproduce the characteristic transient patterns that emerge as wave ripples respond to changes in the flow, which we have documented with time-lapse imagery of laboratory wave tank experiments. We then show how this result informs interpretations of two-dimensional wave ripple patterns preserved in the geologic record.