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Dynamic Scaling of Desert Dunes

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Wind-blown sand creates some of the most impressive inanimate dynamic structures in nature, from the neat ripple patterns on beaches to vast shifting dune fields swallowing roads and settlements. The robustness of dune shapes, and their "exactitude of repetition and geometric order" (Bagnold) is partly attributable to the self-similarity of turbulent wind. However, closer inspection reveals several distinct levels of self-organisation that span about four decades of length, from ripples through dunes to megadunes and draas. On each scale, structure formation obeys similar rules, while admitting considerable shape variations. The so called minimal model of sand dune formation accounts, in simple terms, for the scaling of steady-state dune shapes. Building on this success, we show here that also the time evolutions of dune shape and size, in response to naturally varying conditions such as wind strength and sand supply, are subject to a dynamical similarity law, closely controlled by the instability modes of steady-state solutions. By this dynamical similarity, the multitude of observed shapes and time evolutions of desert dunes is traced back to a unified underlying growth law, and to the elementary scales provided by grain size and wind speed.