Hillscapes in wet and dry conditions: Contrasting climates produce dramatically different critical zone architectures

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Critical zone architecture, the characteristics and thickness of mobile regolith and weathered rock, depends on weathering and erosion processes operating over long periods of time. Although rock type, biota, and tectonics are important drivers of both weathering and erosion rates, we focus on the effects of climate, in particular the delivery of water through the critical zone to a weathering front. We use numerical models that incorporate chemical weathering along realistic hydrologic flowpaths, and geomorphic rules for soil production and transport to explore the evolution of a hillscape, a two-dimensional slice of a hillslope along the fall line from drainage divide to channel. Hydrologic flow paths are vertical in the vadose zone, and are deflected laterally below the water table toward a downcutting channel. We track alterations in both solid phase (plagioclase to clay) and water chemistry along these flowpaths. Climate is represented by rates of recharge; to isolate its effect, we simulate dry and wet cases and prescribe identical landscape evolution rules. The topography evolves on timescales of order million years. The critical zone architectural patterns that emerge beneath the resulting parabolic interfluves differ dramatically under different water recharge rates. In the dry case, incomplete weathering is shallow and surface-parallel, whereas in the wet case, intense weathering occurs to depths near the base of the bounding channels, well below the water table. The weathering boundary layer in the dry case therefore bounds the topographic surface whereas it bounds the base of the water flow system in the wet case. While there are undoubtedly direct roles for tectonics, rock type, and biota in controlling the critical zone architecture, and yet more likely feedbacks between these and climate, we show here that differences in hillscape-scale weathering patterns and weathering fluxes can be strongly controlled by climate.