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Coupled tectonic-climatic processes limit silicate weathering in orogenic systems

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Weathering of silicate minerals influences Earth's carbon cycle and climate. Mountain building is thought to enhance silicate weathering by uplifting weatherable minerals to the surface and by building topographic relief that can focus rainfall and increase the reactivity of silicate minerals. Considered in isolation, both these effects should promote CO_2 drawdown and climate cooling. However, coupling among climate, tectonic, and surface processes generate more complex responses that can disrupt this cooling feedback. Here, we develop an idealized, dynamically coupled numerical model of a convergent mountain range that simulates how changing environmental conditions during mountain building affect weathering fluxes predicted by different silicate weathering models. We find that current weathering models make divergent predictions, which can either support conventional associations between mountain building and enhanced CO_2 drawdown, or alternatively, support peak weathering fluxes at moderate erosion rates, limiting conditions where silicate weathering can operate as a CO_2 sink. We introduce a mechanistic framework to show how varying tectonic, climatic, and geomorphic controls can influence weathering fluxes from an orogen, which reveals key differences from considering these processes as a coupled system rather than in isolation. For example, we show that accelerating rock uplift and shifts toward wetter climates can drive decreases in silicate weathering flux from upland landscapes. Further, synthetic "data" generated by this model match existing compilations of weathering and erosion, suggesting that this coupled tectonic-climate influence is observed in data from orogens around the world. These model conclusions may imply heightened importance of downstream weathering controls, both in general and to characterize weathering responses to specific orogenic events. Together, these results advance understanding about the roles silicate weathering and mountain building play in the carbon cycle.