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Thermodynamic limits of hydrologic cycling within the climate system

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The hydrologic cycle results from the combination of energy conversions and atmospheric transport, and the laws of thermodynamics set limits to both. Here, we apply thermodynamics to derive the limits to the intensity of hydrologic cycling within the climate system, about the properties and processes that shape these limits, but also how these limits are affected by vegetation on land. We set up simple models to derive analytical expressions of the limits of evaporation and precipitation in relation to vertical and horizontal differences in solar radiative forcing. These limits result from a fundamental trade-off by which a greater evaporation rate reduces the temperature gradient and thus the driver for atmospheric motion that exchanges moistened air from the surface with the air aloft. The limits on hydrologic cycling thus reflect the strong interaction between the hydrologic flux and its driving gradient. Despite the simplicity of the models, they yield estimates for the limits to hydrologic cycling that are within the observed magnitude, suggesting that the global hydrologic cycle operates near its maximum strength. We close with a discussion how thermodynamic limits can provide a framework to better characterize the interaction of vegetation and human activity with hydrologic cycling within the climate system.