Land-ocean contrasts under climate change: theory and simulations

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Abstract:
Observations and climate models show a pronounced land-ocean contrast in the responses of surface temperature and the hydrological cycle to global warming: Land temperatures increase more than ocean temperatures, low-level relative humidity increases over ocean but decreases over land, and the water cycle has a muted response over land in comparison to ocean regions at similar latitudes. A comprehensive physical understanding of these land-ocean contrasts has not been established, despite the robustness of the features and their importance for the regional and societal impacts of climate change.

We investigate land-ocean contrasts in the responses of temperature, relative humidity, and precipitation minus evaporation (P-E) to climate change using both idealized and full-complexity models. As in previous studies, we find enhanced surface warming over land relative to the ocean at almost all latitudes. In the tropics and subtropics, the warming contrast is explained using a convective quasi-equilibrium (CQE) theory that reveals a strong link between temperature and relative humidity changes over land. The decreases in land relative humidity under warming are understood using a conceptual model of moisture transport between the land and ocean boundary layers and the free troposphere.

Changes in P-E over ocean are closely tied to the local temperature changes via a simple thermodynamic scaling; the so-called "rich-get-richer" mechanism. Over land, however, the simple scaling fails to give any regions with decreases in P-E, and it overestimates projected increases in P-E. An extended scaling, incorporating horizontal gradients of changes in temperature and fractional changes in relative humidity, is shown to better capture the response of P-E over land, including a smaller increase in global-mean runoff and several regions with decreases in P-E. In the zonal mean over land, the gradient terms lead to a robust drying tendency at almost all latitudes. This drying tendency is shown to relate, in part, to the polar amplification of warming in the Northern Hemisphere, and to the amplified warming over continental interiors and on the Eastern side of midlatitude continents.