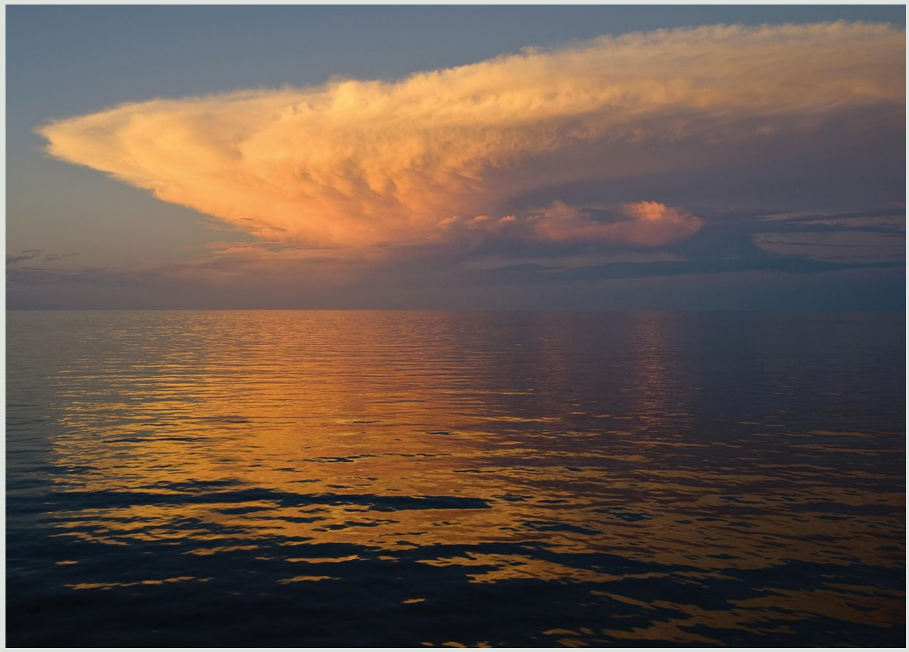
ANNIVERSARY RETROSPECTIVE

Rainfall and climate feedbacks



Credit: Nigel Prosser / Alamy Stock Photo

Most of Earth's precipitation falls over the oceans. In the tropics, rainfall is organized into zonally oriented bands that reside over warm waters with sea surface temperatures greater than about 27 °C. Here, strong low-level winds and moisture converge, which provides the latent energy that drives intense convection, thunderstorms and rainfall. But how climate warming might affect these processes was unclear.

Using measurements of sea surface temperature and precipitation, as well as numerical simulations, Johnson and Xie showed that the sea surface temperature threshold for convection co-varies with the tropical mean sea surface temperature on inter-annual and longer time scales (*Nat. Geosci.* **3**, 842–845; 2010). That is, they showed that the bar for rain rises, because climate change amplifies warming of the upper atmosphere — an idea predicted by theory and numerical models, but not previously verified using observations.

This theory and its validation partly inspired my own PhD research. I wanted to better understand what the increase of the convective threshold meant for concepts linking rainfall response to climate change, such as the wet-get-wetter view (Held and Soden, *J. Clim.* **19**, 5686–5699; 2006). This theory proposes that if tropical sea surface temperatures increase uniformly in space, the distribution of convective regions does not change: warmer air can hold more water vapour, so rainfall is expected to increase in the current rainy regions and decrease in dry areas due to enhanced moisture transport from the latter to the former. However, in my numerical simulations, weakening of the tropical atmospheric circulation counteracted the effect of an increased moisture-holding capacity of the atmosphere (Ma et al., *J. Clim.* **25**, 2979–2994; 2012).

Counteractions between increased moisture and weakened circulation give rise to a concept dubbed the warmer-get-wetter view. Because the convective threshold rises with the tropical average increase in sea surface temperatures, deviations of surface ocean warming from the tropical mean can dominate convection change: rainfall would increase over water that warms more, and decrease where less warming occurs (Ma and Xie, *J. Clim.* **26**, 2482–2501; 2013).

Clearly, the feedbacks between patterns in the tropical ocean warming and rainfall change are manifold complex. Climate models do not always accurately capture these mechanisms, which leads to large spread between the models. Water vapour and cloud feedbacks add to these uncertainties. There is a rich field for future research in understanding how climate change will interact with tropical precipitation patterns. ❐

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