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Regime change behaviour during Asian monsoon onset

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Recent idealised aquaplanet studies suggest that the fast onset of the monsoon may correspond to a sudden transition in the dynamical regime of the Hadley circulation. During monsoon onset, the tropical circulation changes from an equinoctial regime with two near symmetric eddy driven cells, to a monsoon regime with a strong, thermally direct cross-equatorial cell, and a weak summer hemisphere cell. This change occurs faster than would be expected if the ITCZ shifted sinusoidally, following the seasonal cycle. Dynamical feedbacks are proposed to act during this transition to give the fast monsoon onset observed in the real world.

To investigate the relevance of this behaviour to Earth, experiments are presented using both aquaplanet configurations and a more realistic configuration including Earth's land and topography. This allows conclusions drawn from the simpler dynamics of the aquaplanets to be tested in a set-up much closer to Earth. Evidence for a change in dynamical behaviour is found in both the aquaplanets and more realistic experiment, with a change in the relationship between ITCZ latitude and overturning circulation strength observed as the ITCZ shifts poleward.

Analyses of the upper level vorticity and zonal momentum budgets of the semi-realistic experiment highlight the roles of the Tibetan plateau and land-sea contrast in monsoon onset. In all experiments, the modelled monsoon onset is associated with a reduction in the magnitude of upper level absolute vorticity, which indicates a transition to a thermally direct regime. The vorticity budget analysis reveals that ascent occurring off the equator is associated with a vortex stretching tendency that acts to lower upper level absolute vorticity. While this ascent may initially be weak, as the circulation becomes more thermally direct the associated ascent strengthens, further increasing the magnitude of the vortex stretching term. The result is a fast regime change and a rapid increase in precipitation. In sufficiently shallow aquaplanets, off-equatorial ascent occurs when the sub-solar point shifts from the equator over the seasonal cycle. In our more realistic experiment, a low pressure system develops over the Asian continent and Tibetan plateau, which results in local off-equatorial ascent over East Asia. The circulation changes induced by this system then extend over South Asia. Implications for our understanding of the relationship between the East and South Asian monsoon systems, and for monsoon onset in future climates, are discussed.