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Stirring up a storm: convectively-driven climate variability on tidally locked exoplanets

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Earth-sized exoplanets are extremely common in the galaxy and many of them are likely tidally locked, such that they have permanent day- and nightsides. Astronomers are starting to probe the atmospheres of such planets, which raises the question: can tidally locked planets support habitable climates and life?

Several studies have explored this question using global circulation models (GCMs). Not only did these studies find that tidally locked Earth-analogs can indeed sustain habitable climates, the large day-night contrast should also create a distinct cloud structure which could help astronomers identify these planets. These studies, however, relied on GCMs which do not explicitly resolve convection, raising the question of how robust their results are.

Here we consider the dynamics of clouds and convection on a tidally locked planet using the System for Atmospheric Modeling (SAM) cloud-resolving model. We simulate a 3d 'channel', representing an equatorial strip that covers both day- and nightside of a tidally locked planet. We use interactive radiation and an interactive slab ocean surface and investigate the response to changes in the stellar constant. We find mean climates that are broadly comparable to those produced by a GCM. However, when the slab ocean is shallow, we also find internal variability that is far bigger than in a GCM. Convection in a tidally locked domain can self-organize in a dramatic fashion, with large outbursts of convection followed by periods of relative calm. We show that one of the timescales for this behavior is set by the time it takes for a dry gravity wave to travel between day- and nightside. The quasi-periodic self-organization of clouds can vary the planetary albedo by up to $\sim$50%. Changes this large are potentially detectable with future space telescopes – raising the prospect of using convectively-driven variability to identify high-priority targets in the search for life around other stars.