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Understanding precessional variations in tropical precipitation

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Paleo-records of various climate variables show significant variability at precessional timescales even though the precessional cycle is associated with a zero annual mean forcing. This points at the existence of nonlinear rectification mechanisms translating the zero-annual-mean forcing into a non-zero-annual-mean response. While the need for such mechanisms in the climate system has been previously acknowledged, very little work has been done to specifically identify and understand them.

Traditionally, precession is thought to have the largest signature on tropical climate, in particular the monsoon systems. Indeed, high-resolution stable oxygen isotope records – proxies for monsoon strength – from Chinese and Brazilian caves display strong precessional variability. The Chinese and Brazilian records anti-correlate on orbital timescales, suggesting an interhemispheric anti-phasing of rainfall or in other words precessional movements of the ITCZ. A similar interhemispheric anti-phasing is found in climate simulations of the past 140 kyr.

In the tropics a nonlinear relationship exists between SSTs and convective precipitation which represents a potential rectification mechanism for the precession forcing: a change in the seasonality of tropical SSTs will translate nonlinearly into a change in annual mean precipitation. Because the effect of precession on the range of the seasonal cycle in SST is out of phase between the northern and southern hemisphere, this rectification mechanism might account for the precessional movements of the ITCZ.

Two climate simulations of the last 140 kyr were available for an in-depth analysis of this rectification mechanism: a run of ECHO-G – with orbital forcing only – and a run of LOVECLIM – with both orbital and ice sheet forcing. For both models we parameterized the relationship between tropical SSTs and precipitation and used this to estimate the convective rainfall. We found that the parameterized precipitation shows a good agreement with the modelled precipitation in large parts of the tropical ocean, most notably the eastern equatorial Pacific and tropical Atlantic. In other parts of the ocean, such as the western warm pool and the ITCZ region, the parameterization works less well. Here precipitation is not driven by local SSTs, but rather by anomalous monsoonal wind-convergence driven by SST gradients. Due to the coupled nature of the tropical ocean-atmosphere system, SST induced convection and precipitation changes will drive additional circulations that will be associated with convection and descending motion. We therefore forced the intermediate tropical atmosphere model of Fu & Wang (1999) with the ECHO-G SSTs to distinguish between the thermodynamic and dynamic response of the atmosphere and to explain simulated tropical precipitation variations in ECHO-G and LOVECLIM that exhibit more complex orbital signals.