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A Conceptual Model for the Response of Tropical Rainfall to Orbital Variations

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Tropical rainfall to first order responds to variations in Earth's orbit through shifts of the Intertropical Convergence Zone (ITCZ) and changes in zonally averaged rainfall intensity. We have developed a conceptual model that represents both processes and their response to orbital insolation variations. The model predicts the seasonal evolution of tropical rainfall between 30°S and 30°N. Insolation variations impact seasonal rainfall in two different ways: thermodynamically, leading to variations in rainfall intensity through modulation of the water vapor content of the atmosphere; and dynamically, leading to shifts of the ITCZ through modulation of the global atmospheric energy budget. Thermodynamic and dynamic effects act together to shape the annual-mean response of tropical rainfall to changes in Earth's orbit. The model successfully reproduces changes in annual-mean rainfall inferred from paleoproxies across several glacial-interglacial cycles. It illuminates how orbital precession and variations of Earth's obliquity affect tropical rainfall differently near the equator and farther away from it, with spectral signatures of precession and obliquity variations that shift with latitude. It also provides explanations for the observed different phasings of rainfall minima and maxima near the equator and away from it. For example, the model reproduces a phase shift of $\sim$10 ka between rainfall records from caves in Northern Borneo (4°N) and from China (approximately 30°N). The model suggests that such phase shifts arise through a different weighting of ITCZ shifts and variations in rainfall intensity, thus providing insight into the mechanisms that drive tropical rainfall changes on orbital time scales.