Modality and seasonal variation of the tropical rain belt across climates and models

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The tropical rain belt is composed of rain bands that lie along the rising branches of the tropical atmospheric overturning circulation. The properties of these rain bands determine the zonal-mean tropical precipitation distribution, which varies between uni- and bimodality. Here we define tropical modality as an index that varies continuously between 1 and 2 for purely uni- and bimodal distributions. We examine the relation of tropical modality to the seasonal cycle of the tropical rain belt across a wide range of climate models from phases 5 and 6 of the climate model intercomparison project, simulations of Earth's climate over geological timescales (~300Ma to present), and observations. Our analysis shows that modality is an essential characteristic of tropical climate, which binds together fundamental properties of the tropical rain belt and its associated tropical overturning circulation. Specifically, tropical modality is found to efficiently parse differences across models and climates, especially in regions where variance is greatest. Increased tropical modality (i.e., tendency toward bimodality) is strongly related to increased width of the tropical rain belt, wider and weaker Hadley circulation, colder equatorial cold tongues, and more severe double-intertropical convergence zone bias in modern climate models. As tropical modality increases, considering shifts of hemispheric precipitation peaks becomes crucial. In particular, counter to general wisdom, for large tropical modality (i.e., ~2), seasonal migrations of the tropical rain belt do not follow the Hadley circulation paradigm, to the extent that hemispheric rain bands might not follow the Sun.