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Multi-decadal to millennial scale variation in the South American summer monsoon during the Holocene

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Zhou and Lau (1998) were the first to formally describe the South American summer monsoon (SASM), which is now recognized as the major driver of precipitation in most of the tropics and sub-tropics of the continent. Inter-annual variability in the intensity and duration of the SASM produces economically and environmentally important variability of tropical precipitation, such as the austral summer Amazonian drought of 2005. Yet, little is known about the causes of inter-annual variability, beyond its weakly significant association with ENSO. On longer timescales, the lack of instrumental records has precluded inference of extrinsic factors that force decadal and longer timescale variability of tropical SA precipitation.

For the past several years, we have used lacustrine sediment records in the tropical central Andes to reconstruct the history of effective moisture. On orbital timescales, regional lakes show massive changes in lake level due to mechanisms related to global-scale drivers, such as forcing of the SASM by summer insolation varying at precessional timescales. Thus, lake levels were high during the Last Glacial Maximum and decreased more than 85 m during the mid-Holocene. Here we use stable isotopic and paleobiotic records from Lake Titicaca, as well as two smaller lakes in the Lake Titicaca drainage basin, to show that multi-decadal to millennial scale precipitation variability is superimposed upon the envelope of change at orbital time scales. A quantitative reconstruction of precipitation from stable isotopic data indicates that the central Andes underwent significant wet/dry alternations at multi-centennial frequencies with an amplitude of 30 to 40% of total precipitation. The variation is similar in timing and pattern to the ice-rafted debris record of Holocene Bond events in the North Atlantic, suggesting that tropical/North Atlantic sea-surface temperature (SST) variability may partly control regional (monsoonal) precipitation. In the instrumental pe-

riod, regional precipitation variability on inter-annual timescales is clearly influenced by Pacific modes; for example, most El Ninos produce dry and warm conditions in much of tropical South America, including the central Andes. However, on longer timescales, the existence of tropical Pacific modes is less clear, much less their control on precipitation in tropical South America. Our reconstructions suggest that the cold intervals of the Holocene Bond events are periods of increased precipitation in the central Andes, thus indicating an anti-phasing of precipitation variation in the southern tropics of South America relative to the Northern Hemisphere monsoon region. If solar forcing of monsoon variation at multi-decadal to millennial time scales is to be supported, the mechanism must rationalize the asymmetry of precipitation response on opposite sides of the equator.