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Atacama Desert paleo-humidity of the last 10 Ma quantified by triple oxygen and hydrogen isotopes in gypsum

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Recurring lake deposits in the Atacama Desert suggest that pluvial intervals interrupted hyperaridity in Earth's driest desert during the generally warmer-than-present Miocene. Global climatic changes and local ones related to uplift and basin drainage events are debated as causes of these humid intervals, which may also represent potentially future global warming scenarios. Here, we use stable isotopes (^{1}H, ^{2}H, ^{16}O, ^{17}O, ^{18}O) of paleo-lake water preserved in crystal-bonded water of U-Pb dated gypsum to precisely quantify relative humidity (RH) and the isotopic compositions of vapour and meteoric water over the Miocene pluvial Atacama Desert. An atmosphere with RH = 69 (62,77) %, much higher than present-day RH = 45% implies that lower evaporation rather than more rainfall sustained the late Miocene Atacama Desert *Tilliviche* lake 9 Ma ago. A lower $\delta^{18}O$ of Miocene atmospheric vapour by 6.7 (3.0,10.4) ‰ suggests intensified hydrologic cycling in the desert's vapour advection path and weaker Hadley cell subsidence. This represents Southeastern Pacific hydroclimatologic conditions 1 Ma before the global subtropical expansion of drought-tolerant C4 plants. Local uplift and fluvial erosion subsequently defined the landscape's topography and extent of wetlands, but reduced tropical vapour export determined Atacama Desert extreme hyperaridity.