

# ENSO sentinels in the Americas' humid tropics: We need combined hydrometric and isotopic monitoring for improved El Niño and La Niña impact prediction

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## Abstract

The El Niño-Southern Oscillation (ENSO) phenomena, originating in the tropical Pacific region, is an interannual climate variability driven by sea surface temperature and atmospheric pressure changes that affect weather patterns globally. In Mesoamerica, ENSO can cause significant changes in rainfall patterns with major impacts on water resources. This commentary presents results from a nearly 10-yr hydrometric and tracer monitoring network across north-central Costa Rica, a region known as a headwater-dependent system. This monitoring system has recorded different El Niño and La Niña events, as well as the direct/indirect effects of several hurricane and tropical storm passages. Our results show that ENSO exerts a significant but predictable impact on rainfall anomalies, groundwater recharge, and spring discharge, as evidenced by second-order water isotope parameters (e.g., line conditioned-excess or LC-excess). The Oceanic Niño Index (ONI) is correlated with a reduction in mean annual and cold front rainfall across the headwaters of north-central Costa Rica. During El Niño conditions, rainfall is substantially reduced (by up to 69.2%) during the critical cold fronts period, subsequently limiting groundwater recharge and promoting an early onset of baseflow conditions. In contrast, La Niña is associated with increased rainfall and groundwater recharge (by up to 94.7% during active cold front periods). During La Niña, the long-term mean spring discharge (39 Ls<sup>-1</sup>) is exceeded 63-80% of the time, whereas, during El Niño, the exceedance time ranges between 26% and 44%. These stark shifts in regional hydroclimatic variability are imprinted on the hydrogen and oxygen isotopic compositions of meteoric waters. Drier conditions favored lower LC-excess in rainfall (-17.3 and spring water (-6.5 values (rainfall=+17.5LC-excess values in rainfall corresponded to the very strong 2014-16 El Niño and 2018 La Niña, respectively. During the recent triple-dip 2021-23 La Niña, LC-excess exhibited a significant and consistently increasing trend. These findings highlight the importance of combining hydrometric, synoptic, and isotopic monitoring as ENSO sentinels to advance our current understanding of ENSO impacts on hydrological systems across the humid Tropics. Such information is critical to constraining 21<sup>st</sup> century projections of future water stress across this fragile region.

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