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A modal/thermodynamic attribution analysis suggests that climate change is making La Niña and El Niño events stronger, longer and more energetic

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As the science of climate attribution continues to gain importance, we should remember that this discipline reaches back to the 1920s, when catastrophic droughts motivated research into the Southern Oscillation (Walker and Bliss 1932). Climate attribution existed before human-induced climate change, and this deep literature belies recent suggestions that limited research categorically constrains contributions to efforts like loss and damage compensation (King et al. 2023). Some hazards, like droughts and extreme temperatures, are much easier to link to climate change (Noy et. al, 2023). ENSO-related droughts, in particular, represent a very important and well-studied type of hazard. Techniques for linking droughts to impacts in food insecure countries are well-developed, and formal attributions of eastern and southern African droughts (e.g. Funk et al. 2016, 2018, 2019, 2023A, 2023B) have supported advances in long-lead forecasting.

Building on this work, in this talk we connect 'modal' analyses of sea surface temperatures (SST) with an evaluation of reanalysis 'atmospheric heating'. Our modal framework grows out of analyses of ENSO-residual SST (Compo and Sardeshmukh, 2010; Newman and Solomon 2012; Lyon et al. 2014); most of the variance of observed and simulated global SST can be described an ENSO mode and an ENSO-residual West Pacific Warming Mode (WPWM, Funk and Hoell 2015; Funk 2023B).

In this talk we describe observed and CMIP6-simulated changes in ENSO and WPWM Principal Components (PC) time series, and highlight the real-world implications of two key characteristics: the long term increases in both, and their modest inverse correlation on decadal time scales, which leads to more extreme ocean states. Strong El Niños correspond to large ENSO PC values. La Niña events in a warming Pacific Ocean are associated with exceptionally warm west Pacific SST, corresponding to the increasing WPWM PC, and La Niña-related droughts (Funk et al. 2023B).

While these PC extremes produce very warm Pacific SST, and strong SST gradients, formally evaluating the impact of these SST patterns can be challenging. Tropical Pacific atmospheric heating, which drives many ENSO-related teleconnections provides a useful metric of ENSO strength. This heating combines diabatic heating due to precipitation, radiation, sensible heating

and evaporation and adiabatic heating due to heat convergence. Using 1950-2023 ERA5 reanalyses, and CPC Oceanic Niño Index-based ENSO event definitions, we suggest that ***when ENSO events occur***, ENSO-related atmospheric heating extremes have become substantially and significantly more energetic. Contrasting 1996-2022 and 1950-1996 El Niño events, we find very large increases in January-to-June heating over the equatorial eastern Pacific. A similar contrast for La Niña events indicates large heating increases over the western Pacific that extend from June of into September of the following year. Hence, ENSO events are likely becoming stronger and longer due to climate change. We conclude by showing how CMIP6 SST simulations and statistical heating/SST relationships can be used to estimate climate change-related enhancements to these heating extremes.

Facing a future "*characterized by unprecedented aridification/wetting punctuated by more severe extremes*" (Stevenson et al. 2021), these insights can help support the formal attribution of ENSO-related droughts.