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Linking Extreme ENSO Years to the Global Methane Budget

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The El Niño–Southern Oscillation (ENSO) plays a notable yet limited role in modulating atmospheric methane (CH_4) concentrations, accounting for up to **36% of its interannual variability**, particularly in the **southern tropics** (Schaefer et al., 2018). ENSO-driven climate anomalies influence CH_4 fluxes through changes in **wetland emissions, biomass burning, and soil** CH_4 **uptake.** While **El Niño-induced droughts** enhance soil CH_4 consumption in tropical wet forests (Aronson et al., 2019) and suppress wetland emissions, La Niña leads to increased wetland CH_4 production (Hodson et al., 2011). Understanding the drivers of atmospheric CH_4 variability is critical for constraining the global budget and mitigating climate impacts. Strong ENSO periods influence CH_4 emission and removal rates, affect atmospheric chemistry through the abundance of hydroxyl and ozone, and moderate microbial processes, with effects that are spatially and temporally complex.

Using dual isotope-informed inversion modeling, we evaluate ENSO-driven CH_4 flux variations by comparing top-down atmospheric observations with bottom-up inventory estimates across multiple emission scenarios. These scenarios include ENSO-weighted prior emissions, CO-based pyrogenic inversions (Zhao et al., 2025), and multimodal mean estimates for wetland and biomass burning emissions. Our findings support that El Niño reduces wetland CH_4 emissions while increasing pyrogenic emissions, leading to higher $\delta^{13}CH_4$ values, whereas La Niña enhances wetland emissions and suppresses pyrogenic sources, decreasing $\delta^{13}CH_4$ values. Notably, prior emissions (e.g. LPJ-wsl) from wetlands correlate more strongly with ENSO than posterior estimates, suggesting inversion overestimation, while posterior emissions from pyrogenic sources exhibit stronger ENSO correlations than priors (e.g. ACCMIP/MACCity, GFAS), indicating inventory underestimation. ENSO-adjusted priors for pyrogenic emissions before 2000 are lower than top-down inverted estimates, particularly in the Northern Hemisphere. Some ENSO years exhibit a phase lag between hemispheric pyrogenic emissions, likely due to tropospheric OH variability. Our findings refine existing CH_4 budget estimates by distinguishing ENSO-driven emissions from background variability. Given methane's short atmospheric lifetime and its high global warming potential (≈80 times that of CO_2 over 20 years), accurately modeling ENSO-driven fluxes is essential for predicting future atmospheric trends and assessing its role in global climate feedback mechanisms.