Unravelling the role of atmospheric nonlinearities to sea surface temperature to ENSO asymmetrical rainfall response

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Introduction

- The El Niño Southern Oscillation (ENSO) arises from air-sea interactions in the tropical Pacific and affects climate worldwide through atmospheric teleconnections. El Nino is characterized by anomalously warm Sea Surface Temperature (SST) anomalies in the central and eastern equatorial Pacific and by enhanced deep atmospheric convection and westerly wind anomalies in the central equatorial Pacific. While La Niña can broadly be viewed as a mirror image of El Niño, asymmetries between these two ENSO phases have recently become a prominent research interest.
- This interest relates to the fact that El Niño events can occasionally reach much larger amplitudes than La Niña events, like in 1982, 1997 and 2015. The most obvious ENSO asymmetry is related to its amplitude, with stronger El Niño than La Niña SST and rainfall anomalies in the eastern Pacific and the nonlinearities (both atmosphere and ocean) are required to explain ENSO asymmetries (An et al. 2020). Here, in the study we focus on the relative roles of atmospheric nonlinearities and asymmetrical SST anomalies forcing to ENSO asymmetrical rainfall response during its peak phase.

Data and Methods

- The monthly mean fields of SST, precipitation, evaporation and the 3-dimensional specific humidity, zonal and meridional components from the latest version of European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis (ERA5; Hersbach et al. 2020).
- The vertically integrated water budget

$$\frac{d<W>}{dt} = <E> - <P> + <V_{tot}> + <I> \qquad (1)$$

$$<V_{tot}> \equiv -<\vec{\nabla}\left(\frac{1}{g}\int_{p_s}^{p_t}\vec{v}q\,dp\right)> = -\vec{\nabla}\left(\frac{1}{g}\int_{p_s}^{p_t}(\langle\vec{v}\rangle\langle q\rangle + \langle\vec{v}''q''\rangle)dp\right) \approx V_{lf} + V_{hf} \qquad (2)$$

Equation (1) states that low-frequency filtered total atmospheric column water vapour (<W>). The source term associated with surface evaporation (<E>), a sink term precipitation (<P>), and a sink or source term associated with vertically-integrated moisture convergence ($<V_{tot}>$) and <I> is the residual. We further decompose V_{tot} into contributions from intra-seasonal (V_{hf}) and low-frequency (V_{lf}) q and $\vec{v}$ components. V_{lf} is the first-order linear function of convergence. Given this relationship, V_{lf} can be approximated as:

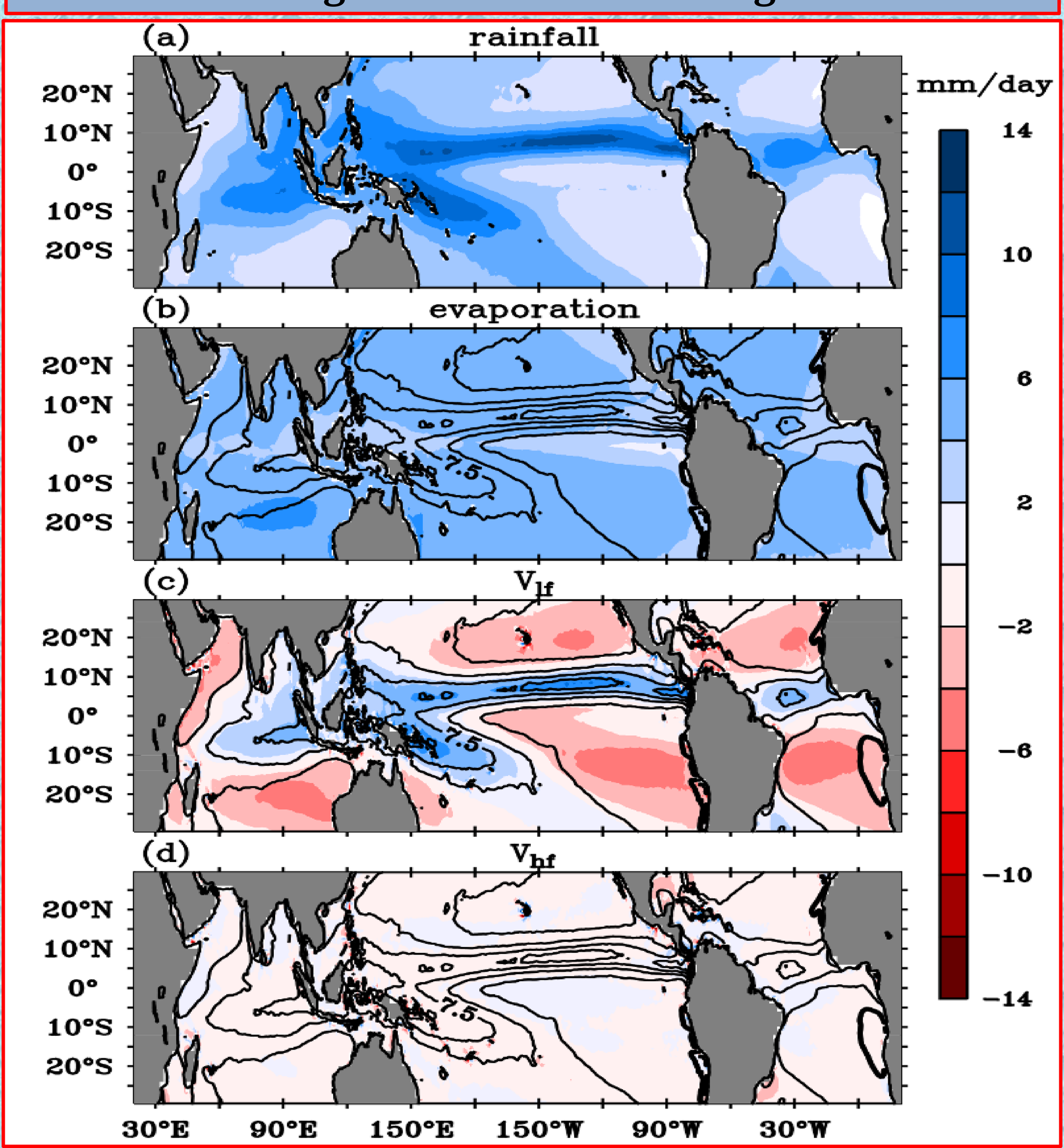
$$V_{lf} \approx V = -m(T)(d - d_0) \qquad (3)$$

Here, m(T) is the SST-dependent gross moisture stratification and can be obtained as the slope of various curves displayed in Figure 4.

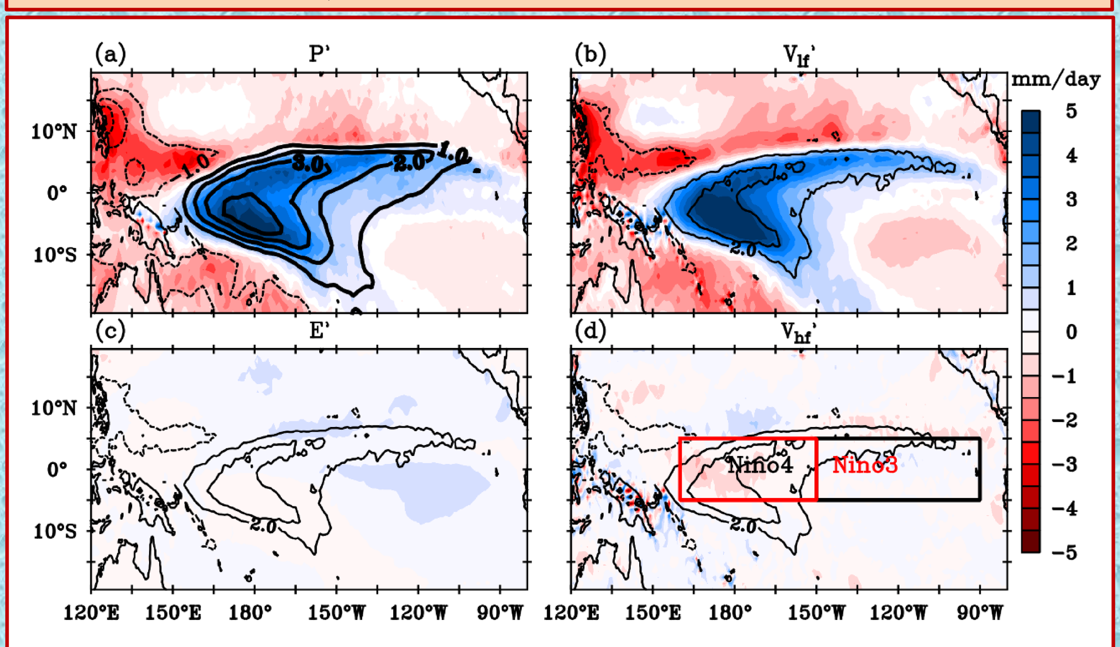
Results and discussion

Vertically integrated water budget

Climatological means of the budget terms

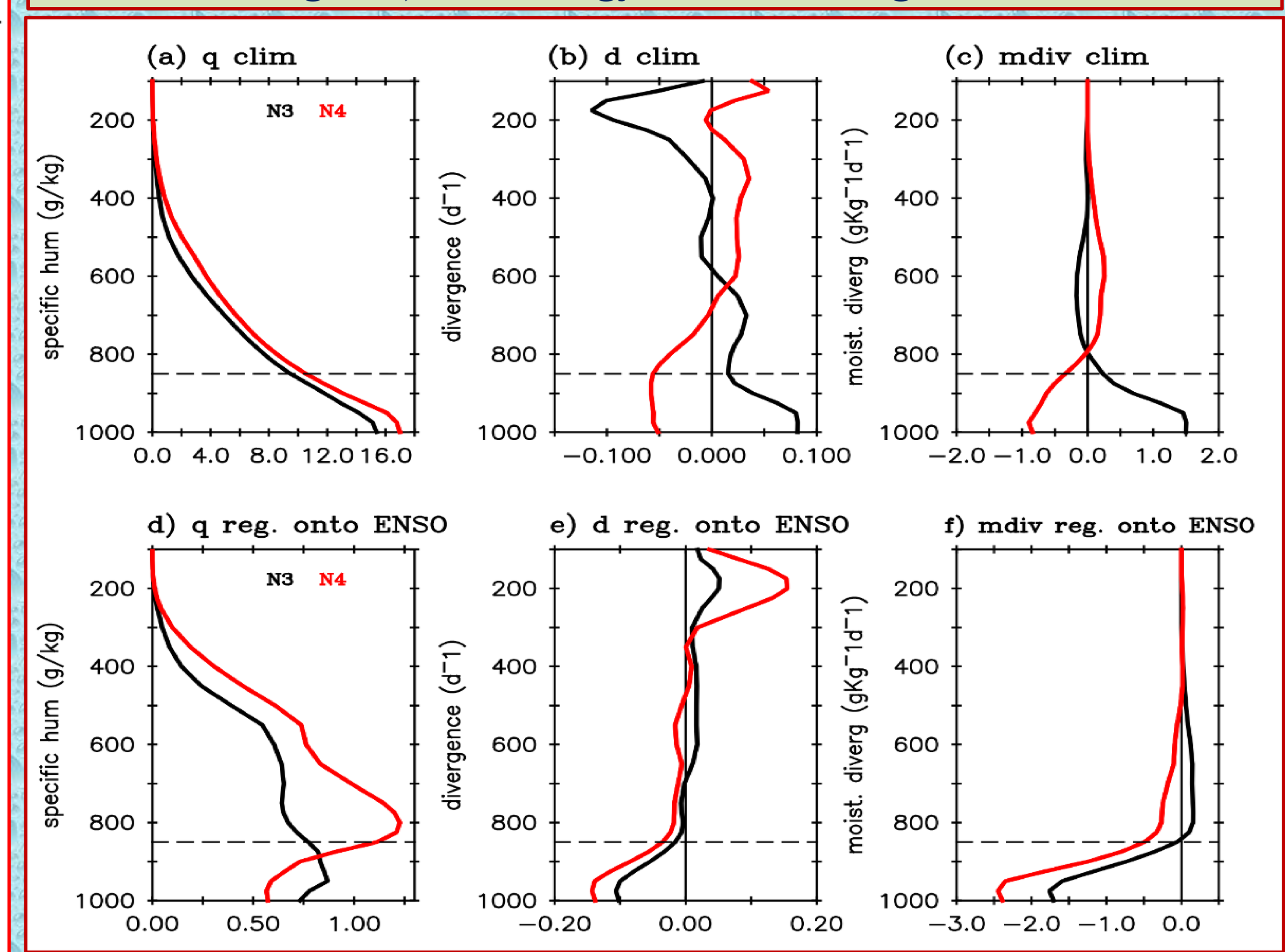


DJF seasonal means of ENSO symmetrical anomalous vertically-integrated moisture budget terms. The ENSO symmetrical composite is ½ x (El Nino – La Nina).

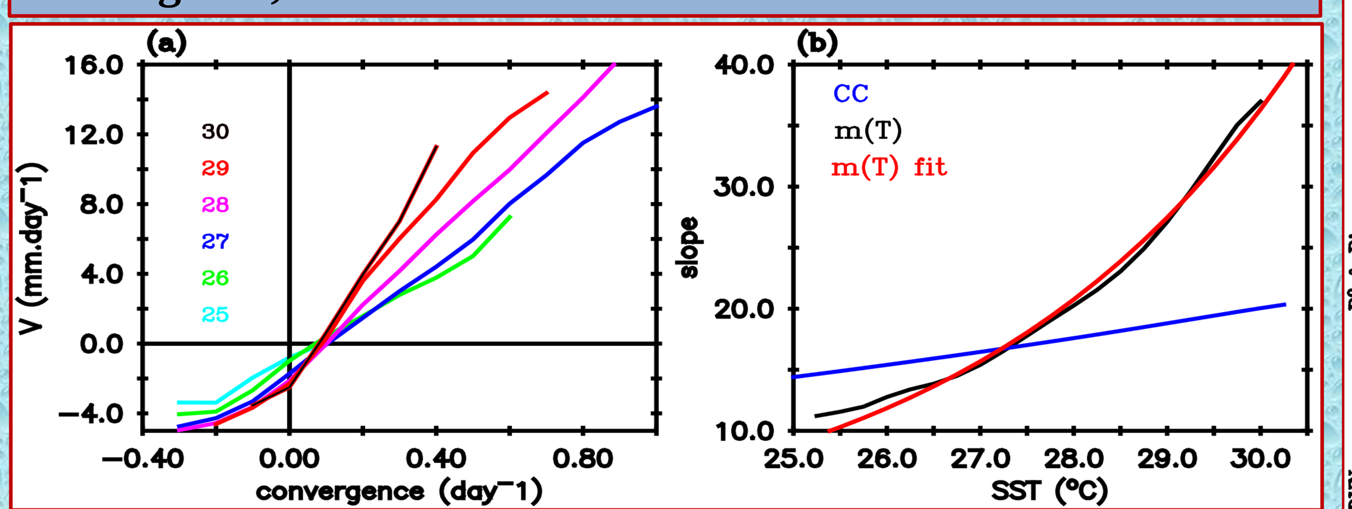


Precipitation as a function of surface properties

Vertical profiles (specific humidity, divergence and near-surface moisture divergence) climatology and ENSO regressions.



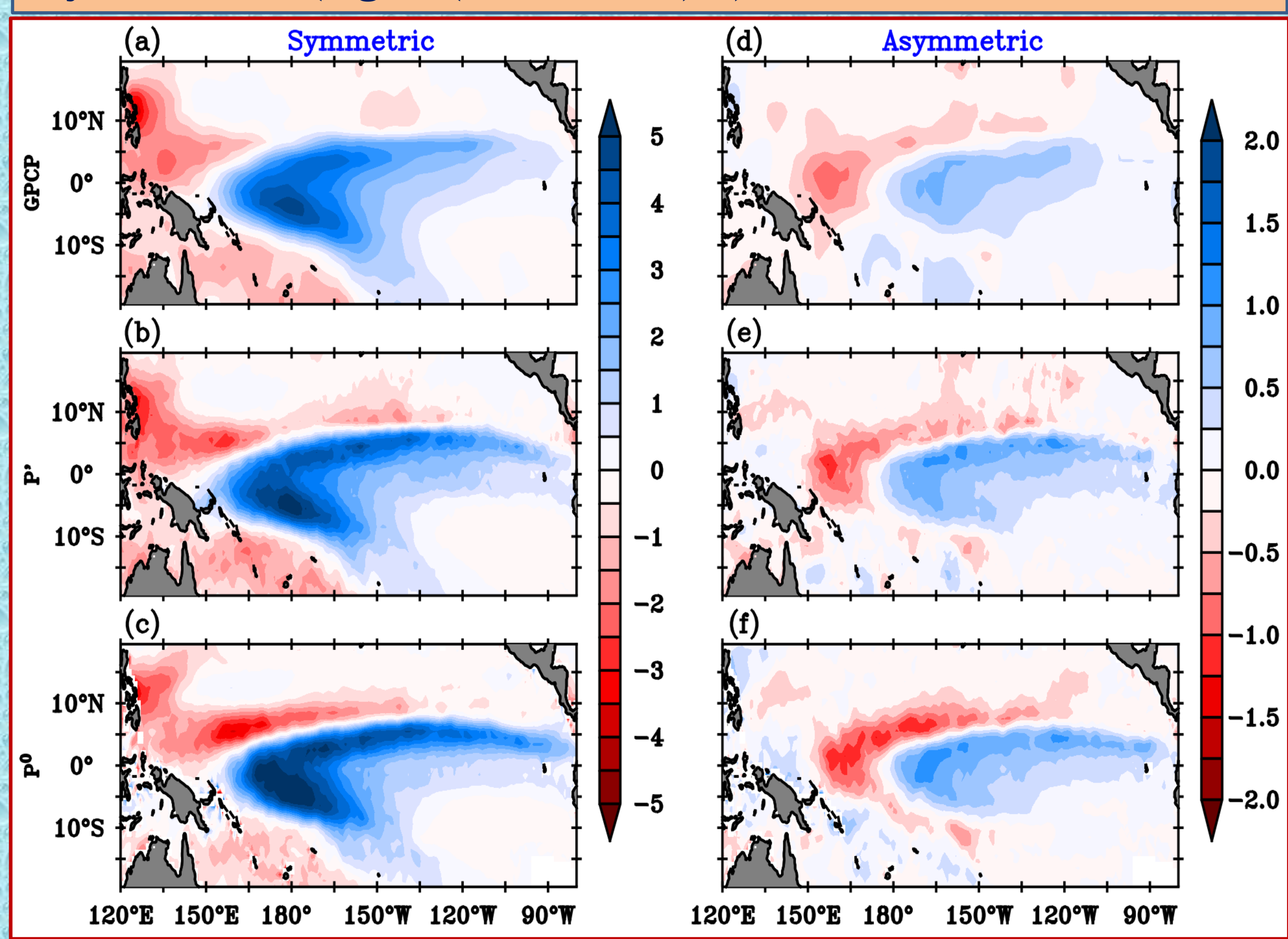
low-frequency components of the vertically-integrated moisture convergence V_{lf} as a function of 1000-850 hPa average convergence, for various SST.



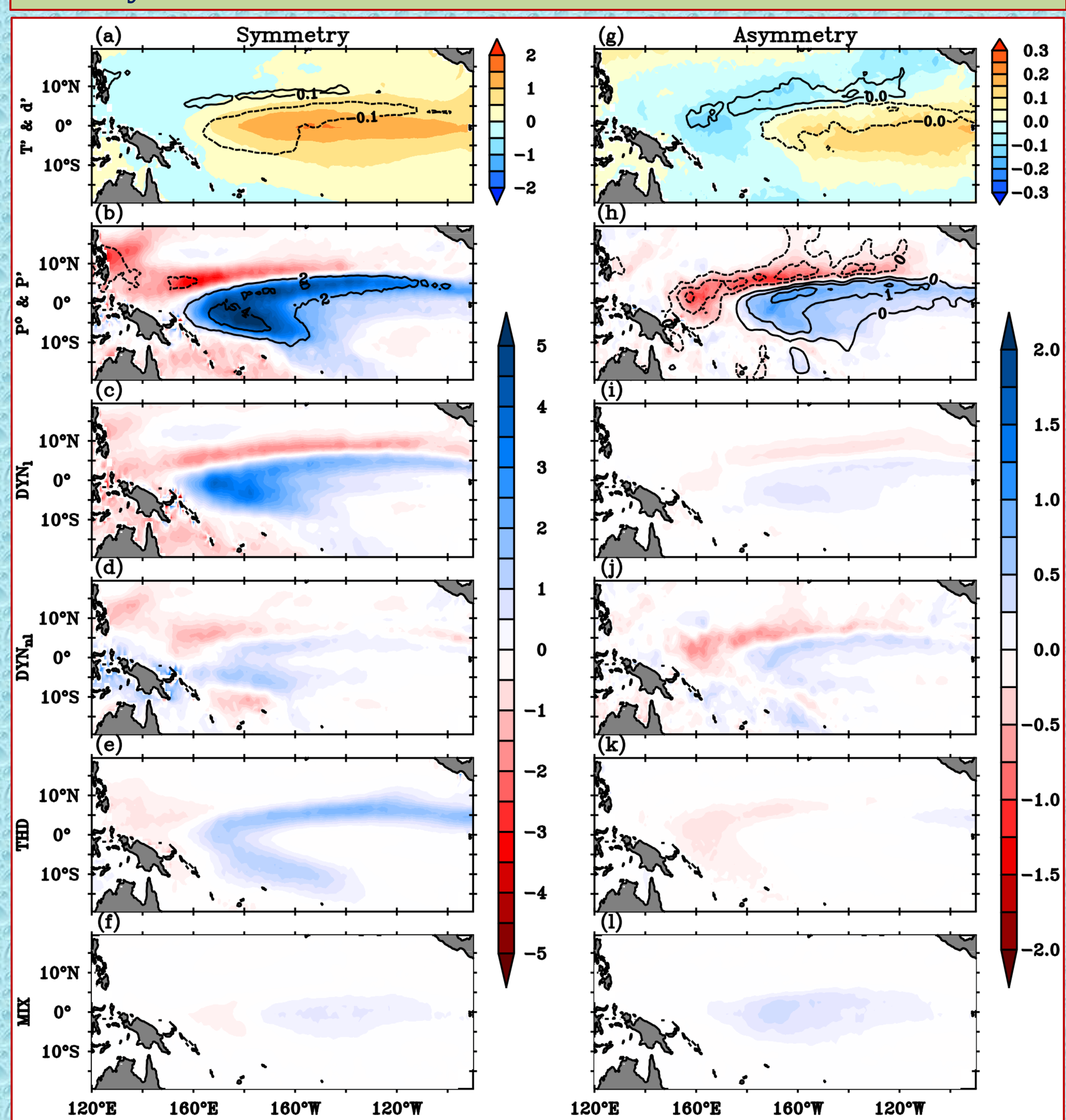
- The SST-dependent gross moisture stratification m(T) can be fitted as $m(T) = m_0 e^{\beta(T-T_0)}$ (black curve) where T_0=25°C, β =0.28 °C^{-1} and m_0 =9 mm.
- $P' \approx P^0(\bar{T},\bar{d},T',d') = -m(\bar{T})\left(\underbrace{d'}_{DYN} + \underbrace{\beta(\bar{d}-d_0)T'}_{THD} + \underbrace{\beta(T'd')'}_{MIX}\right)$

El Niño-La Niña precipitation asymmetries

ENSO composite symmetrical (left, (Niño-Niña)/2) and asymmetrical (right, (Niño+Niña)/2) anomalies.



P^0 various budget terms contribution to ENSO symmetrical and asymmetrical anomalies



	P° asymmetry (mm)	SST contrib. (%)	Atm. NL contrib. (%)
CEP	0.42	30	70
WP	-0.43	53	47

Summary and conclusions

- Here, we investigated the relative roles of atmospheric nonlinearities and asymmetrical SST forcing in the El Nino–Southern Oscillation (ENSO) asymmetrical rainfall response.
- Applying a vertically integrated water vapor budget to the ERA5 reanalysis leads to a simple analytical equation for precipitation anomalies.
- ENSO rainfall anomalies are dominated by the linear component of the dynamical term (i.e., the anomalous moisture convergence due to the effect of circulation anomalies on climatological humidity).
- Nonlinearities in this term and the linear thermodynamical term (i.e., the effect of climatological circulation on humidity anomalies) both strengthen central Pacific rainfall anomalies for both ENSO phases.
- Overall, atmospheric nonlinearities directly account for ~70% of the positively skewed ENSO rainfall distribution east of the date line, and ~50% of the negatively skewed rainfall distribution in the western Pacific.

References

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