Nonlinearity in the Northern Hemisphere atmospheric response to a linear ENSO forcing

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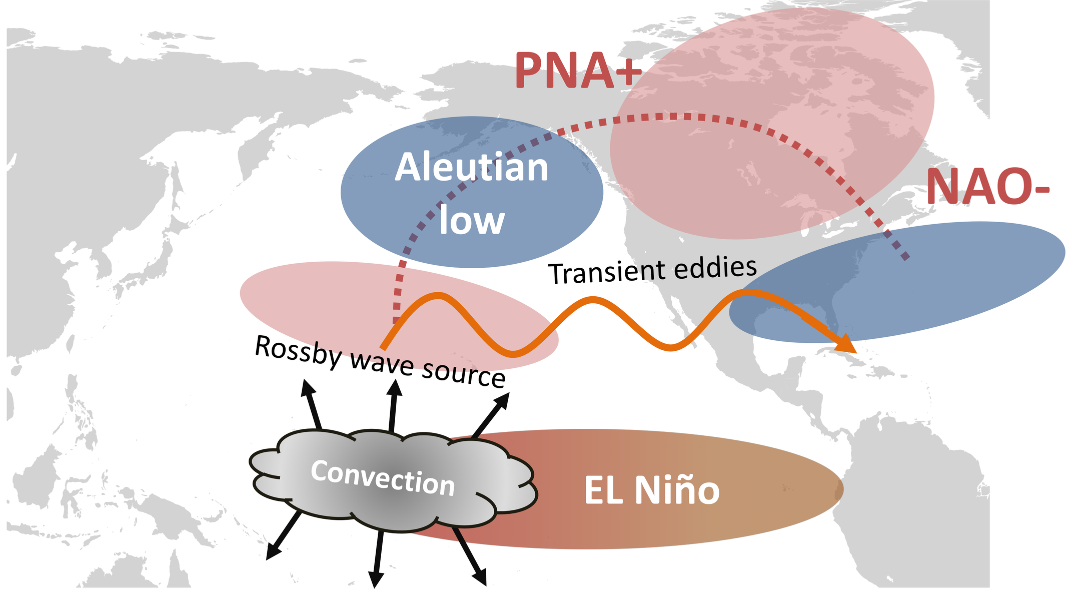
1 Introduction

El Niño Southern Oscillation (ENSO) exerts a remote impact on the North Pacific and North American winter climate. Both observational and model studies have suggested nonlinearities in this teleconnection. However, it remains unclear if possible nonlinearities arise from the forcing strength or the forcing location in the tropical Pacific, or from factors external to the tropical Pacific. To separate these factors, an idealized model is forced with seasonally varying sea surface temperature (SST) with **linearly varying strength at a fixed location.**

Nonlinearity in the North Pacific response has important impacts on the **teleconnection to the North Atlantic/European region across North America** and through the stratosphere (Jiménez-Esteve and Domeisen, 2018). In addition, nonlinearity in ENSO teleconnections may have important consequences for potential changes in the diversity of ENSO with climate change.



Schematic of the El Niño wintertime North Pacific teleconnection

Red/blue shading denote positive/negative geopotential anomalies. The dotted red line indicates the direction of propagation of the PNA Rossby wave train.

2 Model Simulations

In this study we use **Isca** (Vallis et al., 2018), a framework for idealized modelling of the global circulation of planetary atmospheres. It uses the **GFDL dynamical core** and simplified parametrizations, including **moist and radiative processes.**

We design a set of **experiments to mimic the tropical Pacific ENSO-like SST forcing**. The simulations consist of a climatological run, following the 1958-2016 monthly climatology from NOAA ERSSTv4 (Huang et al. 2015), and 4 experiments with ENSO-like forced SSTs (with **linearly varying strength at a fixed location**). Forced SST anomalies are obtained by regressing the standardized ONDJF mean Niño3.4 index onto the SST field for each month into the future for January to July and into the past for December to May. To generate a **smooth seasonal cycle** the May–July values are averaged between the regressions into the future and the past.

MODEL CONFIGURATION

- T42 resolution and 50 levels in the vertical up to 0.02 hPa
- Prescribed seasonally evolving sea surface temperatures and sea ice.
- Simple convection scheme (Betts-Miller) but no cloud microphysics.
- Multi-band radiation scheme (CO_2, ozone, water vapor)
- Realistic topography and land-sea contrast following Thomson and Vallis (2018)

Experiments	Years	NINO3.4 DJF anomaly
Strong El Niño	129	3.0 K
Moderate El Niño	129	1.5K
Climatology	130	0.0 K
Moderate La Niña	129	-1.5K
Strong La Niña	129	-3.0K

3 From the tropical convection to the Aleutian low

First, we study the model North Pacific winter (DJF) response to the 4 idealized tropical Pacific ENSO SST forcings (see table in section 2) . We analyze the response in terms of precipitation, upper tropical troposphere divergent wind and North Pacific sea level pressure (SLP). The chain of mechanisms that lead to the nonlinear North Pacific response is described below.

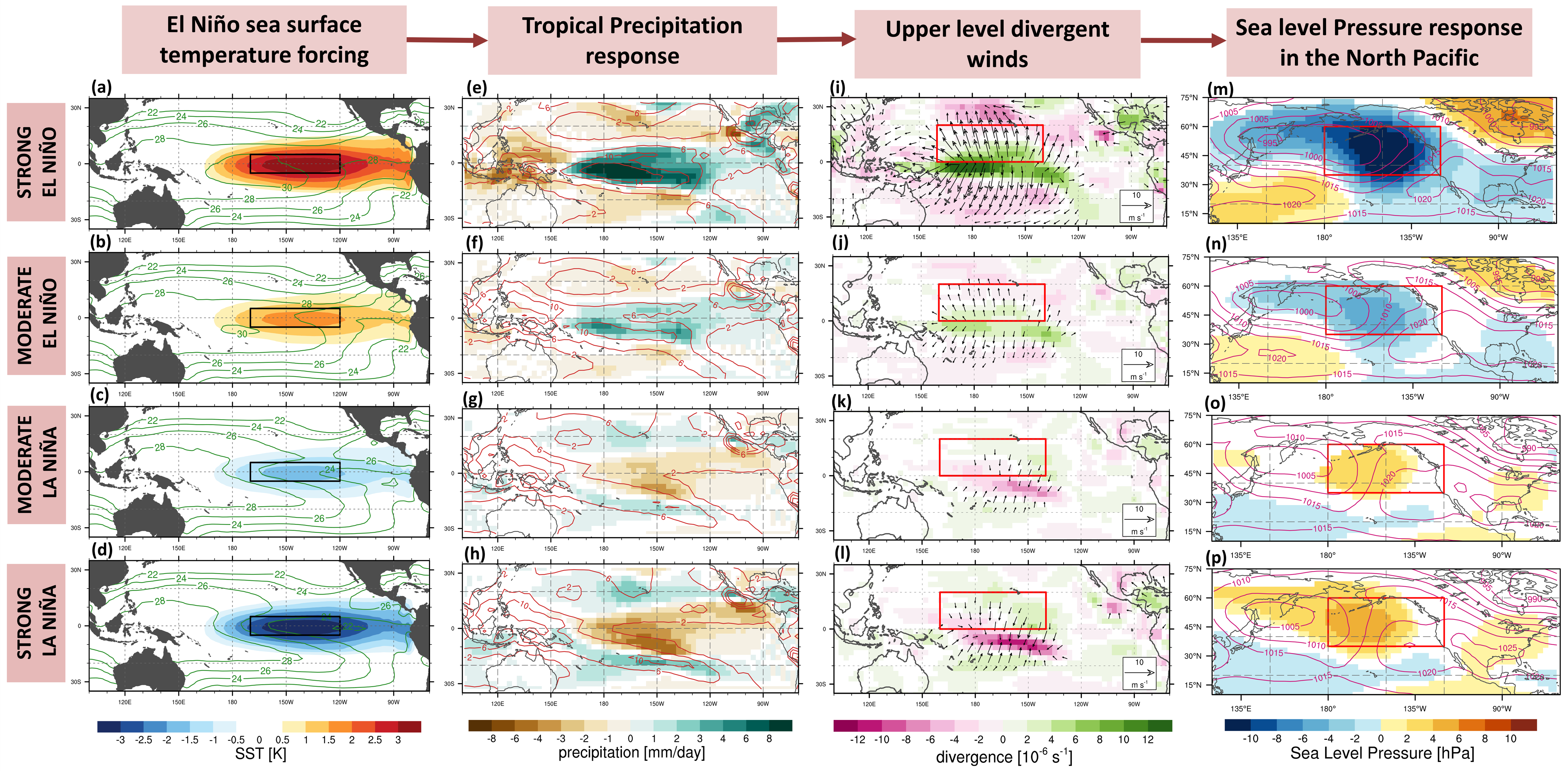


__Figure 1 .__ (a–d) December-January-February (DJF) SST forcing, (e–h) mean precipitation (resolved + parameterized), (i-l) divergence (shading) and the associated divergent wind (arrows) response at 150 hPa and (m–p) SLP response in the North Pacific region, for strong and moderate El Niño and strong and moderate La Niña forcings. Red boxes indicate the area where (i–l) the meridional divergent wind and (m–p) the Aleutian low SLP indices are defined, that is, [0–20◦N, 160–220◦E] and [35–60◦N, 180–240◦E], respectively. Only statistically significant values above the 99% confidence level are shown. Contour lines indicate absolute values of the respective fields

4 Seasonal evolution

- While the forced SSTs are linearly spaced by design, the divergent wind response exhibits nonlinear behavior with respect to the forcing. This nonlinearity also appears in the extratropical SLP response.
- For strong El Niño events SLP anomalies in the eastern North Pacific reach almost -10 hPa in JFM, whereas for moderate events they only reach −3 hPa. For moderate La Niña the DJF SLP anomalies reach around 2 hPa and for strong La Niña only slightly over 3 hPa.
- The peak in SST anomalies is in December (see NDJ mean), while for the upper divergent wind the response peaks 1 month later (DJF).

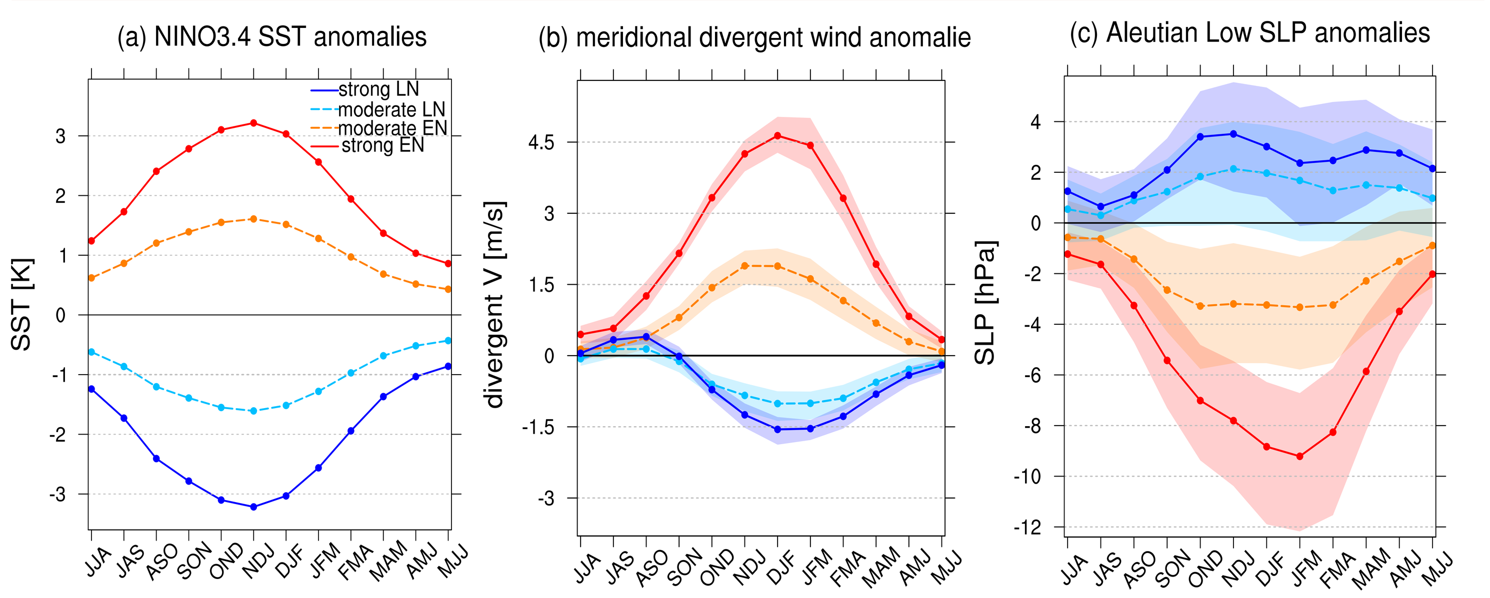


__Figure 2.__ Seasonal evolution of the 3-month running mean of (a) the Niño3.4 index anomalies, (b) the meridional divergent wind index response, and (c) the Aleutian low SLP index response. Shading upper and lower limits display the upper and lower quartiles, respectively. The indices are computed by averaging over the boxes in Figures 1.

5 On the origin of the nonlinearity

The nonlinearity can be traced back to the relationship between the SST and the tropical upper troposphere divergent wind (due to convection). The relationship between the divergent wind and the extratropical SLP response is very linear.

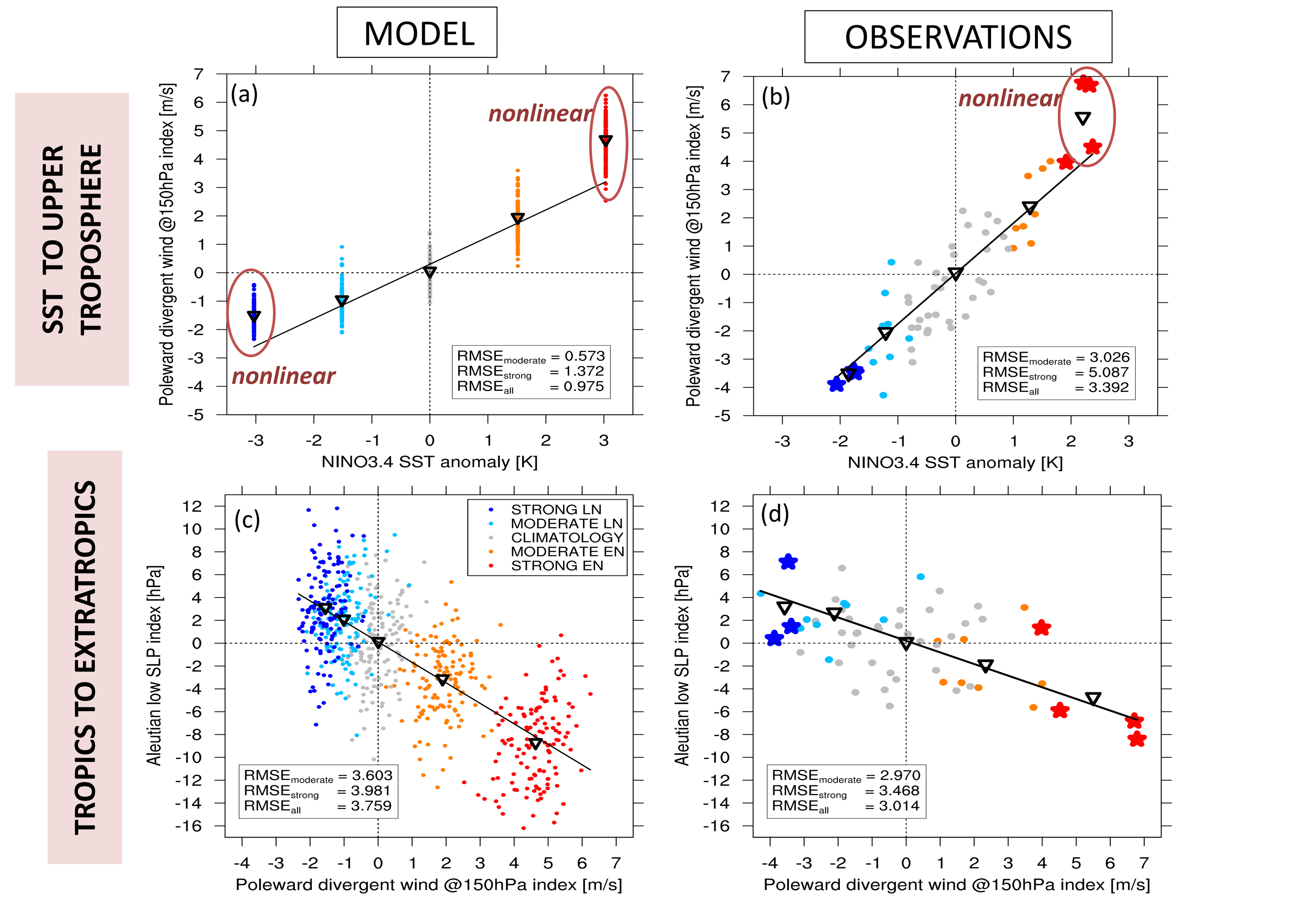


__Figure 3 .__ (a) Isca model and (b) JRA-55 reanalysis (Kobayashi et al., 2015) DJF tropical upper troposphere poleward divergent wind anomaly index with respect to the Niño3.4 anomaly. Panels (c) and (d) as in panels (a) and (b) but for the poleward divergent wind and the Aleutian low SLP anomaly indices, respectively.

6 Spatial pattern of the nonlinearity

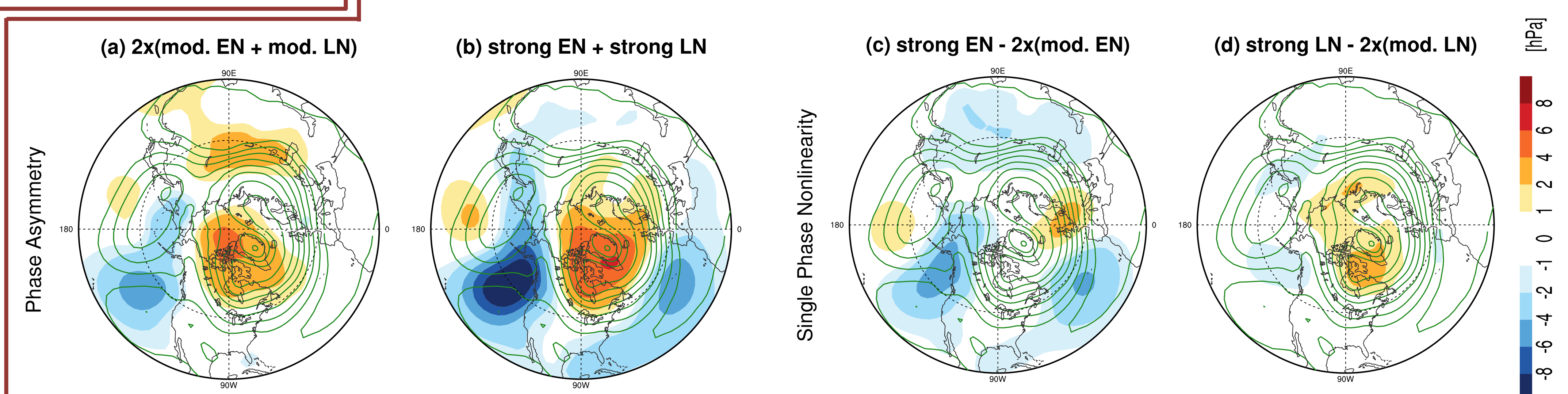


__Figure 4.__ DJF model sea level pressure response asymmetry for (a) twice the moderate and (b) strong ENSO forcings. (c) El Niño and (d) La Niña single phase nonlinearity. Green contours indicate climatological values computed from the climatological simulation. The contour interval is 5 hPa.

- The **asymmetry** is found to be stronger (more than double) for strong events than for moderate events. For a strong ENSO forcing, the asymmetry is more than 8 hPa in the eastern North Pacific and extends well into the North Atlantic.
- The **single phase nonlinearity** is stronger for El Niño than for La Niña phase. In the North Atlantic, a negative NAO dipole anomaly suggests the existence of nonlinear eddy feedbacks that strengthen the negative NAO during strong El Niño events.

7 Conclusions

1. In a simplified physics atmospheric model, linear changes in strength of ENSO SST forcings yield nonlinear teleconnections in the Northern Hemisphere.
2. The ENSO teleconnection to the North Pacific exhibits strong nonlinearity mainly for strong El Niño.
3. The North Pacific extratropical nonlinearity can be traced back to the relation between convection (divergent wind) and the underlaying SST in the tropical Pacific.

For more detailed information: Jiménez-Esteve, B., & Domeisen, D. I. V. (2019). Nonlinearity in the North Pacific atmospheric response to a linear ENSO forcing. *Geophysical Research Letters*, 46, 2271– 2281

Huang, B. et al., (2015). Extended reconstructed sea surface temperature version 4 (ERSST.v4). Part I: Upgrades and intercomparisons. *Journal of Climate*, *28*(3), 911–930. **Jiménez-Esteve, B., & Domeisen, D. I. V. (2018).** The tropospheric pathway of the ENSO-North Atlantic teleconnection. *Journal of Climate*, *31*(11), 4563–4584. **Kobayshi, S. et al., (2015).** The JRA-55 Reanalysis: General Specifications and Basic Characteristics. *Journal of the Meteorological Society of Japan. Ser. II*, *93*(1), 5–48. **Thomson, S. I., & Vallis, G. K. (2018).** Atmospheric Response to SST Anomalies. Part I: Background-State Dependence, Teleconnections, and Local Effects in Winter. *Journal of the Atmospheric Sciences*, *75*(12), 4125–4138. **Vallis, G. K, et al., (2018).** Isca, v1.0: A framework for the global modelling of the atmospheres of Earth and other planets at varying levels of complexity. *Geoscientific Model Development*, *11*(3), 843–859.

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