Nonlinearity in the Tropospheric Pathway of ENSO to the North Atlantic

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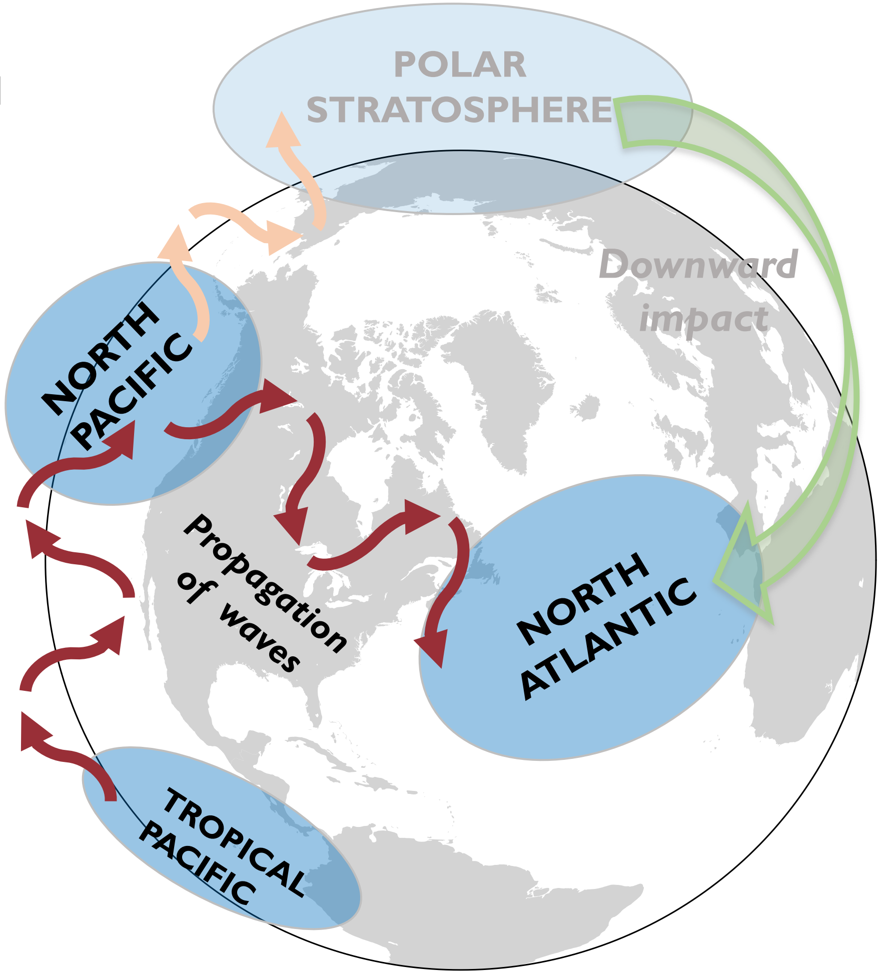
Objectives of the study

1. To **separate the tropospheric** from the stratospheric **pathway of ENSO** to the North Atlantic during boreal winter.
2. To **quantify the nonlinearity** and **asymmetry** in the North Atlantic response to ENSO.



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Outline

1. Key points
2. Methods: model simulation setup and stratospheric nudging
3. Results:
   I. The SLP response to the tropospheric pathway of ENSO
   II. Asymmetry in the response
   III. Single phase nonlinearity
   IV. North Pacific – North Atlantic tropospheric link
   V. The role of transient and quasi-stationary eddies for the NAO response to ENSO
4. Appendix Figures

Key points

1. Without a stratospheric influence on the troposphere, the North Atlantic atmospheric response to ENSO forcing can be explained in terms of the upstream influence from the North Pacific.

2. The ENSO tropospheric pathway to the North Atlantic exhibits significant nonlinearity and asymmetry with respect to the tropical Pacific SST forcing, both in terms of the location and the strength of the impacts

3. The Aleutian low and the NAO modes of variability are significantly correlated at monthly and seasonal timescales through tropospheric dynamics only.

4. In the model EN forcing increases (decreases) the eastward wave activity flux (WAF) of transient eddies (large-scale QS waves) across North America. The NAO response to ENSO results from a constructive interference between the impacts of the two WAF.

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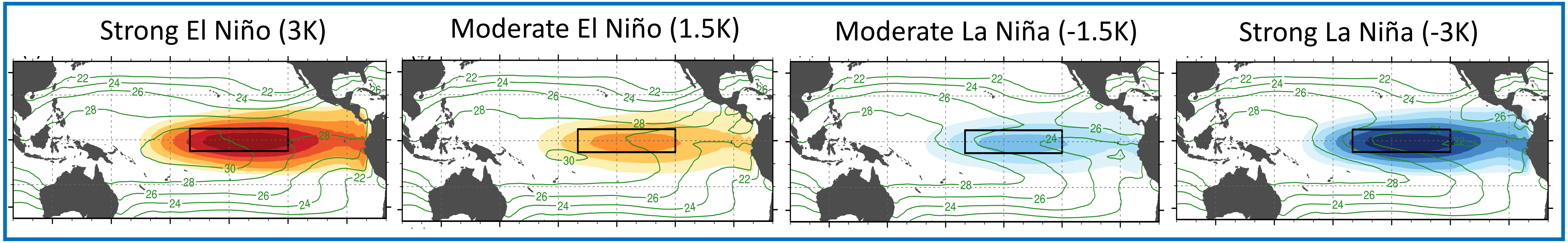
Methods: Atmospheric model simulations

Simplified atmospheric model **(Isca)** with prescribed SSTs (Vallis et al., 2018)

- Seasonally evolving monthly SST climatology form the NOAA ERSSTv4 (Huang et al., 2015)
- **4 idealized ENSO forcing** experiments (strong and moderate events)
- Extratropical SST anomalies follow the climatology
- 80 years of integration for each ENSO forcing experiment

ENSO forcings of linearly varying strength at a fixed location

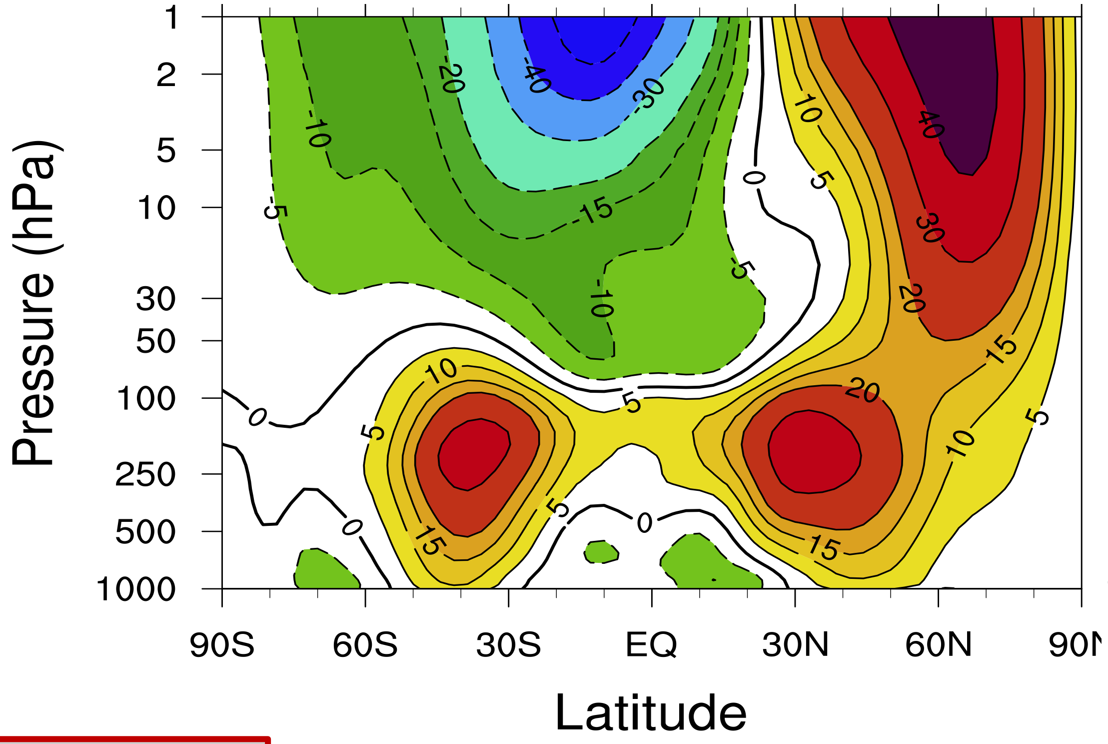


Methods: Model stratospheric nudging

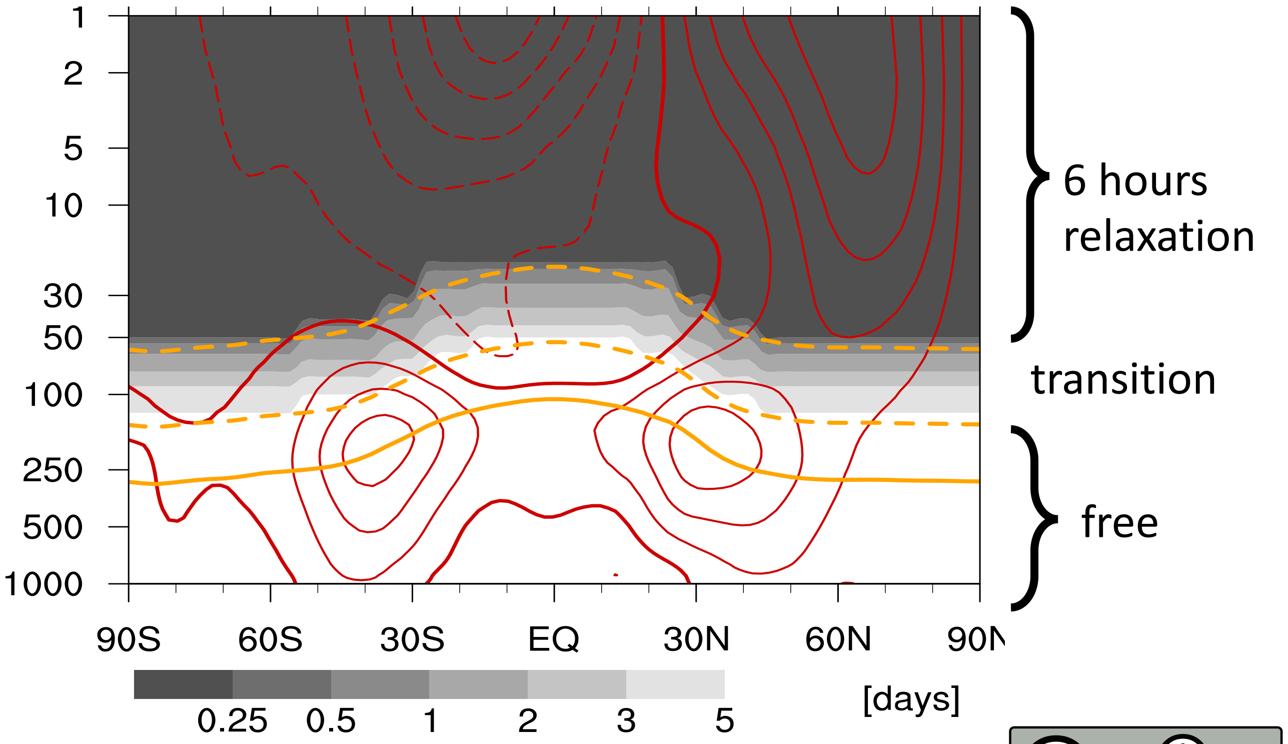
To remove the stratospheric pathway of ENSO, the stratospheric zonal mean winds are **drawn (nudged)** towards the model climatology

$$\frac{dU}{dt} = \ldots + \frac{(\overline{U} - \overline{U_{clim}})}{\tau}$$

DJF Model Climatology ($\overline{U_{clim}}$)



DJF relaxation time (τ)



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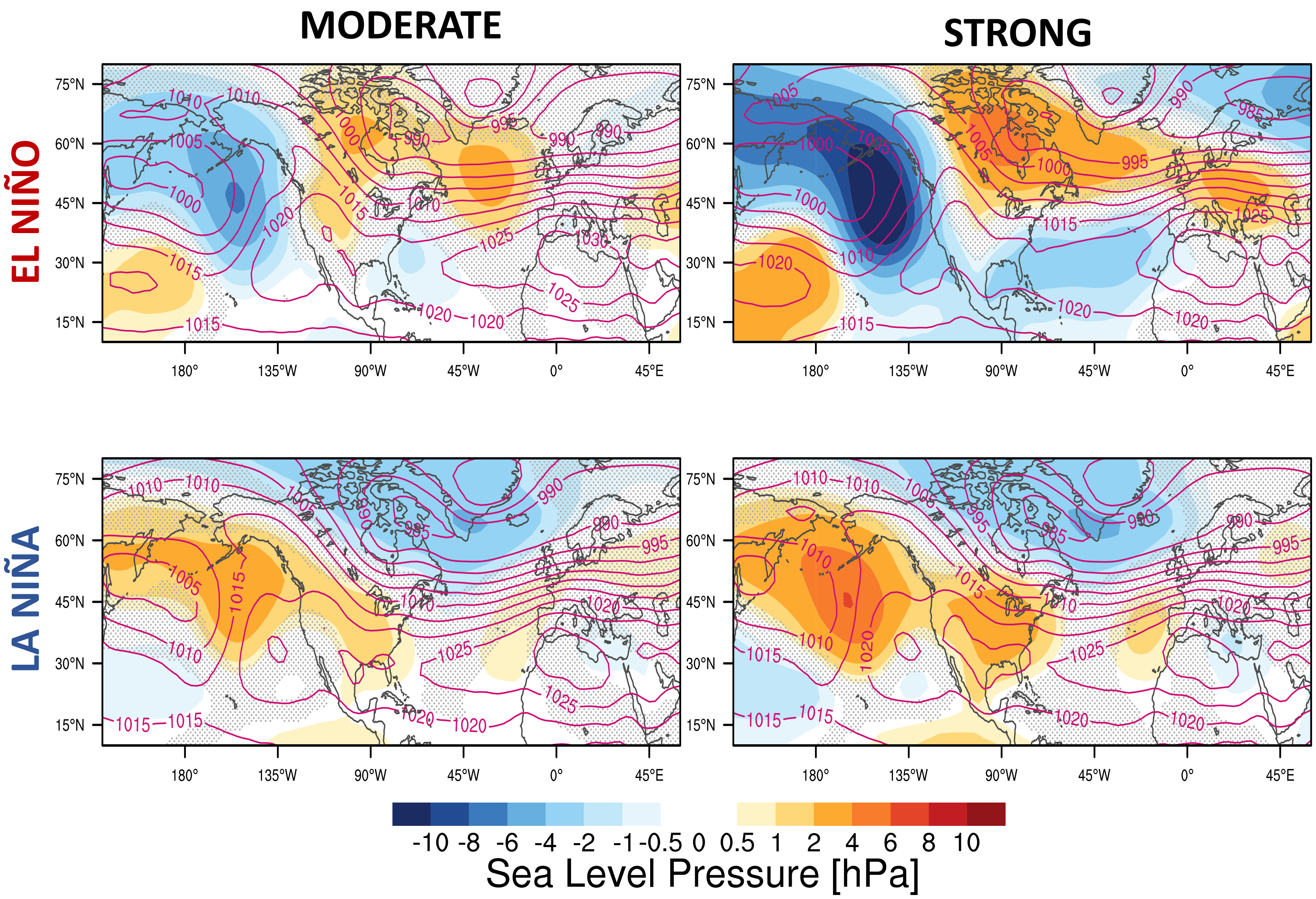
I. The SLP response to the tropospheric pathway of ENSO



During El Niño

- Deeper Aleutian low, positive PNA
- Weakening of the Icelandic low
- Negative NAO dipole only for the strong forcing and positive SLP over Europe.

During La Niña

- Weaker Aleutian Low, negative PNA
- Stronger Icelandic low, with saturation of the response, i.e. no further impact despite doubling the SST forcing

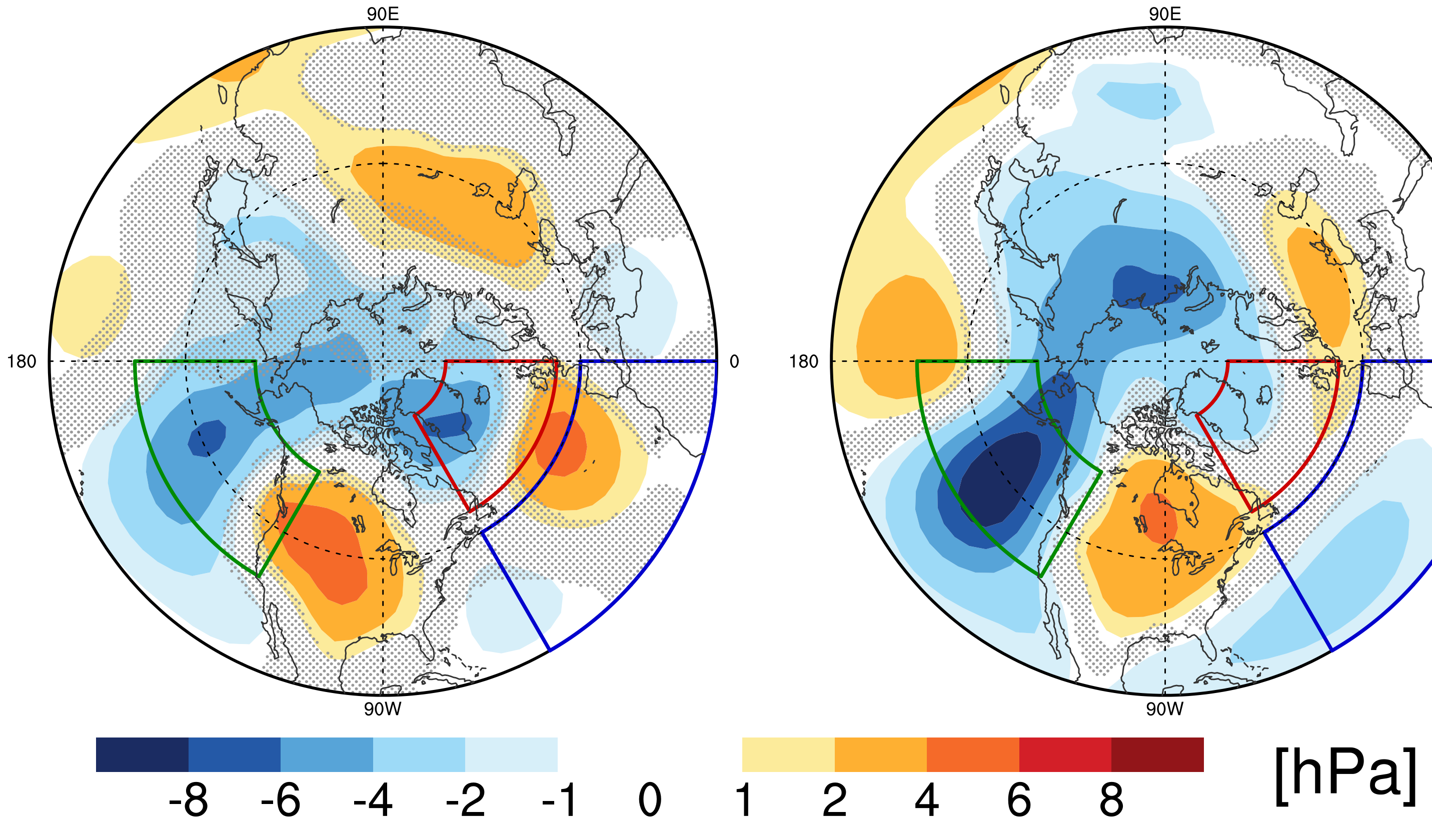
II. Asymmetry in the response

STRONG EVENTS (3K)

MODERATE EVENTS (1.5K)

(a) 2x(mod. EN + mod. LN)

(b) strong EN + strong LN



Link to the statistical robustness

Link to the DJF mean response

North Pacific

The asymmetry is larger for strong events, with a stronger impact during El Niño (deeper Aleutian low). This effect is larger for the strong events (Jiménez-Esteve and Domeisen, 2019)

North Atlantic

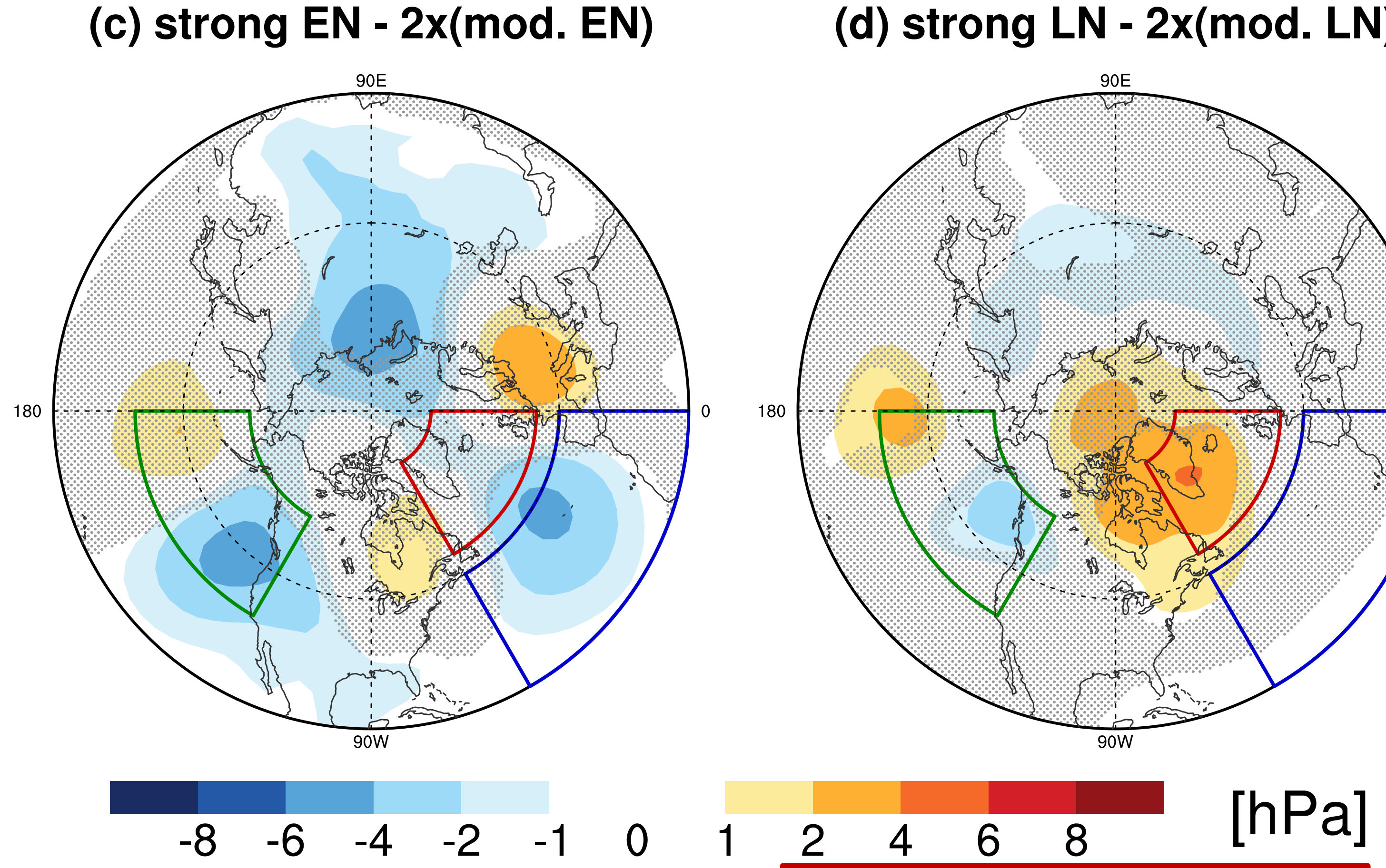
The **moderate LN response** projects stronger on the positive NAO compared to **moderate EN** on the negative NAO.

For strong events the asymmetry results from a stronger Azores high response for EN than for LN and **positive SLP anomaly over Europe**, probably due to an enhanced tropical North Atlantic Pathway.

III. Single Phase Nonlinearity

EL NIÑO

LA NIÑA



Link to the statistical robustness

Link to the DJF mean response

North Pacific

Superlinear Aleutian low (AL) deepening during El Niño but sublinear (saturation) weakening for La Niña phase.
(Jiménez-Esteve and Domeisen, 2019)

North Atlantic

El Niño: Proportionally stronger impact on the Azores high (blue box) for strong EN compared to moderate EN. Positive SLP anomaly over Europe for strong EN is absent for moderate EN.

La Niña: Within LN phase positive anomalies over the North Atlantic result from a saturation of the Icelandic low response (same impact for moderate and strong LN forcings).

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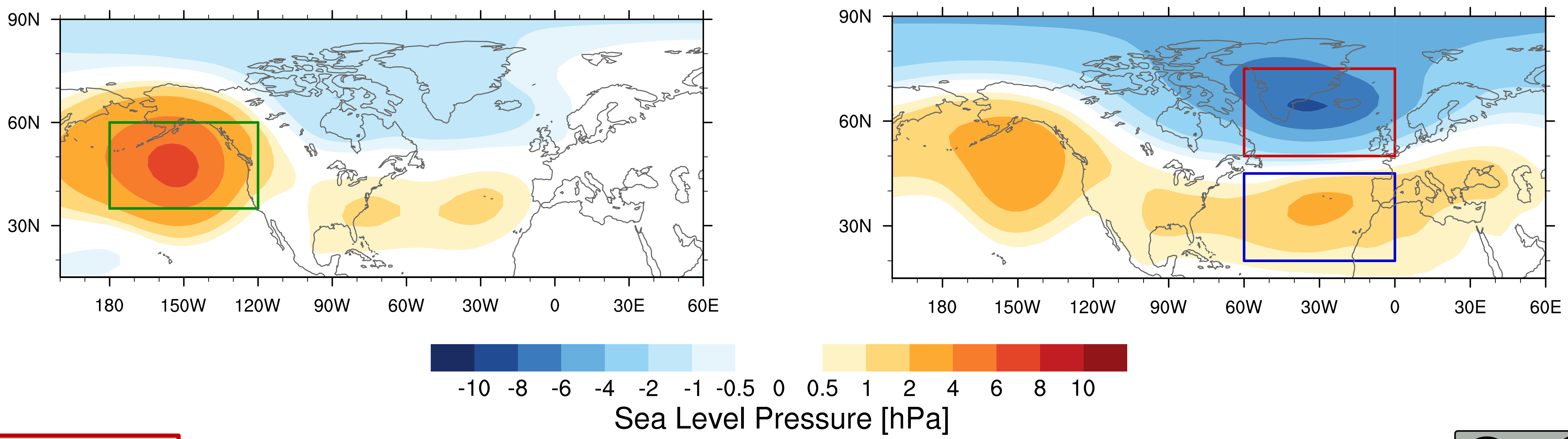
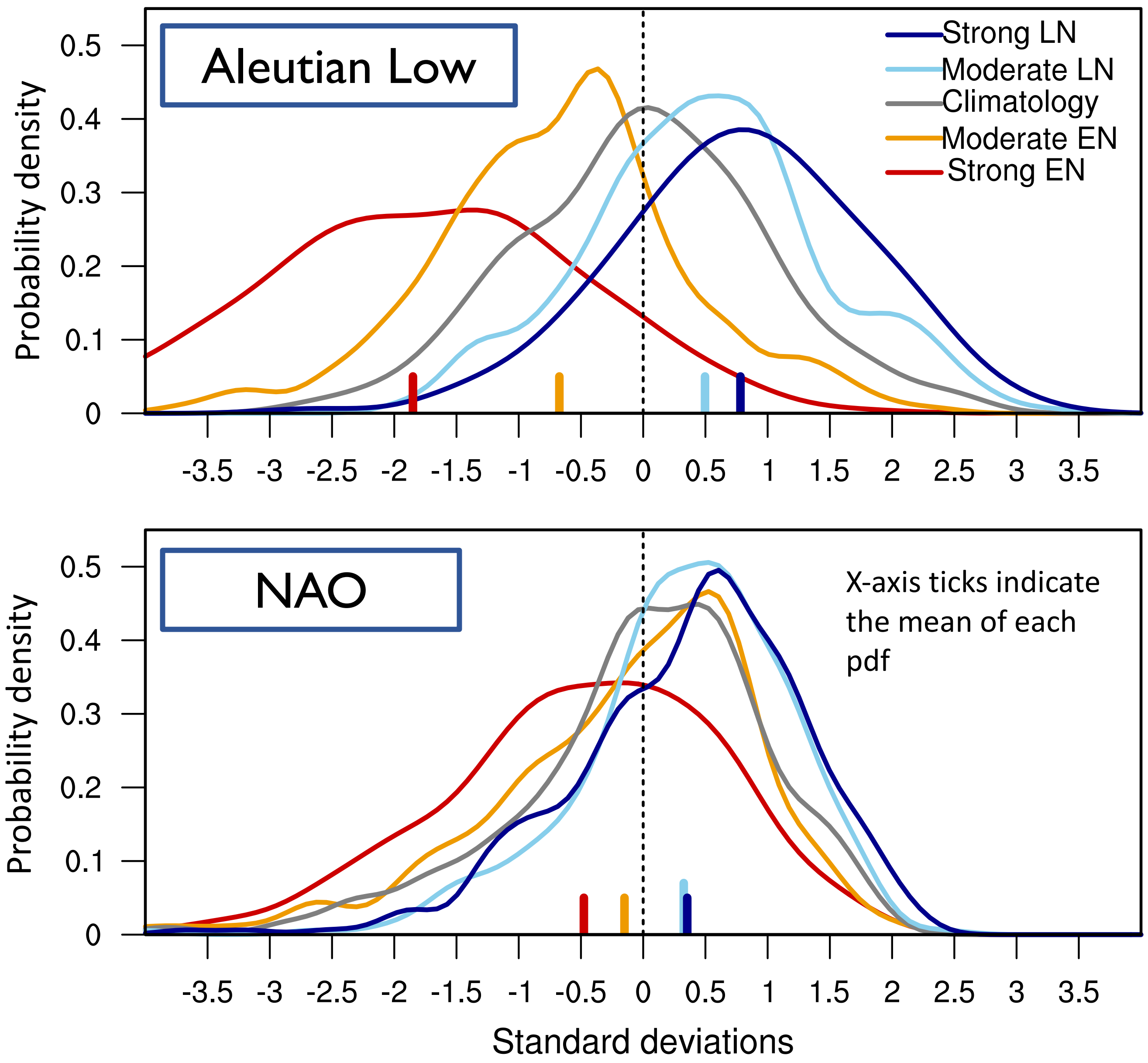
IV. The North Pacific – North Atlantic tropospheric link

- We define **the AL and the NAO indices** as the sea level pressure (SLP) averaged over the North Pacific (green box) and North Atlantic (blue minus red box), respectively.
- The **DJFM monthly mean regression maps** suggest a connection between these two modes through the troposphere. The mechanism in terms of wave activity flux (WAF) is investigated.

Aleutian Low index | **North Atlantic Oscillation index**



IV. The North Pacific – North Atlantic tropospheric link



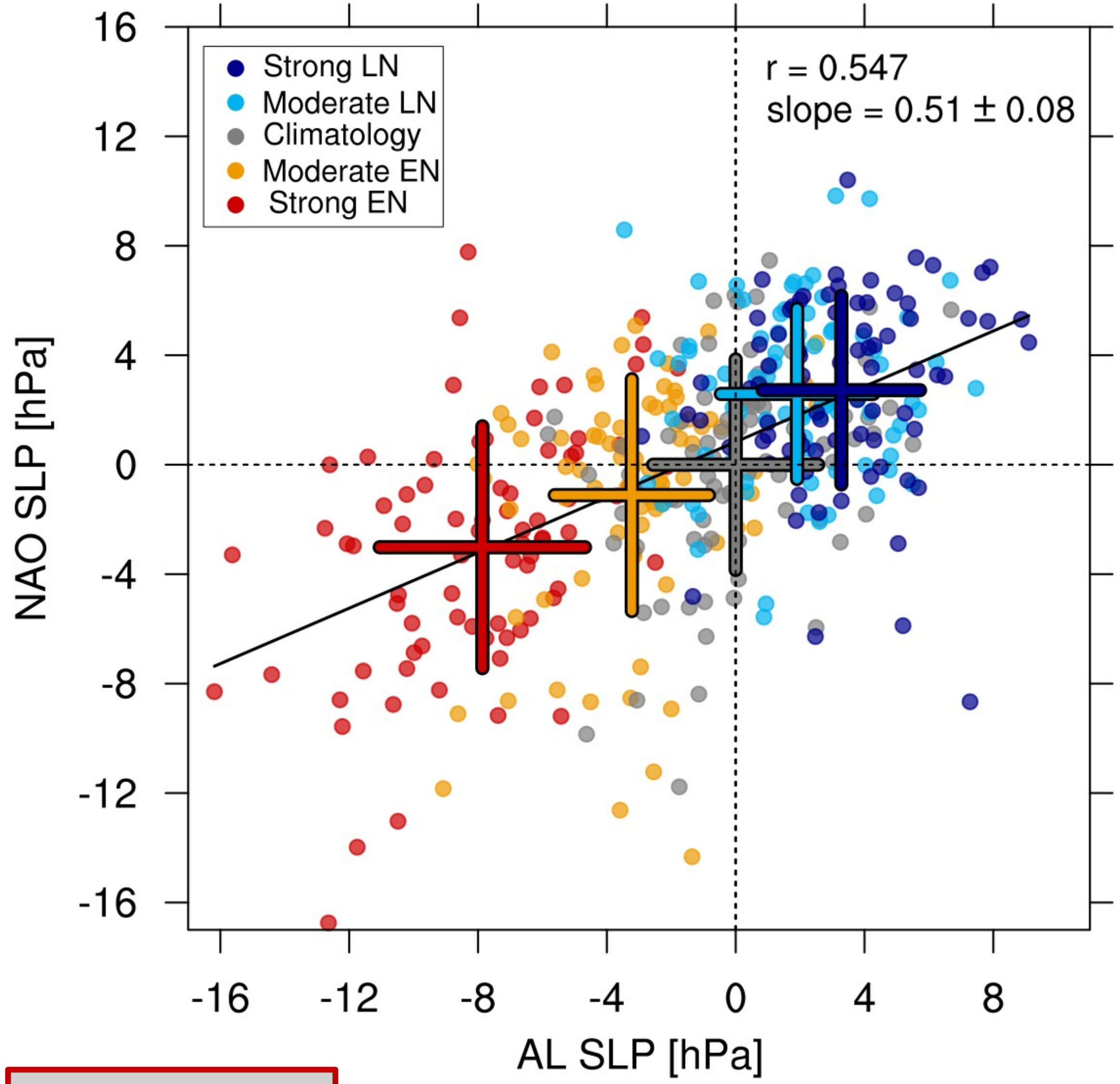
North Pacific

Nonlinear response for the AL, mainly for strong forcings. (Jiménez-Esteve and Domeisen, 2019)

North Atlantic

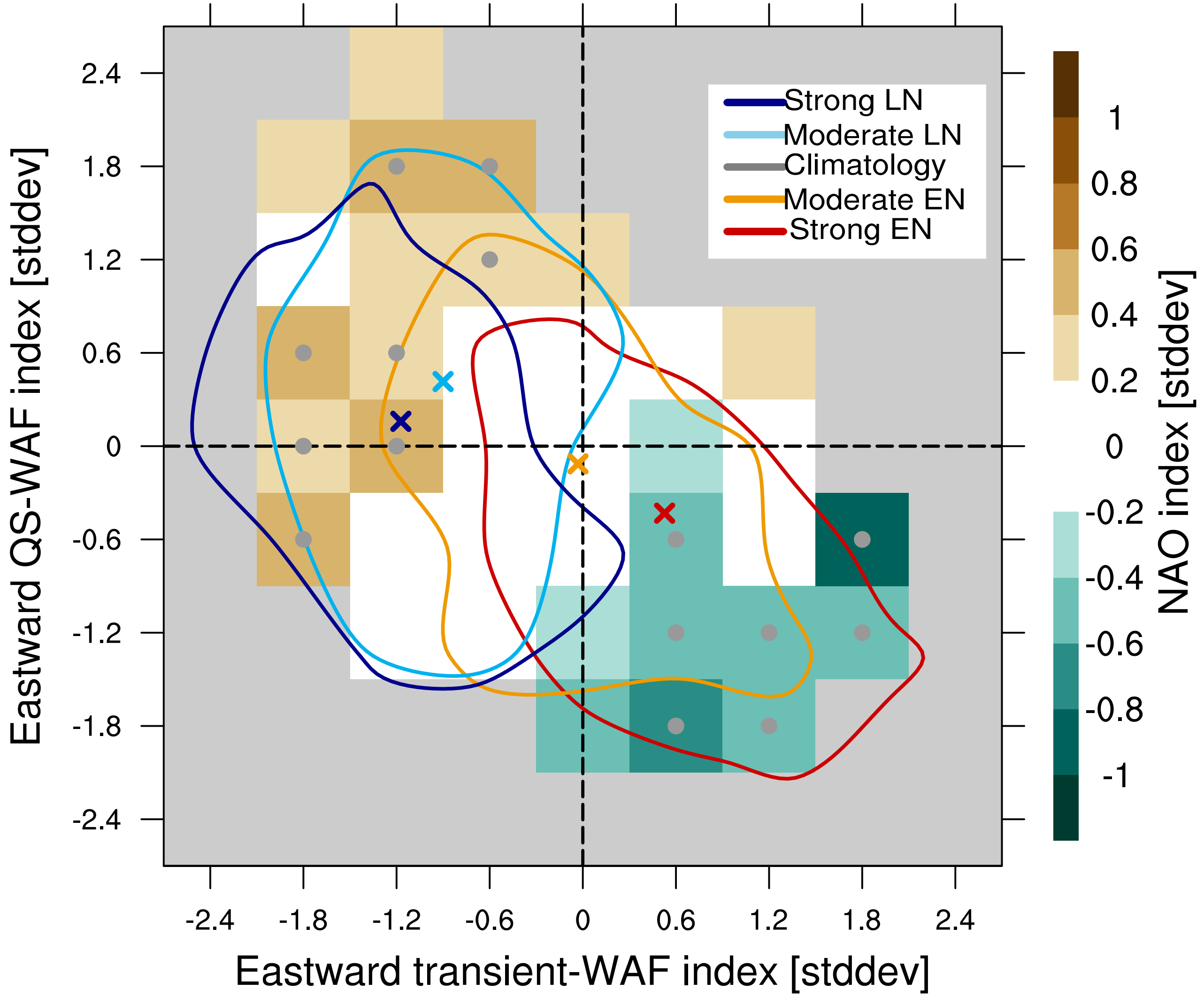
Weaker, but **nonlinear response** for the NAO, mainly for La Niña (saturation). Also stronger response for moderate LN compared to moderate EN.

IV. The North Pacific – North Atlantic tropospheric link



- The **correlation coefficient** between the winter AL and the NAO indices **is significant** and larger than 0.5, which is much larger than in reanalysis (less than 0.2).
- The **small signal-to-noise ratio** in the extratropics can mask the North Pacific influence on the NAO variability.
- **The asymmetry** between the strong EN and strong LN forcing projecting onto the NAO pattern **mainly originate** from the **asymmetry in the tropical Pacific** upper level divergent wind response (see Figure 4a in Jiménez-Esteve and Domeisen (2019)).

V. The role of transient and quasi-stationary (QS) eddies for the NAO response to ENSO



- This figure shows **the NAO index** (color) **dependence on the transient and the QS eastward WAF indices** (a measure of the downstream propagation from the North Pacific to the North Atlantic).
- The **saturation of the NAO response during LN** is consistent with the strong LN forcing leading to weaker transient WAF than the moderate LN, which is compensated by the stronger QS WAF response.
- This figure also explains why the **moderate EN forcing projects weakly onto the negative NAO** phase, as neither the transient nor the QS WAF distribution is significantly shifted from the climatological values.

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Key points

1. Without a stratospheric influence on the troposphere, the North Atlantic atmospheric response to ENSO forcing can be explained in terms of the upstream influence from the North Pacific.

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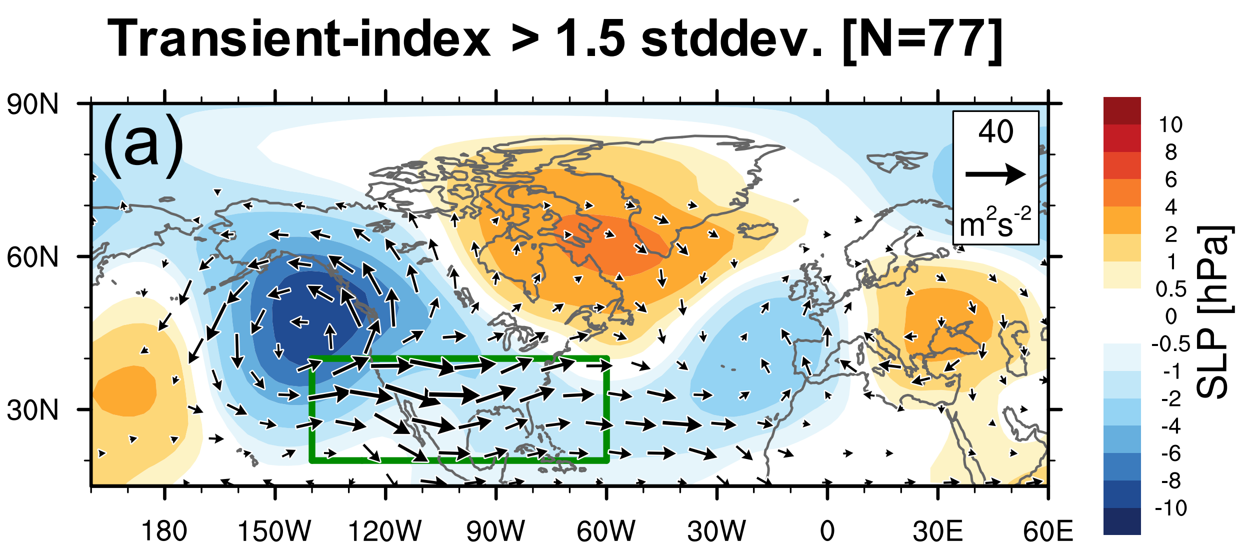
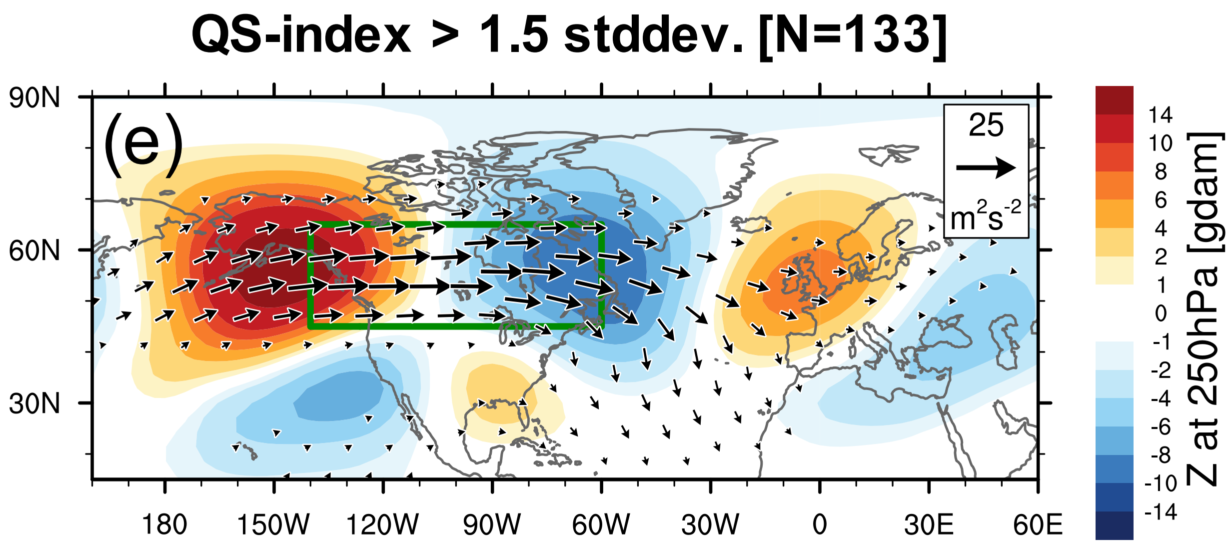
APPENDIX FIGURES

Wave Activity Fluxes composites for Transients and QS waves



Eastward propagation associated with:

- Deeper Aleutian Low
- Positive PNA
- Projects onto a negative NAO
- Weaker vortex (not shown)



Eastward propagation associated with:

- Weaker Aleutian low
- Negative PNA
- Projects onto a positive NAO
- Stronger vortex over Canada

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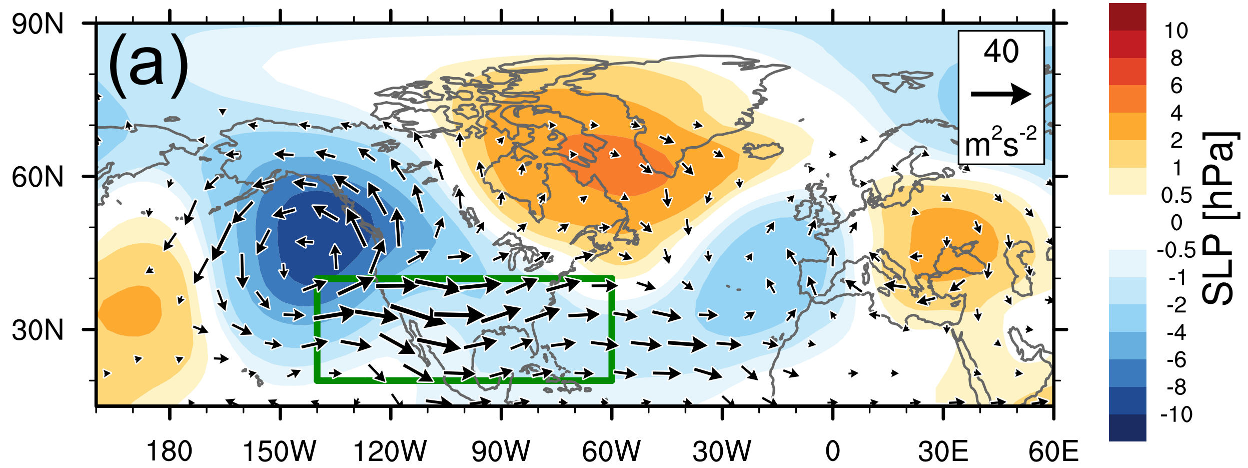
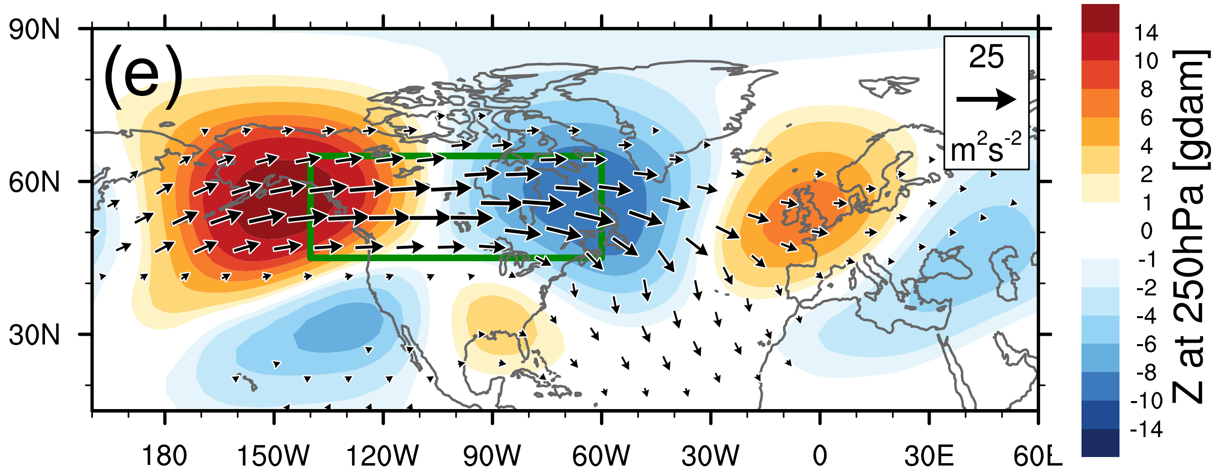
Wave Activity Fluxes response to the ENSO SST forcing

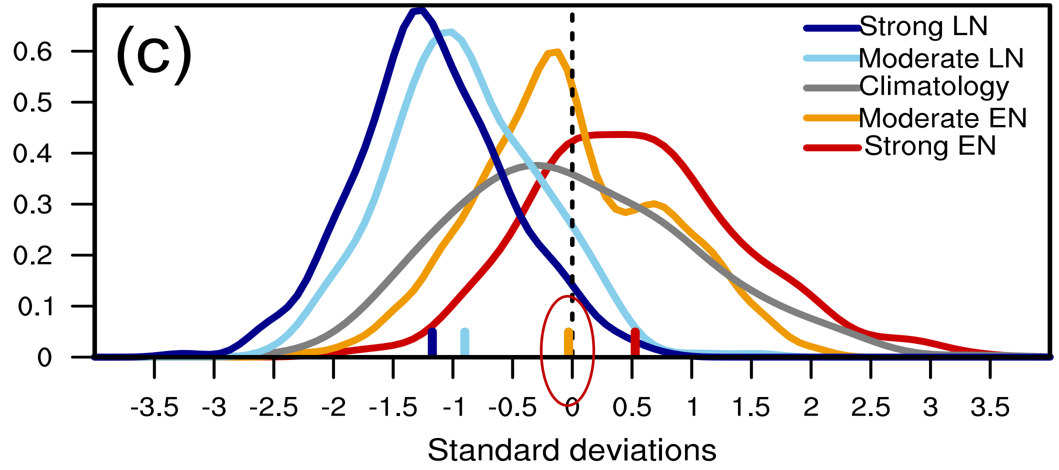
Transient-index > 1.5 stddev. [N=77]



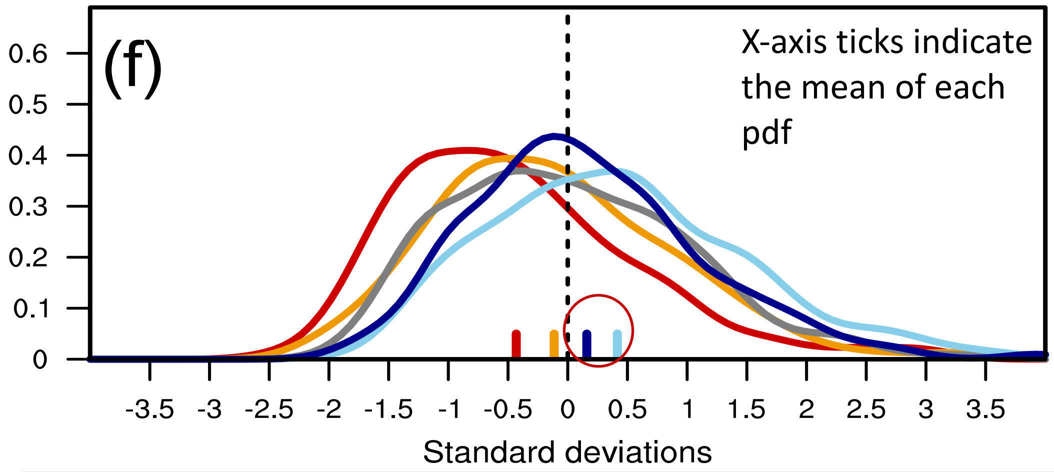
QS-index > 1.5 stddev. [N=133]



DJFM monthly PDFs of the WAF averaged over the green box



DJFM monthly PDFs of the WAF averaged over the green box



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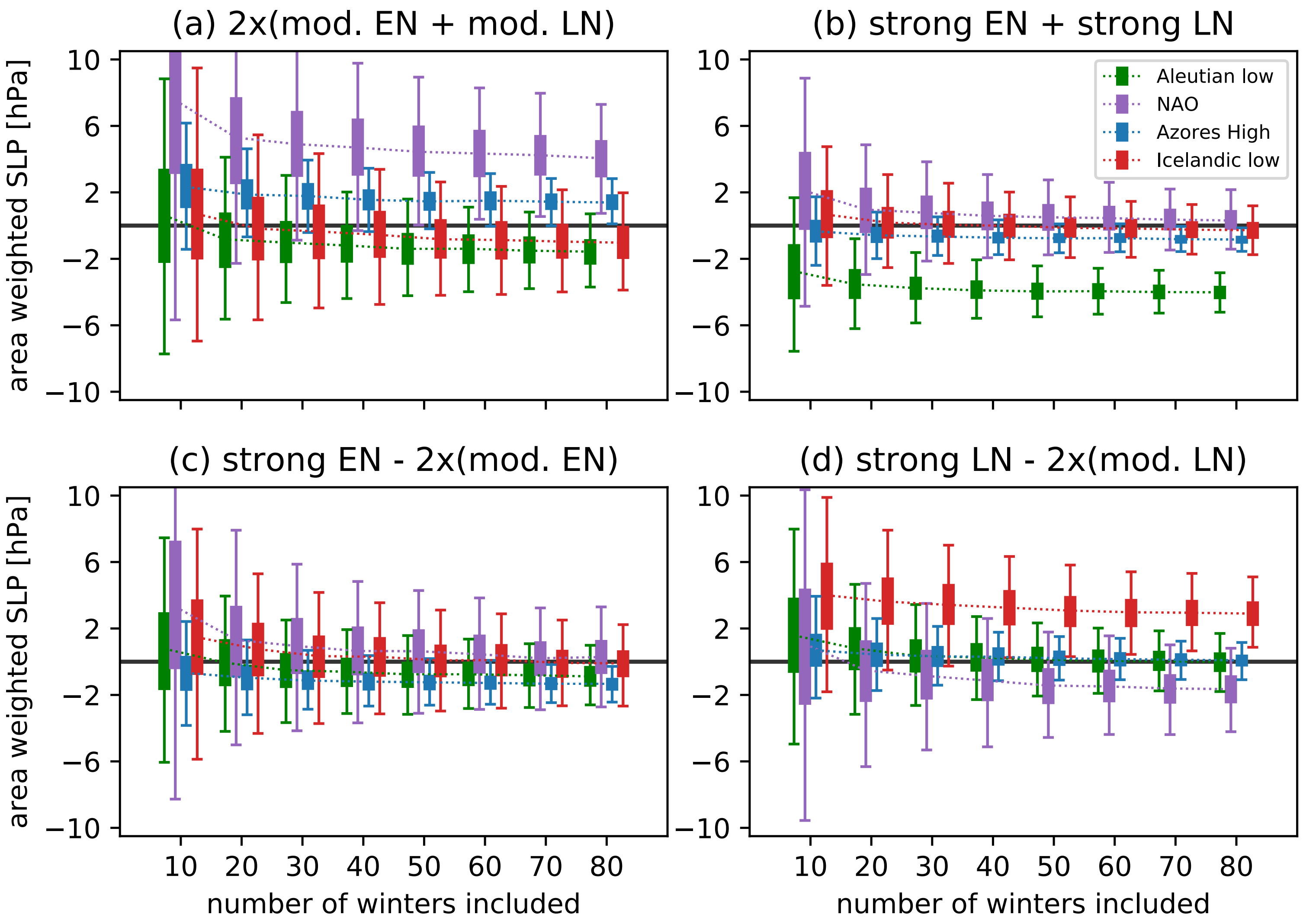
The lack of transient WAF response for mod. EN explains the asymmetry over the Azores high

Stronger QS WAF response for moderate LN explains the saturation in the Icelandic low response

Statistical robustness of the Nonlinearity and Asymmetry



Box plot displaying the 95(50)% confidence intervals indicated by the whiskers (solid boxes) of the DJF model SLP asymmetric response for (a) twice the moderate and (b) strong ENSO forcings when the winter anomalies in these experiments are randomly sub-sampled in groups of increasing size (shown on the x-axis). Colors indicate the different SLP indices (green: Aleutian low, purple: NAO, blue: Azores High, red: Icelandic low). (c) the same as (a,b) but for EN and (d) LN single phase nonlinearity. When the whiskers do not touch the zero-line for a specific sample size and magnitude, then the asymmetry/nonlinearity is statistically detectable at the 95% confidence level.

Link to asymmetry

Link to single phase nonlinearity

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