# Nonlinearity in the Tropospheric Pathway of ENSO to the North Atlantic

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## **Objectives of the study**

- 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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- 1. Key points
- 2. Methods: model simulation setup and stratospheric nudging
- 3. Results:
  - I. <u>The SLP response to the tropospheric pathway of ENSO</u>
  - II. <u>Asymmetry in the response</u>
  - 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









- 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.



# 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)
- 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





# I. The SLP response to the tropospheric pathway of ENSO

**STRONG** 

#### MODERATE



## 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**



## **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 <u>(Jiménez-</u> <u>Esteve and Domeisen, 2019)</u>

## **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**



## **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**

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**North Atlantic Oscillation index** 



-0.5

0.5

0

Standard deviations

1.5

2

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.



-3.5

-3

-2.5

-2

\_1

.5 -1

2.5

3.5

3



# **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)).





(†)



Strong 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.
- 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.
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# APPENDIX FIGURES







## Wave Activity Fluxes composites for Transients and QS waves

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

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



#### Eastw



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			Climatology	0 E			



DJFM monthly PDFs of the WAF averaged over the green box

#### DJFM monthly PDFs of the WAF averaged over the green box

X-axis ticks indicate the mean of each pdf

-10

-14

Back to	- The lack of tra	ansient WAF response fo	r mod. EN	<u> </u>
<u>outline</u>	explains the a	symmetry over the Azor	es high	LN
J.J <b>-</b>	0.5 -		Moderate	∍ FN

Stronger QS WAF response for moderate LN explains the saturation in the Icelandic low response 15/17 0.5 -

# **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.

<u>Link to</u> asymmetry <u>Link to single phase</u> <u>nonlinearity</u>





(†)

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