ENSO influence on the North Atlantic : Nonlinearity and interaction between the stratospheric and the tropospheric pathways

Bernat Jiménez-Esteve[1] and Daniela I.V. Domeisen[1]

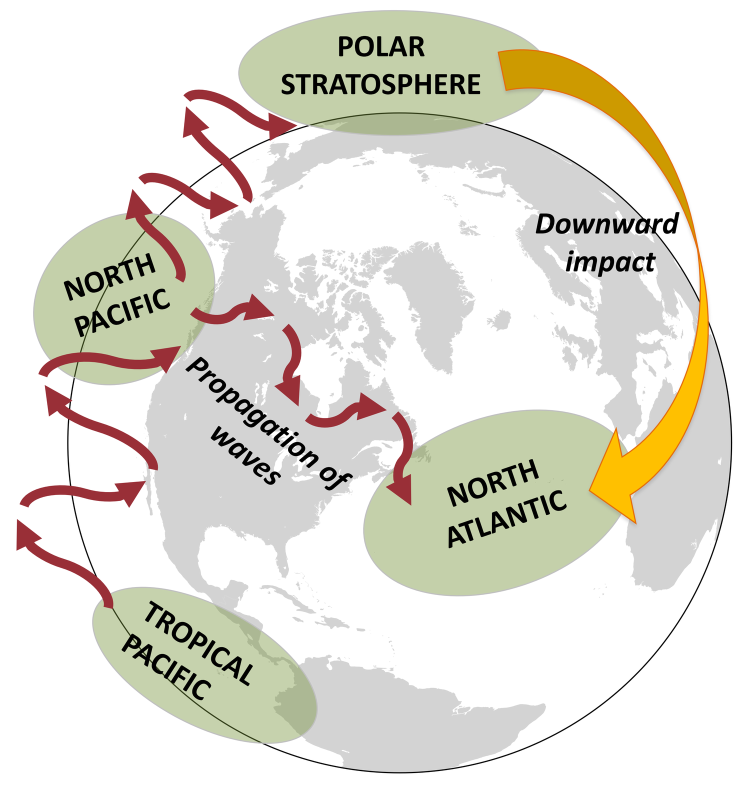
[1]Institute for Atmospheric and Climate Science, ETH Zurich,Zurich,Switzerland

1 Introduction

El Niño Southern Oscillation (ENSO) exerts an influence on the **North Atlantic** region. However, this teleconnection is non-linear and non-stationary due to the superposition and interaction of a multitude of influences. The key players of this teleconnection are the **North Pacific** area and the **stratosphere** (Brönimann, 2007).

Using reanalysis data, Jiménez-Esteve and Domeisen (2018) studied the **tropospheric and stratospheric pathways** of this teleconnection and found that both pathways work in tandem to produce the North Atlantic response, which consists of e.g. a negative NAO response during El Niño. A consistent separation of these pathways is however not possible in reanalysis due to the limited sample size and the difficulty to fully remove the stratospheric signal.

Here, by employing an atmosphere-only model forced with fixed SSTs we **isolate the tropospheric from the stratospheric pathway and quantify the nonlinearity** in the extratropical response. The findings using targeted model experiments corroborate the results from reanalysis (see section 2).



Schematic with the main ENSO pathways to the North Atlantic

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**. Our configuration uses a **realistic topography and land sea contrast**. We choose a resolution of **T42** and **50 vertical levels** up to 0.02 hPa.

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** (Jiménez-Esteve and Domeisen, 2019, GRL).

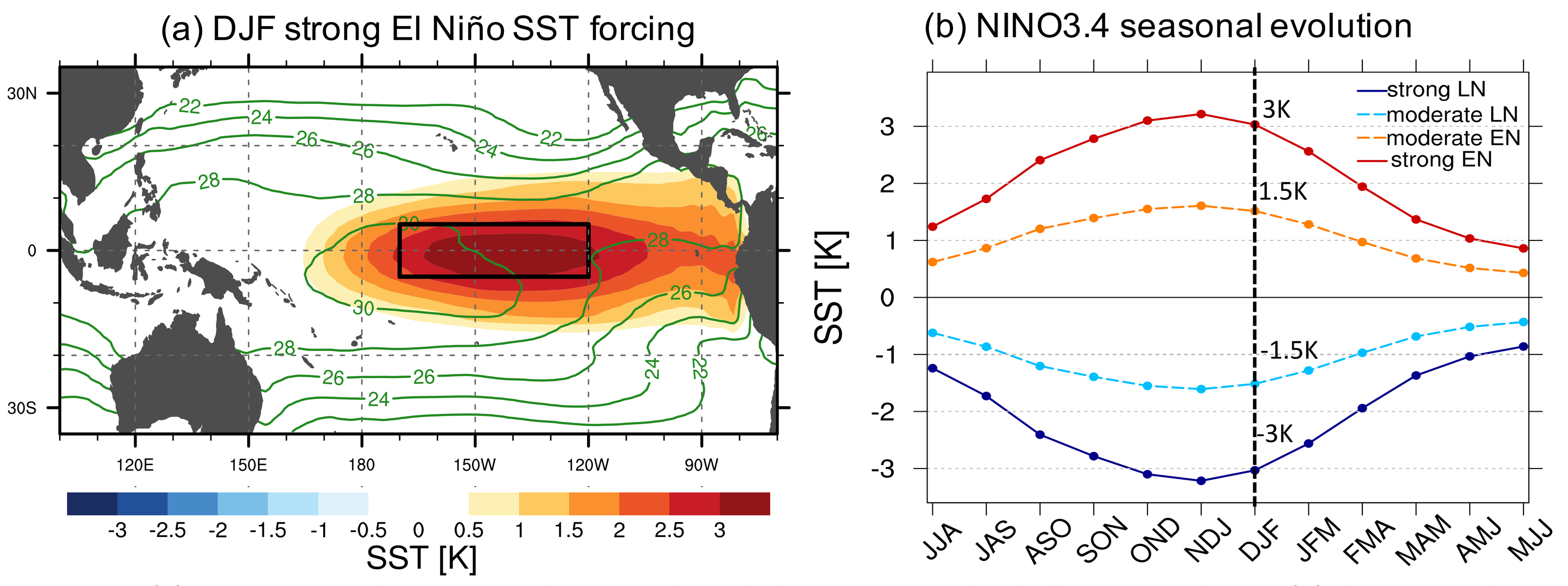


Figure 1: (a) DJF SST anomaly pattern in the tropical Pacific for the strong El Niño forcing simulation. (b) The seasonal evolution of the SST anomalies in the NINO3.4 region (black box in (a)) for the four types of SST ENSO forcings.

To **isolate the tropospheric from the stratospheric pathway,** the zonal mean winds in the stratosphere are relaxed towards the zonal mean seasonal cycle of the climatological simulation.

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

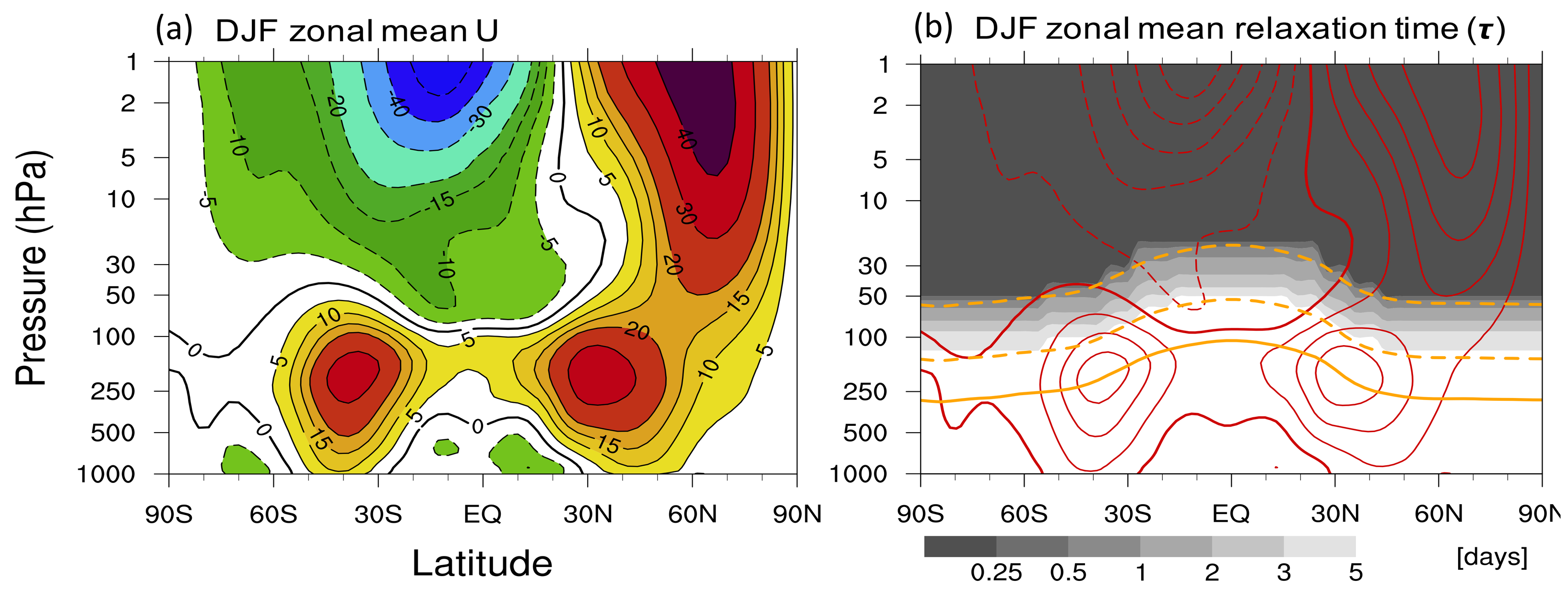
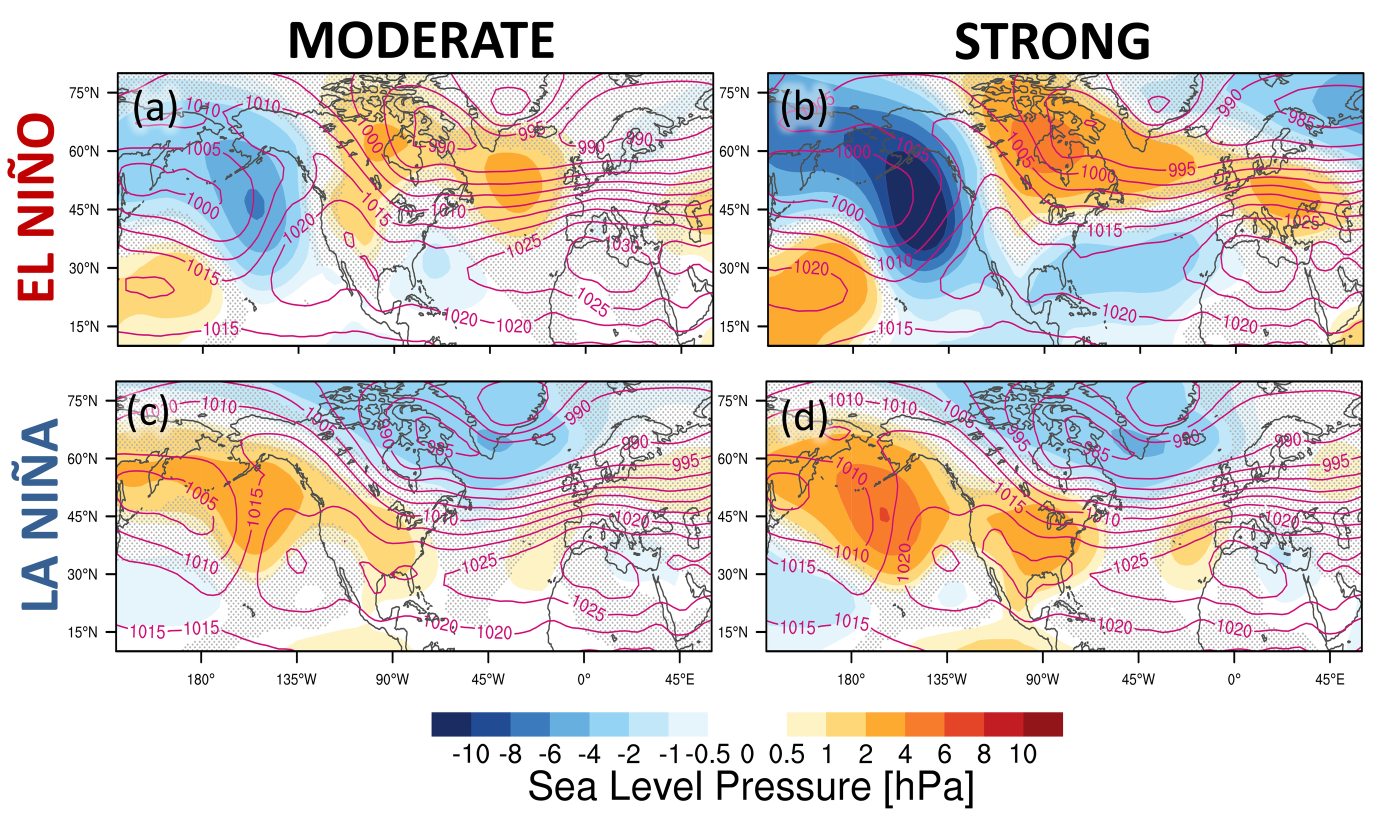


Figure 2: (a) The DJF zonal mean zonal wind (U) in the climatological SST simulation. (b) The DJF zonal mean relaxation timescale (τ) in days. In (b), red contours represent U as in (a), the solid orange line represents the DJF mean tropopause height and the dashed orange lines denote the limits for the transition area of the nudging.

3 The sea level pressure response to ENSO forcing



- Deeper Aleutian low
- Positive PNA
- Weakening of the Icelandic low
- Negative NAO dipole only for the strong forcing

- Weaker Aleutian Low
- Negative PNA
- Stronger Icelandic low.
- Saturation of the response despite double the SST forcing

Figure 3: Model DJF mean SLP response (shading) and total filed (contours) for (a) moderate and (b) strong EN, (c) moderate and (d) strong LN experiments. Dotted regions indicate insignificant regions at the 1% confidence level according to a 1000 samples Monte-carlo test.

4 Nonlinearity in the Aleutian low and NAO response

The North Pacific and the North Atlantic atmospheric circulation is investigated using two indices based on the monthly mean (December to March) **SLP averaged: Aleutian low** [35-60N,180-240E], and **NAO** as the difference between a northern box [50-75N,70-0W] and a southern box [20-45N,180-240E].

a) **Nonlinear response in the North Pacific,** mainly for strong forcings. (Jiménez-Esteve and Domeisen, 2019, GRL)

b) Weaker but **nonlinear response in the North Atlantic,** mainly for La Niña (saturation).

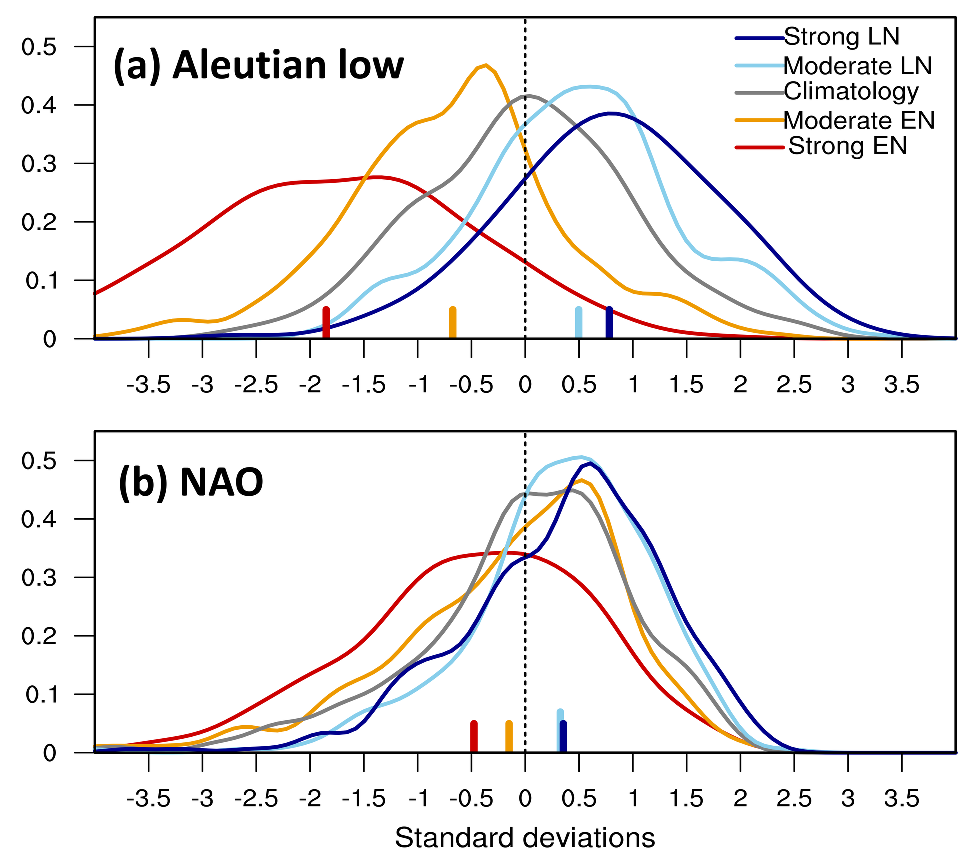


Figure 4: The probability distribution functions of the December-January-February-March standardized monthly means for (c) the Aleutian low and (d) the NAO indices. Colors represent the different ENSO forcings (red: strong EN, orange: moderate EN, grey: climatology, light blue: moderate LN, dark blue: strong LN).

5 The combined effect of the North Pacific and the stratosphere

- **The stratosphere exerts a stronger impact on the NAO** than the downstream effect of the AL, i.e. the variability in the vertical direction is larger than in the horizontal direction.
- The **impact on the NAO is amplified** in the lower-left and upper-right quadrants, **when there is a constructive interference** between the two pathways.

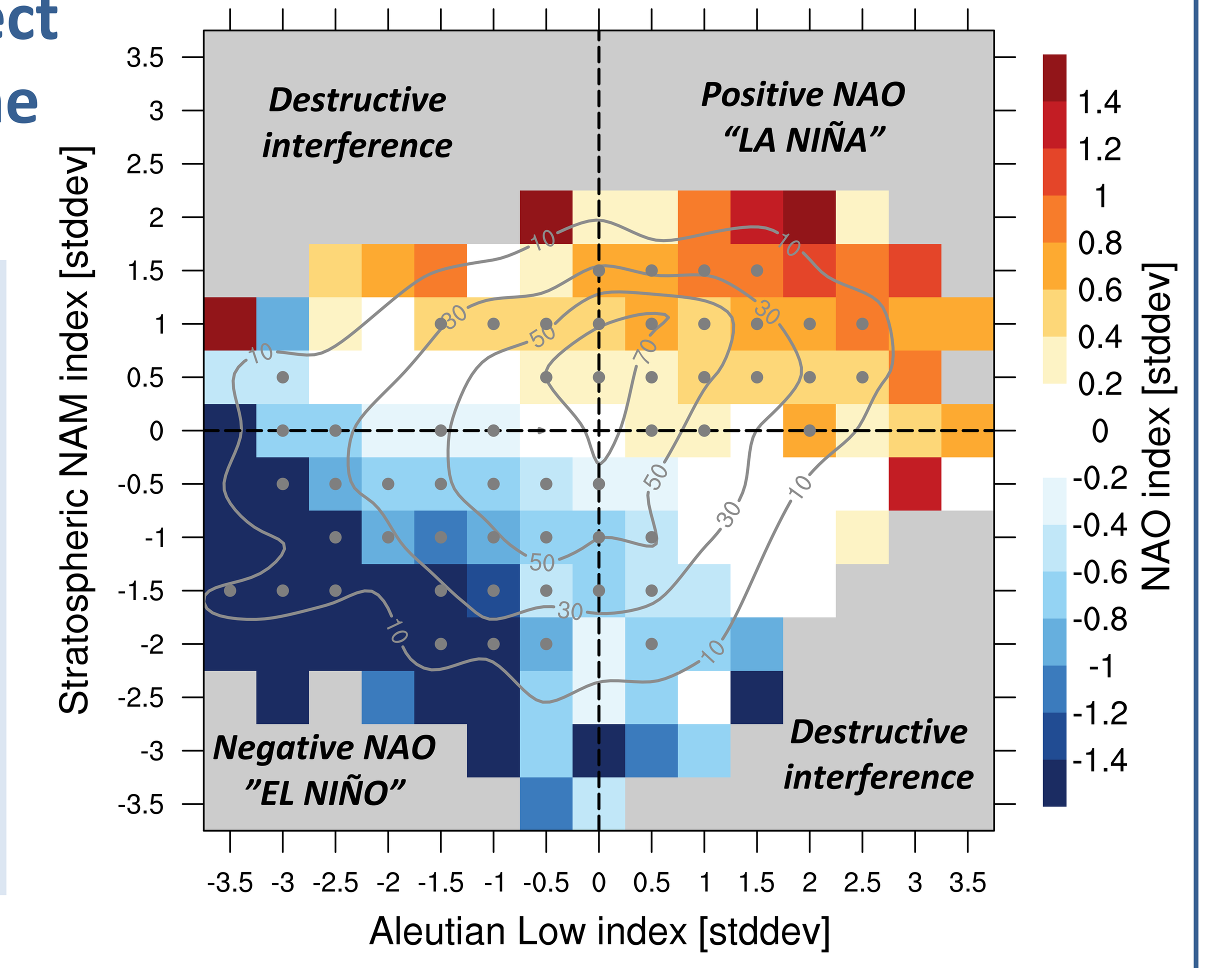


Figure 5: December to March monthly mean NAO index (color shading) as a function of the AL and the stratospheric Northern Annular mode (NAM) indices for the five simulations with a freely evolving stratosphere (646 years). Grey dots in the middle of each cell indicate statistically significant values at the 95% confidence level according to a t-test with at least 10 data points. Grey contours indicate the distribution of the number of events that fall into each bin and light grey cells correspond to combinations of the AL and NAM indices with zero events.

6 The contribution from stratospheric variability

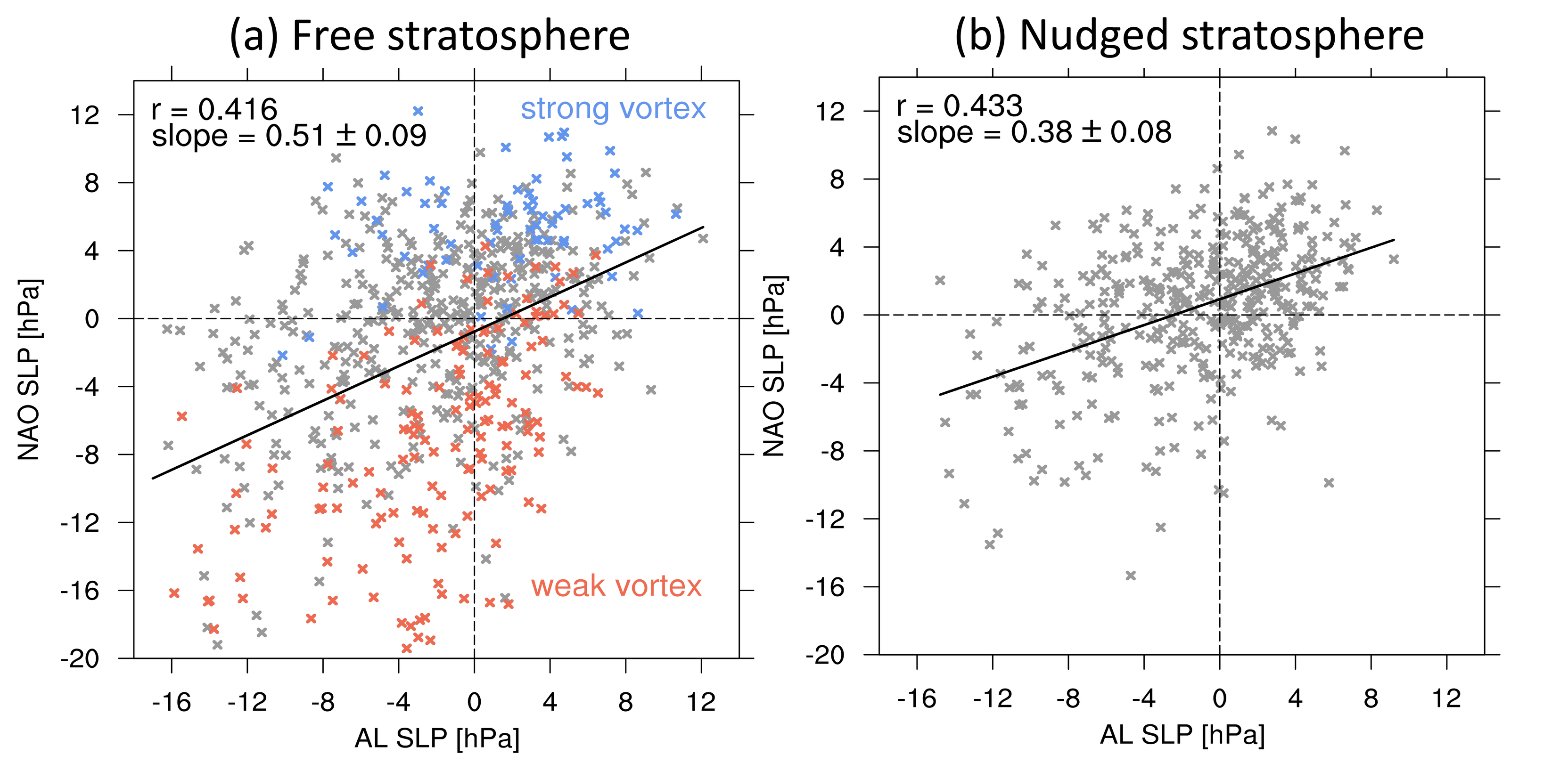


Figure 6: Scatter plot of the JFM mean NAO versus the JFM AL indices for all five experiments (a) without stratospheric nudging (646 years) and (b) with stratosphere nudging (396 years). In (a) experiments without nudging are further separated into years with the stratospheric NAM index lower (higher) than -1.0 (1.0) standard deviations, shown in red (blue).

- **The correlation** between the AL and the NAO does not significantly change.
- **The slope** is significantly larger when the stratosphere is freely evolving
- **The variance** of the NAO index decreases by 40% when stratospheric winds are nudged

	Free stratosphere	Nudged stratosphere
AL	5.2 hPa	4.7 hPa
NAO	6.7 hPa	4.2 hPa

Table 1. Interannual variability measured as the standard deviation of JFM mean of the AL and NAO indices

7 Conclusions

1. The **North Atlantic response to the ENSO** forcing changes due to the upstream influence from the North Pacific (i.e. 'tropospheric pathway'). The response to ENSO in the North Atlantic projects onto a negative (positive) NAO during El Niño (La Niña).
2. The **ENSO tropospheric pathway** to the North Atlantic exhibits **significant nonlinearity** with respect to the tropical SST forcing.
3. **Stratospheric variability** contributes to approximately 40% of the NAO interannual in late winter, and significantly increases the slope of the regression between the AL and the NAO indices.

Brönnimann, S. (2007), Impact of El Niño–Southern Oscillation on European climate, *Rev. Geophys.*, 45, RG3003, doi: 10.1029/2006RG000199. **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. **Jiménez-Esteve, B., and D. I.V. Domeisen (2019).** "Nonlinearity in the North Pacific Atmospheric Response to a Linear ENSO Forcing." *Geophysical Research Letters* 46 (4): 2271–81. doi:10.1029/2018GL081226. **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.

Contact
Bernat Jiménez Esteve
bernat.jimenez@env.ethz.ch