Multi-model assessment of the late-winter extra-tropical response to El Niño and La Niña

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I. Introduction

El Niño-Southern Oscillation (ENSO) is a natural phenomenon in the tropical Pacific and the dominant mode of climate variability on interannual timescales. The first term, El Niño, refers to a recurring warming of the tropical Pacific Ocean (every 2-7 years), while the opposite phase, an anomalous cooling, is called La Niña. These variations in sea surface temperature (SST) are accompanied by changes in the tropical atmospheric circulation (Southern Oscillation), thus making ENSO a coupled phenomenon involving ocean-atmosphere interactions. Furthermore, ENSO can affect climate in regions far from the tropical Pacific, producing a cascade of global impacts through so-called 'teleconnections'. Understanding the extra-tropical impacts of ENSO is important to improve seasonal forecasts, for which it represents the most important source of predictability.

In the North Atlantic-European (NAE) sector, the ENSO teleconnection is still controversial in several aspects. A first cornerstone was set in a review by Brönnimann (2007) [1], who concluded that a robust, 'canonical' ENSO signal exists over the NAE region in late winter (January to March, JFM): a dipole in sea-level pressure (SLP) with centers over the mid-latitude and high-latitude North Atlantic. While Brönnimann described this pattern as "close to symmetric" for El Niño and La Niña, recent studies deliver contradictory results, with some reporting a symmetric signal (e.g. [2] [3] [4]) and others claiming asymmetry (e.g. [5] [6] [7]). The actual linearity of the ENSO-NAE teleconnection thus remains unresolved, and addressing this issue is the primary objective of this study. We will also investigate another key aspect of the ENSO-NAE teleconnection that is nothing but settled: the dynamical mechanism leading to the 'canonical' SLP dipole.

The underlying idea of this study is to use idealized experiments with atmospheric models forced by symmetric anomalous SST patterns representing El Niño and La Niña to diagnose symmetries and asymmetries in the extra-tropical response. A multi-model approach is used, as the experiments analyzed here are run with the same protocol using three state-of-the-art models. We aim not only at diagnosing asymmetries in the extra-tropical ENSO-related SLP signal, but also at understanding their cause by examining all the steps involved in the atmospheric response, starting from the tropical Pacific.

II. Methods

All experiments are atmosphere-only simulations. The multi-model ensemble consists of the atmospheric components of three state-of-the-art models:

- EC-EARTH3.2 (T255L91, 0.01 hPa) [8]
- CNRM-CM6-1 (T127L91, 0.01 hPa) [9]
- CMCC-SPS3 (∼110 km, L46, 0.3 hPa) [10]

The set of experiments include a control simulation and two perturbed runs. The control simulation (CTL) is run with climatological SSTs from observations (HadISST2.2). The El Niño (EN) experiment is performed with SST anomalies that mimic a strong, canonical El Niño event (Fig. 1), while the La Niña experiment (LN) has identical prescribed pattern but with flipped-sign SST anomalies. The forced atmospheric response associated with El Niño (La Niña) is estimated by computing the difference between the ensemble mean of the 50 winters in EN (LN) and CTL. The target season is JFM.

III. Main Results

Asymmetries arise in the SLP response over both the North Pacific (Aleutian Low) and NAE sector (North Atlantic dipole): the response to cold (La Niña) SST anomalies tend to be weaker and shifted westward with respect to the one associated with warm (El Niño) anomalous forcing (Fig. 2). The same behaviour is present in the upper troposphere (200-hPa geopotential height) in the large-scale Rossby wave train that is ENSO's dominant extra-tropical response.

The response of tropical convection to the SST forcing is underlying the extra-tropical asymmetries: warm (cold) SST anomalies superimposed to the mean state enlarge (restrict) the region suitable for the triggering of deep convection (SST above 27°C) and increase (decrease) the amount of available heating, while the longitude of maximum convection is found east (west) of the Date Line due to the different SST gradient. The convective response is followed by anomalous divergent

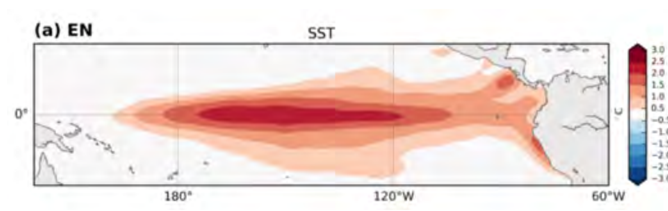

Fig. 1. JFM average of the anomalous SST pattern prescribed in EN.

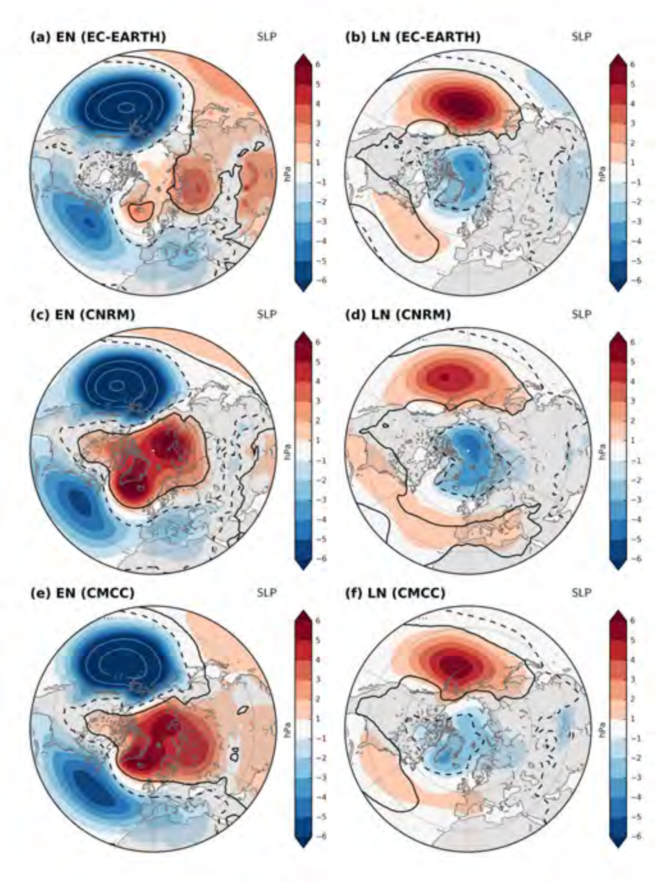

Fig. 2. Ensemble-mean SLP anomalies for (left) EN and (right) LN with respect to CTL in JFM: EC-EARTH (top), CNRM (middle), CMCC (bottom). Blue contours show values exceeding the color scale limit at -8, -12,-16 hPa. Black contours indicate statistically significant areas at the 95% confidence level.

wind with similar properties, but in order to explain the longitudinal shift of the extra-tropical SLP signal, the anomalous divergence needs to be considered in tandem with the mean flow, namely diagnosing the Rossby wave source.

The ENSO surface signal in the NAE sector is the 'canonical' dipole between mid and high latitudes, with asymmetries in terms of amplitude and longitude but not structure. These asymmetries are not indicative of different mechanisms driving the teleconnection for El Niño and La Niña; instead, in both cases the ENSO teleconnection to the North Atlantic is mainly associated with the large-scale tropospheric Rossby wave train and its westward tilt with height.

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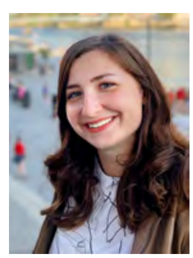

Bianca Mezzina holds a BSc in Physics and a MSc in Terrestrial and Environmental Physics from the University of Trieste, Italy. Following mysterious signs from the universe, in 2016 she started a PhD at the Barcelona Supercomputing Center, within the Earth Sciences Department. No regrets so far.