Multi-model assessment of the late-winter ENSO teleconnection in the Euro-Atlantic sector

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1. Experimental set-up

- **CTL**: control experiment with prescribed climatological Sea Surface Temperature (SST) from HadISST (1981-2010)
- **EN**: sensitivity experiment with SST anomalies of a canonical (strong) El Niño event on top of seasonal cycle
- **LN**: as EN but with flipped-sign anomalies

× 3 models:

- **EC-EARTH3.2** (T255L91, 0.01hPa)
- **ARPEGE6.3** (T127L91, 0.01hPa)
- **CAM5.2** (1°×1°,L46, 0.3hPa)

▸ 1-year integrations × 50 members

state-of-the-art models!

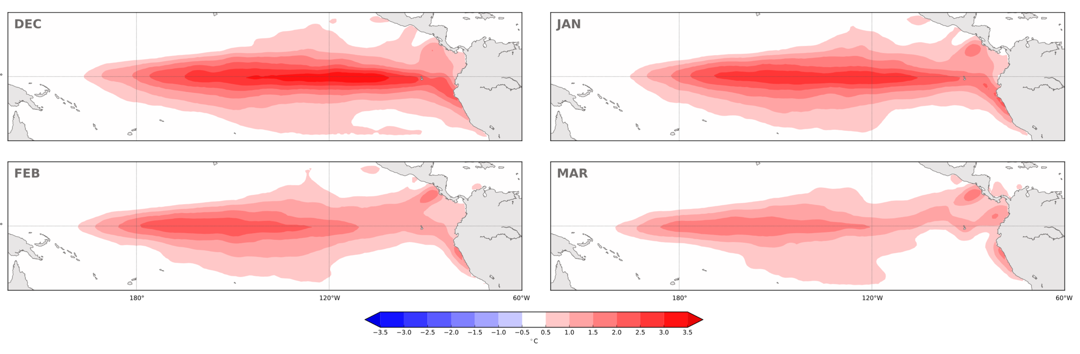
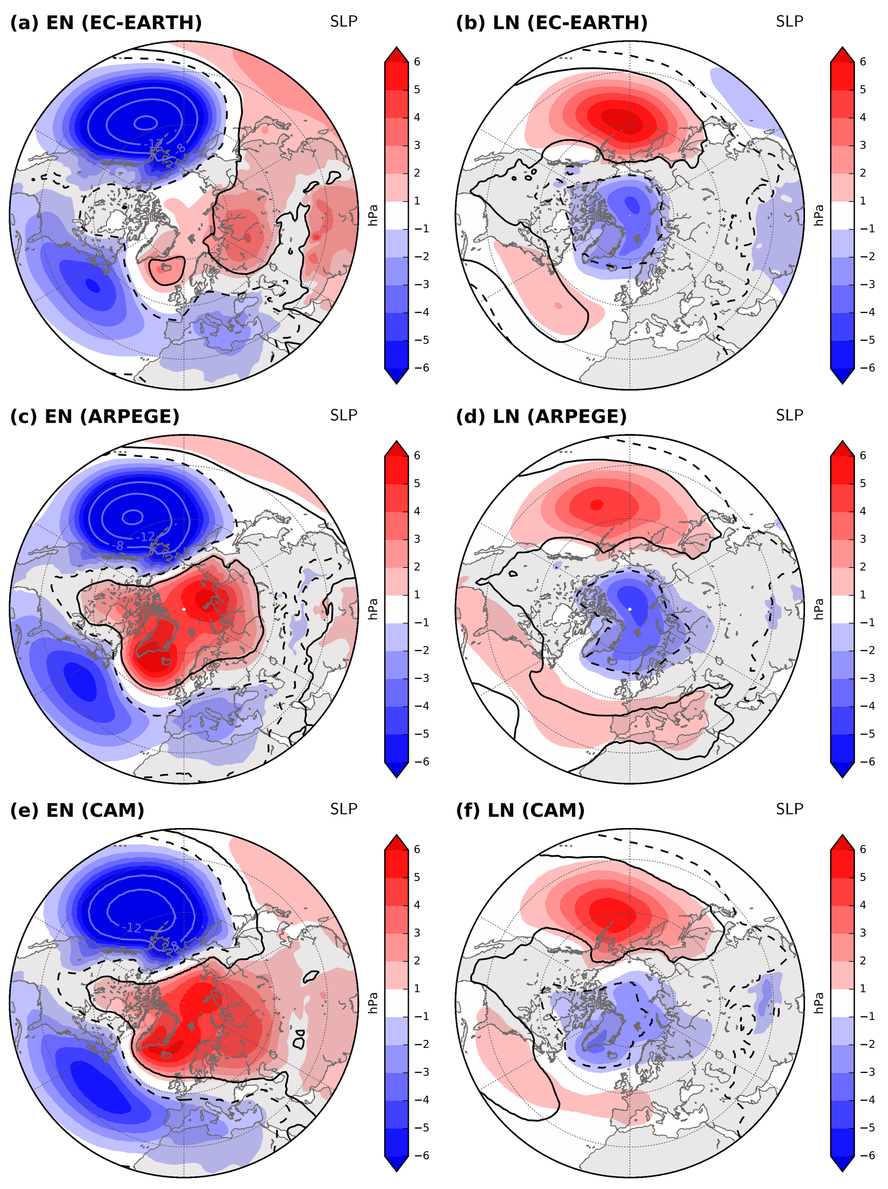


Figure 1. *Monthly means of the superimposed SST anomalies in EN from Nov to Mar.*

2. EN versus LN: sea-level pressure (NH)



The late-winter **(JFM) ENSO-forced response** in sea-level pressure (SLP) is evaluated as the ensemble-mean difference wrt CTL.

▸ The strongest response is in the North Pacific (Aleutian Low), but **weaker** (about half) and **shifted westward in LN** (10°-20°).

▸ In the North Atlantic, a **dipole** is present between mid and high latitudes. Again, LN shows a weaker response in all models.

Zonal shift & different amplitude: why?

Figure 2. *SLP anomalies in EN and LN with respect to CTL, for the three models. JFM. Contours indicate 95% statistical significance.*

3. A step back: tropical convection

▸ The SST **threshold** for tropical convection (around 27°C) is reached over the entire Tropical Pacific for EN, but only in the western Tropical Pacific for LN (grey contours).

The longitude of moisture convergence and convection is determined by the **zonal gradient** of total SST (red and blue contours).

▸ Maximum precipitation (convection) is found east (west) of the Date Line for EN (LN), 30°-40° shift.

▸ Weaker anomalies in LN (smaller diabatic heating despite same SST forcing).

Perturbed convection leads to anomalous upper-level divergence: end of the story?

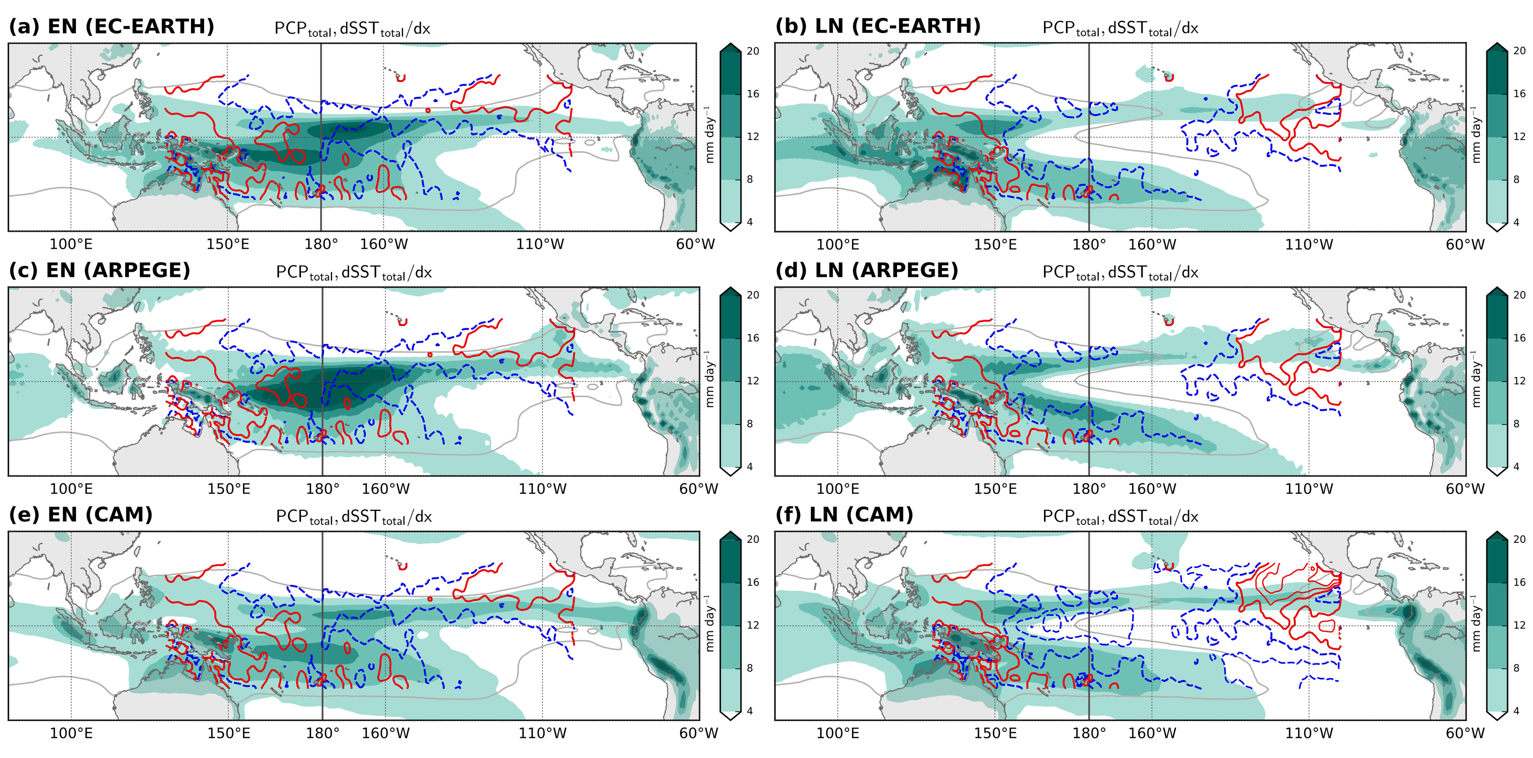


Figure 3. *Shading: total precipitation. Red and blue contours: zonal gradient of total SST (interval: ± 0.2 °C/m). Grey contours : 27°C in total SST. Anomalies in EN (left) and LN (right) with respect to CTL. JFM.*

4. Rossby waves: sources and wave trains

Tropical Rossby Wave Source (shading):

$$TRWS = -\vec{v}'_{div} \cdot \nabla(\bar{\zeta} + f)$$

Waves are generated according to the **interaction** between **anomalous divergence** and **climatological vorticity** (*Sardeshmukh and Hoskins, 1988; Qin and Robinson, 1993*).

▸ TRWS maximum around 30°N due to the North Pacific jet (strong $\nabla(\bar{\zeta} + f)$), with westward shift in LN with respect to EN (20°-30°) and weaker amplitude. Secondary one closer to equator (strong $\vec{v}'_{div}$, arrows).

▸ The extra-tropical response **follows the shift in TRWS**: the **wave train** (contours) propagating towards mid and high latitudes has a similar structure in EN and LN, but the centers of action are again weaker and shifted westward in LN.

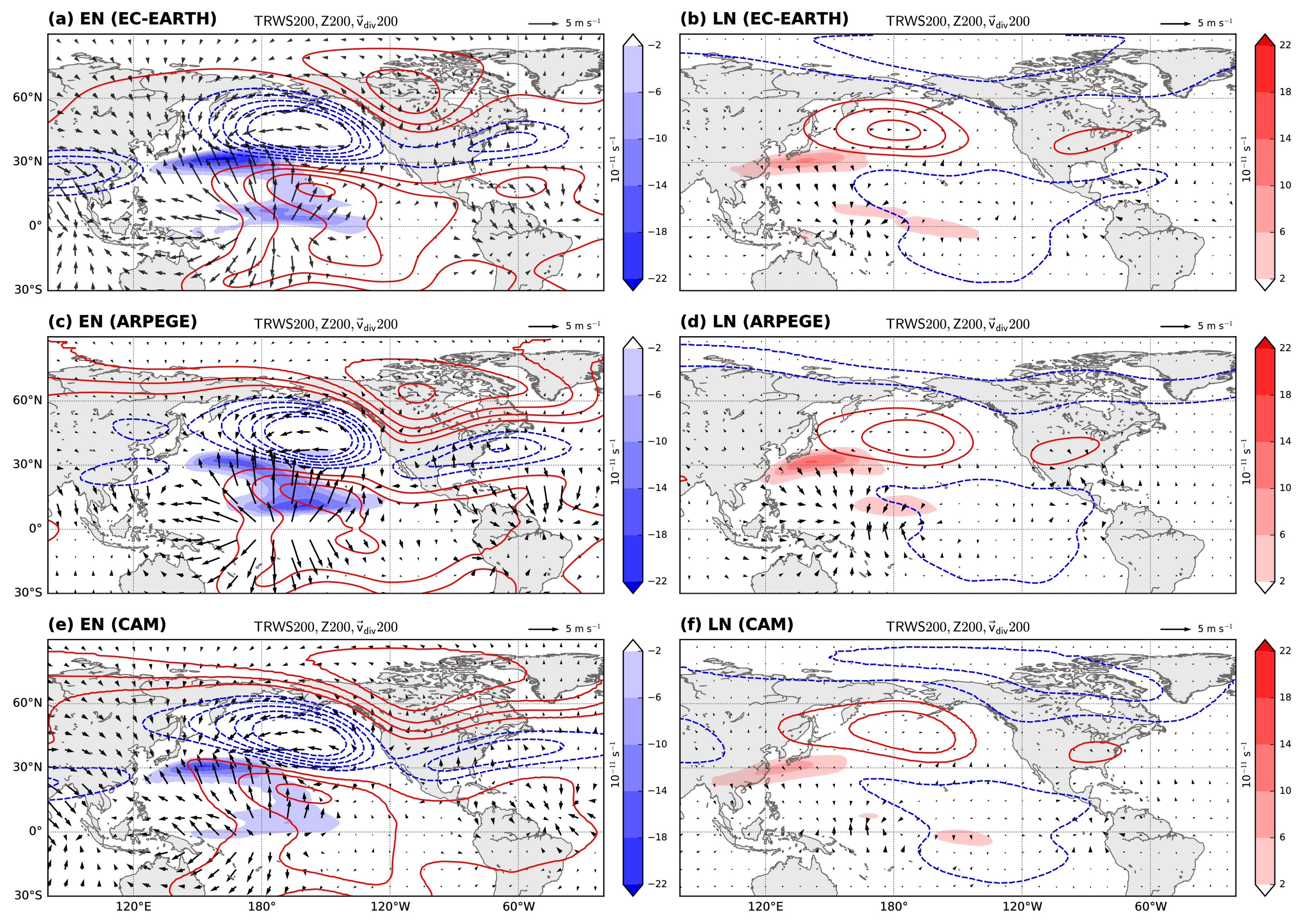


Figure 4. *Shading: anomalous TRWS (weaker values outside Tropical Pacific masked out). Arrows: anomalous divergent wind. Contours: anomalous geopotential height at 200 hPa (Z200). EN(left) and (LN) with respect to CTL. JFM. Contour interval in Z200: 30 m.*

5. Fitting the pieces

Summarizing the behaviour of SLP, Z200, TRWS and tropical precipitation in EN and LN to understand the asymmetry: **shift** to represent variations in longitude, **ratio** |EN/LN| for variations in amplitude.

▸ In the North Pacific, SLP and Z200 have a similar ratio and shift; TRWS tend to cluster with them, while tropical precipitation shows a different behaviour (Fig. 6).

▸ In the North Atlantic only the center of action over the mid-latitudes is considered, whose tilt (Fig. 5) yields the dipolar pattern at surface (Fig. 2).

The overall result is similar, with some differences in SLP (Fig. 7), likely due to the fact that the wave train in LN projects over land at surface (Fig. 5).

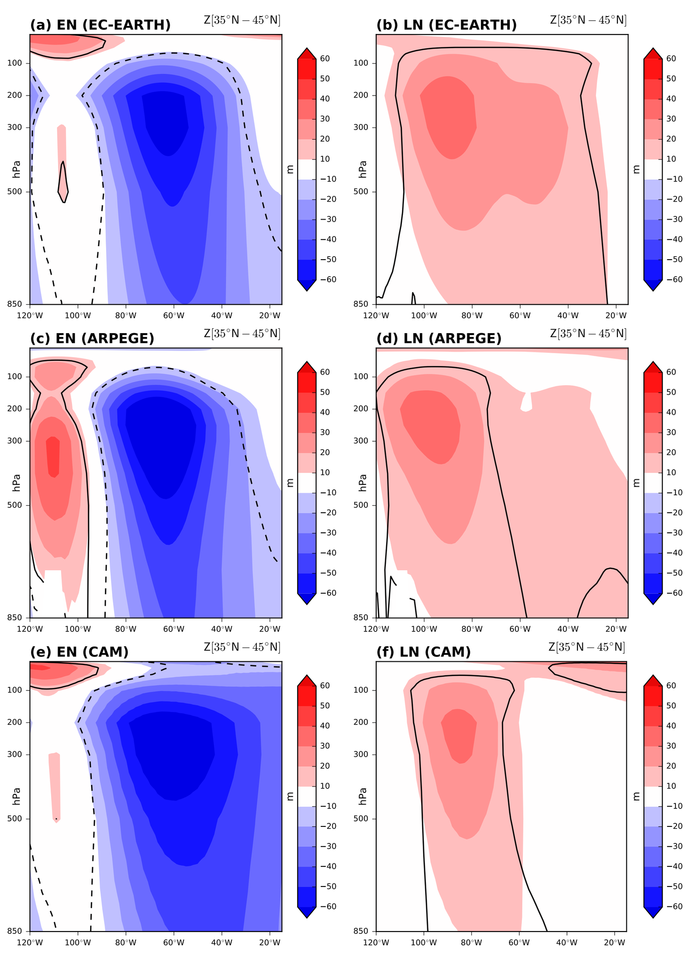


Figure 5. *Vertical cross section of geopotential height anomalies averaged over 35°N-45°N in the North Atlantic sector. EN (left) and LN (right) with respect to CTL. JFM.*

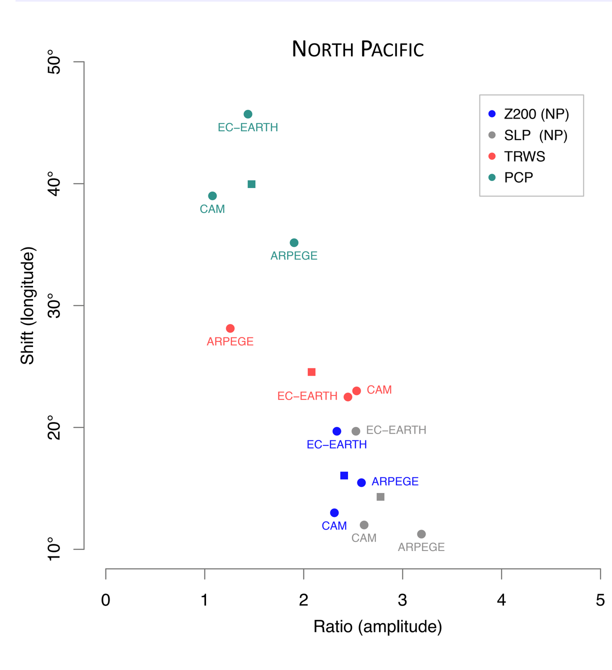


Figure 6. *Scatter plot of shift versus ratio for the indicated fields, considering SLP and Z200 anomalies over the North Pacific. Square: multi-model mean.*

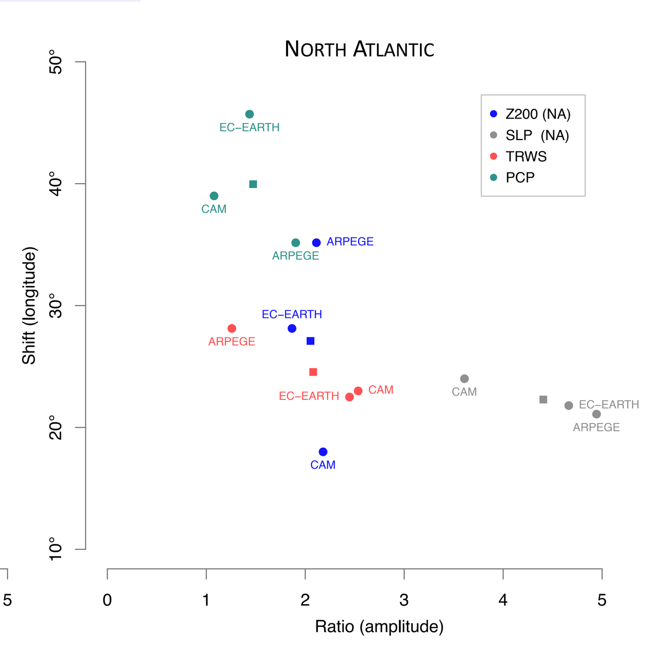


Figure 7. *As Figure 6 but for the North Atlantic (SLP and Z200).*

Key messages

- **Asymmetry of the extra-tropical ENSO response to EN versus LN (longitudinal shift + different amplitude) in SLP despite symmetric forcing.**
- **The SLP behaviour is mostly inherited from the large-scale Rossby wave train at upper levels.**
- **Tropical convection is underlying the asymmetry in amplitude, but the divergence needs to be considered in tandem with the mean flow for the shift.**
- **The extra-tropical wave train follows the asymmetry in Tropical Rossby Wave Source.**
- **Asymmetry, but same dynamical mechanisms for EN and LN.**
- **The ENSO teleconnection in the North Atlantic is associated with the Rossby wave train and its tilt with height.**
- **Results supported by 3 state-of-the-art models!**

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