Elements for the production of Objective Seasonal Forecasts: MedCOF sub-region

ENSO as a source of predictability for the North Atlantic-Mediterranean region

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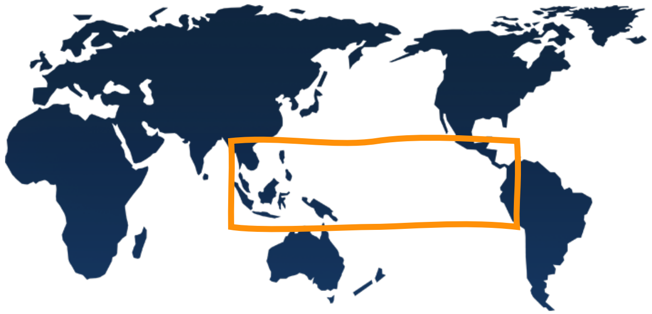
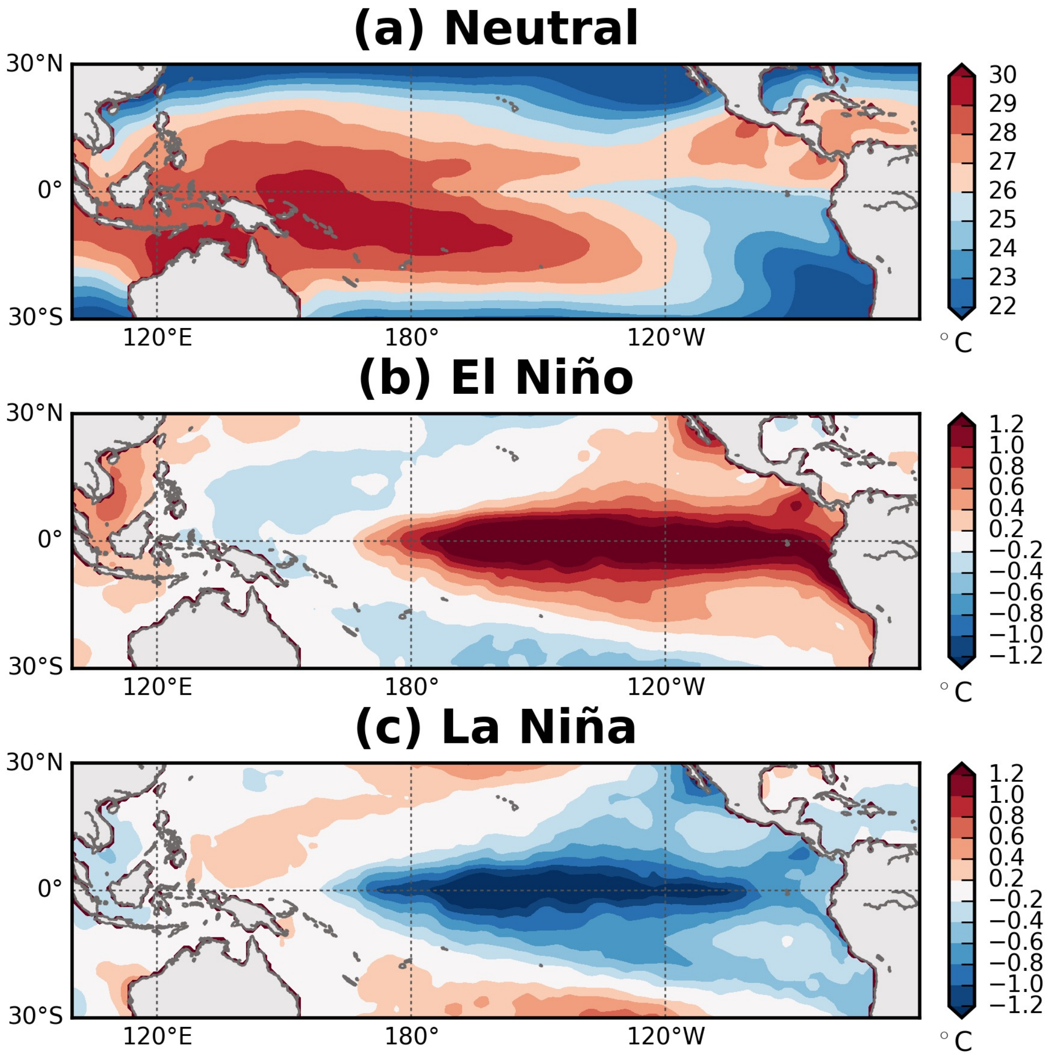
ENSO BASICS: WHAT IS ENSO?

ENSO = El Niño-Southern Oscillation

- Recurring **natural** phenomenon in the **tropical Pacific** region
- *Coupled* oscillation: variations in **ocean** (El Niño) and **atmosphere** (Southern Oscillation)
- Fluctuation between 3 phases: Neutral, El Niño (warm) and La Niña (cold)



ENSO BASICS: SEA SURFACE TEMPERATURE (SST)



(a) DJF observed SST average during neutral years

(b,c) Composite of DJF observed SST anomalies during El Niño and La Niña years

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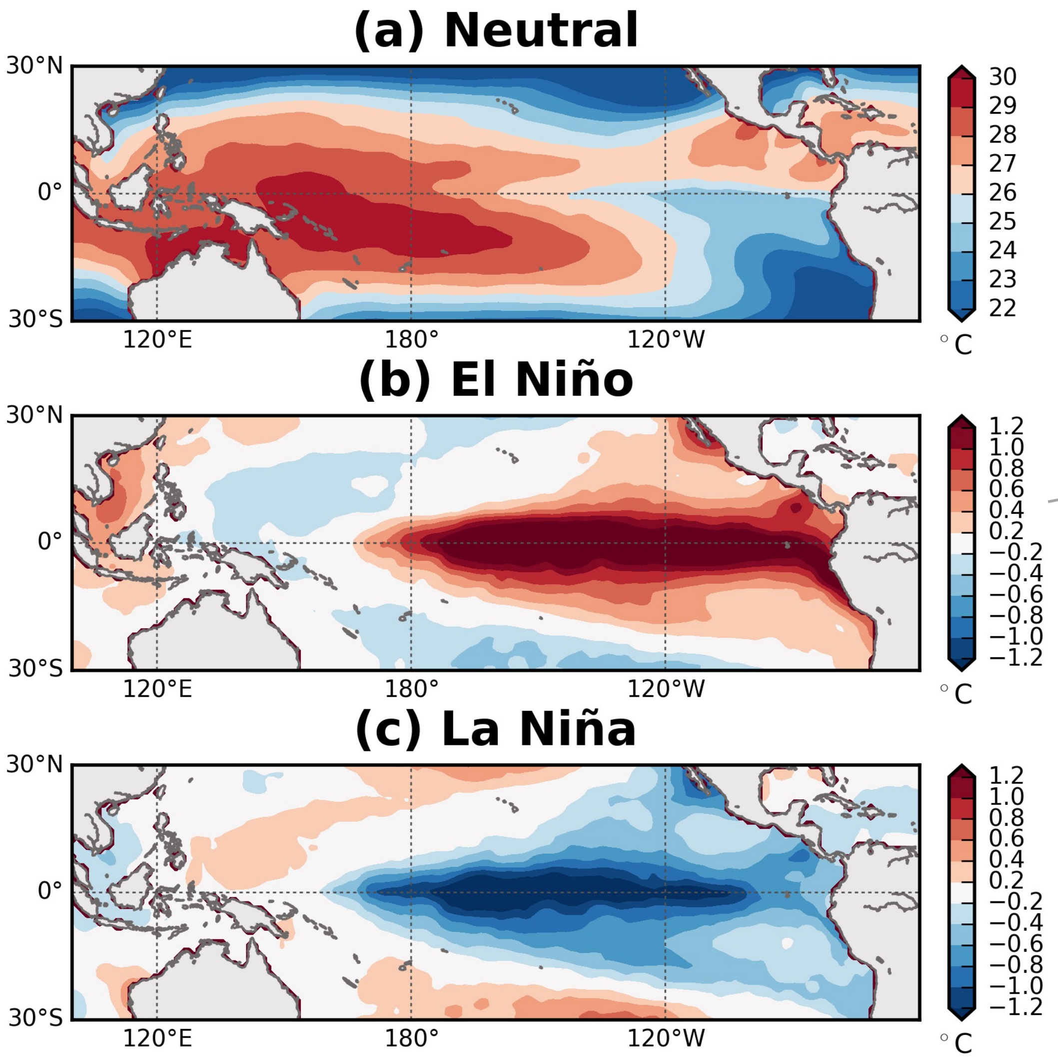
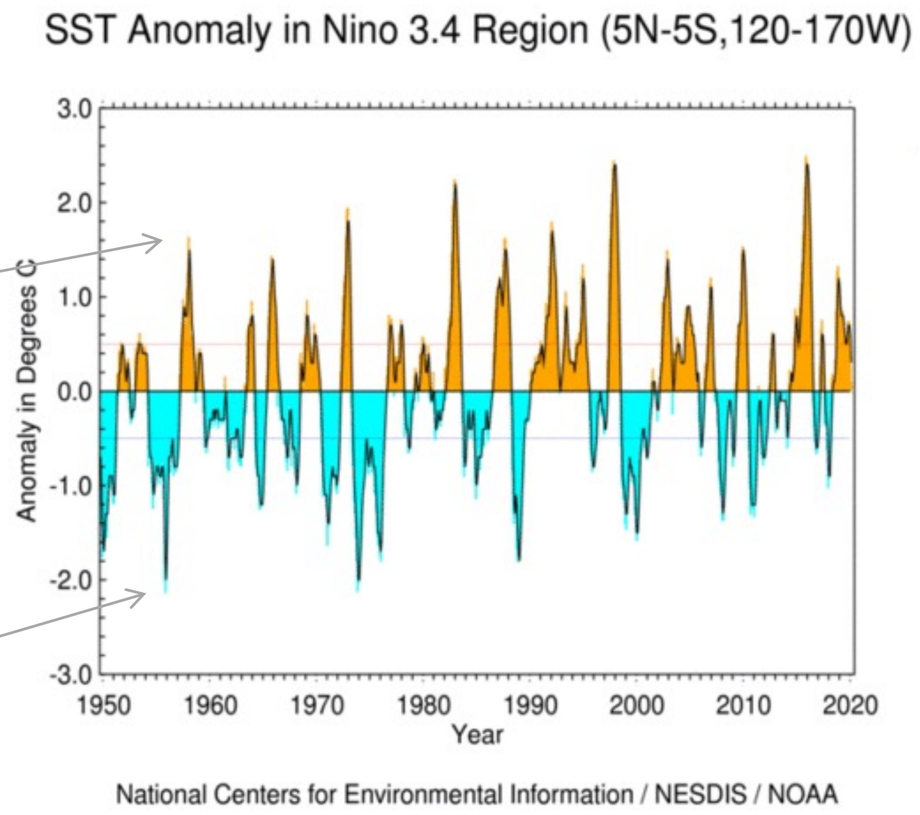


(a) DJF observed SST average during neutral years
(b,c) Composite of DJF observed SST anomalies during El Niño and La Niña years

Niño3.4 index

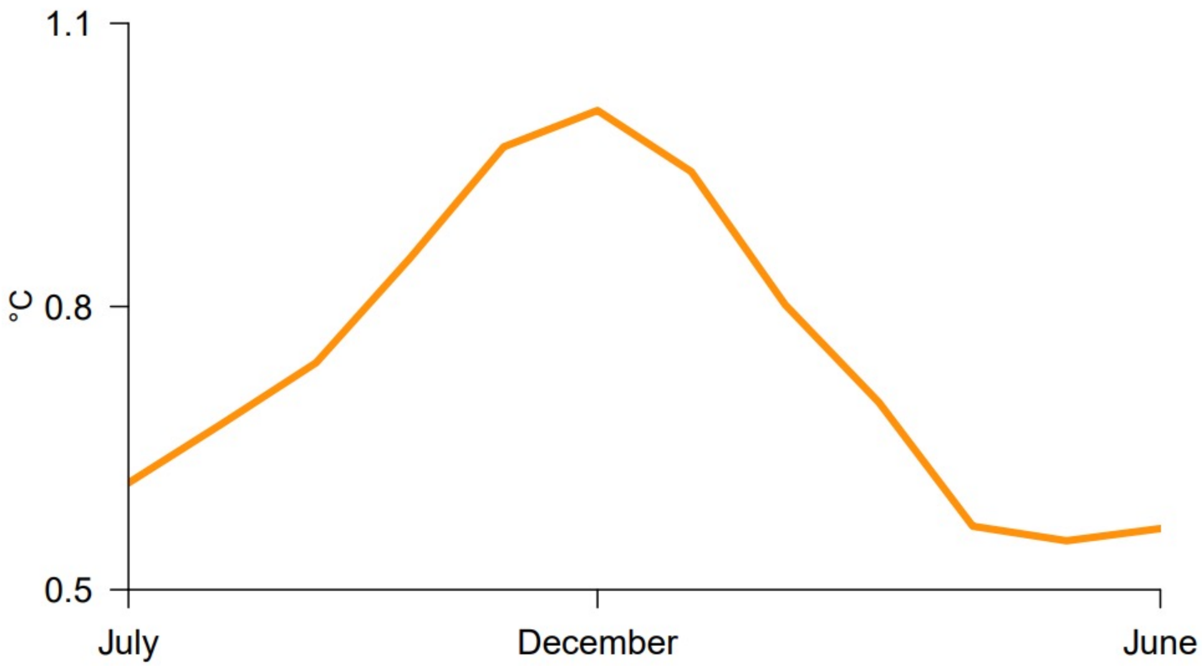


ENSO BASICS: WHEN AND WHY

El Niño/La Niña event every **2-5 years**

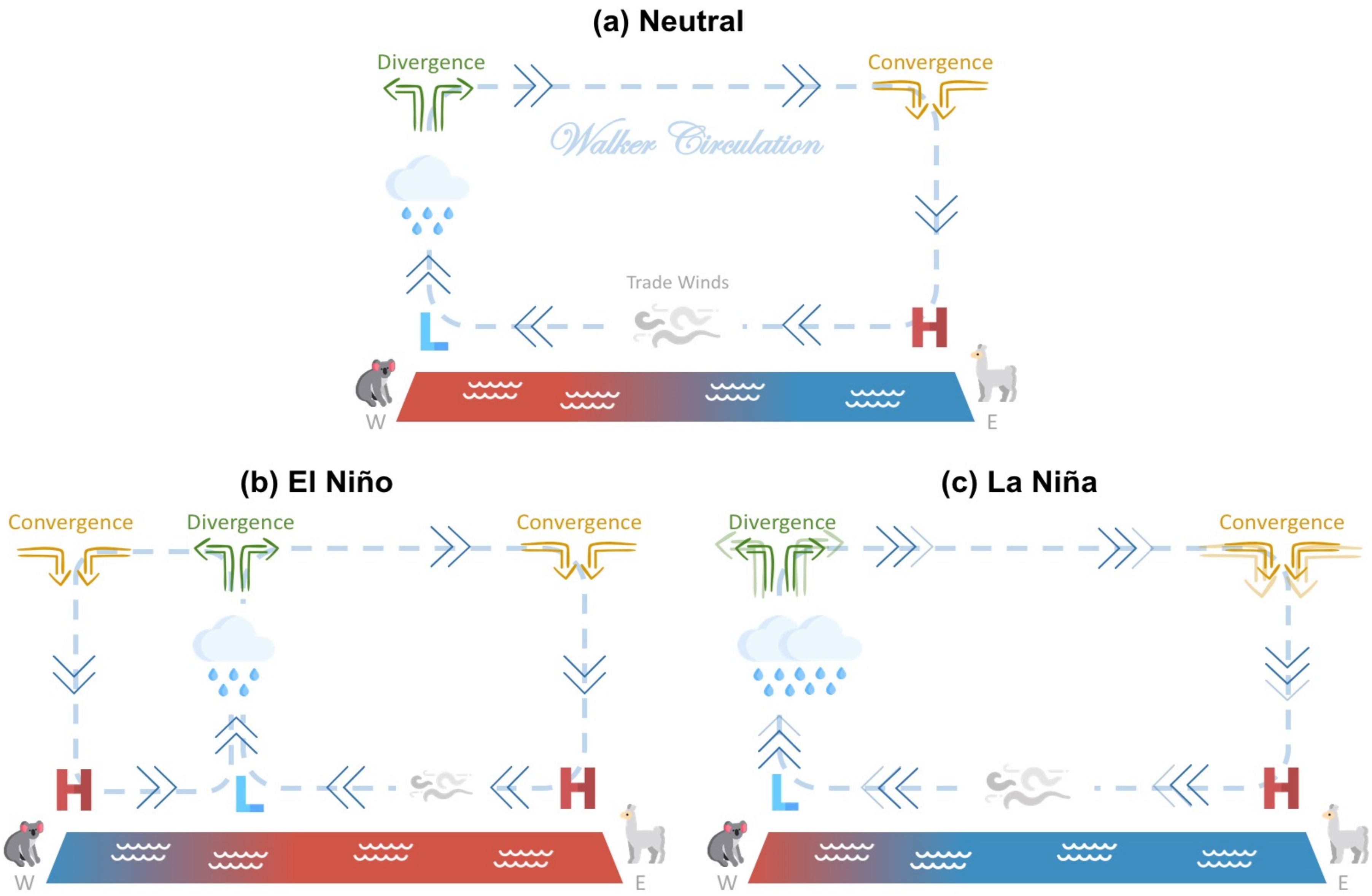
Begins in summer, peaks in **winter** (December)

Lasts **9-12 months**



Standard deviation of observed monthly Niño3.4 index

ENSO BASICS: LOCAL ATMOSPHERIC CIRCULATION



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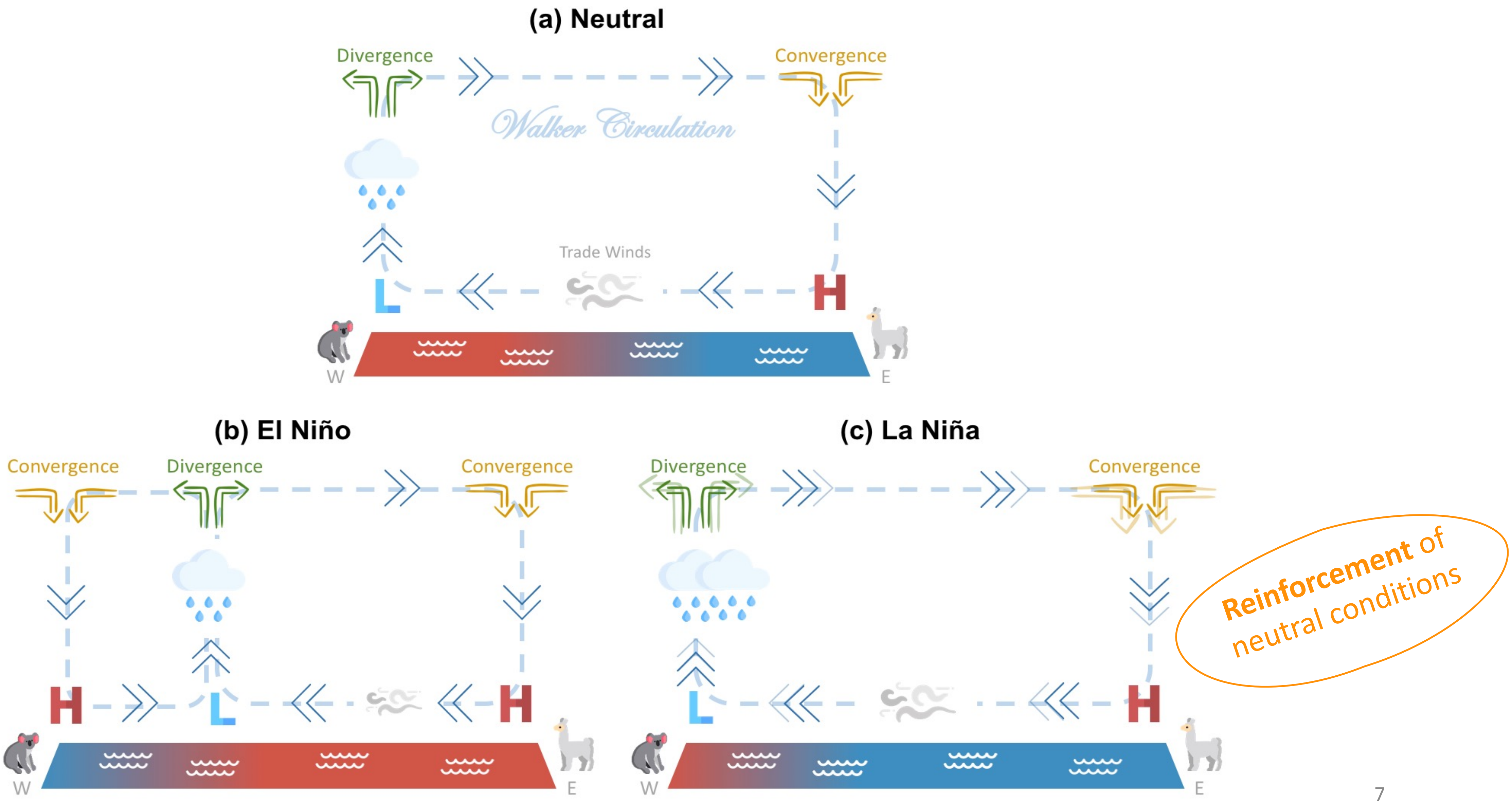

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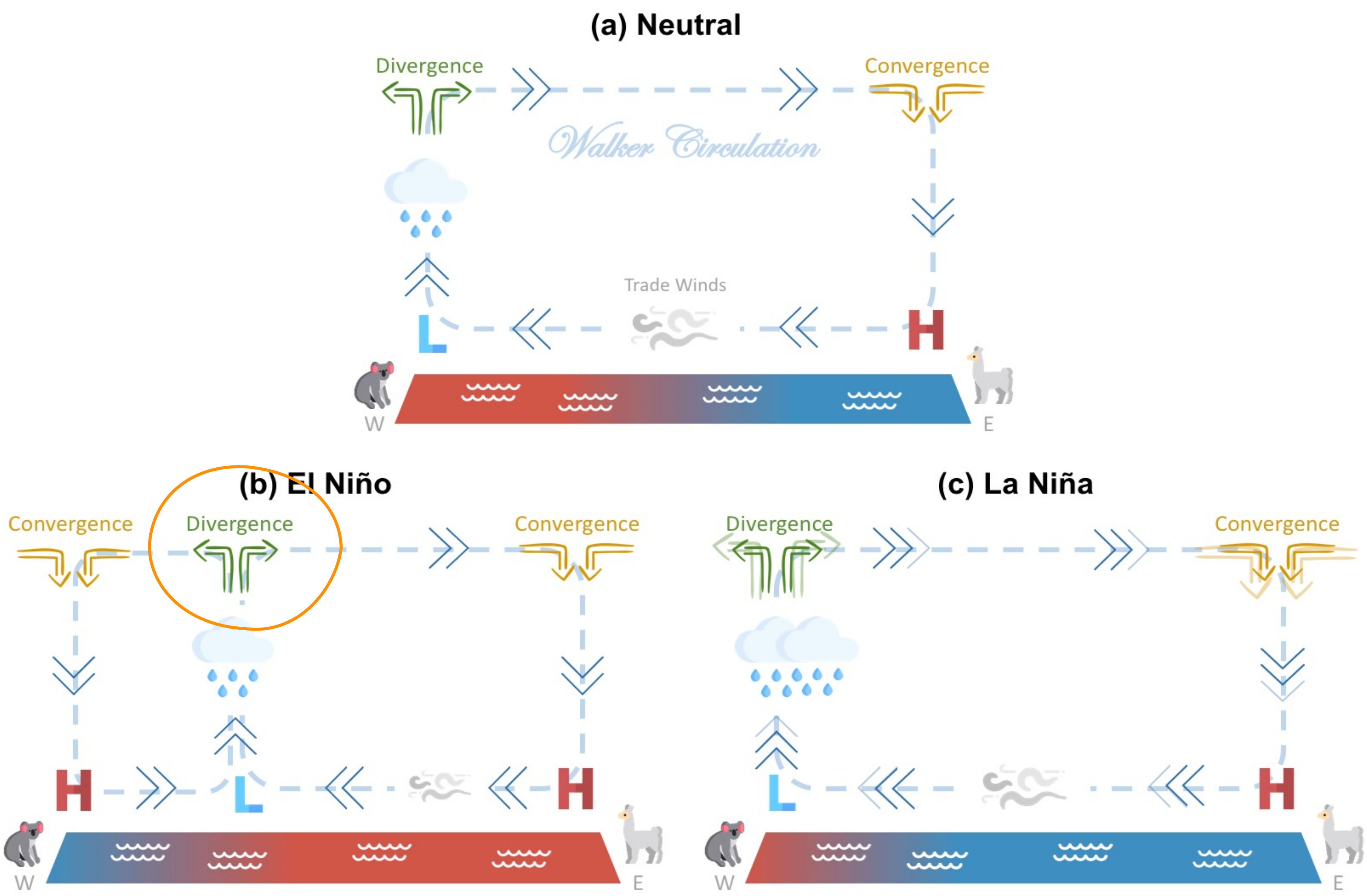
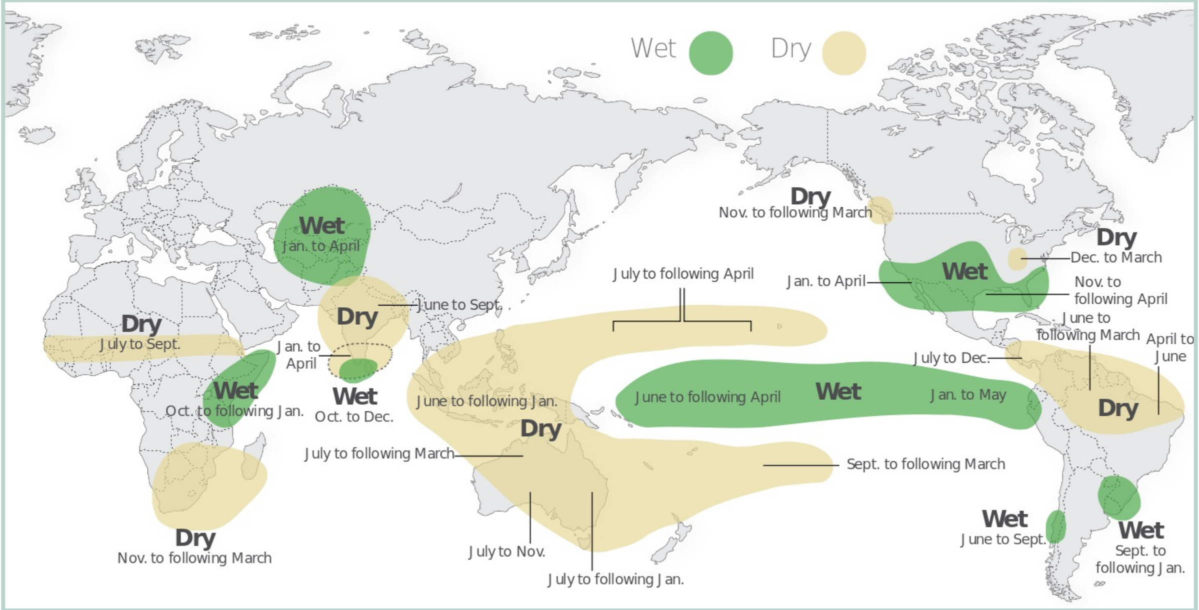


ENSO-NAE TELECONNECTION

ENSO has **global** impacts on climate → TELECONNECTIONS! (links between distant regions)

El Niño and rainfall



Source: iri.columbia.edu

ENSO is a potential **source of seasonal predictability** for mid-latitude regions

ENSO-NAE TELECONNECTION

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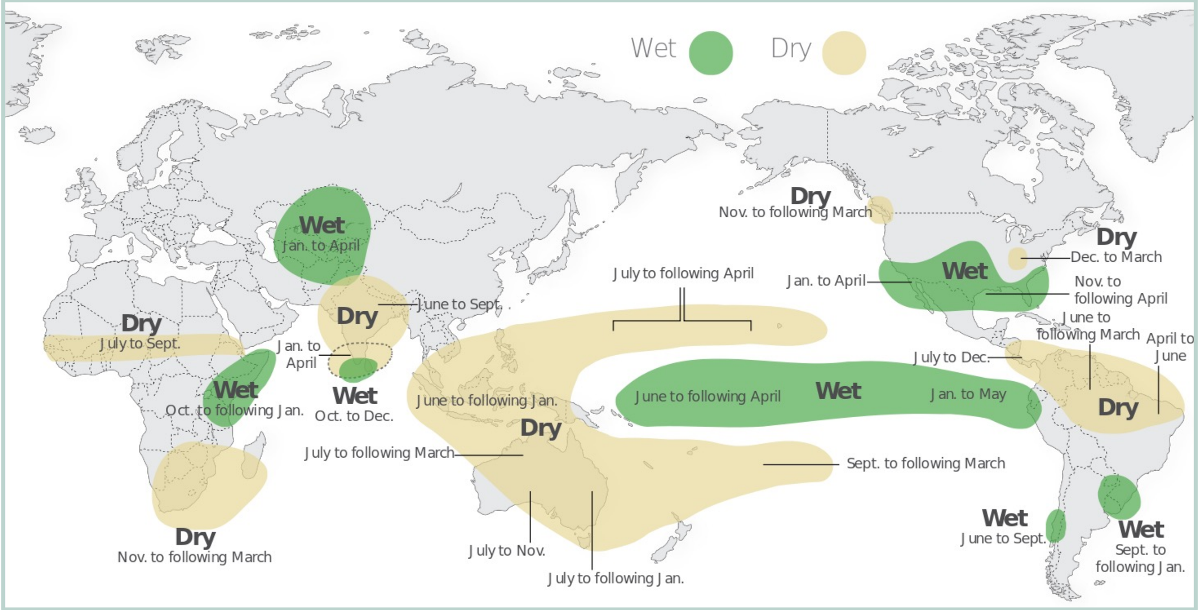

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ENSO is a potential **source of seasonal predictability** for mid-latitude regions

...And a very powerful one!

ENSO PREDICTABILITY

ENSO can be predicted several **months in advance**

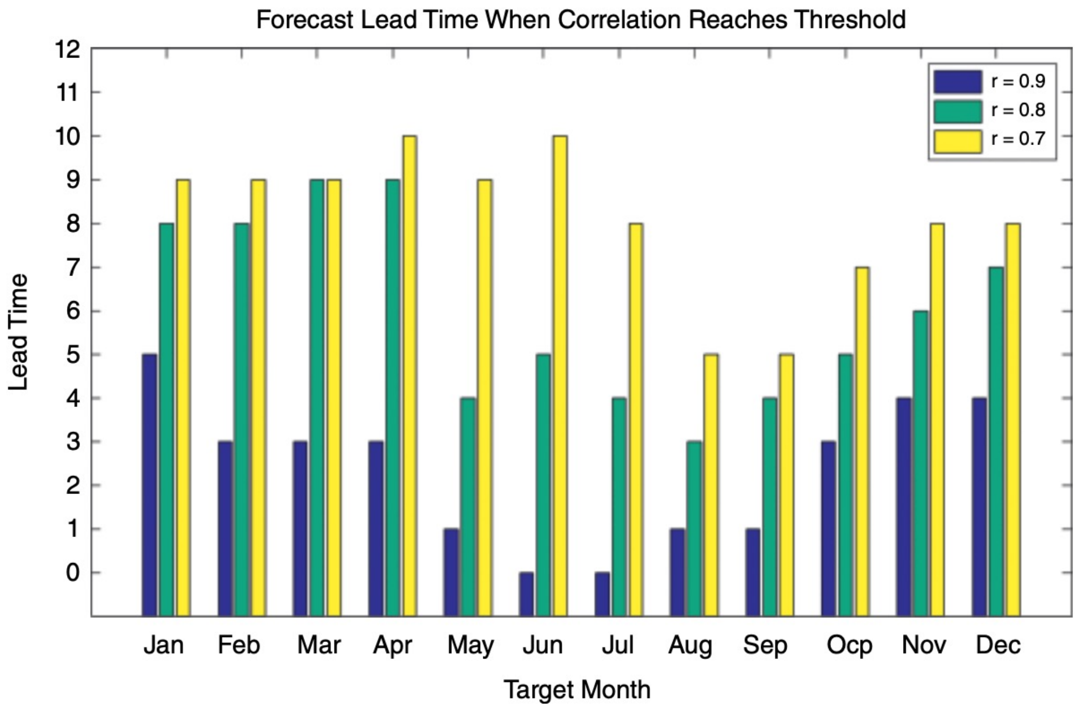


Figure 10.3 The forecast lead-time (*y*-axis) when Niño-3.4 index skill exceeds certain correlation thresholds. On the *x*-axis, the target month of the forecast is presented. Model data is based on the ensemble average of ~100 members from the North American Multi-Model Ensemble from 1982 to 2018. Departures in the Niño-3.4 index are based on 1982–2010 monthly averages.

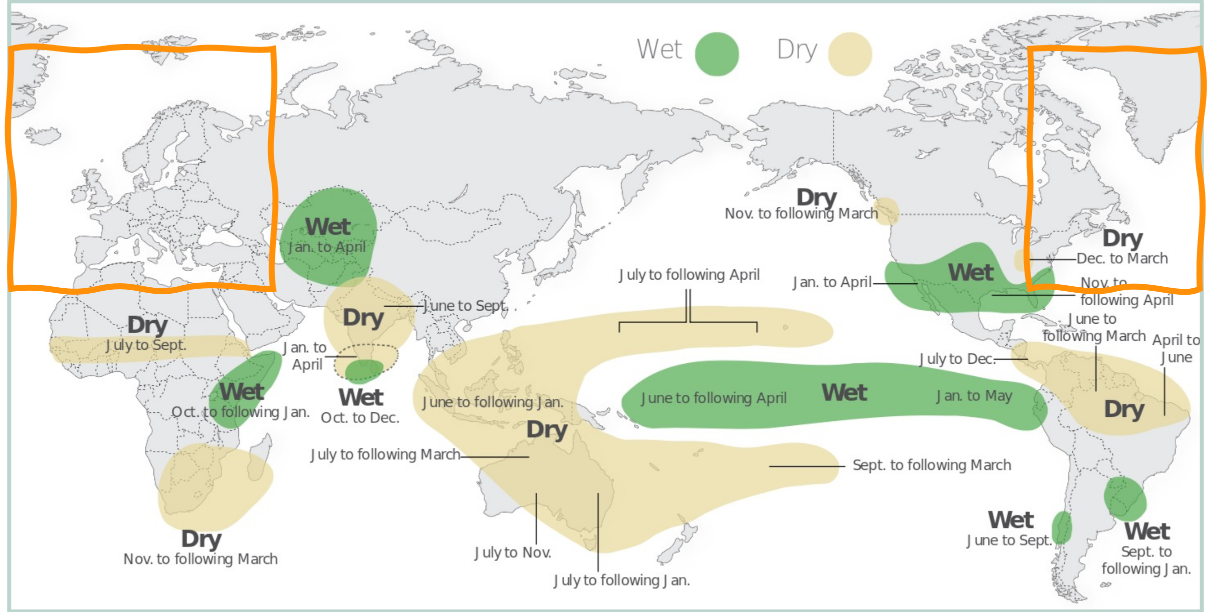
L'Heureux et al. (2020)

ENSO-NAE TELECONNECTION

(Mediterranean)

What about the **North Atlantic-European (NAE)** region?

El Niño and rainfall



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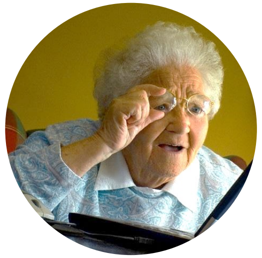

No impact?

ENSO-NAE TELECONNECTION

(Mediterranean)

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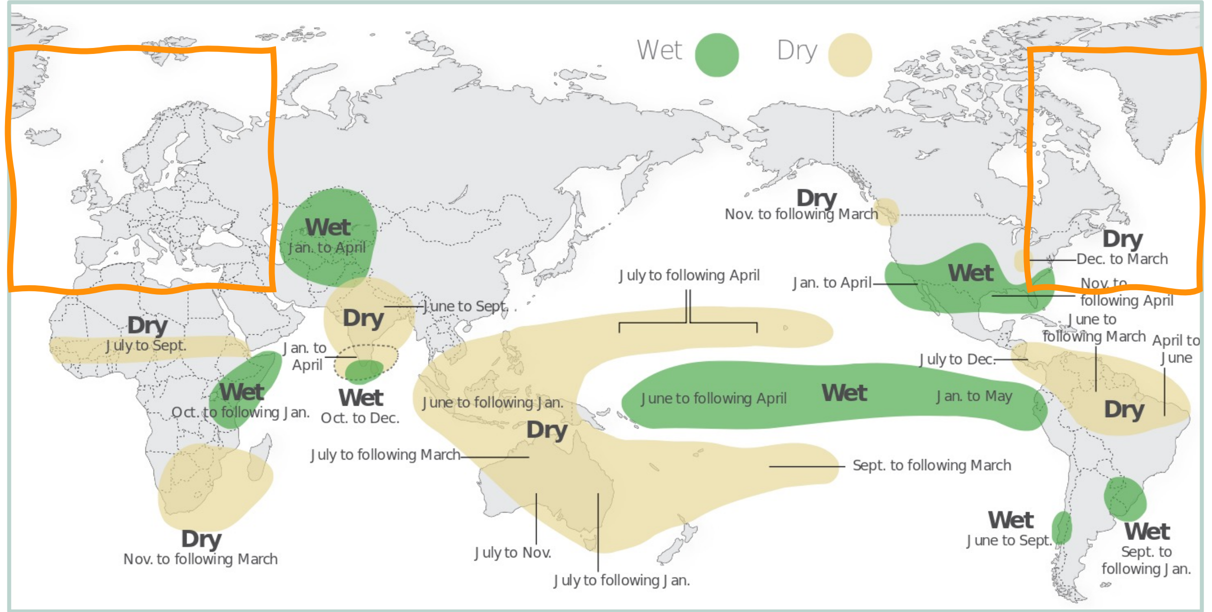
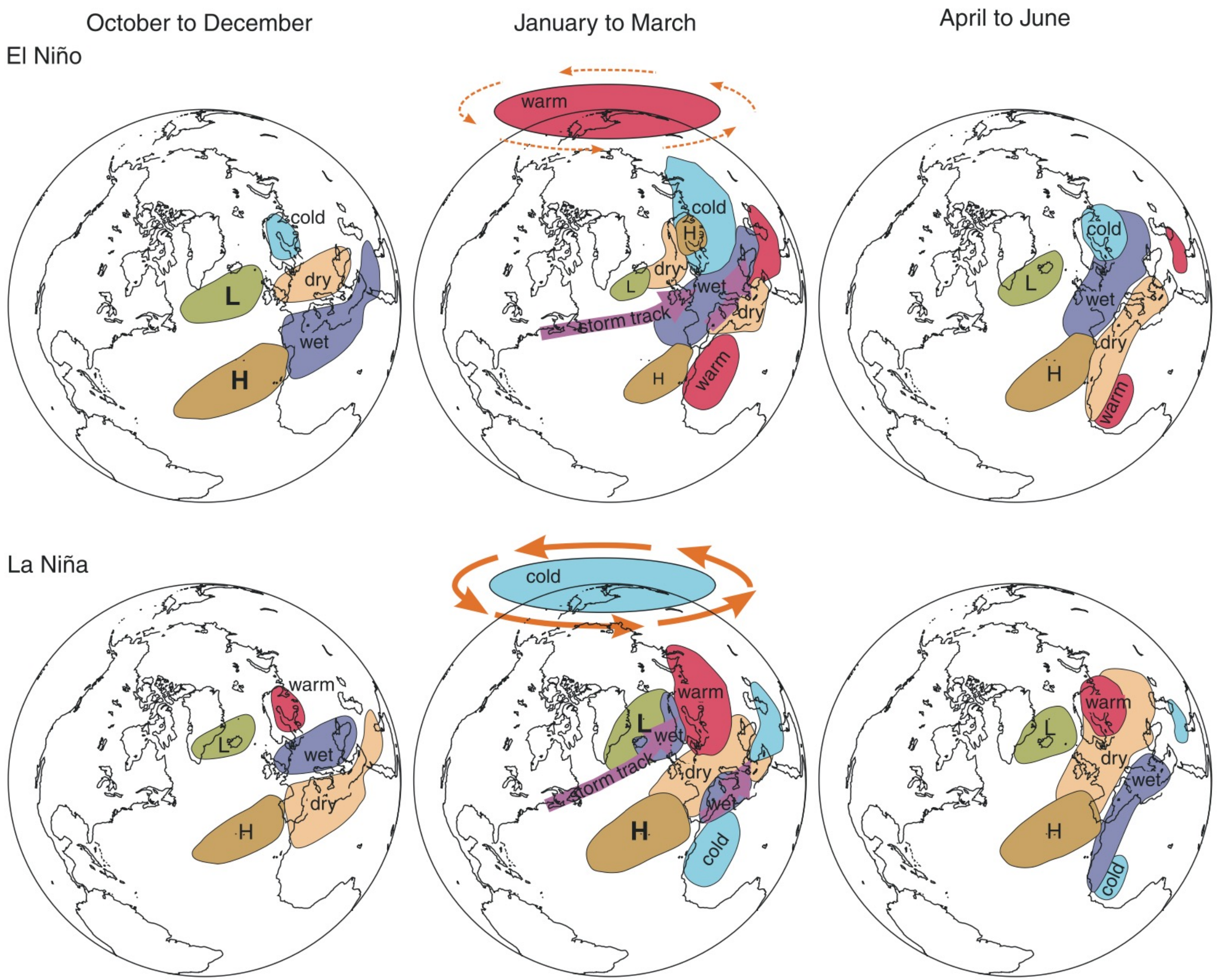


Source: iri.columbia.edu

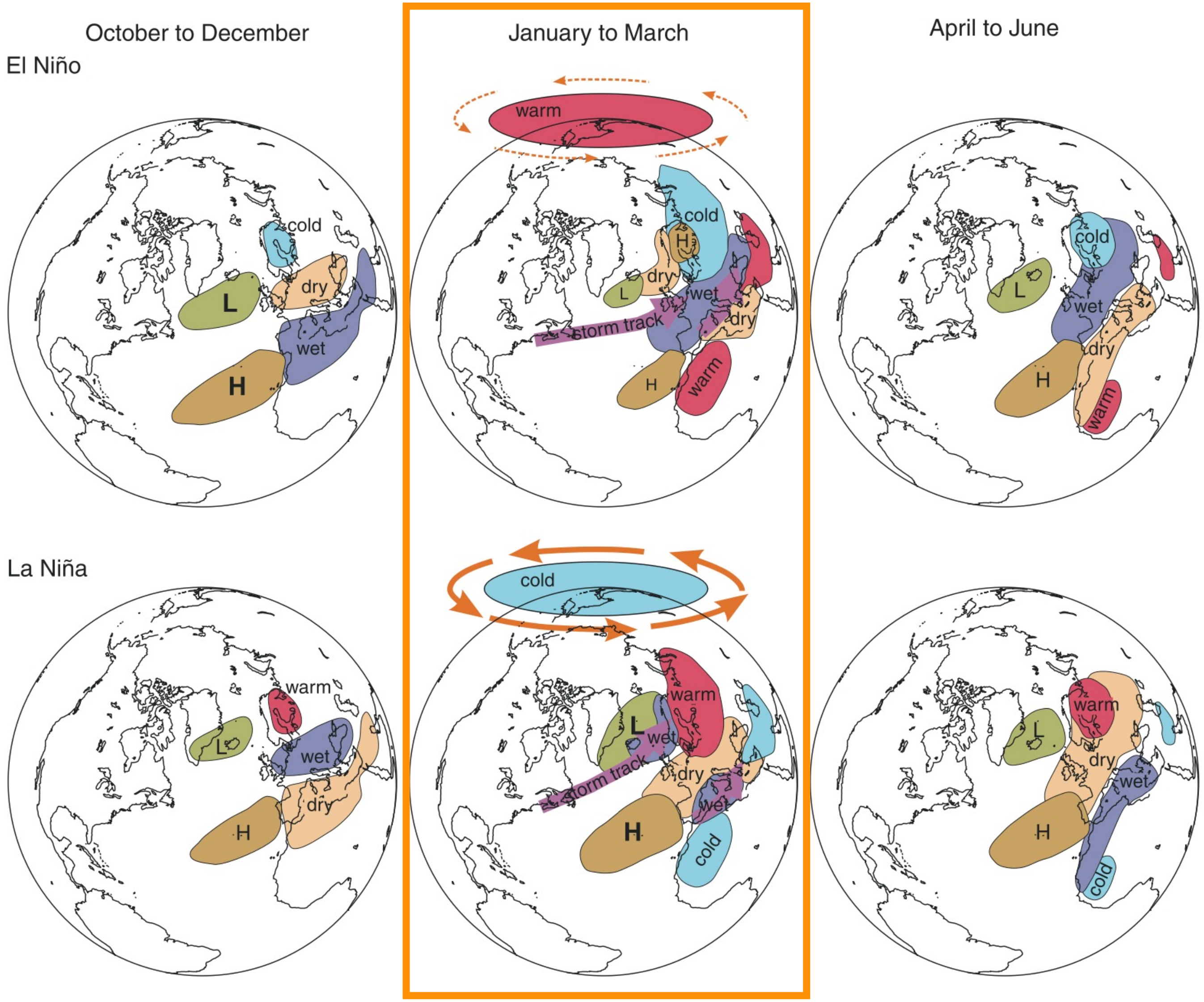
Some impact, but **hard to detect…**

ENSO IMPACTS



Brönnimann (2007)

ENSO IMPACTS



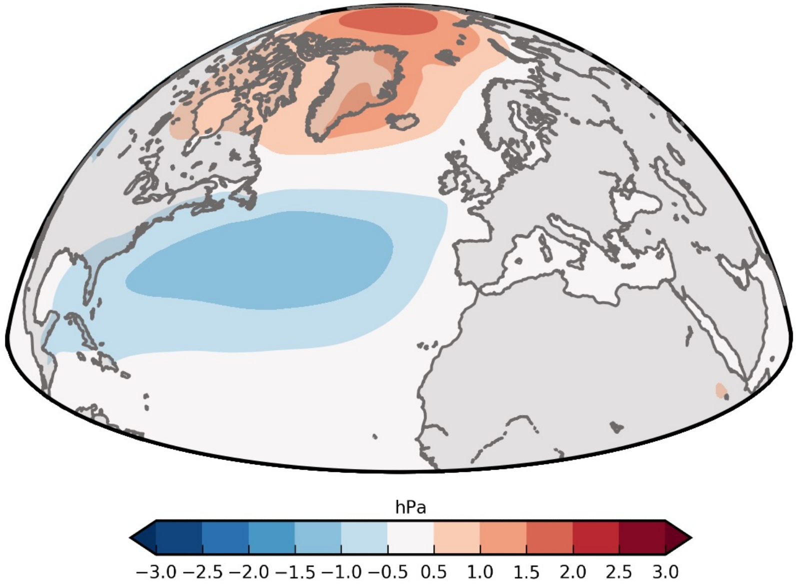
Brönnimann (2007)

ENSO-NAE TELECONNECTION: “CANONICAL” DIPOLE

Late-winter **sea-level pressure** (SLP) dipole

Dipole between **high latitudes** and **mid-latitude North Atlantic**

Robust and *significant* in **late winter** (January-March; JFM)



Observed SLP anomalies associated with El Niño

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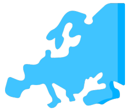
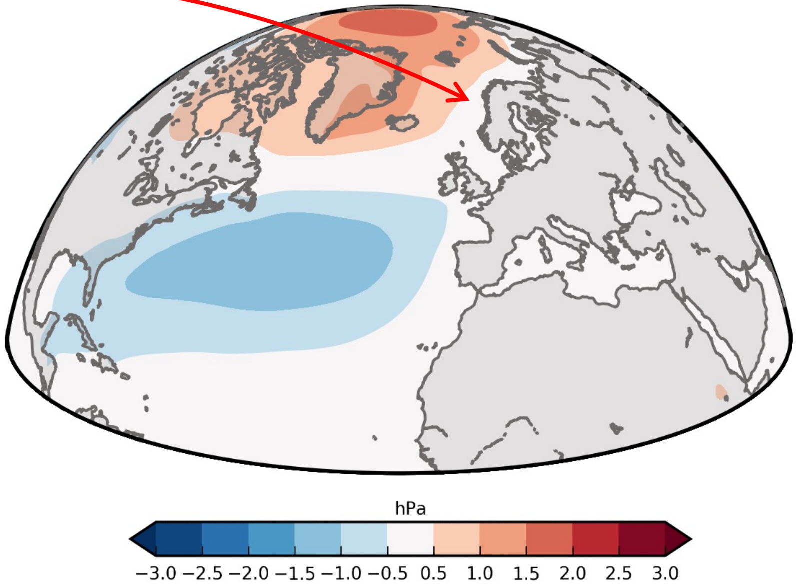


What about **Europe** and the **Mediterranean**?



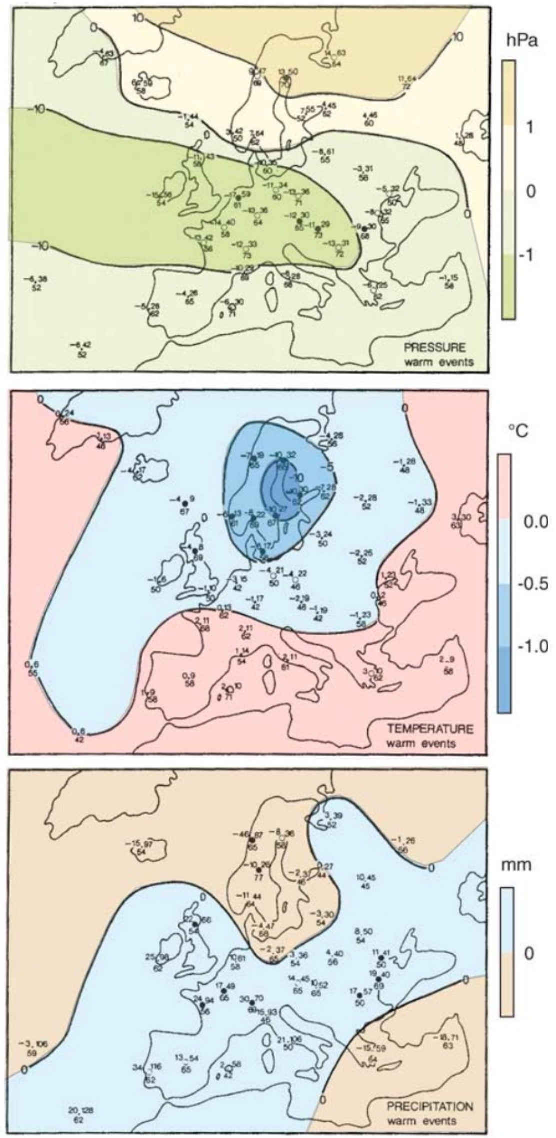
Observed SLP anomalies associated with El Niño

ENSO-NAE TELECONNECTION: “CANONICAL” SIGNAL

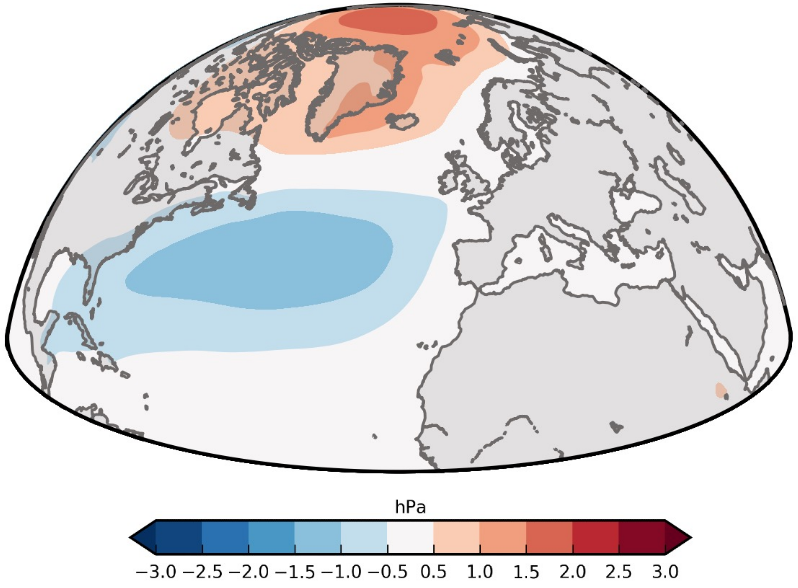
SLP

T

PCP

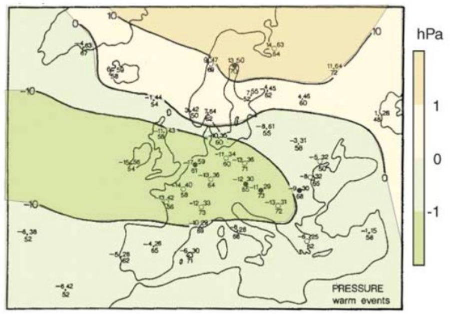


Brönnimann (2007)



Observed SLP anomalies associated with El Niño

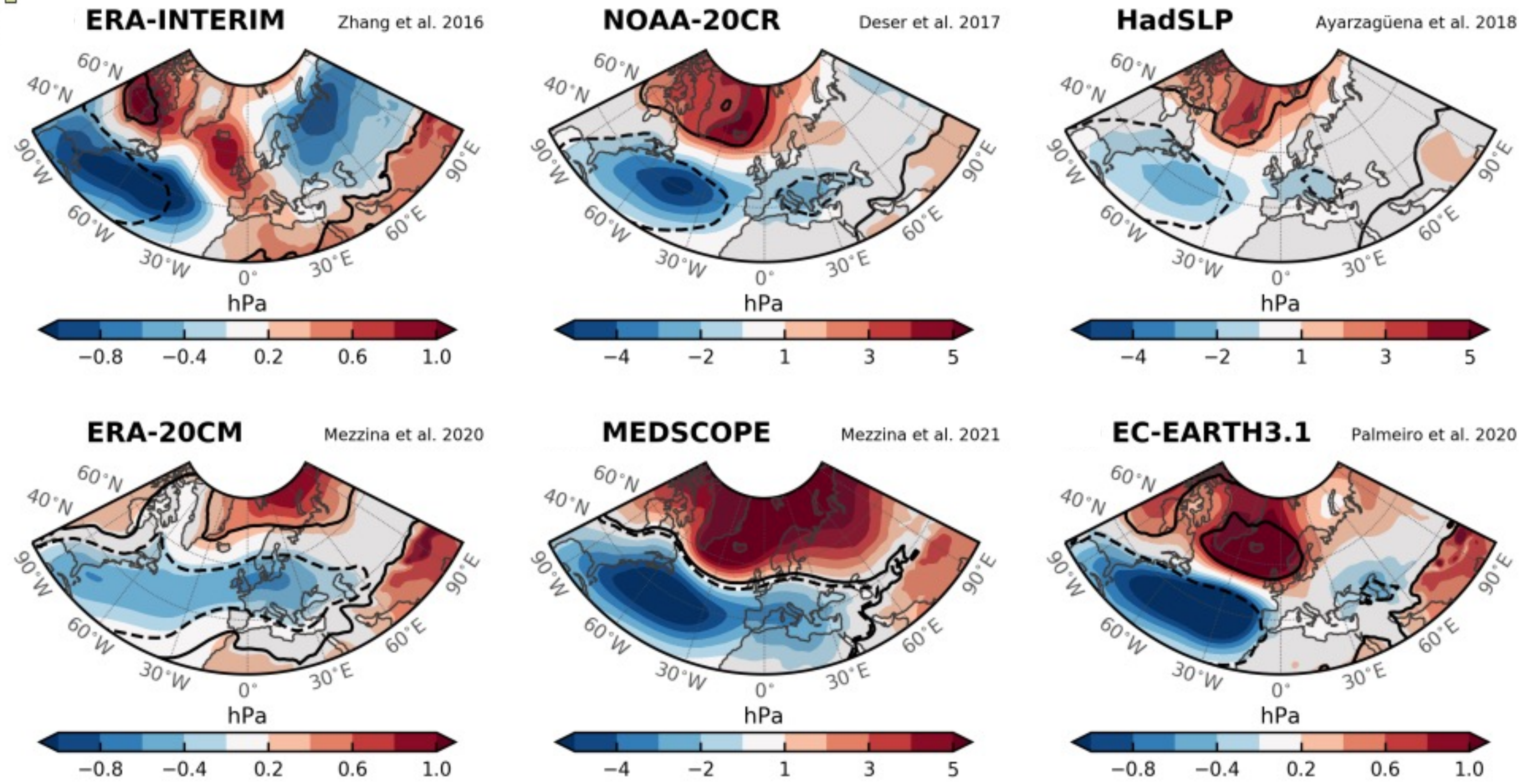
LATE-WINTER SIGNAL OVER EUROPE



❌ **Disagreement** in models and observations

OBS

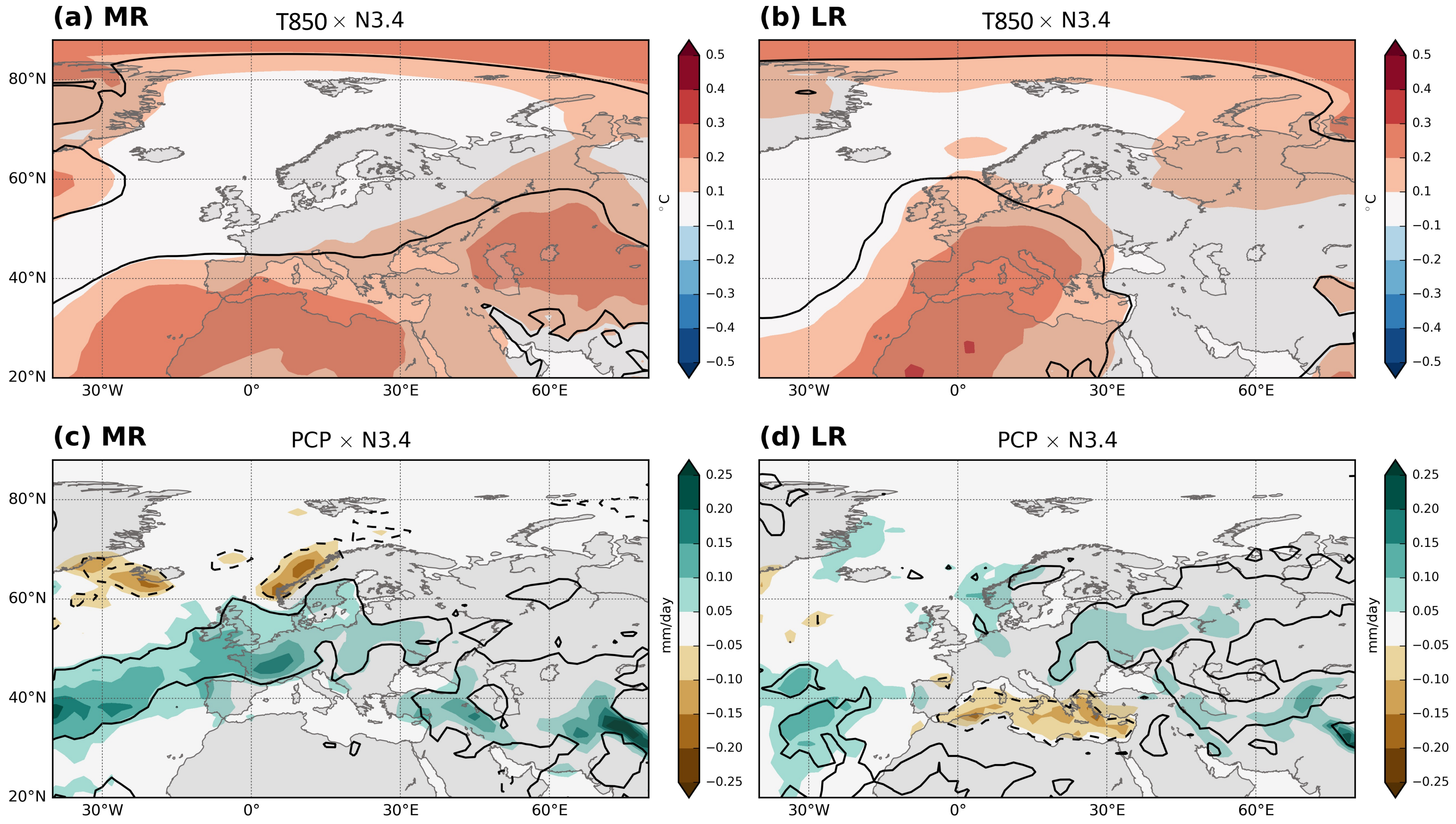
MODELS



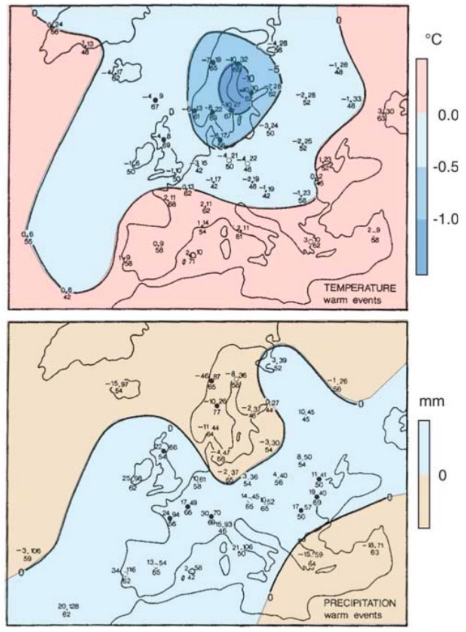
Mezzina et al. (under review)

ENSO IMPACTS

An example from CMIP5 historical runs…



cf.



Brönnimann (2007)

Regression of Nino3.4 index onto T850 and precipitation for two versions of the MPI-ESM model (historical runs, 1 member)

ENSO IMPACTS

Challenges in detecting an ENSO signal in Europe:

- Large **internal variability** (low signal-to-noise ratio)

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- **Sampling issues:**
  - Limited observational record (100 years) → ”few” ENSO events
  - In models: how many years/members do we need?

ENSO IMPACTS

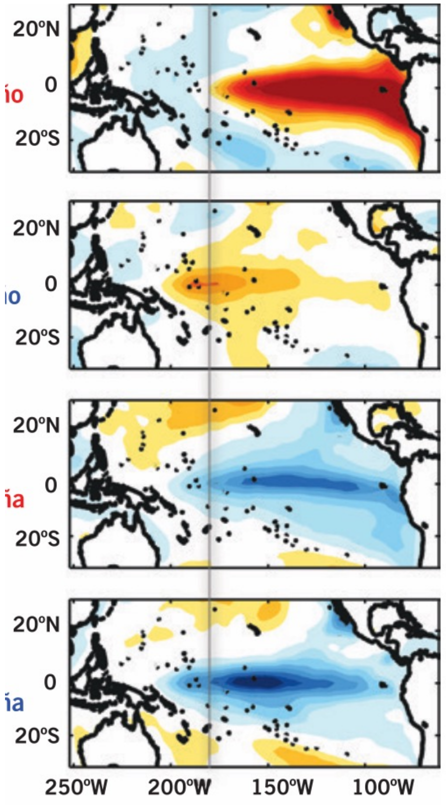
Challenges in detecting an ENSO signal in Europe:

- Large **internal variability** (low signal-to-noise ratio)

- **Sampling issues:**
  - Limited observational record (100 years) → "few" ENSO events
  - In models: how many years/members do we need?

- ENSO **diversity**

- Non-stationarity? (more on this later!)



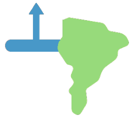
Capotondi et al. (2015)

Thank you MEDSCOPE

SENSITIVITY EXPERIMENTS

Experiments:

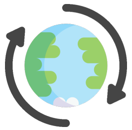
- **EN**: SST anomalies of a canonical *El Niño* event (on top of seasonal cycle)



- **LN**: as *EN* but with flipped-sign anomalies
- **CTL**: climatological SST (HadISST)

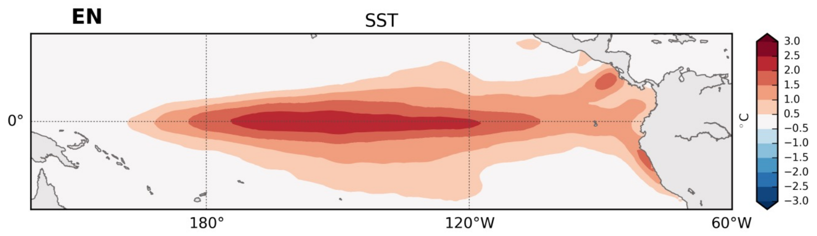
→ 1-year integrations × 50 members

Models:

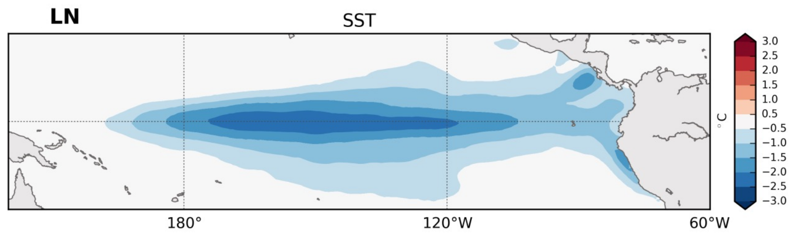


- **EC-EARTH** (EC-EARTH3.2) 512×256, L91, 0.01 hPa
- **CNRM** (ARPEGE6.3) 256×128, L91, 0.01 hPa
- **CMCC** (CAM5.3) 360×180, L46, 0.3 hPa

EN

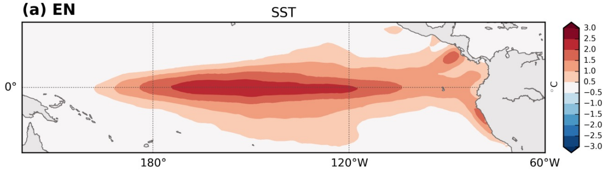


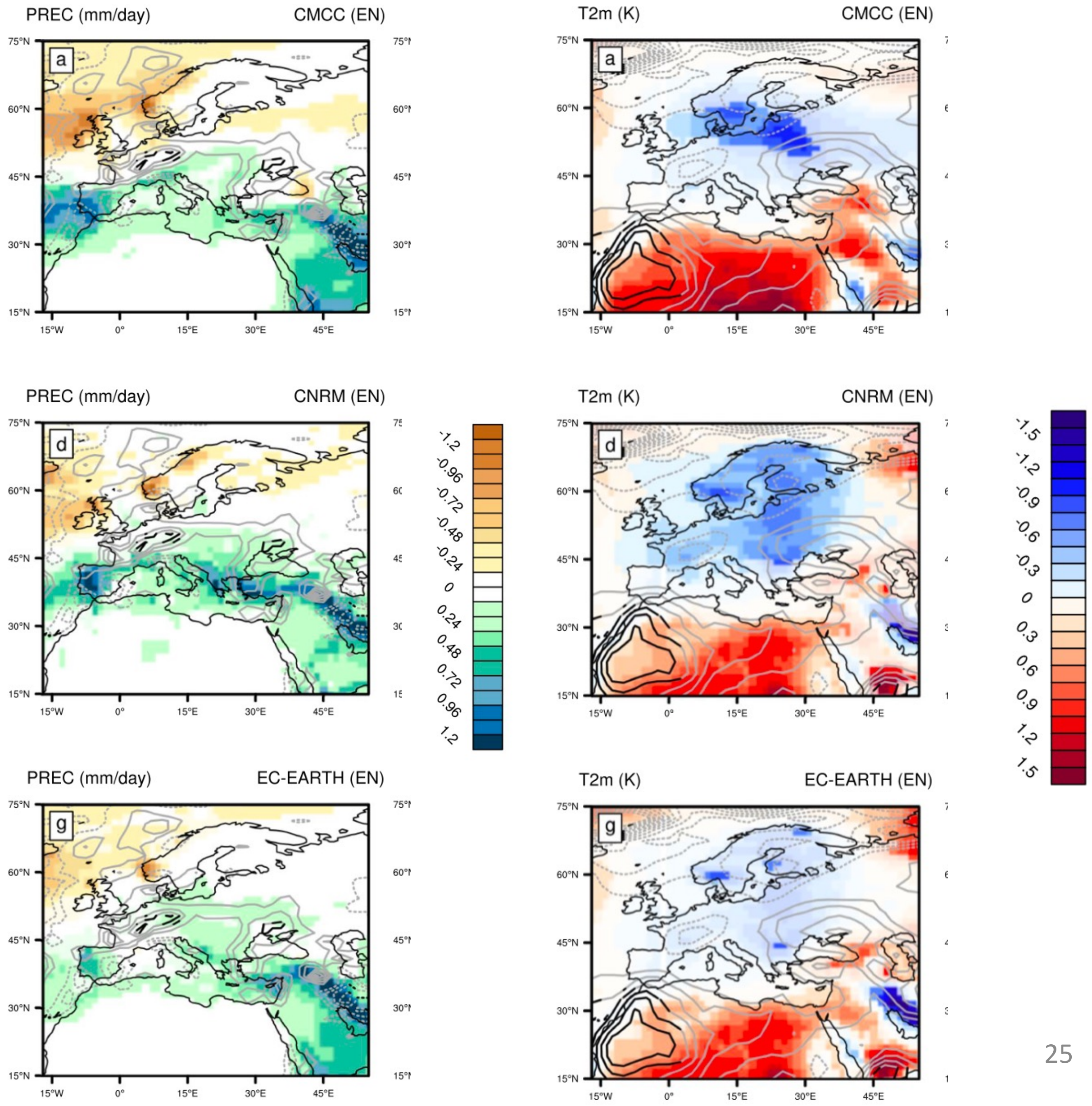
LN



ENSO IMPACTS

EN





Benassi et al. (2021)

(POSSIBLE) MECHANISMS

1. **Via the troposphere**
2. Via the stratosphere
3. Others

THE "MAIN" WAVE TRAIN

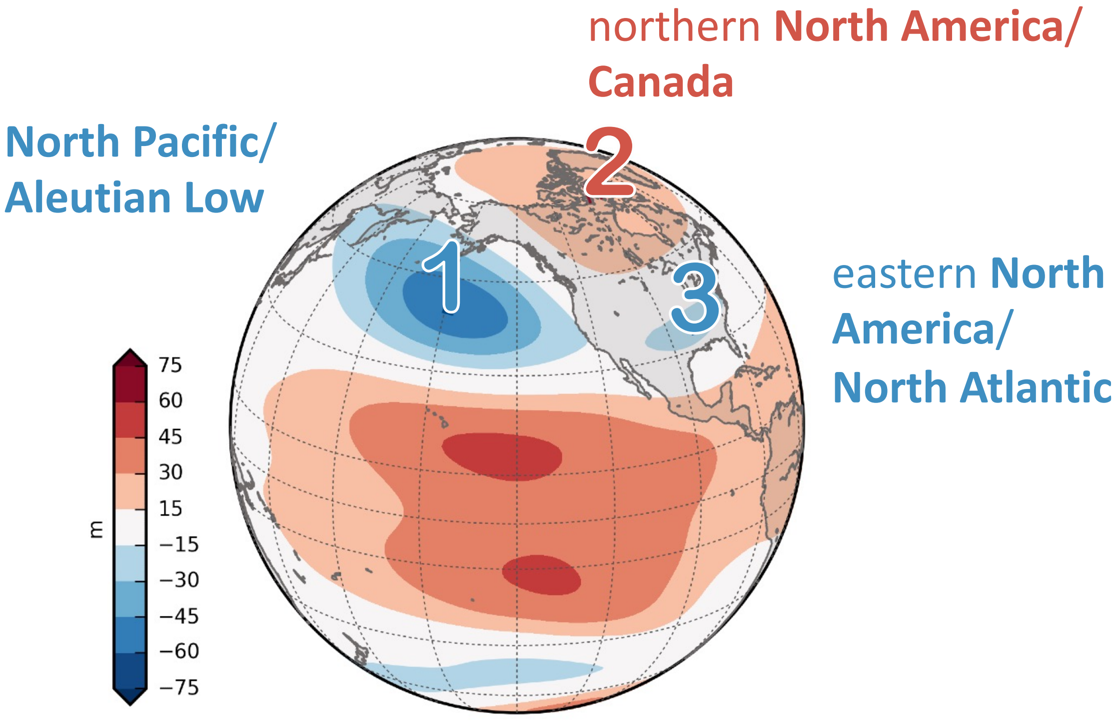
Quasi-stationary **tropospheric** Rossby wave train

Propagates at **upper levels**

Largely *barotropic*

Anomalies of **alternating sign**

Curved path



Observed 200-hPa geopotential height anomalies associated with ENSO

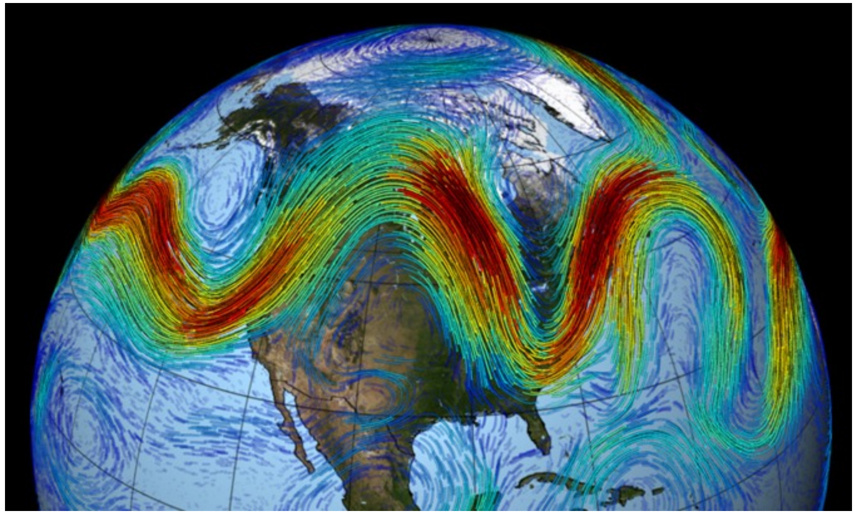
THE "MAIN" WAVE TRAIN

Quasi-stationary **tropospheric** Rossby wave train

For a **free** wave (horizontal motion):

$$\overbrace{\frac{D(\zeta + f)}{Dt}}^{\substack{\textbf{Propagation} \\ \text{(horizontal motion)}}} = 0$$

Conservation of absolute vorticity



$$\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$ *Vertical component of relative vorticity*

$+$

$$f = 2\Omega sin\phi$$ *Planetary vorticity*

Absolute vorticity

THE "MAIN" WAVE TRAIN

Quasi-stationary **tropospheric** Rossby wave train

For a **forced** wave (horizontal motion):

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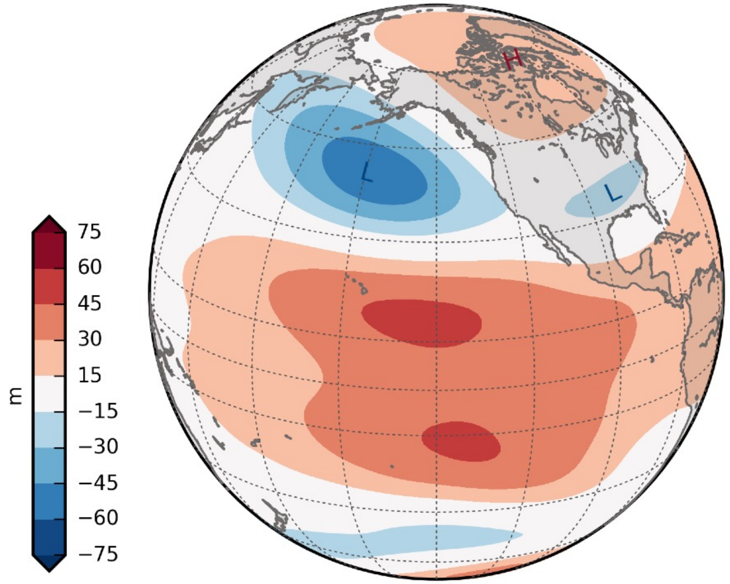
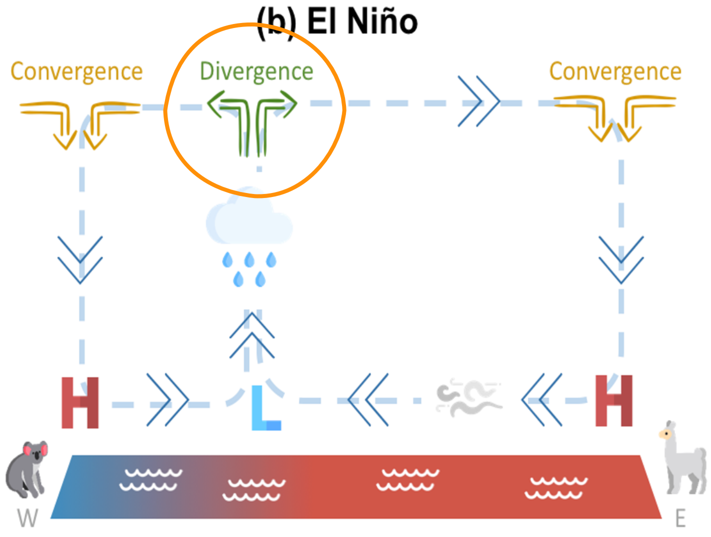


Observed 200-hPa geopotential height anomalies associated with ENSO

THE "MAIN" WAVE TRAIN

Ingredients:

- Anomalous **upper-level divergence**



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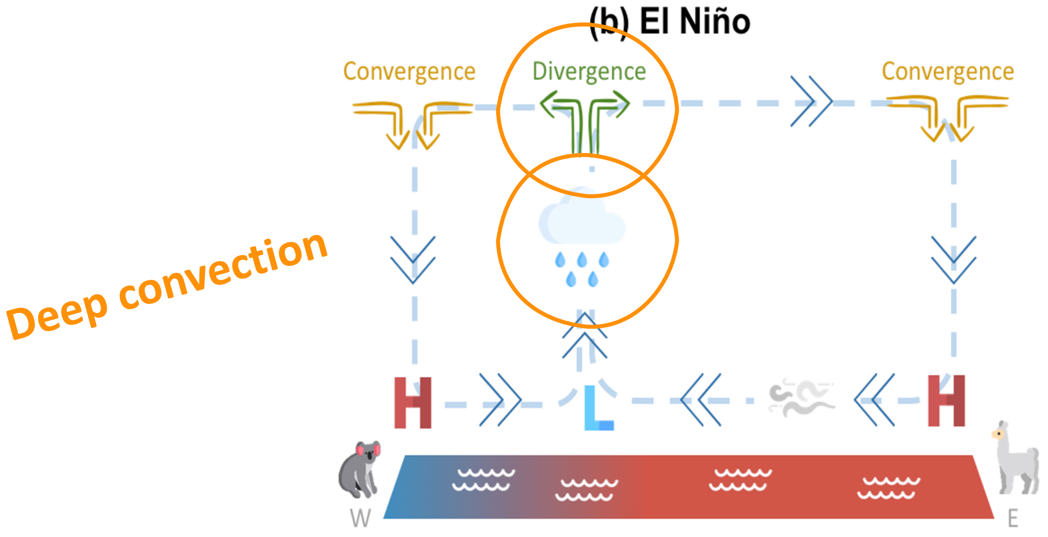


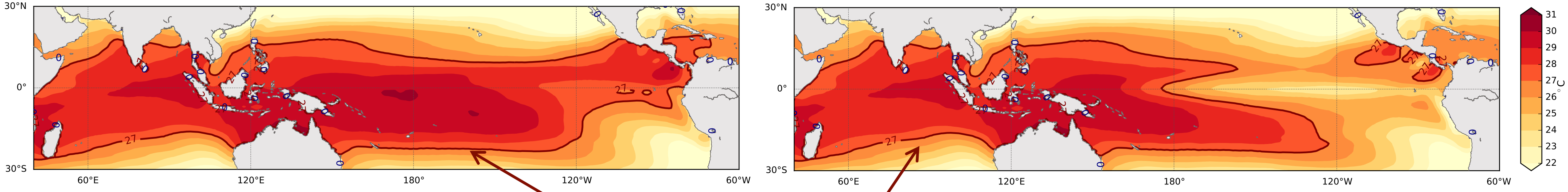
THE "MAIN" WAVE TRAIN

Ingredients:

- Anomalous **upper-level divergence**

SST threshold of **~27°C** required to trigger **deep convection**

EN **LN**



Total SST

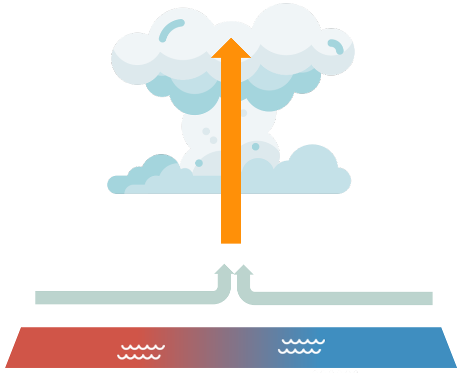
27°C

THE “MAIN” WAVE TRAIN

Ingredients:

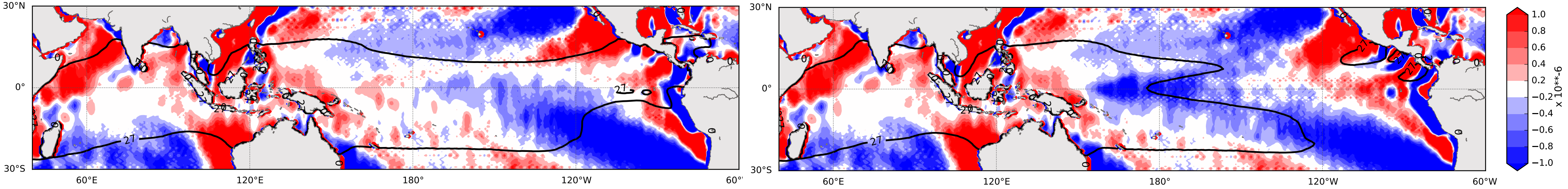
- Anomalous **upper-level divergence**

Convection ↔ low-level moisture convergence ↔ SST gradient



EN

LN

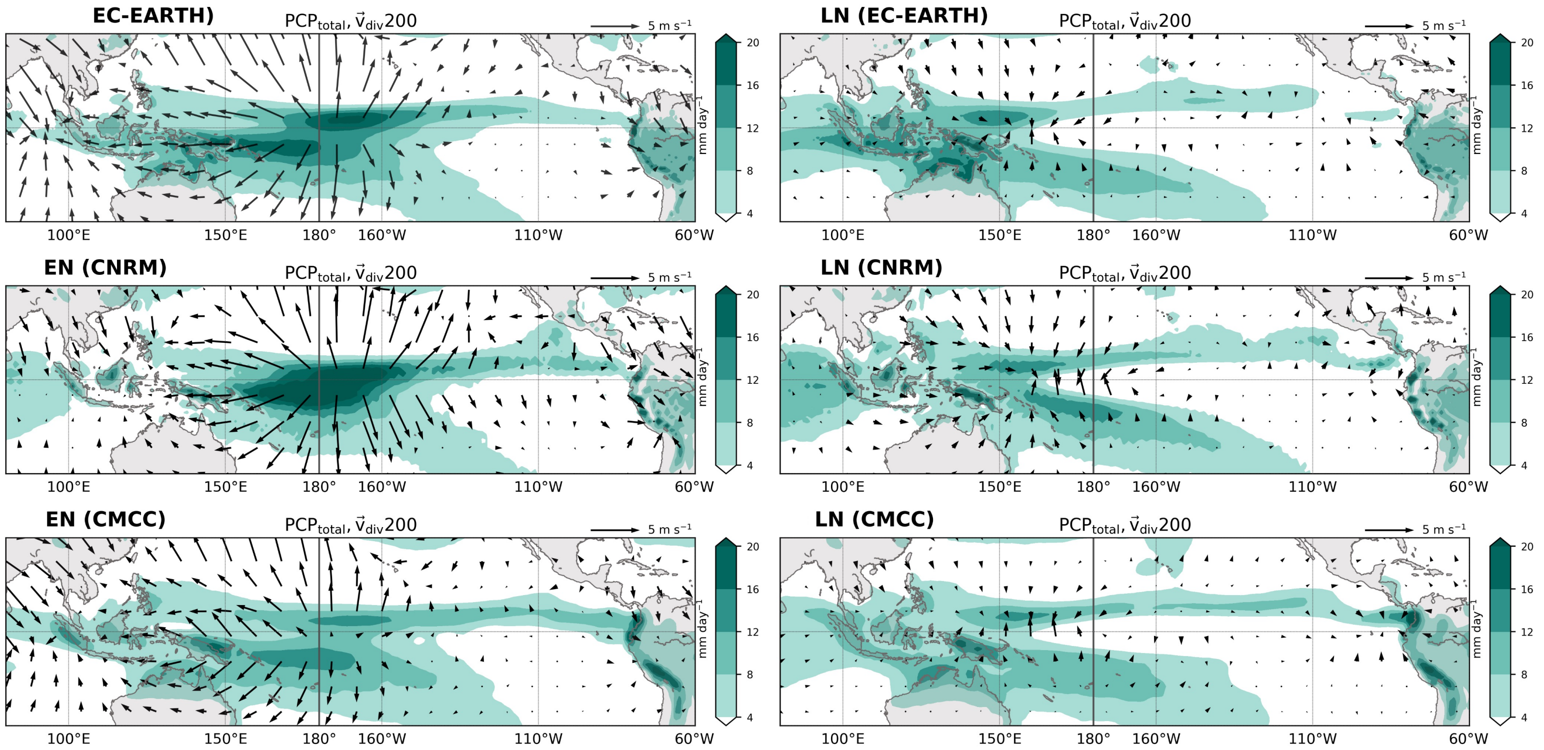


Zonal gradient of total SST

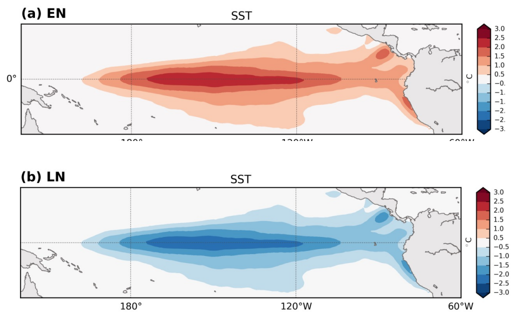
THE “MAIN” WAVE TRAIN

EN LN

EC-EARTH
CNRM
CMCC

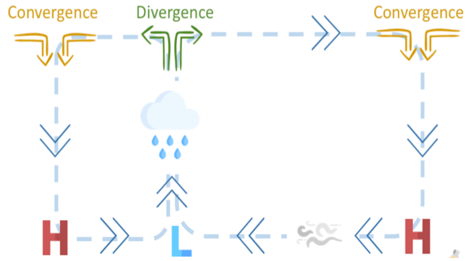


Forcing



Total precipitation and anomalous 200-hPa divergent wind

(b) El Niño



(c) La Niña

Mezzina et al. (2021)

THE “MAIN” WAVE TRAIN

Ingredients:

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THE "MAIN" WAVE TRAIN

Ingredients:

- Anomalous **upper-level divergence**
- **Mean flow**

THE "MAIN" WAVE TRAIN

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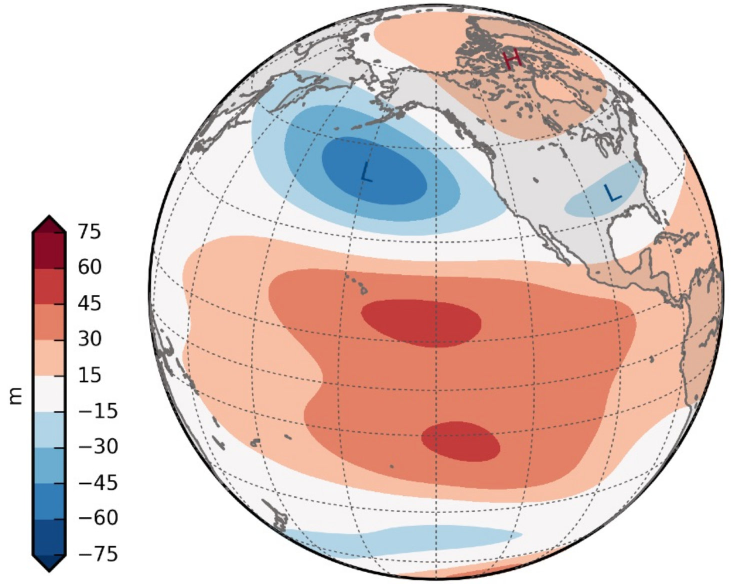


Observed 200-hPa geopotential height anomalies associated with ENSO

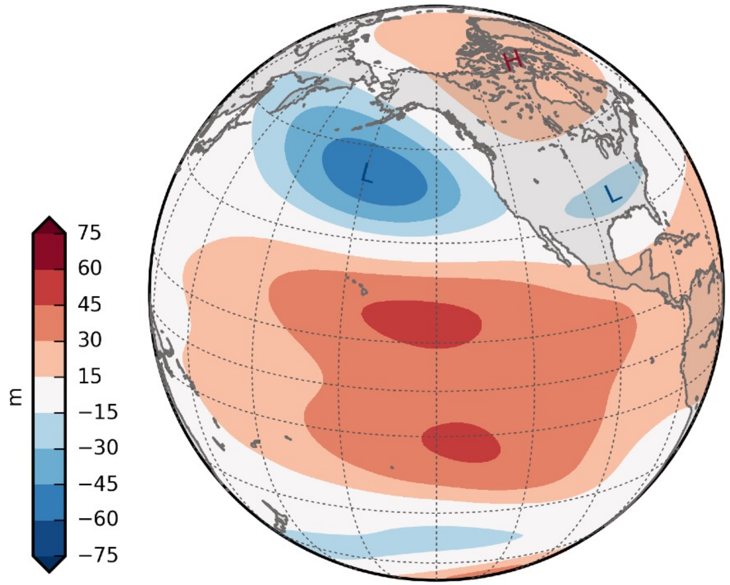
THE “MAIN” WAVE TRAIN

Quasi-stationary **tropospheric** Rossby wave train

For **ENSO**:

$$\overbrace{\frac{D(\zeta + f)}{Dt}}^{\substack{\textbf{Propagation} \\ \text{(horizontal motion)}}} = \overbrace{TRWS}^{\substack{\textbf{Tropical Rossby} \\ \textbf{Wave Source}}}$$

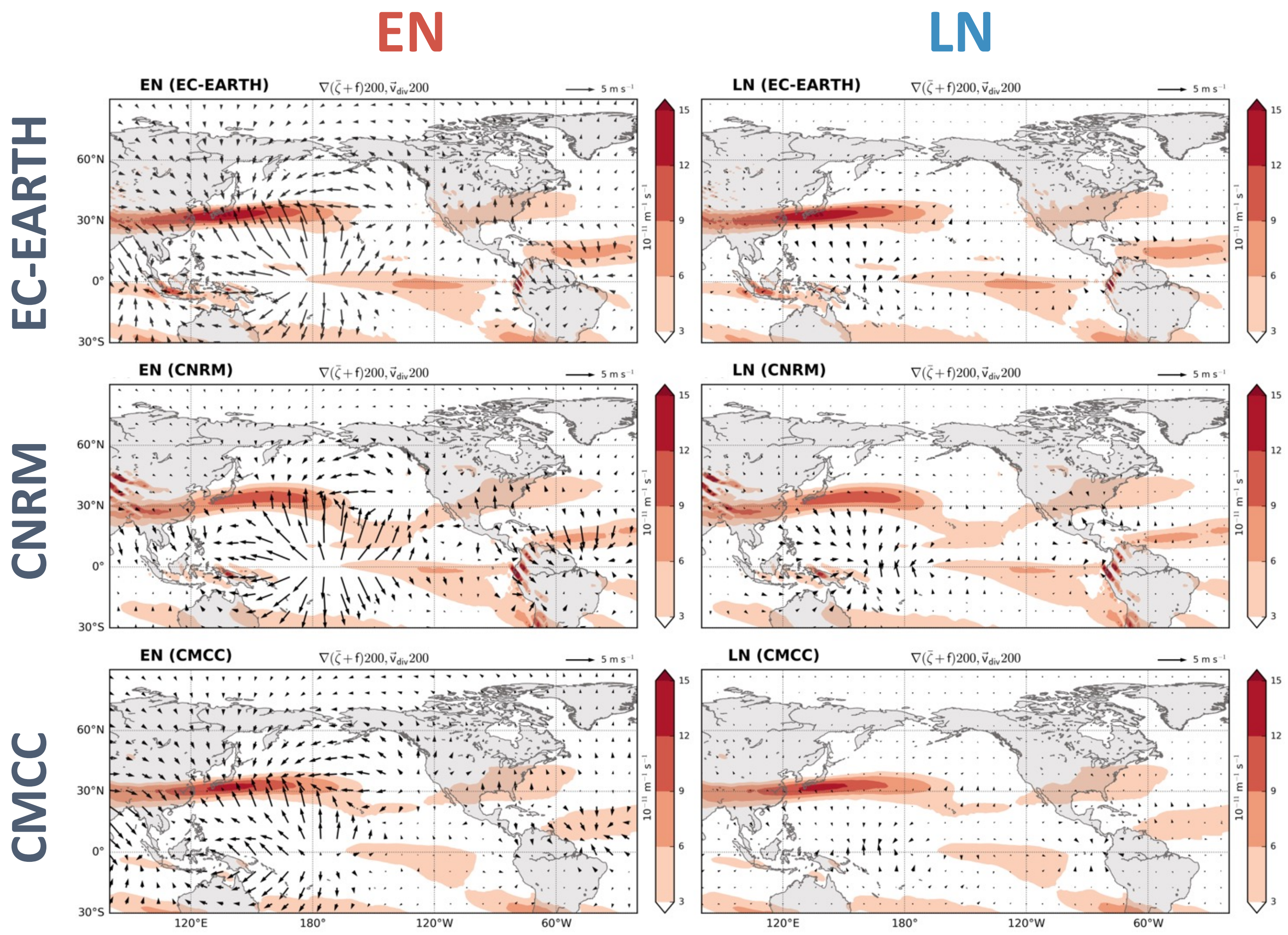
Interaction between **anomalous divergence** and **mean flow**



Observed 200-hPa geopotential height anomalies associated with ENSO

Sardeshmukh and Hoskins (1988)
Qin and Robinson (1993)

THE "MAIN" WAVE TRAIN



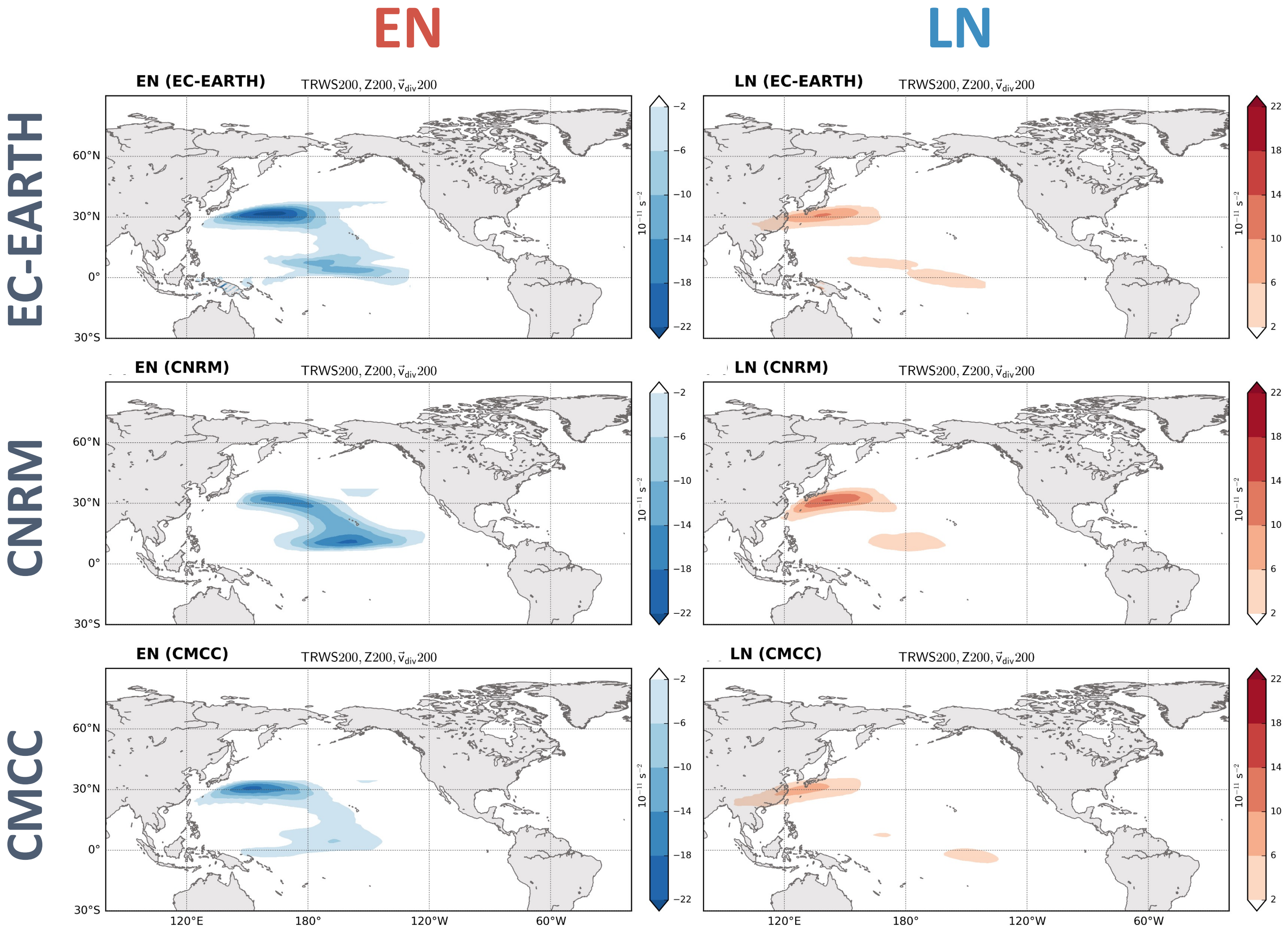
$$TRWS = -v'_{div} \cdot \nabla(\bar{\zeta} + f)$$

Anomalous divergent wind
(arrows)

Gradient of *climatological* vorticity
(shading)

Mezzina et al. (2021)

THE "MAIN" WAVE TRAIN



Mezzina et al. (2021)

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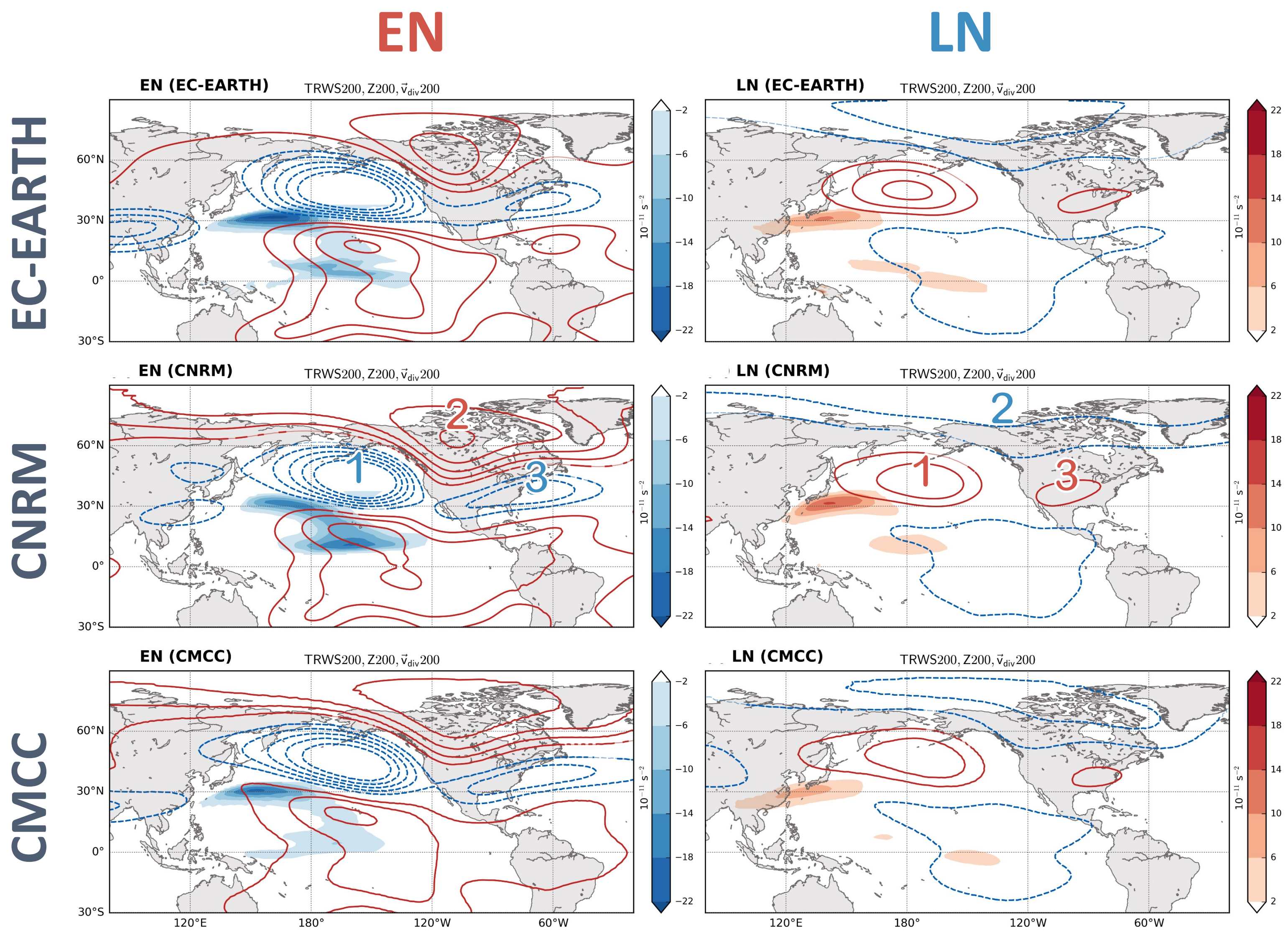

Amplitude EN > LN

Westward **shift** LN wrt to EN

Mezzina et al. (2021)

CHALLENGES

Challenges in representing the ENSO-NAE teleconnection:

0. Getting “ENSO” right (SST pattern, timing, amplitude, ...)
1. Getting the right **tropical response**
2. Importance of the **mean flow**

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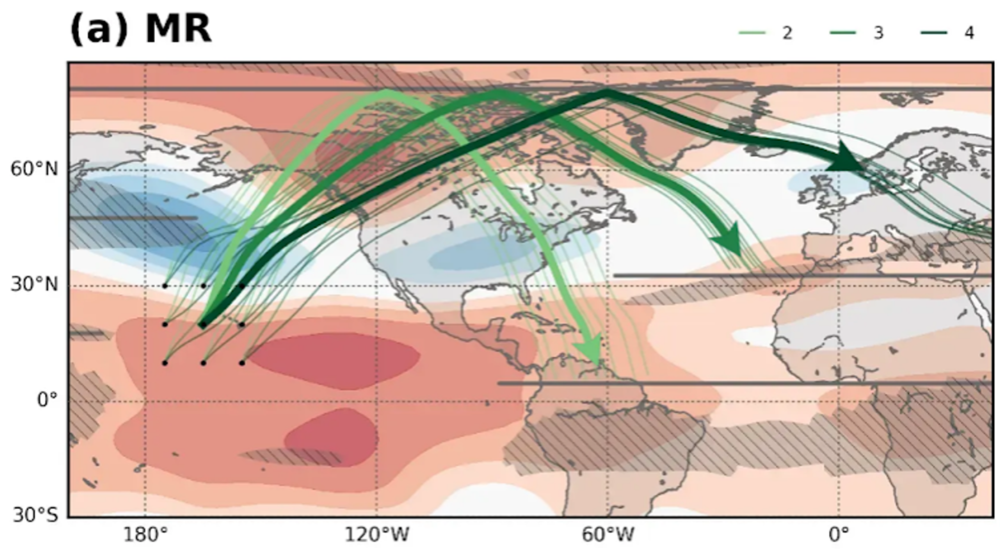


(POSSIBLE) MECHANISMS

1. Via the troposphere

2. **Via the stratosphere**

3. Others

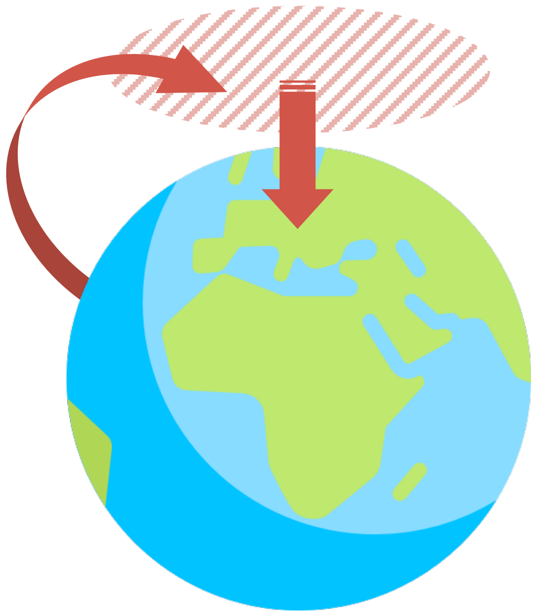
STRATOSPHERIC PATHWAY

ENSO impacts on the winter **mean state** of the *polar stratosphere* have been shown

STRATOSPHERIC PATHWAY

ENSO impacts on the winter **mean state** of the *polar stratosphere* have been shown

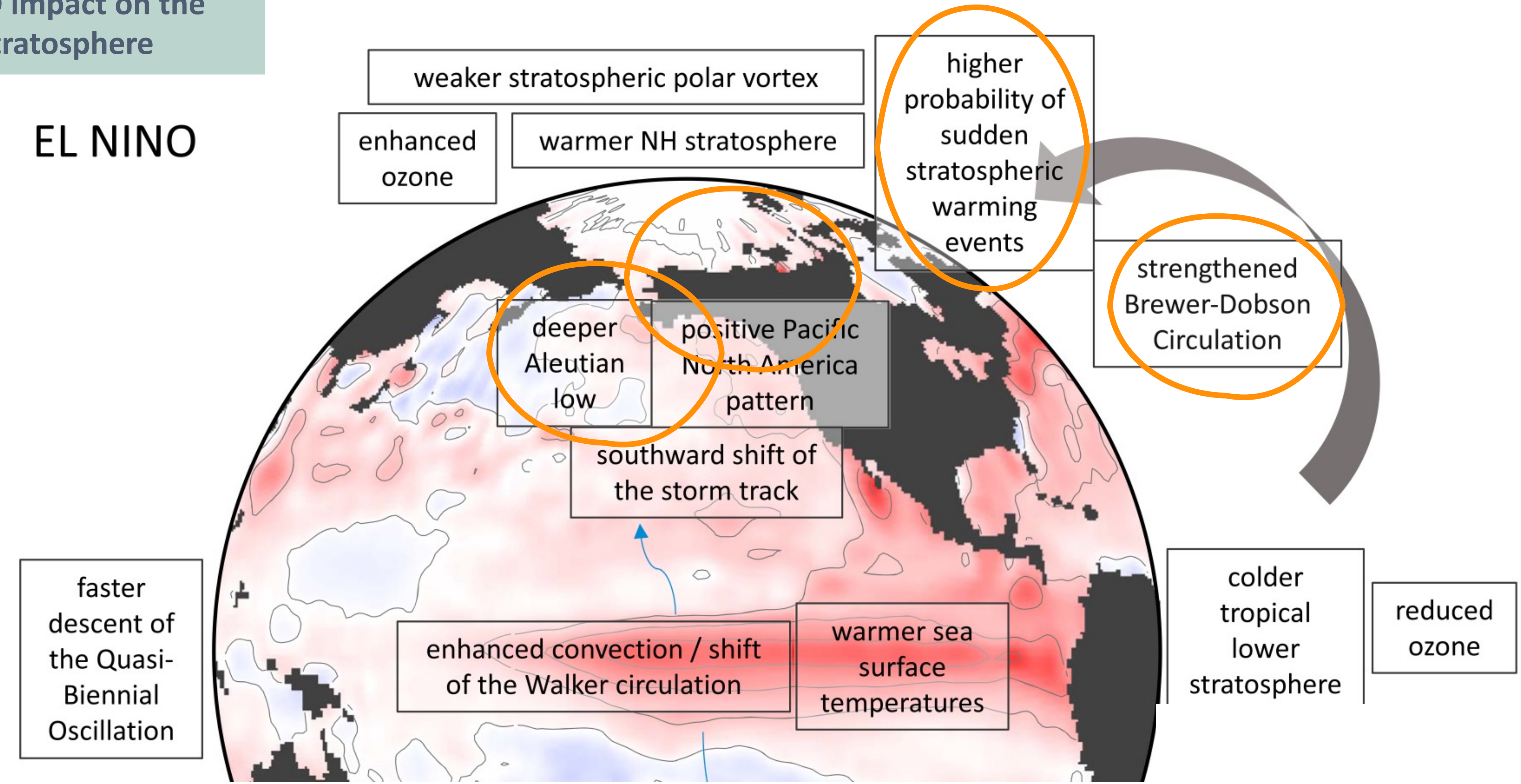
This stratospheric ENSO signal could *propagate downwards* and affect the surface (**Stratospheric Pathway hypothesis**)



STRATOSPHERIC PATHWAY

ENSO impact on the stratosphere

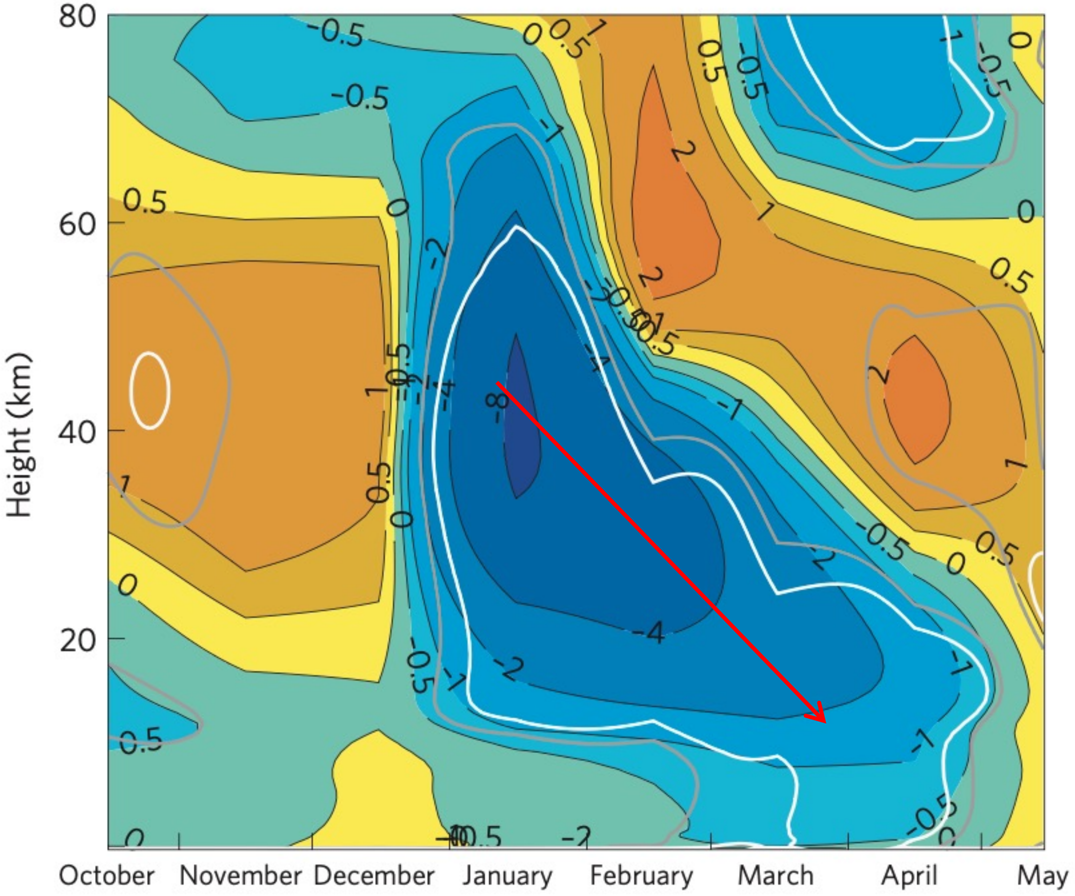
EL NINO



Domeisen et al. (2019)

STRATOSPHERIC PATHWAY

Downward propagation of stratospheric signal



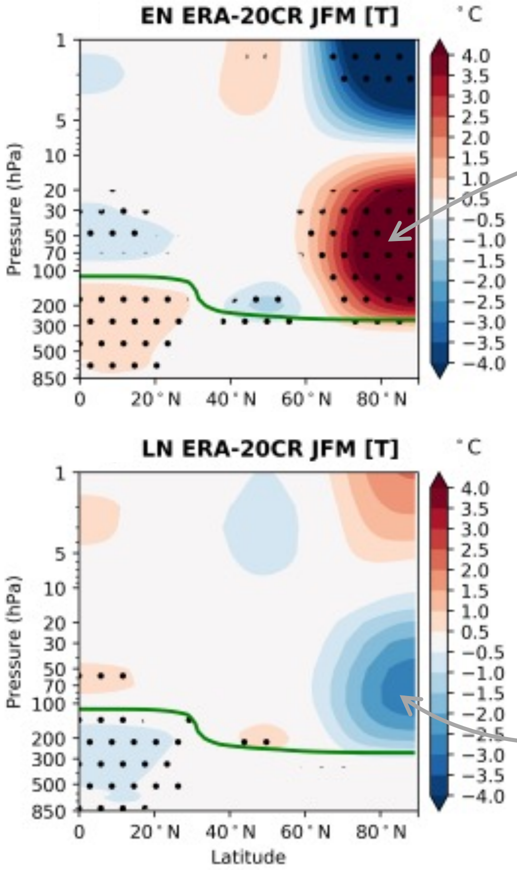
Ineson and Scaife (2009)

ENSO IMPACT ON THE STRATOSPHERE: ZONAL-MEAN T

What we expect from observations:

EN

LN



Surface

Equator

Us!

North Pole

Anomalous **warming** of polar lower stratosphere

Anomalous **cooling** of polar lower stratosphere

(…probably)

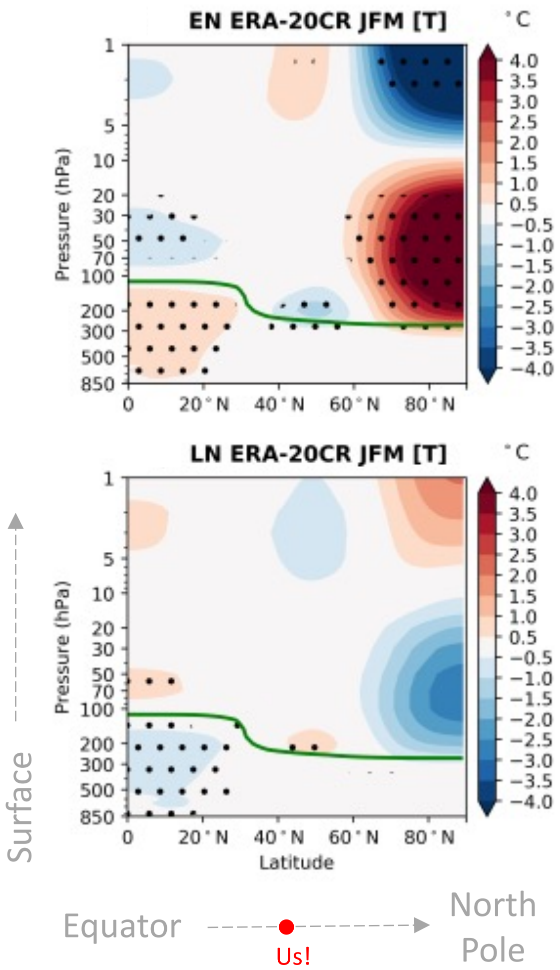
Mezzina et al. (2021)

ENSO IMPACT ON THE STRATOSPHERE: ZONAL-MEAN T

What we expect from observations:

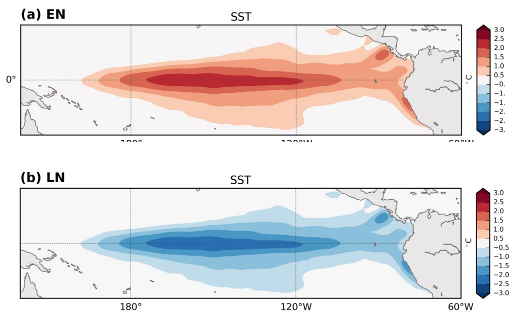
EN

LN



What we get from the models:

Forcing



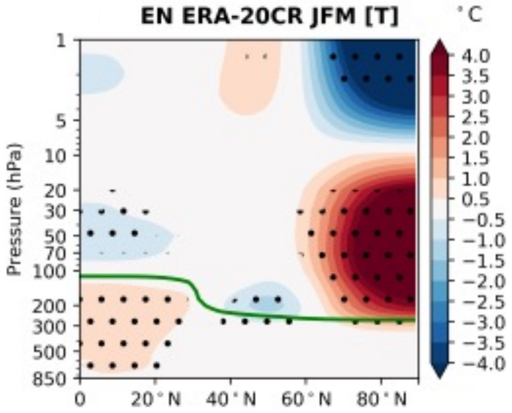
Mezzina et al. (2021)

ENSO IMPACT ON THE STRATOSPHERE: ZONAL-MEAN T

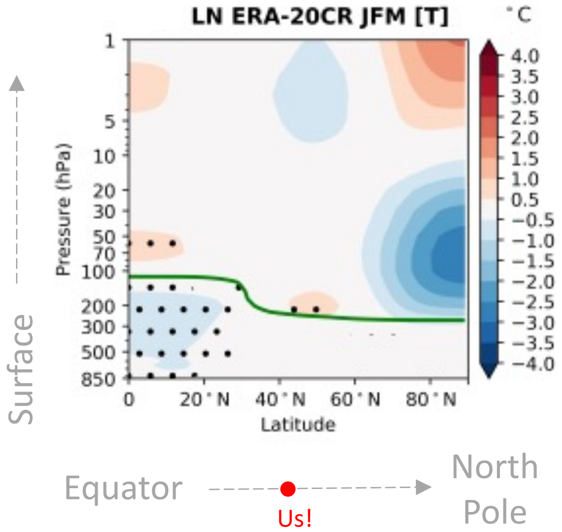
What we expect from observations:

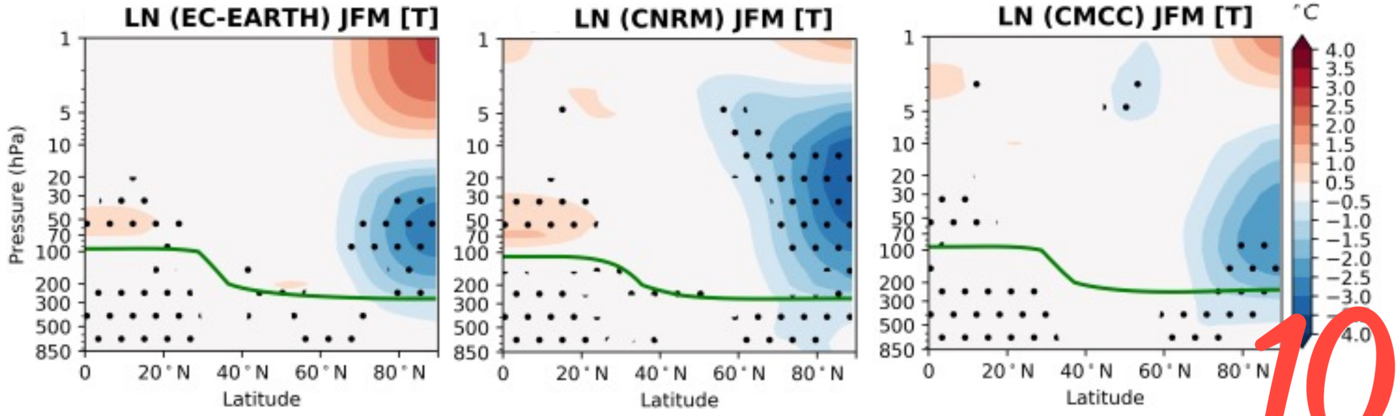
What we get from the models:

EN



LN





EC-EARTH

CNRM

CMCC

Mezzina et al. (2021)

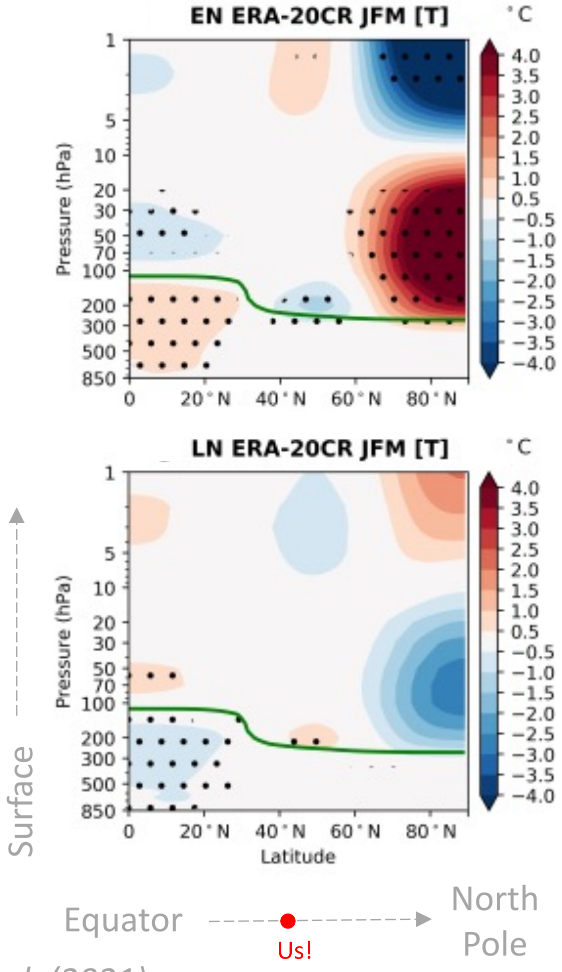
ENSO IMPACT ON THE STRATOSPHERE: ZONAL-MEAN T

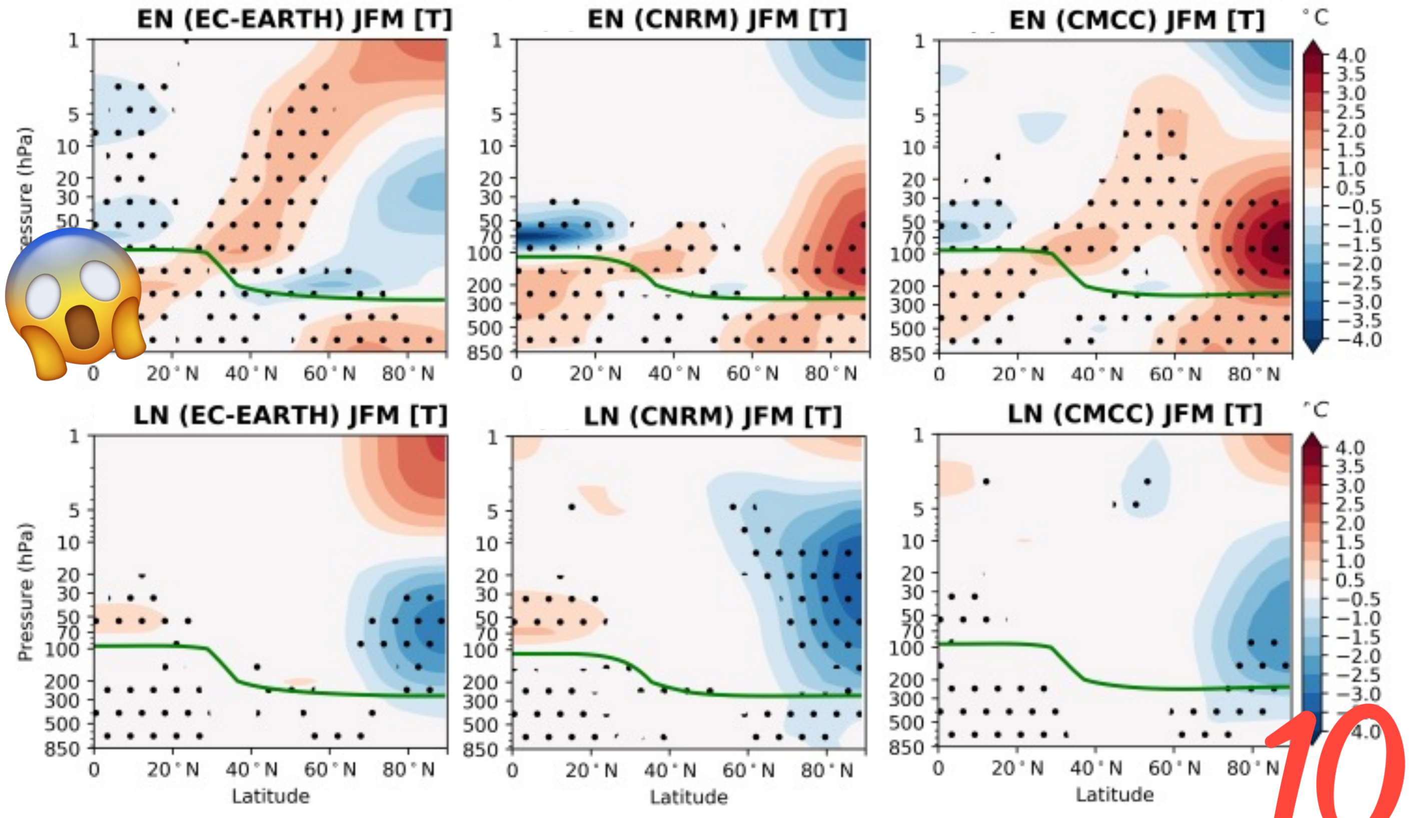
What we expect from observations:

What we get from the models:

EN

LN





EC-EARTH CNRM CMCC

Mezzina et al. (2021)

CHALLENGES

Challenges in representing the ENSO-NAE teleconnection:

0. Getting “ENSO” right (SST pattern, timing, amplitude, ...)

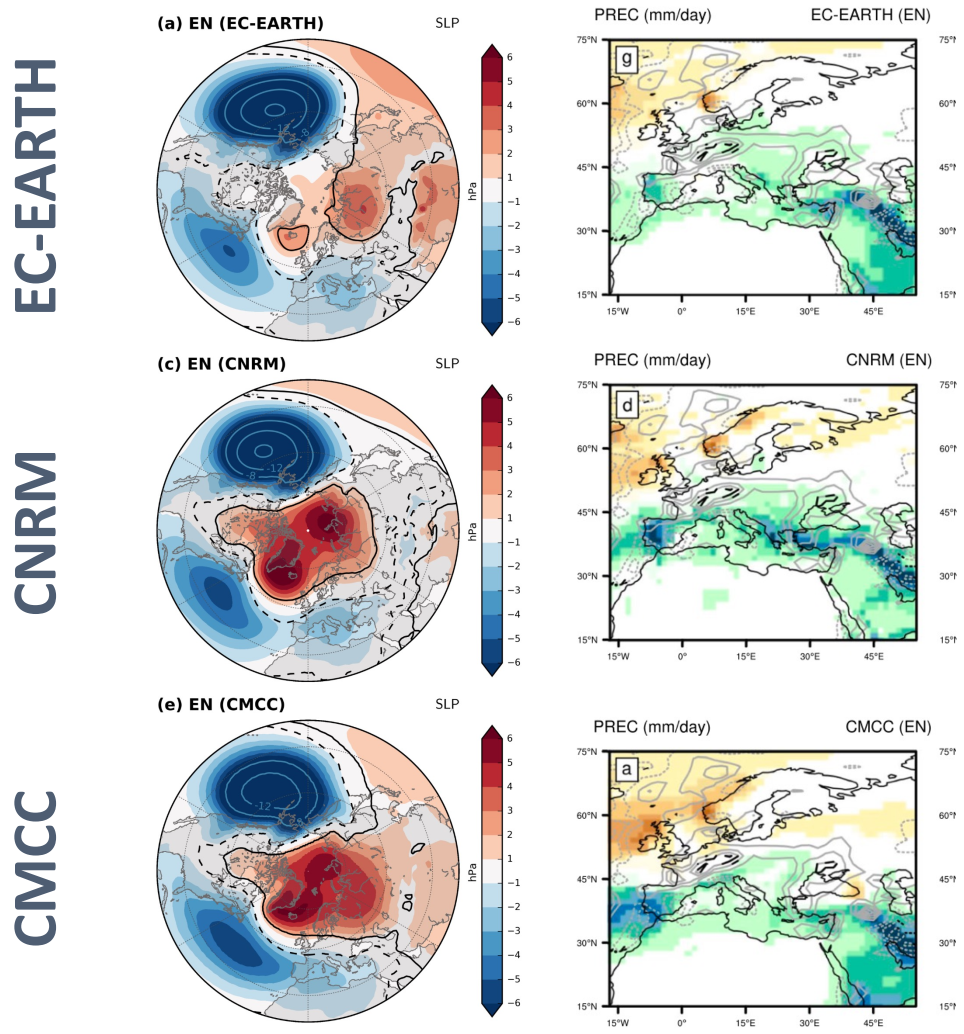
1. Getting the right **tropical response**

2. Importance of the **mean flow**

3. Having the expected **stratospheric signal** (≠ high resolution in the stratosphere) *

EXTRA-TROPICAL RESPONSE: SLP

EN



* Even though the contribution of the stratosphere to the surface JFM signal is not clear

(POSSIBLE) MECHANISMS

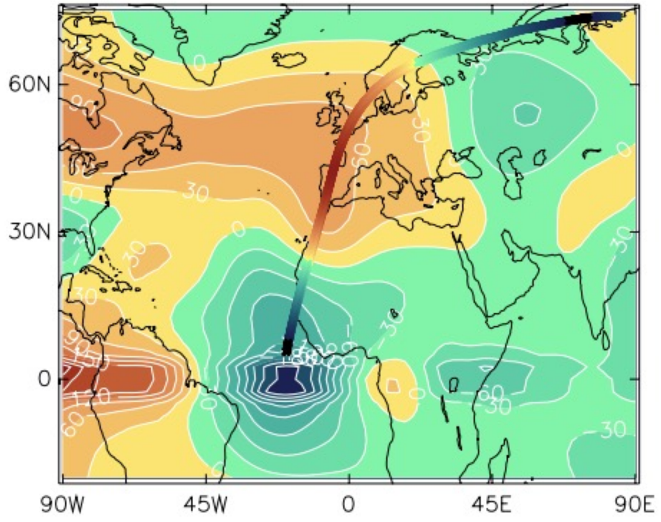
1. Via the troposphere

2. Via the stratosphere

3. **Others**

   e.g.

   - Delayed impacts through other basins (North Atlantic?)
   - Secondary wave sources
   - Splitting of main wave train
   - …



Toniazzo and Scaife (2006)

CHALLENGES

Challenges in representing the ENSO-NAE teleconnection:

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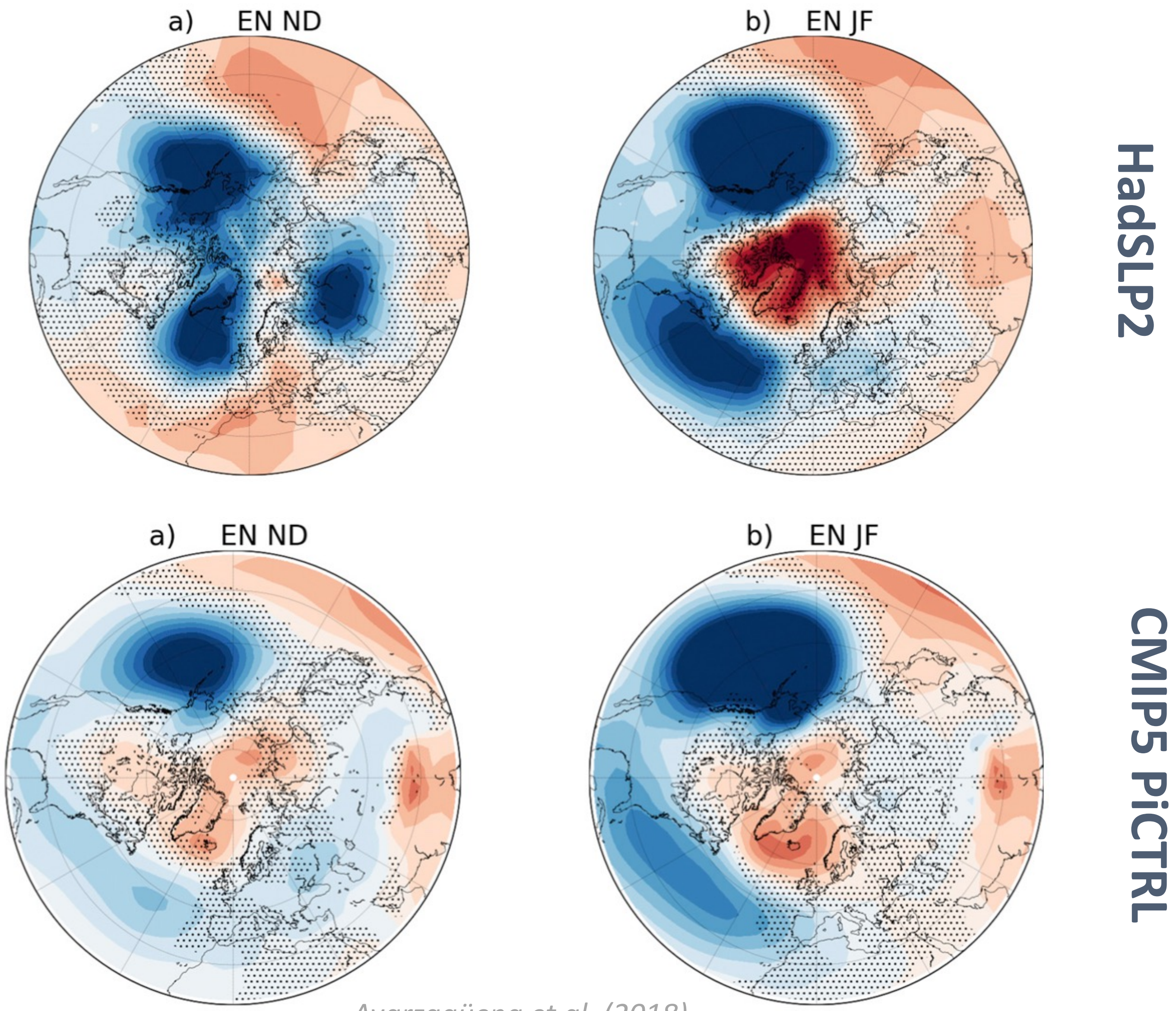
4. **Timing** is everything

INTRA-SEASONAL EFFECTS

Observed intra-seasonal **shift** of the ENSO surface response between ***early* winter** (Nov-Dec) and ***late* winter** (Jan-Feb)...

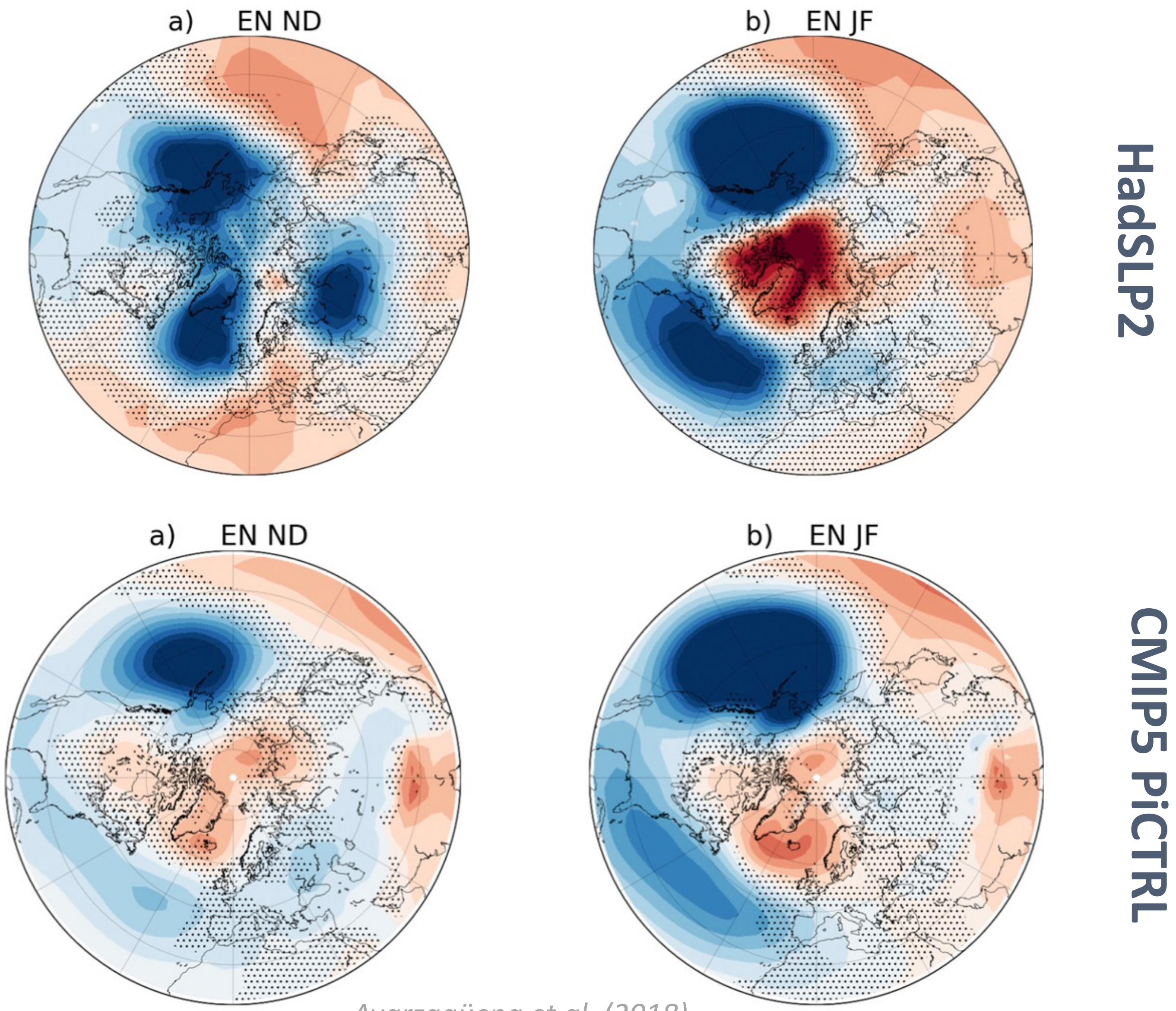


Ayarzagüena et al. (2018)

INTRA-SEASONAL EFFECTS

Observed intra-seasonal **shift** of the ENSO surface response between ***early*** **winter** (Nov-Dec) and ***late*** **winter** (Jan-Feb)...

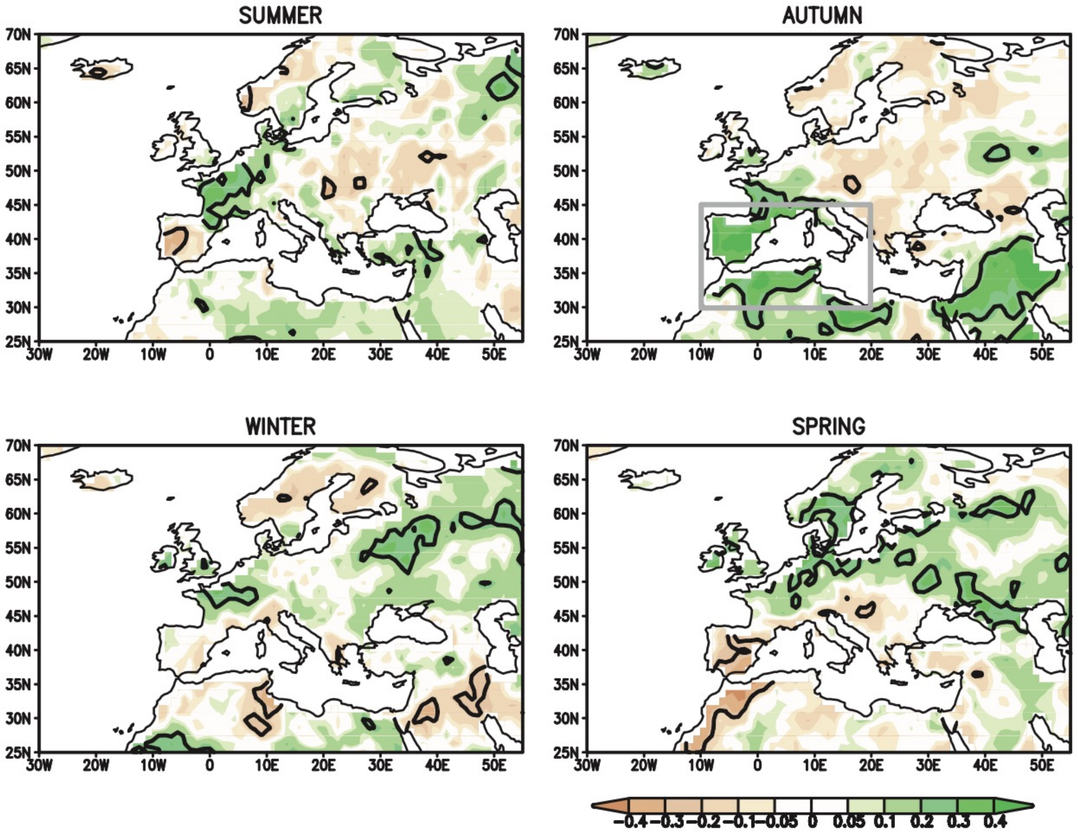
... **Not** always captured by **models**



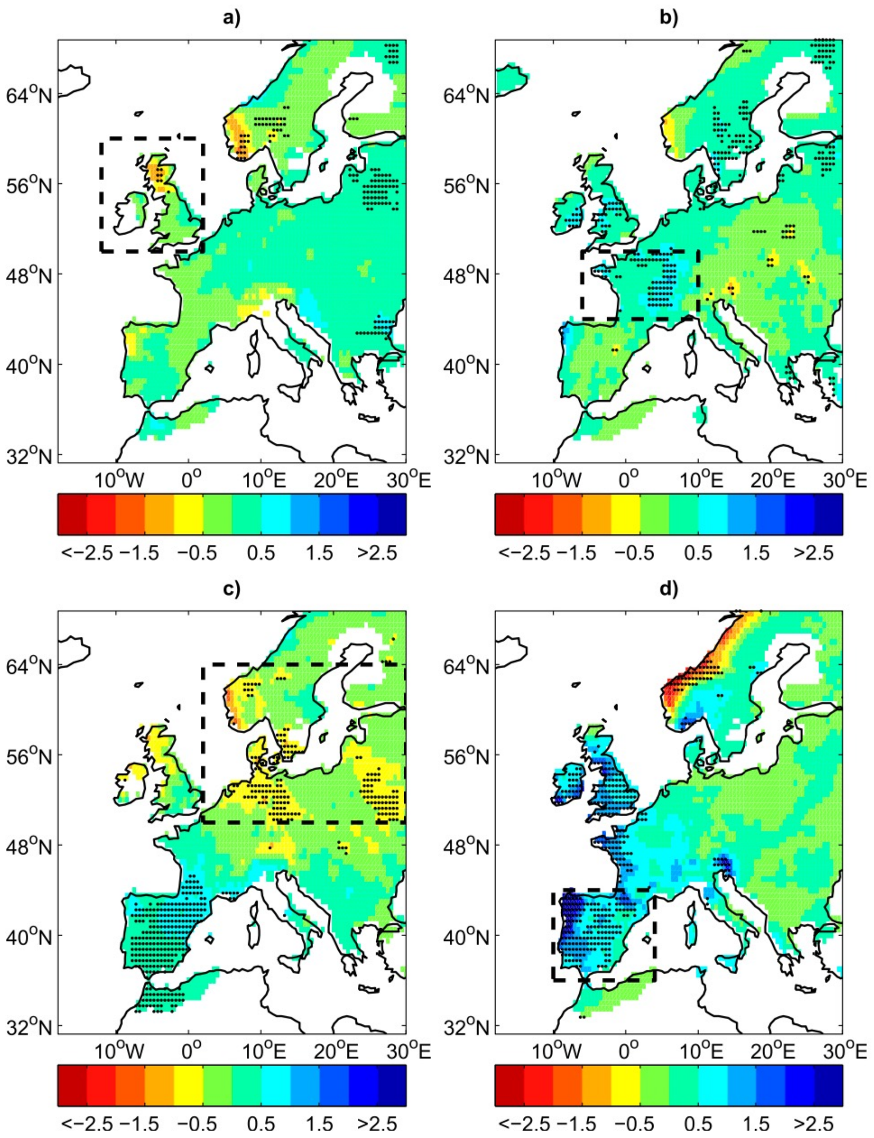
Ayarzagüena et al. (2018)

SEASONAL MODULATION

Precipitation



Mariotti et al. (2006)



Shaman et al. (2006)

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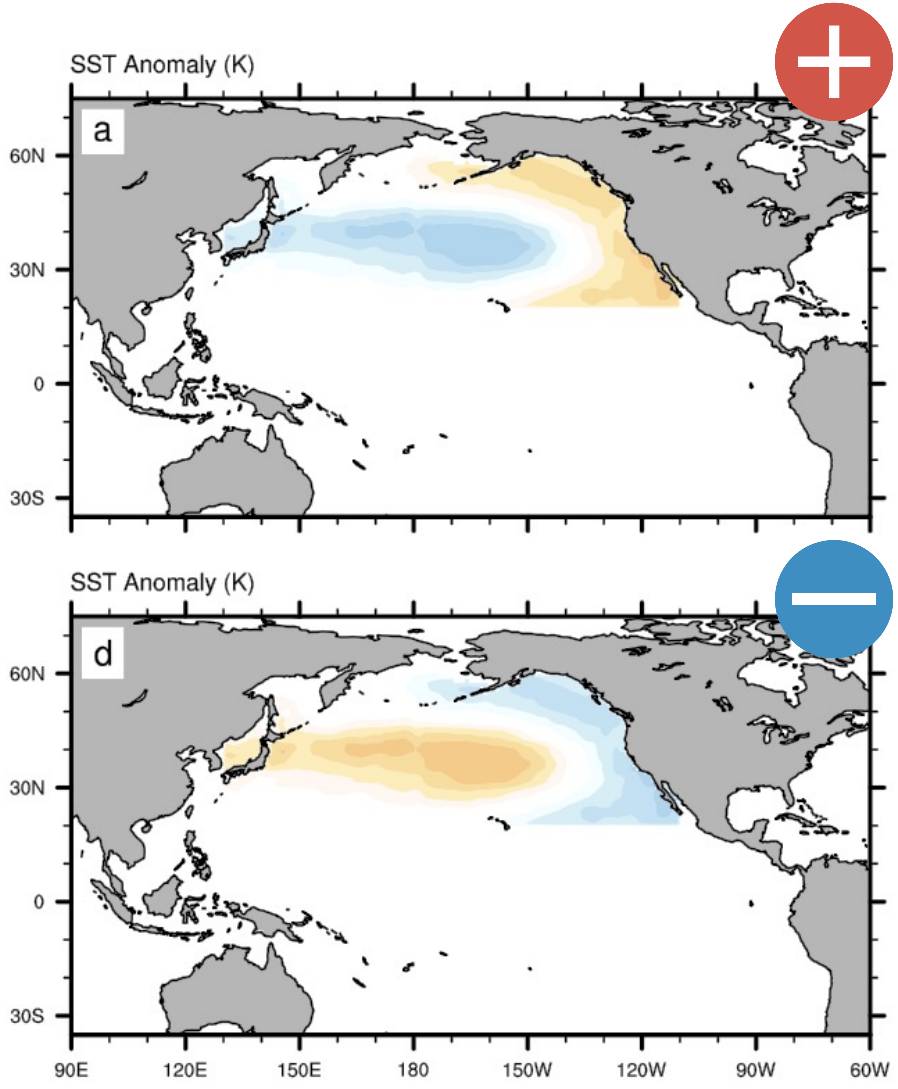
3. Having the expected **stratospheric signal** (≠ high resolution in the stratosphere)
4. **Timing** is everything
5. Modulation by **other factors** (e.g. PDO)

A QUICK LOOK AT THE PDO



Benassi et al. (2021)

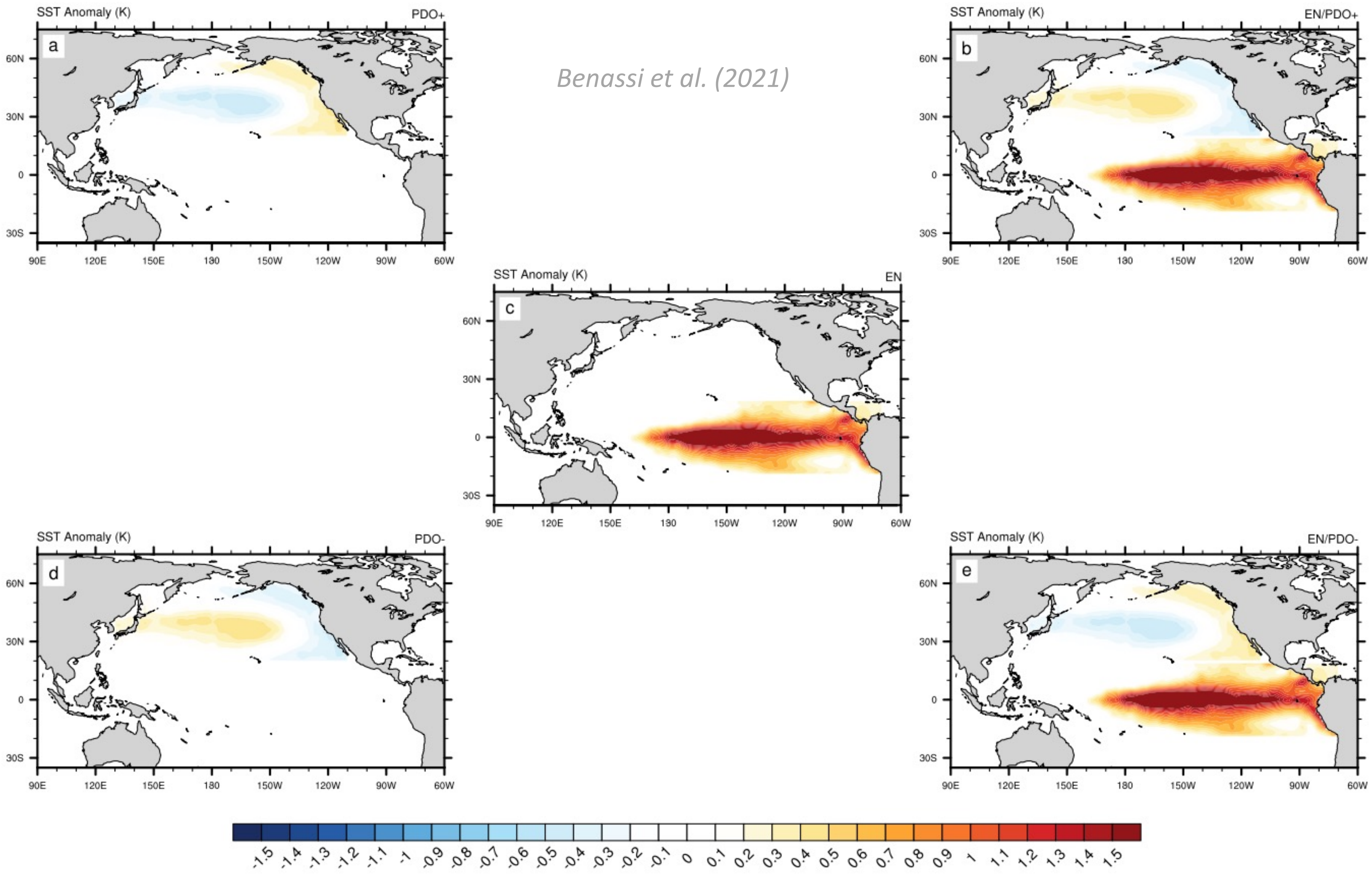
PDO = **P**acific **D**ecadal **O**scillation

- Leading mode of variability in the **North Pacific**
- **Low-frequency** variability (10-30 years)
- **Positive** and **negative** phases
- Combination of different processes

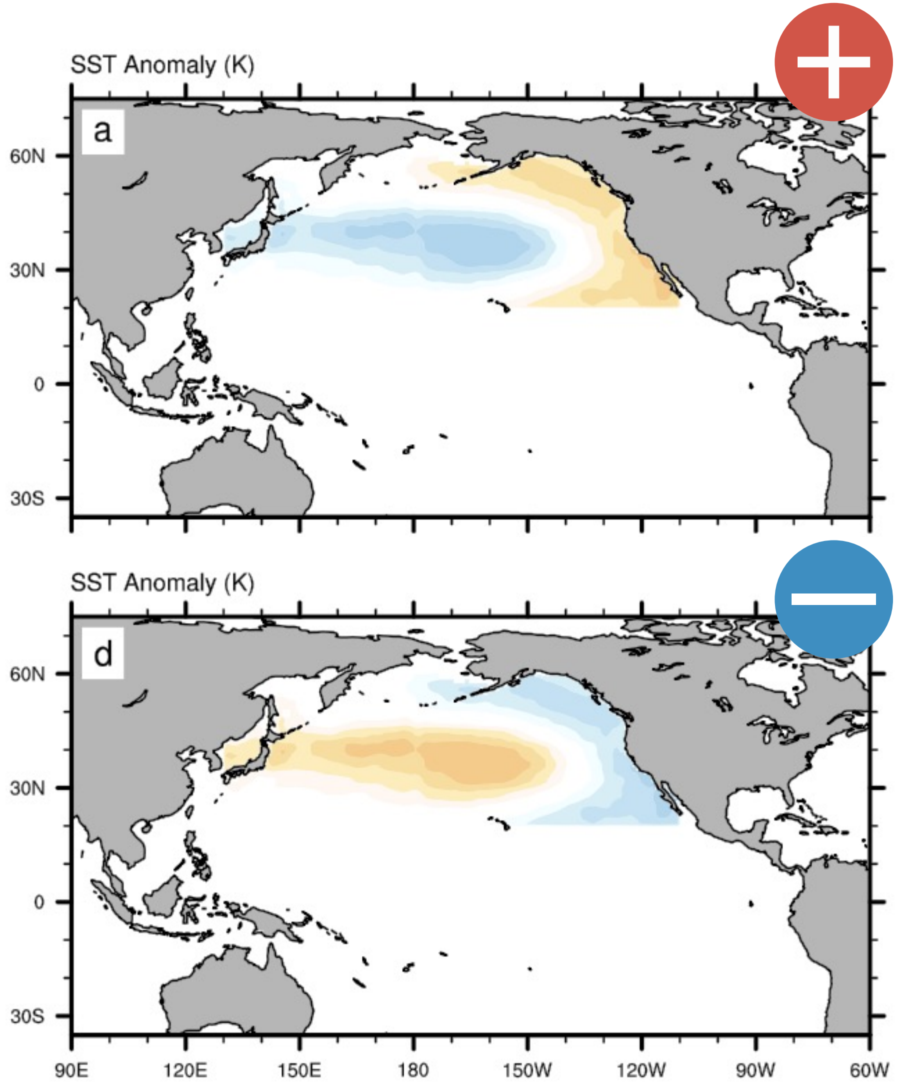
EL NIÑO AND THE PDO

Thank you MEDSCOPE

Benassi et al. (2021)



EL NIÑO AND THE PDO



Benassi et al. (2021)

The PDO can modulate the **amplitude** of the ENSO-NAE teleconnection.

PDO- : amplification of canonical EN pattern

By **altering the mean flow** and favoring a more poleward propagation of planetary waves across the North Pacific-American sector

CHALLENGES

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