ENSO-Europe teleconnections: a modelling approach using an intermediate complexity AGCM

Ivana Herceg Bulić

Thanks to Čedo Branković, Martin P. King, Fred Kucharski, Bianca Mezzina, Paolo Ruggieri

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Founded in 1861

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ICTP/ECMWF/Univ. L'Aquila Workshop on OpenIFS,
Trieste, Italy, 5th - 9th June 2017

ENSO impact on North Atlantic European (NAE) region

El Niño-Southern Oscillation (ENSO): strong generator of climate variability around the globe

- influences tropics and mid-latitudes

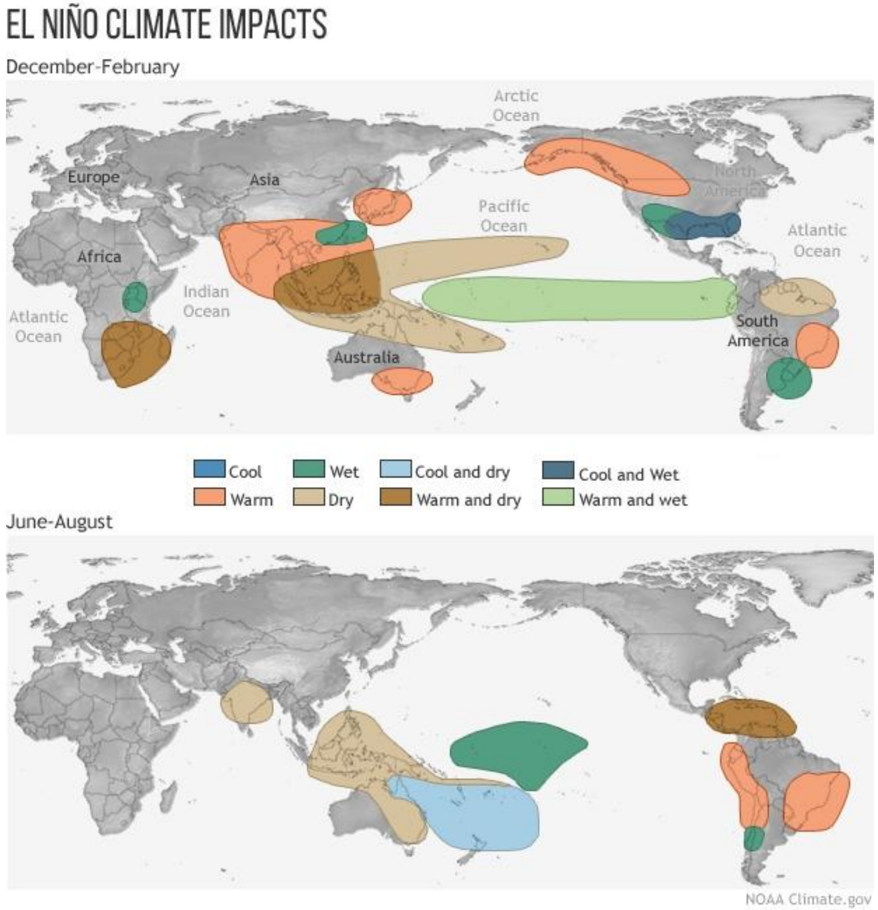
- clear impact on North America and Australia

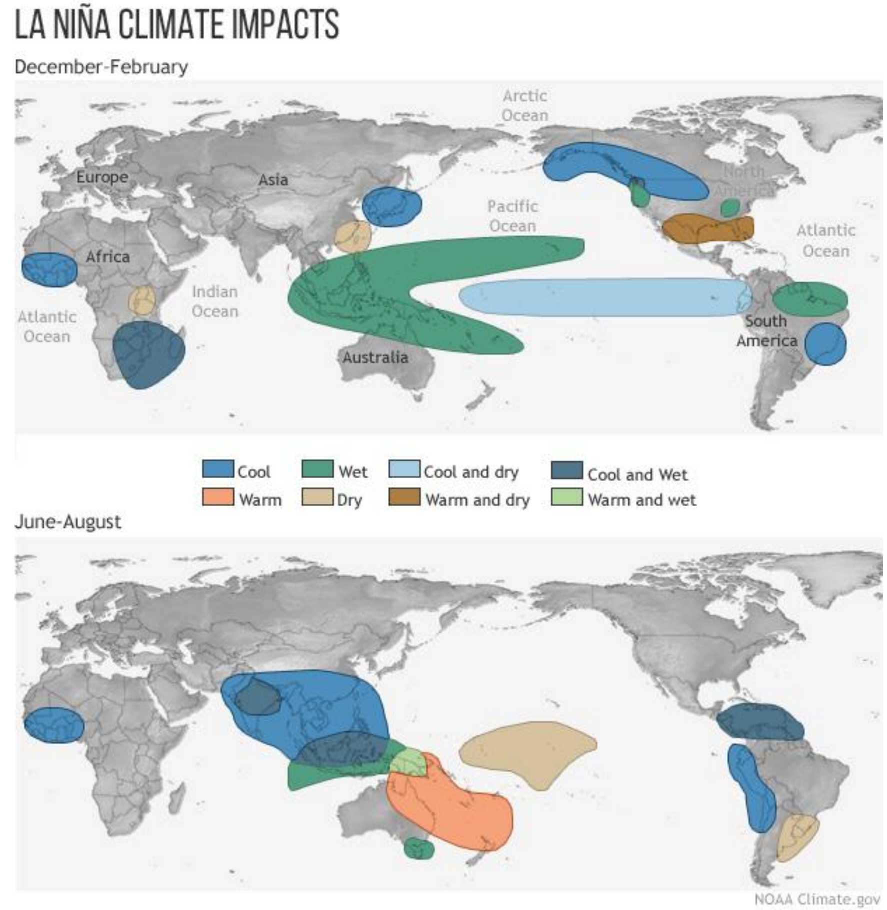
ENSO impact on NAE: difficult to asses

NAE sector:

- large internal variability of the atmosphere may mask the response to ENSO (Kumar and Hoerling, 1997)
- influenced by other phenomenon such as NAO which is a major source of variability on the Northern Hemisphere (Hurrell and van Loon, 1997; Greatbatch, 2000)

  - **Interactions with regional seasonal cycle, chaotic properties, complexity of feedbacks can mask ENSO signal over Europe**


EL NIÑO CLIMATE IMPACTS
December-February
Arctic Ocean
Europe
Asia
North America
Pacific Ocean
Atlantic Ocean
Africa
Indian Ocean
Atlantic Ocean
South America
Australia
Cool
Warm
Wet
Dry
Cool and dry
Warm and dry
Cool and Wet
Warm and wet
June-August
NOAA Climate.gov


LA NIÑA CLIMATE IMPACTS
December-February
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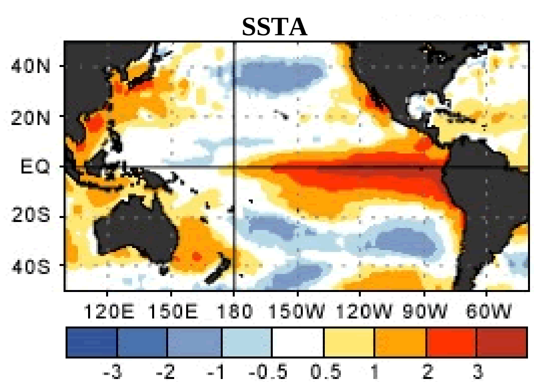
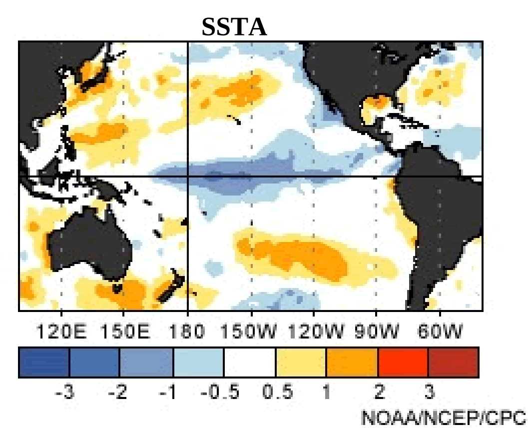
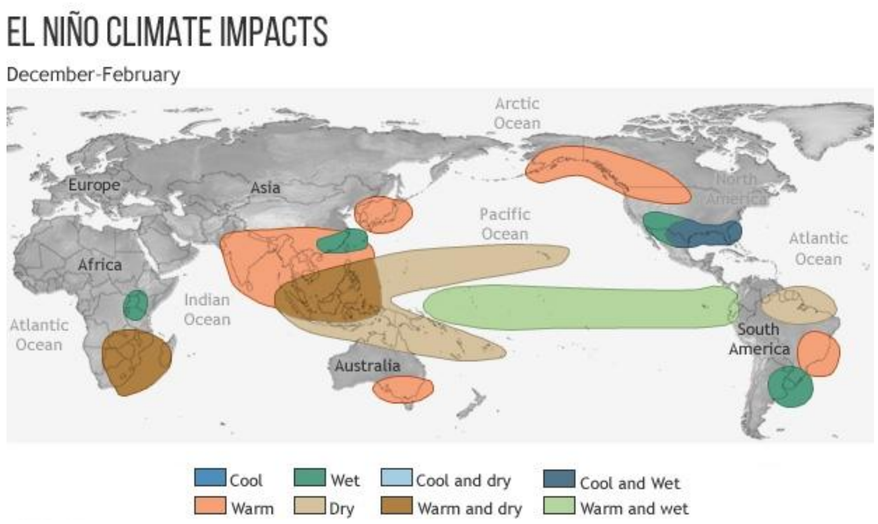

SSTA
40N
20N
EQ
20S
40S
120E 150E 180 150W 120W 90W 60W
-3 -2 -1 -0.5 0.5 1 2 3


SSTA
120E 150E 180 150W 120W 90W 60W
-3 -2 -1 -0.5 0.5 1 2 3
NOAA/NCEP/CPC


EL NIÑO CLIMATE IMPACTS
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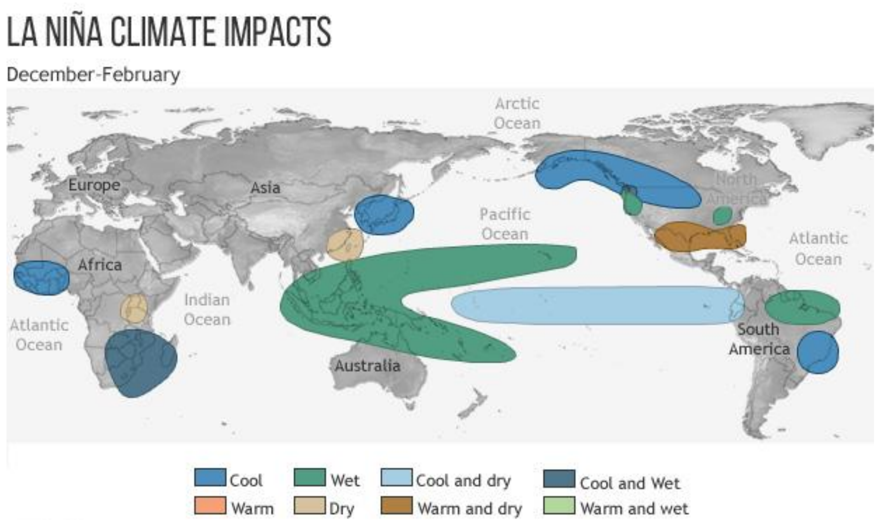
LA NIÑA CLIMATE IMPACTS
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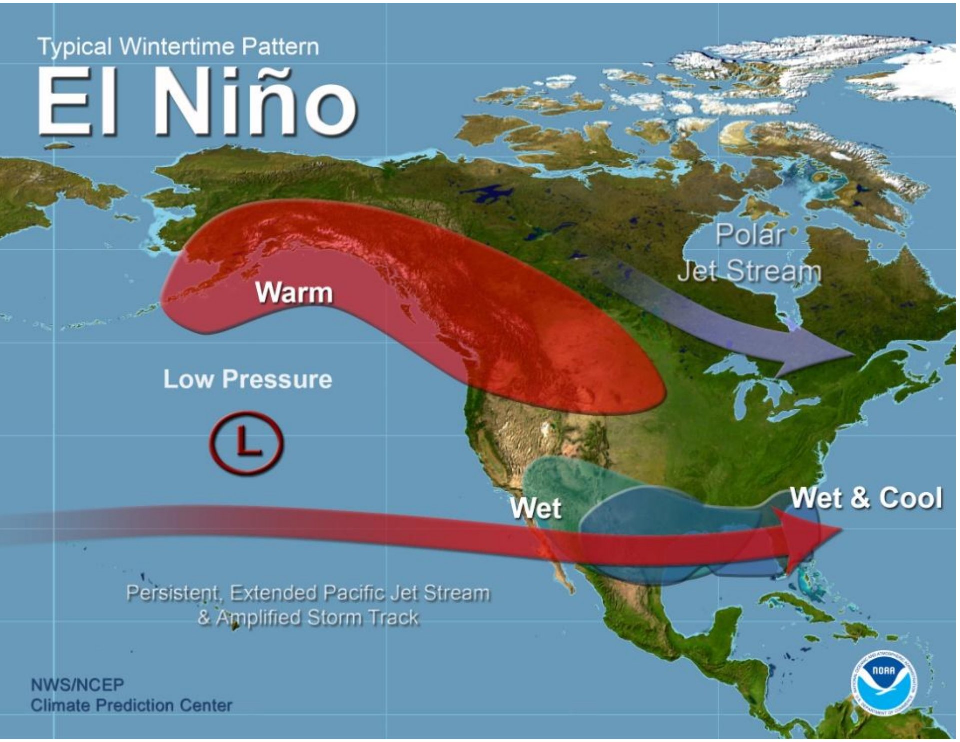
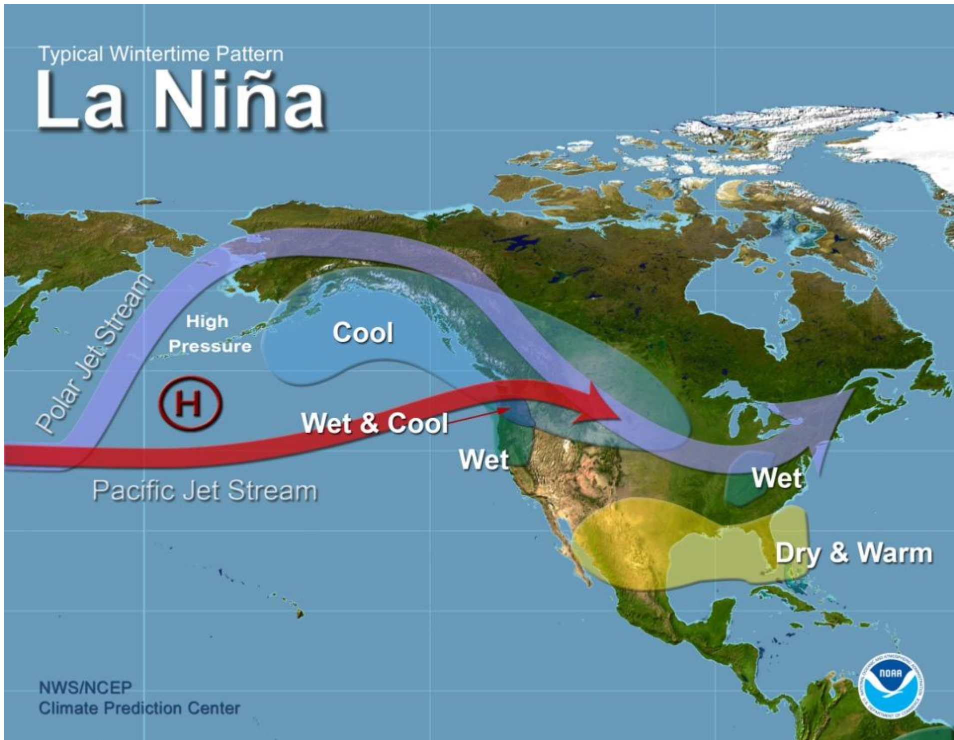

Typical Wintertime Pattern
El Niño
Warm
Polar Jet Stream
Low Pressure
L
Wet
Wet & Cool
Persistent, Extended Pacific Jet Stream & Amplified Storm Track
NWS/NCEP
Climate Prediction Center


Typical Wintertime Pattern
La Niña
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H
Cool
Wet & Cool
Wet
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Wet
Dry & Warm
NWS/NCEP
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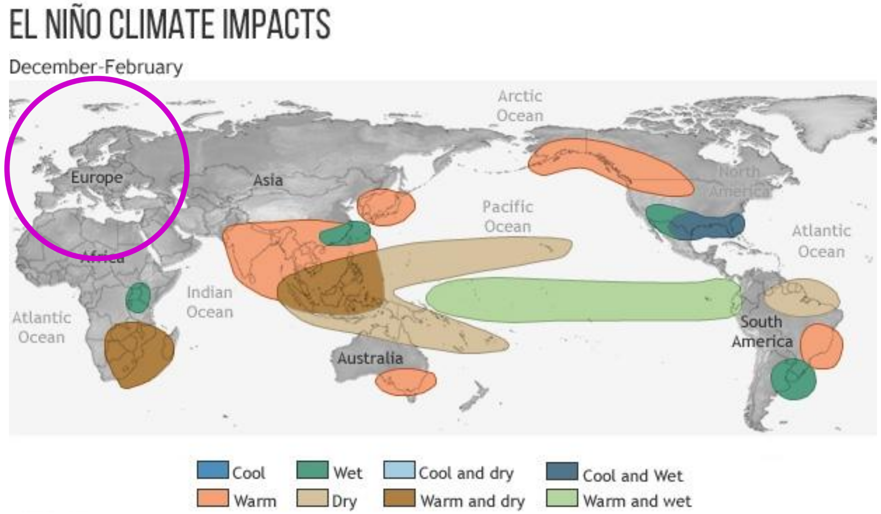
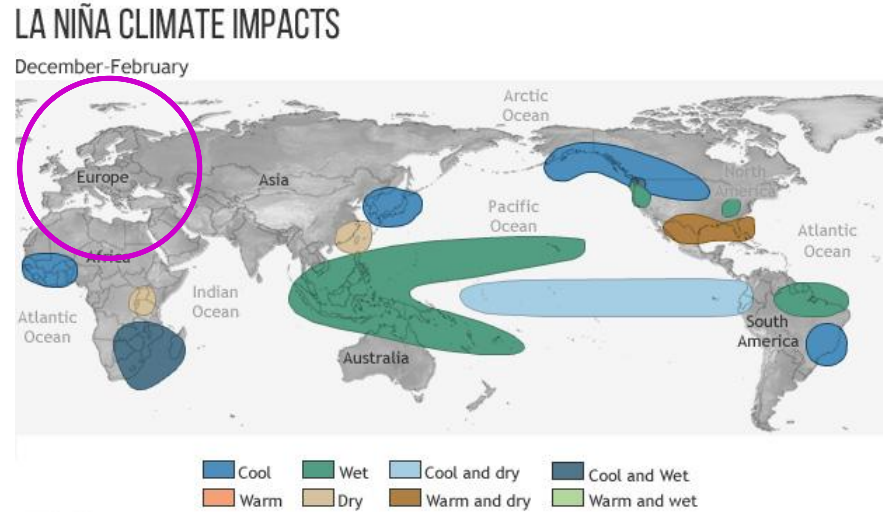
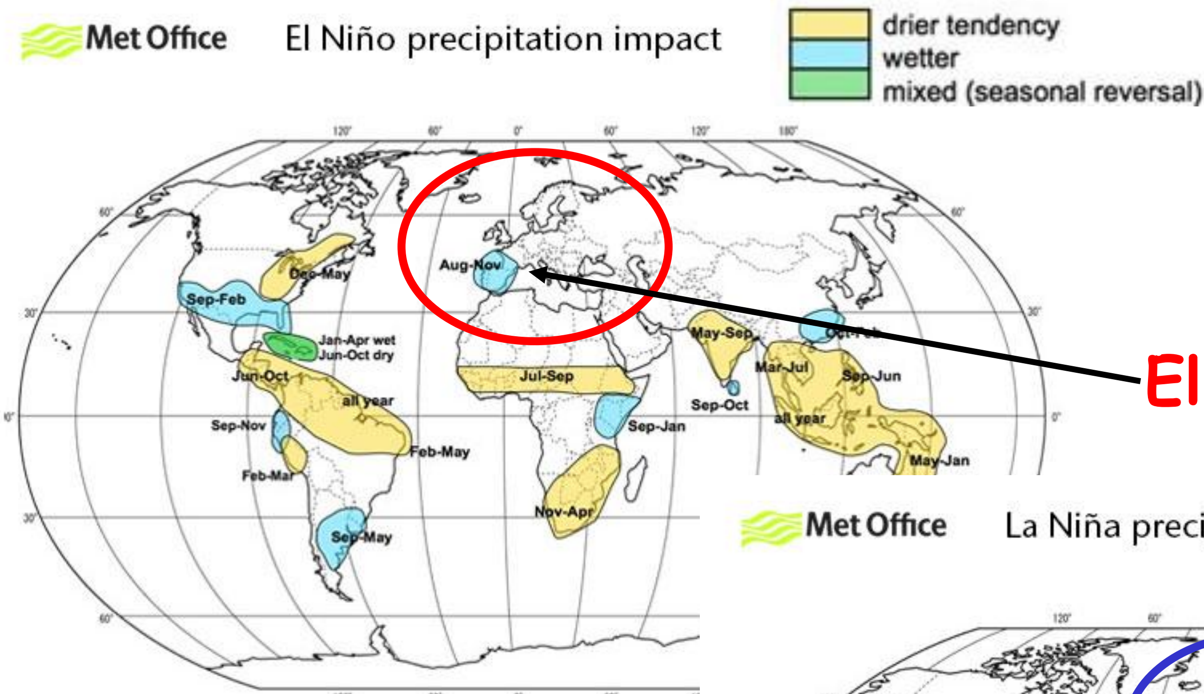


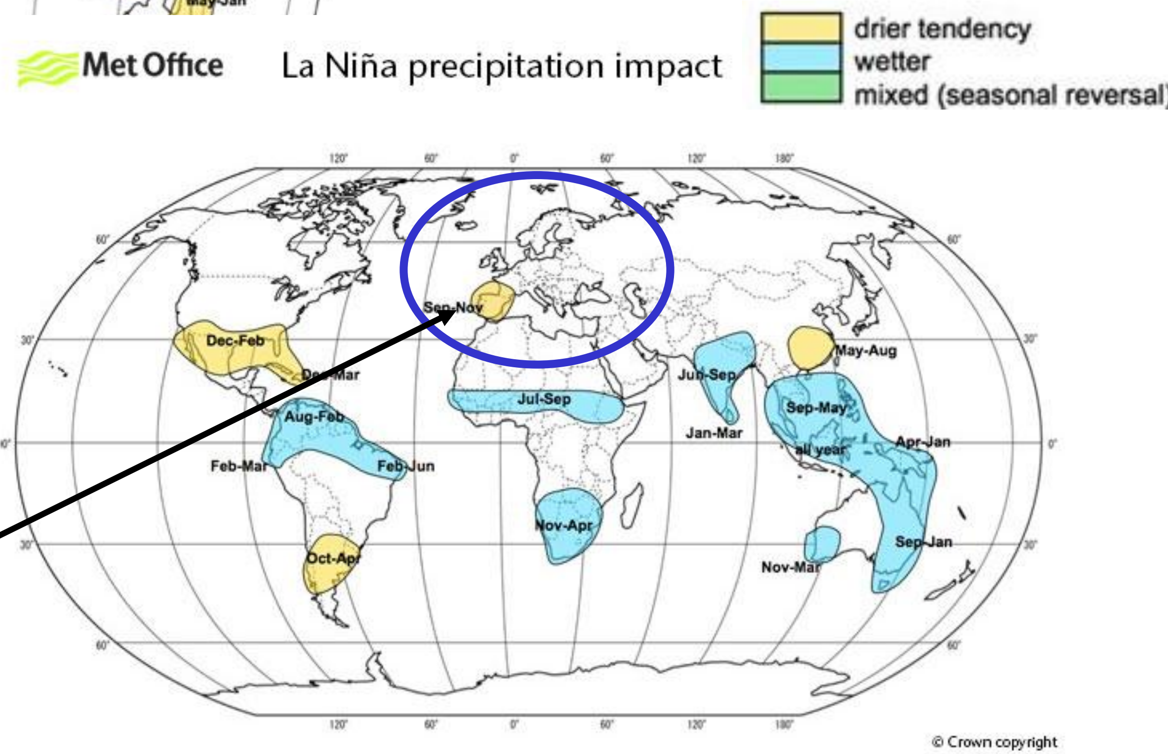


ENSO impact on North Atlantic European (NAE) region?

Impact of ENSO on precipitation



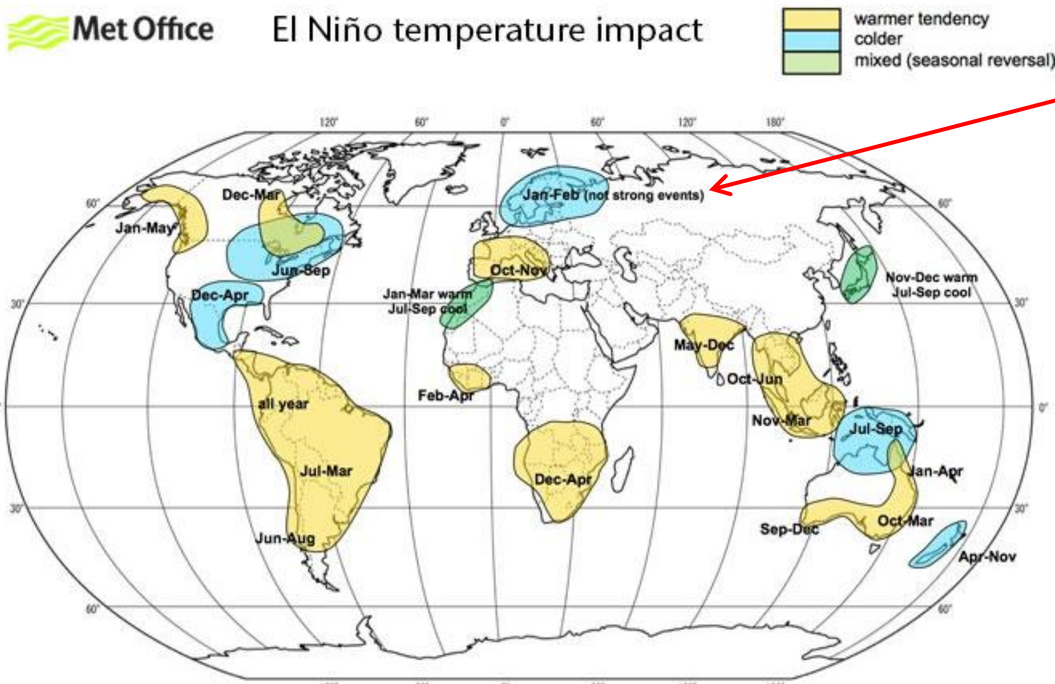
El Niño

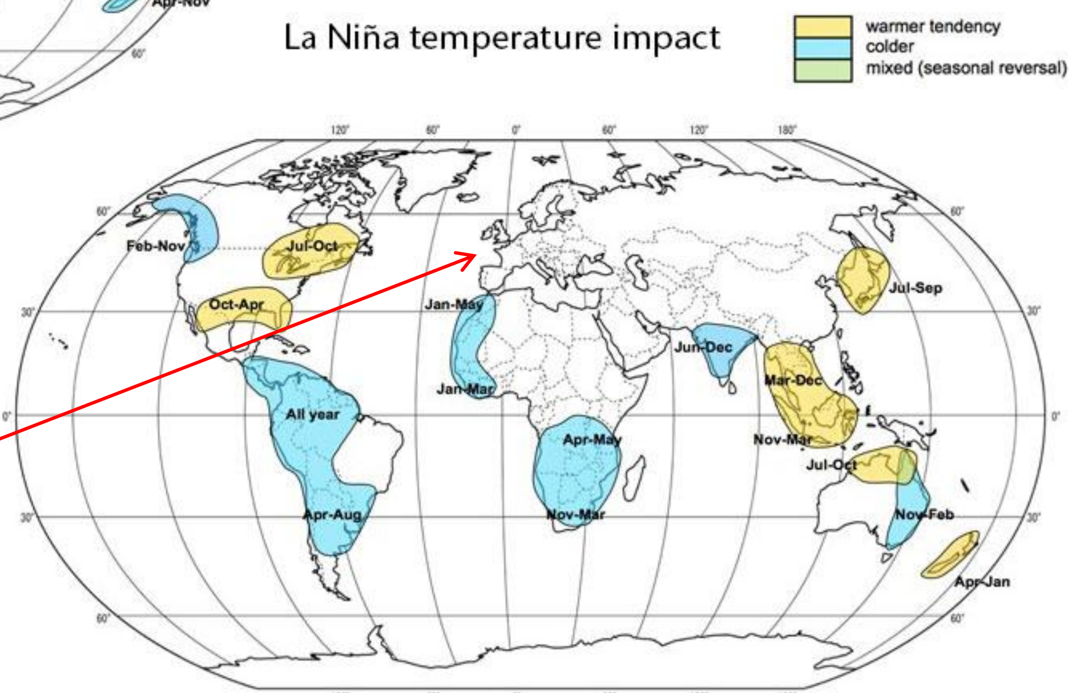


La Niña

Source: metoffice.gov.uk

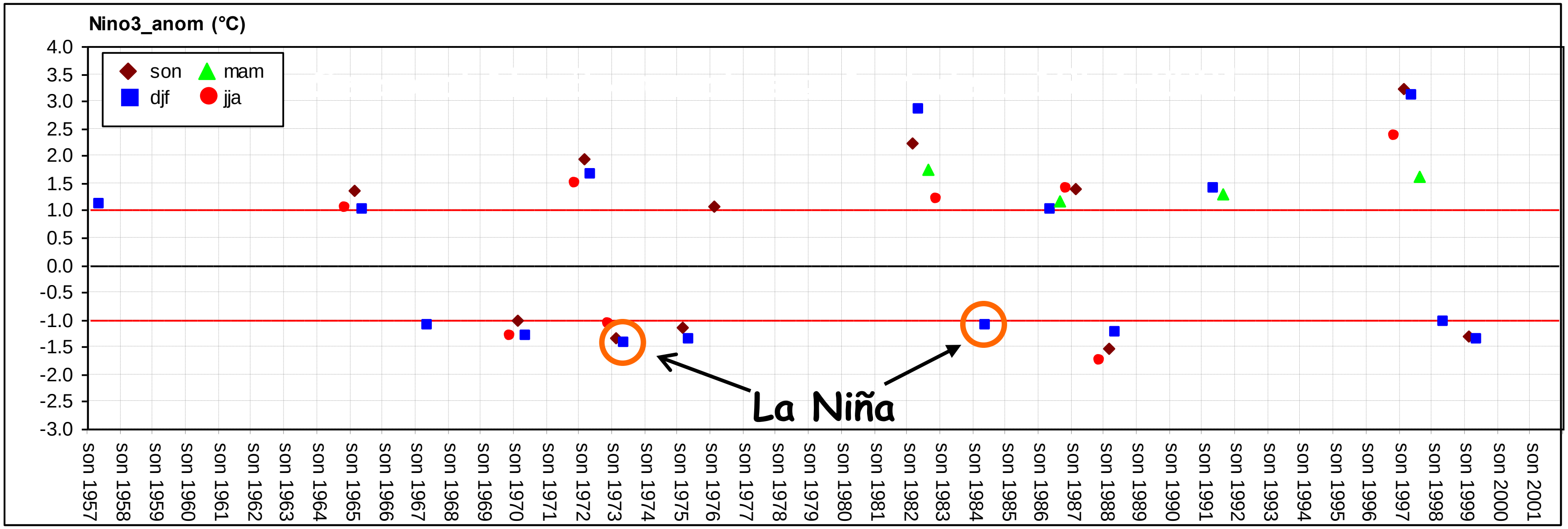
ENSO impact on Europe: sometimes controversial…

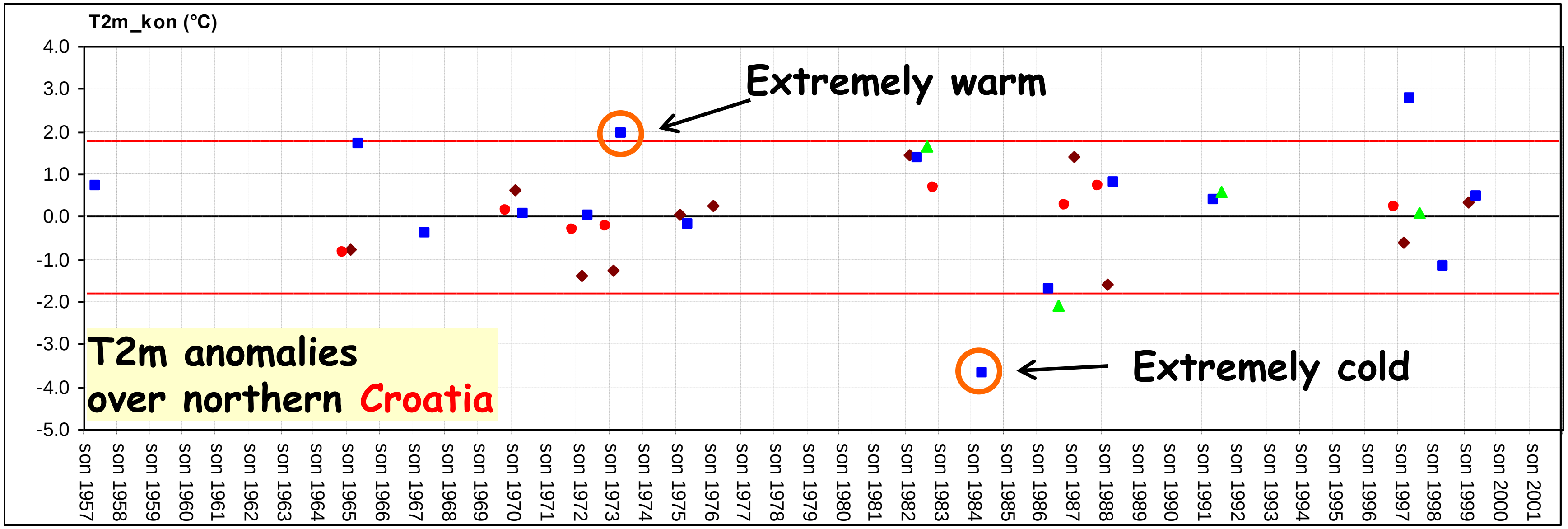




… or very weak

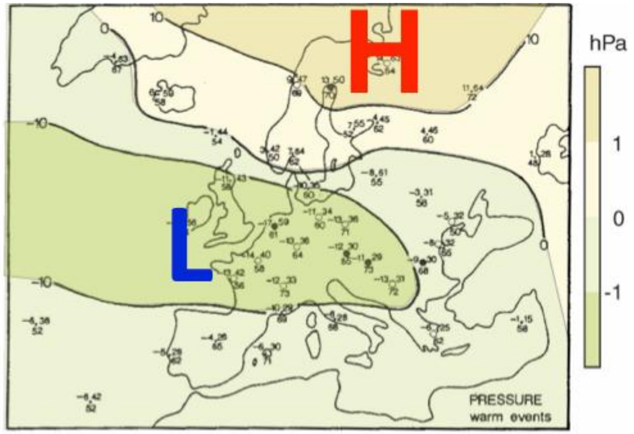
Local impact of ENSO: sometimes controversial





Author: Lidija Srnec (DHMZ)

ENSO impact on North Atlantic European (NAE) region



Fraedrich and Müller [1992]

Observational and modelling studies: detectable ENSO signal in European climate (e.g. van Loon and Madden 1981, Fraedrich and Müller 1992, Oldenborgh et al. 2000, Brönnimann 2007, Nieves Lorenzo et al. 2010)

DJF season: warm (cold) ENSO events are related to a southward (northward) shift of the North Atlantic storm track (Fraedrich and Müller 1992)

ENSO impact on NAE: seasonally and regionally dependent (Shaman 2014)

Lagged ENSO impact (e.g. Rodó et al. 1997, van Oldenborgh et al. 2000, Knippertz et al. 2003, Feddersen 2003, Nieves Lorenzo et al. 2010)

ENSO impact on NAE region – physical mechanisms and modelling

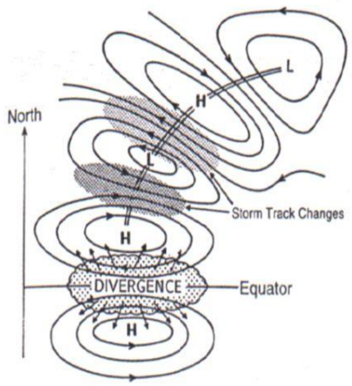
ENSO impact on NAE region – physical mechanisms and modelling

- **tropospheric pathway**: a barotropic Rossby wave train (Horel and Wallace 1981,Trenberth et al, 1998)
- **stratospheric link** between ENSO and European climate (e.g. Brönnimann 2004, 2007, Ineson and Scaife 2009, Butler et al. 2014)

Propagation of Rossby waves

from a region of tropical convection (schematic)

Horel and Wallace (1981)



Trenberth et al. (1998)

Modelling point of view:

- numerical simulations of ENSO-NAE teleconnection: AGCMs, AOGCMs (Bengtsson et al., 1996; Grötzner et al., 2000; Kang et al., 2002)
- need of models with higher horizontal resolution (Merkel and Latif 2002)
- need of models with dynamically active stratosphere (Bell et al. 2009, Cagnazzo and Manzini 2009, Ineson and Scaife 2009)

Modelling impact of ENSO on Europe
ICTP AGCM - Speedy

ICTP AGCM (SPEEDY) – **S**implified **P**arametrizations, primitiv**E**-**E**quation **DY**namics (Molteni, ClimDyn 2003)

An intermediate complexity model

T30L8 ~ 400 km (3.75°) → computational efficiency

The two model levels representing the lower stratosphere/upper troposphere are approximately located at 30 and 100 hPa

Speedy is successfully used in a number of studies dealing with various aspects of dynamical climatology (Kucharski et al. 2006, 2013)

- ENSO influence on climate variability of North Atlantic-European region; teleconnections in a warmer climate, direct vs. indirect impact of elevated CO_2, wintertime ENSO impact on spring climate over the NAE, the role of North Atlantic in time delayed response to wintertime ENSO and NAO; the response of Speedy's stratosphere to ENSO forcing…

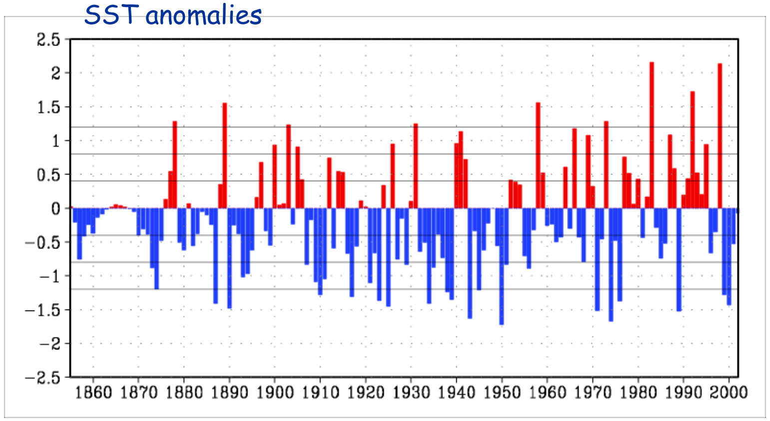
ENSO forcing of European climate

Herceg Bulić and Branković: ENSO forcing of the Northern Hemisphere climate in a large ensemble of model simulations based on a very long SST record, ClimDyn 2007.

ENSO impact on Europe:

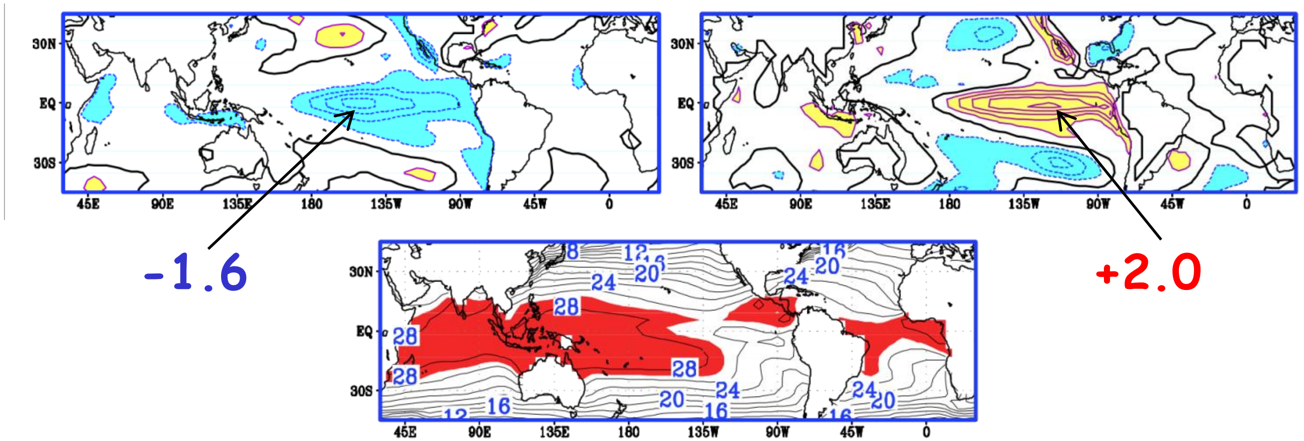
- Speedy forced with observed SSTs
- **Composite analysis**:
    strong La Niña (18), strong El Niño (9)
- 35-member ensemble; 1854-2002
- Season analysed: **JFM**

JFM Niño3.4
SST anomalies



JFM La Niña

JFM El Niño

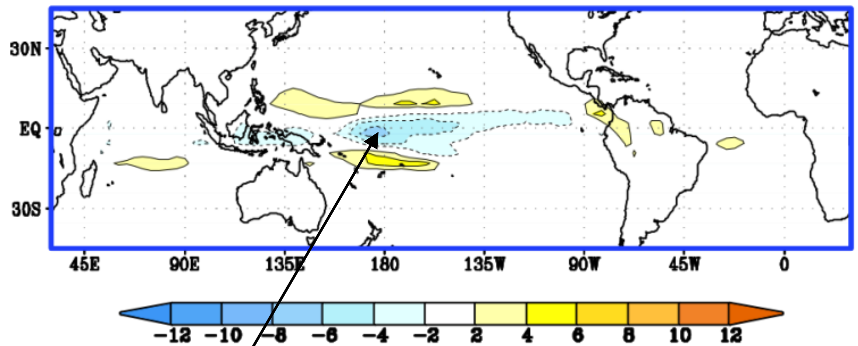


SPEEDY precipitation composites in the tropics

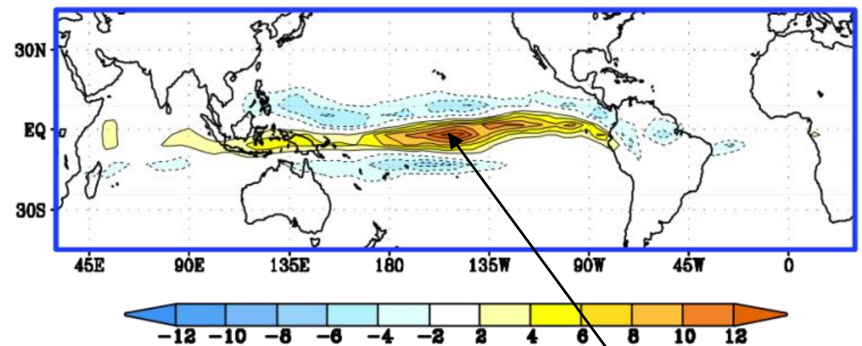
* Amplitude of JFM precipitation anomaly for La Niña is one half of that for El Niño, although amplitudes of SST anomalies are relatively similar

* Precipitation maxima shifted westward relative to maxima in SSTs

JFM La Niña



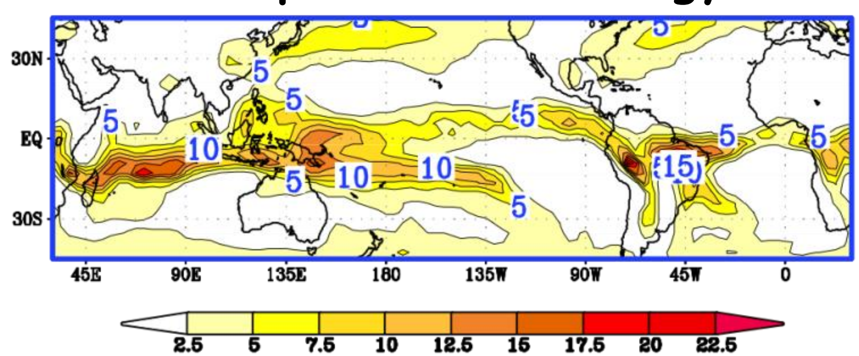
JFM El Niño



-7 mmday^{-1}

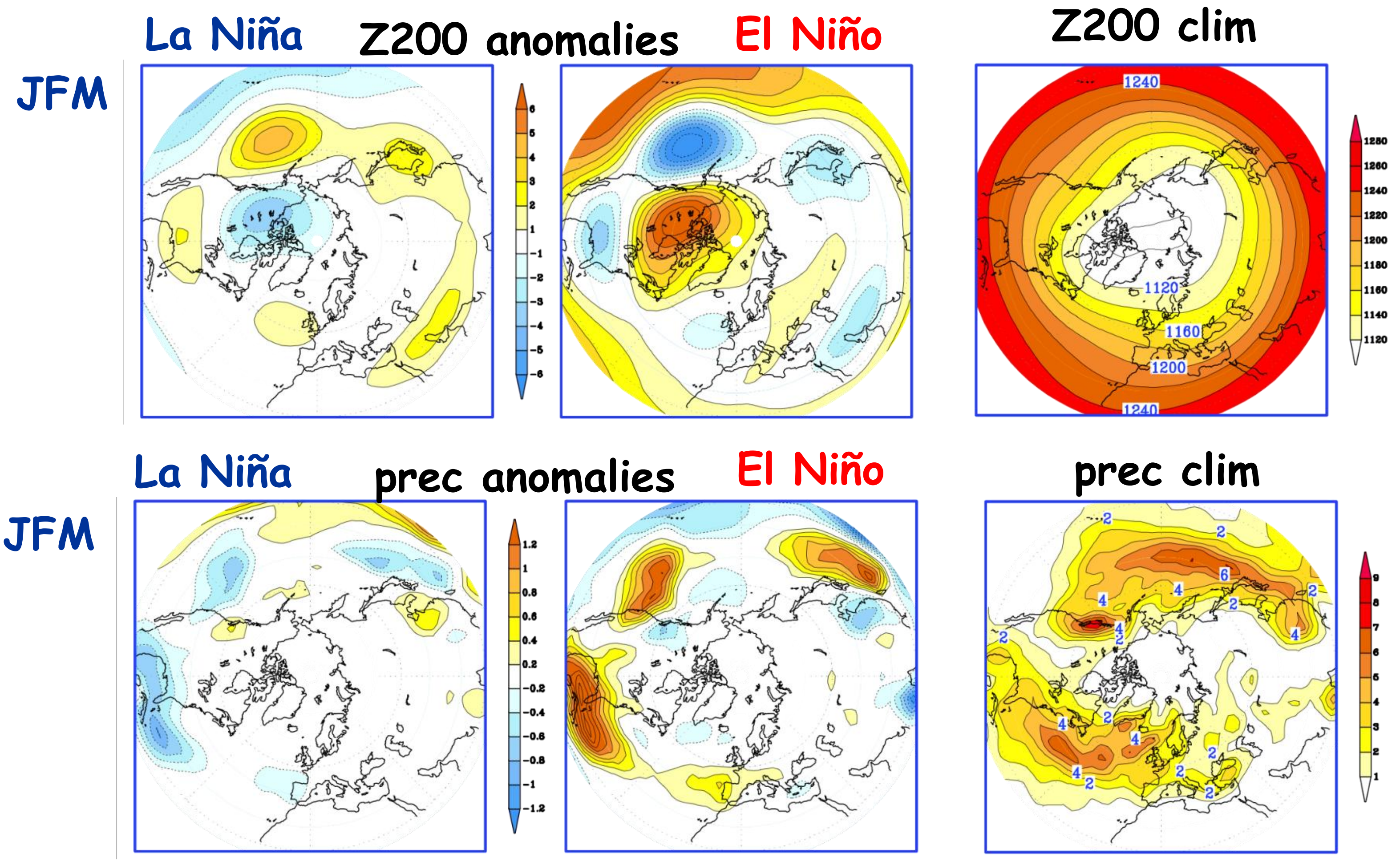
+14 mmday^{-1}

Precipitation climatology



SPEEDY Northern Hemisphere composites

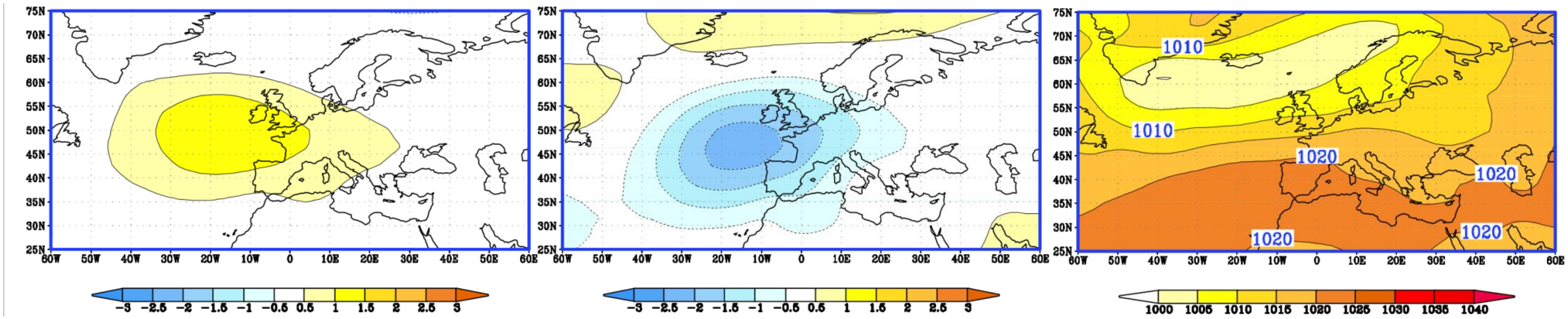
* Pacific anomalies stronger for warm than for cold composites;
  no shift between cold and warm phases despite shift in tropical prec.
* Strong symmetry in pattern and location (but not in amplitude) between
  composites of opposite polarity → too linear response to ENSO forcing



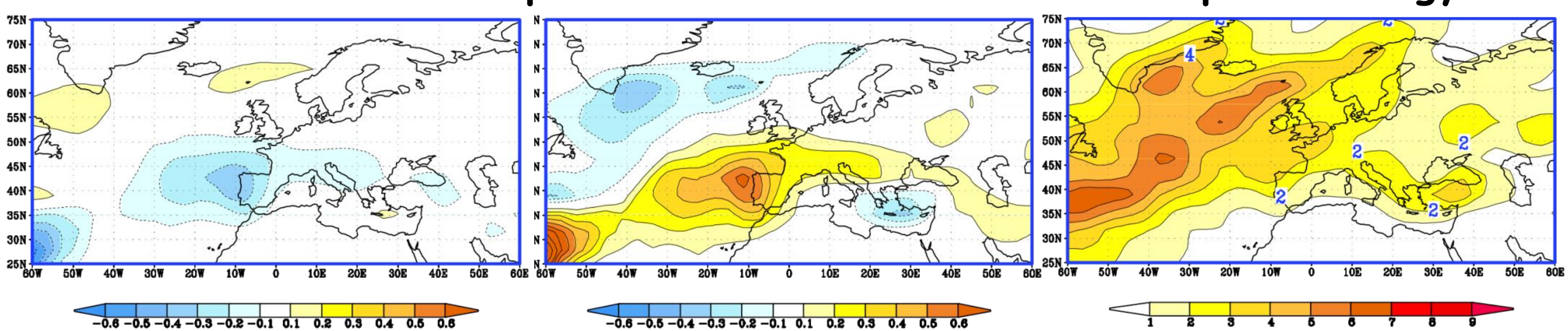
SPEEDY North Atlantic/Europe composites

* Signal for warm events stronger than that for cold events
* Model response insensitive to the strength of the Niño3.4 index
* Similarity with PNA region: spatial symmetry and amplitude asymmetry
* Good agreement with observations (Fraedrich and Müller 1992)

La Niña JFM MSLP anomalies El Niño MSLP climatology



La Niña JFM Precip anomalies El Niño Precip climatology



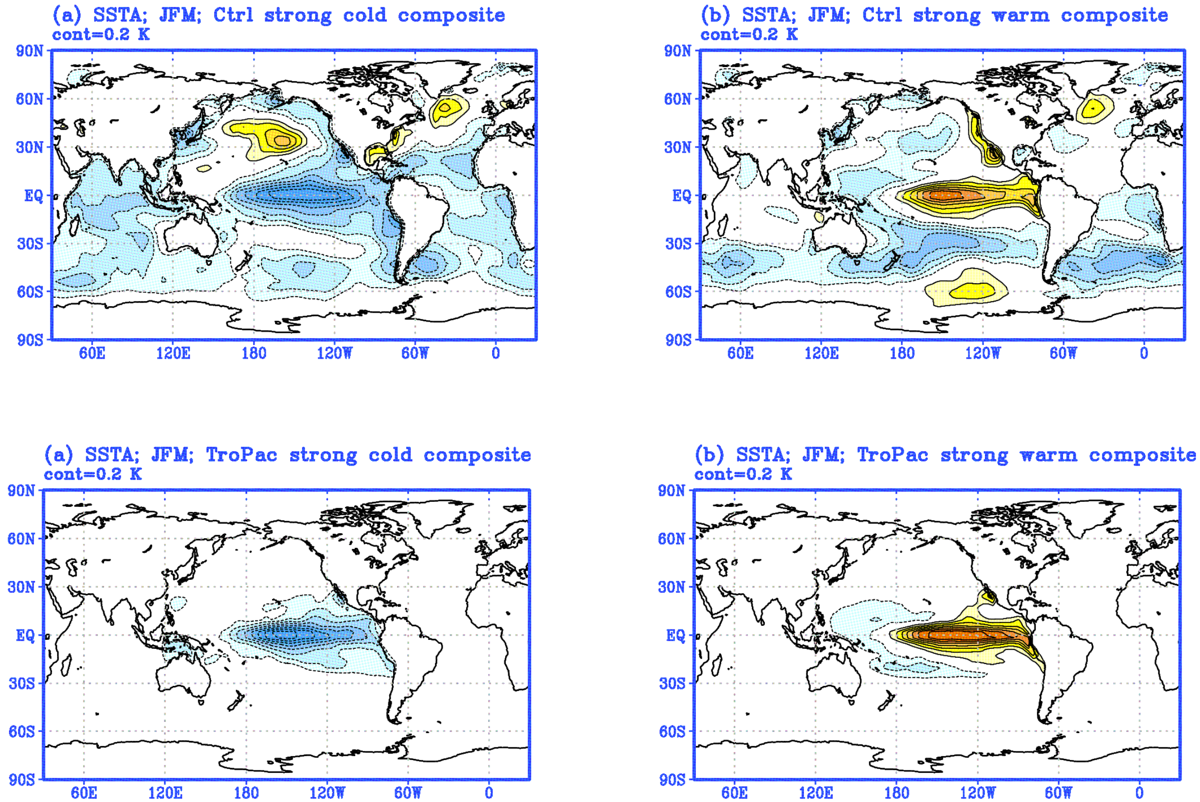
TroPac – SPEEDY experiment with SST forcing constrained to the tropical Pacific

TroPac – SPEEDY experiment with SST forcing constrained to the tropical Pacific

Ctrl: SST anomalies prescribed globally

TroPac: SST anomalies constrained to the tropical Pacific; climatological SSTs elsewhere

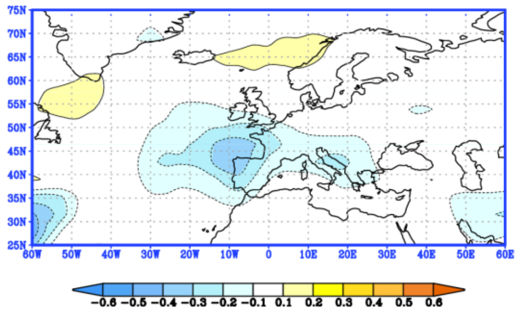
La Niña JFM SSTA El Niño



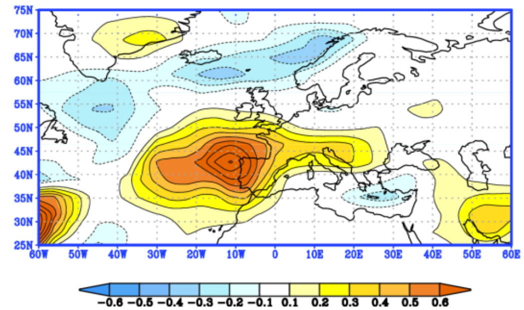
TroPac – SPEEDY experiment with SST forcing constrained to the tropical Pacific

La Niña JFM prec. anomalies El Niño

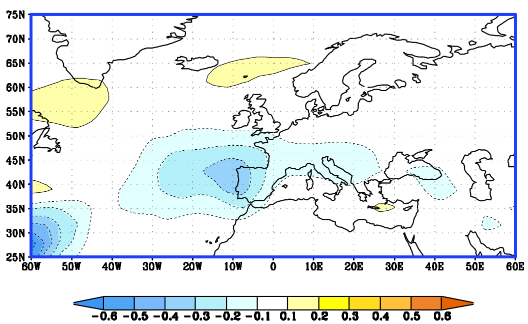
TroPac



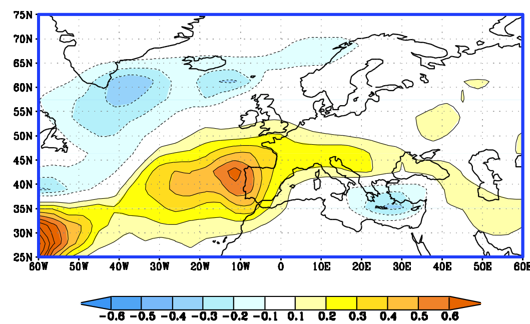
TroPac



Ctrl



Ctrl



Spatial correlation TroPac-Ctrl	strong cold	strong warm
prec	0.94	0.88
GH200	0.80	0.90
mslp	0.81	0.91
T850	0.91	0.80

Sumarry

- **ENSO** has an **detectable impact** on climate variability over the **NAE** region
- SPEEDY response: quite consistent with observations and other results
- **JFM El Niño**: **cyclonic** type of weather in winter, increased (decreased) precipitation over the northern (southern) Europe
- **JFM La Niña**: **anticyclonic** type of weather increased (decreased) precipitation over the northern (southern) Europe

ENSO impact in a **warmer** climate?

SPEEDY: ENSO impact on Europe in a warmer climate

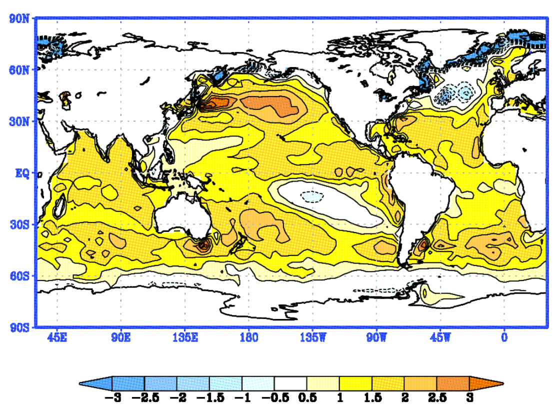
CTRL experiment – current climate

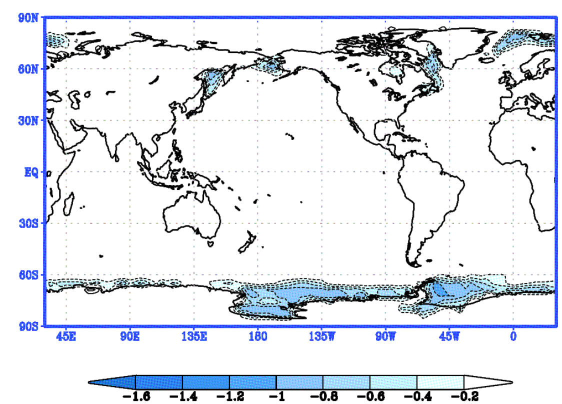
- **CO_2** – average value for 1961-1990 (**$1xCO_2$**)
- **SST** climatology and anomalies: observed 1855-2002 (NOAA_ERSST_V2 data) + sea-ice (HadSSTI)
- **Sea-ice**: HadISST (1961-1990)

$2xCO_2$ experiment – warmer climate

- **CO_2** – doubled (**$2xCO_2$**)
- **SST climatology** and **sea-ice** – simulated with HadCM3 forced with $2xCO_2$ conditions
- **SST anomalies** – same as in CTRL

JFM SST clim **$2xCO_2$-CTRL** **JFM SICE clim**

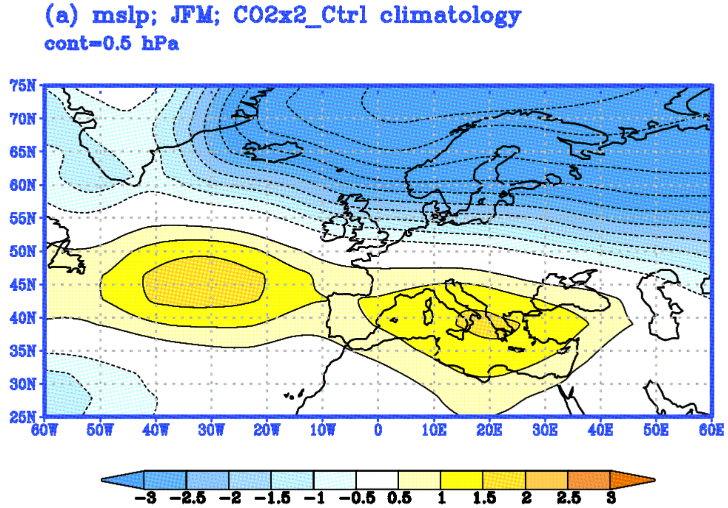




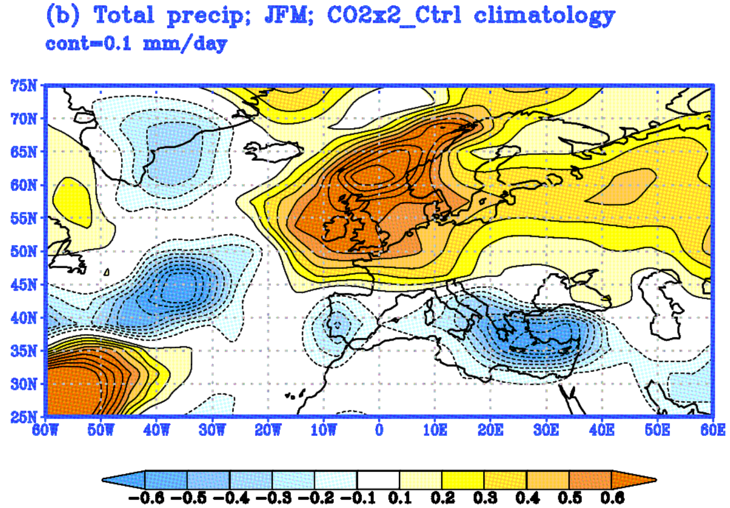
Herceg-Bulić, Branković and Kucharski:
Winter ENSO teleconnections in a warmer climate. ClimDyn 2012.

$2xCO_2$ - Ctrl climatology difference

JFM mslp

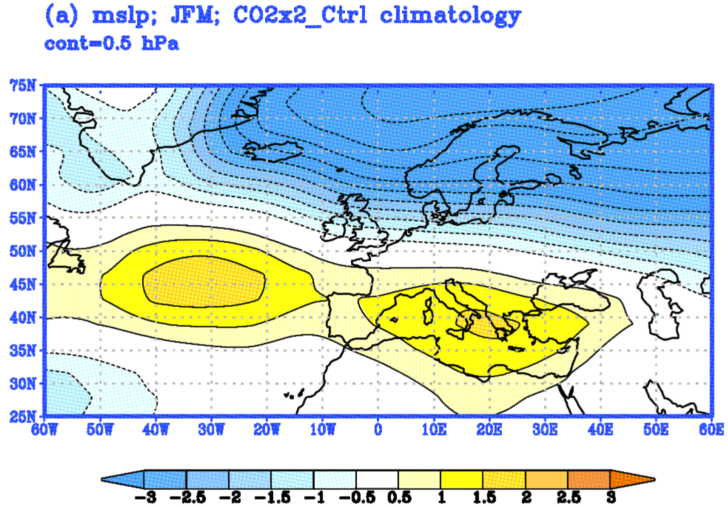


JFM prec

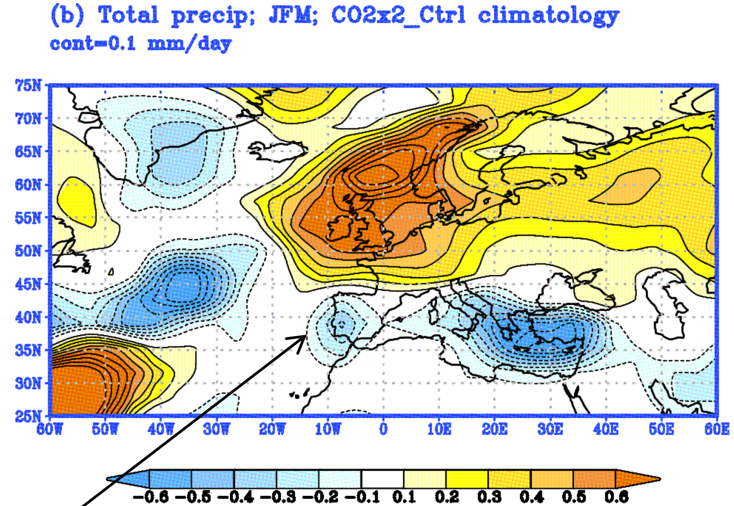


$2xCO_2$ - Ctrl climatology difference

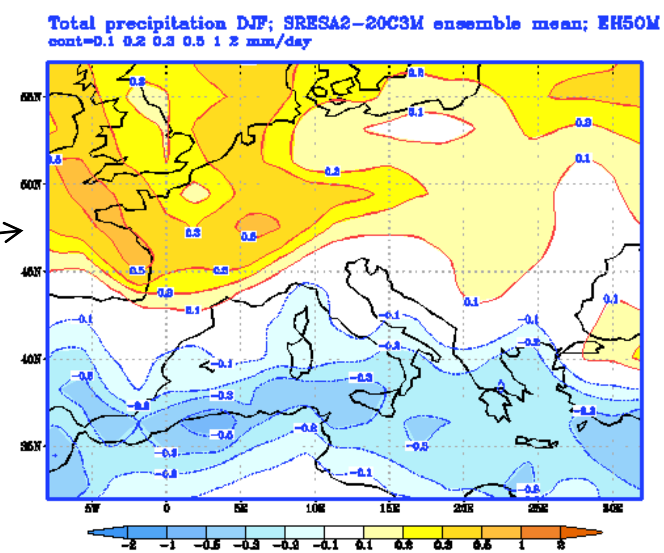
JFM mslp



JFM prec

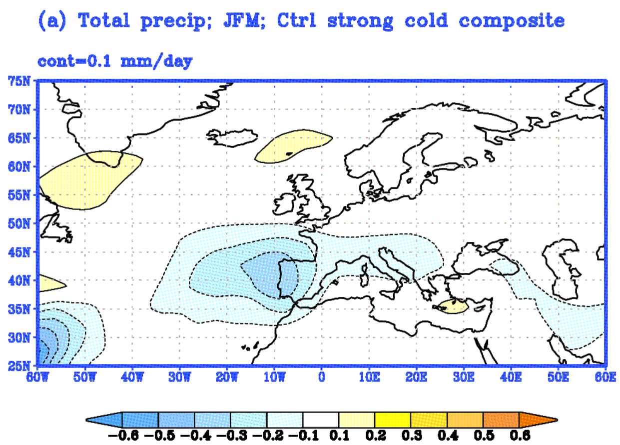


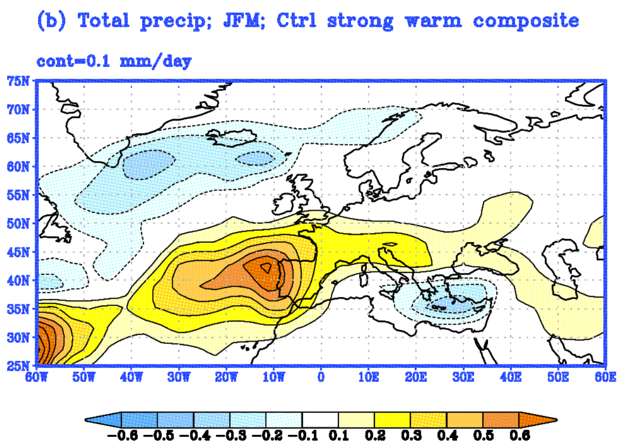
Similar pattern of precipitation change to that obtained by **EH5OM** for SRESA2



An assessment of global and regional climate change based on the EH5OM climate model ensemble (Branković, Srnec and Patarčić, ClimChange 2010)

ENSO signature in warmer ($2xCO_2$) climate: JFM precipitation

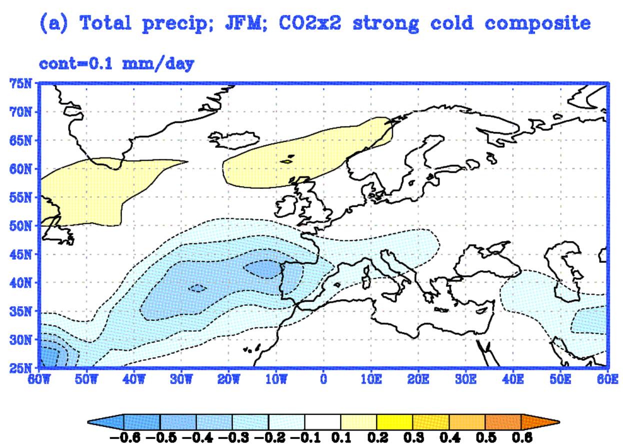


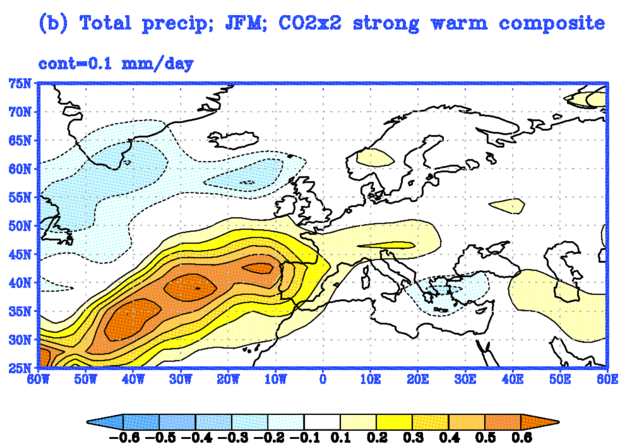


CTRL

La Niña

El Niño





$2xCO_2$

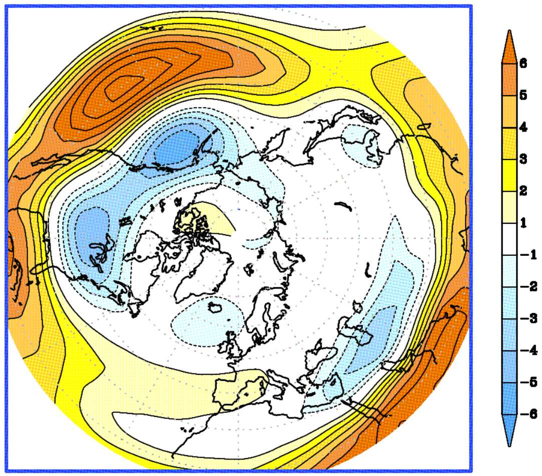
ENSO signature in warmer ($2xCO_2$) climate - JFM u200

El Niño

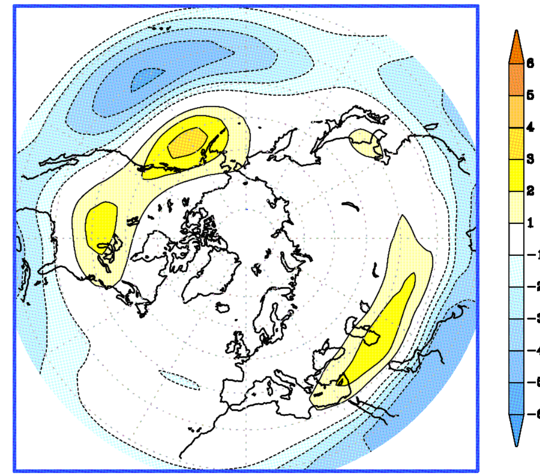
La Niña

CTRL

(a) u-wind 200; JFM; CTRL strong warm composite
cont=1.0 m/s

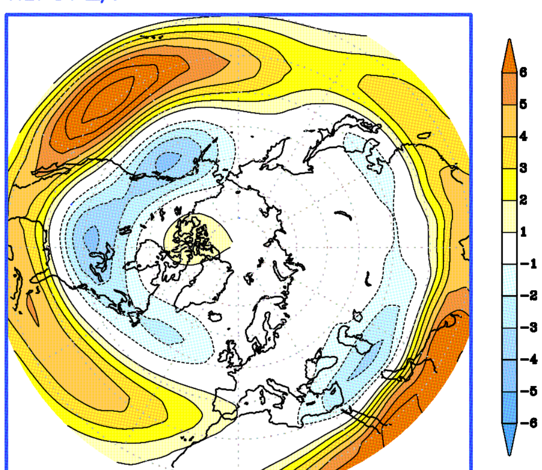


(b) u-wind 200; JFM; CTRL strong cold composite
cont=1.0 m/s

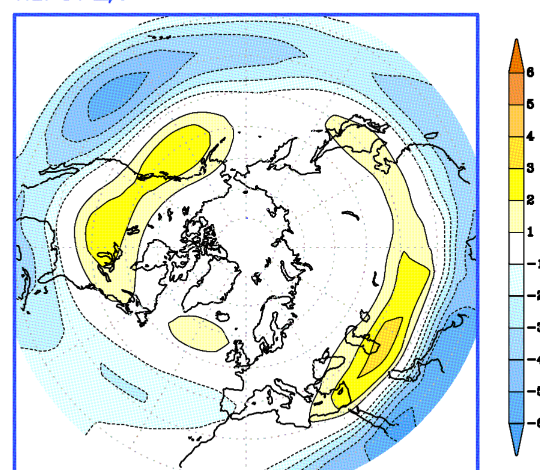


$2xCO_2$

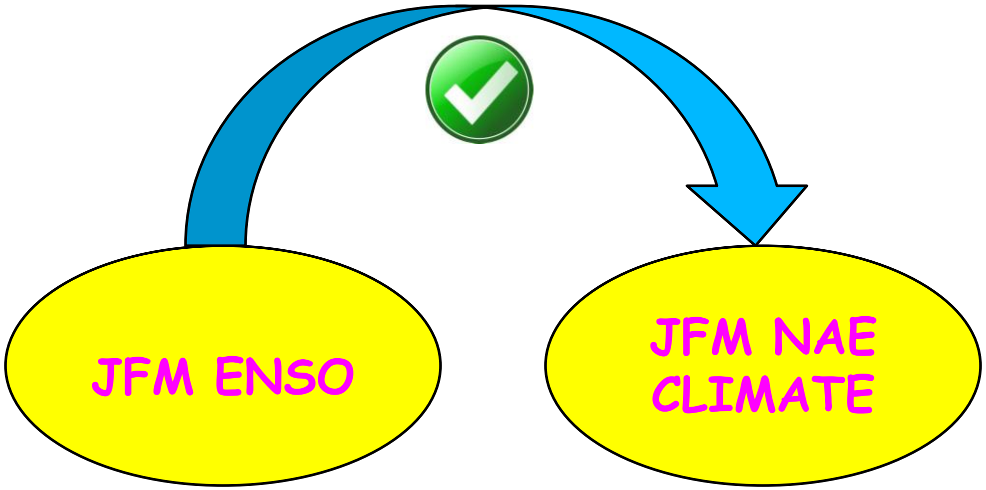
(c) u-wind 200; JFM; 2xCO2 strong warm composite
cont=1.0 m/s



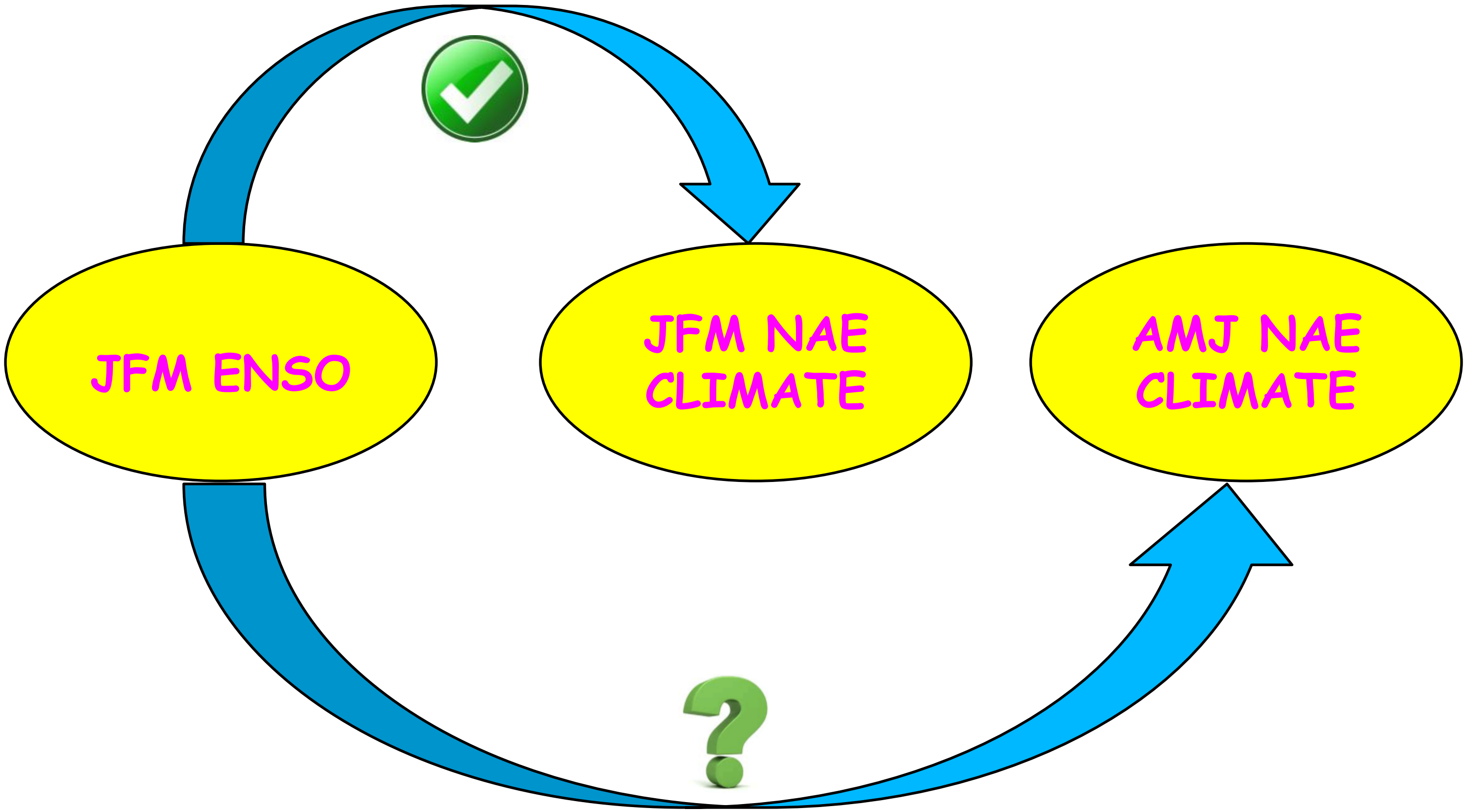
(d) u-wind 200; JFM; 2xCO2 strong cold composite
cont=1.0 m/s



ENSO influence on NAE



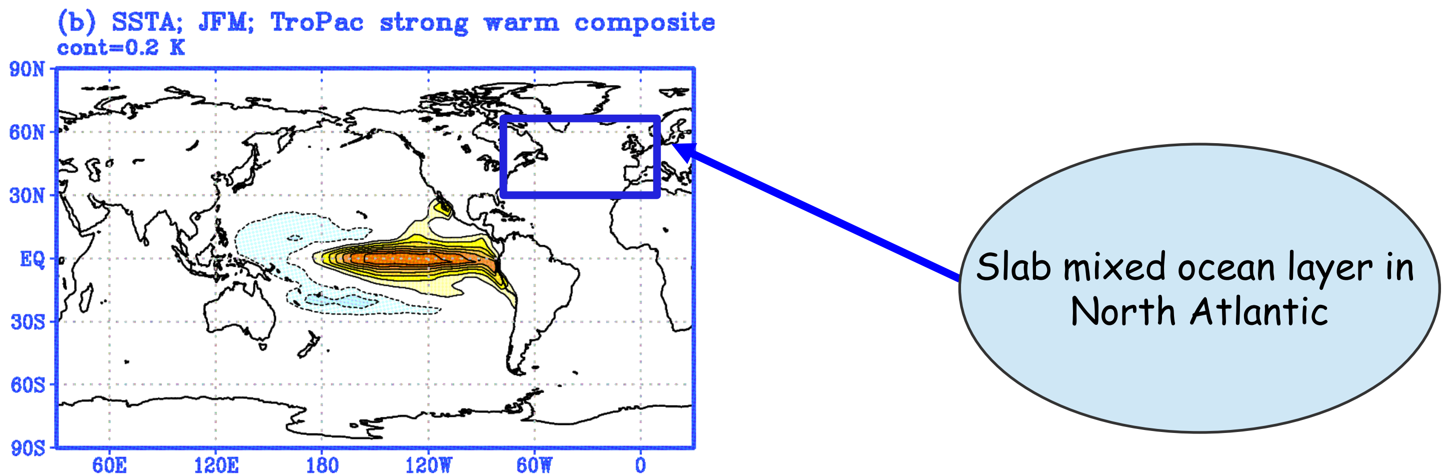
Delayed ENSO influence on NAE?



Delayed ENSO influence on NAE

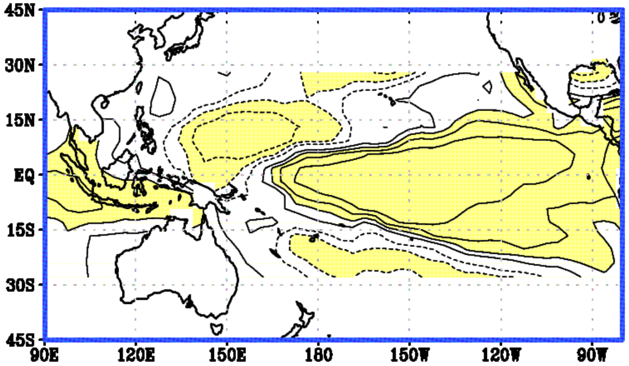
Herceg-Bulić and Kucharski F: Delayed ENSO impact on spring precipitation over North/Atlantic European region. ClimDyn 2012.

- **CTRL** experiment – observed SSTs 1854-2002 (NOAA_ERSST_V2 data)
- **MIX** experiment – observed SSTs in the tropical Pacific + climatological SSTs elsewhere + mixed slab ocean in North Atlantic



Delayed ENSO influence on NAE

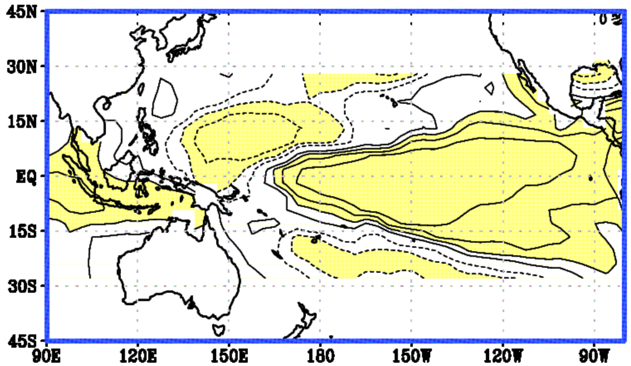
Correlation
PC1(**AMJ** NAE precipitation) –
JFM SSTA



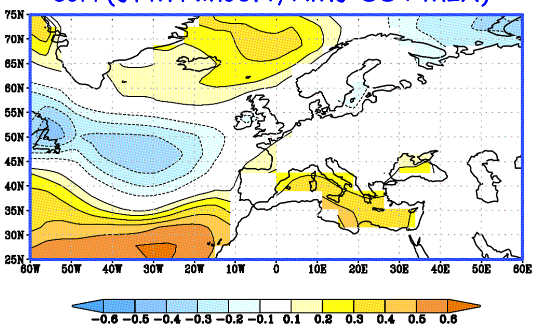
AMJ precipitation variability is correlated with **JFM SSTA** in tropical Pacific

Delayed ENSO influence on NAE

Correlation
PC1(**AMJ** NAE precipitation) – **JFM** SSTA

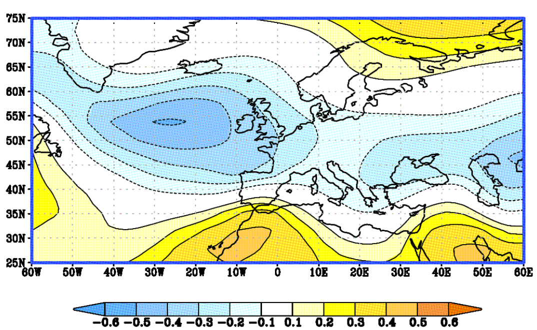


corr(JFM Niño3.4, AMJ SST MIX)

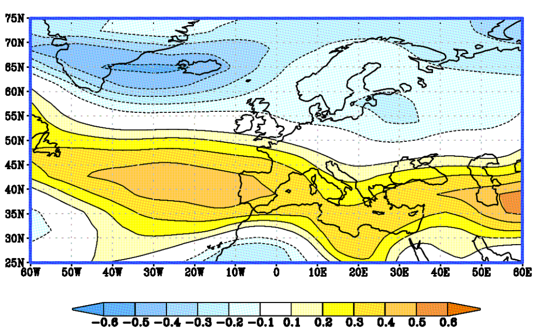


Correlation
JFM Niño3.4 – **AMJ**
European climate

corr(JFM Niño3.4, AMJ SLP MIX)

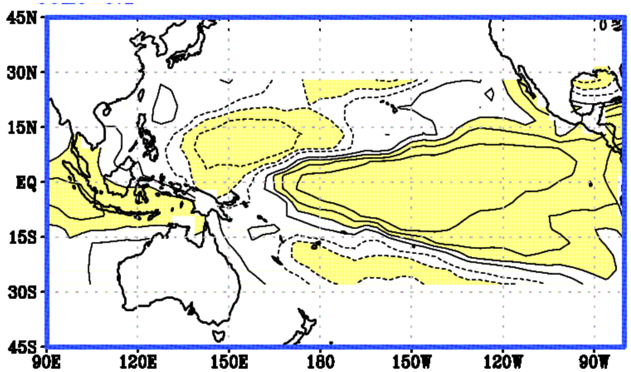


corr(JFM Niño3.4, AMJ u850)



Delayed ENSO influence on NAE

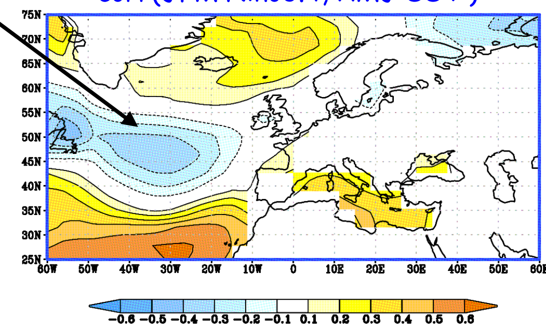
Correlation
PC1(**AMJ** NAE precipitation) –
JFM SSTa (tropical Pacific)



NAE **AMJ precipitation** is
significantly correlated
with **JFM SSTA**
in the tropical Pacific

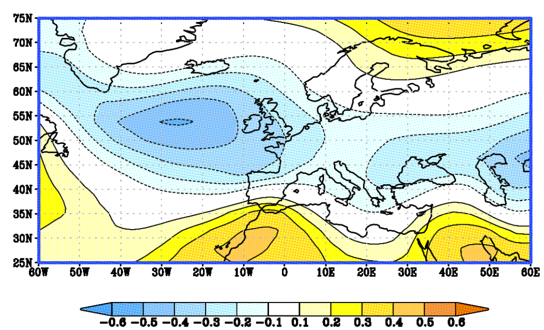
North Atlatic SSTs
as a link between
the wintertime ENSO and
springtime European climate

corr(JFM Niño3.4, AMJ SST)

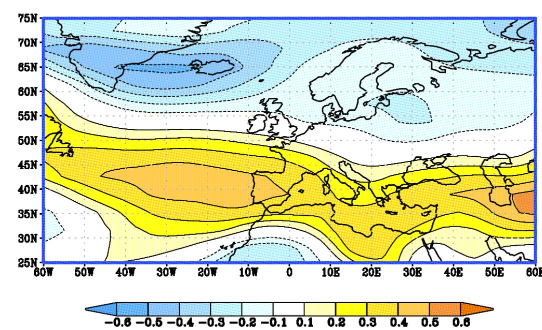


Correlation
JFM Niño3.4 – **AMJ**
European climate
(MIX experiment)

corr(JFM Niño3.4, AMJ SLP)



corr(JFM Niño3.4, AMJ u850)

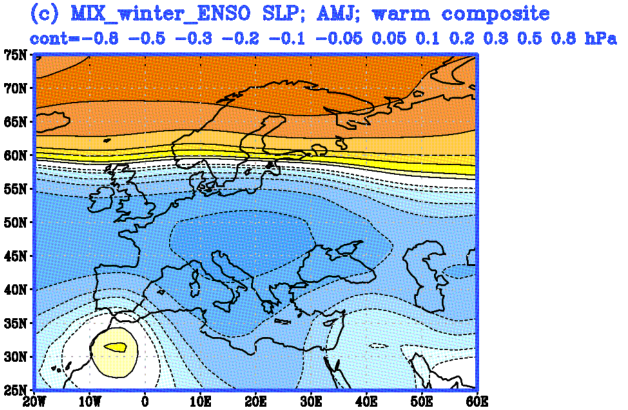


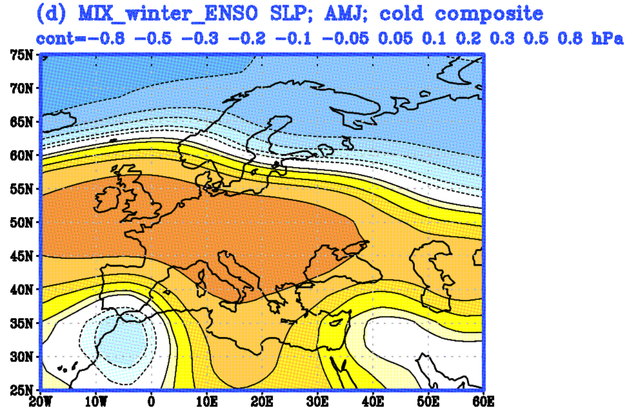
Delayed (JFM) ENSO impact on (AMJ) SLP (modelled and observed)

AMJ SLP composites based on JFM Niño3.4 index

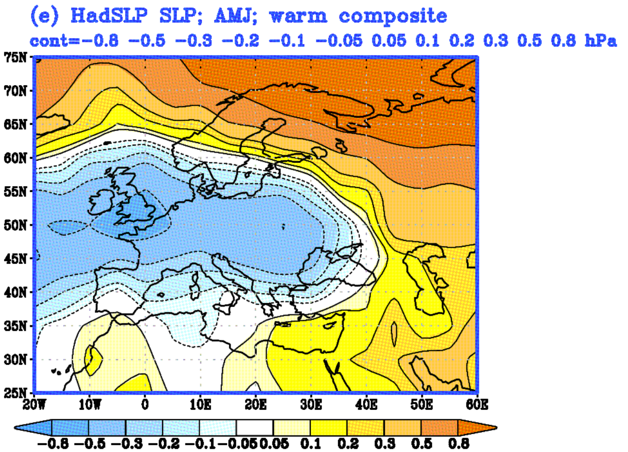
El Niño

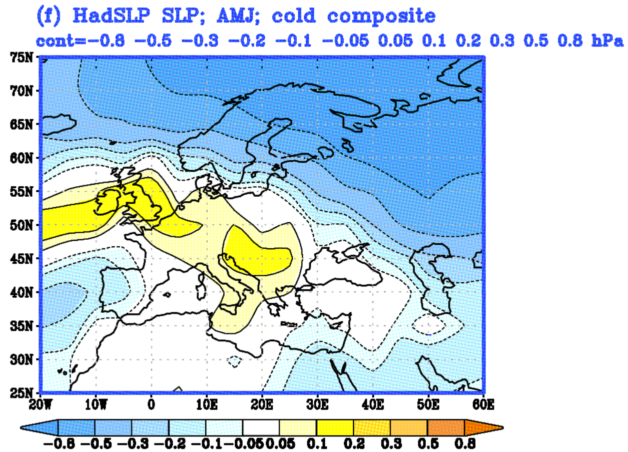
La Niña



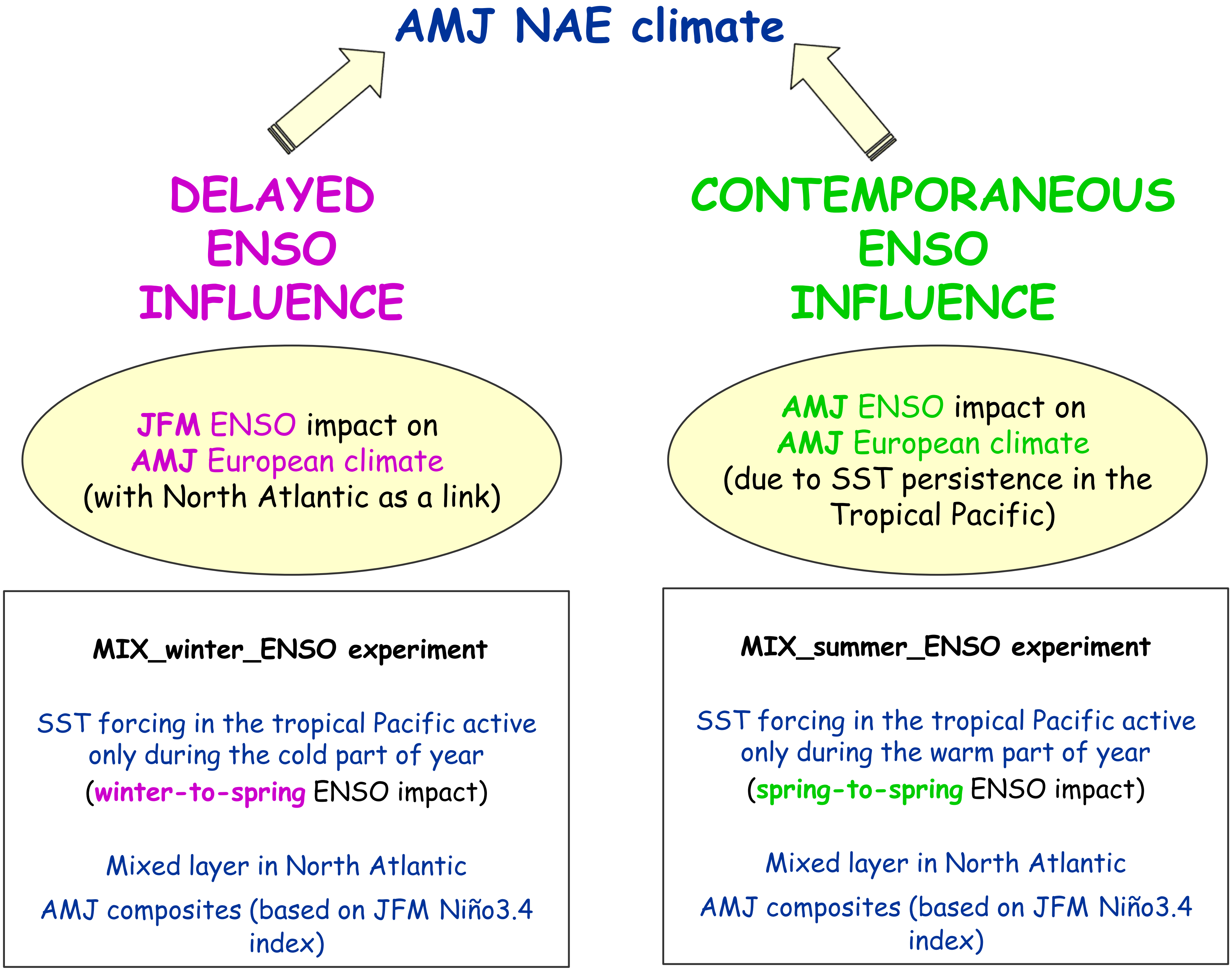


Speedy





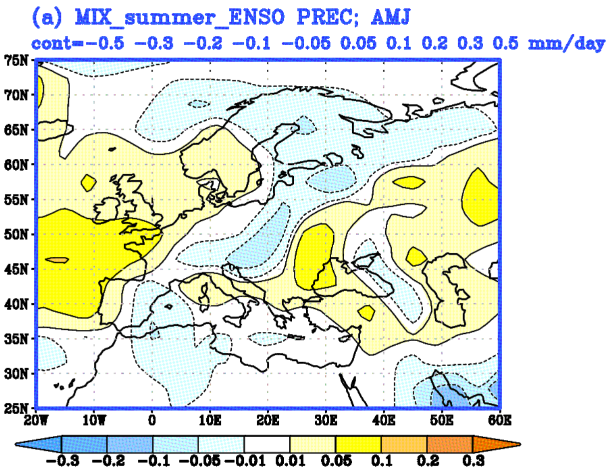
observed (HadSLP)


AMJ NAE climate
DELAYED ENSO INFLUENCE
CONTEMPORANEOUS ENSO INFLUENCE
JFM ENSO impact on AMJ European climate (with North Atlantic as a link)
AMJ ENSO impact on AMJ European climate (due to SST persistence in the Tropical Pacific)
MIX_winter_ENSO experiment
SST forcing in the tropical Pacific active only during the cold part of year (winter-to-spring ENSO impact)
Mixed layer in North Atlantic
AMJ composites (based on JFM Niño3.4 index)
MIX_summer_ENSO experiment
SST forcing in the tropical Pacific active only during the warm part of year (spring-to-spring ENSO impact)
Mixed layer in North Atlantic
AMJ composites (based on JFM Niño3.4 index)

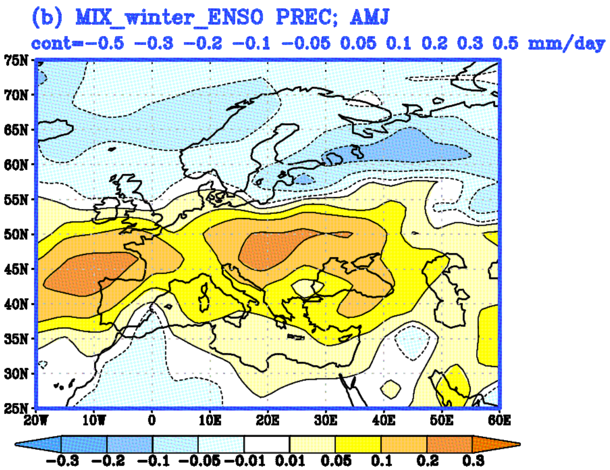
Delayed and contemporaneous ENSO influence

AMJ precipitation composites (based on JFM Niño3.4 index)

Tropical Pacific: SUMMER SSTs
NAtl: slab ocean
Contemporaneous ENSO effect
AMJ ENSO – AMJ PREC

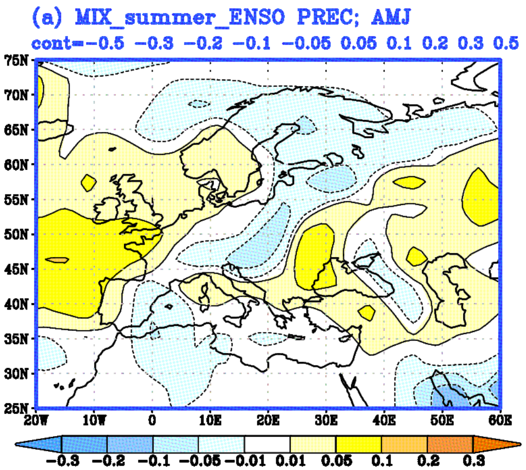


Tropical Pacific:WINTER SSTs
NAtl: slab ocean
Delayed ENSO effect
JFM ENSO – AMJ PREC

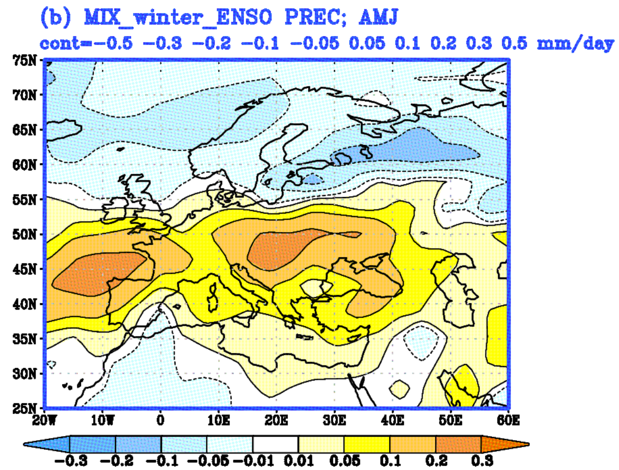


AMJ prec. may be affected with both JFM and AMJ ENSO

Tropical Pacific: SUMMER SSTs
NAtl: slab ocean
Contemporaneous ENSO effect
AMJ ENSO – AMJ PREC

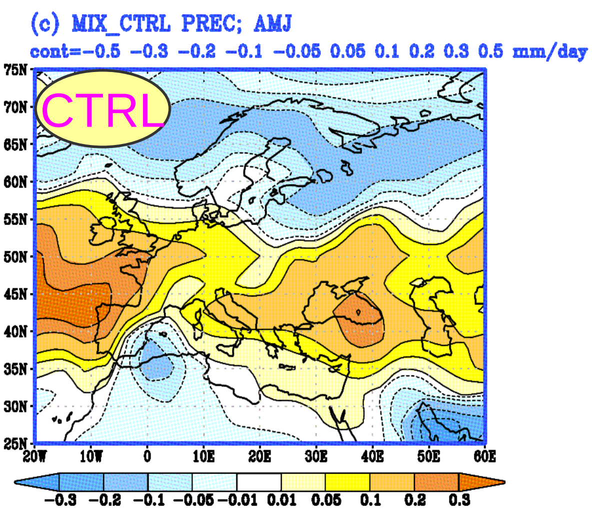


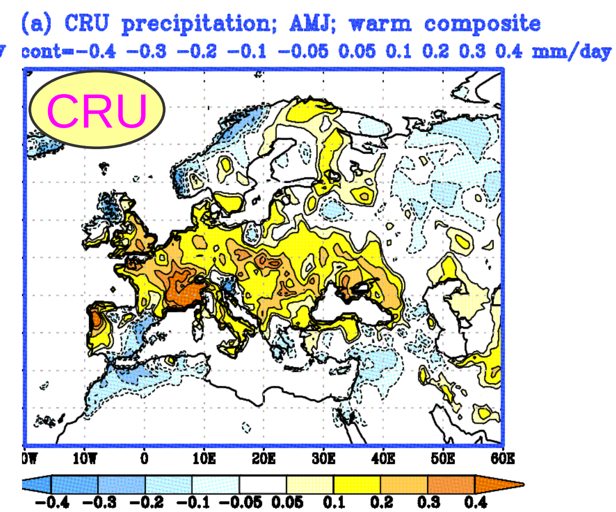
Tropical Pacific: WINTER SSTs
NAtl: slab ocean
Delayed ENSO effect
JFM ENSO – AMJ PREC



Global ocean: CONTINUOUS observed SSTs

Contemporaneous (**AMJ-AMJ**) and delayed (**JFM-AMJ**) ENSO effect on AMJ precipitation





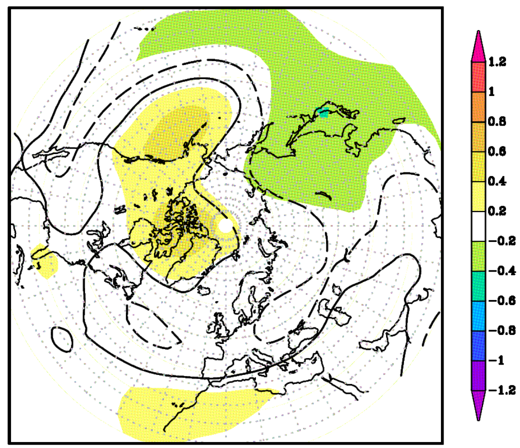
- **Speedy:** tropospheric and surface response to ENSO
- What is going on in the stratosphere?

Speedy: Stratospheric response to JFM ENSO

T30 (El Niño-La Niña) composites

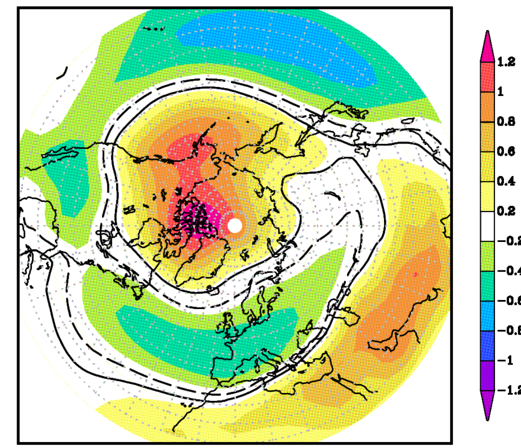
Jan

(a) EN−LN TroPac composite Jan temp30
cont=0.2



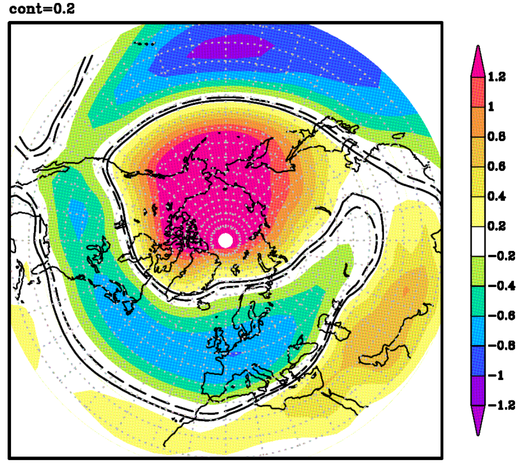
Feb

(b) EN−LN TroPac composite Feb temp30
cont=0.2



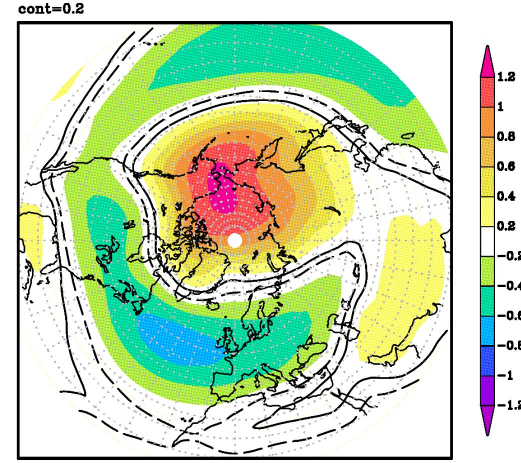
Mar

(c) EN−LN TroPac composite Mar temp30
cont=0.2



Apr

(d) EN−LN TroPac composite Apr temp30
cont=0.2



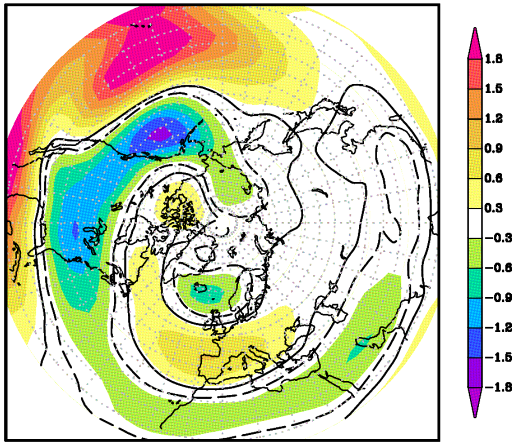
Herceg-Bulić et al.: Wintertime ENSO influence on late spring European climate: the stratospheric response and the role of North Atlantic SST. IntJClim 2017.

Warming of the **polar stratosphere**

Speedy: Stratospheric response to JFM ENSO

u500

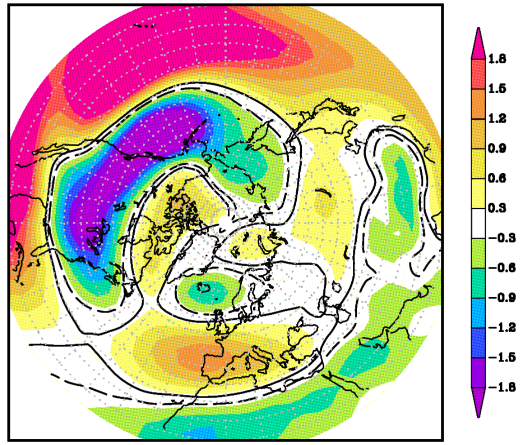
(a) EN−LN TroPac composite Jan u500
cont=0.3



Jan

u500

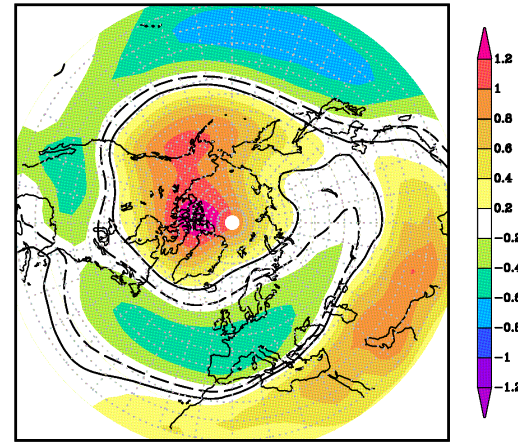
(b) EN−LN TroPac composite Feb u500
cont=0.3



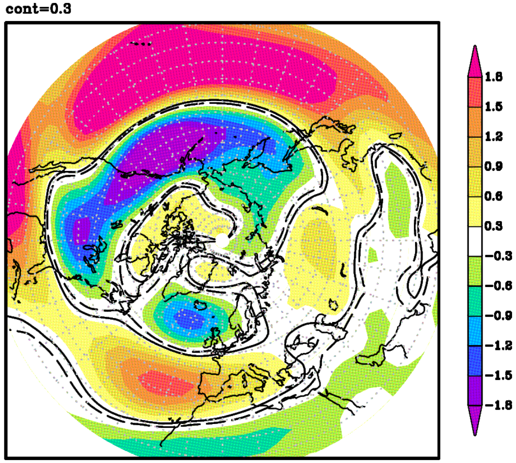
Feb

T30

(b) EN−LN TroPac composite Feb temp30
cont=0.2

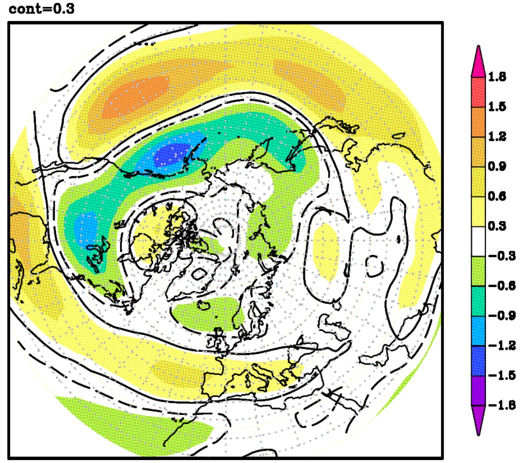


(c) EN−LN TroPac composite Mar u500
cont=0.3



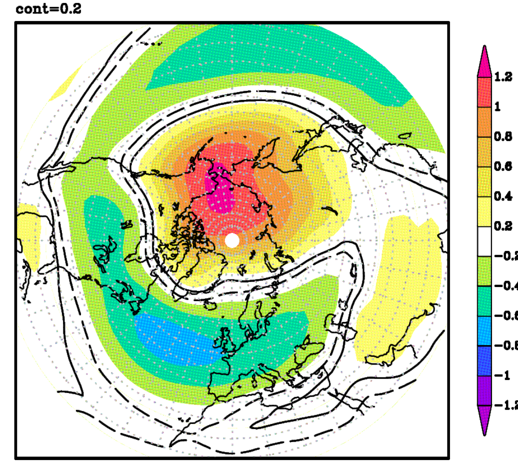
Mar

(d) EN−LN TroPac composite Apr u500
cont=0.3



Apr

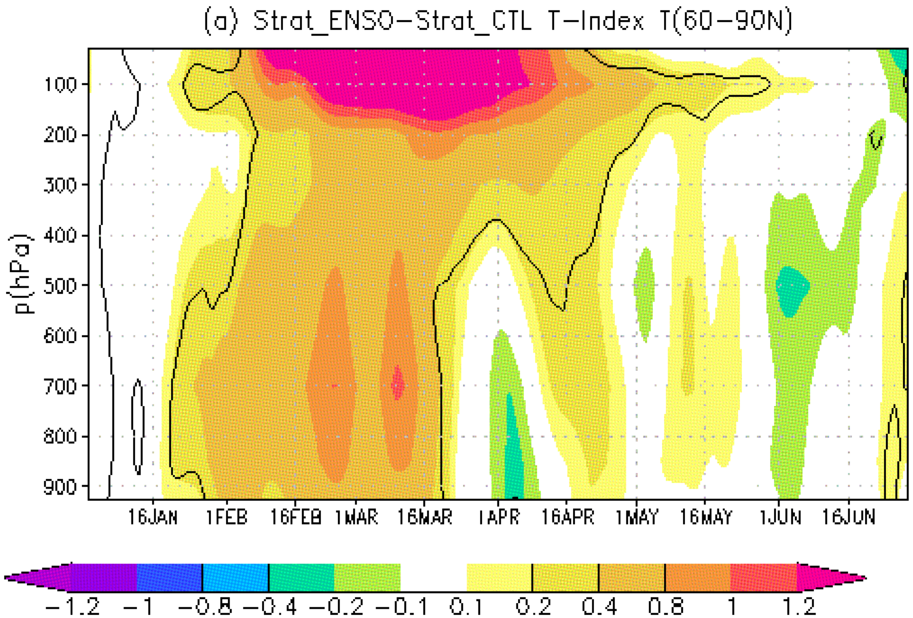
(d) EN−LN TroPac composite Apr temp30
cont=0.2

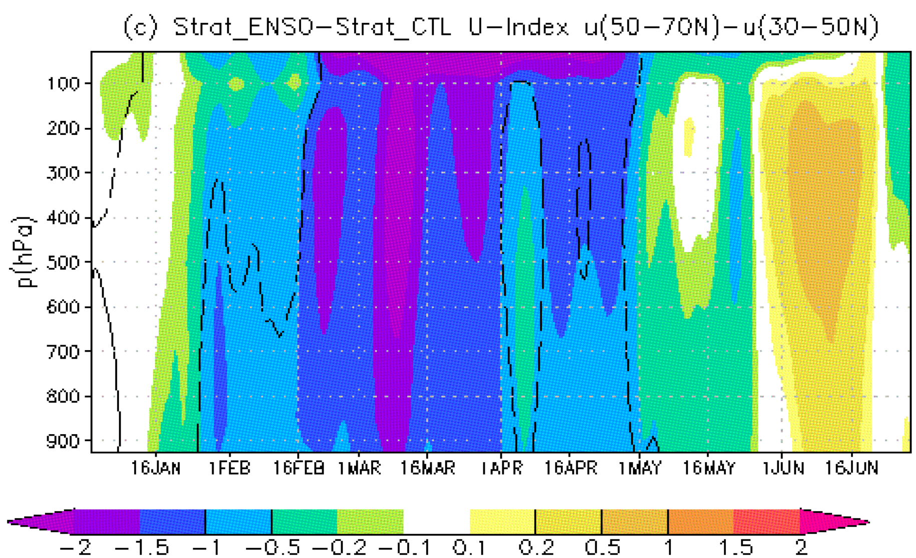


U500
Northern Annular Mode
NAM

T30
Warming of the polar stratosphere

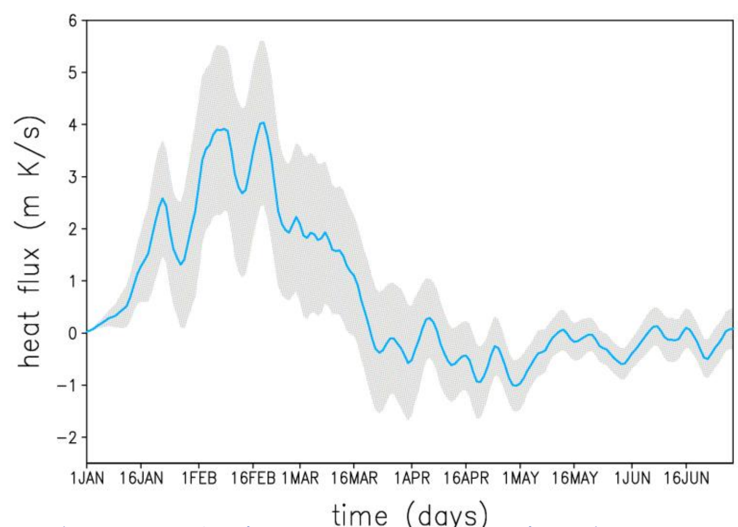
Speedy: Stratospheric response to idealized ENSO forcing





Idealised experiment Strat_ENSO:

- Daily data
- El Niño forcing in the tropical Pacific (constant from Jan to mid Feb, after that decreases linearly reaching zero at Mar16)
- No mixed layer
- TI = aveT(60-90°N)
- UI = aveU(50-70°N) - aveU(30-50°N)



100-hPa daily meridional heat flux anomaly: increased incoming heat flux precedes the strongest polar warming

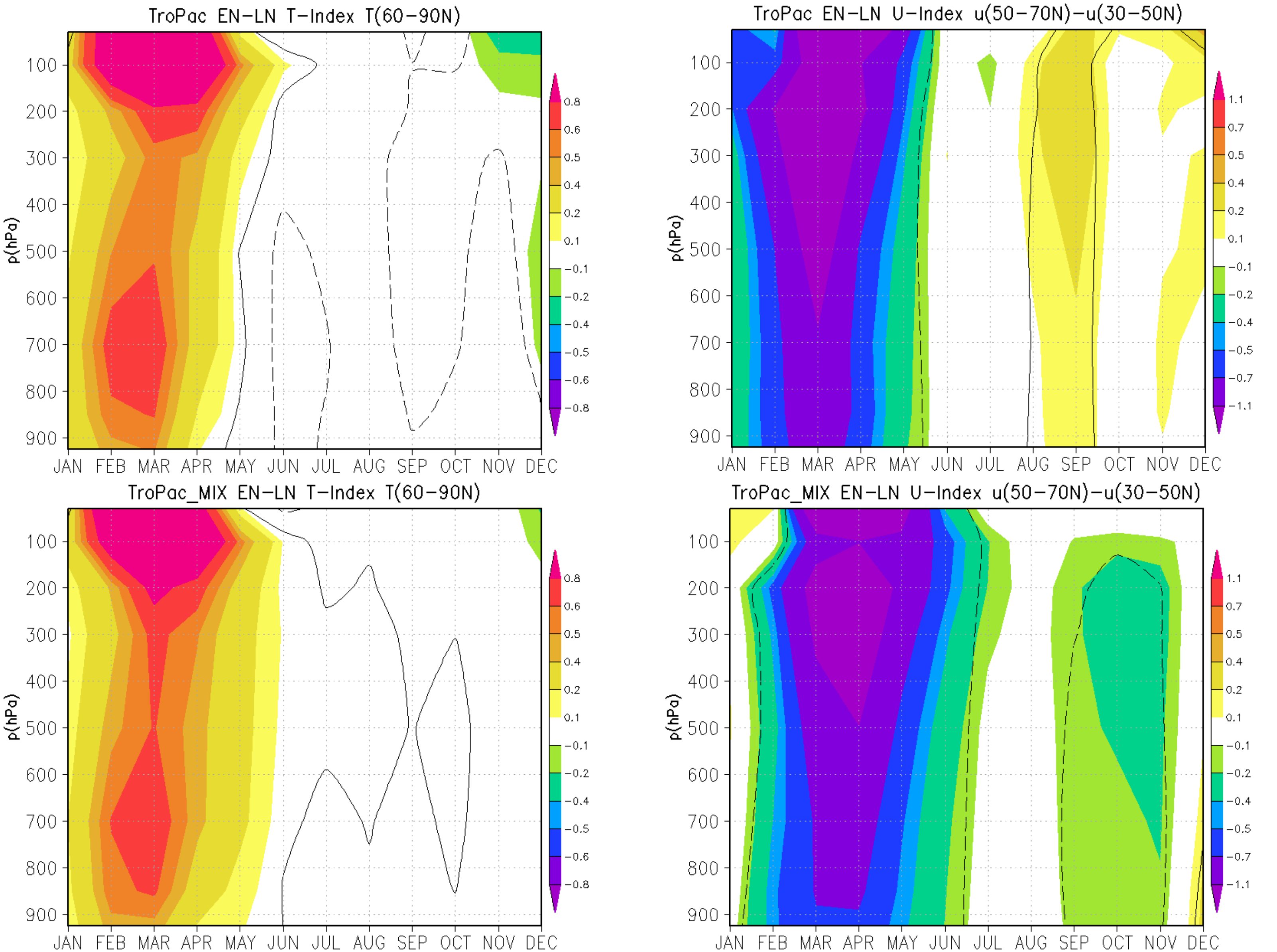
Contribution of the North Atlantic

TI =T(60-90°N)

UI =U(50-70°N)-U(30-50°N)

JFM ENSO forcing with **NO** slab ocean

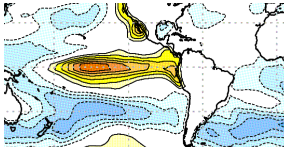
JFM ENSO forcing **WITH** slab ocean in North Atlantic



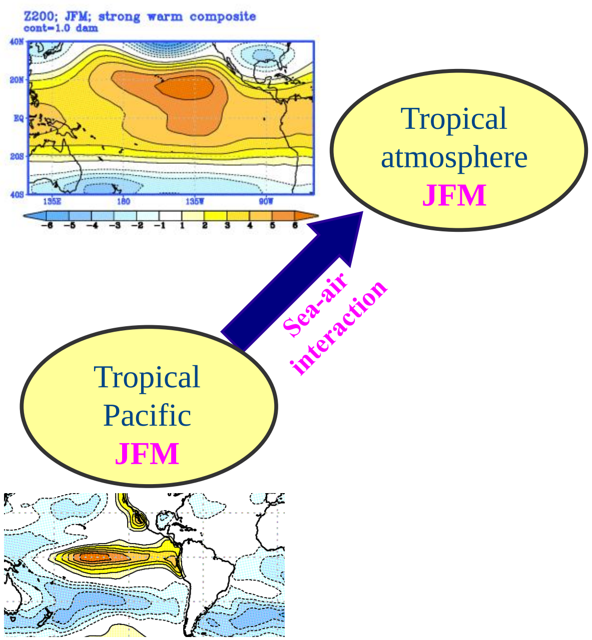
How does an ENSO impact on European climate looks like from the Speedy's perspective?

ENSO impact on European climate: Speedy perspective

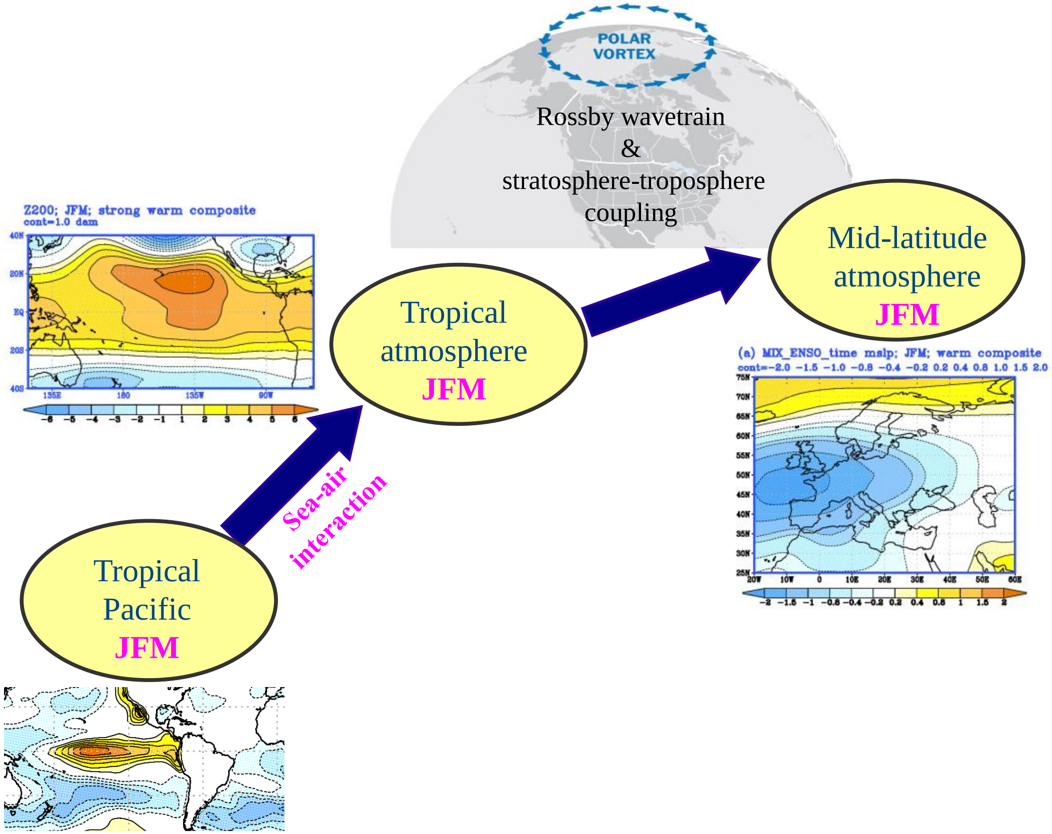
Tropical
Pacific
JFM



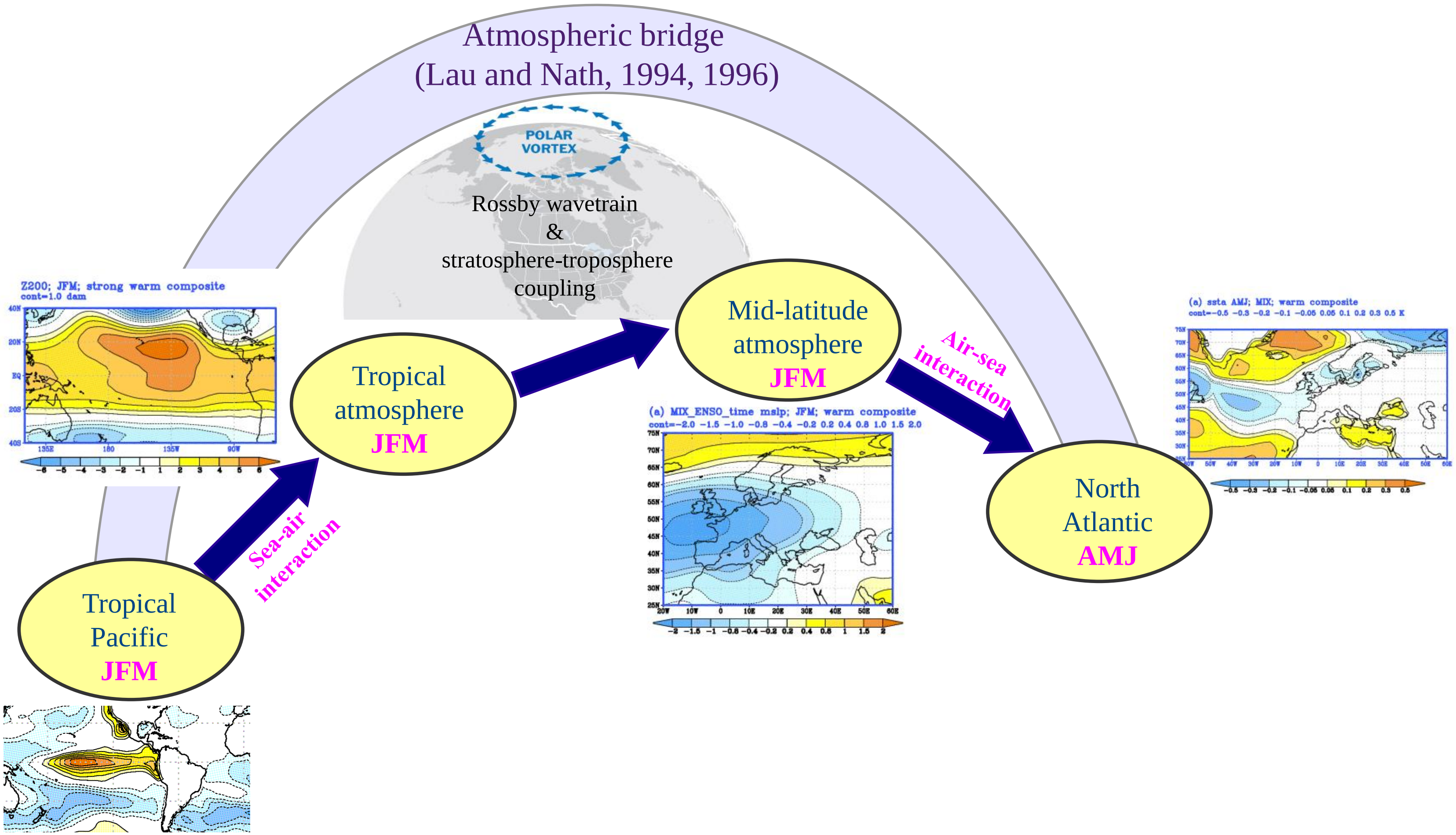
ENSO impact on European climate: Speedy perspective



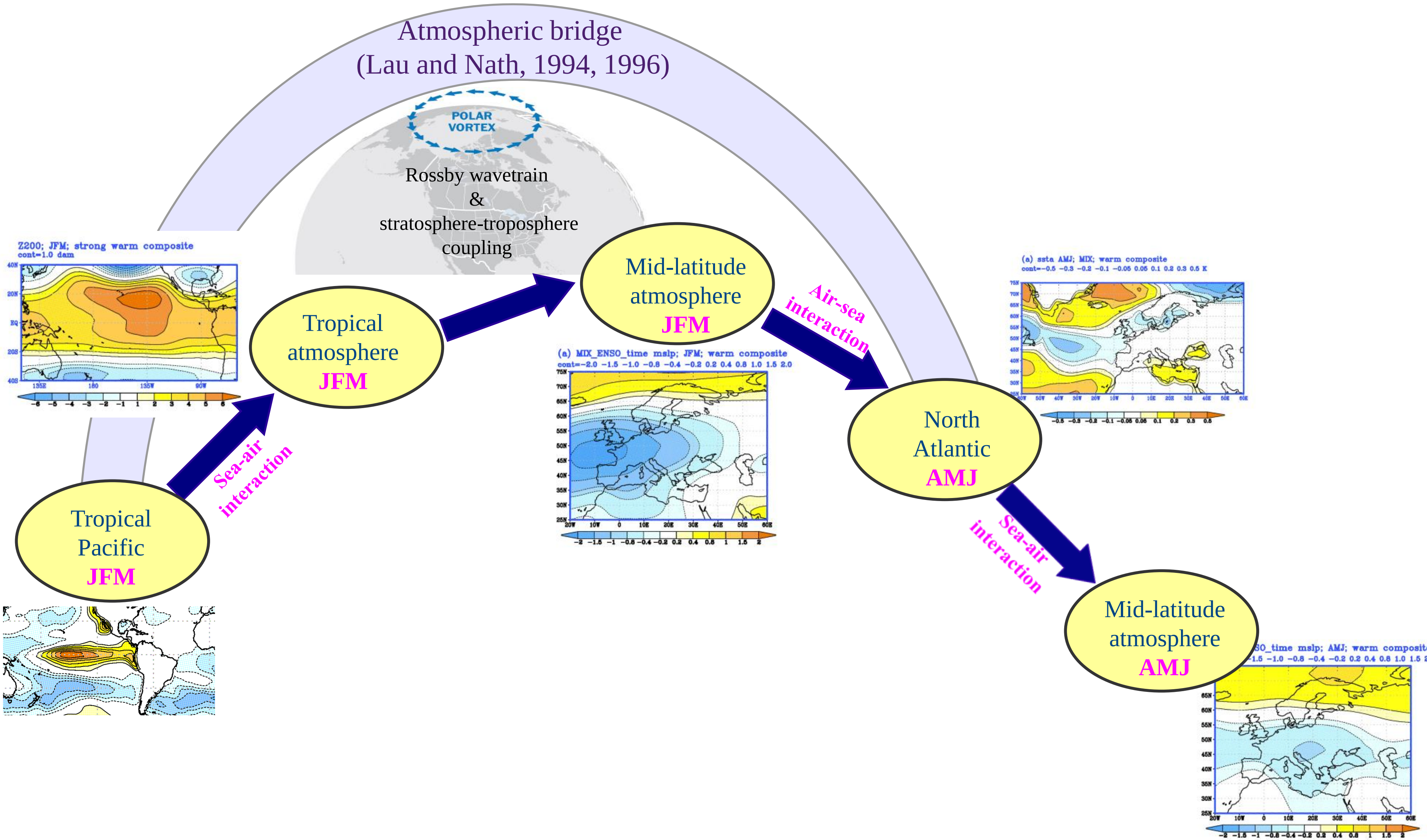
ENSO impact on European climate: Speedy perspective



ENSO impact on European climate: Speedy model perspective



ENSO impact on European climate: Speedy model perspective



ENSO impact on European climate: Speedy model perspective