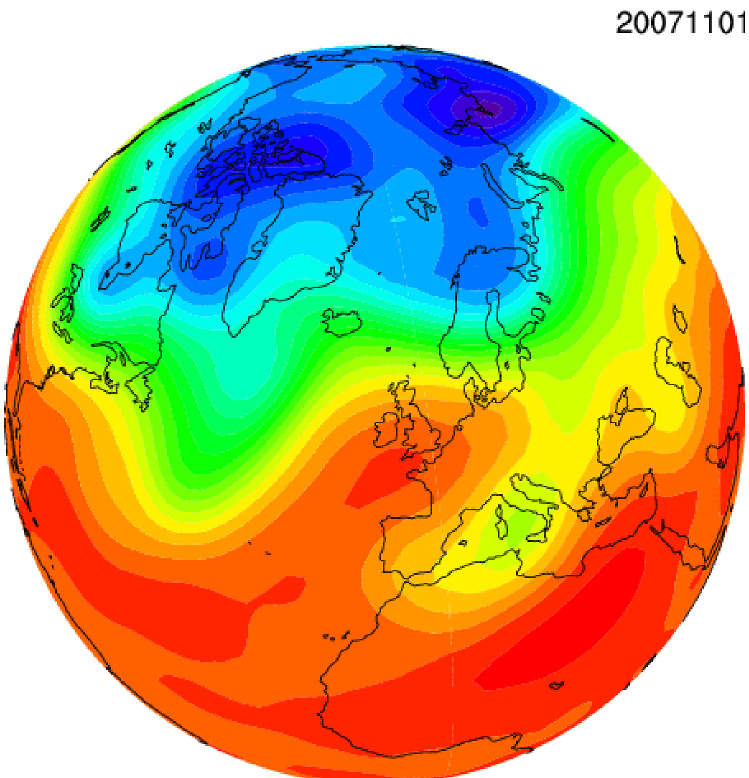
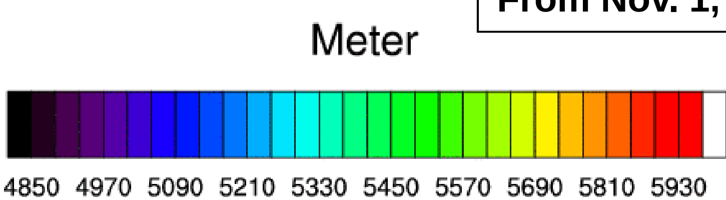
ECMWF Annual Seminar

Euro-Atlantic Regimes and their teleconnections

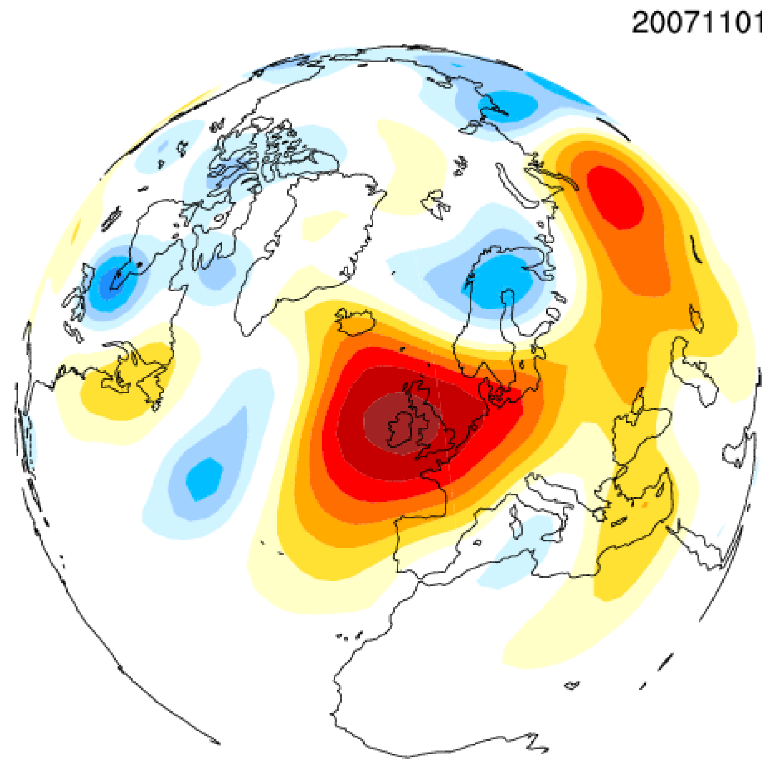
Christophe Cassou
CNRS-Cerfacs

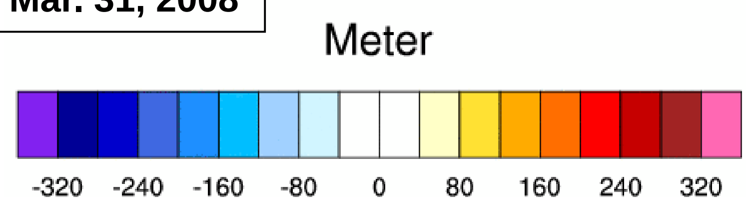
Daily Geopotential Height at 500 hPa (Z500)





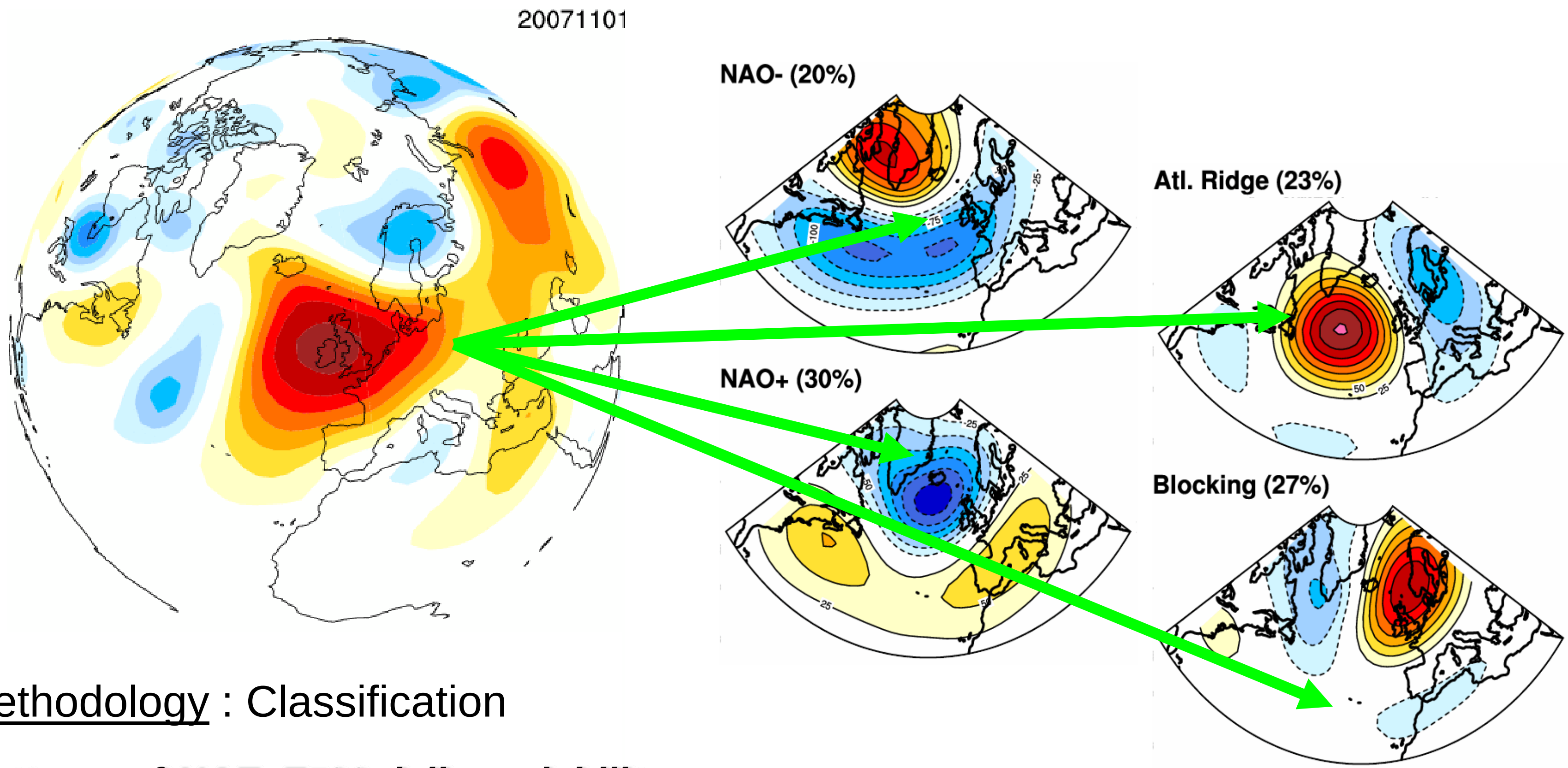
Daily *ANOMALOUS* Z500





From Nov. 1, 2007 to Mar. 31, 2008

NCEP-NCAR Reanalysis
Reference period: 1974-2007



Methodology : Classification

Patterns of NAE Z500 daily variability :

Weather regimes = Elementary bricks of the large scale extratropical atmospheric circulation that are spatially well-defined, recurrent, with a typical 6-10 day lifetime (persistent)

Weather regimes = Statistical-dynamical equilibria defined by averaging the dynamical tendencies on a timescale longer than the typical baroclinic transients (Molteni et al. 2006)

Extensive literature on regime paradigm

e.g. Lorenz (1963), Reinhold and Pierrehumbert (1982), Vautard et al (1988), Kimoto and Ghil (1993), Palmer (1999), Corti et al (1999), Whooling et al (2010) etc.

Several algorithms used to obtain regimes : clustering methods

- **Hierarchical classification (or tree algorithm):** eg. Cheng et al (1993) among others
- **Partition classification : k-means** (e.g. Michelangeli et al 1995 among others)
- **Self Organizing Method –SOM (based on artificial neural network) :** e.g. Johnson et al (2008) among others

Several timescales and several spatial domains (North Atlantic-Europe/North Pacific)

- **Daily variability => weather regimes** (e.g Robertson et Ghil 1999 etc.)
- **Monthly variability => climate regimes** (e.g Martineu et al 1999, Cassou et al 2004, Straus and Molteni 2004, etc.)

Several critics on the existence and determination of the regimes

- **non-existence of multimodality (Stephenson et al 2004)**
- **“how may clusters?” (Christiansen 2007) : dependence on the algorithm and the period**

But several robust applications and physical understanding from what may be considered as a spatio-temporal filter of the active extratropical dynamics

- **Statistical downscaling (see Christiansen et al 2007 for a review)**
- **Statistical-dynamical downscaling (e.g. for the ocean, Cassou et al 2010, Minvielle et al 2010)**
- **Seasonal forecast (EUROSIP etc.)**

Outline of the seminar:

1. North Atlantic-Europe weather regimes : an episodic approach of the extratropical dynamics

2. Teleconnection at intra-seasonal timescales: links with the Madden-Julian Oscillation (MJO)

3. Teleconnection at interannual-to-decadal timescales : role of the tropical Atlantic

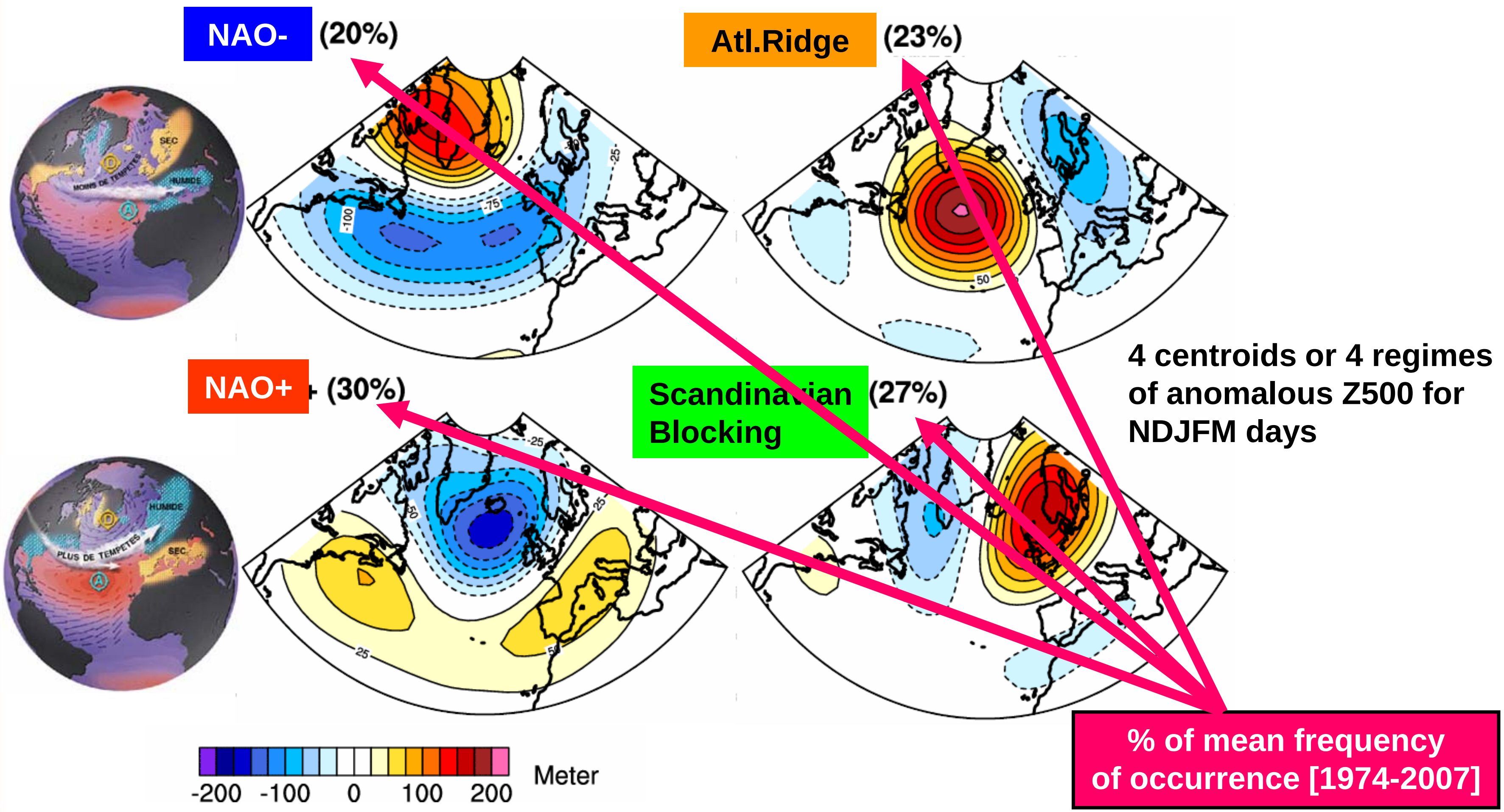
4. Teleconnection at interannual timescale : ENSO
   Implication for seasonal forecast: the winter 2010 case study.

5. Conclusions


The Euro-Atlantic weather regimes

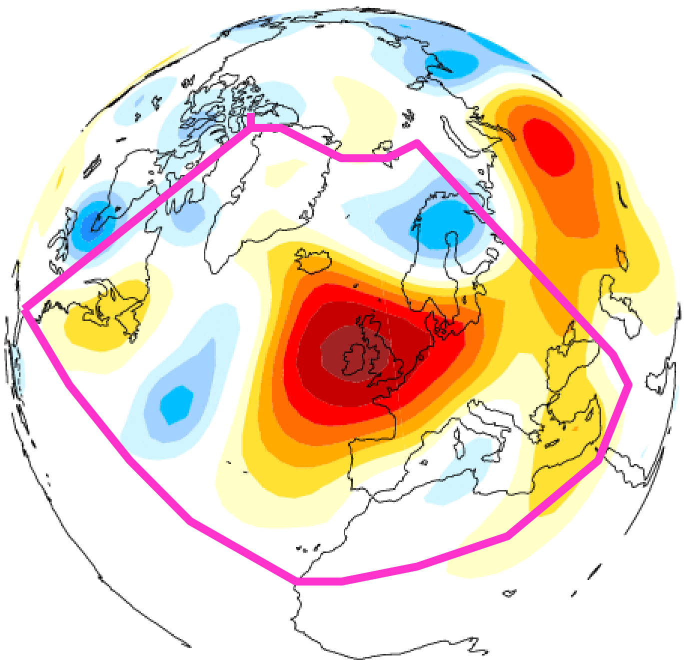
Methods: Clustering analysis based on the k-means algorithm (Michelangeli et al, JAS-1995)

Data: Daily Geopotential Height at 500hPa from NCEP-NCAR reanalysis from Nov.1 1974 to 31 March 2008 (= 4991 extended-winter days)



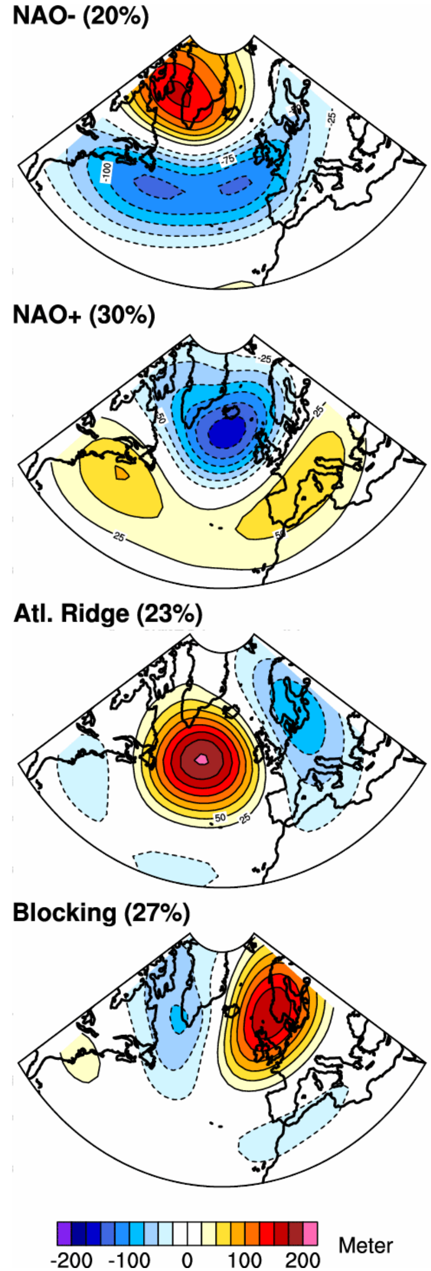
From Nov. 1, 2007 to Mar. 31, 2008

20071101

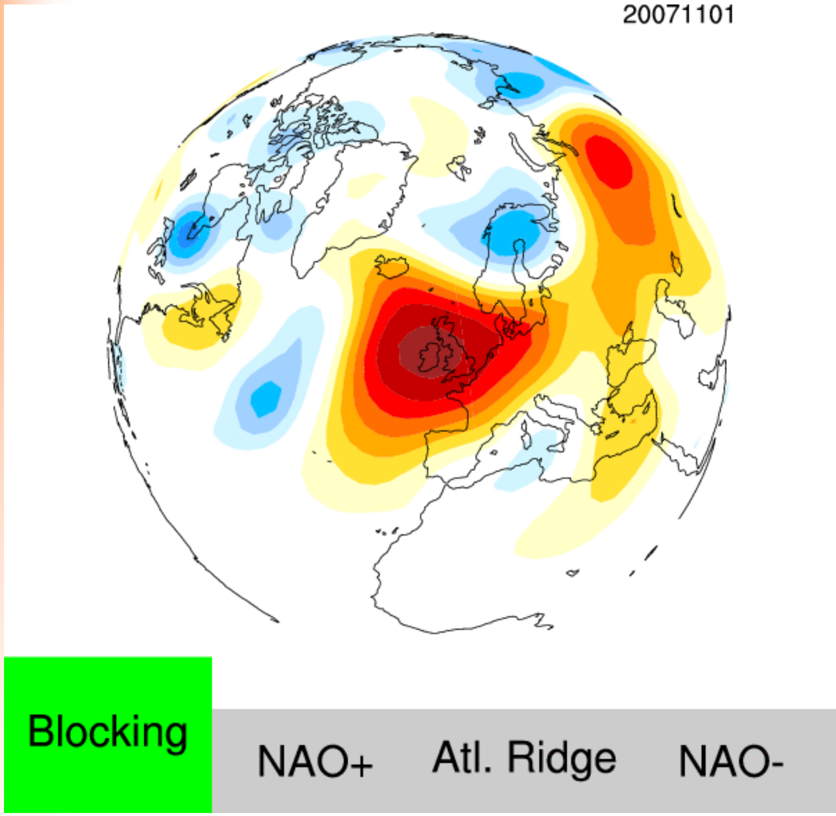


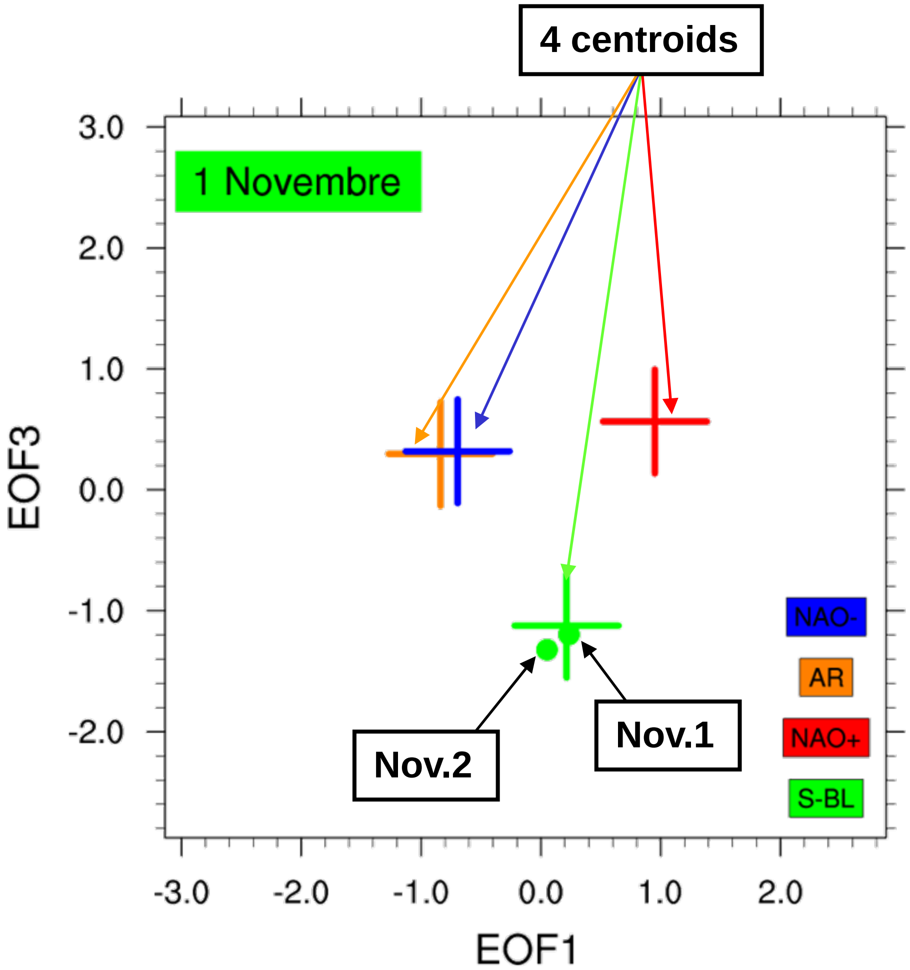
Blocking | NAO+ | Atl. Ridge | NAO-

Attribution of daily anomalous circulation to one of the four North Atlantic regimes



From Nov. 1, 2007 to Mar. 31, 2008

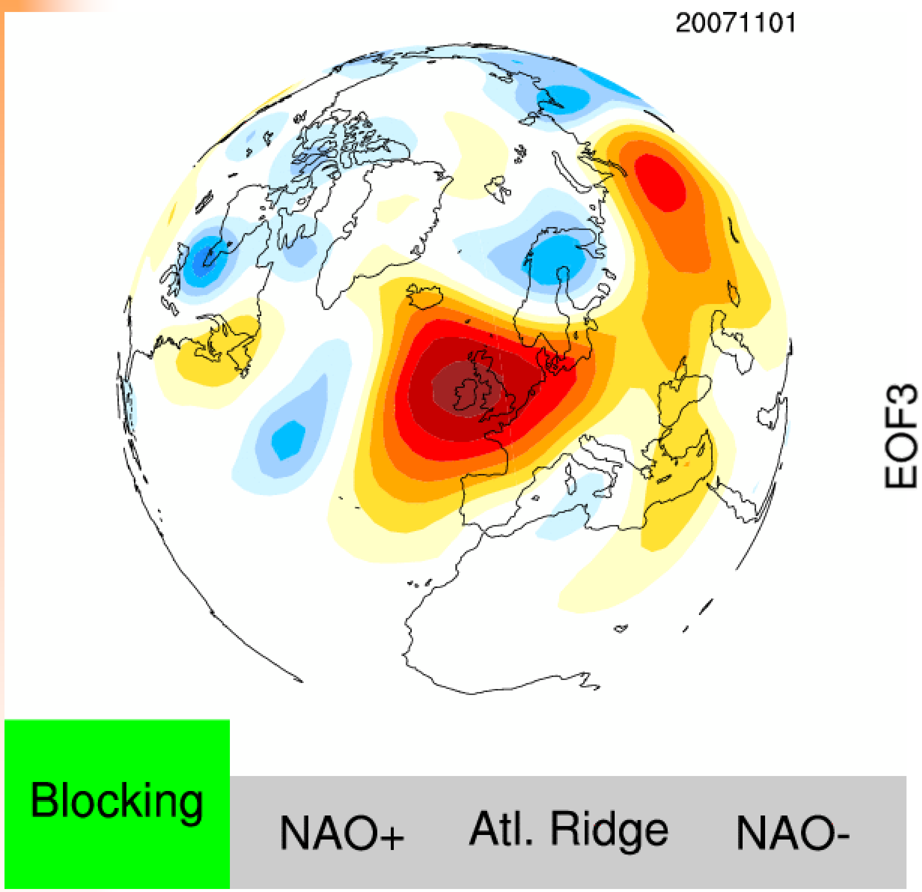




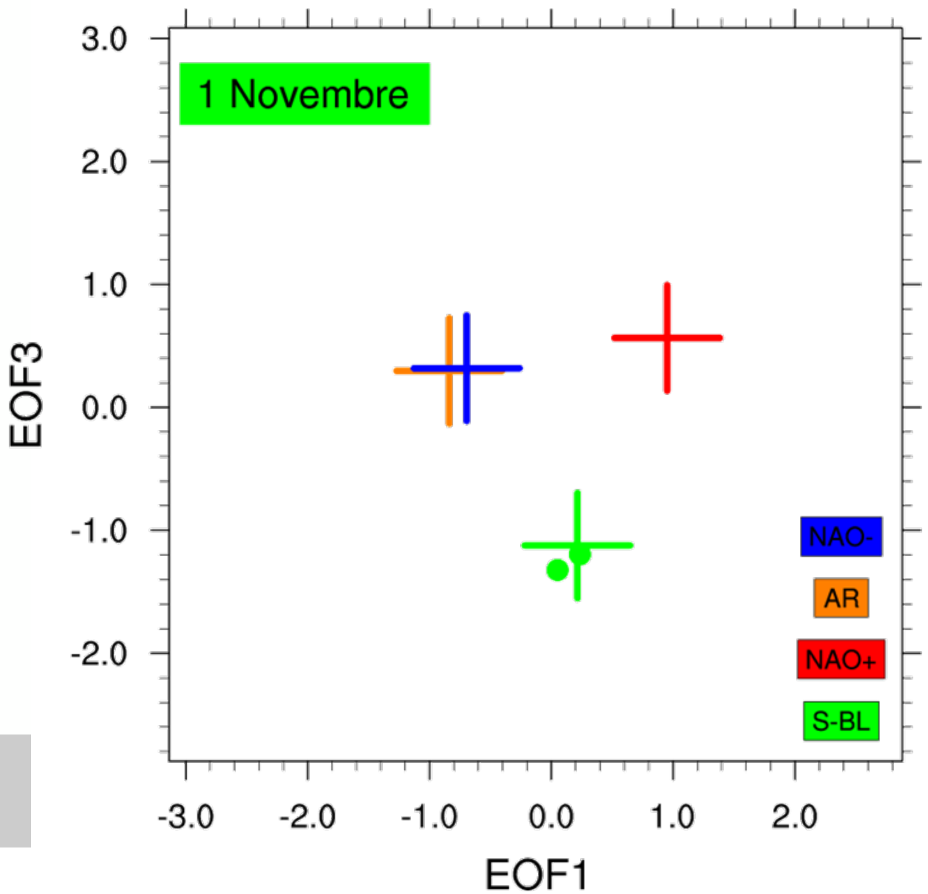
Attribution of daily anomalous circulation to one of the four North Atlantic regimes

Daily path of the anomalous circulation In the EOF phase space (2 EOFs)

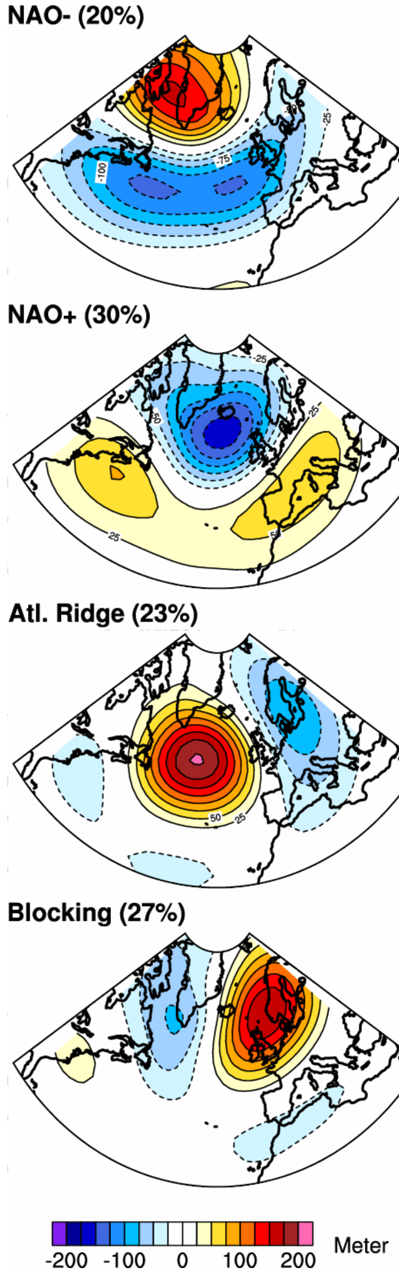
From Nov. 1, 2007 to Mar. 31, 2008

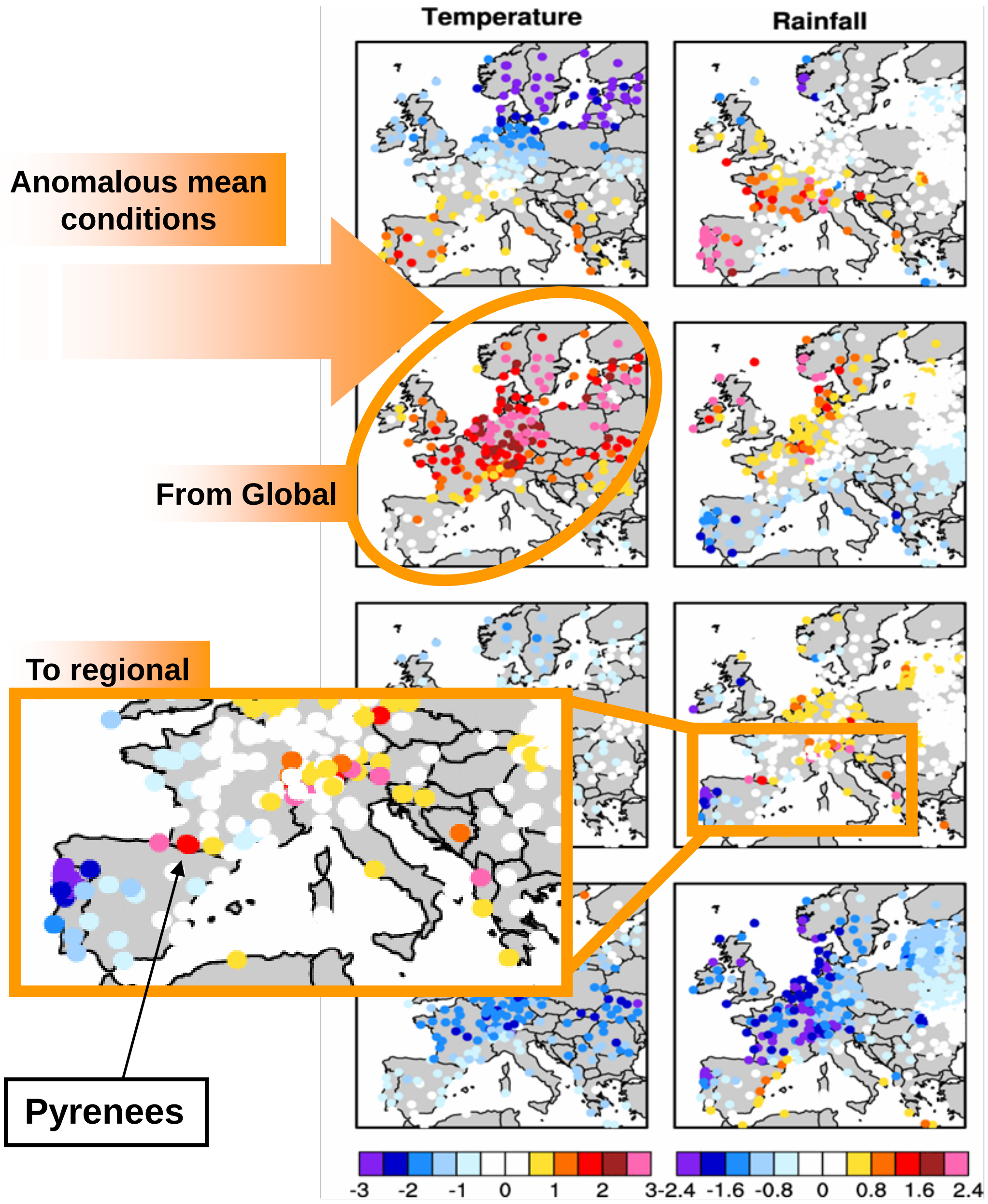


Attribution of daily anomalous circulation to one of the four North Atlantic regimes

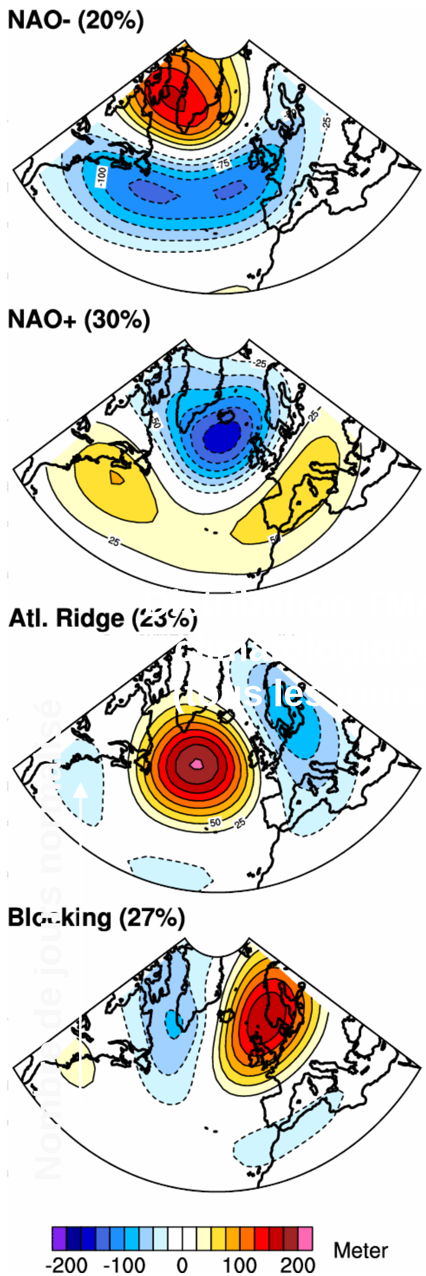


Daily path of the anomalous circulation In the EOF phase space (2 EOFs)


NAO- (20%)
NAO+ (30%)
Atl. Ridge (23%)
Blocking (27%)
-200 -100 0 100 200
Meter


Temperature
Rainfall
Anomalous mean conditions
From Global
To regional
Pyrenees
-3 -2 -1 0 1 2 3
-2.4 -1.6 -0.8 0 0.8 1.6 2.4

(ECA data)


NAO- (20%)
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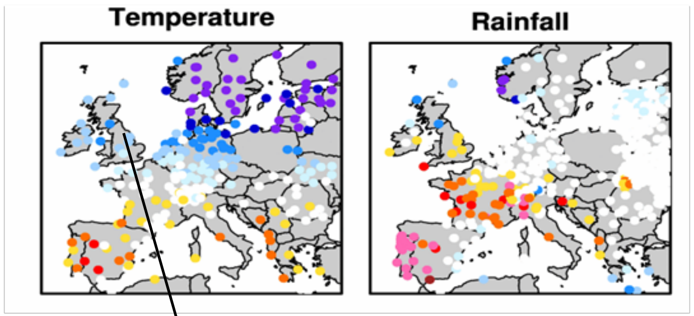
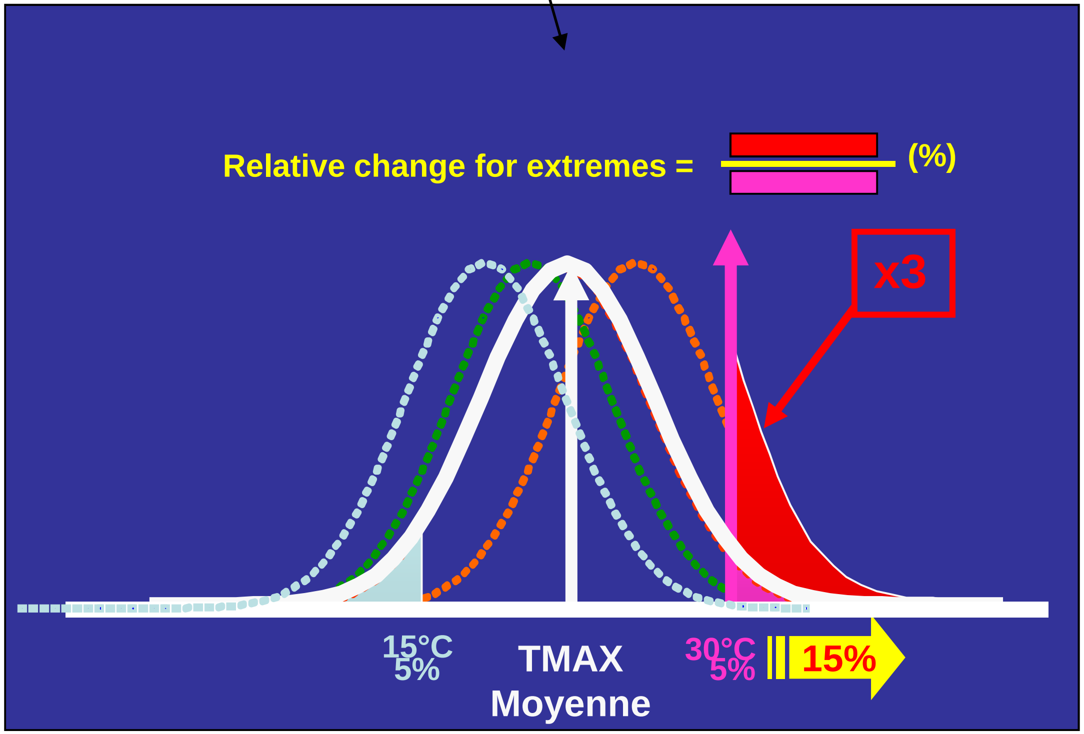
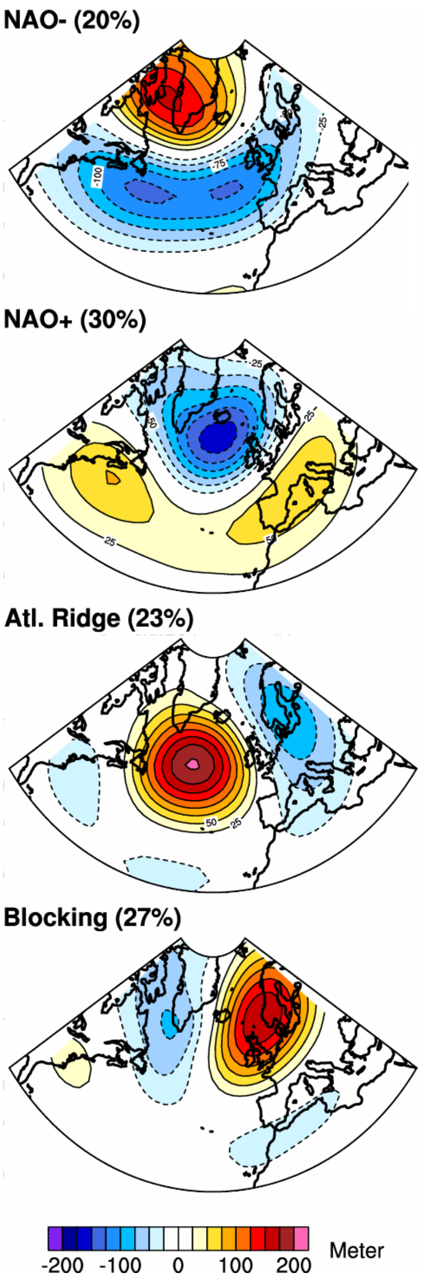

Temperature
Rainfall


Relative change for extremes =
(%)
x3
15°C
5%
TMAX
Moyenne
30°C
5%
15%

(ECA data)

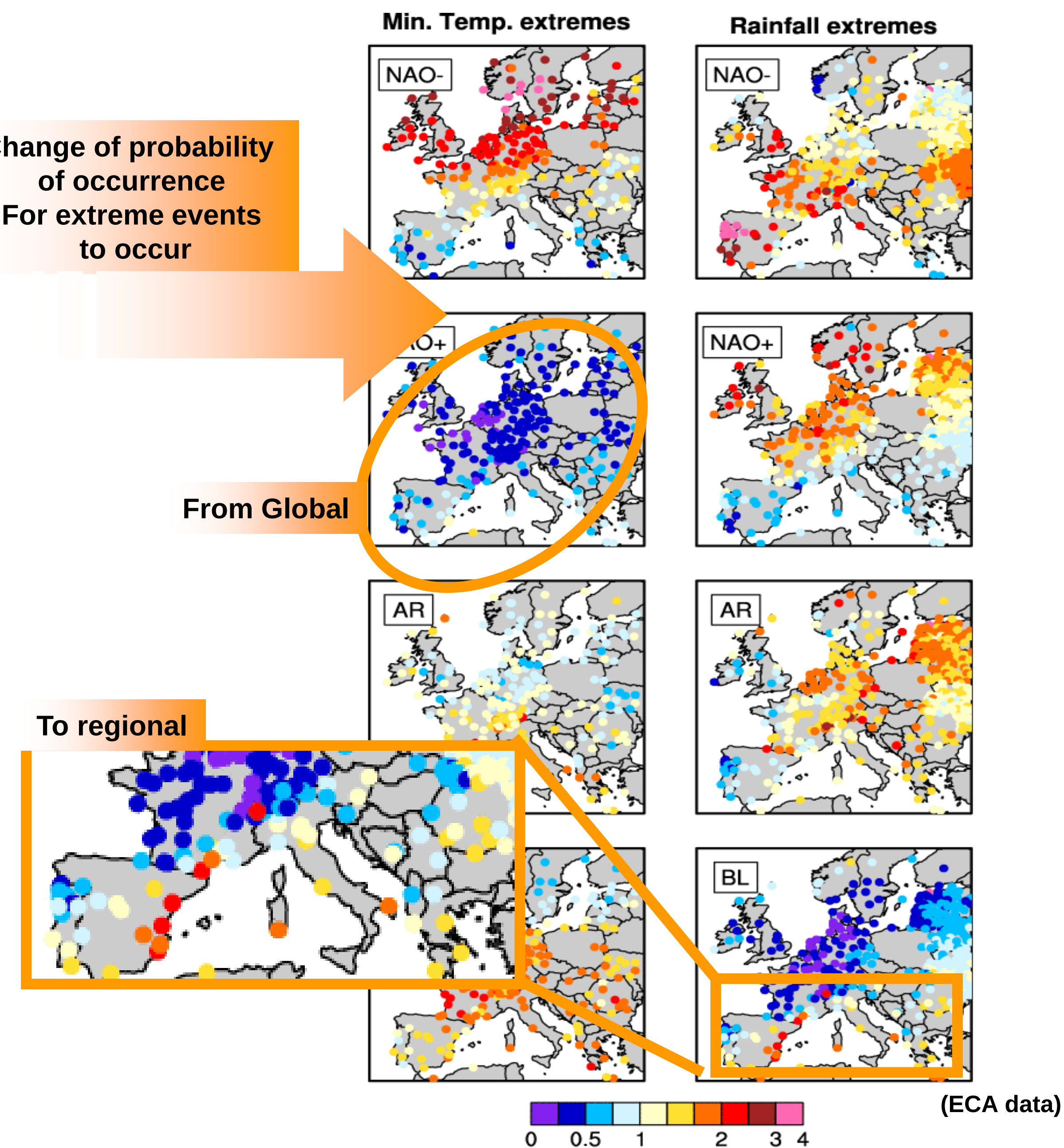
6. Relationships weather regimes/extremes



Change of probability of occurrence For extreme events to occur

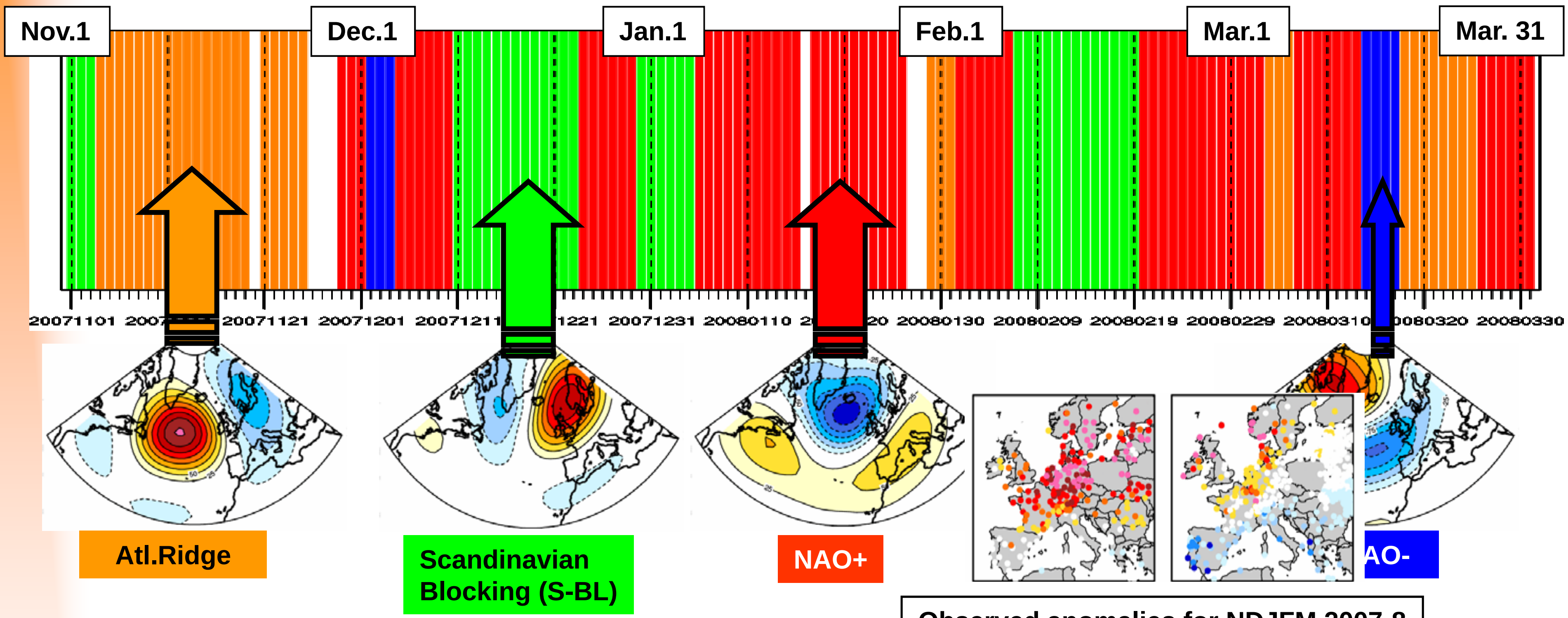
From Global

To regional



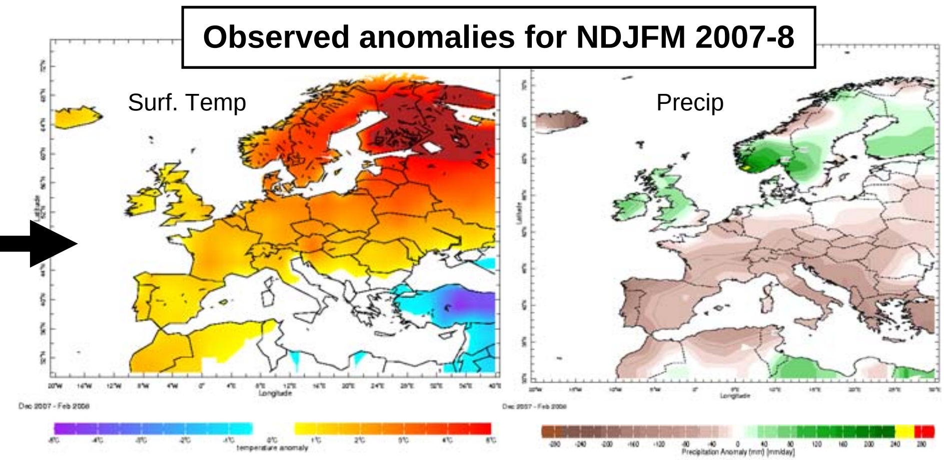
<u>Methods</u>: Each day is attributed to one of the 4 regimes

2007-2008

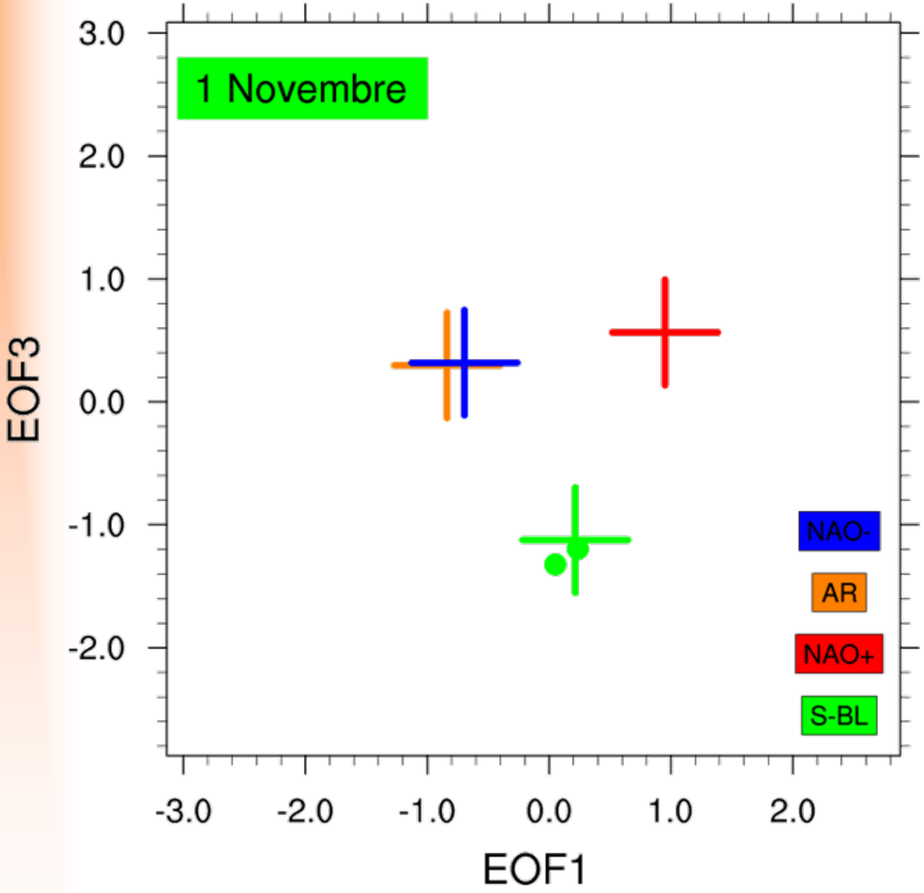


∑ Statistics:

NAO+ : +62%, AR:+16%,
NAO- : -75%, BL:-3%



Interannual variability=time integration of higher frequency fluctuations



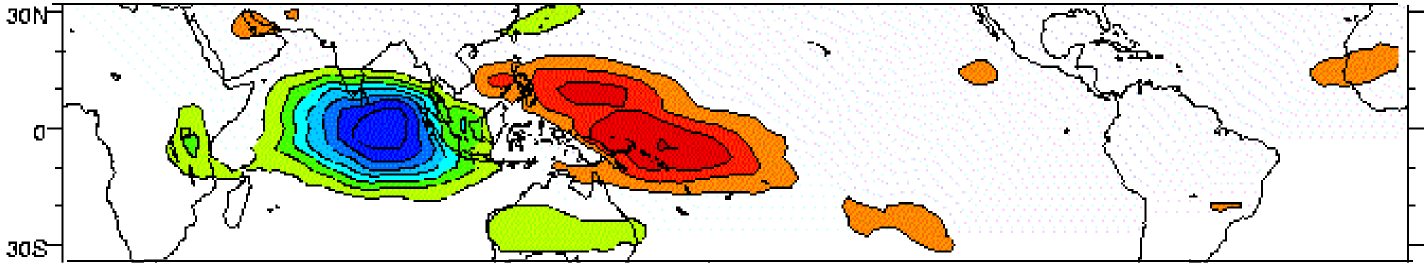
Are transitions between regimes random?

A preferred route :
NAO+ → Blocking → NAO-
(North Atlantic dynamics)
Vautard (1988)

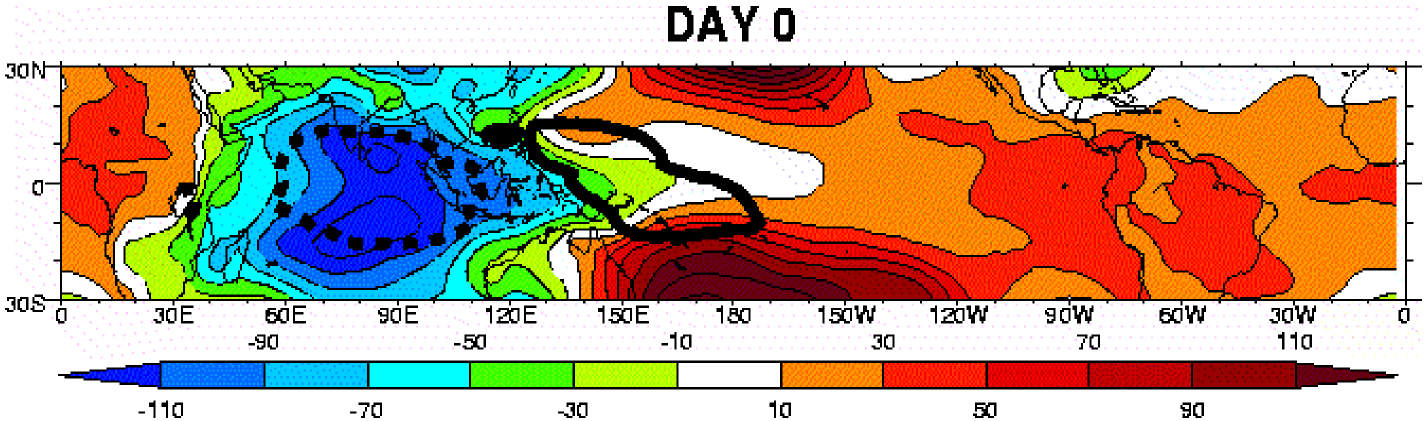
A perturbed route ???:
By so-called external factors to North Atlantic
opening space for predictability
At different timescales :
Role of the teleconnection

Teleconnection at intra-seasonal timescale
Links with the Maddden-Julian Oscilation (MJO)

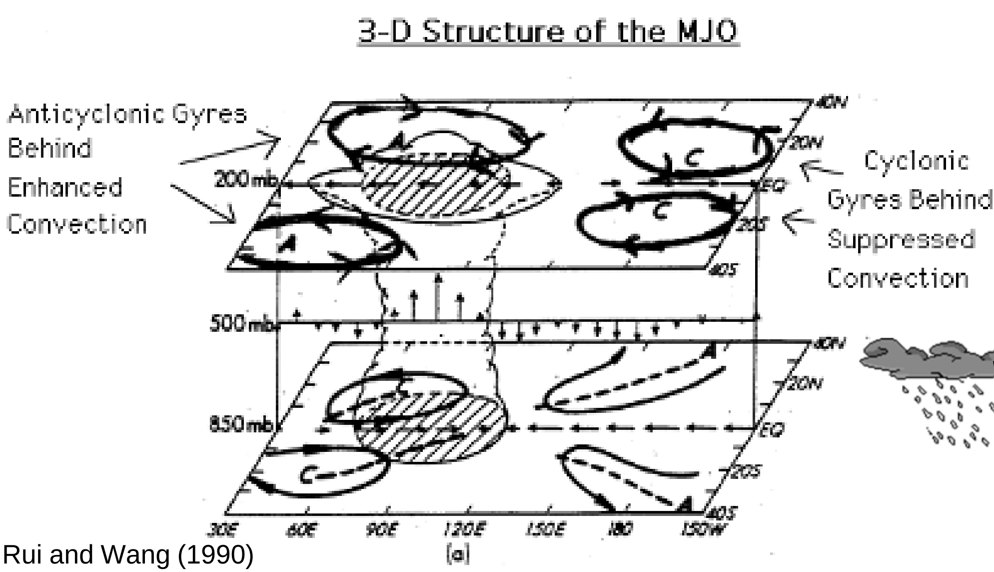
MJO : Dominant intra-seasonal oscillation in the entire tropics, also referred to as 30-70 day oscillation involving rainfall, upper-level and lower-level wind, Surface pressure etc. and propagating eastward



Animation of daily OLR anomaly maps, formed by regression onto first two EOFs of 20-200-day filtered OLR. Contour interval is 5 W m^{-2}.



Animation of daily SLP anomaly maps, formed by regression onto first two EOFs of 20-200-day filtered OLR. Contour interval is 10 hPa



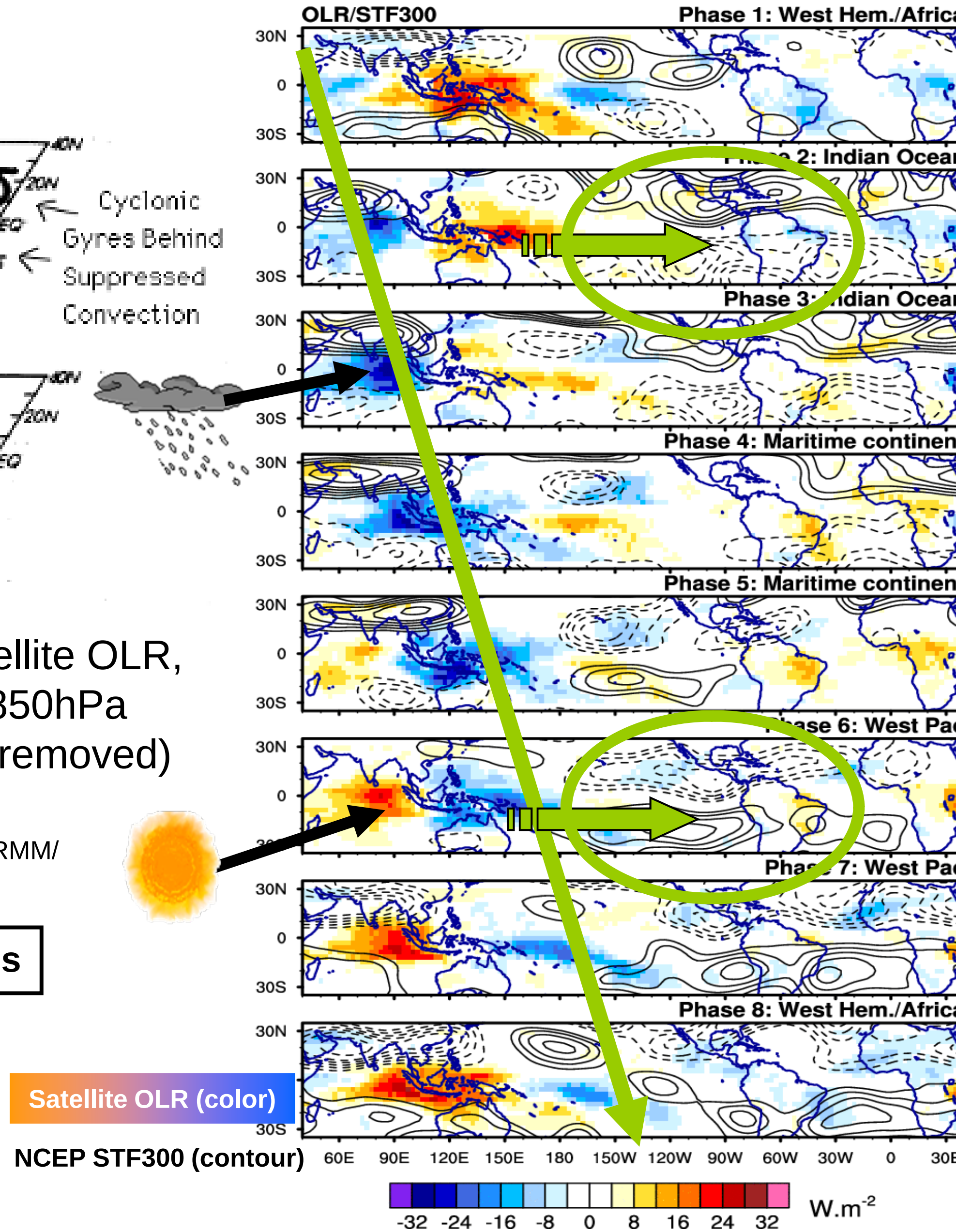
Rui and Wang (1990)

<u>Method</u>: Combined EOF including satellite OLR, NCEP-NCAR zonal wind at 200 and 850hPa (annual and interannual components removed)

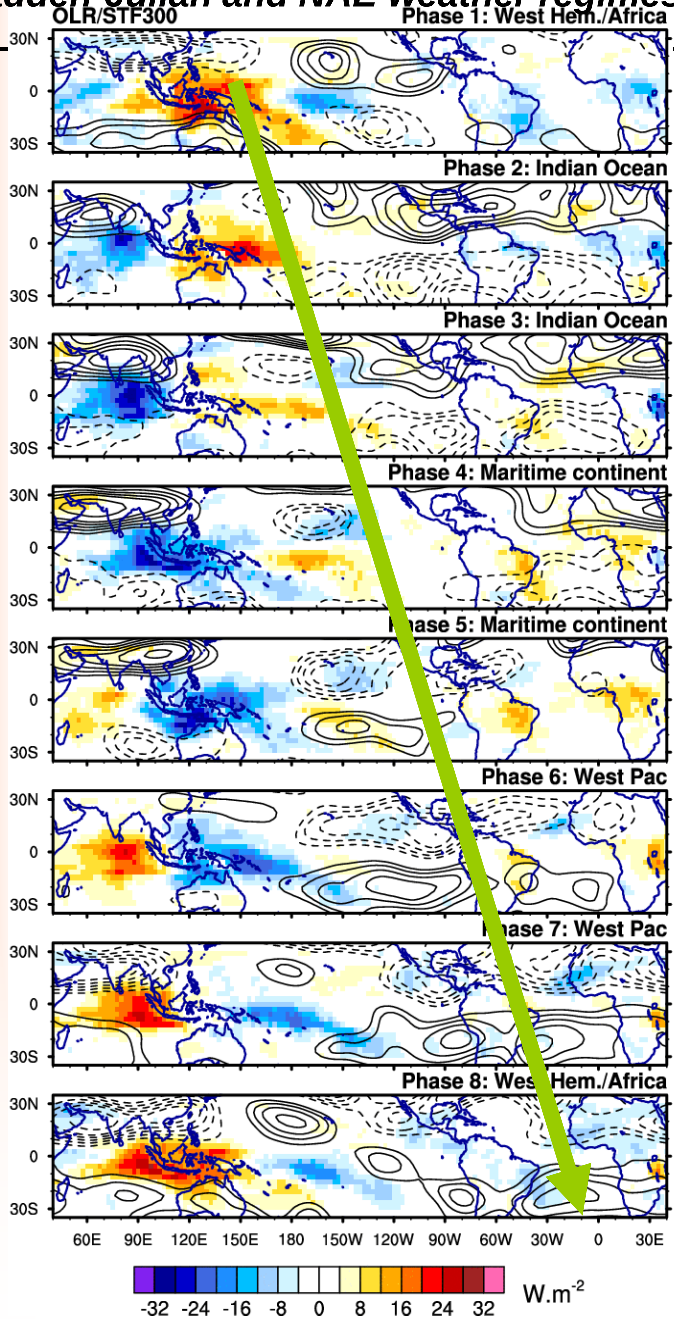
Wheeler and Hendon (MWR-2004)

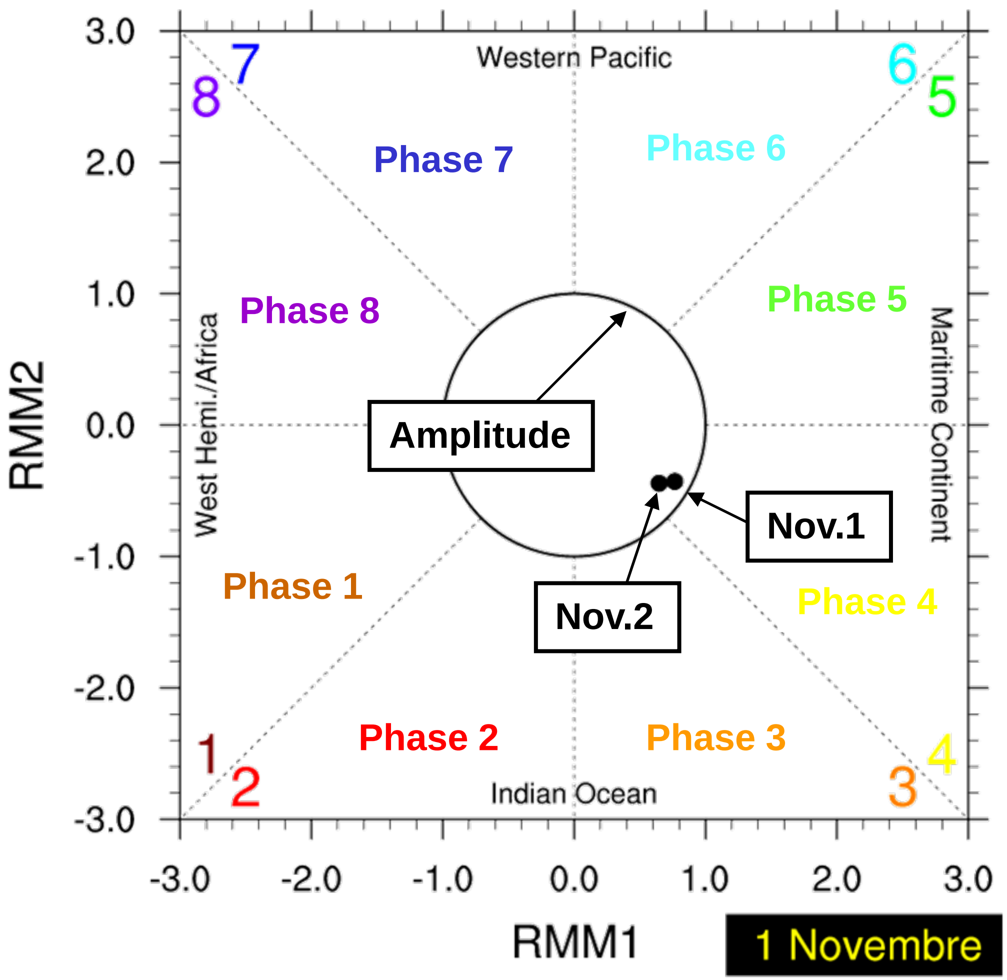
http://www.bom.gov.au/bmrc/clfor/cfstaff/matw/maproom/RMM/

8 centroids or 8 phases



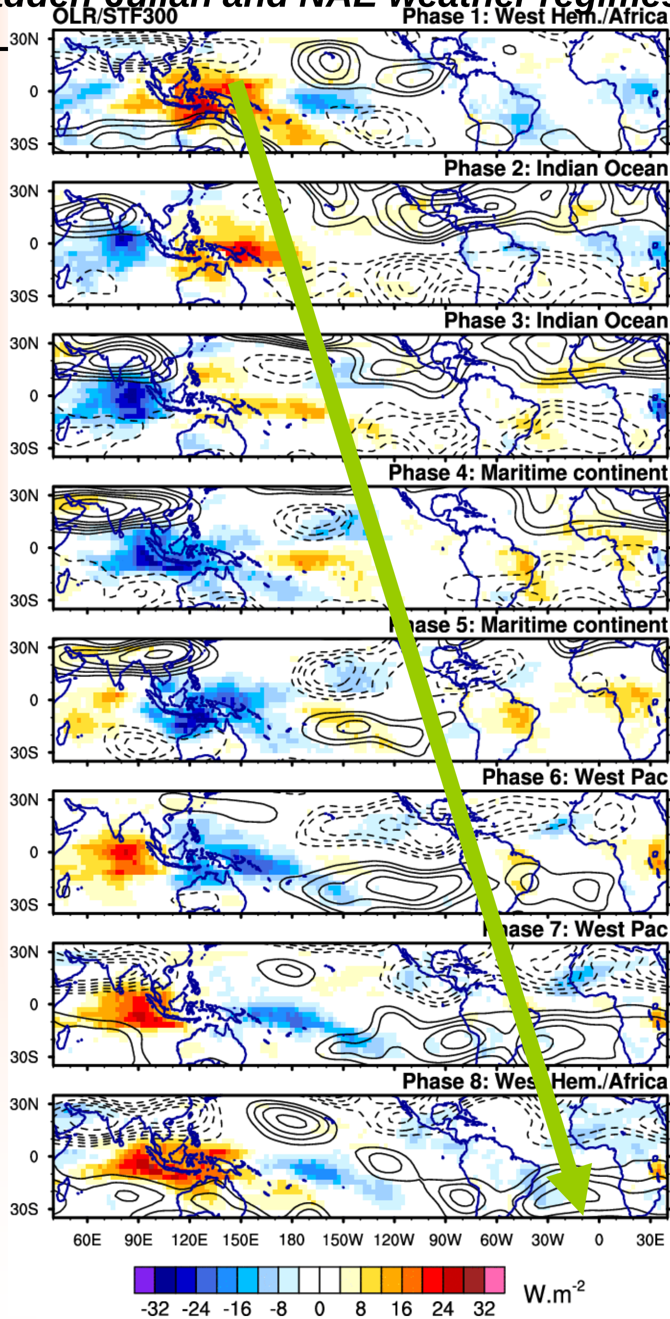
3. The MJO in winter 2007-2008 (1)

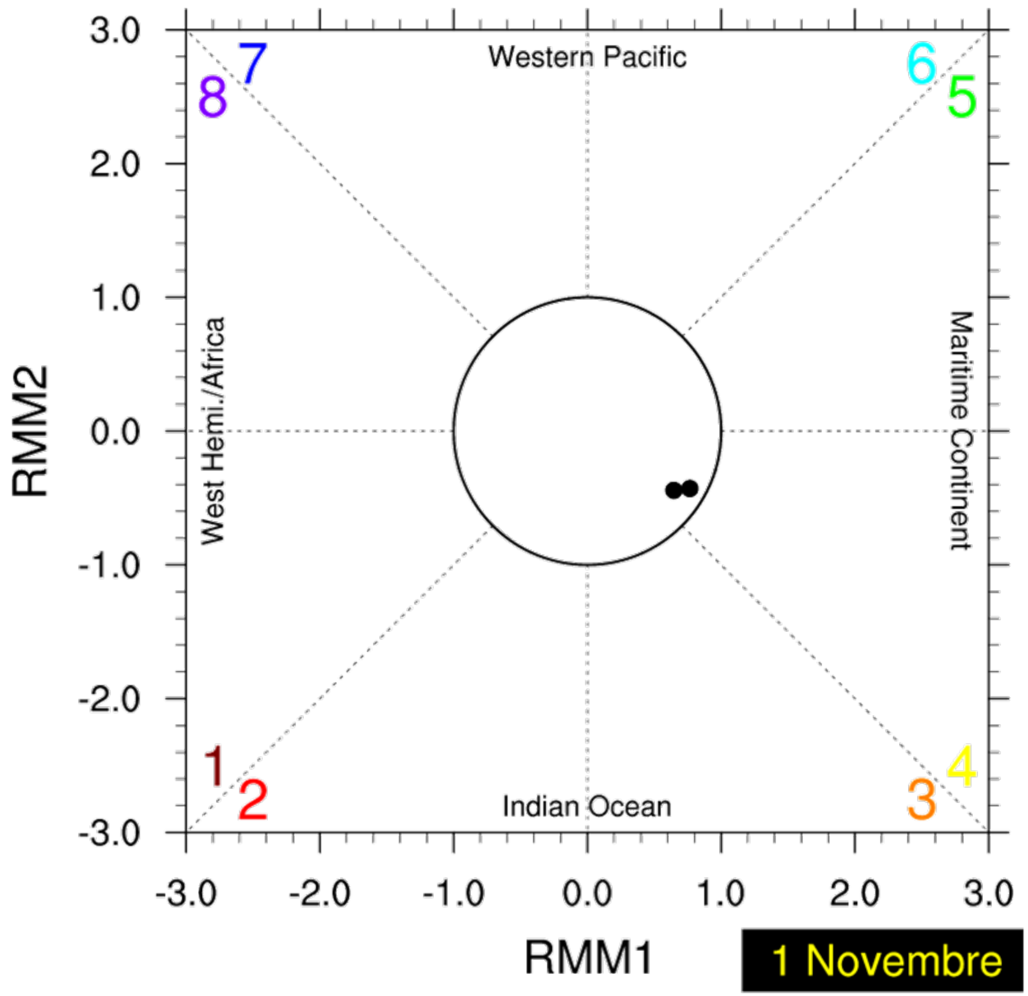




The 8 phases can be spanned in the 2 first EOFs
From combined thermodynamical (OLR) and dynamical (NCEP) fields

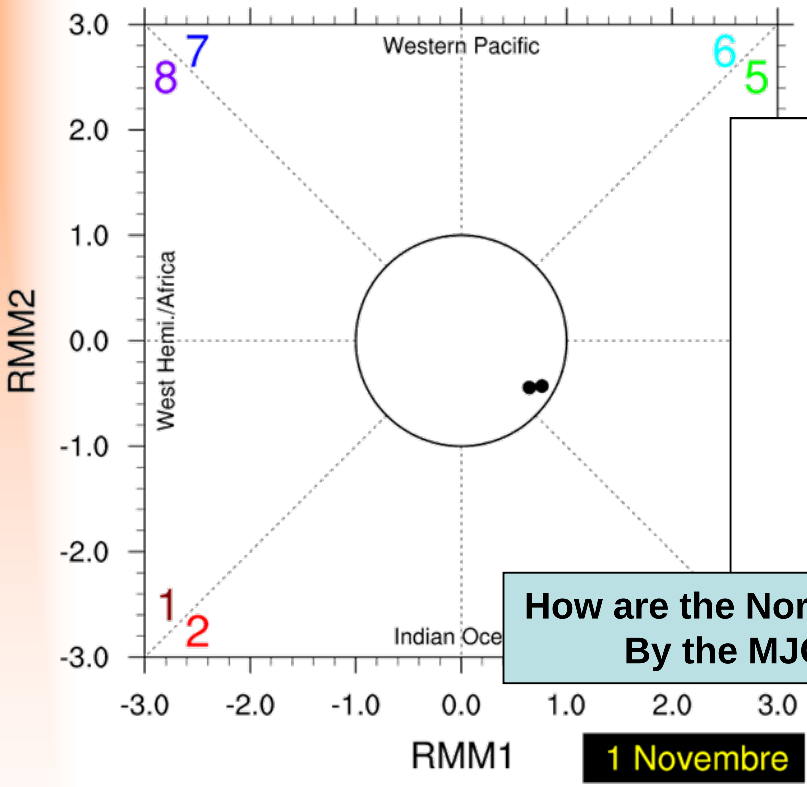
4. The MJO in winter 2007-2008 (2)



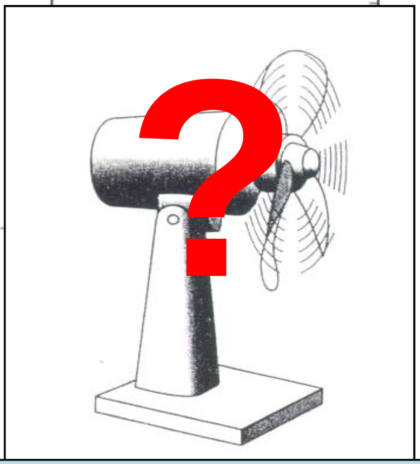


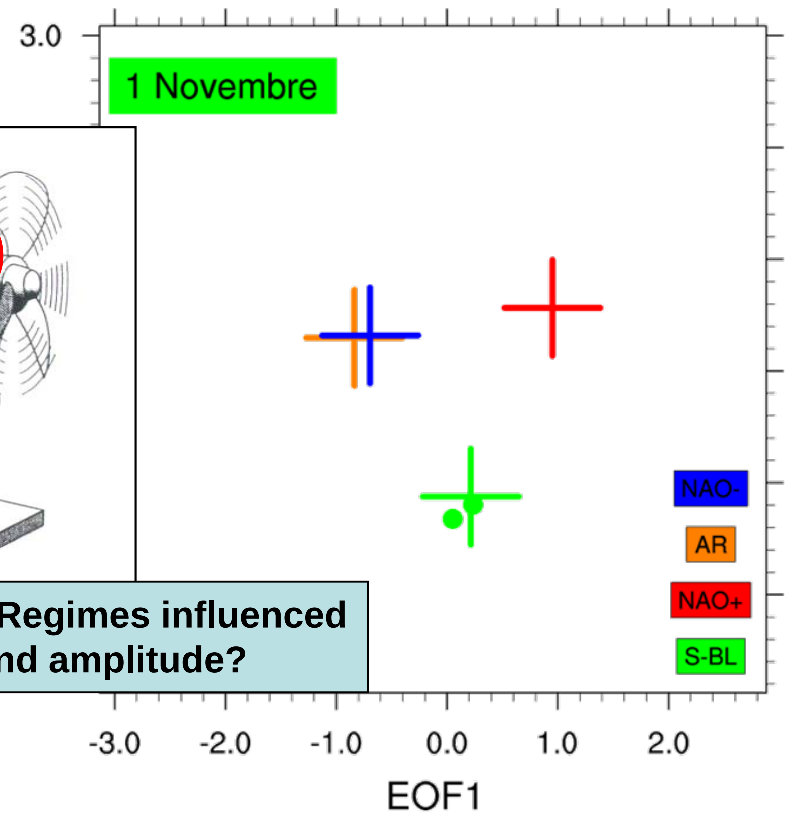
The 8 phases can be spanned in the 2 first EOFs
From combined thermodynamical (OLR) and dynamical (NCEP) fields

QUASI-OSCILLATORY
Madden-Julian Oscillation



EPISODIC
North Atlantic regimes



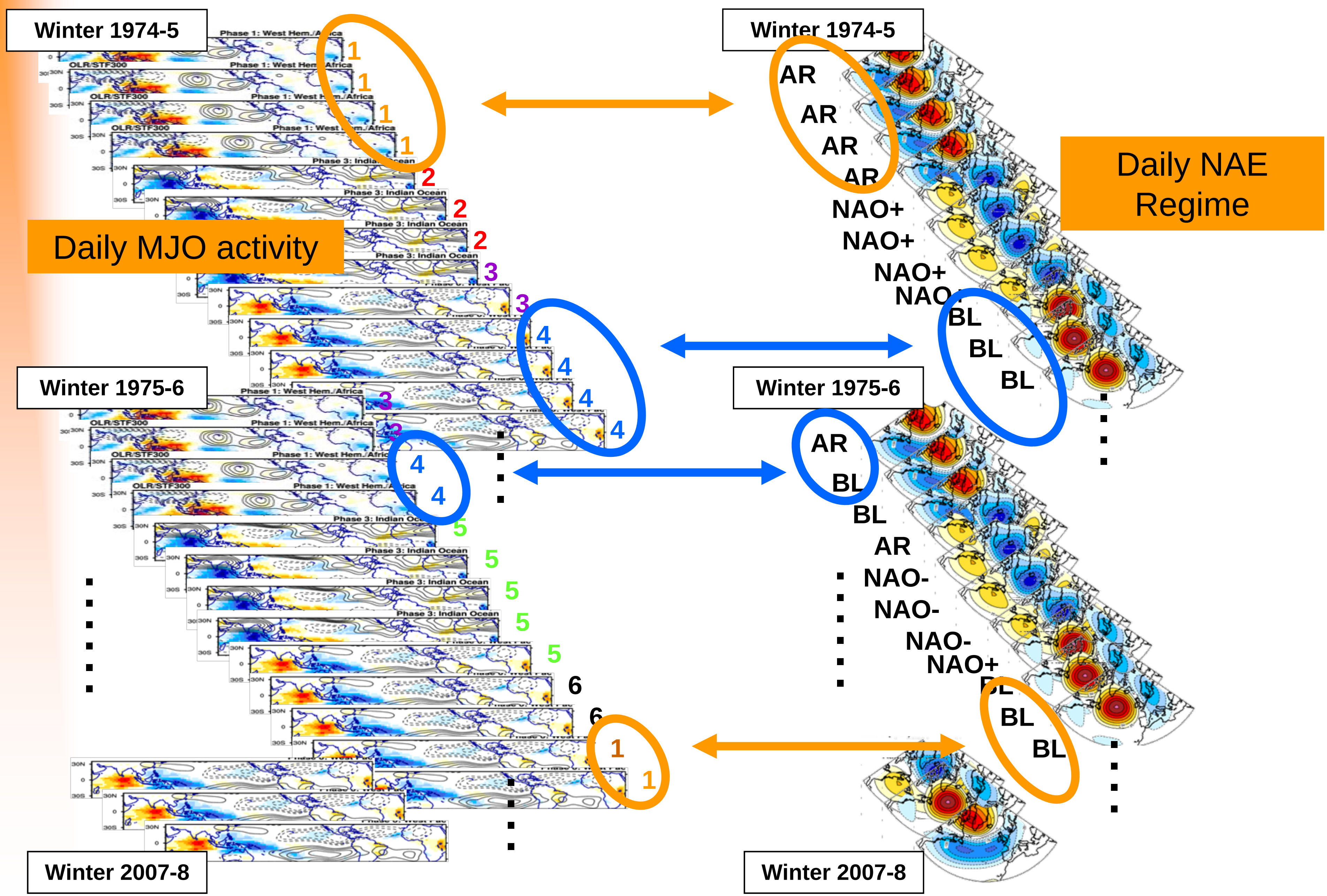


How are the North Atlantic Regimes influenced By the MJO phases and amplitude?

The 8 phases can be spanned in the 2 first EOFs
From combined thermodynamical (OLR) and dynamical (NCEP) fields

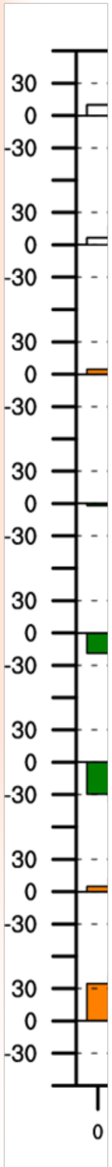
Daily data for MJO and NAO regimes
from Nov.1 1974 to 31 March
(= 4991 extended-winter days)

6. Partition of the MJO phases into regimes (1)



NAO-

Anomalous probability of occurrence (percentage)



Phase 1

Phase 2

Phase 3

Phase 4

Phase 5

Phase 6

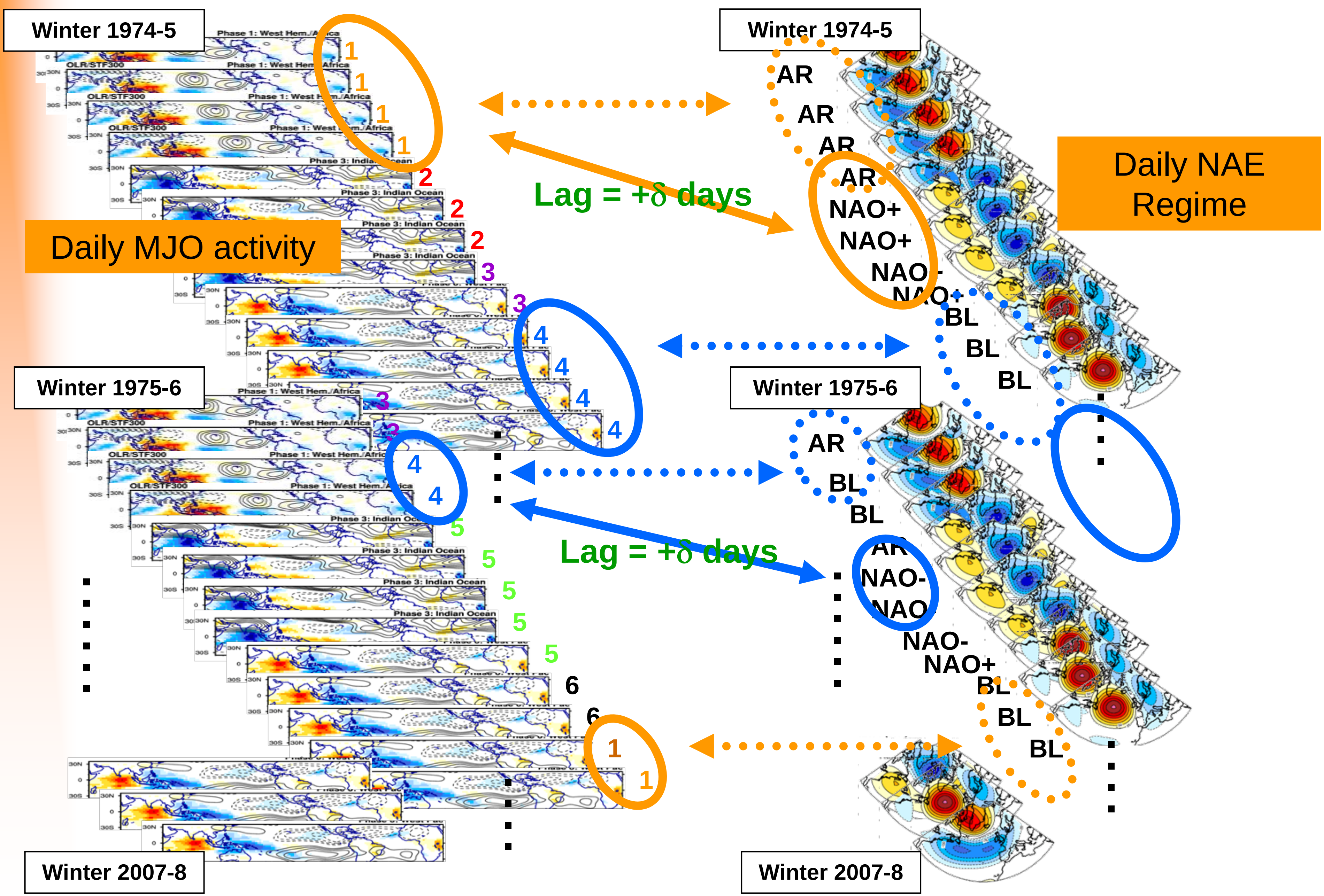
Phase 7

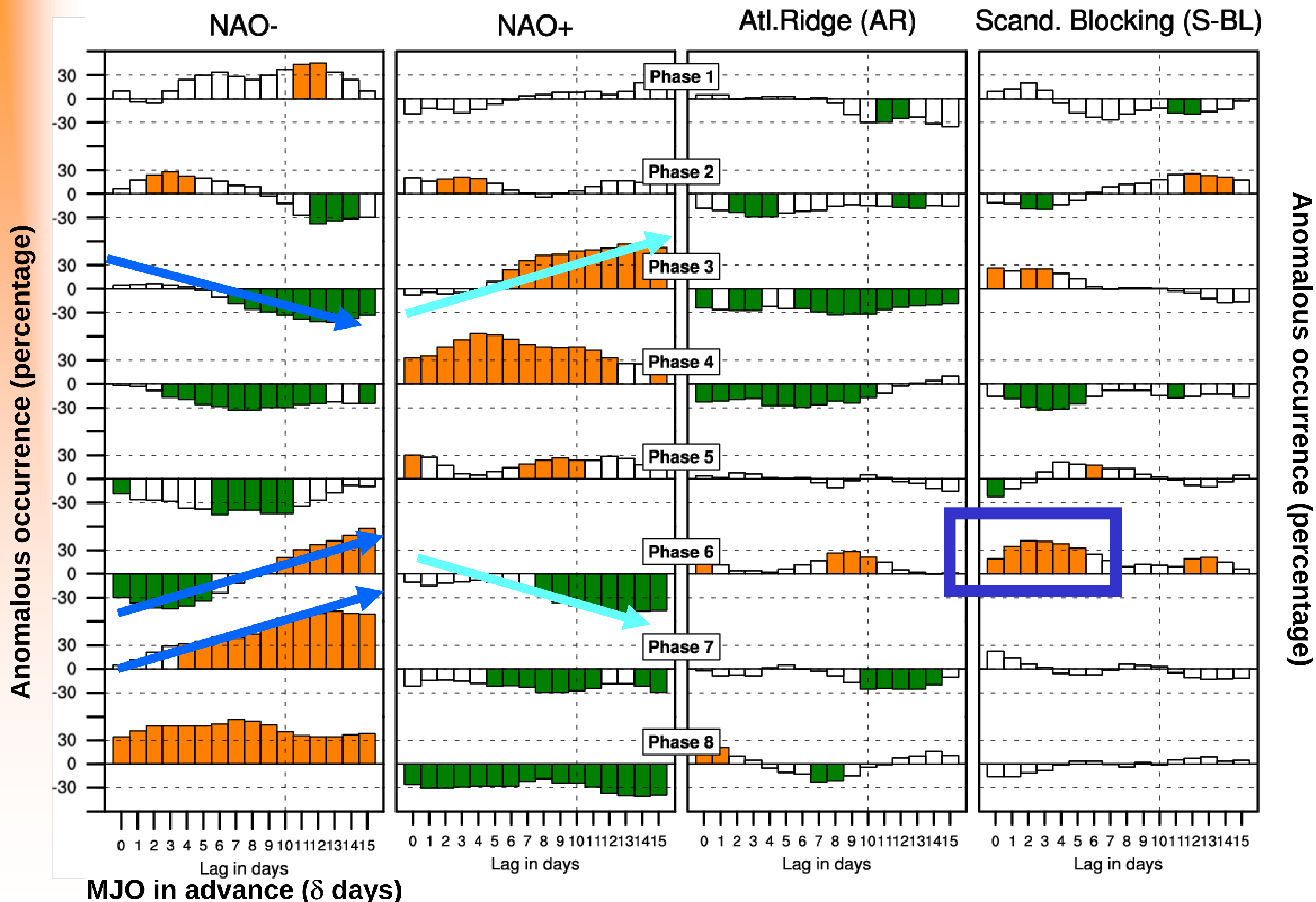
Phase 8

MJO in phase

Anomalous probability of occurrence (percentage)

8. Partition of the MJO phases into regimes (1)





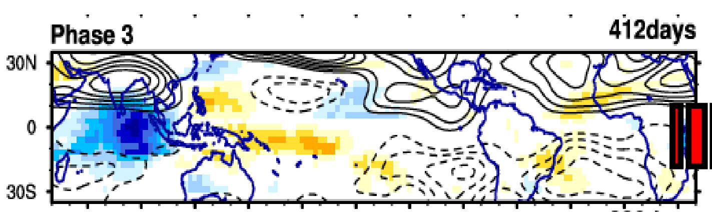
Significance based on χ^2 test and binomial test

Conclusions:

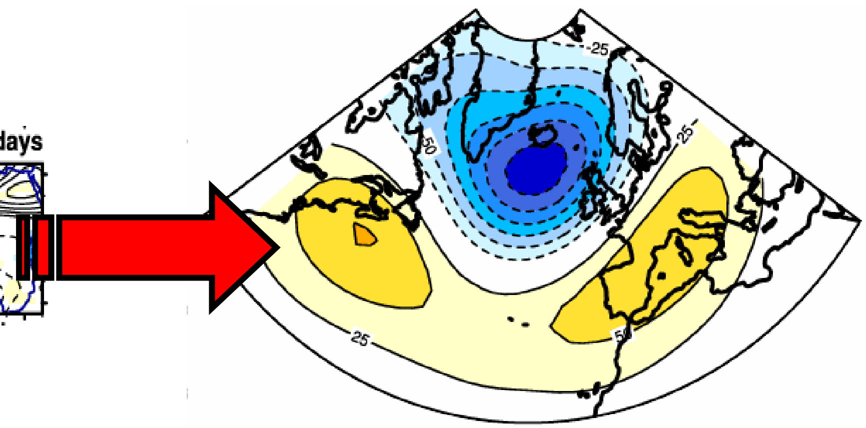
NAO+ regimes tend to be preceded by phase 3-4 of the MJO
NAO- regimes tend to be preceded by phase 6-7 of the MJO
S-Blocking tend to be present during phase 5 of the MJO

The time-scale of the MJO influence on the North Atlantic regimes is About ~10/12 days

What are the physical mechanisms of the MJO-NAO regimes connection?

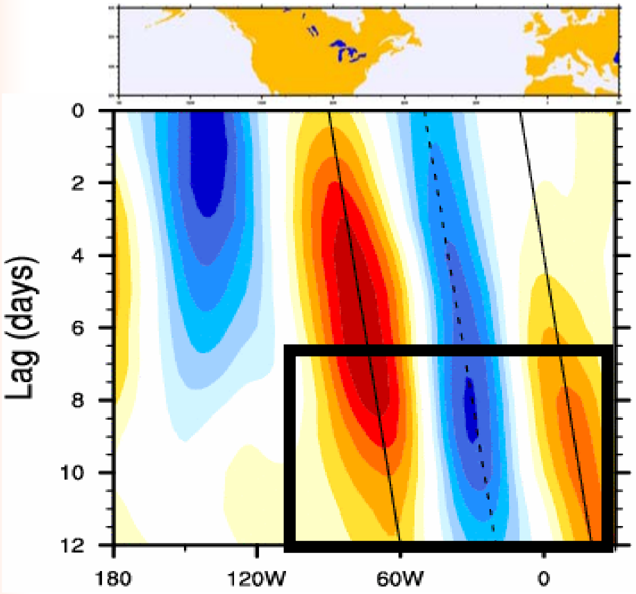


MJO Phase 3



NAO+ regime

MJO Phase 3/NAO+



Z500 lagged composites[40ºN-55ºN]

Traveling low-frequency wave initiated in the Pacific (MJO kick in phase 2-3) and propagating to the North Atlantic

MJO Phase 3/NAO+

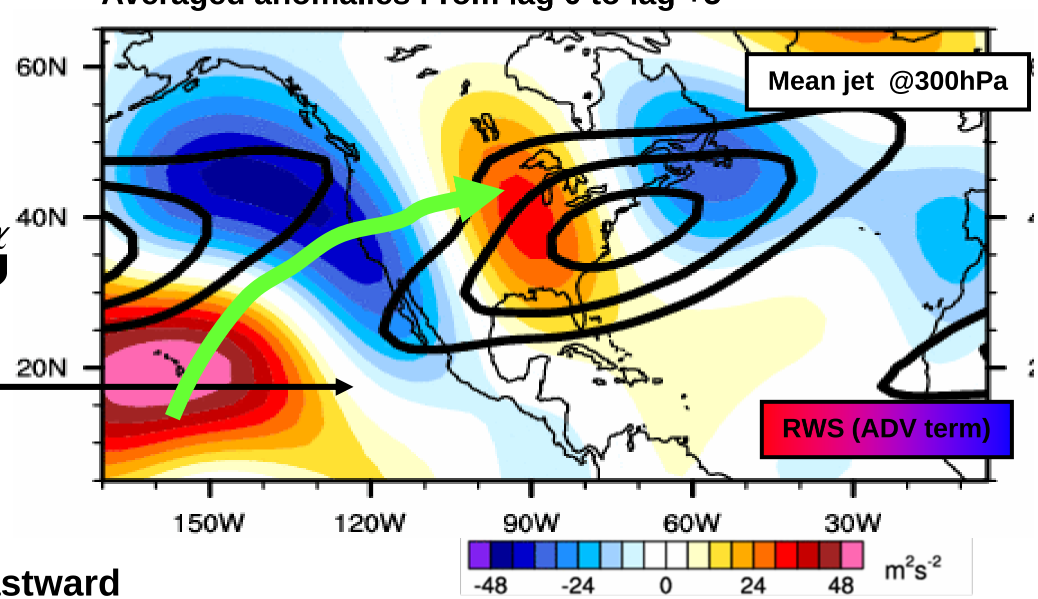
Rossby wave source:

$$RWS = -\nabla.[v_\chi(\xi + f)]$$
$$= -v_\chi.\nabla(\xi + f) - (\xi + f)\nabla.v_\chi$$

Advection term — Stretching term

(Qin and Robinson, JAS, 1993)

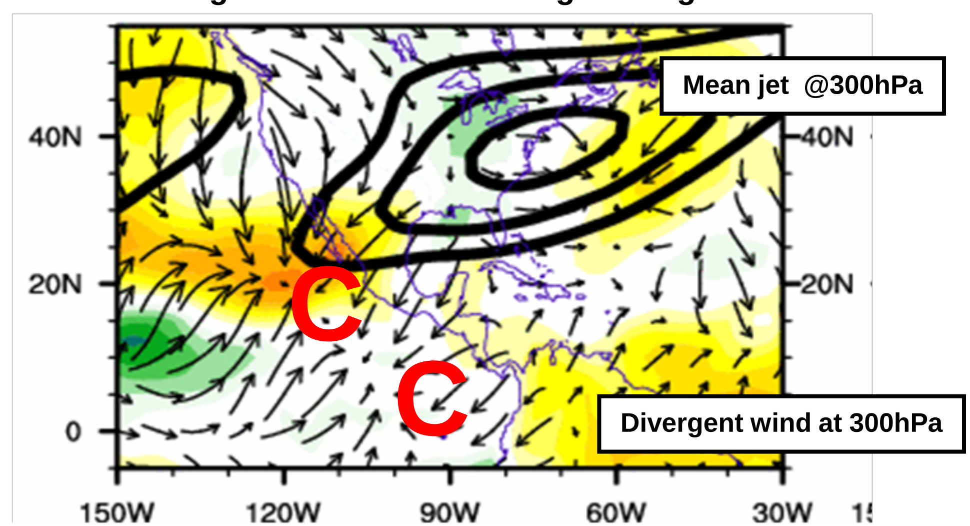
Averaged anomalies From lag 0 to lag +5



- **Strong Rossby Wave Source in the Central Pacific propagating Northeastward**

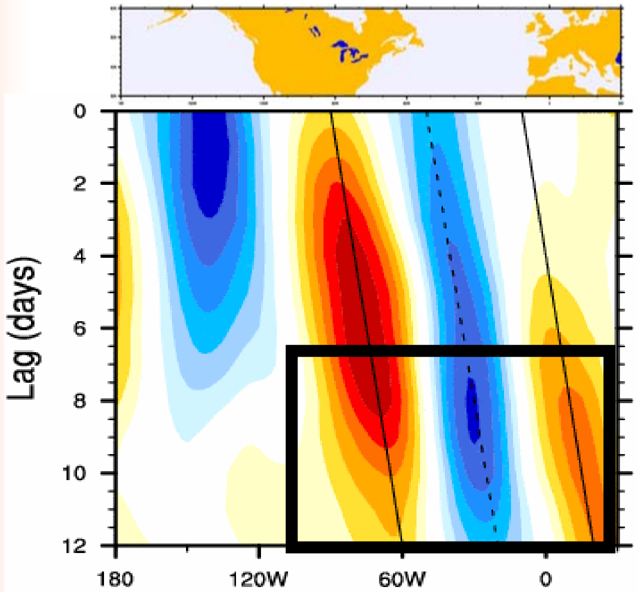
Averaged anomalies From lag 0 to lag +5

Precipitable water (color)/Divergent wind @300hpa



- **Strong upper-level convergence on the Eastern Pacific and at the entrance of the Mean North Atlantic jet**
- **Dry conditions at the entrance of the jet**

MJO Phase 3/NAO+

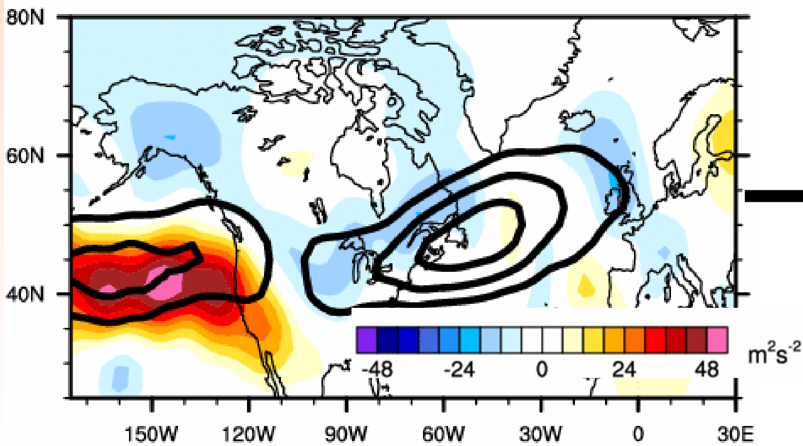


Z500 lagged composites[40ºN-55ºN]

Traveling low-frequency wave initiated in the Pacific (MJO kick in phase 2-3) and propagating to the North Atlantic

Interaction with North Atlantic transients favoring anticyclonic Wave breaking leading to NAO+ regime excitation

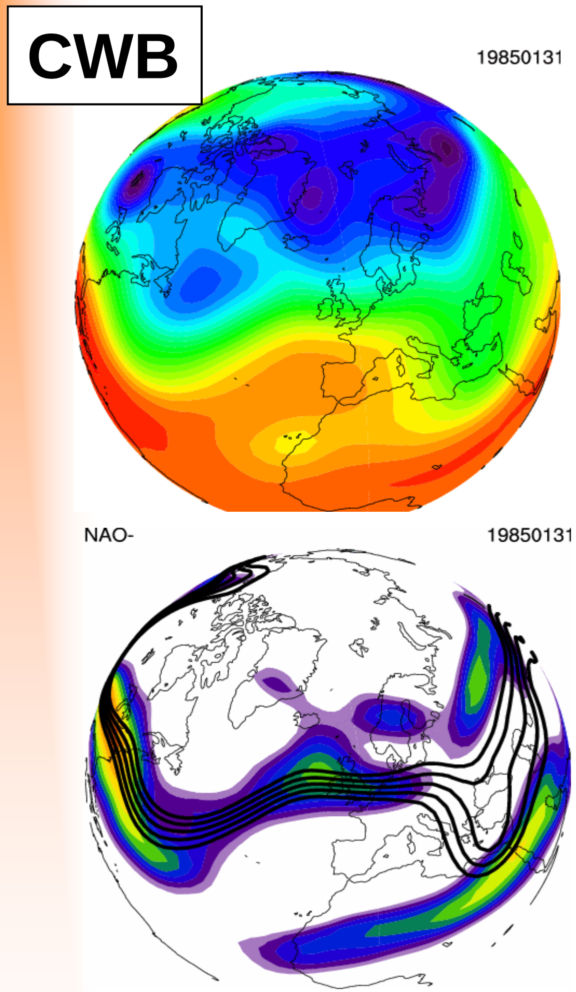
Franske et al (2004), Benedict et al (2004), Feldstein (2003) among others

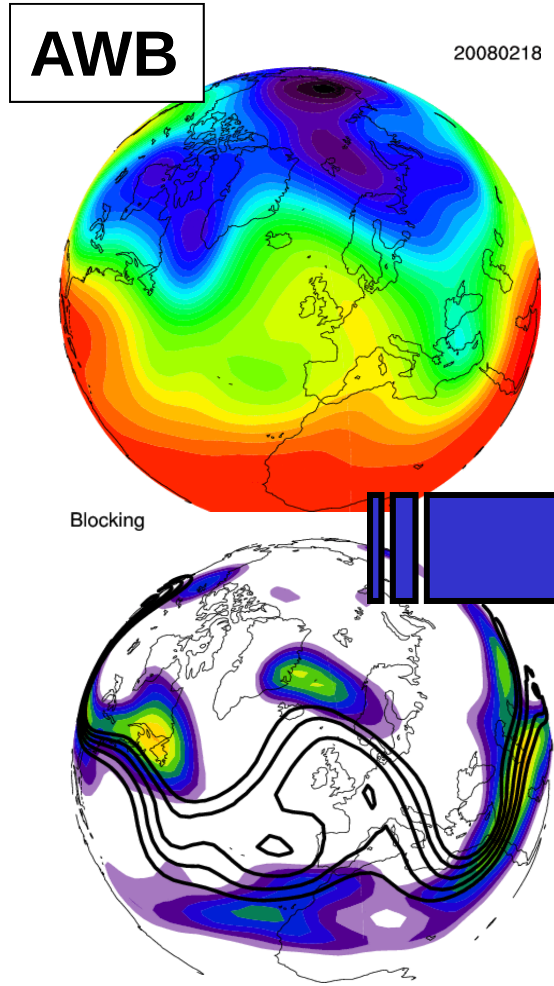


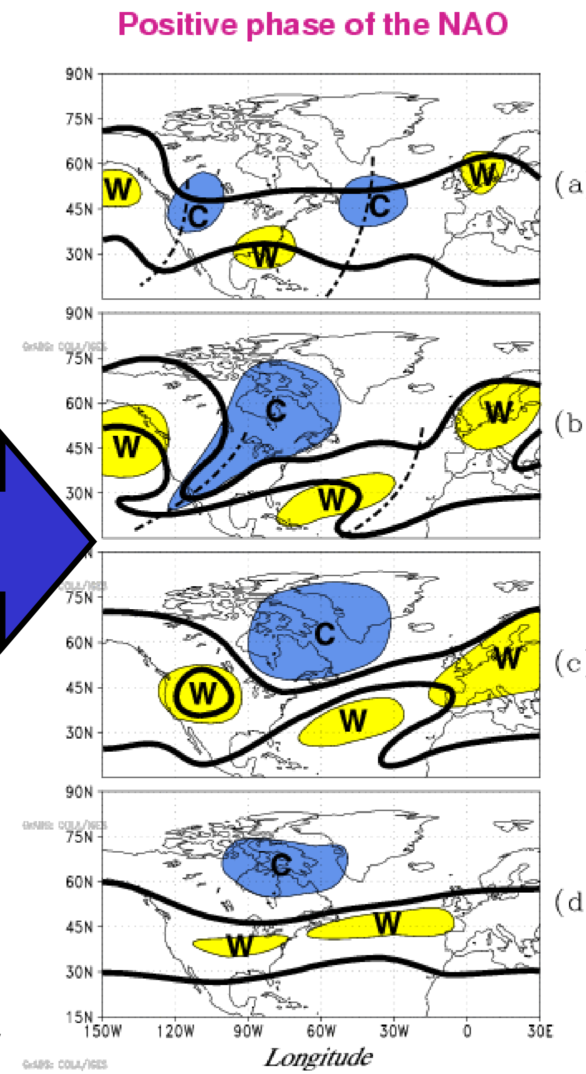
Averaged anomalies From lag 0 to lag +5

Storm track (2-6 day band pass filter of EKE)

Reinforced tail end of the Pacific storm track
Unaffected North Atlantic storminess







Daily Z500 (contours)
Daily U300 (colors)

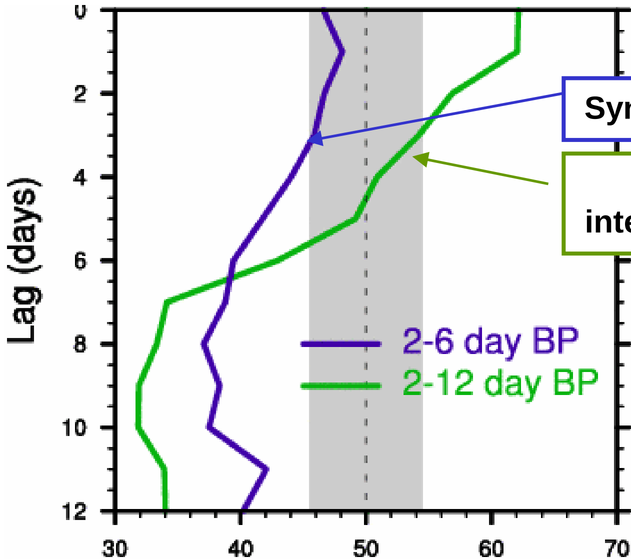
CWB: Southeastt/Northwest tilt of the flow

AWB: Southwest/Northeast tilt of the flow

Benedict et al 2004

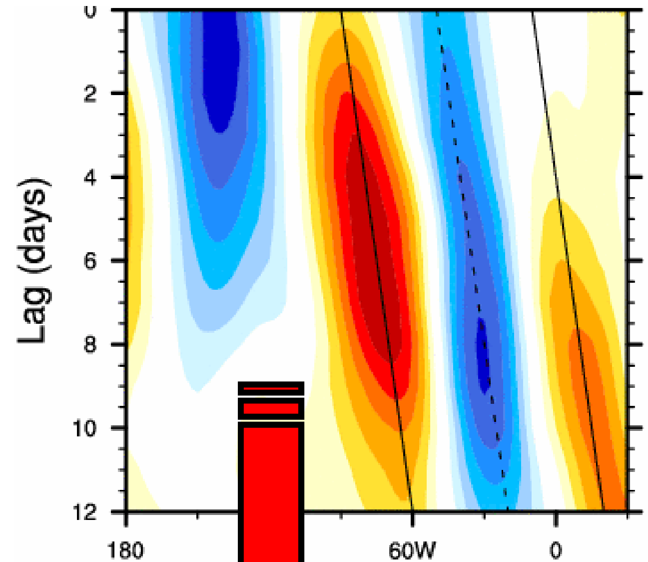
MJO Phase 3/NAO+

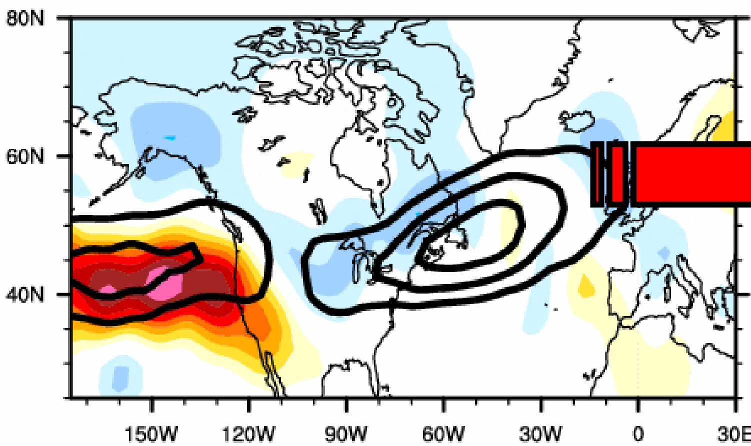
Interaction with North Atlantic transients



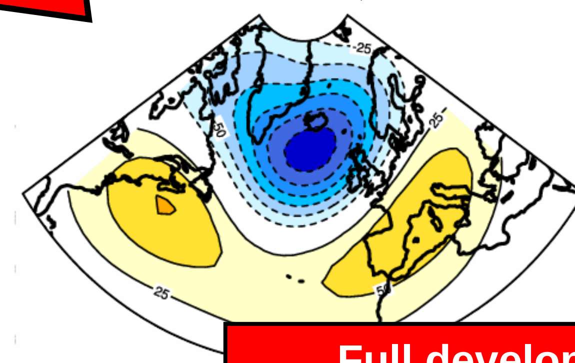
Number of CWBs (%)
(eddy momentum fluxes index along the storm track)
(Riviere and Orlanski 2007)

Traveling low-frequency Rossby wave





Storm Track change



Full development of NAO+ regimes

Conclusions (Cassou, 2008: Intraseasonal interaction between the Madden-Julian Oscillation and the North Atlantic Oscillation. Nature, doi:10.1038/nature07286, 523-527):

- **NAO+ regimes tend to be preceded by phase 3-4 of the MJO**
- **NAO- regimes tend to be preceded by phase 6-7 of the MJO**
- **S-Blocking tend to be present during phase 5 of the MJO**

The time-scale of the MJO influence on the North Atlantic regimes is about ~10/12 days

MJO Phase 3/NAO+

MJO triggers forced Rossby waves in the Pacific (Phase 2 and 3) propagating eastward towards the NAE region, modifying the background flow leading to NAO+ due to interaction with North Atlantic High frequency + intermediate transients (AWB).

Remote influence for NAO+ regimes (consistent with recent literatures)

MJO Phase 6/NAO-

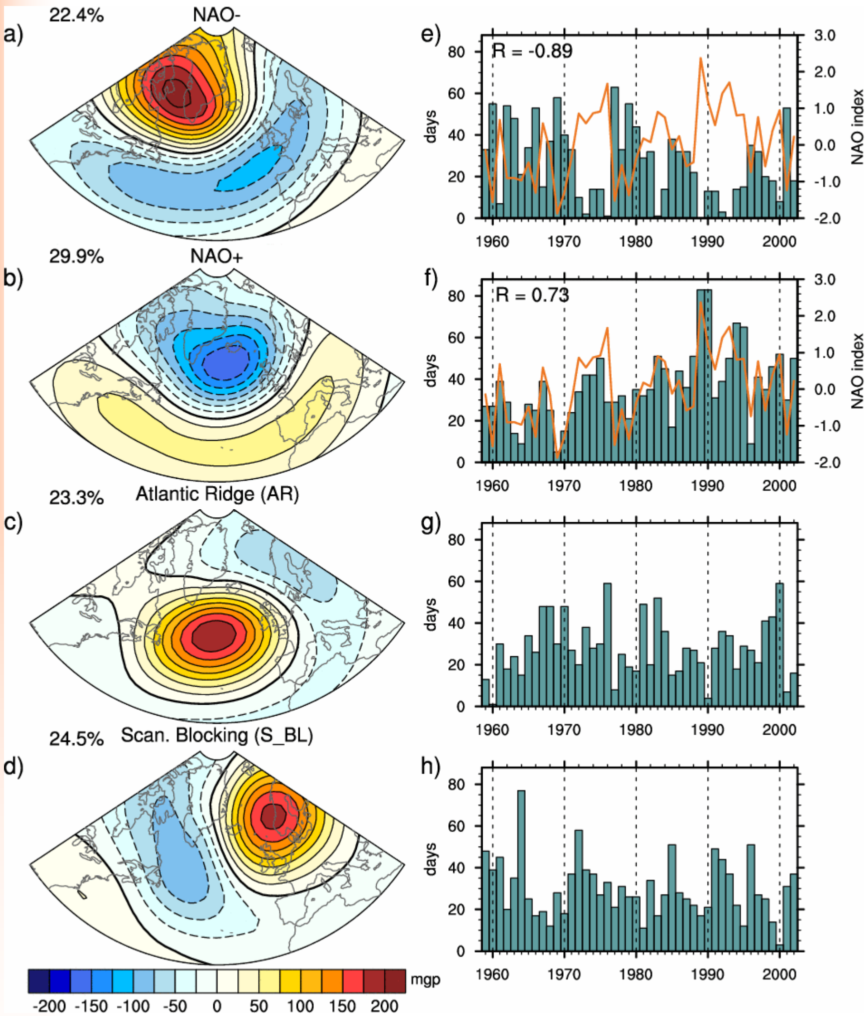
1. Development in situ favored by previous Blocking conditions as part of the NAO+ -> S-BL -> NAO- most favored transition path

Response to direct forced Rossby wave initiated by MJO (Phase 6-7) in the eastern Pacific + associated enhanced moisture leading to NAO- after interaction with North Atlantic high frequency Transients (CWB).

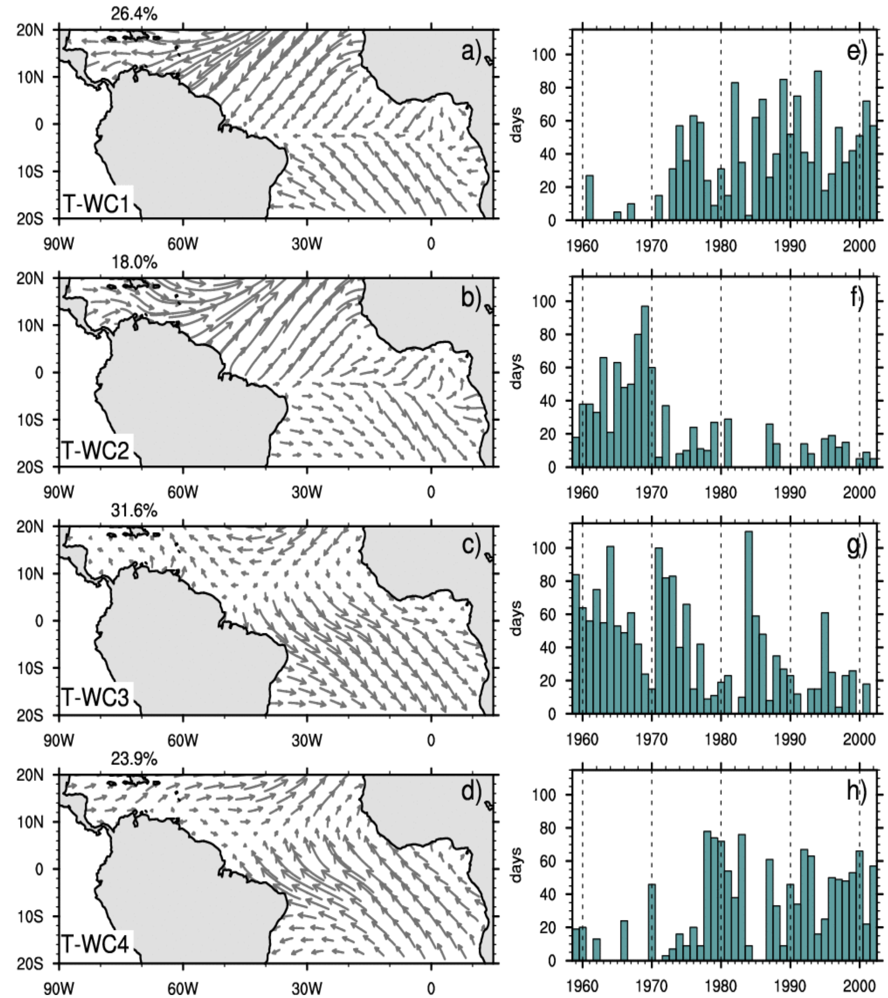
Local development for NAO- regimes (consistent with recent literature)

Asymmetrical tropical-extratropical relationship between MJO and NAO

Teleconnection at interannual-to-decadal timescale
Role of the tropical Atlantic



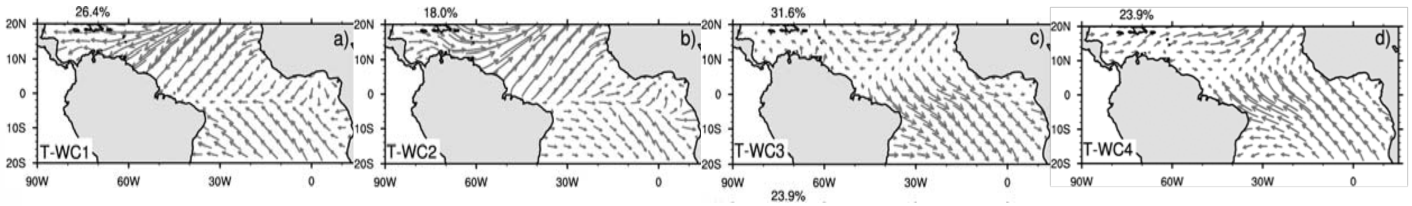
Euro-Atlantic weather regimes

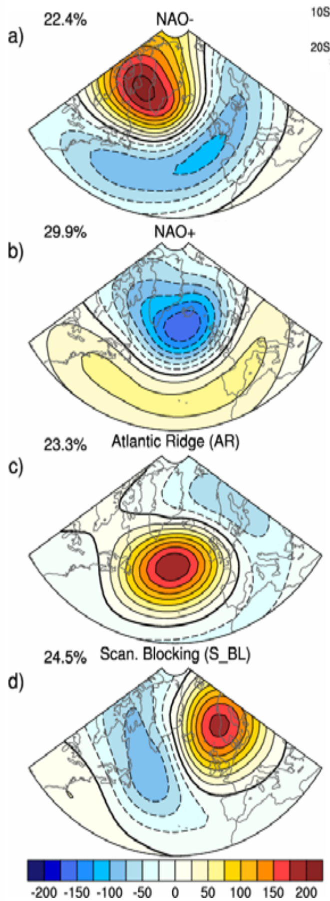


Tropical Atlantic UV1000 wind classes

Cassou et al, 2010, clim_dyn, in press.

Tropical Atlantic UV1000 wind classes





Euro-Atlantic weather regimes

	T-WC1	T-WC2	T-WC3	T-WC4
NAO-	11.3	32.4	20.8	29.2
NAO+	48.6	12.5	32.2	19.1
AR	12.9	41.8	15.7	30.8
BL	27.2	13.2	31.2	20.9

Table of contingency (%)

Cassou et al, 2010, clim_dyn, in press.

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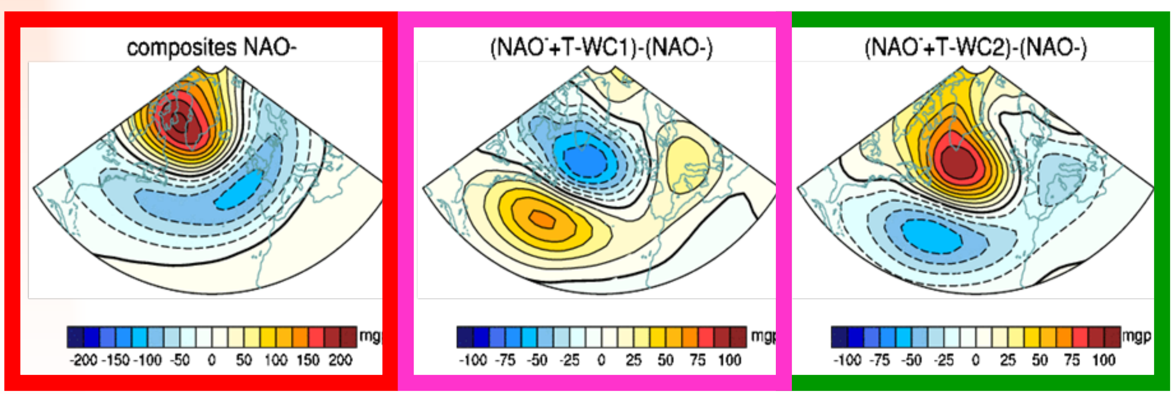
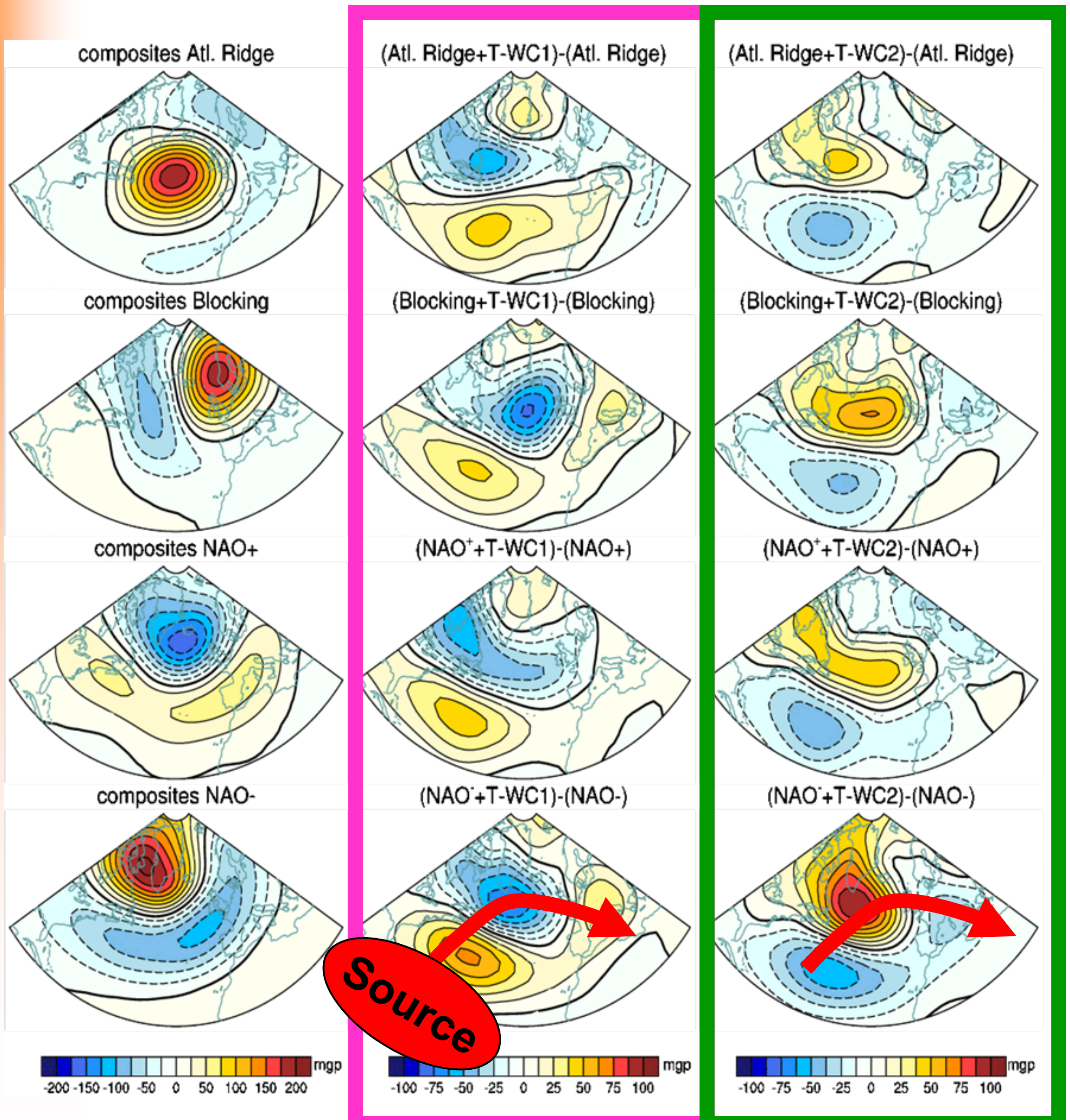
Difference between subclasses and total sample



Minvielle (2010)

3. Modulation by Rossby wave (2)



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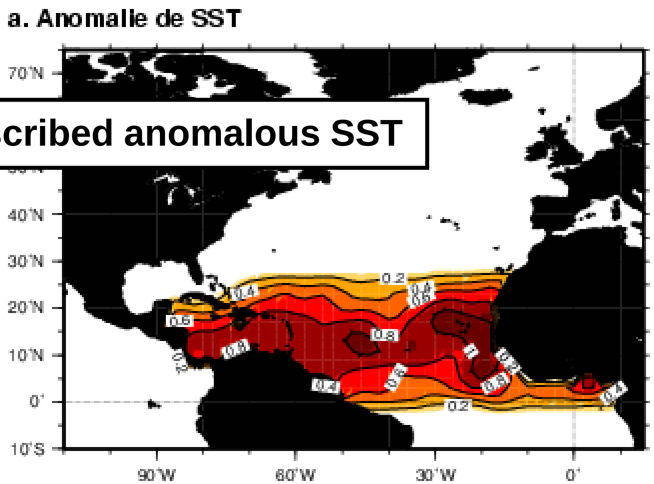
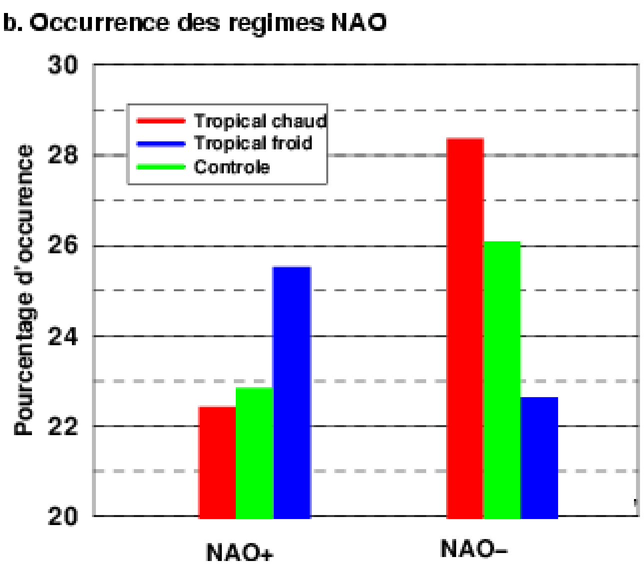
Modulation of the NAE weather Regimes by the tropical Atlantic

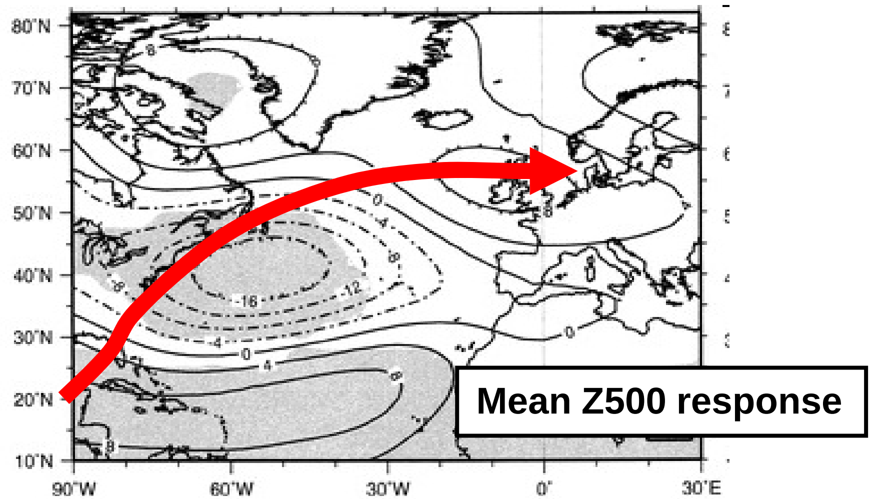
Rossby wave structure Superimposed onto NAE daily variability

Minvielle (2010)

Response of the ARPEGE model (Meteo-France) to
Anomalous SST conditions in the North Tropical Atlantic



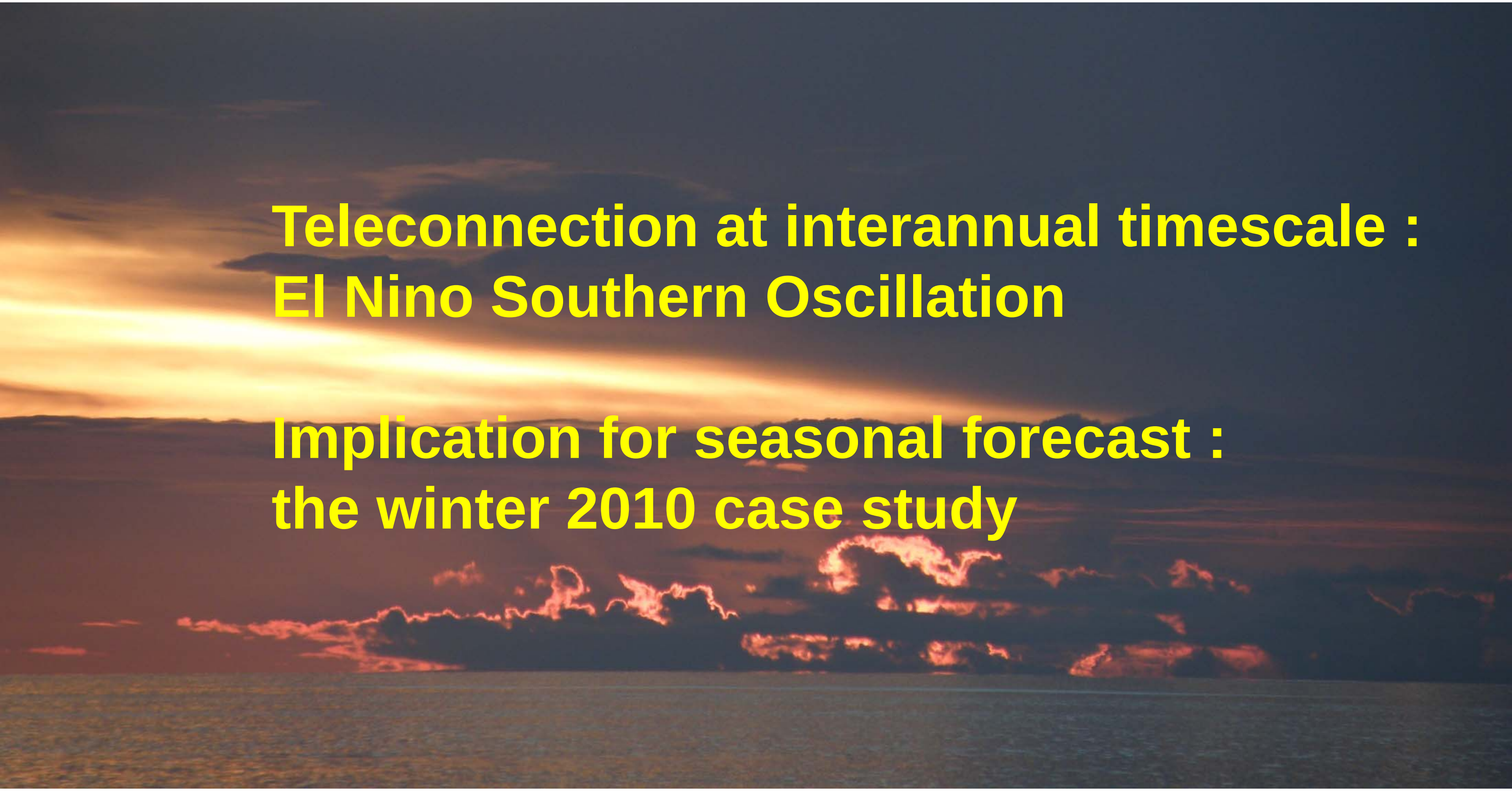




Tropical SST Anomalies modify:
1. The occurrence of the NAE regimes

2. Their strength via forced Rossby wave
Originating from the western tropical basin

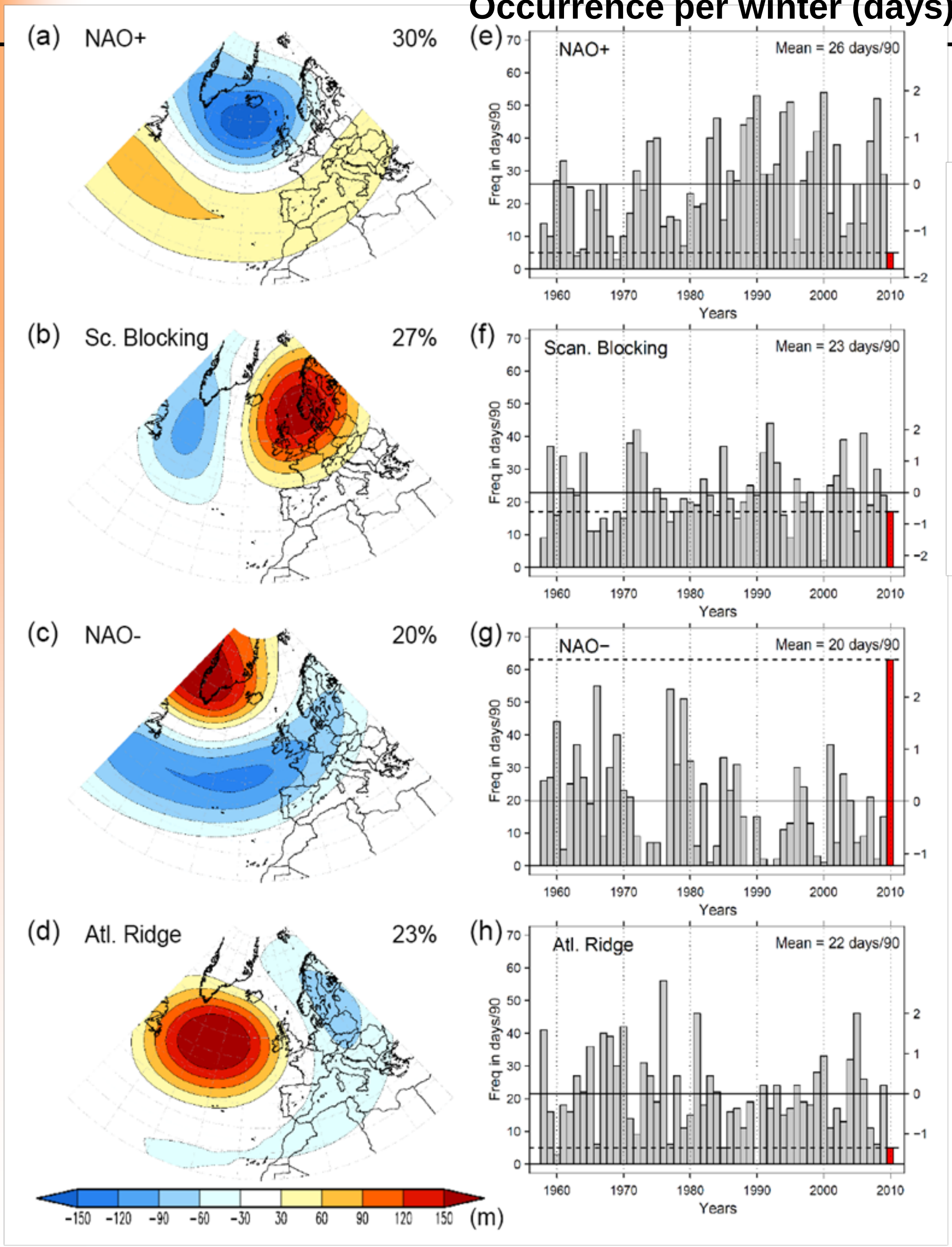
Terray and Cassou (2002).

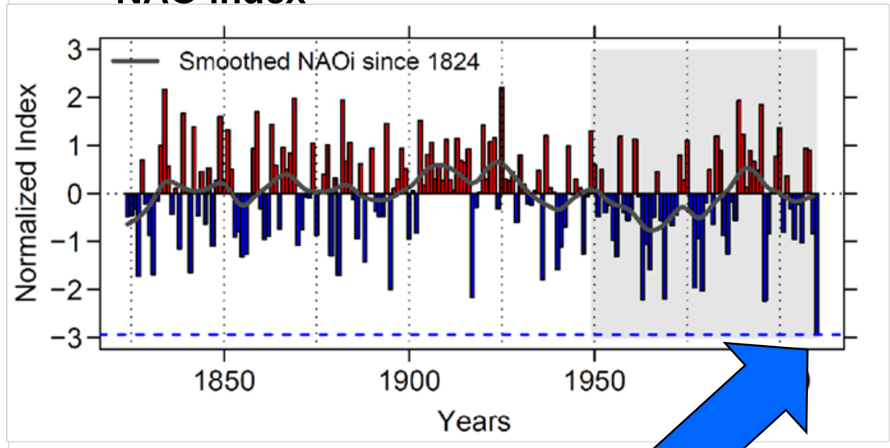


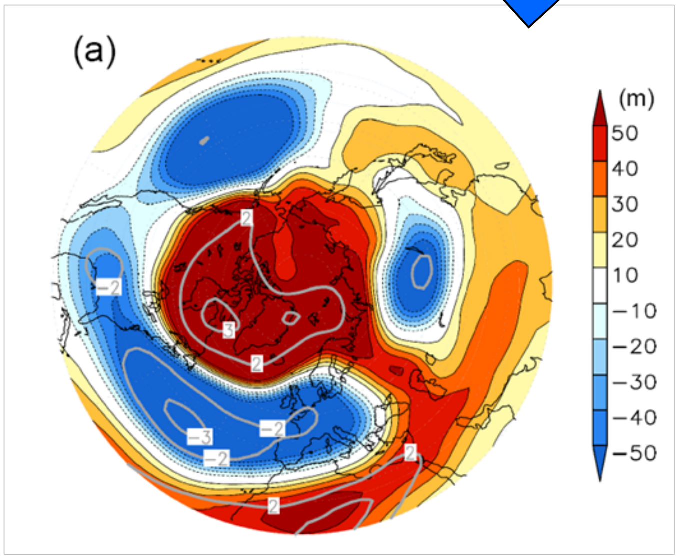
Teleconnection at interannual timescale :
El Nino Southern Oscillation

Implication for seasonal forecast :
the winter 2010 case study

1. Occurrence of NAE regimes in winter 2010

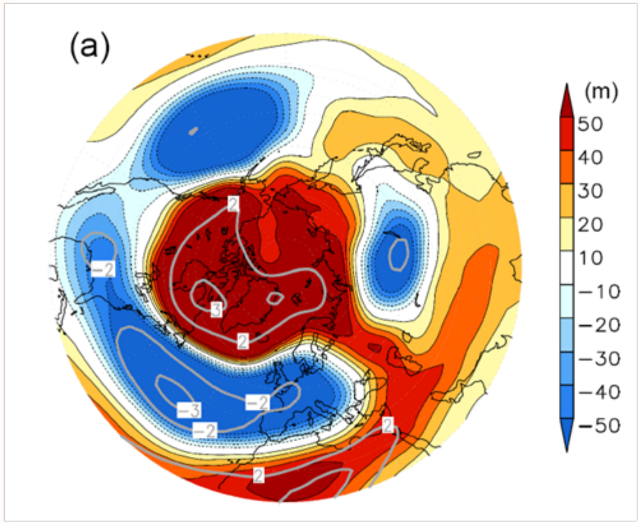




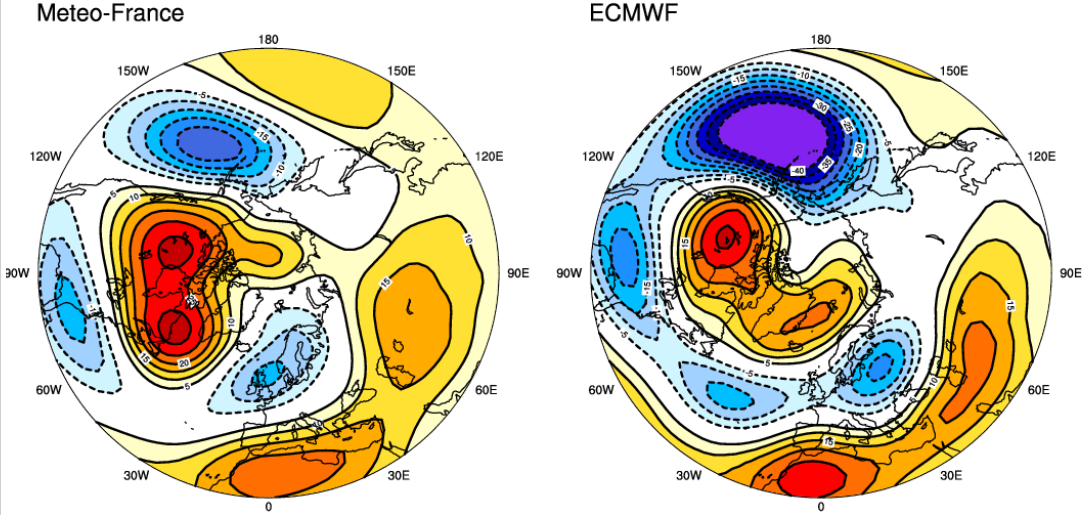


DJF 2010 Z500 anomalies

Cattiaux et al (2010, GRL in press)

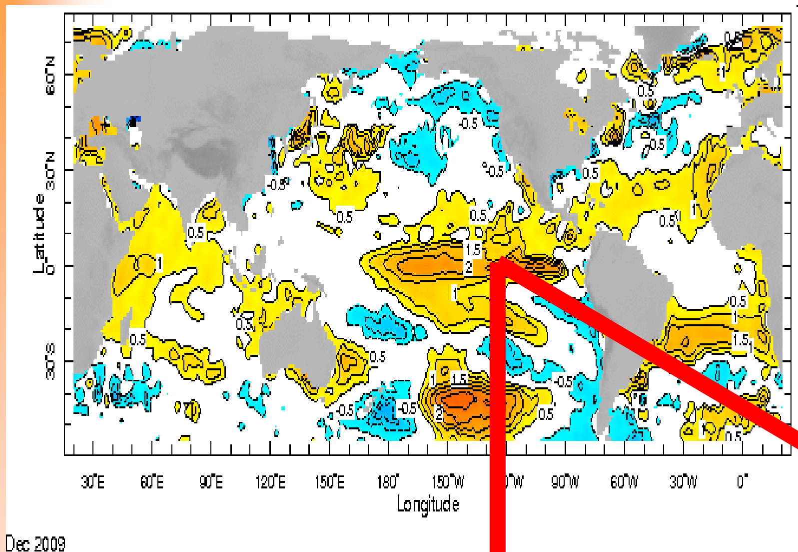


JFM Z500 Forecast [IC = Dec. 2009]

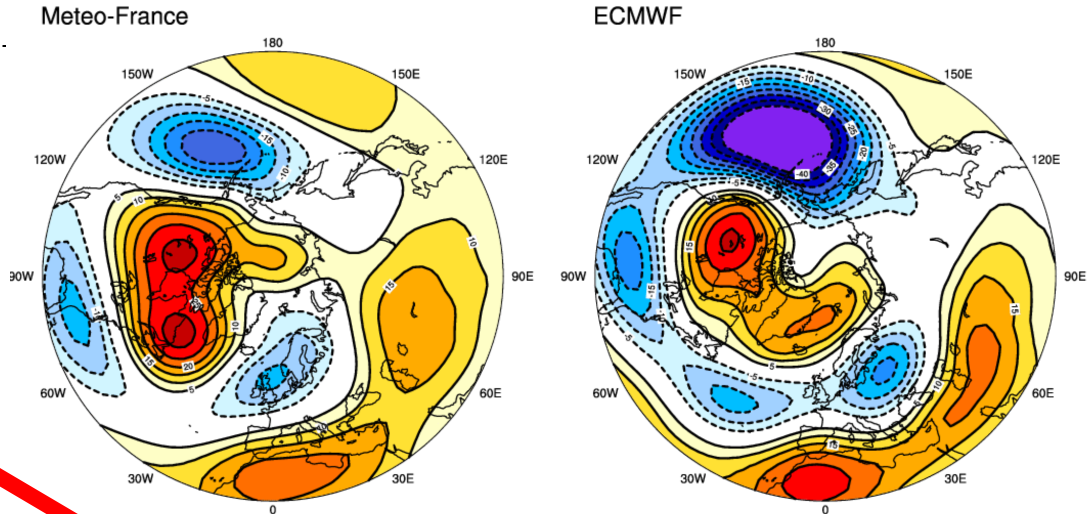


NOT TOO BAD !!

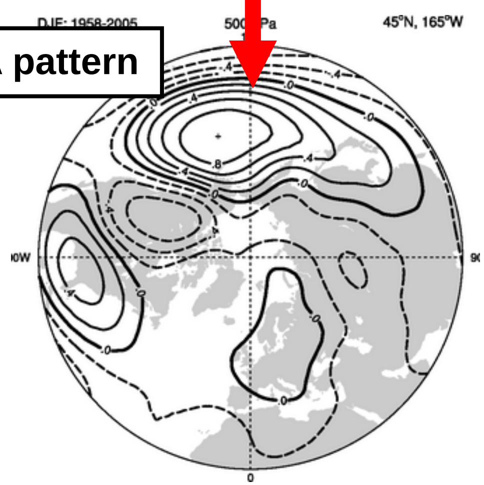
Anomalous SST given in initial Conditions for seasonal forecast



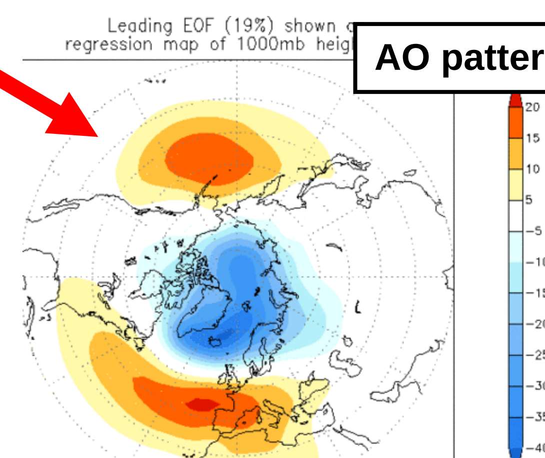
JFM Z500 Forecast [IC = Dec. 2009]



PNA pattern

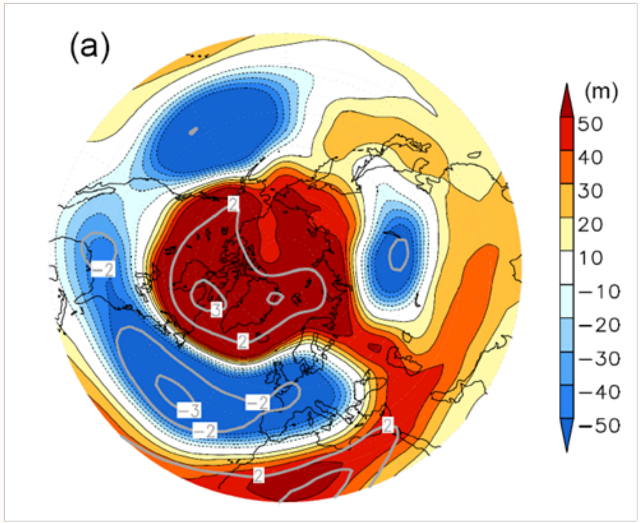


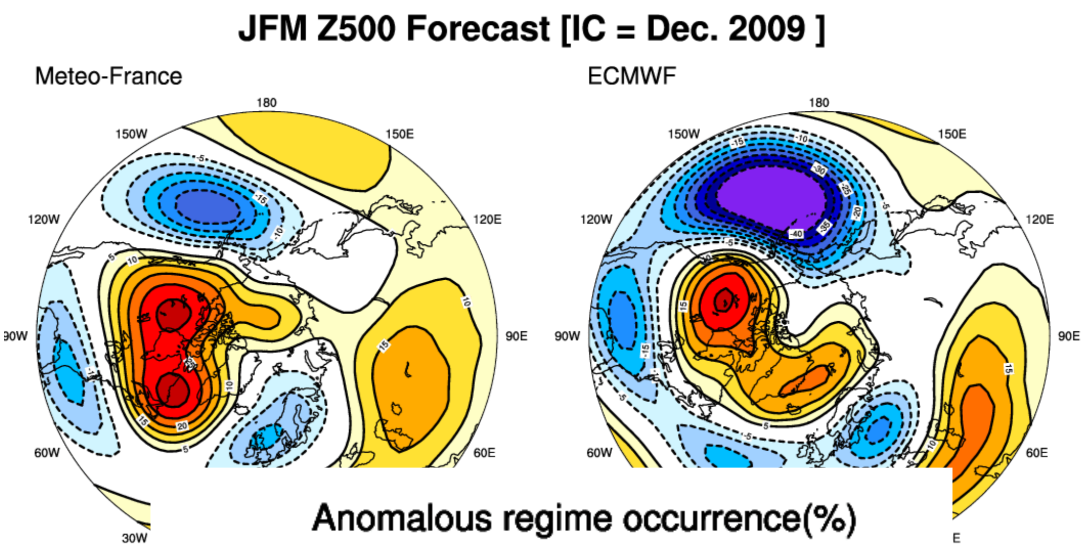
AO pattern

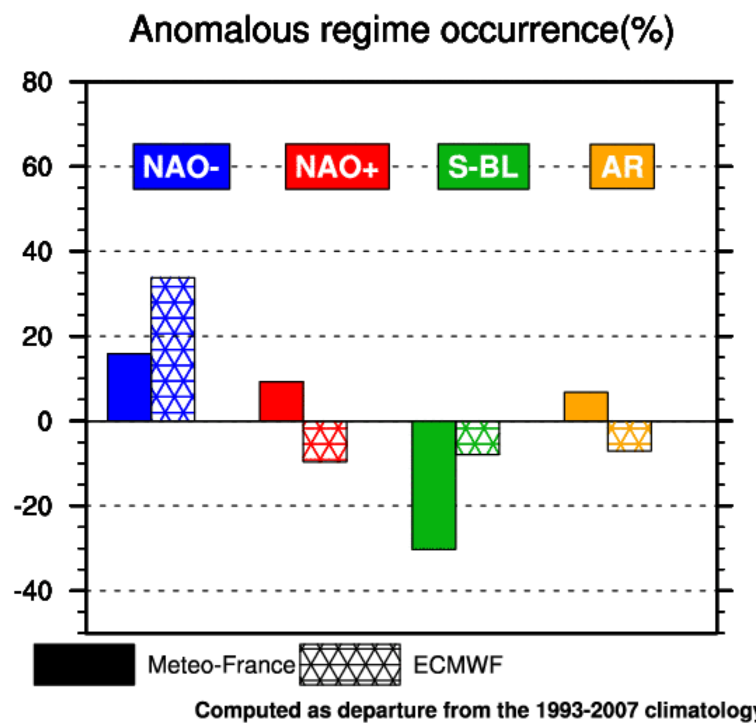


PNA extension that occurs sometimes
(e.g. Cassou and Terray 2001)

Role of the stratosphere during ENSO
(e.g. Ineson ans Scaife 2009,
Cagnazzo and Manzini 2009 …)

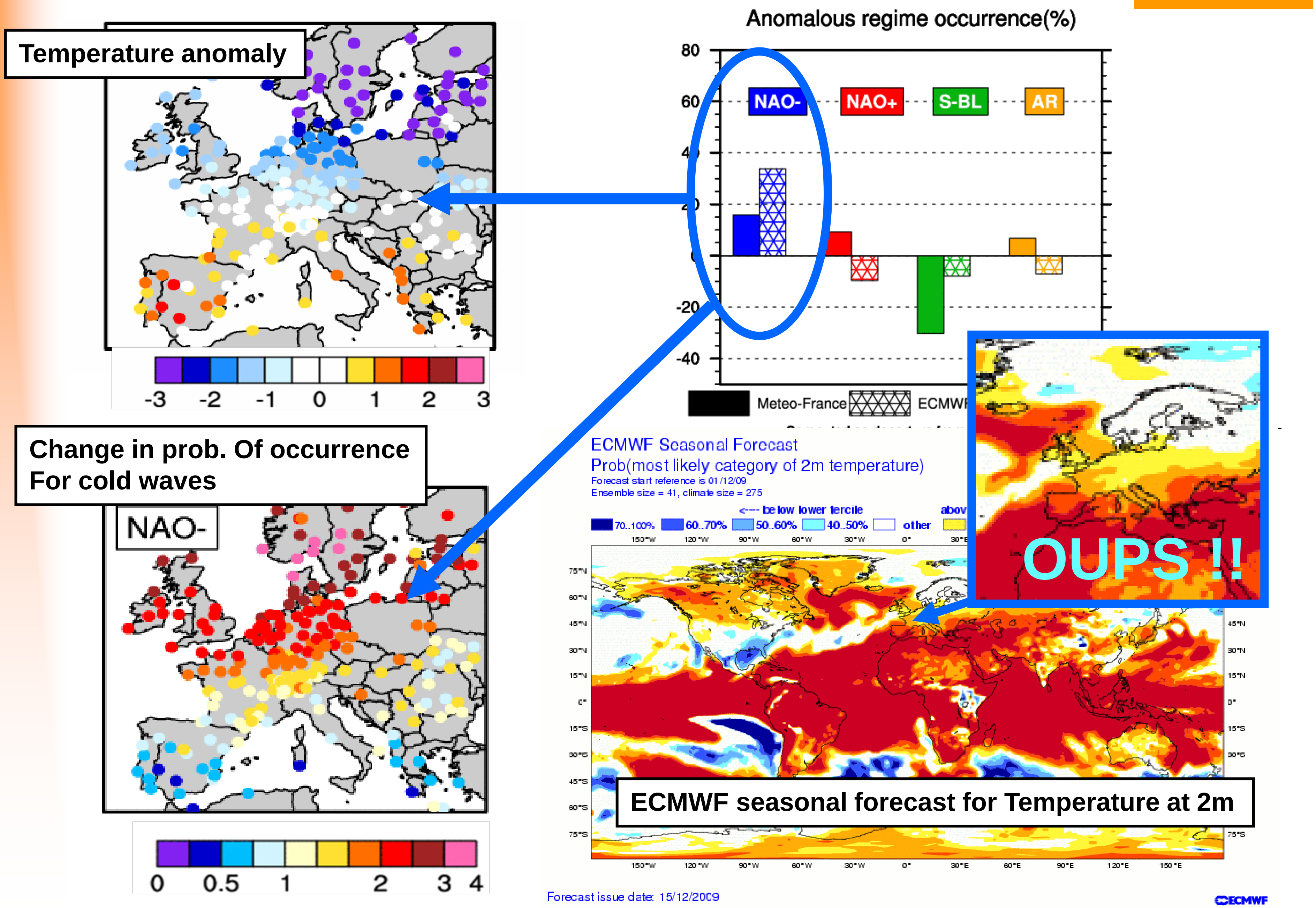


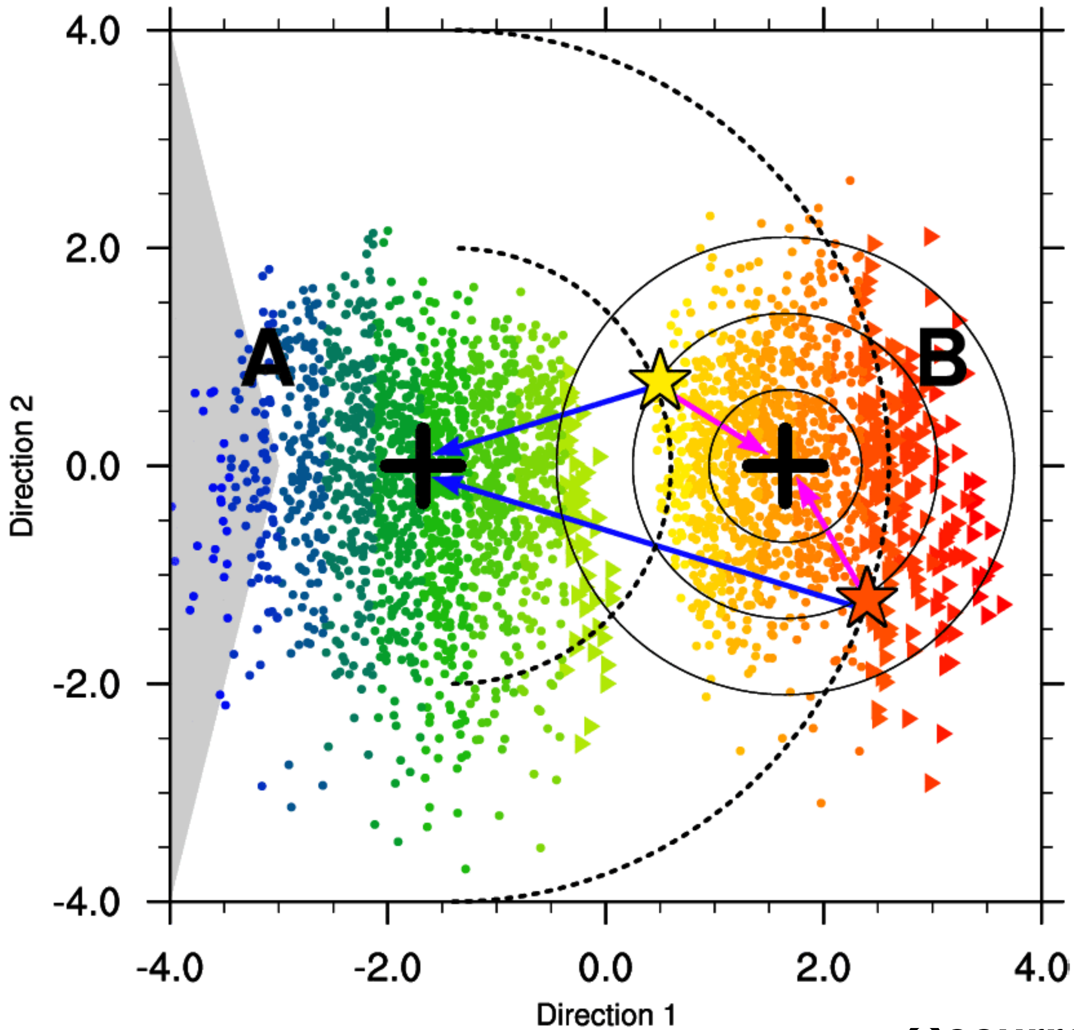




NOT TOO BAD AT ALL !!

5. Prediction of the surface temperature





Occurrences +
Relative positions matter

Modulations by teleconnections

Thank you

Christophe Cassou
CNRS-Cerfacs