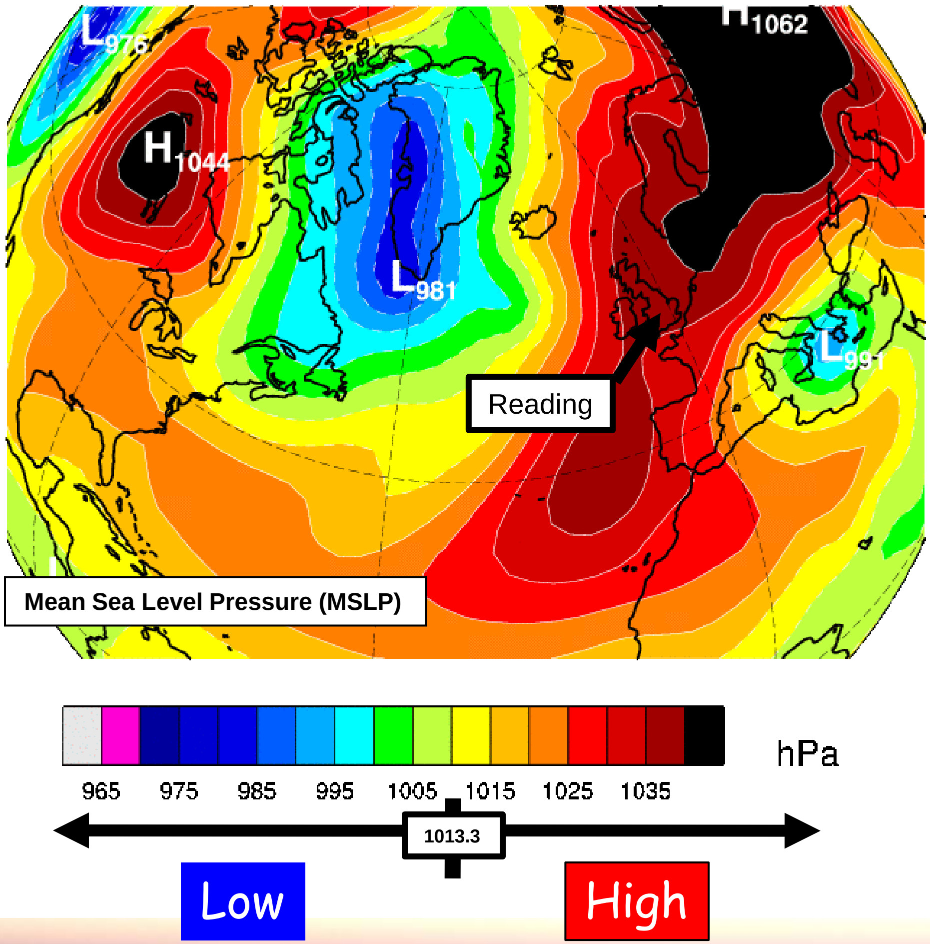
Sources of intraseasonal to interannual predictability over the North Atlantic/Europe region

Christophe Cassou
(CNRS-Cerfacs)

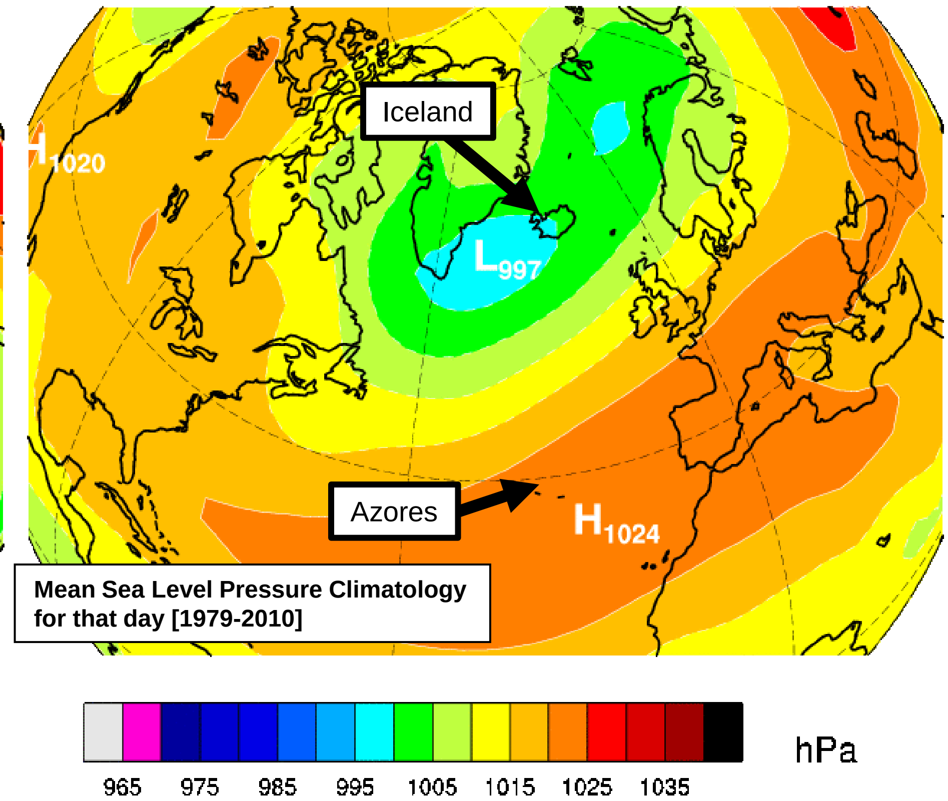
ECMWF Annual Seminar, Sept.2012

A weather map…

Mardi 7 Fevrier 2012, 00h

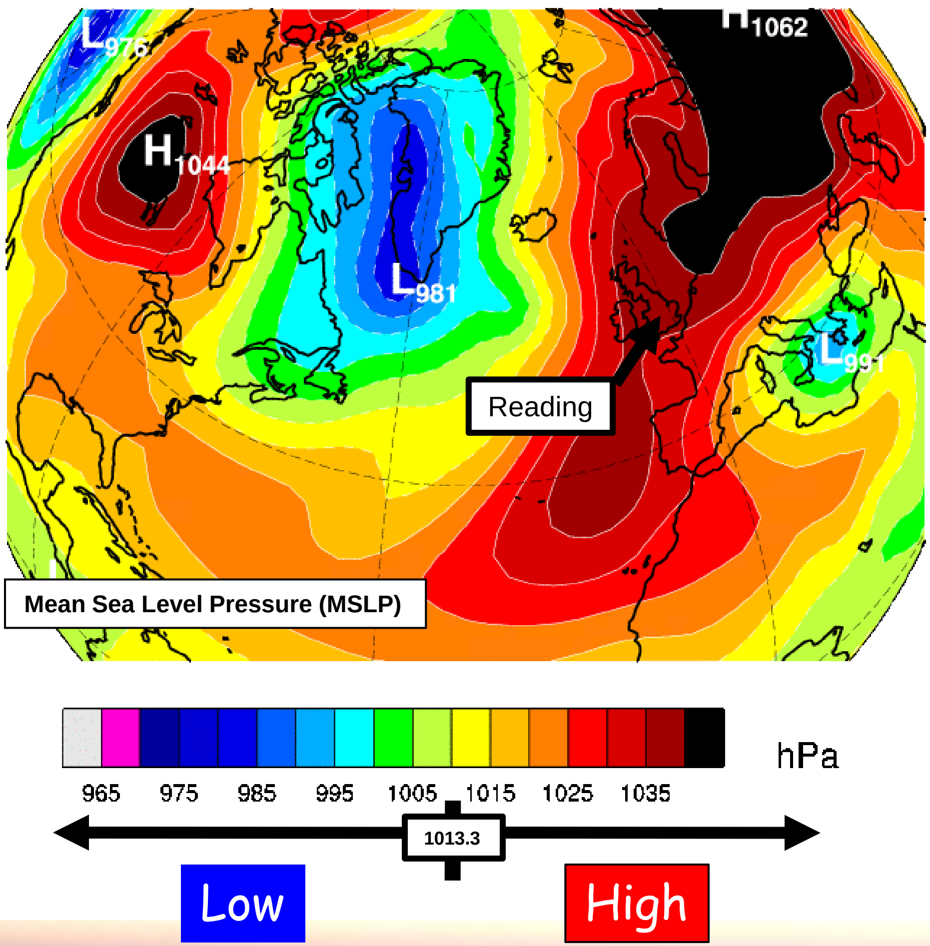


7 Fevrier [climatologie 1979-2010]

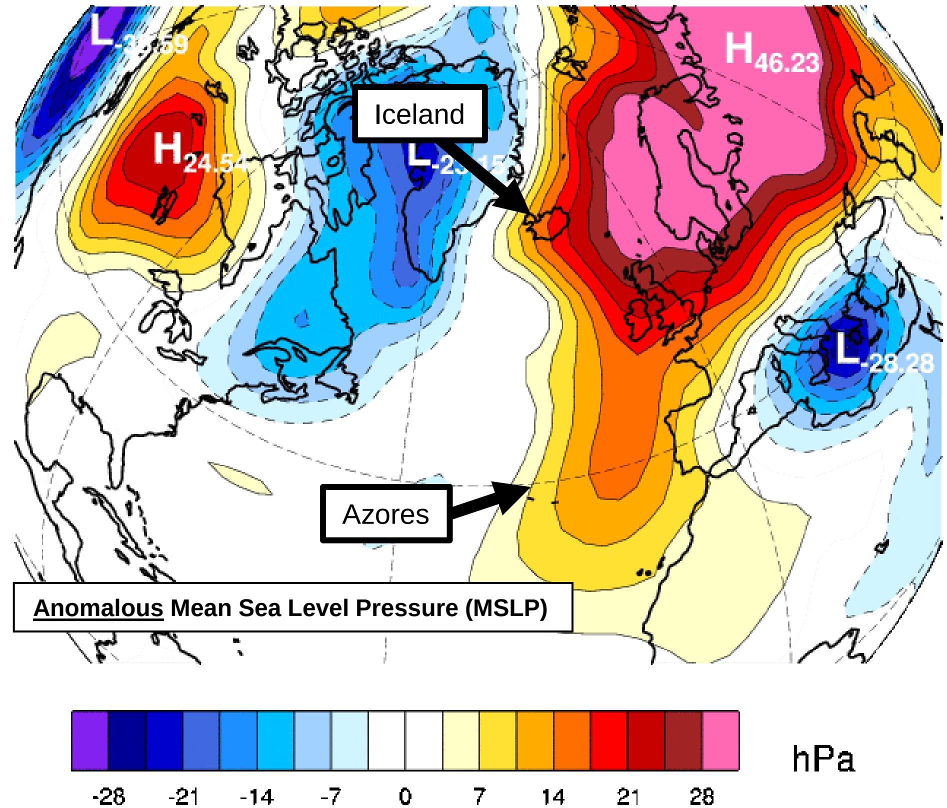


Meteorologist versus climatologist

Mardi 7 Fevrier 2012, 00h

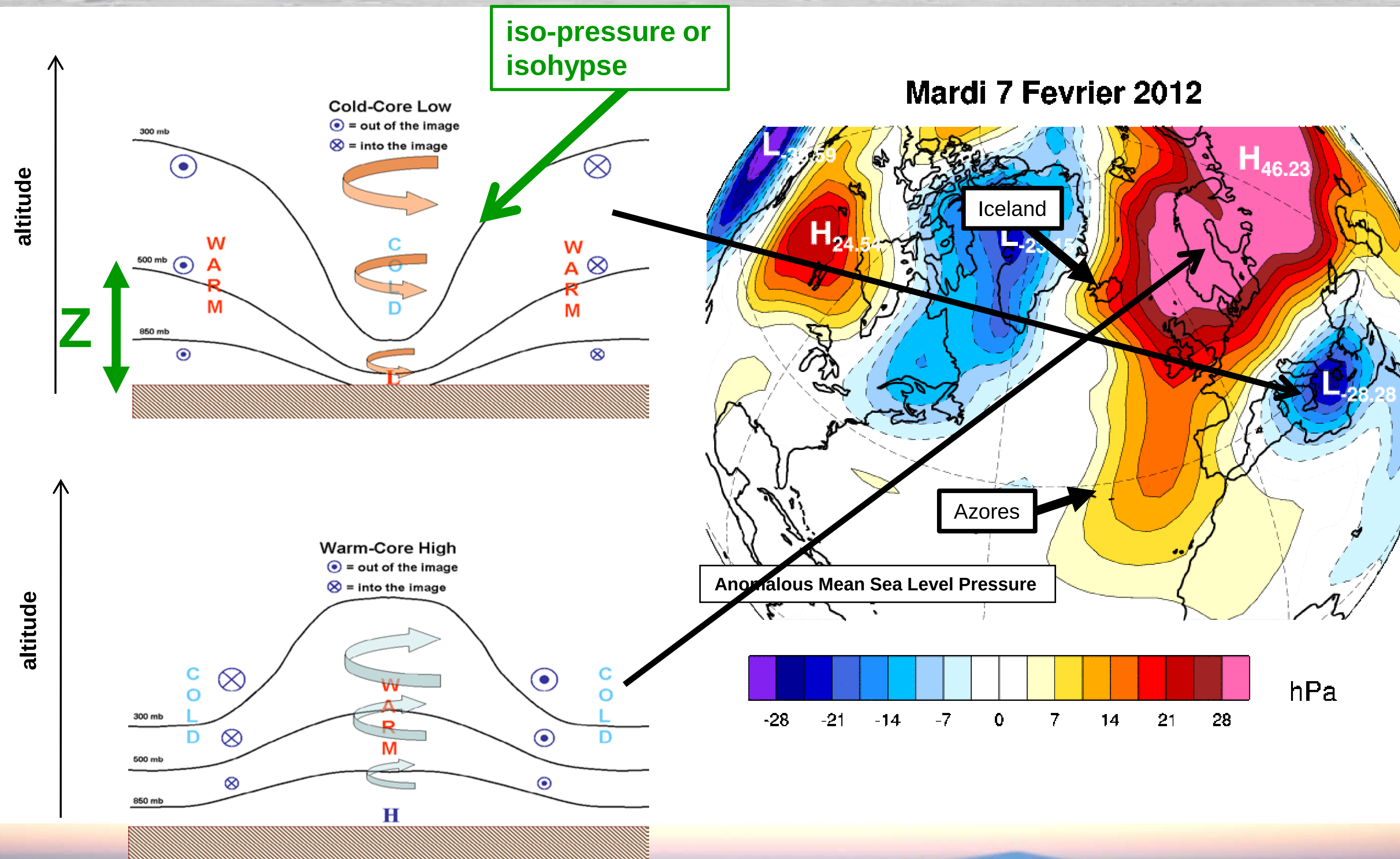


Mardi 7 Fevrier 2012



Source: Operational ECMWF analysis

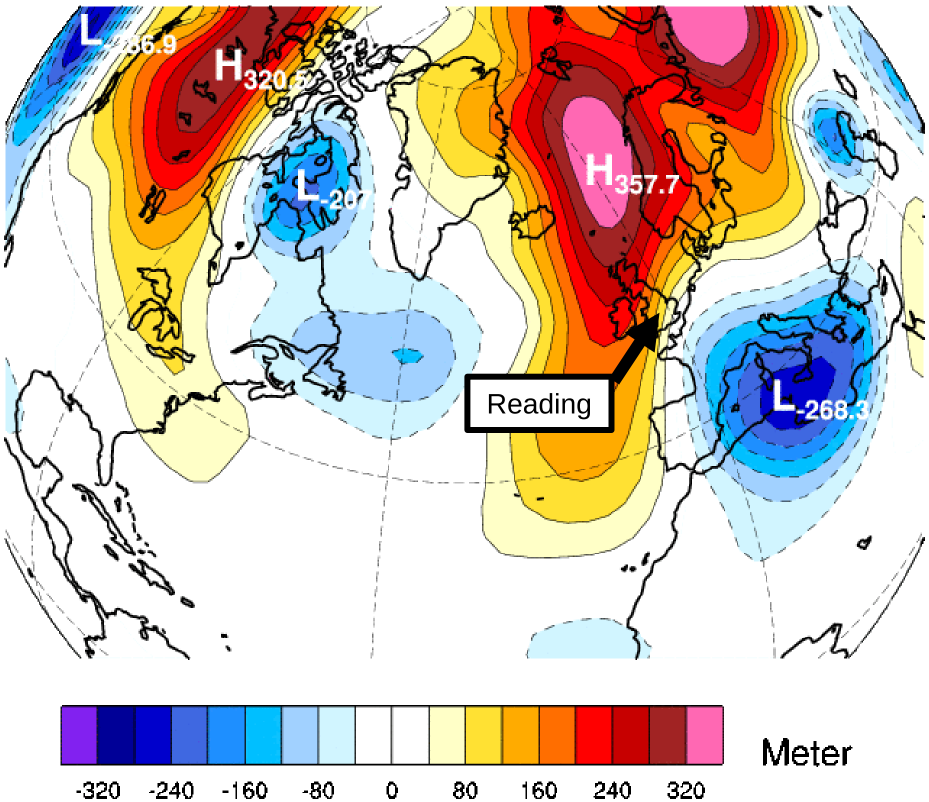
From surface to free atmosphere (Z500)



Source: Operational ECMWF analysis

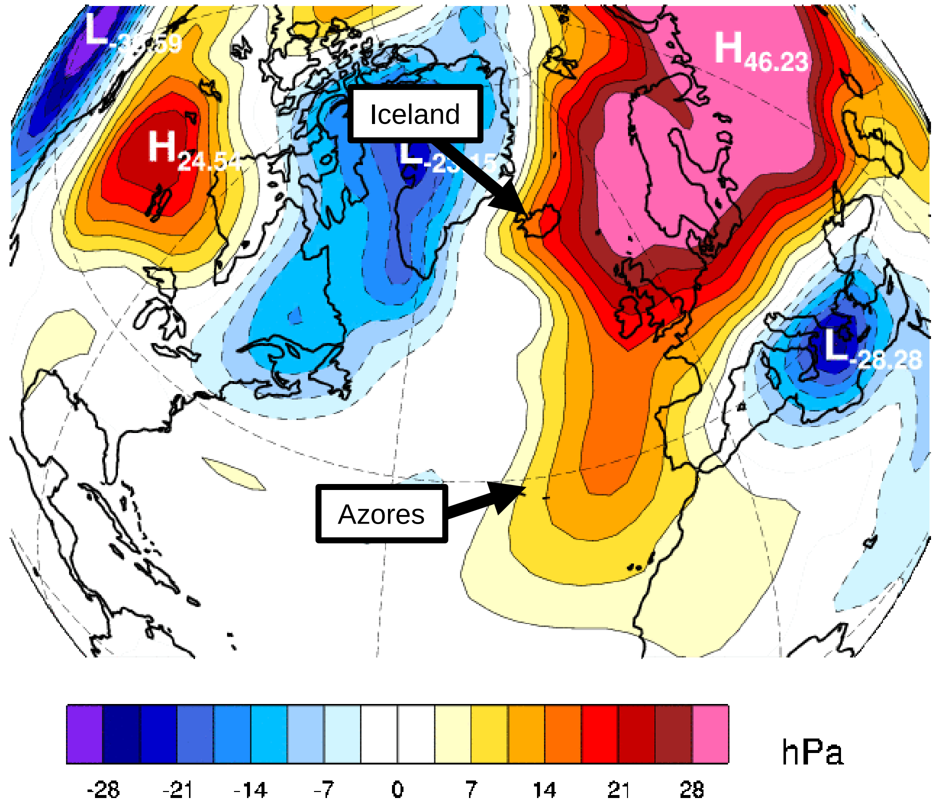
Rather barotropic ...

Mardi 7 Fevrier 2012, 12h



Anomalous Geopotential Height anomaly at 500hPa

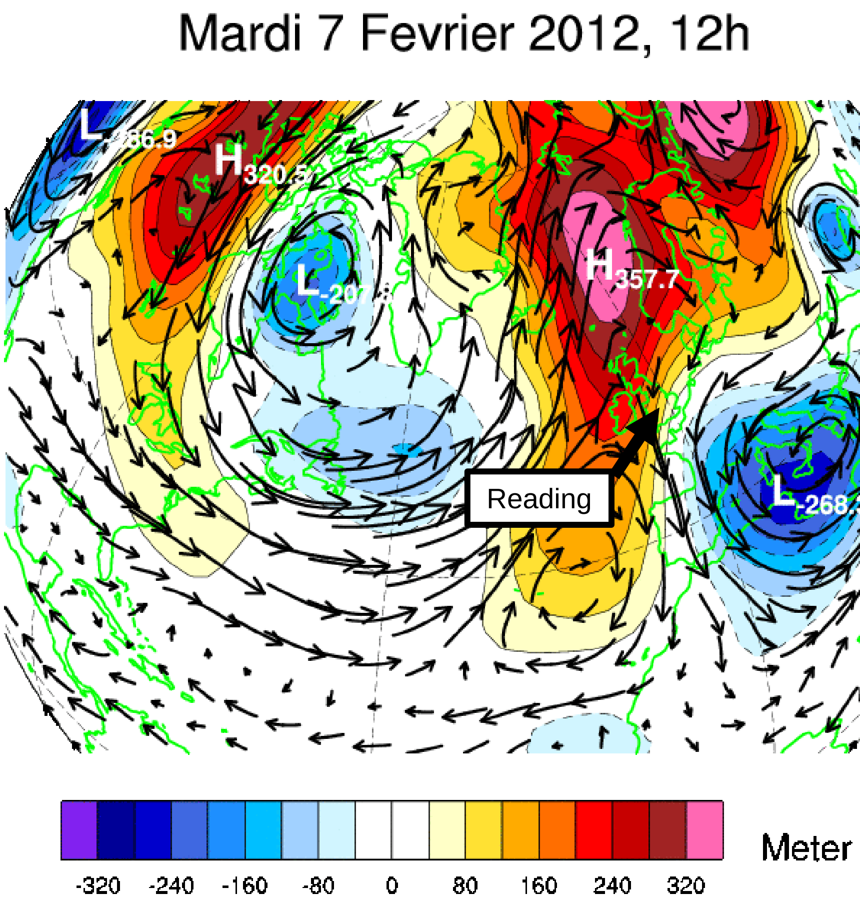
Mardi 7 Fevrier 2012



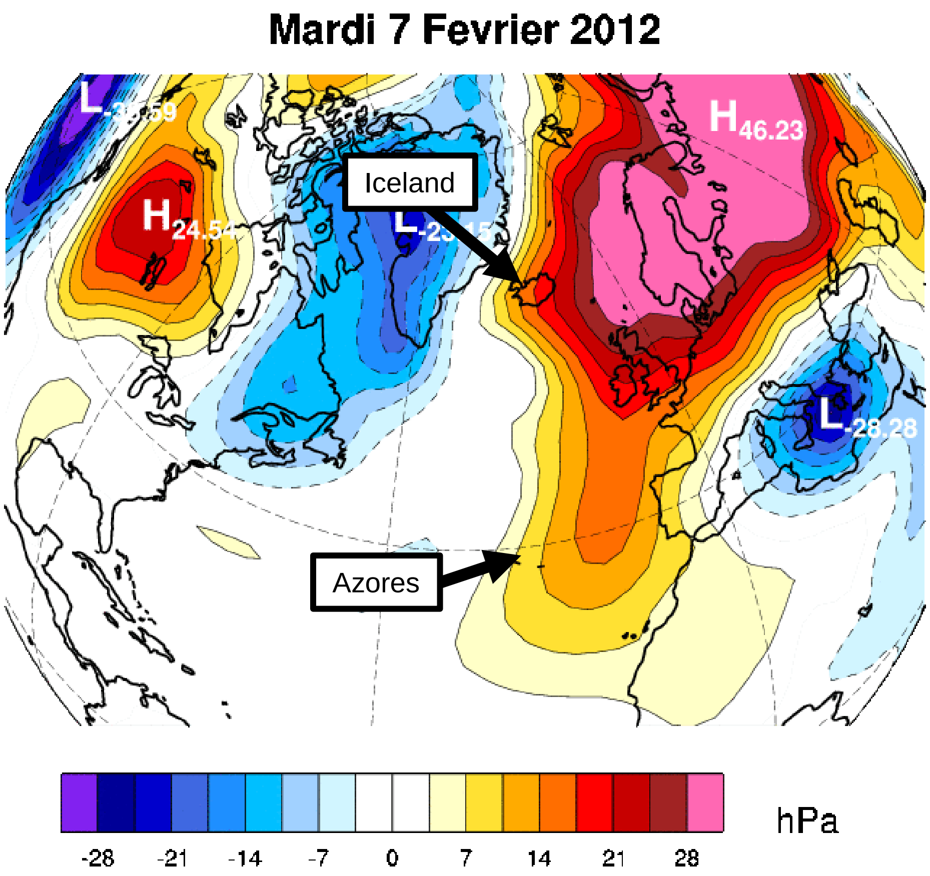
Anomalous Mean Sea Level Pressure

Source: Operational ECMWF analysis

… and rather geostrophic : the Moscow-Paris express

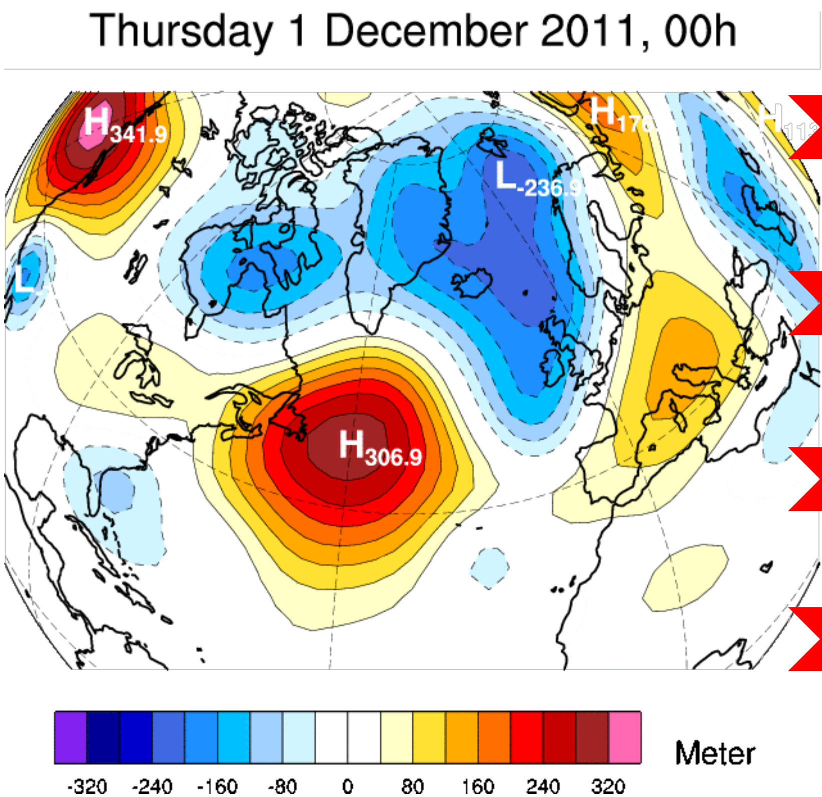


700 hPa wind circulation + anomalous Z500



Anomalous Mean Sea Level Pressure

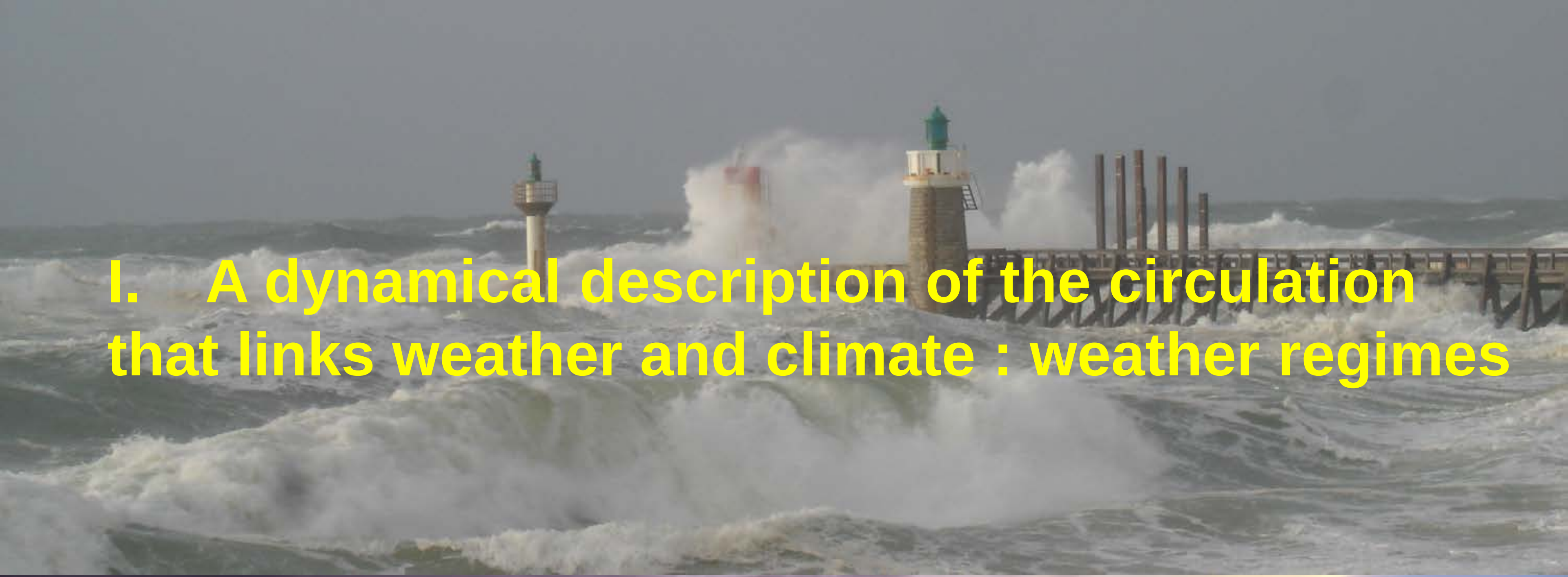
Last winter circulation (2011-2012)



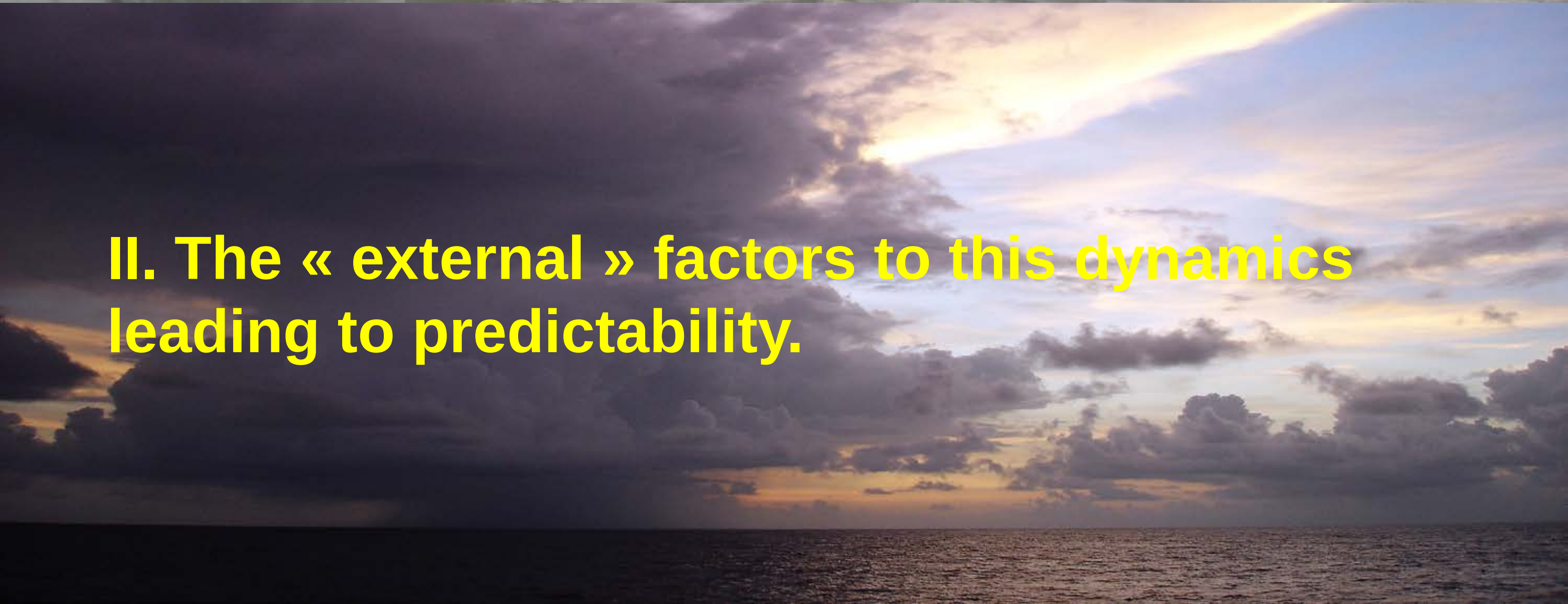
- Variety of spatial scales (synoptic + teleconnections)
- Propagation along the mean westerlies … or retrograde propagation
- Existence of quasi-stationary entities
- Orographic perturbations (e.g. Groenland)
- Etc………

A rather complex picture.
Goal of the seminar : is there any predictability of the atmospheric North Atlantic/Europe daily variability from intra-seasonal to interannual timescale?

Source: Operational ECMWF analysis



I. A dynamical description of the circulation that links weather and climate : weather regimes

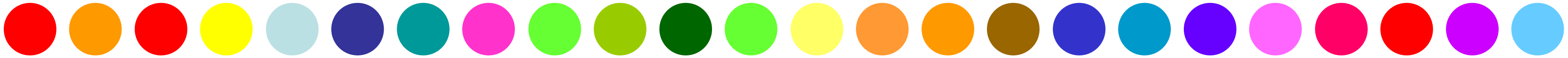


II. The « external » factors to this dynamics leading to predictability.

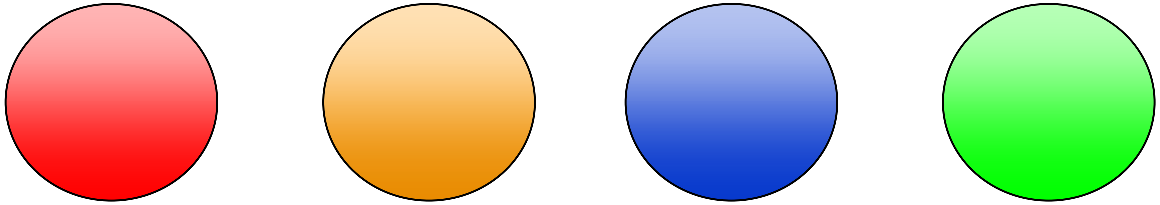
Clustering techniques

Determination of the weather regimes using classification algorithms

Ex: Geopotential at 500 hPa over the North-Atlantic/Europe region for winter days over 1957-2011 (NCEP-NCAR)



Predetermined choice of the *k*-number of clusters based on statistical test assessing the stability of the partition.



Optimal classification: Maximization of the inter-regime variance

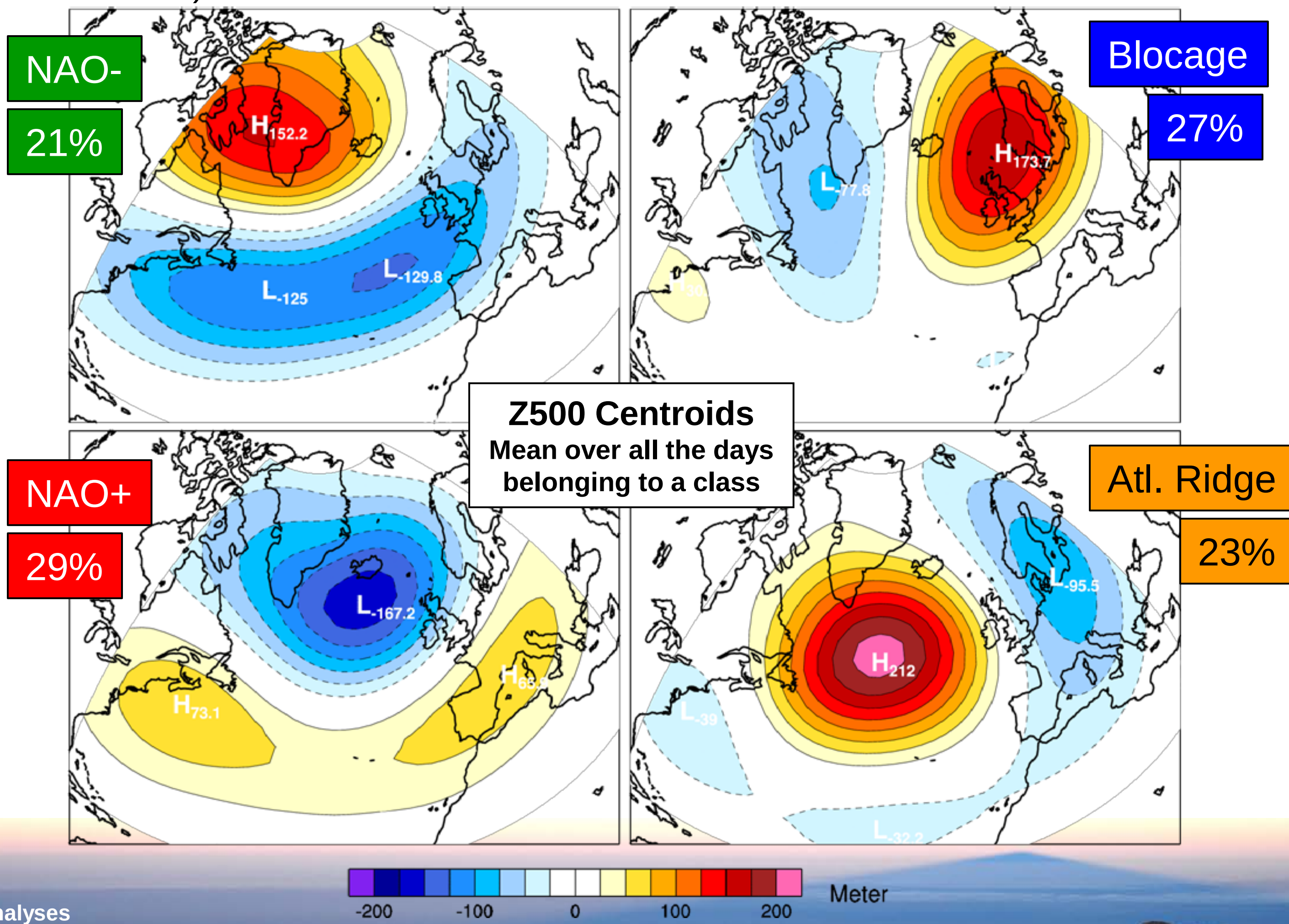
AND minimisation of the *intra*-régime variance

Source: Michelangeli et al (JAS, 1995) among others

The 4 wintertime weather regimes over the North-Atl. Europe region

Weather regimes = Elementary bricks of the large-scale atmospheric circulations in the Extratropics that are spatially well-defined, recurrent and have a lifetime in the order of 5-10 days (i.e. persistent)

Weather regimes = Efficient reading grid to simplify complex dynamics (existence of several spatio-temporal scale entities).



Source: NCEP Reanalyses

Source: Michelangeli et al (JAS, 1995) Vautard (JAS 1990) Molteni et al (1993),among others

Literature

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

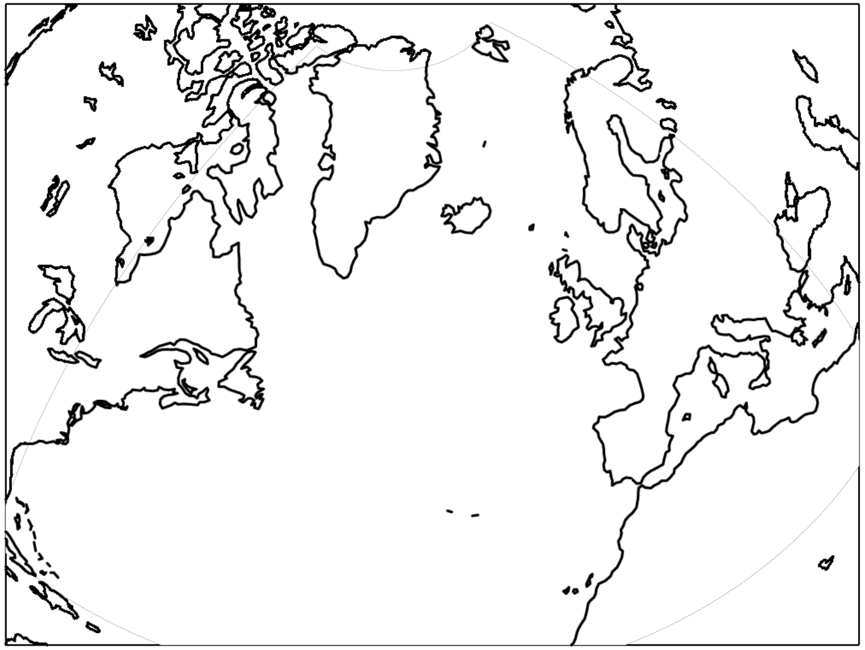
- **non-existence of multimodality (Stephenson et al 2004)**
- **“how may clusters?” (Christiansen 2007) : dependence on the algorithm and the period**

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

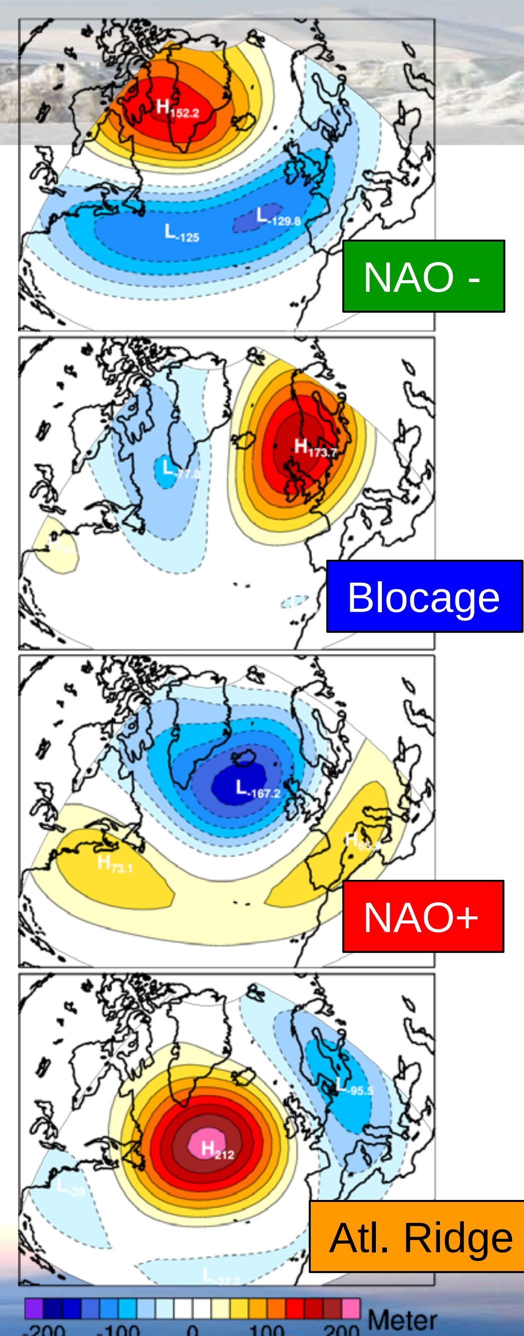
- **Statistical downscaling (see Christiansen et al 2007 for a review)**
- **Statistical-dynamical downscaling (e.g. for the ocean, Cassou et al 2010, Minvielle et al 2010)**
- **Seasonal forecast (EUROSIP etc.)**

Daily classification

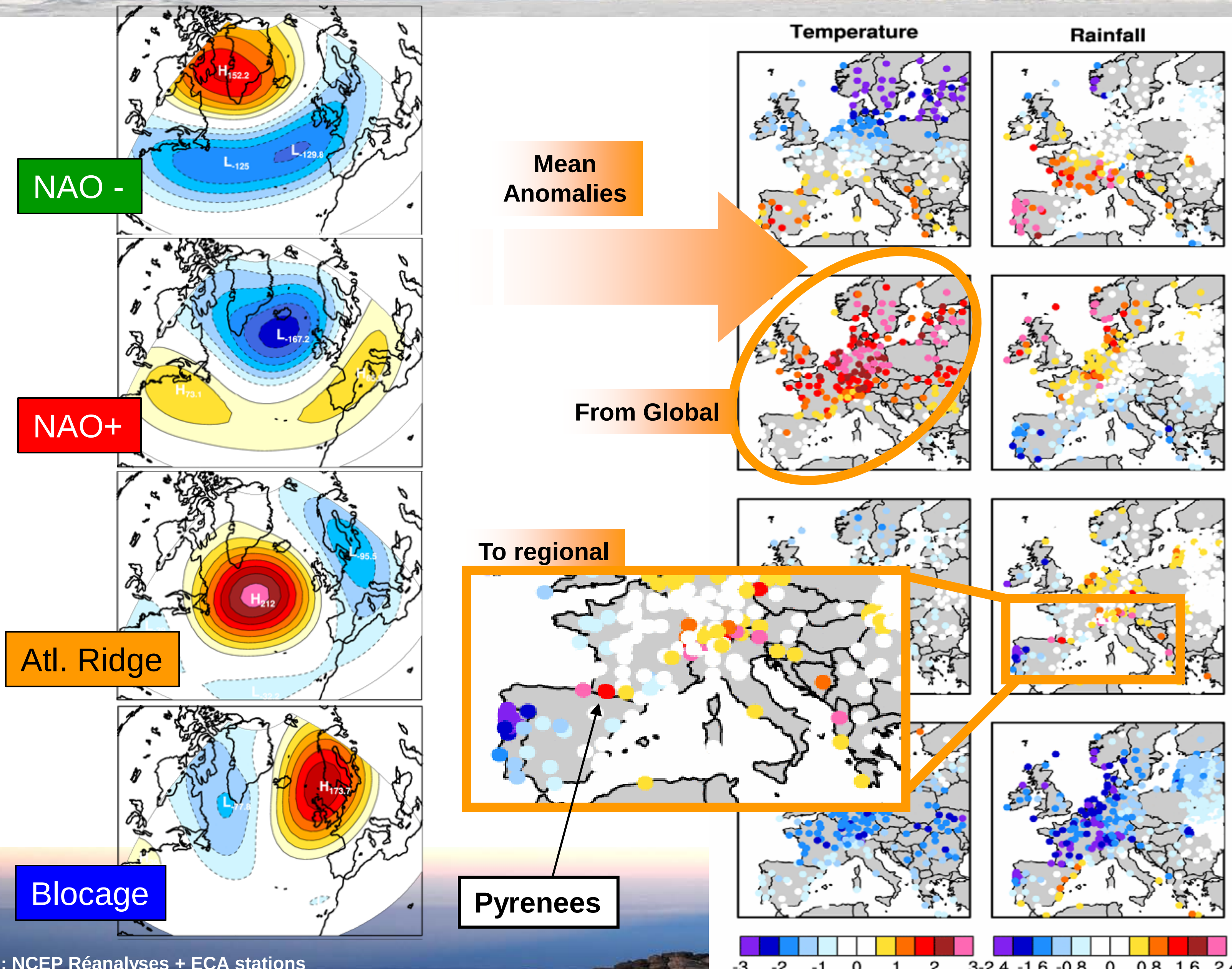
Reload



NAO- Blocking NAO+ Atl. Ridge

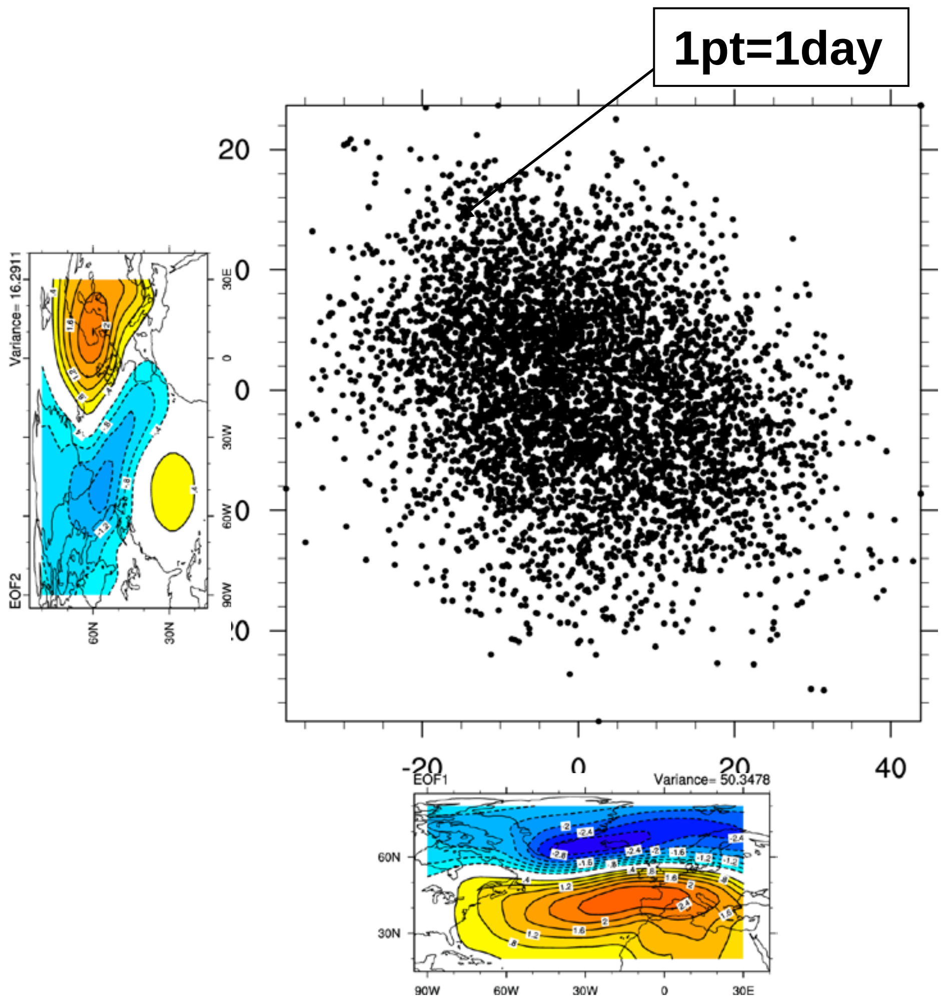


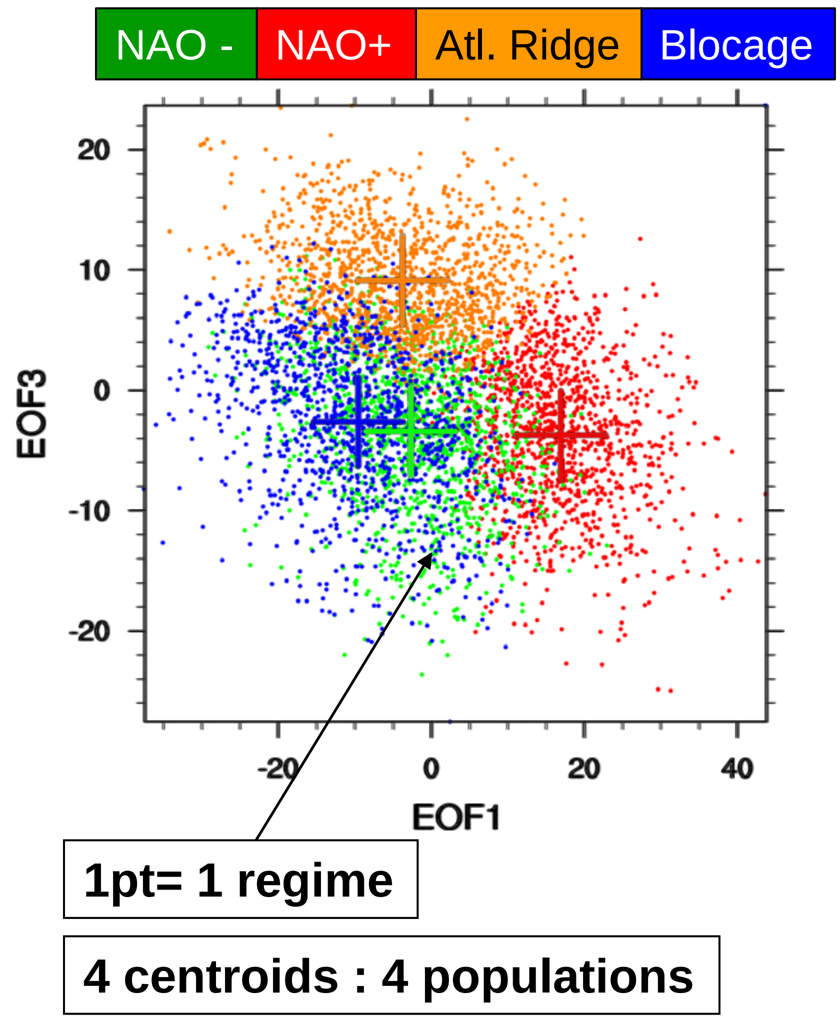
Links Regimes / Temperatures / Precipitation : The mean



Source: NCEP Réanalyses + ECA stations

A simplified view in the EOF phase space





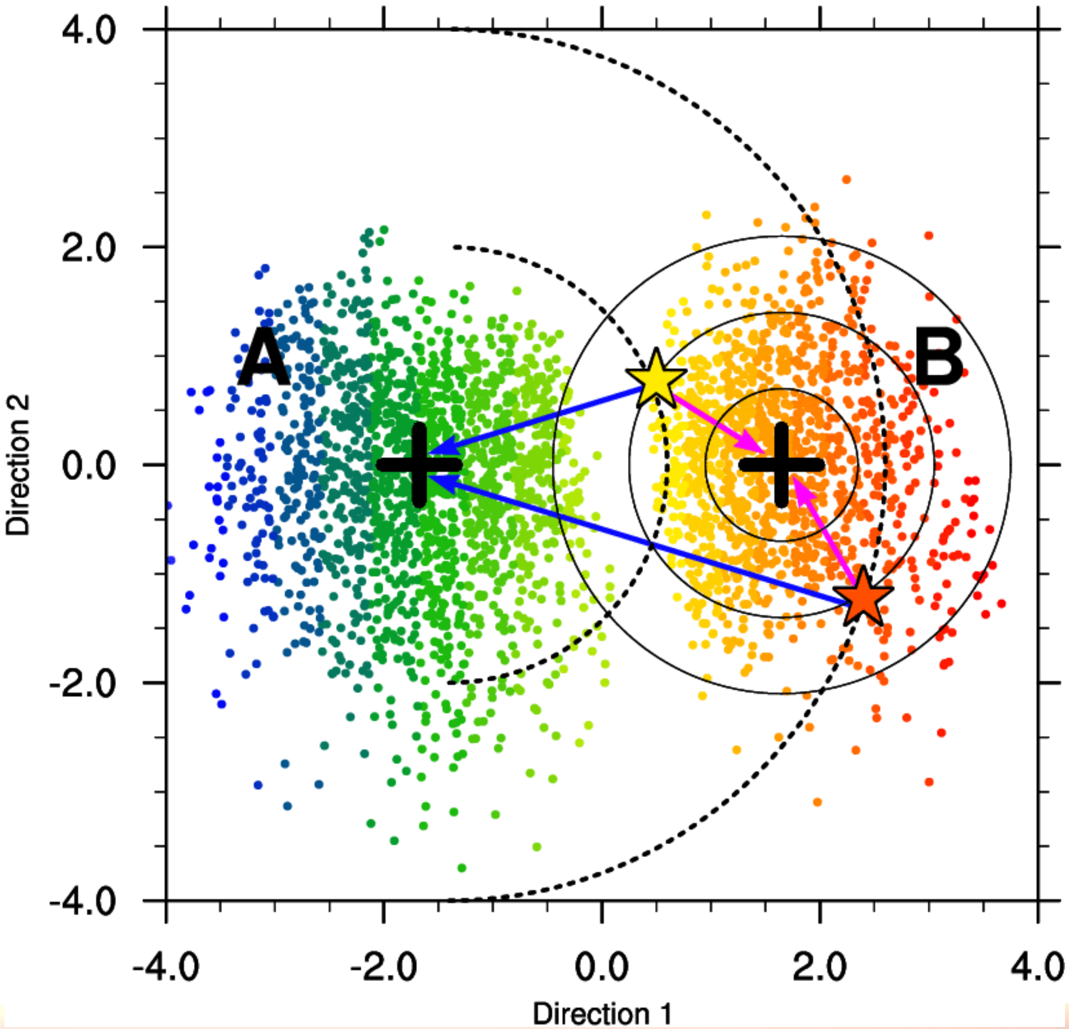
The circulation in a « cube »

TODAY (weather forecast),

THIS WEEK (monthly forecast),

THIS WINTER (seasonal forecast)

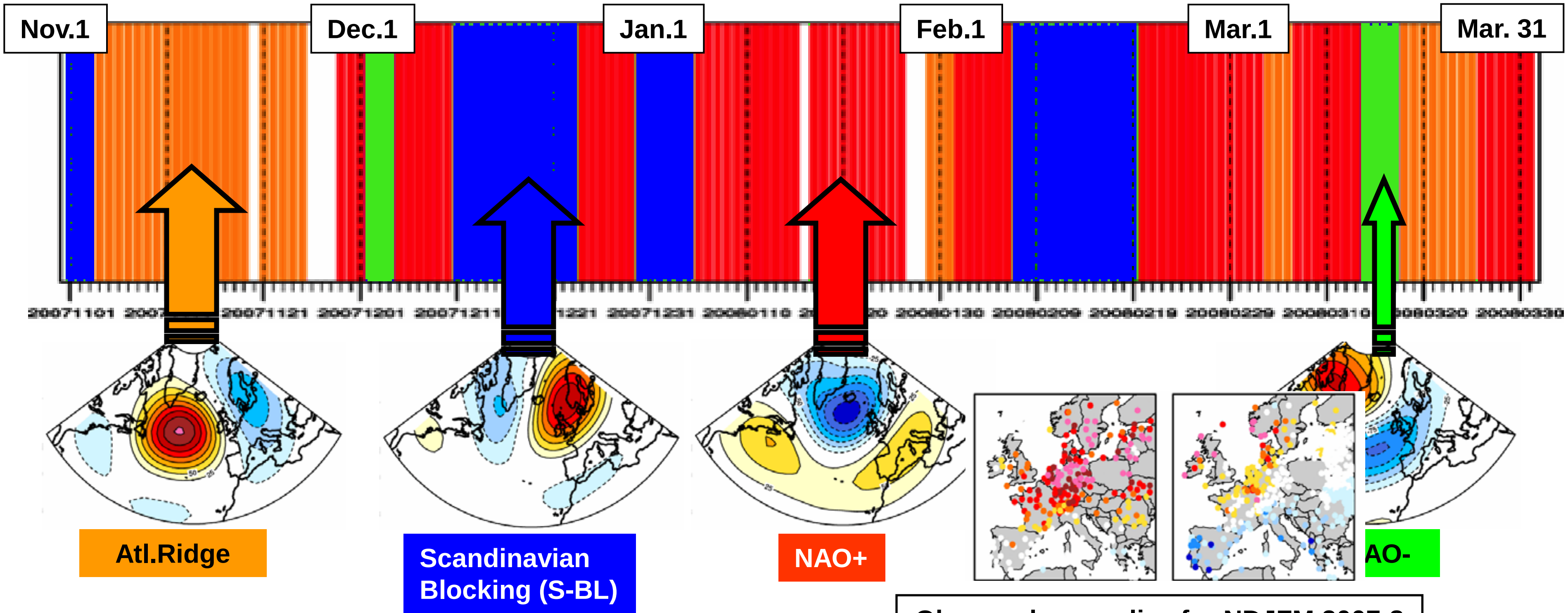
Summary

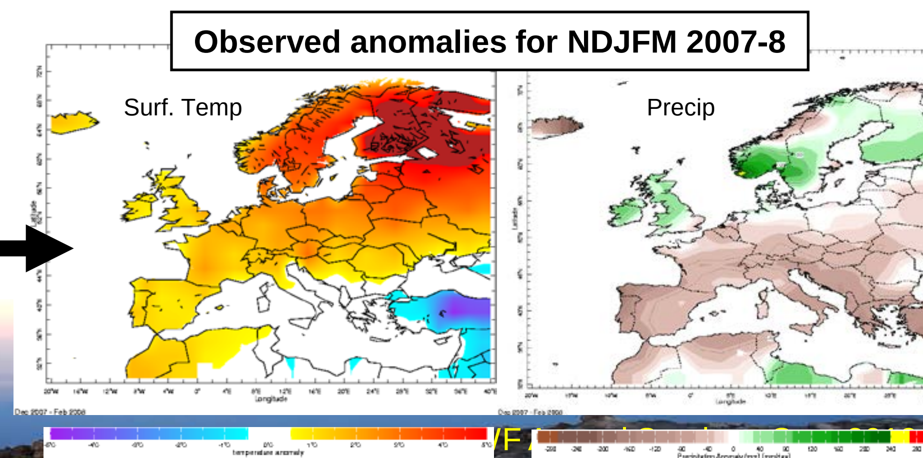


Source: Cassou et al (2011, Clim.Dyn)

Interannual variability = temporal integration of daily occurrence

Winter 2007-2008





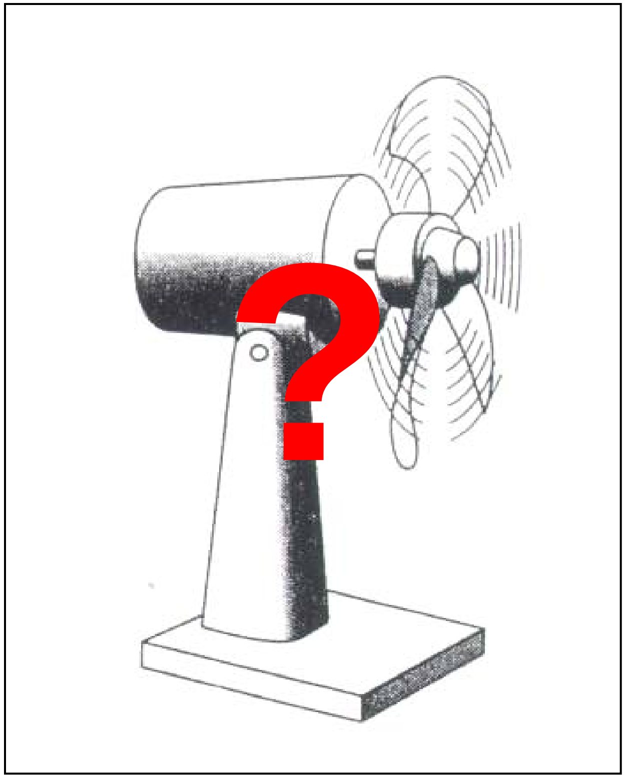
Σ **Statistics:**

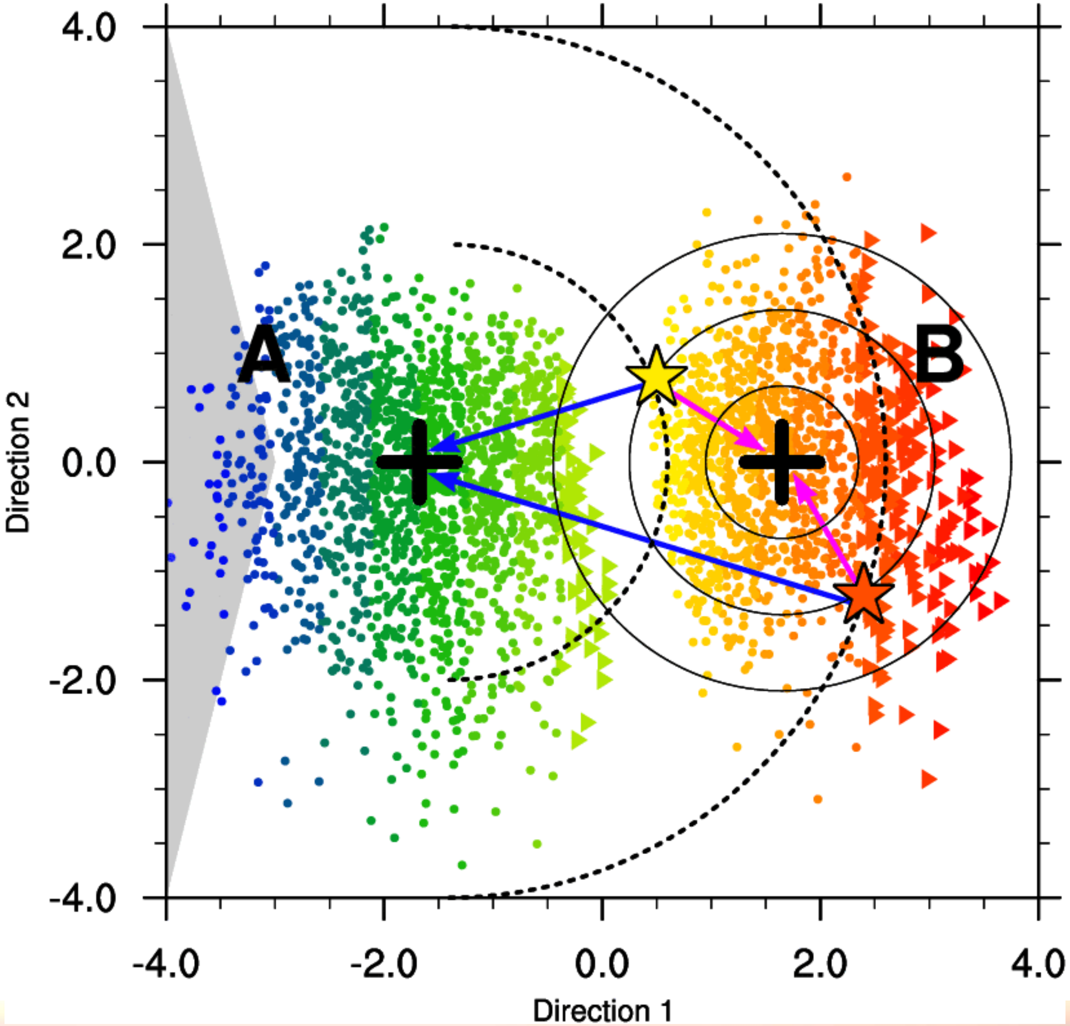
NAO+ : +62%, AR:+16%,

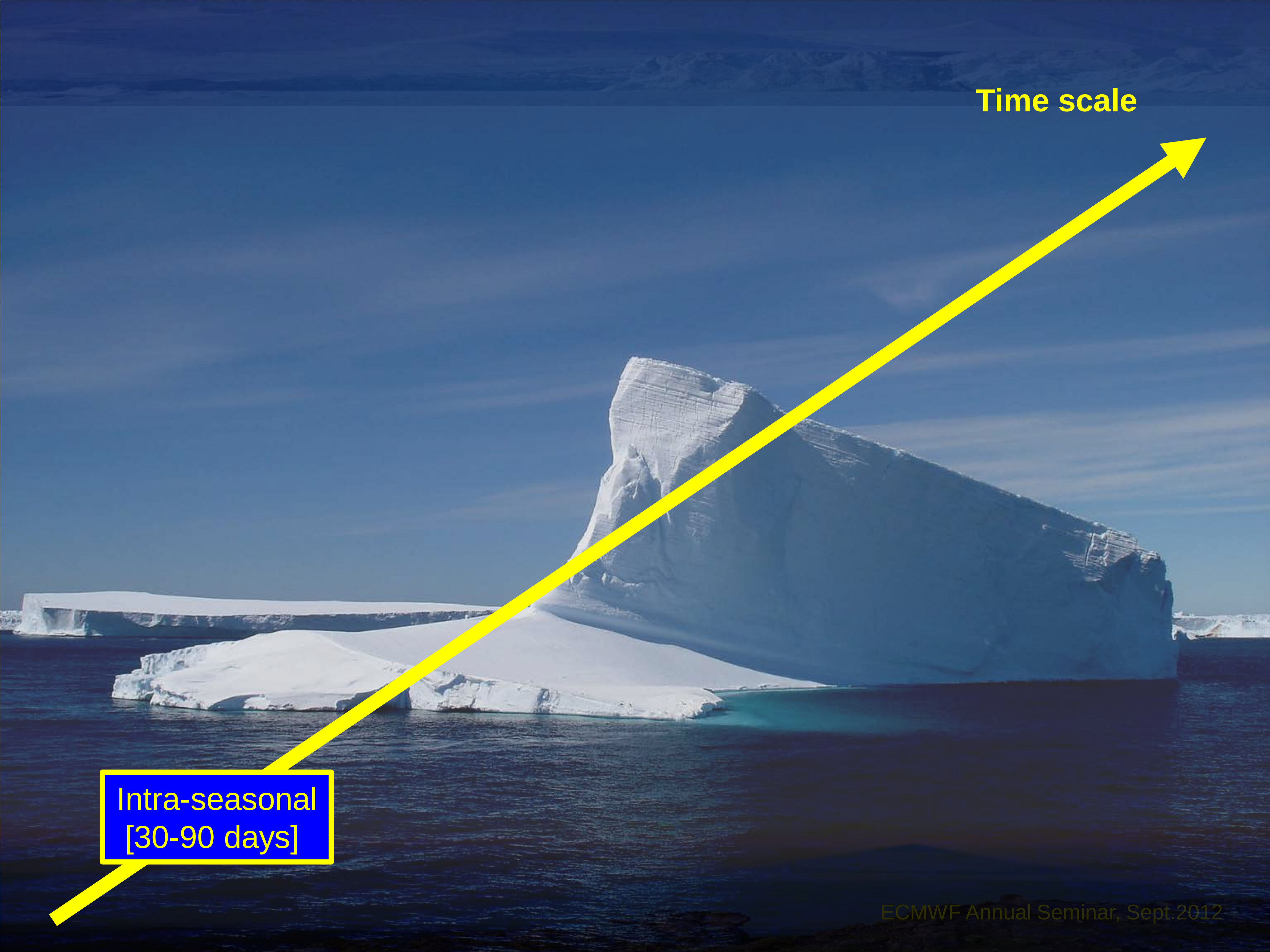
NAO- : -75%, BL:-3%

Interannual variability=time integration of higher frequency fluctuations

A fan…

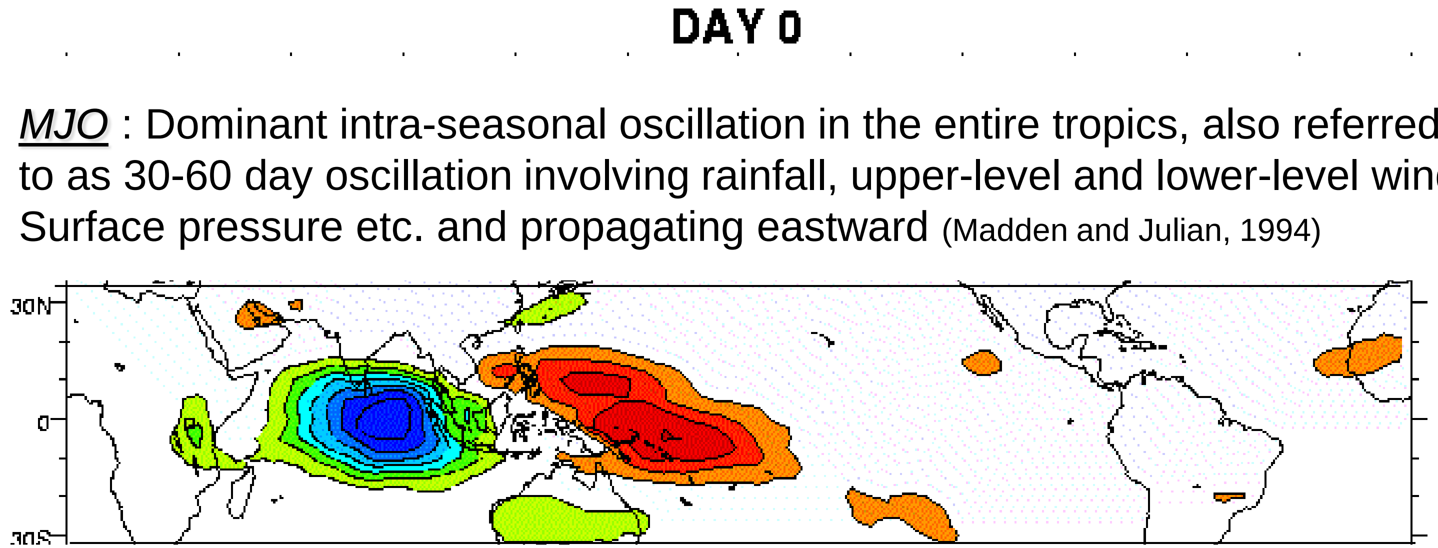


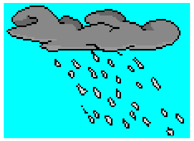


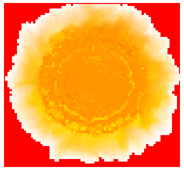

Time scale
Intra-seasonal
[30-90 days]
ECMWF Annual Seminar, Sept.2012

The Madden-Julian Oscillation (MJO)

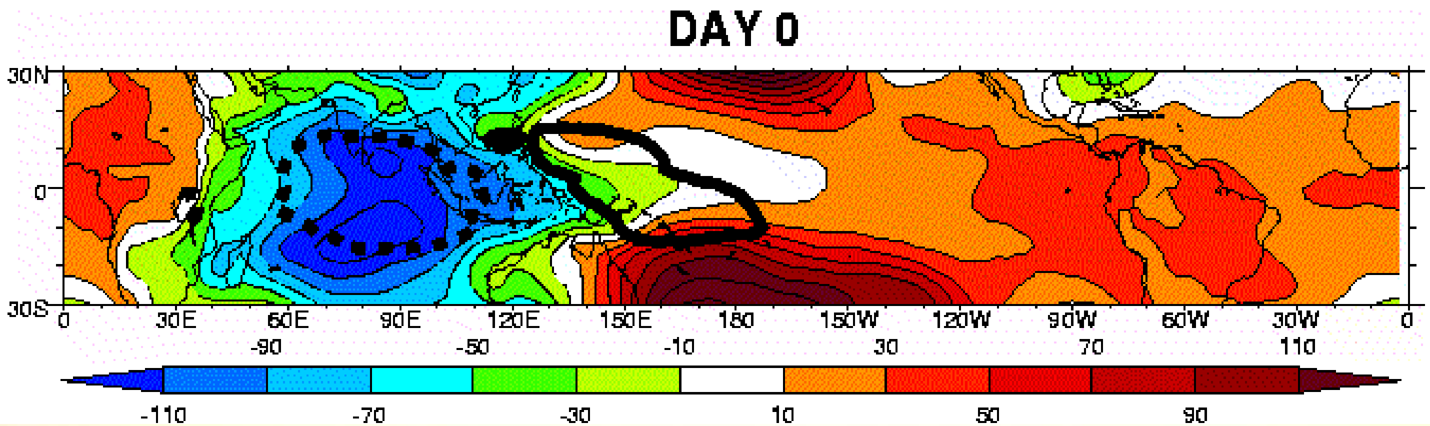
MJO : Dominant intra-seasonal oscillation in the entire tropics, also referred to as 30-60 day oscillation involving rainfall, upper-level and lower-level wind, Surface pressure etc. and propagating eastward (Madden and Julian, 1994)







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}.

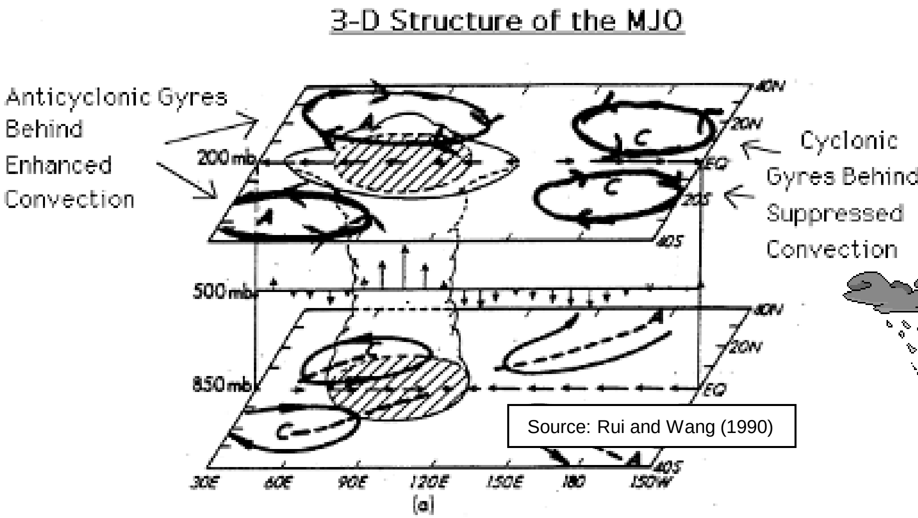


Low

High

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

The 8 phases of the MJO

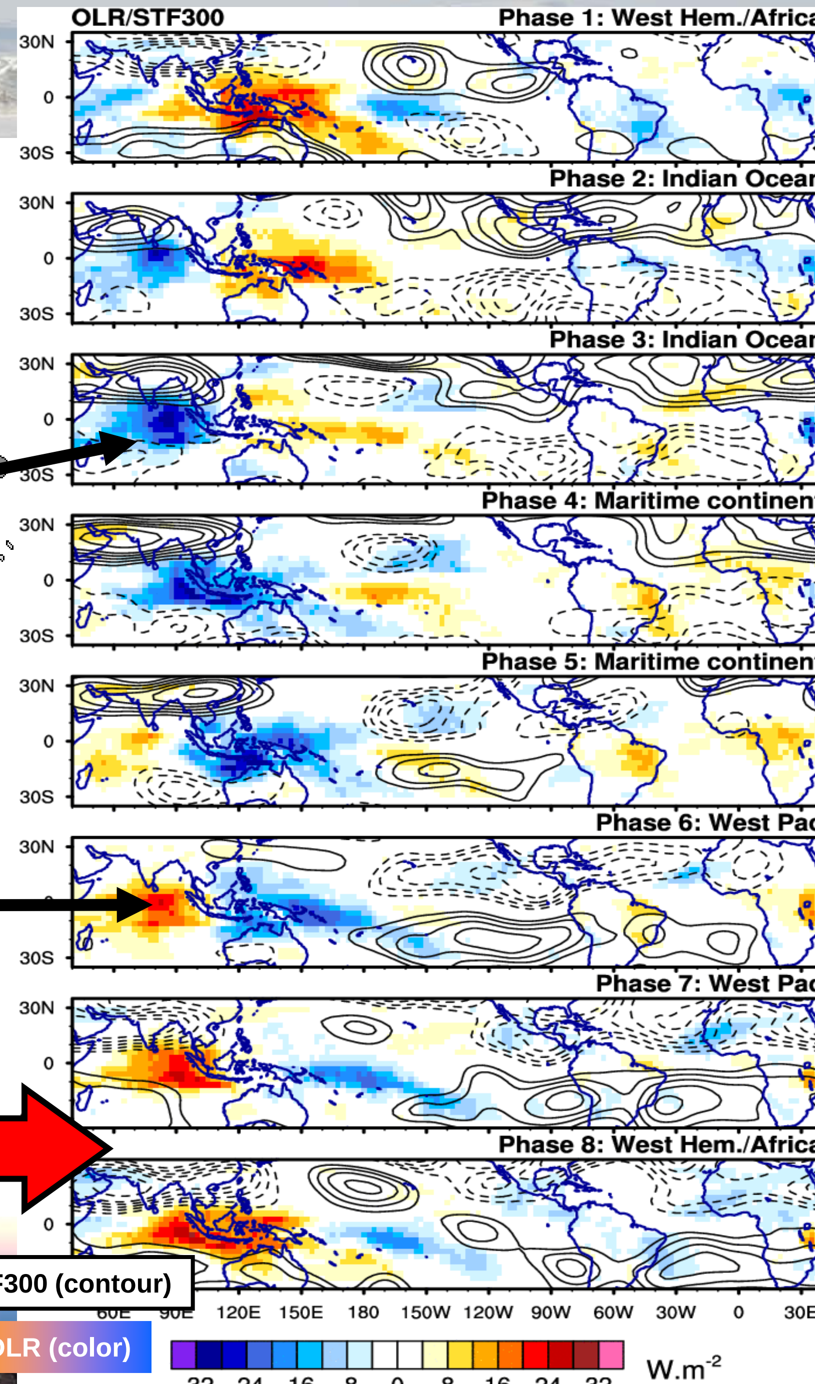


Method: Principal component analysis combining Outgoing Longwave Radiation (OLR, proxy for convection), and 850hPa and 200hPa NCEP-NCAR reanalyses

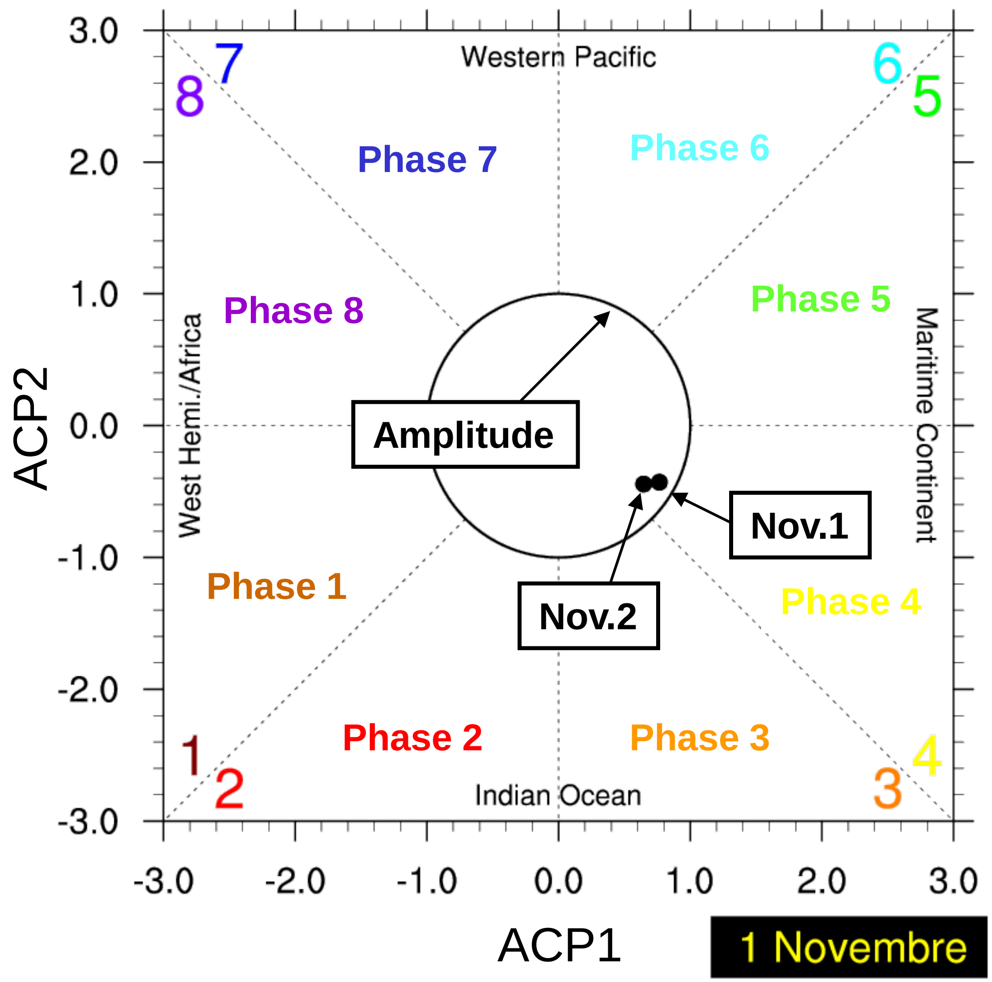
(Source: Wheeler and Hendon, MWR-2004)

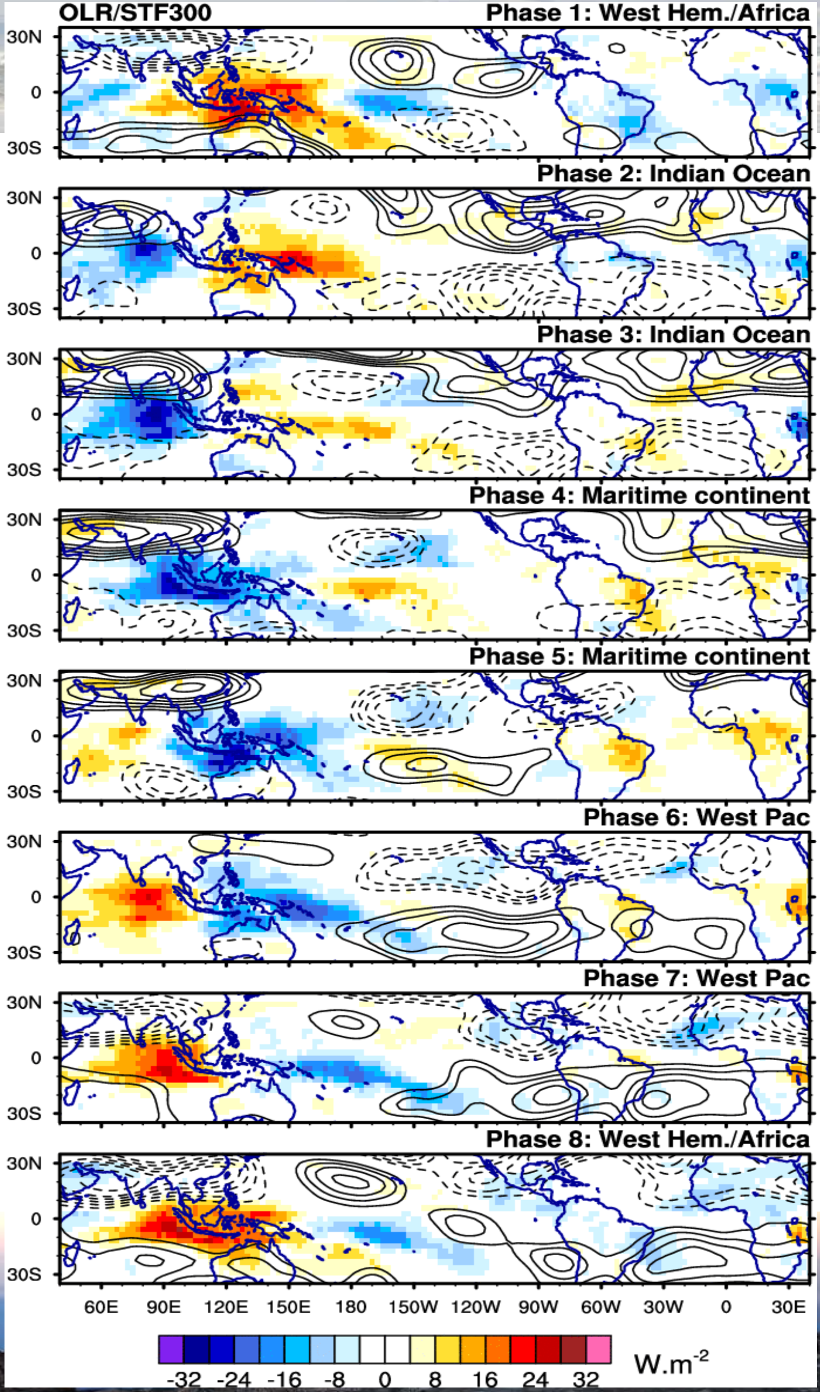
Data : http://www.bom.gov.au/bmrc/clfor/cfstaff/matw/maproom/RMM/

8 centroids (analogy with extratropical regimes) or 8 phases
Nominal duration: 7-8 days



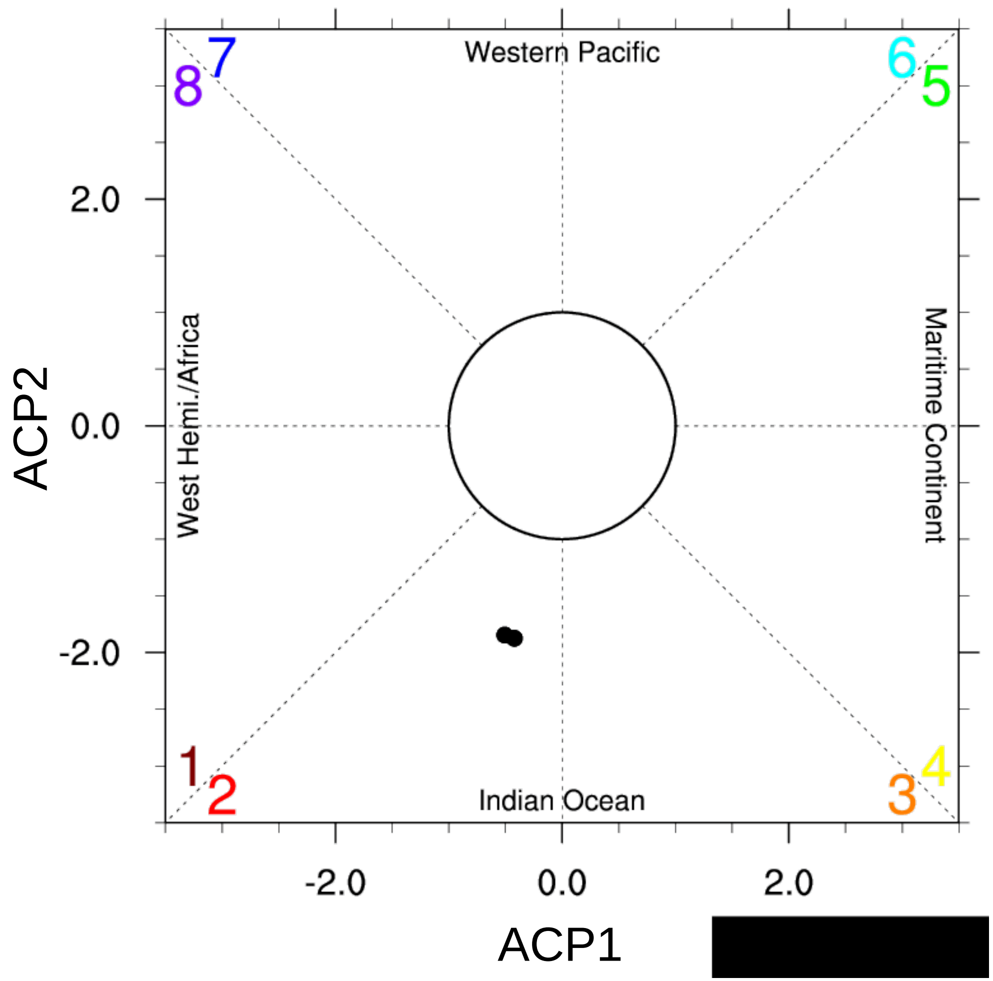
The MJO in the EOF space

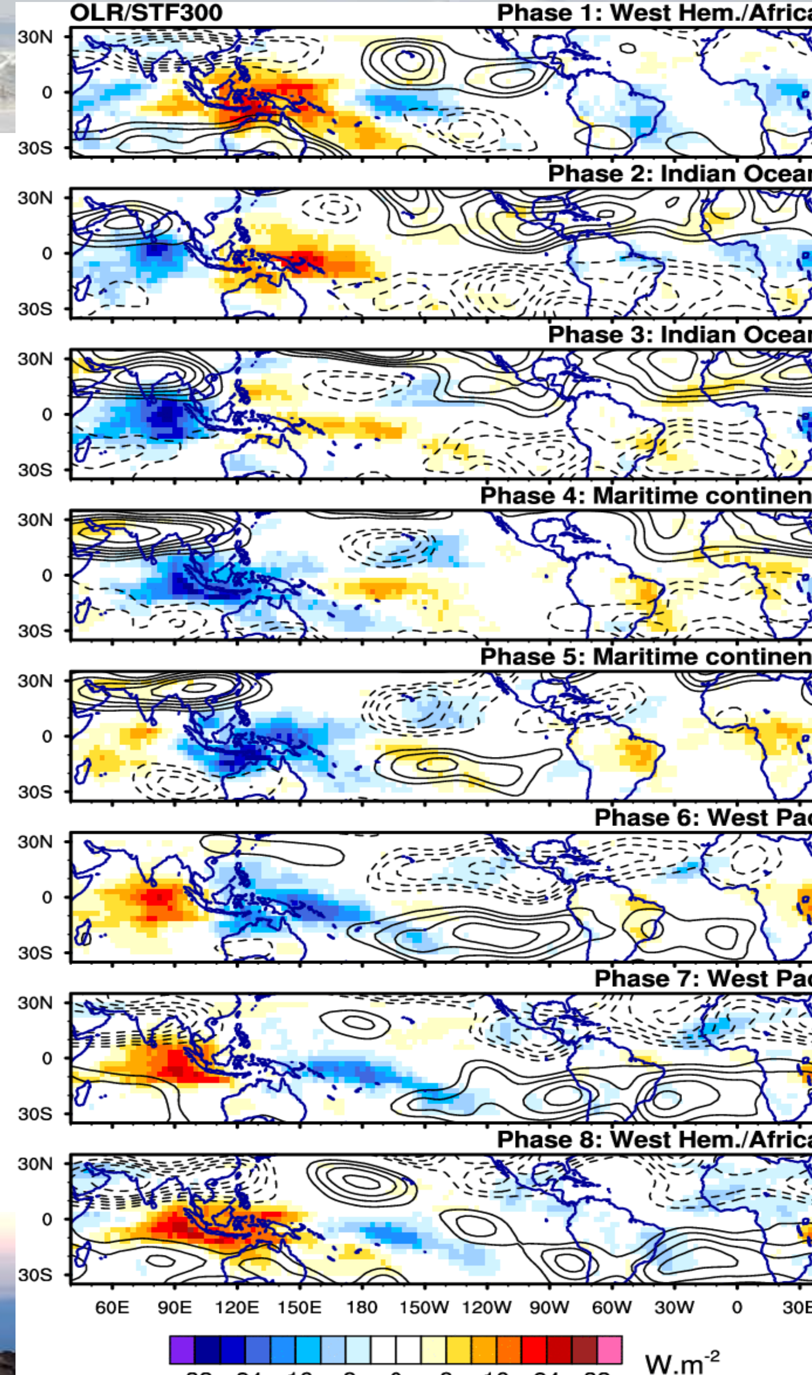




The 8 phases can be spanned in the 2 first EOFs
From combined thermodynamical (OLR) and dynamical (NCEP) fields

The 2011-2012 winter : an active one

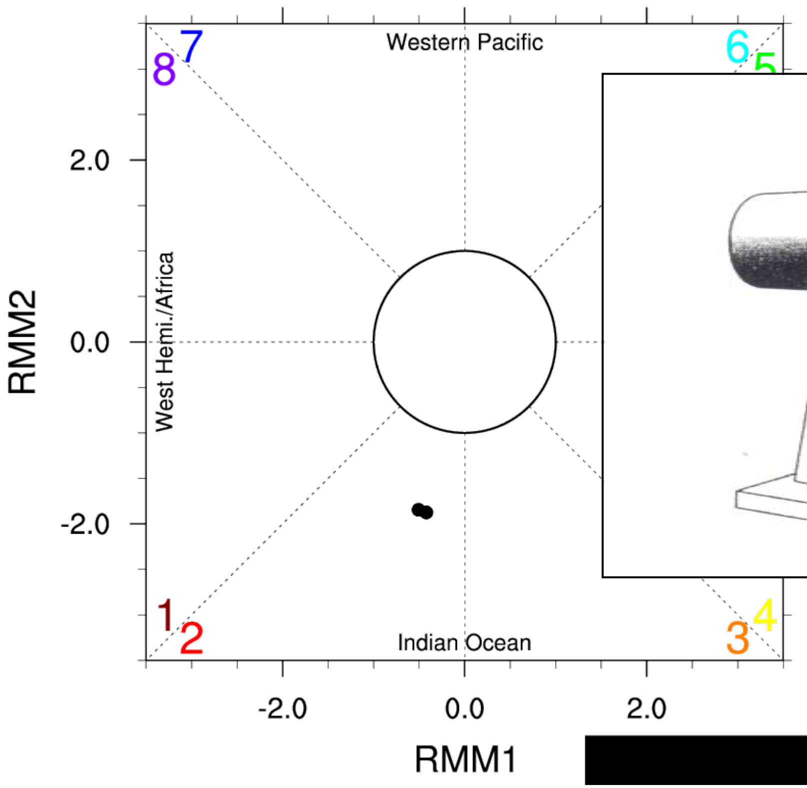




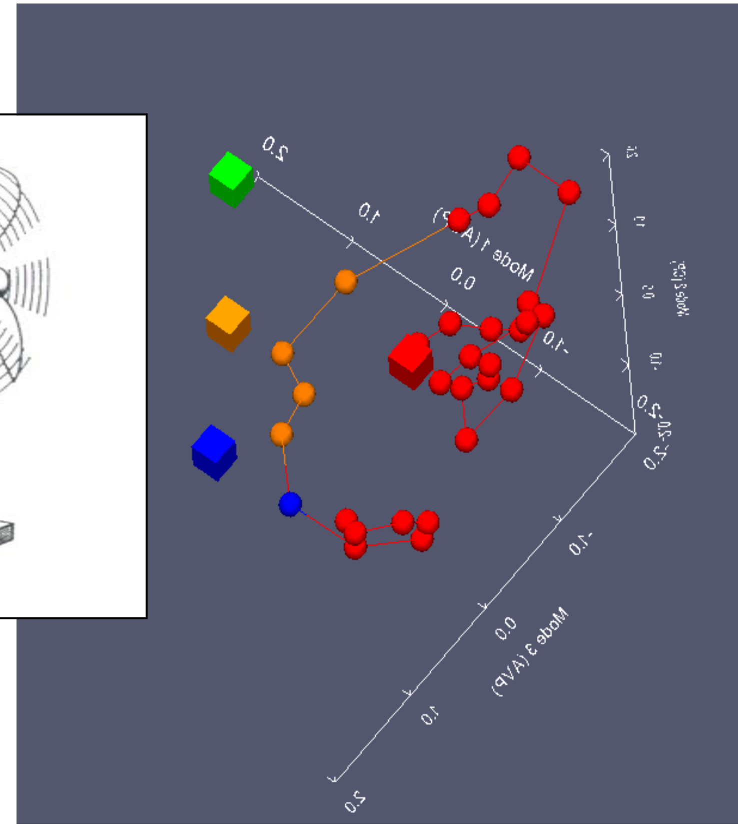
The 8 phases can be spanned in the 2 first EOFs
From combined thermodynamical (OLR) and dynamical (NCEP) fields

MJO, a fan at intraseasonal timescale ?

QUASI-OSCILLATORY
Madden-Julian Oscillation



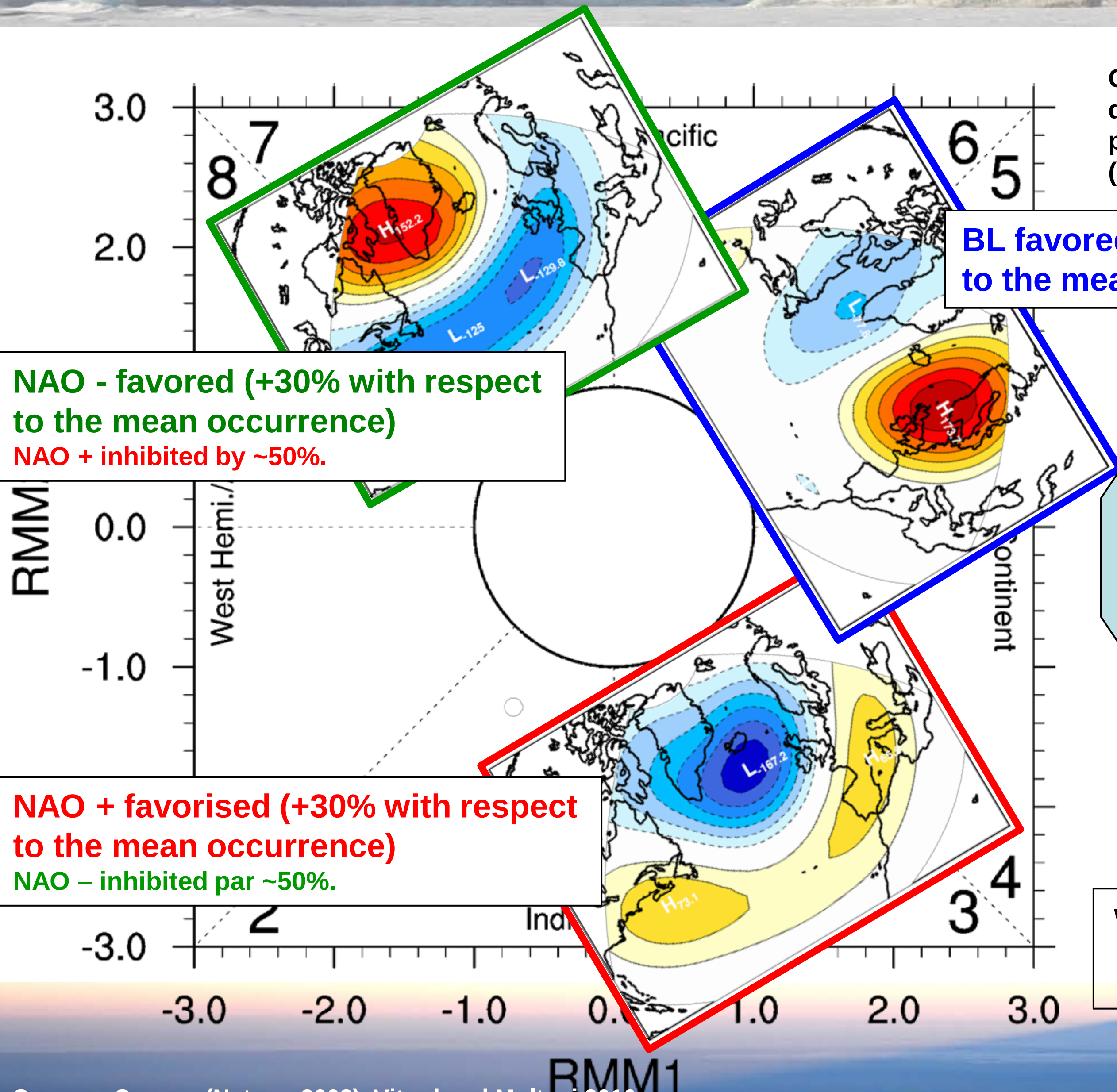
EPISODIC
North Atlantic regimes



Does the MJO influence the occurrence of the weather regimes?
Is, by which mechanims?

The MJO as a precursor for some regimes

Cohérent avec le cycle a 40 jours dans les régimes et les transitions privilégiées : NAO+ → BL → NAO- (Vautard 1990)



NAO - favored (+30% with respect to the mean occurrence)
NAO + inhibited by ~50%.

BL favored (+15% with respect to the mean occurrence)

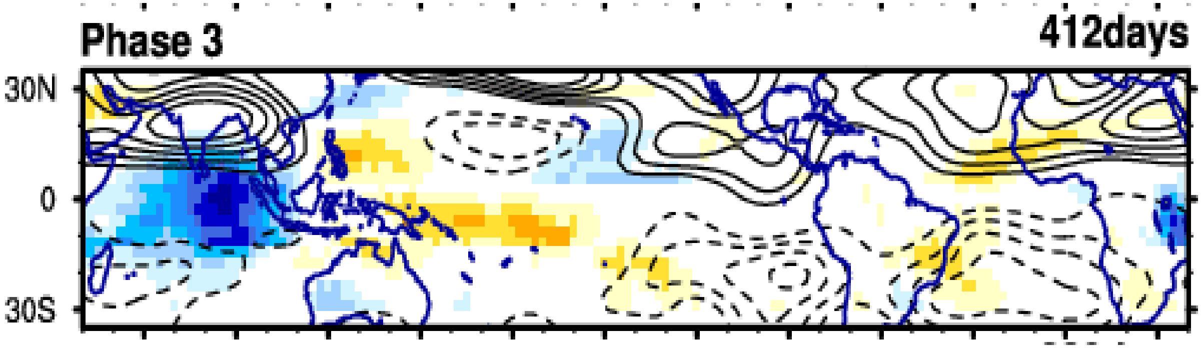
NAO + favorised (+30% with respect to the mean occurrence)
NAO – inhibited par ~50%.

MJO leading by 5 to 10 days the weather regime response

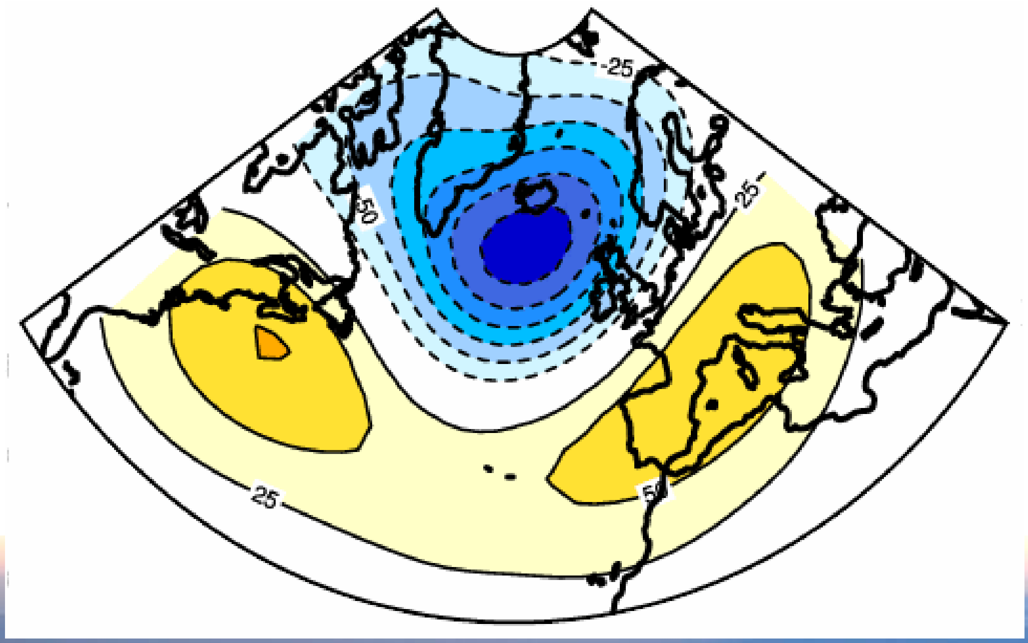
Window of opportunity for monthly forecast

Source : Cassou (Nature, 2008), Vitard and Molteni 2010.

Mechanism for teleconnection (MJO-NAO+)

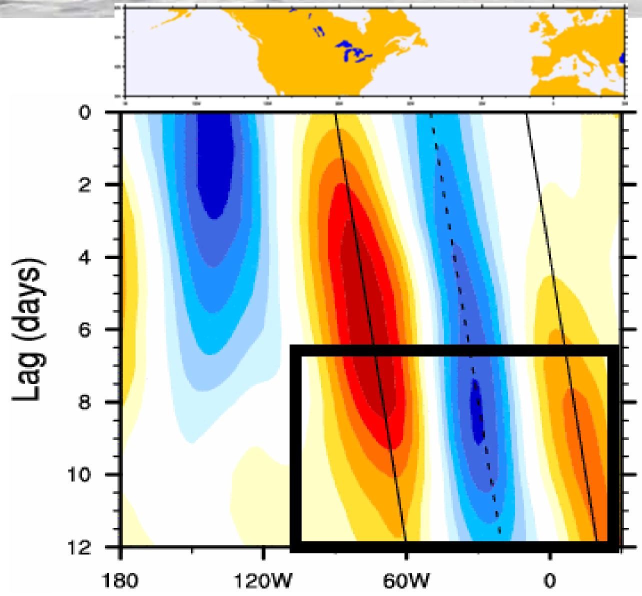


MJO Phase 3



NAO+ regime

Low frequency wave along the westerly wave guide



Z500 lagged composites[40ºN-55ºN]

MJO Phase 3/NAO+

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

Rossby wave + synoptic storms

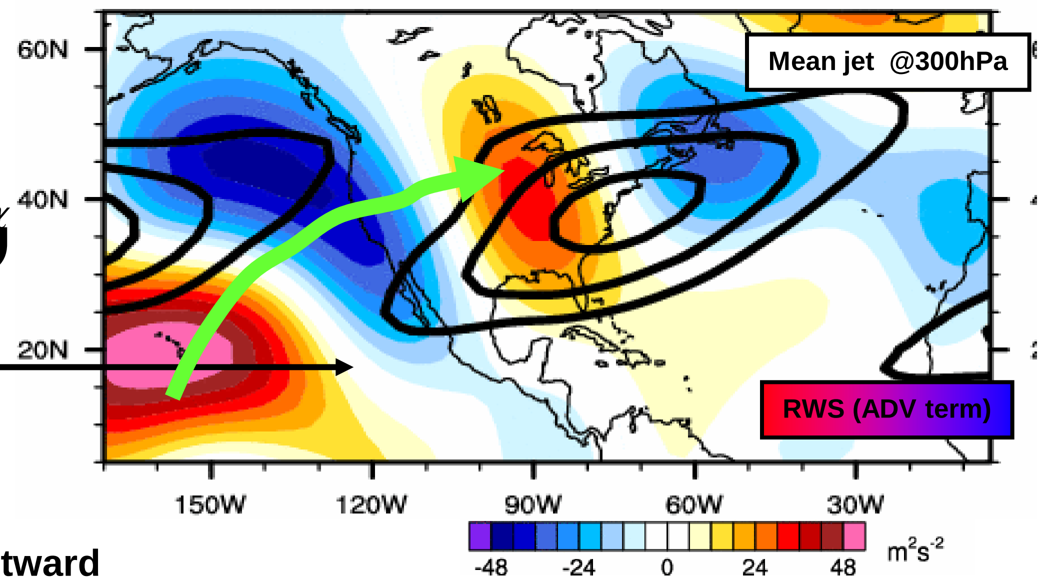
Rossby wave source:

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

Advection term — Stretching term

(Qin and Robinson, JAS, 1993)

Averaged anomalies From lag 0 to lag +5

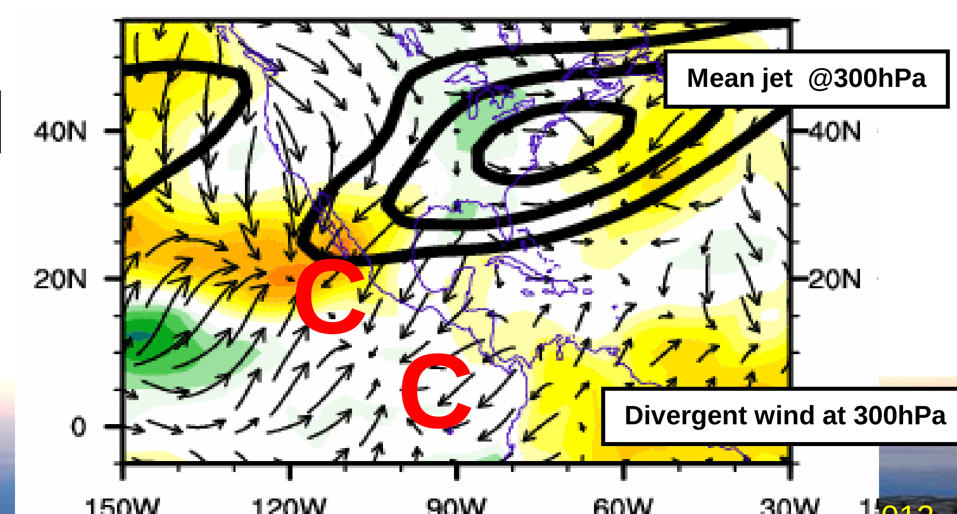


- Strong Rossby Wave Source in the Central Pacific propagating Northeastward

MJO Phase 3/NAO+

Precipitable water (color)/Divergent wind @300hpa

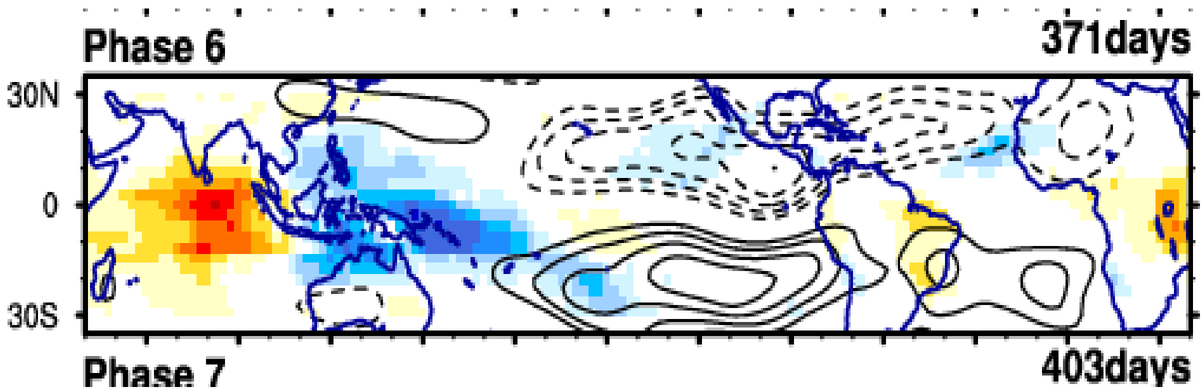
Averaged anomalies From lag 0 to lag +5



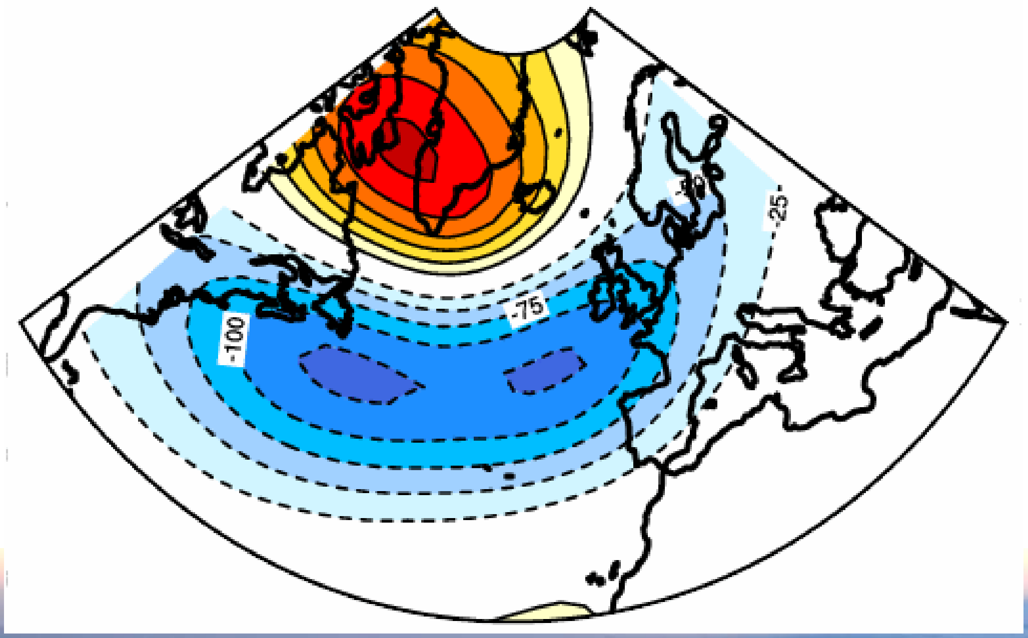
- Strong upper-level convergence on the Eastern Pacific and at the entrance of the Mean North Atlantic jet
- Dry conditions at the entrance of the jet
- Inhibition of the storm formation

Source : Cassou (Nature, 2008)
Lin et al (JCLIM 2009), Riviere and Orlanski (2007)

Mechanism for teleconnection (MJO-NAO-)



MJO Phase 6



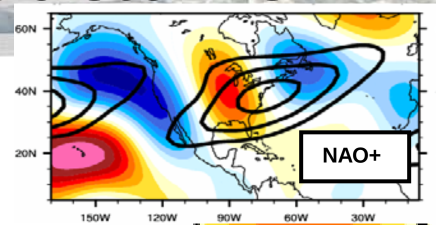
NAO- regime

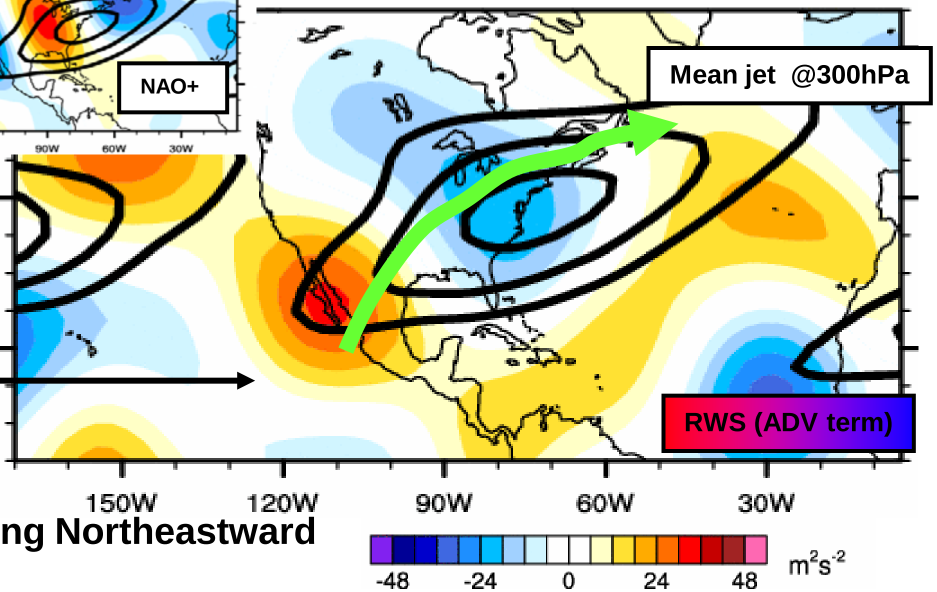
Rossby wave + synoptic storms

Rossby wave source:

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

Advection term **Stretching term**

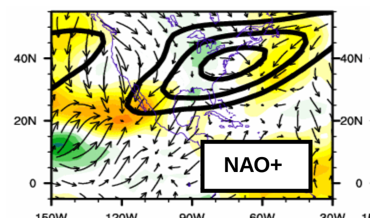




- **Moderate Rossby Wave Source in the Eastern Pacific/West Caribbean propagating Northeastward**

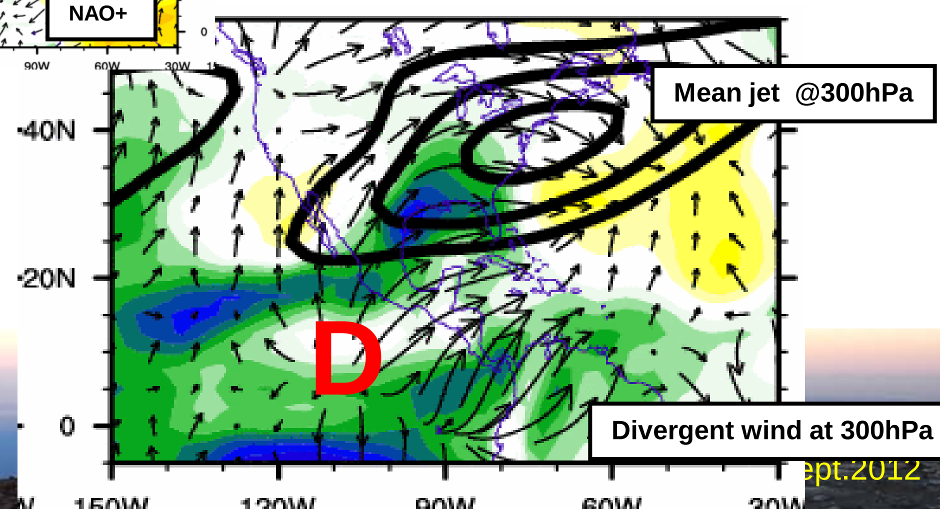
Ambrizzi and Hoskins (1997)

MJO Phase 6/NAO-



Averaged anomalies From lag 0 to lag +5

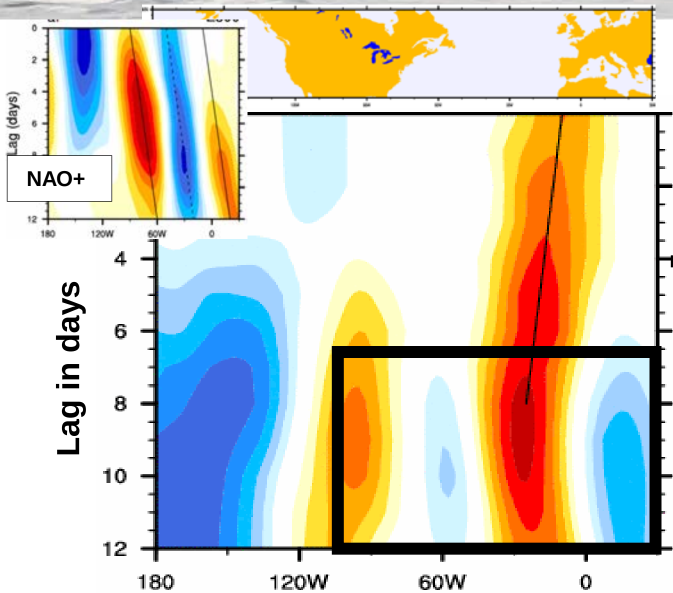
Precipitable water (color)/Divergent wind @300hpa



- **Strong upper-level divergence on the Eastern Pacific and convergence at the Equator side of the mean North Atlantic jet**
- **Wet conditions at the entrance of the jet**

Retrograde propagation + storm

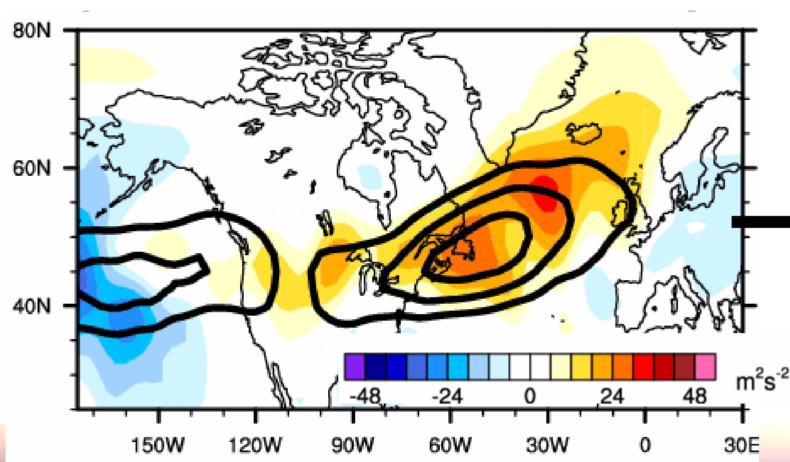
MJO Phase 6/NAO-



Z500 lagged composites[40ºN-55ºN]

Westward propagation of High from Europe to central Atlantic (Blocking favored occurrence)
Scherrer et al (2006),Vautard (1990)

Interaction with North Atlantic transients favoring Cyclonic Wave breaking leading to NAO- regime excitation (Role of high frequency eddies) Riviere and Orlanski (2007)

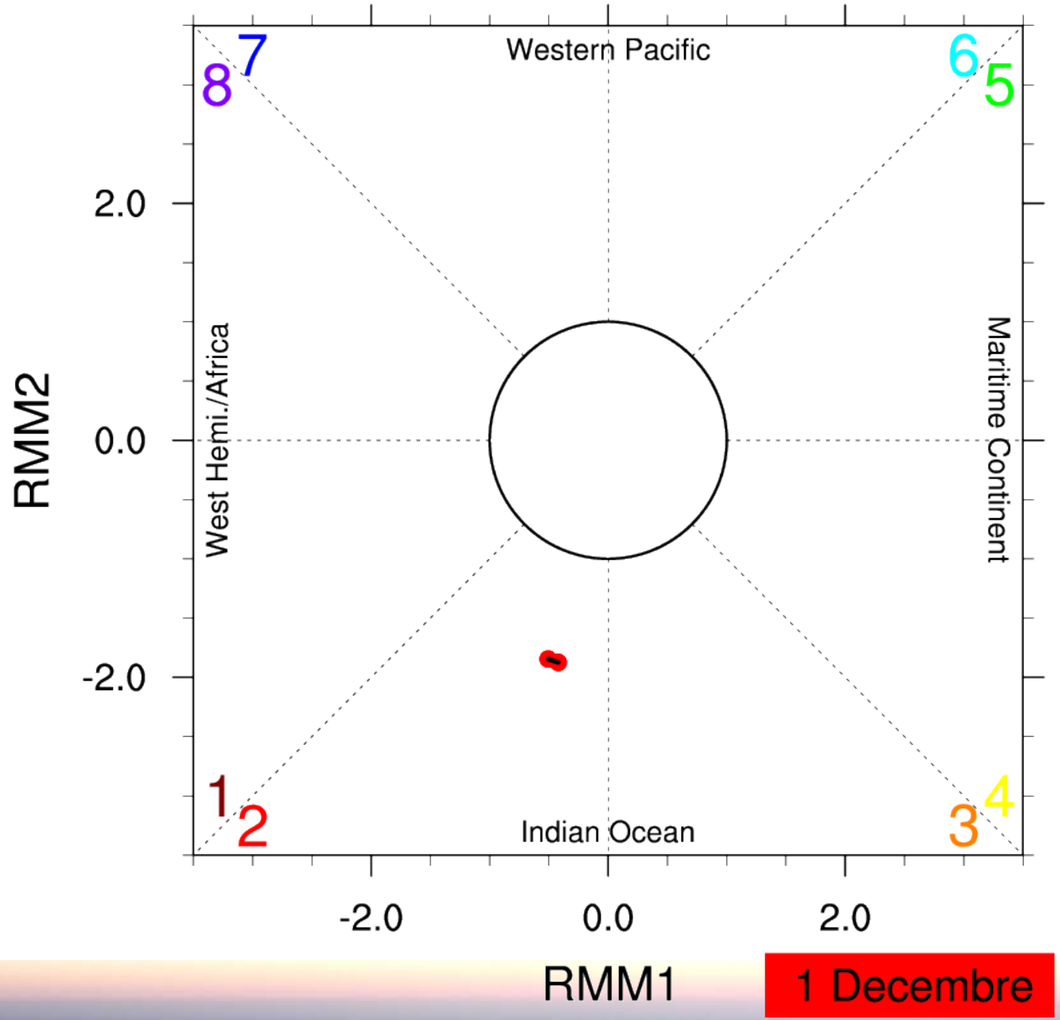


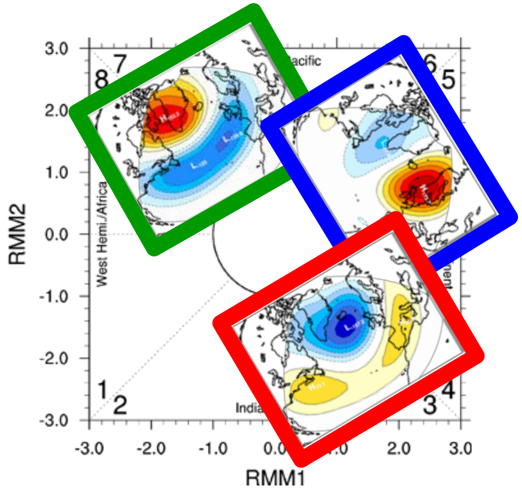
Averaged anomalies From lag 0 to lag +5

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

Reinforced North Atlantic storm track Except at its tail end (Europe)

MJO/Regimes relationship for the last winter : 2011-2012





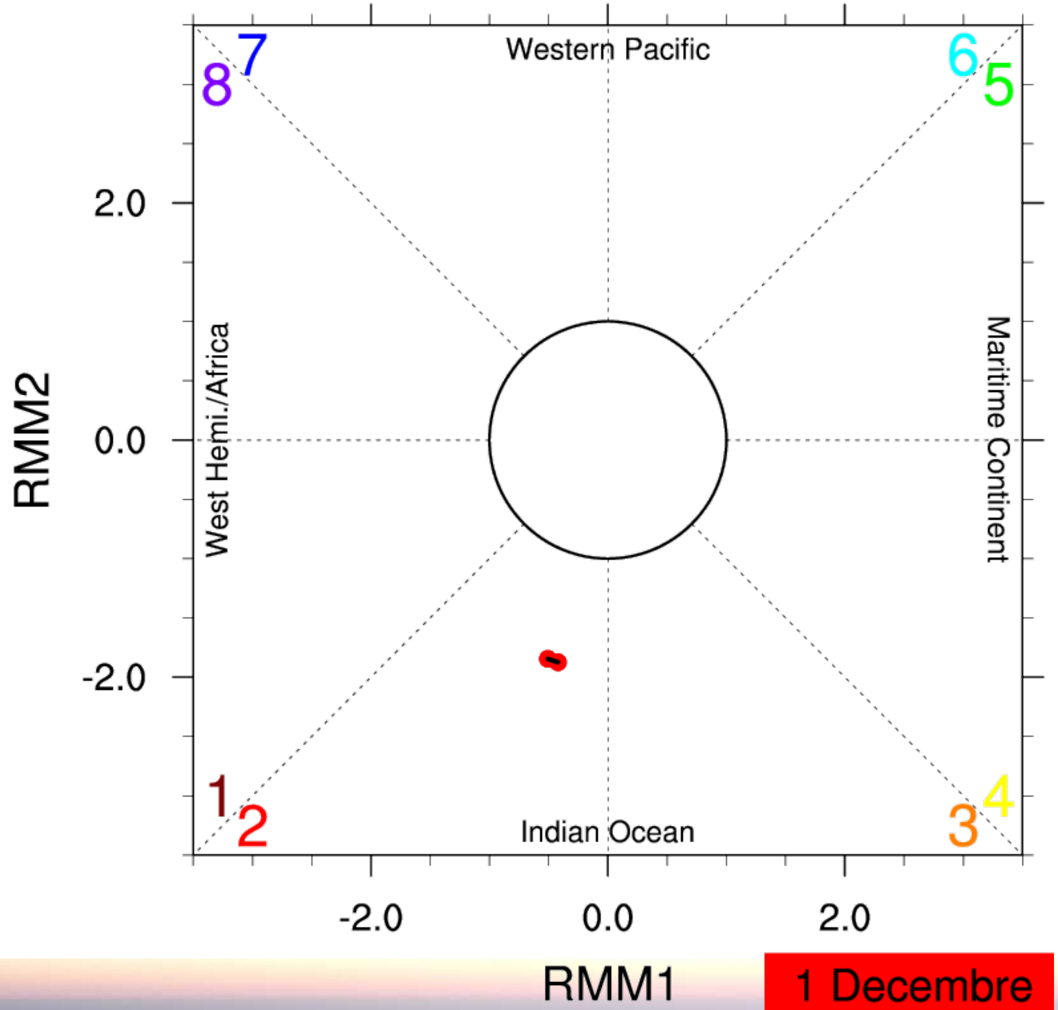
NAO+ | Atl. Ridge

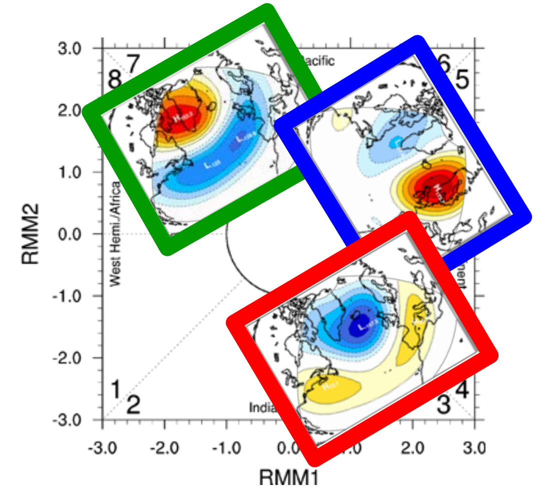
Blocage | NAO -

<u>MJO dots</u>: 7 days before the date of the regime (counter)

<u>Colors</u> : Type of régimes

MJO/Regimes relationship for the last winter : 2011-2012





NAO+ | Atl. Ridge

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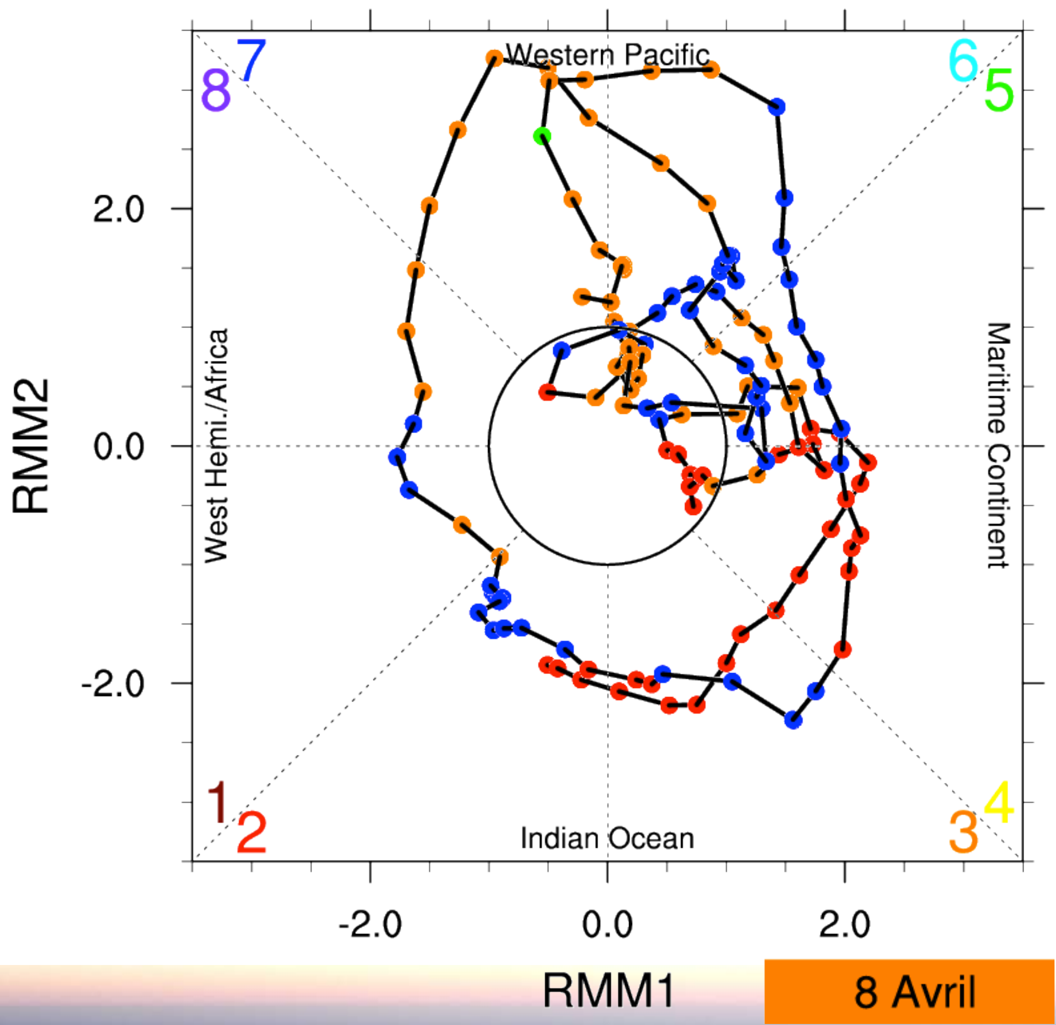
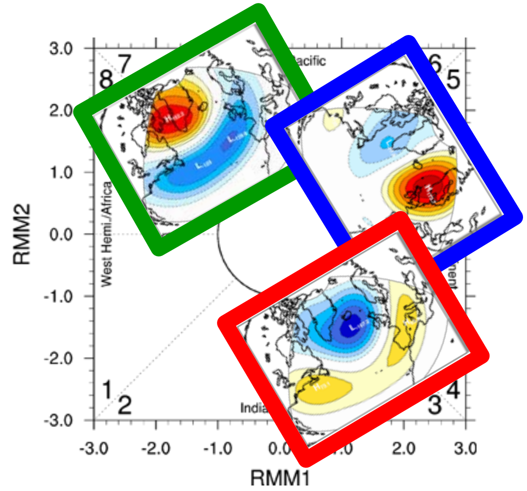
MJO/Regimes relationship for the last winter : 2011-2012



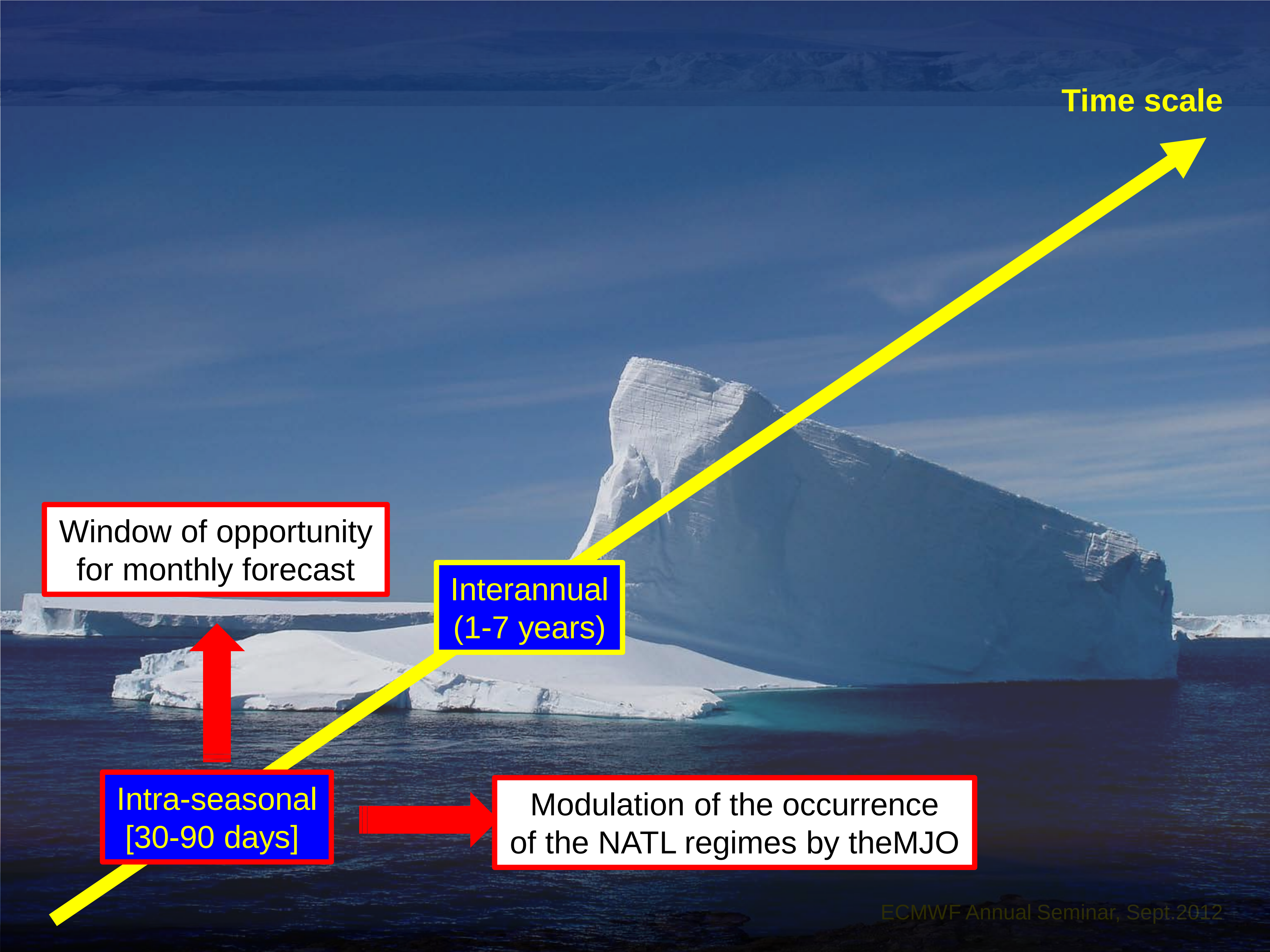


NAO+ | Atl. Ridge | Blocage | NAO -

MJO dots: 7 days before the date of the regime (counter)

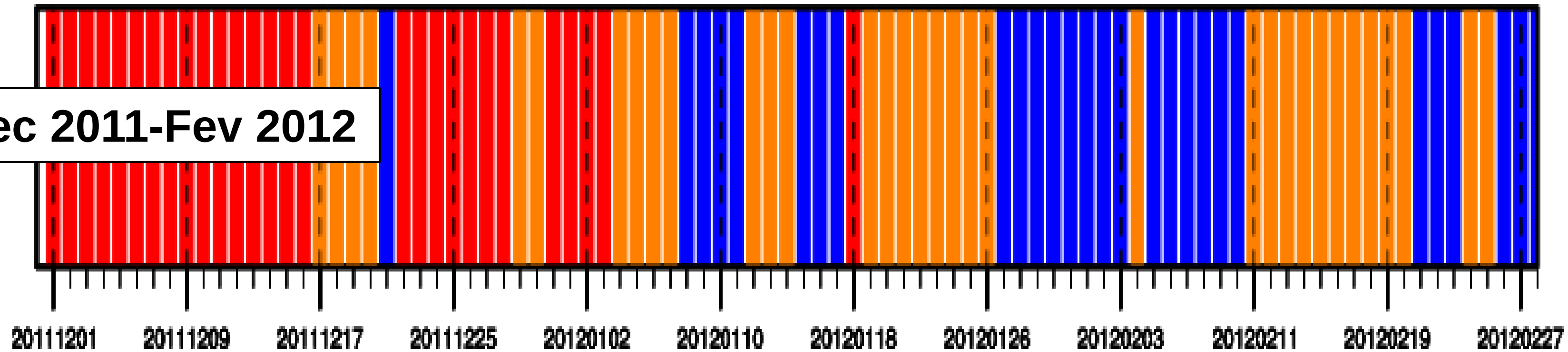
Colors : Type of régimes

NOT TOO BAD!


Time scale
Window of opportunity for monthly forecast
Interannual (1-7 years)
Intra-seasonal [30-90 days]
Modulation of the occurrence of the NATL regimes by theMJO
ECMWF Annual Seminar, Sept.2012

Statistics for winter 2011-2012

Dec 2011-Fev 2012



Normal Statistics :

NAO- : 20 days

NAO+ : 26 days

AR :22 days

BL :23 days

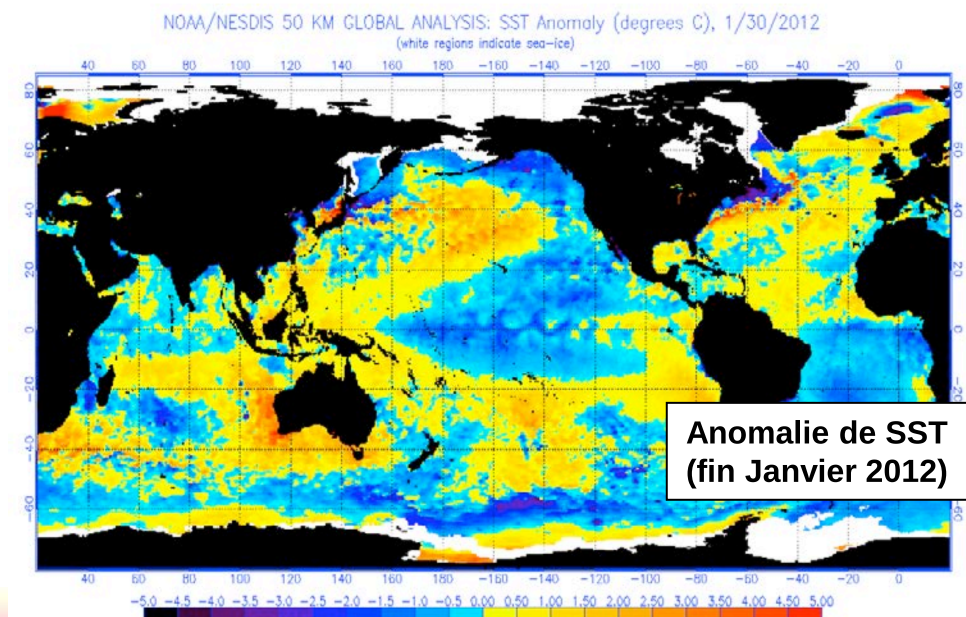
2011-2012 Statistics :

NAO- : 0 days ---> - 20-day

NAO+ : 28 days ---> + 2 days

AR :34 days ---> +12 days

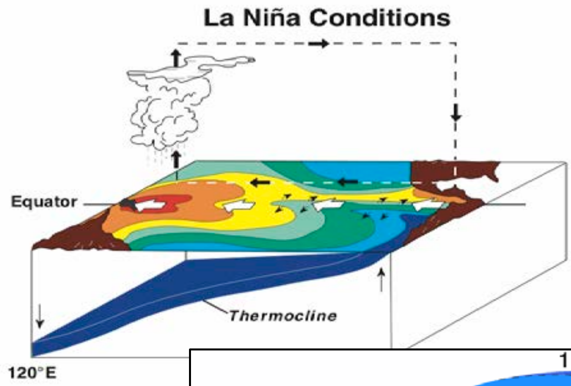
BL :28 days ---> + 5 days

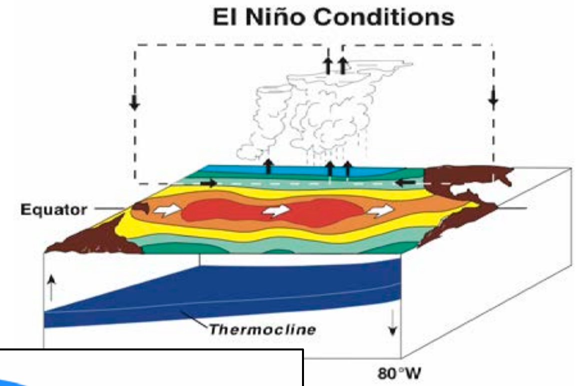


Anomalie de SST (fin Janvier 2012)

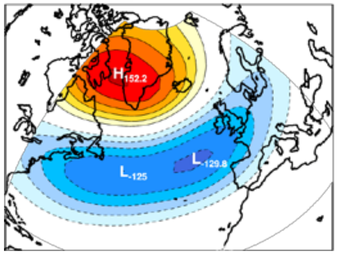
NAO+ | Blocage | Atl. Ridge | NAO -

ENSO as a *weak* fan for interannual timescale

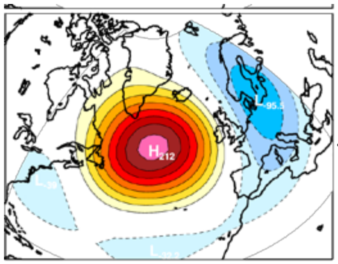


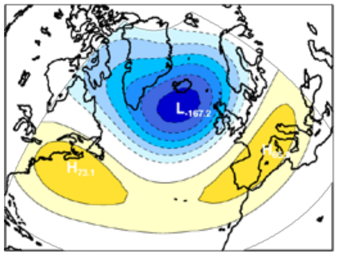


NAO-

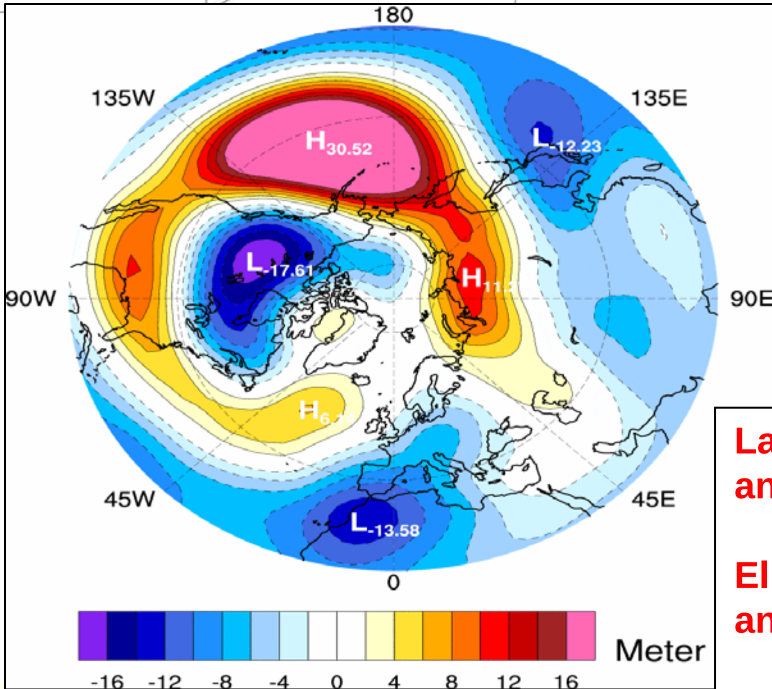


Atl.Ridge





NAO+



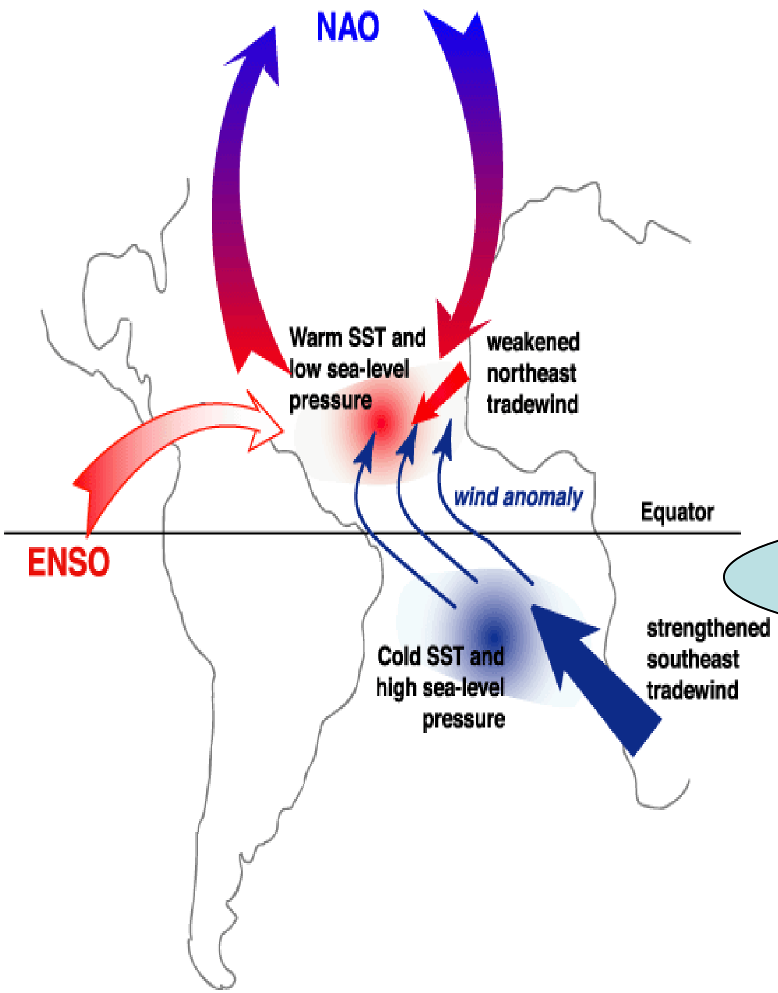
Z500 regression upon SOI index (NCEP 1958-2010)

La Nina favors AR occurrences and NAO+ (to a lower extent)

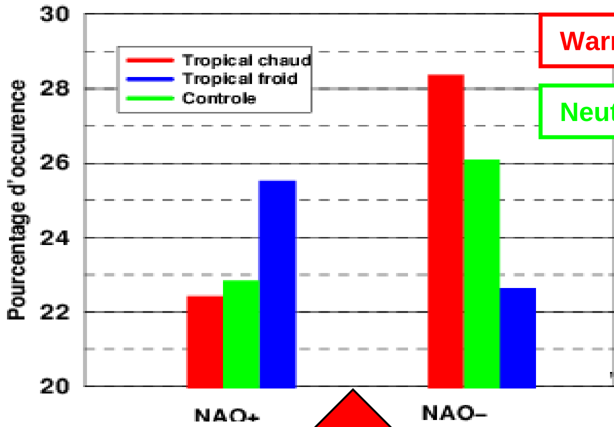
El Nino favors NAO- occurrences and inhibits AR

ENSO influences are weak though and not stationary.

Tropical Atlantic : a *stronger* fan



% of occurrence of NAO regimes

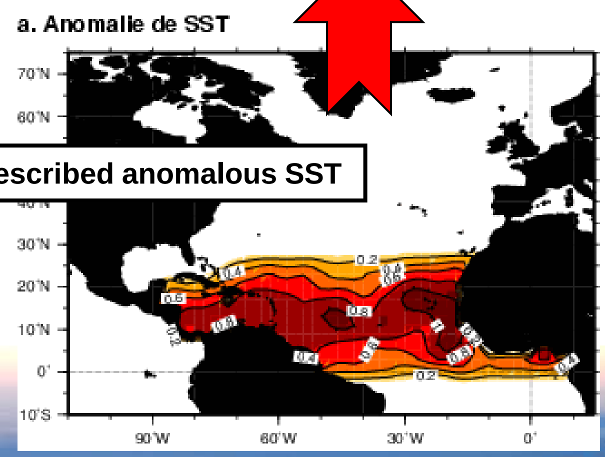


Cold north tropical Atl.

Warm north tropical Atl.

Neutral north tropical Atl.

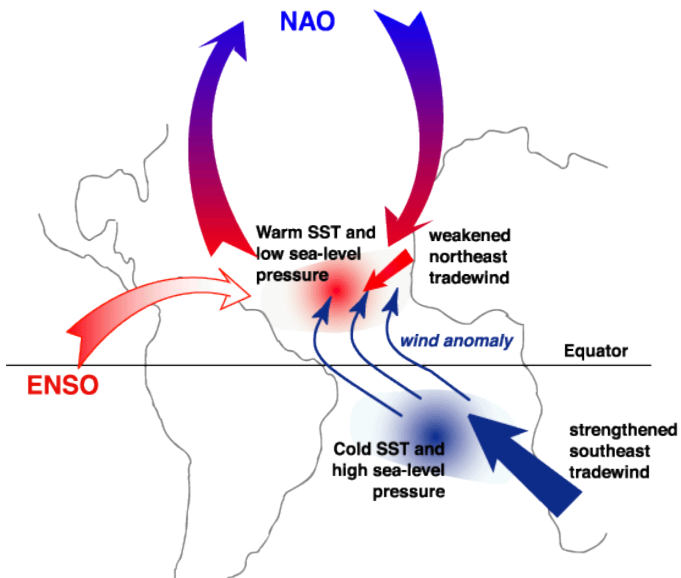
General Circulation Model
Forced by anomalous SST.



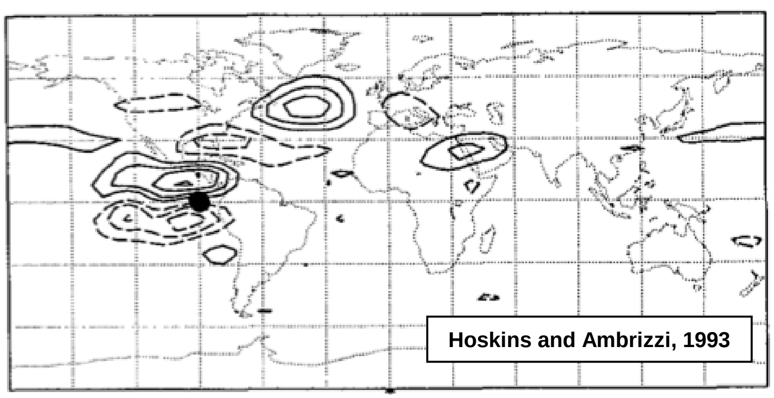
Prescribed anomalous SST

Source : Cassou et al (JCLIM, 2004)

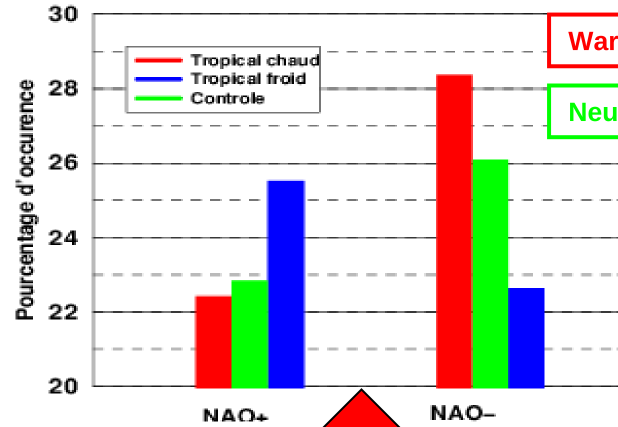
Tropical Atlantic : a *stronger* fan



Rossby wave excitation from the western tropical Atl.



% of occurrence of NAO regimes



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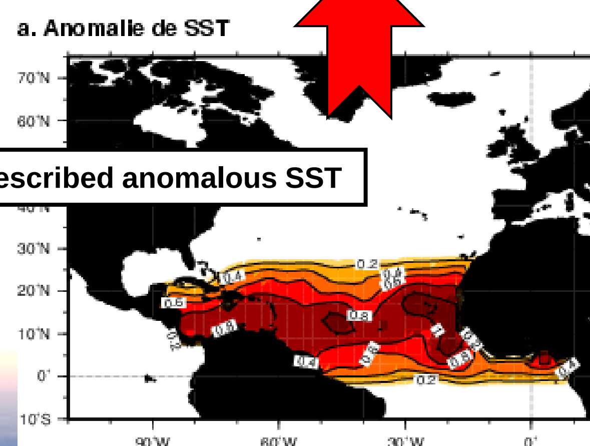
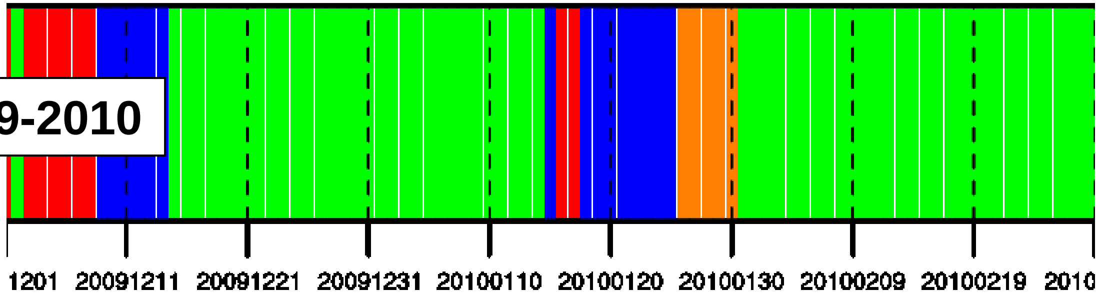


Prescribed anomalous SST

Source : Cassou et al (JCLIM, 2004)

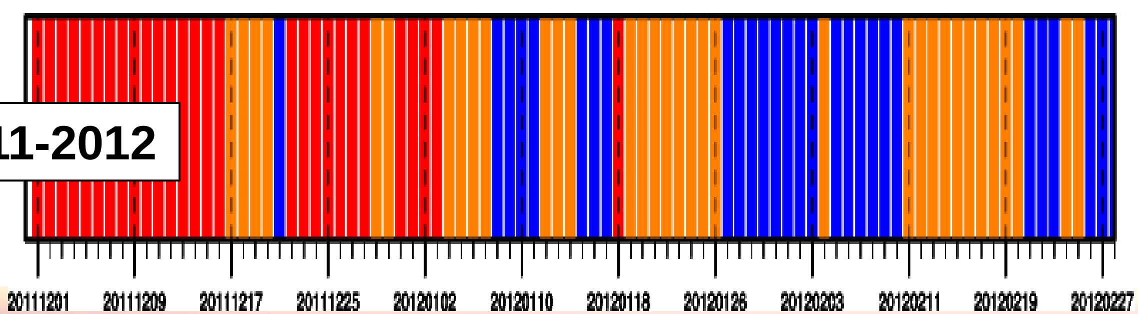
2 extreme winters

2009-2010



Consistent with the 2009-2010 El Nino
+ warm tropical ATL
(weak modulation by the MJO)

2011-2012

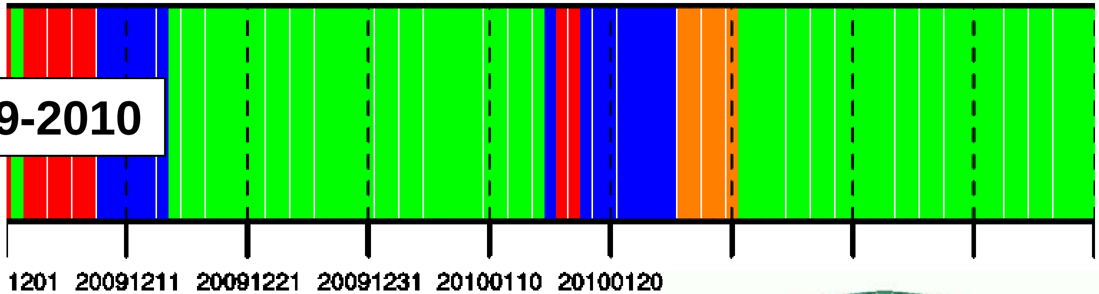


Consistent with the 2011 La Nina
(strong modulation by the MJO)

NAO+ | Blocage | Atl. Ridge | NAO -

Seasonal forecast

2009-2010



Consistent with the 2009-2010 El Nino
+ warm tropical ATL
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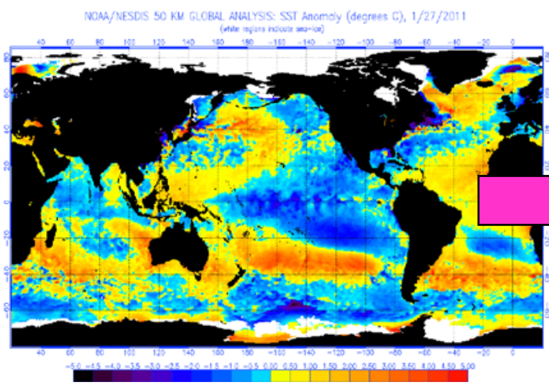
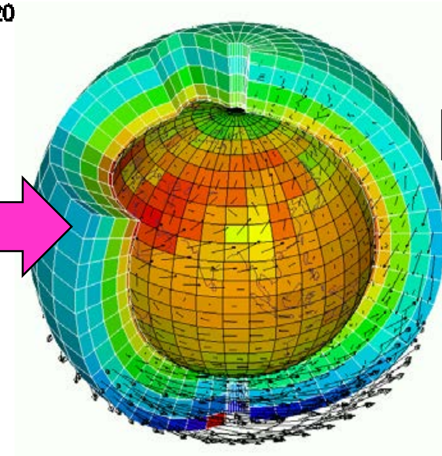
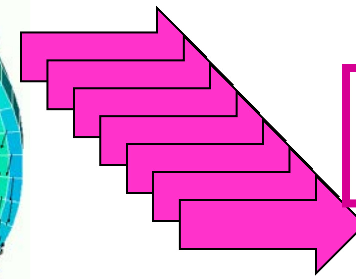
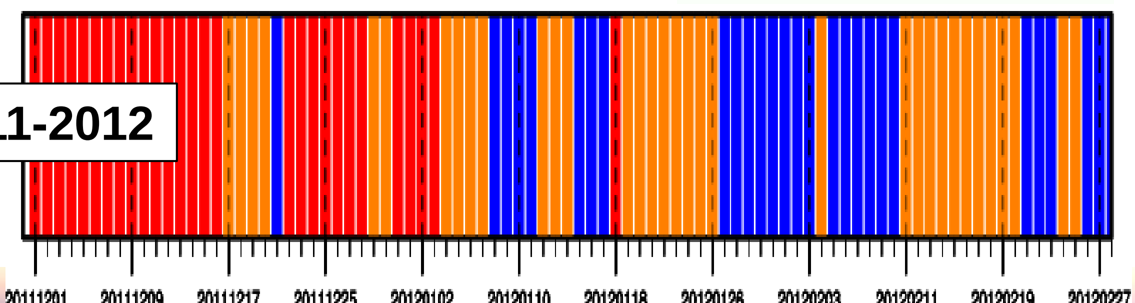






Ensemble Prediction

2011-2012

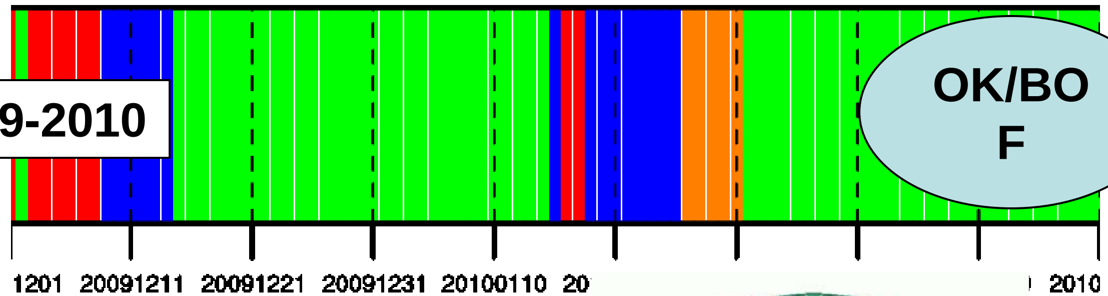


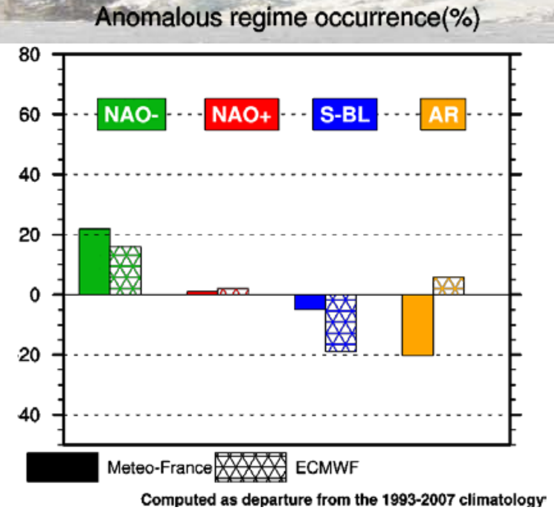
Consistent with the 2011 La Nina
(modulation by the MJO)

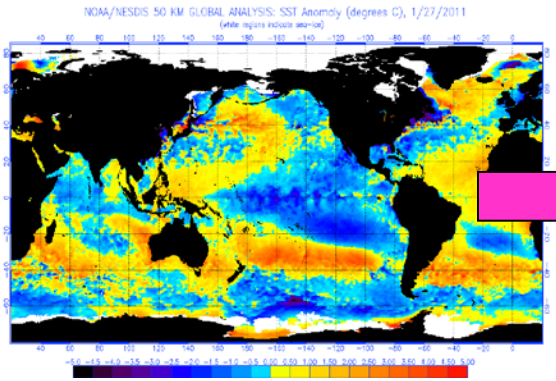
NAO+ | Blocage | Atl. Ridge | NAO -

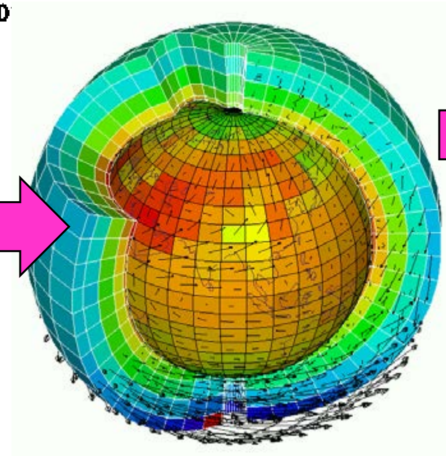
Prediction of weather regime anomalous occurrence

Observations

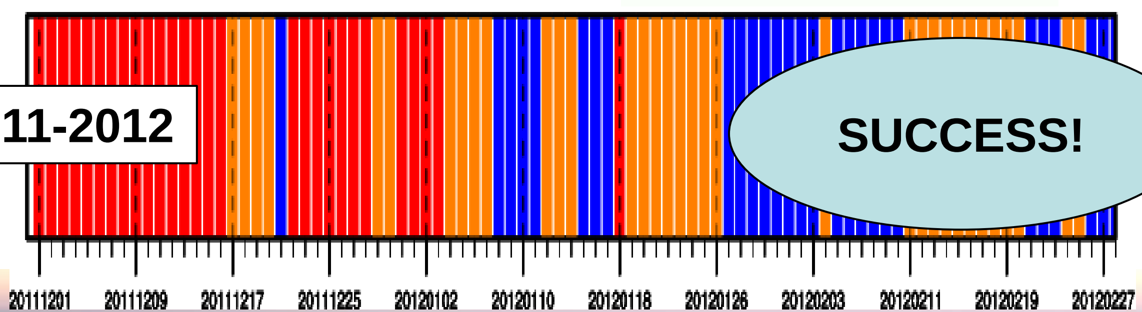


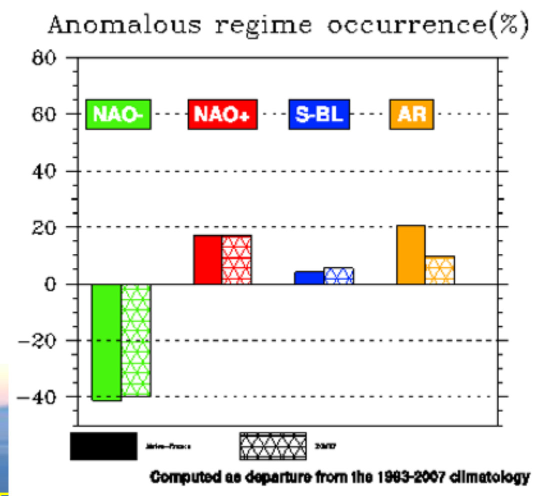






Statistics for weather regime occurrence



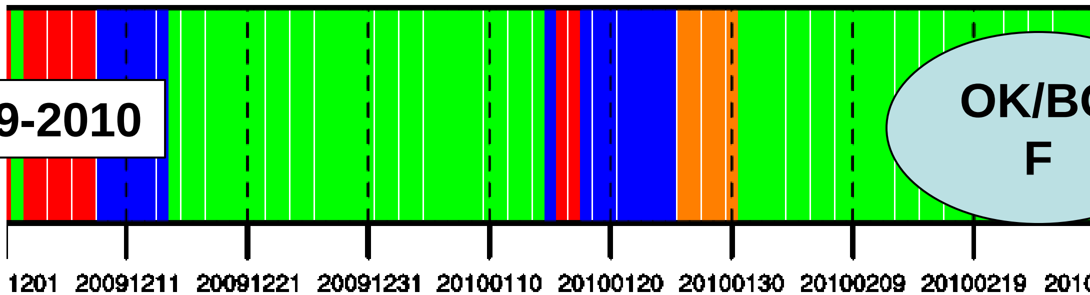


DJF Prediction initialized on Nov.

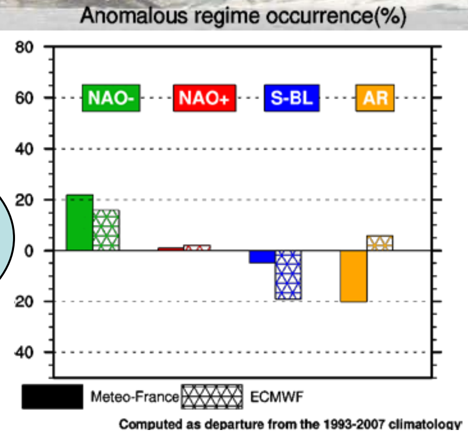
Prediction of weather regime anomalous occurrence

Observations

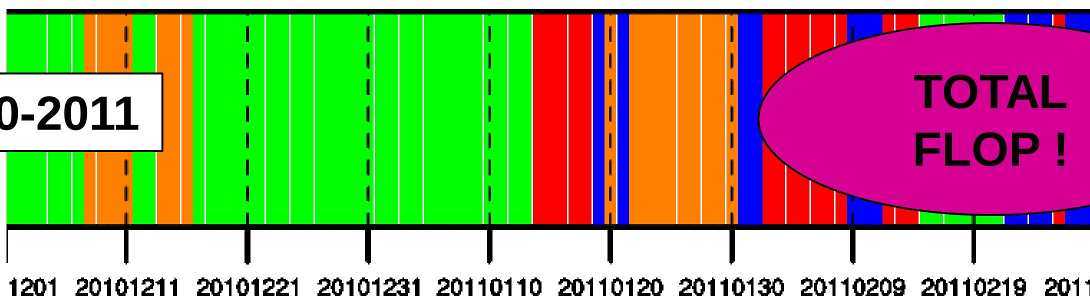
2009-2010



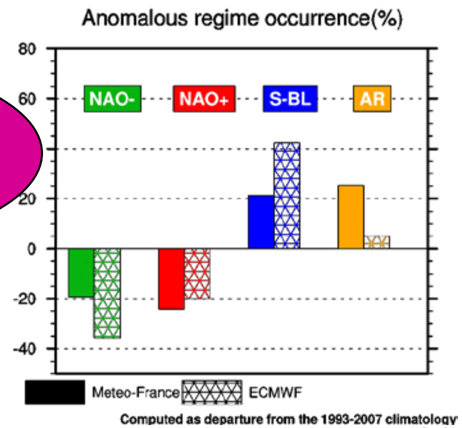
OK/BOF



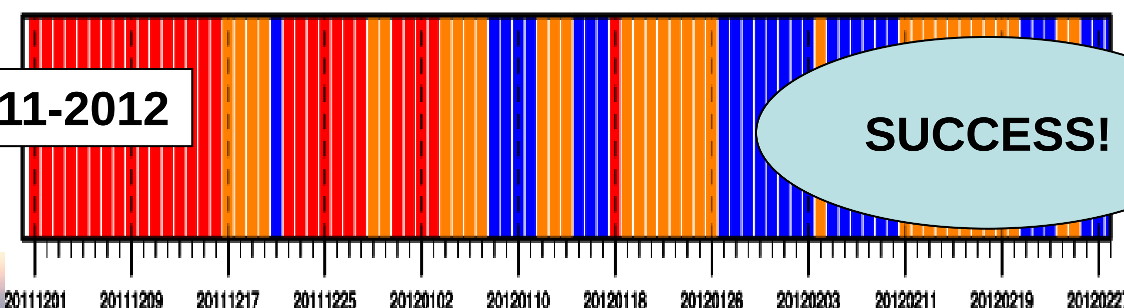
2010-2011



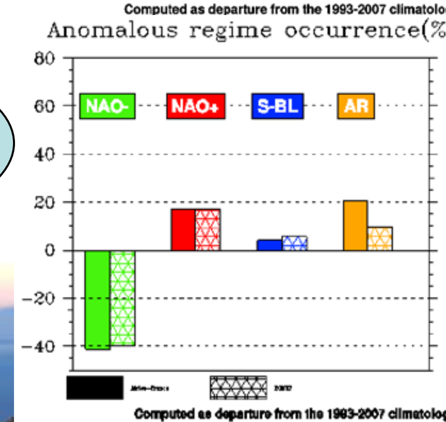
TOTAL FLOP !



2011-2012

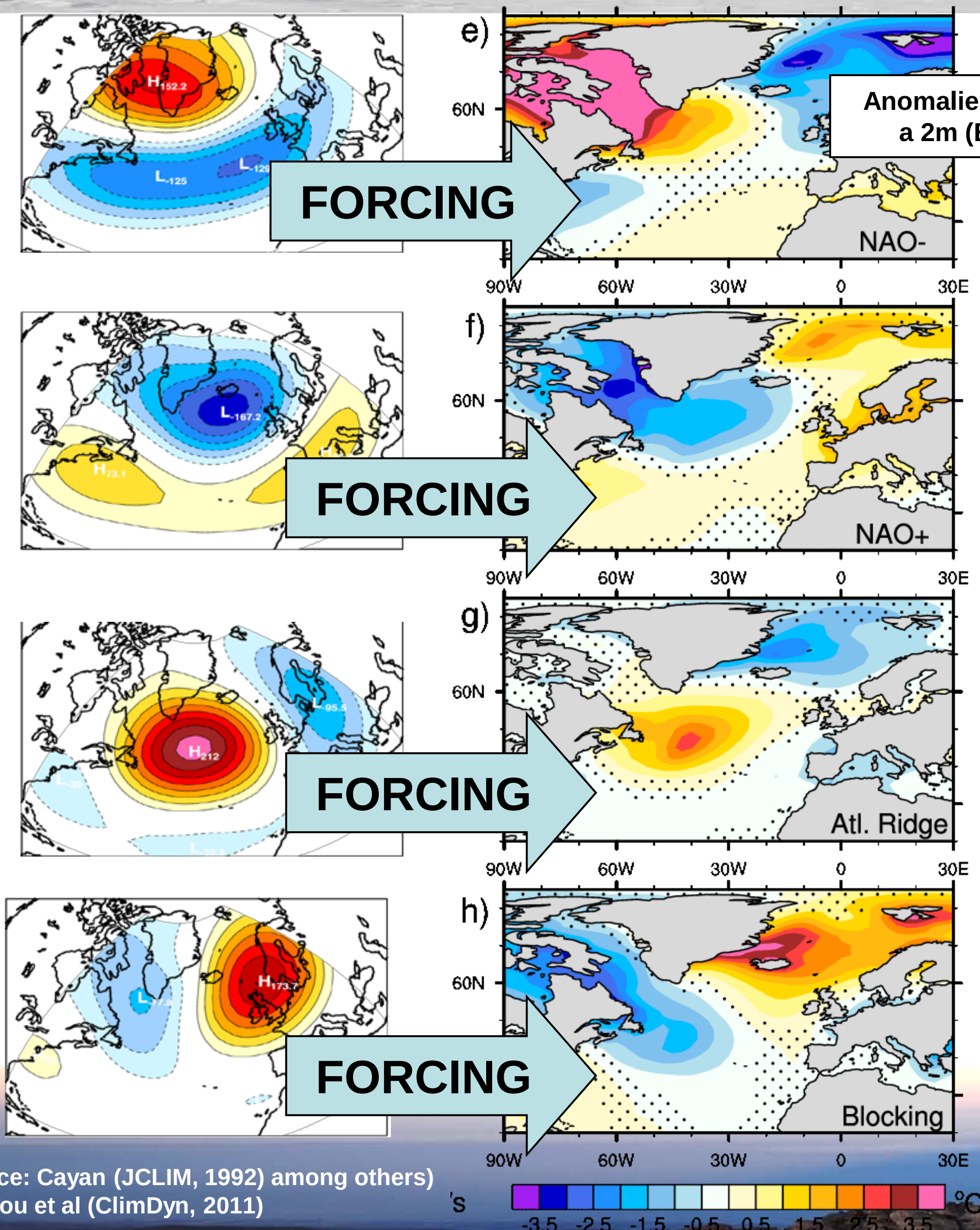


SUCCESS!



DJF Prediction initialized on Nov.

Weather regime forcing of the ocean



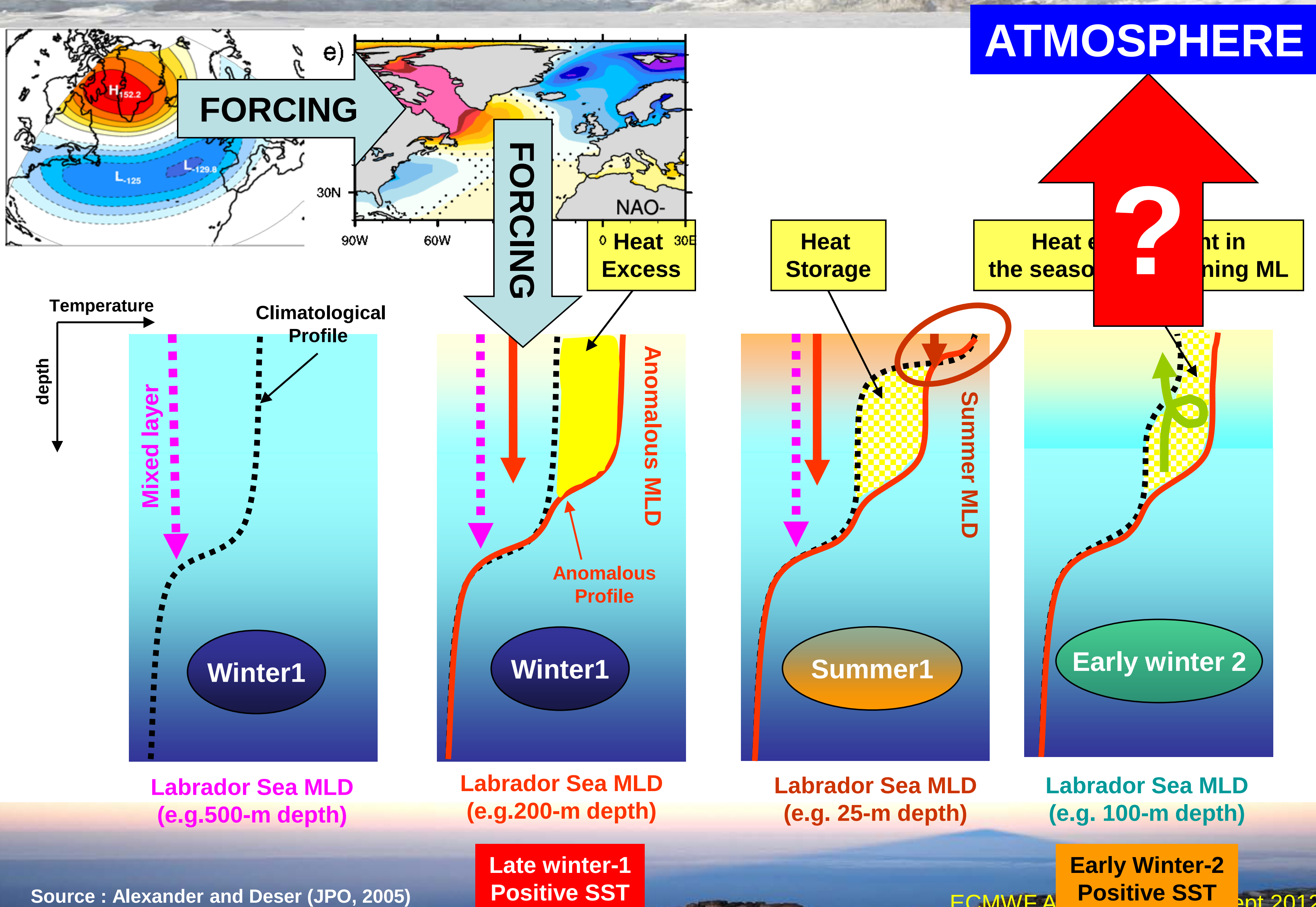
Anomalie de temp. a 2m (ERA40)

Maximum covariance/correlation between SST and regimes found when the atmosphère **preceeds** the océan by 3 to 8 weeks.

Signature of the atmospheric forcing on the surface ocean as well as in the subsurface

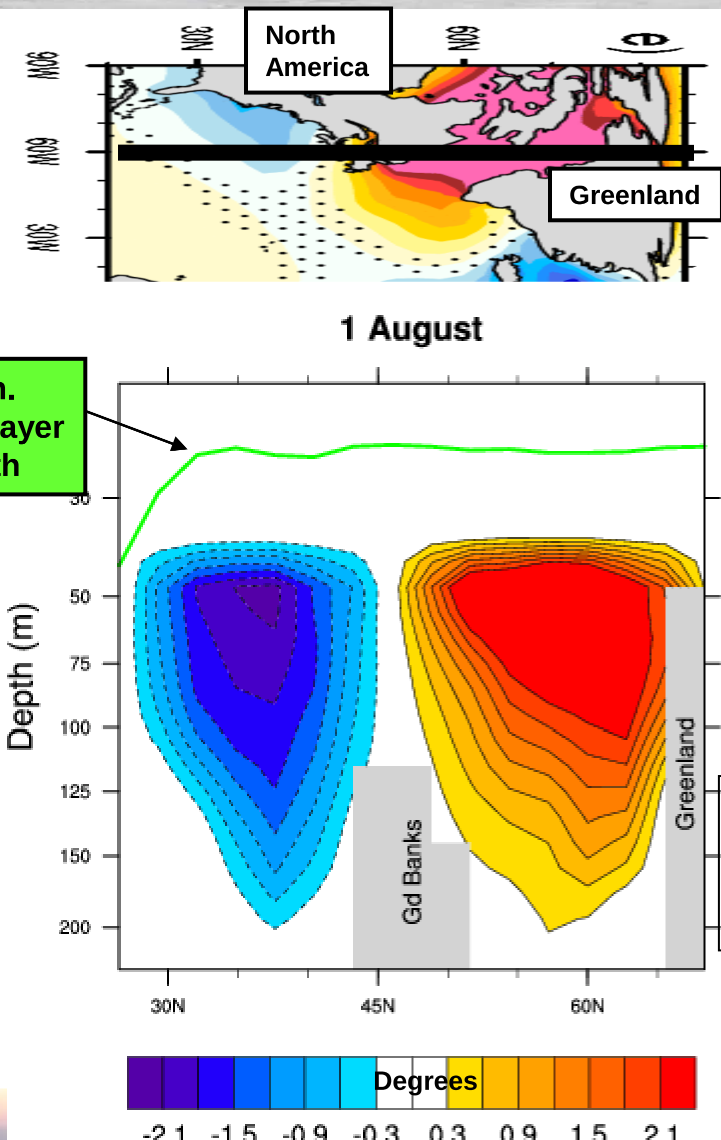
Source: Cayan (JCLIM, 1992) among others)
Cassou et al (ClimDyn, 2011)

The oceanic re-emergence



Source : Alexander and Deser (JPO, 2005)

Impact of the re-emergence upon the atmosphere

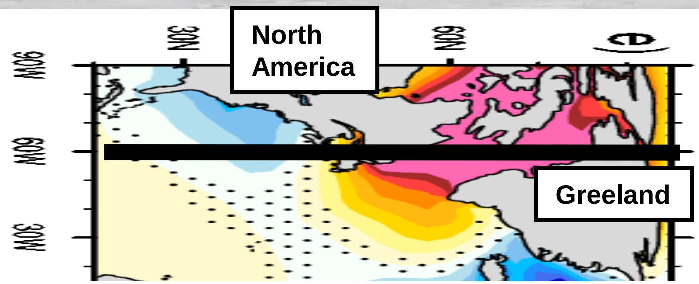


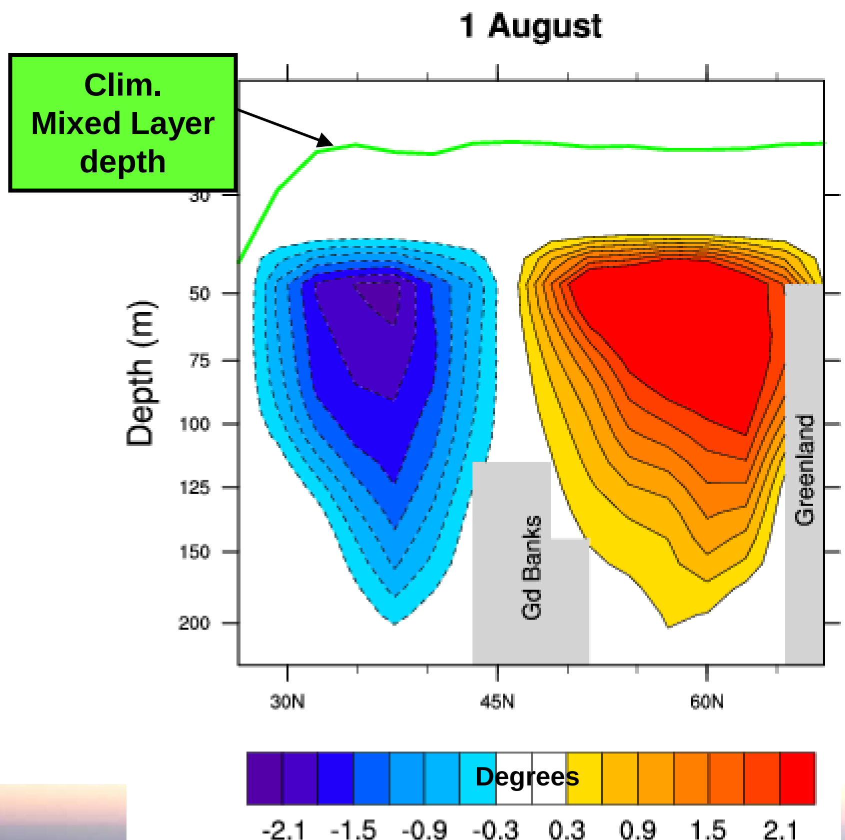
Coupled global circulation model (NCAR : CCSM)

Re-emergence of anomalous heat at the surface created by a negative phase of the NAO in the previous winter and stored beneath the seasonal mixed layer (Section @ [60º - 40ºW] from 25º to 68ºN)

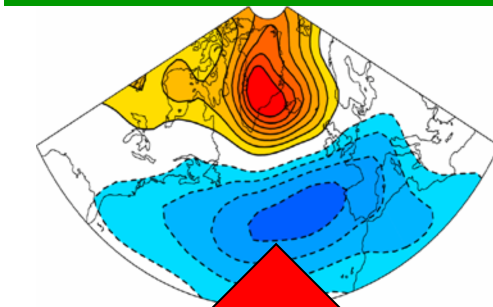
Source : Cassou et al (JCLIM, 2007)

Model response to re-emergence





NAO – (early winter +1)



MSLP model response

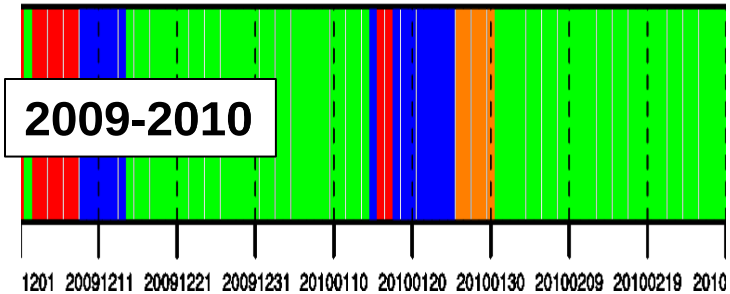
Coupled global circulation model (NCAR : CCSM)

Re-emergence of anomalous heat at the surface created by a negative phase of the NAO in the previous winter and stored beneath the seasonal mixed layer (Section @ [60º - 40ºW] from 25º to 68ºN)

NAO – (hiver 0)

Source : Cassou et al (JCLIM, 2007)

Evidence for observed re-emergence in late 2009.

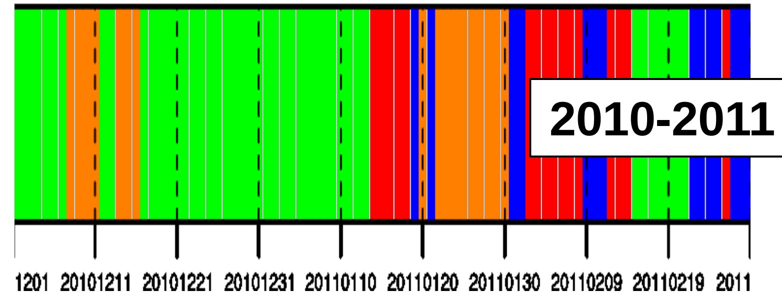


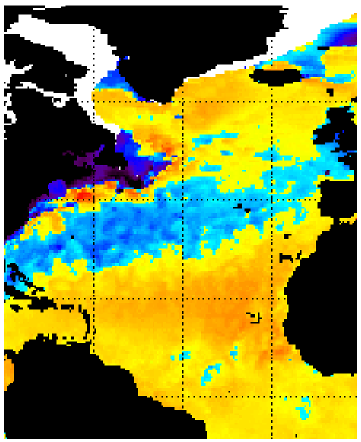
NAO+

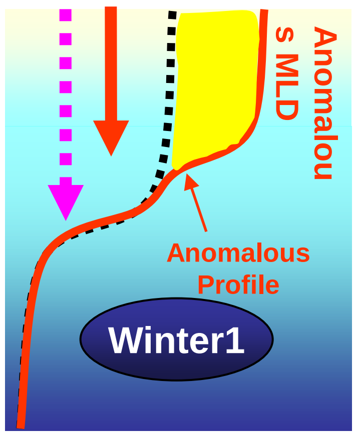
Blocage

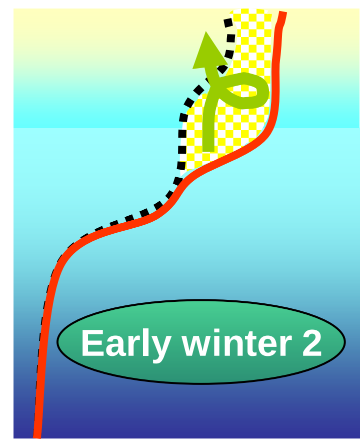
Atl. Ridge

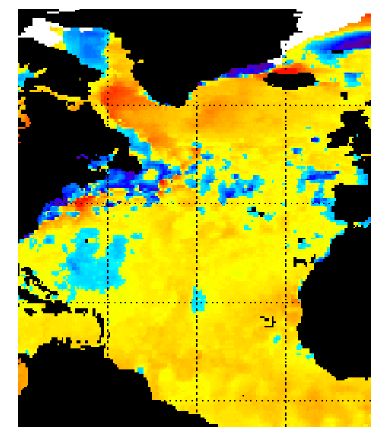
NAO -

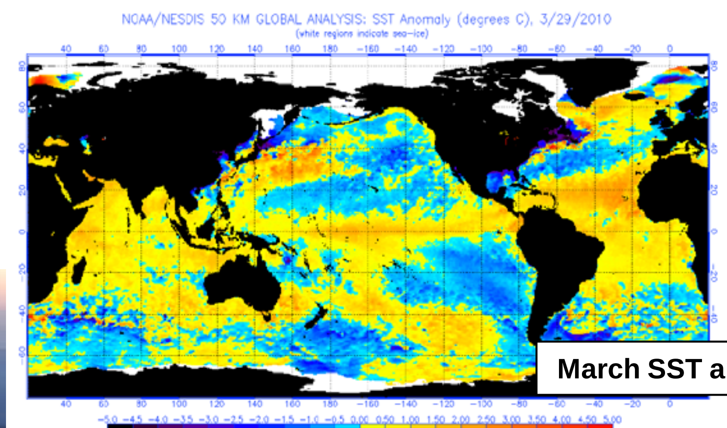




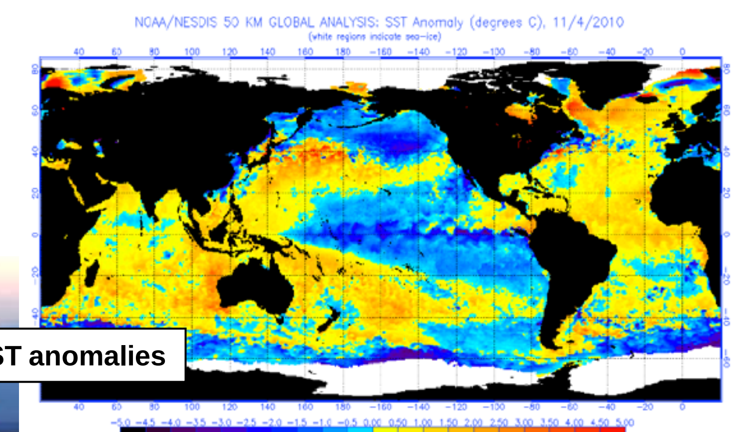




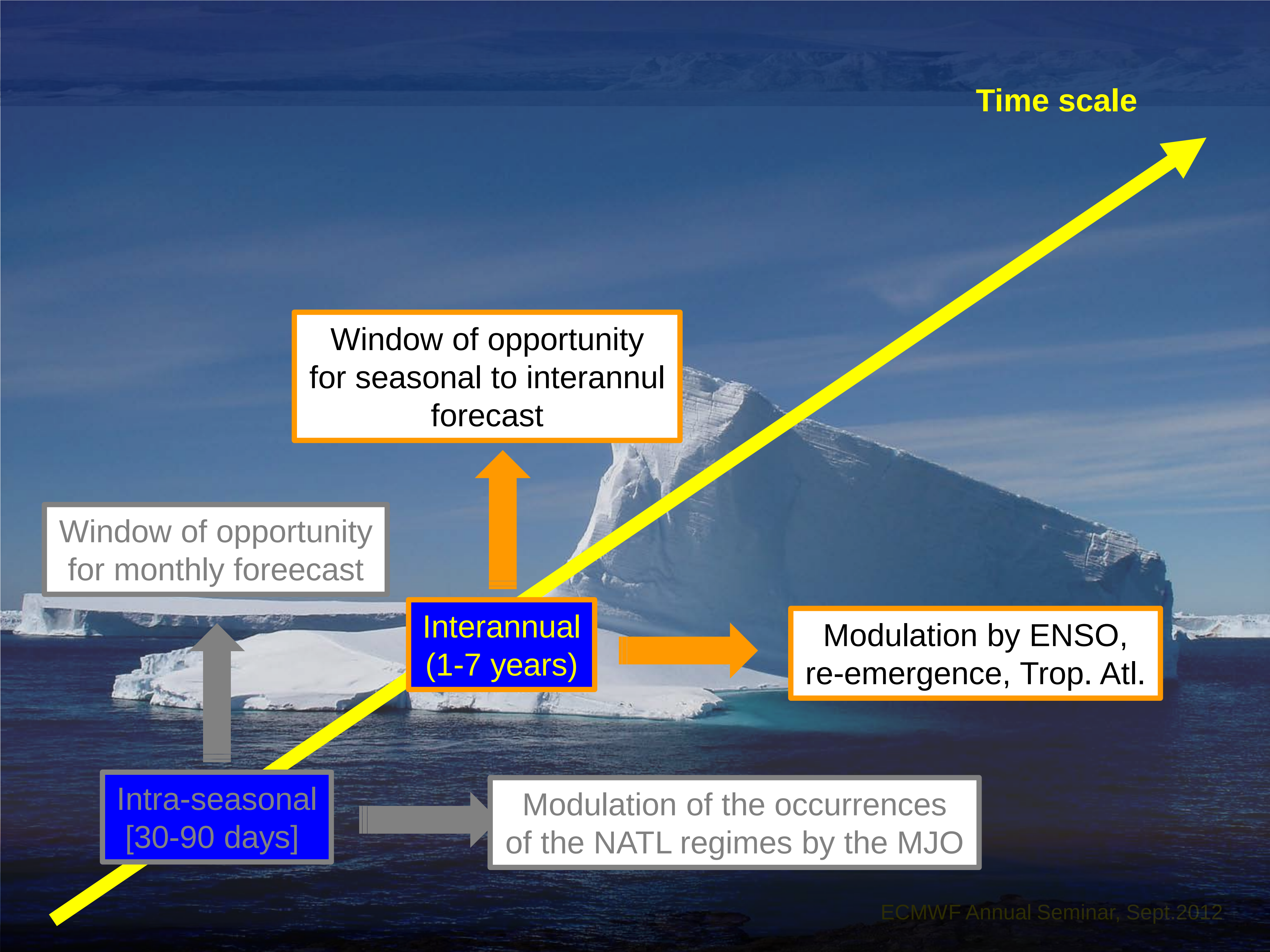


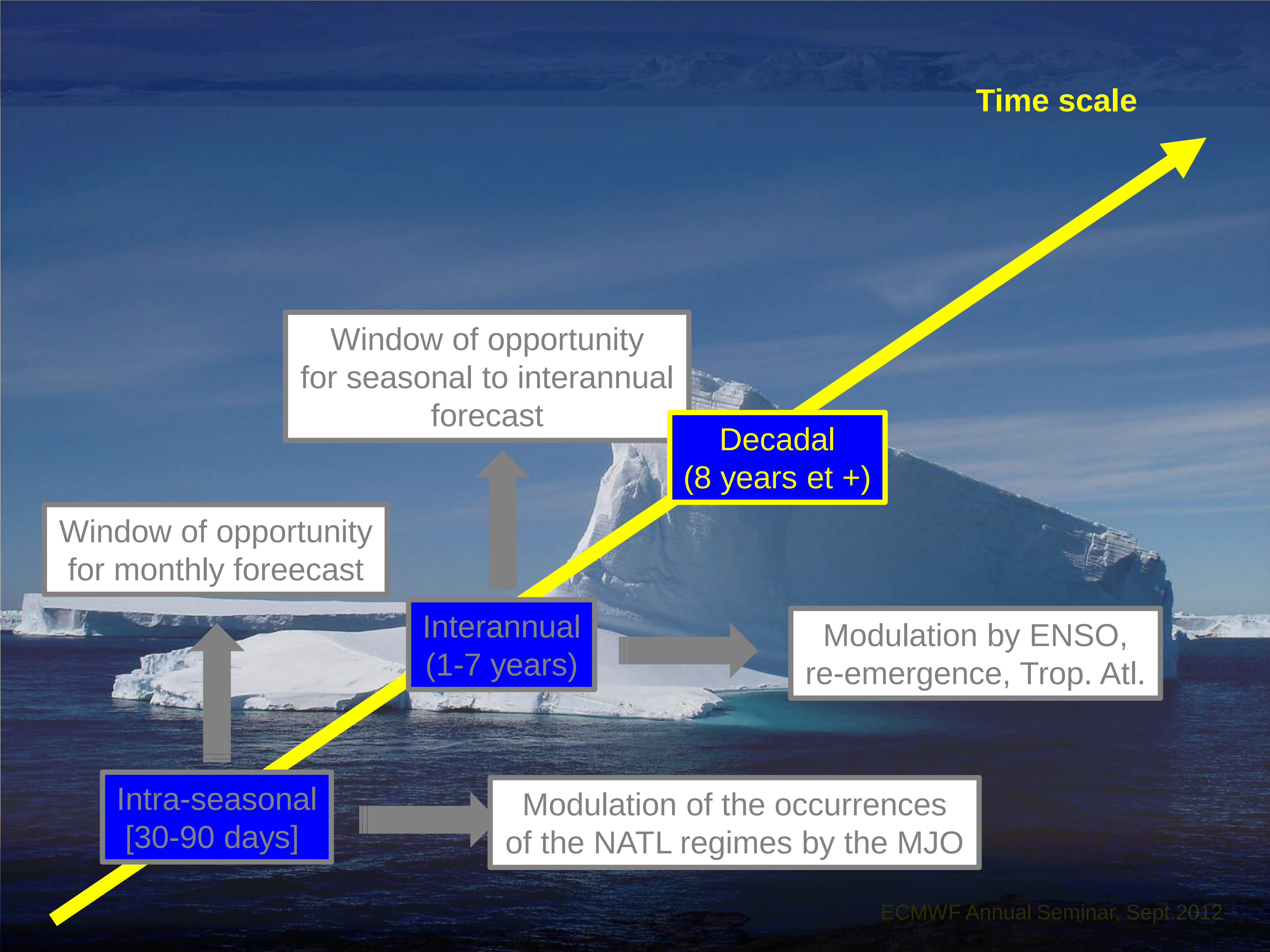


March SST anomalies

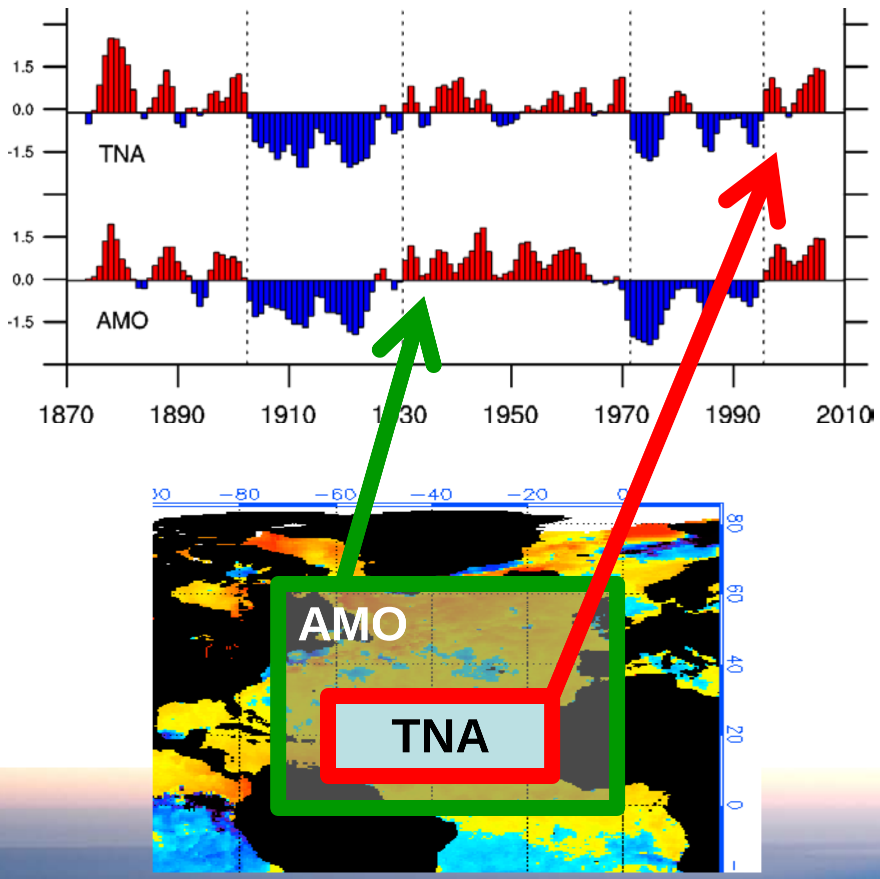


Nov. SST anomalies


Time scale
Window of opportunity
for seasonal to interannul
forecast
Window of opportunity
for monthly foreecast
Interannual
(1-7 years)
Modulation by ENSO,
re-emergence, Trop. Atl.
Intra-seasonal
[30-90 days]
Modulation of the occurrences
of the NATL regimes by the MJO
ECMWF Annual Seminar, Sept.2012

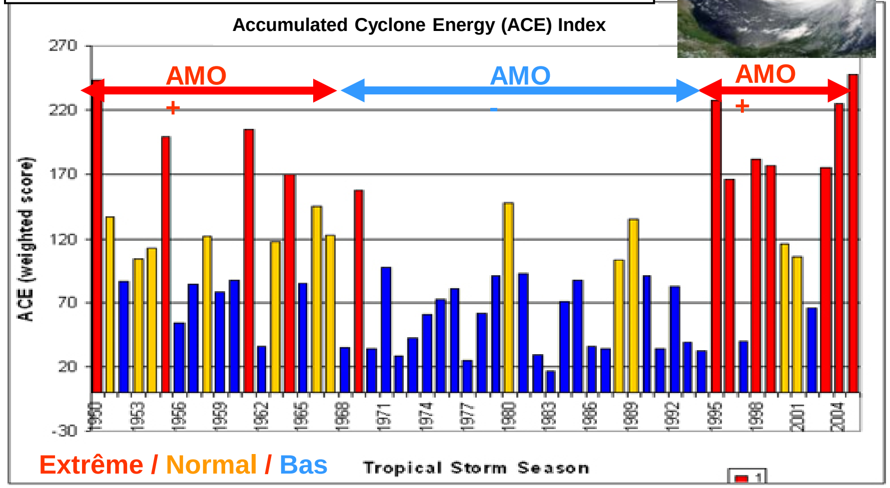

Time scale
Window of opportunity for seasonal to interannual forecast
Decadal (8 years et +)
Window of opportunity for monthly foreecast
Interannual (1-7 years)
Modulation by ENSO, re-emergence, Trop. Atl.
Intra-seasonal [30-90 days]
Modulation of the occurrences of the NATL regimes by the MJO

Decadal modulation of regimes occurrence by the Tropical Atl.



Impact on sahel precipitation

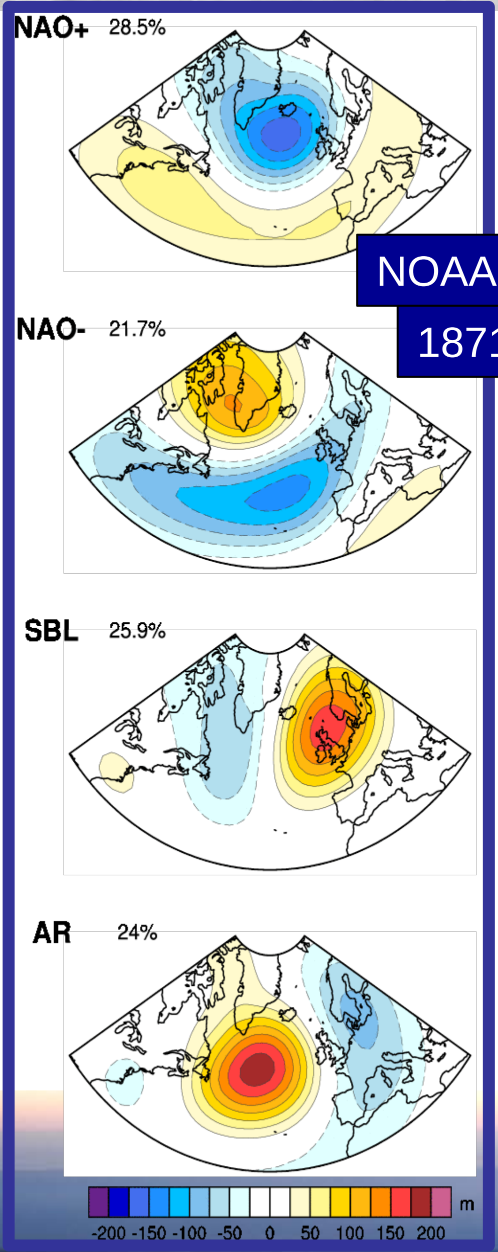
Impact on Atlantic hurricanes



Goldenberg et al (2001) Science

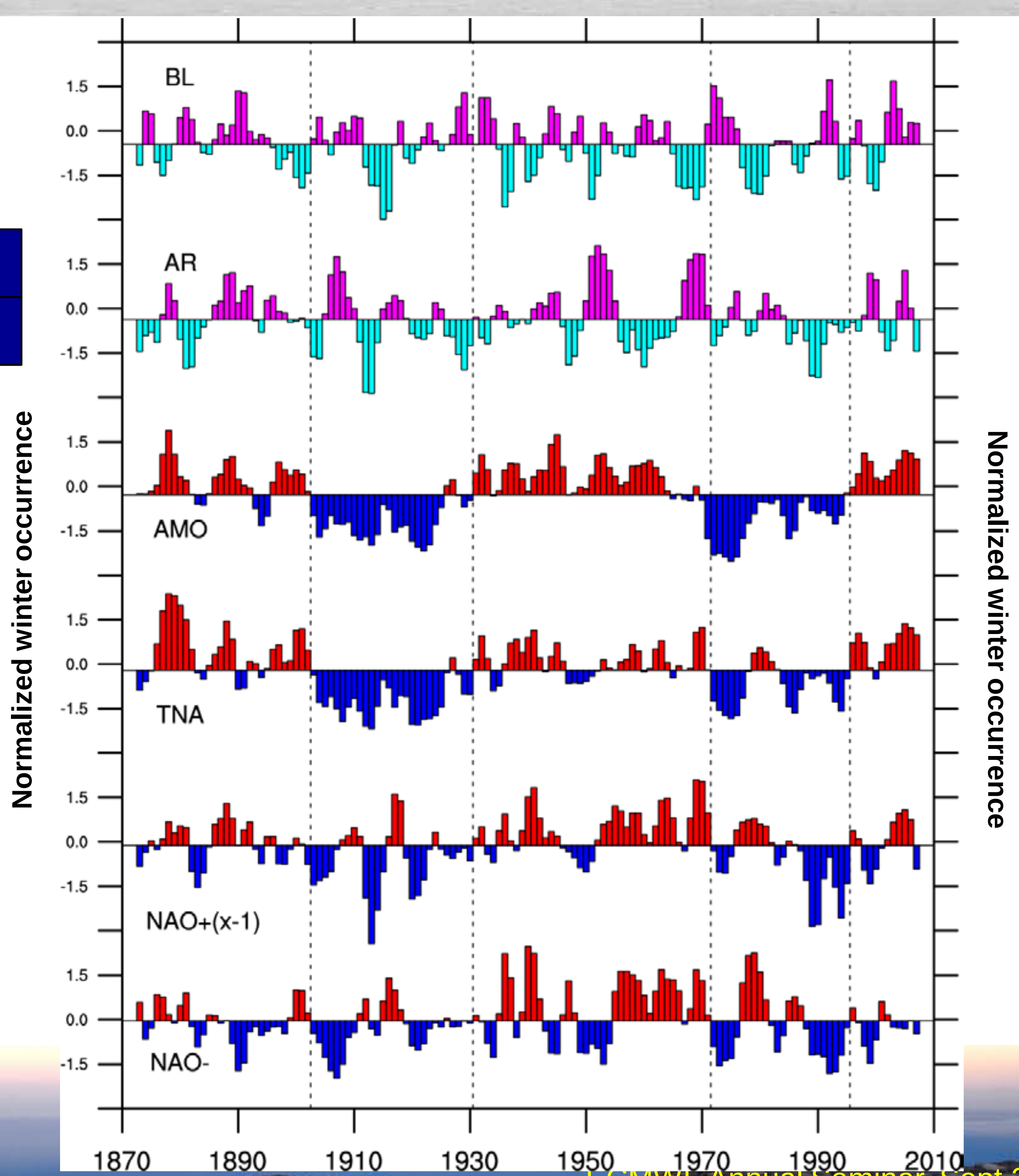
Source : Minvielle et Cassou (en preparation, 2012)

Winter occurrence of regimes (1871-2008)

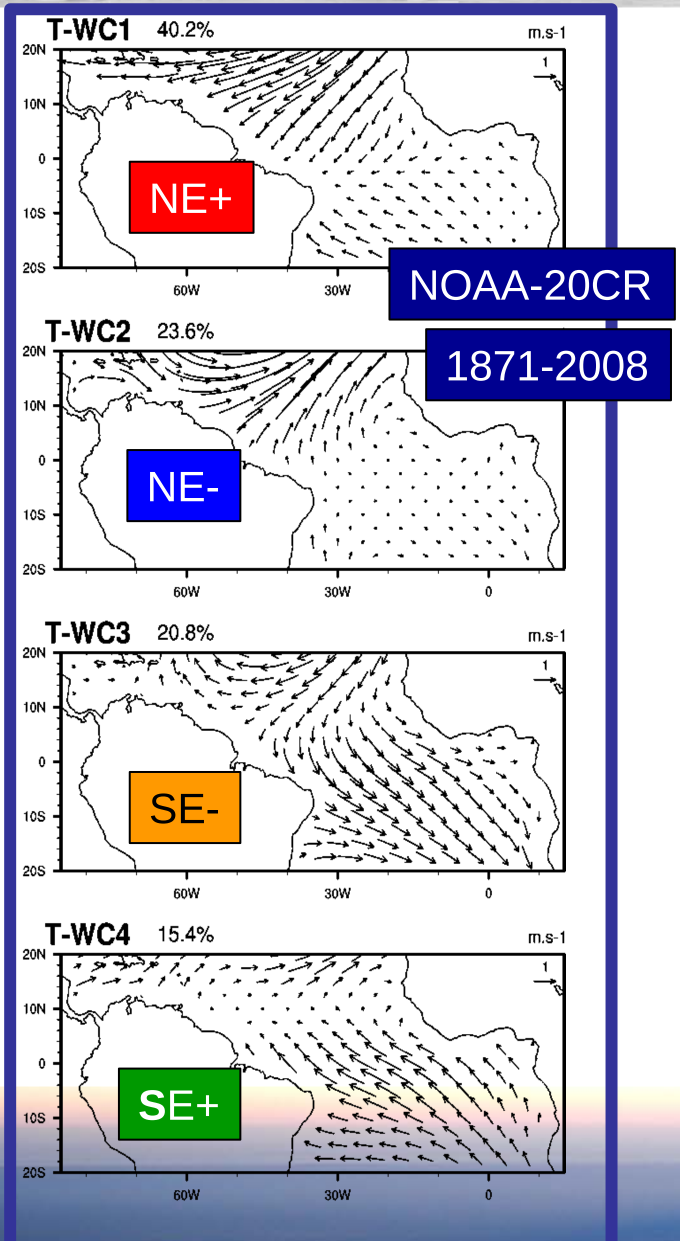


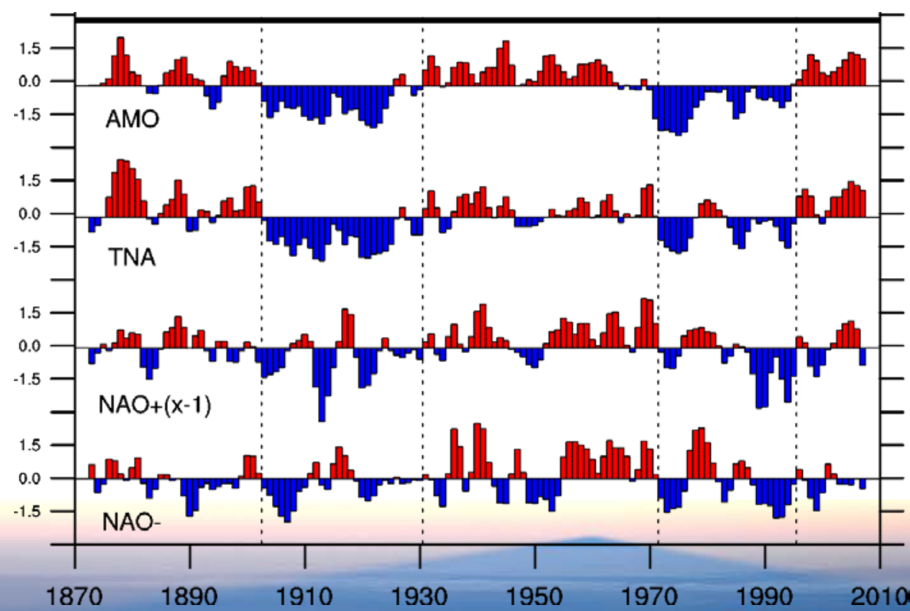
NOAA-20CR

1871-2008

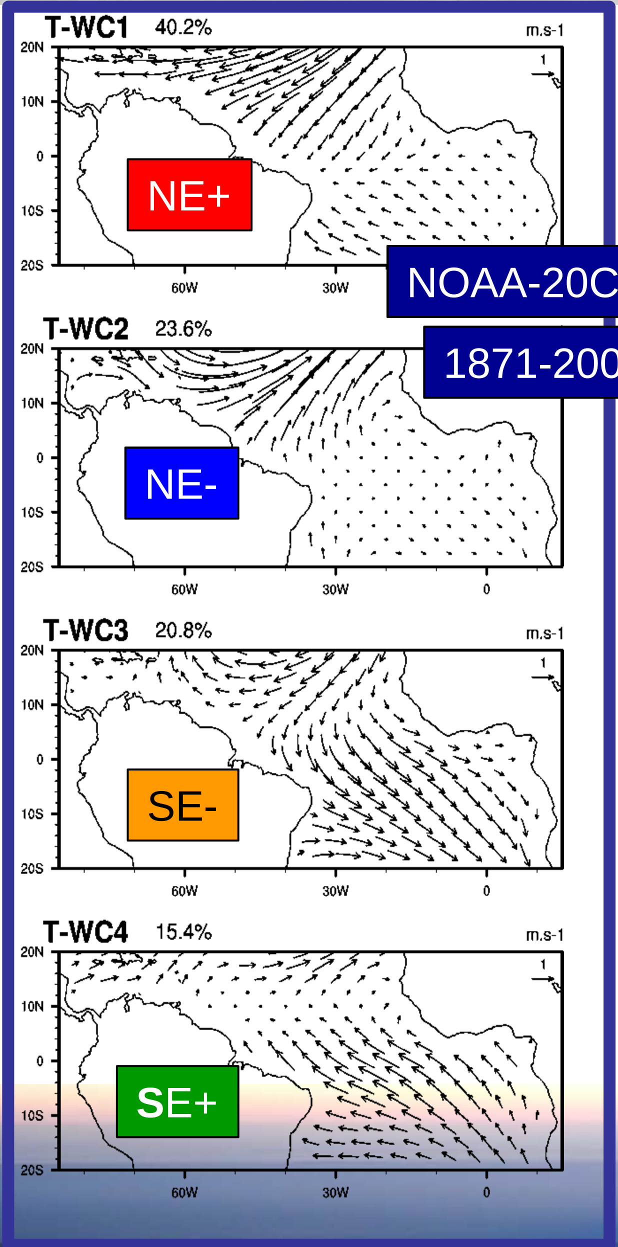


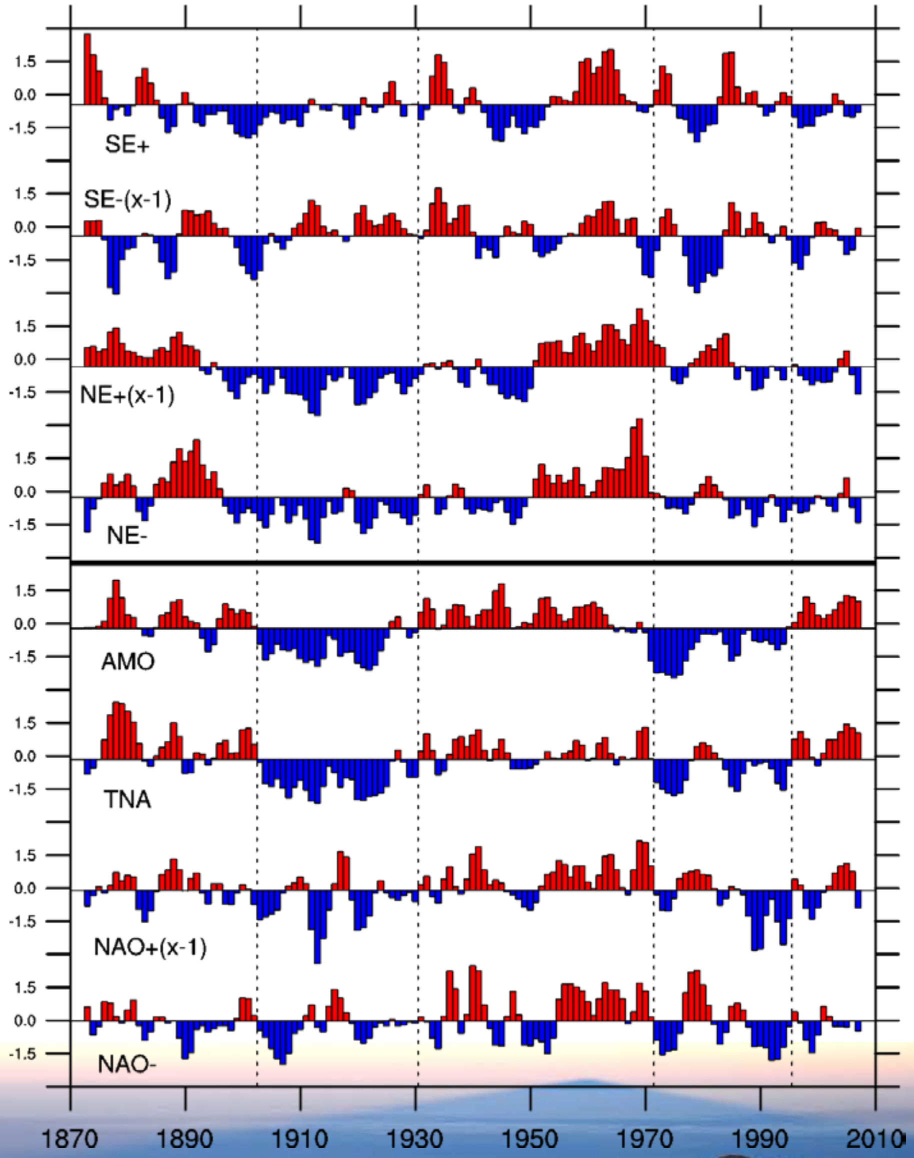
Tropical wind classes (1871-2008)





Tropical wind classes (1871-2008)



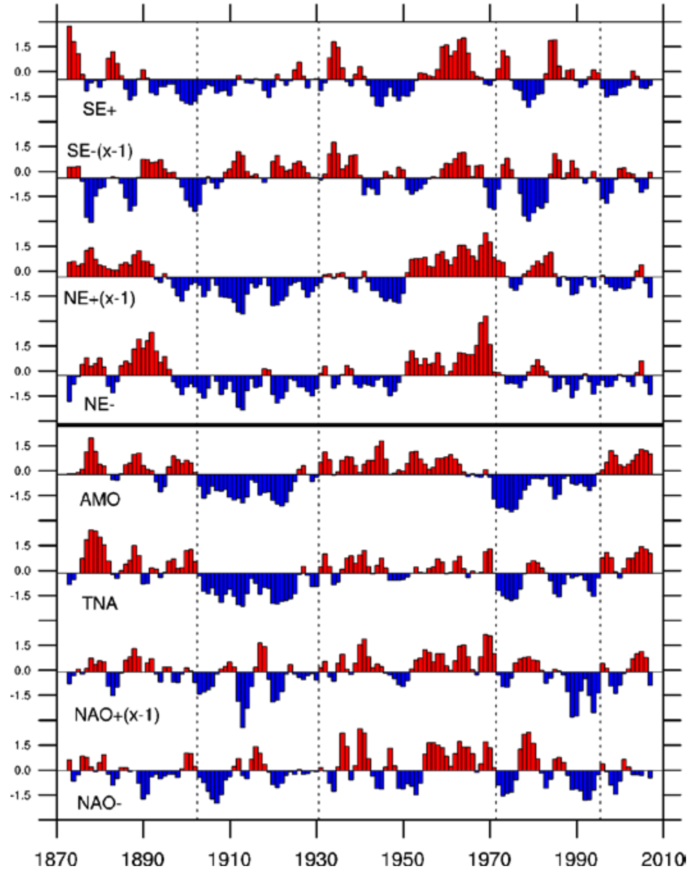


Temporal correlation

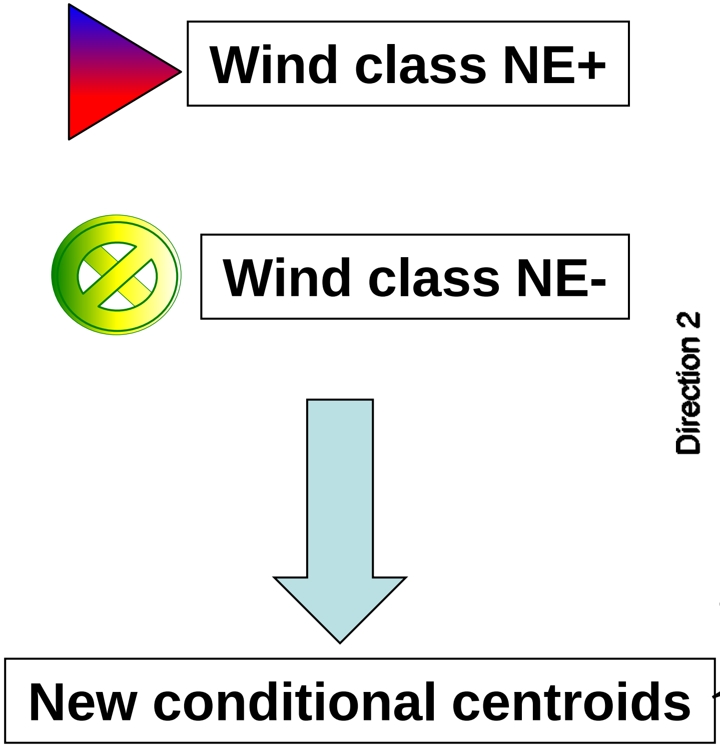
Cross-correlation

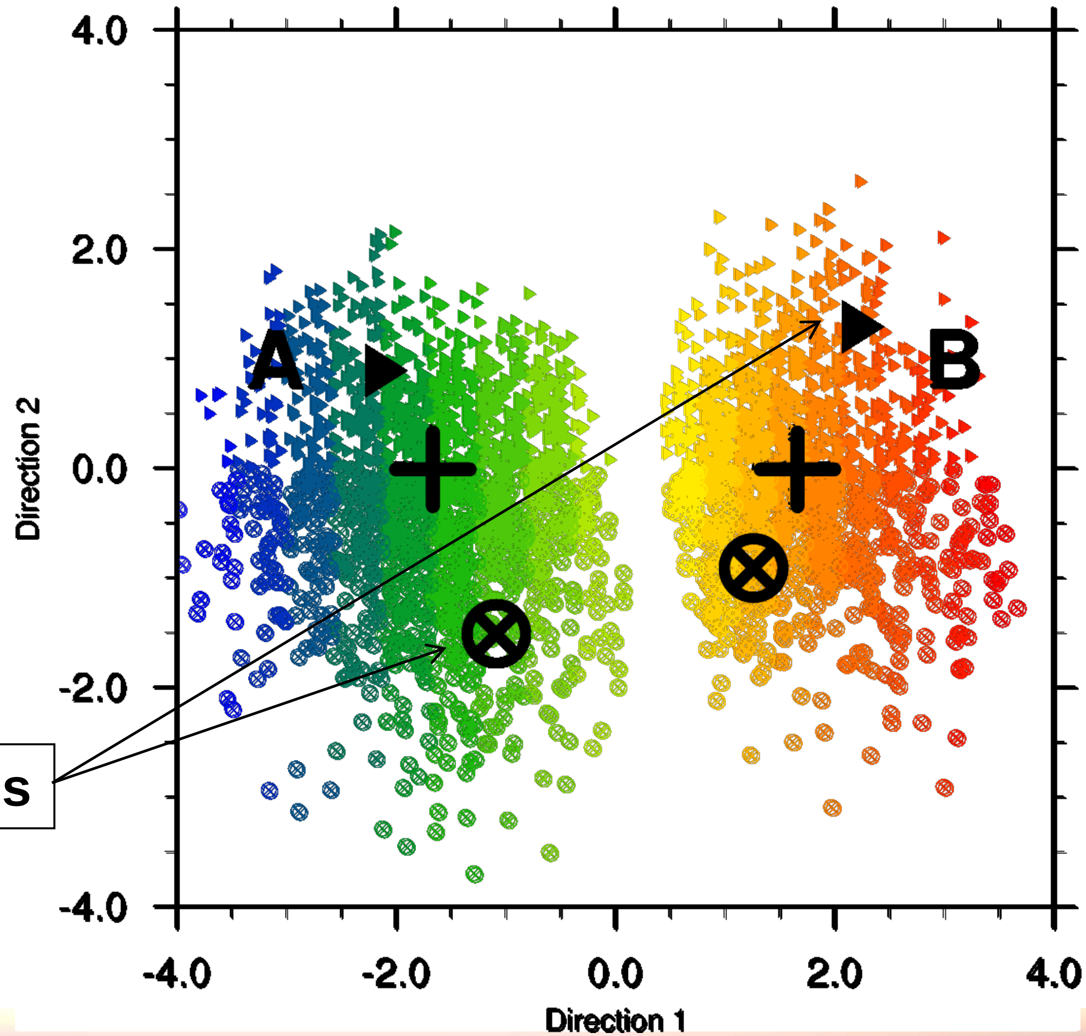
	NAO-	NAO+	TNA	AMO	NE-	NE+	SE-	SE+
NAO-	1	-0.57	0.37	0.17	0.17	-0.30	-0.18	0.08
NAO+		1	-0.48	-0.35	-0.57	0.56	-0.30	0.02
TNA			1	0.80	0.45	-0.46	-0.35	0.17
AMO				1	0.35	-0.36	-0.22	0.01
NE-					1	-0.78	-0.15	0.01
NE+						1	-0.25	0.40
SE-							1	-0.55
SE+								1

Statistical significance in red

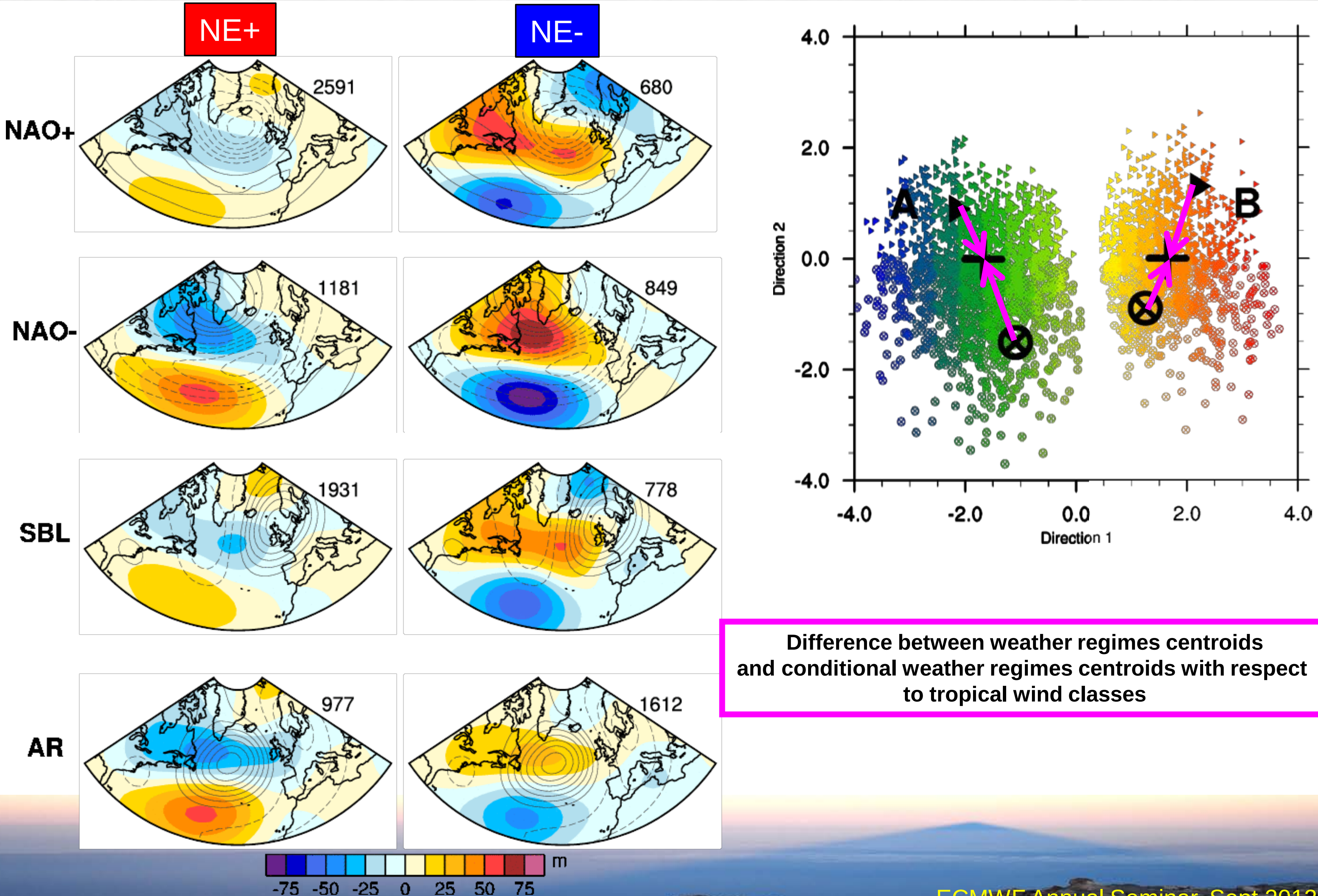


Conditional sub-sampling in WR





Conditional Z500 composites with respect to tropical wind classes



Difference between weather regimes centroids and conditional weather regimes centroids with respect to tropical wind classes

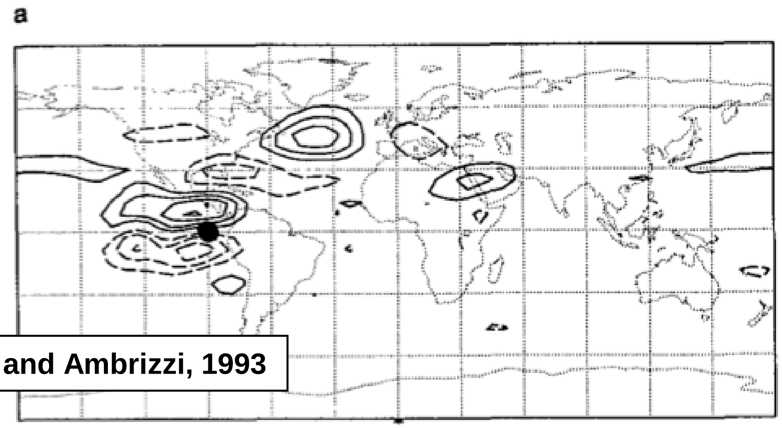
Conclusions (decadal)

❖ Existence for a significant modulation of the weather regime internal properties with respect to tropical wind classes

❖ Independence of the tropical modulation with respect to the weather regimes: Results could be interpreted as a change of the mean background states over which internal variability, here WR, occurs.

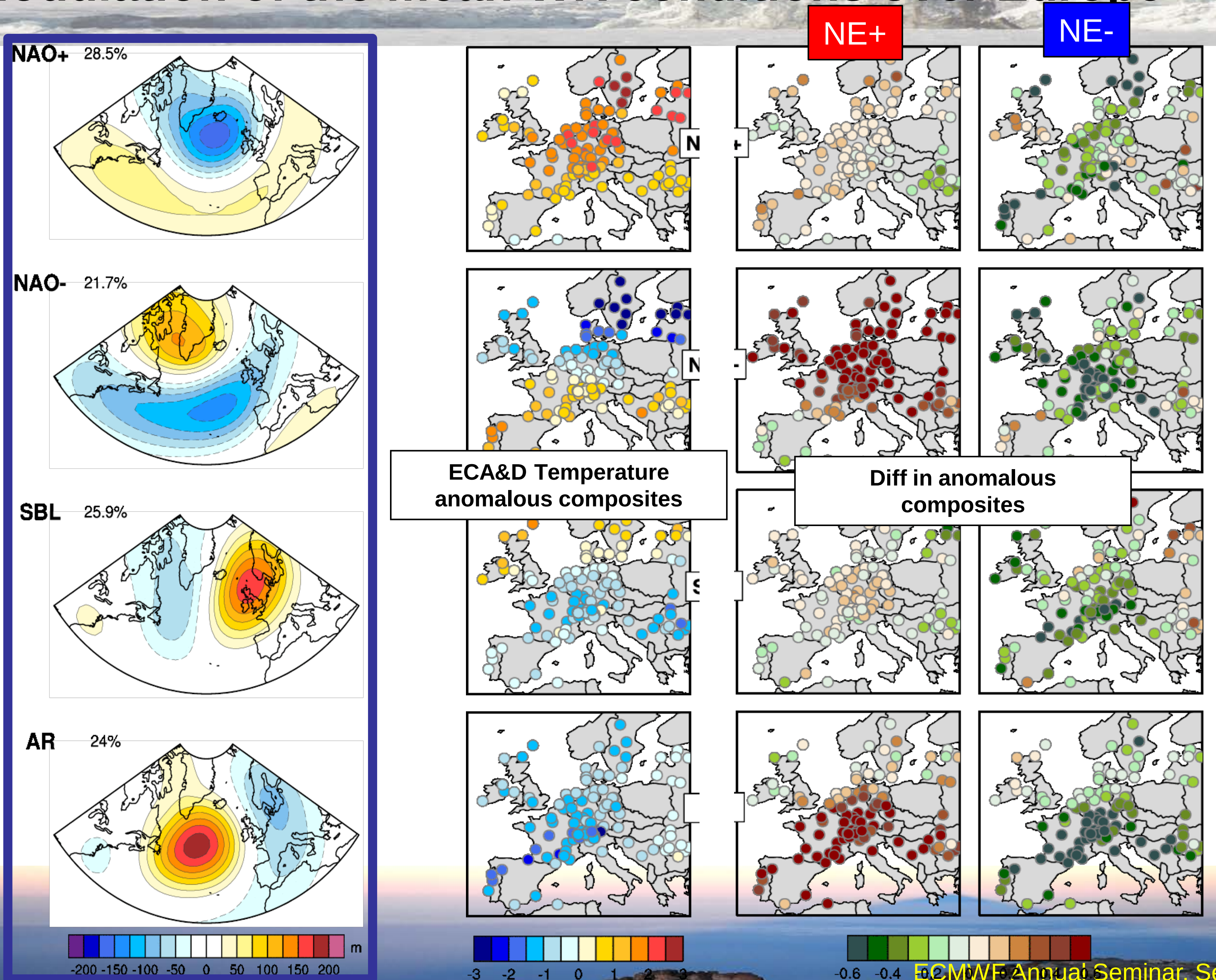
❖ Evidence of linear "behaviour" of the atmospheric dynamics

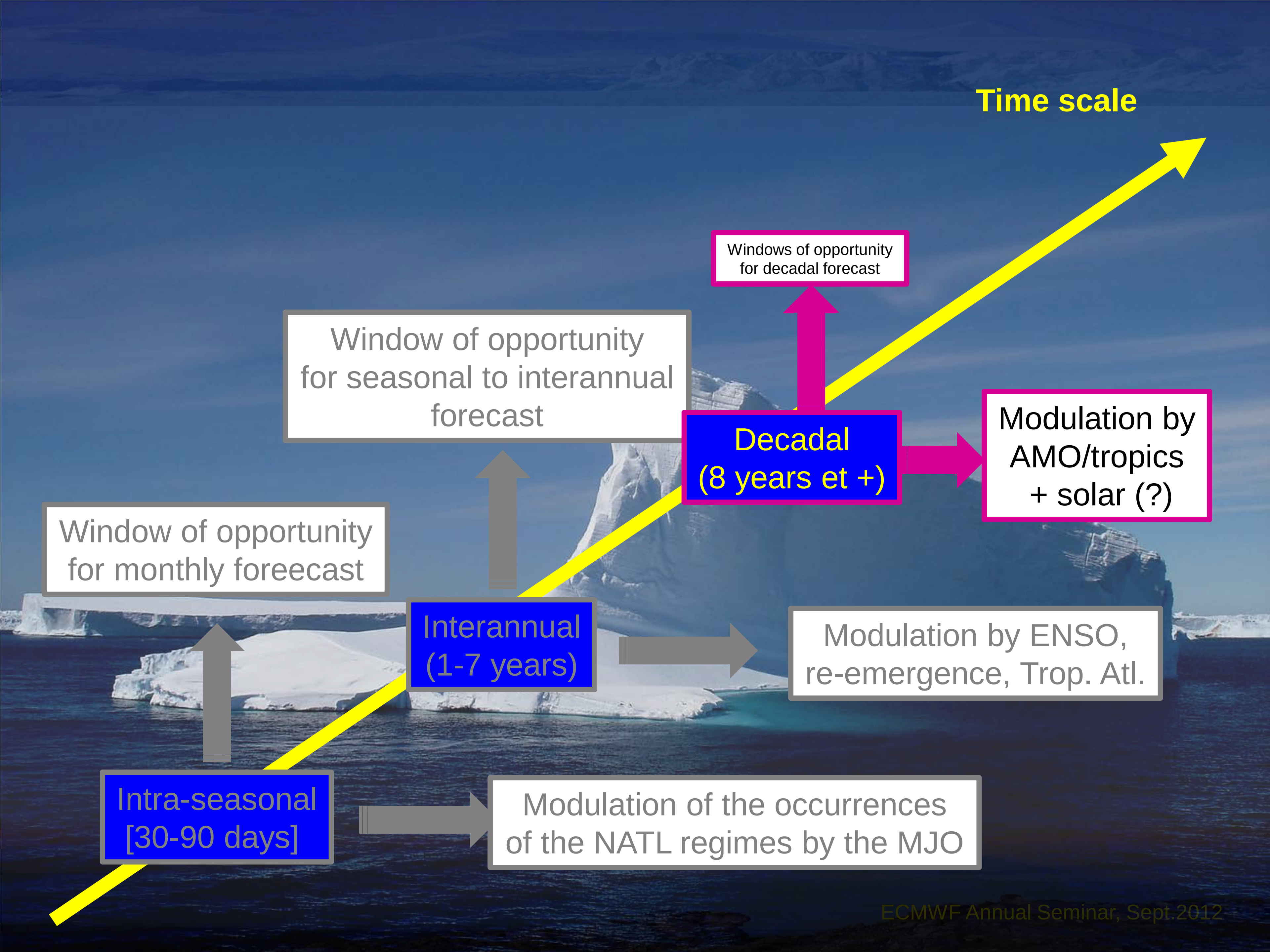
❖ Strong projection of the signal on a tropical forced Rossby wave.

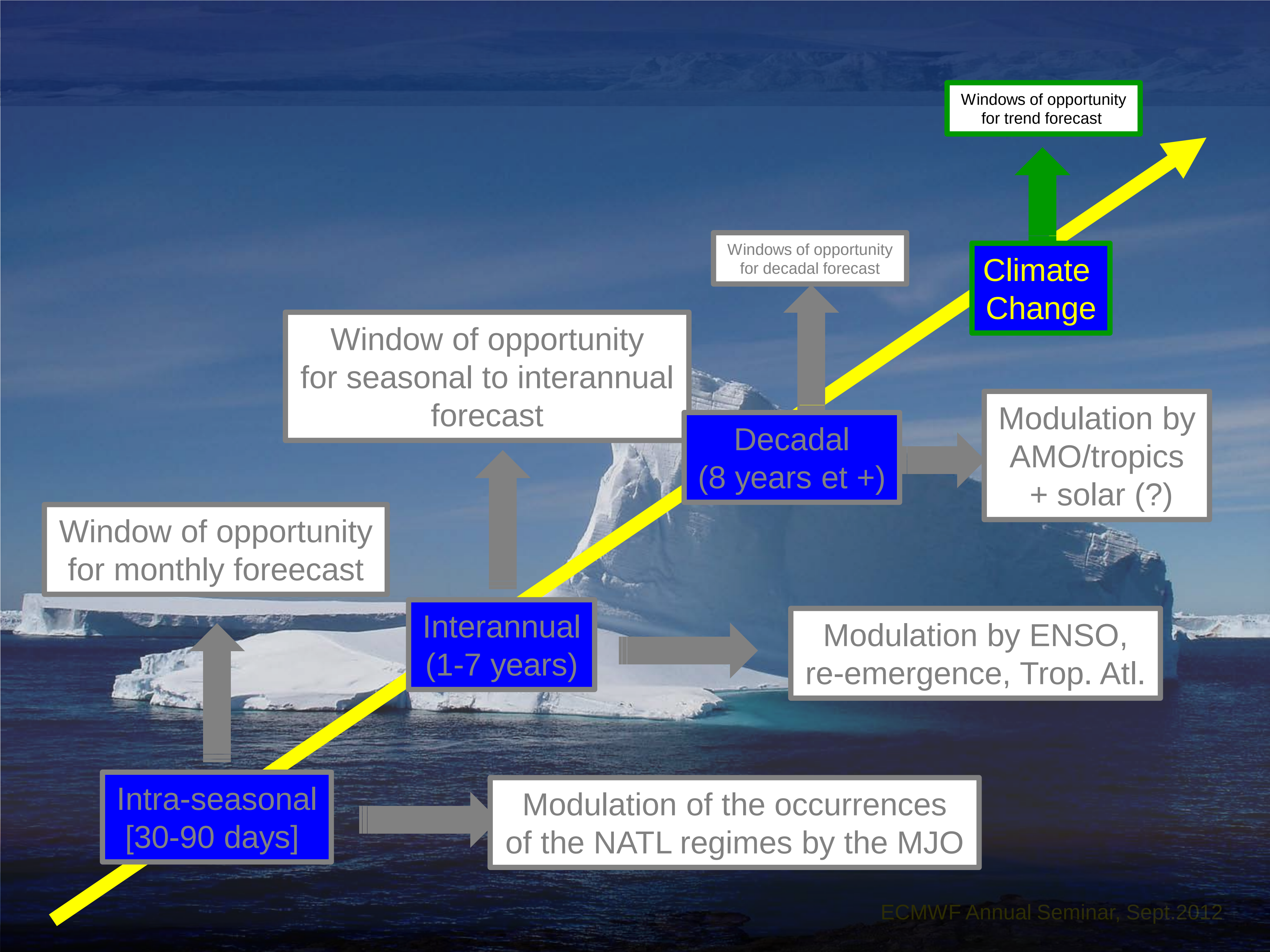


Hoskins and Ambrizzi, 1993

Modulation of the mean WR conditions over Europe




Time scale
Windows of opportunity
for decadal forecast
Window of opportunity
for seasonal to interannual
forecast
Decadal
(8 years et +)
Modulation by
AMO/tropics
+ solar (?)
Window of opportunity
for monthly foreecast
Interannual
(1-7 years)
Modulation by ENSO,
re-emergence, Trop. Atl.
Intra-seasonal
[30-90 days]
Modulation of the occurrences
of the NATL regimes by the MJO
ECMWF Annual Seminar, Sept.2012


Windows of opportunity
for trend forecast
Climate
Change
Windows of opportunity
for decadal forecast
Window of opportunity
for seasonal to interannual
forecast
Decadal
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Modulation by
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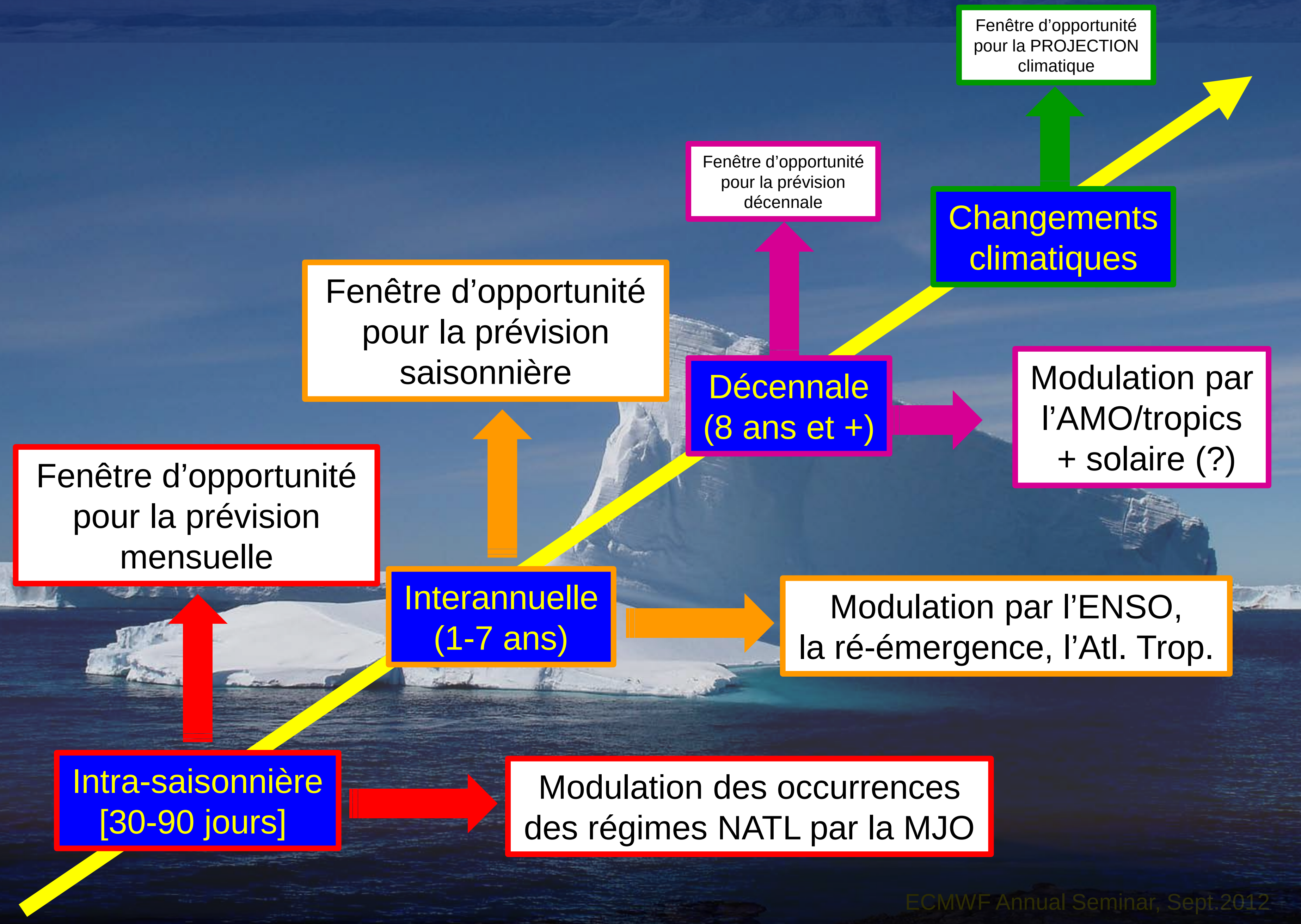
Echelle de temps




Thank you