The influence of the variability of the ocean circulation on the large-scale atmospheric circulation : observational evidence and possible mechanisms

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based on work with

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Dima Smirnov, Matthew Newman, Mike Alexander (NOAA/ESRL, Boulder),
and Young-Oh Kwon (WHOI)

Extratropical SST anomaly influence on the large-scale atmospheric circulation

Difficult to detect in the observations:

large natural atmospheric variability, small signal-to-noise ratio
need to distinguish between cause and effect

Main method:

atmospheric timescale timescale << oceanic timescale

use relation between the atmosphere and previous oceanic anomalies
(lagged regression, maximum covariance analysis, …)

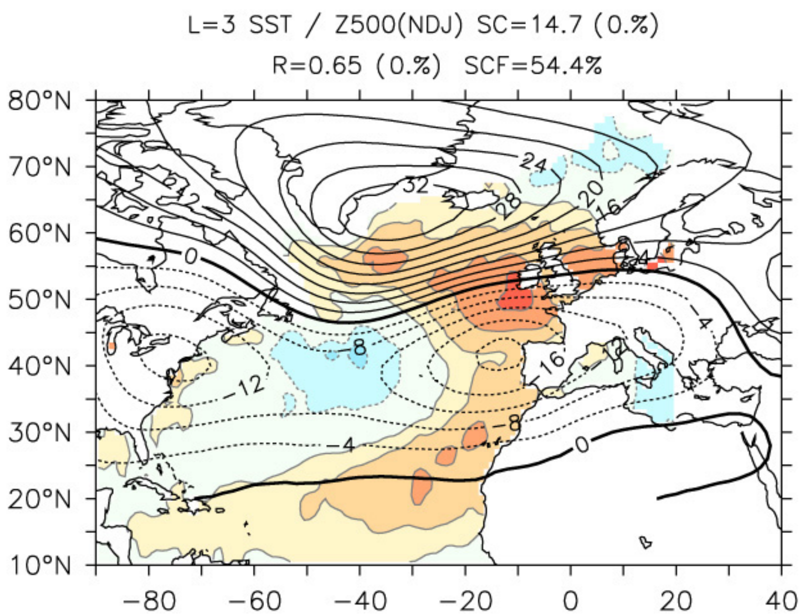
only valid if there is no other persistent atmospheric component or they are removed
(ENSO teleconnections, trends, external forcing…)

need to be distinguished from other concomitant boundary forcing

Extratropical SST anomaly influence at seasonal to interannual time scales

First observational estimate for North Atlantic (Czaja and Frankignoul 1999, 2002)

Further analysis (20th Century Reanalysis for 1966-2010, global warming trend and ENSO removed



First MCA mode for SST leading NDJ Z500 by 3 mo

OND/NDJ response is equivalent barotropic

5% significant for SST leading by up to a lag 9 months
No other concomitant boundary forcing
(SST, snow cover, Arctic sea ice)

The negative NAO response is

driven by the NAH SST anomaly

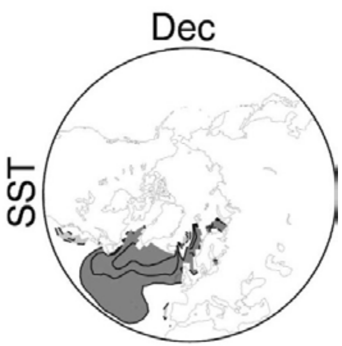
Modeling studies suggest that
the atmospheric response
Is larger for the North Atlantic SST tripole
(e.g., Peng et al. 2002; Cassou et al. 2007)

Gastineau and Frankignoul, submitted

Main dynamics

SST ➔ heat flux ➔ diabatic heating ➔ baroclinic response ➔ eddy-mean flow interactions ➔ barotropic response resembling dominant modes of intrinsic atmospheric variability (e.g. Deser et al. 2007; Peng et al. 2002)

CCM3 (T42, 18 layers)
240-member ensemble



Large prescribed SST (contour 2 K) starting in December

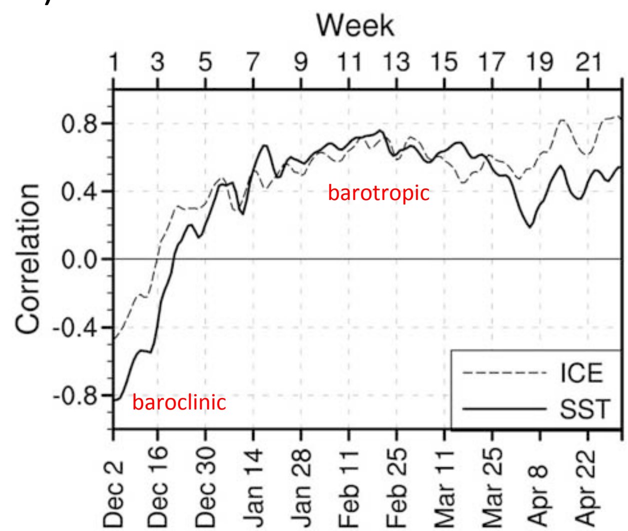
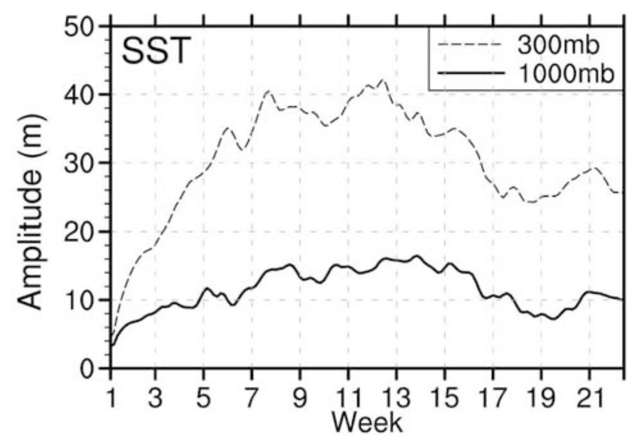


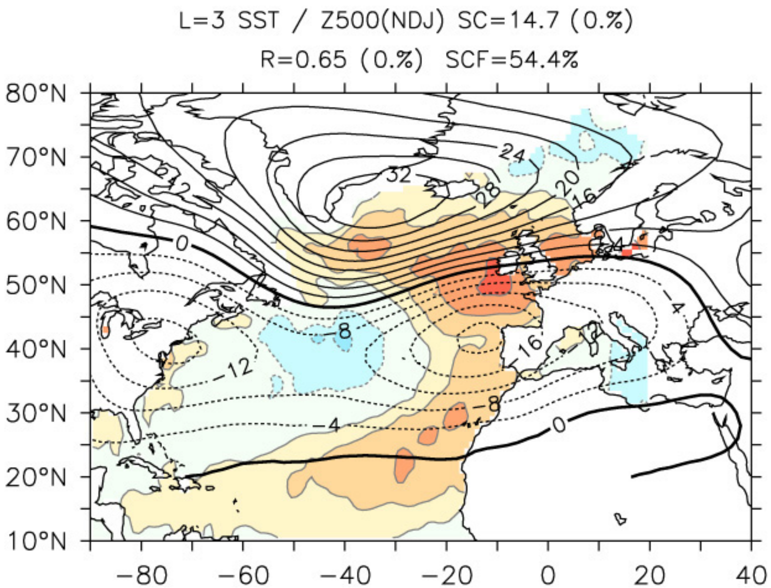
FIG. 4. Spatial correlation coefficients between daily geopotential height responses at 1000 and 300 hPa for the SST and ICE experiments.



Rms of area-weighted anomalies north of 30°N

Deser et al. 2007

Dynamics more difficult to establish in observations or climate model simulations



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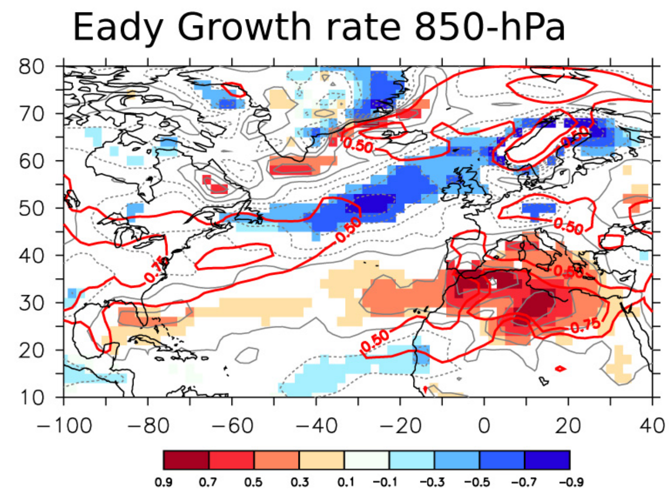
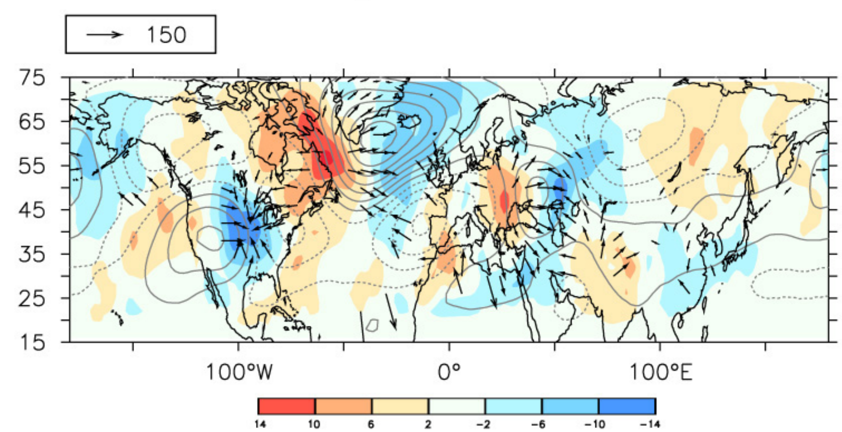
Lagged regression in NDJ on MCA SST time series in ASO



Climatology in red

Wave Activity Flux At 250 hPa

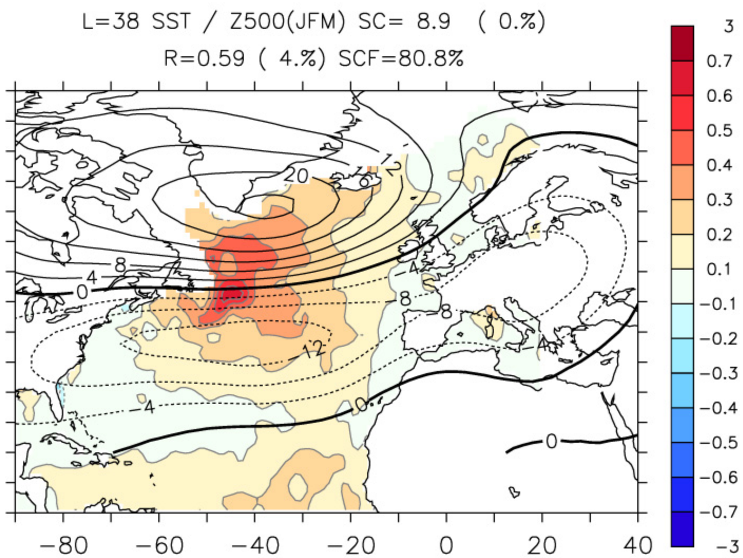


Gastineau and Frankignoul, submitted

Links to oceanic circulation? Easier to see at low frequency

Weak smoothing: JFM(t) given by ¼ JFM(t-1) + ½ JFM (t) + ¼ JFM(t+1)

20th Century Reanalysis for **1930-2010** (limited data coverage before 1966); global trend and SST removed



First MCA, SST leads JFM Z500 by 38 months

NAH with larger subpolar warming

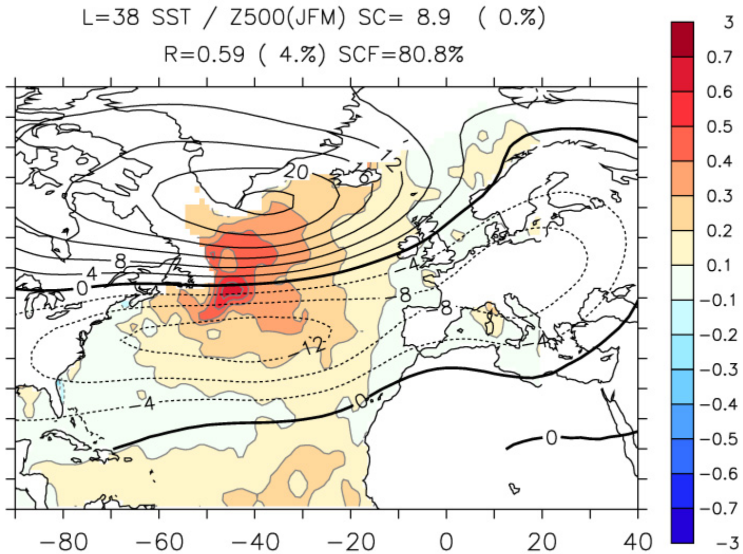
5% significant for SST leading by up to 48 months

No concomitant SIC or snow cover anomaly

Gastineau and Frankignoul, submitted

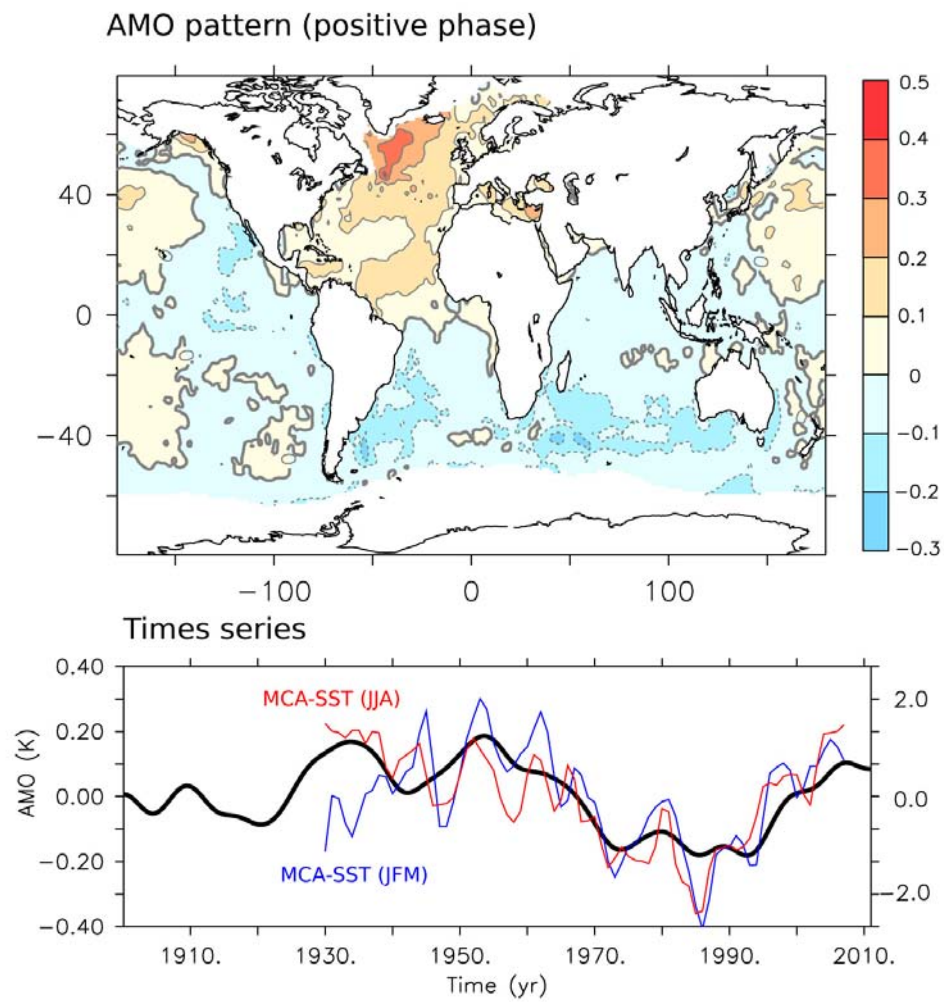
The NAH at low frequency resembles the Atlantic Multidecadal Oscillation driven by the variability of the Atlantic meridional overturning circulation (AMOC) in climate models

(a NAO- response to the AMOC seen in many models, Gastineau and Frankignoul 2012)



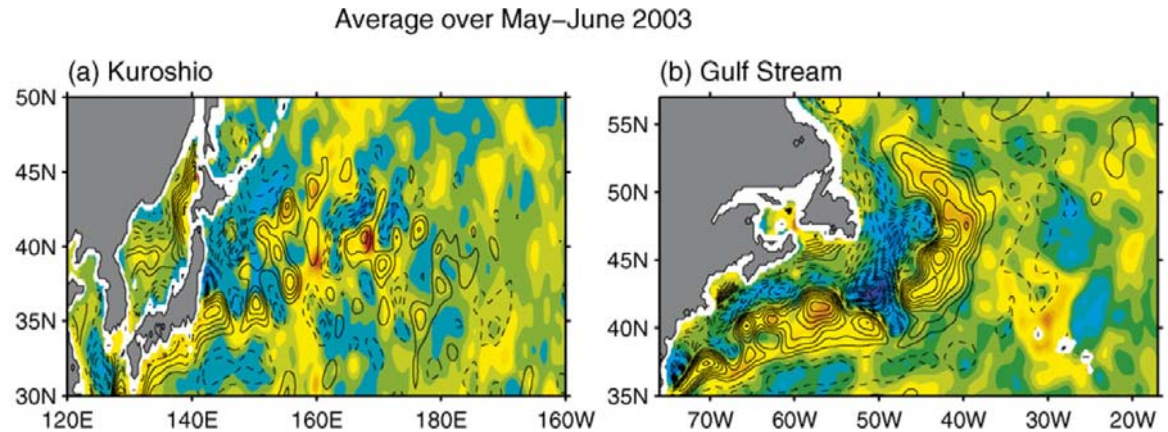
First MCA, SST leads JFM Z500 by 38 months

The AMO also influences the lower troposphere
in summer (as in Sutton and Hodson 2005



Gastineau and Frankignoul, submitted

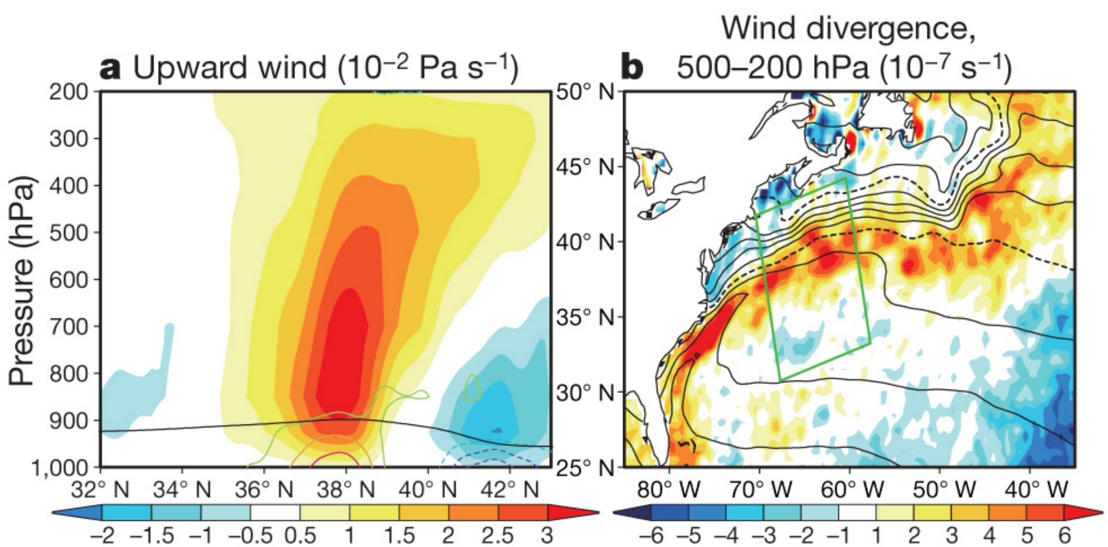
Oceanic fronts and mesoscale eddies also influence the atmosphere



High-pass filtered 2-month averaged wind stress magnitude (color) and SST (contour)
Larger surface wind over warm SST

Chelton, O'Neill, …

Small et al. 2008



Annual mean upward velocity, BL height and wind convergence across the GS front

Annual mean upper tropospheric wind divergence

Climatological imprint of Gulf Stream front throughout the troposphere

Ocean fronts have a strong Impact on the mean atmospheric circulation

Minobe et al 2008

Large-scale response to the variability of the western boundary currents

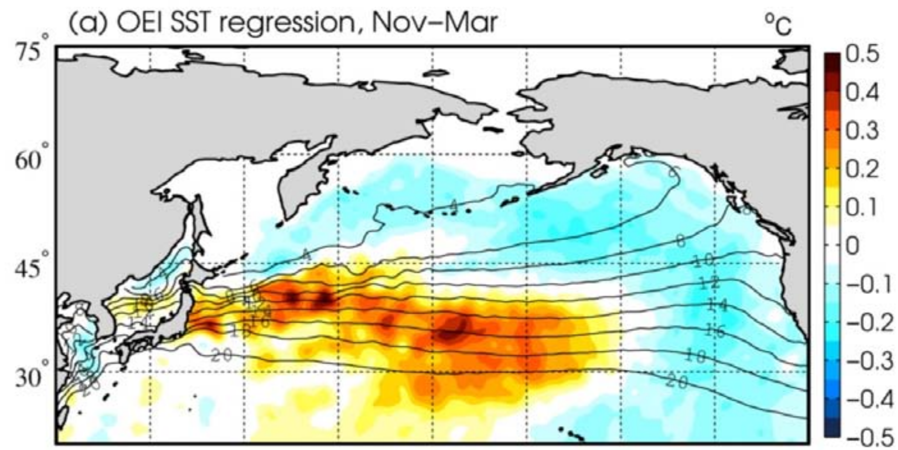
Oyashio Extension (subarctic front): sharp SST front

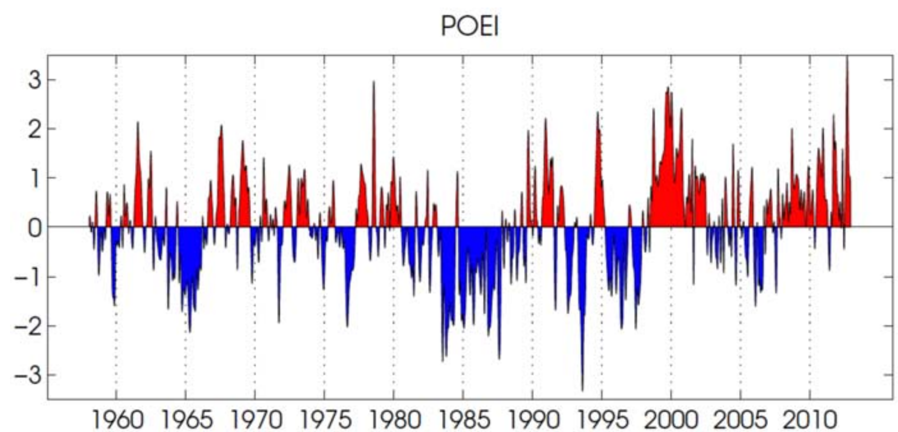
(Frankignoul et al. 2011; Taguchi et al. 2002, with different response pattern (NPO versus Aleutian Low. Non-stationnarity?)

An attempt to simulate and understand the response using CAM5

(Smirnov, Newman, Alexander, Kwon, and Frankignoul , submitted)

Regression on OE index





Large-scale response to the variability of the western boundary currents

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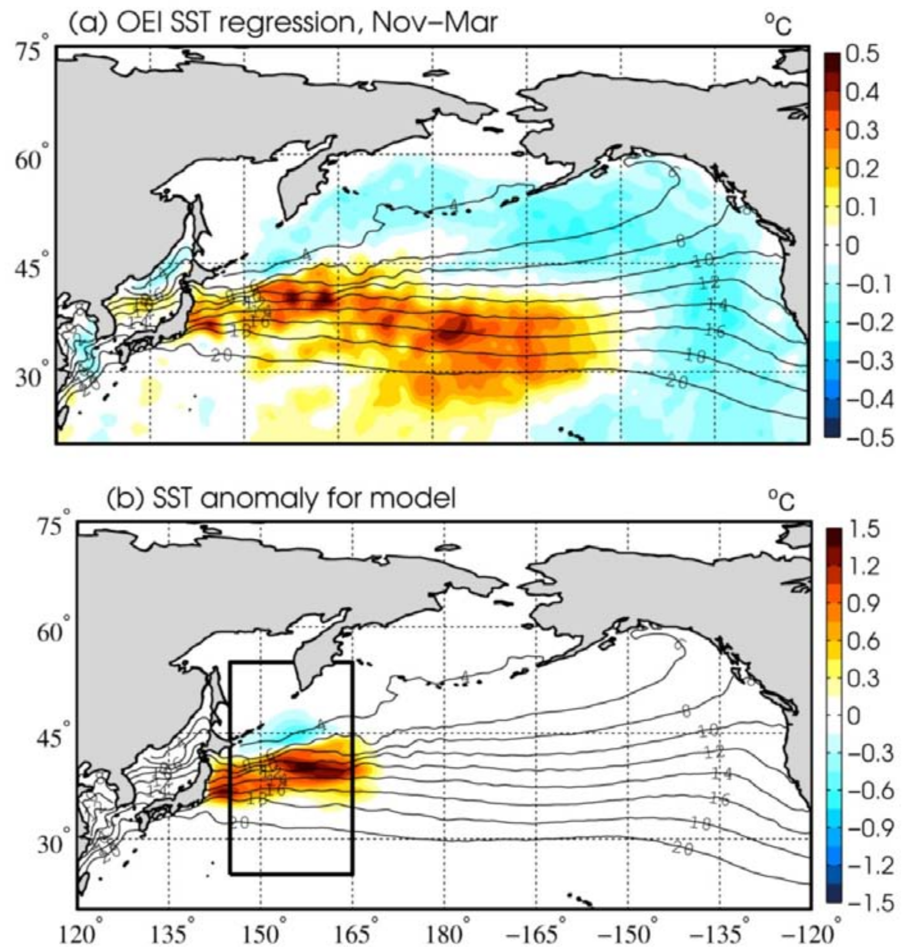
Regression on OE index

Prescribed SST Anomaly

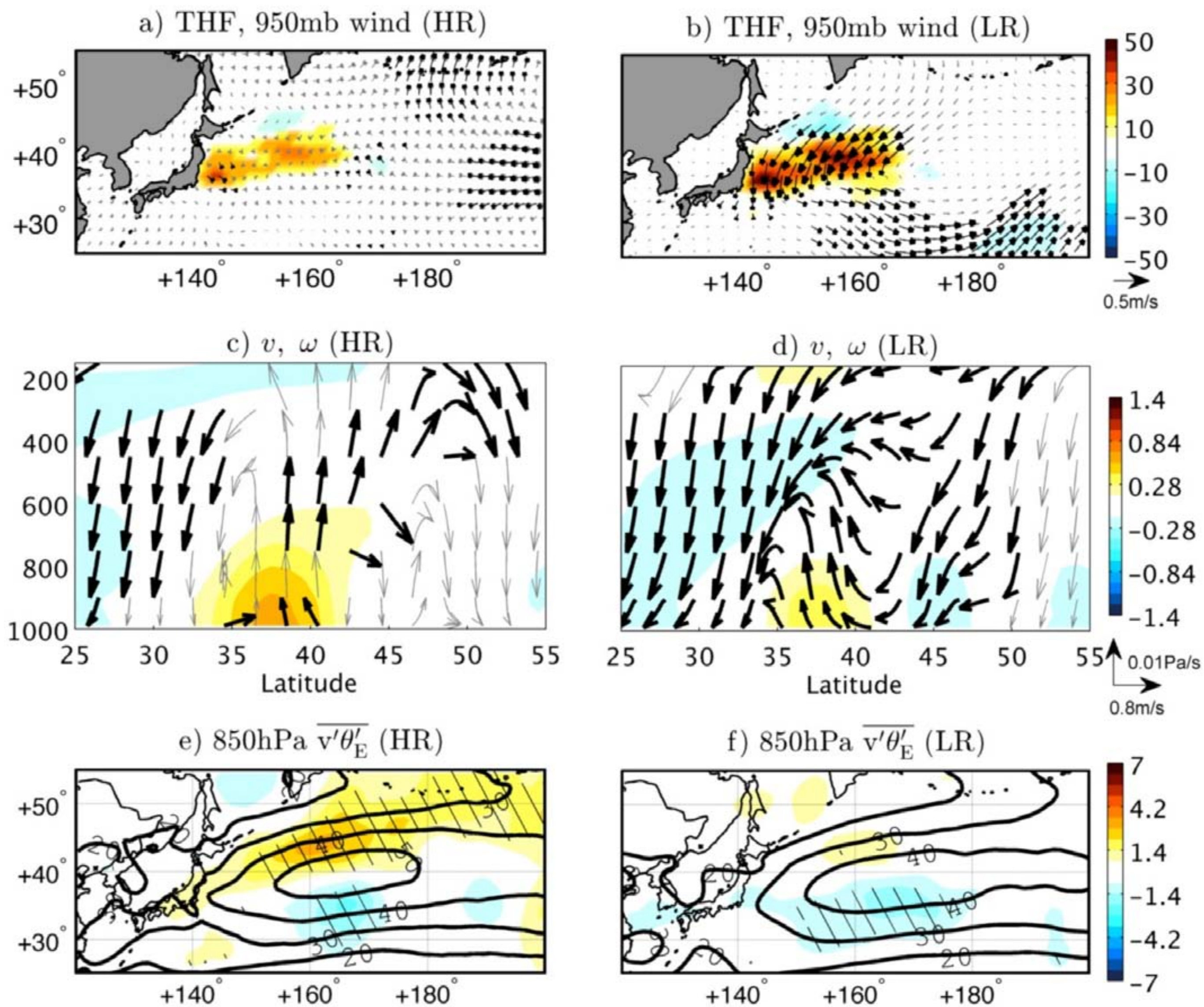
(OE region only, SST x 3)



CAM5 at ¼° and 1° resolution, 25-member ensembles starting in November 1

Warm – cold case, December-March average

¼°



1°

Stronger surface Wind and THF

Local temperature response in lower troposphere

Weaker eddy fluxes

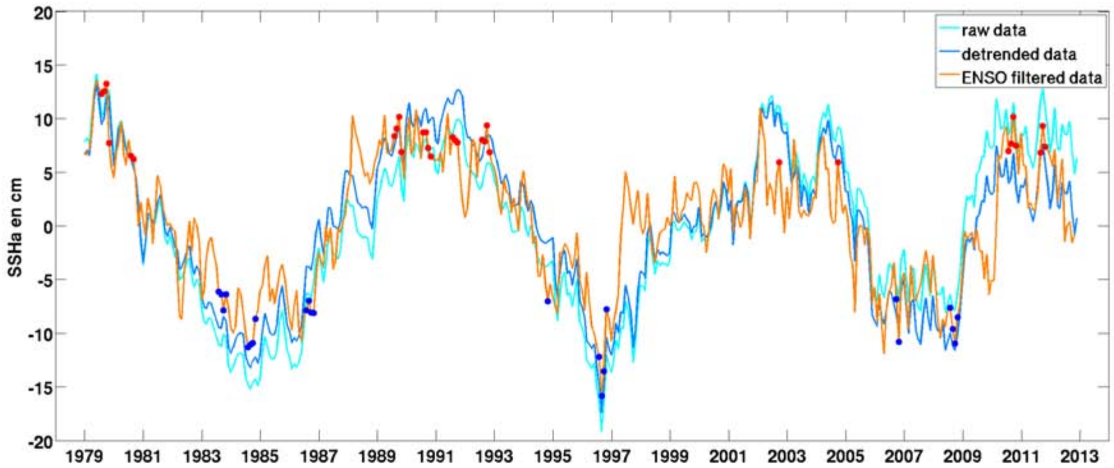
Shallow diabatic Heating balanced by cold air advection

(Smirnov et al.)

Resolution-dependent response!

Large-scale response to the variability of the western boundary currents

Kuroshio Extension sharp SSH front, weaker SST front



Decadal KE variability largely driven by NPO wind stress curl in central and Eastern North Pacific 3-4 years earlier

Kuroshio Extension index from Qiu et al. 2014

averaged SSH in 31°–36°N, 140°–165°E based on altimetry (1993-2012) and OFES (1979-92)
Global trend and ENSO teleconnections removed

Positive index:
stable state with northerly path, increased transport and southern recirculation, decreased eddy energy

Negative index: opposite, unstable state

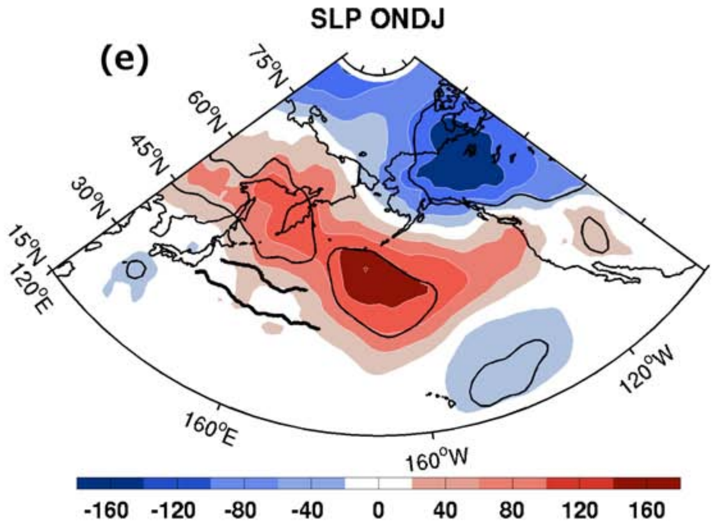
Révelard et al., in preparation

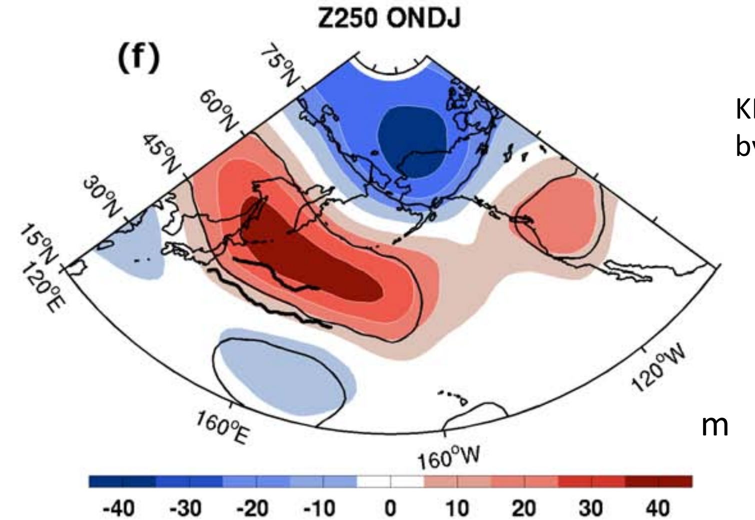
Cold season response to KE variability in 1979-2012

Consistent response pattern from October to January

ERA-Interim

Black line
10% sign.

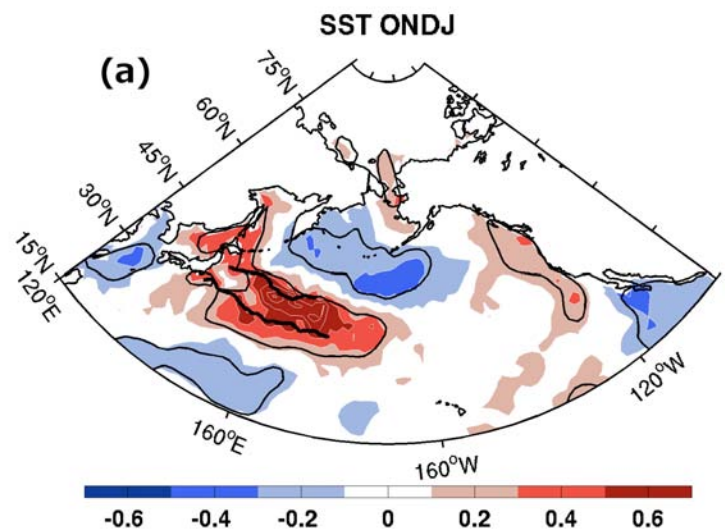




KE leads
by 2 months

Broad warming
in KOE region

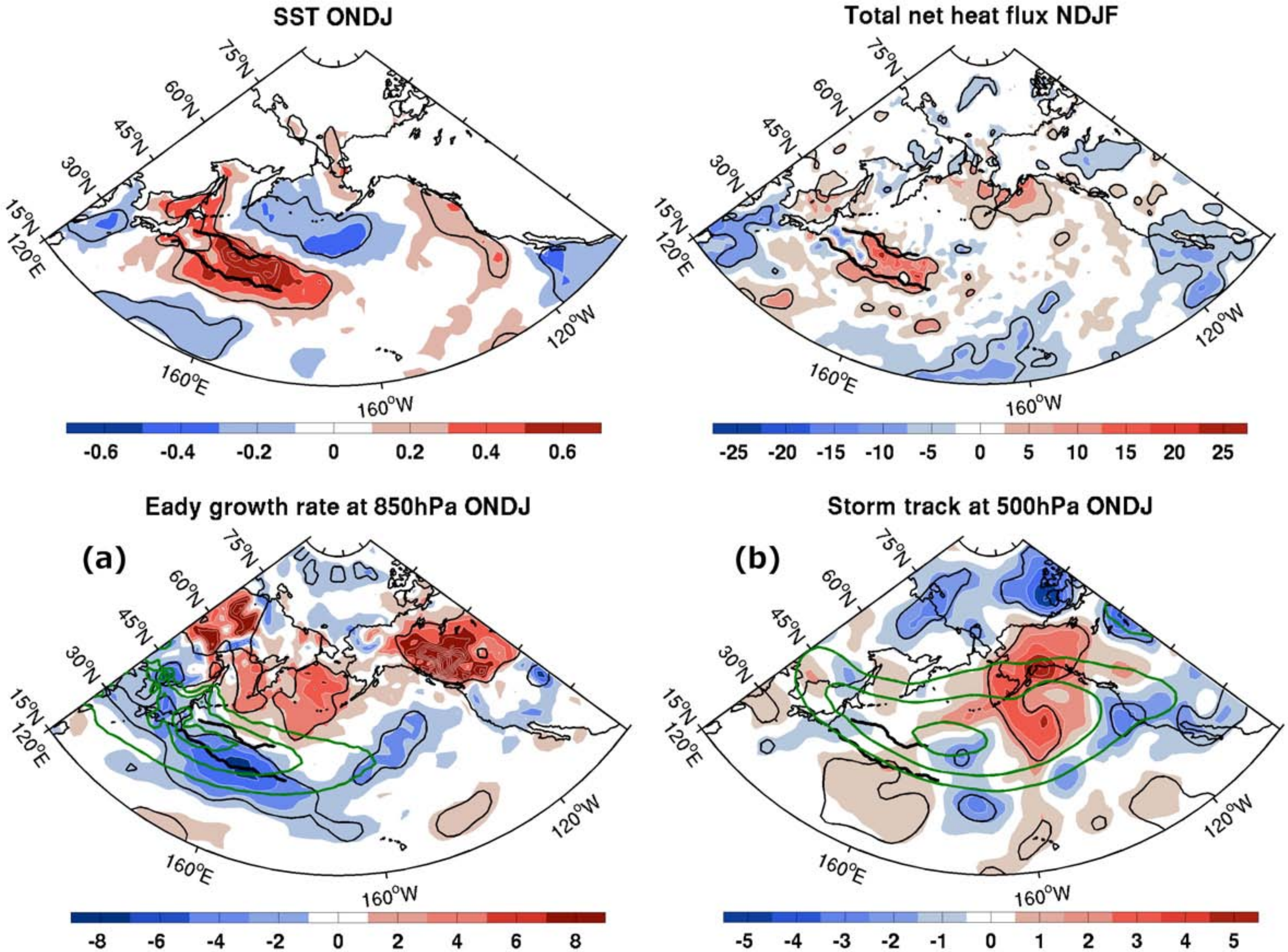
No sharp
SST front as
for OE



Equivalent barotropic pattern
Significant for KE index leading by up to 13 months

The response is due to the decadal KE variability (short sample)

Révelard et al., in preparation



OA flux

Climatology in green

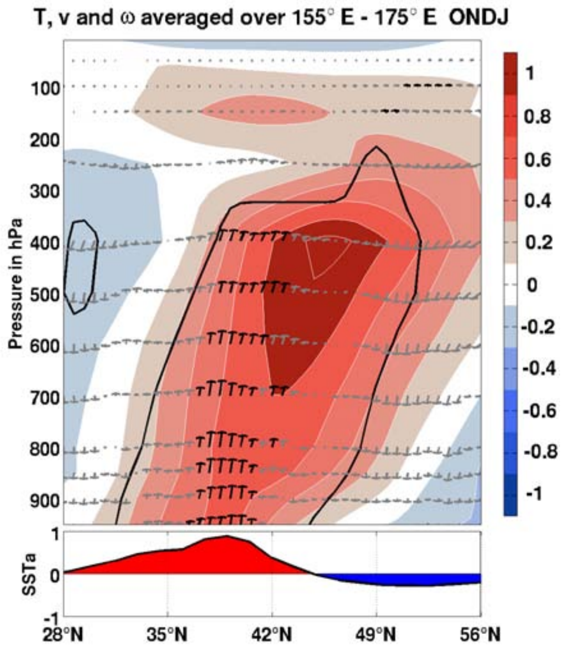
Lagged regression by 2 months on KE index in ASON

Révelard et al., in preparation

Maximum temperature perturbation in the upper troposphere

Vertical velocity is noisy, but

upward motion in KOE region

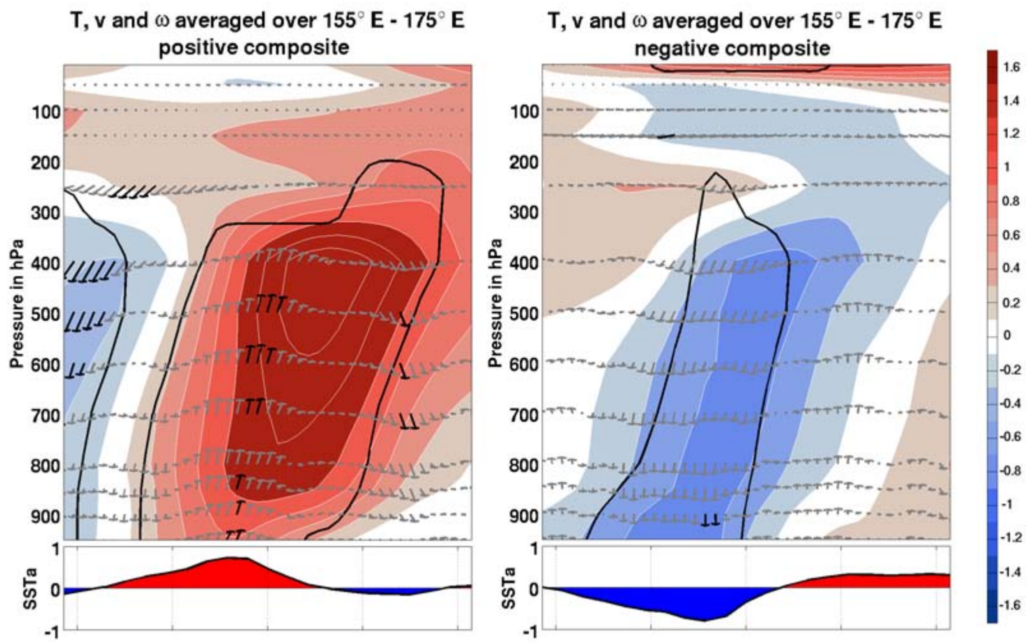


In black, 10% significance

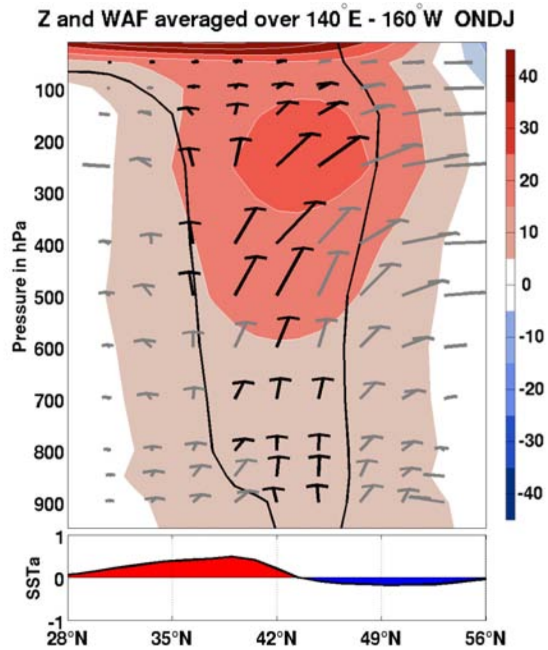
Composites for positive and negative KE index show a strong asymmetry

Much stronger and significant response for KE+

Convection increases above + SST anomaly

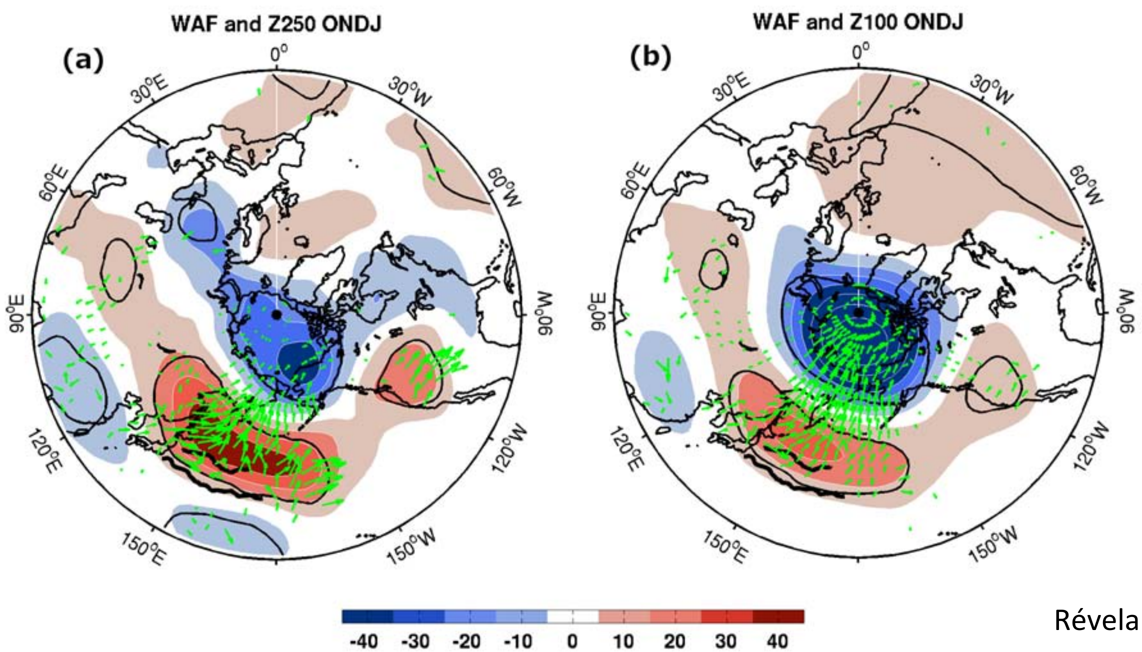


The Kuroshio-Oyashio region is a source of Rossby wave activity that extends the response upward and northward



Upward and northward wave activity flux

Strong signal in Stratosphere



Hemispheric Pattern

Révelard et al., in preparation

Conclusions

The variability of the ocean circulation has significant climatic impacts at low frequency

The mechanisms of the atmospheric response need to be better understood

High-resolution response studies are needed

Caveat:

- The earlier observations are limited and the sample is small
- There is some predictability of the AMOC and the KE fluctuations, but is there useful predictability of their climatic impacts?