Mechanisms of the North Atlantic internal variability at multidecadal timescale in the CNRM-CM5 model

Yohan Ruprich-Robert and Christophe Cassou
Study the North Atlantic internal variability with the Pre-industrial control run of CNRM-CM5

1) Characteristics of the CNRM-CM5 AMV

2) Link between AMV and AMOC

3) Mechanism leading to AMV/AMOC variability

4) Importance of the SPG (?)

5) Conclusion
Outline

1) Characteristics of the CNRM-CM5 AMV

2) Link between AMV and AMOC

3) Mechanism leading to AMV/AMOC variability

4) Importance of the SPG

5) Conclusion
The AMV in CNRM-CM5
(Atlantic Multidecadal Variability)

NASST = annual North Atlantic SST averaged over Eq-60°N

$\sigma_{\text{NASST}} = 0.14^\circ\text{C}$

Power Spectrum

![Power Spectrum Diagram]

NASST Spectrum

![NASST Spectrum Diagram]
The AMV in CNRM-CM5
(Atlantic Multidecadal Variability)

\[ \sigma_{\text{NASST}} = 0.14^\circ \text{C} \]

\[ \text{NASST} = \text{annual North Atlantic SST averaged over Eq-60^\circ \text{N}} \]

### Power Spectrum

- Frequency: 0.1, 0.2, 0.3, 0.4
- Period (yr): 3, 7, 13, 25, 50, 100

**NASST Spectrum**

- 95% Confidence level

- Period: ~80-120 yr
The AMV in CNRM-CM5
(Atlantic Multidecadal Variability)

NASST = annual North Atlantic SST averaged over Eq-60°N

\( \sigma_{\text{NASST}} = 0.14°C \)

Power Spectrum

Period (yr)

\(~80-120\text{yr}\)

NASST Spectrum
The AMV in CNRM-CM5
(Atlantic Multidecadal Variability)

NASST = annual North Atlantic SST averaged over Eq-60°N

σ_{NASST} = 0.14°C
σ_{AMV} = 0.09°C
VAR = 50%

AMV = 25yr low pass filtered NASST

NASST Spectrum

Power Spectrum

~80-120yr

Period (yr)

AMV Autocorrelation

Lag (year)
The AMV in CNRM-CM5
(Atlantic Multidecadal Variability)

NASST = annual North Atlantic SST averaged over Eq-60°N

$\sigma_{\text{NASST}} = 0.14^\circ C$
$\sigma_{\text{AMV}} = 0.09^\circ C$

VAR = 50%

The AMV is a non oscillating mode of variability
at multidecadal to centennial timescale

~80-120 yr
1) Characteristics of the CNRM-CM5 AMV

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5) Conclusion
The AMOC variability explains more than 80% of the AMV
The AMOC variability explains more than 80% of the AMV

- **AMOCy**
  - Annual time resolution
  - Same low-frequency than AMOC_PC
  - Useful for O/A relationships

(Msadek and Frankignoul 2009)
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The atmosphere and the AMOC variability

a) North Atlantic Europe Annual SLP EOF1: **NAO**

39.9%

b) North Atlantic Europe Annual SLP EOF2: **EAP**

14.7%

NAO/EAP and AMOC Cross-correlation

AMOC_PC leads

Correlation

Lag (year)
The atmosphere and the AMOC variability

In CNRM-CM5 the EAP is the main atmospheric forcing of the AMOC variability
The EAP seasonality and the AMOC variability

b) Seasonal EAP/AMOC cross-correlation

AMOCy leads

Correlation

-0.10
-0.05
0.00
0.05
0.10
0.15

Lag (year)

-40 -20 0 20 40

ANNUAL

significativity > 95%
The EAP seasonality and the AMOC variability

b) Seasonal EAP/AMOC cross-correlation

AMOC_y leads

Annual EAP combination of: Winter EAP forcing
The EAP seasonality and the AMOC variability

b) Seasonal EAP/AMOC cross-correlation

AMOCy leads

Annual EAP combination of:
Winter EAP forcing

\[ \text{Correlation} \]

\[ \text{Lag (year)} \]
The EAP seasonality and the AMOC variability

b) Seasonal EAP/AMOC cross-correlation

AMOCy leads

Annual EAP combination of:
Winter EAP forcing
Summer EAP response

Summer response consistent with:
Kushnir 2002
Hodson 2010
Msadek and Frankignoul 2010
The EAP seasonality and the AMOC variability

ANNUAL
NDJFM
MJJAS
• significativity > 95%

Annual EAP combination of:
- Winter EAP forcing
- Summer EAP response

Summer response consistent with:
- Kushnir 2002
- Hodson 2010
- Msadek and Frankignoul 2010

Importance of seasonality on O/A relationships

AMOCy leads
The winter EAP forcing [-40yr;-20yr]

Regression of annual barotropic STF on winter EAP

Msadek and Frankignoul 2009
Barrier et al. 2013
The winter EAP forcing [-40yr;-20yr]

Msadek and Frankignoul 2009
Barrier et al. 2013
The winter EAP forcing [-40yr;-20yr]

Regression of salt@0-200m on AMOCy

Msadek and Frankignoul 2009
Barrier et al. 2013

Regression of annual barotropic STF on winter EAP

Significativity > 95%

Regression of salt@0-200m on AMOCy

Significativity > 95%
The winter EAP forcing [-40yr; -20yr]

SPG salinity

Salinity transport from subtropics

Regression of annual barotropic STF on winter EAP
The winter EAP forcing [-40yr;-20yr]

SPG salinity

SPG density

Winter EAP

Salinity transport from subtropics

Regression of annual barotropic STF on winter EAP
The winter EAP forcing [-40yr;-20yr]

Regression of annual barotropic STF on winter EAP

Internal Salinity feedback, see Levermann and Born 2007
The winter EAP forcing [-40yr;-20yr]

SPG heat

SPG salinity

heat transport from subtropics

SPG density

Internal salinity feedback

Internal Salinity feedback, see Levermann and Born 2007

Salinity transport from subtropics

SPG strength

Winter EAP

Regression of annual barotropic STF on winter EAP
The winter EAP forcing [-40yr; -20yr]

SPG salinity

SPG density

SPG strength

heat transport from subtropics

SPG heat

Internal salinity feedback, see Levermann and Born 2007
The winter EAP forcing [-40yr; -20yr]

Internal Salinity feedback, see Levermann and Born 2007

The EAP initiates the internal salinity feedback
- increasing STG $\rightarrow$ SPG transport
- Cooling the SPG by heat fluxes

SPG heat

SPG salinity

SPG strength

heat from tropics

heat from subtropics

Winter EAP

Regression of winter turbulent heat fluxes on winter EAP

Positive flux means ocean heating
The AMOC upper branch acceleration
[-20yr;+10yr]

Current southward propagation ~10yr
The AMOC upper branch acceleration
[-20yr;+10yr]

Current southward propagation ~10yr
The AMOC upper branch acceleration
[-20yr;+10yr]

Current southward propagation ~10yr
The AMOC upper branch acceleration
[-20yr;+10yr]

Current southward propagation ~10yr

AMOC decline:
- Heat SPG increase
  (advection + surface fluxes)
- Advection of Arctic freshwater
- Advection of tropical freshwater

More details in *Ruprich-Robert and Cassou 2013* submitted to Clim Dyn
AMOC variability summary

In CNRM-CM5, the AMOC internal variability is a multidecadal non oscillating mode (taking ~40 years for build-up and ~20 years to be damped)

→ Main precursor of the internal AMV (leading by ~5 years, correlation of 0.91)

→ initiated by the integration of atmospheric white noise forcing: the winter EAP
  (Hakkinen et al. 2011)

→ timescale controlled by oceanic processes

→ leads to weak atmospheric response (summer EAP, winter NAO, summer NAO)

→ AMOC variability mainly impacted by the SPG density fluctuations

→ AMOC conditional predictability mainly comes from SPG density
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Many thanks for your attention
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Importance of the SPG density

SPG T-S Diagram

one point one year

b) AMV / AMOC_PC / AMOCy time series

Normalized Indices

year
Importance of the SPG density

**SPG T-S Diagram**

- AMOC > +1σ
- AMOC < -1σ

**Data Points:**
- Lag = -10 yr
- 1028.76 kg.m⁻³

**Graphs:**
- AMV / AMOC_PC / AMOCy time series

**Axes:**
- Temp@0-500m
- Salinity@0-500m
Importance of the SPG density

AMOC > +1σ
AMOC < -1σ

Temp@0-500m
salinity@0-500m

Lag = -10yr

1028.76 kg.m⁻³

b) AMV / AMOC_PC / AMOCy time series

Normalized Indices

year
Importance of the SPG density

SPG T-S Diagram

- AMOC > +1σ
- AMOC < -1σ

Temp@0-500m

Salinity@0-500m

Lag = -10yr

1028,76 kg.m⁻³
Importance of the SPG density

AMOC < -1
\[ \sigma \]
AMOC > +1
\[ \sigma \]

Temp@0-500m

\[ 1028.76 \text{ kg.m}^{-3} \]

Lag = -10yr

SPG T-S Diagram

Lead time (yr)

Normalized Indices

100 200 300 400 500 600 700 800 900

year

b) AMV / AMOC_PC / AMOCy time series

AMOC_PC

AMV

b) AMV / AMOC_PC / AMOCy time series
Importance of the SPG density

**AMOC**

- Lead time 1 yr
- Lead time 6 yr
- Lead time 12 yr
- Lead time 18 yr
- Lead time 24 yr
- Lead time 30 yr

**1028.76 kg.m$^{-3}$**
Importance of the SPG density

**AMOC**

Standardized anomalies

**Importance of the SPG density initialization**

1028.76 kg.m$^{-3}$

b) AMV / AMOC_PC / AMOCy time series

**Normalized Indices**

AMOC_PC

AMV
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