An event-based approach to understanding decadal variability in the Atlantic Meridional Overturning Circulation

Lesley Allison, Ed Hawkins & Tim Woollings

NCAS-Climate, University of Reading

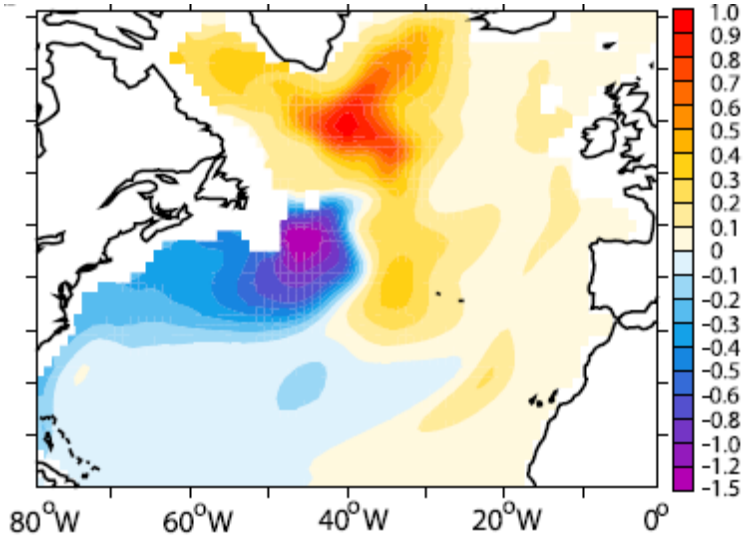
l.c.allison@reading.ac.uk

National Centre for Atmospheric Science
NATURAL ENVIRONMENT RESEARCH COUNCIL

University of Reading

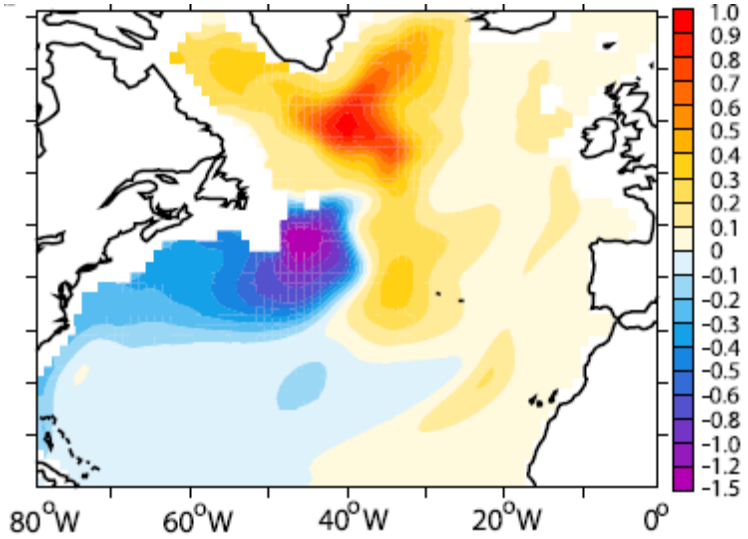
Many coupled climate models exhibit natural decadal AMOC variability, with impacts on other climatic fields

Many coupled climate models exhibit natural decadal AMOC variability, with impacts on other climatic fields



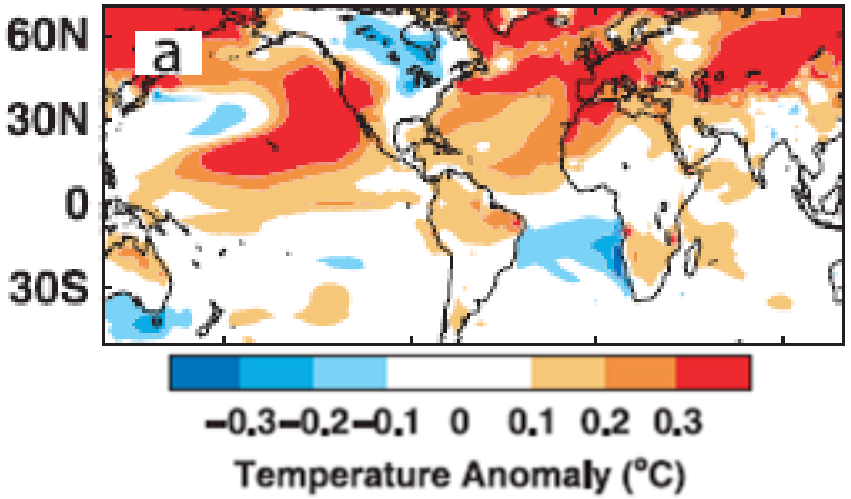
Zhang (2008)
400m ocean temperature,
GFDL CM2.1

Many coupled climate models exhibit natural decadal AMOC variability, with impacts on other climatic fields

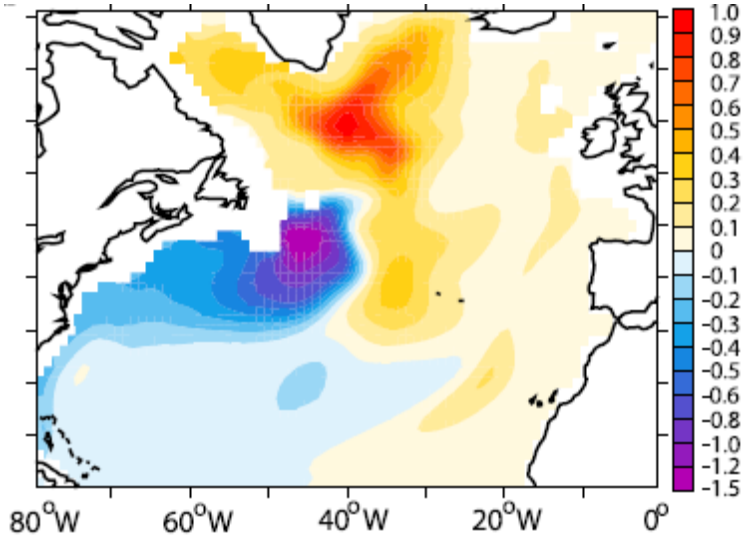


Zhang (2008)
400m ocean temperature,
GFDL CM2.1

Knight *et. al*. (2005)
Surface temperature
HadCM3

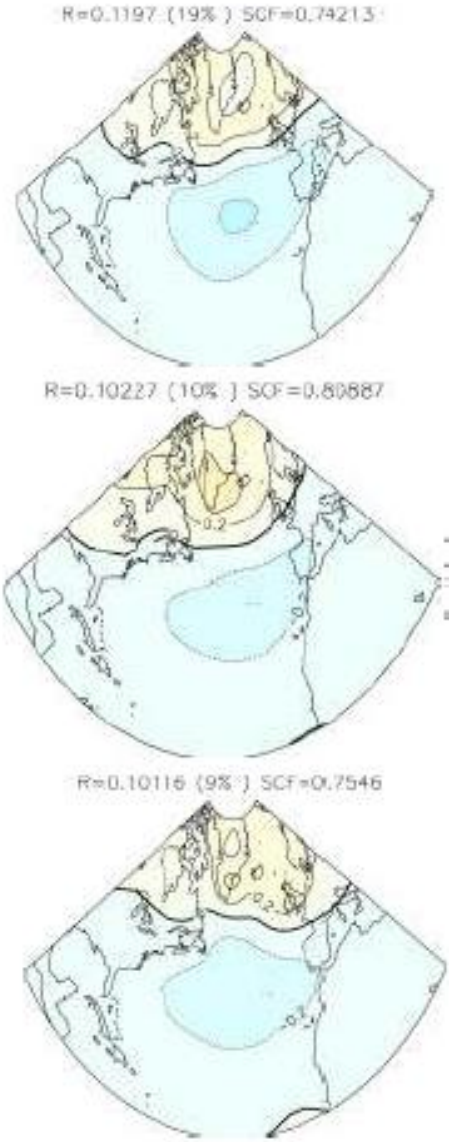


Many coupled climate models exhibit natural decadal AMOC variability, with impacts on other climatic fields

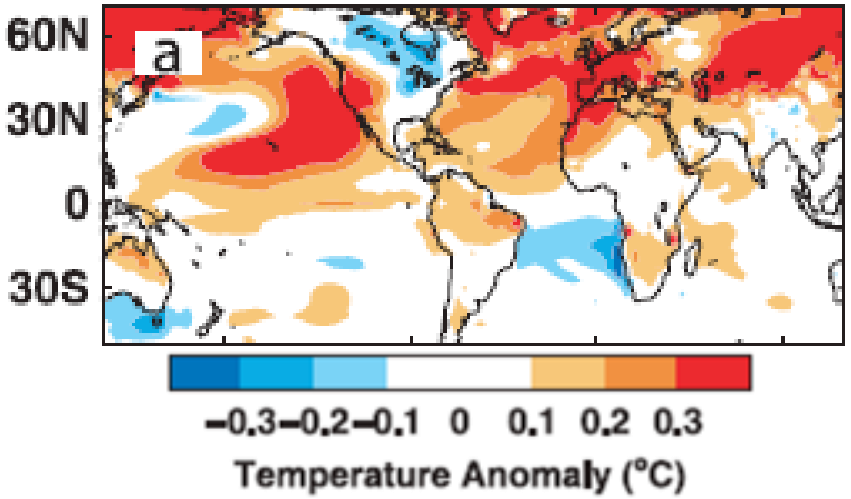


Zhang (2008)
400m ocean temperature,
GFDL CM2.1

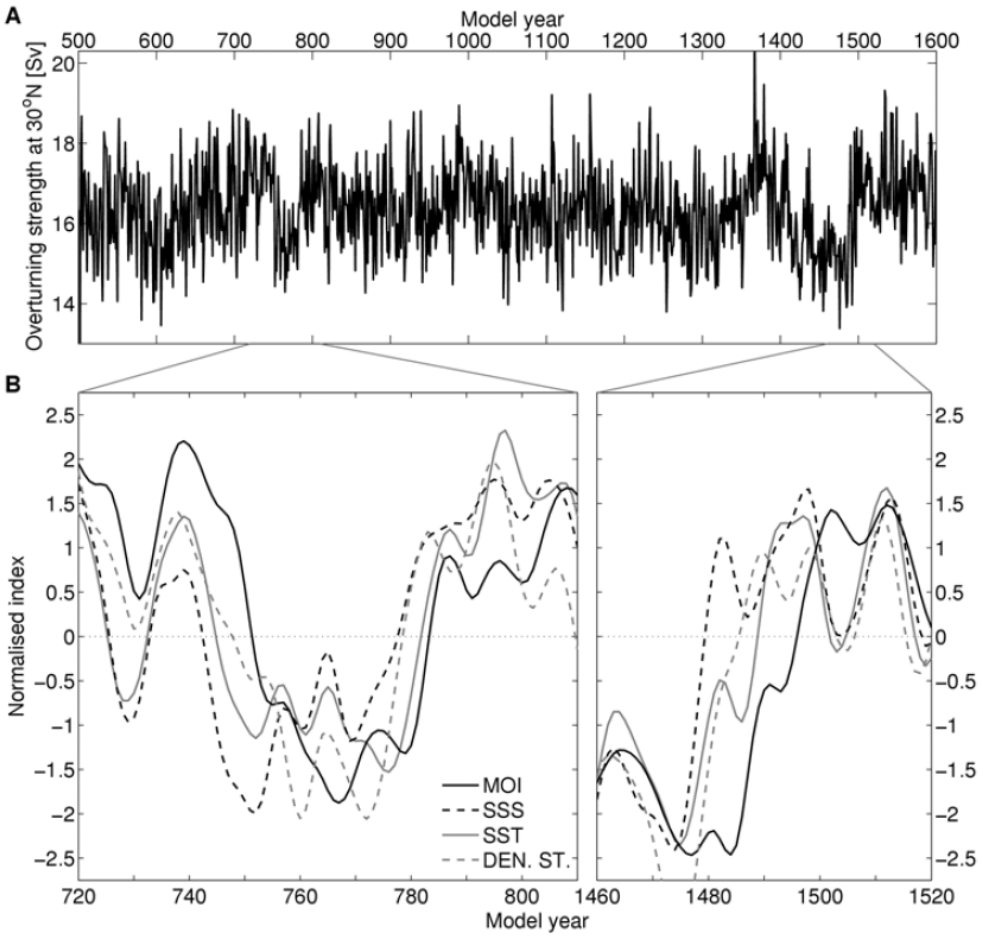
Gastineau & Frankignoul (2012)
Wintertime mean sea level pressure
(Multiple models)



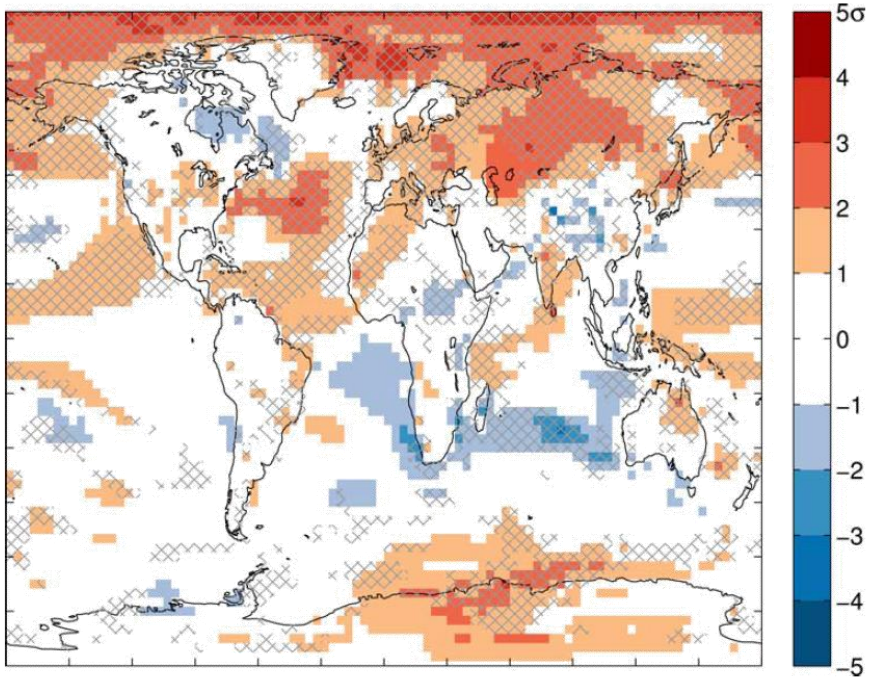
Knight *et. al*. (2005)
Surface temperature
HadCM3



Large decadal AMOC fluctuation events



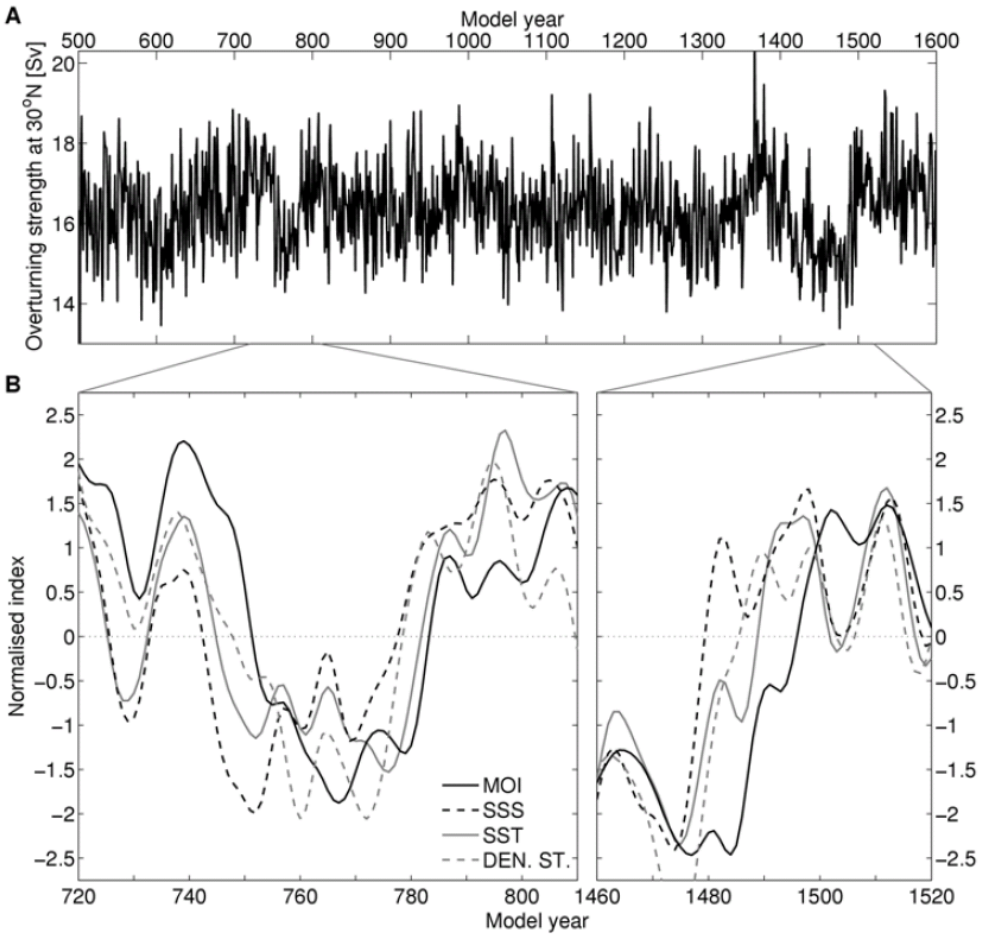
Composite of decadal surface air temperature change



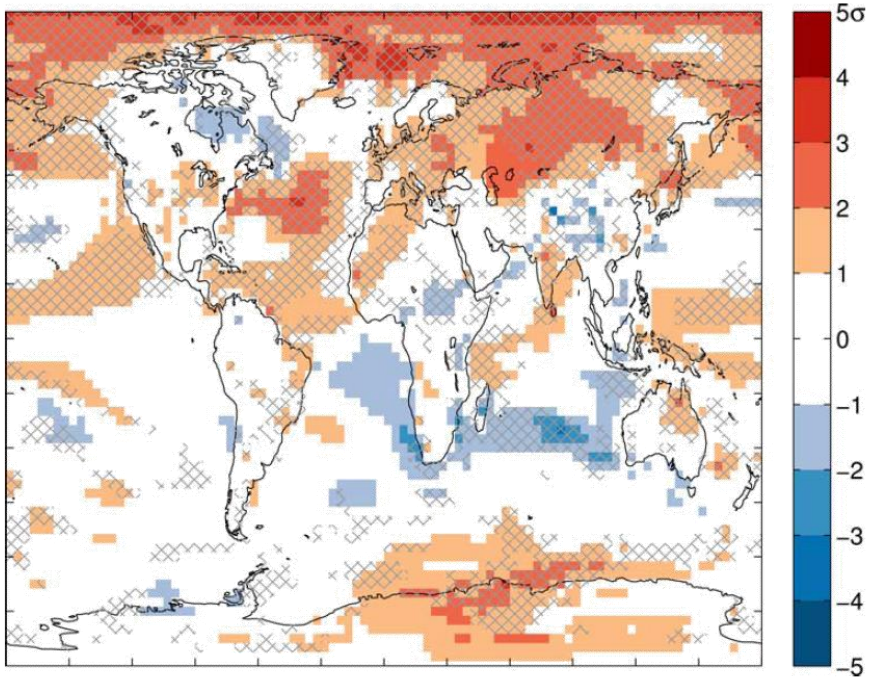
Hawkins & Sutton (2008)

Large decadal AMOC fluctuation events

How robust are the characteristics and impacts of discrete AMOC events within each model and across different models?



Composite of decadal surface air temperature change



Hawkins & Sutton (2008)

Outline

- Models and event detection method
- AMOC event characteristics
- Do the events have robust climatic impacts? Are the events special?
- Are the impacts of positive and negative events equal and opposite?
- What controls the temperature response over Europe?

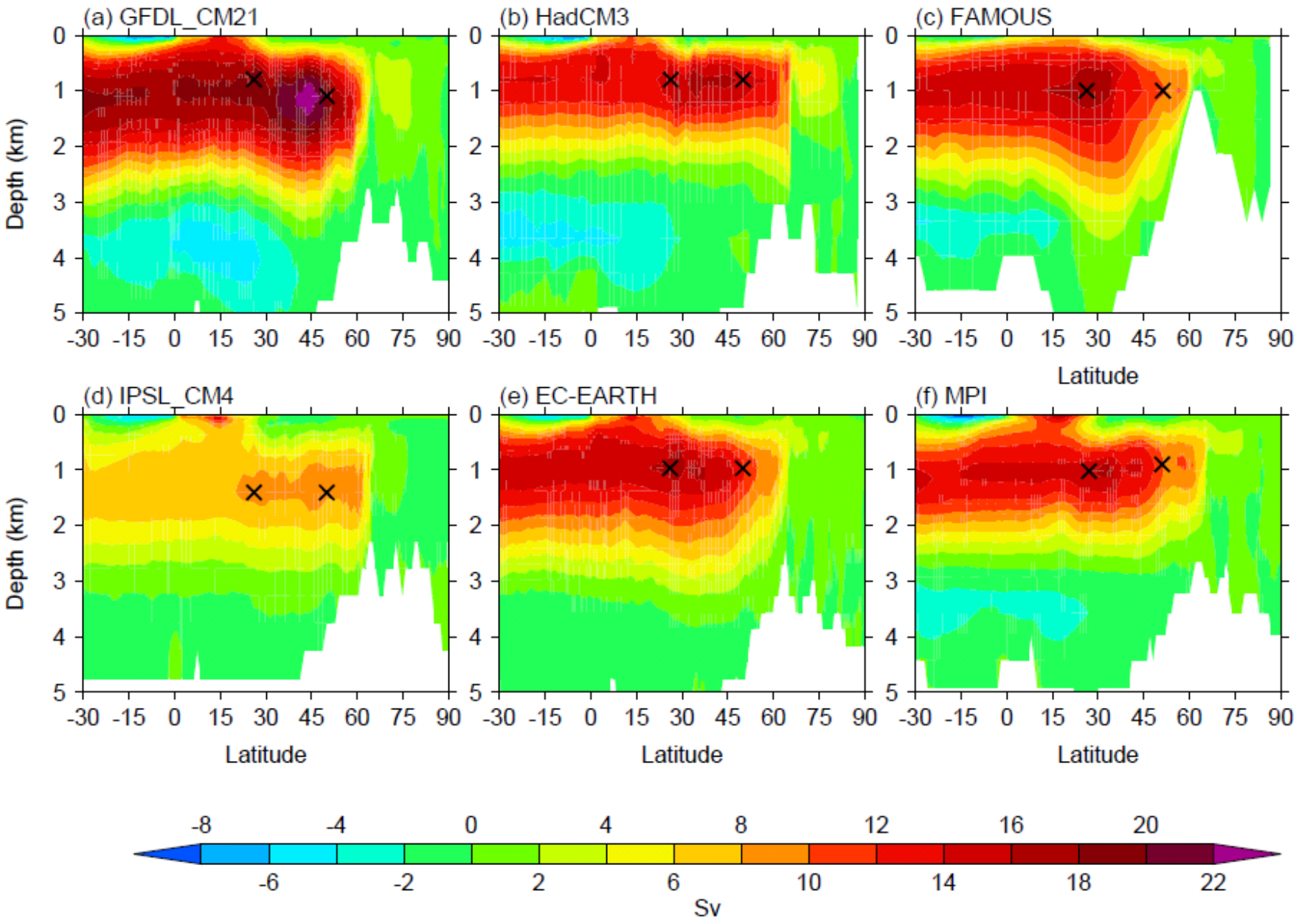
Outline

- Models and event detection method
- AMOC event characteristics
- Do the events have robust climatic impacts? Are the events special?
- Are the impacts of positive and negative events equal and opposite?
- What controls the temperature response over Europe?

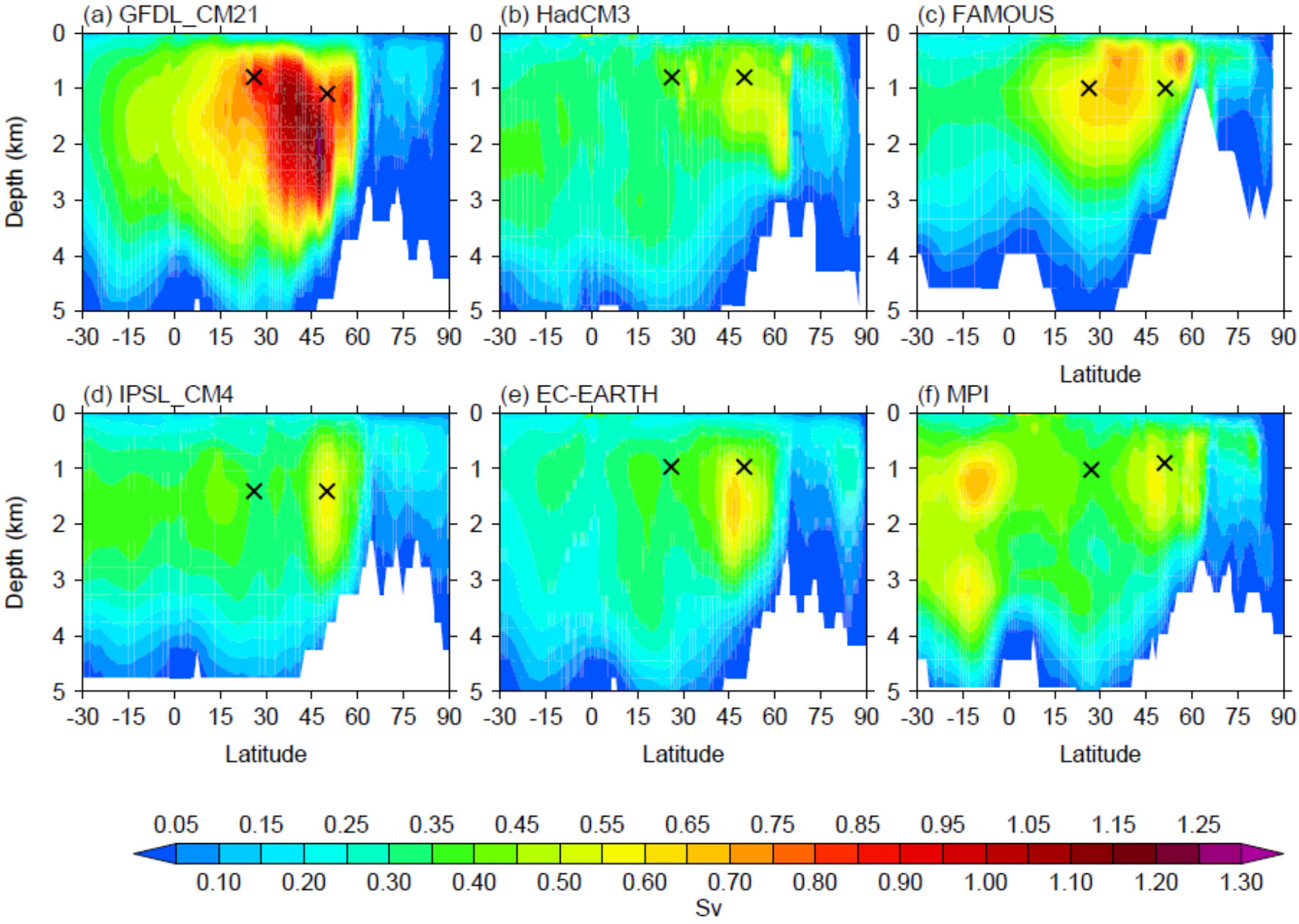
Model details

Model	Reference	Spatial resolution	Ocean model	Simulation length
GFDL CM2.1	[Delworth *et al.*(2006)]	Atmos: 2°lat × 2.5°lon, 24 levels Ocean: 1°× 1°, ($\frac{1}{3}$°lat in tropics), 50 levels	OM3P4	500 years
HadCM3	[Gordon *et al.*(2000)]	Atmos: 2.5°lat × 3.75°lon, 19 levels Ocean: 1.25°× 1.25°, 20 levels	HadOM3	5000 years
FAMOUS	[Smith *et al.*(2008)]	Atmos: 5°lat × 7.5°lon, 11 levels Ocean: 2.5°lat × 3.75°lon, 20 levels	HadOM3	1200 years
IPSL CM4	[Marti *et al.*(2010)]	Atmos: 2.5°lat × 3.75°lon, 19 levels Ocean: 2°× 2°, (1°lat in tropics), 31 levels	NEMO	1000 years
EC-EARTH v2	[Hazeleger *et al.*(2010)]	Atmos: 1.125°× 1.125°, 62 levels Ocean: 1°× 1°, 42 levels	NEMO	578 years
ECHAM5/MPI-OM (Referred to as MPI)	[Jungclaus *et al.*(2006)]	Atmos: 1.875°× 1.875°, 31 levels Ocean: 1.5°× 1.5°, 40 levels	MPI-OM	2000 years

Mean AMOC streamfunction



Variability (5-20 year time scale)



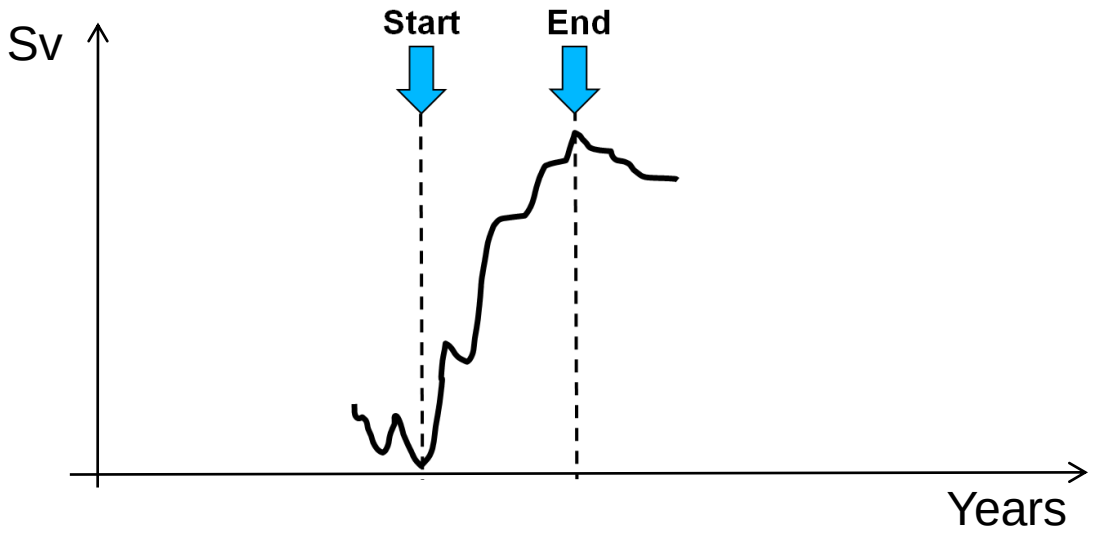
Identifying AMOC fluctuation events

- AMOC transport at 26°N or 50°N
- Depth of maximum at that latitude
- Smoothed with 5-year running mean

For each year, identify the preceding time-window (between 5 & 20 years) over which the largest AMOC change occurred.

Search for positive and negative events separately.

When events overlap, the one with the largest magnitude is retained.



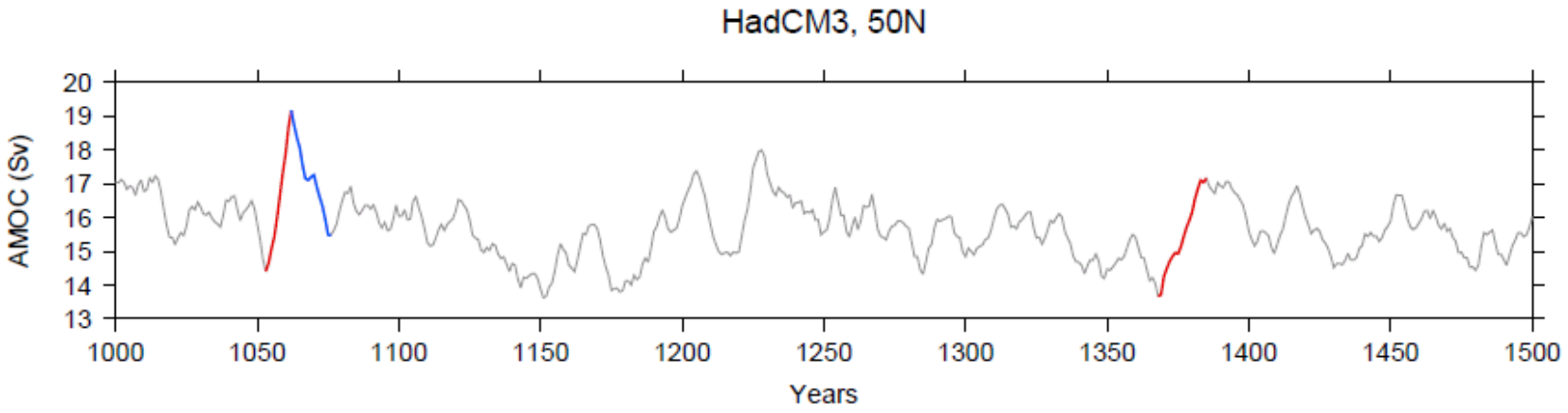
Identifying AMOC fluctuation events

- AMOC transport at 26°N or 50°N
- Depth of maximum at that latitude
- Smoothed with 5-year running mean

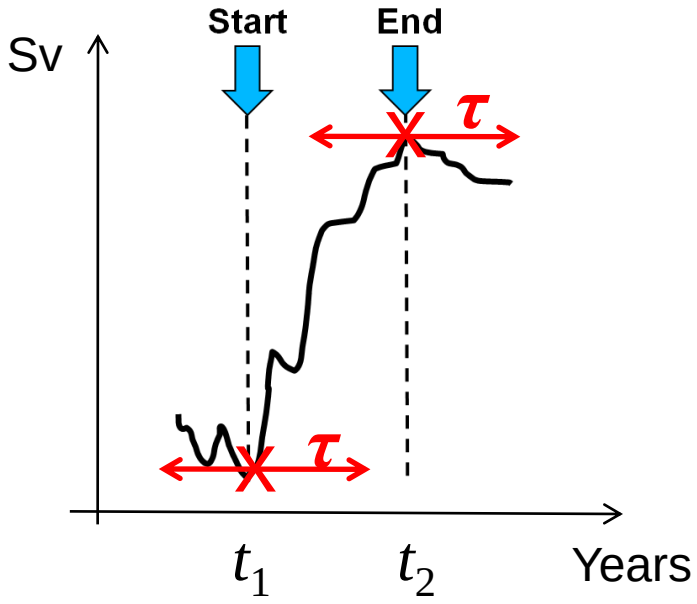
For each year, identify the preceding time-window (between 5 & 20 years) over which the largest AMOC change occurred.

Search for positive and negative events separately.

When events overlap, the one with the largest magnitude is retained.



Defining climate field anomalies

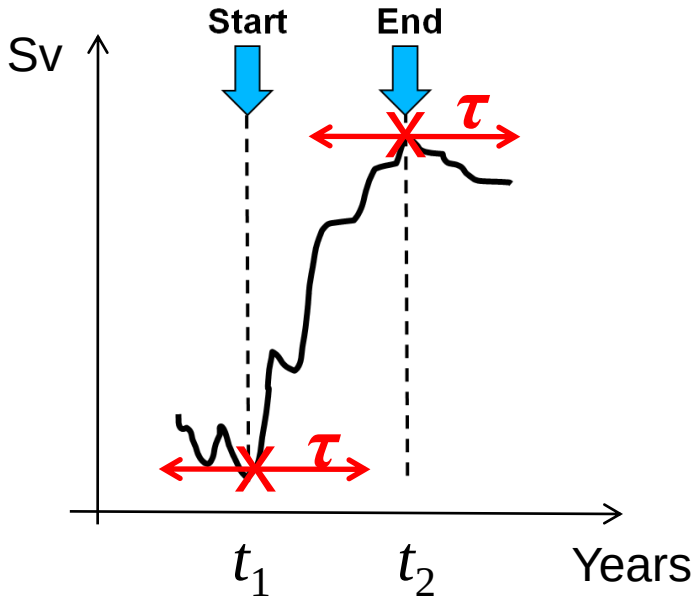


$$\alpha_F(\tau) = \frac{1}{N}\sum_N \frac{F(t_2+\tau) - F(t_1+\tau)}{A_\phi(t_2) - A_\phi(t_1)}$$

AMOC transport

- Standardise by AMOC change
- Averaged over 10 events of each sign (N=10)
- Range of lags considered
- Many of the following plots use the difference between 5-year means centred on the start and end of the events

Defining climate field anomalies



$$\alpha_F(\tau) = \frac{1}{N}\sum_N \frac{F(t_2+\tau) - F(t_1+\tau)}{A_\phi(t_2) - A_\phi(t_1)}$$

AMOC transport

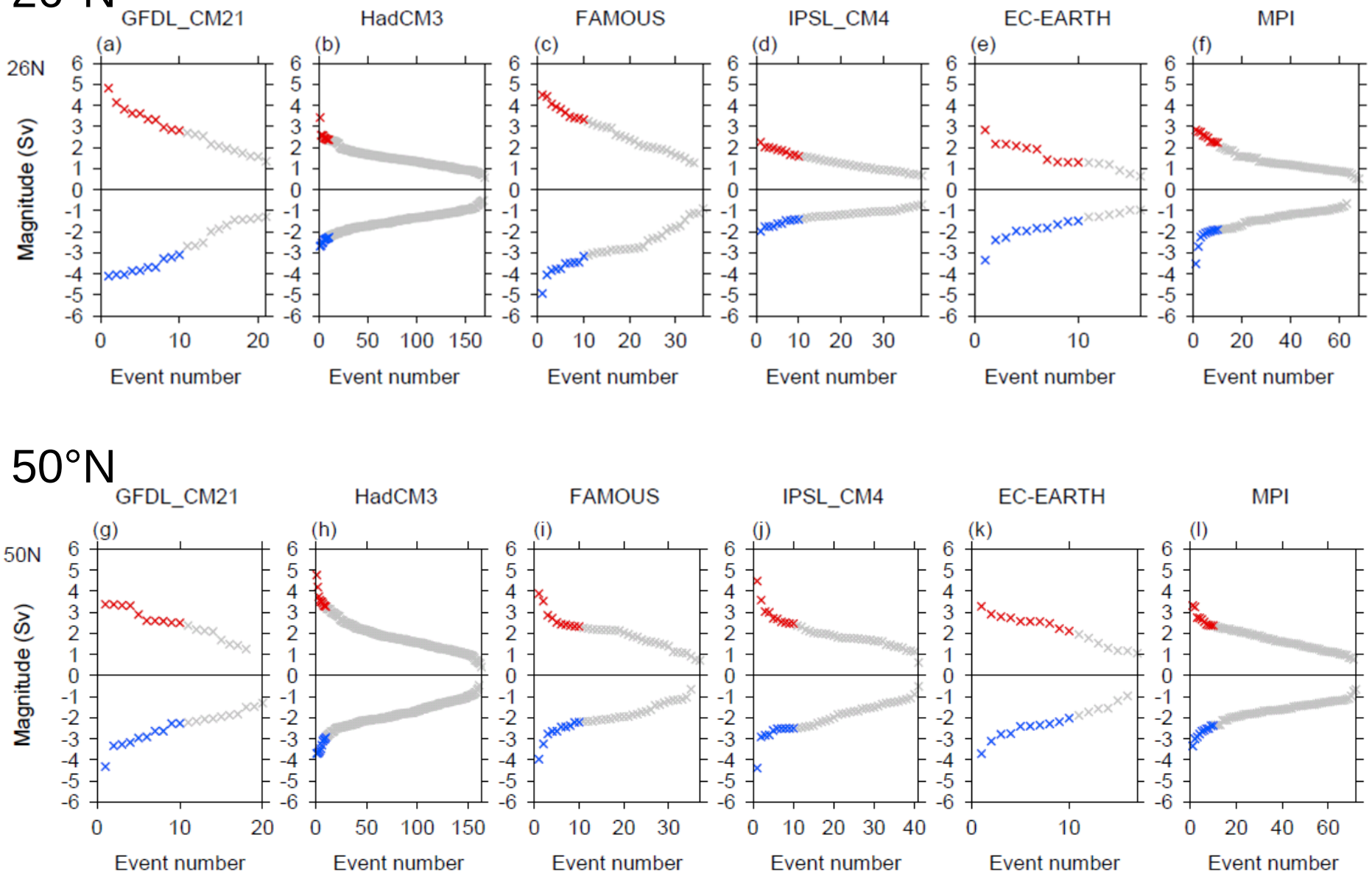
This means that if the response to positive and negative events is equal and opposite, the signal should look the same for each.

- Standardise by AMOC change
- Averaged over 10 events of each sign (N=10)
- Range of lags considered
- Many of the following plots use the difference between 5-year means centred on the start and end of the events

Outline

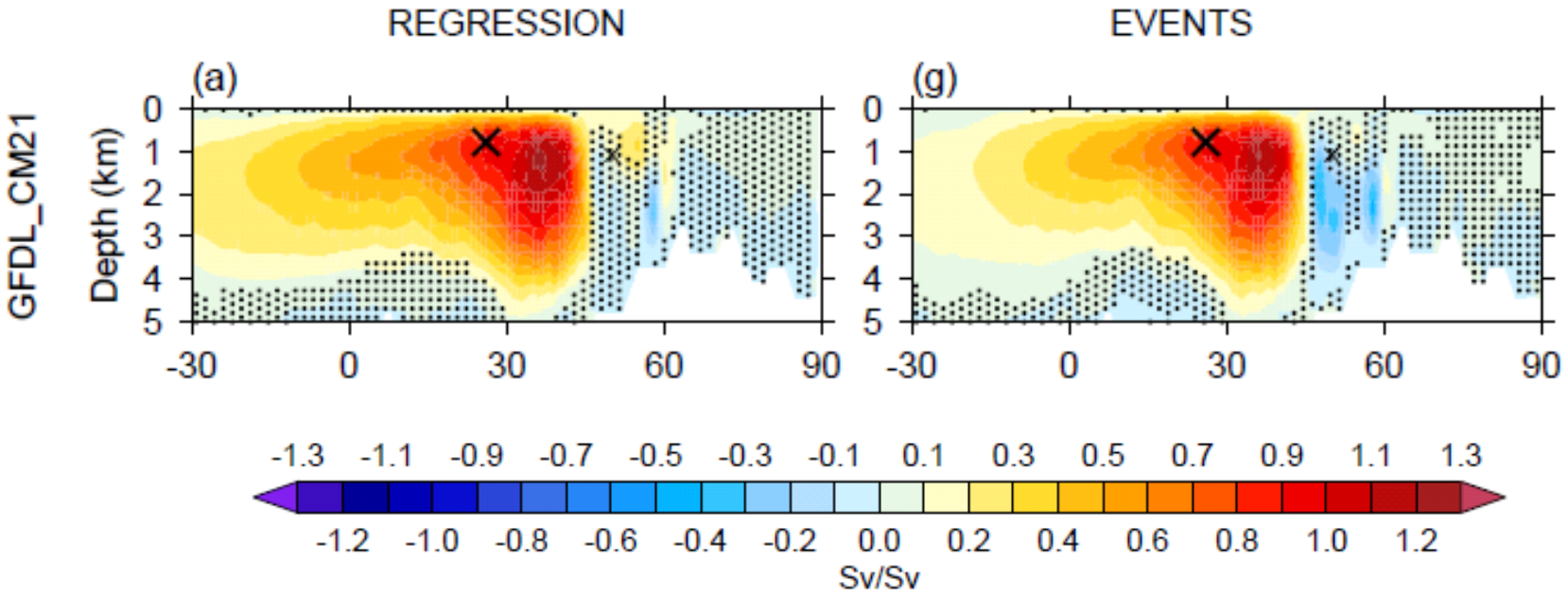
- Models and event detection method
- AMOC event characteristics
- Do the events have robust climatic impacts? Are the events special?
- Are the impacts of positive and negative events equal and opposite?
- What controls the temperature response over Europe?

Event magnitudes

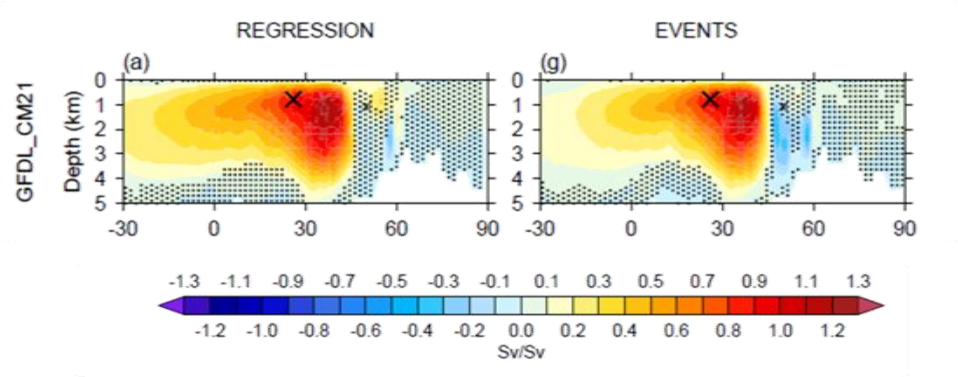


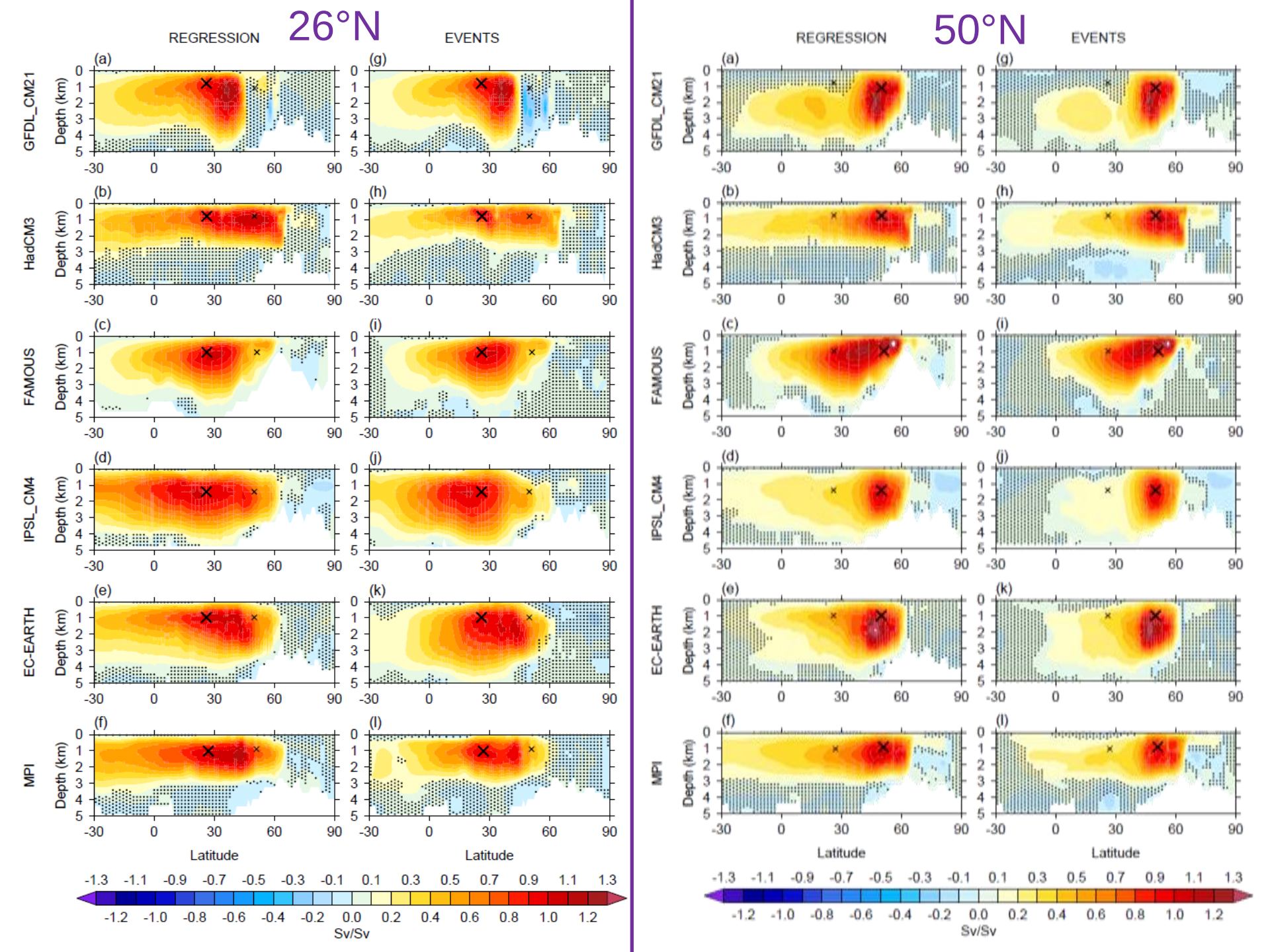
Spatial structure

- AMOC variability detected at 26°N
- GFDL CM2.1



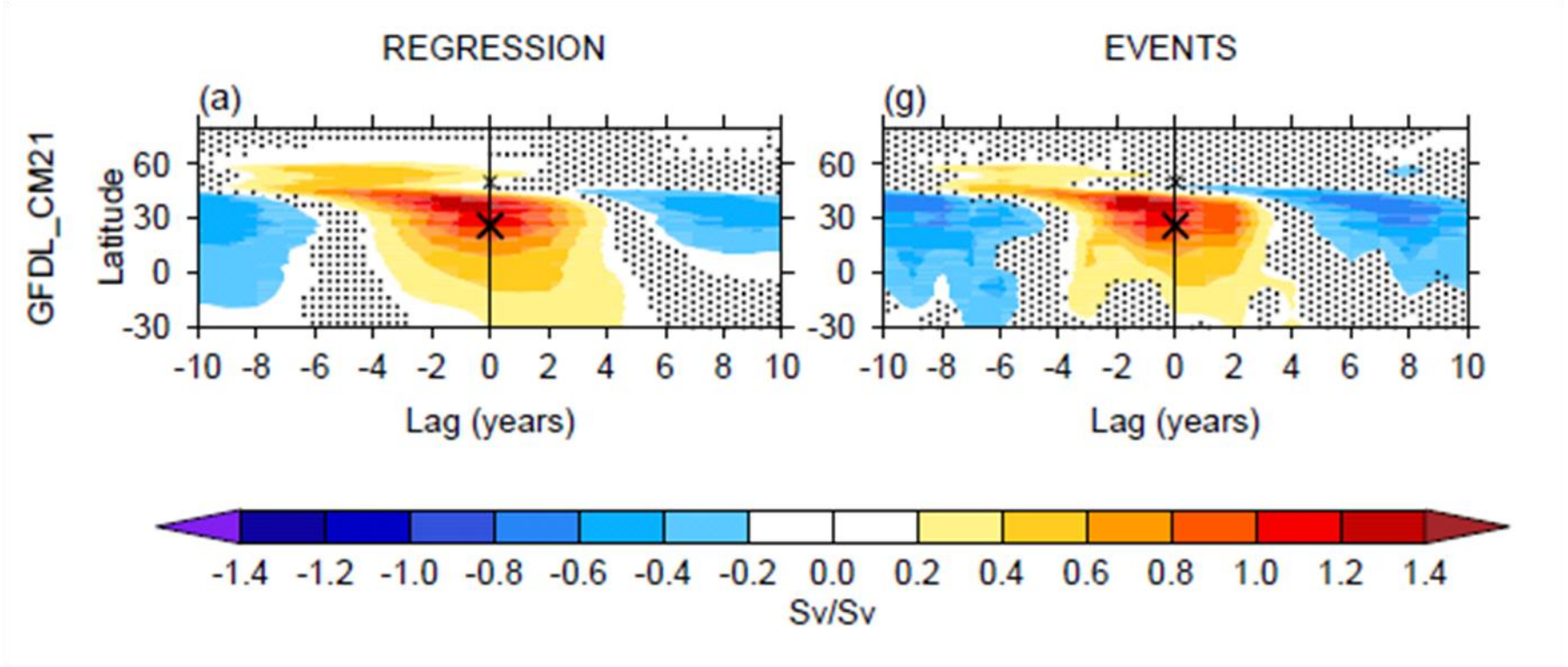
$$\frac{\Delta \mathrm{AMOC}(\phi, z)}{\Delta \mathrm{AMOC}(26^{\circ}\mathrm{N})}$$


REGRESSION
EVENTS
(a)
(g)
GFDL_CM21
Depth (km)
0
1
2
3
4
5
-30
0
30
60
90
-1.3 -1.1 -0.9 -0.7 -0.5 -0.3 -0.1 0.1 0.3 0.5 0.7 0.9 1.1 1.3
-1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0 1.2
Sv/Sv

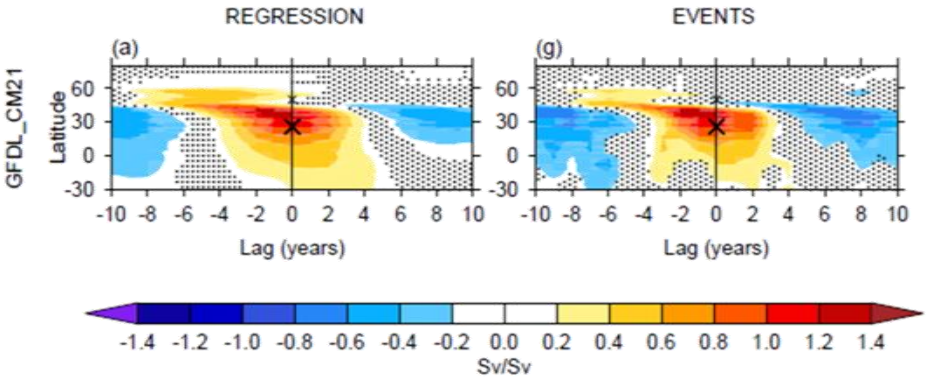

26°N
50°N
REGRESSION
EVENTS
GFDL_CM21
HadCM3
FAMOUS
IPSL_CM4
EC-EARTH
MPI
Depth (km)
Latitude
Sv/Sv
-1.3 -1.1 -0.9 -0.7 -0.5 -0.3 -0.1 0.1 0.3 0.5 0.7 0.9 1.1 1.3
-1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0 1.2

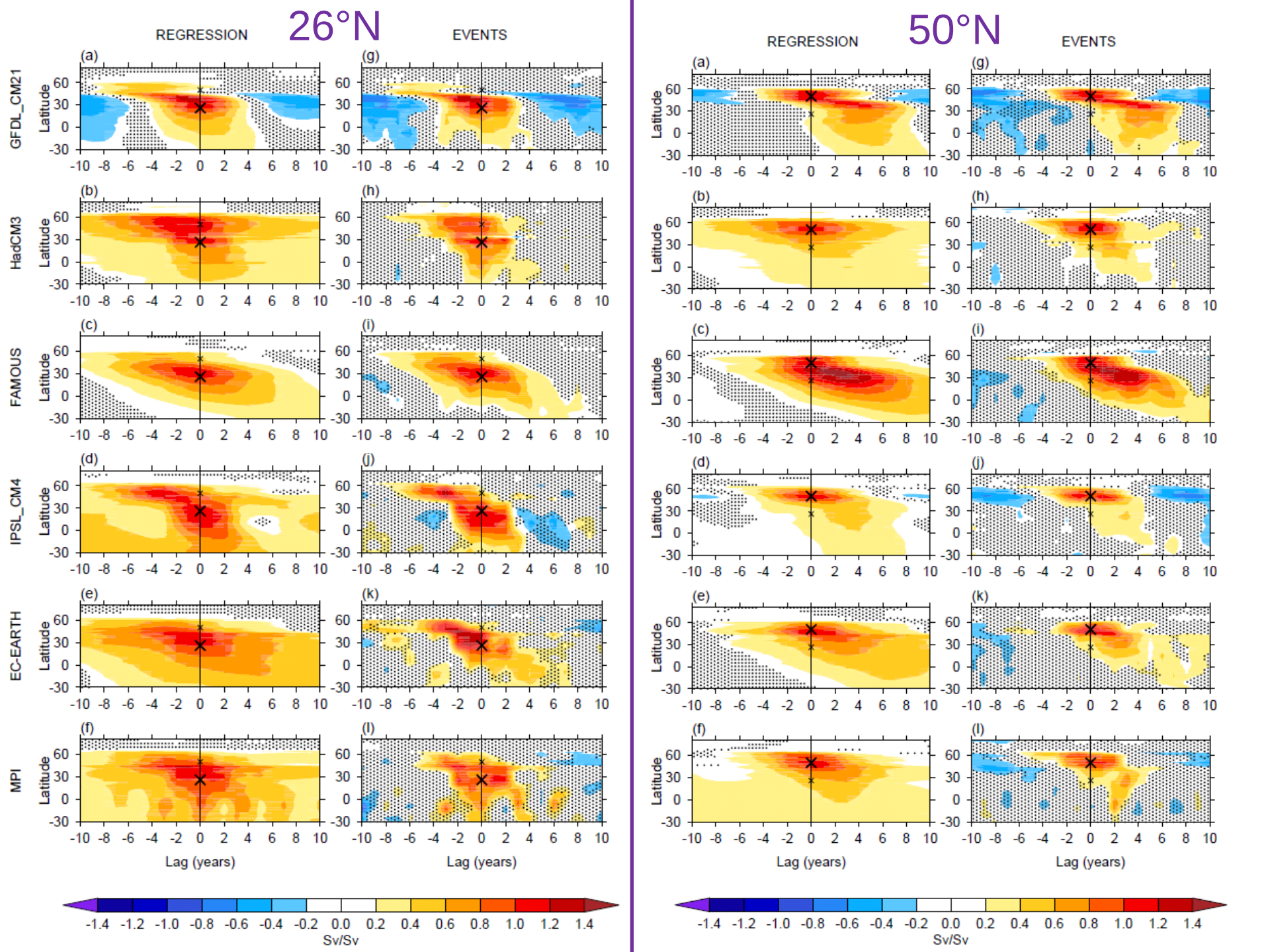
Meridional coherence

- AMOC variability detected at 26°N
- GFDL CM2.1



$$\frac{\Delta \mathrm{AMOC}(\phi, \tau)}{\Delta \mathrm{AMOC}(26^{\circ}\mathrm{N})}$$


REGRESSION
EVENTS
(a)
(g)
GFDL_CM21
Latitude
60
30
0
-30
-10 -8 -6 -4 -2 0 2 4 6 8 10
Lag (years)
-1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4
Sv/Sv


26°N
50°N
REGRESSION
EVENTS
GFDL_CM21
HadCM3
FAMOUS
IPSL_CM4
EC-EARTH
MPI
Latitude
Lag (years)
Sv/Sv
-1.4 -1.2 -1.0 -0.8 -0.6 -0.4 -0.2 0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4

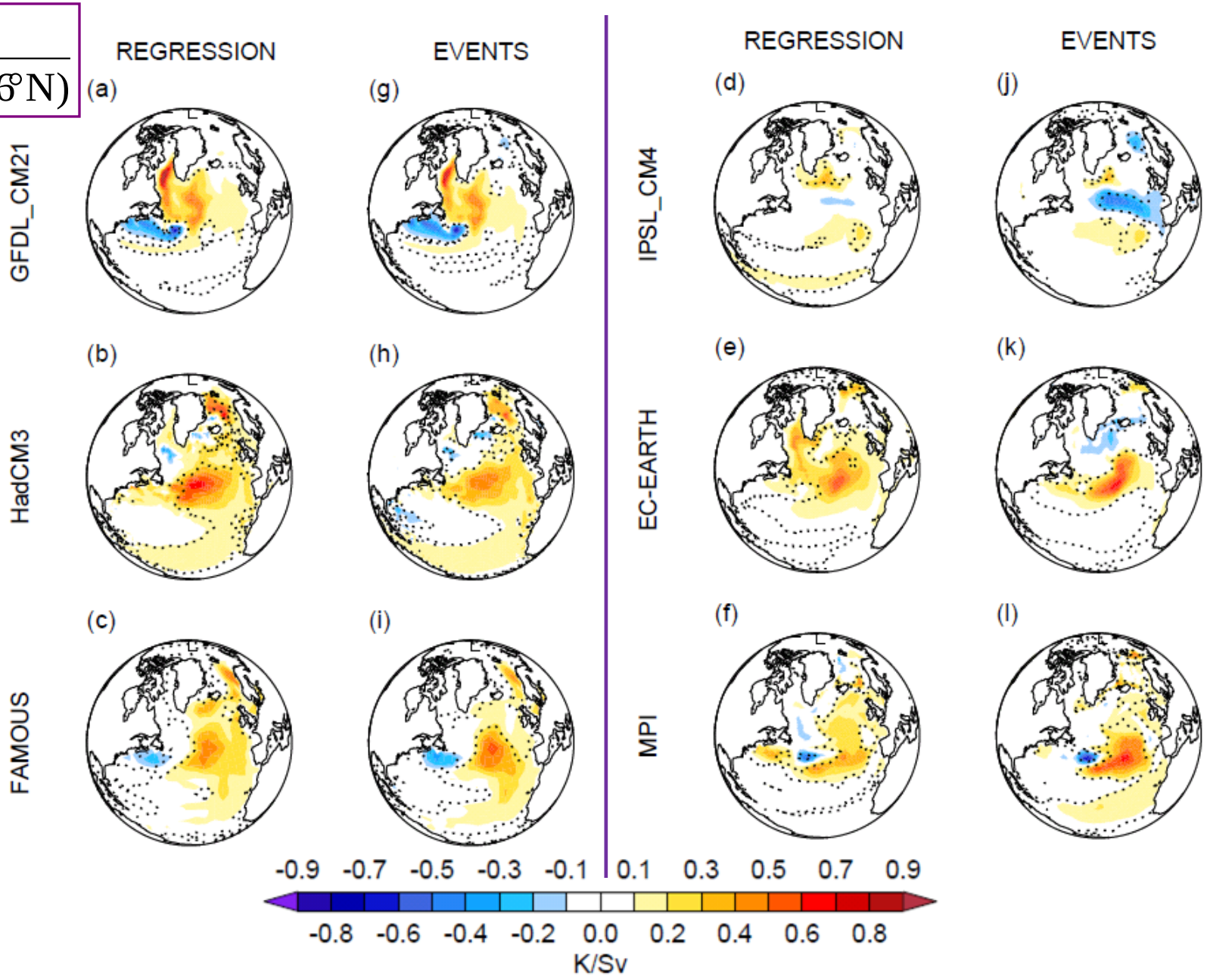
Outline

- Models and event detection method
- AMOC event characteristics
- Do the events have robust climatic impacts? Are the events special?
- Are the impacts of positive and negative events equal and opposite?
- What controls the temperature response over Europe?

Sea surface temperature changes are generally robust across the largest events in each model, but the spatial patterns can differ substantially between models

$$\frac{\Delta SST}{\Delta AMOC(26^{\circ}N)}$$

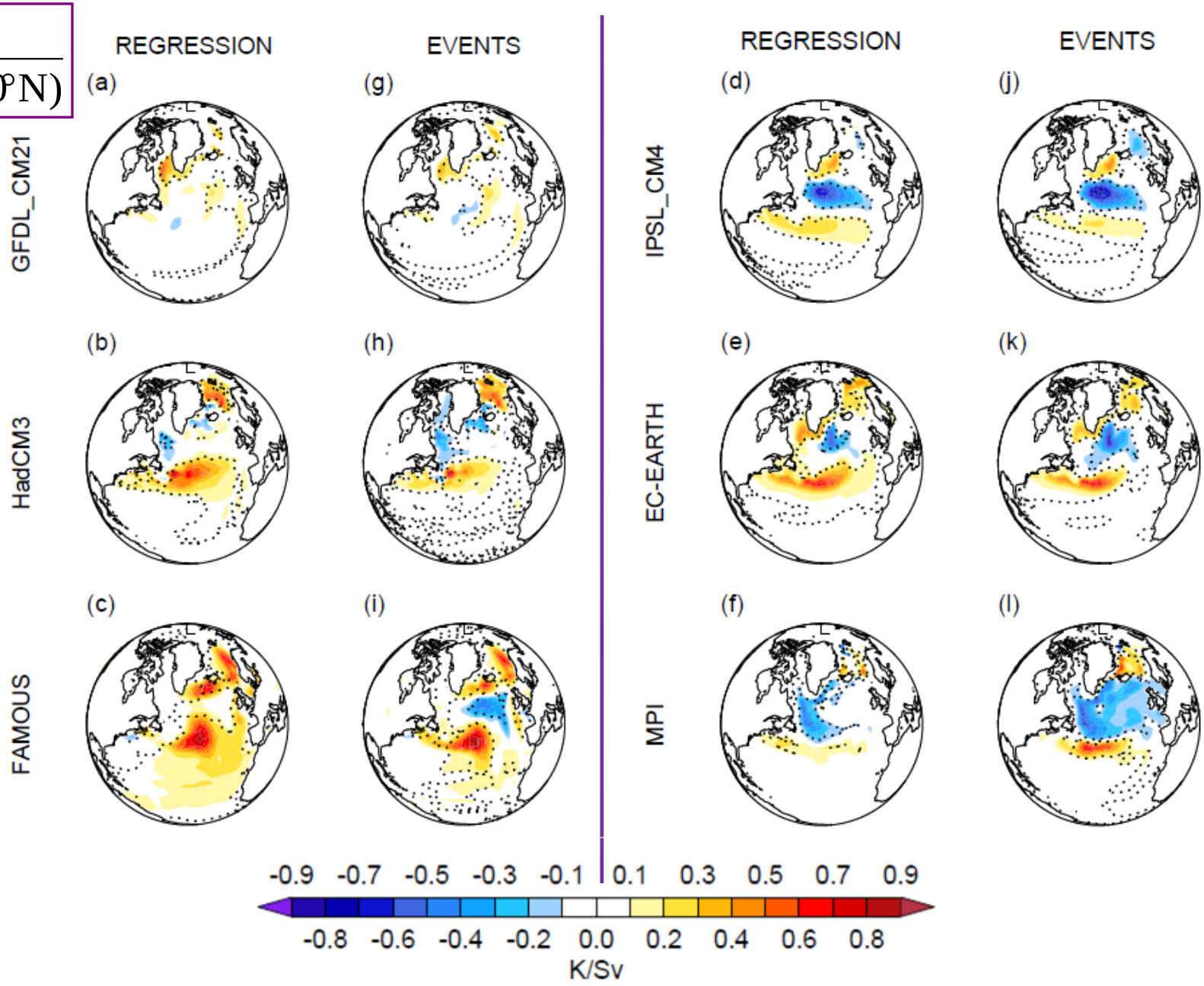
26°N



Sea surface temperature changes are generally robust across the largest events in each model, but the spatial patterns can differ substantially between models

$$\frac{\Delta SST}{\Delta AMOC(50^{\circ}N)}$$

50°N



Outline

- Models and event detection method
- AMOC event characteristics
- Do the events have robust climatic impacts? Are the events special?
- Are the impacts of positive and negative events equal and opposite?
- What controls the temperature response over Europe?

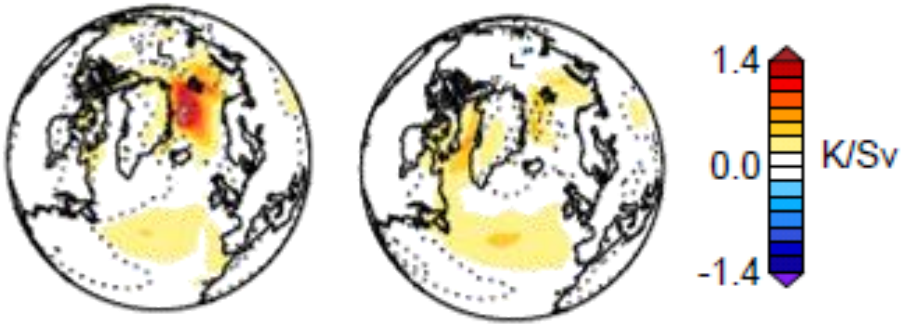
Asymmetrical behaviour in HadCM3

$$\frac{\Delta \text{field}}{\Delta \text{AMOC}}$$

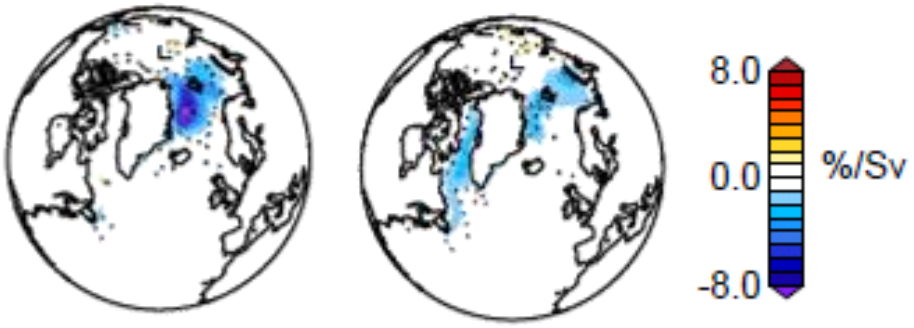
Positive events

Negative events

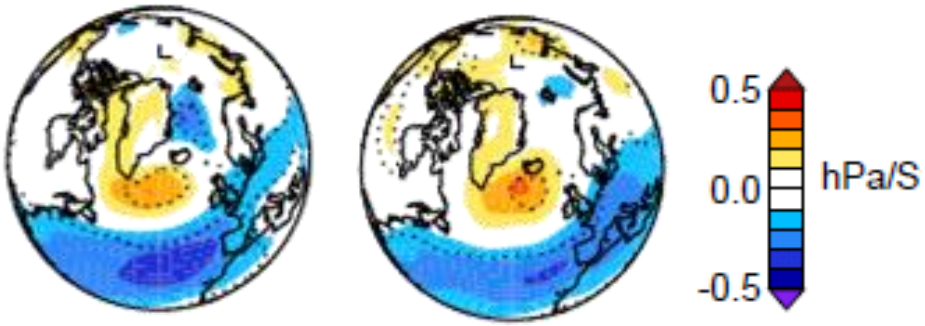
Surface air temperature



Sea ice concentration



Mean sea level pressure



Positive events:

Large surface warming and sea ice loss in Nordic Seas.

Local low atmospheric pressure anomaly.

Associated atmospheric circulation anomaly may drive increased ice loss in Nordic Seas and suppress the ice loss in the Labrador Sea (e.g., Strong & Magnusdottir, 2010).

Outline

- Models and event detection method
- AMOC event characteristics
- Do the events have robust climatic impacts? Are the events special?
- Are the impacts of positive and negative events equal and opposite?
- What controls the temperature response over Europe?

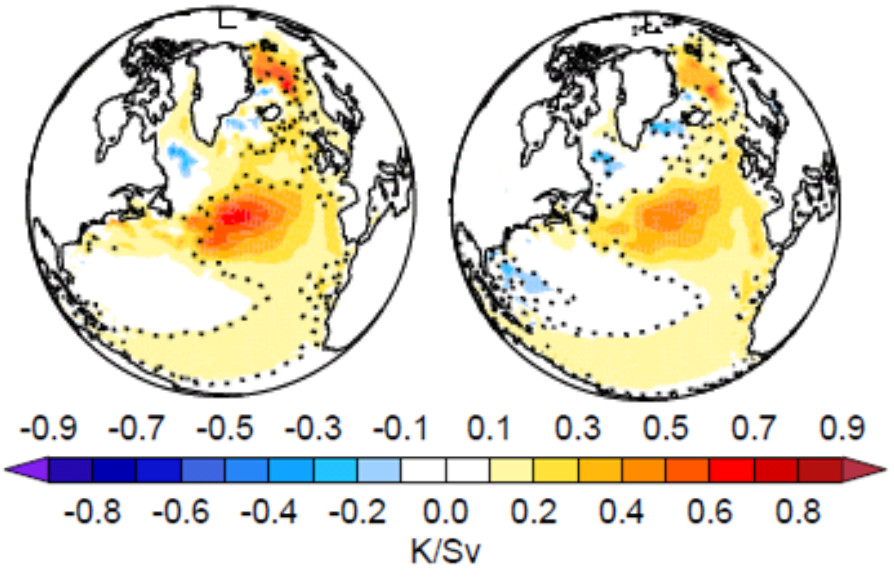
What controls the European temperature response?

HadCM3, AMOC 26N

Sea surface temperature

Regression

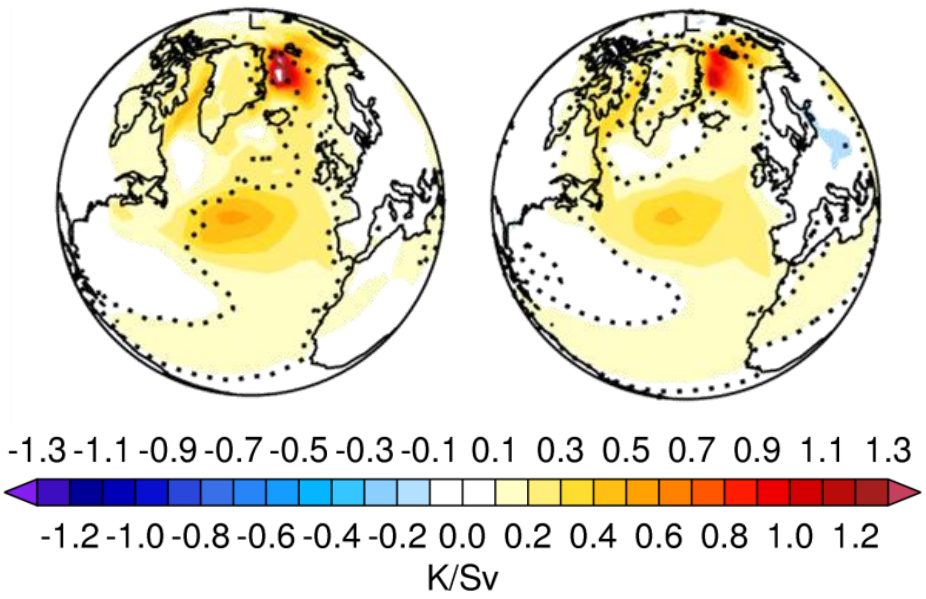
Events



Surface air temperature

Regression

Events

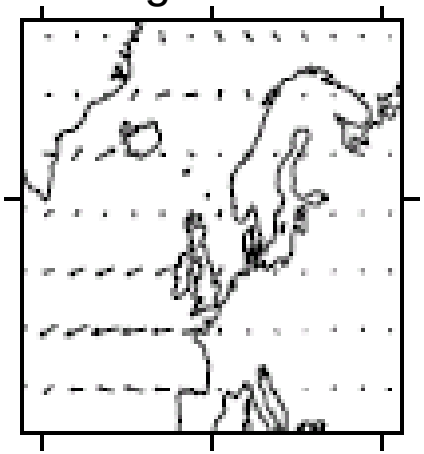


Since Western Europe usually has a strong maritime influence, why is the land response so weak?

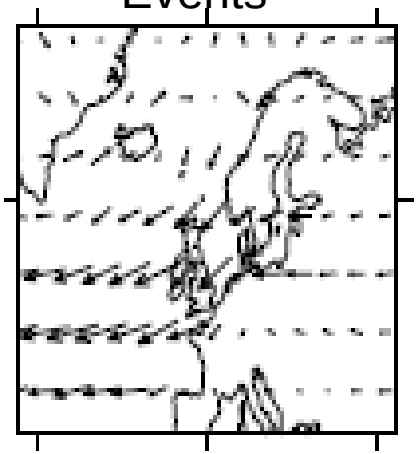
What controls the European temperature response?

Surface winds

Regression

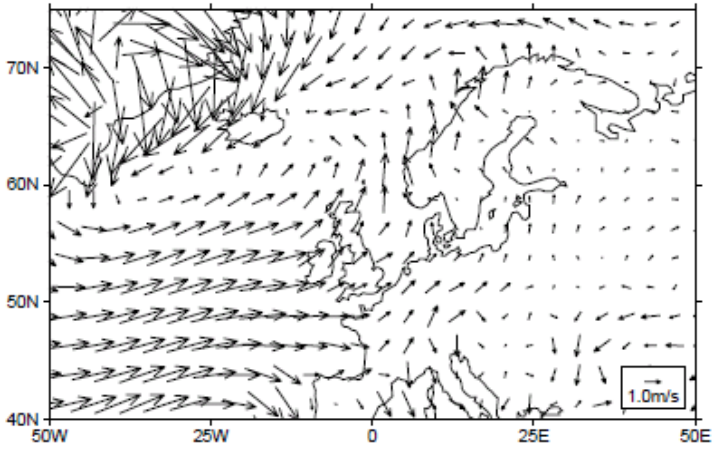


Events



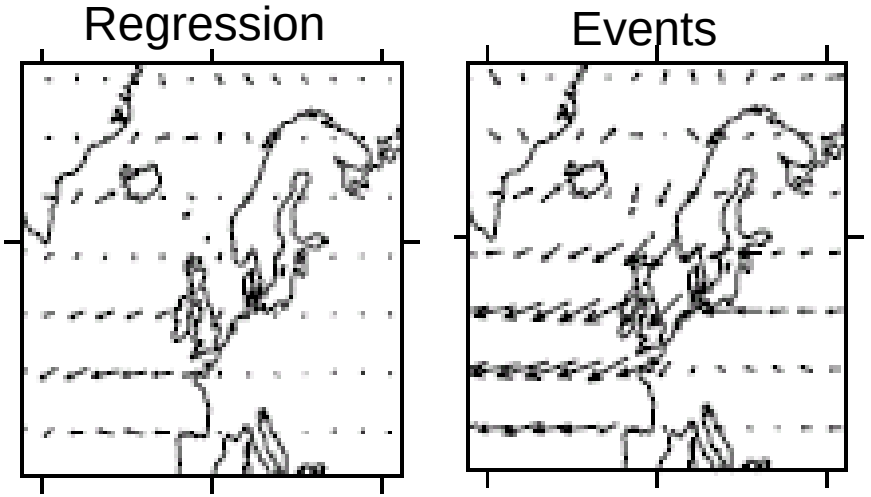
Weakening of westerly winds for positive events (strengthening for negative events)

Long-term mean



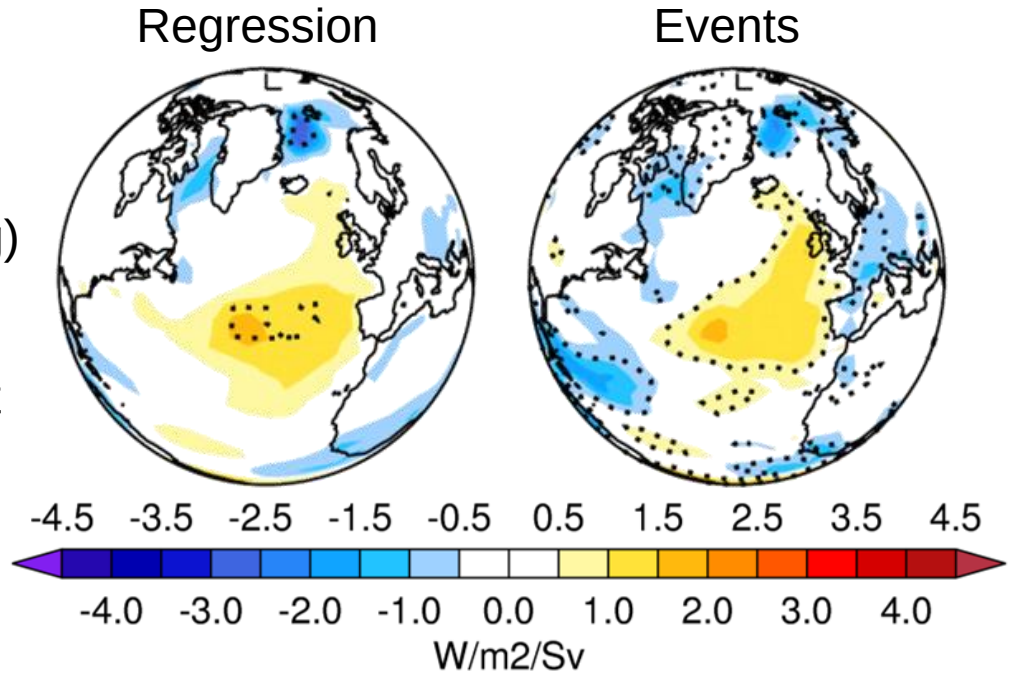
What controls the European temperature response?

Surface winds



Weakening of westerly winds for positive events (strengthening for negative events)

Surface downward shortwave



Land-sea contrast in cloudiness.
Positive events: Decreased cloud cover over ocean (enhances warming)
Increased over land (cooling).
Opposite for negative events.
(See also AMOC collapse experiment of Laurian *et al,* 2010)

Summary

• Studying the largest decadal-scale AMOC events in unforced climate model simulations.

•The surface signatures are generally robust across the largest events in each model, but can differ substantially between models.

• The characteristics and impacts of the largest discrete AMOC changes are generally in line with regression analyses...

• ... however there are some exceptions, where nonlinear behaviour is found (e.g., Asymmetric behaviour in HadCM3 may be related to nonlinearities in the sea ice response).

• HadCM3 shows a subdued temperature response in Europe. This may be linked to changes in winds and/or differences in cloud cover changes over land and ocean.

• Further work is required to better understand the inter-model differences in the characteristics and impacts of AMOC events, to improve the prediction and attribution of such events in reality.

Summary

• Studying the largest decadal-scale AMOC events in unforced climate model simulations.

•The surface signatures are generally robust across the largest events in each model, but can differ substantially between models.

• The characteristics and impacts of the largest discrete AMOC changes are generally in line with regression analyses...

• ... however there are some exceptions, where nonlinear behaviour is found (e.g., Asymmetric behaviour in HadCM3 may be related to nonlinearities in the sea ice response).

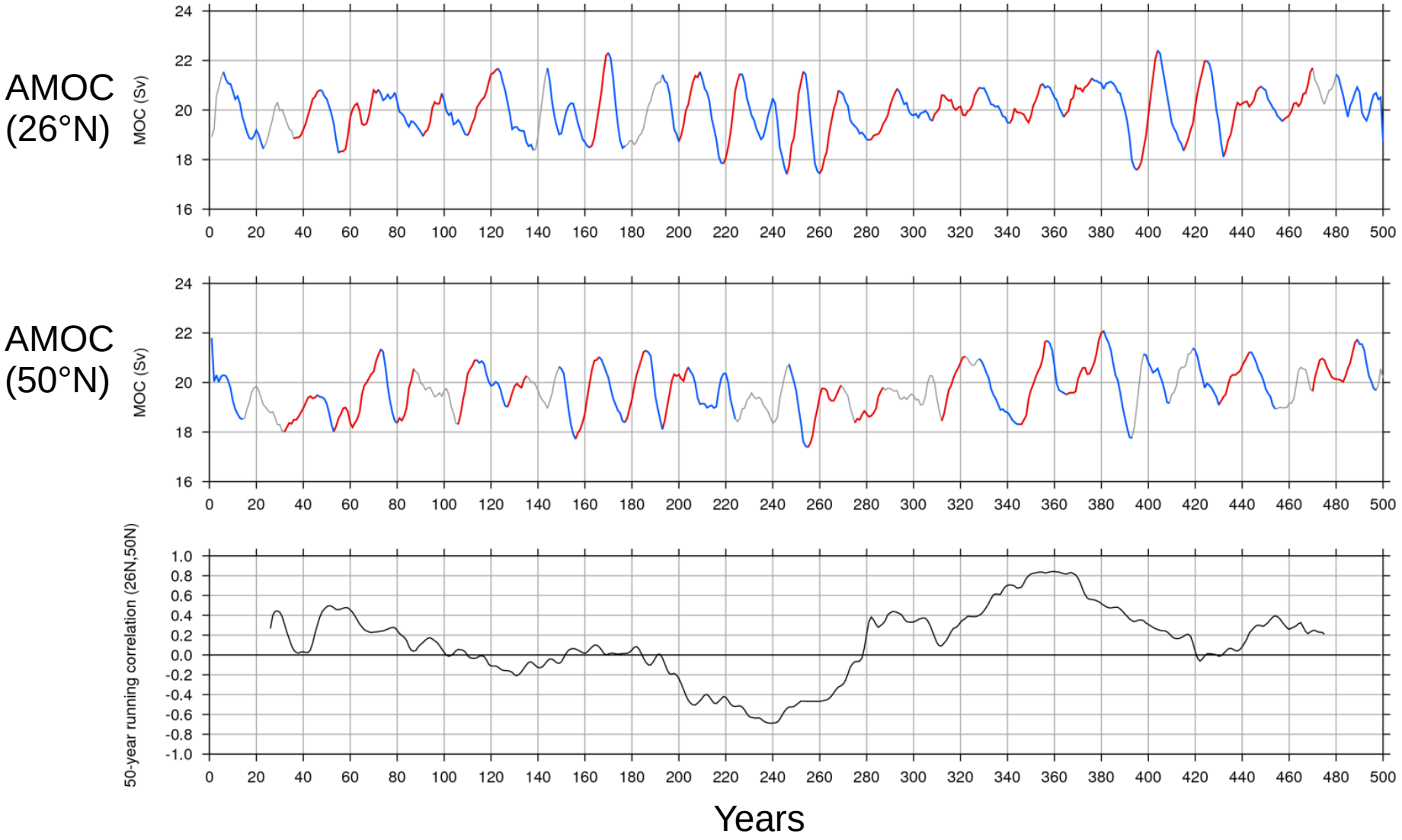
• HadCM3 shows a subdued temperature response in Europe. This may be linked to changes in winds and/or differences in cloud cover changes over land and ocean.

• Further work is required to better understand the inter-model differences in the characteristics and impacts of AMOC events, to improve the prediction and attribution of such events in reality.

Thank you

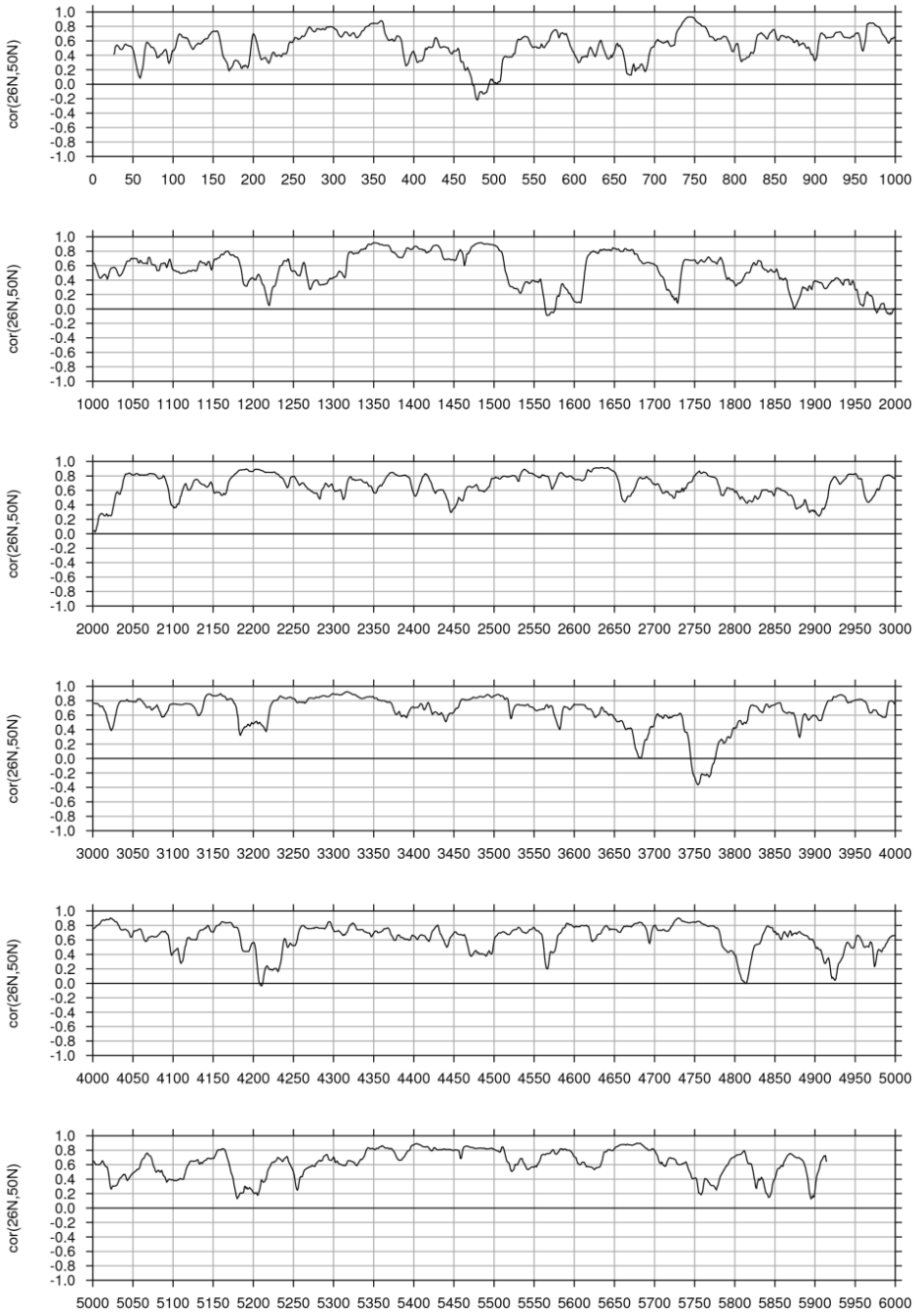
50-year running correlation: AMOC(26°N) & AMOC(50°N)

GFDL CM2.1



... and for HadCM3?

No similar periods of negative correlation between AMOC(26°N) and AMOC(50°N).



Event evolution: Largest 10 events of each sign