Rapid AMOC fluctuation events in coupled climate models

Early results from the RAPID-RAPIT project

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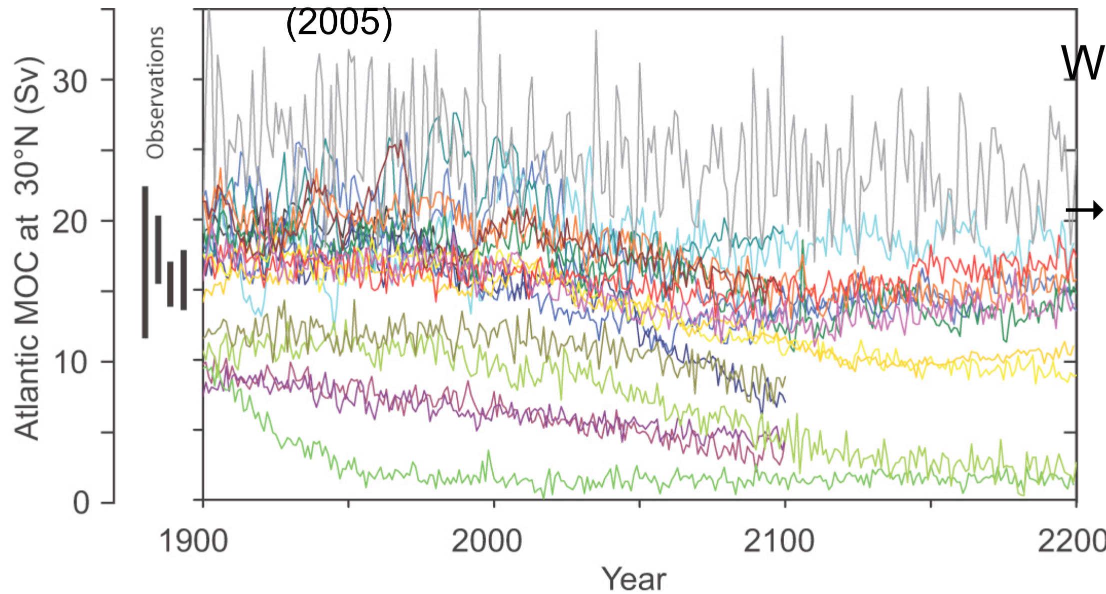
Part 1: Plans for RAPID-RAPIT

Part 2: Rapid AMOC events in coupled climate models

IPCC AR4, adapted from Schmittner et al. (2005)

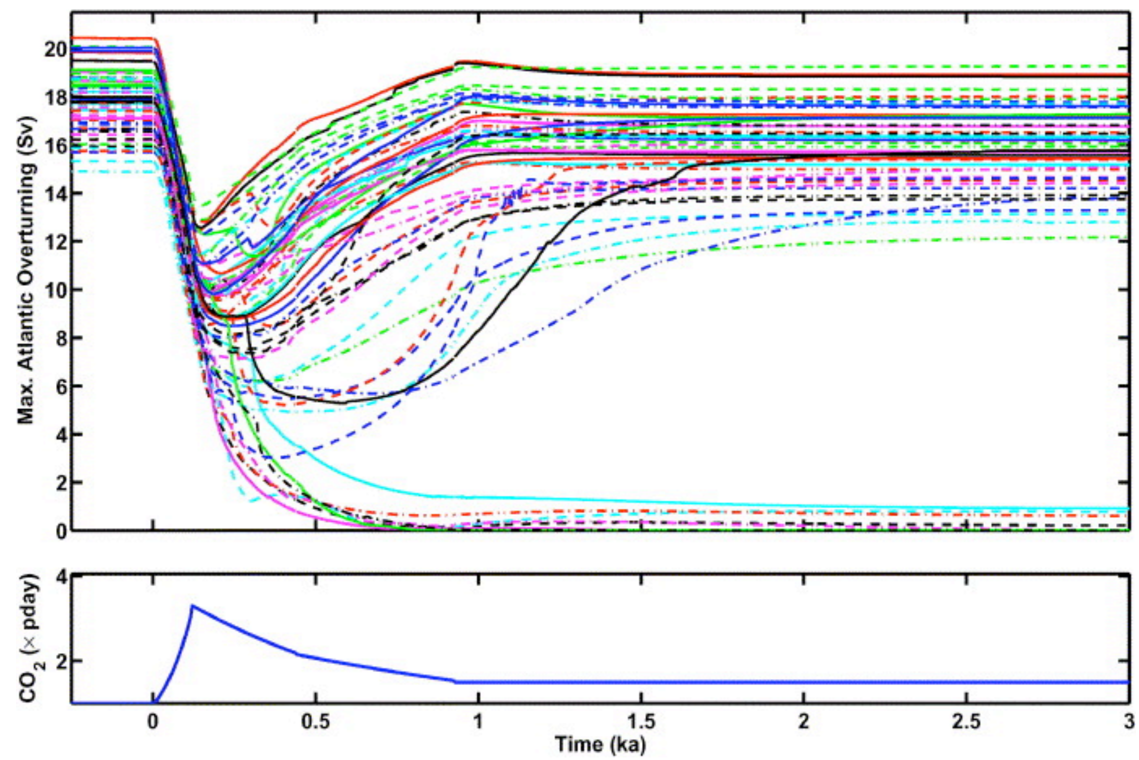


We would like to understand the risk of a collapse of the AMOC

→ Probability and impacts.

Climate model projections are sensitive to (amongst other things) various model parameters, the values of which are not well known.

- Hargreaves and Annan (2006)
- EMIC, 54 ensemble members.
- Large spread in MOC response due to parameter perturbations.



RAPID-RAPIT Risk Assessment, Probability and Impacts Team

Objectives

1. A risk assessment of the collapse of the overturning circulation in the North Atlantic
2. An assessment of how the RAPID-WATCH observations will contribute to such a risk assessment
3. An assessment of the impacts of a collapse of the overturning circulation
4. A better understanding of the physical mechanisms of a severe slowdown or collapse of the North Atlantic overturning.

RAPID-RAPIT Risk Assessment, Probability and Impacts Team

RAPIT will use two coupled GCMs to produce a risk assessment for AMOC collapse:

HadCM3

Atmosphere: 19 levels, 2.5˚ lat × 3.75˚ lon

Ocean: 20 levels, 1.25˚ × 1.25˚

Used extensively for climate prediction, detection and attribution, and other climate sensitivity studies

CHIME

Coupled Hadley-Isopycnic Model Experiment

Developed at National Oceanography Centre, Southampton

Same atmosphere model and ice model as HadCM3

Isopycnic ocean model (HYCOM), instead of HadCM3's depth-level vertical coordinate.

Spherical 1.25˚ × 1.25˚ grid south of 55˚N, with bipolar grid covering Arctic

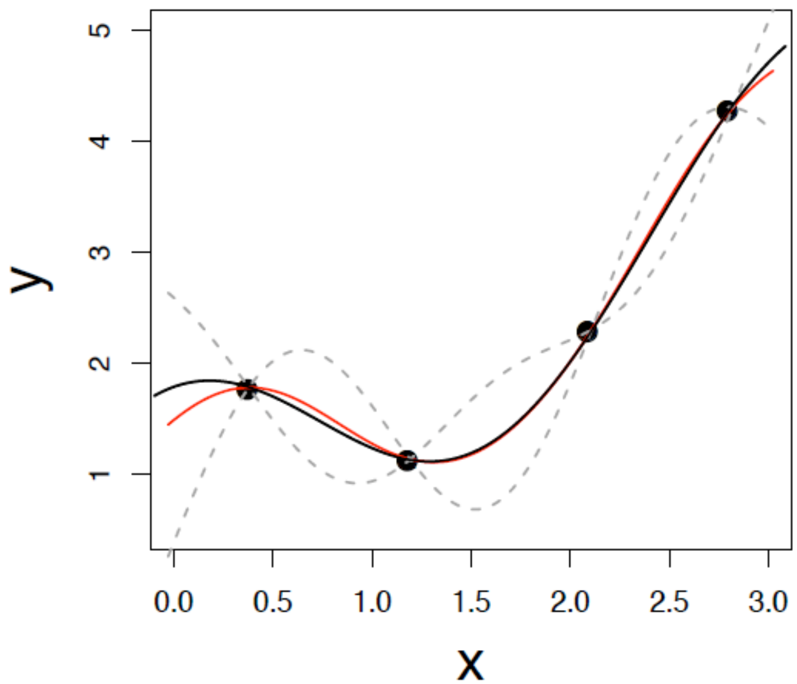
So far neither GCM has shown AMOC collapse without external freshwater forcing (hosing) being applied.

RAPIT will carry out a systematic search of input parameter space to look for any regions in which a collapse is likely.

RAPID-RAPIT Risk Assessment, Probability and Impacts Team

A very large (~10,000+ members) perturbed physics ensemble is being designed and set up for *climateprediction.net*

Statistical emulators will be built based on the results and used to fill the gaps in parameter space, and to estimate sensitivity and uncertainty.



Emulator:
A fast statistical approximation to a climate model.

Rapid AMOC fluctuation events in coupled climate models

RAPIT WP1: Mechanisms and impacts of rapid MOC changes

- Many simple climate models (e.g., EMICS) show complete shutdown of AMOC under suitable conditions, but this behaviour is rare in GCMs.

- As a first step towards understanding the differences between models, we examine smaller, rapid, natural AMOC fluctuation events in GCMs to determine important physical mechanisms and impacts.

Are the largest, most rapid events special?

- Are the largest, most rapid changes associated with any specific feedback mechanism?

- Eventually we want to look for a time-varying fingerprint of precursors to, and impacts of, large rapid AMOC changes.

- Is there a signal which is robust across different models?

- We plan to build up a database of rapid events from many different models.

  ...to start with: GFDL CM2.1, ECHO-G, IPSL CM4, FAMOUS

A selection of GCMs

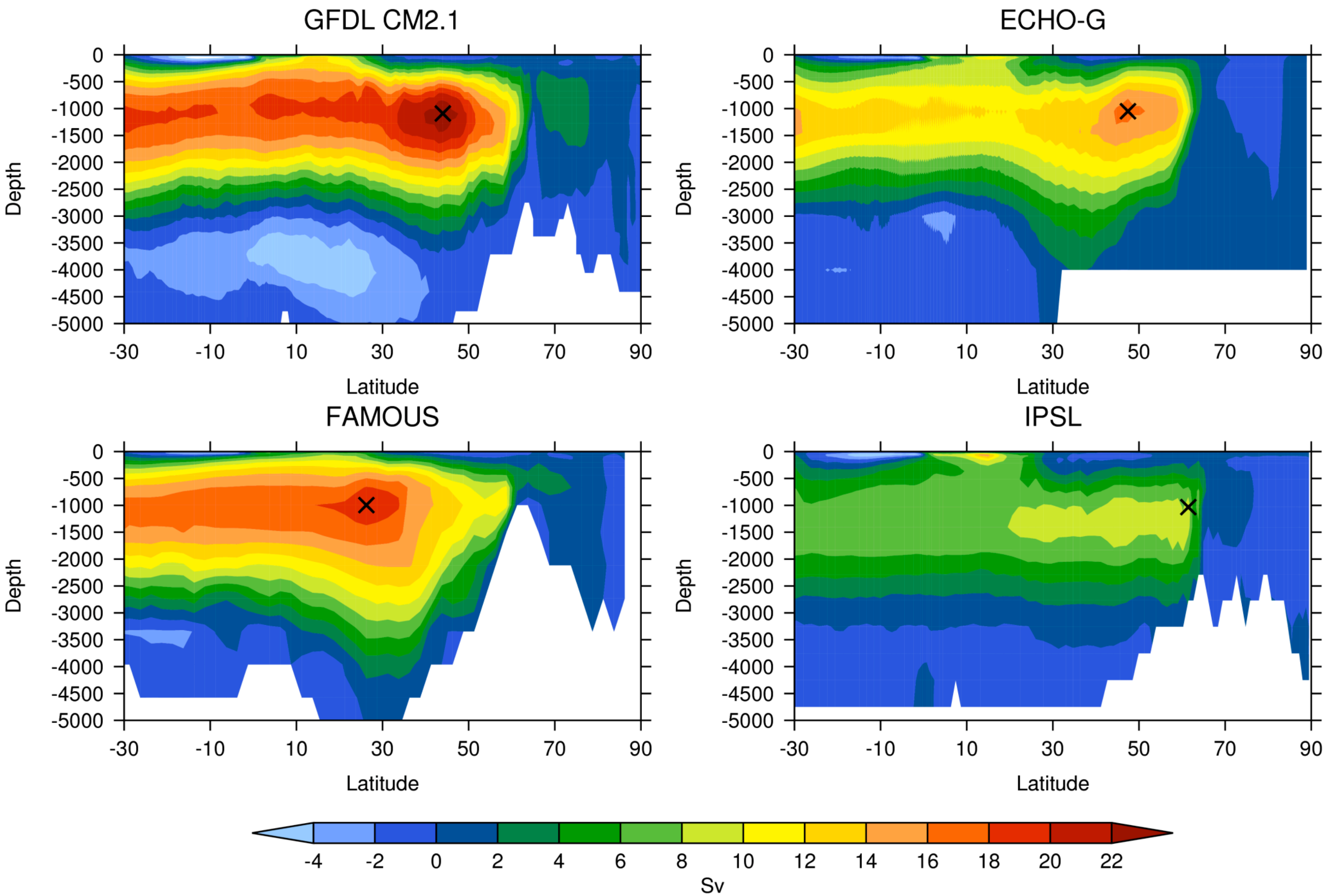
<u>GFDL CM2.1</u>
Atmosphere: 2.5˚ lon × 2˚ lat, 24 levels
Ocean: 1˚× 1˚ (1/3˚ latitude in tropics), 50 levels
500-year control integration

<u>ECHO-G</u>
Atmosphere: ECHAM4, 3.75˚× 3.75˚, 19 levels
Ocean: HOPE-G, 2.8˚× 2.8˚ (0.5˚ lat in tropics), 20 levels
1000-year control integration

<u>IPSL CM4</u>
Atmosphere: LMDZ-4, 2.5˚ × 3.75˚, 19 levels
Ocean: ORCA, 2˚ × 2˚ (1˚ in tropics), 31 levels
1150-year control integration

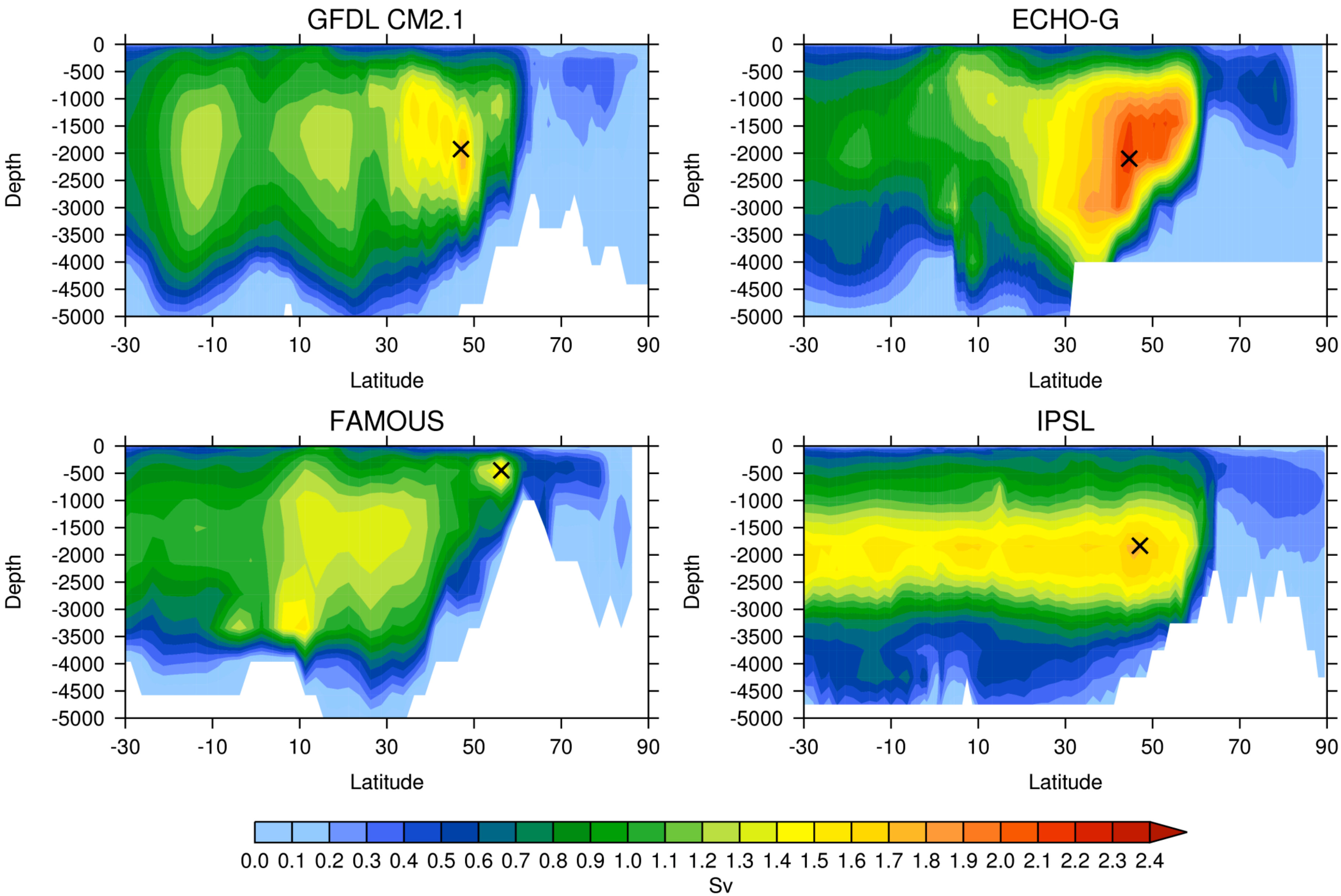
<u>FAMOUS</u>
Atmosphere: 7.5˚ lon 5˚ lat, 11 levels
Ocean: 3.75˚ lon × 2.5˚ lat, 20 levels
4045-year control integration

Mean AMOC

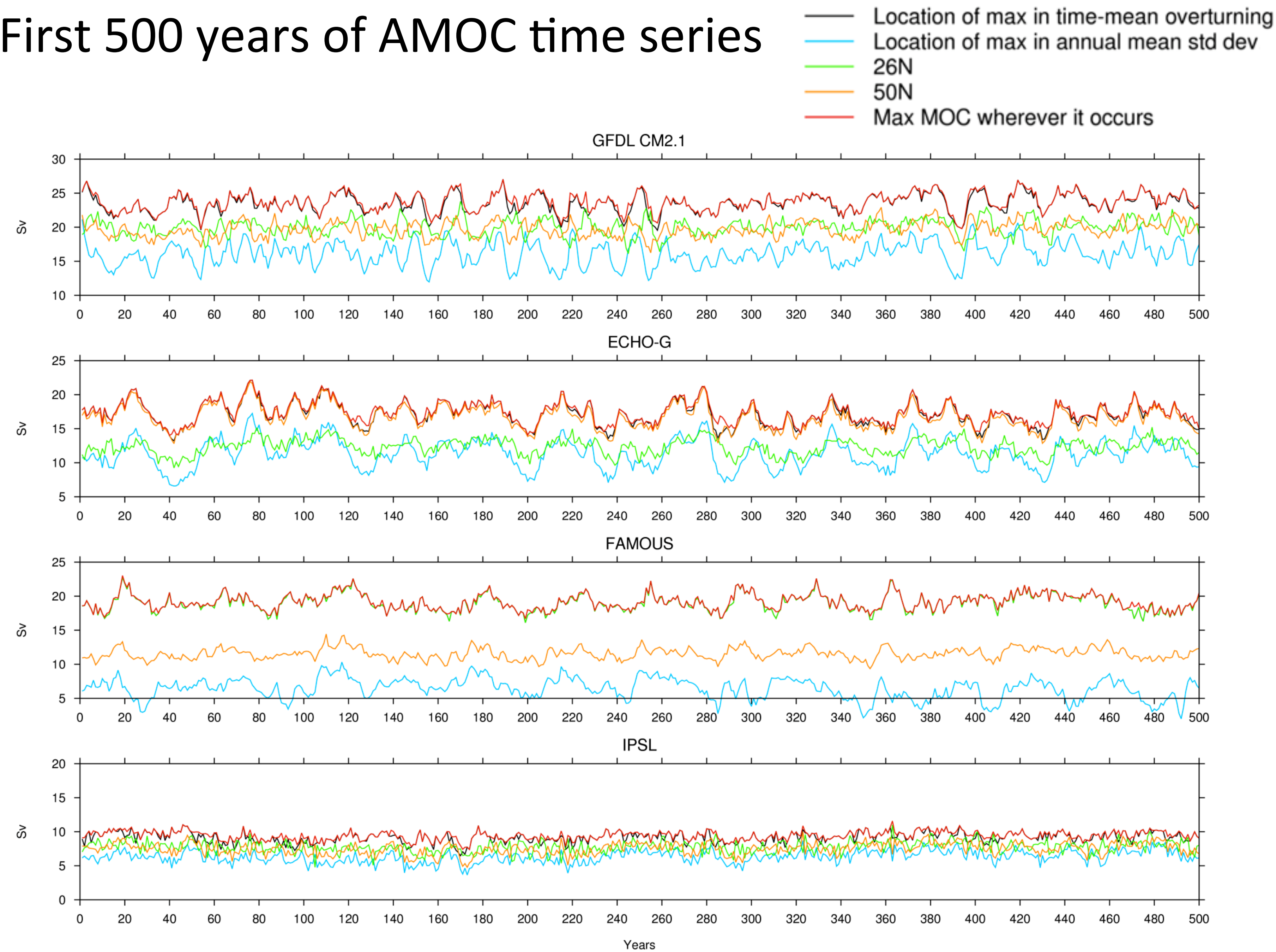


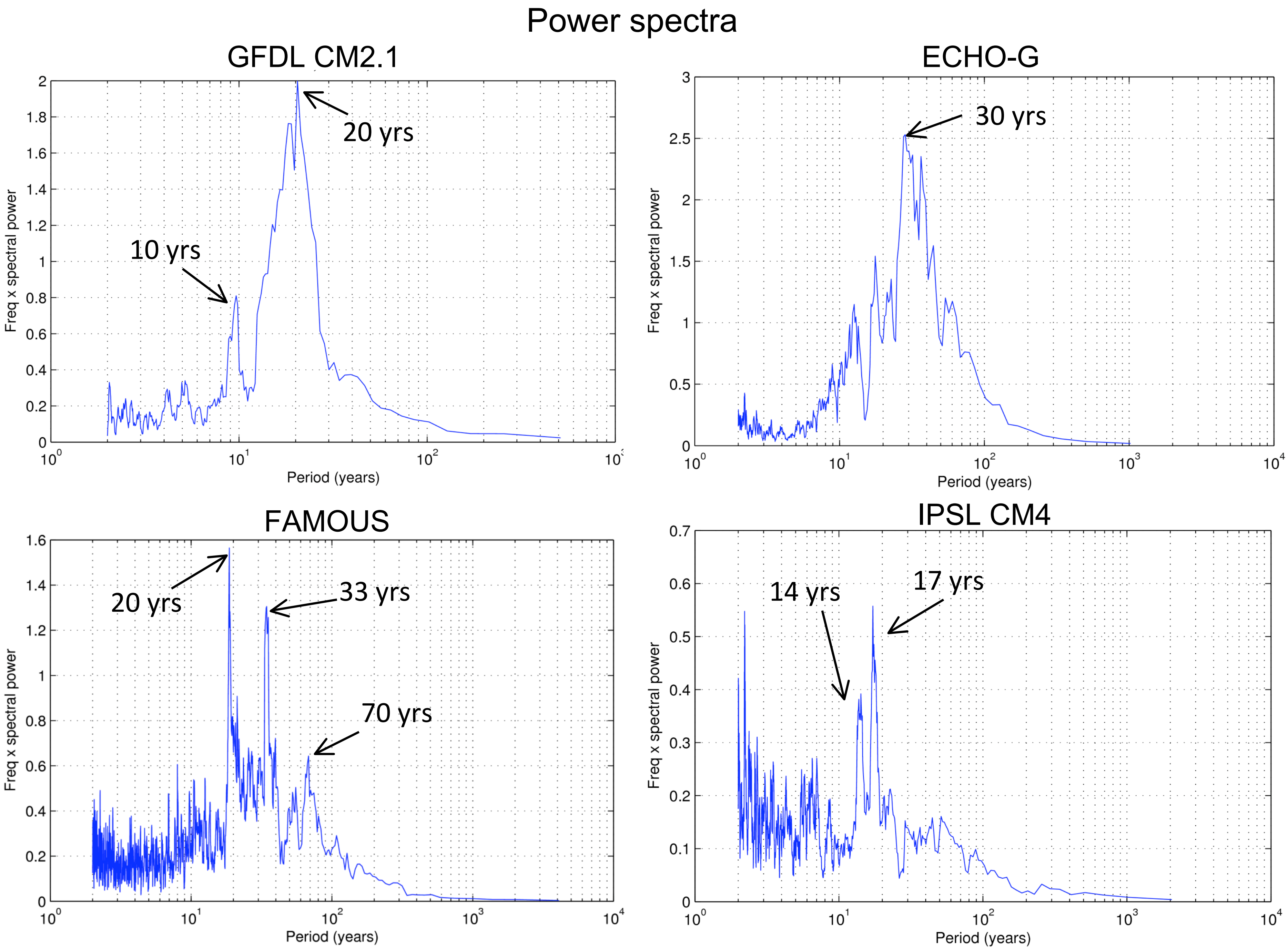
GFDL CM2.1
ECHO-G
FAMOUS
IPSL
Depth
Latitude
0
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500
-5000
-30
-10
10
30
50
70
90
-4
-2
0
2
4
6
8
10
12
14
16
18
20
22
Sv

Standard deviation of annual mean streamfunction



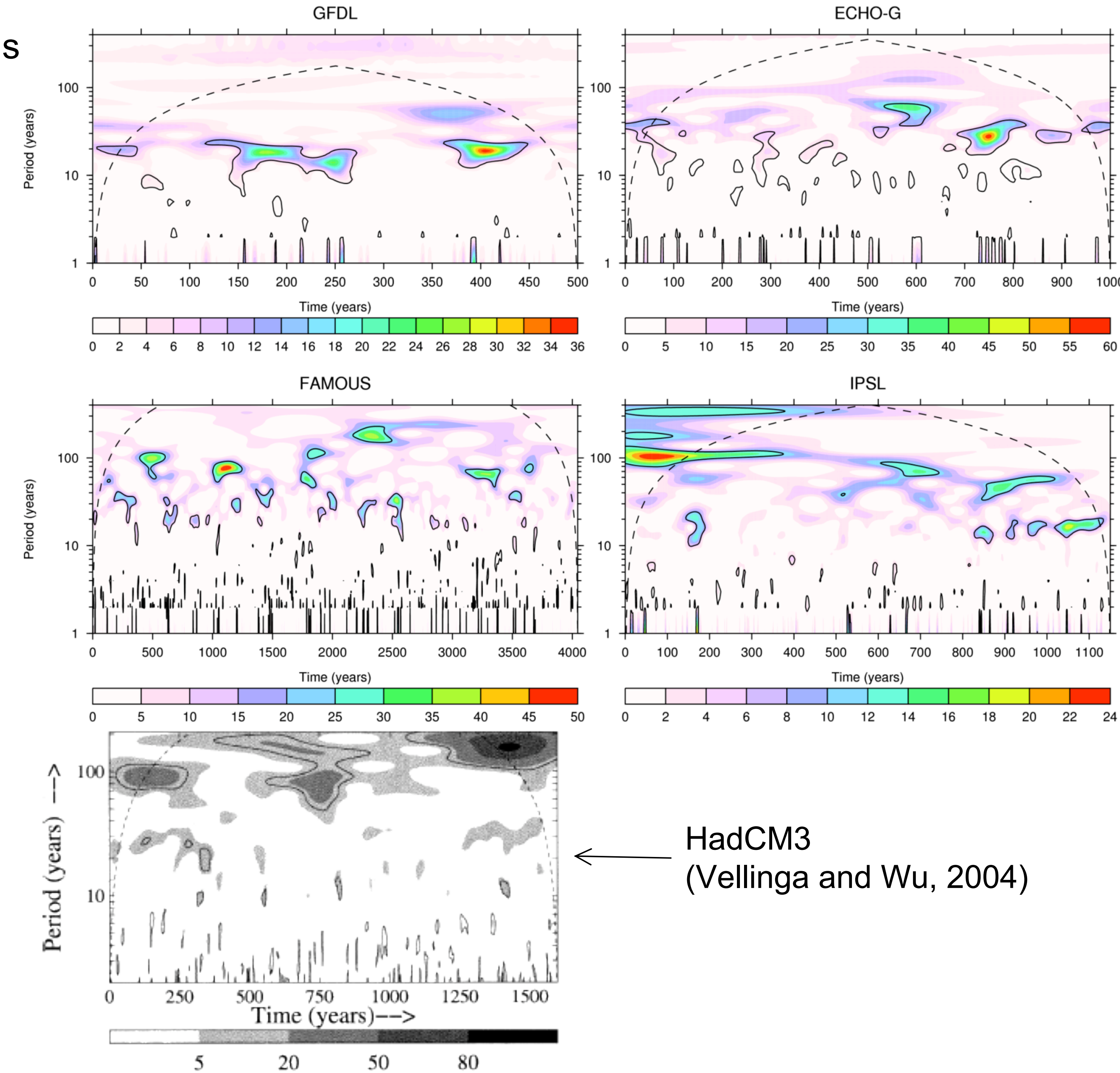
First 500 years of AMOC time series





Power spectra
GFDL CM2.1
ECHO-G
FAMOUS
IPSL CM4
20 yrs
10 yrs
30 yrs
20 yrs
33 yrs
70 yrs
14 yrs
17 yrs
Freq x spectral power
Period (years)

Wavelet analysis



HadCM3
(Vellinga and Wu, 2004)

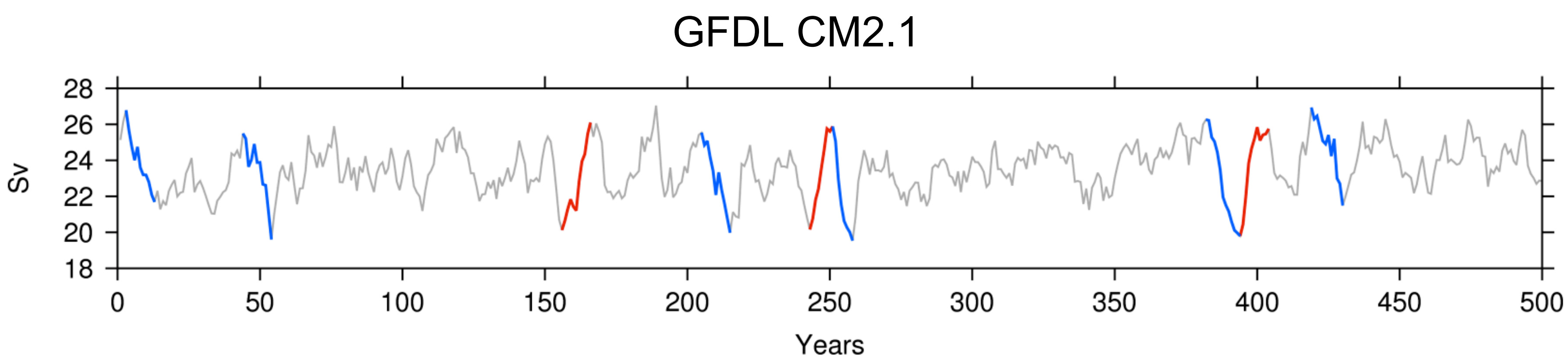
Defining a large, rapid event

We need a consistent definition that can be applied to different models, which have different characteristics of AMOC variability.

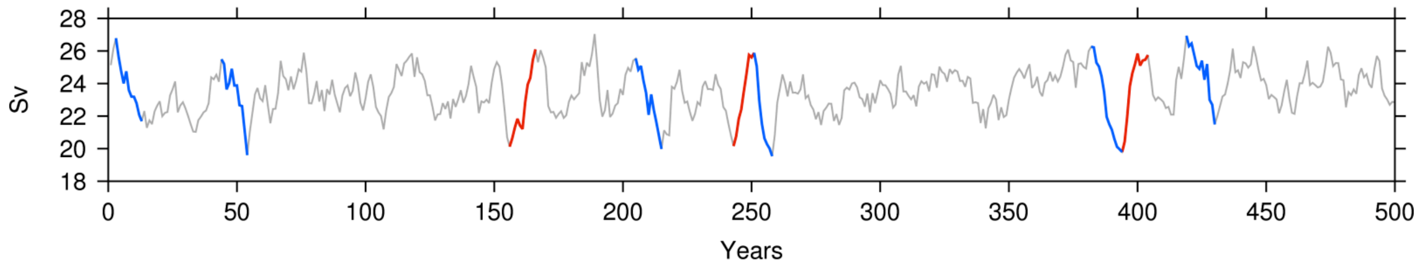
<u>Example</u>

• For each time point, determine the proceeding time window over which the largest AMOC change occurs (7-20 years).

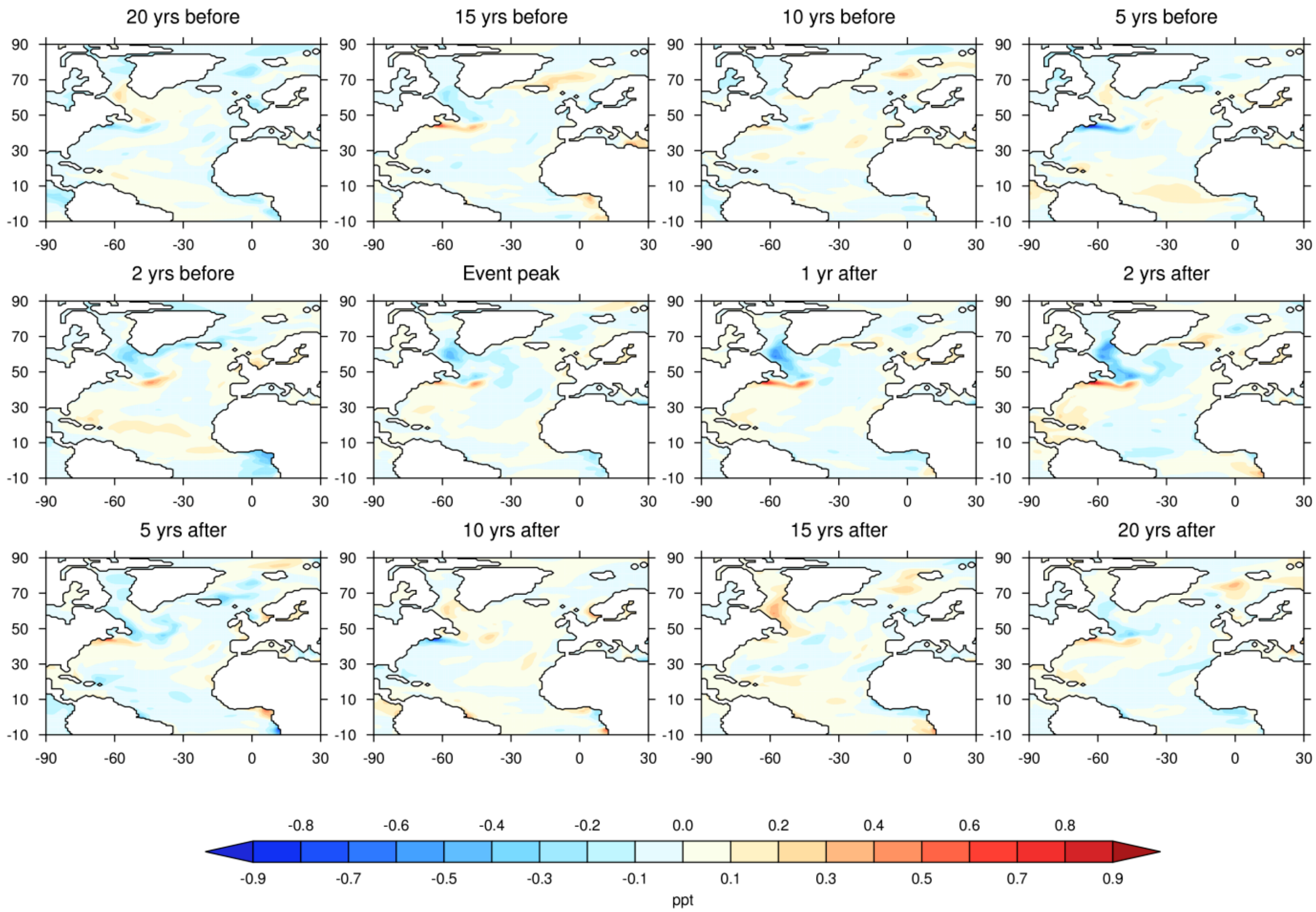
• Event is detected if the magnitude and rate of the change across the time window both exceed given thresholds.



GFDL CM2.1



SSS anomalies associated with a composite of negative AMOC events



Questions to be considered

1. Do the range of GCMs exhibit common features in rapid MOC changes?
2. Why don’t small rapid slowdowns develop into full shutdowns? Specific negative feedbacks or absence of positive feedbacks?
3. Do rapid events have dynamics that are different from slower MOC variations?
4. Are rapid increases driven by the same processes as rapid decreases?
5. What measure of the MOC captures these rapid changes most effectively? Could RAPID-WATCH observations detect or predict the changes?
6. Is the frequency of the MOC variability related to the likelihood of a rapid event?
7. What are the most important climate impacts of MOC changes across a range of GCMs?
8. How predictable are the rapid changes? Optimal regions/variables for observations?
9. How do the frequency and characteristics of rapid events change with increased radiative forcing?

Thank you

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RAPID - RAPIT

Rapid Climate Change

University of Reading

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National Centre for Atmospheric Science

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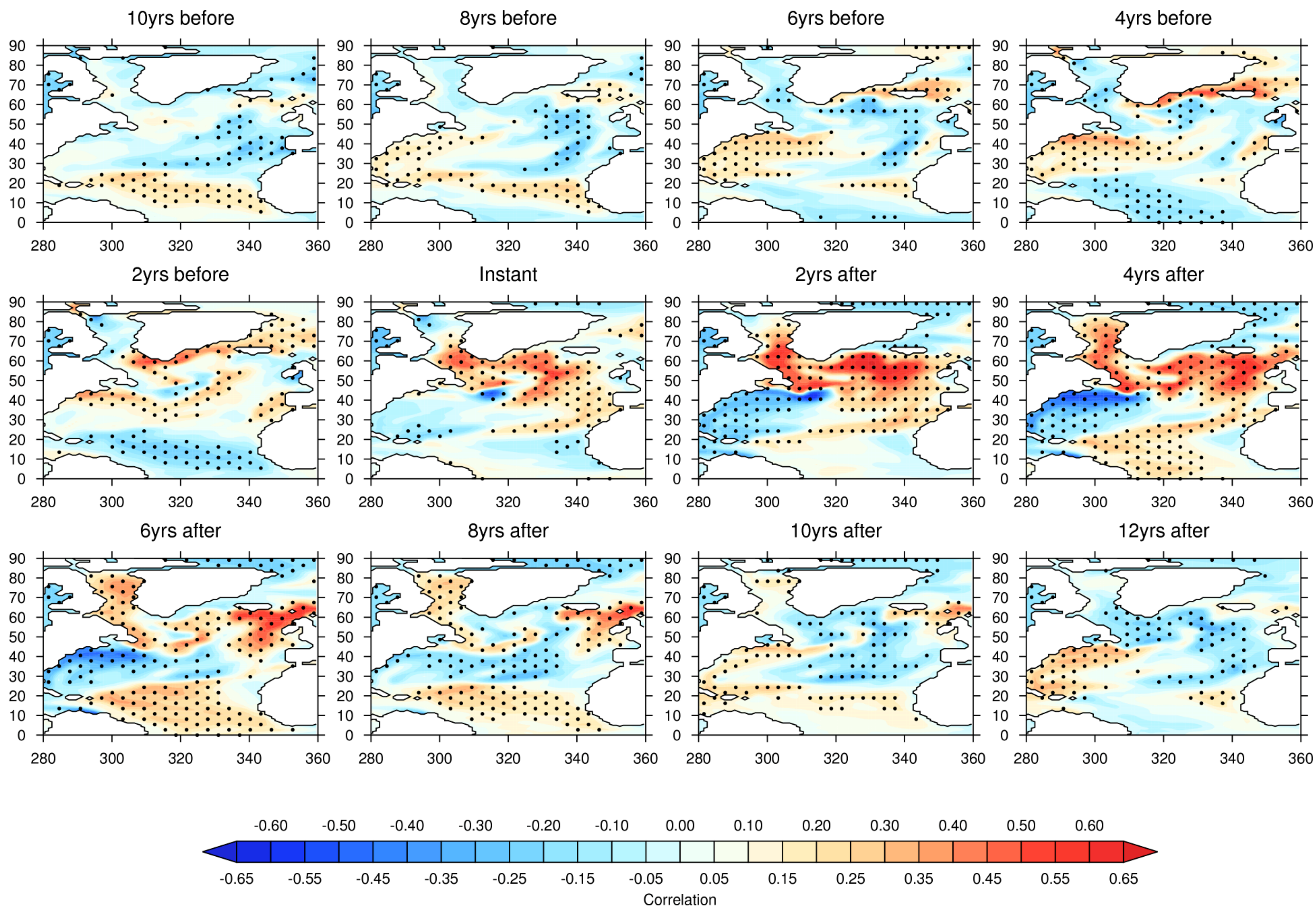
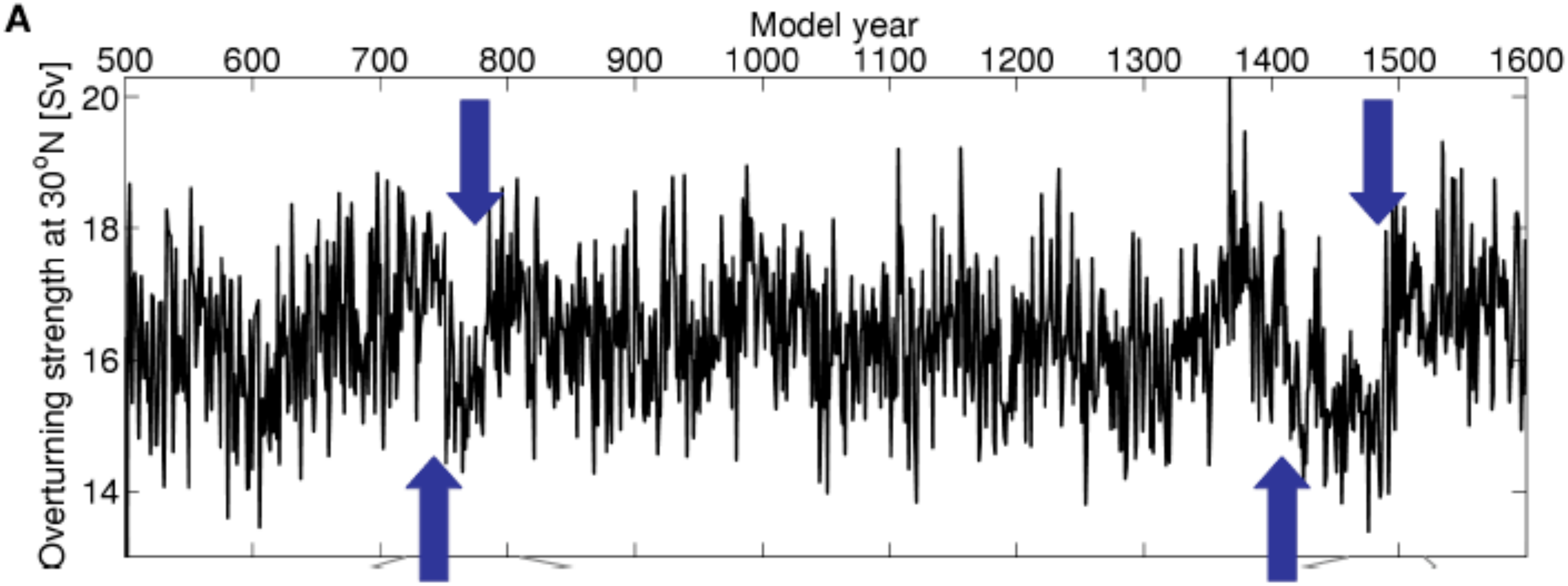
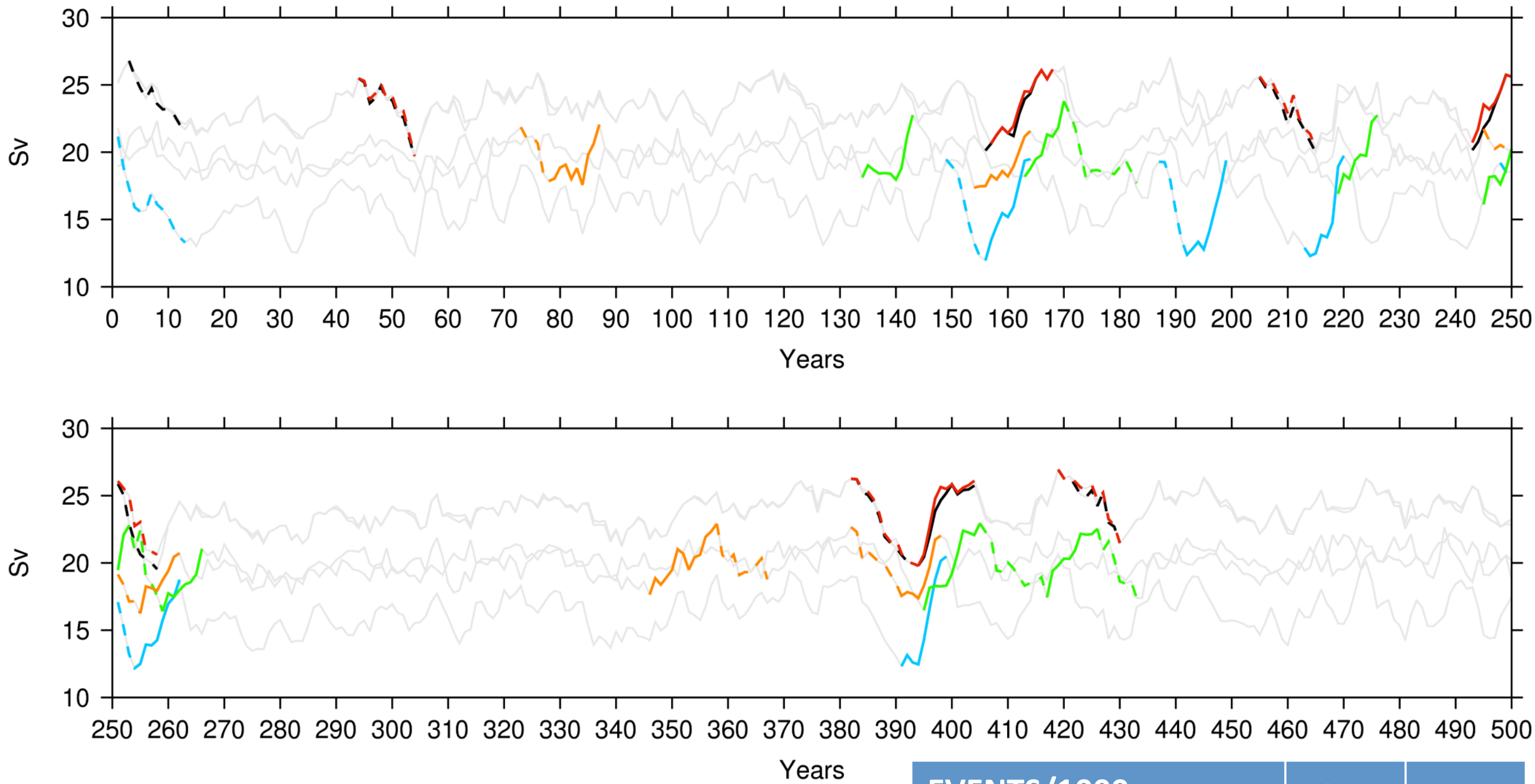
Lag correlations between AMOC and SSS





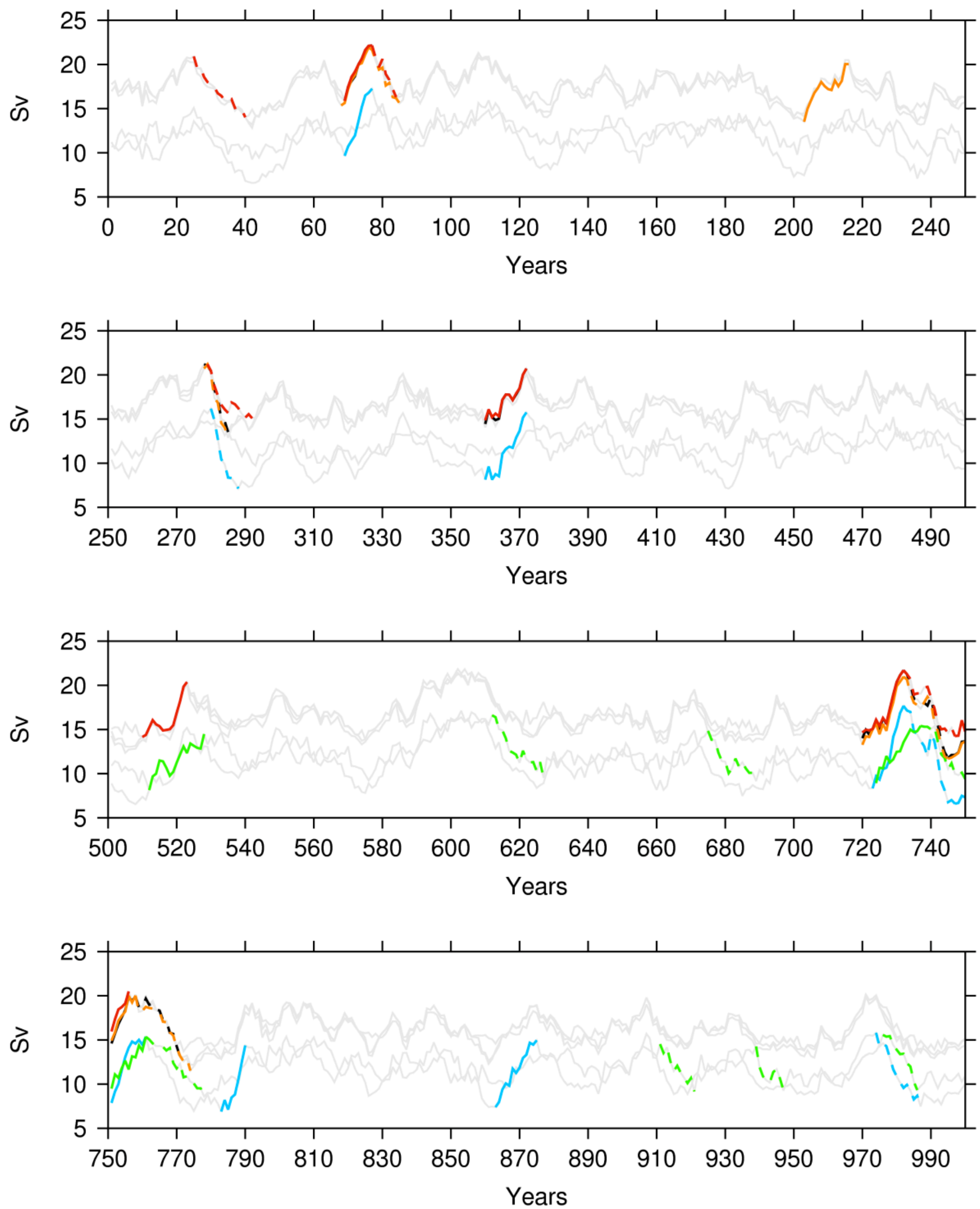
Hawkins and Sutton, GRL 2008

GFDL CM2.1



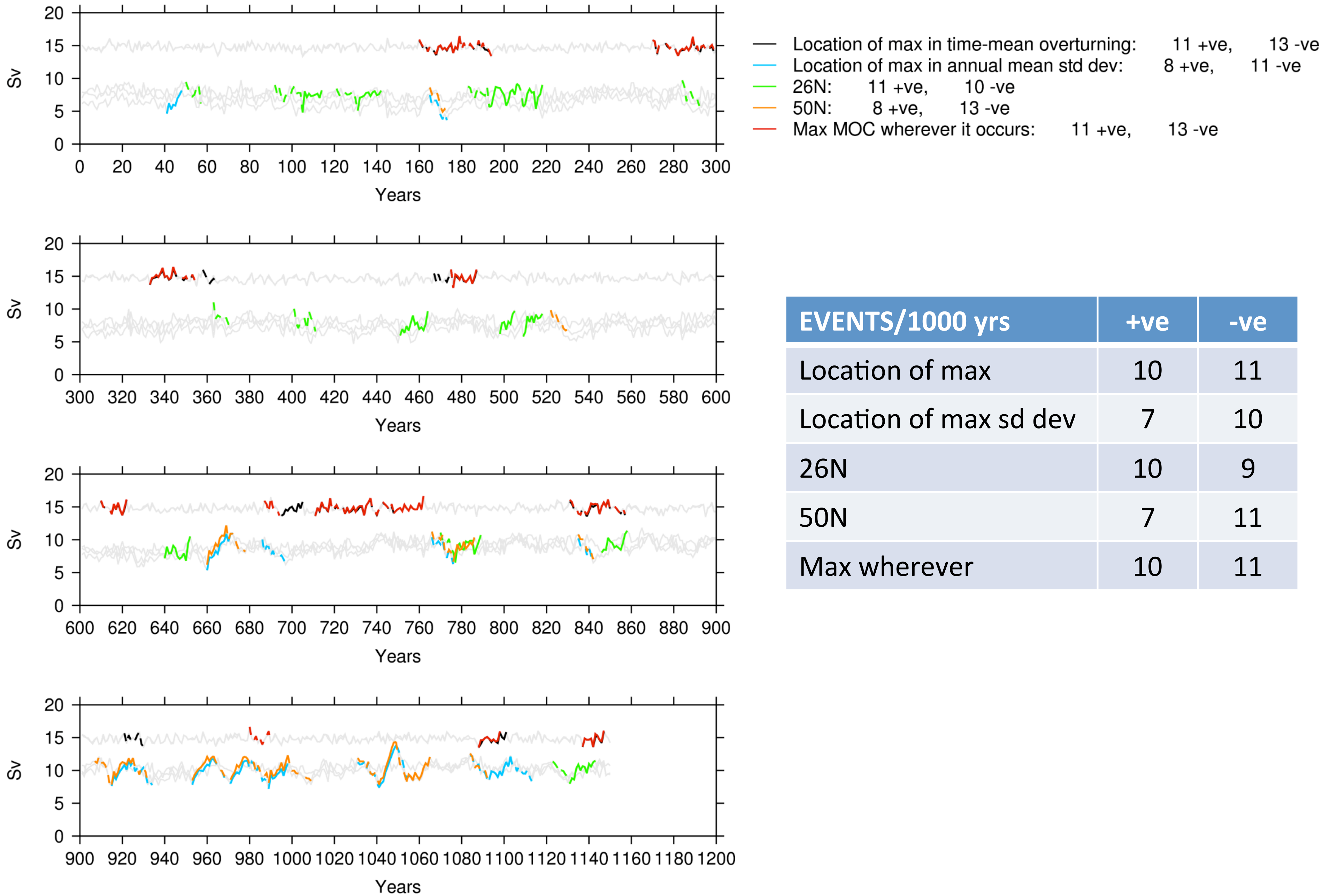
EVENTS/1000 yrs	+ve	-ve
Location of max	6	12
Location of max sd dev	10	8
26N	14	8
50N	20	8
Max wherever	6	10

ECHO-G

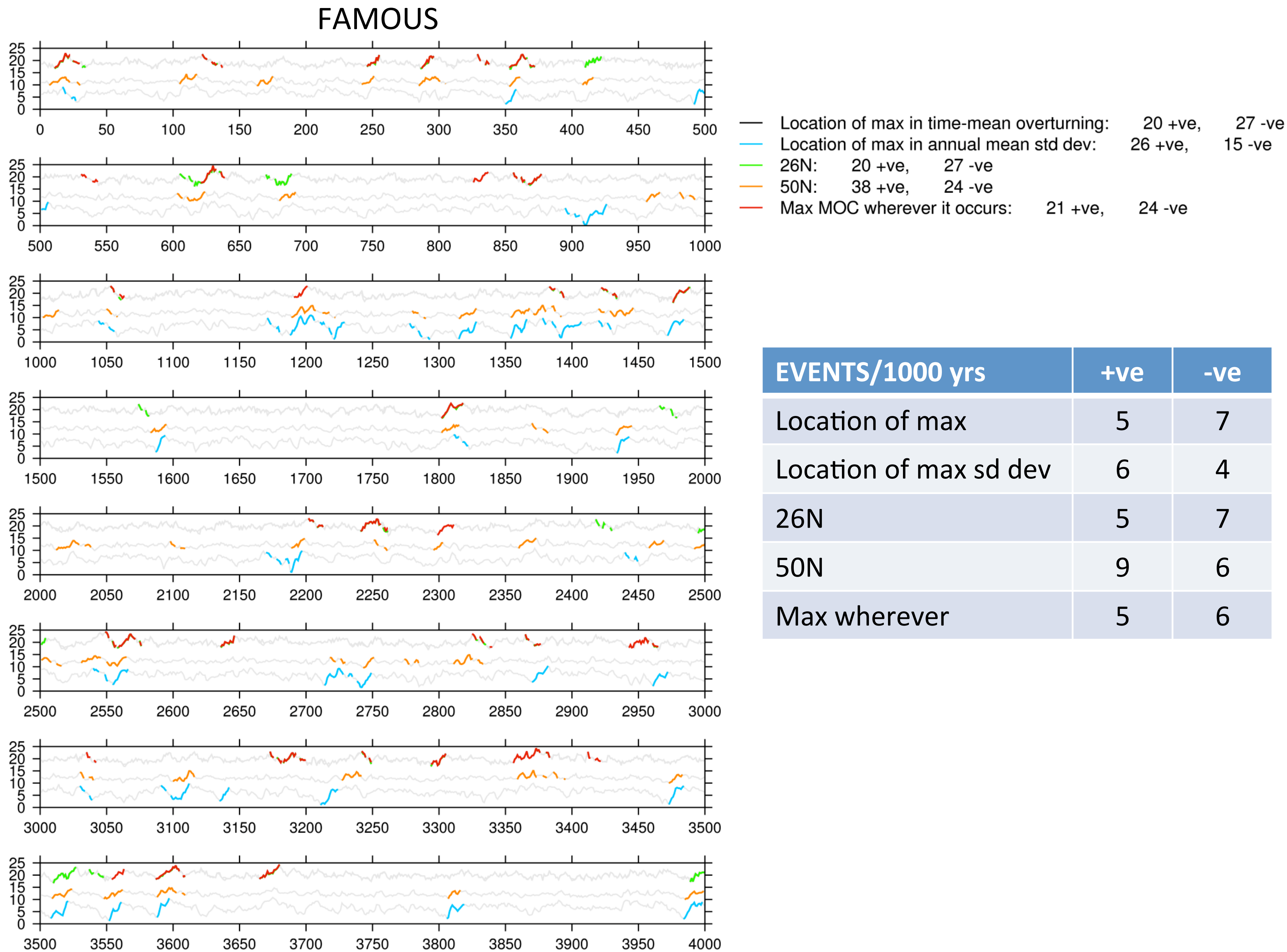


EVENTS/1000 yrs	+ve	-ve
Location of max	4	3
Location of max sd dev	6	3
26N	3	7
50N	4	4
Max wherever	5	4

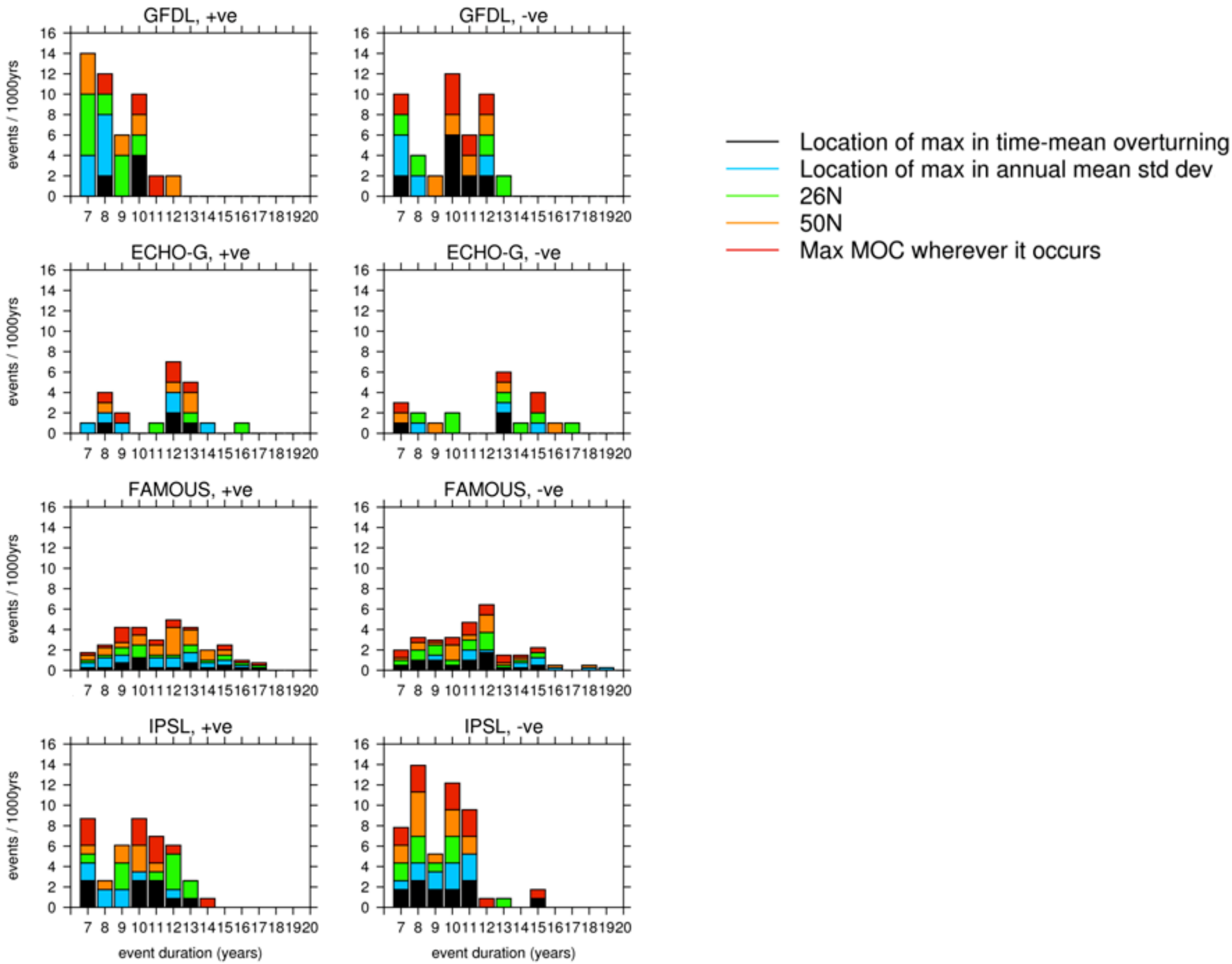
IPSL



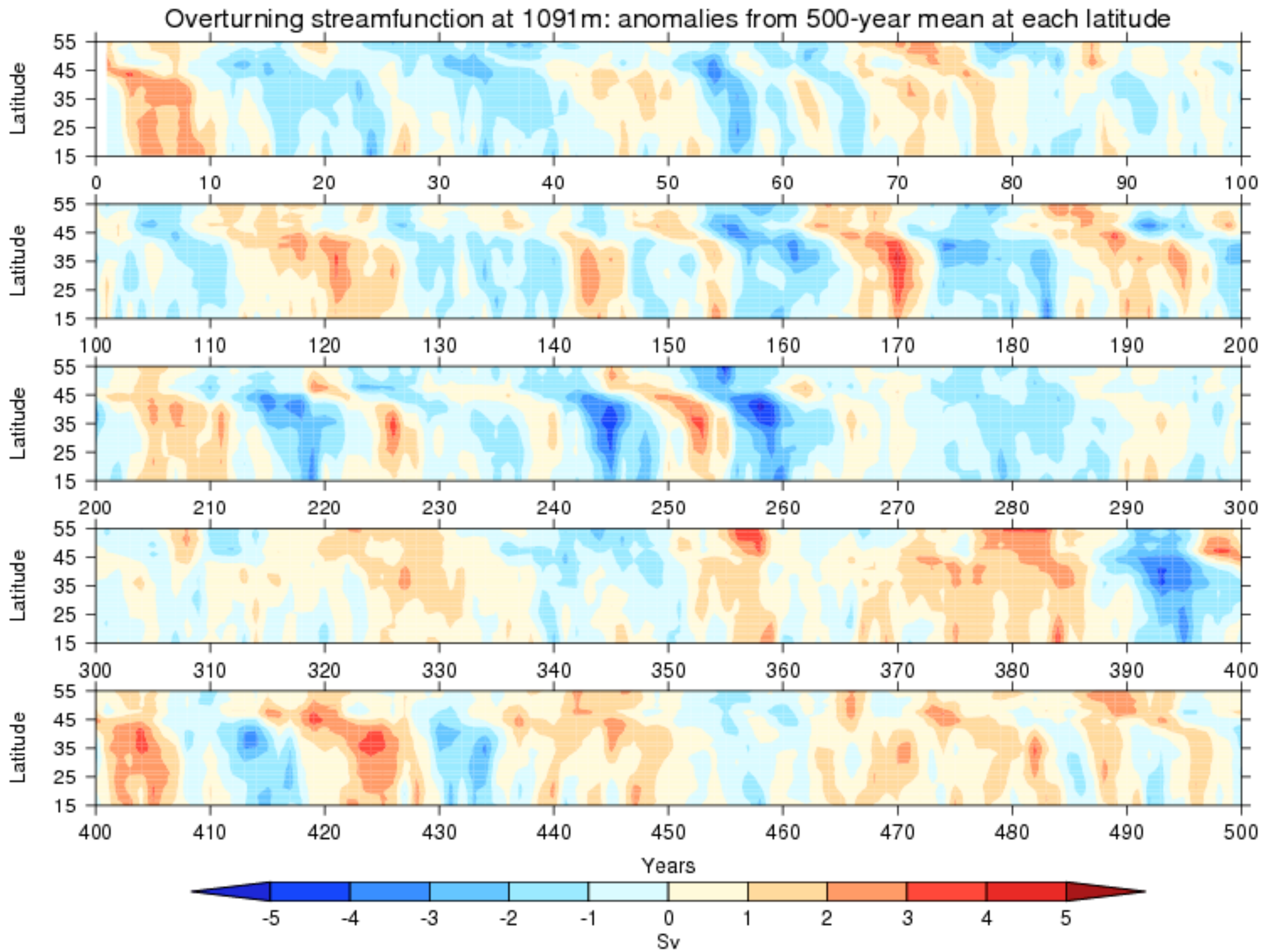
EVENTS/1000 yrs	+ve	-ve
Location of max	10	11
Location of max sd dev	7	10
26N	10	9
50N	7	11
Max wherever	10	11



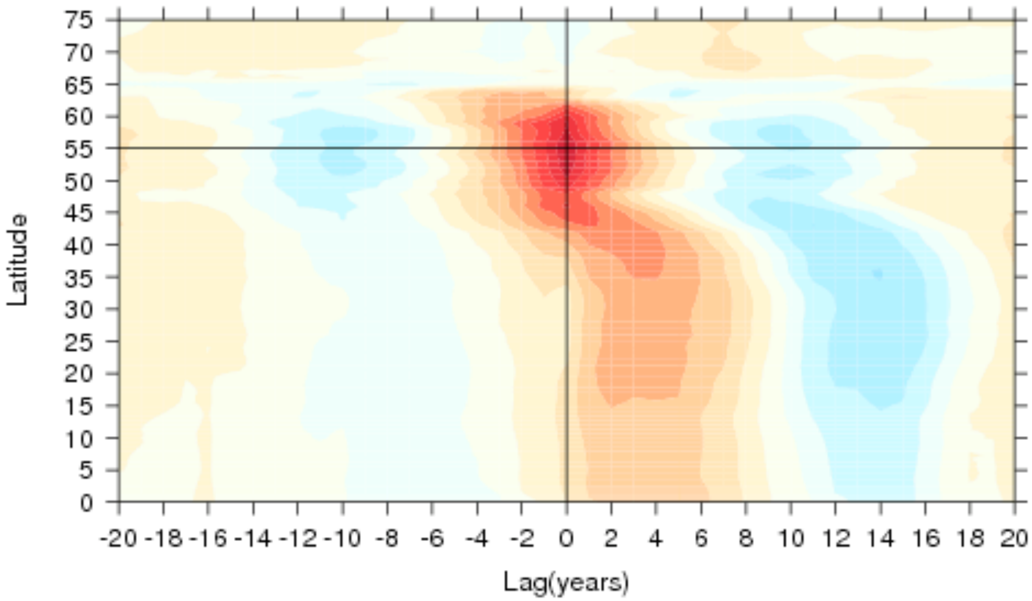
EVENTS/1000 yrs	+ve	-ve
Location of max	5	7
Location of max sd dev	6	4
26N	5	7
50N	9	6
Max wherever	5	6


GFDL, +ve
GFDL, -ve
ECHO-G, +ve
ECHO-G, -ve
FAMOUS, +ve
FAMOUS, -ve
IPSL, +ve
IPSL, -ve
events / 1000yrs
event duration (years)
Location of max in time-mean overturning
Location of max in annual mean std dev
26N
50N
Max MOC wherever it occurs

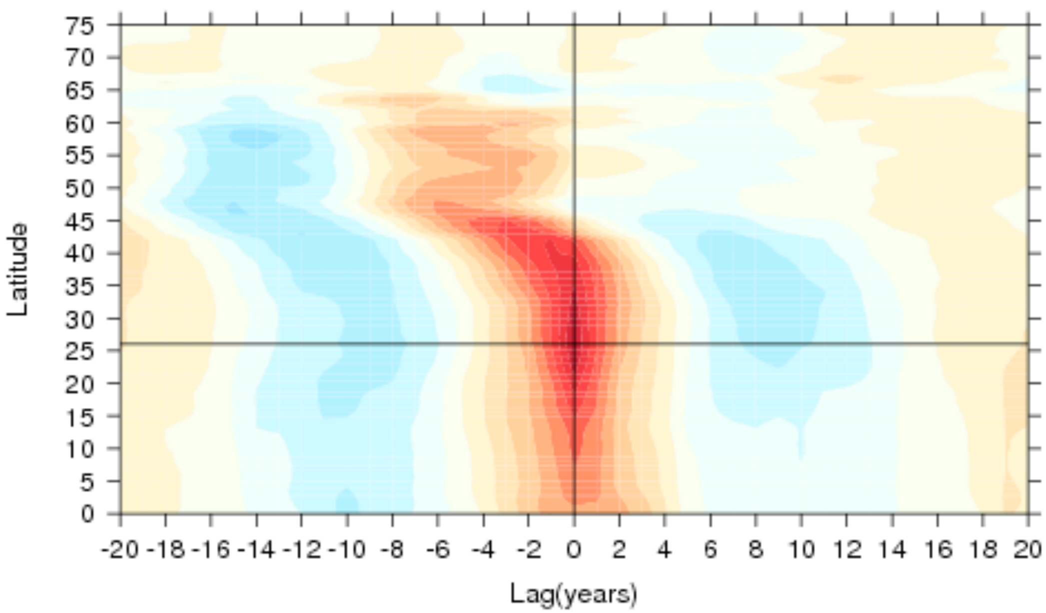
Southward propagation of overturning anomalies



Southward propagation of overturning anomalies



Lagged correlations between overturning streamfunction at 55˚N (1091 m) and other latitudes...



... and between overturning streamfunction at 26˚N and other latitudes