AMOC variability and predictability

- Why do we care about the AMOC variability?

  ➡ climate impacts of AMOC variations

insights from coupled climate models

- How does the AMOC vary?

  ➡ a few ideas on AMOC variability in climate models

- Is there anything we can do about it?

  ➡ predictability and predictions of the AMOC

Juliette Mignot

IRD Institut de recherche pour le développement
LOCEAN
Sciences de l'environnement
Institut Pierre Simon Laplace

MORDICUS
BLUE ACTION

AMOC variability and predictability

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  ⇨ **climate impacts of AMOC variations**

- How does the AMOC vary?

  ⇨ a few ideas on AMOC variability in climate models

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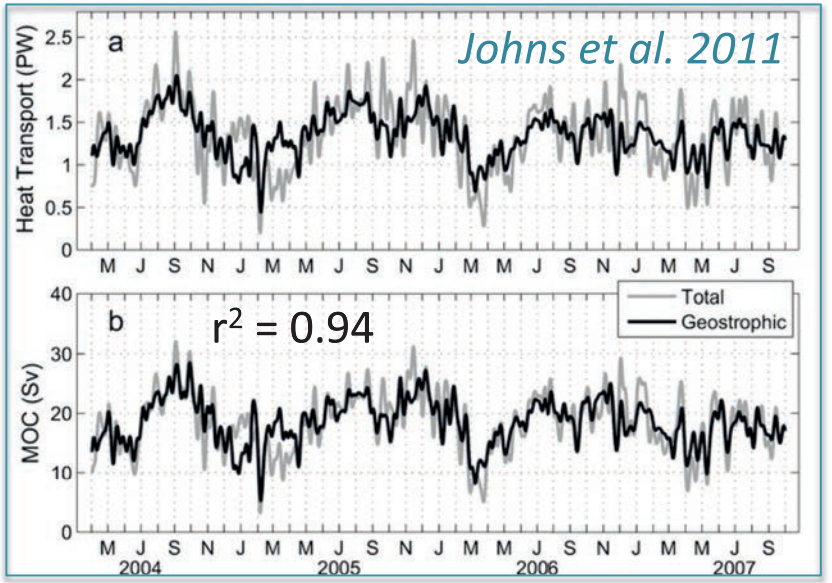
  ⇨ predictability and predictions of the AMOC

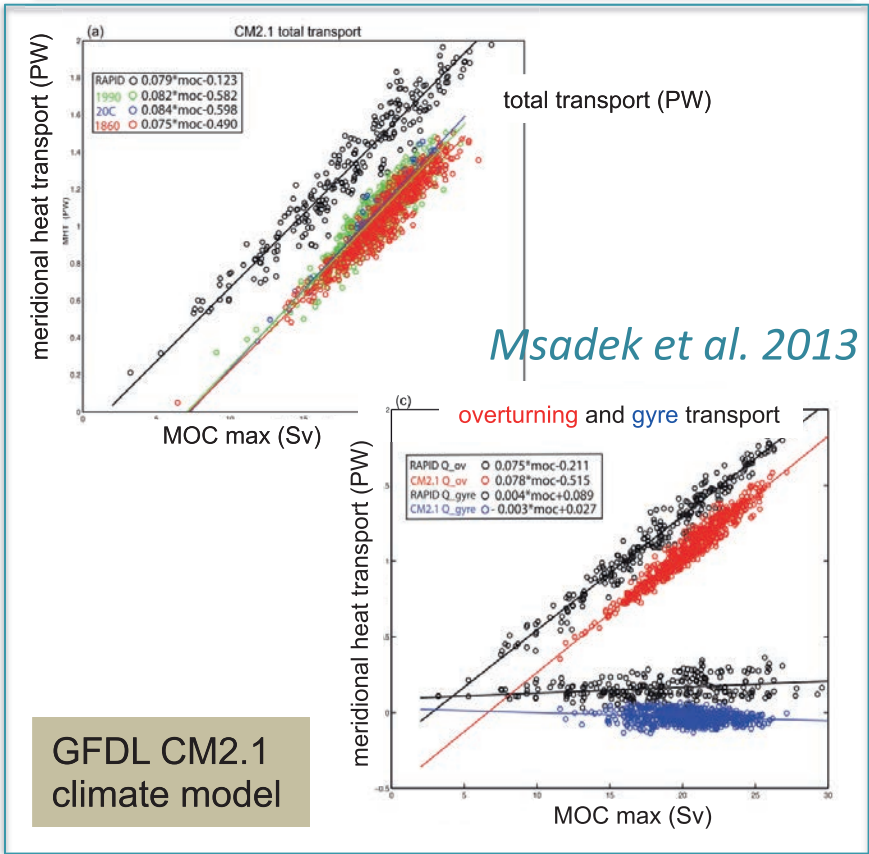
1. Impacts of the AMOC Variability

on the ocean heat transport

Analysis at 26.5 °N

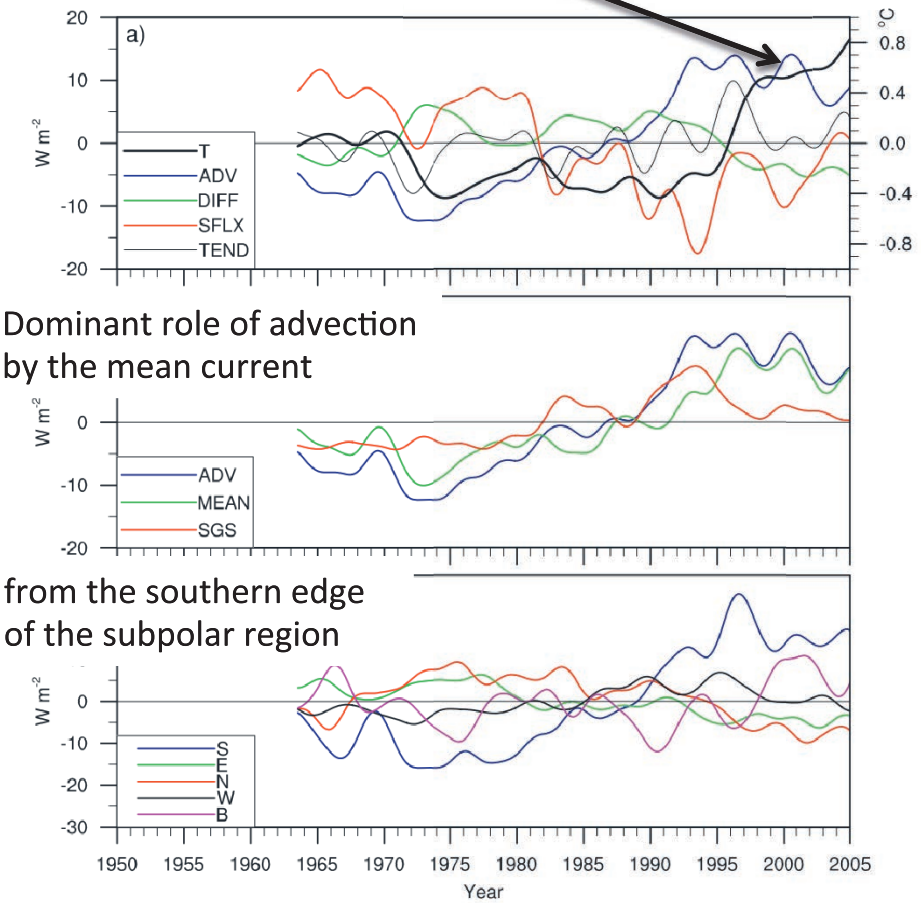
- large co-linearity between MOC and the oceanic meridional heat transport in observations
- Confirmed in climate models
- Dominant role of the transport by the overturning component





1. Impacts of the AMOC Variability **on the ocean heat content** *decadal timescale*

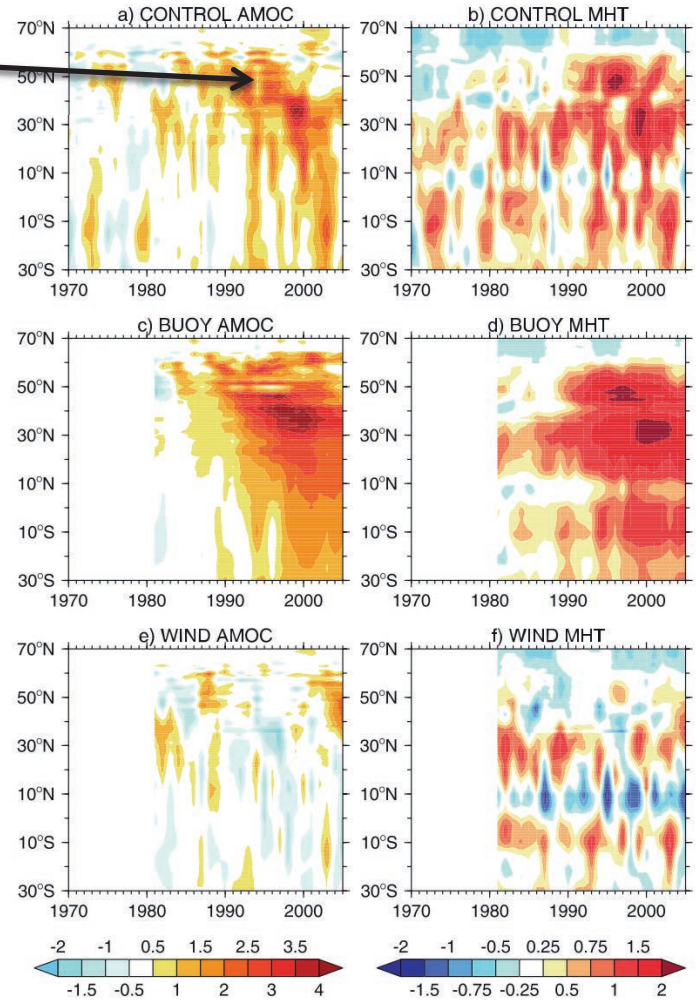
Case study of the 1990s warming in the subpolar North Atlantic



Yeager et al 2012

CCSM4

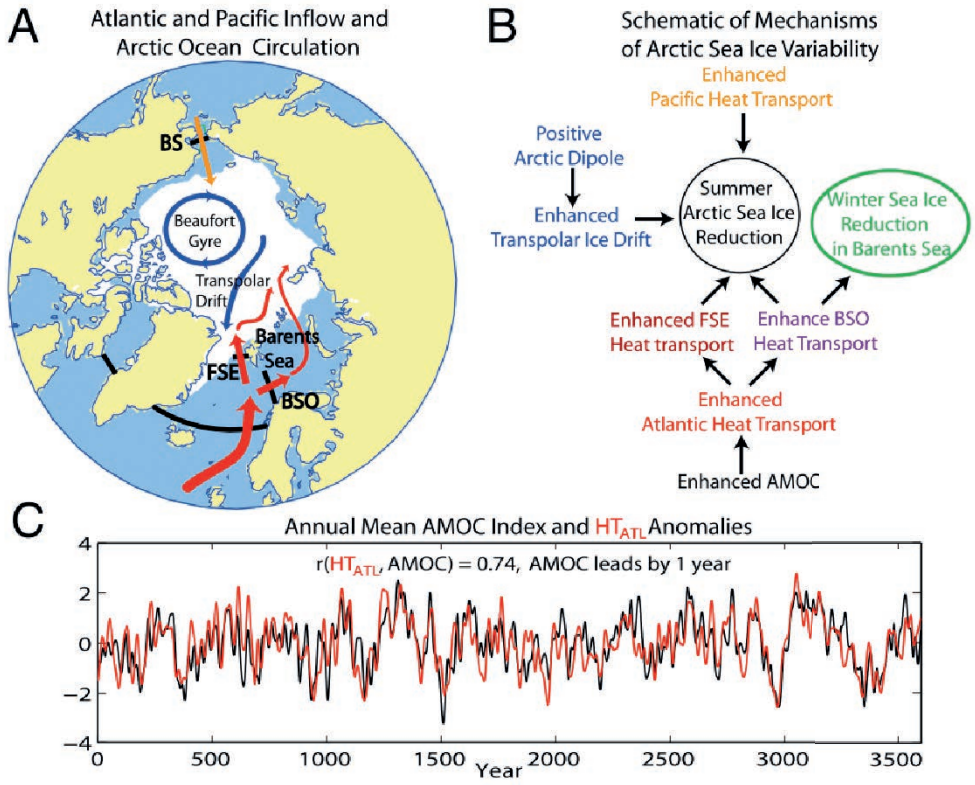
Anomalous northward heat transport associated with anomalous AMOC



HadCM3

Robson et al 2012

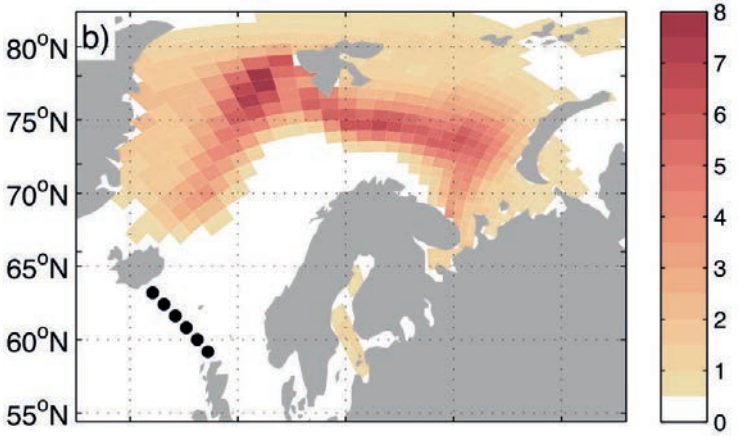
1. Impacts of the AMOC Variability on the arctic sea ice



GFDL CM2.1

Zhang et al. 2015

influence of ocean heat transport into the Nordic Seas on sea ice concentration loss (%)



The ocean transport leads by 2 years

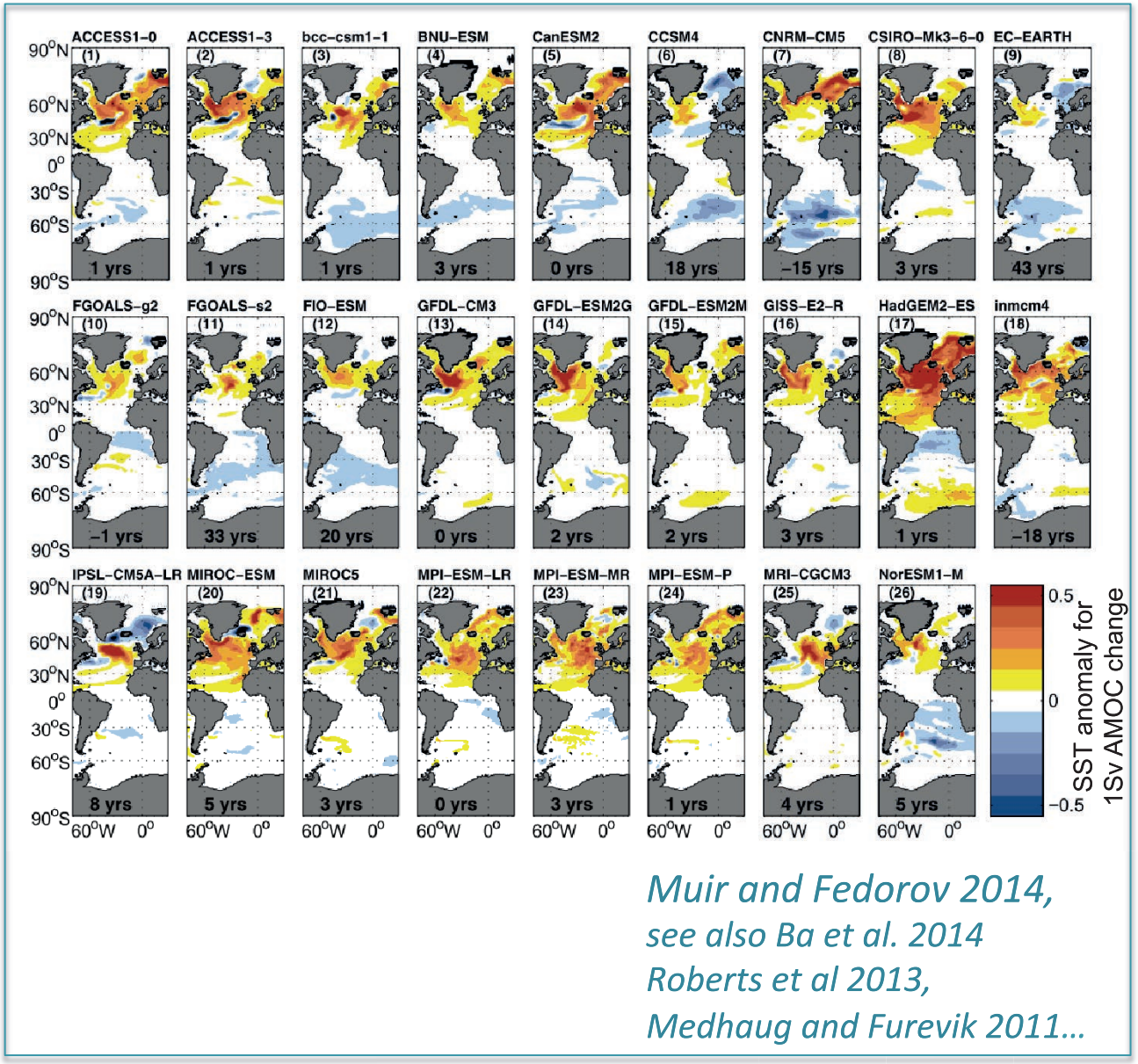
Bergen climate model

Arthun and Eldevik 2016

1. Impacts of the AMOC Variability on the sea surface temperature

Analysis of CMIP5 models at decadal timescales

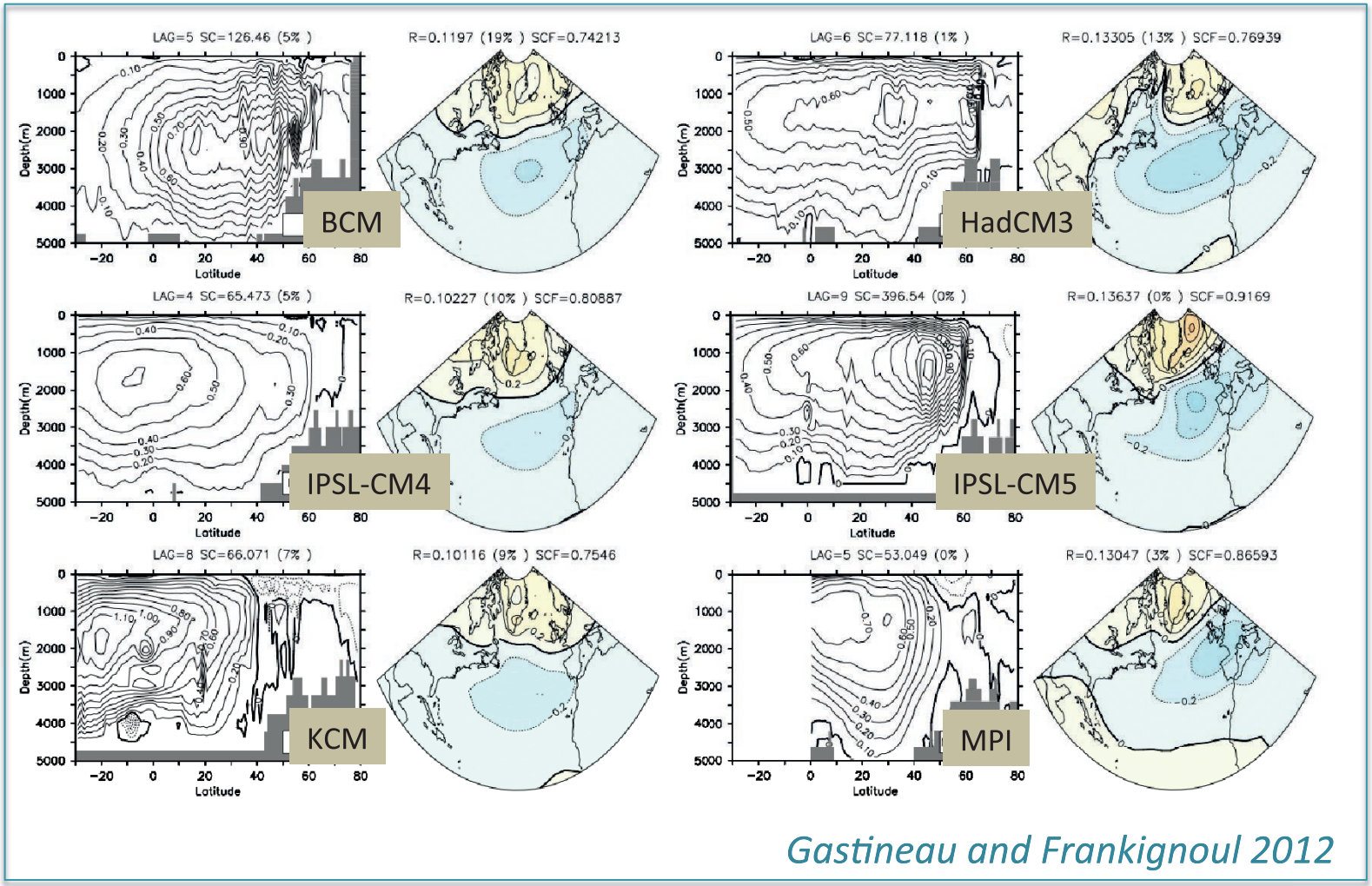
- Robust warming in the North Atlantic
- More diffuse cooling in the southern hemisphere



Muir and Fedorov 2014,
see also Ba et al. 2014
Roberts et al 2013,
Medhaug and Furevik 2011…

1. Impacts of the AMOC Variability on the atmosphere dynamics

- SST anomalies induce anomalous heat loss along the North Atlantic current and the subpolar gyre, consistent with a negative phase of the NAO in winter (JFM)



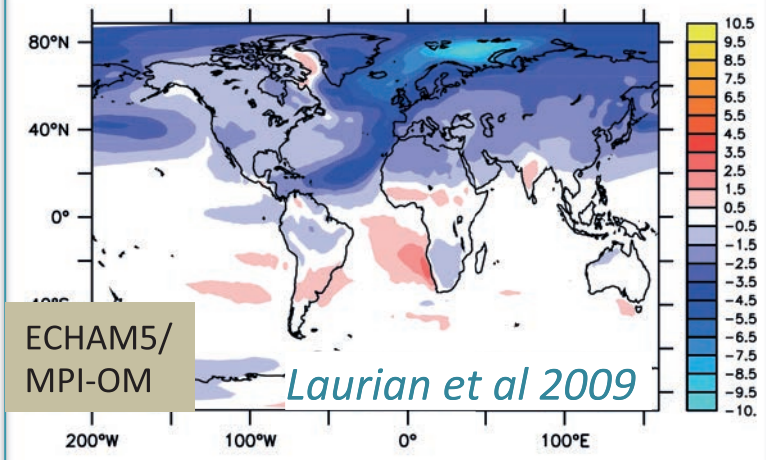
Gastineau and Frankignoul 2012

see C. Frankignoul and Y. Ruprich-Robert talks

1. Impacts of the AMOC Variability on the atmosphere thermodynamics

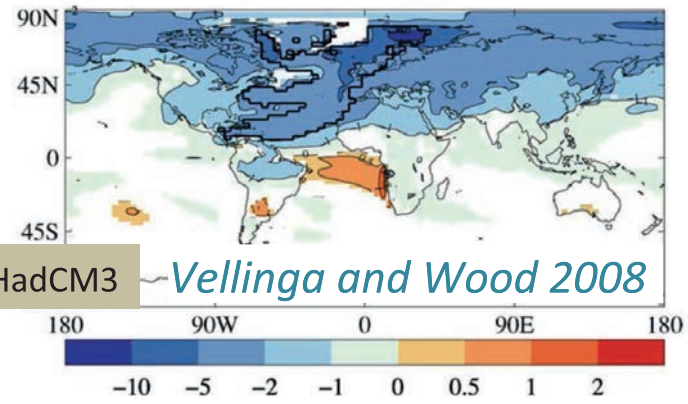
- Atmospheric temperature response to an AMOC collapse

coarse resolution climate models
(~1.4° x T63)



ECHAM5/
MPI-OM

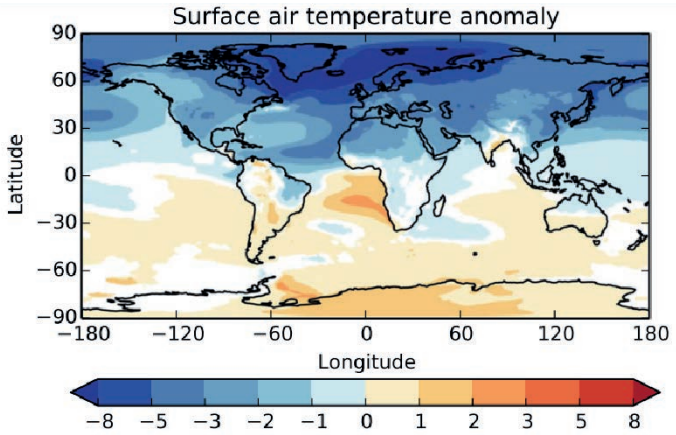
Laurian et al 2009



HadCM3

Vellinga and Wood 2008

high resolution climate model

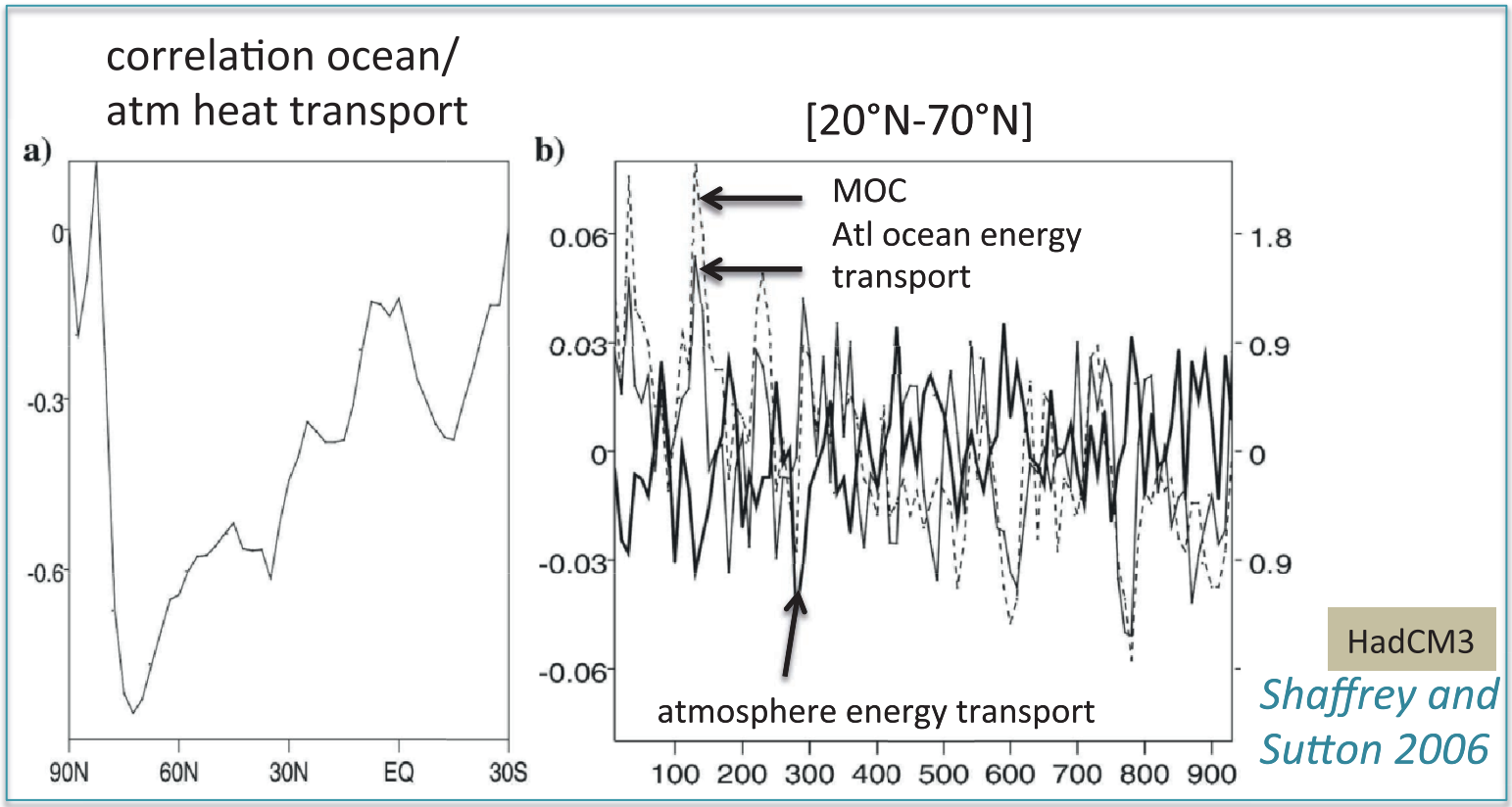


HadGEM3

Jackson et al 2015

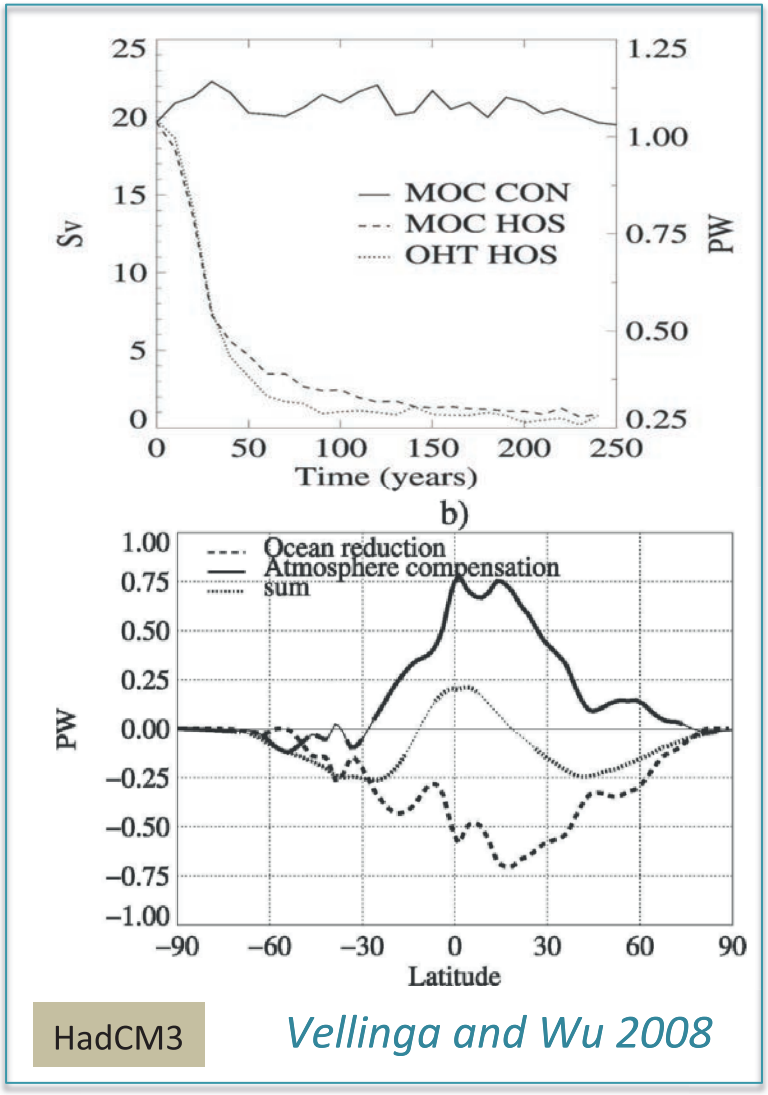
1. Impacts of the AMOC Variability on the atmosphere thermodynamics

- Prominent anticorrelation of **decadal** Atlantic ocean and atmosphere meridional energy transport at midlatitudes
- Major role of the AMOC
- Consistent with Bjerkness compensation, but not complete



1. Impacts of the AMOC Variability on the atmosphere thermodynamics

- Response of the heat transports to an AMOC collapse
- Overcompensation in the Tropics, undercompensation at midlatitudes
- Reduced overall meridional energy transport in the northern extratropics, compensated for by reduced outgoing net radiative flux at the TOA north of 30°N



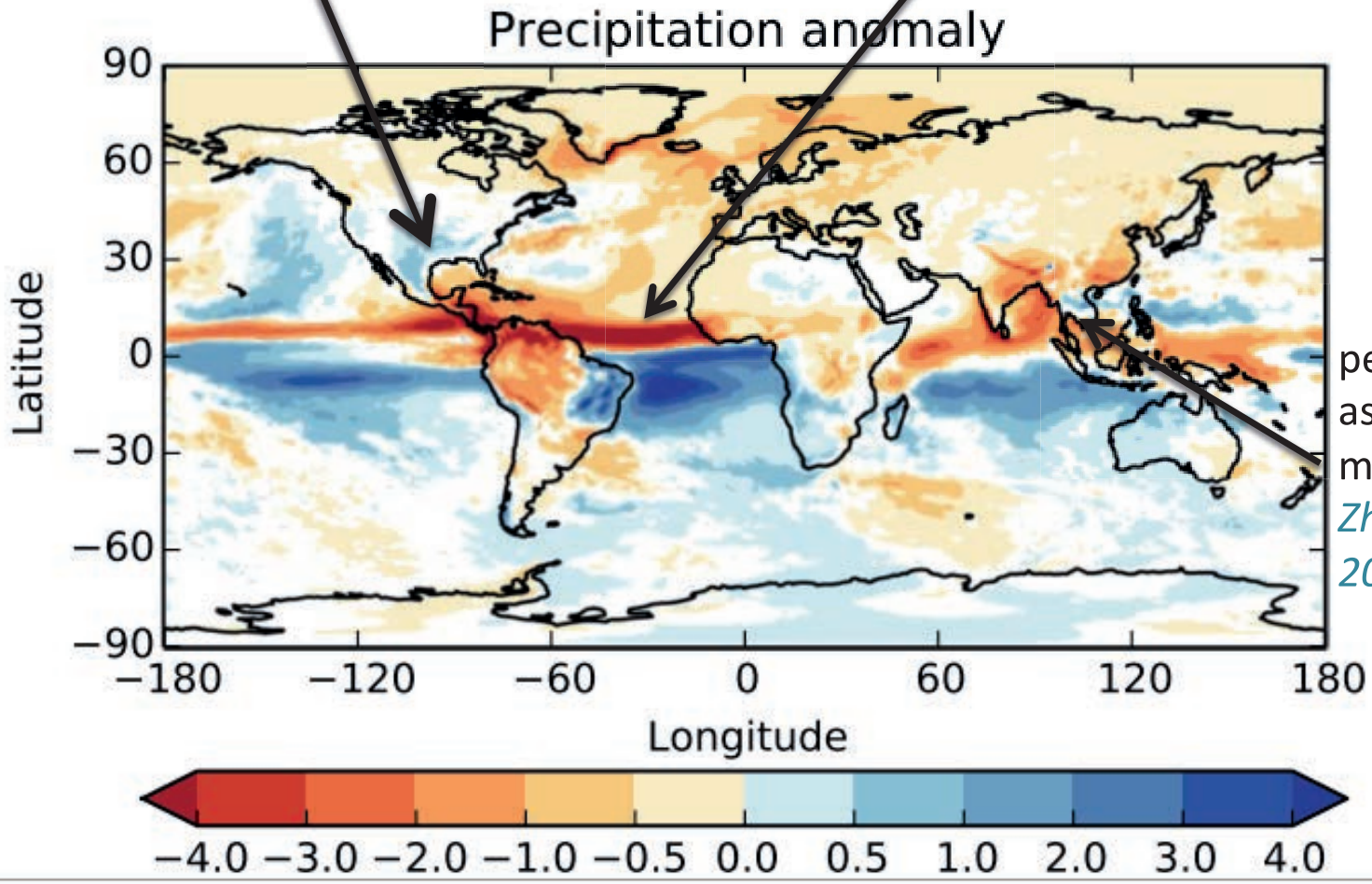
HadCM3

Vellinga and Wu 2008

1. Impacts of the AMOC Variability on precipitations

drought at midlatitudes in the US
McCabe et al. 2014

shift of the ITCZ
e.g. *Vellinga and Wood 2002, Zhang and Delworth 2005, Menary et al. 2012…*



perturbation of the asian and indian monsoon
Zhang and Delworth 2006

HadGEM3

Jackson et al. 2015

AMOC variability and predictability

- Why do we care about the AMOC variability?

  ⇨ climate impacts of AMOC variations

- **How does the AMOC vary?**

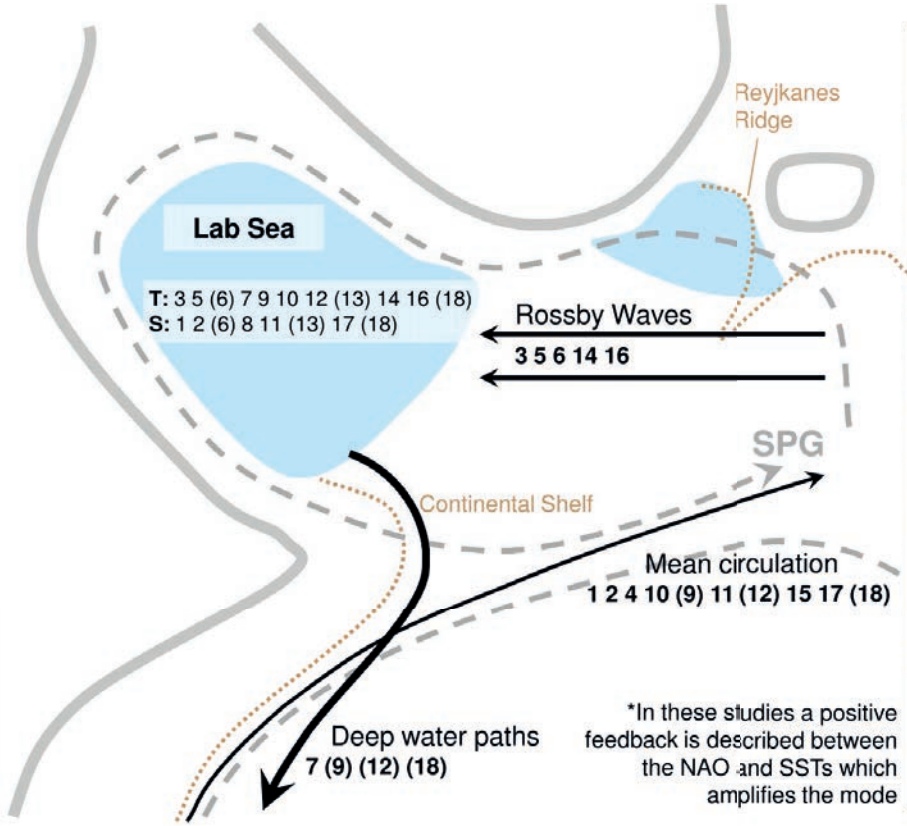
  ⇨ **a few ideas on AMOC variability in climate models**

- Is there anything we can do about it?

  ⇨ predictability and predictions of the AMOC

2. AMOC variability at decadal timescales

- A wide variety of mechanisms, different timescales, different models, different methods



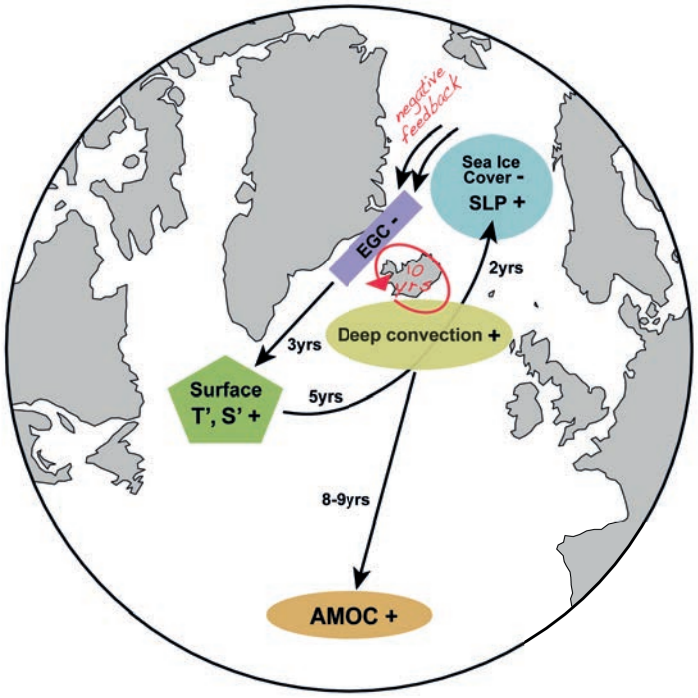
	Study	Period (years)	Mech-anism
1	Delworth '93	50	Ocean
2	Timmermann '98	35	Coupled
3	Grotzner '98	17	Coupled
4	Visbeck '98	12-16	Ocean*
5	Watanabe '99	~10	Ocean*
6	Dong '01	-	-
7	Eden '01	12-18	Coupled
8	Holland '01	20	Ocean
9	Eden '03	16	Ocean*
10	Dai '05	24	Ocean
11	Dong '05	25	Ocean
12	Àlvarez-Garcia '08	24	Ocean*
13	Danabasoglu '08	21	-
14	Frankcombe '10	20-30	Ocean
15	Born '12	15-20	Ocean
16	Sevellec '13	24	Ocean
17	Escudier '13	20	Ocean
18	Kwon '14	20 "regime 1"	Ocean*

Menary et al. 2015

2. AMOC variability at decadal timescales

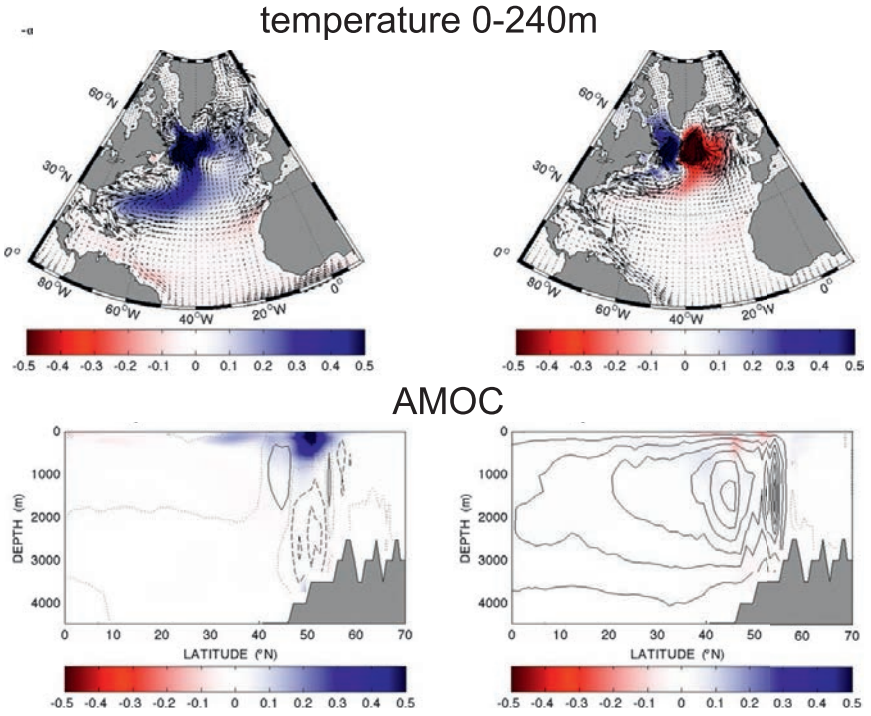
- A wide variety of mechanisms, different timescales, different models, different methods
- Recent reviews (*Buckley and Marshall 2016, Yeager and Robson 2017*) distinguish 2 broad mechanisms for decadal variability:

changes in deep convection



Escudier et al. 2013

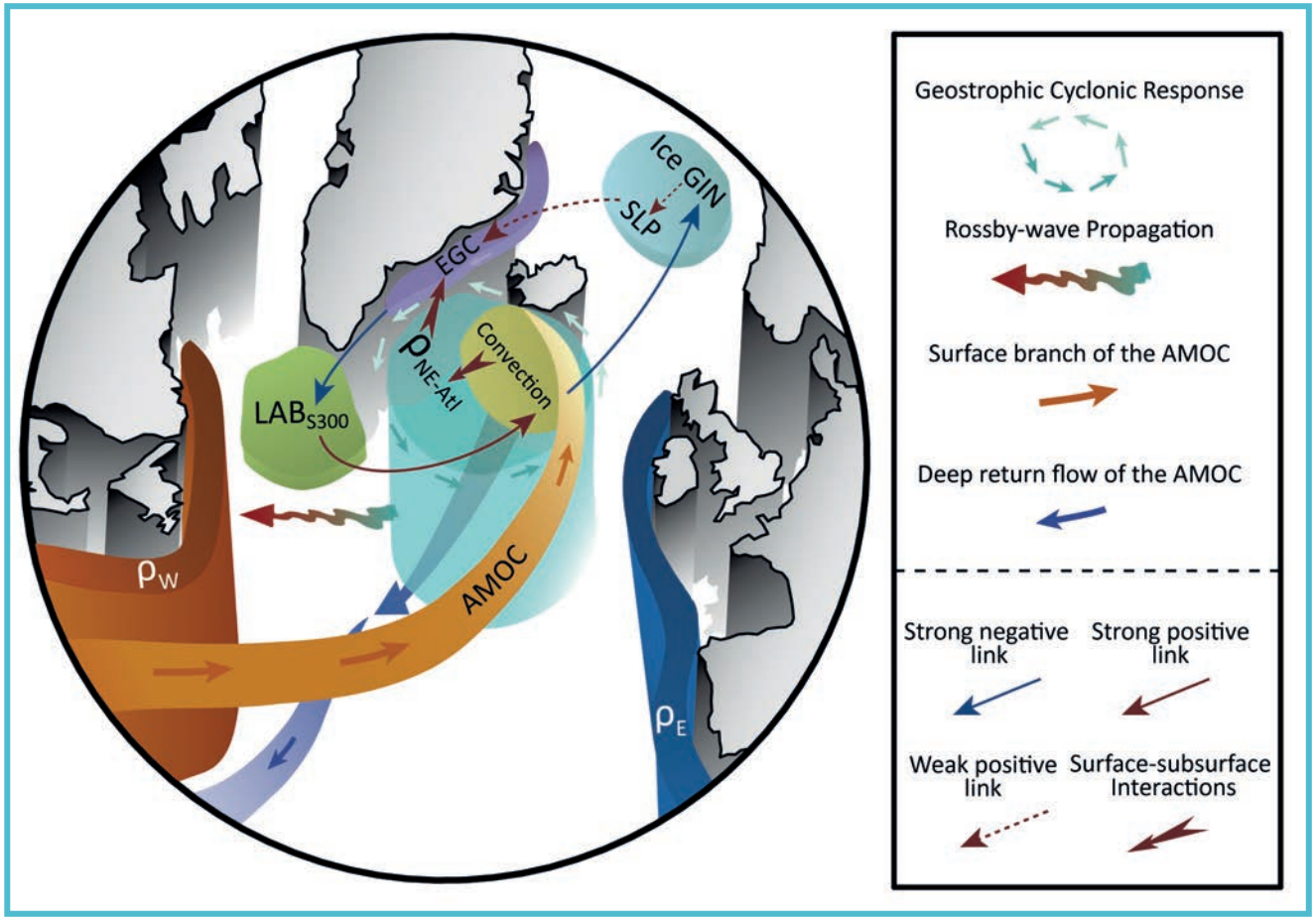
baroclinic Rossby waves



Sévellec and Fedorov 2013

2. AMOC variability at decadal timescales

- A wide variety of mechanisms, different timescales, different models, different methods
- Recent reviews (*Buckley and Marshall 2016, Yeager and Robson 2017*) distinguish 2 broad mechanisms for low frequency mechanisms
- Reconciling these two mechanisms in a climate model: *Ortega et al. 2016*

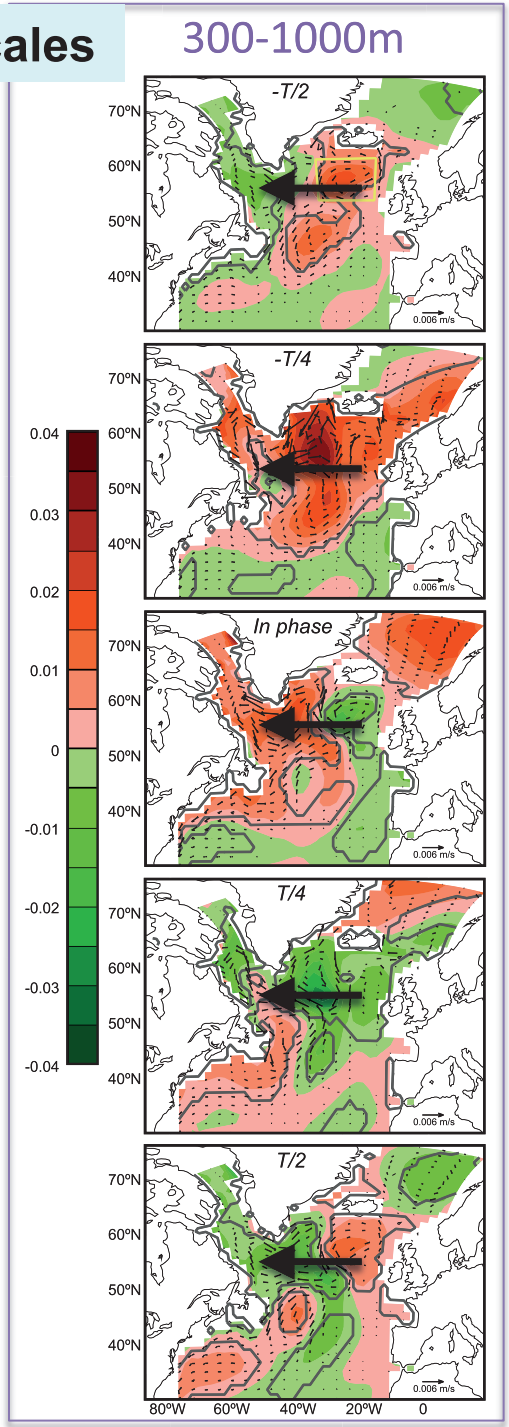


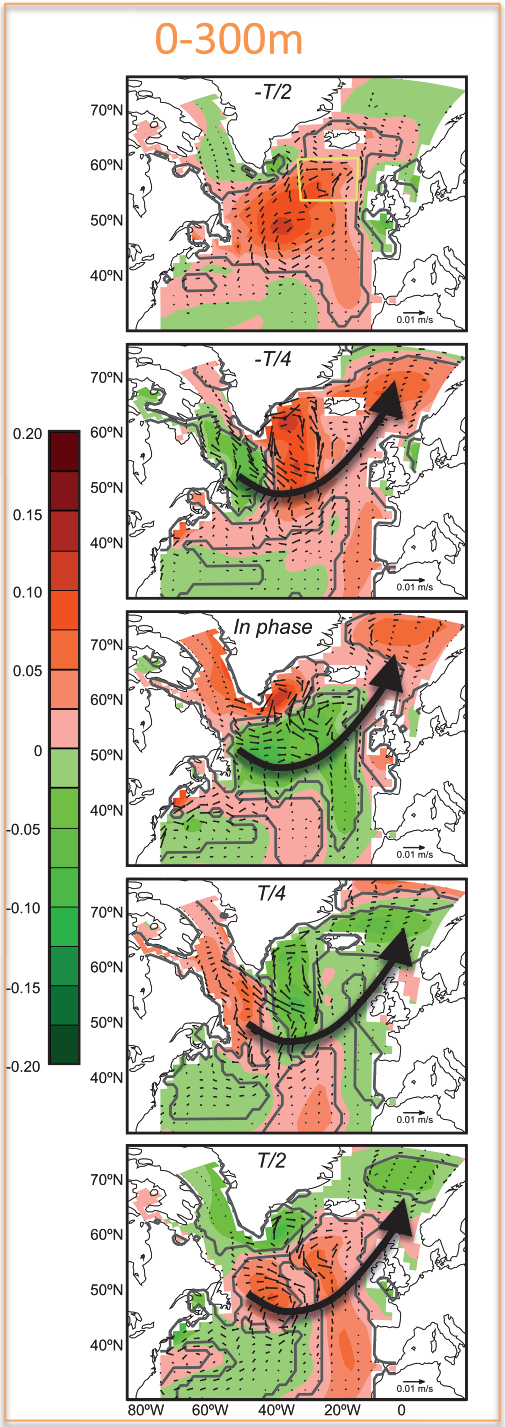
2. AMOC variability at decadal timescales

- Reconciling these two mechanisms in a climate model

- Temperature anomalies in the ocean interior propagating westward through Rossby thermal waves and inducing perpendicular geostrophic flow

- Temperature anomalies in the upper layer propagating along the subpolar gyre, triggering deep convection and anomalous AMOC flow



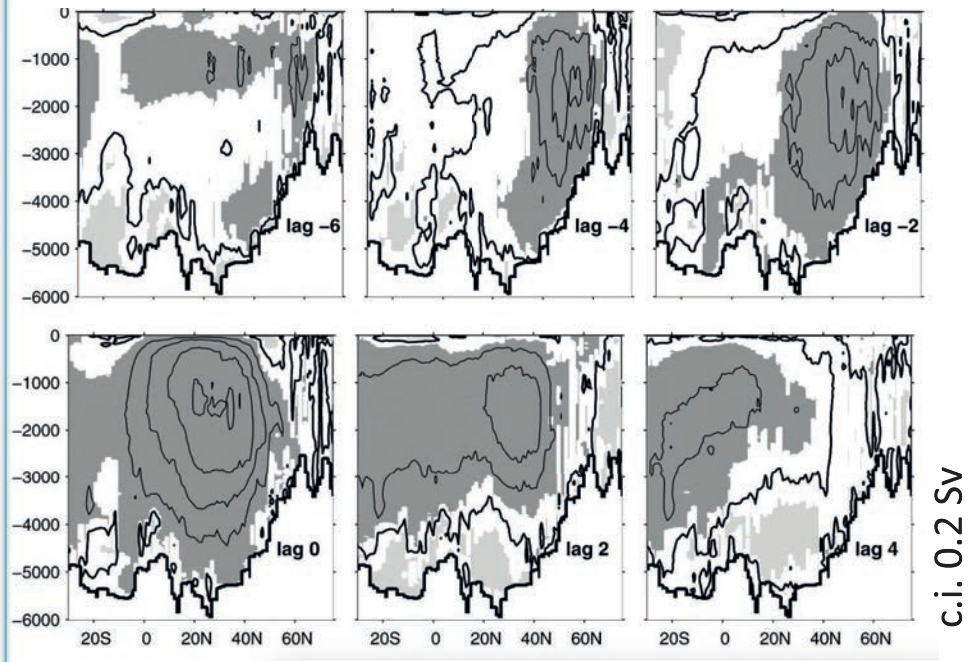


IPSL-CM5A-LR

Ortega et al. 2016

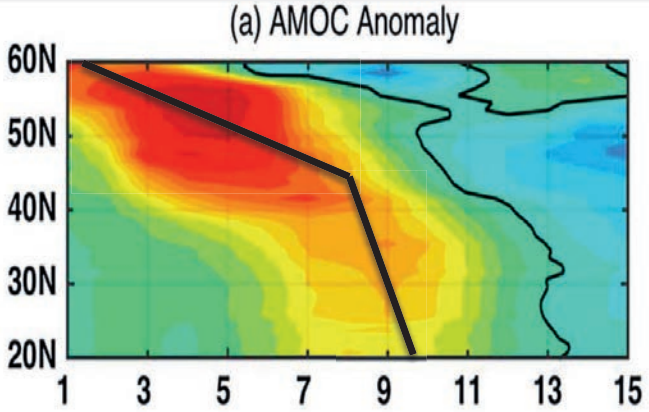
2. AMOC variability at decadal timescales

- Subsequent basin-scale propagation of the AMOC anomalies: meridional propagation at slow advection speed in the subpolar gyre and fast coastal Kelvin waves in the subtropical gyre



lead-lag regression of the AMOC on the index of AMOC maximum

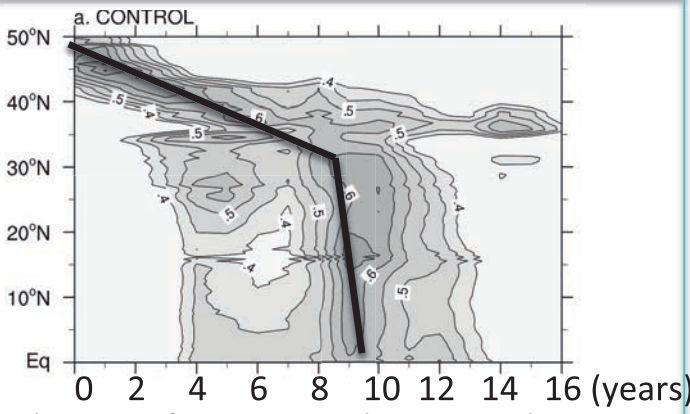
IPSL-CM4-v2 ***Mignot and Frankignoul 2005***



time evolution of an AMOC anomaly as a function of latitude

GFDL CM2.1 ***Zhang and Zhang 2015***

CESM1



correlation of AMOC with SSH in the Labrador Sea

Yeager and Danabasoglu 2014

AMOC variability and predictability

- Why do we care about the AMOC variability?

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- How does the AMOC vary?

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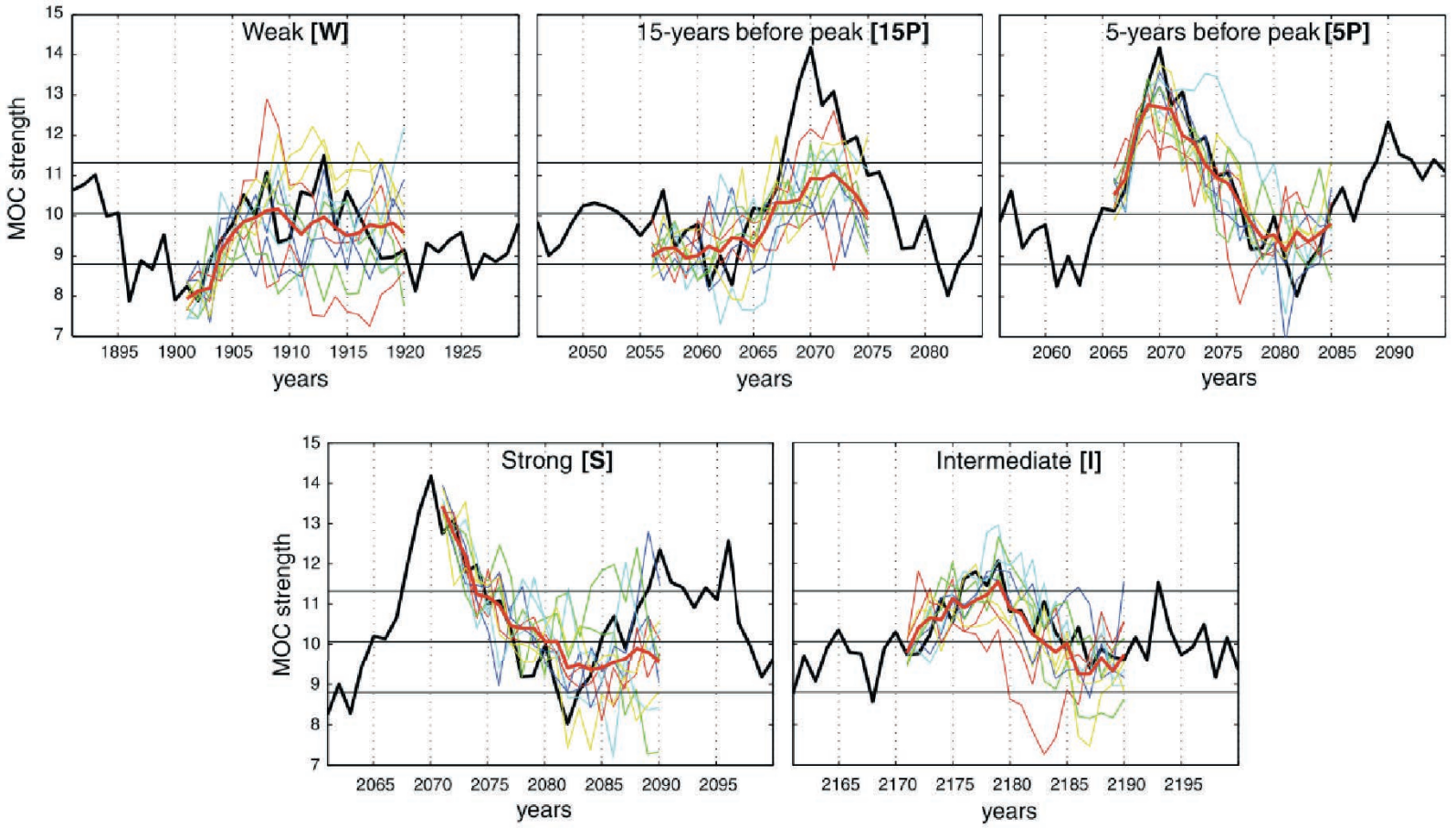
- **Is there anything we can do about it?**

  ⇨ **predictability and predictions of the AMOC**

- The AMOC is potentially predictable a decade ahead



Persechino et al 2013

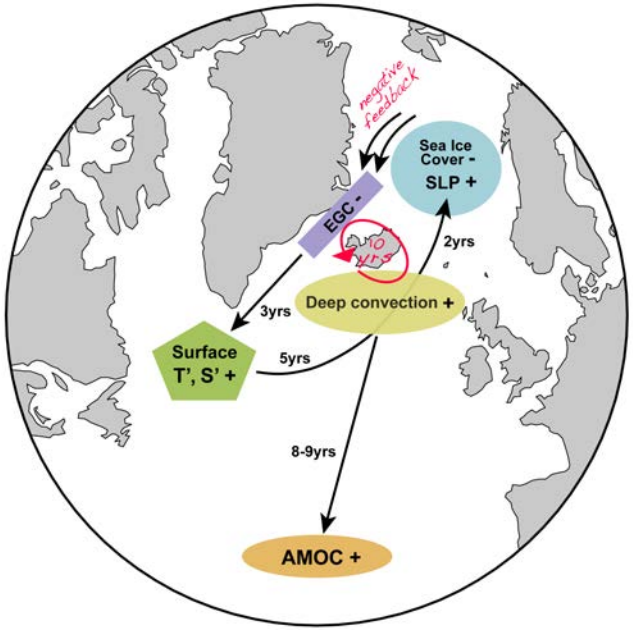
IPSL-CM5A-LR

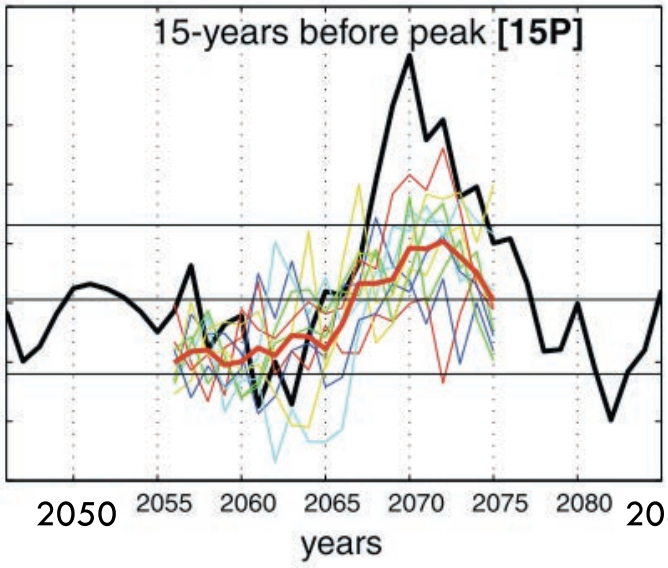
see also Collins 2002, Pohlmann et al. 2004, *Msadek et al 2010*

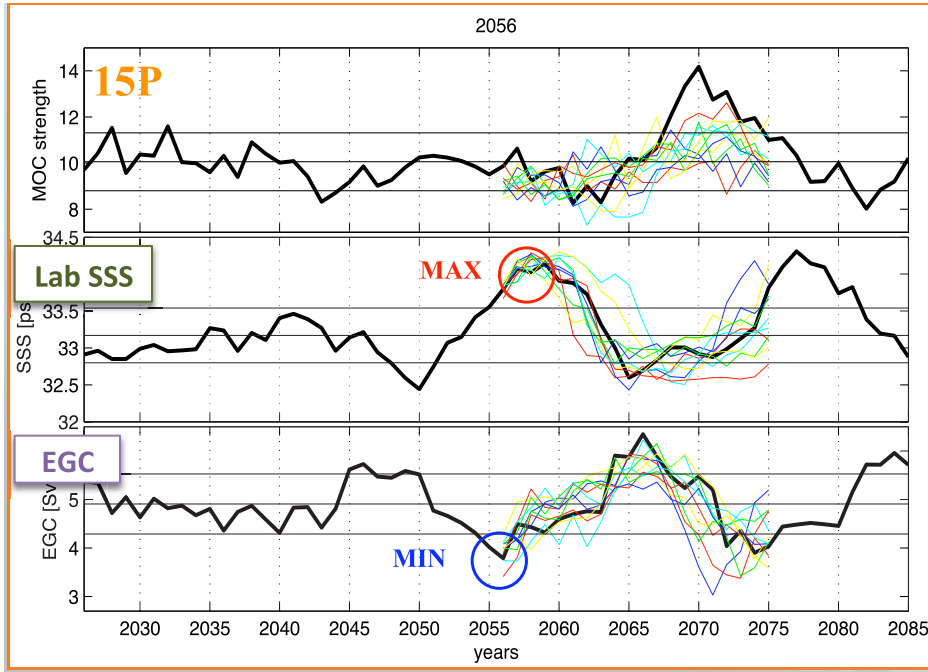
3. Predictability and predictions of the AMOC variability

Potential predictability

- The AMOC is potentially predictable a decade ahead
- Predictors can be identified, consistently with variability mechanisms







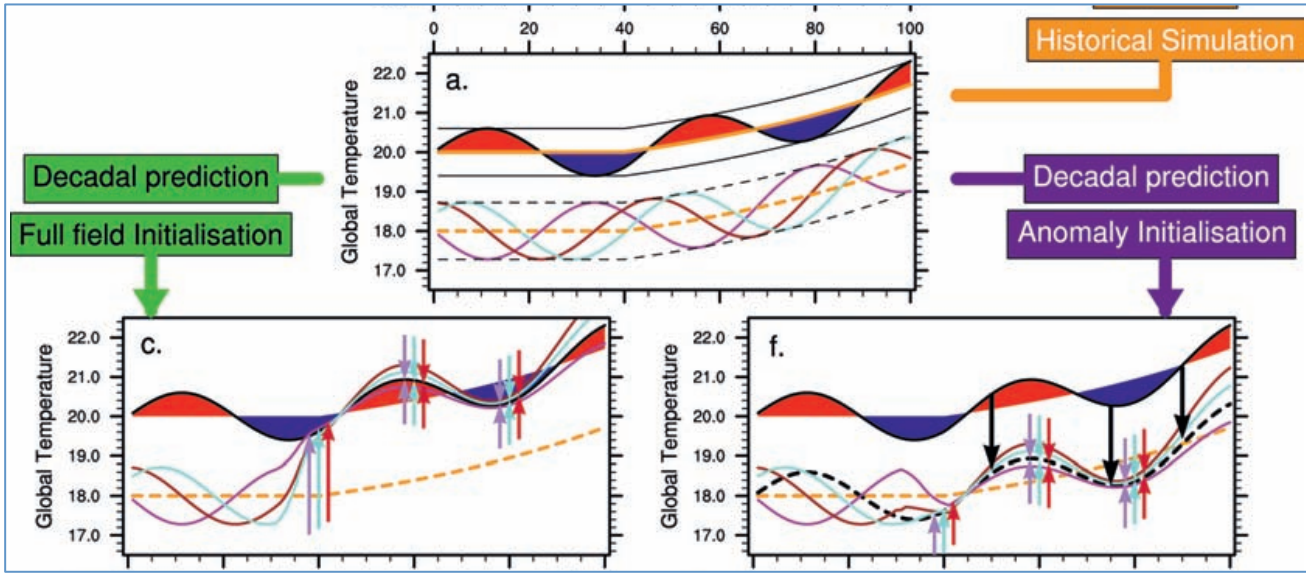
- **Labrador Sea SSS** = AMOC predictor for AMOC 7-10 yrs in advance
- **EGC** = predictor for >10yrs

IPSL-CM5A-LR

Persechino et al 2013

3. Predictability and predictions of the AMOC variability

- Encouraged by these results, the models were initialized to observations…



Cassou and Mignot 2013

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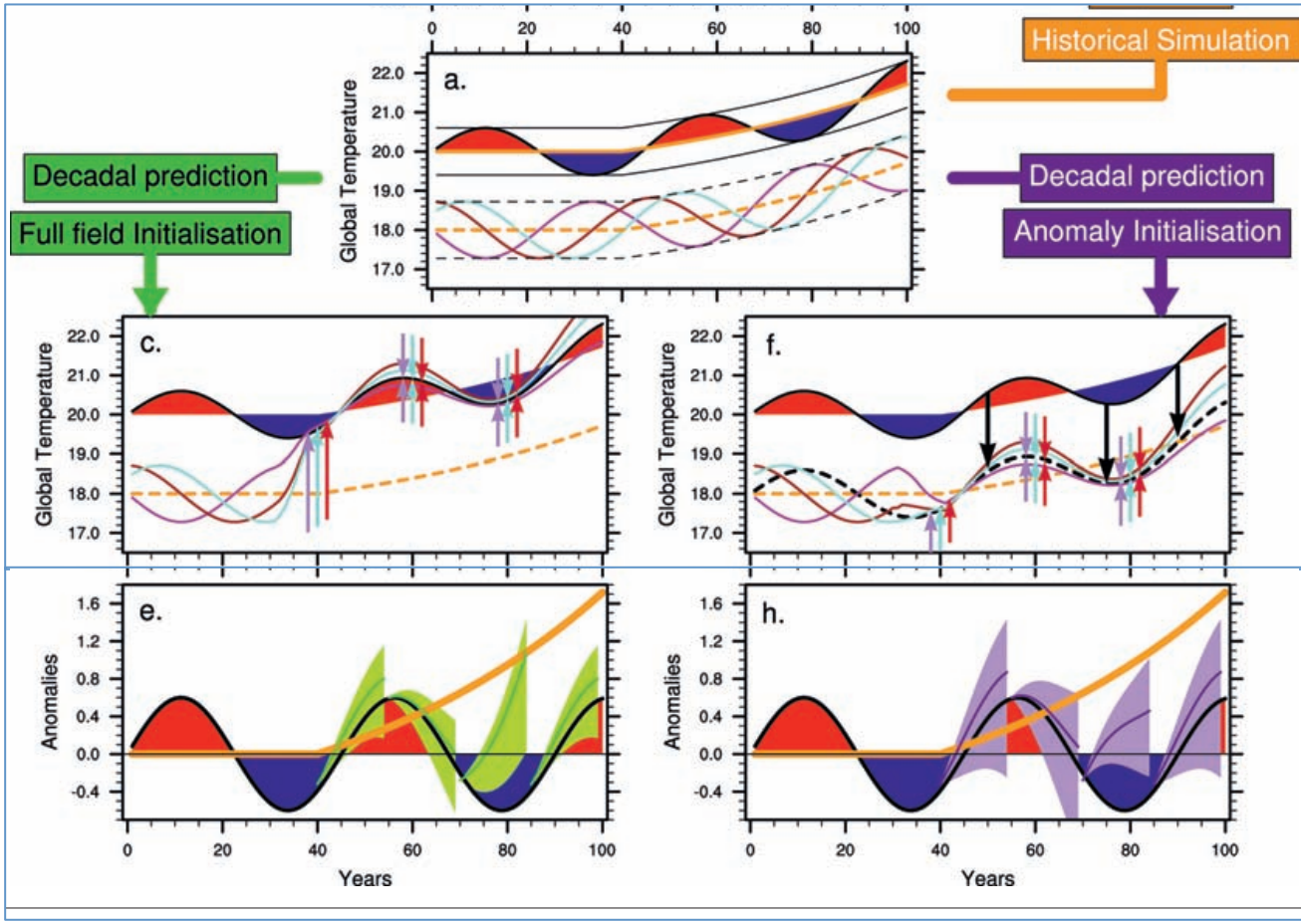
- … and ensemble predictions have been run for selected dates in the past



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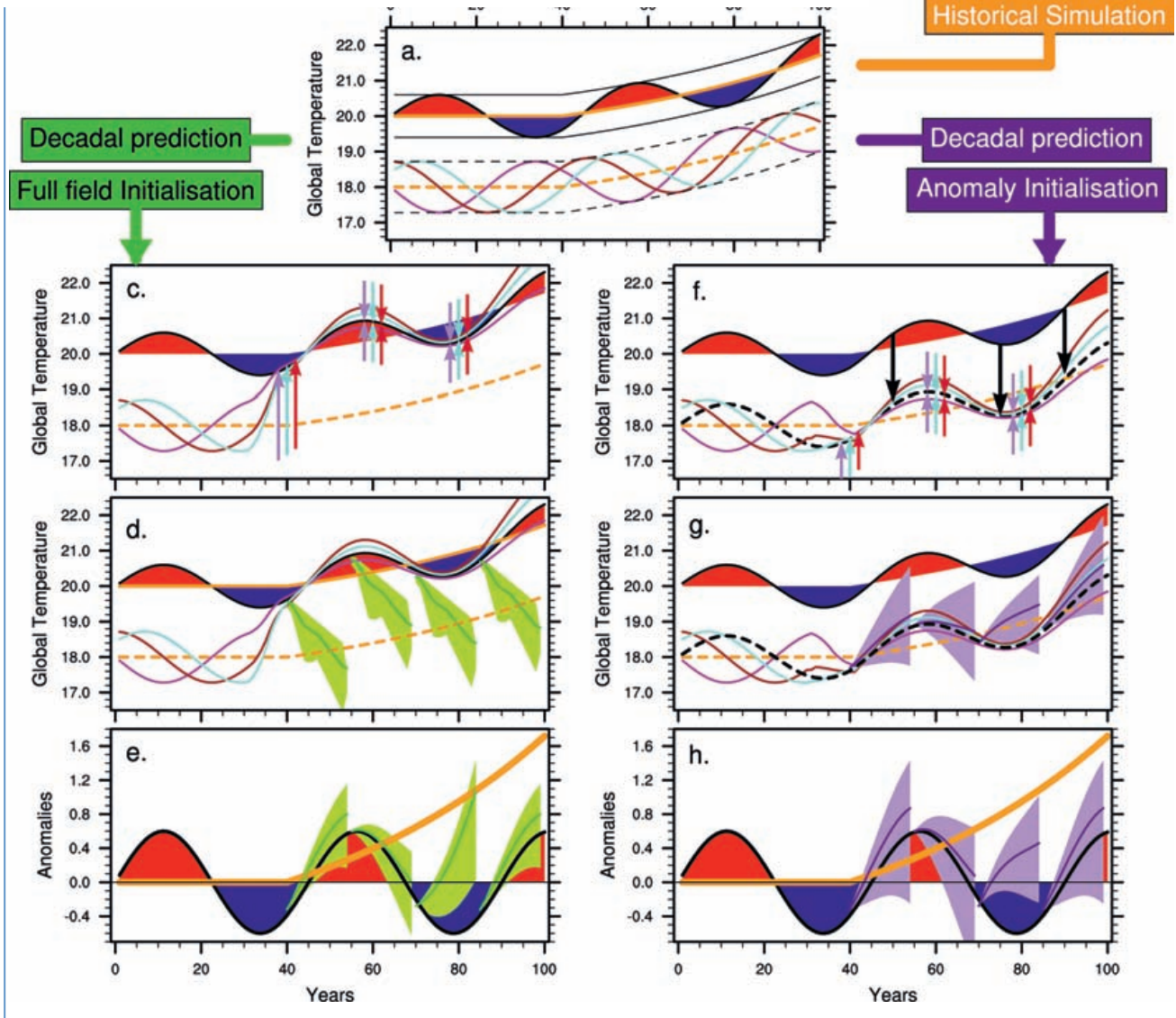
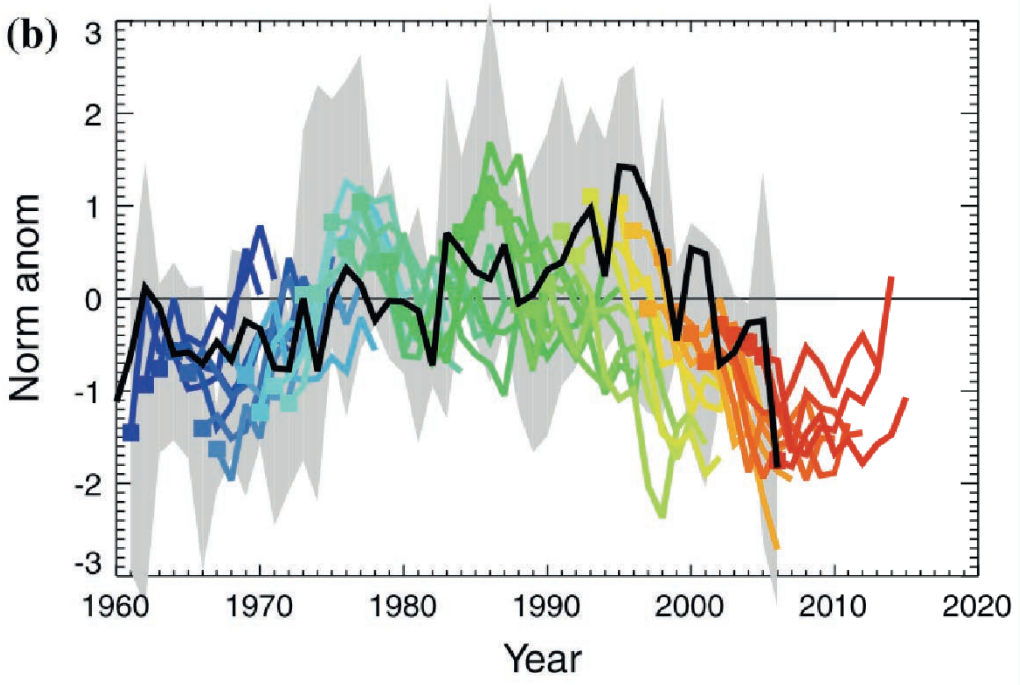


3. Predictability and predictions of the AMOC variability

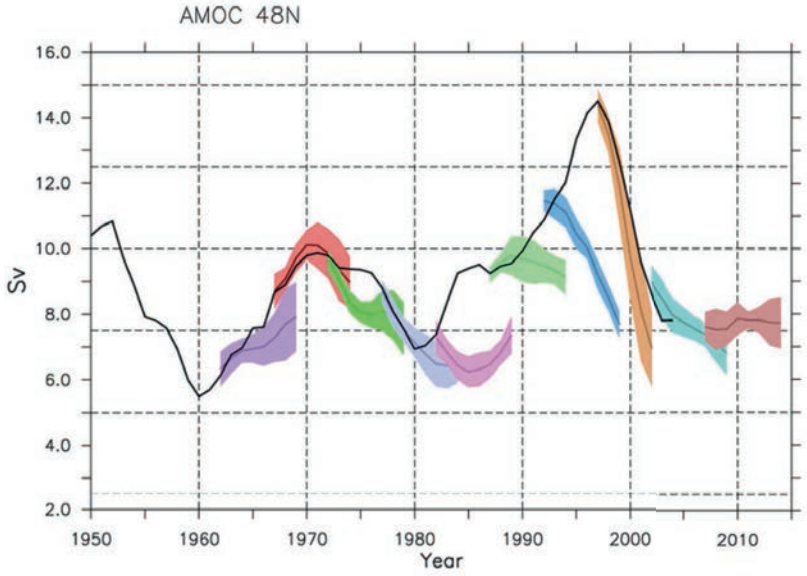
multi-model predictions



Pohlmann et al. 2013

IPSL decadal prediction system

IPSL-CM5A-LR



Swingedouw et al 2013

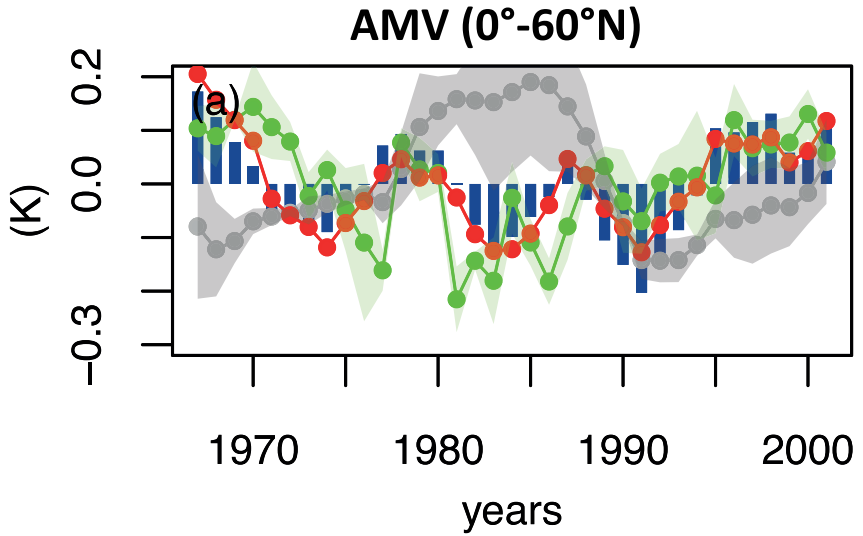
➢ Much less encouraging results

3. Predictability and predictions of the AMOC variability

- Limited data to verify AMOC predictions
  -> Use its fingerprint: large scale SST variations (AMV)

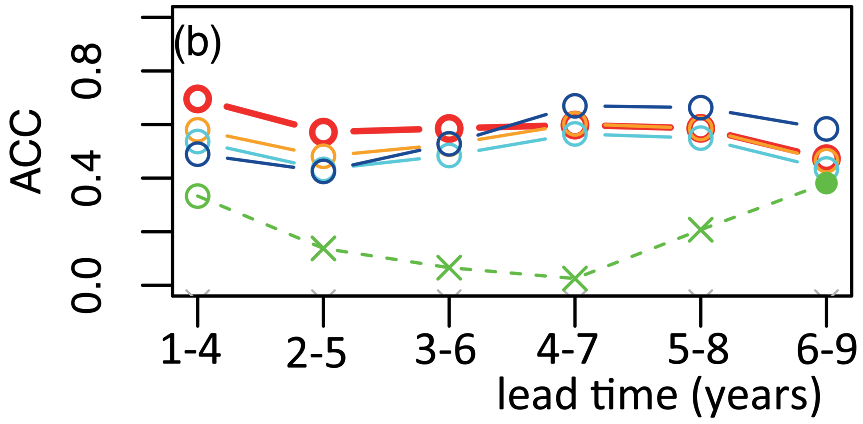
IPSL-CM5A-LR

ERSST observations
Unitialized simulation
Nudged (constrained) simulation
initialized hindcast (lead time 2-5 years)



Mignot et al. 2016

Correlation to the nudged (constrained) time series
Correlation to observations

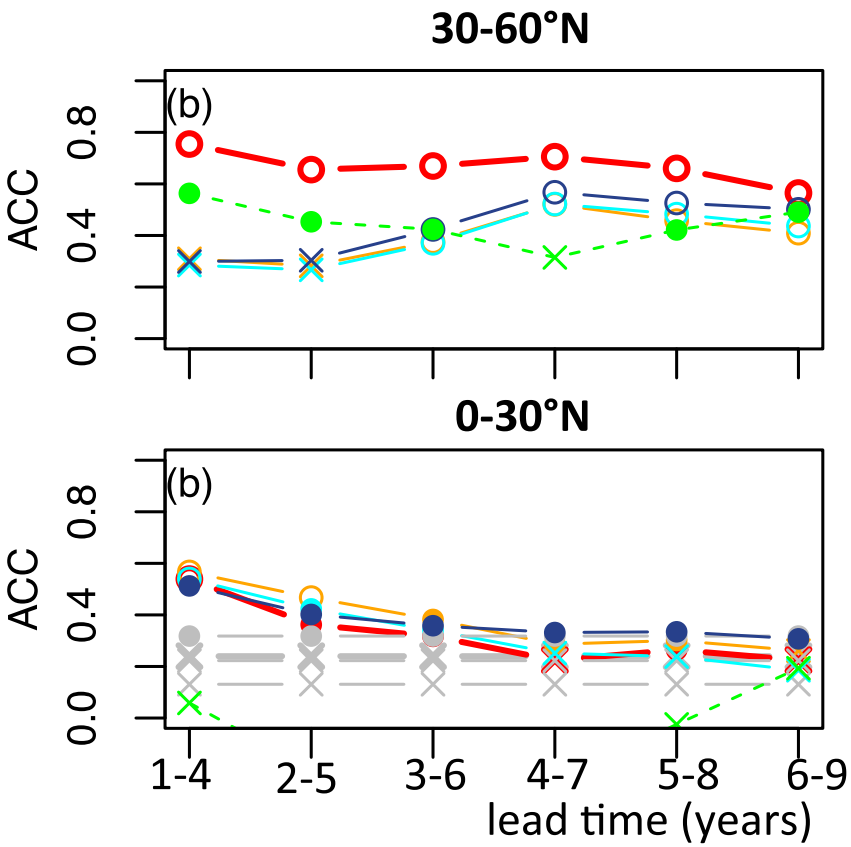


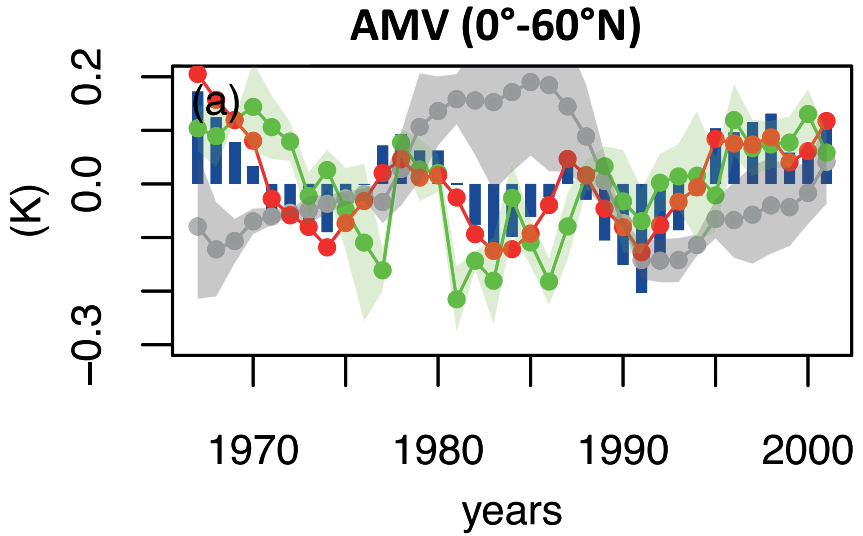
3. Predictability and predictions of the AMOC variability

- Decomposing the AMV predictability

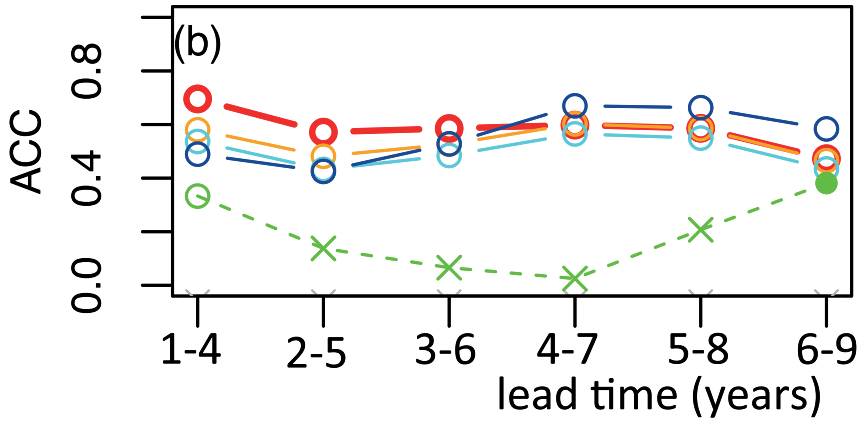
IPSL-CM5A-LR

- Enhanced predictability in the subpolar gyre



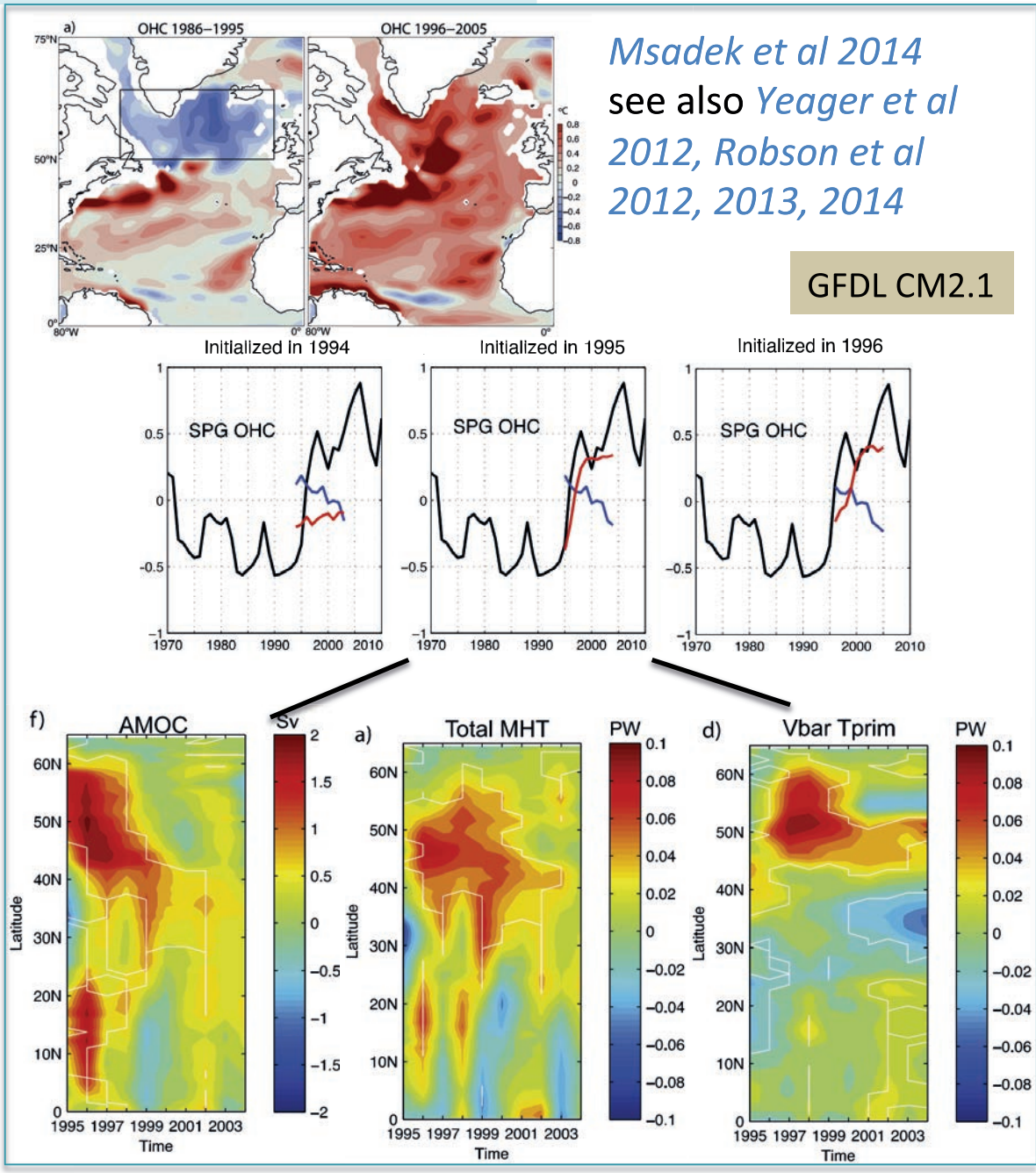


Mignot et al. 2016



3. Predictability and predictions of the AMOC variability

- implications for case studies: example of the 1990s warming in the subpolar gyre
- Some skill in predicting the anomalous ocean heat content rise in the mid-1990s
- Skill associated to the AMOC initialization

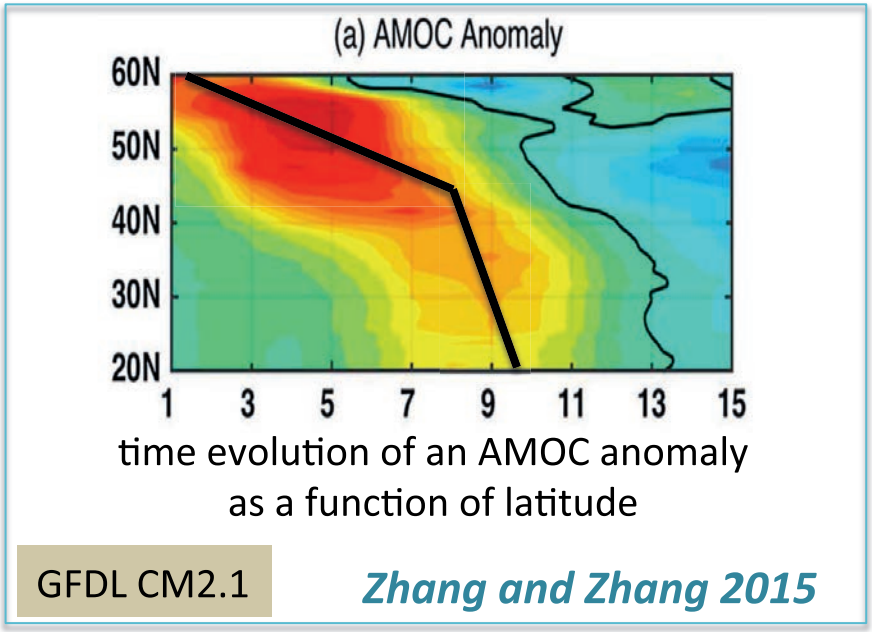


Msadek et al 2014
see also *Yeager et al 2012, Robson et al 2012, 2013, 2014*

GFDL CM2.1

3. Predictability and predictions of the AMOC variability

- Link to the slow propagation of AMOC anomalies in the SPG, giving rise to anomalous heat convergence



time evolution of an AMOC anomaly as a function of latitude

GFDL CM2.1

Zhang and Zhang 2015

- Some skill in predicting the anomalous ocean heat content rise in the mid-1990s

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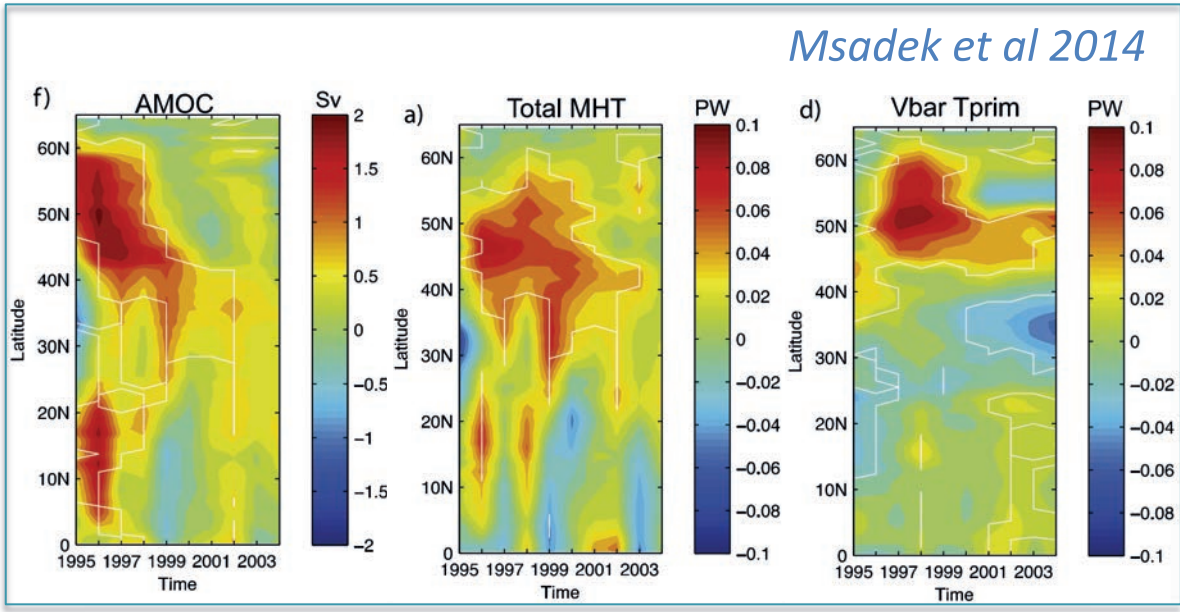
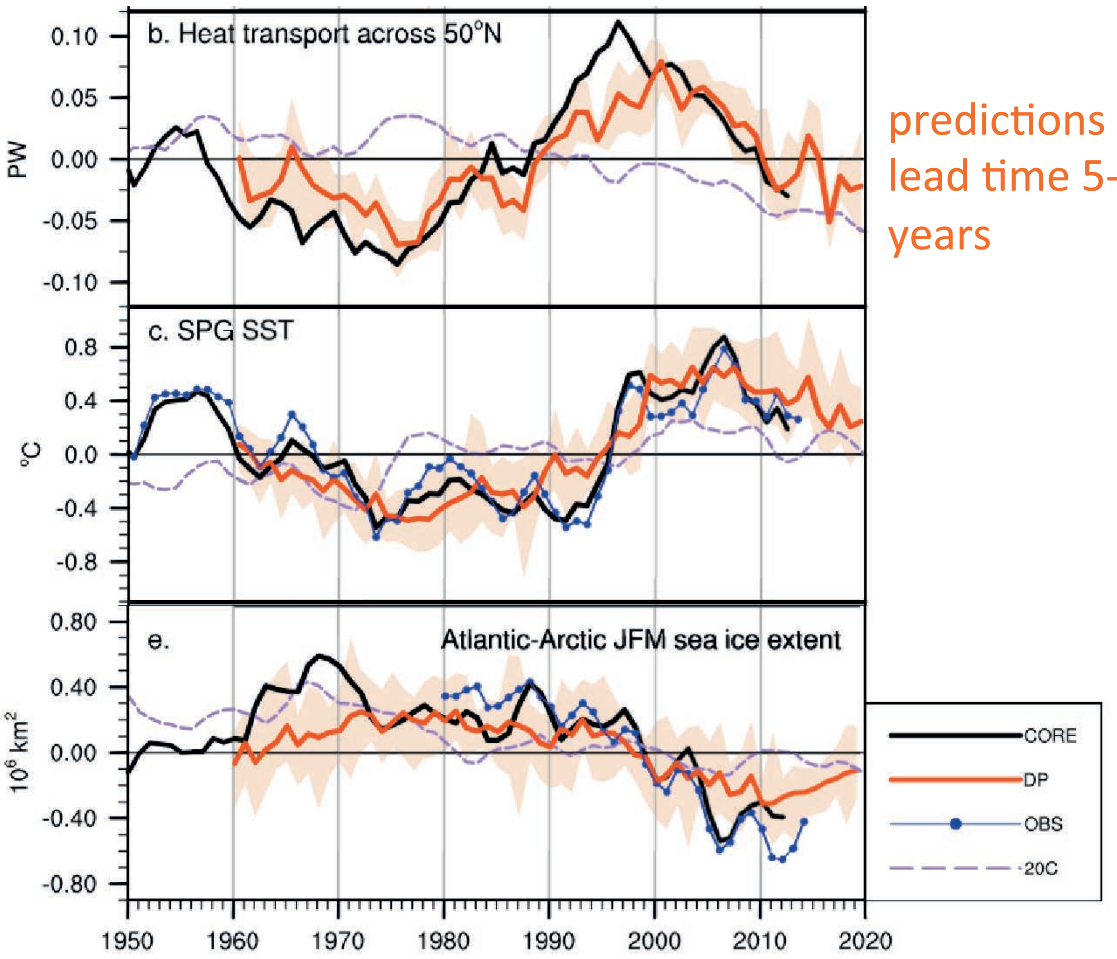
Msadek et al 2014



3. Predictability and predictions of the AMOC variability

- Prediction of climate impacts to the AMOC: ex of the sea ice.

- see also
  Sahel Rainfall (*Mohino et al. 2015*),
  CO2flux (*Li et al. 2016*)
  L. Hermanson's talk tomorrow



predictions at lead time 5-7 years

CCSM4

Yeager et al. 2015

AMOC variability and predictability

Conclusions

- Why do we care about the AMOC variability?

  ⇨Impacts on the N. Atlantic ocean heat transport and heat content, atmopshere dynamics and thermodynamics,

  ⇨ implications for extreme atmospheric events, precipitations, land and ocean biogeochemistry

- How does the AMOC vary?

  ⇨Diversity of mechanisms from climate models. But steps forward toward a unification of mechanisms.

  ⇨Density anomalies along the western boundary of the subpolar north Atlantic

- Is there anything we can do about it?

  ⇨Remarkable potential predictability of the AMOC (~5-15 years).

  ⇨ Skillfull predictions of AMOC fingerprints, in particular in the subpolar gyre.