# North Atlantic internal, decadal variability in HadGEM3

*Joint U.S. AMOC / U.K. RAPID meeting, Baltimore, 17th July 2013*

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# Summary

HadGEM3 (¼° ocean resolution) is the basis for future Met Office Hadley Centre seasonal and decadal prediction

This PhD aims to understand the model's North Atlantic internal, decadal variability and ultimately how that interacts with externally forced variability

The model does a relatively good job of representing the AMOC mean and seasonal cycle, although the latter is slightly weak. The streamfunction level of no motion is too shallow compared to RAPID (though this may be a function of the different methodology used)

There are northward propagating anomalies visible in near surface T/S/ρ (particularly S) and large decadal variability at depth. ρ anomalies appear to be temperature controlled

Regression analysis of the heat budget suggests a 10-year time scale for a reversal in OHC, consistent with a 20-year periodicity. (Southern boundary) advective fluxes, surface heat fluxes, and OHC show significant lagged correlations

Comparison with other model work shows many similarities – in particular southward return flow in the model follows the DWBC as well as interior pathways

# PhD scope

Goals

- Inform priorities for improving decadal predictions by
    1. understanding the internal, decadal variability within a state-of-the art climate model,
    2. and how this projects on to externally forced variability,
    3. all the while within the framework of the available observations.

The importance of the ocean for decadal prediction stems from its large thermal inertia (“memory”) and the existence of slow modes of propagating heat and freshwater signals. The purpose of this PhD is to examine the ocean’s role in climate variability, particularly on decadal timescales, considering both internal variability and the response to external forcings.

# Background and introduction

Delworth et al. (1993): A 50 year period in the preindustrial control AMOC in the GFDL model. An ocean-only mechanism forced by atmospheric white noise, after the work of Hasselmann (1976) and similar to the later work of Frankignoul et al. (1997).

Dong and Sutton (2005): Found the mechanism of Delworth et al. (1993) in the HadCM3 model. However, this time the period was reduced to 25 years. The mechanism was again ocean-only but heavily damped so would appear to require atmospheric noise to excite it

Dai et al. (2005): Further analysis of coupled models suggested a 24 year period in the modelled AMOC was related to SPG temperature effects.

Danabasoglu (2008): Analysis of the same ocean model coupled to an atmosphere model at two different resolutions suggested that the atmosphere didn't affect the 20 year period of the AMOC signal but did affect the amplitude, and hence detectability. This would suggest that the stochastic forcing hypothesis is perhaps a good one. Danabasoglu (2008) also found that the mechanism of Delworth et al. (1993) did not exist here and that changing the averaging region when attempting to determine the causes of density change severely affected the results as the phase relationships were different in different parts of the SPG.

Centennial timescale variability of the AMOC in HadCM3 (Vellinga and Wu, 2004) (see also Hawkins and Sutton (2007) for an Arctic modulation of this mechanism) and in other climate models (Park and Latif , 2008; Menary et al., 2012) also exists, with the longer timescale due to the long advective timescales. In all these studies salinity is the dominant component of the density-AMOC relationship.

Frankcombe et al. (2010): noted that modelled multidecadal variability generally falls into two regimes: 20/25 year variability possibly related to the NAO, and longer 70+ year variability related to the advective timescales from faraway sources (Arctic or tropics). Of the shorter timescale variability, the relative role of ocean-only and coupled processes (whether actively coupled or with the atmosphere playing a stochastic forcing role) is still unclear and will be addressed by this PhD.

# Background and introduction

**Interdecadal Variations of the Thermohaline Circulation in a Coupled Ocean–Atmosphere Model**

T. Delworth, S. Manabe, and R. J. Stouffer

50 year period, ocean-only, forced by atmospheric white noise

**Mechanism of Interdecadal Thermohaline Circulation Variability in a Coupled Ocean–Atmosphere GCM**

Buwen Dong

*Hadley Centre for Climate Prediction and Research, Met Office, Exeter, United Kingdom*

Rowan T. Sutton

As above, period reduced to 25 years, heavily damped ocean-only, forced by atmospheric white noise

**Atlantic Thermohaline Circulation in a Coupled General Circulation Model: Unforced Variations versus Forced Changes**

Aiguo Dai, A. Hu, G. A. Meehl, W. M. Washington, and W. G. Strand

24 year period in simulated AMOC related to SPG temperature effects

**On Multidecadal Variability of the Atlantic Meridional Overturning Circulation in the Community Climate System Model Version 3**

Gokhan Danabasoglu

Atmosphere sets magnitude but not periodicity of 20 year mechanism. Did not find the mechanism of Delworth ’93

**North Atlantic Multidecadal Climate Variability: An Investigation of Dominant Time Scales and Processes**

Leela M. Frankcombe, Anna von der Heydt, and Henk A. Dijkstra

Simulated multidecadal variability falls into 2 regimes: 20/25 year possibly related to NAO, and 70+ years related to advective timescales from faraway sources

# HadGEM3 (development version)

Hadley Centre Global Environment Model 3 (development version)

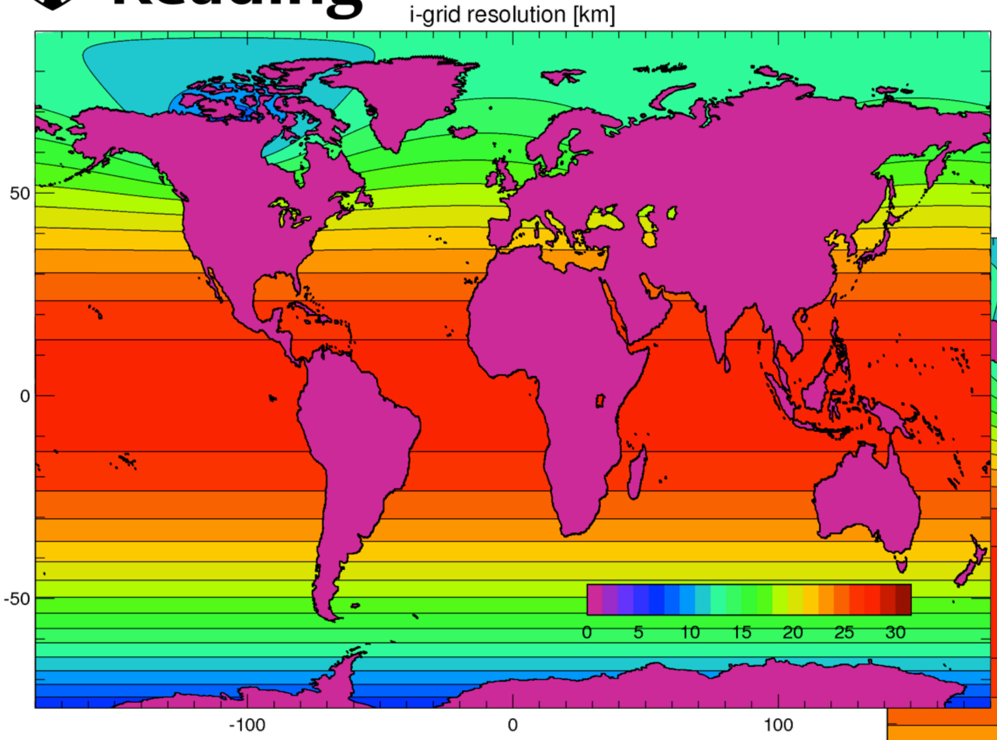
- Atmosphere: Global Atmosphere 3.0, N216 resolution
- Ocean: NEMO vn3.2, ORCA025 (¼°) resolution
- Provides the foundation for the GloSEA5 *seasonal* prediction model, which is closely related to the new *decadal* prediction model

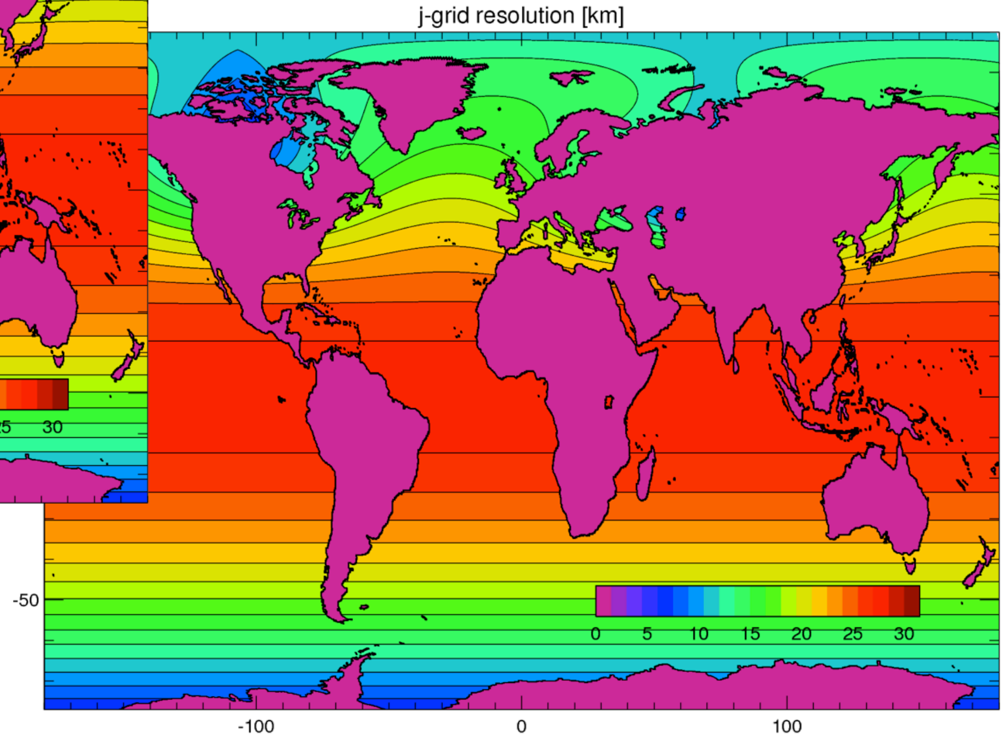
**The Met Office Unified Model Global Atmosphere 3.0/3.1 and JULES Global Land 3.0/3.1 configurations**

**D. N. Walters, M. J. Best, A. C. Bushell, D. Copsey, J. M. Edwards, P. D. Falloon, C. M. Harris, A. P. Lock, J. C. Manners, C. J. Morcrette, M. J. Roberts, R. A. Stratton, S. Webster, J. M. Wilkinson, M. R. Willett, I. A. Boutle, P. D. Earnshaw, P. G. Hill, C. MacLachlan, G. M. Martin, W. Moufouma-Okia, M. D. Palmer, J. C. Petch, G. G. Rooney, A. A. Scaife, and K. D. Williams**

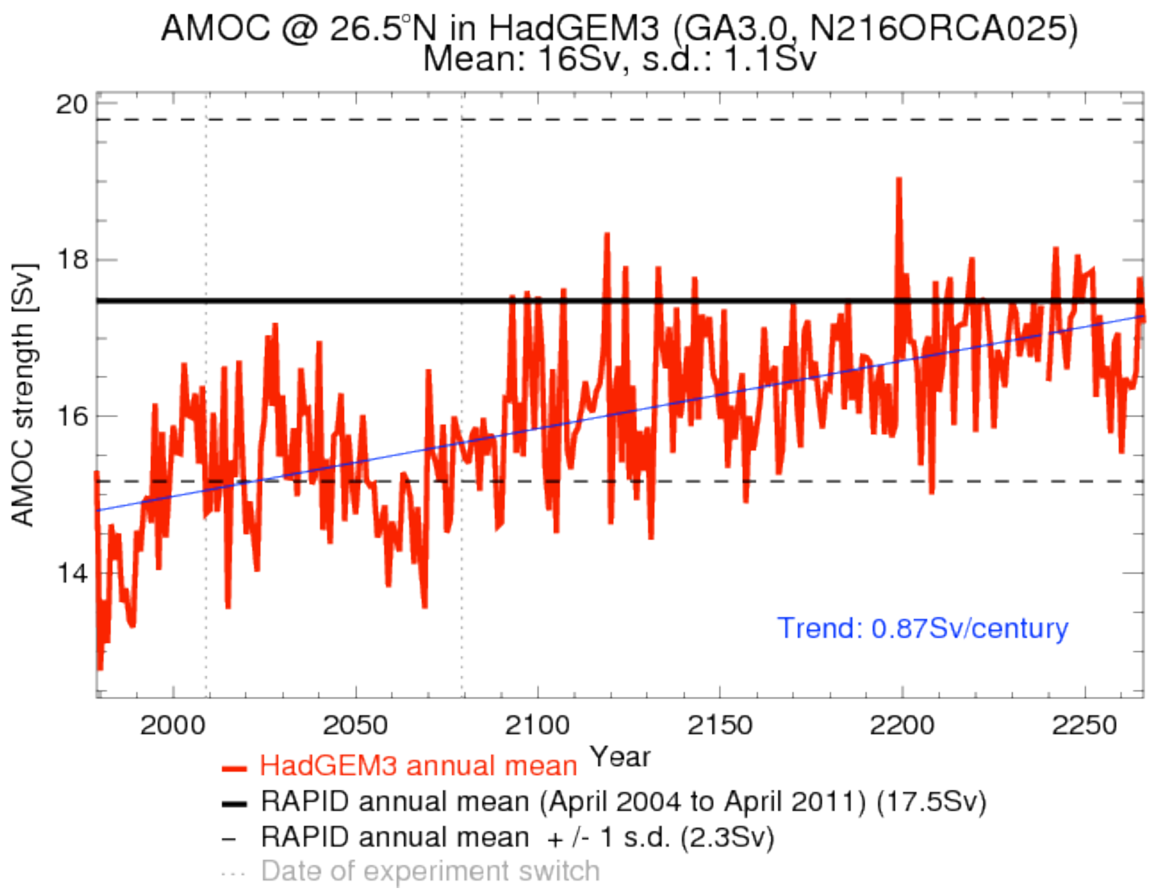
Met Office, FitzRoy Road, Exeter, EX1 3PB, UK

# HadGEM3 (development version)



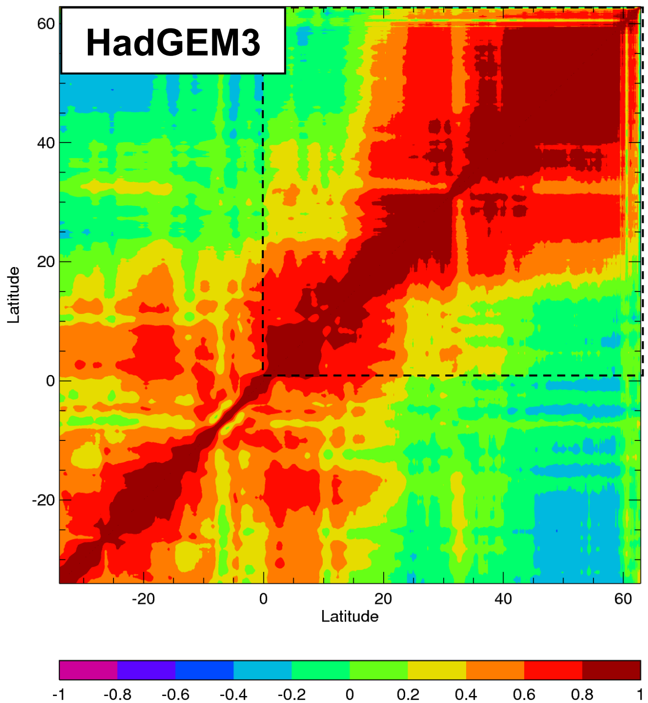
# AMOC time series

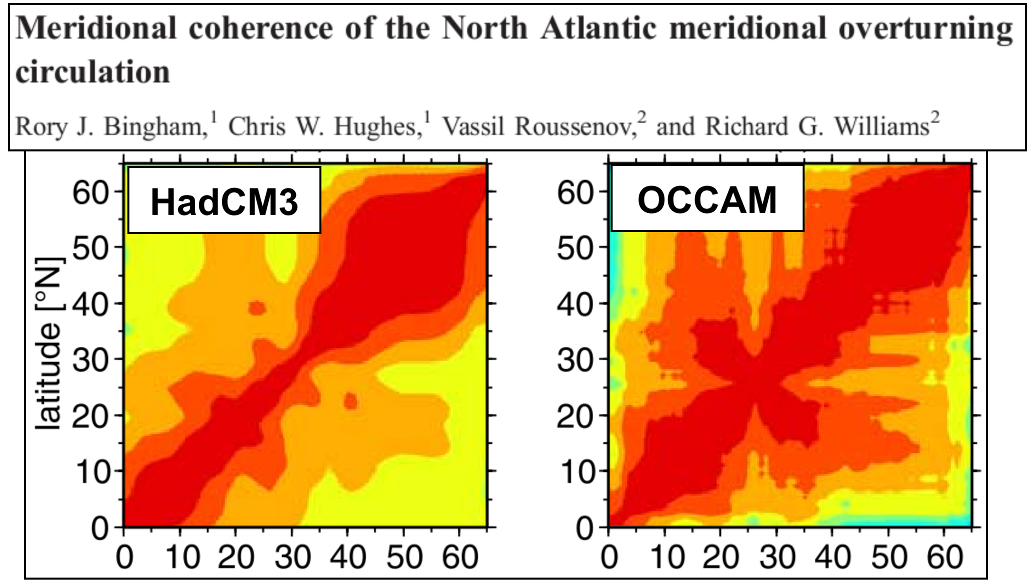


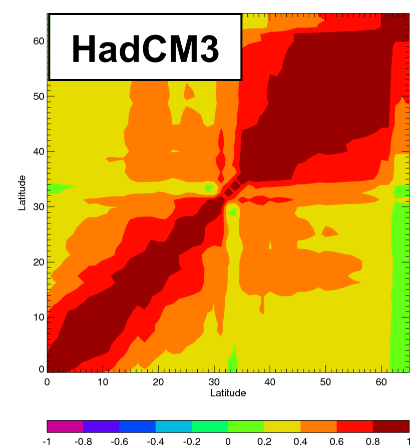
# AMOC meridional coherence

University of

Correlation across latitudes of AMOC transport
(92-996.7m)
(183 years)
(Bandpass filtered: [05-100 years])




◄ Full 5000 years

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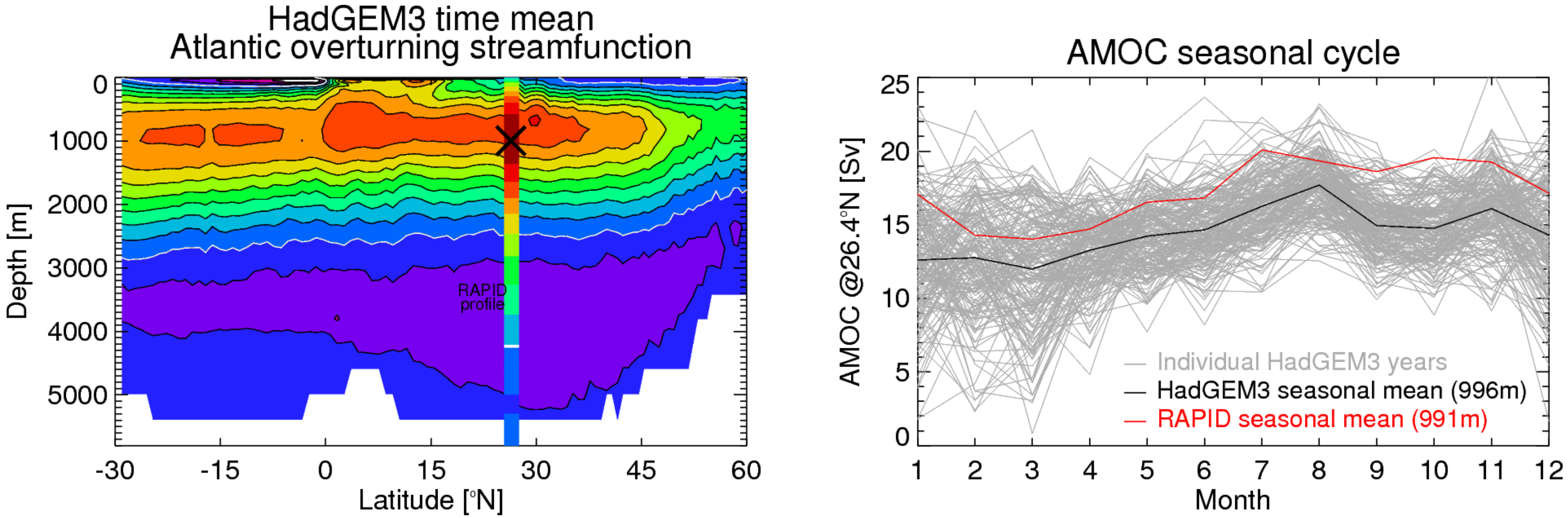
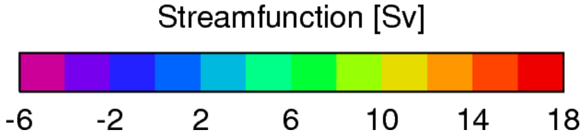
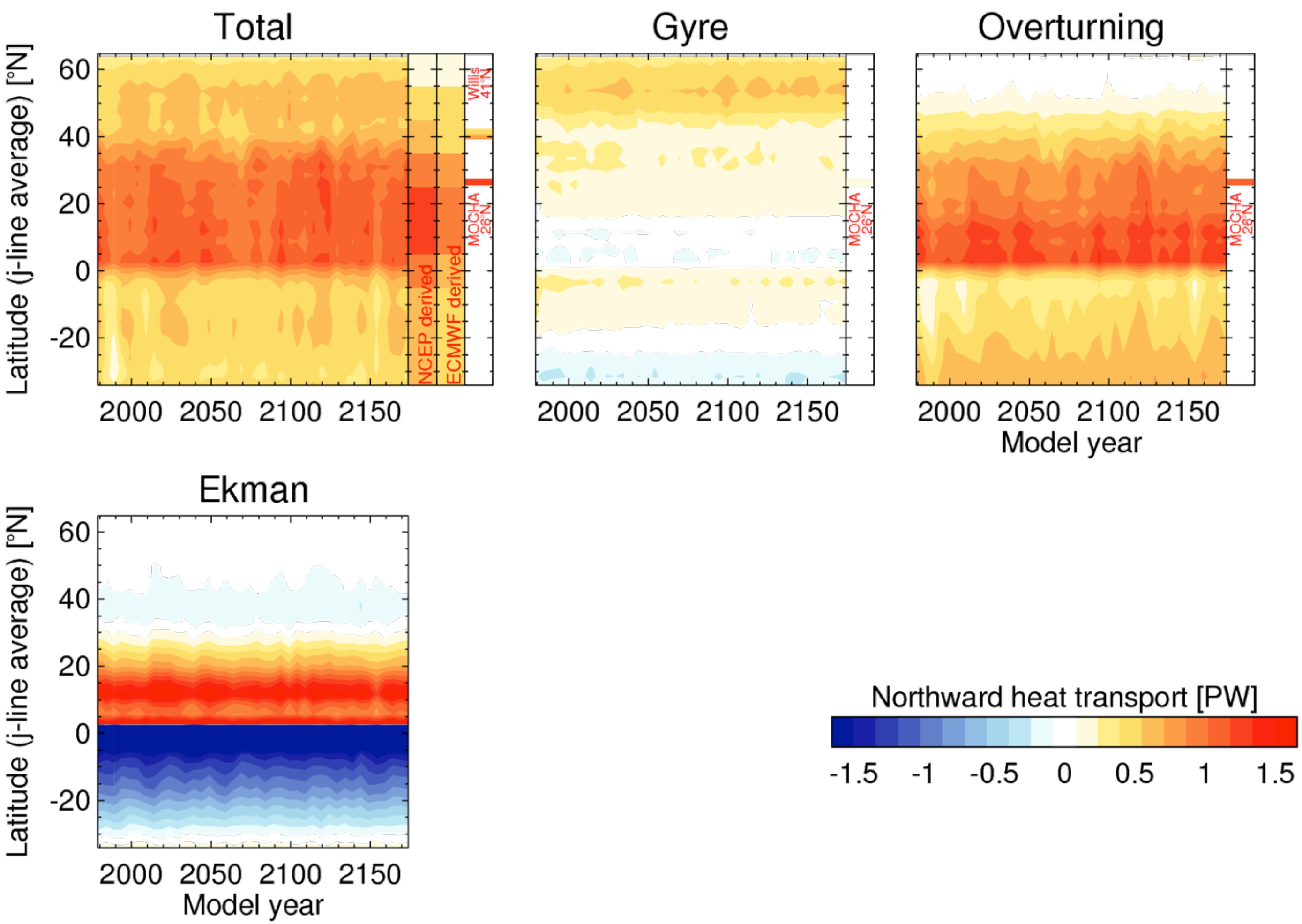
# AMOC (HadGEM3) v RAPID



# AMOC heat transport

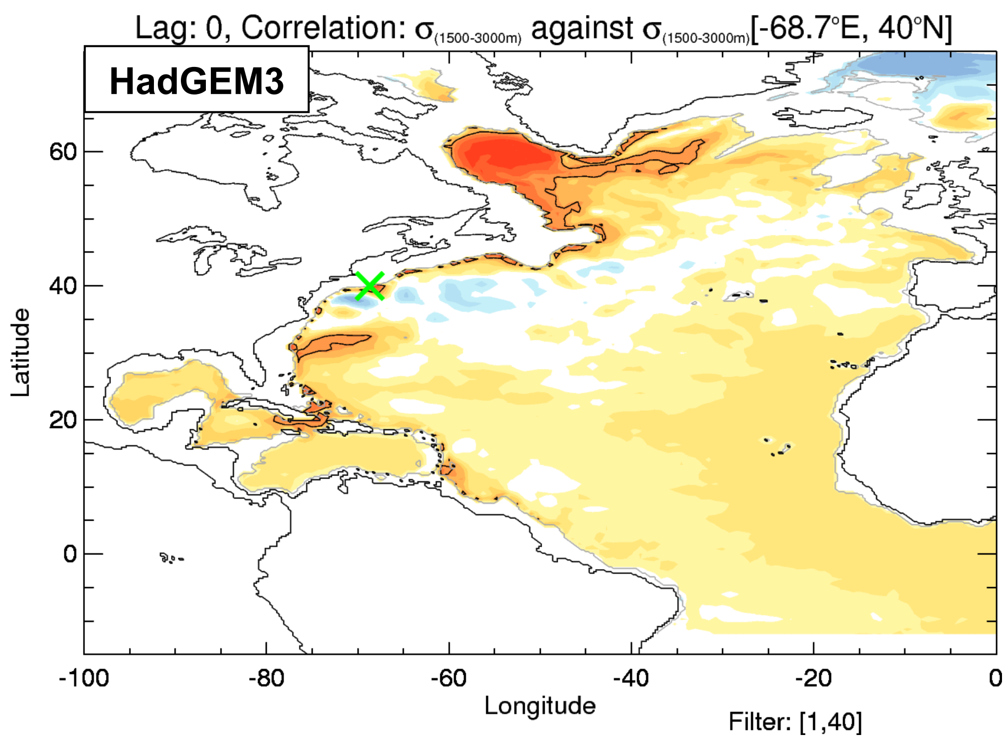
NCEP and ECMWF-derived from Trenberth & Caron (2001, Figure 5)

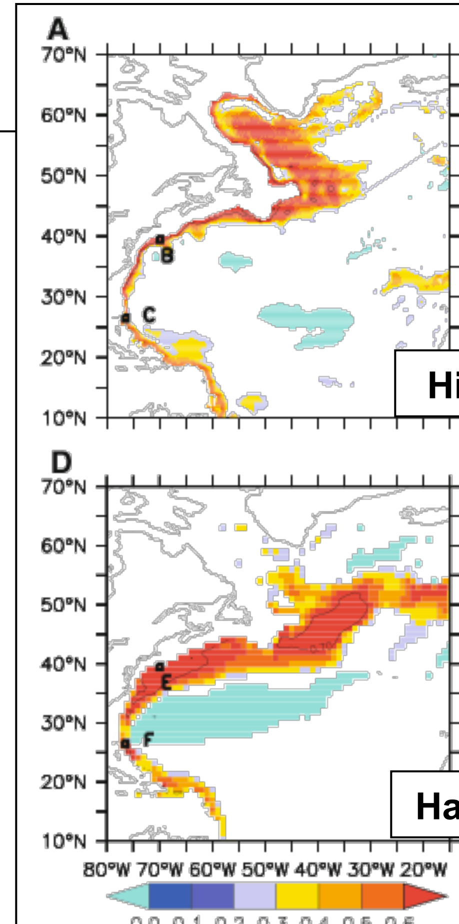


# Comparison with previous work – Hodson 2012

**The impact of resolution on the adjustment and decadal variability of the Atlantic meridional overturning circulation in a coupled climate model**

**Daniel L. R. Hodson · Rowan T. Sutton**




HiGEM1.2 (⅓°)

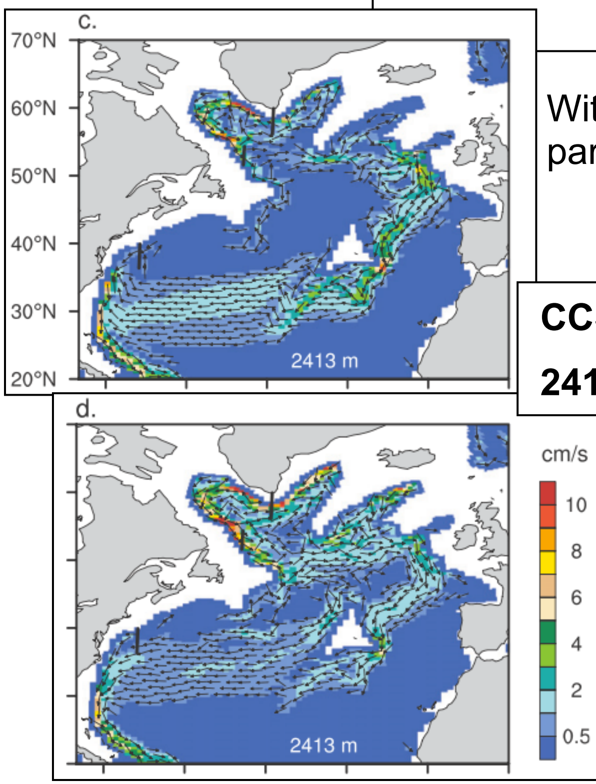
HadGEM1.2 (1°)

Integrated ocean density (1500-3000m) correlated with same at point B/E

# Comparison with previous work – Yeager 2012

**Sensitivity of Atlantic Meridional Overturning Circulation Variability to Parameterized Nordic Sea Overflows in CCSM4**

STEPHEN YEAGER AND GOKHAN DANABASOGLU

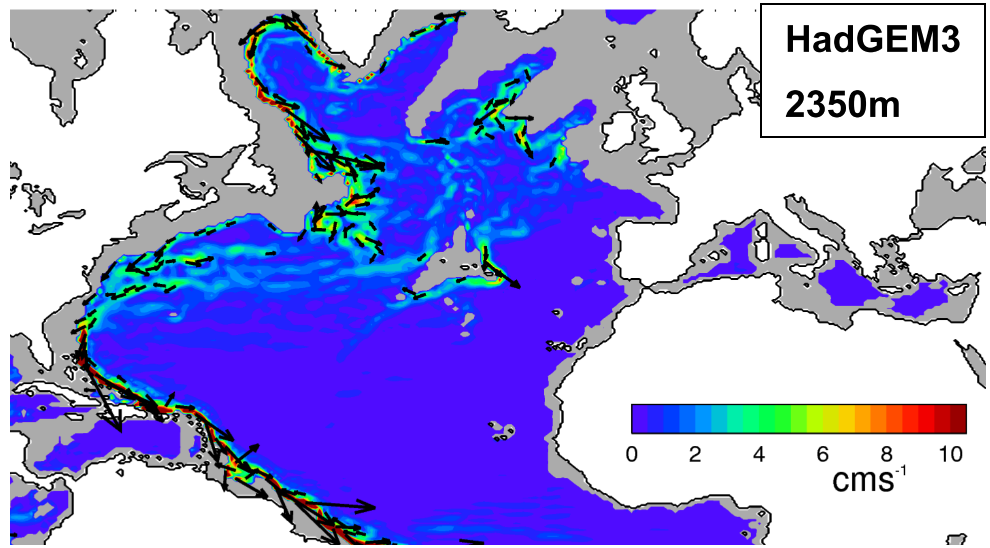



Without parameterization

**CCSM4**

**2410m**

With parameterization



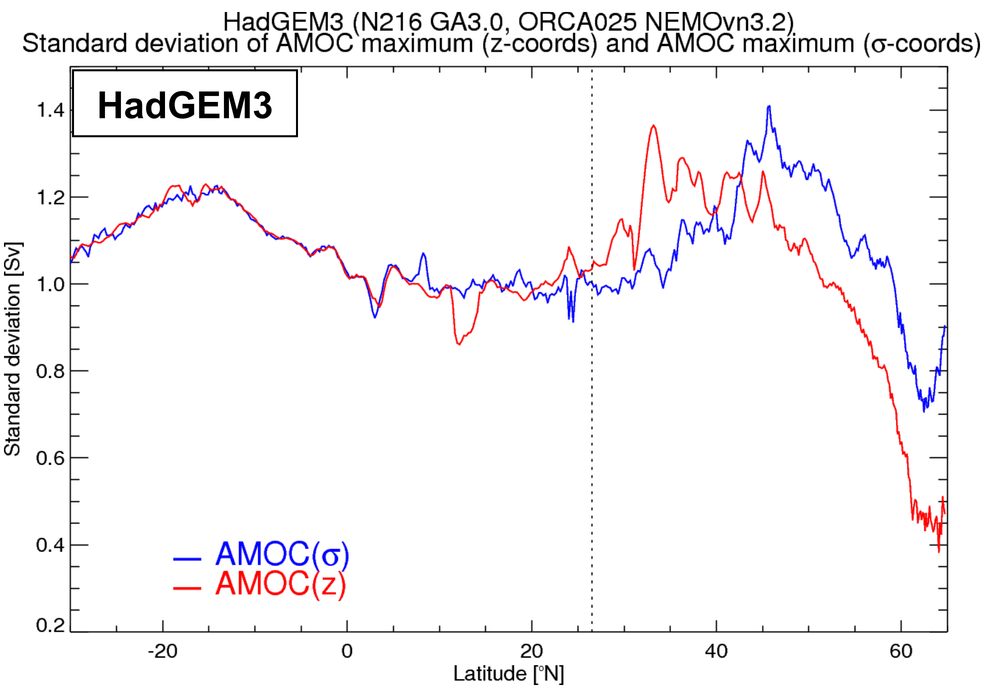

**HadGEM3**

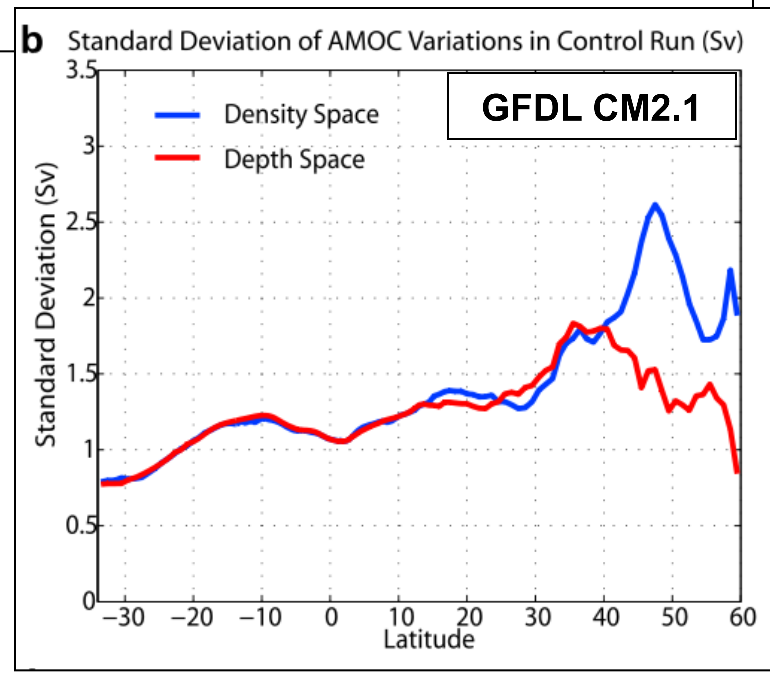
**2350m**

# Comparison with previous work – Zhang 2010

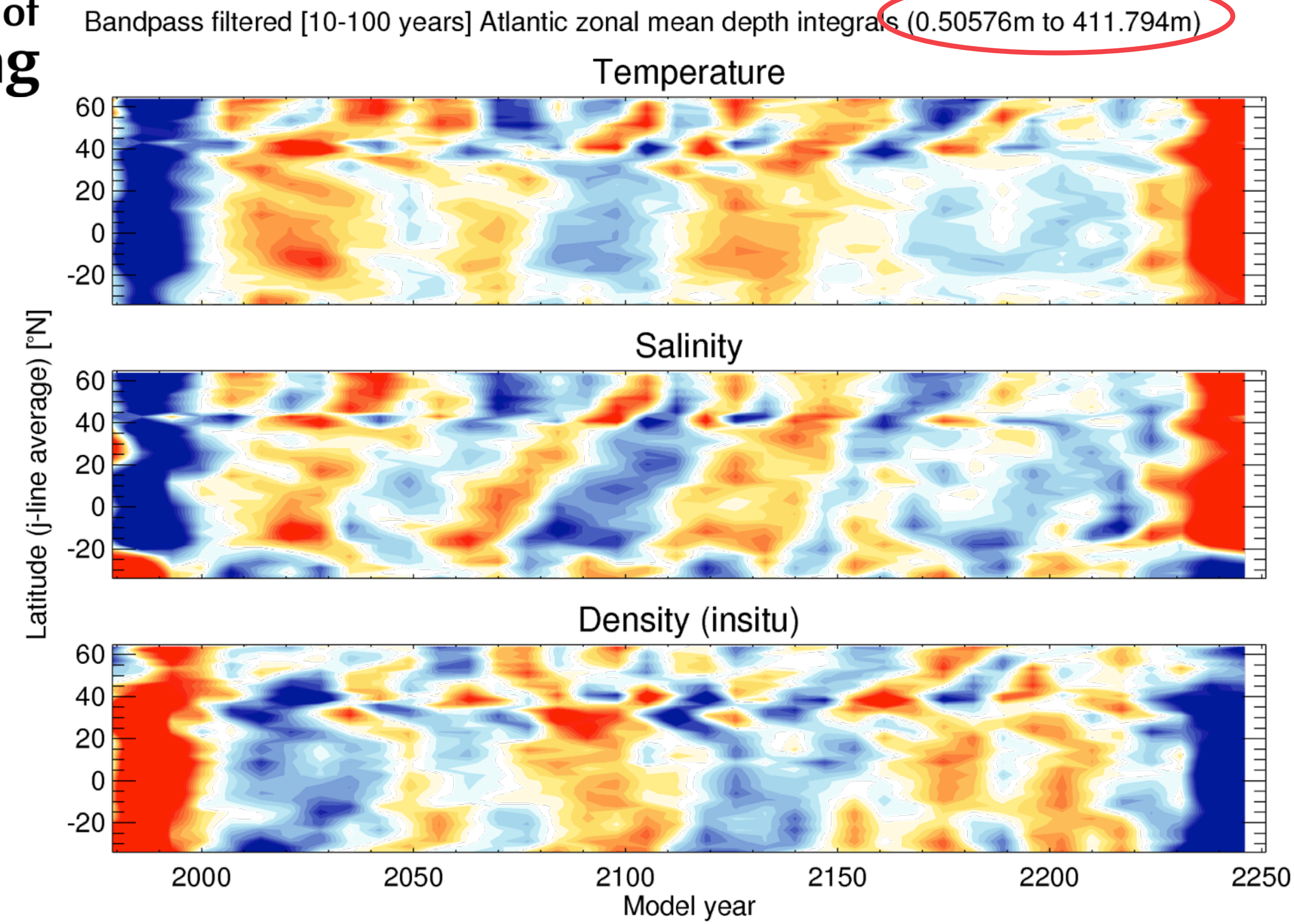
**Latitudinal dependence of Atlantic meridional overturning circulation (AMOC) variations**

Rong Zhang[1]



# Propagation of T/S/ρ anomalies



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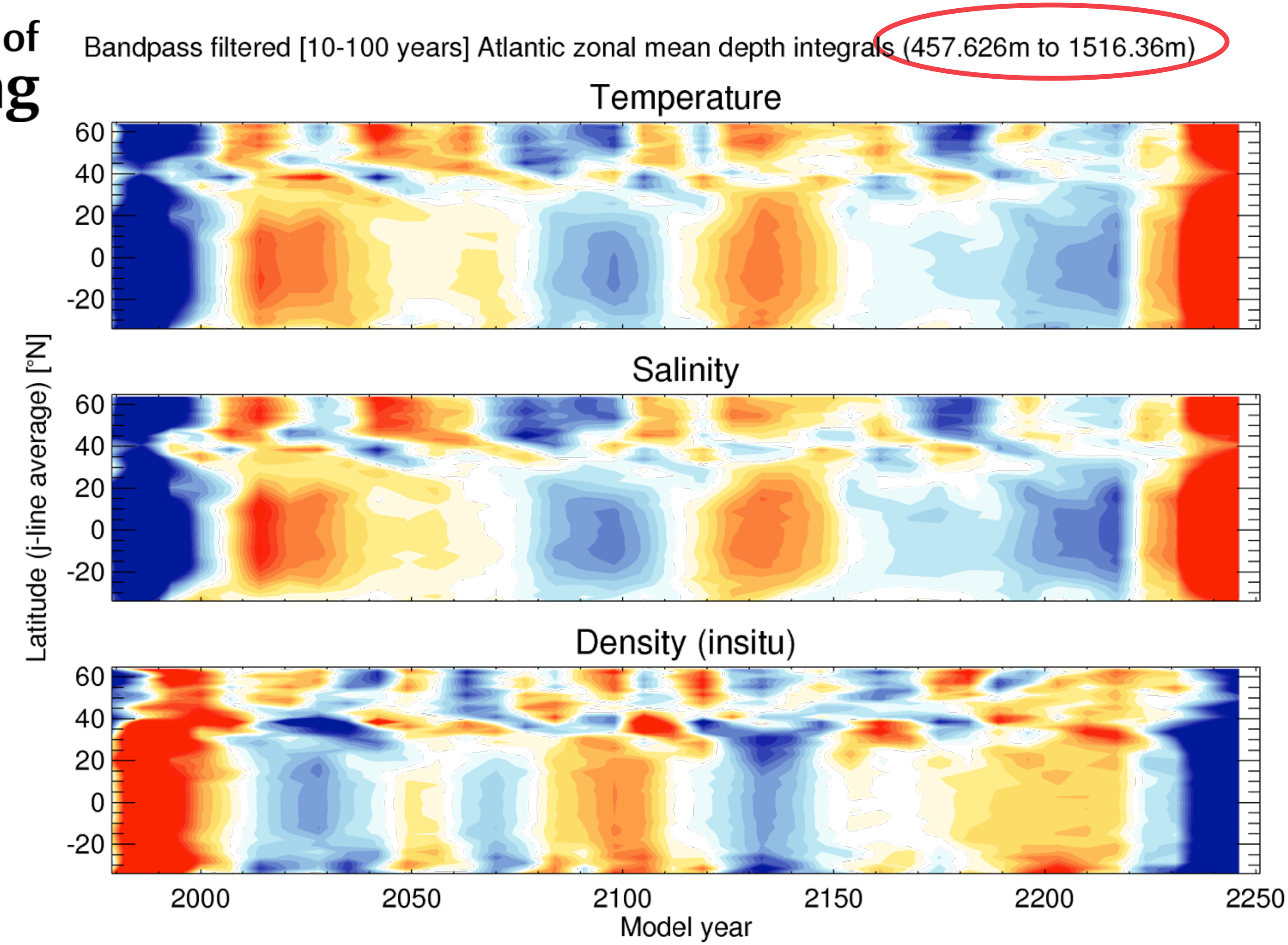

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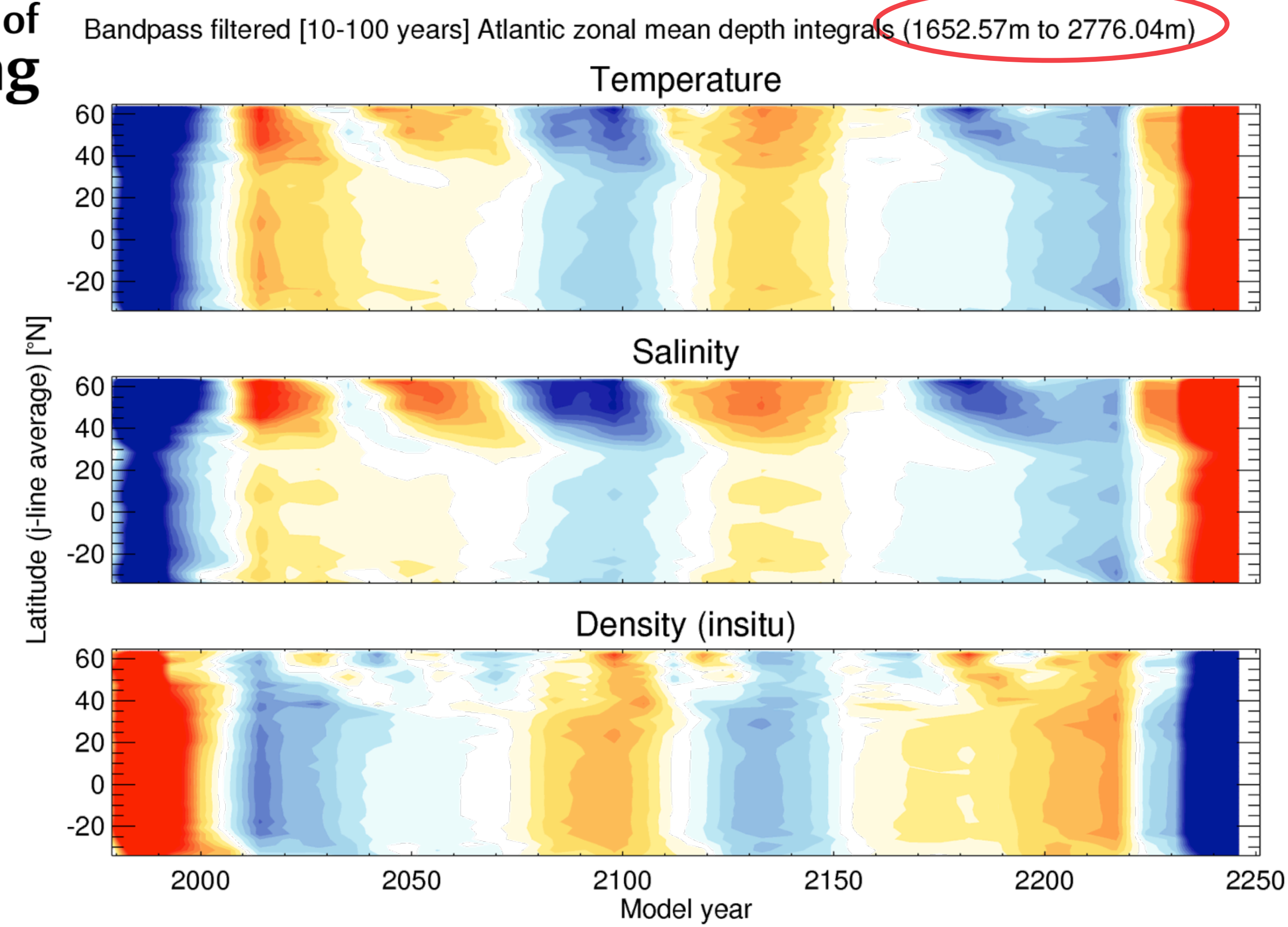
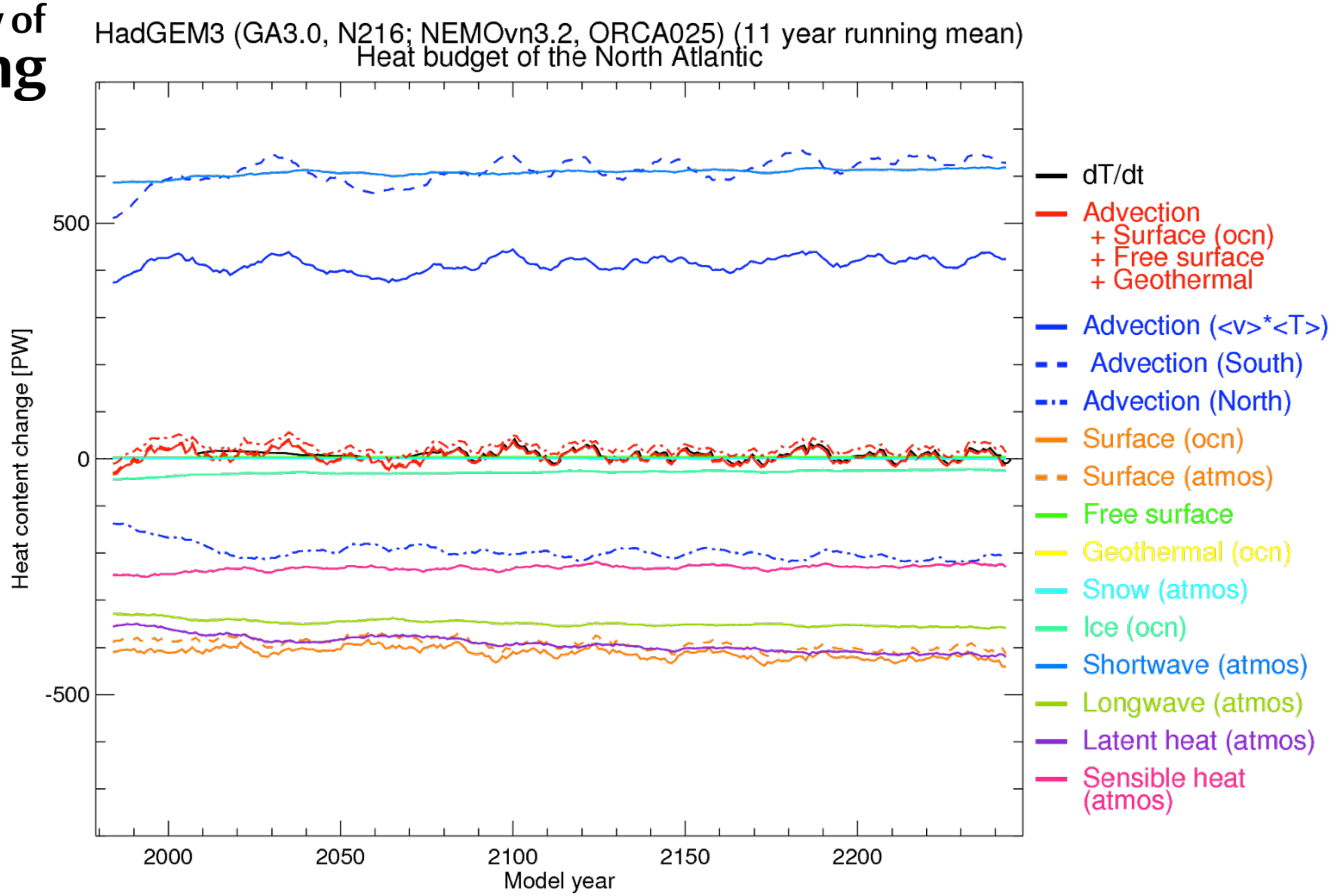


# North Atlantic heat budget



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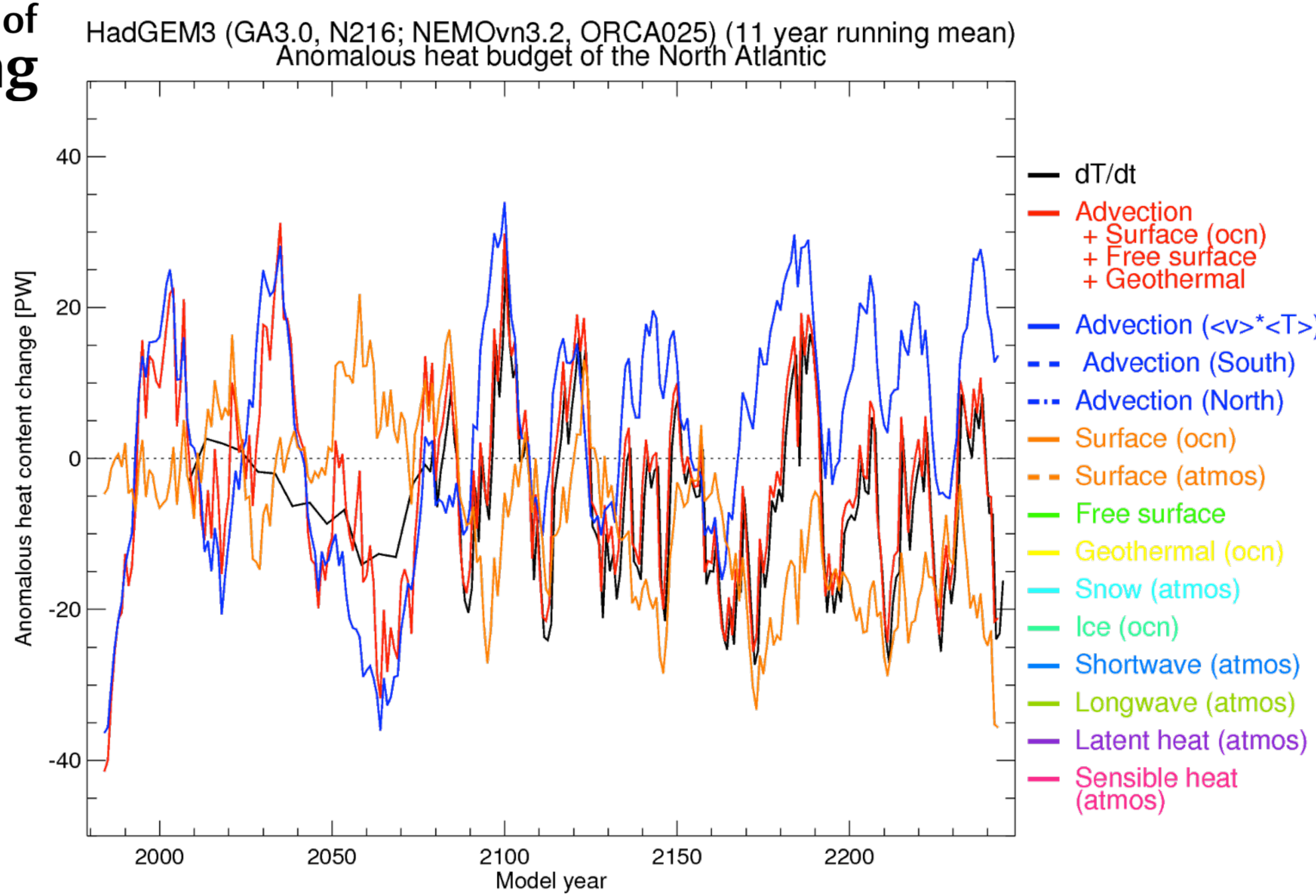

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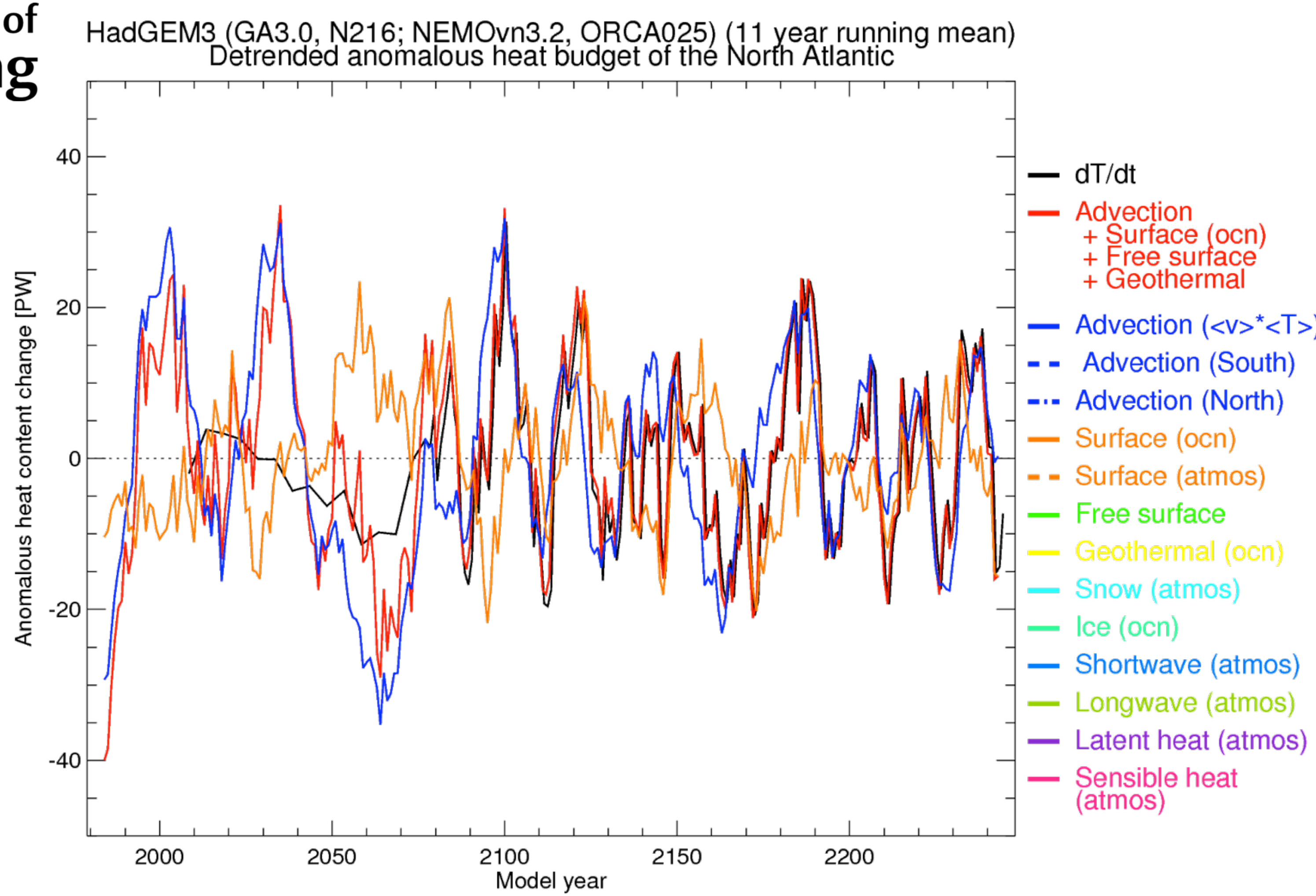

Met Office
Hadley Centre

University of Reading

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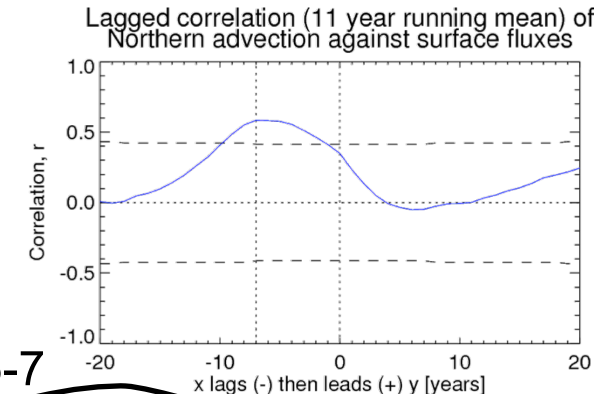
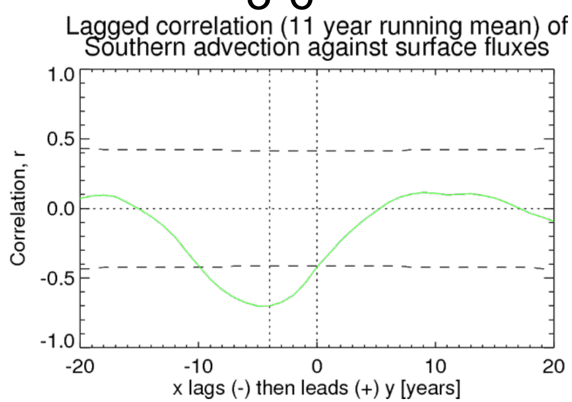
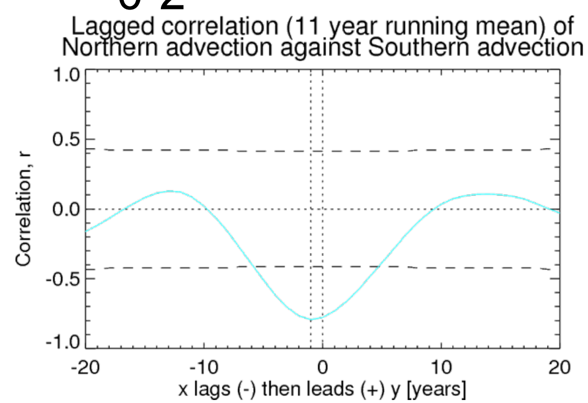



5-7

SHF ▲ → (3-6) → S. Advection ▼ → (0-2) → N. advection ▲

SHF ▲ → (5-7) → N. advection ▲



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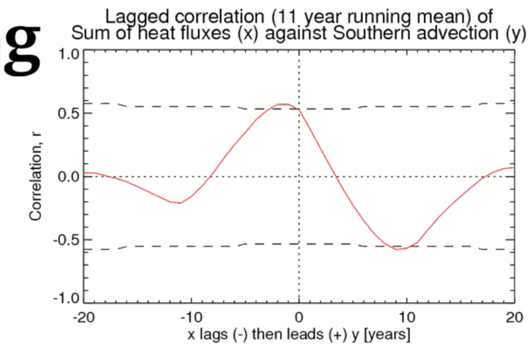
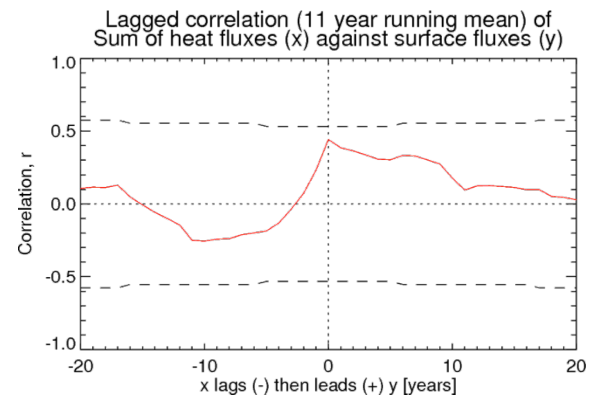
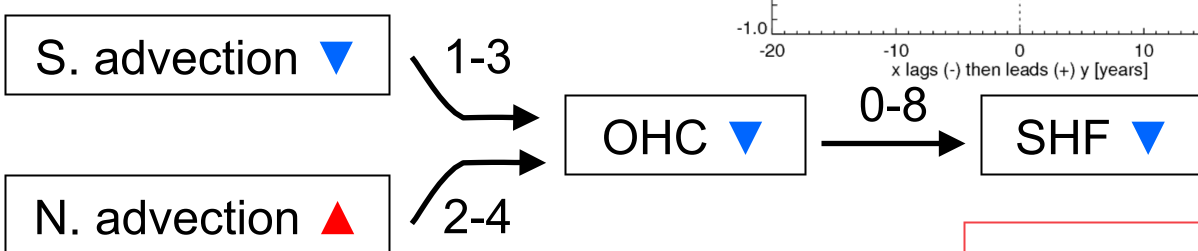
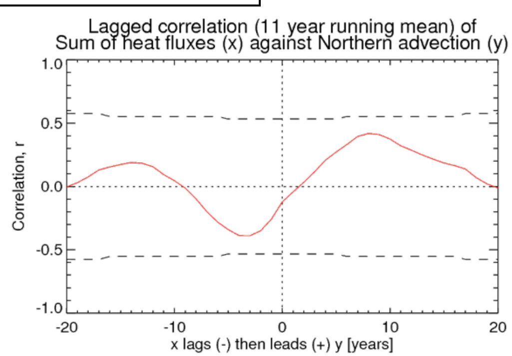
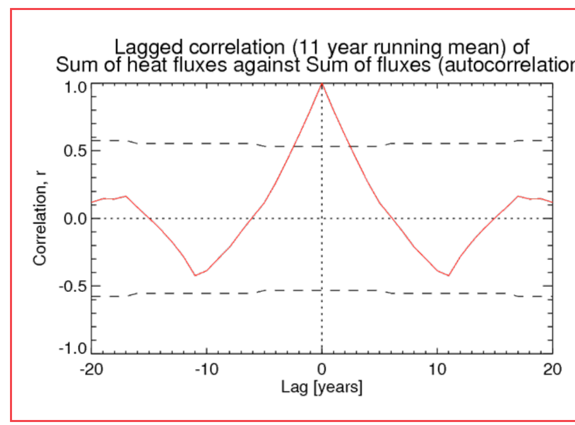


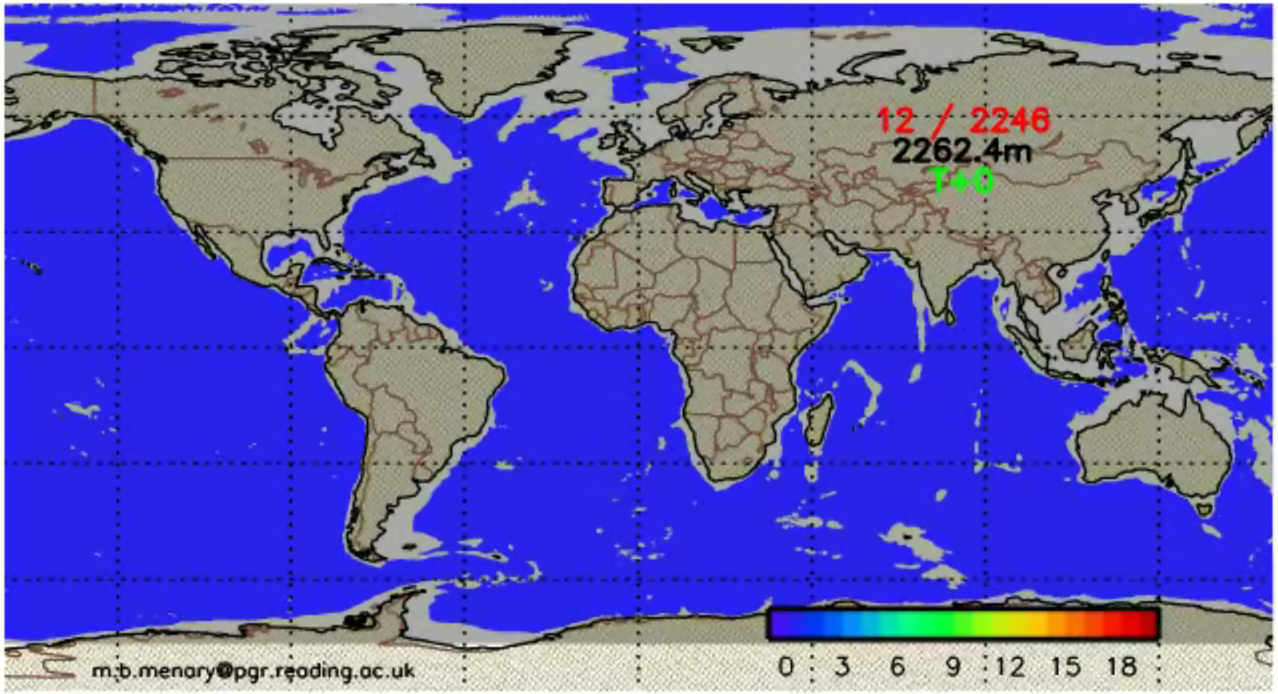
# Tracer release experiments

Modified the NEMO ocean code to include additional passive tracers. Two experiments:

1. Age of Water
    - Water continually ages each timestep unless at surface where it is set to **`age=0`** and is otherwise advected around
    - To determine key sinking regions and *ocean pathways* (when in equilibrium, 1000s of years from now…) However, the transient response also highlights where the model sinking regions are
2. Continuous tracer release
    - Tracer in a particular region (cube defined by `i,j,k` values) is set to **`concentration=1`** each timestep and is otherwise advected around
    - 3 separate releases, ~5 years before large AMOC changes
    - To understand the DWF/advective role in large AMOC events and to highlight the relative roles of the western boundary current and interior pathways

# Tracer release experiments

HadGEM3 Age of Water tracer, animation of first 18 years



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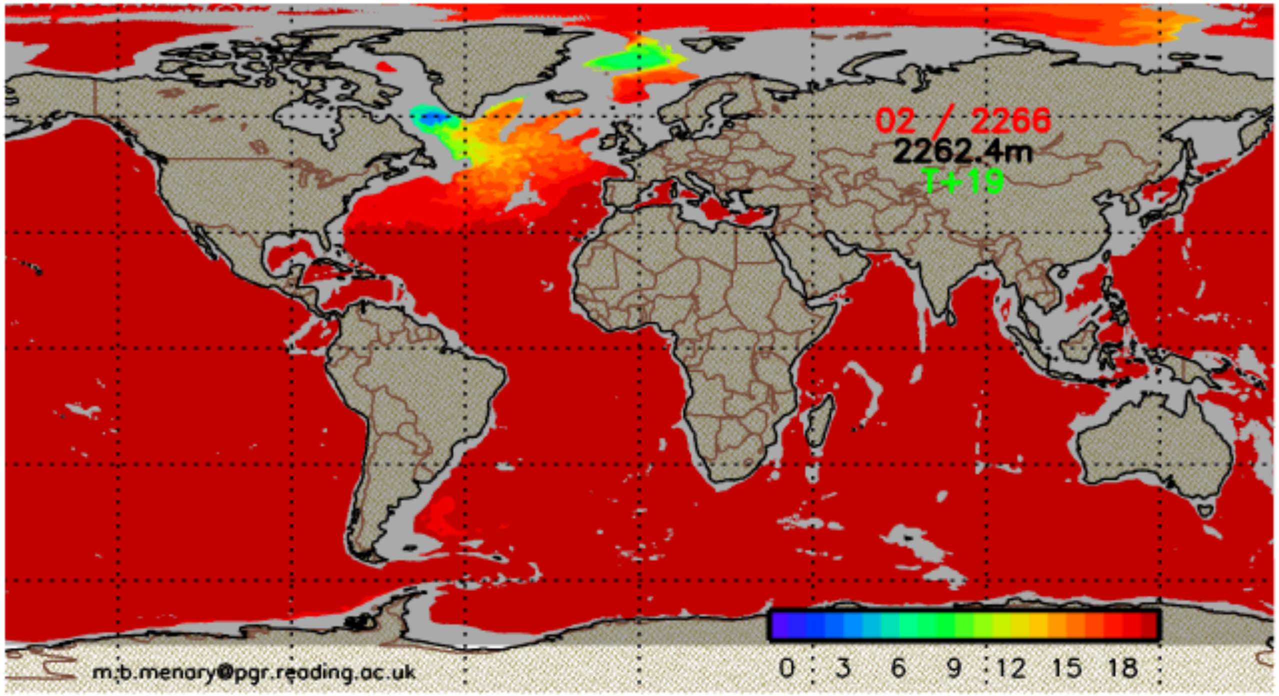
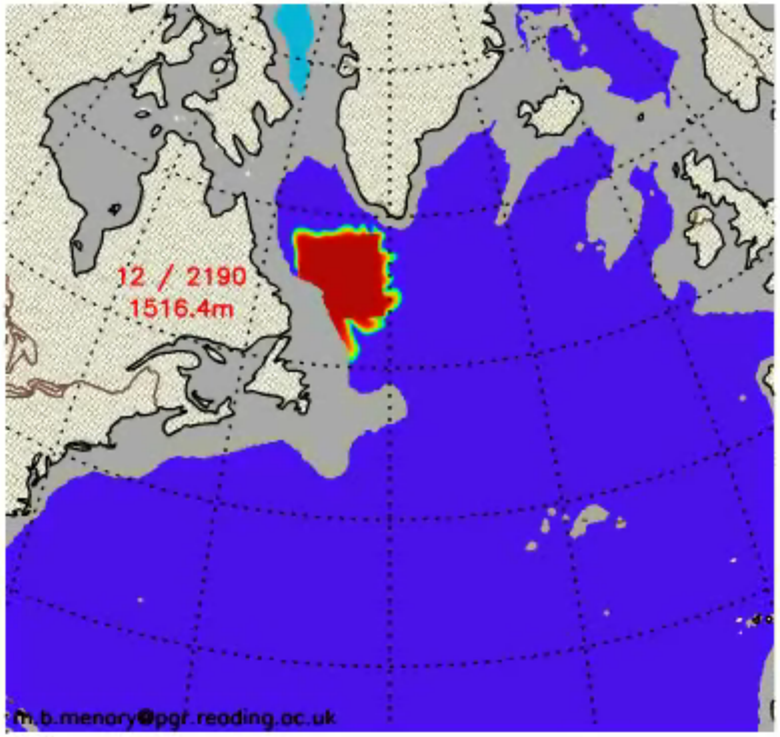


# Tracer release experiments

HadGEM3 Labrador Sea continuous tracer release, first 5 years



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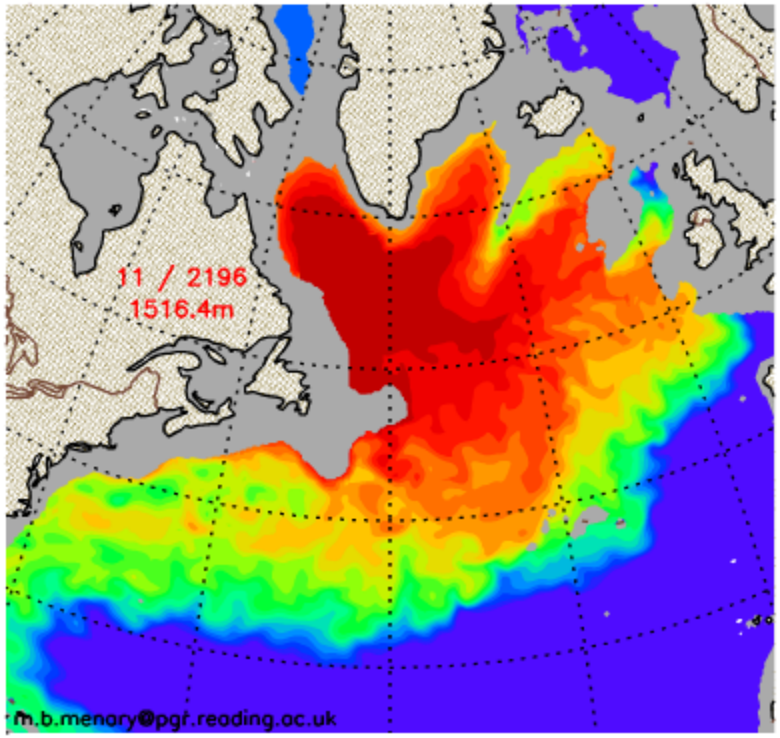
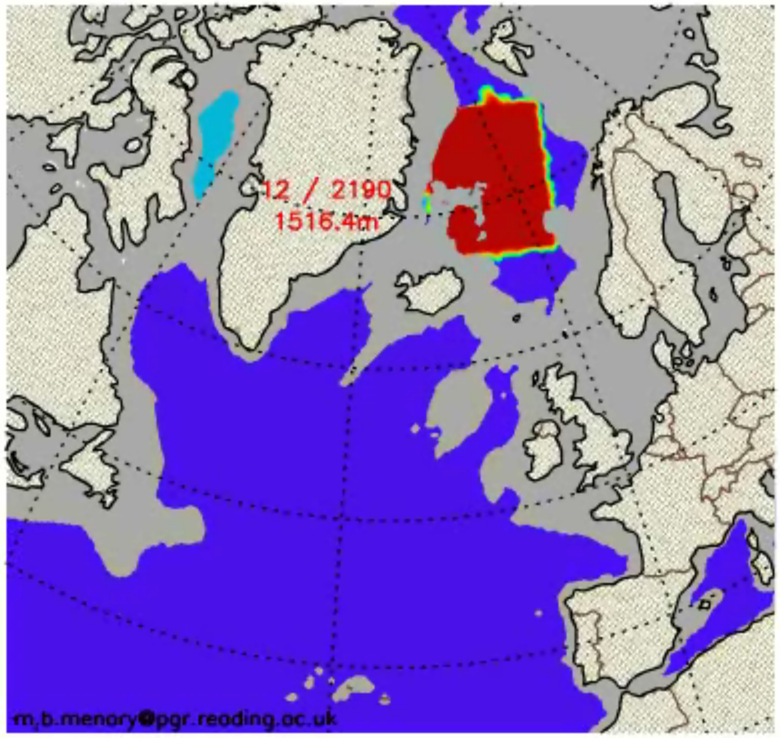


# Tracer release experiments

HadGEM3 GIN Seas continuous tracer release, first 5 years



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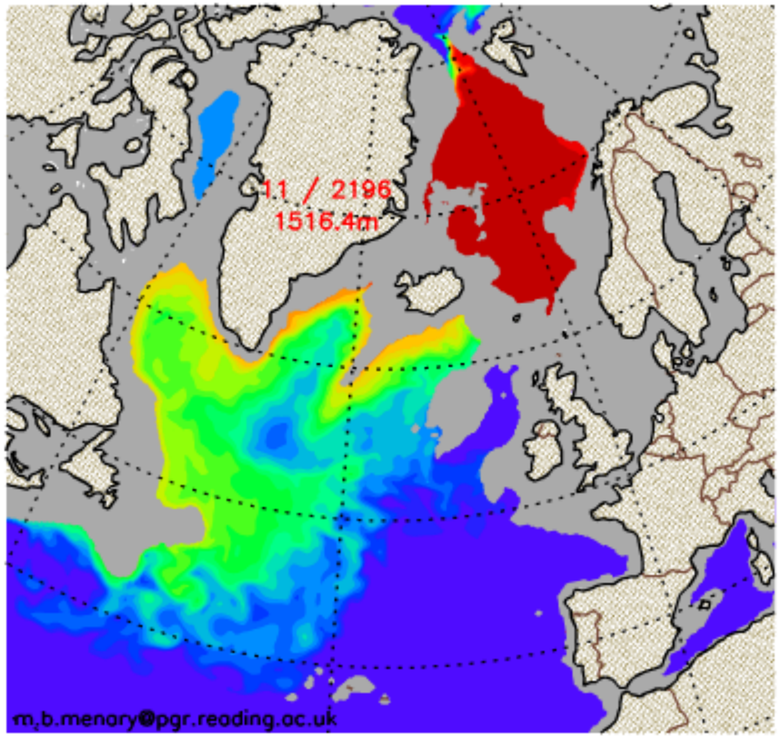

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