An anatomy of the projected North Atlantic warming hole in CMIP5 models

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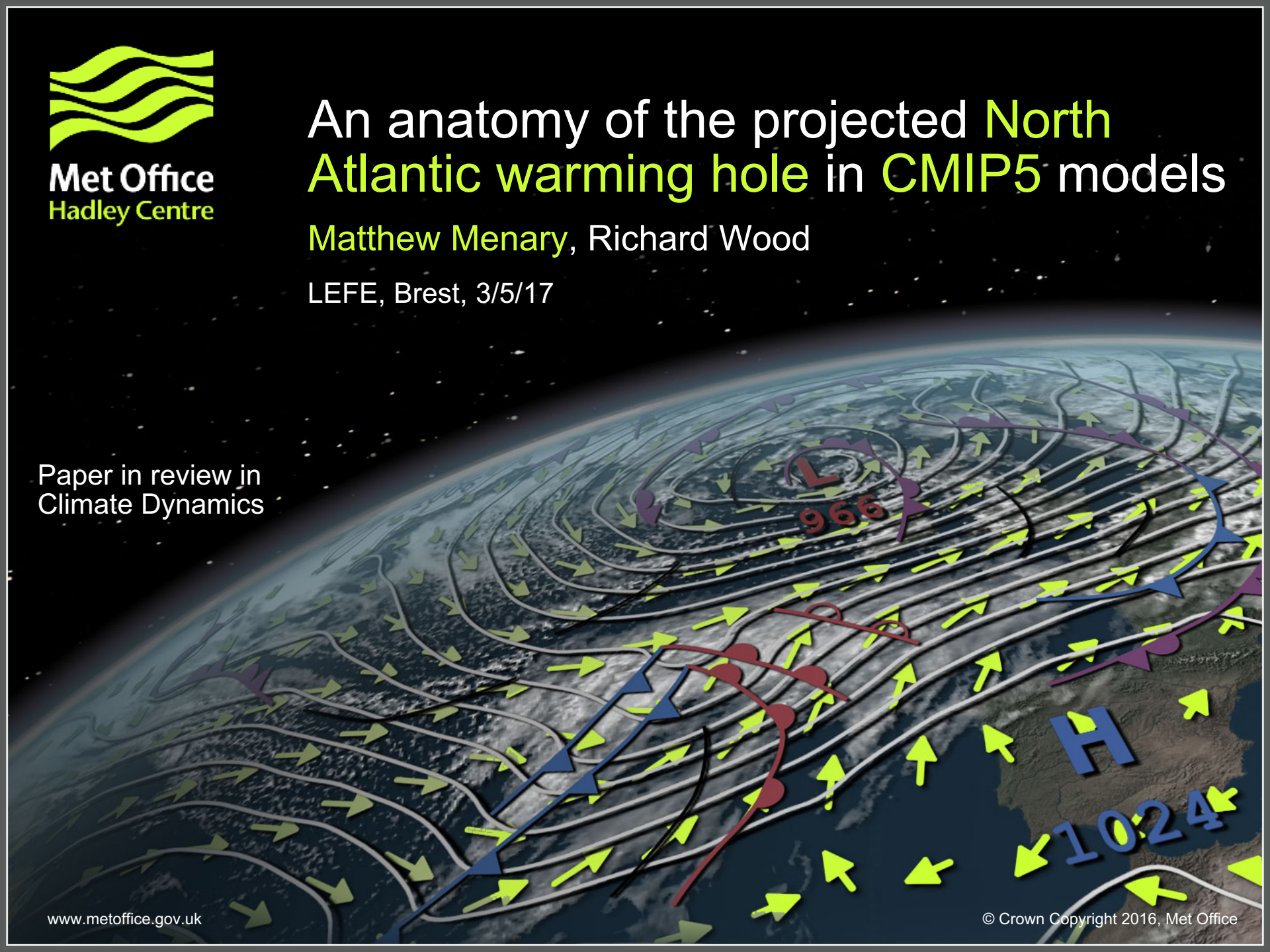
LEFE, Brest, 3/5/17

Met Office Hadley Centre

Paper in review in Climate Dynamics



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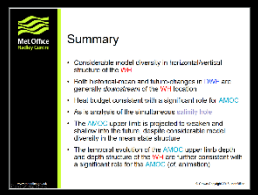
Contents

- Introduction
  - Competing hypotheses
- Models/data used
- The Warming Hole (WH)
  - Heat budget
  - AMOC
  - “Salinity hole”
  - Time evolution
- Summary



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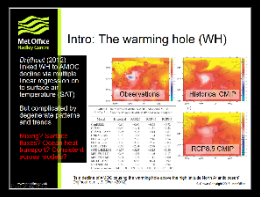
Summary

- Considerable model diversity in horizontal/vertical structure of the WH
- Both historical-mean and future-changes in DWF are generally *downstream* of the WH location
- Heat budget consistent with a significant role for AMOC
- As is analysis of the simultaneous salinity hole
- The AMOC upper limb is projected to weaken and shallow into the future, despite considerable model diversity in the mean state structure
- The temporal evolution of the AMOC upper limb depth and depth structure of the WH are further consistent with a significant role for the AMOC (*cf.* animation)

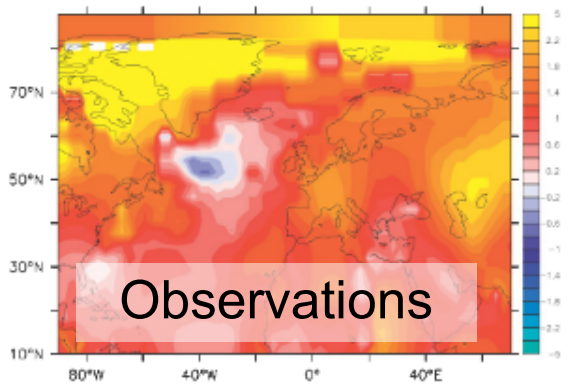


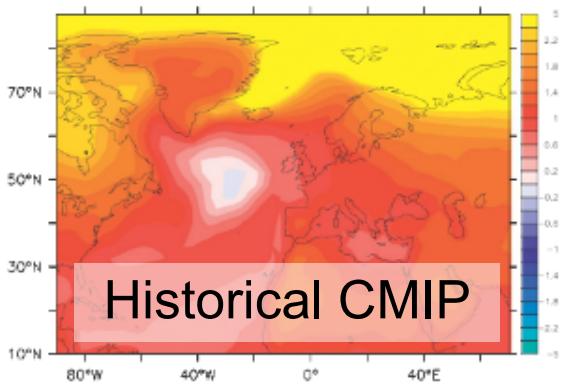
Intro: The warming hole (WH)

Drijfhout (2012) linked WH to AMOC decline via multiple linear regression on to surface air temperature (SAT)

But complicated by degenerate patterns and trends

Mixing? Surface fluxes? Ocean heat transport? Consistent across models?





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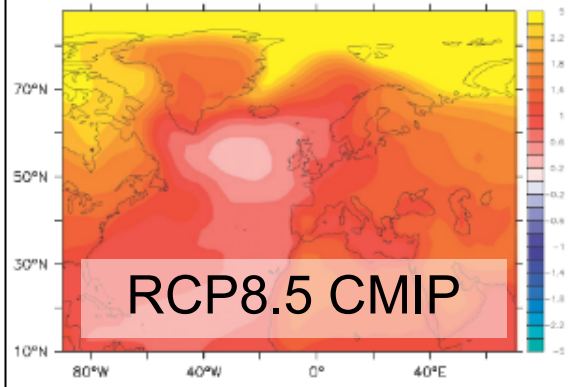


TABLE 1. The regression of the AMOC-index on GMT in 10^6 m^3 s^{-1} K^{-1} for the 12 models of CMIP5 that were analyzed.

Model	Historical	RCP2.6	RCP4.5	RCP8.5
CanESM2	0.60	−0.80	−0.78	−0.72
CCSM4	−0.90	−1.44	−1.51	−1.52
CESM1-CAM5	−0.05	−2.23	−2.14	−1.81
CNRM-CM5	−0.98	−1.47	−1.24	−1.02
FGOALS-g2	0.35	−2.76	−2.16	−1.54
FGOALS-s2	−1.00	−3.00	−2.86	−2.03
GFDL-CM3	0.63	−2.84	−2.48	−2.11
GFDL-ESM2M	−1.37	−3.15	−3.13	−2.80
MPI-ESM-LR	−0.48	−1.53	−1.46	−1.17
MPI-ESM-MR	0.31	−1.03	−1.11	−1.00
MRI-CGCM3	−0.04	−0.88	−0.74	−0.92
NorESM1-M	0.89	−1.78	−1.88	−1.94
Ensemble mean	−0.4 ± 0.8	−1.9 ± 0.8	−1.8 ± 0.8	−1.5 ± 0.6

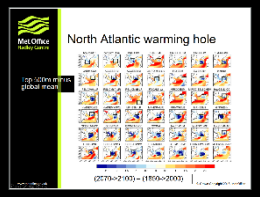
"Is a decline of AMOC causing the warming hole above the high latitude North Atlantic ocean" Drijfhout et al., *J. Clim.* (2012)

Models/data

This study

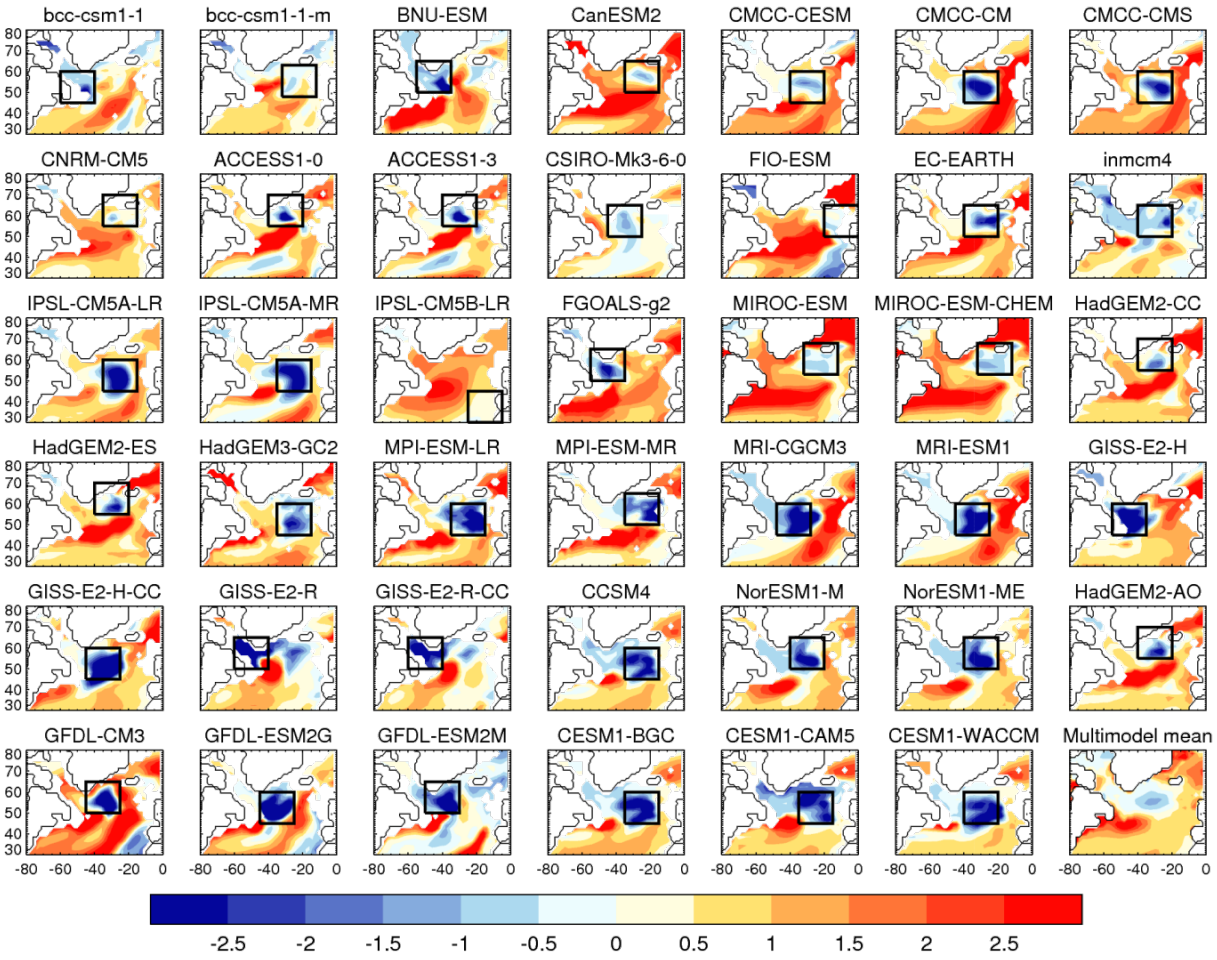
- 41 models
- 25 with March mixing data
- 19 with AMOC data
- 17 with heat budget data

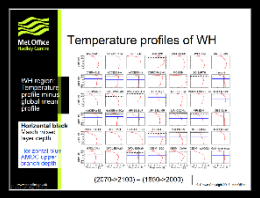
Institute (CMIP5 name)	Model (CMIP5 name)	thetao and so	mlotst	omlmax	msftyyz or msftmyz	hfy	hfds
BCC	bcc-csm1-1	X	-	-	-	-	X
BCC	bcc-csm1-1-m	X	-	-	-	-	X
BNU	BNU-ESM	X	-	-	-	-	X
CCCma	CanESM2	X	X	X	X	-	-
CMCC	CMCC-CESM	X	-	-	-	X	X
CMCC	CMCC-CM	X	-	-	-	X	X
CMCC	CMCC-CMS	X	-	-	-	X	X
CNRM-CERFACS	CNRM-CM5	X	X	X	X	-	-
CSIRO-BOM	ACCESS1-0	X	X	X	X	X	X
CSIRO-BOM	ACCESS1-3	X	X	X	X	X	X
CSIRO-QCCCE	CSIRO-Mk3-6-0	X	X	-	-	-	X
FIO	FIO-ESM	X	-	-	-	-	X
ICHEC	EC-EARTH	X	-	X	-	-	X
INM	inmcm4	X	X	-	X	-	X
IPSL	IPSL-CM5A-LR	X	-	X	-	X	-
IPSL	IPSL-CM5A-MR	X	-	X	-	X	-
IPSL	IPSL-CM5B-LR	X	-	X	-	X	-
LASG-CESS	FGOALS-g2	X	-	-	X	-	X
MIROC	MIROC-ESM	X	-	-	-	-	X
MIROC	MIROC-ESM-CHEM	X	-	-	-	-	-
MOHC	HadGEM2-CC	X	X	-	X	X	X
MOHC	HadGEM2-ES	X	X	-	X	X	X
MOHC (non-CMIP5)	HadGEM3-GC2	X	X	-	X	X	X
MPI-M	MPI-ESM-LR	X	X	X	X	X	X
MPI-M	MPI-ESM-MR	X	X	X	X	X	X
MRI	MRI-CGCM3	X	X	X	X	X	X
MRI	MRI-ESM1	X	X	X	X	X	X
NASA-GISS	GISS-E2-H	X	-	-	-	-	-
NASA-GISS	GISS-E2-H-CC	X	-	-	-	-	-
NASA-GISS	GISS-E2-R	X	-	-	-	X	X
NASA-GISS	GISS-E2-R-CC	X	-	-	-	X	X
NCAR	CCSM4	X	-	X	X	-	-
NCC	NorESM1-M	X	X	-	X	X	X
NCC	NorESM1-ME	X	X	-	X	X	X
NIMR-KMA	HadGEM2-AO	X	-	-	-	-	-
NOAA-GFDL	GFDL-CM3	X	X	X	X	X	-
NOAA-GFDL	GFDL-ESM2G	X	-	X	-	X	X
NOAA-GFDL	GFDL-ESM2M	X	X	X	X	X	-
NSF-DOE-NCAR	CESM1-BGC	X	-	X	X	-	-
NSF-DOE-NCAR	CESM1-CAM5	X	-	X	-	-	-
NSF-DOE-NCAR	CESM1-WACCM	X	-	-	-	-	-



North Atlantic warming hole

Top 500m minus global mean





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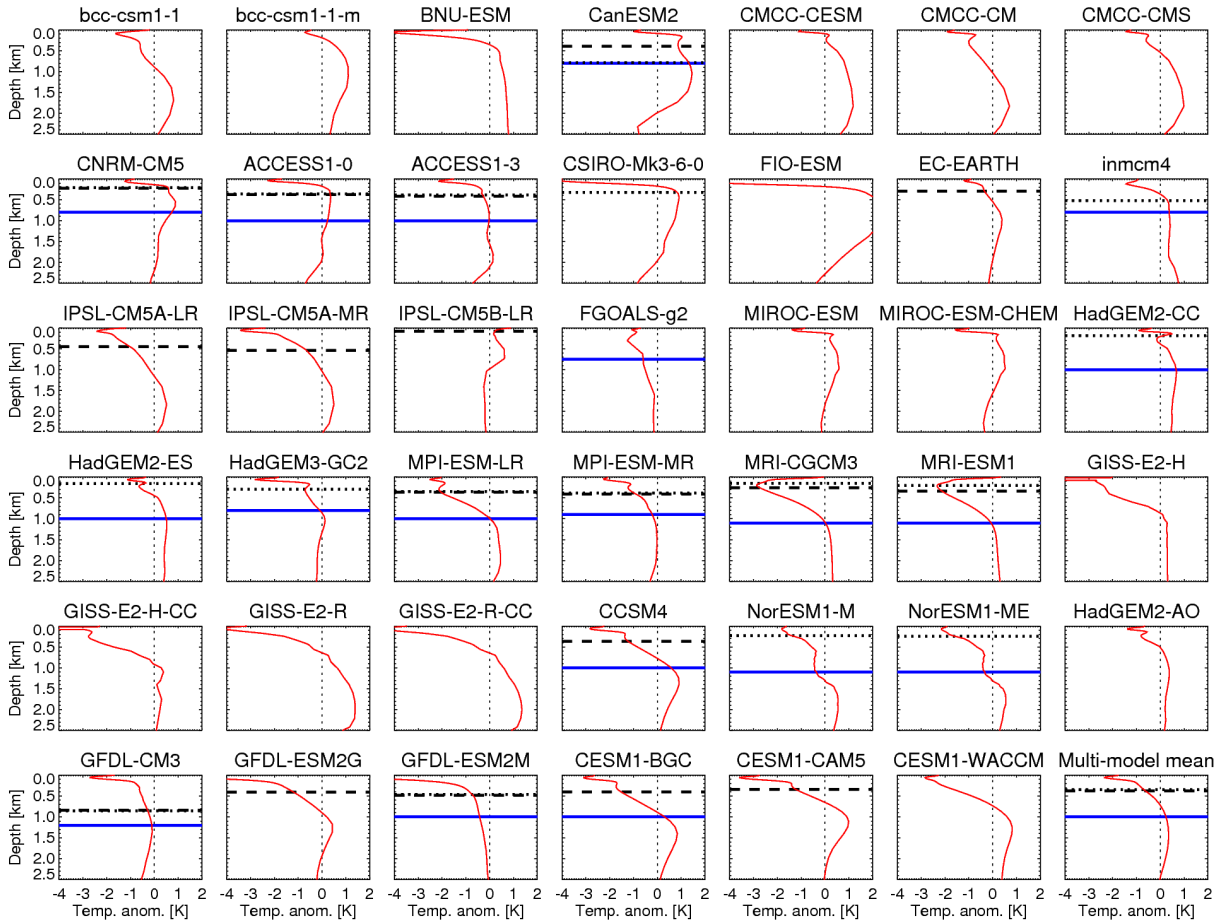
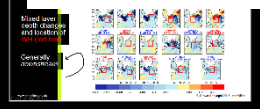
Temperature profiles of WH



WH region: Temperature profile minus global mean profile

Horizontal black March mixed layer depth

Horizontal blue AMOC upper branch depth



(2070->2100) – (1850->2000)

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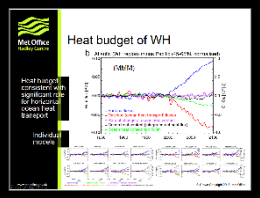
Mixed layer depths

Mixed layer depth changes and location of WH (red box)

Generally *downstream*



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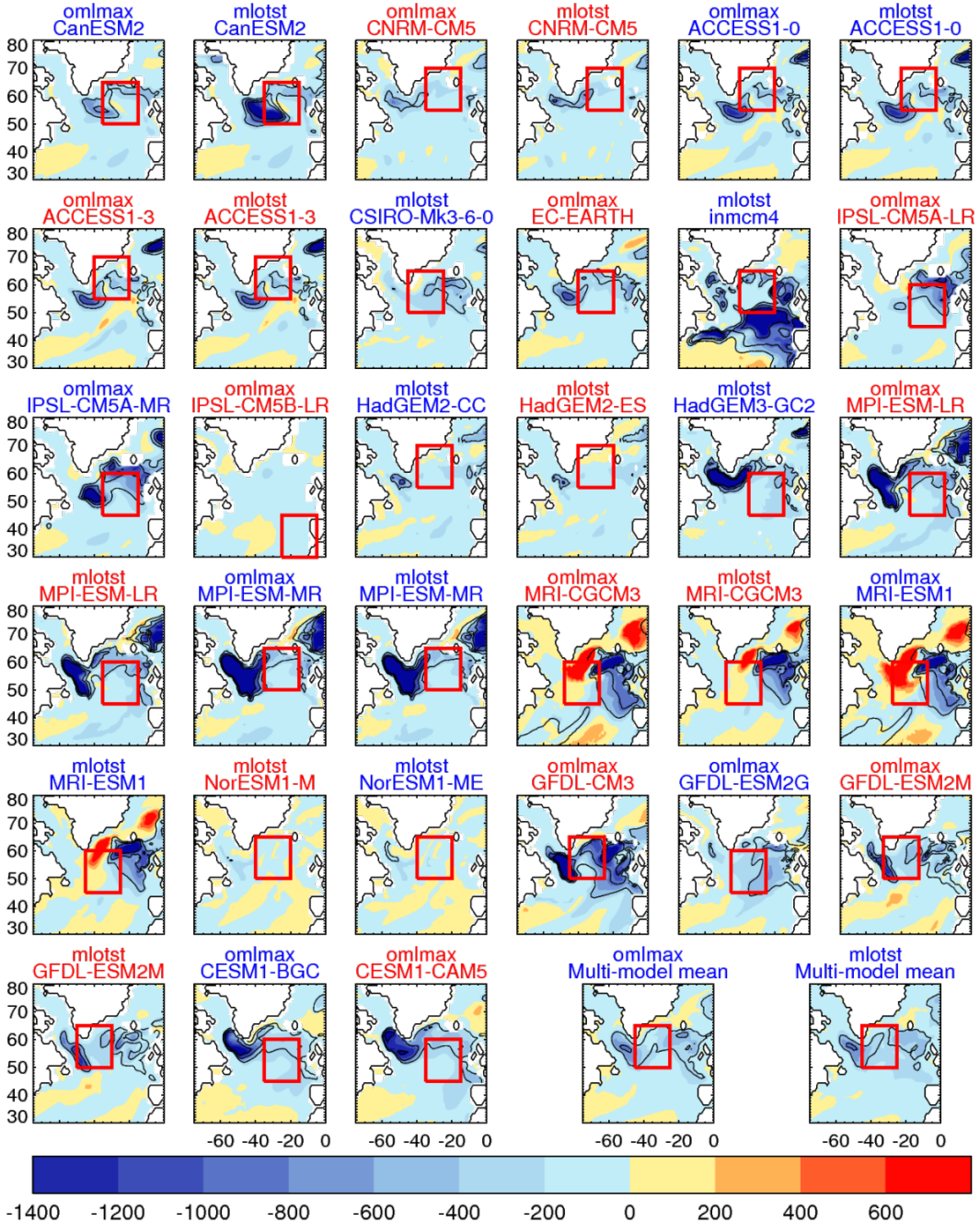
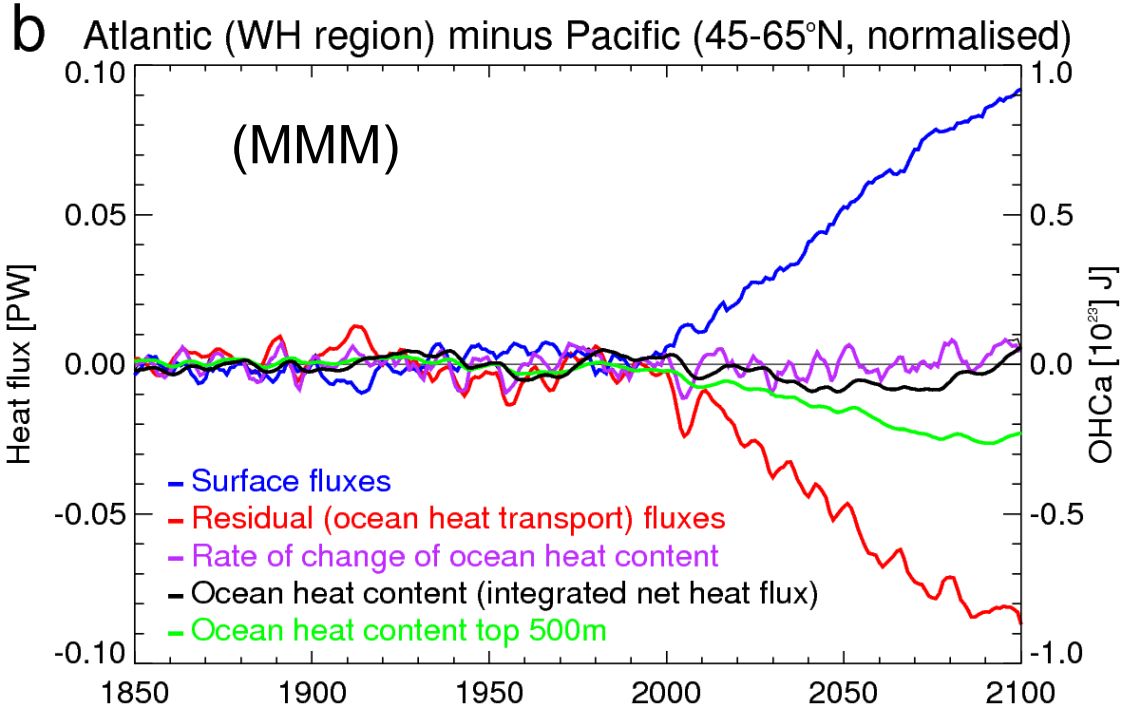
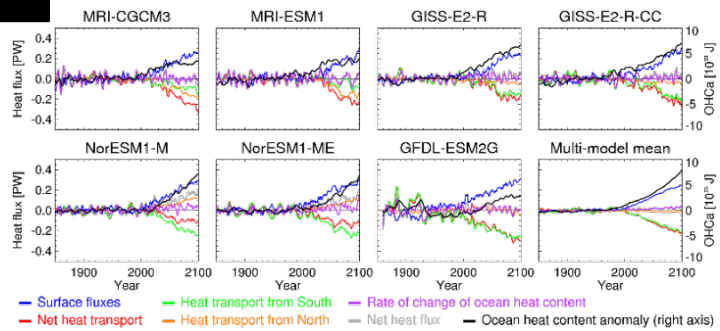


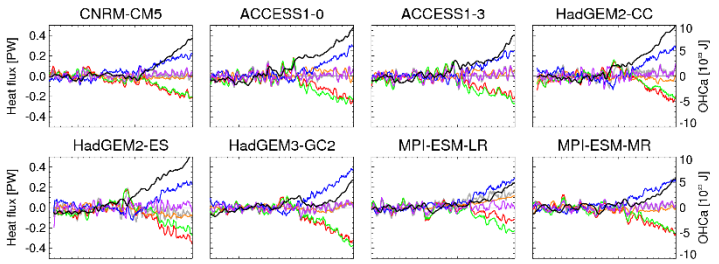
Heat budget of WH

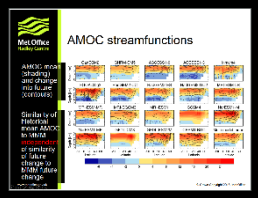
Heat budget consistent with significant role for horizontal ocean heat transport

Individual models









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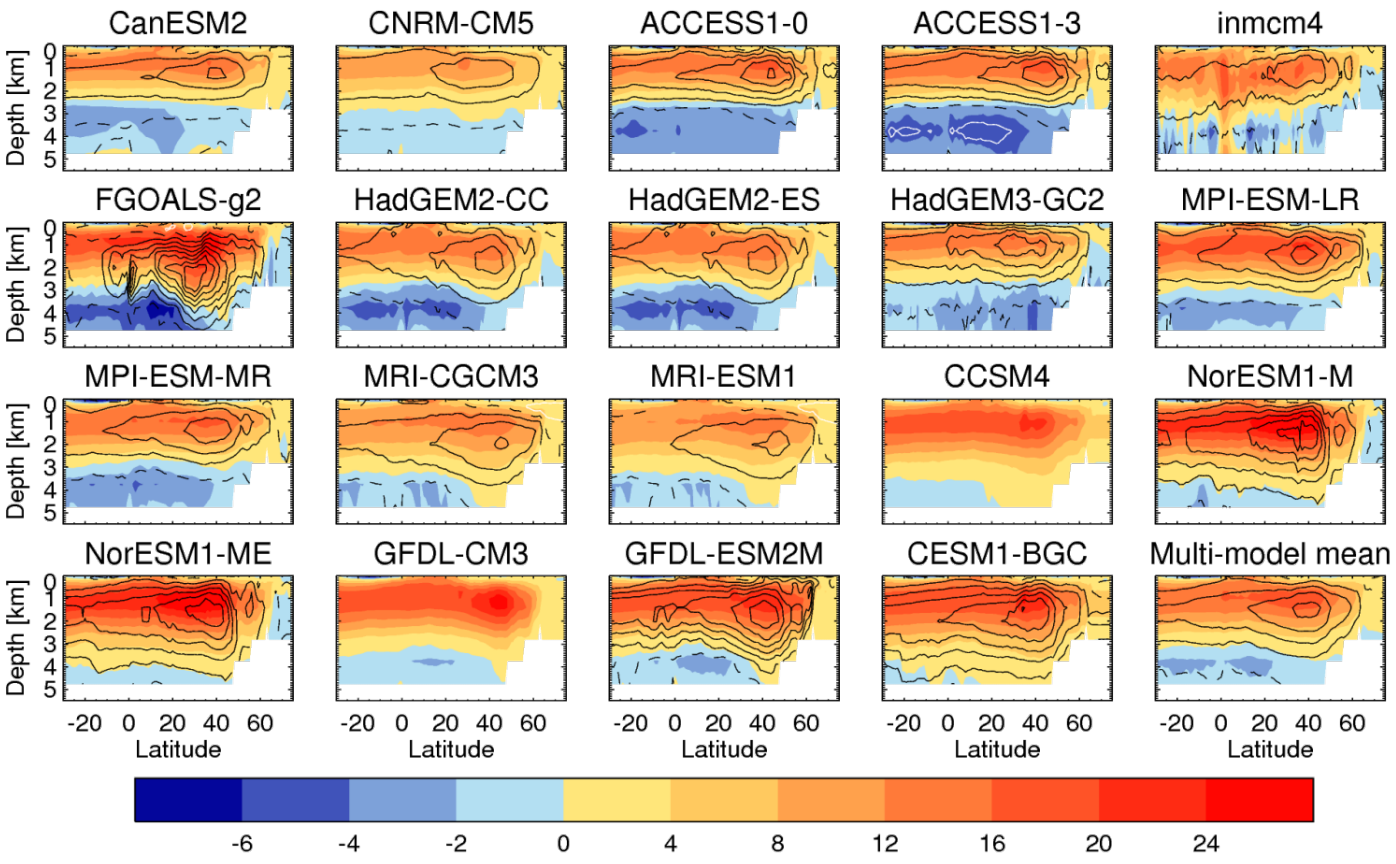
AMOC streamfunctions

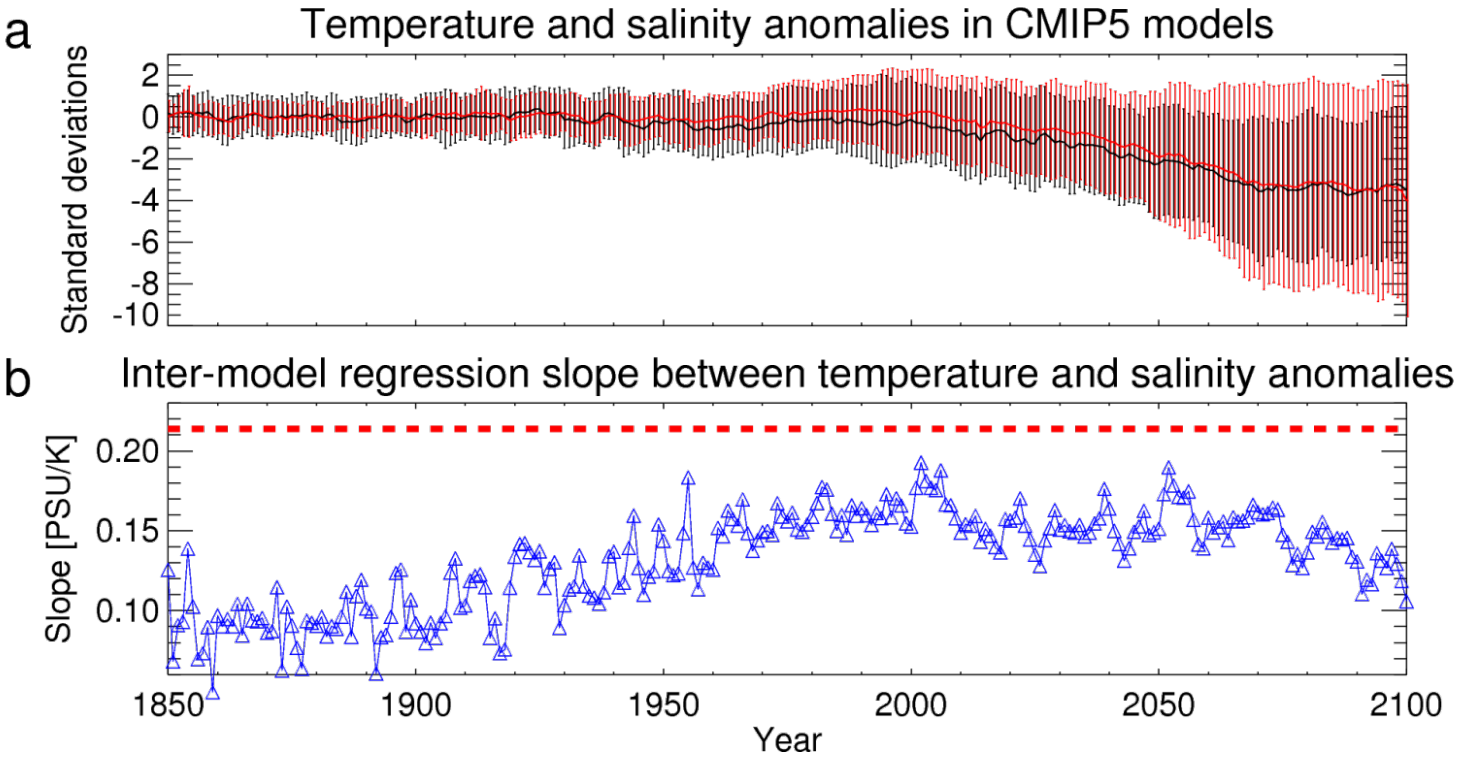
AMOC mean (shading) and change into future (contours)

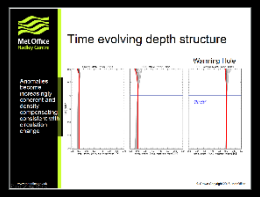
Similarity of historical mean AMOC to MMM independent of similarity of future change to MMM future change



Co-existing “salinity hole”

Anomalies become increasingly coherent and density compensating, consistent with circulation change





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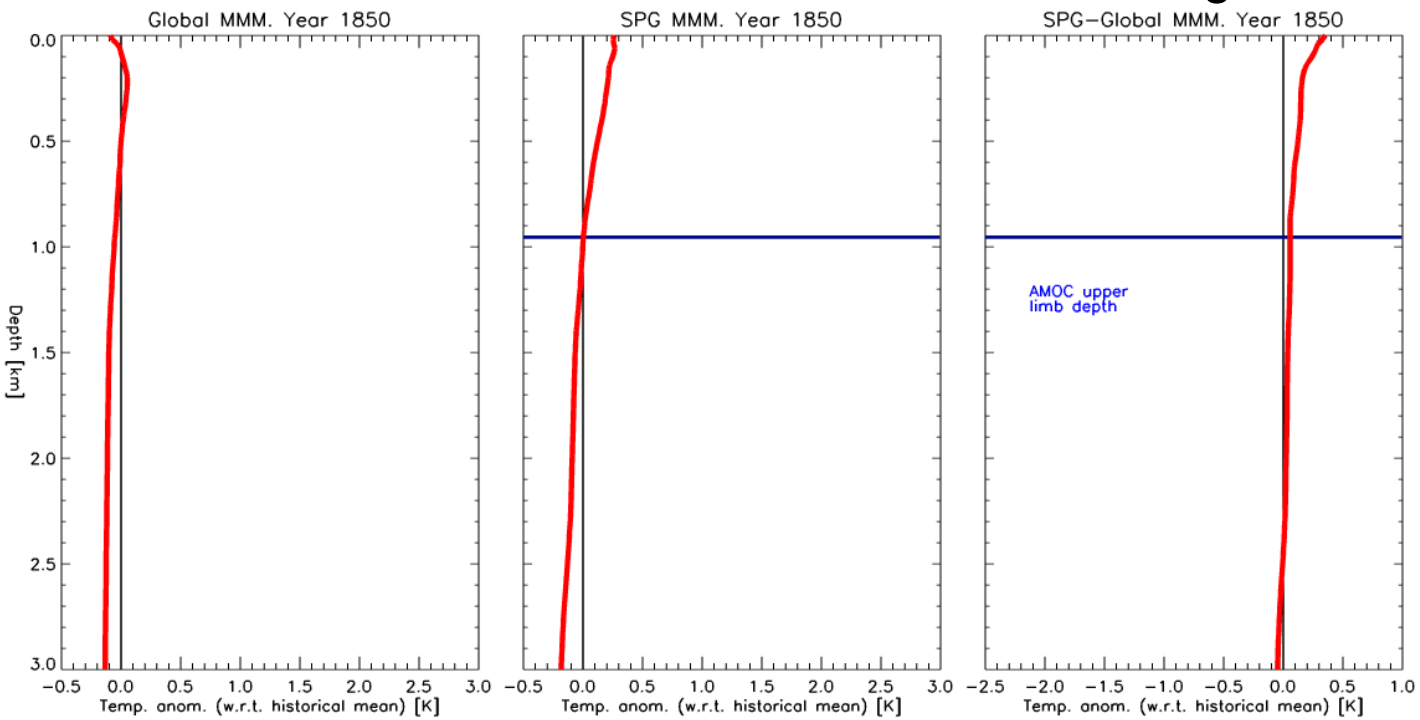
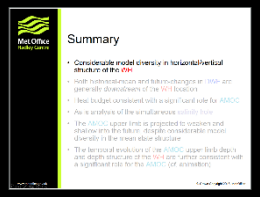
Time evolving depth structure

Anomalies become increasingly coherent and density compensating, consistent with circulation change

Warming Hole





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The end