Met Office
Hadley Centre

The 2009/10 AMOC minimum and subtropical cooling in NEMO-based ocean reanalyses

US AMOC PI meeting, Boulder, 15th August 2012

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Overview

1. Motivation: brief summary of recent observations from 26°N and sub-tropical Atlantic

2. Evaluation of AMOC in ocean reanalyses using observations from 26°N

3. Sub-tropical Atlantic heat budget terms estimated from ocean state estimates

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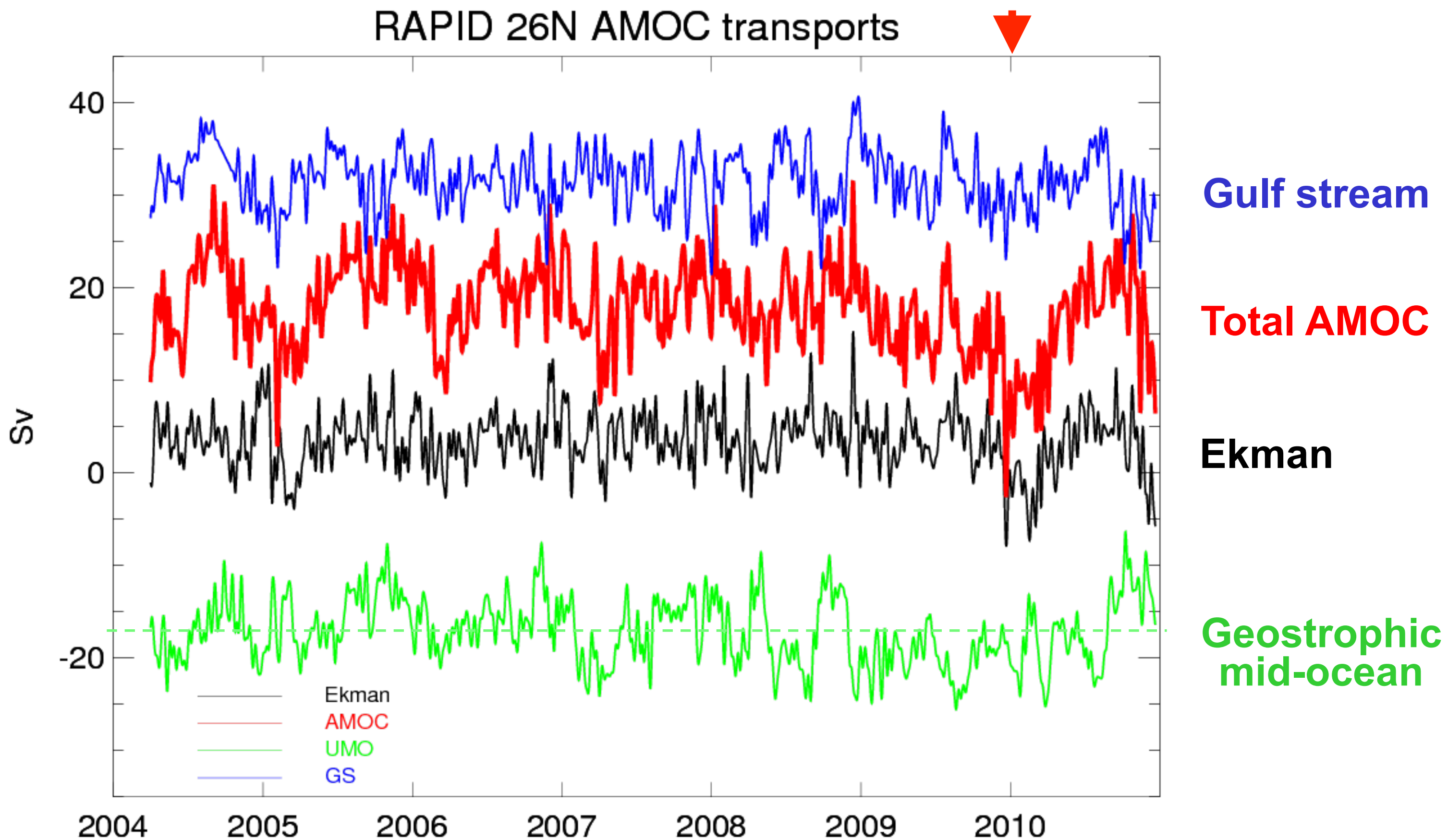
Observations from the RAPID/MOCHA 26°N array

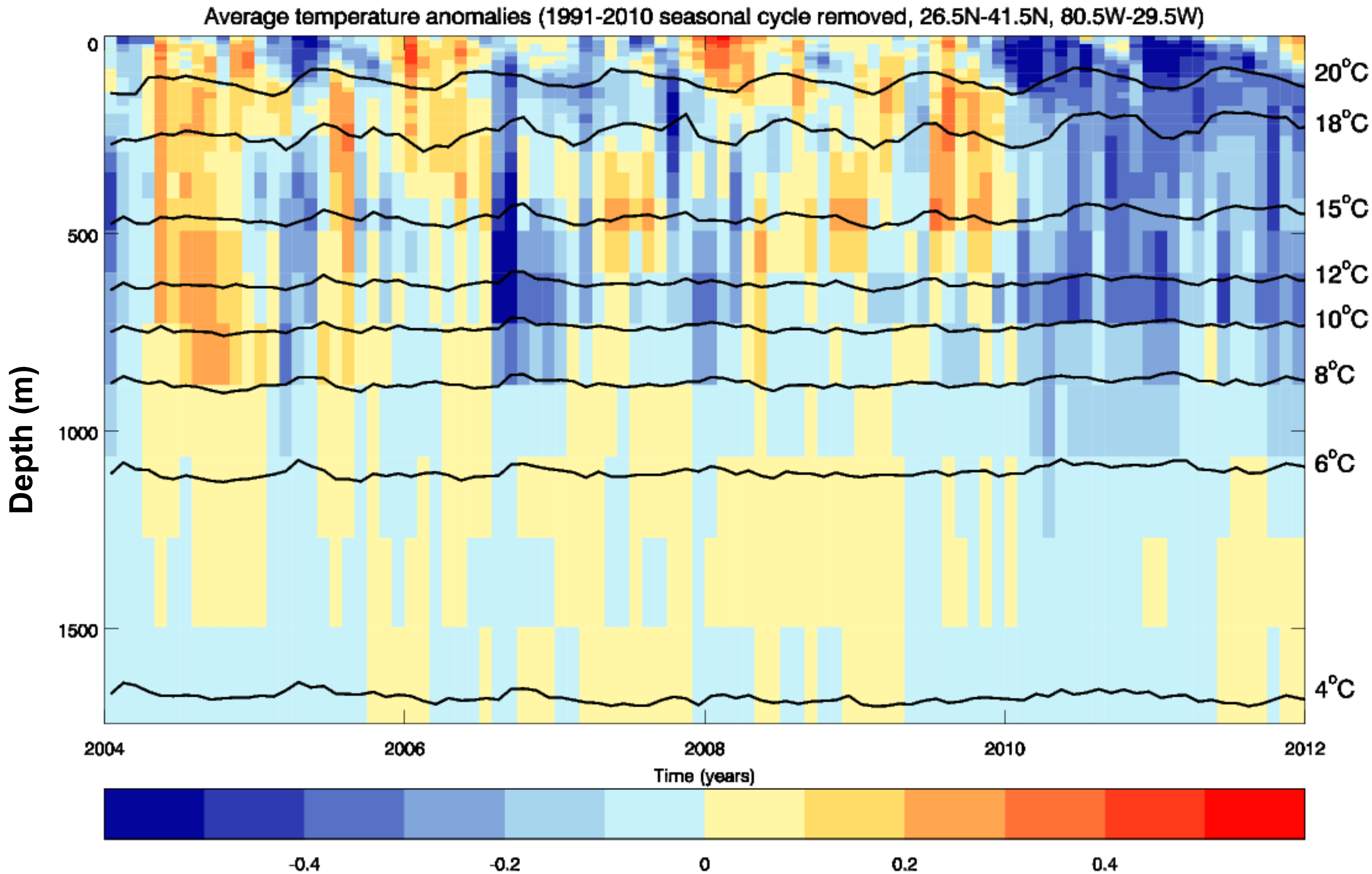


April-April transports (Sv)	17.2	19.3	18.8	17.9	17.4	12.2

Cunningham et al. (2007), Kanzow et al. (2010). Most recent data are described by McCarthy et al. (submitted to GRL)

Associated cooling of the subtropical North Atlantic

26.5°N to 41.5°N OHC anomaly 1×10^{22} Joules ≈ 0.3 PW for 1 year



Calculated from Met Office EN3 v2a objective analysis (Ingleby and Huddleston, 2007)

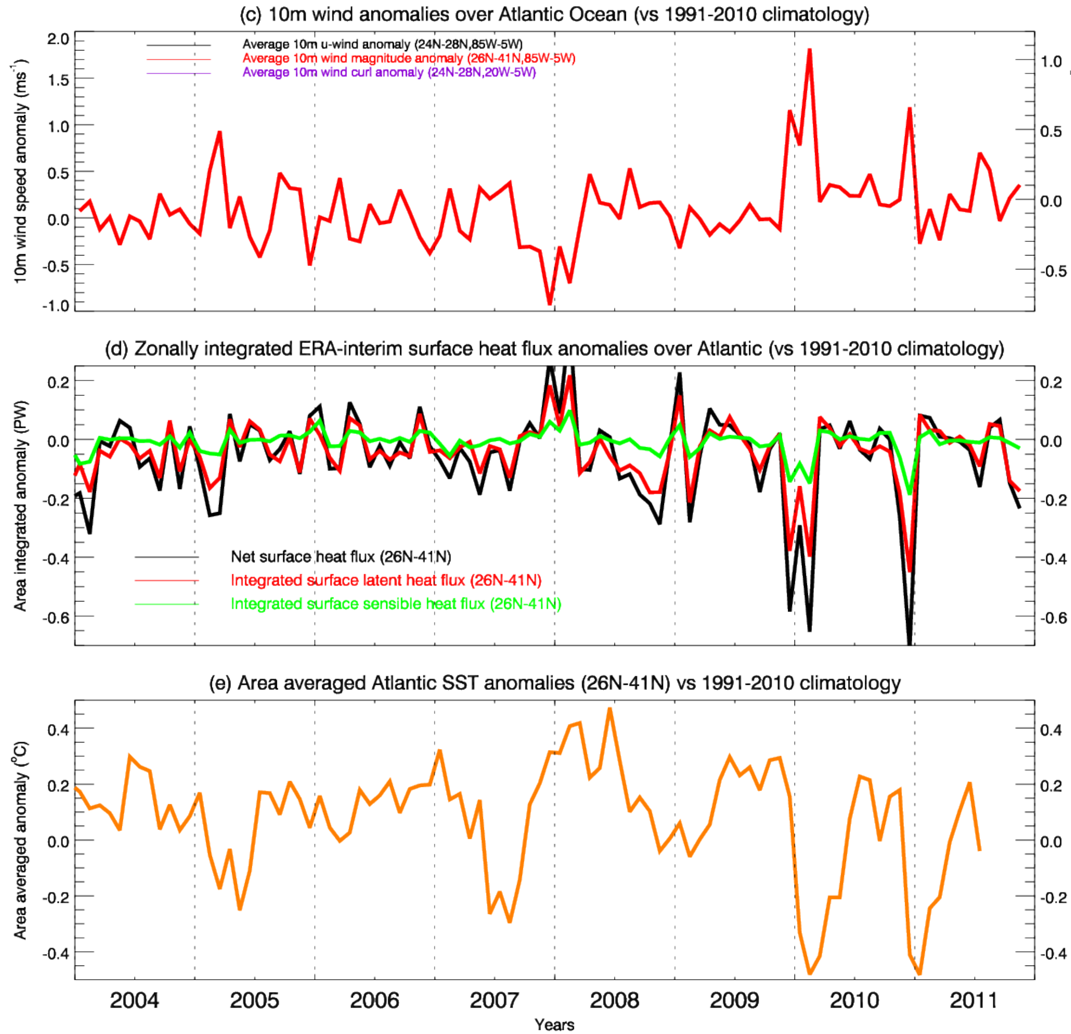
Extreme NAO events of winter 2009/10 and Dec 2010

Anomalies vs 1991-2010 in selected climate variables (26°N-41°N)

Wind speed magnitude anomalies (ERA-interim)

Surface heat-flux anomalies (ERA-interim)

Sea surface temperature (HadISST)



ERA-interim atmospheric re-analysis described in Dee et al. (2011). HadISST dataset described in Rayner et al. (2003).

Motivation for understanding this event

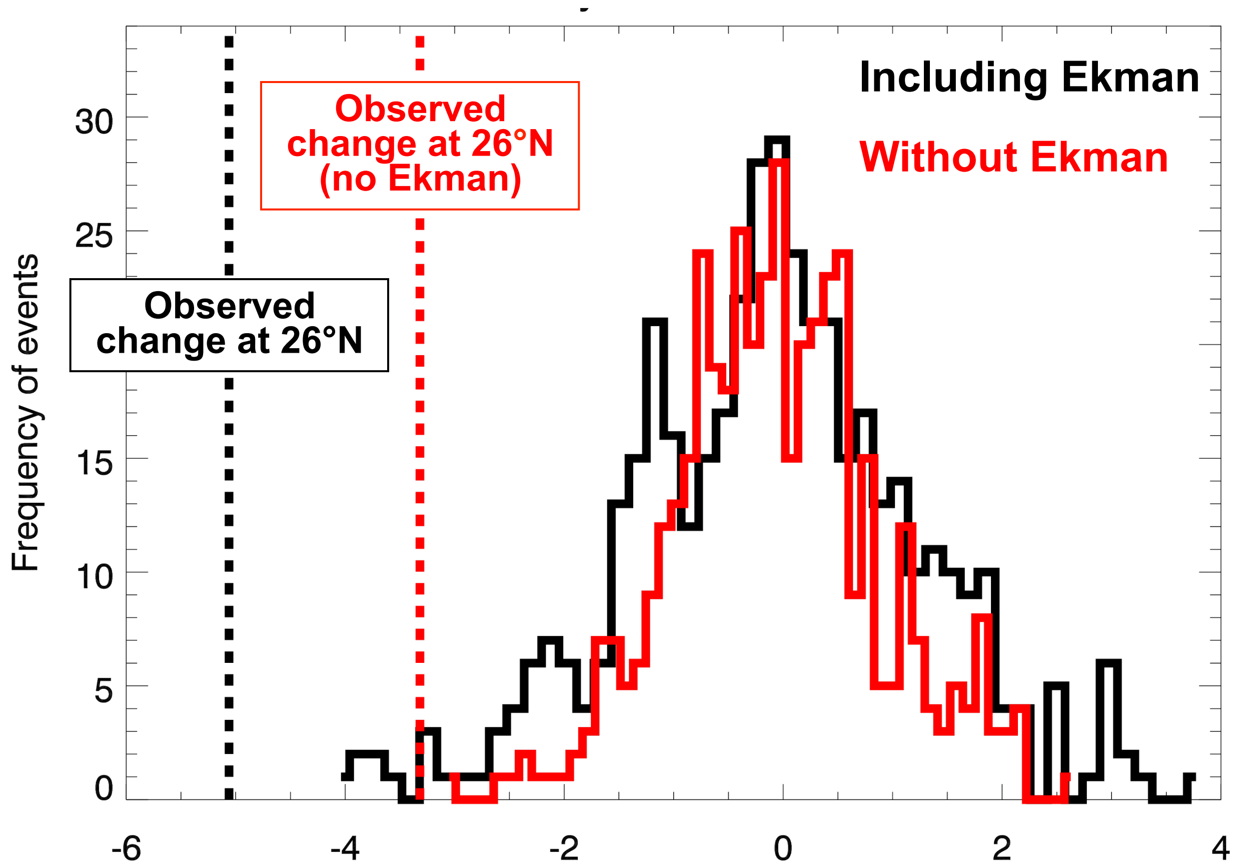
1. Are such AMOC changes captured by Met Office ocean simulations, analyses and climate forecasts?

2. What is the role of such AMOC changes in inter-annual climate variability?

3. Are there any implications for improved seasonal to decadal prediction? AMOC role in repeat negative NAO of December 2010?

Are similar AMOC changes present in coupled climate models?

Distributions of annual mean AMOC change between consecutive years in ~500 years of HadGEM2-ES control simulation



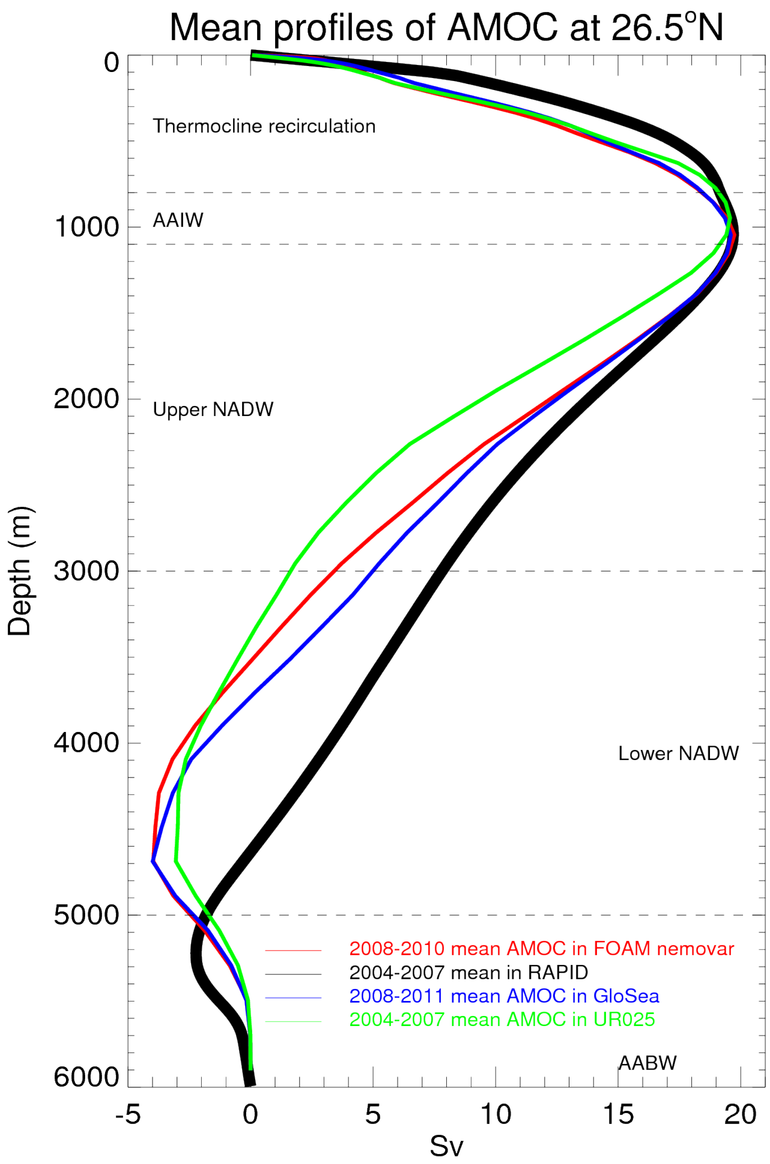
Distributions in HadCM3 and HadGEM1are almost identical to those in HadGEM2-ES

Summary of ocean state estimates used in this presentation

	FOAM NEMOVAR (Met Office)	**GloSea5 (Met Office)**	**UR025.4 (Reading/MO)**
Period covered	2008-2010	1994-2011 (covered by multiple start dates)	1989-2010 (continuous run)
Ocean model	NEMO ¼ degree L75	NEMO ¼ degree L75	NEMO ¼ degree L75
Surface fluxes	Direct fluxes from Met Office NWP model	**Bulk formula from ERA interim reanalysis**	**Bulk formula from ERA interim reanalysis**
Assimilation scheme	**3DVAR (NEMOVAR)**	**3DVAR (NEMOVAR)**	Analysis Correction (old FOAM system)
Data assimilated	SST, SSH anomalies, T & S profiles and sea ice concentration.	SST, SSH anomalies, T & S profiles and sea ice concentration.	SST, SSH anomalies, T & S profiles and sea ice concentration.
Run by	Jennie Waters (+ FOAM team)	Drew Peterson (+ GloSea team)	Keith Haines and Hao Zuo (+ FOAM team)

Main differences are in assimilation scheme, surface forcings, initial conditions and details of physical model configuration. Multiple start dates from GloSea indicate that experiments with different initial conditions rapidly converge.

Comparison of mean AMOC stream functions at 26°N



✓ Mean strength and depth of maximum pretty good – similar in all model estimates.

Meridional heat transport by MOC at 26°N	
FOAM (2008-2010)	1.03 PW
GloSea (2008-2011)	1.13 PW
UR025 (2004-2007)	1.04 PW
RAPID (2004-2007)*	1.19 PW

**From Johns et al. (2011)*

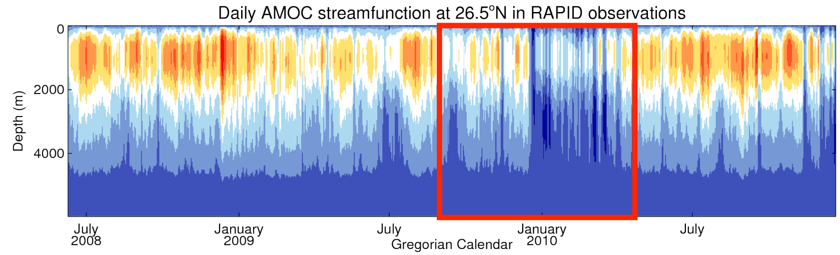
✘ AMOC return flow too shallow in models – does this contribute to bias in modelled heat transports?

✘ Boundary between AMOC and AABW cells too shallow and AABW cell stronger in models.

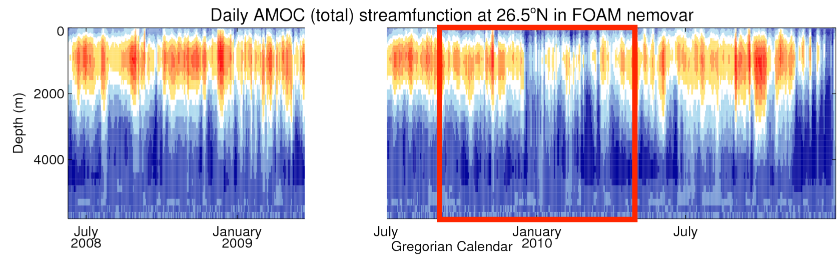
Model profiles calculated using velocities

Hovmöller plots of AMOC profiles at 26°N (2008-2010)

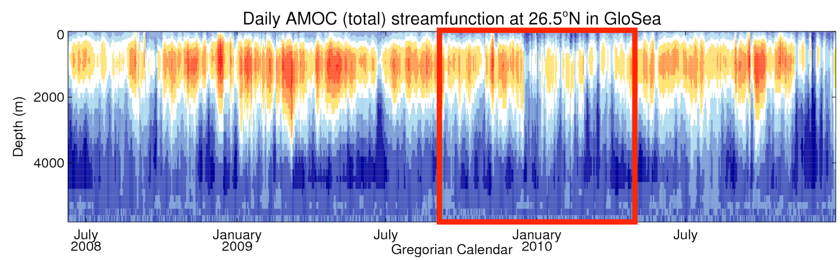
RAPID 26°N (daily)



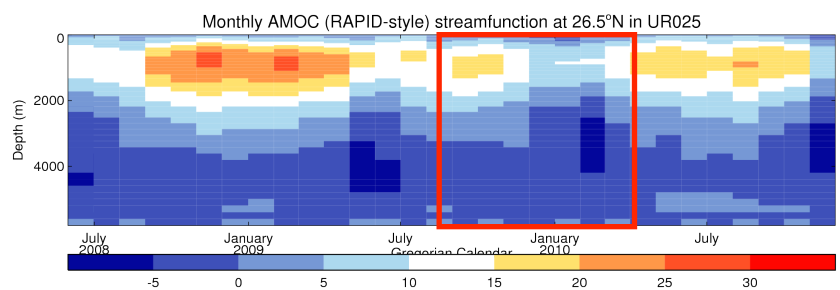
FOAM NEMOVAR (daily)



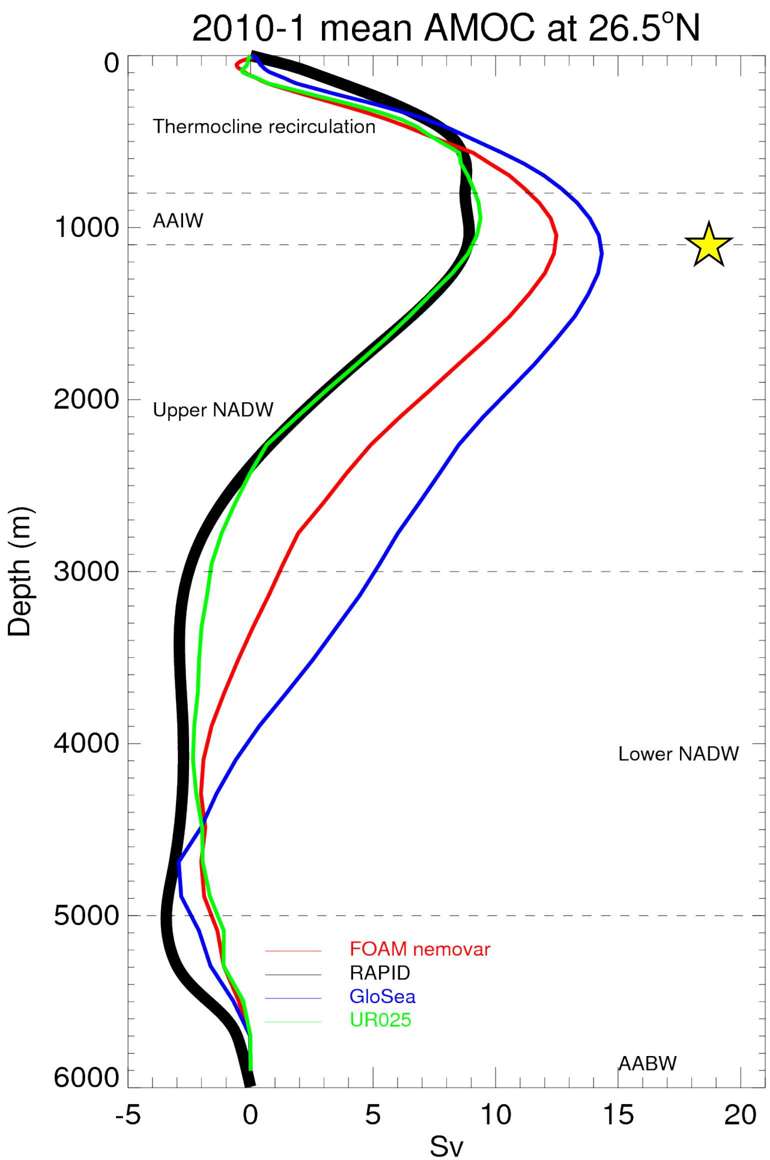
GloSea5 (daily)



UR025 (monthly)



January 2010 AMOC stream functions at 26°N



✓ UR025 seems to accurately capture magnitude and depth structure of AMOC during depth of minimum. Heat transport by AMOC reduced by ~50%

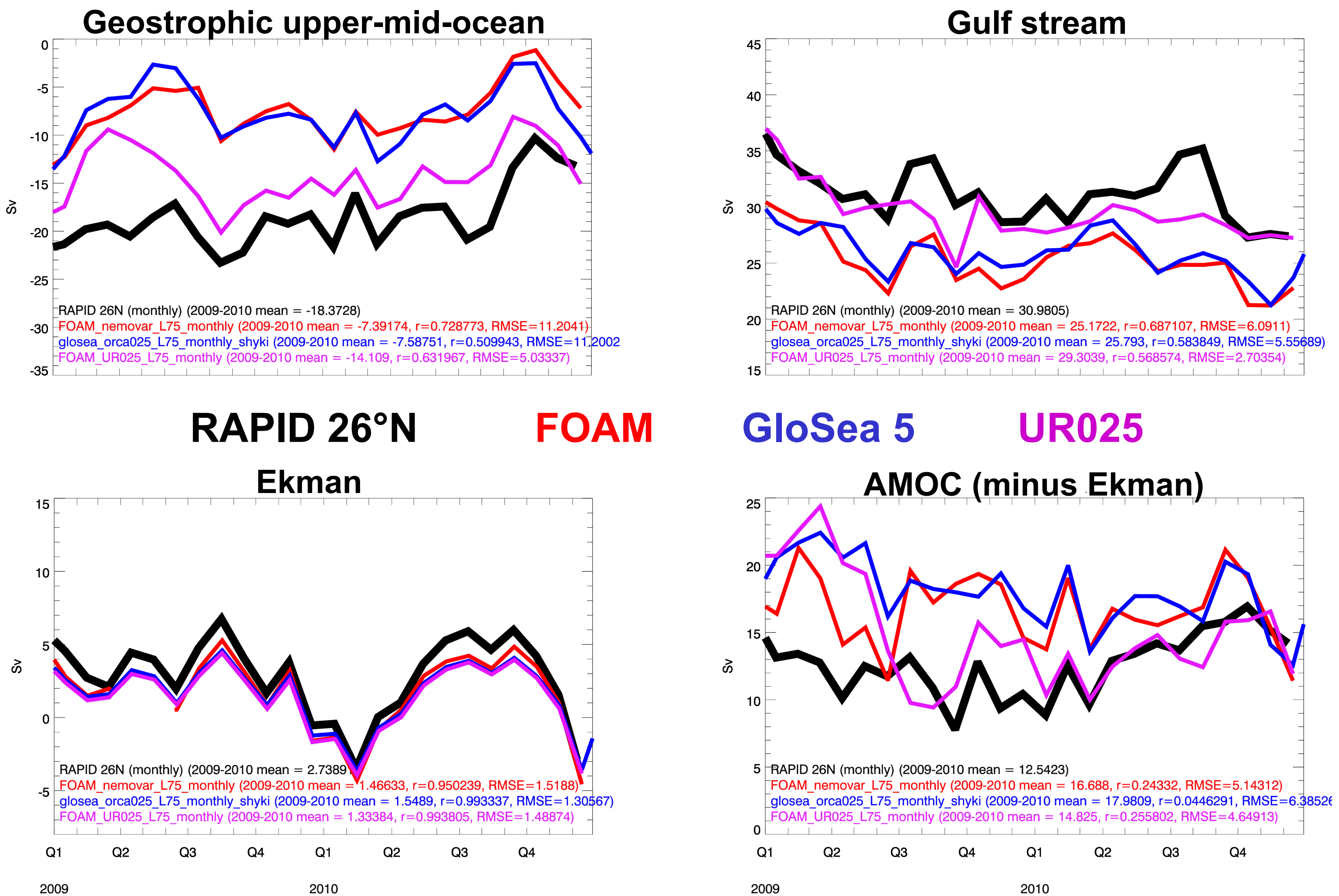
2010/01 heat transport by MOC at 26°N	
FOAM	0.61 PW
GloSea	0.76 PW
UR025	0.45 PW
RAPID	?

✗ AMOC and OHT are reduced in FOAM and GloSea, but not to the same extent as UR025.

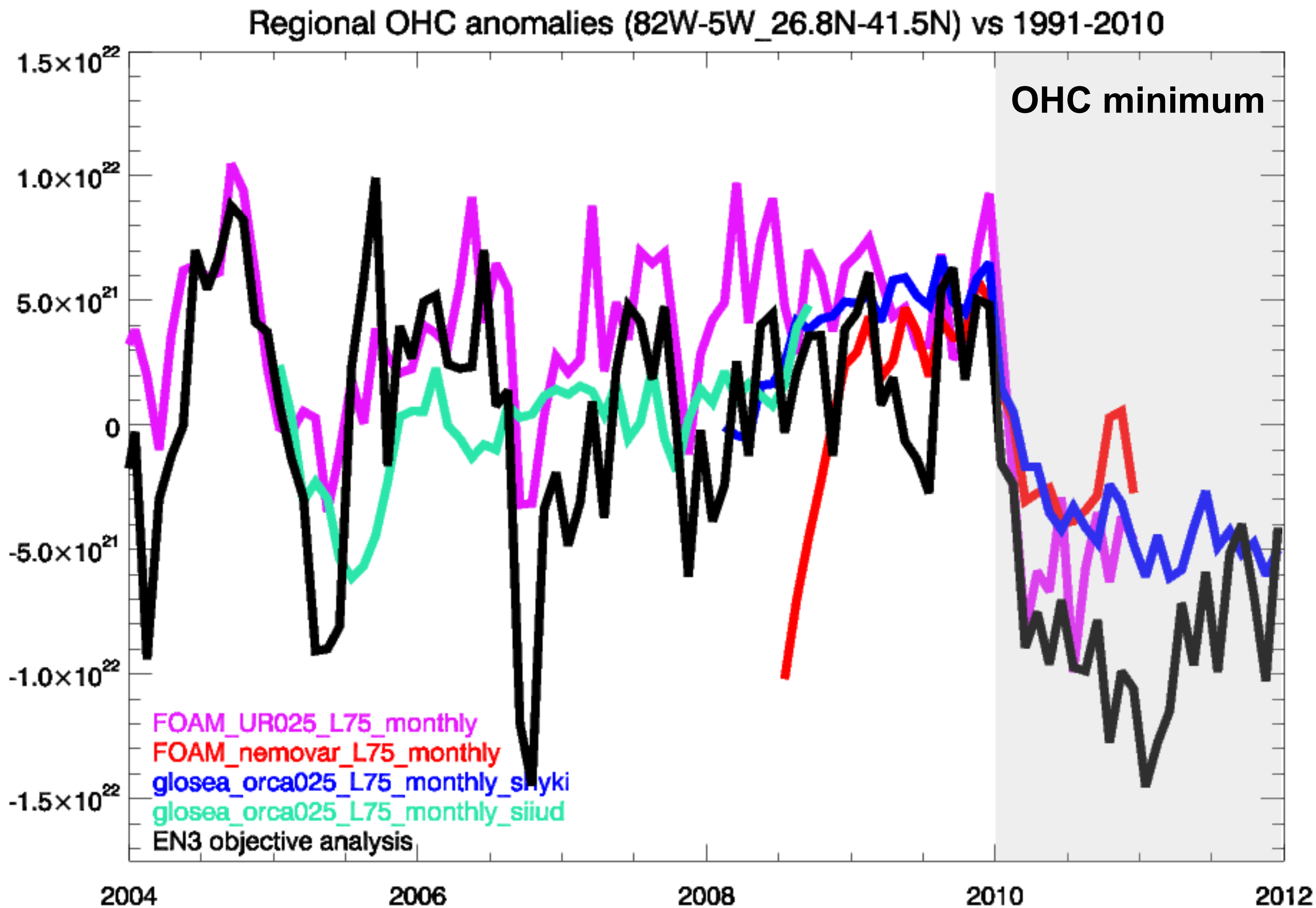
✗ GloSea and FOAM fail to capture transport compensation in lower NADW layer.

Model profiles calculated using velocities

What is source of model differences in AMOC at 26°N?



Sub-tropical heat content anomalies in state estimates



EN3 v2a **FOAM** **GloSea 5** **UR025**

Sub-tropical Atlantic heat budget (26°N-41°N)

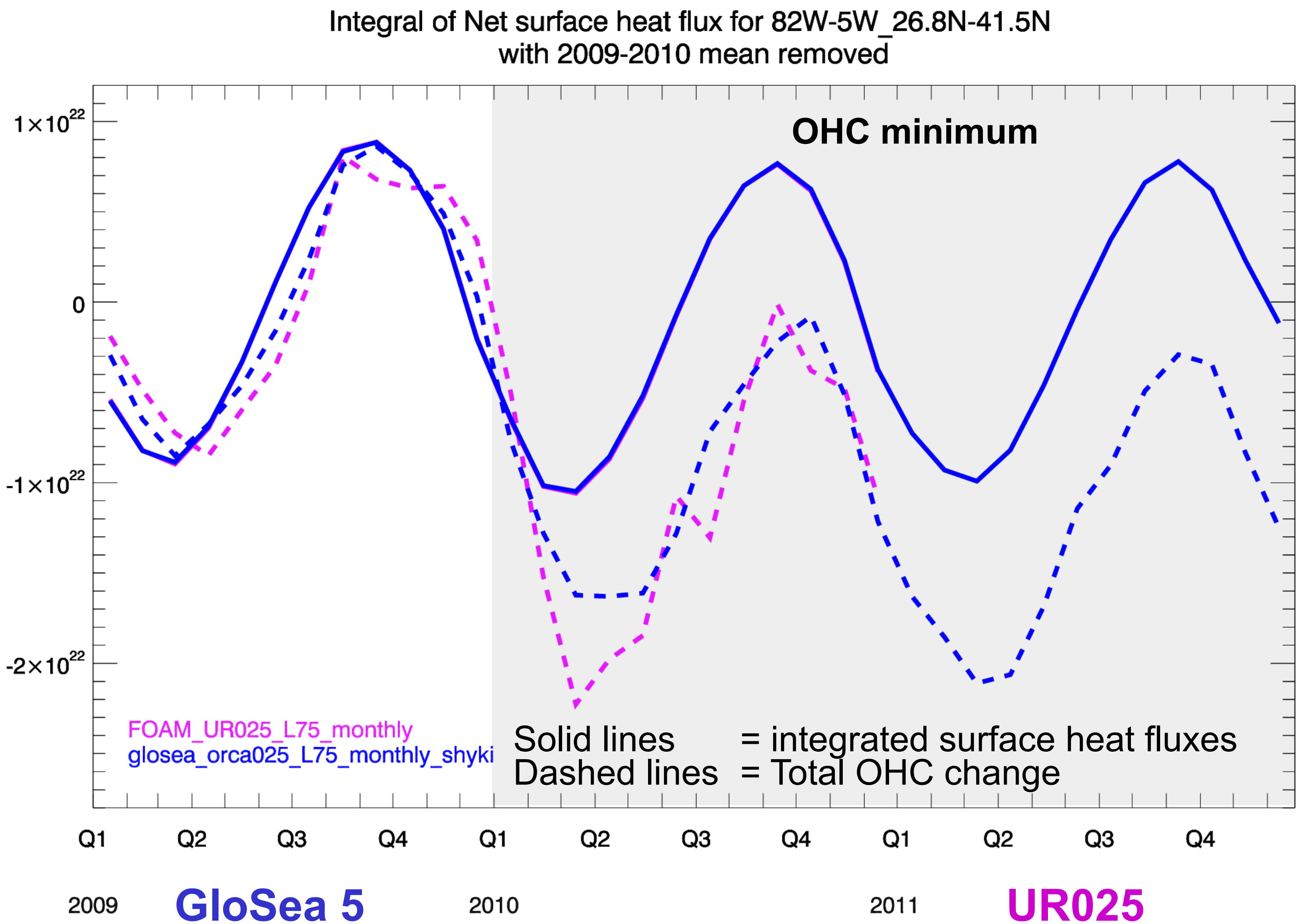
1. Following slides show components of heat budget for GloSea 5 and UR025 experiments.

2. Total OHC changes are compared with the
   - *Integrated ERA-interim surface fluxes*
   - *Integrated Ekman heat transport divergence*
   - Integrated MOC heat transport divergence

3. UR025 seems to better capture AMOC weakening at 26N, so should give us an indication of role for non-Ekman AMOC transports in recent sub-tropical cooling.

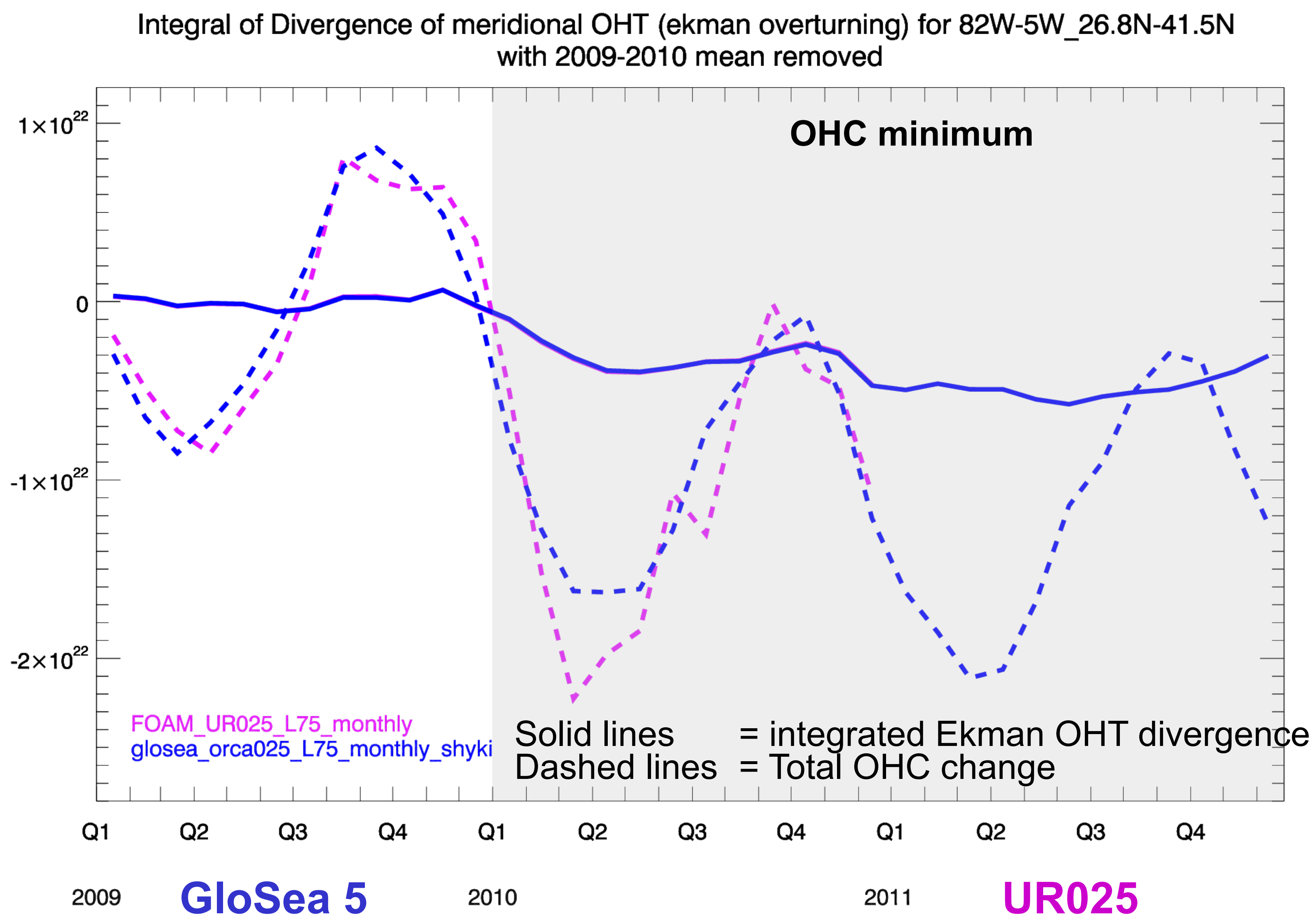
Sub-tropical heat budget: surface heat fluxes

Integrated ERA-interim heat fluxes are insufficient to explain sub-tropical cooling



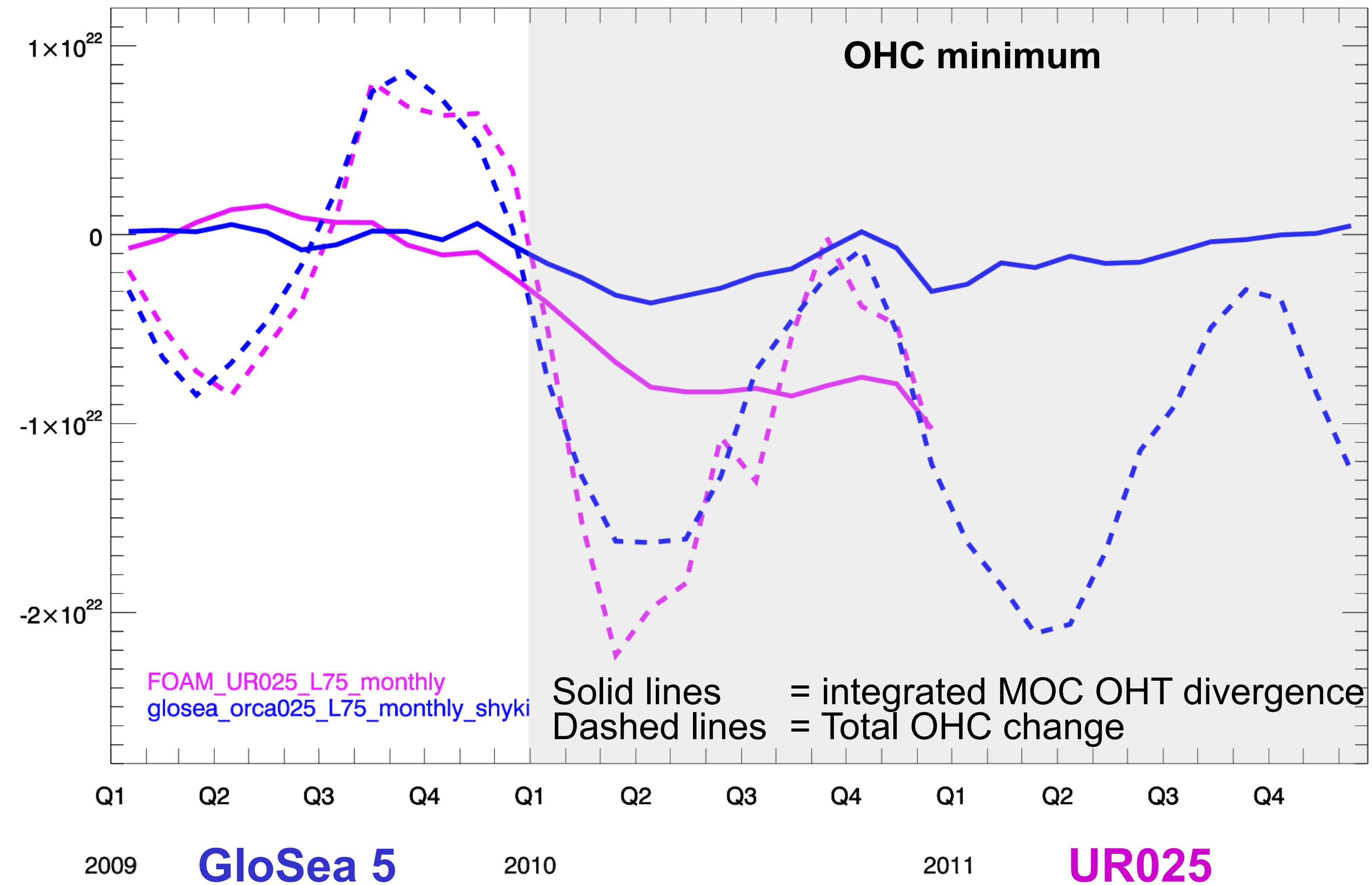
Sub-tropical heat budget: Ekman transport divergence

GloSea and UR025 are forced with identical ERA-interim wind-stress



Sub-tropical heat budget: MOC transport divergence

UR025, which better simulates AMOC at 26°N, indicates a significant role for AMOC in sub-tropical cooling.



Summary

1. AMOC in reanalyses is sensitive to data assimilation and/or details of physical model configuration.
   - *Sensitivity experiments ongoing*

2. Model that best captures AMOC weakening during 2009/10 indicates a substantial role for non-Ekman AMOC transports in recent sub-tropical cooling.
   - *Any implications for predictability of Dec 2010 NAO?*

Questions?

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Extra slides

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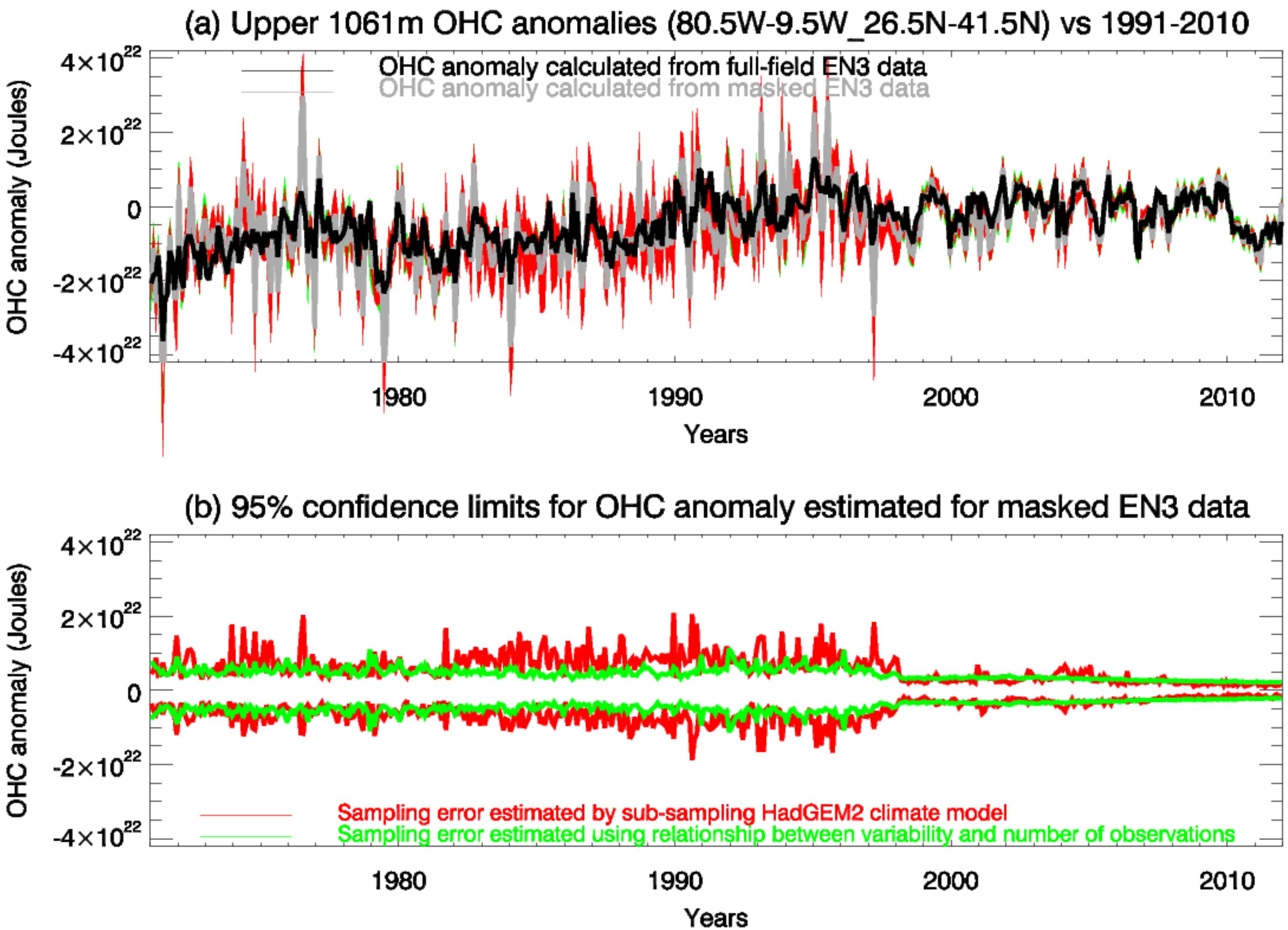
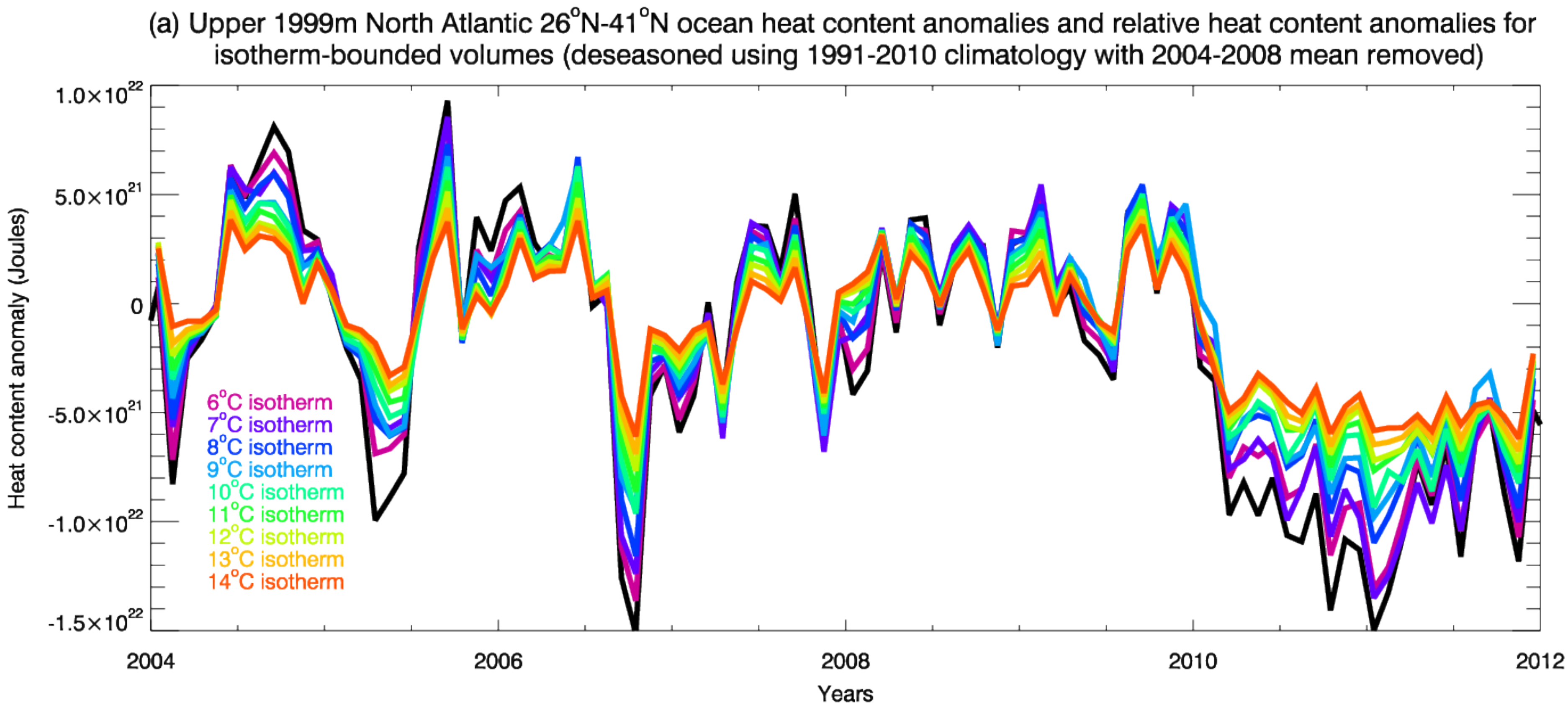
Is observed cooling an artefact of sampling uncertainty?



Attribution of OHC anomaly: heat content anomalies bounded by isotherms

Relative heat content anomalies bounded by isotherms in EN3 v2a

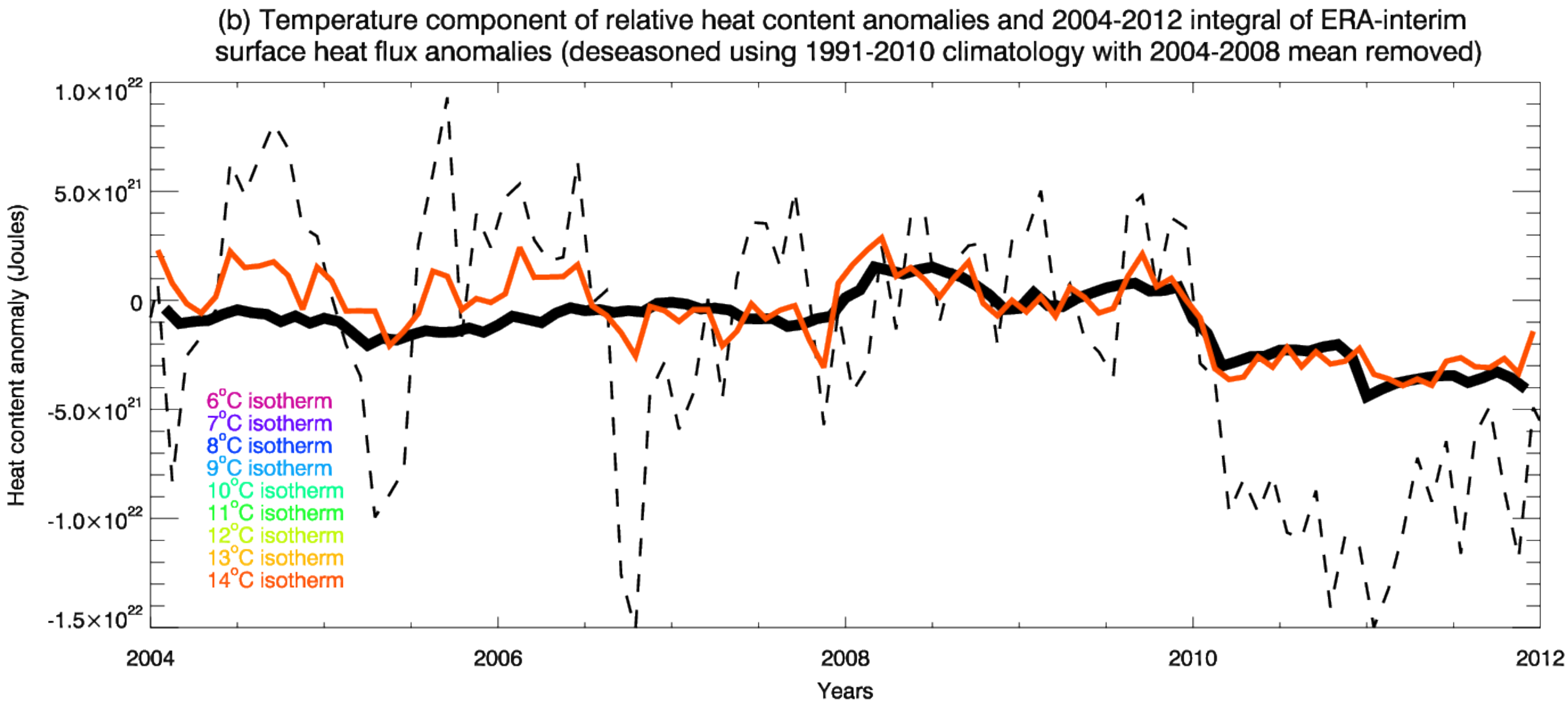


Total relative OHC anomaly = advective component + surface flux component

Surface flux component can be approximated by average temperature change above a reference isotherm (see Palmer and Haines, 2009)

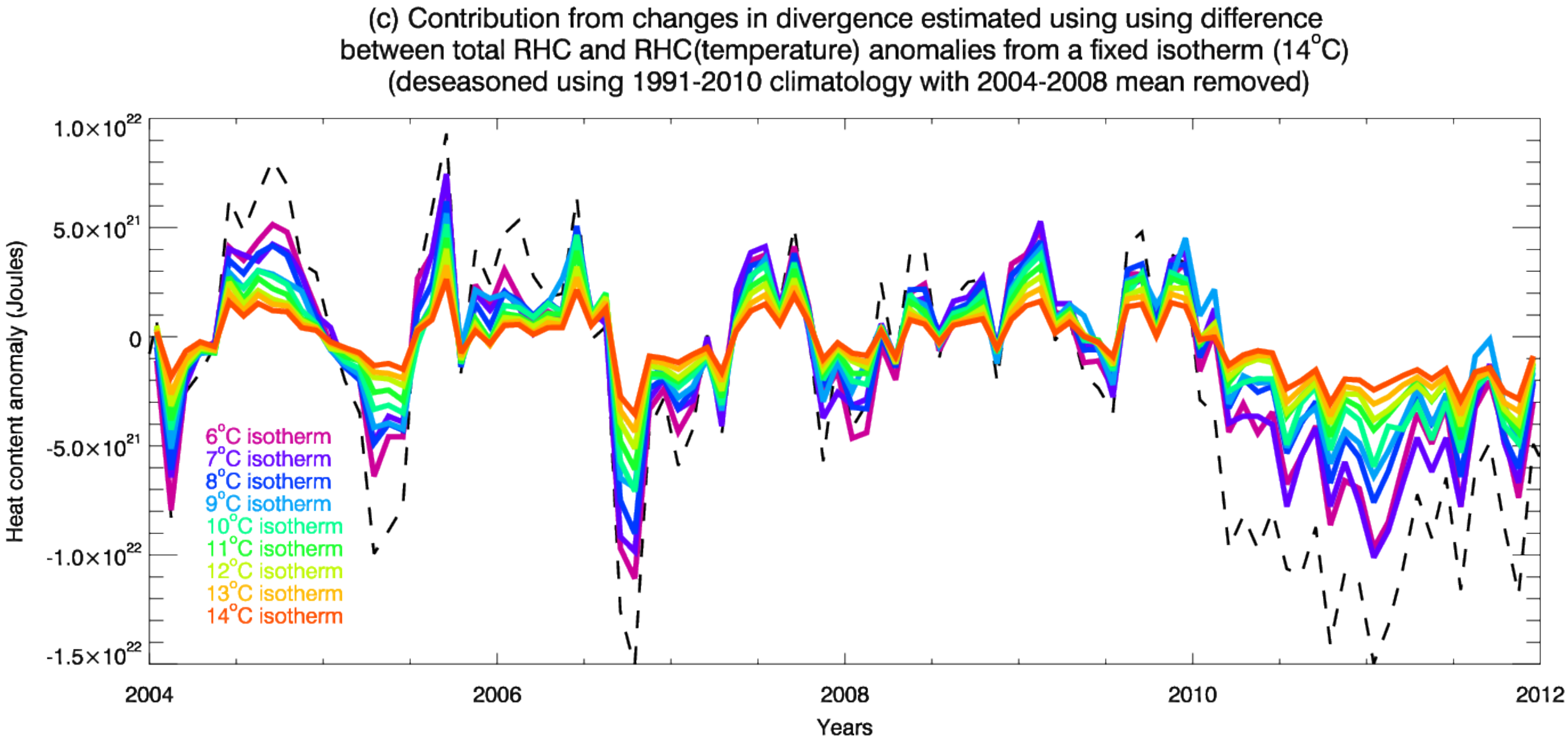
Component of OHC change attributed to surface fluxes

OHC anomalies due to changes in average temperature above 14C isotherm compared with integral of ERA-interim surface flux anomalies



Heat content anomalies due to changes in the average temperature above the 14C isotherm closely track the integral of surface heat anomalies from ERA-interim.

Component of OHC change attributed to advection



Large fraction of heat content change is occurring due to changes in the volume of temperature classes cooler than 10°C.