# Heat and Freshwater Convergence Anomalies in the Atlantic Ocean Inferred from Observations

### Kathryn Kelly

Applied Physics Laboratory University of Washington, Seattle, Washington

> Kyla Drushka & LuAnne Thompson University of Washington

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### **Atlantic Meridional Overturning Circulation (AMOC)**

AMOC expected to weaken with climate change

- What is the source of anomalies?
- Will AMOC slowdown increase freshwater convergence (feedback)?



Kuhlbrodt et al. (2007)

## **Heat & Freshwater Budgets**

- 8 regions (box model)
- Infer heat transport convergence (HTC)
- Infer freshwater convergence (FWC)
- data assimilation with a Kalman filter



### **Heat Transport Convergence**



change in heat content = surface flux + heat transport

#### convergence

change in freshwater content = surface flux + freshwater convergence

### **Meridional Heat Transport from HTC**



- Compute HTC for adjacent boxes
- Integrate HTC from north to south
- Add an integration constant: 41°N estimate [Willis 2010]

# **Model Equations**

Sea level anomalies: sum of mass & steric components

$$\eta = \eta_M + \eta_T + \eta_S$$

with dependence on temperature and salinity as

$$\eta = \eta_M + \int_z \frac{\alpha \delta T - \beta \delta S}{\rho_0} \, dz$$

Thermosteric component forced by surface heating Q<sub>net</sub>

$$\frac{\partial \eta_T}{\partial t} = \frac{\alpha Q_{net}}{\rho_0 c_p} + U_T$$

Halosteric component forced by freshwater fluxes

$$\frac{\partial \eta_S}{\partial t} = \beta \tilde{S} \left( P - E \right) + U_S$$

Residuals U are heat (HTC) & freshwater convergence (FWC)

### **MHT Anomalies**

Integrate HTC & match 41°N MHT

Anomalies increasing from North to South

High level of coherence from 40°N to 35°S



1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014

# **Sensitivity to Flux Products**



# **Sensitivity to Freshwater Flux**



*Similar, but* ERA Interim has smaller trend in FWC than GPCP + OAFlux flux (baseline)

# **Sensitivity to GRACE Products**



#### Steric estimates: SSH-OM vs. TSL+HSL

#### JPL/RL05M better match than GRCTellus RL05

=> small difference in FWC

### MHT Estimates at RAPID/MOCHA Array



#### MHT estimates within error bars

(extended using SSH-OM as thermosteric proxy)

### **Coherent MHT Anomalies**

Where do interannual MHT anomalies originate?

- no obvious propagation
- South Atlantic?





1994 1996 1998 2000 2002 2004 2006 2008 20 0 2012 2014

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### **Agulhas Leakage Estimates**

1.5

0.75 <sup>L</sup> ayuamic topography.

-1.5

- 1. Estimate net transport using SSH:Agulhas Current minus Agulhas Return Current
- 2. MHT from Agulhas rings (pinched off): area X SSHA





### **MHT and Agulhas Leakage**

MHT at 35°S *correlated* with both Agulhas Leakage and ring heat flux

AL somewhat smaller than MHT (using 0.05 PW/Sv)

Ring heat flux much smaller (Loveday et al 2015)



# **Freshwater Flux Convergence**

FWC (interannual) resembles Atlantic river discharge (GRDC)

#### MHT (MOC) is weakening as FWC is increasing after 2004:

FWC trend (0.079 Sv/decade) matches Greenland Ice Sheet melt trend (0.080 Sv/decade)

[Enderlin et al 2015]

No evidence that the weakening AMOC causes increase in FWC



# Conclusions

Heat and freshwater box model for MHT & FWC

- Results robust for inputs of surface fluxes, hydrography, ocean mass
- MHT coherent from Gulf Stream to Agulhas Current (no lag)
- Agulhas Leakage correlated with MHT, but somewhat smaller
- Interannual FWC anomalies from rivers
- FWC trend from Greenland Ice Sheet (not MOC)

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# Sensitivity to TSL, HSL



- original (UK Met Office)
- minimize steric/(SSH-OM) differences [baseline]
- using SSH-OM proxy for TSL