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SMR/1837-3

2007 ICTP Oceanography Advanced School

30 April - 11 May, 2007

Monitoring the Atlantic Ocean Circulation for Rapid Climate Change

H. Bryden
National Oceanography Centre
Southampton, UK

Monitoring the Atlantic Ocean Circulation for Rapid Climate Change

Lecture for ICTP Advanced School on Oceanography
International Centre for Theoretical Physics
Trieste, Italy April-May 2007

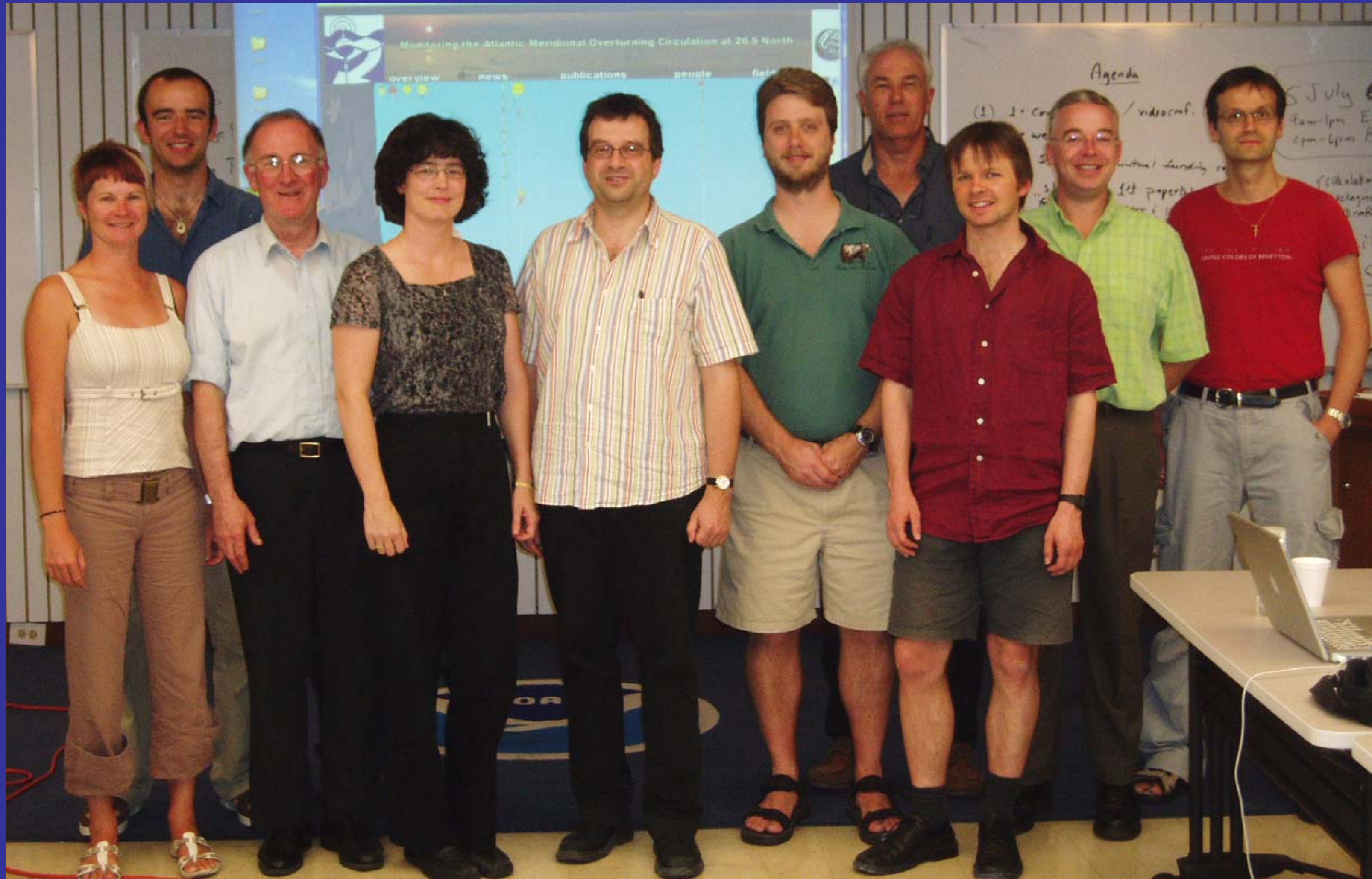
Harry L. Bryden

School of Ocean and Earth Science

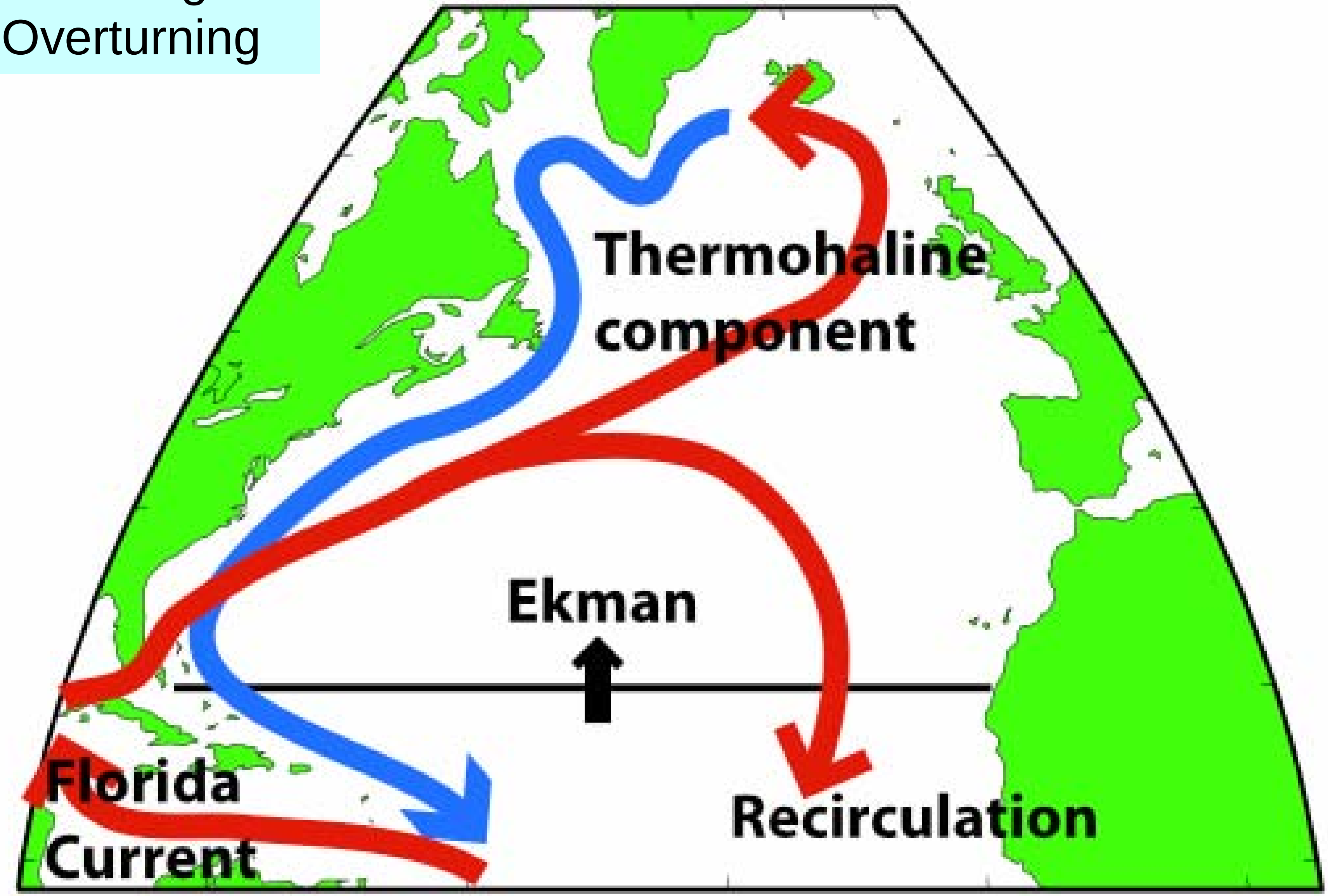
University of Southampton

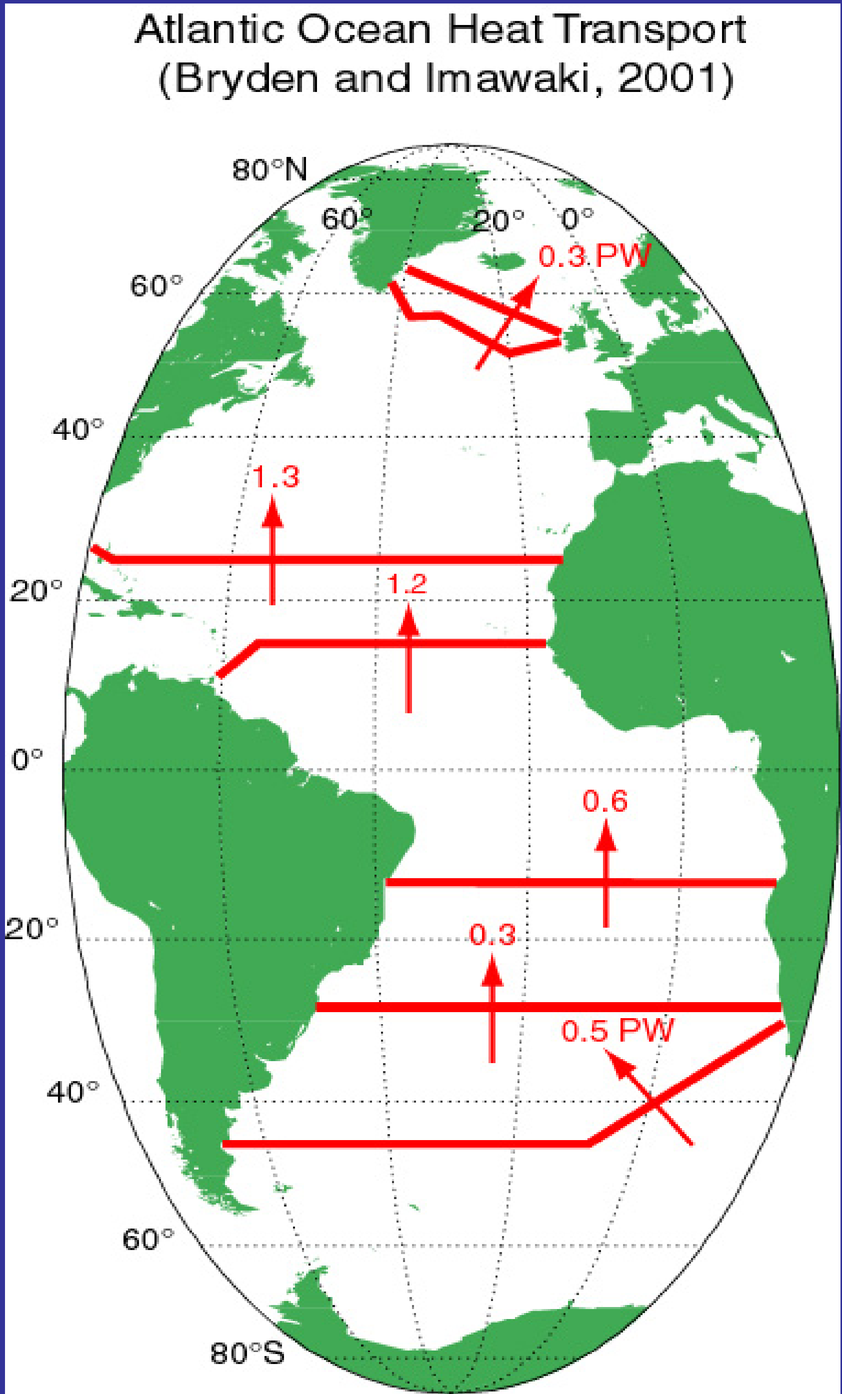
National Oceanography Centre, Southampton

UNIVERSITY OF SOUTHAMPTON AND
NATURAL ENVIRONMENT RESEARCH COUNCIL


Monitoring the Atlantic Meridional Overturning Circulation at 26.5 North
overview
news
publications
people
Agenda

Circulating and Overturning

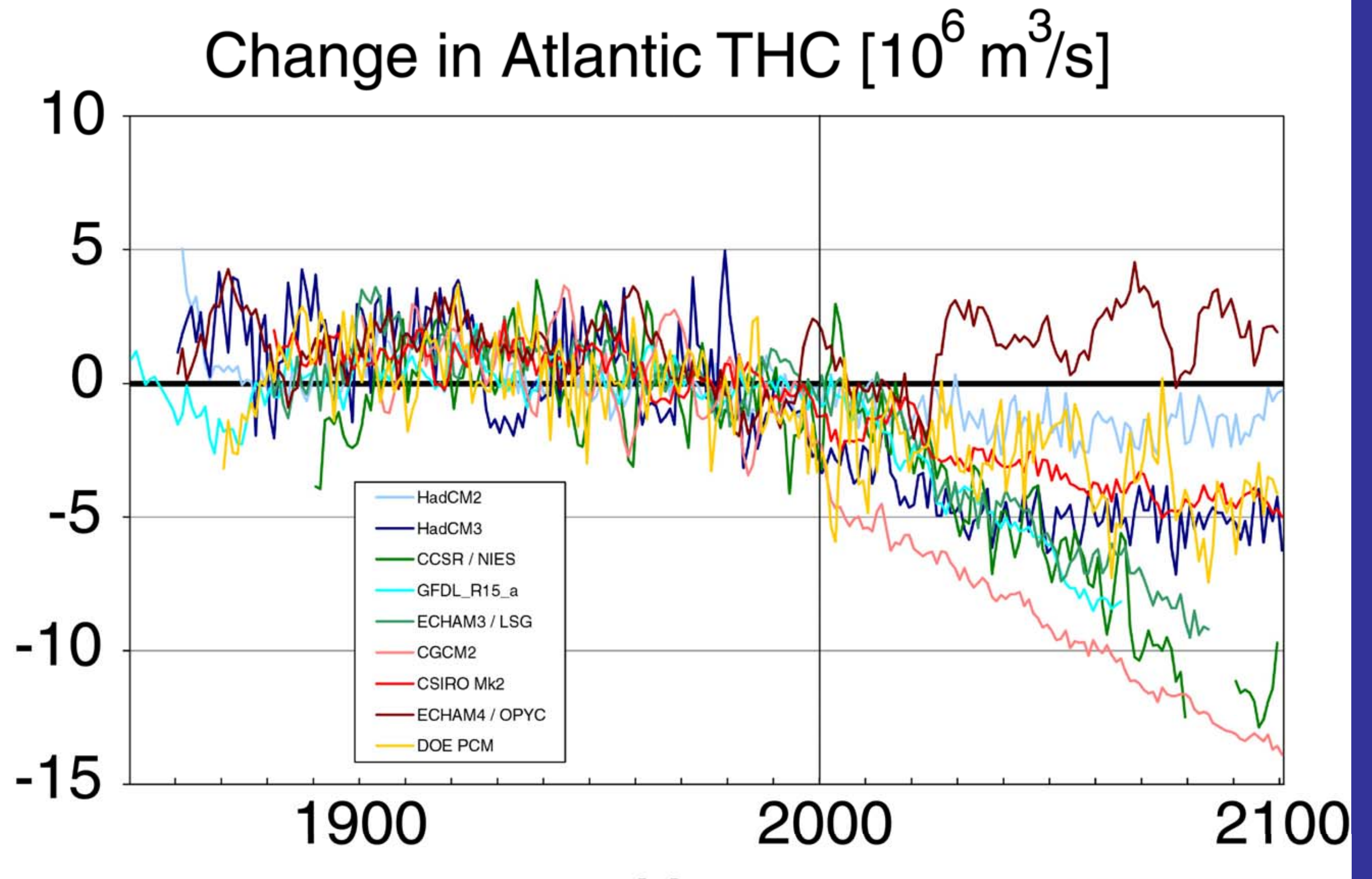




The Atlantic Meridional Overturning Circulation (MOC) in which warm upper waters flow northward and cold deep waters flow southward transports heat northward throughout the Atlantic Ocean. This heat is given up to the atmosphere north of 26°N.

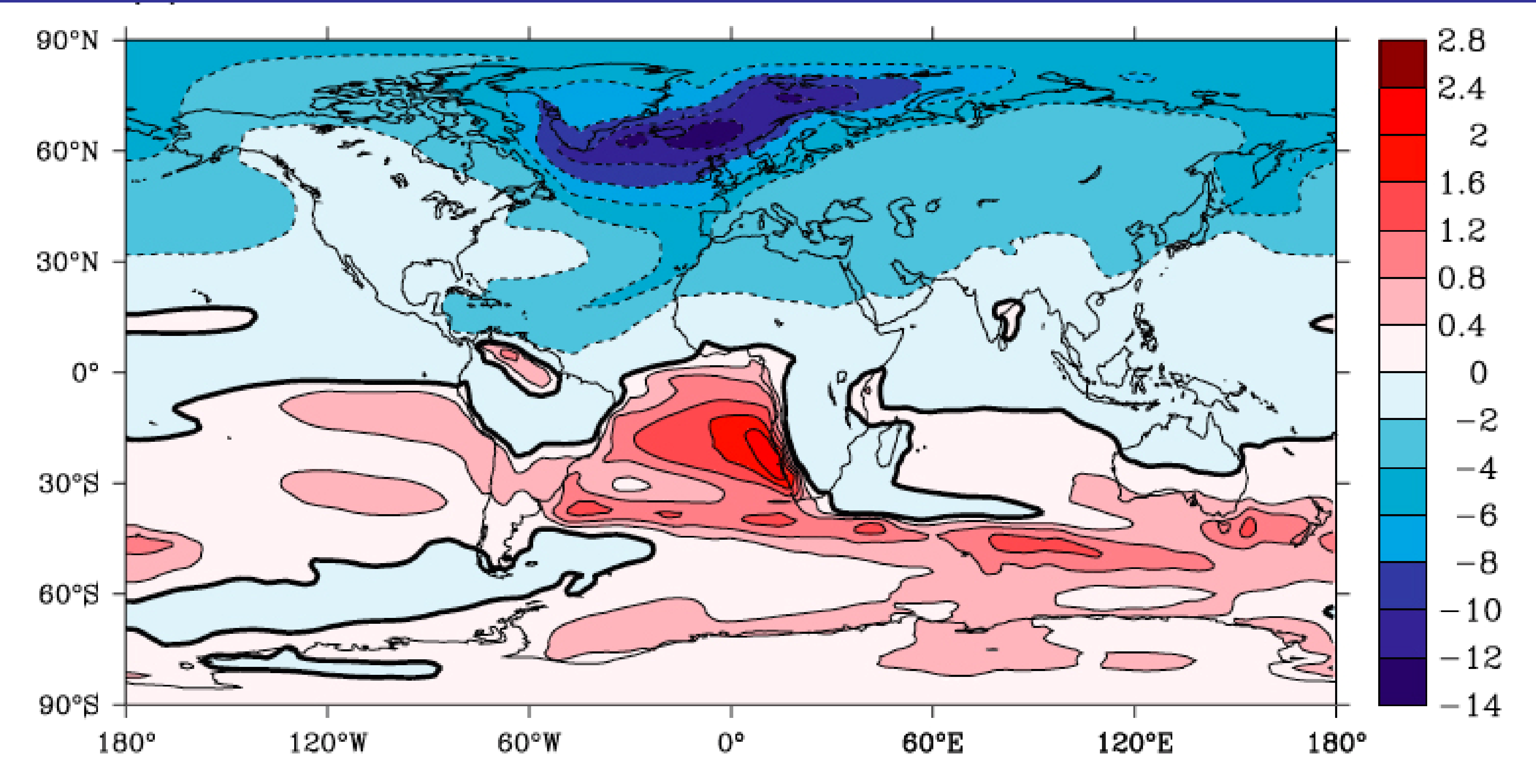
The ocean heat transport across 26°N in the Atlantic accounts for 25% of the maximum poleward heat transport required of the combined ocean and atmosphere to balance the global radiation budget of the earth

Could the Atlantic MOC be slowing down?

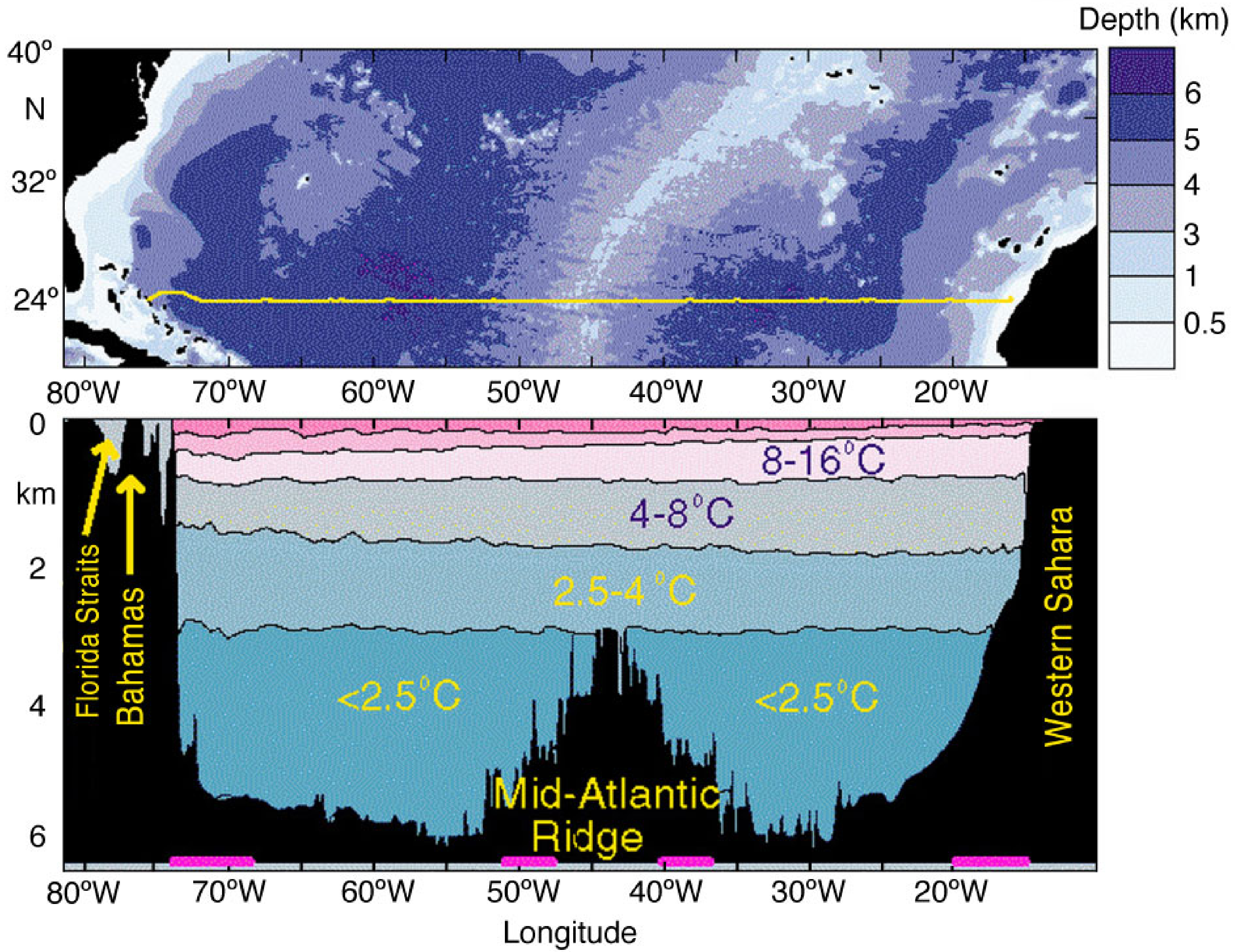


IPCC, 2001

Temperature Change after the Atlantic MOC has been shut down for 100 Years according to coupled climate models

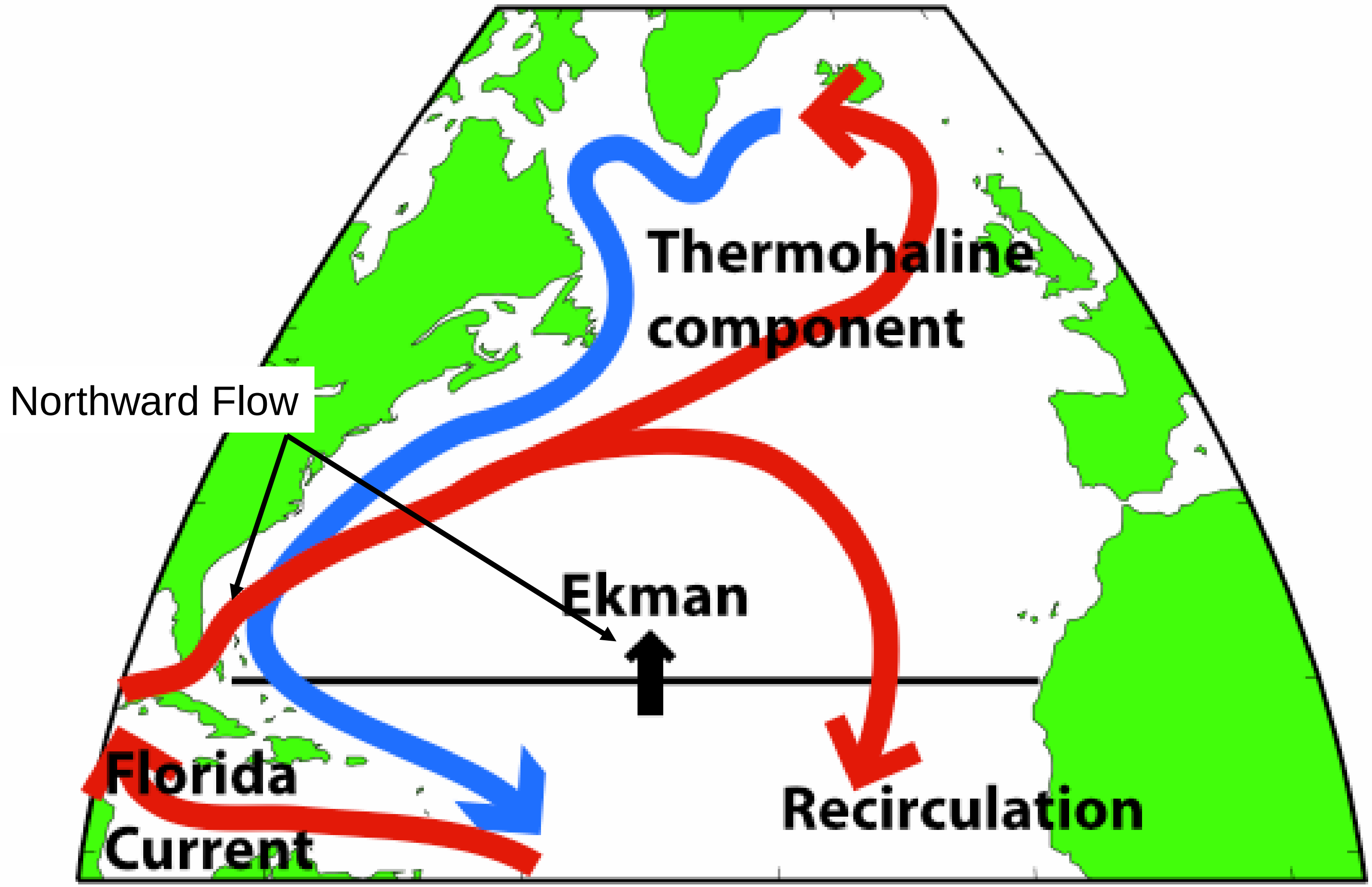


Stouffer et al., 2005



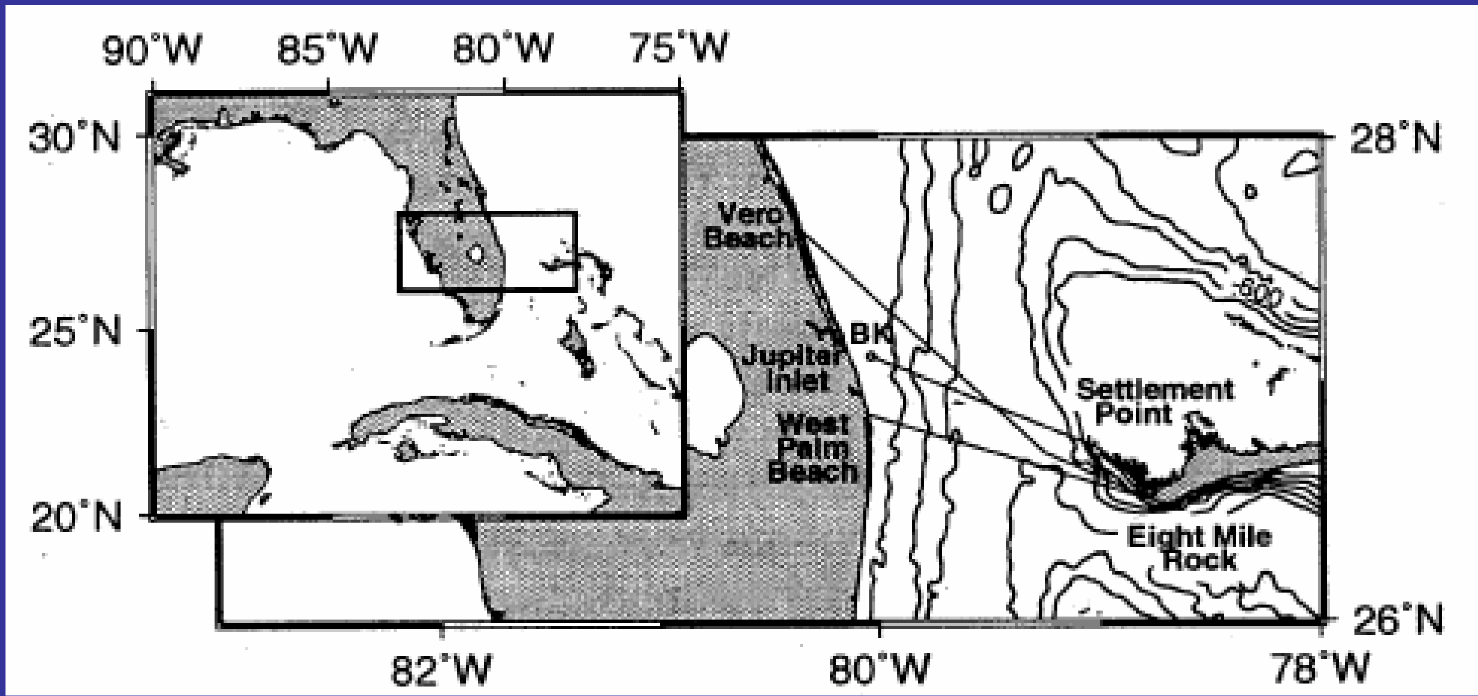
Depth (km)
6
5
4
3
1
0.5
40°
N
32°
24°
80°W
70°W
60°W
50°W
40°W
30°W
20°W
0
km
2
4
6
8-16°C
4-8°C
2.5-4 °C
<2.5°C
<2.5°C
Florida Straits
Bahamas
Western Sahara
Mid-Atlantic
Ridge
Longitude

Northward Flow across 26°N occurs in surface Ekman layer and in Florida Straits



Florida Straits Transport

Gulf Stream transport time series from electromagnetic cable.

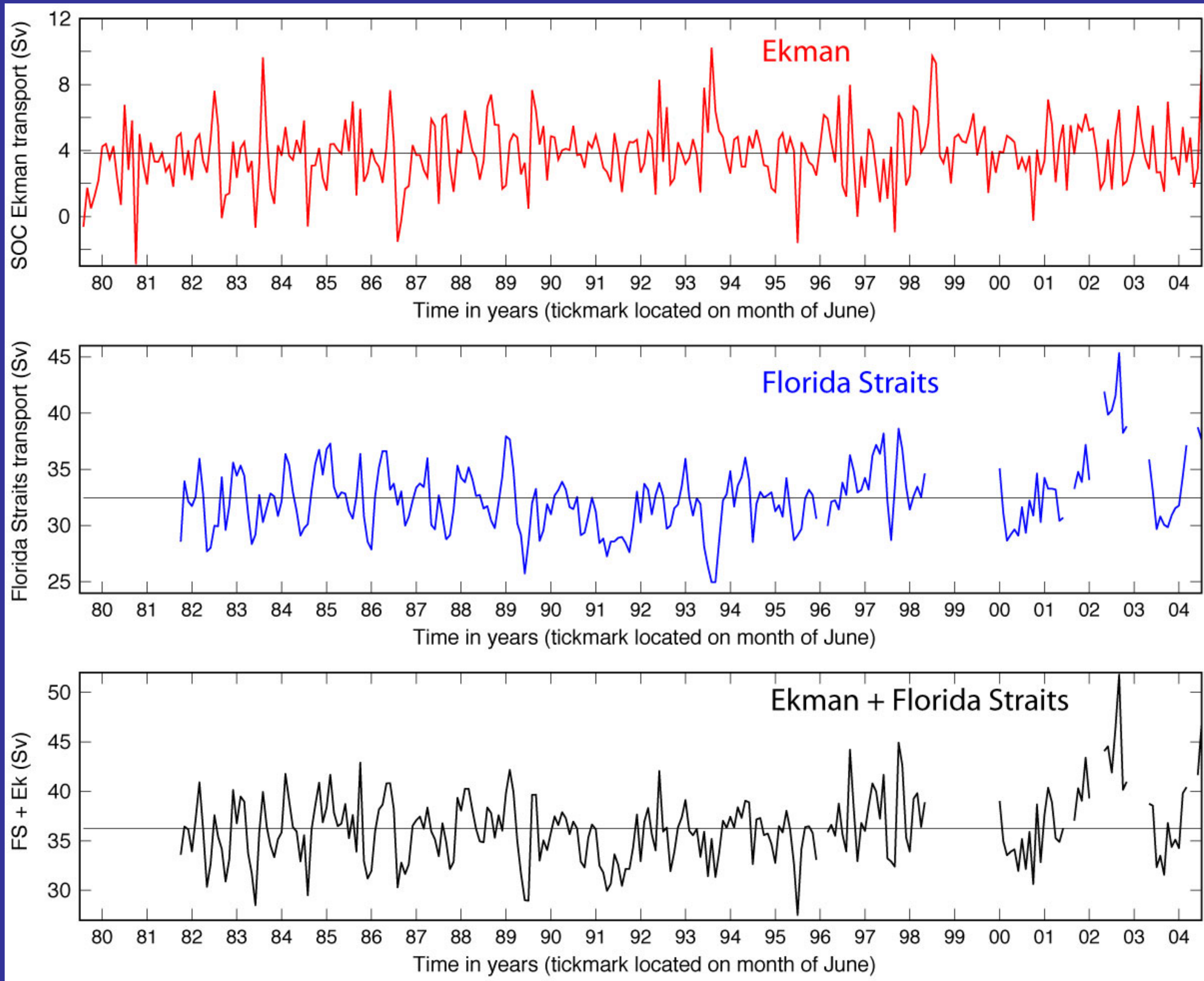


Continuous record between 1982 and present except between October 1998 and and March 2000.

Baringer and Larsen, 2001

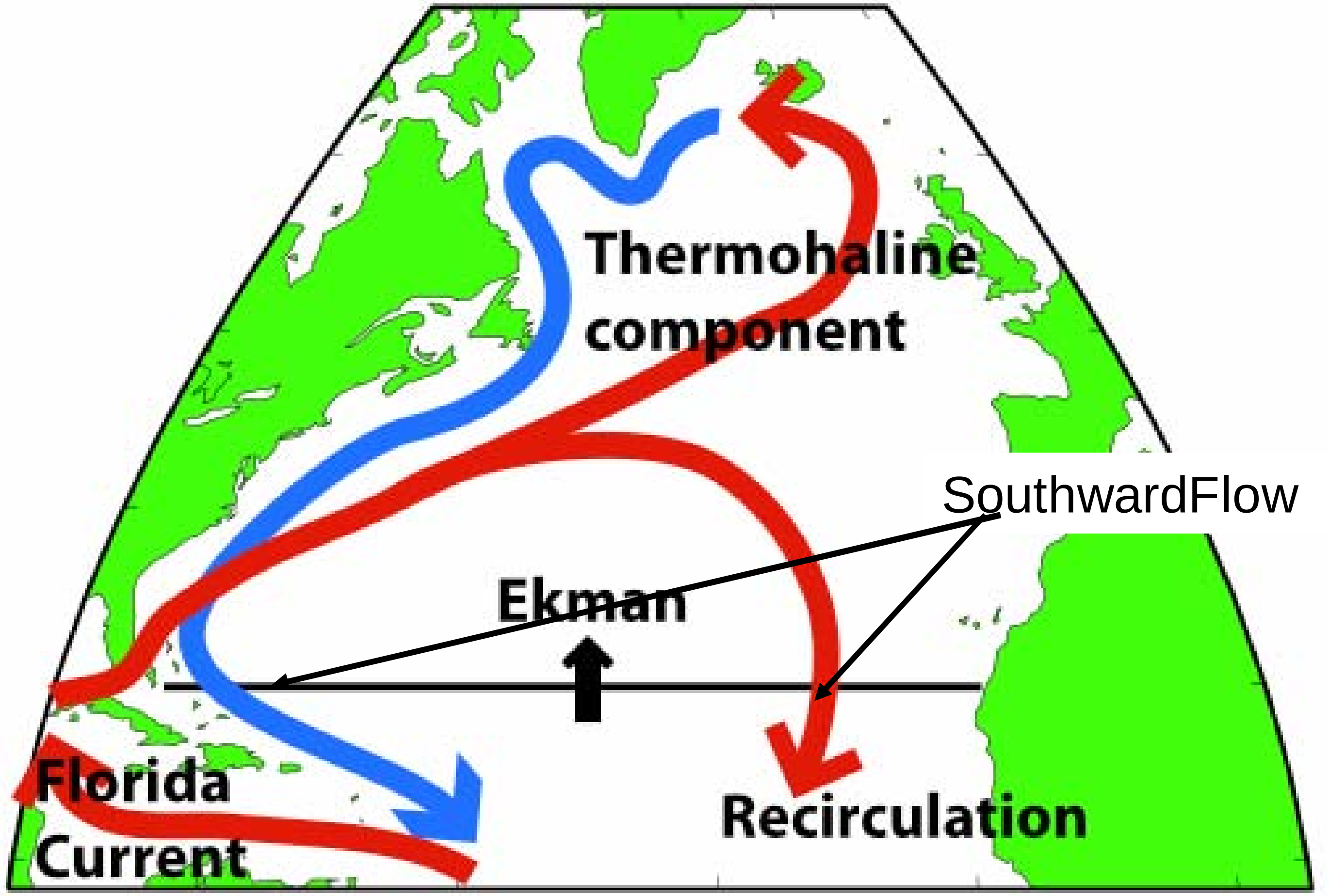
We can easily monitor the northward flows across 26°N

25 Years of Ekman Transport and Florida Straits Transport



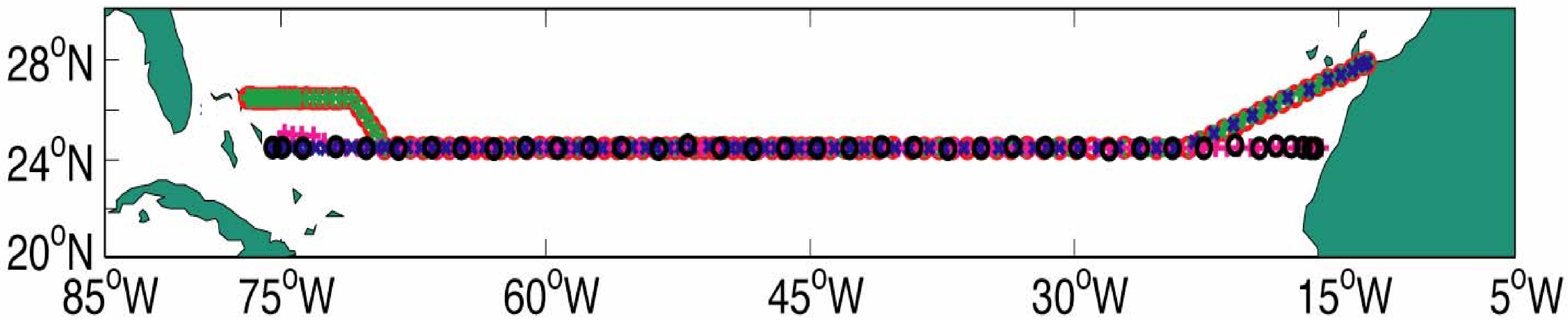
Mean	STD
3.8	1.9
32.4	3.0
36.3	3.5

The southward transport is more difficult to monitor and requires measurements across the basin

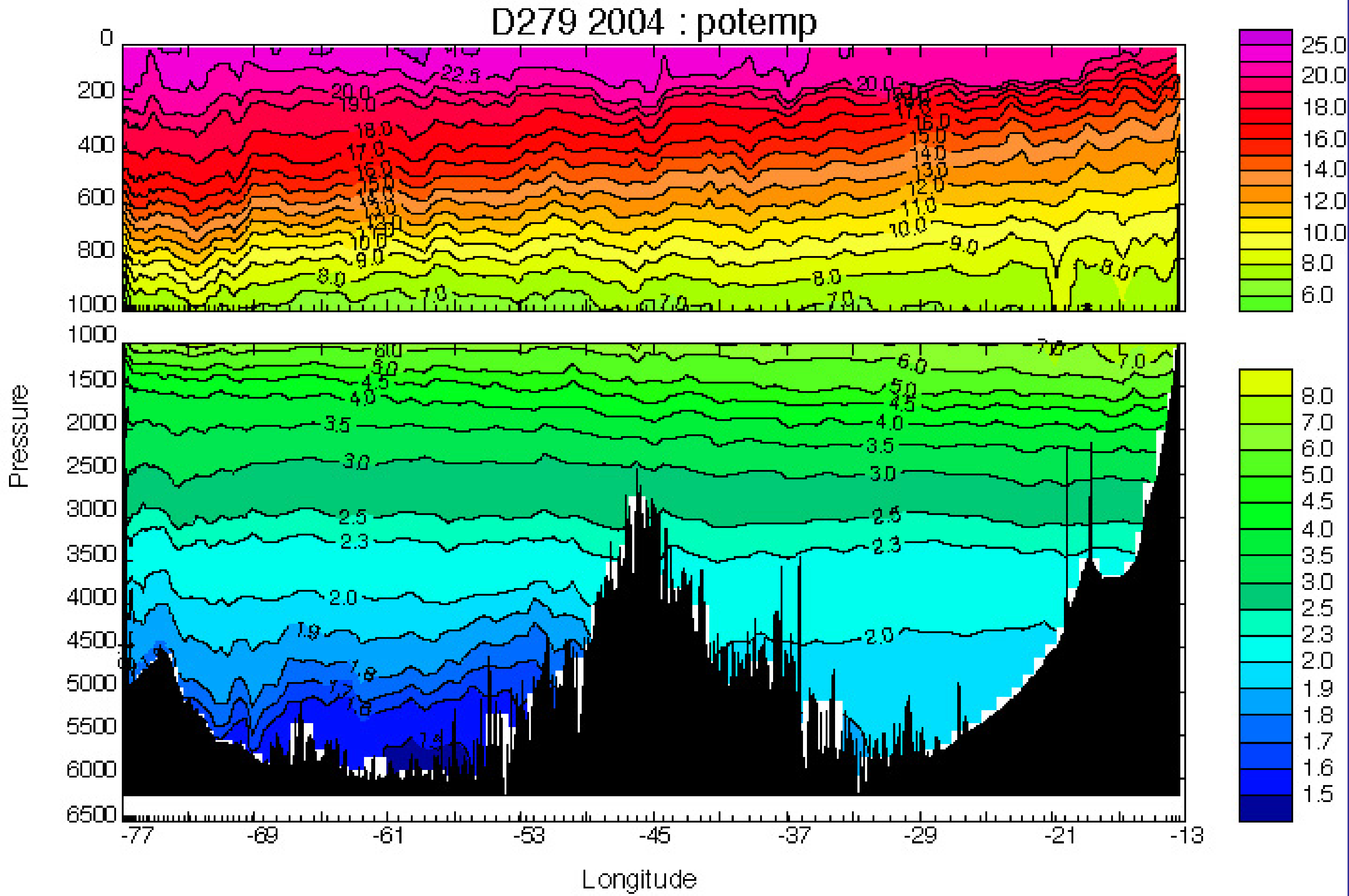


Traditional Monitoring of Mid-Ocean Circulation

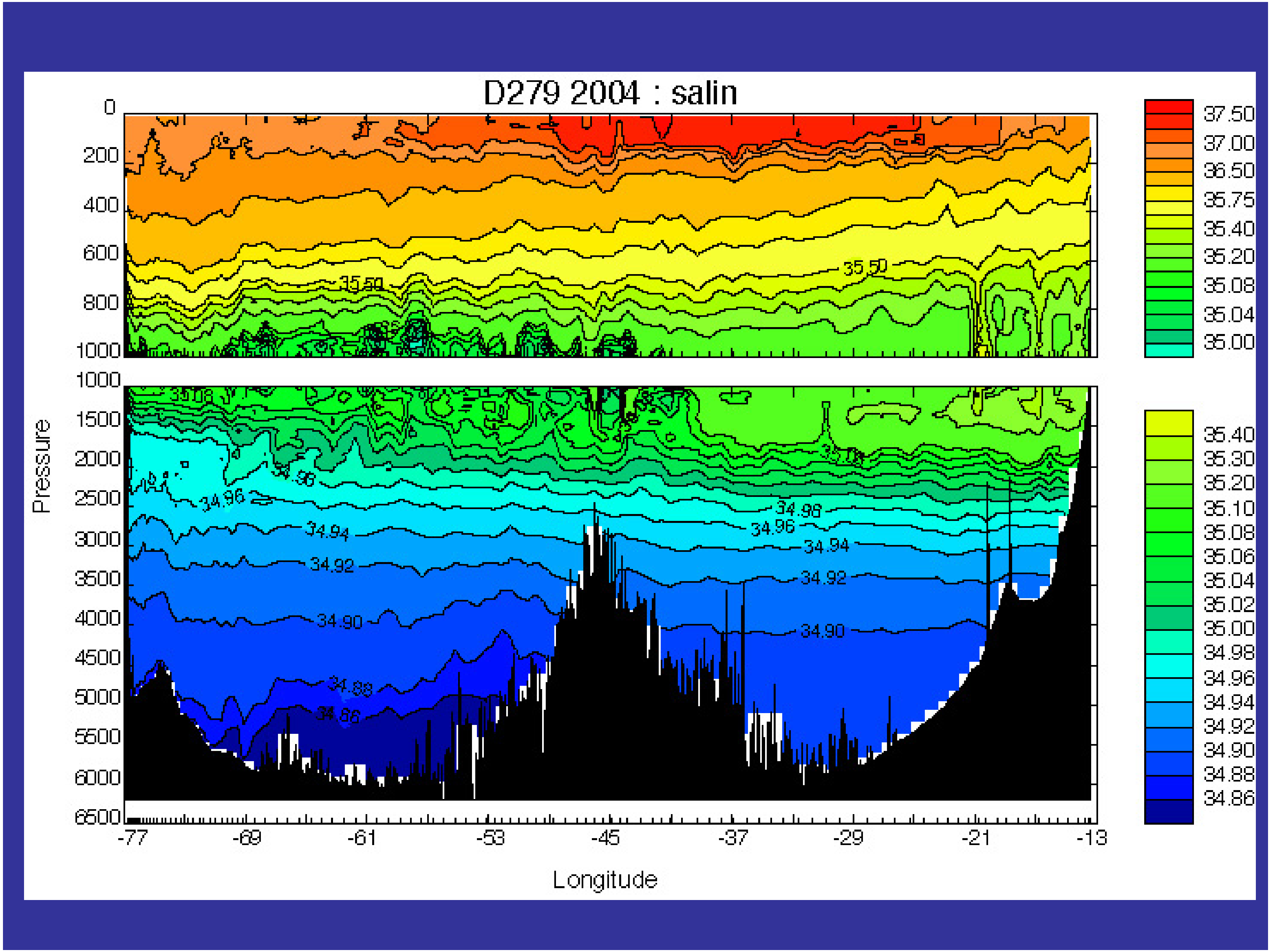
Hydrographic Sections at 25ºN



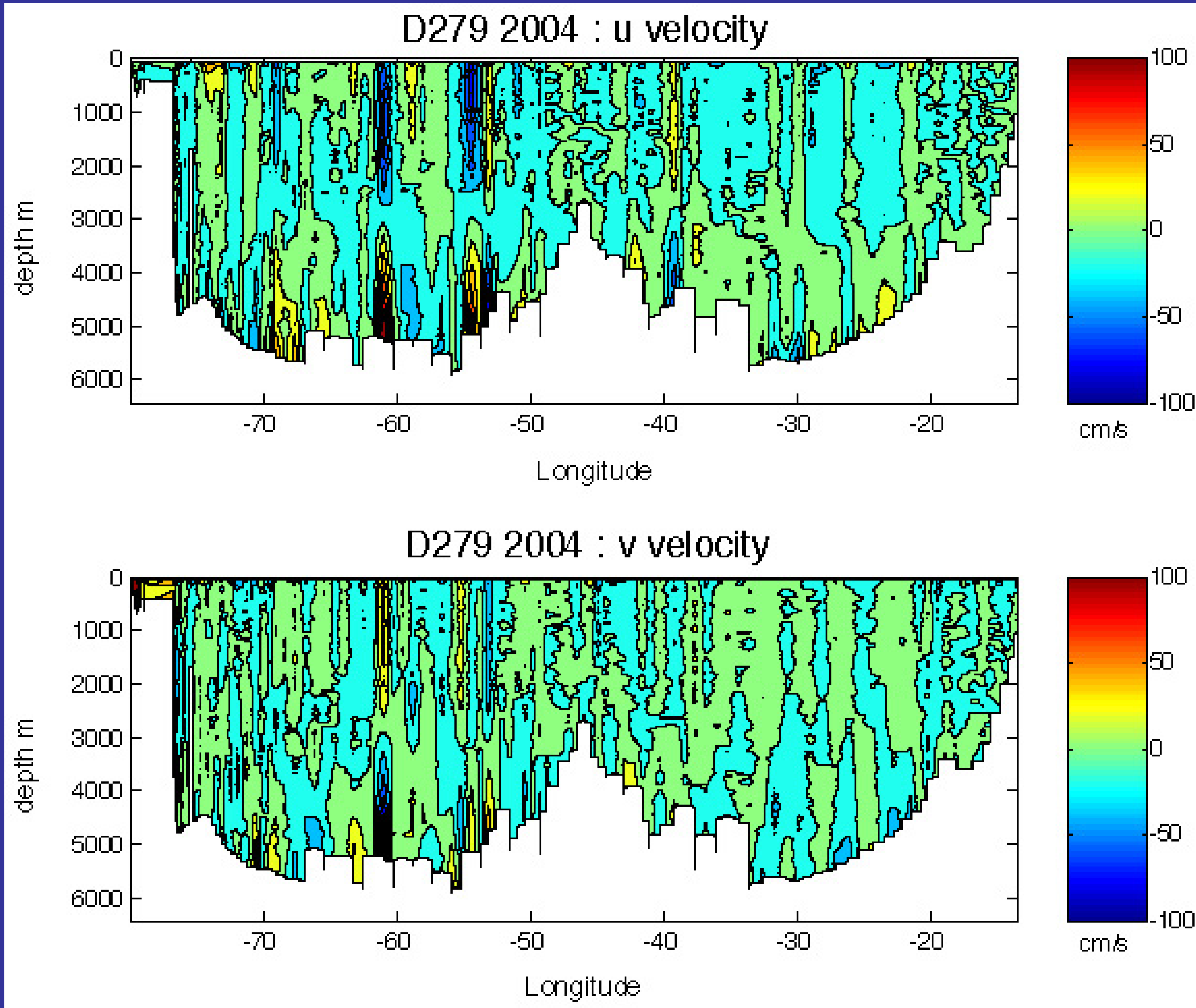
Hydrographic station locations of the 1957 (o), 1981 (x), 1992 (+), 1998 (+) and 2004 (o) transatlantic cruises. Shaded regions are above sea level.

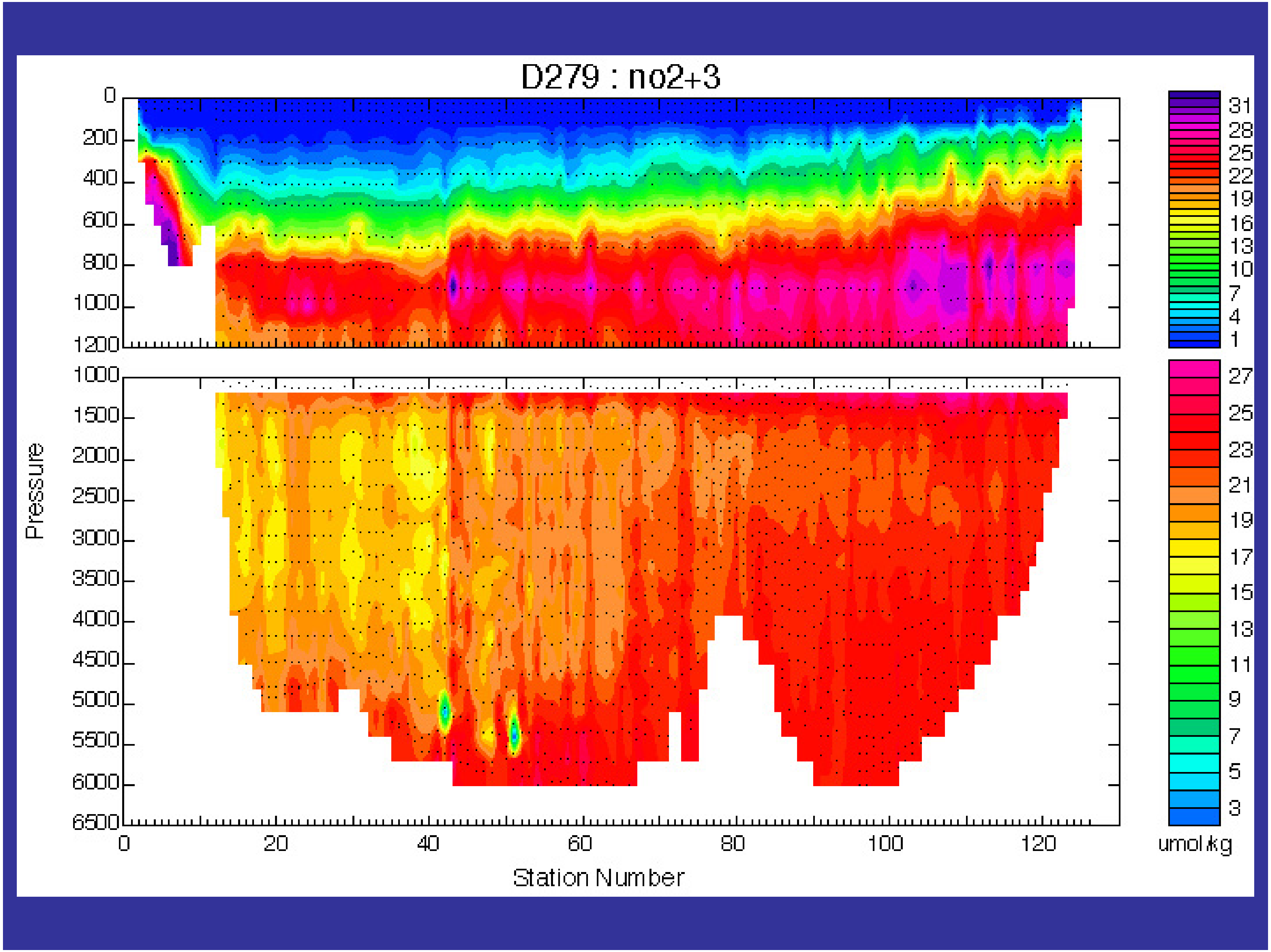


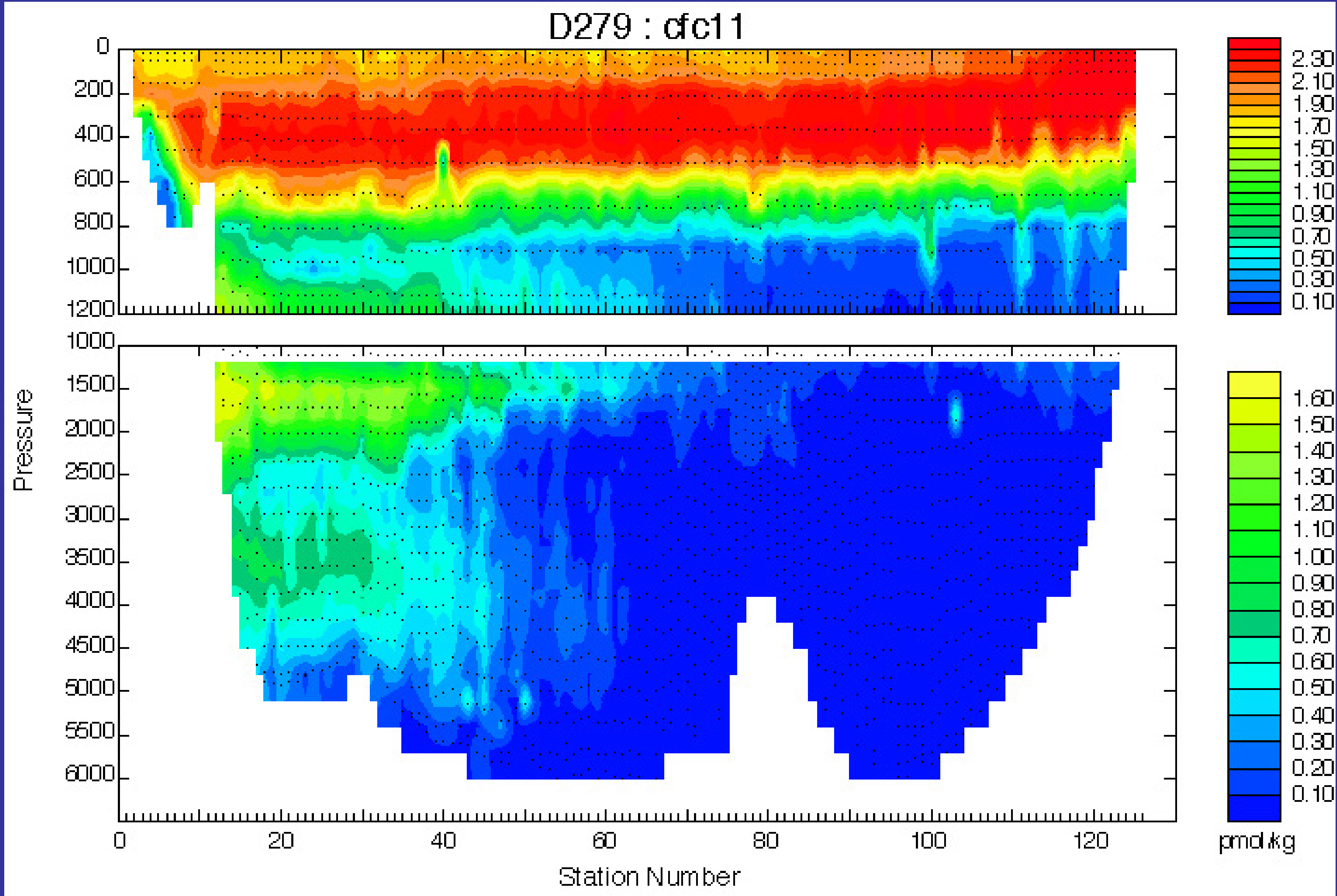
D279 2004 : potemp
Pressure
Longitude
-77
-69
-61
-53
-45
-37
-29
-21
-13
0
200
400
600
800
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
25.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
7.0
5.0
4.5
4.0
3.5
3.0
2.5
2.3
2.0
1.9
1.8
1.7
1.6
1.5



D279 2004 : salin
Pressure
Longitude
0
200
400
600
800
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
-77
-69
-61
-53
-45
-37
-29
-21
-13
35.50
34.96
34.94
34.92
34.90
34.88
34.86
34.98
37.50
37.00
36.50
35.75
35.40
35.20
35.08
35.04
35.00
35.30
35.10
35.06
35.02

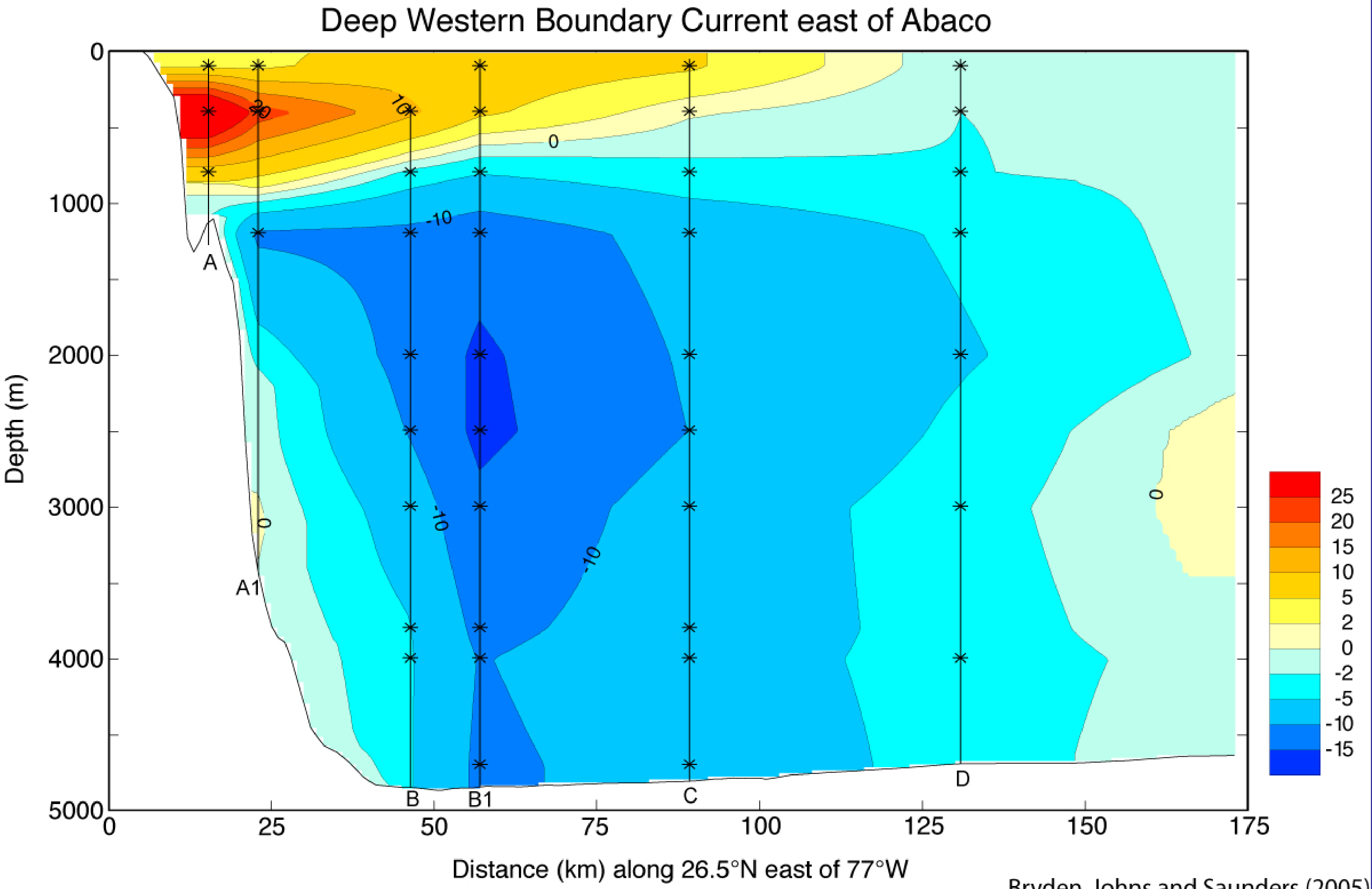

D279 2004 : u velocity
depth m
Longitude
cm/s
D279 2004 : v velocity
depth m
Longitude
cm/s


D279 : no2+3
Pressure
Station Number
umol/kg
0
200
400
600
800
1000
1200
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
0
20
40
60
80
100
120
31
28
25
22
19
16
13
10
7
4
1
27
25
23
21
19
17
15
13
11
9
7
5
3



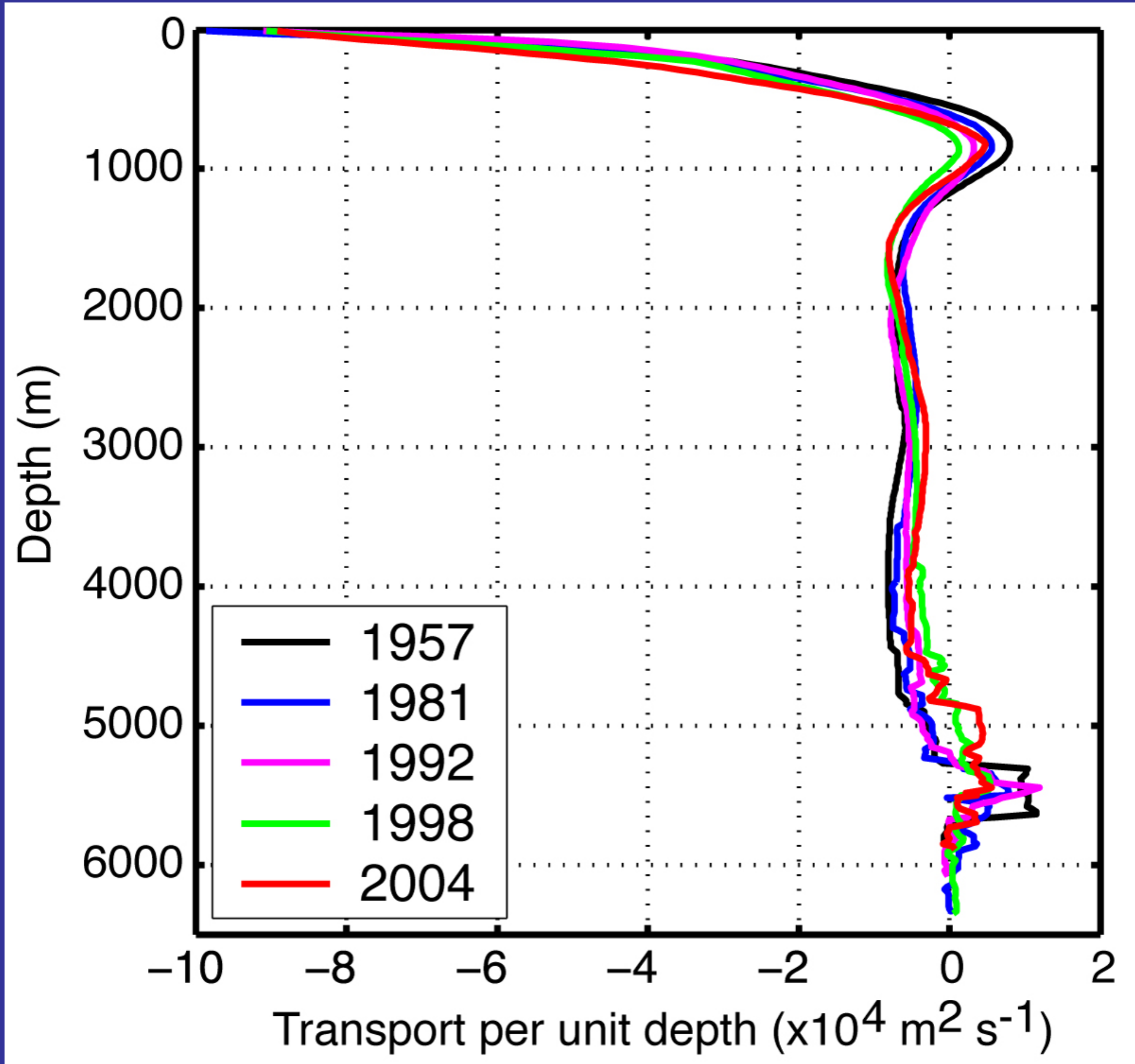
D279 : cfc11
Pressure
Station Number
0
200
400
600
800
1000
1200
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
0
20
40
60
80
100
120
2.30
2.10
1.90
1.70
1.50
1.30
1.10
0.90
0.70
0.50
0.30
0.10
1.60
1.50
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
pmol/kg

Structure of Deep Western boundary Current at 26.5°N from Abaco arrays (1987-1998)

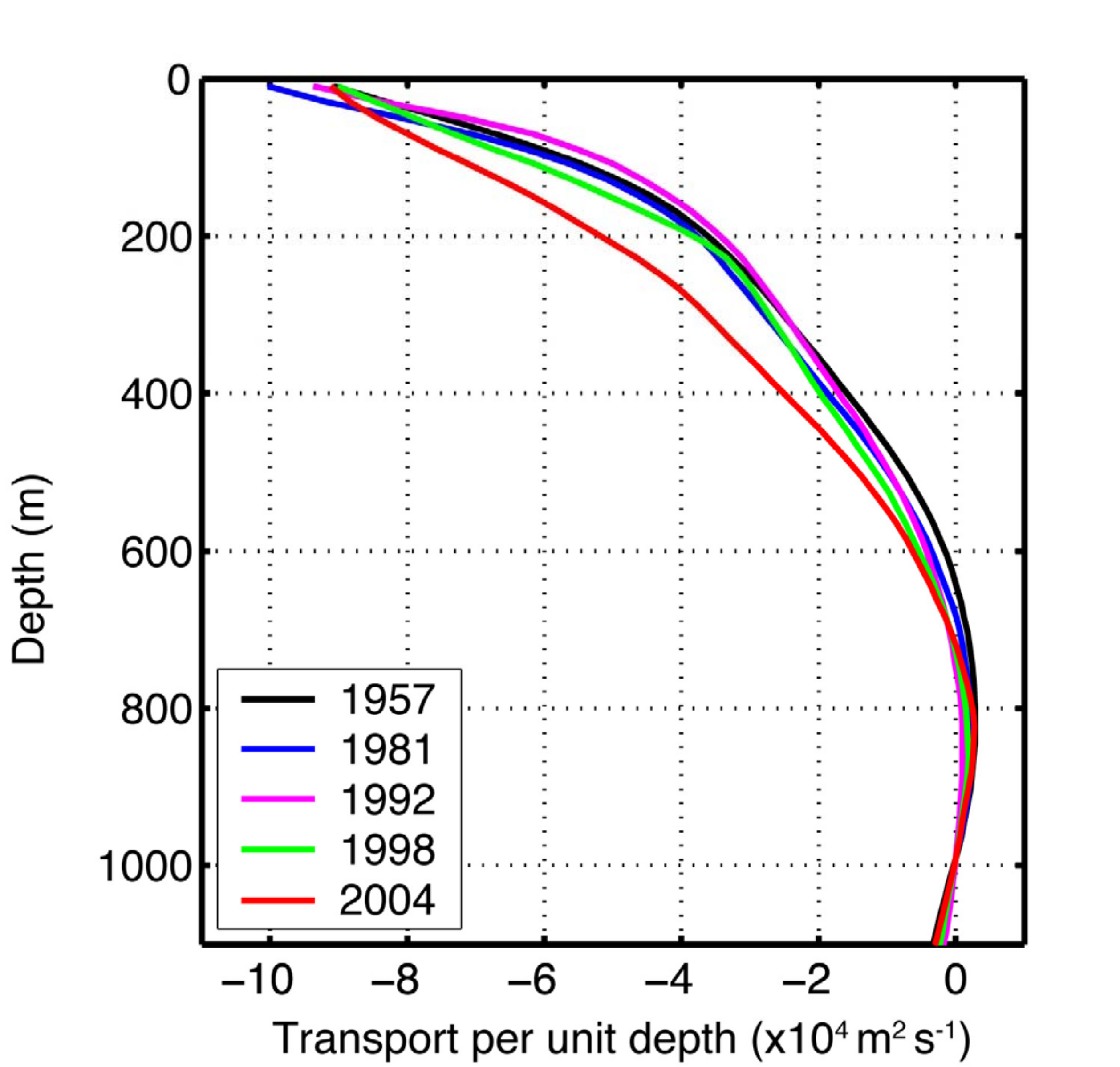


Bryden, Johns and Saunders (2005)

Mid Ocean Geostrophic Transport Profiles from 25°N Sections



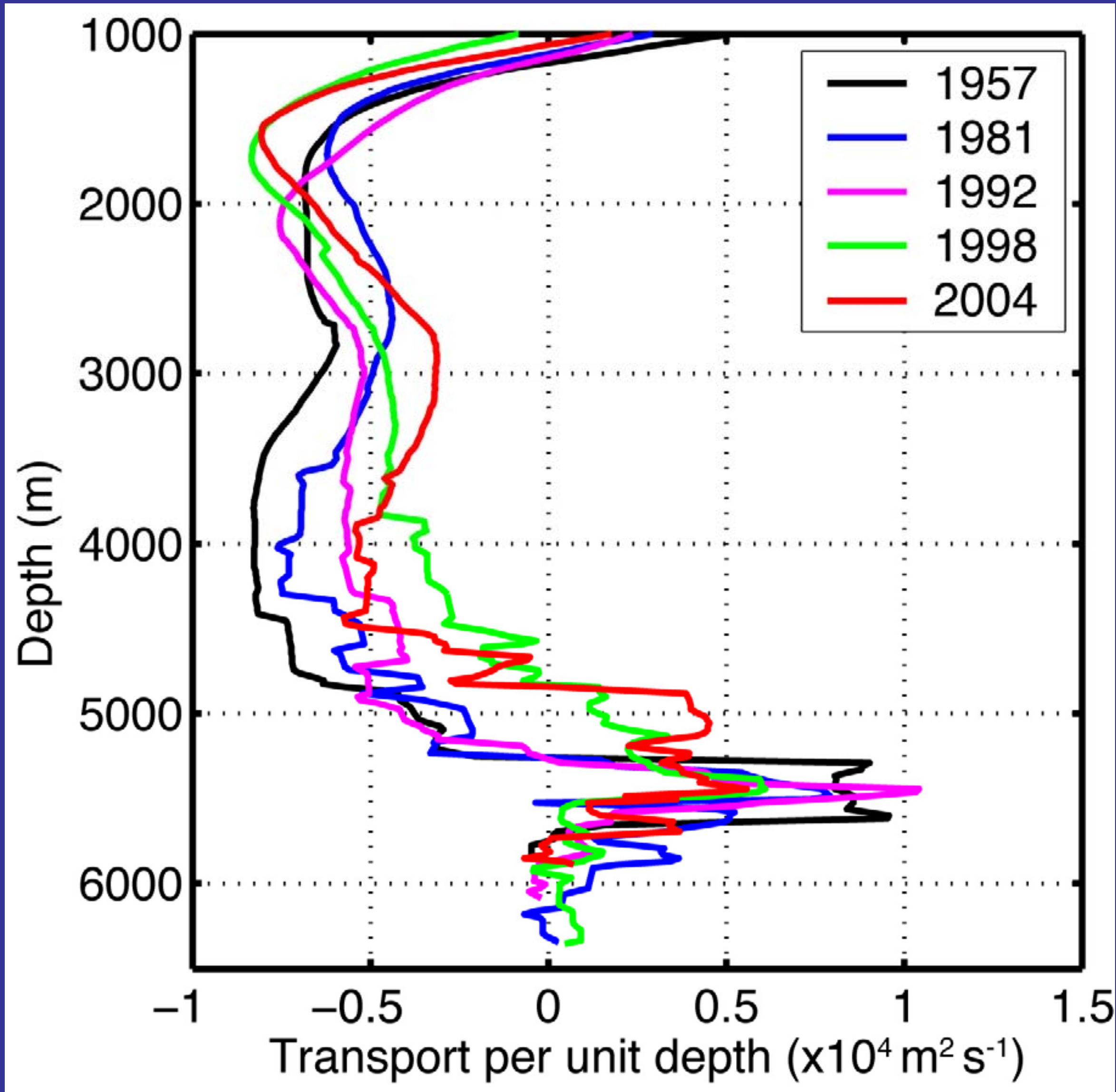
Stronger, deeper southward thermocline flow in 2004 than in 1957, 1981, 1992 (Bryden, Longworth and Cunningham 2005)



Thermocline Recirculation Stronger in 2004

Transport (Sv)	Shallower than 1000m
1957	-13.03
1981	-16.92
1992	-16.41
1998	-21.37
2004	-22.82

Weaker Southward transport of Lower North Atlantic Deep Water (3000-5000m) in 1998 and 2004

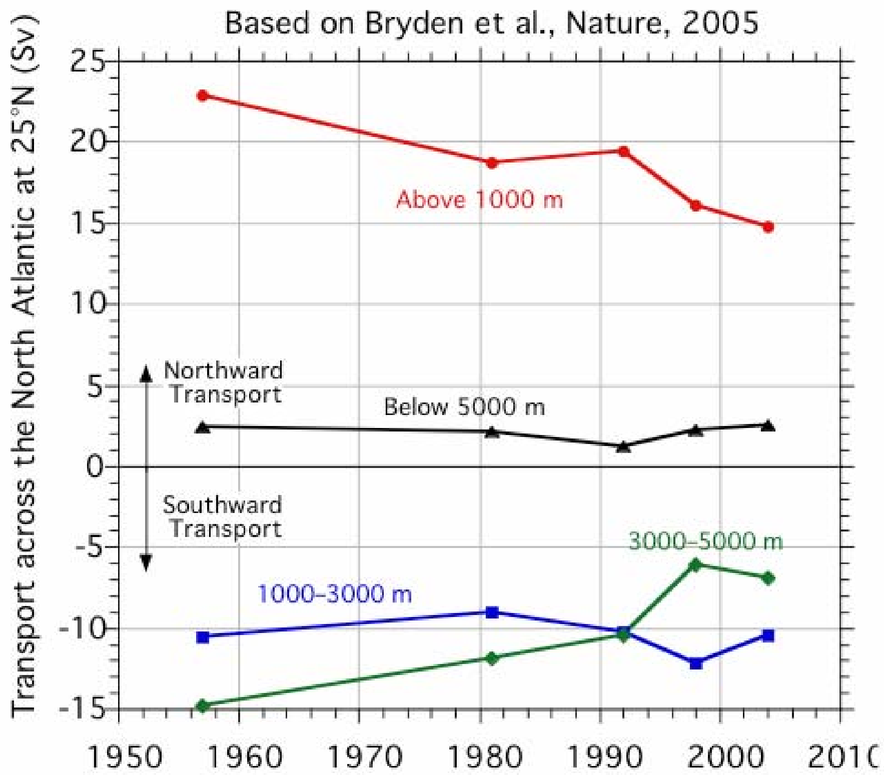


Bryden, Longworth and Cunningham (2005)

Reduction in southward transport of LNADW in 1998 and 2004

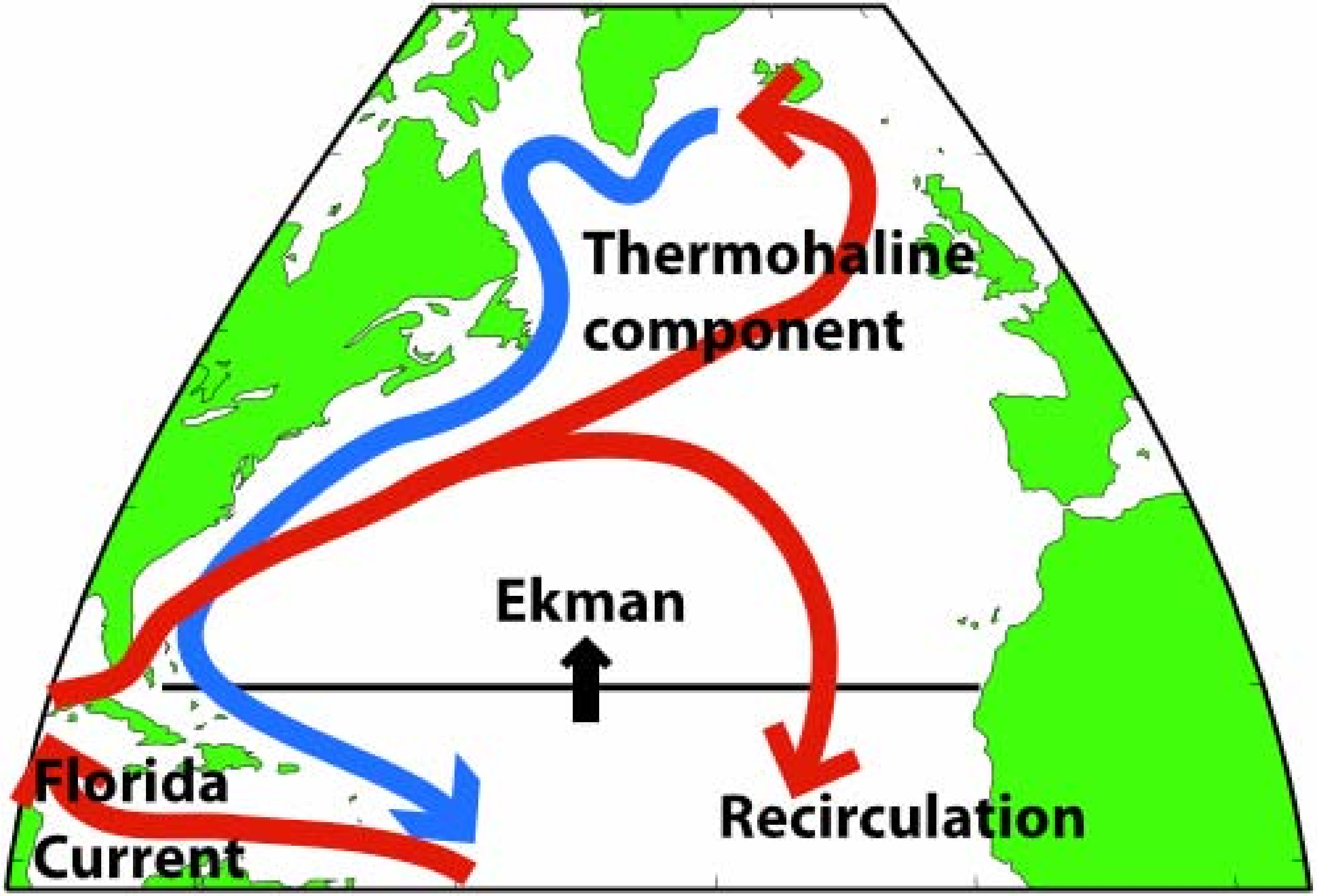
	UNADW	LNADW
Transport (Sv)	1000-3000m	3000-5000m
1957	-11.07	-14.55
1981	-8.99	-11.84
1992	-10.60	-10.24
1998	-12.05	-6.30
2004	-10.33	-6.88

	1957	1981	1992	1998	2004
Shallower than 1000 m depth					
Gulf Stream + Ekman	+35.6	+35.6	+35.6	+37.6	+37.6
Mid-Ocean Geostrophic	-12.7	-16.9	-16.2	-21.5	-22.8
Net	+22.9	+18.7	+19.4	+16.1	+14.8
1000-3000 m	-10.5	-9.0	-10.2	-12.2	-10.4
3000-5000 m	-14.8	-11.8	-10.4	-6.1	-6.9
Deeper than 5000 m	+2.4	+2.1	+1.2	+2.2	+2.5



Trends in Transports Across 25°N

North Atlantic: More Circulating, Less Overturning in 2004



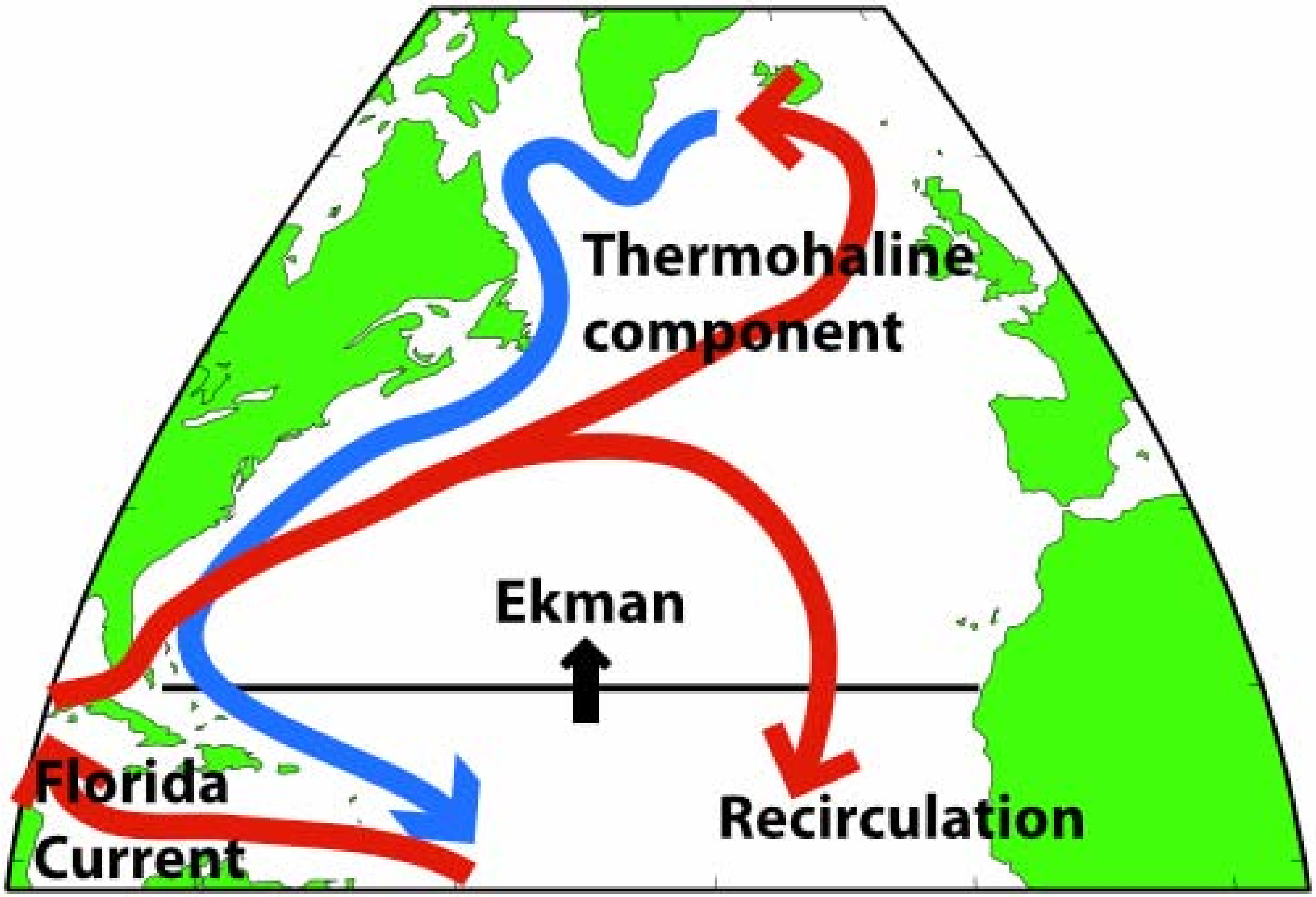
INSIDE THIS ISSUE: TECHNOLOGY QUARTERLY
The Economist
David Cameron v Gordon Brown
Trade, farms and the poor
Iraq's coming election
Books of the year
Don't despair
Grounds for hope on global warming

Is this a real slowdown in the Atlantic Meridional Overturning Circulation?

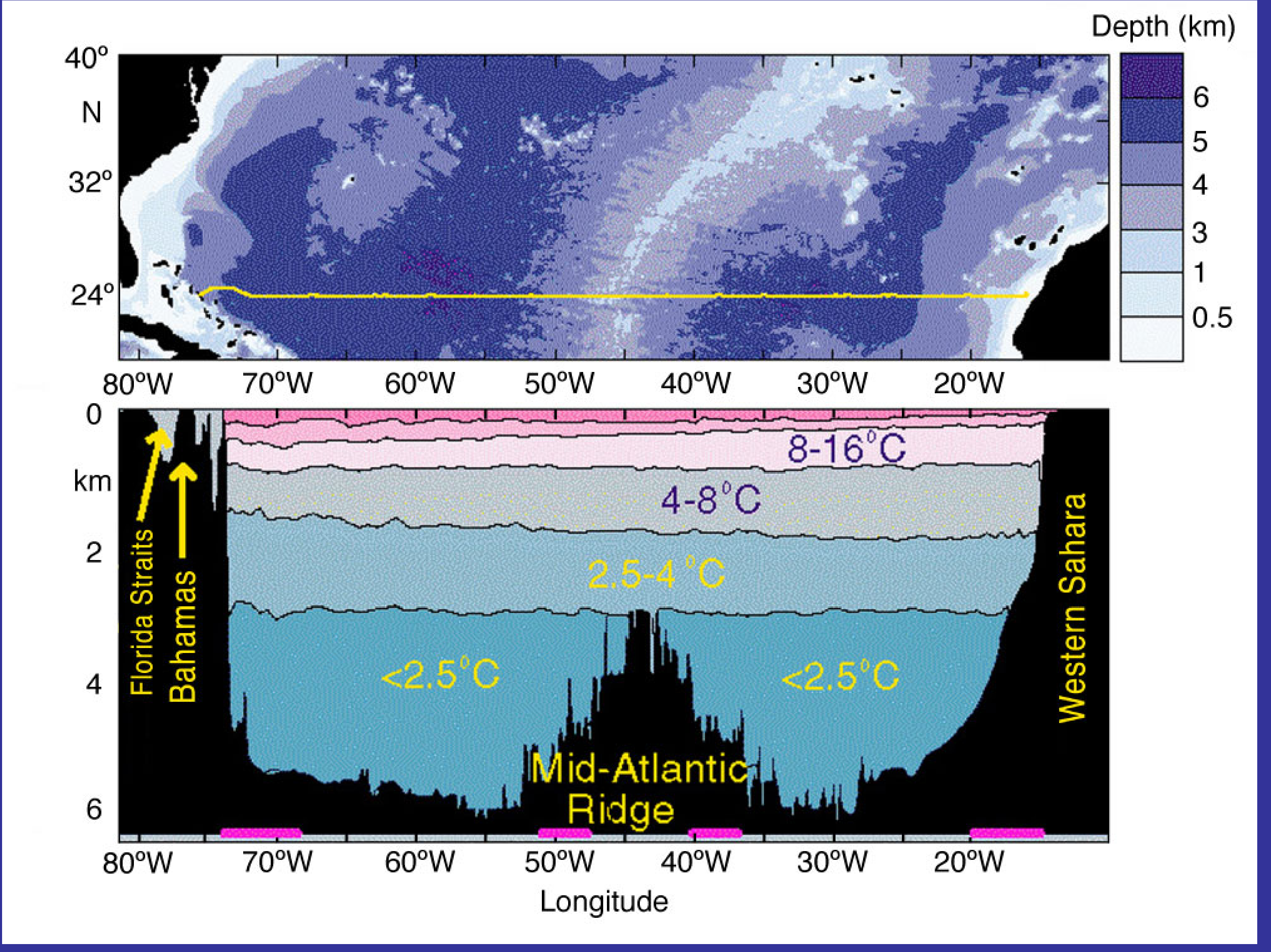
Or is it due to typical subannual or interannual variability?

To find out it is essential to measure the subannual to interannual variability. We must continuously monitor the meridional overturning

Monitoring System at 26°N where Ocean Heat Transport is a Maximum



We designed an array of moored instruments on the eastern and western edges of the 26°N section and over the flanks of the Mid Atlantic Ridge to monitor the MOC



Array to monitor interior geostrophic flow

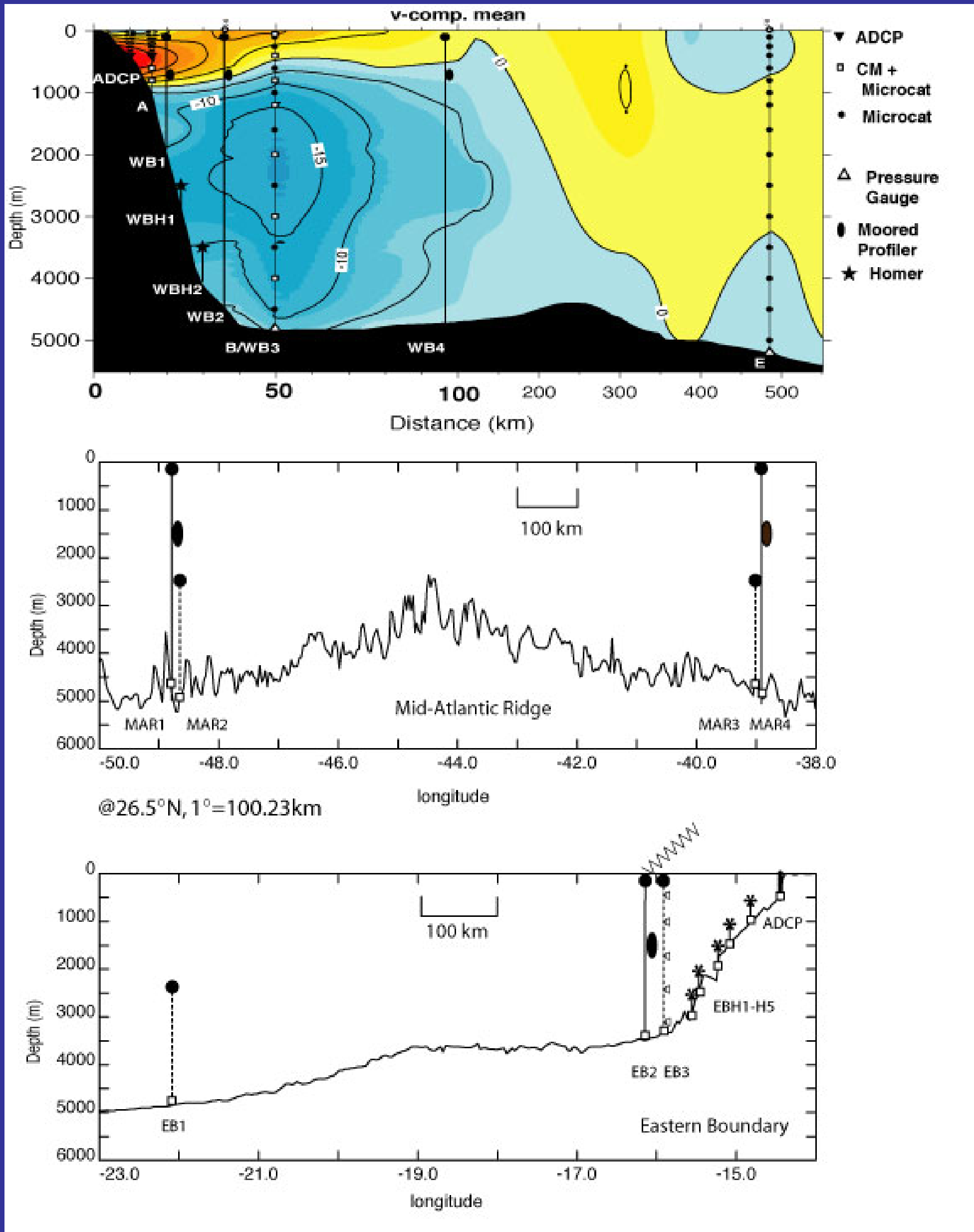


Figure 1: Mooring array for monitoring the Atlantic meridional overturning circulation at 26.5°N. a) Western boundary; b) Mid-Atlantic Ridge; c) Eastern boundary

Western Boundary

Mid Atlantic Ridge

Eastern Boundary

Hirschi, Baehr, Marotzke, Stark, Cunningham and Beismann (2003)

Blue:

Covered

OCCAM 26.4N

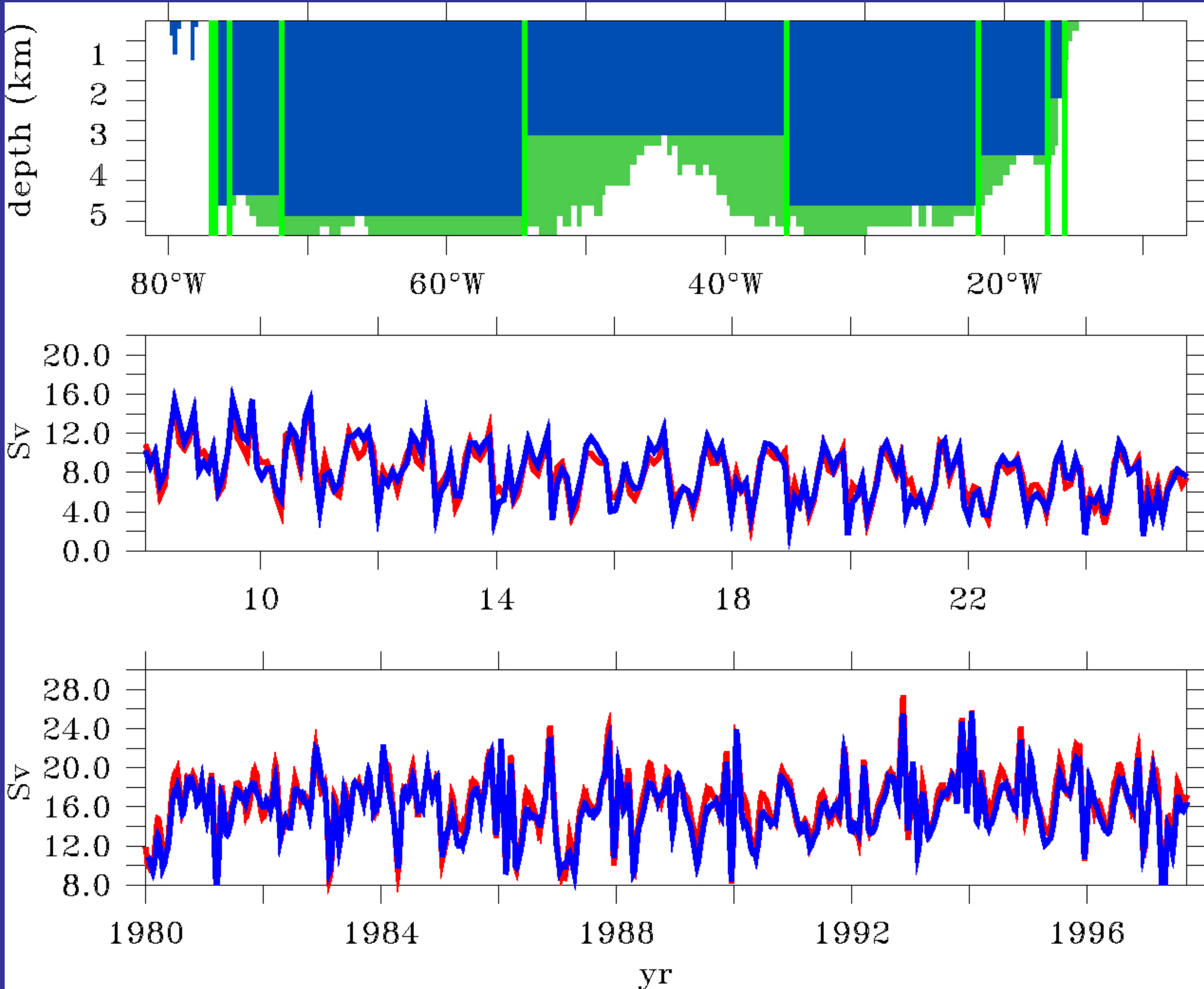
Red:

MOC

Blue:

Recon-
struction

FLAME 26N



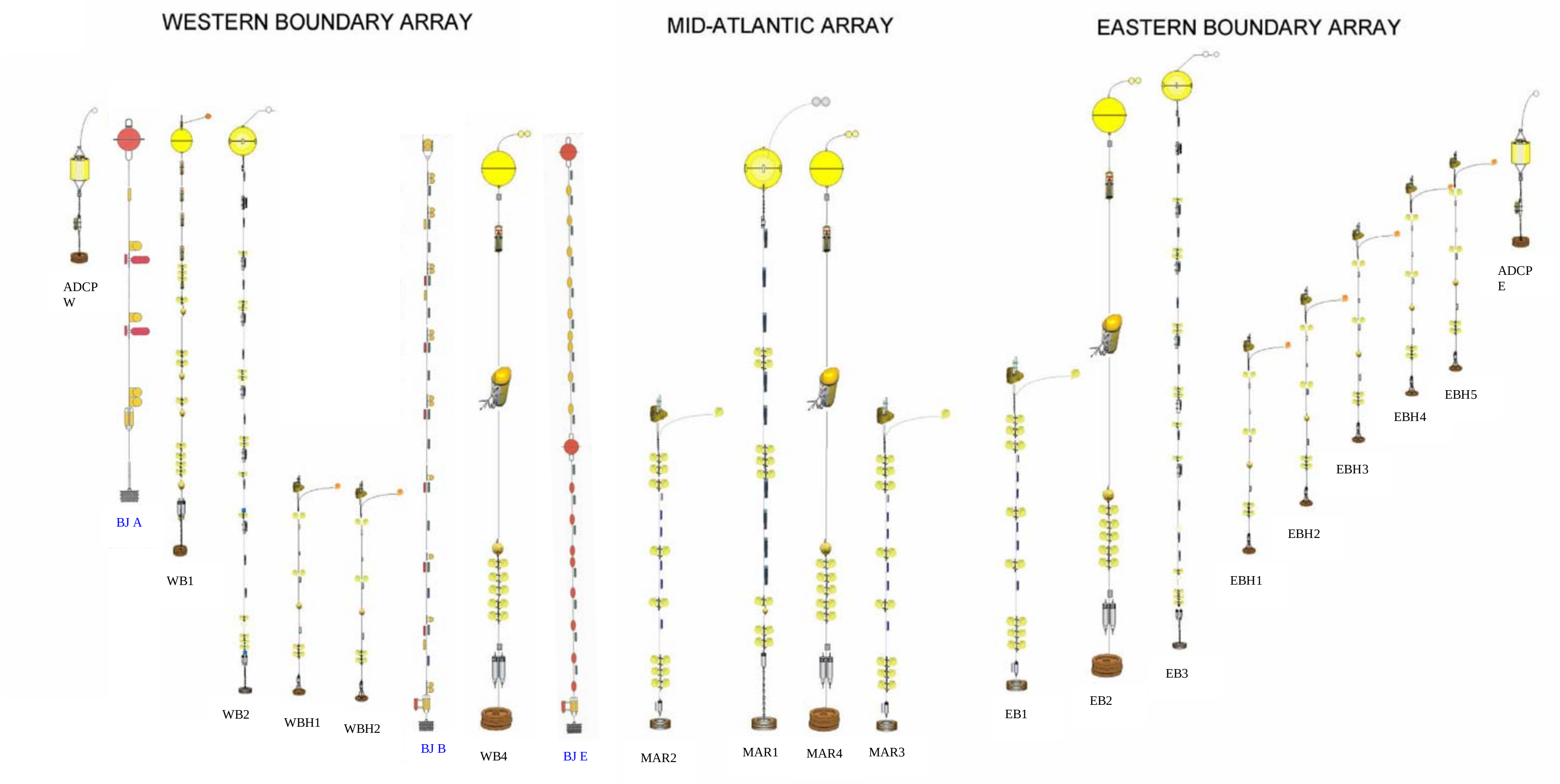
The Mid-Ocean Array

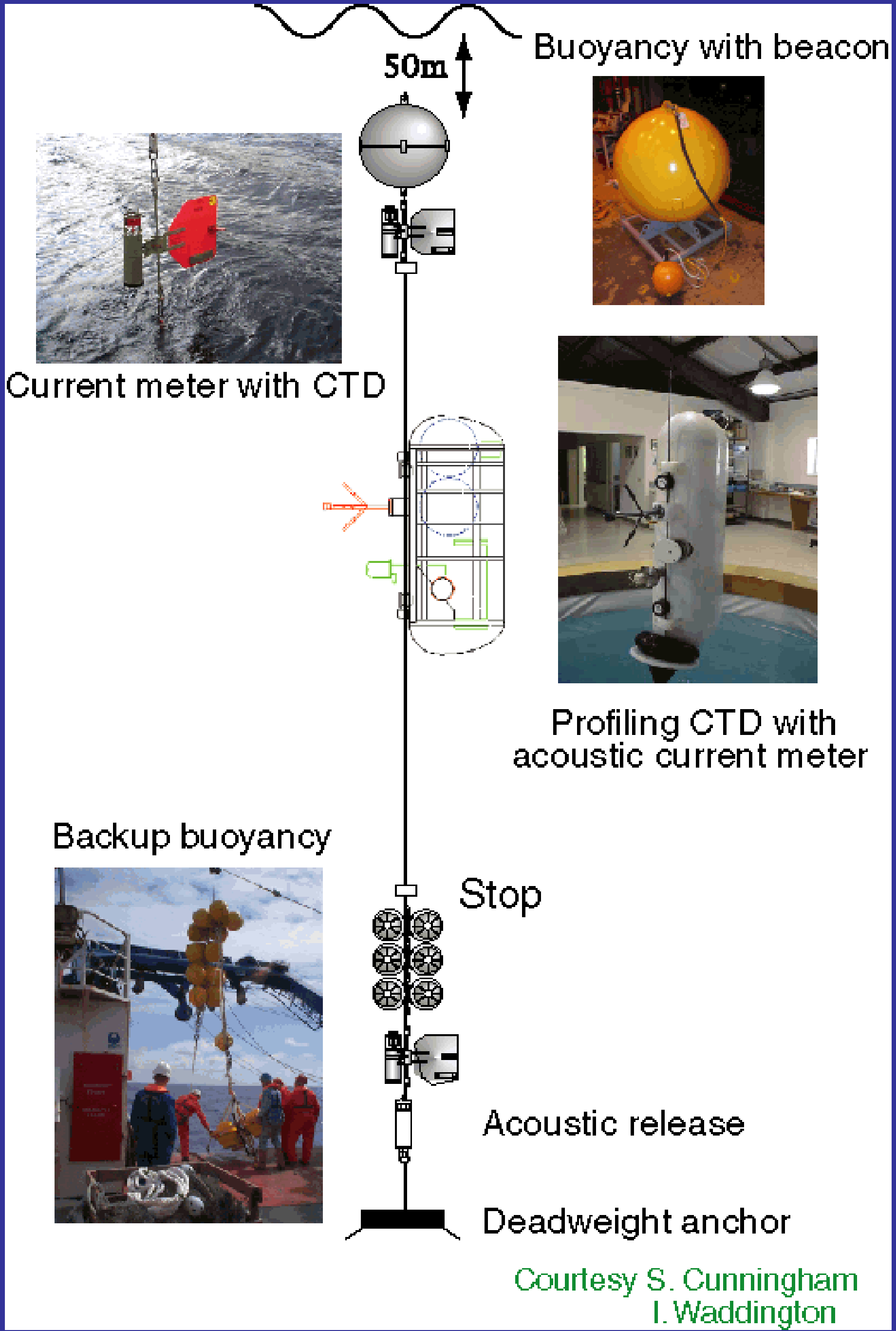
Deployed February-March 2004

Recovered and Redeployed April-May 2005

Recovered and Redeployed April-May 2006

Rayner and Cunningham





The array relies on top-to-bottom profiles of temperature and salinity, continuous hydrographic stations from which geostrophic velocity can be estimated

Key instrument is the profiling CTD


EMERGENCY
ESCAPE

Rapid MOC Monitoring

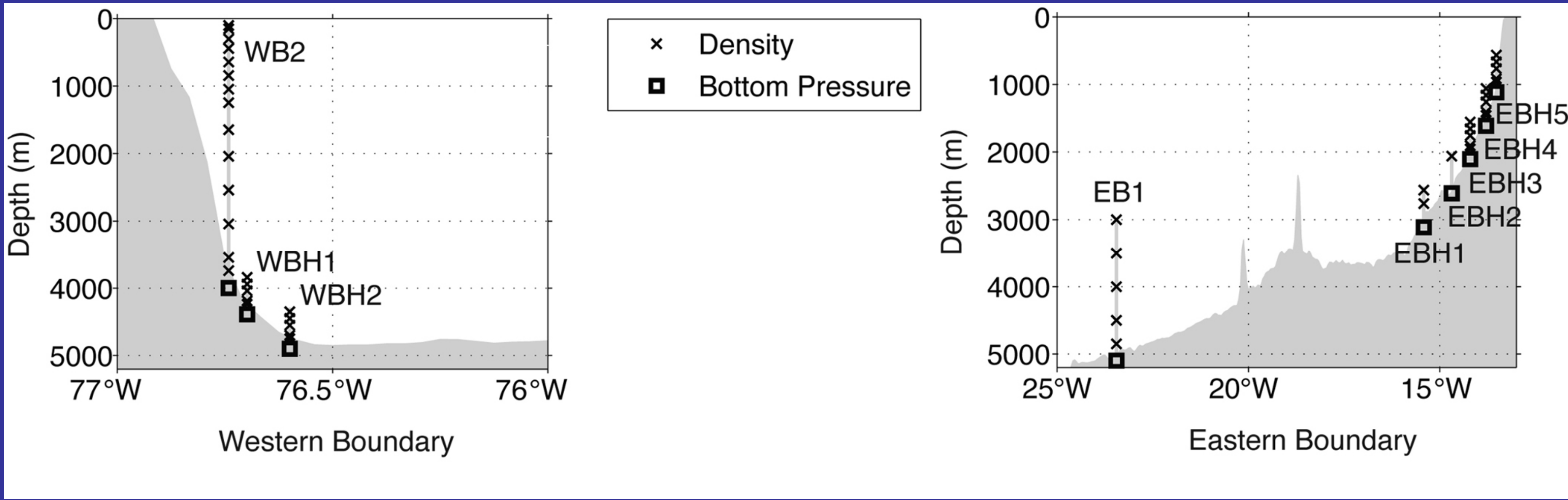
Cooperation between UK and US: NERC and NSF and NOAA joint proposals and funding

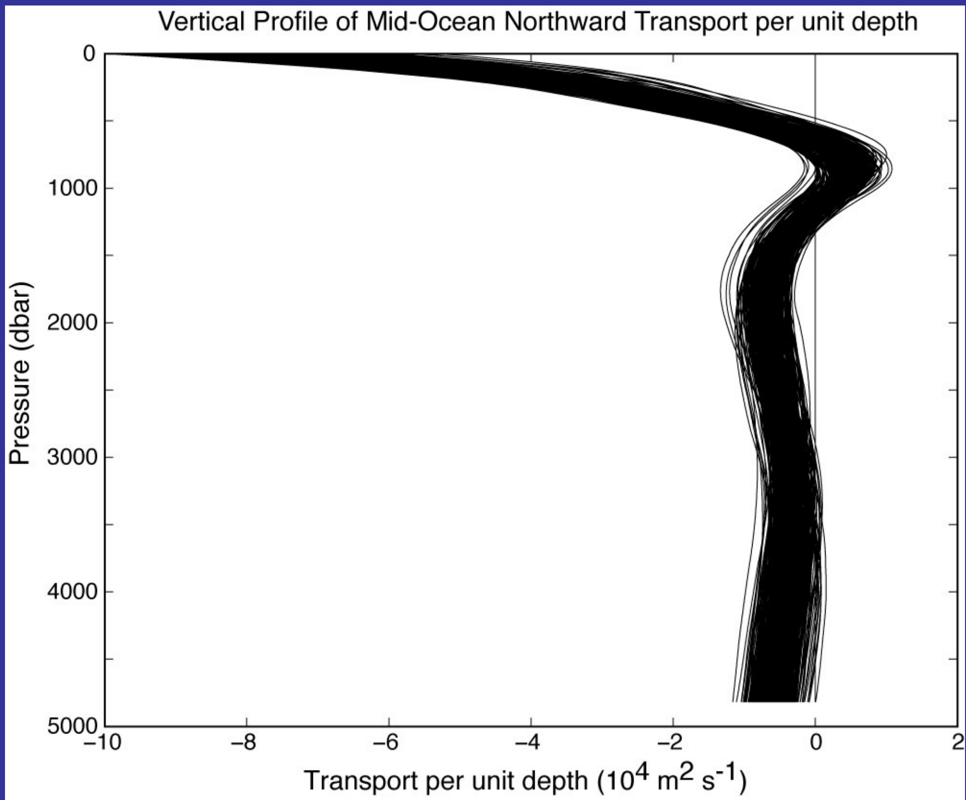
AOML - Miami responsible for Florida Straits monitoring with support from NOAA

University of Miami monitoring deep western boundary current with support from NSF

National Oceanography Centre - Southampton monitoring the mid-ocean circulation and overall overturning with support from NERC

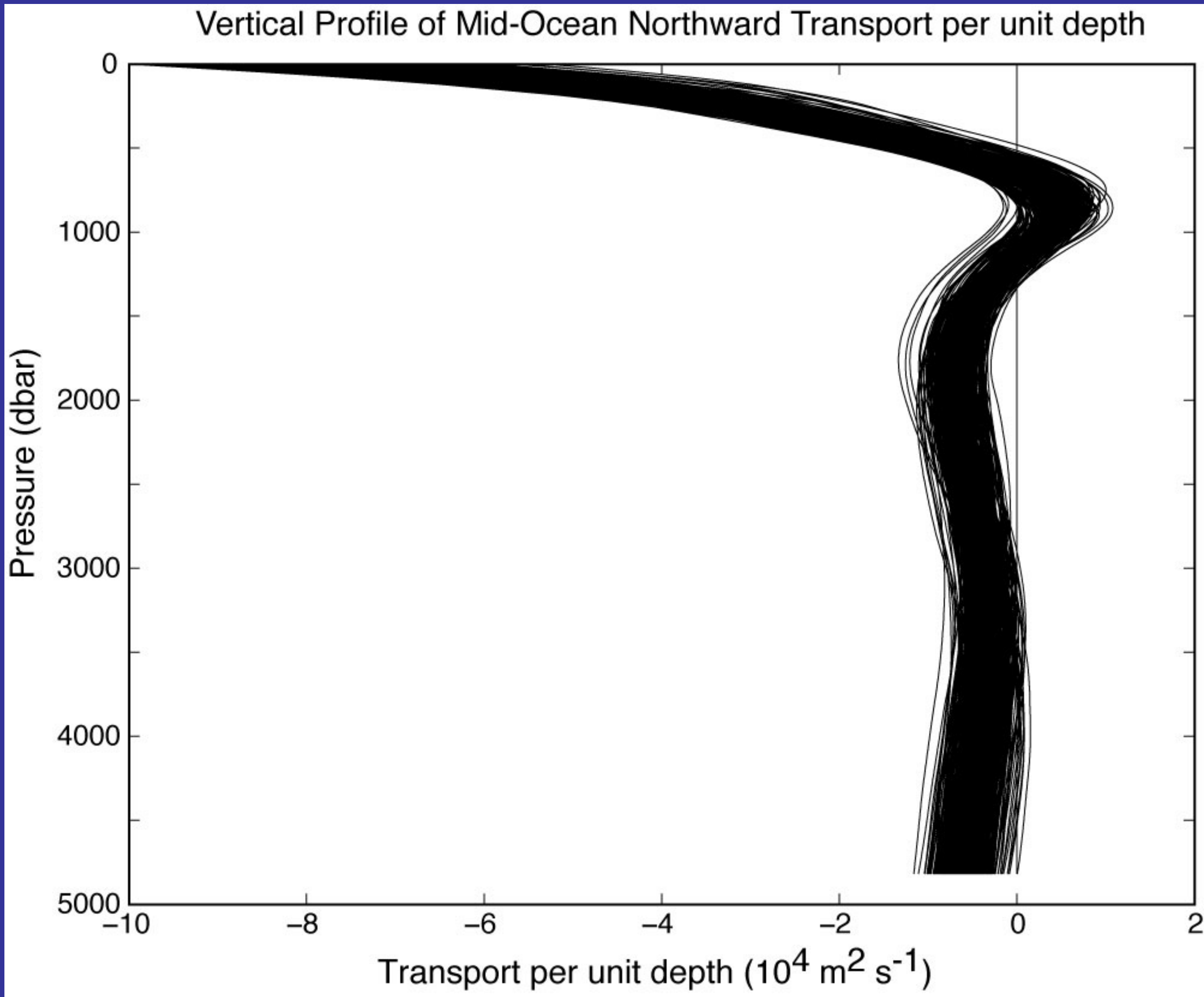
Working Together-SOC and University of Miami mooring teams





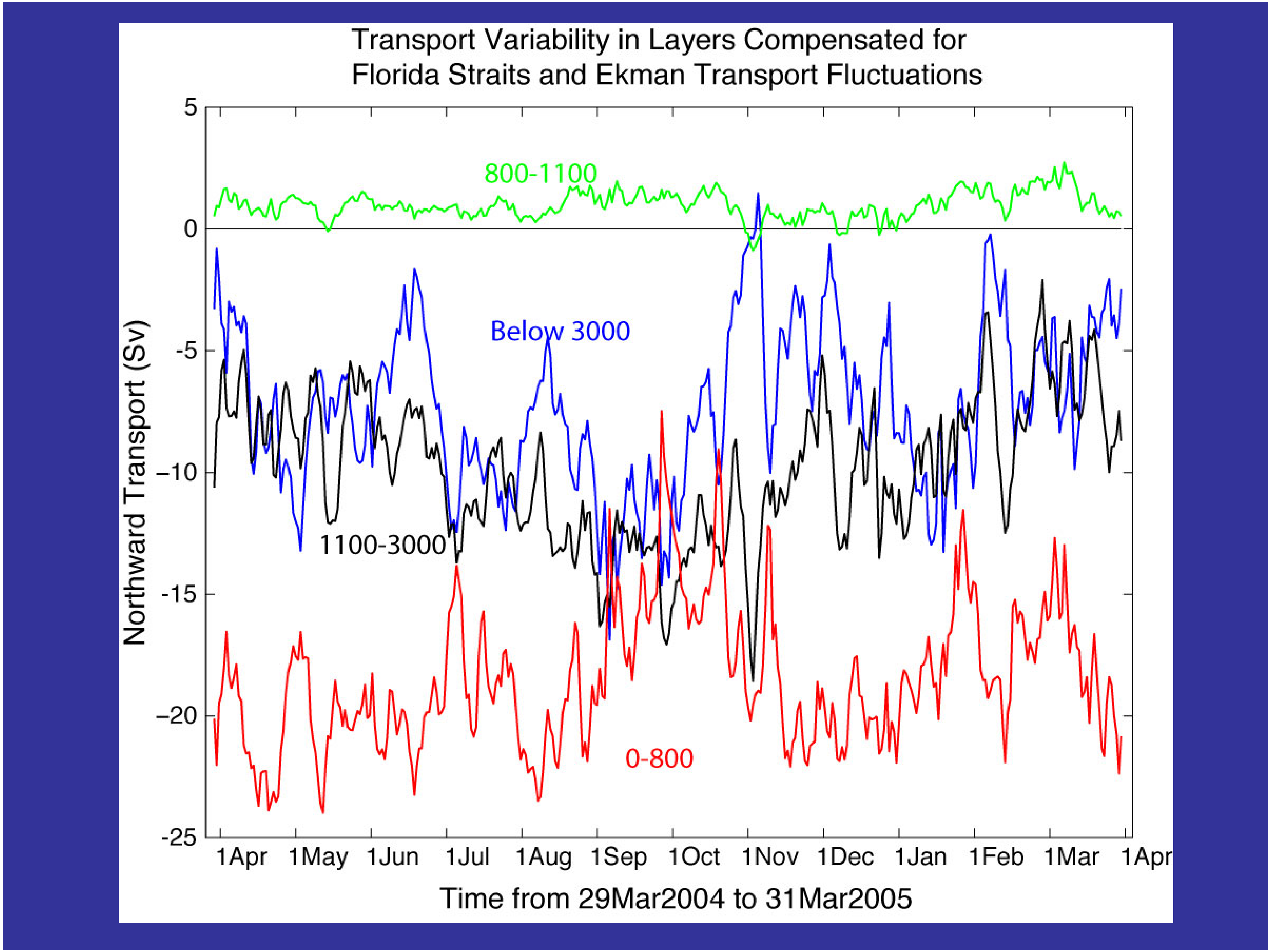
T,S,p >> Dynamic Height(p)

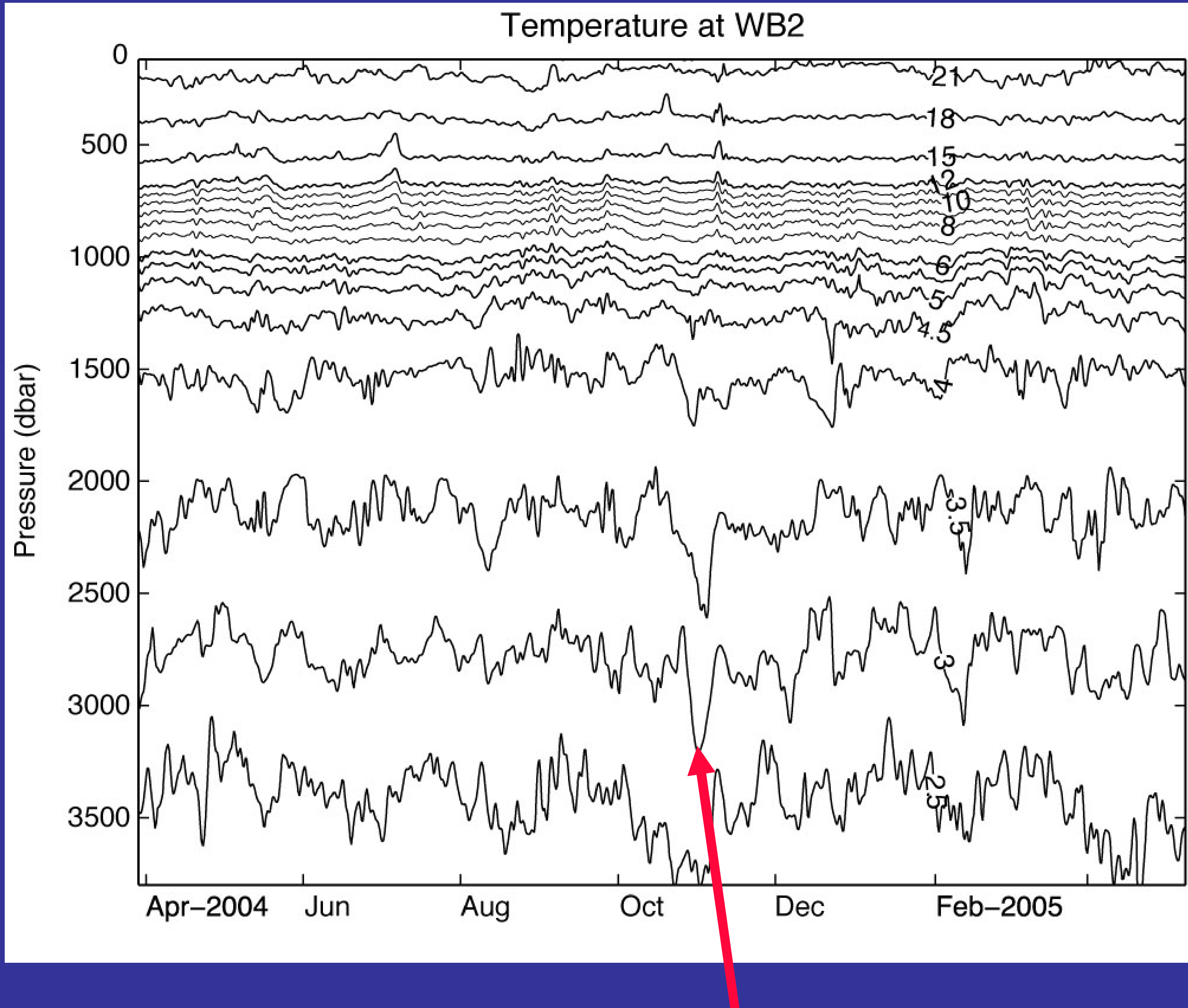
(DyHt (east)-DyHt(west))/f



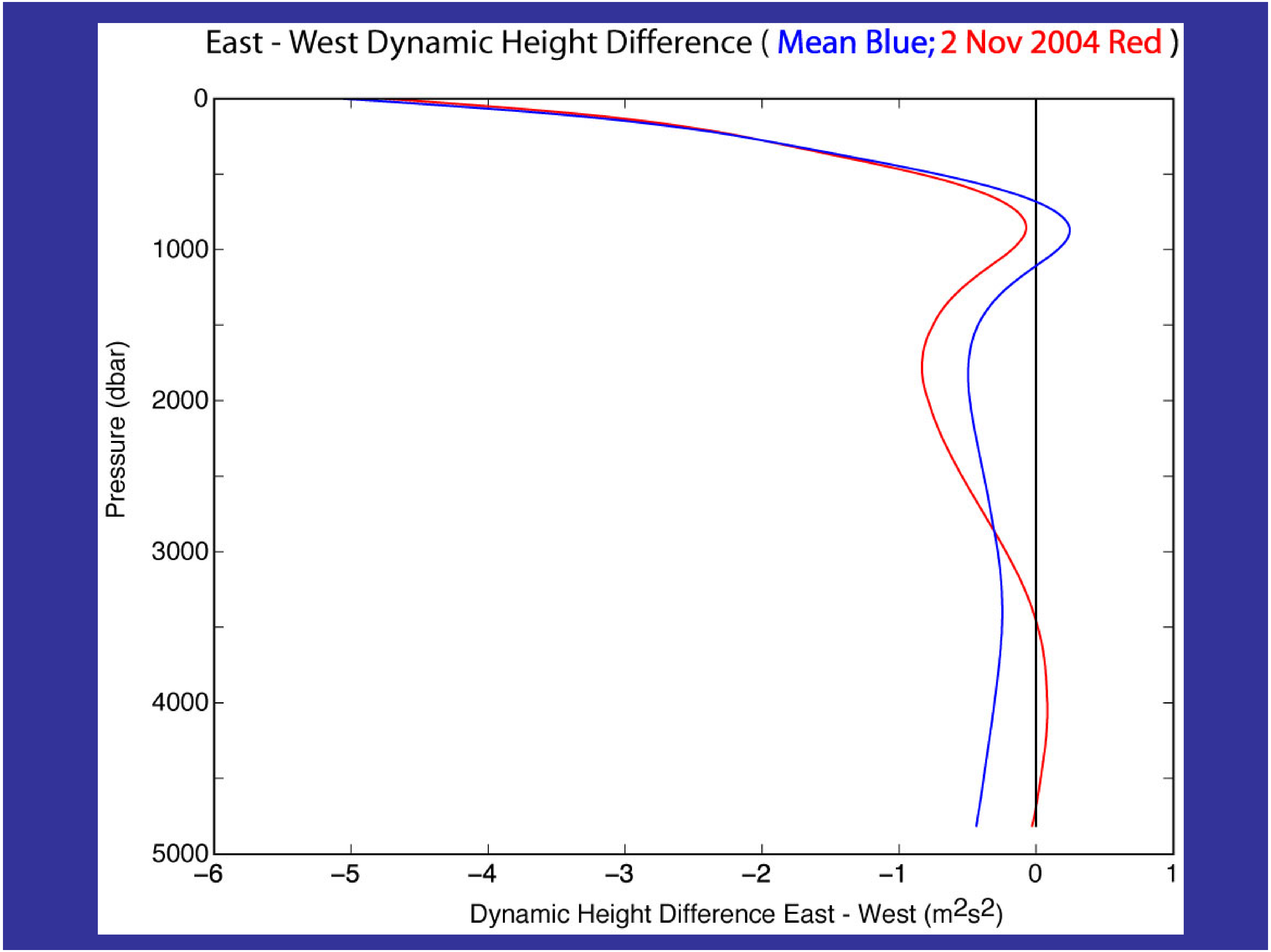
Each day's Profile is adjusted to give a southward geostrophic transport equal to the Ekman plus Florida Straits transport for that day

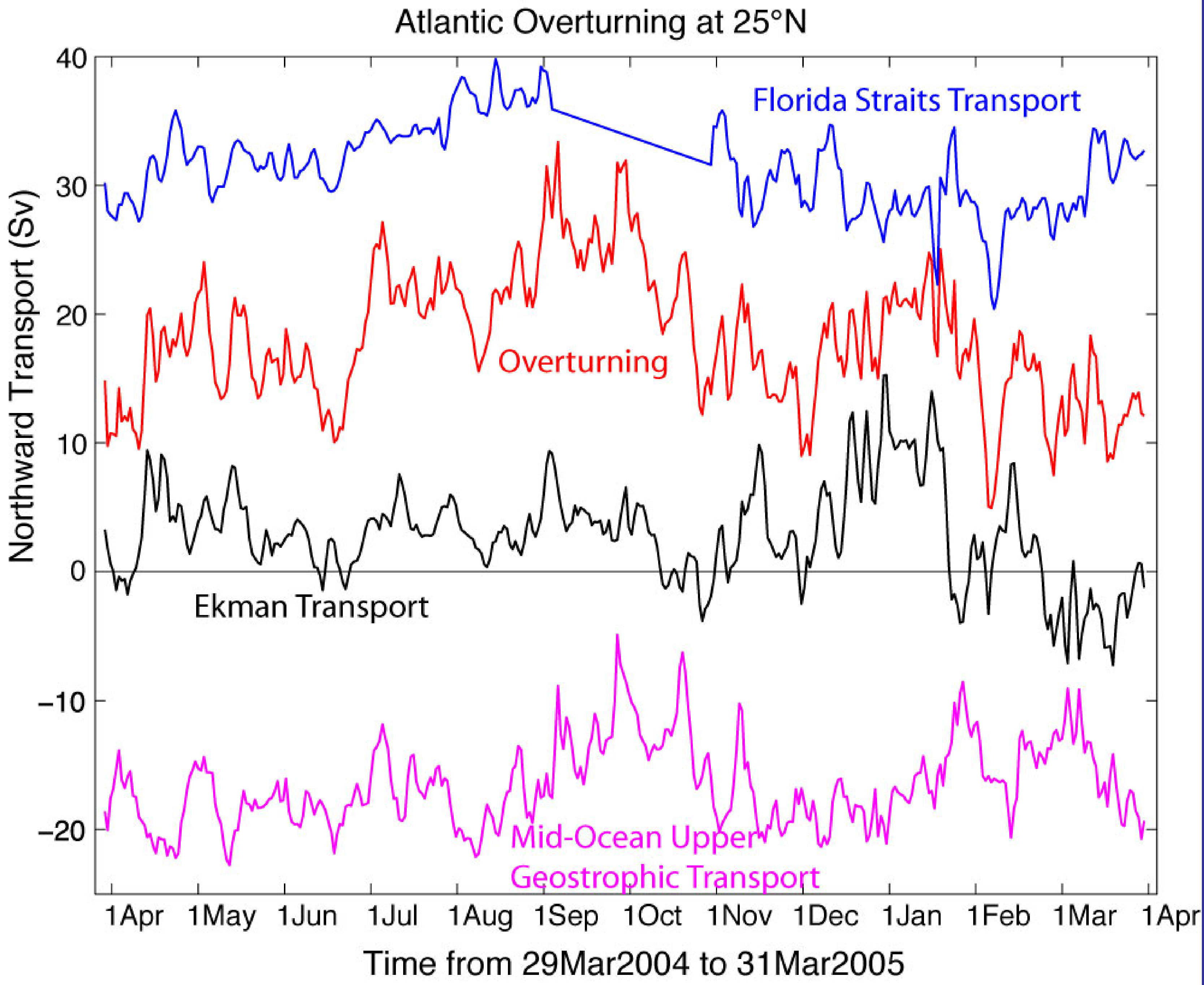
Grant and Bryden (2006)


Transport Variability in Layers Compensated for
Florida Straits and Ekman Transport Fluctuations
800-1100
Below 3000
1100-3000
0-800
Northward Transport (Sv)
5
0
-5
−10
-15
−20
-25
1Apr
1May
1Jun
1Jul
1Aug
1Sep
1Oct
1Nov
1Dec
1Jan
1Feb
1Mar
1Apr
Time from 29Mar2004 to 31Mar2005



November event
LNADW disappears


East - West Dynamic Height Difference (Mean Blue; 2 Nov 2004 Red)
Pressure (dbar)
0
1000
2000
3000
4000
5000
−6
−5
−4
−3
−2
−1
0
1
Dynamic Height Difference East - West (m2s2)


Atlantic Overturning at 25°N
Florida Straits Transport
Overturning
Ekman Transport
Mid-Ocean Upper
Geostrophic Transport
Northward Transport (Sv)
40
30
20
10
0
−10
−20
1Apr
1May
1Jun
1Jul
1Aug
1Sep
1Oct
1Nov
1Dec
1Jan
1Feb
1Mar
1Apr
Time from 29Mar2004 to 31Mar2005

	Mean	Standard Deviation
Florida Straits Transport	31.7	3.3
Ekman Transport	2.9	3.8
Upper Mid-Ocean Geostrophic Transport	-16.5	3.2
Overturning Transport	18.1	5.1

Each component (Florida Straits, Ekman, Mid-Ocean Geostrophic) has a standard deviation in its temporal variability of about 3.5 Sv

The components do not appear to be correlated, so the standard deviation in Overturning is about 5 Sv

Summary

With the Rapid array we can monitor the size and vertical structure of the mid-ocean geostrophic transport and its temporal variability.

Upper layer mid-ocean geostrophic transport exhibits temporal variability with a standard deviation of about 3.2 Sv, similar to the variability in Florida Straits or Ekman transports.

The temporal variability in the Atlantic overturning has a standard deviation of about 5 Sv.

Based on the 2004-05 Rapid measurements, we estimate that the year-long average overturning can be defined with a standard error of about 1.5 Sv.

Summary

Warm upper waters flow northward and cold deep waters flow southward in what is called the Atlantic Meridional Overturning Circulation (MOC). This circulation transports 1.3 PW of heat across 26°N

Climate Models suggest anthropogenic CO2 increases may lead to a slowdown in the MOC with consequences for European climate

We have developed a monitoring array at 26°N to provide an early warning system for changes in the Atlantic Overturning

Present Rapid Monitoring is presently planned for 4 years 2004-2008 but we hope to continue for at least a decade.