The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

SMR/1837-2

2007 ICTP Oceanography Advanced School

30 April - 11 May, 2007

What Sets the Size of Ocean Circulation

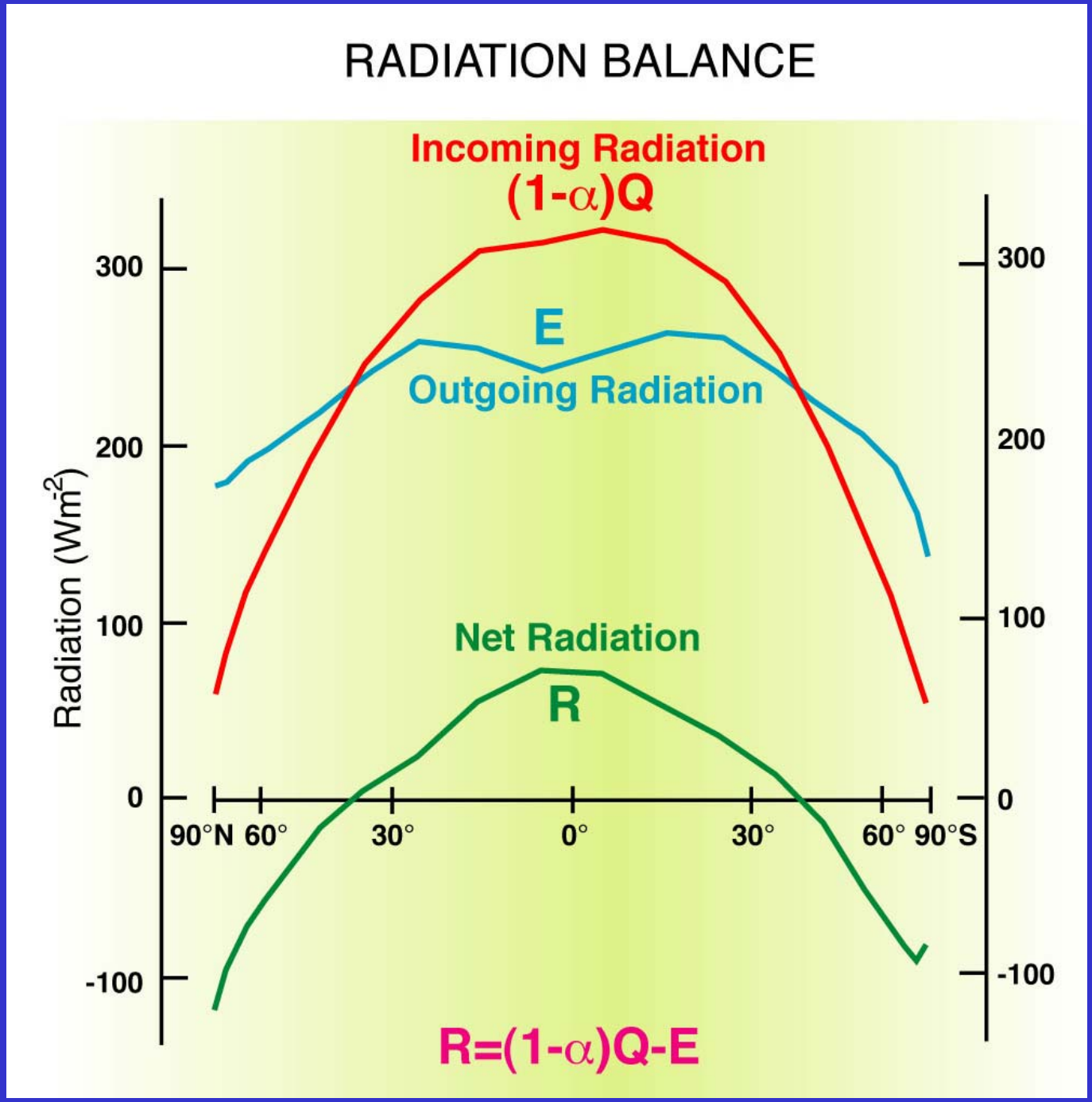
H. Bryden

National Oceanography Centre
Southampton, UK

What Sets the Size of Ocean Circulation

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

Prof. Harry L. Bryden



Distribution of heating sets Wind pattern

SOL HELLERMAN AND MEL ROSENSTEIN

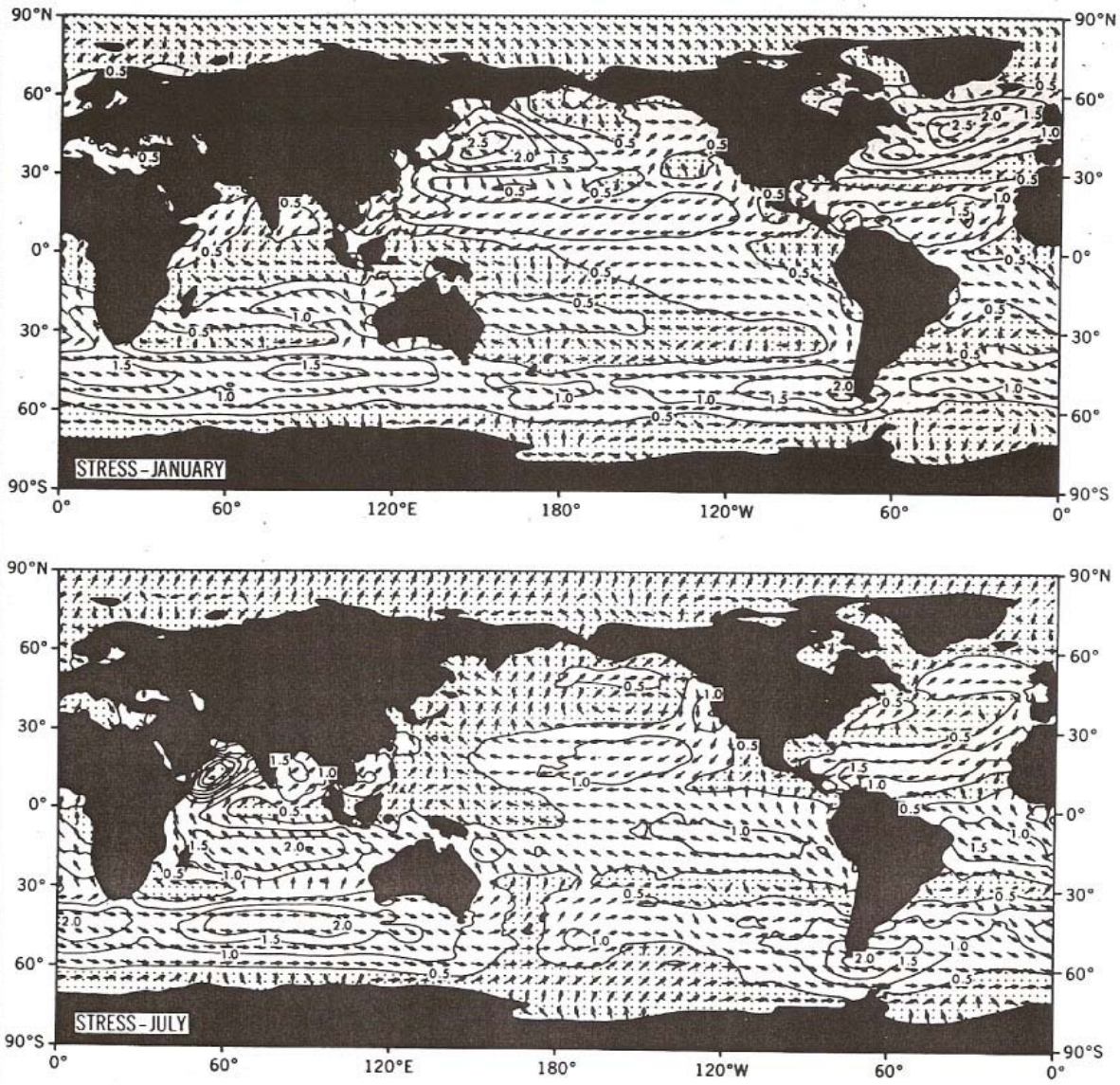
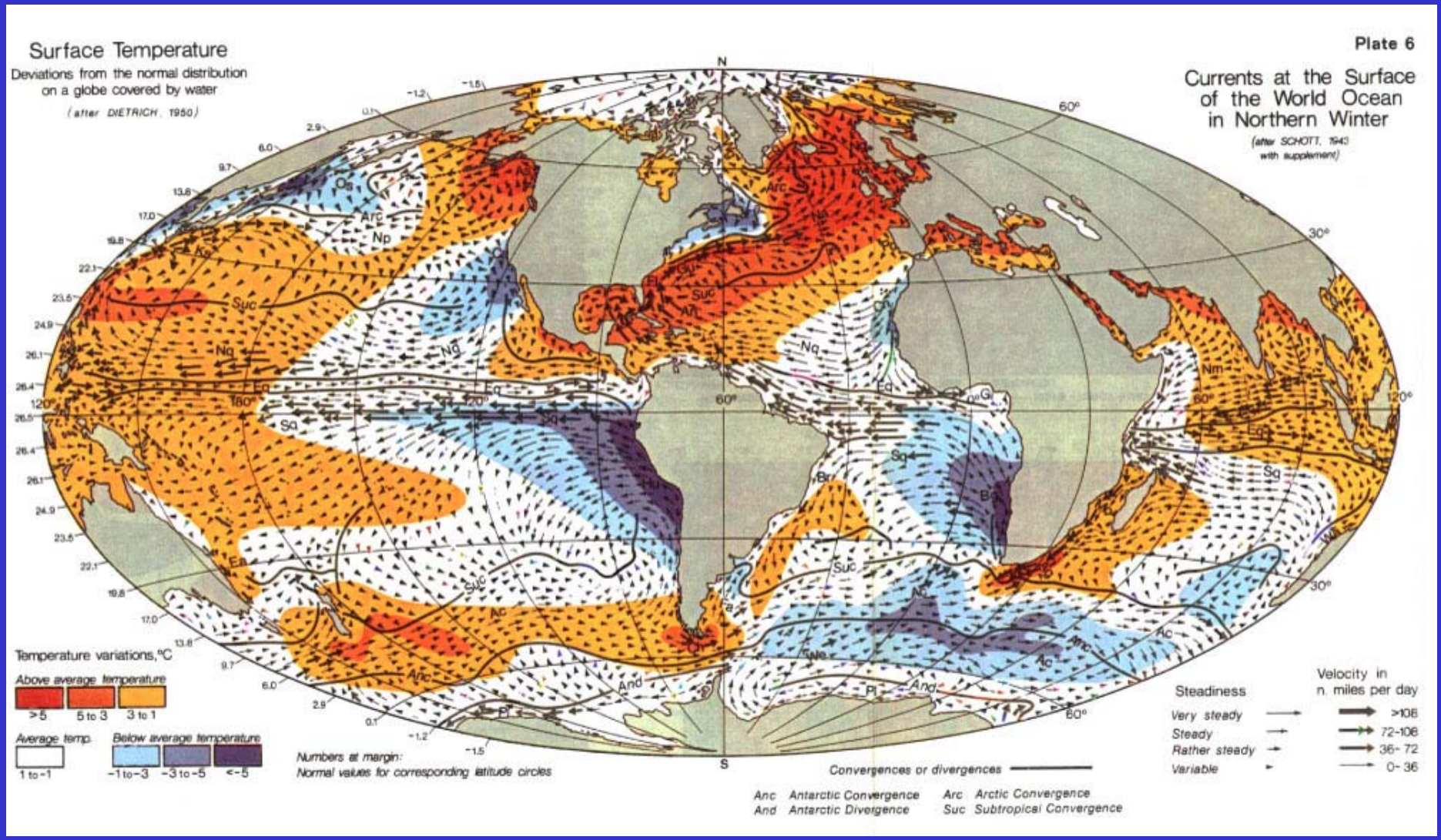


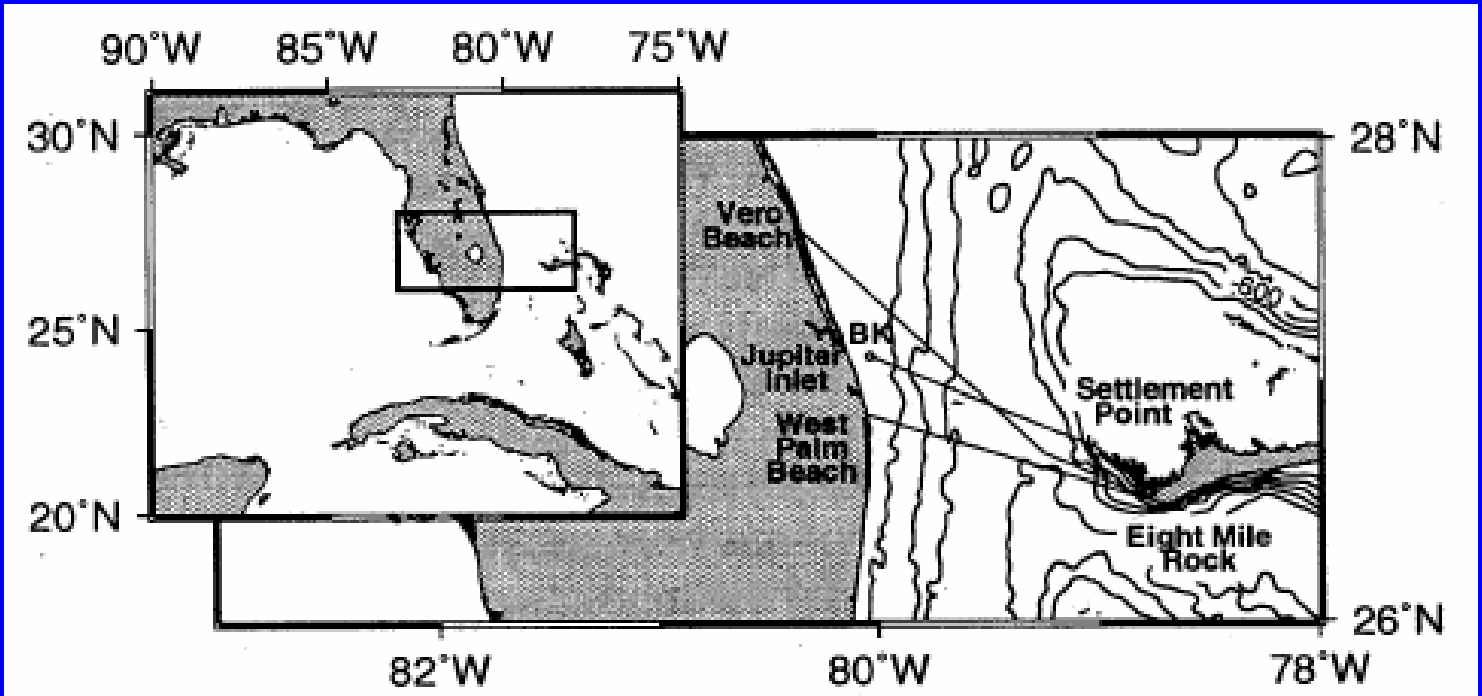
FIG. 4. Wind stress fields. Arrows indicate direction and contours the magnitude (dyn cm^{-2}) of the wind stress vectors. Shading marks magnitudes < 0.5 dyn cm^{-2}.

Wind Patterns

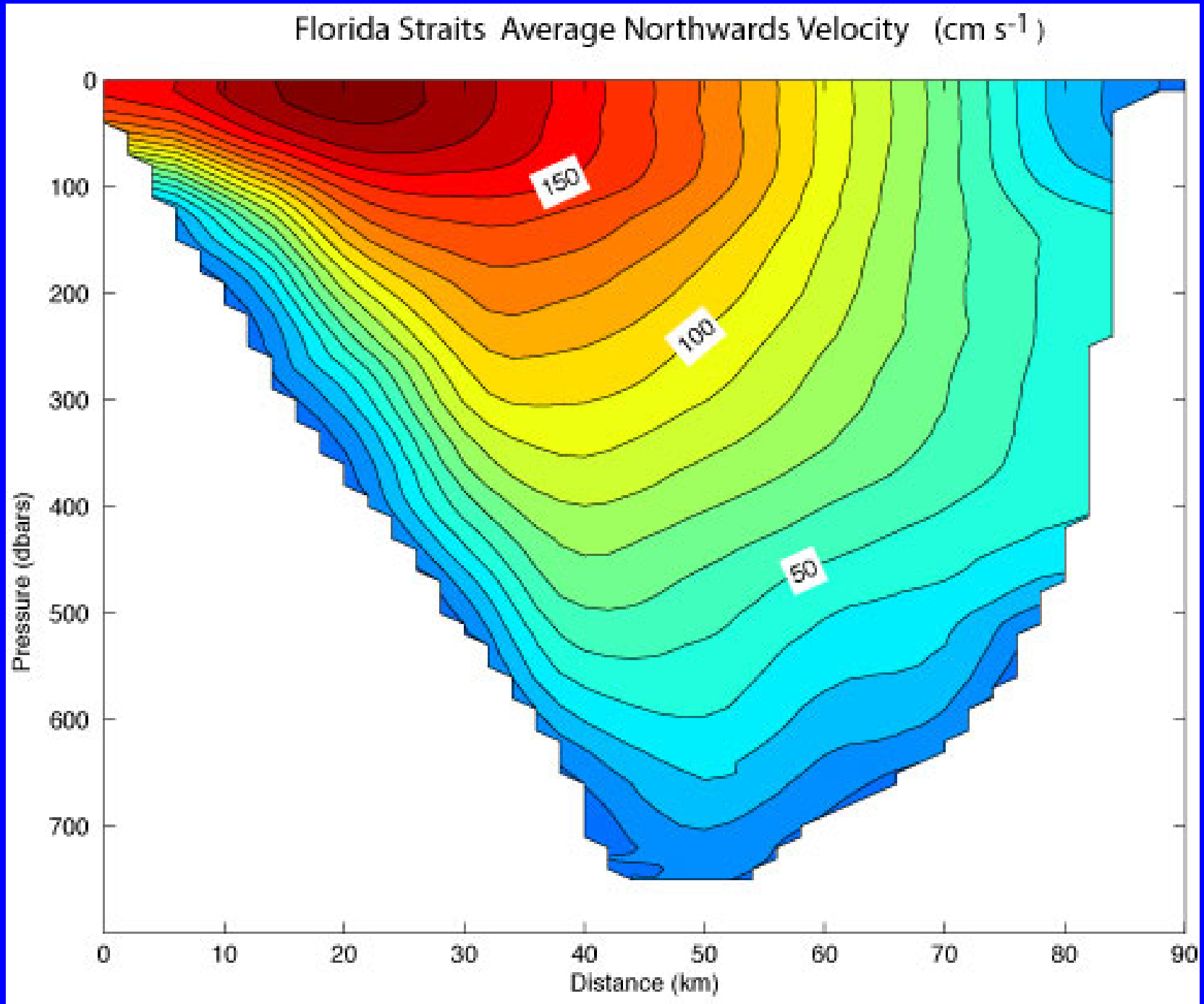

Surface Temperature
Deviations from the normal distribution on a globe covered by water
(after DIETRICH, 1950)
Plate 6
Currents at the Surface of the World Ocean in Northern Winter
(after SCHOTT, 1943 with supplement)
Temperature variations, °C
Above average temperature
>5
5 to 3
3 to 1
Average temp.
1 to -1
Below average temperature
-1 to -3
-3 to -5
<-5
Numbers at margin:
Normal values for corresponding latitude circles
Convergences or divergences
Anc Antarctic Convergence
And Antarctic Divergence
Arc Arctic Convergence
Suc Subtropical Convergence
Steadiness
Very steady
Steady
Rather steady
Variable
Velocity in n. miles per day
>108
72-108
36-72
0-36

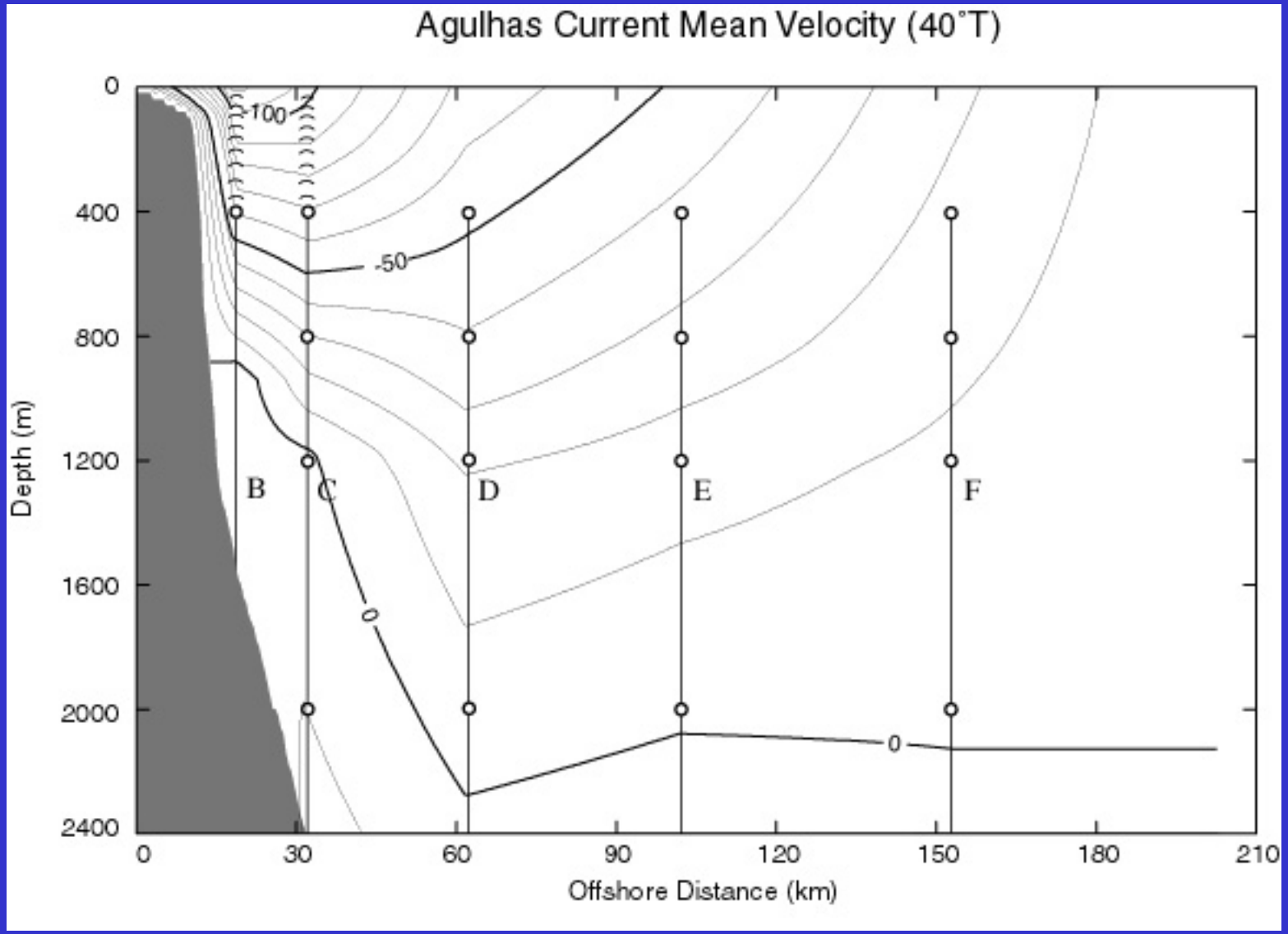
Florida Straits Transport

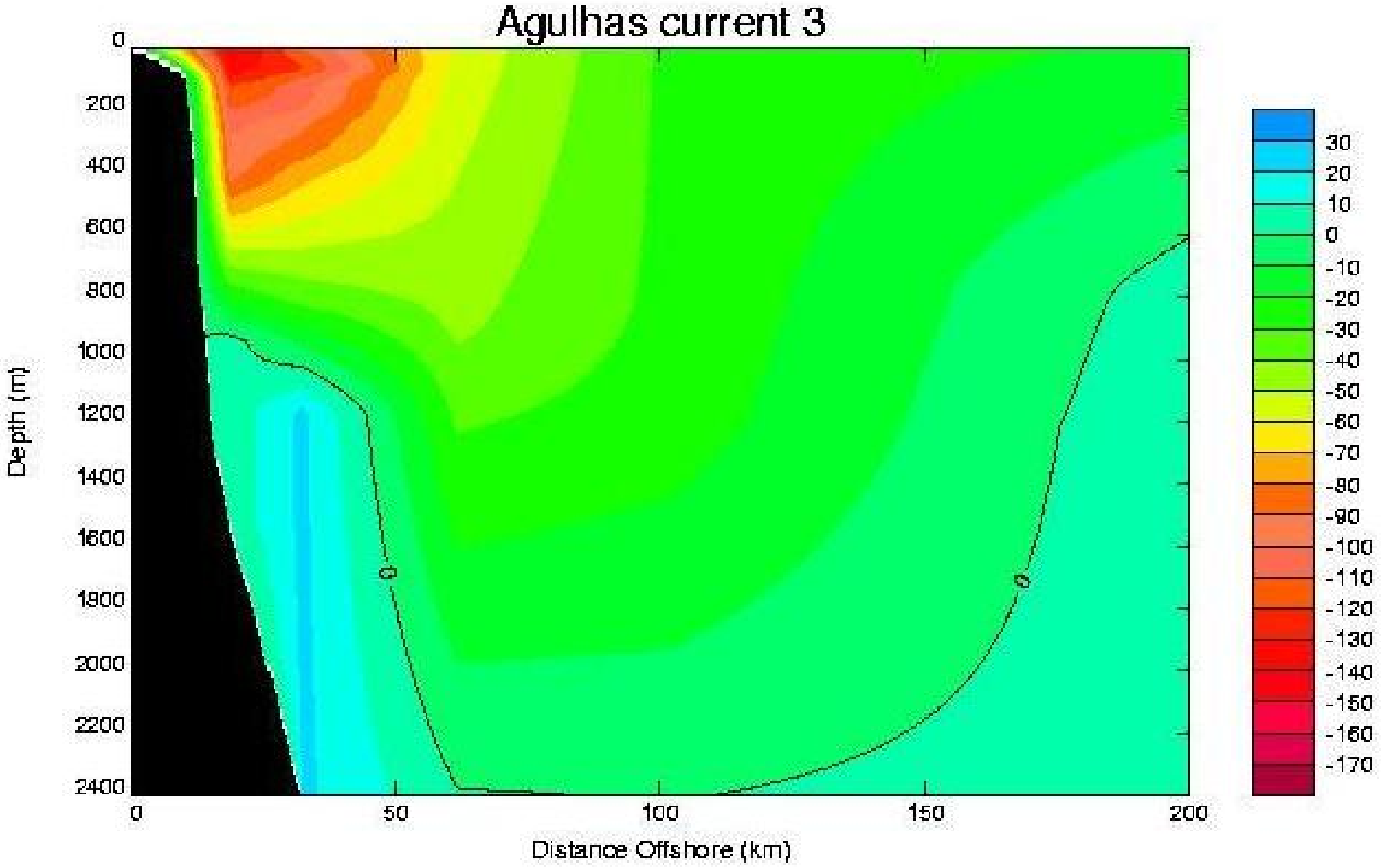
Gulf Stream transport from electromagnetic cable and sections

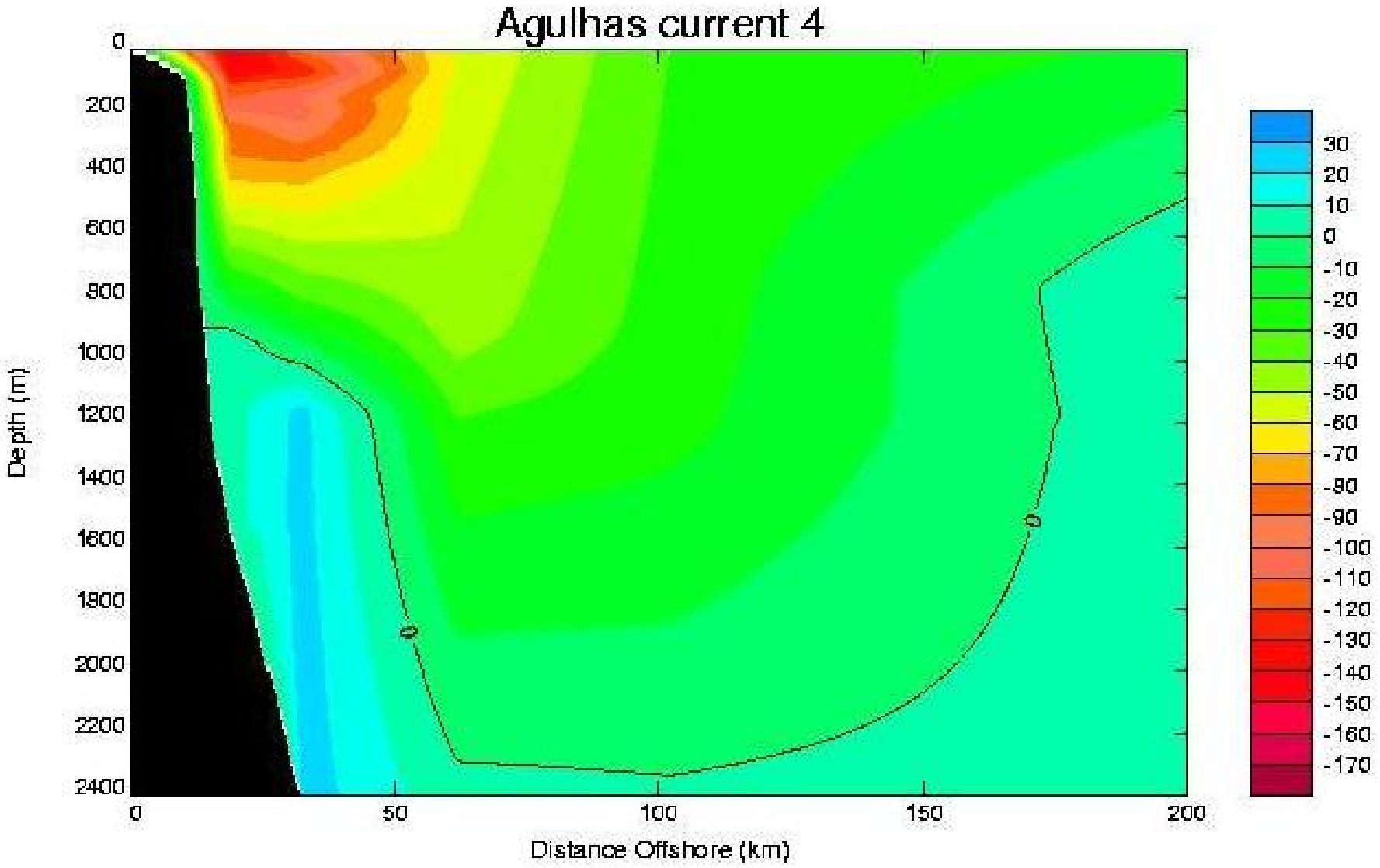


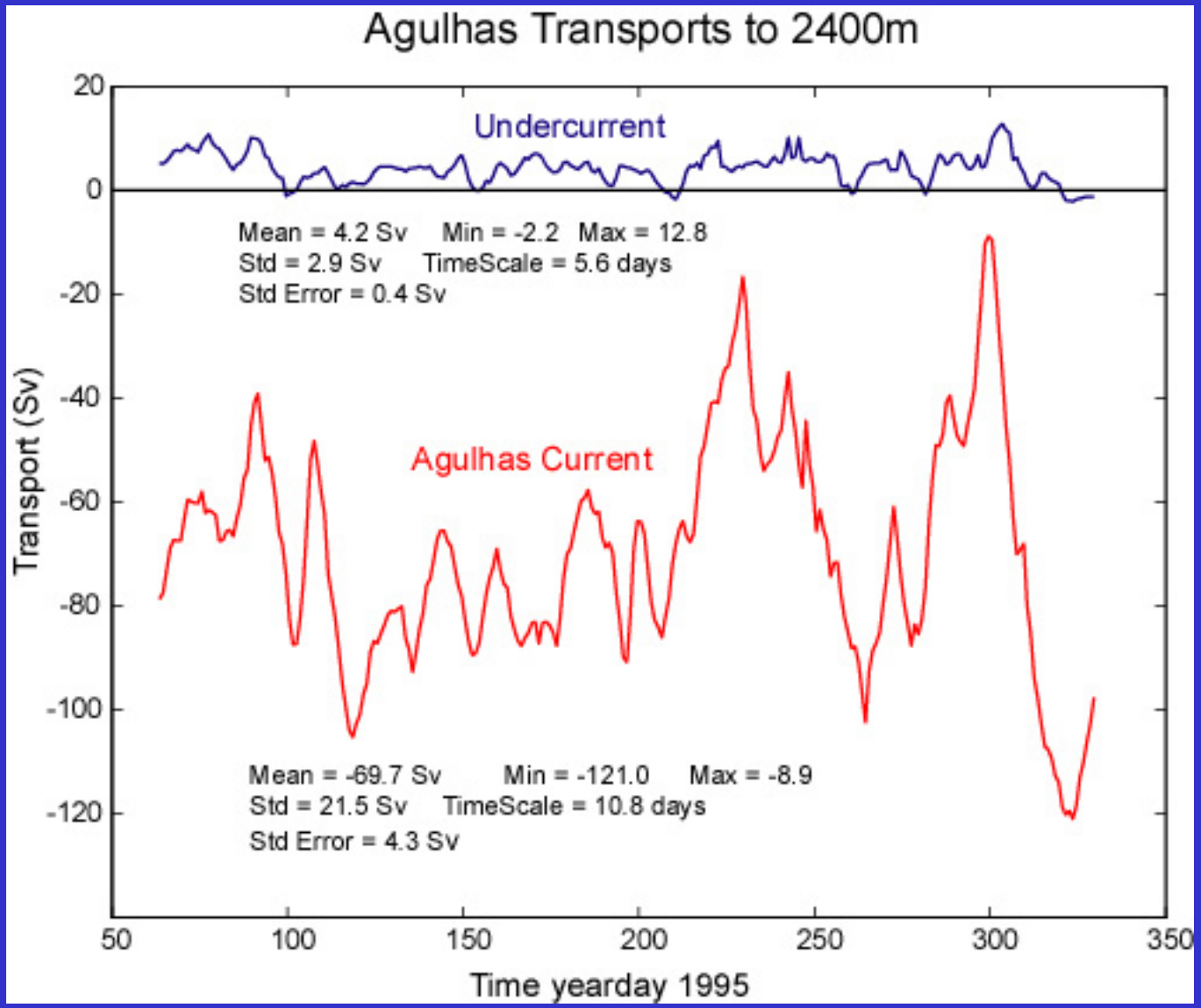
Baringer and Larsen, 2001

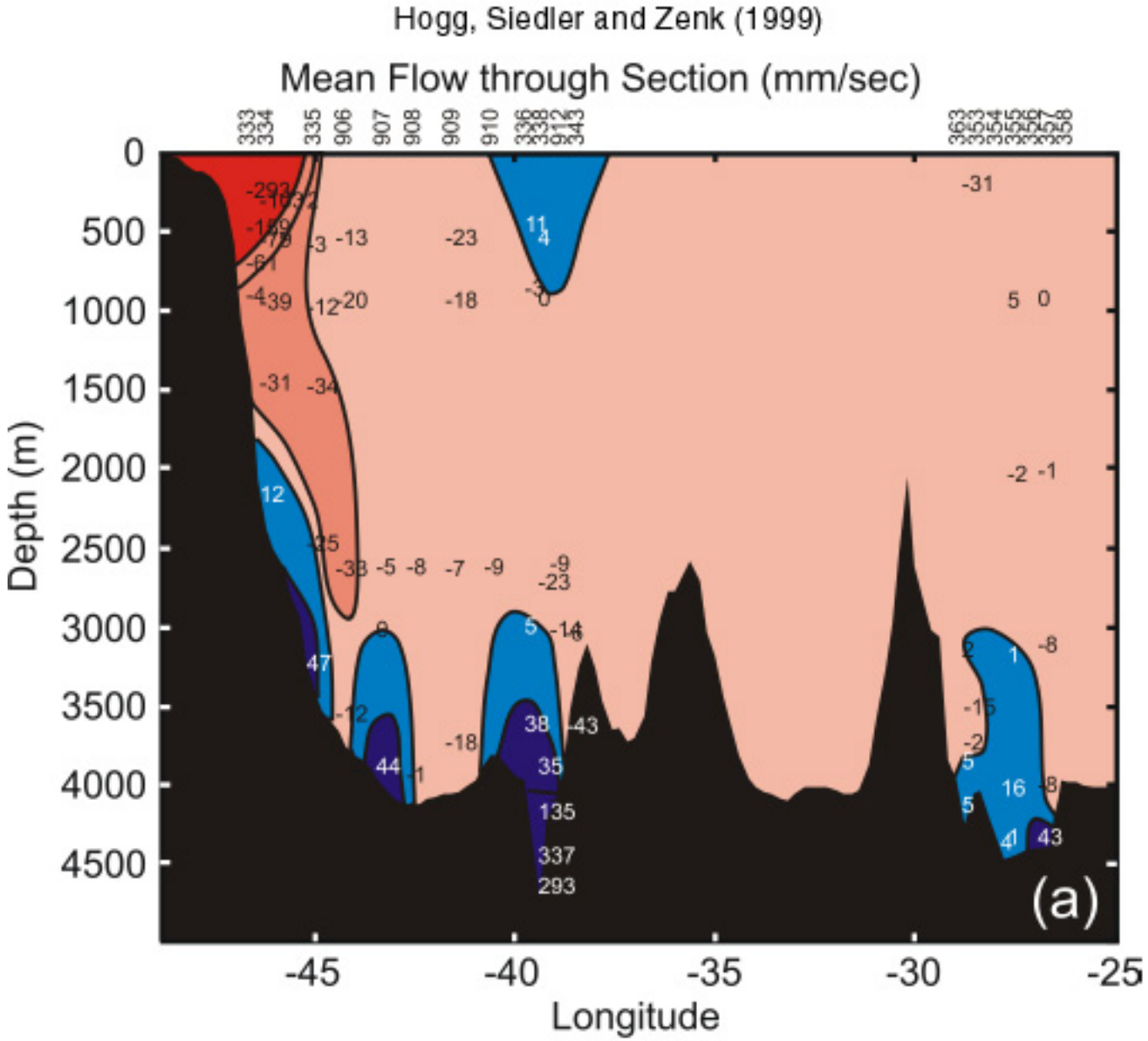

Florida Straits Average Northwards Velocity (cm s-1)
Pressure (dbars)
Distance (km)
0
100
200
300
400
500
600
700
0
10
20
30
40
50
60
70
80
90
150
100
50


Agulhas Current Mean Velocity (40˚T)
Depth (m)
0
400
800
1200
1600
2000
2400
-100
-50
0
0
B
C
D
E
F
0
30
60
90
120
150
180
210
Offshore Distance (km)


Agulhas current 3
Depth (m)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
0
50
100
150
200
Distance Offshore (km)
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170

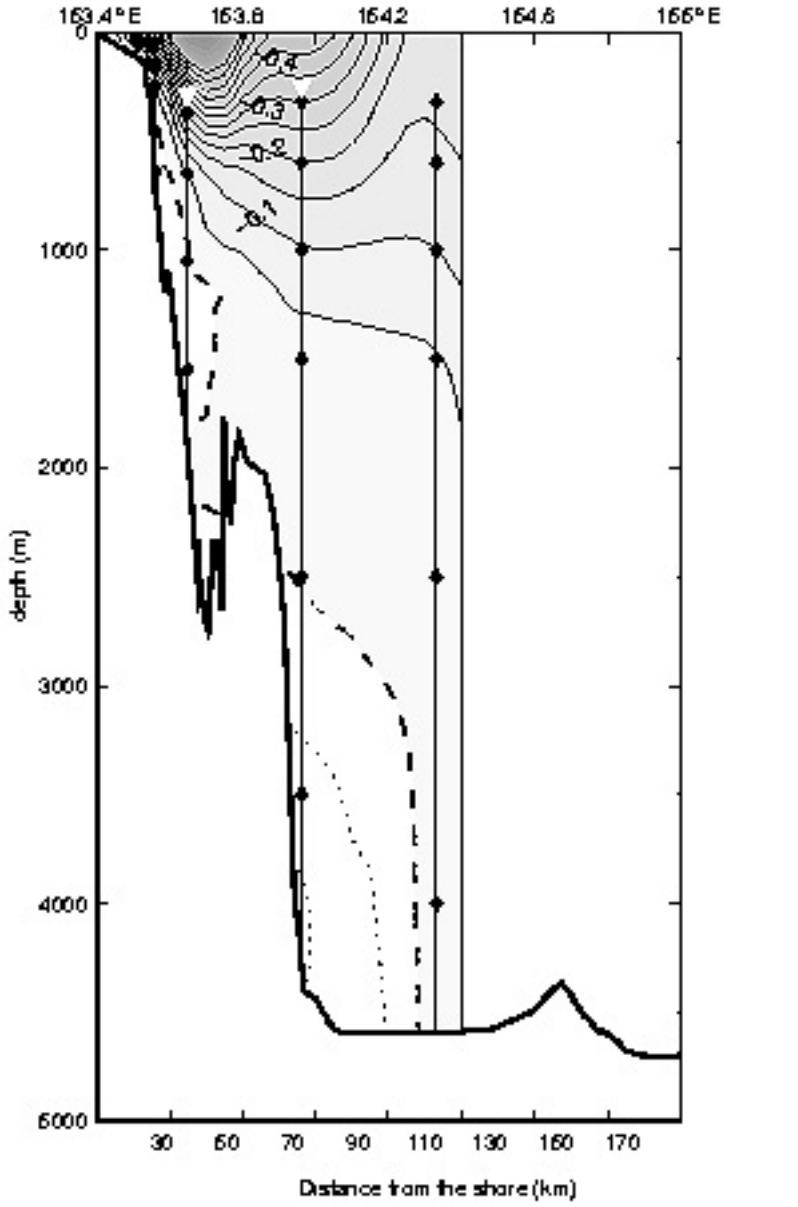

Agulhas current 4
Depth (m)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
0
50
100
150
200
Distance Offshore (km)
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170


Agulhas Transports to 2400m
Undercurrent
Mean = 4.2 Sv Min = -2.2 Max = 12.8
Std = 2.9 Sv TimeScale = 5.6 days
Std Error = 0.4 Sv
Agulhas Current
Mean = -69.7 Sv Min = -121.0 Max = -8.9
Std = 21.5 Sv TimeScale = 10.8 days
Std Error = 4.3 Sv
Transport (Sv)
Time yearday 1995
20
0
-20
-40
-60
-80
-100
-120
50
100
150
200
250
300
350

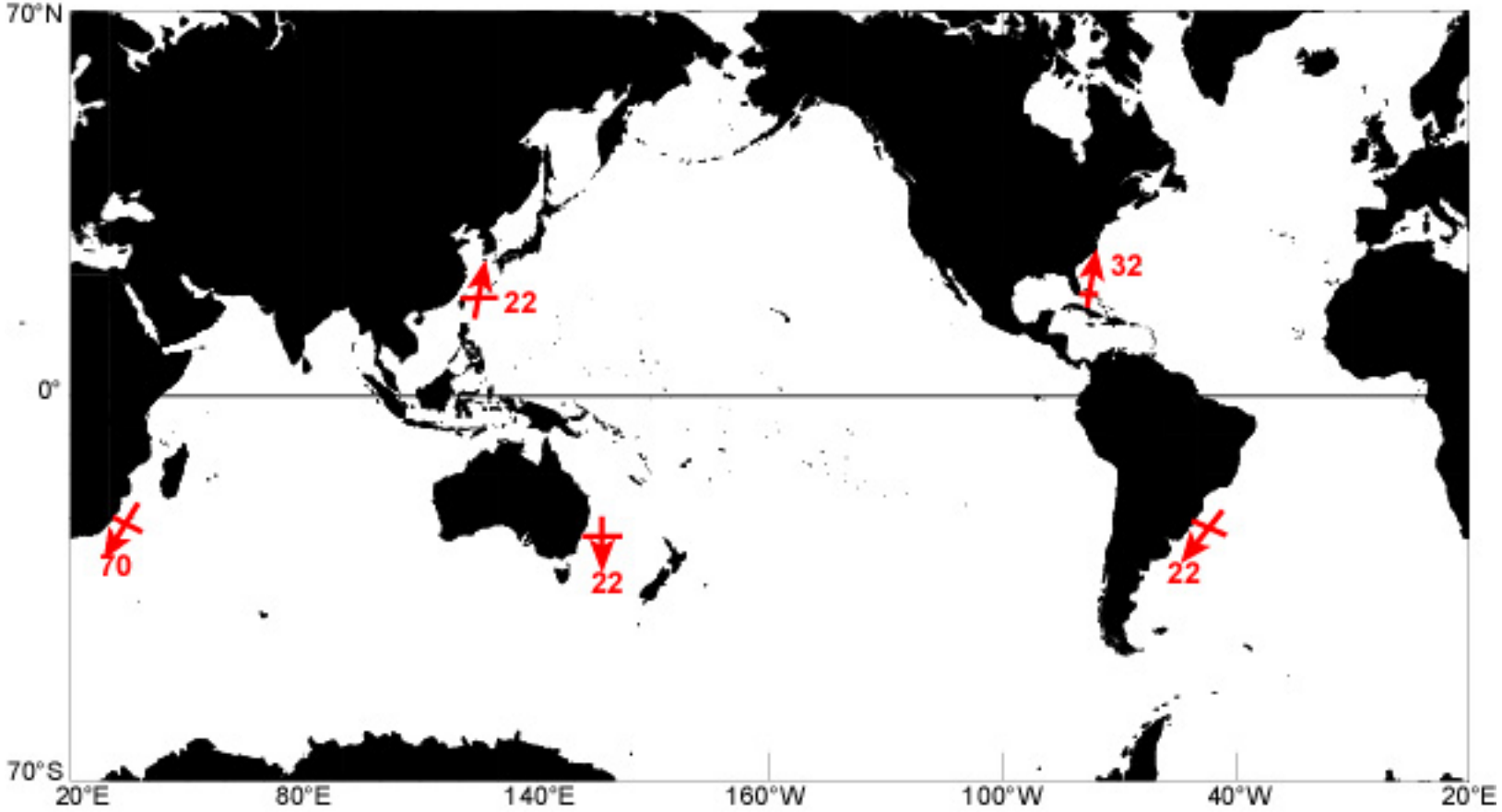

Hogg, Siedler and Zenk (1999)
Mean Flow through Section (mm/sec)
333 334 335 906 907 908 909 910 336 338 912 343 363 353 354 355 356 357 358
Depth (m)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
-45
-40
-35
-30
-25
Longitude
(a)

East Australian Current

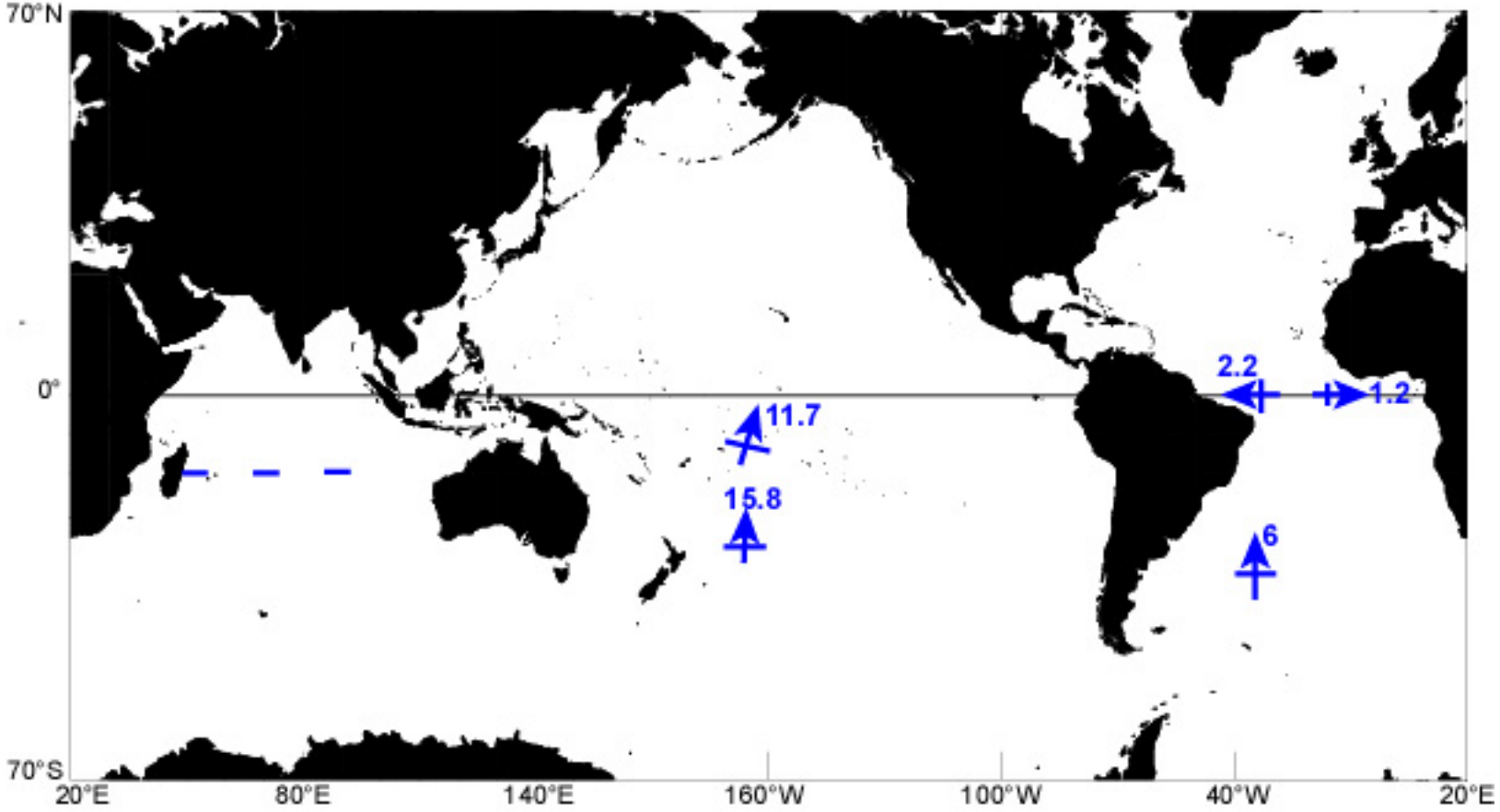
Mata, Tomczak, Wijffels
and Church (2000)



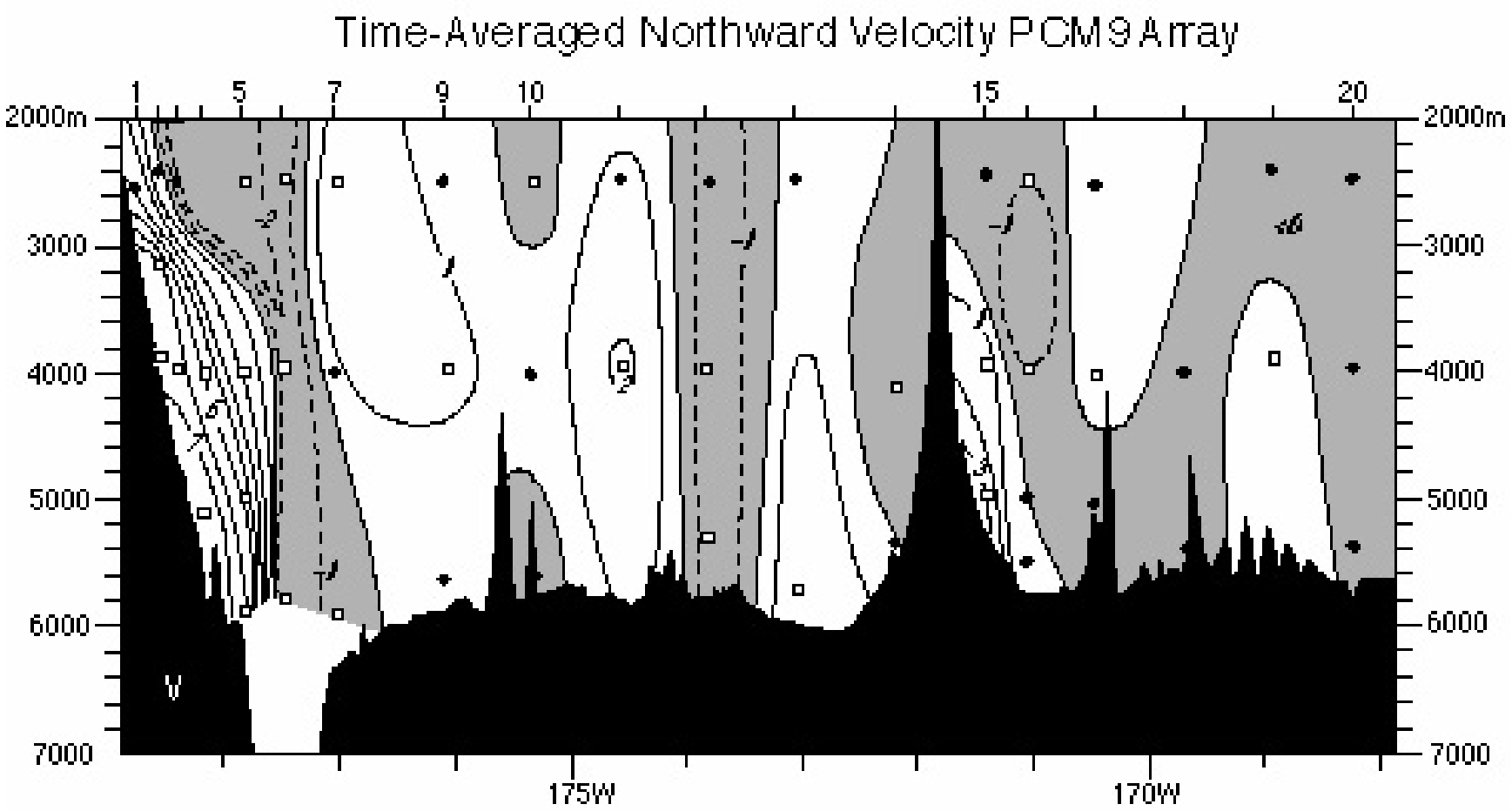
Thermocline Western Boundary Current Transports



Bottom Water Transport

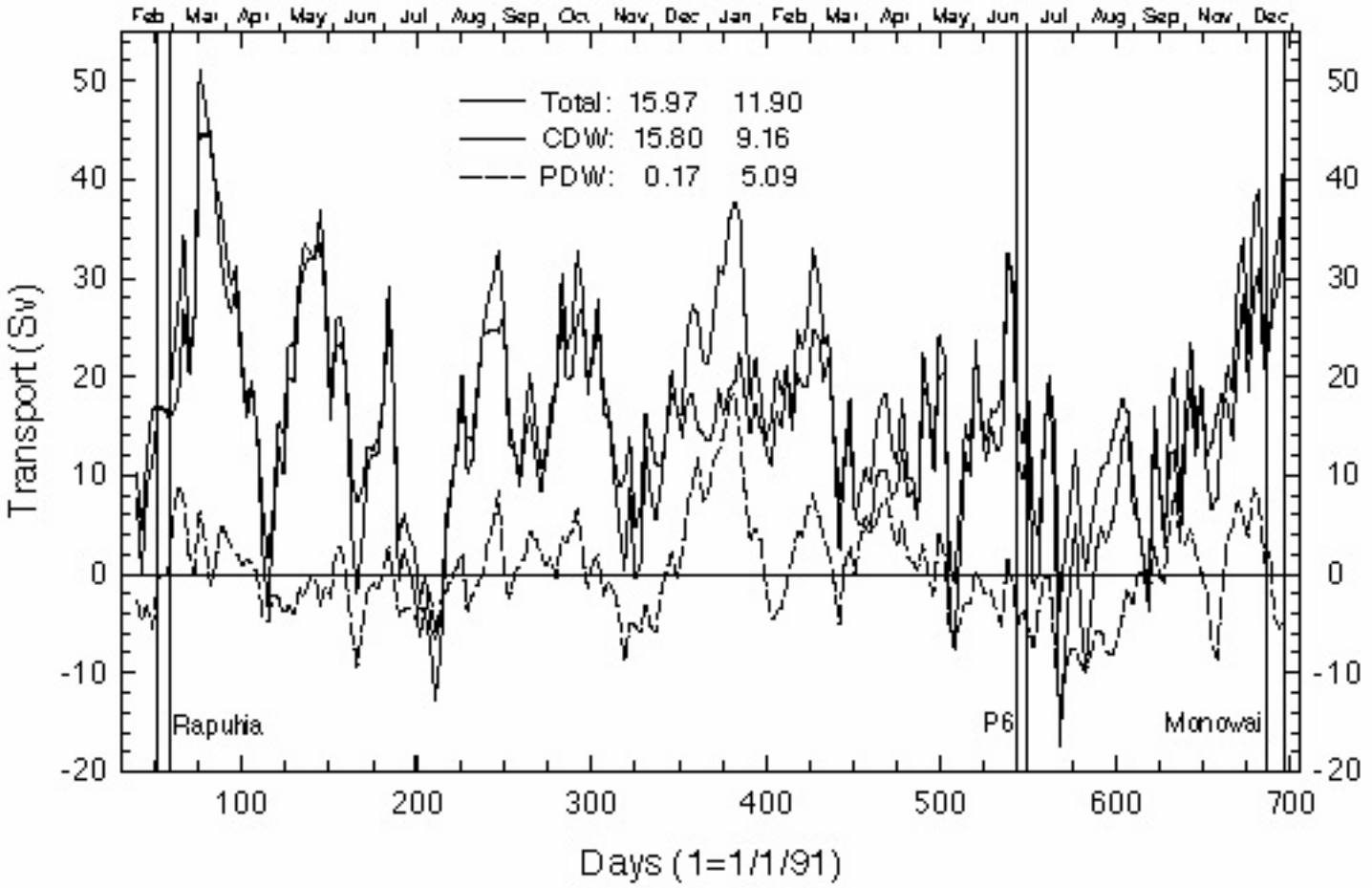


Whitworth, Warren, Nowlin, Rutz,
Pillsbury and Moore (1999)

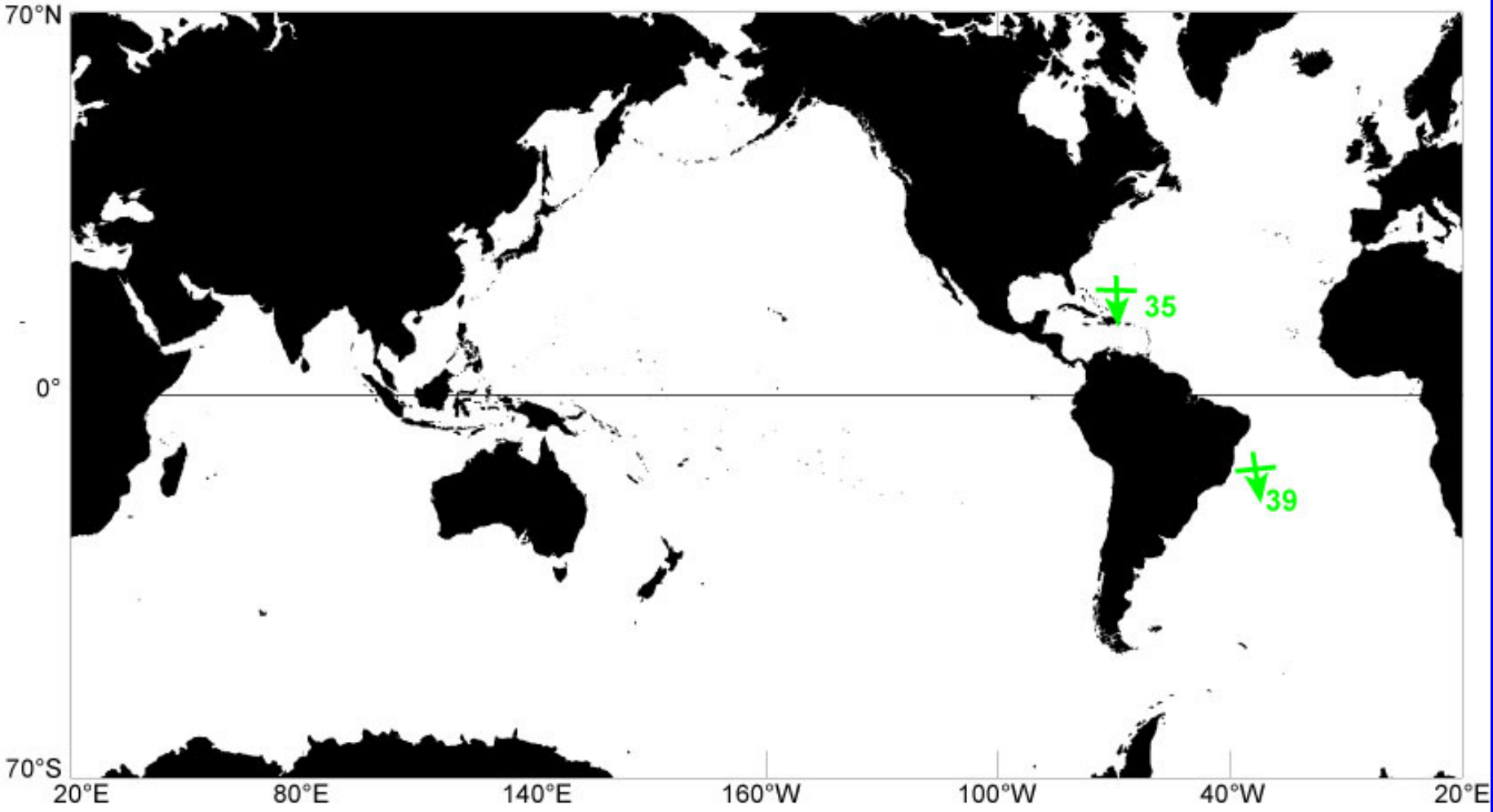


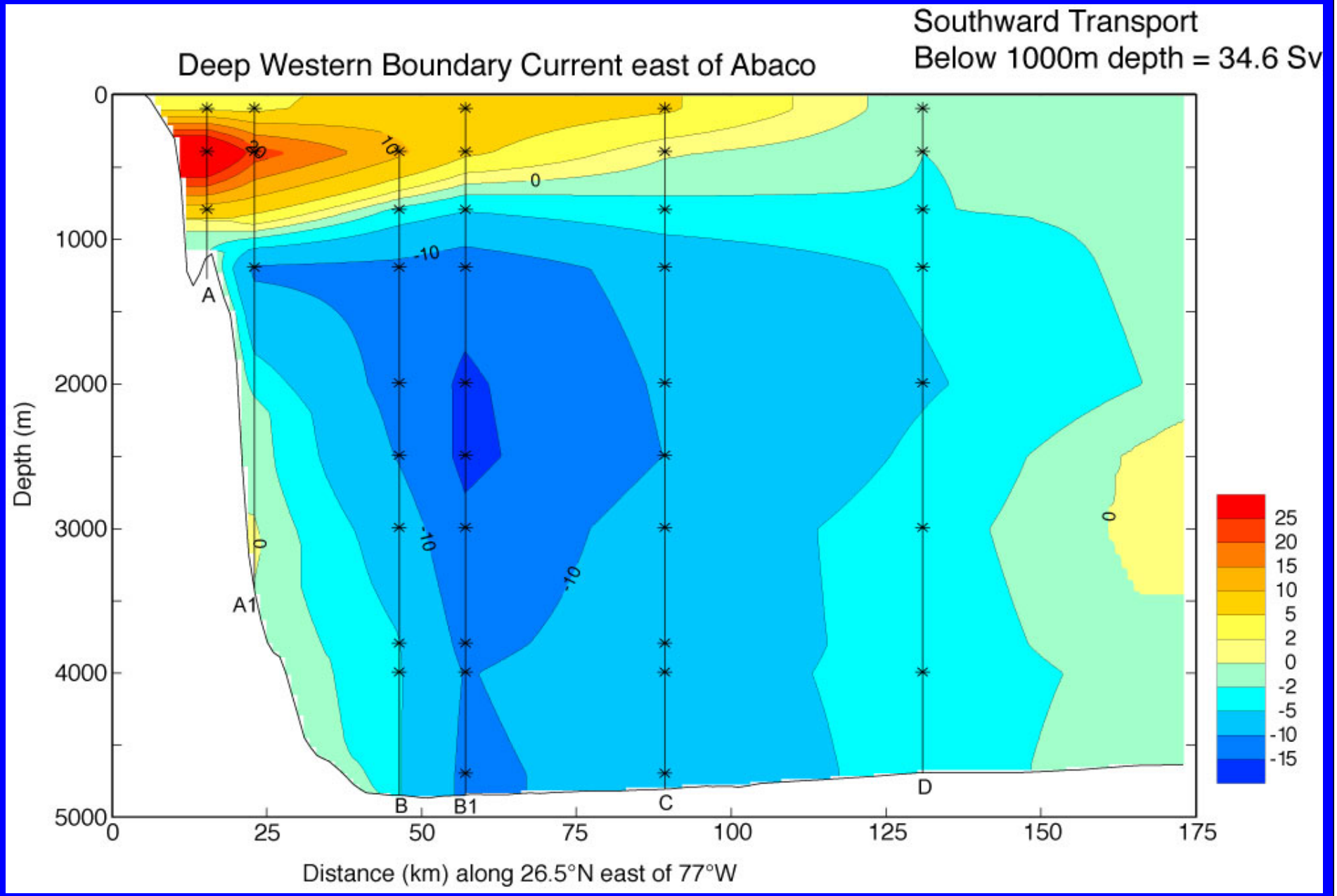
Whitworth, Warren, Nowlin, Rutz,
Pillsbury and Moore (1999)

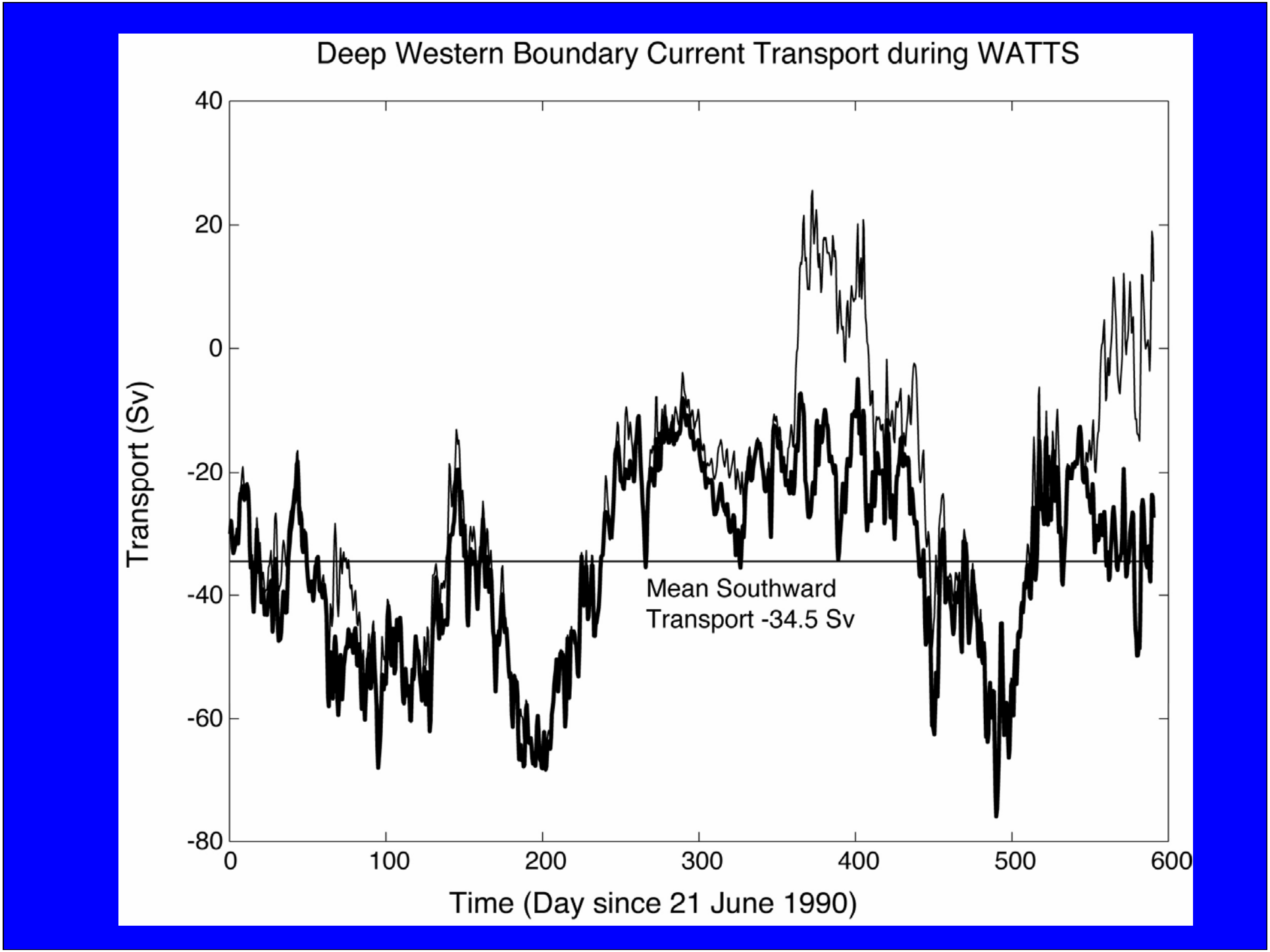
Pacific Deep Western Boundary Current Transport--PCM9

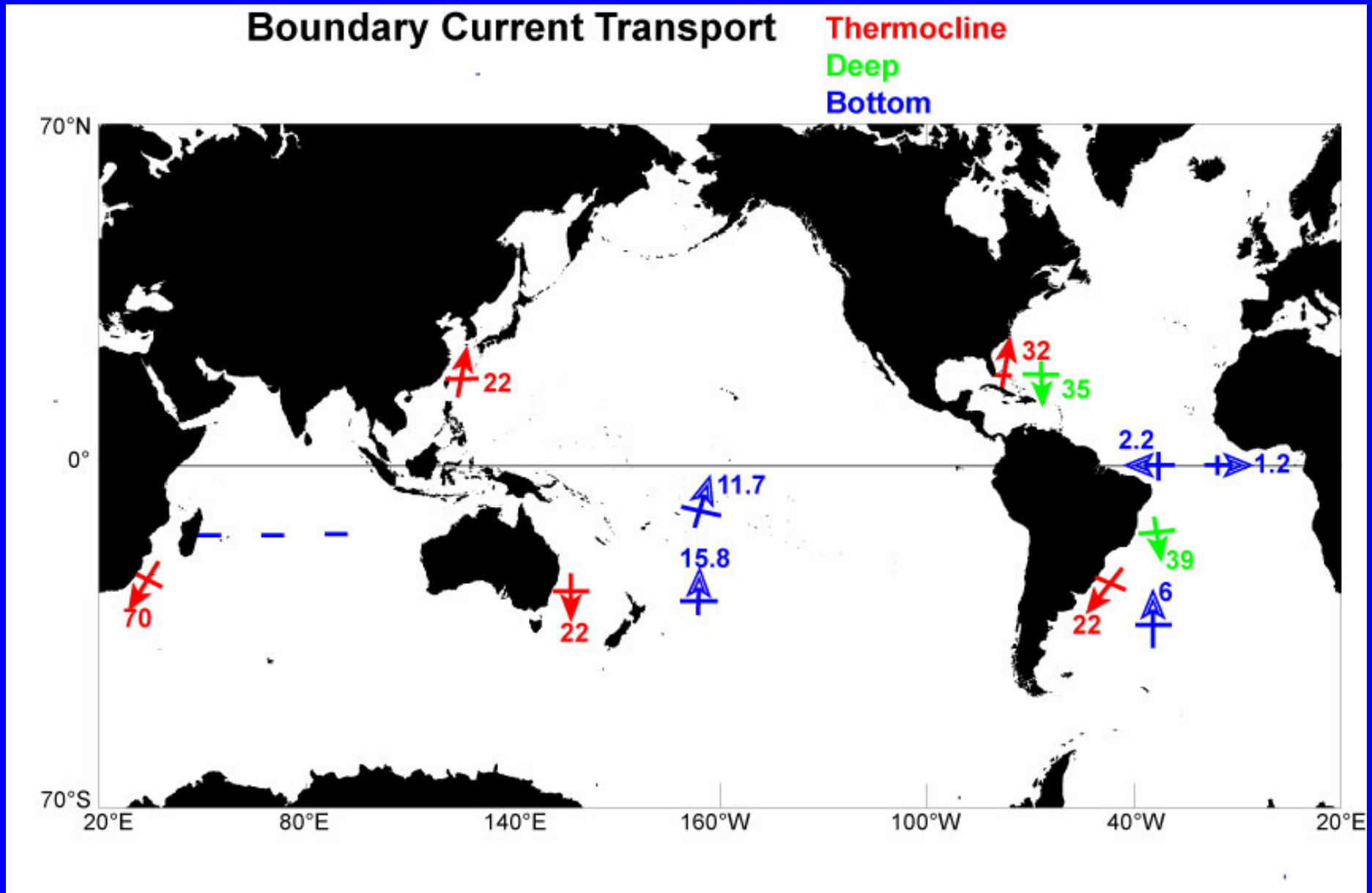


Deep Water Transport




Deep Western Boundary Current east of Abaco
Southward Transport
Below 1000m depth = 34.6 Sv
Depth (m)
Distance (km) along 26.5°N east of 77°W
A
A1
B
B1
C
D
25
20
15
10
5
2
0
-2
-5
-10
-15

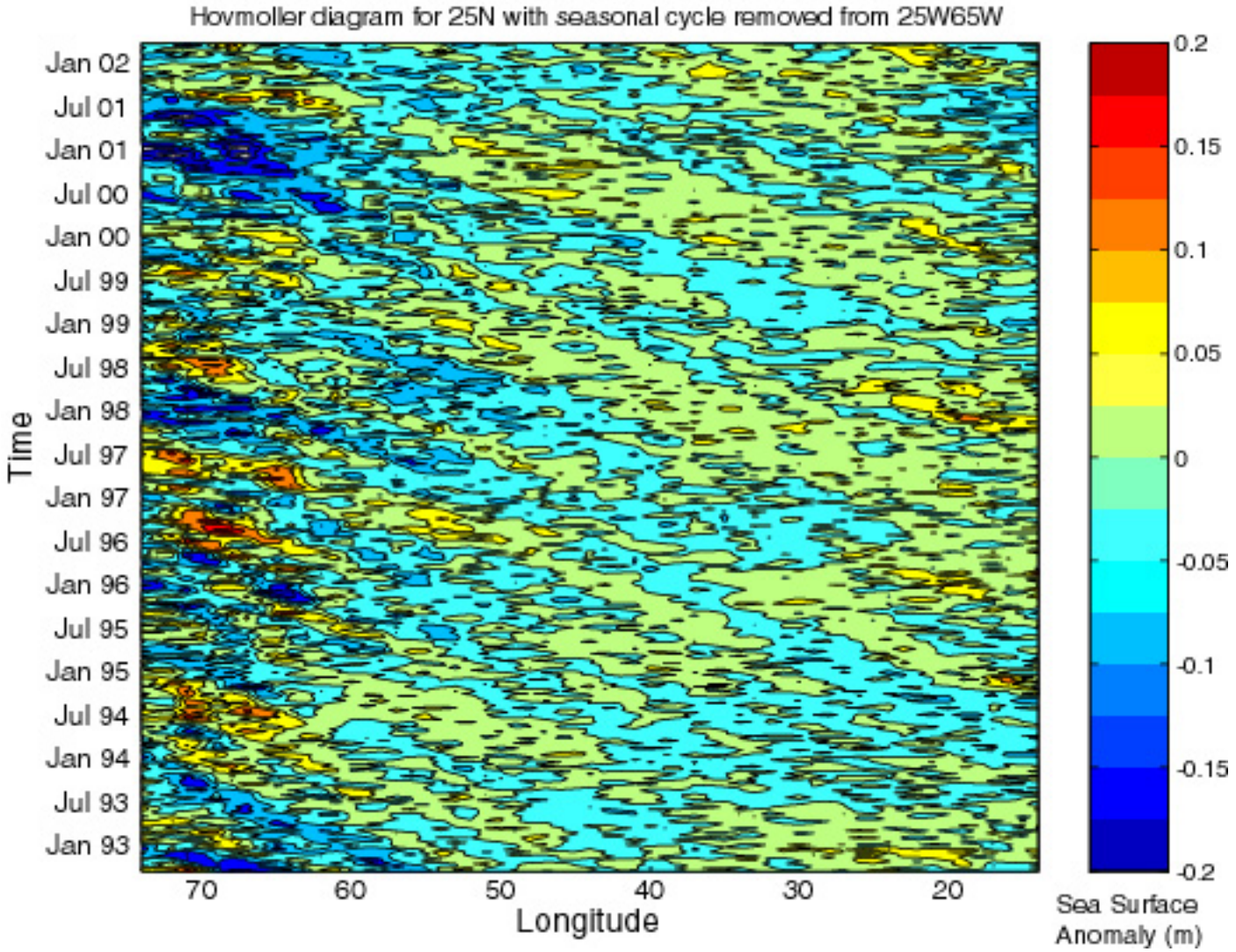

Deep Western Boundary Current Transport during WATTS
Transport (Sv)
40
20
0
-20
-40
-60
-80
0
100
200
300
400
500
600
Time (Day since 21 June 1990)
Mean Southward
Transport -34.5 Sv


Boundary Current Transport
Thermocline
Deep
Bottom
70°N
0°
70°S
20°E
80°E
140°E
160°W
100°W
40°W
20°E
22
32
35
2.2
1.2
11.7
15.8
39
6
70
22
22

Issues

1. What causes fluctuation in boundary current transport?

Westward Propagation at 25°N in the Atlantic



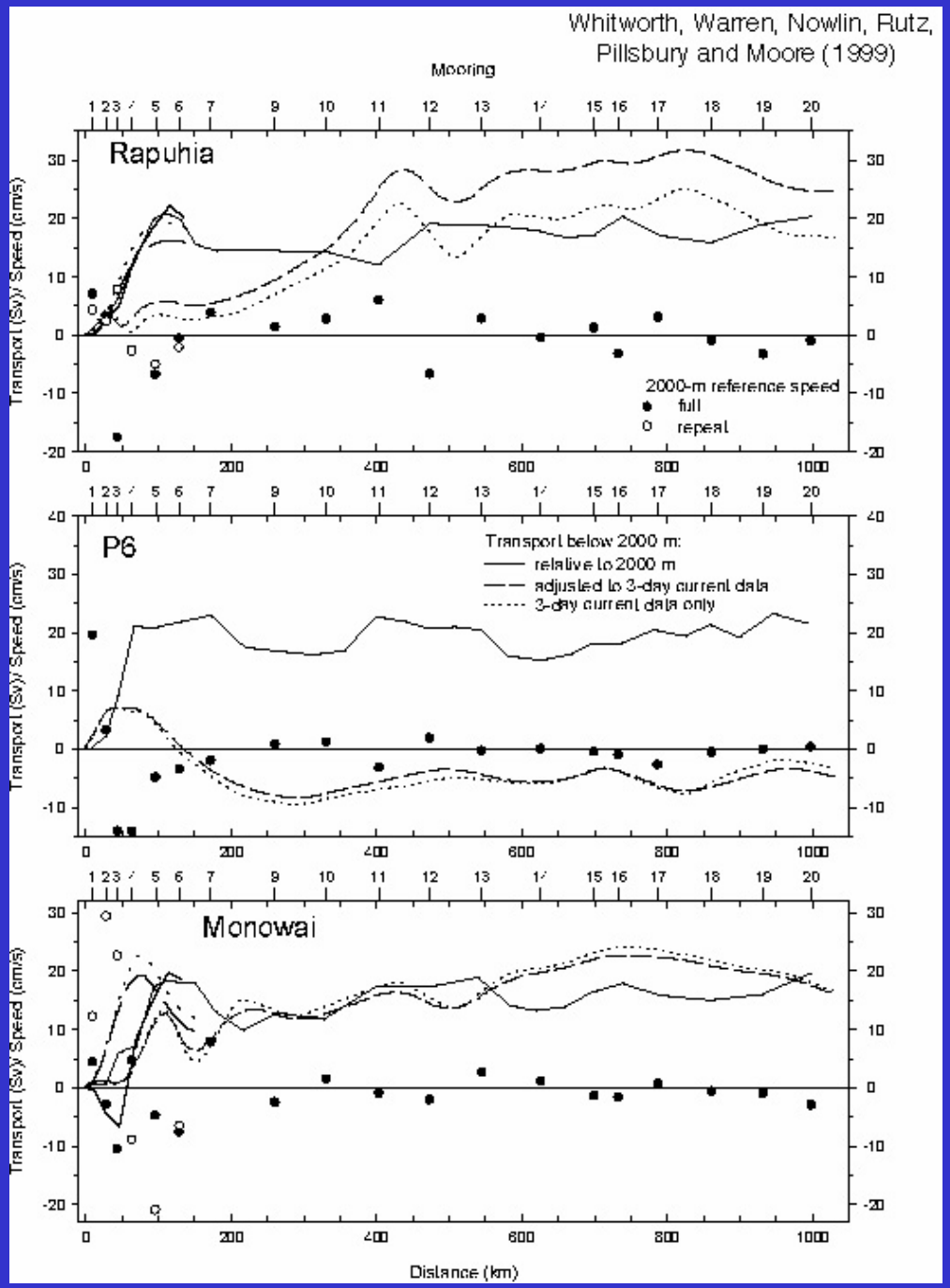
Issues

1. What causes fluctuation in boundary current transport?

Barotropic velocities represent the favourite answer. BUT there has not yet been a comprehensive study of the variability in baroclinic structure over weekly to annual time scales.

Issues

2. Can the transport be estimated from a synoptic section referenced to current meter measurement?


Whitworth, Warren, Nowlin, Rutz,
Pillsbury and Moore (1999)
Mooring
Rapuhia
P6
Monowai
2000-m reference speed
full
repeat
Transport below 2000 m:
relative to 2000 m
adjusted to 3-day current data
3-day current data only
Transport (Sv)/ Speed (cm/s)
Distance (km)

Issues

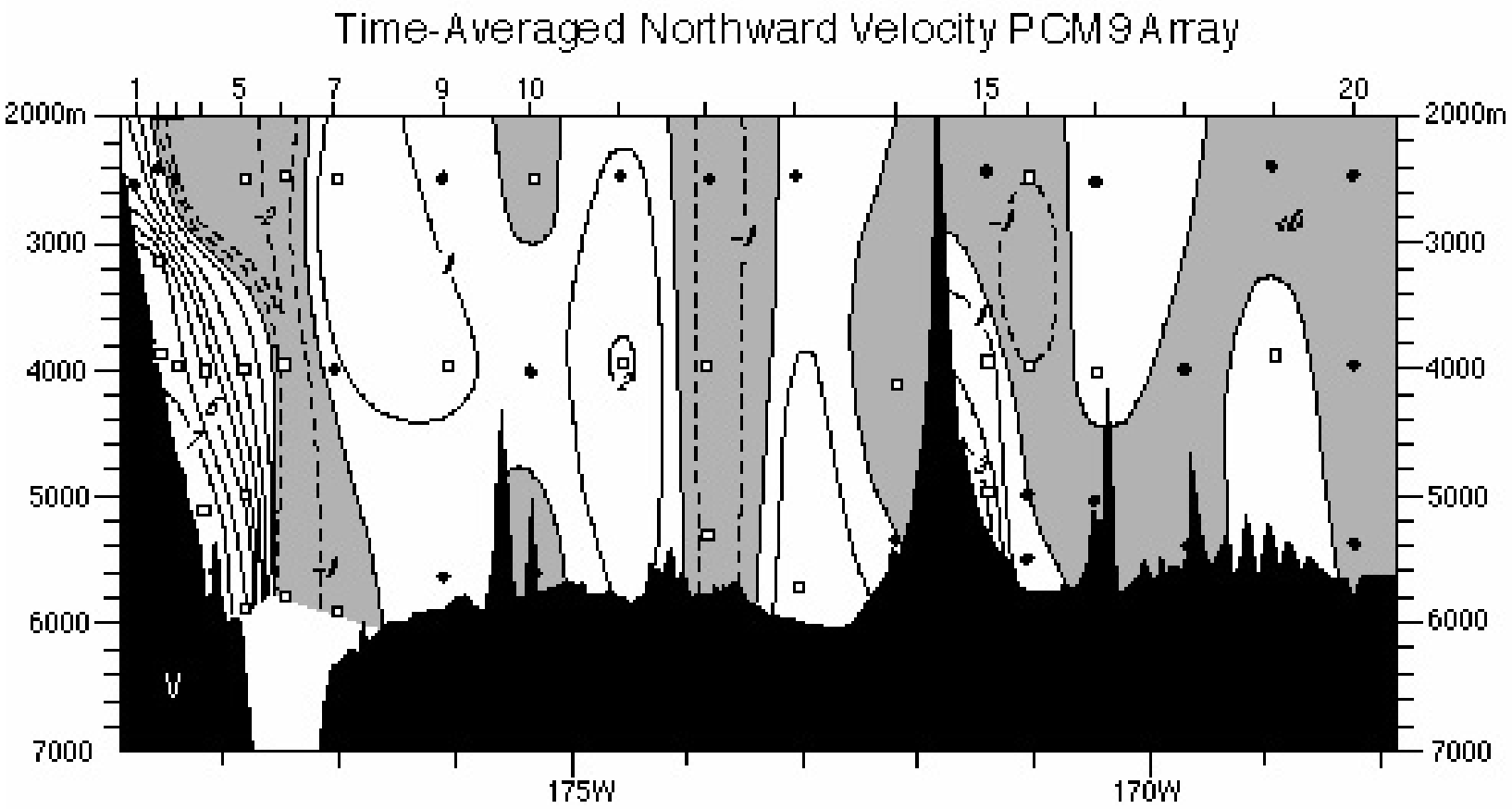
2. Can the transport be estimated from a synoptic section referenced to current meter measurement?

Yes, but it is a synoptic transport estimate that may have little to do with the long-term boundary current transport.

Issues

3. Is there a reference level?

Whitworth, Warren, Nowlin, Rutz,
Pillsbury and Moore (1999)



Issues

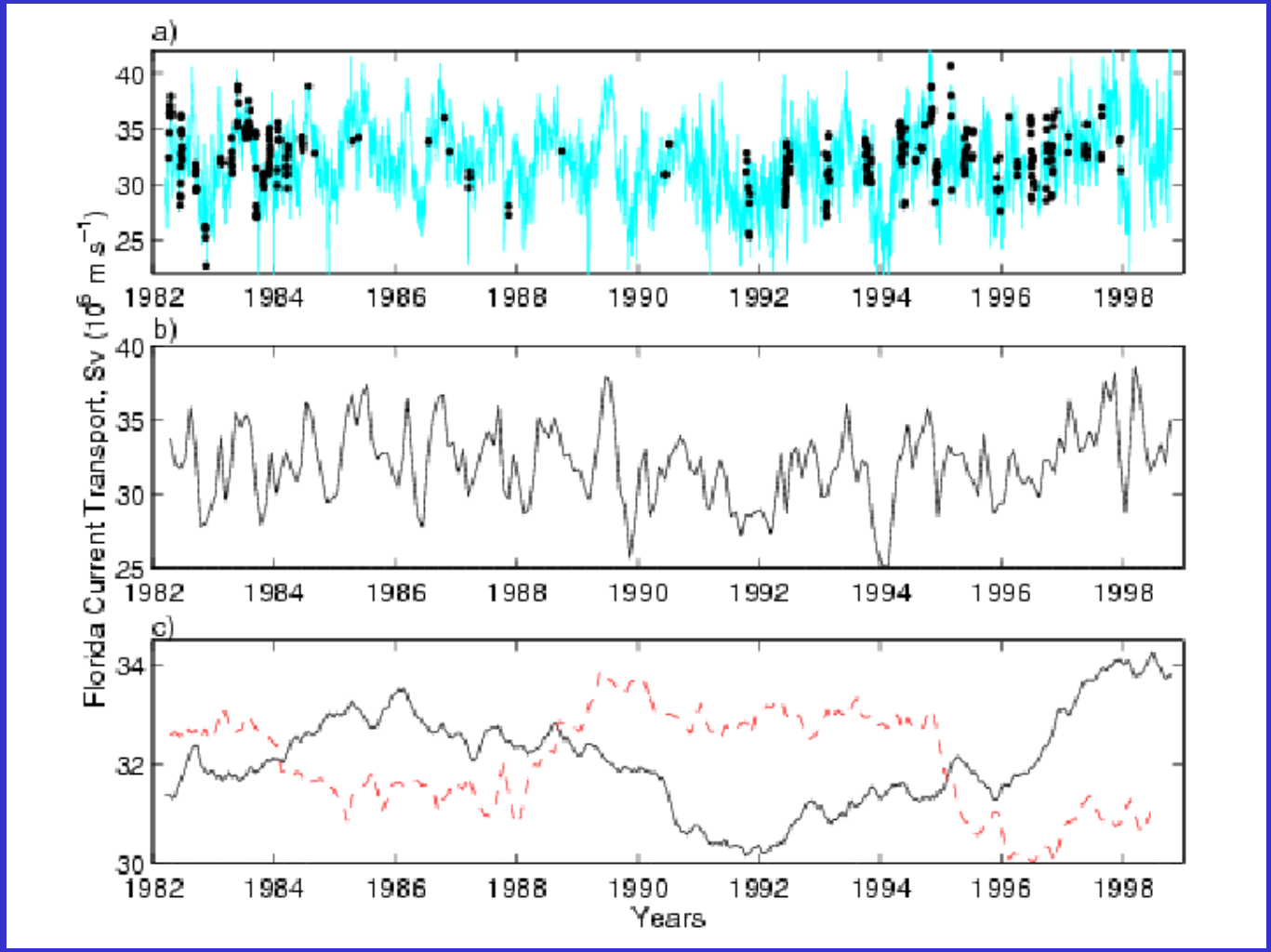
3. Is there a reference level?

Yes but the reference level velocity is not necessarily a zero velocity surface.

Issues

4. Are the boundary current transports useful for defining the basin-scale circulation?

Baringer and Larsen (2001)



Florida Straits Transport

Issues

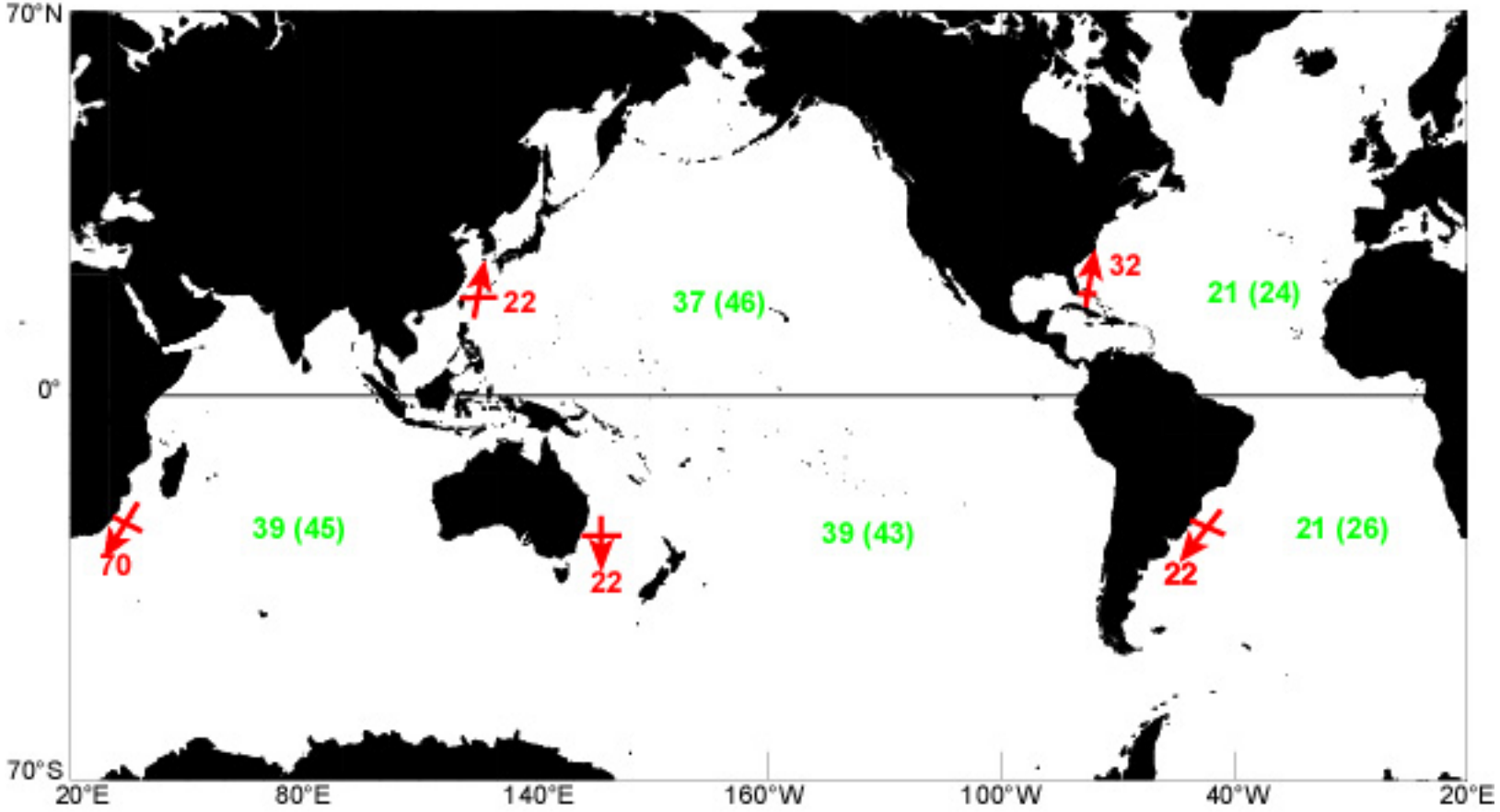
4. Are the boundary current transports useful for defining the basin-scale circulation?

Yes, without question.

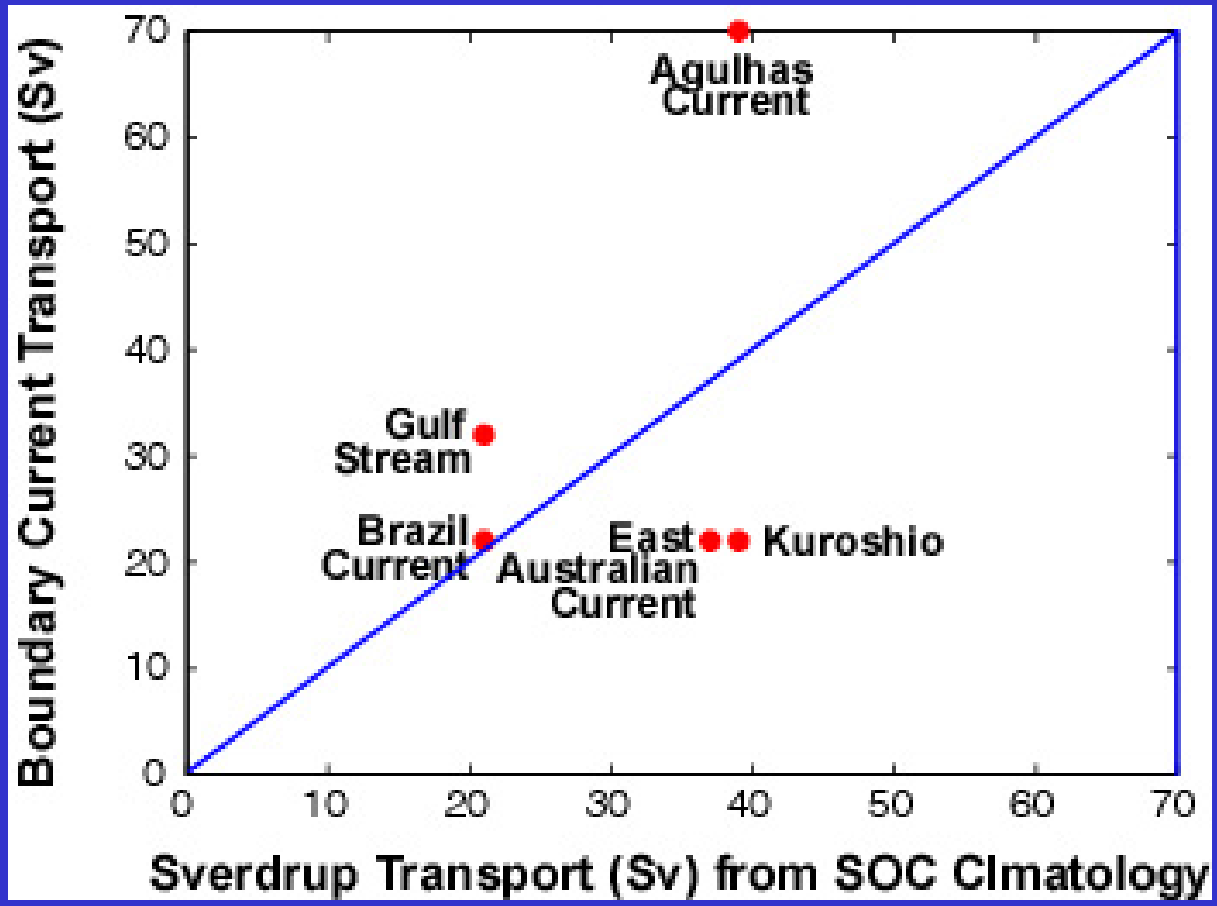
What Sets the Transports

1. Thermocline Western Boundary Currents

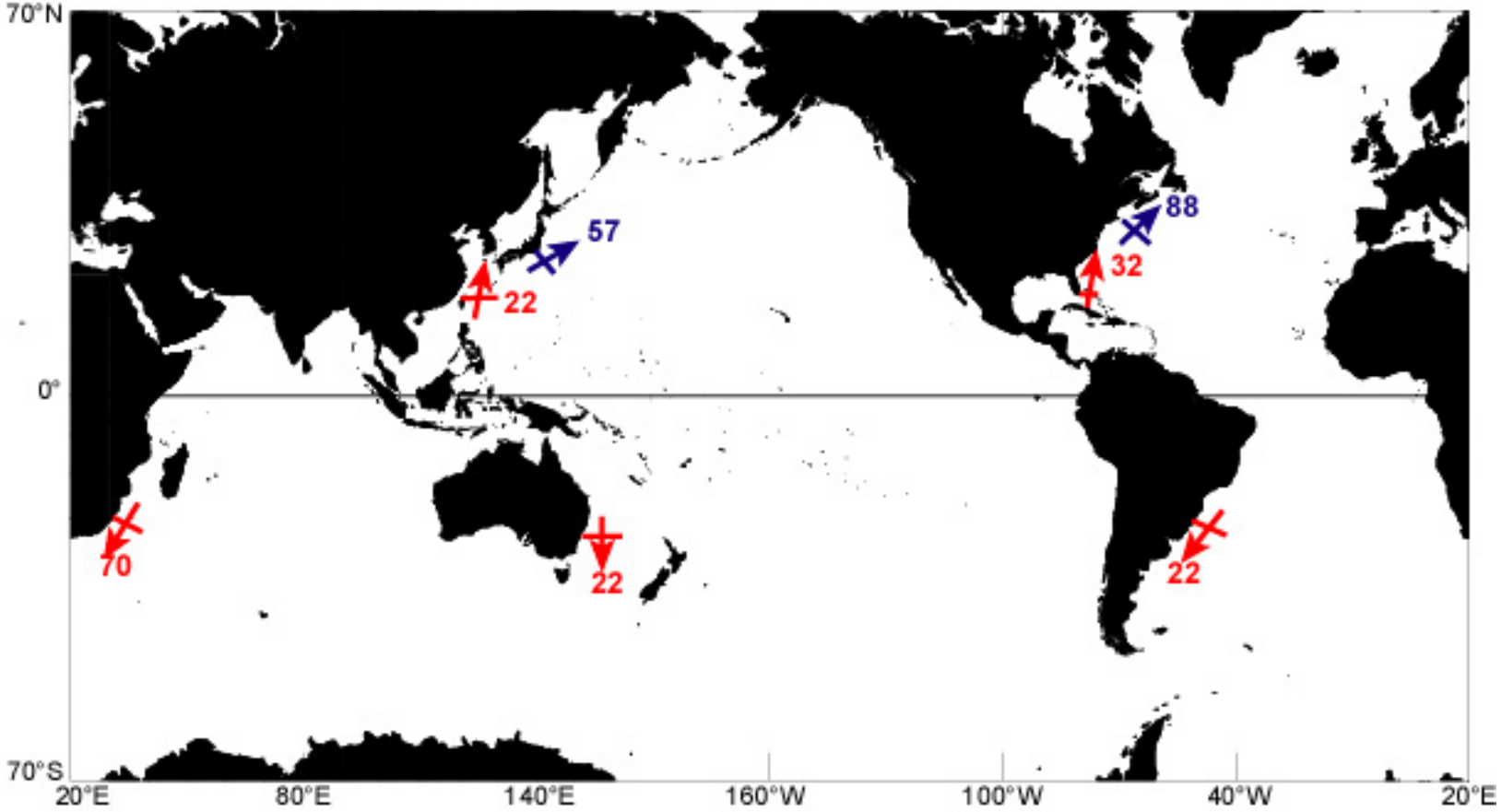
Thermocline Western Boundary Current Transports



Sverdrup Transport based on SOC Climatology (Hellermann and Rosenstein)


Boundary Current Transport (Sv)
Sverdrup Transport (Sv) from SOC Climatology
0
10
20
30
40
50
60
70
Agulhas Current
Gulf Stream
Brazil Current
East Australian Current
Kuroshio

Thermocline Western Boundary Current Transports



What Sets the Transports

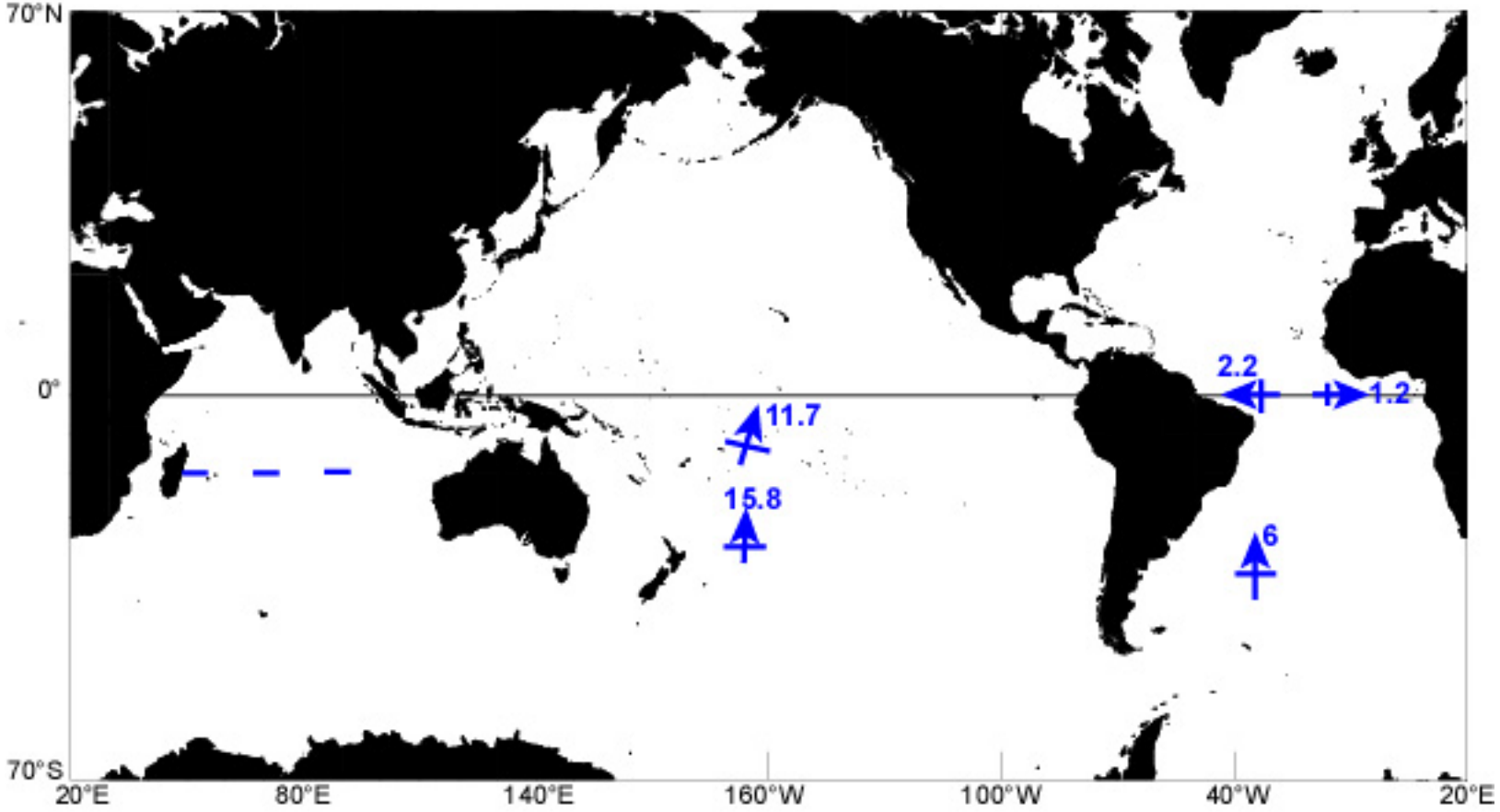
1. Thermocline Western Boundary Currents

Primary answer is Sverdrup transport--wind stress curl--which gives the right sign and right order of magnitude. But, there is information about ocean circulation in the amount by which western boundary current transports are larger or smaller than Sverdrup transport.

What Sets the Transports

2. Northward Flow of Bottom Water

Bottom Water Transport



What Sets the Transports

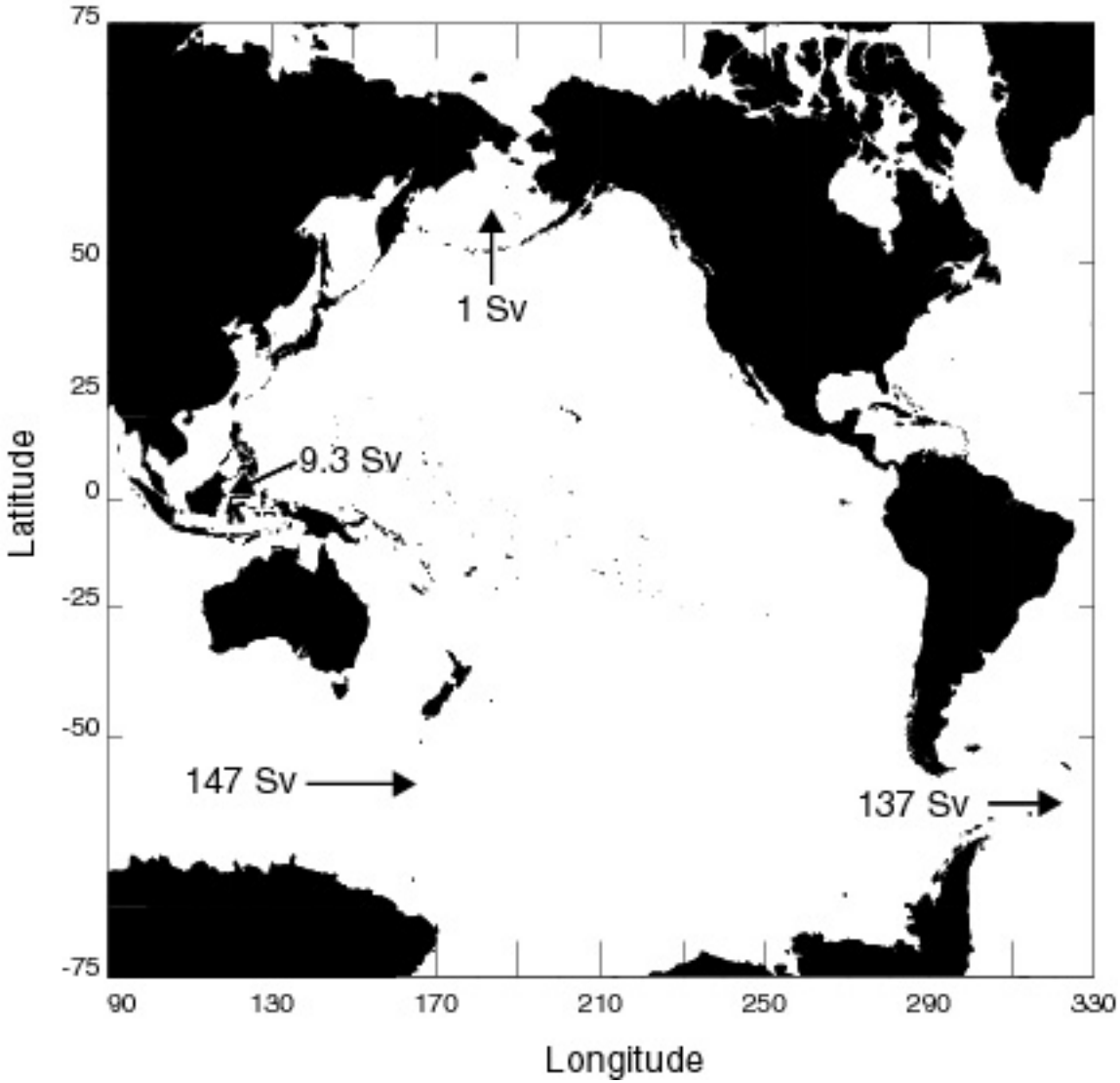
2. Northward Flow of Bottom Water

Area of ocean sets the ratios implying that mixing is the controlling factor.

What Sets the Transports

3. Indonesian Throughflow

Cunningham, Alderson, King and Brandon (2002)



What Sets the Transports

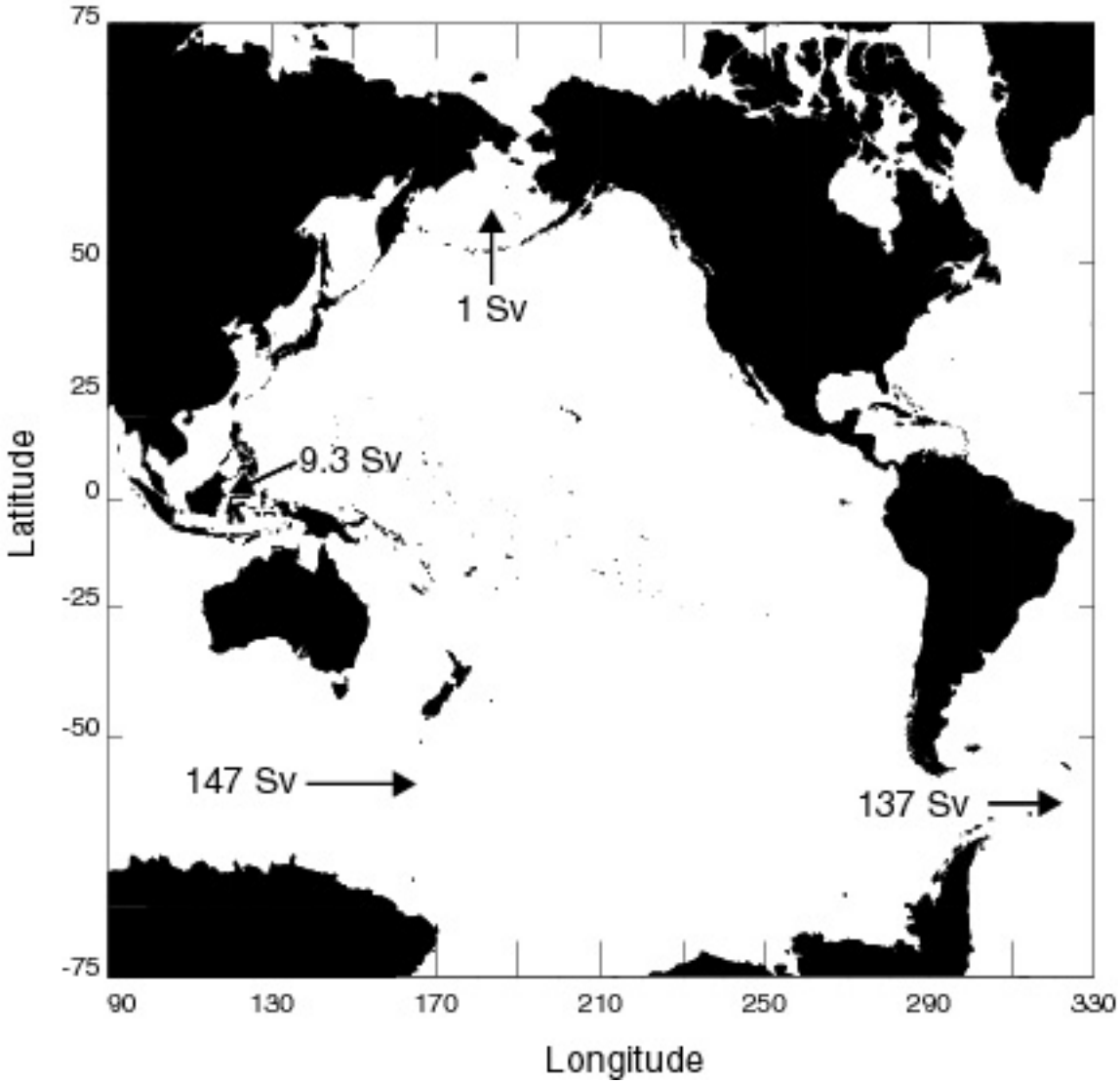
3. Indonesian Throughflow

Wind stress and wind stress curl.

What Sets the Transports

4. Antarctic Circumpolar Current

Cunningham, Alderson, King and Brandon (2002)



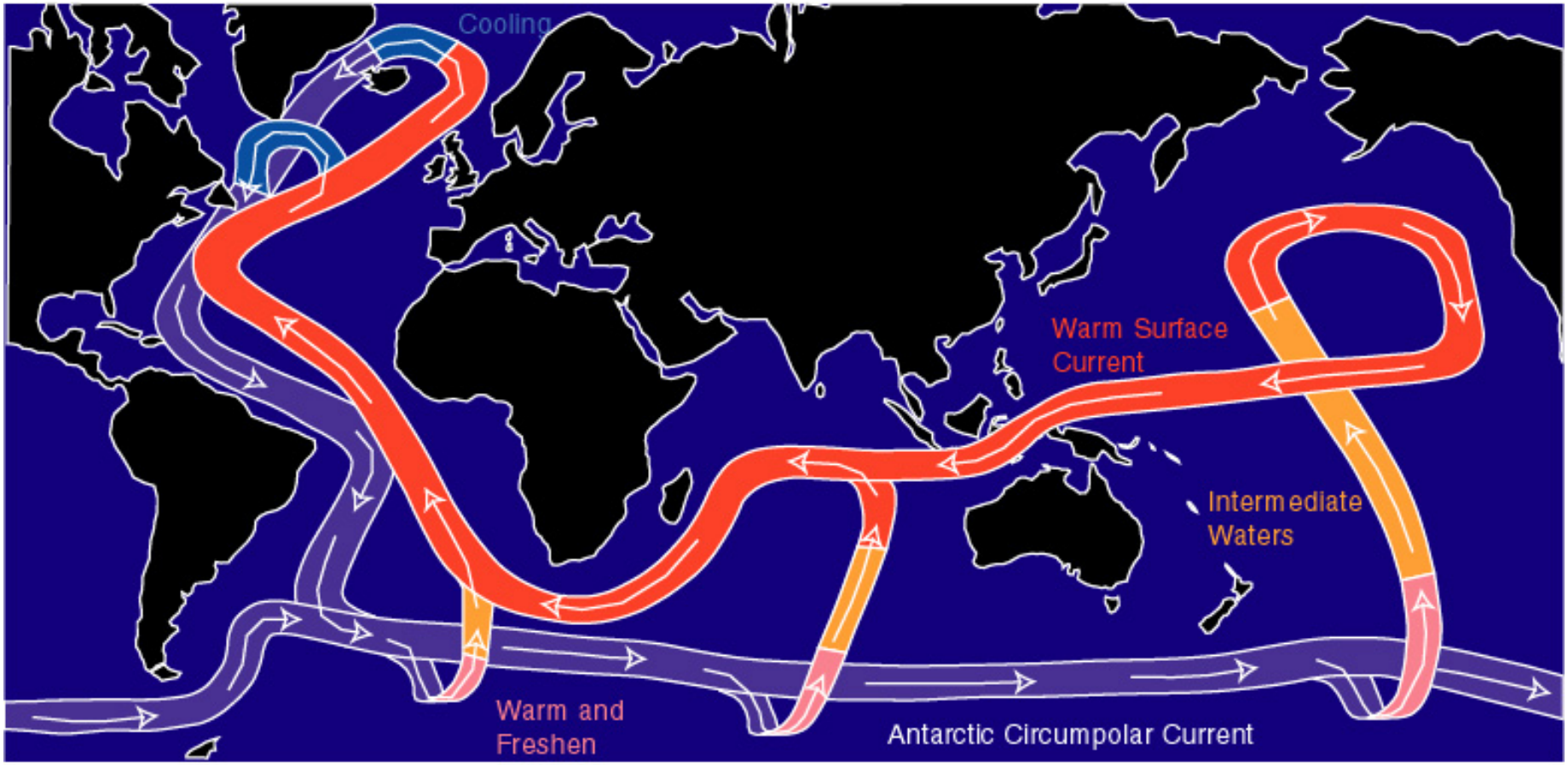
What Sets the Transports

4. Antarctic Circumpolar Current

Wind stress, square root of wind stress, wind stress curl.

What Sets the Transports

5. Upwelling around Antarctica



Thermohaline Conveyor Belt (after Doos and Webb)

t96g_occam/thermohaline2

What Sets the Transports

5. Upwelling around Antarctica

Eddies ultimately set up by wind stress.

Request

We would like the wind stress doubled or halved please. And for a long time so we can see the baroclinic as well as the barotropic adjustment

Summary

WOCE boundary current transport measurements have defined the size of the circulation in the thermocline, bottom, and deep waters as well as some of the interbasin flows.

Understanding what sets the sizes of these flows in the modern ocean is a central problem in ocean circulation.

Long time series boundary current measurements at a few locations where wind and buoyancy forcing may be expected to vary over interannual time scales represent essential observations required to test our understanding of ocean circulation and how it would change under different climate conditions.