Deep Ocean Heat and Freshwater Storage

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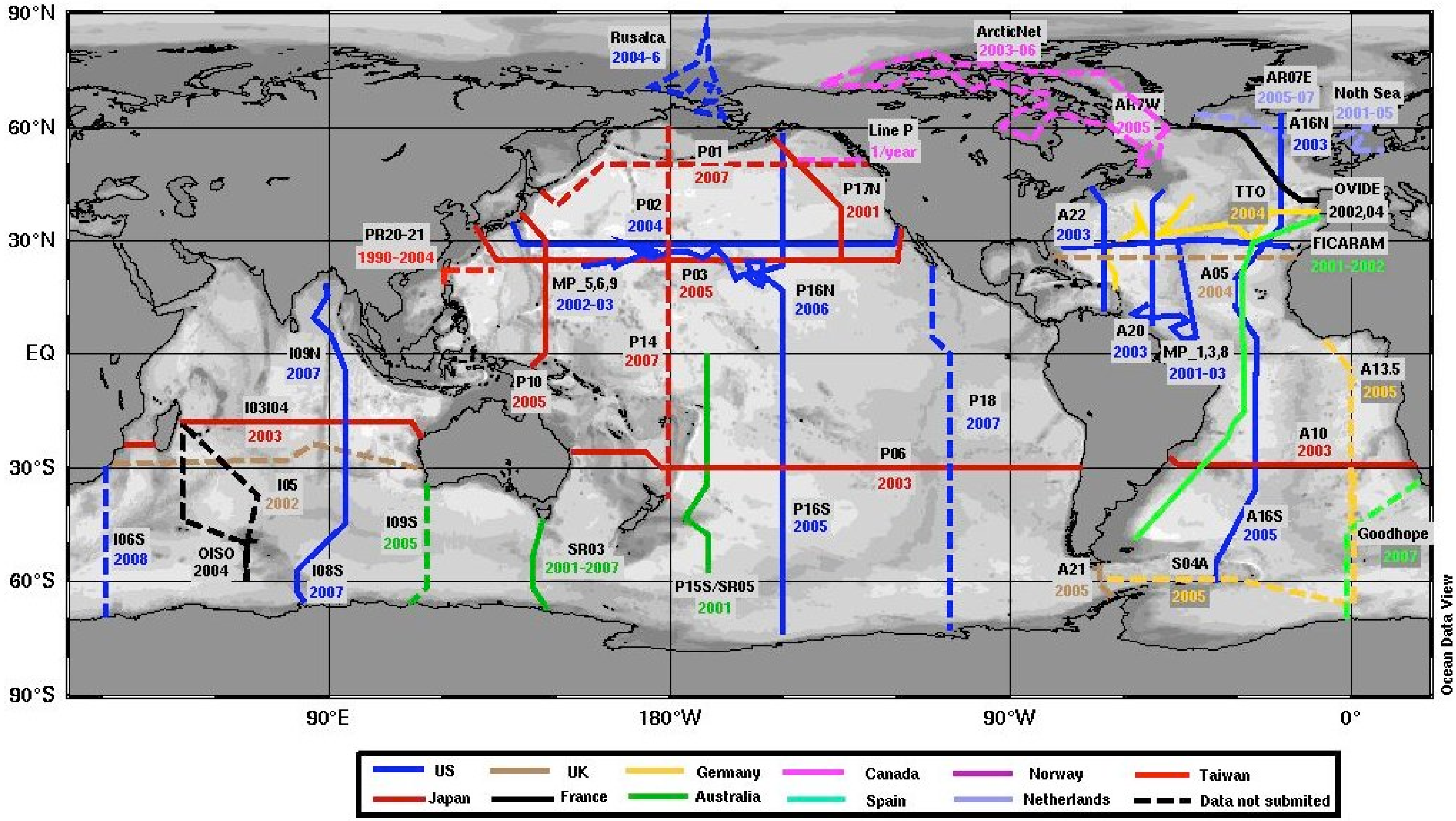
S. Wijffels, & Many Others

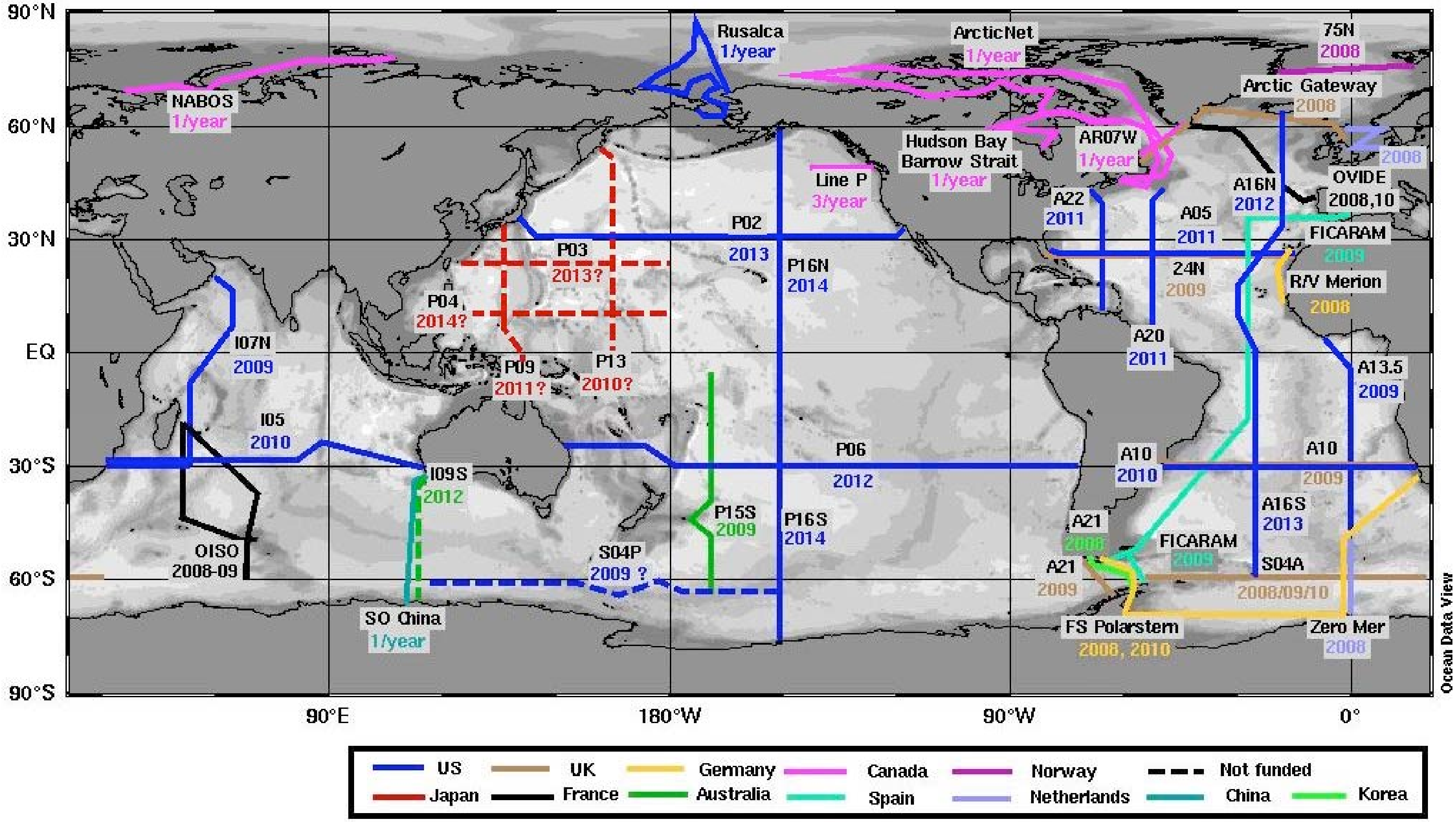
- Recent & Planned Global Deep Observations
- Antarctic Bottom Water vs. NADW
- AABW variability throughout the global abyss
- Role in heat and sea level budgets
- What observing system for the abyss?

Recent Repeat Hydrographic Cruises



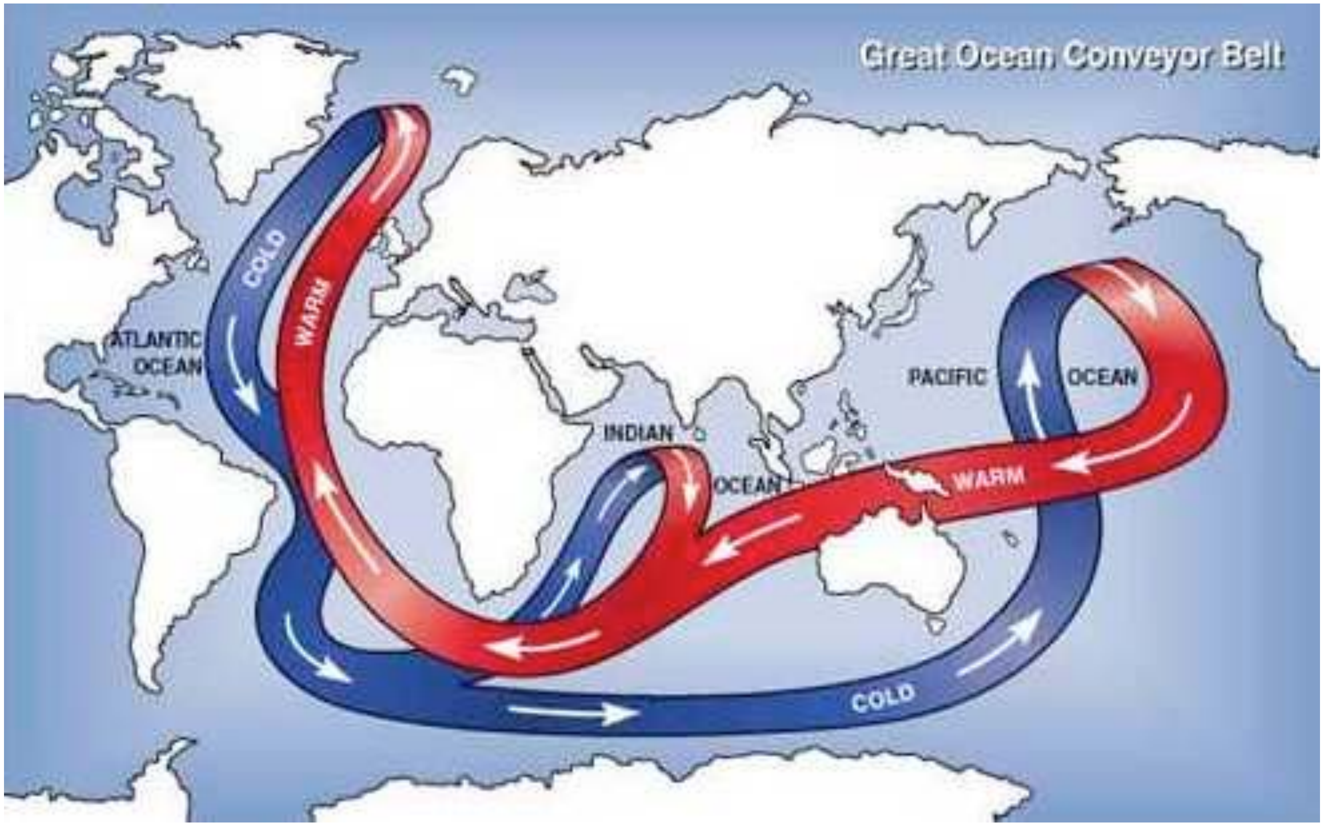
- Meridional sections across most major deep basins
- Zonal subtropical sections (max in meridional heat & CO_2 transports)
- Does not address subpolar & tropical meridional freshwater transport maxima
- Western Indian, Central Indian, and Eastern S. Atlantic Basins undersampled
- Only Weddell Sea boxed off (lacking Ross, Adelie, etc.)

Planned Repeat Hydrographic Cruises



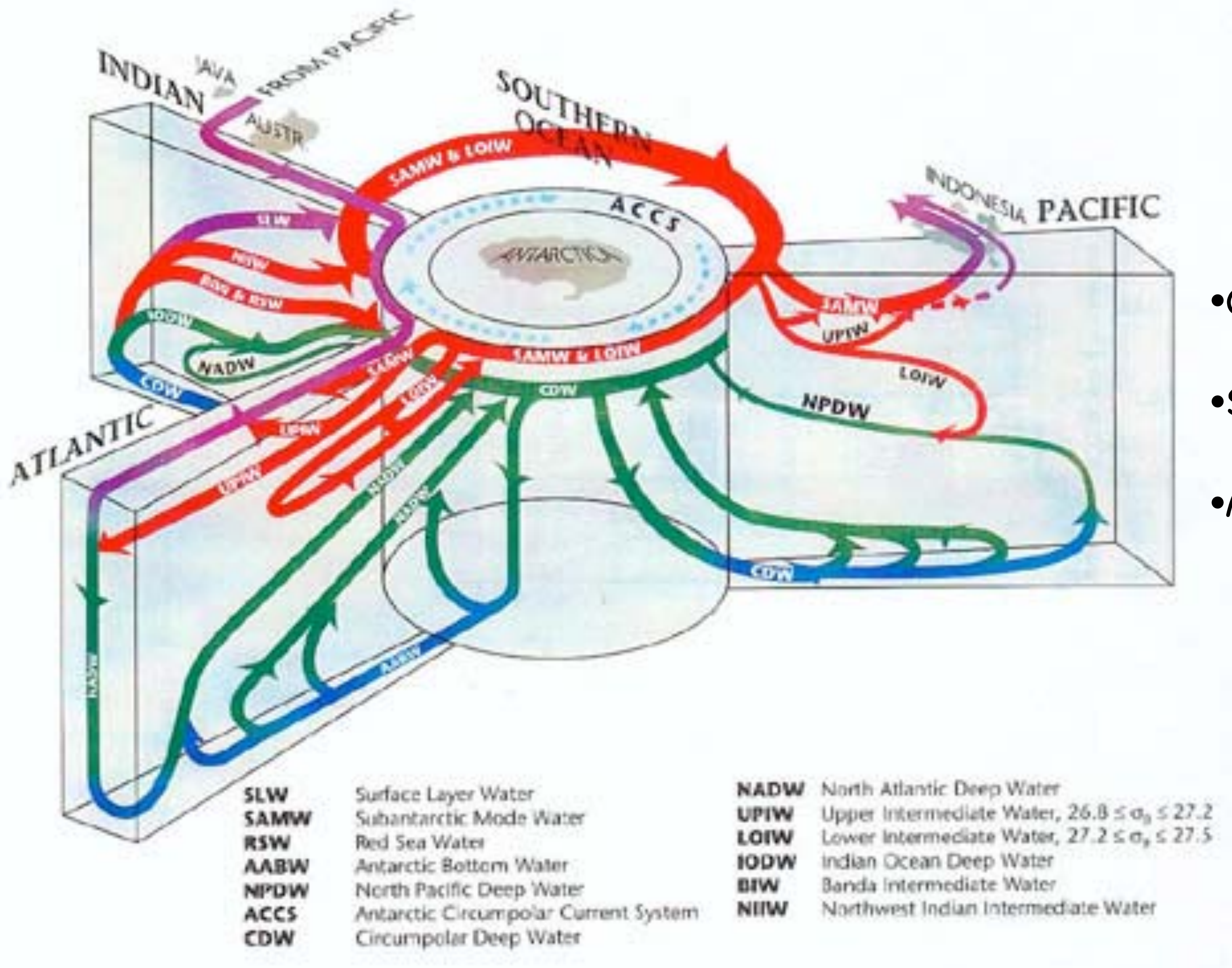
- Start to reoccupy sections a third time in some locations (multiple for N. Atl.)
- Box off Ross Sea (maybe Adelie coast too)
- Still a very sparse network
- US plans only out about 5 years & subject to adjustment

"Great Ocean Conveyor" (Broecker 1987)



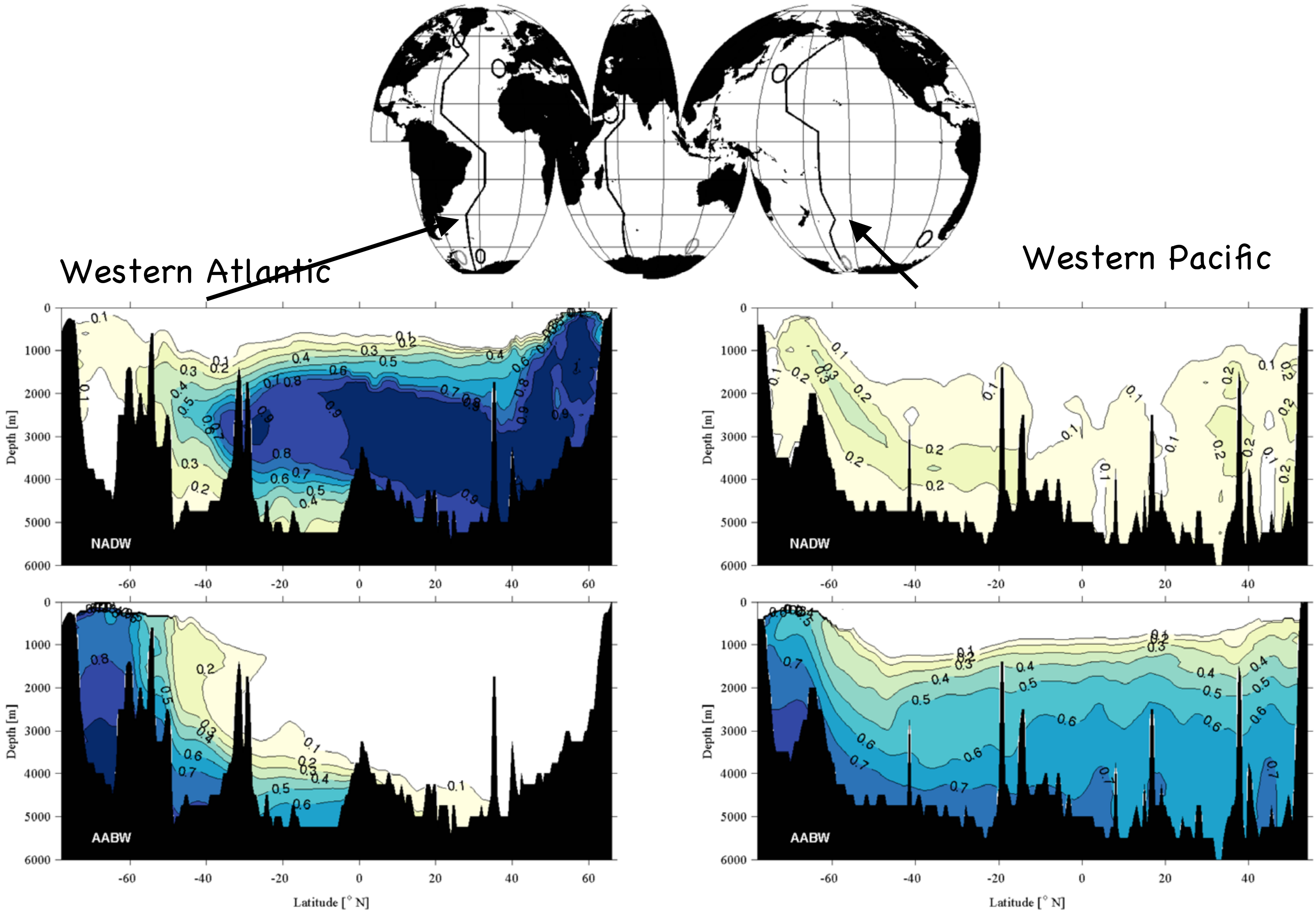
- Widely used schematic for Meridional Overturning Circulation (MOC)
- All sinking appears to be North Atlantic Deep Water in the North Atlantic
- Upwelling appears located in Pacific and Indian Oceans
- What about sinking of Antarctic Bottom Water in the Southern Ocean?

S. Ocean Interchange (Schmitz 1996)

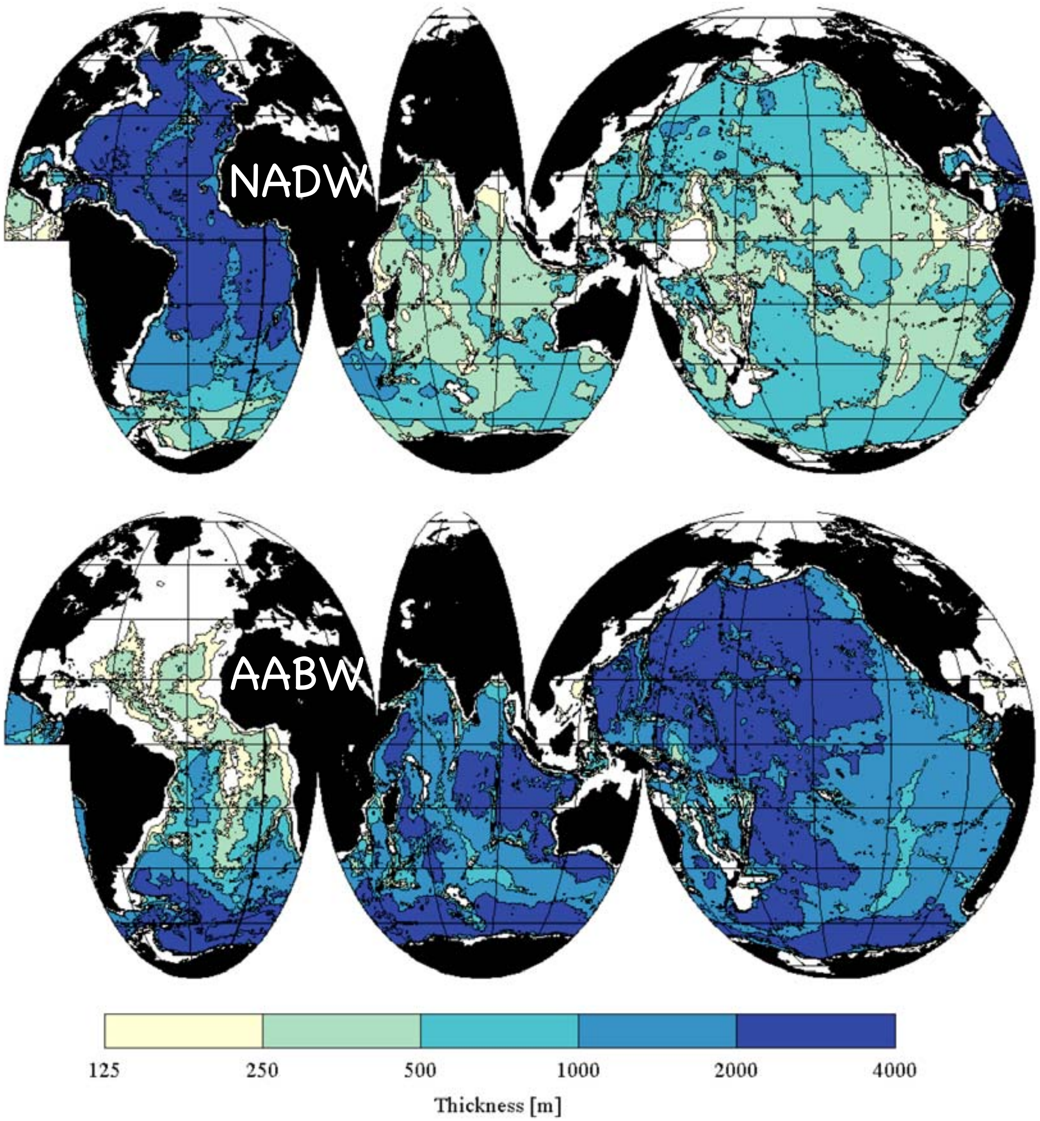


- Complex picture
- S. Ocean Sinking
- AABW fills abyss

AABW & NADW Fractions (Johnson 2008)



AABW and NADW Volumes (Johnson 2008)



•Volume integrate the fraction of AABW at each location

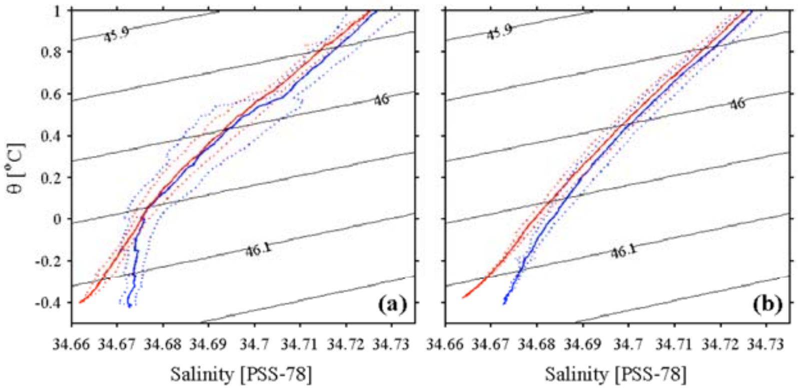
•Logarithmic Scale

•NADW 21% of the global ocean volume

•AABW 36% of the global ocean volume

•AABW has at least 1.7 times the volume of NADW

SE Indian Ocean 1994/5 & 2007



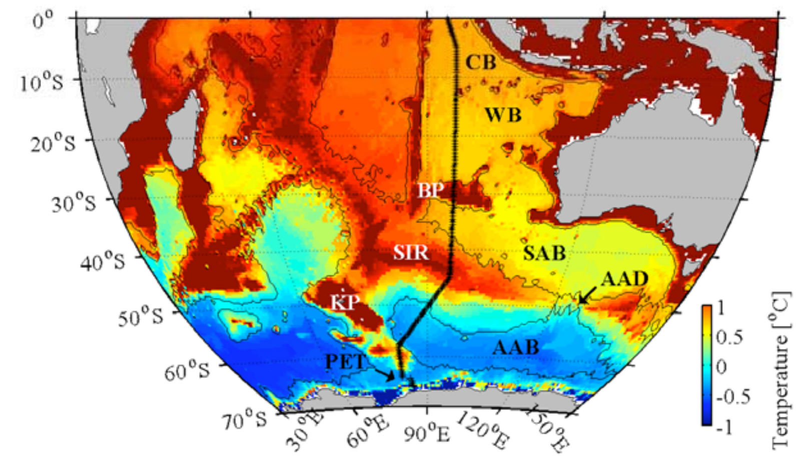
Johnson, Purkey, & Bullister (in press)

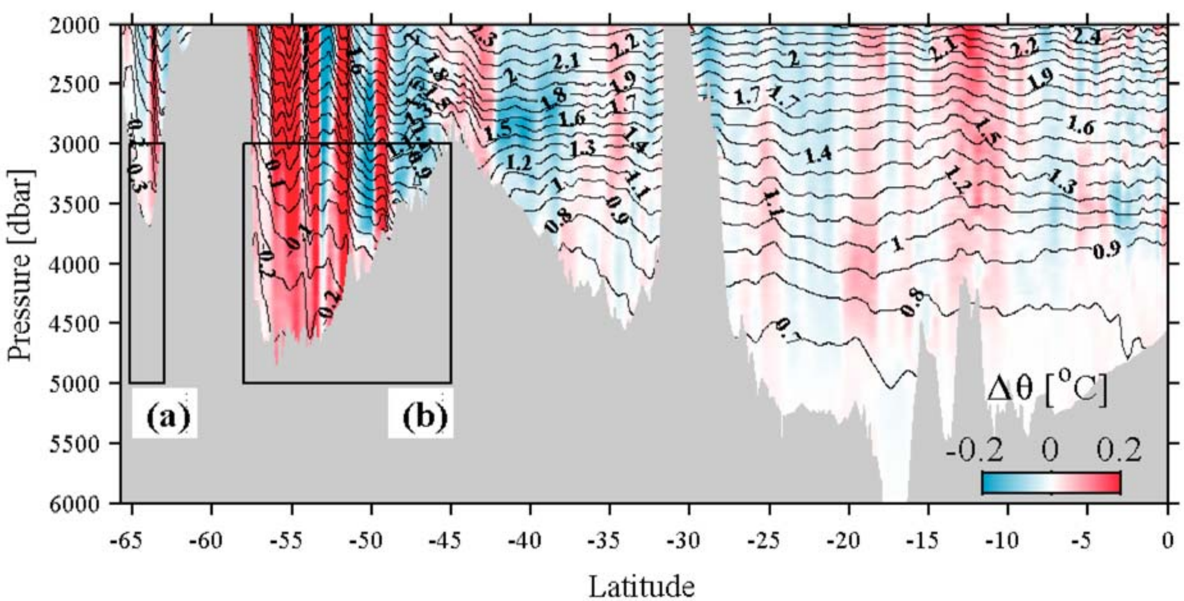
13-year time interval 2007- 1994/5

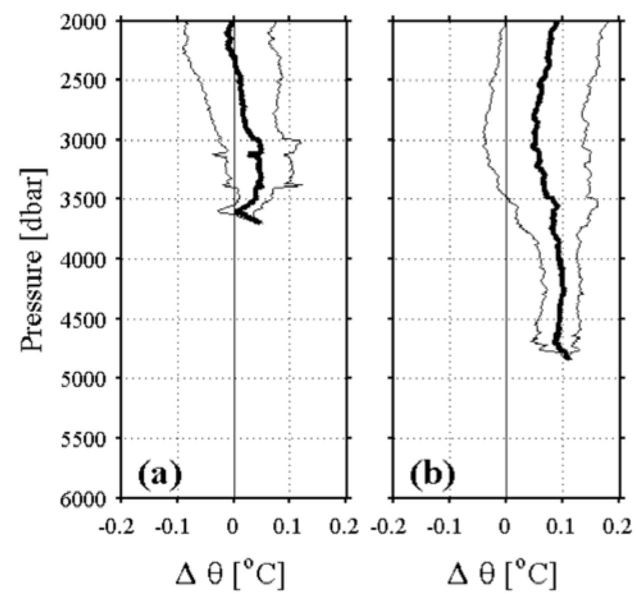
0.1°C abyssal warming

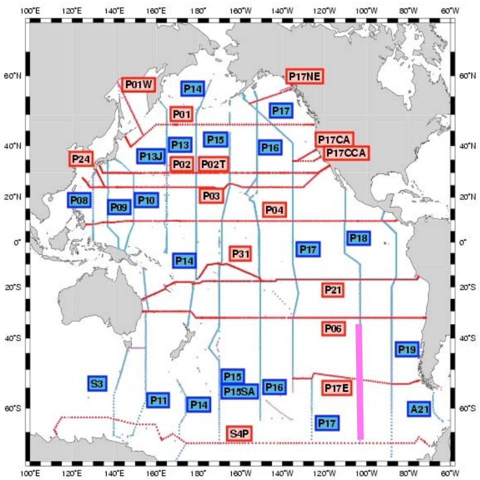
θ-S changes (fresher)

Isolated to southern basins









103°W: 2007/8 - 1994

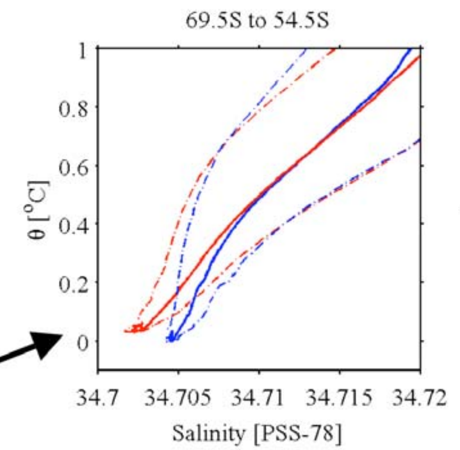
Preliminary (in prep)

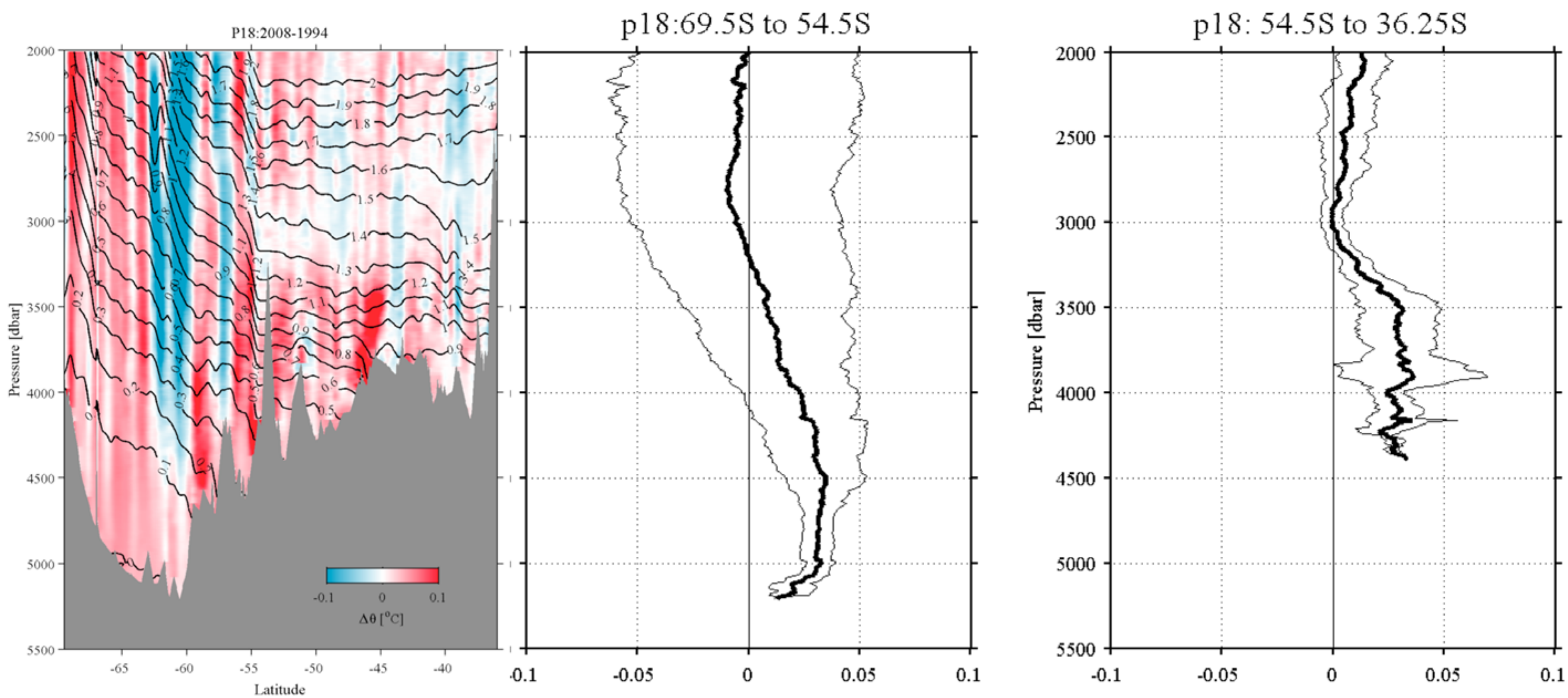
14-year time interval

0.03°C abyssal warming

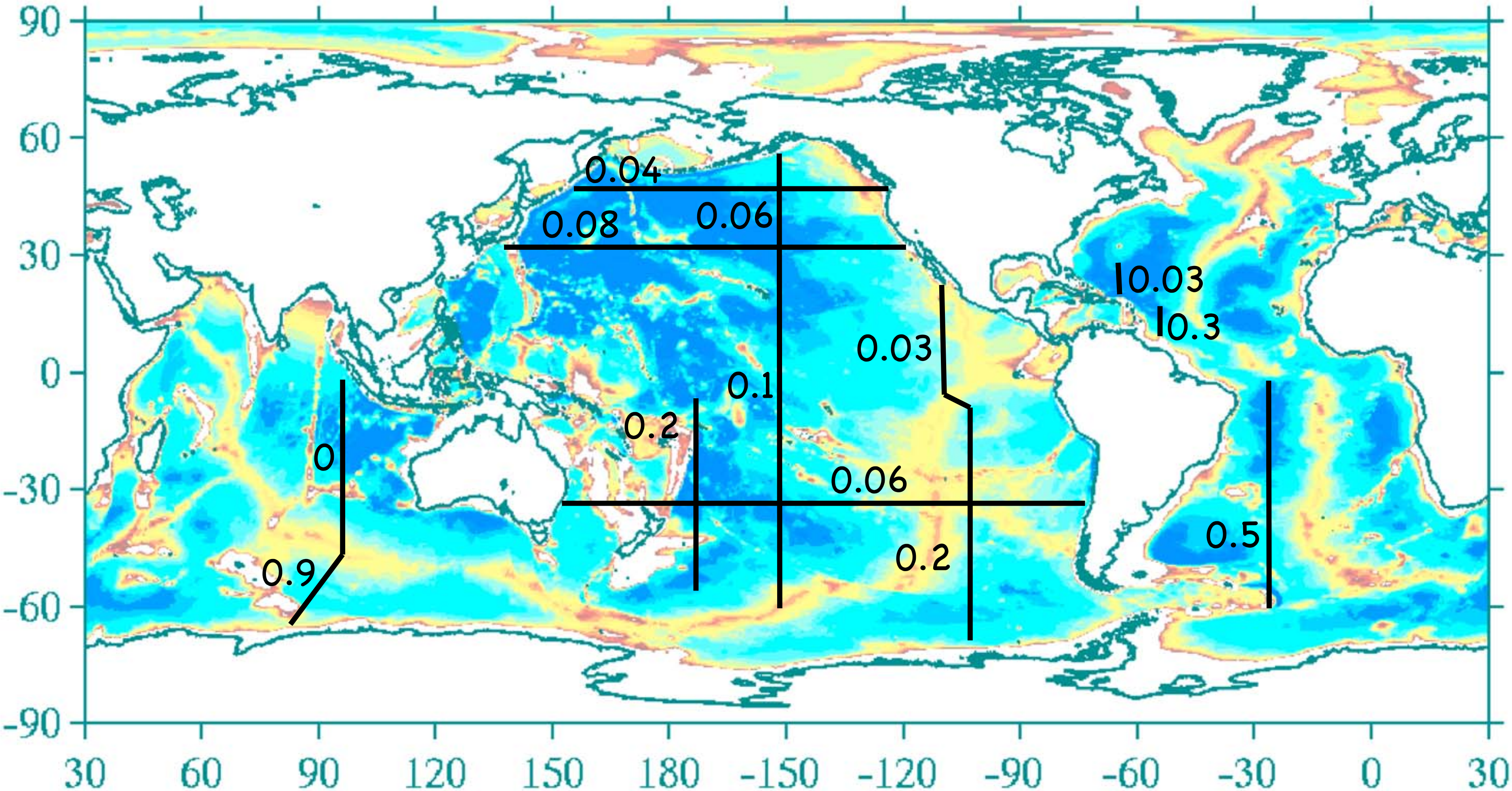
Starts at 3000 dbar

θ-S changes (fresher) in SO





Summary: AABW Heat Content Changes



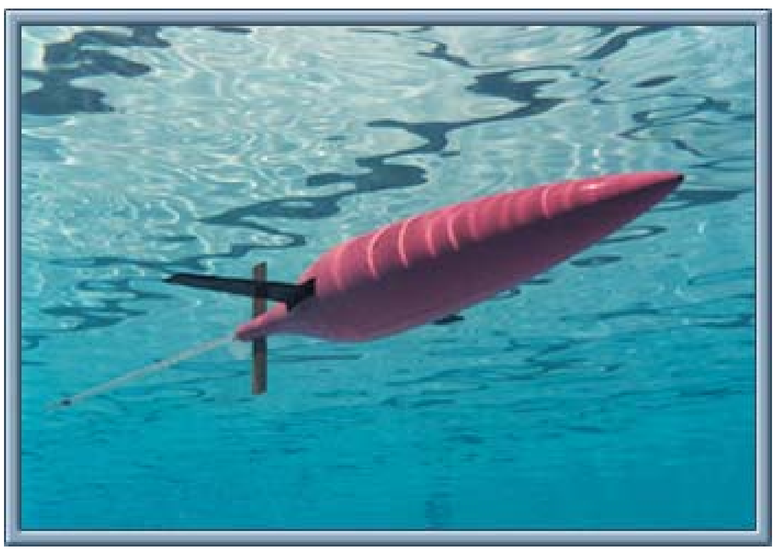
- Integrate section-averaged heat content change (W m^{-2}) below 3000 dbar
  Use ratio of section length at each depth to section length at 3000 dbar
  (P06 use 4000 dbar; A20 & A22 4200 dbar)
- The closer to AABW sources, the larger the heat gain.
- Recent upper ocean changes ~0.6 W m^{-2} globally (not locally)

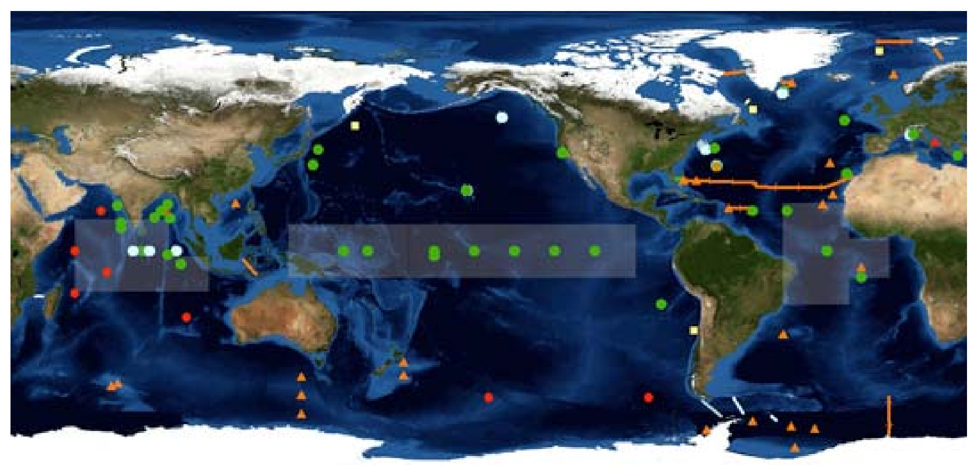
Conclusions

- Abyssal ocean warming widespread since 1990's
- Associated with AABW (not NADW)
- Antarctic changes spreading throughout the abyss
  - Even to the western North Atlantic
  - Pacific warming largest near AABW source
- Also AABW freshening in S. Pacific & S. Indian Oceans
- Warming of 0.1°C over 13 years in SE Indian Ocean
  - Local heat gain of 0.9 W m^{-2} below 3000 m
  - 4 cm sea level rise (with freshening) below 3000 m
- Abyssal ocean changes may contribute to
  - Global heat budget
  - Global sea level rise

Discussion

- Small horizontal & vertical gradients in many deep basins allows detection of small interior temperature changes
- These small changes are found over large areas (entire basins)
- These small changes are found over large depth ranges (1000's of m)
- Interior abyssal warming is larger closer to AABW sources
- Abyssal contribution to global heat & sea level budgets may be significant
- Data are decadal repeat sections (& a few time-series in source regions)
- Can't confidently quantify changes for global budgets
- What are the time-scales?
- Need improved abyssal observing system

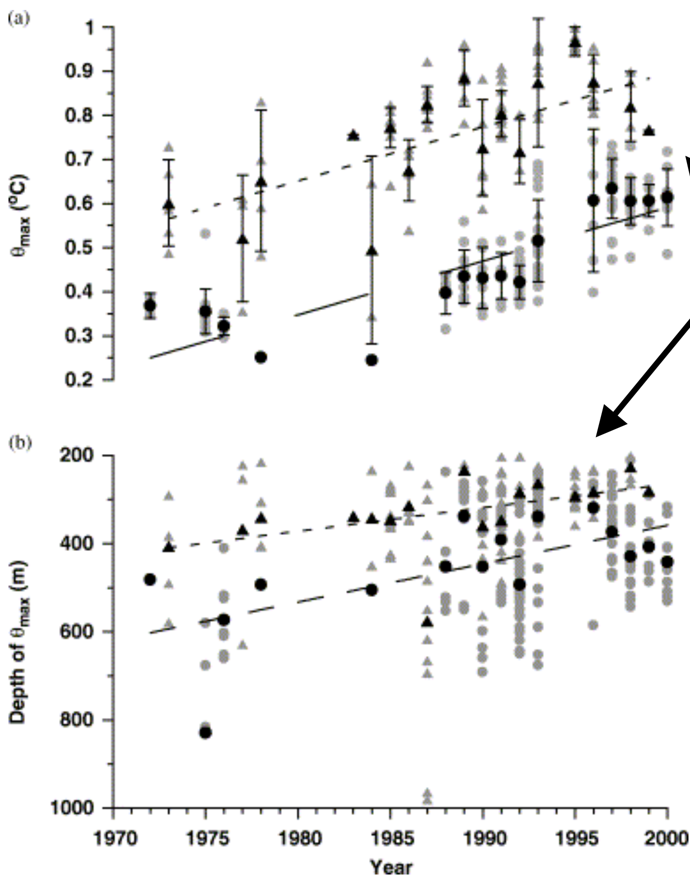




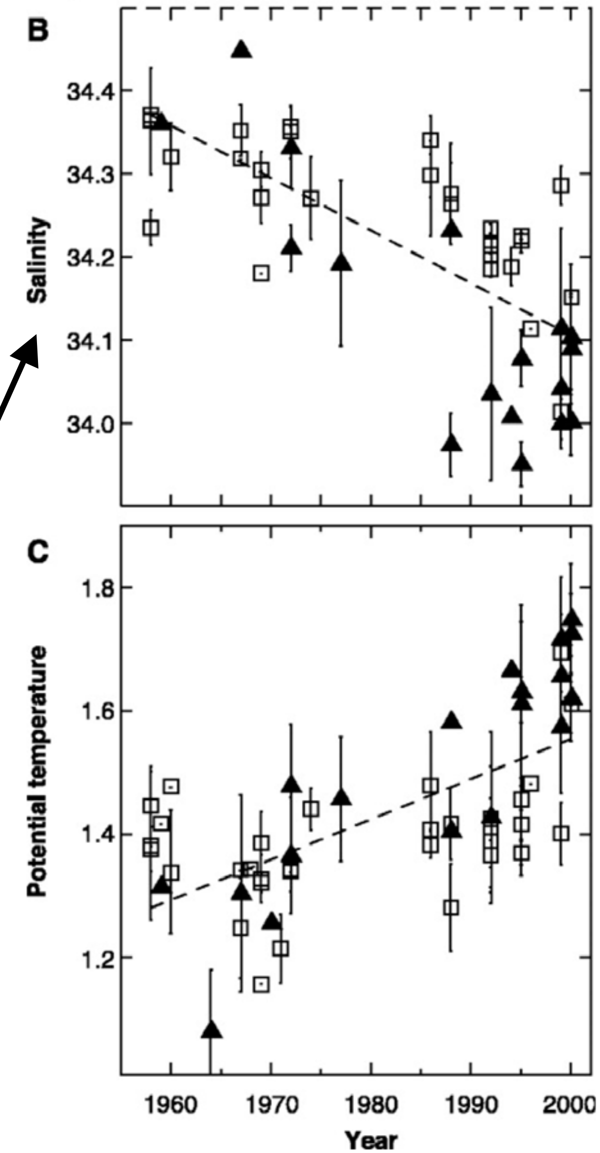
AABW Constituent Time-Series

- T-max water one AABW constituent
- T-min water another

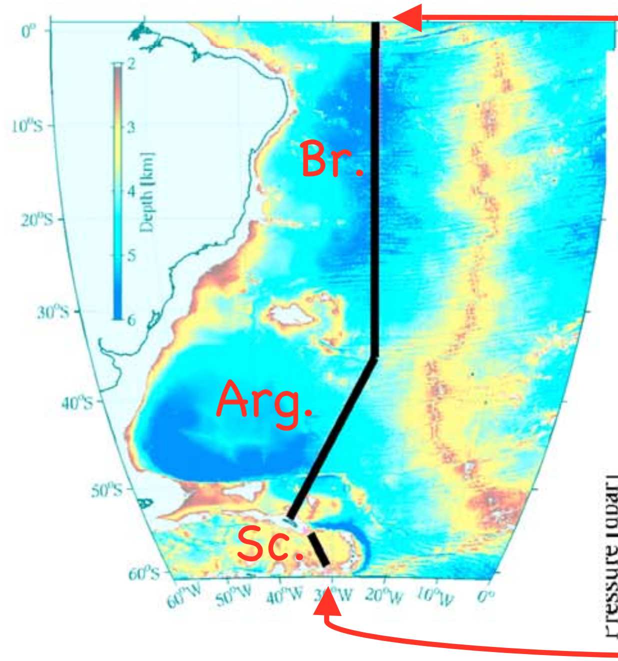
Robertson et al. (2002):
- Shallow Weddell Sea
- T-max Warmer
- T-max Shallower
- Partial 1990's reversal (Fahrbach et al. 2004)

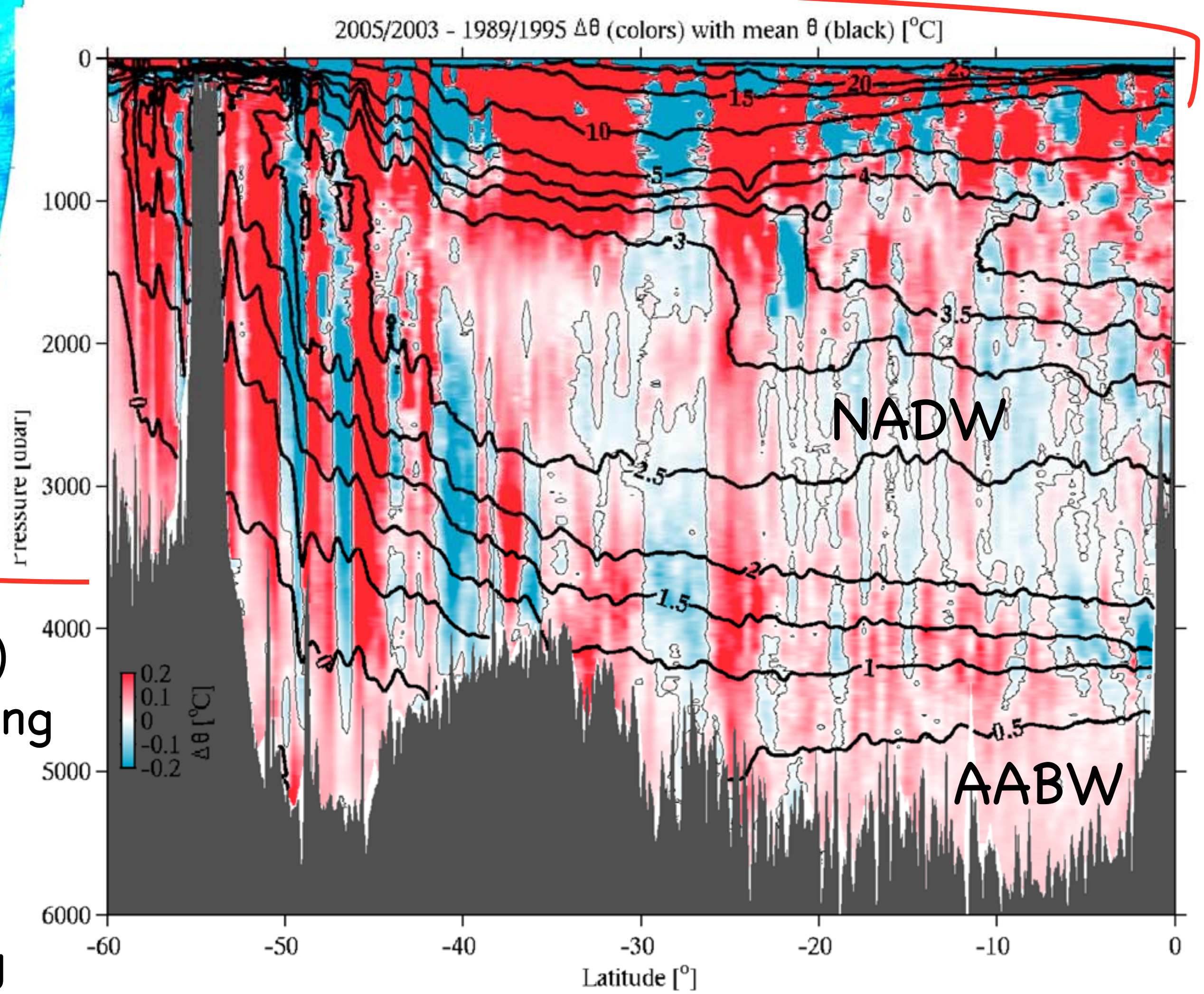


Jacobs (2002):
- Shallow Ross Sea
- T-min Fresher
- T-max Warmer



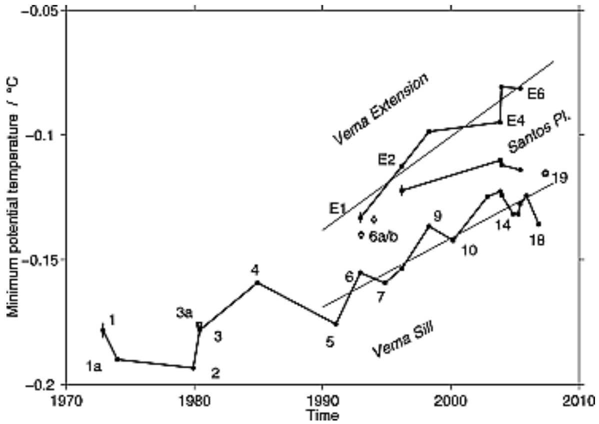
S Atlantic 2005/2003 - 1989/1995 θ



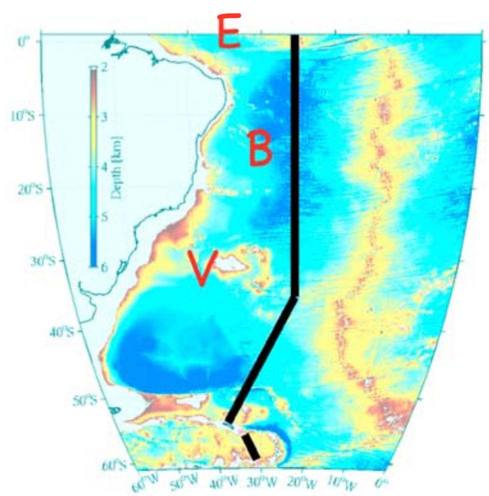


- Johnson & Doney (2006)
- Large Scotia Sea warming
- NADW > 1.5°C
  - little change
- AABW < 1.5°C
  - Significant Warming
  - ~0.04°C in Brazil & Argentine Basins

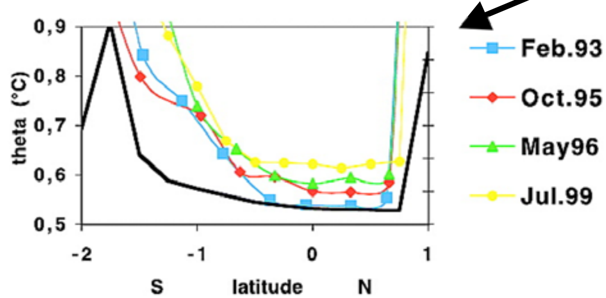
2005 - 1989 Brazil Basin Δθ



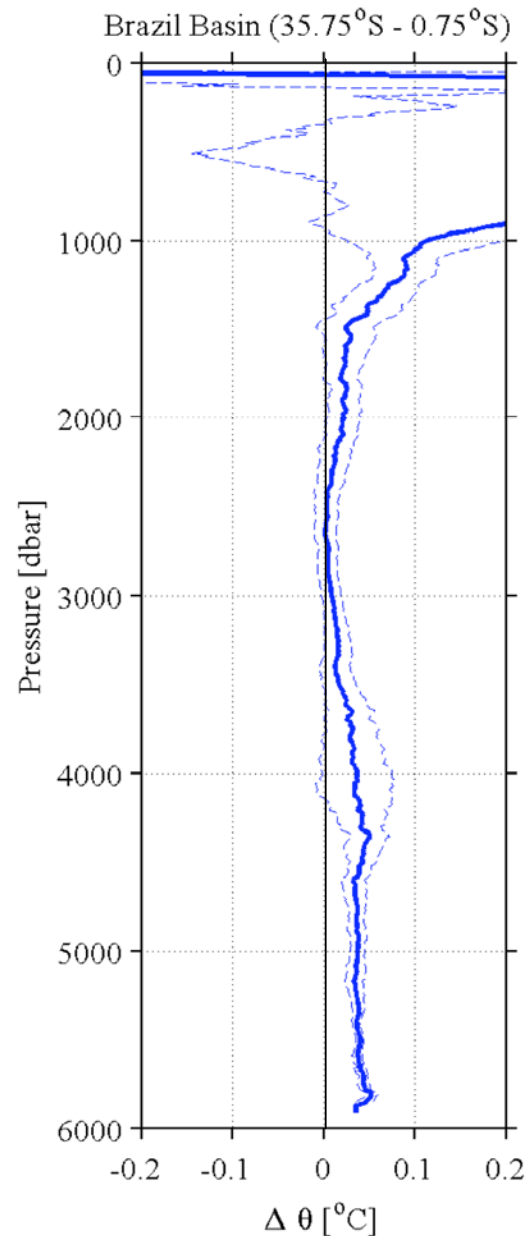
- Vema Channel near 32°S (Zenk & Morozov, 2007)
- warming ~0.003°C yr^{-1} since 1992



- Brazil Basin Interior (Johnson & Doney, 2006)
- 2005-1989 warming
- ~0.04°C
- In AABW (not NADW)



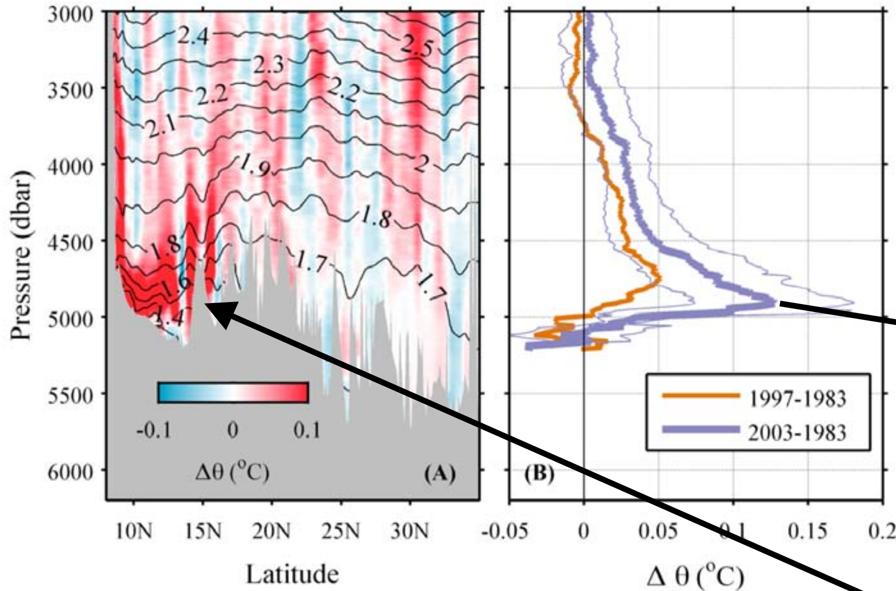
- Equator at 35°W (Andrie et al., 2003)
- 1990's Bottom warming
- < 0.1°C

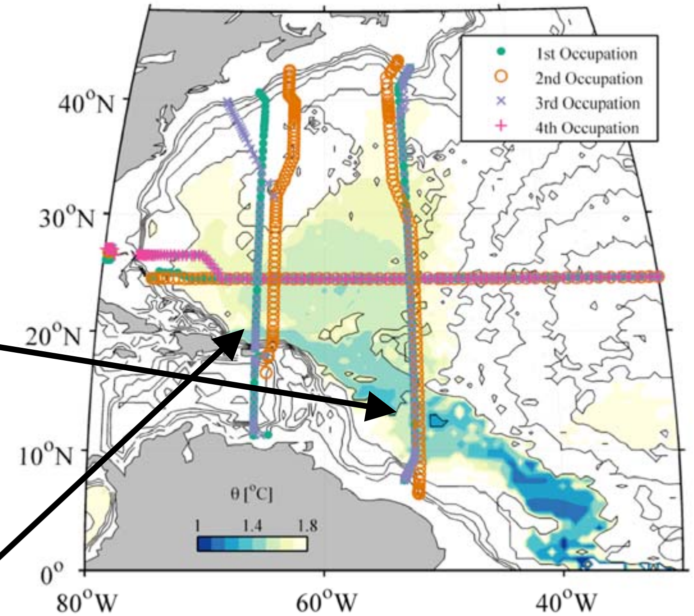


2000's – 1980's
NW Atlantic Δθ

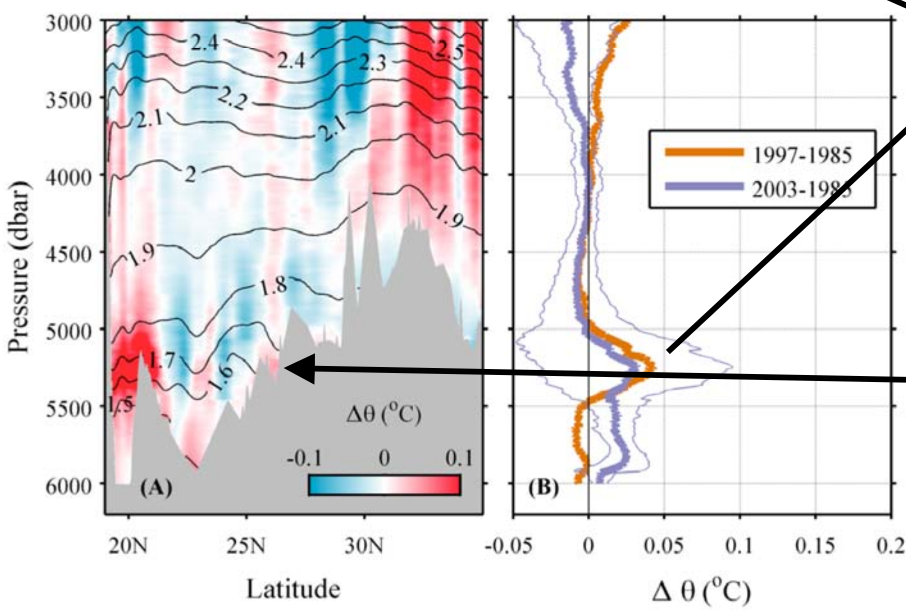
(Johnson & Purkey, & Toole, submitted)

- WOCE Bottom θ

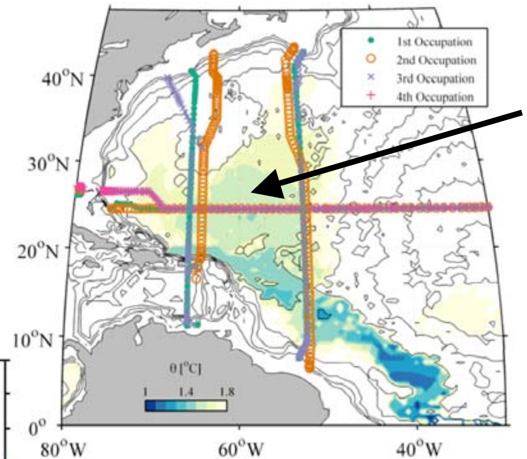


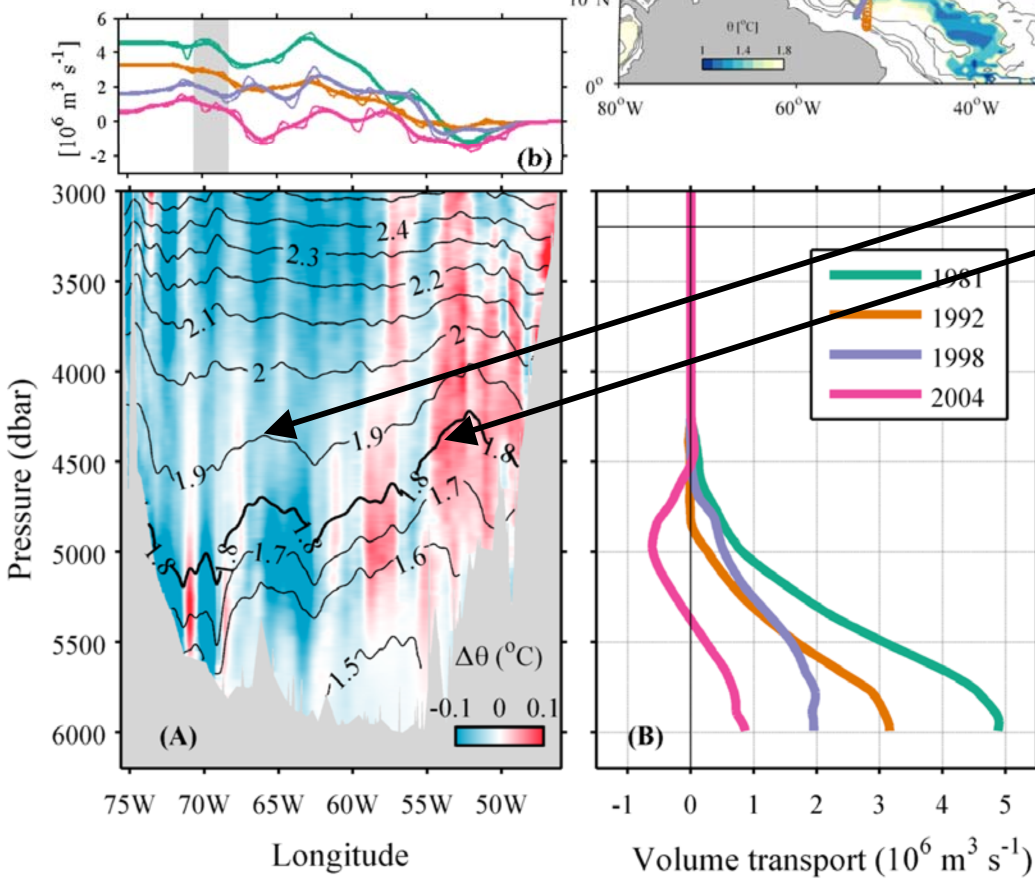


- Abyssal thermocline sinks
- 52°W: 1983, 1997, 2003
  - 2003 – 1983:
  - 8 – 18°N:
  - Warming of >0.1°C
- 66°W: 1983, 1997, 2003
  - 2003 – 1983:
  - 18 to 27°N:
  - Warming of ~0.05°C



2000's - 1980's Western N. Atlantic $\Delta\theta$





(Johnson, Purkey, & Toole, submitted)

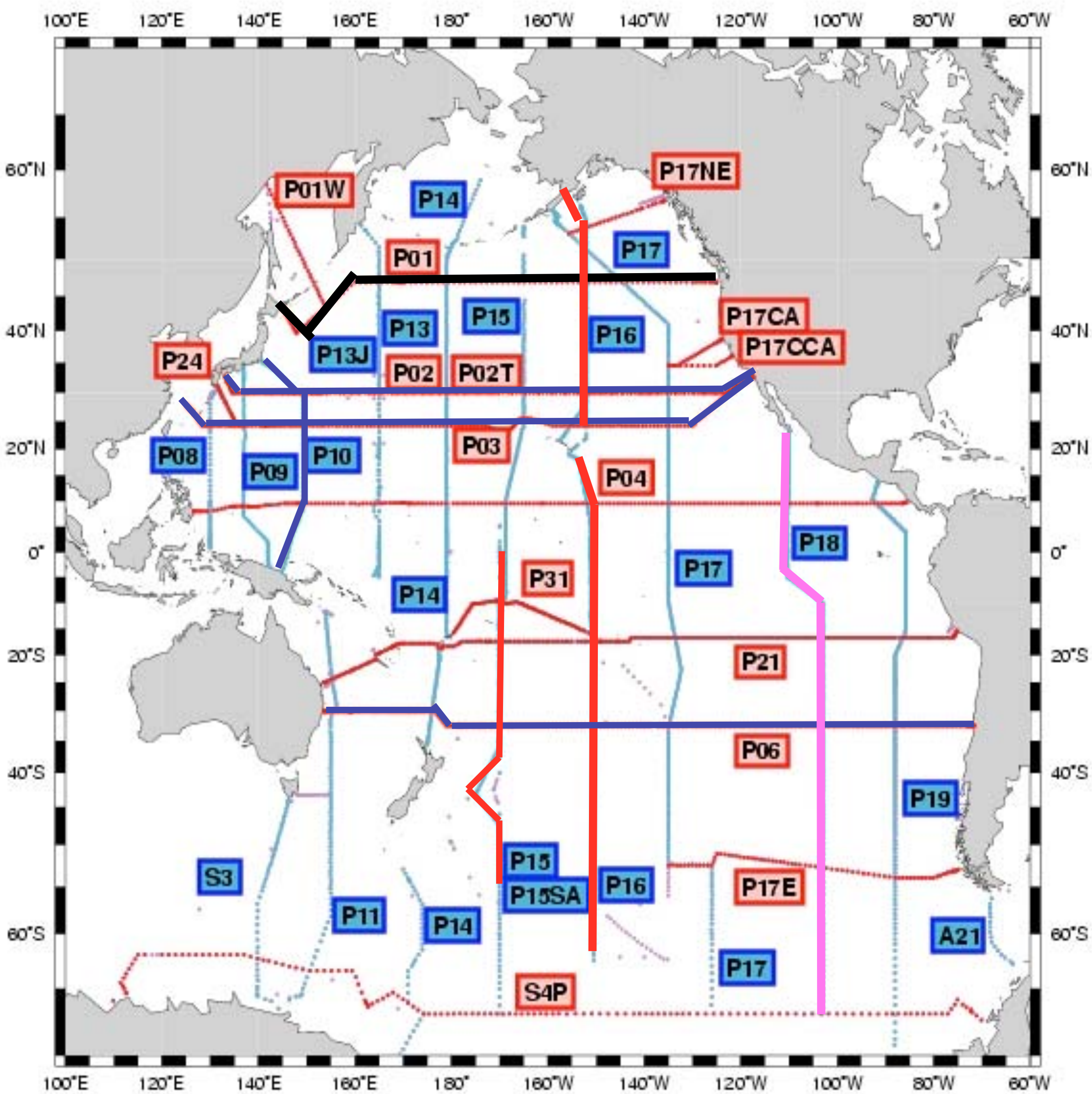
- Western Basin at 24°N
- 2004, 1998, 1992, & 1981
- Near end of AABW influence

- 2004 - 1981
  - Cooling in western half
  - Warming in eastern half

- Reduced deep dv/dz

- Assume 3200 dbar ZVS
- Northward transport of "AABW" (θ < 1.8°C & east of ~70°W) steadily reduced from 1981 -> 2004 (5 Sv -> 1 Sv)

Pacific Abyssal Temperature Changes



Fukasawa et al. (2004)

47°N: 1999 - 1985

Kawano et al. (2006)

30°N: 2004 - 1994

32°S: 2003 - 1992

(150°E: 2005 - 1993)

(24°N: 2005 - 1985)

Johnson et al. (2007)

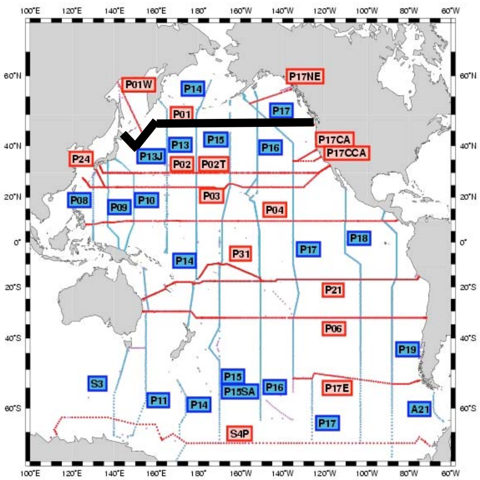
170°W: 2001 - 1996

150°W: 2006/5 - 1992/1

(& 1984)

Preliminary (in prep)

103°W: 2007/8 - 1994



47°N: 1999 - 1985

Fukasawa et al. (2004)

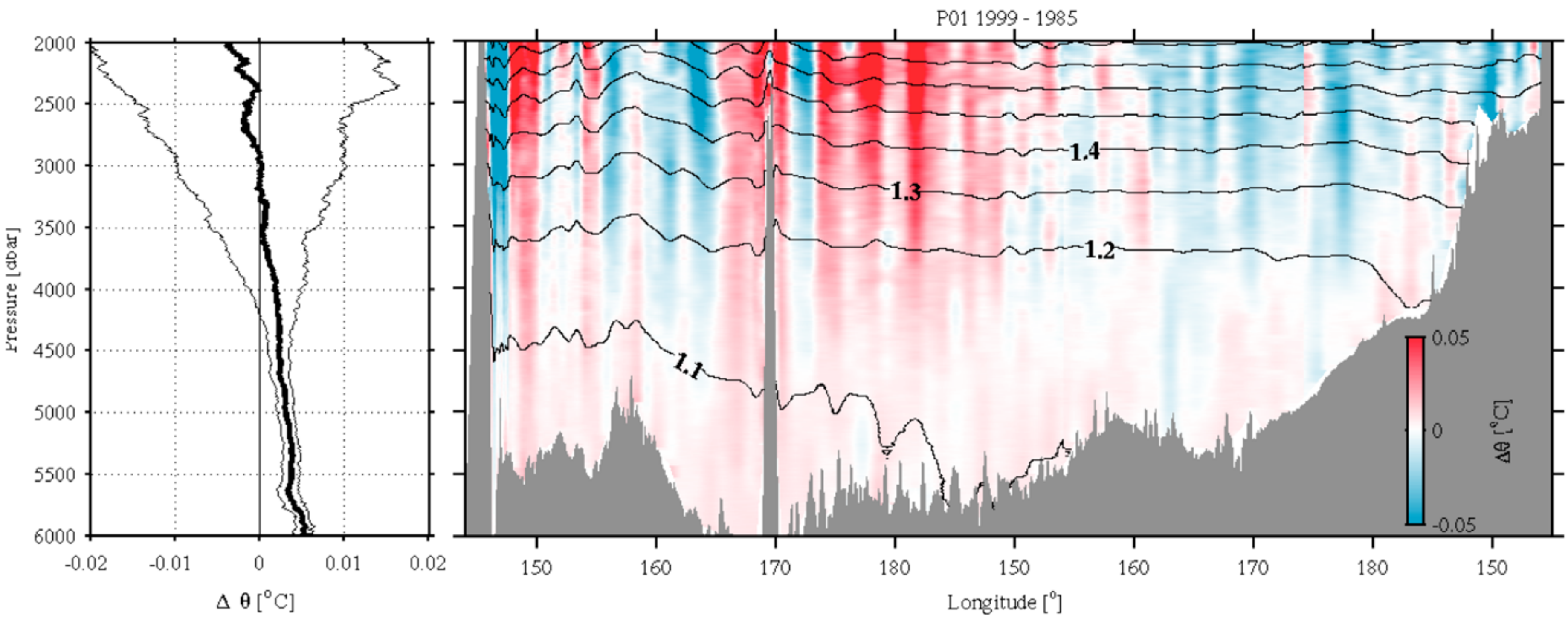
14-year interval

0.005°C abyssal warming

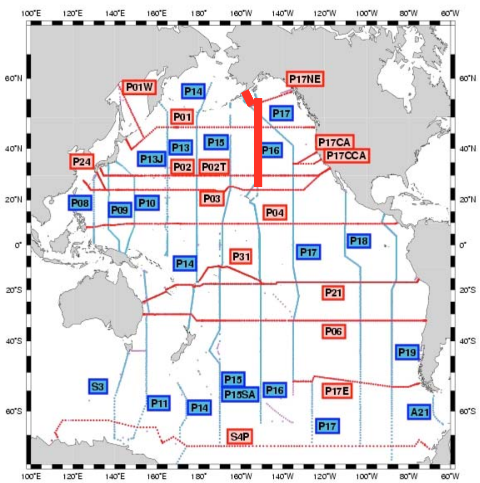
Coldest, weakest stratified waters warm

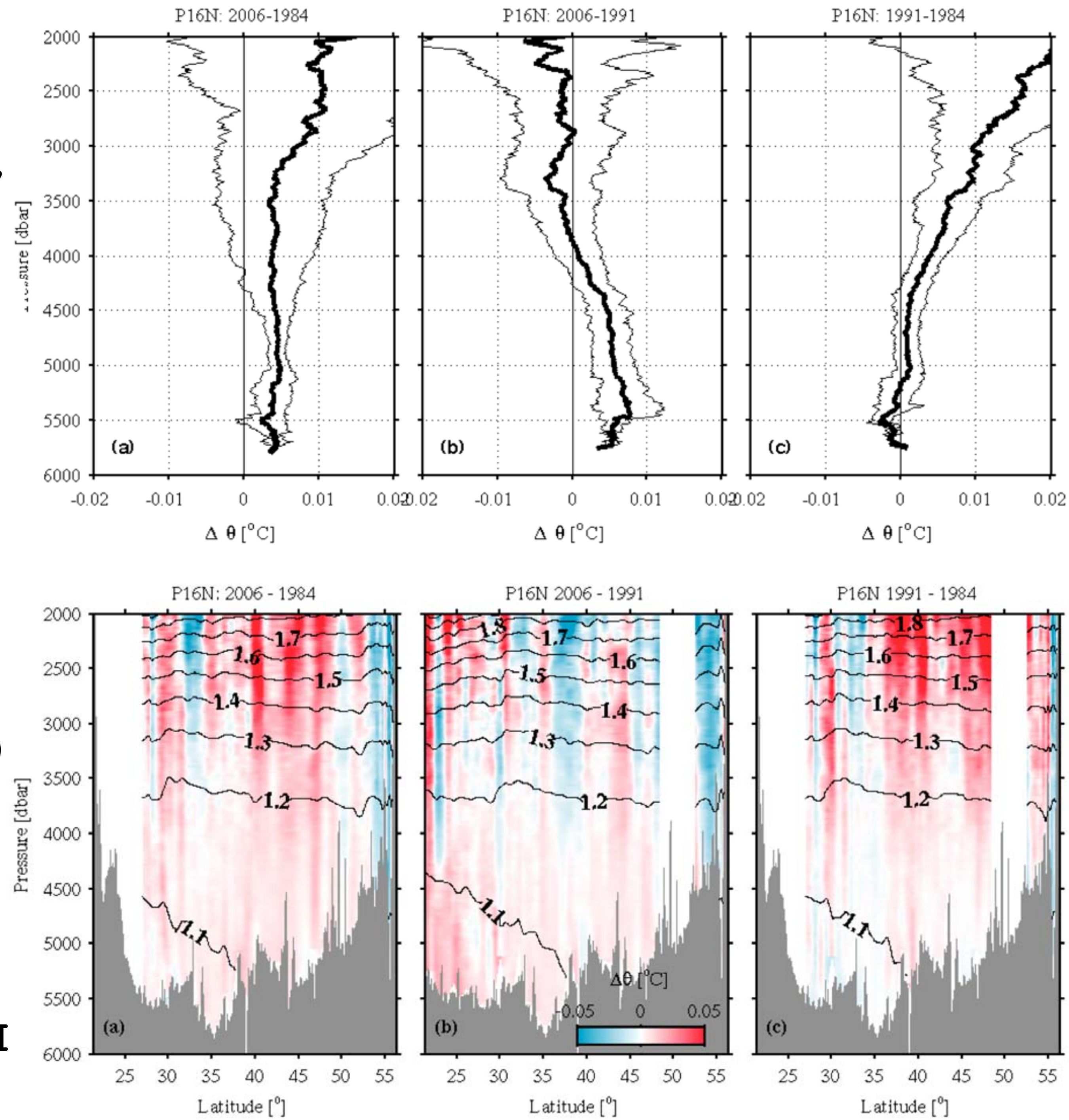
Eddy variabililty smaller than S. Atlantic

Significant at 95% CI below 4200 dbar



150°W: 2006, 1991, & 1984





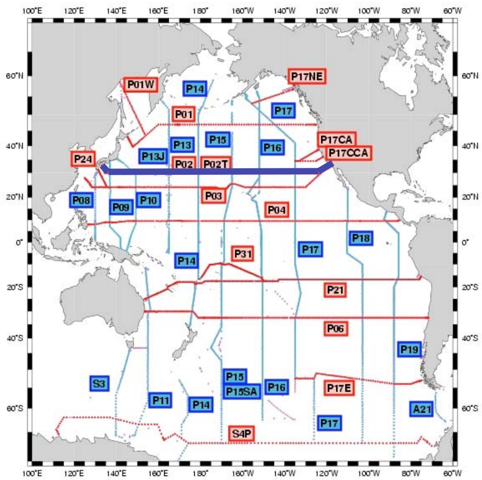
Johnson et al. (2007)

0.005°C abyssal warming 2006-1991

None for 1991-1984

Starts ~3500 dbar

Significant at 95% CI below 4200 dbar



30°N: 2004 - 1993/1994

Kawano et al. (2006)

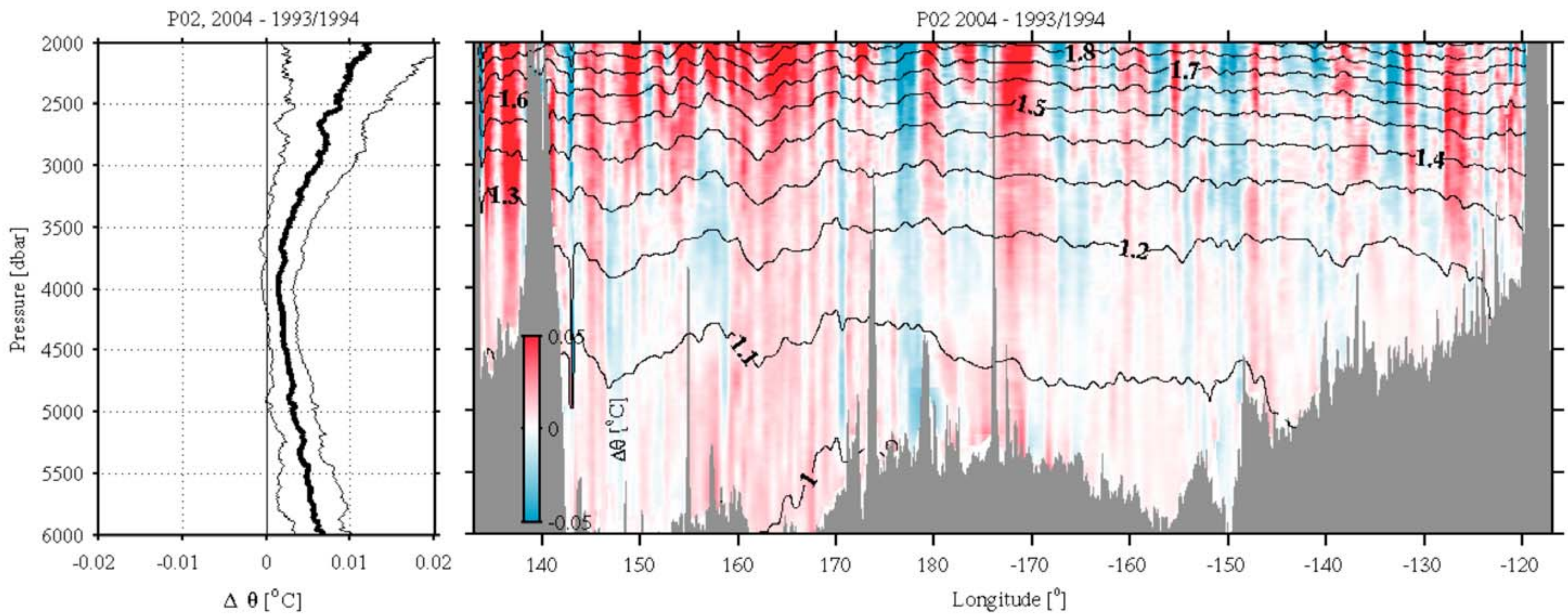
10-year time interval

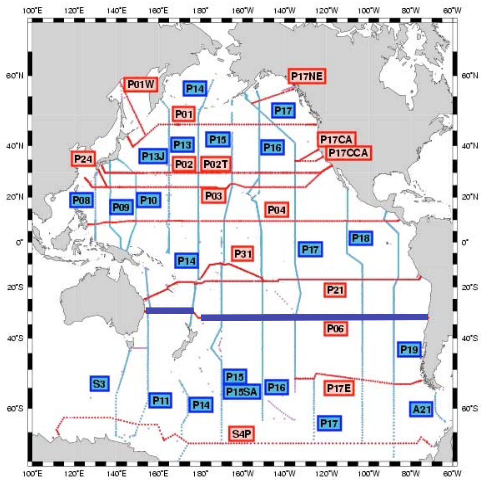
> 0.005°C abyssal warming

Coldest, weakest stratified waters warm

Starts at 4000 dbar

Significant at 95% CI below 4000 dbar





32°S: 2003 - 1992

Kawano et al. (2006)

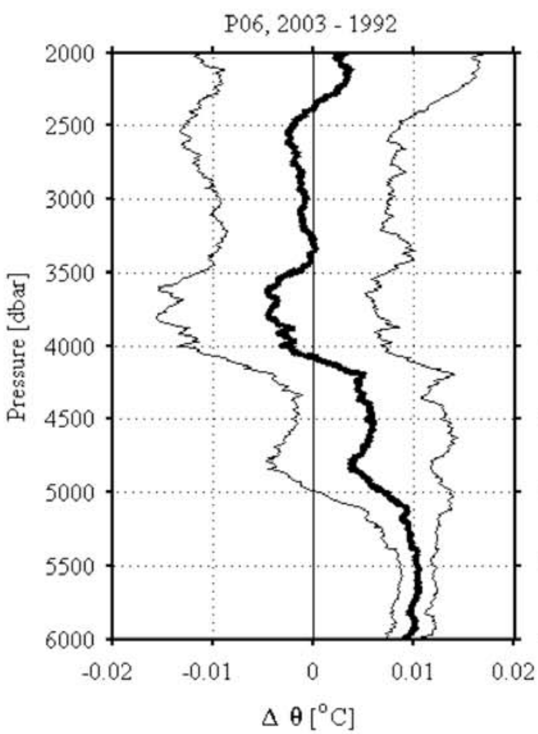
11-year interval

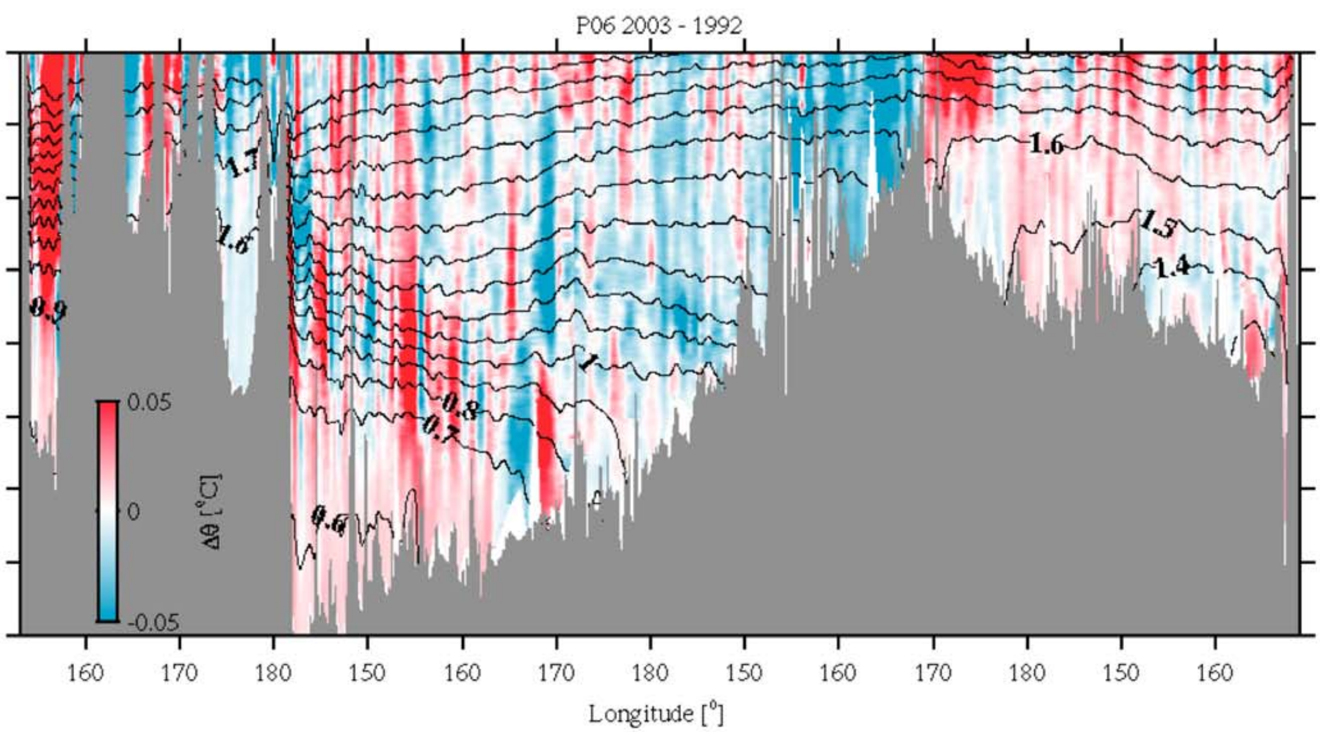
0.010°C abyssal warming

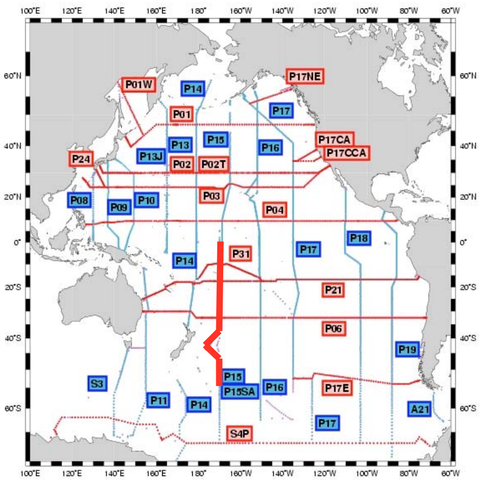
Coldest, weakest stratified waters warm

Starts at 4000 dbar

Significant at 95% CI below 5000 dbar







170°W: 2001 - 1996

Johnson et al. (2007)

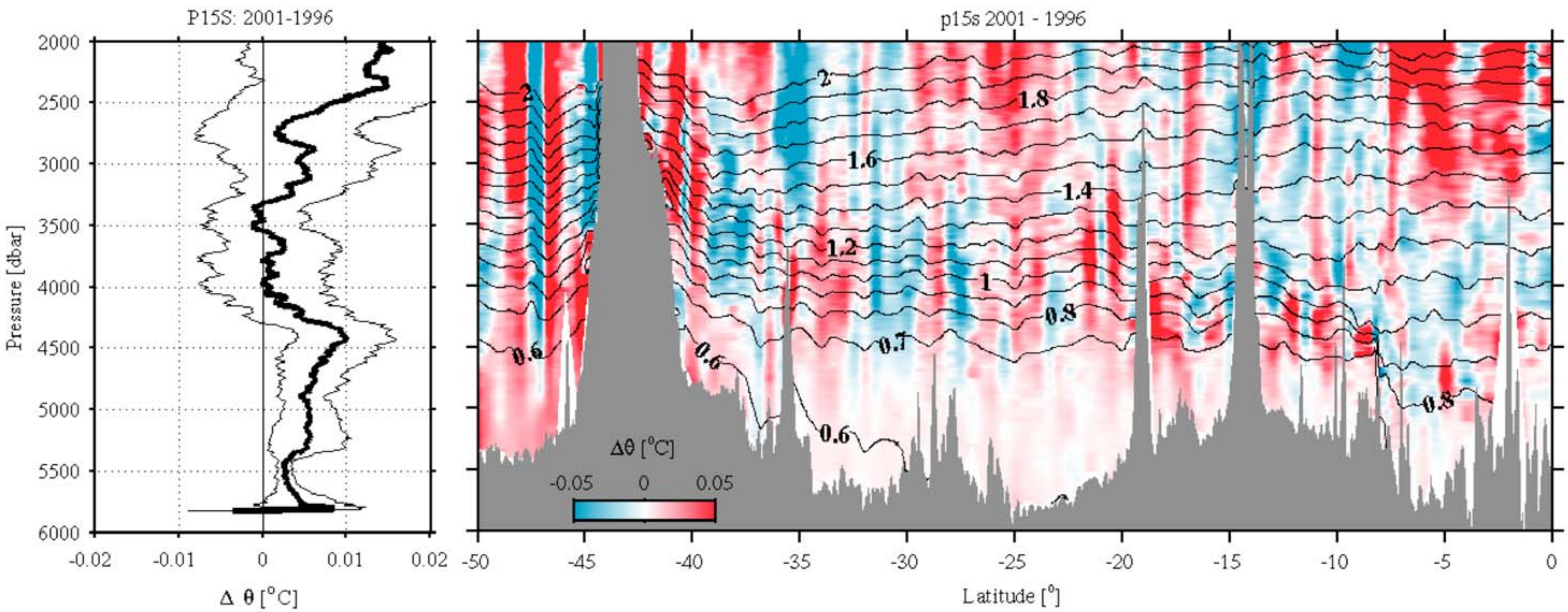
Only 5-year time interval

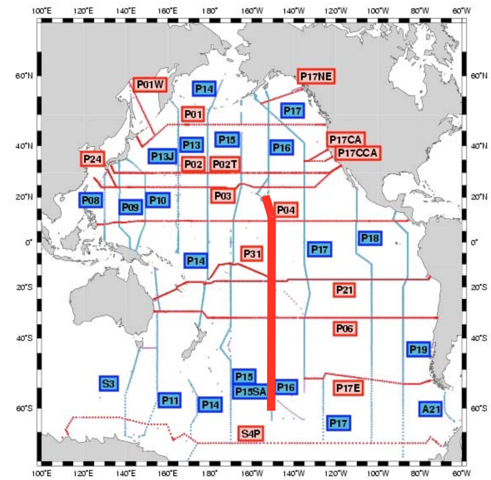
0.005 to 0.010°C abyssal warming

Starts at 3500 dbar

Significant at 95% CI below 4200 dbar

Warming stronger in the south





150°W: 2006/2005-1992/1991

Johnson et al (2007)

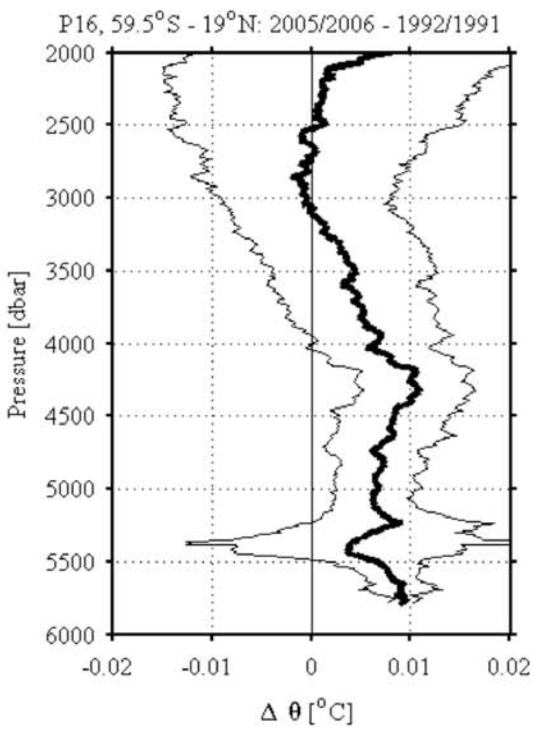
13-year interval

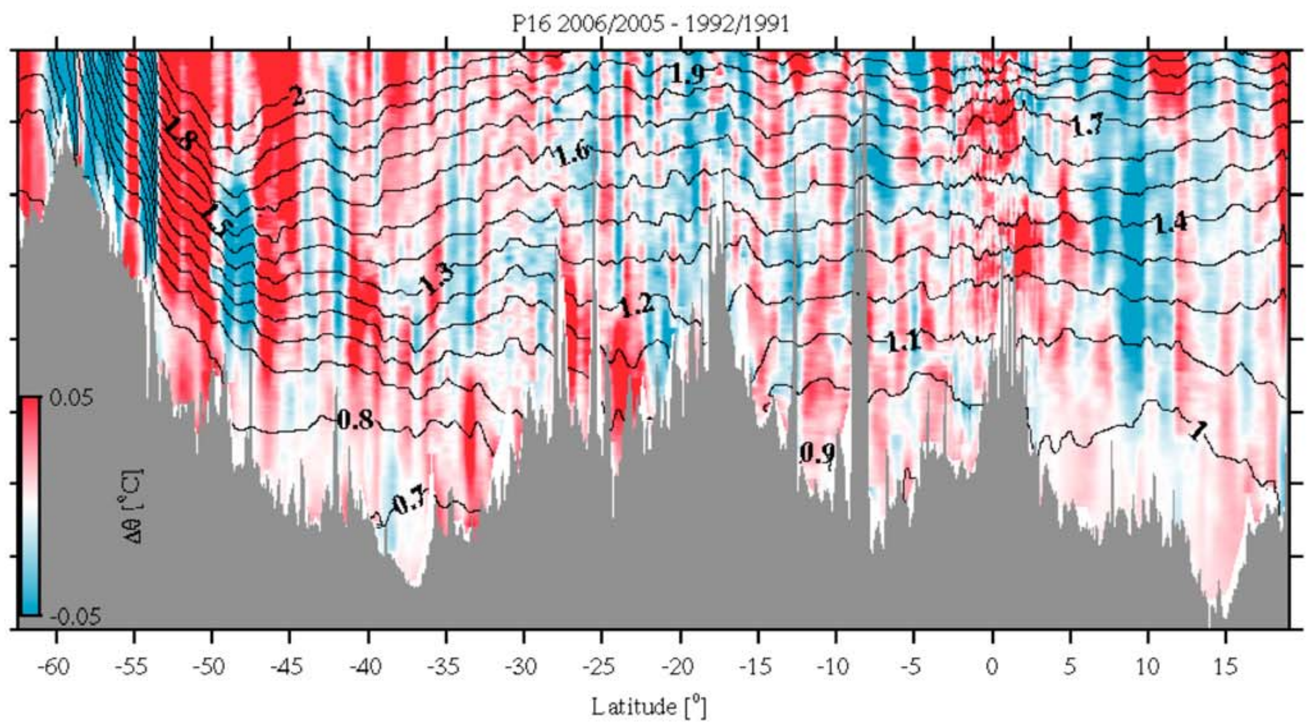
Abyssal waters warm in all basins

Mostly starts at 3000 dbar

0.005 to 0.010°C abyssal warming

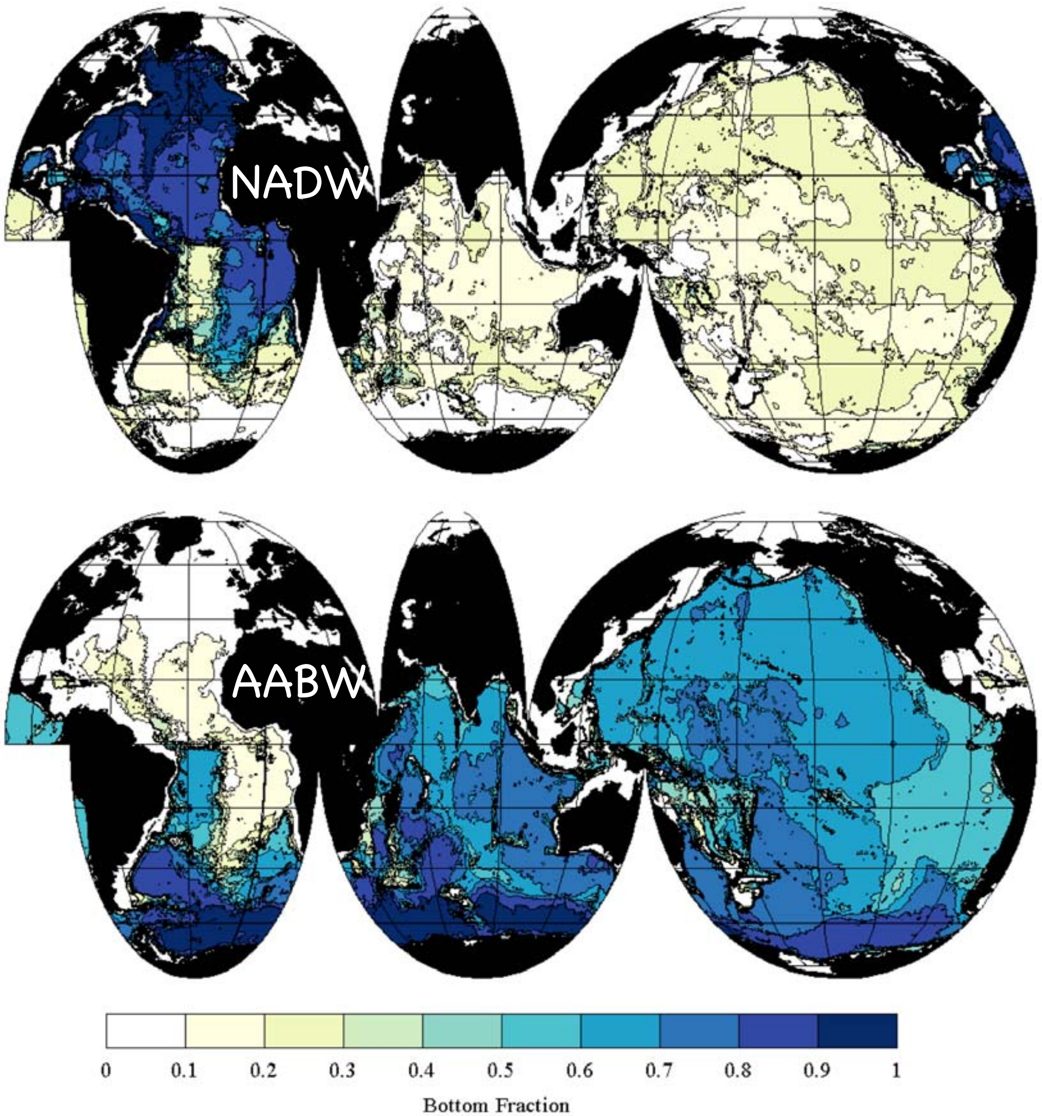
Southernmost end warms about 0.04°C





AABW & NADW Bottom Fraction

(Johnson 2008)



- AABW covers 2.2 times the ocean floor covered by NADW
- Water Property Model (OMP-like)
- Pick Water Masses
- Most extreme AABW end member (WSBW)
- Two NADW end members to span space (ISOW & LSW)
- Conservative for AABW, liberal for NADW
- Four thermocline ventilating end-members: AAIW, NPIW, MSOW, & RSOW (not shown)
- Conserve volume, θ, S, PV, NO, PO, & SO
- Use non-negative least-squares (positive fractions)
- 58% covered by AABW
- 26% covered by NADW