Decadal-Scale Temperature Variability in the Southern Ocean

Sarah Gille

Scripps Institution of Oceanography and Department of Mechanical and Aerospace Engineering
UCSD, La Jolla, CA
Global Temperature Trends

Levitus et al., Science, 1998
Outline

• Observing the Ocean
• Decadal Scale Changes
• Possible Mechanisms
• Speculation on Impact
Southern Ocean data (900 m depth)
Autonomous Floats: ALACE and PALACE in the 1990s
ALACE/PALACE measurements from the 1990s
Temperature at 900 m

Atlas (1930s-1990s)
Floats (1990s only)

Gouretski and Jancke, 1998
Temperature Difference at 900 m
Nearest neighbor comparisons

hydrography: SODB (Olbers et al., 1992); WODB (Levitus et al., 1998)

floats: ALACE and PALACE (courtesy of R. Davis)
Mean difference within 220 km radius: 0.09 ± 0.02°C
Temperature Trends (700 to 1100 m depth)

Gille, Science, 2002
Temperature Trends (700 to 1100 m depth)

Gille, Science, 2002
Trends in the coordinates of the flow

variations on streamlines

trend (°C/yr)

0.02
0.01
0.00
-0.01
-0.02

0.8 1.0 1.2 1.4 1.6

dynamic height (m)

0.4 0.5 0.6 0.7 0.8 0.9 1.0 1.1 1.2 1.3 1.4 1.5 1.6

m
Nearest Neighbor Comparisons for Profiling Floats

- **Hydrography**: World Ocean Database 2001 data quality flags—reject questionable values. CTD, BT, XBT, Bottle Data: up to 150,000 obs.
- **Floats**: PALACE (1990s) courtesy of R. Davis. up to 9600 observations
- Analysis on WOD01 standard levels: 10, 20, 30, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500, 600, 700, 800, 900, 1000, (1100)
- As many as 3.5 million data pairs at each depth
Stratification changes (from PALACE vs Hydrography)
Temperature trend in vertical structure
Heat content changes

Ocean heat content (10^22 J) for the 0-1000 m layer, 5-YR running composites, showing changes in the Southern Hemisphere, Northern Hemisphere, and World Ocean from 1945 to 1995. The graph also includes a line plot showing heat content at the top 1000 m over time from 1930 to 2000.
Southern Ocean Vertical Structure
Mechanisms

- Heat input from atmosphere
- Southward displacement of ACC
- Oceanic heat transport
Mechanisms: Eddy heat flux

Estimate: $\langle u'T' \rangle$ from float data
Mechanisms: Meridional heat flux

Gille, JPO, 2003
Mechanisms: Net meridional heat flux

Total heat flux at 900 m: 4.7 to 7.5 kW/m$^2$. Implies 0.3 PW heat loss to atmosphere south of ACC. Temperature change at 900 m in 50 years: $> 2^\circ$ C.

Gille, JPO, 2003
Mechanisms: Heat flux from atmosphere

2 W/m$^2$ for 40 years spread over region implies $20 \times 10^{22}$ J
Mechanisms: How well sampled are heat fluxes?

Hsiung, JPO, 1985
Mechanisms: Changes in wind (NCEP)

Zonal mean $u$
Temperature change suggests geostrophic transport change

1950s

1990s
Temperature change implies transport reduction

net reduction of 9 Sv between 40 and 63°S
Mechanisms: Shift in core of wind (NCEP)
Mechanisms: Trend in maximum wind (NCEP)

Consistent with southward migration of front.
Mechanisms: Shift in speed/curl (NCEP)

Consistent with more upwelling in ACC; more downwelling north of ACC

Caveat: NCEP warns not to use Southern Ocean winds
Open Questions: Are these patterns anthropogenic?

Banks and Wood, J. Climate, 2002
Open Questions: Does warming the ocean destabilize ice?

Ross Sea, 2003
Open Questions: Does warming reduce CO$_2$ uptake?

CO$_2$ is more soluble in cold water than in warm water. Warming of 0.3°C (e.g. skin vs bulk temperature) implies 0.6 Gt C/yr reduction in uptake.

Caldeira and Duffy, Science, 2003
Summary

- Mid-depth warming of about 0.17°C from 1950s to 1990s
- Water column has heated everywhere
- Warming concentrated within Antarctic Circumpolar Current.
- Possible cooling to north.
- Mechanisms uncertain—may be associated with poleward displacement of ACC or heating from atmosphere.
Continuing these Inquiries in the Future

Argo Network, as of April 2003 (770 Floats)

- **AUSTRALIA** (24)  
- **CANADA** (59)  
- **CHINA** (13)  
- **DENMARK** (4)  
- **EUROPEAN UNION** (72)  
- **FRANCE** (24)  
- **GERMANY** (44)  
- **INDIA** (9)  
- **JAPAN** (134)  
- **KOREA (Rep. of)** (25)  
- **NEW ZEALAND** (3)  
- **NORWAY** (3)  
- **RUSSIAN FEDERATION** (3)  
- **UNITED KINGDOM** (55)  
- **UNITED STATES** (298)