Southern Ocean Variability Determined from Limited Observations

WGOMD-GSOP Workshop on Decadal Variability, Predictability and Prediction: Understanding the Role of the Ocean.
Bernadette Sloyan,
20 September 2010
Workshop Motivation

• To assess how well the ocean models and ocean syntheses reproduce observed decadal variability;
• To understand and evaluate the robustness of simulated ocean internal variability;
• To identify the underlying physical mechanisms in the ocean in decadal climate variability and;
• To evaluate the outcomes of the CMIP5 decadal prediction experiments.
Key Topics: Southern Ocean Perspective

- Observed decadal variability: What is the observed decadal variability in the climate system (observations and syntheses)? What are the observed signals in the ocean? Are the present ocean observations adequate for decadal variability studies?

- Predictability and state of the ocean models: Are the ocean models up to the task? How sensitive are small/regional changes to the ocean initial state? How sensitive are the model results to model resolution?

- Physical Mechanisms: What are the sources of decadal variability? What determines the propagation and decay of decadal anomalies?

- Initial conditions, predictions, and verification: What fields should be carefully initialized in the ocean? What are the common verification techniques?

What are the observed climate impacts?
What sustained observations are needed?
POTENTIAL GLOBAL CLIMATE IMPACT

Southern Ocean variability will influence:

- Meridional Heat and Freshwater Flux
- Ocean Stratification
- Biological Productivity
- Carbon
- Earth’s Energy Balance and Sea Level Rise

Variability in Southern Ocean

- Bottom water
- Intermediate depth Water Masses – Subantarctic Mode Water (SAMW) and Antarctic Intermediate Water (AAIW)
Indian and Pacific Deep Ocean Circulation
Western Pacific Ocean: Western Boundary

Decadal Change


Temperature Change

Sloyan et al., in prep
Western Pacific Ocean: Eastern Basins

Decadal Change

Section Year:

Temperature Change
Deep Ocean Change extend to North Pacific

Kawano et al., 2010, Deep Sea Research II
Western Pacific Temperature Change

Temperature Change

Southern O.  SW Pacific  North of 10°S

Tasman Sea  W. Pacific

170°W  32°S
Eastern Indian Temperature Change

90°E

32°S

Temperature Change

Ant-Aust Basin

S. Aust Basin

Wharton B.

S. Aust Basin

Perth Basin

$\frac{dT}{dt} \times 10^{-3}$ °C yr$^{-1}$
Global Assessment of Deep Ocean Change

Purkey and Johnson, 2010, J. Clim, under revision

Used data from 26 lines that have been occupied at least twice between 1981 and 2009 from WOCE/GO-SHIP
• Temporal distribution varies. Mean difference between first and last occupation is ~13 year.
• Defined 32 deep basins (gray curve) based on topography and $\theta$ and Southern Ocean by SAF (white curve)
• Generally good world coverage but missing some basins
Local heat fluxes implied from Temperature Change

Mean local heat fluxes through 4000 m implied by abyssal warming below 4000 m from the 1990s to the 2000s indicated by black numbers and color (see key), as well as 95% confidence intervals. The local contribution to the heat flux through 1000 m south of the SAF (maroon line) implied by deep Southern Ocean warming from 1000–4000 m is also given (maroon number) with its 95% confidence interval.
Comparison of 50 year Temperature Trend

Difference between models is the resolution used.
Comparison of 50 year Temperature Trend

Model difference is start year from control run of 20th Century.
Deep Ocean Contribution to Sea Level Rise

Basin means of Sea Level Rise (SLR) from the 1990s to the 2000s due to abyssal thermal expansion below 4000 m and deep thermal expansion in the Southern Ocean from 1000–4000 m south of the SAF.
Bottom-water warming signal identified by an adjoint sensitivity analysis

Pathway and temporal time-scales of bottom-water temperature change at 47°N-170°E [5200-m depth (A)]. Arrows denote the Kelvin and equatorial Rossby wave propagations. 4-DVAR model show change in North Pacific can be traced to air-sea heat flux change at the Adelie Coast.

Masuda et al. 2010, Science
Temporal Evolution of Bottom Water

4D-VAR reanalysis of bottom temperature in the North Pacific. What is the potential to use reanalysis to determine alias spatial and temporal scale due to sampling interval of hydrographic sections.

Repeat Hydrography is the only observational program for deep ocean (> 2000 m) and full depth chemical and carbon.

Temporal evolution of water temperature from 1984 to 2000 averaged within the North Pacific abyssal basin (155°-170°E, 40°- 50°N, 4500- to 5200-m depth). The units are in Kelvin.
Variability of AABW formation and properties.

Temperature and salinity variability in Ross Sea from 1958 to 2008. The profiles show a general shift to fresher shelf water.

Slight warming trend consistent with change in freezing point for observed change in salinity.

Jacobs and Giulivi, 2010, J. Clim
Causes of AABW variability

Decadal trend in salinity of water masses in the Ross Sea region compared to (inverted) Southern Annular Mode (SAM).

Authors suggest strong correlation between declining salinity and rising SAM index, is indicative of link of water mass property variability with large-scale atmosphere change.

Jacobs and Giulivi, 2010, J. Clim
Time Series of AABW export in Weddell Sea

Atlantic Ocean variability will be covered by Mike Meredith in a following presentation.

Potential temperature section south of the South Orkney Islands with the location of the mooring array superimposed. Inset: Bathymetric map of the Weddell Sea Gyre indicating the position of several streams of newly formed Weddell Sea Bottom Water [Gordon et al. 2001].
Mean Decadal Trends above 1000m

Warming and freshening of Southern Ocean upper ocean and associated slumping and southward displacement of isopycnals.

Boning et al., 2008 Nat. Geo.

Temperature and salinity changes across the ACC. Mean decadal trends averaged on isobaric surfaces, of (a) potential temperature and (b) salinity.
Variability of Intermediate Depth Water Masses


Example of use T-S property changes of SAMW and AAIW

McCarthy, et al., 2010, JPO
Decadal Ventilation of SAMW and AAIW

From CFC tracer studies, SAMW and AAIW ventilate the subtropical gyres in the order of 3-20 years depending on proximity to formation region.

These water masses are vital for the ventilation and renewal of nutrient in the subtropical thermocline.

Fine et al., 2008 DSR I
Variability of SAMW and AAIW – Drake Passage

24 hydrographic section spanning 1969-2005 show variability of SAMW and AAIW in Drake Passage.

SAMW and AAIW properties in resultant from water masses formation in Southeast Pacific. Use time series of SST and ENSO and SAM to examine drives of variability.

Naveira Garabato et al., 2009, J Clim
Interannual cross correlation of SST with ENSO and SAM. ENSO significant correlations at 4-6 months and ~19 months. SAM (marginally) at 1-6 months and 22 months.

Red, green and blue lines linear regression of SST with ENSO (35% variance) and SAM (6%) explains 38% of SST anomalies.

Naveira Garabato et al., 2009, J Clim
Mixed Layer Depth Variability

Sallee et al., 2010, Nat. Geo.

Seasonal cycle of MLD and first EOF. Data is monthly determined from Argo profiles 2002-2009.

Intraseasonal and interannual variability is largest in winter.

Time series is only 8 year long.
MLD anomaly Associate with SAM

Sallee et al., 2010, Nat. Geo.

Mapped composite of MLD anomaly during positive and negative SAM. MLD time series is too short for similar analysis with ENSO.
SAM Mixed Layer Heat Budget forcing

Sallee et al., 2010, Nat. Geo.

Left panel: Observed composite MLD anomaly weighted with corresponding SAM events (2002 -2009). Right panel: Expected deepening of MLD for positive SAM for air-sea synthesis (JRA) air-sea and Ekman heat fluxes regressed onto SAM.

Air-sea and Ekman heat fluxes explain MLD variability. MLD heat budget dominated by ocean heat loss due to anomalously southerly winds in eastern Pacific and Indian sectors of Southern Ocean.
Ocean mixing: impact of MLD variability

Layer Mean Diffusivity in (a) winter and (b) summer determined from XCTD and CTD profiles. Summer mixing preconditions the water column for deep winter mixing in Southeast Pacific sector.

Sloyan et al., 2010 JPO
Mean Decadal Trends above 1000m

Warming and freshening of Southern Ocean upper ocean and associated slumping and southward displacement of isopycnals.

Boning et al., 2008 Nat. Geo.

Black contours illustrate the migration of isopycnal surfaces during the past four decades: continuous (dashed) curves represent potential densities obtained by subtracting (adding) the linear trends over two decades from (to) the climatological values (Black contours in b).
Eddy Kinetic Energy Variability

Meredith and Hogg, 2006, GRL

Positive SAM event lagged (2-years) by increased EKE in Southern Ocean.

Eddies act to transfer excess energy from the ocean surface to the deep ocean. This has impact of the meridional overturning circulation. Implies climate models need to properly account for eddies in Southern Ocean.
Southern Ocean Sustained Observations: Argo

3189 Floats
16-Sep-2010
Southern Ocean Sustained Observations: Repeat Hydrography
Southern Ocean Sustained Observations: OceanSITES

OceanSITES Status Map 2009 - Operating Sites

OceanSITES Moorings and Observatories (91) Transport sites (16)
- OPERATING Real time data (44)
- OPERATING Delayed Mode data (47)
- OPERATING
- Transport Stations

Note: This status was based on information provided in 2009.
Southern Ocean Observations: Process Studies

From CLIVAR Southern Ocean Panel
(http://www.clivar.org/organization/southern/CLIVAR_CliC_Obs.html)
Improvements to Southern Ocean Observations

Is the observational network to understanding the drivers, impact and model assessment of Southern Ocean variability, its spatial and temporal time-scales adequate? Will progress be (severely) hampered unless we improve the observational record?

For example:
• Global estimates of deep ocean heat content change are based on basin-scale and decadal time-scale resolution of the data and could be aliased by smaller spatial scales and shorter temporal scales;
• Monitoring of key circulation pathways (deep western boundaries, deep passage) is generally project based with times series of < 2 years
• Southern Ocean MOC
• Time-series in AABW formation regions are short (< 5 years).
Thank you
To gain more precise estimates of the deep ocean’s contribution to sea level and global energy budgets, and to understand better how the warming signal of AABW spreads from the Southern Ocean around the globe, higher spatial and temporal resolution sampling of the deep ocean is required. The basin space-scale and decadal time-scale resolution of the data used here could be aliased by smaller spatial scales and shorter temporal scales.
Bonning et al., 2008, Nat. Geo.