Future of OCB Research in the Southern Ocean

Chairs: Kendra Daly (USF) and David Ho (U Hawaii)

0830 Summary of Southern Ocean Scoping Workshop (Kendra Daly)

0915 Overview of the Southern Ocean GasEx Project (David Ho)

0930 SO GasEx Results and Long Term Changes in Southern Ocean CO2 Sources/Sinks (Pete Strutton, OSU)

1000 Discussion

1030 Break

1100 Southern Ocean Particle Fluxes (Phoebe Lam, WHOI)

1130 Discussion

OCB Workshop 20-23 July, 2009, WHOI
Summary of the OCB Scoping Workshop: New Frontiers in Southern Ocean Biogeochemistry and Ecosystem Research

8 – 11 June 2009, Princeton University

http://www.us-ocb.org/
Outline

- Goals of workshop
- Recent advances in scientific understanding
- Key research questions
- Workshop recommendations
The Southern Ocean Plays a Critical Role in the Global Climate System Owing to Its Unique Physical, Biogeochemical, and Ecological Features

NASA MODIS Ocean Color
Facilitate interaction between physical, biogeochemical, and ecosystem research communities to develop research strategies, resolve current limitations, gaps and discrepancies in our understanding and prediction of the Southern Ocean ecosystems, biogeochemical cycles, and carbon uptake.
Workshop Objectives

- Provide a critical overview of recent advances in scientific understanding of Southern Ocean
- Build a collaborative Southern Ocean community across disciplines
- Identify key research questions of scientific significance
- Formulate implementation plans for collaborative research in the Southern Ocean
Bottom Up Processes: Physical Forcing
The Southern Ocean is Undergoing Substantial Changes in Response to Climate Trends and Variability

Ocean is warming strongly in the near-surface layers, but also becoming more saline...

Cause appears to be atmospheric-induced reduction in ice production, combined with seasonal bias in sampling...

... but both T and S trends are positive feedbacks, acting to sustain and enhance the atmospheric & cryospheric change.

Mike Meredith talk
Atmosphere-Ocean Interactions: ENSO and Southern Annual Mode (SAM)

Start with clear, well-known examples of Southern Ocean response to climatic forcing.

(Near-)instantaneously, both ENSO and SAM have characteristic footprints in the Southern Ocean SSTs...

Sea ice concentration responses strongly linked to SST response (see also Kwok & Comiso, Stammerjohn etc)

Mike Meredith talk
Southern Hemisphere Annular Mode (SAM)

- The dominant mode of climate variability across the Southern Hemisphere

- SAM is an expression of the meridional pressure gradient between the sub-Antarctic and middle latitudes.

- SAM has been increasing towards its positive polarity since the late 1960s, leading to lower surface pressures over Antarctica.
Summary

- Models and observations find that the Southern Ocean is a sink for atmospheric $\text{CO}_2$.
- The magnitude of the sink is model dependent and a function of physical and biogeochemical parameterizations.
- A number of model studies have shown that the Southern Ocean $\text{CO}_2$ sink has weakened over the past few decades as a result of stronger winds and overturning.
- There is some observational evidence to support the idea of a weakening $\text{CO}_2$ sink.

Nikki Lovenduski talk
Upwelling is tied to efficiency of the ocean’s “biological pump”

Surface nitrate illustrates high efficiency of the biological pump over most of the ocean. Principal exception is the Southern Ocean.

From: iridl.idso.columbia.edu/SOURCES/LEVITUS94

Bob Anderson talk
Efficiency of the Biological Pump: Mechanisms to Increase Nutrient Utilization

- Increase nutrient utilization
  (John Martin’s Fe hypothesis)

  [No evidence for this]

- Decrease nutrient supply
  (Glacial stratification hypothesis)
Upwelling Summary

Deglacial Si supply to surface waters south of the APF exceeded supply before or after; increased upwelling is the only plausible cause.

Increased upwelling (opal burial) coincided with earlier periods of rising atmospheric CO₂.

Wind-driven upwelling in the Southern Ocean is a primary mechanism driving changes in atmospheric CO₂.

Bob Anderson talk
Ocean-Atmosphere Interactions: Southern Annual Mode (SAM)

- **Models** suggest that there a latitudinal shift southward in the ACC (impacts on stratification, CO2 flux, primary productivity, etc.)

- SAM intensification implies a poleward shift in winds

- A poleward shift in winds implies a poleward shift in the ACC

- An ACC shift implies either an increase in Ekman transport, intensification of the overturning circulation and change in isopycnal slope, OR a change in eddy energy (not seen in coarse-scale IPCC models)

- **Sea level measurements** indicate that the ACC transport does change on these time scales in response to winds, with little lag – but response is small. - Need more observations.

Sara Gille, Mike Meredith, Kevin Speer talks
Current Debate in the Community - Can a shift in winds affect carbon sink in Southern Ocean?

Böning et al. 2008 Nature Geoscience Vol. 1

- Observations show intensification of westerlies
- Argo float and historical oceanographic data show warming and freshing of ACC to >1,000 m
- Did not detect increase in tilt of surfaces of equal density.
- Concluded ACC transport and meridional overturning are insensitive to decadal changes in wind stress.
Climate Change West of the Antarctic Peninsula
Effects on Biology

Average winter (June-July-August) temperature (Faraday Base)

+1.1°C per decade: 6°C (11°F) since 1950: 5 x global average
-1.8°C (sea ice formation)

Antarctic Peninsula one of most rapidly warming regions on the planet
Western Antarctic Peninsula & Bellingshausen Sea

**Decreased Sea Ice Duration**

- Sea ice retreating 31 days earlier in spring
- Advancing 54 days later in fall
- Related to a shift towards positive values of the Southern Annual Mode since the 1990s

(Stammerjohn et al. 2008)

CZCS - SeaWiFS

-90%  +66%

Montes-Hugo et al, Science, 2009

Hugh Ducklow talk
1998-2006 SeaWiFS ocean color climatology shows persistent, large aggregations in the southern sector of the Antarctic Peninsula & Bellingshausen Sea.

January ocean color climatology 1998-2008

Marrari, Daly, & Hu 2008 DSR II 55
The Southern Ocean is Undergoing Substantial Changes in Response to Climate Trends and Variability

30% decline in Antarctic krill in South Atlantic in last 30 years

Atkinson et al. (2004)
Penguin Populations in the Palmer Station region
(75% decline since 1975)

Adelie breeding pairs

78% decline

YEAR

Gentoo and Chinstrap breeding pairs
What happened in the past?

Harvesting has generated massive perturbations over more than 2 centuries.

*Fur-seals*
From 1778; economic extinction within 35 years

*Whales*
1906 to 1966, residual thereafter

*Fin-fish, krill*
From late 1960s, continuing

Top-down effects => Krill surplus?
Top Down Food Web Perturbations

Dan Costa talk
Marine Mammals Fertilize the Ocean

- Ocean is stratified
- Whales excrete waste at the surface
- Whale excretion is liquid and nutrient rich

Trish J Lavery, Laurent Seuront, James G Mitchell
Flinders University of South Australia

Photo by Dr. Nick Gales, AAD
Faecal nutrient content

Krill, Salps, Cephalopods

$N = 20 \text{ mg g}^{-1}$
$Fe = 1 \text{ mg g}^{-1}$

Consumes\(^{(8)}\) 1 tonne d\(^{-1}\)

$N = 20,000 \text{ g}$
$Fe = 1,000 \text{ g}$

Excretes\(^{(9)}\)

$17,000 \text{ g N d}^{-1}$
$850 \text{ g Fe d}^{-1}$

Total whales = 300,000 tons Fe y\(^{-1}\)

Dan Costa talk
Models

Scott Doney, Andrew Constable, Eileen Hofmann talks
Simulating Southern Ocean Dynamics in Coupled Climate Models

Scott Doney (WHOI)

In collaboration with:
Ivan Lima (WHOI)
Keith Moore (UCI)
Keith Lindsay (NCAR)
Irina Marinov (U. Penn)
CCSM-3 BGC core group

Supported by: NASA, NSF, NOAA
"IPCC-class" Coupled Climate Models

- Atmosphere GCM
- Land Surface Model
- Ocean GCM
- Sea-Ice Model

Energy and mass conserving
Internally driven climate variability
External climate perturbations (e.g., fossil fuel CO₂)
**Major uncertainties:**
- $CO_2$ emissions (social, political, economic, geological)
- Atmospheric $CO_2$ (carbon sinks, climate-carbon feedbacks)
- Climate sensitivities (clouds, water vapor)
"IPCC-class" Climate Models

**Opportunities**
- Coupled dynamics & modes - atm.-ocean-sea ice
- Past & future projections - extend beyond reanalysis
- Carbon-climate feedbacks - major source of uncertainty
- Ecological impacts - climate & acidification
- Flagship computations - computer resources, multi-model ensembles

**Challenges**
- Coarse resolution - at best eddy-permitting
- Internal variability - statistical matching with data
- Coupled systems - large regional errors
- Simplified biology - lower trophic levels

Coupled models have large regional errors – sea ice, mixed layer depth, very simplified biology
Spatial and temporal operation of food webs: Scales of interaction in oceanic ecosystems

Eugene Murphy

Jon Watkins, Phil Trathan, Nadine Johnston, Rachel Cavanagh, Simeon Hill (BAS)

Eileen Hofmann (ODU)
Alternative Food Web Pathways

Alternative pathways buffer change - sustainable in long-term? Need better quantification of alternative pathways

High krill

Low krill
Southern Ocean food web research & Southern Ocean Sentinel

Andrew Constable

Antarctic Climate & Ecosystems Cooperative Research Centre & Australian Antarctic Division

Thanks to many involved in ACE, AAD, CCAMLR, ICED, SOOS
Breakout Group Recommendations
At present, we do not have a sufficient understanding to predict climate change impacts on Southern Ocean ecosystems.

We need a multi-tiered approach to fill in knowledge gaps.

- Compile database of historical data – retrospective analyses (ICED Office www.iced.ac.uk/)
- Three focus regions for time-series data
  - West Antarctic Peninsula
  - Ross Sea
  - Open Ocean (1-3 sectors?)
Need sustained observations of physical, chemical, and biological parameters

Southern Ocean Observatory System (SOOS)
http://www.clivar.org/organization/southern/expertgroup/SOOS.htm

Interdisciplinary process studies

Laboratory studies of multiple stressors on key organisms

Determine level of biological complexity required for predictive ecosystem models

Develop nested models
Satellite Capability Essential

- Ocean color
- SST
- Sea ice
- Collaboration with other countries
- Stress importance for earth mission inside NASA
- Wind fields
- Clouds
- Altimetry
- Orbit matters – South Hemisphere; frequency
- Follow up to OCO