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 CO_2 Sources/Sinks (Pete Strutton, OSU)

1000 Discussion

1030 Break

1100 Southern Ocean Particle Fluxes (Phoebe Lam, WHOI)

1130 Discussion

Summary of the OCB Scoping Workshop: New Frontiers in Southern Ocean Biogeochemistry and Ecosystem Research

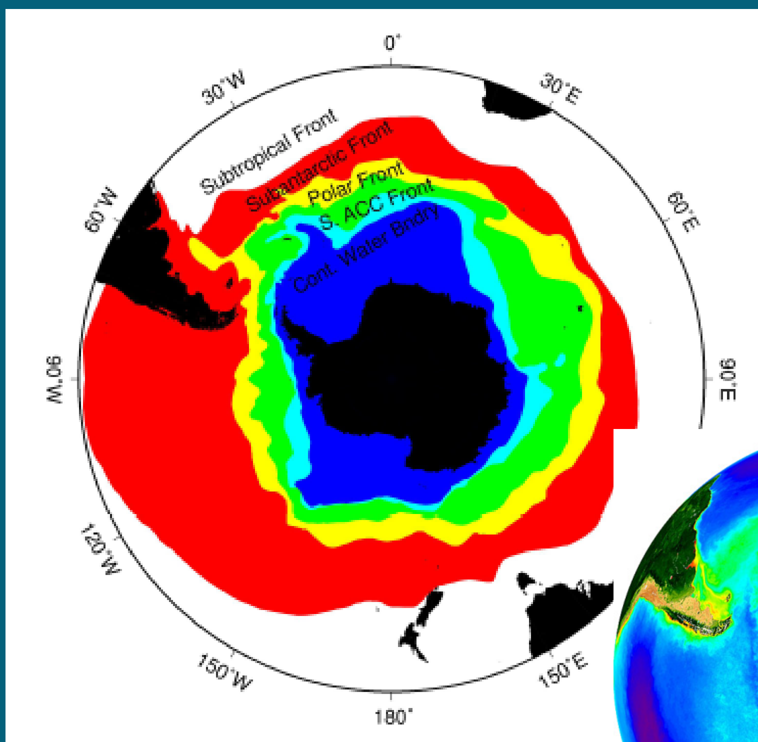
8 – 11 June 2009, Princeton University

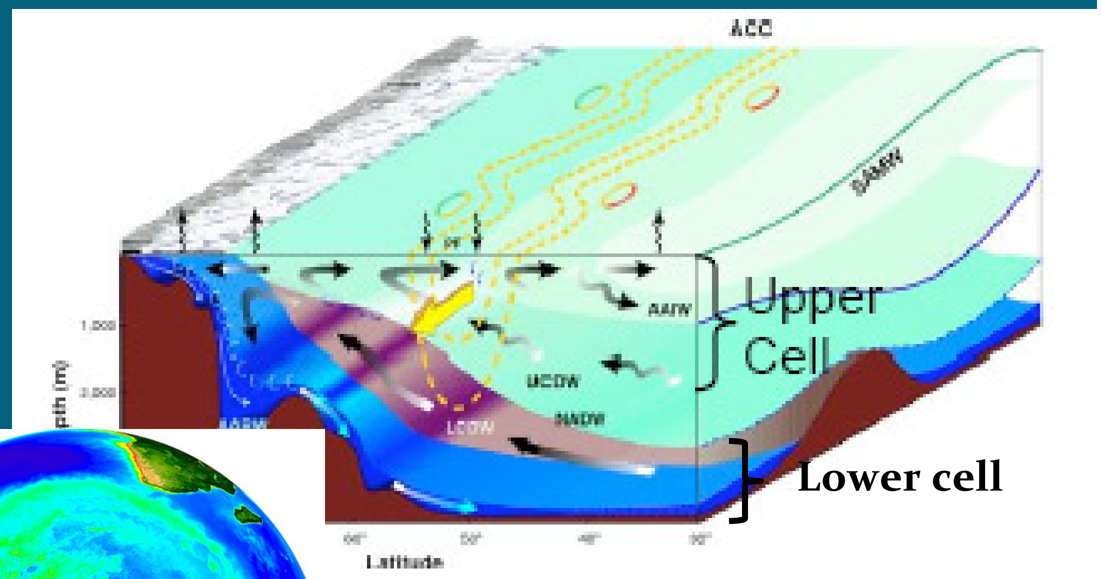
http://www.us-ocb.org/

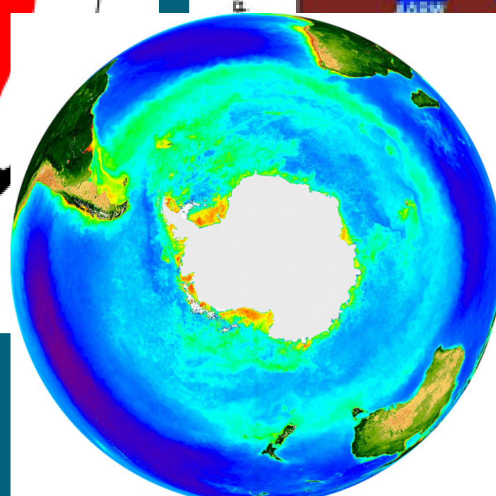
Outline

- 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

Workshop Goal

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

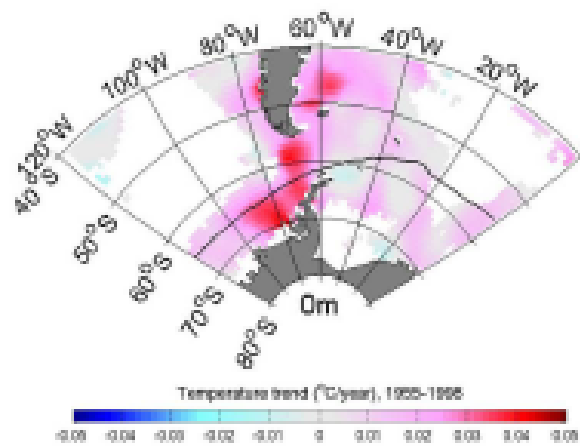
- Identify key research questions of scientific significance

- Formulate implementation plans for collaborative research in the Southern Ocean

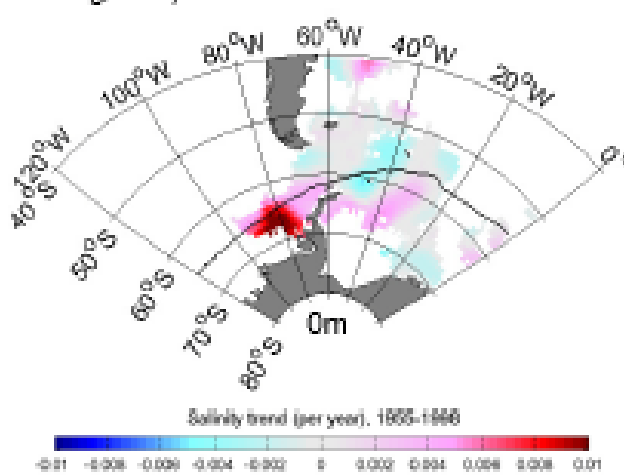
Bottom Up Processes: Physical Forcing

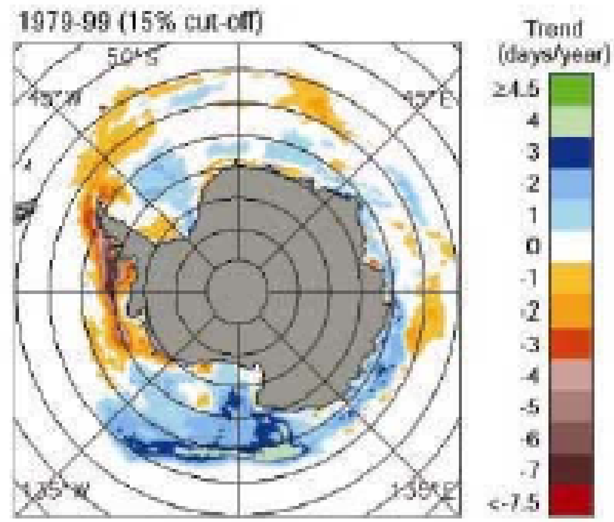
The Southern Ocean is Undergoing Substantial Changes in Response to Climate Trends and Variability

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



(Meredith & King, 2005)



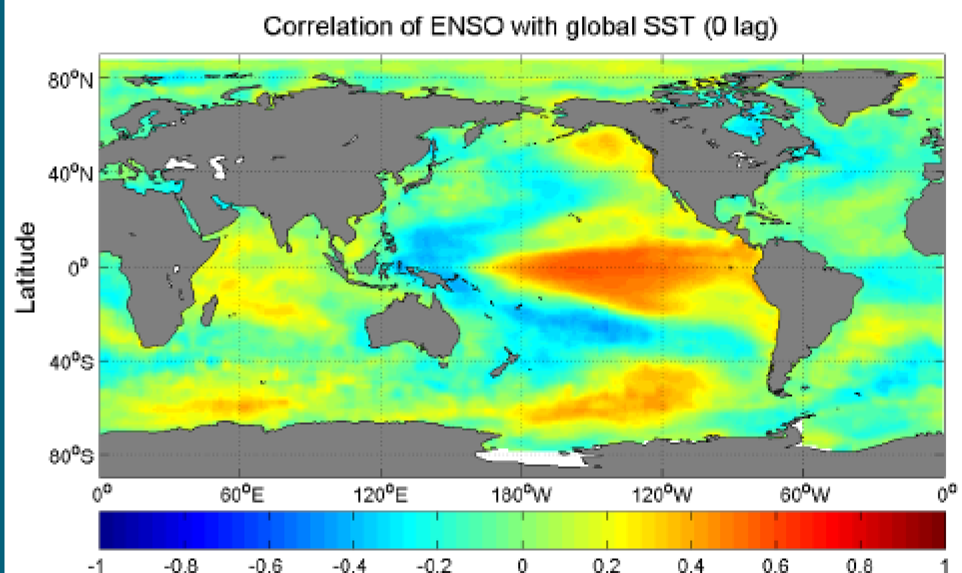


Cause appears to be atmospheric-induced reduction in ice production, combined with seasonal bias in sampling…

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

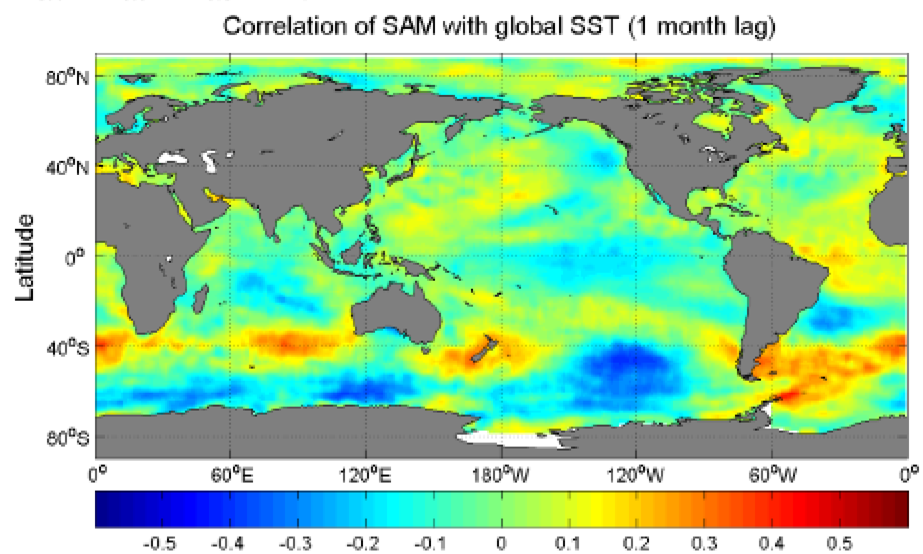
Mike Meredith talk

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)

British Antarctic Survey
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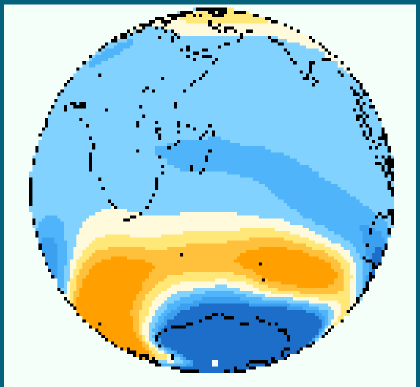
Mike Meredith talk

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.

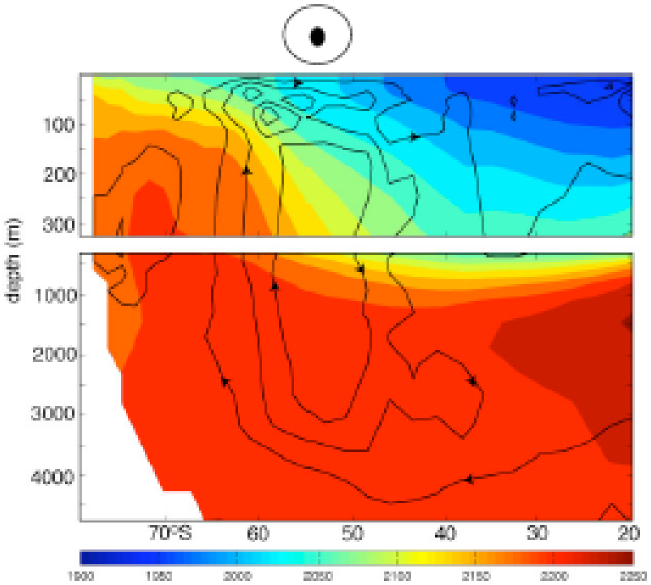
- SAM has been increasing towards its positive polarity since the late 1960s, leading to lower surface pressures over Antarctica.



Changes in the Southern Ocean CO2 Sink

Summary

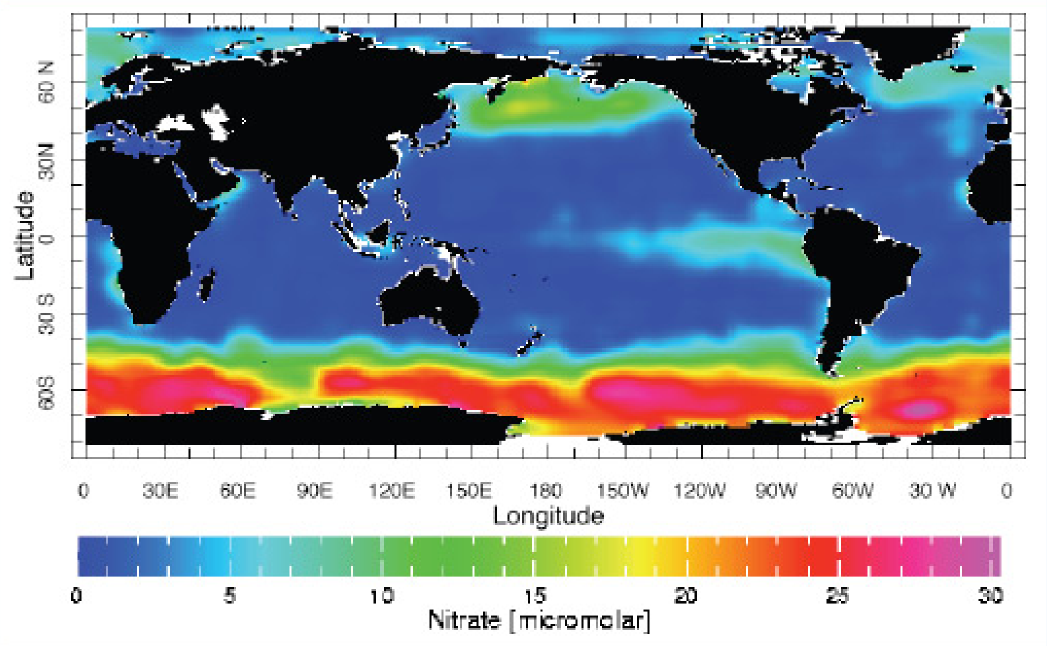
- Models and observations find that the Southern Ocean is a sink for atmospheric CO_2.
- The magnitude of the sink is model dependent and a function of physical and biogeochemical parameterizations.
- A number of model studies have shown that the Southern Ocean CO_2 sink has weakened over the past few decades as a result of stronger winds and overturning.
- There is some observational evidence to support the idea of a weakening CO_2 sink.



Nikki Lovenduski talk

Wind Driven Upwelling and Impact on CO_2

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.ldeo.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

Bob Anderson talk

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 CO_2.

Wind-driven upwelling in the Southern Ocean is a primary mechanism driving changes in atmospheric CO_2.

Bob Anderson talk

Ocean-Atmosphere Interactions: Southern Annual Mode (SAM)

- **Models** suggest that there a latitudinal shift southward in the ACC (impacts on stratification, CO_2 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.- <u>Need more observations.</u>

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

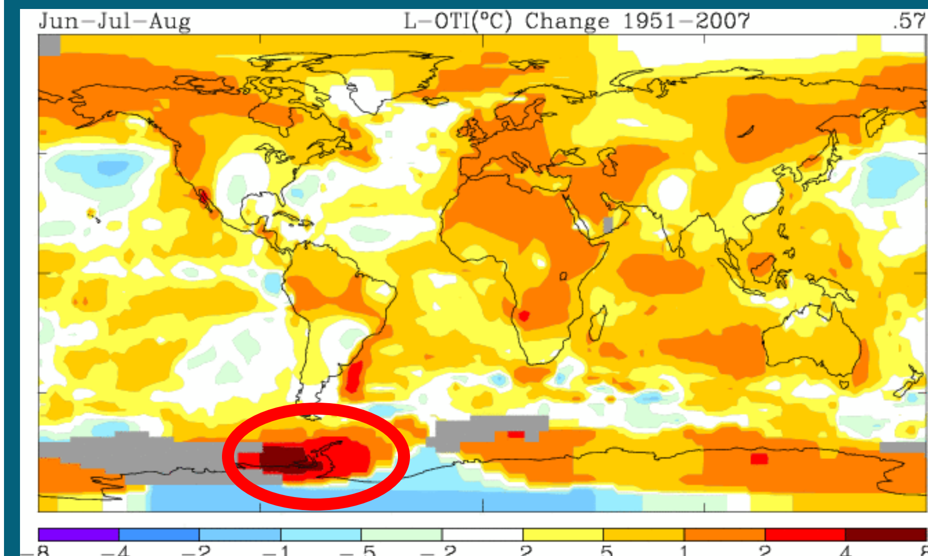
- Observations show intensification of westerlies
- Argo float and historical oceanographic data show warming and freshing of ACC to >1,000 m
- Did not detect increase in tilt of surfaces of equal density.
- Concluded ACC transport and meridional overturning are insensitive to decadal changes in wind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

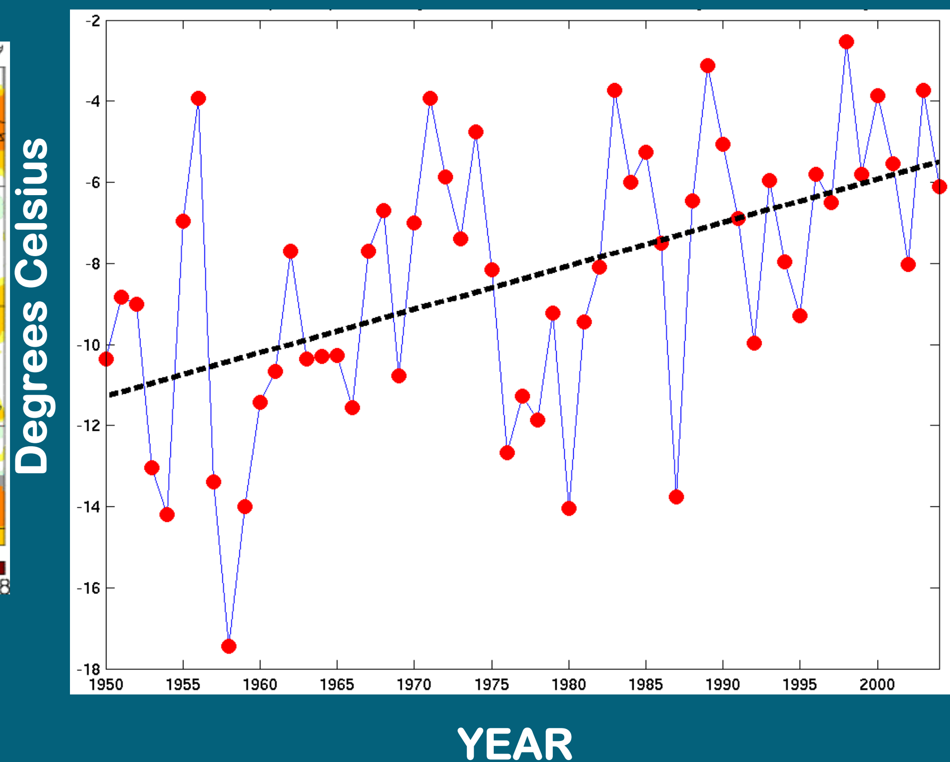
Climate Change West of the Antarctic Peninsula Effects on Biology

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)

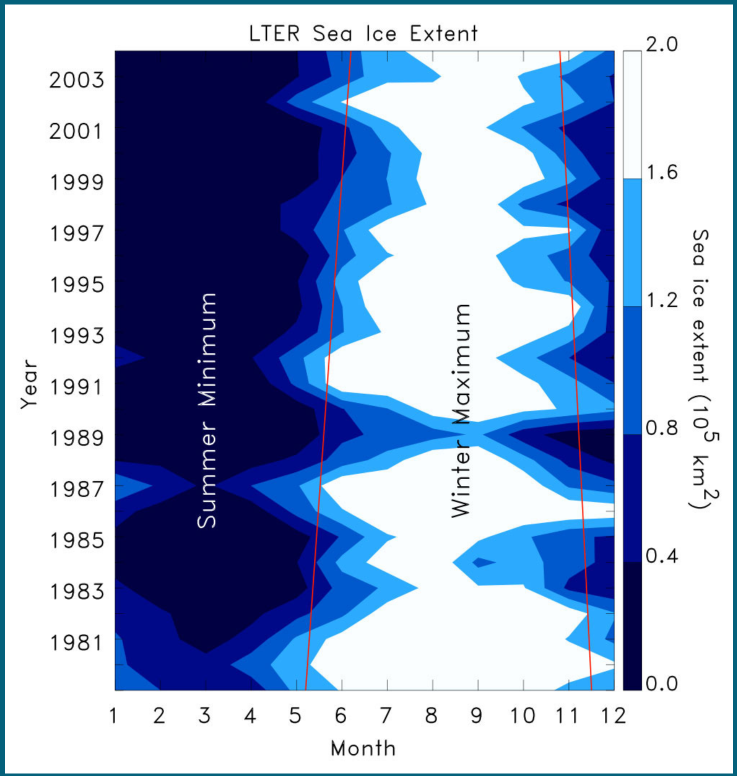




Antarctic Peninsula one of most rapidly warming regions on the planet

Western Antarctic Peninsula & Bellingshausen Sea

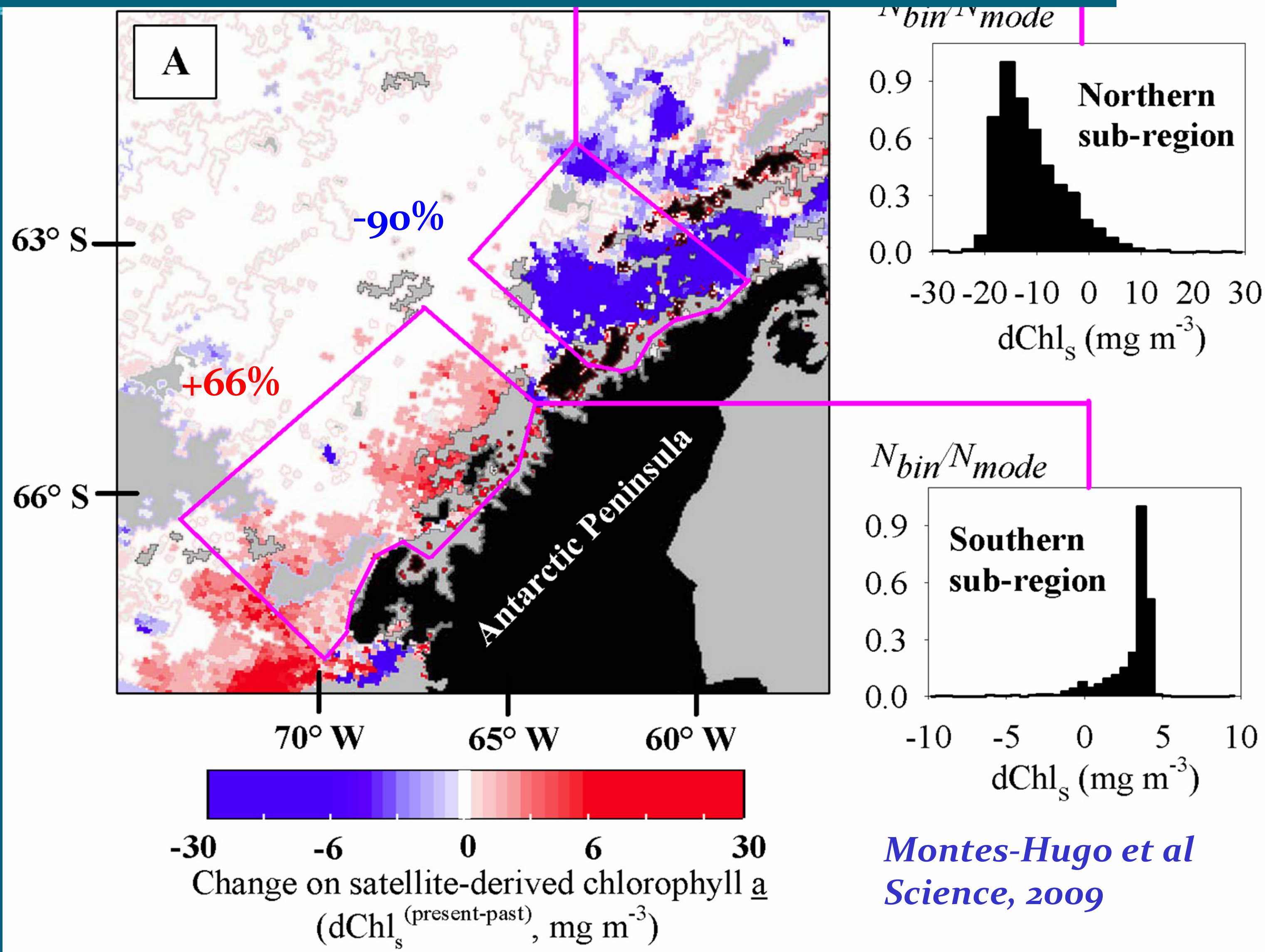
Decreased Sea Ice Duration



- ➢ 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)

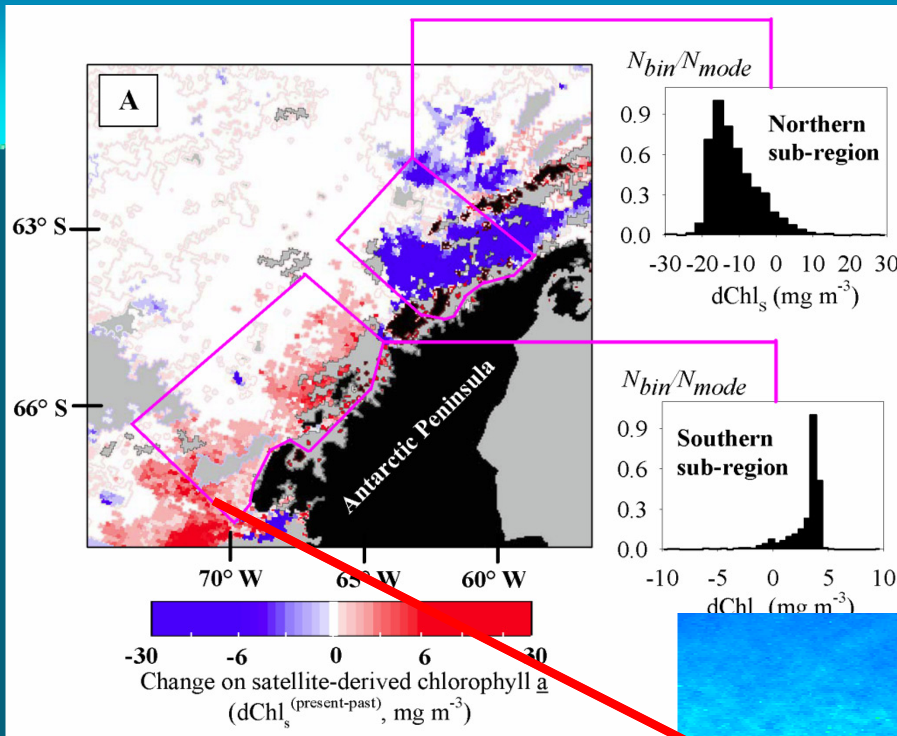
(1978-86 to 1998-2006) Decrease in Phytoplankton Concentrations
CZCS - SeaWiFS

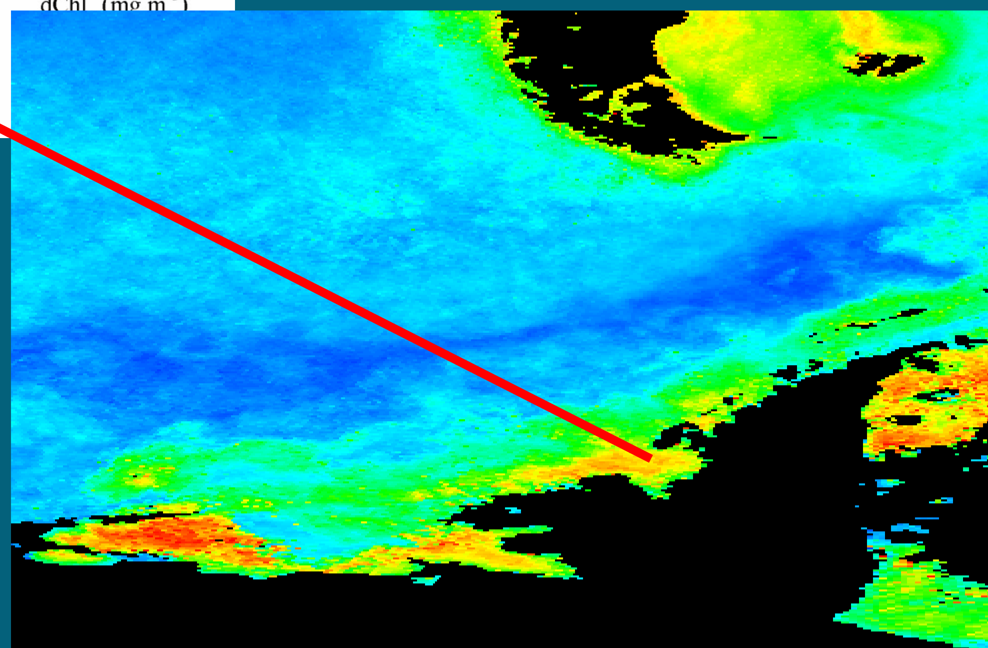


Montes-Hugo et al Science, 2009

Hugh Ducklow talk

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



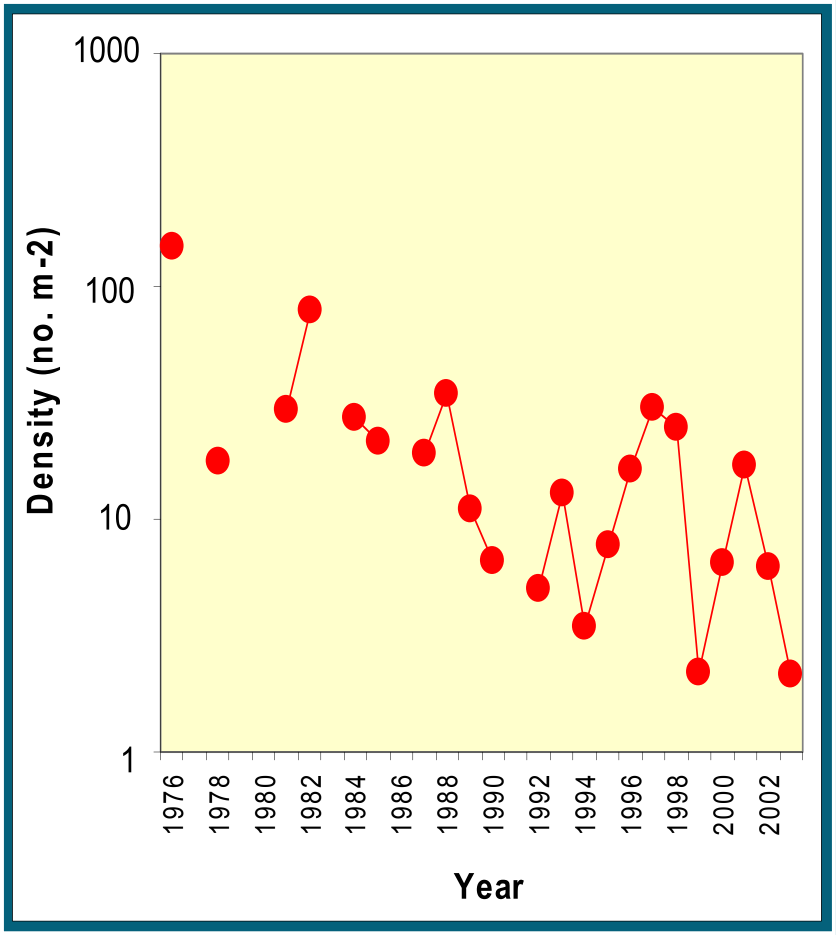


January ocean color climatology 1998-2008

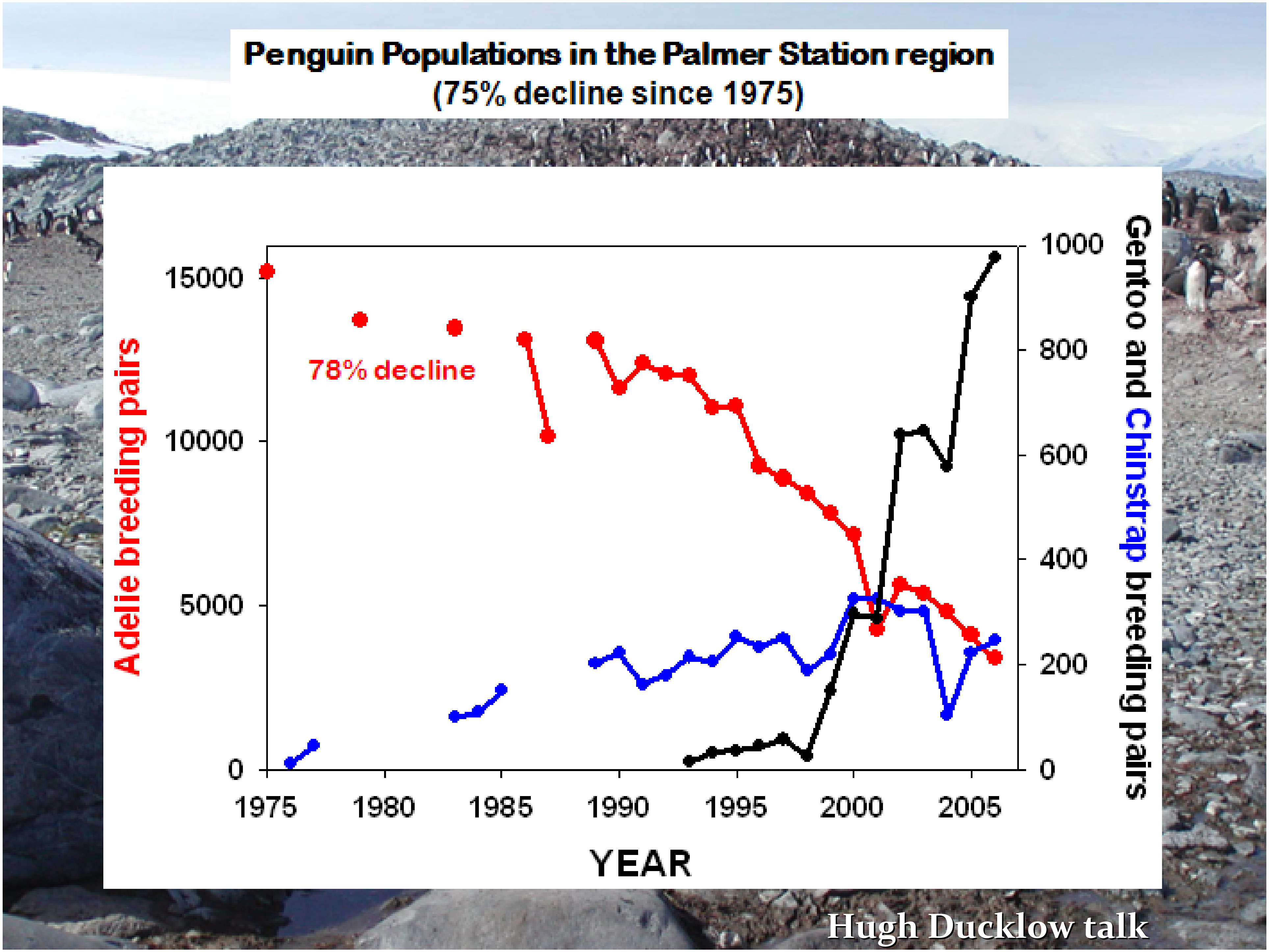
Marrari, Daly, & Hu 2008 DSR II 55

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

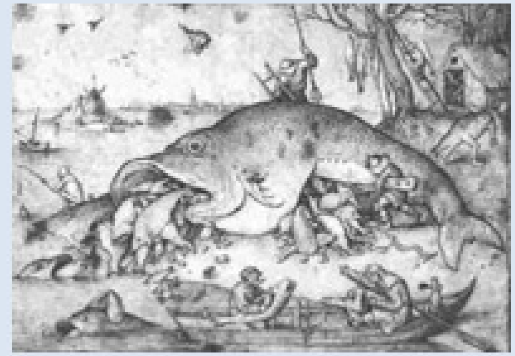


Atkinson et al. (2004)


Penguin Populations in the Palmer Station region
(75% decline since 1975)
78% decline
Adelie breeding pairs
Gentoo and Chinstrap breeding pairs
15000
10000
5000
0
1000
800
600
400
200
0
1975
1980
1985
1990
1995
2000
2005
YEAR
Hugh Ducklow talk

Top Down: Food Web Perturbations

What happened in the past?



Harvesting has generated massive perturbations over more than 2 centuries

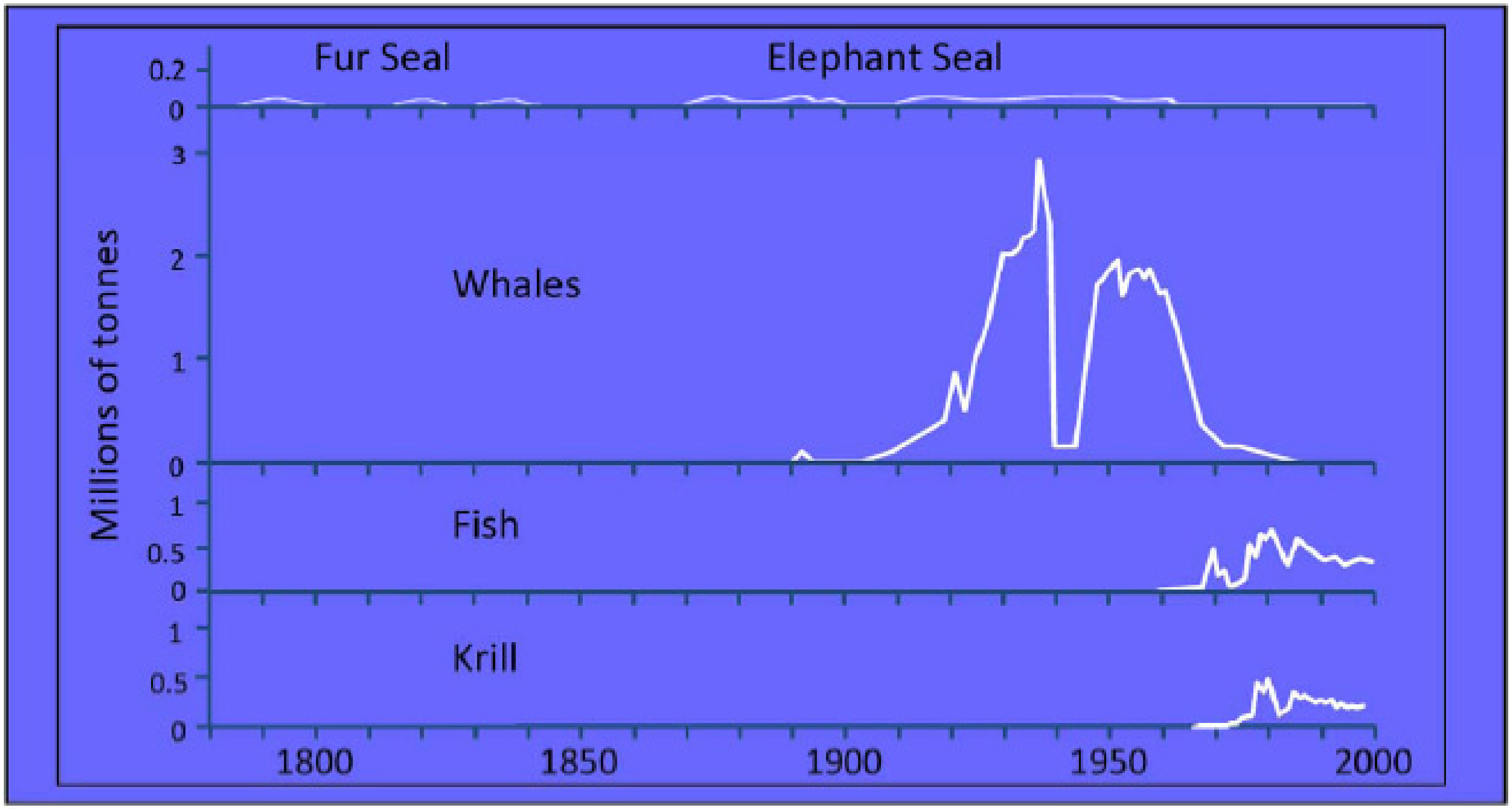
Fur-seals
From 1778; economic extinction within 35 years

Whales
1906 to 1966, residual thereafter

Fin-fish, krill
From late 1960s, continuing

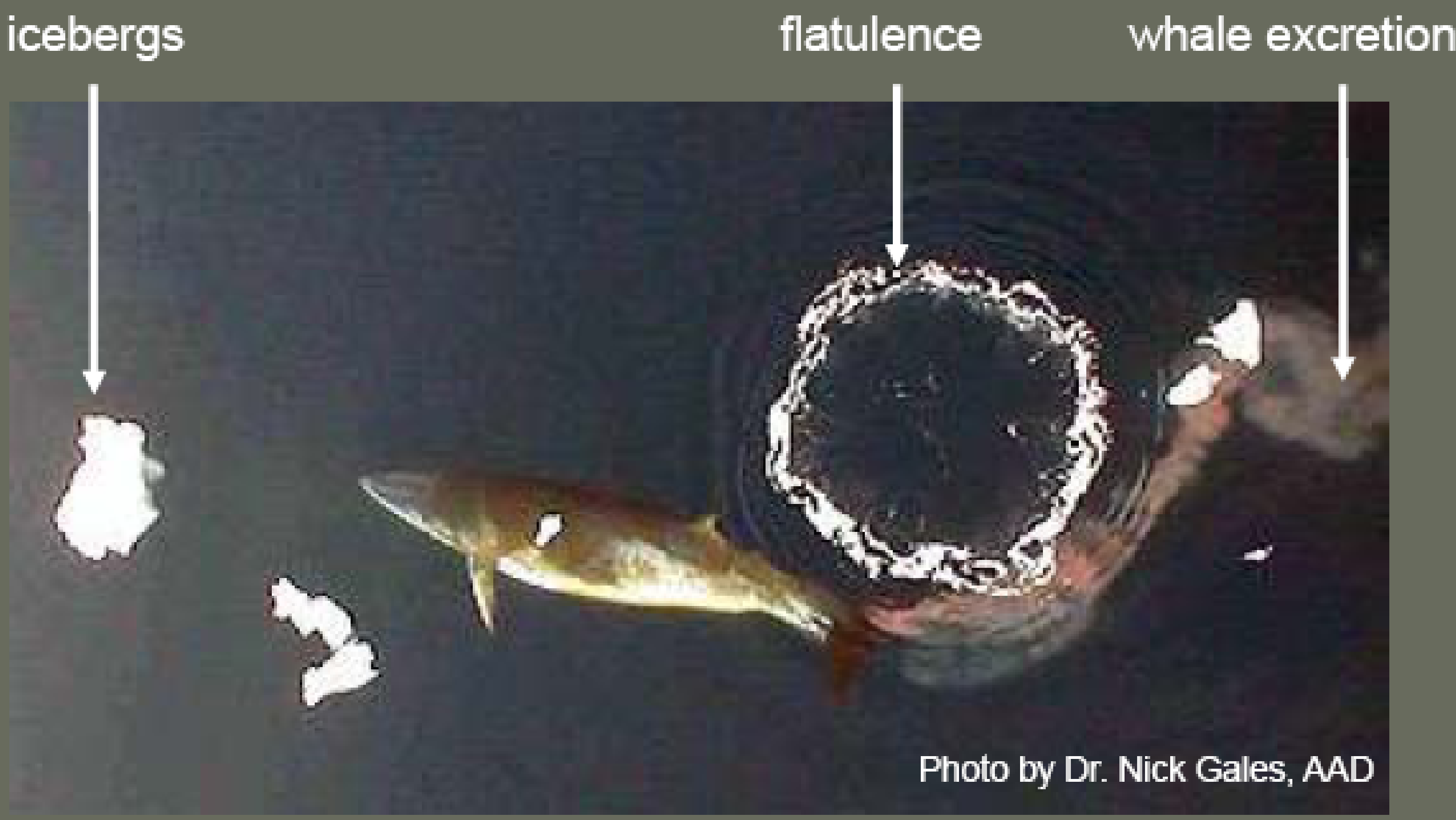
Top-down effects => Krill surplus?

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

Dan Costa talk

Faecal nutrient content

Krill, Salps, Cephalopods[4,5,6,7]

N = 20 mg g^{-1}

Fe = 1 mg g^{-1}

Consumes[8] 1 tonne d^{-1}

N = 20,000 g

Fe = 1,000 g

Excretes[9]

17,000 g N d^{-1}

850 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)

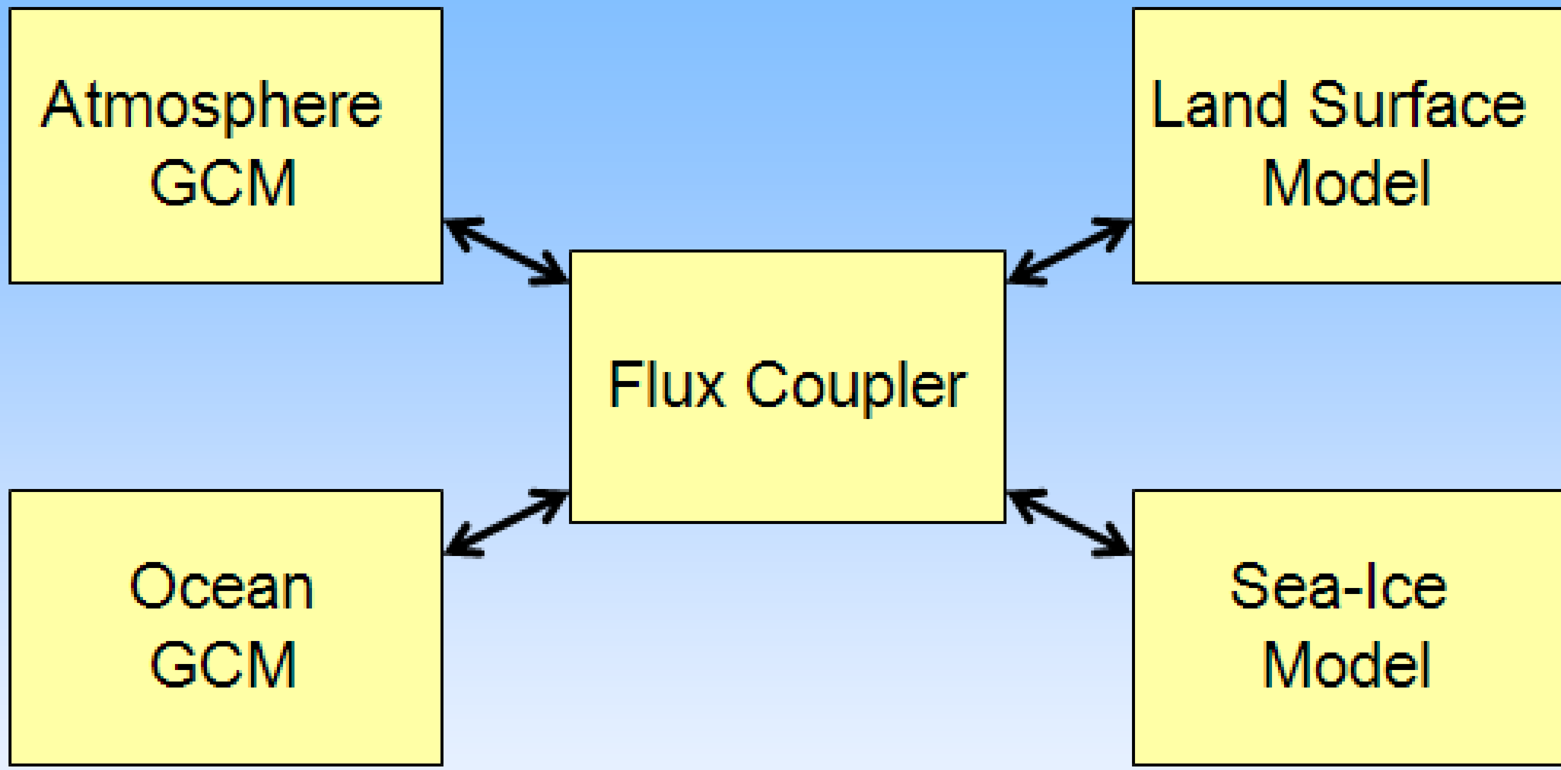
<u>In collaboration with:</u>

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

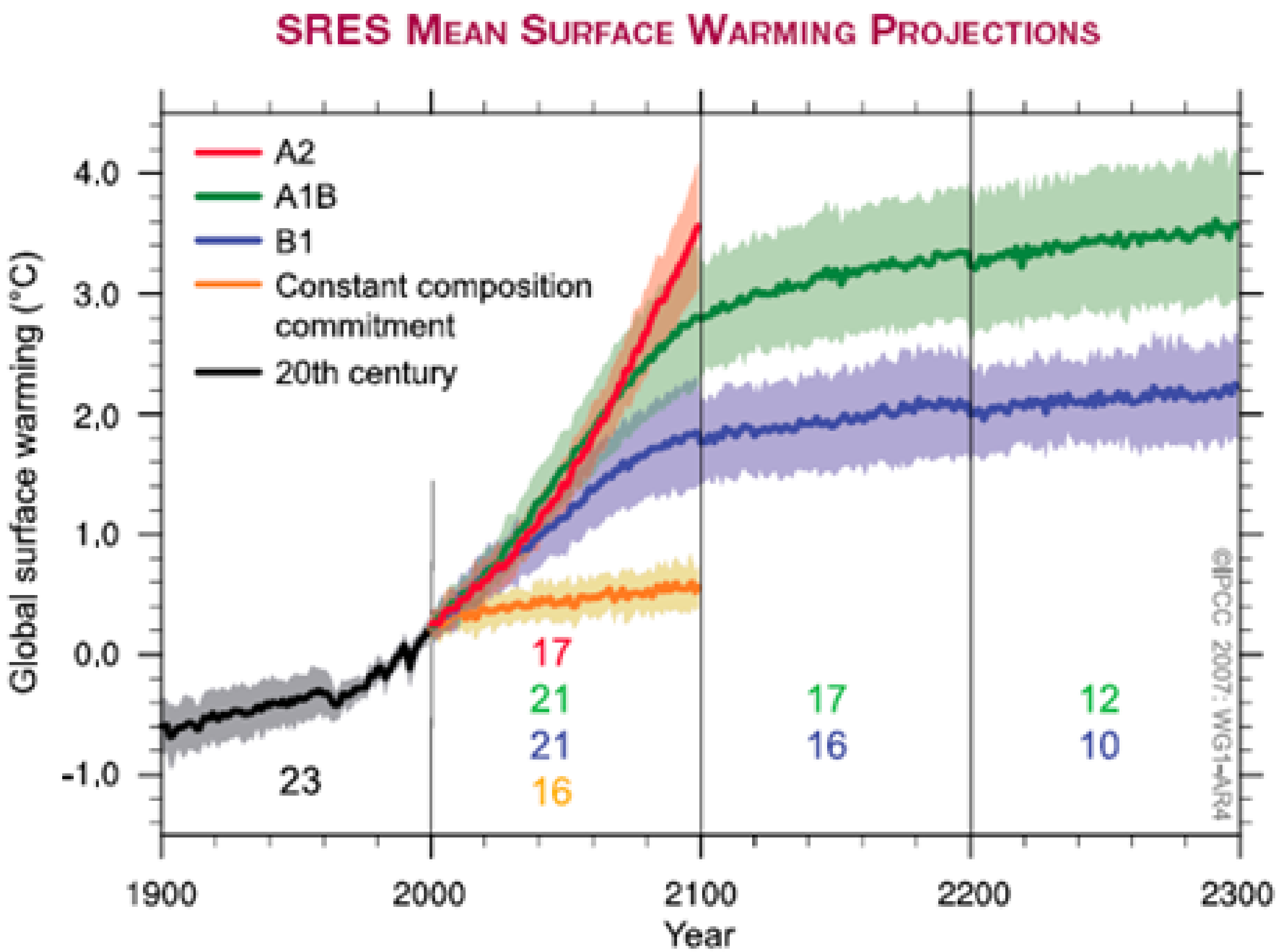
Ocean Carbon & Biogeochemistry

Supported by:

"IPCC-class" Coupled Climate Models



-energy and mass conserving
-internally driven climate variability
-external climate perturbations (e.g., fossil fuel CO_2)



Future Climate Projections

IPCC (2007)

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)

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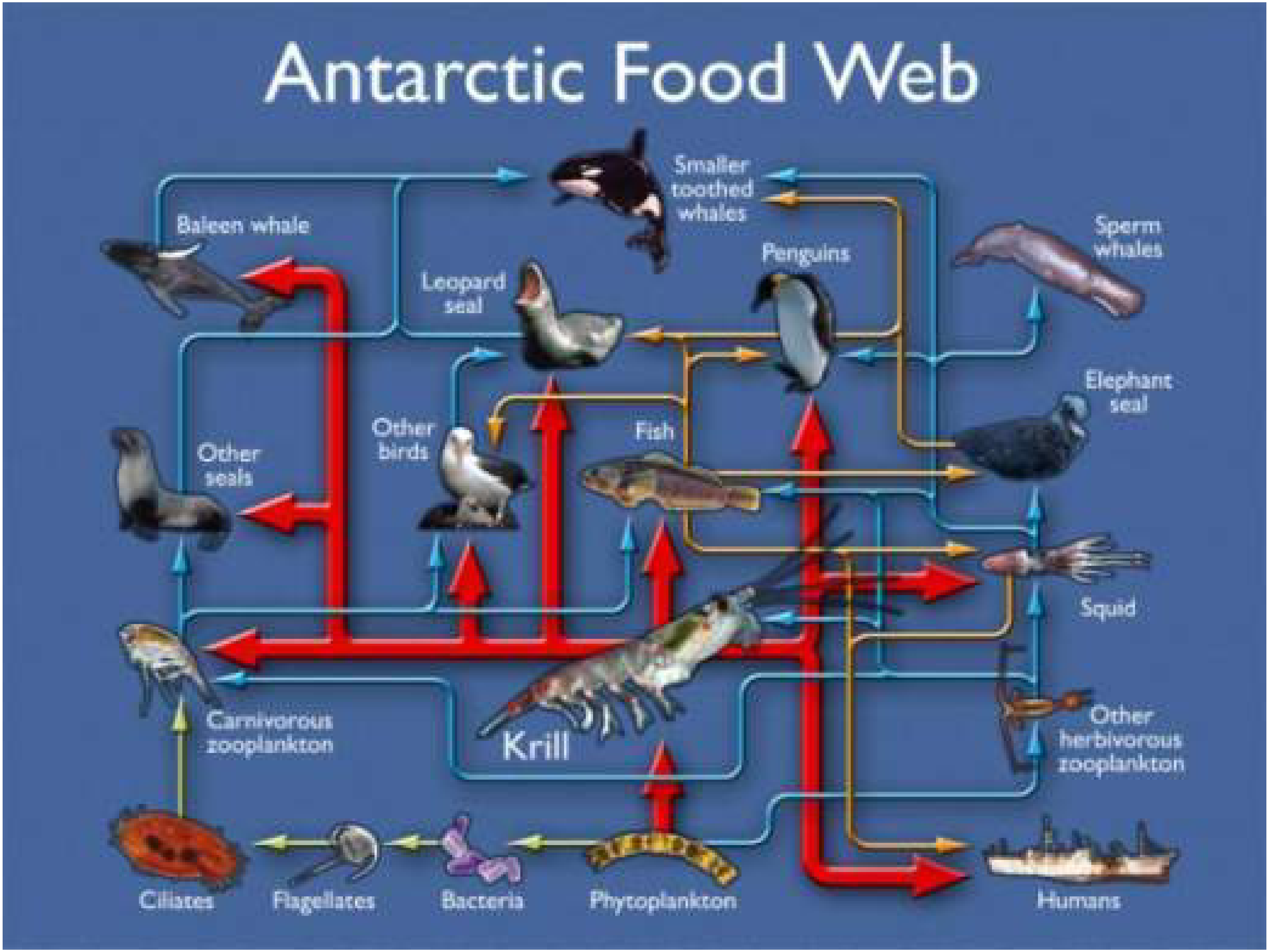
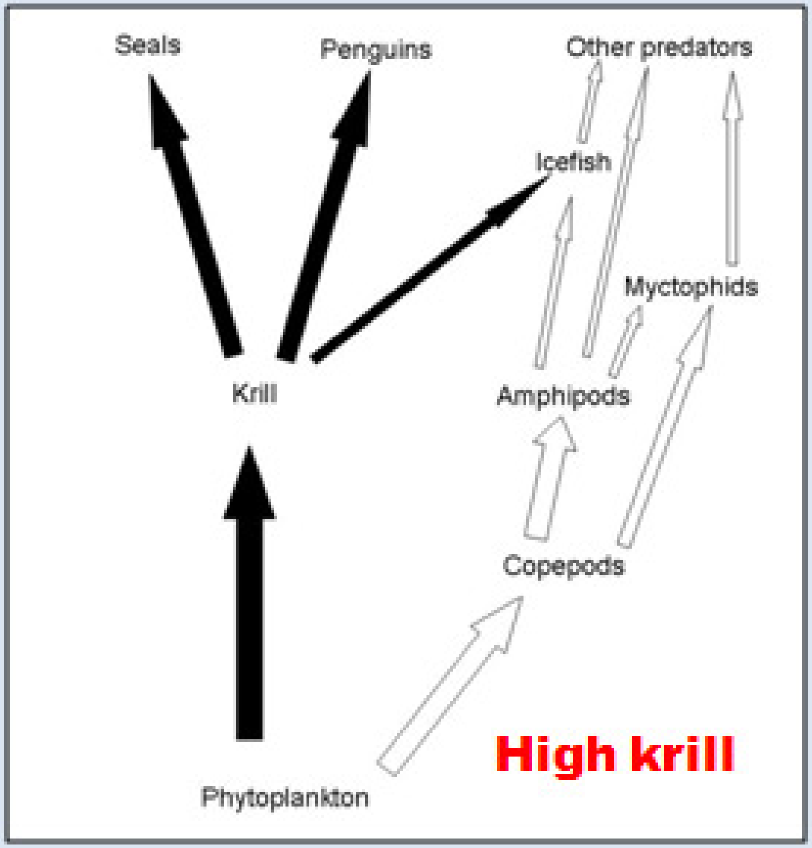
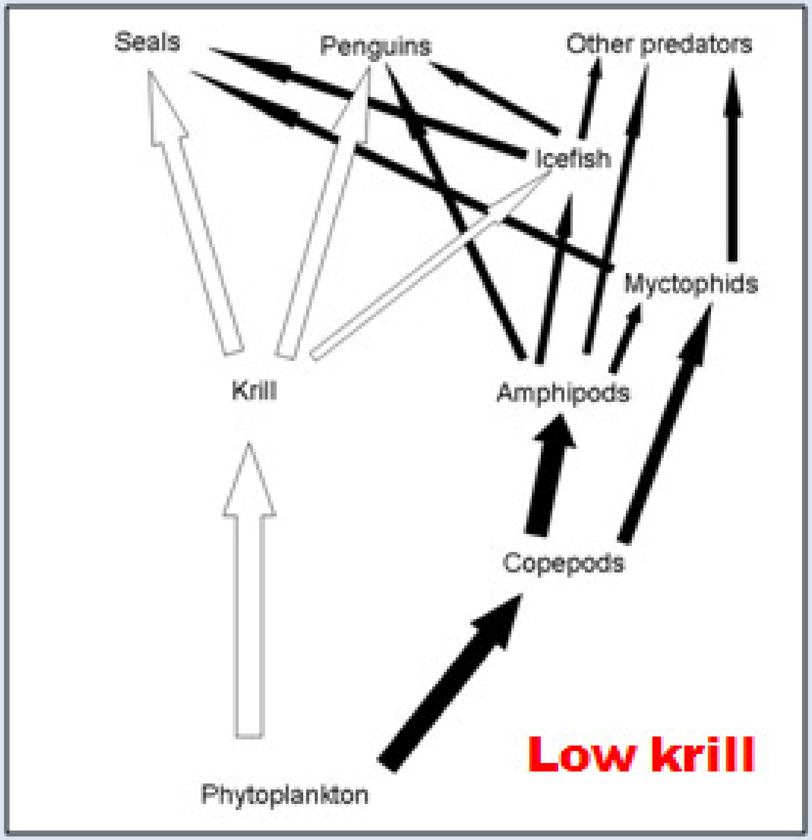
CENTER FOR COASTAL PHYSICAL OCEANOGRAPHY
OLD DOMINION UNIVERSITY



Antarctic Food Web
Smaller toothed whales
Baleen whale
Sperm whales
Penguins
Leopard seal
Elephant seal
Other birds
Fish
Other seals
Squid
Krill
Carnivorous zooplankton
Other herbivorous zooplankton
Ciliates
Flagellates
Bacteria
Phytoplankton
Humans

Alternative Food Web Pathways





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

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

(Gales)

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