

Climate Change & Marine Biogeochemical Modeling from Local to Global Scales

Scott Doney (WHOI & Palmer LTER)

NSF Forum: Understanding Climate Change Through Long-Term Ecological Research (March 2011)



Outline

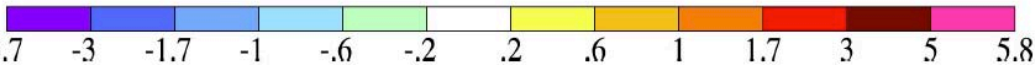
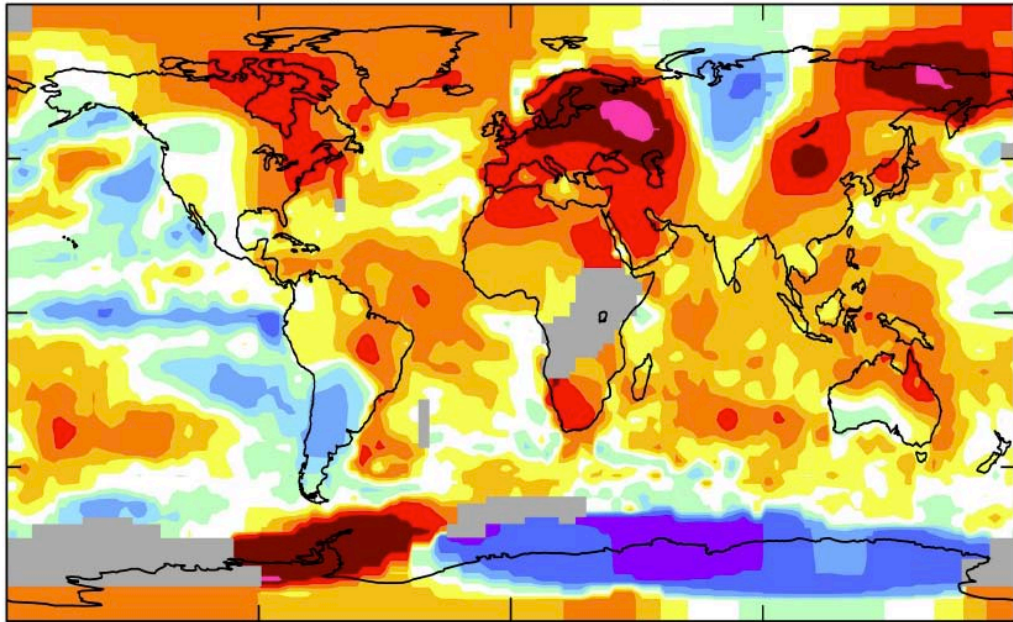
- Climate change trends on West Antarctic Peninsula (WAP)
- Local & regional food-web impacts
- Global primary production & plankton community structure trends

Climate Trends along Western Antarctic Peninsula

July 2010 Surface Temperature Anomaly ($^{\circ}\text{C}$)

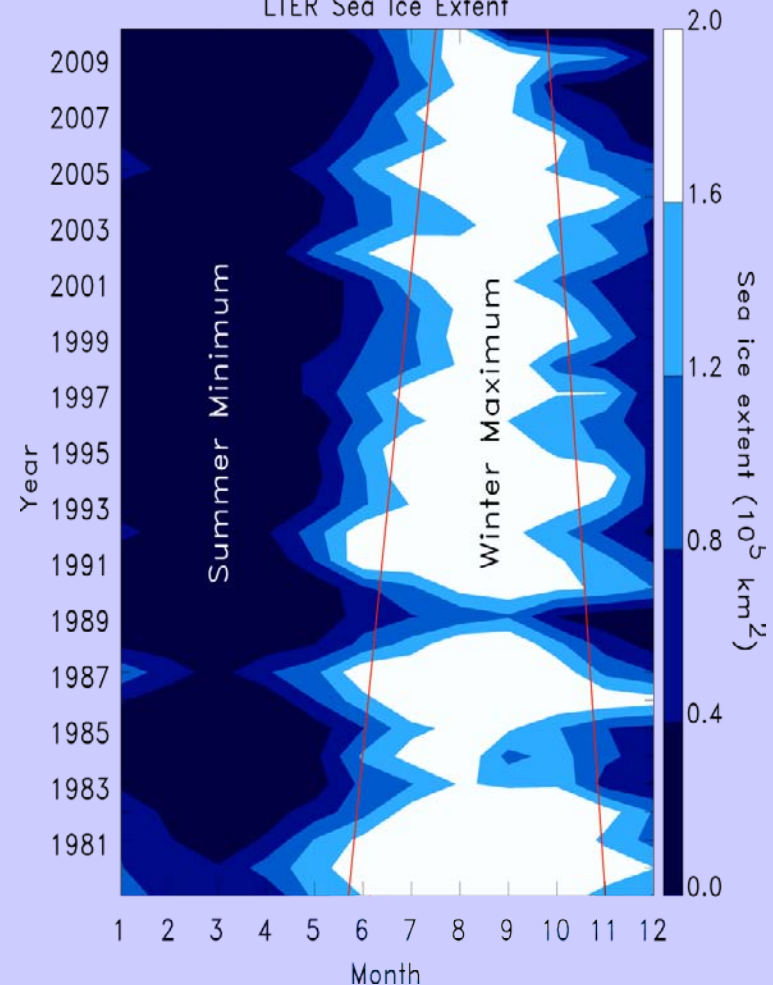
[Base Period: 1951-1980]

.55

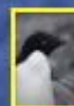


- Rapid warming along WAP
~5x global average
- Reduced sea-ice cover & expanding seasonal ice free conditions

LTER Sea Ice Extent



Palmer LTER Study Region along the WAP: 300 x 700 km: Process Studies Embedded in a Long-Term Observational Context



Sediment Trap

Palmer Station (US)

Anvers Island

LTER local Time series
Semi-weekly, Oct -April

Rothera Base (UK)

Avian Island

BAS RaTS Local Time Series
Weekly, year-round

Charcot Island

● Annual Hydrographic Survey

● (CTD-Rosette, Net Tows)

● Thermistor Moorings

Adélie Penguin Colonies

Process Studies

SLOCUM Glider Base

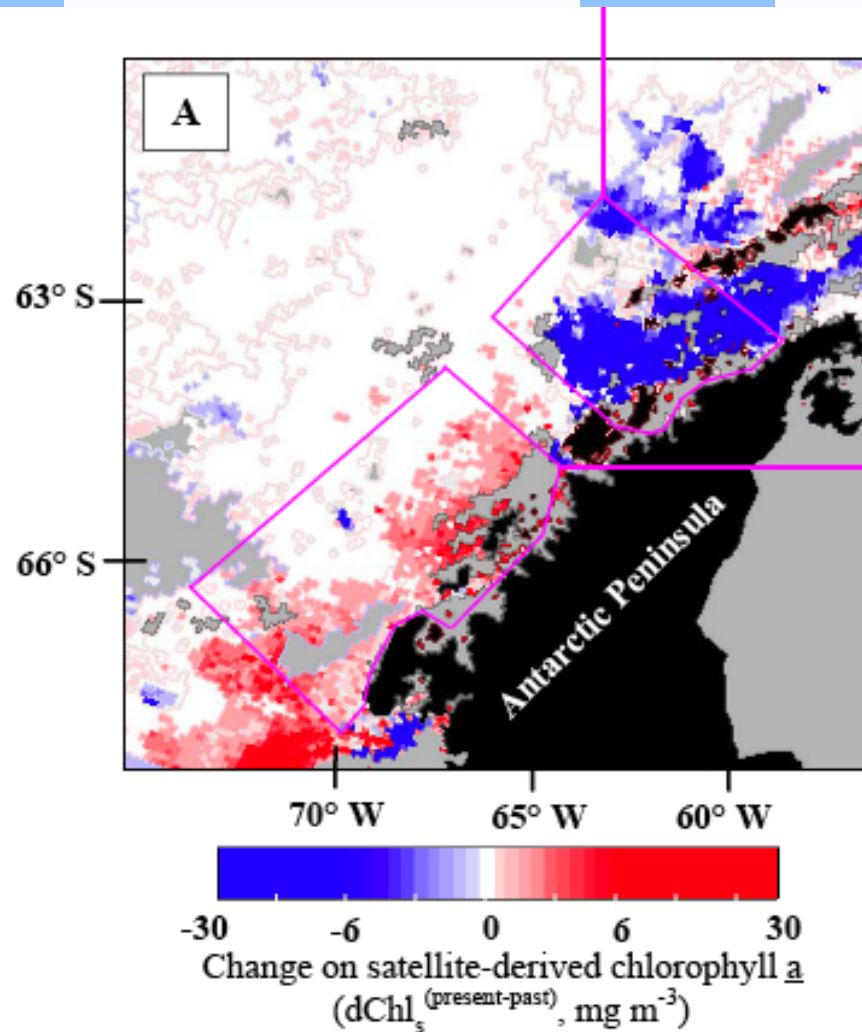
Canyons & Deepes

Satellite remote sensing
ocean color (chlorophyll)
surface temperature
sea ice, 1978-present

Antarctic Peninsula

Ecological Responses to Retreating Sea-Ice

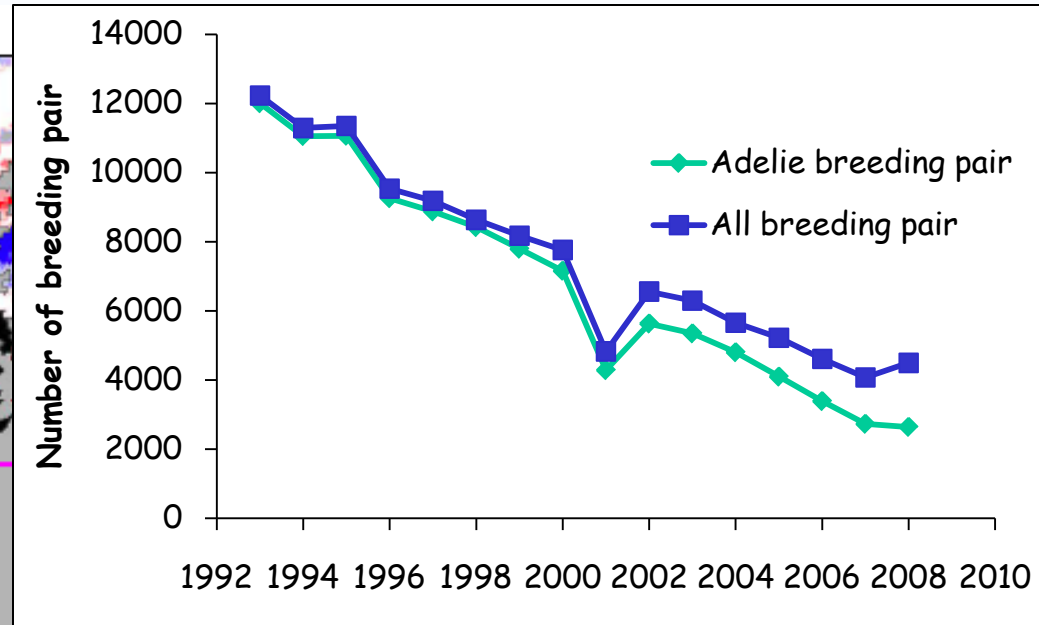
Decadal Change in Surface Chlorophyll



Montes et al. Science (2009)

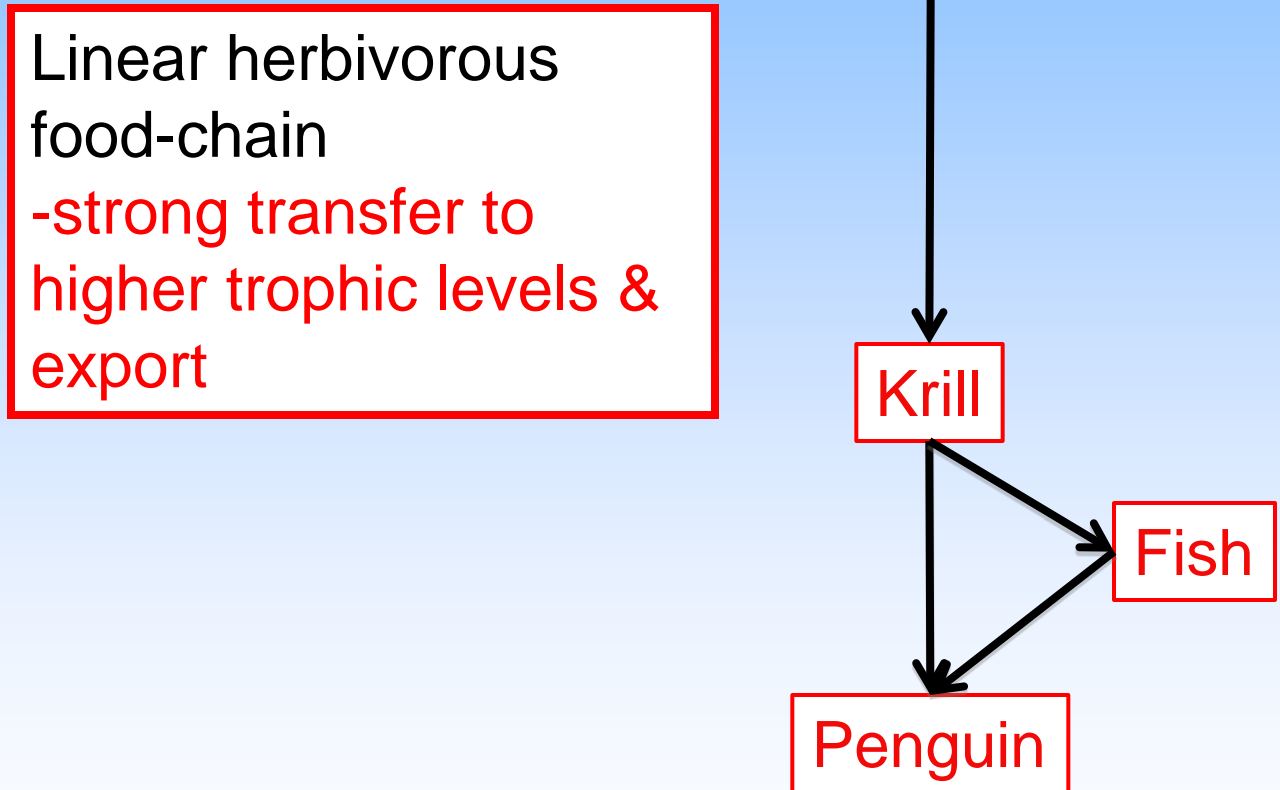
Penguin Populations near Palmer Station

Adélies declining, Gentoos and Chinstraps invading and increasing

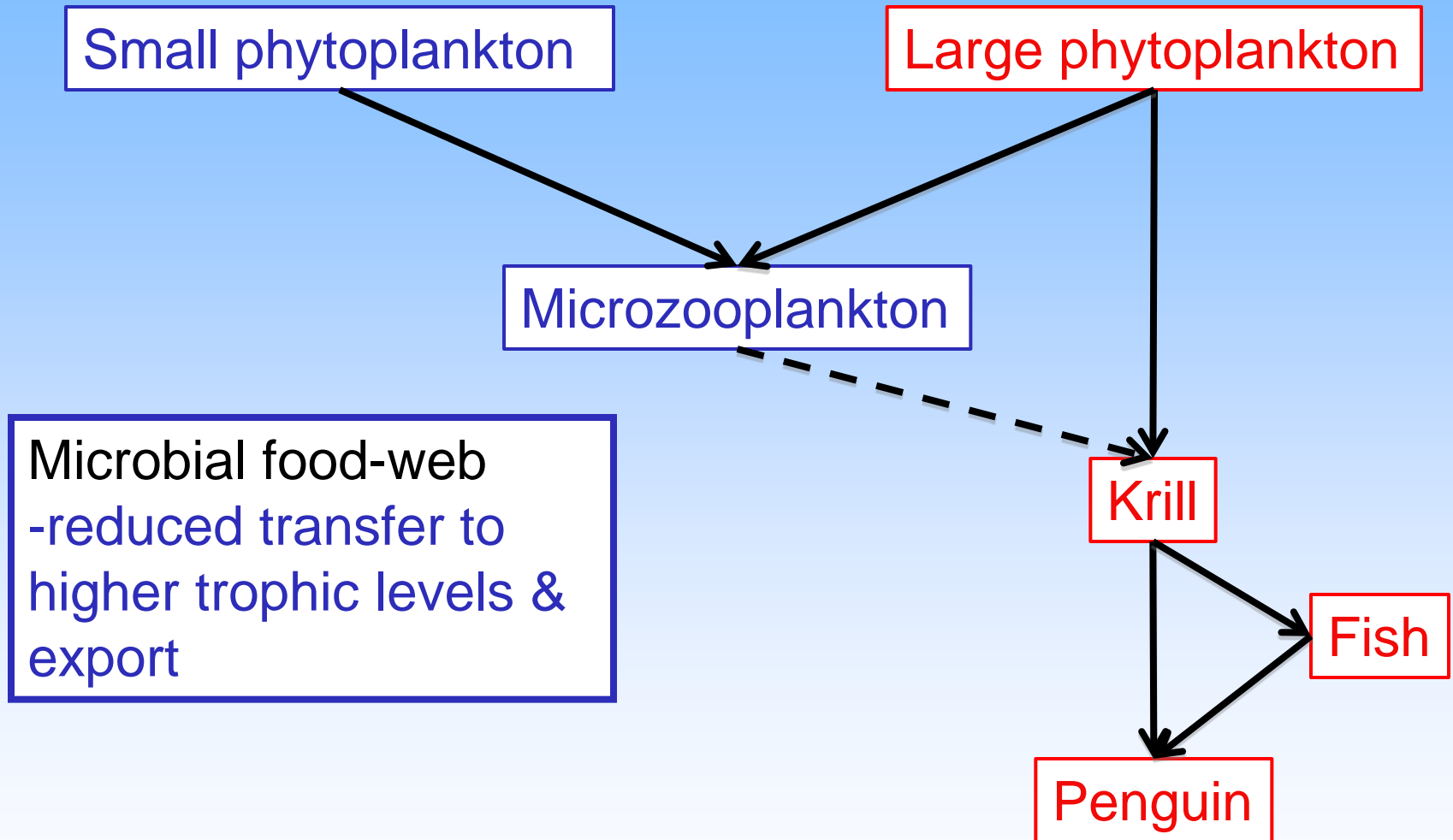


Bill Fraser

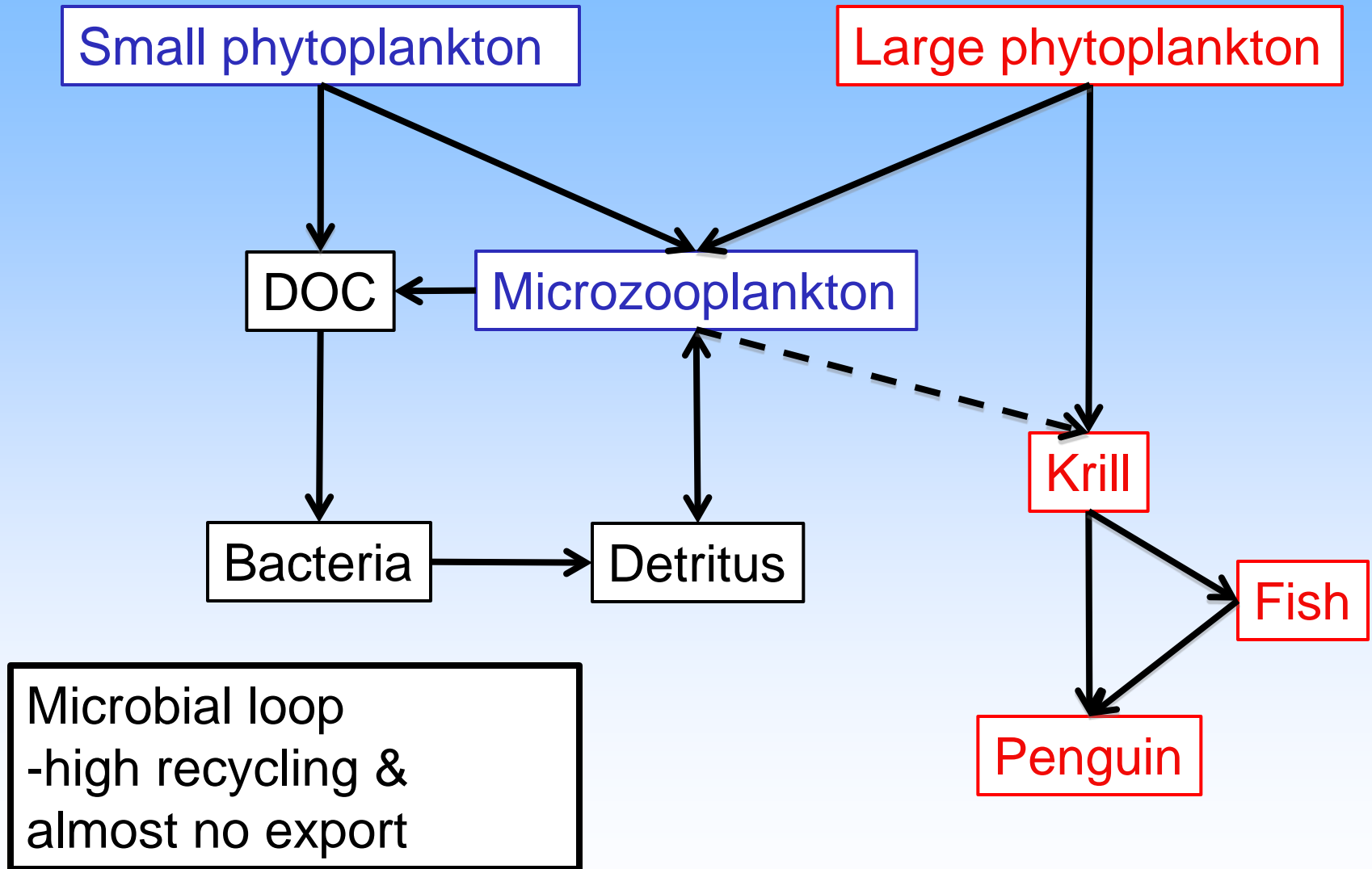
Inverse Model of WAP Food Web



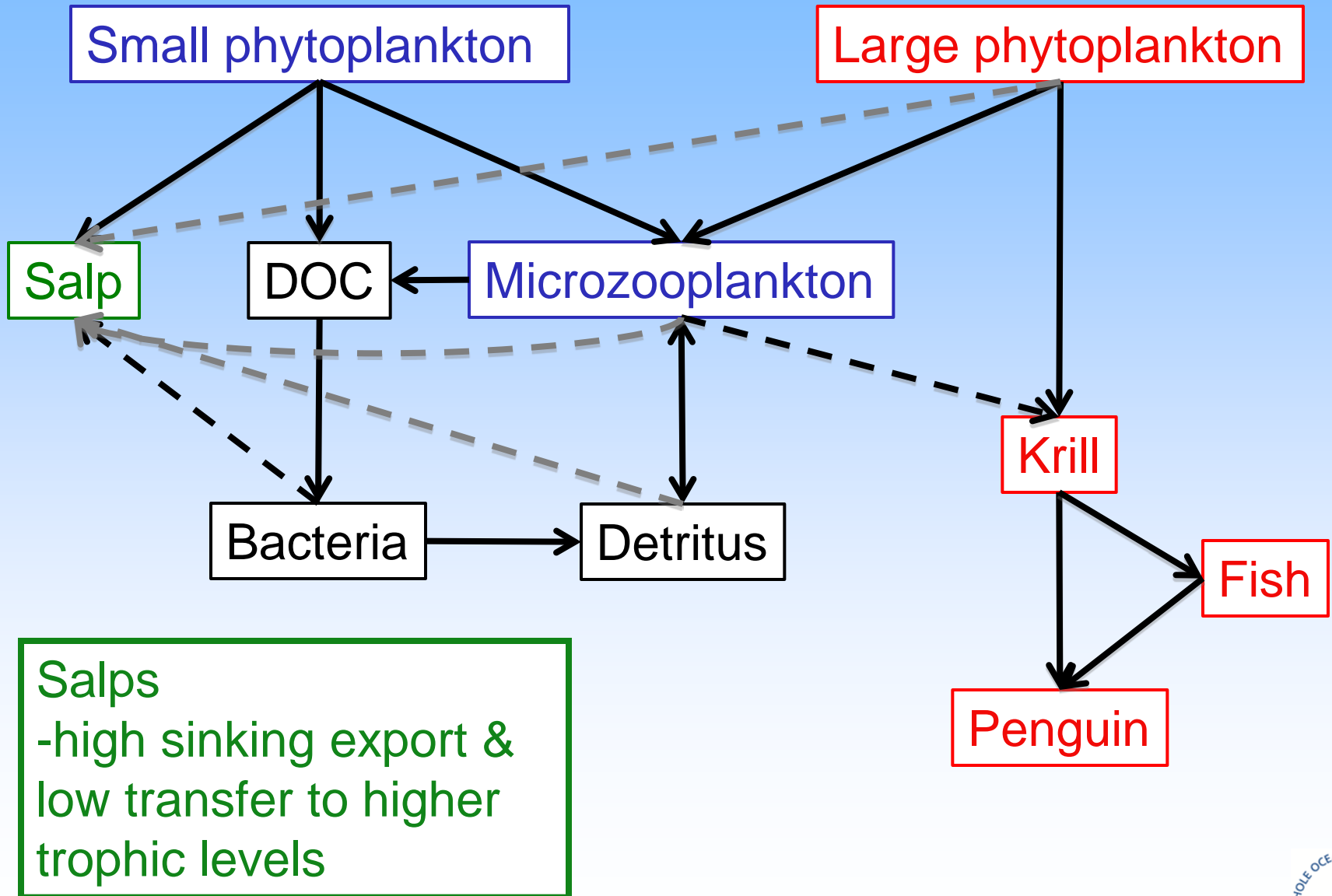
Inverse Model of WAP Food Web



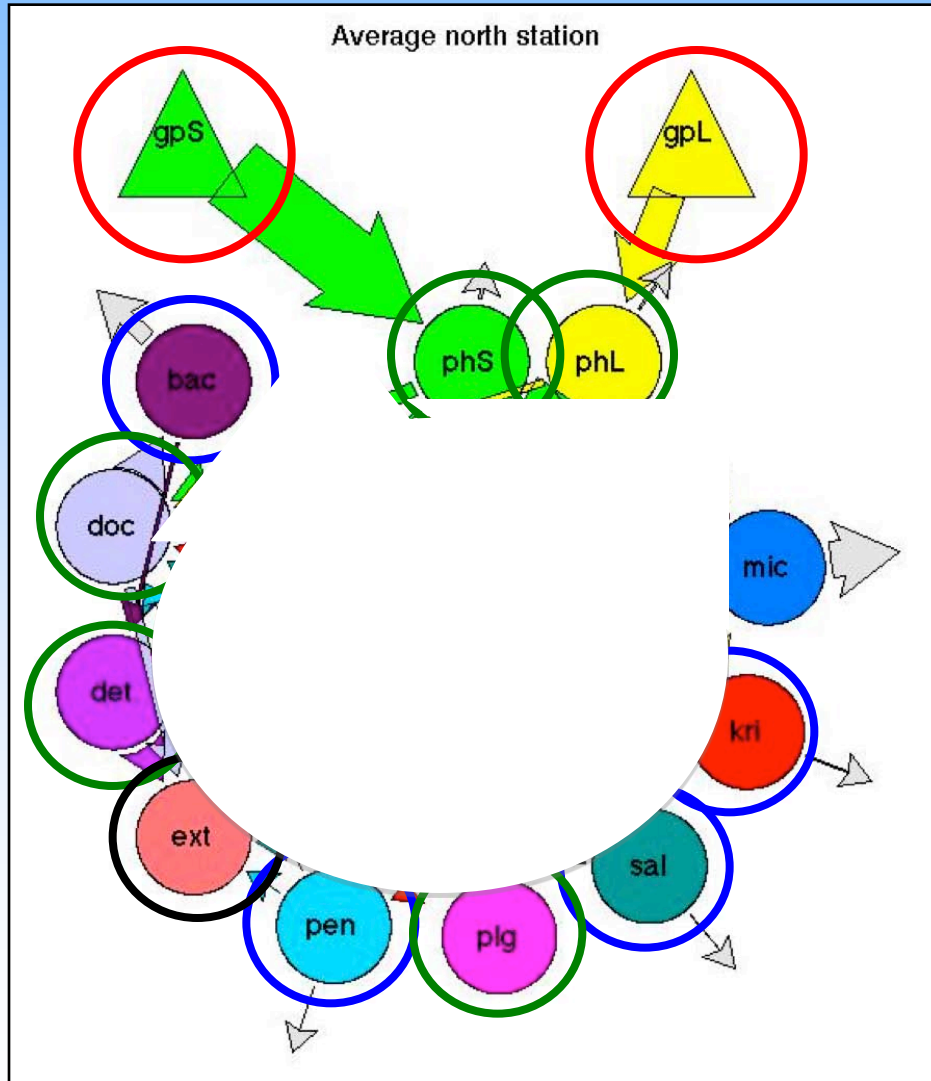
Inverse Model of WAP Food Web



Inverse Model of WAP Food Web



Inverse Model: example of a solved system



Primary production, input

Constrained compartment

Constrained through other compartment

Model estimated flows, export & respiration

Legend

gpS: primary production small, phS:
phytoplankton small, gpL: primary production
large, phL: phytoplankton large, mic:
microzooplankton, kri: krill, sal: salp, plg: fish
(pleuragramma sp.), pen: penguin (Adelie sp.),
ext: export, det: detritus, doc: DOC, bac:
bacteria

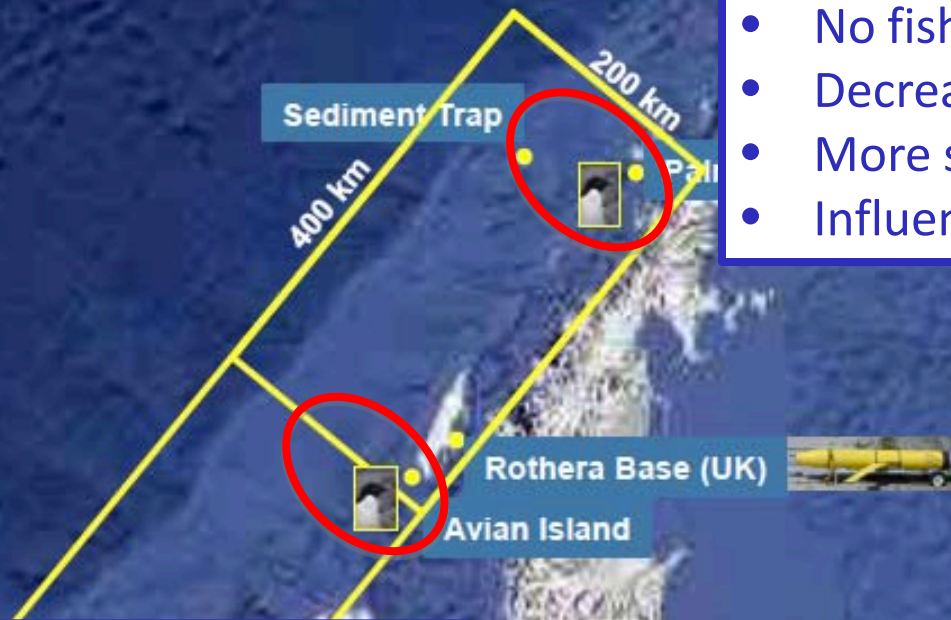
Palmer LTER Study Region along the WAP





North

- No fish in penguin diet
- Decreased penguin population
- More salps
- Influenced earlier by warming

South

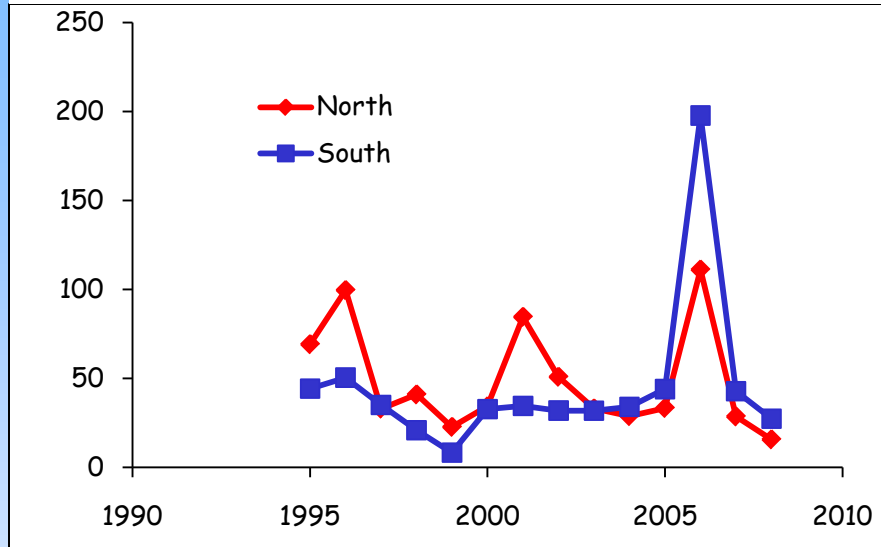
- Increased primary production
- Fish as part of penguin diet
- Probably in the state the north was 10-20 years ago



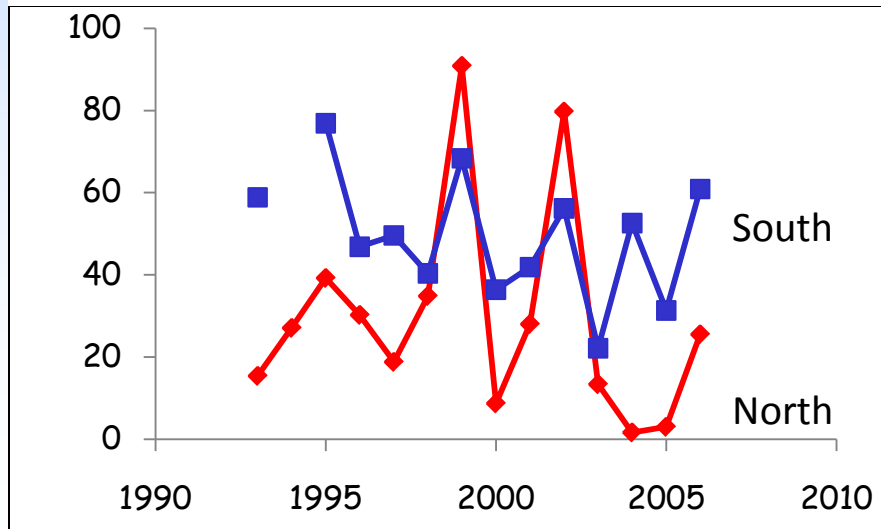
-  Hydrographic Grid
-  Adélie Penguin Colonies
-  Process Study Sites
-  Slocum Glider Base

Observed Trends

Primary Production ($\text{mmolC m}^{-2} \text{d}^{-1}$)

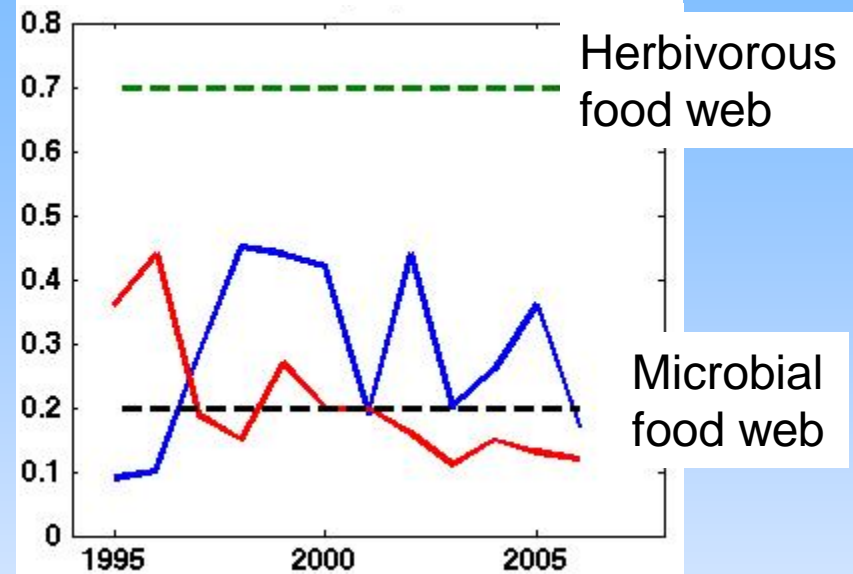


Phytoplankton structure (% large cells)

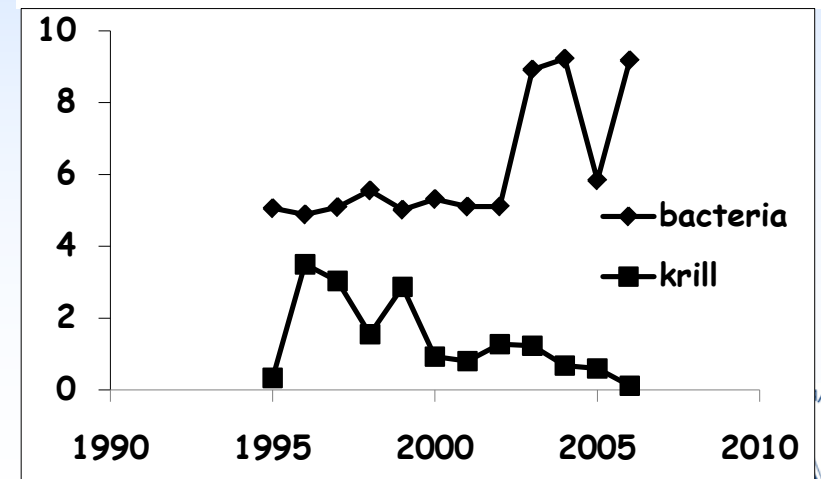


Model Estimates

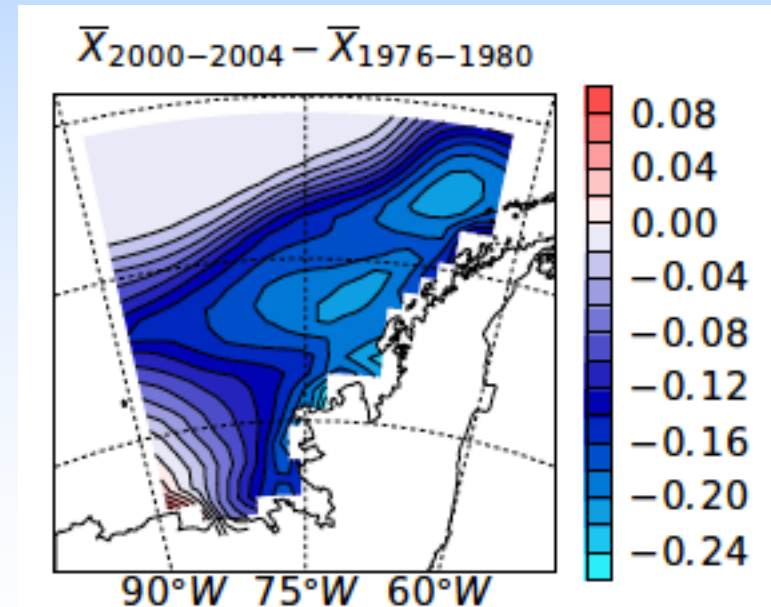
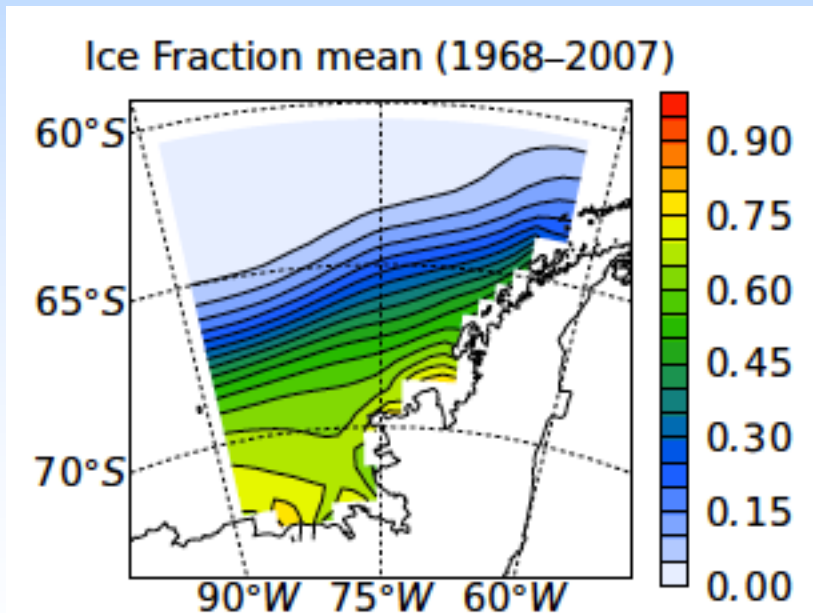
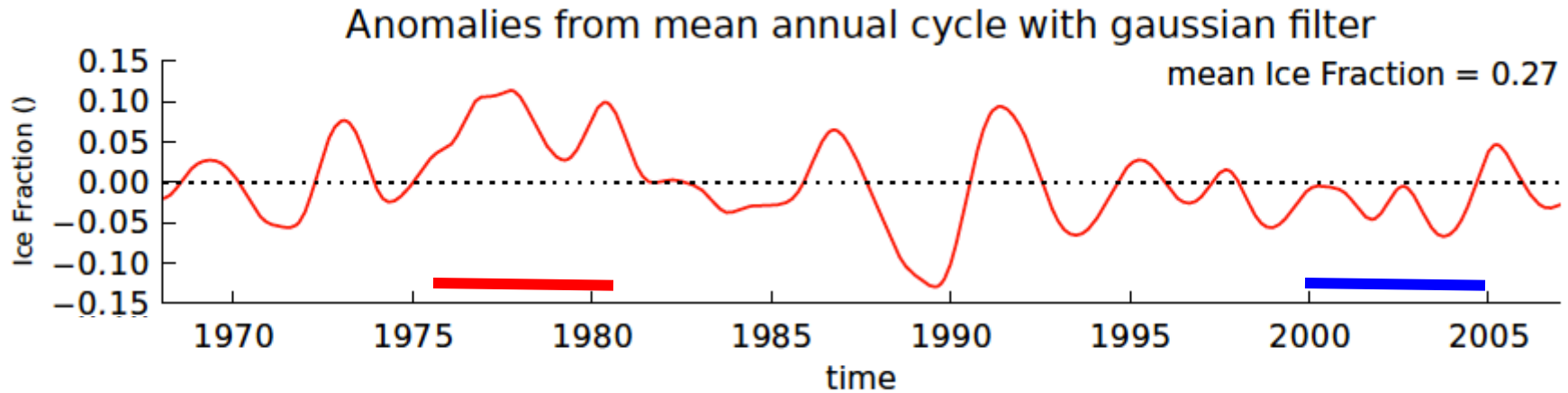
Export Ratio



Transfer from compartment as % primary production at North station



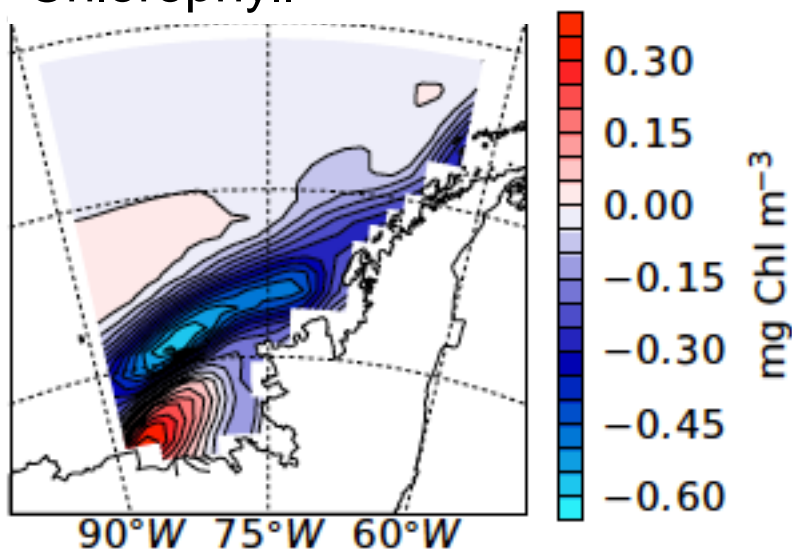
Ocean-Ice Hindcast Simulation (CESM1)



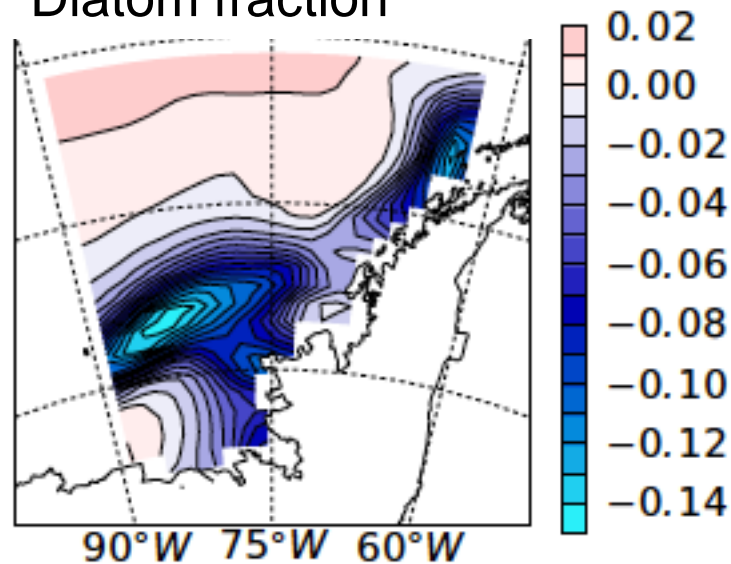
Global NCAR CESM1 forced with NCEP Reanalysis & Satellite data

Biogeochemical Impacts of Ice Retreat

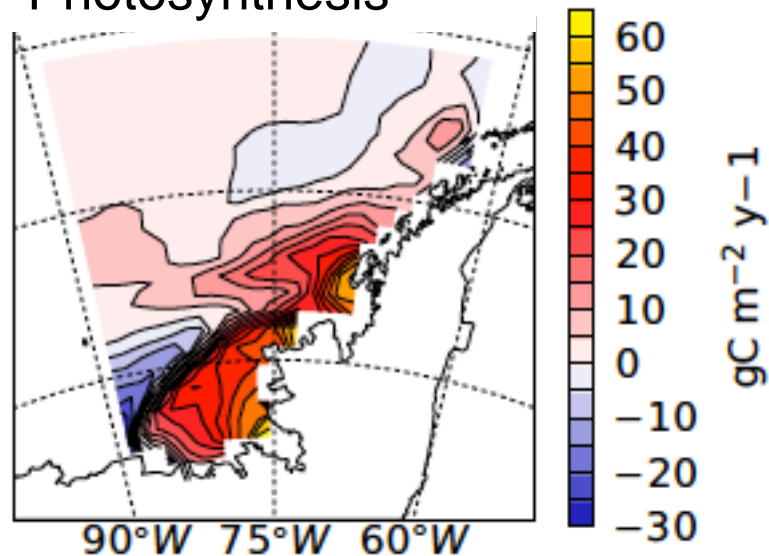
Chlorophyll



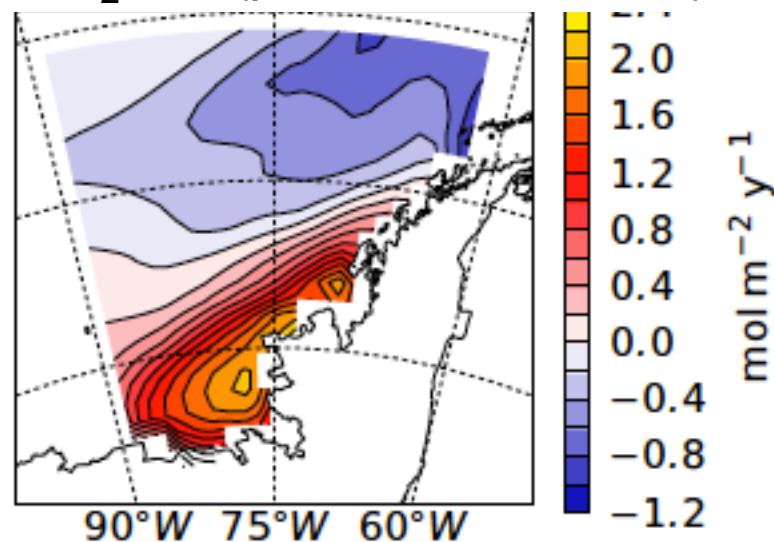
Diatom fraction



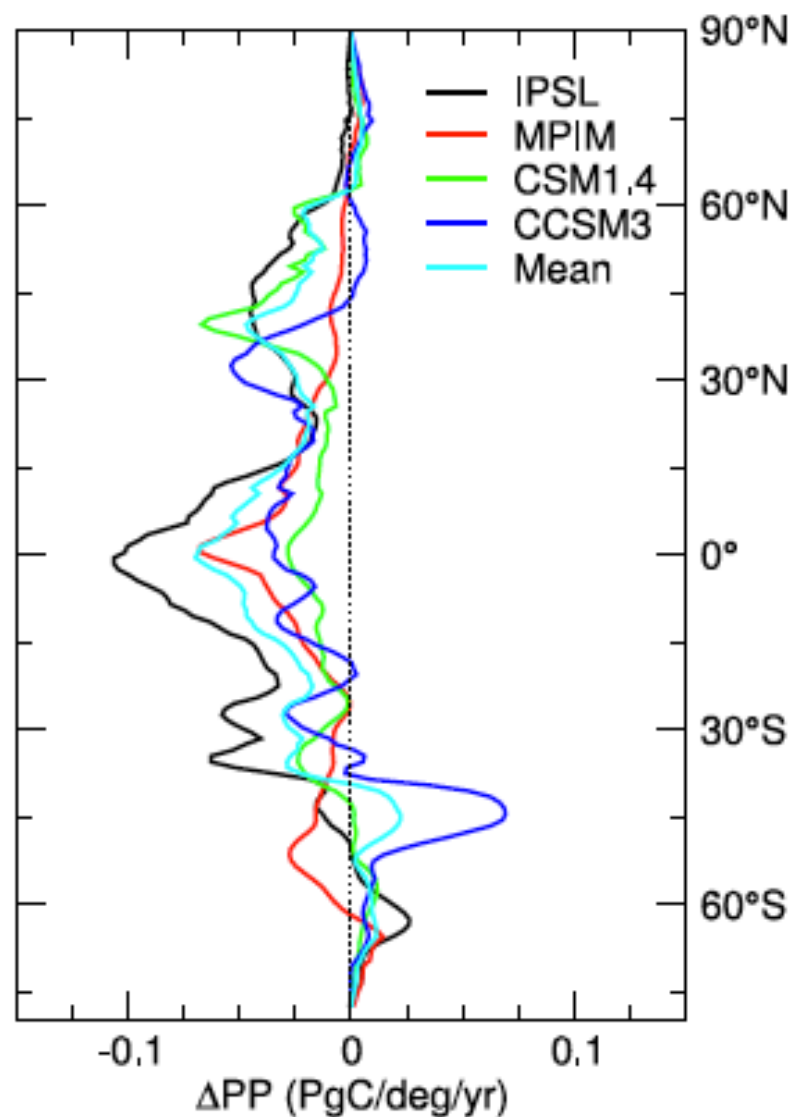
Photosynthesis



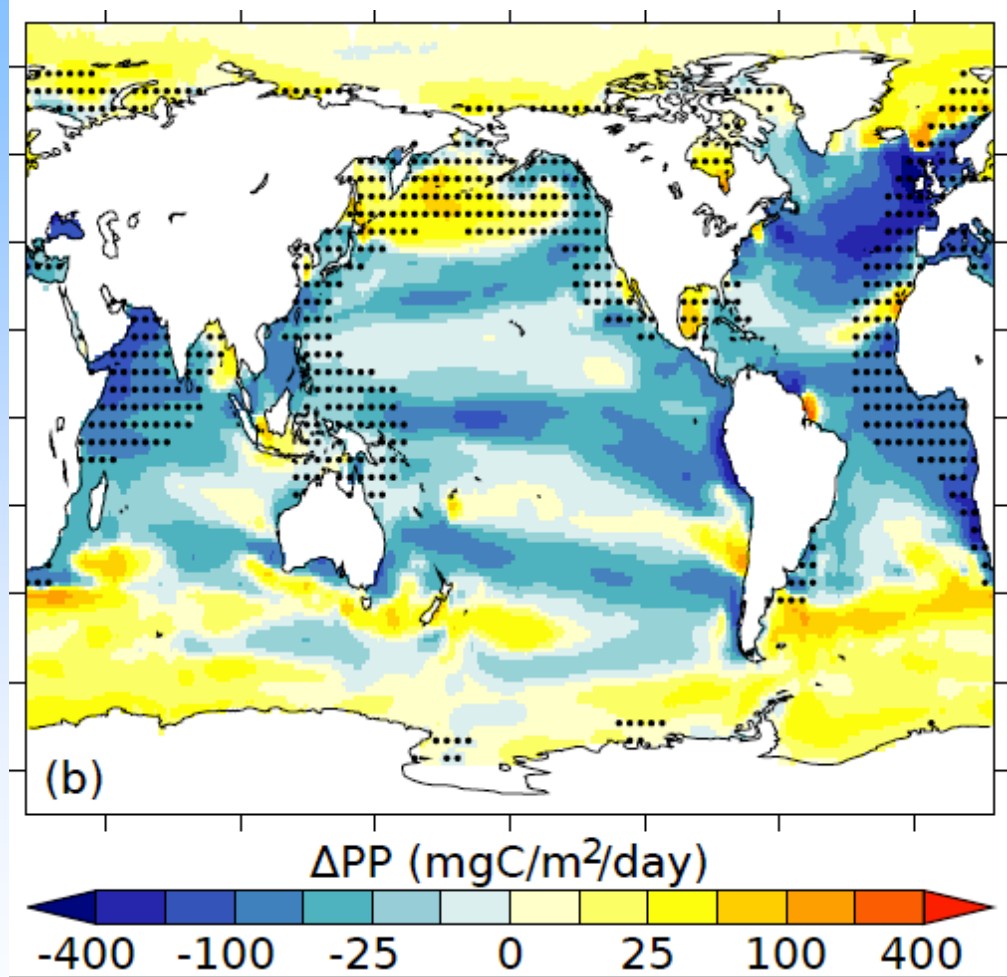
CO₂ flux (positive into ocean)



21st Century Change in zonal integrated primary production

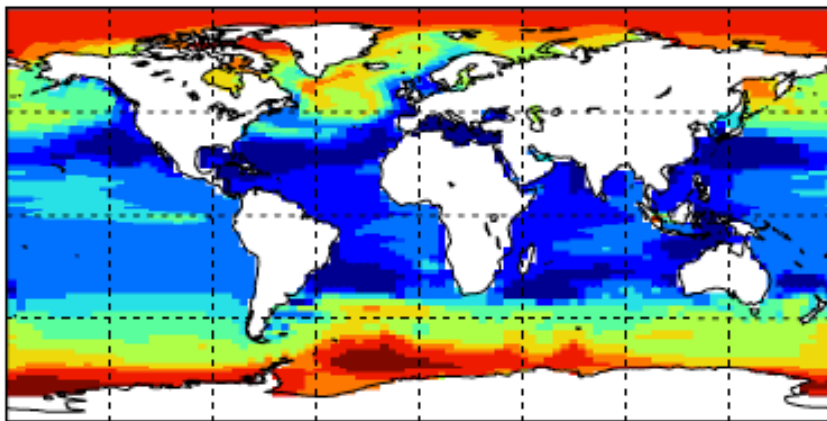


Spatial patterns from multi-model ensemble (stippled regions of large contemporary errors)

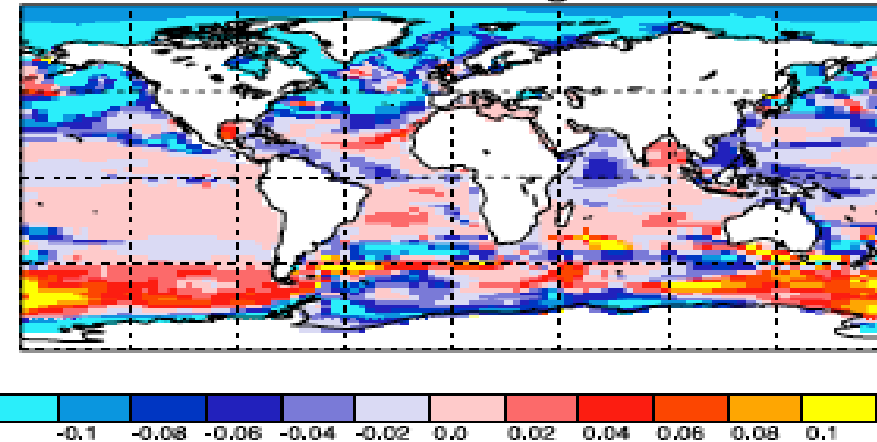


Phytoplankton Community Structure

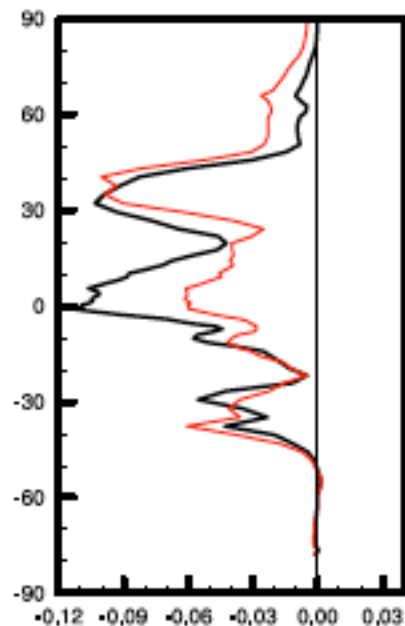
Diatom relative abundance



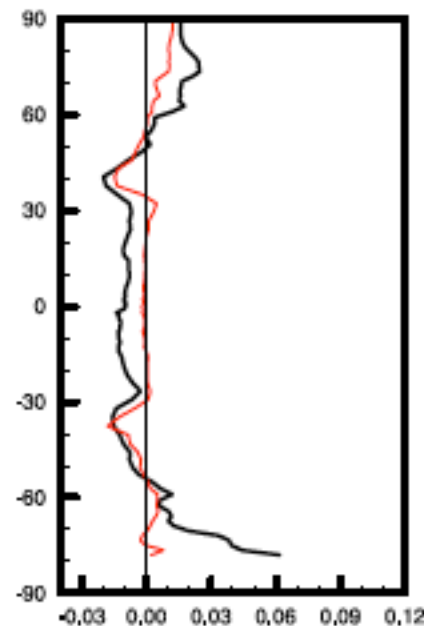
h. Rel. Abundance change



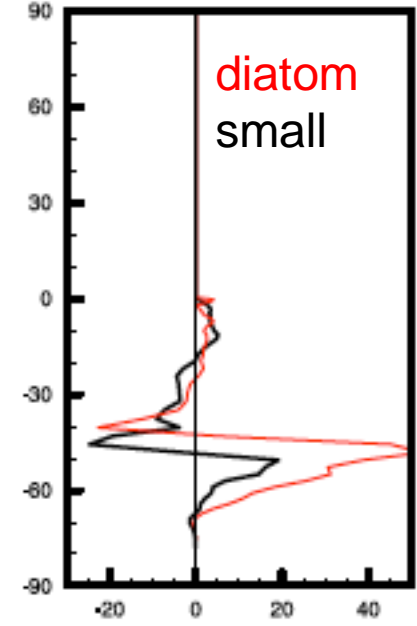
Changes in temperature, nutrients, light & transport => shifts in relative abundance of diatoms to small phytoplankton (critical nutrient hypothesis)



c. $\Delta\mu$: nutrient contrib



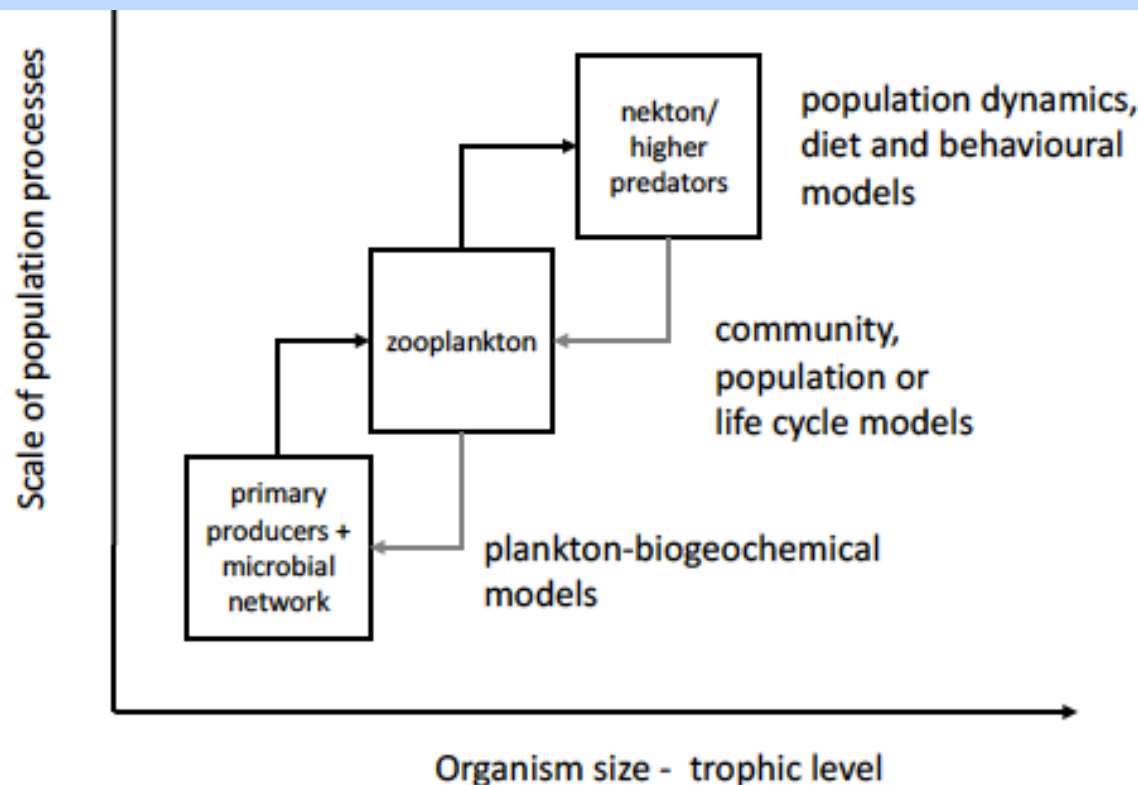
d. $\Delta\mu$: light contrib



f. Δ Biomass transp

Conclusions & Future Directions

- Rapid regional warming along Antarctic Peninsula driven by interactions with winds & ACC (upwelling)
- Marine & terrestrial ecosystems responding at all trophic levels
- Impacts on key biogeochemical process: productivity, plankton composition, export & air-sea CO₂ flux
- Lessons applicable to regional & global questions



-Advances or delays in life cycle, disrupting phenological coupling between trophic levels

Murphy et al. *Prog. Oceanogr.* Submitted
ICED Southern Ocean Food Web Modeling Workshop

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Acknowledgements

WHOI Modeling Group:

S. Sailley, I. Lima, I. Marinov (U. Penn) & H. Moeller (Stanford)

Palmer Team:

H. Ducklow, B. Fraser, D. Martinson, O. Schofield, S. Stammerjohn, D. Steinberg, K. Baker; other past & present members

Community Climate/Earth System Model:

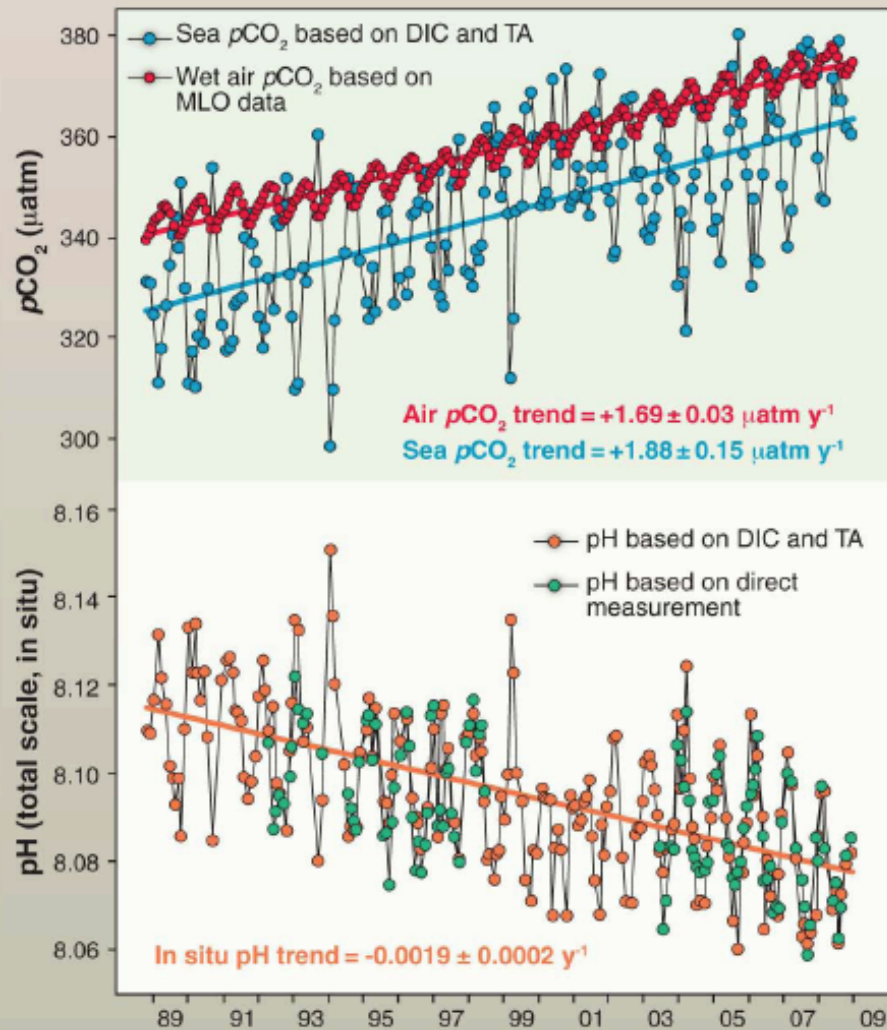
Keith Lindsay, Keith Moore & BGC Working Group

NSF & NCAR

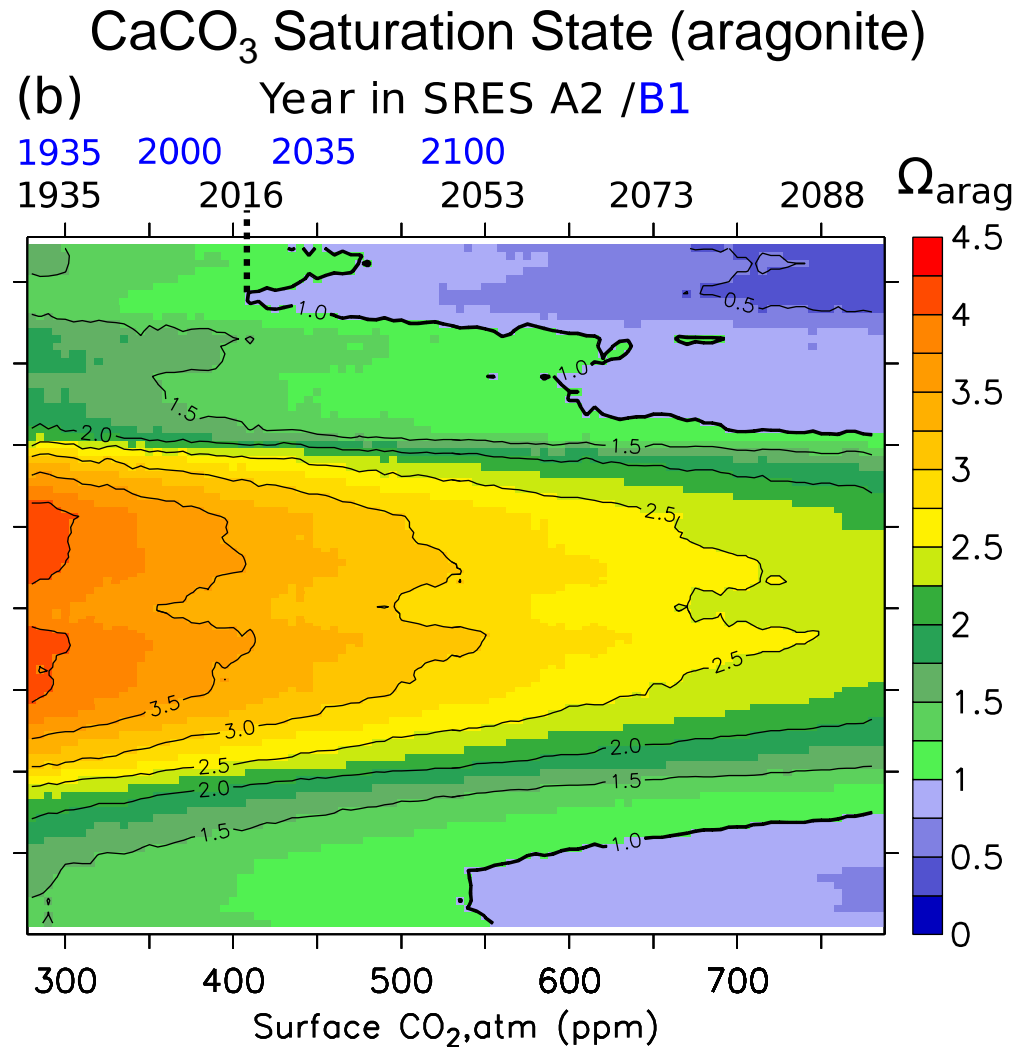
(funding & computer time)



Ocean Acidification

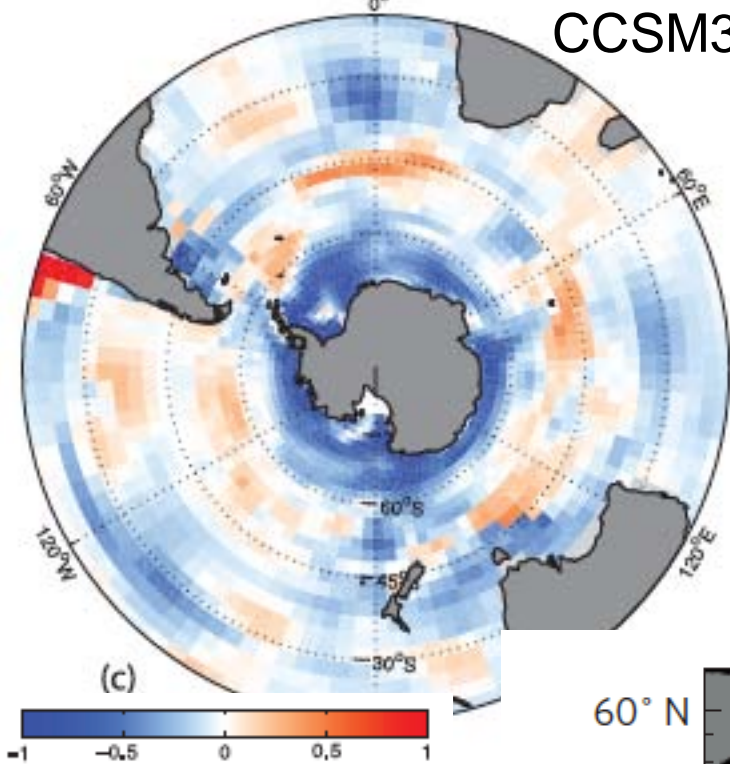


-Rising CO_2 ; declining pH & CaCO_3 saturation state
 -Polar waters undersaturated for aragonite by mid-century



Doney et al. *Ann. Rev. Mar. Sci.* 2009
 Dore et al. *PNAS* 2009; Steinacher et al. *Biogeosciences* 2009

Contemporary $\Delta p\text{CO}_2$ Model
CCSM3



Lovenduski, Gruber
& Doney *Global
Biogeochem.
Cycles* (2008)

Le Quere et al. *Nature
Geosciences* (2009)

Sea-Air $p\text{CO}_2$ Trends

- Rising atmospheric anthropogenic CO_2
- Stronger westerly wind stress & upwelling
- Positive sea-air $p\text{CO}_2$
=> weaker CO_2 uptake

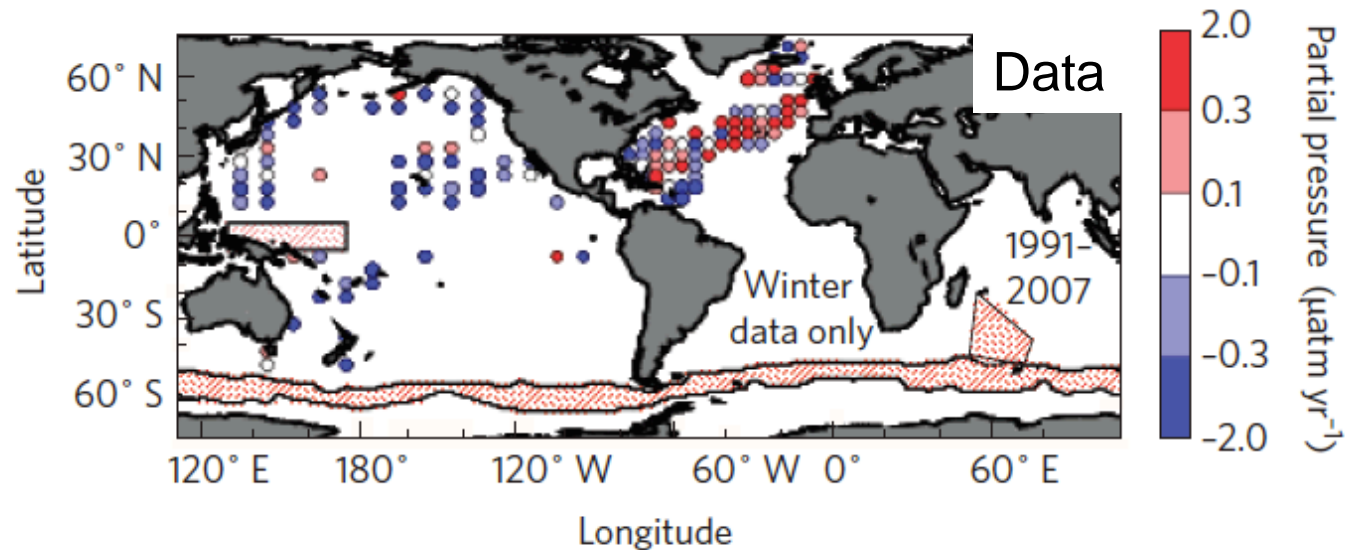


Figure 3 | Trends in the observed partial pressure of CO_2 for ocean minus air, for 1981-2007. The observed trends are calculated by fitting a

Inverse Model of WAP Food-Web

Topological food web

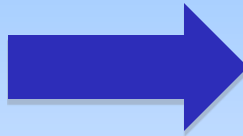
- “who eats who”
- primary food sources
- export pathways

Physiological constraints

- maximum rates
- growth & assimilation efficiency

Site-specific data

- Palmer survey grid
- biomass & flow data
- respiration rates



Internally consistent food-web

- match available data
- mass conservative
- steady-state

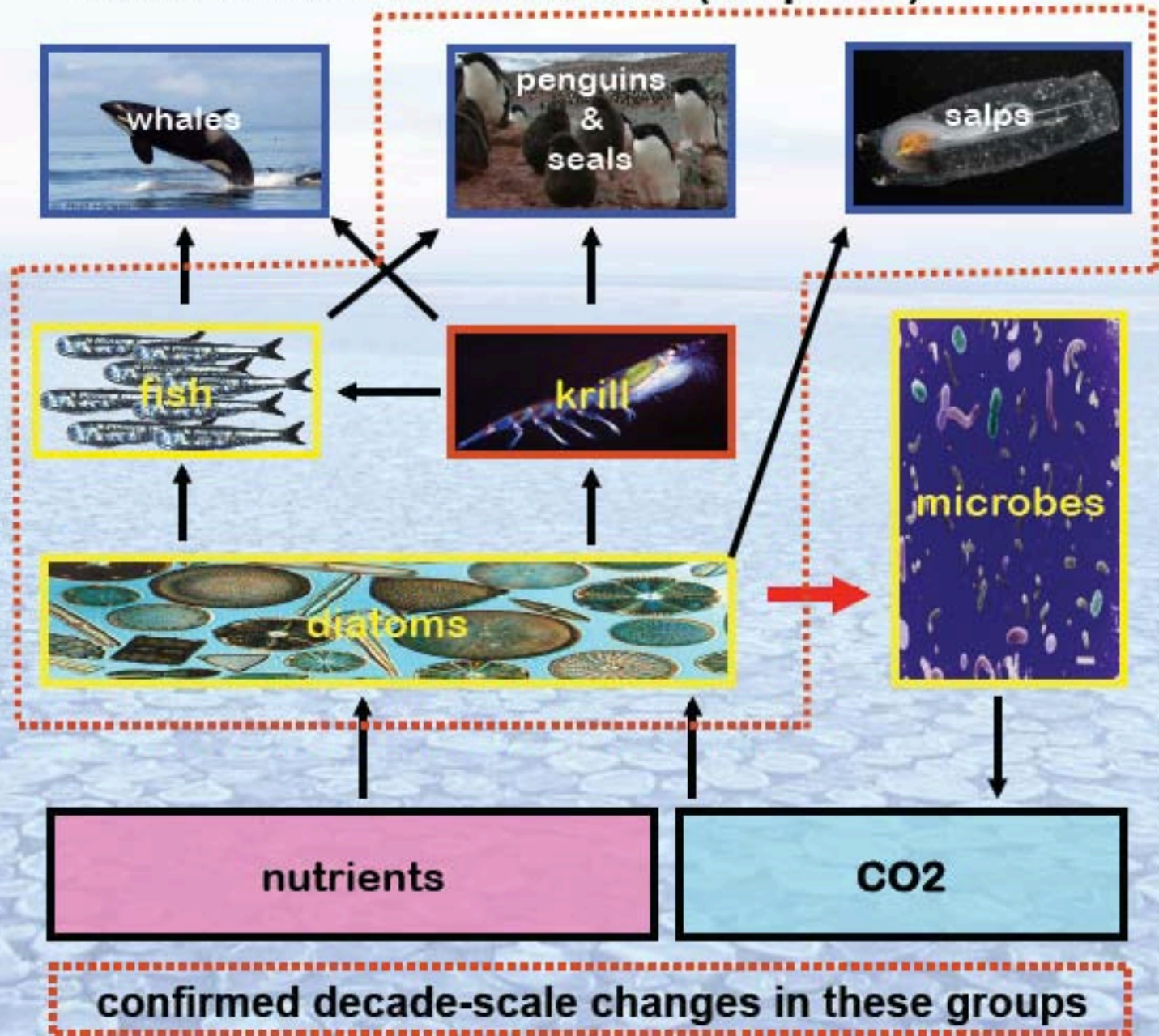
Constraints on other stocks & flows

- unmeasured parts of the ecosystem
- minimization criteria
- Monte-Carlo methods to give error bounds

Daniels, Richardson & Ducklow, *Deep-Sea Res. II* (2006)

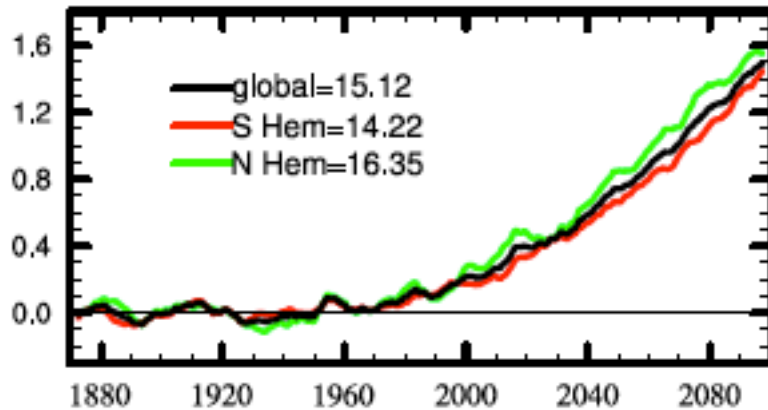
Soetaert and Von Oevelen, *Oceanography* (2009)

Palmer LTER Marine Food web (simplified)

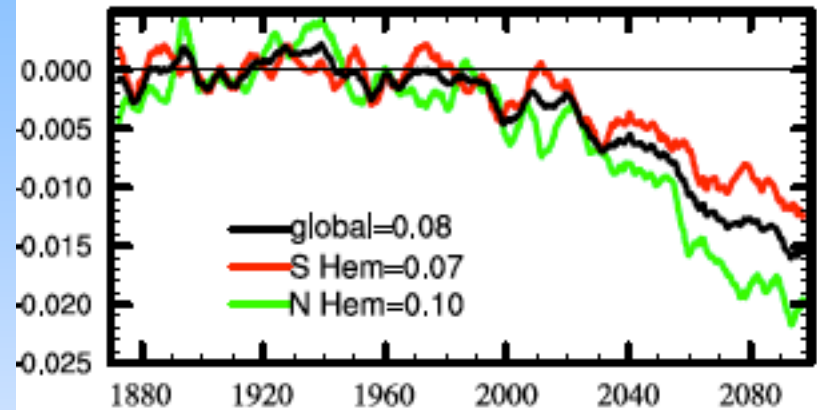


Coupled Ocean-Atmosphere Model: CCSM-3 21st Century Projections

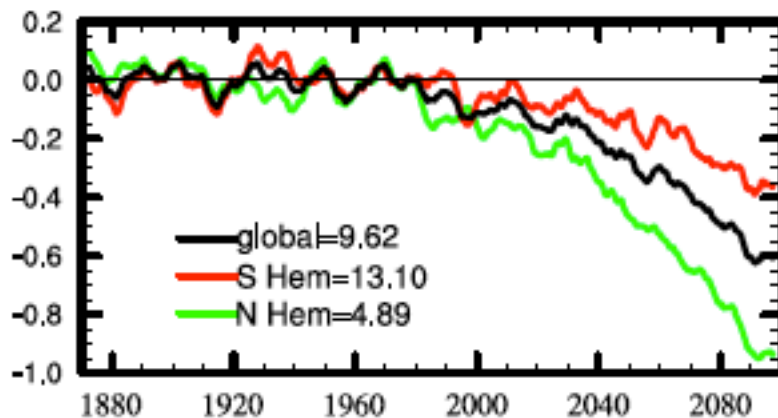
a. SST ($^{\circ}\text{C}$)



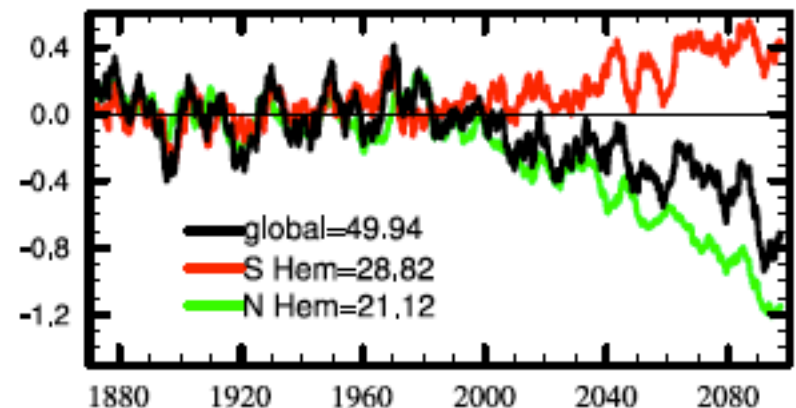
d. Ice Fraction (%)



e. Nitrate (mmol N/m^3)

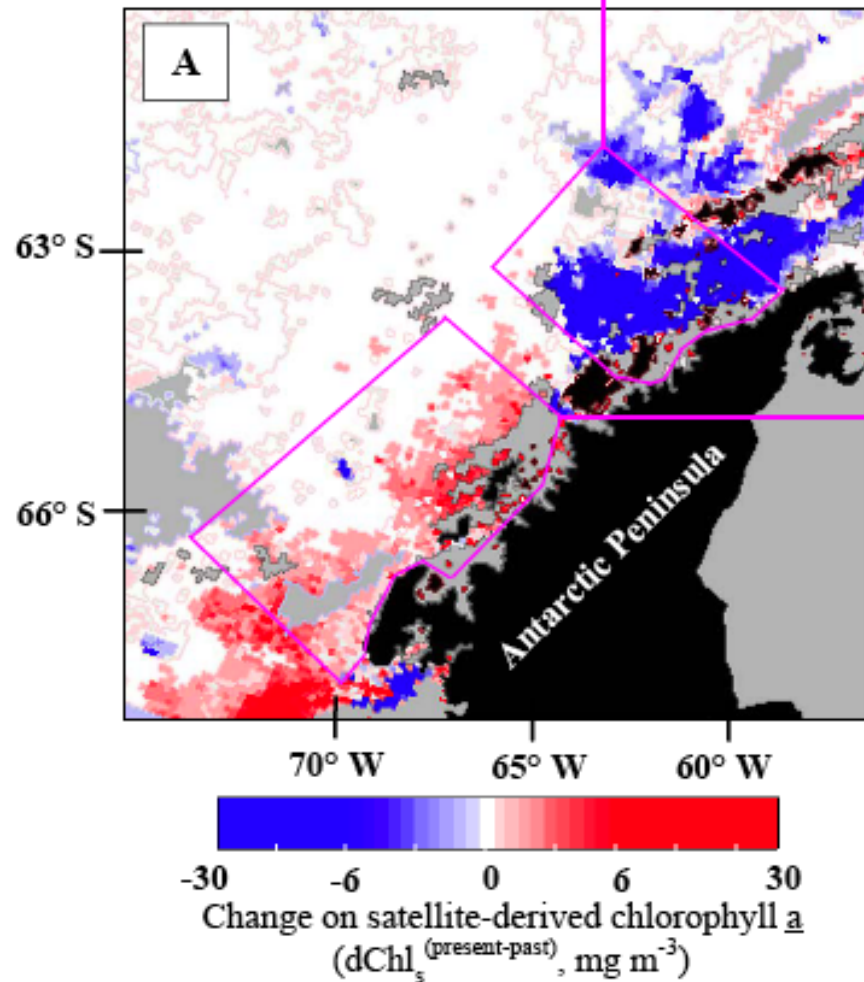


j. Total Primary Prod (PgC/yr)



Ecological Responses to Retreating Sea-Ice

Decadal Change in Surface Chlorophyll



Montes et al. Science (2009)

Penguin Populations near Palmer Station Adélies declining, Gentoos and Chinstraps invading and increasing



Bill Fraser
Ducklow et al. (in press)