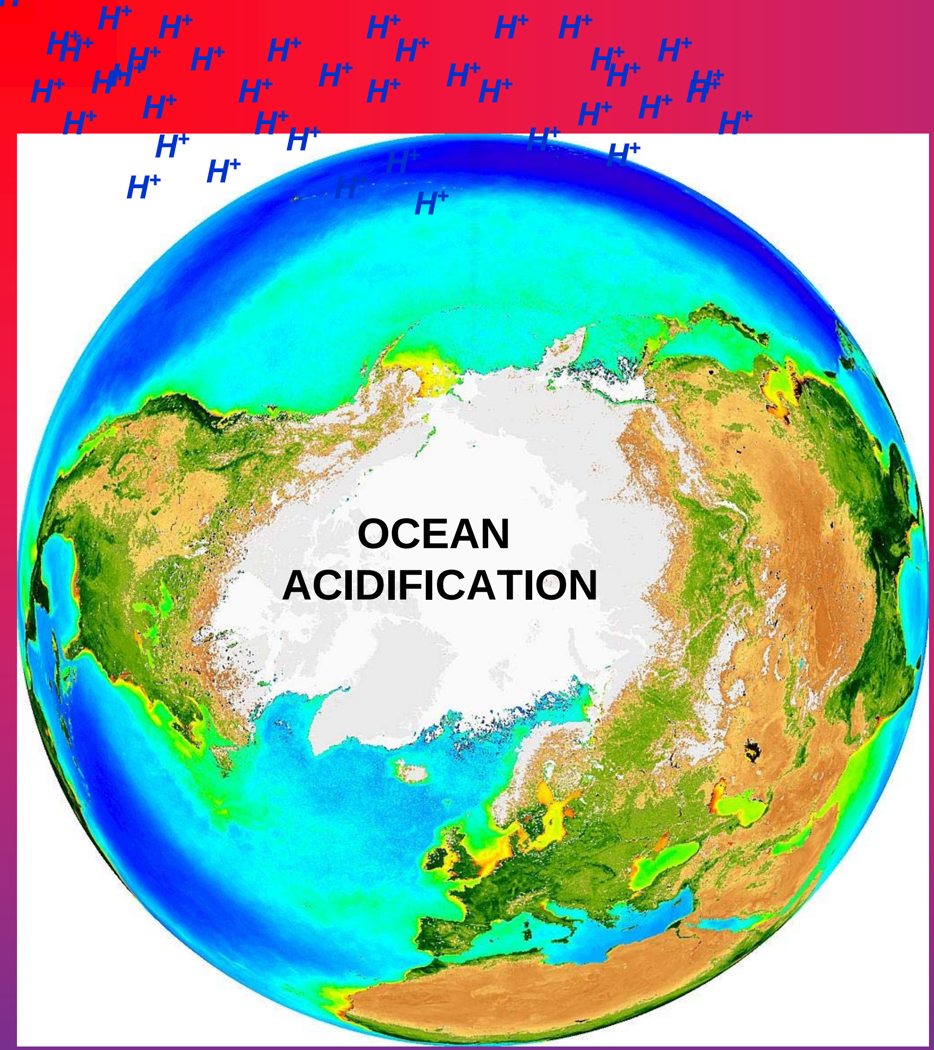
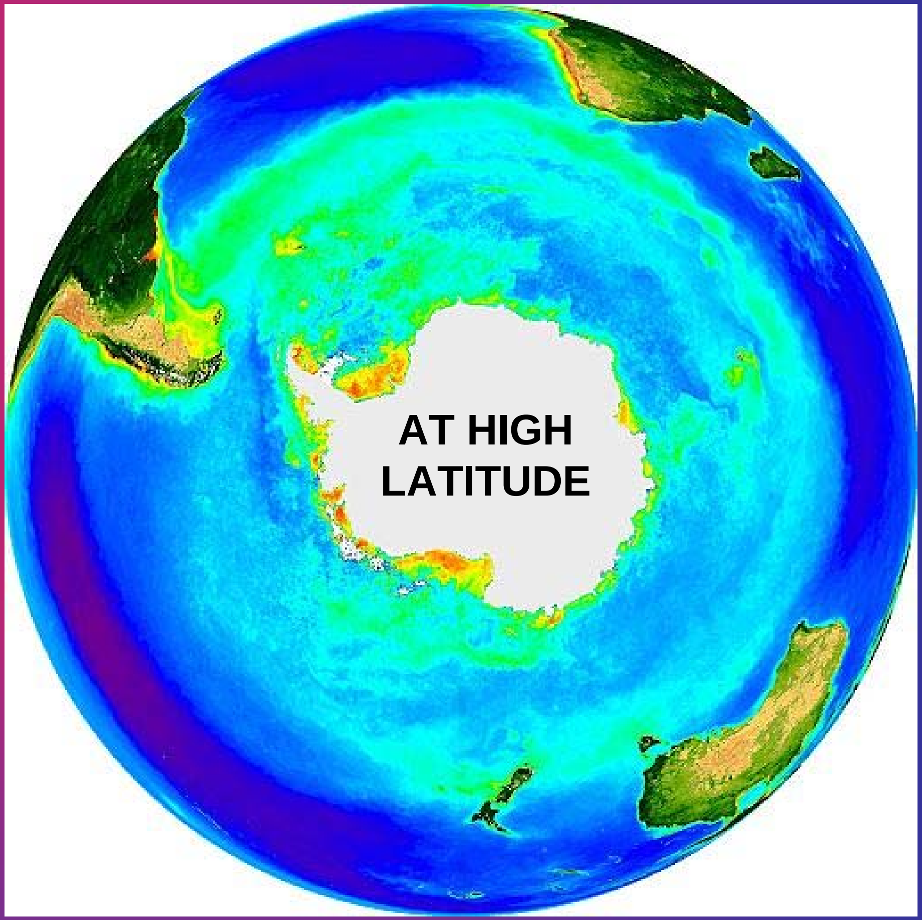




How will polar plankton ecosystems respond to ocean acidification?

Hugh Ducklow
The Ecosystems Center, MBL
Woods Hole

Ocean Acidification Workshop
SIO La Jolla
9 October 2007

How will polar plankton ecosystems respond to ocean acidification?

Hugh Ducklow 09 Oct. 2007

The following presentation is brought to you by the Ocean Carbon and Biogeochemistry Program and Palmer LTER

OUTLINE of TALK

Effects on ecosystems:

Bottom-up
Top-down
Biogeochemistry

Projection of changes in pH and CaCO3 saturation state
Monitoring DIC, ALK, pCO2 and pH at Palmer LTER site

Effects on Pteropods

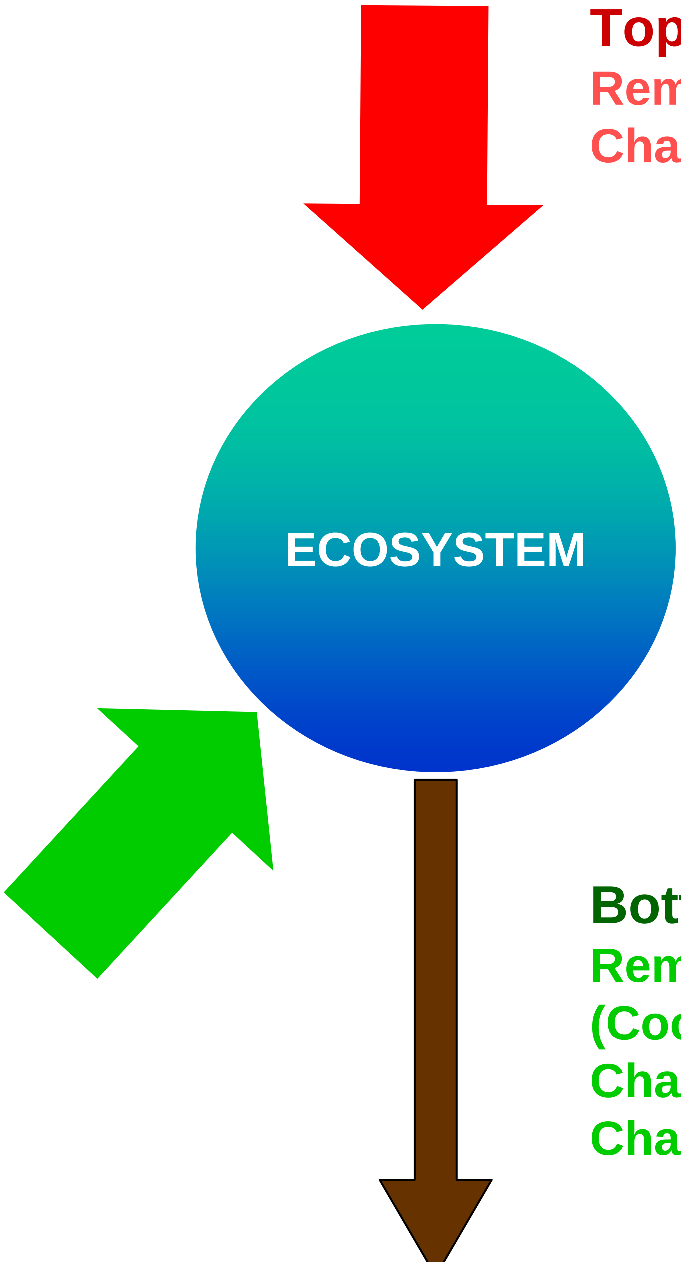
Standing stocks and changes in LTER region
But what do they eat? What are they competing against?

Effects on coccolithophorids

North: blooms in Bering, Barents Seas – increasing?
Southern Ocean uncertainties
Views from models

Other groups and potential effects
Research Priorities

3 groups of effects:



Top-down effects:

Removal of calcifying predators (Pteropods)

Changes in competition, foraging?

Effects on Ecosystem properties

Community composition & biodiversity

Apex & keystone species

Energy capture & transformation

Materials & energy flow networks

Net production and Export (Biological Pump)

Bottom-up effects

Removal of calcifying phytoplankton (Coccolithophorids)

Changes in decomposers and remineralizers?

Changes in nutrient & organic matter chemistry?

1. High Latitude Acidification:

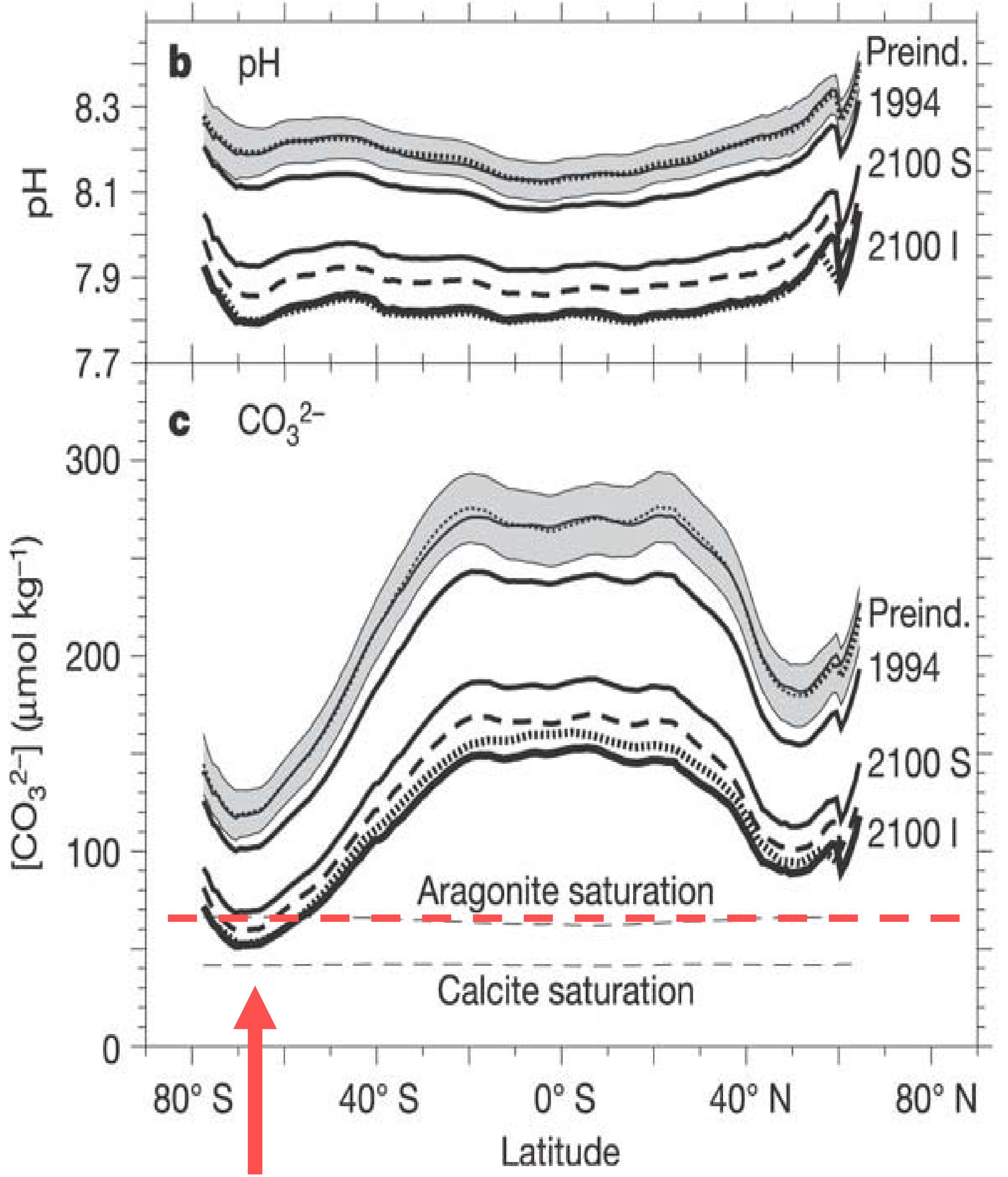
What changes are predicted?

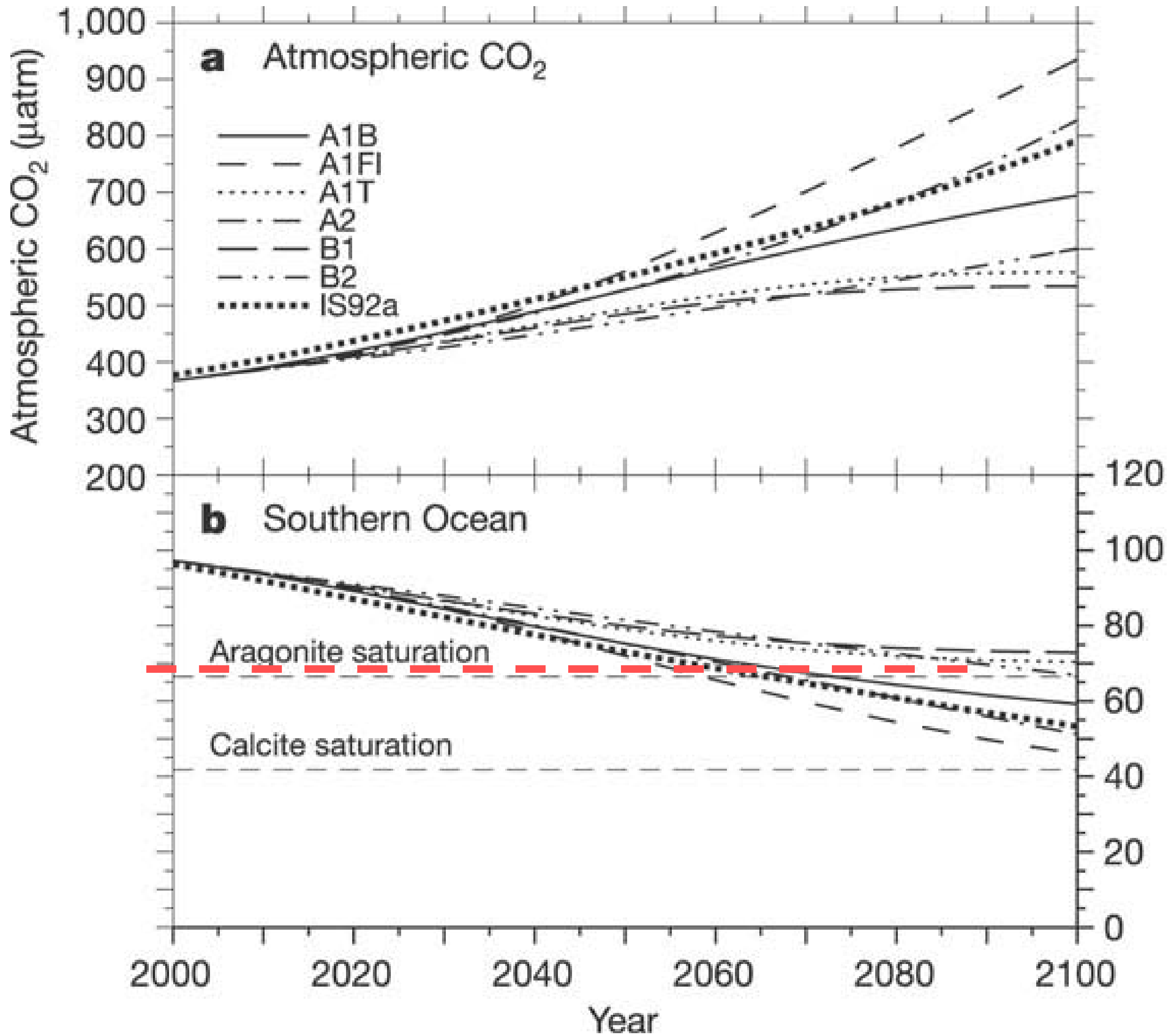
High Latitudes: areas of active CO_2 absorption and high solubility (cold)

Thus areas of potentially high OA

Especially the Southern Ocean

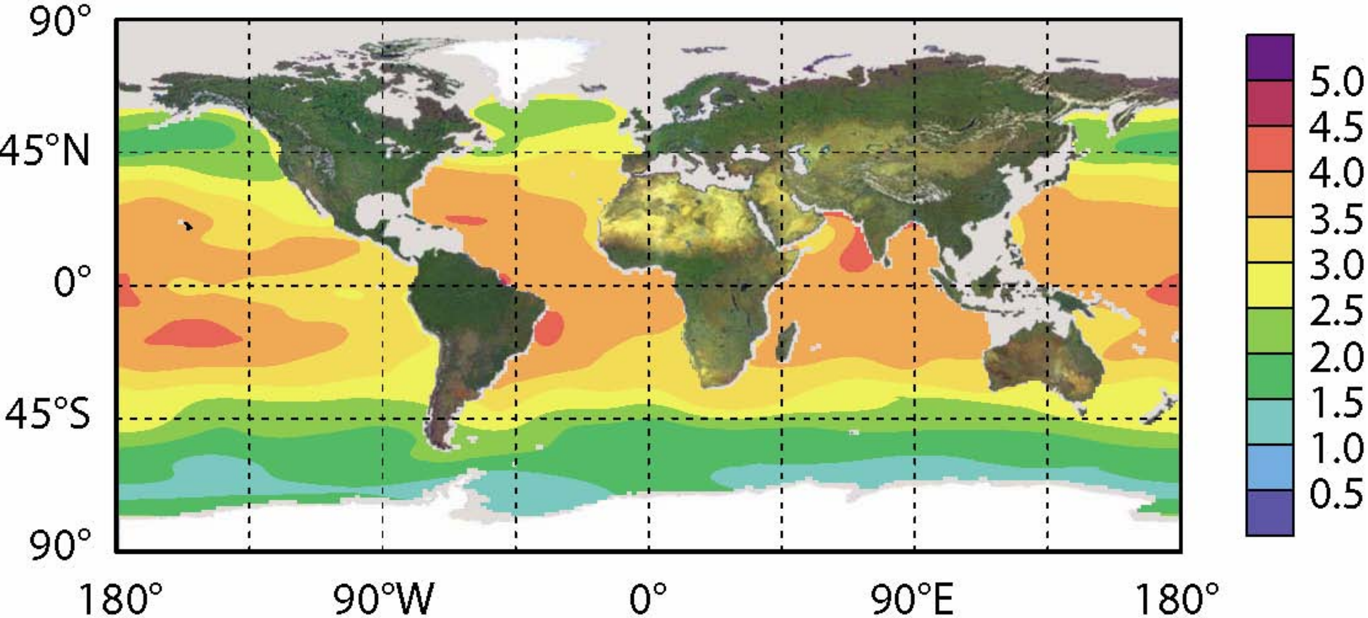
Especially for aragonite





Time series of average surface $[CO_3^{2-}]$ in the Southern Ocean for the PIUB-Bern reduced complexity model (see Fig. 3 and Supplementary Information) under the six illustrative IPCC SRES scenarios. The results for the SRES scenarios A1T and A2 are similar to those for the non-SRES scenarios S650 and IS92a, respectively.

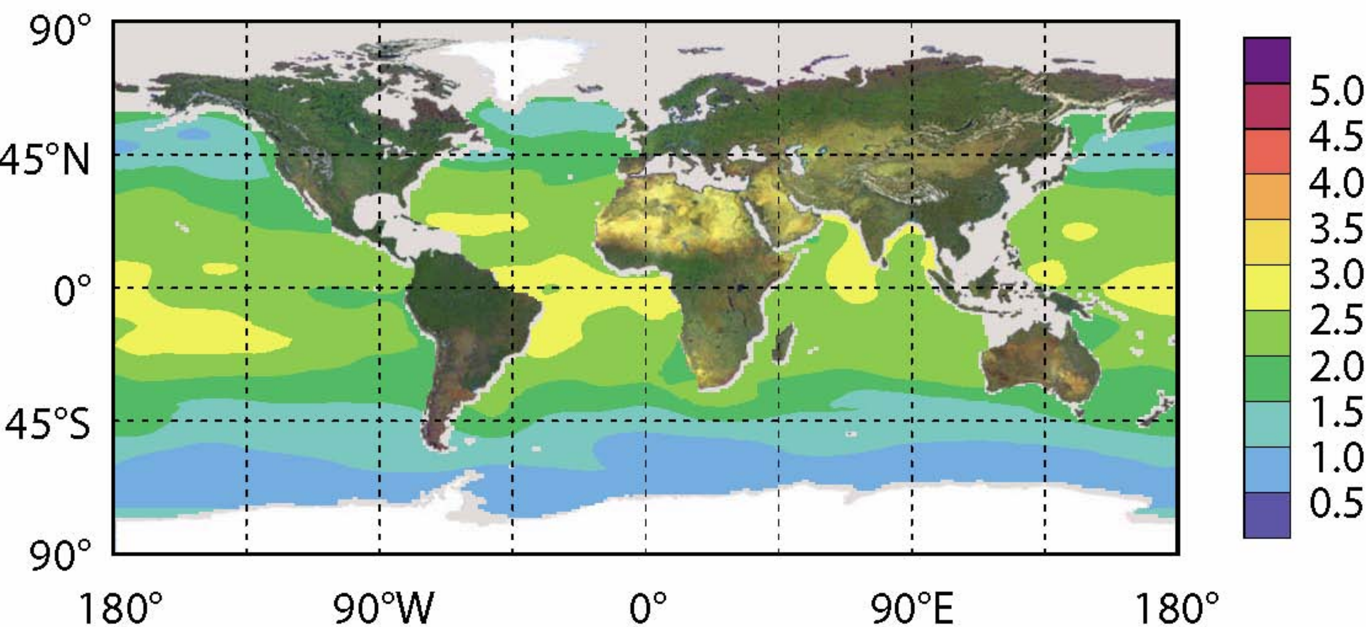
Aragonite Saturation Levels - 2005



N Pacific: 2.5 – 2.0

Antarctic: 2.0 – 1.5

Aragonite Saturation Levels - 2099



N Pacific: 1.5

Antarctic: 1.5 – 1.0

The Backdrop for High Latitude Ocean Acidification

High Latitude (Polar) Climate and Environmental Change:
“Broken Ecosystems” (D. Ainley)

Rapid warming (especially in winter)
Glacier & Ice Sheet melting & retreat (freshening ocean)
Sea ice decline in extent and duration
Increasing winds & upwelling (Antarctica)

Pollutant accumulation (leapfrog effect)
Transient recovery/response to whaling and sealing in late 19 – early 20 century
E. huxleyi blooms in Bering, Barents Seas
Freshening of North Atlantic, Arctic oceans
Shifts from diatoms to flagellates Antarctic peninsula
Possibly declining krill and increasing salps
Adelie penguin decline and replacement by subantarctic congeners

Palmer Station Antarctica
Long Term Ecological Research

OBSERVATIONS

1993-2007

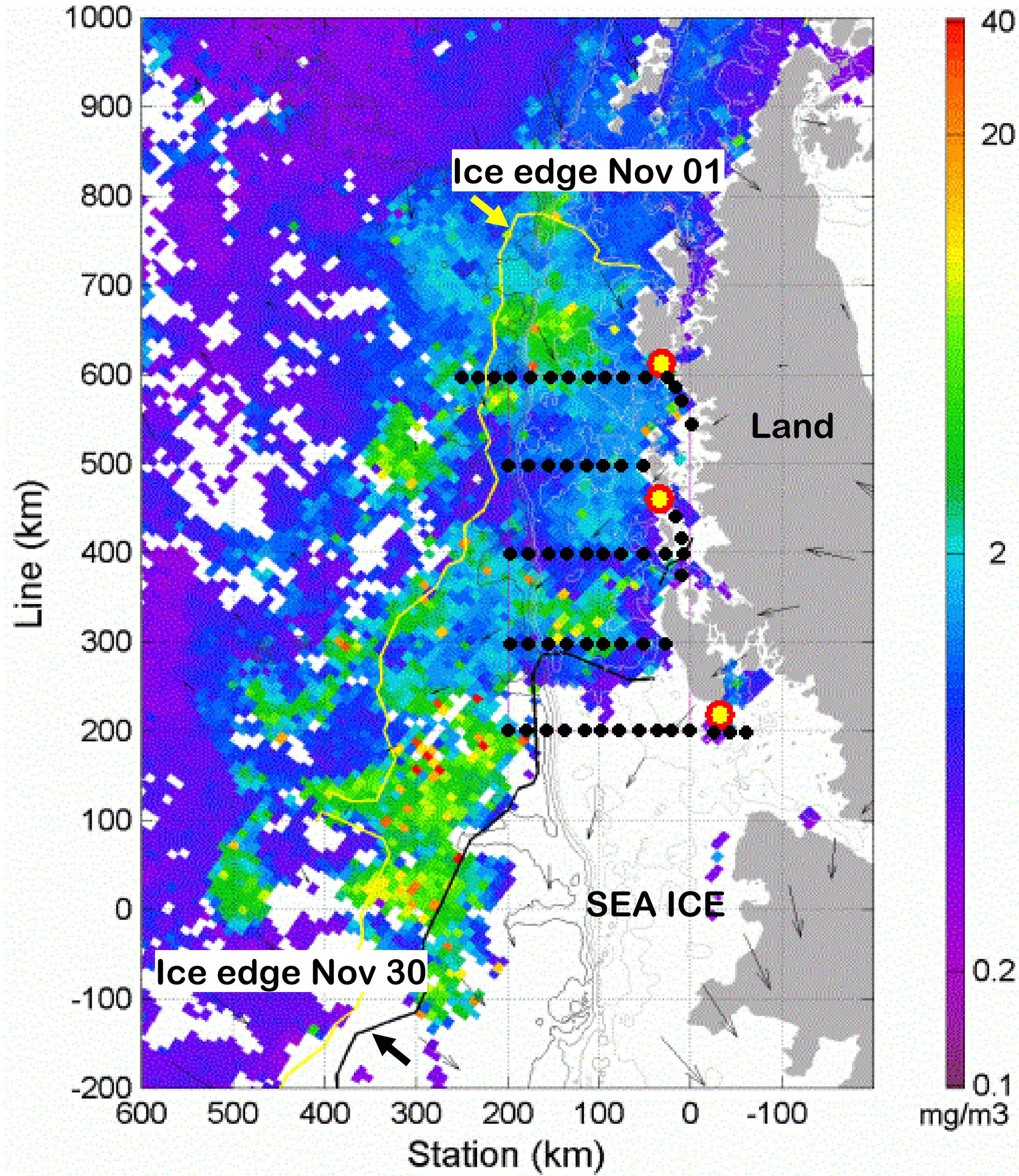
Study region along west Antarctic Peninsula

Region already warming rapidly

OA to follow?

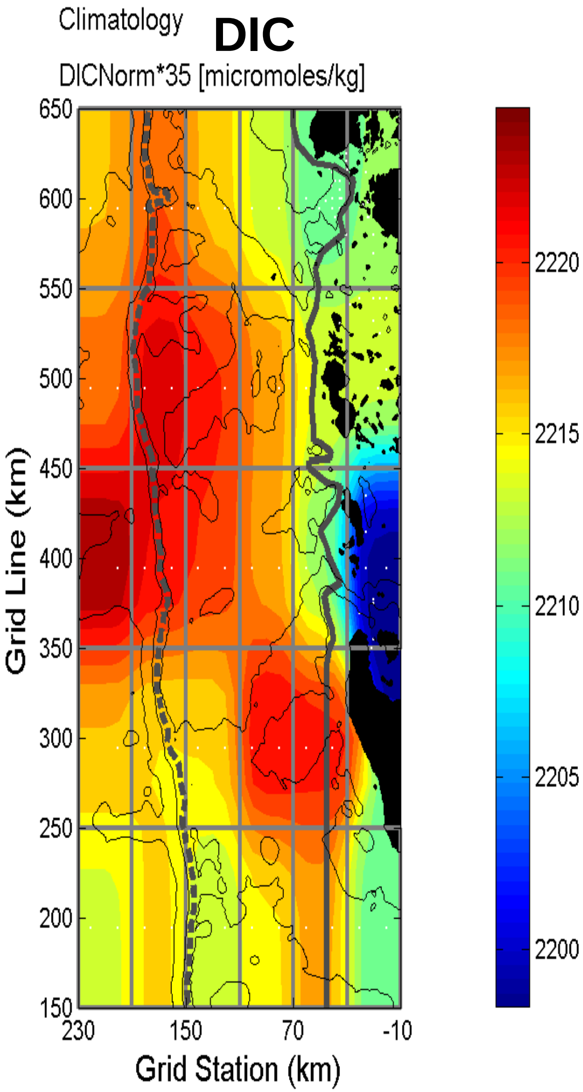
Observation system in place

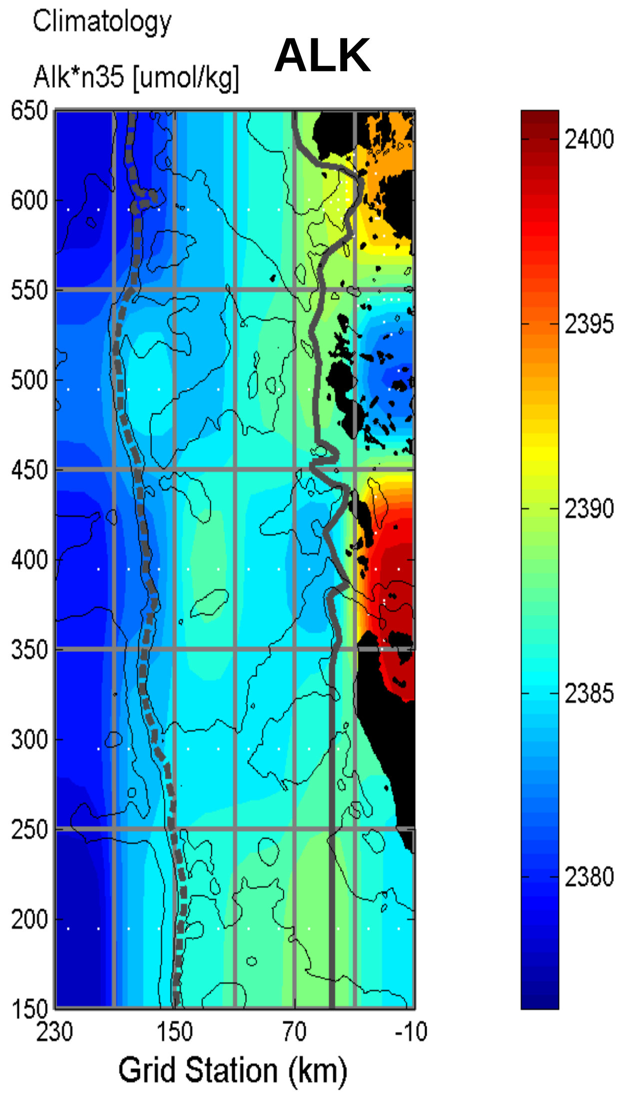
Like BATS & HOT, but just every January and regional focus (600 x 300 km)

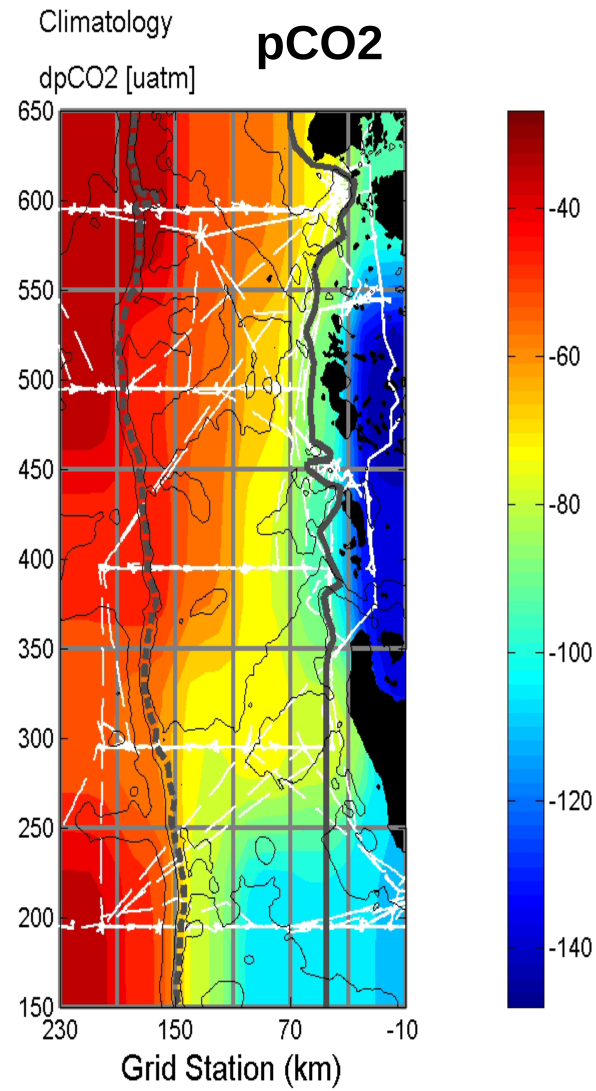


Palmer Station Antarctica
Long Term Ecological Research

Distributions and climatologies for DIC, ALK and pCO2 January (1993 – 2006)

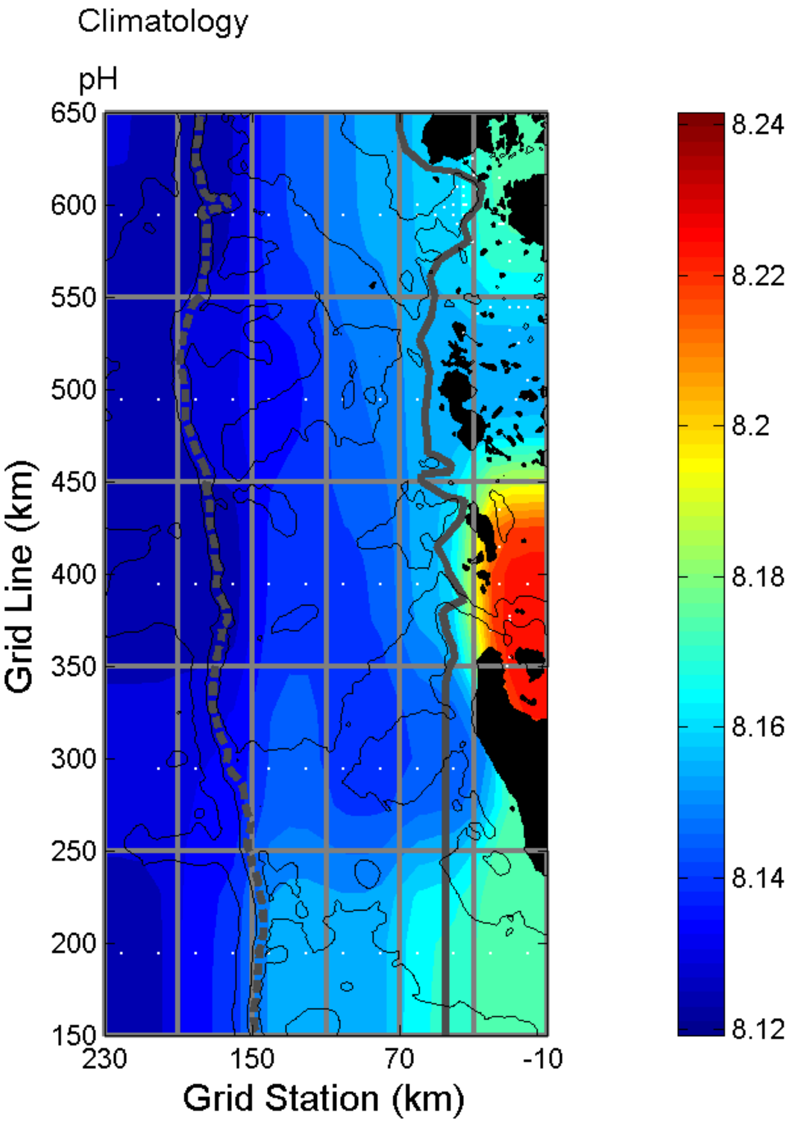




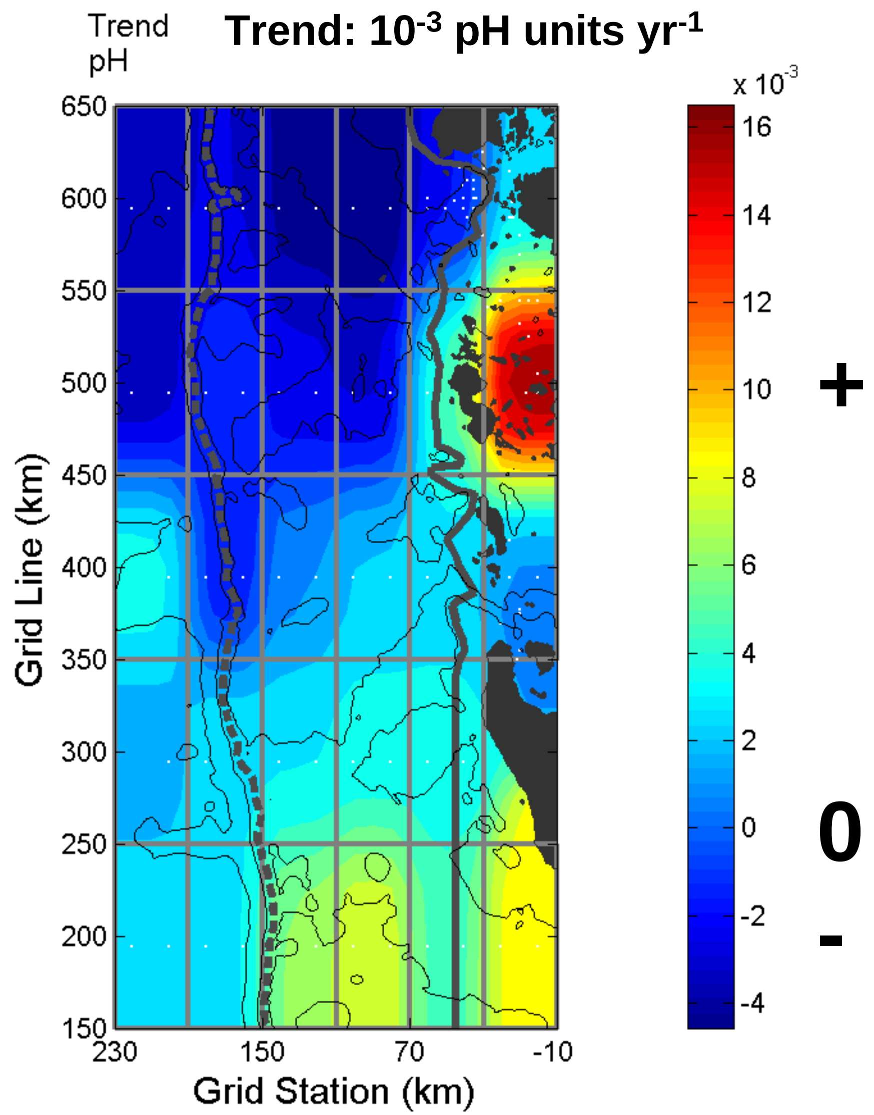


DIC and ALK 1993-2002 D Karl; pCO2 C. Sweeney

pH West Antarctic Peninsula continental shelf, 1993-2006

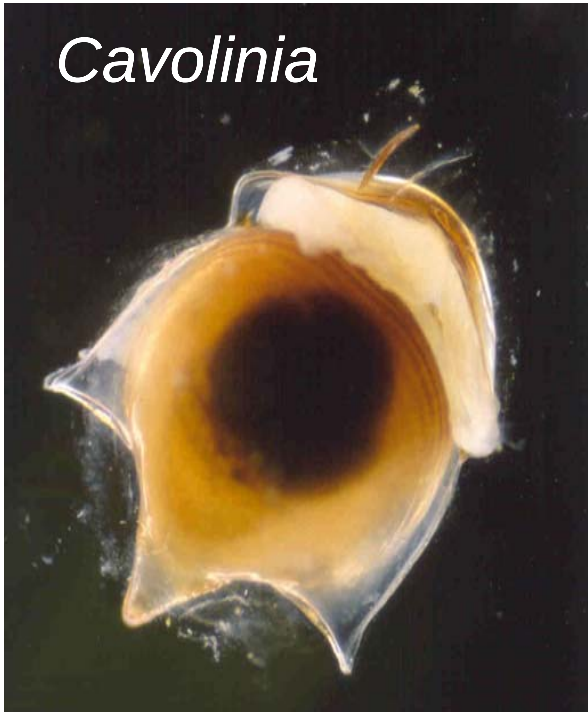


Trend: 10^{-3} pH units yr^{-1}



Thecosomes - shelled pteropods

- tend to be most abundant (~ 1/L), some swarm-forming
- feeding specialization: passive filter - feeders using mucous nets and strings
- shell made of aragonite and/or organic material (readily dissolved)



Debbie Steinberg

Relative Abundance % of mesozoop

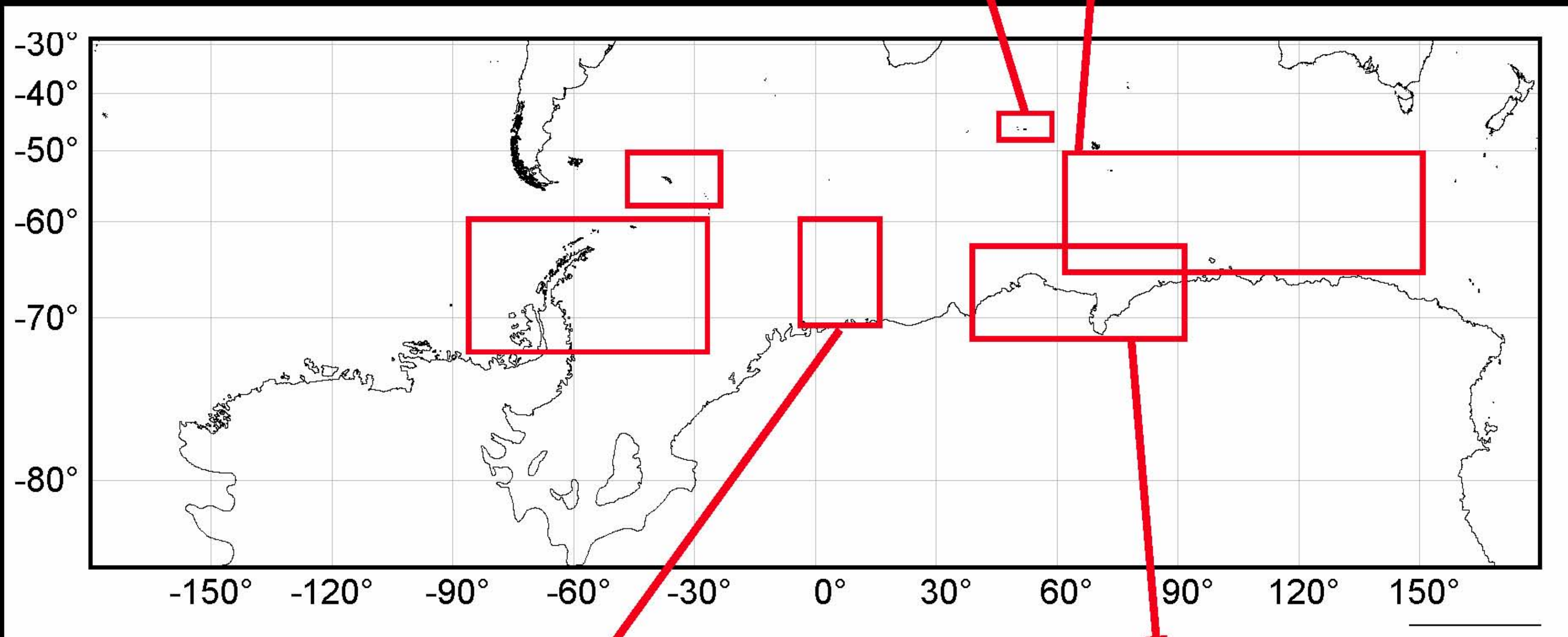
Prince Edward Islands meso

1996-2005 ave = 11%

2000 ave = 27%

CPR survey meso

1997-2005 ave = 2.5 ± 8.6



Lazarev Sea

meso ave = 1.1%

macro ave = 1.1%

East Antarctic macro

1985-1990 ave = 11.6%

1985, 1987 ave > 20%

B Hunt, E Pakhomov, G Hosie, V. Siegel, P.d, K. Bernard, accessed online, www.pices.int

Zooplankton sampling in Palmer LTER region:

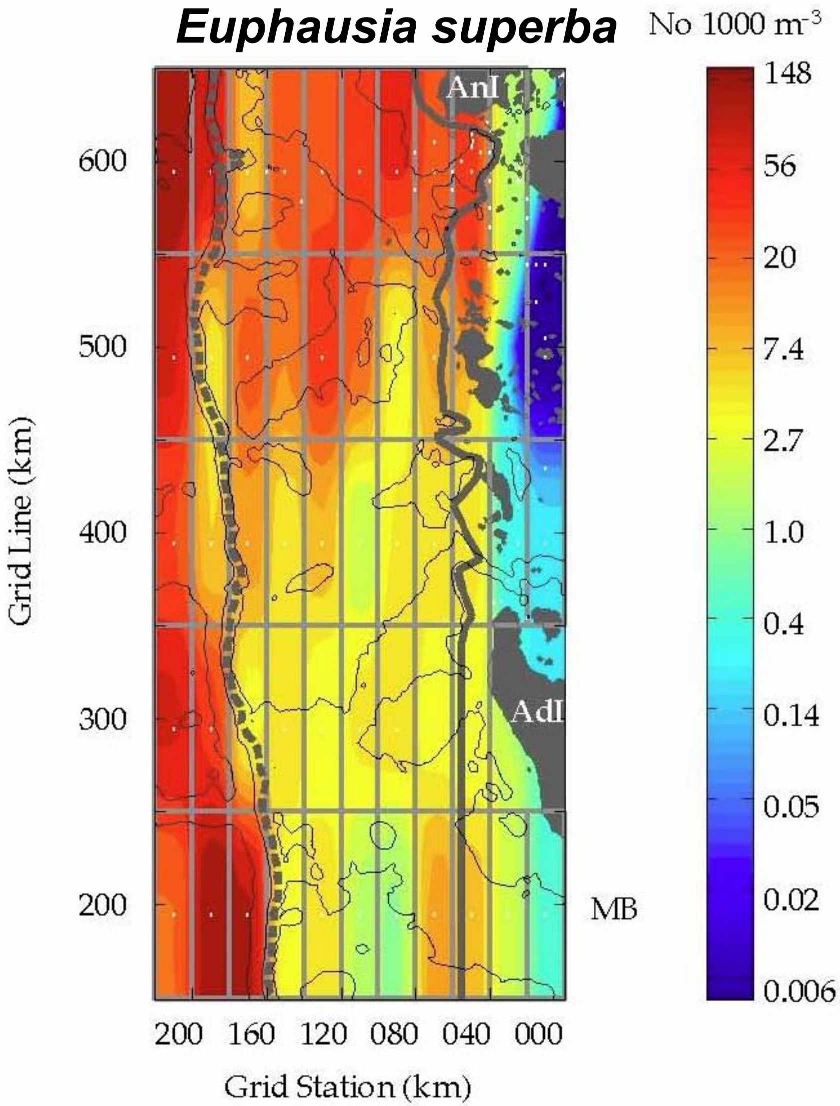
% of individuals caught over 12 years (> 2 mm; January 1993-2004)

Euphausia superba	**22%**
E. crystallorophias	**4%**
Thysanöessa macrura	***46%***
Salpa thompsoni	***10%***
Limacina helicina	***15%***

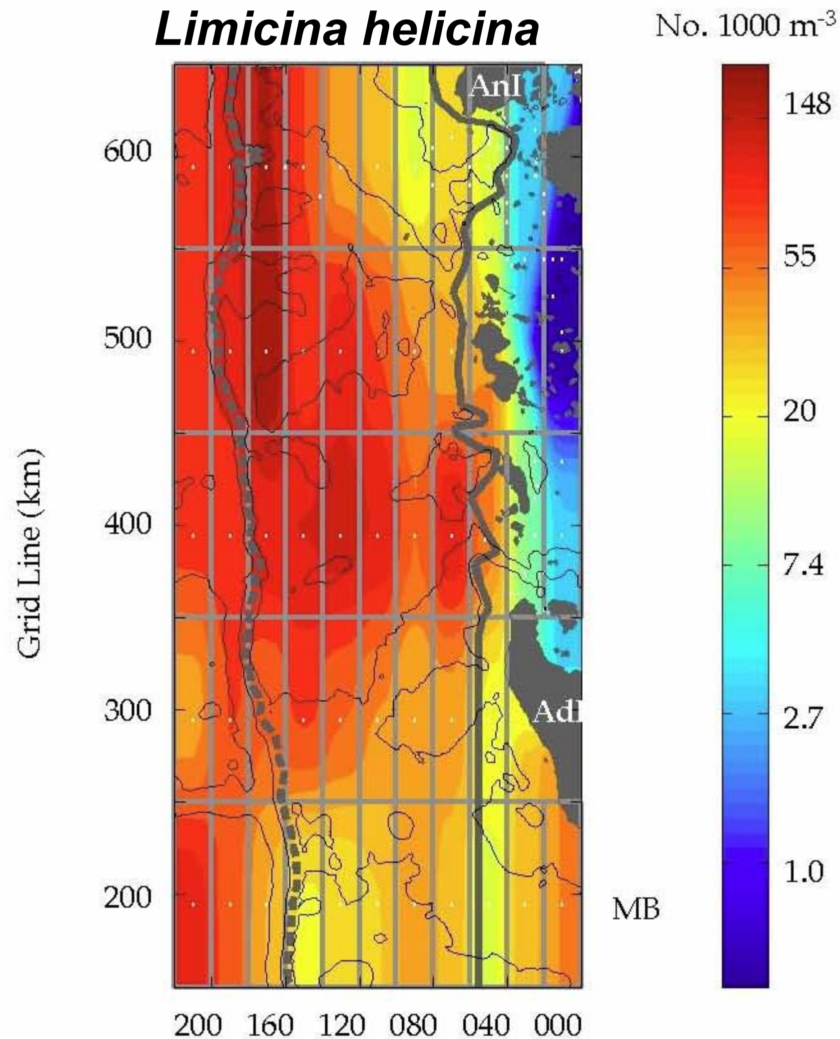
Palmer Station Antarctica
Long Term Ecological Research

Zooplankton abundance, distribution and trends, 1993-2006

Antarctic Krill
Euphausia superba



Pteropod
Limicina helicina

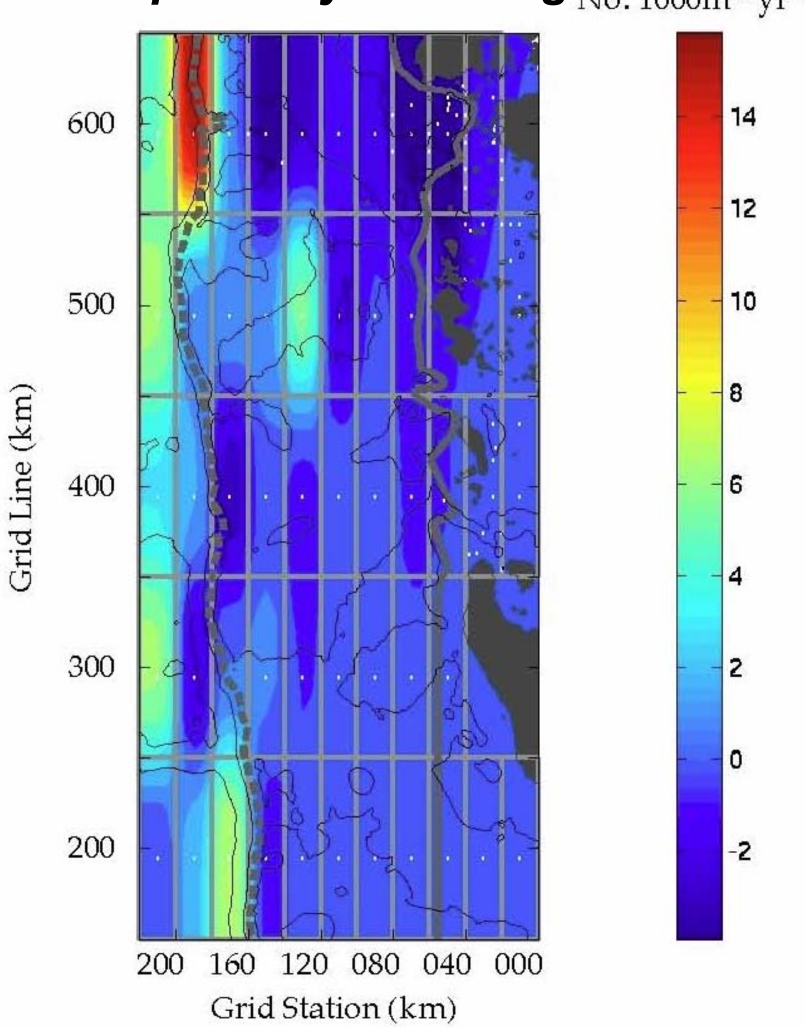


R Ross et al., Deep-Sea res II (accepted)

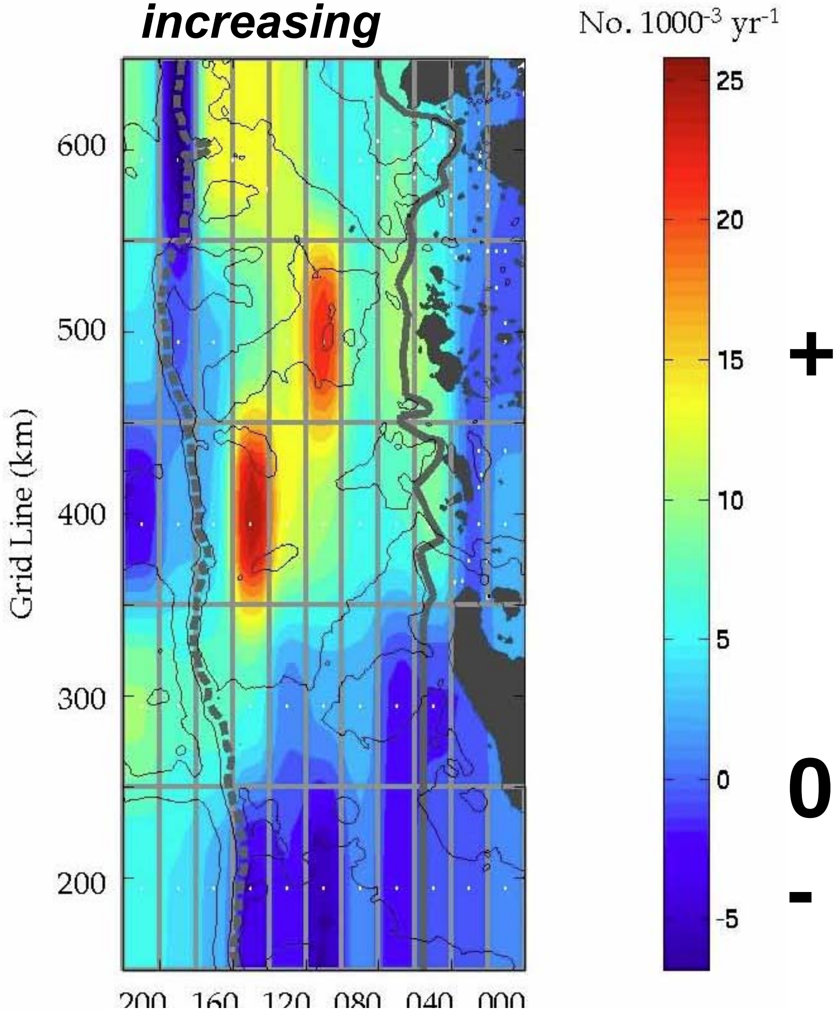
Palmer Station Antarctica
Long Term Ecological Research

Zooplankton trends, 1993-2006

Antarctic Krill
Euphausia superba
possibly declining



Pteropod
Limacina helicina
increasing



R Ross et al., Deep-Sea res II (accepted)

Diet composition of Thecostome Pteropods

R. W. Gilmer, *G.* R. Harbison. 1991. Diet of *Limacina helicina* (Gastropoda: Thecosomata) in Arctic waters in midsummer. Mar. Ecol. Progr. Ser. 77:125

Indiscriminant mucus-net feeders

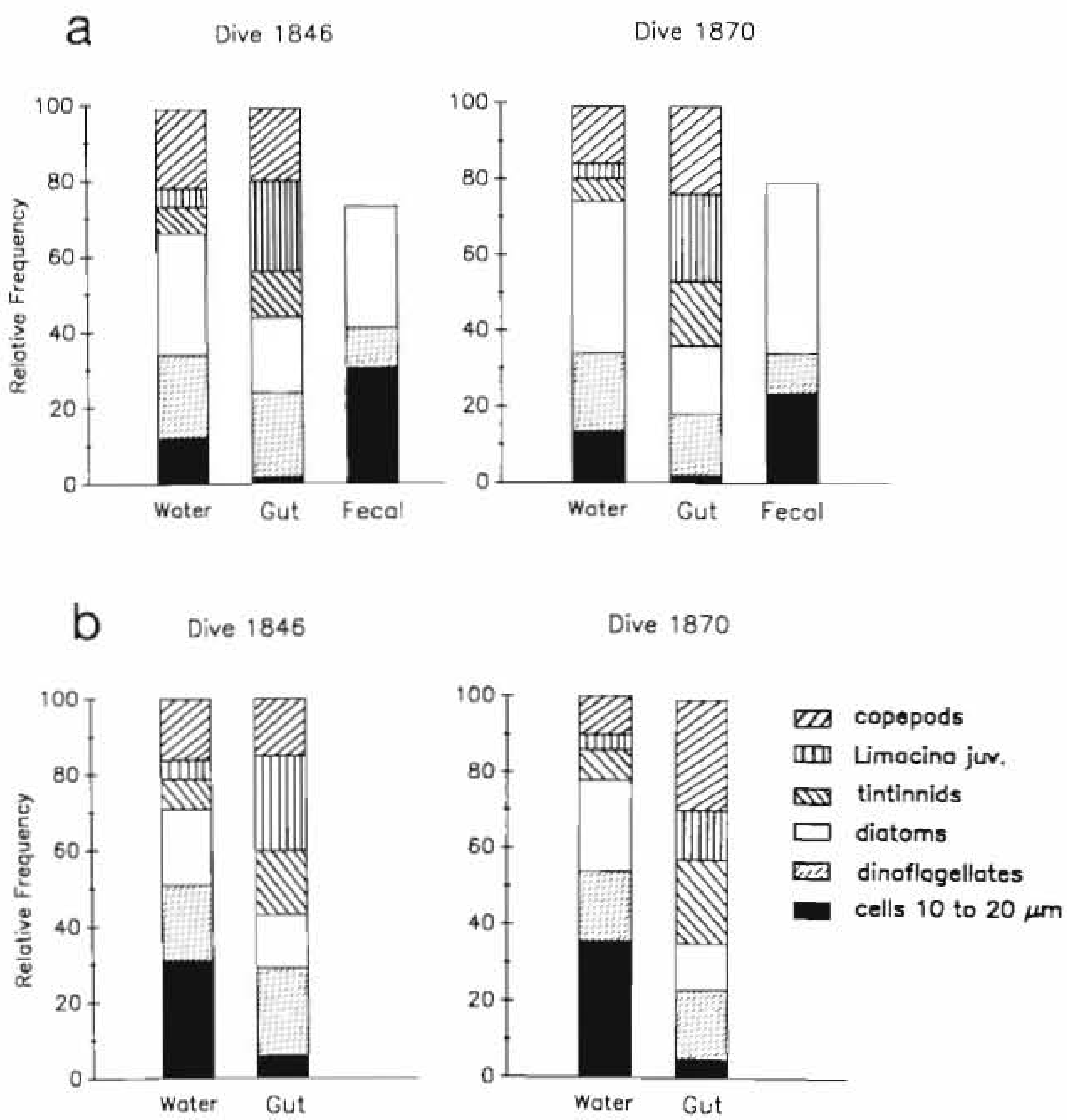


Fig. 4. *Limacina helicina*. Relative frequency (%) of intact food items in water samples, gut contents, and fecal pellets, for pteropods collected in situ at the 2 dive sites (a) by volume and (b) by carbon, using values from Table 1. Although fragments of pteropod shells, copepod exoskeletons and empty tintinnid loricae were found in guts and pellets, this material was not scored for this figure

Pteropods: A lot of uncertainties:

Importance in S.O. systems: generalizations from relatively few studies

- few studies of diet & grazing rates
- stable isotopes suggest primarily herbivorous
- up to 50% mesozooplankton density (25% biomass)
- very high ingestion rates (may equal salps)
- up to 50% of total grazing impact
- great regional, seasonal, interannual variability
- assimilation rates and fecal pellet production rates UNKNOWN
- Poor understanding of life cycle, predation rates and predators
- 50% of carbonate flux ?
- important in ballasting C_{org} flux?

Effects of acidification on Pteropods

Reduction in abundance at high latitudes

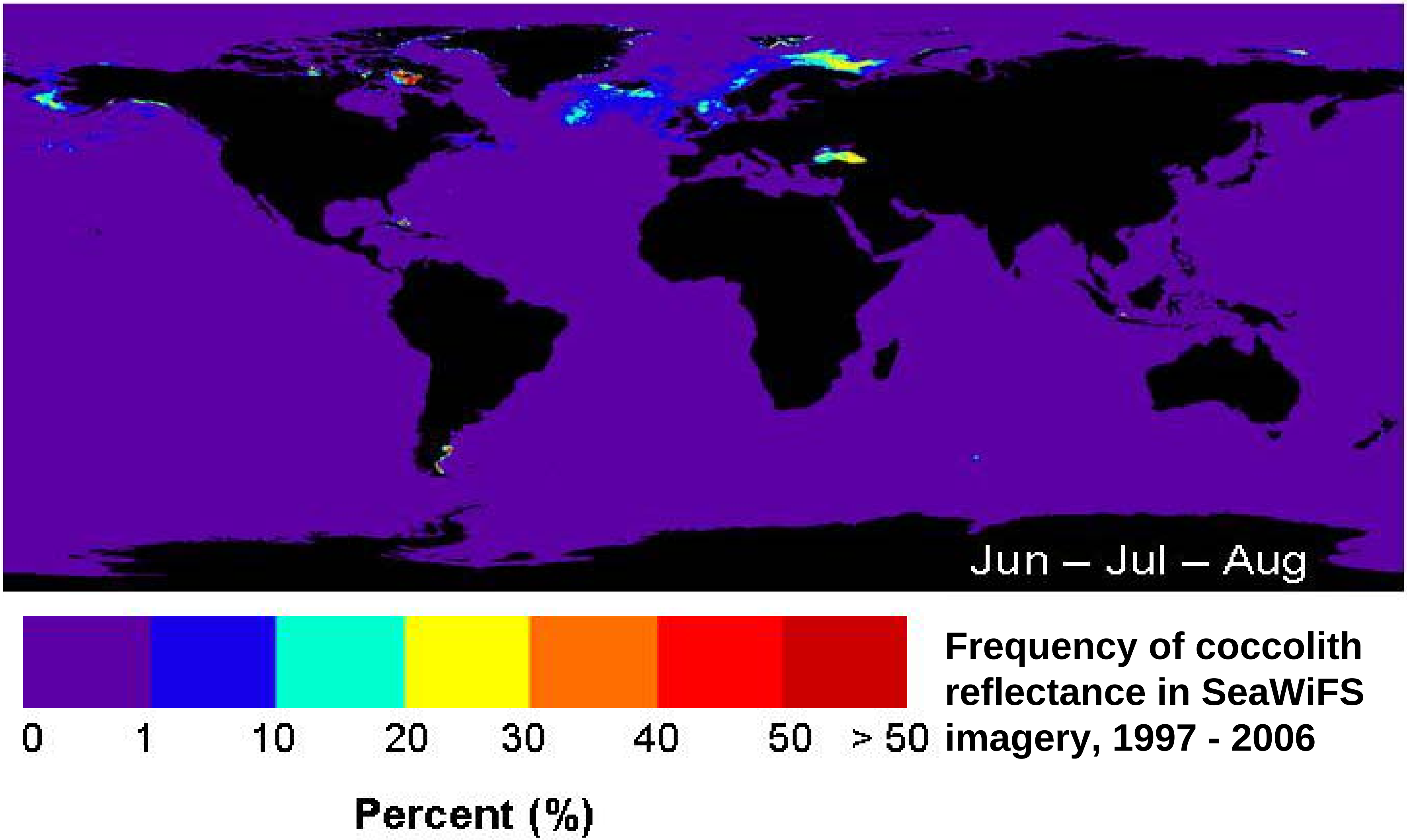
Northward shift in distribution?

B Hunt, E Pakhomov, G Hosie, V. Siegel, P.d, K. Bernard, accessed online, www.pices.int


2 microns

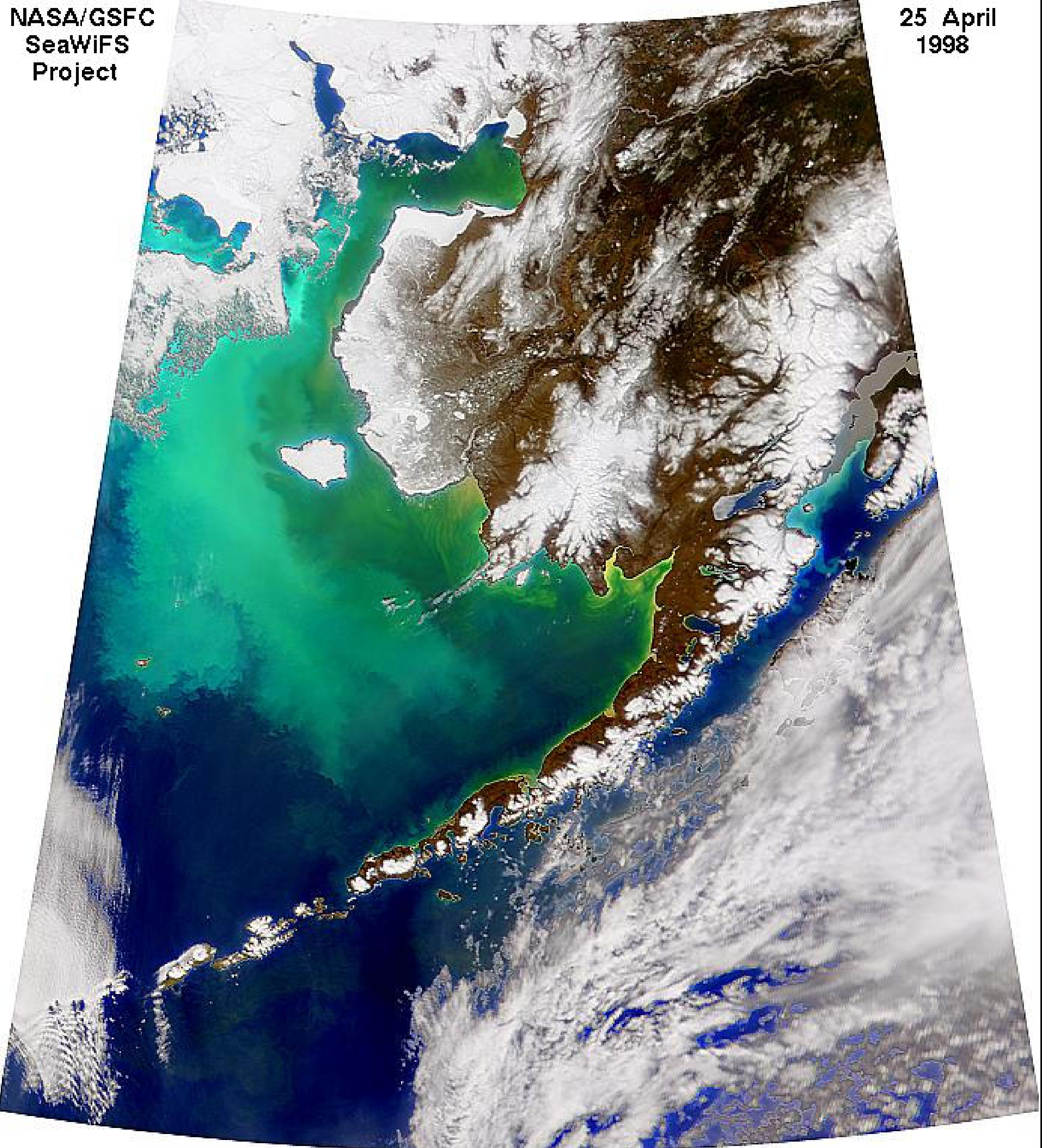
Vulnerability of coccolithophorids to OA

- Calcite less soluble than aragonite
- Well-documented blooms at high latitude in North
- Change in North slower/less than South



Frequency of coccolith reflectance in SeaWiFS imagery, 1997 - 2006

Image courtesy Chris Brown, NOAA



Coccolithophorid Blooms in Bering Sea After 1997

Also Barents Sea

Cocco’s seem to be increasing, not decreasing in north -- at expense of diatoms

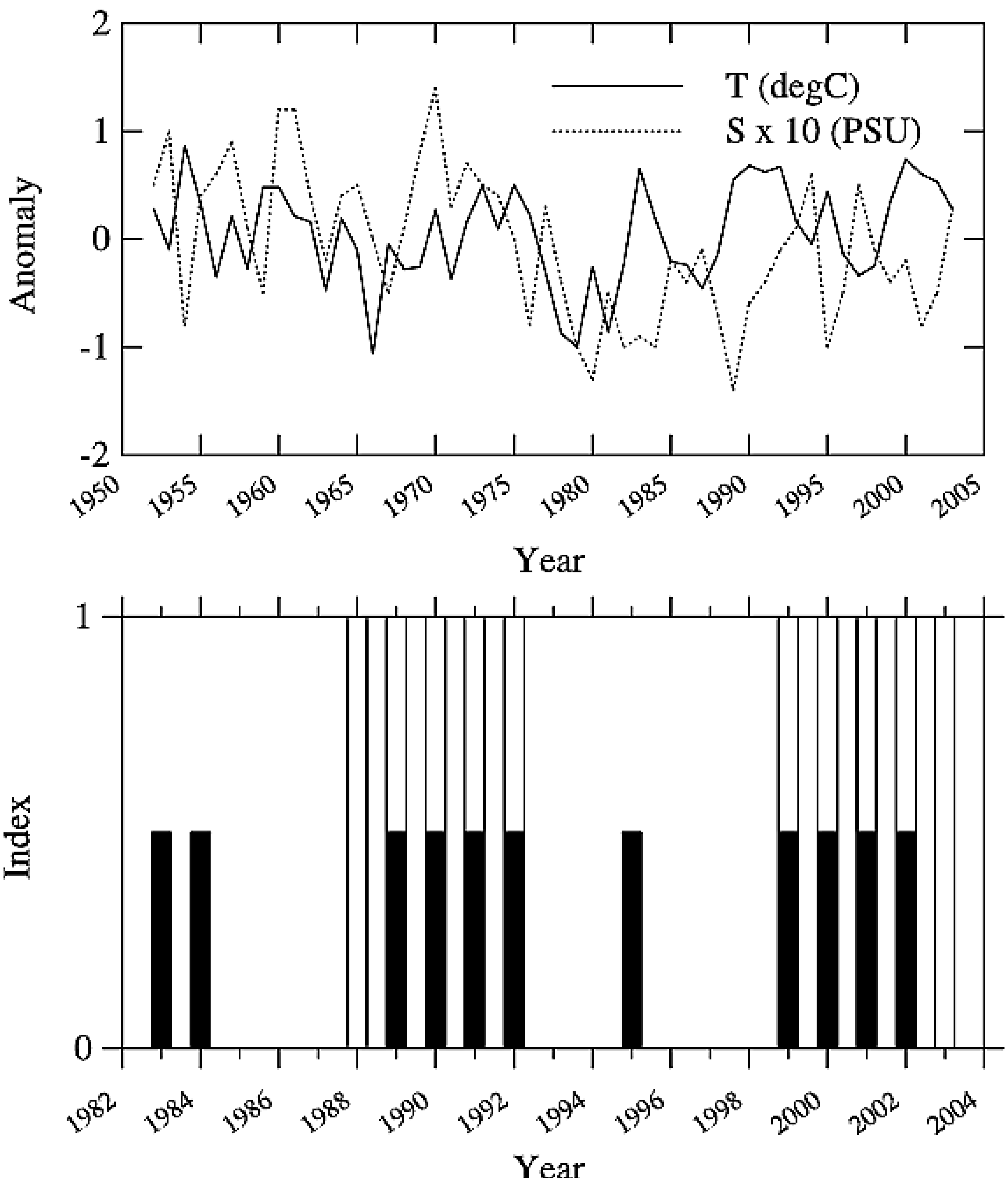
Climate change response?

Change in PDO, AO, ENSO state: Warmer, more stratified, less mixing, lower nutrients

Changes in water transparency:

Changes throughout foodweb (seabirds, salmon

High latitude coccolithophore blooms are increasing in response to regional warming

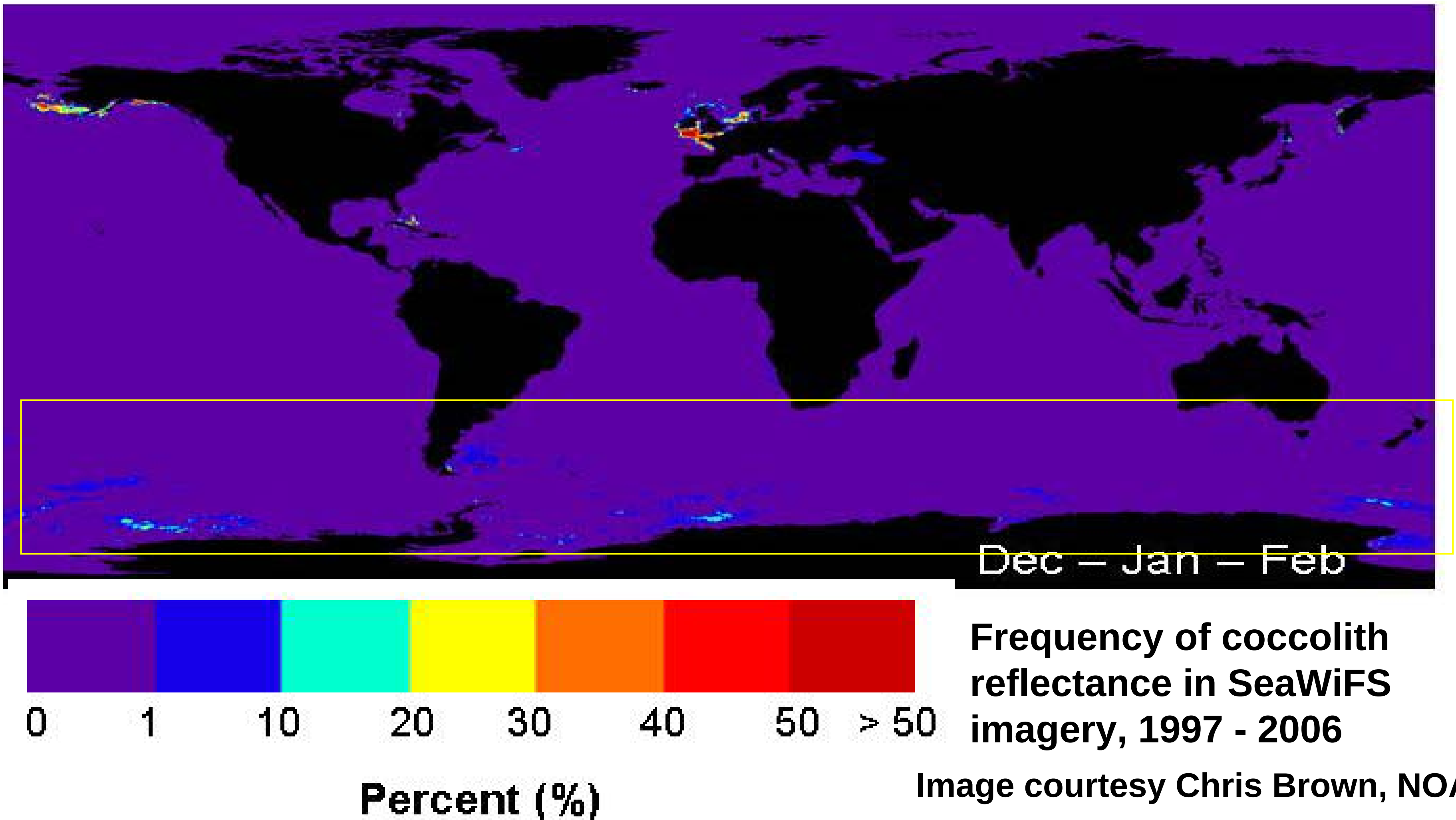


Smyth, T. J., T. Tyrrell, and B. Tarrant (2004), Time series of coccolithophore activity in the Barents Sea, from twenty years of satellite imagery, Geophys. Res. Lett., 31,

Top panel shows the annual average temperature and salinity anomalies for the Kola transect (0–200 m; between 70°30'–72°30'N along 33°30'E) compared with the 1951–1990 mean. The lower panel shows the AVHRR detected bloom occurrence as unfilled bars and the positive temperature - negative salinity anomaly occurrence as filled bars.

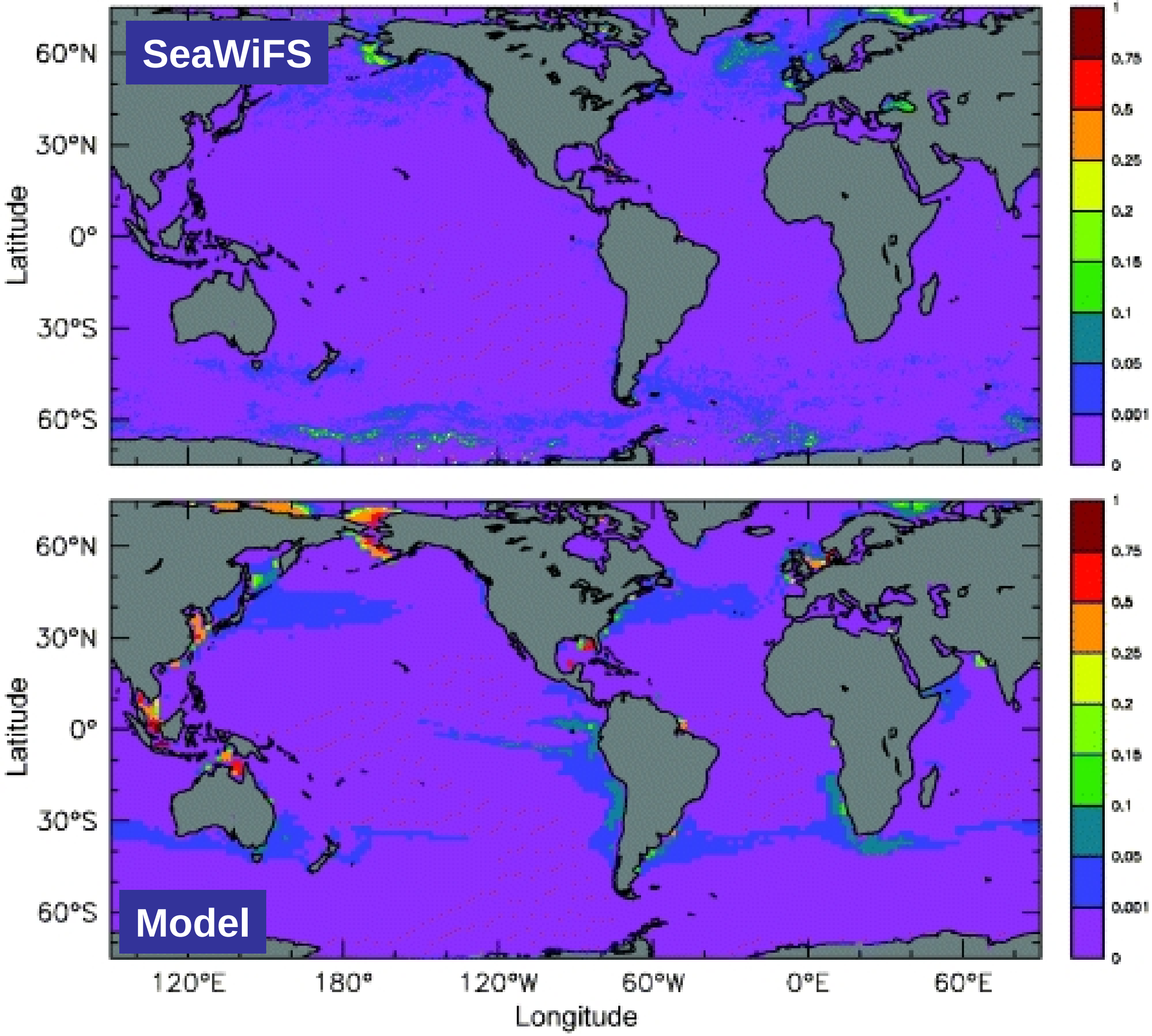
The Southern Ocean Coccolithophorid "Controversy"

Are there coccolithophorids growing south of Polar Front?
SeaWiFS Optical Backscattering Algorithm
Possible interference from bubbles / few observations to validate.
Some scattered collections of coccos at various Antarctic locations.
But No direct observations of coccolithophorid blooms in S. Ocean …?



Frequency of coccolith reflectance in SeaWiFS imagery, 1997 - 2006

Image courtesy Chris Brown, NOAA



Frequency of Coccolithophorid Blooms

SeaWiFS

(Brown algorithm)

Dynamic Green Ocean Model (DGOM)

C. LeQuere et al. 2005. Ecosystem dynamics based on plankton functional types for global ocean biogeochemistry models Global Change Biology 11, 2016–2040.

Balch, W.M. et al 2005. Calcium carbonate measurements in the surface global ocean based on Moderate-Resolution Imaging Spectroradiometer data. J. Geophys Res.110:

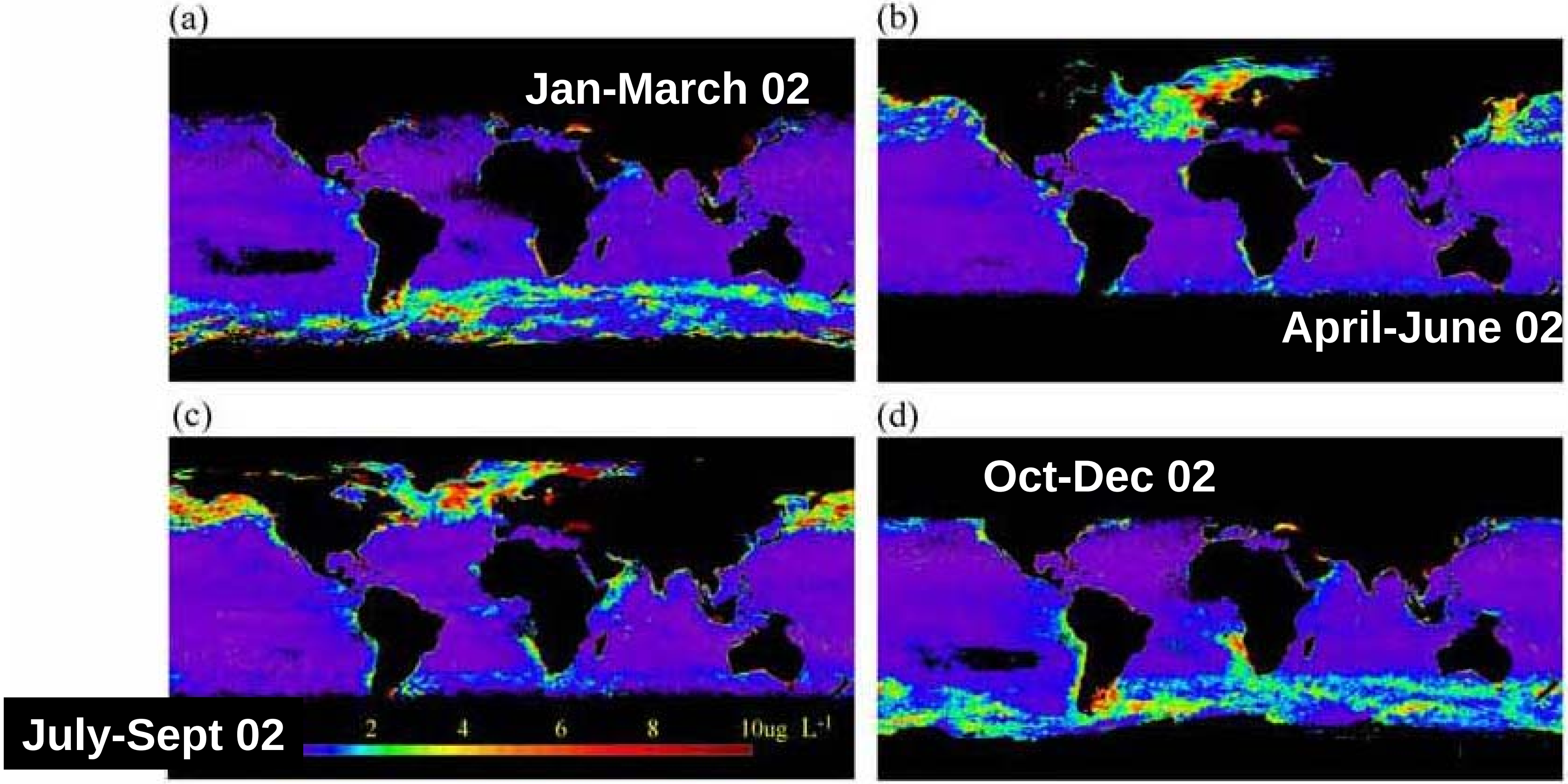
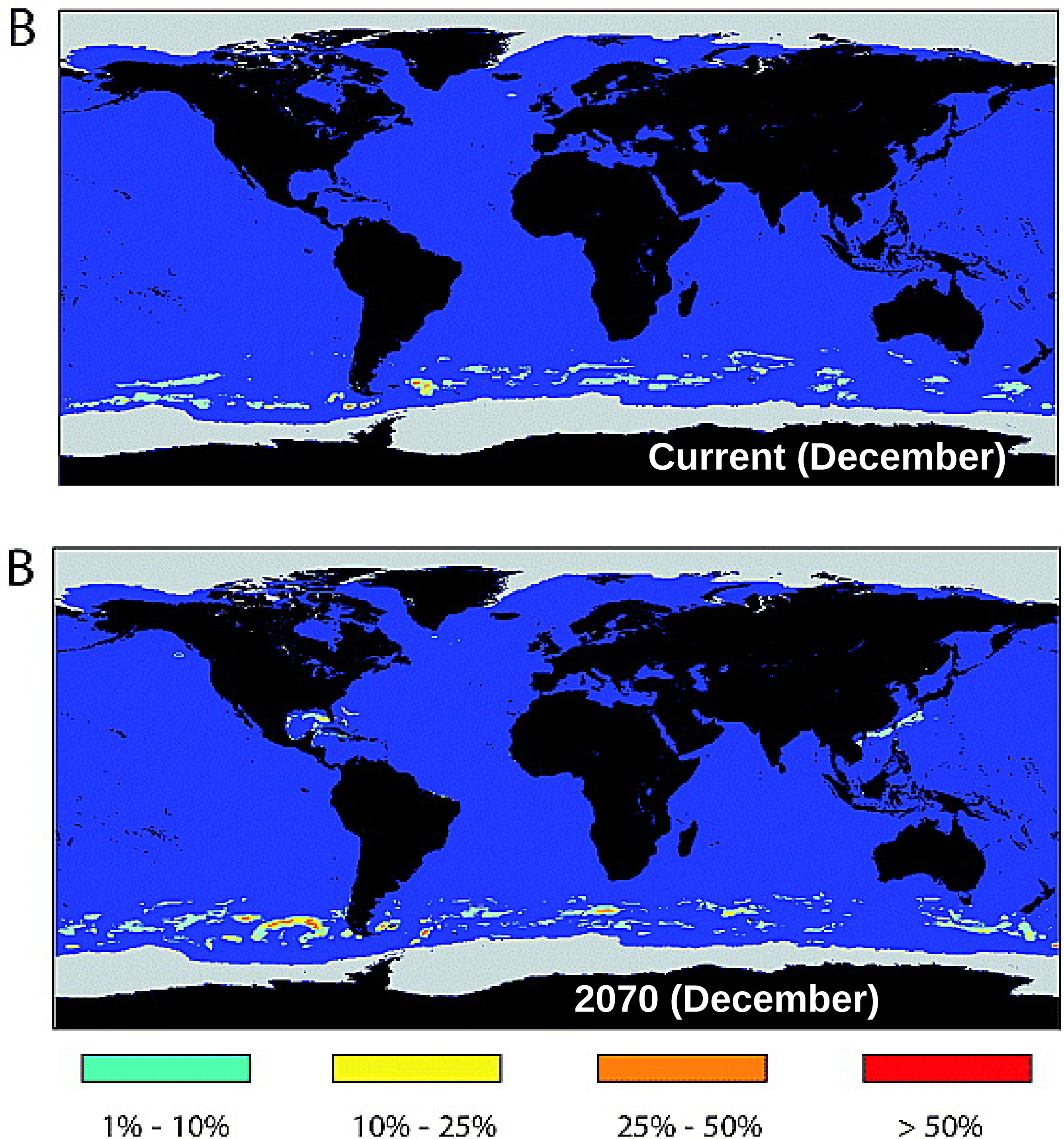


Figure 5. Global composite images of suspended PIC concentration calculated from MODIS/Terra data using two-band calcite algorithm. See text for other details of how the data were processed. The color scale is highlighted in Figure 5c. These data were binned into 36 km and 90 day averages, and thus the standard error will be <0.08 μgPIC L^{-1} (see Table 2), well below the average seawater concentration of ~2 μgPIC L^{-1}. (a) January March. (b) April June. (c) July September. (d) October December.

Balch et al's biogeographical province analysis (after Longhurst)

	Jan-Mar	Apr-Jun	Jul-Sept	Oct-Dec
	-----------------------------------% total PIC-----------------------------------			
Province				
Boreal polar	0	0.8	3.5	0
Atlantic Arctic	0	1.7	2.5	0
Atl subarctic	0	1.8	2.6	0
N Pacific	0.2	2.5	2.8	0.2
Antarctic	10.2	0	0	7
Austral polar	2	0	0	0.2
Biome				
Polar	12.4	6.8	11.4	7.4
North	0.2	6.8	11.4	0.2
South	12.2	0	0	7.2
Westerlies	39.4	38.5	35.2	41.9
Trades	32.8	38.0	35.1	34.8
Coastal	15.3	16.6	18.1	15.8



Probability of bloom

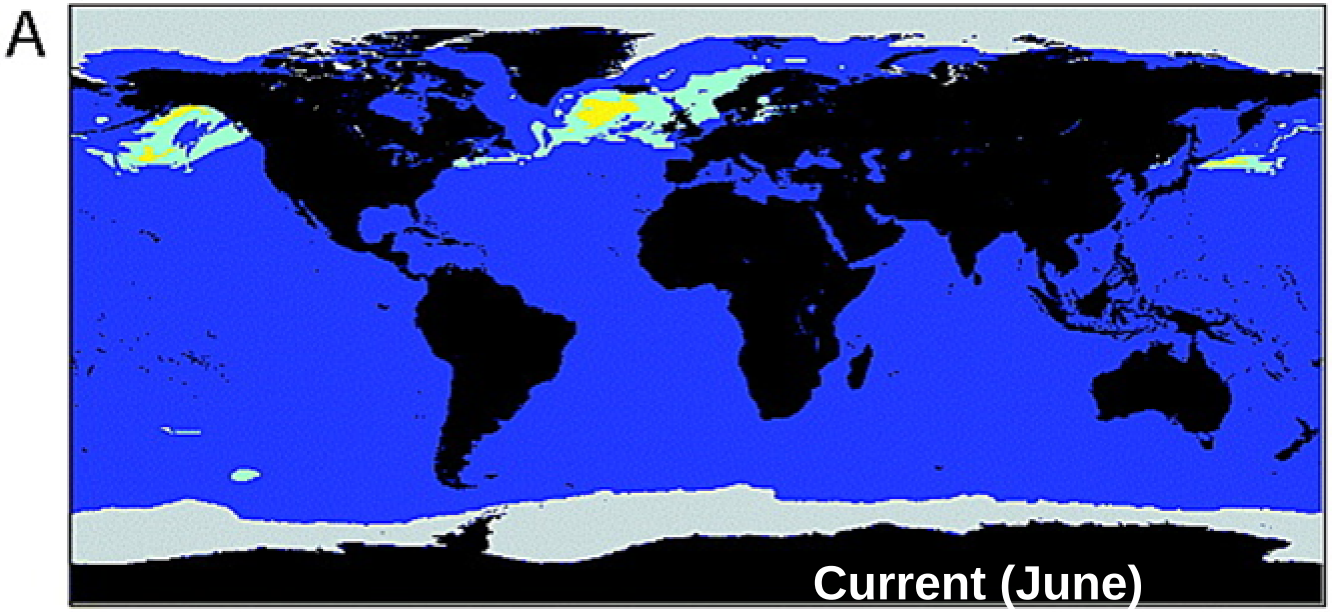
Iglesias-Rodrı´guez, M. D., C. W. Brown, S. C. Doney, J. Kleypas, D. Kolber, Z. Kolber, P. K. Hayes, and P. G. Falkowski, 2002. Representing key phytoplankton functional groups in ocean carbon cycle models: Coccolithophorids, Global Biogeochem. Cycles, 16(4)

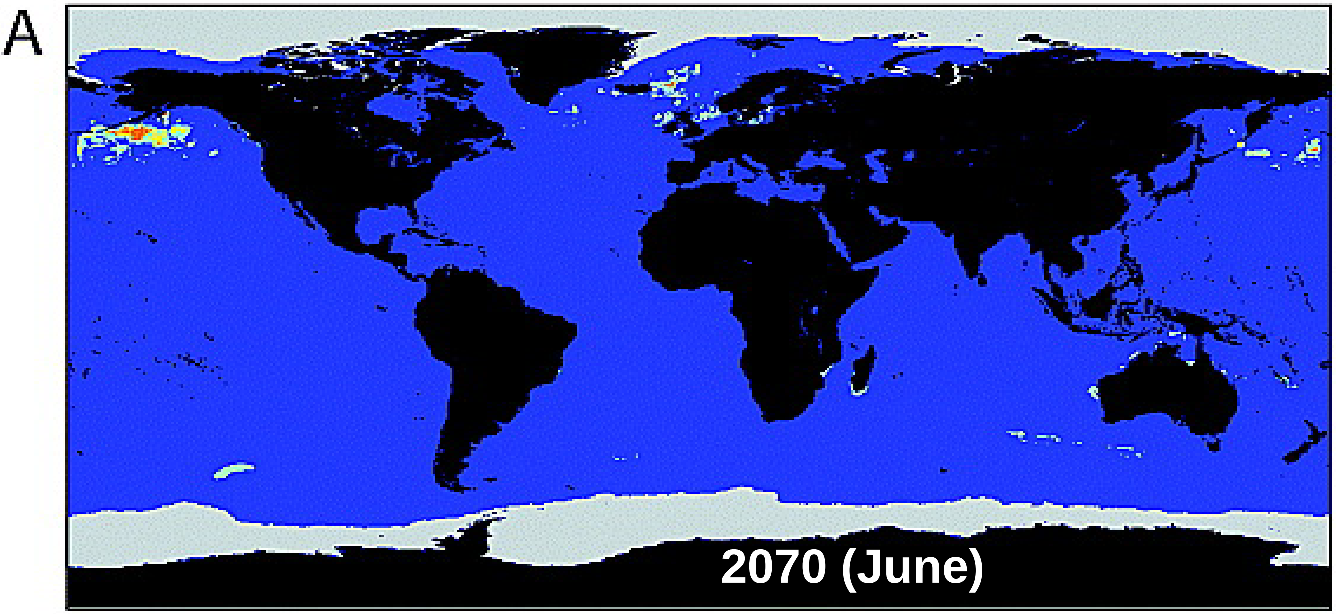
5% decline in bloom area in south

Probability of bloom

Iglesias-Rodriquez et al (2002 GBC)

50% decline in bloom area in north





Uncertainties and priorities for research on coccolithophorids:

North polar region:

- **What factors stimulate cocco blooms?**
- **Will warming and stratification increase bloom frequency?**
- **How will acidification interact with climate change?**

South polar region:

- **Are there cocco blooms in Southern Ocean?**
- **What is the relative importance of coccos as primary producers?**
- **What is their role in S. Ocean foodwebs?**

Research need:

- **Long-term, realistic experimental studies of effects and and potential adaptation to low-pH, low-carbonate environment**

Some other issues:

LTER: shift in community composition from diatom to cryptophyte-dominated response to warming & freshening?

Will increasing pH and other changes affect bacterial activity and community composition?

Bacteria use exoenzymes to hydrolyze particles

Hydrolytic enzymes "unzip" organic coatings protecting diatom frustules

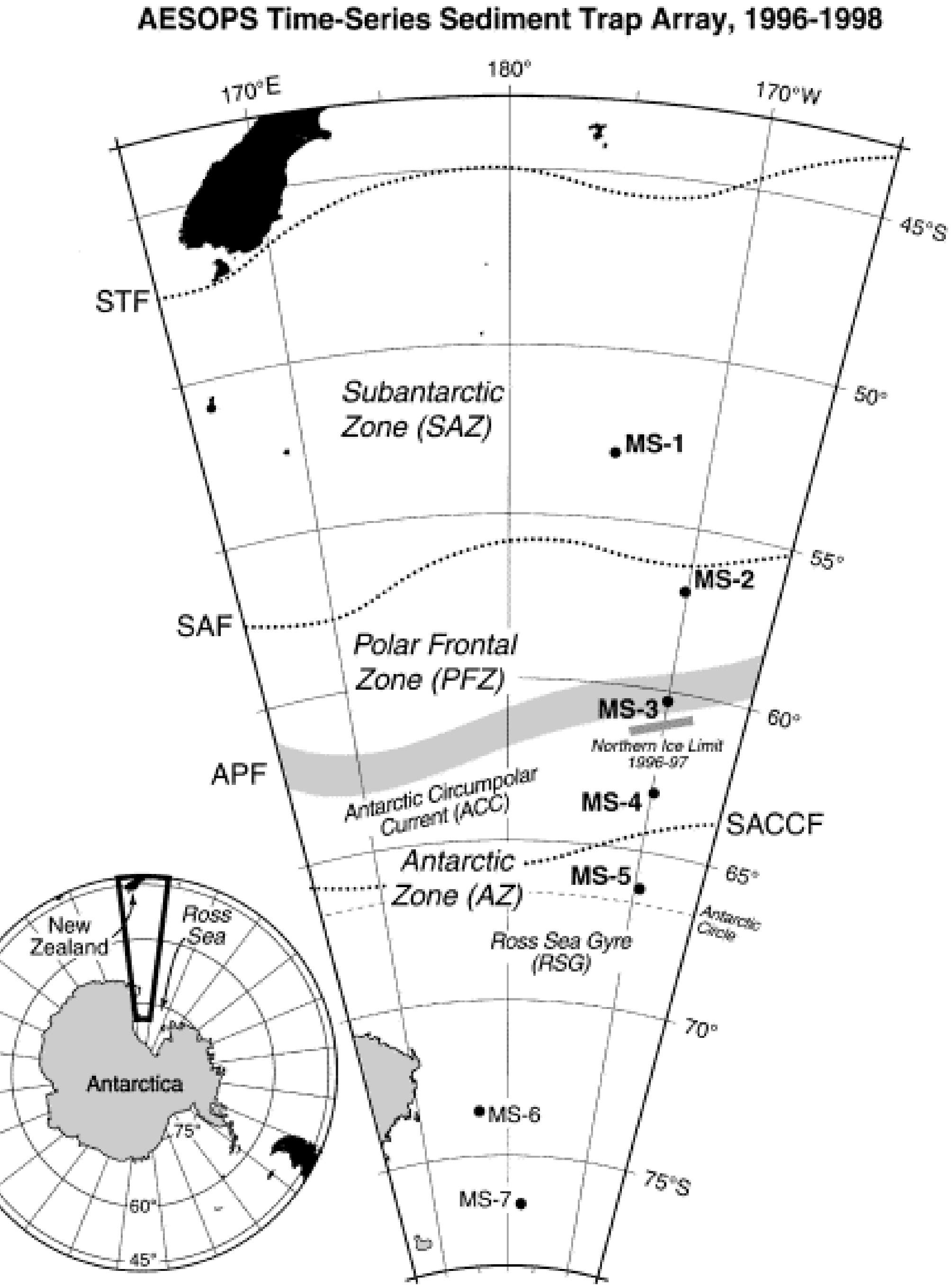
Many enzymes have generally acidic pH optima

Will enzyme activity respond to pH change?
How will this change recycling, remineralization, export of particles?

-- Need experimental work.

Priority Research

- **Feeding ecology and foodweb role of L. helicina.**
- **Interactions between warming and acidification**
- **Long-term experimental studies on responses to slow acidification, increasing DIC, warming**
- **Phytoplankton, zooplankton and bacteria community structure**

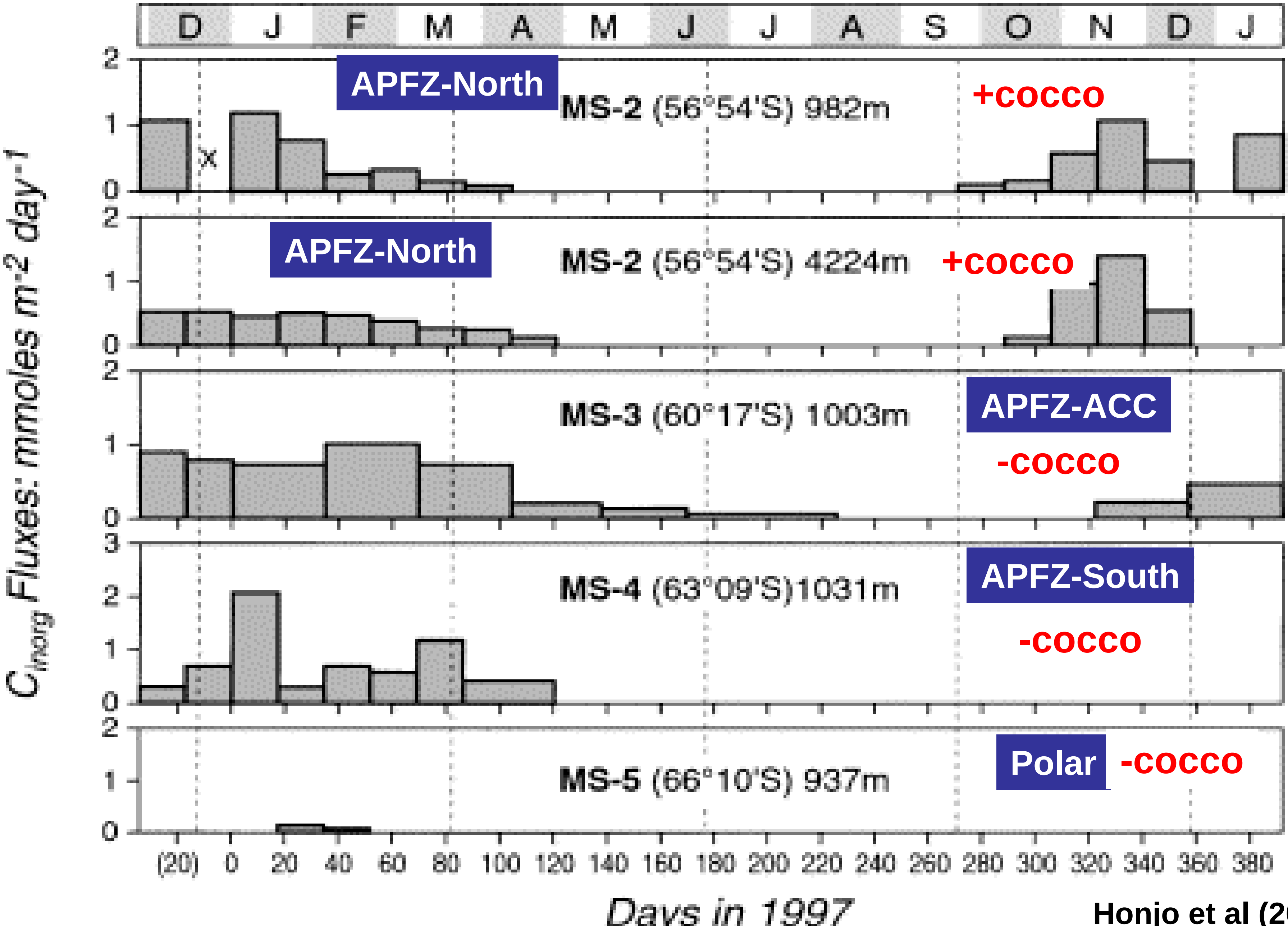


Biological pump: contribution of carbonate fluxes in Antarctic

R. Collier, J. Dymond, S. Honjo, S. Manganini, R. Francois and R. Dunbar. 2000. The vertical flux of biogenic and lithogenic material in the Ross Sea: moored sediment trap observations 1996–1998. Deep Sea Research II 47:3491-3520

S. Honjo, R. Francois, S. Manganini, J. Dymond and R. Collier. 2000. Particle fluxes to the interior of the Southern Ocean in the Western Pacific sector along 170°W Deep Sea Research II 47:3521-3548

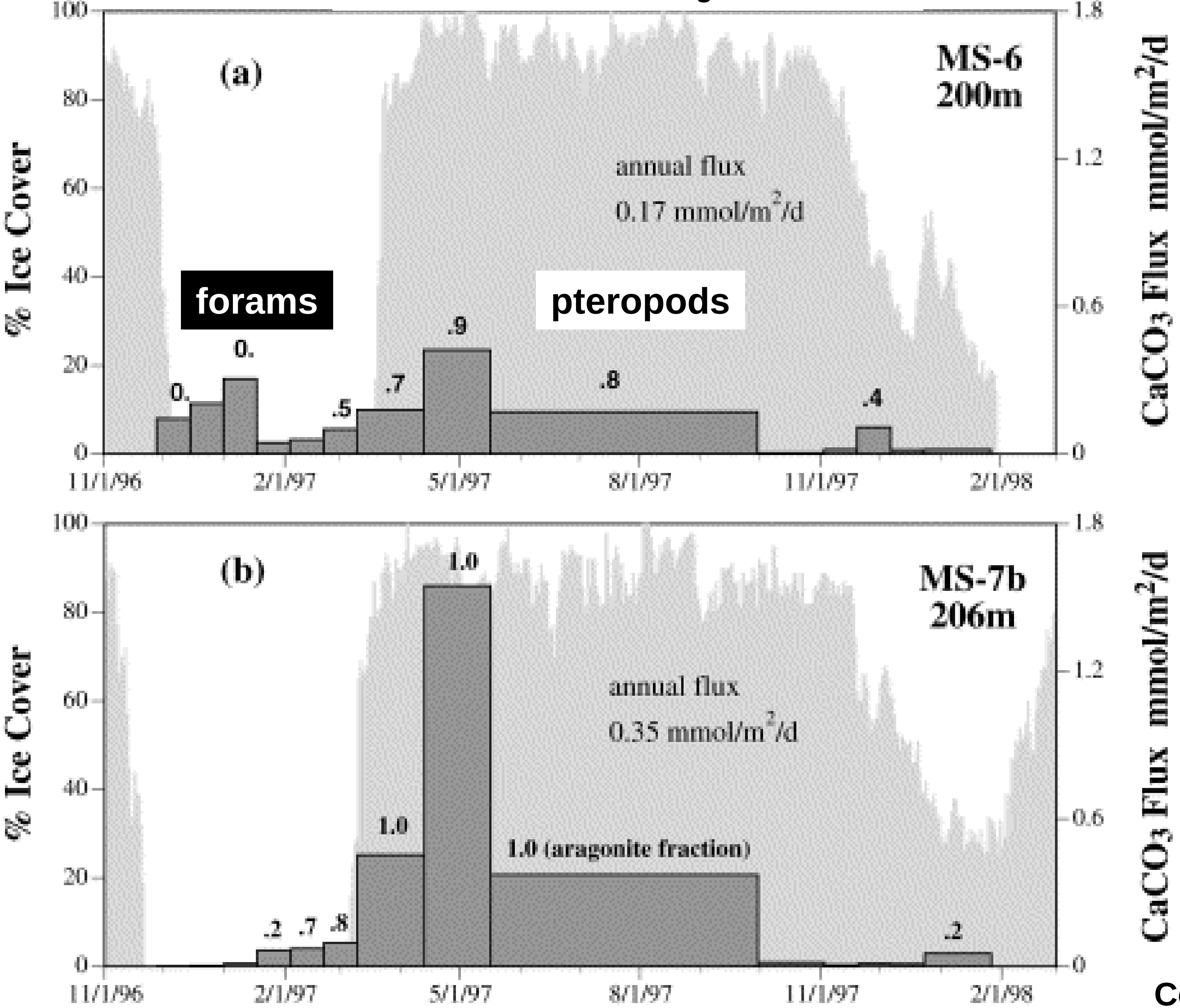
AESOPS CaCO3 flux: Ant Polar Front Zone (APFZ)



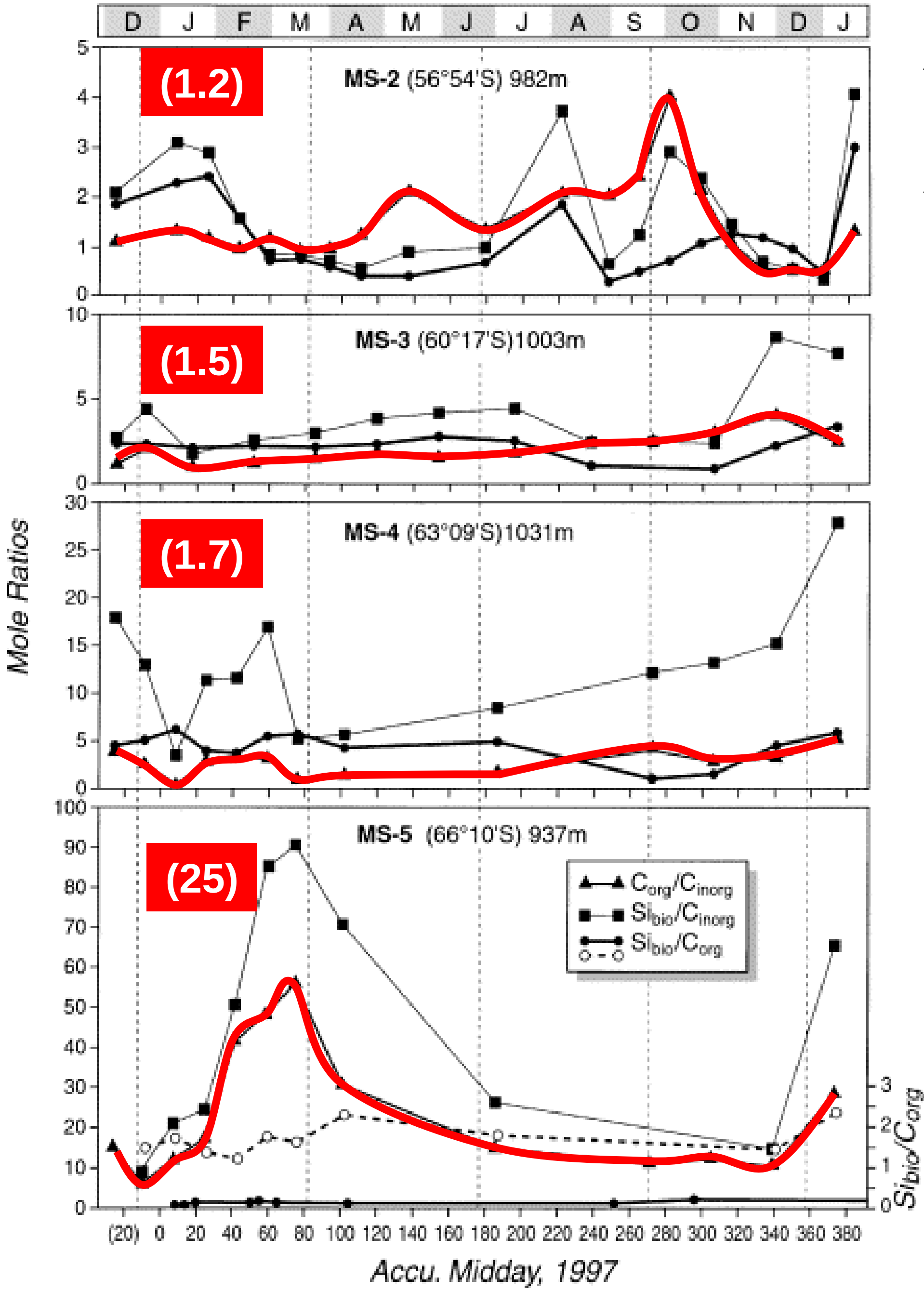
Honjo et al (2000)

AESOPS CaCO3 flux (Ross Sea)

Numbers over bars = aragonite fraction



Collier et al (2000)

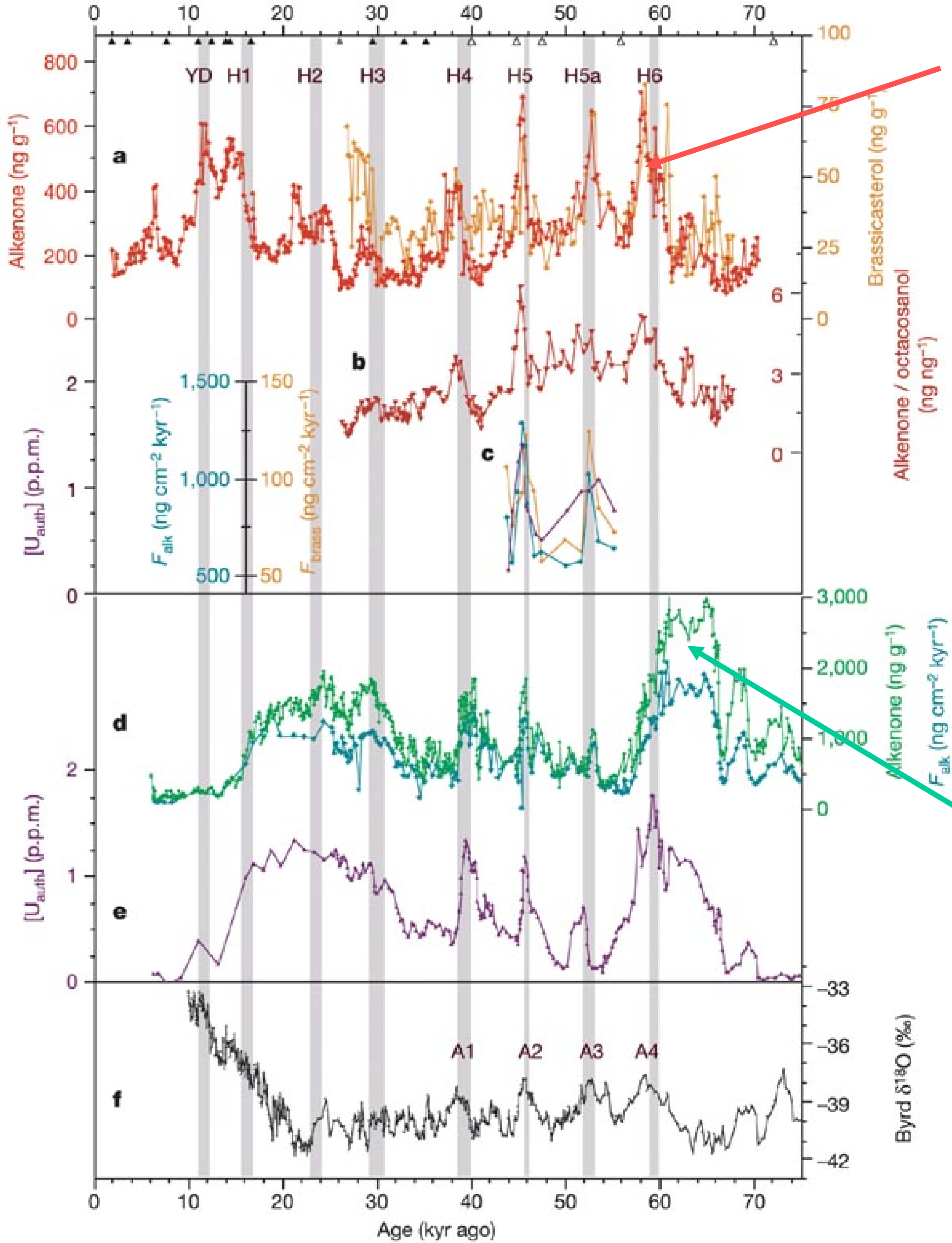


AESOPS C_{org}:C_{inorg} flux ratio

Ant Polar Front Zone (APFZ)

(red lines; box = annual mean)

Region	Annual CaCO3 flux $g\ m^{-2}\ y^{-1}$
APFZ	11-13
EQPAC	19
NABE	11-13



Alkenones (indicator of coccolithophore production)

core MD97-2120, Chatham rise, 45° 32.06' S, 174° 55.85' E;1,210 m

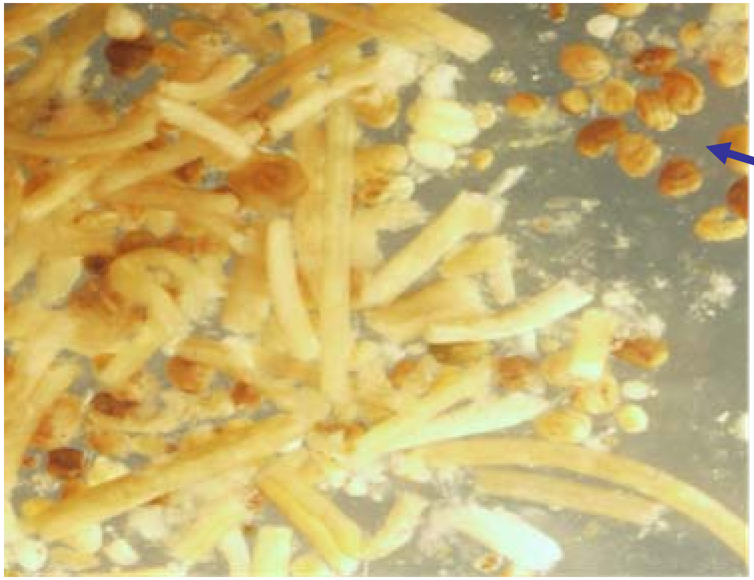
core TN057-21-PC2, Cape Basin 41° 08' S, 7° 49' E; 4,981 m

J.P. Sachs and R.F. Anderson
Increased productivity in the subantarctic ocean during Heinrich events
Nature 434, 1118-1121 (2005)

Biological pump

CaCO3 fluxes

- fluxes north of APFZ comparable to other regions
- lower south of front
- no coccoliths in flux south of front
- pteropods vs forams
- C_{org}: C_{inorg} rain ratio
- fossil record: cocco flux in subantarctic zone



Palmer LTER trap contents
Pteropod fecal pellets?

Some other issues:

LTER: shift in community composition from diatom to cryptophyte-dominated response to warming & freshening?

Will increasing pH and other changes affect bacterial activity and community composition?

Bacteria use exoenzymes to hydrolyze particles

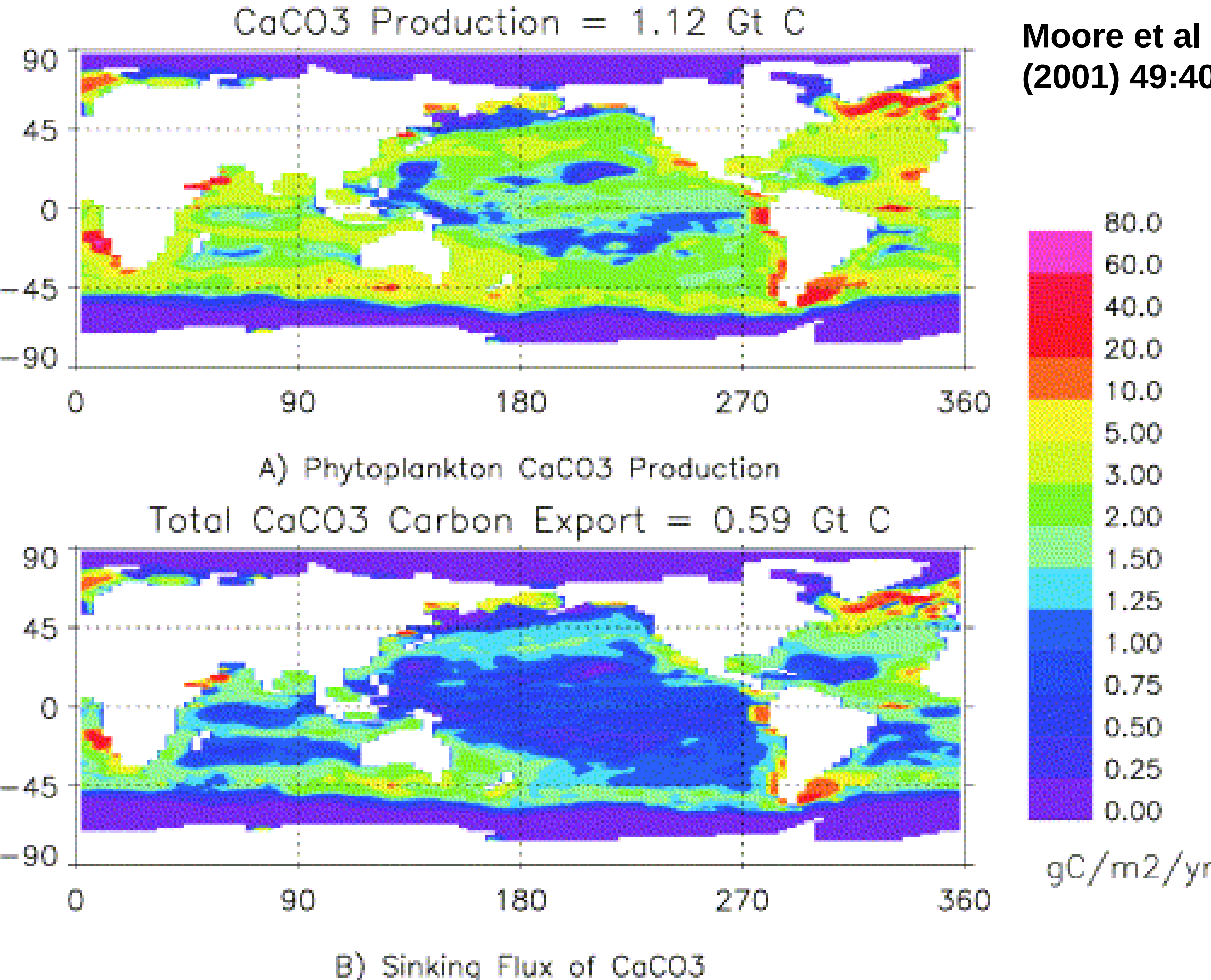
Hydrolytic enzymes “unzip” organic coastings protecting diatom frustules

Many enzymes have generally acidic pH optima

Will enzyme activity respond to pH change?

-- Need experimental work.

Moore et al DSR-2 (2001) 49:403-62



Areas of high reflectance in Southern Ocean:

- **Sampled on 3 British AMT cruises**
- **PIC is elevated in these regions**
- **Also areas of high wind and intense turbulence**
- **Bubble formation could also cause the reflectance**
- **This will be tested by observation next February**

"One hypothesis is that the high levels result from higher winds, generating more bubbles in the surface layer, hence higher optical backscattering" **-- Barney Balch, pers comm.**

"I believe that most of the high reflectance conditions are due to the presence of coccolithophorid blooms because of their appropriate latitudinal position and their distance from land. Others, however, are not as convinced…Unfortunately, no one has collected samples within one of these high reflectance features in the Southern Ocean to ascertain their cause." – Chris Brown, pers comm

Some scattered collections of coccos at various Antarctic locations.
But No direct observations of coccolithophorid blooms in S. Ocean …?