CROSSING DECADAL TIME SCALES - ANTARCTIC

Rapid Climate Warming and Ecosystem Response on the West Antarctic Peninsula from Microbes to Elephant Seals and Penguins

Gordon Conference on Polar Marine Science
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http://pal.lternet.edu/

MBL VIMS LTER NSF

OUTLINE:

1. Climate change along the WAP
2. Regional climatologies and variability for selected oceanographic properties
3. Ecosystem response to climate change
4. Bacteria – phytoplankton relationships

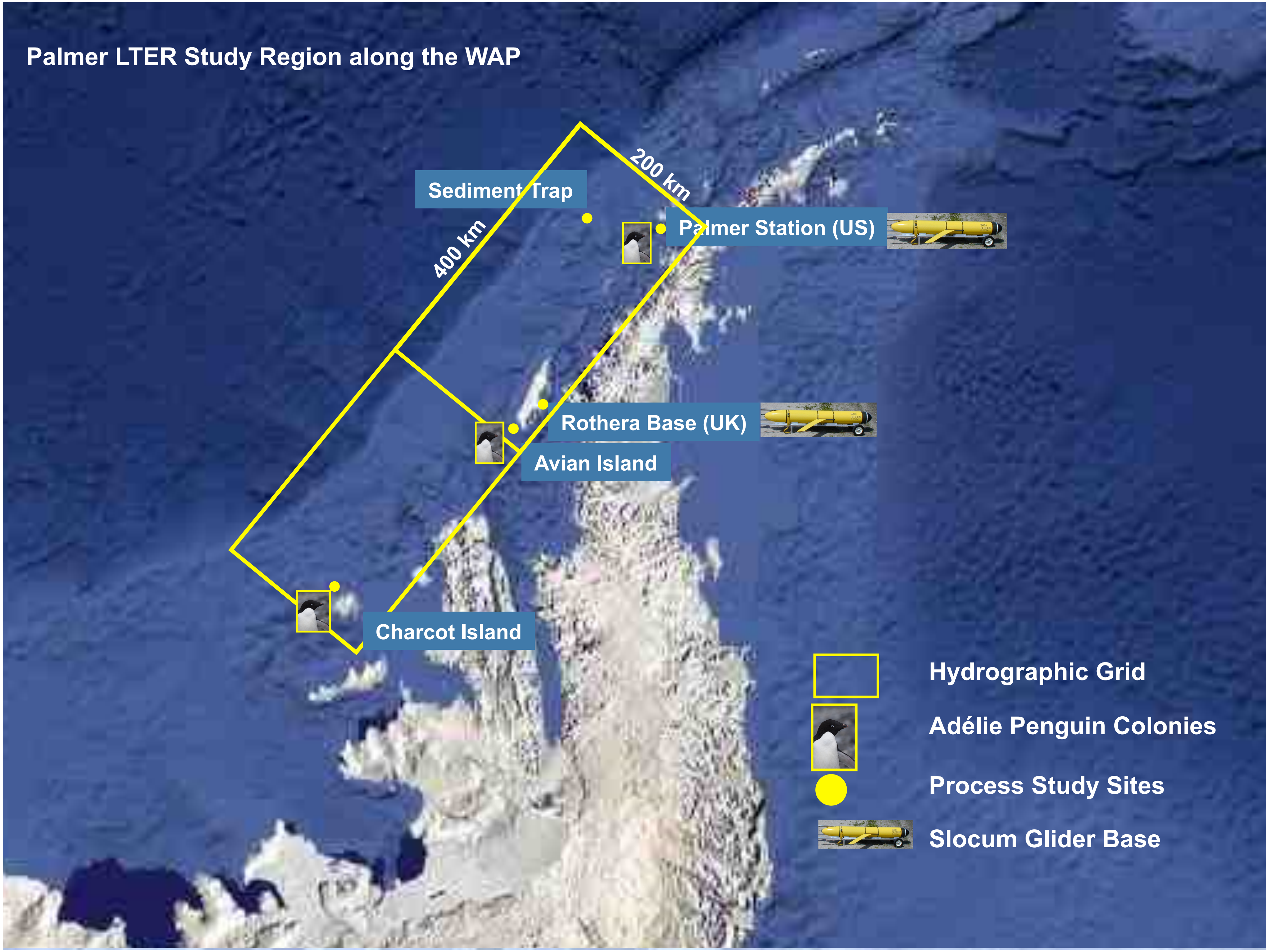
CONTRIBUTORS:

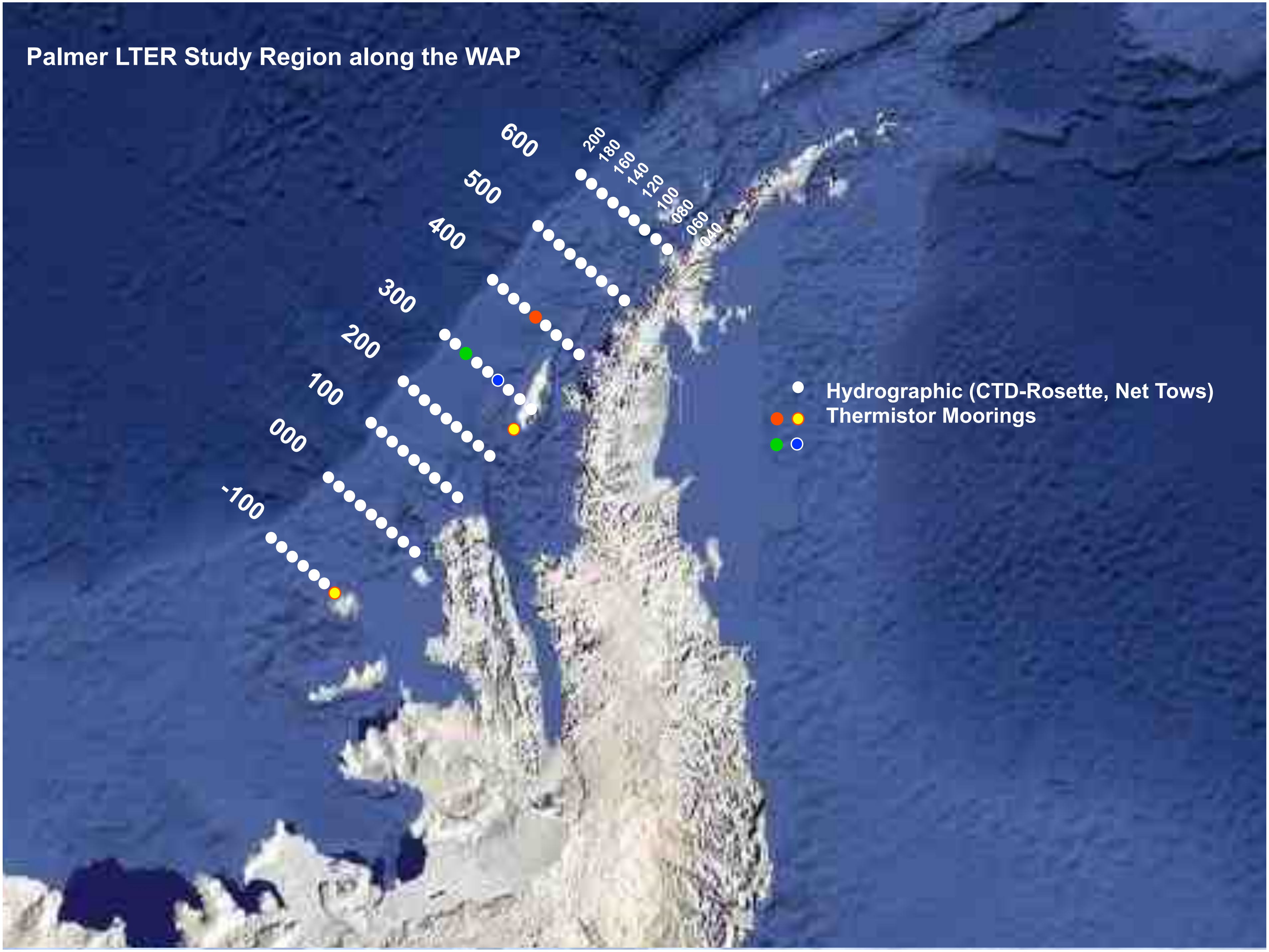
Bill Fraser, David Kirchman, Doug Martinson, Martin Montes-Hugo, Xelu Moran, Alison Murray, Langdon Quetin, Robin Ross, Oscar Schofield, Sharon Stammerjohn, Debbie Steinberg, Maria Vernet.

Karen Baker: Information Management

PAL-LTER DataZoo: http://oceaninformatics.ucsd.edu/datazoo/

Palmer Station and LM GOULD
seen from Torgerson Island
Adélie penguin colony (75% decline since 1975)


Palmer LTER Study Region along the WAP
200 km
400 km
Sediment Trap
Palmer Station (US)
Rothera Base (UK)
Avian Island
Charcot Island
Hydrographic Grid
Adélie Penguin Colonies
Process Study Sites
Slocum Glider Base


Palmer LTER Study Region along the WAP
600
500
400
300
200
100
000
-100
200
180
160
140
120
100
080
060
040
Hydrographic (CTD-Rosette, Net Tows)
Thermistor Moorings

ARSV Laurence M GOULD

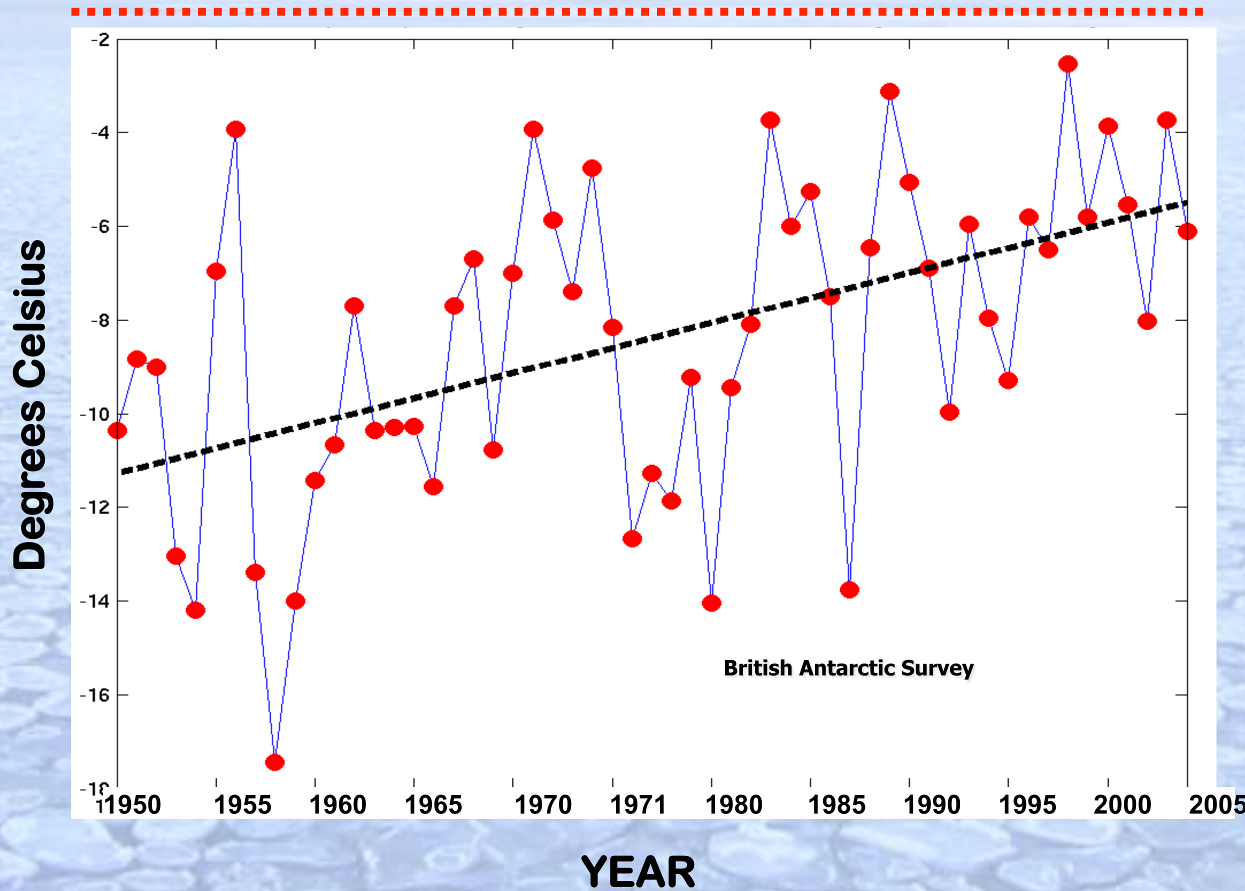
1998 – 2010 ???

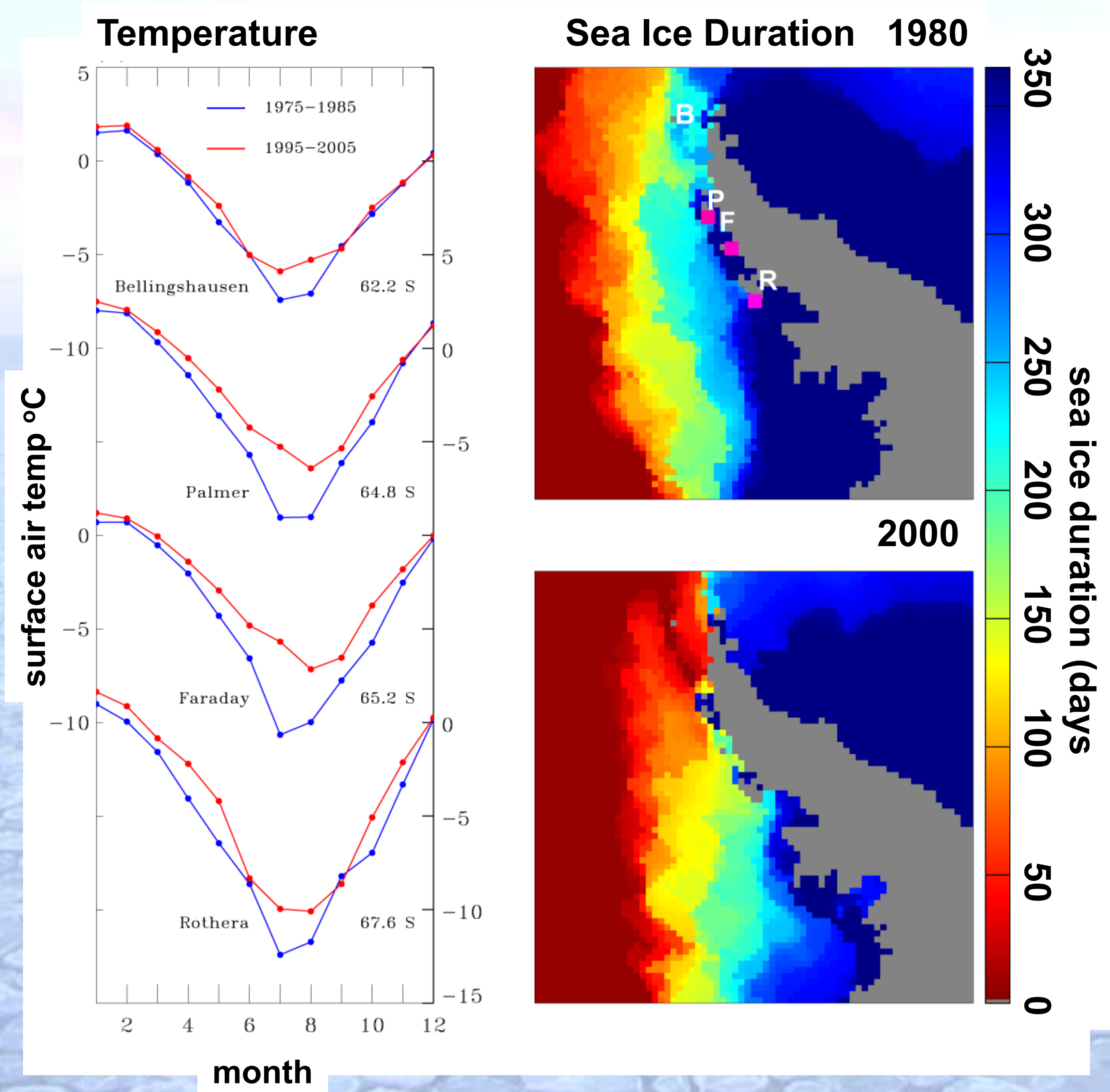
1. Climate change along the WAP

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

+1.1°C per decade: 6°C (11F) since 1950: 5 x global average

-1.8°C (sea ice formation)

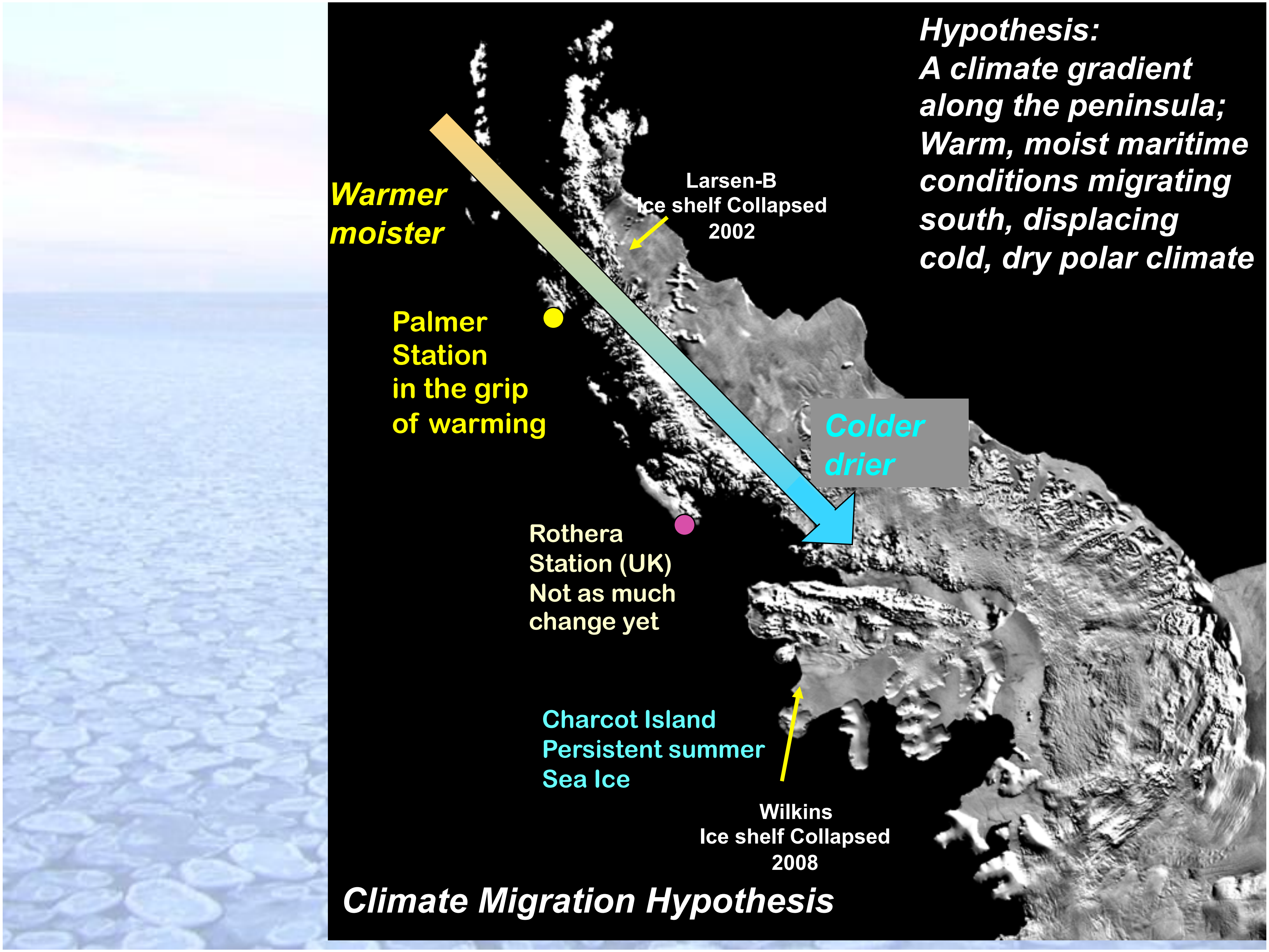




Surface air temperature and sea duration gradients along the WAP

Warmer and less sea ice cover in the north; colder and more sea ice in the south.

Reduction in sea ice duration: 90 days since 1978



Hypothesis:
A climate gradient along the peninsula;
Warm, moist maritime conditions migrating south, displacing cold, dry polar climate
Warmer moister
Larsen-B Ice shelf Collapsed 2002
Palmer Station in the grip of warming
Colder drier
Rothera Station (UK) Not as much change yet
Charcot Island Persistent summer Sea Ice
Wilkins Ice shelf Collapsed 2008
Climate Migration Hypothesis

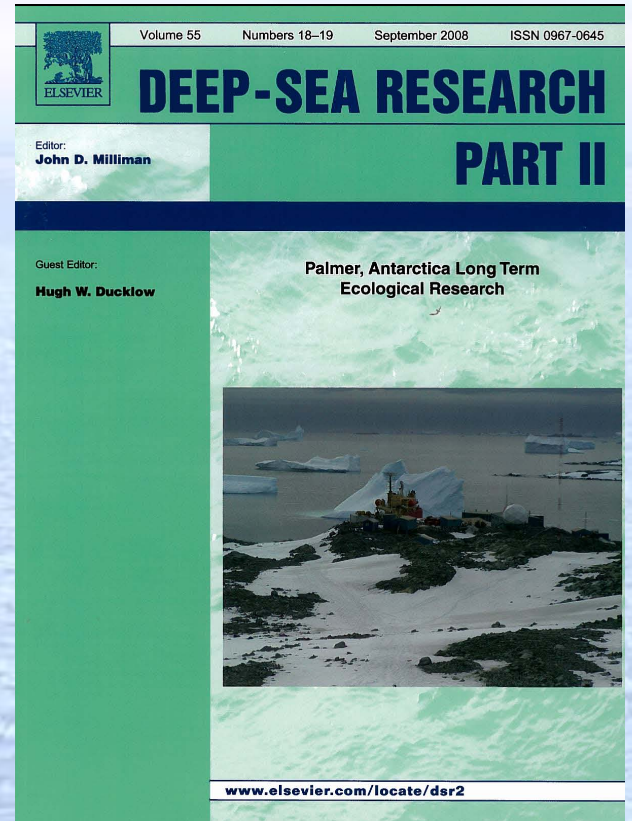
2. Regional climatologies and variability for selected oceanographic properties

Derived from hydrographic grid surveys, 1993 – 2004

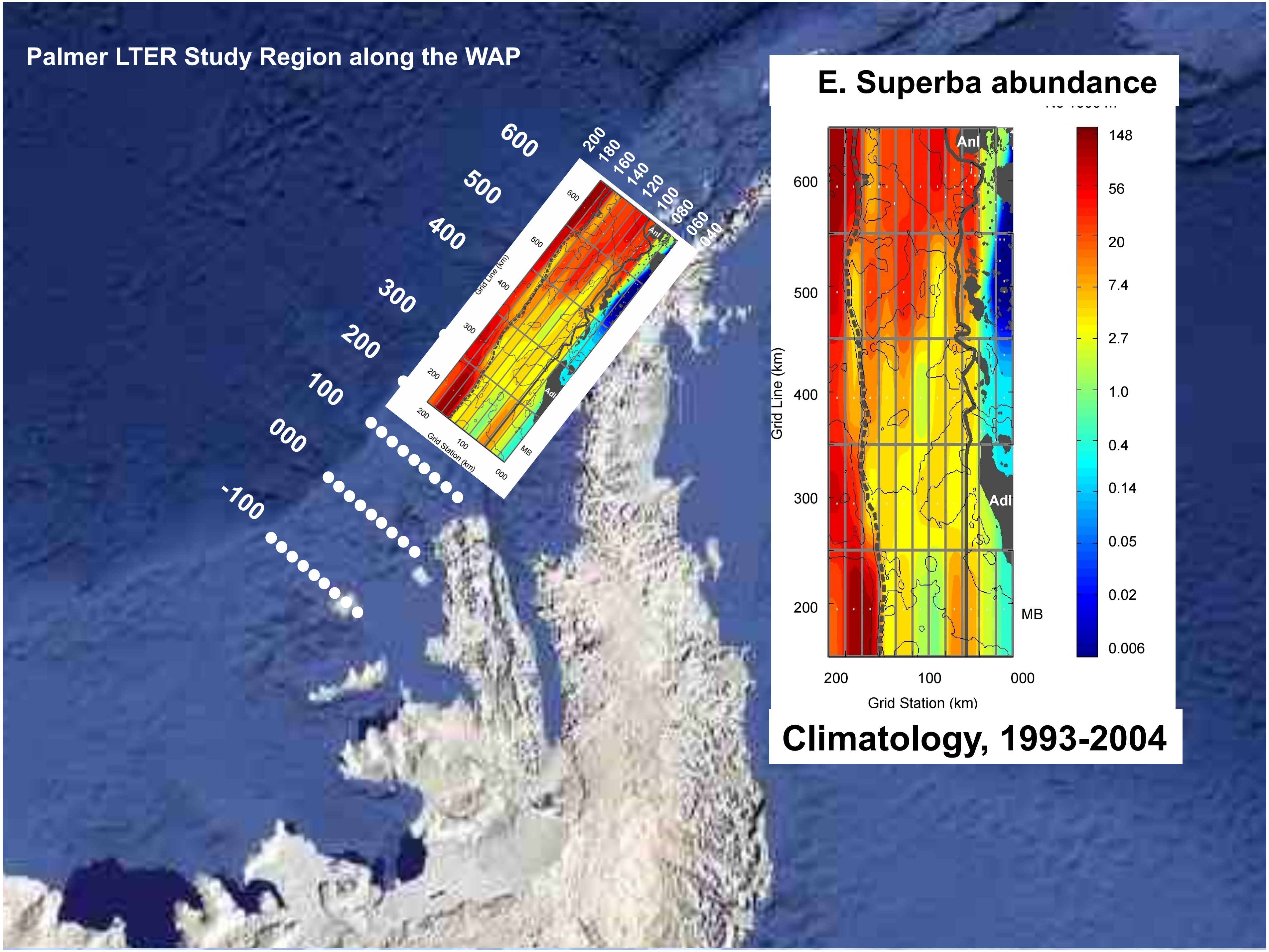
Means and variability of spatio-temporal distributions (climatologies)

Empirical orthogonal function (EOF) analyses reveal major modes of variability.

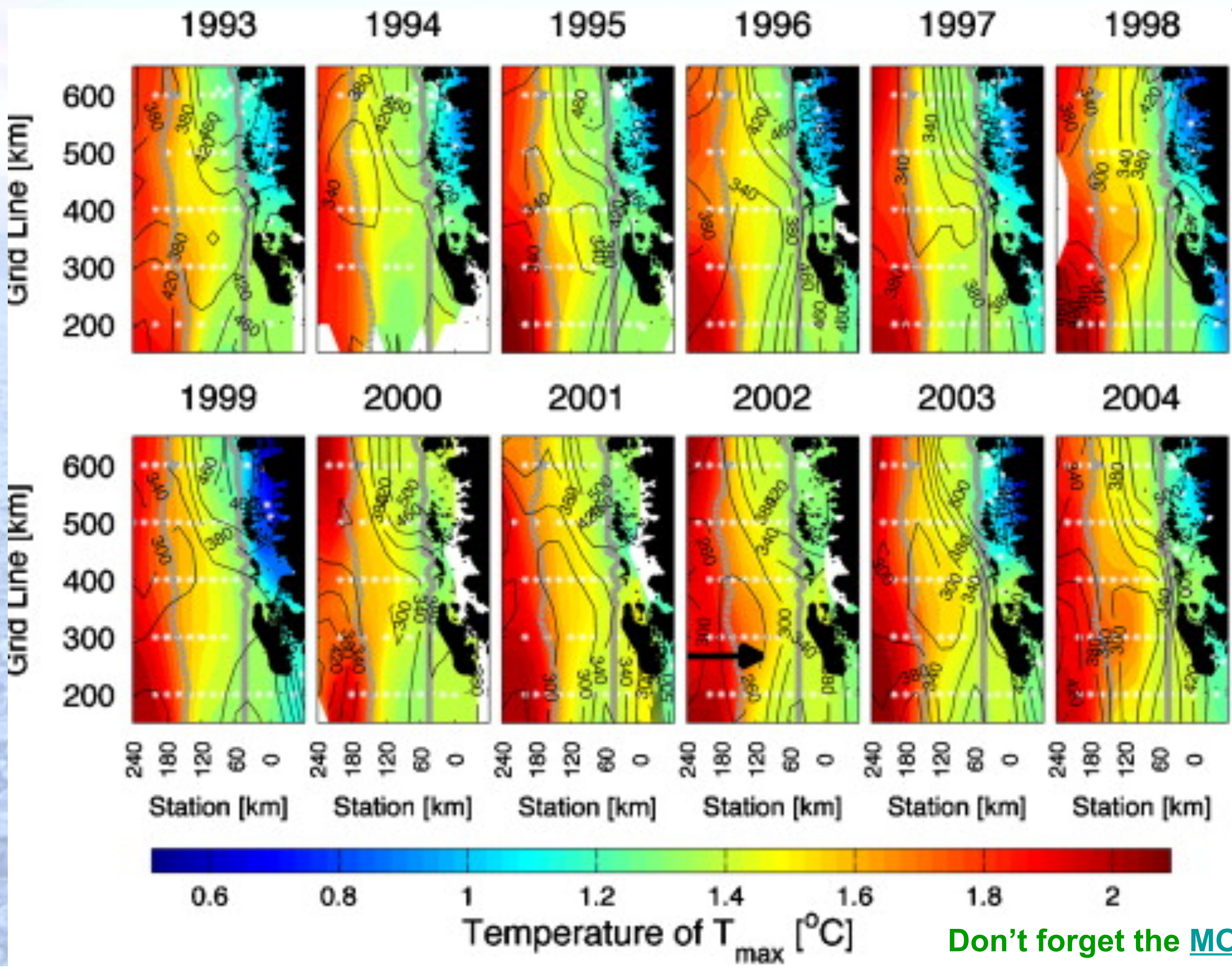
Canonical correlation analyses reveal interactions between variables.



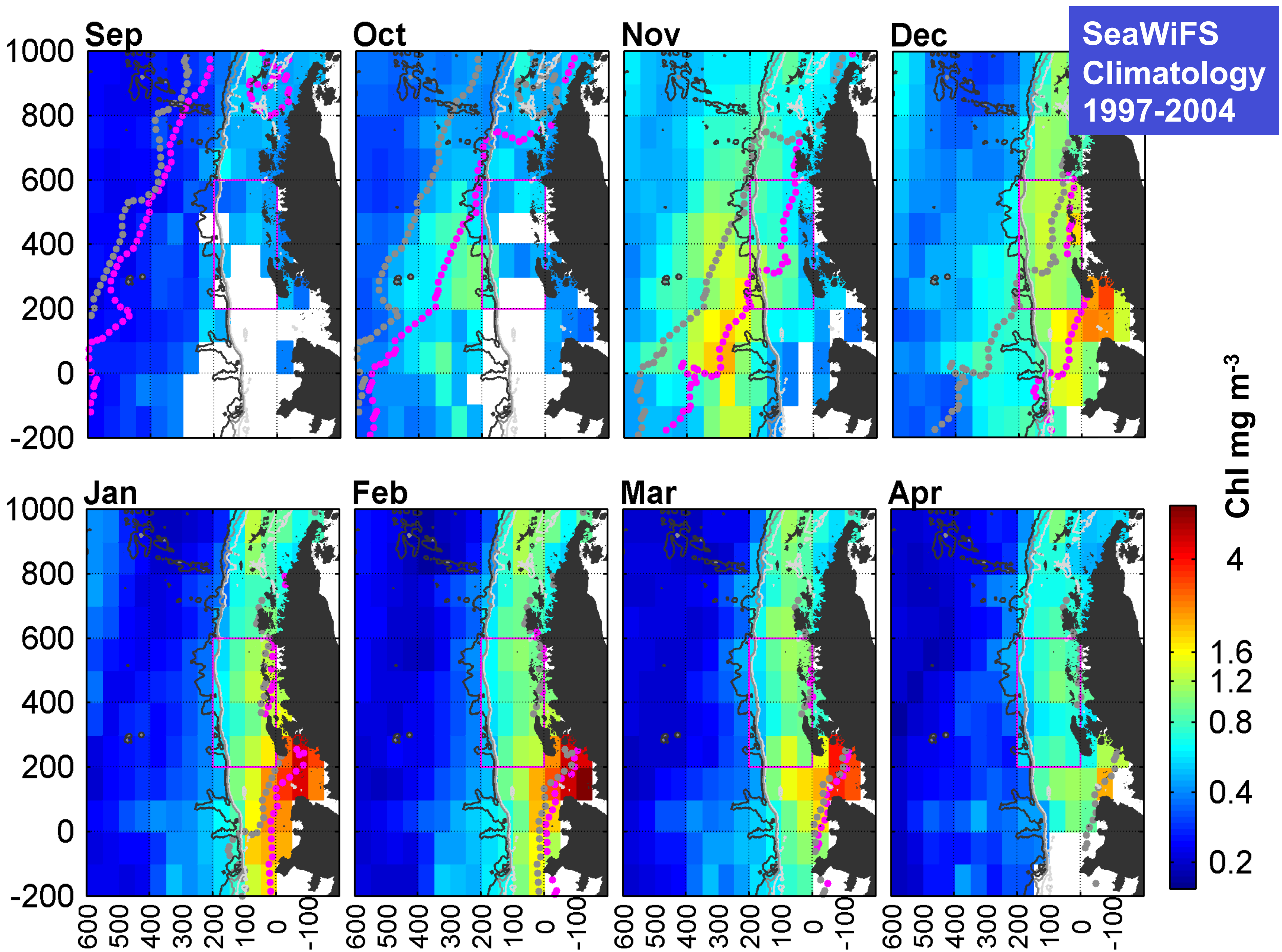
Deep-Sea Research Part II
55 (18-19) (2008)


Palmer LTER Study Region along the WAP
600
500
400
300
200
100
000
-100
200
180
160
140
120
100
080
060
040
E. Superba abundance
Anl
Adl
MB
Grid Line (km)
Grid Station (km)
600
500
400
300
200
100
000
148
56
20
7.4
2.7
1.0
0.4
0.14
0.05
0.02
0.006
Climatology, 1993-2004

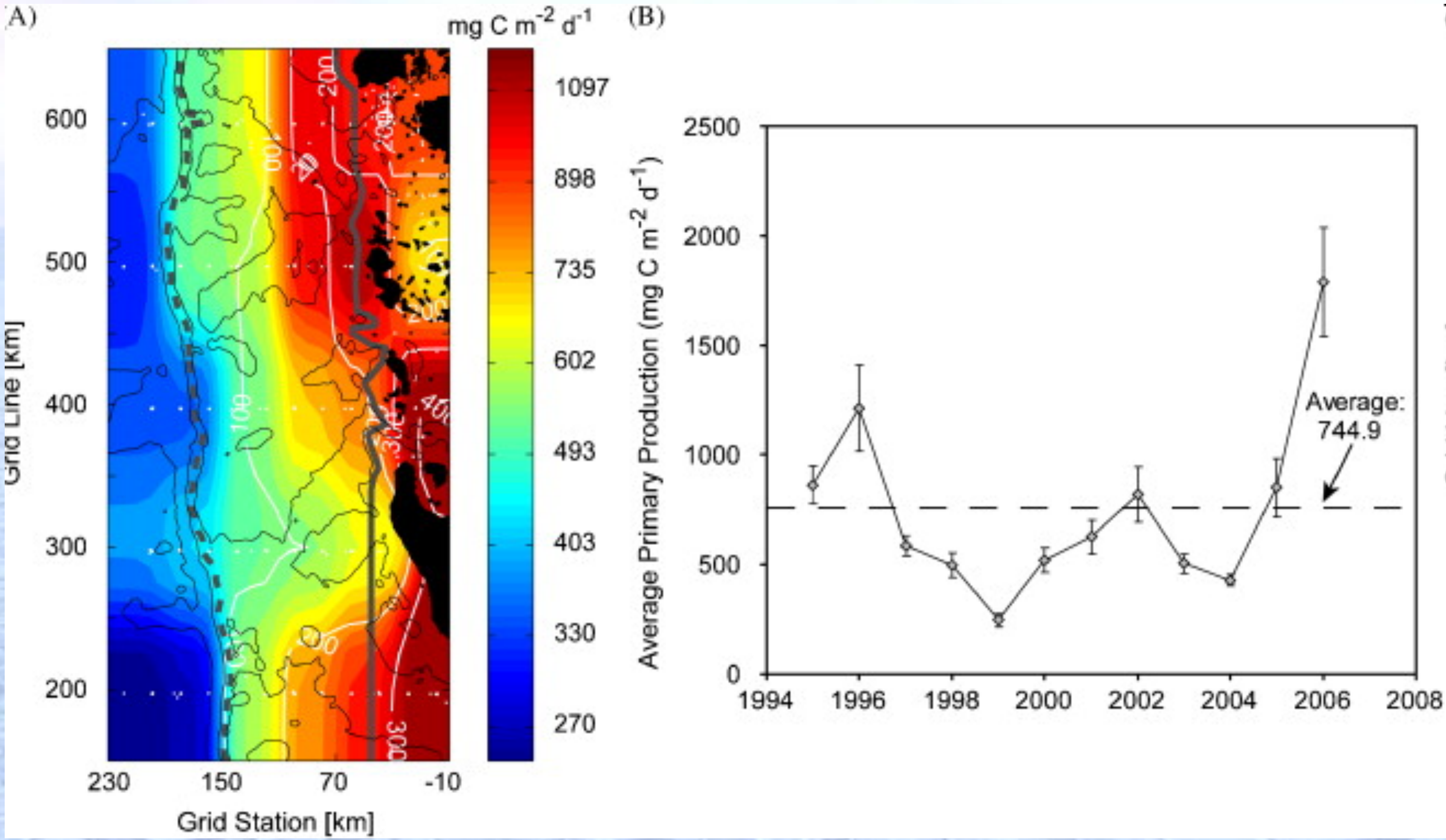
Tmax – warmest temperature in water column – indicator of ACDW input

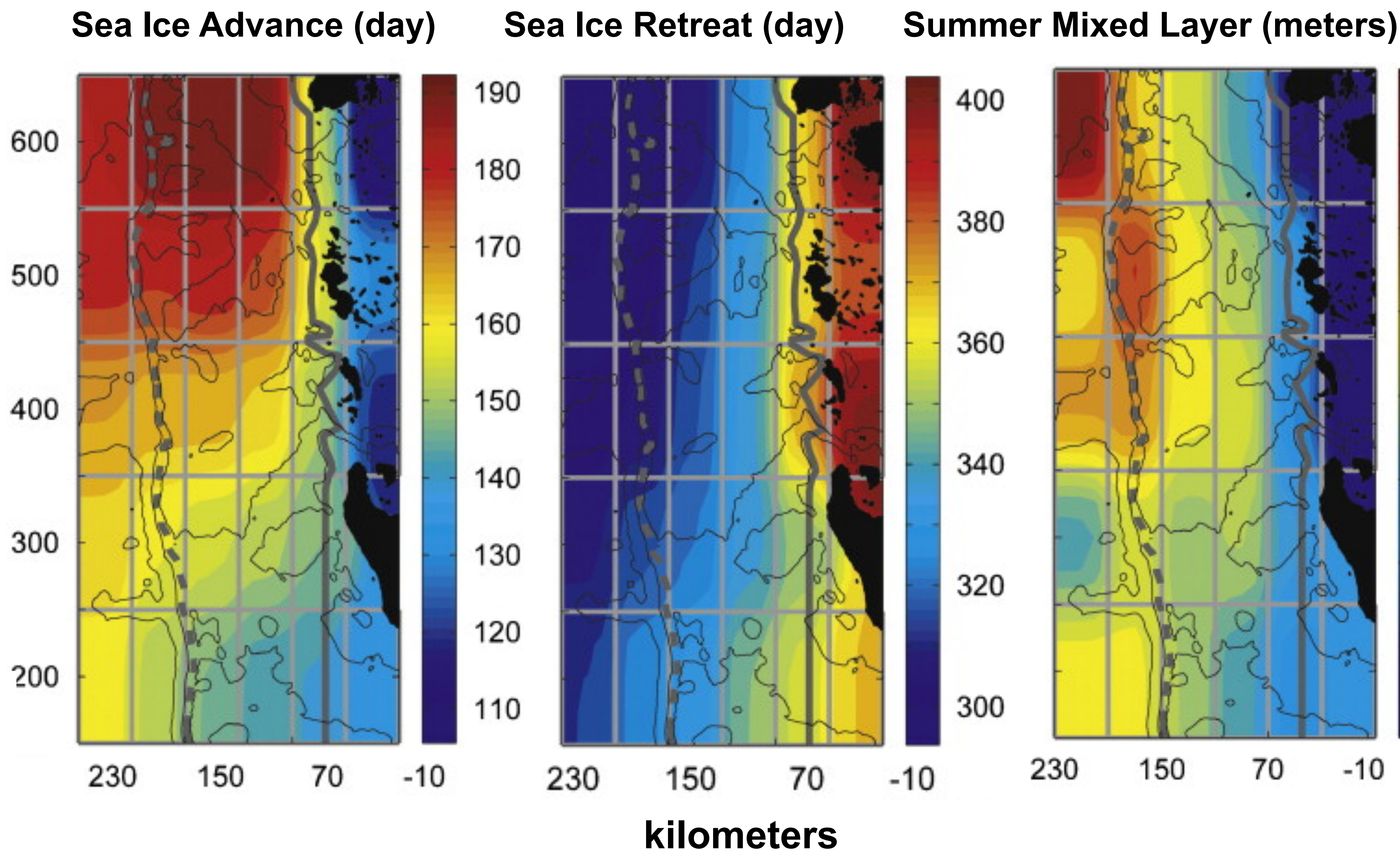


Don't forget the MOVIE!

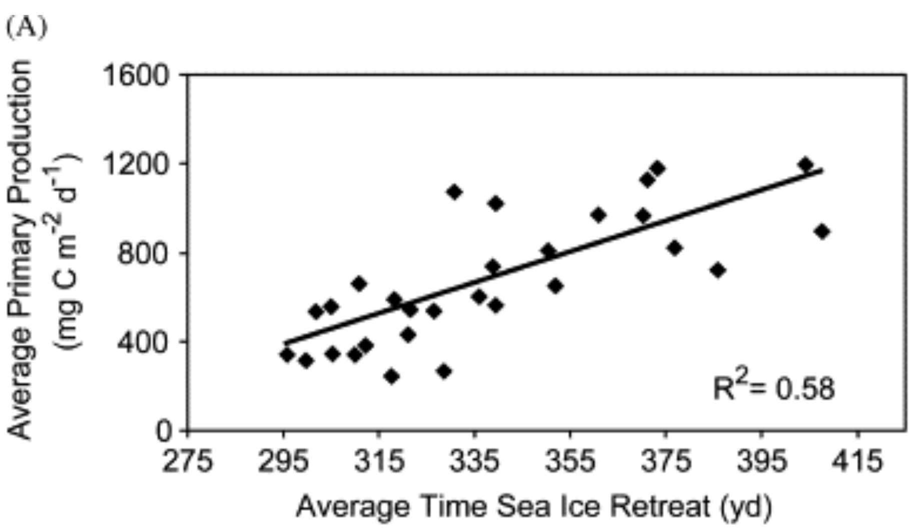

SeaWiFS Climatology 1997-2004
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
1000
800
600
400
200
0
-200
600
500
400
300
200
100
0
-100
Chl mg m-3
4
1.6
1.2
0.8
0.4
0.2

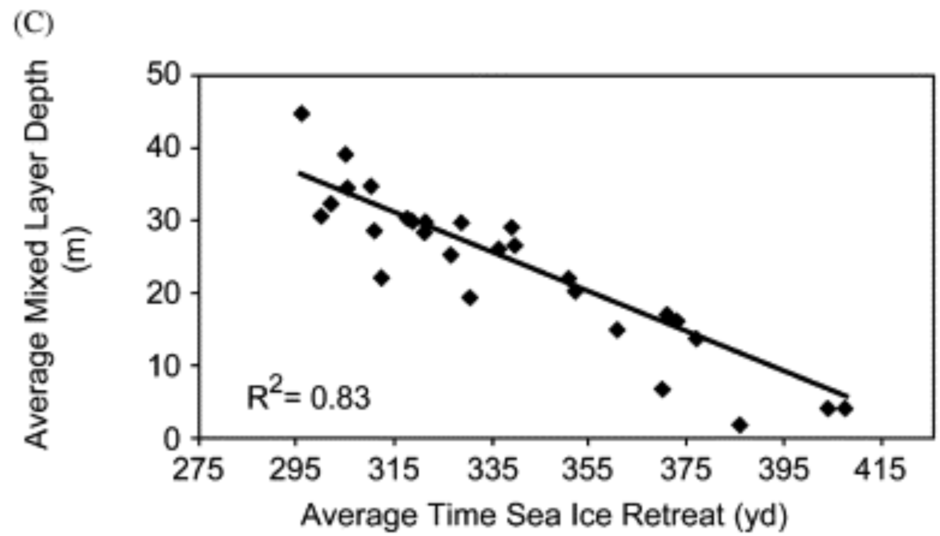
Primary Production (January) 1995-2006

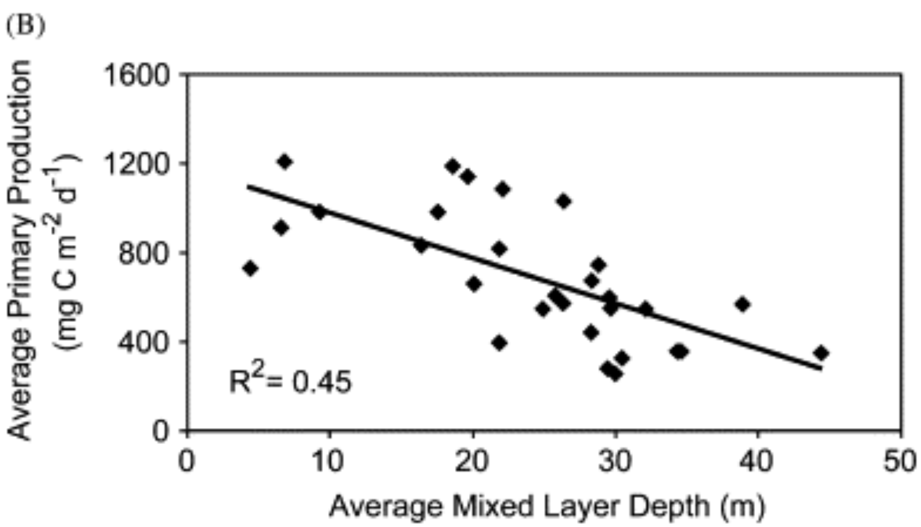




Sea Ice Advance (day)
Sea Ice Retreat (day)
Summer Mixed Layer (meters)
600
500
400
300
200
190
180
170
160
150
140
130
120
110
400
380
360
340
320
300
40
35
30
25
20
15
10
5
230
150
70
-10
kilometers

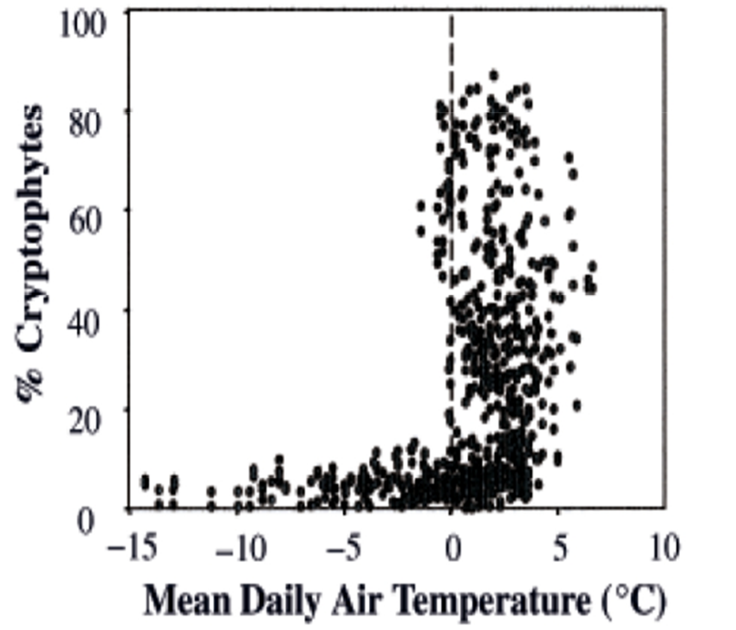


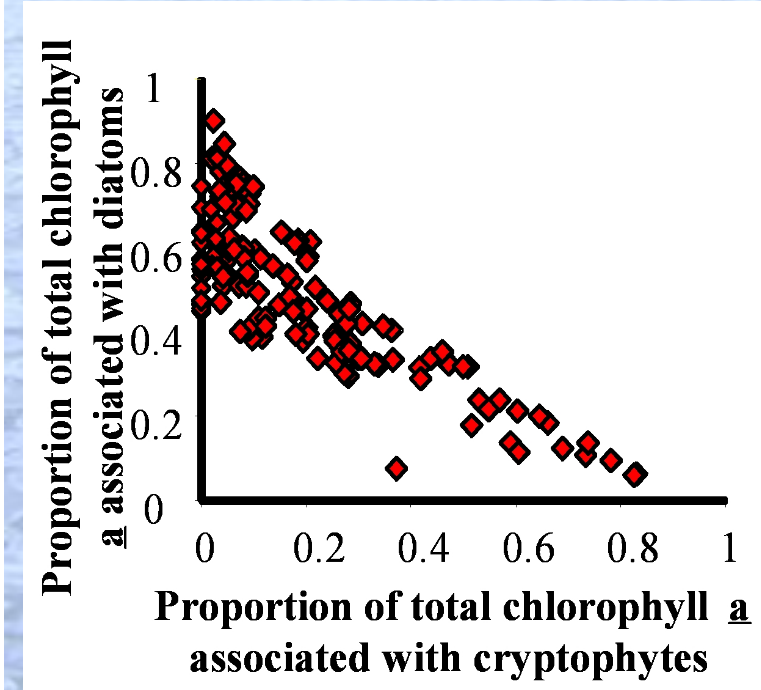


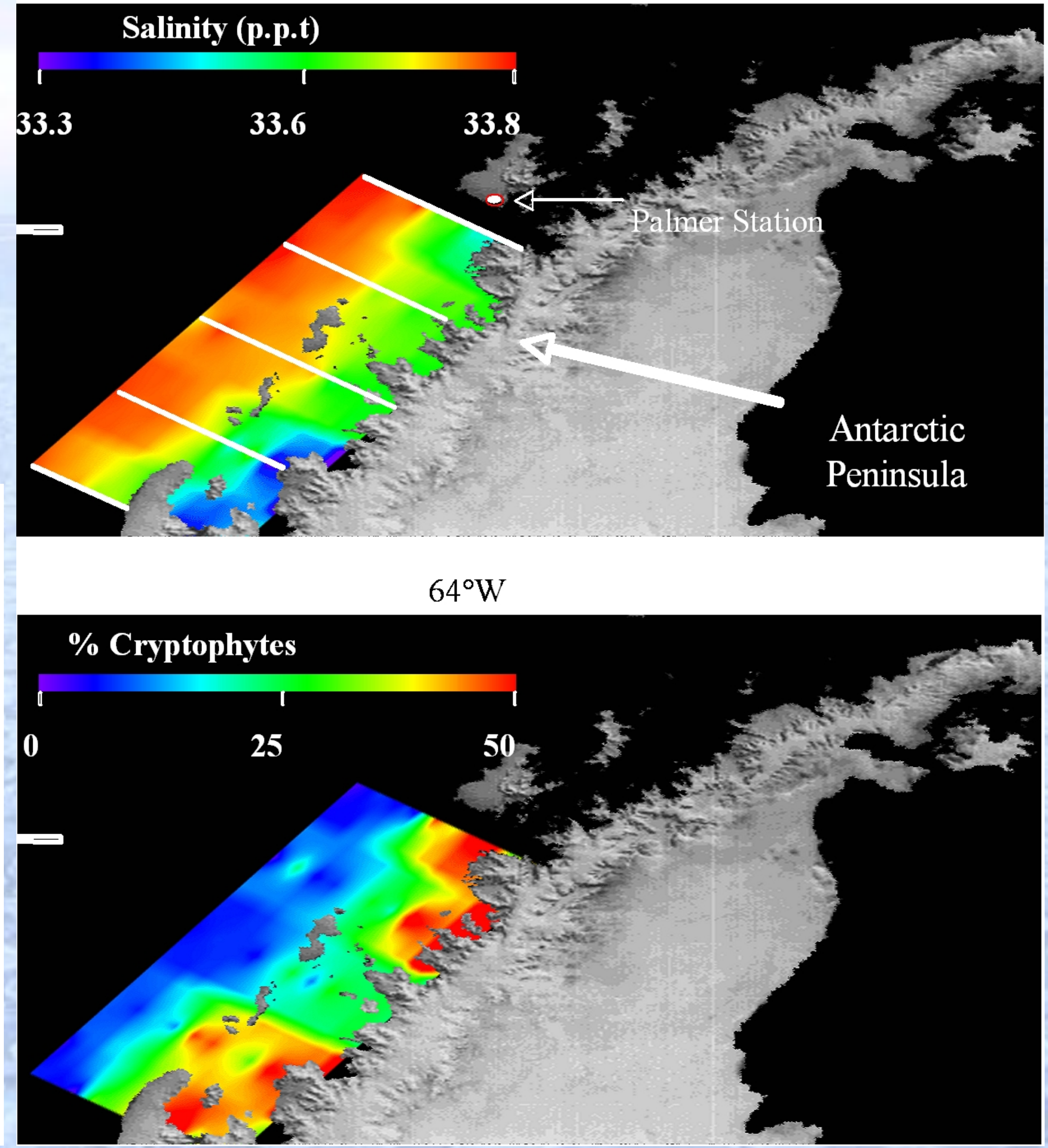


The primary production climatology in time and space is driven by interactions among sea ice dynamics and mixed layer depth

Changing phytoplankton community composition:
Shifts from diatoms to cryptophytes (Moline et al 2004)







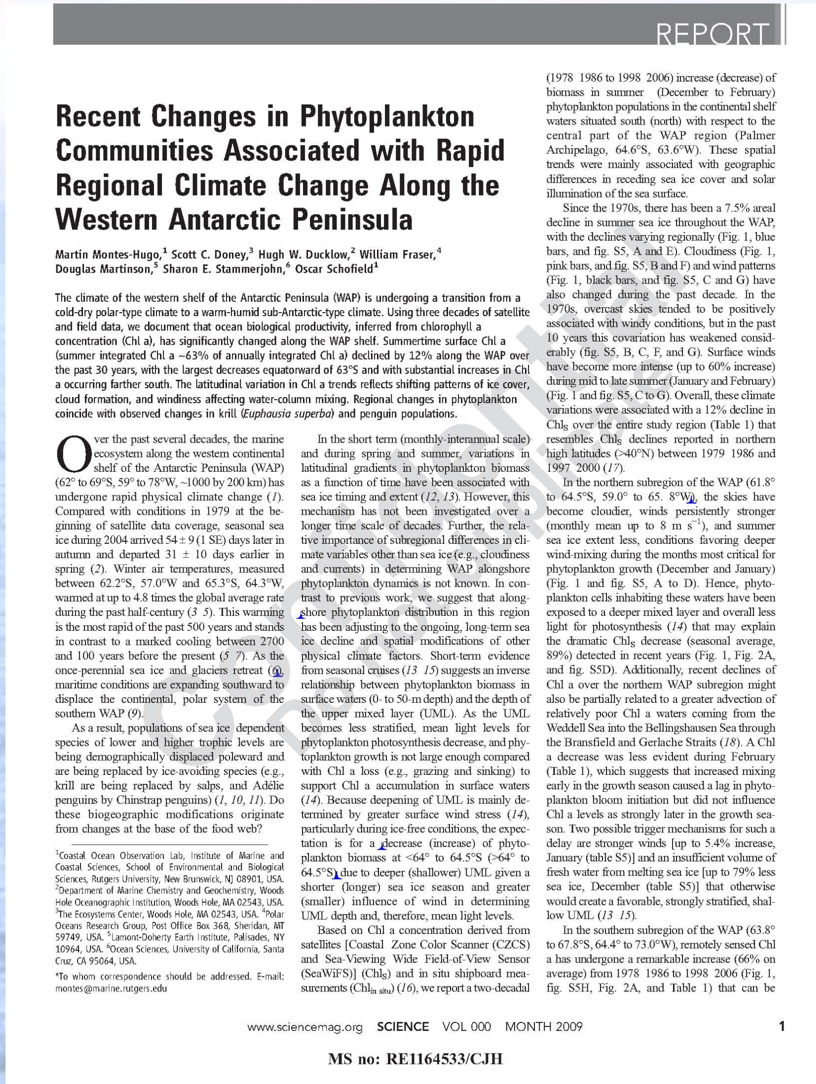
3. Ecosystem response to climate change:

a) Phytoplankton stocks and cell sizes

b) Apex Predators

c) Phasing (phenology) of sedimentation

Recent Changes in Phytoplankton Communities Associated with Rapid Regional Climate Change Along the Western Antarctic Peninsula. Martin Montes-Hugo et al. Science 13 March 2009 Vol 323 (5920):



Recent Changes in Phytoplankton Communities Associated with Rapid Regional Climate Change Along the Western Antarctic Peninsula

Martin Montes-Hugo,[1] Scott C. Doney,[3] Hugh W. Ducklow,[2] William Fraser,[4] Douglas Martinson,[5] Sharon E. Stammerjohn,[6] Oscar Schofield[1]

The climate of the western shelf of the Antarctic Peninsula (WAP) is undergoing a transition from a cold-dry polar-type climate to a warm-humid sub-Antarctic-type climate. Using three decades of satellite and field data, we document that ocean biological productivity, inferred from chlorophyll a concentration (Chl a), has significantly changed along the WAP shelf. Summertime surface Chl a (summer integrated Chl a ~63% of annually integrated Chl a) declined by 12% along the WAP over the past 30 years, with the largest decreases equatorward of 63°S and with substantial increases in Chl a occurring farther south. The latitudinal variation in Chl a trends reflects shifting patterns of ice cover, cloud formation, and windiness affecting water-column mixing. Regional changes in phytoplankton coincide with observed changes in krill (*Euphausia superba*) and penguin populations.

Over the past several decades, the marine ecosystem along the western continental shelf of the Antarctic Peninsula (WAP) (62° to 69°S, 59° to 78°W, ~1000 by 200 km) has undergone rapid physical climate change (*1*). Compared with conditions in 1979 at the beginning of satellite data coverage, seasonal sea ice during 2004 arrived 54 ± 9 (1 SE) days later in autumn and departed 31 ± 10 days earlier in spring (*2*). Winter air temperatures, measured between 62.2°S, 57.0°W and 65.3°S, 64.3°W, warmed at up to 4.8 times the global average rate during the past half-century (*3 5*). This warming is the most rapid of the past 500 years and stands in contrast to a marked cooling between 2700 and 100 years before the present (*5 7*). As the once-perennial sea ice and glaciers retreat (*6*), maritime conditions are expanding southward to displace the continental, polar system of the southern WAP (*9*).

As a result, populations of sea ice dependent species of lower and higher trophic levels are being demographically displaced poleward and are being replaced by ice-avoiding species (e.g., krill are being replaced by salps, and Adélie penguins by Chinstrap penguins) (*1, 10, 11*). Do these biogeographic modifications originate from changes at the base of the food web?

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In the short term (monthly-interannual scale) and during spring and summer, variations in latitudinal gradients in phytoplankton biomass as a function of time have been associated with sea ice timing and extent (*12, 13*). However, this mechanism has not been investigated over a longer time scale of decades. Further, the relative importance of subregional differences in climate variables other than sea ice (e.g., cloudiness and currents) in determining WAP alongshore phytoplankton dynamics is not known. In contrast to previous work, we suggest that alongshore phytoplankton distribution in this region has been adjusting to the ongoing, long-term sea ice decline and spatial modifications of other physical climate factors. Short-term evidence from seasonal cruises (*13 15*) suggests an inverse relationship between phytoplankton biomass in surface waters (0- to 50-m depth) and the depth of the upper mixed layer (UML). As the UML becomes less stratified, mean light levels for phytoplankton photosynthesis decrease, and phytoplankton growth is not large enough compared with Chl a loss (e.g., grazing and sinking) to support Chl a accumulation in surface waters (*14*). Because deepening of UML is mainly determined by greater surface wind stress (*14*), particularly during ice-free conditions, the expectation is for a decrease (increase) of phytoplankton biomass at <64° to 64.5°S (>64° to 64.5°S) due to deeper (shallower) UML given a shorter (longer) sea ice season and greater (smaller) influence of wind in determining UML depth and, therefore, mean light levels.

Based on Chl a concentration derived from satellites [Coastal Zone Color Scanner (CZCS) and Sea-Viewing Wide Field-of-View Sensor (SeaWiFS)] (Chl_S) and in situ shipboard measurements ($Chl_{in\ situ}$) (*16*), we report a two-decadal (1978 1986 to 1998 2006) increase (decrease) of biomass in summer (December to February) phytoplankton populations in the continental shelf waters situated south (north) with respect to the central part of the WAP region (Palmer Archipelago, 64.6°S, 63.6°W). These spatial trends were mainly associated with geographic differences in receding sea ice cover and solar illumination of the sea surface.

Since the 1970s, there has been a 7.5% areal decline in summer sea ice throughout the WAP, with the declines varying regionally (Fig. 1, blue bars, and fig. S5, A and E). Cloudiness (Fig. 1, pink bars, and fig. S5, B and F) and wind patterns (Fig. 1, black bars, and fig. S5, C and G) have also changed during the past decade. In the 1970s, overcast skies tended to be positively associated with windy conditions, but in the past 10 years this covariation has weakened considerably (fig. S5, B, C, F, and G). Surface winds have become more intense (up to 60% increase) during mid to late summer (January and February) (Fig. 1 and fig. S5, C to G). Overall, these climate variations were associated with a 12% decline in Chl_S over the entire study region (Table 1) that resembles Chl_S declines reported in northern high latitudes (>40°N) between 1979 1986 and 1997 2000 (*17*).

In the northern subregion of the WAP (61.8° to 64.5°S, 59.0° to 65. 8°W), the skies have become cloudier, winds persistently stronger (monthly mean up to 8 m s^{-1}), and summer sea ice extent less, conditions favoring deeper wind-mixing during the months most critical for phytoplankton growth (December and January) (Fig. 1 and fig. S5, A to D). Hence, phytoplankton cells inhabiting these waters have been exposed to a deeper mixed layer and overall less light for photosynthesis (*14*) that may explain the dramatic Chl_S decrease (seasonal average, 89%) detected in recent years (Fig. 1, Fig. 2A, and fig. S5D). Additionally, recent declines of Chl a over the northern WAP subregion might also be partially related to a greater advection of relatively poor Chl a waters coming from the Weddell Sea into the Bellingshausen Sea through the Bransfield and Gerlache Straits (*18*). A Chl a decrease was less evident during February (Table 1), which suggests that increased mixing early in the growth season caused a lag in phytoplankton bloom initiation but did not influence Chl a levels as strongly later in the growth season. Two possible trigger mechanisms for such a delay are stronger winds [up to 5.4% increase, January (table S5)] and an insufficient volume of fresh water from melting sea ice [up to 79% less sea ice, December (table S5)] that otherwise would create a favorable, strongly stratified, shallow UML (*13 15*).

In the southern subregion of the WAP (63.8° to 67.8°S, 64.4° to 73.0°W), remotely sensed Chl a has undergone a remarkable increase (66% on average) from 1978 1986 to 1998 2006 (Fig. 1, fig. S5H, Fig. 2A, and Table 1) that can be

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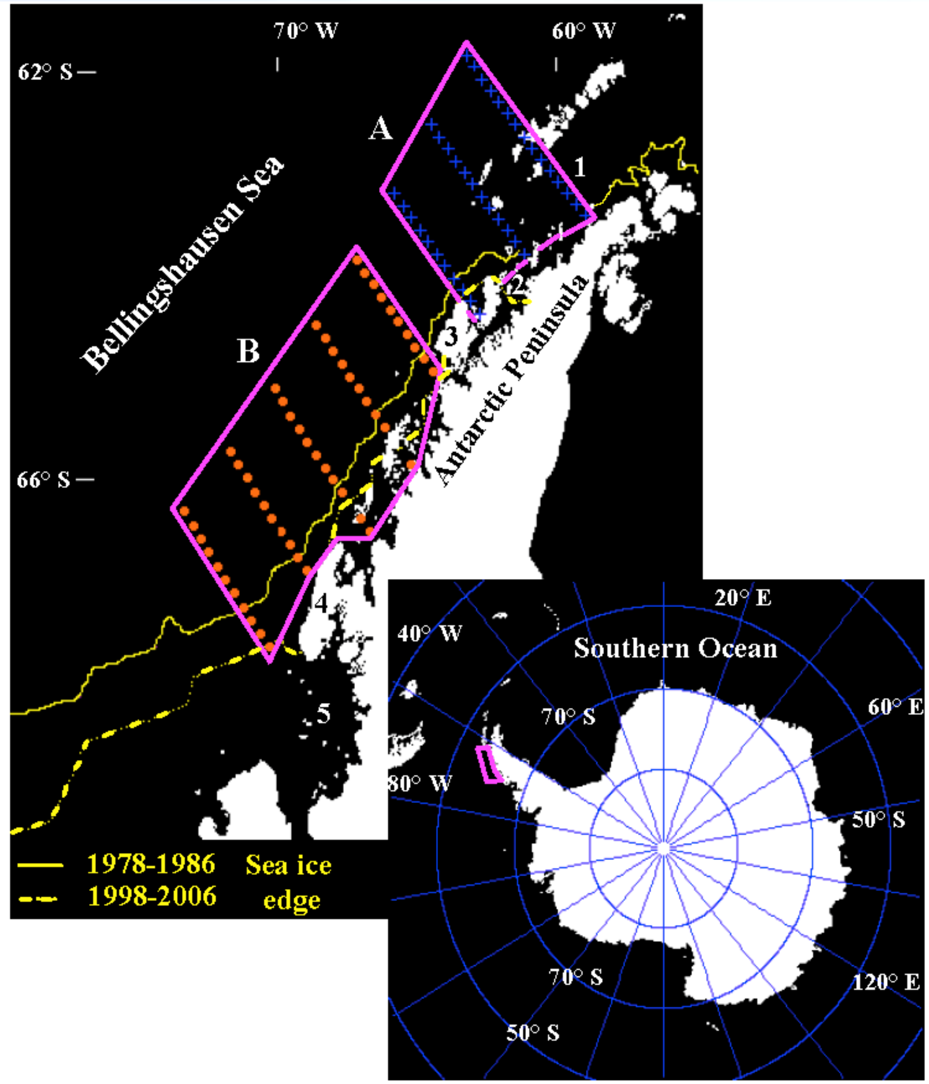
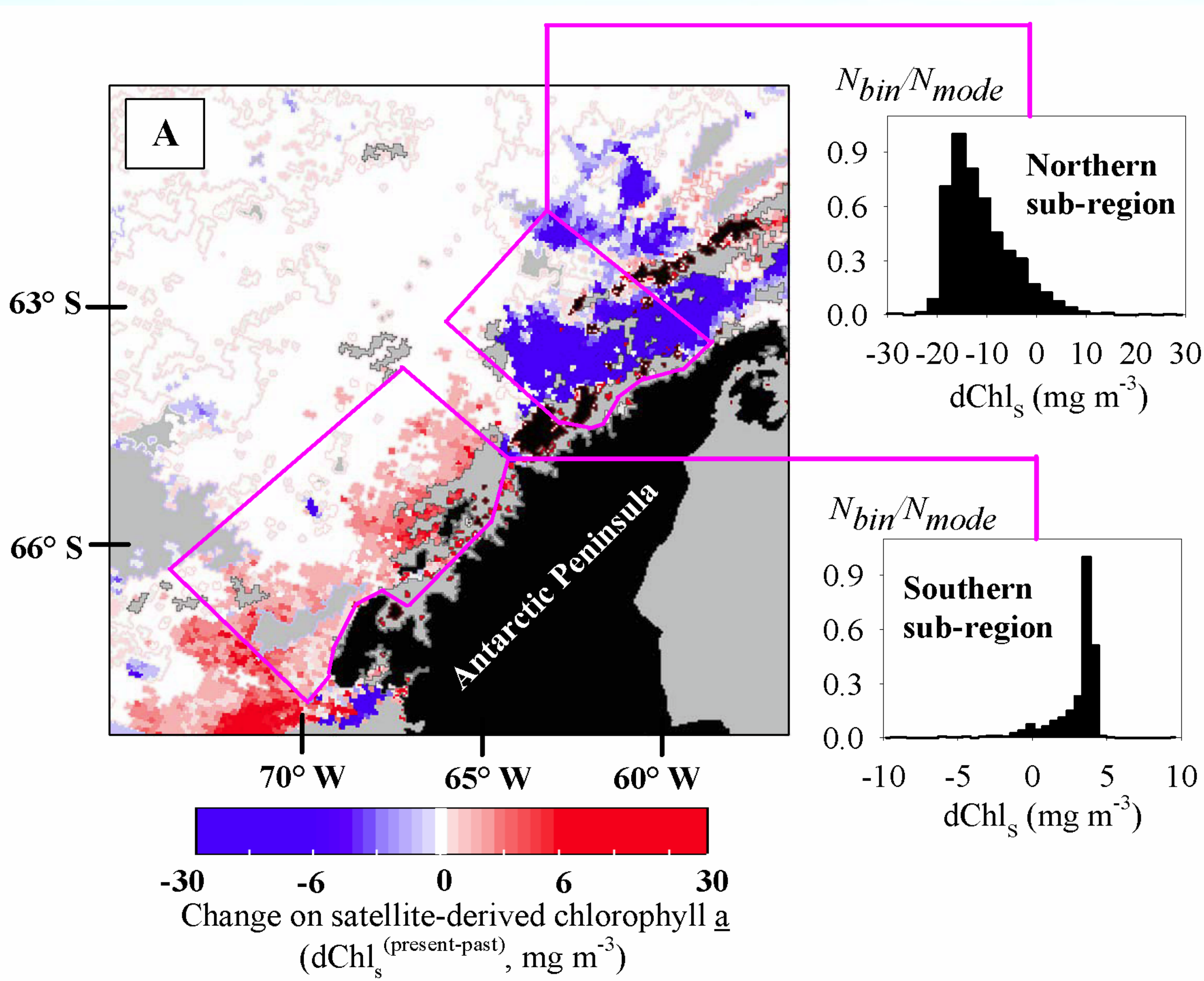
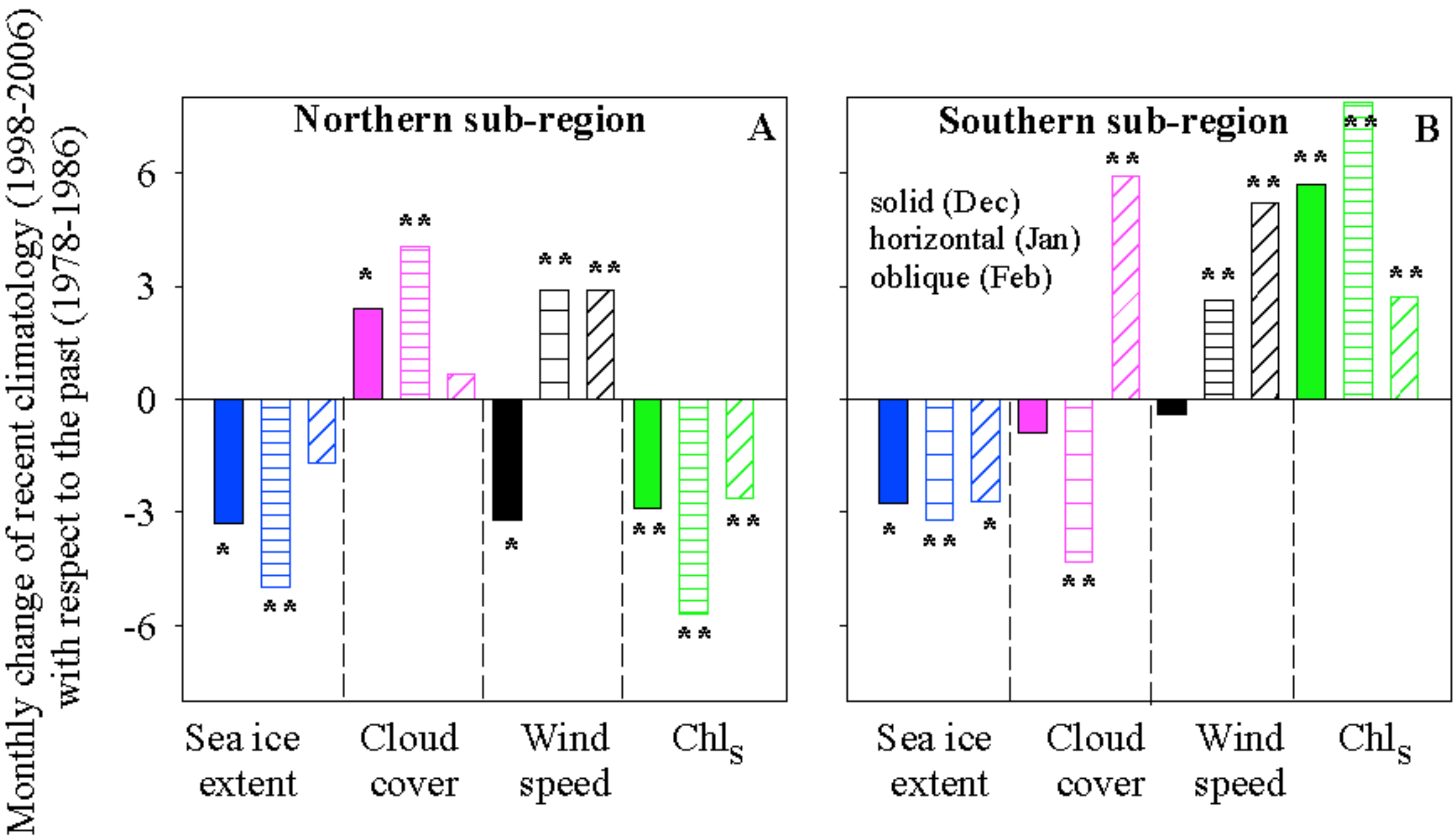
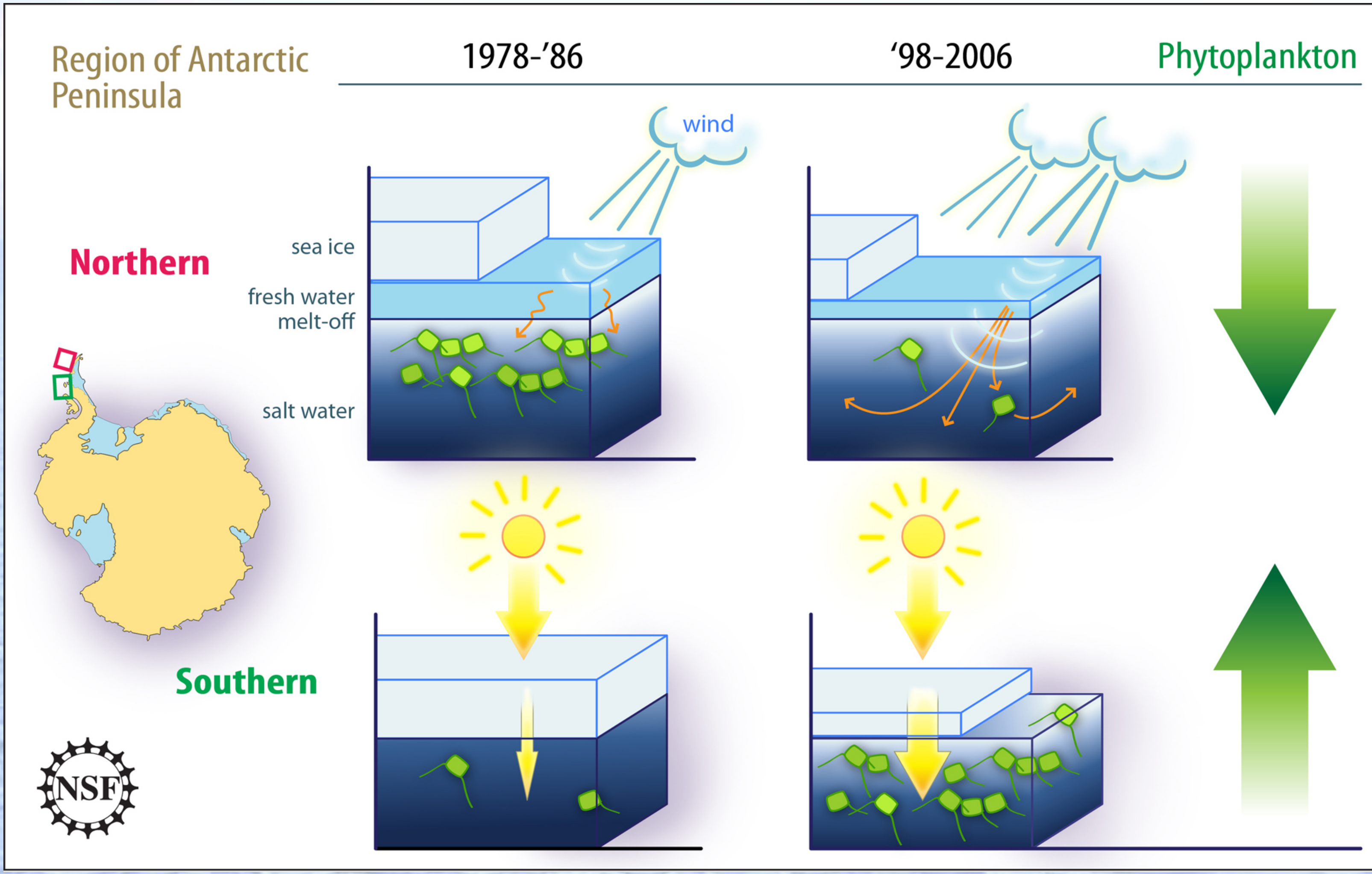



A
63° S
66° S
70° W
65° W
60° W
Antarctic Peninsula
-30
-6
0
6
30
Change on satellite-derived chlorophyll a
(dChl_s^(present-past), mg m^-3)
N_bin/N_mode
0.9
0.6
0.3
0.0
Northern sub-region
-30 -20 -10 0 10 20 30
dChl_s (mg m^-3)
N_bin/N_mode
0.9
0.6
0.3
0.0
Southern sub-region
-10 -5 0 5 10
dChl_s (mg m^-3)

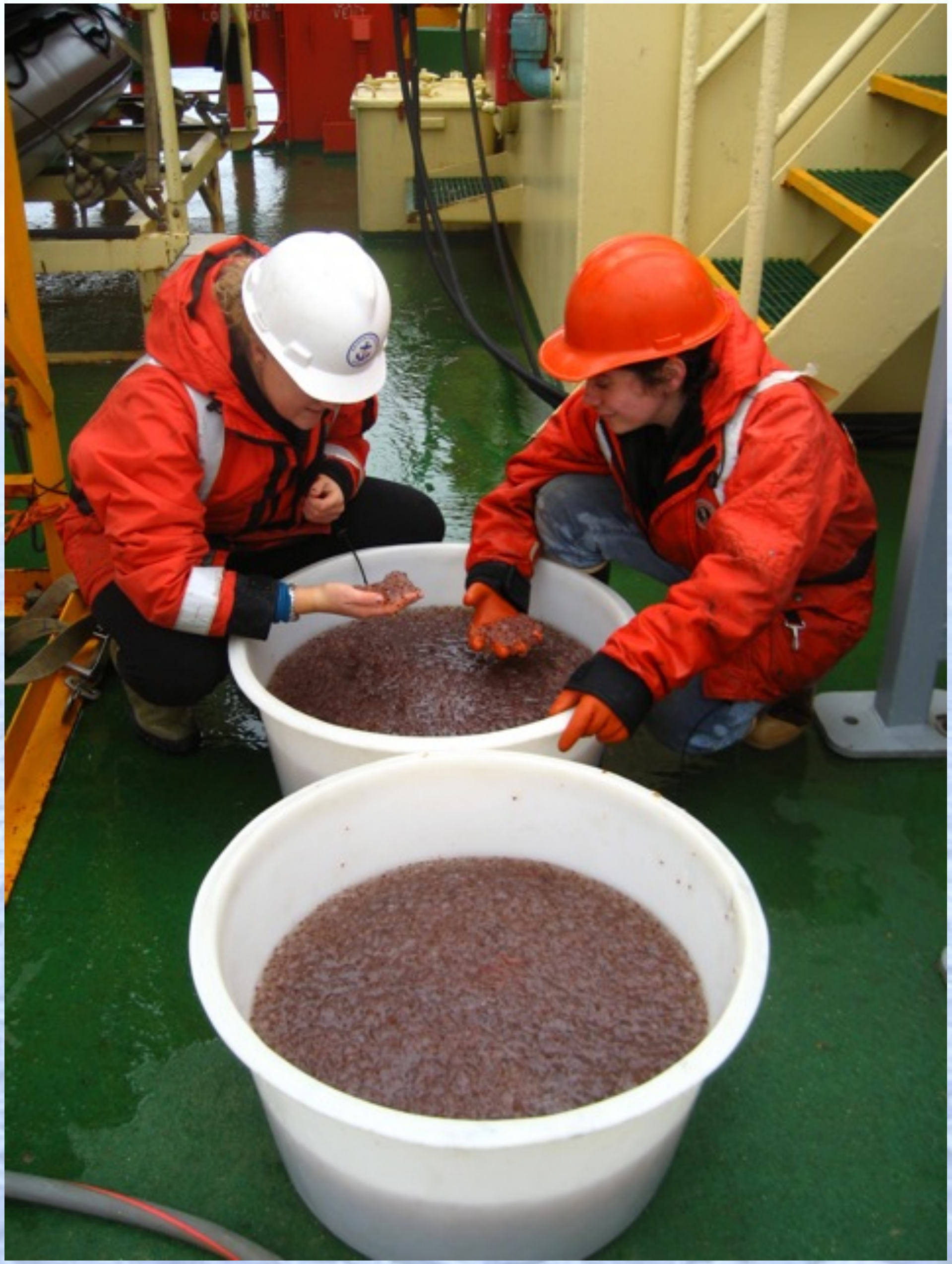

Monthly change of recent climatology (1998-2006) with respect to the past (1978-1986)
Northern sub-region
A
Southern sub-region
B
solid (Dec)
horizontal (Jan)
oblique (Feb)
6
3
0
-3
-6
Sea ice extent
Cloud cover
Wind speed
Chl$_S$

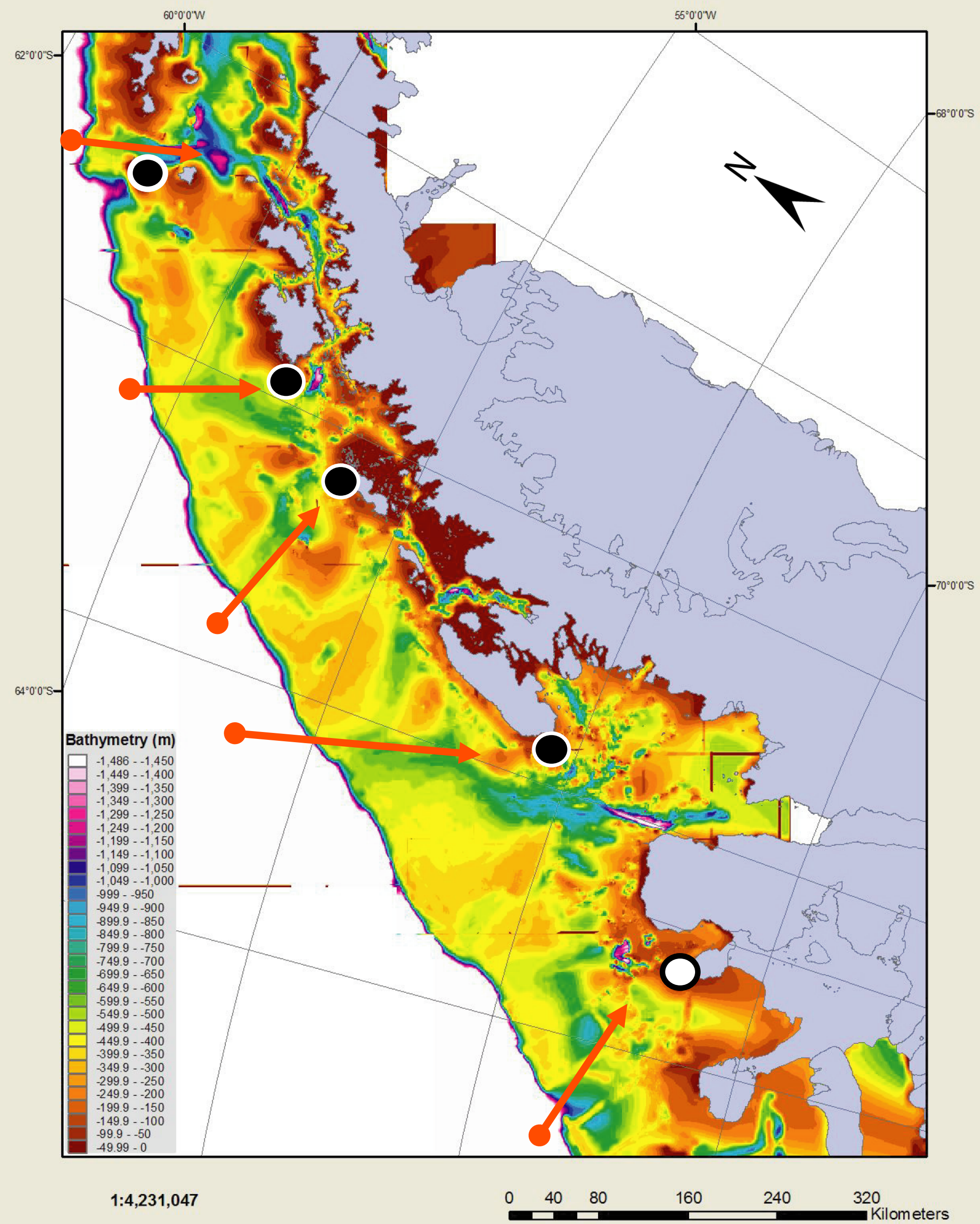
Summary: Sea Ice, wind and phytoplankton along the WAP 1978-2006



Courtesy Zina Deretsky, NSF

Lots of Salps

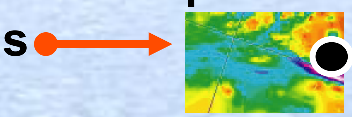




Penguins and Bathymetry

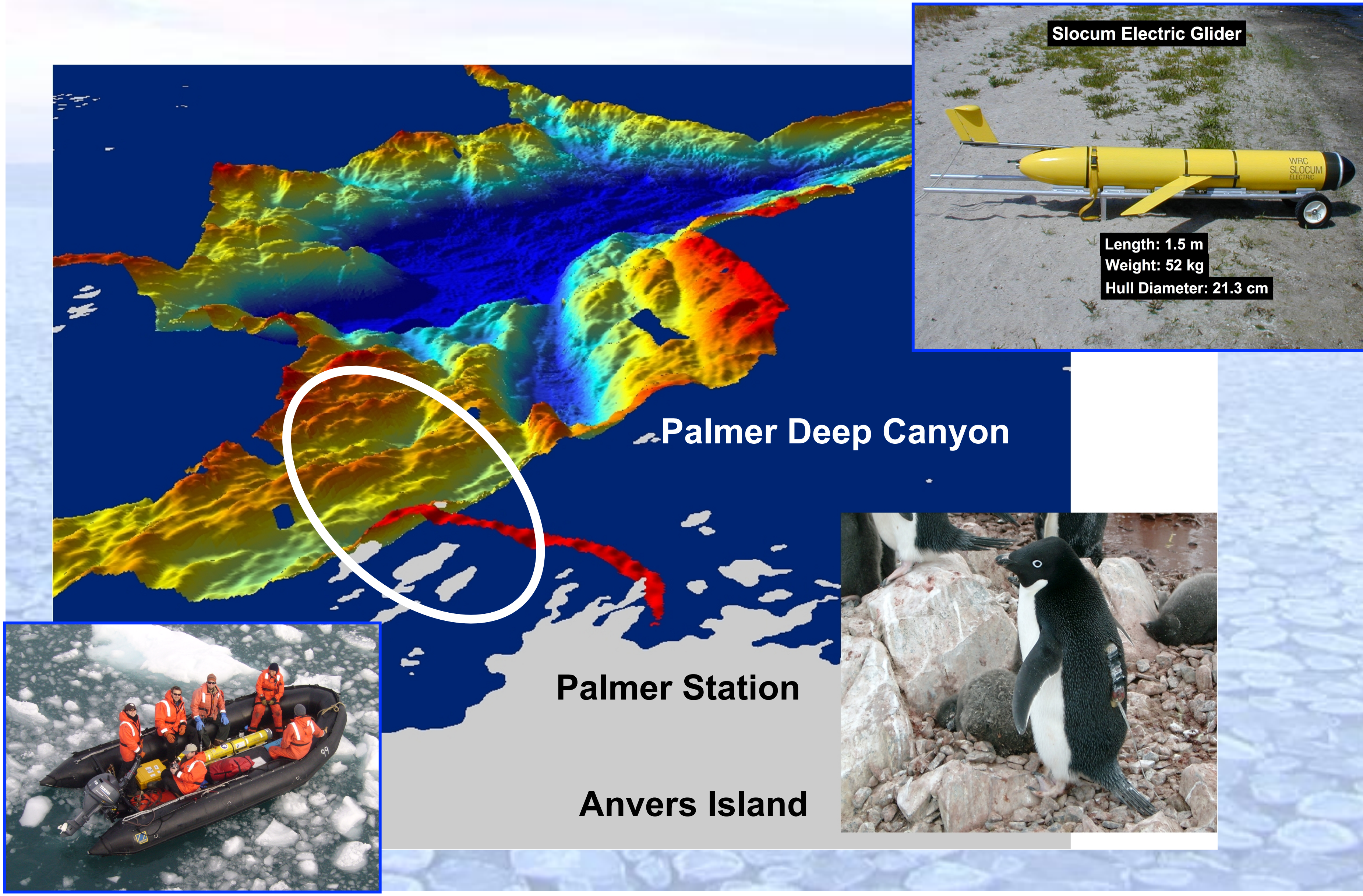
Green-blue-purple shading: Deeper water – troughs and canyons cutting across the shelf

Penguin colonies proximal to canyons



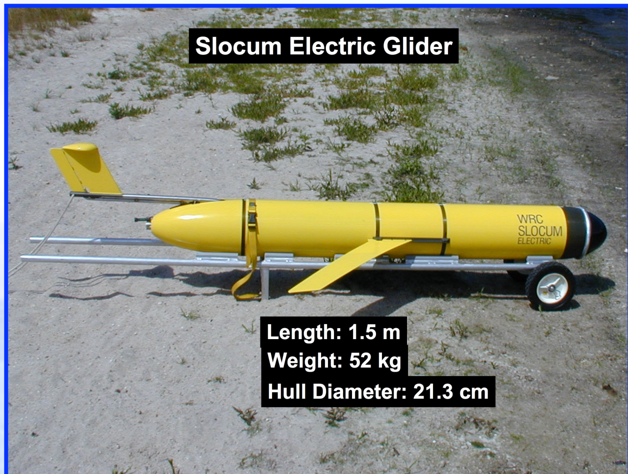
Penguins concentrate foraging activity over canyon heads and/or polynyas associated with canyon circulation features

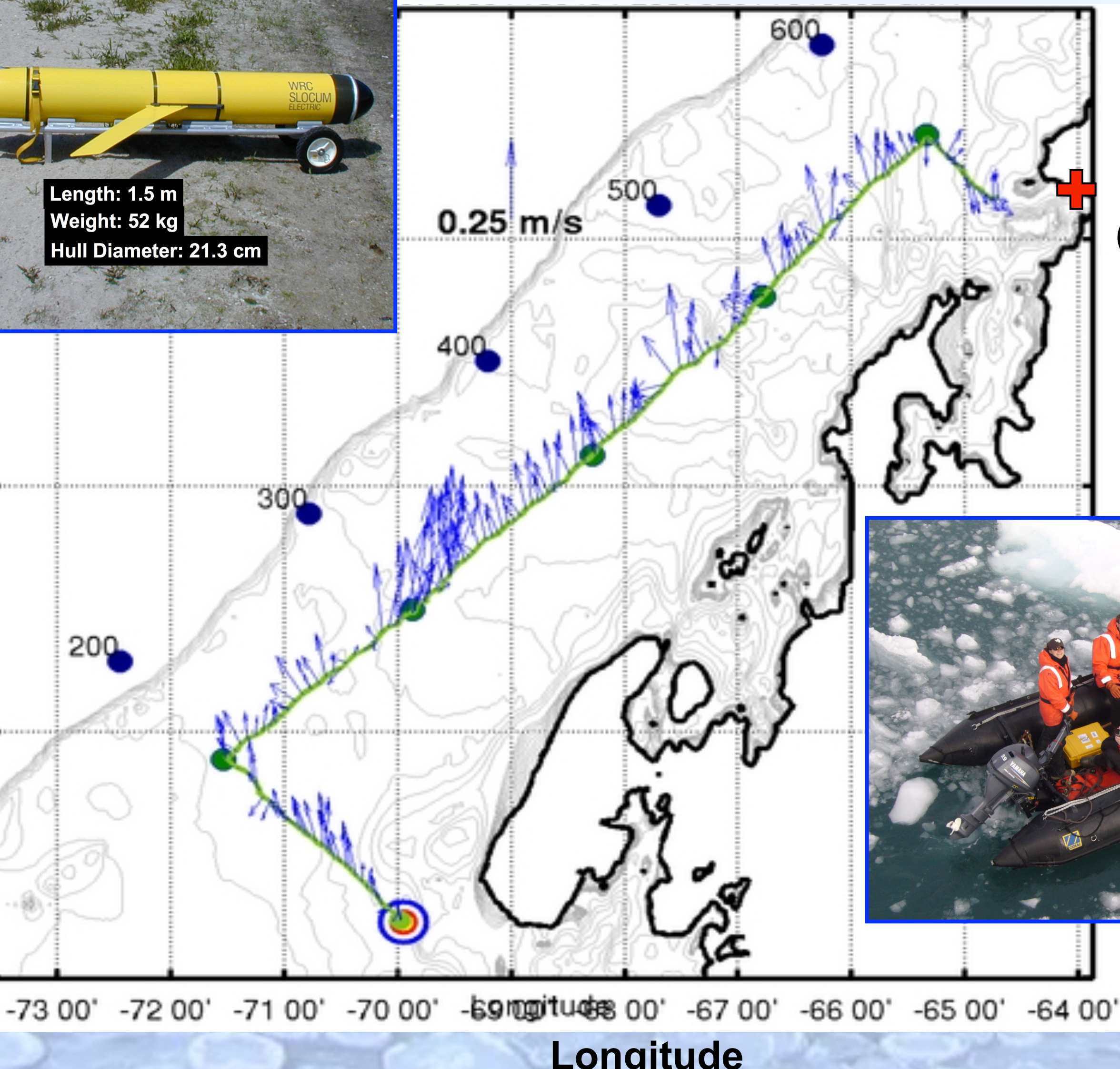
Glider Survey of Palmer Deep Adélie Penguin Foraging Region



Ocean circulation from the Webb-Slocum* Rutgers Glider

Jan 6-23 07

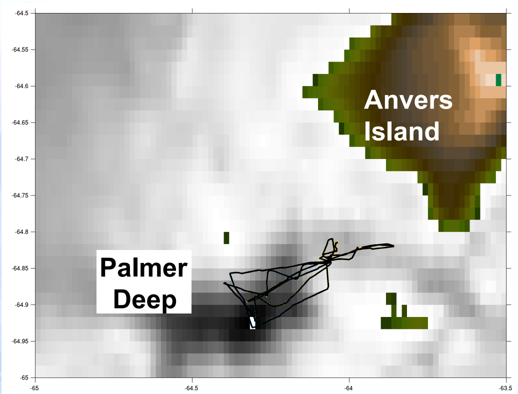


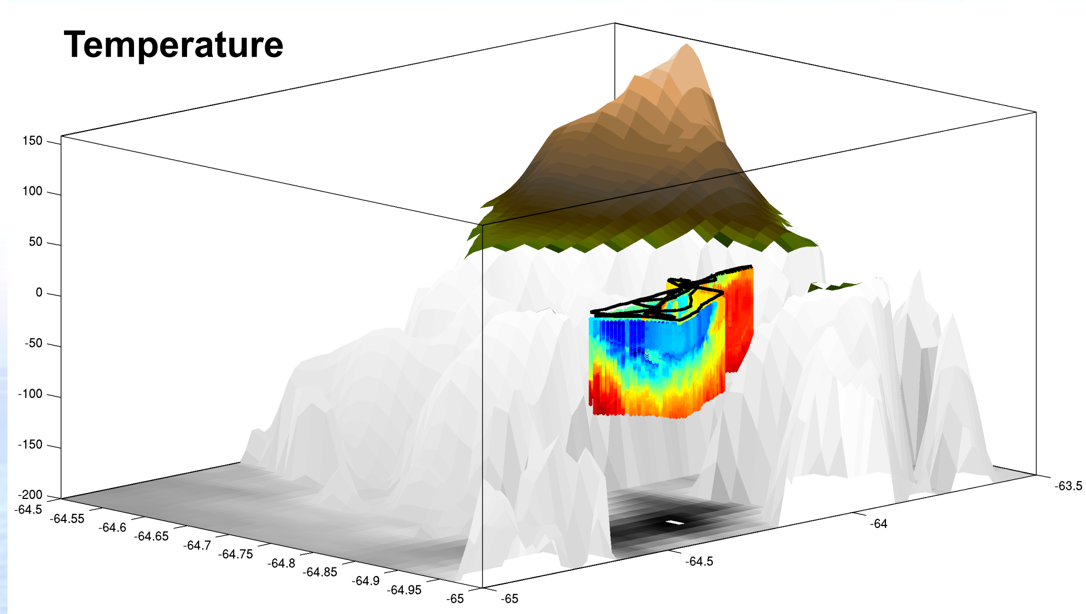


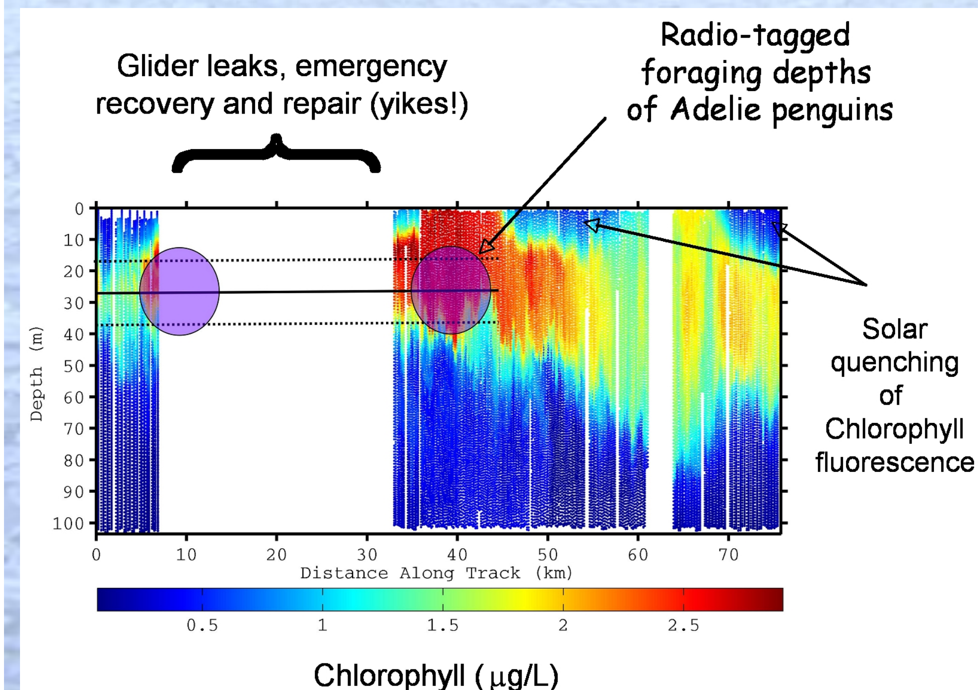
confirms that surface circulation pumps ACC water (MCDW) onto shelf

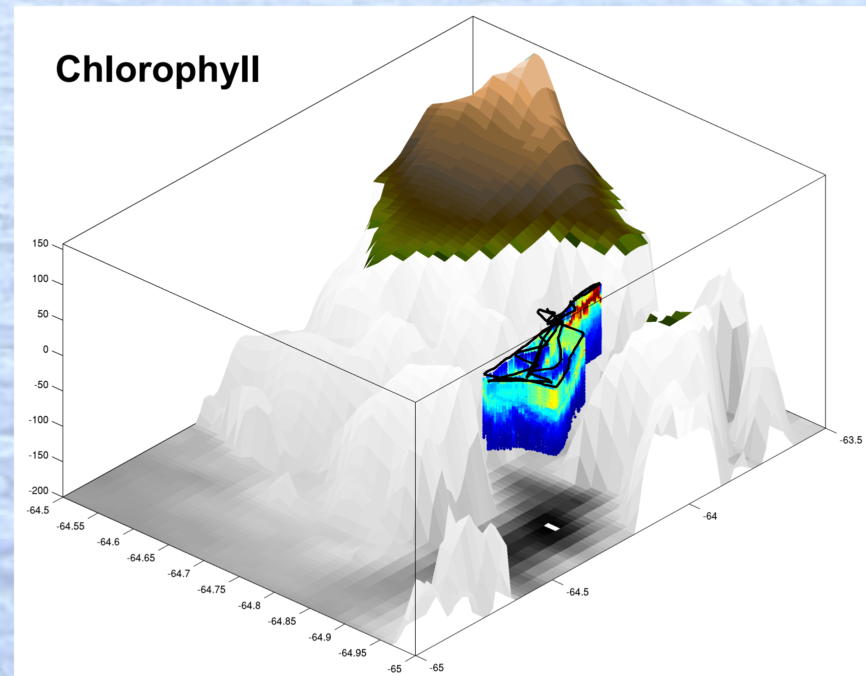
Palmer Deep Glider Survey:

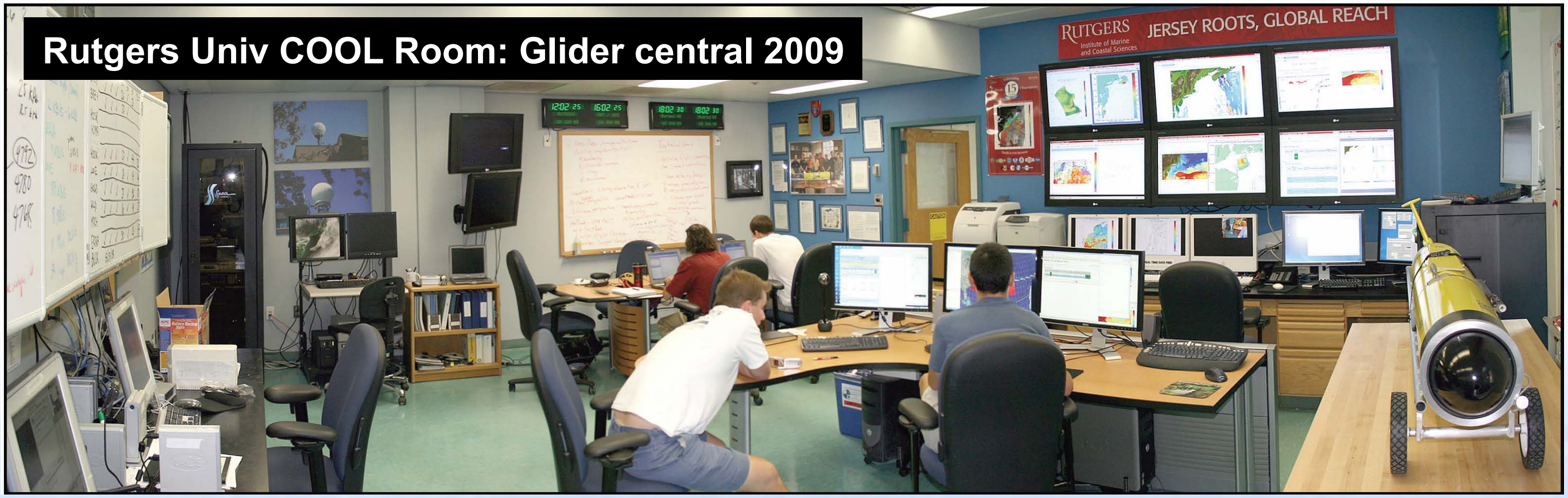
Penguins concentrate foraging activity over canyon heads and/ or polynyas associated with canyon circulation features









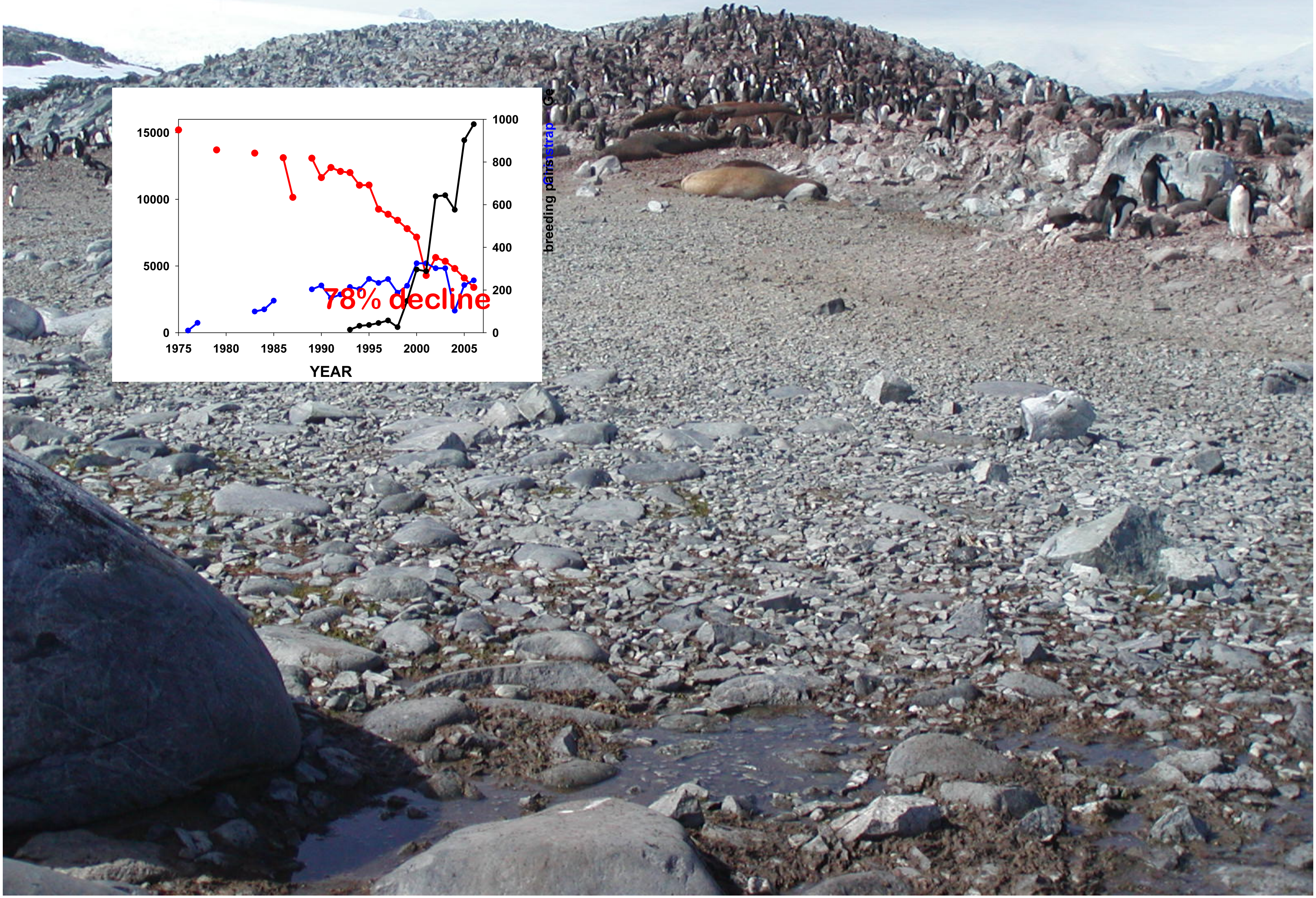


Rutgers Univ COOL Room: Glider central 2009


Palmer Station Ham Radio 1988

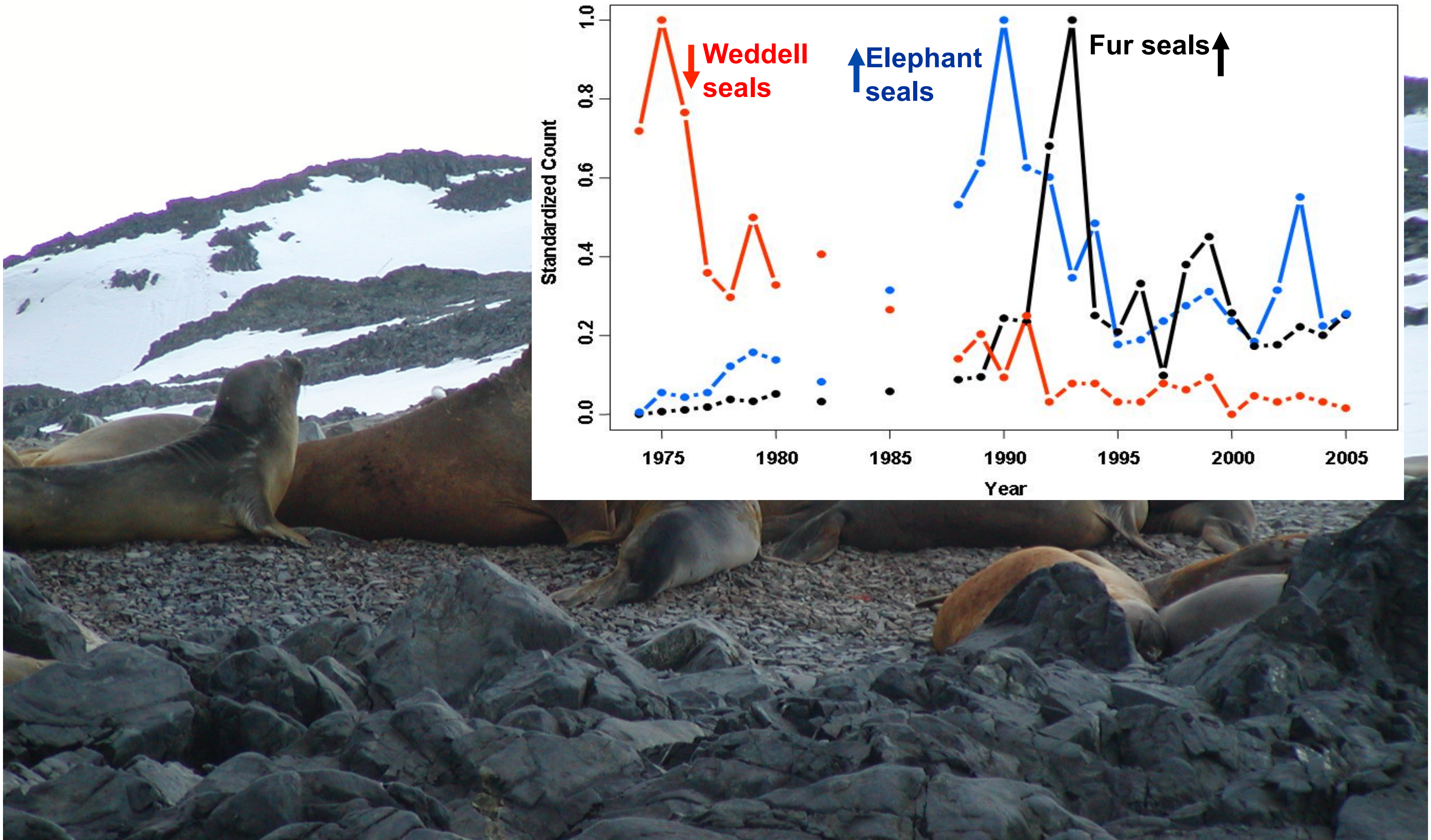
Rothera Glider Recovery 2009

Penguin Populations in the Palmer Station region



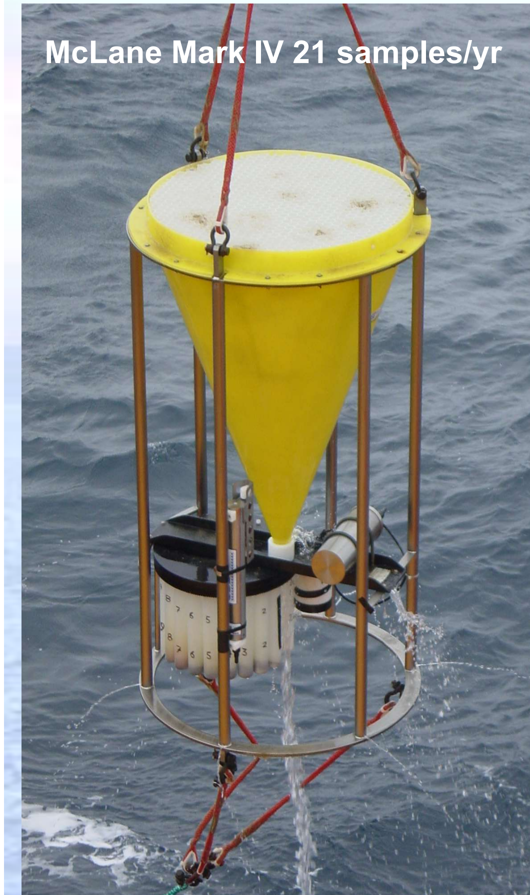

Avian Island, 400 km south of Palmer: 65,000 pairs and growing
Gene Burreson

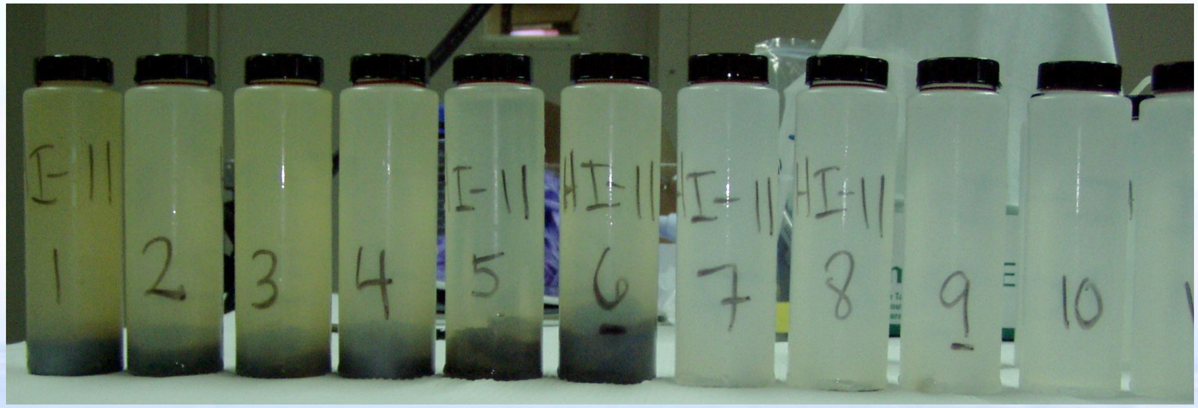
Changes in seals at Palmer Station 1975 - 2006

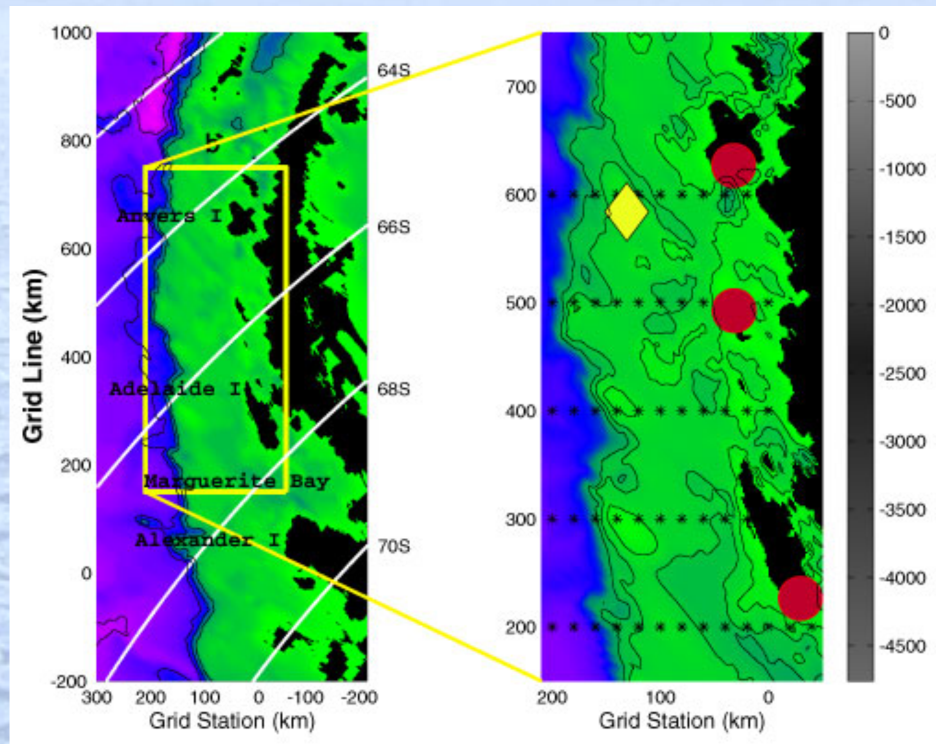


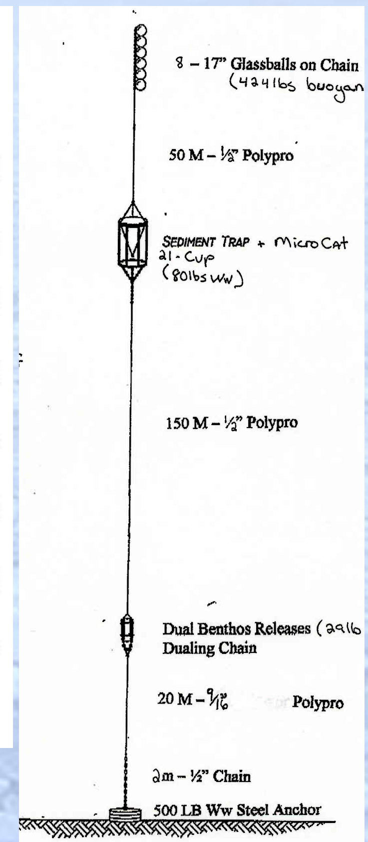
Ice-dependent: Adélies, Crabeater & Weddell seals.
Ice-independent: Chinstrap & Gentoo penguins, Elephant & fur seals Bill Fraser.

Sedimentation: export production 1993 – 2006

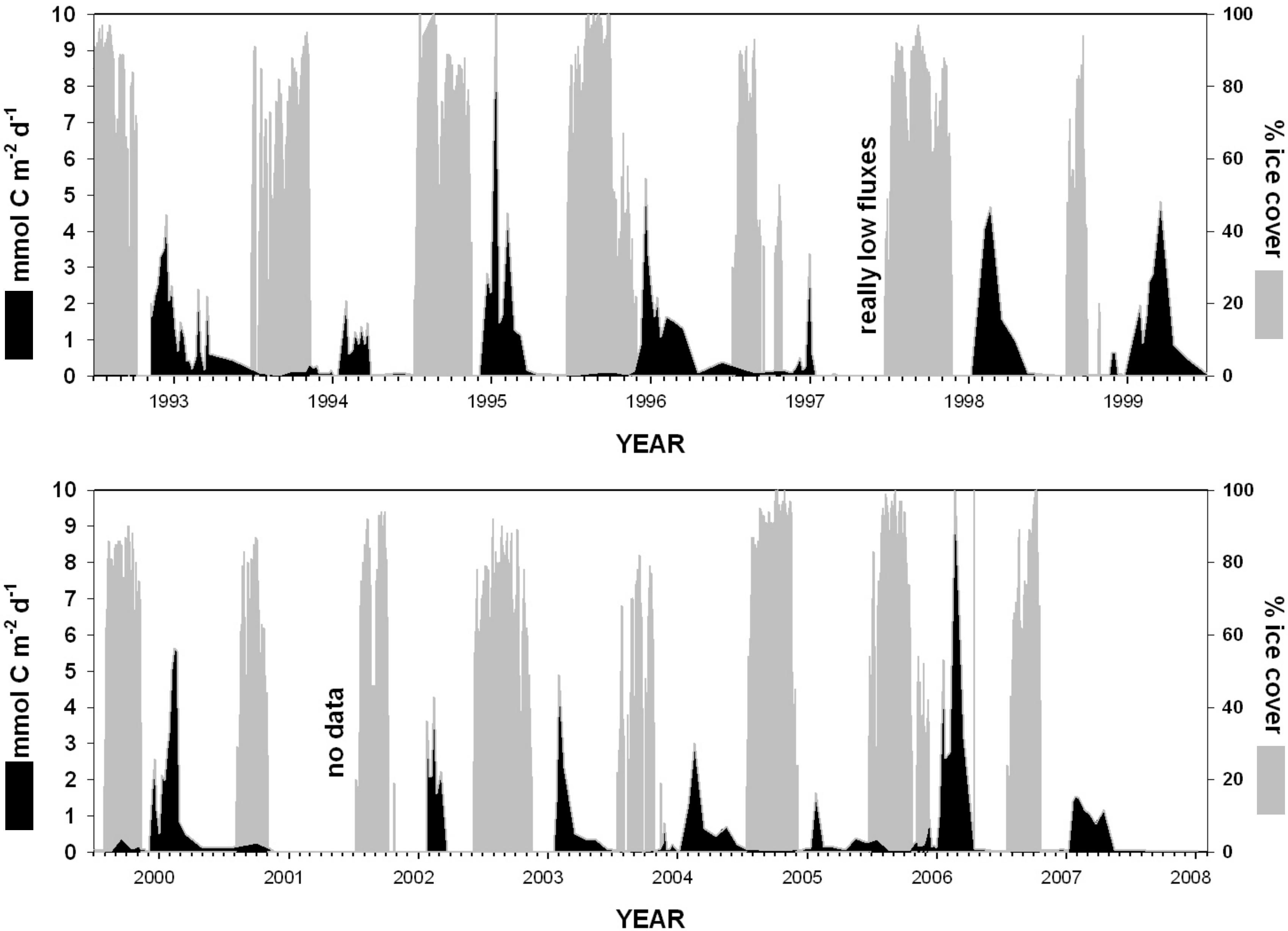






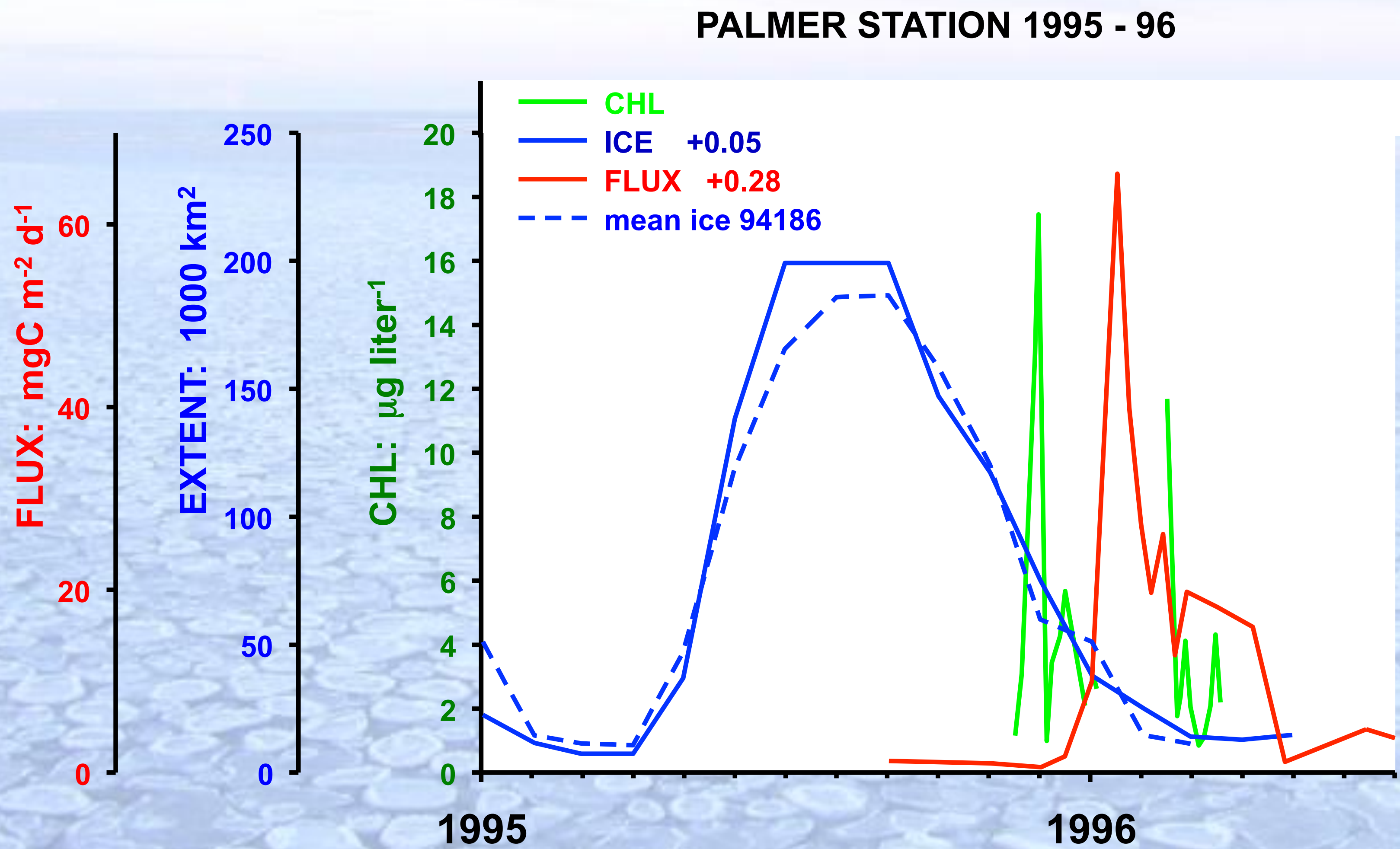


Particle Sedimentation Rates 1993 - 2008

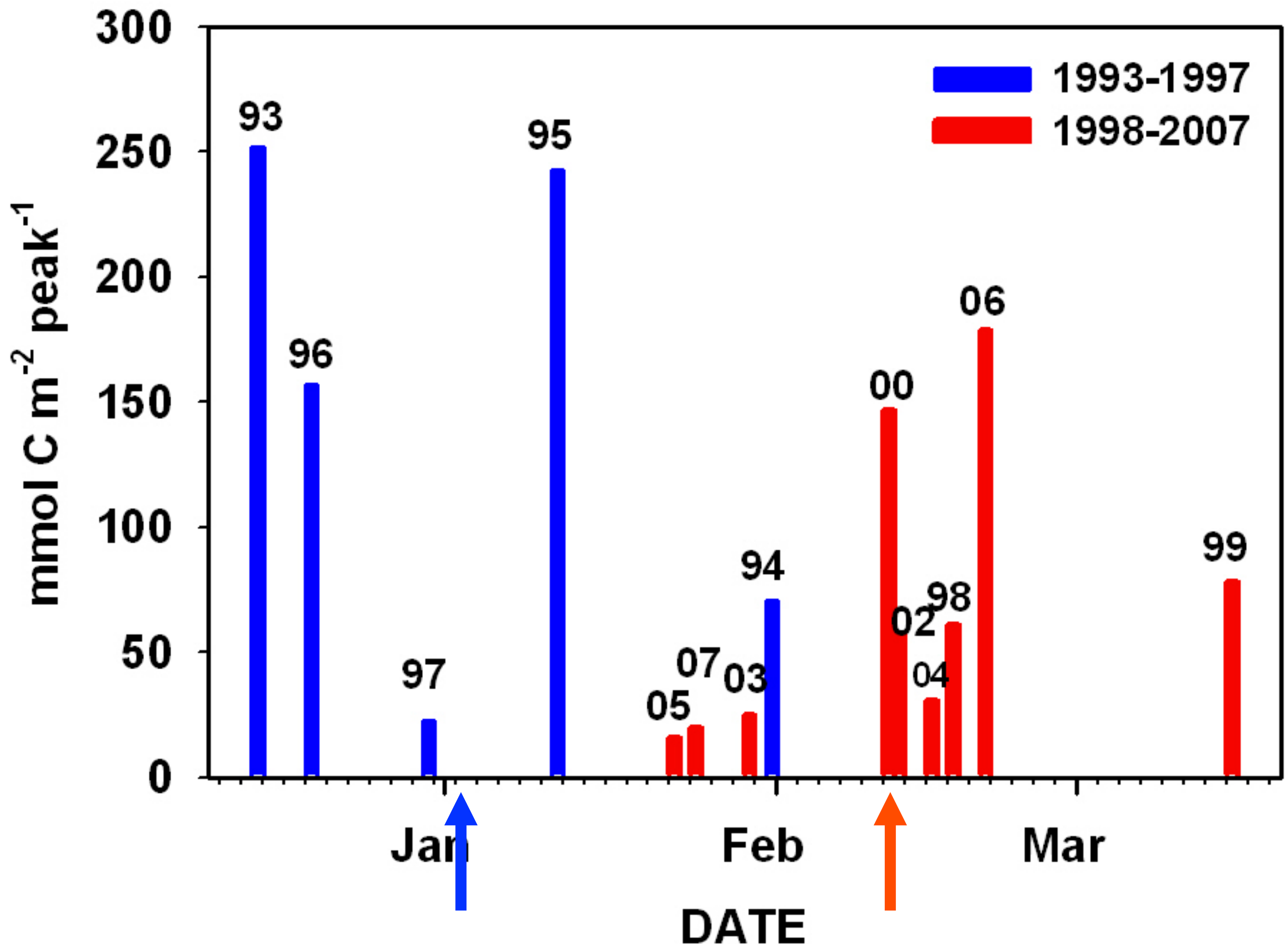


CONCEPTUAL MODEL OF MIZ DYNAMICS

Ice extent & retreat → bloom → sedimentation



Changing date of sedimentation peak: 1993-2007

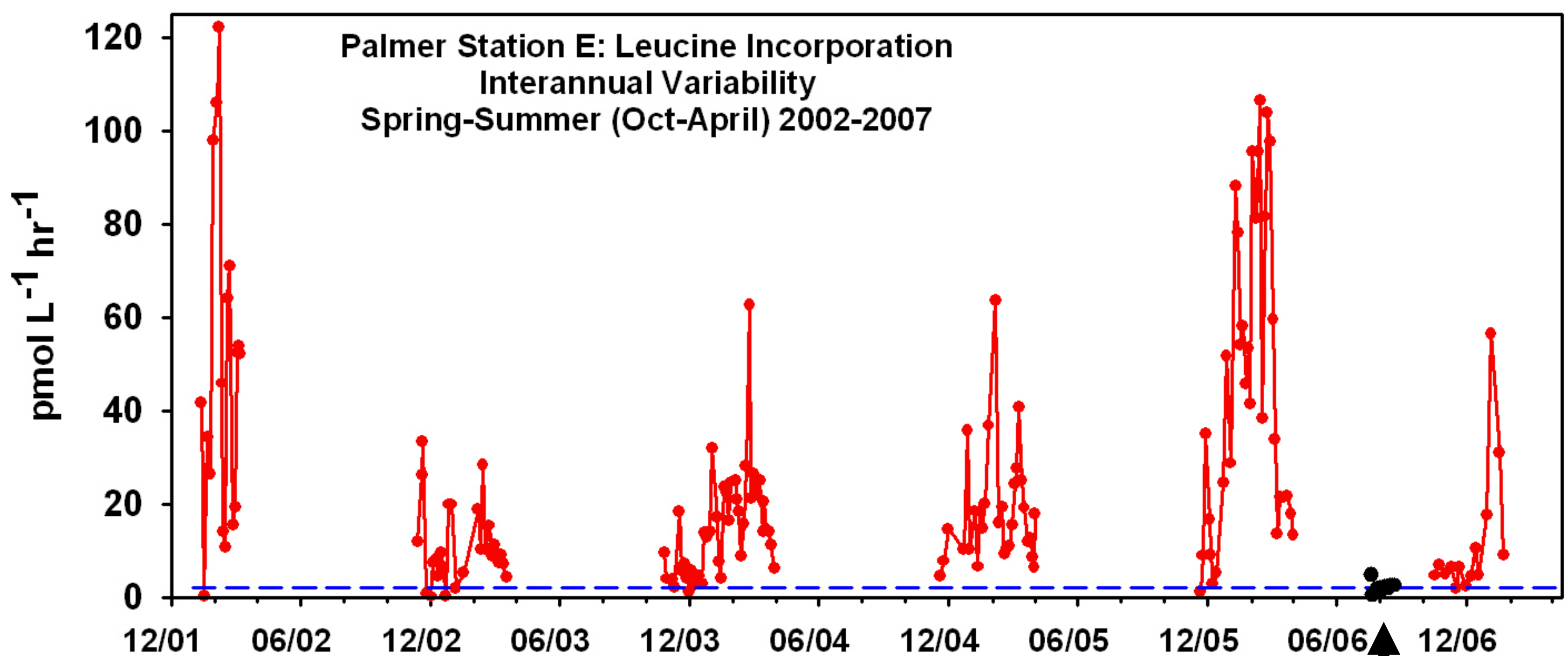


Jan 03 ± 17 days
149 ± 91 mmolC/peak

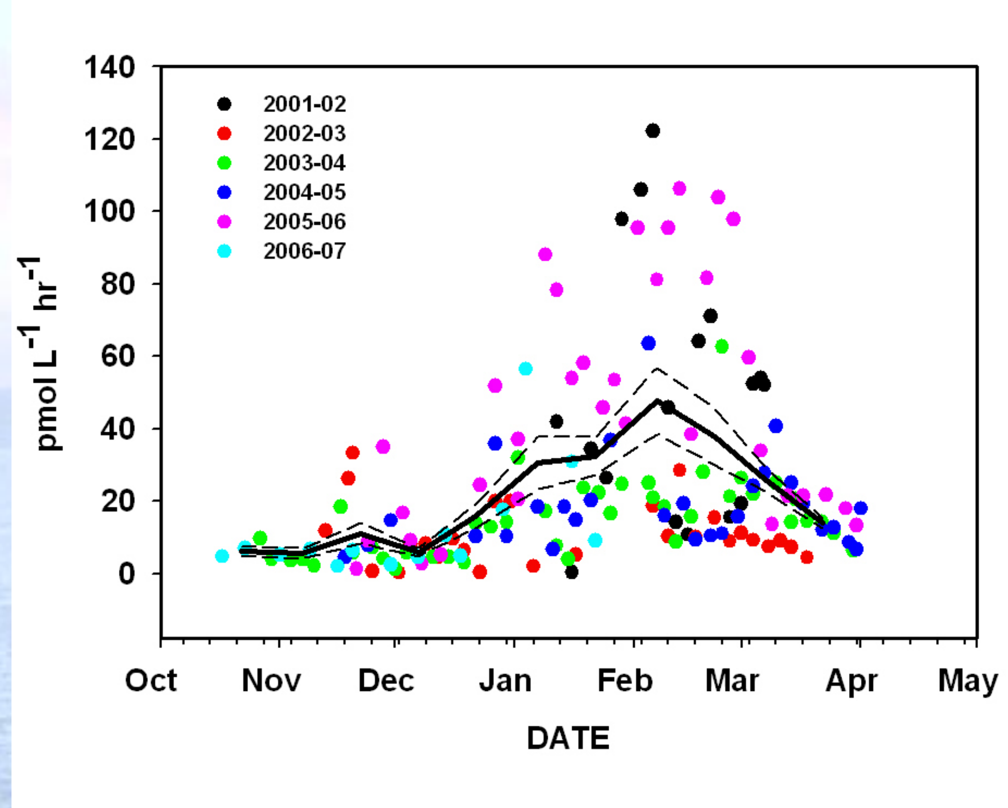
$p<0.01$
$p< 0.05$

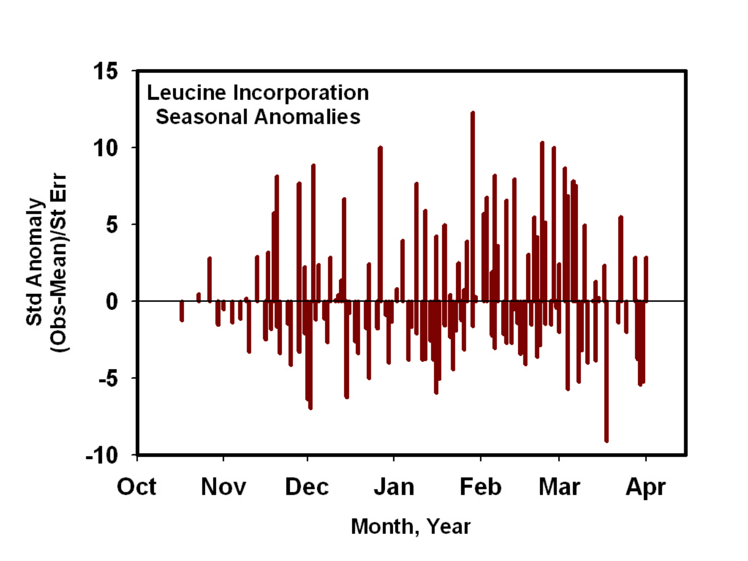
Feb 12 ± 16 days
68 ± 58 mmolC/peak

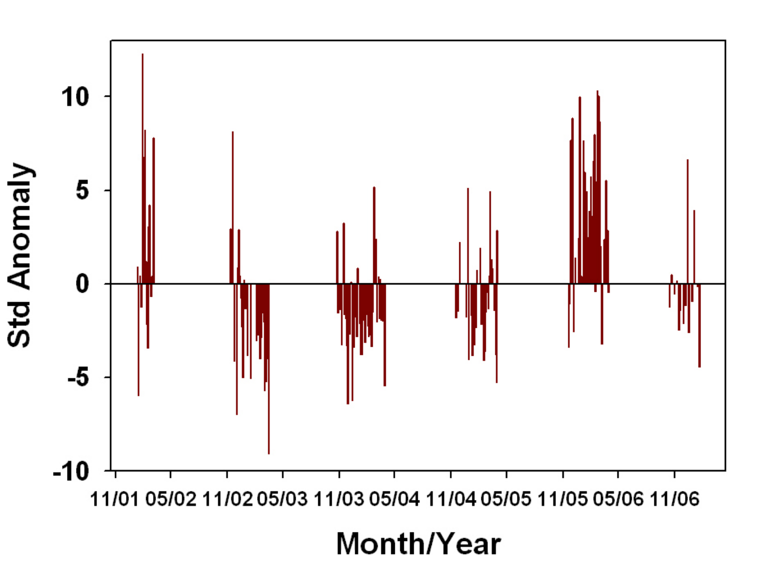
4. Bacteria – Phytoplankton Relationships



Mean winter rate:
5 pM/hr; July-Sept 2008

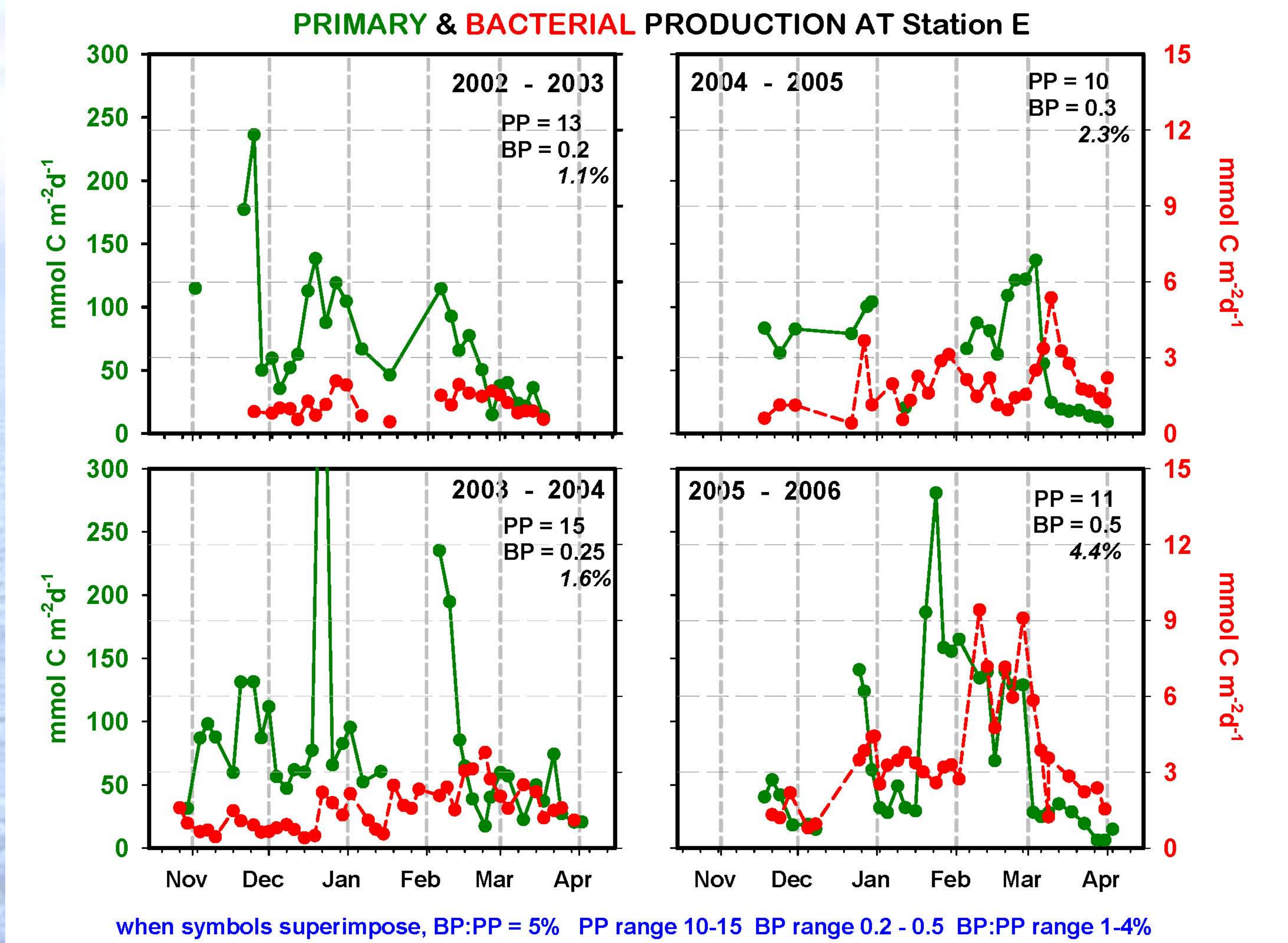


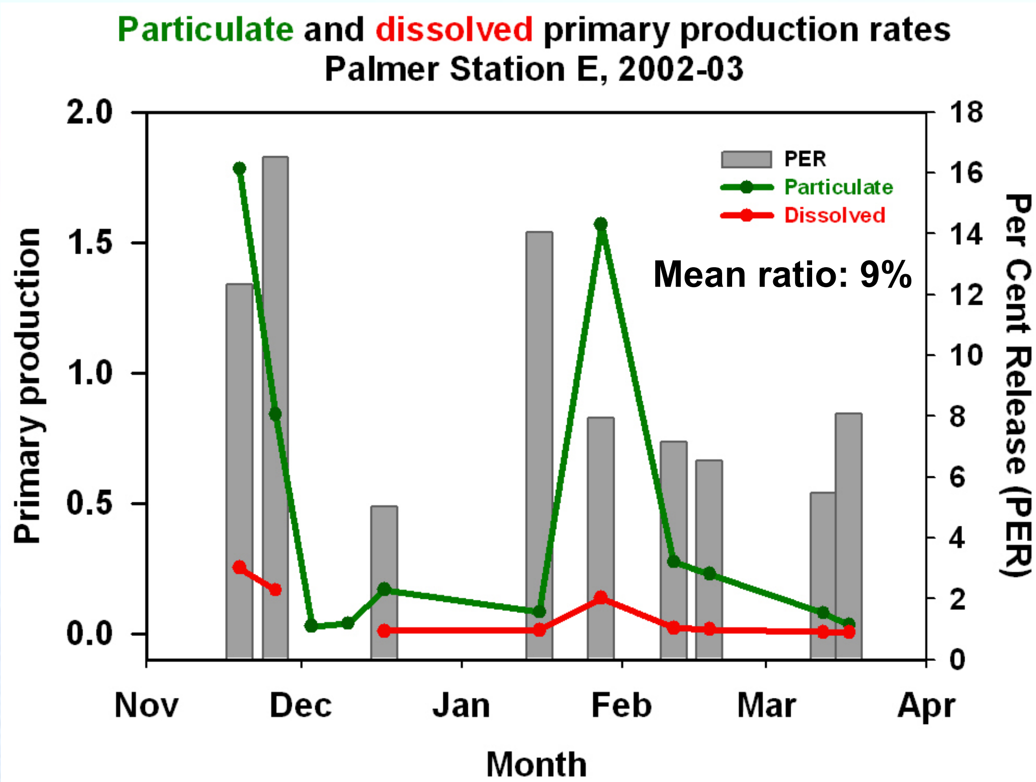


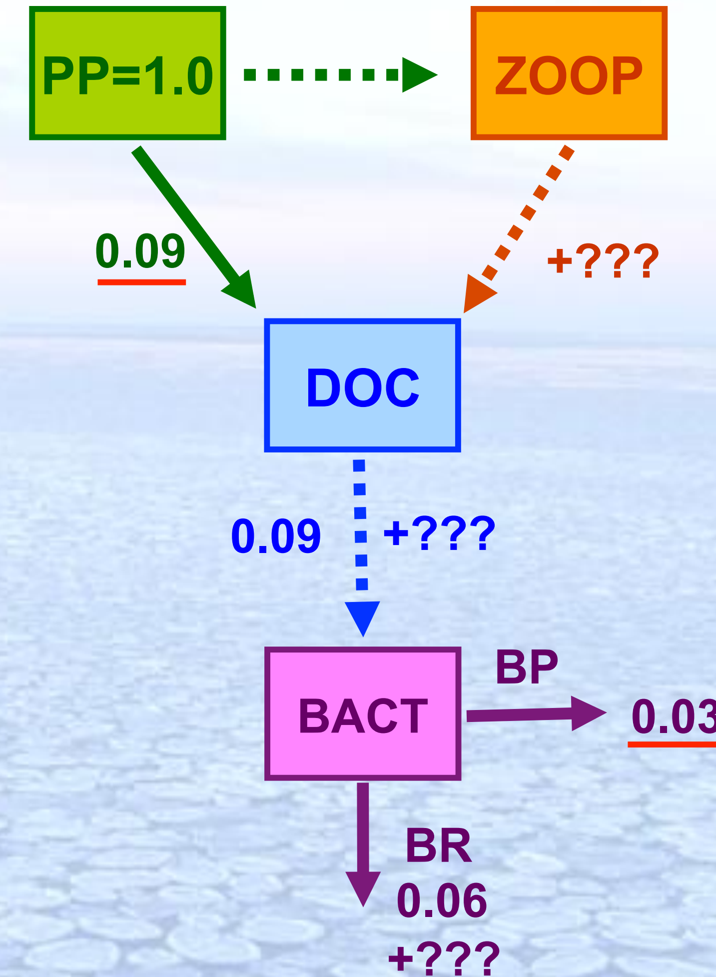


Bacterial Production: Seasonal Cycle inshore near Palmer Station:

Late summer peak
Uniform variability throughout season
Possible 4-5 year cycle following primary production rates


PRIMARY & BACTERIAL PRODUCTION AT Station E
2002 - 2003
PP = 13
BP = 0.2
1.1%
2004 - 2005
PP = 10
BP = 0.3
2.3%
2003 - 2004
PP = 15
BP = 0.25
1.6%
2005 - 2006
PP = 11
BP = 0.5
4.4%
mmol C m-2d-1
Nov
Dec
Jan
Feb
Mar
Apr
when symbols superimpose, BP:PP = 5%   PP range 10-15 BP range 0.2 - 0.5 BP:PP range 1-4%





Bacterial production rates follow primary production, seasonally and interannually, but comprise a low fraction of the PP.

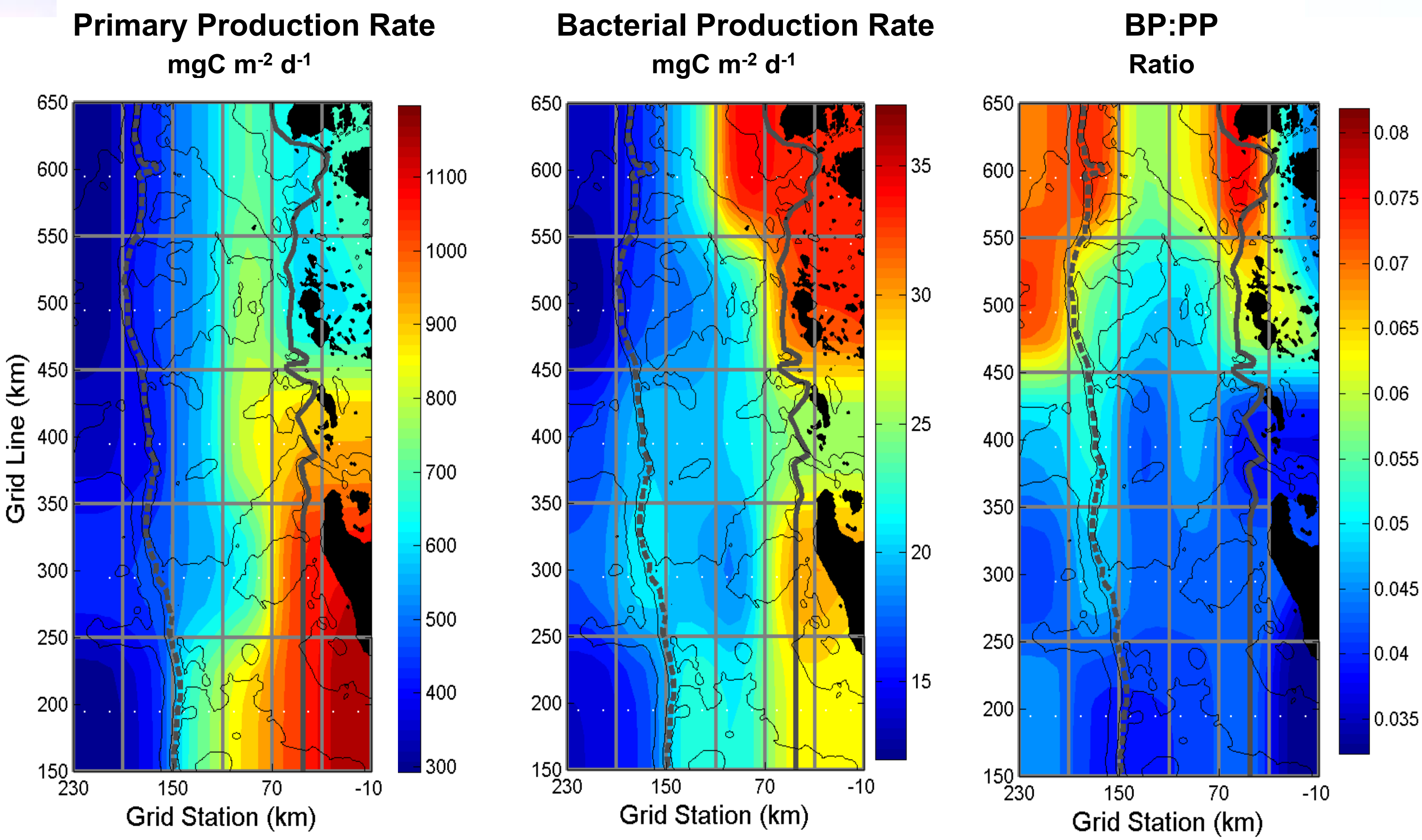
Flux of labile DOC from healthy phytoplankton alone is sufficient to satisfy the bacterial demand, assuming reasonable growth efficiency

Will BP change as PP responds to warming?

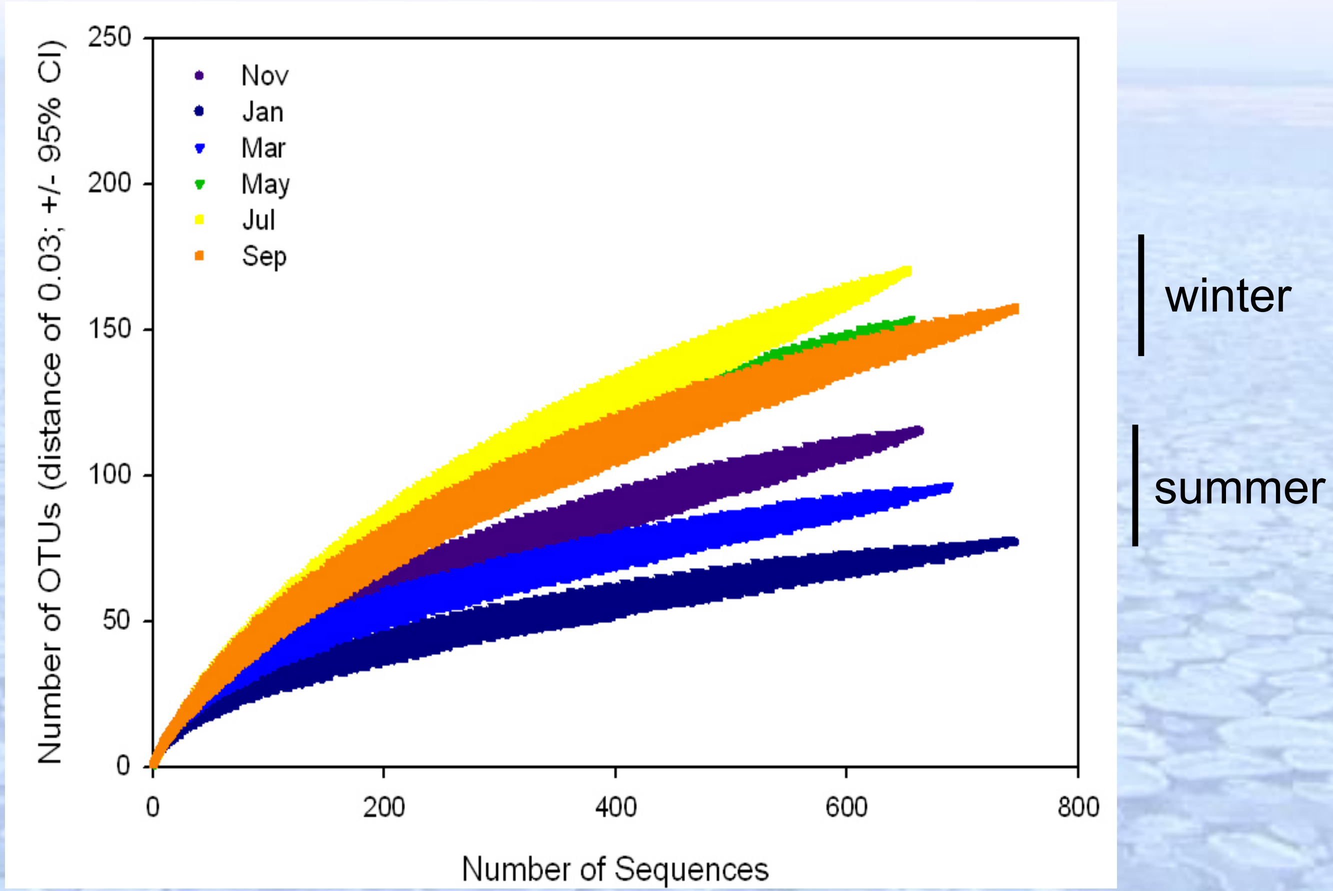
Apparent Growth Efficiency ???

Scenarios:
DOC limitation (low flux)
More flux, lower BGE

Production Rate Climatologies 2003 - 2008



Variation in Antarctic bacterioplankton over the annual cycle - rarefaction

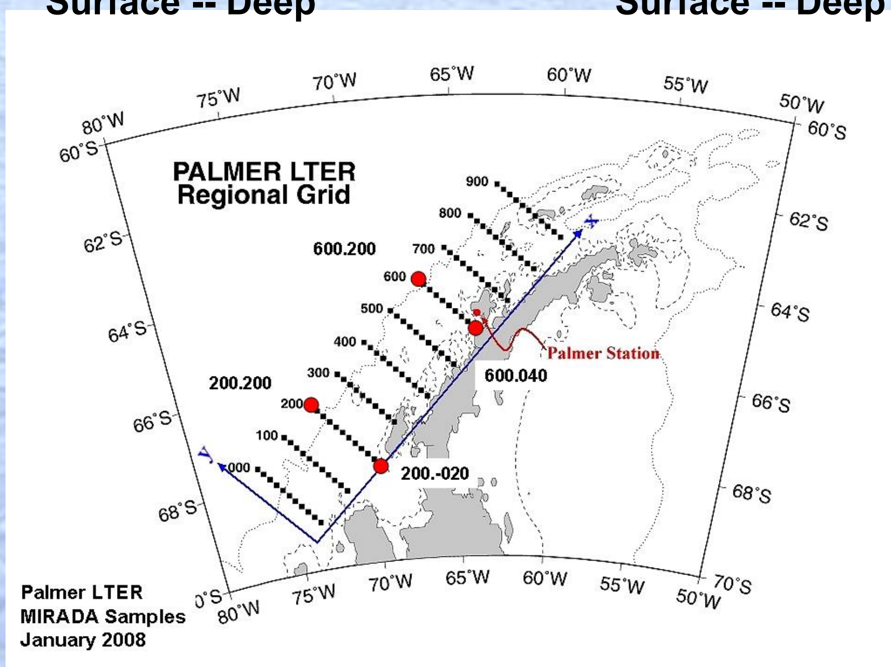


A. Murray & J Grzymski, in prep

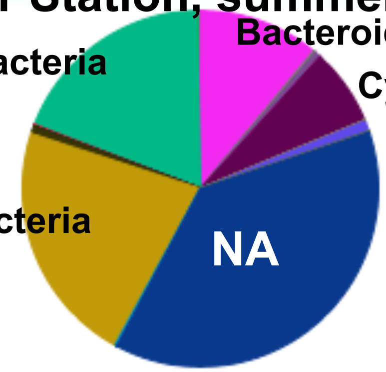
Linda Amaral-Zettler, MBL-Bay Paul Center

Summer:
Inshore – Offshore
North – South
Surface -- Deep

Winter:
Inshore
North
Surface -- Deep



Preliminary 454 Sequencing Results Palmer Station, summer



TOTAL: 32192

3 *	Acidobacteria Acidobacteria
9 *	Actinobacteria Actinobacteria
7 *	Bacteroidetes Bacteroidetes
3516 *	Bacteroidetes Flavobacteria
49 *	Bacteroidetes NA
174 *	Bacteroidetes Sphingobacteria
14	Chlamydiae Chlamydiae
3	Chloroflexi Anaerolineae
2257 *	Cyanobacteria Cyanobacteria
12 *	Firmicutes Bacilli
324 *	Firmicutes Clostridia
23 *	Firmicutes Mollicutes
5 *	Firmicutes NA
12206 *	Bacteria NA
60 *	Planctomycetes Planctomycetacia
7087 *	Proteobacteria Alphaproteobacteria
231 *	Proteobacteria Betaproteobacteria
2 *	Proteobacteria Deltaproteobacteria
45 *	Proteobacteria Epsilonproteobacteria
6061 *	Proteobacteria Gammaproteobacteria
89 *	Proteobacteria NA
2	Spirochaetes Spirochaetes
2	TM7 Unassigned
7	Verrucomicrobia Verrucomicrobiae
4	no_ref_match NA

SUMMARY

Rapid regional warming along West Antarctic Peninsula: +6C in winter since 1950

Driven by interactions with winds and Antarctic Circumpolar Current

Marine ecosystem responding at all trophic levels:

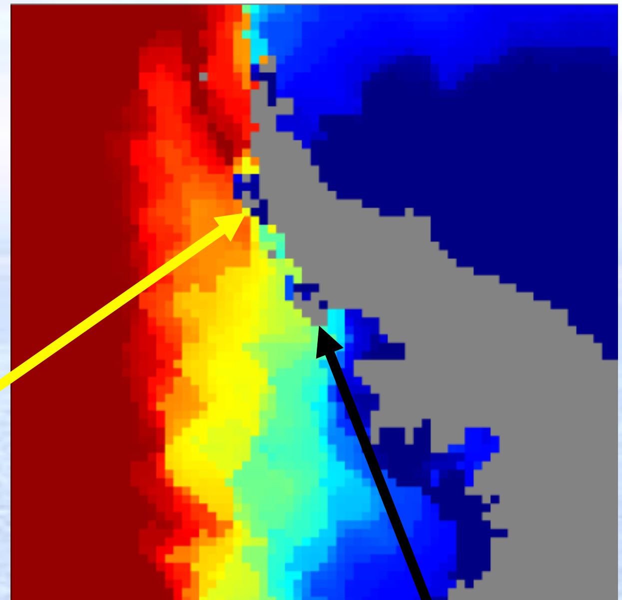
- **Phytoplankton production - in north, + in south**
- **Local changes in penguin, seal populations**
- **Changes in penguin diets > in N than S**
- **Delay of annual sedimentation event**

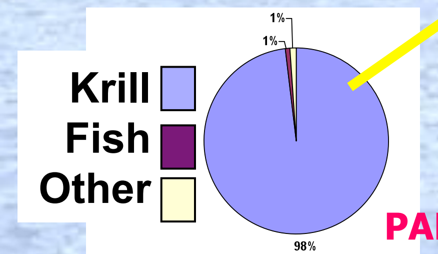
Changes caused by climate-driven advances or delays in key life cycle events, disrupting the phenological couplings between trophic levels

Yet to document changes in bacterial dynamics and communities

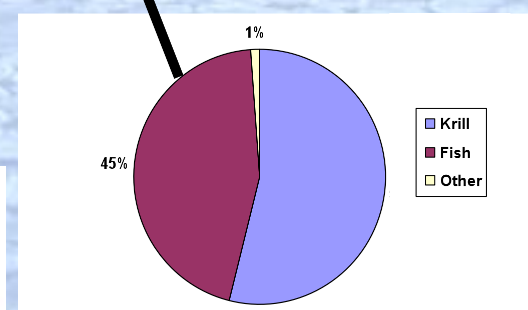
Temporal (1974 – 2006) and geographic (500 km north-south) Changes in Antarctic silverfish (*Pleuragramma antarctica)* in Adélie penguin diets

Penguin stomach contents

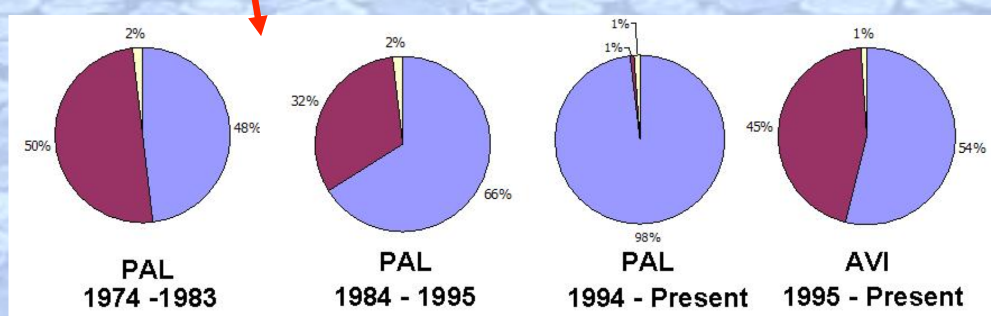




PALMER NOW and PAST



AVIAN Island NOW



Effect of physical environment: change in fish habitat space
Coldest water in water column, (January) 1993 – 2005:
no silverfish >0°C (red areas)