HOT DAYS ALONG THE WEST ANTARCTIC PENINSULA

The man!

Polar Biol (1992) 11:525–531

Polar Biology
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Increases in Antarctic penguin populations: reduced competition with whales or a loss of sea ice due to environmental warming?

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Received 25 June 1991; accepted 6 August 1991

Summary. A central tenet of Antarctic ecology suggests that increases in Chinstrap Penguin (*Pygoscelis antarctica*) populations during the last four decades resulted from an increase in prey availability brought on by the decrease in baleen whale stocks. We question this tenet and present evidence to support the hypothesis that these increases are due to a gradual decrease in the frequency of cold years with extensive winter sea ice cover resulting from environmental warming. Supporting data were derived from one of the first, major multidisciplinary winter expedition to the Scotia and Weddell seas; recent satellite images of ocean ice cover; and the analysis of long-term surface temperature records and penguin demography. Our observations indicate there is a need to pay close attention to environmental data in the management of Southern Ocean resources given the complexity of relating biological changes to ecological perturbations.

Introduction

Populations of many krill-eating, Southern Ocean predators have exhibited significant changes during the last four decades. Notable among these, have been increases in the abundance of Chinstrap Penguins (*Pygoscelis antarctica*), which breed mainly on the Antarctic Peninsula and islands of the Scotia Sea (Watson 1975). At many colonies, numbers have increased 6–10% per annum (Laws 1985), and at some localities fivefold increases have occurred in the last 20 years (Rootes 1988). Chinstraps have also expanded their range southward along the western side of the Antarctic Peninsula (Parmelee and Parmelee 1987; Poncet and Poncet 1987) into areas historically dominated by the closely related adelie Penguin (*P. adeliae*; Fig. 1). A central tenet of Antarctic ecology explains these population changes in terms of a presumed increase in food availability that resulted from the decrease in baleen whale stocks due to commercial whaling (Sladen 1964; Emison 1968; Conroy 1975; Croxall and Kirkwood 1979; Croxall and Prince 1979; Croxall et al. 1984). This tenet is based on the fact that the dominant component in the summer diets of both Chinstraps and whales is the Antarctic krill (*Euphausia superba*). Although this tenet has been widely accepted, the possible mechanism by which a decrease in whales could have led to an increase in Chinstraps has not been questioned (cf. Horwood 1980). Indeed, the long-standing view has simply been that whaling led to a "krill surplus" that was used by krill-eating predators when competitive release altered the existing patterns of consumption (Laws 1985).

Although this whale reduction hypothesis has clearly been useful in guiding research on trophic interactions in the Southern Oceans, it is now apparent that increases in Chinstrap populations have not been mirrored by their sympatric, most closely related congener, the Adelie Penguin. Adelies share a significant portion of their range on the Antarctic peninsula and islands of the Scotia Arc with Chinstraps (Watson 1975). Alike in size and general appearance, both exhibit broad ecological similarities, not the least of which is a predominance of krill in their summer diets (Volkman et al. 1980; Trivelpiece et al. 1987, 1990; Trivelpiece and Trivelpiece 1990). Yet, when compared to Chinstraps, population increases in Adelies have not been as substantial, and at many sites appear to represent nothing more than recovery after human disturbance and exploitation (Poncet and Poncet 1987). Adelies, in fact, have declined noticeably at several localities on the Antarctic Peninsula, a change considered "unexplainable" by Poncet and Poncet (1987). This raises an interesting challenge to the whale reduction hypothesis: If the decrease of baleen whale stocks actually led to a krill surplus, why have populations of the ecologically similar Adelies residing in the same geographical areas shown such different responses?

Here we propose that the answer to this question does not rest with the idea of a krill surplus. Instead, we suggest

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Key point: If the decimation of baleen whale populations did in fact lead to a "krill surplus", why were krill-dependent , top predator populations exhibiting such dichotomous trends?

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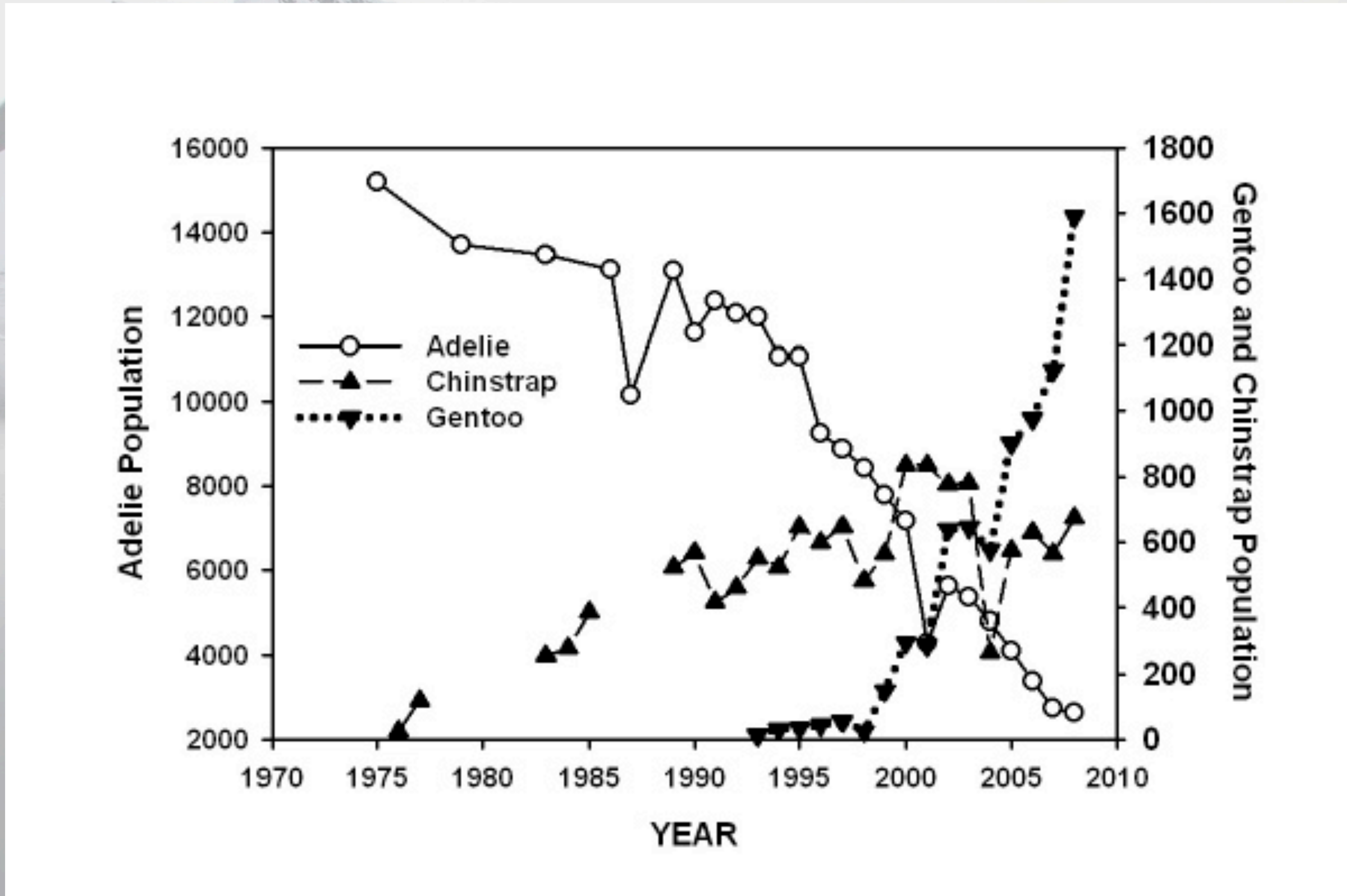
"...the day bird people have something to tell us about climate warming is perhaps the day logic in climate science is abandoned..."

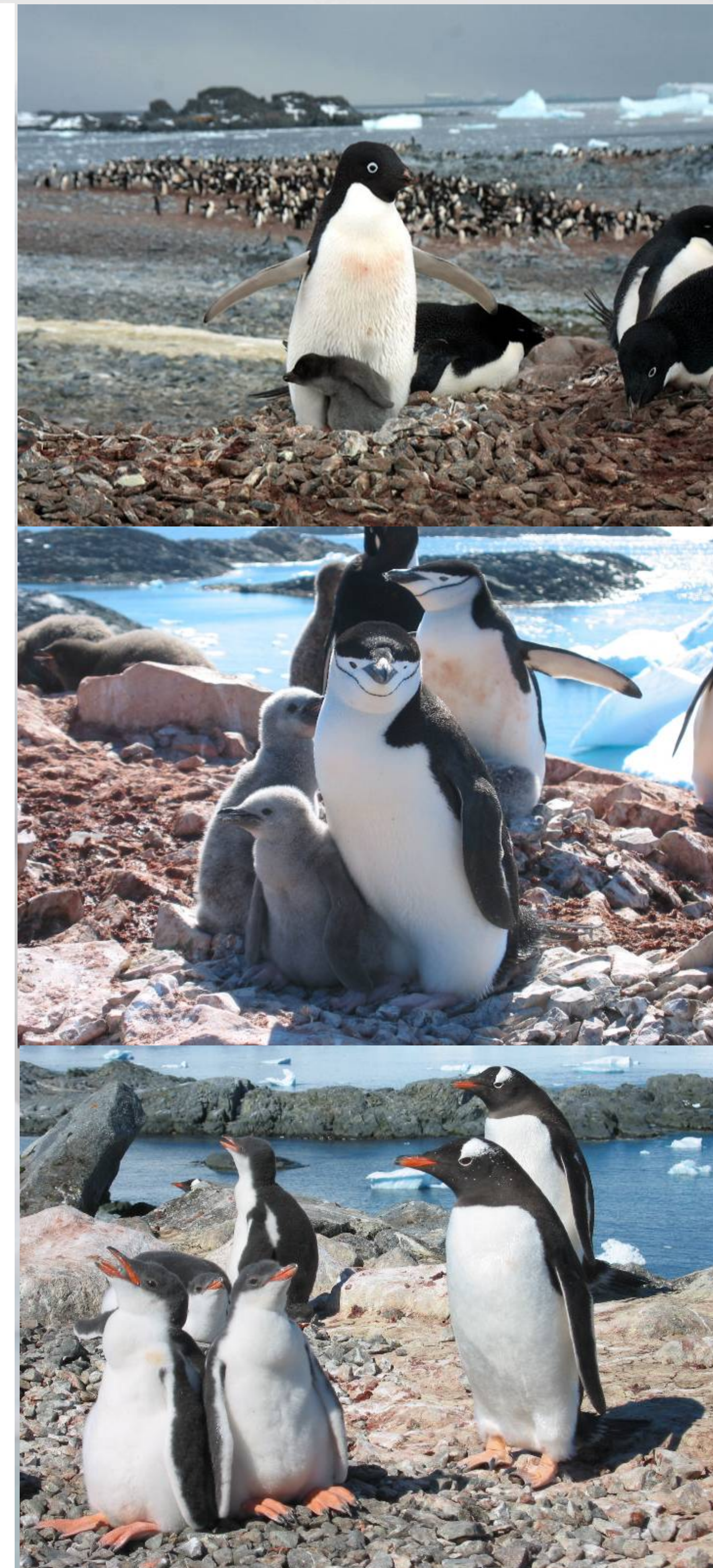
Anonymous Reviewer, Nature

"...a paper that creates this kind of controversy should be positive for science and the journal..."

G. Hempel, Editor, Pol. Biol.

The trends that reflecting a changing system





LTER Palmer has maintained a 22 year time series along the West Antarctic Peninsula

The Boss!

Current team

Our Current grid

PI Hugh Ducklow (MBL)
Bacteria-Biogeochemistry

Bill Fraser (Polar Associates)
- Penguins & Fish

James Connor (Scripps)
- Data management & Informatics

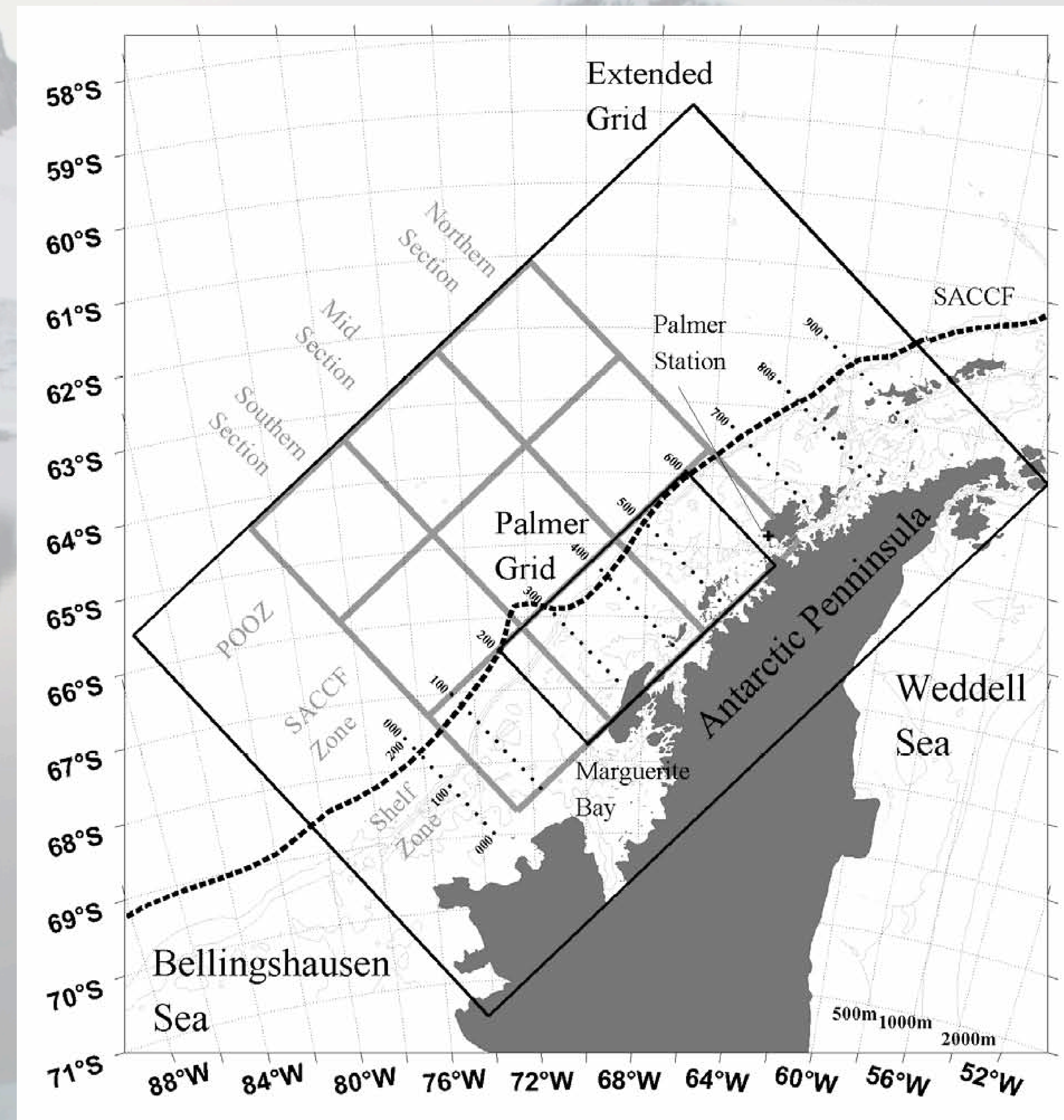
Scott Doney (WHOI)
- Ocean Modeling

Beth Simmons (Scripps)
- Education & Outreach

Oscar Schofield (Rutgers) - Phytoplankton
Doug Martinson (LDEO) - Ocean Physics
Debbie Steinberg (VIMS) - Zooplankton

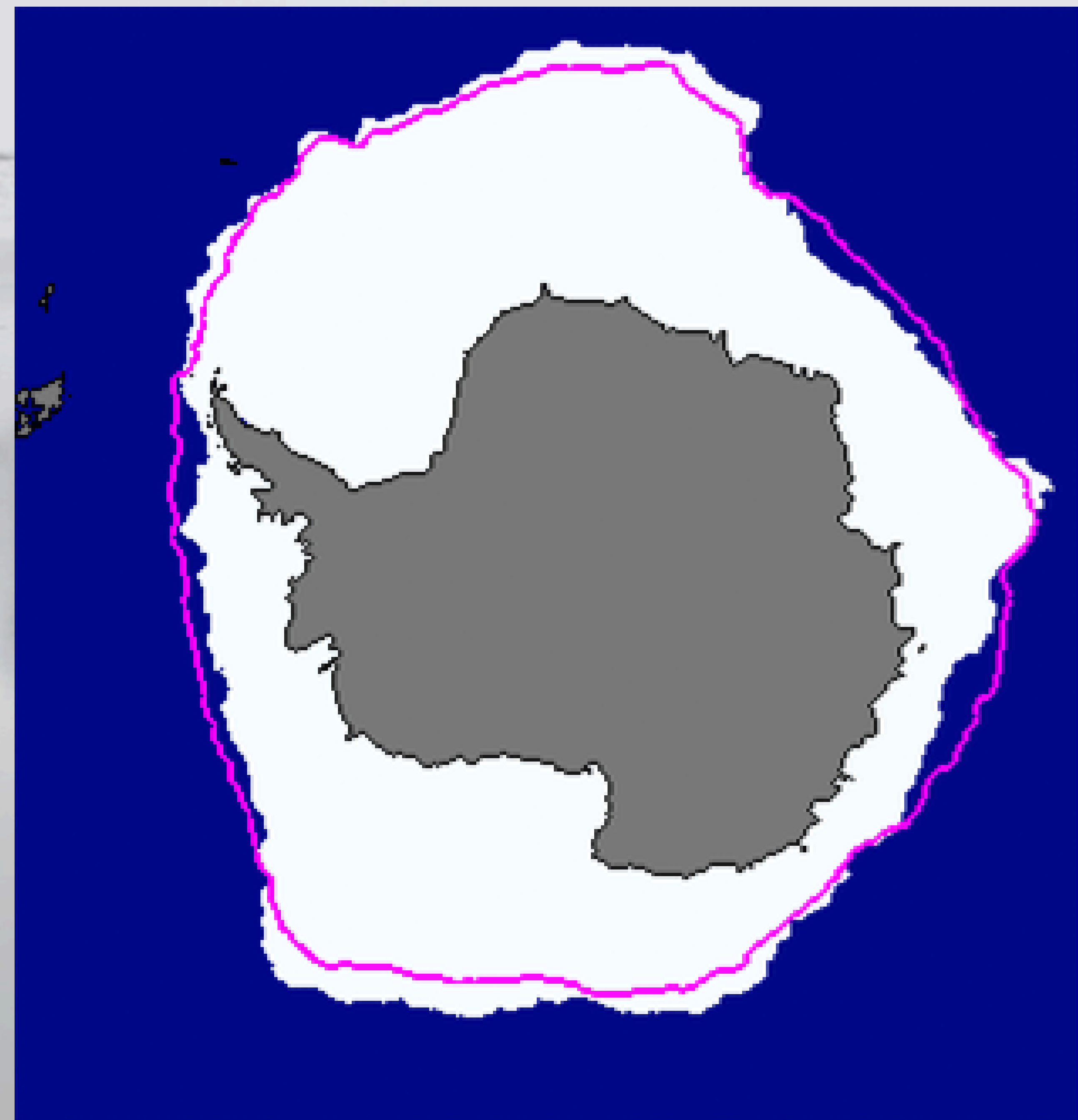
Sharon Stammerjohn (UCSC)
- Climate and Ice

Ari Friendlander (OSU)
Marine Mammals

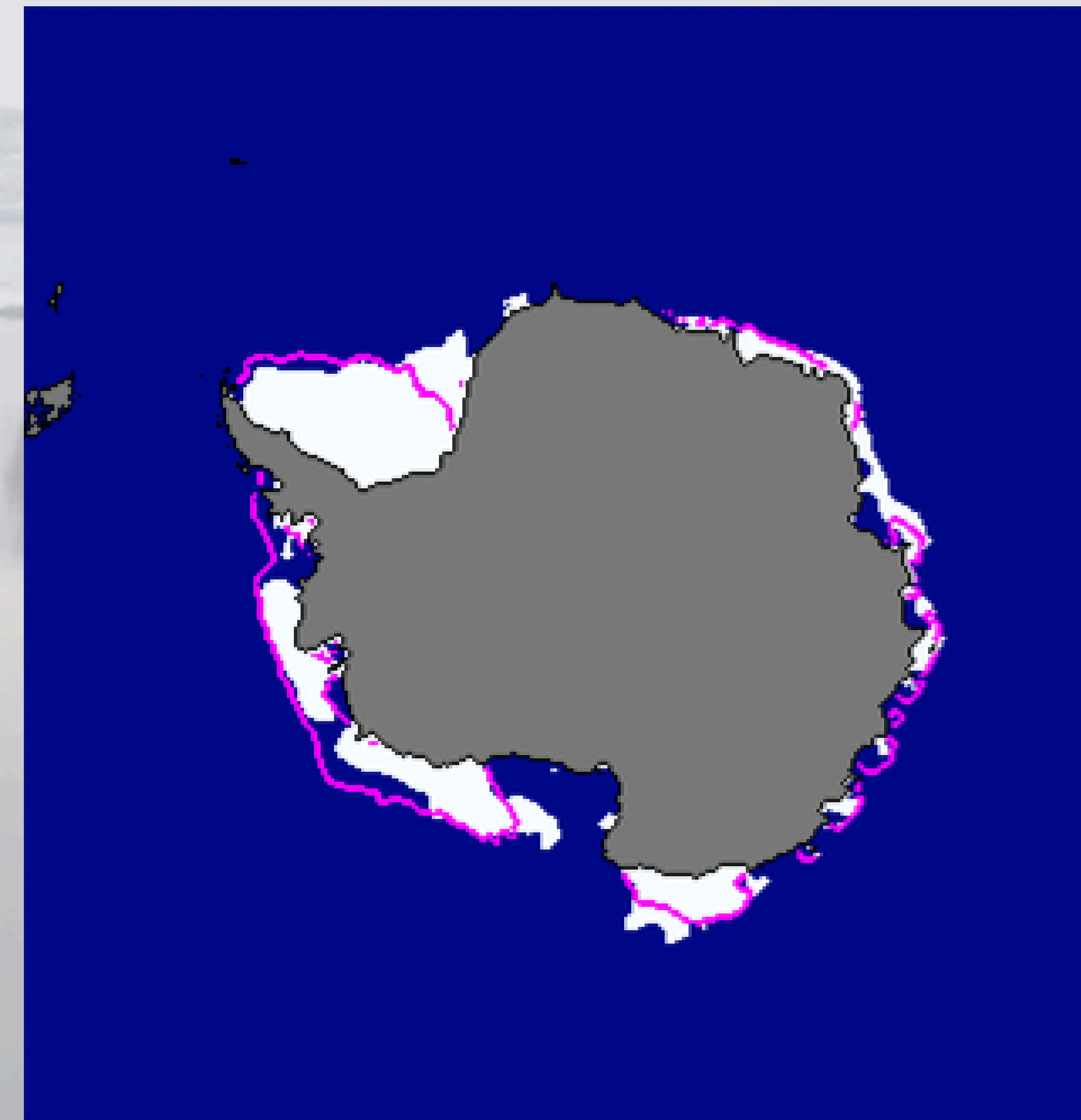


Acknowledgements to past LTER PIs: Ray Smith, Barbara Prezelin, Robin Ross, Langdon Quetin, Dave Karl, Maria Vernet, Eileen Hoffman, John Klinck, Dave Karl

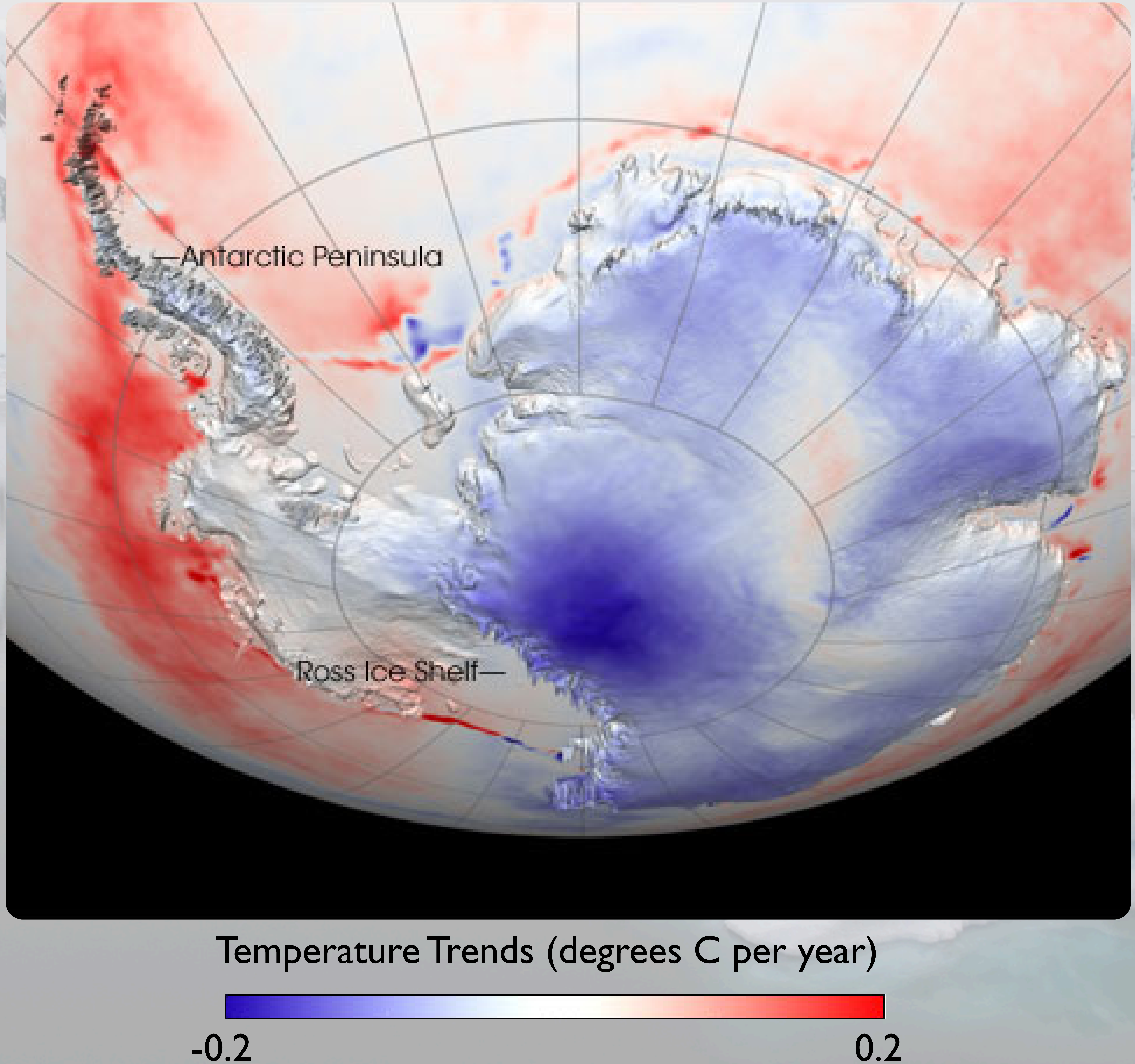
The central hypothesis when the LTER began was that sea ice timing and magnitude structure the productivity and composition of the Antarctic ecosystem. The ice dynamics are driven by large-scale interactions of the atmosphere and ocean.



Winter 2007



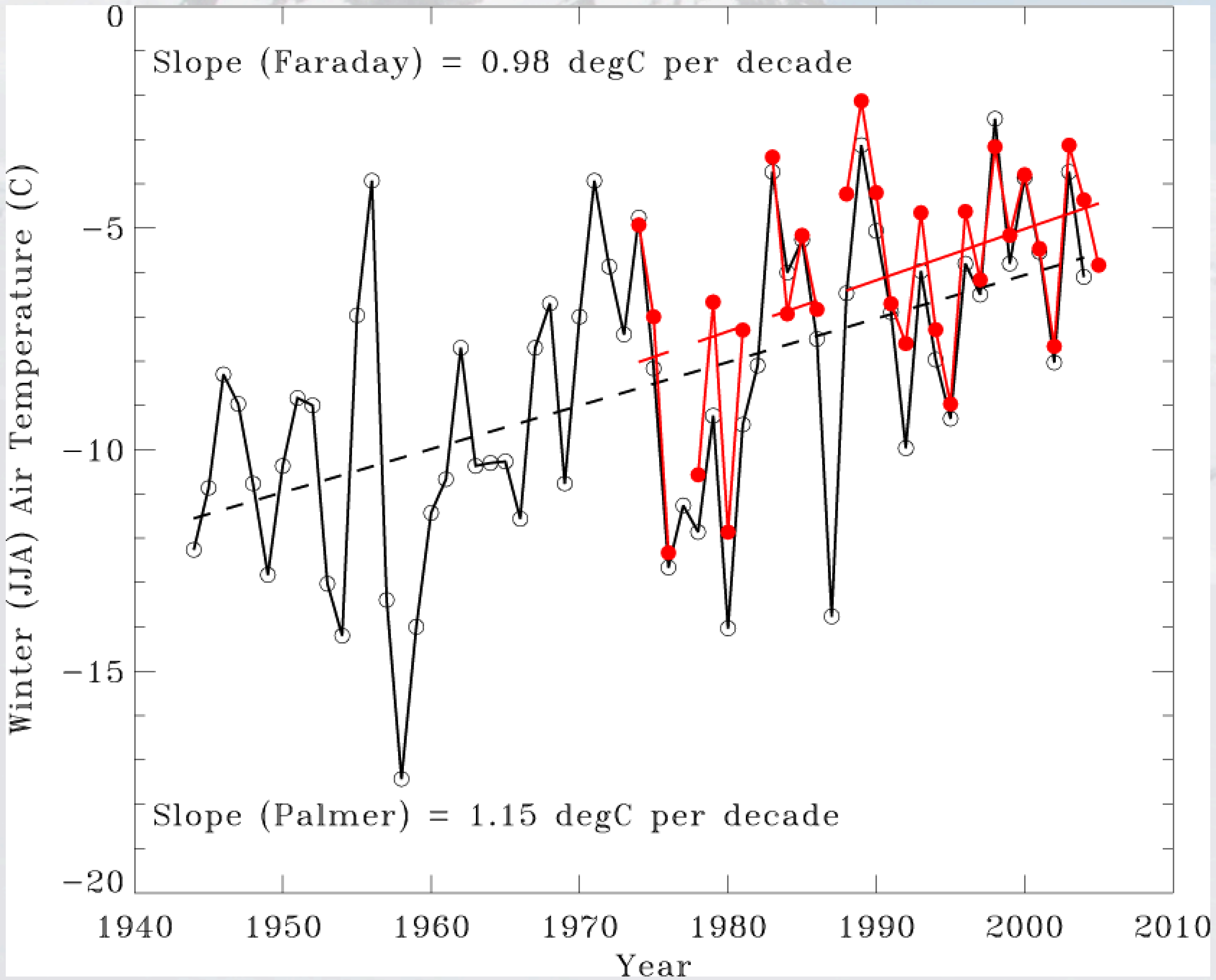
Summer 2007



—Antarctic Peninsula
Ross Ice Shelf—
Temperature Trends (degrees C per year)
-0.2
0.2

The WAP peninsula is experiencing the largest winter warming on Earth

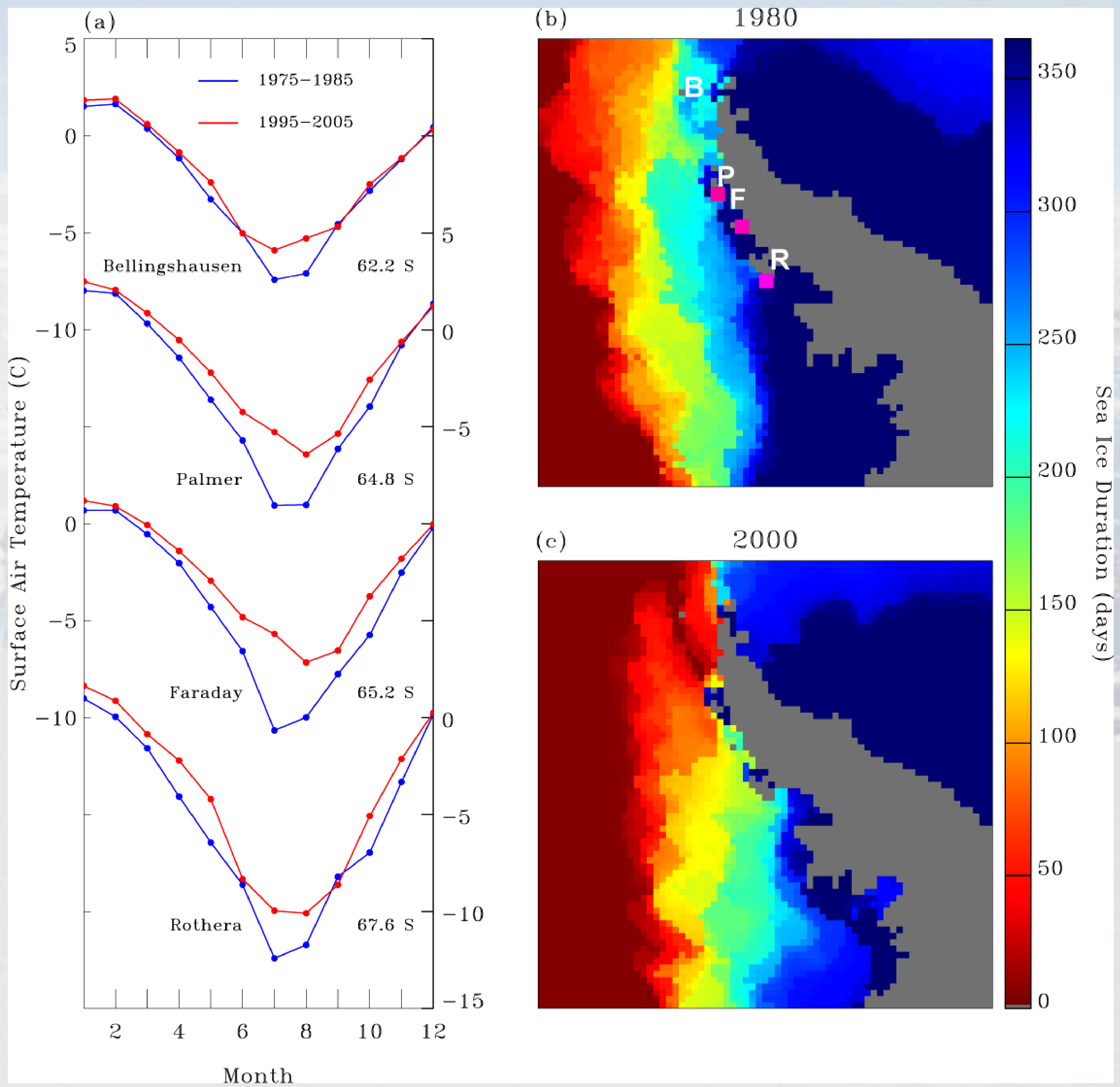
Mean Winter Temperatures



Black is British Faraday & Ukraine Vernadsky Station
Red is US Palmer Station

Air temperature increases over the peninsula

Sea ice duration drops



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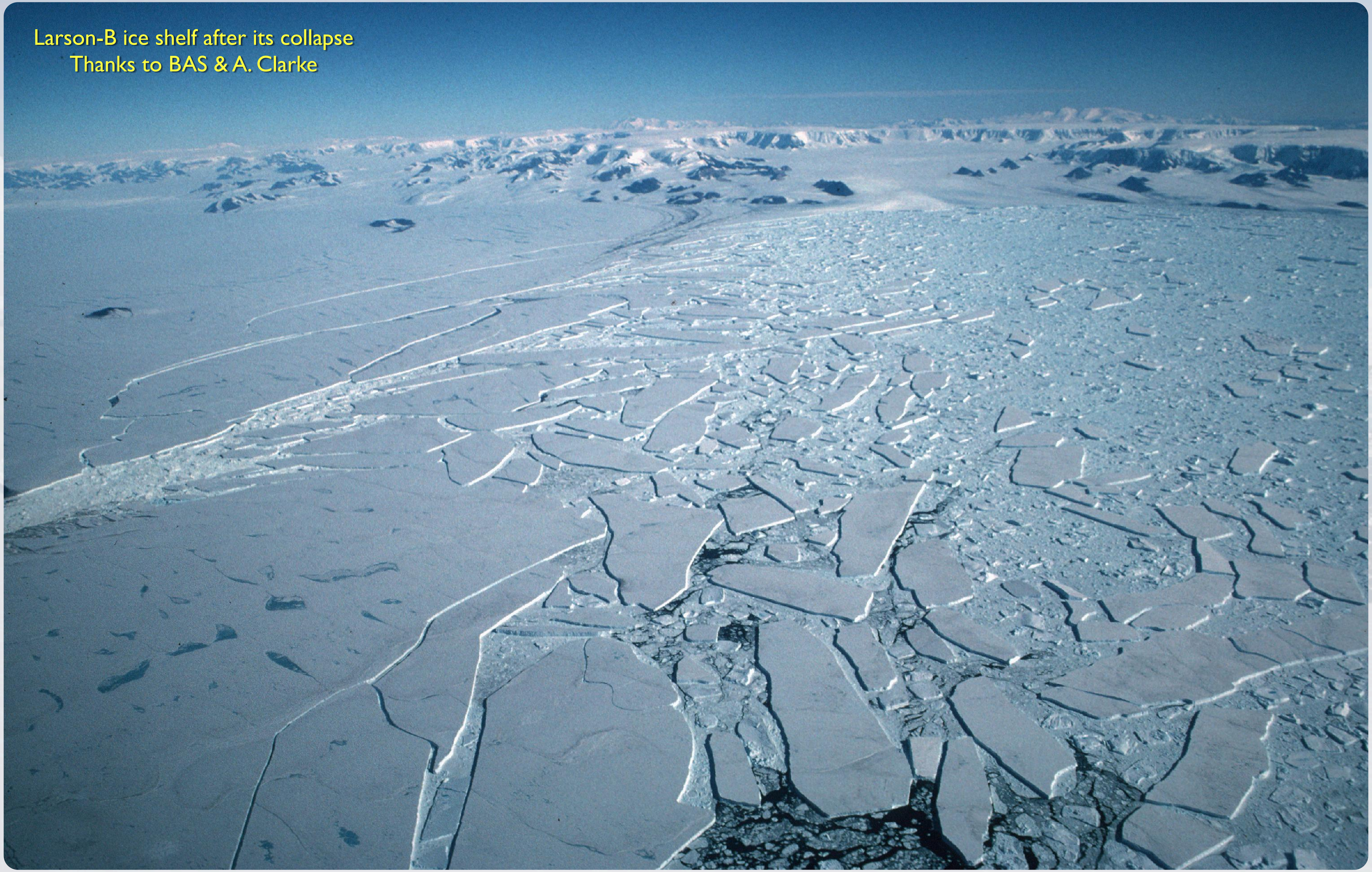
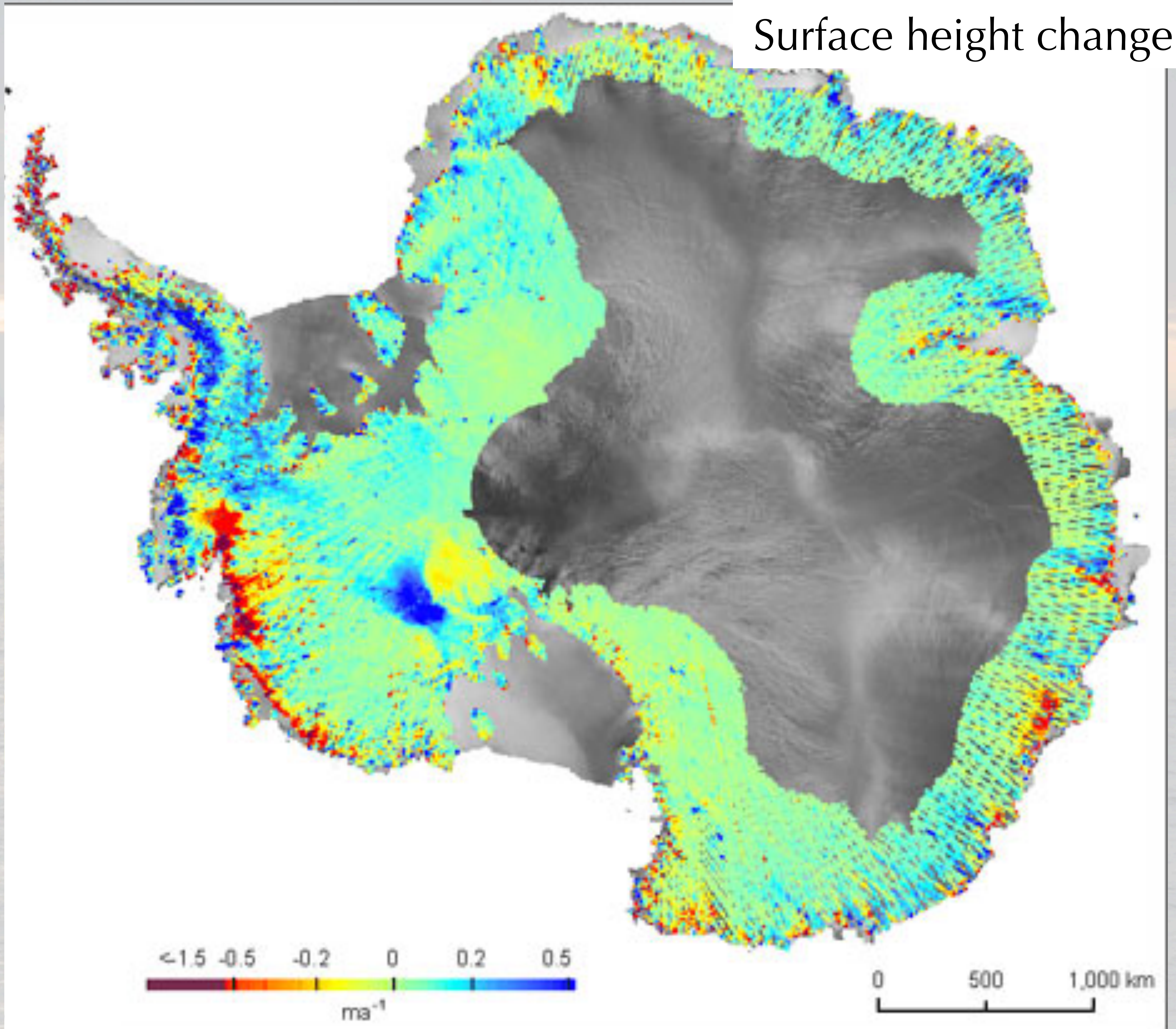


Melt pools on surface of King George VI Sound
(from a BAS twin otter, January 2004)

Ice sheets in this region are melting rapidly

Surface height change (2003-2008)



The PIG, Smith and Thwaites glaciers are thinning at a rate of 9 meters per year

Pritchard et al. 2009

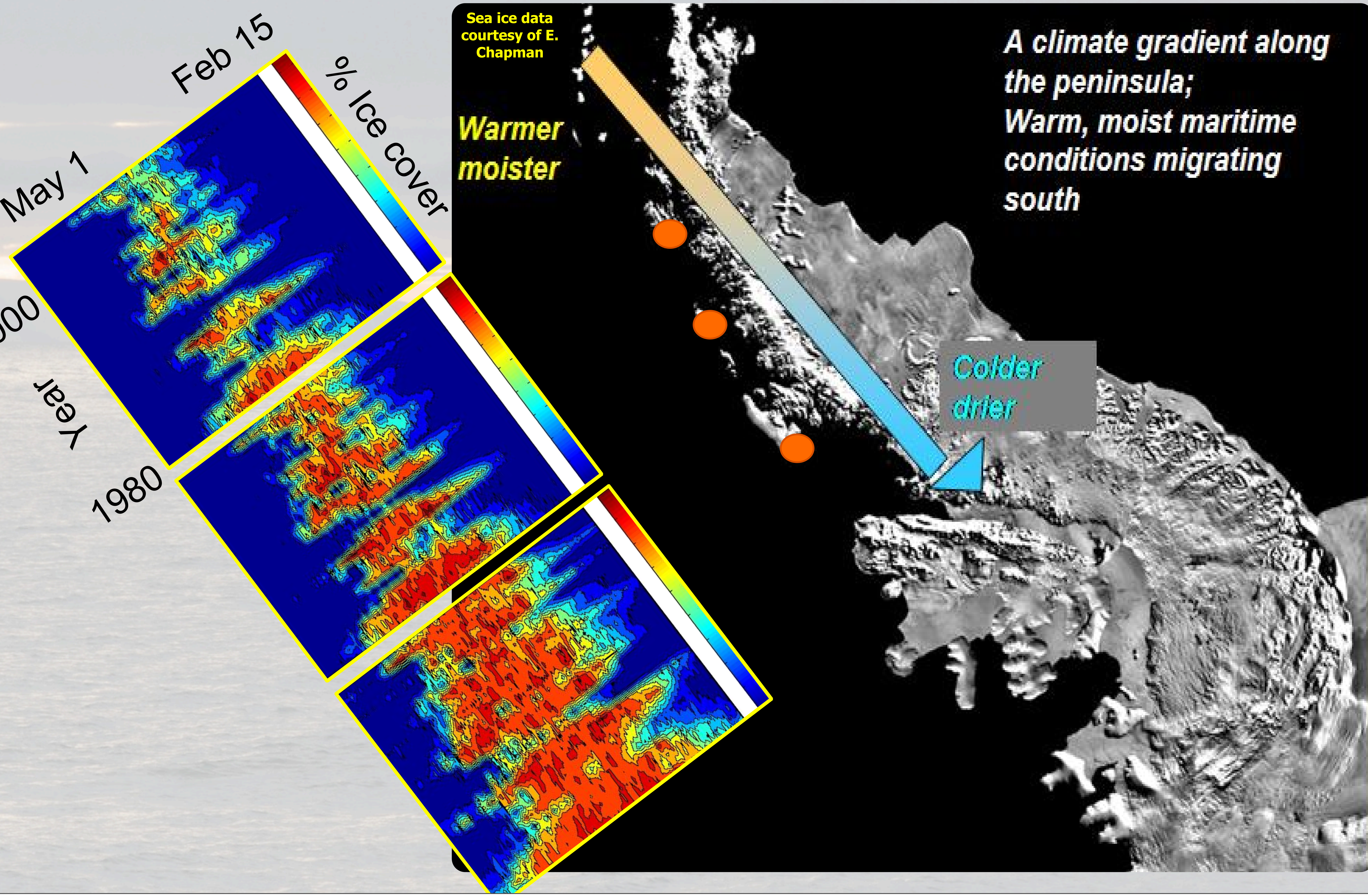
As a grad student


LAWRENCE
M.
GOULD

Palmer Station in the present

Plants at Palmer Station, the greening of Antarctica

Seasonal ice has declined over the few decades resulting to a climate migration to the South



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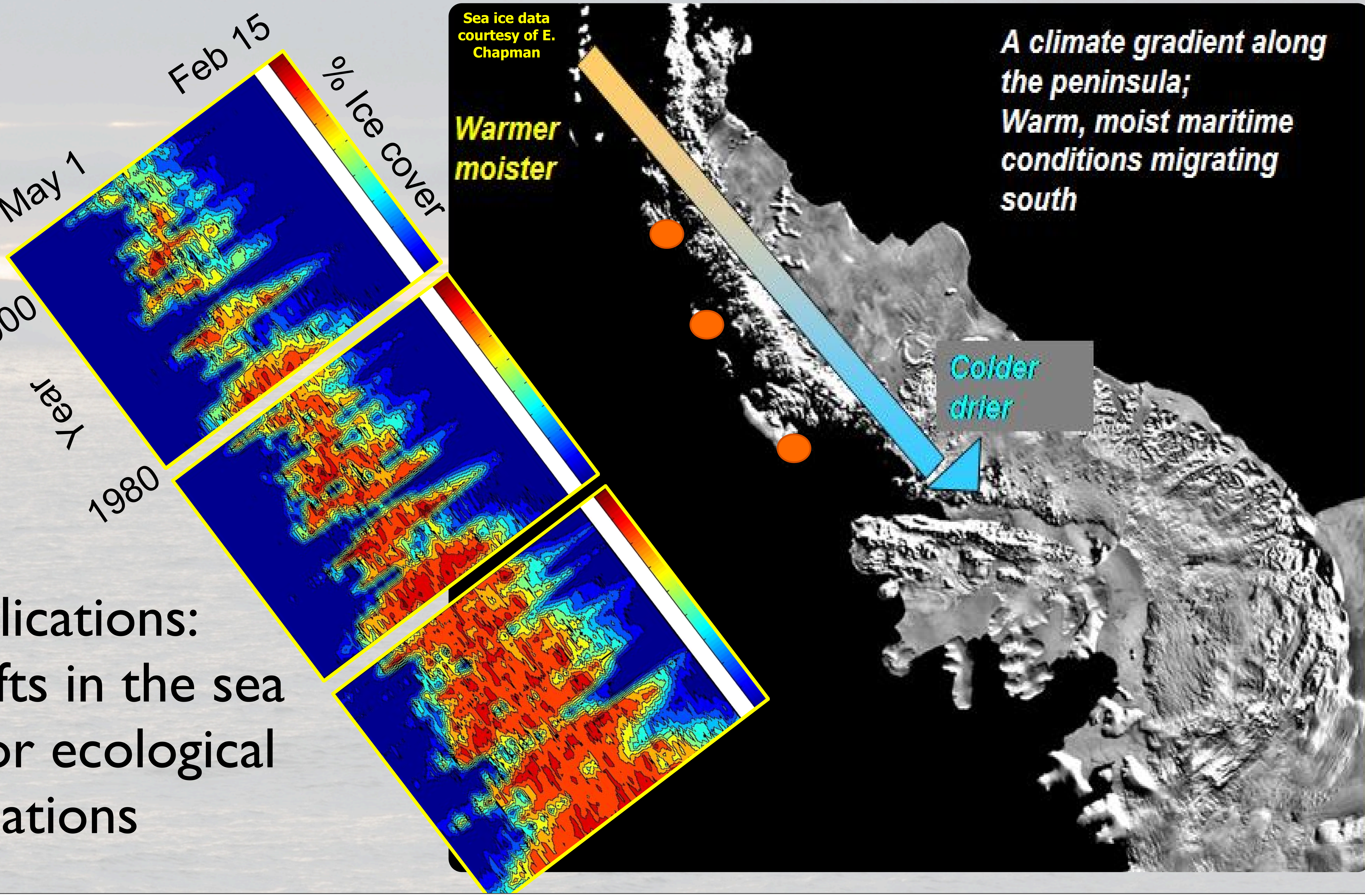
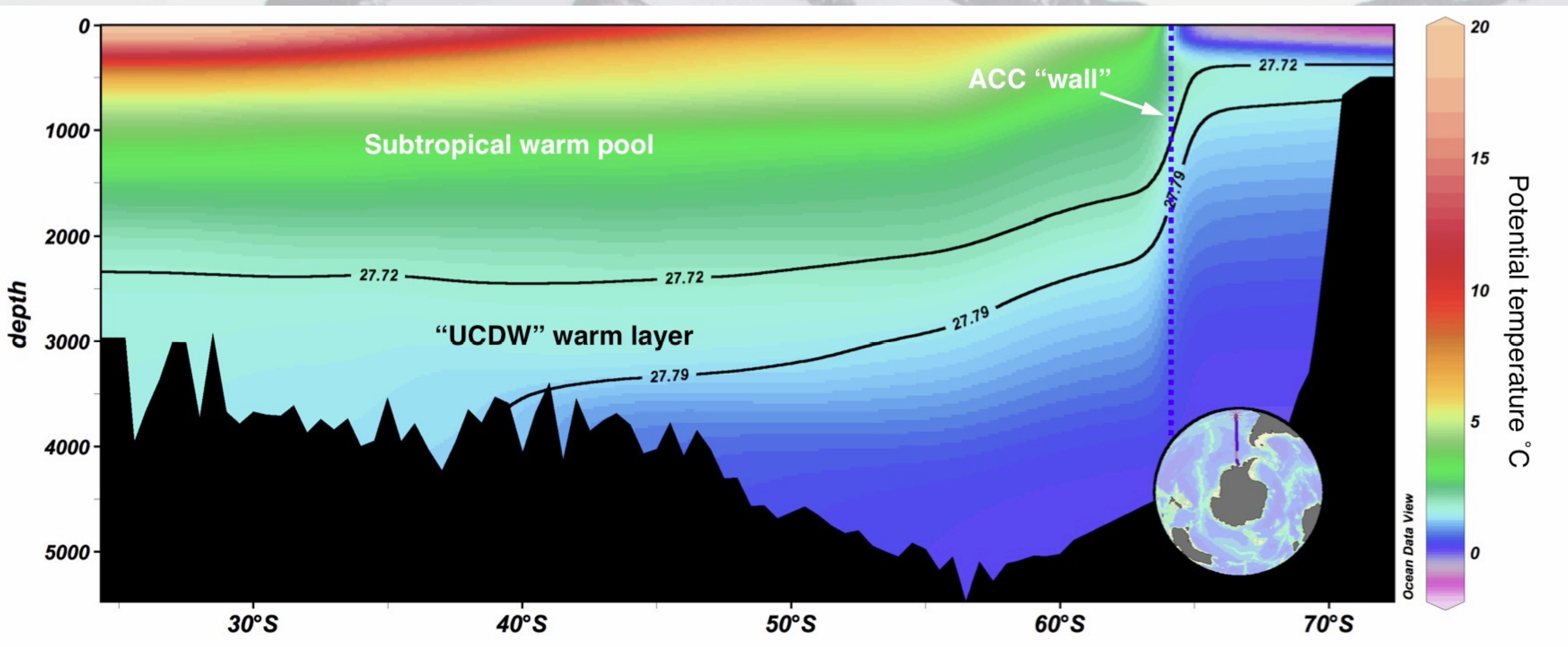
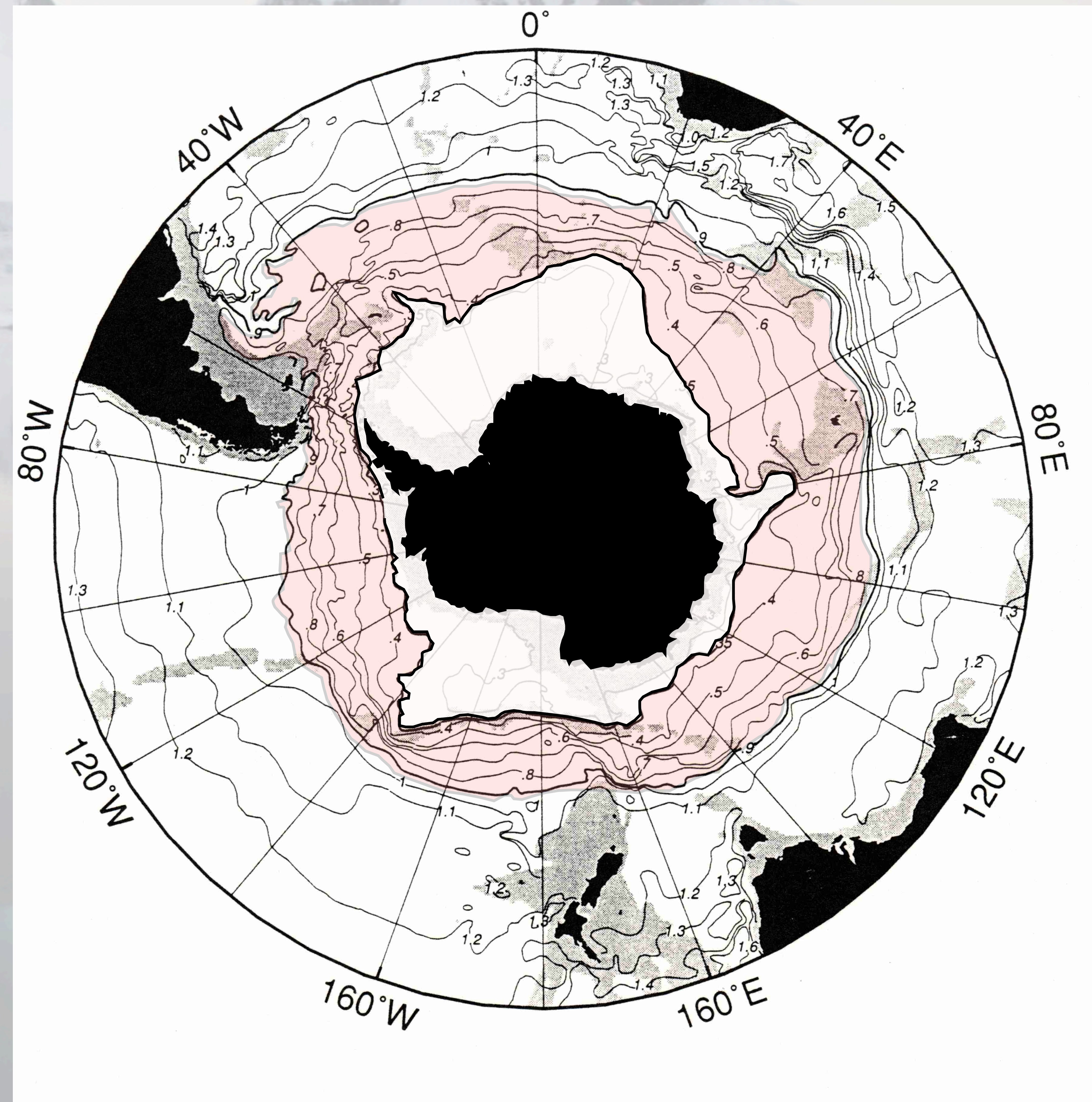


Key Implications: Regional shifts in the sea ice has major ecological implications


Let’s go the sea: What is driving the change?

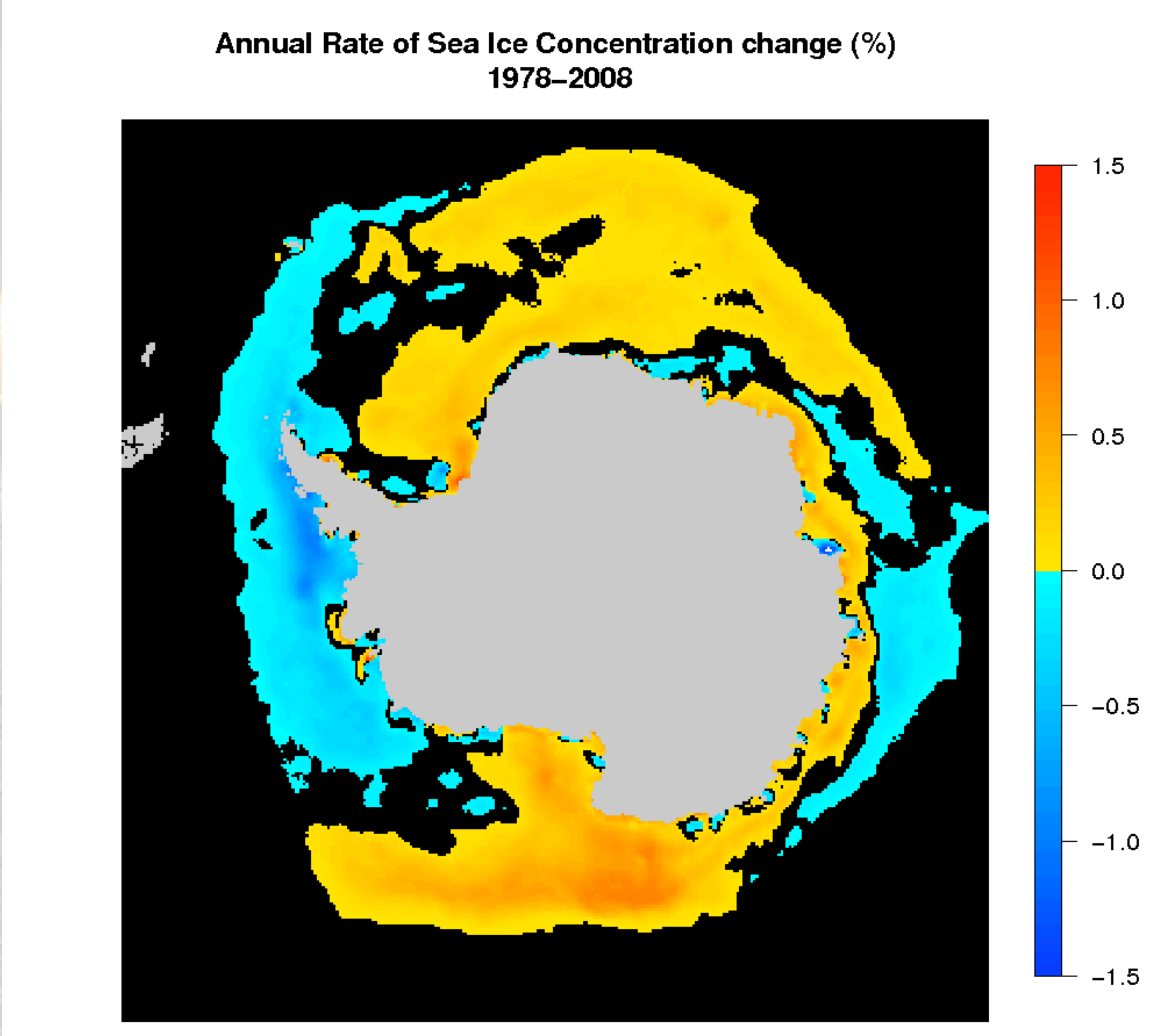
Heat input from Antarctic Circumpolar Current (ACC - world's largest ocean current = ~30,000 Niagara Falls). The heat is driven onto the shelf by intensification of upwelling-favorable winds.



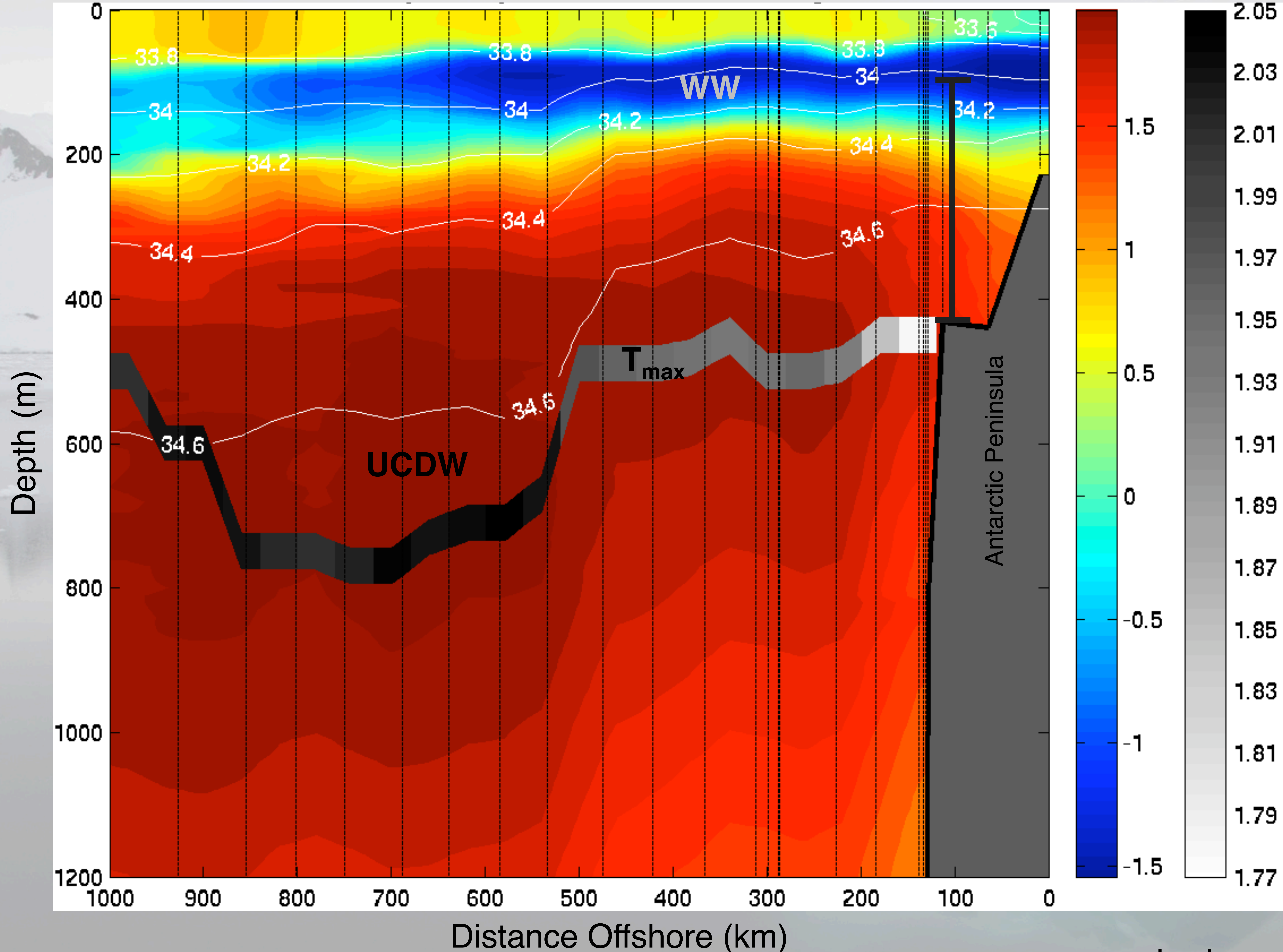


Antarctic Peninsula to the Amundsen Sea: one of the few regions in Antarctica where the Antarctic Circumpolar Current (ACC) *directly* impinges on the shelf break. Upper Circumpolar Deep Water (UCDW) is Antarctica's warmest water.

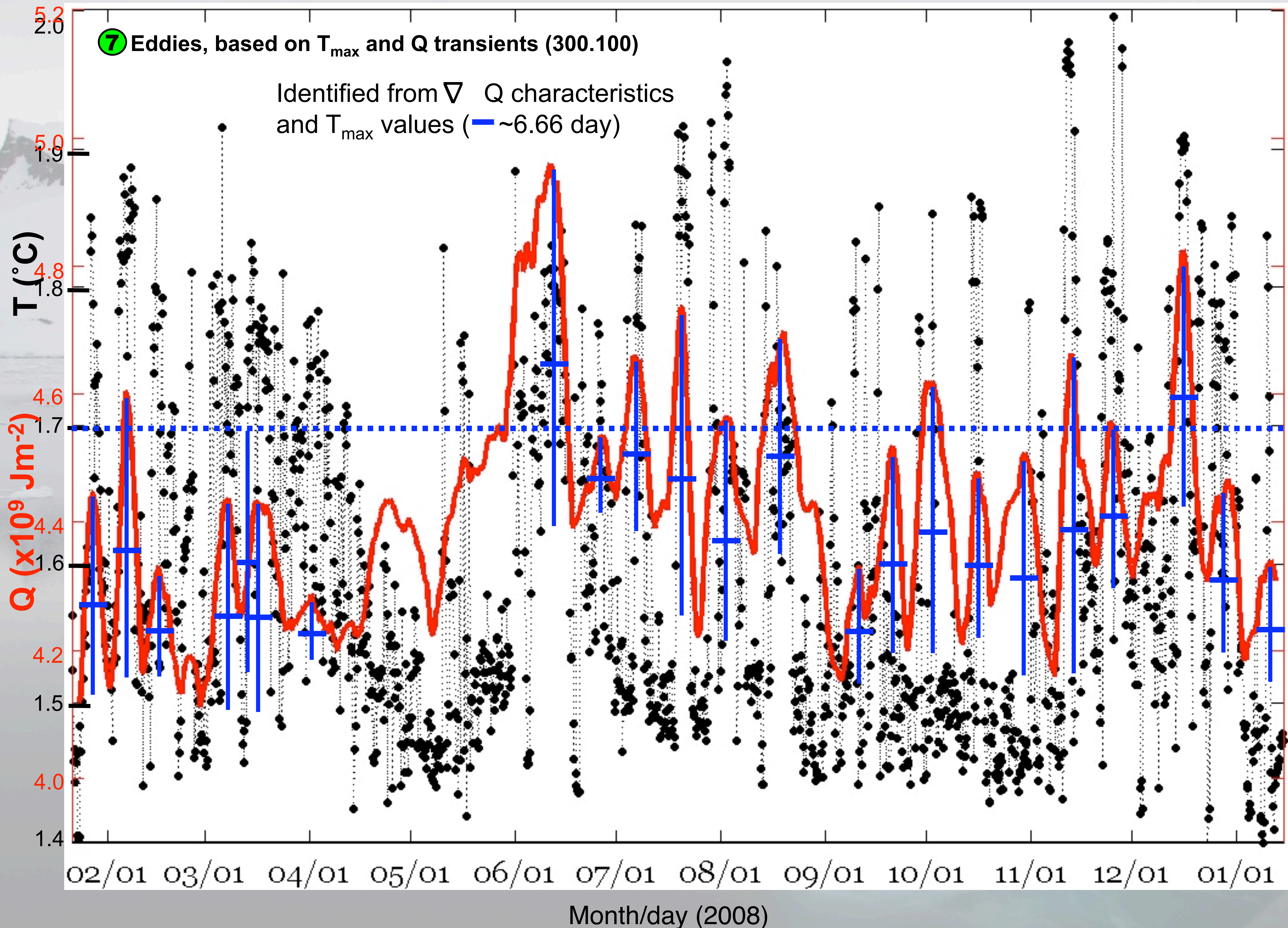
10 year analysis annual trends



ice decline

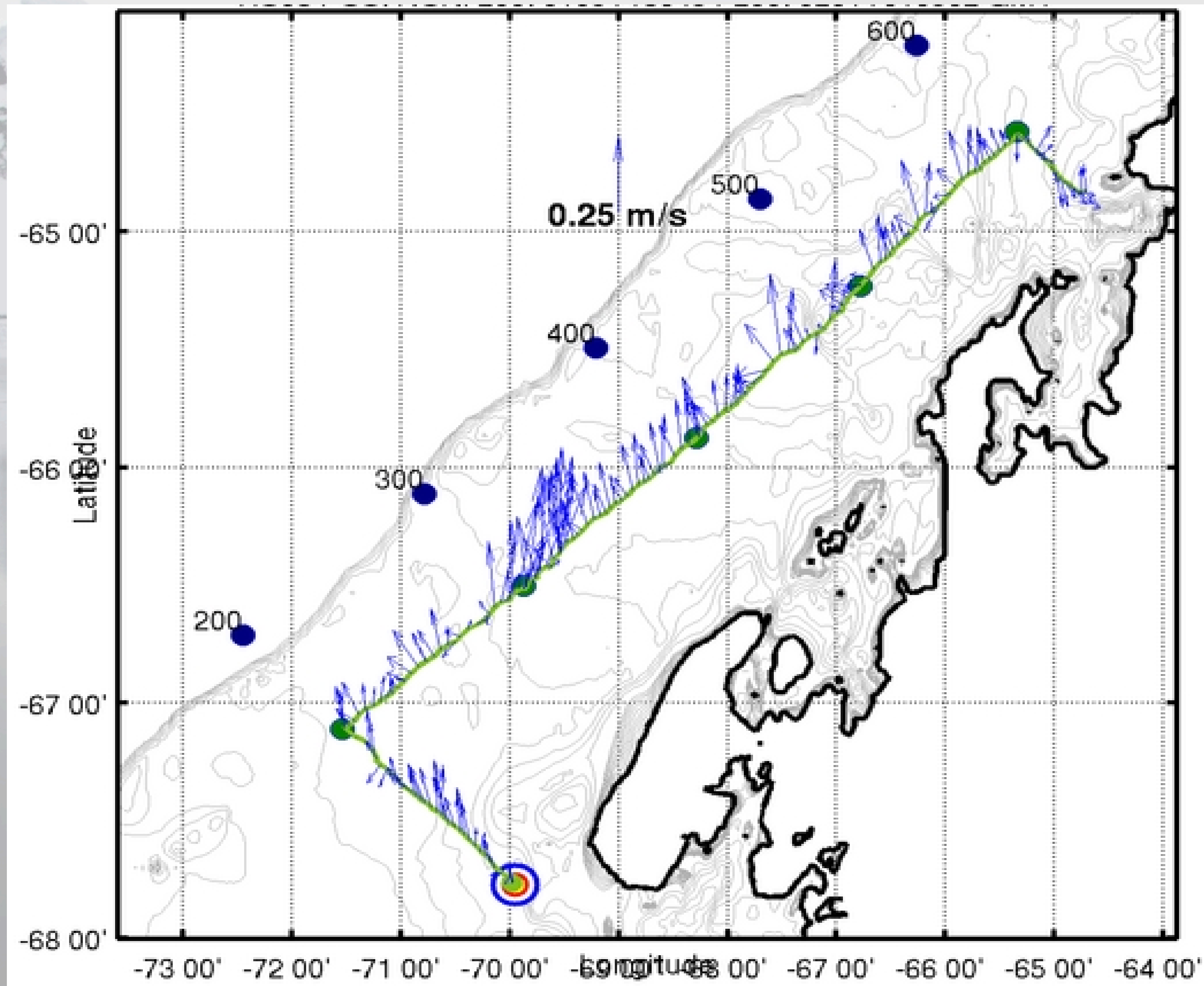


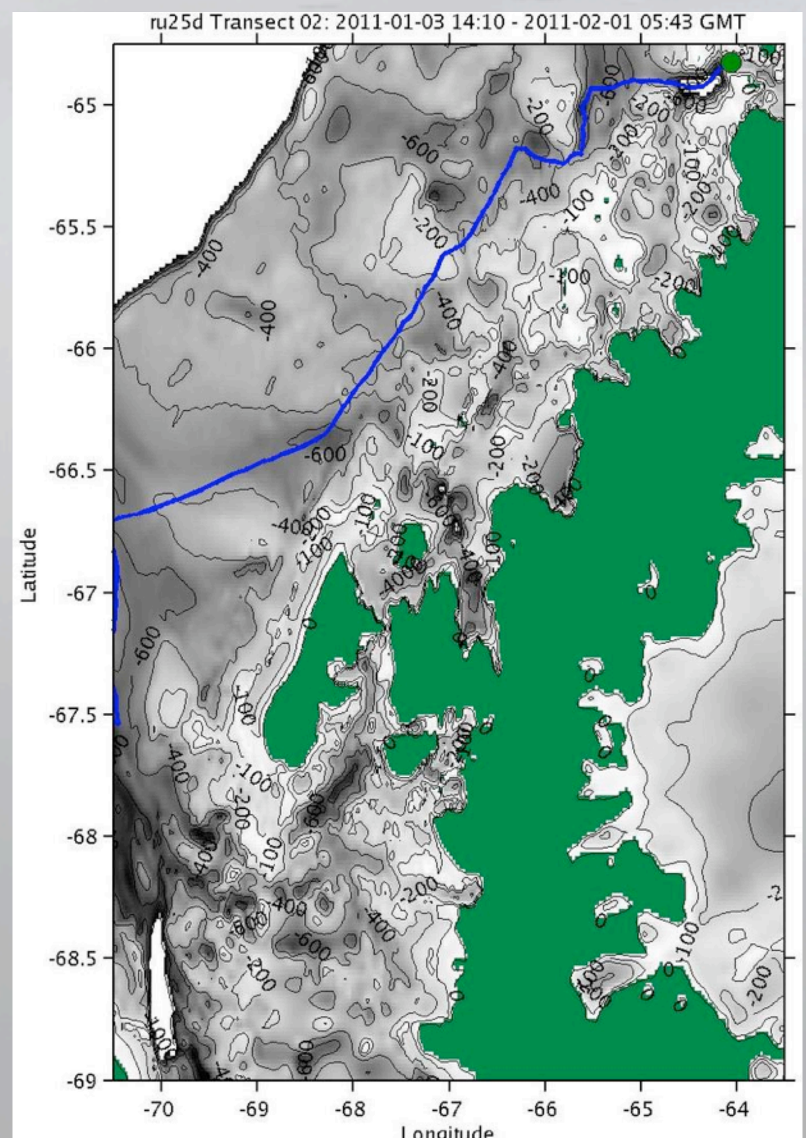
thanks to Doug Martinson

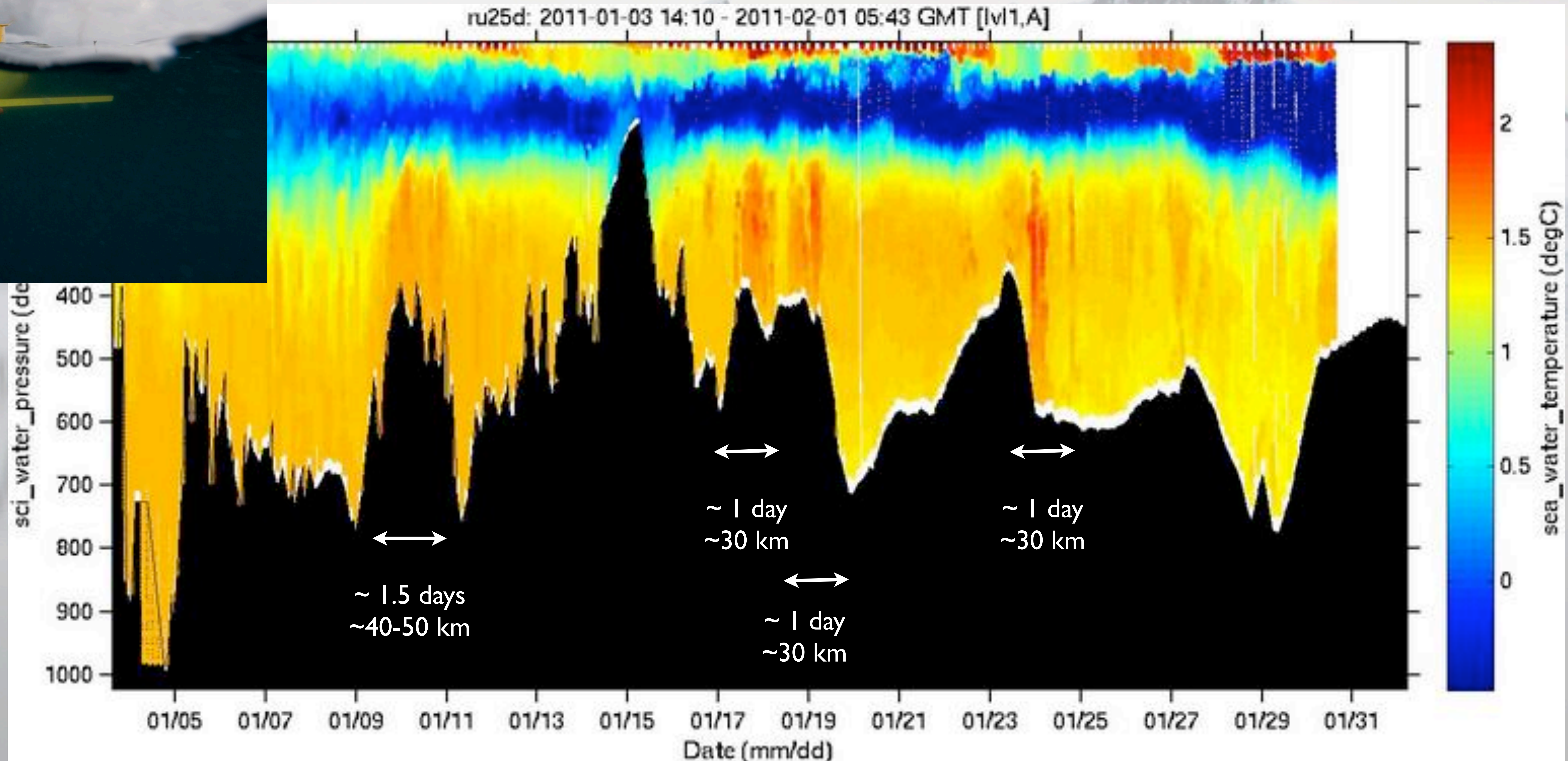


thanks to Doug Martinson

Upwelling favorable winds result in Ekman mass transport offshore

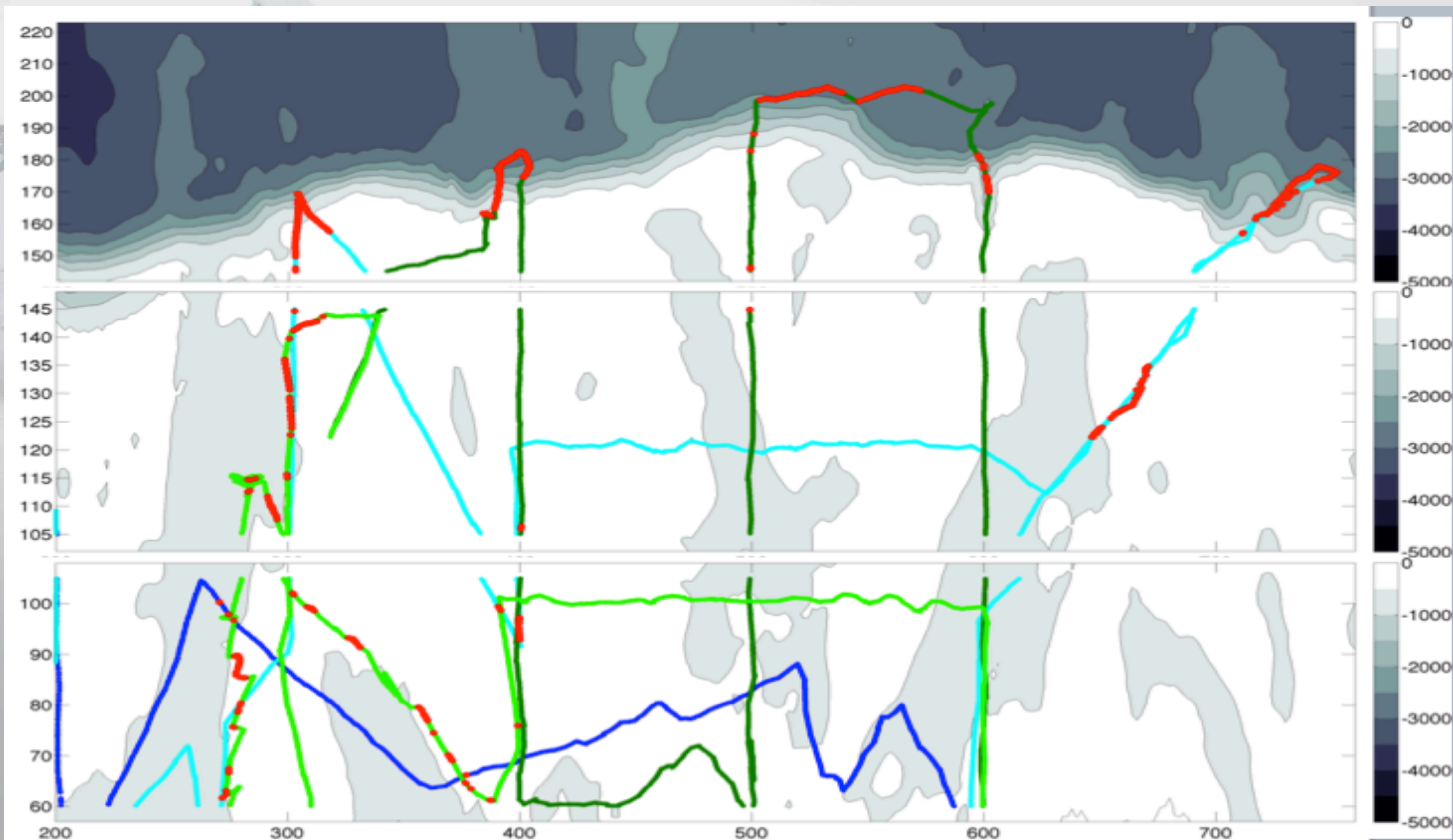






2011: Eddies moving across shelf?

Subsurface eddies spatially associated with northern side of the sea floor canyons across the Peninsula

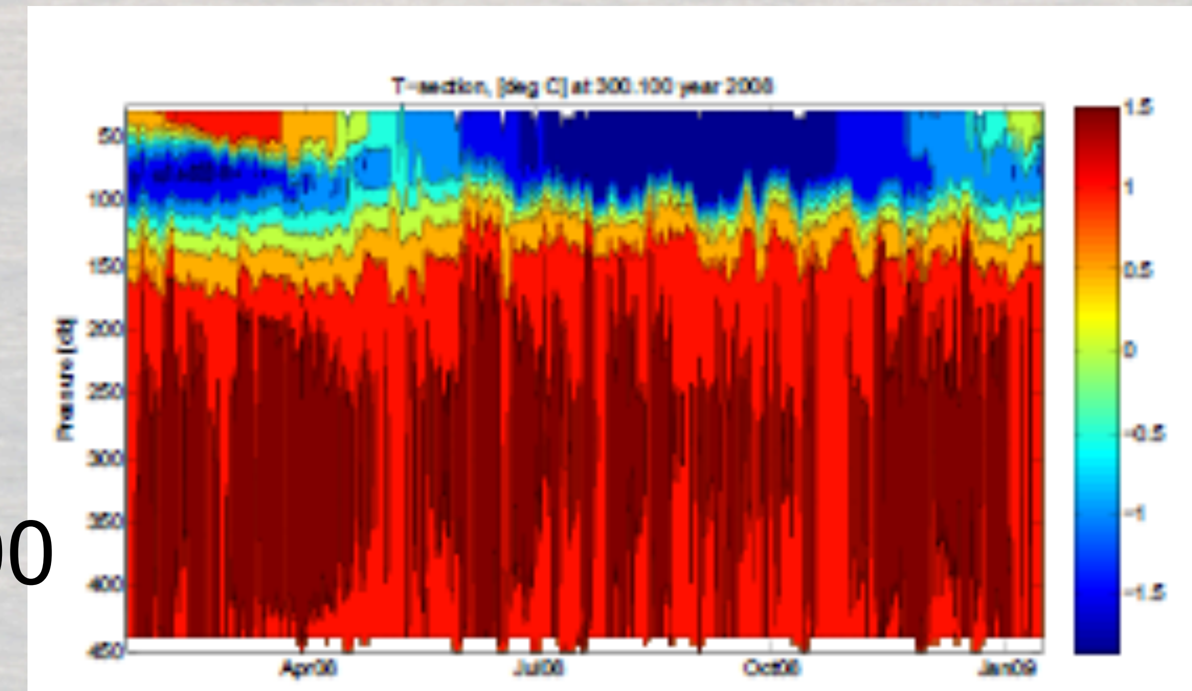


thanks to Nicole Cuorto

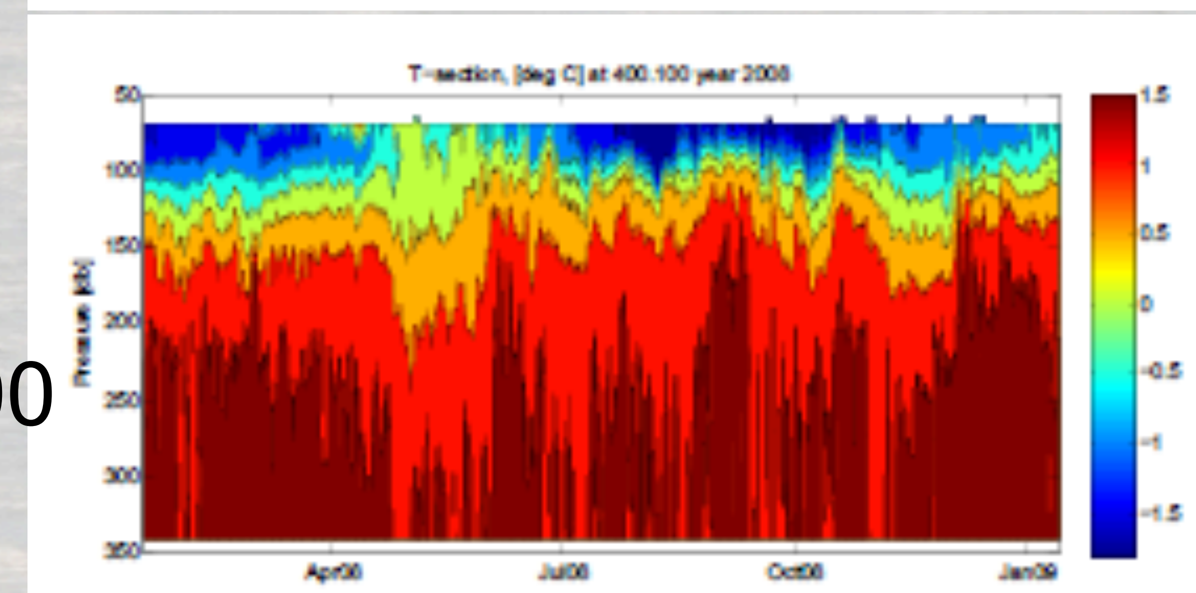
•Current meters at 300.100 and 400.100 + model depth-averaged currents reveal clear advective path for heat.

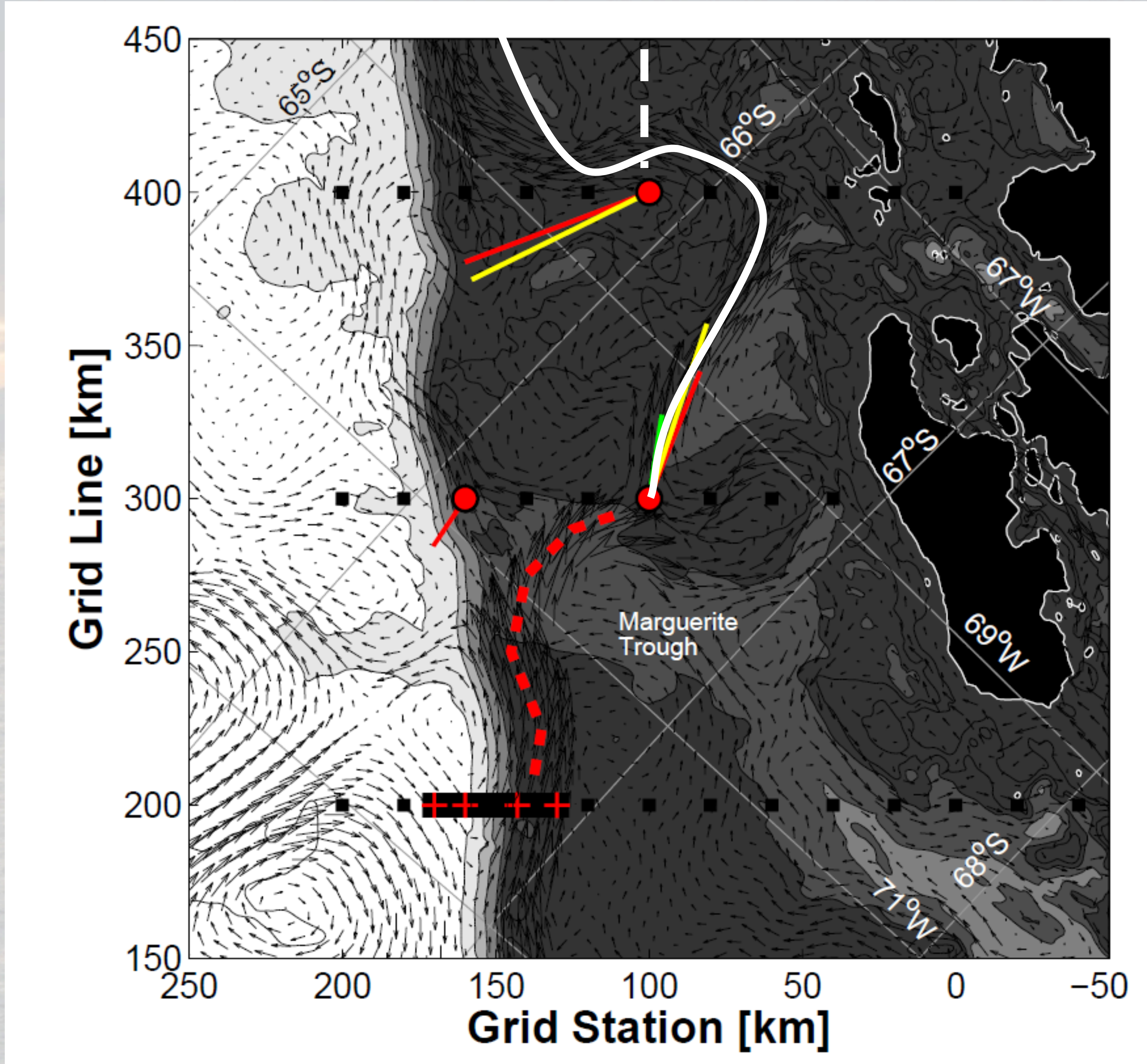
•Need to head south anyway, so might as well make the most of the trip.

300.100



400.100

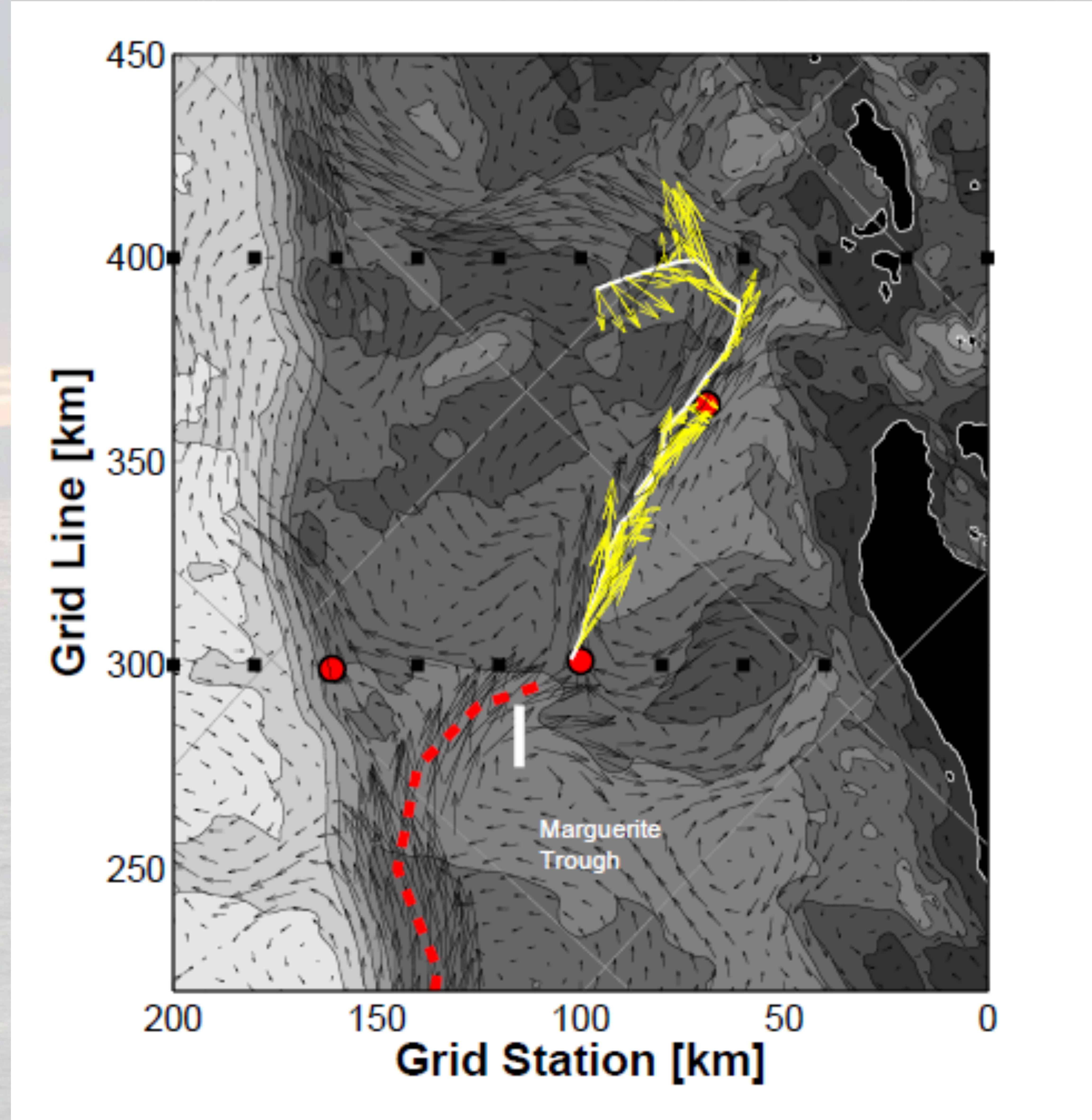




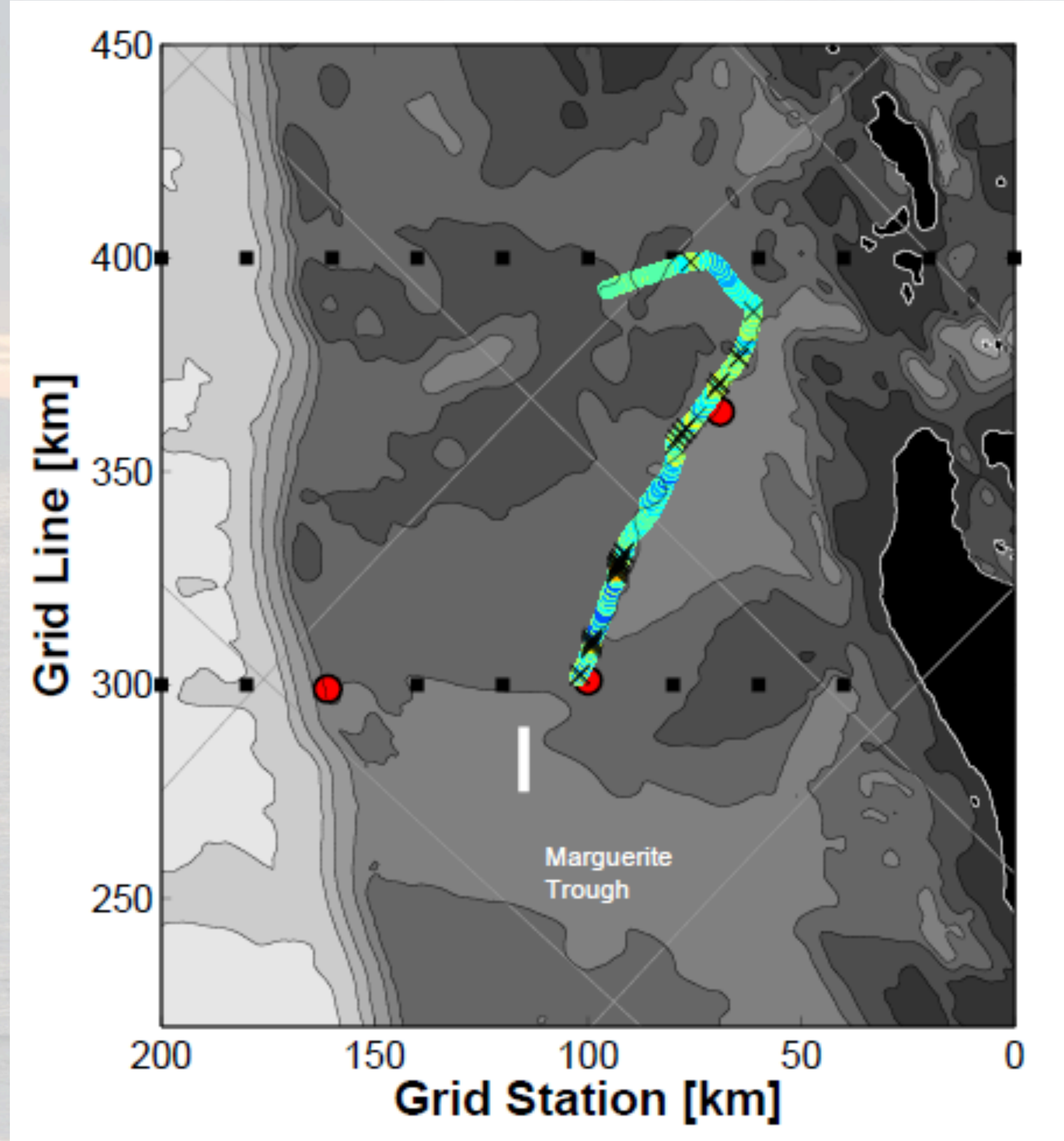
Model vectors: Dinniman et al., 2011

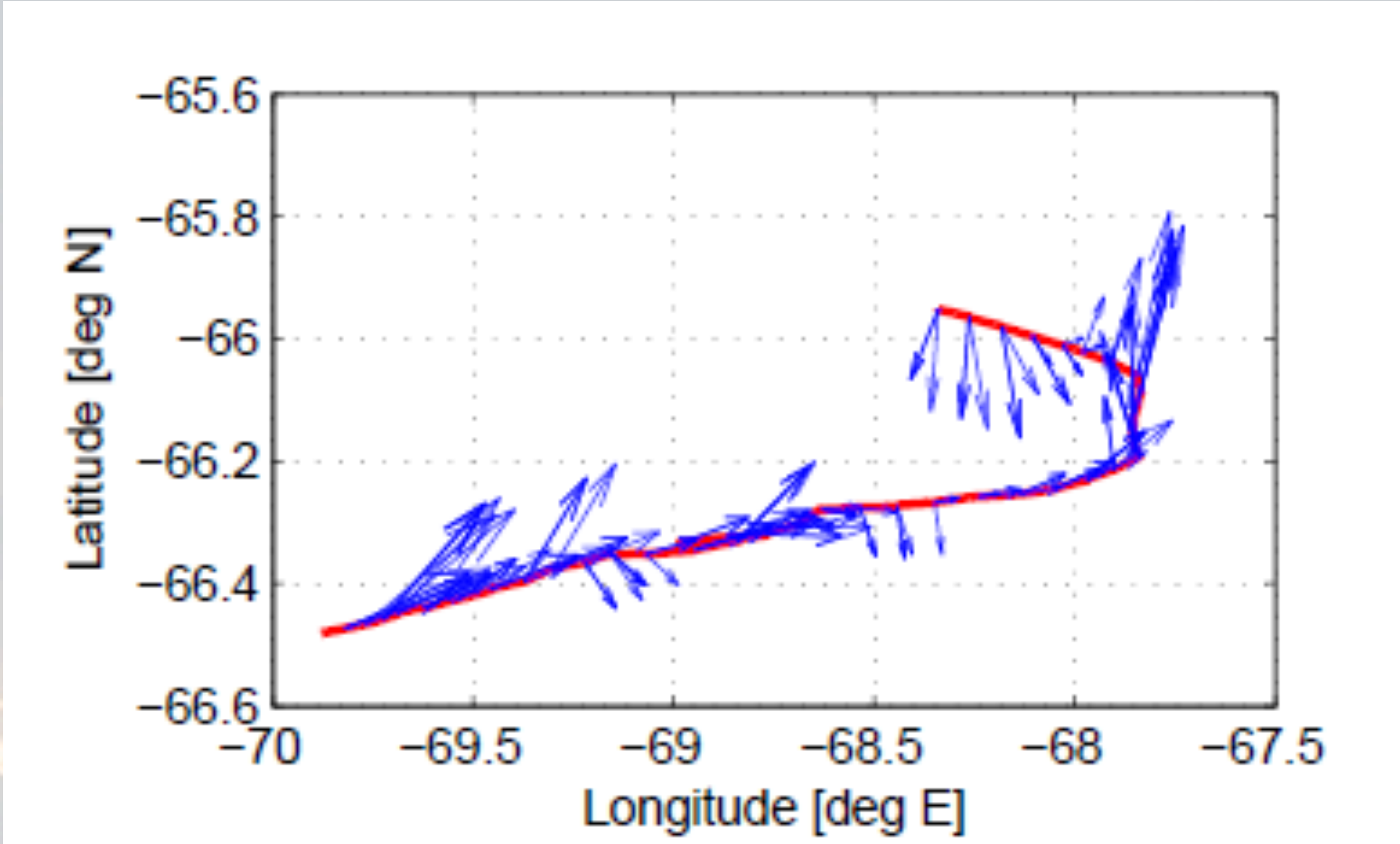
thanks to Darren McKee (LDEO)

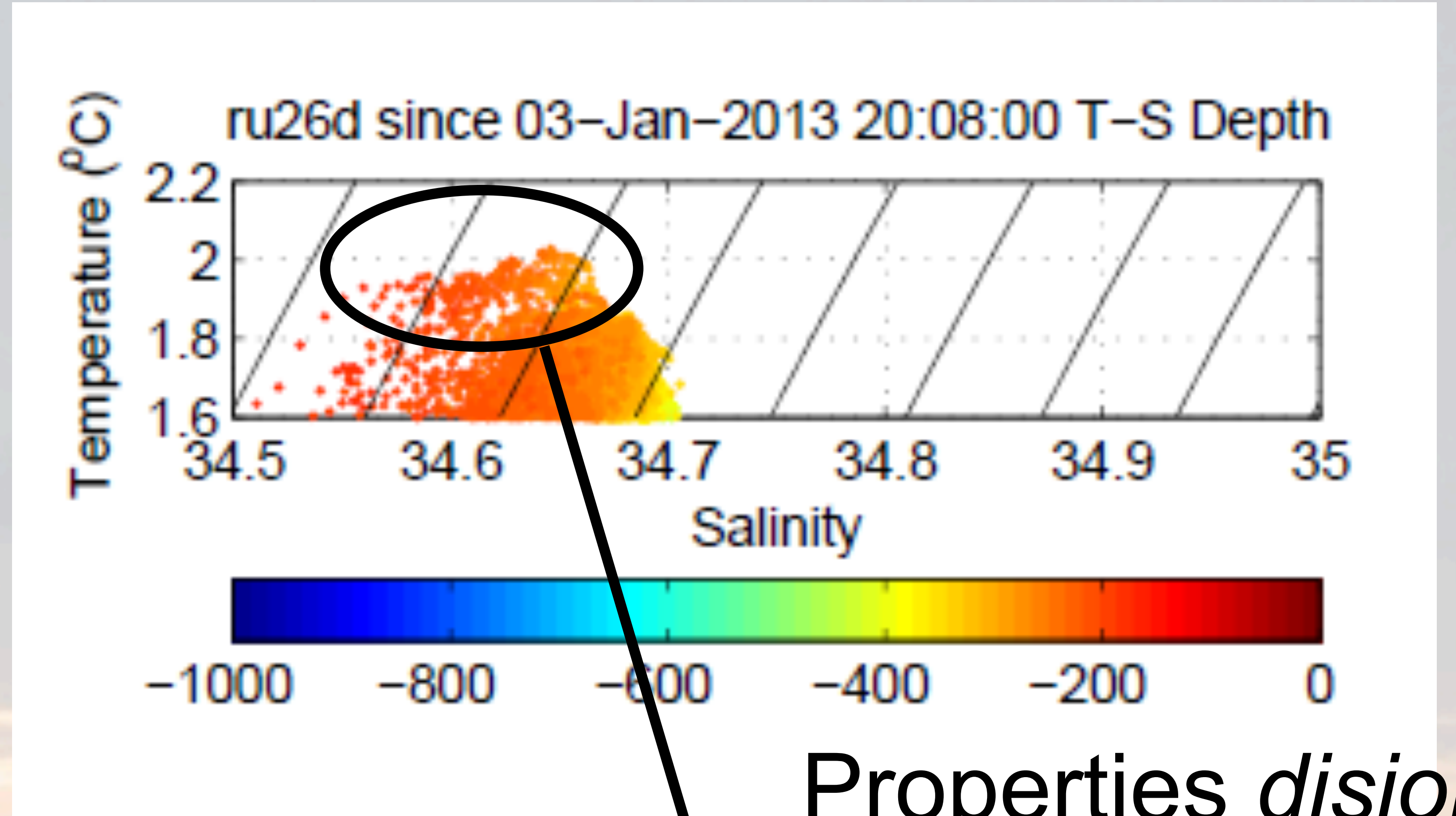
- Glider depth-averaged currents: agree well with moorings + model!



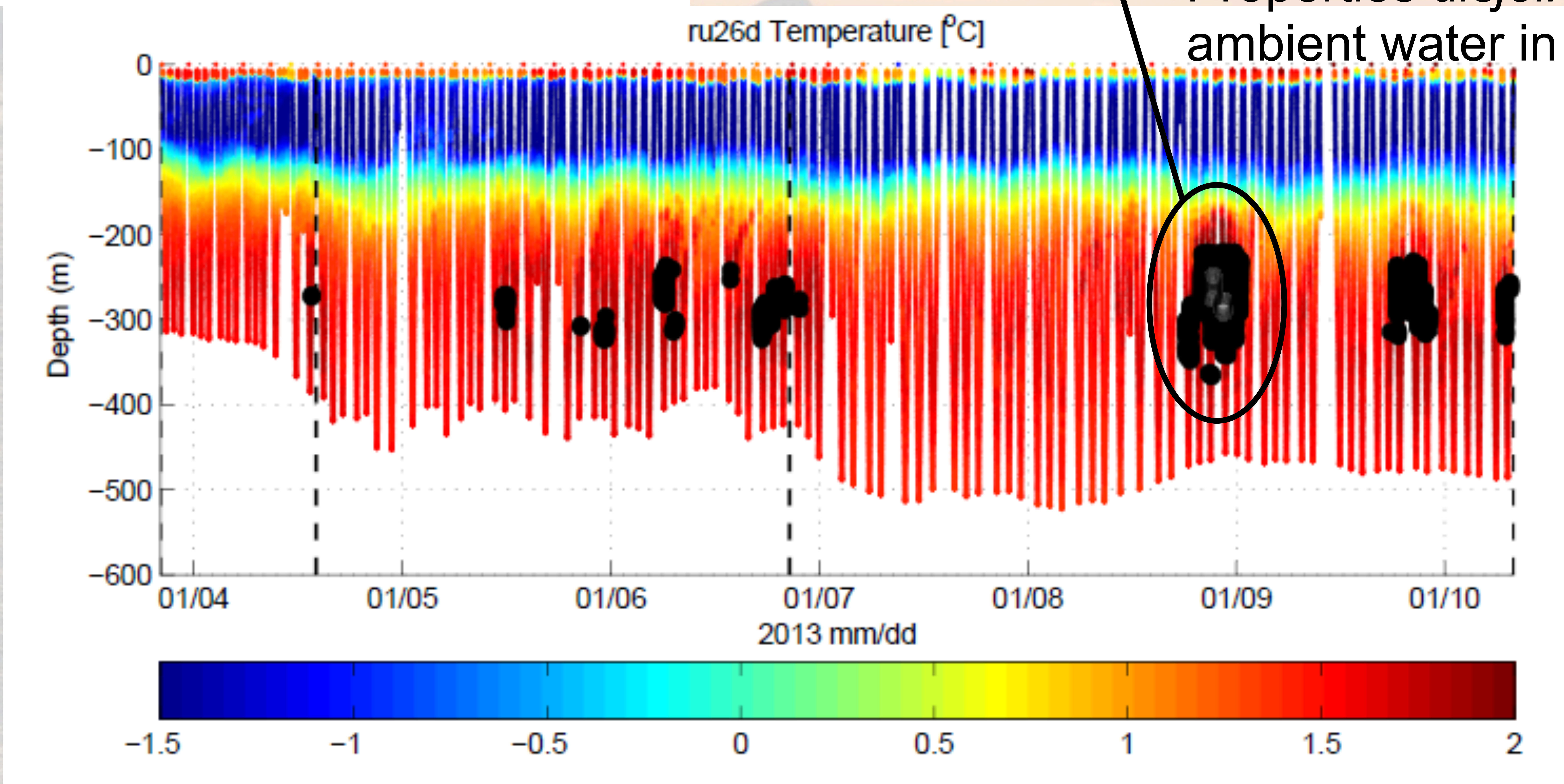
- Glider depth-averaged currents: agree well with moorings + model!
- Glider deep water (> 220 db) temperatures: episodic warming!

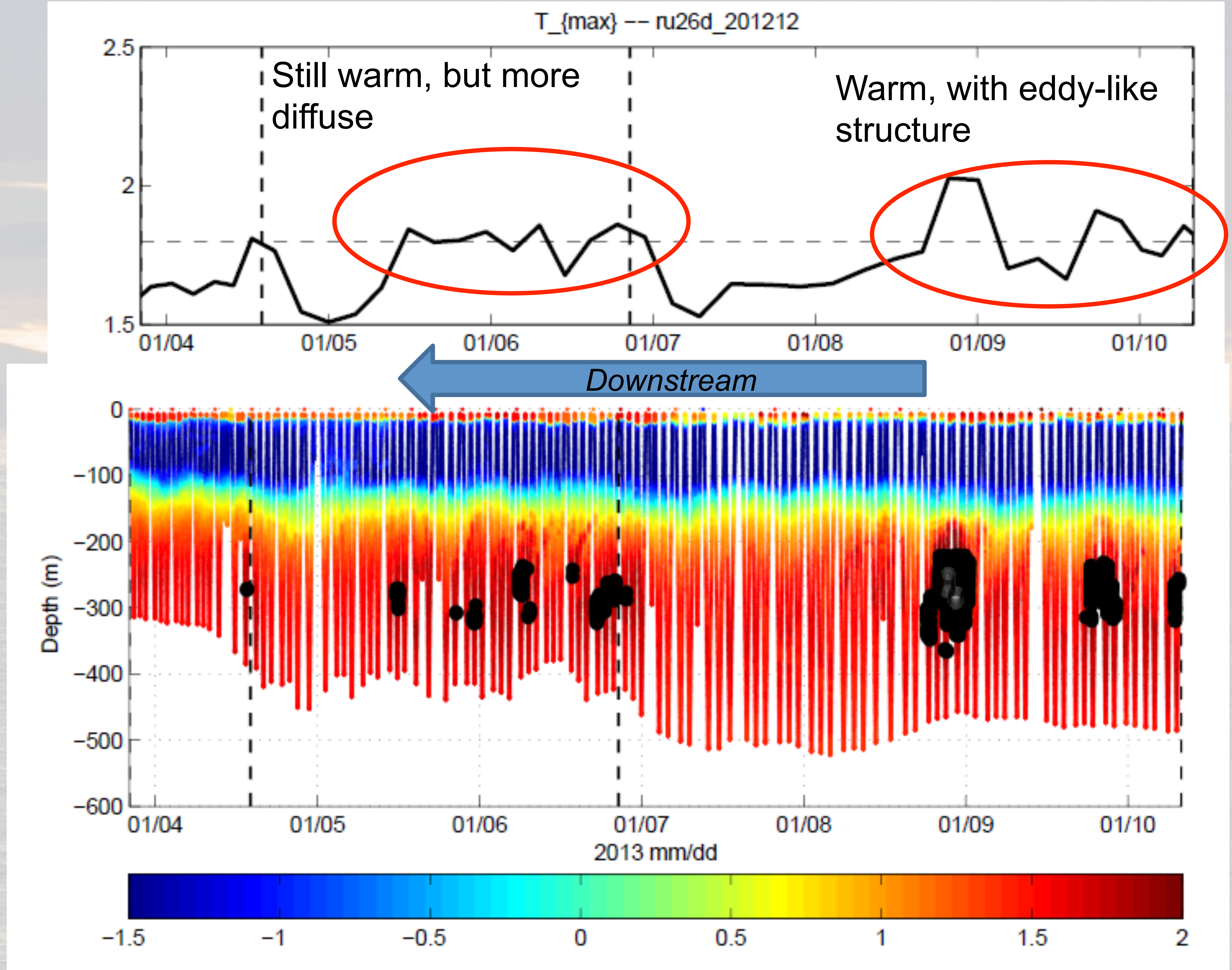






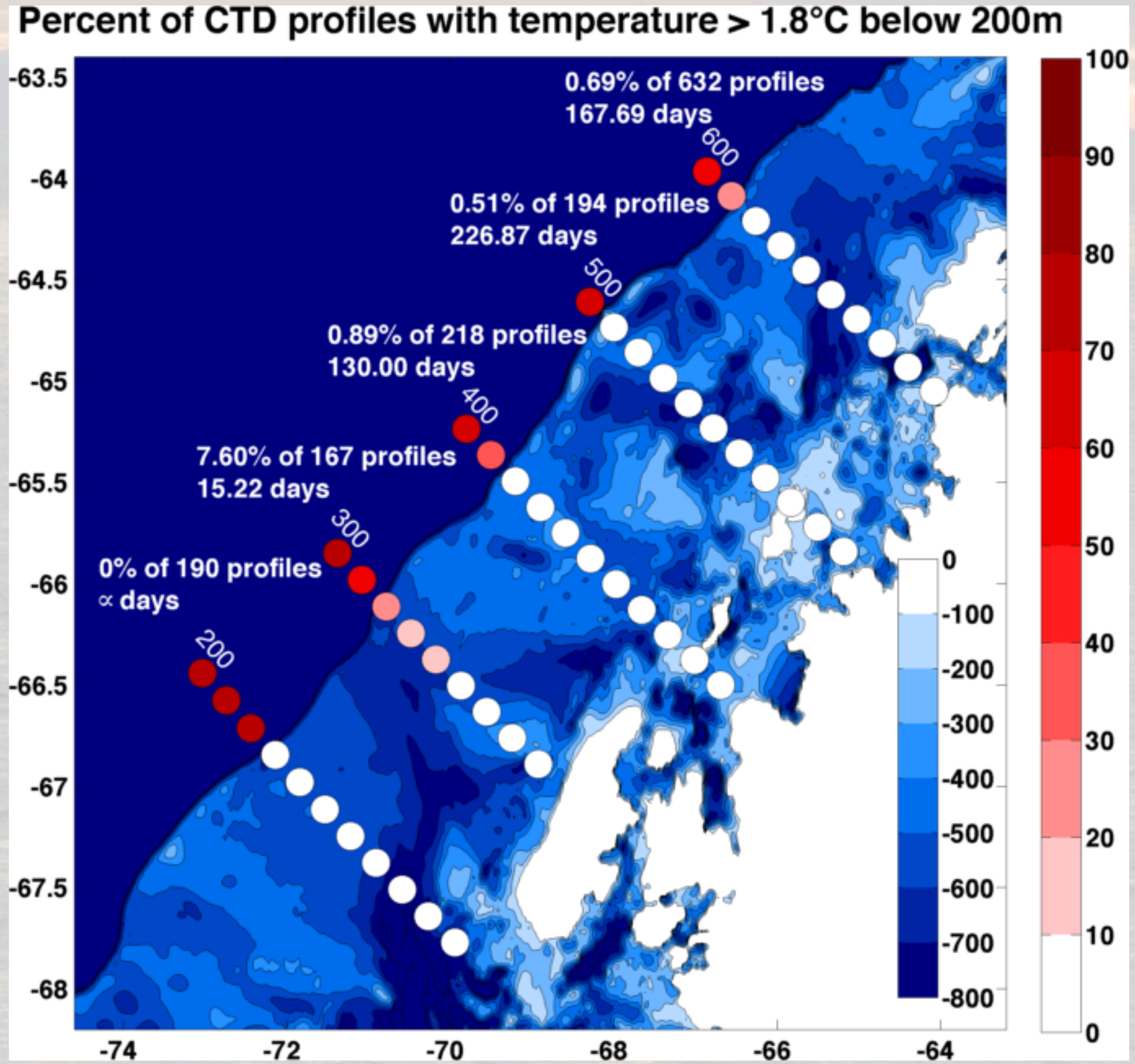
Properties *disjoint* from ambient water in T-S space.



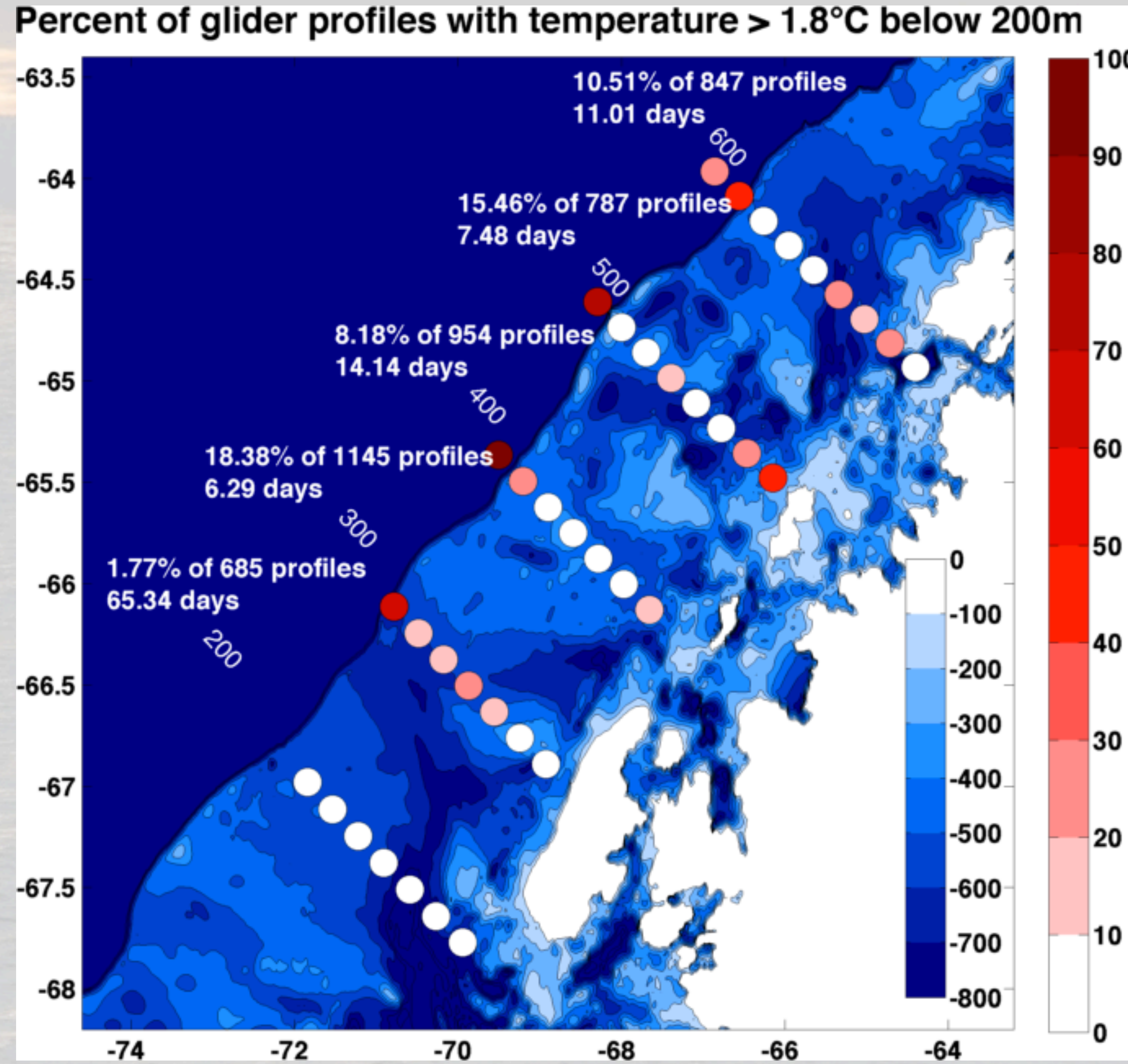

T_{max} -- ru26d_201212
2.5
2
1.5
Still warm, but more diffuse
Warm, with eddy-like structure
01/04
01/05
01/06
01/07
01/08
01/09
01/10
Downstream
0
−100
−200
−300
−400
−500
−600
Depth (m)
2013 mm/dd
−1.5
−1
−0.5
0
0.5
1
1.5
2

Ships not effective at sampling the subsurface eddy transport of modified ACC water

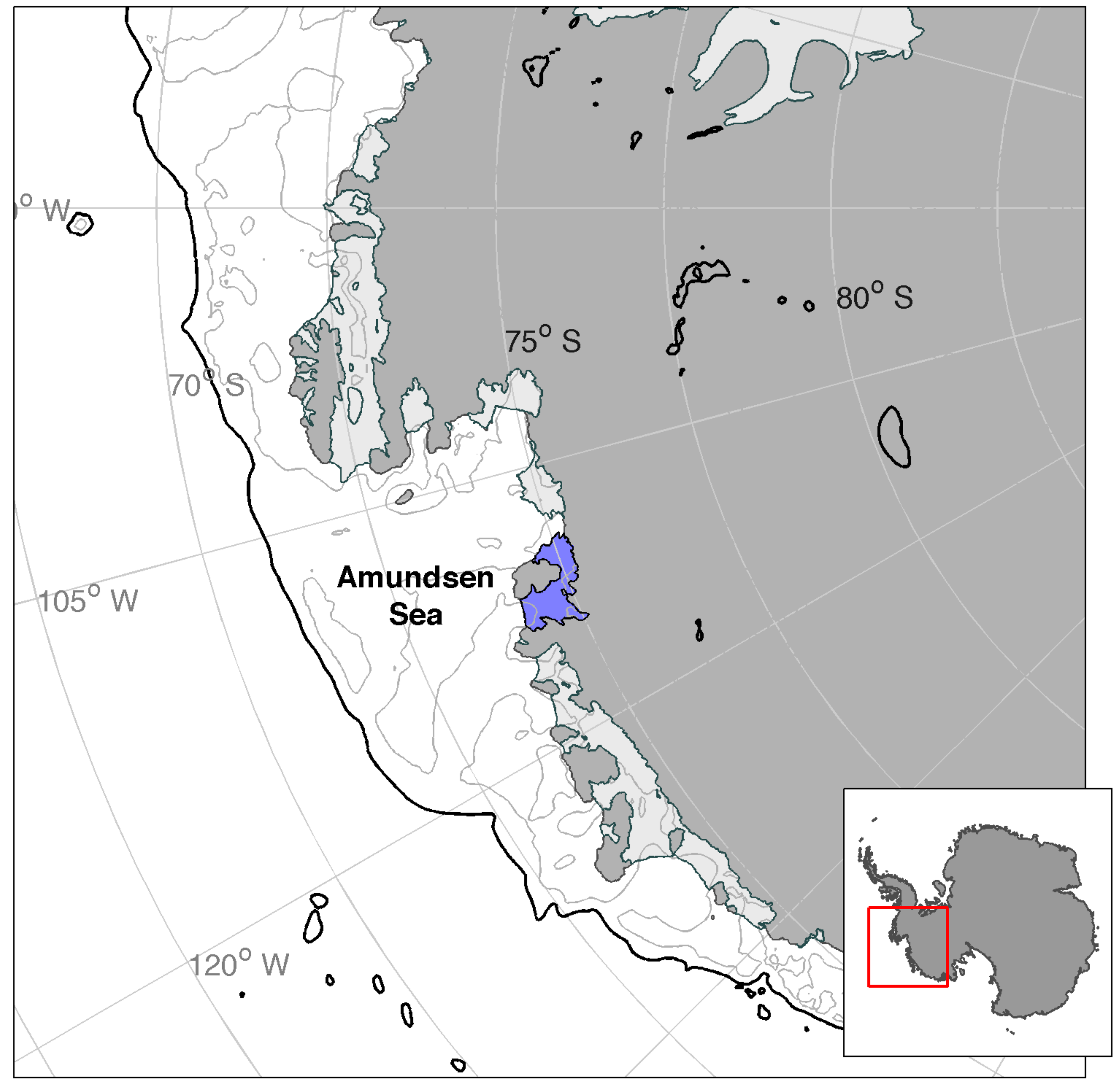
22 Years of cruises (924 days at sea)

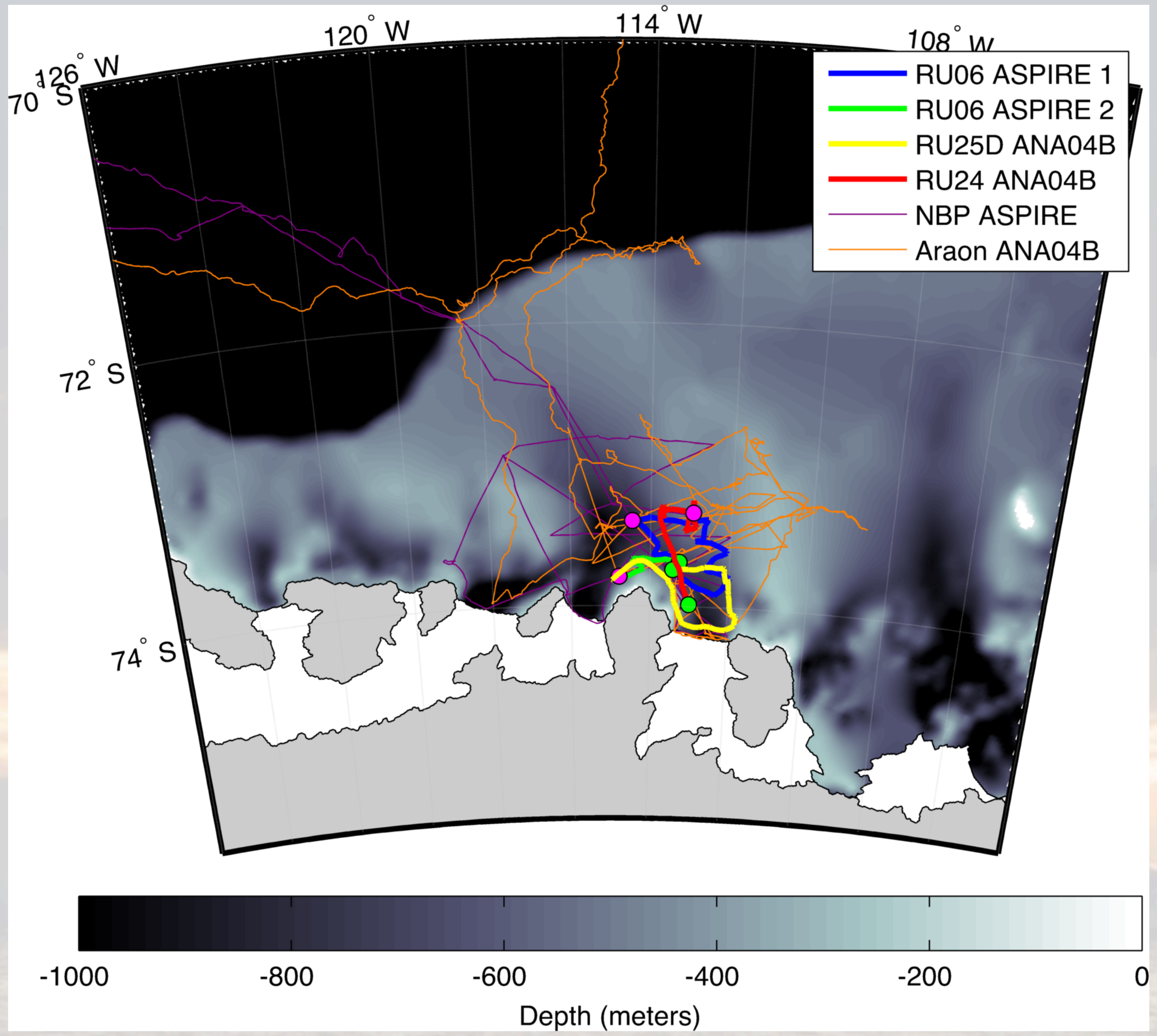


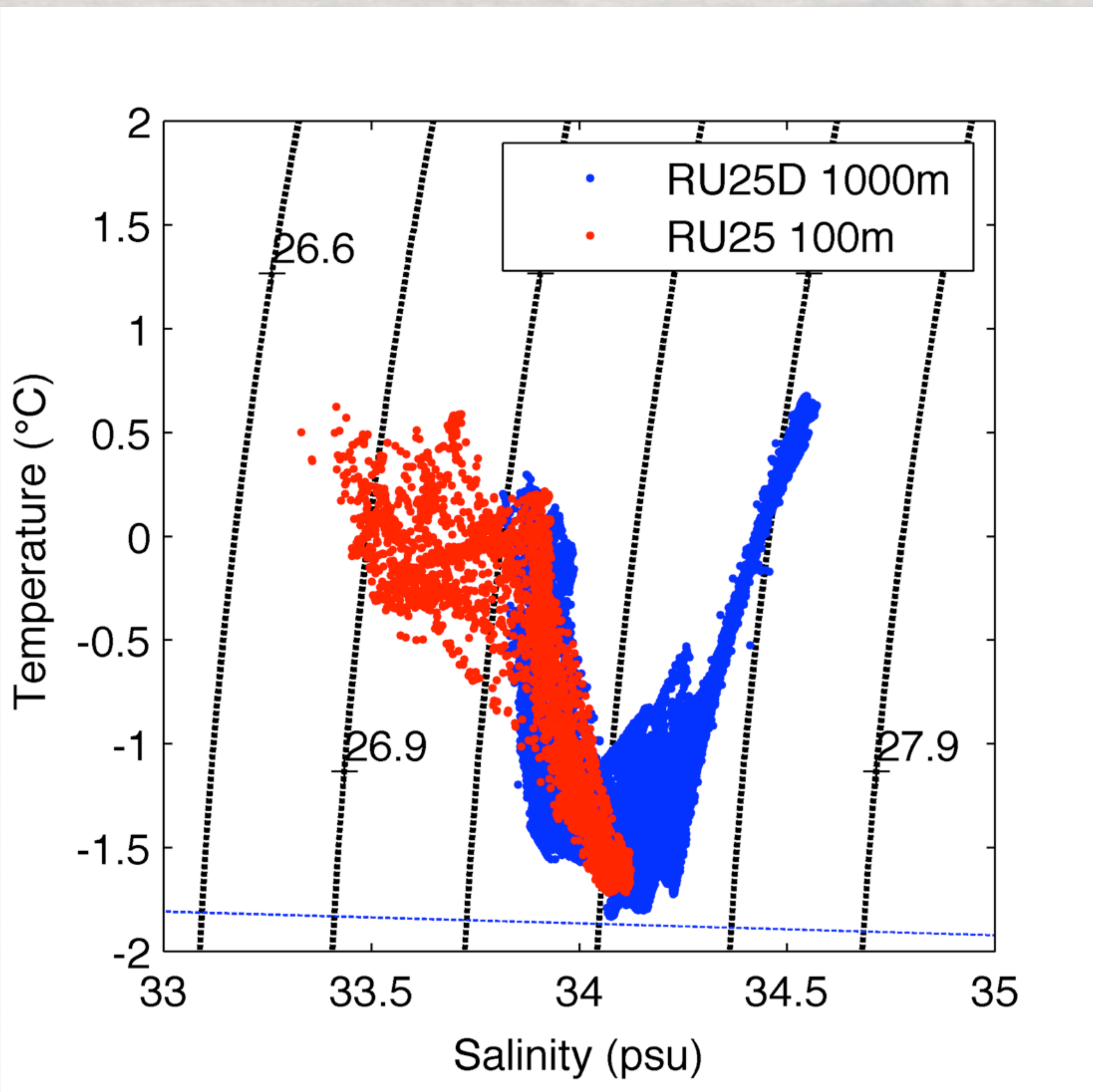
4 Glider missions (85 days at sea)

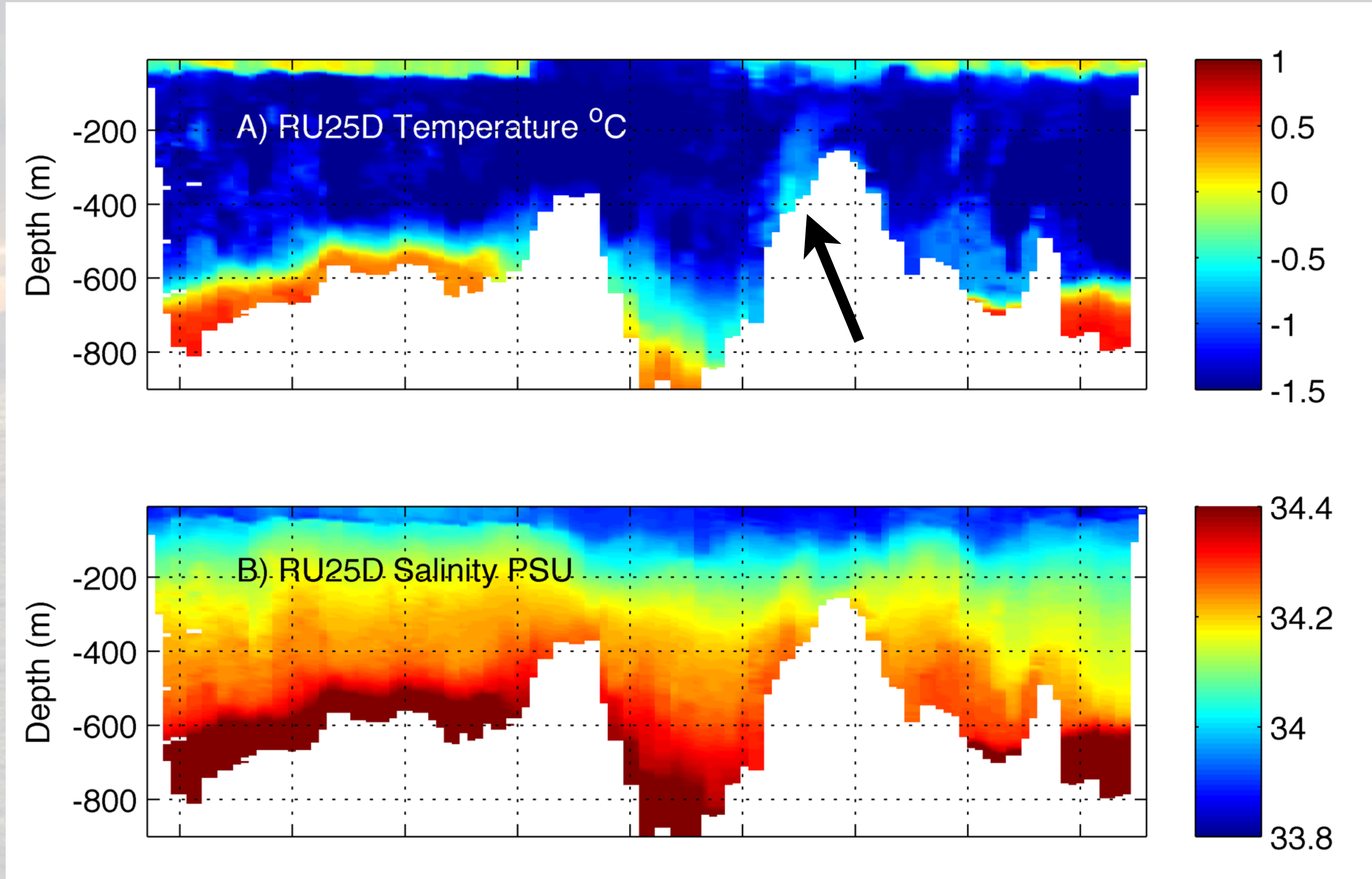


Mechanism relevant in other locations? Amundsen Sea



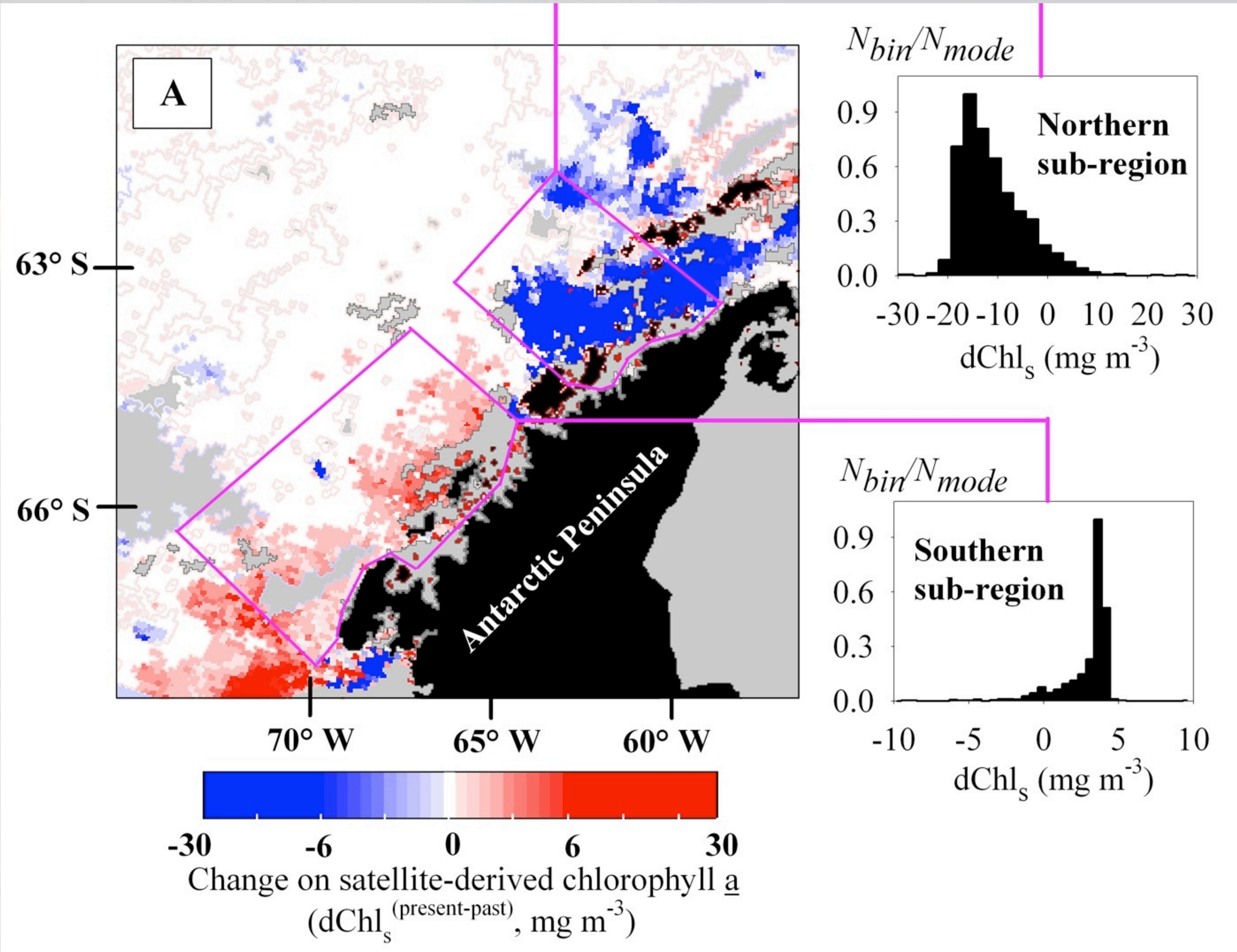

RU06 ASPIRE 1
RU06 ASPIRE 2
RU25D ANA04B
RU24 ANA04B
NBP ASPIRE
Araon ANA04B
126° W
120° W
114° W
108° W
70° S
72° S
74° S
-1000
-800
-600
-400
-200
0
Depth (meters)


RU25D 1000m
RU25 100m
26.6
26.9
27.9
Temperature (°C)
Salinity (psu)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
33
33.5
34
34.5
35

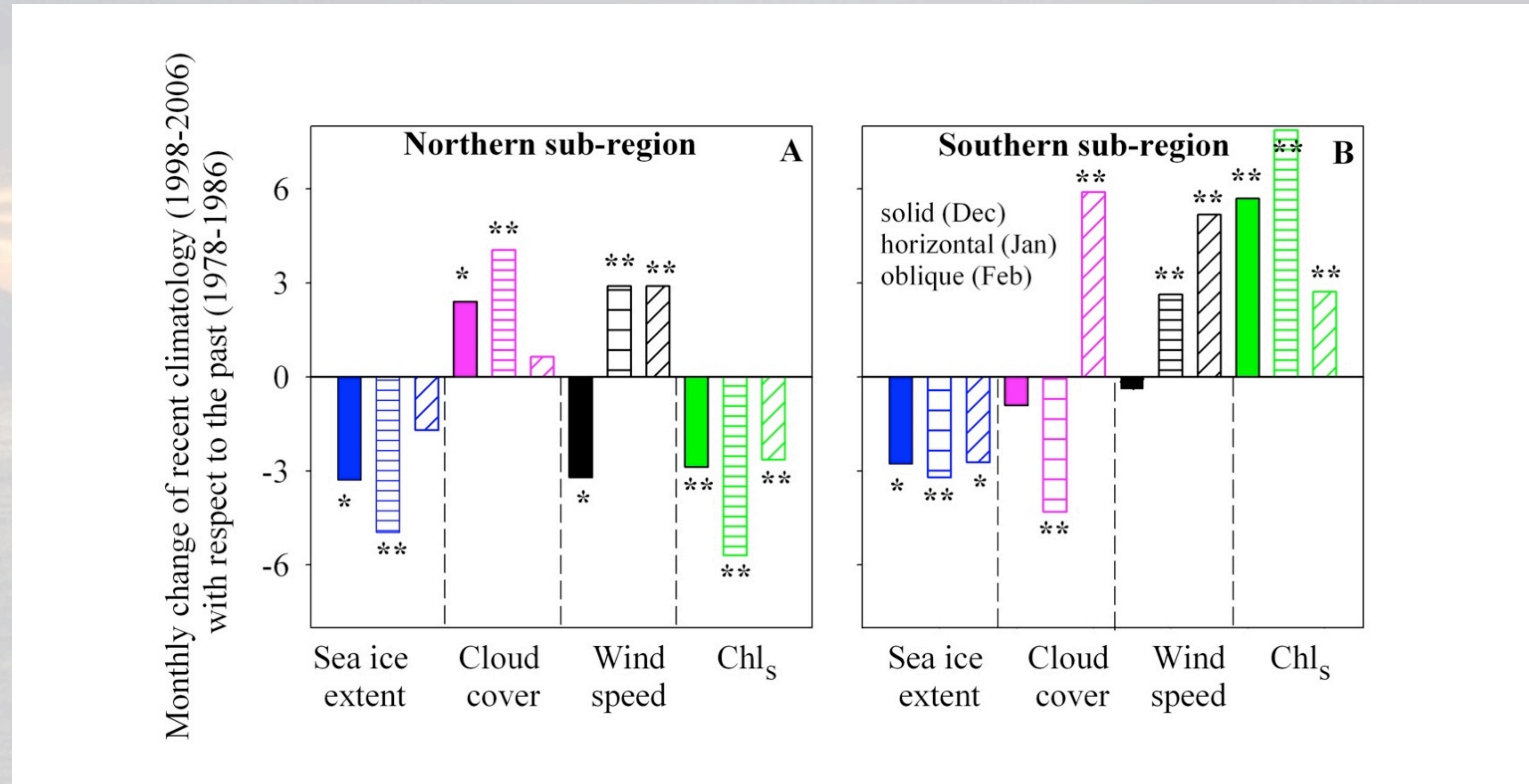

A) RU25D Temperature °C
Depth (m)
-200
-400
-600
-800
1
0.5
0
-0.5
-1
-1.5
B) RU25D Salinity PSU
Depth (m)
-200
-400
-600
-800
34.4
34.2
34
33.8


Is there a response in the marine food web?

The decadal changes have resulted changes in the phytoplankton

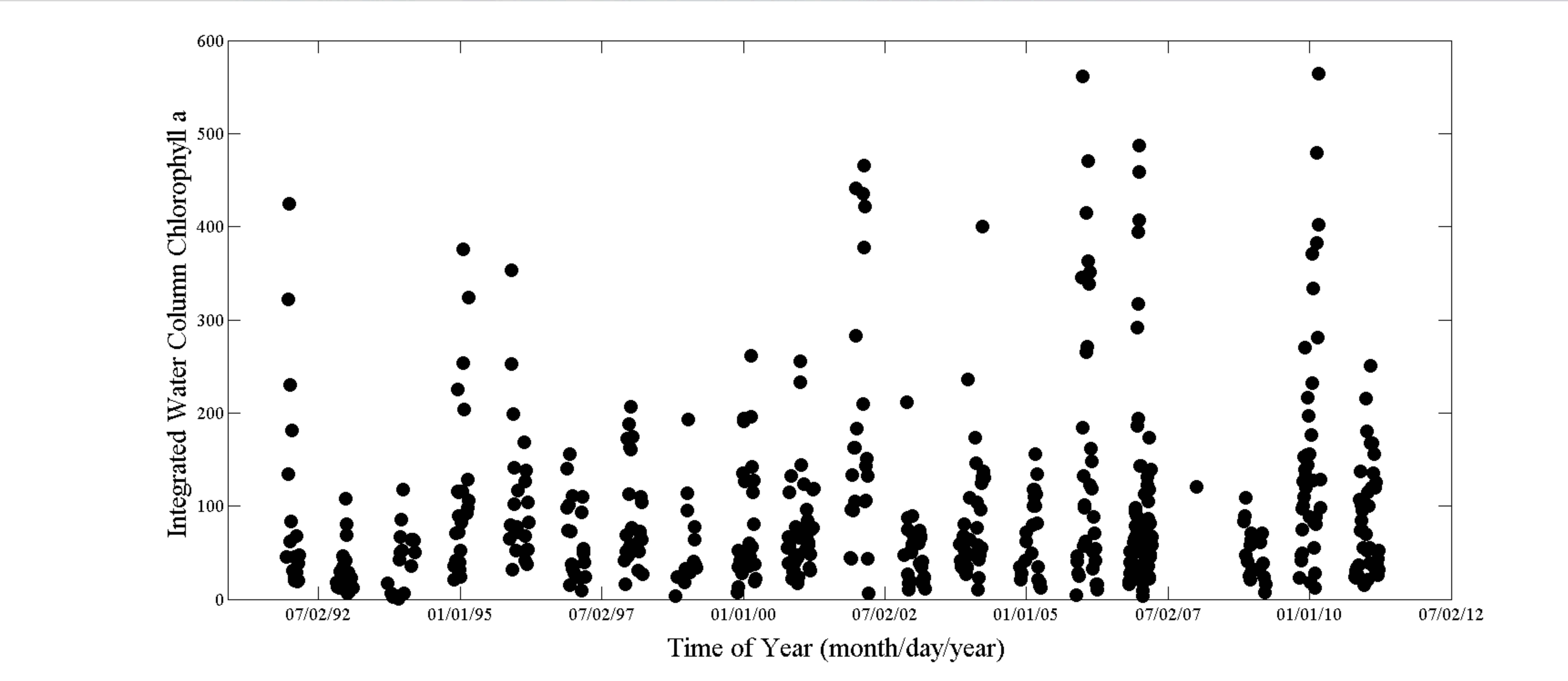


Montes Hugo et al. Science 2009

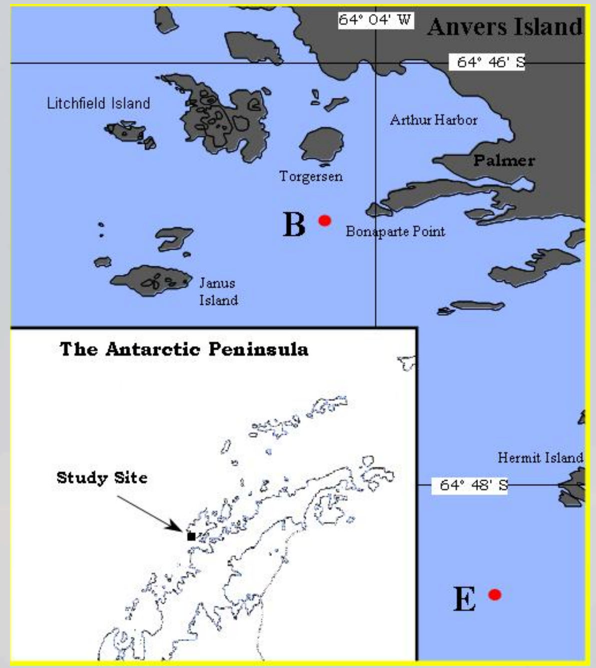


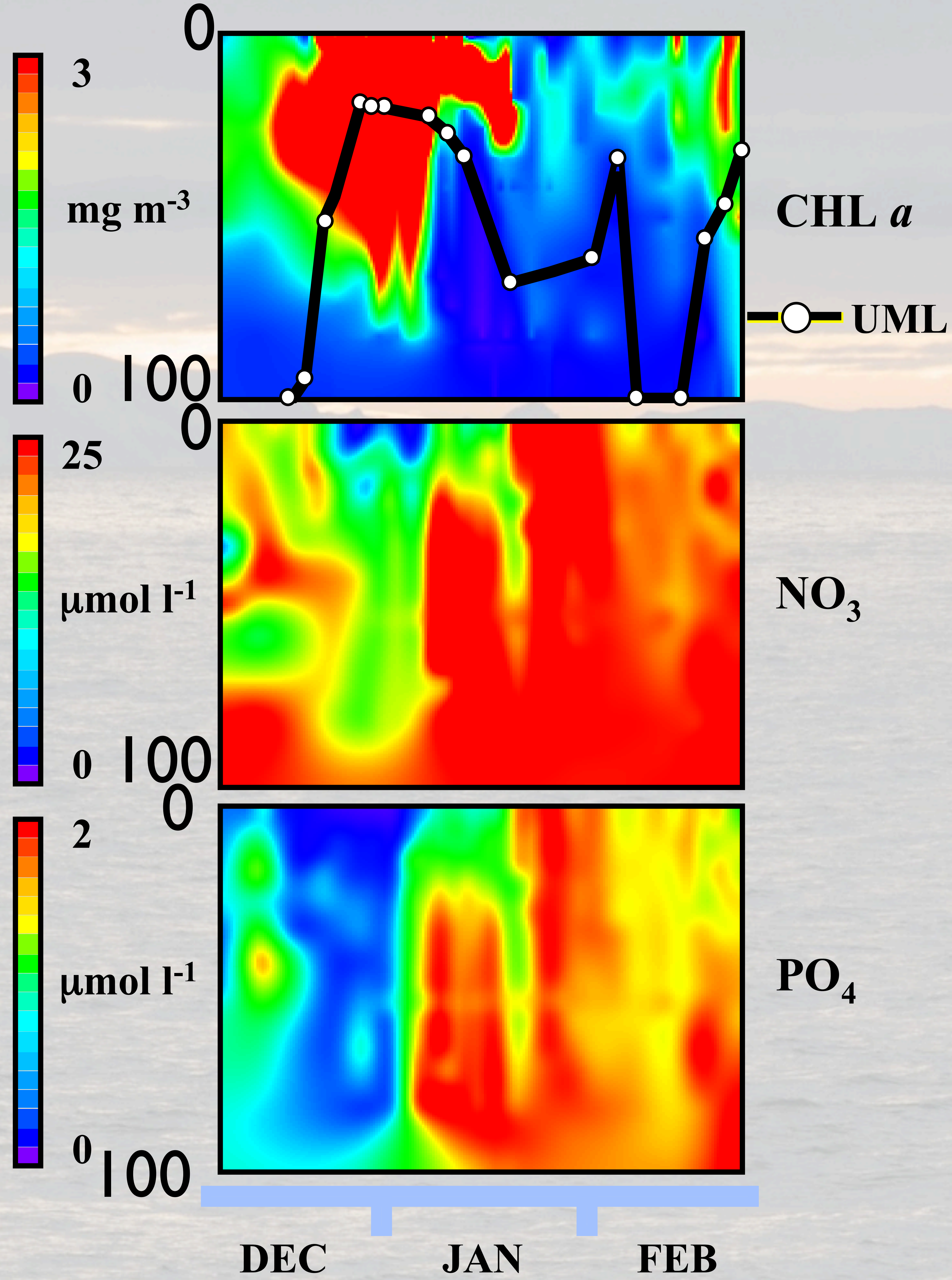
The changes driven by a decline in sea ice, wind and sun

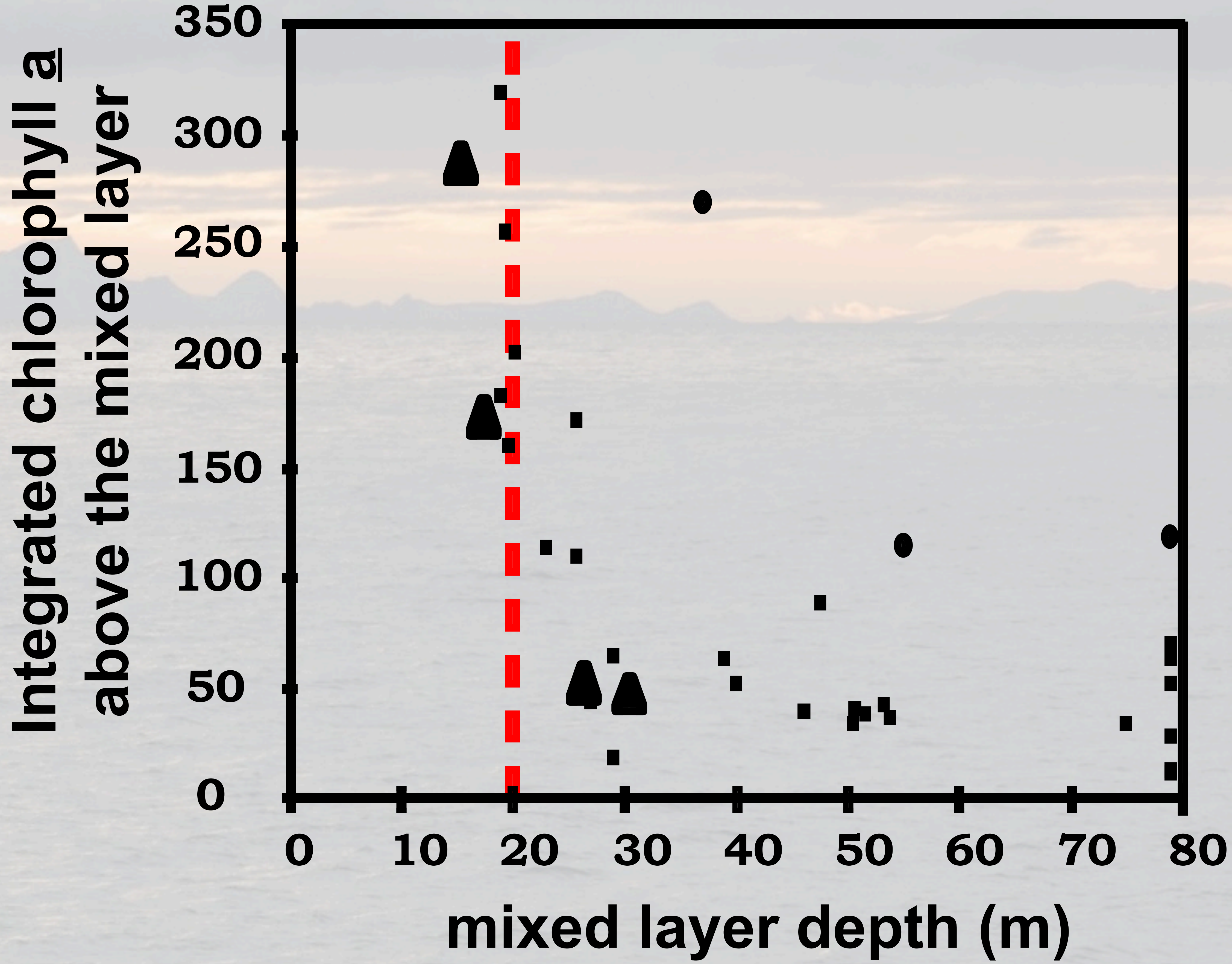
Time series at Palmer Station

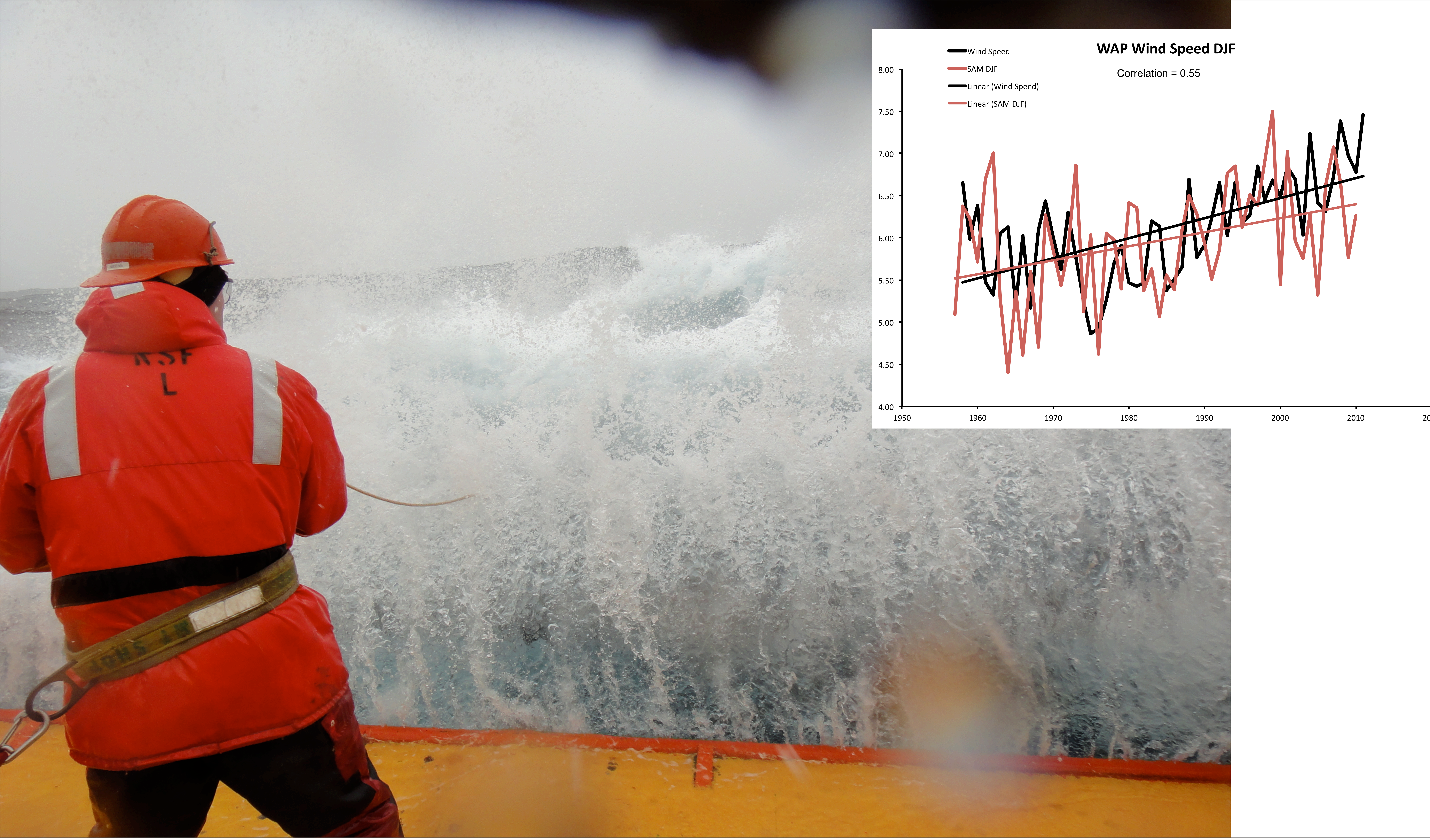


What regulates phytoplankton blooms in this region?

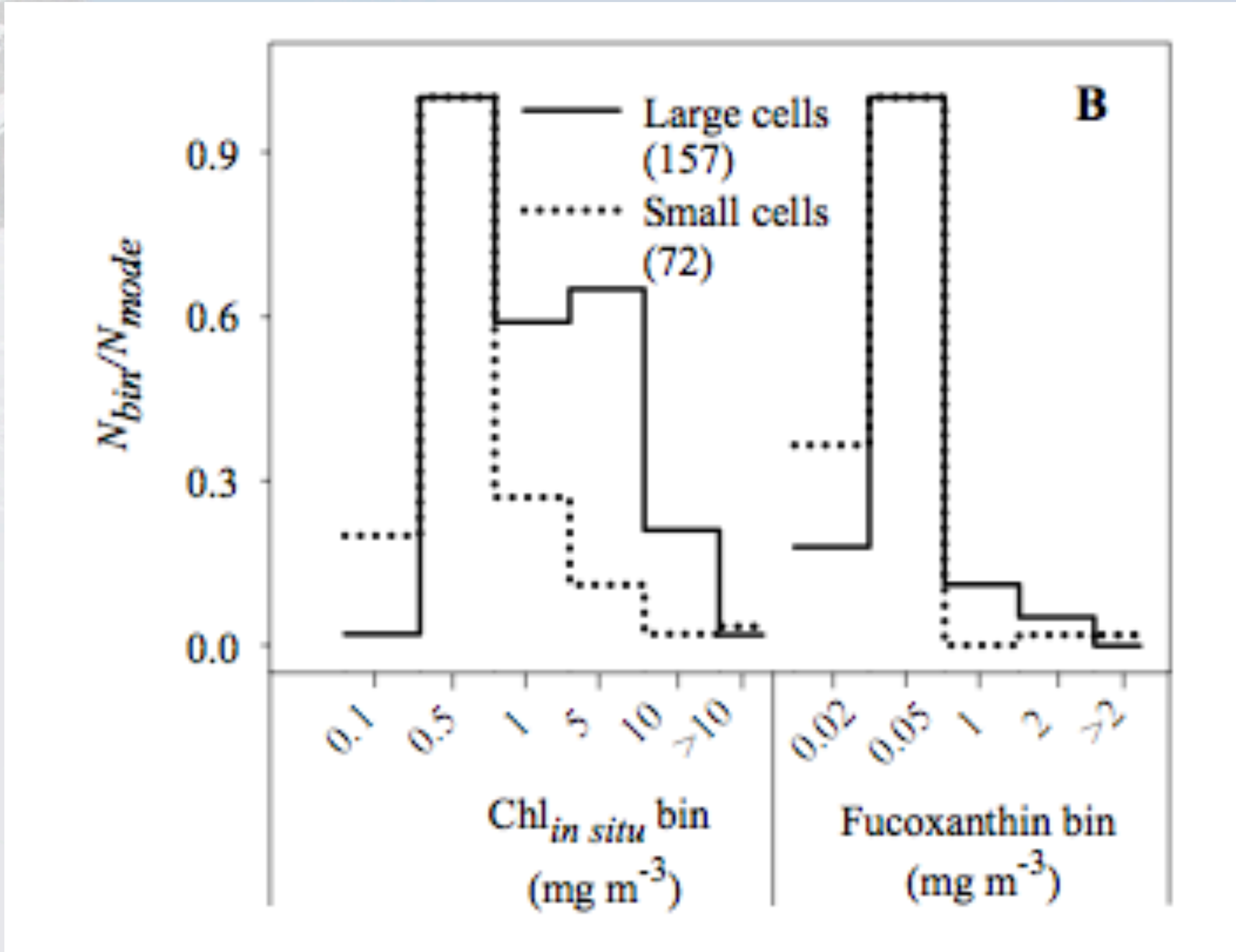




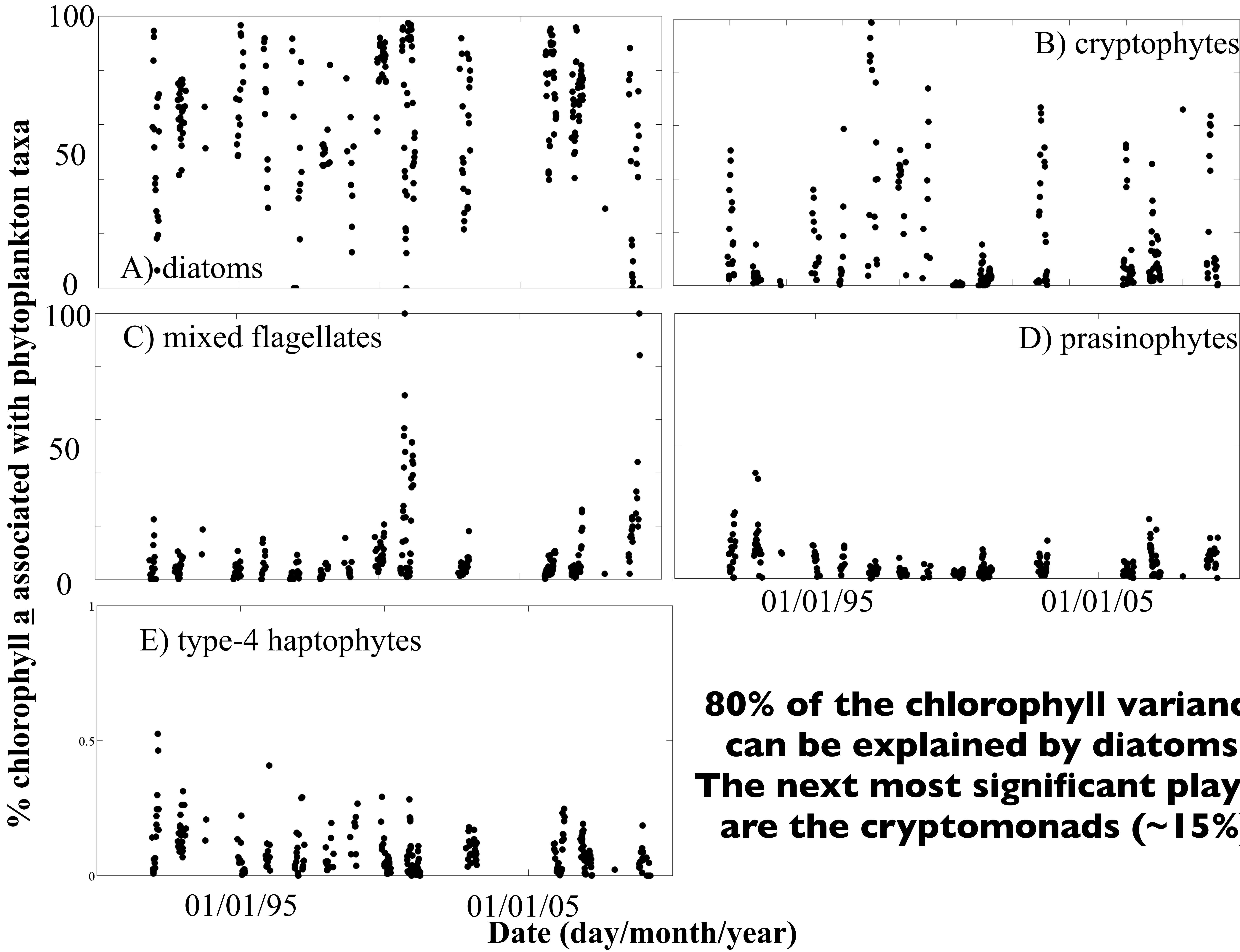



NSF
L
WAP Wind Speed DJF
Correlation = 0.55
Wind Speed
SAM DJF
Linear (Wind Speed)
Linear (SAM DJF)
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
4.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00
-4.00
1950
1960
1970
1980
1990
2000
2010
2020

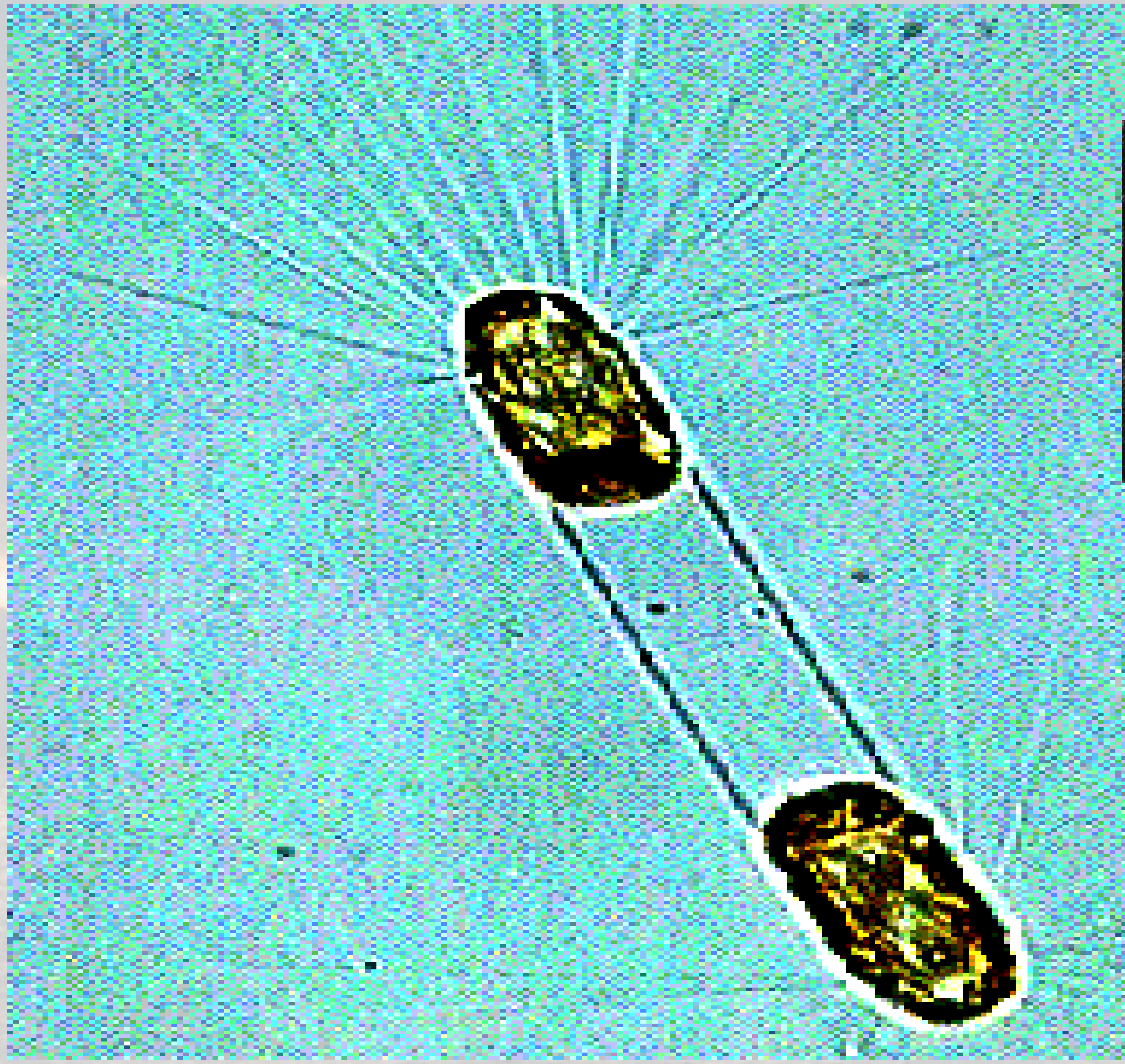
When chlorophyll is high, phytoplankton cells are big and are largely diatoms



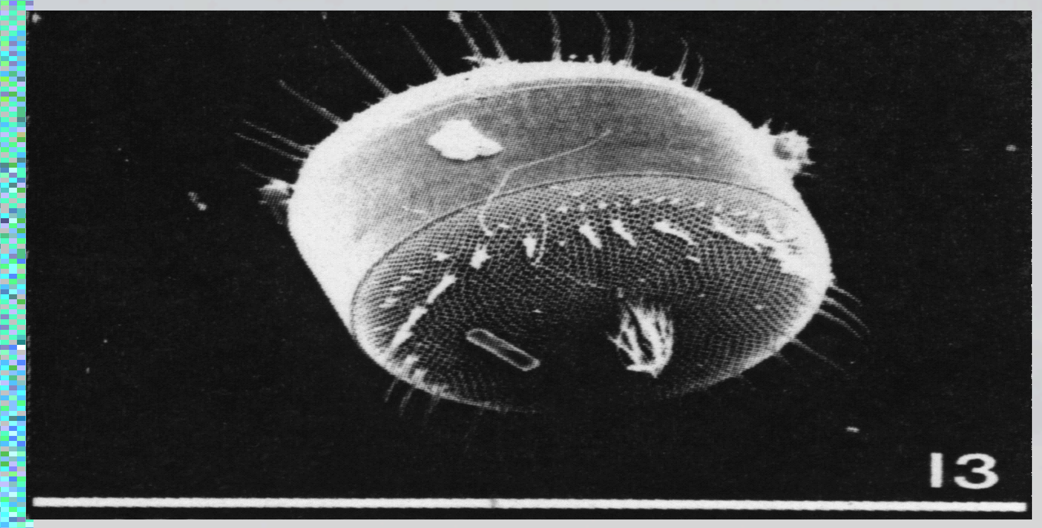
Montes Hugo et al. 2009



80% of the chlorophyll variance can be explained by diatoms. The next most significant player are the cryptomonads (~15%)



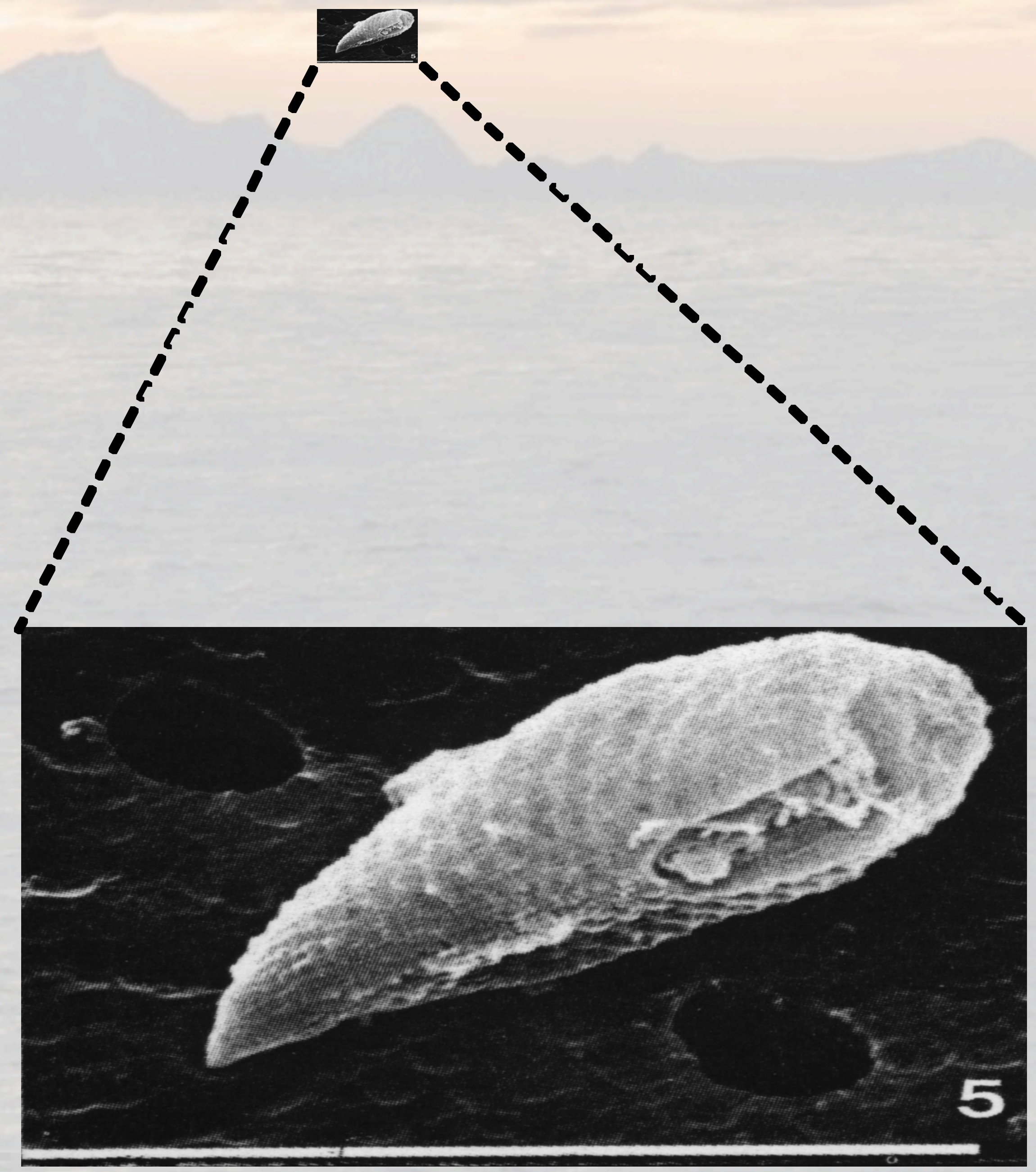
Corethron criophilum



100µm

Thalassiosira antarctica

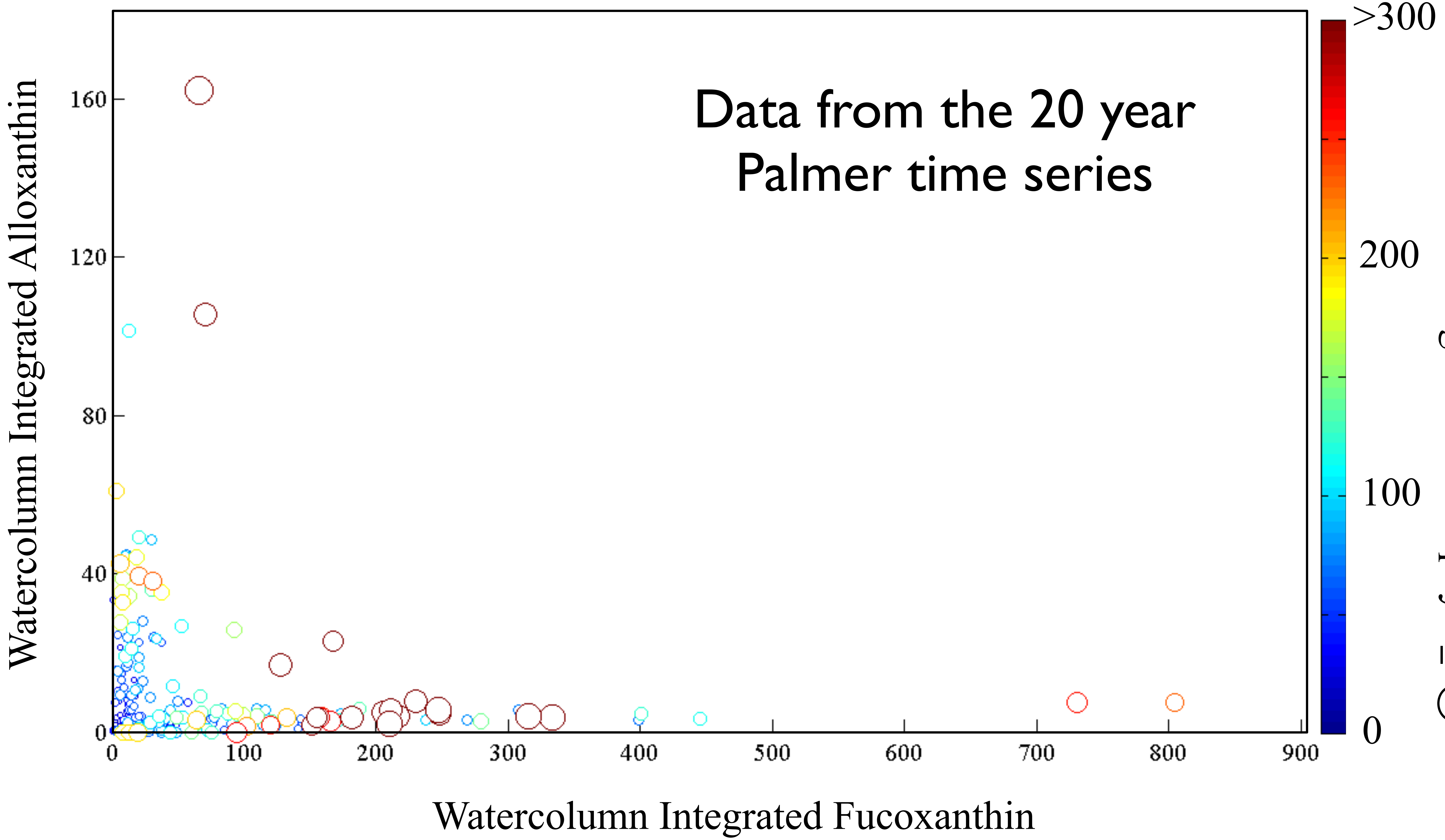
Palmer Cryptophytes --> 8 ± 2µm

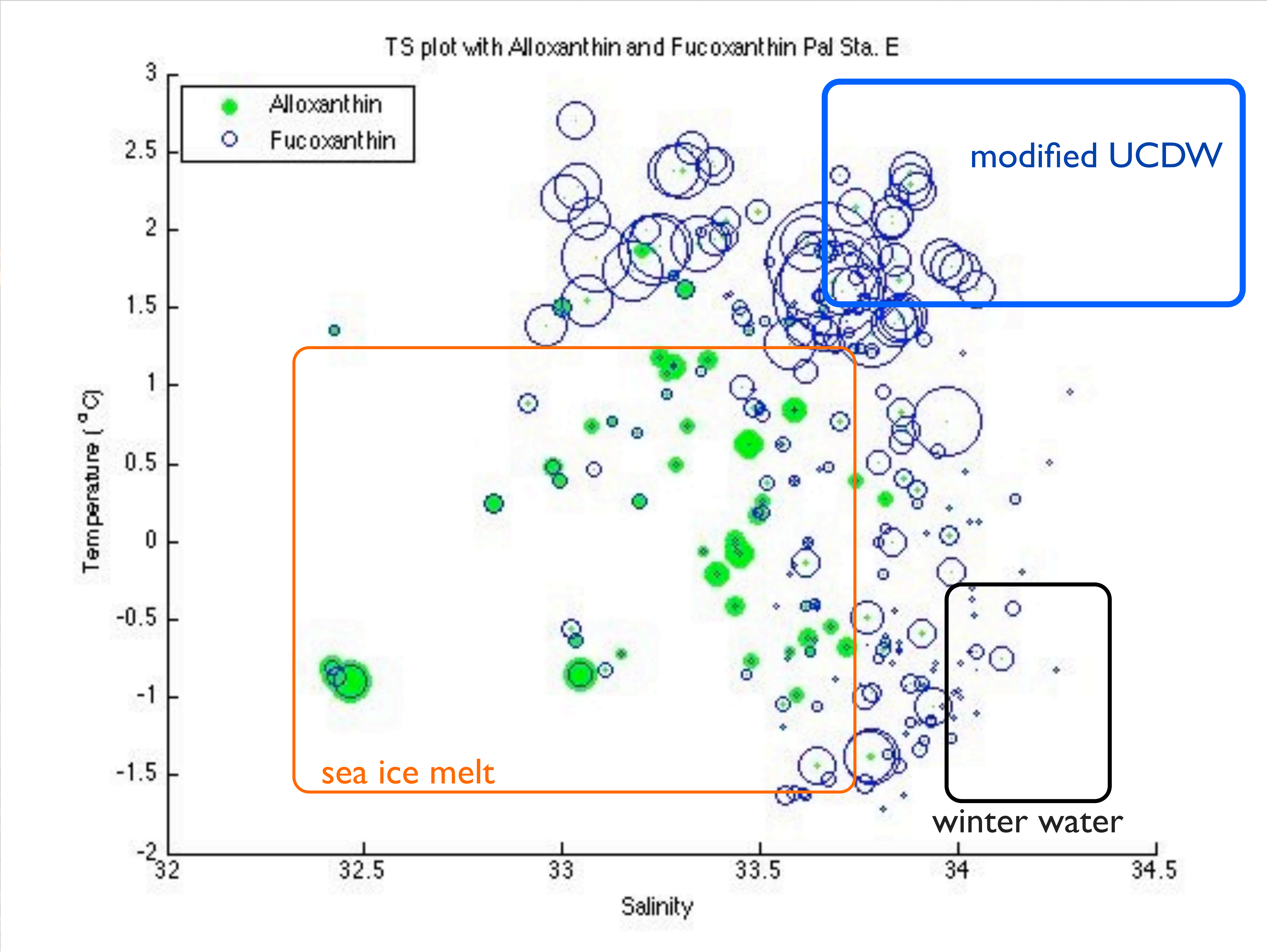


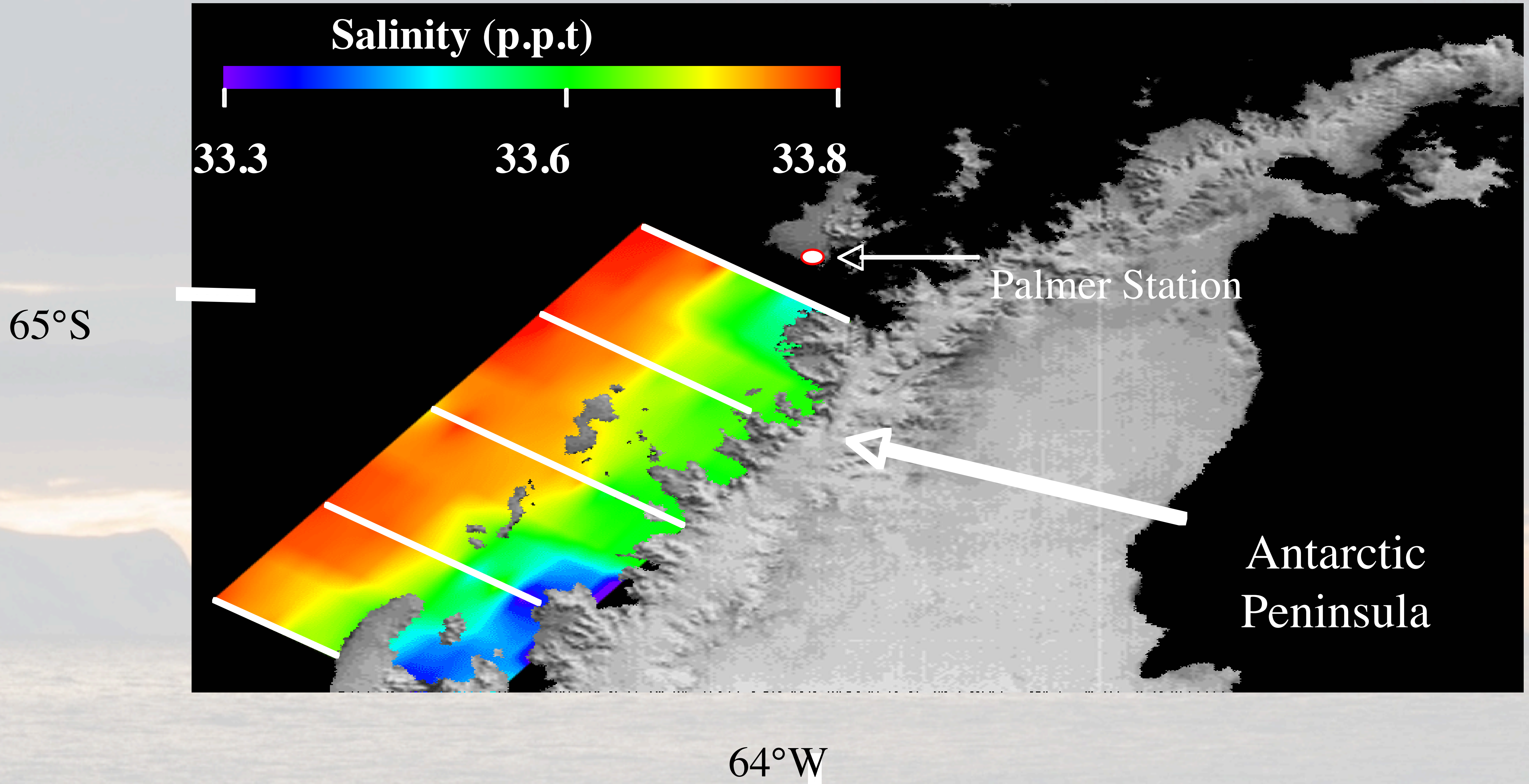
10µm

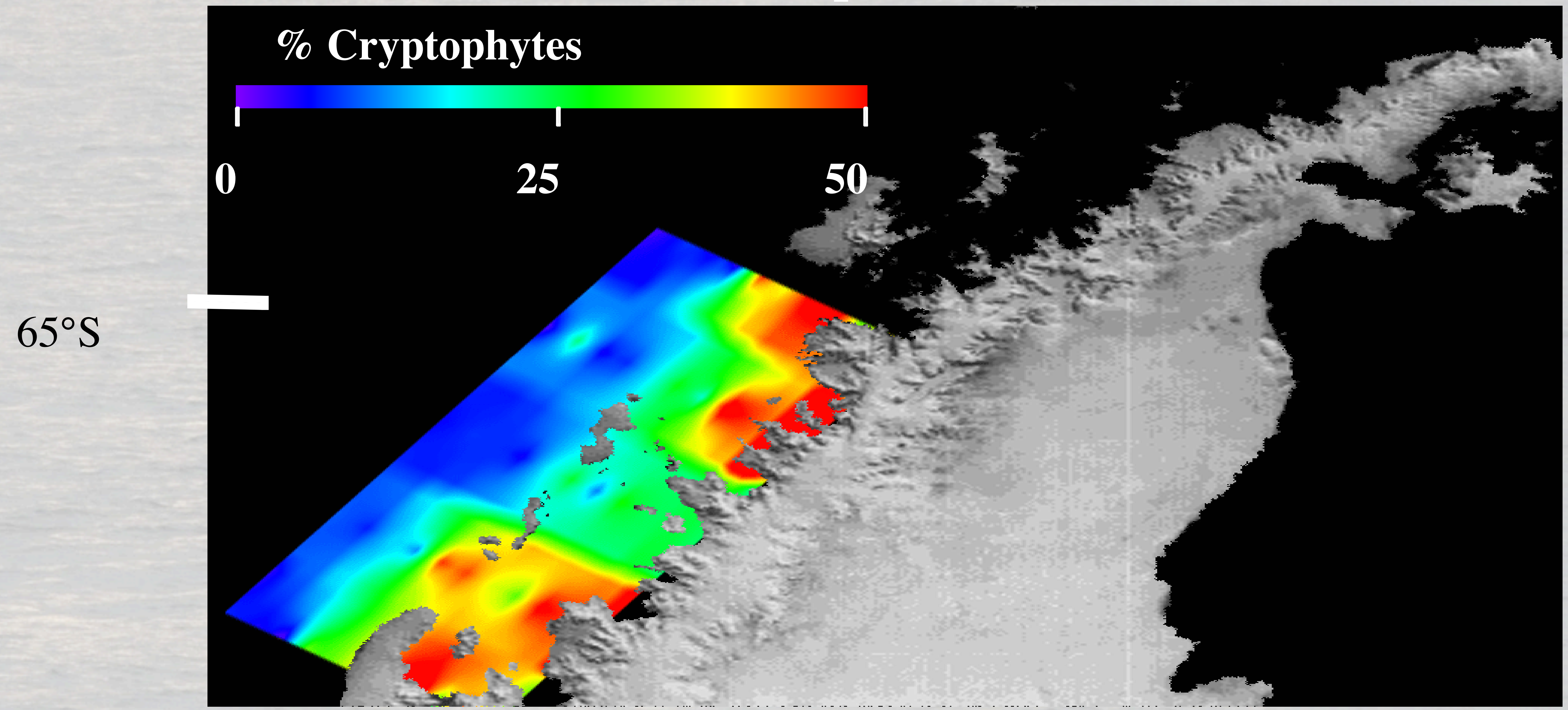
Cryptomonas cryophila

SEM Micrographs from*McMinn and Hodgson* 1993

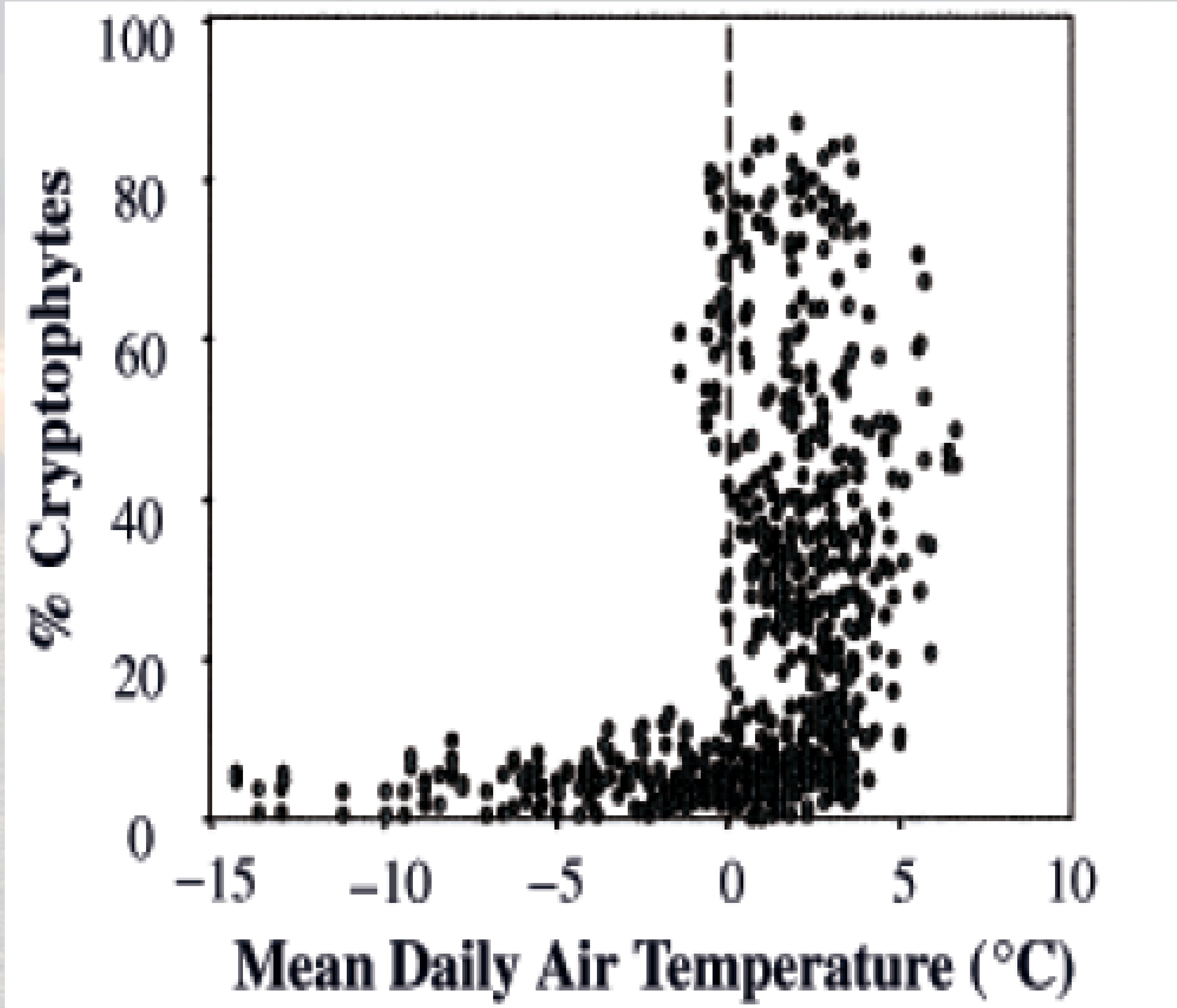

Data from the 20 year
Palmer time series
Watercolumn Integrated Alloxanthin
160
120
80
40
0
0
100
200
300
400
500
600
700
800
900
Watercolumn Integrated Fucoxanthin
>300
200
100
0
Watercolumn Integrated Chlorophyll a


TS plot with Alloxanthin and Fucoxanthin Pal Sta. E
Alloxanthin
Fucoxanthin
modified UCDW
sea ice melt
winter water
Temperature (°C)
Salinity
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
32
32.5
33
33.5
34
34.5



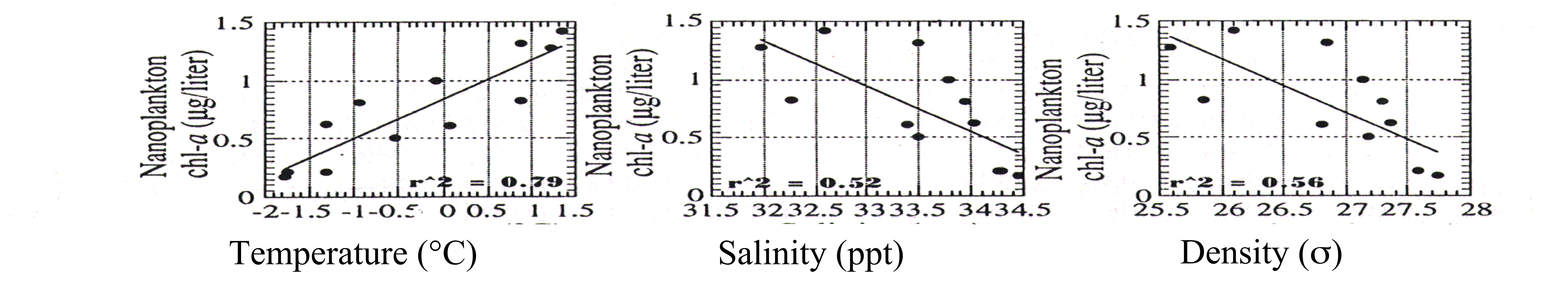


Moline et al.
GBC 2004



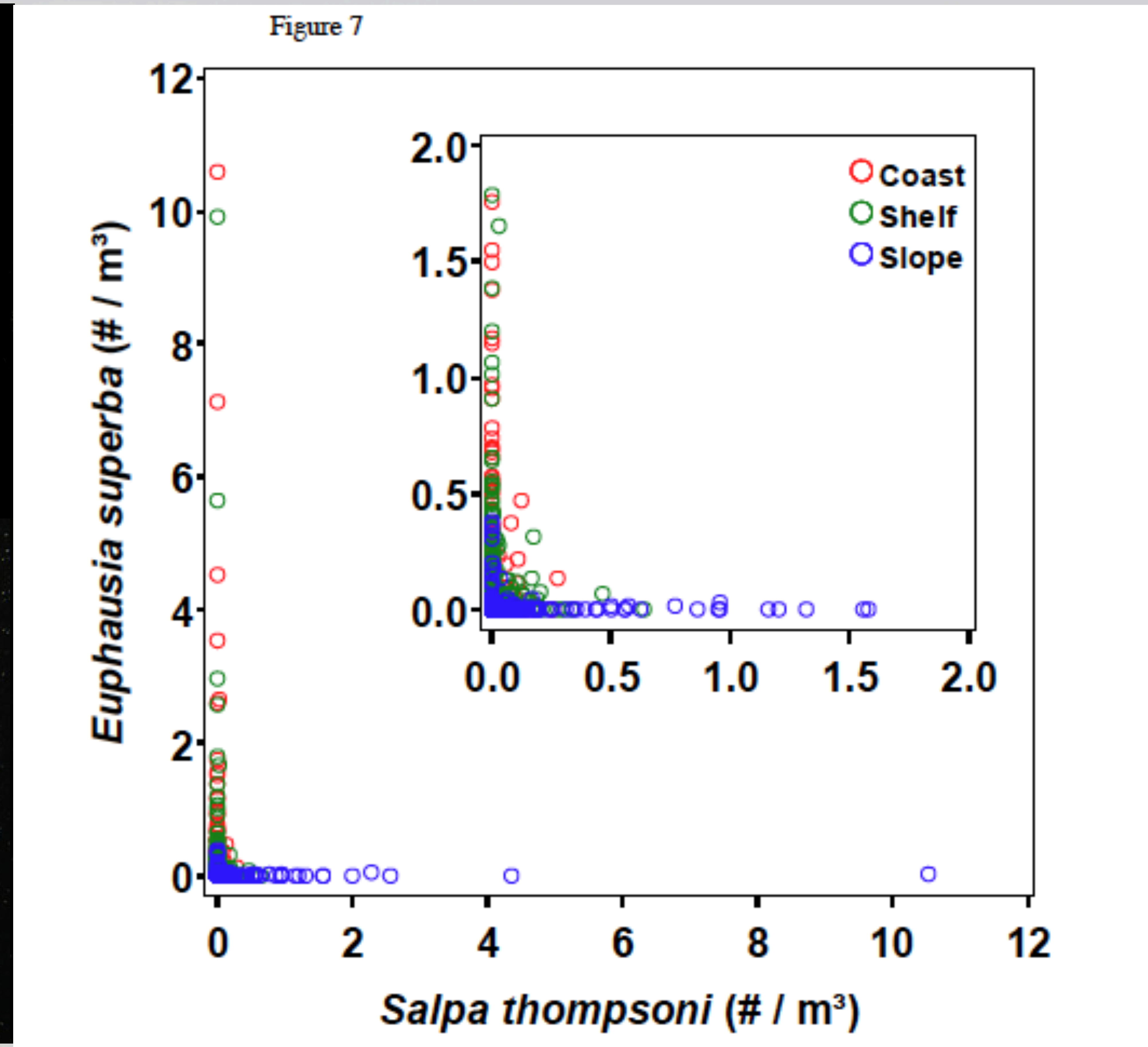
Moline et al.
GBC 2004

A general feature in the warming WAP?

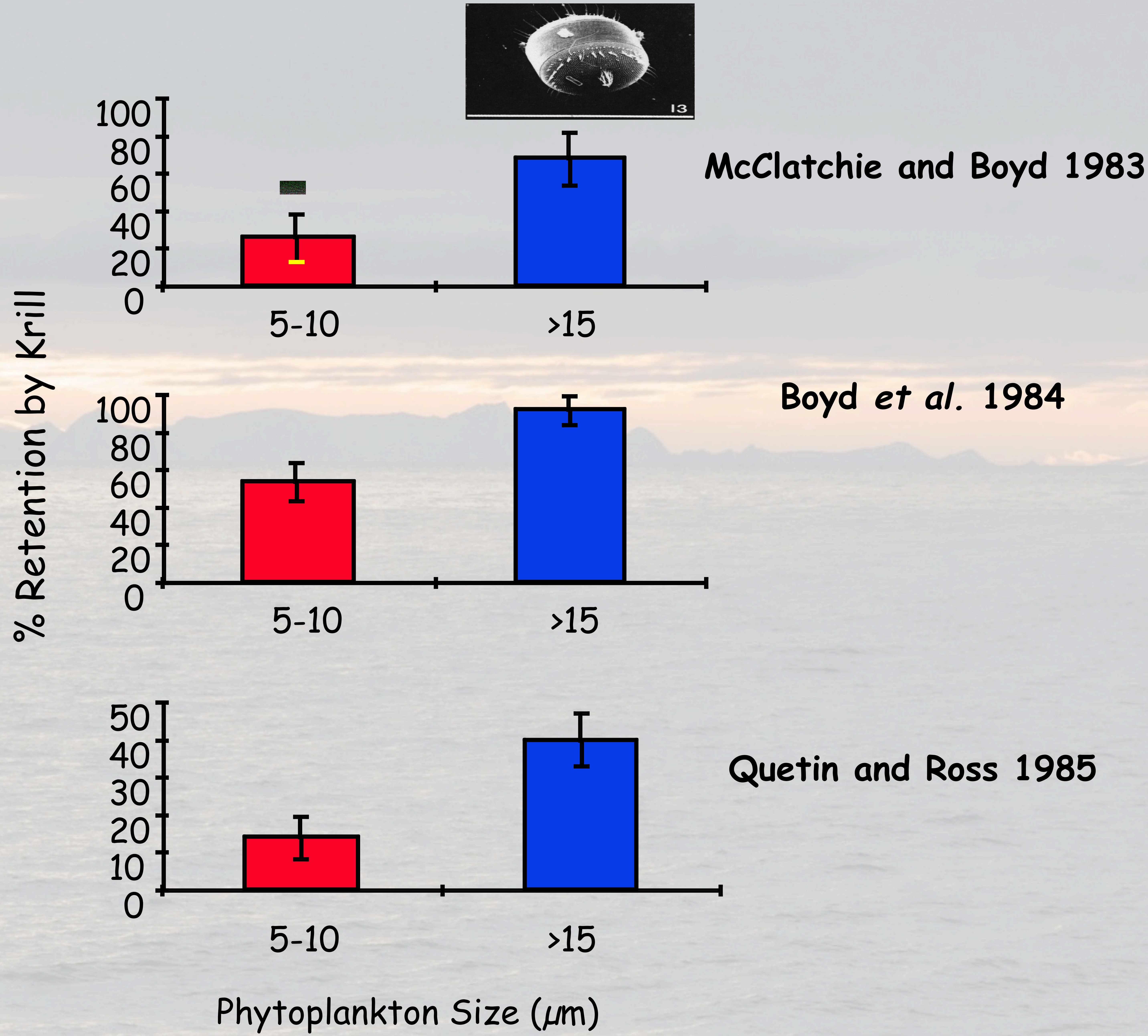


Location	Reference
South Shetland Islands	*V illafañe et al.*, 1995; *Kang, S-H et al.*, 1997; *Kang, J-S et al.*, 1997
Weddell-Scotia- Bellingshausen Confluence Areas	*Lancelot et al.*, 1991; *Nothig et al.*, 1991 *Tréguer et al.*, 1991; *Buma*, 1992; *Mura et al.*, 1995; *Kang and Lee*, 1995; *Aristegui et al.*, 1996
Ellis Fjord	*McMinn and Hodgson*, 1993
Bransfield Strait	*Kang and Lee,* 1995; *Kang et al.*, 1995
Historical Data	
Anvers Island	*Krebs*, 1983
Signy Island	*Whitaker*, 1982

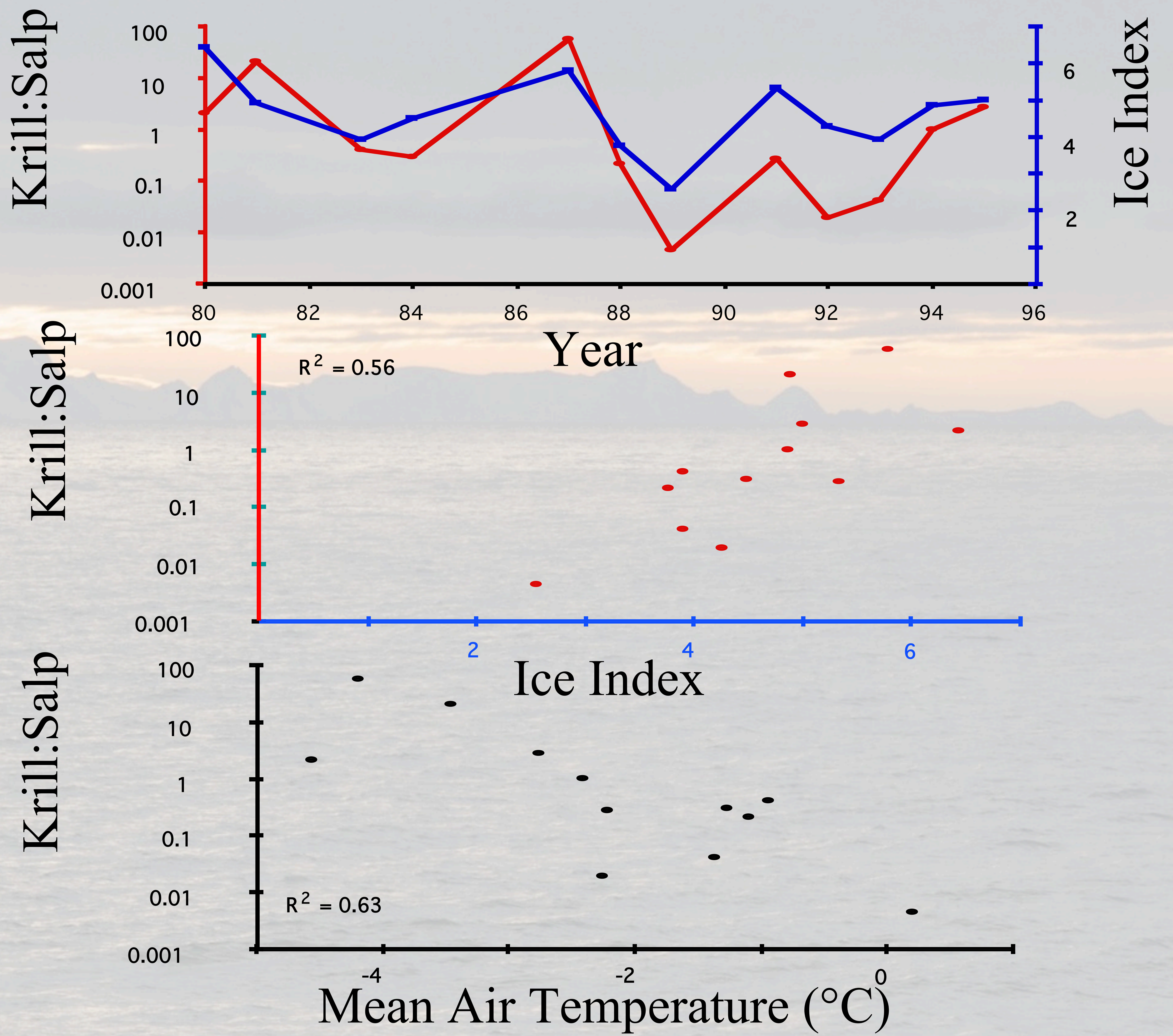
Zooplankton are dominated by krill or salps



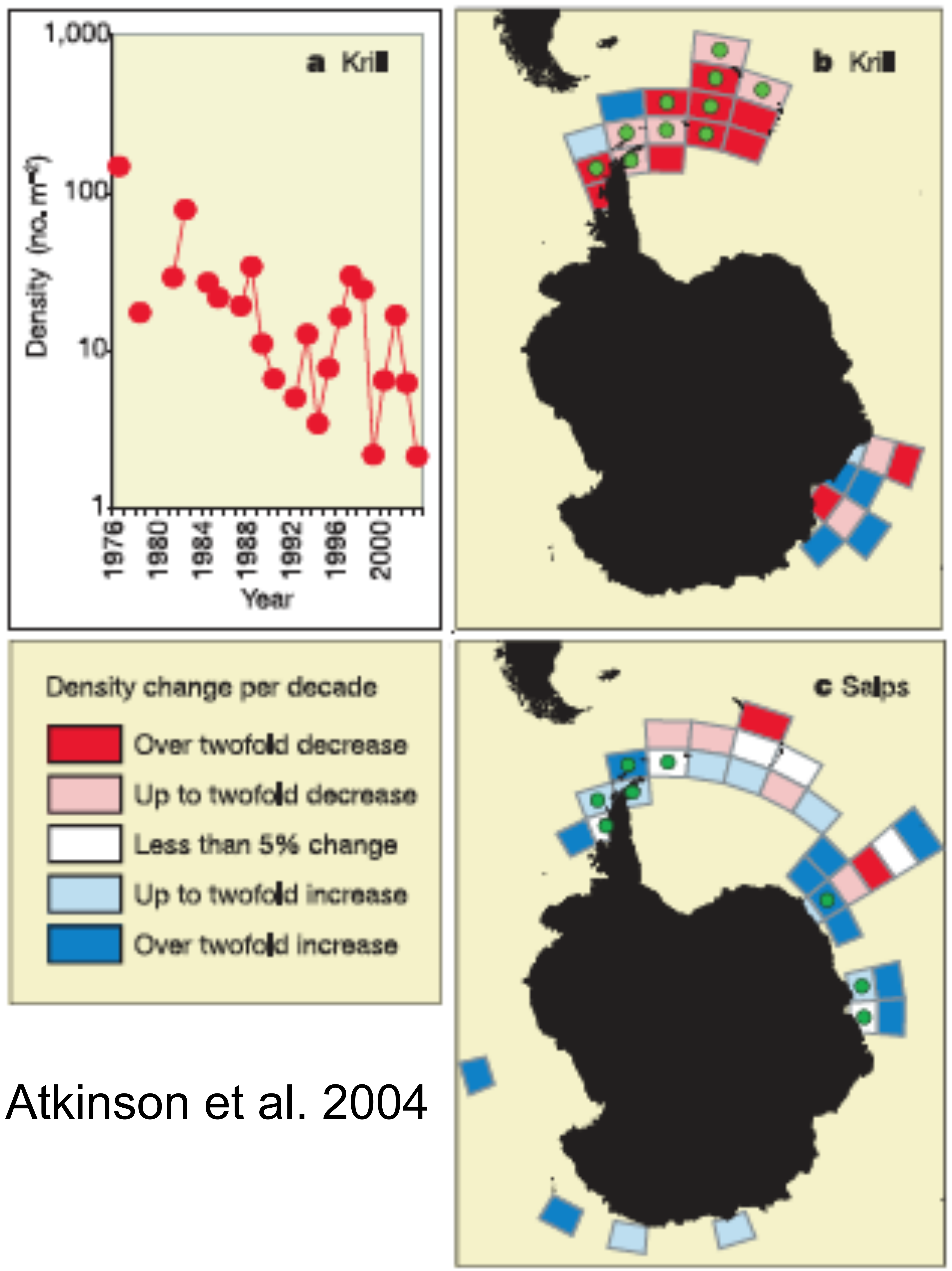
Thanks to Deborah Stienberg


McClatchie and Boyd 1983
Boyd et al. 1984
Quetin and Ross 1985
% Retention by Krill
100
80
60
40
20
0
50
30
10
5-10
>15
13
Phytoplankton Size (μm)

From *Loeb et al.*, 1997

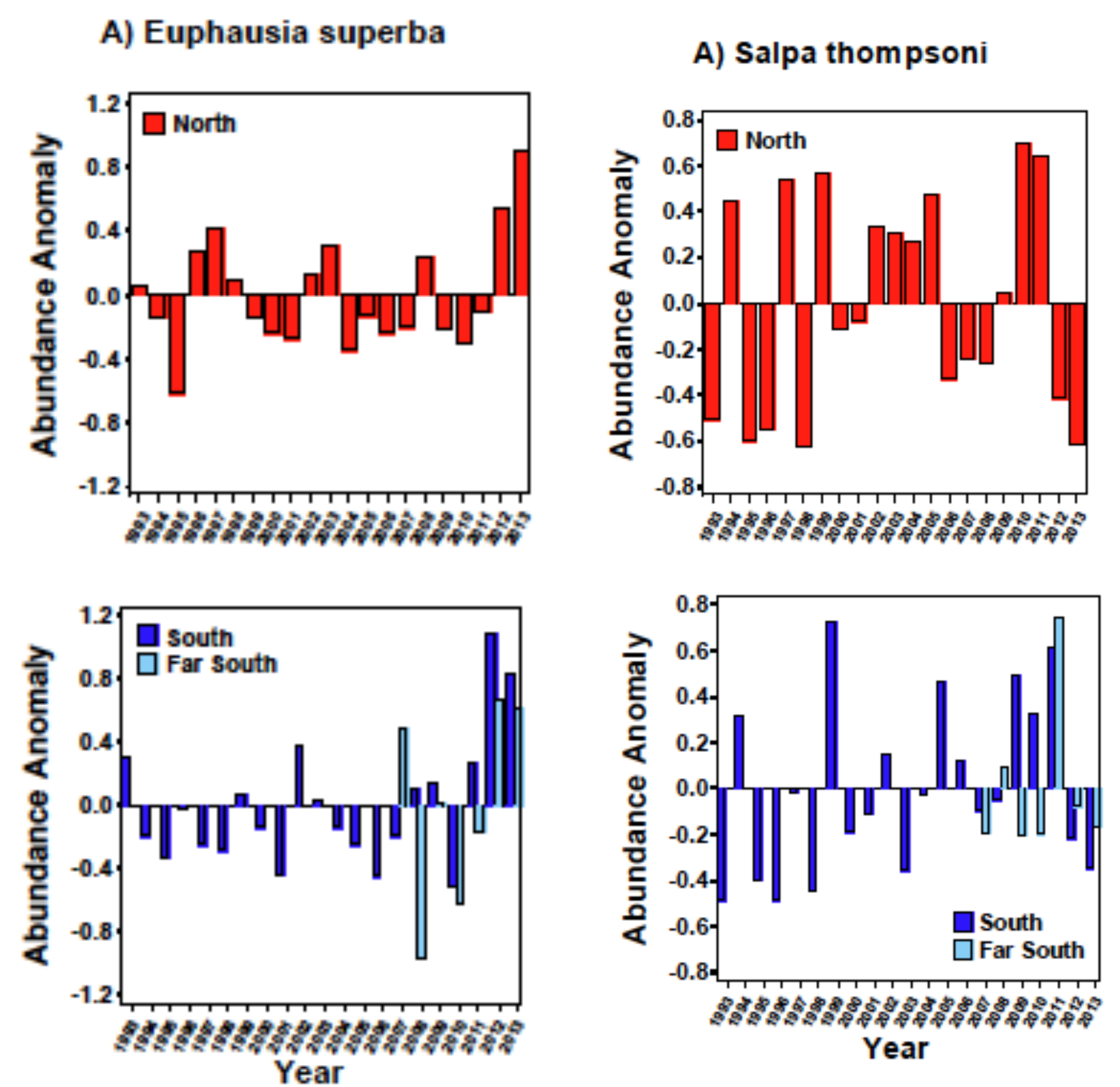


Decadal patterns suggest a shift



Atkinson et al. 2004

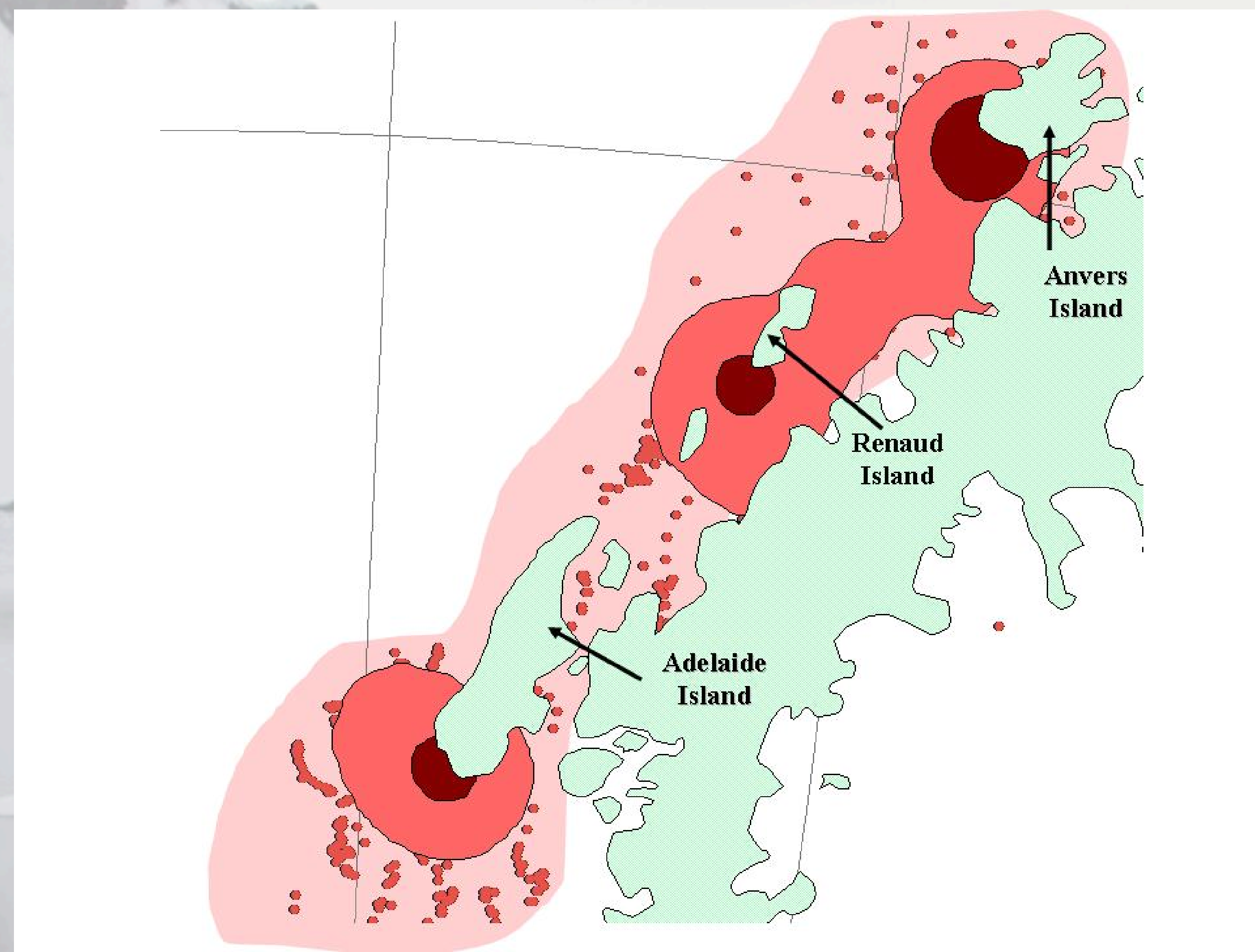
Not as clear in LTER



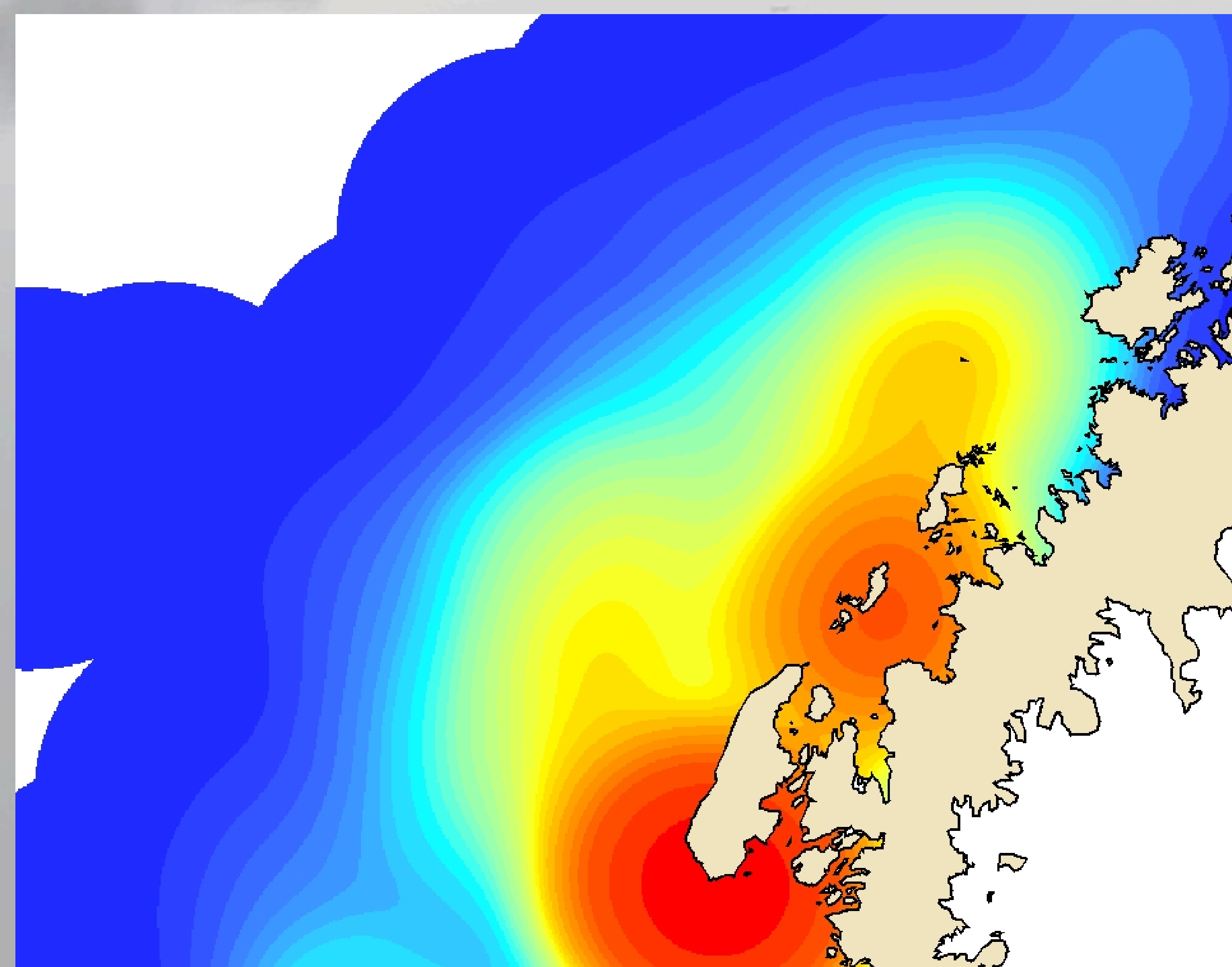
Is there an impact on higher trophic levels?

One focus idea of the LTER is testing, is that system is undergoing climate migration. We have structured sampling around the major Adelie penguin breeding areas along the peninsula.

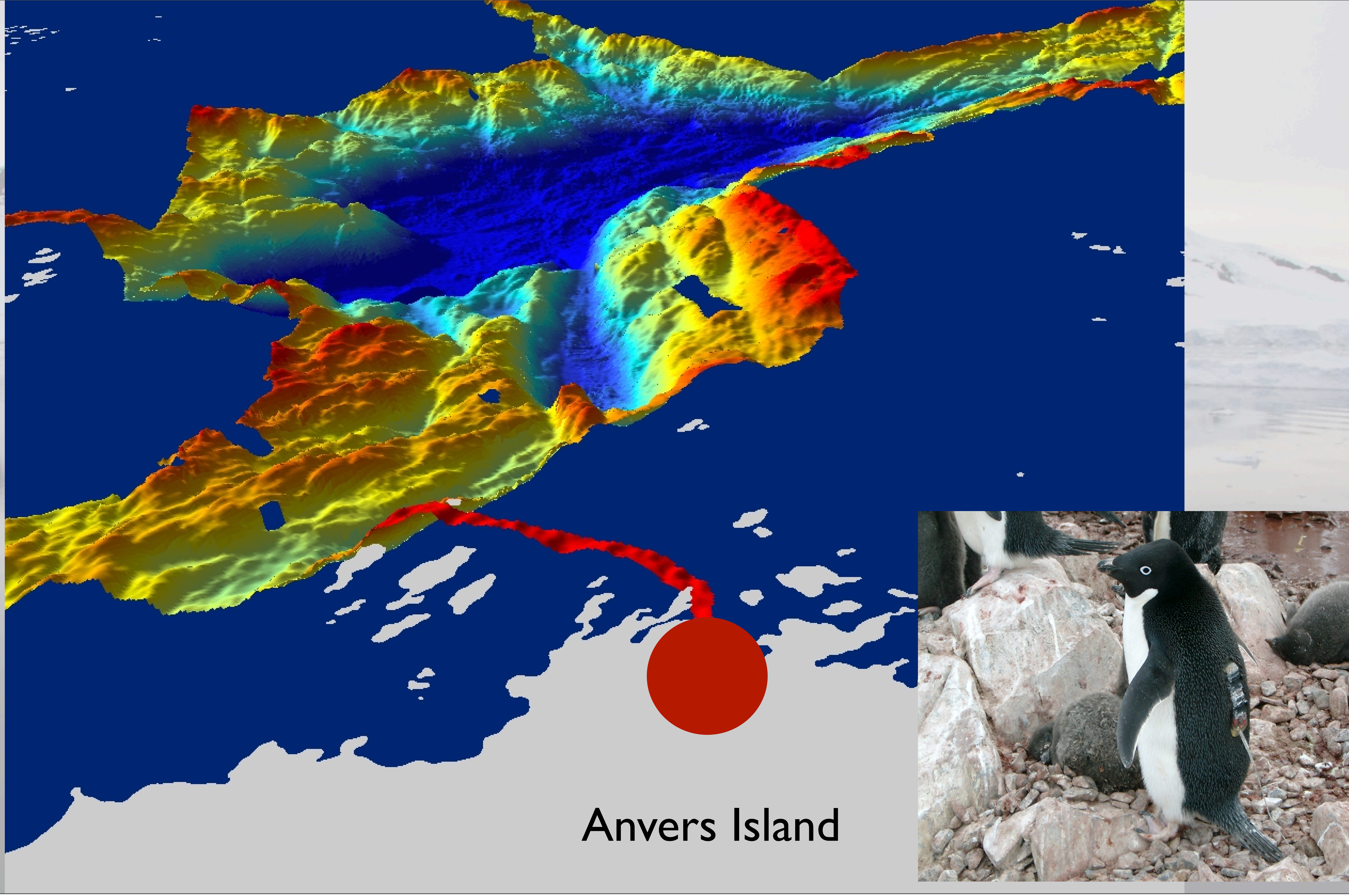
Summer foraging areas for Adelie penguins

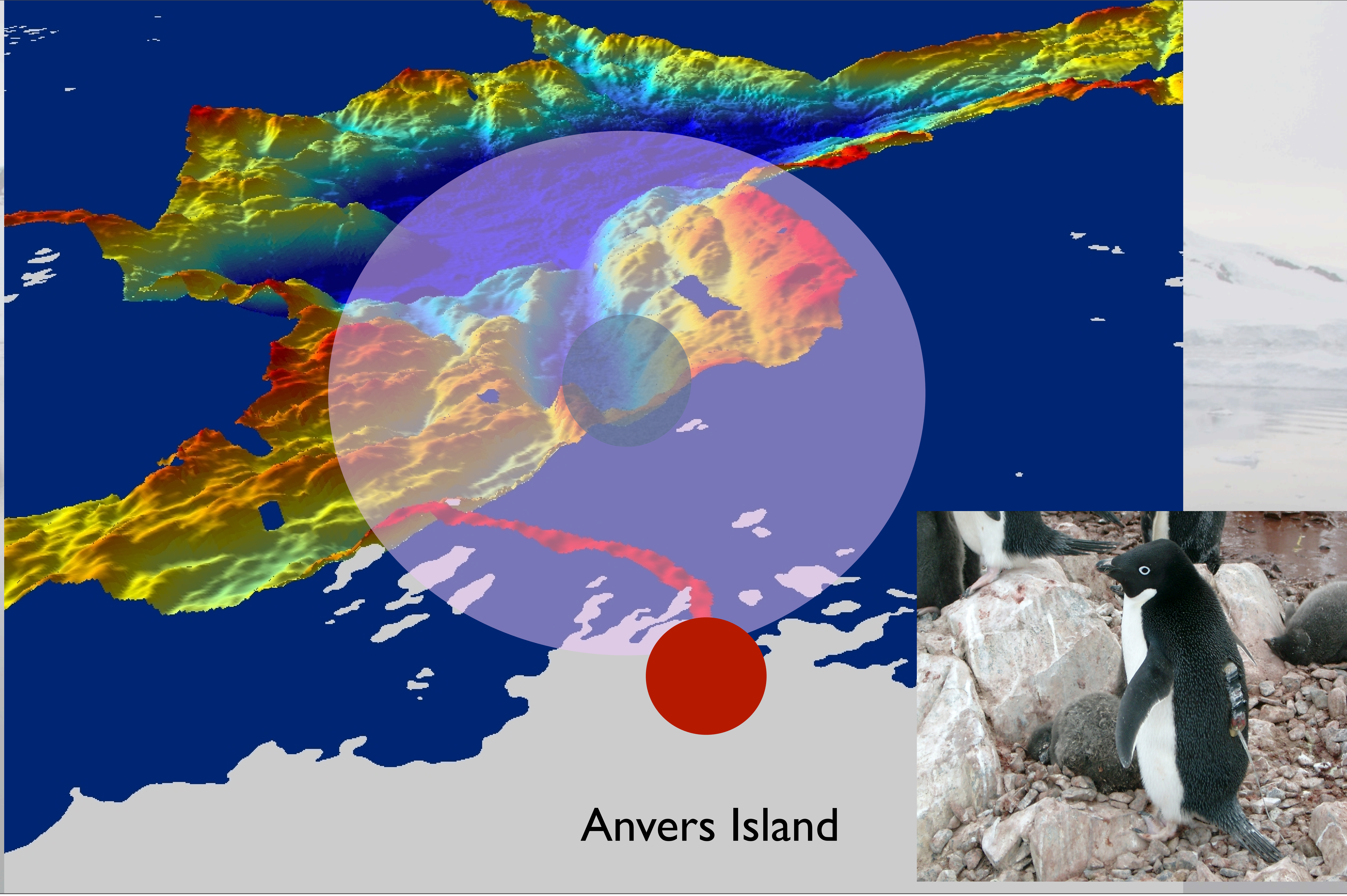


Winter foraging areas for Adelie penguins

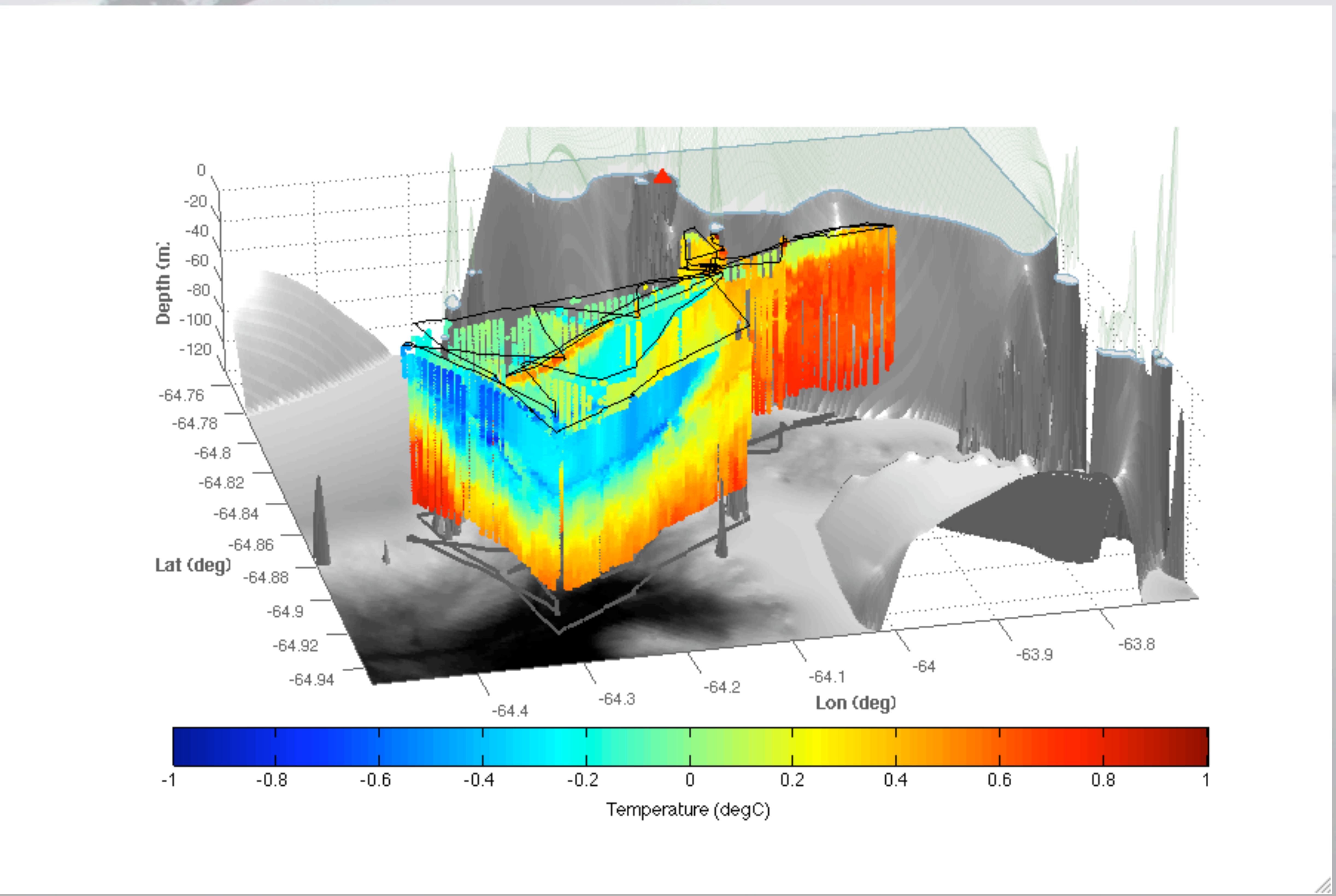


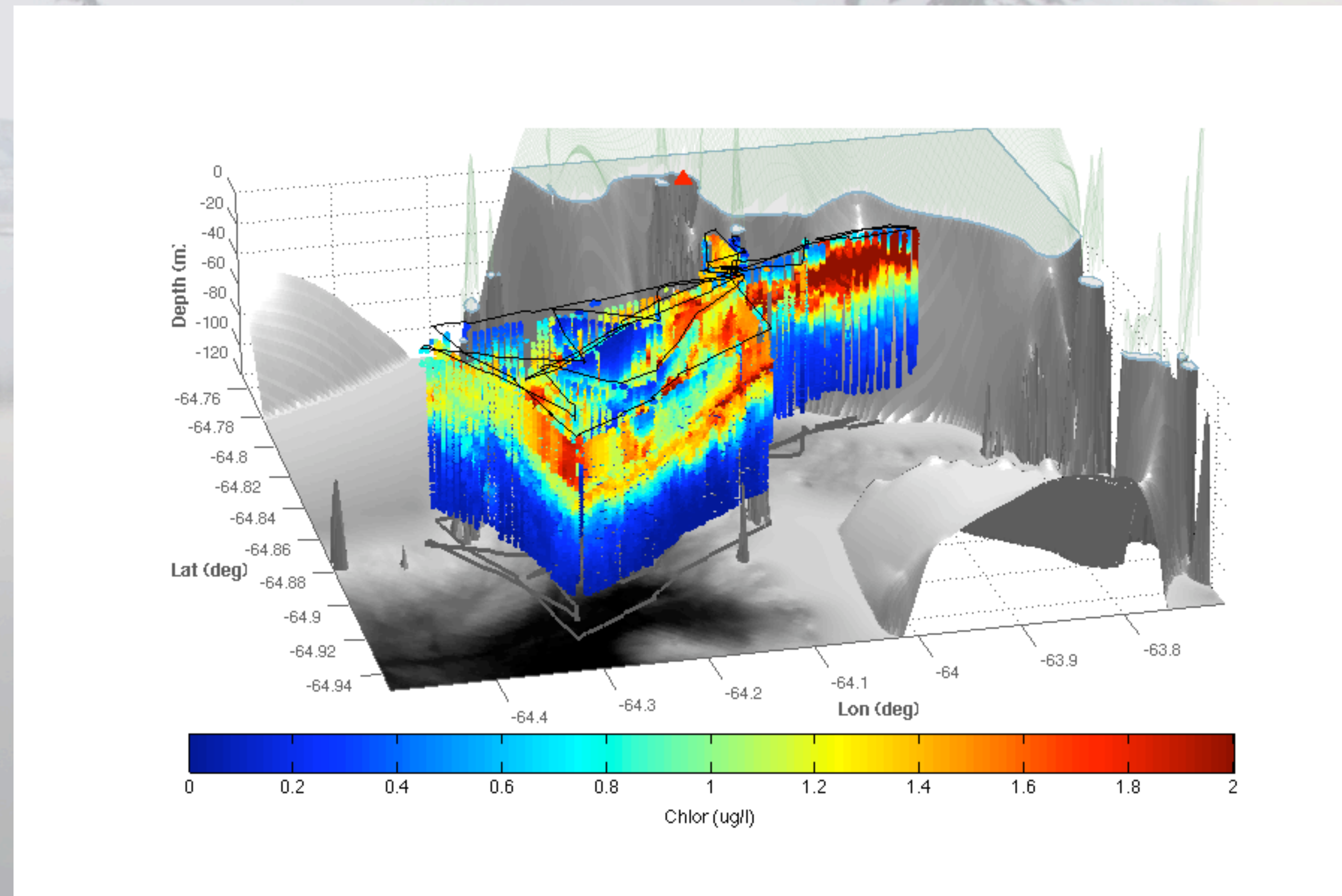
To be expanded by NASA grant awarded in Dec.


Anvers Island

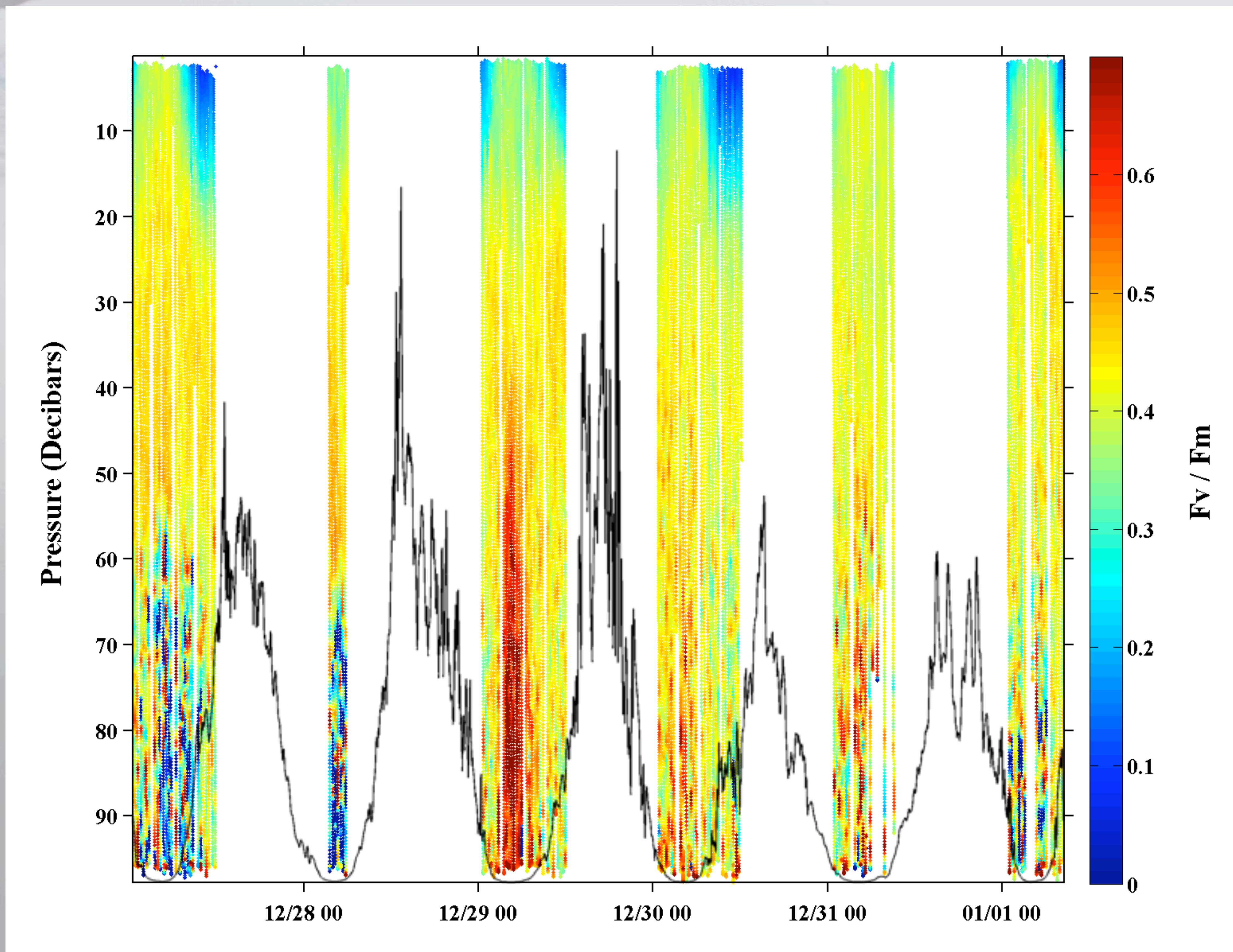

Anvers Island

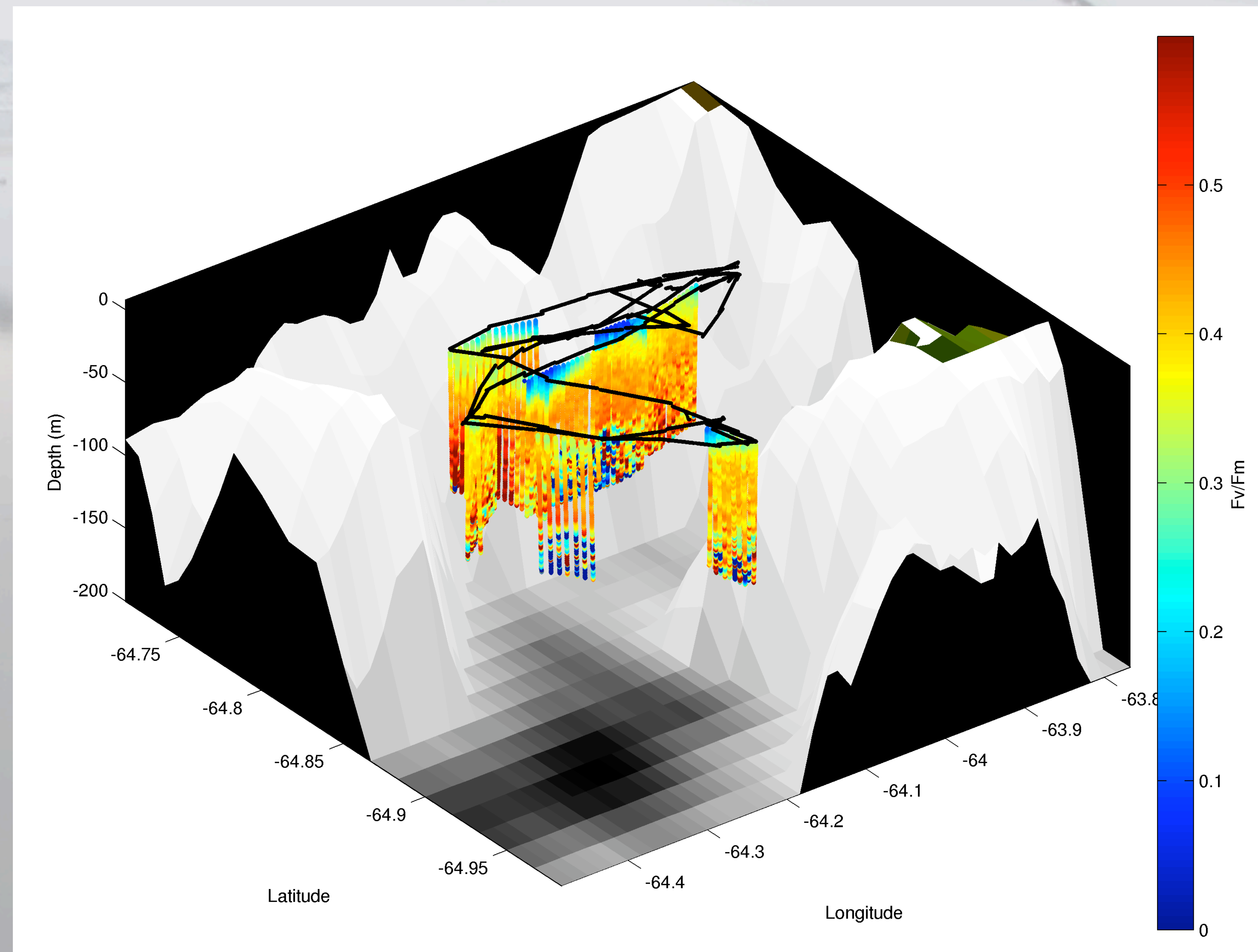
Enhanced productivity is associated with the warm upwelled water

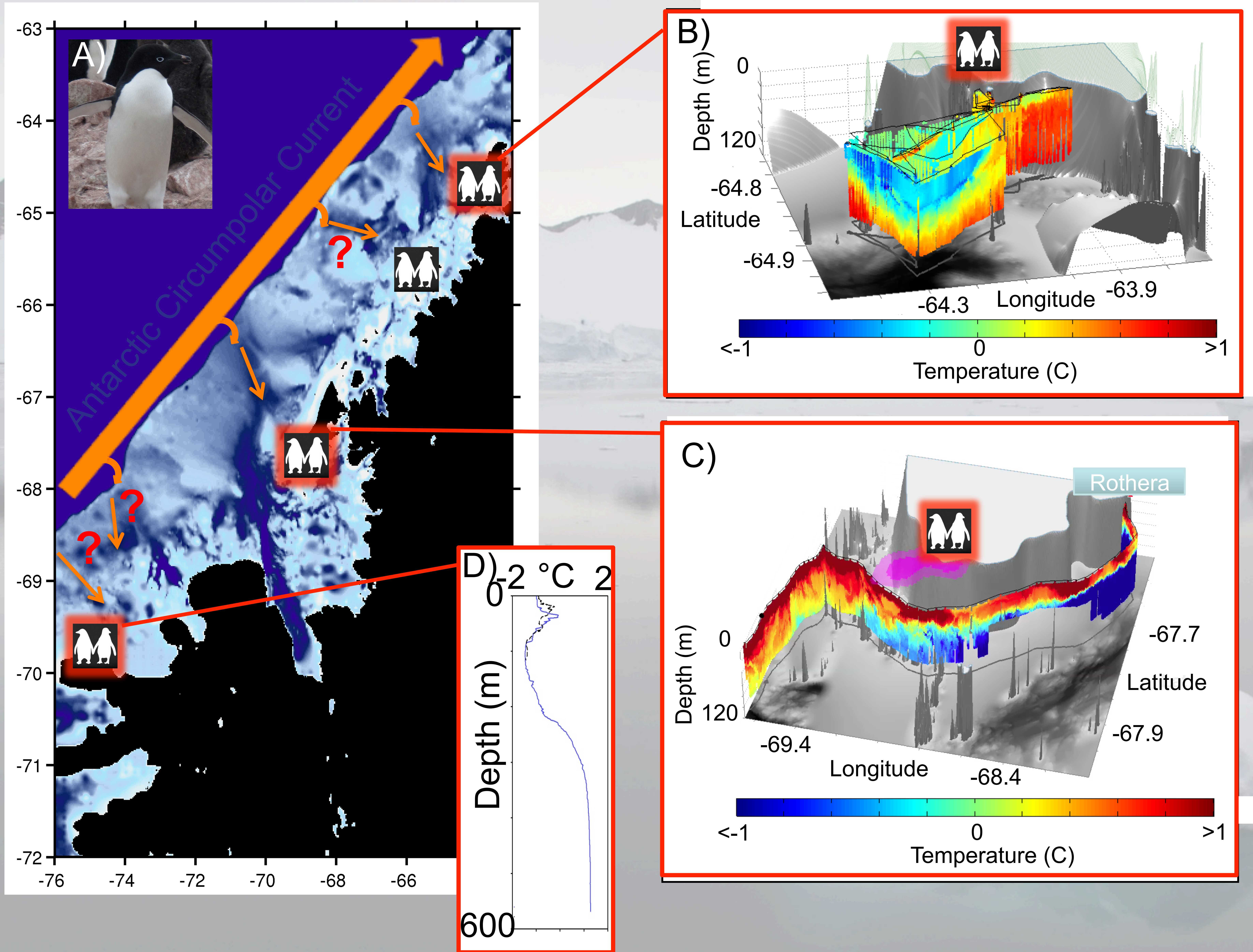




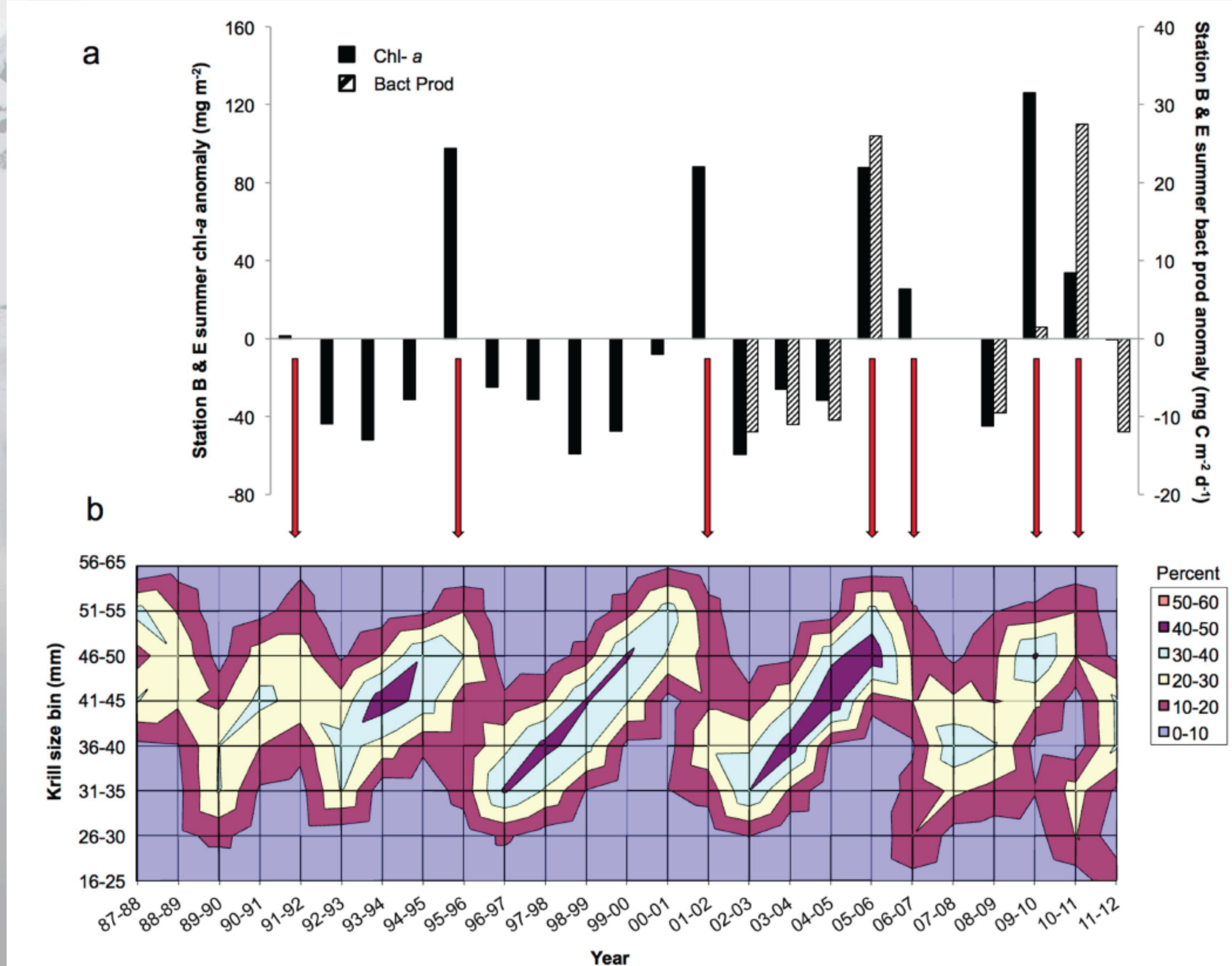
Glider measurements of Fv/Fm indicate that the phytoplankton populations associated with upwelling are healthy

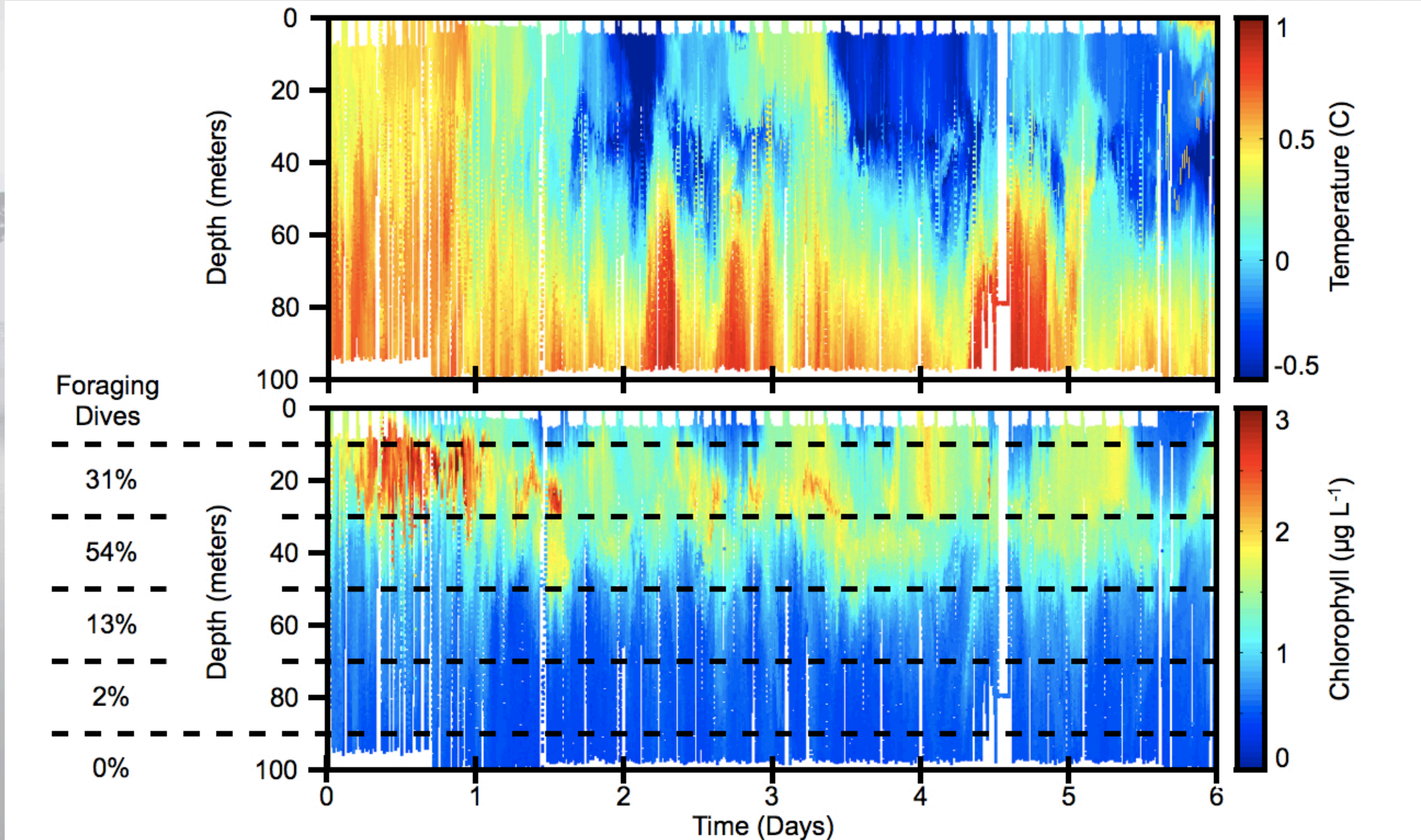





A)
Antarctic Circumpolar Current
?
?
?
-63
-64
-65
-66
-67
-68
-69
-70
-71
-72
-76
-74
-72
-70
-68
-66
B)
Depth (m)
0
120
-64.8
Latitude
-64.9
-64.3
Longitude
-63.9
<-1
0
>1
Temperature (C)
C)
Rothera
Depth (m)
0
120
-67.7
Latitude
-67.9
-69.4
Longitude
-68.4
<-1
0
>1
Temperature (C)
D)
-2 °C 2
0
Depth (m)
600

Big Ice Winters Drive the Larger Phytoplankton Spring Blooms Which Primes the Food Web as a Whole

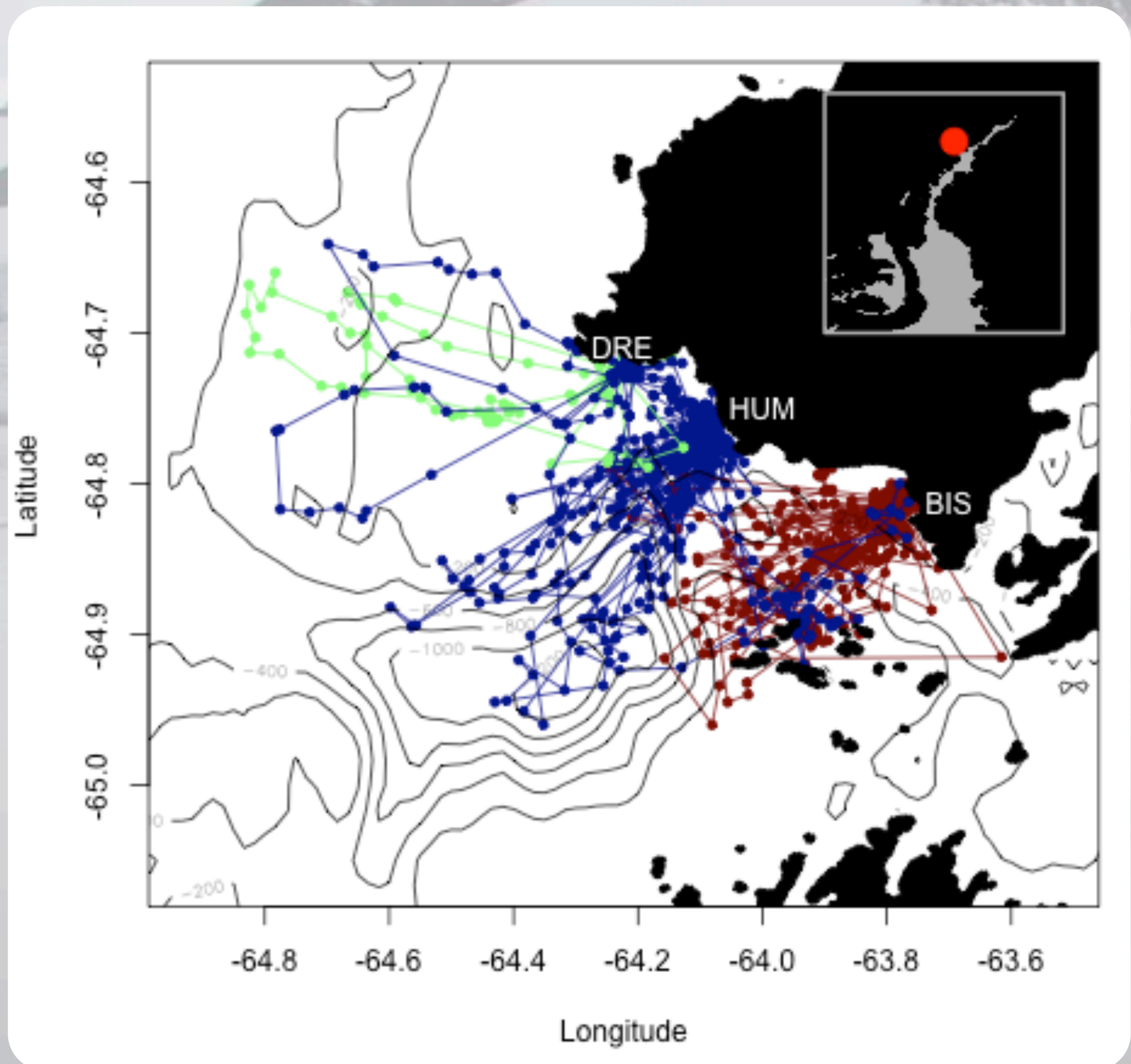




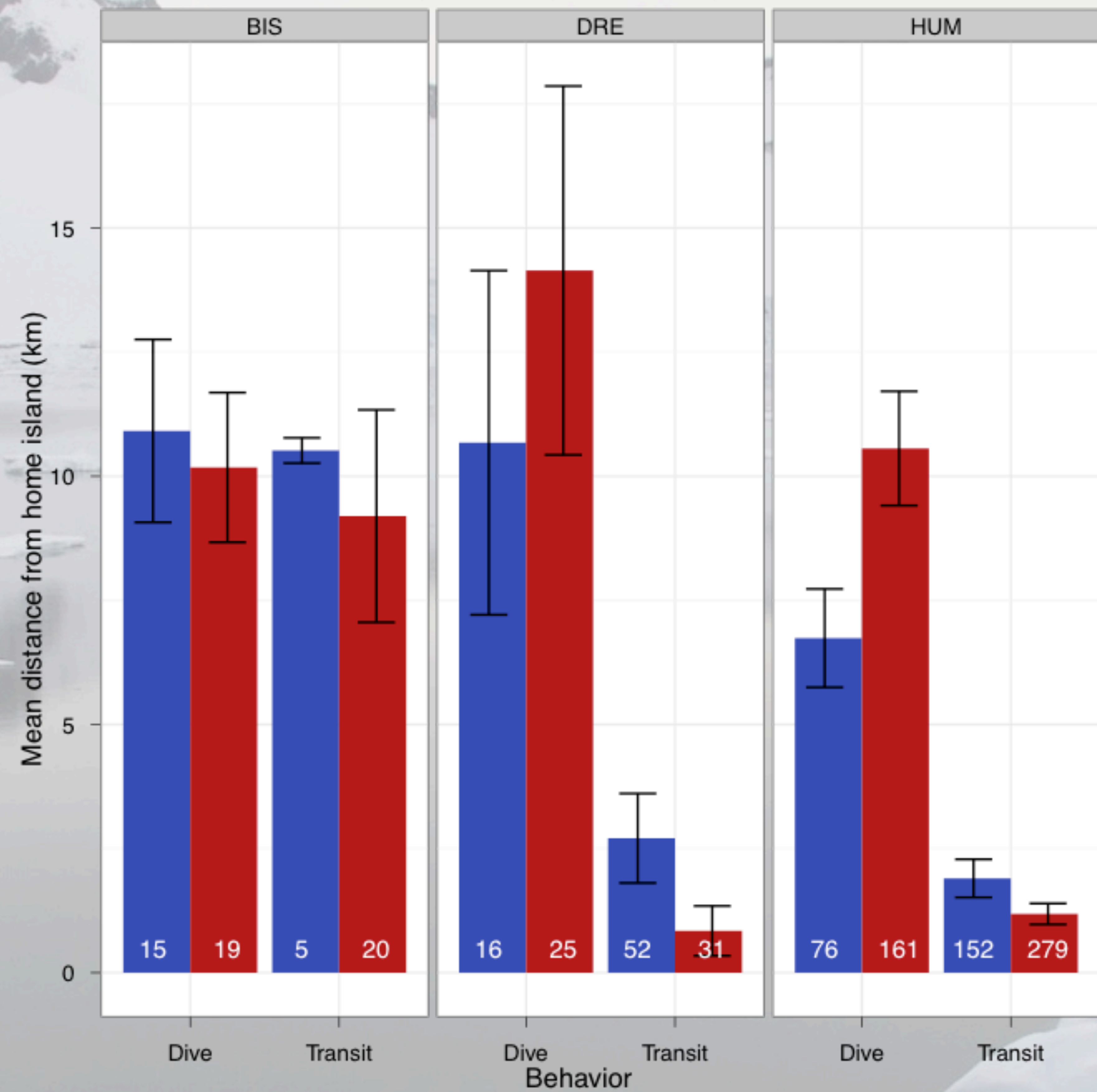
Depth (meters)
0
20
40
60
80
100
Temperature (C)
1
0.5
0
-0.5
Foraging
Dives
31%
54%
13%
2%
0%
Chlorophyll (µg L-1)
3
2
1
0
0
1
2
3
4
5
6
Time (Days)

Results from the 2011 field season: Tidal structuring of the penguin foraging

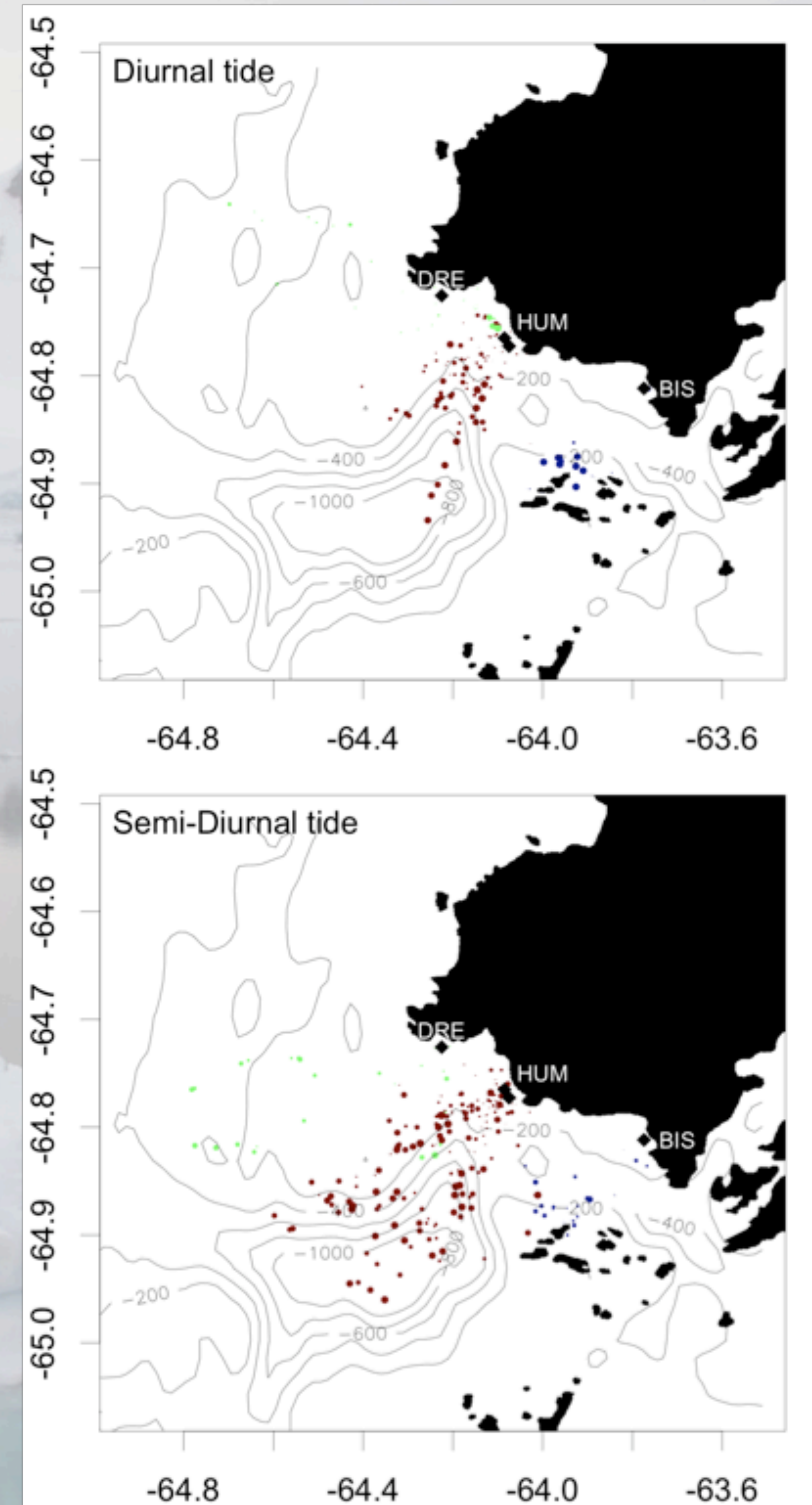
Moline, Oliver, Frazer, Kohut, Schofield



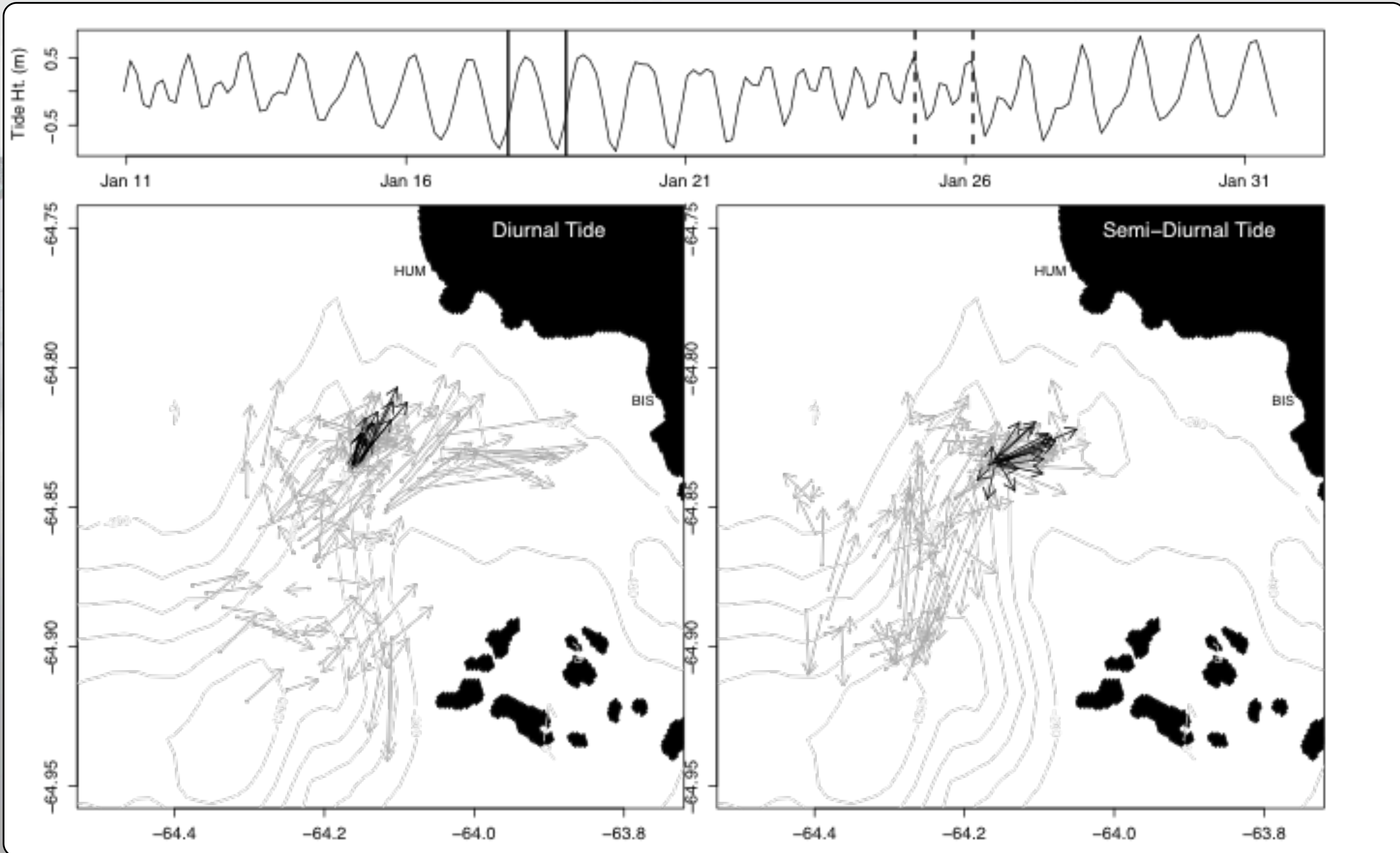
Radio-tagged penguins
Adelie (blue)
Gentoo (red)
Chinstrap (green)



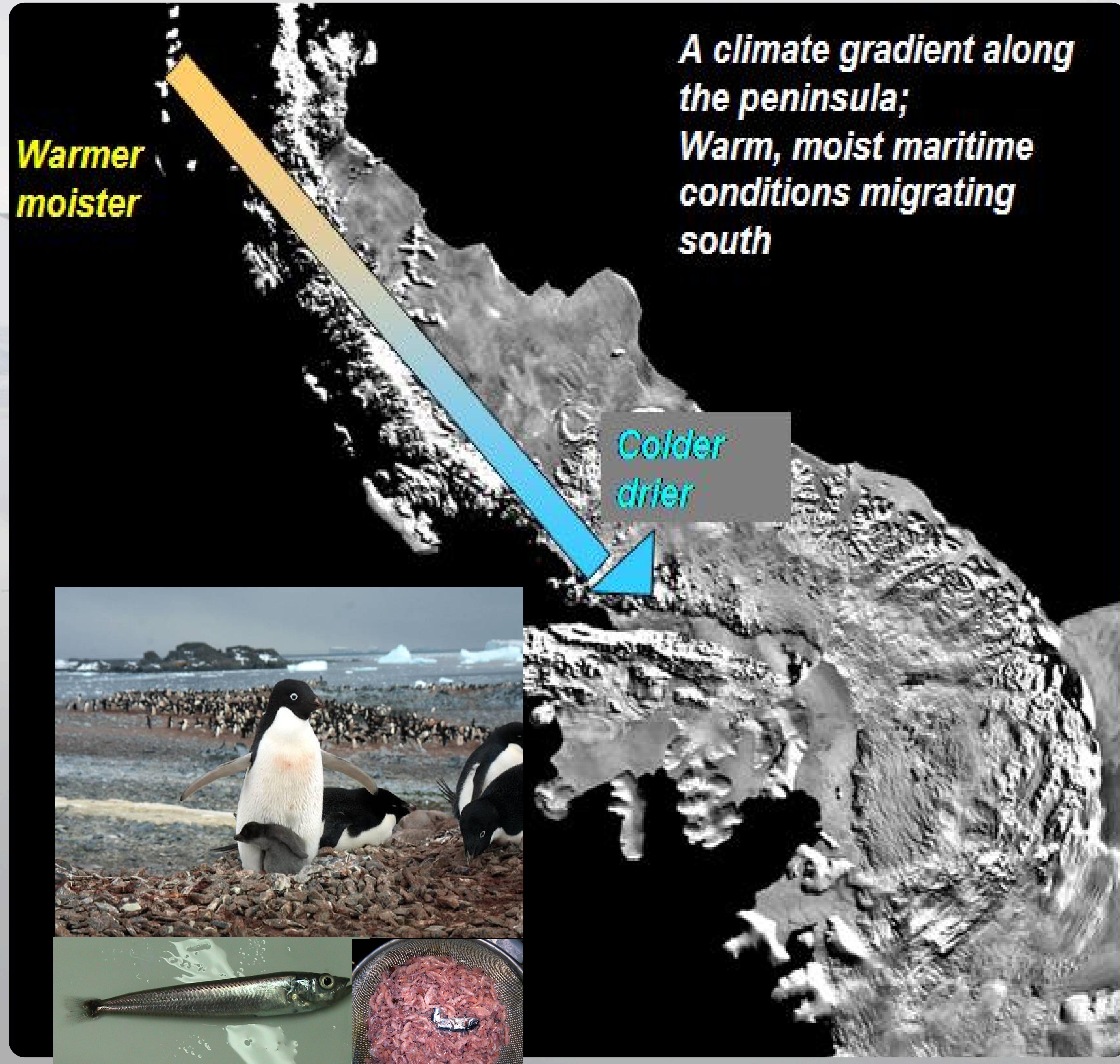
Blue = semi-diurnal tides
Red = diurnal tides



Glider currents

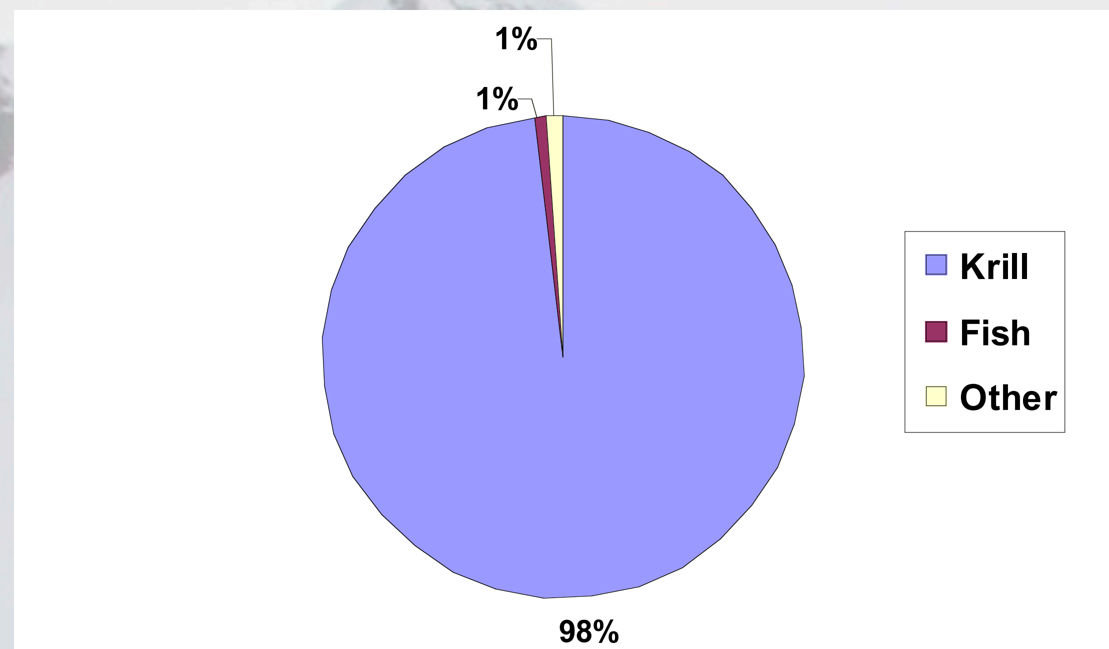


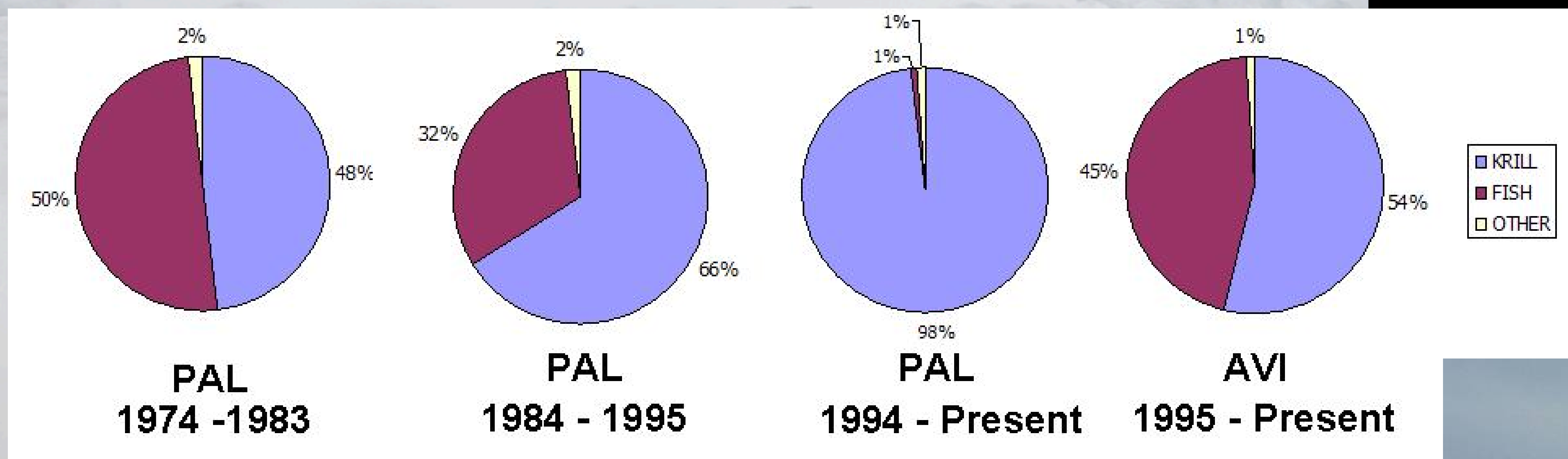
Changing diets for the Adelie penguins

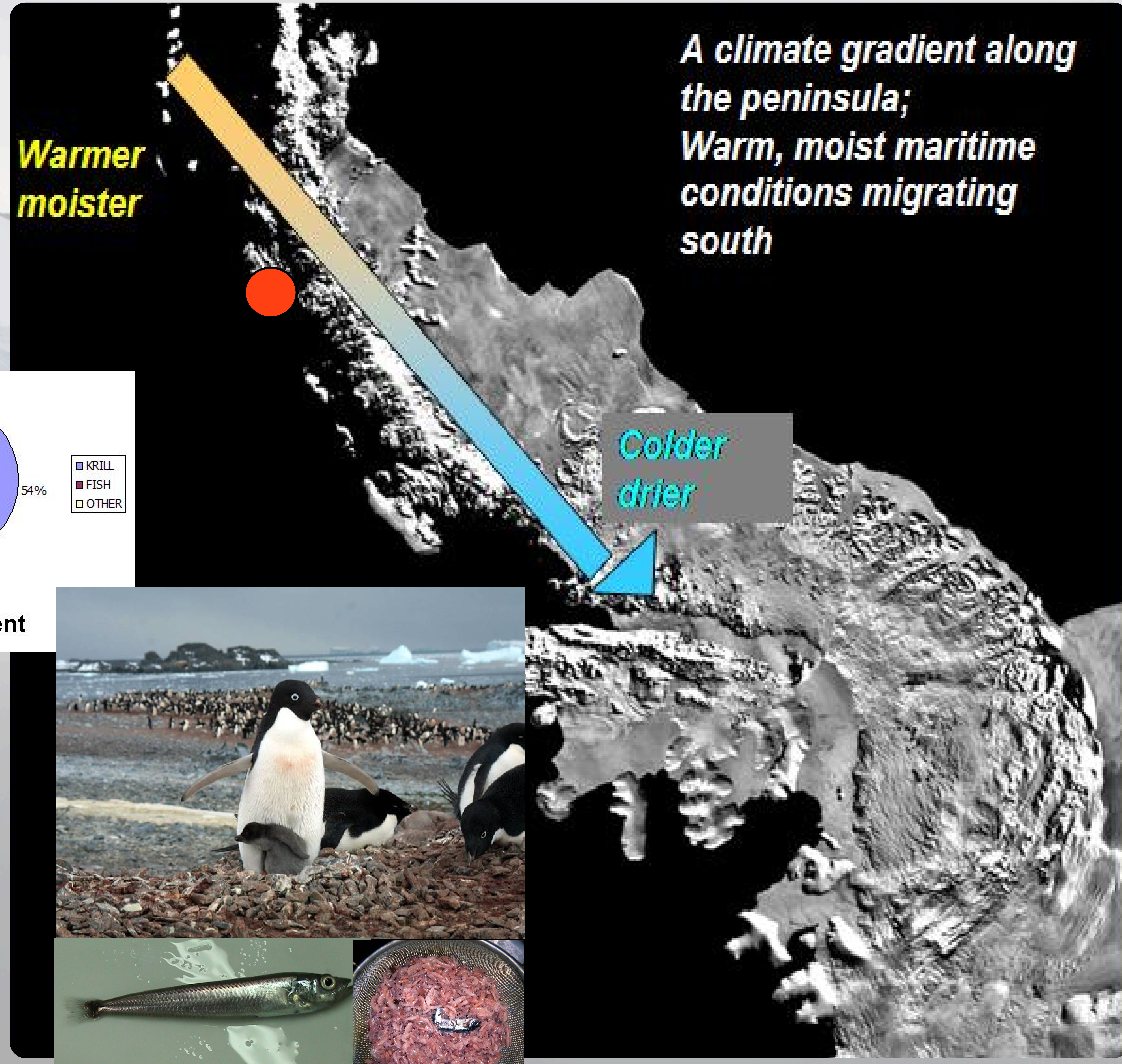


Changing diets for the Adelie penguins

1994-
present

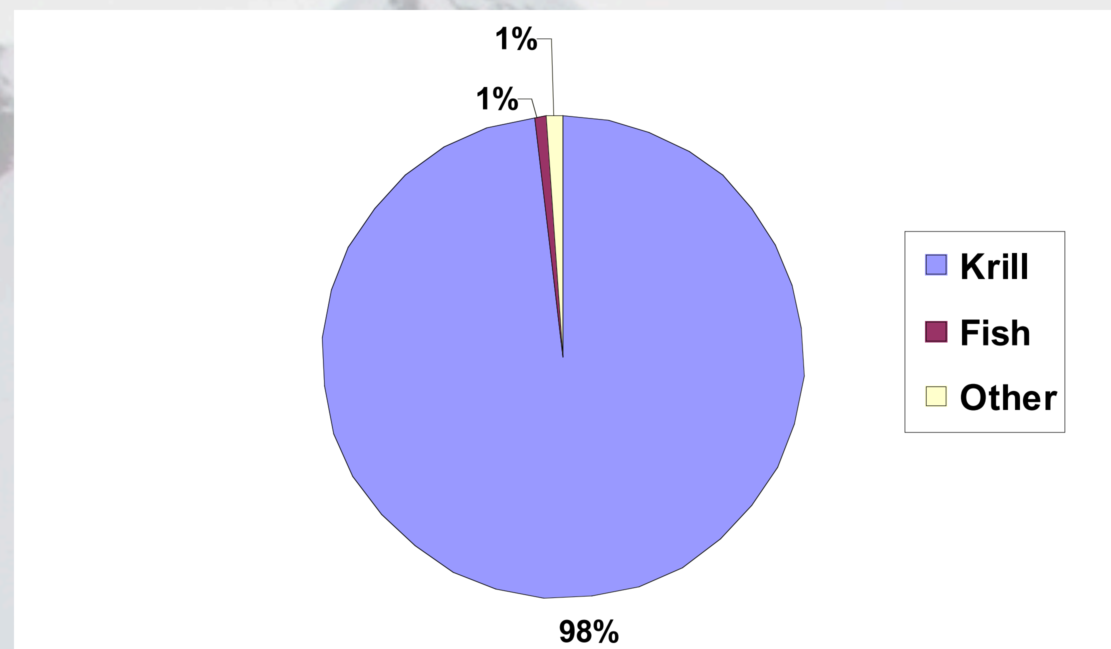


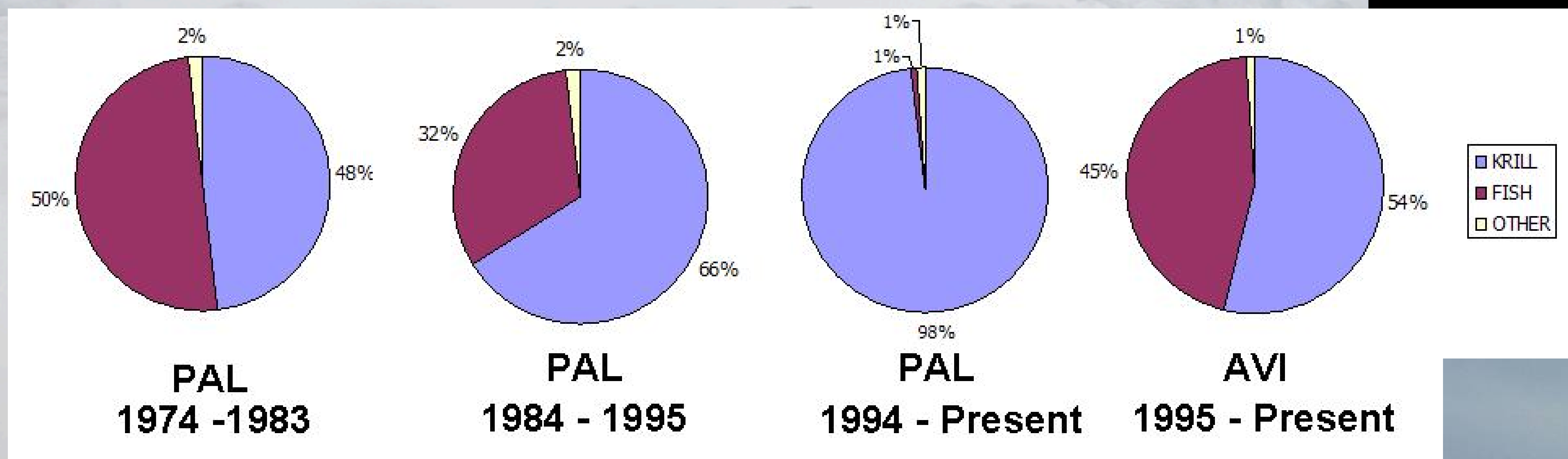




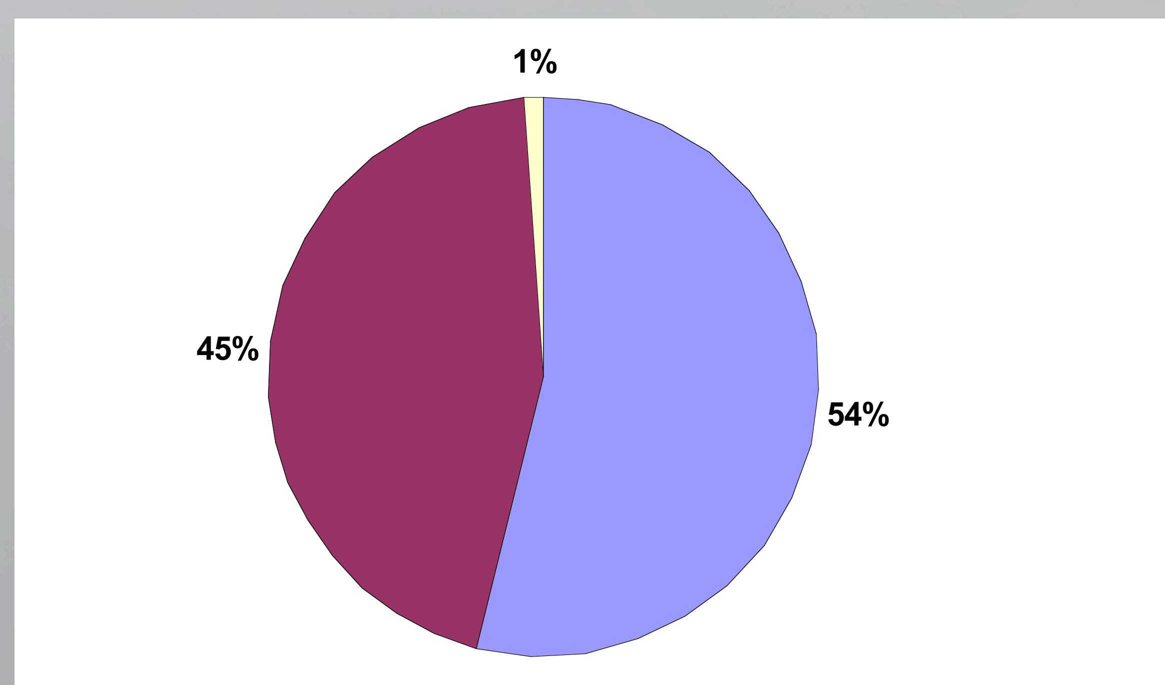
Changing diets for the Adelie penguins

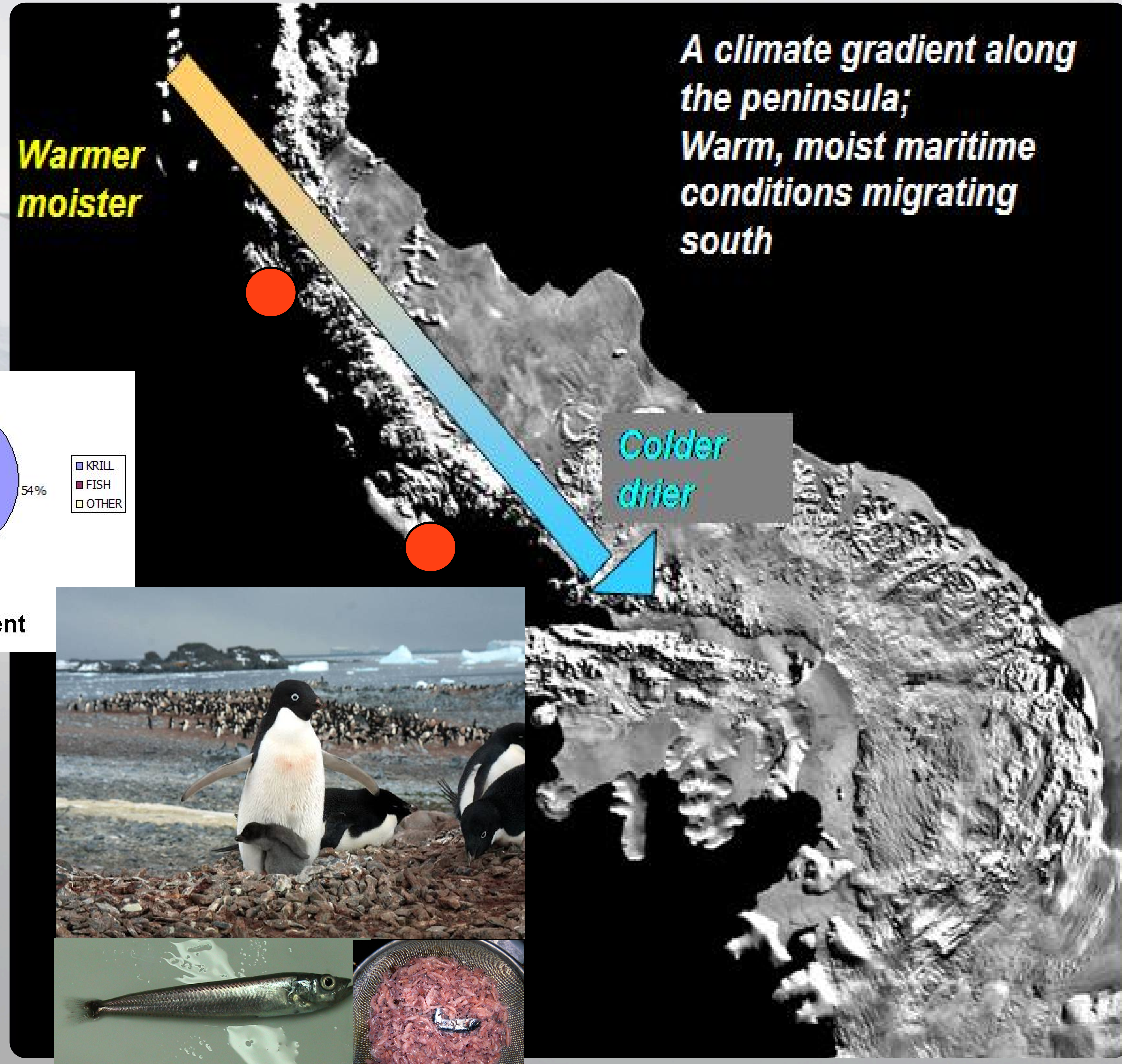
1994-
present



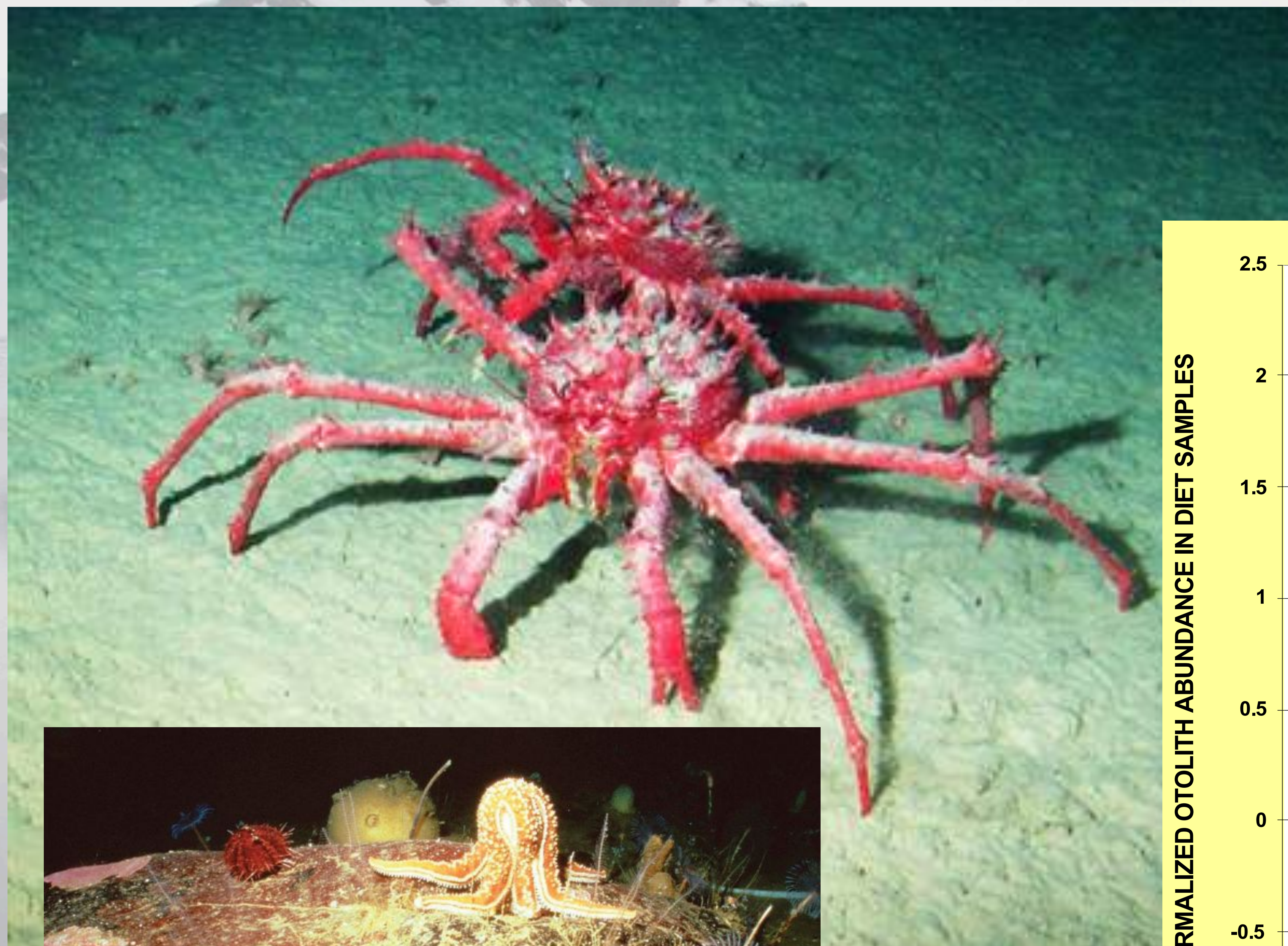


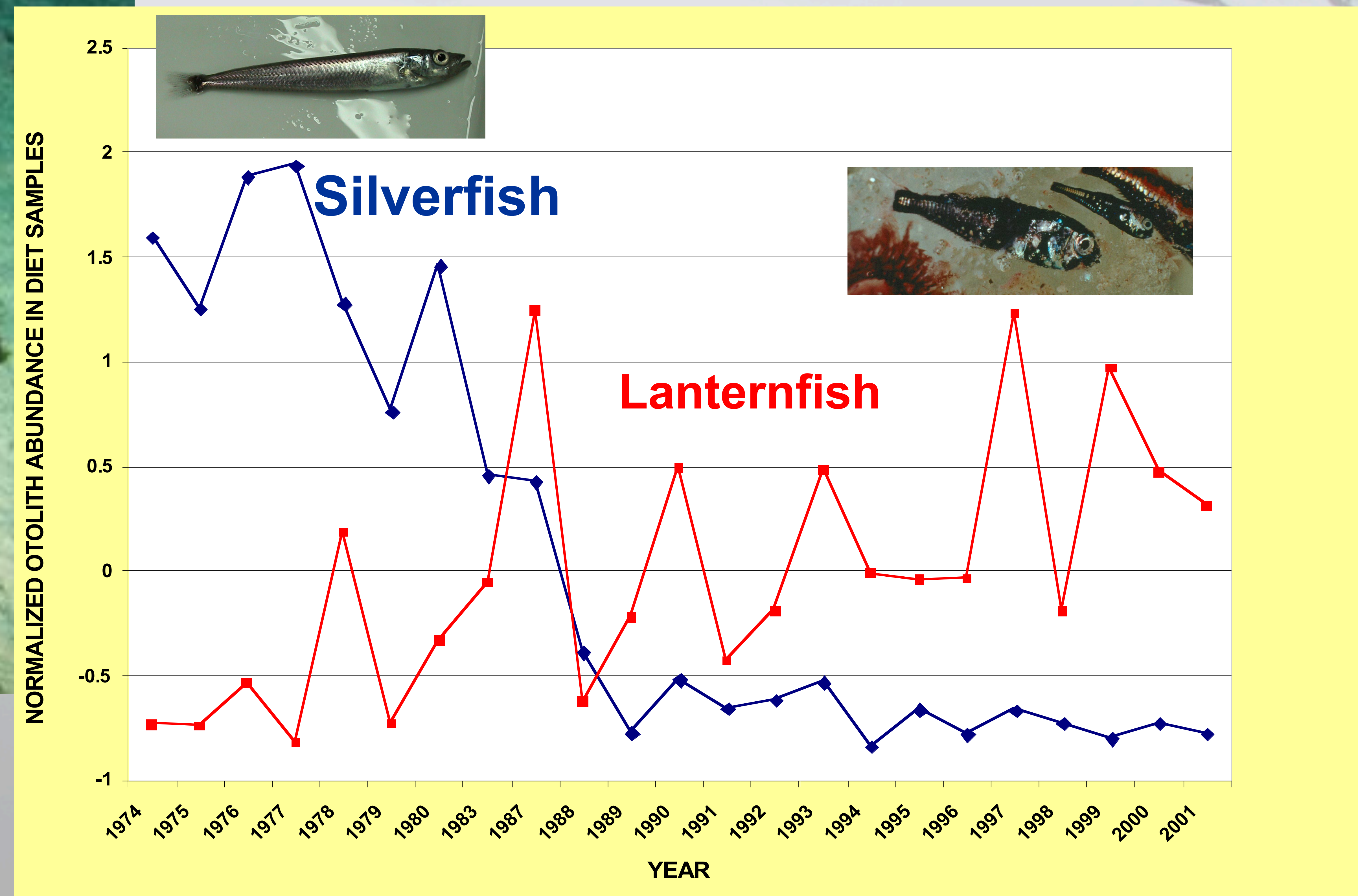
1995-
present



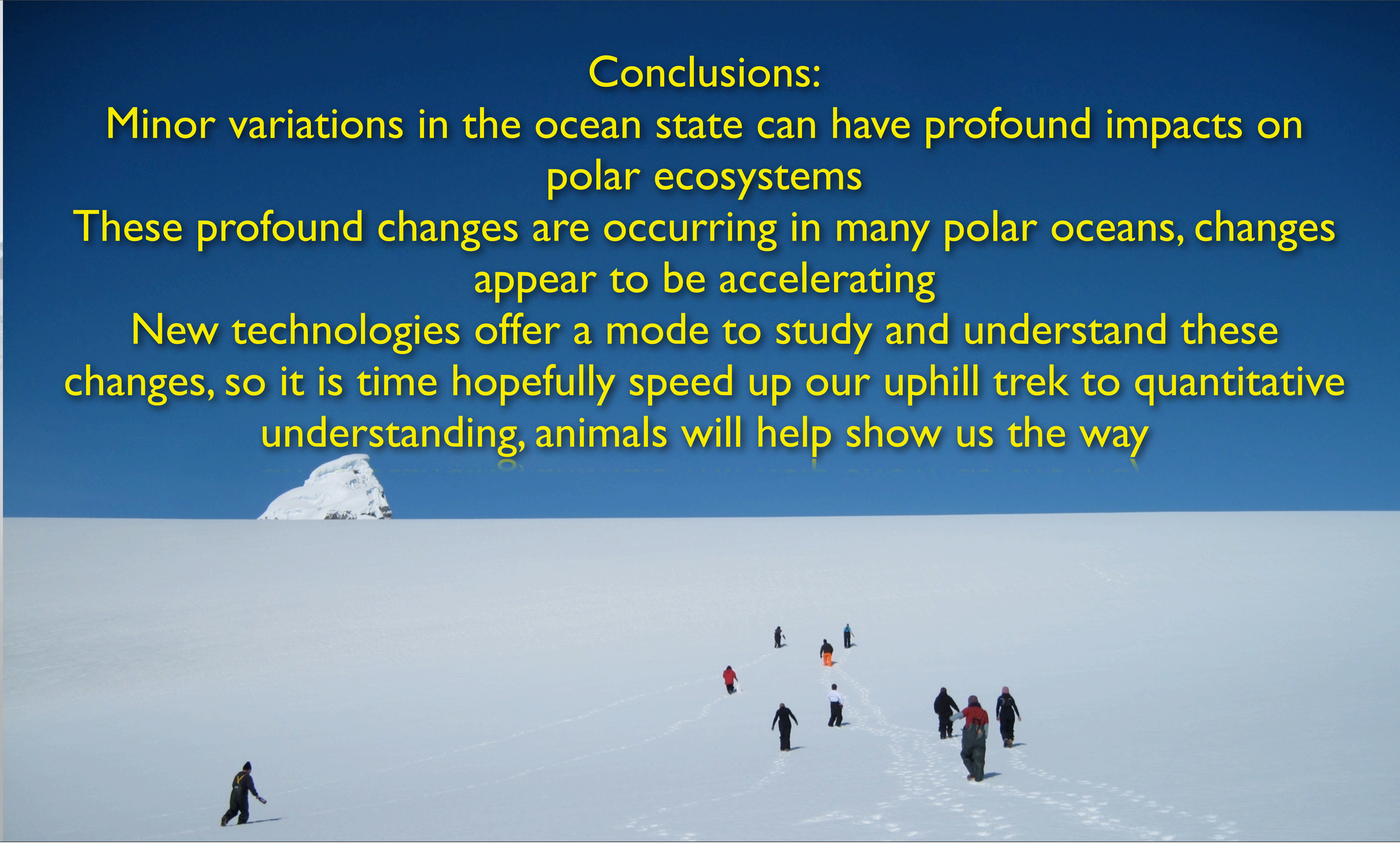


Shifts in water temperatures open up the Antarctic to invasive species





If that was not enough, warmer temps leads to more moisture and more snow. Breeding failure..........


Conclusions:
Minor variations in the ocean state can have profound impacts on polar ecosystems
These profound changes are occurring in many polar oceans, changes appear to be accelerating
New technologies offer a mode to study and understand these changes, so it is time hopefully speed up our uphill trek to quantitative understanding, animals will help show us the way