# Climate mediated changes in phytoplankton productivity and air-sea $CO_2$ exchange on the Western Shelf of the Antarctic Peninsula over the last 30 years

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LTER

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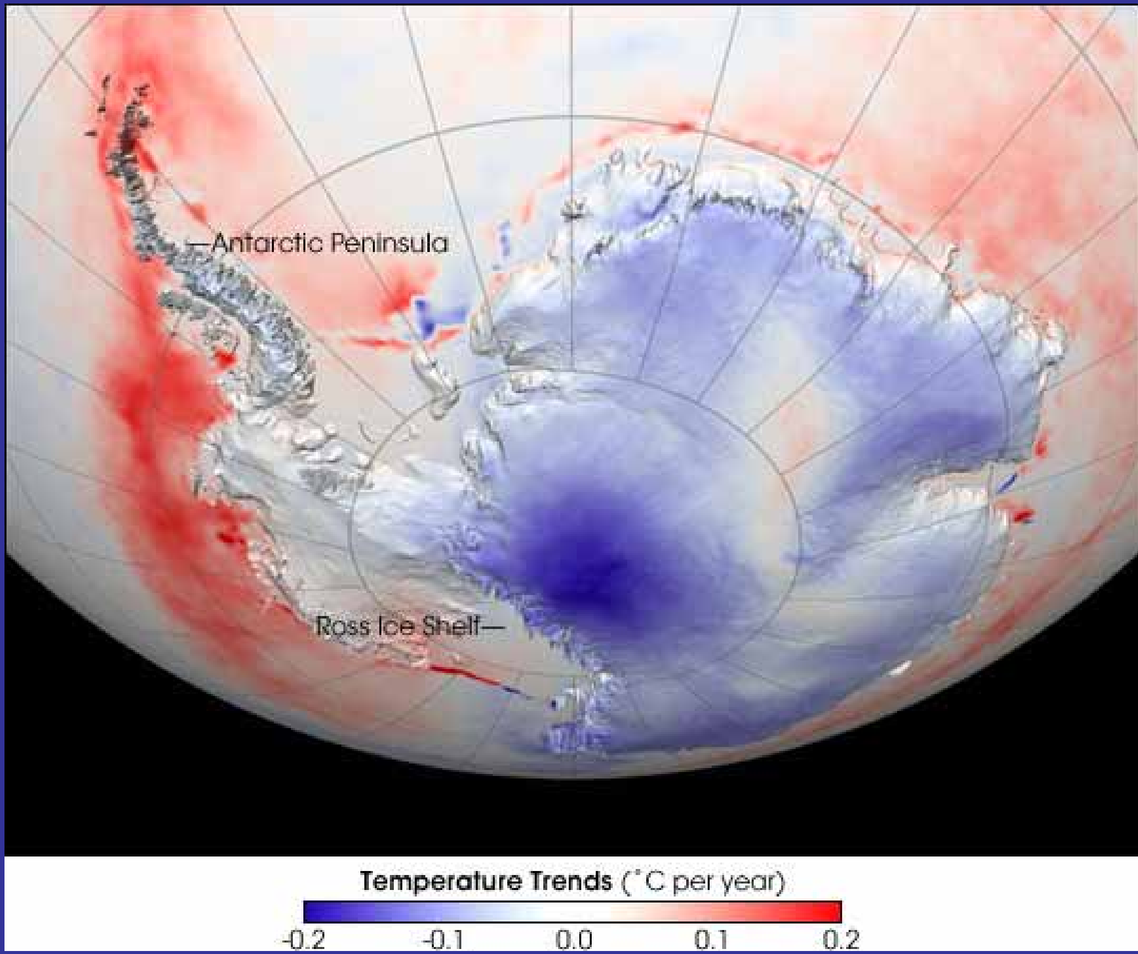
# Bellings is hot these days...

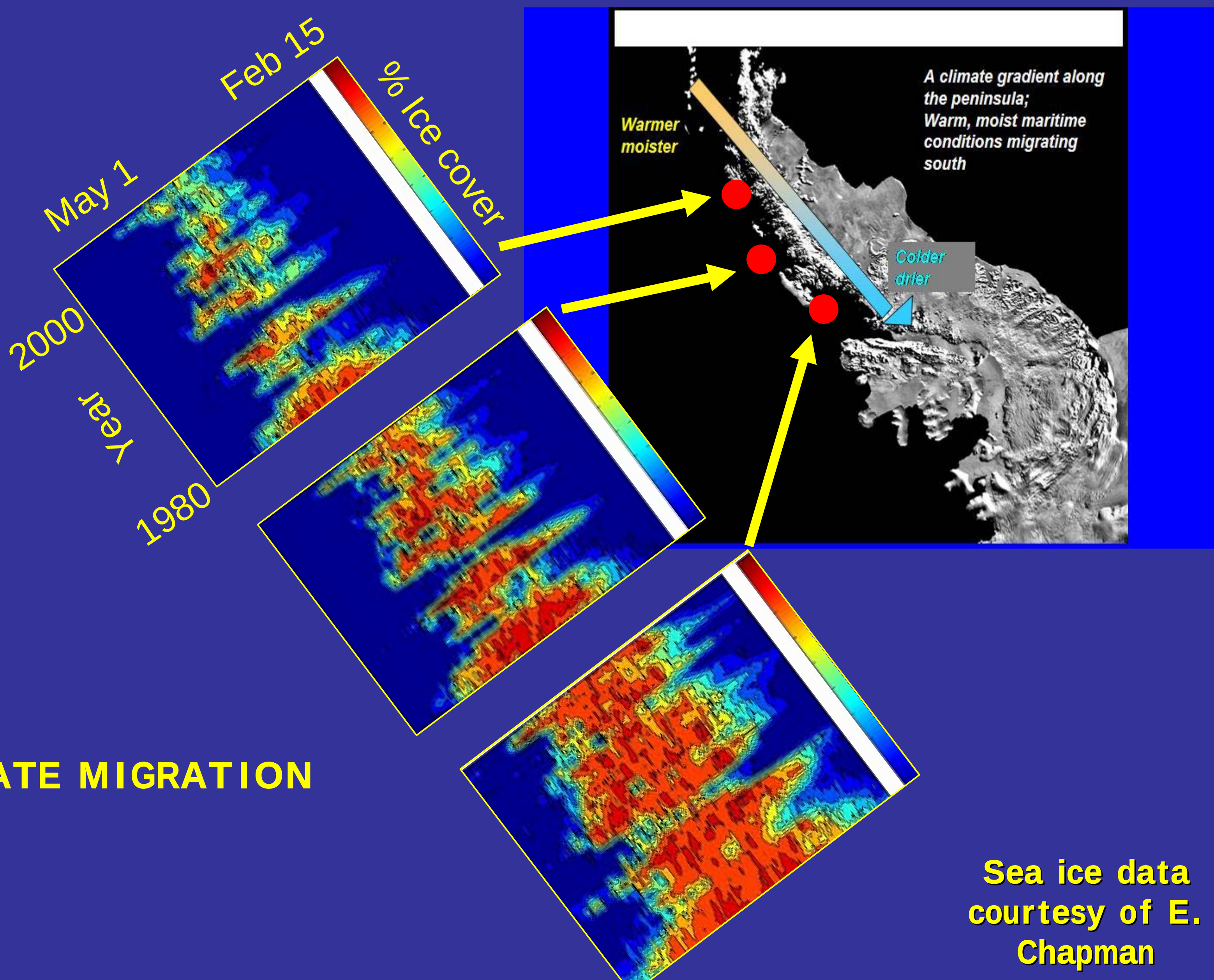
**The climate migration along the Antarctic Peninsula was first detected half-century ago based on air temperatures**

**Smith and Stammerjohn (2001)**




*1980-2004 AVHRR, NASA*

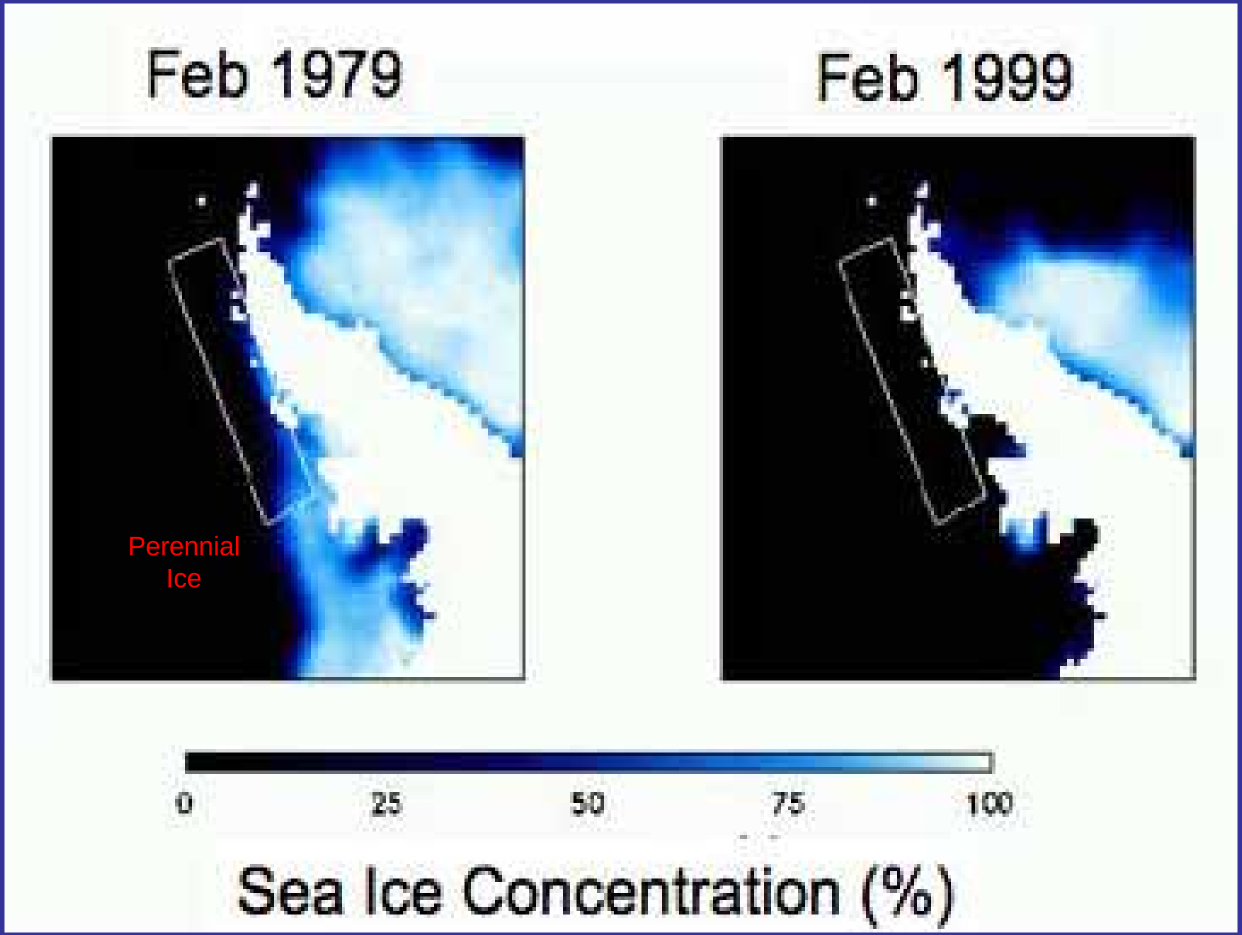
# Seasonal sea ice




**CLIMATE MIGRATION**

**Sea ice data courtesy of E. Chapman**

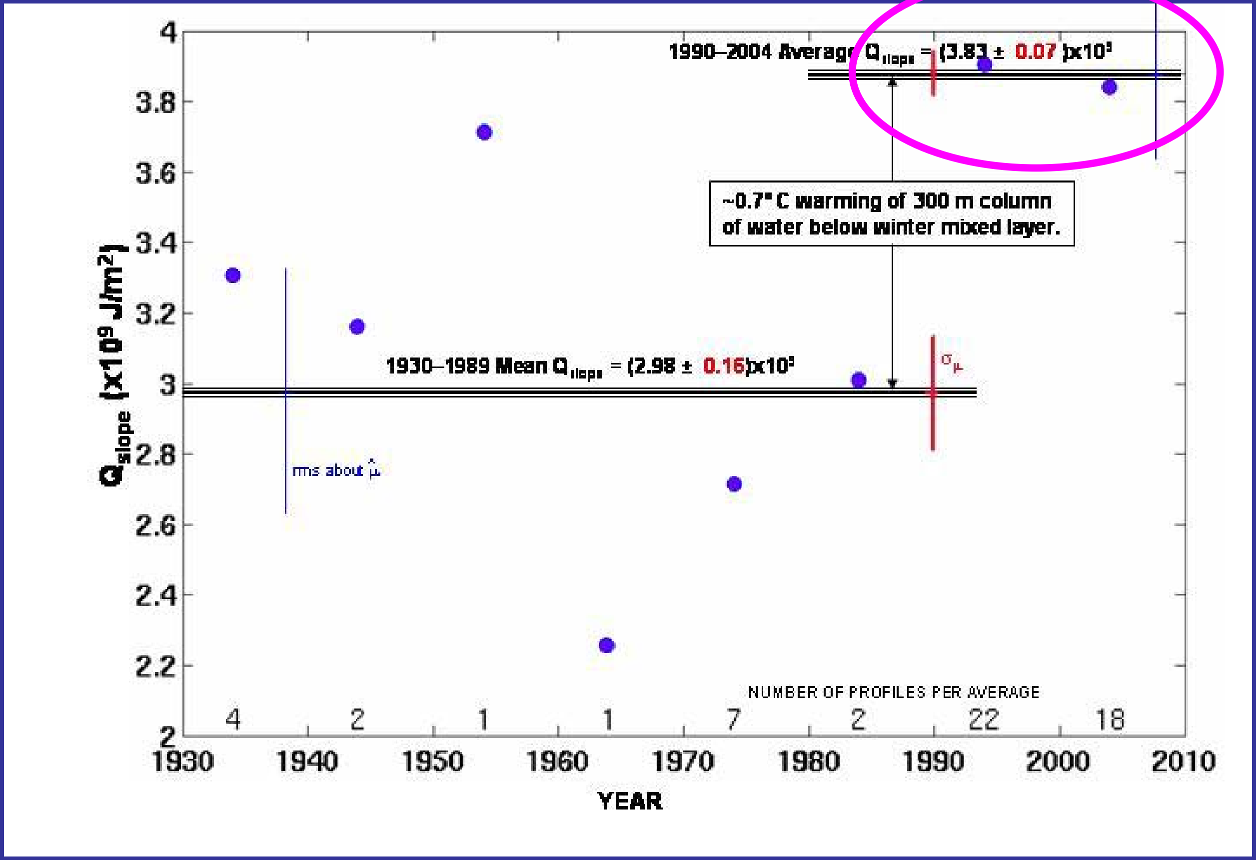
# Perennial sea ice decline




Data Source
NSIDC

# The heating is driven by the deep ocean circulation patterns

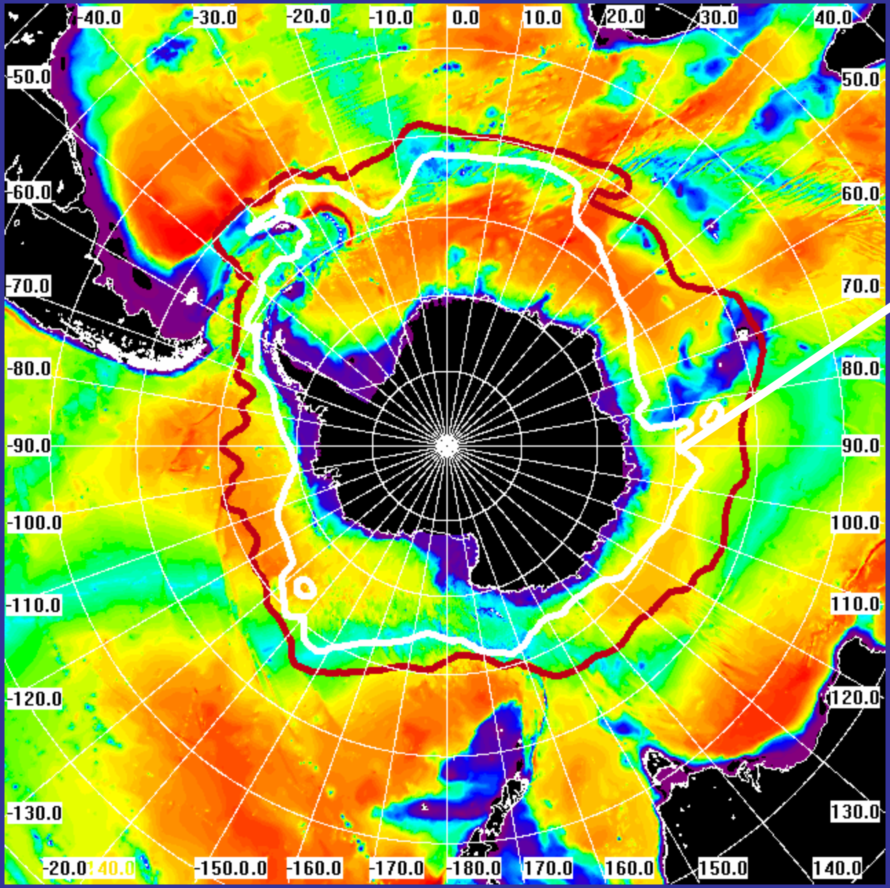
## Big jump in the last decade




Thanks to Doug Martinson et al.

# Biogeochemical response to climate migration

**UCDW intrusions onto the shelf**
**(increase of iron, decrease of oxygen)**




**SACCF**

**CO2 system??**

# Biological response to climate migration

1) Krill/Salp ratio increases as sea ice cover increases (Loeb et al. 1997)

2) Replacement of ice-dependent species by ice-avoiding species (Fraser et al., 2008)

e.g., Adelie by Gentoo penguin,
e.g., Silverfish by Lanterfish

Phytoplankton??

# Objectives

1) To investigate influence of climate on phytoplankton communities along the WAP

2) To quantify impact of long-term phytoplankton variability on air-sea exchange of atmospheric $CO_2$

3) To determine the relative effect of wind stress, sea ice cover and phytoplankton biomass trends on $CO_2$ transference trough the ocean-atmosphere interface

# Hypotheses

**$H_1$ Gradual decline on sea ice cover during the last three decades was accompanied by a reduction on primary productivity due to the absence of MIZ blooms**

**$H_2$ Concomitant modifications on seawater carbonate equilibrium will occur as result of long-term decline on phytoplankton biomass**

# Methods

**Climatologies:**
wind stress, cloud fraction, 'skin' temperature, 2.5 x 2.5° resolution, 1979-2006, NCEP-NCAR (NOAA), PAR SeaWiFS L3 9km resolution, SST-AVHRR 4 km resolution, 1985-2006 (validation skt), NASA, Sea ice concentration-SMMR-SSM/I, 12.5 km resolution, 1978-2006, (NSIDC), MLD, 1998-present, SODA and FNMOC, QuickScat 1999-2006, 2.5 x 2.5 km resolution.

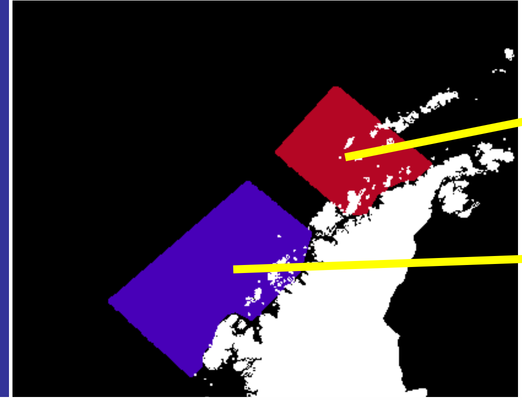
**Pal-LTER datasets:** 1993-2006 DIC, Alkalinity, Chlorophyll a concentration, HPLC markers, S, T, nutrients, 0-20 m depth

**Historical field data (cross validation of Chl changes)** National Oceanographic Data Center, 1978-2006.

**Satellite imagery:** CZCS (1978-1986) and SeaWiFS (1998-2006) L2 GAC 4.5 x 4.5 km resolution

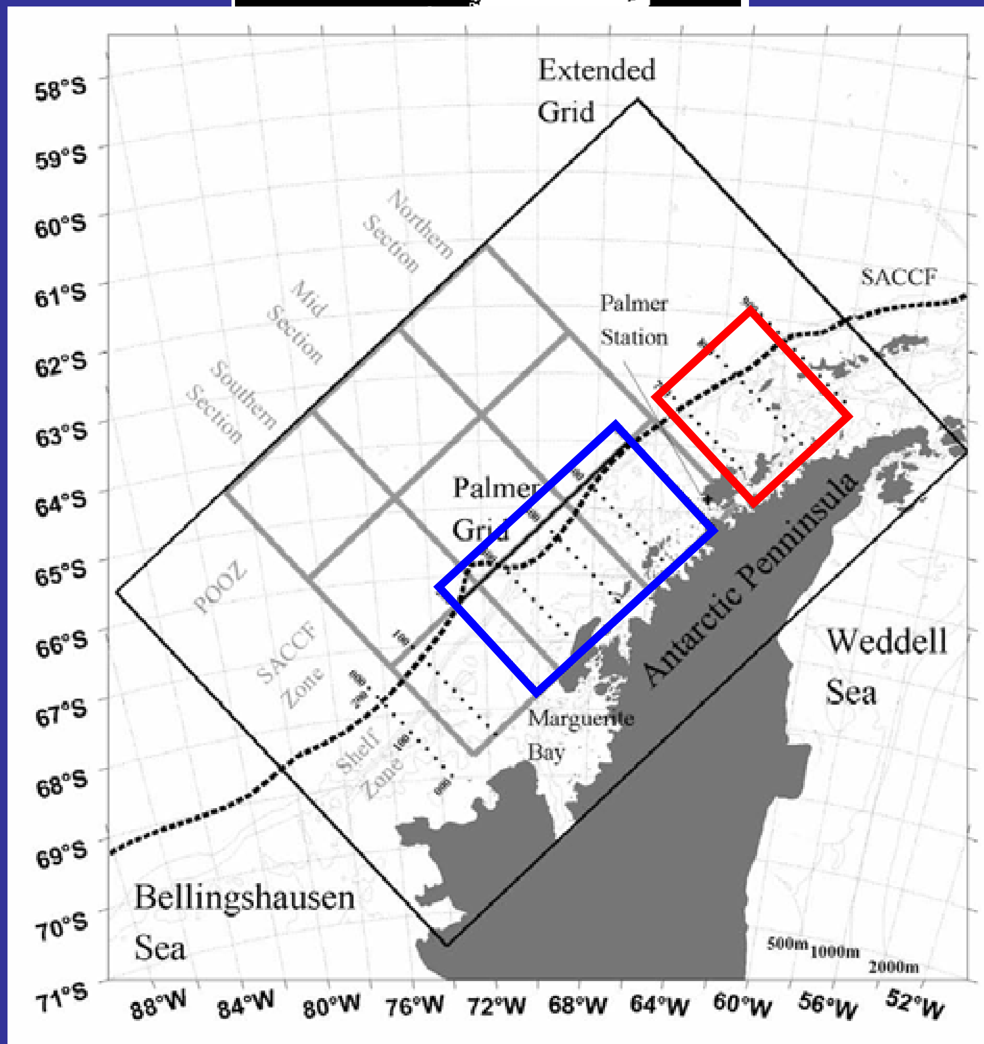
**Spaced-derived Chl a distributions:** Dierssen and Smith (2000), only December to February

**$fCO_2$ calculations:** seawater $pCO_2$ from DIC and Alk, CDIAC code, Alfred Wegener Institute for Polar and Marine Research, atmospheric $pCO_2$ from Jubany Station (1994->), Kw from Liss (1973). NOAA independent dataset to validate Chl- $pCO_2$ relationships

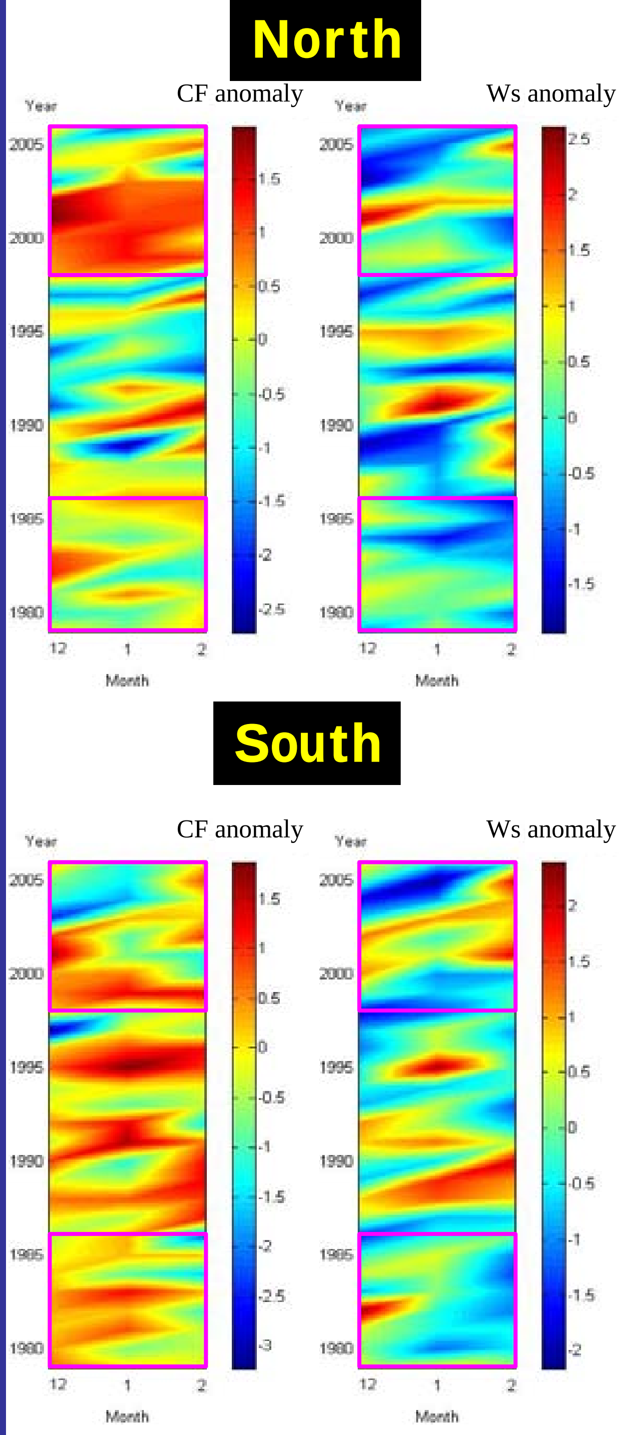


North Grid

South Grid



**Cloudy**

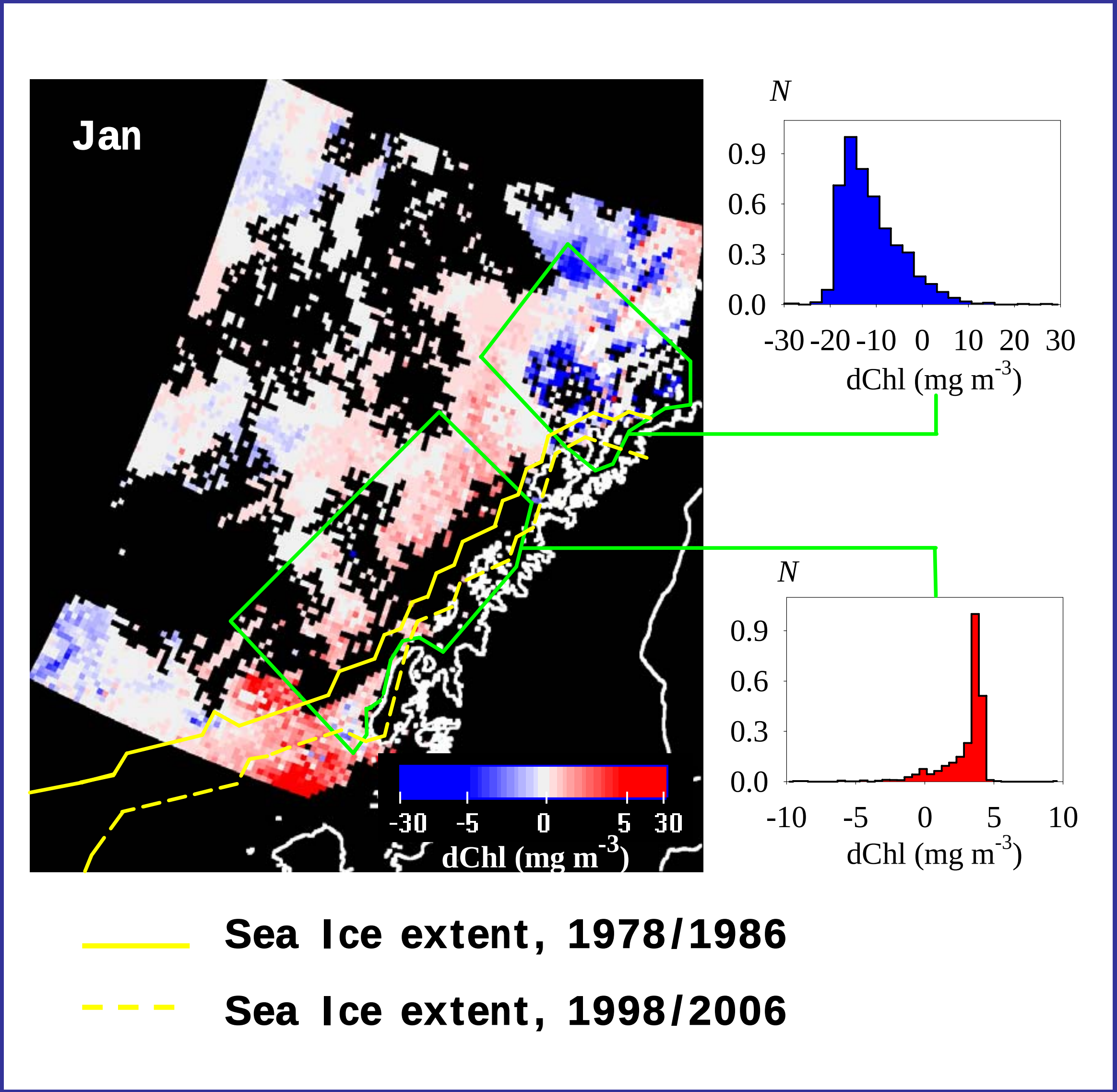



**Windy February**

**Sunny**

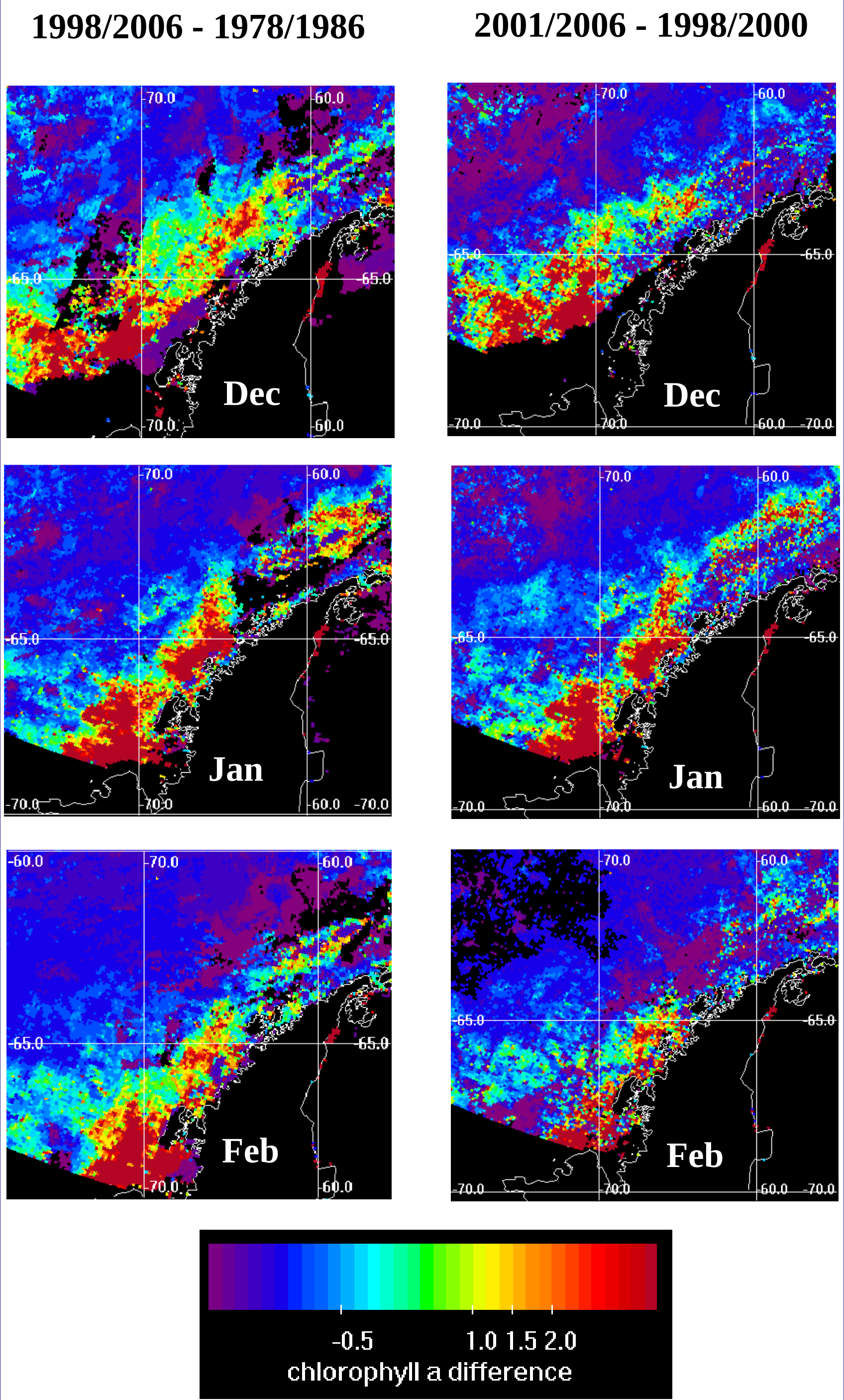
**Windy February**

# dChl = seawifs(1998/2006)-czcs(1978/1986)




North

South




# Pelagic primary productivity is increasing south during summer!!

# Summary of Chl and climate forcing variations between 1978/1986 and 1998/2006

1. A recent 60% relative increase of phytoplankton biomass toward southern waters of WAP

2. An opposite and more drastic trend from 1978 to 2006 on Chl of northern locations (~89% summer average)

3. Overall the phytoplankton biomass over WAP has declined on 12% since 1978

4. Sea ice loss 7.5%, 3-fold greater south

5. Summer skies 5% cloudier north of WAP

6. Early summer skies 5% less cloudiness south of WAP

7. General wind intensification in the late summer and especially in southern locations of BS (2-fold)

# A few key questions

Now we know the origin of greater Chl south of WAP in the last decade (less light limitation)

Also, we have evidence to accept $H_1$: 'Decadal sea ice decline will cause an overall reduction of PP'

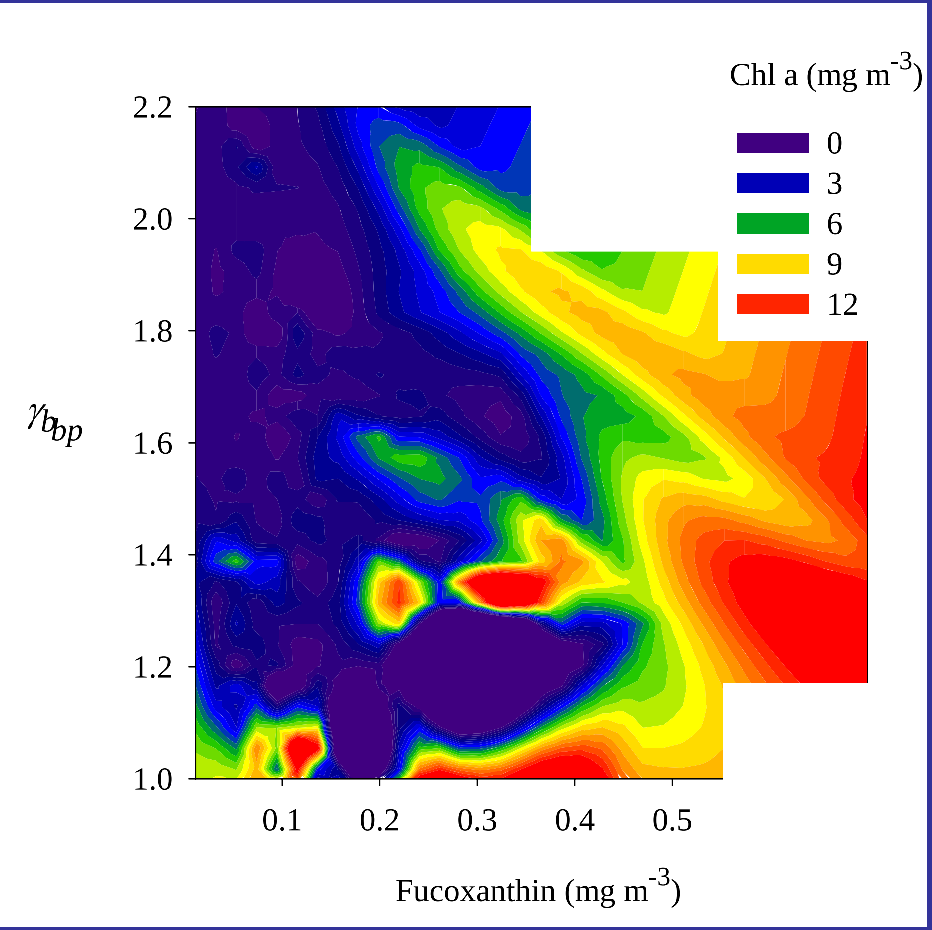
- ❑ Which phytoplankton groups are responsible of southern blooms?

- ❑ How these latitudinal gradients on primary productivity affect biological uptake of $CO_2$ by the ocean

# Largest phytoplankton blooms dominated by **large cells** and **diatom** assemblages

**Diatoms is the main source of 'large' cells in BS**

**Multivariate regressions analysis suggests that Chl over the WAP region is mainly determined by diatoms (~80%)**

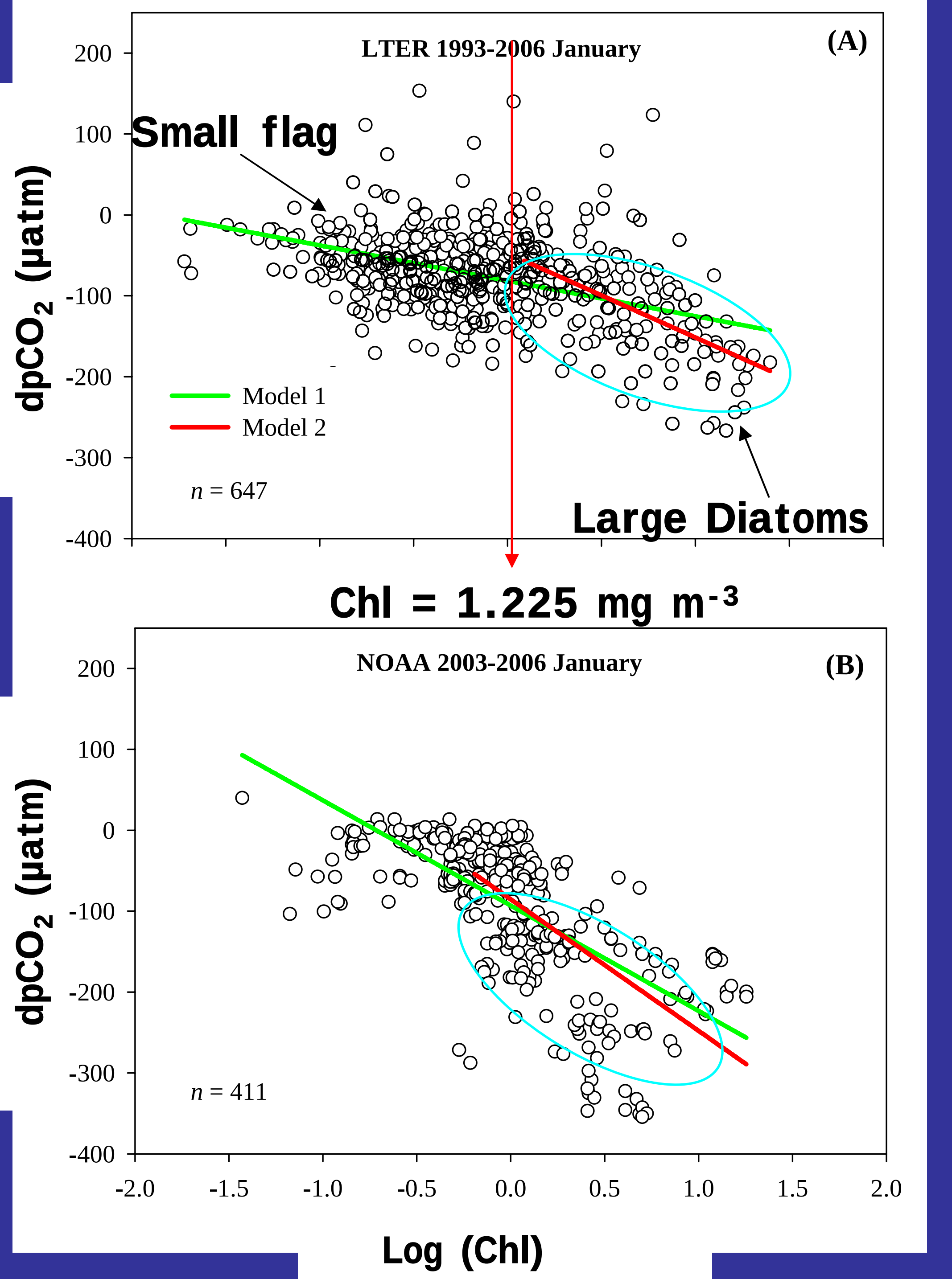


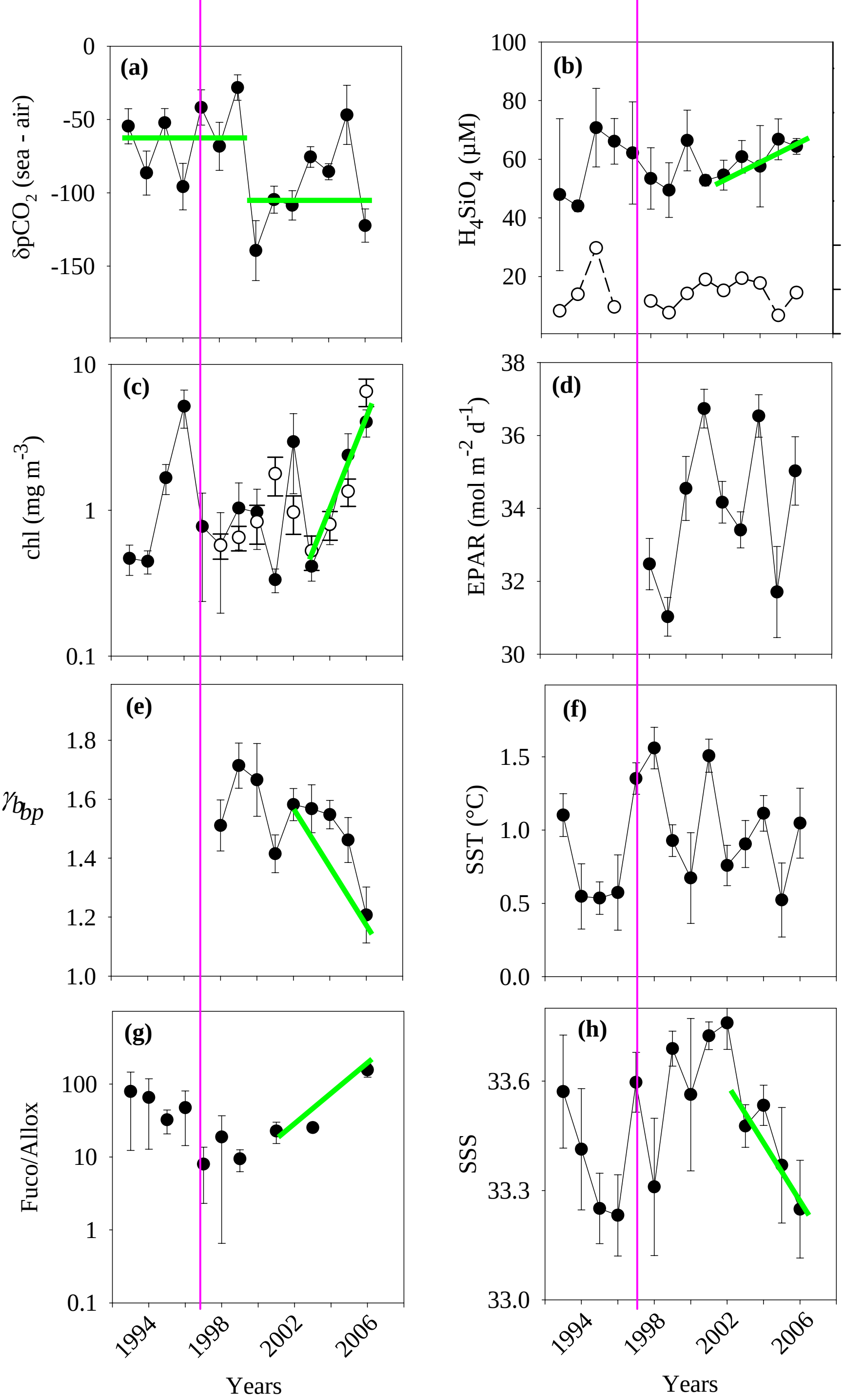

**2001 data not plotted**

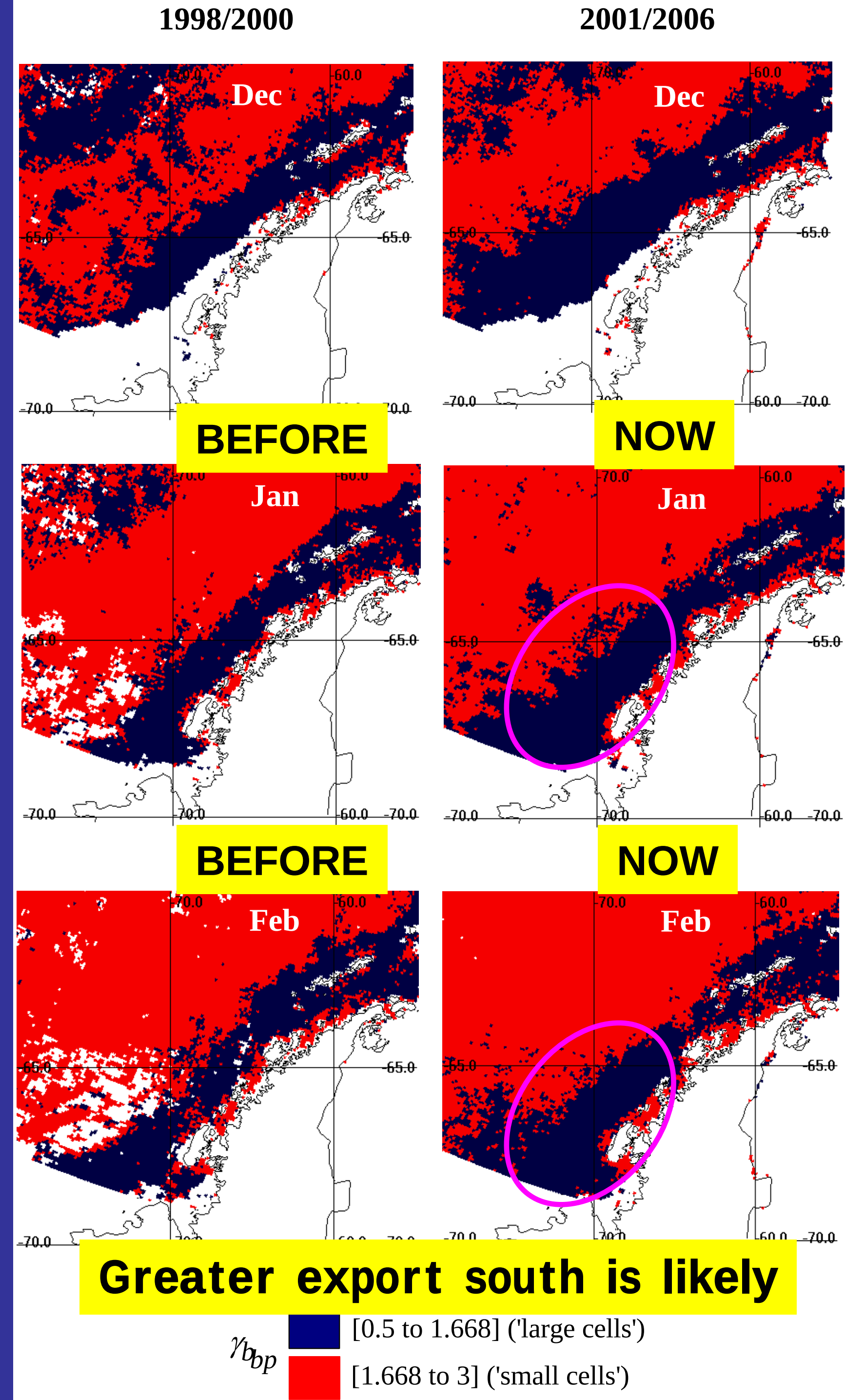
## The greater Chl accumulation the greater $pCO_2$ depletion in surface waters

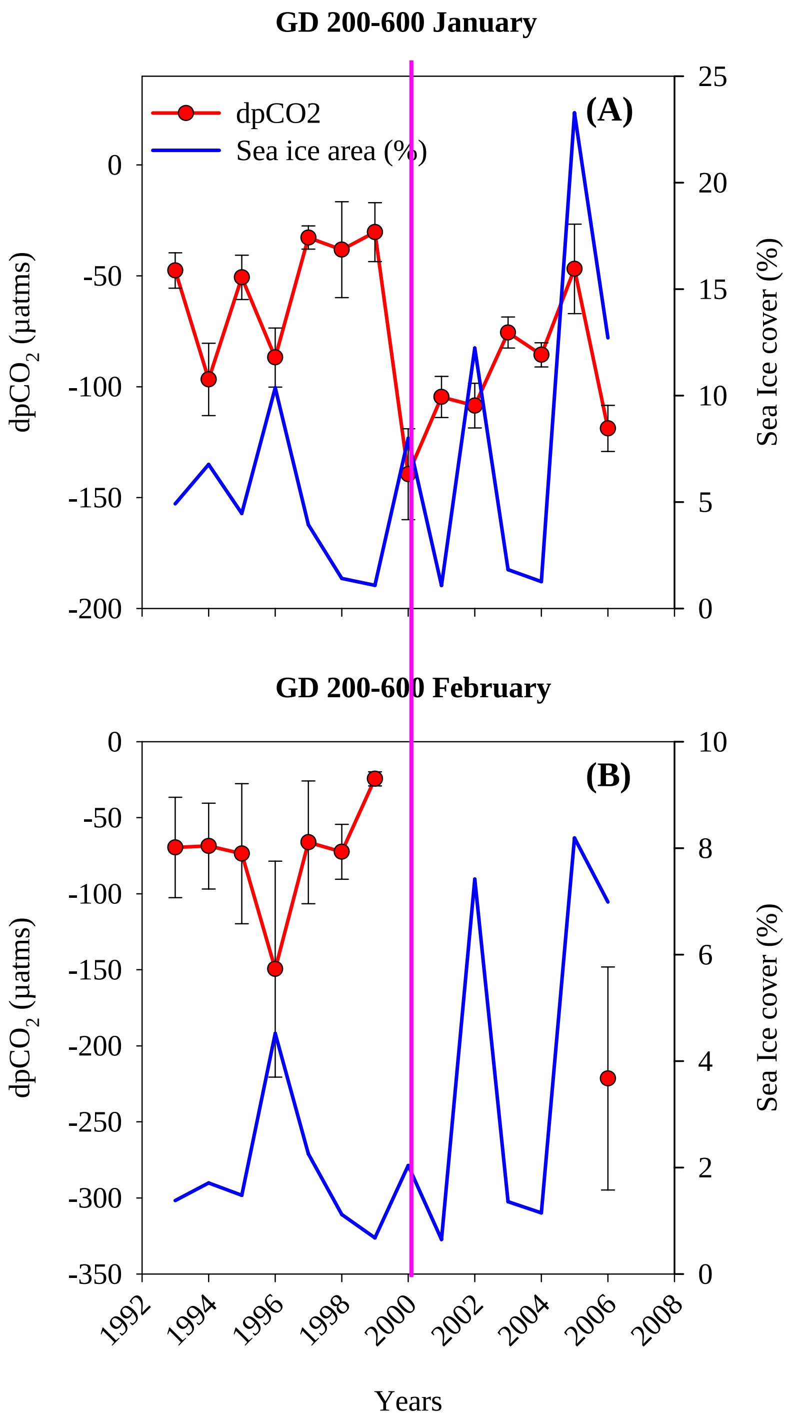
Phytoplankton uptake of dissolved $CO_2$ vary with trophic status (>2-fold change on slope)

$dpCO_2$ variations for 1993-2006 were more sensitive to Diatoms abundance




(a)
δpCO2 (sea - air)
(b)
H4SiO4 (μM)
N/P
(c)
chl (mg m-3)
(d)
EPAR (mol m-2 d-1)
(e)
γbbp
(f)
SST (°C)
(g)
Fuco/Allox
(h)
SSS
1994
1998
2002
2006
Years


1998/2000
2001/2006
Dec
Jan
Feb
BEFORE
NOW
BEFORE
NOW
Greater export south is likely
γbbp
[0.5 to 1.668] ('large cells')
[1.668 to 3] ('small cells')



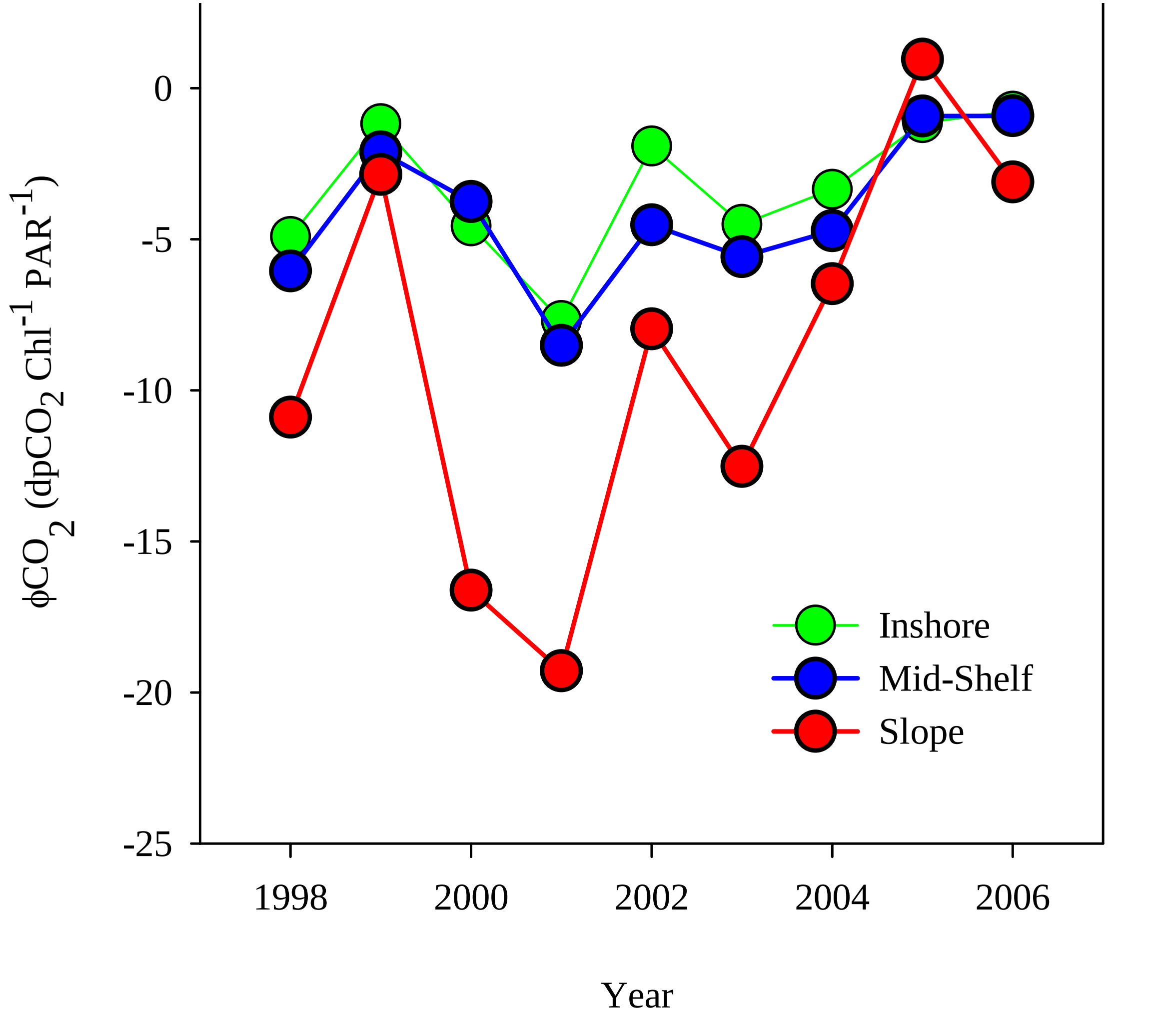

# Sea ice and $DpCO_2$

Before 2000 more ice favors 'sink'

After 1999 dual response of $dpCO_2$ as a function of summer sea ice cover

# Oceanic phytoplankton more efficient to uptake $CO_2$ than coastal phytoplankton!!

**$\phi CO_2$ = mole C/[mole Chl a x mol photons in one day]**



# Budgets of $dpCO_2$, Chl, and $fCO_2$ for WAP

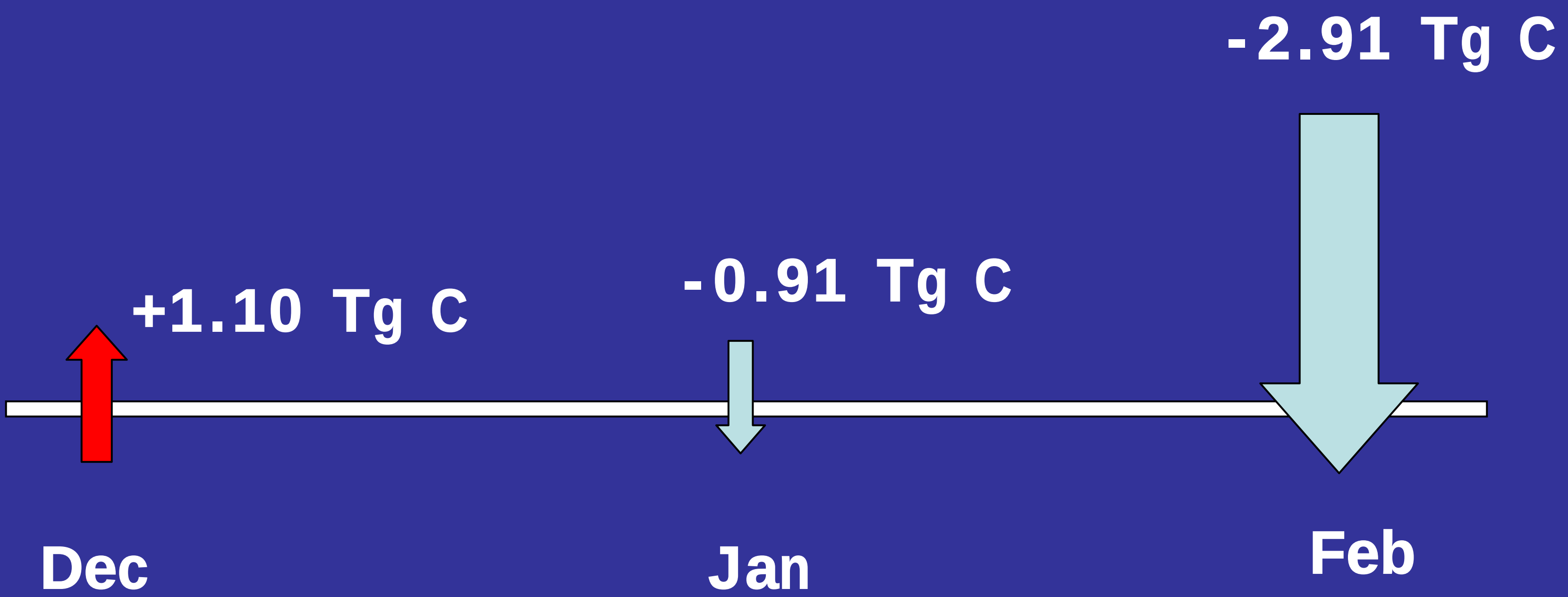
Δ = 1978/1986->1998/2006

Sink Source Increase Decrease

| | | ΔChl | $\Delta dpCO_2$ | $\Delta fCO_2$ |
|---|---|---|---|---|
| North | Dec | -1.36 ↓ | +6.68 ↑ | +2.52 ↑ |
| | Jan | -5.43 ↓ | +46.2 ↑ | -0.66 ↓ |
| | Feb | -2.12 ↓ | +21.4 ↑ | -3.02 ↓ |
| | | | | |
| South | Dec | +1.25 ↑ | -1.22 ↓ | -0.32 ↓ |
| | Jan | +0.49 ↑ | -0.92 ↓ | -1.16 ↓ |
| | Feb | +0.02 ↑ | +16.3 ↑ | -3.18 ↓ |

# Cilmate migration and net summer $fCO_2$ in BS

$\Delta_{(1978/1986-1998/2006)}$



# In the global context

**WAP surface area (north+south GD) is 3.22% BS**

**BS is 0.8% of ocean surface area**

**BS uptake ($\Delta FCO_2$) is -0.91 Tg C $y^{-1}$ (mean summer)**

**0.04% of yearly ocean uptake (2.5 Gigaton C)**

**C injected to the atmosphere: 6.1 Gigaton C $y^{-1}$**

**C injected 1978-2006: 170.8 Gigaton C $y^{-1}$**

**Note: 1 Gigaton C = $10^{15}$ g C = $10^{3}$ Tg C**

**Global Trend = 1.4 ppm $CO_2$ $y^{-1}$**

# Summary of Results so far…

1) **We accept $H_2$** since we found a quantitative change on $dpCO_2$ due to Chl enrichment

2) We put in evidence different phytoplankton $CO_2$ uptake kinetics in eutrophic vs oligo/mesotrophic waters

3) Greater $CO_2$ sink associated with Chl accumulation above ~1 mg $m^{-3}$ and dominance of large diatoms. Diatom dominance was more connected with ecological differences (e.g., lower grazing) and not with physiological advantages

4) Based on LTER data, synchronicity between MIZ blooms and sea ice timing changed after year 2000. However, $CO_2$ invasion into the ocean was accelerated due to greater frequency of massive phytoplankton blooms (Chl> 5 mg $m^{-3}$) dominated by large (>20 µm) diatoms to the south of BS

# Take home message

WAP and BS are under an ongoing transformation that is affecting climate modes and biological response to increasing atmospheric $CO_2$

This is the first report showing large scale variations on Chl and $fCO_2$ along a latitudinal gradient in BS since 1978

LTER data since 1993 is consistent with a 20.5% undersaturation of $CO_2$ in surface waters of WAP

Combined satellite imagery since 1978 revealed opposite regional trends on Chl as a function of latitude and a greater 'sink' of atmospheric $CO_2$ in the southern part of BS in the last decade due to more illuminated waters

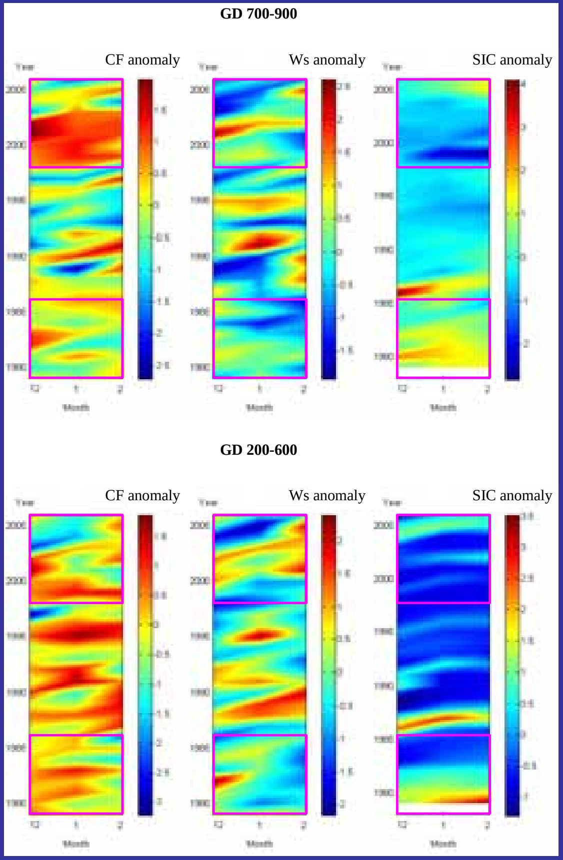
# Take home message

In the process of converting WAP into a sub-Antarctic ecosystem overall Chl has declined but the $CO_2$ sink (negative $fCO_2$) has been amplified in 100% as result of more windy conditions and sea ice loss to the south of BS

The estimated three decadal increase on air to sea ‘pumping’ of atmospheric $CO_2$ over BS was relatively modest compared to annual intake by the oceans and yearly anthropogenic input to the atmosphere

# Thanks!!


**A new beach resort?**


GD 700-900
CF anomaly
Ws anomaly
SIC anomaly
GD 200-600
CF anomaly
Ws anomaly
SIC anomaly