Melting ice, primary production, and particle export in the Southern Ocean- what's the connection?

Ken O. Buesseler

Much of today's talk taken from:

"The effect of marginal ice-edge dynamics on production and export in the Southern Ocean along 170° W" submitted Oct. 2001 to DSRII

Co-authors include: R.T. Barber, M-L Dickson, M.R. Hiscock, J.K. Moore, R. Sambrotto

Funding: NSF & DOE

Collaborators: US JGOFS & SOFeX

Thanks to:

Outline

- Southern Ocean: background

- Synthesis US JGOFS Antarctic Environment and Southern Ocean Process Study (AESOPS)
  - 4 cruise summary- 1997/1998
  - Satellite data 170° W
  - Seasonal extrapolations
  - Controls on So. Ocean blooms
  - Role of iron

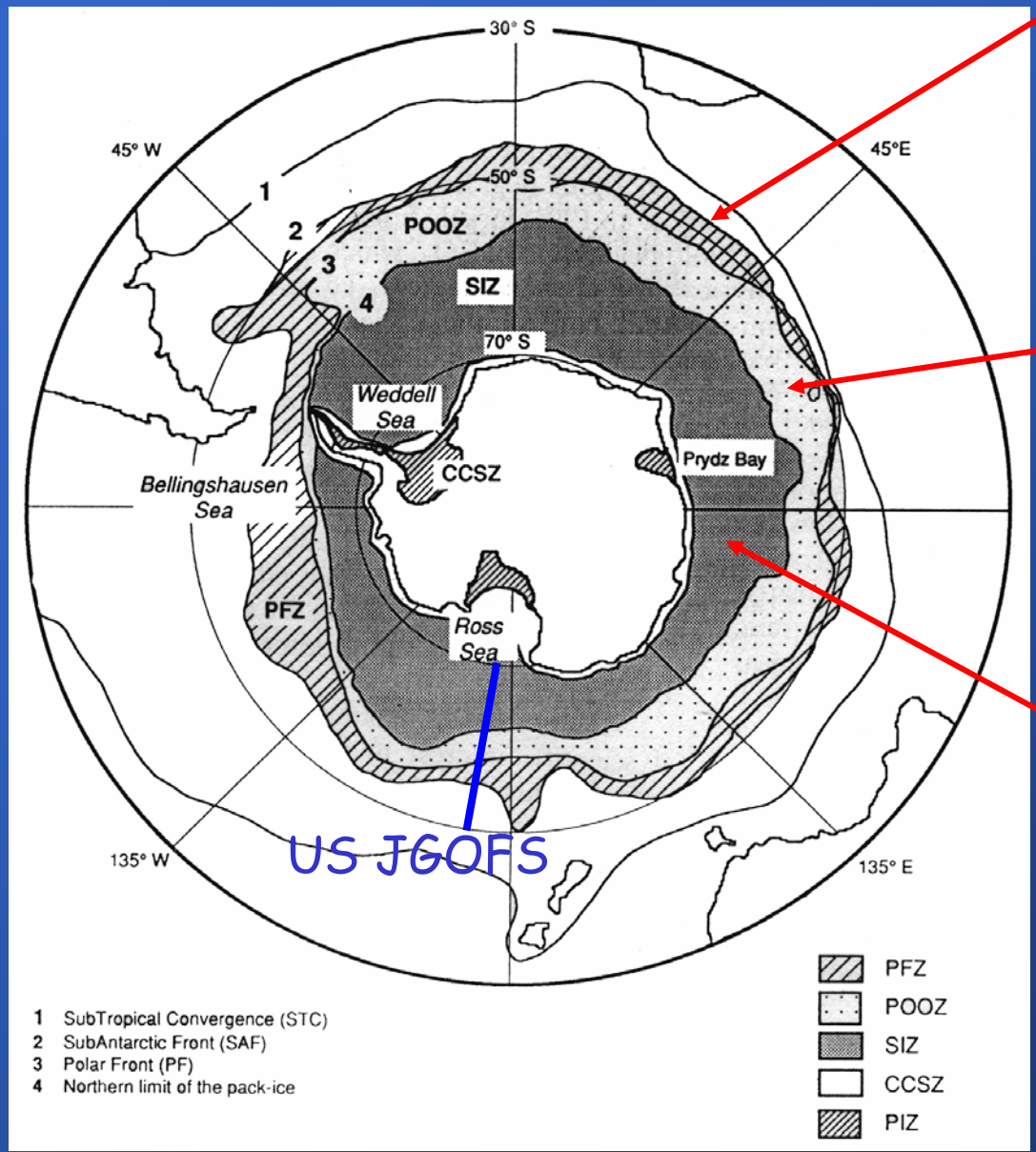
- SOFeX- Southern Ocean Iron Experiment (Jan./Feb. 2002)

Southern Ocean – who cares?

- Largest HNLC region in the world
- Major site of deep & intermediate water formation
- Controls on paleo climate
  - regulate atmospheric CO_2 via biological pump?
- Opal "paradox"

  - does enhanced preservation or flux of bSi lead to high sediment Si in the "opal belt"?

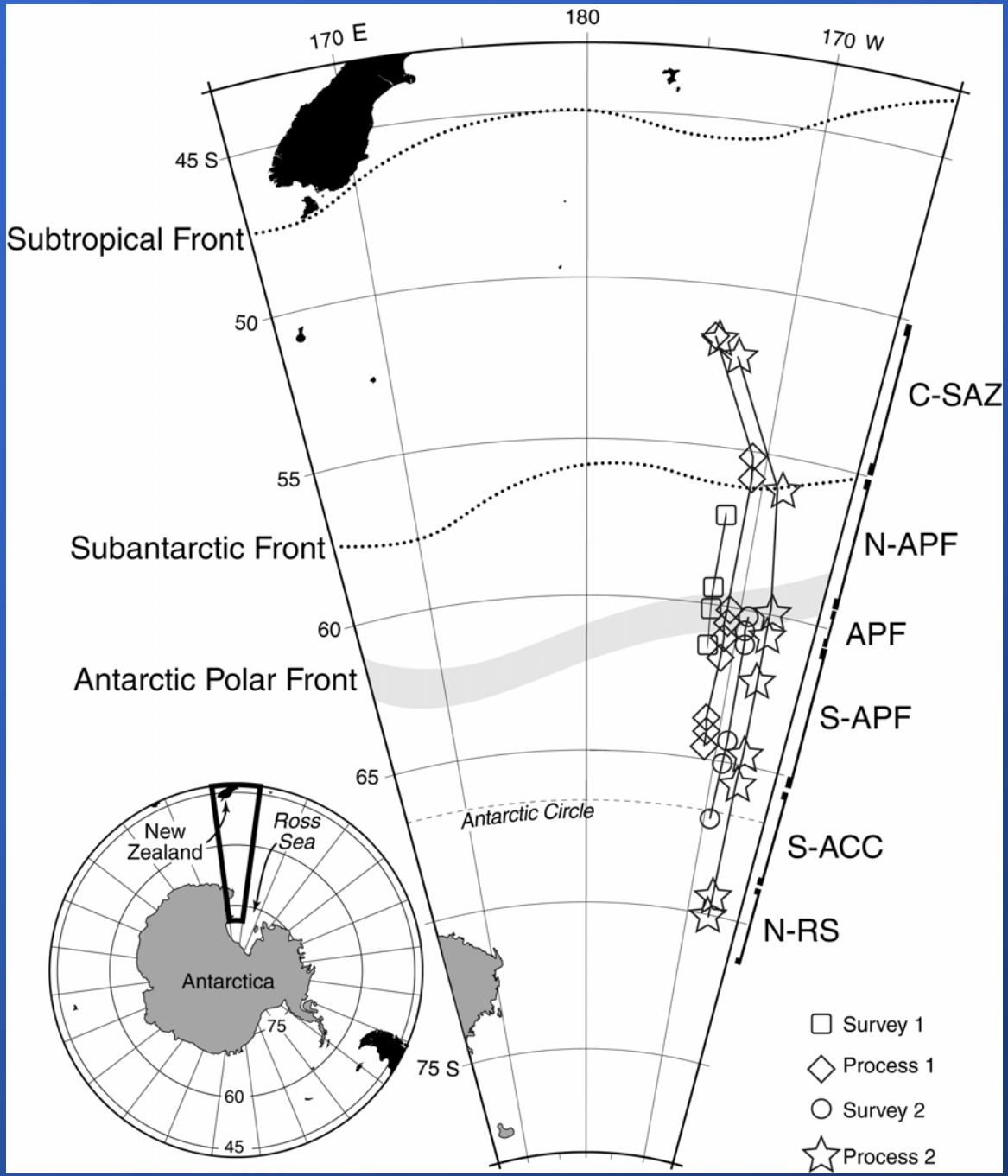
Southern Ocean



- PFZ = Polar Frontal Zone
  (boundary where N-flowing waters sink; strong Δtemp)
- POOZ = Permanently Open Ocean Zone

  (varies in extent- narrow along 170° W)
- SIZ = Seasonal Ice Zone

  (area = Antarctic continent; short growth season; melt water effects)



Antarctic Environment and Southern Ocean Process Study (AESOPS)

- 4 cruises: Oct. '97 – Mar. '98 along 170° W

50-55°S: Central Subantarctic Zone

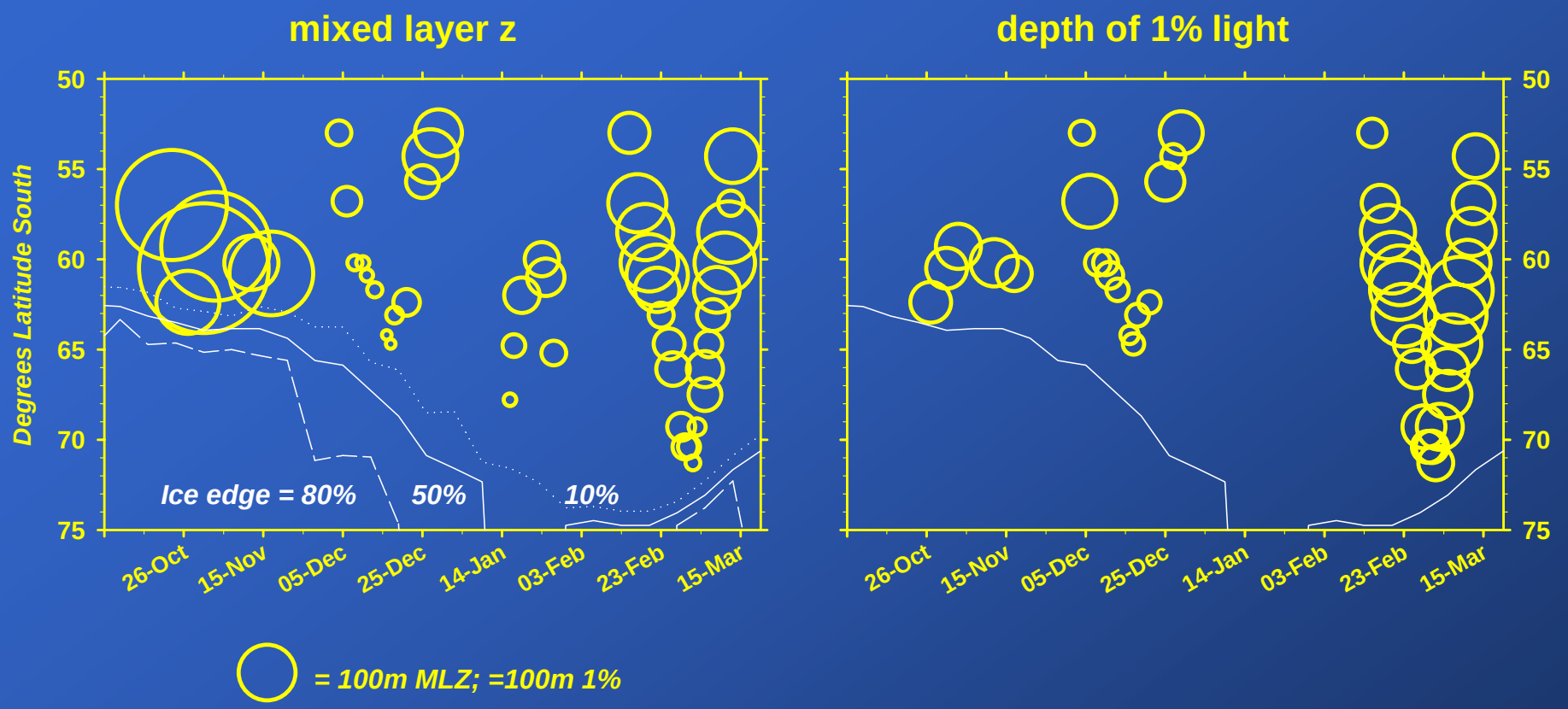
55-59°S: North of Antarctic Polar Front

59–61.5°S: Antarctic Polar Front

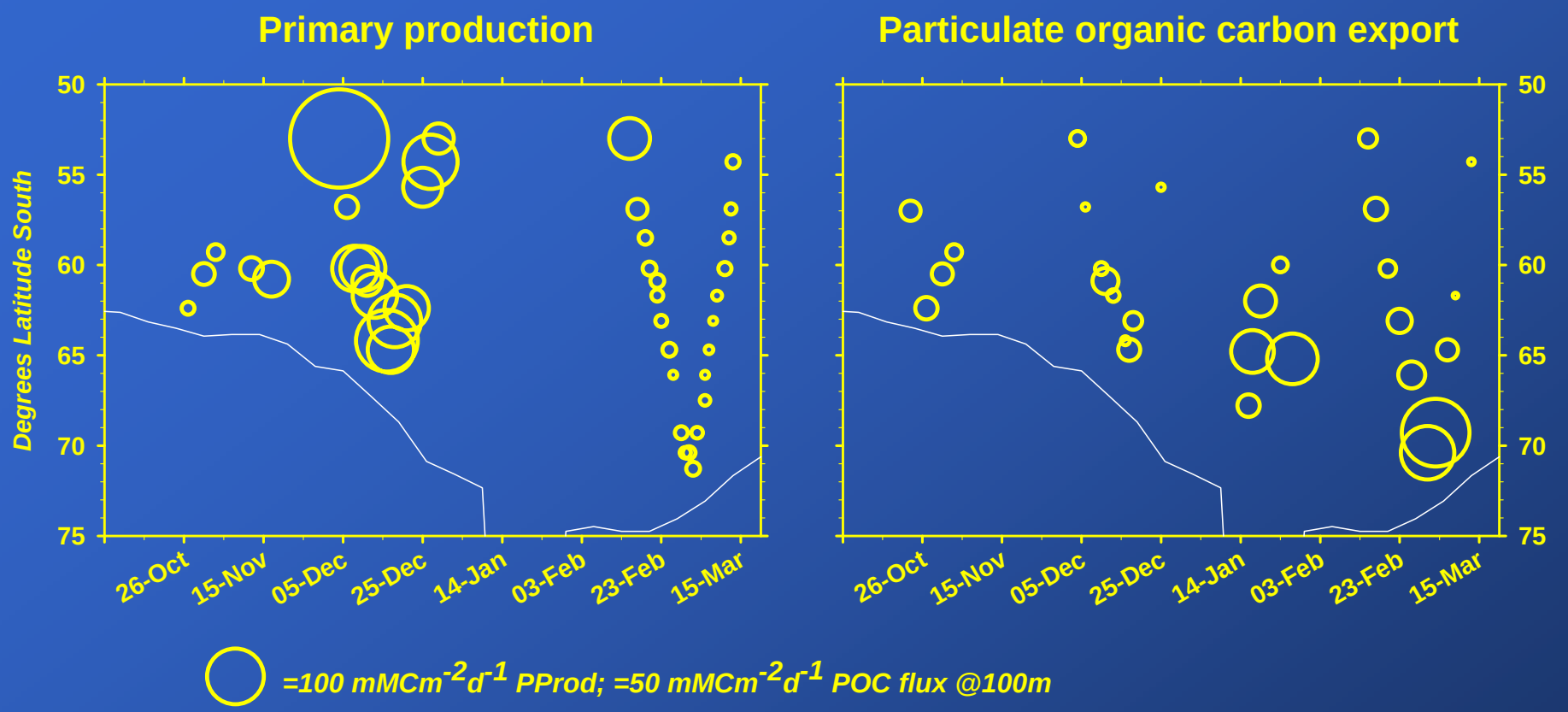
61.5-65.5°S: South of Antarctic Polar Front

65.5-68°S: South of Antarctic Circumpolar Current

68-72°S: North of Ross Sea



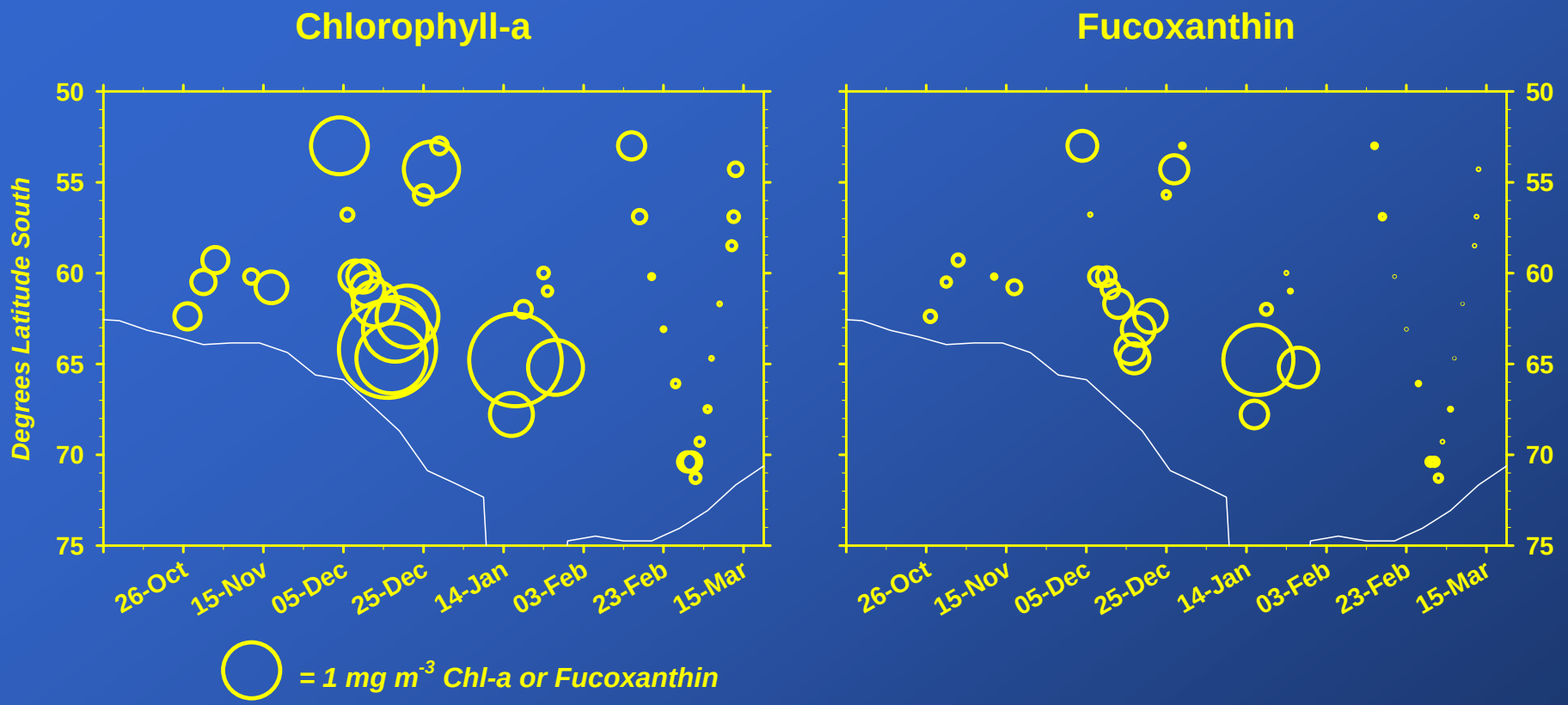
- Deep winter mixed layers
- Ice retreat from 62 to >72° S leads to rapid shoaling of MLZ w/spring warming & low salinity melt waters
- North of 59° S, deeper mixed layers return earlier
- 1%/MLZ <1 = light limits in Oct/Nov and north of 59° S



- Primary Production highest in December all latitudes
- No Prim Prod work in Jan/Feb

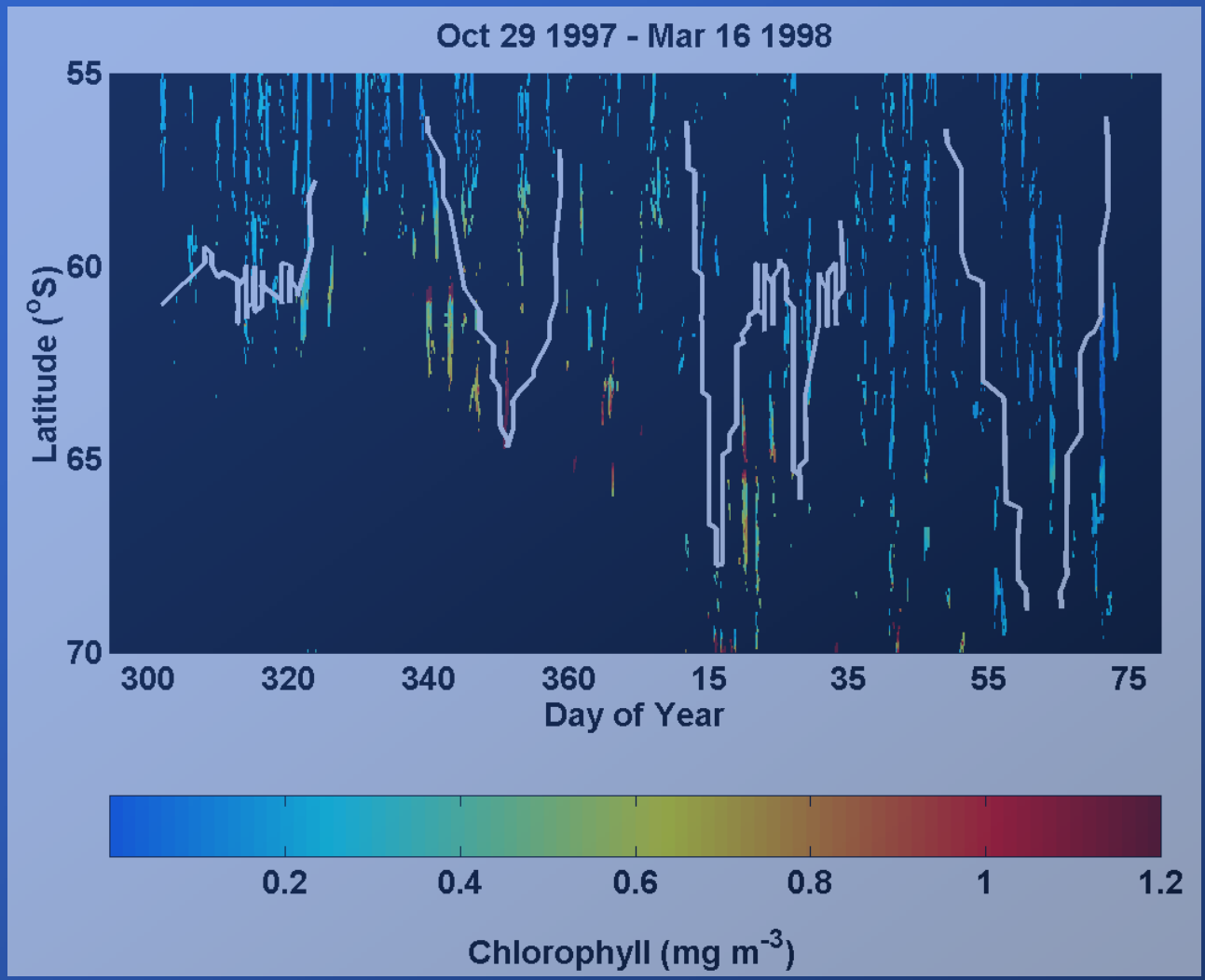
  & very low Prim Prod in Feb/Mar
- POC flux increases Jan/Feb 60-65° S

  and Feb/Mar 65-72° S



- Chlorophyll-a highest at all latitudes in Dec. and 63 – 67° S in Jan/Feb
- Lowest Chl in Feb/Mar
- Fucoxanthin diatom pigments high Dec. 60-65° S and highest 65° S in Jan/Feb

AESOPS- first JGOFS Process study during SeaWiFS

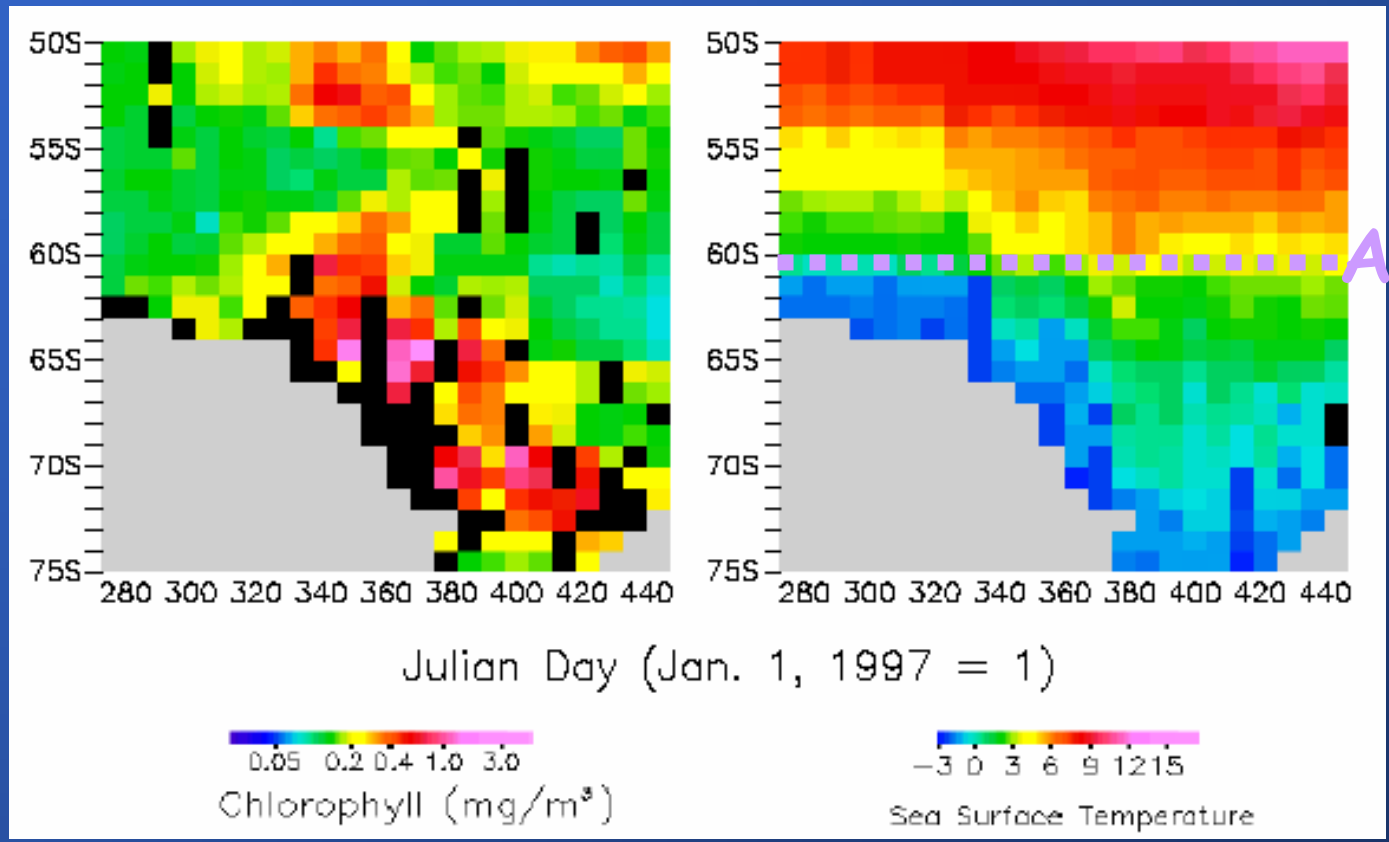


- Satellite ocean color ~ chlorophyll
- So. Ocean is cloudy (black area) and ice covered (black lower left region)
- So. Ocean has low chlorophyll in general
- Cruise tracks (white lines) catch only small portion of high chlorophyll regions

Fig. from Landry et al.

Satellite data binned by week and 1 degree latitude along 169-171° W

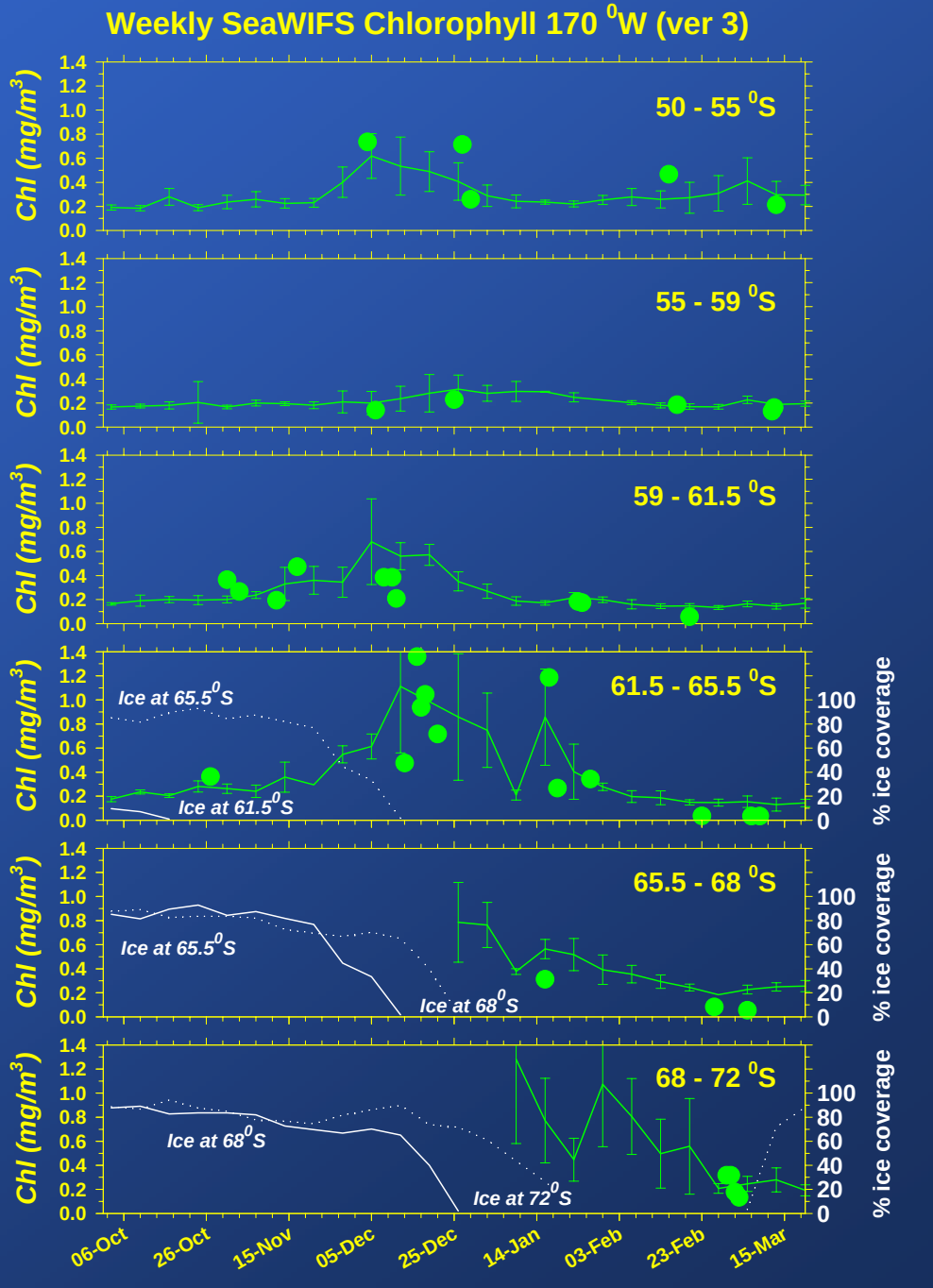
- Melt waters along ice edge (gray) show lowest temp & highest Chl.



- So. Ocean blooms associated with retreating ice edge and not Polar Front

Use satellite color to extend ship's data in space and time

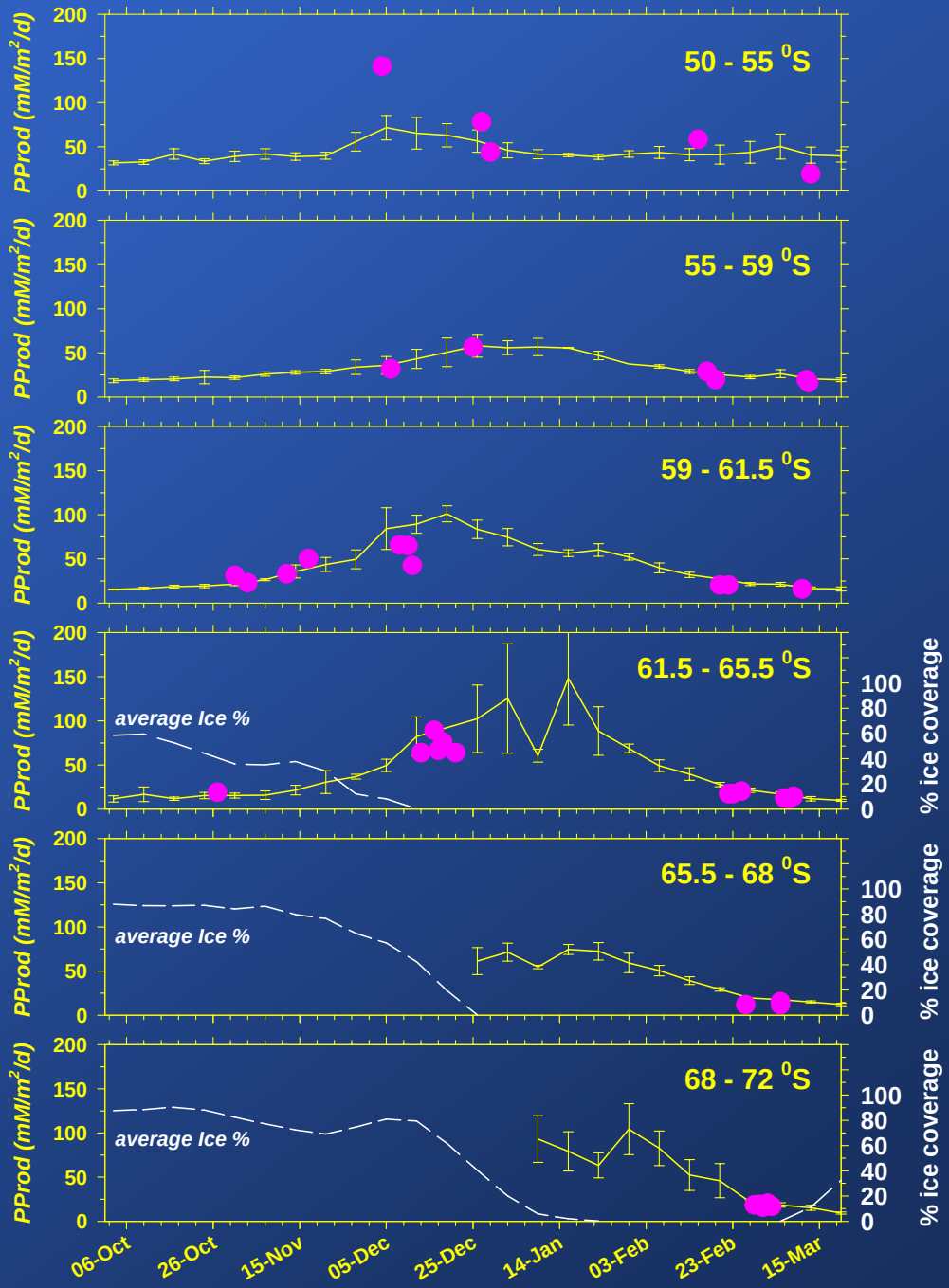
- Compile data along latitude bins
- Weekly satellite data shown as line w/variability
- Comparison to surface Chl. good
- Note high Chl. follows ice retreat



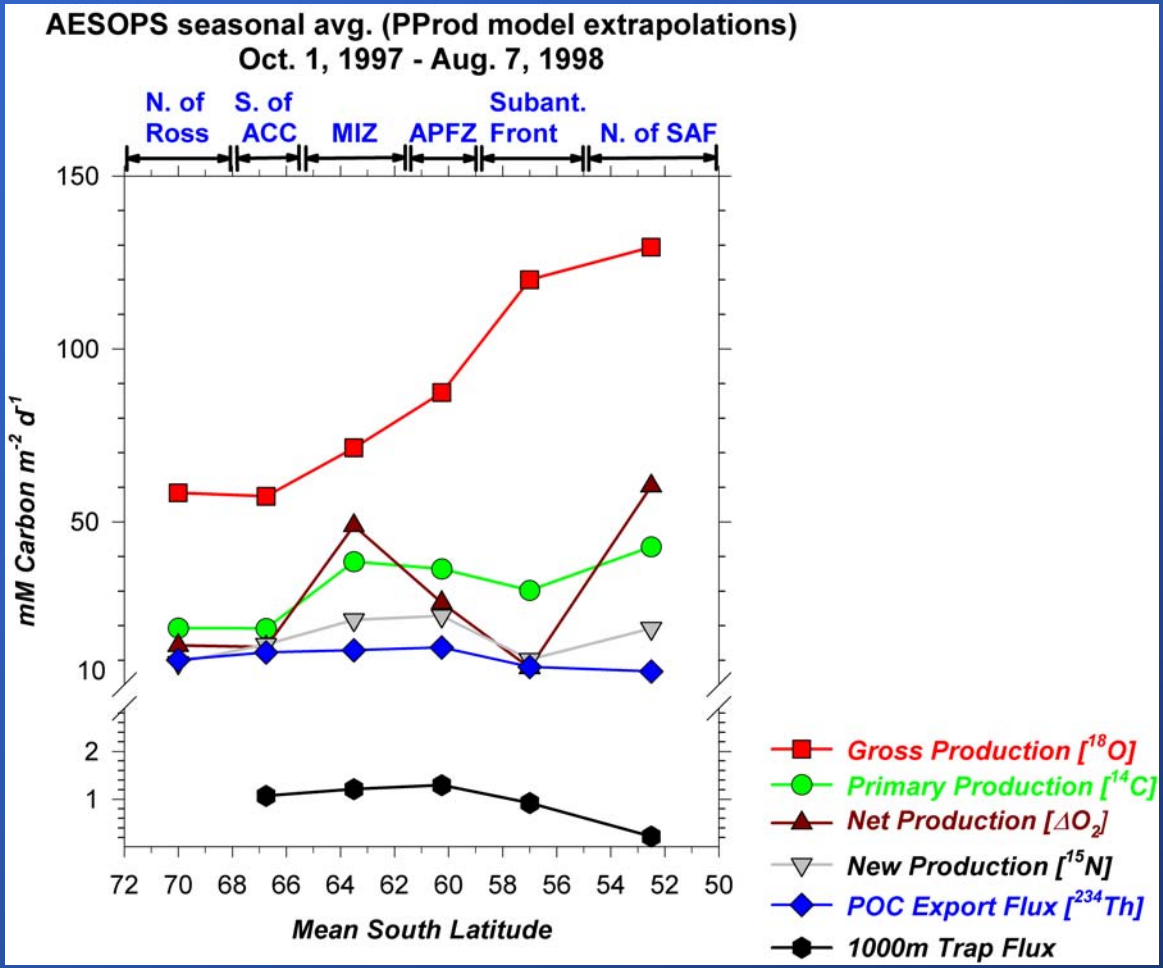
Calculate seasonal PProd

(Behrenfeld & Falkowski)

- Need Chl, photo period, irradiance, depth of 1%, P^Bopt
- Measured and calculated PProd agree
- See 2x higher PProd than "traditional" B&F would predict- higher P^Bopt used here
- Missed SIZ bloom peaks on ship



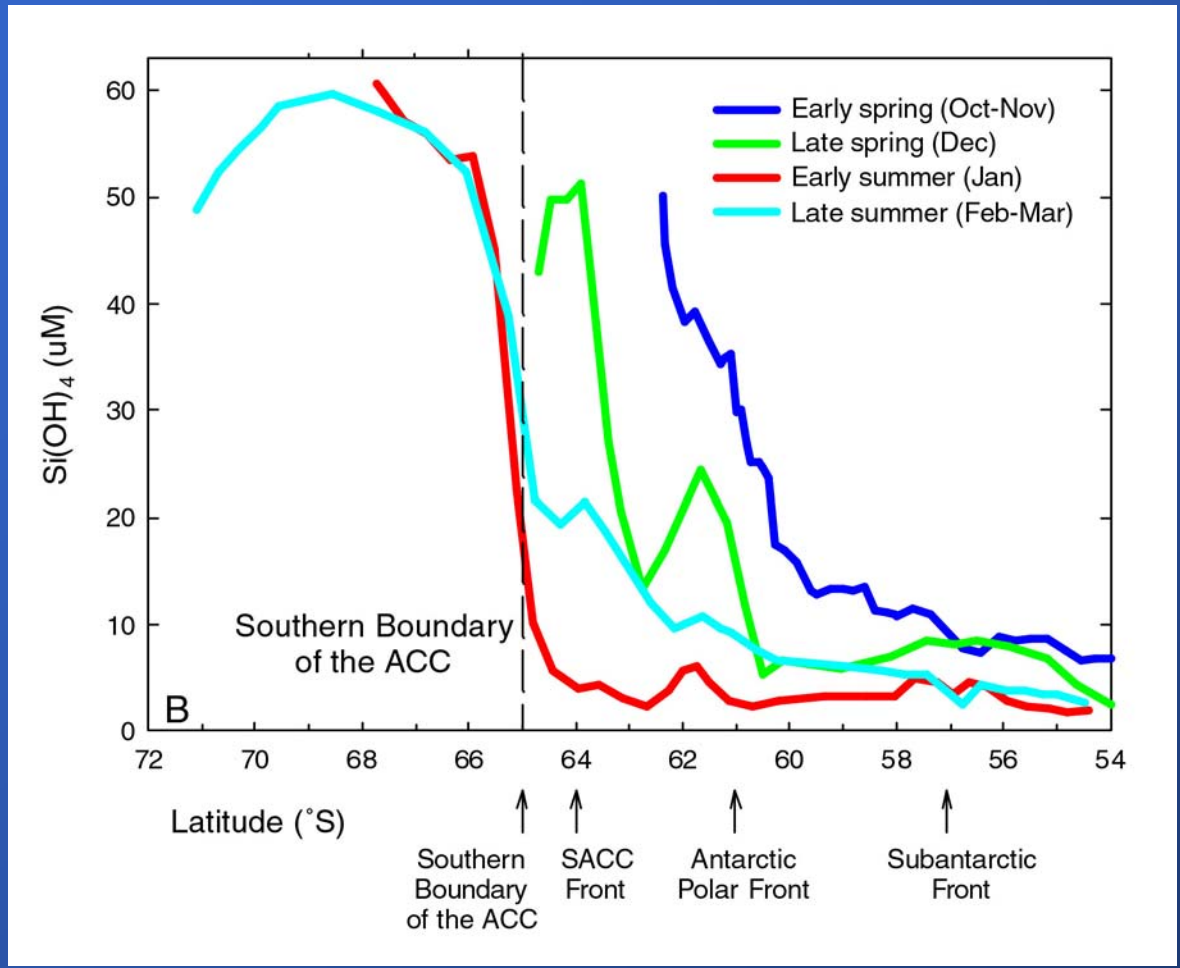
Calculate seasonal balance of Production and export from ship's measurement and extrapolate using satellite based PProd model



- Primary Production deceases towards south
- New production ~ POC export flux
- Particle export/PProd = high, especially in south

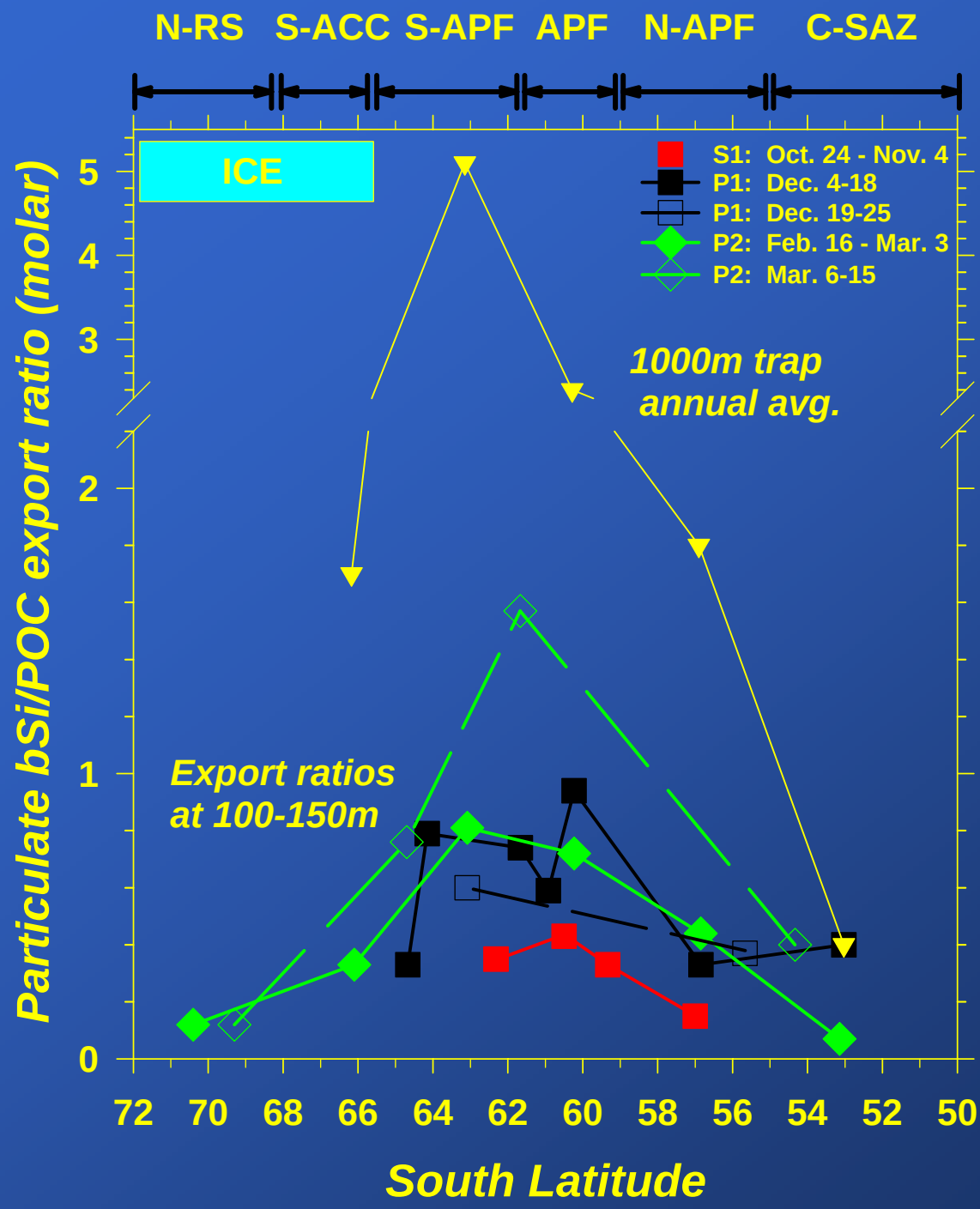
Despite low PProd, shallow POC flux is relatively high *i.e. biological pump is very efficient!*

What geochemical changes follow ice edge blooms?



Southward progression of Silica front associated with diatom bloom

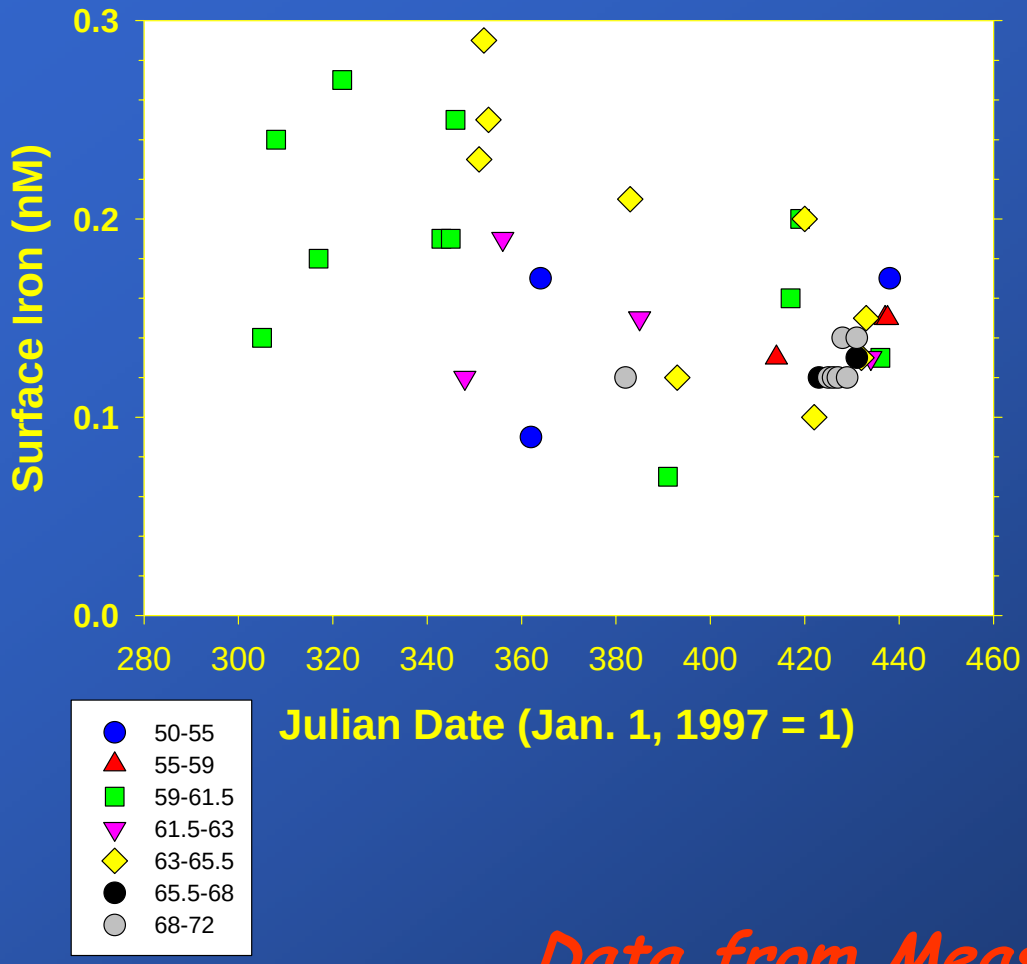
Fig. from Hiscock et al.



Particulate bSi flux associated with diatom export 59-65°S *(end of opal "paradox")*

Buesseler et al., 2001

What about micro-nutrients? Iron story



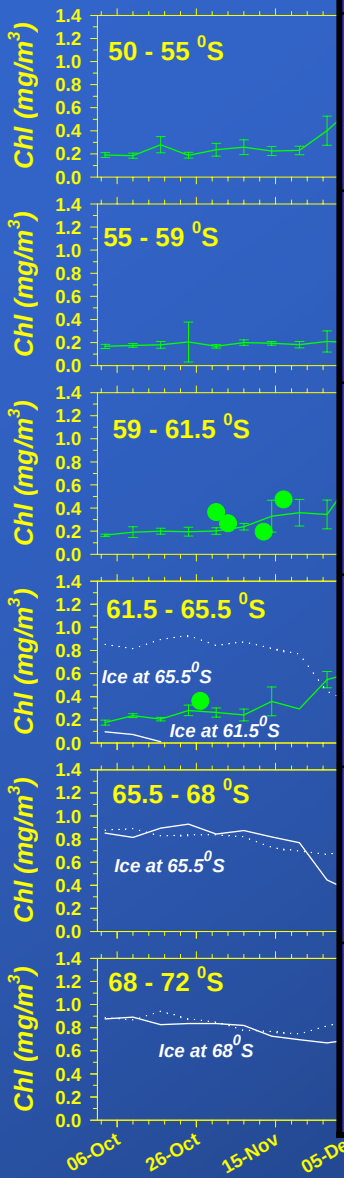
- Fe decreases from >0.2 to <0.2 nM in region of Polar Front & south (59-65.5° S)
- Fe always low north of APF and south of ACC (<0.2 nM)

Data from Measures and Vink, 2001

How does the phytoplankton community change in response to:

- Light
- Stratification/mixing
- Macro/micro nutrients
- Grazing
- Self shading
- Temperature/salinity

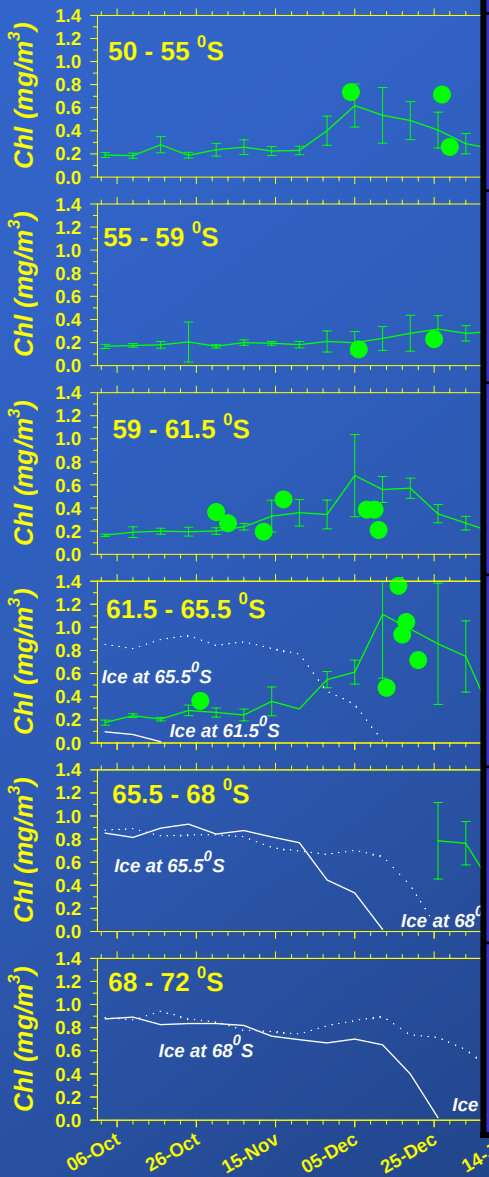
Early Spring



1%/ MLZ	Phyto types	Si	Fe	P^B opt	POC flux
low		<2			
low		9.4			15
0.4	Phaeocystis; chain diatoms; small centrics	22	0.21	2.8	13
0.6	Phaeocystis; pennate diatoms	46		1.5	16
	Ice				
	Ice				

- Light limited
- Low Chl & PProd
- Low photo efficiency
- Smaller diatoms & phaeo at Polar Front

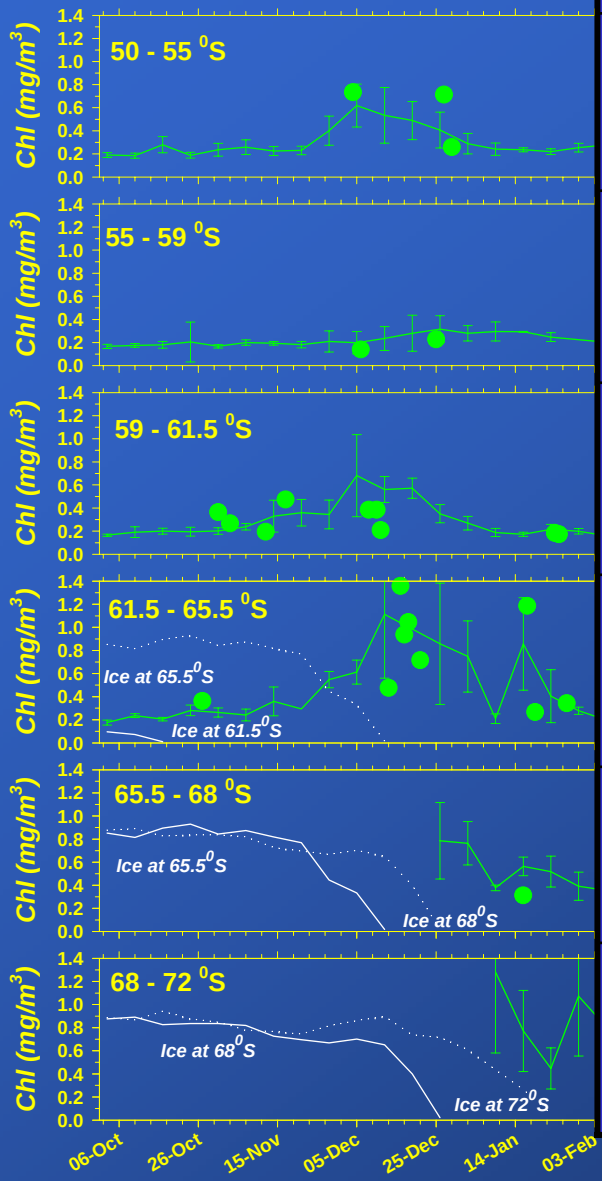
Spring Bloom at Polar Front



1%/ MLZ	Phyto types	Si	Fe	P^B opt	POC flux
0.9	Small prymnesiophytes	1.8	0.13	5.0	8
1.8	Small prymnesiophytes	8.9		4.1	5
1.9	Small diatoms	14	0.21	5.4	14
1.5	Large mixed diatoms/centrics	46	0.21	4.2	11
high?	Phaeocystis; pennate diatoms	high			
ice					

- N = small phyto
- Large diatoms south of Polar Front
- Ice edge spp. in far south

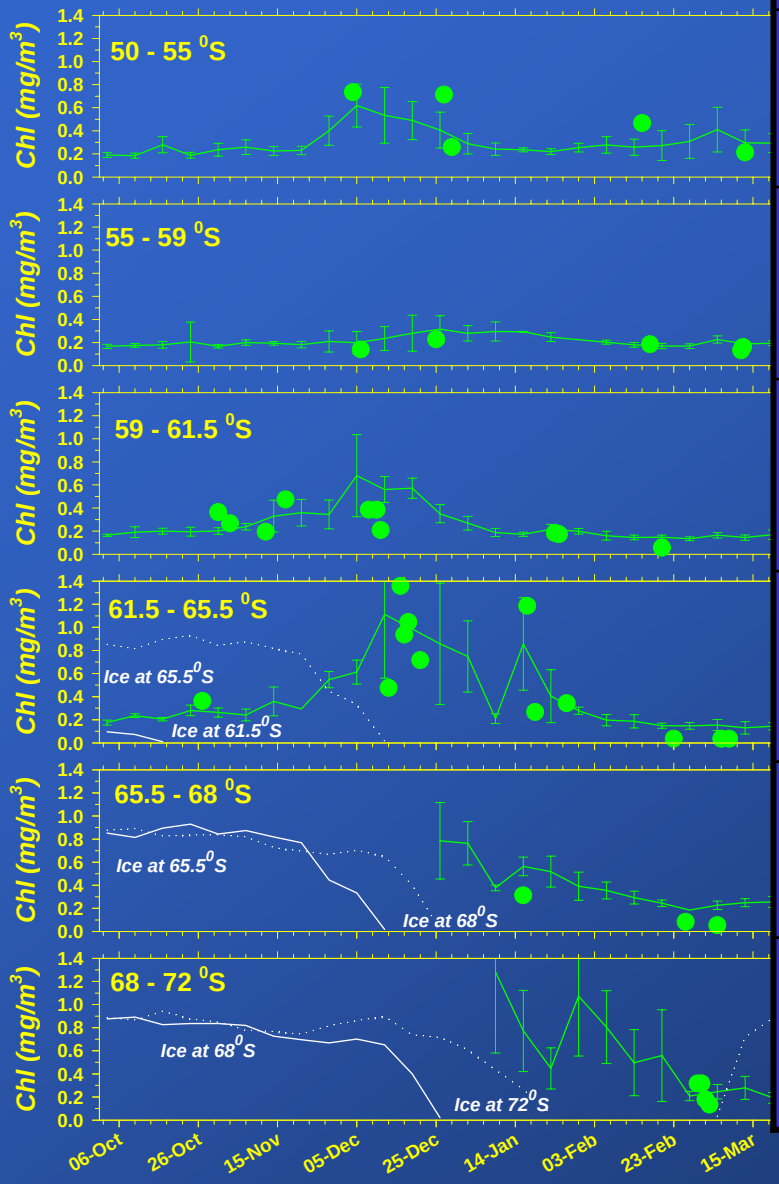
Bloom Moves South



1%/ MLZ	Phyto types	Si	Fe	P^B opt	POC flux
1?		<2			
1?		5-8			
>1		7	0.07		11
>1	Large centric diatoms esp. at 64-65 S	40	0.16		30
>1	Phaeocystis; pennate diatoms	High			
>1		high			

- Si & Fe drops
- High fucox. @65S
- Ice edge spp. >65S

Post-bloom of Ice Edge Spp. in far South



1%/ MLZ	Phyto types	Si	surf Fe	P^B opt (Fv/ Fm)	POC flux
0.8	Synechococcus; small phyto only	1.8	0.17	5.0 (0.48)	9
1.1	Cryptophytes, pennate diatoms, synechococcus	5	0.15	3.5 (0.44)	16
0.9	Low #'s smaller pennate diatoms; cryptophytes	8	0.16	5.0 (0.41)	12
1.8	Low #'s smaller pennate diatoms; cryptophytes	26	0.14	4.6 (0.32)	12
1.2	Phaeocyctis; pennate diatoms;	60	0.13	1.6 (0.30)	20
1.8	Phaeocyctis; pennate diatoms; larger phyto only	62	0.13	2.8 (0.28)	34

50-59° S; N-PFZ & C-SAZ

- Always low Si
- Iron <0.2 nM
- Generally deeper MLZ
- Smaller phytoplankton
- High photo efficiency
- Low particle flux

59 – 65.5° S; PFZ & S-PFZ

- High Si front moves south
- Iron starts >0.2 nM & decreases
- Shallow spring MLZ
- Centric diatom bloom moves S
- High photo efficiency
- High POC and highest bSi flux

65.5 - 72° S; S-ACC & N-RS

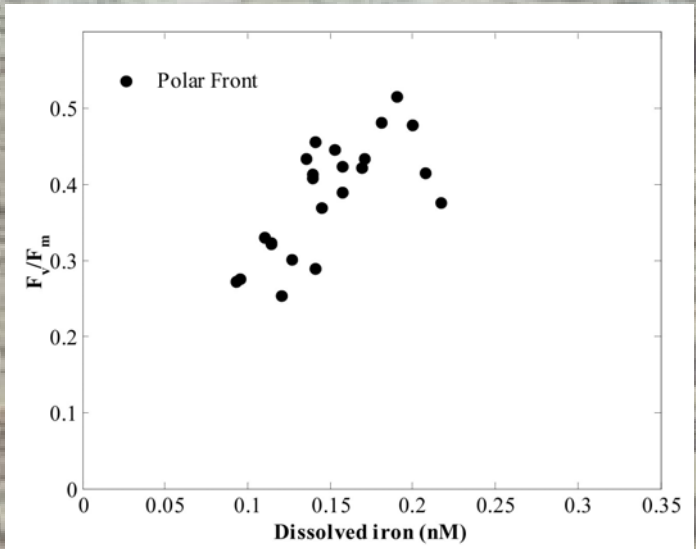
- High Si always
- Iron <0.2 nM
- Shallow spring MLZ
- Ice edge species only
- Low photo efficiency
- High POC flux

Melting ice, primary production, and particle export in the Southern Ocean- what's the connection?

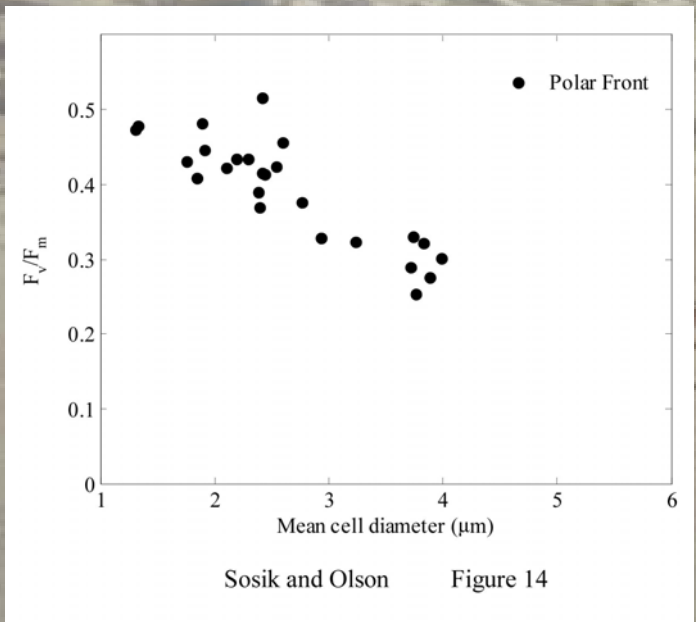
- Onset of blooms related to stratification (heating N of APF & melting S of APF
- Relative levels of Fe & Si determine species composition
- Fe stress leads to end of/lack of large diatoms

- Grazing plays a larger role in north (small cells/no ice cover) & later in Polar Front region after diatom crash
- Polar Front region starts with relatively high Fe (Fe from upwelling & not melting ice)
- Southern Ocean has high export for both bSi & POC despite low Chl & primary productivity

The iron story, cont.



Sosik and Olson Figure 13

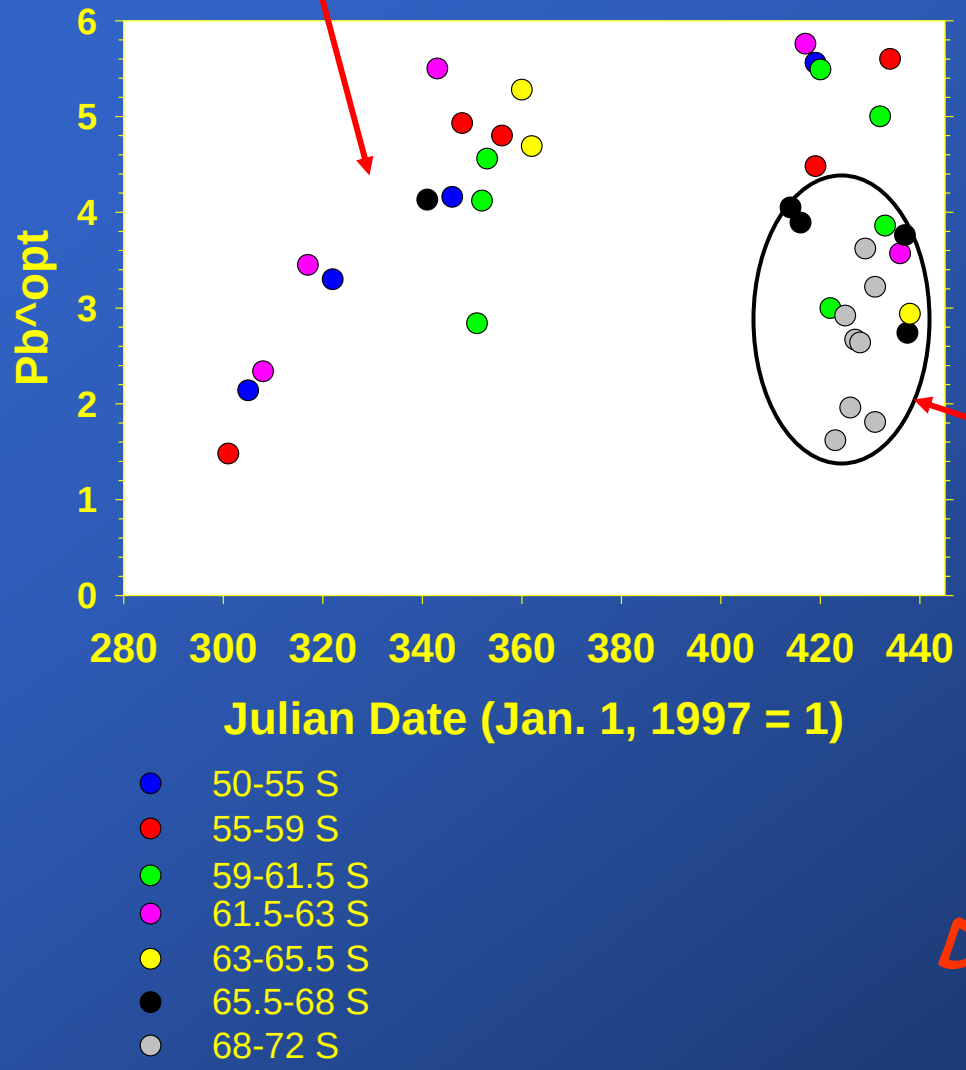


Sosik and Olson Figure 14

- Fv/Fm = photo efficiency, increases with higher iron
- Higher Fv/Fm and Fe associated w/smaller phytoplankton in north *(but higher Fe thought to favor larger phytoplankton?)*

Sosik & Olson

59-65 S and further north- seasonal increase & maintained high



>65 S- always low P^Bopt (and Fv/Fm)?

Data from Hiscock et al.

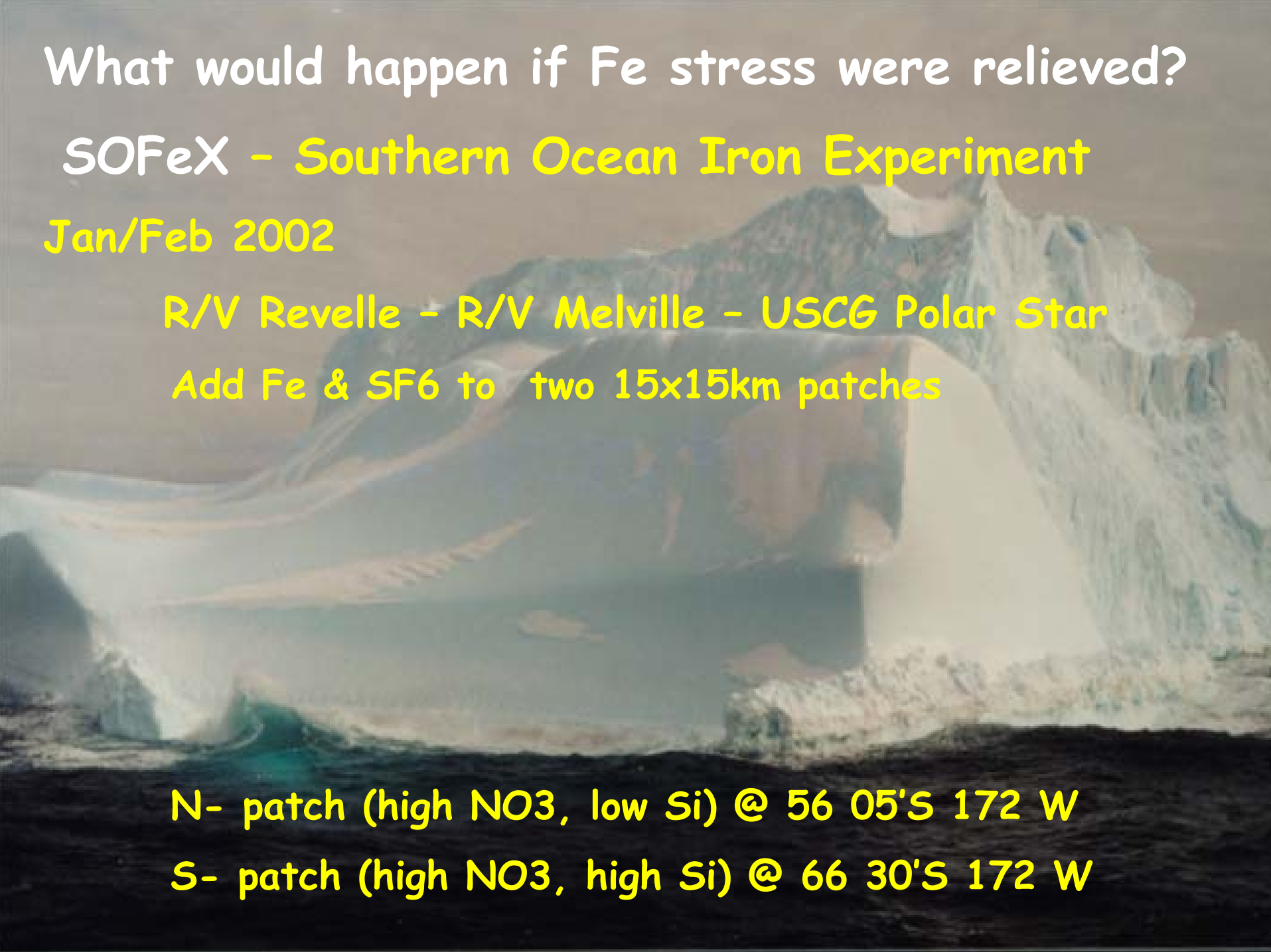
What would happen if Fe stress were relieved?

SOFeX – Southern Ocean Iron Experiment

Jan/Feb 2002

R/V Revelle - R/V Melville – USCG Polar Star

Add Fe & SF6 to two 15x15km patches

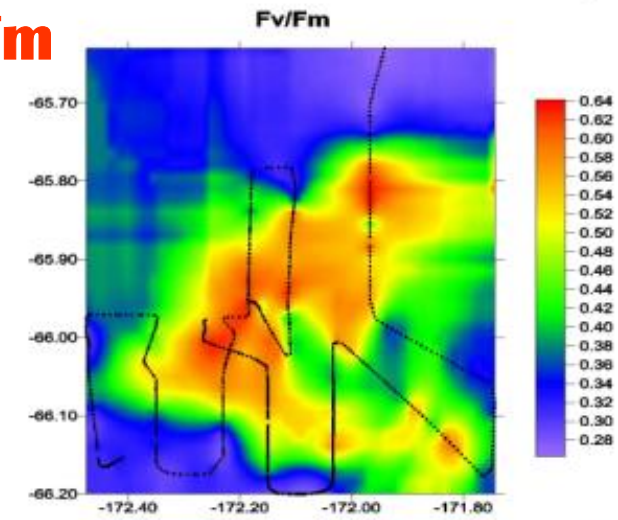


N- patch (high NO3, low Si) @ 56 05'S 172 W

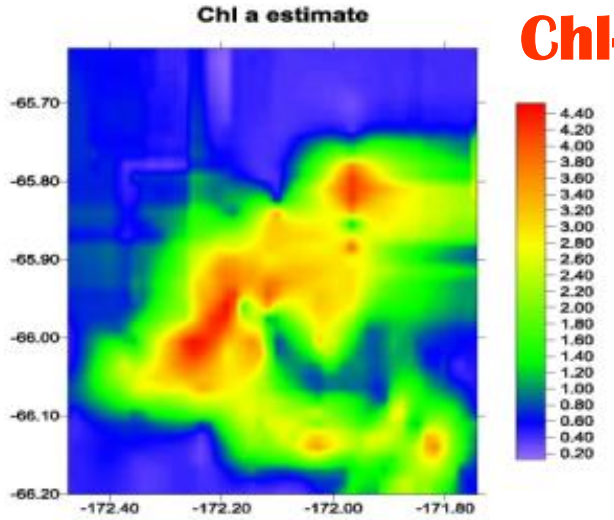
S- patch (high NO3, high Si) @ 66 30'S 172 W

RV Melville- last data from Feb. 14th
3.5 weeks after first addition of iron & SF6 to S-patch

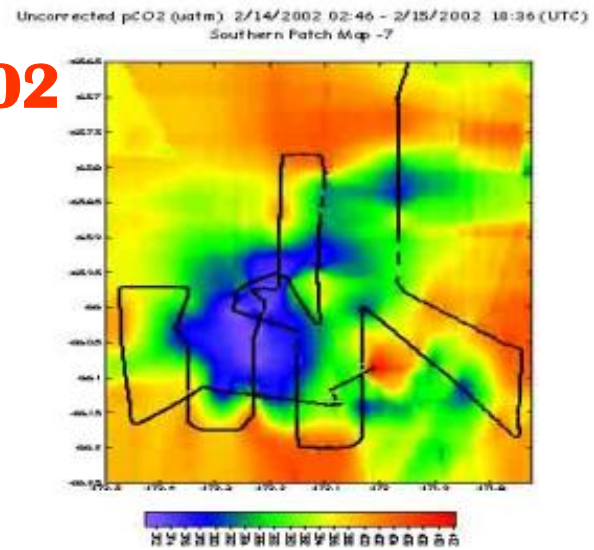
Fv/Fm



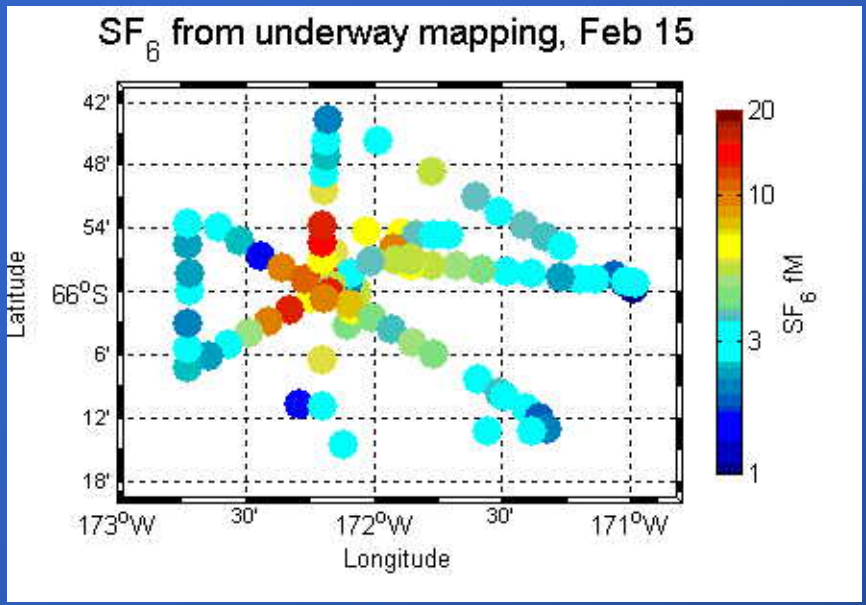
Chl-a

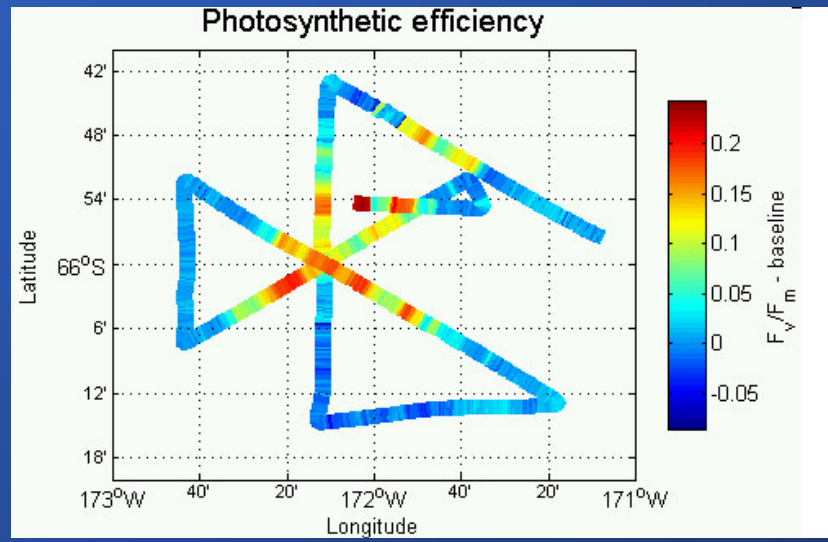


pCO2



First Survey from USCG Polar Star



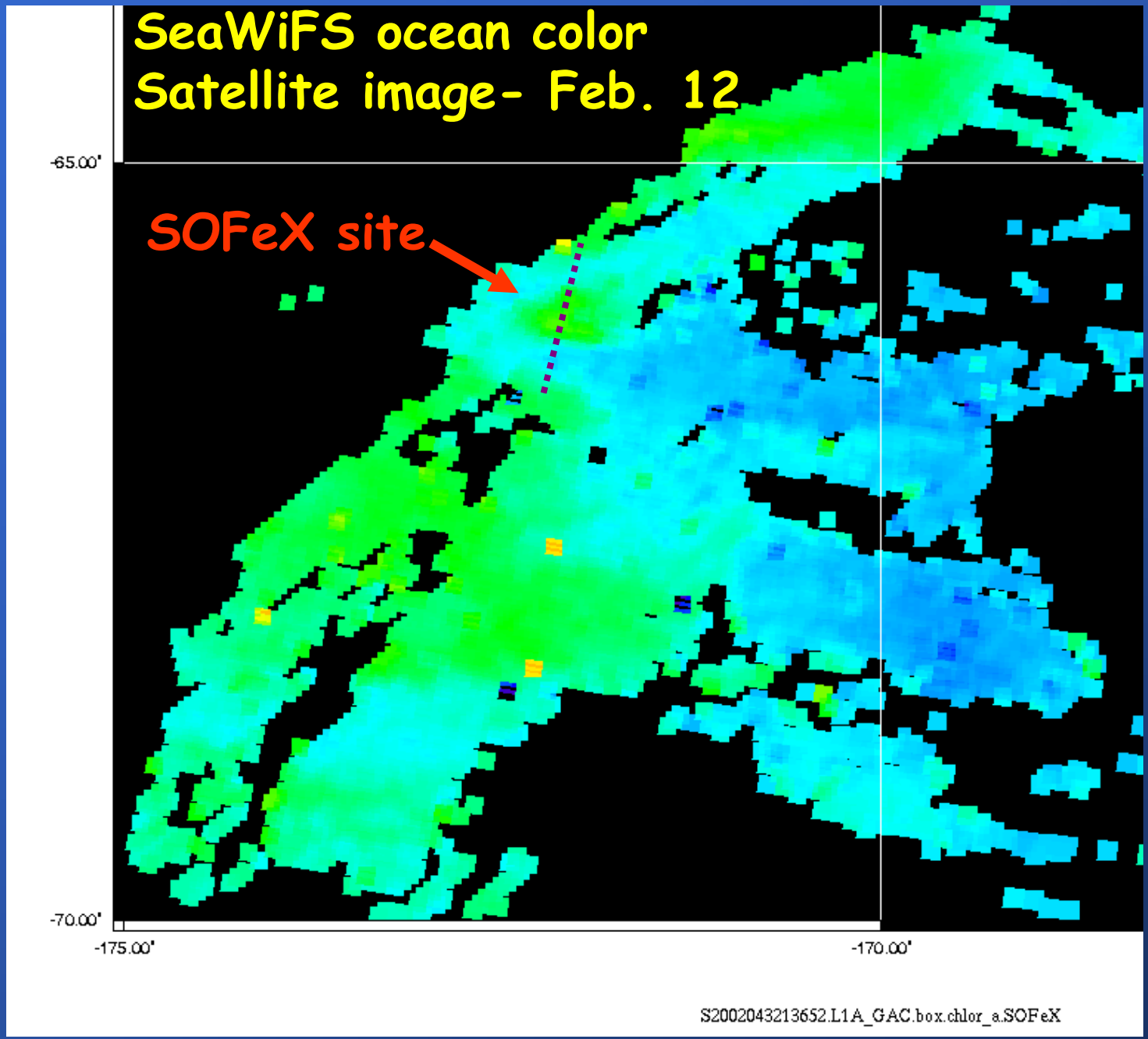


SF6 positively identifies this as the SOFeX patch *(SF6 & iron added 4 weeks earlier!)*

L. Houghton & L. Goldson

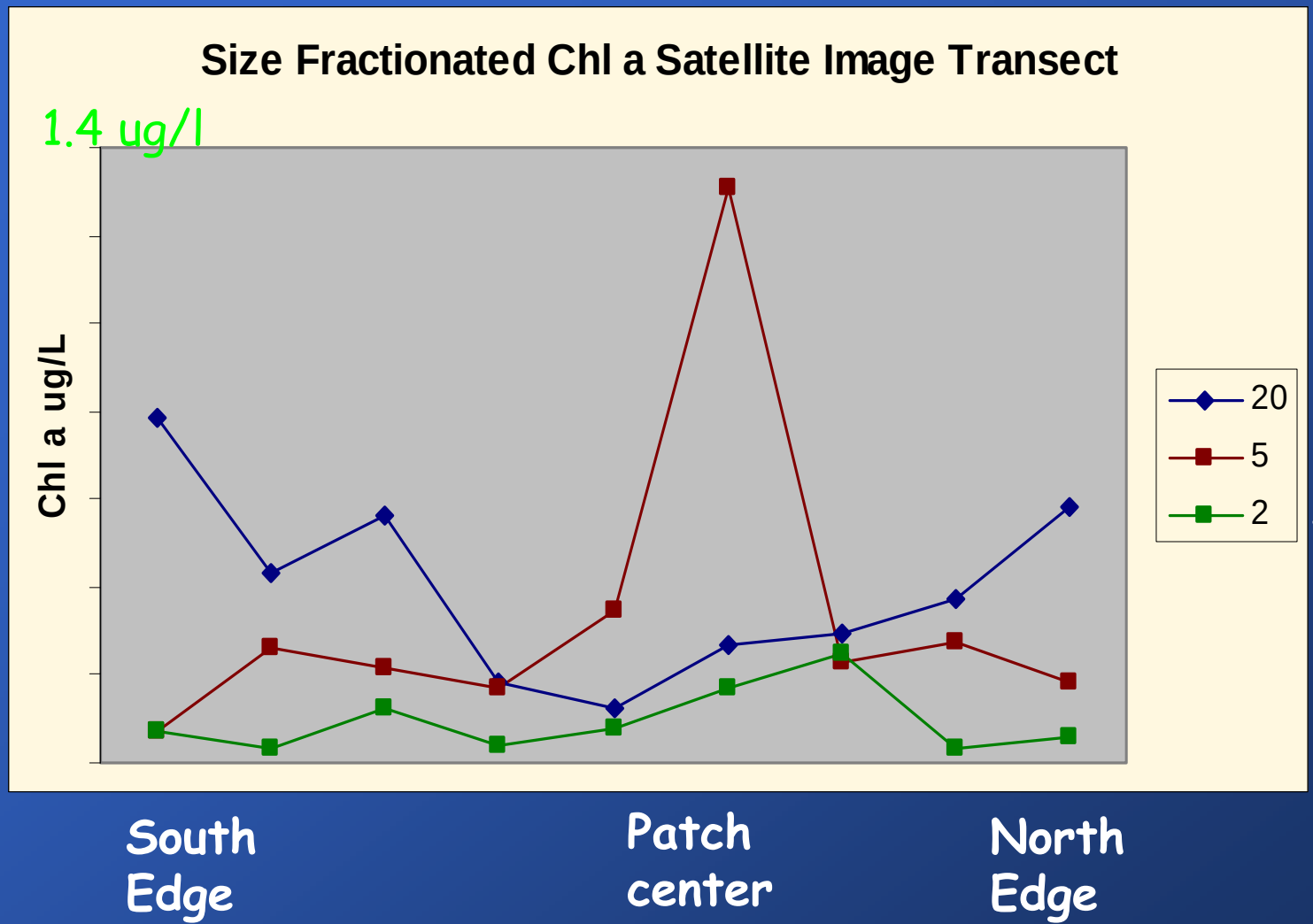
Phytoplankton show positive response to iron addition

E. Abraham



F. Chavez et al.

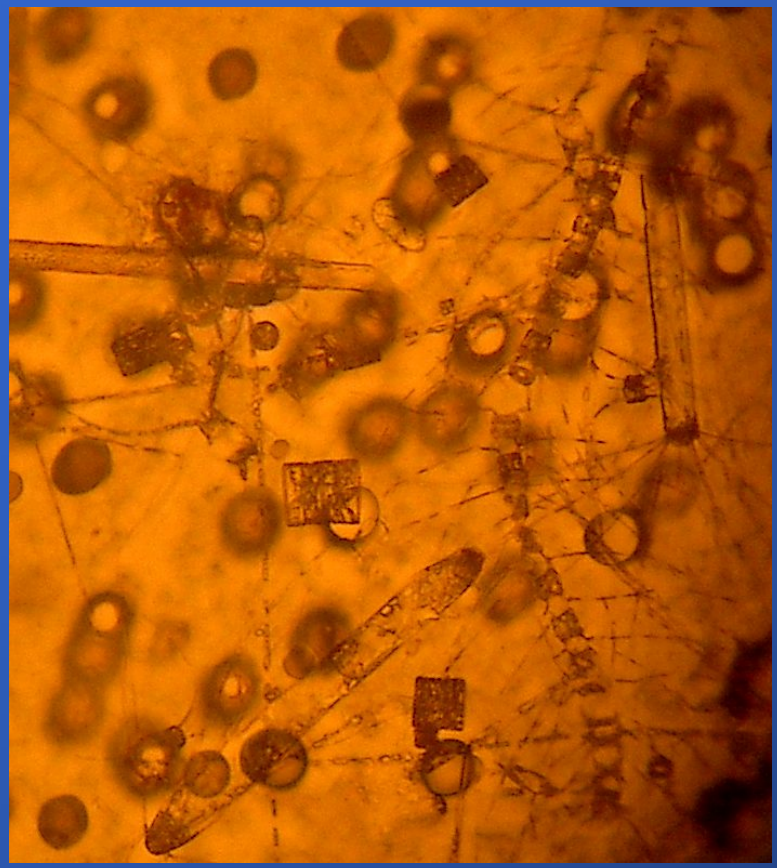
South to North transect through patch center



Bloom within patch- 5-20 um phytoplankton dominate

Blooms outside patch- even larger phytoplankton?

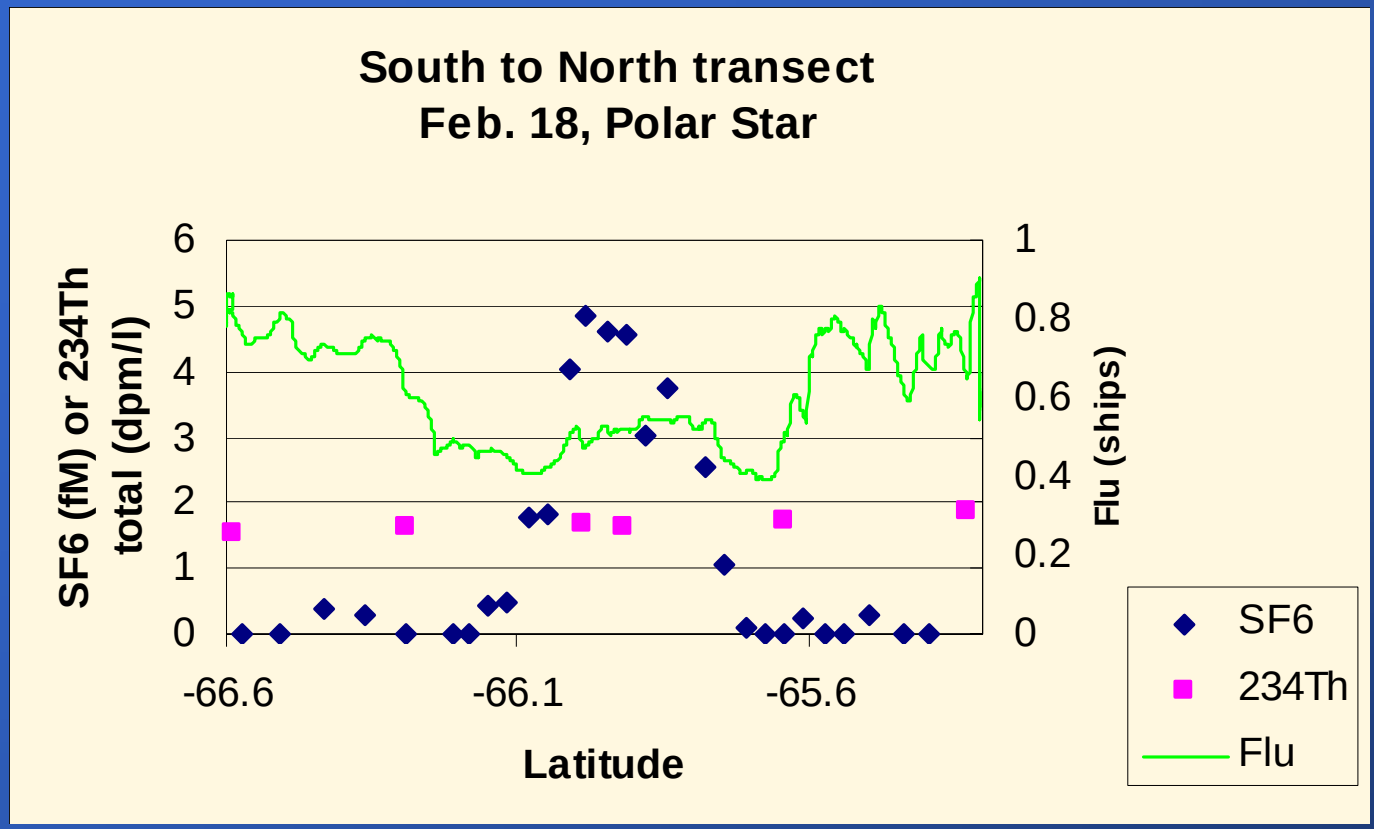
Microscopic views of phytoplankton within patch *(400x views)*



- see lots of chain forming diatoms & other large centric and pennate species

P.Croot et al.

So what about particle export during SOFeX?



- Despite high Chl & diatoms- no difference in vs. out in thorium-234
- Yes, there was export, but not "crash" after 1 mo.
- May still be enhanced bSi and POC export if large cells were sinking?

SOFeX Summary

- Logistical success
- Elevated Chlorophyll both N & S of Polar Front
- pCO_2 decreased
- Nutrients depleted (NO_3 & Si)
- Enhanced Fv/Fm
- Blooms of pennate diatoms in N-patch
- Blooms of centric and large chain diatoms in S-Patch
- Did not see crash of S (and N?) bloom-
  - maintained high photo efficiency
  - low loss terms w/efficient recycling of Fe

Would natural or artificial Fe fertilization ever lead to significant carbon export & sequestration?

- climate links remain uncertain