ECOLOGY of the ANTARCTIC SEA ICE ZONE
EASIZ

WATER COLUMN PROCESSES

Comparative Plankton Ecology

Hugh Ducklow & Robert Daniels

College of William & Mary

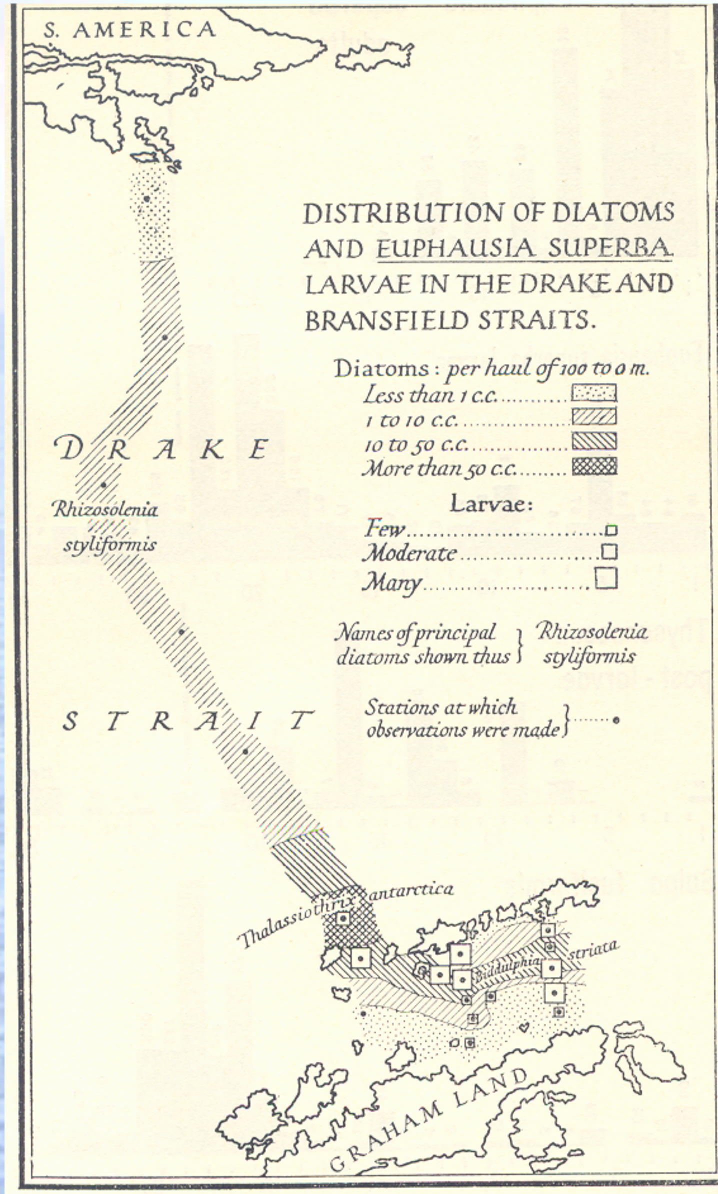
Ray Smith, Maria Vernet, Dave Karl, Doug Martinson
Sharon Stammerjohn, Robin Ross, Langdon Quetin,
Bill Fraser, Karen Baker, Andy Clarke

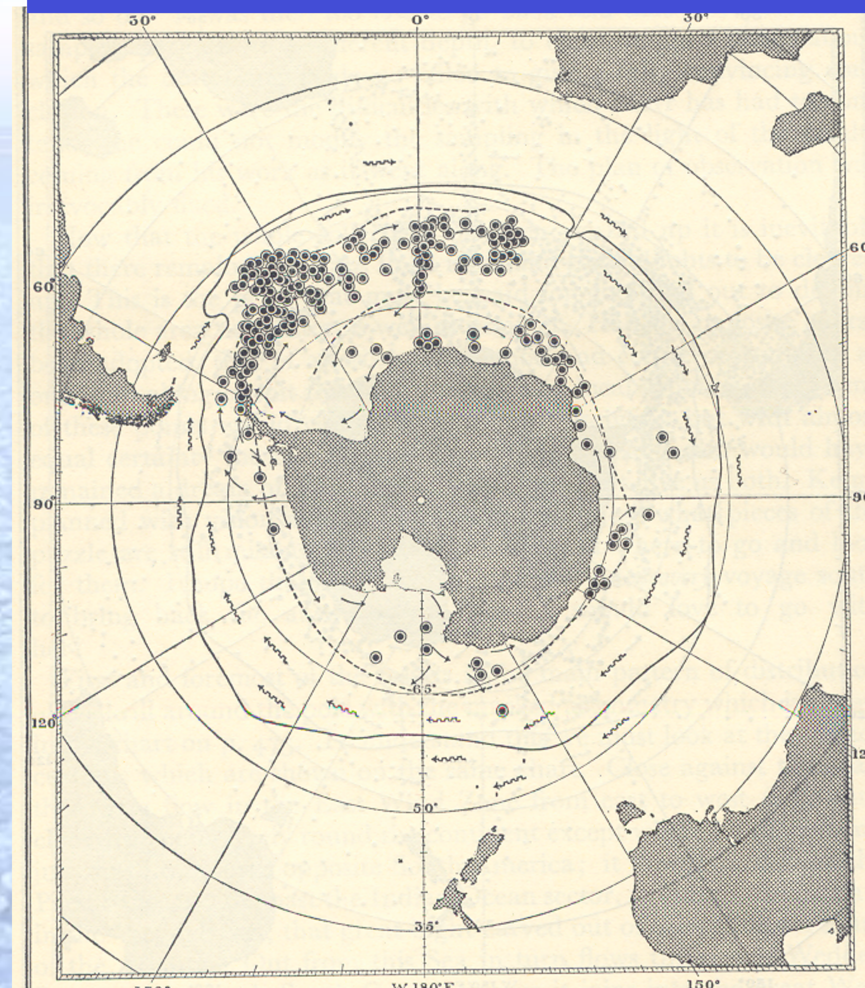
Palmer Antarctica LTER

EASIZ Final Symposium
Korcula, Croatia
27 September 2004

ANTARCTIC SEA ICE ZONE

Productivity long-recognized





Sir Alastir Hardy, Great Waters

QUESTIONS

1. **HOW DO VARIATIONS IN SEA ICE EXTENT & DURATION INFLUENCE WATER COLUMN ECOLOGY & BIOGEOCHEMISTRY?**

   -- ***primary production & sedimentation in LTER study region along West Antarctic Peninsula***

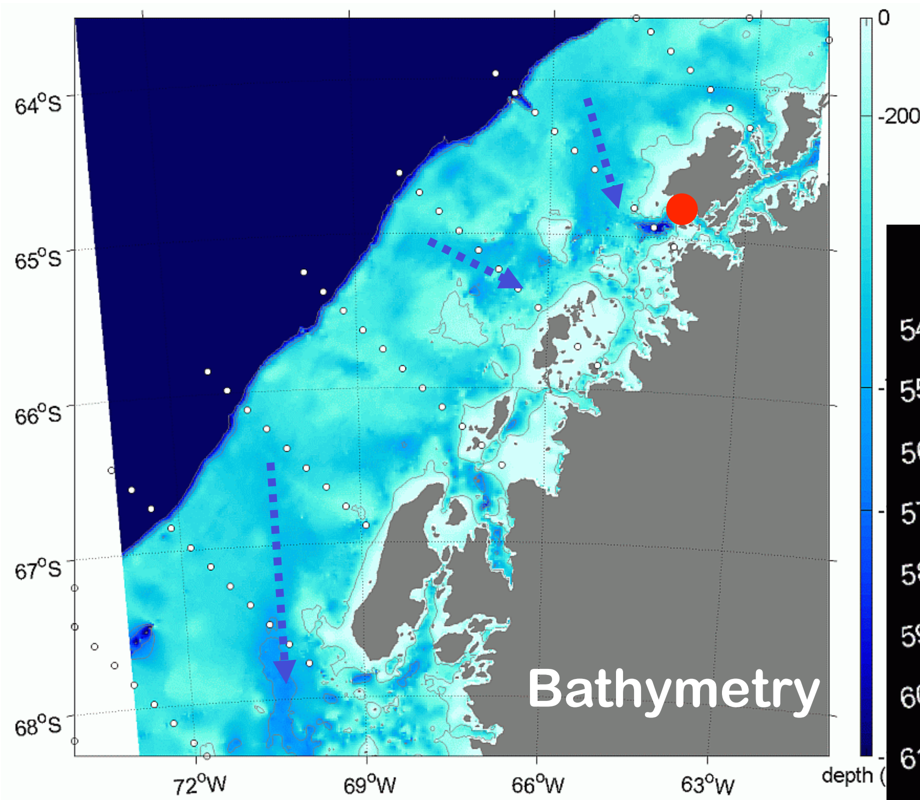
2. **HOW DOES PHYTOPLANKTON COMMUNITY STRUCTURE INFLUENCE BIOGEOCHEMICAL PROCESSES?**

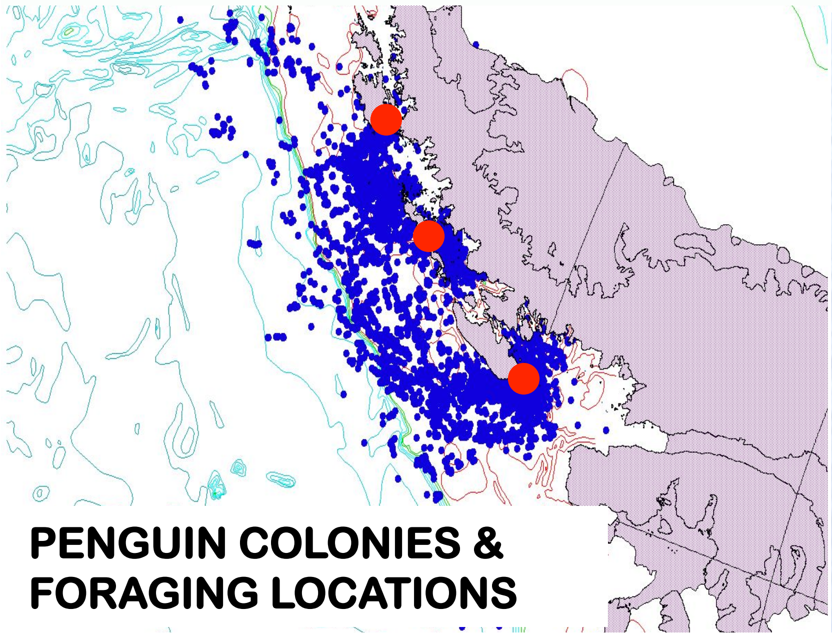
   -- ***structure of carbon exchanges in Ross Sea and WAP foodwebs.***

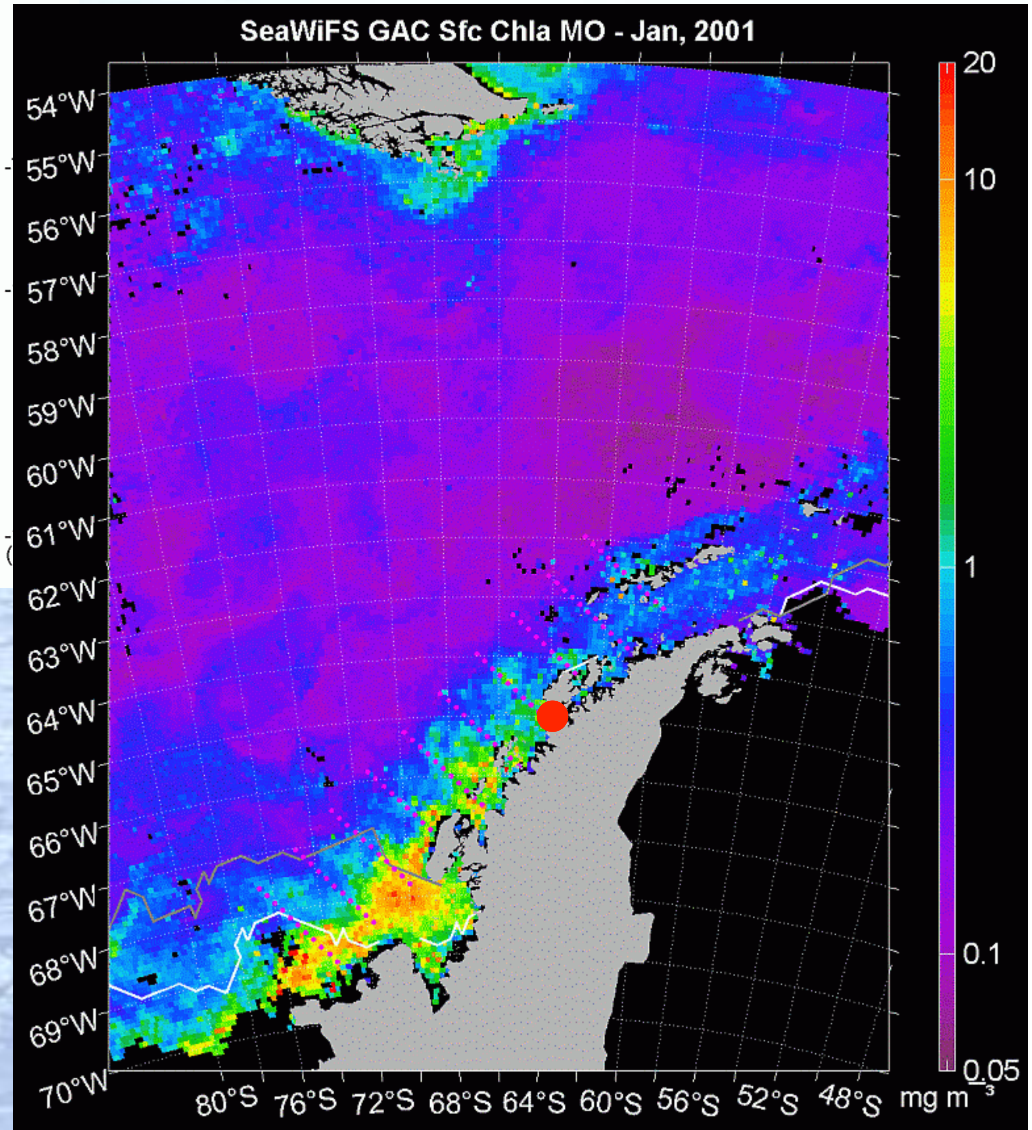
3. **EMPHASIS ON LARGE-SCALE PROCESSES AND INTERANNUAL VARIATIONS**

PALMER, ANTARCTICA Long Term Ecological Research Program (LTER)

- Part of US LTER Network of 26 sites
- 1991 – present
- Regional (200,000 km^2) and local sampling
- Focus on sea ice dynamics, water column processes and apex predators
- Physics, remote sensing and ice, microbial biogeochemistry, sedimentation, primary production, krill, penguins


Bathymetry
64°S
65°S
66°S
67°S
68°S
72°W
69°W
66°W
63°W
0
-200
depth (

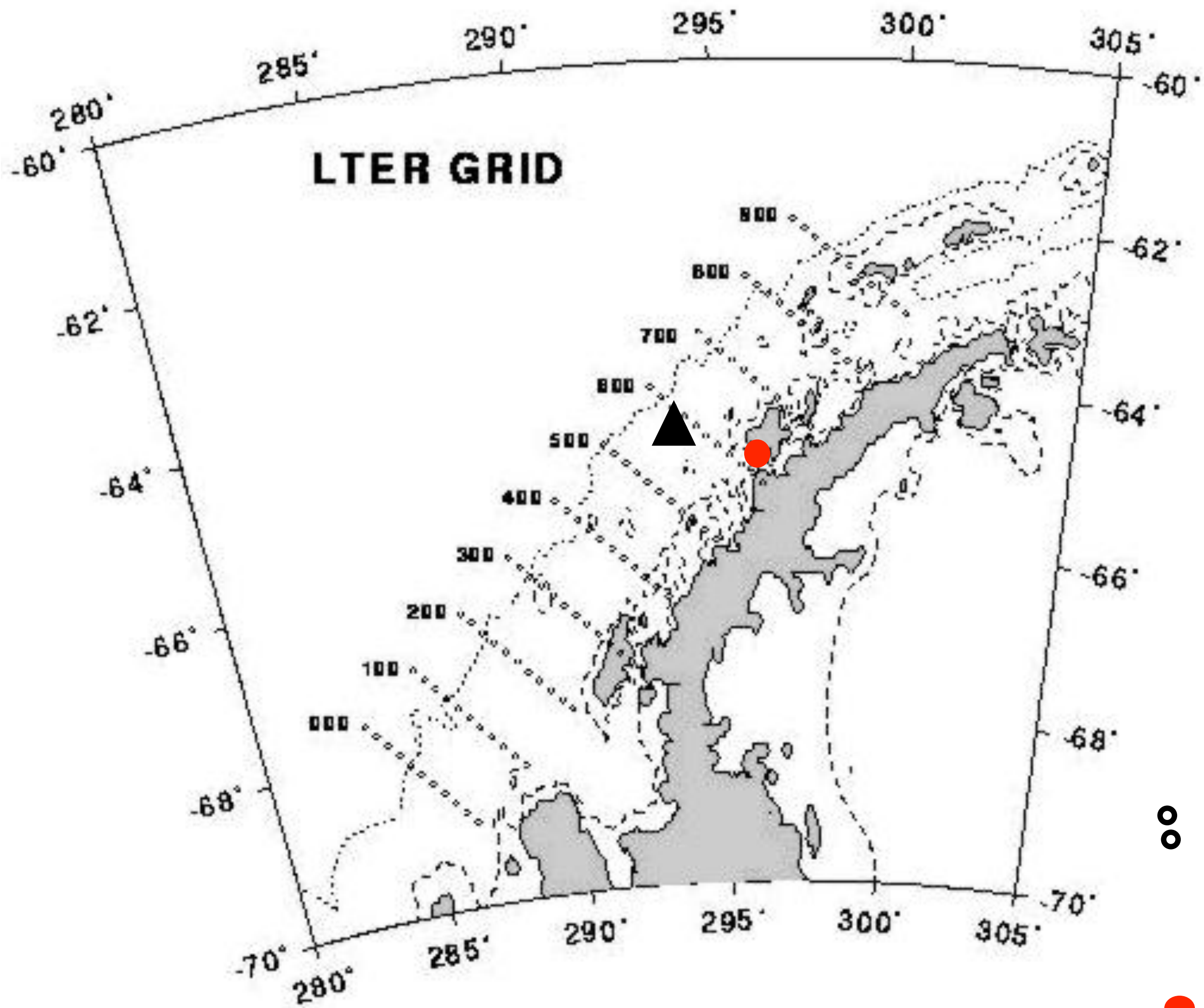

PENGUIN COLONIES &
FORAGING LOCATIONS


SeaWiFS GAC Sfc Chla MO - Jan, 2001
54°W
55°W
56°W
57°W
58°W
59°W
60°W
61°W
62°W
63°W
64°W
65°W
66°W
67°W
68°W
69°W
70°W
80°S
76°S
72°S
68°S
64°S
60°S
56°S
52°S
48°S
20
10
1
0.1
0.05
mg m⁻³

1. SEA ICE VARIABILITY AND WATER COLUM PROCESSES

- Sea ice extent, duration and retreat
- Primary production
- Sedimentation – integrator of water column processes – and link to benthos
- Relationships among these processes

LTER Sampling Grid

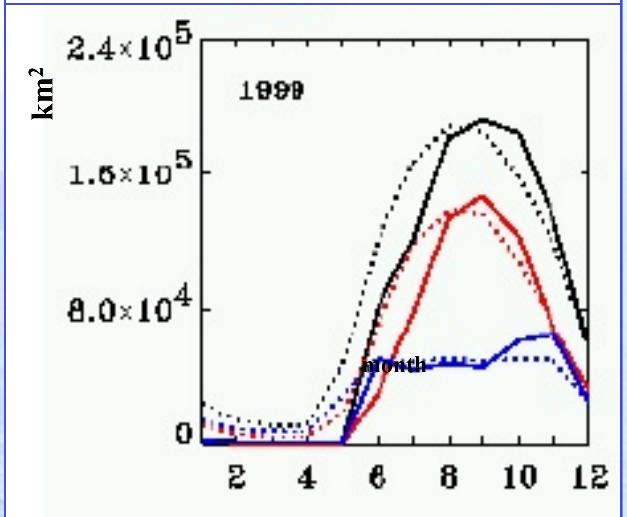


~100 stations surface to bottom grid sampled every January, 1991-2004

- LTER sample grid
- Palmer Station
- Sediment Trap

Measuring and characterizing sea ice:

Sea Ice in Palmer LTER Study Area



Solid lines: Observations
Dotted lines: 1991-01 mean

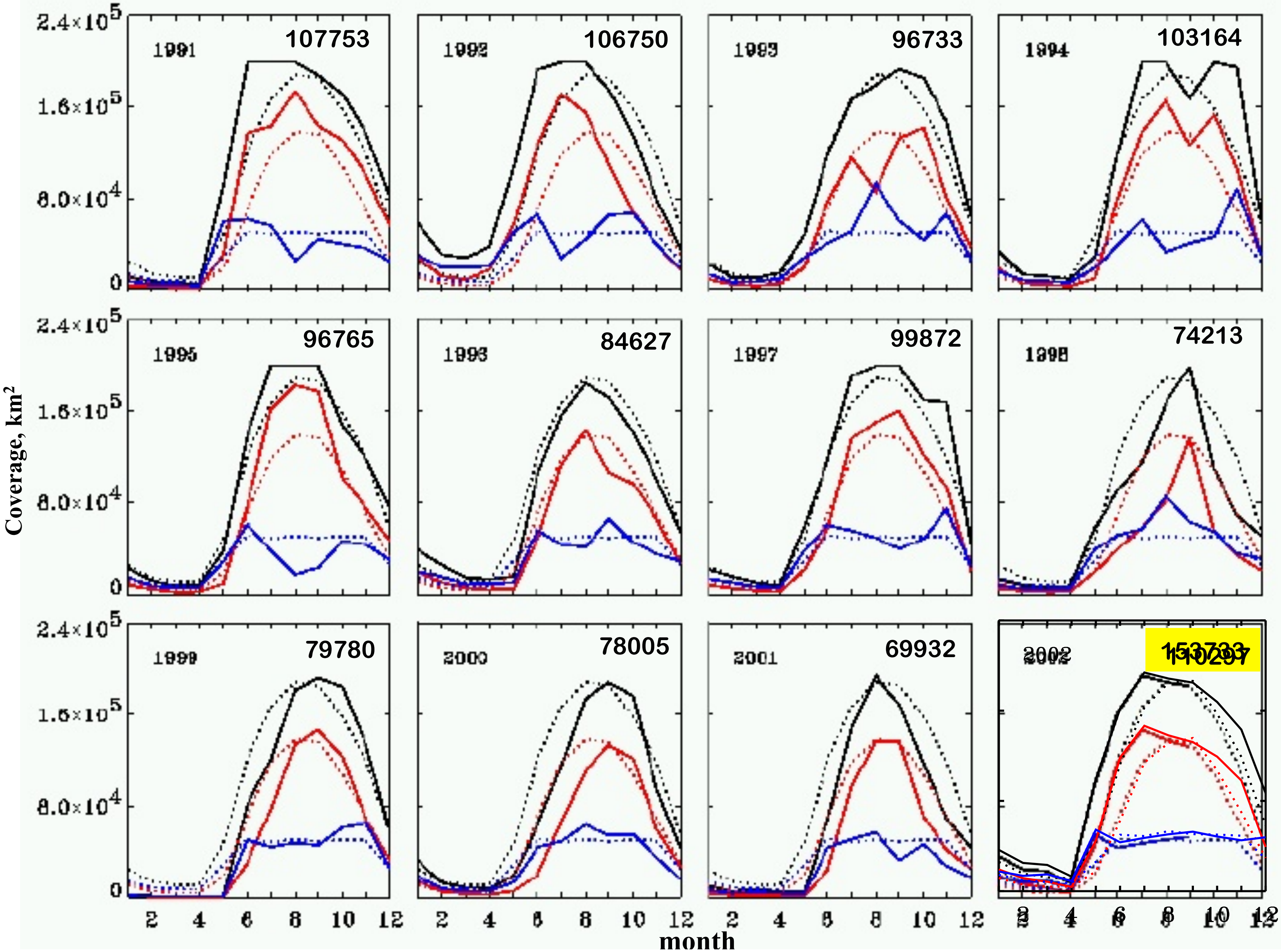
Extent **(black lines): the area enclosed by the 15% sea ice concentration contour – includes open water in the SIZ.**

Area **(red): the area covered by sea ice concentrations > 15% within the total extent.**

Open water **(blue): Extent minus area.**

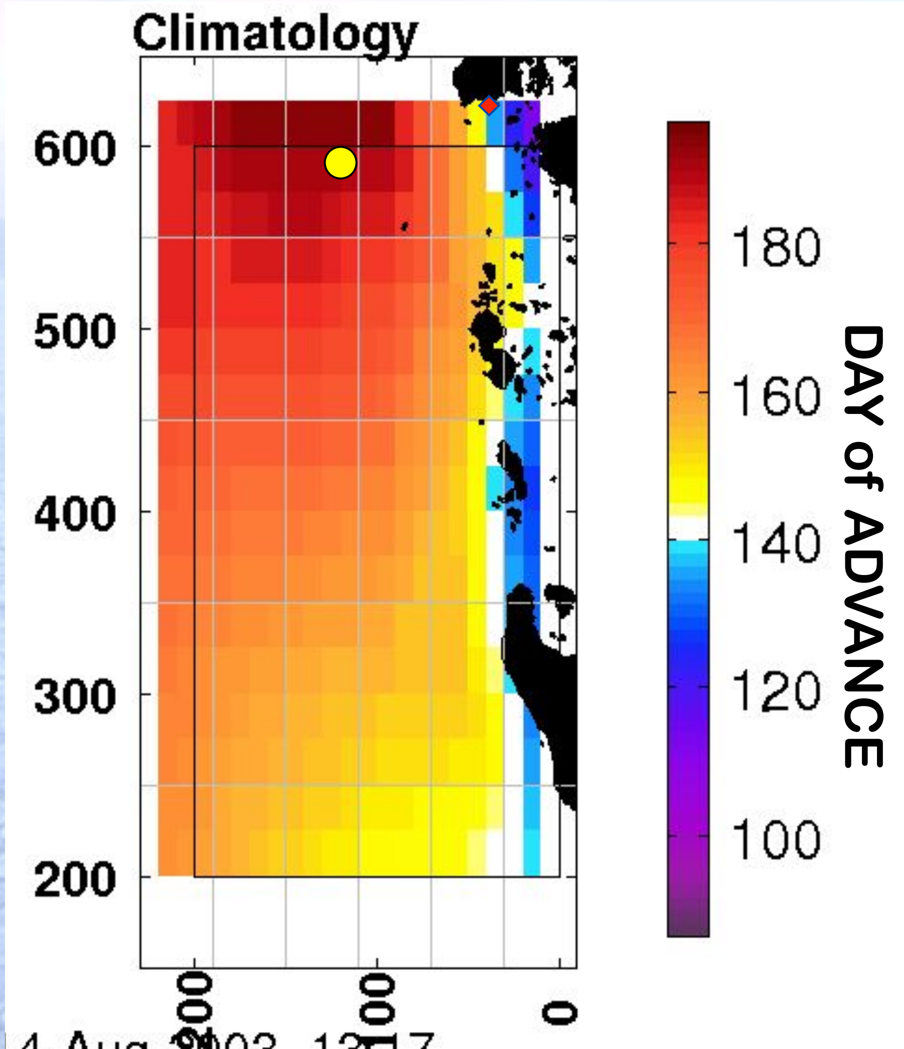
Data from NASA-GSFC SSMI-SSMR Time Series processed by Sharon Stammerjohn and Ray Smith for Palmer LTER

Palmer LTER Sea Ice Indices, 1991 - 2002

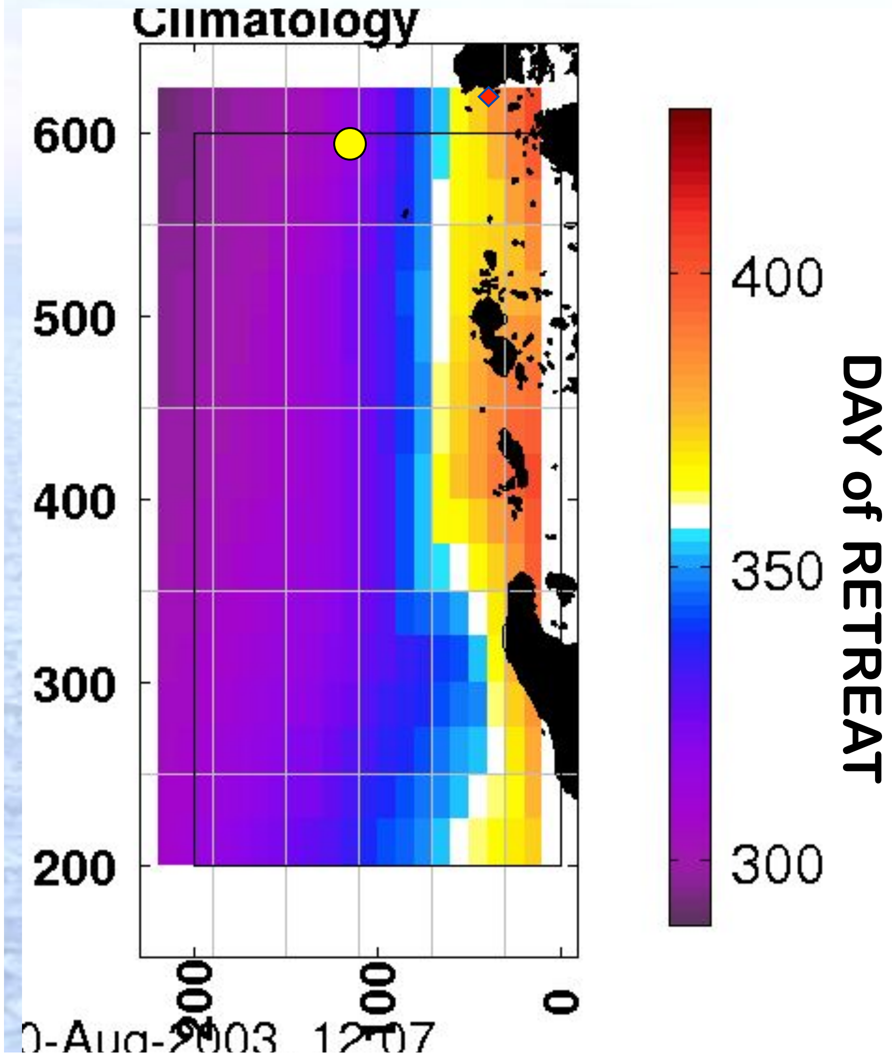


Mean extent given for each year. Total area 200,000 km2; max: 1980, 150,000, min: 1989, 42,000

Sea Ice Advance and retreat in LTER grid

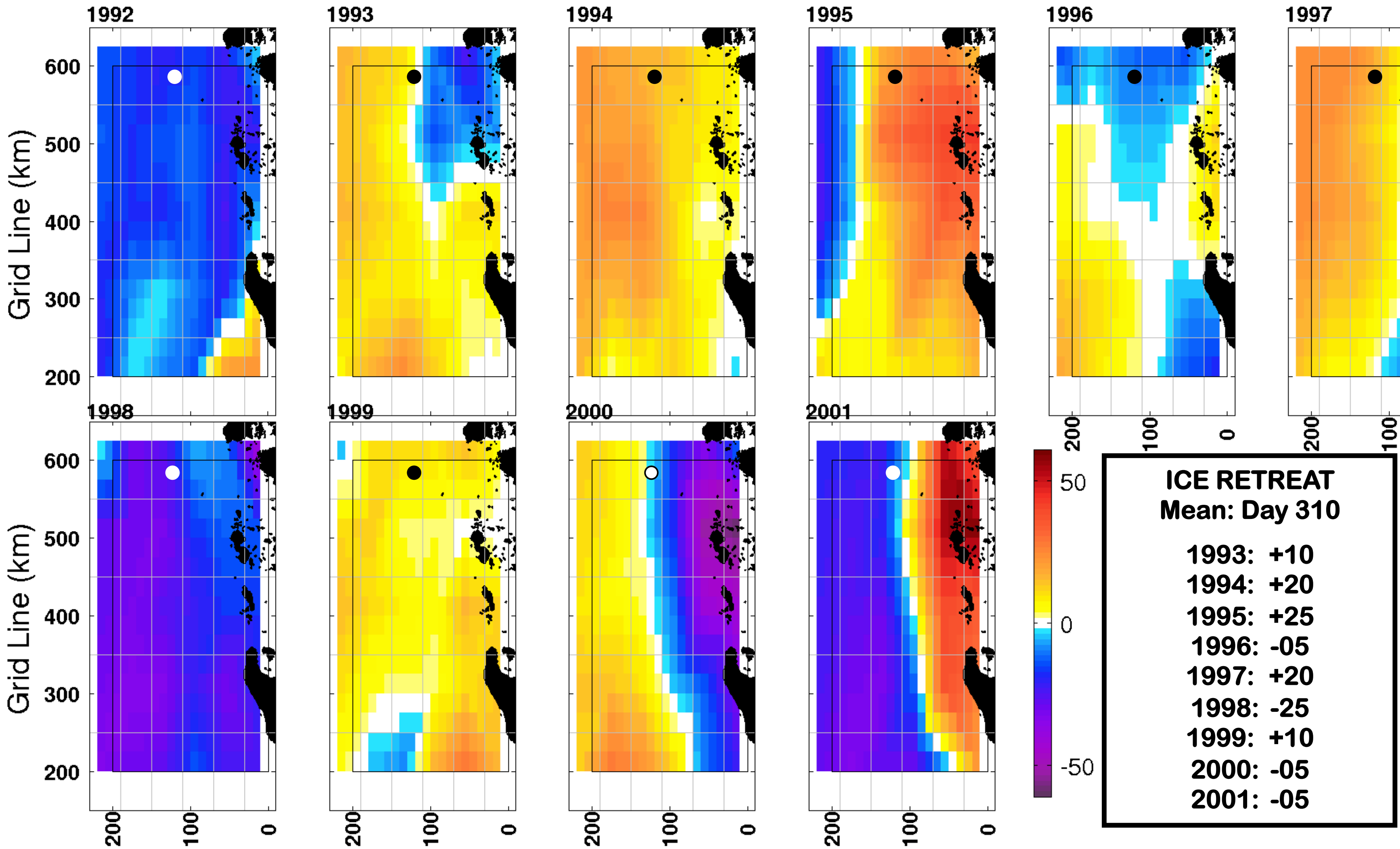


1991-2001 mean at Trap: Day 190



1991-2001 mean at Trap: Day 310

Interannual anomalies in date of ice retreat (WAP)



Symbol in upper center of contour plots is location of sediment trap mooring at 64.5S, 66W

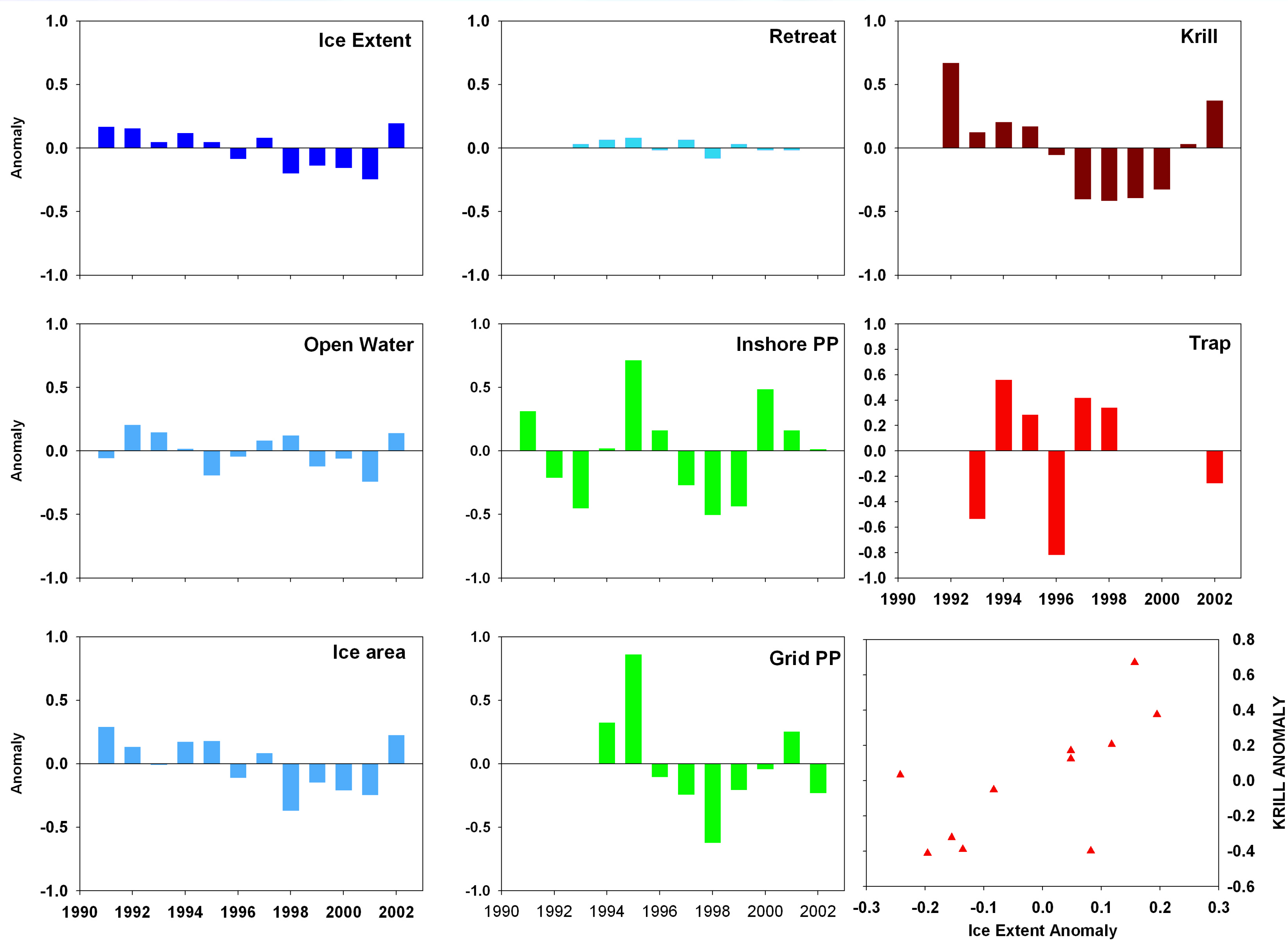
To describe interannual variability over the decade of sampling:

Standardized anomaly = $(X_i - \bar{X}) / \bar{X}$

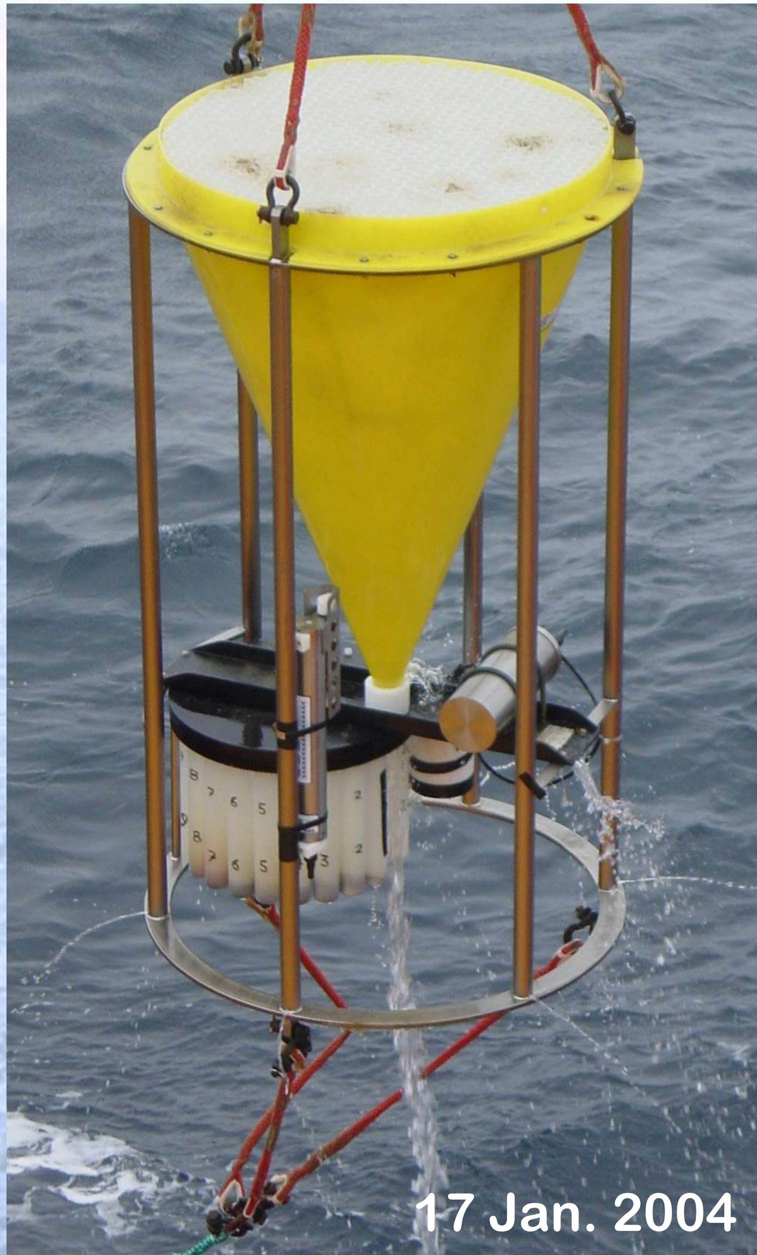
where $\bar{X}$ is annual mean over the decade.

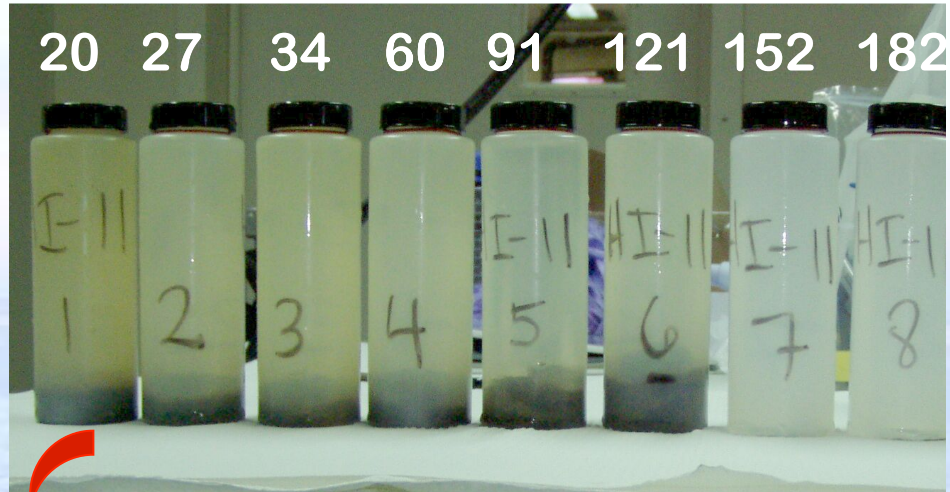
range –1 to +1 (0 = average)

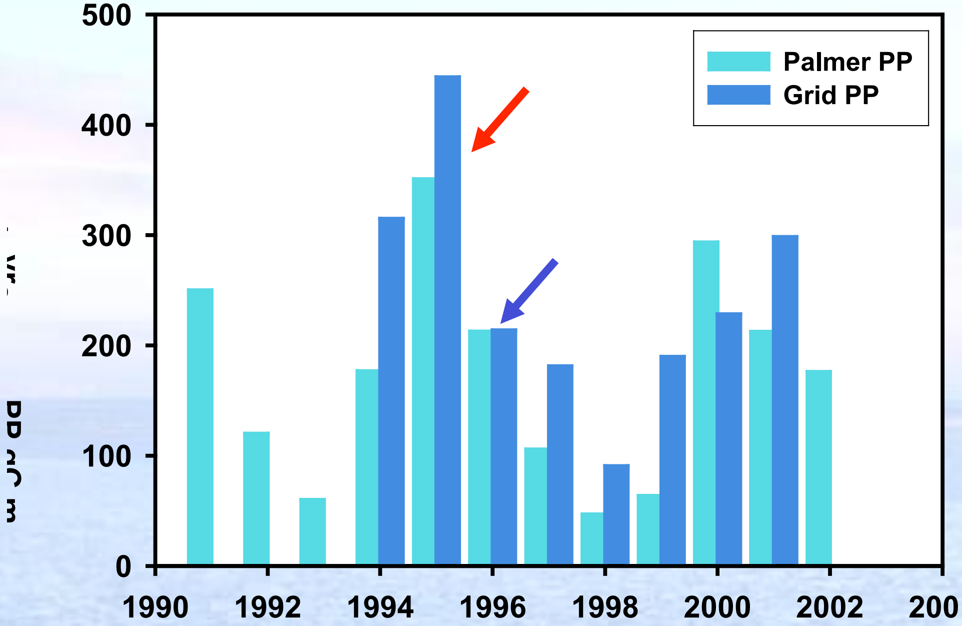
INTERANNUAL ANOMALIES

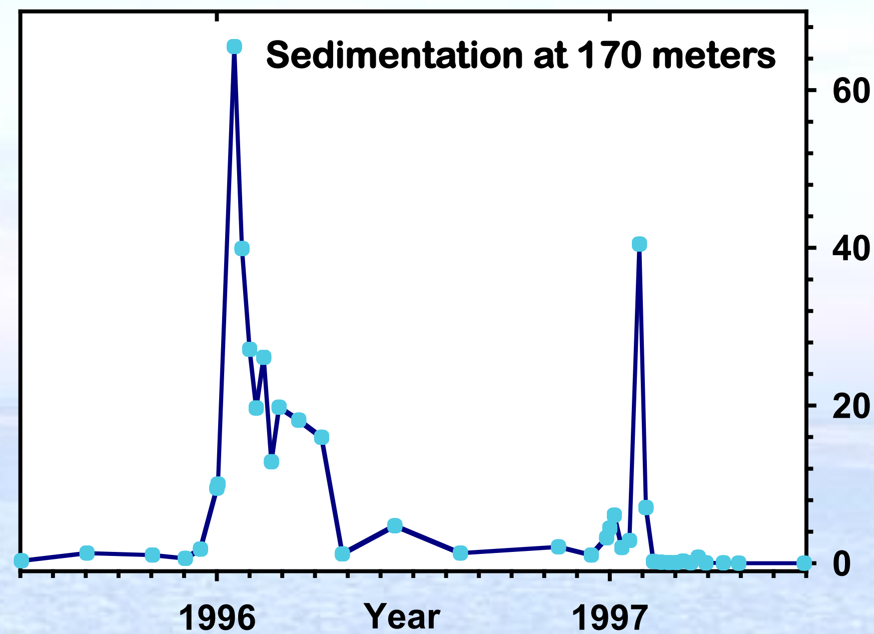


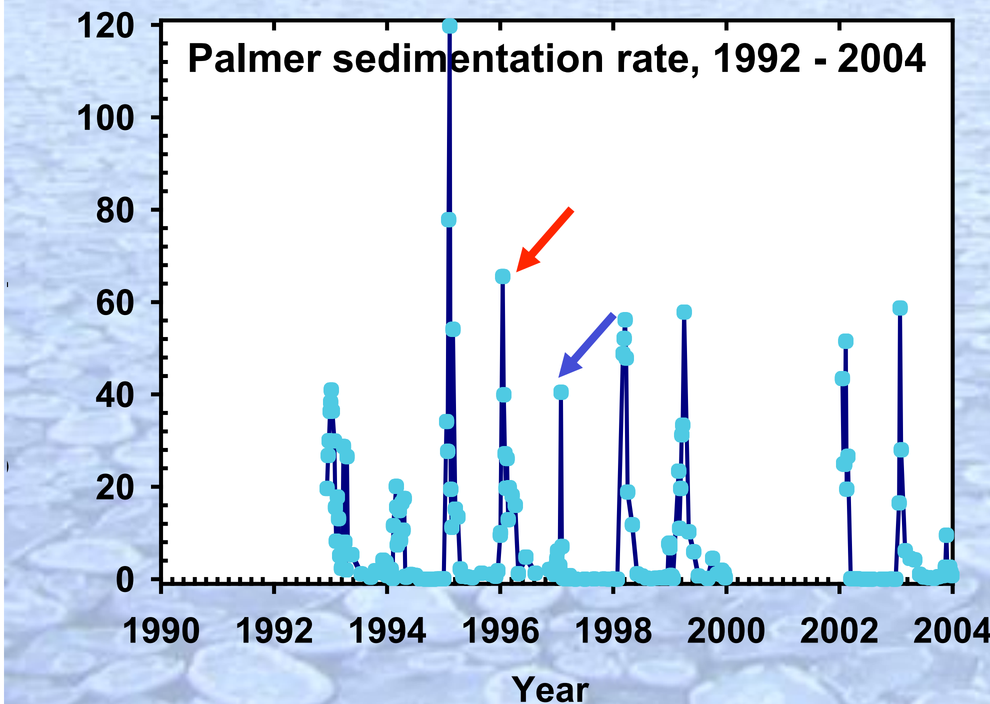
Sediment trap variability, 1993-2003





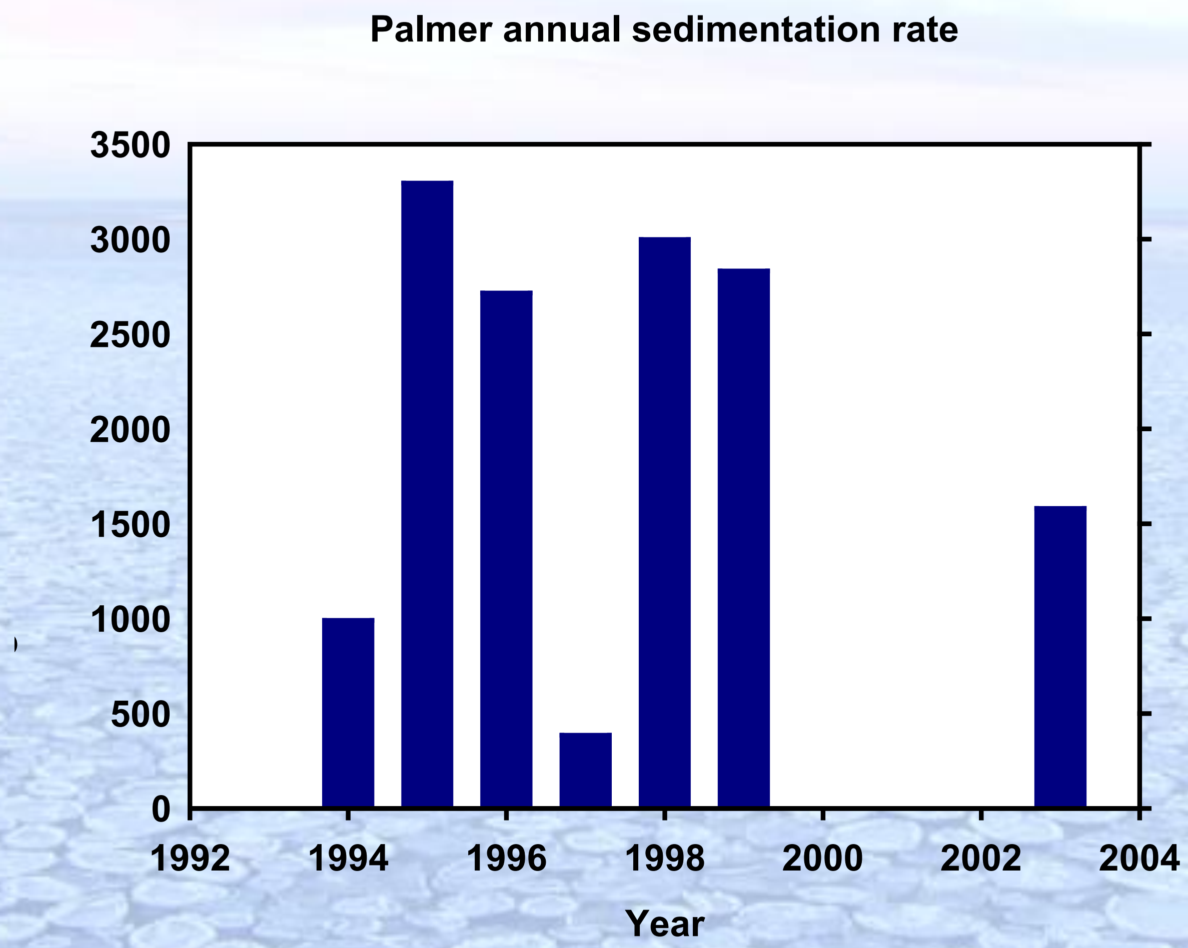




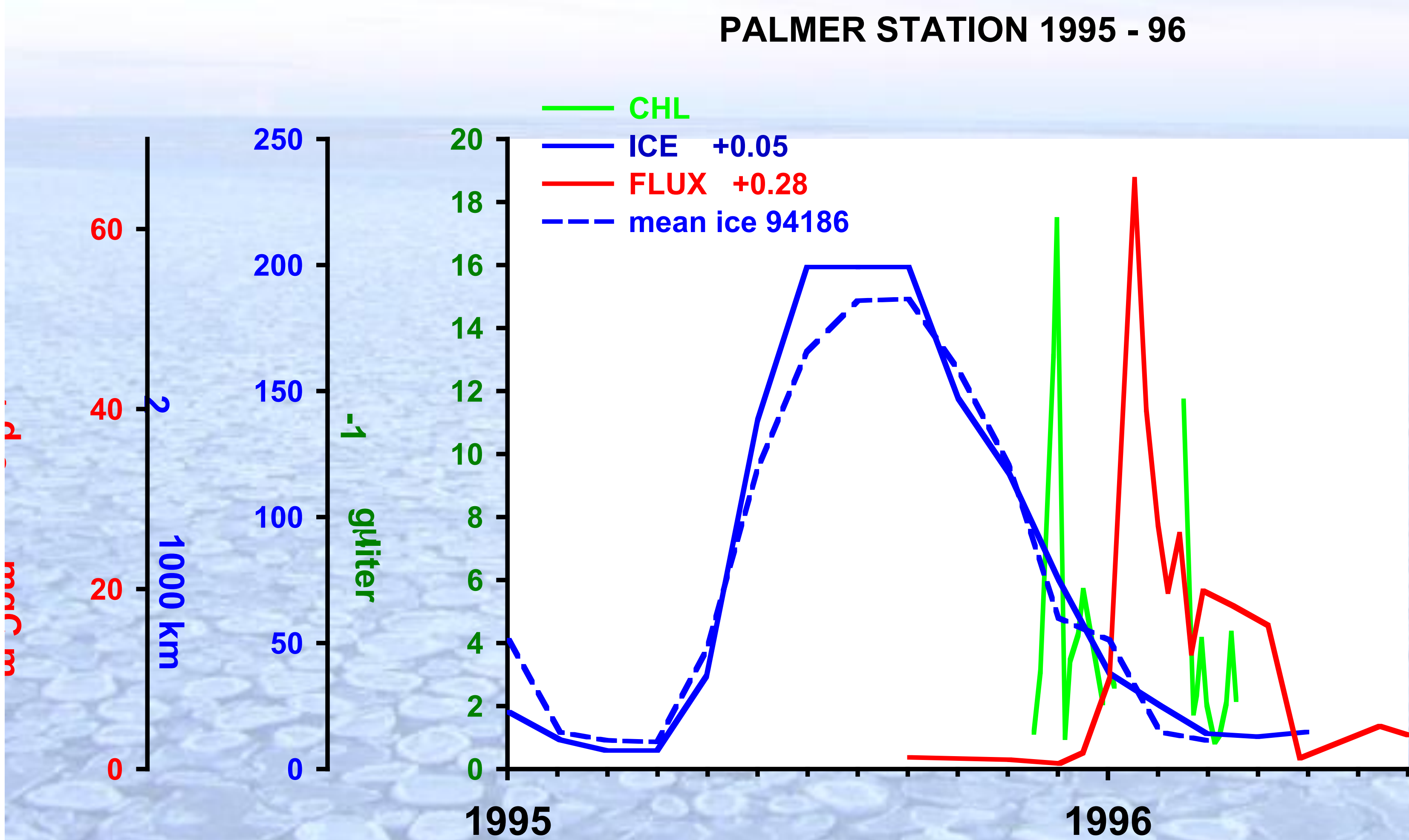


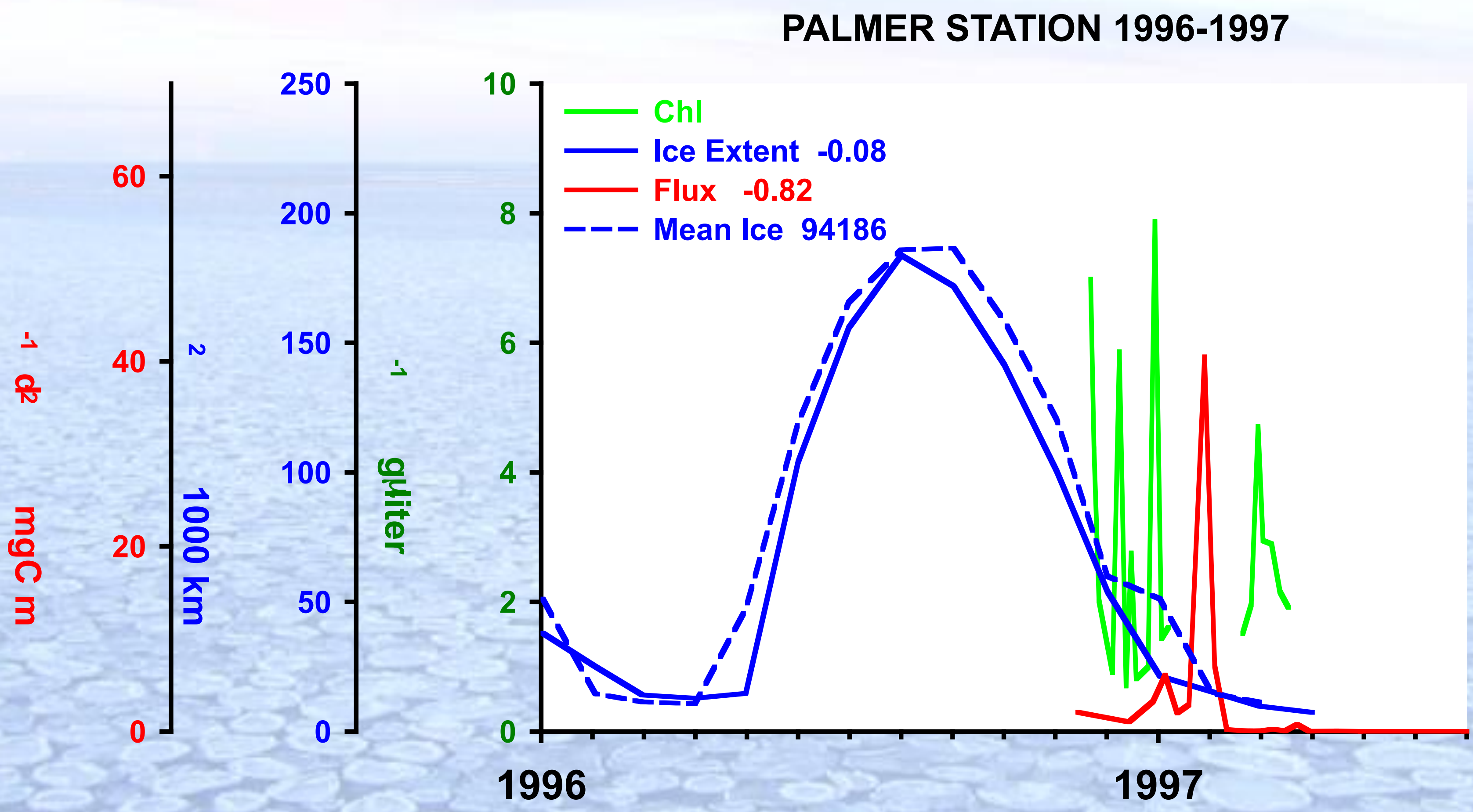
Annual sedimentation

Year	mgC m^{-2} y^{-1}	%PP
1994	1057	1.8
1995	3467	2.0
1996	3308	0.9
1997	402	0.2
1998	3164	3.0
1999	3082	6.6 !!
2003	1769	1.0

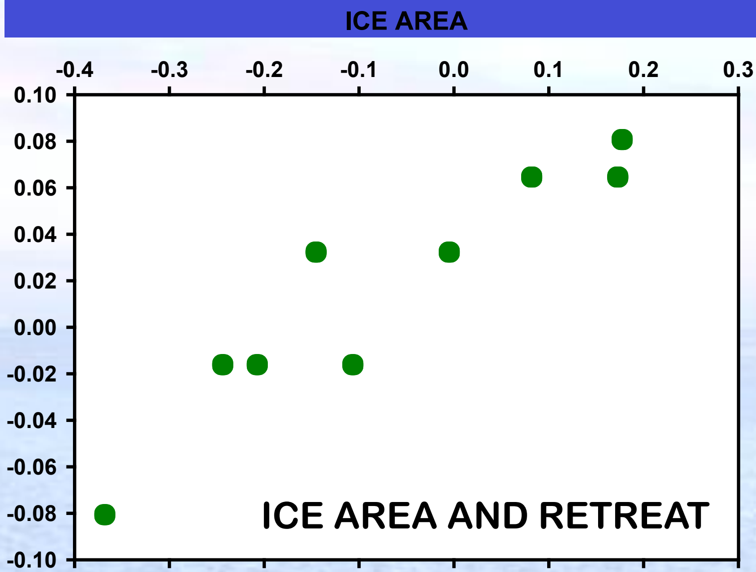

Palmer annual sedimentation rate
3500
3000
2500
2000
1500
1000
500
0
1992
1994
1996
1998
2000
2002
2004
Year

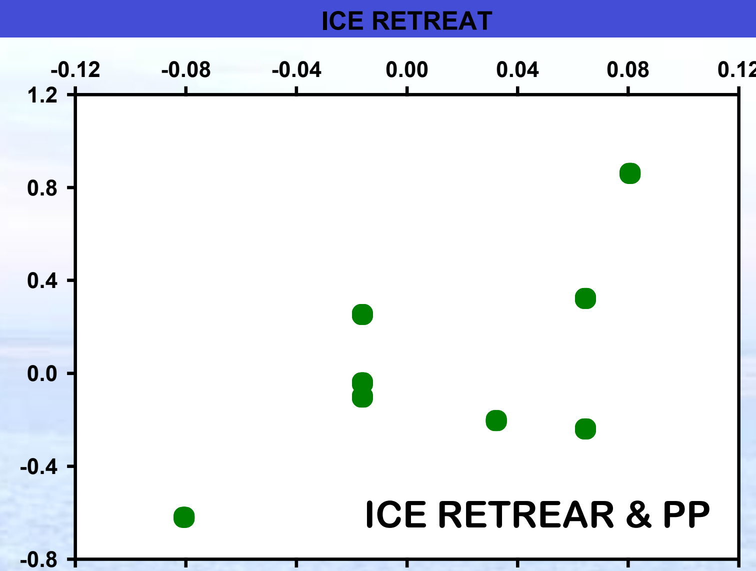
CONCEPTUAL MODEL OF SIZ DYNAMICS
Ice extent & retreat ⟶ bloom ⟶ sedimentation



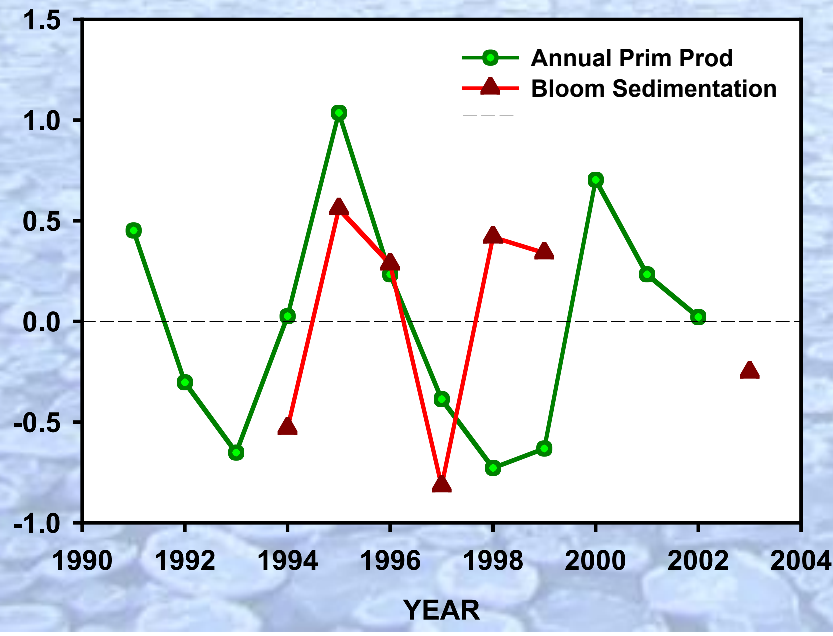

PALMER STATION 1996-1997
Chl
Ice Extent -0.08
Flux -0.82
Mean Ice 94186
mgC m^{-2} d^{-1}
1000 km^{2}
µg liter^{-1}
0
20
40
60
0
50
100
150
200
250
0
2
4
6
8
10
1996
1997

ICE RETREAT, PRIMARY PRODUCTION AND SEDIMENTATION

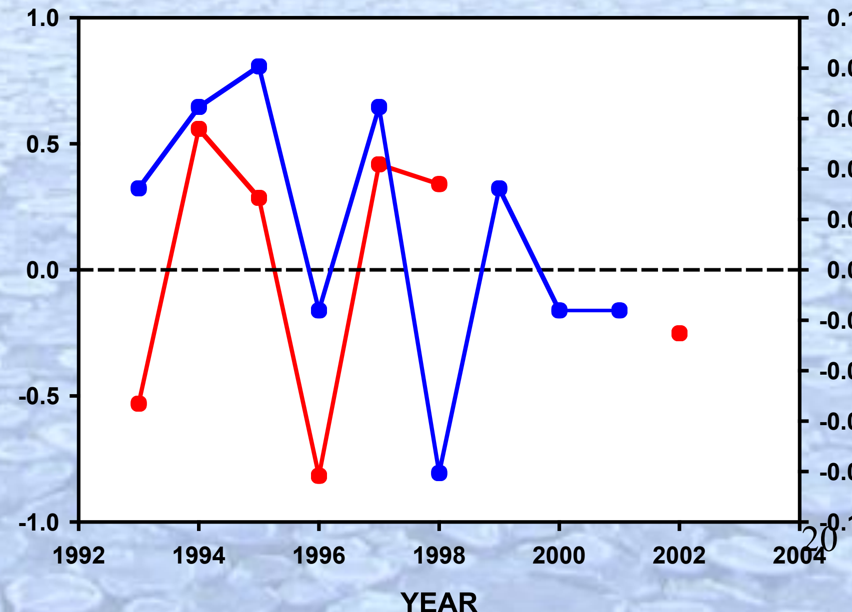




PRIMARY PRODUCTION and SEDIMENTATION



SEDIMENTATION and ICE RETREAT



SEA ICE VARIABILITY AND WATER COLUM PROCESSES

SUMMARY

- +/- 10-25% variations in ice translate to order of magnitude interannual variability in PP and sedimentation

- Sea ice coverage and duration (day of retreat) appear to influence annual variations in production and sedimentation

- 1999: “average” sedimentation but anomalous high relative to PP and ice retreat…a year dominated by salps not krill.

- Need more years!!

2. COMPARATIVE FOOD WEB STRUCTURE
EFFECTS OF PHYTOPLANKTON COMPOSITION

HOW DOES PHYTOPLANKTON COMMUNITY STRUCTURE INFLUENCE BIOGEOCHEMICAL PROCESSES?

COMPARISON OF FOODWEBS IN ROSS SEA POLYNYA AND WEST ANTARCTIC PENINSULA IN JANUARY USING AN INVERSE APPROACH

- ✓ **Fates of primary production**
- ✓ **POC and DOC fluxes**
- ✓ **Foodweb characterization (Legendre & Rassoulzedegan)**

FOODWEB RECONSTRUCTION
Chesapeake Bay

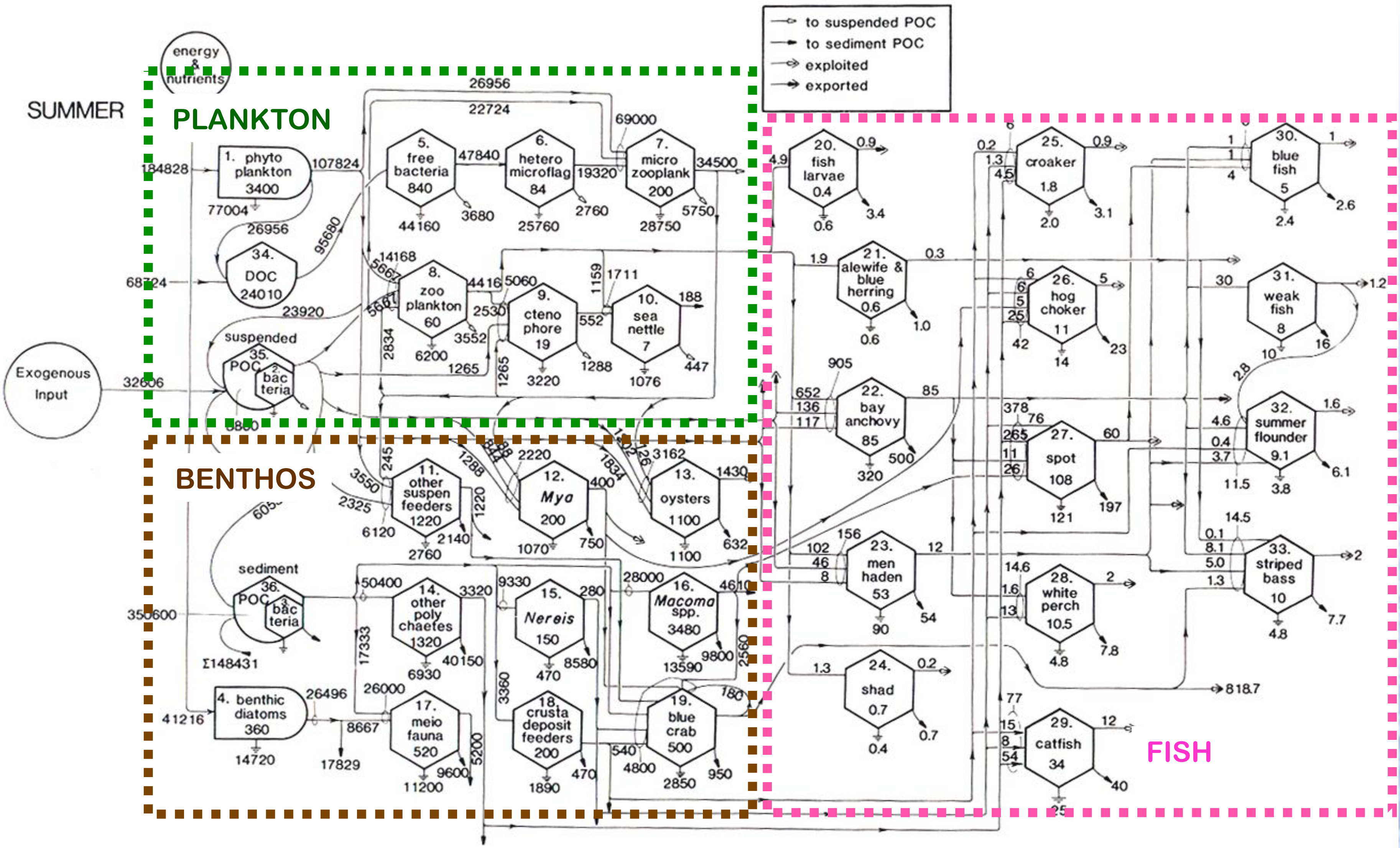
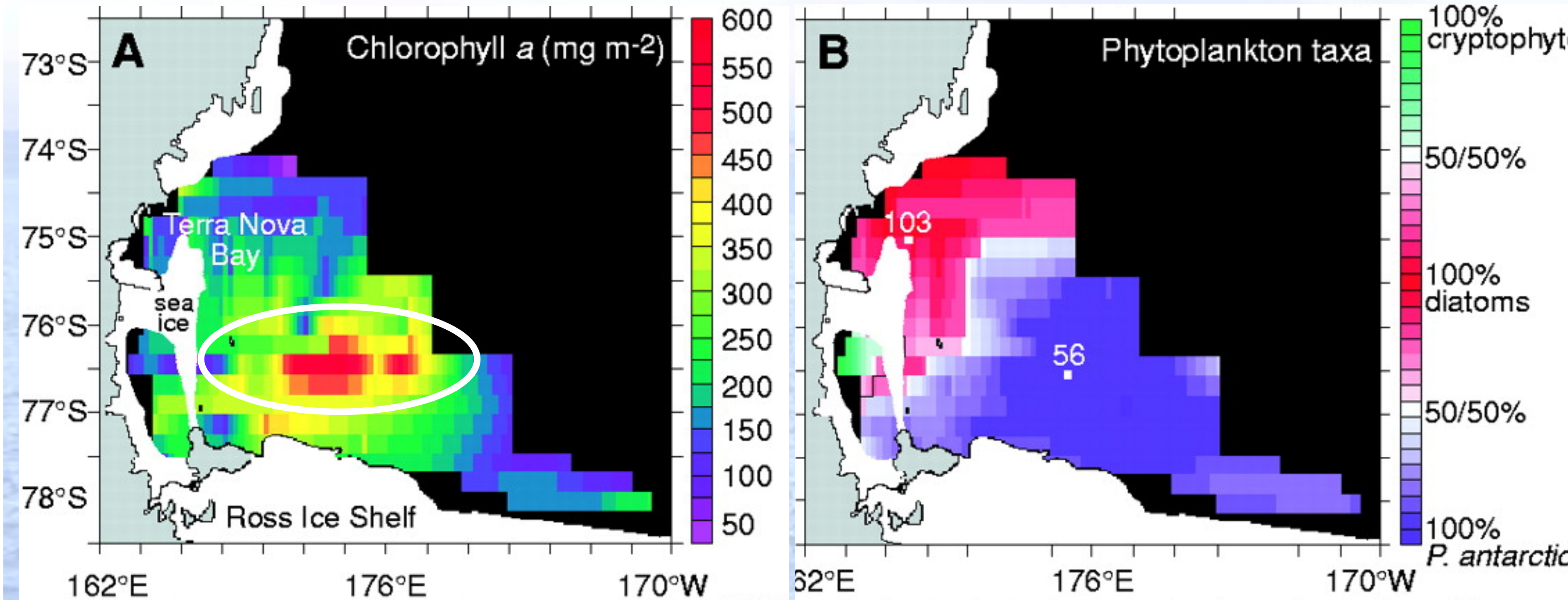


FIG. 2. Energy flow network of the mesohaline area of Chesapeake Bay during summer (biomass C in mg/m², carbon flows in mg·m⁻²·summer⁻¹).



Arrigo et al. Science 1999

ROSS SEA POLYNYA STUDIED INTENSIVELY 1994-1999
US JGOFS AESOPS PROGRAM
ROAVERRS PROGRAM
ITALIAN RESEARCH IN TERRA NOVA BAY
PHYTOPLANKTON COMMUNITIES WELL CHARACTERIZED

ROSS SEA vs WAP

1. ROSS: dominated by Phaeocystis.
   WAP: diatoms

2. ROSS: grazer biomass low (but few data for polynya)
   WAP: dominated by krill

3. BACTERIAL PRODUCTION is ~10% of annual NPP
   and lower during bloom.

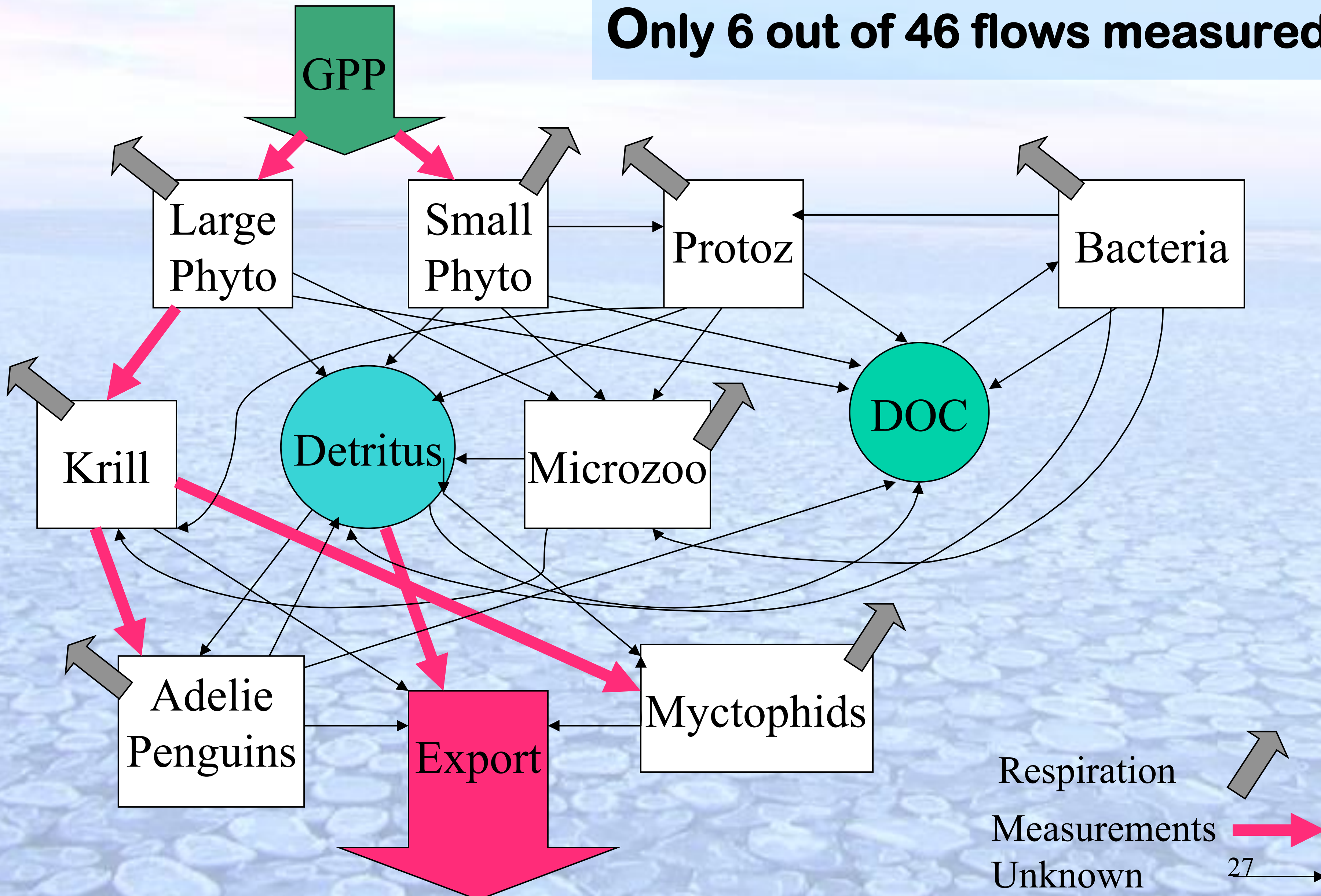
4. ROSS: dominated by POC accumulation
   WAP: ???

RECONSTRUCTING FOODWEBS: THE PROBLEM

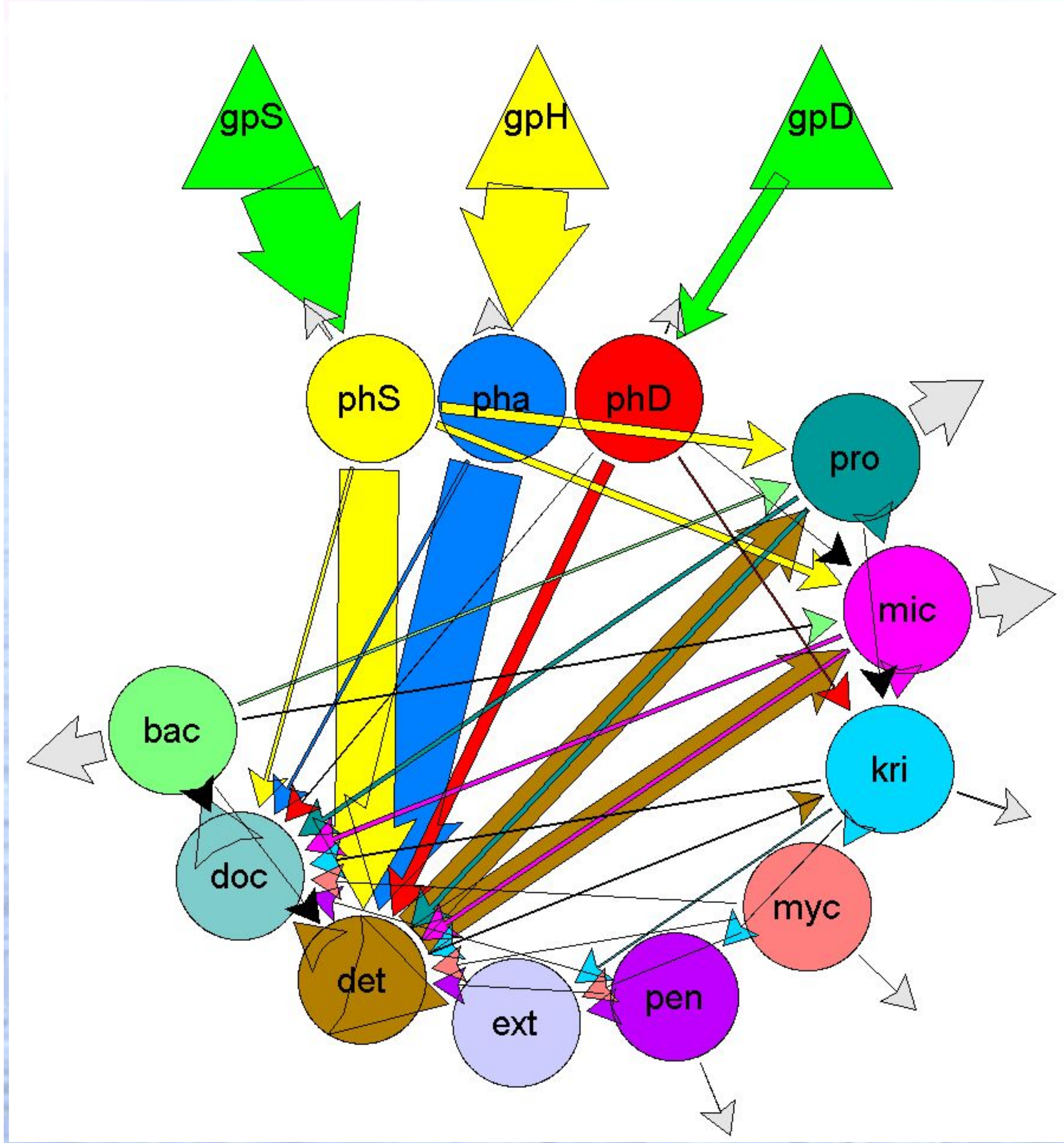
1. MEASUREMENTS ARE NOT ADEQUATE TO FULLY SPECIFY FLOW STRUCTURES IN FOODWEBS. MANY PATHWAYS OR COMPARTMENTS CANNOT BE MEASURED EASILY OR ROUTINELY.

2. WHAT LEVEL OF DETAIL IS NECESSARY? FUNCTIONAL GROUPS? INDIVIDUAL SPECIES?

WAP 1996:
Only 6 out of 46 flows measured.



AGGREGATED FOOD WEB STRUCTURE



Small phytoplankton*
Phaeocystis colonies
Diatoms
Protozoan grazers
Microzooplankton
Krill +Mesozooplankton
Myctophids
Penguins
Bacteria
Detritus
DOC

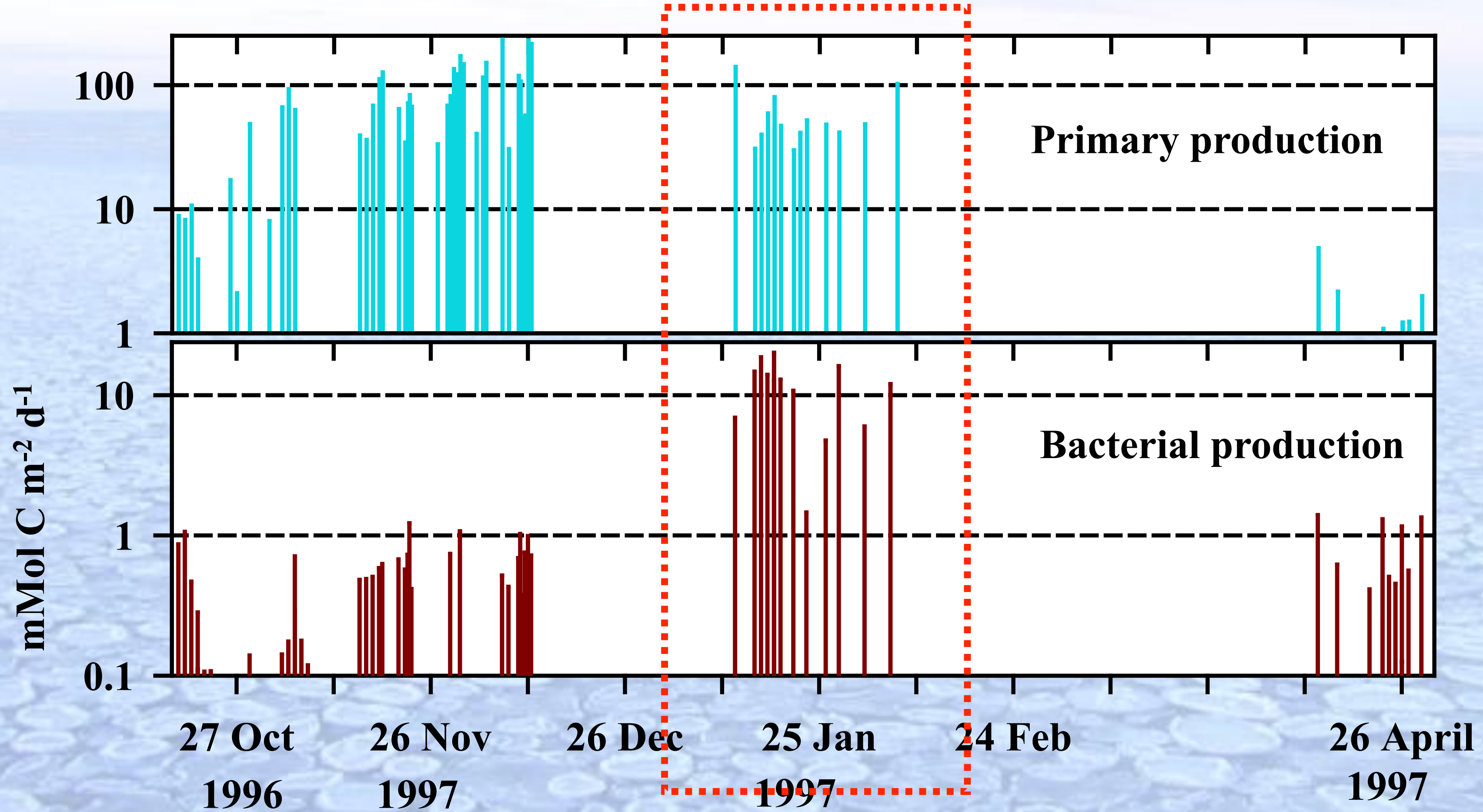
***mostly Phaeocystis unicells < 5 um.**

Flows proportional to width of arrows

THE INVERSE METHOD

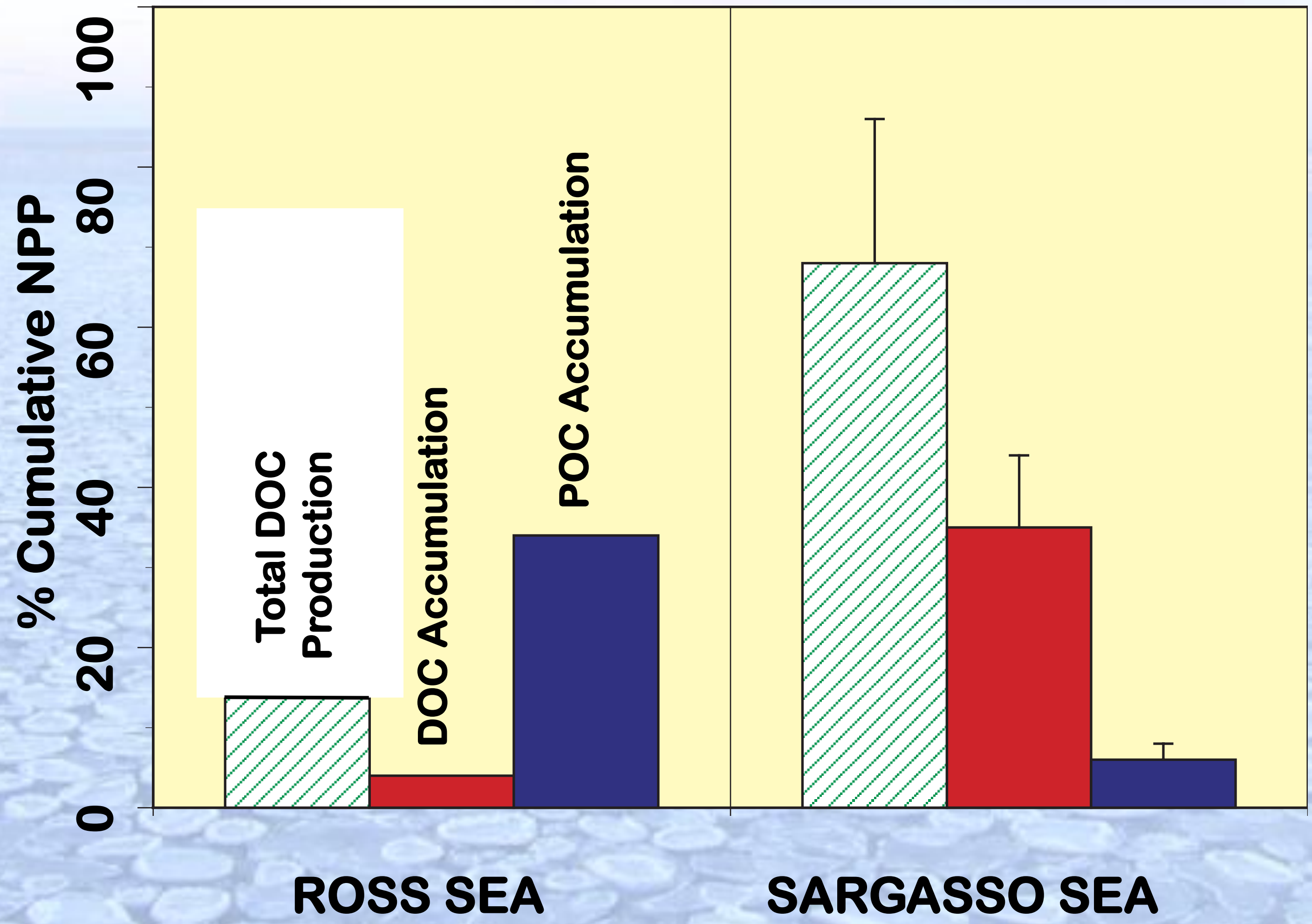
1. APPROACH BORROWED FROM GEOPHYSICS (EG, SEISMOLOGY). APPLIED TO FOODWEB RECONSTRUCTION BY VEZINA AND PLATT (1986) – GROWING NUMBER OF STUDIES.
2. USES OBSERVATIONS AND KNOWN BIOLOGICAL CONSTRAINTS (EG, GROWTH & ASSIMILATION EFFICIENCY, BIOMASS-SPECIFIC RESPIRATION) TO GIVE BEST-FIT PATTERNS OF FLOWS IN SPECIFIED FOODWEBS.
3. IN ESSENCE, SOLVING SYSTEMS OF LINEAR BALANCE EQUATIONS. NONSTEADY STATES ARE ADDRESSED.
4. PROVIDES AND OBJECTIVE AND CONSISTENT METHOD FOR FOODWEB RECONSTRUCTION. DIFFERENT ASSUMPTIONS CAN BE TESTED.

INPUT DATA: ROSS OBSERVATIONS
(Primary & Bacterial Production)



NPP data courtesy Walker Smith

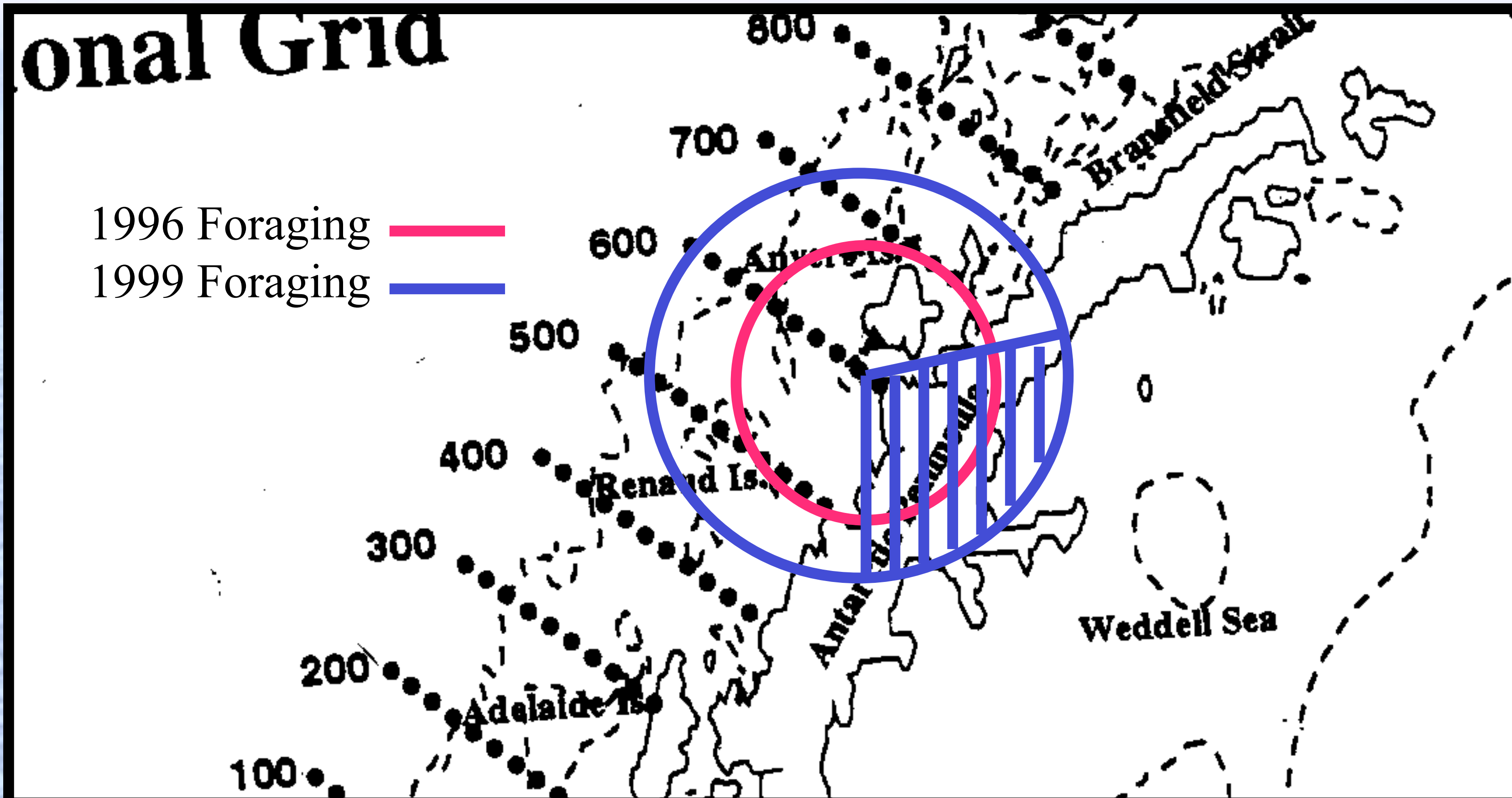
INPUT DATA: ROSS OBSERVATIONS (POC and DOC accumulation)



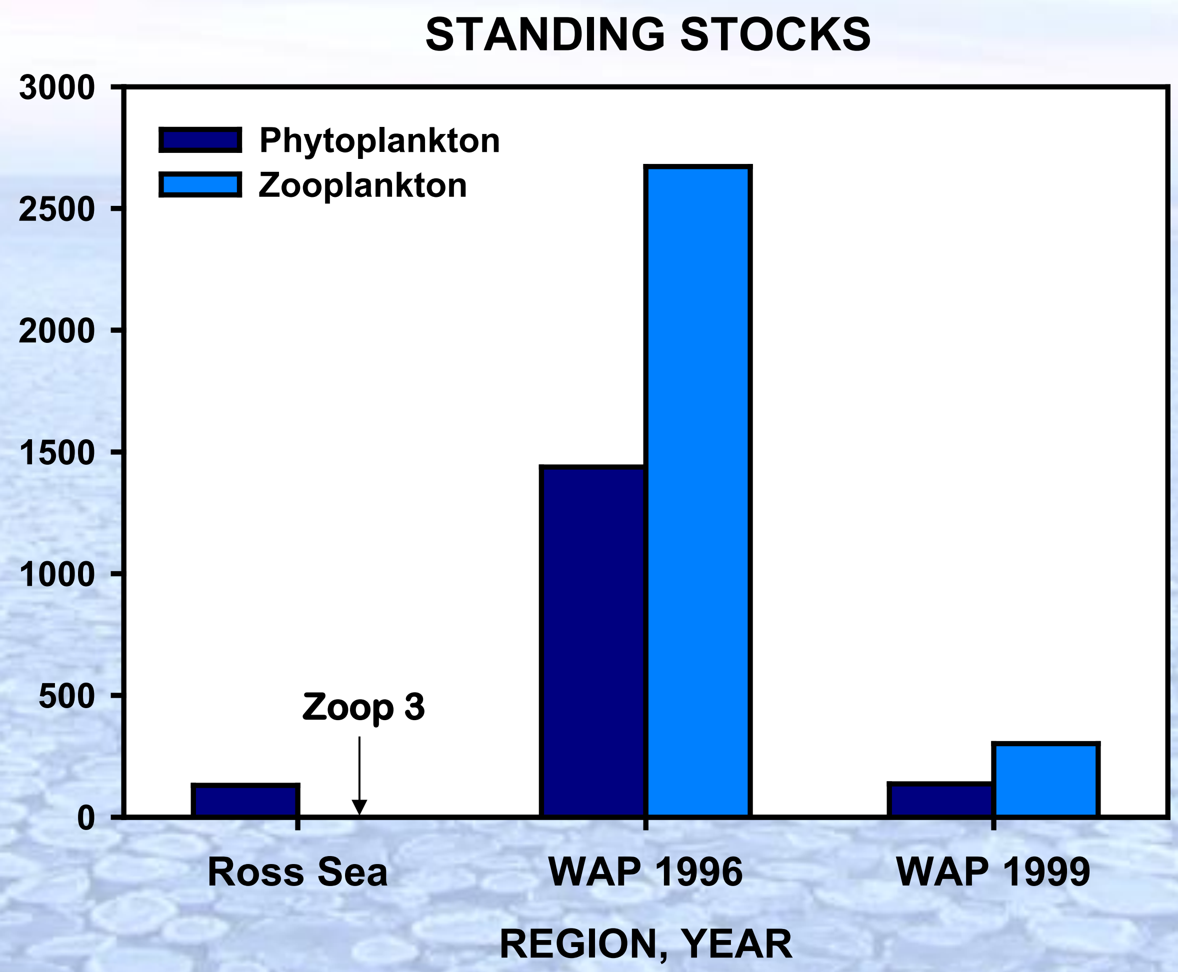
Carbon budgets during 60-70 d spring blooms
Courtesy Craig Carlson

INPUT DATA: WAP OBSERVATIONS (example)

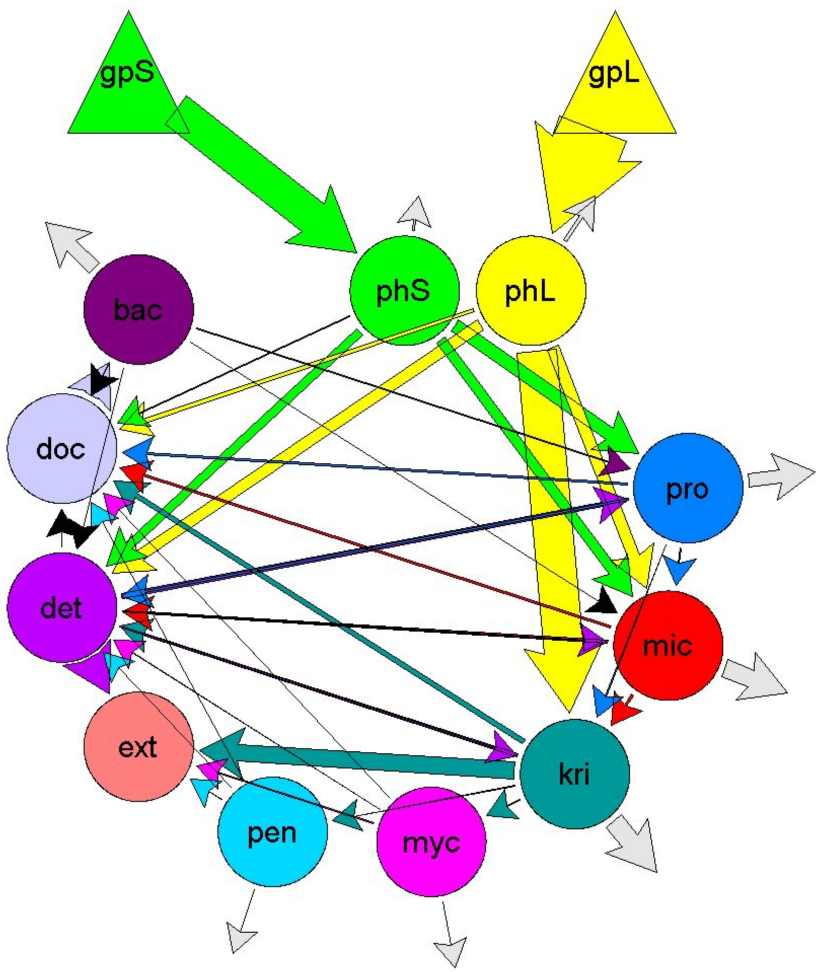
Observations taken from grid stations within Adelie penguin foraging region determined with remote transmitters on birds.



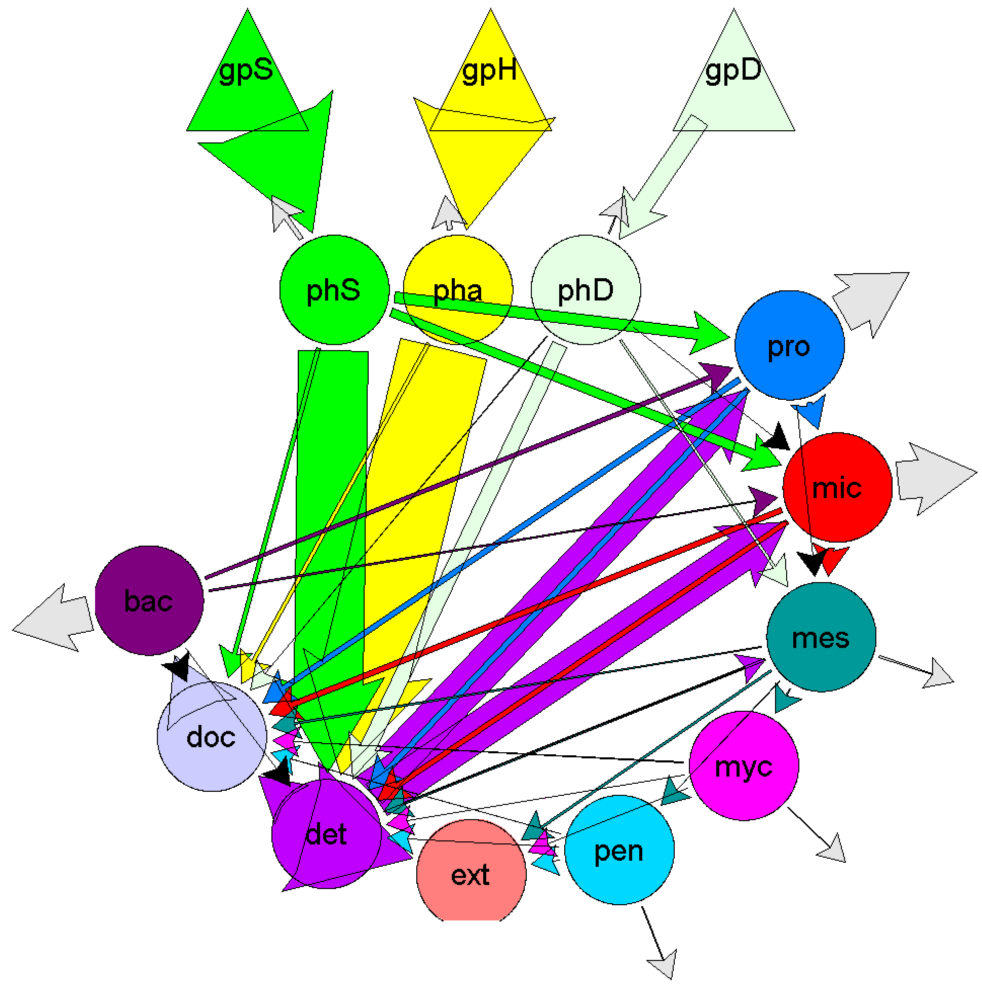
INPUT DATA: WAP OBSERVATIONS (example)



WAP 1996 GPP = 1200 ROSS SEA 96 GPP = 550

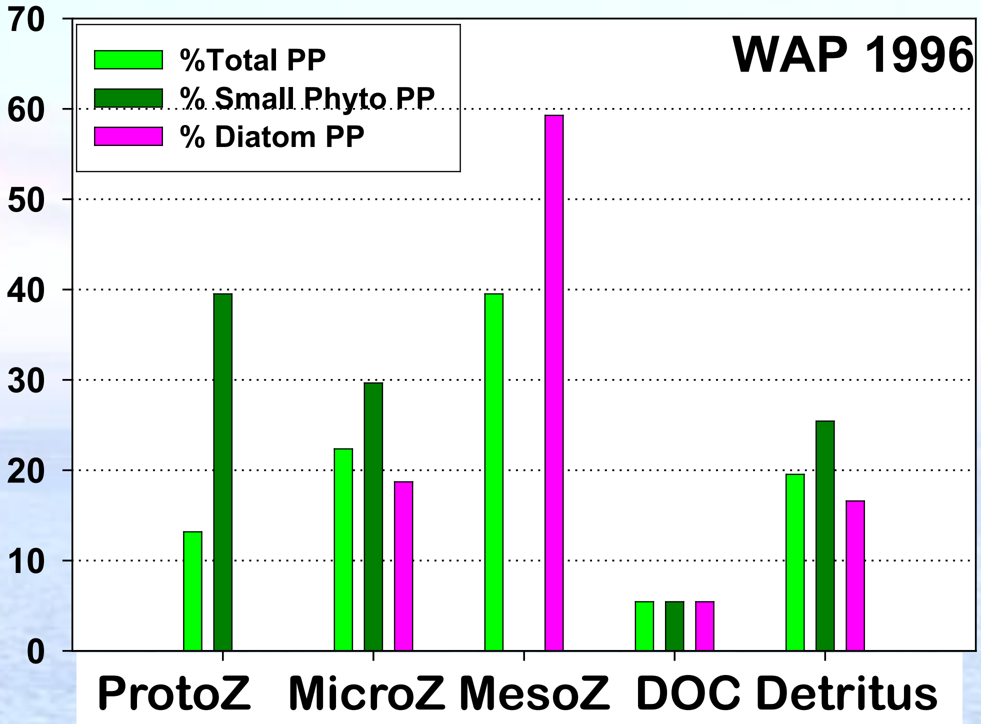


1.26 0.1%



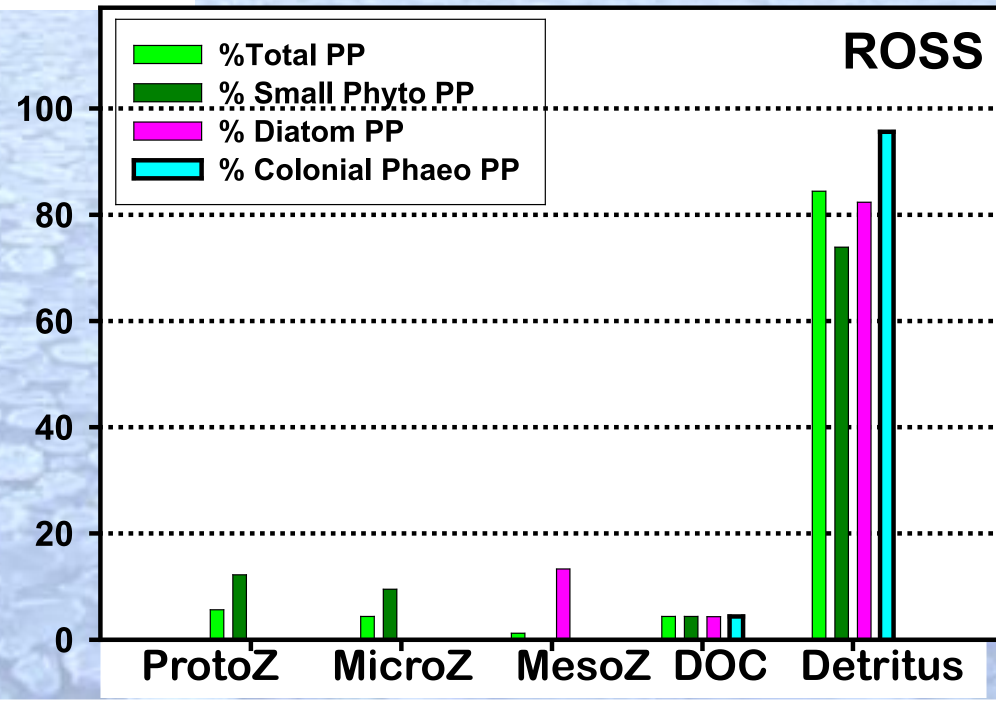
2.16 0.4%

RESULTS: FATE of PRIMARY PRODUCTION

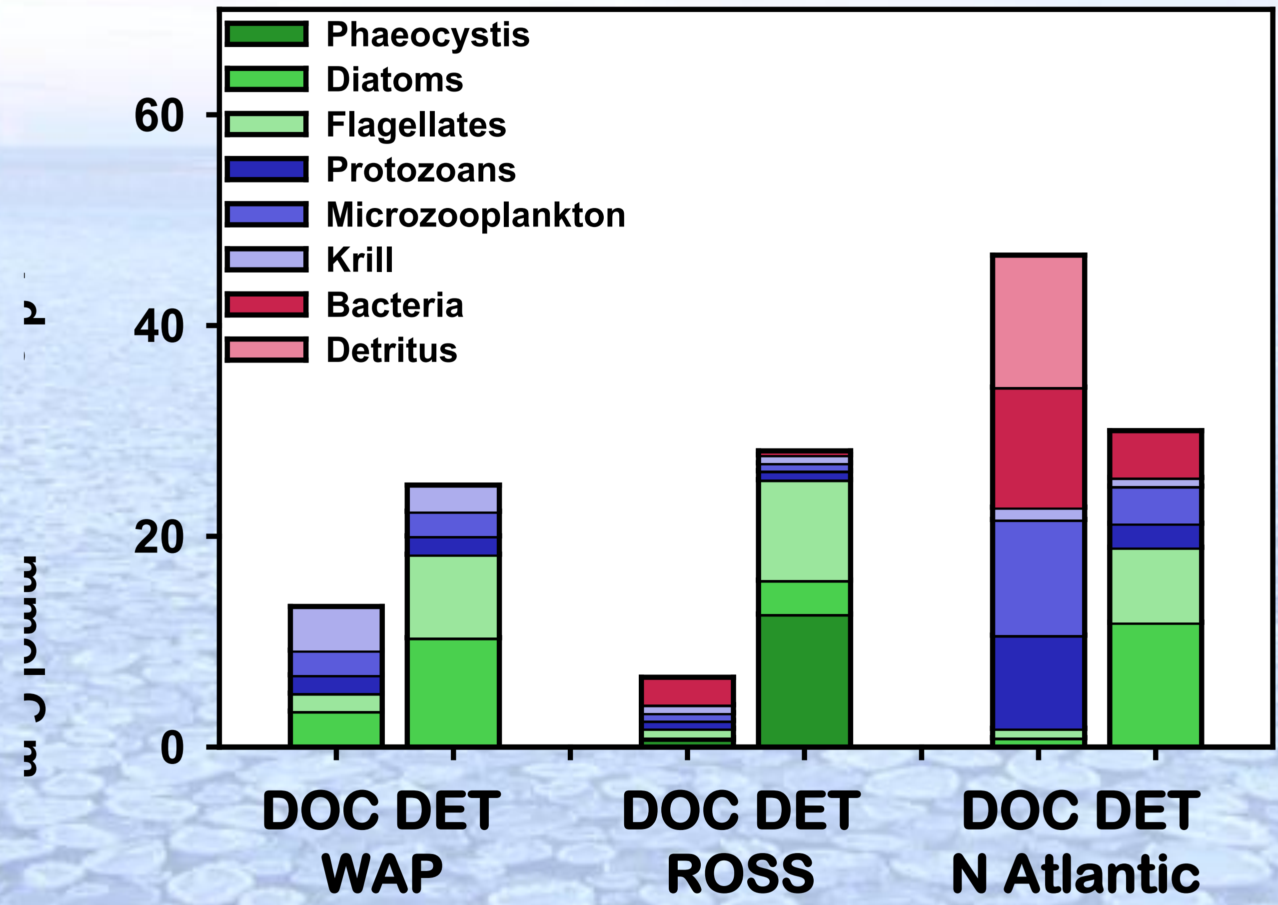


West Antarctic Peninsula: Grazer-dominated system

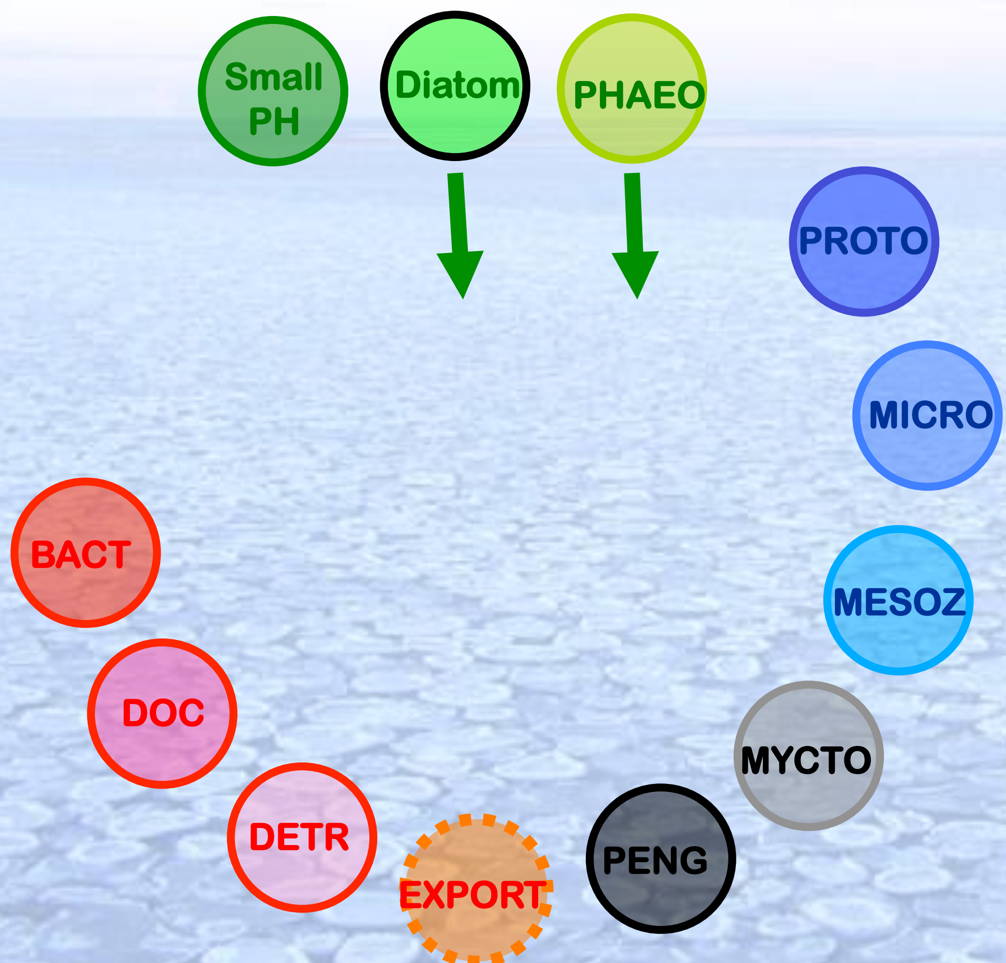
Ross Sea: Detritus-dominated system



RESULTS: DOC and POC PRODUCTION



RESULTS: FOODWEB CLASSIFICATION
after Legendre and Rassoulzedegan, 1996

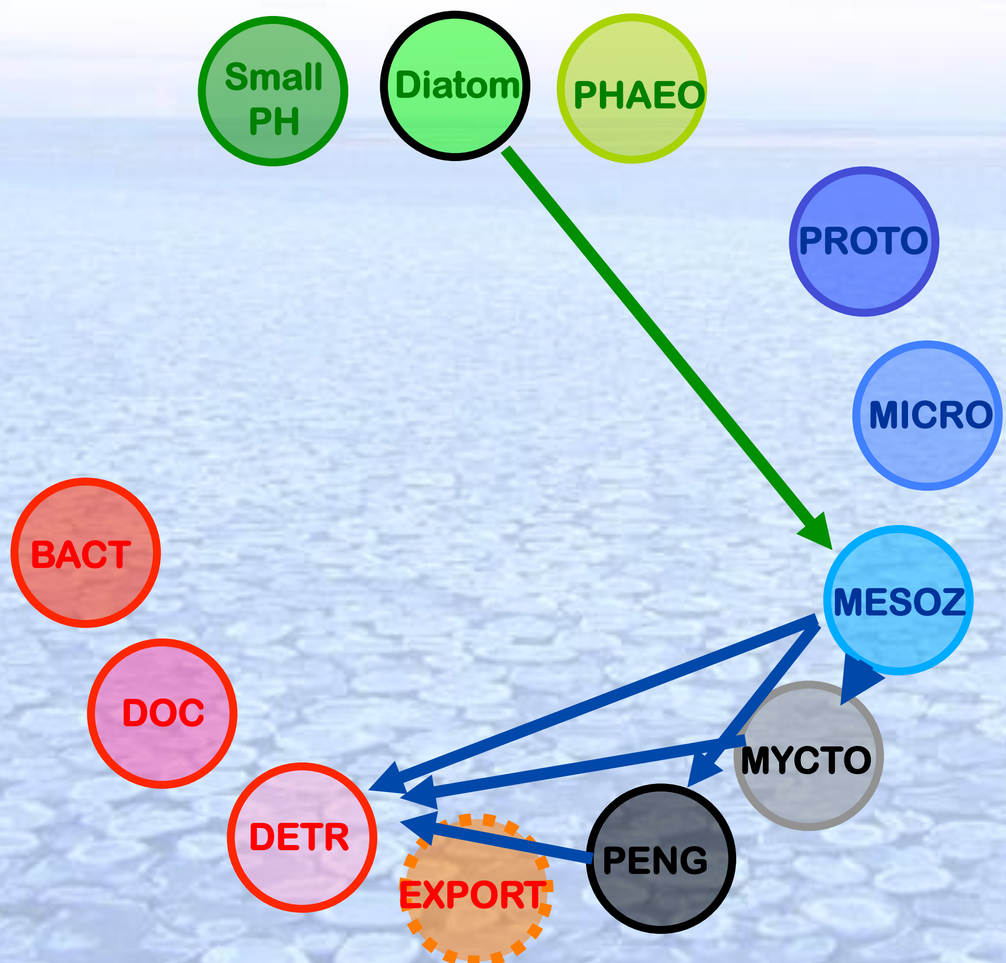


Key Structuring Flows In the foodweb:

1. **Large Phytoplankton Production (P_T)**

Flows normalized to total NPP

RESULTS: FOODWEB CLASSIFICATION

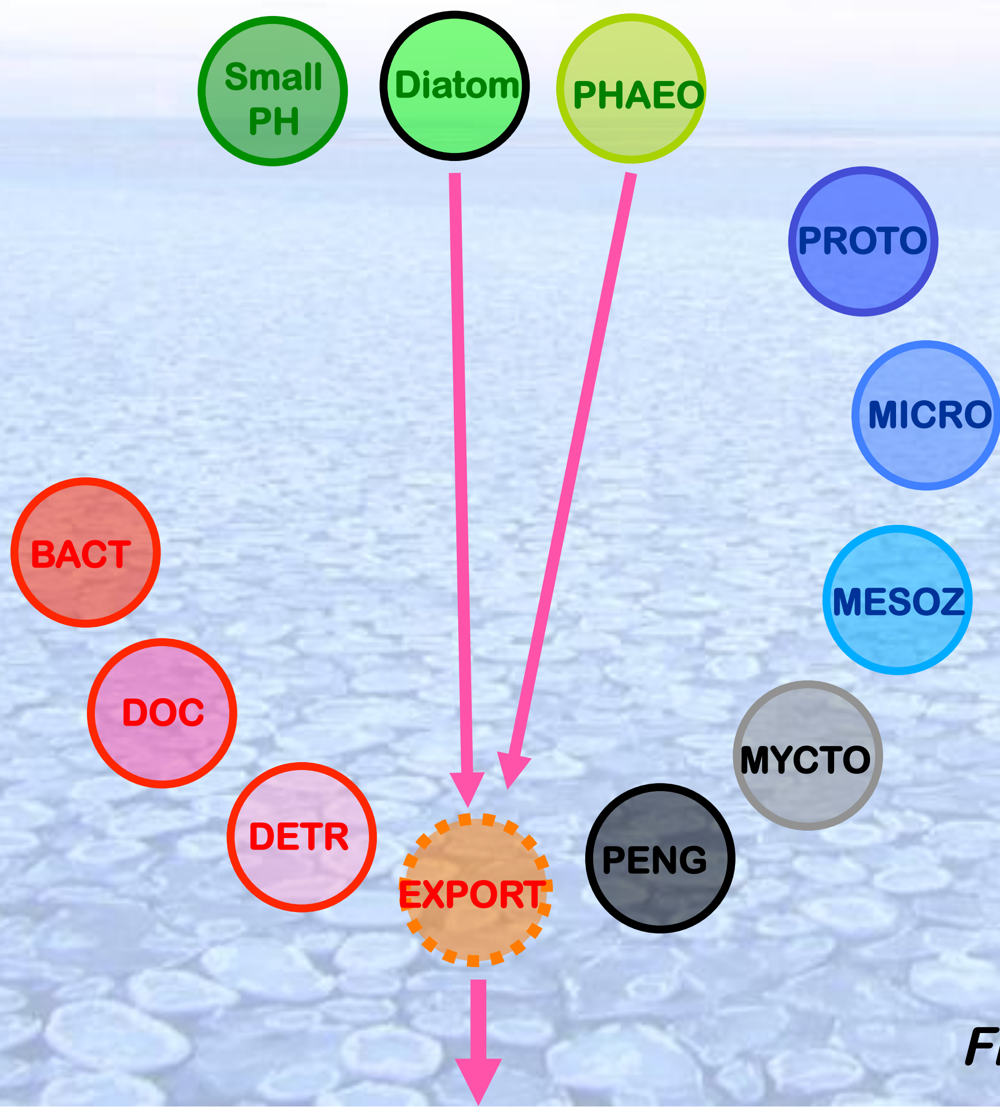


Key Structuring Flows In the foodweb:

1. Large Phytoplankton Production
2. Consumption and export via large grazers & predators (F_T)

Flows normalized to total NPP

RESULTS: FOODWEB CLASSIFICATION

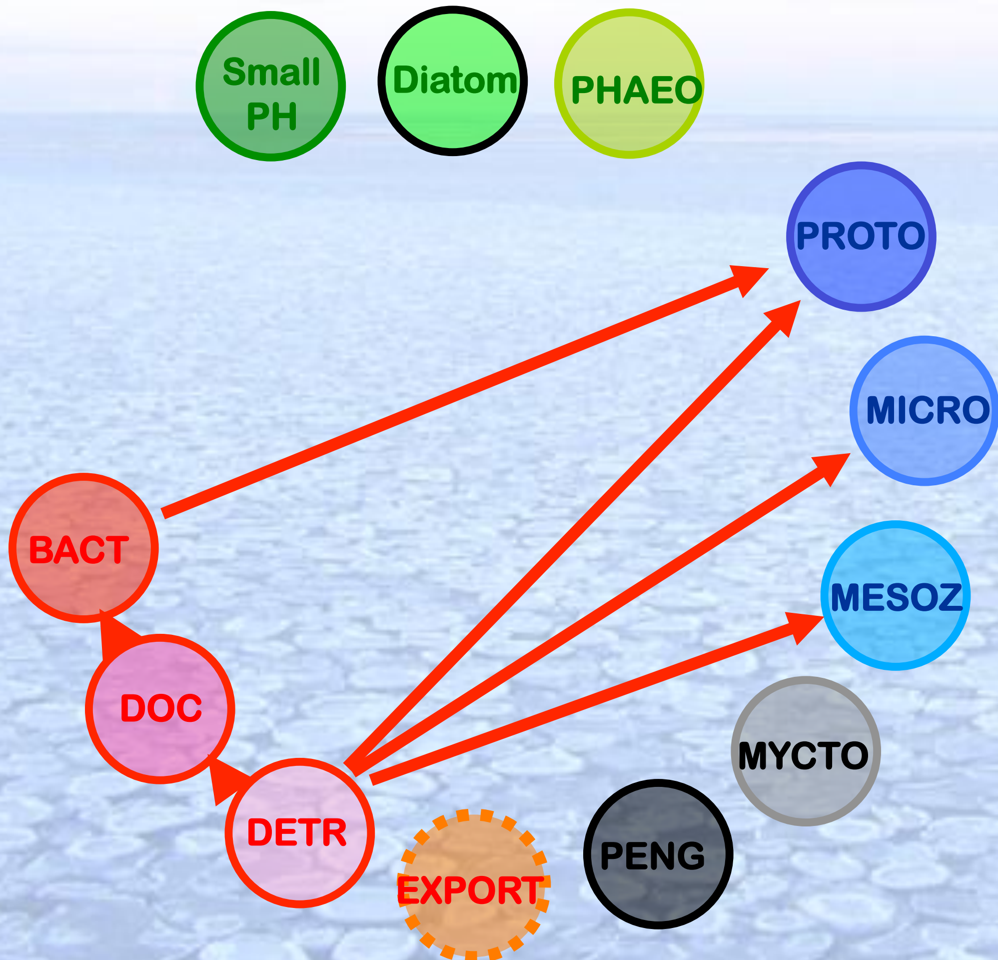


Key Structuring Flows In the foodweb:

1. Large Phytoplankton Production
2. Consumption and export via large grazers & predators
3. Ungrazed, sinking phytoplankton (D_T)

Flows normalized to total NPP

RESULTS: FOODWEB CLASSIFICATION



Key Structuring Flows In the foodweb:

1. Large Phytoplankton Production (P_L)
2. Consumption and export via large grazers & predators (F_T)
3. Ungrazed, sinking phytoplankton (D_T)
4. Recycled flows via detritus and DOC $= 1-(F_T + D_T)$

Flows normalized to total NPP

RESULTS: FOODWEB CLASSIFICATION

Legendre & Rassoulzedegan Foodweb models	P_L/P_T	R_T/P_T	F_T/P_T	D_T/P_T
Sinking of ungrazed cells	1.00	0	0	1.00
Herbivorous foodweb	0.80	0.30	0.60	0.10
Multivorous foodweb	0.35	0.60	0.30	0.10
Microbial foodweb	0.10	0.80	0.20	0
Microbial Loop	0	1.00	0	0
INVERSE RESULTS				
North Atlantic Bloom	0.50	0.78	0.04	0.18
WAP 1996	0.67	0.69	0.19	0.11
ROSS SEA 1996	0.54	0.47	0.02	0.50

COMPARATIVE FOOD WEB STRUCTURE SUMMARY

1. PLAUSIBLE FOODWEBS, CONSISTENT WITH OBSERVATIONS, CAN BE RECOVERED FOR BOTH AREAS.

2. BOTH REGIONS DOMINATED BY LARGE PHYTOPLANKTON BUT TAXON DIFFERENCES LEAD TO CONTRASTS IN GRAZER ABUNDANCE AND IMPACTS

3. WAP: GRAZER-DOMINATED SYSTEM
   ROSS: DETRITAL-DOMINATED

4. MOST DETRITAL FLOW ORIGINATES FROM UNGRAZED PHYTOPLANKTON

5. FOODWEB STRUCTURE DOMINATED BY LARGE PHYTOPLANKTON BUT TEND TOWARDS MICROBIAL FOODWEB STRUCTURE – EVEN WITH LOW BP AND DOC.

FINAL THOUGHTS

1. **IMPORTANCE OF SEA ICE IN STRUCTURING SYSTEMS**

2. **NEED TO WORK LONG TERM AT REGIONAL SCALES**

5. **NEED FOR MODELS TO INTEGRATE SPARSE OBSERVATIONS**

ACKNOWLEDGEMENTS and THANKS

Palmer LTER Colleagues

US JGOFS Colleagues: Walker Smith & Bob Anderson (AESOPS)

ROAVERRS Project: Jack DiTullio et al.

George Jackson & Tammi Richardson (TAMU – inverse models)

Helen Quinby, Joann Kelly and many others for lab help

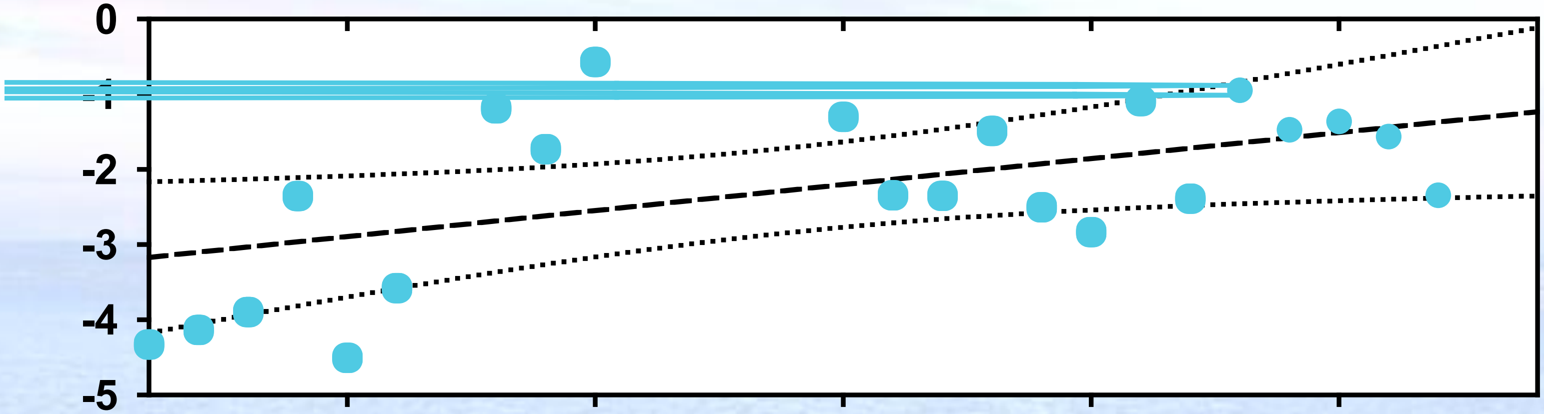
NSF-OPP

Andy Clarke and EASIZ, for the invitation

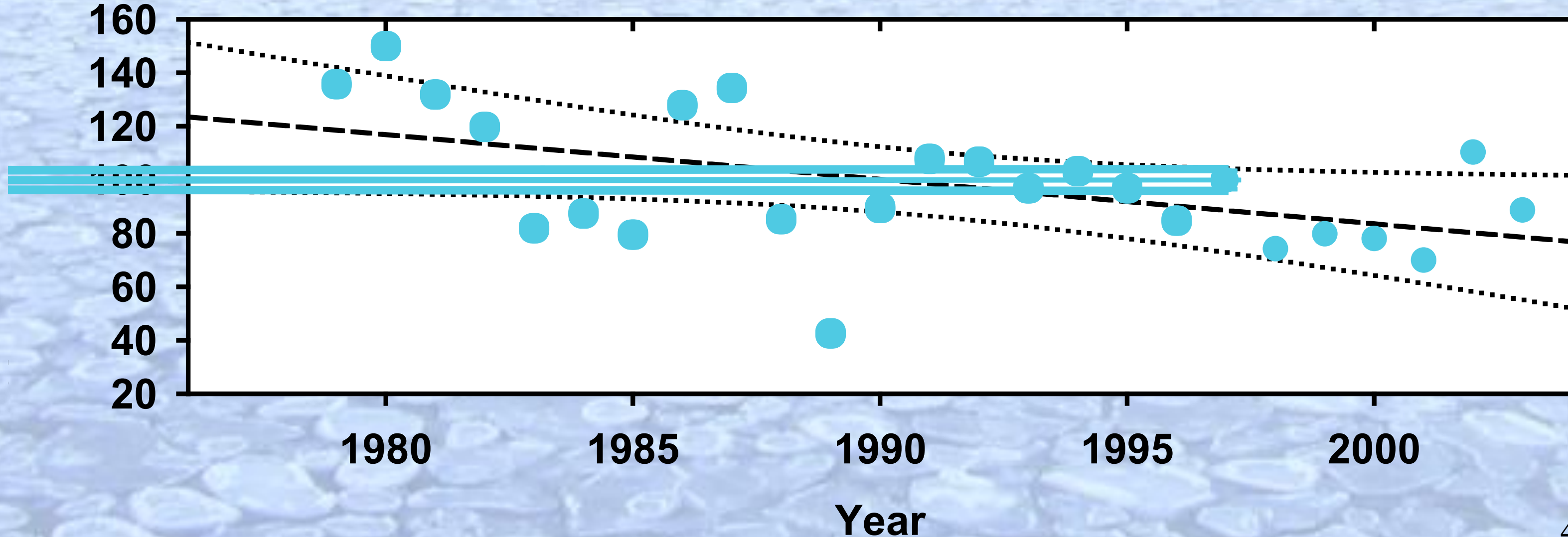
All of you, for your attention


Inshore, local area sampling
Twice per week, October - April


PALMER MEAN ANNUAL TEMPERATURE 1979-2003

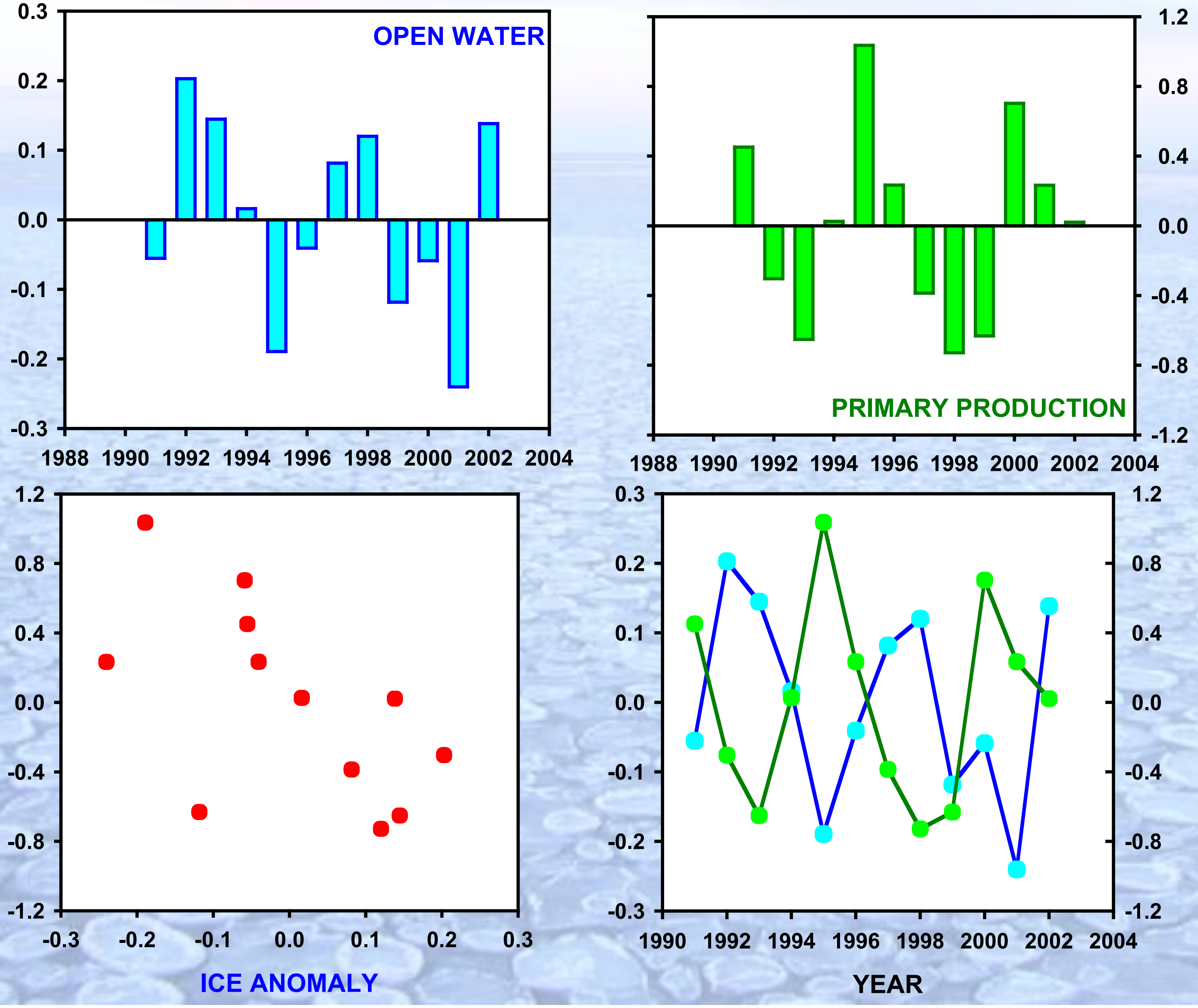


PALMER MEAN SEA ICE EXTENT 1979-2003



Open water in ice margin and primary production

More open ice margin, less PP



Sea Ice Area and Day of Retreat
larger area – later retreat