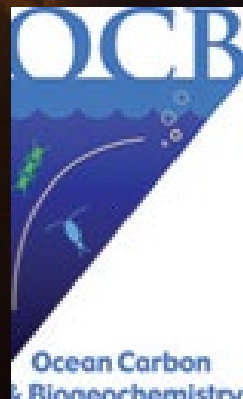
Organic matter utilization in Polar Seas

Hugh Ducklow
The Ecosystems Center/MBL
Palmer Long Term Ecological Research (LTER)

SO Scoping Workshop
Princeton University
8 June, 2009



From my invitation letter:

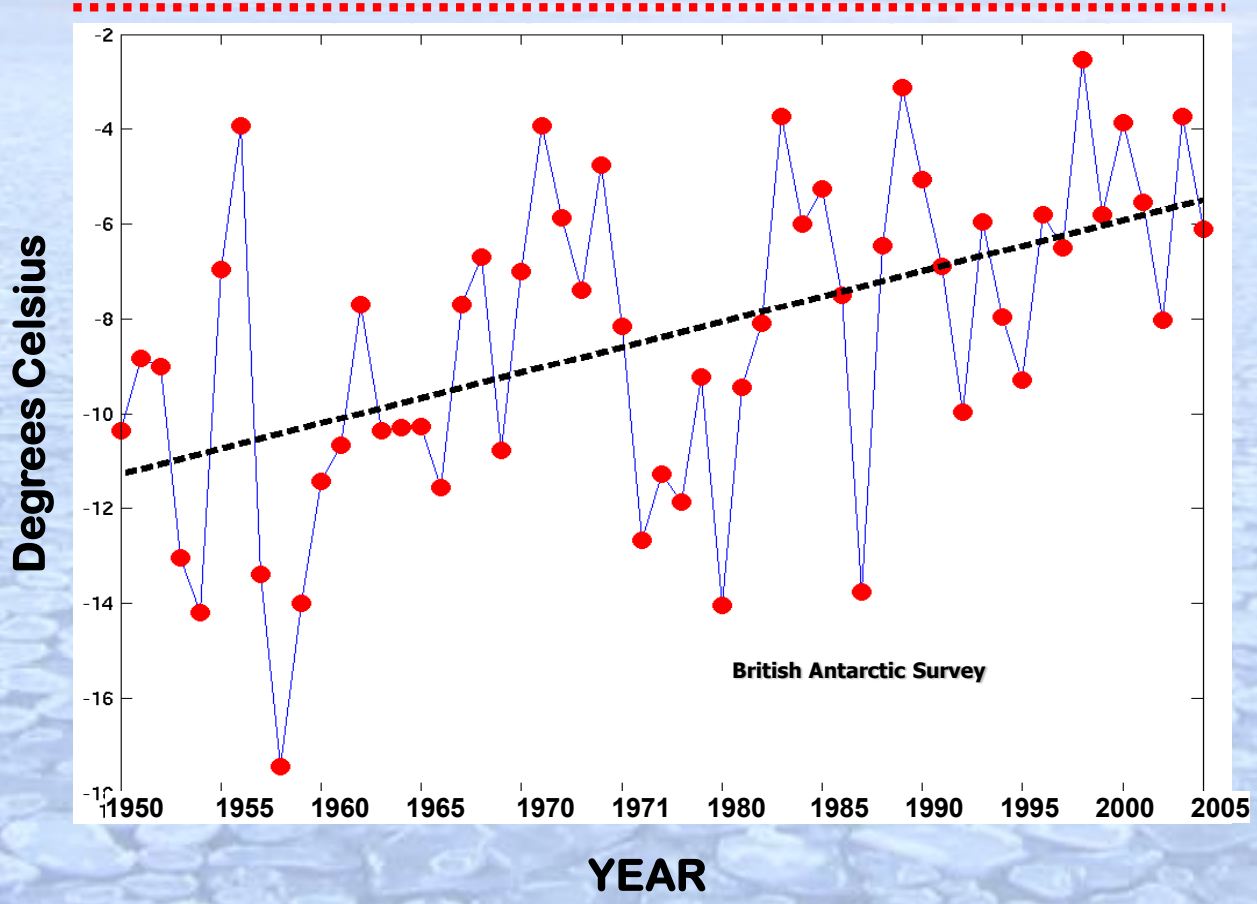
We would like to invite you to provide a plenary presentation dealing with "**Marine food webs and ecosystems: the need to represent the effects of ecosystem processes on carbon cycles**". This presentation should present an overview the current status of research in this area and provide a basis for subsequent working group discussions.

Climate change along the WAP

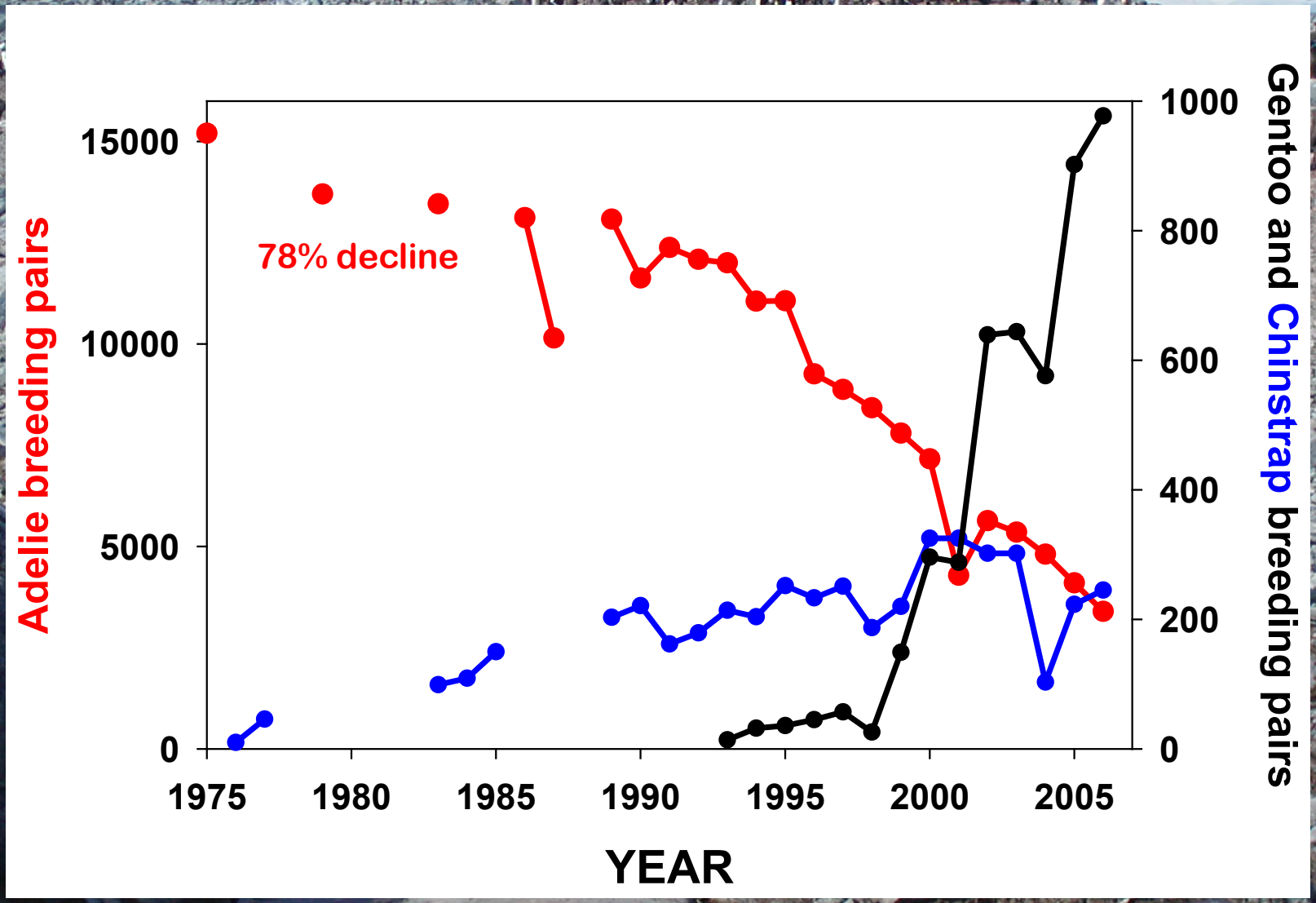
Average winter (June-July-August) temperature (Faraday Base)

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

-1.8°C (sea ice formation)

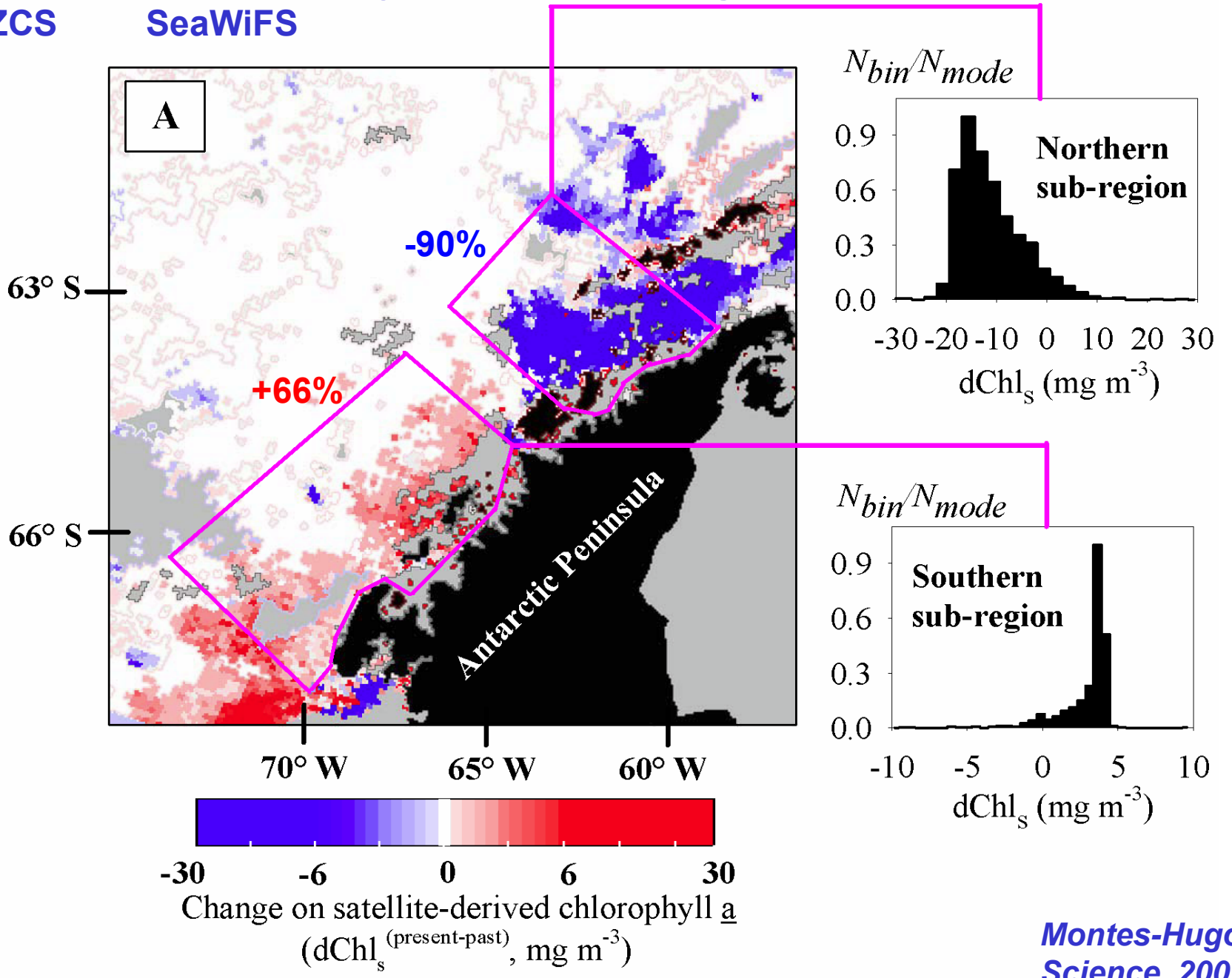


Penguin Populations in the Palmer Station region
(75% decline since 1975)



(1978-86 to 1998-2006) Phytoplankton Changes:

CZCS SeaWiFS



Montes-Hugo et al Science, 2009

This Ocean Carbon and Biogeochemistry (OCB) scoping workshop in Princeton, New Jersey, will focus on carbon cycling and marine ecosystems in the context of climate variability in the Southern Ocean….

Despite increased efforts to understand these processes, significant discrepancies still exist between models and observations, and a number of key processes remain poorly quantified.

There is a clear and increasing need to develop a coordinated approach that advances our understanding of climate variability in the Southern Ocean and its implications for ecosystem dynamics and biogeochemical cycling.

Most of the global ocean has microbial-biogeochemical/ecosystems that cycle most of the primary production through dissolved organic matter

(including mid-latitude regions characterized by phytoplankton blooms and the Arctic).

In the Southern Ocean, most of the primary production cycles through particulate organic matter.

(including permanently open-ocean and marginal ice zones)

This seems like something we should understand better

(if we want to predict the carbon cycle in the future)

OUTLINE

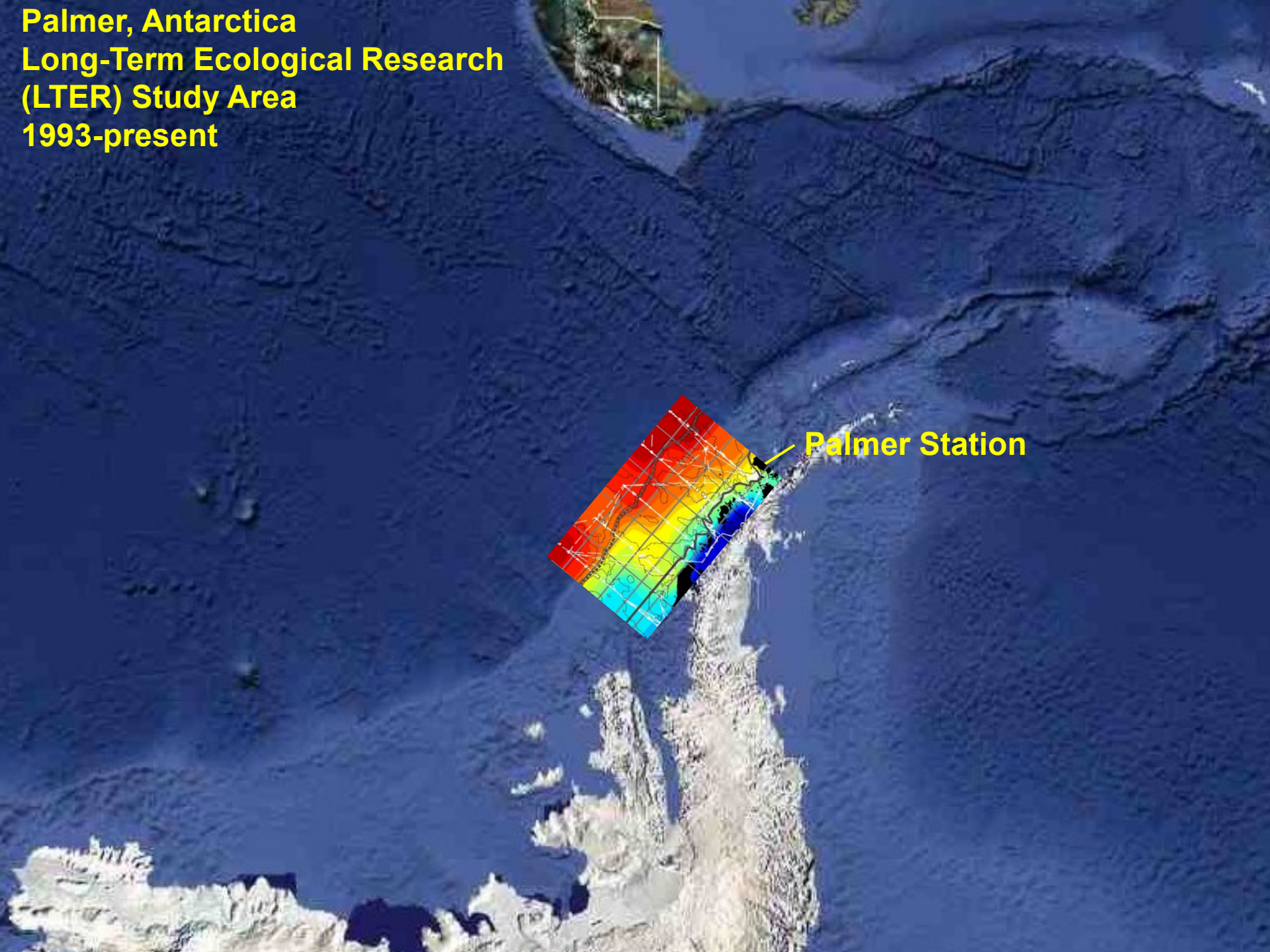
Observations of POC and DOC in Antarctica and Hawaii

Bacterial Production/Carbon utilization (Palmer LTER)

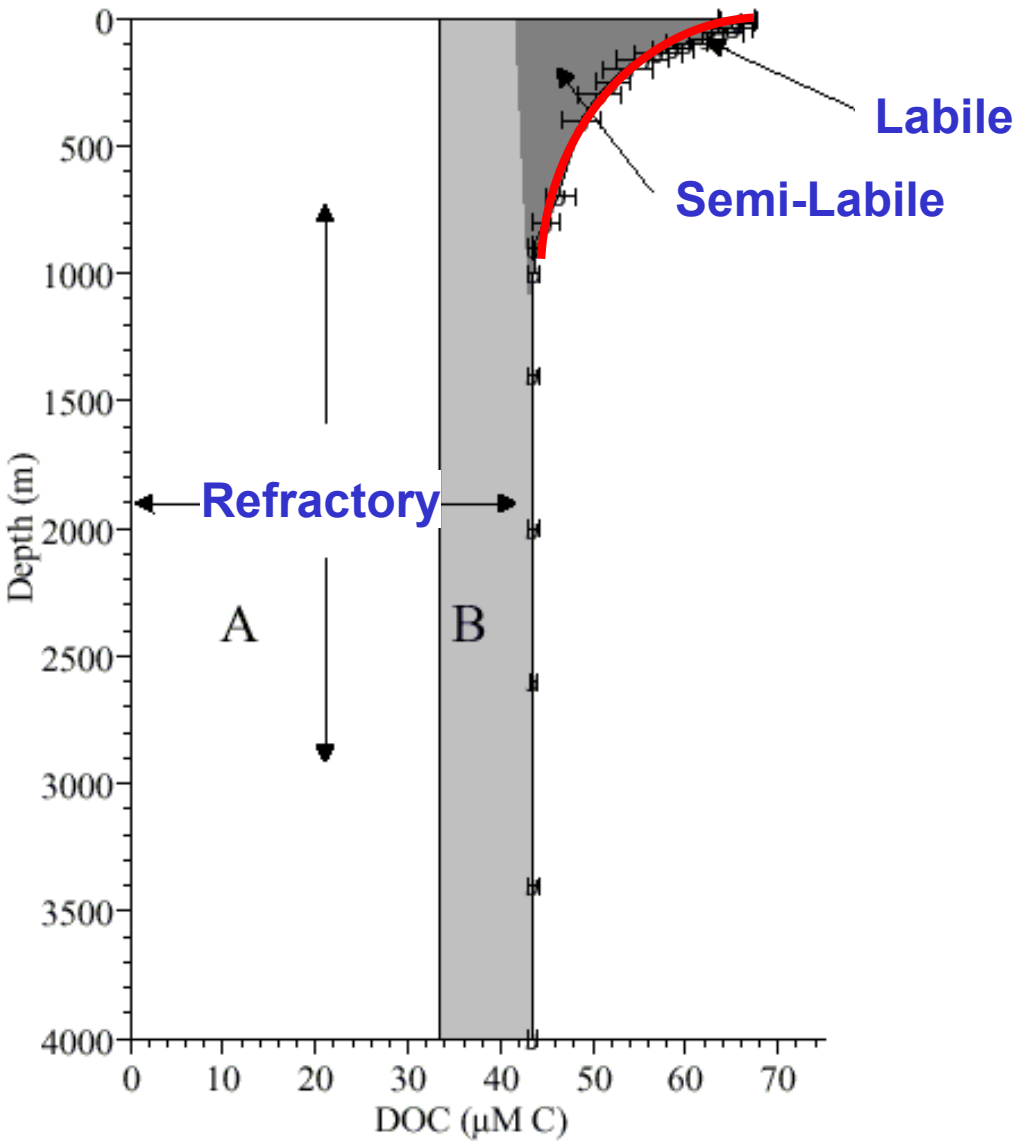
Bacterial:Primary Production Ratio as an ecosystem diagnostic (BP:PP): Global synthesis (JGOFS Redux)

Modeling microbial – organic matter fluxes

Scoping statement


Palmer, Antarctica
Long-Term Ecological Research
(LTER) Study Area
1993-present
Palmer Station

Oceanic DOC vertical distribution

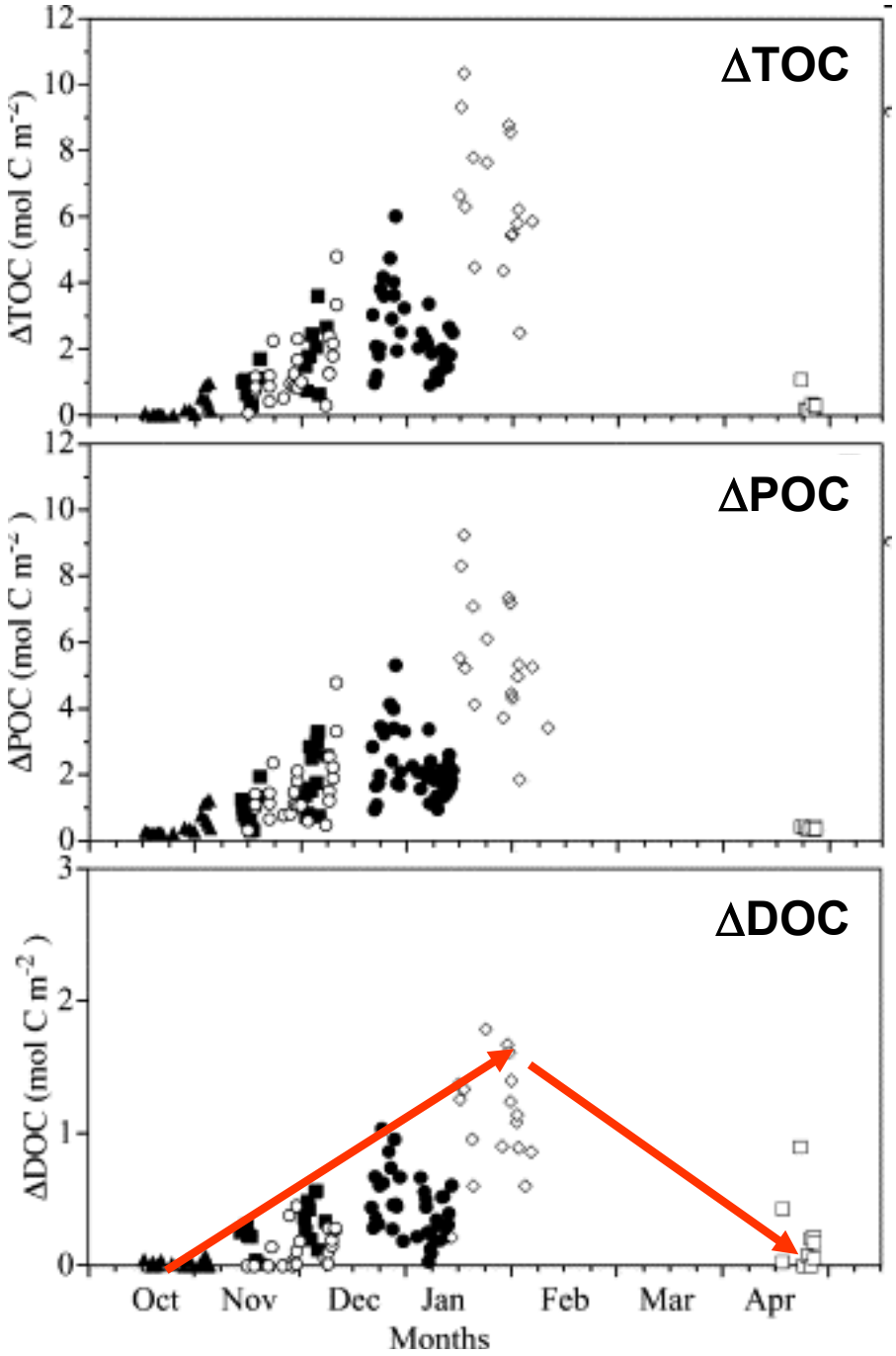


Labile: nanomolar, T=hours/days
Semi-labile: 0-50 μM, T=100 d
Refractory: 35-45 μM, T=1000 y

Excess (Δ-) DOC above deepwater Background concentration is available for export with resumption of convective overturn in winter.

This is exportable DOC

Net production in summer may or may not consume the exportable DOC before winter.



Seasonal production and utilization of semilabile DOC (ΔDOC) in the Ross Sea

(US JGOFS AESOPS, 1996-97)

ΔDOC: [$DOC_{surface}$] – [DOC_{deep}]

ΔDOC = 0 in winter

Net production in spring-summer

Net utilization in autumn

No exportable DOC at start in winter mixing.

Symbols signify different cruises, years.

Carlson et al (2000)

In the Ross Sea, 90% of the seasonal PP accumulated* in the particulate pool.
In the Sargasso Sea, 90% of the bloom PP accumulated* in the dissolved pool.

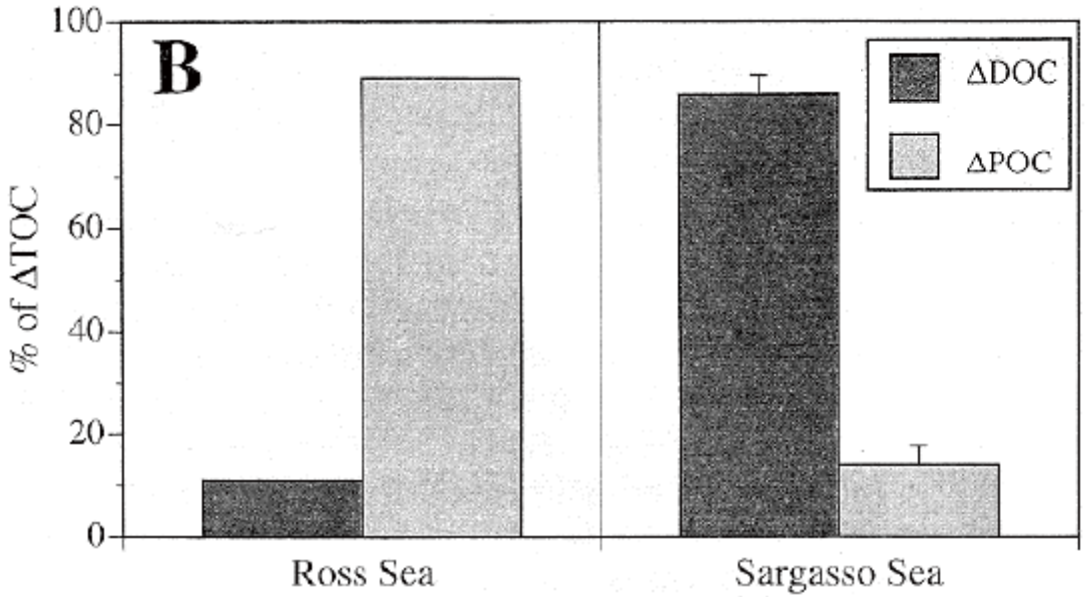


Fig. 4. A. Stocks of DOC and POC that which accumulated during blooms in the Ross Sea (RS) and the Sargasso Sea (SS). B. The percentage of TOC that accumulated as POC and DOC in the Ross Sea and Sargasso Sea. Error bars represent standard error.

*** or cycled through the pool**

Carlson et al. 1998

Exportable DOC (surface excess)

No Exportable DOC

Dennis A. Hansell
(2002)

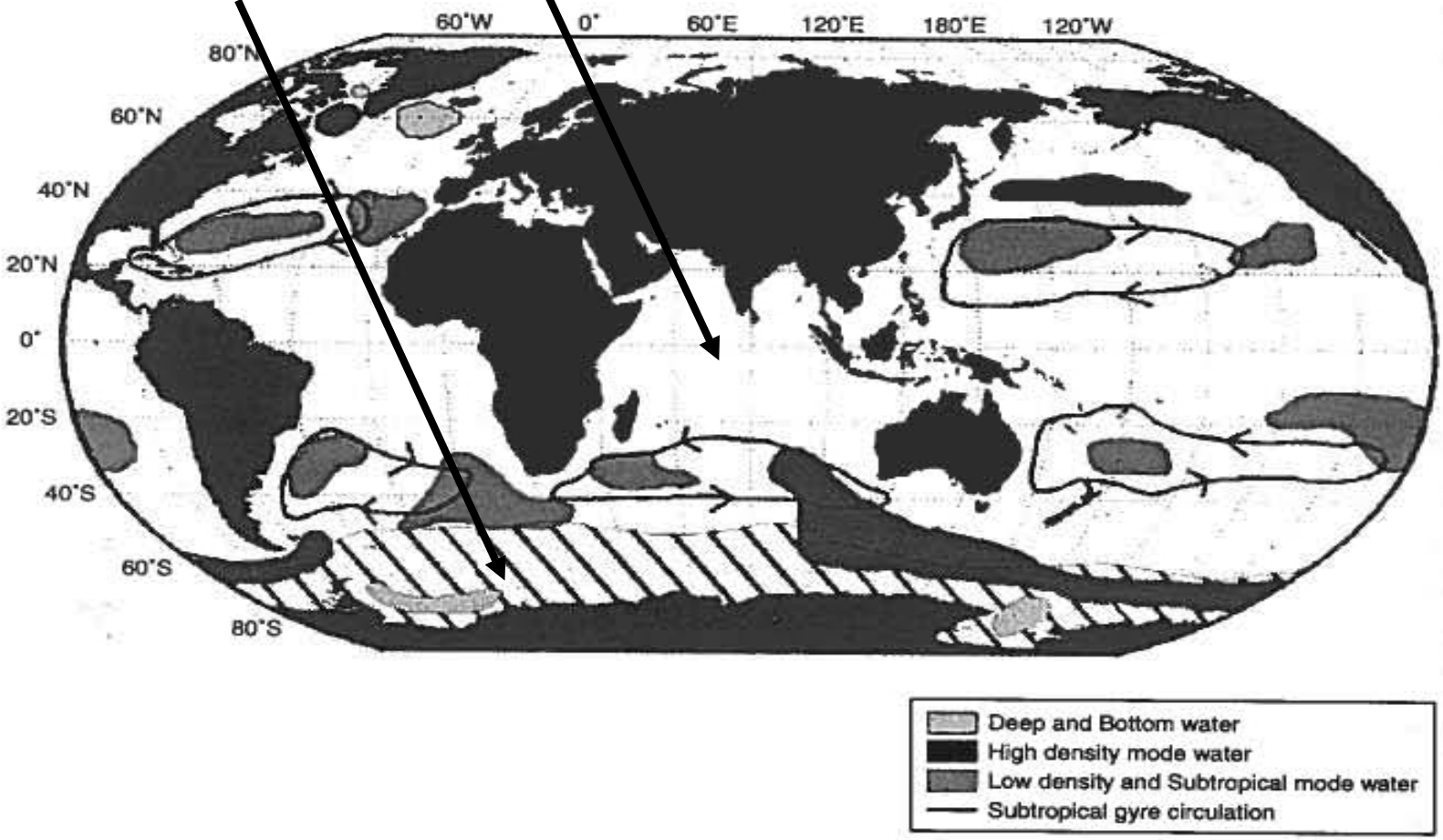
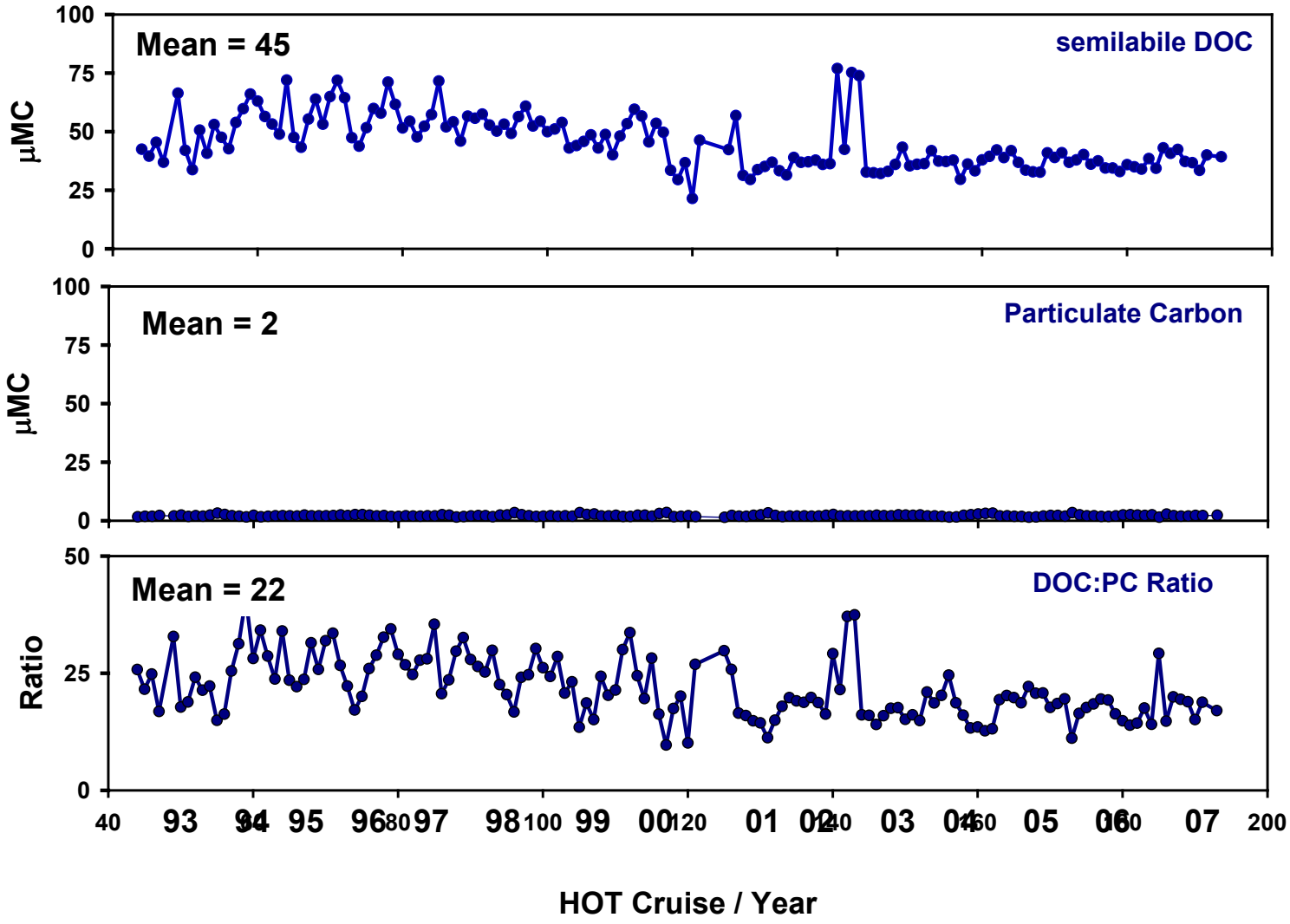
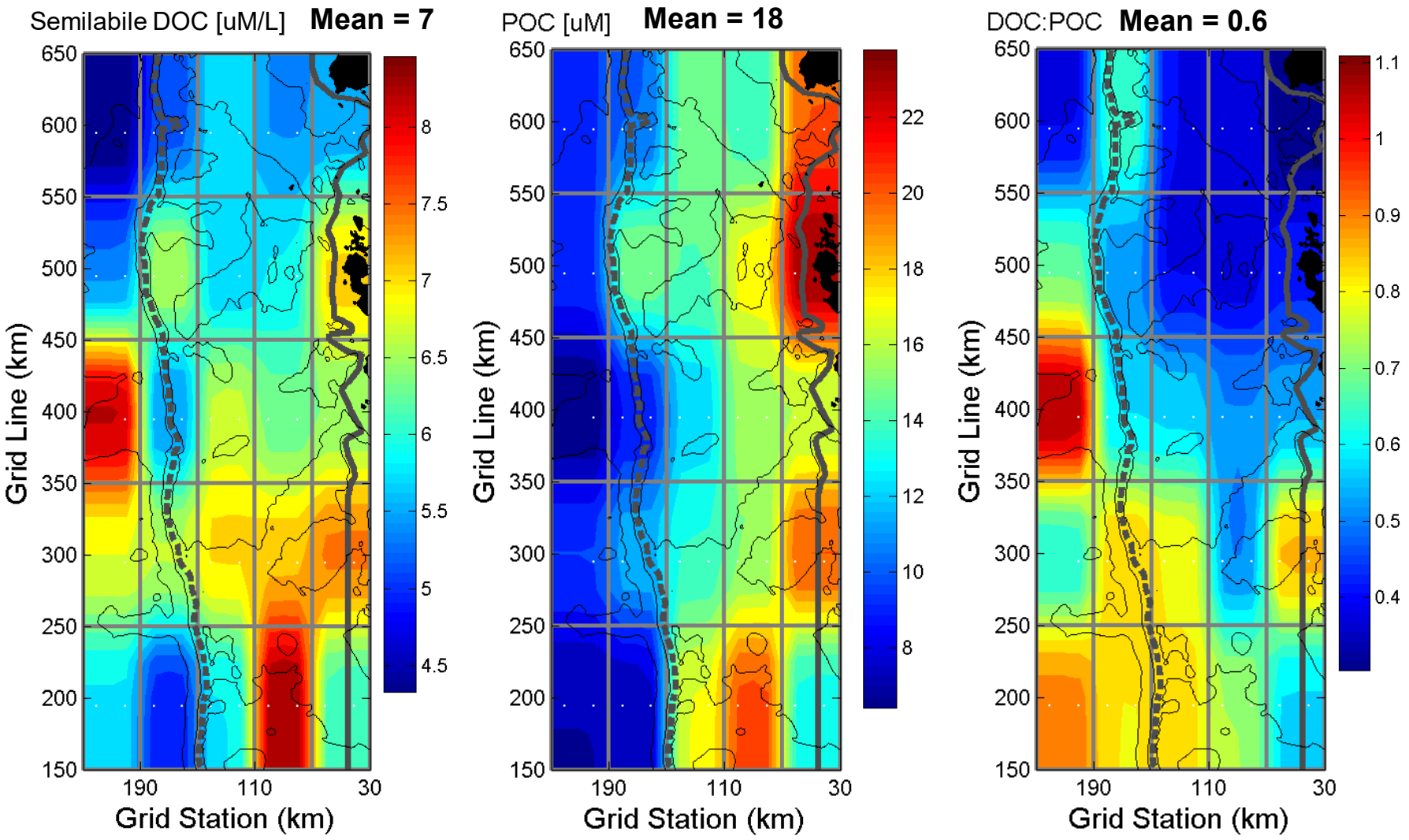


Figure 8 Distribution of sites of water column overturn (from Talley, 1999), general patterns of surface circulation in the subtropical gyres, and proposed distribution of *exportable* DOC. Overlap in the distribution of *exportable* DOC (background field of white) and sites of ocean ventilation (sites colored by gray scale) favors DOC export; a lack of overlap precludes export. The waters of the Southern Ocean (slanted stripes) are without *exportable* DOC present, so where these waters overlap sites of ventilation, little export is expected.

HOT Organic Carbon Standing Stocks (surface)



LTER S-DOC and POC Climatology, January-February 2003-2008 (n=250)



Particulate and Dissolved Organic Carbon

Site	POC, μM	S-DOC, μM	Ratio
HOT	2	45	22
PAL	18	7	0.6

Why so little exportable DOC in the Southern Ocean?

Low production rates?
High and efficient consumption by bacteria?
The DOC produced is highly labile?
Lack of processing by foodweb?
Bacterial community structure?
UV-activation?

TROPHODYNAMIC VIEW OF BACTERIAL ECOLOGY

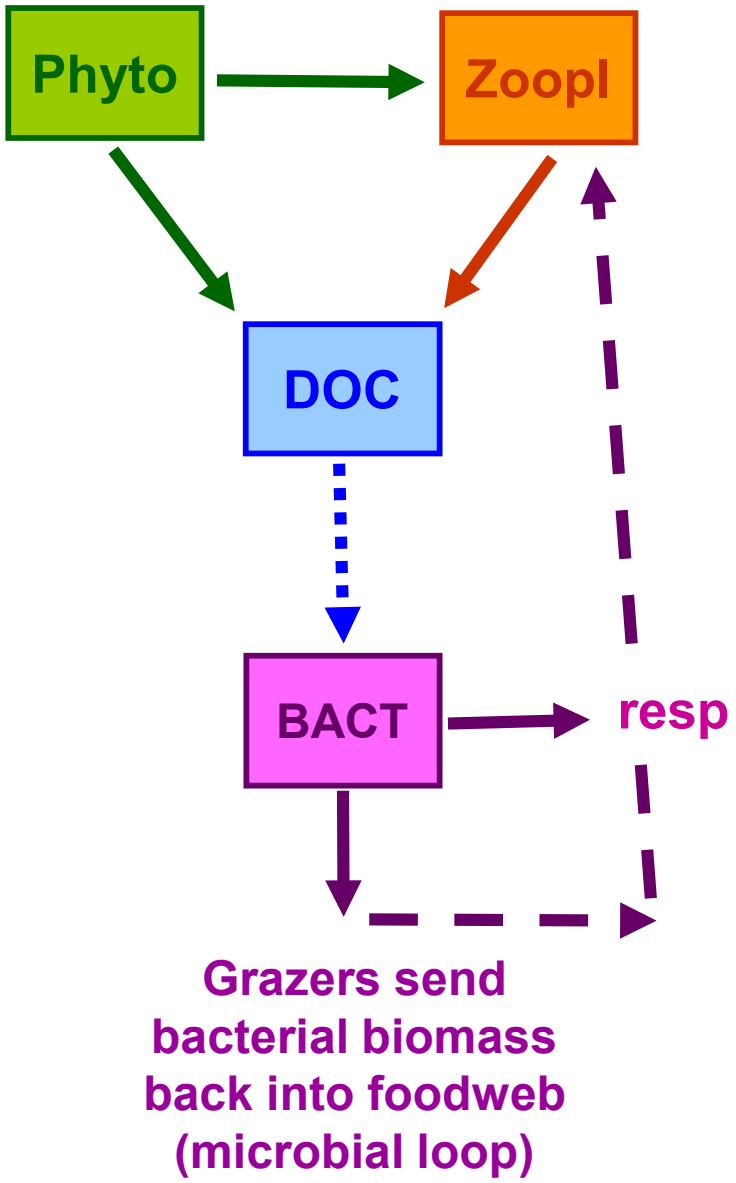
Bacterial biomass production is based primarily on flows of dissolved organic matter from other organisms.

Bacteria are consumed by grazers and this the DOC "lost" from the foodweb is recovered by bacterial activity

This process is the Microbial Loop

We can measure rates of bacterial biomass production and primary production by phytoplankton (photosynthesis) to understand the relationships among these flows.

Global mean BP:PP ~ 10%

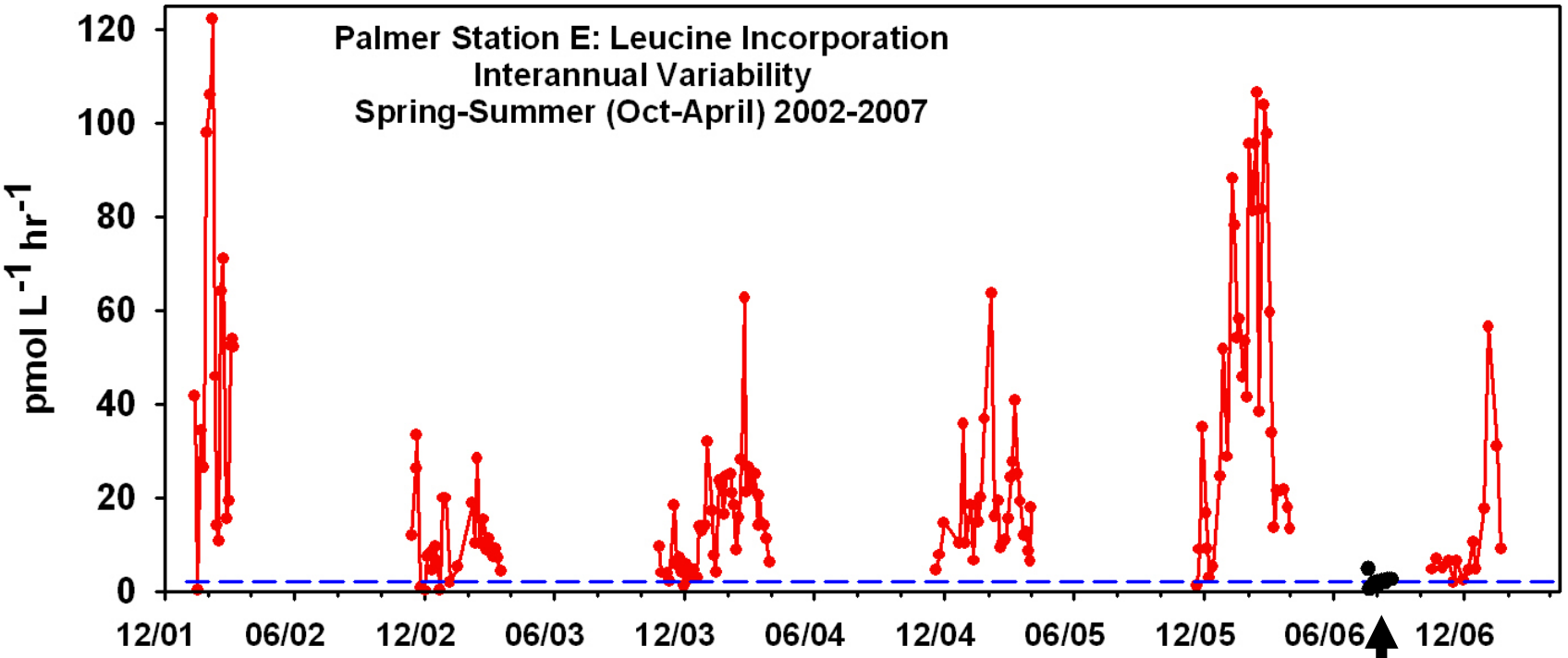


Microbial ecology at Palmer Station:

Humpback whales at Palmer Station E, March 2008

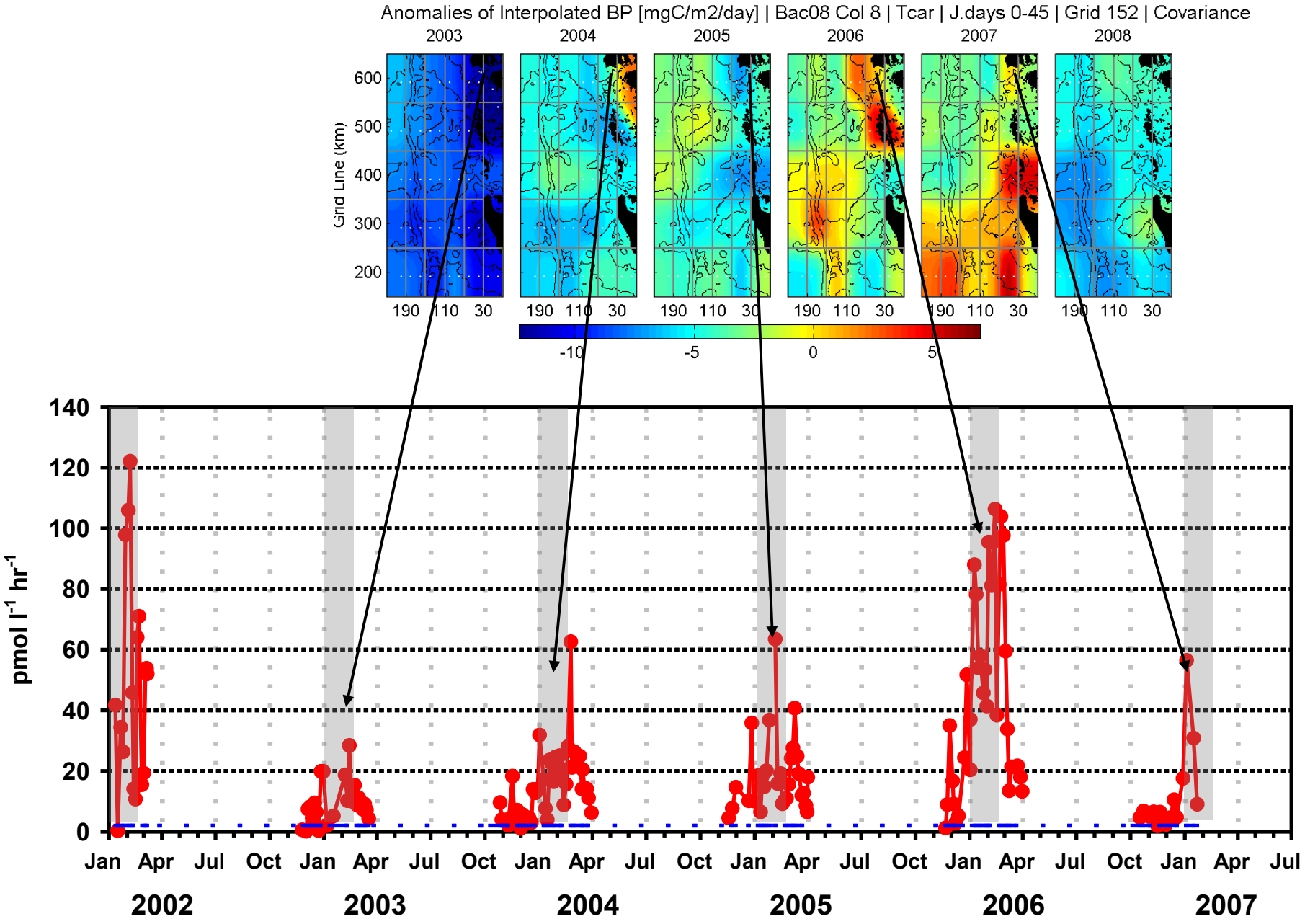
Bacteria – Phytoplankton Relationships

Bacterial production rates measured by radioactive leucine uptake

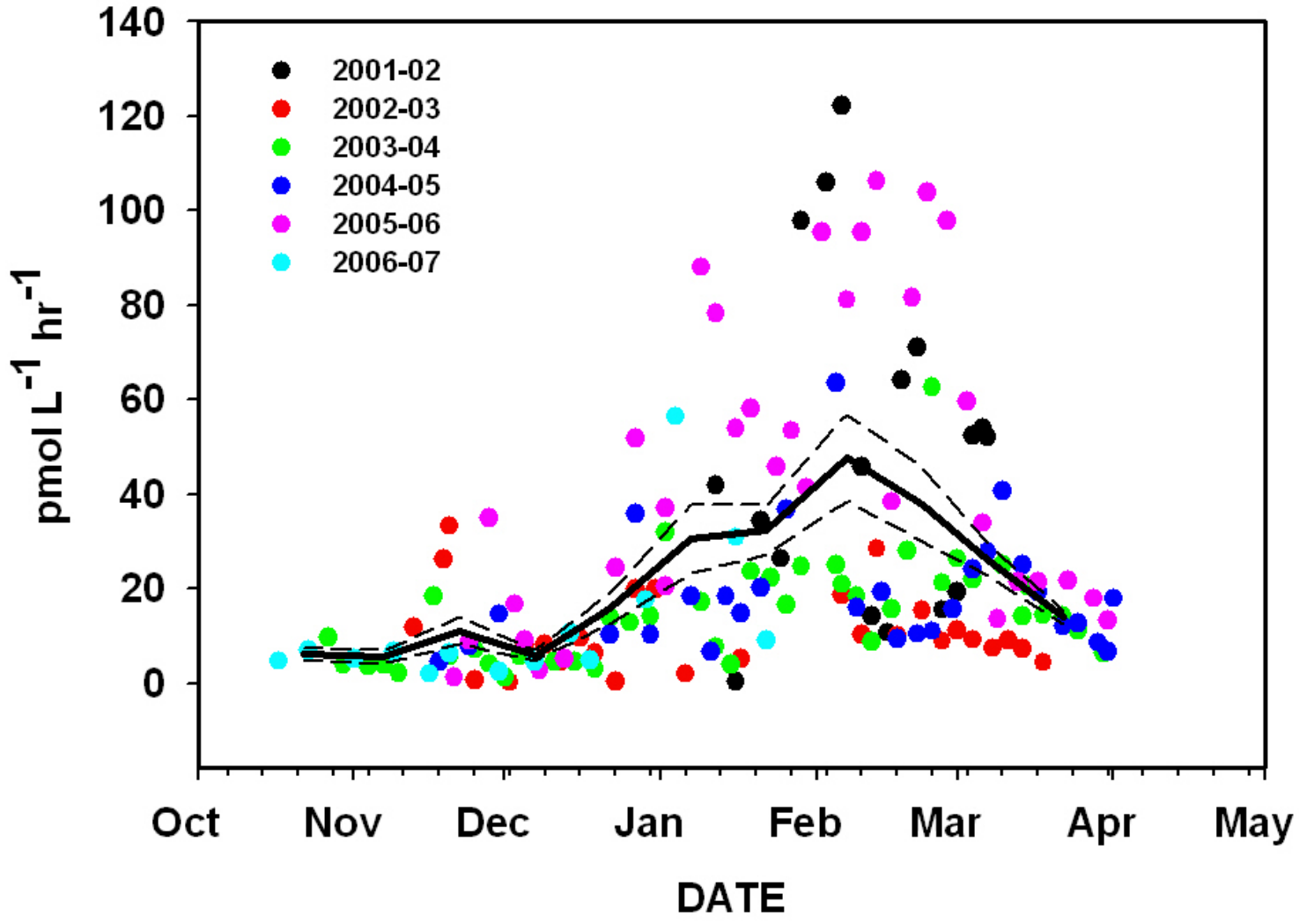


Possible 4-5 year cycle following primary production rates

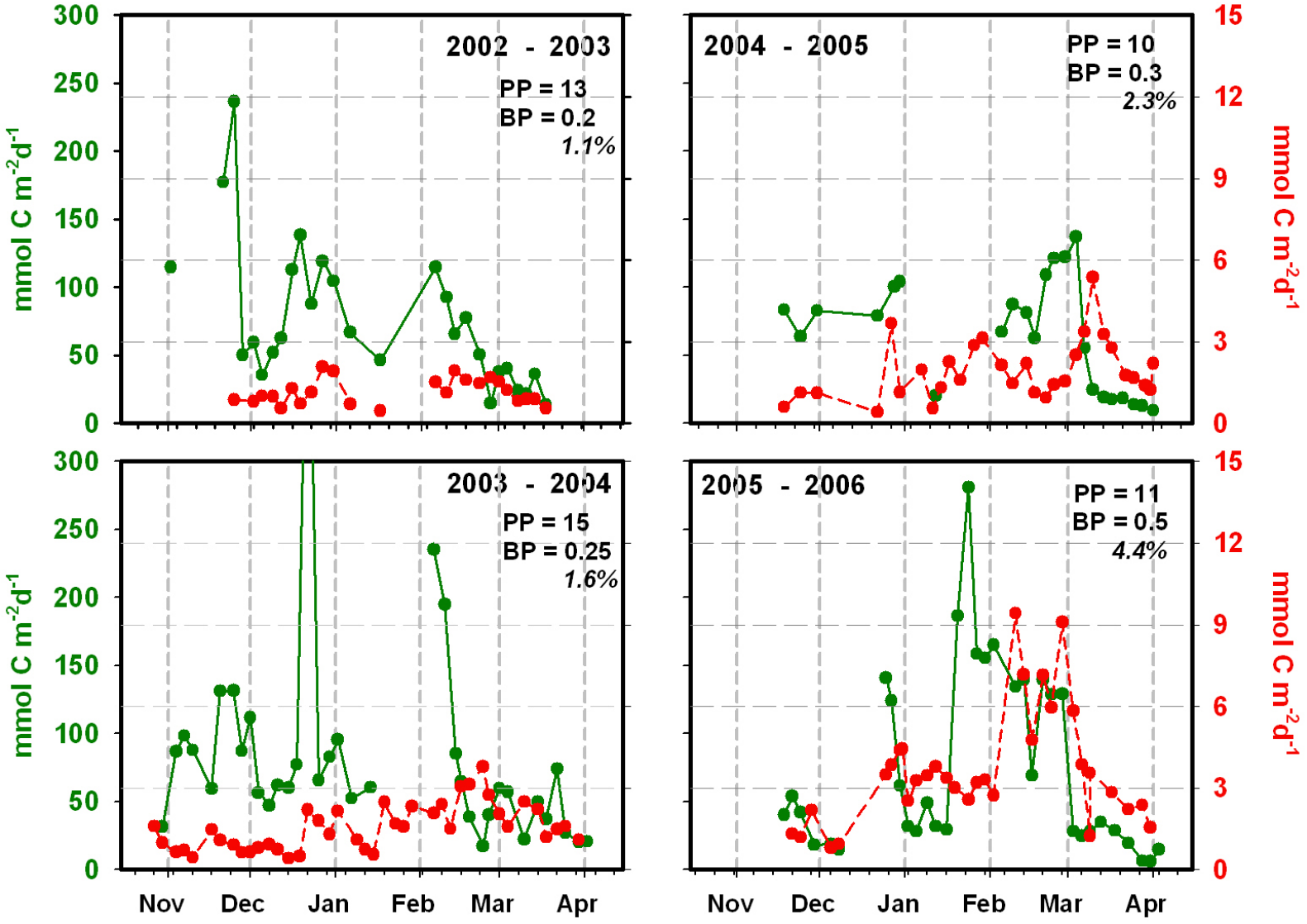
Mean winter rate:
5 pM/hr; July-Sept 2008


Anomalies of Interpolated BP [mgC/m2/day] | Bac08 Col 8 | Tcar | J.days 0-45 | Grid 152 | Covariance
2003
2004
2005
2006
2007
2008
Grid Line (km)
600
500
400
300
200
190 110 30
-10
-5
0
5
pmol l-1 hr-1
140
120
100
80
60
40
20
0
Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul Oct Jan Apr Jul
2002
2003
2004
2005
2006
2007

Bacterial Production: Composite Seasonal Cycle and interannual variability

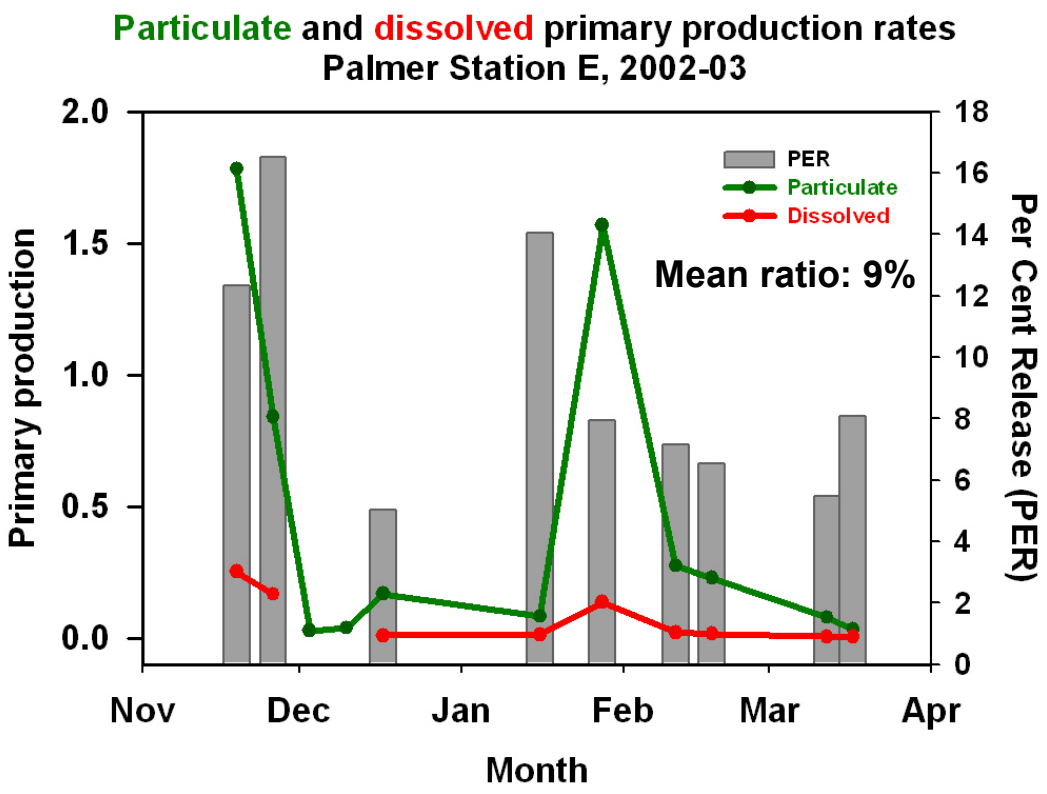


PRIMARY & BACTERIAL PRODUCTION AT Station E



The values in the upper corners are annual integrals over 150 days excluding 01 Apr to 01 Nov. (Mol C m^{-2} a^{-1}). When symbols superimpose daily BP:PP = 5%. Winter adds ~0.06 Mol of BP to these totals (10-20%).

The mean BP:PP is ~2-3%

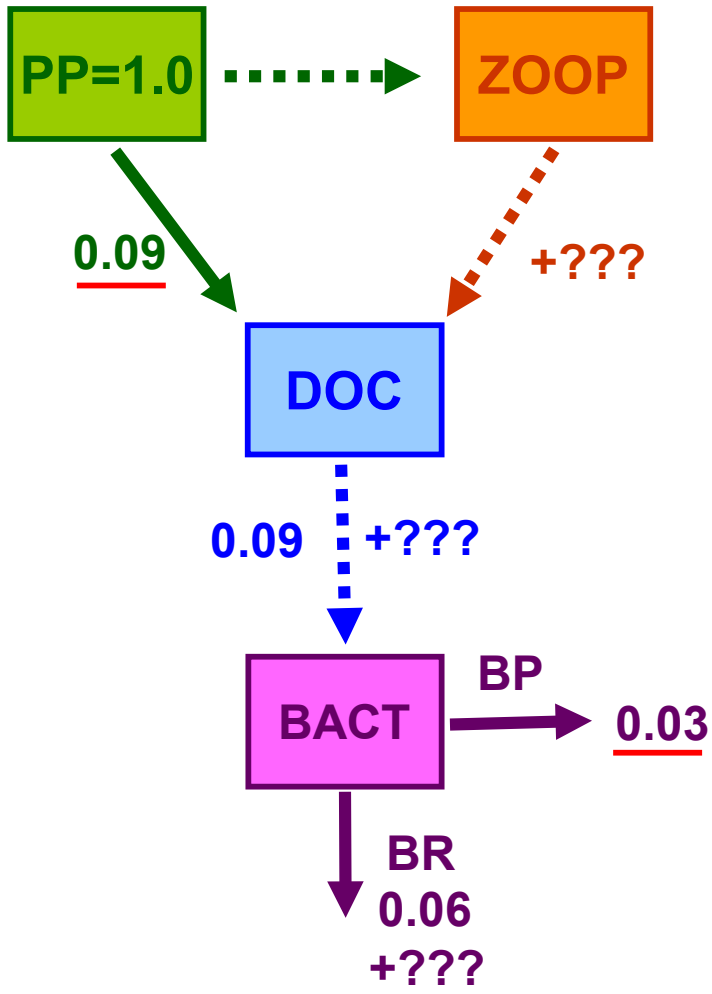


Bacterial production rates follow primary production, seasonally and interannually, but comprise a low fraction of the PP.

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?

flow analysis:

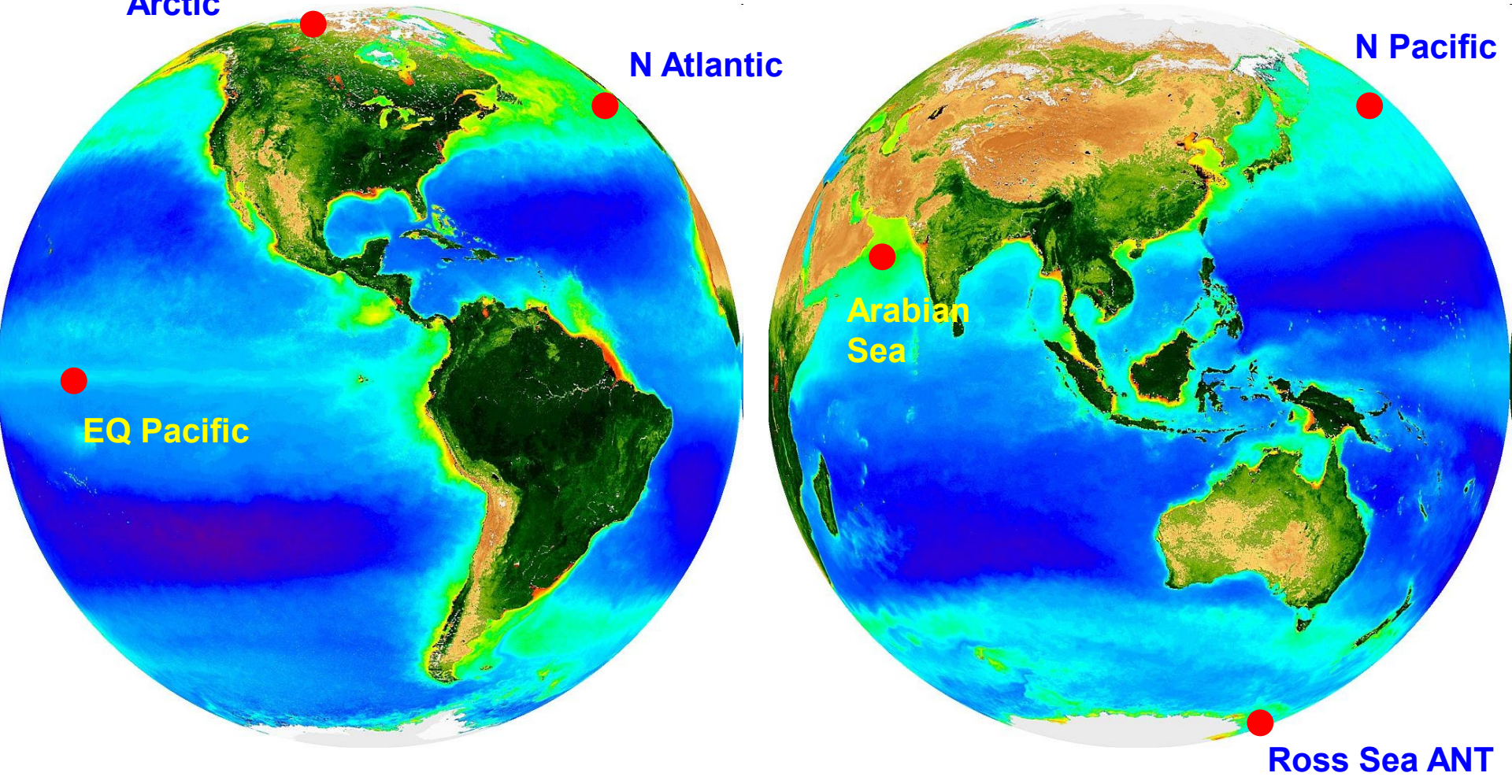


Apparent Growth Efficiency ???

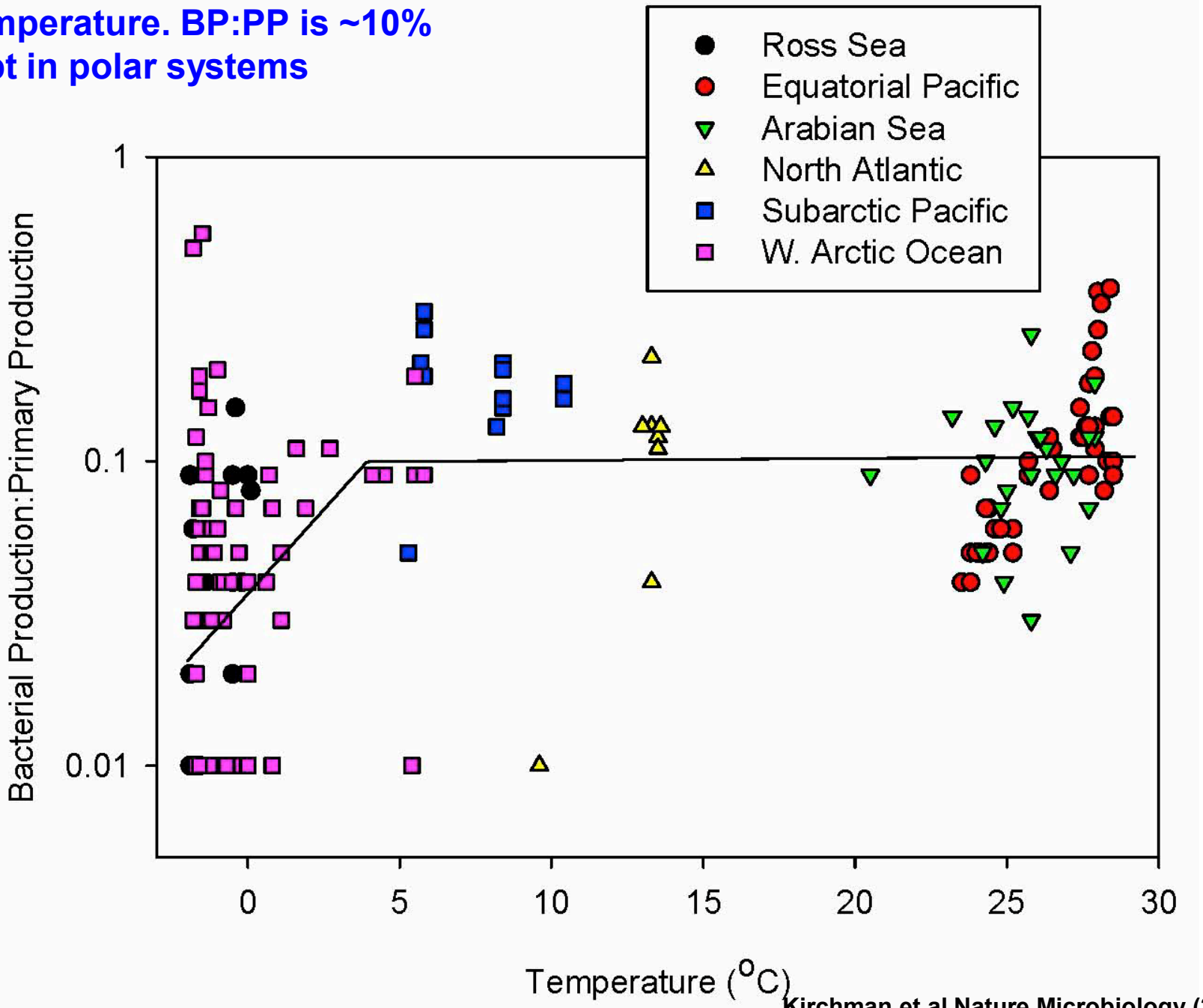
Scenarios:
DOC limitation (low flux)
More flux, lower BGE

Global perspective:

Are polar microbes different from lower latitude systems? A global meta-analysis (JGOFS bacterial and phytoplankton biomass and production data) ***Kirchman et al. Nature Microbiology 2009***

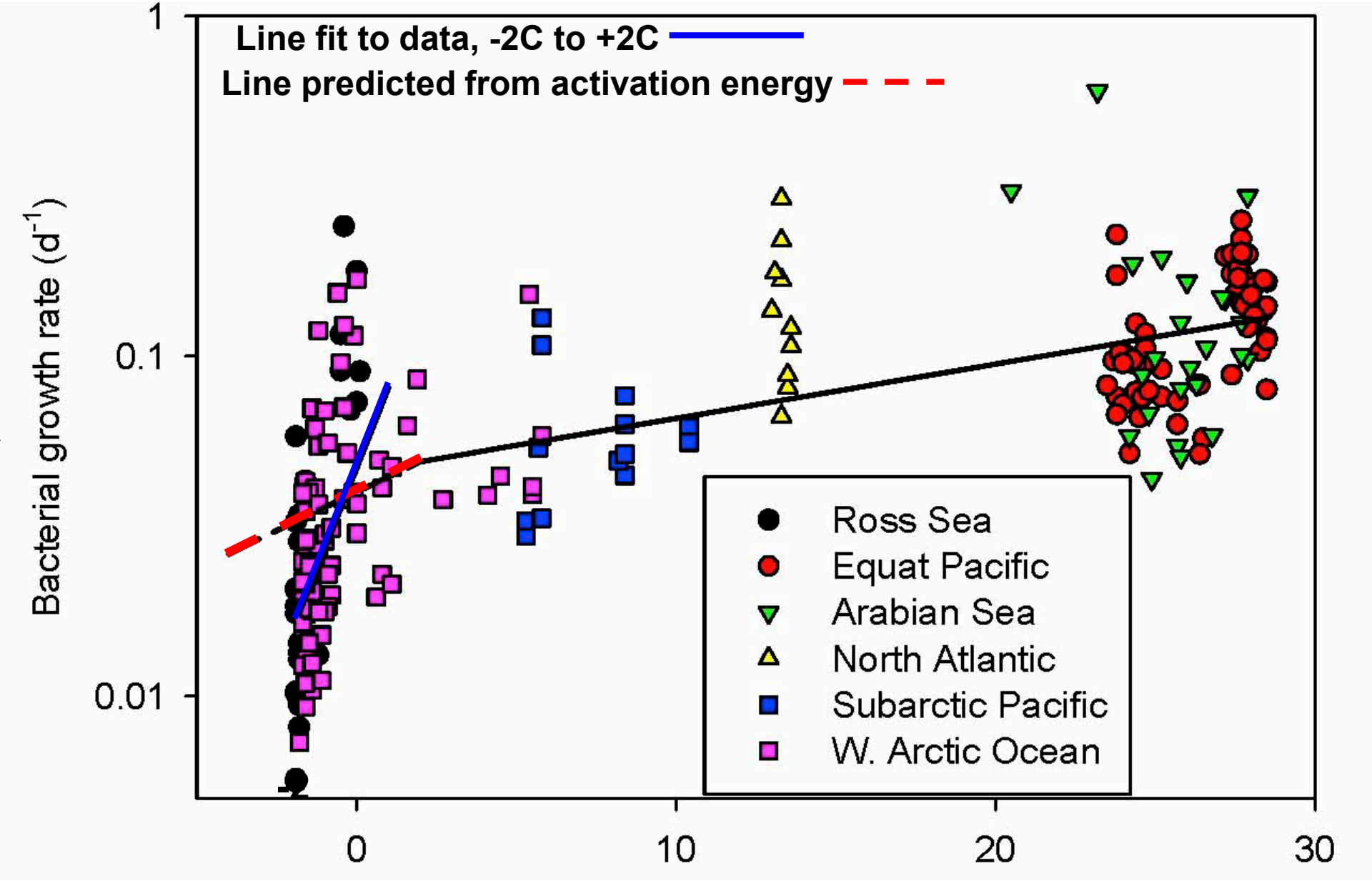


Ratio of bacterial to primary production vs temperature. BP:PP is ~10% except in polar systems



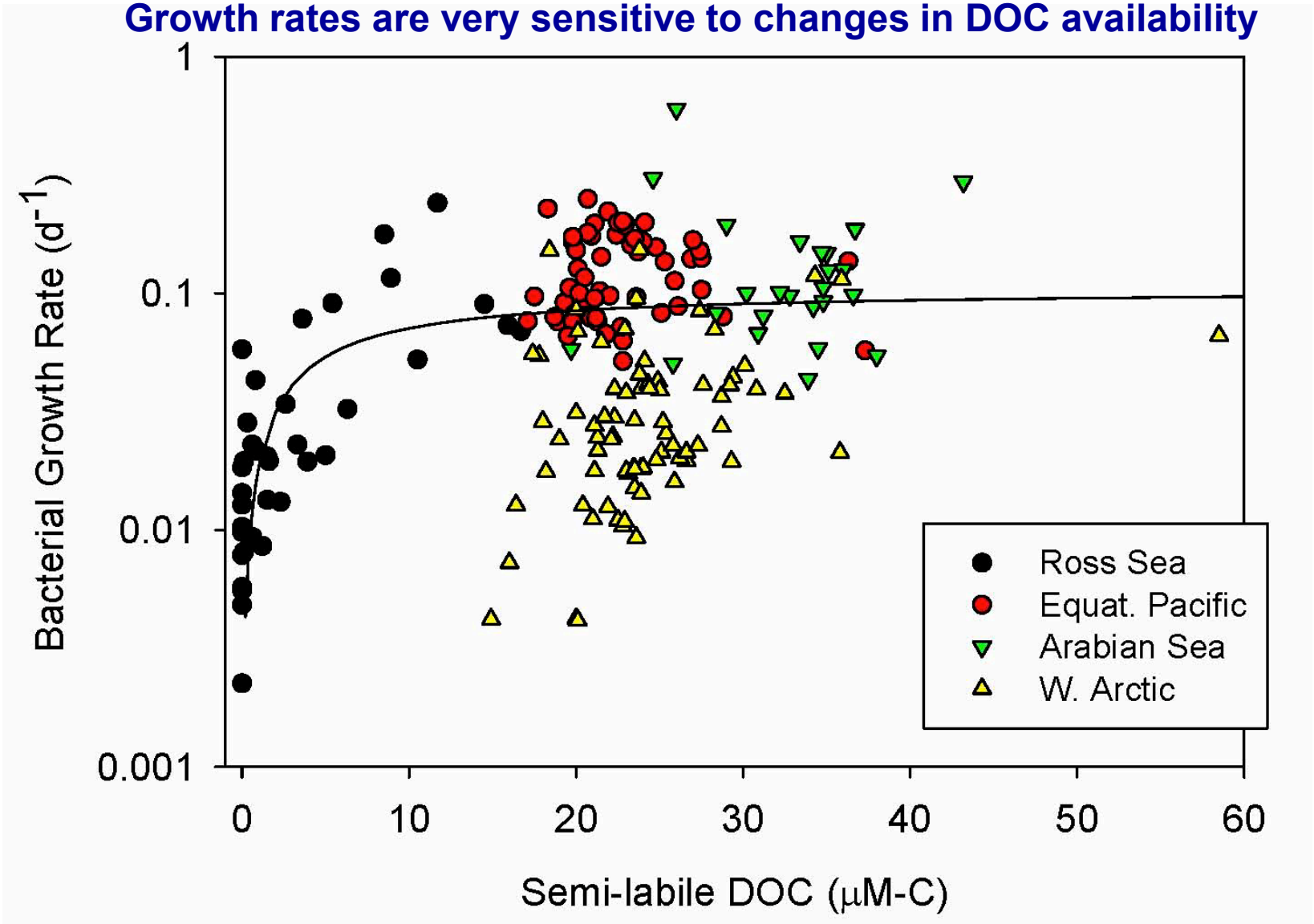
Kirchman et al Nature Microbiology (2009)

Temperature alone is not the answer



Kirchman et al Nature Microbiology (in review)

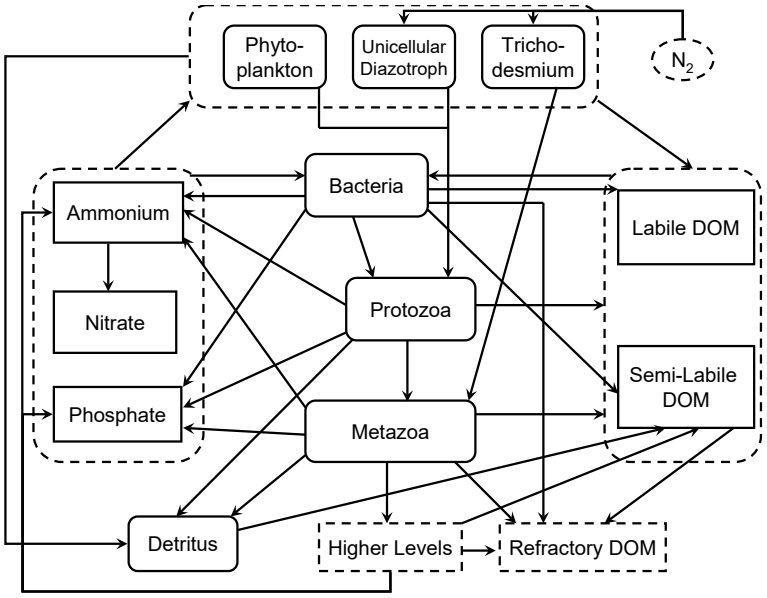
Bacterial growth rate and semi-labile Dissolved Organic Carbon
Growth rates are very sensitive to changes in DOC availability

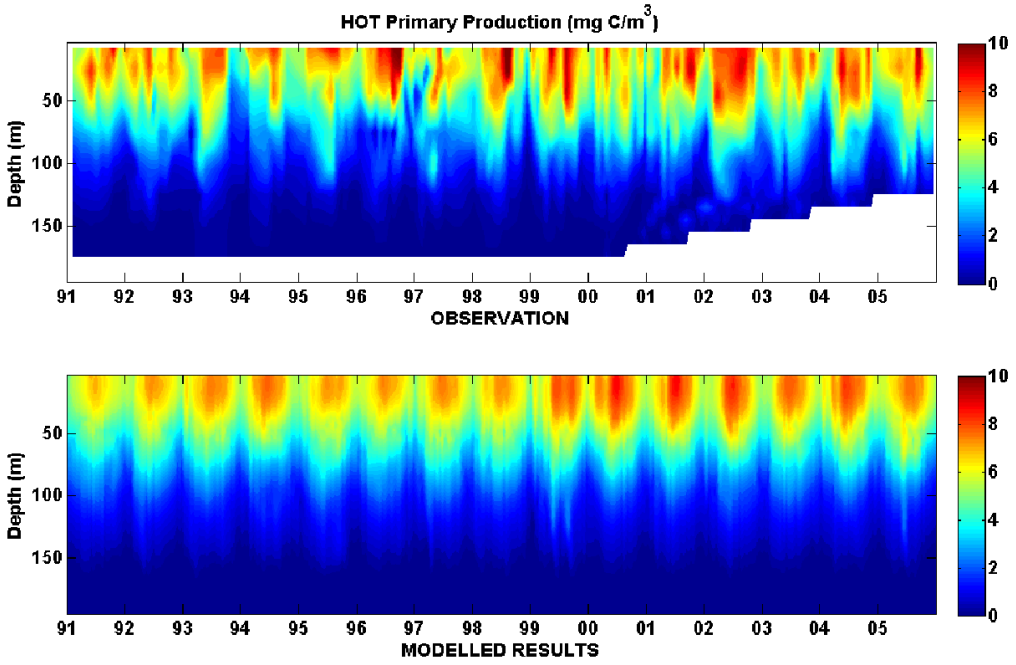


Kirchman et al Nature Microbiology (2009)

Heterotrophic Microbial Dynamics in the Open Ocean Revealed by Data Assimilative Modeling

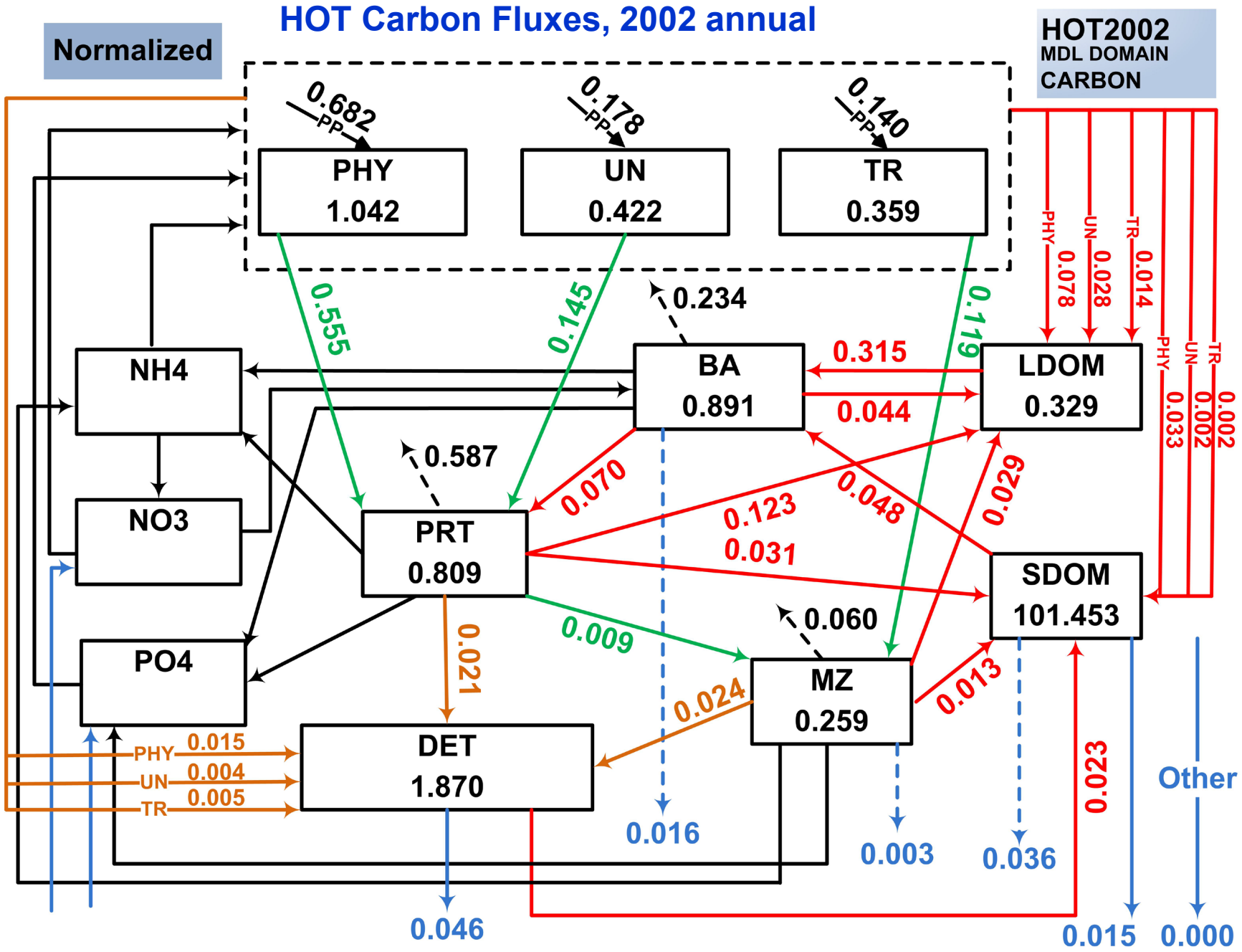
Yawei Luo*, Hugh Ducklow, Marjy Friedrichs, Scott Doney and Matthew Church



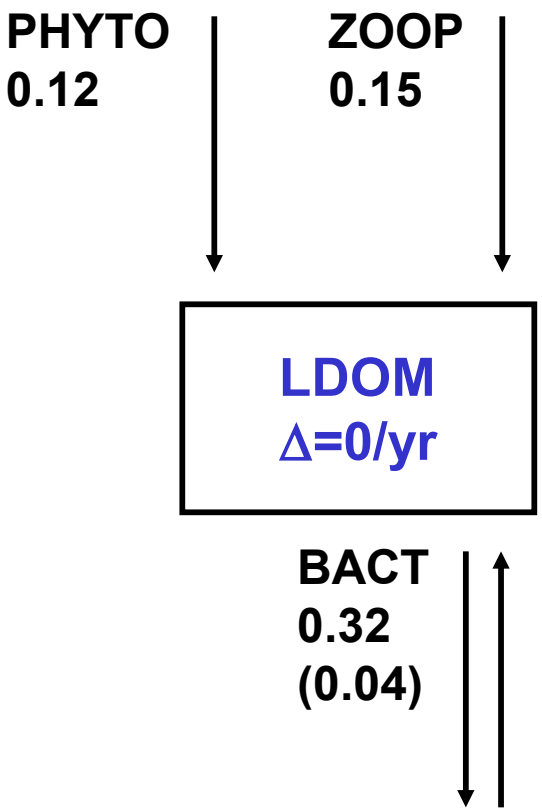


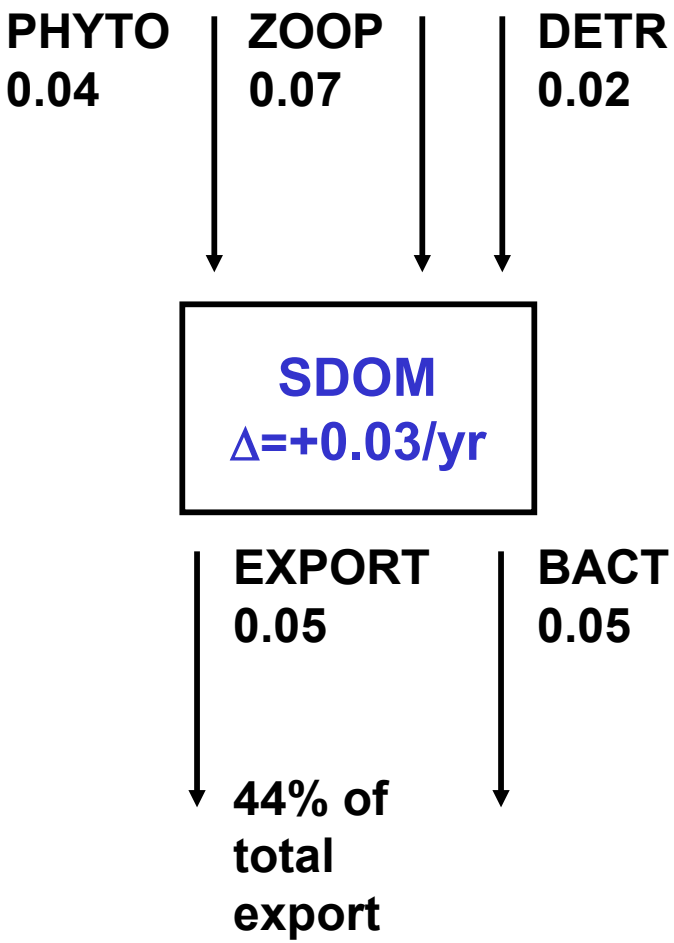
Multi-element (C,N,P), variable stoichiometry
Optimized with HOT data (NO3, PO4, NH4, DOC, DON, DOP, Bact #, PP, BP, Export, Zoop, CHL, POC, PN, PP

** PhD, Brown Univ/MBL 2009; Aquat. Microb. Ecol. Submitted.*


HOT Carbon Fluxes, 2002 annual
Normalized
HOT2002
MDL DOMAIN
CARBON
PHY
1.042
UN
0.422
TR
0.359
0.682
PP
0.178
PP
0.140
PP
NH4
NO3
PO4
BA
0.891
LDOM
0.329
PRT
0.809
SDOM
101.453
MZ
0.259
DET
1.870
0.234
0.587
0.060
0.555
0.145
0.119
0.315
0.044
0.070
0.123
0.031
0.048
0.029
0.009
0.021
0.024
0.013
PHY 0.078
UN 0.028
TR 0.014
PHY 0.033
UN 0.002
TR 0.002
PHY 0.015
UN 0.004
TR 0.005
0.016
0.003
0.036
0.023
0.046
0.015
0.000
Other

HOT DOM Annual Fluxes normalized to PP = 1.00





Throughput: LDOM – 32% of PP
SDOM – 13% of PP
TOTAL – 45% of PP

Y Luo et al. 2009 (submitted)

SCOPING Statement/Questions:

Is the Southern Ocean unique in how organic matter is cycled, stored and exported?

What are the mechanisms and agents of cycling and transformation?

What is the role of temperature?

What about plankton/bacterial community composition?

NEEDS:

More work in winter (what fuels BP in winter?)
Better areal coverage (is Peninsula an anomaly? Is it already changed?)

More process and experimental studies (Δtemp, Δorg matter, ΔCO2, Fe)

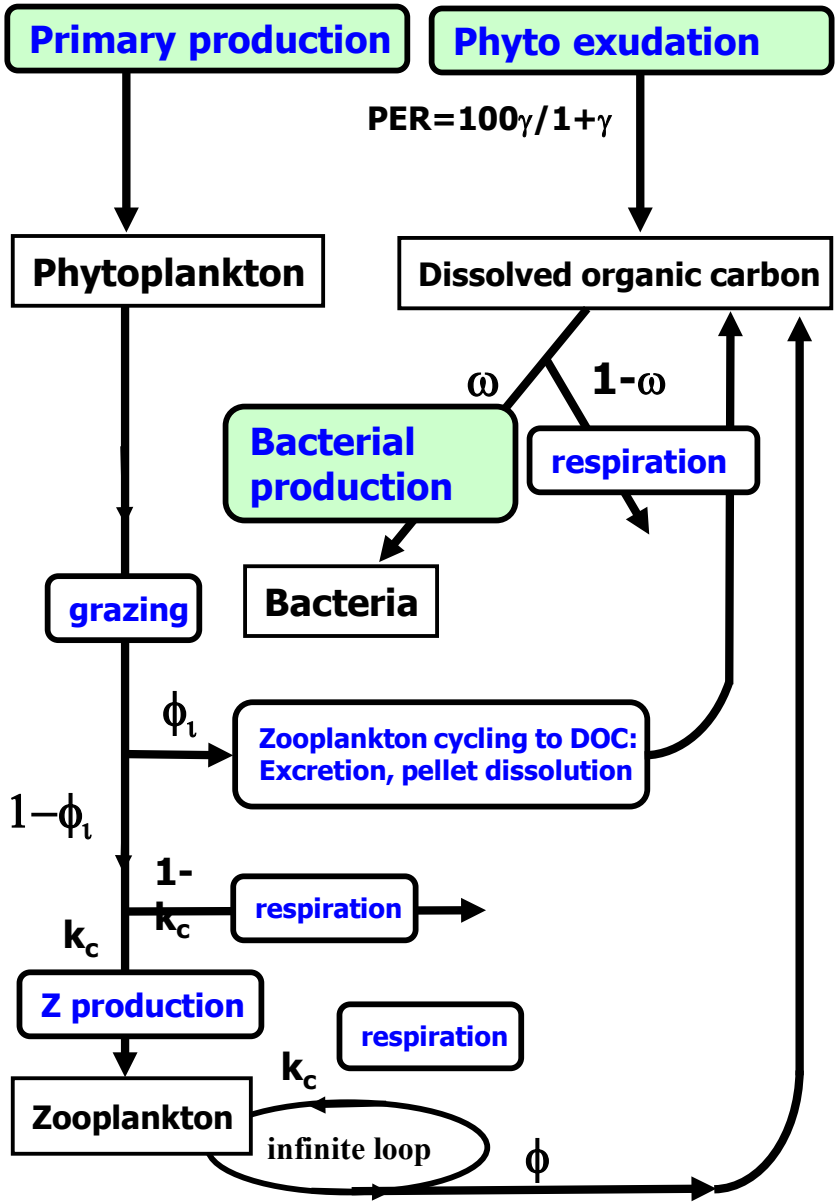
Better models and data to optimize & test them

QUESTION: How will Southern Ocean ecosystems change as warming migrates south?


In Memoriam
ARSV Laurence M GOULD (1999-2010)
Last USAP cruise, May 2010
What do we need in the next 10 years?
What will be there for us?


Thanks:
OPP 0823101 (Palmer LTER)
Dave Kirchman
Yawei Luo
Matthew Church
Scott Doney
Matthew Erickson
Marjy Friedrichs
Xelu Moran
Alison Murray
Many many PAL LTER members
LTER
NSF

Why 10%?



Oceanic BP Flow analysis (with Tom Anderson):

1. Consider first internal sources in near steady-state regimes.
2. Examine labile DOC fluxes & utilization.
3. Analyze physiological & trophic processes supplying DOC pools.
4. Derive BP from PP, DOC flux and ϕ, k_c, ω (zooplankton & bacterial growth efficiency, and DOC allocation).
5. Is BP "too high"?

   Is a subsidy needed?