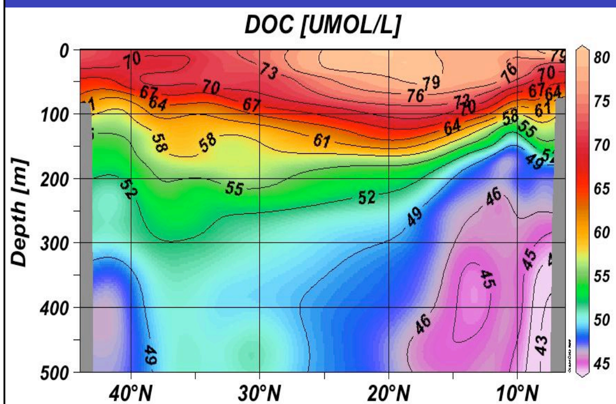
Temporal and Spatial Variability of Oceanic DOM: Assessing Various Scales of Turnover and Its Implications



Quality index

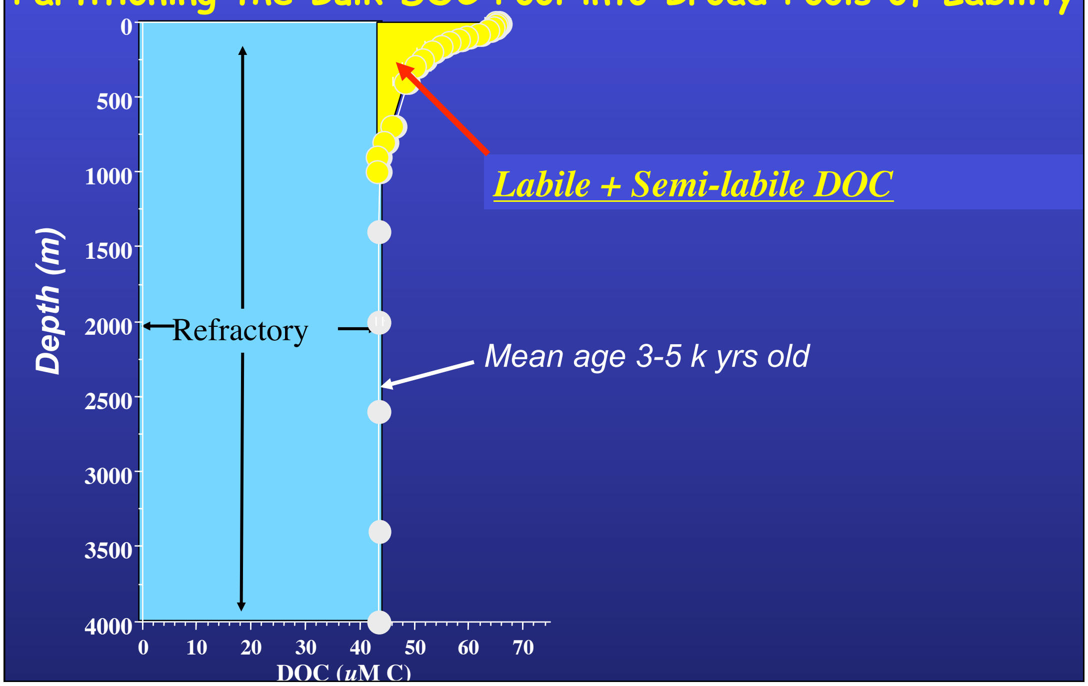
Assessing Turnover:

Labile – Bacterial Carbon Demand and factors that affect growth efficiency

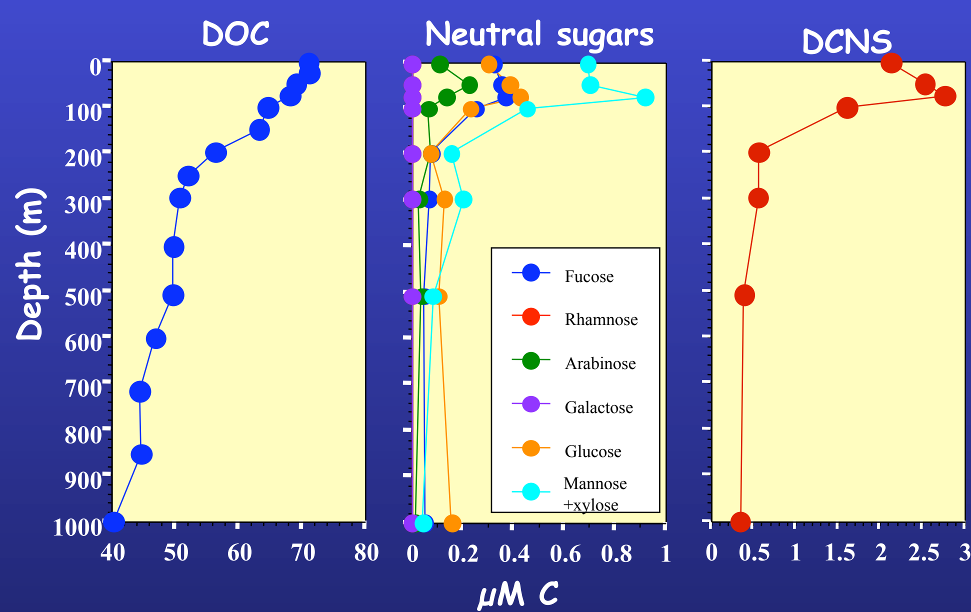
Semi-Labile – seasonal variability

Recalcitrant – spatial trends and relationship to transient tracers

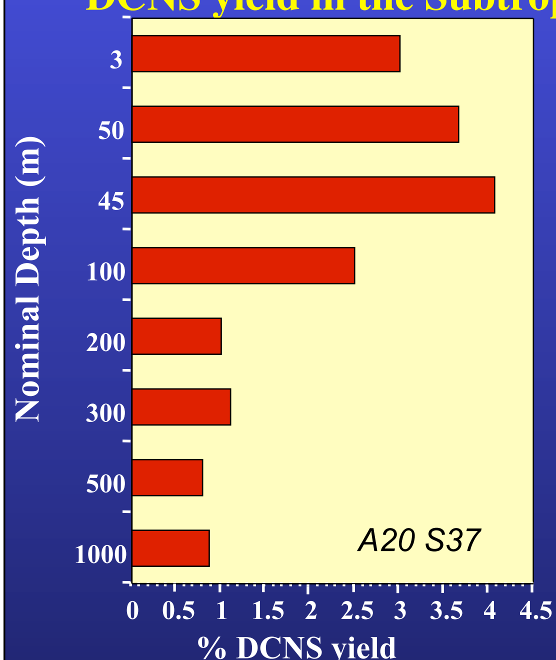
Partitioning the Bulk DOC Pool into Broad Pools of Lability



Characterization of DOC pool in North Atlantic



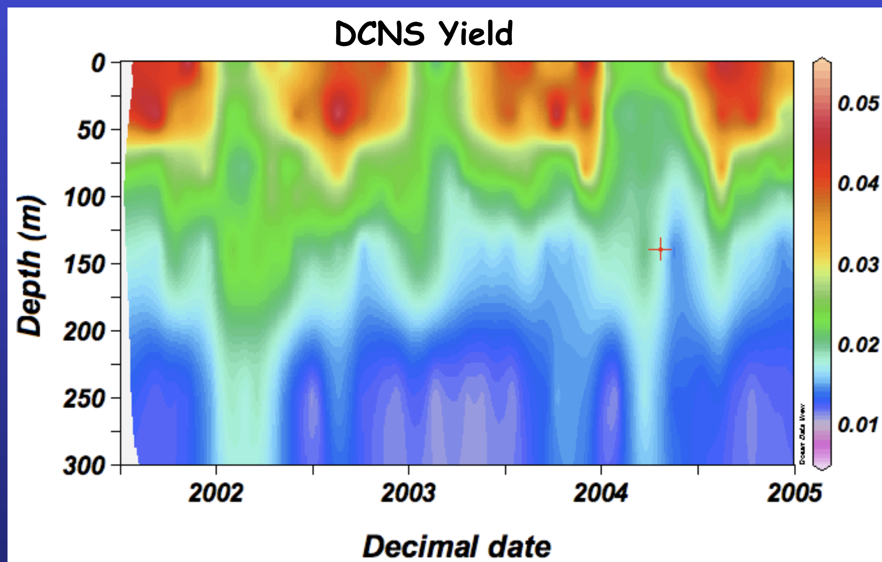
DCNS yield in the Subtropical Atlantic



- Contribution of specific compounds like DCNS to bulk DOC can be used as and index of diagenetic state (Cowie and Hedges, 1994 & Skoog and Benner, 1997)

- The lower the yield the more highly degraded the organic matter is

Diagenetic Index of DOC quality at BATS

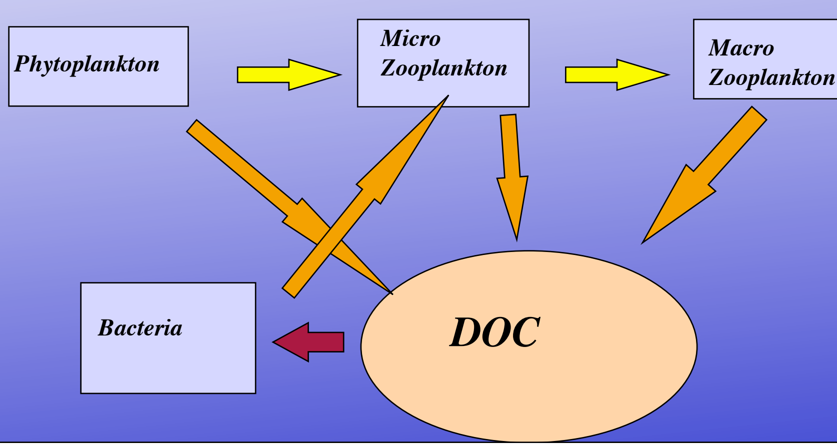


Goldberg et al. 2009

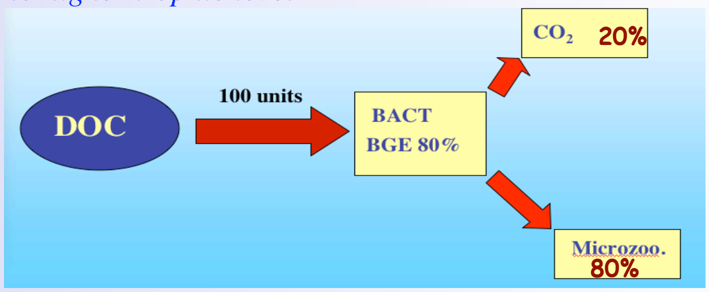
The Microbial Loop (Pomeroy 1974; Azam et al. 1983)

- salvage pathway in which bacterioplankton repackage and reincorporate DOC back into the aquatic food web

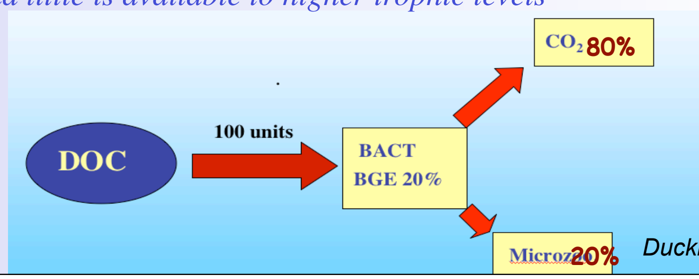
Classical Food Chain with the Microbial Loop



***Link**: At high bacterial growth efficiencies a significant amount of carbon can be passed on to higher trophic level*



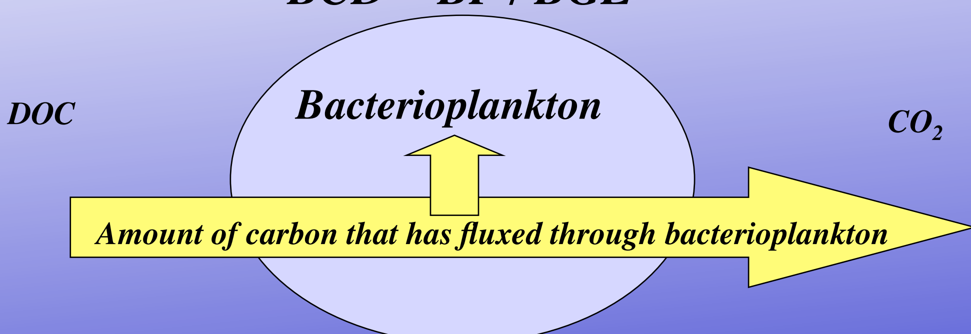
***Sink:** At low bacterial growth efficiencies a significant amount of carbon is respired and little is available to higher trophic levels*



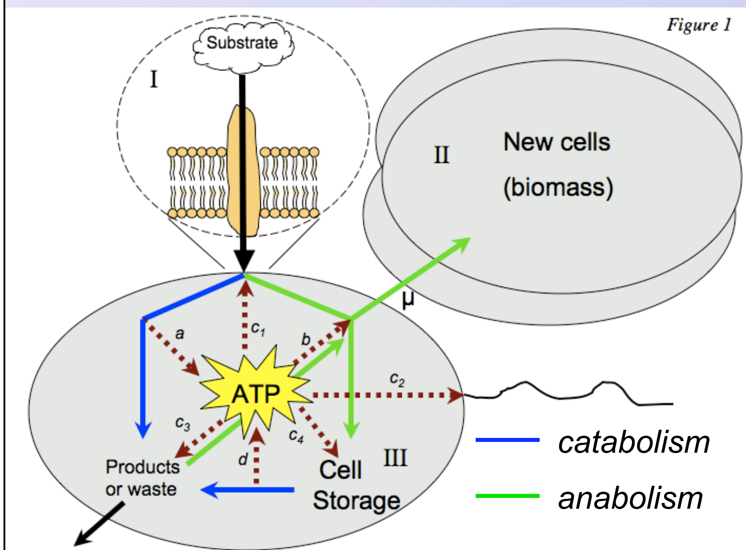
Ducklow et al 1986

Bacterial Carbon Demand - The amount of carbon processed by bacteria to produce given biomass.
…. Gross bacterial production

$$BCD = BP / BGE$$



Bacterial Growth Efficiency (BGE) - *is an integration of all the anabolic and catabolic processes needed to meet the cells energy budget*



Partitioning of E for biosynthesis is variable

E demand for maintenance remains constant

↑ *CAT: ANAB* ↓ *BGE*

BGE = BP/(BP+BR)

Carlson et al. 2007

I. Regulation of BGE… complicated

A. Temperature

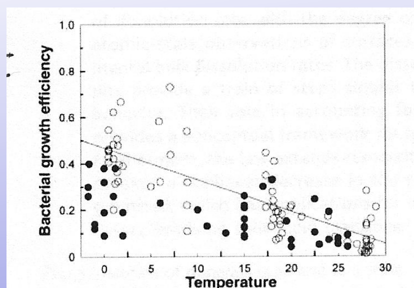


Fig. 1. Scatter plot of bacterial growth efficiency as a function of temperature for bacterioplankton from polar, temperate, and tropical oceans. Bacterial growth efficiency was determined from concurrent measurements of bacterial production and DOC uptake (open symbols) or of bacterial production and size-fractionated O_2 uptake (filled symbols). The ordinary least squares regression (regression line shown) between temperature (T) and bacterial growth efficiency (BGE) is: BGE = 0.374[±0.04] – 0.0104[±0.002]T, (r^2 = 0.54, n = 107, F = 84.27, $P < 0.001$). Values in brackets are the 95% confidence intervals of the regression parameters.

Rivkin and Legendre 2001

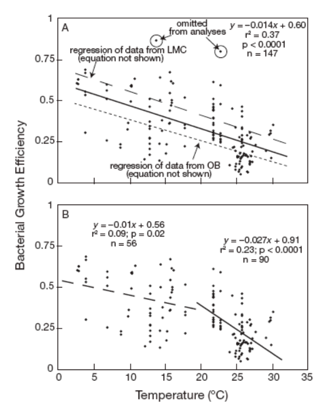


Fig. 6. Linear relationships between bacterial growth efficiency and temperature for (A) the entire dataset and (B) warmer versus colder ambient water temperatures. In A, best-fit lines for regressions of data from Little Monie Creek (LMC) and the open bay (OB) are indicated by broken lines; solid line represents regression of all data

Apple et al. 2006

Temporal Variability in BGE

North Sea

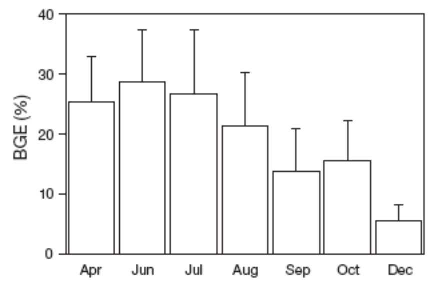
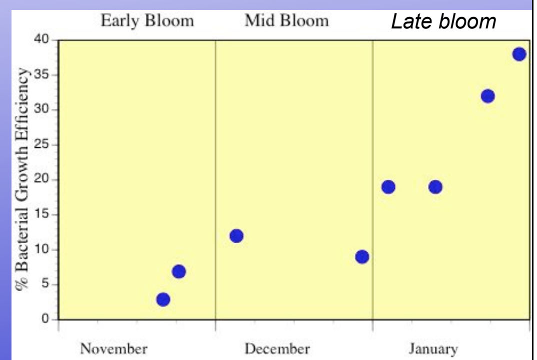


Fig. 8. Seasonal dynamics of bacterial growth efficiency (BGE) calculated as BGE = BP/(BP + BR) × 100 from April to December. Means (+SD); N = 9 to 21 estimates for the different months

Reinthaler and Herndl 2005

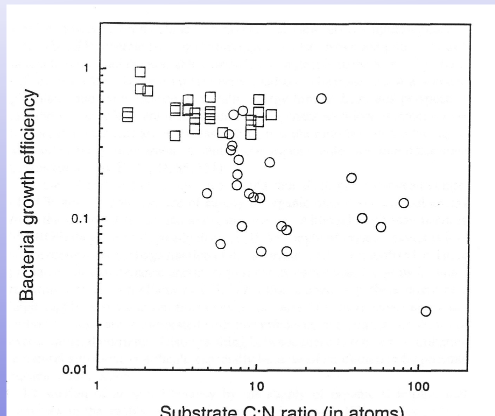
Ross Sea (change in temp < 4°C)



Carlson and Hansell 2003

I. Regulation of BGE

B. Substrate Stoichiometry



Del Giorgio and Cole 1998

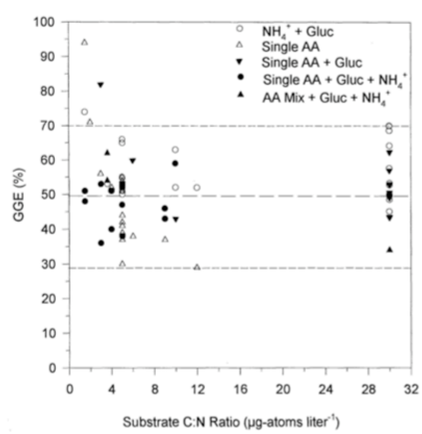
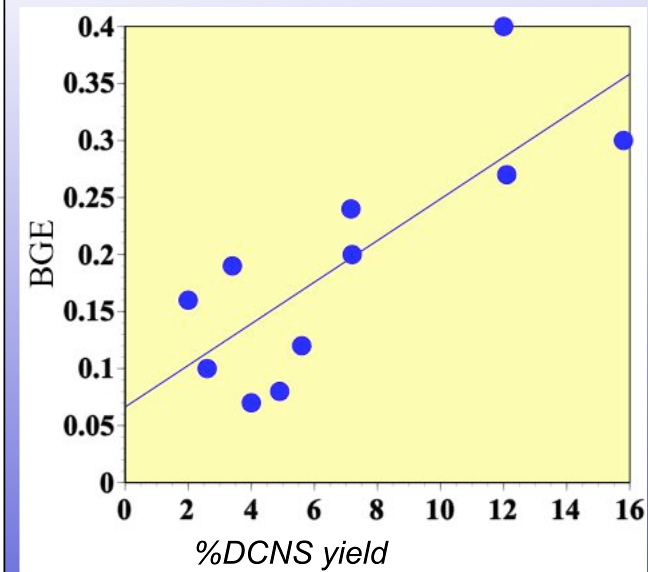


Fig. 10. Summary of GGE data as a function of substrate C : N_s ratio from current and previous experiments (Goldman and Dennett 1991; Goldman et al. 1987) with natural assemblages of marine bacteria grown with different carbon and nitrogen substrates in batch and continuous cultures. Average GGE from Table 3 is broken line and represents all data encompassed by dashed lines.

Goldman and Dennett 2000

Multiple C&N sources --relationship falls apart

C. DOC quality



However- uptake of bioavailable compounds does not always result in enhanced BGE…

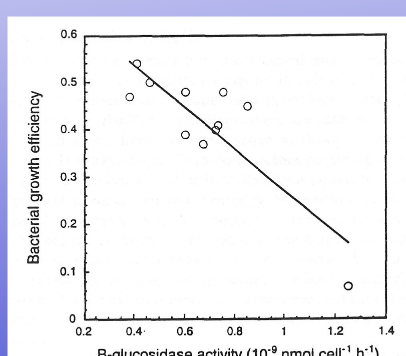
Energize membranes & support transport systems for other limiting nutrients

Cano, Goldberg, Carlson in prep

D. Supply vs nature of organic matter

Energetic Cost of:

•***Uptake and Transport***- *at low concentration of substrate may scavenge other substrates*



•***Enzymatic breakdown***:
DOC is polymeric and needs to be broken down to LMW compounds

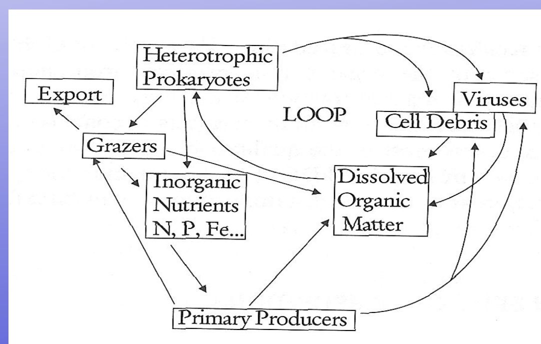
Middleboe and Sondergaard (1993)

II. Regulation of BGE on the Community Level:

Factors that affect community BGE are:

Predation:Selective removal of rapidly growing bacteria may impact mean BGE of assemblage.

- ***viral infection***- *lytic loop may display low BGE decrease BGE of non infected cells*



Fuhrman 2000

- ***Phylogenetic composition**: little known at this time*

2264 REINTHALER ET AL.

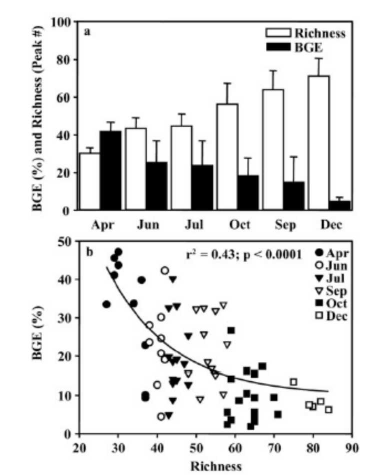


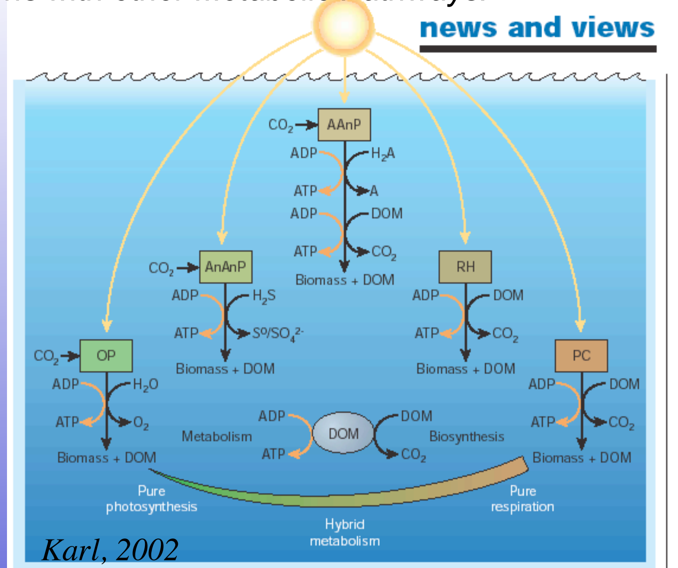
FIG. 5. Dynamics of bacterial growth efficiency (BGE) and richness during the seasonal cycle in the southern North Sea. (a) Monthly averages of BGE and bacterioplankton richness measured by T-RFLP. Error bars indicate standard deviations of the means (n = 8 to 19). (b) Relationship between BGE and bacterioplankton richness, with months indicated by different symbols.

Reinthaler and colleagues found:

- *BP decreased with bacterioplankton richness*
- *BR was variable along richness gradients*
- *This resulted in an inverse relationship between BGE and richness*

Reinthaler et al. 2005

Interactions with other Metabolic Pathways:



Light harvesting for photoheterotrophy could have impact on BGE

Proteorhodopsin - impact growth efficiency??

Pelagibacter ubique

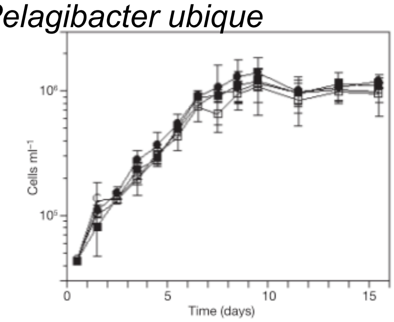
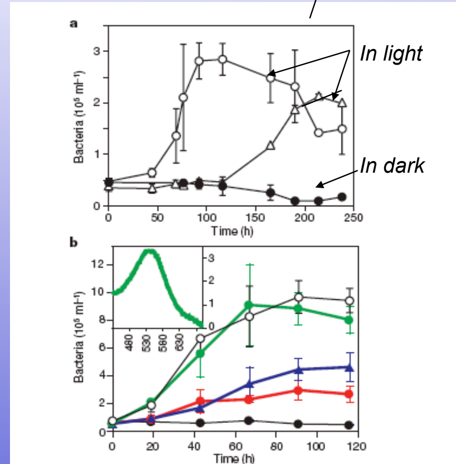


Figure 4 | Growth characteristics of HTCC1062. Bacteria were grown in seawater supplemented with N and P (LNHM) with no added organic carbon, on a diurnal light cycle (open symbols) or in darkness (closed symbols) under high-range light intensity (circles, 680 µmol m^{-2} s^{-1}) or middle-range light intensity (squares, 250 µmol m^{-2} s^{-1}). Error bars show standard deviation for triplicate experiments. No difference was observed for replicates with and without added retinal (data not shown).

Giovannoni et al. 2005

Marine Flavobacteria



Gomez-Consarnau et al 2007

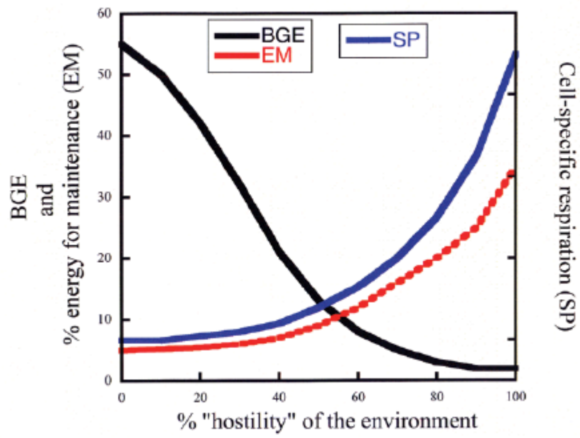
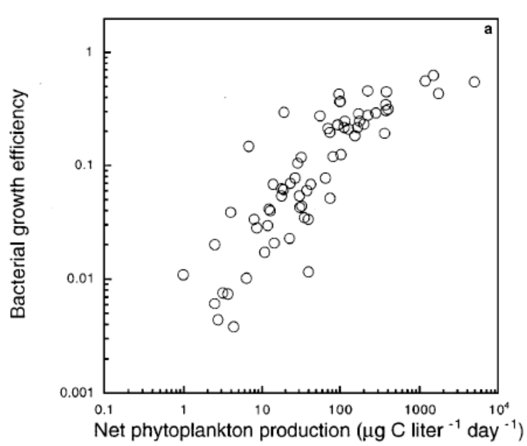


Figure 3. Conceptual diagram demonstrating the relationship between environmental stressors or environmental "hostility" and the partitioning of energy within a bacterial cell, the resulting bacterial growth efficiency (BGE), and cell specific respiration. As environmental hostility increases, more energy is partitioned into maintenance energy (EM). Thus, bacterial growth efficiency decreases and cell-specific respiration (SP) increases. Some combination of both physical (temperature, pH, salinity) and chemical (toxins, substrate availability) factors contribute to environmental hostility

Allocation of carbon and energy in marine bacteria depends on many factors

…difficult if not impossible to place variation of BGE on a single variable

Relationship between BGE and trophic status



Ducklow and Carlson 1992

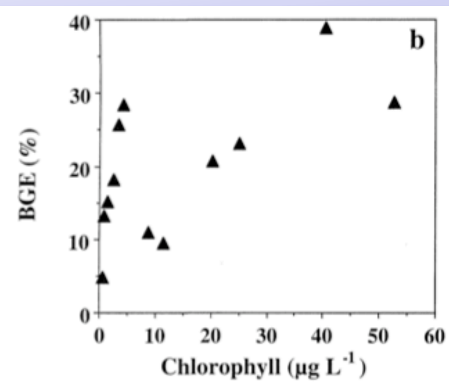


Fig. 3. Relationship of (a) bacterial respiration (BR) as a percent of planktonic respiration (PR) to chlorophyll concentration ($n = 12$, $r^2 = 0.420$, $p < 0.05$) and (b) bacterial growth efficiency (BGE; $n = 12$, $r^2 = 0.414$, $p < 0.05$) to chlorophyll concentration.

Biddanda et al. 2001

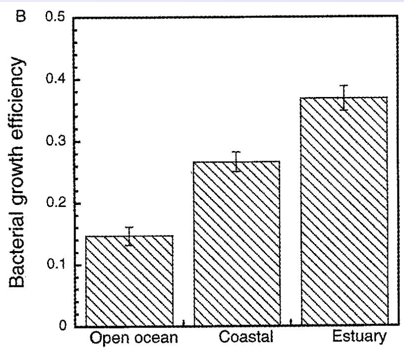


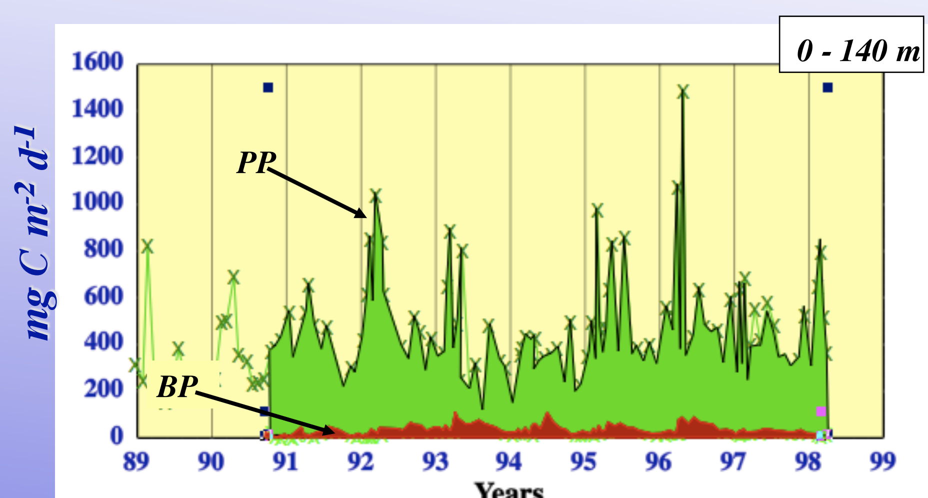
Figure 3. Summary of literature data on direct measurements of bacterial metabolism and growth efficiency in natural aquatic systems, from Table 1. (A) Bacterioplankton production (BP) and respiration (BR) averaged by system (open-ocean, coastal, and estuarine systems). (B) The resulting average bacterial growth efficiency (BGE = *BP*/(*BR* + *BP*)] for each system. Bars represent 1 standard error.

- BGE in marine systems < 0.4

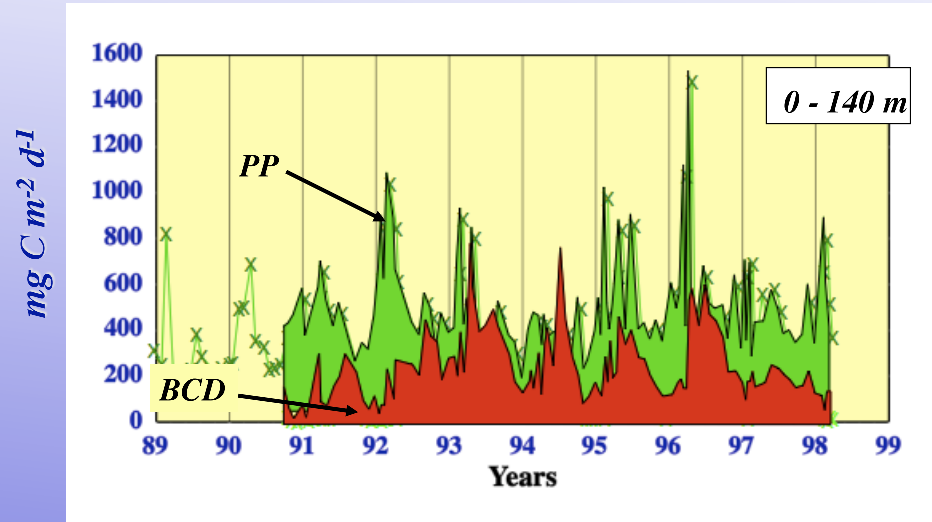
- decrease in BGE from coast to open ocean and is likely related to overall system productivity

Del Giorgio 2000

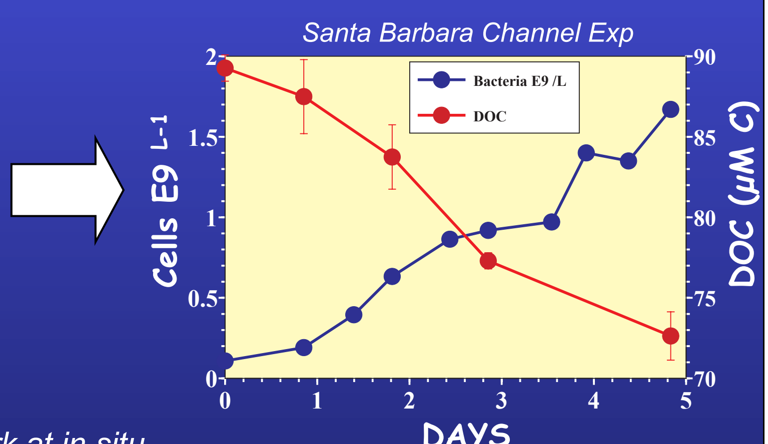
Integrated primary production and net bacterial production



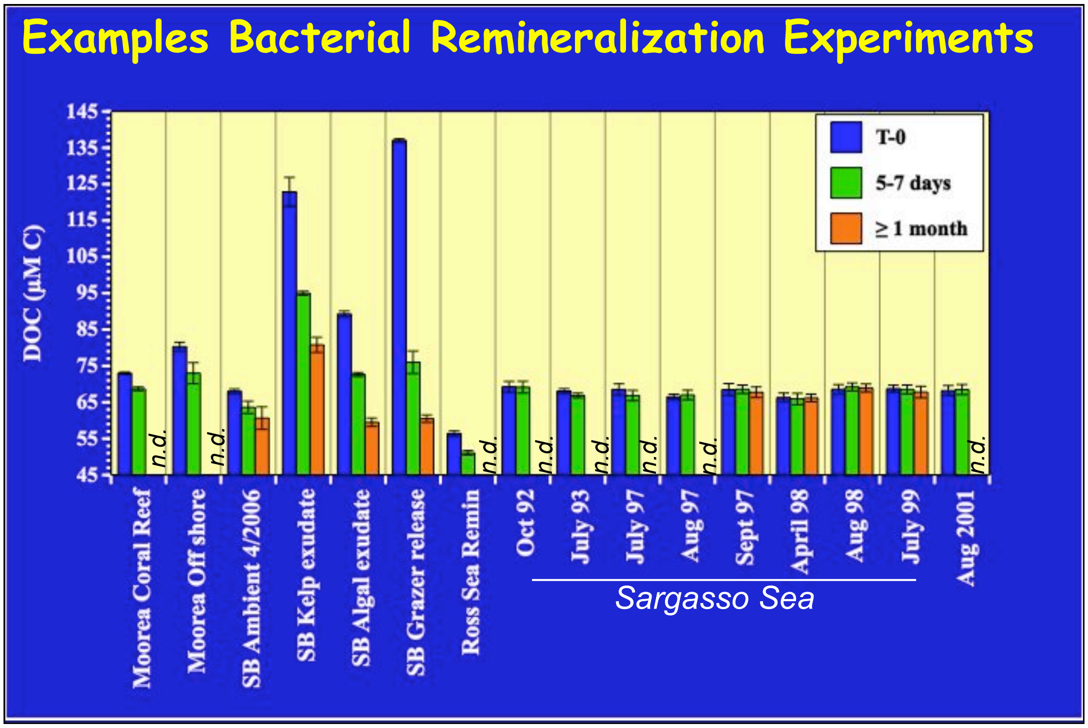
Integrated primary production and bacterial C demand at BATS



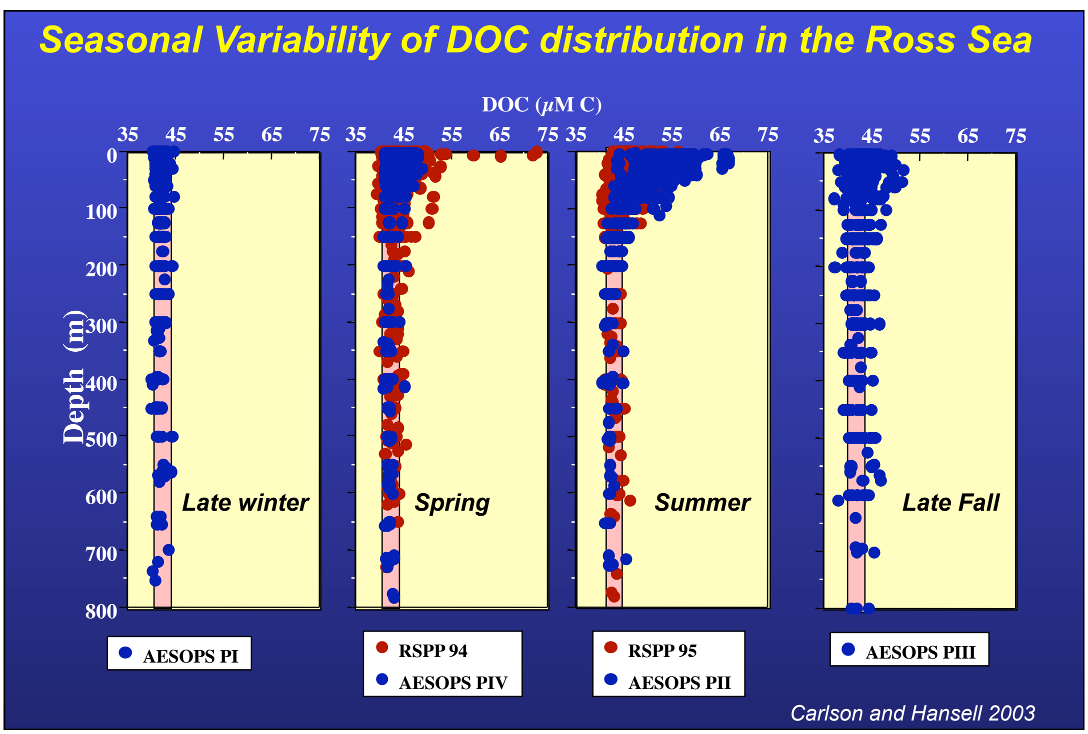
Example of a Remineralization Experiment used to examine the magnitude of the “labile” DOC pool



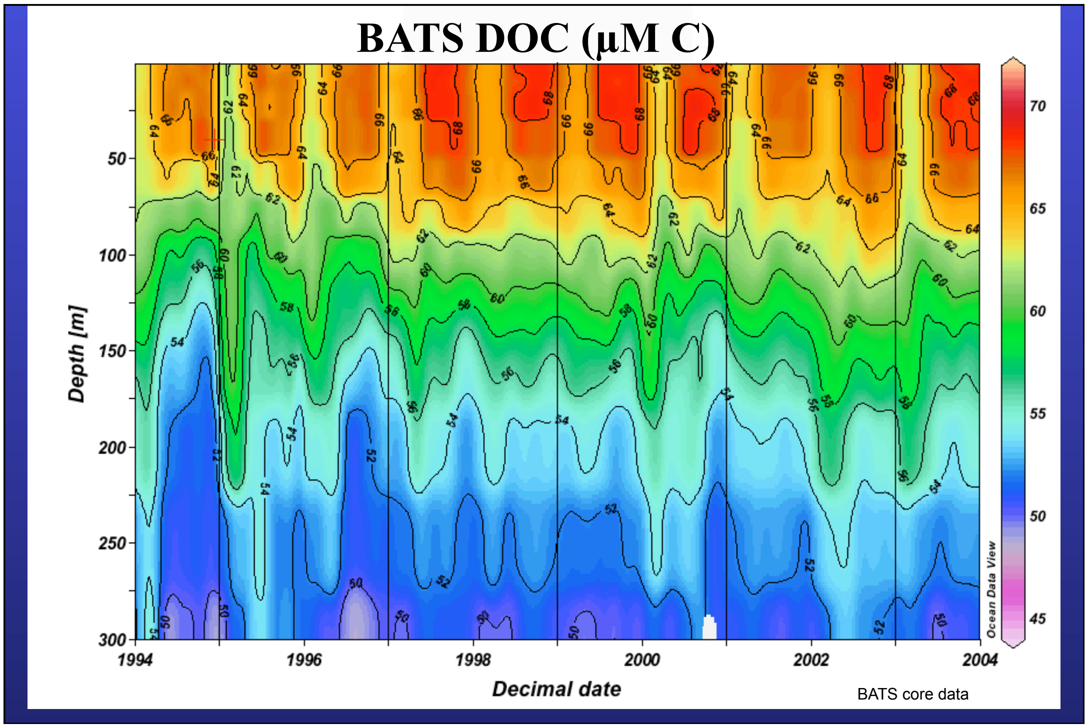
• *incubate in the dark at in situ temperature*

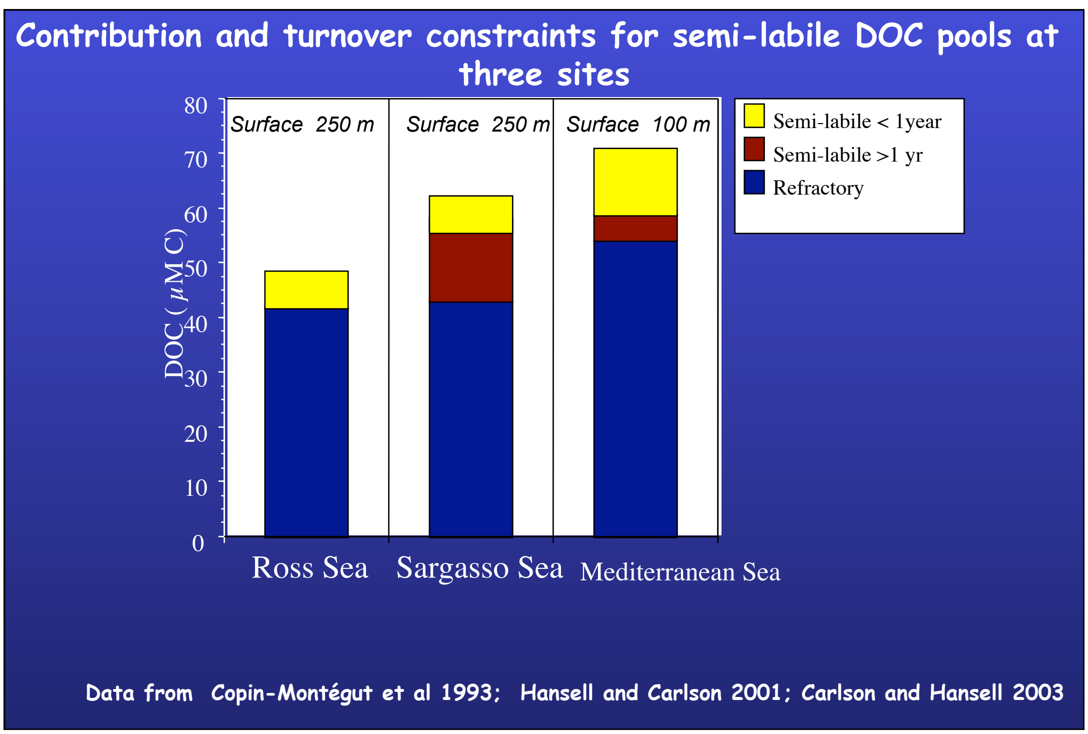


Examples Bacterial Remineralization Experiments
DOC (µM C)
145
135
125
115
105
95
85
75
65
55
45
T-0
5-7 days
≥ 1 month
n.d.
Moorea Coral Reef
Moorea Off shore
SB Ambient 4/2006
SB Kelp exudate
SB Algal exudate
SB Grazer release
Ross Sea Remin
Oct 92
July 93
July 97
Aug 97
Sept 97
April 98
Aug 98
July 99
Aug 2001
Sargasso Sea

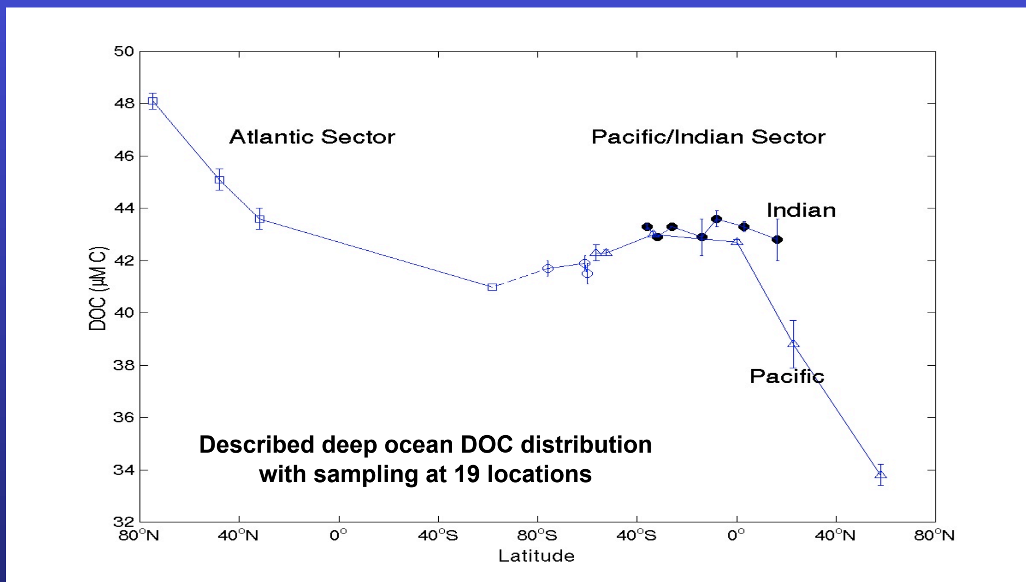


Seasonal Variability of DOC distribution in the Ross Sea
DOC (µM C)
35 45 55 65 75
Depth (m)
0
100
200
300
400
500
600
700
800
Late winter
Spring
Summer
Late Fall
AESOPS PI
RSPP 94
AESOPS PIV
RSPP 95
AESOPS PII
AESOPS PIII
Carlson and Hansell 2003


BATS DOC (µM C)
Depth [m]
Decimal date
BATS core data
Ocean Data View


Contribution and turnover constraints for semi-labile DOC pools at three sites
DOC (µM C)
Surface 250 m
Surface 250 m
Surface 100 m
Semi-labile < 1year
Semi-labile >1 yr
Refractory
Ross Sea
Sargasso Sea
Mediterranean Sea
Data from Copin-Montégut et al 1993; Hansell and Carlson 2001; Carlson and Hansell 2003

DOC in the Deep Global Ocean (Hansell and Carlson, 1998)



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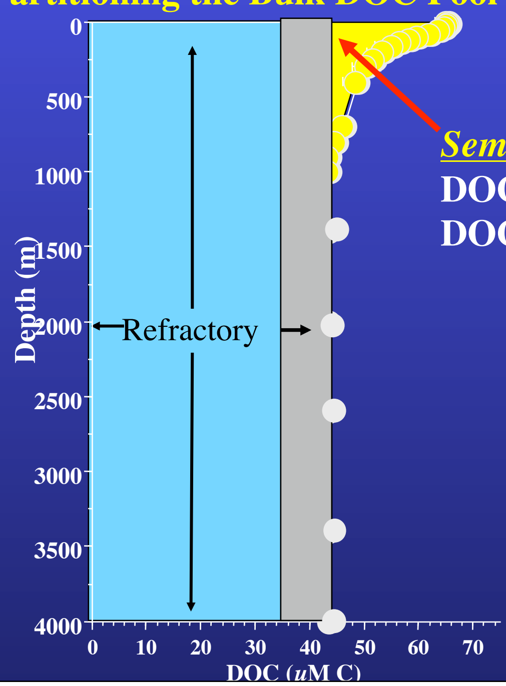
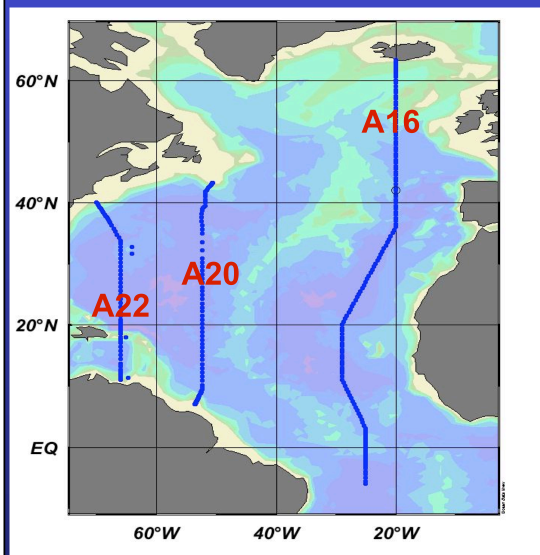
Partitioning the Bulk DOC Pool into Broad Pools of Lability



Semi-labile DOC - portion of bulk DOC that is in excess of deep water DOC concentrations

Decay rate?

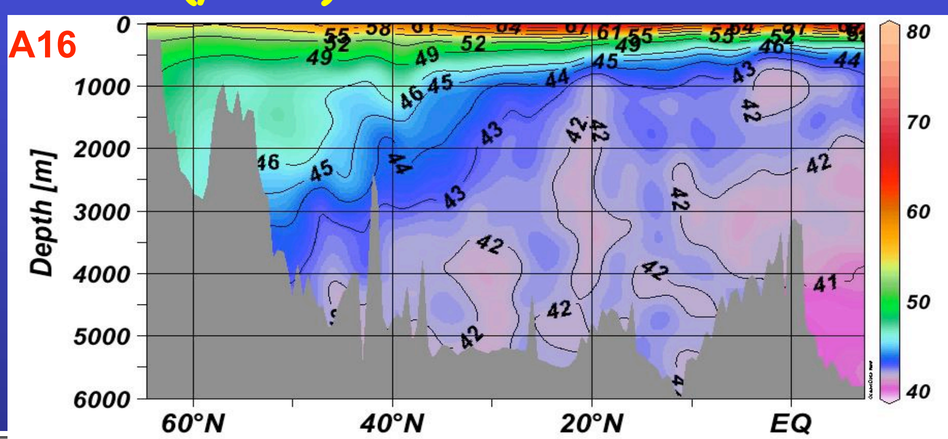
Distribution and Decay of DOC in the Interior of the North Atlantic Basin

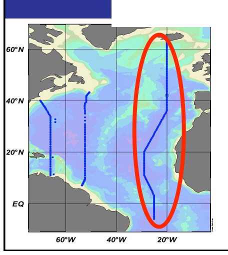


CLIVAR - US Repeat Hydrography

- ocean transport
- decadal variability of climatically important parameters

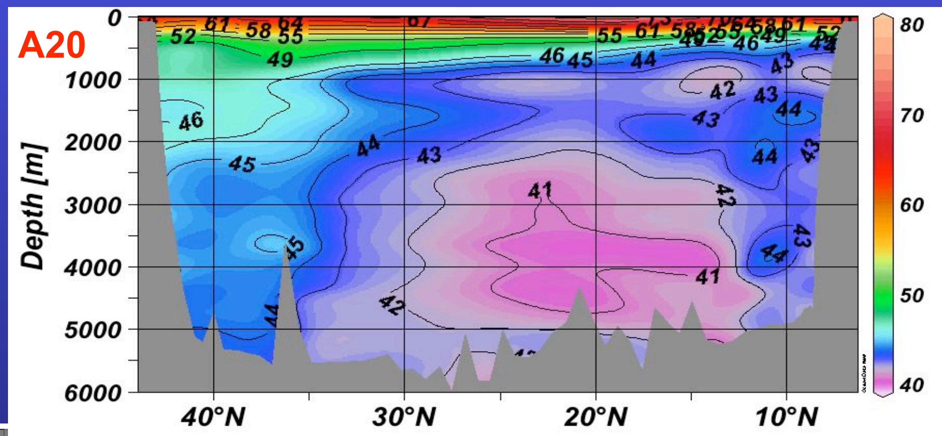
DOC (μM C) in the N. Atlantic

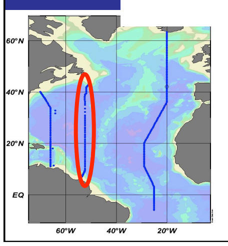




Carlson et al. submitted

DOC (µM C) in the N. Atlantic

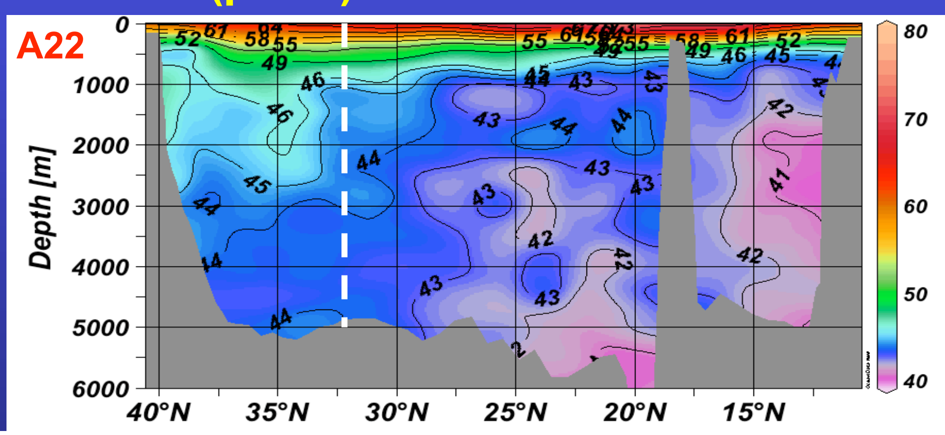


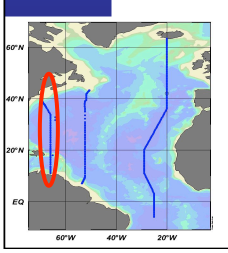


- greater DOC variability within the ocean's interior than previously thought to exits….
- how does it correlate with other tracers??

Carlson et al. submitted

DOC (µM C) in the N. Atlantic

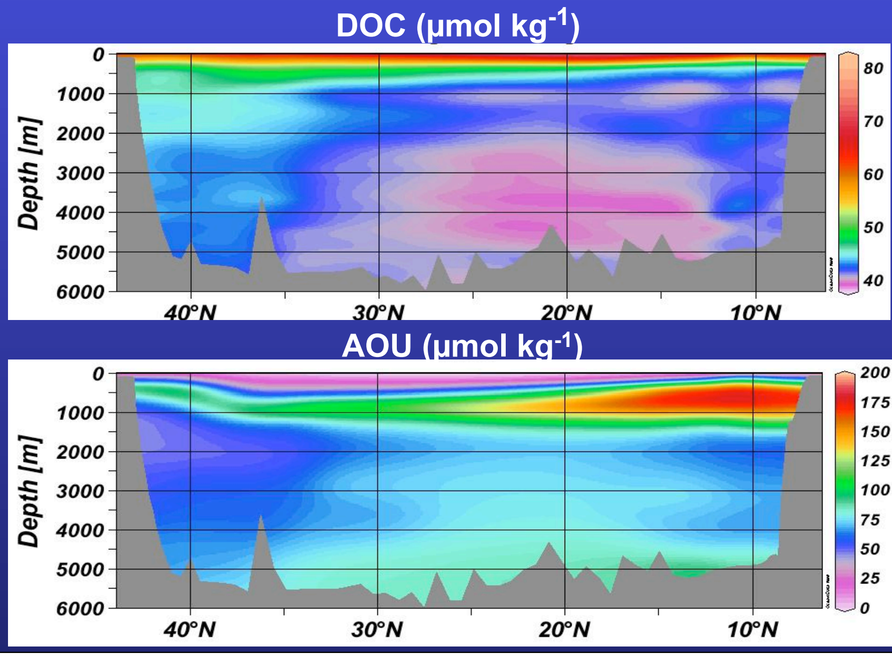




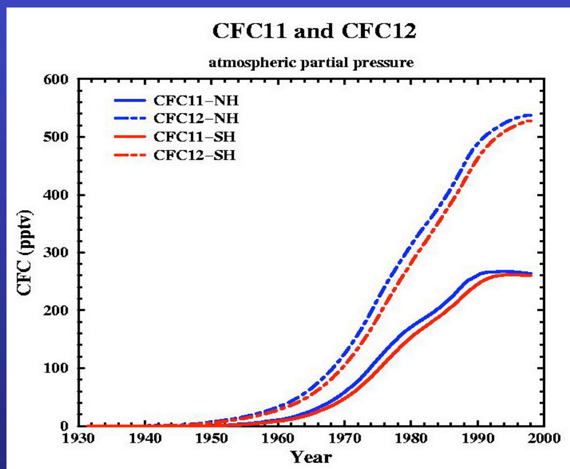
- greater DOC variability within the ocean's interior than previously thought to exits….
- how does it correlate with other tracers??

Carlson et al. submitted

Variability of DOC and AOU along A20



CFC's as Transient Tracers



Mixing with ocean imprints ventilated waters w/ CFC levels

Provides a ventilation "age" for water mass

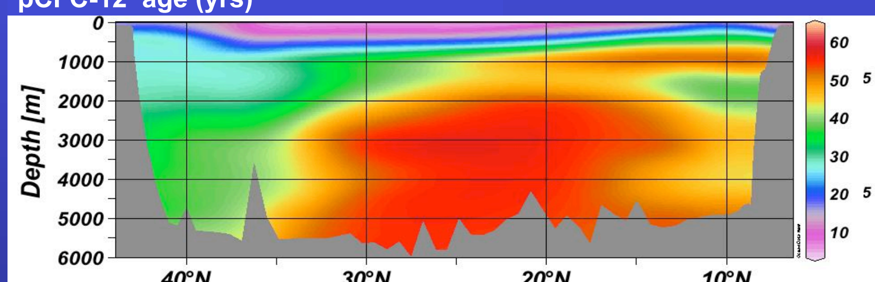
Atmospheric CFC's are now dropping

- Good for the O_3 hole
- Bad for tracer work…

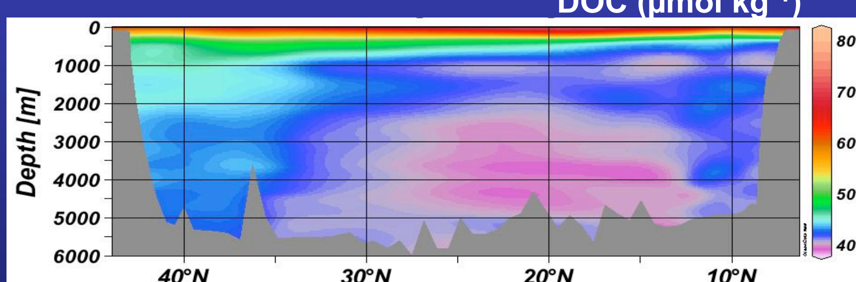
Work by Rana Fine and Bill Smethie

Variability of CFC-12, DOC and age along A20

pCFC-12 age (yrs)



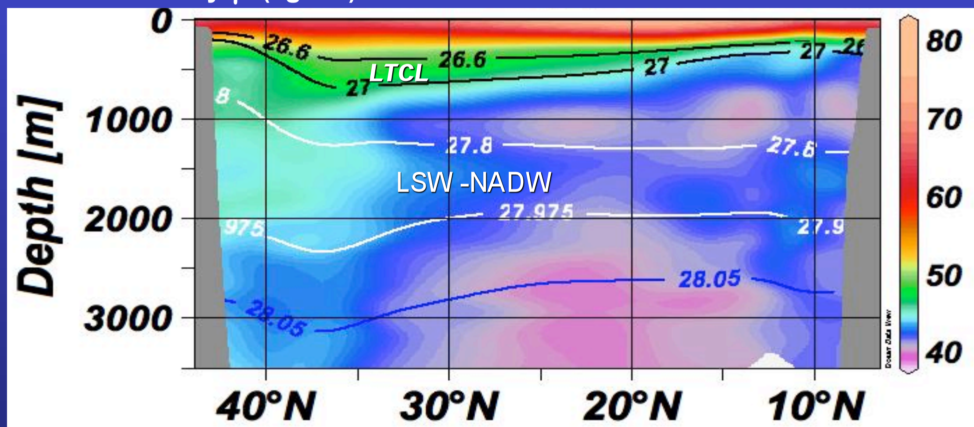
DOC (µmol kg^{-1})



Age calculations by Bill Smethie & Samar Khatiwala [LDEO]

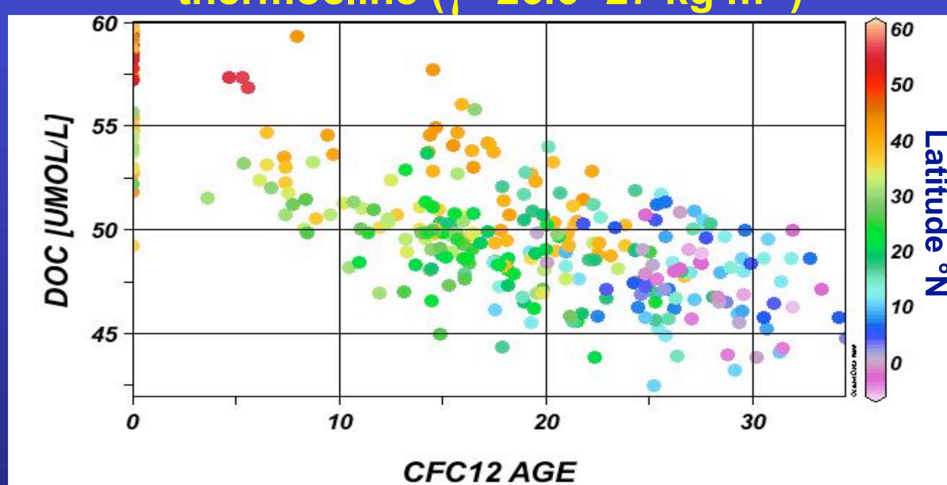
DOC variability within Neutral density layers

Neutral Density γ^n (kg m^{-3}) DOC (µmol kg^{-1})



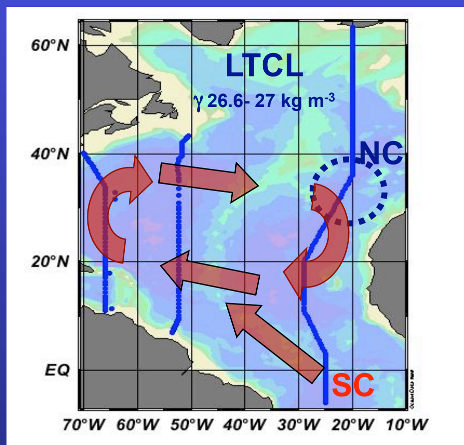
Focus on variability within water masses of similar density

DOC compared to ventilation age in the Lower thermocline (γ^n 26.6- 27 kg m^{-3})

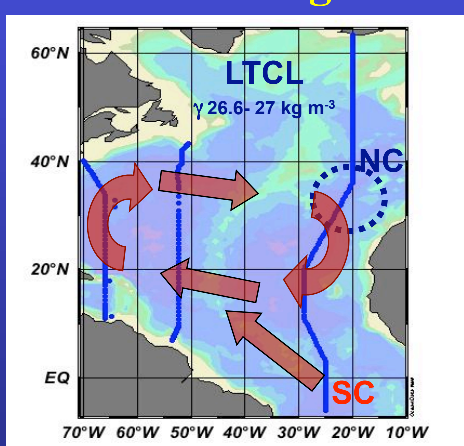


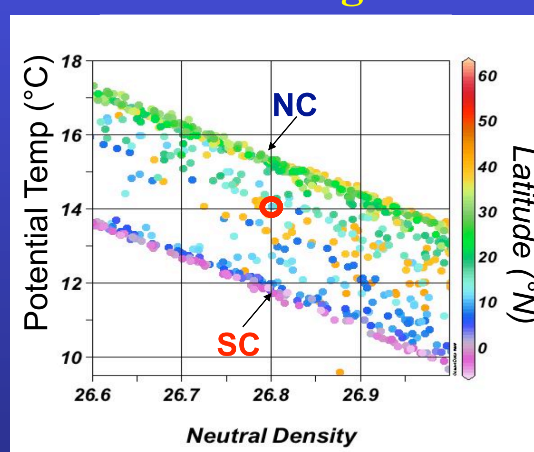
….but what about isopycnal mixing??

Accounting for End-member Mixing



Accounting for End-member Mixing





Gruber and Sarmiento 1997

Binary Mixing Model:

1. $1 = f_n + f_s$
2. $C° = f_n C_n + f_s C_s$

C°= concentration due to mixing of northern and southern end-members

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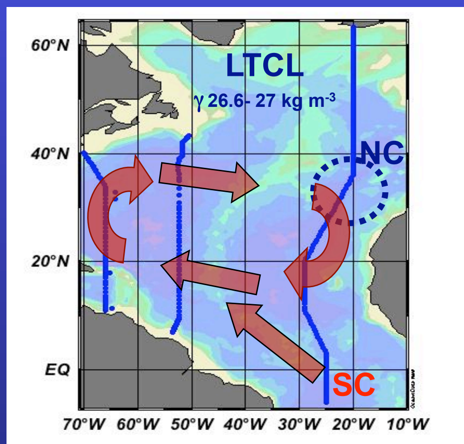

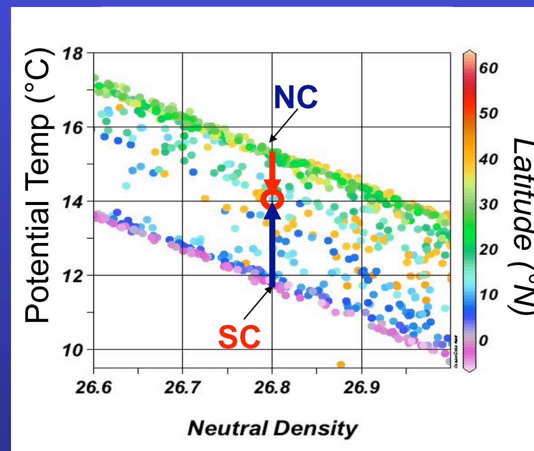

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Binary Mixing Model:

1. $1 = f_n + f_s$

2. $C° = f_n C_n + f_s C_s$

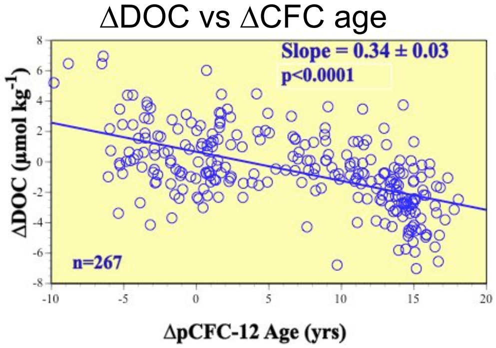
$C°$= concentration due to mixing of northern and southern end-members

3. $C_{obs} - C° = \Delta C$

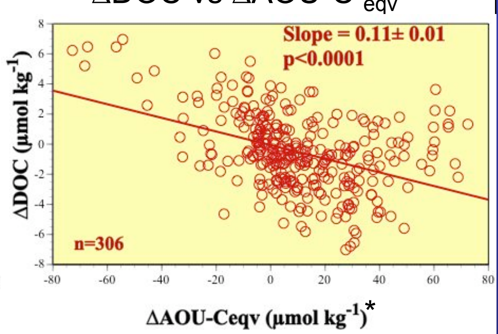
ΔC = measure of concentration changes due to processes other than mixing

Model II major axis regression

ΔDOC vs ΔCFC age

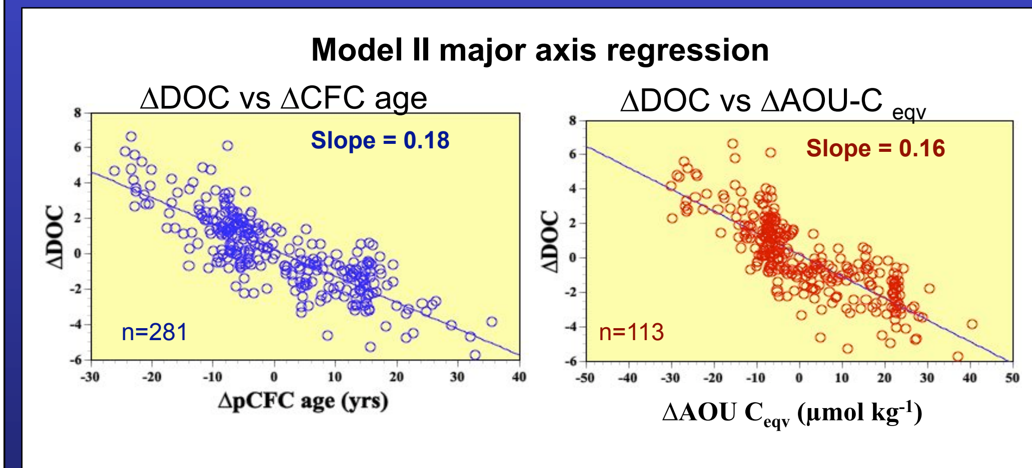


ΔDOC vs ΔAOU-C_{eqv}



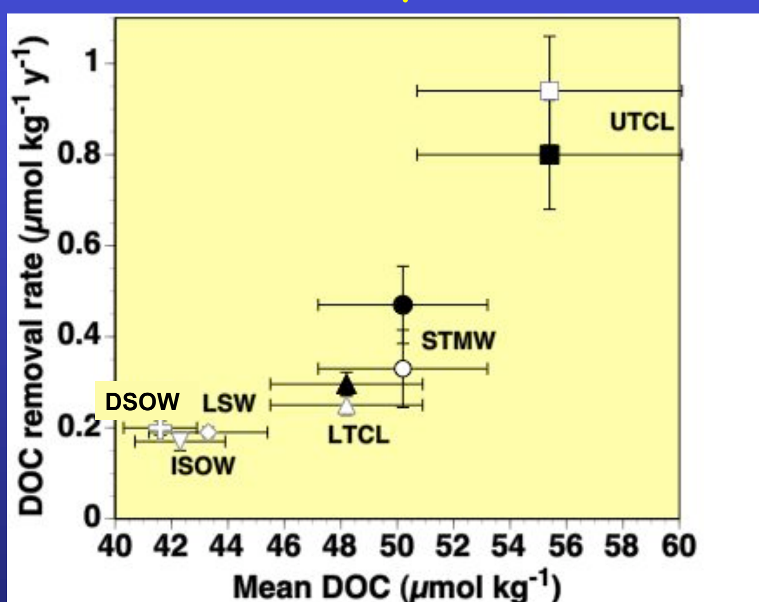
* AOU * 0.72 = AOU C_{eqv}

For LSW need to use a 3 end-member mixing model to correct for mixing along isopycnals

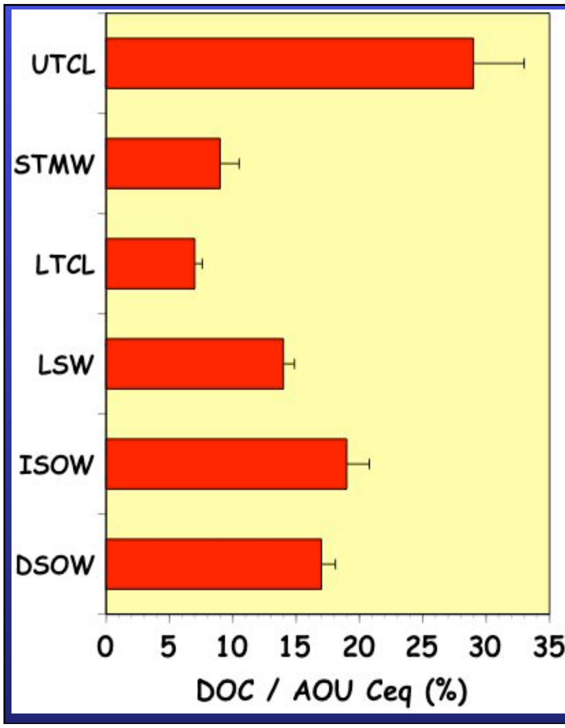


* AOU * 0.72 = AOU C_{eqv}

Estimates of DOC decay rates within NA water masses



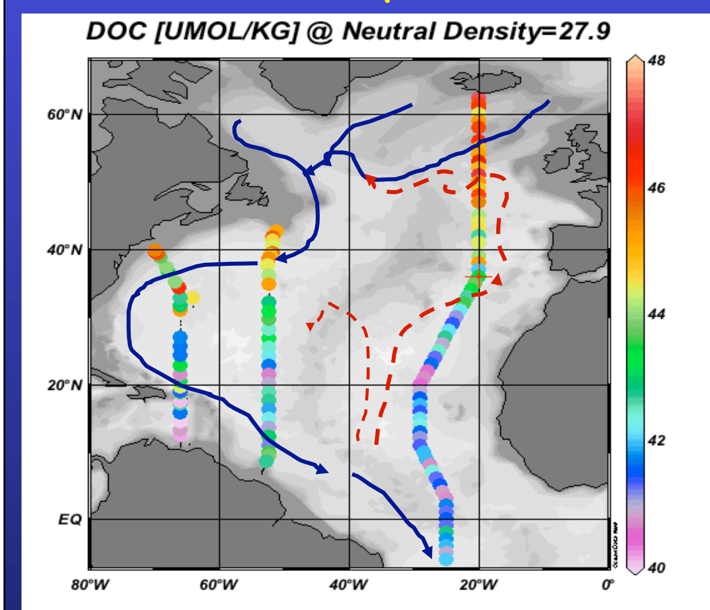
Carlson et al. submitted



Contribution of DOC oxidation to oxygen consumption within the various water masses

Carlson et al. submitted

North Atlantic Deep Water Circulation



Decay along East - West NADW flow

LSW

0.46 µmol kg^{-1} yr^{-1}

ISOW

0.26 µmol kg^{-1} yr^{-1}

DSOW

0.31 µmol kg^{-1} yr^{-1}

END

2. In all processes or reactions, some of the energy involved irreversibly loses its ability to do work.

Growth efficiency (yield) - is the quantity of biomass synthesized per unit of substrate assimilated

Bacterial Growth Efficiency = BP / (BP+BR)

-BP easy measure to make (accuracy ???)

--BR more important but hard measure to make