Terrestrial carbon and nutrient fluxes and the biogeochemical responses in the Mississippi River plume and Northern Gulf of Mexico

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Ocean Carbon & Biogeochemistry

Studying marine biogeochemical cycles and associated ecosystems in the face of environmental change

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Acknowledgement

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- NASA— (2005-2008)
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outline

- River delivery of C and nutrients to coastal oceans
  - Global flux
  - Mississippi River flux
  - The effect of river loading on coastal metabolism
- Biogeochemical responses in the river plume and nearby areas
  - Nutrient behavior
  - Biological production
  - Control on the CO_2 system
- Carbon budget in the Northern Gulf of Mexico

Global river delivery of C and nutrients to coastal oceans

Major River Basins of the World

North America
1 Yukon
2 Mackenzie
3 Nelson
4 Mississippi
5 St. Lawrence

South America
6 Amazon
7 Paraná

Europe
25 Danube

Africa and West Asia
8 Niger
9 Lake Chad Basin
10 Congo
11 Nile
12 Zambezi
26 Orange
24 Euphrates and Tigris

Asia and Australia
13 Volga
14 Ob
15 Yenisey
16 Lena
17 Kolyma
18 Amur
19 Ganges and Brahmaputra
20 Yangtze
21 Murray Darling
22 Huang He
23 Indus

Source: United Nations Environment Programme (UNEP); World Conservation Monitoring Centre (WCMC); World Resources Institute (WRI); American Association for the Advancement of Science (AAAS); *Atlas of Population and Environment*, 2001.

Global riverine C, N, and P flux

C, N and P inputs from land to the global coastal ocean (10^{12} mol/yr)

Item	Meybeck 1982&1993	NEWS-model 2005	Smith et al. 2003	Adopted here	ratio	
DIC	32		LOICZ	33.9	C:N	21
DIN	0.52	1.8	1.35	1.5	N:P	30
DIP	0.03	0.03	0.07	0.05	C:P	640
			(Smith & Hollibaugh, 1993)			
DOC	20.5	14	17	18	C:N	26
DON	0.85	0.71		0.7	N:P	35
DOP	0.027	0.019		0.02	C:P	900
PIC	14			14		
POC	18.2		17	18	C:N	6
PON	2.9			2.9	N:P	5
PP(Inorg)	0.6			0.6	C:P	30
Total C	84.7			83.9	C:N	16
Total N	4.3			5.1	N:P	8
Total P	0.65			0.67	C:P	121
autotrophic loading based on DIN input and Redfield ratio						10
assuming 50% of DIN will be denitrified in coastal zone						5
assuming 80% of DIN will be denitrified						2
heterotrophic loading						
assuming xx% of land OC is respired in coastal ocean					0.70	25
N recyled						3
net heterotophic loading						23

- DIC flux ~ TOC flux
- Heterotrophic loading >> auto…

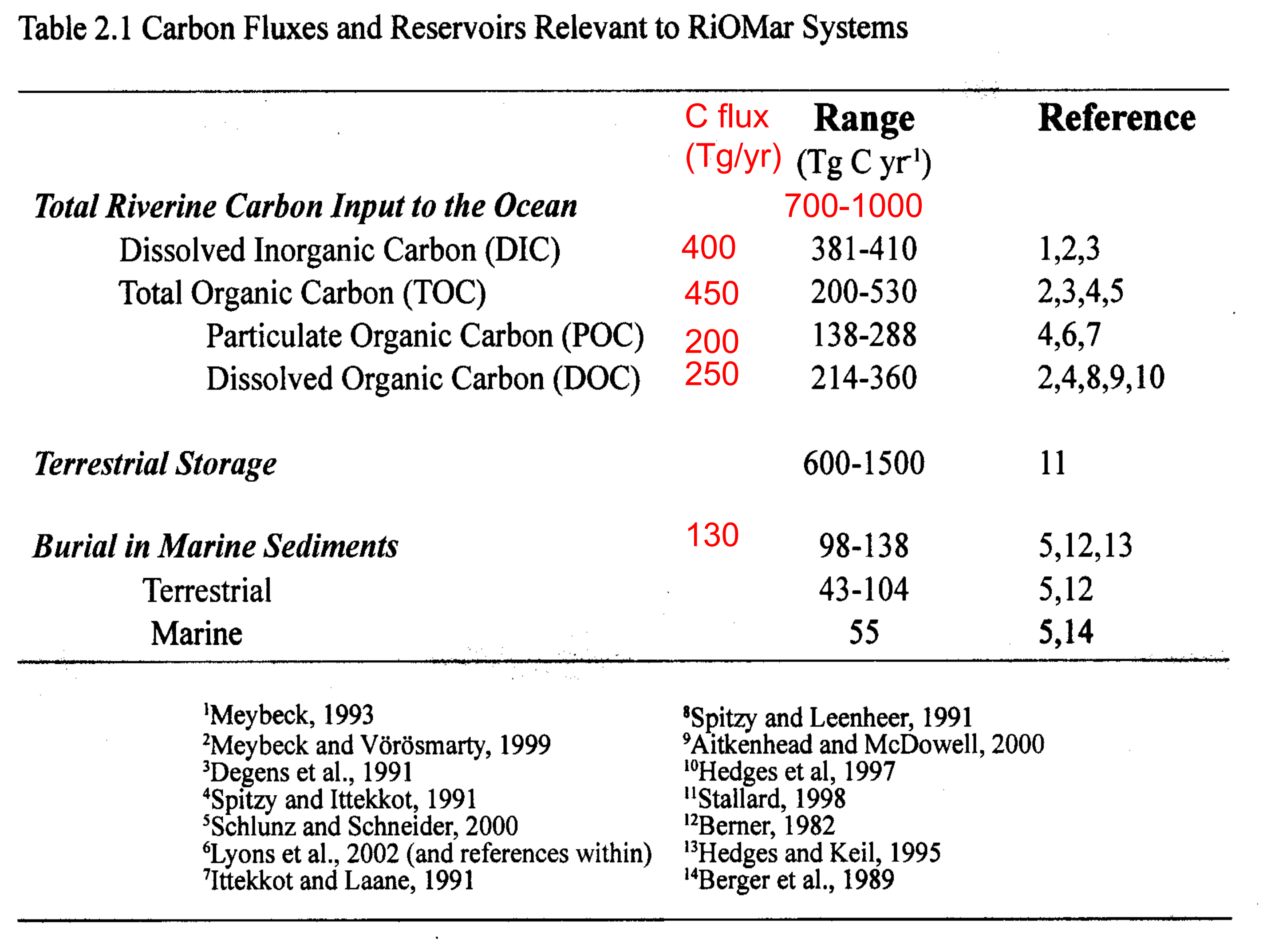


Table 2.1 Carbon Fluxes and Reservoirs Relevant to RiOMar Systems

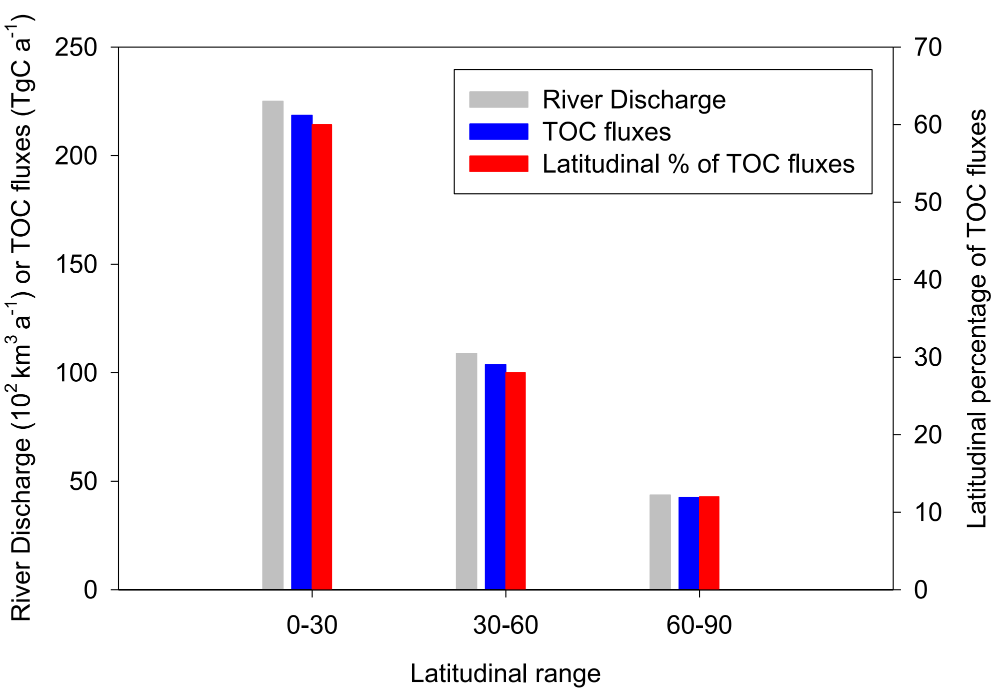
	C flux (Tg/yr)	**Range** (Tg C yr^{1})	**Reference**
Total Riverine Carbon Input to the Ocean		700-1000	
Dissolved Inorganic Carbon (DIC)	400	381-410	1,2,3
Total Organic Carbon (TOC)	450	200-530	2,3,4,5
Particulate Organic Carbon (POC)	200	138-288	4,6,7
Dissolved Organic Carbon (DOC)	250	214-360	2,4,8,9,10
Terrestrial Storage		600-1500	11
Burial in Marine Sediments	130	98-138	5,12,13
Terrestrial		43-104	5,12
Marine		55	5,14

[1] Meybeck, 1993
[2] Meybeck and Vörösmarty, 1999
[3] Degens et al., 1991
[4] Spitzy and Ittekkot, 1991
[5] Schlunz and Schneider, 2000
[6] Lyons et al., 2002 (and references within)
[7] Ittekkot and Laane, 1991
[8] Spitzy and Leenheer, 1991
[9] Aitkenhead and McDowell, 2000
[10] Hedges et al, 1997
[11] Stallard, 1998
[12] Berner, 1982
[13] Hedges and Keil, 1995
[14] Berger et al., 1989

RiOMar 2001 report, (B. McKee et al.)

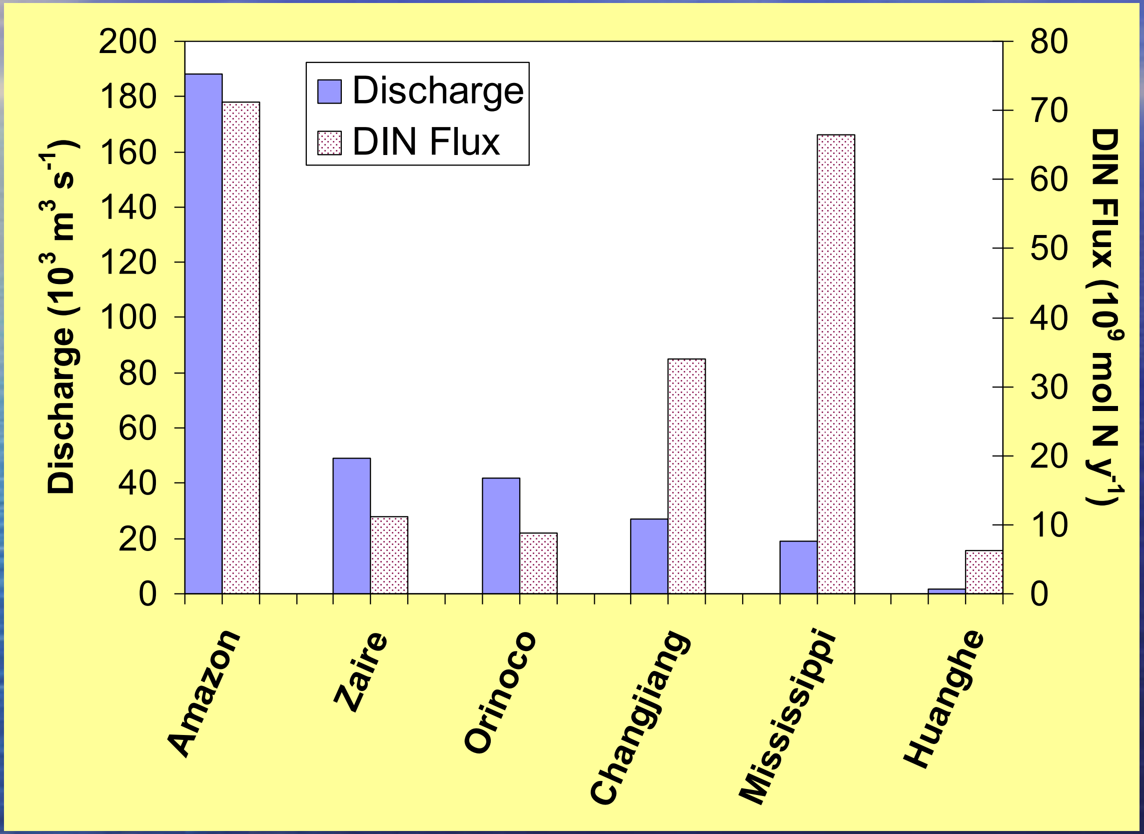
Contrast in organic C input

- deliver more heterotrophic loading to low-lat margins



Compiled by M. Dai and W-J. Cai; also see Borges papers

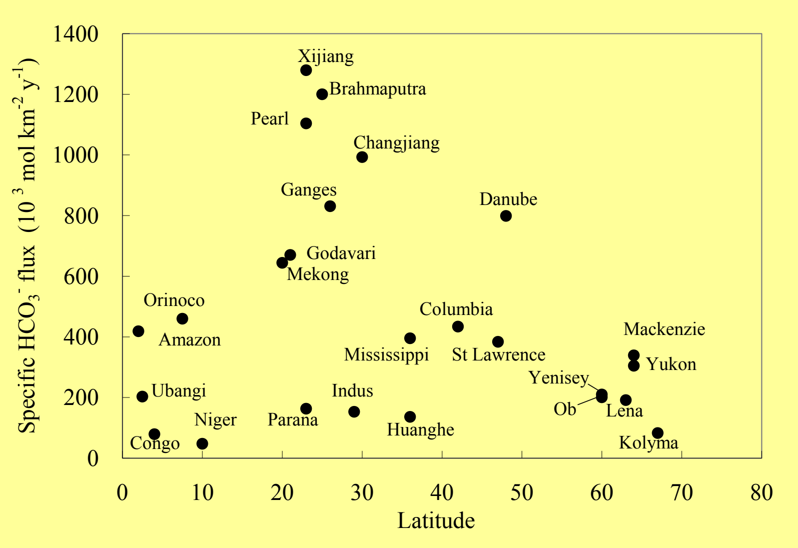
DIN flux in world’s major rivers



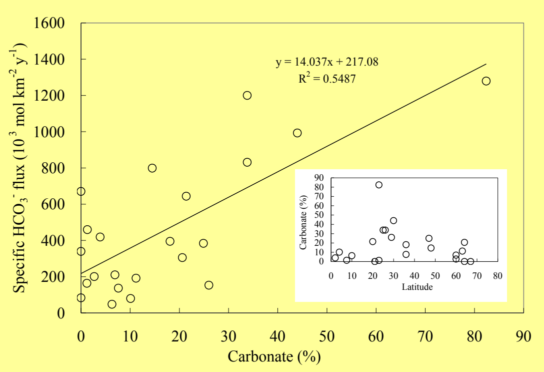
Source: Dagg et al. 2004

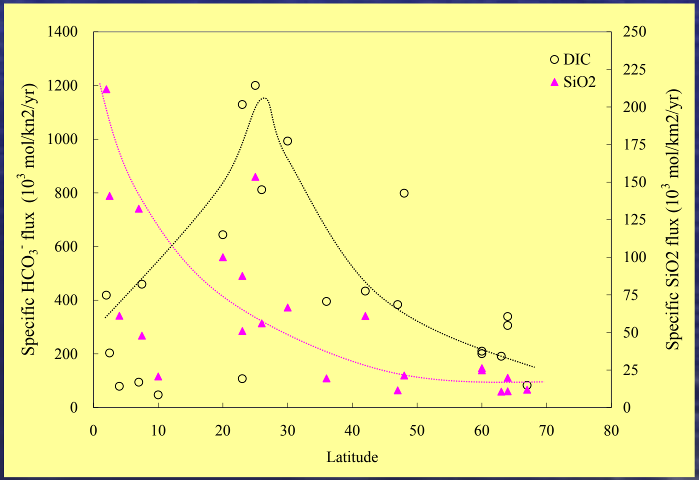
Speculate: River loading drives tropical margins towards heterotrophic, and mid lat margins to autotrophic.

Distribution of riverine HCO_3^- & Si flux



1. Latitudinal distribution in HCO_3 flux
2. $CaCO_3$ minerals in drainage basin
3. Contrast to silicate flux

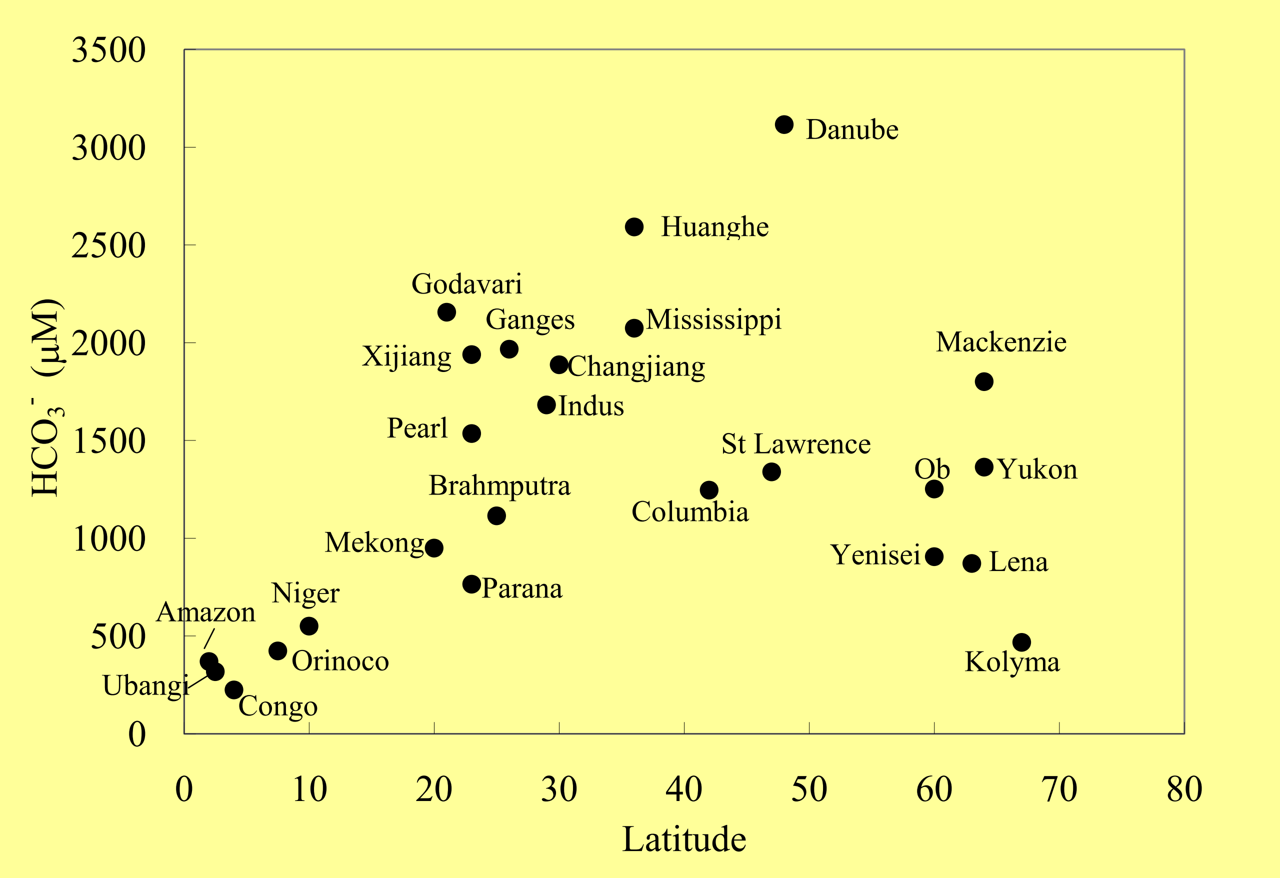




From Cai et al. 2008
Continental Shelf Research 28:1538-1549.

Cai unpublished

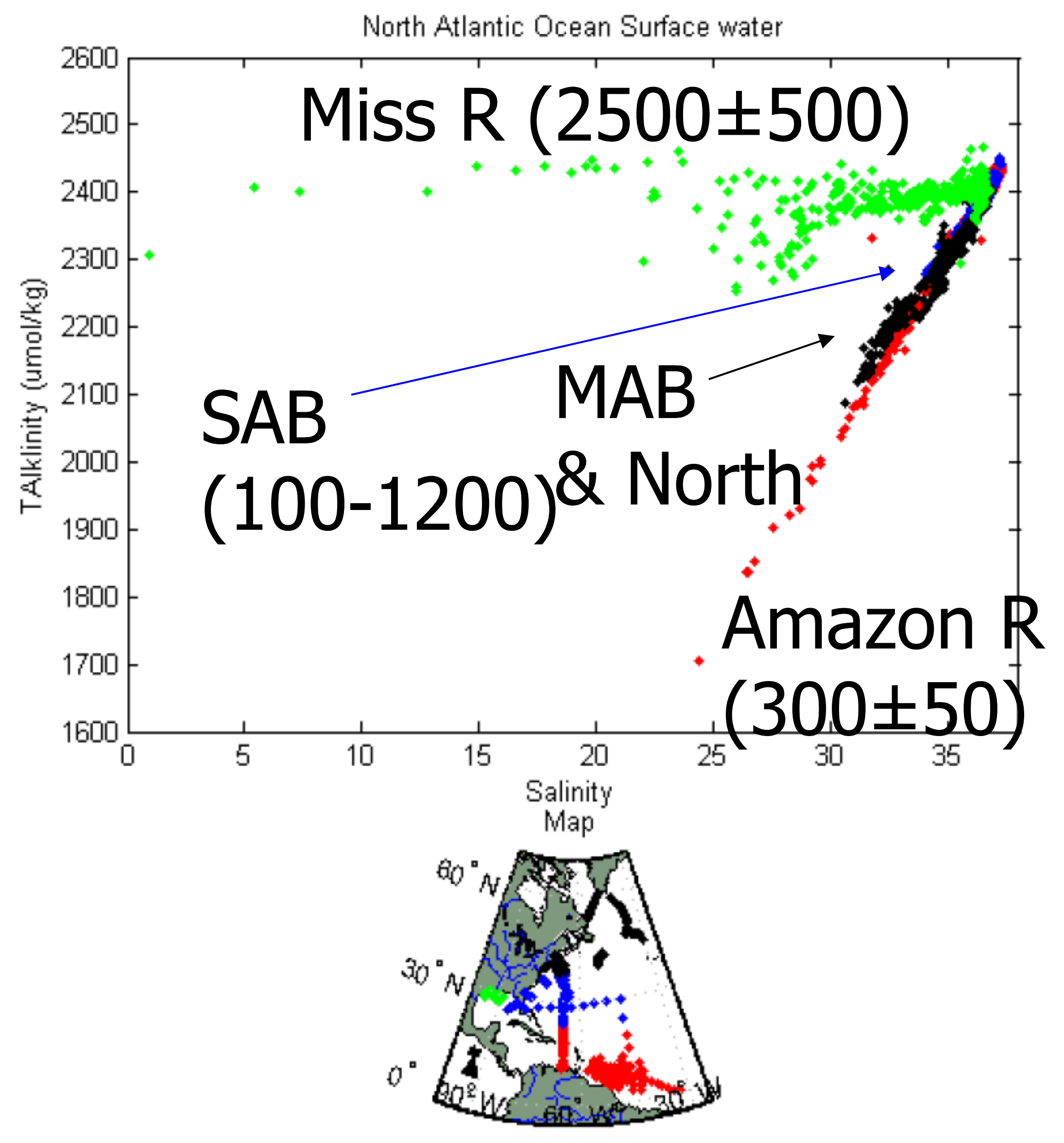
Distribution of riverine HCO^{3-} concentration



Maximum shifted to higher latitude as a result of precipitation pattern

From Cai et al. 2008
Continental Shelf Research 28:1538-1549.

Influence on TAlk distr in Ocean Margins



Miss R (2500±500)

SAB
(100-1200)

MAB
& North

Amazon R
(300±50)

Mississippi River flux

- Largest river basin in North America and third largest in the world
- Drainage basin encompasses 41% of the lower 48 United States

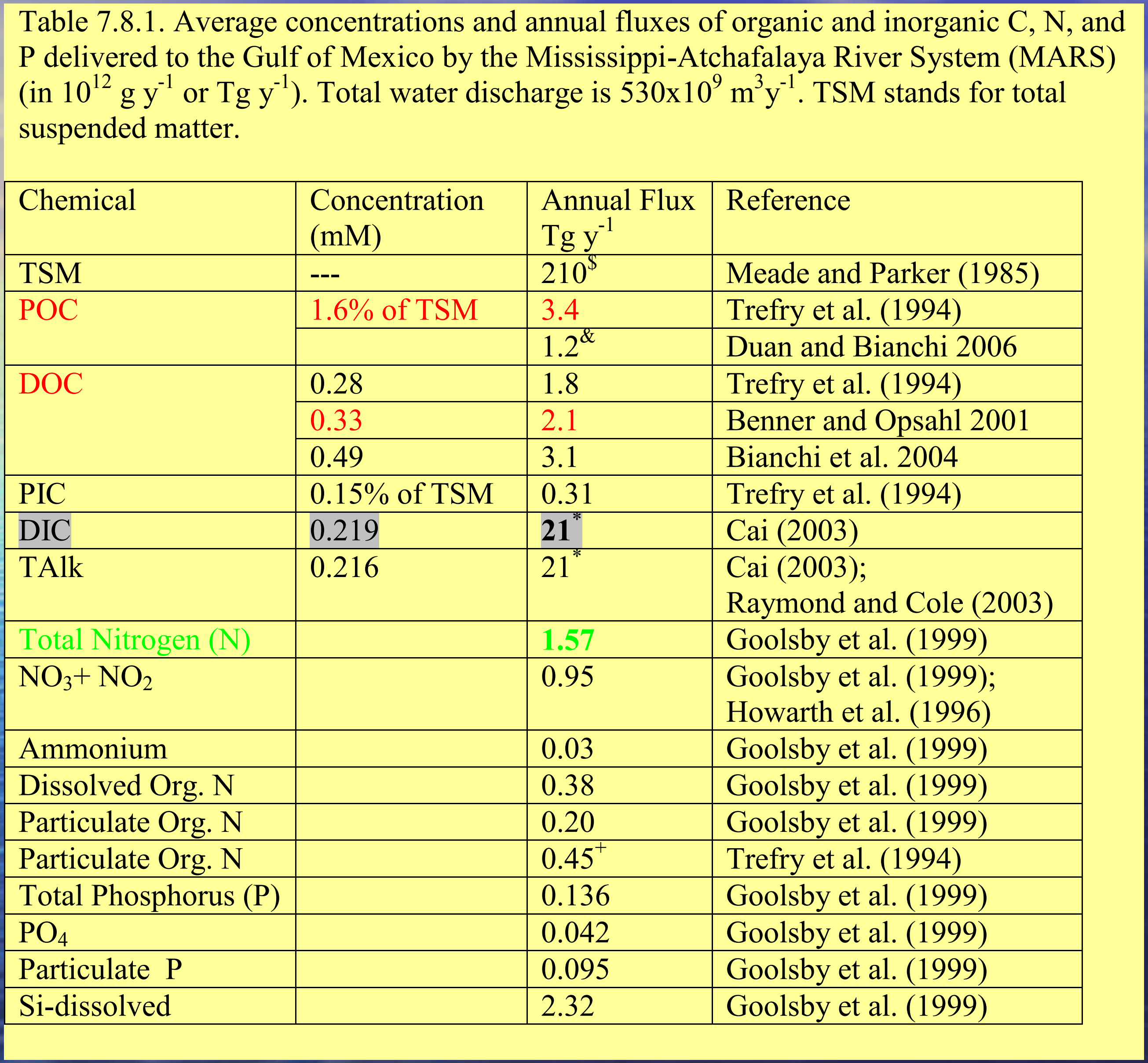


Table 7.8.1. Average concentrations and annual fluxes of organic and inorganic C, N, and P delivered to the Gulf of Mexico by the Mississippi-Atchafalaya River System (MARS) (in 10^{12} g y^{-1} or Tg y^{-1}). Total water discharge is 530×10^9 $m^3 y^{-1}$. TSM stands for total suspended matter.

Chemical	Concentration (mM)	Annual Flux Tg y^{-1}	Reference
TSM	---	$210^{\$}$	Meade and Parker (1985)
POC	1.6% of TSM	3.4	Trefry et al. (1994)
		$1.2^{\&}$	Duan and Bianchi 2006
DOC	0.28	1.8	Trefry et al. (1994)
	0.33	2.1	Benner and Opsahl 2001
	0.49	3.1	Bianchi et al. 2004
PIC	0.15% of TSM	0.31	Trefry et al. (1994)
DIC	0.219	**21***	Cai (2003)
TAlk	0.216	21^{*}	Cai (2003); Raymond and Cole (2003)
Total Nitrogen (N)		**1.57**	Goolsby et al. (1999)
$NO_3 + NO_2$		0.95	Goolsby et al. (1999); Howarth et al. (1996)
Ammonium		0.03	Goolsby et al. (1999)
Dissolved Org. N		0.38	Goolsby et al. (1999)
Particulate Org. N		0.20	Goolsby et al. (1999)
Particulate Org. N		0.45^{+}	Trefry et al. (1994)
Total Phosphorus (P)		0.136	Goolsby et al. (1999)
PO_4		0.042	Goolsby et al. (1999)
Particulate P		0.095	Goolsby et al. (1999)
Si-dissolved		2.32	Goolsby et al. (1999)

1. DIC>>TOC

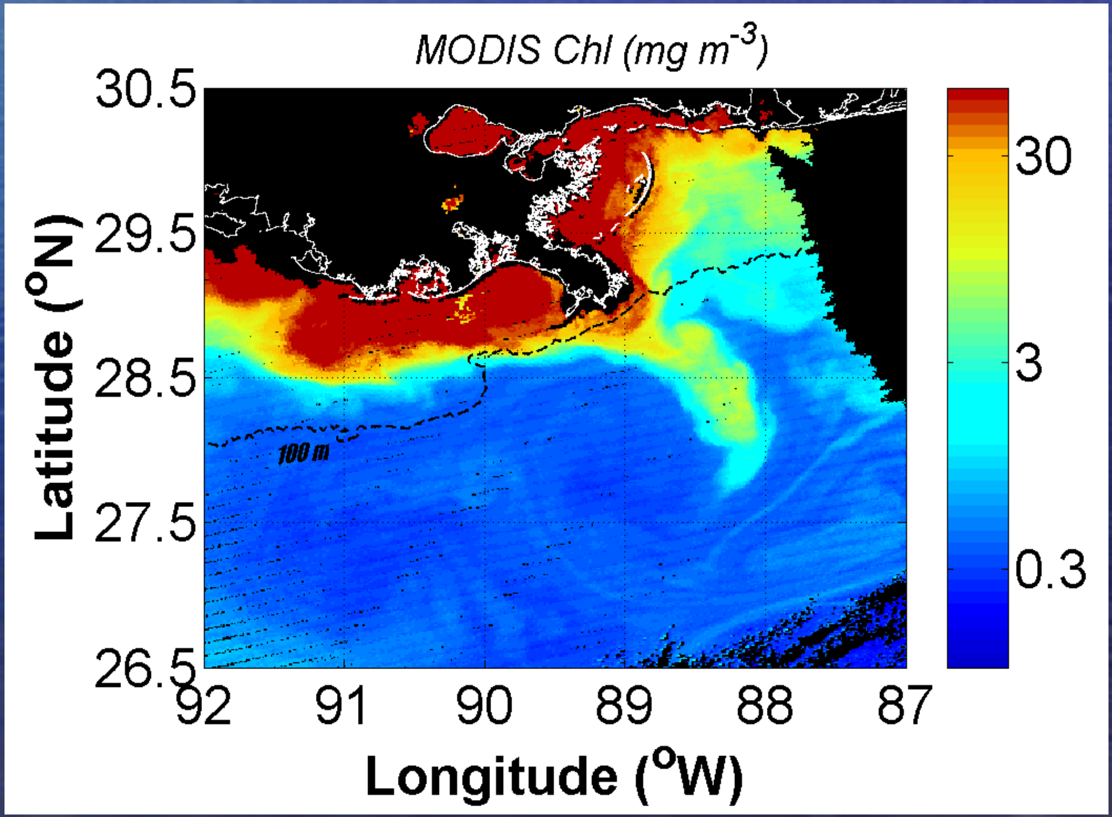
2. Heterotrophic loading ~ autotrophic loading

3. Disparate time scales

Cai and Lohrenz (2008) in KK Liu et al book.

Biogeochemical responses in the river plume and nearby area — biological production

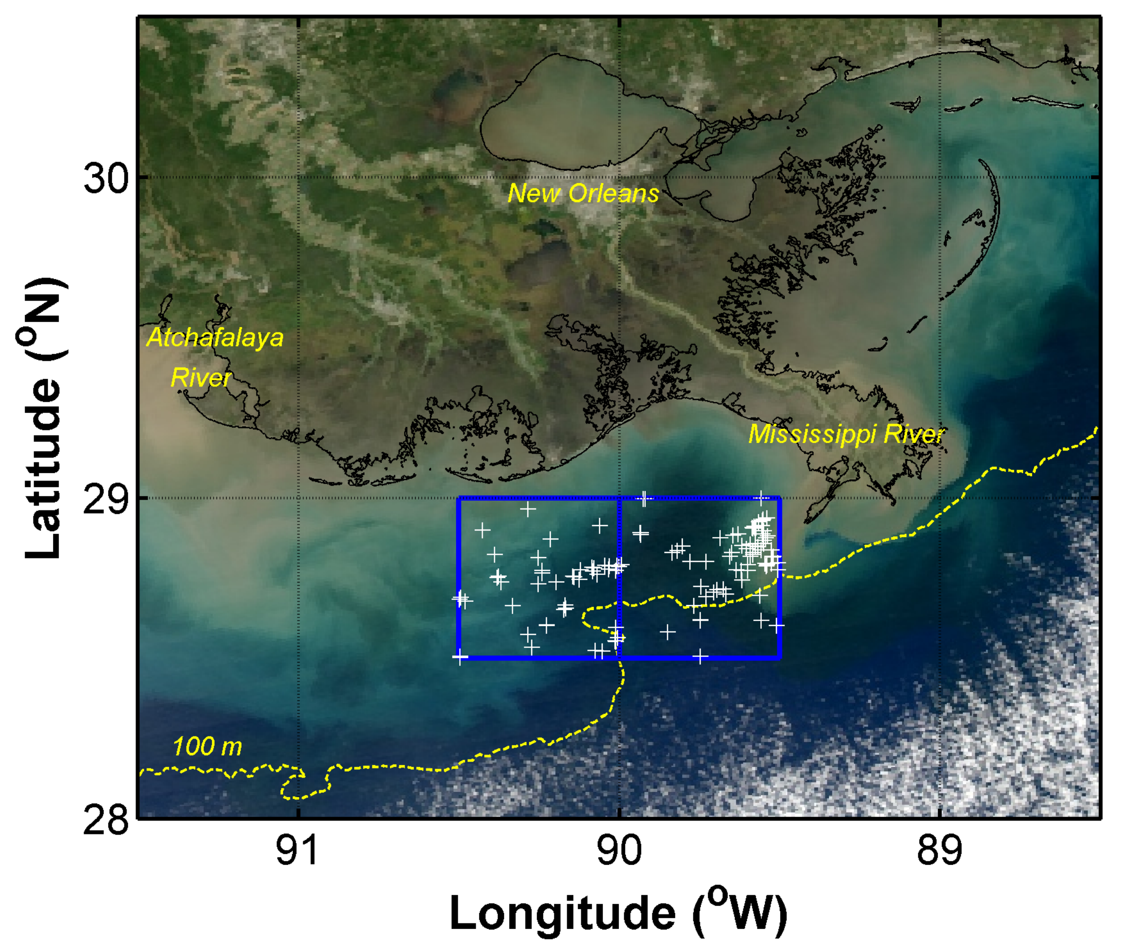
- Satellite evidence points towards linkages between high chlorophyll and river outflow



Relationship Between River Inputs and Coastal Ecosystem Properties

3 May 2004

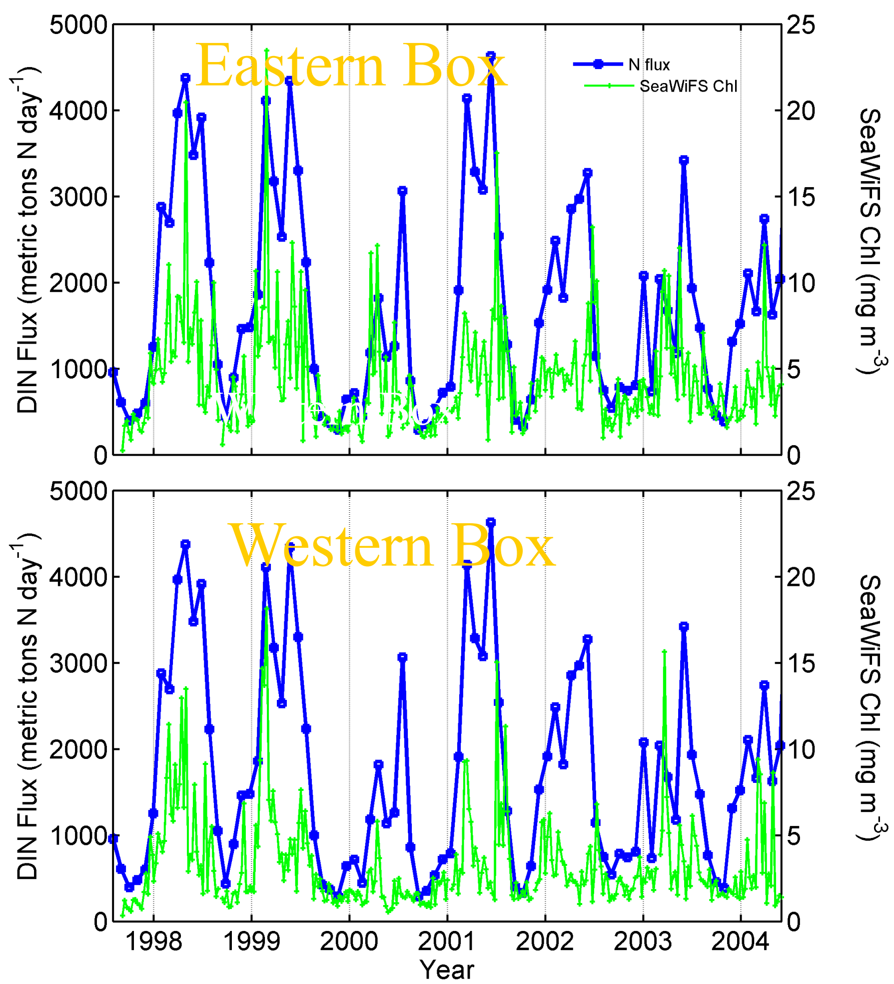
- Satellite evidence points towards linkages between high chlorophyll and river outflow



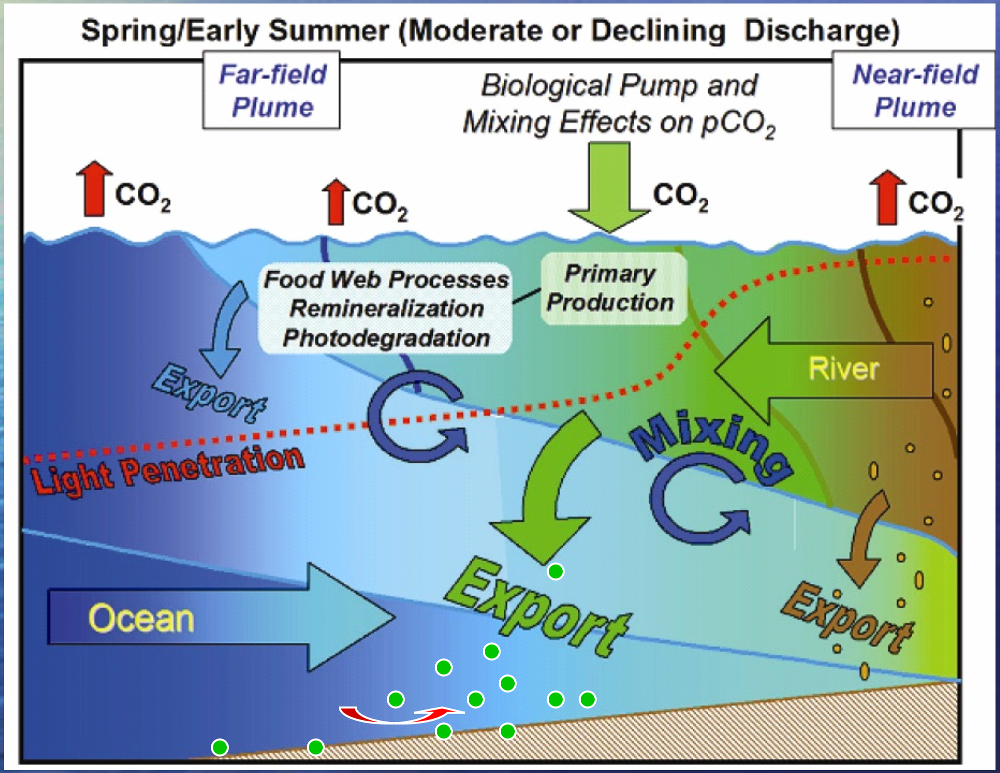
Relationship Between River Inputs and Coastal Ecosystem Properties

- Relationship between river DIN flux and satellite-derived chlorophyll

Source: Lohrenz et al. (2008)



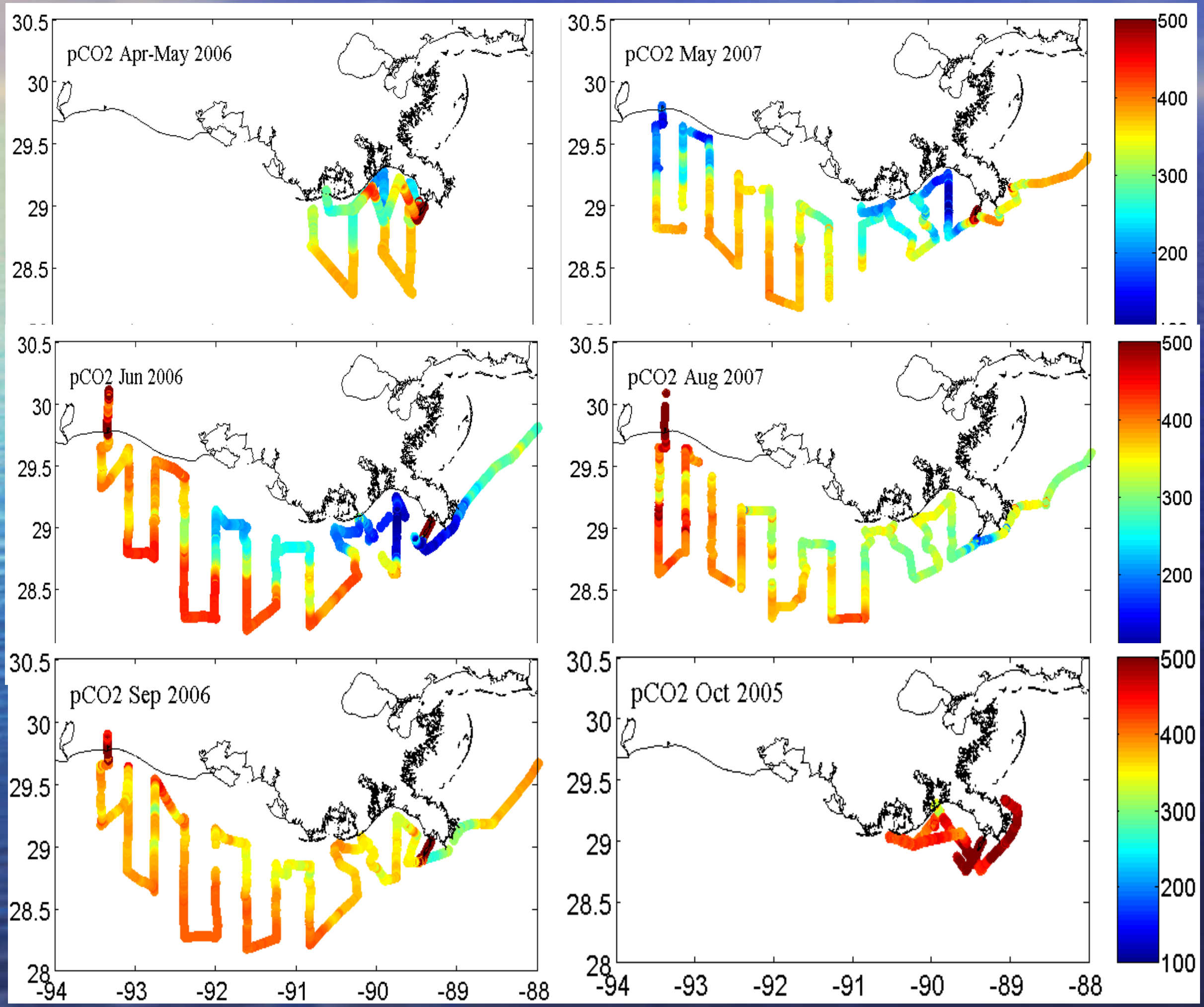
Biogeochemical responses — nutrients and CO_2 system



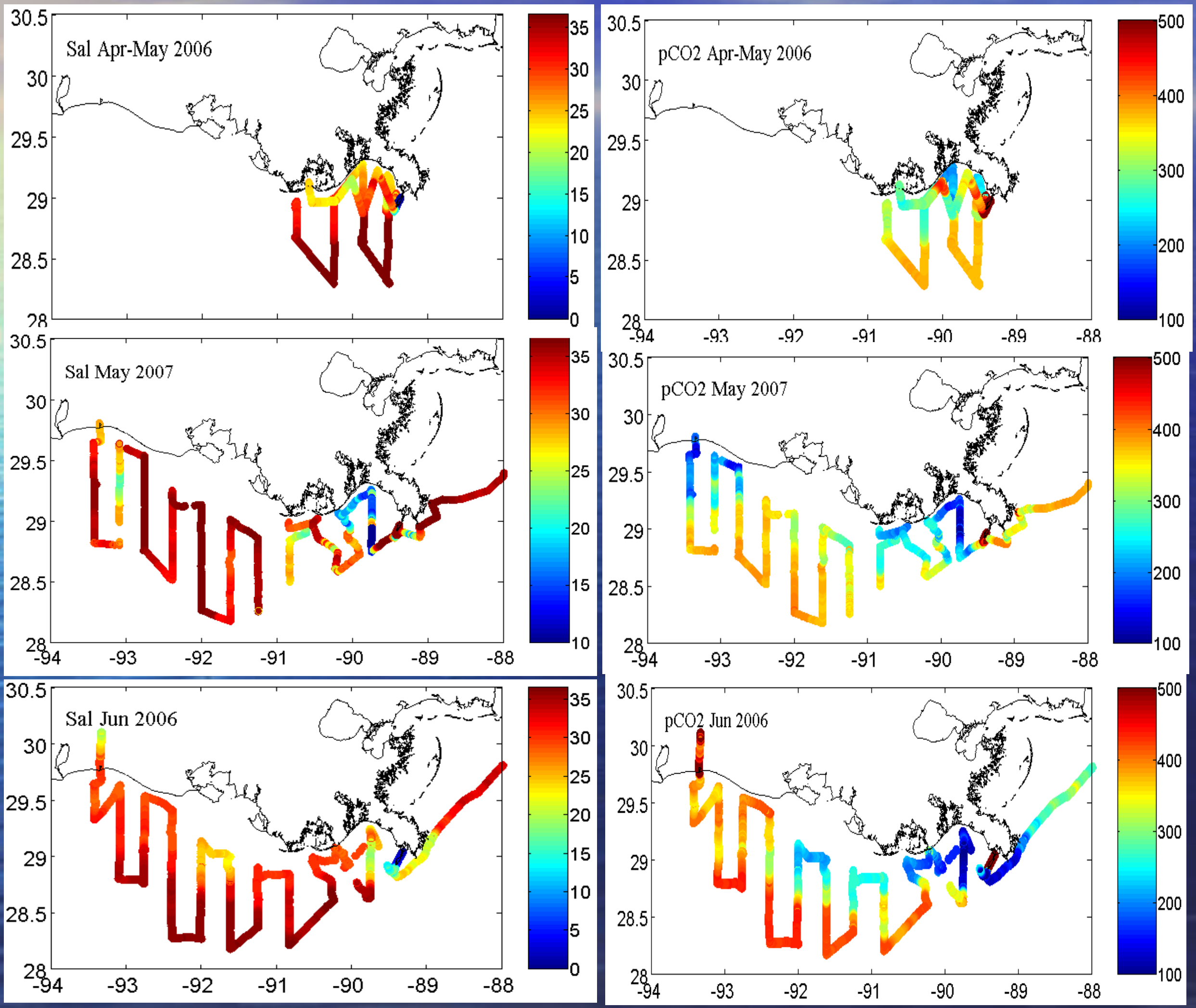
Spring/Early Summer (Moderate or Declining Discharge)

The high nutrient loading and the short turnover time contribute to a strong biological pump for carbon uptake in the mid-field

pCO_2 distribution



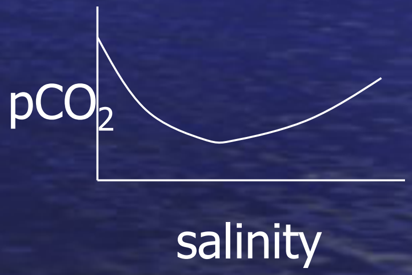
Salinity *p*CO_2 (spring & summer)



Salinity explains some but not all features

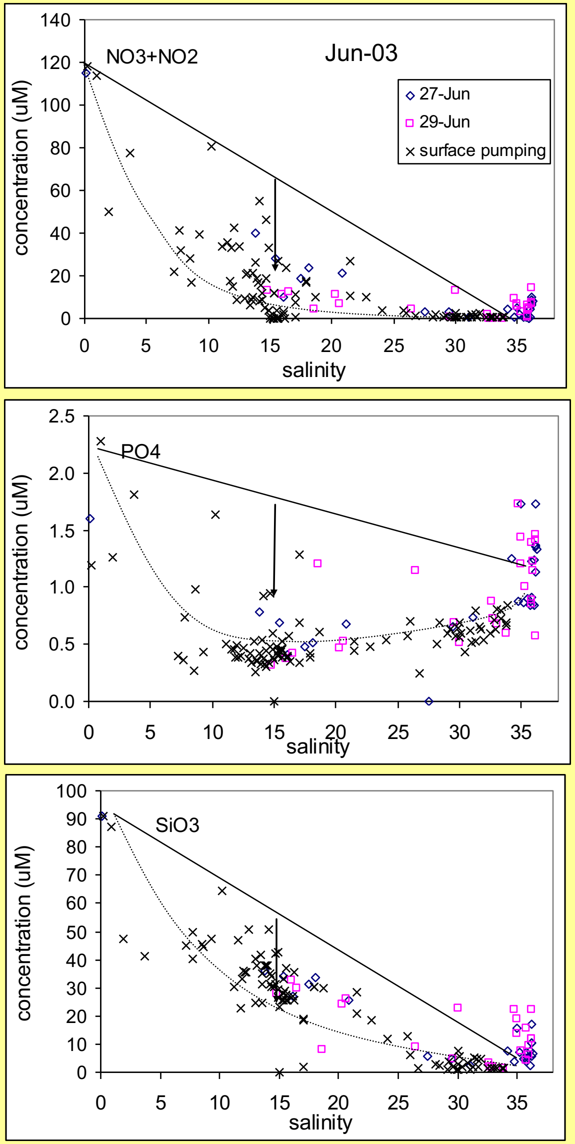
1. Inside river channels & embayment, low S high pCO_2 (turbidity)

2. In the plume, low S low pCO_2 (bio uptake)

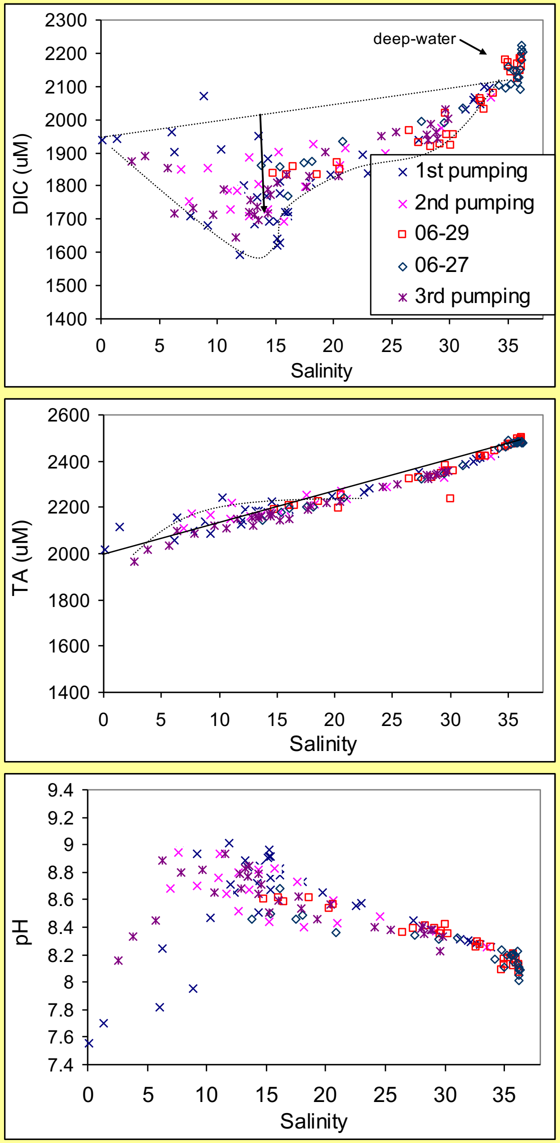


3. Variability

Mississippi River plume, June 2003



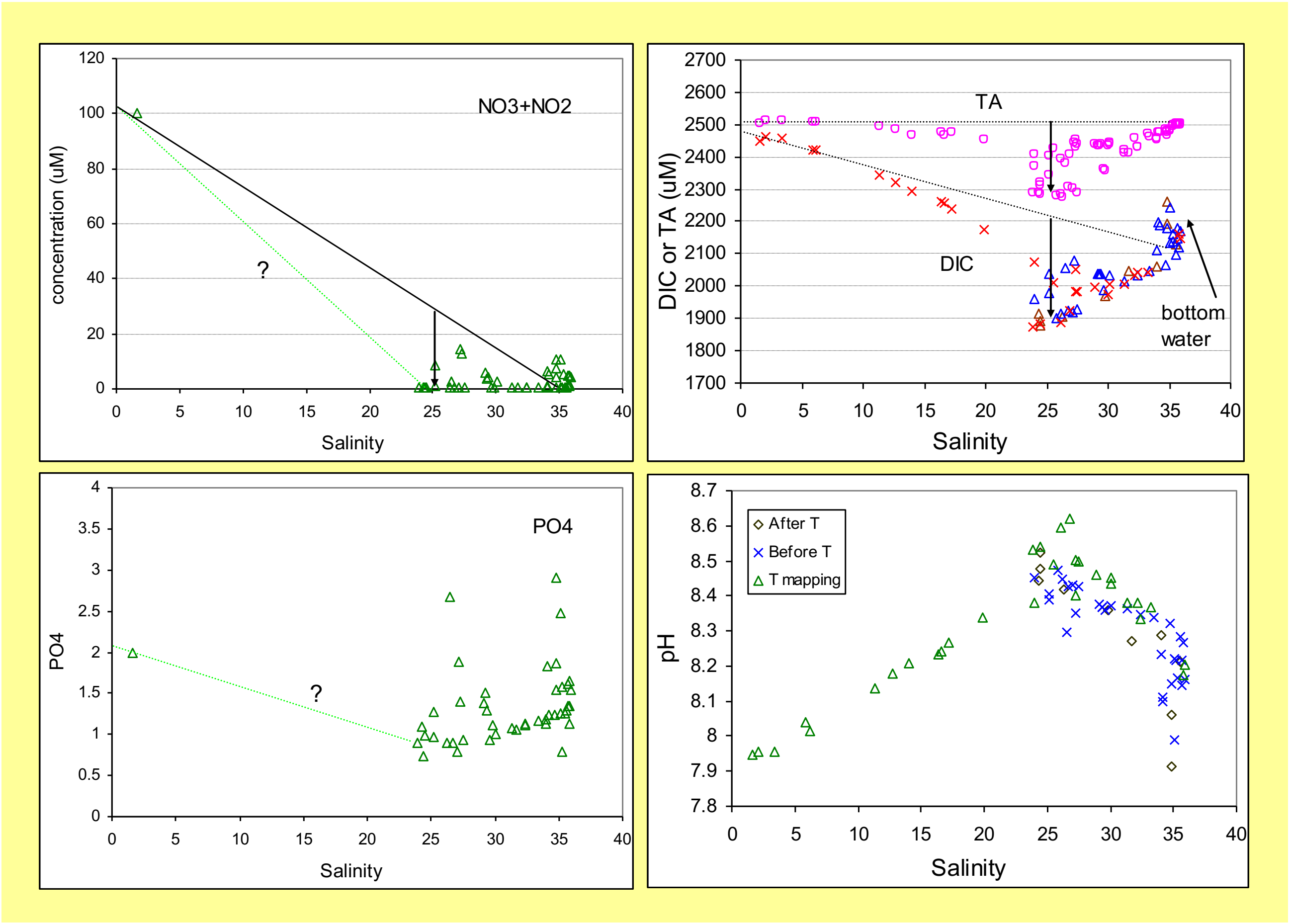
(Rodney Powell)

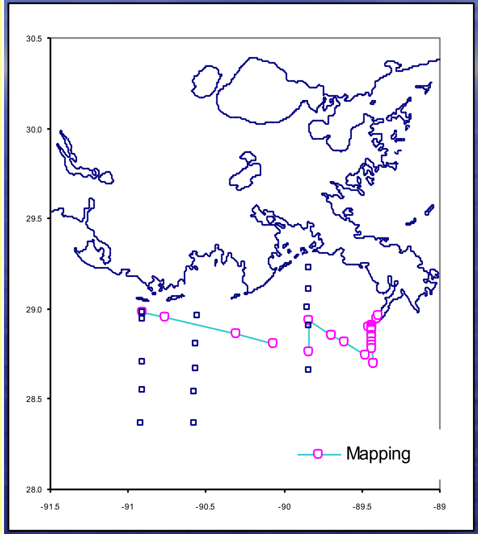


(W.-J Cai)

1. Great DIC removal & nutrient removal at S=15.
2. No TA removal.
3. At S=15, maxΔDIC ~ 430 uM. Appling a Redfield ratio of 6.6, we would predict a max NO$_3$ removal of 65 uM.

Mississippi River plume, August 2004



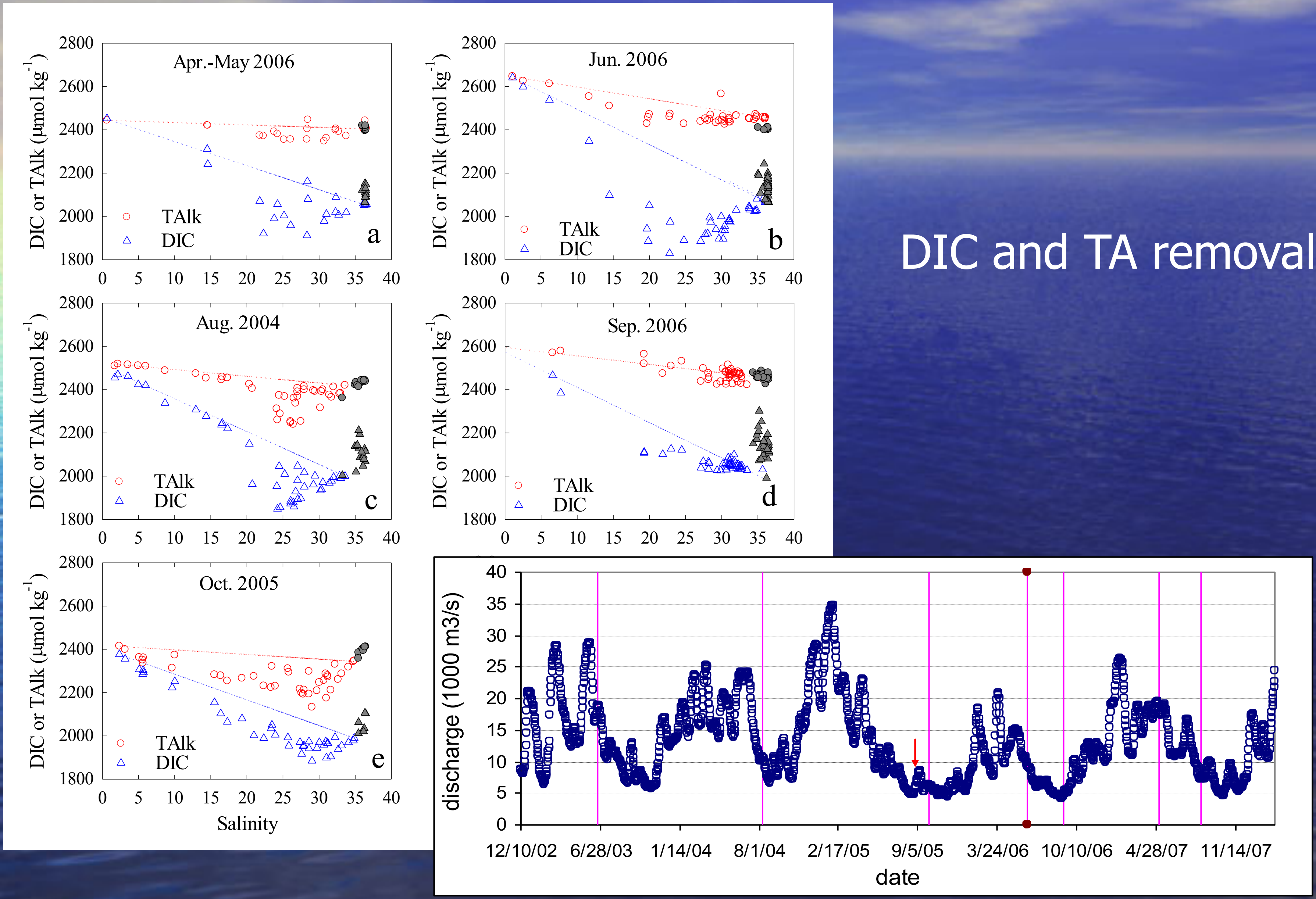


ΔDIC = 320 uM, ΔTA=210 uM

DIC removal due to OC = 320 - 210/2 = 215 uM

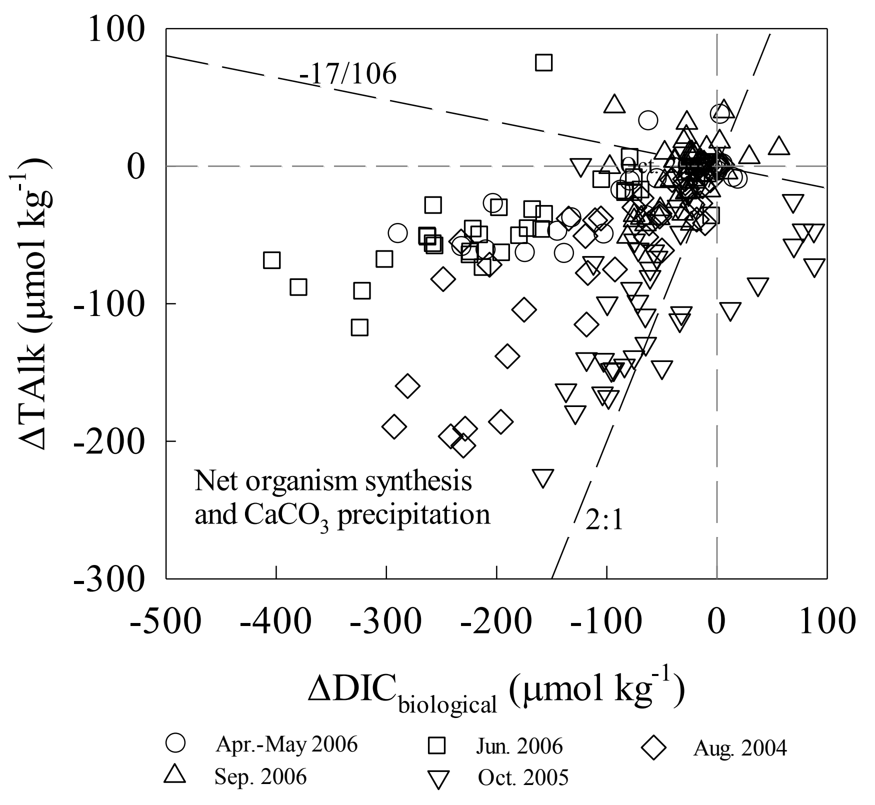
Predicted NO$_3$ removal = 33 uM

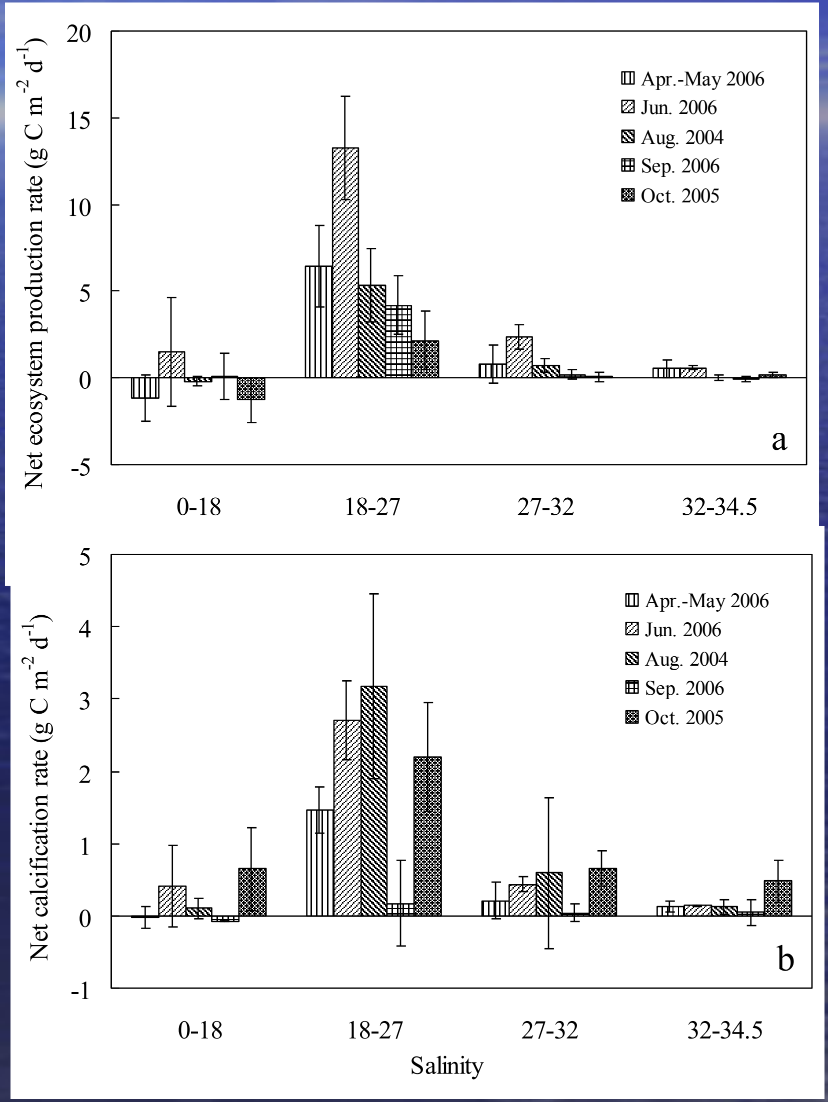
DIC and TAlk in the Mississippi River plume



DIC and TA removal

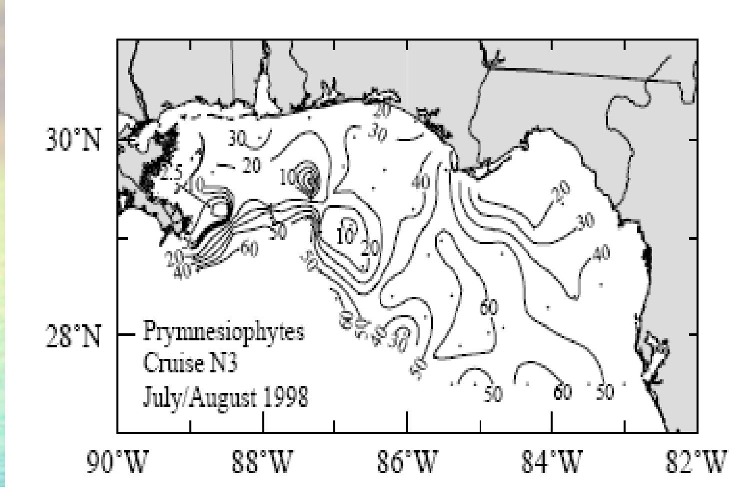
Net community production (NCP) & net calcification



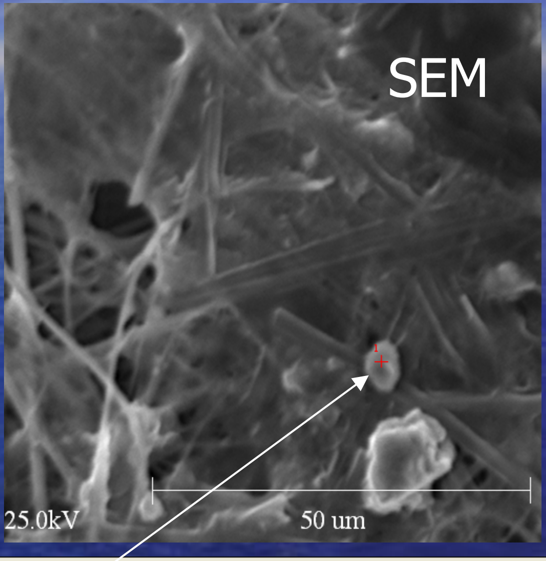


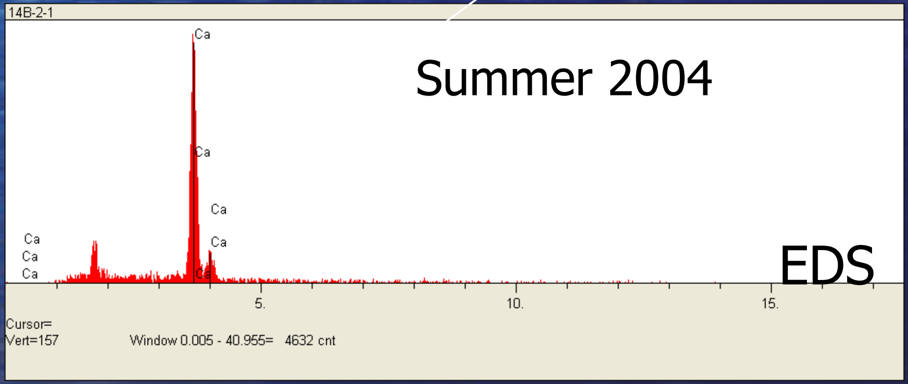
Mixing layer depth and water residence time taken from Green et al. (2006)

evidence of coccolithophores



Y. Qian et al. / Continental Shelf Research 23 (2003) 1–17





Summer 2004

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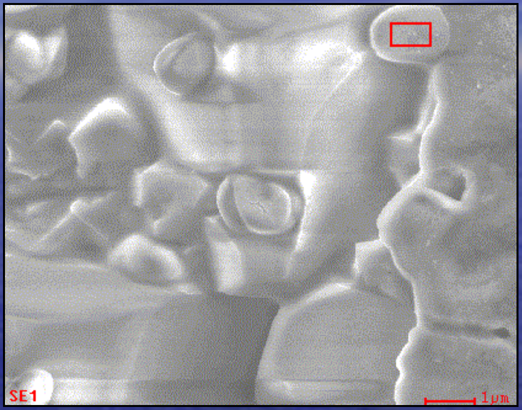
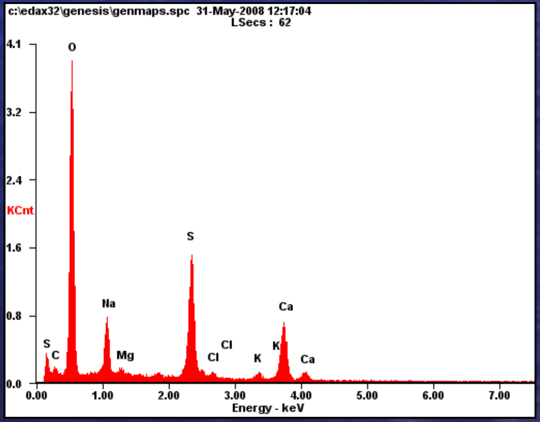
Robert Stavn, Naval Research Laboratory





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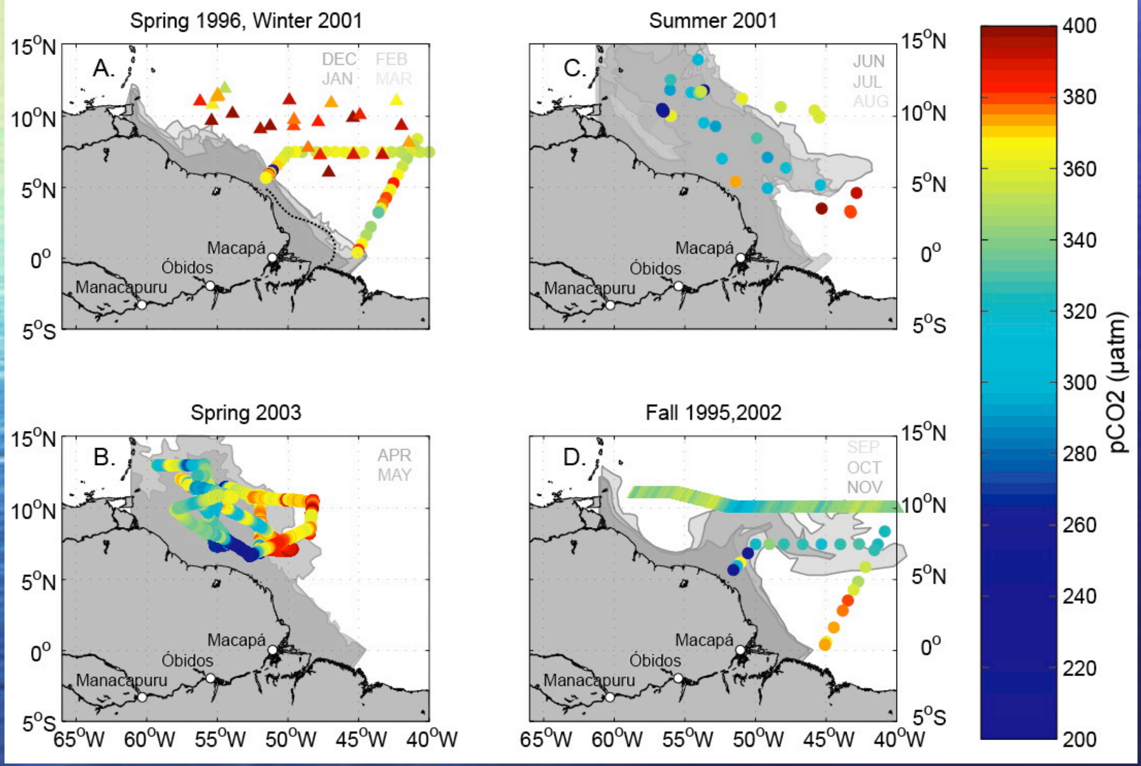
Summer 2008
W-J Cai (unpub)

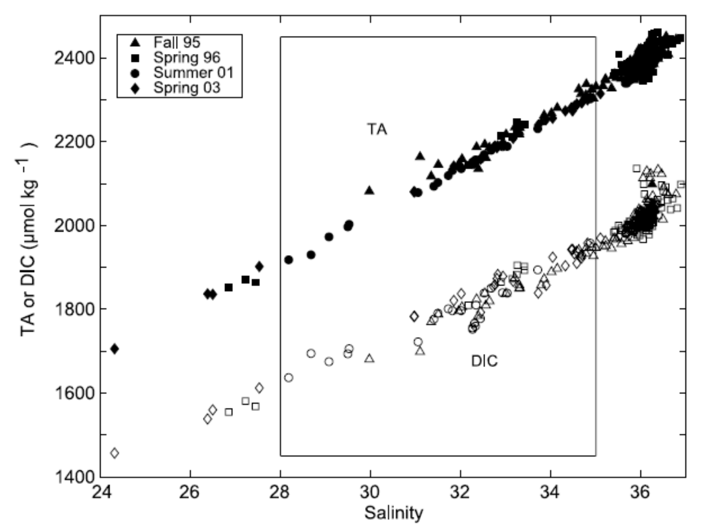
Significance of potential coccolith bloom in the Miss R plume

- It increases pCO_2 (opposite to diatom)

  $2HCO_3^- + Ca^{2+} \rightarrow CO_2 + CaCO_3$
- Diatom bloom creates a low pCO_2, high pH & high CO_3^{2-} condition for coccolith bloom (ecosystem succession)
- No such response reported in the Amazon plume. Why? (ecosystem shift under anthropogenic pressure)

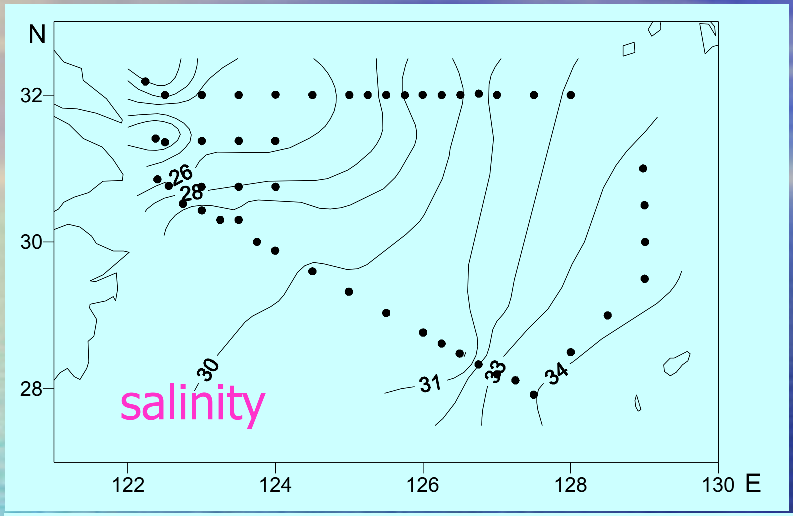
$p\mathrm{CO}_2$ in the Amazon plume

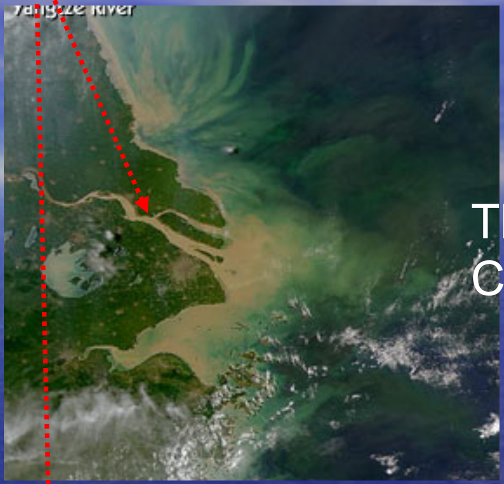


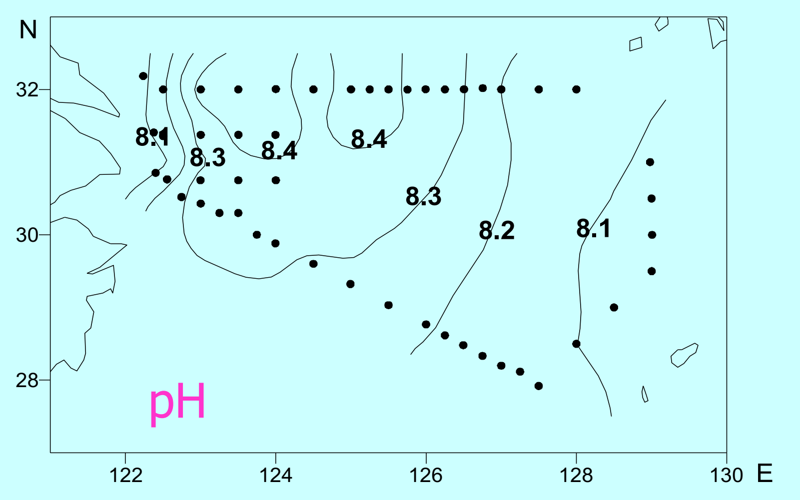


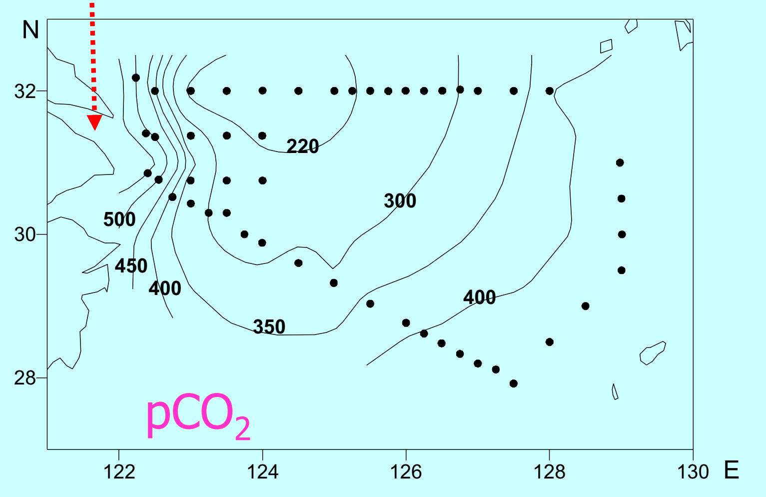
Cooley et al. GBC : 21, GB3014, doi:10.1029/2006GB002831, 2007

pCO_2 in the Changjiang plume



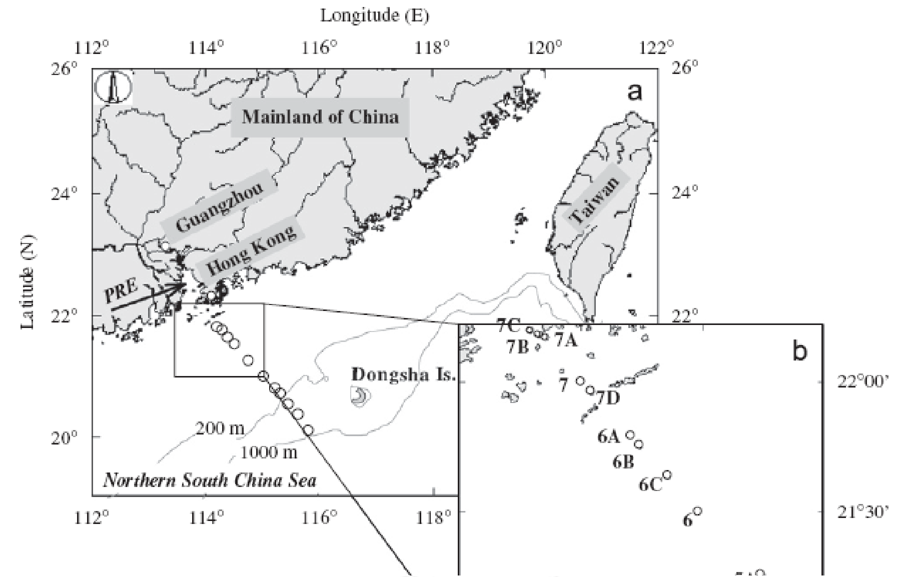


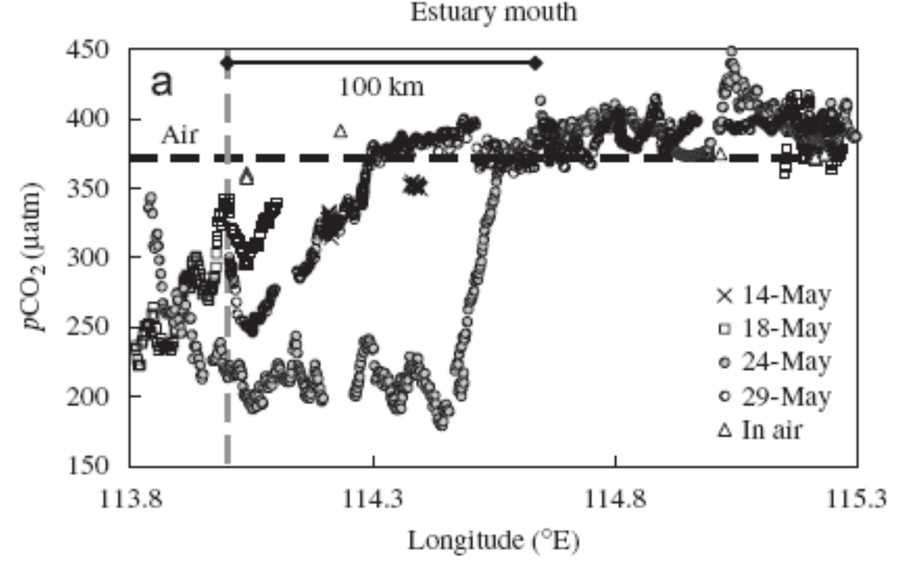


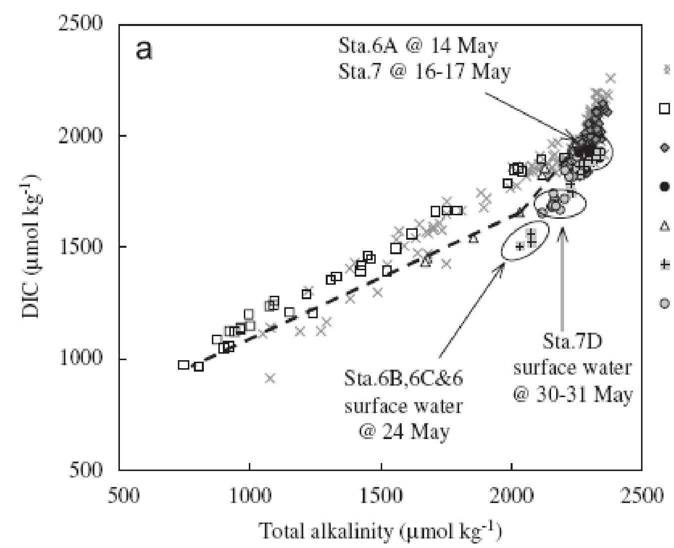


pCO_2 in the East China Sea in summer 1998 during the great flood period (Results from the Chinese JGOFS, L. Zhang pers. comm.)

$p\mathrm{CO_2}$ in the Pearl River plume

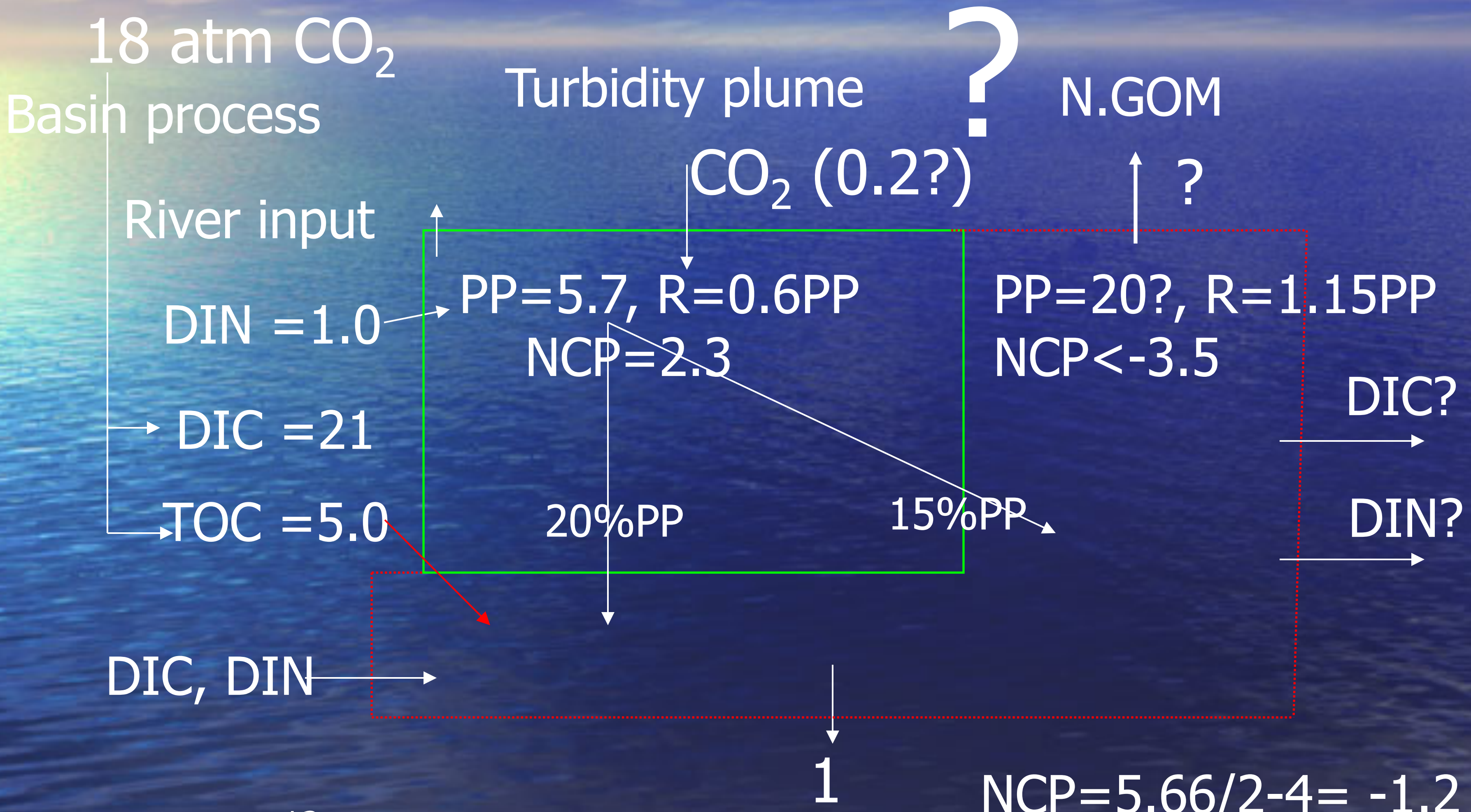






Dai et al. CSR (2008)

Carbon budget in the Northern GOM



18 atm CO$_2$

Basin process

Turbidity plume

?

N.GOM

CO$_2$ (0.2?)

?

River input

DIN =1.0

PP=5.7, R=0.6PP

NCP=2.3

PP=20?, R=1.15PP

NCP<-3.5

DIC =21

DIC?

TOC =5.0

20%PP

15%PP

DIN?

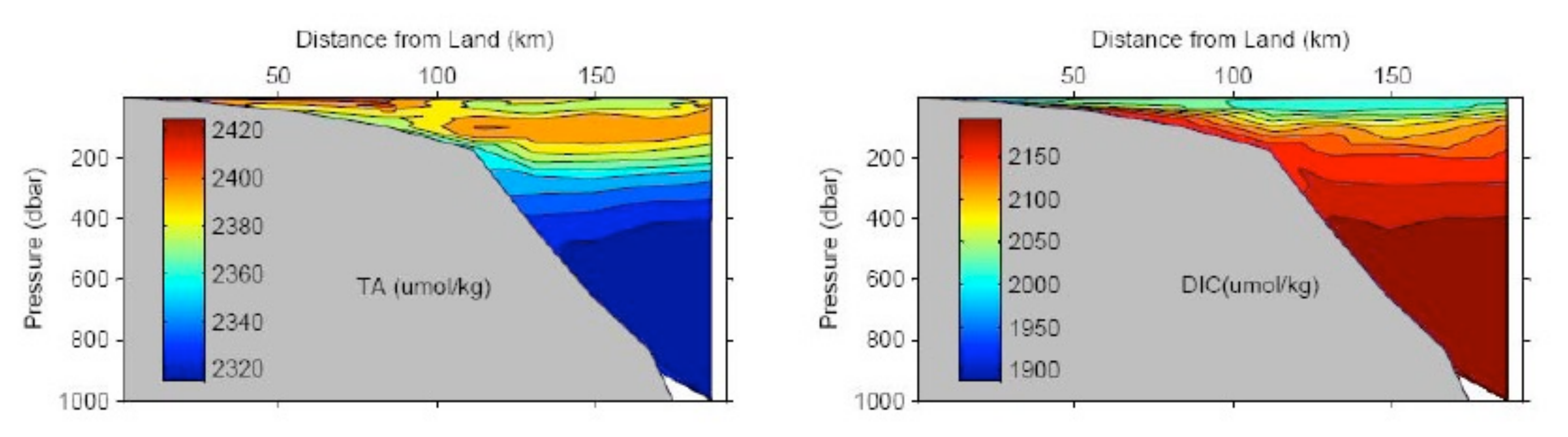
DIC, DIN

1

NCP=5.66/2-4= -1.2

(unit = 10^{12} gC/yr)

GOMECC-Mississippi Transect



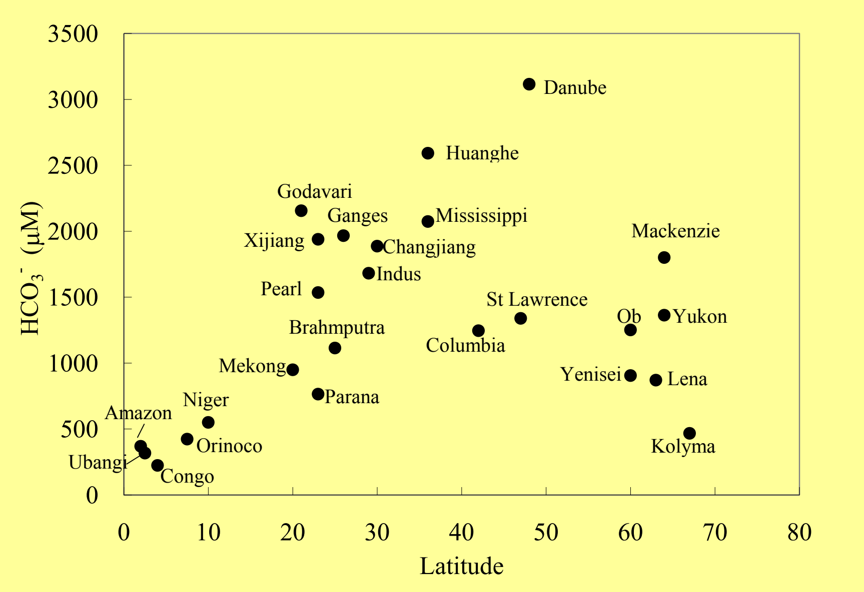
- Great DIC enrichment in the bottom water

Summary

- Globally, river loadings are heterotrophic, in particular, this is the case for tropical rivers.
- Large river plumes are autotrophic and a sink of CO_2. This is particularly true for rivers with high anthropogenic DIN loading.
- River HCO_3^- affects coastal TAlk distribution.
- pCO_2 in large river plumes has a great spatial and seasonal variability.
- Potential coccolith bloom may be an important mechanism controlling surface water pCO_2 for some large river plumes.

Thank you!

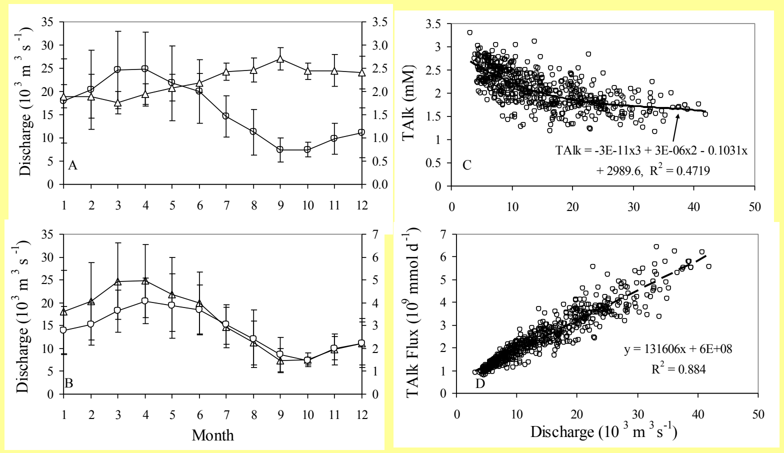
Distribution of riverine HCO^{3-} concentration



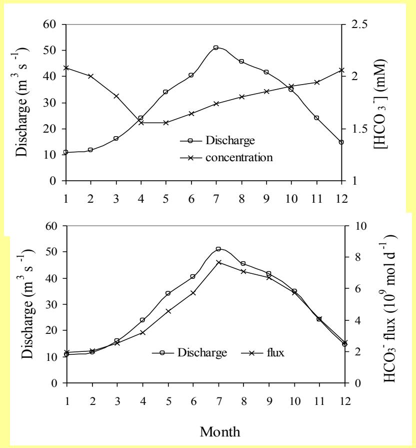
Maximum shifted to north as a result
Of precipitation pattern

From Cai et al. 2008
Continental Shelf Research 28:1538-1549.

The Mississippi River

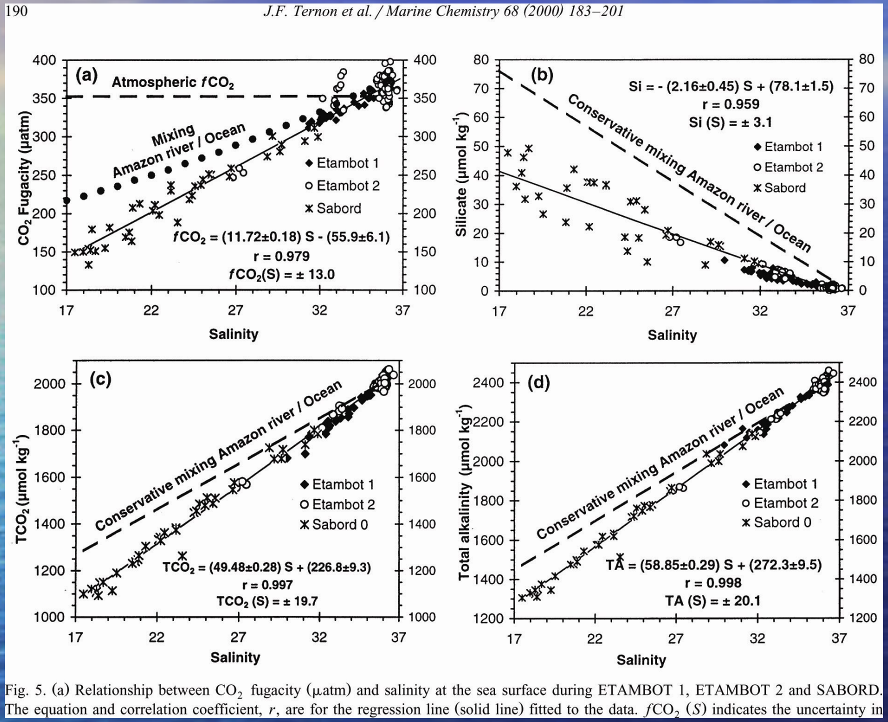


The Changjiang (Yangtze River)



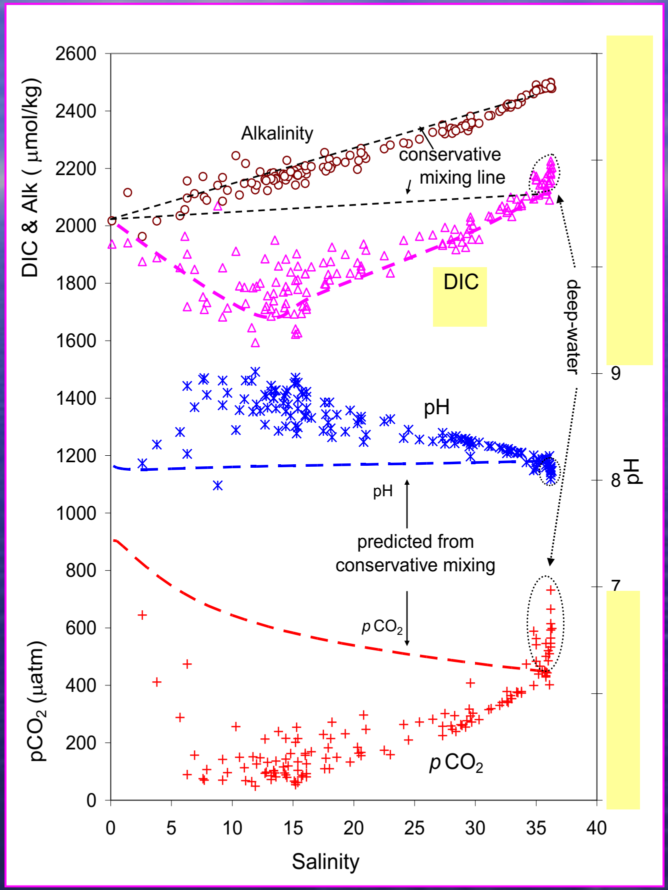
Mixing in the Amazon River plume

vs. in the MR plume



190 J.F. Ternon et al. / Marine Chemistry 68 (2000) 183–201

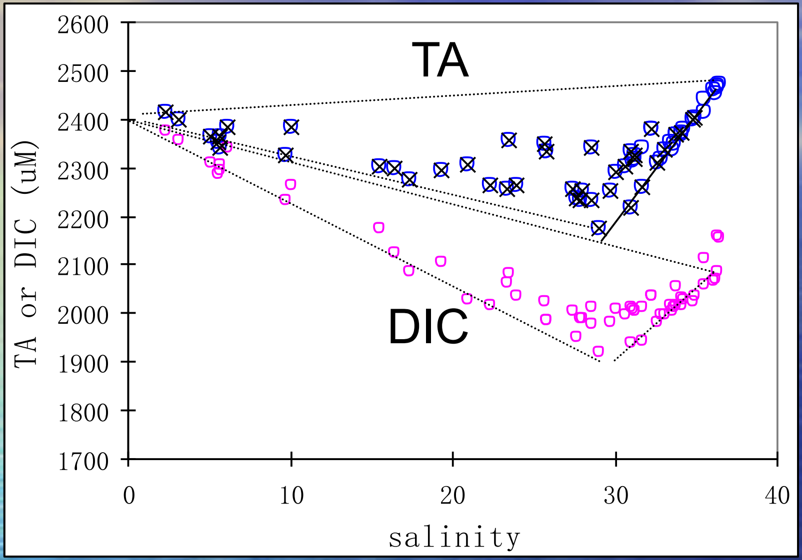
Fig. 5. (a) Relationship between CO_2 fugacity (µatm) and salinity at the sea surface during ETAMBOT 1, ETAMBOT 2 and SABORD. The equation and correlation coefficient, *r*, are for the regression line (solid line) fitted to the data. fCO_2 (S) indicates the uncertainty in

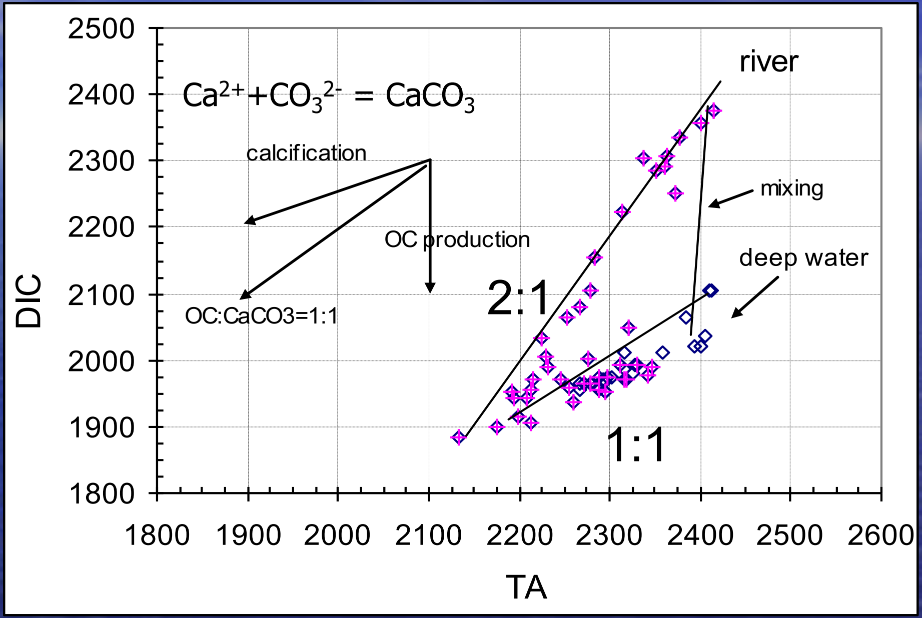


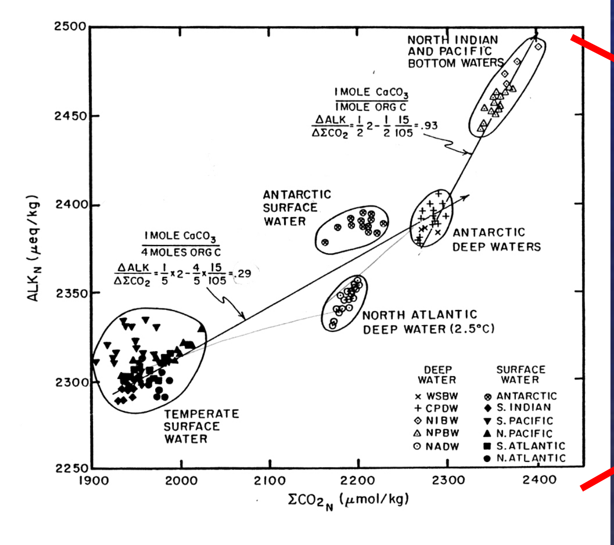
Amazon River water has low TA & low buffer capacity; in contrast, MR water has high TA and high buffer capacity.

October 2005

mixing







$$\xcancel{\frac{\Delta Alk}{\Delta TCO_2} = \frac{1}{2}x2 - \frac{1}{2}x\frac{15}{105} = 0.93}$$

$$\xcancel{\frac{\Delta Alk}{\Delta TCO_2} = \frac{1}{5}x2 - \frac{4}{5}x\frac{15}{105} = 0.28}$$

Satellite image of $CaCO_3$

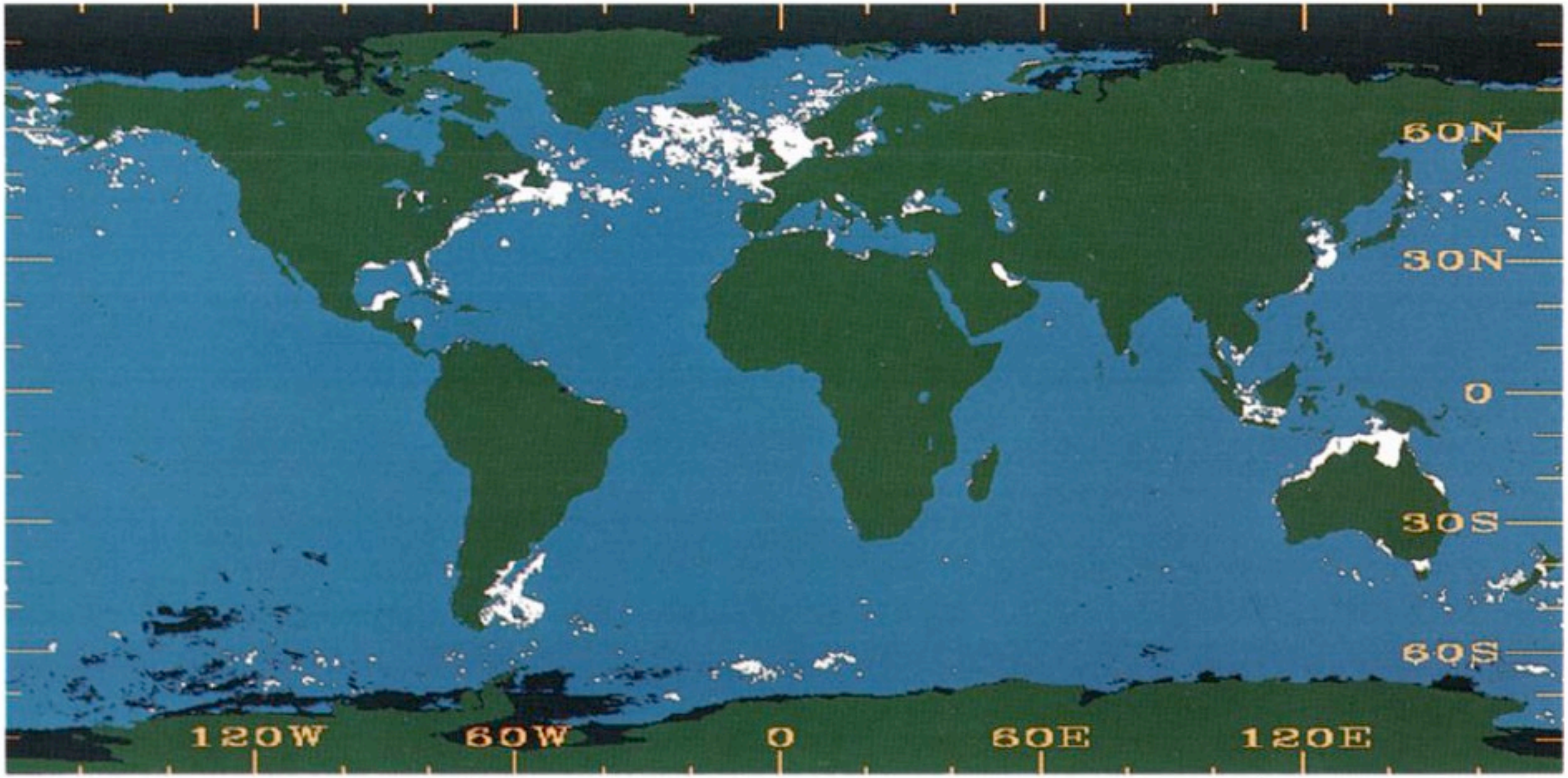
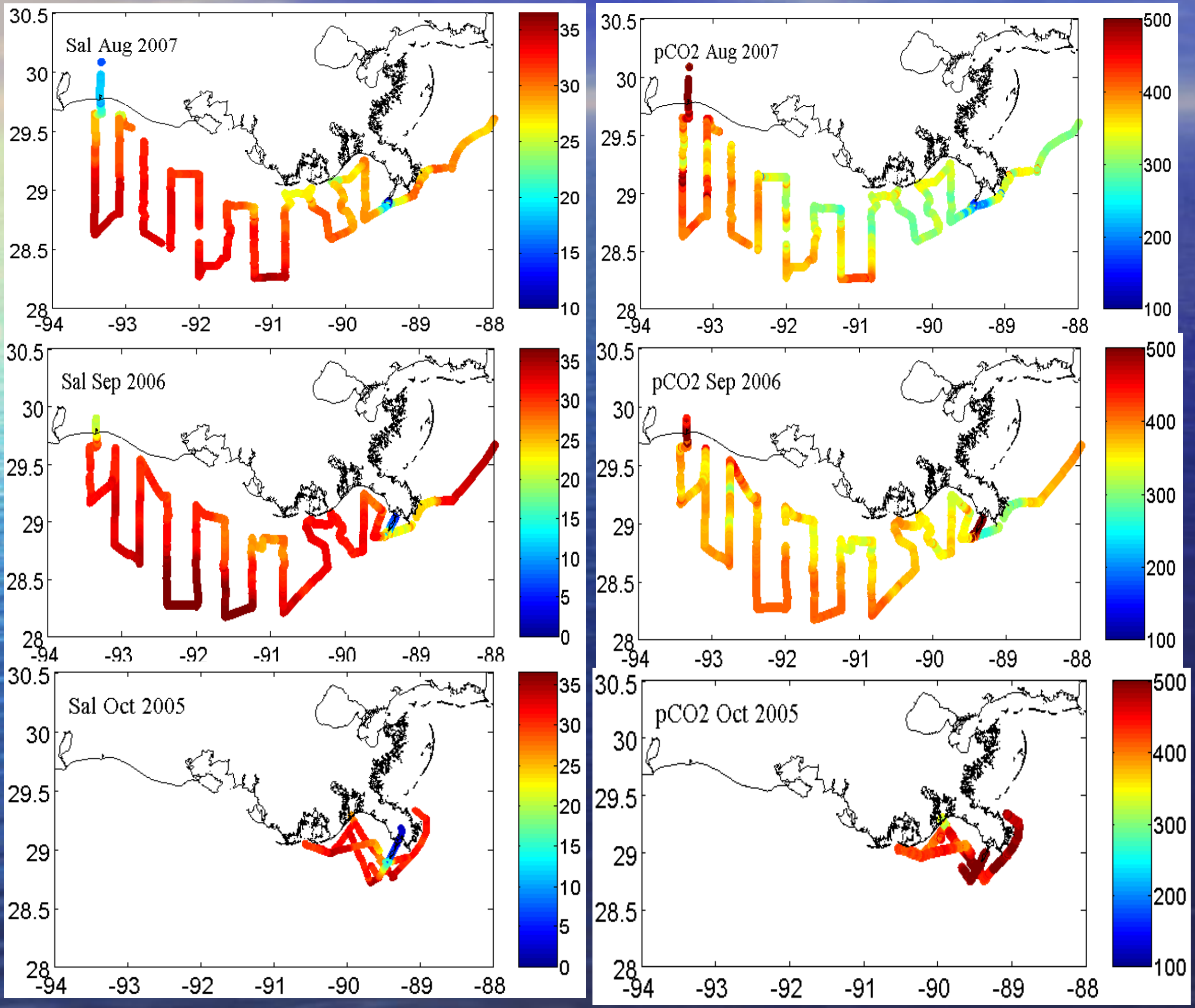


Plate 1. Climatology of classified coccolithophorid blooms (measuring >4800 km^2) for the world's oceans in CZCS imagery dating from November 1978 to June 1986. The maximum spatial extents of blooms detected during this period are displayed. The coccolithophorid bloom class is white, the noncoccolithophorid bloom class is blue, and the land is green. Black indicates areas lacking image coverage.

Brown & Yoder, JGR-Ocean 1994

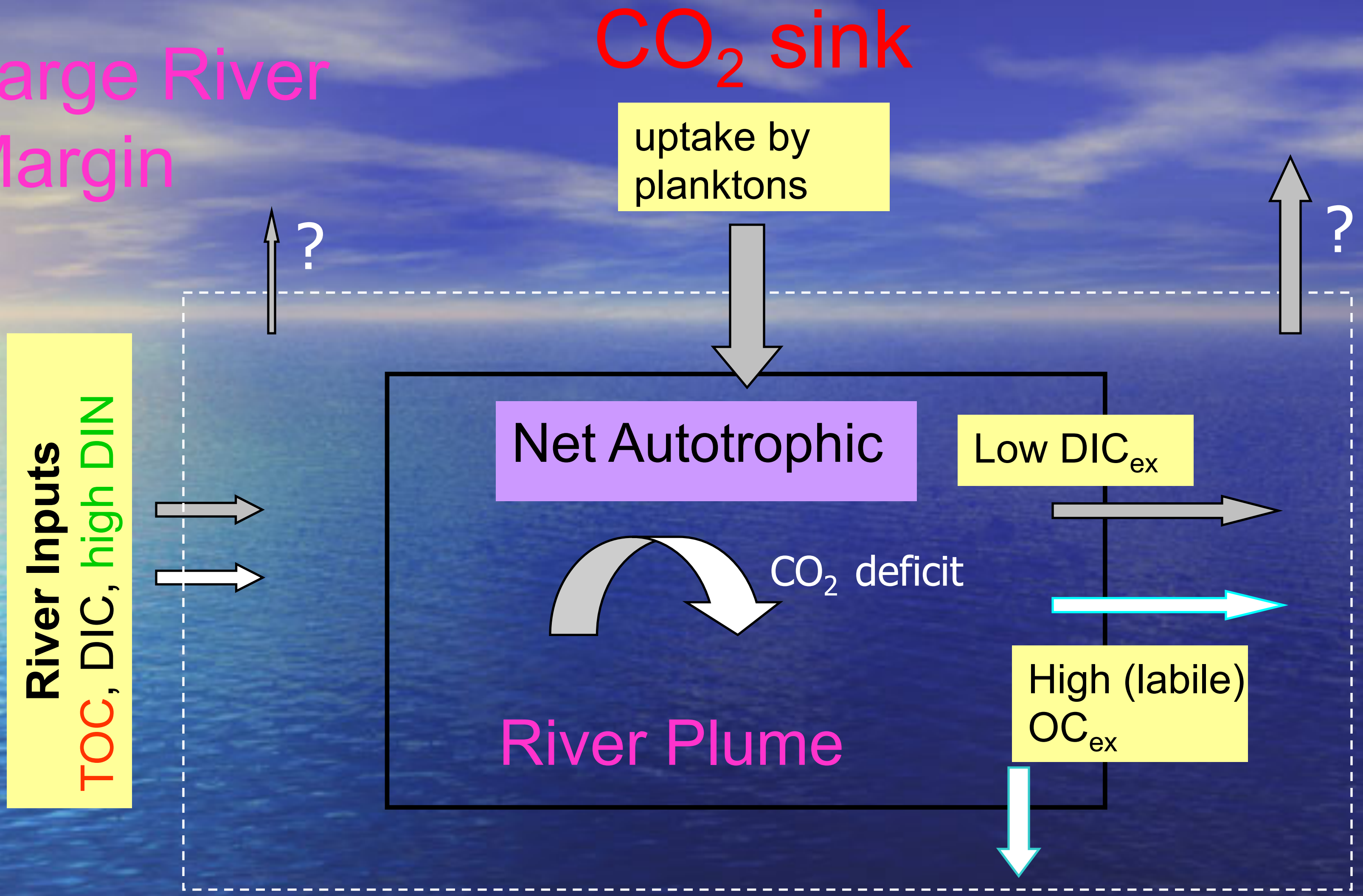
salinity $p\mathrm{CO}_2$ (late summer & fall)



Seasonal variation

1. Low pCO2 in spring and early summer
2. High CO2 in late summer and fall

Large River Margin



CO_2 sink

uptake by planktons

?

?

River Inputs

TOC, DIC, high DIN

Net Autotrophic

Low DIC_{ex}

CO_2 deficit

High (labile) OC_{ex}

River Plume

NCP> 0 (net autotrophic) or GPP > R

OC exports > OC imports & DIC import > DIC export

Results: low DIC, & low pCO_2