River Plume Processes and Dynamics

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Overview

- Brief description of river plume physics
- Watershed-river interactions and fluxes of freshwater, carbon, and nutrients
- Transformation and transport of carbon and nutrients in river outflow regions
- Questions for future research

Questions for future research

- Plume physics and biogeochemistry: what are consequences of freshwater residence times and mixing?
- Extent of river influence: how far do river impacts extend on continental margins and beyond?
- What are the sources and fate of autochthonous and allocthonous sources of organic matter in river systems?
- Human alteration and climate: river exports are highly influence by human activities in the watershed as well as climate. Can we predict such changes?

River plume physics

- Bottom vs. surface trapped plumes
- Plume circulation dynamics
- Plume frontal dynamics and mixing

River plume physics

- Bottom vs. surface trapped plumes
  - Yankovsky and Chapman (1997)

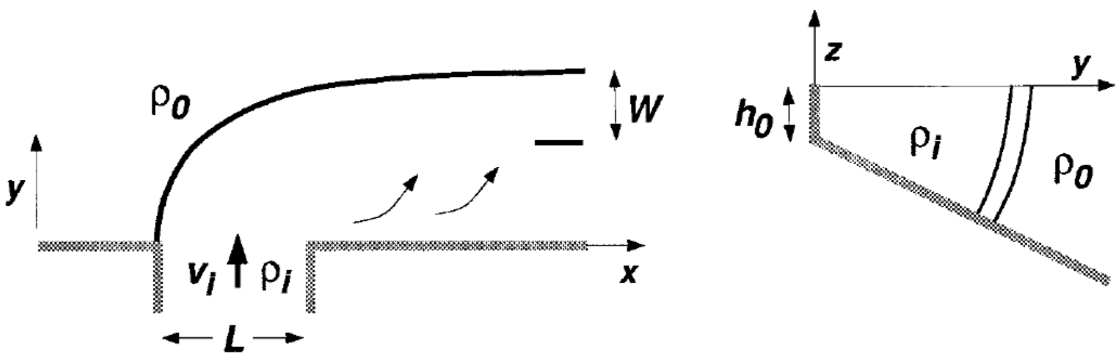


FIG. 1. Schematic of a bottom-advected plume.

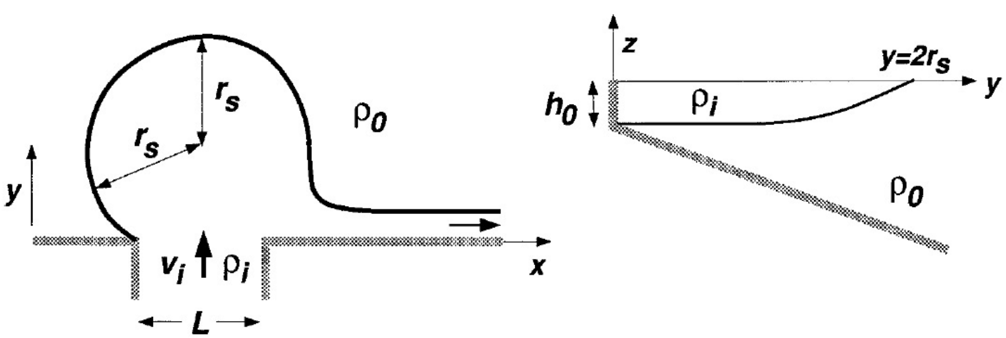


FIG. 2. Schematic of a surface-advected plume.

River plume physics

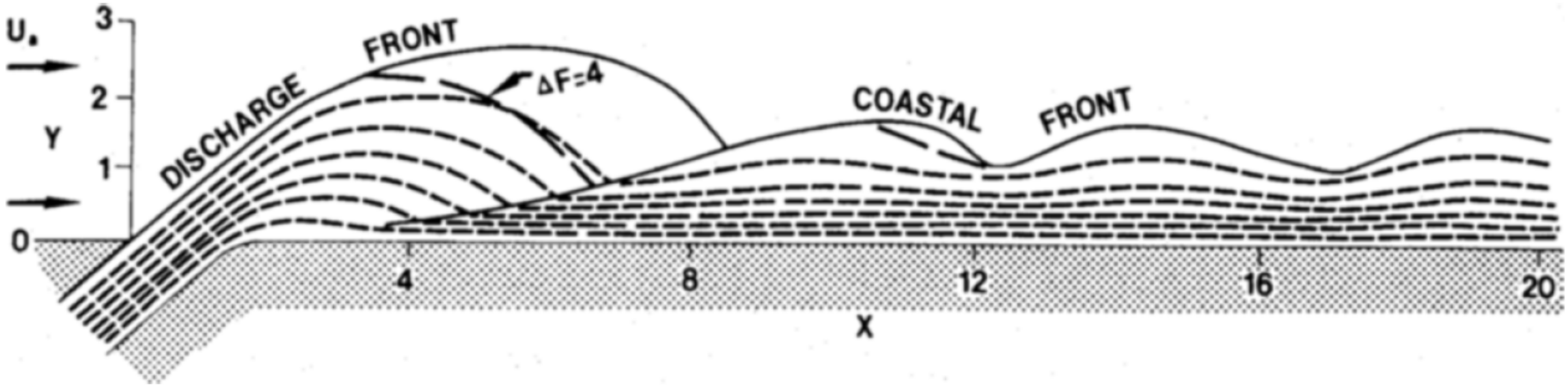


Fig. 2. Front and lines of constant transport stream-function for a numerical experiment with K = 0.68 and constant alongshore ambient flow. (Reprinted from Garvine 1987, *Journal of Physical Oceanography*, with permission of the American Meteorological Society.)

- Plume circulation dynamics
- Plume transport in the presence of constant alongshore flow
  - Garvine (1987) in Wiseman and Garvine (1995)

River plume physics

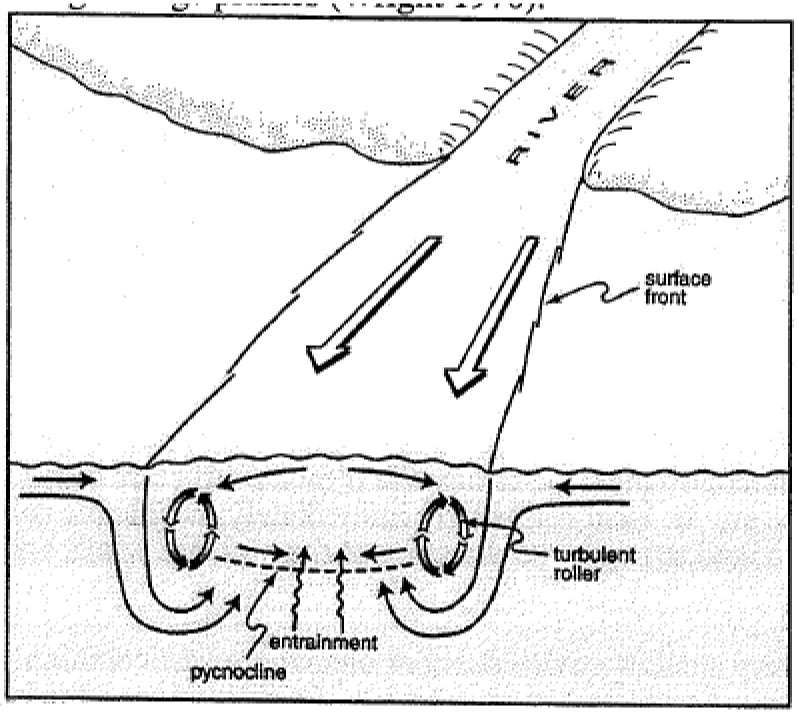


Figure 2.1. Schematic diagram of mixing processes and secondary circulations within a bottom-detached effluent plume.

- Wiseman et al. (1999) – NOAA Coastal Ocean Program Decision Analysis Series No. 14

River plume physics

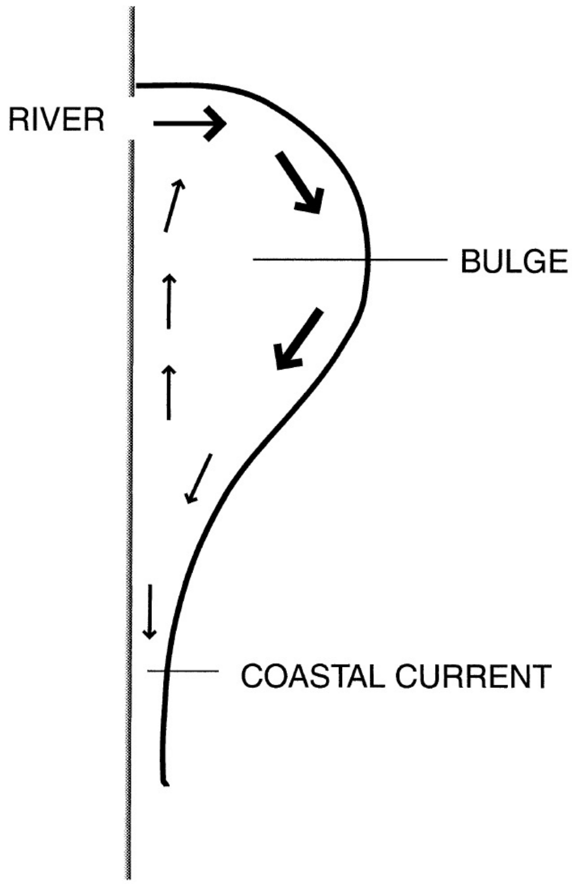
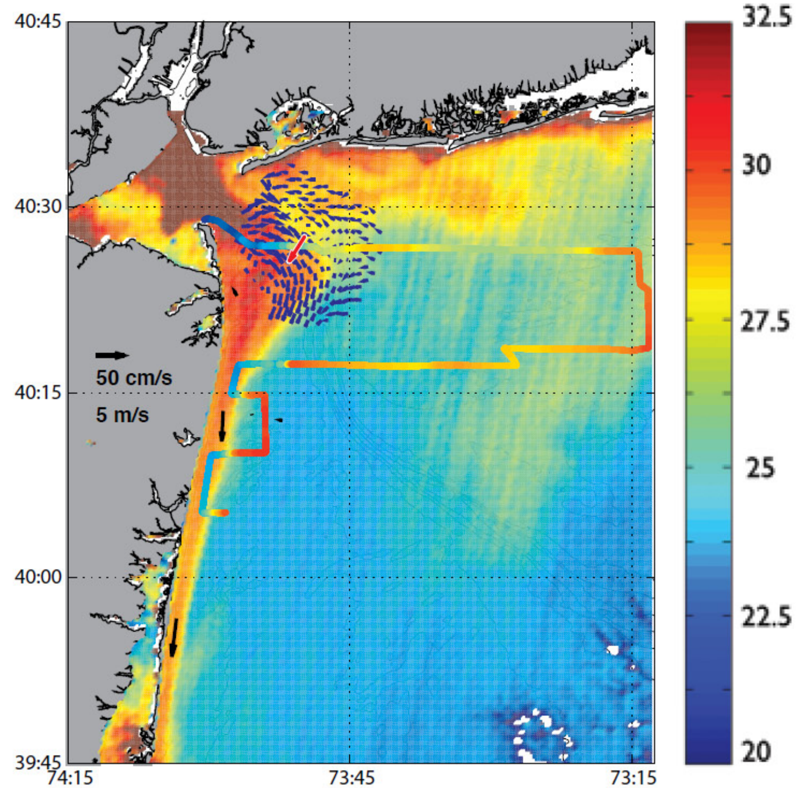


FIG. 4. Cartoon of circulation within a bulge and coastal current. The flow along the seaward side of the bulge transports water that supplies both the coastal current and the continually growing recirculation within the bulge.

- Plume circulation dynamics
  - Fong and Geyer (2002)
  - Characteristics of surface trapped plume

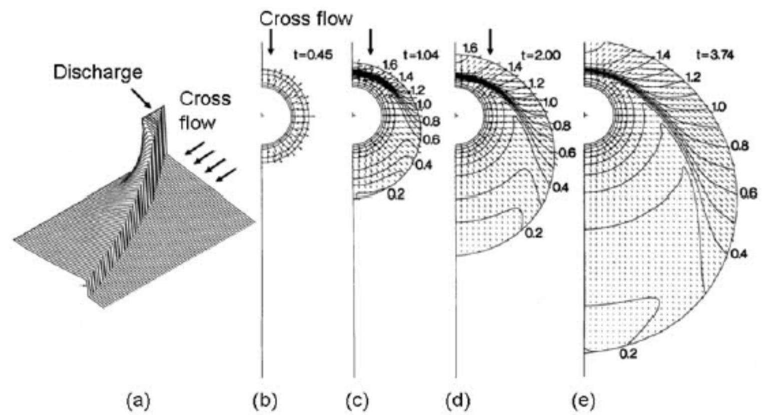
River plume physics

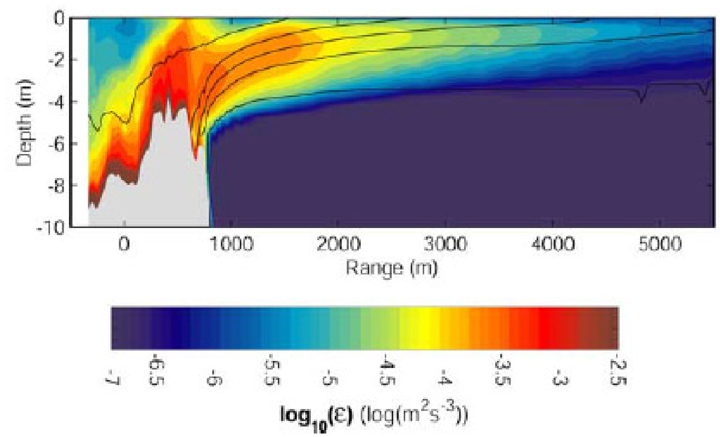
- Plume circulation dynamics
  - Hudson River plume (Chant et al., 2008)



River plume physics

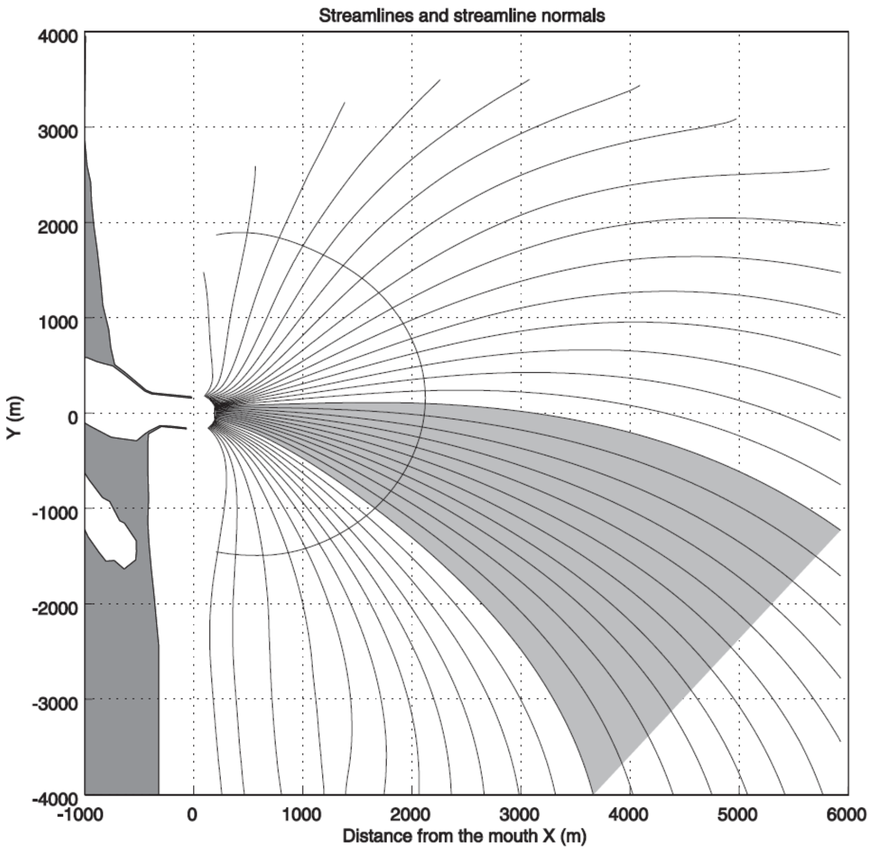
- Plume circulation dynamics
  - O'Donnell et al. (2008)
    - Spatial scales of a plume
    - Plume thinning and spreading
  - MacDonald et al. (2007)
    - Along front characterization of turbulent dissipation rates
    - Complex relationship between plume spreading and mixing





River plume physics

- Plume frontal dynamics and mixing
  - Chen et al. (2009)
    - plume spreading and mixing
    - complex relationship between spreading and mixing during the early stages of plume evolution



River plume physics

- Plume frontal dynamics and mixing
  - Importance of wind and tidal forcing; buoyancy and wind forces determine pattern of horizontal freshwater dispersal (e.g., Walker et al., 1996; Choi et al., 2007)
  - Interactions between physics and biogeochemistry of Hudson plume; optical properties influence both productivity and buoyancy circulation (Cahill et al., 2008)
  - Differing residence times affect biomass accumulation and productivity in plume-influenced regions
  - Higher accumulation of larval fish in plume frontal zones (Grimes and Finucane, 1991; Govoni and Grimes, 1992; Grimes and Kingsford, 1996)

Watershed-river interactions and fluxes of freshwater, carbon and nutrients

- Discharge
- Nutrients
- POC/DOC/CDOM
- Separating climate and human impacts
- DIC and Alkalinity*

Watershed-river interactions and fluxes of freshwater, carbon and nutrients

- Discharge
  - Milliman et al. (2008)
    - Global change in river discharge
    - In some cases parallels precipitation patterns
    - Also influenced by storage, evapotranspiration

J.D. Milliman et al. / Global and Planetary Change 62 (2008) 187–194 189

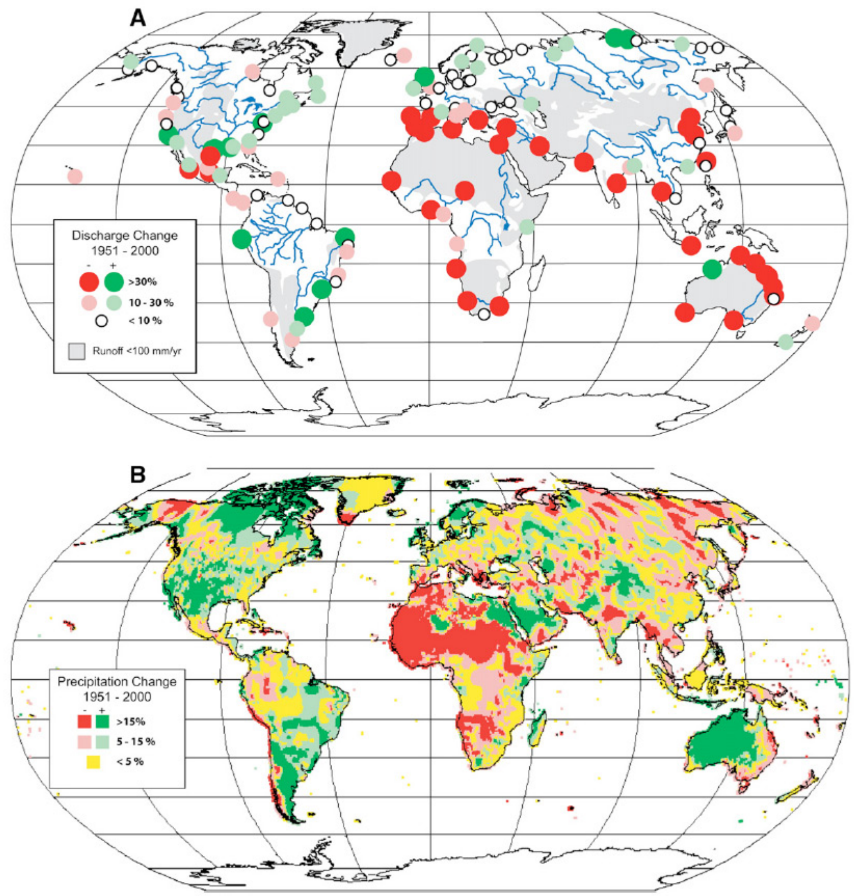
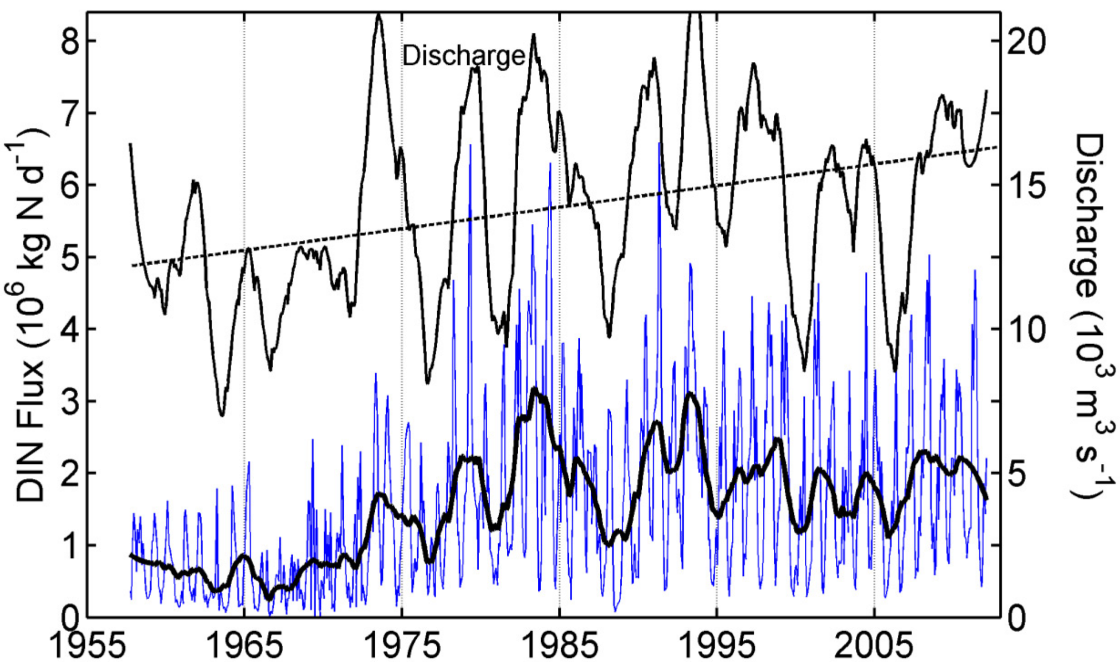


Fig. 2. (A) 1951–2000 discharge trends for 137 global rivers, 109 of which are based on ≥45 yr of data (Table S1). With few exceptions (Kolyma, Lena, Fraser), <10% changes are not statistically significant (Table S2). Shaded regions represent water-scarce areas, mean annual runoff <100 mm/yr. (B) 1951–2000 global precipitation trends based on 0.5-degree grid cells; data from Climatic Research Unit (CRU), University of East Anglia.

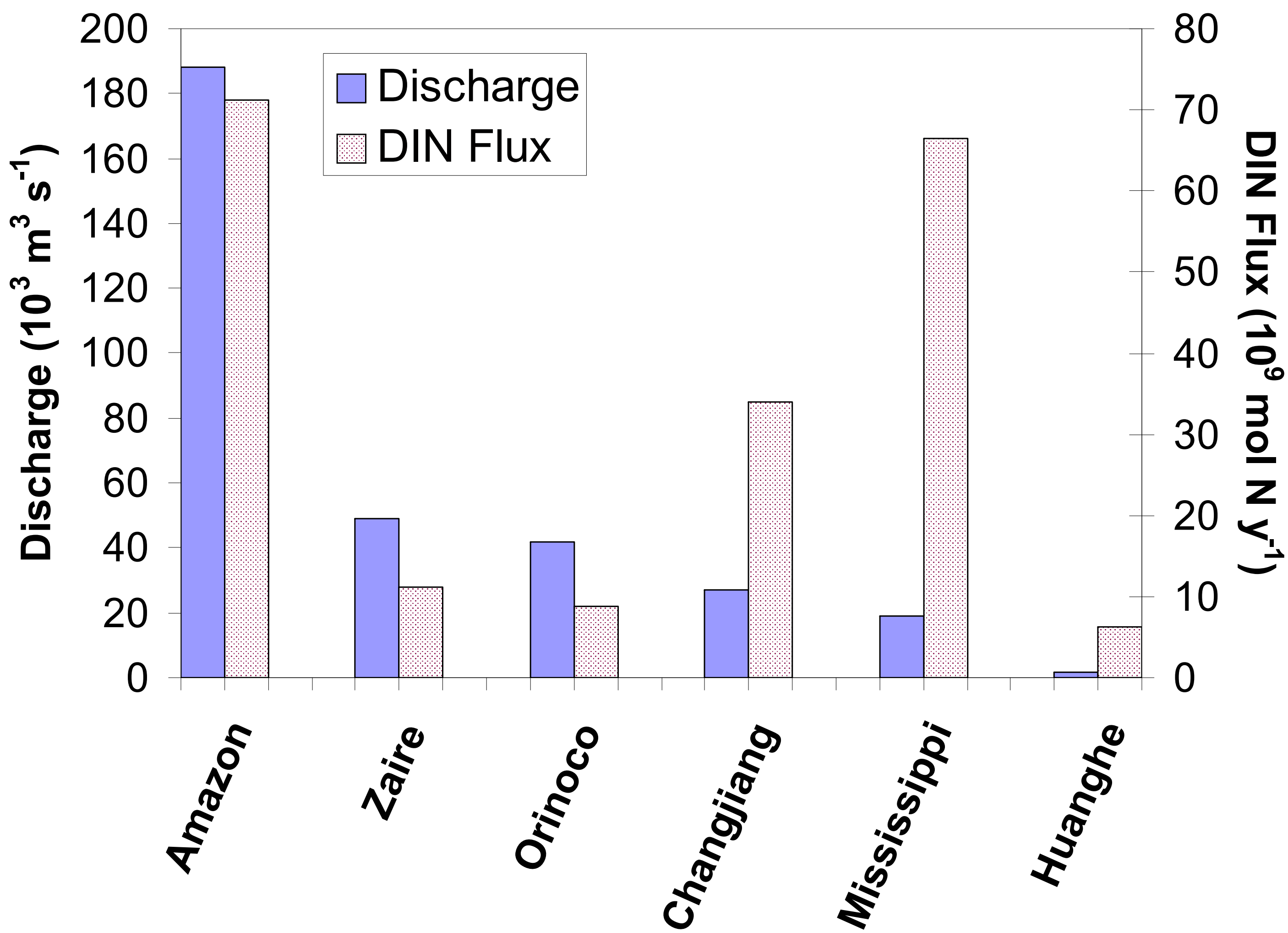
Watershed-river interactions and fluxes of freshwater, carbon and nutrients



- Dissolved Mississippi River discharge at Tarbert Landing (U.S. Army Corps of Engineers) in comparison to dissolved inorganic nitrogen flux based on measurements at the St. Francisville USGS NASQAN site (water quality station number 07373420).
- Monthly flux was estimated by using a simple interpolation of discharge and nutrient concentration to a monthly sampling frequency. The upper black line is river discharge smoothed to a 35 mo window. The dashed line is a linear regression fit to the discharge data (r^2=0.135; p=0.001). The slope of the regression was 74.8 m^3 s^{-1} yr^{-1}

Lohrenz et al., modified from Cai and Lohrenz, 2010

Watershed-river interactions and fluxes of carbon and nutrients

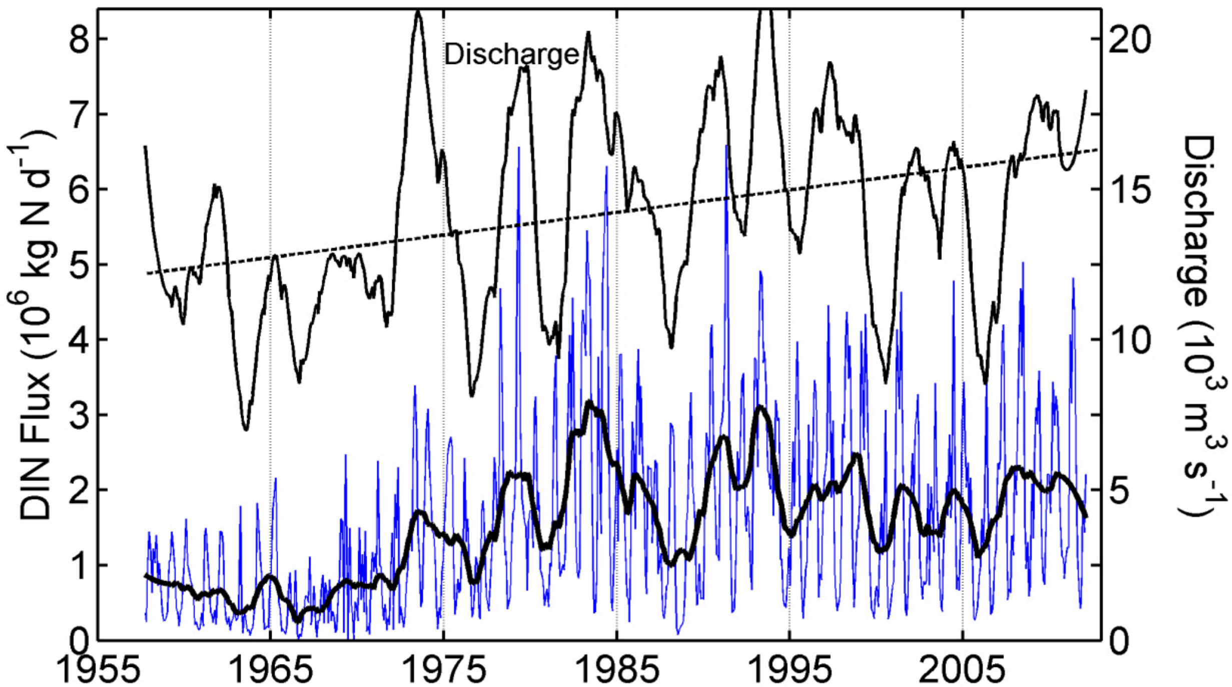


Dagg et al., 2004

Watershed-river interactions and fluxes of freshwater, carbon and nutrients

- Nutrients
  - Long term patterns in nutrient inputs in global watersheds using Nutrient Export from Watersheds (NEWS) model (Mayorga et al., 2010; Seitizinger et al., 2010)
  - DIN related to agricultural practices while DIP linked to sewage and detergent inputs
  - Projected increases due to increasing population growth
  - Silica retention in watersheds resulting in shifting nutrient ratios with implications for altering food web structure (Turner et al., 1998; Humborg et al., 2006; Conley et al., 2009)

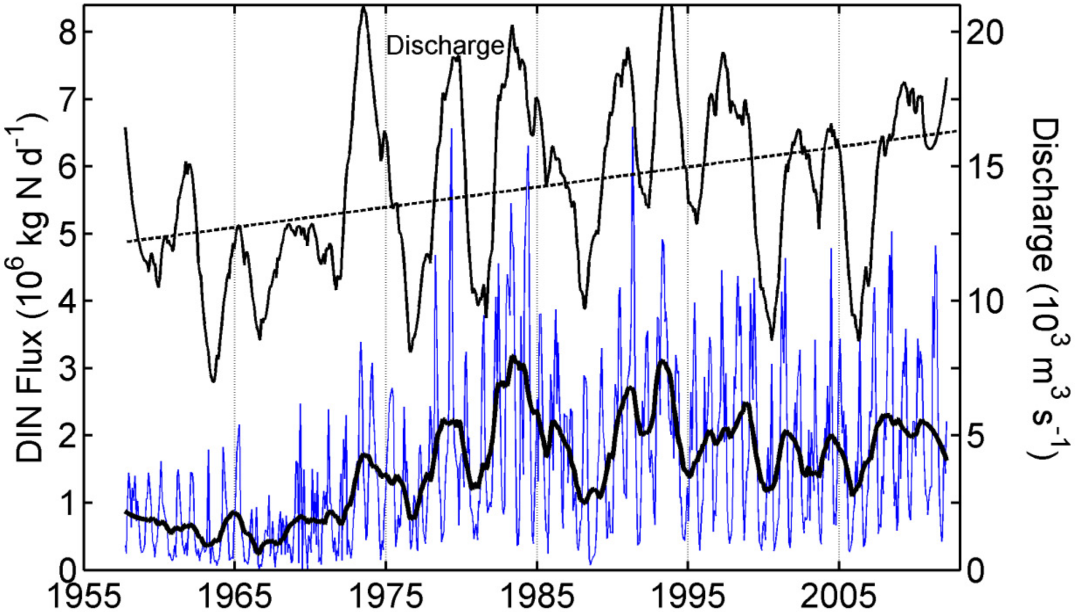
Watershed-river interactions and fluxes of freshwater, carbon and nutrients

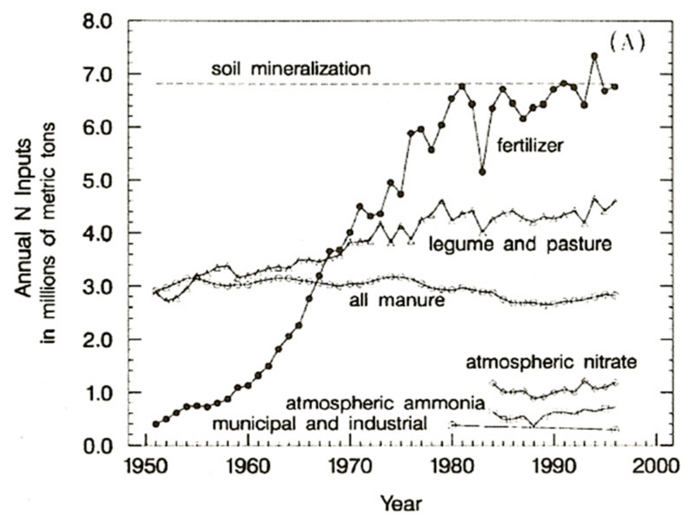


Lohrenz et al., modified from Cai and Lohrenz, 2010

- DIN flux showed large increase after 1967
- Increase also seen in discharge

Watershed-river interactions and fluxes of freshwater, carbon and nutrients





Source: Rabalais and Turner, 2001

- Increases in DIN flux parallel fertilizer use
- See also Raymond et al., 2008; 2012

Watershed-river interactions and fluxes of freshwater, carbon and nutrients

- POC/DOC

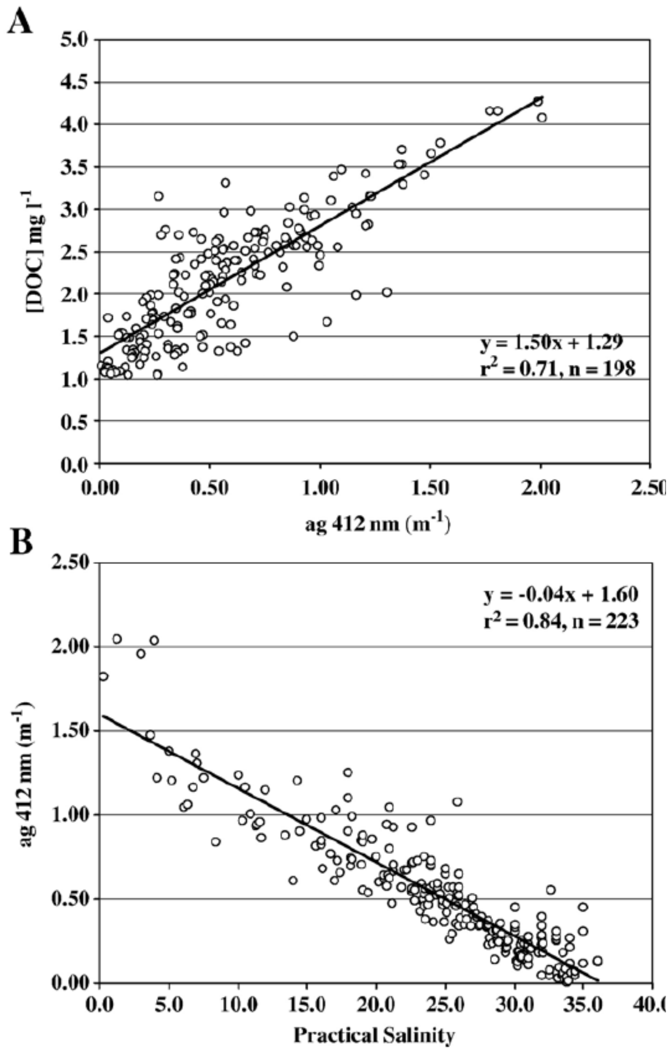
Cai & Lohrenz
in Liu et al. (2010)

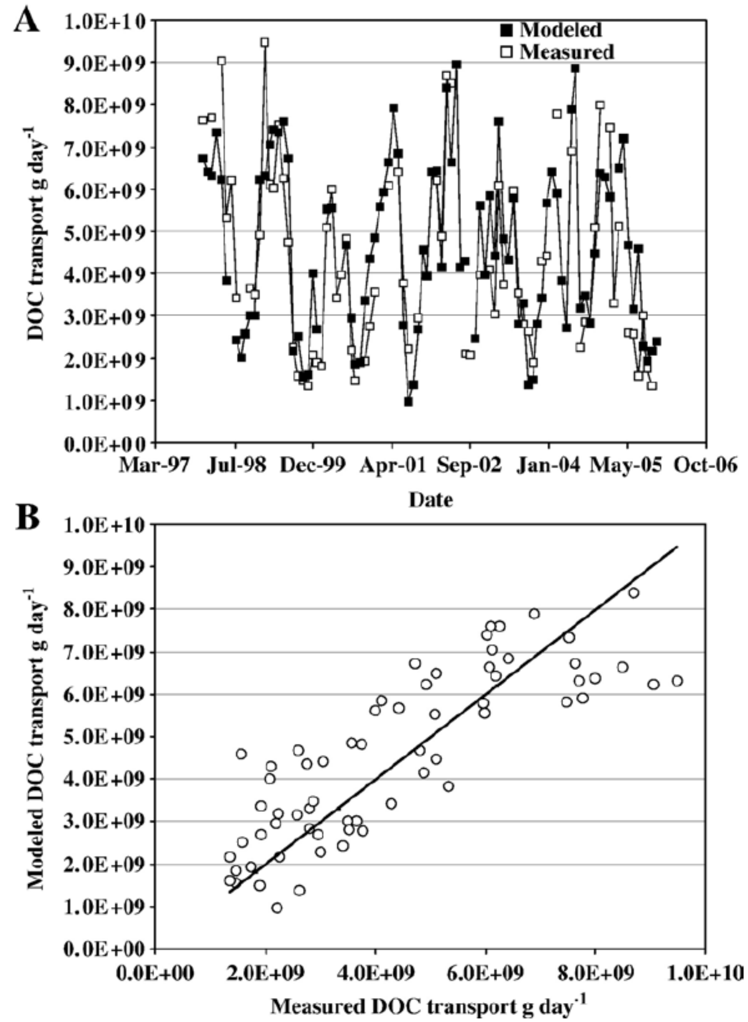
Table 7.8.1. Average concentrations and annual fluxes of organic and inorganic C, N, and P delivered to the Gulf of Mexico by the Mississippi-Atchafalaya River System (MARS) (in 10^{12} g y^{-1} or Tg y^{-1}). Total water discharge is 530×10^9 $m^3 y^{-1}$. TSM stands for total suspended matter.

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)

Watershed-river interactions and fluxes of freshwater, carbon and nutrients

- Satellite estimation of DOC/CDOM flux from the Mississippi River

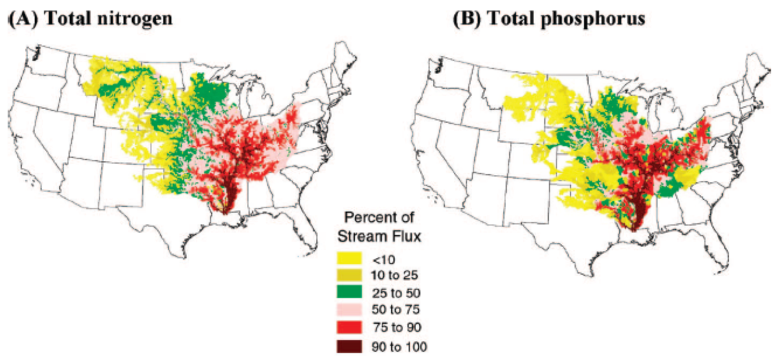




Del Castillo and Miller (2008)

Watershed-river interactions and fluxes of freshwater, carbon and nutrients

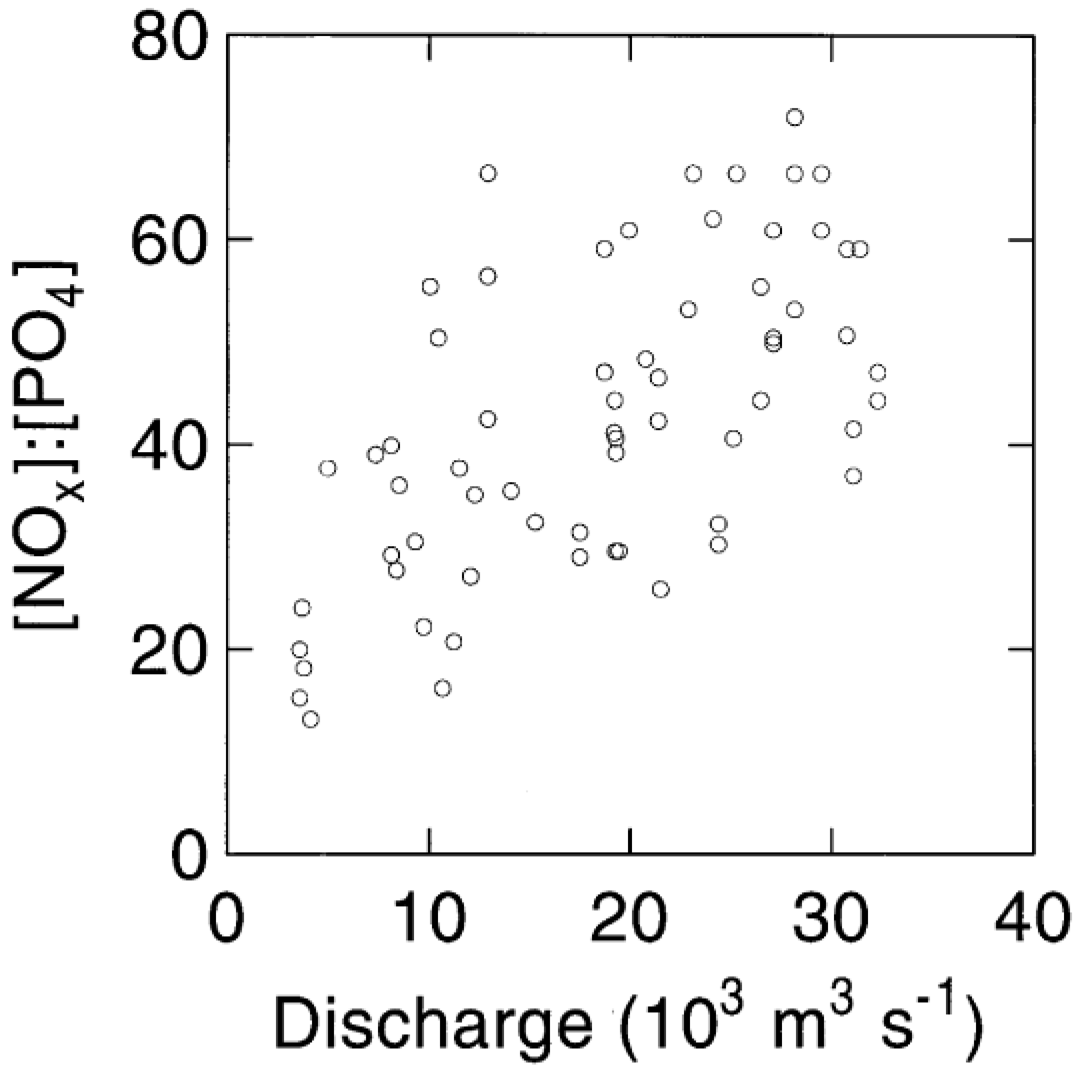
- Separating climate and human impacts
  - Impacts of Three Gorges Dam on carbon system properties and organic inputs to East China Sea uncertain (Chen et al., 2009) – may increase or diminish eutrophication
  - Large delta ecosystems as both drivers and recorders of long term anthropogenic and climate-related change such as eutrophication and hypoxia (Bianchi and Allison, 2009)
  - High nutrient delivery from agricultural regions involving corn and soybean Alexander et al. (2008)



  - Agricultural practices increase water throughput and decrease water and nitrogen residence time and processing (Raymond et al., 2012)

Dynamics of nutrients and productivity in river plumes

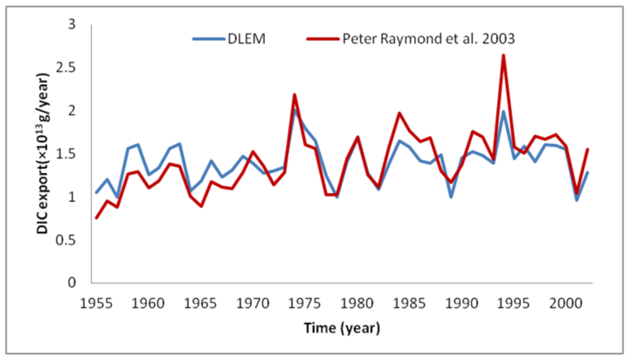
- Nutrient stoichiometry
  - Strong relationship between dissolved N:P and discharge in Mississippi River (Lohrenz et al., 2008)
  - Changes in nutrient stoichiometry linked to human activities (Justic et al., 1995; Turner et al., 2003)

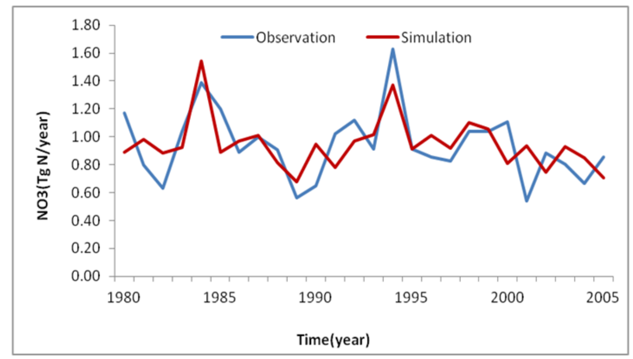


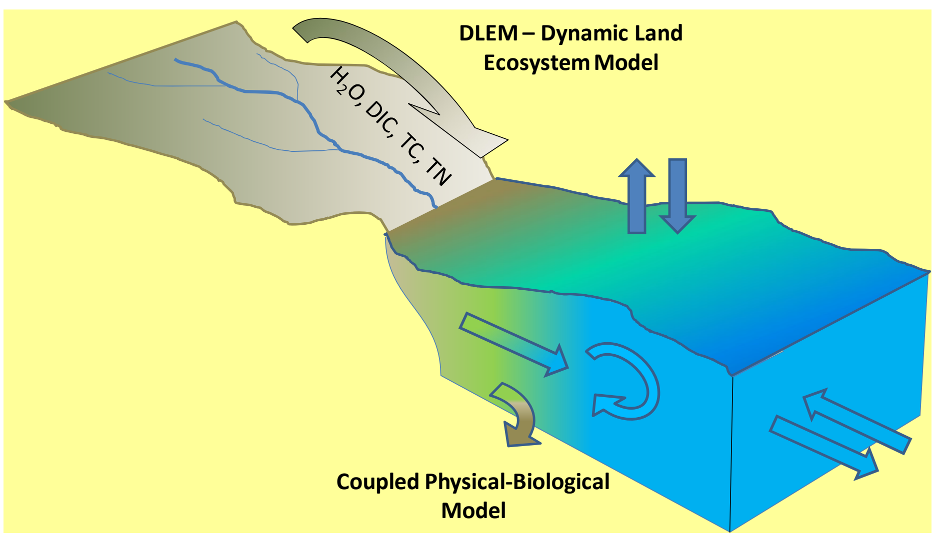
Watershed-river interactions and fluxes of freshwater, carbon and nutrients

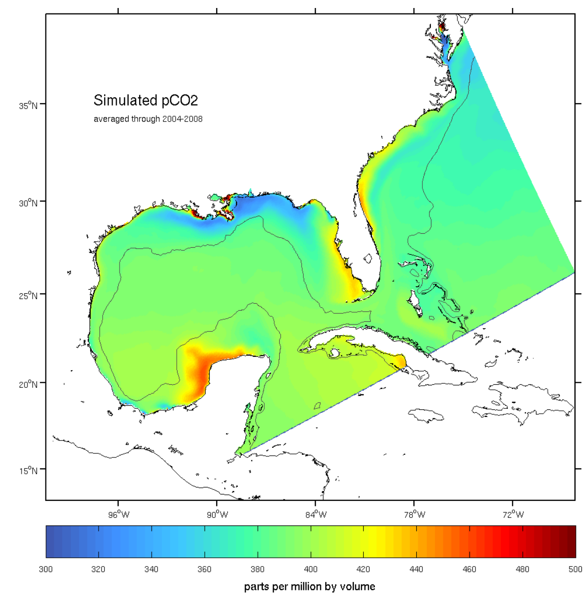
- Linking watershed dynamics and coastal margin processes
- NASA IDS project (Lohrenz, Cai, Tian, He, and Howden)

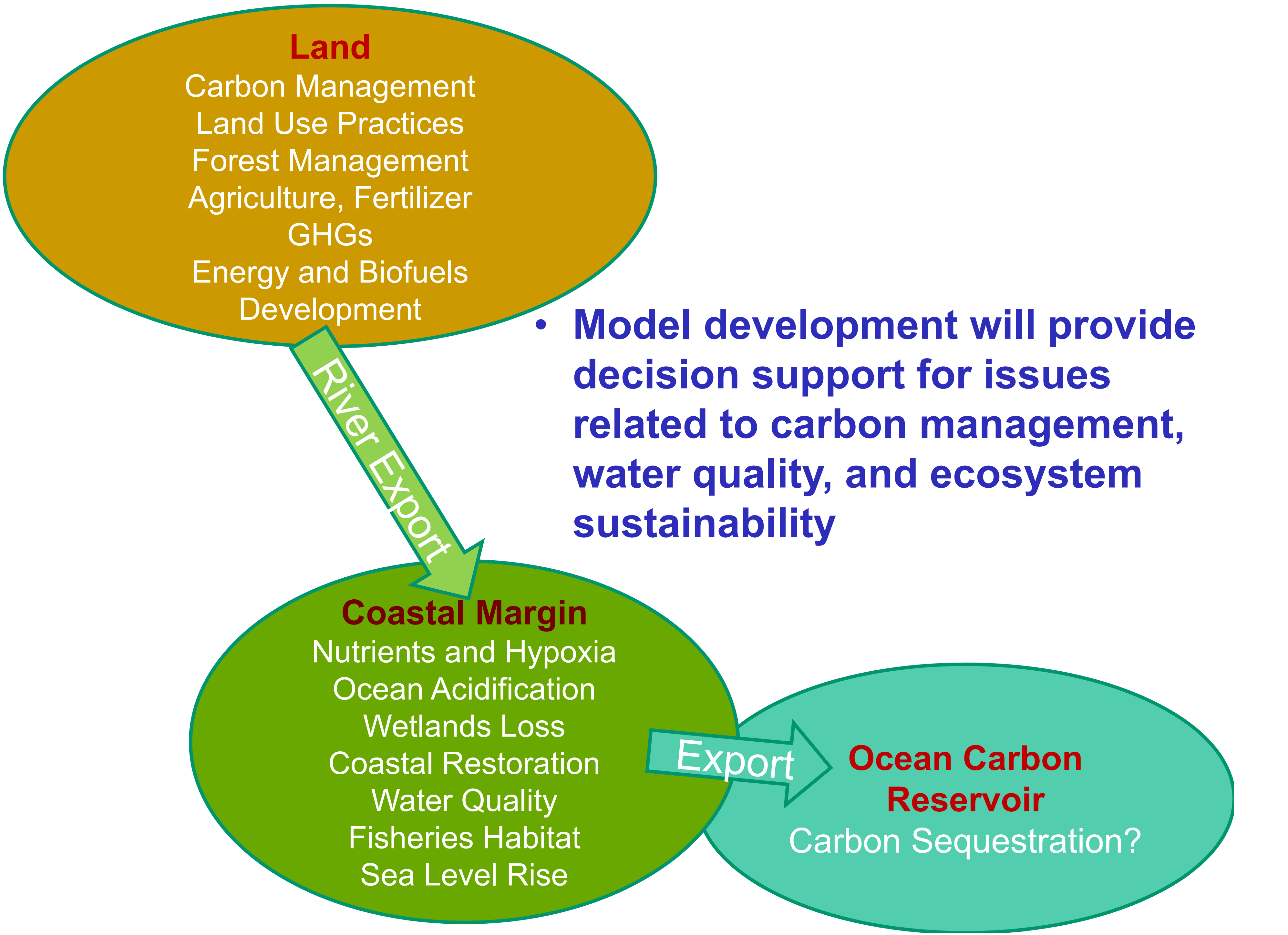
Terrestrial hydrological-ecosystem models coupled with hydrological-biogeochemical models of coastal and estuarine systems to examine water quality, transport, and ecosystem function











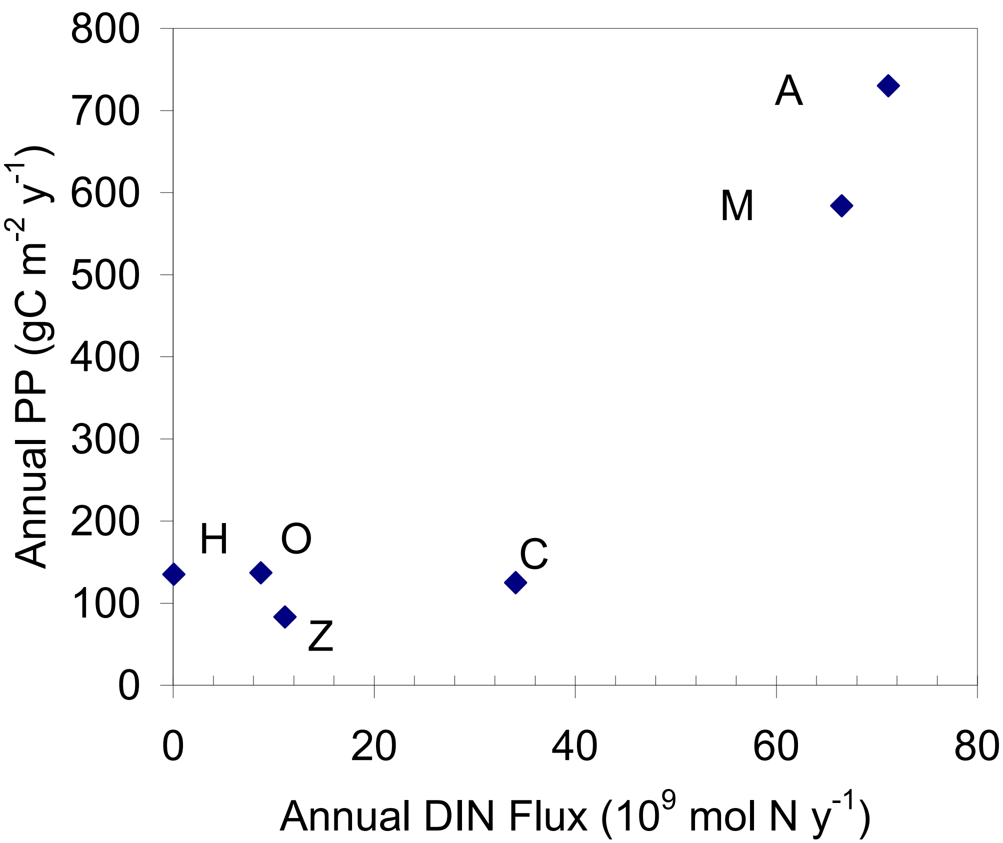
- **Model development will provide decision support for issues related to carbon management, water quality, and ecosystem sustainability**

Transformation and transport of carbon and nutrients in river outflow regions

- Dynamics of nutrients and productivity in river plumes
- Carbon system dynamics
- Benthic processes*

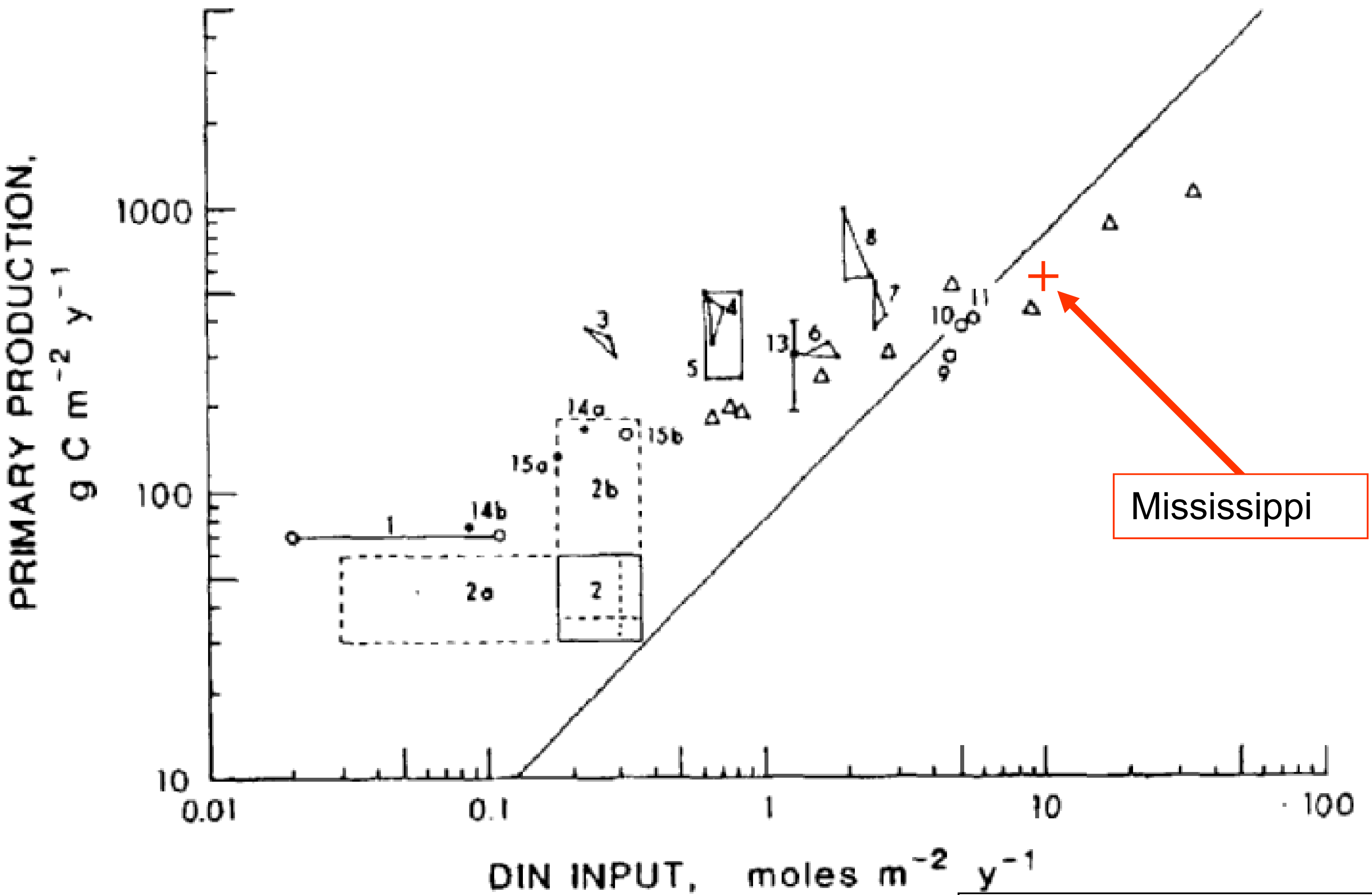
Dynamics of nutrients and productivity in river plumes

- Trends seen for large rivers



Dagg et al., 2004

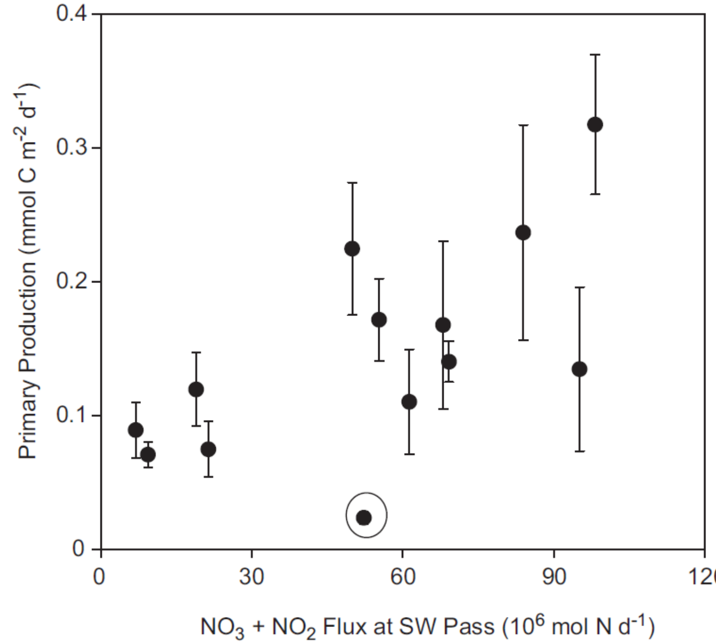
- Analogous relationships seen for estuarine systems

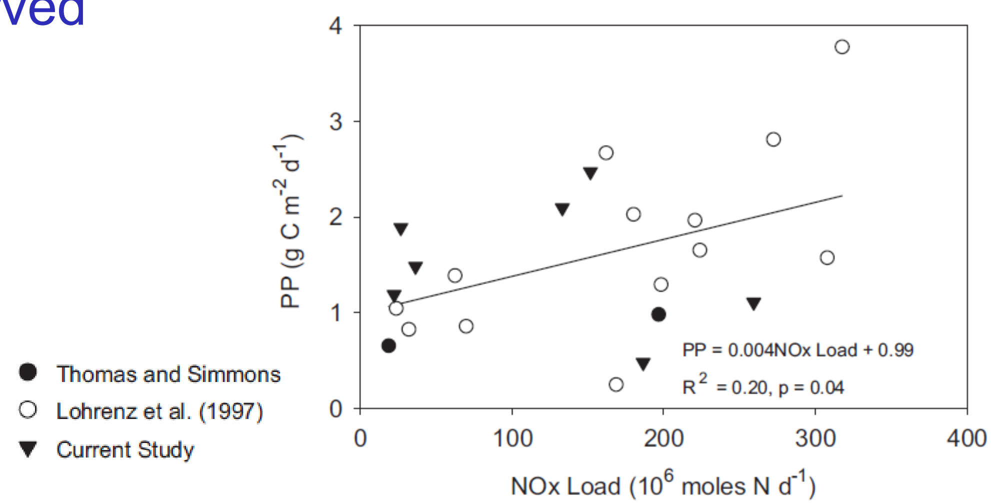


Nixon (1992) in Hinga et al. (1995)

Dynamics of nutrients and productivity in river plumes

- Average daily-integrated primary production in plume impacted waters in relation to riverborne NOx flux at the Southwest Pass of the Mississippi delta for the period of 1988-1994 (Lohrenz et al, 2008)
- Similar relationship observed by Lehrter et al. (2009)

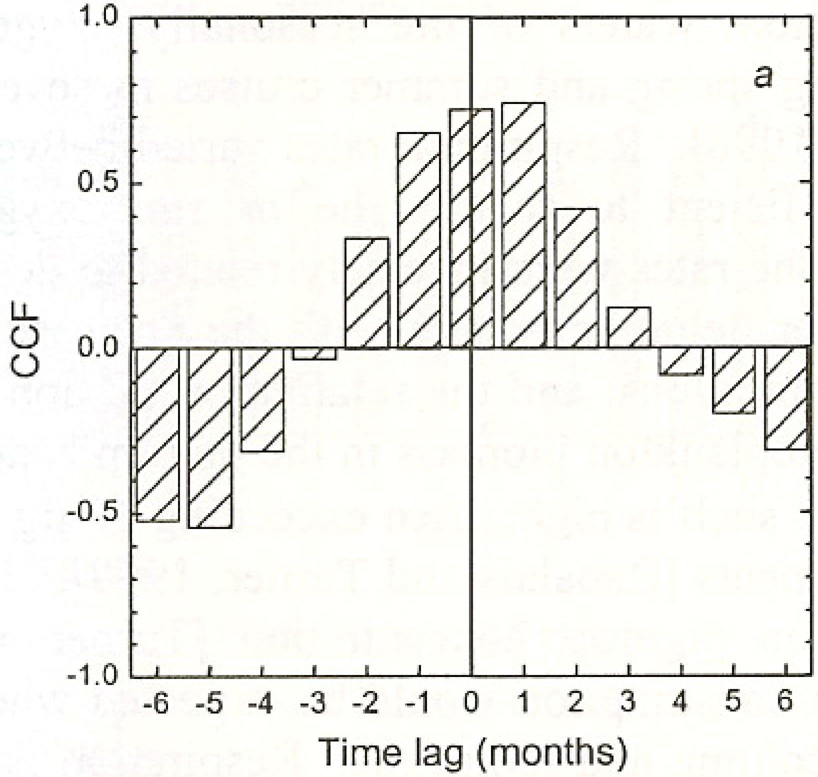


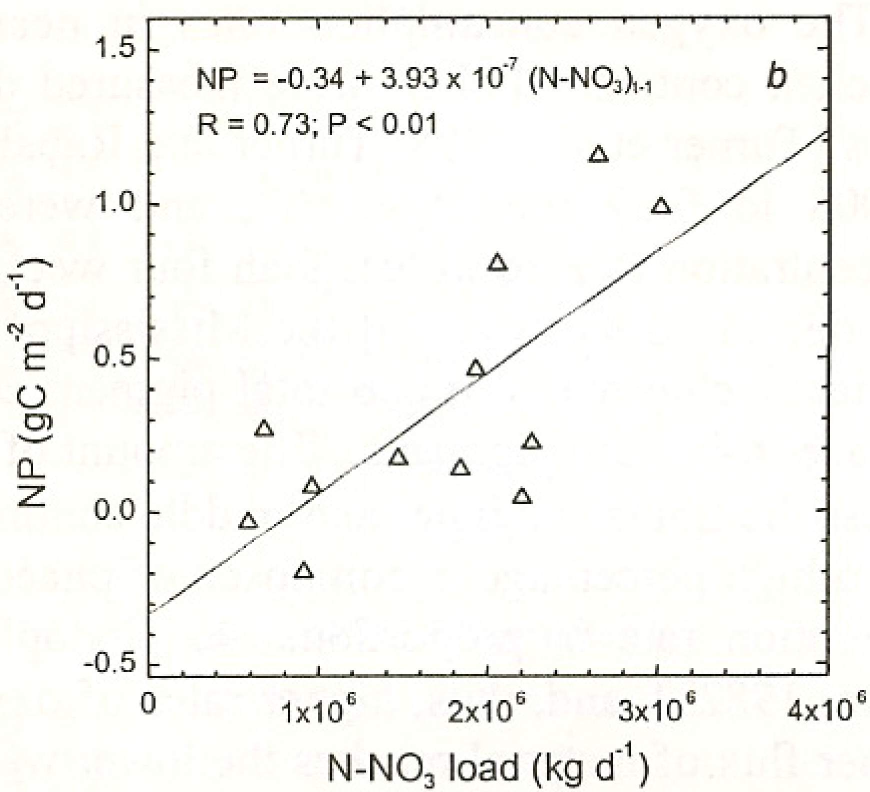


Dynamics of nutrients and productivity in river plumes

- Relationship between net community production and N loading from Mississippi River

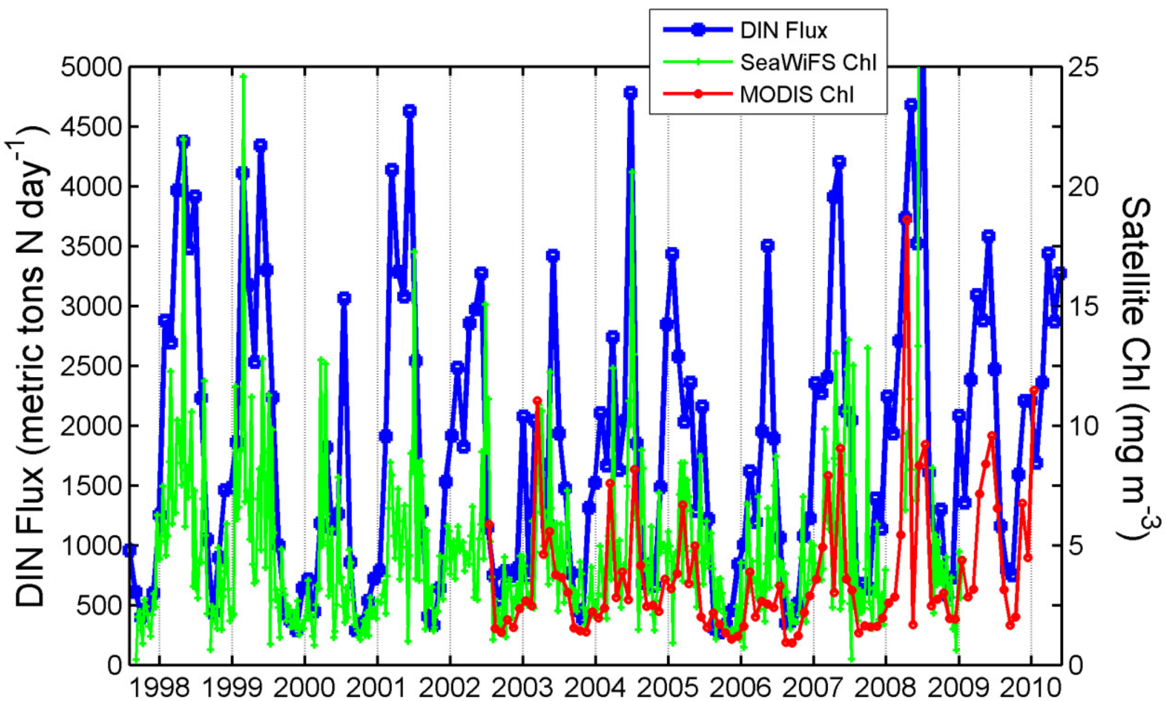
Justic' et al. 1997



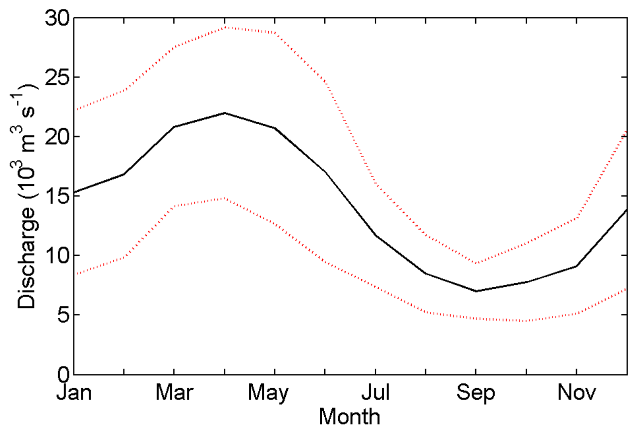


Dynamics of nutrients and productivity in river plumes

- Correlations between satellite (SeaWiFS, MODIS) chl and DIN flux in the Mississippi River (modified from Lohrenz et al., 2008)

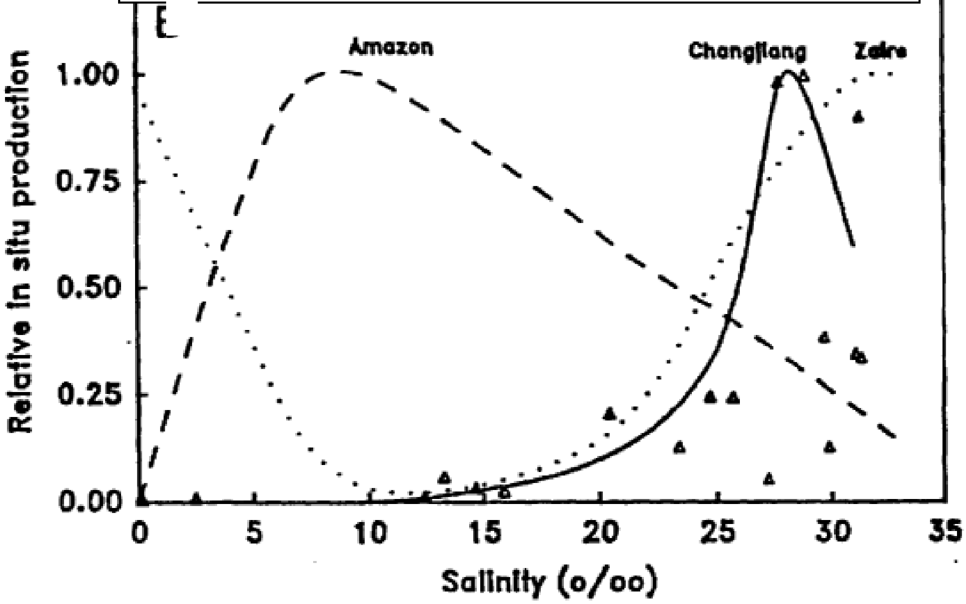


Average monthly discharge from 1961-2004

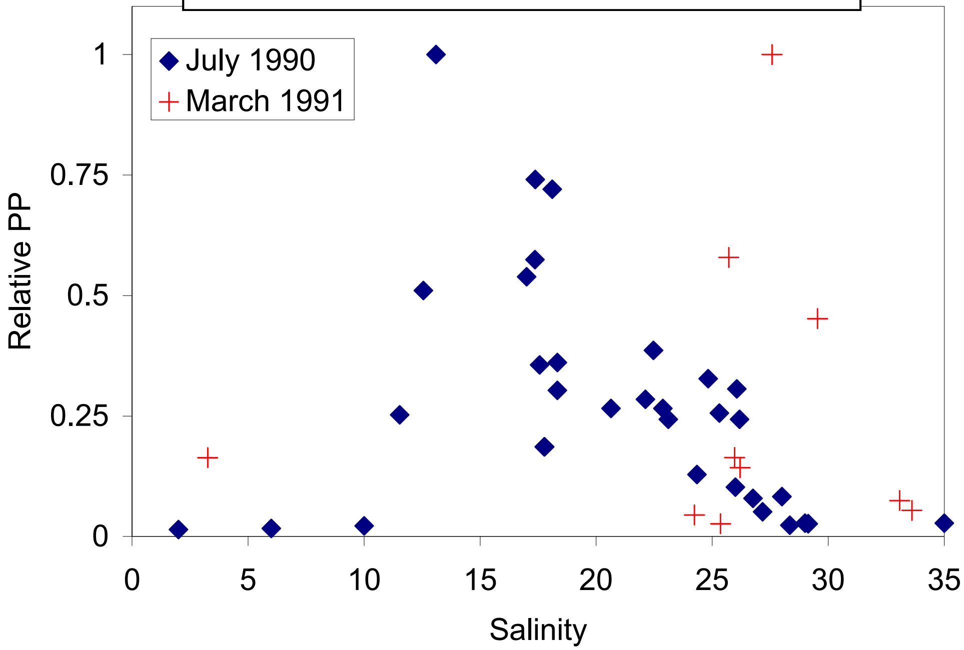


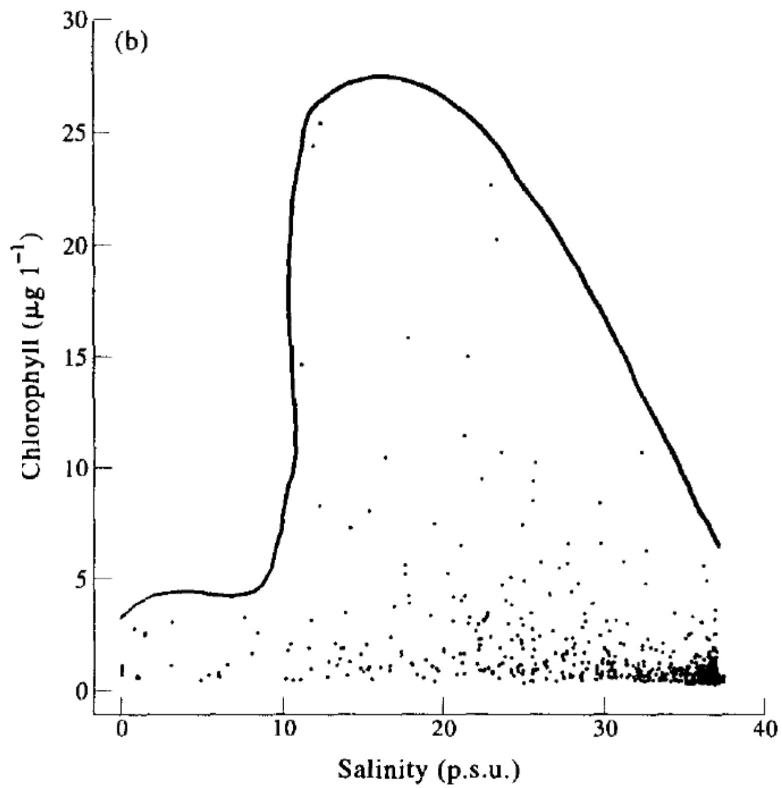
Optimal Growth Zone in River Plumes

Ning et al., 1988 and references therein



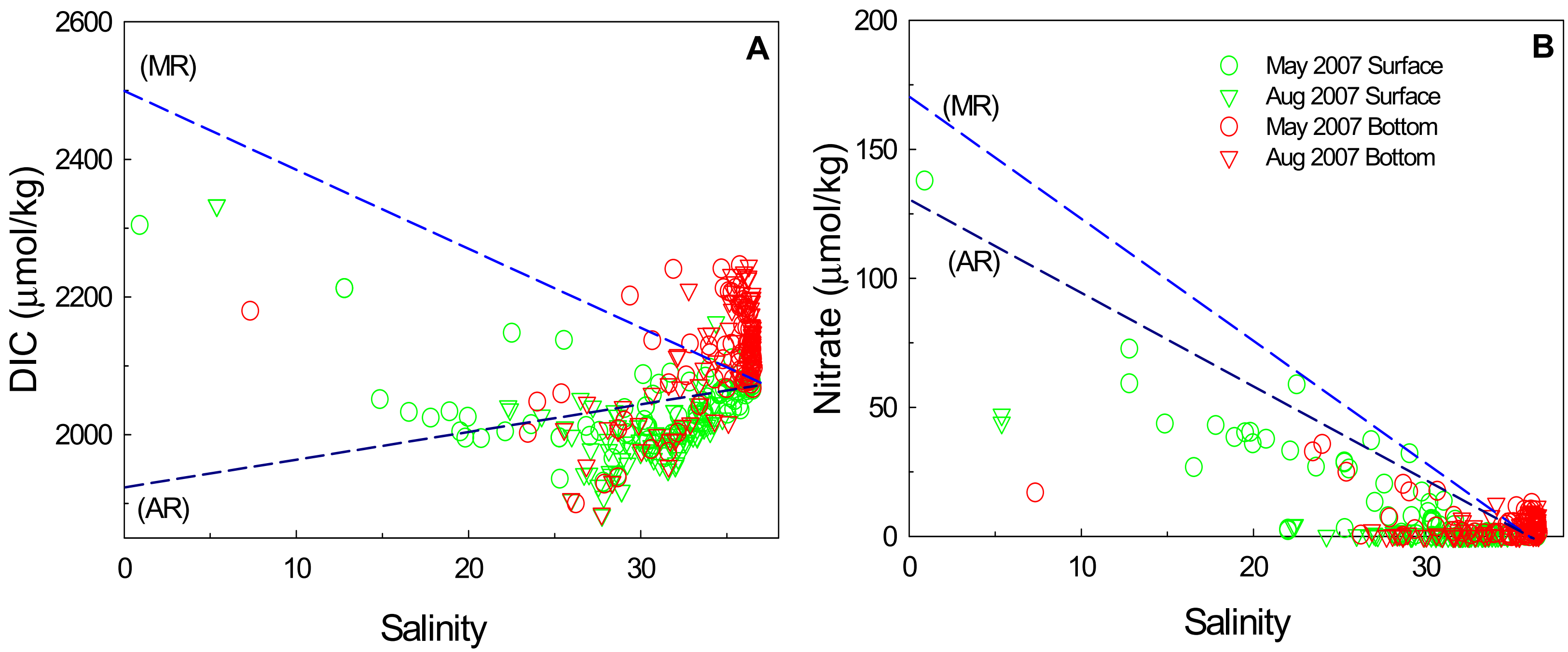
Mississippi - Lohrenz et al., 1999





Amazon - Smith and Demaster, 1996

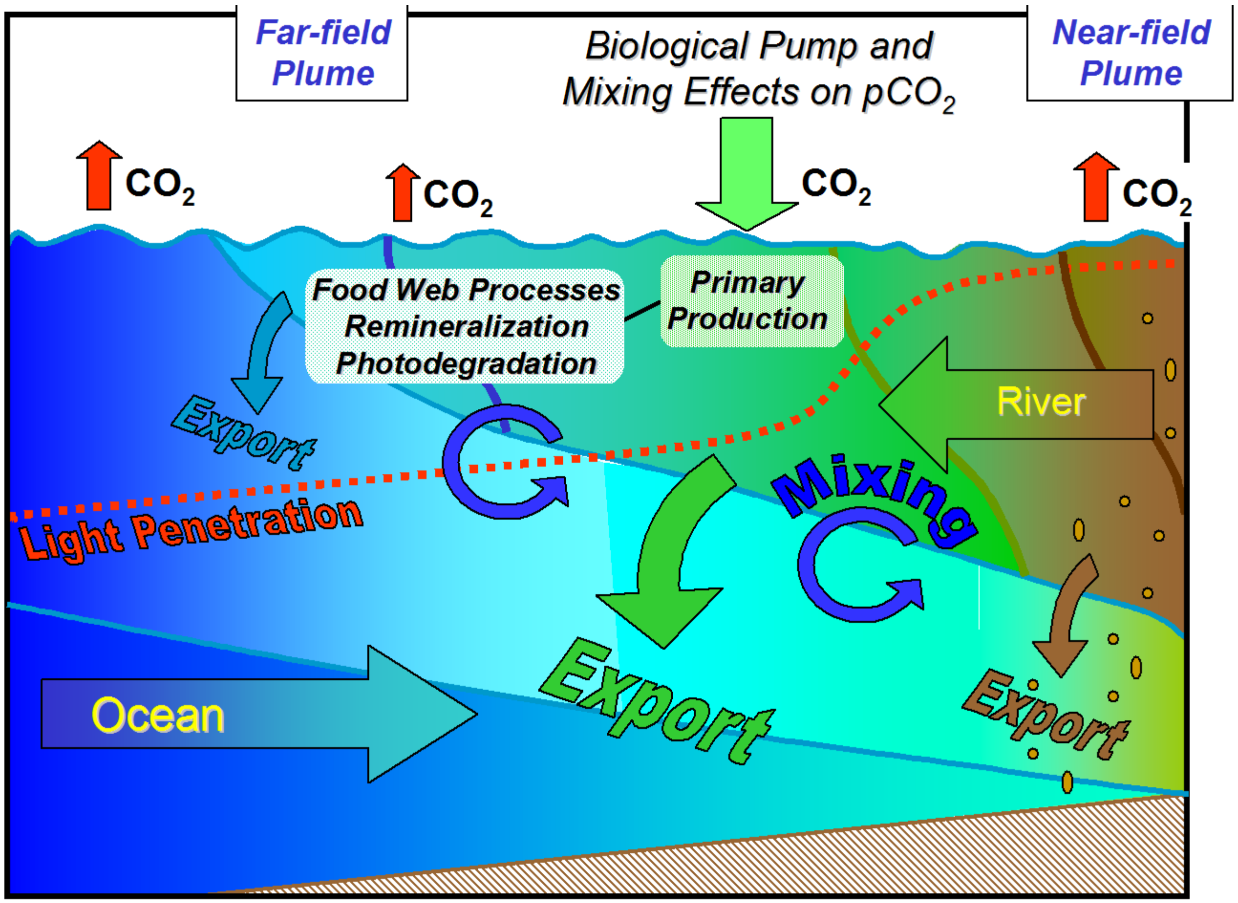
DIC and nutrient removal



- Both DIC and Nitrate are strongly removed in the middle salinity areas

Source: W. Cai

Conceptual Model of Ecosystem Processes

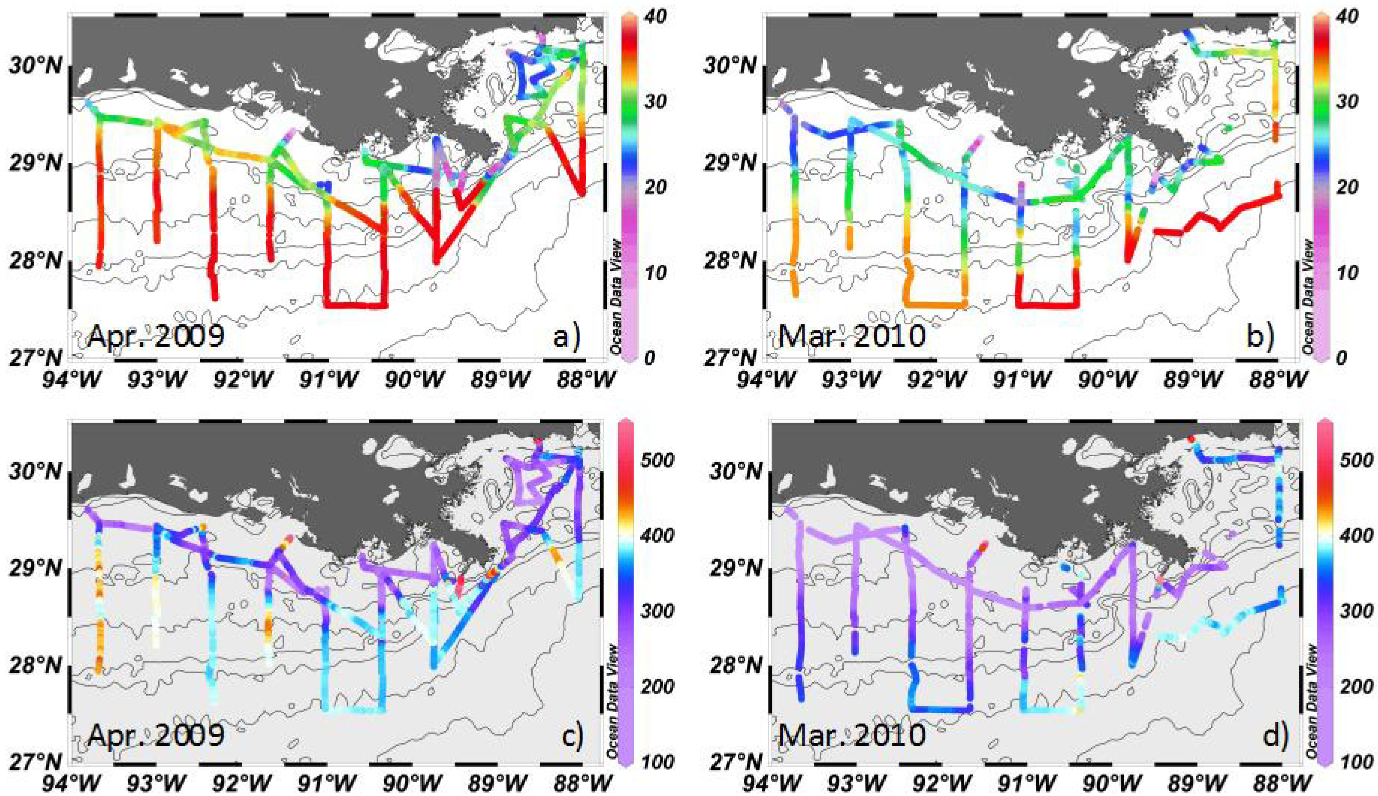


Cai and Lohrenz, 2010

- The high nutrient loading of this system contributes to a strong biological pump for carbon uptake

Transformation and transport of carbon and nutrients in river outflow regions (cont.)

- Carbon system dynamics
  - pCO_2 in Mississippi River outflow region shows enhanced drawdown (Lohrenz et al., 2010; Guo et al., 2012; Huang, Cai, in prep.)

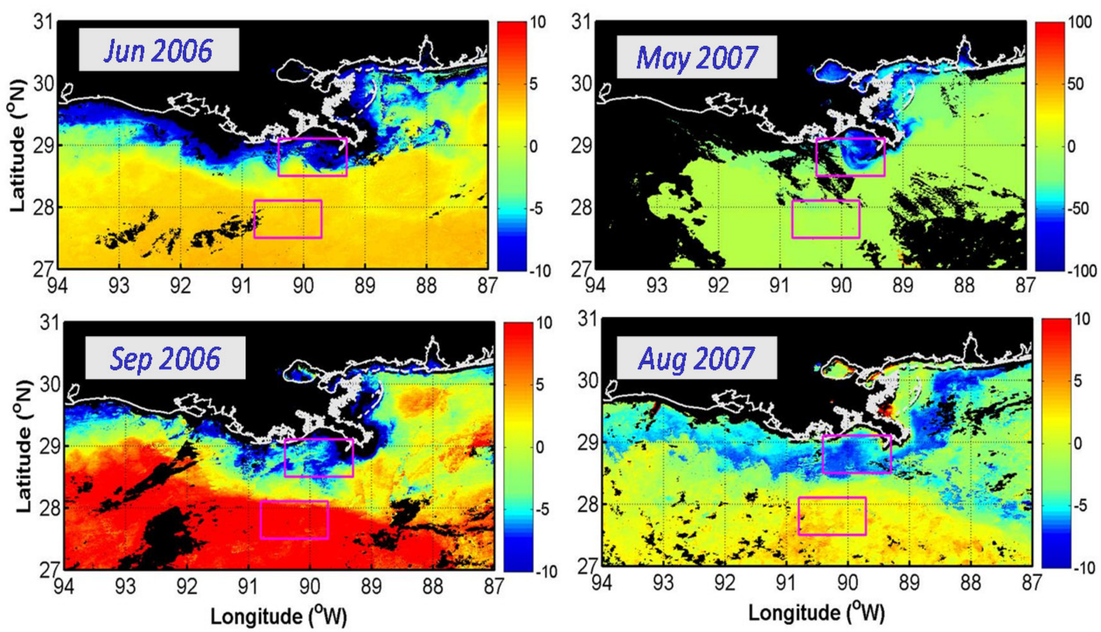


Transformation and transport of carbon and nutrients in river outflow regions (cont.)

- Carbon system dynamics
  - Satellite-based algorithms for pCO_2 in Mississippi River outflow region (Lohrenz et al., in prep.)

Table 1. Sea to air flux of CO_2 (mmol C m^{-2} d^{-1})

Date	Inner Shelf	Outer Shelf	Entire Region
Jun 2006	-4.0 - -5.9	2.6 – 3.8	0.92 – 1.4
Sep 2006	-5.1 – -6.9	8.3 – 11.0	3.4 – 4.6
May 2007	-29 - -35	-2.9 - -3.5	-6.7 - -8.2
Aug 2007	-4.7 - -5.8	1.6 – 2.0	-0.58 - -0.71

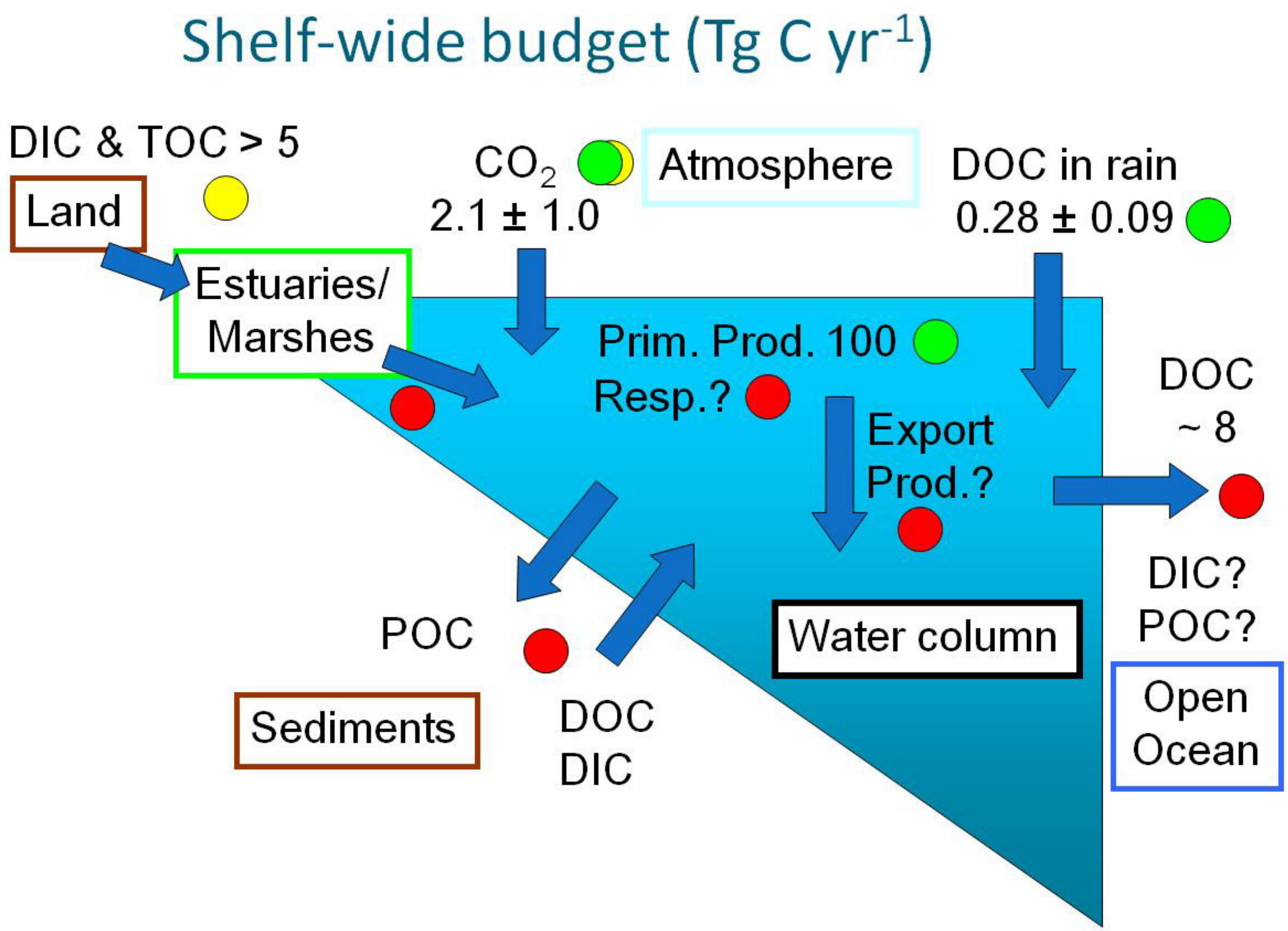


Transformation and transport of carbon and nutrients in river outflow regions (cont.)

- Biogeochemical models of carbon processes
  - Mississippi plume was net sink for CO_2; allocthonous carbon sources a large fraction of total carbon inputs (Green et al., 2006)
  - Northern Gulf of Mexico primary production and phytoplankton biomass are positively correlated with nutrient load, phytoplankton growth rate is not; accumulation of biomass in this region controlled bottom by top down loss processes (Fennel et al., 2011)
  - Need for incorporating “priming” in biogeochemical models examining processing of terrestrial organic matter in aquatic systems (Bianchi, 2011)

Transformation and transport of carbon and nutrients in river outflow regions (cont.)

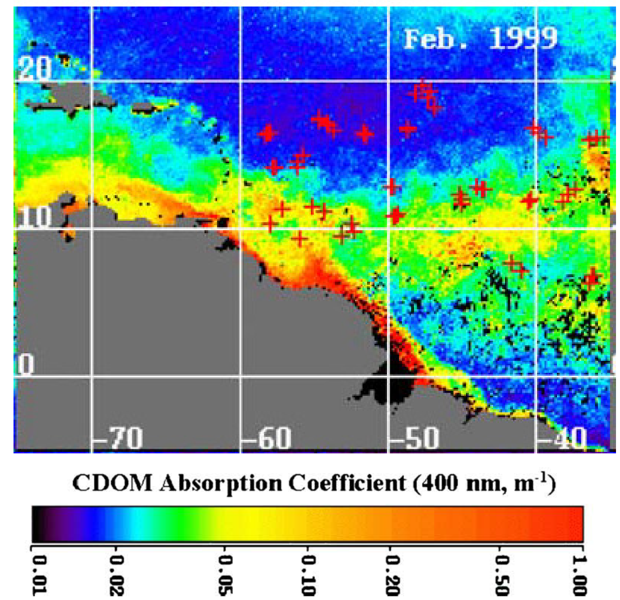
- Coastal carbon synthesis: Gulf of Mexico

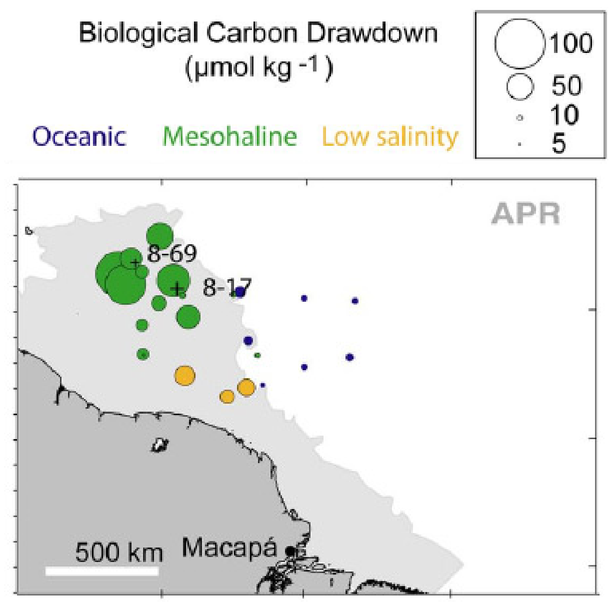


Coble et al.

Carbon system dynamics

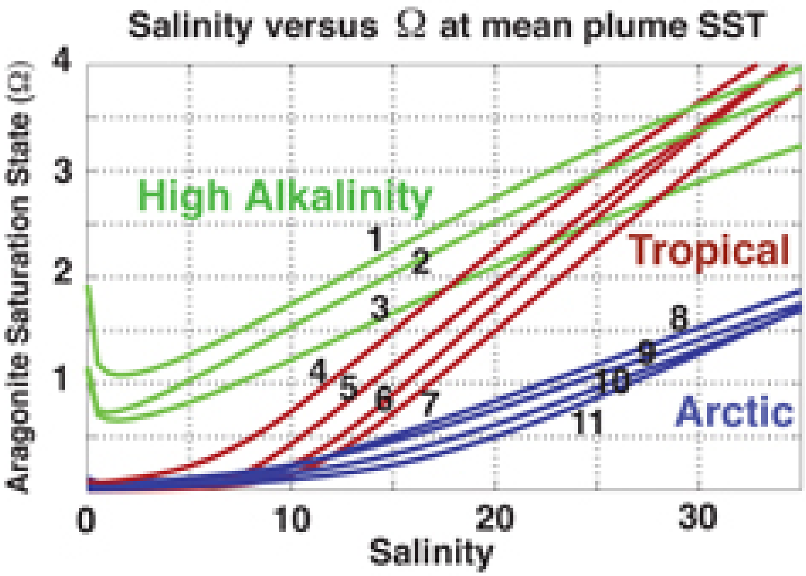
- Broad extent of river influence
  - Comparison of CDOM from SeaWiFS in conjunction with S-PALACE float observations of SSS (Hu et al., 2004, Amazon)
  - Amazon River plume supports N_2 fixation far from the mouth and sequestration of atmospheric CO_2 in the western tropical North Atlantic (Subramaniam et al., 2008)

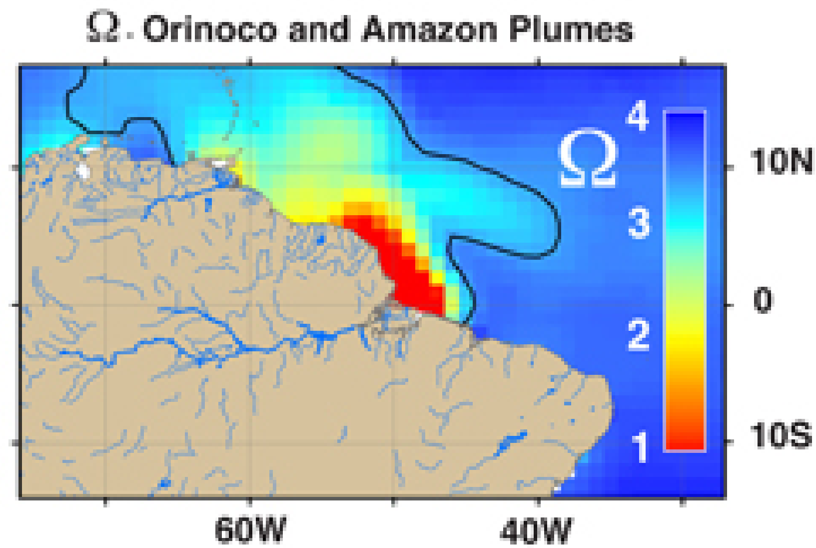




Carbon system dynamics

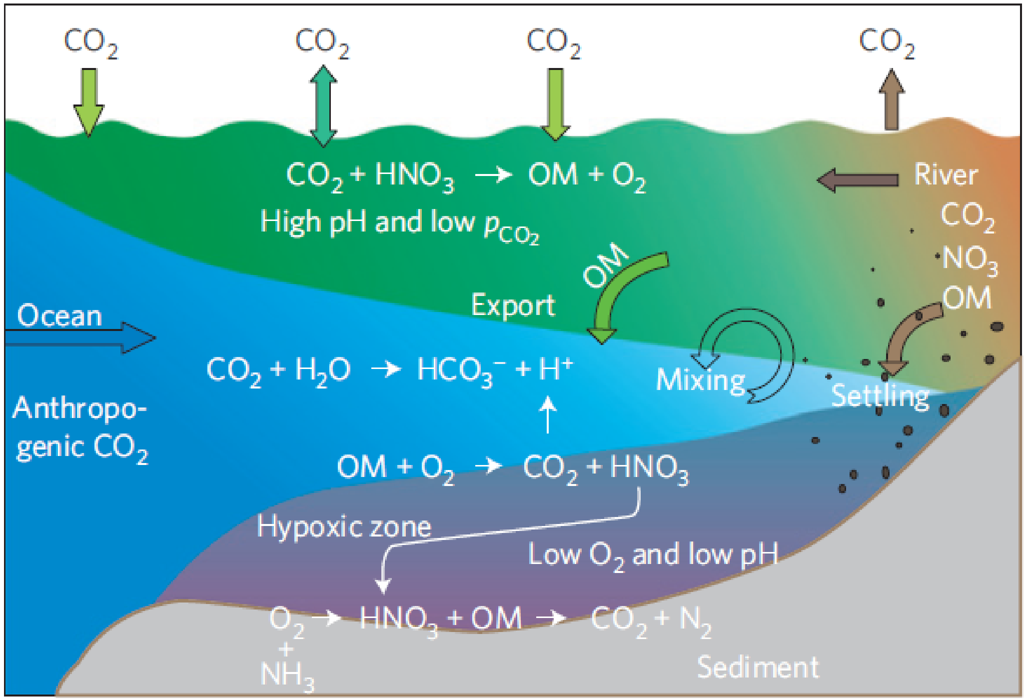
- Low alkalinity freshwater inputs may promote ocean acidification (Salisbury et al., 2008)
- Eutrophication and nutrient management may dominate carbonate dynamics in nearshore coastal environments (Borges and Gypens, 2010)





Carbon system dynamics

- Enhanced ocean acidification in hypoxic bottom waters (Cai et al., 2011 and presentation)



Questions for future research

- Plume physics and biogeochemistry: what are consequences of freshwater residence times and mixing?
- Extent of river influence: how far do river impacts extend on continental margins and beyond?
- What are the sources and fate of autochthonous and allocthonous sources of organic matter in river systems?
- Human alteration and climate: river exports are highly influence by human activities in the watershed as well as climate. Can we predict such changes?