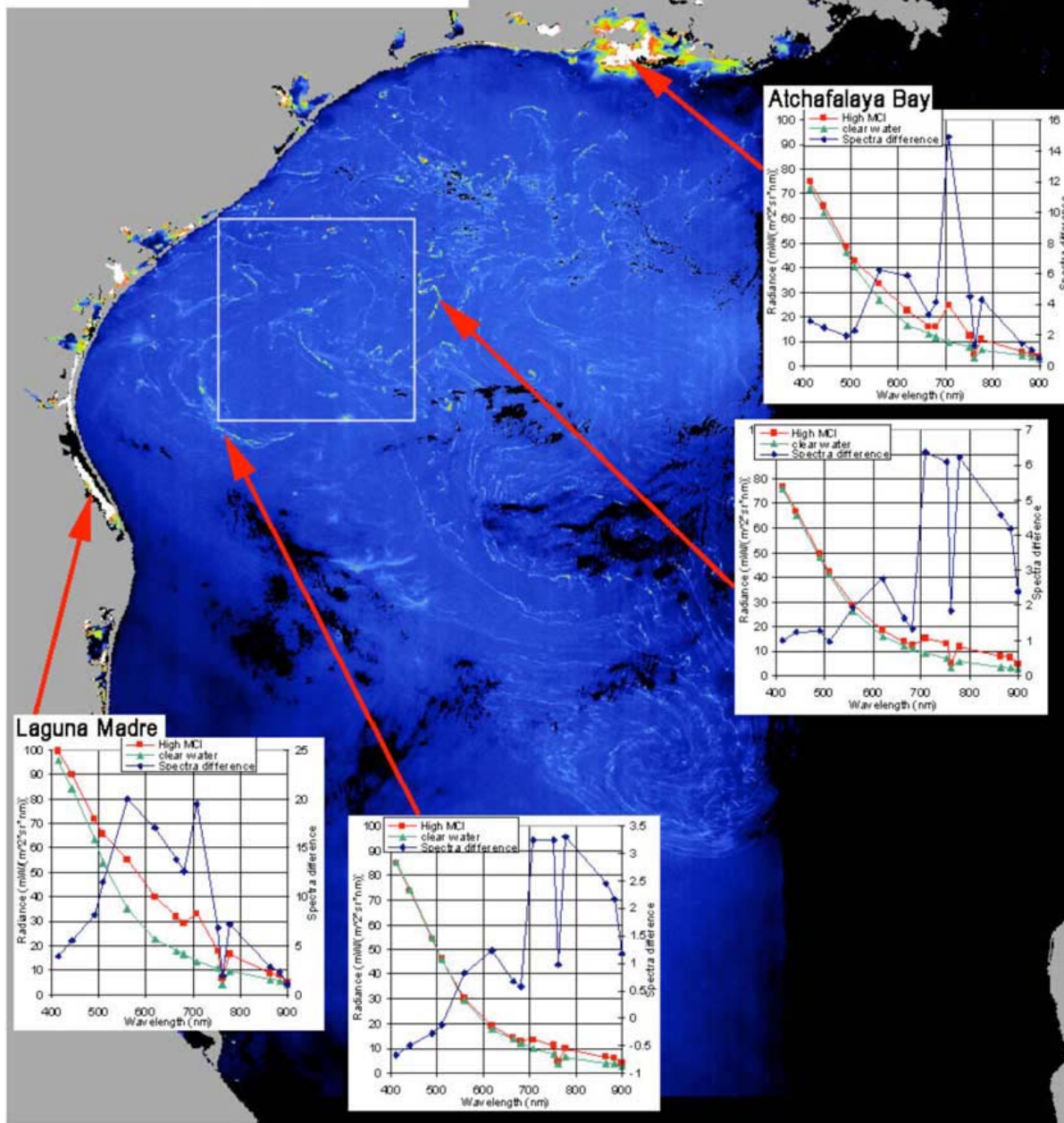
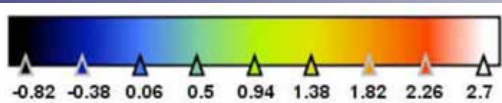
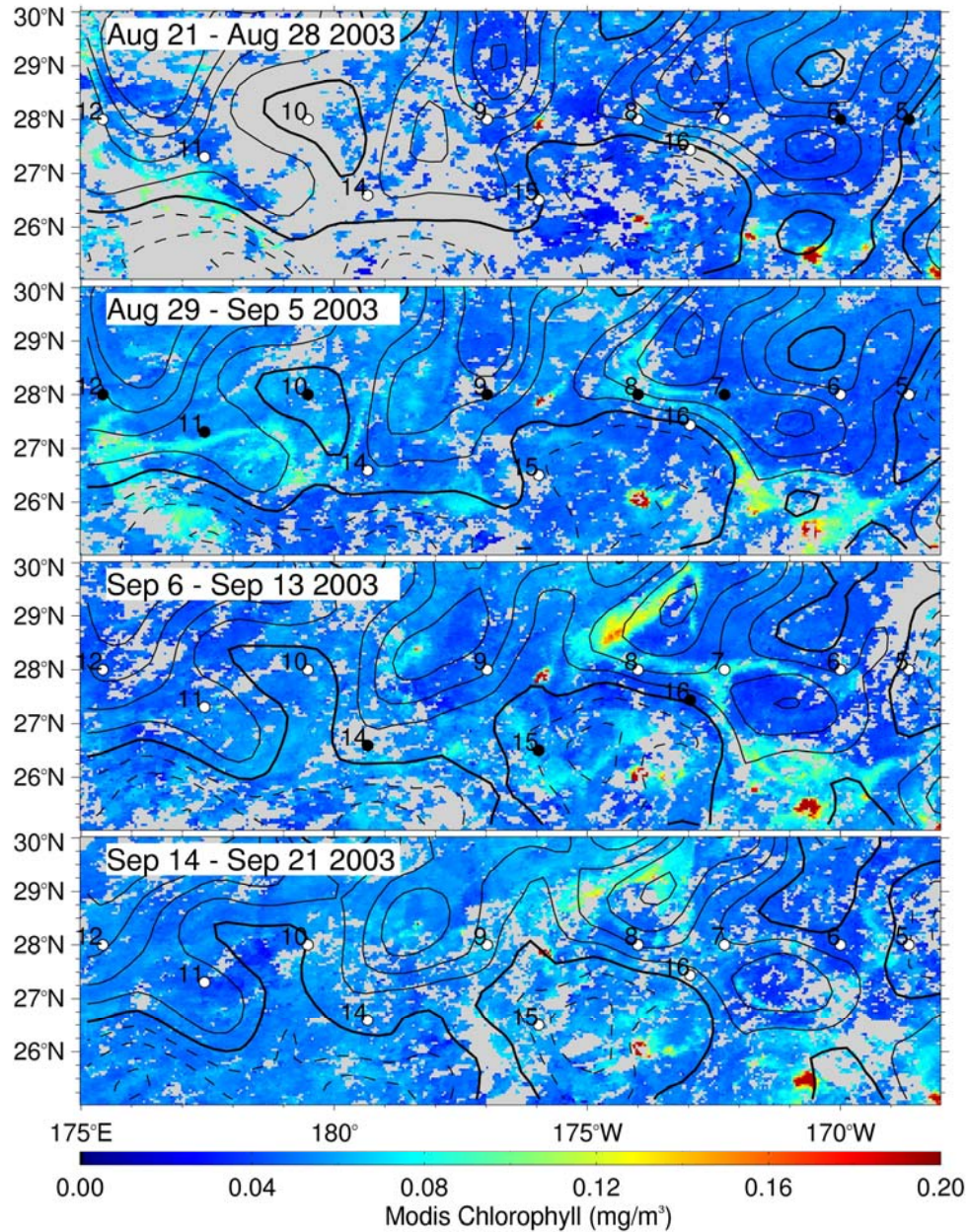


The floating Sargassum

- extensive lines of floating Sargassum in the western Gulf of Mexico in the summer of 2005
- first ever observation from space. The images have spatial resolution down to 300 m [Medium Resolution Imaging Spectrometer (MERIS) full-resolution mode], with most [MERIS reduced resolution (RR) and Moderate Resolution Imaging Spectroradiometer (MODIS) bands eight and above] having resolution of 1–3 km depending on distance from satellite nadir.
- Photosynthetic vegetation is characterized by an abrupt change in reflectance (the chlorophyll “red edge”) from low (< 0.1) in the visible, to high (> 0.4) at wavelengths longer than about 730 nm.







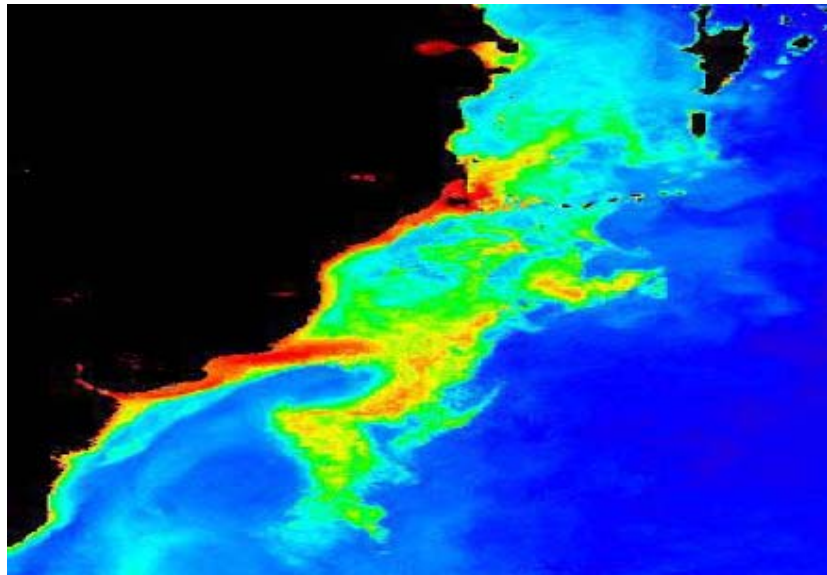


Week 8-9

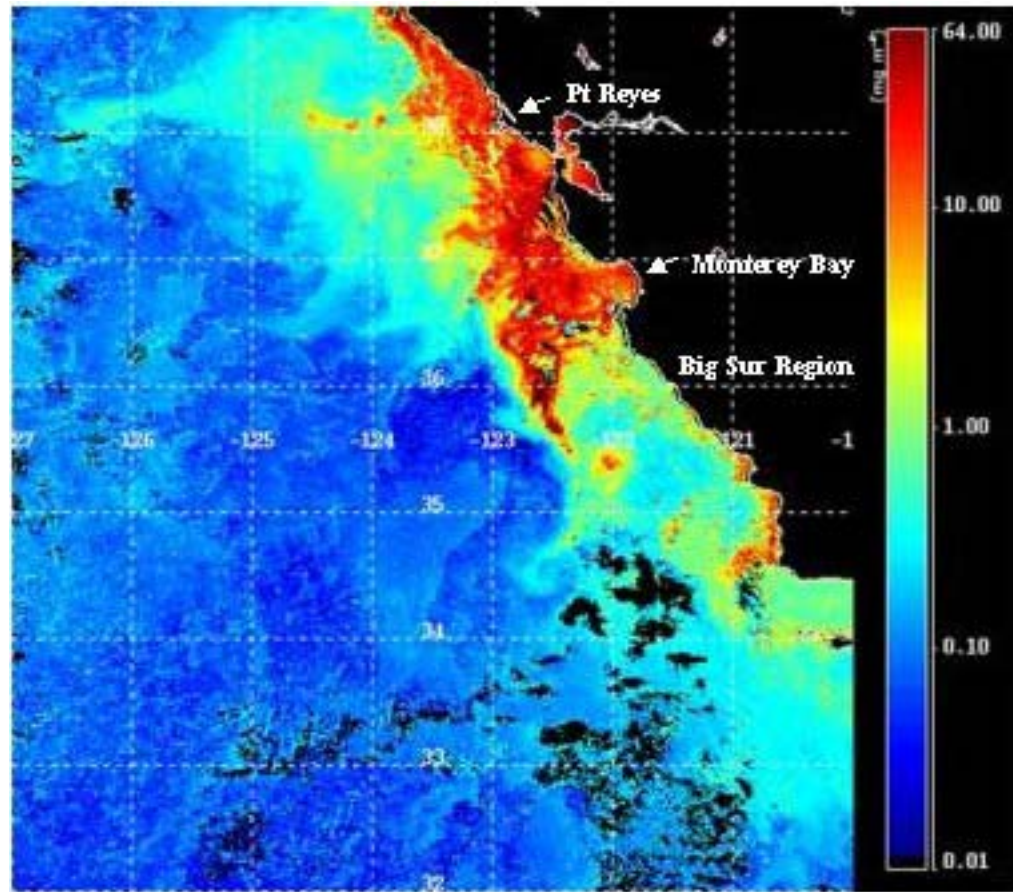
Continental Margin Exchanges

Why worrying about continental margins?

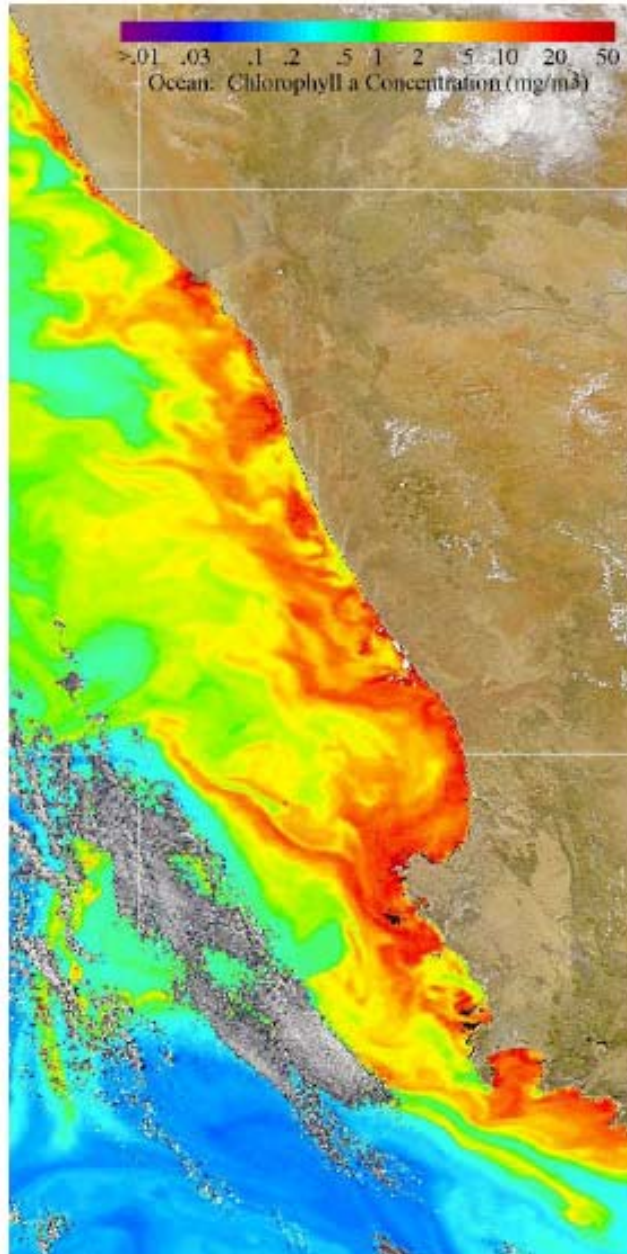
- They occupy 7% of the ocean surface (defined as regions where the water column is 200m or shallower) and 0.5% of the ocean volume
- ~80-90% of new production, 14% of total production and ~50% of denitrification takes place in the ocean margins
- They contain ~ 80% of the organic carbon from oceanic and land processes and 50% of global carbonate deposition



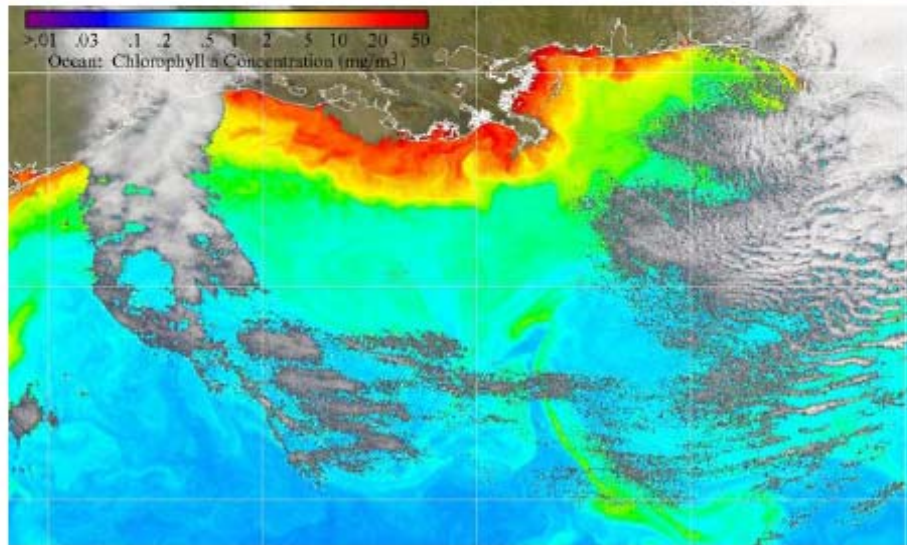
Amazon River



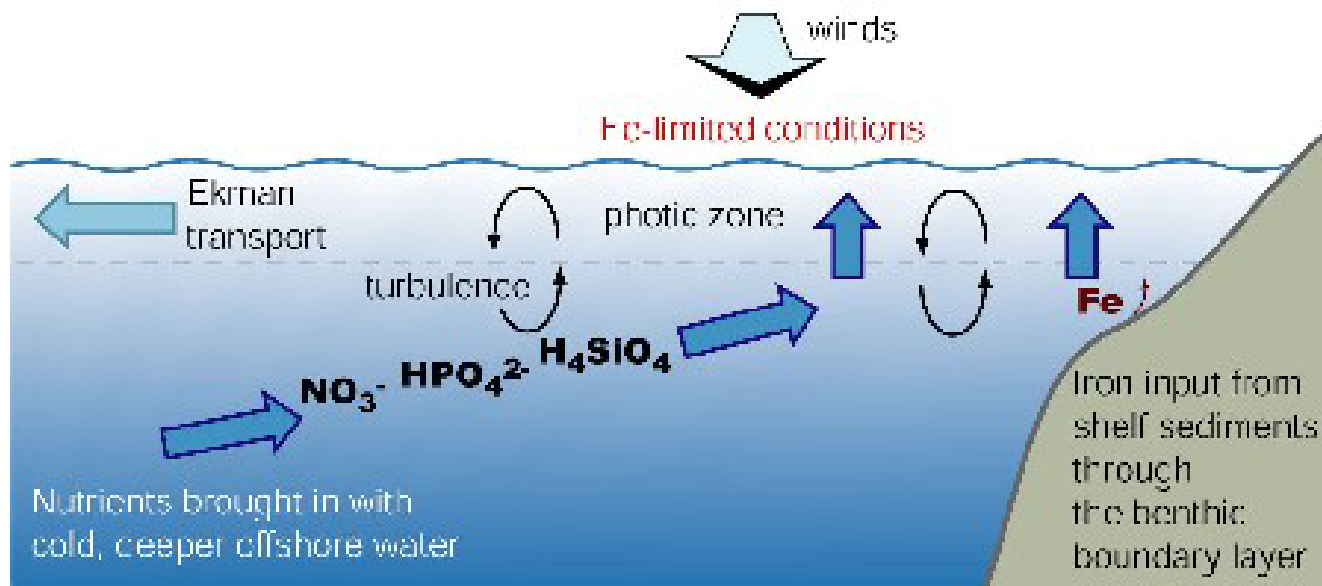
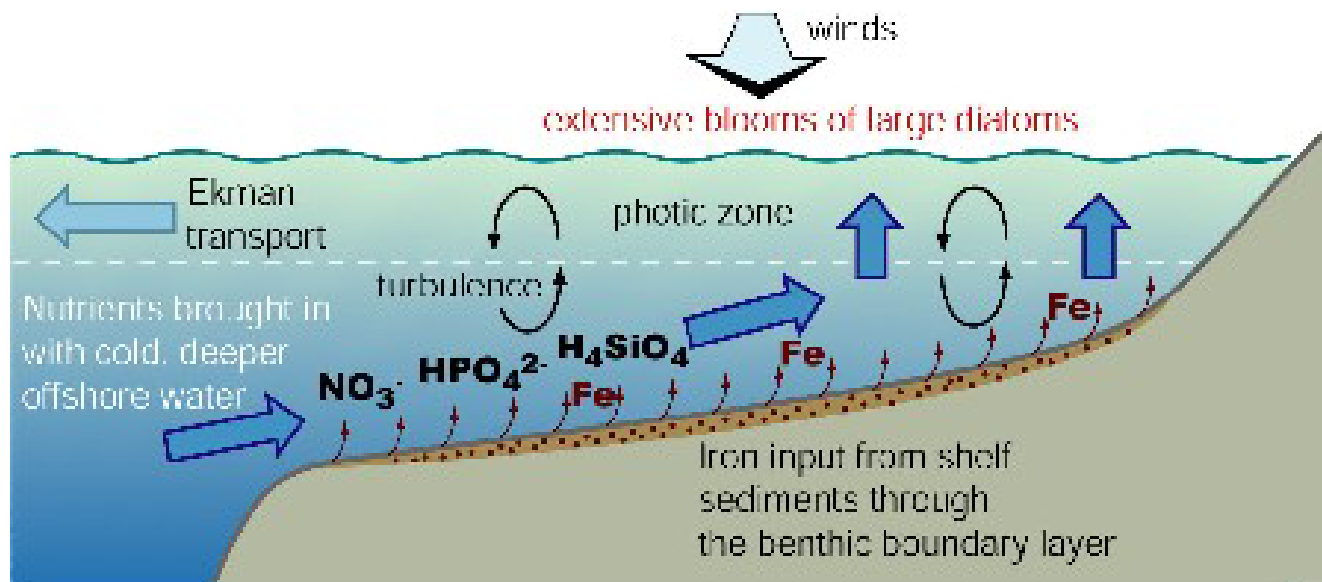
California coast



Upwelling zone off the west coast of South Africa (Feb. 21, 2000)



The Gulf of Mexico region for February 25, 1999.



Carbon fluxes in continental margins

- open question:

How quickly anthropogenic CO₂ is absorbed by the ocean?

- Why is it difficult to assess?

The difference between uptake and release of CO₂ at the sea surface is small ($\sim 2 \text{Pg C yr}^{-1}$, Pg=10¹⁵g vs $\sim 90 \text{Pg C yr}^{-1}$ in uptake/release)

- Ocean margins are active sites where physical and biological processes transform, transport or bury carbon

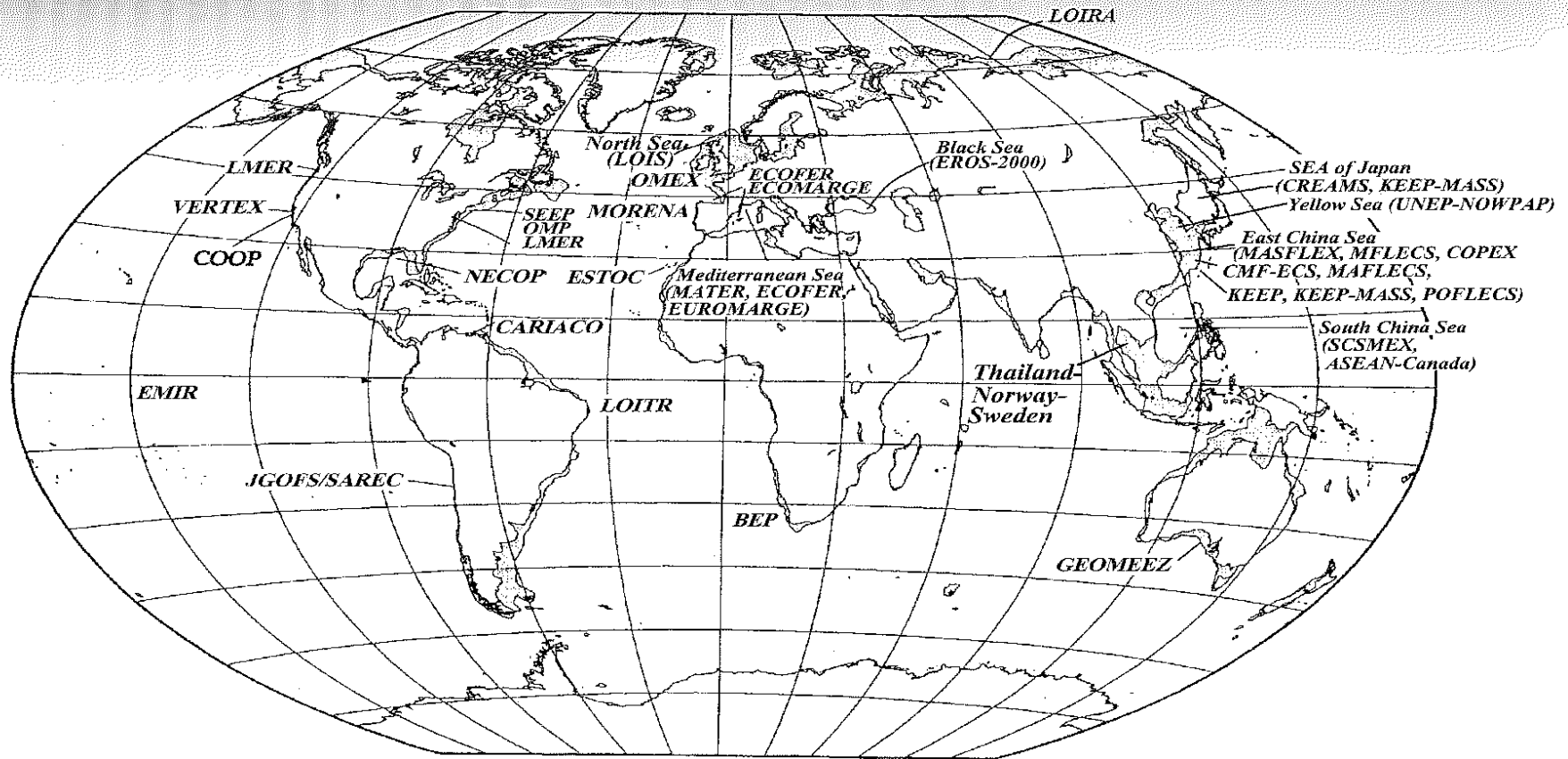
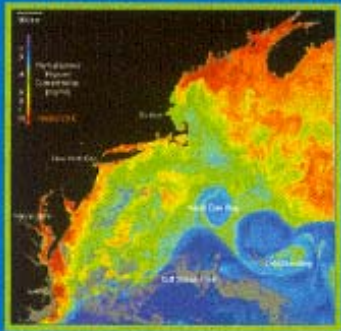


Fig. 3.1. Map of continental margins. Stippled areas represent the continental shelves with depths less than 200 m. Selected programs for continental margin studies, both completed and ongoing, are shown. The acronyms are as follows: *BEP* (Benguela Ecology Programme); *CARIACO* (Carbon Retention in a Colored Ocean); *CMF-ECS* (Continental Margin Flux-East China Sea); *COPEX* (The Coastal Ocean Processes Experiment of the East China Sea); *COOP* (Coastal Ocean Processes); *CREAMS* (The Circulation Research Experiment in Asian Marginal Sea); *ECOFER* (Ecosystème du canyon du cap Ferret program); *ECOMARGE* (Ecosystems de Marge); *EMIR* (Exportation de Carbon sur une Marge Insulaire Recifale); *EROS-2000* (European River-Ocean System); *ESTOC* (European Station for Time-Series on the Ocean, Canary Islands); *GEOMEET* (Marine Geological and Oceanographic computer model for Management of Australia's EEZ); *JGOFS/SAREC* (Eastern Boundary Current Programme); *KEEP* (Kuroshio Edge Exchange Processes); *KEEP-MASS* (Kuroshio Edge Exchange Processes-Marginal Seas Studies); *LMER* (Land Margin Ecosystem Research); *LOIRA* (Land/Ocean Interactions in the Russian Arctic); *LOISE* (Land Ocean Interaction Study); *LOITRO* (Land-Ocean Interaction in Tropical Regions); *MAFLECS* (Marginal Flux in the East China Sea); *MASFLEX* (The Marginal Sea Flux Experiment); *MATER* (Mass Transfer and Ecosystem Response); *MFLECS* (The Margin Flux in the East China Sea Program); *MORENA* (Multidisciplinary Oceanographic Research in the Eastern Boundary of the North Atlantic); *NECOP* (Nutrient Enhanced Coastal Ocean Productivity); *OMEX* (The Ocean Margin Exchange); *OMP* (US Ocean Margins Programme); *POFLECS* (The Key Processes of Ocean Fluxes in the East China Sea); *SEEP* (Shelf Edge Exchange Processes); *UNEP-NOWPAP* (The United Nations Environment Program - Northern Western Pacific Area Protection); *VERTEX* (Vertical Transport and Exchange)

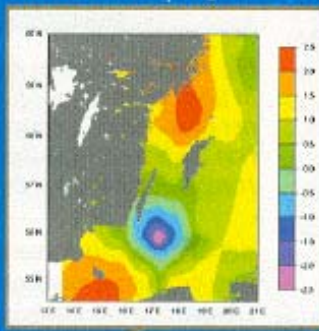
CoOP, OMP, SEEP I & II



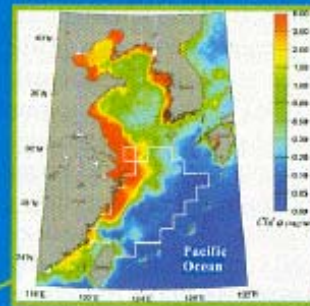
OMEX I & II



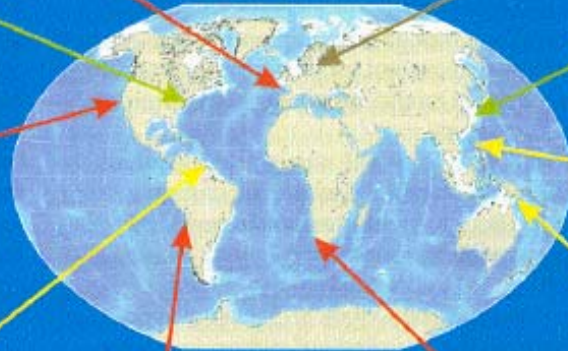
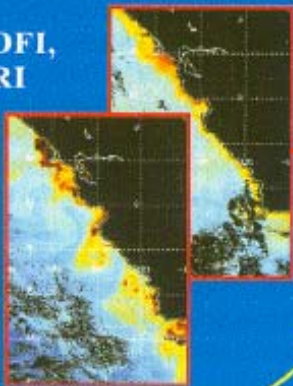
Baltic Sea CO₂ Uptake Flux



KEEP, LORECS, MASFLEX, MFLECS

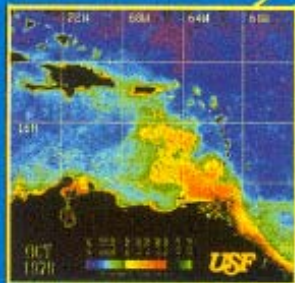


CalCOFI, MBARI Time-series

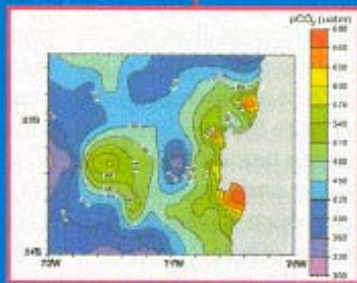


Biogeochemical Budgeting Project

Liu et al., 2000 EOS



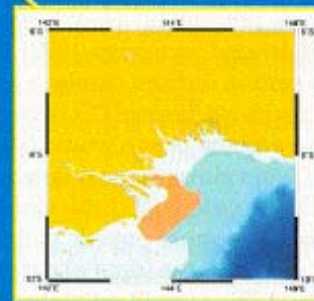
CARIACO Project



FONDAP Humboldt Program



Benguela Ecosystem Project



Sediment Transport in Tropics

Fig. 1. Examples of continental margin biogeochemical studies in recent years. The margins are classified into five types: Western boundary current systems (indicated by arrows in green), eastern boundary current systems (red), marginal seas (brown), tropical coasts (yellow), and polar margins. For each area, the type of image is explained. Clockwise, starting from upper left-hand corner: 1. Mid-Atlantic Bight: CZCS pigment image; 2. Bay of Biscay & Iberian Coast: bathymetry; 3. Baltic Sea: distribution of CO₂ uptake [Thomas and Schneider, 1999]; 4. East China Sea: chlorophyll distribution in summer with CZCS image as the background; 5. Lingayen Gulf, Philippines: a study site (courtesy of LOICZ Newsletter); 6. Gulf of Papua: bathymetry with mud patch of the Fly Delta [Harris et al., 1993]; 7. West coast of South Africa: SeaWiFS image; 8. Chilean coast at 23°S: PCO₂ map for July 1997 [N. Lefevre et al., pers. comm., 2000]; 9. Cariaco Basin area: CZCS image; 10. California current system: SeaWiFS images during strong and weak upwelling conditions.

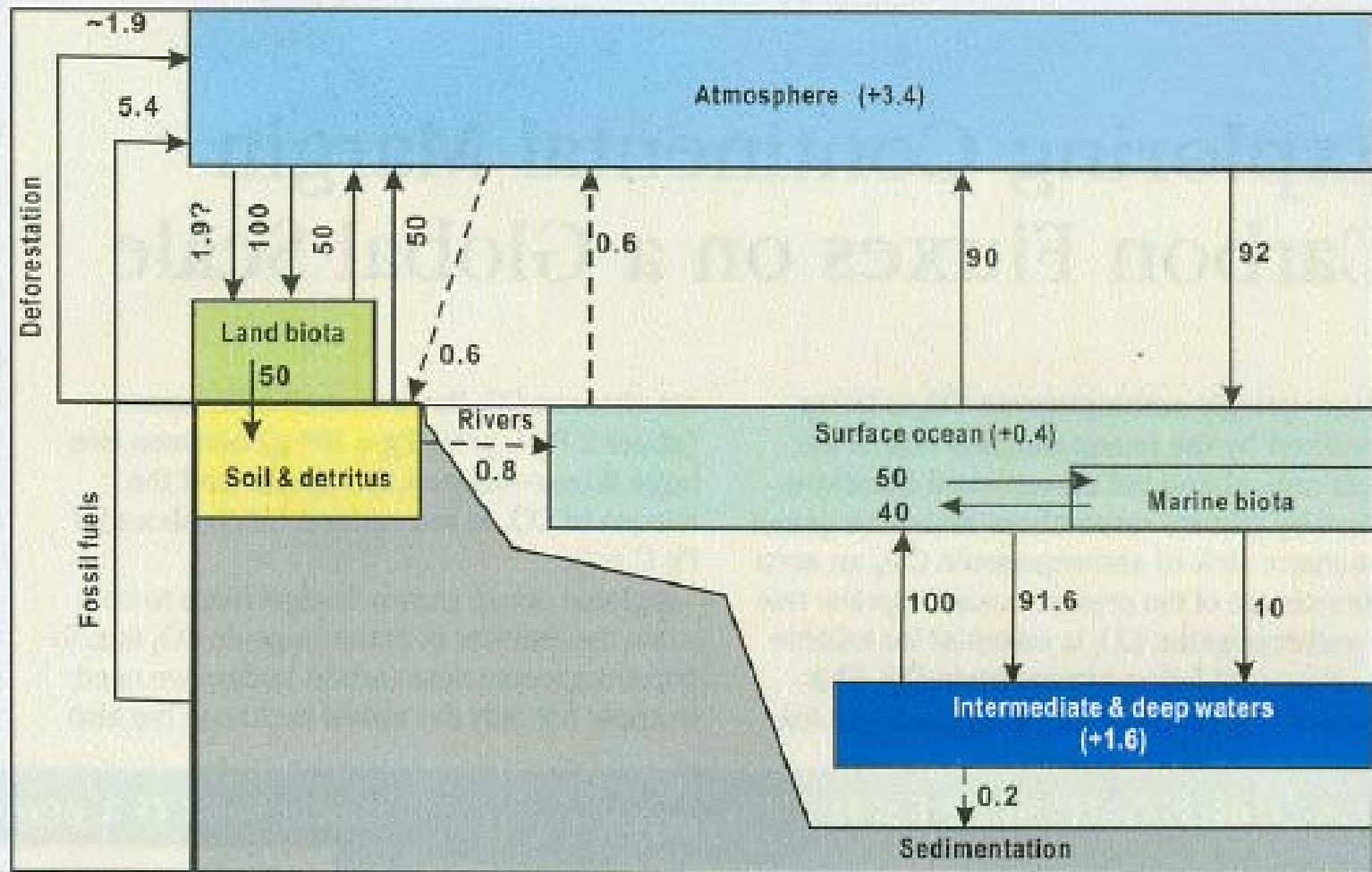


Fig. 2. Global carbon cycle 1980–1989 [Siegenthaler and Sarmiento, 1993]. The carbon fluxes are in units of Pg C yr^{-1} ($10^{15} \text{ g C yr}^{-1}$). The oceanic uptake of anthropogenic CO_2 is 2 Pg C yr^{-1} , but the net air-to-sea CO_2 transfer is offset by 0.6 Pg C yr^{-1} , which represents outgassing of the riverine carbon (indicated by dashed arrows). However, if all of the remobilized riverine carbon is outgassed in continental margins, then there will be no offset for the CO_2 flux in the interior ocean.

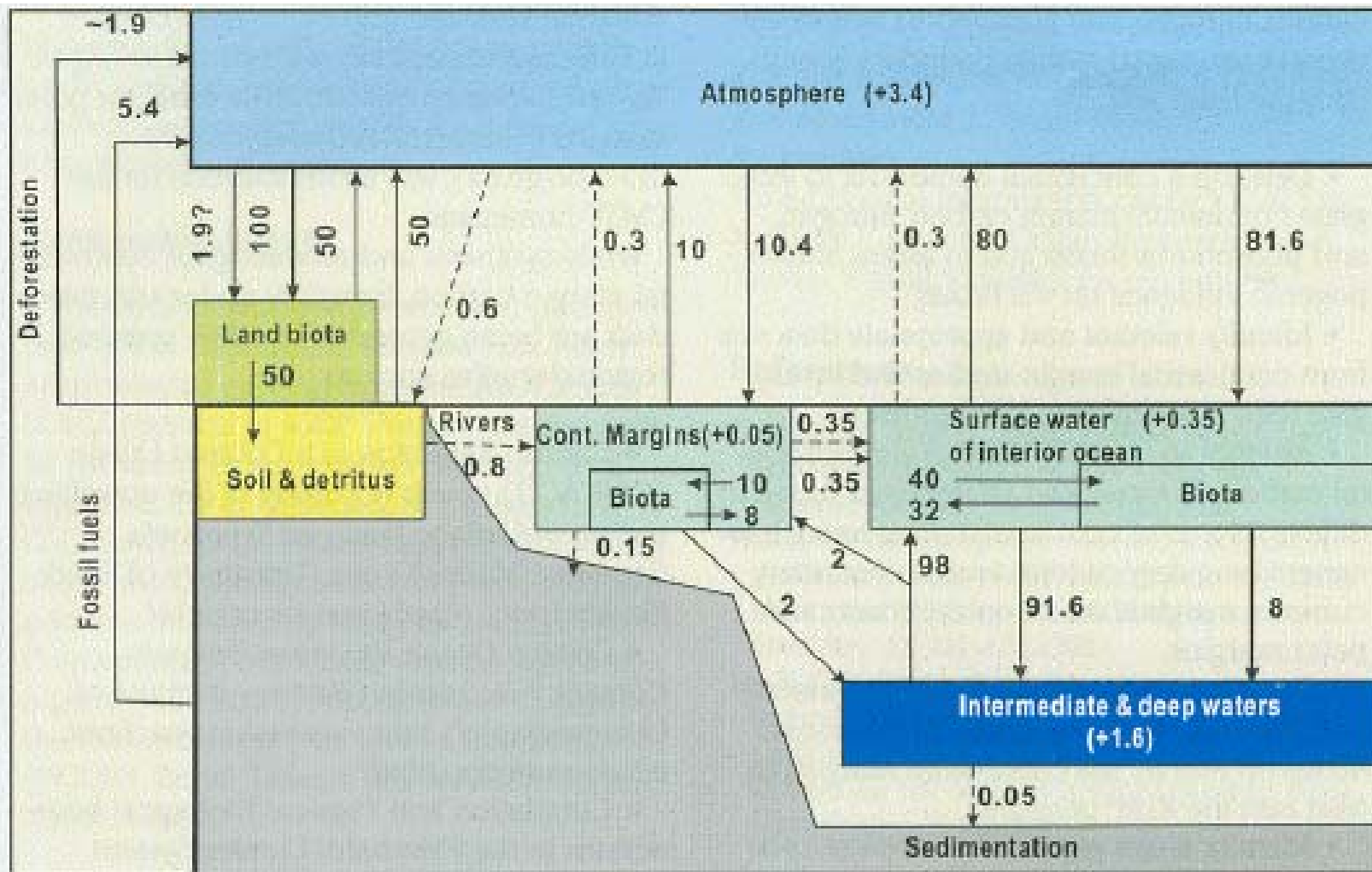



Fig. 3. A modified global carbon cycle with consideration of continental margin carbon fluxes. The net exchanges between the ocean and other reservoirs remain the same as those in Figure 2. It is assumed that continental margins are a net CO_2 sink (0.1 Pg C yr^{-1}), and the shelf export accounts for 20% of the oceanic biological pump, which is compensated by upwelling of dissolved inorganic carbon of the same strength, and about half of the total riverine carbon flux gets exported from the shelf. (See text for details.)

- 
- Each margin needs to be addressed to establish the contribution to the C, N and P budgets.
 - Although coastal upwelling stimulates primary productivity, the high partial pressure of CO₂ in the upwelled waters may (and often does) offset the CO₂ consumption resulting in a net release

Which factors have to be accounted for?

- Shelf width, depth, shape
- Long-shore vs cross-shelf scales: for large long-shore transport the retention of material on the shelf is favored
- River input: large rivers discharge beyond the shelf break, while small rivers on the shelf affecting the local buoyancy
- winds and orientation of the coast: upwelling / downwelling cycles, eddies...
- heat balance and fluxes: affect stratification
- retention time: whether is less or greater than 1 month impact the balance between 'recycling' or 'export'

River dominated recycling systems (JGOFS 1997)

- biologically mediated; tidal and geostrophic circulation; benthic bioturbation
- broad shelves (>50km); forcing and responses on seasonal time scales
- Long water exchange time (> 1 month)
- East China Sea, North Sea, Baltic Sea, Sea of Japan, South China Sea, NW Atlantic, Great Barrier Reef, Barents Sea, Sea of Okhotsk

Ocean dominated, export systems

- Physically forced: Ekman shelf-edge upwelling, boundary currents, can be forced by river input
- Narrow shelves (<50km)
- Episodic response to forcings
- Short water exchange time (<1month)
- Western Boundary currents of the Americas and Africa, Amazon, Mackenzie and Mississippi river systems


Results from 2000 synthesis (EOS paper)

- The continental margin as a whole are a weak CO₂ sink (0.1 PgCyr⁻¹)
- The storage of anthropogenic CO₂ in margins (~0.05PgCyr⁻¹) is proportional to their seawater volume
- Three quarters of carbon burial occurs in margins (0.15 PgCyr⁻¹)
- Half of the carbon that can be remobilized from the river run-off is released to the atmosphere from margins (0.3 PgCyr⁻¹)
- The export of shelf primary production accounts for 20% of the biological pump (2PgCyr⁻¹ from margins to deep waters), which is compensated by upwelling of dissolved inorganic carbon

One example: the Middle Atlantic Bight

Fennel et al., GBC 2006

- MAB shelf: from Nantucket Shoals in the north to Cape Hatteras in the south
- Cool and fresh water from the north (nordic and Labrador Sea), with entrainment of warm and salty Gulf Stream water in the south.
- No big rivers, but few small ones
- Along shelf mean circulation, with cross-shelf exchanges due to eddies and mesoscale structures

- 
- Nitrogen limited system. New N is supplied by river inputs, upwelling, wind-induced intrusions of slope water and warm-core ring
 - Chl concentrations are higher close to coast (mainly nanoplankton $< 20\mu\text{m}$ - and diatoms) and decrease seaward (nanoplankton)
 - Spring bloom and secondary fall bloom

Modeling set-up

- ROMS in domain of interest (a bit more extended) nested in a N Atlantic run (all 10 km)
- River input from USGS. No tides
- Biological model: complicated!

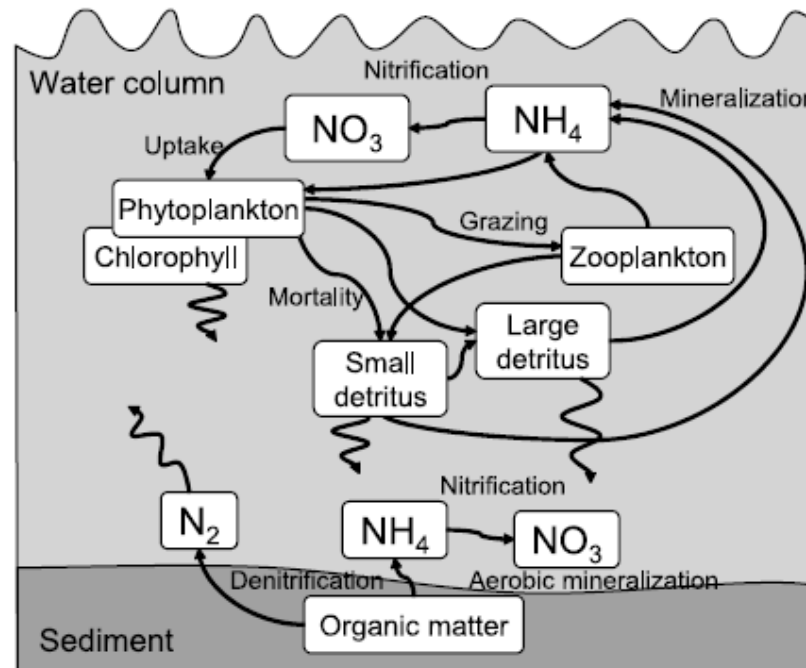
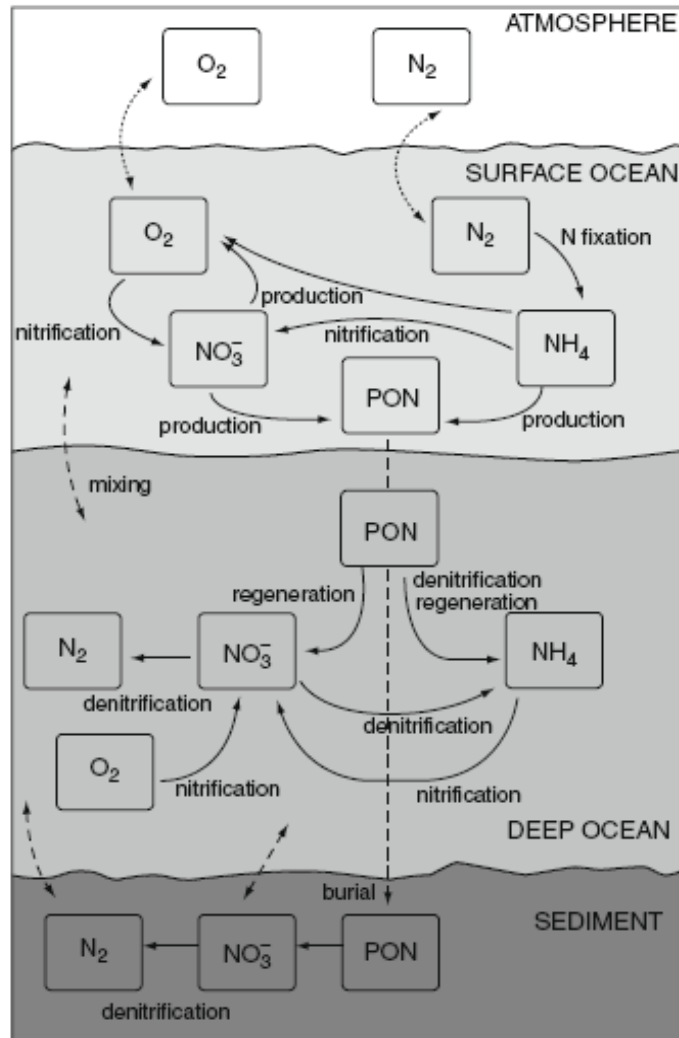


Figure 1. Biological model schematic.

Is this complicated enough?



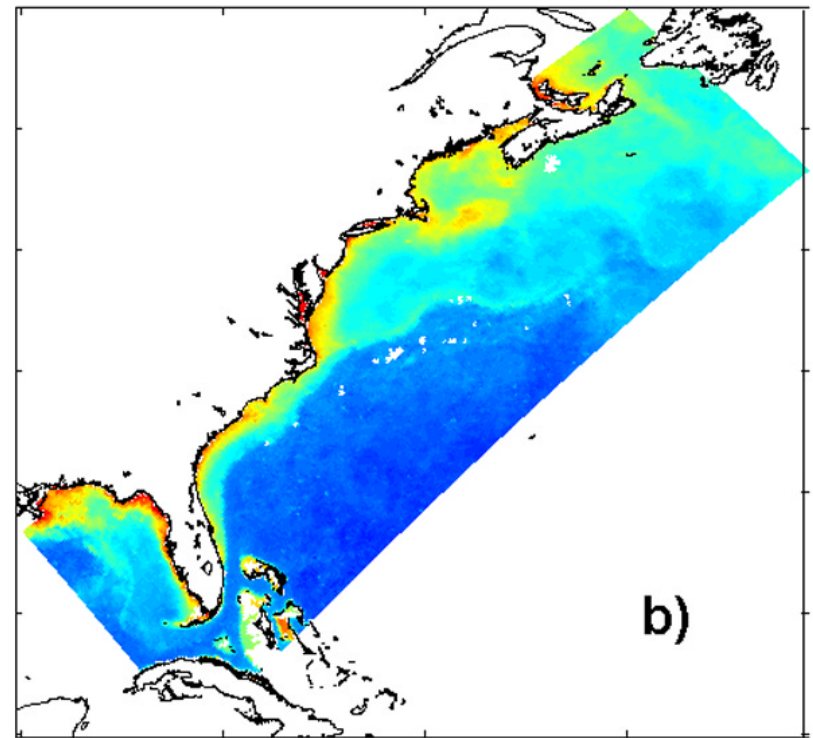
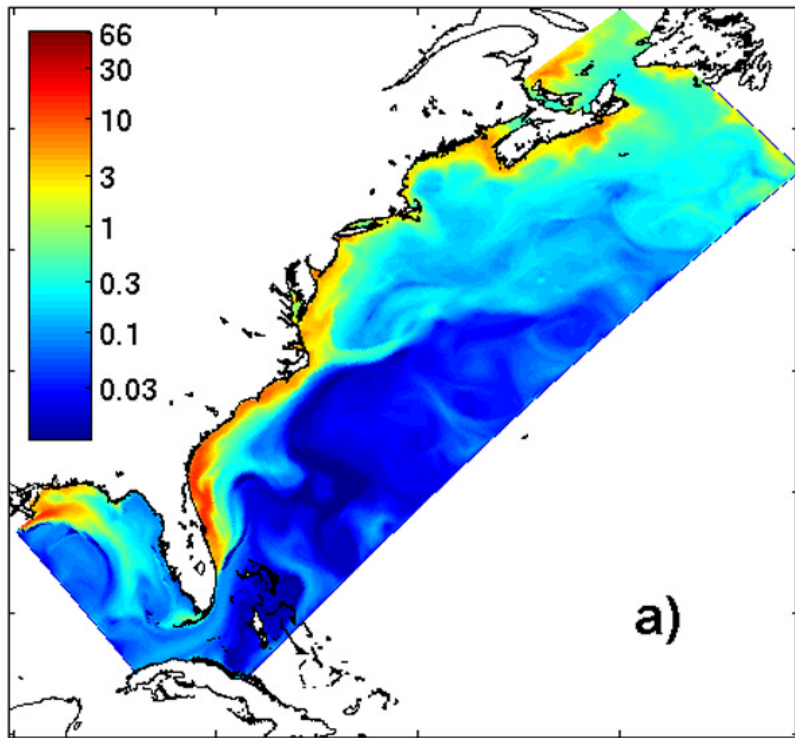
Schematic depiction of the coupled, global ocean nitrogen and oxygen cycles. Dissolved inorganic nitrogen and nitrogen fixation fuel oxygenic photosynthesis in the surface ocean, helping to sustain atmospheric and deep ocean oxygen levels. In the deep ocean, oxygen is consumed during microbial respiration of organic matter, producing dissolved inorganic nitrogen. However, in low oxygen waters and sediments, denitrification fuels the oxidation of organic matter, removing dissolved inorganic nitrogen from the water column.

Berman-Frank et al. 2008

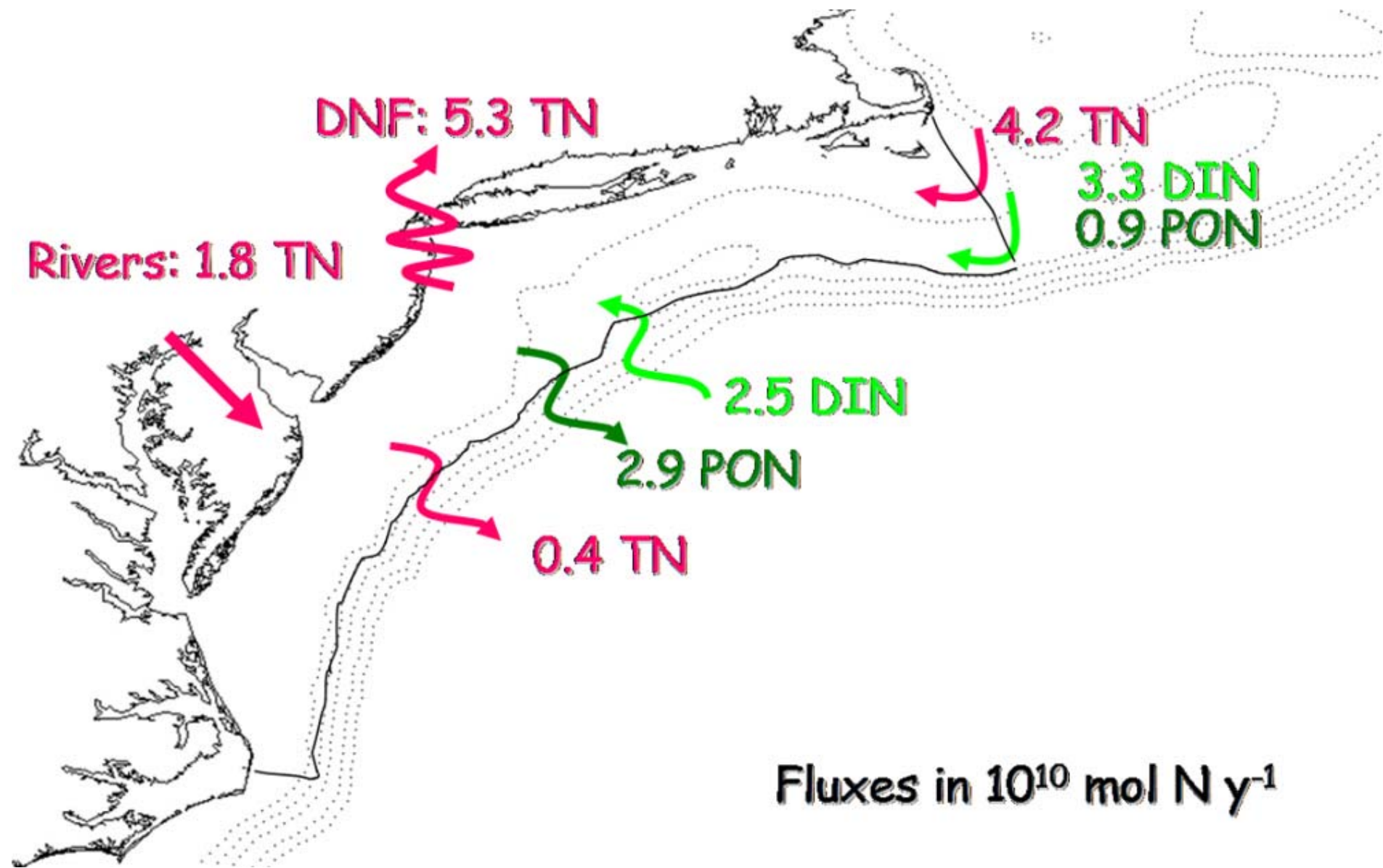
anyway... going back to the 'simpler' version:

- seven state variables: phytoplankton, zooplankton, nitrate (NO₃), ammonium (NH₄), small and large detritus, and phytoplankton chlorophyll, Chl (similar to Fasham as far as functional terms)
- The growth rate of phytoplankton, depends on the temperature T through the maximum growth rate $\mu_{max} = \mu_{max}(T) = \mu_0 \times 1.066^T$ [Eppley, 1972]
- and on the photosynthetically available radiation I
- Sediment processes: The nitrogen from with the organic matter reaching the bottom is returned rapidly to the overlying water in the form of ammonium. The rate of the process is unknown

- Sediment treated with an intermediate complexity model: a mass conserving formulation assumes immediate equilibrium between particle deposition and the return flux of dissolved constituents from the sediment
- Assumed the fraction of carbon oxidation that occurs through each mineralization route is fixed: linear relationship between sediment oxygen consumption and denitrification ($\text{NO}_3^- \rightarrow \text{NO}_2^- \rightarrow \text{NO} + \text{N}_2\text{O} \rightarrow \text{N}_2$)
- The integration is for 2 years (plus 1 yr spin-up)



(a) Model-simulated mean surface chlorophyll for July of 1994 and (b) SeaWiFS mean chlorophyll for July of 2003 (same colorscale).



Nitrogen budget