"The Ocean Carbon System: Recent Advances and Future Opportunities":
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ABSTRACTS

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Interpretation of satellite ocean colour data for phytoplankton functional types and photosynthetic parameters

We measured water leaving reflectance, phytoplankton pigments, photosynthetic parameters and optical properties in the southern Benguela ecosystem in October 2002. We observed: robust inter-pigment relationships; pigment ratios (Total Chlorophyll to Total Pigment, TChla/TP) were not constant but increased with increasing biomass, as did photosynthetic parameters (Photosynthetic Quantum Efficiency, PQE) and optical ratios (a676/a440). PQE, pigment ratios and optical proxies were significantly correlated. We observed distinct bio-optical properties (traits) for phytoplankton functional types (PFTs): picoplankton (prokaryotes) had very low biomass, TChla/TP fraction and photosynthetic rates (PQE); nano-flagellates, had low to intermediate biomass, pigment ratios and PQE; micro-plankton (diatoms and dinoflagellates) had high biomass, pigment ratios and PQE. We present SeaWiFS, MERIS (and MODIS) data analysed for PFTs and PQE.

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Continuous underway microbial enzyme activity measurements in seawater: The first step towards automated in situ measurements

The goal of this Biocomplexity (IDEA) Project is to develop an instrument for automated measurements of in situ microbial enzyme activities at ocean observatories. As a first step, we have automated shipboard underway enzyme activities using a flow injection system. Three cruises to the eutrophic Louisiana Shelf, supported by another project, provided an opportunity for automated measurements of alkaline phosphatase (AP) activity during March, May, and July of 2004. This system, which is capable of continuous automated sampling, ran concurrently with manual AP activity assays, conducted with a fluorescence microplate reader, during all three cruises. In July, both manual and automated systems systematically mapped Louisiana Shelf AP activity from Head-of-Passes (Mississippi River) to the mouth of the Atchafalaya River. Contour maps from both systems showed very similar features of high activity near the mouth of the Mississippi River, decreasing at higher salinities. The automated system consistently yielded somewhat higher AP activity than manual assays despite identical solutions and water samples, probably because of shorter incubation times and better mixing. Sampling rates of the automated instrument were approximately four times faster than the manual assays, resulting in higher density spatial coverage. Short incubation times, limited substrate usage, greatly reduced operator involvement, and potentially more accurate results are the advantages of this novel method for mapping microbial rate measurements at nearly the same frequency as temperature and salinity.

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A modified technique for the measurement of marine DOC concentrations and isotope ratios

Dissolved Organic Carbon (DOC) is the largest oceanic reservoir of organic carbon, yet its sources and sinks are not well understood. In an effort to help constrain the current understanding of this carbon pool's

biogeochemical cycling, a modified UV-oxidation/vacuum line technique has been developed to measure DOC concentrations and $\Delta^{14}C$ via AMS (accelerator mass spectrometry). The system's description and general performance are presented with preliminary measurements of seawater collected from the northeast Pacific (Station M, 34° 50'N, 123° W) during October, 2004.

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NAO-related interannual variability of macro-nutrients in the western North Atlantic Ocean

Climate variability related to the North Atlantic Oscillation (NAO) may regulate ocean circulation and the carbon cycle in the western North Atlantic. Thus, it is reasonable to examine the effects of the NAO on North Atlantic circulation and macro-nutrient distributions. World Ocean Atlas hydrographic and macro-nutrient data were binned into periods corresponding to largely positive (1950-1969) and negative (1970-1989) NAO winter indices. Objective analysis of each data set at 32 depths (0-5000 m) and 1-degree spatial resolution allows temporal differences in the hydrographic and macro-nutrient distributions related to the state of the NAO to be studied. Furthermore, use of objectively-analyzed hydrographic and macro-nutrient fields for both basin-wide and regional diagnostic numerical modeling will allow the role of NAO-related interannual shifts in the path of the Gulf Stream and slope water volume to be studied. A data analysis and regional modeling effort currently underway will seek to understand how ocean circulation, nutrients, and biological processes are related to ocean-atmosphere climate variability within shelf, slope, and Gulf Stream waters. Through use of this data analysis and modeling approach, we will examine interannual and interdecadal variability of new primary production (NPP) related to the NAO using potential new production as a proxy for NPP within western North Atlantic waters, including the Gulf of Maine located off the New England coast.

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On the relationship between primary, net community, and export production in subtropical gyres

It has been suggested that the relationships of net primary production (NPP), net community production (NCP), and particulate organic carbon export (Phi-POC) are governed by local environmental conditions that favor either a recycling loop typically dominated by pico- and nanophytoplankton or an export pathway typically dominated by larger phytoplankton. We analyze data from JGOFS stations in the subtropical gyres of the North Pacific (HOT) and the North Atlantic (BATS) in order to investigate the hypothesis that higher nutrient input causes intensified primary production favoring the export pathway via a selection of larger phytoplankton, resulting in higher export and a higher ratio between export and NPP (e-ratio). In the decadal long-term mean, the relationships between NPP, particle export and NCP, which we take here as a proxy for total export production, reveal export pathway characteristics at BATS, while HOT is dominated by the recycling loop, with the difference being consistent with the stronger seasonal forcing at BATS. However, these system characteristics are only valid for parts of the year. Especially at BATS the export pathway characteristic exists only in spring and reverts to a recycling loop system in summer and fall, consistent with our hypothesis given the strong summer-time stratification. On interannual time-scales we find little evidence for statistically significant alterations of the long-term mean characteristics, a finding we ascribe to a combination of limited magnitude of forcing, length of the data records, and possibly an inherent lack of predictability. A comparison of our results for the e-ratio and pe-ratio (Phi-POC/NPP) with those predicted by the models of Laws et al. [2000] and Dunne et al. [2004], respectively, show reasonable agreement for the long-term mean, but these models fail to capture the observed interannual variability in these ratios.

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Uptake of atmospheric carbon dioxide by ocean margins

Improved determinations of CO_2 uptake by the ocean, atmospheric and oceanic tracer models and terrestrial models all suggested that currently the terrestrial biosphere and the ocean are roughly two equally large sinks (1.9 Petagrams carbon per annual or Pg C a^{-1}) for anthropogenic CO_2 emitted into the atmosphere. However, none of the measurements or models has resolved the ocean margin from either the land or the open ocean. Recent CO_2 studies in a few continental shelves have indicated that shelves can potentially be either a large sink or a source for atmospheric CO_2. This previously unknown CO_2 sink/source term would substantially alter our current view of the global carbon budget for land and oceans. These fieldworks and synthesis scheme have focused on a few shelves in the northern temperate zone near populated areas, attention to other shelves including the low latitude shelves are necessary for a better understanding of their role in global carbon budget.

I have reassessed this issue by dividing the continental shelves into seven provinces. I first determined an average air-sea CO_2 flux for each shelf province based on a database of 46 publications and then calculated a total or net global shelf flux weighted to province areas. I show that the continental shelves are a sink for atmospheric CO_2 at mid-high latitudes (0.33 Pg C a^{-1}) and a source of CO_2 at low latitudes (-0.12 Pg C a^{-1}). While the net uptake (0.20 Pg C a^{-1}) is smaller than past estimates (0.4-1.0 Pg C a^{-1}), the contrast of uptake to release of CO_2 from high to low latitudes could alleviate the presumed terrestrial biosphere "missing CO_2 sink" significantly.

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Stocks, Distribution and Bioreactivity of DOM along a Meridional Transect in the North Atlantic Basin

The U.S. Repeat Hydrography program was instituted to sustain sampling of ocean transports and inventories of climatically significant parameters on decadal time scales. In 2003, DOM was included as a level one measurement for this set of cruises. Paucity of high spatial resolution DOM data has resulted in a limited understanding of the stocks and distributions and the processes that control these patterns throughout the World's oceans. Here we report a basin scale view of bulk DOC and carbohydrate distribution for a meridional transect (A20) in the North Atlantic. The data display high- resolution information on the export of DOC and transport and decay with the formation of North Atlantic Deep Water (section III). We also observe a larger but systematic variability in DOC concentrations within the interior of the North Atlantic than previously thought to exist (section III).

While the majority of DOM remains uncharacterized, the ratio of total hydrolysable carbohydrates (TCHO) or dissolved combined neutral sugars (DCNS) to bulk DOC can provide insight into the bioreactivity of DOC (Cowie and Hedges, 1994; Skoog and Benner, 1997). Here we present a high spatial resolution data set of TCHO, DCNS, concentrations and their relative concentration to bulk DOC in the surface layer of the A20 line (section IV). Highest rates of bacterial production were spatially offset from indices of bioreactivity indicating that the TCHO and DCNS pools were not supporting instantaneous bacterial production.

TCHO and DCNS analyzed from the same sample were spatially offset meridionally indicating differential production and/orr utilization of the hydrolysable TCHO & DCNS pools.

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A physical-biogeochemical model of the Gulf of Maine: Near-real time simulation of ecosystem dynamics

With recent advancing in ocean observations and improving in coastal circulation modeling, ecosystem dynamics and its response to change of physical conditions can be investigated by conducting near-real time physical-biological model simulations. A multiple nutrient and plankton ecosystem model has been implemented into a circulation nowcast/forecast system for the Gulf of Maine, which is an integral component of the Gulf of Maine Ocean Observing System (GoMOOS, gomoos.org). The nowcast/forecast system, which is based upon the Princeton Ocean Model (POM), has produced daily short-term forecasts of the circulation and hydrographic properties in the Gulf of Maine. The physical-biogeochemical model has been used to reproduce daily nutrients and chlorophyll fields for the period of January 2002 to June 2005. The model performance is evaluated with both the SeaWiFS and GoMOOS in situ chlorophyll observations at several key locations in the Gulf. The spring phytoplankton blooms for the past four years (2002 to 2005) have shown strong interannual variability from the SeaWiFS derived chlorophyll concentration, but the model tends to produce weaker year-to-year spring bloom. The potential factors that might cause such difference will be discussed.

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Carbonate related parameters of subsurface waters in the West Philippine, South China and Sulu Seas

Like most other deep basins in Southeast Asia, the deep Sulu Sea (SS) basin is isolated from the neighboring seas by surrounding topography. While the near-surface circulation is mainly governed by the seasonally reversing monsoon winds, below the warm and fresh surface layer, the core of the incoming Subtropical Lower Water from the West Philippine Sea (WPS), by way of the South China Sea (SCS), can be seen, at a depth of around 200 m, to have a distinct salinity maximum. It lies well above the sill depth (420 m) in the Mindoro Strait and thus, its spreading is not hampered by topography. The deep circulation is forced by an inflow of upper North Pacific Intermediate Water (NPIW) from the SCS through the Mindoro Str. Below 1000 m, the physico-chemical properties are remarkably homogeneous. The higher temperature, but lower salinity, oxygen and nutrients, of the deep SS waters, compared to those of the SCS, are indicative of the intrusion of NPIW above the sill depth. The excess, anthropogenic CO_2 penetrates the entire water column, because of the over-spill of the excess CO_2 - laden water from the SCS.

It has been reported that the bottom of the SS is $CaCO_3$ rich, relative to the SCS. Previous investigators attribute this to the higher θ in the SS. Indeed, the aragonite does not become undersaturated in the SS until below 1400 m, compared to 600 m in both the WPS and SCS; and the calcite does not become undersaturated until below 3800 m in the SS, compared to 2500 m in the SCS and around 1600 m in the WPS. However, the temperature effect is relatively small. These large differences are, in fact, largely a result of higher CO_3^{2-} oncentrations in the SS, relative to the WPS and SCS. The higher CO_3^{2} concentration in the SS, in turn, is mainly caused by the smaller amounts of organic carbon decomposition.

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BATS and ESTOC: A comparison between Western and Eastern parts of the Subtropical Atlantic Ocean

The two in situ time series stations BATS and ESTOC are located on either side of the Subtropical Atlantic Ocean and provide an opportunity to study differences that exist between the eastern and western boundaries of the Subtropical Gyre. Here we will show and compare the seasonal and interannual variability at both stations using a concomitant multi year data set. To obtain a clearer picture of both stations, we investigate mixed layer and main thermocline variabilities, as well as the relationship between the hydrographic characteristics of the water column and the distribution of nutrients, oxygen, and phytoplankton biomass. The ESTOC and BATS annual cycles are driven by seasonal changes in surface heat flux and wind stress. The winter mixed layer varies from 150 to 300 m at BATS while the maximum depth at ESTOC is around 200 m. The seasonality of wind stress is markedly different between BATS and ESTOC; while in the former the stress decreases during summer favoring mixed layer stratification, it increases at ESTOC because of the NE Trade winds. Some of these characteristics will be correlated with nutrient distributions to investigate differences in the supply of new nutrients at both sides.

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Methane and carbon dioxide fluxes on the continental margin: Process studies off the Oregon Coast

The long-range goal of our research is to help characterize the sources, transformations and fluxes of methane and carbon dioxide from the continental margins to the surface ocean and atmosphere through the shelf/slope environment. The Cascadia Accretionary Prism on the convergent margin off Oregon hosts numerous sources of methane to the coastal environment. Gas and cold seeps are associated with both the major submerged headland banks and the deeper complexes offshore. In particular, we are focused on the potential exchange of methane with the atmosphere through upwelling and vertical mixing along this well-known eastern boundary current system (EBC). Although the fluxes of methane from the deeper hydrate-bearing systems on this margin are dramatic, there is little evidence from existing surveys that a significant fraction of this methane is currently transported into the surface ocean locally. Equally significant inventories of thermogenic methane exist on the upper slope at density horizons that are regularly in contact with the atmosphere. The physical processes that transport methane from the thermocline to the surface ocean in the EBC also serve as a conduit for carbon dioxide moving into or out of the coastal ocean.

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Robust estimates of preindustrial air-sea carbon dioxide flux and ocean carbon transport

Accurate estimates of pre-industrial air-sea carbon fluxes and ocean transports are crucial to understanding the processes driving oceanic carbon uptake and interpreting observed atmospheric gradients of CO_2. We use inverse methods to estimate preindustrial air-sea carbon fluxes from ocean interior observations of inorganic carbon properties and information about large-scale ocean circulation from an Ocean General Circulation Model (OGCM). Previous sensitivity studies have shown that errors in model circulation and uncertainties in the determination of that component of the observed DIC that is due to pre-industrial gas exchange, ΔC_{gasex}, may cause substantial biases in the ocean inversion. In order to address these issues, we present estimates of preindustrial air-sea carbon dioxide exchange using a suite of nine different OGCM's and explore the effect of likely biases in the derived ΔC_{gasex} tracer on the inverse estimates.

We find a pattern of substantial pre-industrial out gassing in the Southern Ocean between 44 S and 58 S, vigorous uptake at mid-latitudes, and out gassing in the tropics. In contrast, forward simulations using the same models generally find a slight uptake in the Southern Ocean between 44S and 58S and considerably less uptake at southern mid-latitudes. This pattern in the inverse estimates is robust with respect to model transport, and is driven by spatial gradients in the observations. These fluxes imply that preindustrial carbon is transported equator-ward from southern high-latitudes and pole-ward from southern mid-latitudes, with convergence and out gassing between 44S and 58S. In the northern hemisphere, the inverse fluxes imply that pre-industrial carbon taken up at high- and mid- latitudes is transported equator-wards. Much of this pre-industrial carbon is returned to the atmosphere in the tropics, leading to a modest southward cross-equatorial transport. This does not support the hypothesis of strong pre-industrial transport of carbon from the northern hemisphere to the southern hemisphere, which has been proposed to explain the northern hemisphere carbon sink.

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The Regional Ecosystem Modeling Testbed Project

As an integral part of recent large-scale observational programs such as JGOFS (Joint Global Ocean Flux Study) and GLOBEC (Global Ocean Ecosystems Dynamics), models have been developed to simulate biogeochemical cycling in specific oceanographic regions; however, few quantitative comparisons of these models across regions have been made. As part of the Regional Ecosystem Modeling 'Testbed' Project, we are conducting intercomparisons to critically examine which ecosystem structures and formulations are best able to simulate observed data across regions, and to explore the reasons for their success. To facilitate these intercomparisons, we are developing a set of regional testbeds that contain one-dimensional physical forcing fields and biogeochemical data that can be used for assimilation or model validation. By running different ecosystem models using identical physical forcing fields, and by implementing the variational adjoint method to assimilate the same biogeochemical data, we can objectively compare different ecosystem models and modeling approaches.

Work to date has focused on two regions: the equatorial Pacific (140W) and the Arabian Sea (15.5N, 61.5E); plans for other regions including the Southern Ocean, BATS, HOT, and IronEx II are currently underway. Results presented will include those obtained from the optimization of models for individual sites, as well as the simultaneous assimilation of data from multiple sites. Participating models vary from the simplest four component (NPZD) models, to complex, multi-nutrient, multi-size class models. Initial results indicate that simple NPZD models can fit data well at individual sites, but are less likely to be able to simultaneously fit data at multiple sites. Multiple size class models with iron explicitly included as a state variable are best able to simultaneously fit data from the equatorial Pacific and the Arabian Sea.

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Modeling carbon and silicon cycling in the equatorial Pacific

The equatorial Pacific is a region of significant calcite and biogenic silica sedimentation, the majority of which is carried out by coccolithophorids and diatoms. To examine the effect of coccolithophorids and diatoms on carbon and silicon cycling, we developed a biogeochemical model for the equatorial Pacific that explicitly represents three phytoplankton groups (dinoflagellates, coccolithophorids and diatoms) along with multiple nutrients and zooplankton function groups. Sensitivity studies of the model in response to source (120m depth) silicic acid concentrations show an increase of downward flux of POC, calcite and biogenic silica with an increase of silicic acid concentrations at 120m, and a maximum rain ratio at intermediate concentrations of source silicic acid. The increase in the downward calcite flux is due to reduced grazing pressure on coccolithophorids by mesozooplankton resulting from switching grazing pressure on diatoms by mesozooplankton. Both surface TCO_2 and alkalinity decrease with source silicic acid concentrations. The two compensating effects result in a maximum CO_2 flux to the atmosphere at intermediate concentrations of silicic acid at 120m. This study suggests that the passage of an instability wave that elevates a concentration of silicic acid at 120m significantly affects carbon cycling as well as silicon and nitrogen cycling.

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The Coastal Carbon Cycle Challenge

The coastal oceans and continental margins are among the most productive and biogeochemically active marine environments, with about half of the global integrated primary production and the bulk of the sedimentary carbon sequestration. Relative to open-ocean cycling however, comparatively little is known about the overall role of the coastal/margin system in the global carbon cycle, its natural variability, or its potential responses and feedbacks to global climate change. This more limited understanding of the carbon cycle in coastal/margin environments is in large part due to their being characterized by much more vigorous interactions of physical, chemical, and biological processes, leading to intense variability on all scales.

I discuss three discrete challenges that we encountered over the last few years while making a combined modeling-data gathering attempt at gaining insight into the carbon cycle along the California Coast: i) The role of meso- and submesoscale variability in shaping the magnitude and spatial distribution of new production, export production, and air-sea CO_2 fluxes, ii) the importance of the diurnal cycle (tides and sea breeze), and iii) the unexpected drawdown of DIC in late summer and fall in Santa Monica Bay, when no macronutrients are present. I will discuss the nature of these challenges and present some ideas how these can be addressed. It is too early to have final results, but it makes for a very interesting journey!

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Seasonal patterns of *Trichodesmium* primary production at the Bermuda Atlantic Time-series Study (BATS) site

Primary production by the diazotrophic cyanobacteria *Trichodesmium* was investigated seasonally over a two-year period at the BATS site using ^{14}C-bicarbonate. Colonies of *Trichodesmium* puffs and tufts were collected at monthly intervals in 1995 and 1996 and placed in a deck-board incubator with *in situ* sea surface temperature and light conditions. In contrast to N_2 fixation and N-doubling times, primary production and the corresponding C-doubling times showed a strong seasonal pattern.

Due to spatial scaling, the significance of primary production by *Trichodesmium* may have eluded the standard method of primary production performed in the BATS program. By accounting for the temporal and spatial abundance distribution of *Trichodesmium* colonies and trichomes, and a PI-curve developed locally, we were able to estimate the amount of C incorporated by the diazotrophs. Seasonal depth integrated estimates of *Trichodesmium* primary production are significant in surface waters in summer and the incorporation of C by the cyanobacteria is in the same order of magnitude as the observed draw-down of DIC at the BATS site.

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Interannual variability in Atmospheric Potential Oxygen from the Scripps atmospheric oxygen flask sampling network

Although land biota have a greater influence over atmospheric O_2 and CO_2 changes, the effects of air-sea fluxes can be discerned with the tracer Atmospheric Potential Oxygen (APO), approximately the sum of atmospheric O_2 and CO_2. Contributions from the land cancel each other out in APO, but the oceanic variability is preserved, because air-sea O_2 and CO_2 fluxes generally do not oppose each other in a ratio near one. We present measurements of APO since 1995 from nine locations around the globe in the Scripps Institution of Oceanography global flask sampling network. After removal of the anthropogenic trend and local seasonal cycles, a principal component analysis demonstrates that the dominant mode of variability is an interannual cycle coherent over the northern extra-tropics. In these northern hemisphere stations, APO exhibits a steady increase through mid-1999 followed by an abrupt two year decrease and then smaller variations. This maximum appears to correlate with anomalies in North Pacific sea surface temperature and wind speeds for the same time period. We explore the possible mechanisms driving the observed variability in APO, which may be caused by persistent large-scale changes in gyre circulation and ventilation, sea surface temperature, biological production and/or wind-driven gas exchange.

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Vanished without a trace: sedimentation pulses in the deep sea, can we determine their origin?

After decades of sediment trap deployment there is still a debate on what they really catch and where this matter originates from. There is a high probability that everything what is found in a sediment trap came from above (even though not even this is absolutely certain) every other aspect of the particle transport is subject to various influences which preclude a direct predictability of the particle pathway.

Horizontal advection and vertical pumping add to gravitational sinking. Additionally, aggregation, uptake of ballast material and transformation into fecal pellets changes the sinking velocity of particulate matter up to three orders of magnitude. Nevertheless, to connect deep sea fluxes to sea surface biological processes it is substantial to know about the source region for the material caught in the deep. The attempt to link surface to deep sea flux is made traditionally by correlating about nine area averages of satellite sea surface data around the trap location with sediment trap time-series. We pursued this approach but enhanced the spatial resolution, and hence the number of areas, to several thousands. The higher resolution not only improves the statistical link of surface and deep sea but also opens a window to a better mechanistical understanding of sedimentation processes. After a first testing of this approach off the Northwest African coast at Cape Blanc, the two North Atlantic sediment trap time-series stations BATS (western North Atlantic) and ESTOC (eastern North Atlantic) are selected for further verification.

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Light and iron limitation in the Southern Ocean

Despite the completion of ten iron enrichment experiments of various sizes and durations, the degree to which iron addition will draw down nutrients and export carbon below the mixed layer is poorly understood. This question will likely be difficult to fully resolve in the field due to the exponential expansion and dilution of an iron-enriched patch. For example, in the Southern Ocean Iron Experiments (SOFeX) of 2002, the two iron enriched patches increased in area by an order of magnitude in twenty days. Such a ten-fold dilution increases the macronutrients available to the patch while decreasing the concentration of iron and biomass within the patch and is not reflective of the potential drawdown and bloom of a basin scale Southern Ocean iron enrichment. With a combination of in situ iron-enrichment measurements and climatological data we model an iron-replete Southern Ocean in an attempt to answer these questions: Is it possible to draw down the vast supplies of nutrients in the various physical zones of the Southern Ocean? To what extent is an iron-replete Southern Ocean light limited?

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Ocean interior data suggest that there is no fertilization sink

We have constructed a joint inverse estimate of surface carbon fluxes incorporating constraints from both the atmosphere and the ocean interior. The air-sea fluxes derived from the ocean component of this inversion are significantly different in the Southern Hemisphere from fluxes derived from other methods, notably both delta pCO2-based analyses and forward simulations. These differences can be attributed to preindustrial air-sea fluxes and are demonstrably insensitive to identified uncertainties in the estimation of anthropogenic carbon concentrations. The boundary condition imposed by these new air-sea flux estimates on the atmospheric inversion problem drives a repartitioning of tropical and southern land (TSL) flux estimates. In contrast to previous atmospheric inversions, we find that the TSL regions are a large source of carbon to the atmosphere. This source is of a magnitude comparable to estimates of the tropical carbon flux due to land use change alone estimated from field studies, process models, and satellite observations. It is therefore unnecessary to invoke a large CO2 fertilization sink in the tropics to close the global carbon budget.

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Physical controls on the seasonal cycle of surface pCO_2 in the equatorial Pacific

The controlling mechanism of the seasonal cycle of surface partial pressure of CO_2 (pCO_2) in the eastern equatorial Pacific is studied using a coupled physical biogeochemical model. The results indicate that the physical transport of CO_2 controls the seasonal cycle of surface total CO_2 (TCO_2), and as a consequence, the seasonal cycle of SST controls the surface pCO_2 cycle. The biological drawdown and air-sea CO_2 flux combined balance the net transport, which is an order smaller than each individual component of transport. The implication of these results is that dynamical processes in other timescales, such as El Niño, La Niña and tropical instability waves, in the equatorial Pacific could induce significant imbalances between physical transport, biological drawdown and air-sea exchange and thus change the dominance of SST on the surface pCO_2 variability.

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The biogeochemical effects of a patch iron fertilization-results from an eddy-permitting model

Ocean iron fertilization has been considered as a means to enhance the net oceanic uptake of CO_2 from the atmosphere to slow down the buildup of atmospheric CO_2. Field experiments in which high iron concentrations are maintained in a relatively small patch of surface water have resulted in increases in biomass and drawdown of surface nutrients and CO_2. Yet little is known about the increase in export and the net effect of the air-sea CO_2 flux. The sizes of these in situ experiments were small, typically 10 by 10 km, and they usually lasted only a few weeks. How can insights from these studies provide guidance for large-scale experiments? For example, in order for iron fertilization to have any substantial impact on atmospheric CO_2 they would need to be scaled up by a factor of at least 1000. Most models of fertilization experiments have been done at coarse resolution, creating a gap between in situ and global scale model studies. To bridge this gap, we use a Pacific Ocean setup of ROMS (the Regional Oceanic Modeling System) at an eddy-permitting resolution of 0.5 degrees. By coupling an ecosystem model to this circulation model and performing experiments in scale ranging from the same patch size of the in situ experiments to the several 100 km size of the coarse resolution model, we can establish a connection between these model studies and the many insights emerging from the very small-scale patch fertilization studies. The biogeochemical model features three phytoplankton functional groups and multiple nutrient limitation (N, P, Si, Fe). We will present preliminary results of the biogeochemical effects of a patch iron fertilization experiment simulated with our ROMS model.

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The use of in-situ light transmissometers in studies of POC dynamics

In recent years, several studies have demonstrated that optical properties such as beam attenuation (as derived from light transmissometer measurements) can be used as bulk descriptors of suspended particles and particulate organic carbon (POC) in the open ocean. The use of in situ optical profilers can therefore dramatically enhance the spatial and temporal resolution at which biogeochemical fields can be measured. Single wavelength optical measurements, however, respond to the bulk of the particulate material and the relationship between beam attenuation or scattering and particle concentrations can vary from one environment to another, depending on the size, composition and surface properties of the particles. Here we (1) demonstrate the applicability of beam attenuation measurements to studies of POC dynamics in coastal waters and (2) compare and discuss relationships between beam attenuation and POC in various environments.

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CDIAC/ORNL

The new CDIAC Web-Accessible Visualization and Extraction System (WAVES) for oceanographic data

WAVES is an Internet-based, data delivery mechanism that automates the process of delivering oceanographic data to the Carbon Dioxide Information Analysis Center (CDIAC) user community. The Web-Accessible Visualization System (WAVES) provides a system whereby users can view a graphical summary of data collection points (cruise paths), and via provided metadata viewing tools and graphing options, identify and download data sets of interest.

WAVES automates the distribution of oceanographic data via the Internet by satisfying the following objectives:

a) The web interface consists of a search function allowing the user to perform a sub-setting search by any combination of the following:

i. data type(underway or discrete)

ii. measurement location(s)

iii. measurements date(s)

iv. measurement depth(s)

v. experiment, section, cruise name

vi. cruise leg

vii. expedition code

viii. measurement method(s)

ix. PI name

x. measurement parameter(s)

b) Provides users with a graphic depicting the world's oceans and all cruise paths.

c) Provides users with the ability to zoom on particular geographic extents containing selected data, cruises, or geographic areas of interest.

d) Provides users with a dynamic on-screen display of summary metadata elements

associated with each sampling location along the zoomed geographic extent. The on-screen display will automatically be updated as the user moves their mouse over different points on the cruise path graphic. Summary metadata elements for underway measurements and discrete measurements are a subset of the full metadata.

e) Provides users with links from the full metadata to the data set containing the selected data point of interest.

f) Provides users with a seamless, on-the-fly method for creating scatter plots, single station plots for property versus depth, and property versus property plots. In addition, the graph contents are available to save to an image file in .jpg, .gif, and .ps formats for use in other applications.

h) Provides users with the ability to download the current data and metadata selection as ASCII, CSV, and NetCDF formatted files.

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Seasonal carbon cycling in Santa Monica Bay, Southern California

The ocean margins form the transition zone between terrestrial and open ocean areas and represent up to 30% of total ocean productivity, yet their role in the global carbon cycle is ill quantified. In order to address this issue, a bi-weekly time-series program was established in Santa Monica Bay in January 2003 to measure the seasonal evolution of the upper ocean carbon cycle at this coastal site. Our measurements reveal a strong seasonal cycle with an amplitude in salinity normalized dissolved inorganic carbon (DIC) reaching nearly 200 µmol/kg and $p\mathrm{CO_2}$ changes of more than 200 µatm. The seasonal cycle of DIC is characterized by a maximum in late winter/early spring, which is caused by upwelling bringing high DIC concentrations from the upper thermocline during this time of the year. The concomitant supply of high levels of nutrients fuels an intense bloom, whose strength varies from year to year in response to large interannual variations in upwelling. In 2003 and 2004, substantial surface DIC decreases were observed under nitrate depleted conditions i) right after the occurrence of upwelling, and i) about three months after upwelling. This implies that during these times, either organic matter production occurred with a very high stoichiometric C:N ratio and/or an additional source of new nitrogen existed that supplied nitrogen without supplying DIC. The seasonal cycle of $p\mathrm{CO_2}$ follows that of DIC with a late winter/early spring maximum, whose levels far exceed that of the atmosphere, and a summer-time minimum with undersaturated $p\mathrm{CO_2}$ values. Annually, Santa Monica Bay acts as a weak to moderate sink for atmospheric CO_2. We suggest that this is mainly due to biological production and in part driven by the uptake of anthropogenic CO_2.

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Particulate matter origin, distribution, and fate in the Cariaco Basin, Venezuela

To accurately interpret the paleoclimate record stored in the sediments of the Cariaco Basin, it is necessary to understand sources of the particulate material that settles there. The CARIACO time series program has occupied an oceanographic station at 10.5N, 64.40W at least once a month since October 1995, and maintains sediment trap and current meter moorings at this location. Regional cruises to assess spatial distribution were conducted in 2003 and 2004.

The Cariaco Basin has an intensive upwelling season, with integrated primary production ranging from ~1.5 to ~2.10 gC m^{-3} d^{-1} during the first half of the year. Viewed as a purely vertical system, the Cariaco upwelling system is a source of CO_2. Surface $f\mathrm{CO_2}$ values fluctuate, on average, between 360 and 420 µatm., being most variable during the upwelling season. During the nine-year time series, only two months, March 1997 and March 1998, showed a negative flux of CO_2 from the atmosphere to the water (-10 mmol C $m^{-2}d^{-1}$, and -40 mmol C $m^{-2}d^{-1}$, respectively). Particulate organic carbon (POC) is high in surface (0-15m) waters during upwelling (400-500 mg/m^3) and the increased organic matter flux can be observed in CARIACO sediment traps deployed at 125, 275, 475, 900, and 1225 m. However, POC concentrations are very variable through the water column and with time (~45 - ~450 mg/m^3 at surface (1-15m); ~25 - ~70 mg/m^3 at depth (200-400m)). The flux of POC into the sediment traps does not always covary with the POC suspended in the water column. Very little is known about lateral processes in the basin and one hypothesis is that particulate matter could be advected to the trap location. There are other

sources of carbon to the basin, such as the oxic-anoxic interface, which supports a variety of microorganisms. The oxic-anoxic interface seems to be a region of accumulation of POC, as observed with beam attenuation (c660) and discrete POC measurements (~55 mg/m^3 compared to ~35 mg/m^3 below and above the interface). Some of the recorded increases in total organic carbon in the 275m sediment trap correspond to shifts in the interface upwards. While the interface is frequently at ~250 m, it has been observed to rise to ~200m and deepen to >300m. This may be due to processes such as upwelling and water mass intrusions.

Other sources of particles to the basin are local rivers. During the second half of the year, upwelling decreases, along with POC concentration, and rainfall increases. During this time local rivers deliver terrestrial material to the basin, and this is carried into the basin via bottom nepheloid layers (BNL). This terrigenous flux is recorded in the sediment traps. In November-December 1999-2000 torrential rains affected the eastern coast of Venezuela, increasing river flow and terrigenous sediment transport (4.52 g/m^2/day, November 1999) to the basin above normal levels (0.55 g/m^2/day) for this time of the year. The result was the highest terrigenous sediment contribution to the basin seen so far through the project.

The CARIACO time-series program has therefore identified two main sources of particulate matter to the basin: primary production as a result of upwelling and local riverine input. The oxic-anoxic interface, acting as a region of POC accumulation, may be the cause for the lack of covariance between the values of POC observed in the sediment traps and the ones found in the water column.

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The seasonal cycles of pCO_2 and CO_2 fluxes in the North Atlantic north of 40°N

Surface seawater pCO_2 and related parameters were measured at high frequency in the North Atlantic ocean between 36 and 52°N onboard the volunteer observing ship MS Falstaff. Over 90,000 datapoints are used to produce the seasonal cycles of seawater pCO_2 and CO_2 fluxes for 2002/2003. The surface ocean carbon cycle is largely controlled by three factors: thermodynamics, biology and air-sea gas exchange. The first two factors have an opposing effect on pCO_2 whereas the gas exchange has a smaller influence on pCO_2 levels. Generally, the CO_2 flux shows a seasonal cycle with close to zero fluxes or outgassing in the summer and CO_2 fluxes into the ocean during fall and winter in this region. The CO_2 air-sea fluxes are compared using two averaging schemes In the first, the fluxes are calculated for each location from the measured ΔpCO_2 and gas transfer velocity determined from a relationship with windspeed determined at the location of the ship. In the second method the ΔpCO_2 is averaged over each 4˚ by 5˚ pixel and multiplied by an averaged gas transfer velocity for this pixel. The fluxes determined by the first method are 47 % lower than the averaged fluxes and this bias is mainly caused by the variability in wind speed. The Falstaff fluxes are compared to the climatology by Takahashi et al. (2002) and the difference is between 2 and 5 % depending on the time-correction scheme. Furthermore we use two wind speed sources to analyze the effect on the CO_2 flux: co-located satellite data (QuikSCAT) and 6-hourly reanalysis data (NCEP/NCAR). The annual CO_2 sink is 22 % lower when using 6-hourly NCEP/NCAR wind speeds compared to the QuikSCAT wind speed data.

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The importance of continental margins in the global carbon cycle

The main objectives of this project are to a) estimate the flux of POC settling to the bottom and to the permanent thermocline along continental margins as compared to the global deep ocean, and b) assess how much of this carbon may be buried in the sediment. As an initial framework, we use four years of remote sensing data (1998-2001) as input into the VGPM (Behrenfeld and Falkowski, 1997) to calculate primary productivity. Our global primary productivity estimate is ~ 48 Pg C y^{-1}, with 10-15% of this production attributed to the margins (bottom <2000 m). From this estimate we calculate flux to the bottom of the ocean and to the thermocline using the Pace et al. (1987) model for the margin and the deep ocean. It was found that approximately 0.68 Pg C y^{-1} sink below the thermocline on the margins as compared to 1.01 Pg C y^{-1} in the deep ocean. Additionally, over 0.62 Pg C y^{-1} settles to the sea floor on the margins and only 0.31 Pg C y^{-1} settles to the deep ocean sediments. The amount of Carbon buried was calculated based on flux assuming 30% burial in the deep ocean and 10% on the margins. Results are now being compared with global sediment type maps, global sediment organic carbon content maps, and with maps of various other oceanographic variables. Results indicate that the continental margins do contribute greatly to global carbon flux (> 40% of carbon sequestered in the ocean based on our burial estimates). Therefore we need to develop strategies to include margins in global carbon cycle models.

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Modeling the diversity of nitrogen – fixing organisms in the North Central Pacific Gyre

In the ocean, most of the fixed N required by primary production comes from two sources, nitrate from deep water and N_2-fixation by bacteria. Organic-N produced by N_2-fixing bacteria has a $\delta^{15}N$ of 0 to -1‰. Nitrate has a mean $\delta^{15}N$ value of 5‰ in the deep ocean. Therefore, the value of exported $\delta^{15}N$ from surface can be used as an indicator of N_2-fixation rate. The Hawaii Ocean Time-series (HOT) program measured $\delta^{15}N$ in sediment traps, as well as vertical profiles of suspended particulate $\delta^{15}N$ every month from March 2000. The N_2-fixation rate was estimated as 53 mmol m^{-2} $year^{-1}$ by sediment trap $\delta^{15}N$. The seasonal variation of sediment trap $\delta^{15}N$ was generally consistent with the hypothesized controlling factors on N_2-fixation, particularly the aerosol optical thickness deduced from MODIS satellite, which is the potential indicator of iron deposition from the atmosphere.

The suspended particulate $\delta^{15}N$ profiles showed extremely low $\delta^{15}N$ in the surface that might reflect the N_2-fixation. However, there is a competing alternative explanation for this low $\delta^{15}N$. Zooplankton appear to release ammonium which has a lower $\delta^{15}N$ than their food source, and therefore making their tissues and wastes ~3‰ higher than the food.

A model was constructed to include the above processes influencing $\delta^{15}N$ in the mixed layer, and was successfully tuned to satisfy the variations of suspended particulate $\delta^{15}N$ as well as the exported $\delta^{15}N$. There are seven state variables: *Trichodesmium*, unicellular N_2-fixers, other phytoplankton, zooplankton, detritus, iron and ammonium. The model is forced by light, iron deposition estimated from MODIS aerosol optical thickness, seawater temperature, mixed layer depth, nitrate and phosphate concentrations from HOT data.

We still know almost nothing about unicellular N_2 fixers. But there are several hypotheses about them: 1) they occur at depth, so are more tolerant to mixing than *Trichodesmium*; and 2) they may be subjected to higher grazing than *Trichodesmium*. To include these hypotheses, the variable of unicellular N_2 fixers was given by 1) a higher initial slope α of the P-E curve; and 2) a higher maximum removal rate. *Trichodesmium* has been hypothesized to be capable of sinking below the thermocline to take up phosphate. Therefore, the limitation of phosphate on *Trichodesmium* is relaxed in the model. Results from this model-in-progress compare runs with unicellular N-fixers present or absent and as a function of iron supply and mixing.

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Transport of carbon from the Chukchi Sea into the Arctic Basin via a cold core eddy

The continental margin of the Chukchi Sea is a highly dynamic area, experiencing very high rates of primary and secondary production. Some of the shelf waters are exported into the deep basin of the western Arctic Ocean, perhaps carrying a signature for this shelf production. One of the mechanisms of off-shelf transport is eddies formed at the shelf break. These eddies entrain shelf water and move them into the Canada Basin where they eventually dissipate and mix with surrounding waters. These eddies play a potentially important role in the transport of carbon into the deep Arctic Ocean. Here we show the distribution of DOC, POC, and DIC in a cold core eddy surveyed in September 2004. This work will provide insights on carbon exchange between shelf and basin waters in the western Arctic Ocean, and the role of eddies in the Arctic carbon cycle.

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North Pacific carbon cycle response to climate variability on seasonal to decadal timescales

We compare 7 carbon cycle models in the North Pacific and discover that the models' upper ocean pCO_2 and air-sea CO_2 flux respond similarly to seasonal to decadal timescale climate variability. Modeled seasonal cycles of pCO_2 and its temperature and non-temperature driven components at regions near the Kuril islands, Ocean Station P and Hawai'i capture the basic features of the seasonal cycles in observations [Takahashi et al. 2002, Takahashi et al. 2005], but have difficulty representing the total pCO_2 cycle at high latitudes because it results from the difference of these two large and opposing components. Modeled air-sea CO_2 flux interannual variablity in the North Pacific is smaller (Variability (1 sigma)= 0.03 to 0.10 PgC/yr) than in the Tropical Pacific (0.06 to 0.23 PgC/yr) in all but one model. In the four longest-running models, the timeseries of the first EOF of modeled interannual variability in the air-sea CO_2 flux has a significant correlation with the Pacific Decadal Oscillation (PDO). Regression of pCO_2 components on the PDO on illustrates that, analogous to the seasonal cycle, the three key drivers of pCO_2 (temperature, dissolved inorganic carbon (DIC) and alkalinity) respond to the PDO in a cancellatory fashion that minimizes pCO_2 anomalies and damps sea-to-air CO_2 flux variability across the North Pacific. Windspeed variability also plays a role in the sea-to-air CO_2 flux response to the PDO.

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Mesoscale Variability in the Metabolic Balance of the Sargasso Sea

Net community production (NCP) experiments based on in vitro changes in dissolved oxygen were carried out in three mesoscale eddies investigated in the Sargasso Sea in the summer of 2004. NCP estimates ranged from negative to positive values, with the age and type of the sampled eddy being the principal factors responsible for this variability. This information was combined with a nine-year data set from the BATS program and satellite altimeter data to assess the role of mesoscale eddies in the metabolic balance of the Sargasso Sea. Indirect NCP estimates were obtained from rates of 14C incorporation by phytoplankton and bacterial growth. The results showed highly variable NCP rates that spanned the variability range of direct NCP observations. Monthly averages of NCP values were always positive except during the summer. Our direct NCP estimates suggest that the averaged metabolic balance reported for summer months is the result of highly variable NCP rates associated with mesoscale eddies. The analysis of the available in situ biogeochemical data and altimeter satellite images, suggest that eddy-eddy interactions may also have an important effect on the metabolic balance in the region.

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Inversion of remote sensing reflectance to obtain phytoplankton community size structure: methodology and ecological implications

Phytoplankton cell size is important to biogeochemical and food web processes. The ultimate goal of the study is to estimate the size parameter of a phytoplankton community (S_f) from satellite imagery of remote sensing reflectance (R_{rs}). A previous study indicates each phytoplankton size class has distinctive absorption spectra despite the physiological and taxonomic variability in an assemblage. The chlorophyll specific absorption spectra for pico- (0.2 – 2 µm) and microplankton (> 20 µm) size classes are used as the basis of determination. As a first step to determining the feasibility of this approach, a forward model is constructed in which a range of absorption and scattering properties of natural water is used to estimate R_{rs}. Preliminary results indicate that small changes in pico- and microplankton can be differentiated with satellite R_{rs}. The forward modeling further indicates that S_f can be retrieved under natural water body conditions when chlorophyll concentration is relatively high and absorption due to the combined effect of colored dissolved material and non-algal particles is moderate to low. Such waters exist in ocean margins. To retrieve S_f for satellite-based observations, satellite derived R_{rs} is inverted to estimate the absorbing and scattering properties of the various in water constituents. An existing inversion model will be modified to produce maps of S_f (percentage of picoplankton), chlorophyll concentration, backscattering due to particles and the absorption due to the combined effects of colored dissolved material and non-algal particles. The methodology is most promising for the application in ocean margin waters on a regional basis and can be applied to in situ optical observations. The estimates of S_f have implications for new production models and carbon cycling investigations.

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Zonal variability in Southern Ocean POC and biogenic silica export and mesopelagic remineralization: Indian Ocean synthesis and sector comparisons

Substantial international efforts over the past decade have been directed at quantifying carbon and silica export dynamics in the Southern Indian Ocean and examining the role of this vast sector in Southern Ocean carbon and silica cycling budgets. The research efforts include the Australian Subantarctic Zone

(SAZ) Program and the SOIREE Iron Release Experiment along 140° E, the French ANTARES/KERFIX Programs conducted between the Subtropical Zone and the Permanent Open Ocean Zone (POOZ) in the Kerguelen Plateau region, and the joint US-China-Australia program at ~62° S, 75°E in the open-ocean Seasonal Ice Zone (SIZ) off Prydz Bay. Results document major differences as well as some unexpected similarities between the circumpolar zones. For example, despite dramatically different plankton communities and seasonal nutrient dynamics, the Indian Ocean SAZ deepwater export of POC is very similar to that of the POOZ whereas carbon export in the PFZ and SIZ is approximately half that of the SAZ and POOZ. The Indian Ocean POOZ exhibits the highest Si:C molar export ratios at or below 1 km among the three Southern Ocean sectors even though annual opal export is greater in the Pacific POOZ by factor of almost 2 over the Indian Ocean. A synthesis of Southern Indian Ocean carbon export and remineralization data sets from $\geq$1 km is presented and compared to JGOFS Pacific and Atlantic sector data, with an emphasis on the efficiency of organic carbon preservation at 1 km, Si:C molar export ratios in the mesopelagic zone, and patterns of variability within the circumpolar zones of the Southern Ocean.

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Ocean carbon cycling and CO_2 air-sea exchange along the U.S. West Coast

The processes controlling the variability and magnitude of the coastal carbon cycle are not yet well understood. In particular, the net export of carbon from the coast to the open ocean and the contribution of the coastal oceans to the net flux of CO_2 between the ocean and atmosphere remain unclear.

We investigate the coastal ocean carbon budget for the U.S. West Coast on the basis of a coupled physical-biogeochemical model, with a focus the central upwelling region off California. This region is dominated by intense coastal upwelling, highly turbulent flow, and a high biological production. The ocean model is based on the Regional Oceanic Modeling System (ROMS), coupled to an NPZD-type ecosystem model including a formulation of the ocean carbon cycle, which is driven by climatological mean forcing.

Our analyses suggest that the air-sea flux of CO_2 constitutes only a small component of a very active and dynamic carbon cycle in the euphotic zone. The central California upwelling region is nearly balanced with regard to CO_2 air-sea gas exchange, overall constituting a weak source of CO_2 to the atmosphere of roughly 0.2 mol C $m^{-2}yr^{-1}$. This is the consequence of upwelling-driven CO_2 outgassing nearshore and biologically-driven CO_2 uptake offshore, often associated with filaments originating at capes and other prominent topographical features along the coast. The net CO_2 flux is small compared to e.g., photosynthesis that fixes approximately 8.8 mol Cm^{-2},yr^{-1}. New production amounts to 3.3 mol C $m^{-2}yr^{-1}$ and thus accounts for 37% of total production. Spatially averaged export production nearly equals averaged new production, but locally new and export production are substantially decoupled in this dynamic ocean region. This is due to lateral transport associated with mean horizontal fluxes induced by persistent meso- and submesoscale circulation structures and to lesser degree by the mean lateral offshore transport induced by Ekman transport.

We will report on these budgets as well as ongoing efforts to estimate the magnitude of the lateral transport of carbon and nutrients between the coastal and open ocean, which we expect to be substantial.

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Decadal changes in the $^{13}C/^{12}C$ of dissolved inorganic carbon in the Atlantic Ocean

Decadal changes in the $^{13}C/^{12}C$ of dissolved inorganic carbon (DIC) in the Atlantic Ocean were estimated from measurements on samples collected over the last 20 years. Based on ~900 surface ocean δ^{13}C-DIC measurements, there is a basin-wide δ^{13}C decrease of ~0.15 ‰ per decade and a corresponding DIC concentration increase of ~ 12 umole/kg per decade. The greatest surface ocean δ^{13}C-DIC decrease was observed in the subtropics and, contrastingly, little decrease was observed in the Southern Ocean. A comparison was made of δ^{13}C-DIC measurements on samples from the Repeat Hydrography A16N (2003) with measurements on samples collected in 1993 along the same cruise track (~20ºW). The greatest δ^{13}C decrease in surface waters occurred in subpolar waters (north of 40ºN), at a rate (-0.5 ‰ per decade) that exceeded the atmospheric δ^{13}C decrease, and was associated with increases in phosphate. Based on δ^{13}C-DIC depth profile comparisons, normalized for changes in water mass properties, the anthropogenic δ^{13}C-DIC changes extended to about 1000m in the subtropics and shallower in the subpolar latitudes. The observed surface ocean and depth integrated δ^{13}C-DIC changes in the Atlantic were compared to changes simulated by MOM. The model simulations were fairly realistic for the subtropical and equatorial latitudes but substantially overestimated in the northern subpolar latitudes and in the Southern Ocean.

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Autonomous seagliders help create a seamless climatology of phytoplankton biomass off the Washington coast, USA

Advances in autonomous in situ observations in marine biogeochemistry are being realized through the development and operational deployment of ALPS (Autonomous Lagrangian Platforms and Sensors). Seaglider, an autonomous, buoyancy-driven glider, has provided a nearly continuous data record from August 2003-Present in waters off the coast of Washington, USA. Highly-resolved (5 km horizontal spacing, 1 m vertical resolution, 15 d temporal resolution) sections across the northern California Current system provide measurements of temperature, salinity and dissolved oxygen to 1000 m, and chlorophyll a fluorescence and optical backscattering to 150 m. A strong correlation between Seaglider fluorescence and SeaWiFS-derived chlorophyll concentration was obtained after surface fluorescence mearurements were corrected for mid-day fluorescence quenching (r=0.94). Using this relationship, merged SeaWiFS/Seaglider data products are being generated to yield quasi-4-dimensional representations of regional phytoplankton distributions. One such merged data product was created using data from September and October 2004 when Seaglider collected optical measurements within a large (125 km), persistent (>1 mo), cyclonic eddy located in deep oceanic waters off the Washington coast. Glider observations provide a particularly efficient and cost-effective way of supplying a vertical context to satellite data, and are unique in their ability to revisit features of interest once they have been detected. The overall influence of cyclonic eddies off the Washington coast is a question that can be effectively addressed by combining satellite and in-water data from ALPS.

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A new global model of the marine ecosystem, oxygen, nutrient and carbon cycles: First sensitivity tests

I present a new model of the ocean carbon cycle including a simple representation of the marine ecosystem as well as interactive cycling of nitrate, oxygen and phosphate. First sensitivity tests are presented concerning the representation of POC fluxes, Redfield ratios and ocean mixing. The model is extensively validated with available observations. It is suitable for paleo applications and long term future warming and carbon uptake experiments using large ensembles.

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Observations of porewater release during an episodic sediment resuspension event

The flux of dissolved organics from marine sediments into the water column, and its effects on water column DOC concentration, is a poorly constrained component of the ocean carbon cycle. DOC concentrations within sediments can be elevated by up to an order of magnitude relative to the water column. It is thought that diffusive fluxes of DOC into the water column alone represent a significant source of DOC, but quantities and qualities of episodic inputs resulting from porewater release due to storm-driven bottom resuspension have not, to our knowledge, been evaluated. It has been estimated that resuspension of on the order of a millimeter of sediment could result in a doubling or tripling of nutrient flux into the water column. Such changes in nutrient concentration or nutrient ratios could lead to blooms or shifts in phytoplankton community structure, with resulting changes in primary productivity and carbon export rates. Changes in water optical properties associated with sediment resuspension were monitored during Fall 2004 at one meter above bottom in 15m of water off the coast of Martha's Vineyard, Massachusetts. Optical absorption due to chromophoric dissolved materials (a-cdm) was measured in situ using a WETLabs ac-9 spectrophotometer with inline 0.2 micron filter. In general, an inverse relationship between salinity and a-cdm was observed, as expected in a nearshore riverine-influenced environment. We observed deviations from this relationship with a-cdm increasing by approximately 50% as a result of storm-driven resuspension of bottom sediments into the water column and associated liberation of interstitial pore waters enriched in dissolved materials. We also observed that, based on the slope of the spectral absorption curve, dissolved material ejected into the water column tended to be more refractory than the material present before the resuspension event.

Pete Strutton
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Interannual biological and chemical variability in the equatorial Pacific

Since 1997, biological and chemical measurements have been made across the equatorial Pacific during mooring cruises to maintain the TAO mooring array. These cruises span the basin twice per year, thus quantifying the variability in chlorophyll and nutrients at seasonal to El Nino time scales. The data are used to quantify (1) the spatial and temporal changes in nutrient ratios, (2) the magnitude of seasonal variation in productivity and nutrient uptake, and (3) the relative impact of weak (2002-2003) and strong (1997-1998) El Nino events. The results are linked to the dominant spatial and temporal changes in CO2 fluxes and phytoplankton community composition. Formalizing the current ad hoc equatorial Pacific sampling as a time-series program would permit investigation of long-term variability associated with the PDO and climate change.

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Colored dissolved organic matter (CDOM) as a water mass tracer in the Pacific and North Atlantic oceans

We have sampled selected lines of the CO_2/CLIVAR Repeat Hydrography Survey (A16N, A16S, P02, P16S, A20/A22) to construct the first in situ dataset of open ocean chromophoric dissolved organic matter (CDOM). CDOM is the optically active component of the total dissolved organic pool (<0.2um) and is detected in surface waters by ocean color satellite sensors. Differences in CDOM surface concentration and spectral signature potentially allow for use as a tracer of vertical exchange processes. Our preliminary studies have examined the vertical distribution of CDOM in relation to CFC and AOU (accepted tracers) and reflect features such as subtropical Atlantic mode water, North Pacific and Antarctic Intermediate waters, and possibly warm or cold-core eddies. These data also allow for quantitative inter-basin comparisons to address questions about rates of local CDOM production and destruction. We hypothesize that CDOM cycling is driven by photochemical bleaching in the surface ocean and microbially-mediated production at depth. We are currently examining the link between CDOM and the gradients/quality of nutrients and DOC as they relate to bacterial activity, and are conducting laboratory simulations to constrain rates of solar bleaching of CDOM.

Daniela Turk[1], Maurice Levasseur[2] and C-SOLAS Project Leaders
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Canadian SOLAS Research Network

This poster presents an overview and the first accomplishments of the Canadian SOLAS Research Network. The scientific focus of the Canadian SOLAS research effort largely reflects its integration with the International SOLAS Project and its stated objective of addressing the key interactions among the marine biogeochemical system, the atmosphere and climate, and how this system affects and is affected by past and future climate and environmental changes.

Two major expeditions in the Pacific and Atlantic provided the data to address C-SOLAS objectives; In July, 2002 a mesoscale Fe-addition experiment was carried out in the subarctic Pacific to determine the influence of this limiting trace nutrient on biological production and resulting dynamic changes in the cycling of climatically relevant gases. In 2003, three cruises in the northwest Atlantic were carried out to quantify the impact of the spring bloom on trace gasses production and exchange. The responses in the two ecosystems will be compared and the field data integrated into coupled ocean-atmosphere models.

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MEDFLUX: Organic biomarkers in time-series and sinking velocity traps

In recent experiments at the French JGOFS DYFAMED site in the western Mediterranean, we collected sinking particles using time-series traps and a trap modified to fractionate particles in-situ by their sinking velocity between <1.6 !> 1000 m/d. Our goal was to characterize the in-situ sinking nature of particles, followed by analysis of their chemical composition to evaluate relationships between organic matter, mineral ballast, sinking, and decomposition. Analyses of lipids and amino acids in these trap samples and application of multivariate analysis separates trap samples dominated by fresh diatom-derived organic matter from those that contain substantial amounts of OM that has been reworked by zooplankton and bacteria. The majority of particles (~40% of total mass) were observed to sink at 200-500 m/d and were dominated by large diatom-derived aggregates that were delivered primarily during the spring bloom period. The more slowly sinking particles carry with them a greater zooplankton and bacterial signature. The combination of time-series and sinking-velocity traps provides a unique capability to determine the behavior of sinking particulate matter with minimal handling.

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Interannual and decadal variability of ecosystem, biogeochemistry and carbon cycle in the Equatorial Pacific: a model study of ENSO and PDO impacts

The equatorial Pacific Ocean is known to undergo significant physical and biogeochemical changes that are associated with natural variability. There are two prominent modes of variability which are the El Niño/Southern Oscillation (ENSO), and the Pacific Decadal Oscillation (PDO). A basin-scale three-dimensional physical-biogeochemical model is applied to simulate physical, biological, and chemical processes in the upper ocean of the Equatorial Pacific for the past 50 years. The model is forced with 6-day mean surface wind-stresses from the NCEP reanalysis.

While the model produces significant variability in ecosystem, biogeochemistry, and carbon cycle associated with physical changes on seasonal-to-interannual time scales, the simulations also indicate pronounced decadal variations and regime shift post 1976-77 in the high-chlorophyll-low-nitrate (HNLC) region. Major changes include weakening of iron entrainment, change of the HNLC fronts, shift of ecosystem structure, decrease of new production, and weakening of CO_2 outgassing. These changes have significant influence on the carbon cycles in the equatorial Pacific and also impact on the carbon source and sink in the global carbon budget.

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The role of feeding behavior in sustaining copepod populations in the tropical ocean

A fundamental question regarding marine copepods is how the many species co-exist and persist in the oligotrophic environment. This question is addressed with a stochastic Lagrangian model that explicitly simulates the distinct foraging behaviors of three prominent tropical species: *Clausocalanus furcatus*, *Paracalanus aculeatus*, and *Oithona plumifera*. Along with the copepod population, the model individually tracks all prey cells. Each particle's motion combines sinking, turbulent diffusion, and active swimming when applicable. Results from these experiments demonstrate that the model successfully simulates observed size-partitioned carbon uptake rates. The model indicates that the wide-ranging translational ambit employed by *C. furcatus* is best suited for the acquisition of passive prey, while the relatively stationary sampling method of *O. plumifera* promotes the acquisition of larger, quickly sinking cells. The model results further suggest that the slow velocities and feeding current employed by *P. aculeatus* make it the most likely to satisfy basal metabolic demands though its grazing proficiency appears to be more vulnerable to prey patchiness. Overall, these numerical experiments indicate that a prey concentration of 530 cells/mL is proximal to a resource threshold below which fulfilling basic needs is problematic.

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Time-series of carbon, DMS and iron at Station P (50ºN, 145ºW) in sub-arctic Northeast Pacific: Effect of El Niño, La Niña and regime shift

The Climate Chemistry Laboratory at the Institute of Ocean Sciences has been conducting time-series measurements of organic and inorganic carbon by moored sediment traps since 1982, dimethylsulphide in upper ocean since 1995 and iron species and distribution since 1997. El Niño enhances surface productivity and detritus fluxes of organic and inorganic carbon into deeper ocean, evasion of oceanic DMS into the atmosphere. La Niña and associated cooling favours cold-water plankton species which in turn, affect DMS production. Regime shift, e.g. in 1999, from a warm phase to a cold phase, affects plankton species after 1999. Iron time-series at Station P shows possible atmospheric input of dust from Gobi Desert in China, glaciated till in Alaska and volcanic eruption in Kamchatka Peninsula, which enhanced opal silica and detritus carbon flux.