OS51E-09 1050h

The Influence of Topography on Shelfbreak Frontal Currents

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Flow instabilities of shelfbreak frontal currents can provide significant temporal and spatial variability of the front, which can lead to the mixing of coastal and open ocean waters. Our recent study of the shelfbreak current in the Middle Atlantic Bight found the current to be highly unstable (with growth rates on the order of one day) over a wide range of background conditions. To test the applicability of these results to other shelfbreak frontal currents, we have assessed the degree to which topography influences the nature and strength of the instability of a baroclinic shelfbreak frontal current. To characterize the frontal instabilities, a linearized primitive equation stability model is employed to determine the three-dimensional propagation of perturbations superposed on a two-dimensional mean flow field, which varies continuously across the stream and with depth. The role of topography in destabilizing or stabilizing the flow is investigated for both retrograde and prograde jets. Additionally, the role of stratification in establishing the stability characteristics for retrograde and prograde jets is investigated.

OS51E-10 1105h INVITED

Preliminary Results of a New Dye Tracer Experiment at a Shelfbreak Front

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A pilot cruise to study the coupling of the circulation, mixing and productivity at the shelfbreak front on the New England shelf was conducted July 9-18, 2001. This was the first of 3 cruises of an interdisciplinary collaborative project involving Houghton and Marra (LDEO), Prater and Herbert (URI), and Hales (OSU). An objective was to test the hypothesis that nutrient rich water from the bottom boundary layer that detaches at the shelfbreak upwells along the front and sustains the summertime chlorophyll maximum at the base of the euphotic zone. A dye tracer and COOL floats were deployed to define a Lagrangian reference frame of the upwelling water while a pumping SeaSoar was used to monitor the nutrient and bio-optical properties of this water. Presented here are very preliminary results of only the dye tracer portion of the experiment.

Due to unanticipated technical limitations the tracer, Fluorescein, was injected into the outer edge of the cold pool at 50 m depth inshore of the front instead of near the base of the shelfbreak front as intended. In this region the isopycnal surfaces, virtually horizontal, have density compensating cross-shelf temperature and salinity gradients. The dye patch moved westward along the shelfbreak with a mean speed of 0.17 m/s. No significant upwelling or downwelling was detected. The dye patch moved slightly offshore through the T/S gradient on the isopycnal perhaps 2 km in 4 and a half days. Vertical shear in the flow produced profiles with multiple dye peaks and contributed to the lateral dispersion of the dye patch. From the rate of the variance increase of the dye patch we estimate a vertical diffusivitiy of $3\text{x}10^{-5}$ m^2/s in a region where the buoyancy frequency is $9\text{x}10^{-3}$ rad/s, i.e., period of 11 minutes. Cross-shelf and along-shelf diffusivities are estimated to be 0.3 and 6 m^2/s respectively.

OS51E-11 1120h

The Onset of Seasonal Stratification in the Southern Middle Atlantic Bight

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The Ocean Margins Program was a multidisciplinary exploration of processes leading to the transformation, retention, and export of biogenic materials on and from the broad continental shelf between Cape Hatteras and Chesapeake Bay. As this area forms the terminus of the equatorward coastal current, it was expected to exhibit maximal cross-shelf transports. The field effort took place from late winter through mid-summer. During this seasonal progression, the hydrographic structure undergoes a major transformation from unstratified winter conditions, to strongly stratified summer conditions. This change has a major impact on the chemical and biological processes in the area. This presentation describes how the hydrographic transformation takes place in an area where five water masses vie locally for dominance and are subject to strong wind stress, heat flux, and offshore forcing. A total of eight hydrographic cruises made repeated cross- and alongshelf transects in the area providing snapshots of conditions. In 1996, the shipboard hydrographic measurements were augmented by an array of 26 moorings, supporting 126 temperature and 118 salinity sensors. The mooring data has been optimally interpolated to provide a detailed, three-dimensional time history of the seasonal hydrographic evolution. The results show that the region is subject to large-scale intrusions from north and south, both of which materially affect the timing and development of stratified conditions. Intrusions from the north are wind driven and provide cold, moderate salinity, unstratifed water, delaying the development of stratified conditions. Intrusions from the south of warmer, generally more saline waters, driven into the area by alongshore winds from the South Atlantic Bight, and/or intrusions of Gulf Stream waters pushed shoreward by frontal eddies, tend to promote stratification. In 1996, an intrusion of saline water from the south, combined with decreased winds from the north, slowed the southward flow of cold Middle Atlantic Bight water, and subsequently caused low salinity Virginia Coastal Waters to spread from the coastal plume, out over the denser water from the north. With the reduced alongshelf flow, solar insolation and sensible heat fluxes were then able to warm the surface waters, providing an initial stratification, which was then further augmented by an outflow of low salinity coastal waters.

OS51E-12 1135h

On vertical advection truncation errors in terrain following numerical models: Comparison to a laboratory model for upwelling over submarine canyons

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Submarine canyons which indent the continental shelf are frequently regions of steep (up to 45 degrees), three-dimensional topography. Recent observations have delineated the flow over several submarine canyons during 2-4 day long upwelling episodes. Thus upwelling episodes over submarine canyons provide an excellent flow regime for evaluating numerical and physical models. Here we compare a physical and numerical model simulation of an upwelling event over a simplified submarine canyon. The numerical model being evaluated is a version of the S-Coordinate Rutgers University Model (SCRUM). Careful matching between the models is necessary for a stringent comparison. Results show a poor comparison for the homogeneous case due to non-hydrostatic effects in the laboratory model. Results for the stratified case are better but show a systematic difference between the numerical results and laboratory results. This difference is shown not to be due to non-hydrostatic effects. Rather, the difference is due to truncation errors in the calculation of the vertical advection of density in the numerical model. The calculation is inaccurate due to the terrain following coordinates combined with a strong vertical gradient in density, vertical shear in the horizontal velocity and topography with strong curvature.

OS51E-13 1150h

Observations of Current Driven Upwelling About the Separation Point of the East Australian Current.

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A multidisciplinary experimental program was undertaken during the 1998 − 1999 Austral Summer to investigate upwelling processes on the continental shelf of New South Wales (NSW) Australia. The observational program was conducted in the vicinity of the separation point of the East Australian Current (EAC), which is generally between Port Stephens and Coffs Harbour. Oceanographic time series data was obtained from two shore-normal arrays of current meters and thermistors moored across the continental shelf at Smoky Cape ($30^o55'$S) and Diamond Head ($31^o44'$S) for a 2 month period. Two intensive hydrographic surveys were also conducted aboard the RV Franklin during mooring deployment and retrieval.

The observations show that the EAC dominates the physical processes across the narrow continental shelf at Smoky Cape. It is responsible for driving colder nutrient rich water through the bottom boundary layer from the continental slope north of Smoky Cape into the near surface waters in the coastal region south of Smoky Cape. Furthermore, current driven upwelling occurs on a more massive scale than that driven by local wind forcing by an order of magnitude. North of the separation point the EAC is the dominant cause of upwelling, whereas south of the separation point local wind forcing also plays a role.

The findings of this study have implications for the prediction and possible management of algal blooms which can occur as a response to substantial nutrient enrichment events.

OS51F HC: 317 A Friday 0830h

The Science and Human Dimensions of Purposeful Ocean Carbon Sequestration

Presiding: **K Caldeira,** DOE Center for Research on Ocean Carbon Sequestration**; L J Hansen,** World Wildlife Fund

OS51F-01 0830h

Comparing pH impacts of oceanic CO_2 injection and atmospheric CO_2 release

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Direct injection of CO_2 into the ocean has been proposed as a means of diminishing the climate effects of fossil-fuel burning. The release of CO_2 to the atmosphere from the burning of fossil fuels increases atmospheric CO_2 content and warms the planet.

Direct injection of CO_2 into the ocean could produce significant reductions in deep ocean pH. However, the release of CO_2 to the atmosphere also drives a CO_2 flux into the ocean, thereby also decreasing ocean pH.

We have performed simulations of direct CO_2 injection and atmospheric CO_2 release using an ocean general circulation model. We have computed the volumes of ocean subject to pH perturbation as a function of the magnitude of pH perturbation. We find that the long-term, far-field effects of direct CO_2 injection are similar to the long-term, far-field effects of an equivalent atmospheric CO_2 release. However, direct CO_2 injection produces a region in the vicinity of the injection site with a pH change greater than that produced from atmospheric release. This is because atmospheric release results in CO_2 ingassing over the entire ocean surface, thus diluting the CO_2 impact on ocean chemistry.

To a first approximation, CO_2 released to the ocean or atmosphere ultimately adds the same amount of hydrogen ions to the ocean. Atmospheric CO_2 release introduces these hydrogen ions to the ocean over time and spreads out them out spatially across the entire ocean surface. Direct CO_2 injection introduces them to the ocean immediately and in a smaller initial volume of water. The advantage of direct injection is that it avoids most of the climatic effects of atmospheric CO_2 release.

Direct CO_2 injection can be engineered to minimize near-field pH consequences. If the far-field consequences of direct CO_2 injection are unacceptable, then atmospheric CO_2 release is likely to be similarly unacceptable. Methods have been proposed to diminish adverse impacts of CO_2 dispersal in the ocean, including the dissolution of calcium carbonate. Nevertheless, ocean CO_2 sequestration probably makes most sense within the context of the evolution towards a carbon-emission free economy.

OS51F-02 0845h

Field experiments on direct ocean CO_2 sequestration: the response of deep-sea faunal assemblages to CO_2 injection at 3200 m off Central California.

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Although carbon sequestration by direct injection of liquid CO_2 into the ocean holds promise for mitigating atmospheric CO_2 levels, its biological consequences are understood poorly, and are potentially large. Few direct experiments on the tolerance of midwater and seafloor organisms to changes in ocean chemistry associated with CO_2 injection have been performed. Several factors, however, suggest that deep-living species are more sensitive to CO_2 injection than related groups inhabiting the upper ocean. The evolution of deep-sea faunas in the relatively invariant environment of the deep ocean has likely led to the intolerance of many species to perturbations in seawater chemistry associated with direct CO_2 injection (e.g. pH reduction) that may be more tolerable to shallow-living groups. Food limitation and reduced metabolic rates typical in deep-sea ecosystems may also limit the ability of many organisms to tolerate changes in pH (i.e. pH compensation) or CO_2 (e.g. metabolic depression). We report here on two field experiments at depths of 3200 and 3600 m to evaluate the biological responses of deep-sea organisms to direct CO_2 injection. Pools of liquid CO_2 from 15 to 70 liters were deployed on the seafloor from the ROV *Tiburon* operated by the Monterey Bay Aquarium Research Institute, using a novel CO_2 release system. The survival and physiological responses of the seafloor faunal community were evaluated near ($\sim$1 m) and distant (up to 30 m) from CO_2 pools. Intertial and tidally oscillation of near-bottom currents swept a plume of CO_2-rich water away from the pools as the liquid CO_2 dissolved, leading to periodically reduced pH levels near 6.0 to 7.0 within about 1 m. Rates of survival for bentho-pelagic fishes (zoarcid sp. 1) and octopus (*Benthoctopus* sp.), epibenthic megafauna (echinoderms: urchin sp. 1, holothuroid sp. 1, ophiuroid sp 1; molluscs: gastropod sp. 1) held in cages adjacent to CO_2 pools were very low near CO_2 pools compared to more distant sites after 5 weeks of exposure. Sediment-dwelling macrofaunal crustacea (ampeliscid amphipod; *Haploops lodo*), and meiofaunal organisms (flagellates, ciliates, nematodes) collected in sediment cores showed similar patterns of survival. In addition, the physiological condition (gut fullness and tissue density) of ampeliscid amphipods exposed to CO_2 was poor compared to control groups. A wide variety of field and laboratory studies of a phylogenetically diverse suite of deep-sea species from benthic and midwater habitats, coupled with careful estimation of the degree and areal extent of changes in seawater chemistry to be expected with any CO_2 disposal scenario, is required before any realistic estimate of the impacts of sequestration on deep-sea ecosystems is possible.

OS51F-03 0900h

Into the Deep: Shedding Some Light on the Political, Legal and Ethical Aspects of Ocean Carbon Sequestration

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Purposeful ocean carbon sequestration is currently being examined as a mitigation option of climate change by a number of countries and private entities. This approach includes both direct injection of carbon dioxide into the water column and ocean fertilization. Both of these approaches are predicted to impact, and in fact are predicated on the manipulation of marine ecosystems and food webs. The impact of ocean carbon sequestration is not only a topic for applied biological research but also relates to political, legal and ethical issues. This presentation highlights elements of all three perspectives: the political relationship between the exploration of carbon sequestration technology and involvement in international climate negotiations; the legality of carbon sequestration in the context of major national and international marine and environmental protection laws and agreements, including the Kyoto Protocol; and the bioethical/science ethics questions relating to using the oceans as a repository for anthropogenically generated waste products and proceeding despite a very limited understanding of consequences. The goal of this overview is to consider the context in which purposeful ocean carbon sequestration is proposed and how prudent decisions may be made as the debate over ocean carbon sequestration proceeds.

OS51F-04 0915h

Evaluating Carbon Sequestration Efficiency in an Ocean Circulation Model by Adjoint Sensitivity Analysis

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We demonstrate the application of an adjoint sensitivity method to develop three-dimensional maps of injected-carbon sequestration efficiency and mean tracer residence time in an ocean general circulation model. The adjoint approach provides a computationally efficient tool for characterizing both temporal and spatial variations of sequestration efficiency over a complete model domain.

We examine the properties of a tracer which represents small perturbations to the background ocean carbon distribution and which has possible sources at all interior grid points of the model. The carbon-anomaly tracer is lost to the atmosphere at the ocean surface with an equilbration timescale of one year. In these experiments, for simplicity, the tracer sources are assumed sufficiently small that the partial pressure of carbon in the atmosphere is not significantly changed. We define sequestration efficiency as the percentage of injected carbon tracer that remains in the ocean after an elapsed time during which there is a continuous tracer injection source. It is mapped over the whole model domain as a function of the elapsed time. The mean residence time, defined as the average period that impulsively injected tracer remains within the ocean, is also mapped over the whole model domain. Both efficiency and mean residence time are derived directly from adjoint model variables.

In the particular configuration of ocean model used we map the efficiencies of sources at 935m and find Pacific basin injection sites to be more efficient over decadal and centennial injection timescales. For millenial timescale injections, Atlantic injection sites are more efficient at this depth. These results can be interpreted in terms of the ocean model circulation and the competing influences of wind-driven gyres and meridional overturning circulation. Mapping the mean residence time highlights areas of deep water formation in the North Atlantic as regions where impulsively injected tracers are most effectively sequestered in the ocean, again reflecting the role of the meridional overturning circulation.

The adjoint sensitivity approach allows us to map the efficiency and mean residence time at each model grid-point at only a few times the computational cost of a single perturbation experiment. Using an explicit perturbation approach to obtain similar maps would require some tens of thousands of model integrations. We have demonstrated this approach for a simple injected, carbon-like tracer but it can be extended to examine the relationships between a broad range of ocean physical and biogeochemical processes in the natural and perturbed system.

OS51F-05 0930h

An Effective and Less Environmentally Harmful Way to Store CO_2 in the Ocean

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If it becomes necessary to purposefully capture and sequester fossil-fuel-generated CO_2, ocean storage via i) ocean fertilization and enhanced biological uptake and ii) deep-sea injection of captured CO_2 are methods that are being actively researched. However, these approaches have potentially serious environmental consequences, and may ultimately be ineffective in keeping CO_2 from the atmosphere. As an alternative we propose that CO_2-rich power-plant gases be hydrated with seawater to produce a carbonic acid solution that in turn is reacted on-site with limestone to form Ca^{2+} and HCO_3^-. This calcium bicarbonate solution is then released and diluted in the ocean where it would add minimally to the existing, large pool of these ions in the sea. Such a process simply speeds up natural, abiotic carbonate weathering and dissolution which will otherwise consume anthropogenic CO_2, but over many millennia.

Using a model of ocean chemistry and transport we show that this process would increase ocean alkalinity, effectively neutralizing CO_2 acidity and isolating anthropogenic carbon from the atmosphere. Relative to atmospheric release or direct CO_2 injection into the sea, this method would greatly expand the capacity of the ocean to store anthropogenic carbon while minimizing environmental impacts of this carbon storage on ocean biota. Indeed, our calculations indicate that releasing the carbonate-dissolution effluent to the oceans would be less damaging to the marine environment than releasing an equivalent amount of CO_2directly to the atmosphere.

This sequestration method is also less energy intensive and less expensive than abiotic CO_2 capture and direct ocean or geologic injection schemes. We calculate an energy penalty that may be $<2\%$ with a CO_2 capture efficiency which may exceed 50%. Estimated sequestration costs could be as low as $12 per tonne CO_2 sequestered, dependent on reactor configuration and on limestone and water availability and transport. These compare with $90 to $180/tonne CO_2 and $>>20\%$ energy penalties estimated for direct ocean CO_2 injection. Our initial benchtop-scale experimental simulation of this process indicates that carbonate dissolution could contribute significantly to mitigating adverse impacts of fossil-fuel burning.

OS51F-06 0945h

Dissolution rate of Liquid CO2 at 3600m Depth as Determined by pH Measurements

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We have taken advantage of the unique properties of hydrate film formation to measure directly the dissolution rate of liquid CO2 on the ocean floor at 3600m depth, and 1.55 degrees C. We used the ROV Tiburon to transport and dispense, by actuation of an accumulator system, approximately 2L of liquid CO2 into a small hole on the sea floor made by a push core. A pH electrode (Sea Bird Instruments SBE-18) held in the vehicle arm was then positioned directly above the domed mass of CO2, and scanned closely over and around the mass without detection of local pH gradients.

The electrode, protected by a slotted metal cage with an open circular end of 3cm diameter, was then slowly lowered. Contact of the metal cage with the CO2 surface produced a significant deformation of the liquid-hydrate interface such that a large pocket of water formed, thus enabling the changing pH to be monitored. The electrode was inserted some 3 cm below the liquid CO2 surface. This surface deformation is too great to be caused by simple elastic stretching of the interface. Rather it represents a rapid re-building of the hydrate film as described for laboratory experiments by Aya et al. (2001). In this model cracks appearing in the film are annealed by penetration of unsaturated water, and CO2, which quickly form new hydrate molecules. Once full insertion was complete, the vehicle arm was locked and the pH change was monitored for 15 minutes.

The pH change observed was 4.19 pH units, the local alkalinity was taken from survey data as 2442 micro-mol/kg, and these data were used to calculate a CO2 accumulation rate within the water pocket of 2913 micro-mol/kg/sec. The volume of the pocket, and surface area of hydrate exposed through the slots in the electrode cage, were used to estimate a CO2 dissolution rate of 1.7 micro-mol/cm2/sec. This can be compared to the estimate of 3 micro-mol/cm2/sec determined from the shrinking rate of a rising stream of CO2 droplets at a depth of 800m (Peltzer et al., 2000).

Establishing the accuracy of pH measurements made with a large electrically noisy vehicle is extraordinarily difficult, but there can be little doubt that very large changes in CO2 were observed within the water pocket created. The maximum CO2 concentration observed was close to 2 molar. The CO2 equilibrium value controlled by hydrate formation under the conditions of the experiment is 0.6 molar, indicating that supersaturation by about a factor of 3 was observed. This is most unusual, for hydrate nucleii are clearly present at

the interface. The results suggest that pH extrema below hydrate equilibrium values can be temporarily observed, and also that eventual massive hydrate formation from rapid crystallization of the solution is possible. Such an event was seen in an adjacent experiment.

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OS51F-07 1020h

Modeling Carbon Partitioning in Response to Iron Enrichment in the Equatorial Pacific Ocean

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In situ iron-enrichment experiments in the equatorial Pacific Ocean and the Southern Ocean have shown that additional iron to high-nitrate, low-chlorophyll (HNLC) waters triggers a series of changes in the productivity and growth of phytoplankton. The logistic constraints on the length of observation have prevented these otherwise successful efforts from resolving the full temporal and spatial pattern of carbon partitioning. The use of an ocean ecosystem model developed for the equatorial Pacific Ocean will contribute substantially to understand ecosystem responses on much larger spatial scale and longer time scale. The biogeochemical model consists of ten compartments describing two size classes of phytoplankton and zooplankton, detrital nitrogen and detrital silicon, silicate, total CO2 and two forms of dissolved inorganic nitrogen: nitrate and ammonium, which are treated separately, thus enabling division of primary production into new production and regenerated production. This ten-component biogeochemical model is embedded into a three-dimensional ocean circulation model based on the Modular Ocean Model (MOM), and forced with climatological COADS monthly wind and heat flux. In the eastern equatorial Pacific, multiple iron-enrichment experiments in an area of 360,000 square km are simulated by changing the iron-dependent photosynthetic efficiency in the given spatial domain. With this 3D physical-biogeochemical model it is possible to investigate the physical, biological and geochemical consequences of varying the size of the enriched patch and frequency of enrichment.

OS51F-08 1035h

Changes in atmospheric carbon dioxide and biological productivity induced by patchy ocean fertilization

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Ocean fertilization with micro and macro nutrients has been proposed as a means of purposeful carbon sequestration. Many studies of this process have assumed long-term or large-scale fertilization. The present study considers cases where fertilization is applied over a small region (1 model grid box) in the tropical Pacific Ocean for a short time. We demonstrate that for macronutrient depletion experiments, very little of the carbon exported to the deep ocean ends up coming out of the atmosphere. There can be significant long term reduction of new production, exceeding the oceanic CO2 uptake by as much as a factor of 30. The results are exceedingly sensitive to the profile of remineralization. Since the air-sea CO2 fluxes associated with this scenario are distributed over large space and time scales, they are small in comparison with the natural fluxes, and would thus be impossible to measure directly. Macronutrient addition experiments differ significantly from macronutrient depletion experiments in terms of atmospheric CO2 uptake, impact on production, and sensitivity to remineralization. However, they are likely to be similar in the challenges they present for verification.

OS51F-09 1050h

Iron Limitation Effects on Algal Species Composition and Physiology in the Eastern Equatorial Pacific Ocean

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Diagnostic indicators were used to assess the impact of Fe-limitation on algal species composition. Photosynthetic efficiency of PS II and the Flavodoxin-index provided physiological evidence of the effects of variable Fe-concentrations on algal species composition in the eastern Equatorial Pacific Ocean. Algal species composition was determined using Chemtax analysis of HPLC pigment data. Highly dynamic spatial variability in the algal assemblage was observed in this region with cyanobacteria and Phaeocystis populations dominating the low Fe offshore HNLC region. Threshold Fe values inducing Fe-limitation (as evidenced by the Flavodoxin index) were in the range of 0.2 to 0.4 nM and were dependent on the algal species composition. Cryptophyte and haptophyte algal populations dominated in the low Fe waters off the Peru upwelling compared to large diatom blooms in the high Fe region near the Peru coast. Dynamic physical forcing, however, led to significant variability in the algal species composition and physiological health of the population in the upwelling region. Effects of ambient Fe-concentration on the photosynthetic efficiency and Fe nutritional status of algal populations will be discussed.

OS51F-10 1105h

Assessing the Consequences of Iron Fertilization on Oceanic N_2O Emissions and Net Radiative Forcing

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There has been a recent resurgence of interest in using ocean iron fertilization as a strategy for mitigating the buildup of anthropogenic CO_2 in the atmosphere. Relieving ocean phytoplankton communities from their iron limitation in regions where macronutrients are abundant would stimulate additional growth and increase the export of organic matter to depth. This would lead to a drawdown of the surface ocean inorganic carbon content, which would be compensated by net uptake of CO_2 from the atmosphere. However, Fuhrman and Capone [1991] pointed out that the benefits of such a strategy would likely be partially offset by an increase in the oceanic emission of N_2O, which has a much stronger greenhouse warming potential than CO_2. They argued that this is primarily a consequence of an increase in the rates of nitrification associated with the breakdown of the additional organic material transported to depth. This negative feedback could be accelerated by the fact that hypoxic zones appear to have very high yields of N_2O, and such zones are expected to increase strongly as a result of iron fertilization, particularly when done at low latitudes. We investigate the consequences of iron fertilization on oceanic N_2O emissions with a simple box-diffusion model (HILDA) as well as a 3-D ocean biogeochemistry model (POBM), in which the production of N_2O is modeled according to Suntharalingam et al.[2000]. Initial results obtained from the box-diffusion model indicate that the location and duration of the fertilization has a dramatic impact on the magnitude of the negative feedback associated with N_2O. While the negative feedback in high-latitudes was found to be small, fertilization in low latitudes led to a significantly high offset of the radiative forcing benefit from the atmospheric CO_2 reduction by the increased oceanic emission of N_2O. We are currently repeating these experiments with the 3-D ocean biogeochemistry model and will report and discuss the results.

OS51F-11 1120h

CO_2 Effects on Species Composition and Nutrient Utilization in an Equatorial Pacific Phytoplankton Assemblage

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We report the results of a field incubation experiment demonstrating a substantial shift in the species composition of Equatorial Pacific phytoplankton assemblages exposed to CO_2 levels of 150 and 750 ppm (dissolved CO_2 ∼ 3 - 25 mM). In all samples, the phytoplankton community was dominated by diatoms and Phaeocystis sp. But the relative abundance of these phytoplankton taxa differed significantly between CO_2 treatments. Taxonomic pigment analysis and direct microscopic examination of samples revealed that the abundance of diatoms decreased by ∼50% at low CO_2 relative to high CO_2, whereas the abundance of Phaeocystis increased by ∼60% at low CO_2. This CO2-dependent species shift was associated with a significant change in nutrient utilization, with higher ratios of N:Si and N:P consumption by phytoplankton in the low CO_2 treatment. Despite the significant changes in species composition and nutrient consumption ratios, total primary productivity and biomass accumulation did not differ significantly between the CO_2 treatments. Our results suggest that CO_2 concentrations may influence competition among marine phytoplankton taxa and could affect oceanic nutrient cycling. We discuss the ecological and biogeochemical implications of our preliminary findings and suggest directions for future research.

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An Analysis of Large Scale Ocean Fertilization Under Different Circulation Scenarios

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The efficiency of iron fertilization in reducing atmospheric carbon dioxide depends on the detailed ocean circulation. When nutrients are depleted, the biological pump becomes efficient so that carbon is pumped into the deep ocean. The efficiency of the biological pump depends on the high latitude convection and on the location of deep upwelling in the model. Fertilization can have interesting nonlocal effects which are strongly dependent on circulation. Thus, a Southern Ocean nutrient depletion while increasing the high latitude productivity of the ocean, could result in a decrease in oceanic primary productivity in the low latitudes.

We attempt to explain the efficiency of fertilization through an analysis of the competition between the solubility pump, gas exchange pump, biological pump, and circulation. The influence of circulation on the pumps and on the resulting CO2 flux distribution is examined in a series of five pre-anthropogenic simulations with different circulations due to varying horizontal and vertical diffusivities. The model used is the Princeton GCM with carbon chemistry consistent with OCMIP 2 requirements. Depletion runs are compared to the standard, undepleted scenarios.

In the undepleted case the change in mixing has considerable yet opposite effects on the solubility and biological pumps, i.e., a compensation mechanism takes place. Thus, changing the circulation has a small influence on the total air-sea carbon flux distribution. Rather, we find that imposed boundary conditions determine to a large extent the total air-sea carbon flux. Preliminary results suggest that changing the circulation has a stronger influence on the total air-sea carbon flux distribution in the depleted cases compared to the undepleted cases. GCM results are analyzed and compared to the results of an eight box model simulation.