OCEAN CARBON & BIOGEOCHEMISTRY SUMMER WORKSHOP
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POSTER ABSTRACTS

IMPORTANT NOTES: Please put up your poster on the morning of (during breakfast) your assigned day, and be sure to remove it by the end of the day, as another presenter will need to put up their poster in that space the following morning. Below you will see that each abstract title has been assigned a two-digit identification that includes the day the poster is to be presented (M = Monday, T = Tuesday, W = Wednesday) and a number. On the day of your poster presentation, please look around the meeting area for the number that corresponds with your abstract number. There will be signs posted around the meeting area to help you find your poster space. We will provide the appropriate hanging materials (Velcro tabs, thumb tacks, etc.) at each poster space. Please only use the hanging materials provided for your space.

THEME 1. CLIMATE SENSITIVITY OF ECOSYSTEM STRUCTURE AND ASSOCIATED IMPACTS ON BIOGEOCHEMICAL CYCLES

M1: Dynamics of extracellular enzyme activities under changed atmospheric CO_2 conditions

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Changing oceanic CO_2 concentrations and associated effects may lead to differences in the structure and functioning of the phytoplankton community, which could change the nature and type of organic matter available for heterotrophic processing. This possibility was investigated as part of the *PeECE* project, an experimental study involving manipulation of atmospheric CO_2 levels (to glacial, present, and year 2100 concentrations) in nine replicate enclosures in a Norwegian fjord (http://peece.ifm-geomar.de/approach.htm). Nutrients were then added to the enclosures to induce blooms. To investigate the extent to which microbial processing of organic matter might also be affected by differences in atmospheric CO_2 concentrations, we measured activities of select extracellular enzymes that initiate the microbial degradation of high molecular weight organic matter.

Activities of polysaccharide-hydrolyzing extracellular enzymes were the focal point, since carbohydrates are major components of algal biomass, as well as of particulate and dissolved organic carbon (DOC) and transparent exopolyermic particles (TEP). Extracellular enzyme activities were measured using fluorescently labeled polysaccharides. As substrates, laminarin (diatom storage polysaccharide), xylan (red algae; terrestrial plants), fucoidan (from *Fucus*; composition similar to TEP), and chondroitin (amino sugar and uronic-acid containing polysaccharide) were selected. Enzyme activities were monitored on day 6 (pre-bloom), day 13 (bloom peak) and day 21 (post bloom) in the glacial and future CO_2 enclosures; bacterial concentrations, size, fraction of attached bacteria, bacterial protein production, and bacterial growth were measured concurrently.

Strong temporal, substrate-related, and mesocosm-related differences were observed in enzyme activities during the development and decline of the phytoplankton bloom. Overall, levels of chondroitinase activity were high and laminarinase and xylanase activities were quite low compared to most previous investigations of enzyme activities in seawater under present CO_2 conditions. Furthermore, a remarkably high level of fucoidanase activity was measurable in samples collected during the latter phase of the bloom in the glacial-CO_2 enclosure. This high level of activity contrasts with typical observations of low to unobservable activity in most other locations in seawater, as well as in a previous mesocosm investigation.

Since bacterial abundance did not vary among the enclosures with different pCO_2, the dynamics observed in enzyme activities likely relate to differences in the timing of phytoplankton species succession between the mesocosms during the development of the bloom, and possible corresponding compositional shifts in the microbial communities. These results suggest that changes in phytoplankton community structure in response to changing atmospheric CO_2 concentrations will echo along the heterotrophic food chain, likely causing differences in processing of DOC, one of the largest actively cycling reservoirs of organic carbon on earth. Although previous investigations have used substrate proxies as a means of assessing enzyme activities, this investigation is the first to demonstrate differential responses of a suite of polysaccharide hydrolyzing enzymes to changed atmospheric CO_2 concentrations.

M2: The ‘jelly C pump’: Jellyfish blooms result in a major microbial respiratory sink of C in marine systems

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Large jellyfish blooms of lobate ctenophores (*Mnemiopsis leidyi*) and scyphomedusae (*Chrysaora quinquecirrha*) occur in many coastal areas, including large summer blooms in Chesapeake Bay. High jellyfish biomass coincides with peaks in microbial activity and biomass, but few studies have investigated the potential link between jellyfish blooms and microbial functioning in coastal ecosystems. We measured dissolved organic matter (DOM) production by jellyfish, and the response of free-living bacterioplankton to this C input, in terms of bacterial cell growth, metabolism, and phylogenetic community composition. Both species of jellyfish released large amounts of carbon (C)-rich dissolved organic matter (J-DOM), and bacterioplankton quickly responded with large increases in metabolic activity. Enumeration of prokaryotic phylogenetic groups using fluorescence *in situ* hybridization (FISH) showed specific bacterial groups were responsible for increased metabolism resulting from jellyfish-generated DOM. Furthermore, decreases in bacterial growth efficiency suggest a shunt of C consumed towards bacterial respiration. In the context of worldwide increases in jellyfish, our results suggest the possibility of major shifts in marine microbial structure and function, and a potential for a large bacterial C sink away from higher trophic levels, including commercially important fish species.

M3: Ecological control of subtropical nutrient concentrations

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We examine the interplay between ecology and biogeochemical cycles in the context of a global three-dimensional ocean model where self-assembling phytoplankton communities emerge from a wide set of potentially viable, initialized cell types. Analysis of the model solutions reveals a clear and plausible organization of the emergent community structure by the physical regime. Fast growth rates are important in strongly seasonal regimes, but adaptation to low nutrients is more important in stable, low-seasonality regions. We examine the value of resource control theory for interpreting the complex model solutions. We find it a very useful tool in the non-seasonal regime: here, the dominant phytoplankton are able to grow at low levels of nutrients, and draw the nutrients down to levels where other phytoplankton cannot be supported. The theory therefore predicts not only which organisms dominate but also the chemical environment: we show that the unique physiological properties of the dominant phytoplankton and their loss rates determine the ambient nutrient concentrations. Resource control theory is indeed a powerful tool for interpreting complex model marine ecosystems (and perhaps their real world counterparts) in physical regimes of appropriately low seasonality. We examine the results in context of interannual variability, and conjecture on the sensitivity of this ecological nutrient control to potential changes to the physical environment.

M4: Global biogeochemical cycling with an implicit-ecosystem model

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Estimating biogeochemical fluxes with numerical models is critical in order to predict the large-scale chemical and physical evolution of the Earth system. Biogeochemical models have come into widespread use as embedded components of ocean general circulation models, and the complexity of their ecosystem representations has steadily increased in recent years. For example, many models now contain multiple phytoplankton groups and multiple zooplankton groups, connected by an intricate web of non-linear interdependencies. Of course, even the most complex of these represents only a miniscule fraction of the true complexity of marine ecosystems, and there is certainly plenty of grist for the research mill in exploring the domain of increasing complexity. However, the calibration and validation of ecosystem models is handicapped by the scarcity of data, and by a poor understanding of fundamental processes. We propose an alternative to the complex ecosystem models that focuses simply on the well-measured distributions of inorganic tracers, treating processes internal to the ecosystem as implicit. In essence, this represents a return to the simple principles of early biogeochemical models, in which only the first-order transformations between inorganic and organic pools are resolved, as a function of water temperature and irradiance. This approach greatly reduces the number of tunable parameters, and increases the transparency of the model results. We emphasize that this is not intended to replace models that resolve ecosystem processes, but rather to supplement them as a tool for interpretation, for conducting idealized experiments, for efficient implementation of multiple elements and isotopes, and as a low-cost substitute for use in computationally-demanding high-resolution climate simulations.

M5: Climate change impacts on phytoplankton biodiversity and its consequences for the ecosystem of the Arabian Sea

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Over the past few years the Arabian Sea has witnessed a rapid increase in summer-time phytoplankton blooms due to strengthening of the southwest monsoon winds and intensification of coastal upwelling. In a study based primarily on satellite-based datasets we showed that these changes were linked to the warming trend over Eurasia and a decline in snow cover over the Himalayan-Tibetan Plateau region. Our recent observations suggest that the warming trend is undermining convective mixing responsible for nutrient inputs during the boreal winter component of the monsoon cycle. More recently, we have been able to combine satellite data with shipboard observations to show the Arabian Sea may be experiencing a loss of phytoplankton biodiversity, with traditional wintertime diatom populations being replaced by unprecedented blooms of the heterotrophic dinoflagellate *Noctiluca miliaris*. At the moment, it remains unclear whether these changes are related to the warming trend. One of the difficulties is that, unlike the other major ocean basins, long-term shipboard observations in the Arabian Sea are lacking and continue to be a major impediment to a better understanding of the relationships between the oceanographic processes and biological productivity as they relate to climate change. As part of our studies funded by NASA, we have been working to overcome this shortcoming through the development of a coupled physical-biological model. A detailed analysis of atmospheric data from the region being undertaken simultaneously will be used to identify salient trends in climate and in conjunction with the coupled physical-biological model, for a coherent diagnosis of climate variability on the ecosystem of the Arabian Sea.

M6: Differences in nitrate N and O isotope effects among clades of unicellular plankton

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We investigated the couple N and O isotope enrichment of nitrate during assimilation by various clades of unicellular plankton. The N isotope effects of two strains of diatoms and two *Chlorella* strains were around 5‰. Three cyanobacterial strains of the genus *Synechococcus* showed somewhat lower N isotope effects, around 3‰. As observed previously (Granger et al. 2004), O isotope enrichments of nitrate were roughly equivalent to their corresponding N isotope effects ($^{18}\varepsilon = ^{15}\varepsilon$) among both eukaryotic and cyanobacterial strains. However, a single marine heterotrophic eubacterial strain showed relatively small N isotope enrichment during nitrate assimilation, ≤ 1‰. Moreover, its corresponding O isotope effect was roughly twice it N isotope effect ($2*^{18}\varepsilon = ^{15}\varepsilon$). We present hypotheses as to the origin of this difference in O to N isotope enrichment of this strain, and discuss the potential significance of the difference for interpretation of N and O isotope effects in the environment.

M7: Effect of CO_2 on photosynthesis in iron-limited phytoplankton

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Atmospheric CO_2 levels continue to rise due to human activities and will likely double relative to pre-industrial concentrations within the current century. The impact of rising CO_2 on marine productivity and ecosystem structure is consequently a concern. Productivity may increase at elevated CO_2 if RubisCO is directly stimulated, or as energy saved from down-regulation of the carbon concentrating mechanism (CCM) is redirected toward carbon fixation. Alternatively energy saved from down-regulation of the CCM could allow a reduction of photosynthetic light harvesting and processing proteins. As iron limitation is essentially a limitation of photosynthetic energy generation interesting interactions may arise between the regulation of the iron-rich photosynthetic apparatus, carbon fixation, and the CCM as iron and CO_2 availability change. We assessed the response of the primary components of algal photosynthesis (the energy generating photosynthetic apparatus, the CCM, and carbon fixation) to changes in iron and CO_2 availability in field assemblages from the iron-limited Gulf of Alaska and laboratory cultures of *Thalassiosira weissflogii*. There is evidence that under iron limitation the CCM and photosynthetic apparatus are down-regulated at elevated CO_2 potentially allowing an increased iron-use-efficiency at elevated CO_2. This may allow higher biomass or more rapid growth to be achieved in iron-limited regions. In contrast, under nutrient replete conditions we see instances of elevated productivity and growth at high CO_2 but no changes in abundance of key photosynthetic proteins.

M8: Linking the future biogeochemical cycles of C, N, and Fe: Interactions between cyanobacterial N_2 fixation and Fe limitation in a high CO_2 ocean.

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We examined the Fe requirements of the biogeochemically-critical marine diazotrophic cyanobacteria *Crocosphaera* and *Trichodesmium* at glacial (190 ppm), current (380 ppm), and projected year 2100 (750 ppm) CO_2 levels. N_2 and CO_2 fixation rates of Fe-replete *Crocosphaera* at 750 ppm CO_2 were up to twice as high as those at 190 and 380 ppm CO_2. Cellular Fe quotas varied 3-fold as a linear function of N_2 fixation rates, and N_2 fixation was similarly linearly related to external pCO_2. Thus, Fe requirements were also linearly dependent on external pCO_2 in Fe-replete *Crocosphaera*. N_2 fixation and Fe quotas were, however, decoupled from pCO_2 in severely Fe-limited cultures. A similar tight correlation between N_2 fixation rates, cellular Fe quotas, and external pCO_2 was observed in *Trichodesmium*. These results suggest that anthropogenic CO_2 enrichment could dramatically increase global oceanic N_2 and CO_2 fixation by diazotrophic cyanobacteria, but the magnitude of this effect may be ultimately regulated by Fe availability. The established relationship between the biogeochemical cycles of N and Fe may be fundamentally altered in the future ocean due to this newly recognized strong dependence of N_2 fixation on CO_2 availability. Possible biogeochemical consequences may include accelerated inputs of new N to the ocean and increased potential for Fe

and/or P limitation in the high-CO_2 ocean, and feedbacks to atmospheric pCO_2 in both the near future and over glacial/interglacial timescales.

M9: The biogeochemical impact of climate-induced changes in the Japan/East Sea

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The Japan/East Sea (JES) is a strategically and economically important marginal sea. It is also a physical and biogeochemical mesocosm whose response to climate change may provide valuable insight into the future of global change. The JES as a "model ocean" contains many key physical elements of the global ocean, including subtropical and subpolar gyres, deep open-ocean convection and seasonal sea-ice-mediated brine rejection. Trends in abyssal oxygen, nutrient, and temperature indicate that there was a hiatus in deep water formation in the latter half of the twentieth century. Transient tracer observations in the JES are used in combination with a minimum complexity water mass model to successfully constrain the timing, nature and magnitude of these recent changes in JES ventilation. The data and model indicate that there was a nearly 10-fold decrease in deep water formation rates since during the early 1960s, marked by a transition from sea-ice/brine-rejection-based deep water mass formation to a shallower open-ocean convective renewal. Determination of the ventilation rates also allow the calculation of the regional-scale flux of macronutrients from the abyss to the euphotic zone, and hence basin-scale new production. In addition, water column remineralization rates for phosphate and oxygen utilization rates show expected and consistent patterns as a function of depth. The reduction in abyssal ventilation of the JES led to a 2-fold decrease in basin-scale new production. This decrease has significant implications for the strength and resilience of the marine food web. The change appears consistent with trends in zooplankton biomass estimates in the western JES, and possibly with changes in the character of fish-catches. Recent observations made by others indicate a significant resurgence of brine-rejection related deep water formation during the winter of 2001, but it remains to be seen whether this will be sustained in the face of global warming trends.

M10: Iron limitation in the Arabian Sea during the Southwest Monsoon

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Incubation experiments conducted at 15 stations on the R/V *Roger Revelle* in August- September 2007 indicated that surface waters in the southern Arabian Sea are Fe-limited. Additions of Fe led to significant increases in chlorophyll, DMS and DMSP over a 72-hour period. Si was initially depleted at many stations, and as a result the increase in biomass was not due to diatoms, as in many other studies, but to the haptophyte *Phaeocystis* sp. Results are similar to the findings of Hutchins and coworkers in the Peru Upwelling, another Fe-limited region overlying an oxygen minimum zone. The JGOFS Arabian Sea program concluded that Fe limitation was not an important control on primary production in the Arabian Sea during the SW Monsoon, at odds with our findings. While Fe limitation was never explicitly tested in JGOFS, we suspect there may be significant interannual variability. The Arabian Sea is surrounded by arid regions, which are presumably large potential dust sources, but recent models of Jerry Wiggert, using both GISS- and GOCART-derived simulations to estimate dust fluxes, suggest that there is insufficient aeolian Fe to sustain high levels of monsoon-driven primary production and C export. A critical issue is how much interannual variability there is in air mass trajectories and Fe supply, and how the decadal-scale increase in monsoon intensity reported elsewhere may be influencing these fluxes.

M11: Estimating iron and aluminum removal rates in the eastern equatorial Pacific Ocean using a box model approach

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Iron limitation has been suggested as the reason for the maintenance of the high-nutrient low-chlorophyll condition in the eastern equatorial Pacific Ocean. Changes in the rate and depth of upwelling exert primary control on variable iron supply to the euphotic zone but the effect of biological cycling of iron through scavenging and remineralization remains poorly constrained.

This modeling study constrains the pelagic budget of two trace metals, iron and aluminum. They are co-delivered to the eastern equatorial Pacific surface waters via the Equatorial Undercurrent but show distinct biogeochemical cycling properties. We combine the results of the *in situ* measurements of dissolved Fe and Al from the 2004 and 2005 cruises with the circulation model results to constrain their budgets. Based on the physical balance of fluxes we estimate the net removal rates of Fe and Al through biogeochemical processes. The model calculations are validated with the heat, mass transport, nitrate and silicate budgets, all of which have been previously constrained for the equatorial Pacific. The reported average net removal rates of Fe and Al in the eastern equatorial Pacific are 2.94 μmol-Fe m^2d^{-1} and 21.47 μmol-Al m^2d^{-1}, respectively. The estimated net removal Fe:C ratio varies from 23 to 85 μmol:mol.

The results of our calculations can be used to improve the parameterization of iron cycling in existing ecosystem models and help better constrain the global carbon budget. Moreover, this box model approach, which can be applied to any ocean domain, presents an important alternative to conducting rate measurements in the field.

M12: A Fast Newton-Krylov solver for seasonally varying global ocean biogeochemistry models

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We present a computationally efficient method for obtaining the fully spun-up state of a seasonally varying global ocean biogeochemistry model. The solver uses a Newton-Krylov method to find the fixed points of the map that assigns to an initial state the value of the model state at the end of a one-year run. Apart from the pre-conditioner, which we describe in the paper, the method relies on a black-box public-domain Newton-Krylov solver that does not require the explicit construction of the model's Jacobian matrix. Applied to the PO_4 plus DOP cycle of an OCMIP-2 type model, the solver is more than two orders of magnitude faster than the traditional time-stepping method for spinning up the model. The efficiency of the solver is illustrated by using the seasonally varying globally gridded PO_4 climatology to objectively optimize the parameters that control the mean lifetime of semi-labile DOP and the fraction of new production allocated to DOP. The optimization study demonstrates that the

information in the seasonal variations of PO_4 do not provide a significantly stronger constraint than the annually averaged data used in previous optimization studies.

M13: Potential effects of future changing temperature, light and iron supplies on plankton communities of the Ross Sea, Antarctica

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The Ross Sea, Antarctica features one of the world's largest annual algal blooms, but is also perennially cold and phytoplankton communities have been shown to be periodically light- and iron-limited. This region has been predicted to experience large physical and chemical changes in future climate scenarios, including potentially altered temperature, sea ice cover, stratification and mixed layer depth, as well as possible shifts in aeolian and ice-derived iron supplies. However, little is understood about the potential response of phytoplankton assemblages to the combined influences of these climate-driven changes, and even less is known about potential community dynamics within microzooplankton assemblages. Independent and interactive effects of iron, temperature and light were examined using natural plankton assemblages during two cruises in late austral summer and early austral spring. Increases in temperature (4^oC) and iron (1 nM) individually resulted in significant increases in particulate nutrients, chlorophyll concentration and phytoplankton abundance. An interactive effect of combined increases in temperature and iron resulted in much greater increases in particulates and phytoplankton than would have been predicted by either factor individually. High phytoplankton abundance in iron-replete treatments may be linked to lower observed abundances of microzooplankton. Lower microzooplankton abundance and changes in community composition were likely due to changes in phytoplankton community structure rather than iron toxicity. In contrast, increasing light (300 uE m^2 s^{-1}) and temperature (4^oC) without a concomitant increase in nutrient concentration resulted in little final benefit to phytoplankton assemblages over control treatments. Phytoplankton were quickly driven to iron limitation in this experiment, with concentrations of 0.1 nM or even less in all treatments on the final day and $F_v/F_m \sim 0.3$. Iron limitation appeared to be exacerbated in the combined high light, high temperature treatment relative to the single-factor treatments. Our results highlight the importance of considering interactions among variables and among trophic levels when making predictions about the effects of climate variables on future plankton assemblages.

M14: Links between detrital aggregates on the abyssal seafloor and upper-ocean processes

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A portion of particulate organic carbon (POC) flux to the abyssal seafloor falls as a detrital aggregate material visibly identifiable in photographs. This aggregated material is believed to be underestimated

by sediment traps and could be an important and unaccounted for food input to the deep-sea. Previous estimations of POC flux (food supply) and sediment community oxygen consumption (food demand) in the deep sea have found significant food deficits over interannual timescales. Using time-lapse photographs of the seafloor collected between 1989 and 2006 in the NE Pacific we examined time lagged correlations between the arrival of aggregates on the seafloor and POC flux to 50 and 600 meters above bottom, as well as surface conditions such as zooplankton abundance, satellite-estimated export flux, and upwelling. Using empirically determined relationships between aggregate cover, residence time, and aggregate organic carbon content, we also estimated the degree to which visibly detectable aggregate organic carbon could account for previous discrepancies in food supply and demand. Significant correlations were found between surface ocean processes and detrital aggregates seen on the seafloor. Even when accounting for these aggregates, however, ratios of food supply to demand were still in deficit during the majority of the study period.

M15: Modeling ecosystem dynamics in the Southern Ocean

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We are studying ecosystem dynamics and the carbon cycle in the Southern Ocean with the Biogeochemical Elemental Cycling (BEC) model, which runs within the ocean circulation component of the CCSM3. *Phaeocystis. antarctica* is a key phytoplankton group in the Southern Ocean, which is also an important regulator of carbon and nutrient cycles. We recently added *P. antarctica* as an additional functional group in the BEC model. Currently, the BEC model includes five functional phytoplankton groups (diatoms, diazotrophs, small phytoplankton, coccolithophores and *Phaeocystis*). We explicitly simulate the biogeochemical cycling of multiple key elements (C, N, P, Fe, Si and O). We are seeking the optimum values of ecological parameters for *Phaeocystis* through synthesizing laboratory and field observations and evaluating the model output with observed chlorophyll, biomass and nutrient distributions. There are several main factors that are proposed to control the ecosystem structure and the competition between diatoms and *Phaeocystis*. Those factors are light adaptation, iron requirements and uptake capability, and grazing and other loss processes. Our model sensitivity study examines the competition between diatoms and *Phaeocystis* under bloom conditions in the Southern Ocean. We also propose to evaluate the impacts of *Phaeocystis* on biogeochemical cycles and ecosystem dynamics in the Southern Ocean, which may allow us to better simulate the carbon cycle under different climate scenarios.

M16: Vertical zonation and distributions of Calanoid copepods through the lower oxycline of the Arabian Sea oxygen minimum zone

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Oxygen minimum zones (OMZs) are thought to be expanding in the world's oceans. This phenomenon would have substantial consequences for mesopelagic zooplankton and communities. This report summarizes recent progress in understanding copepod distributions, vertical zonation, and community ecology at midwater depths (300 – 1200 m) through OMZ of the Arabian Sea, especially at the lower oxycline (sharp oxygen gradient at the lower OMZ "edge"). Zooplankton were collected in day and night vertically-stratified MOCNESS tows. Copepod species and species groups differed in their horizontal and vertical distributions relative to environmental and ecological characteristics. Major distributional changes were associated with surprisingly small oxygen gradients at very low oxygen concentrations (0.02 to ~0.3 ml/L) through the lower OMZ. The OMZ also affected diel vertical migration. Although some micronektonic taxa migrated into the OMZ, no apparent diel vertical migration of calanoid copepods was observed at midwater depths in the strongest OMZs. Some prominent species were omnivorous, feeding at multiple trophic levels. OMZ Subzones (Upper Oxycline, OMZ Core, Lower Oxycline, Sub-Oxycline) differed in copepod community structure and ecological interactions. Vertical zonation through the OMZ probably involves complex interactions between physiological limitation by low oxygen, potential predator control, and potential food resources. If OMZs expand in the future as a consequence of climate change, pelagic OMZ and oxycline communities, and their ecological interactions in the water column and with the benthos (where OMZs intersect the seafloor), may become more widespread and important.

THEME 2. CARBON UPTAKE AND STORAGE

T1: Decadal changes in anthropogenic carbon uptake in an isopycnic ocean carbon cycle model

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For recent decades observations indicate a reduction in the strength of major oceanic carbon sinks, in particular those at high latitudes. We use an ocean carbon cycle model based on the isopycnic ocean model MICOM and the ocean biogeochemistry model HAMOCC5.1 to investigate possible mechanisms behind these changes. Isopycnic ocean models represent the ocean as layers of constant density and thus mimic the structure of the interior ocean. This avoids the spurious diapycnal mixing present in z-level models and makes them well suited to simulate tracer transport in the ocean interior. The model was initialised from mean observed nutrient, DIC and alkalinity profiles and spun up using an NCEP-based monthly climatology. We forced the model with observed CO_2 emissions 1860-2000. Global uptake pattern, magnitude and the evolution of the atmospheric CO_2 level in the prognostic slab atmosphere agree well with observations. We investigated the effect of changes in atmospheric forcing on CO_2 uptake by comparing model experiments forced by climatological forcing and NCEP reanalyses 1948-2000. While global CO_2 uptake is not significantly different between the two experiments, large differences appear regionally especially in the North Atlantic, Nordic Seas and Arctic Ocean.

T2: The carbon cycle of Lake Superior: First results from the CyCLeS Project

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CO_2 emissions and seasonal cycling from the Great Lakes may be comparable to that of local terrestrial ecosystems. CO_2 fluxes from Lake Superior are of particular interest because they may

greatly impact observations at nearby Ameriflux towers. Long residence time of water and limited watershed inputs suggests carbon cycling in Lake Superior is tightly coupled with physical processes. We developed a coupled ecosystem-carbon-hydrodynamic model of Lake Superior to estimate carbon fluxes and their spatio-temporal variations. The ecosystem, including two sizes of phytoplankton, macronutrients and a single grazer is implemented to estimate spatial and temporal patterns of carbon cycling in the lake. Carbon as DOC, DIC and POC, and O_2 (as an indicator of biological productivity) are included as state variables upon which ecosystem processes act. Comparison between long term average of chlorophyll data and model predictions are in good agreement. Spatial and temporal patterns of chlorophyll, pCO_2, and CO_2 fluxes as predicted by the model are summarized. These patterns will be used to illustrate some of the factors controlling carbon cycling such as temperature, watershed inputs and some potential consequences of climatic change. Discrepancies between model predictions and measurements will be used to highlight research needs.

T4: Freshwater sources and their influence on carbon flux in the Canadian Arctic Archipelago

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Channels in the Canadian Arctic Archipelago provide the main pathway for the flow of freshwater from the Arctic Ocean to the North Atlantic, mainly via the Labrador Sea. Changes in freshwater transport have possible implications for the deep convection regime in the Labrador Sea, and therefore global thermohaline circulation. Identifying the freshwater distributions and their variability in the Canadian Arctic Archipelago will contribute to our understanding of not only Arctic climate processes, but also of the influence of Arctic water outflow on global climate change. Freshwater dynamics also play an important role in the sequestration and transport of atmospheric CO_2 in the Arctic and to the North Atlantic. River water carries terrestrial carbon including both organic and inorganic forms, while ice melt water contains virtually no carbon. Therefore, distribution of different freshwater sources influences pCO_2 in the surface water and flux to the down stream. Polar oceans are experiencing rapidly decreasing ice coverage and changing hydrological conditions. We will investigate the role of freshwater composition on the carbon uptake in and transport through the Canadian Arctic Archipelago. Dissolved inorganic carbon (DIC) and total alkalinity as well as oxygen isotope composition have been measured annually since 2003 in Barrow Strait (Northwest Passage), in Davis Strait (between Baffin Island and Greenland) since 2004, and in Hudson Bay and Strait during 2003-2006 (MERICA program). Oxygen isotope composition has been used to quantify the freshwater sources, sea ice melt water and meteoric water (precipitation and river runoff) components. DIC is diluted by freshwater in all sections in general, while a stronger relation was observed between freshwater composition and DIC concentration. As the ratio of the sea-ice melt water fraction to meteoric water fraction increases, DIC concentration decreases in Barrow Strait. Introduction of different water masses, multiple freeze-thaw cycles and local biological processes, however, obscure this relationship in Hudson Bay and Hudson Strait, and in Davis Strait. Results from freshwater sources, their geographical distribution and temporal variability, and their influence on carbon dynamics will be discussed further.

T3: Climate impacts on the circulation and thermal structure of Lake Superior

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A three-dimensional hydrodynamic model is applied to Lake Superior on 2-km and 10-km grids to study lake circulation and thermal structure. The model is forced hourly with interpolated meteorological data constructed from land-based weather stations, buoys, and other instruments. A vertical resolution of 5-m near the surface captures the observed thermal structure of the lake, and increasing horizontal resolution from 10 km to 2 km improves the near-shore circulation. The model is able to capture observed seasonal cycles of surface temperature and year-to-year changes in lake thermal structure. We examine the mechanisms controlling lake circulation patterns and consider year-to-year changes in circulation patterns, temperature structure, and stratification onset between 1997 and 2001.

W15: Shedding light on processes that control particle flux and attenuation in the twilight zone

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Upper ocean food webs are responsible for a flux of more than 10 Gt C yr^{-1} exiting the surface ocean, mostly via sinking particles as part of the ocean's "biological pump". More than 90% of that flux is remineralized in the twilight zone, that layer below the euphotic zone and depths of 1000 m. We have used a new analysis of particulate organic carbon (POC) flux at selected sites, and a set of 1-D biological models to shed light on what sets export flux and its attenuation below. Both the data and models suggest that how we sample relative to the depth of the euphotic zone is critical, since this is the layer of net POC production. Current fitting of flux at fixed depths skews our interpretation of twilight zone processes. Our model predicts flux out of the euphotic zone and the extent of attenuation below, which is set by heterotrophic consumption of POC by bacteria and zooplankton, as well as active transport of surface derived POC to depth by zooplankton. Based upon model sensitivity analyses we suggest that variability in zooplankton consumption can have the largest impact on flux vs. depth profiles, and that <30% of the flux can be attributed to active transport, or we'd expect to see more commonly an increase in POC flux at depth. We introduce the Ez-ratio, for the POC flux at the base of the euphotic zone relative to net primary production and T_{100} for the flux ratio 100 m below. A comparison of production, Ez-ratios and T_{100} provides a rapid new metric to classify the ocean into four groups, ranging from high surface export and high subsurface transport efficiency, to sites where one or both of these parameters are low. Future studies would benefit from combined studies of geochemical properties and biological processes that consider such a common sampling and model framework.

T5: Southern Ocean Gas Exchange Experiment

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The Southern Ocean Gas Exchange Experiment (SO GasEx) is the third in a series of US-led open ocean process studies aimed at quantifying air-sea gas exchange. SO GasEx took place in the Atlantic sector of the Southern Ocean near South Georgia Island from February 29 to April 12, 2008. The main objectives of the experiment are to improve quantification of: 1) Gas transfer velocity in a high wind and wave environment; and 2) Air-sea CO_2 fluxes in a region of globally significant CO_2 flux.

An important goal of these efforts is to be able to quantify gas transfer velocities on regional scales from remote sensing such that, when combined with regional ΔpCO_2, global air-sea CO_2 fluxes can be determined. A systematic approach was followed during the cruise and will be continued after the cruise to accomplish this goal that involves the following steps: 1) Perform direct flux measurements to obtain short-term local CO_2 fluxes and gas transfer velocities; 2) Combine integrated measurements of gas transfer velocities using ^3He/SF6 dual tracer technique; 3) Understand the mechanisms controlling ocean mixed layer pCO_2 on short time and space scales and atmospheric forcing; 4) Elucidate the forcing functions controlling gas transfer; and 5) Relate forcing functions to parameters that can be detected by remote sensing.

T6: The impacts of coastal ocean on global biogeochemical cycles

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The continental margins supply organic carbon (OC) and nutrients to the open ocean, which can lead to downstream productivity and respiration changes that influence the air-sea CO_2 balance of the open ocean substantially. However, very little is known about this potentially important interaction of the coastal and open oceans, although some sensitivity studies on the impacts of the coastal ocean on open ocean NPP (net primary production) and air-sea CO_2 flux have been implemented. The purpose of this research is to investigate the impacts of the coastal ocean on global biogeochemical cycles by incorporating a coastal ocean component into the Princeton OCMIP model. The method to include coastal oceans is to restore the model NP (New production) to the NP estimated from satellite chlorophyll data, which include information on nutrient inputs from rivers, sediment re-suspension, and coastal ocean upwelling systems. The initial results show that the coastal oceans have large impacts on the global ocean NPP distributions and air-sea CO_2 fluxes.

T7: Seasonal variability of CO_2 flux estimates in the NW European Shelf

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The magnitude and direction of air-sea CO_2 fluxes in shelf seas is largely unknown but critical for understanding the role of these productive regions in the global carbon cycle, particularly the role of the ocean in taking up anthropogenic CO_2 and the effect of this uptake on ocean pH levels. We analyse the first year's data collected from the PML/CASIX underway pCO_2 instrumentation on the R/V *Prince Madog*, including POL Coastal Observatory cruises in Liverpool Bay and several cruises in the wider Irish Sea. This data is analysed with regard to the annual cycle of pCO_2 and intra-annual modes of variability. Comparison will be made to other areas of the NW European Shelf for which we have data. Future directions to integrate work in the Irish Sea with results from the wider shelf using satellite data and ecosystem modeling approaches will be discussed.

T8: A seasonal CO_2 sink associated with the Mississippi and Atchafalaya Rivers

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Recent studies in the northern Gulf of Mexico and elsewhere have demonstrated that enhanced biological production in large river plumes may influence surface pCO_2 levels, resulting in a net surface influx of atmospheric CO_2. However, such systems deliver large amounts of terrestrial carbon into continental margin waters, and hence, the potential for large and variable signals in carbon flux exists in these regions. Our prior findings for the Mississippi River plume suggest that the late spring and early summer is a period of lower surface pCO_2 corresponding to a strong biological pump and autotrophic fixation of inorganic carbon. Here, we examine an extended set of observations for the northern Gulf of Mexico that includes regions influenced by both the Mississippi and Atchafalaya rivers. A combination of satellite and ship-based observations were used to examine variability in surface pCO_2 and air-sea flux of carbon dioxide. Ship-based observations revealed regions of low surface pCO_2 in June 2006 following a period of moderately high river flow. Low surface pCO_2 was observed in the both the Mississippi and Atchafalaya river outflow regions. These regions corresponded to high chlorophyll concentrations as revealed by ocean color satellite imagery. In contrast, September 2006 surface pCO_2 was uniformly higher with the exception of a localized area around the Mississippi River plume. Our results reinforce earlier findings that large river-dominated margins exhibit highly variable air-sea fluxes of $CO_{2,}$ but may serve as a sink for CO_2 on a seasonal basis.

T9: Effect of dissolved organic matter fractionation on microbial utilization in the ocean

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Microbial utilization of dissolved organic carbon (DOC) in the Atlantic and Pacific oceans was studied using molecular weight fractionation. Low molecular weight (LMW, <500 Da) and high molecular weight (>500 Da) fractions of DOC, along with the whole fraction, were inoculated with filtrate (0.7 μm) surface seawater and incubated in the dark. DOC, oxygen and cell counts analysis were systematically performed to monitor the progress of the incubations. Our results showed that neither DOC degradation nor oxygen consumption occurred during the incubation of the whole samples. On the other hand, LMW sample of Atlantic deep water showed a loss in carbon of up to ~4 μmoles C (~11%) in five days, while oxygen consumption for the same sample was 10 μmoles O_2. The low C/O_2

ratio (0.4) hints that part of the DOC is maybe oxidized to carboxylic acids or similar oxidized carbon compounds. The bacterial growth associated with these incubations was very low, pointing to low cell efficiencies and high respiration rates. Globally, these results suggest that the refractory and old deep DOC could eventually be degraded. Further research is needed to assess the role of physical fractionation of the dissolved organic matter in favoring the degradation of the DOC compared to the non-fractionated samples.

T10: Autonomous measurements of the North Atlantic spring bloom (~61ºN, 25ºW): Early results from the NAB08 experiment

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The North Atlantic spring bloom – one of the largest open-ocean phytoplankton blooms on the planet – is a major component of the oceanic carbon sink. Major impediments to studying phenomena such as the North Atlantic spring bloom have included insufficient temporal coverage with ships, persistent cloud cover, and spatial patchiness. In spring 2008 NAB08 collaborators used a combination of floats, gliders, ships, and satellites to intensively study the spring bloom over a period of time spanning pre- and post-bloom conditions. The primary goals of NAB08 were to 1) provide 3-dimensional coverage of the bloom over time using autonomous platforms, and 2) gain knowledge of how to best use these platforms to study key carbon cycle processes. Two heavily instrumented Lagrangian floats and four Seagliders were deployed near 59.0ºN, -20.5ºW well before the start of the bloom. All measured temperature, salinity, chlorophyll fluorescence and optical backscatter; additionally, floats measured transmission (a proxy for organic carbon), spectral upwelling and downwelling (ir)radiance, and ISUS nitrate. The floats followed water within the mixed layer, additionally profiling once a day between 0 and ~250 m; Seagliders provided a larger spatial context for float measurements and operated to ~1,000m. At the end of June, the experiment was terminated in the vicinity of 61.5ºN, -25.5ºW. Throughout the experiment, mapping of bloom optical signatures by floats and Seagliders revealed km-scale patchiness of about a factor of two and a persistent 10-km scale patch associated with an anticyclonic eddy, as well as larger scale patchiness and eddies.

A process cruise coordinated with floats and Seagliders just as the bloom began in early May; cruise goals were to validate autonomous sensors and enable more comprehensive interpretation of optical data, including those measured by float-based sediment traps and optical plankton counters. Optical signatures of settling particles were observed in chlorophyll fluorescence, optical backscatter, and beam transmission. These signatures first appeared immediately below the mixed layer, over time extending to 250 m and then progressively deeper. They were associated with sinking organic particles, also captured by PELAGRA floating sediments traps. These observations show the power of coordinated autonomous and ship-based sampling, using complementary bio-optical and biogeochemical measurements to measure coupled biophysical processes controlling ocean carbon fluxes.

T11: Carbon in estuaries: Woodwell et al. (1973) revisited

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Because of high area-specific rates of productivity, biogeochemical cycling, and organic/inorganic matter sequestration, understanding fluxes of carbon in estuaries is critical to our understanding of the total global carbon budget. Much research on estuaries in the past decades has refined our thinking about relationships between net primary production, gross production, and total respiration in estuaries, and accordingly measurements of fluxes in estuaries have become more accurate. Recently, researchers have suggested that the net sea- (or ground-) air CO_2 fluxes in estuarine and nearshore systems cannot be constrained precisely until there are good estimates of actual estuarine and marsh area values (Cai et al., 2006). A number of studies have used estimates of estuary areas within the US and the world for calculations that are based on geographic datasets that are more than 35 years old. For example, Woodwell et al. (1973), in a landmark paper on carbon in estuaries, used a geographic dataset that the Department of Interior published in 1970. Given the advent of better geographical data and the revolution that GIS has offered geospatial interpretations in the past decade, we have re-examined the location categories assigned by Woodwell et al. (1973). Using recent NOAA geospatial datasets, we reevaluated estimates and tested the underlying assumption that the ratio of total area of estuary to coastline of the US can be extended to the world. Comparison of area data calculated from recent NOAA data for estuaries in the US with those areas reported in Woodwell et al. (1973) indicates a difference in reported area data ranging from 0.1 to 549%. Estuaries in Hawaii, Alaska, North Atlantic, Pacific Northwest, Pacific Southwest, and Florida show the highest differences in area. These differences could be attributed to technological and data improvements and availability, or to coastal change over the last three decades. The US ratio of total area of estuary:coastline (A_t:L_c) was recalculated to be about 1.2, Australia A_t:L_c = 0.6, and UK A_t:L_c = 0.14. These data emphasize the need to use the latest maps to help bring improvements in the precision of analyses, a conclusion that Woodwell et al. (1973) suggested over 30 years ago. We have recalculated CO_2 evasion rates and carbon budgets using our refined area estimates for estuaries.

T12: Altimetry helps to explain patchy changes in hydrographic carbon measurements

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Observations and five models have been used to evaluate the relative amplitudes of natural variability and the anthropogenic perturbation in dissolved inorganic carbon (DIC) over the upper ocean. There are three main results. First, the amplitude of the natural variability of column inventories of DIC on seasonal to interannual timescales is of the same order of magnitude as the anthropogenic transient signal as it changes over a decade. Second, the latitude/longitude pattern of natural variability is distinct from what is found for the decadal changes in anthropogenic DIC inventories. Third, that dynamically driven variability constitutes at least a first-order component of the total background variability for DIC inventories. In particular, we wish to emphasize that convergence and divergence (column stretching) through the action of Rossby waves can redistribute DIC horizontally in a coherent and persistent way.

Importantly, observations and models indicate that for many regions of the ocean DIC inventory variations on seasonal to interannual timescales are closely related to variability in sea surface height (SSH), which itself reflects variations in the column inventory of density. A notable exception is the well-ventilated North Atlantic, where dynamical variations are not reflected in DIC inventory variations. The implications for the detection of anthropogenic DIC using Repeat Hydrography measurements are discussed.

T13: Rates of net community and gross production in the equatorial Pacific Ocean

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The ocean plays a fundamental role in the natural cycle of CO_2. Changes in the amount of marine net community production (NCP) influence atmospheric CO_2 levels. Understanding the controls on NCP may therefore help us identify possible causes and effects of past climate variability and improve future climate projections. The equatorial Pacific, the largest natural oceanic source of CO_2 to the atmosphere, is an ideal testing ground for theories of the controls of NCP in the ocean because many of the factors that have been proposed to control biological production (i.e. Fe, Si, major nutrients, physical instabilities) vary spatially and temporally throughout the region, making it a natural laboratory. Additionally, the equatorial Pacific is a high nutrient, low chlorophyll (HNLC) region, and processes there are representative of other such regions, including the subarctic Pacific and the Southern Ocean.

In the stratified mixed layer, the geochemical tracer O_2/Ar reflects the balance between new community production (NCP) and gas exchange whereas the triple isotopic composition of oxygen, $\Delta^{17}O$, reflects the balance between gross primary production and gas exchange. In this study, we used continuous measurements of O_2/Ar from an underway membrane inlet mass spectrometer (MIMS), discrete measurements of $\Delta^{17}O$, and estimates of gas exchange in order to constrain NCP and gross production throughout a wide region of the Equatorial Pacific. The extremely dense data coverage allows observation of the heterogeneity in NCP on scales smaller than 100 km. The biological production rates estimated in this study are considered in relation to factors that might be controlling biological production in this climatically important region.

We separately consider three areas of the equatorial Pacific: the eastern equatorial upwelling region, the western equatorial warm pool, and the coastal area near Papua New Guinea. The eastern equatorial upwelling region has the largest gross production, with the greatest rates at the edges of the upwelling zone. The western warm pool has NCP rates from 3 to 12 mmol m^{-2} d^{-1}, with variability on scales as small as 100 km and heterogeneity linked to the influence of ocean islands. The coastal region is marked by elevated gross production and net heterotrophy along the coast, perhaps related to the release of riverine organic material.

T14: Modeling the atmospheric airborne fraction in a simple carbon cycle model

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The airborne fraction - the ratio of the annual increase of atmospheric CO_2 to total emissions from anthropogenic sources – has remained roughly constant over the last 50 years. This quantity has averaged about 50-60%, implying that the ocean and the land biosphere absorb approximately half the human-emitted CO_2. Based on results from state-of-the-art coupled climate-carbon cycle models, this constancy has often been taken as evidence that we are not as yet seeing a “climate-carbon cycle feedback”. On the other hand, recent measurements suggest a slight increase in the airborne fraction, implying a faster increase in atmospheric CO_2 relative to the present rate of anthropogenic emissions, and bringing into question the ability of both the terrestrial and marine carbon systems to take up future anthropogenic CO_2 emissions. Thus, understanding how the airborne fraction responds to anthropogenic emissions is fundamental to our ability to predict future climate change. Here, we apply a simple carbon cycle model to gain insight into this question. Our 3-box model is comprised of a well-mixed atmosphere, a land biosphere component, and an ocean. Ocean uptake of anthropogenic CO_2 is modeled via a transit-time distribution (TTD) or Green's function. The model is able to reproduce both the observed atmospheric CO_2 history and the total inventory of CO_2 in the ocean. Model runs are made for both historical anthropogenic emissions, and for a suite of future climate projections encompassed by the SRES-IPCC emission scenarios. Results are compared with the airborne fraction predicted by more complex climate-carbon models within the C4MIP experiment. Our results suggest that the constancy of the airborne fraction in the last half-century is essentially a consequence of the exponential increase of the historical anthropogenic emissions in that range of time, and should not be taken as a fundamental property of the carbon cycle. In fact, our results suggest that the airborne fraction would increase given an A2-ASF-like emission scenario, and would slightly decrease for a hypothetical “stabilized” scenario, where the anthropogenic emissions were kept constant at present levels for the next century.

T15: Changes in the North Atlantic Oscillation influence CO_2 uptake in the North Atlantic over the past two decades

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Observational studies report a surprisingly rapid decline of the CO_2 uptake in the temperate North Atlantic Ocean during the last decade. We analyze these changes using numerical model simulations for the period 1979-2004, with interannually varying atmospheric forcing. The reorganization in ocean

circulation is a major driver of these CO_2 system changes. NAO climate patterns are overlain by transient events such as the Great Salinity Anomaly. Our analysis indicates that the recent rapid shifts in CO_2 flux are decadal perturbations superimposed on the secular trends and highlights the need for long-term ocean carbon observations and modeling to fully resolve interannual variability, which can obscure detection of the long-term changes associated with anthropogenic CO_2 uptake and climate change.

T16: The CARBOOCEAN-IP: Europe's motor for marine carbon sources and sinks assessment

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CARBOOCEAN is an Integrated Project (IP) funded by the European Commission (Contract 511176-2) with 14.5 Million EUR over a 5 year period to assess the marine carbon sources and sinks with special focus on the Atlantic and Southern Oceans of -200 to +200 years from now. It combines the key European experts in the field from 14 countries and cooperates with 7 research institutes from the US.

Data is made available through the CARBOOCEAN data portal, a search engine that uses a distributed network database that allows access to the data holdings from all partners involved (CDIAC, IFREMER, WDC-MARE).

CARBOOCEAN investigates the following unresolved questions: How large are the Atlantic and Southern Ocean CO_2 sinks precisely? What do European rivers and shelf seas contribute to the large scale CO_2 sources and sinks pattern of the North Atlantic Ocean in relation to uptake within Western Europe? What are the key biogeochemical feedbacks that can affect ocean carbon uptake? What is the quantitative global and regional impact of such feedbacks when forced by climatic change in the next 200 years? With respect to FP7, imperative attention is also being paid to pCO_2 sink monitoring, ocean acidification assessment, and biogeochemical feedback quantification.

In cooperation with CarboEurope IP, CARBOOCEAN IP will generate the missing scientific knowledge that is essential to a global quantitative risk/uncertainty judgment on the expected consequences of rising atmospheric CO_2 concentrations. In order to involve both policy and the general public both IPs created "CarboSchools".

For further information on CARBOOCEAN please visit: http://www.carboocean.org

T17: The sensitivity of air-sea carbon partitioning in a global ocean biogeochemistry model

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A reliable prediction of the future oceanic carbon cycle depends on our ability to quantify the uncertainties associated with parameterization in global ocean biogeochemistry models. We present the sensitivities of the steady-state response of air-sea carbon partitioning with respect to changes in biogeochemical model parameters using a three-dimensional model. We show that the sensitivity of a model in terms of its carbon uptake rate depends critically on the reference parameter values used. For example, the sensitivity of carbon uptake to a change in the parameter controlling the dissolution profile of $CaCO_3$ can differ by a factor of two even when two different equally plausible parameter values are used. This emphasizes the importance of better constraining uncertain model parameters to increase models' predictive skills.

THEME 3. TEMPORAL TRENDS IN ECOSYSTEM VARIABILITY

W1: Temporal variability in SAR11 populations in the euphotic and mesopelagic zones at the Bermuda Atlantic Time-Series study site

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Bacterioplankton belonging to the SAR11 clade of α-proteobacteria were counted by fluorescence in situ hybridization (FISH) over eight depths in the surface layer (0 m- 300 m) at the Bermuda Atlantic Time-Series (BATS) study site from 2003–2005. This quantitative, high-resolution time-series data revealed distinct annual patterns of SAR11 clade abundance in both the euphotic and upper mesopelagic (160–300 m) zones. Spring and summer maxima in integrated SAR11 stocks within the surface 80 m were reproducibly correlated with seasonal stratification of the water column. SAR11 blooms were also observed in the upper mesopelagic each year following convective overturn. Terminal restriction fragment length polymorphism (T-RFLP) data generated from a decade of samples collected at the same site were combined with the quantitative FISH data to model the annual dynamics of SAR11 subclade populations. 16S rRNA gene clone libraries from the spring and summer SAR11 maxima were constructed to verify the correlation of the T-RFLP data with SAR11 clade structure. Clear spatial and temporal transitions were observed in the dominance of three SAR11 ecotypes. The mechanisms that lead to shifts between the different SAR11 populations are not well understood, but are probably a consequence of finely tuned physiological adaptations that partition the populations along physical and chemical gradients in the ecosystem. The correlation between evolutionary descent and temporal/spatial patterns we describe, confirmed that a minimum of at least three SAR11 ecotypes occupy the Sargasso Sea surface layer, and revealed their population dynamics in unprecedented detail.

W2: Spatial and temporal variation of phytoplankton biomass in the Gulf of Maine: Observations and numerical investigations

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A three-dimensional physical-biological model has been used to investigate spatial and temporal variability of phytoplankton growth dynamics in the Gulf of Maine (GoM). The physical model is based on the Gulf of Maine Ocean Observing System (GoMOOS) nowcast/forecast system, which has been issuing 48-hour forecasts of physical conditions since January 2002. The biogeochemical processes are simulated with an ecosystem model consisting of multiple nutrients and plankton

functional groups. The model results are compared with SeaWiFS-derived chlorophyll-a and *in situ* measurements from GoMOOS moorings for the 2002-2008 period. The model reproduces many observed features favorably, such as the timing and intensity of phytoplankton blooms and their spatial distribution in the GoM. The annual mean depth-integrated primary production has the highest value of 380 mg C m^{-2} day^{-1} near the coast and Georges Bank. Ten model sensitivity experiments have been performed to assess the potential impact of several key factors (wind, light, stratification, depth nutrient concentrations, and river discharge) that regulate nutrient transport and phytoplankton productivity.

W3: How changes in ocean color could affect ENSO

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We show that changes in the distribution of shortwave radiation in the upper ocean have the ability to affect the magnitude of ENSO. The response is highly regionally dependent with increased penetration in the subtropical gyres resulting in damping ENSO while increased penetration over the oxygen minimum zones results in enhancing the magnitude of ENSO. This is despite the fact that the thermocline deepens in both cases. The reason for this paradoxical result is that changes in the mean ocean temperatures change the mean state of the atmosphere so as to make it more or less sensitive to changes in sea surface temperature in the East Pacific.

W4: Decadal variability in North Atlantic phytoplankton blooms

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Changes in the timing, intensity and spatial patterns of seasonal phytoplankton blooms have consequences for biogeochemical cycling and ecosystem dynamics. The current ten year record of SeaWiFS ocean colour data allows interannual variability in bloom characteristics to be investigated for the North Atlantic. However, to assess decadal variability, and possible effects of recent climate change, the 10-year SeaWiFS record must be placed in a longer-term context. We apply the same analyses of the phytoplankton bloom to output from a coupled biogeochemical model (MOM4-TOPAZ). The model reproduces the biomes and timing of the bloom well, allowing changes in phytoplankton phenology from 1959-2007 to be addressed. Three biogeographical provinces are identified on the basis of timing of bloom initiation: sub-tropical, sub-polar and a transition region. Decadal variability in the timing of the sub-polar bloom is closely correlated to the phase of the North Atlantic Oscillation. In addition, the transition zone migrates latitudinally with the state of the NAO. Understanding the changes in the underlying physical processes that contribute to this decadal variability will provide insight into the response of lower trophic levels to future climate change. For example, global warming may result in a permanent positive NAO state. Our results suggest that this could result in the start of the sub-polar spring bloom being delayed by > 1 month.

W5: SIBER: Sustained Indian Ocean Biogeochemical and Ecological Research

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There are many outstanding research questions in the Indian Ocean because it is a dynamically complex and highly variable system, yet it is substantially under-sampled compared to the Atlantic and Pacific. The unique physical dynamics of the Indian Ocean arise largely as a result of the Eurasian land boundary to the north, which, among other things, gives rise to the strong seasonally reversing monsoon winds. These winds drive intense upwelling and downwelling circulations and seasonally reversing surface current patterns. These, in turn, give rise to substantial variations in marine biogeochemical and ecosystem response.

Due to this complexity we still do not have a complete characterization and understanding of the primary production variability and dynamics in the Indian Ocean. Nor have the impacts of major physical perturbations, associated with phenomena like the Madden-Julian Oscillation and the Indian Ocean Dipole, been characterized. This is in marked contrast to the Atlantic and Pacific,where the seasonal bloom dynamics and the impacts of interannual influences such as NAO and ENSO are relatively well described and understood. Questions also persist about the role of the Indian Ocean in the global carbon and nitrogen cycles, and about the role of grazing versus nutrient limitation in mediating primary production and bloom dynamics in the Arabian Sea. Furthermore, there is exciting emerging evidence which suggests that Fe limitation may be important in the Indian Ocean and even in the Arabian Sea during the southwest monsoon. However, direct measurements and experiments are limited. Global warming impacts are also becoming apparent in the Indian Ocean, such as the emerging evidence that climate change is influencing the strength of the monsoon winds, and also the rapid warming of the Indian Ocean surface waters, both of which could have profound impacts on biogeochemical and ecosystem dynamics.

The goal of this poster presentation is to raise awareness of the pressing research questions that still need to be addressed in the Indian Ocean and promote research there in general.

W6: Controlling mechanisms of carbon dioxide in the U.S. South Atlantic Bight

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The controlling mechanisms of CO_2 in the South Atlantic Bight (SAB) are examined. After removing pCO_2 variations due to temperature and air-sea gas exchange from the *in situ* pCO_2, residual pCO_2 is estimated. Residual pCO_2, along with other parameters (e.g., DIC (dissolved inorganic carbon), DOC (dissolved organic carbon), DO (dissolved oxygen), Chlorophyll-a, and water currents) are then used to evaluate the CO_2 controlling mechanisms. This study suggests that temperature plays one of the most important roles in the seasonal variations of pCO_2 all over the SAB. Air-sea gas exchange helps to dampen the seasonal changes of pCO_2 on the inner shelf due to the shallow water depth. In addition to annual temperature cycles and air-sea gas exchange, CO_2 shoreward of the coastal frontal zone is largely controlled by terrestrial input of carbon from rivers and salt marshes, and net heterotrophic processes on the inner shelf; CO_2 seaward of the coastal frontal zone is mainly controlled by primary production that is strongly dependent on Gulf Stream-induced intrusions.

W7: Long-term, *in situ* nitrate measurements from Apex profiling floats deployed near HOT and in the Southern Ocean

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The ISUS (In Situ Ultraviolet Spectrophotometer) optical nitrate sensor has been adapted to operate in a Webb Research, Apex profiling float. The Apex float is of the type used in the Argo array and is designed for multi-year, expendable deployments in the ocean. Apex/ISUS floats park at 1000 m depth and make 61 nitrate measurements at depth intervals ranging from 5 m in the upper 100 m to 50 m below 400 m as they profile to the surface. CTD and oxygen are reported at 2 m depth intervals. All data are transmitted to shore by satellite and they are available on the Internet (http://www.mbari.org/chemsensor/floatviz.htm) in real time. Floats equipped with ISUS are capable of making 280 vertical profiles from 1000 m. At a 5-day cycle time, the floats have nearly a four-year endurance. Two floats have now been deployed at HOT and at 50°S, 30°E in the Southern Ocean. The HOT float has made 42 profiles over 175 days and should continue operating for >3 more years. Nitrate concentrations are in excellent agreement with the long-term mean observed at HOT. No significant long-term drift in sensor response has occurred, although particulate matter (marine snow?) settling on the optics has caused constant offsets (<1 μM) in nitrate computed over complete profiles on several ascents. We have corrected for these errors by assuming a constant nitrate at 1000 m and then applying the 1000 m offset over the whole profile. One standard deviation of all corrected nitrate measurements in the upper 100 m, where nitrate is typically <0.1 μM, is 0.25 μM and the detection limit would be near 0.5 μM. A variety of features have been observed in the HOT nitrate data that are linked to contemporaneous changes in oxygen production and density. The impacts of these features will be briefly described. The Southern Ocean float has presently operated for 125 days in HNLC waters (surface nitrate >24 μM) and is now observing reinjection of nitrate into surface waters as winter mixing occurs. We expect that the Southern Ocean float will provide a quantitative measurement of the timing and magnitude of the spring bloom via the drawdown of surface nitrate. Additional Apex/ISUS floats are being prepared for deployment at Ocean Station Papa and at BATS. New sensors in development for float deployments include a high stability ISFET pH sensor. A fleet of profiling floats equipped with sensors for oxygen, nitrate, pH and bio-optics would revolutionize our understanding of seasonal to decadal scale ecosystem processes in the ocean.

W8: Chlorophyll to carbon ratio in marine phytoplankton estimated from satellite measurements

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The physiological variability of chlorophyll to carbon (Chl:C) in phytoplankton complicates the conversion of chlorophyll, which is one of the most prolific and robust biological measurements in the ocean, to phytoplankton biomass and Particulate Organic Carbon (POC). The Chl:C ratio, which depends on light, nutrient limitation, and temperature, has been shown to vary by as much as a factor of 50 in mesocosm experiments. The question is to what extent this variability exists in natural ecosystems. We present a new satellite-based estimate of the Chl:C ratio modeled from the phytoplankton growth rate, a parameter on which the earliest laboratory models for Chl:C were based.

This is done by tracking satellite Chl within the ocean circulation field of a regional model for the Gulf of Maine. The Chl:C ratio calculated from an empirical model is found to be much better constrained than was reported in experiments, and seems to be primarily sensitive to temperature. Its variability is enhanced during the spring and summer, when both temperature and growth rates can be high.

W9: Decadal primary production variability at station ALOHA: Revealed by data assimilation

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A 17-year (1989-2005) data assimilative regional testbed for 1-dimensional ecosystem modeling was set up at the Hawaii Ocean Time-series (HOT) Station ALOHA. The testbed was forced by NCEP reanalysis light radiation, HOT observed temperature and mixed-layer depth, as well as derived vertical eddy diffusivity and velocity from HOT CTD measurements. 15 types of HOT observations were assimilated including nitrate, phosphate, phytoplankton biomass, primary production, heterotrophic bacterial biomass and production, dissolved organic carbon (DOC), nitrogen (DON) and phosphorus (DOP), particulate organic carbon (POC), nitrogen (PON) and phosphorus (POP) and particle flux of carbon, nitrogen and phosphorus. The variational adjoint method was used to optimize model parameters to minimize the misfits between modeling results and the assimilated data. We constructed an ecosystem model focusing on (1) microbial dynamics including N_2-fixing and heterotrophic bacteria and (2) variable stoichiometry of carbon, nitrogen and phosphorus. By implementing this model on the testbed, a set of optimal parameter values was obtained at a specific year and this one-year optimized parameter set was used to simulate the system over the whole period of 17 years. The modeled primary production was comparable to the observations in some years while the misfits were high in other years, which indicated there must be internal variations of the ecosystem. To further investigate possible reasons for this variability, data assimilation was implemented for all 17 years and the optimal parameter values were obtained for each individual year to study their temporal variations. This work demonstrates the prospective values of long-term observations for marine ecosystem modeling.

W10: Particulate biogenic fluxes within the euphotic zone of the Cariaco Basin, Venezuela

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To understand the flux of biogenic particles within the euphotic zone of the Cariaco Basin, seven deployments of drifting sediment traps were carried out between March 2007 and May 2008, collecting settling material at 50 and 100 m. This work aims to: (1) determine if there are significant differences in the flux of particulate organic carbon (POC), nitrogen (PON) and calcite between these two depths, (2) determine the biological source of these components, (3) compare these flux rates with those of the moored traps deployed in the basin, and (4) determine if variability of surface chlorophyll-*a* concentrations affects the sinking rate of these particles. Significant differences in the settling rate of biogenic particulate material were found between sampled depths and months. We found that the flux

of calcium carbonate and planktonic foraminifera were usually higher at 100 m than at 50 m. This suggests that the depth of maximum flux of particulate inorganic carbon in the basin could be controlled by the vertical zonation of the foraminiferal assemblage, which is determined by the temperature structure of the water column.

Our flux measurements of phytoplankton cells show that the settling rate of POC and PON is affected mainly by diatoms, the dominant group of the phytoplankton assemblage. As opposed to the deep moored traps measurements, our data exhibited significant correlations between surface chlorophyll *a* concentrations and biogenic fluxes, suggesting connections between seasonal changes in primary production (PP) and the flux of organic matter within the first 100 m. Future work includes estimating fluxes of opal (biogenic silica), particulate organic phosphorus (POP) and lithogenic material for the periods sampled, and examining factors that influence changes in the isotopic composition of carbon and nitrogen of settling particulate material; the isotopic composition will be examined to investigate the origin of the material.

W11: Satellite retrieval of phytoplankton size distribution

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Phytoplankton cell size is important to biogeochemical and food web processes. The goal is to determine the relative importance of phytoplankton cell size in remote sensing reflectance (Rrs) spectra in the presence of other optically active constituents. This is addressed through implementation of a forward optical model that incorporates the range of absorption and scattering variability due to phytoplankton and colored dissolved matter (CDM) in the global ocean from which Rrs is calculated by the radiative transfer software, Hydrolight. Spectral Rrs is investigated in terms of spectral shape and magnitude to ascertain changes in community size structure and the relative contribution of chlorophyll and size to the overall Rrs spectra. Thresholds for chlorophyll and CDM concentration are determined, above which, the dominant constituent masks any spectral shifting due to size. *In situ* observations of cell size are used in conjunction with matched SeaWiFS Rrs spectra to determine if Rrs shifts can be discerned from a satellite platform. We seek to establish the role phytoplankton cell size has played in the observed change in chlorophyll concentration over the SeaWiFS mission.

W12: Monitoring and modeling of Florida shelf carbonate saturation state

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There is a severe lack of empirical data to evaluate how ocean chemistry is changing due to the absorption of anthropogenic carbon dioxide, and how these changes will affect biogenic calcification rates in coastal waters. Lack of baseline data on carbonate saturation state and pCO_2 on the inner Florida shelf, a low gradient calcium carbonate platform, inhibits managers' and scientists' ability to predict ecosystem change resulting from ocean acidification. Saturation state models using remote sensing data that are now being developed are generally too coarse to be useful for the Gulf of Mexico and do not include near shore and inner shelf data, and are lacking in information for specific important ecosystems, such as Florida coral reefs. Maps depicting pCO_2 and carbonate saturation states over large latitudinal gradients are needed on the Florida shelf and for specific localities where significant decline of carbonate ecosystems, habitats, and calcifying organisms are predicted over the next decade.

To address critical information gaps and nearshore variability of carbon fluxes, USGS is working with University of South Florida (USF) and NOAA to acquire baseline pCO_2, pH, and alkalinity data to create a nearshore to offshore regional carbonate saturation state model for the west Florida shelf. These data are being used in conjunction with habitat data to monitor habitat change over time. Using the Multiparameter Inorganic Carbon Analyzer (MICA) developed by USF, data on air and sea pCO_2, pH, and total carbon were collected during a pilot cruise west of Tampa Bay. Maps depicting carbonate saturation state of the marine water, underlying sediment, and habitat data show relationships in specific localities. Additional cruises are planned for August and December of this year.

W13: An increase in primary productivity at BATS and HOT: Do ocean color models agree?

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The time-series of oceanographic data obtained from the stations at the Bermuda Atlantic Time-Series (BATS) and the Hawaii Ocean Time-Series (HOT) are highly valuable to studies concerned with marine ecosystem and climate change. The suite of parameters measured on a monthly basis provides information on the state of the local ecosystem and its variability through time. Among these parameters, measuring net primary productivity (NPP) is foremost essential in order to understand the dynamics of the marine food web from a bottom-up perspective. Moreover, NPP is a major component of the global carbon cycle in that primary producers serve as sinks for atmospheric CO_2. As important as these measurements are at BATS and HOT, these two stations only represent a very small portion of the ocean, thus we must rely on NPP models to cover the oceans on a global scale. Therefore, NPP models must be tested to determine if they can accurately simulate the observed NPP trends. This is especially important for studies that rely on models to predict the effects of global warming on the marine carbon budget.

At both BATS and HOT, depth-integrated primary productivity has been gradually increasing over the past two decades (BATS $r^2 = 0.030$; HOT $r^2 = 0.034$). The major goal of this study was to test whether or not various types of NPP models simulate the observed increasing trends at both stations. Ocean color models are the most common in the estimation of NPP. Although these models can use multiple input fields, they all rely on sea surface chlorophyll. There are two types of chlorophyll measurements at the two stations, fluorometric and high performance liquid chromatography (HPLC). At both stations, HPLC chlorophyll has been increasing with NPP while fluorometric has not. Therefore, we compared *in situ* NPP at BATS and HOT to ocean color modeled NPP using both measurements of chlorophyll.

Of the 13 ocean color models tested, none estimated the increasing trend of NPP at BATS and HOT when fluorometric surface chlorophyll was used. However, when the models used HPLC chlorophyll, the r^2 values significantly increased and produced an increasing trend at both stations (ANOVA: BATS

P < 0.005; HOT *P* << 0.0001). When using HPLC chlorophyll, only one model produced similar r^2 values to the observed trend at both stations (not the same model at each station). All of the models, however, did not do any better at estimating the mean NPP at both stations when using either source of chlorophyll.

Our results suggest that ocean color models may be limited by the source of chlorophyll when used to estimate trends in NPP, at least in the well stratified tropical regions where BATS and HOT are located. If ocean color models rely on satellite-derived chlorophyll that is typically calibrated to fluorometric *in situ* measurements, they may not be able to estimate NPP trends accurately.

W14: Seasonal variability in phytoplankton carbon and size structure at the Martha's Vineyard Coastal Observatory

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New insights into the controls on coastal phytoplankton communities require interdisciplinary time series observations. We are taking advantage of new observing technologies combined with the capabilities of the Martha's Vineyard Coastal Observatory (MVCO) to focus on processes over the inner shelf off the northeast coast of the US. Our approach depends on high resolution (~hourly) multi-year time series of taxonomically resolved phytoplankton acquired with FlowCytobot and Imaging FlowCytobot, custom-built automated submersible flow cytometers optimized for measurement of picoplankton and microplankton, respectively. From a combination of flow cytometric signals and cell images, we are able to produce time-series of size structured phytoplankton carbon (estimated from cell volume of 100s of millions of individuals). Annually at MVCO, bloom events are typical in fall and winter, which Imaging FlowCytobot measurements show are dominated by microplankton, especially large (often chain-forming) diatoms. As water temperatures warm in spring, the community shifts to one dominated by pico- and small nanophytoplankton. Notably, this transition is associated not only with a decline in biomass of large diatoms, but also with a dramatic increase (100- to 1000-fold for picoplankton) in small cells. Ongoing work is focused on hypotheses about the roles of light, nutrients, and temperature in regulating these seasonal changes.

DATA MANAGEMENT POSTER PRESENTATION
(To be posted for the duration of the workshop)

The Biological and Chemical Oceanography Data Management Office (BCO-DMO)

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Where will the data be published? Authors of research proposals must be able to answer this question. The BCO-DMO (http://www.bco-dmo.org) has been funded by the NSF Biological and Chemical Oceanography Sections to help investigators manage their data in support of the OCB community's research interests. BCO-DMO staff members provide research scientists and others with the tools and systems necessary to work with marine biogeochemical and ecological data from heterogeneous sources with increased efficacy. The key to improving access to data is the availability of supporting documentation or metadata. BCO-DMO data specialists work with investigators to generate metadata records sufficient to enable efficient discovery of published data and to support accurate reuse of data by community members. Additionally, the BCO-DMO data specialists work closely with data liaison scientists of medium- to large-scale projects to help these projects better organize their metadata and data before contribution to the BCO-DMO. The new BCO-DMO data system is being designed to support synthesis of heterogeneous data from distributed repositories, a hallmark of ocean biogeochemistry and ecosystem research.