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POSTER ABSTRACTS

Session 1. Multiple Stressors in Marine Ecosystems

Diel cycling hypoxia and pH: Oyster disease dynamics, ecosystem services, and implications for restoration success

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Diel cycles of dissolved oxygen (DO) and pH occur naturally in shallow coastal waters and reflect the net balance of respiration and photosynthesis during the 24 h light-dark cycle. The magnitude of these cycles, and the severity of hypoxia and acidity that result, increase with anthropogenic nutrient loads that increase algal and macrophyte biomass and photosynthesis, and increase animal and microbial biomass that releases CO_2 through respiration. In many shallow areas of Chesapeake Bay during summer, DO concentrations vary from supersaturated during mid-day to between near zero and about 50% saturation in early morning hours. Over the same daily cycles, pH can fluctuate from 8.0 or higher in mid-day to 7.0 at dawn. Analysis of data from mesohaline sites included in the MD-DNR shallow water monitoring program indicates that mean daily minimum DO concentrations and mean daily minimum pH are highly correlated.

Little is known about the consequences of chronic exposure to diel-cycling hypoxia and pH. During the past several years, we have conducted field and laboratory experiments designed to test the effects of diel-cycling hypoxia on acquisition and progression of *P. marinus* (dermo) infections in the eastern oyster (*Crassostrea virginica*) and on oyster growth and filtration. Laboratory and field experiments both indicated that diel-cycling hypoxia increases acquisition of *P. marinus* infections, most likely by reducing immune responses, and reduces oyster growth. Field experiments also found more rapid progression of infections. Oyster filtration declined in response to decreasing DO, but rapidly recovered as DO increased. Older oysters showed a compensatory response with elevated filtration rates following exposure to hypoxia. qPCR assays indicated that non-lethal diel-cycling hypoxia decreases the release of infective cells – possibly because of lower filtration rates and feces production – and therefore may not increase exposure of nearby oysters to *P. marinus*. Our results indicate that diel-cycling hypoxia can create spatial variation in disease dynamics and is important to consider in restoration siting, but the ability of oysters to access the water column in shallow sites may mean that there is potential for restoration of appropriate scale to create positive feedback favorable for oyster populations at currently degraded sites.

We are now conducting experiments to test effects of diel-cycling pH alone and in combination with diel-cycling hypoxia on disease dynamics, filtration and growth of oysters. Our field experiments and prior physiological research (Boyd and Burnett, 1999) indicate that low pH levels that frequently occur in Chesapeake Bay oyster habitat should increase disease prevalence and intensity. We have developed an automated experimental system controlled by LabView software that regulates the flow of O_2, CO_2, N_2, and CO_2-stripped air to aquaria fed with flowing, unfiltered estuarine water based on feedback from Durafet pH sensors and Oxyguard DO sensors. pCO_2 is continuously monitored. Results of preliminary experiments during summer 2011 indicated that oyster filtration rates were not affected by pH of 7.1 – a level that has been shown to affect oyster hemocyte function.

Gel particles and aggregation under high CO_2 and temperature conditions: *Preliminary results from mesocosm experiment*

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A controlled mesocosm experiment was conducted to study the effect of ocean acidification and increased temperature on phytoplankton growth and community structure, gel particle concentrations (Transparent Exopolymer Particles, TEP, and Coomassie Stainable Particles, CSP), and aggregation processes. Treated mesocosms were manipulated to simulate future CO_2 concentration (750 ppm) by addition of high-CO_2 seawater, at two different temperatures, 16°C and 20°C; each treatment was carried out in triplicate. A third set of mesocosms were maintained at present CO_2 concentration (380 ppm) and 16°C. After nutrient addition, the development and decline of the natural phytoplankton assemblage bloom was monitored for 21 days; during this period, the tanks were sampled four times, and four rolling tank experiments were conducted to study aggregation.

Our results show that TEP in seawater was more abundant during the bloom decline in all the treatments, while highest abundance of CSP coincides with the chlorophyll maximum. This confirms our previous findings that these two particle types are different. Roller tank experiments indicate that aggregates were enriched in gel particles in all treatments, supporting the key role of gel particles in aggregate formation. CSP was relatively more abundant on aggregates during the bloom, while TEP was more abundant on aggregates during the bloom decline, indicating that the role of TEP and CSP on aggregation changes depending on the phase of phytoplankton growth. Higher temperature tanks bloomed earlier, but no significant differences between CO_2 and temperature treatments were observed in overall nutrient uptake, phytoplankton biomass, gel particle concentration or aggregation. These results agree with our 2010 chemostat experiments with cocolithophores, and previous work that suggests that 1) further increase in atmospheric CO_2 may not lead to a higher conversion of DIC to TEP as the rate of TEP production seems to be at its maximum under present atmospheric CO_2 concentrations (Engel 2002), and 2) abiotic formation of TEP is not altered by high CO_2 concentrations and low pH (Passow 2012).

Factors controlling diazotroph biogeography

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We present a theoretical framework, which considers the competition for iron, phosphorus and nitrogen resources to explain the biogeography of nitrogen fixing autotrophs (diazotrophs). Here we assume that diazotrophs require higher iron quotas, and have slower maximum growth relative to other phytoplankton. The theory then suggests that the rate of supply of iron or phosphorus relative to the supply of fixed nitrogen sets the regions where diazotroph can coexist with other phytoplankton. The framework also indicates that iron, phosphate and fixed nitrogen concentrations can be strongly controlled by the local phytoplankton community. We show that the framework allows us to divide the ocean of an earth system model into five clearly defined biogeographical provinces. We consider how these province boundaries shift in a warming world based on the changes to the relative supplies of fixed nitrogen, iron and phosphate.

Metabolically induced pH fluctuations by some coastal calcifiers exceed projected 22nd century ocean acidification: A mechanism for differential susceptibility?

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Anthropogenically mediated decreases in pH, termed ocean acidification (OA), may be a major threat to marine organisms and communities. Research has focused mainly on tropical coral reefs, but temperate reefs play a no less important ecological role in colder waters, where OA effects may first be manifest. Herein, we report that trends in pH at the surface of three ecologically important cold-water calcifiers (a primary producer and herbivores), under a range of fluid flows, differ substantially from one another, and for two of the three calcifiers, the pH, during darkness, is lower than the mean projected pH due to OA for the surface waters of the global ocean beyond the year 2100. Using micro-electrodes, we show that each calcifier had a different pH gradient between its surface and mainstream seawater, i.e. within the diffusion boundary layer (DBL) that appears to act as an environmental buffer to mainstream pH. Abalone encountered only mainstream seawater pH, whereas pH at the sea urchins' surface was reduced by ~0.35 units. For coralline algae, pH was ~0.5 units higher in the light and ~0.35 units lower under darkness than in ambient mainstream seawater. This wide range of pH within the DBL of some calcifiers will probably affect their performance under projected future reductions in pH due to OA. Differing exposure to a range of surface pH may result in differential susceptibility of calcifiers to OA. Such fluctuations are no doubt regulated by the interplay of water movement, morphology and metabolic rates (e.g. respiration, calcification and/or photosynthesis). Our study, by considering physics (flow regime), chemistry (pH gradients vs. OA future projections) and biology (trophic level, physiology and morphology), reveals that predicting species-specific responses and subsequent ecosystem restructuring to OA is complex and requires a holistic, eco-mechanical approach.

Exploring the gene expression and physiological response of pteropods to high CO_2 and its synergistic interaction with low O_2

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Ocean acidification, resulting from the dissolution of excess CO_2 produced by humans into the ocean, is predicted to influence a broad variety of marine taxa, particularly calcifying animals such as the thecosome (shelled) pteropods. In nature, when planktonic organisms experience high CO_2, they frequently are also concomitantly exposed to hypoxia. To achieve a better understanding of the mechanisms of pteropod physiological compensation for acidosis and hypoxia, we are investigating metabolic and transcriptomic responses of various species of euthecosomatous pteropods. Individuals were sampled from the Northwest Atlantic in the Fall of 2011 and were exposed to conditions mimicking predicted CO_2 levels at the end of the century (800 ppm) in a factorial design with O_2 stress (10% O_2), and their oxygen consumption was measured. Although these planktonic mollusks are thought to be sensitive to acidification, there was no significant effect of our brief laboratory exposure to CO_2, although there were species-specific responses to hypoxia and the synergistic effect of CO_2 and hypoxia. To identify additional pathways that may be affected by acidification, we are using RNA-seq to assess transcriptome-wide effects of exposure to elevated CO_2 on the cosmopolitan species *Clio pyramidata*. Thecosome pteropods have no published transcriptome, requiring a *de novo* transcriptome assembly prior to an assessment of differential gene expression patterns. This technique will allow us to quantitatively describe the specific physiological pathways up- or down-regulated by *Clio pyramidata* when they are exposed to high CO_2 in order to direct future work into the costs of maintaining homeostasis under conditions of increasing acidification for these important planktonic calcifiers.

Iron requirement for coastal and oceanic strains of *Emiliania huxleyi*

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Experiments with coastal and oceanic strains of *Emiliania huxleyi* demonstrate that coastal *E. huxleyi* have a significantly higher iron requirement for growth than oceanic *E. huxleyi.* For the oceanic strains from the North Pacific, Equatorial Pacific, and the Sargasso Sea, the growth experiments show a basin scale variability when iron is deplete and replete. In particular, the strain from the Equatorial Pacific (1516) showed very high growth, despite iron deplete conditions. For the two coastal strains originating from Oslo fjord (370) and the English Channel (379) the experiments showed a decrease in growth under iron deplete conditions and reduced growth at high iron conditions, while two strains from the Gulf of Maine only experienced a small reduction in the growth rate at iron limited versus iron replete conditions.

Carbon cycle sensitivities in modeling biological processes in the NASA-GISS climate model

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Sensitivities in modeling the biological pump in the GISS climate model are explored here. Results are presented from twin control simulations of CO_2 gas exchange between the ocean and the atmosphere using two ocean models coupled to the same atmosphere (modelE). The two ocean models (Russell ocean model and Hybrid Coordinate Ocean Model, HYCOM) use different vertical coordinate systems, and therefore different representations of column physics. Both variants of the GISS climate model -- modelE with the Russell ocean and modelE with the HYCOM ocean -- are coupled to the same ocean biogeochemistry module (the NASA Ocean Biogeochemistry Model, NOBM) which computes prognostic distributions for biotic and abiotic fields that influence the air-sea flux of CO_2 and the deep ocean carbon transport and storage. In particular, the model differences due to remineralization rate changes are compared to differences attributed to physical processes modeled differently in the two ocean models such as ventilation, mixing, eddy stirring and vertical advection. The Southern Ocean emerges as a key region where the CO_2 flux is as sensitive to biological parameterizations as it is to physical parameterizations.

An ecophysiological model of particle remineralization in the deep ocean

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Sinking organic particles are a rich food source for heterotrophic bacteria living in the mesopelagic zone of the ocean environment. Bacteria can only transport bits of organic molecules into the cell, and have adapted to overcome this constriction by producing extracellular enzymes to cleave bits of organic matter from larger molecules, effectively transferring an essential function to the external environment. As bacteria metabolize, organic matter is converted back into inorganic nutrients. In order to assess the mechanisms of remineralization, we have developed a 1D Eulerian model of a particles sinking from 150 m to 4000 m to look at production and activity of particle attached bacteria and extracellular enzymes in the context of marine ecosystems. The model includes six state variables: dissolved organic matter, particulate organic matter, free-living bacteria, particle-attached bacteria, extracellular enzyme, and hydrolysate. Key processes include ballast interference with enzyme activity and quorum sensing. The model successfully reproduces the pattern of particle attenuation measured by sediment traps deployed as part of the Bermuda Atlantic Time Series (BATS) and the Oceanic Flux Program (OFP) in the North Atlantic subtropical gyre. A

future application of the model will be to explore the effect of environmental stressors especially temperature on particle remineralization.

Growth and distribution of *Lophelia pertusa* under 'acidified' conditions in the Southern California Bight

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In the California Current System of the Northeast Pacific, water that is undersaturated with respect to aragonite is upwelled along the continental shelf, reaching the surface at some locations. Similar conditions are not predicted for open-ocean North Pacific waters for several decades. The Southern California Bight (SCB) thus provides a "natural laboratory" for studies of deep-water scleractinian corals growing under acidified conditions.

The geographic and vertical distributions of *Lophelia pertusa* in the SCB were characterized using photo and video surveys from >400 submersible dives from NOAA's National Marine Fisheries Service. The environmental conditions surrounding *Lophelia* sites were assessed using data from the California Cooperative Oceanic Fisheries Investigations (CalCOFI) and an algorithm developed to estimate aragonite saturation (Ω_A) from temperature and dissolved oxygen (Juranek et al., 2009; Alin et al., 2012). Preliminary results suggest that coral in this region is found at the lowest aragonite saturation states ever reported for framework-forming scleractinians. Furthermore, dissolved oxygen averaged over the past four years is less than half the global average for the coral. Despite large variation in many environmental conditions for shallow sites relative to deeper sites in the Bight, perhaps a stressor in itself, the range of temperatures for *Lophelia* was remarkably narrow and closely matched global averages.

Lophelia pertusa does not appear to form large reefs in the naturally 'acidic' Southern California Bight. While identifying the environmental parameters that may limit growth, we hope to provide insight to the vulnerability of deep corals to ocean acidification worldwide. At these depths and locations, *Lophelia* in the Bight is facing impending acidification, oxygen declines, and warming temperatures. Environmental data, most notably aragonite saturation state, for deep-water corals is usually extremely limited both spatially and temporally. The extensive data available from over 50 years of CalCOFI hydrographic surveys and regional models developed for estimating the carbonate system can be used to greatly enhance our understanding of how environmental parameters affect coral growth and distribution.

A satellite-data assimilative study of the lower trophic level ecosystem on the northeast U.S. continental shelf

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The last decade has witnessed significant advances in high-resolution numerical models of the coastal ocean carbon cycle. While the large-scale hydrodynamics can now be reproduced reasonably well, the ecosystem counterpart remains less well developed. Recent efforts have been directed toward incorporating complex food webs, including multiple phytoplankton (P) and zooplankton (Z) compartments, into these coupled models. This naturally leads to the question: how much complexity should be included in these models in order to accurately simulate coastal carbon cycles? Specifically, how many P and Z compartments need to be represented? This question is being investigated using data assimilative models and rigorous comparison of the relative performance of models with varying numbers of P and Z compartments. However, first we must answer a critical question: what types and how much data are required to address this model complexity issue?

Here we address this question by implementing a Nitrogen-Phytoplankton-Zooplankton-Detritus (NPZD) type model with 2P and 1Z compartments in a 1D assimilative (variational adjoint) model testbed at six sites along the Mid-Atlantic Bight. The assimilation of satellite-derived chlorophyll concentrations (Chl), size-differentiated chlorophyll concentrations (size-Chl) and particulate organic carbon (POC) fields results in a significant improvement in model skill. Numerical twin experiments assimilating synthetic (i.e. model-derived) data demonstrate that three parameters can be successfully optimized: the maximum Chl to carbon ratio, initial slope of the P photosynthesis-light curve and the maximum P growth rate. Realistic satellite-data assimilation experiments were conducted to investigate: (1) whether data from multiple sites are necessary for the assimilation; and (2) which types of satellite data (Chl, size-Chl, and/or POC) are critical for the assimilation.

When satellite Chl and POC data were assimilated individually at each of the six MAB sites, the model showed significant improvements in model-data misfit; however, the resulting optimized parameter values were often unrealistic as a result of overfitting the model to the data. In contrast, when the same set of data were simultaneously assimilated from multiple (six) sites, model-data misfit was again reduced, but this time the resulting optimized parameter values were generally within the range of those reported in the literature. These simultaneous assimilation experiments also demonstrated that when assimilating only one data type (Chl or POC), the model improved the estimates of this given field, often at the cost of increasing the misfit for the other variable. Overall, the experiment assimilating size-class Chl and POC data generated the lowest model-data misfits. These results suggest that assimilating size-class Chl and POC data at multiple sites may help produce the most realistic simulation of the carbon cycle for a given ecosystem.

Session 2. Ocean biogeochemistry from satellite data

Detection of long-term trends in satellite ocean chlorophyll data

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Global climate change is expected to affect the ocean's biological productivity with impacts for fisheries. Satellite data provides the most comprehensive information about the global distribution of contemporary ocean productivity (SeaWiFS, MERIS and MODIS-Aqua). With 15 years of satellite ocean color data available now, can we start detecting trends in ocean chlorophyll? We show that there are a few regions where trends may be detectable already, but globally the signal is not large enough to be distinguishable from the red noise. The short length of the time series especially challenges the detection of trends in satellite ocean chlorophyll. The additional challenge of an interruption in the measurements is also likely to arise, as the SeaWiFS instrument stopped transmitting in December 2010, MERIS in May 2012, and the last one being operated, MODIS-Aqua, has already exceeded its operational lifetime. We demonstrate how interruptions in the time series at various points would affect our ability to detect trends in ocean chlorophyll. This highlights the importance of maintaining continuous records for climate change detection and attribution studies.

Towards synoptic estimates of the metabolic status of the North Atlantic subtropical gyre

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High concentrations of anthropogenic CO_2 are stored in the upper north Atlantic subtropical gyre (NASG). As atmospheric CO_2 is projected to increase, the fate of this anthropogenic CO_2 will ultimately depend on the metabolic balance of the gyre. This balance results from the competition of autotrophic production and community respiration and determines if the ecosystem is a net source or sink of CO_2.

Despite previous studies, there still is considerable debate about the metabolic status of the NASG: biogeochemists suggest that it is a (weak) sink of atmospheric CO_2, while other researchers report on its net heterotrophy. Based on climatological data (pCO_2, sea-surface temperature and salinity, mixed layer depth, and satellite-based net primary production), we computed estimates of net community production (NCP) and heterotrophic respiration in the upper water column of the NASG. We will analyse the variability of the derived NCP horizontally, vertically and seasonally and present a preliminary annual budget. Finally, the most likely sources of uncertainties will be discussed.

Cyclone-driven terrestrial material transport to the Okinawa Trough: direct satellite observations

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By using satellite-derived water transparency images, we found significant terrestrial material transported to the Okinawa Trough off northeast Taiwan caused by Typhoon Morakot. Three sources were identified, one is from the coast of mainland China, second is from the west coast of Taiwan, and the third is from the east coast of Taiwan. Triggered by Typhoon Morakot, the terrestrial material from the coast of mainland China crossed the Taiwan Strait and transported to the northeast of Taiwan. Carried by the Kuroshio, the terrestrial materials were then transported northeastward along the western edge of the Kuroshio. The event lasted for more than two weeks. Besides the particulate terrestrial material transported to the Okinawa Trough, nutrients were also transported to the Kuroshio main stream. A significant phytoplankton bloom was observed along the Kuroshio path for about 300 km long off northeastern Taiwan. Further, the region of cold water off northeast Taiwan was significantly enlarged by the passage of Typhoon Morakot. Previous studies have all suggested that this effect is caused by the enhancement of upwelling of the Kuroshio Subsurface Water by Ekman pumping, and the motion of the Kuroshio axis to the shelf during typhoon events. This investigation, for the first time, shows that the transport of cold runoff or coastal waters is also responsible. Our result also indicates that the cyclone-driven terrestrial material transport is an important source of mud in the Okinawa Trough.

Resolving the depth of the ocean's productive layer

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The ocean's productive layer extends from the surface to the depth where autotrophic production balances respiration, the compensation depth. Traditionally, the compensation depth has been assumed equivalent to the depth at which surface solar irradiance (broad-band visible) is attenuated to 1% of its surface value, but this has never been verified by direct biological measurement. Thus, a critical dimension to the ocean's carbon cycle remains unknown. Here, we use measurements of net primary production (P) combined with calculated estimates of phytoplankton respiration (Rp) to determine the actual depth of the ocean's productive layer. The compensation depth (where P = Rp) is found to be much deeper than traditionally assumed, especially in offshore waters. It occurs, however, over a depth range that encompasses virtually all autotrophic biomass. The compensation depth also occurs near or at the depth of 1% of surface blue light (490 nm), an environmental index that supports the determination of the ocean's productive layer from satellite ocean color sensors.

Assessment and propagation of uncertainties in input terms through an ocean-colour-based model of primary productivity

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Net primary productivity (NPP) fields, derived from satellite observations of ocean colour, are commonly published without relevant information on uncertainties. In this study, we assessed the uncertainty in NPP estimates of the Vertically Generalized Productivity Model using a Monte Carlo approach. We did not consider the uncertainty stemming from the basic model formulation, but restricted the uncertainty analysis to input terms, which were generated by, or related to, remote sensing. The study was based on global monthly remote sensing data from 2005. We found that the typical distribution of uncertainty around the model output could be approximated by a lognormal probability density function. On average, NPP value in a grid cell was overestimated by 6%, relative to the mean of the corresponding uncertainty distribution. The random component of uncertainty in NPP, expressed as the coefficient of variation, amounted to an average of 108%. The systematic positive errors in individual grid cells built up to an overestimate of 2.5 Pg C in the annual global NPP of 46.1 Pg C. The largest individual contributor to the random uncertainty in NPP was the input term that describes the physiological state of phytoplankton. However, the biggest contribution to the systematic uncertainty in the model output came from the parameter that represents changes in the rate of chlorophyll-normalized photosynthesis with depth. Therefore, improvements in the accuracy of these two terms would have the largest potential to decrease the input-related uncertainty in the model NPP estimates.

Sensitivity of remote sensing reflectance to variability in absorption and backscattering in the southeastern Bering Sea

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Measurements of IOPs (absorption, scattering and backscattering) and AOPs (remote-sensing reflectance ($Rrs(\lambda)$) and diffuse attenuation coefficient ($Kd(\lambda)$)) were characterized across and along the shelf transects in the southeastern Bering Sea. The absorption and backscattering coefficients showed variability within the transects as well as across the transects. The specific phytoplankton absorption was highly variable, consistent with phytoplankton community size

structure, while colored dissolved organic matter was the dominant light absorbing constituent. The implications of this variability for remote sensing reflectance are assessed by using simplified radiative transfer modeling. The outputs from radiative transfer modeling were validated against radiometric profiles to evaluate the extent of optical closure between measured and modeled light fields, and were used to provide a perspective on the measure of the sensitivity of chlorophyll-a empirical algorithms to variability in absorption and backscattering.

CDOM as a deep-ocean proxy for oxygen and AOU

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Chromophoric dissolved organic matter (CDOM) the optically active fraction of DOC, is ubiquitous in the global ocean, and can be detected by absorption or fluorescence measurements as well as by ocean color remote sensing. A global-scale survey of CDOM from sections of the U.S. CO_2/CLIVAR Repeat Hydrography Project has revealed consistent relationships between light absorption signatures and AOU below the thermocline in much of the ocean. Fluorescence-based measurements provide analogous results with the additional possibility of high spatial or temporal resolution measurements from various platforms. Prospects for the assessment of dissolved oxygen or AOU from CDOM absorption and fluorescence measurements will be discussed.

Impact of increasing dimethylsulfide flux on reflectivity in Antarctica: A possible positive feedback on the westerly winds

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An increase of 10% per decade in reflectivity over the Weddell Sea was reported by Herman et al. (2001 and 2009). Using various TOMS (Total Ozone Mapping Spectrometer) instruments and reflectivity data, Herman et al. observed an average increase in reflectivity around Antarctica during the period between 1979-2006 which they attribute to an increase in cloud albedo.

Shindell and Schmidt (2004) confirmed an increase in temperature difference between the southern high latitudes and mid-latitudes causing cooler temperature south of the westerly winds, leading to an increase in the velocity of the southern Westerlies and is responsible for a southward shift of these winds of approximately 3-4° and a 20% increase in wind speed (Gillet and Solomon, 2003).

DMS is produced by phytoplankton and is emitted to the atmosphere, where it is oxidized, producing new particles or adding mass to existing particles (Wingenter, 2007). In either case, cloud albedo is impacted. The southward shift of the Westerly Winds and increase in wind speed may be increasing the flux of dimethysulfide (DMS). Because other oceanic organic materials that form particles may have similar flux patterns, DMS can be viewed as a proxy for other particle precursor material (Wingenter et al., 2010). Wind and sea surface temperature data from the National Center for Environmental Protection (NOAA and NCAR) were employed to determine the change in DMS flux from 1950-1959 to 2000-2009 and from 1980-1989 to 2000-2009.

Our estimates show an increase in DMS flux over these time periods in the Southern Ocean, accompanied by strong poleward transport. For January, the latitudinally averaged flux estimates between 1980-1989 versus 2000-2009 shows a minima between 40-45° south latitude with the latest decade having about 3-4 percent less DMS flux in this region. This is a result of the Westerlies having shifted southward. DMS flux increases sharply with a broad maxima between 55-60° S of approximately 25 percent, coinciding with increased wind speeds. Analysis of the vector wind components shows that there is a significant advection of DMS, particle and precursor materials towards Antarctica. This flux of DMS, its oxidation products and its resulting particles may be contributing to the increased cloud albedo observed by Herman et al. If this hypothesis is correct, then the increased DMS flux is having a positive feedback on the shift of the westerly winds. Increased wind speed is resulting in greater Ekman transport and upwelling of warmer water higher in CO_2 in the Southern Ocean (Anderson et al., 2009; Toggweiler and Russell, 2008). Possible systems level implications include destabilization of ice shelves along the Antarctic Peninsula (Jenkins and Jacobs, 2008) and an increase in pCO_2 of Southern Ocean surface water (Takahashi et al., 2009).

Time scales of variability of chlorophyll and temperature from satellite data

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Temporal scales of variability in chlorophyll and temperature are examined using MODIS satellite data. Data gaps preclude a straightforward analysis using traditional methods, but by binning the data, we estimate the variance as a function of time scale across the globe. Variability on shorter time scales can occur due to advection, as in eddying regions, or in the case of chlorophyll, also due to short term variability in biological growth and losses. By comparing temperature and chlorophyll, we provide a qualitative picture of physical and biological temporal variability that helps to distinguish regimes of physical-biological interaction across the globe.

Examination of nitrogen fixation and microbial community dynamics within mesoscale eddies in the North Pacific Subtropical Gyre using autonomous drifting platforms

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Biological nitrogen fixation by diazotrophs has a significant impact on marine productivity. In the NPSG (North Pacific Subtropical Gyre) controls on diazotroph dynamics are unknown, leading to unpredictability in future climate scenarios. Time-series data in the region show dramatic population shifts on monthly intervals, but with no clear corresponding physical or chemical drivers. To better resolve the distributions and activities of diazotrophs in the NPSG, we used quantitative PCR with the Environmental Sample Processor and labeled isotope incubations with the Submersible Incubation Device on free-drifting platforms along the margin of anticyclonic eddies, which were previously shown to correlate with increased nitrogen fixation rates. We quantified high abundances and tremendous patchiness (order of magnitude changes on daily time scales) despite quasi-Lagrangian sampling, but most diazotrophs demonstrated consistent correlations with the physical and/or chemical environment, lending promise to the prospect of ecological modeling. Despite near-record diazotroph abundances and high sea surface height, dinitrogen assimilation rates were low. As one of the first of its kind, this study emphasizes the utility of drifter sampling, and the extreme patchiness of diazotroph ecology in the NPSG. We conclude that higher resolution spatiotemporal sampling and ecological modeling will result in more accurate extrapolations of diazotroph dynamics. However, our data demonstrate that while open ocean eddies act to concentrate microbial populations, complex water column dynamics at the eddy's edge can lead to unpredicted outcomes, complicating estimations of global biogeochemical budgets.

Remote-sensing-based assessment of the temporal variations of phytoplankton growth rate and mortality

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Radiometric data in the visible wavelengths acquired by satellite remote sensing are proving to be very useful for monitoring the states of the ocean. By implementing advanced techniques of data-assimilation we demonstrate how the time evolution of important biological parameters and unobserved state variables related to nutrient-phytoplankton-zooplankton dynamics can be estimated from remotely-sensed ocean-colour data. The results show that the sensitivity of regional variations of maximum-specific growth rate of phytoplankton with respect to sea-surface temperature can be more than that predicted by temperature-dependent functions reported previously. The estimates will potentially be useful for enhancing our understanding of the biological response of phytoplankton community in a changing environment.

Assessment and impact of carbon variability in the Nordic Seas

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In areas where deep water formation occurs, such as the Nordic Seas, relatively rapid transmission of atmospheric gases to the deep ocean is expected. Together with the Arctic Ocean and the Barents Sea, it makes up a region known as the northern limb of the Atlantic thermohaline circulation, estimated to give rise to significant preindustrial inter-hemispheric transport of inorganic carbon directed from the northern to the southern hemisphere. Therefore, it is important to study the carbon dynamics in the Nordic Seas as they are an integral part of the global carbon cycle. Observational studies report significant variations of the ocean CO_2 sink in the North Atlantic and suggest a reduction of the atmospheric CO_2 uptake during the last two decades, especially in the Subpolar and Nordic Seas. We use a combination of remote sensing data analysis, numerical model experiments, and in situ data to assess the impact of carbon variability in the Nordic Seas. A 3D ice-ocean model is used to drive a 1D ecosystem/carbon model featuring multiple phytoplankton functional groups, which is applied to key biogeochemical provinces within the study regions. Our results address the impact of different phytoplankton functional groups on the seasonal uptake of atmospheric CO_2, the major physical and biological driving mechanisms for the seasonal, interannual, and decadal variations of surface ocean $p$$CO_2$ and sea-air CO_2 flux, and the impact of long-term predicted changes on ocean acidification.

The total area of the Nordic Seas, ranging from 60^{o}N to 78^{o}N and excluding the Barents Sea, is ~3×10^{12} m^2. This area is approximately 0.8% of the total area of the global oceans including adjacent seas (360×10^{12} m^2). The total Nordic Seas sea-air flux estimates for 2006 using three different gas transfer parameterizations ranged from 81.9±17.8 to 121.5±24.0 Tg-C a^{-1}. These estimates are about 4% to 6% of the global oceans annual sea-air flux (~2 Pg-C a^{-1}).

Primary productivity as a function of absorption, pigment based phytoplankton diversity and particle size distribution

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Direct measurements of net primary productivity at the Hawaii Ocean Time-series (HOT), Station ALOHA, in the North Pacific Subtropical gyre reveal a strongly light-driven seasonal cycle of biomass normalized primary productivity (PP) punctuated by episodic surface blooms of large cell-sized organisms in summer months. These episodic and largely uncharacterized blooms lead to significant uncertainties in efforts to model PP. To improve upon the present state of satellite-based algorithms for marine productivity, many researchers have concluded that there is a need for field measurements that combine discrete measurements of phytoplankton physiology and taxonomic composition with classical bio-optics approaches as a means of testing, validating and expanding upon existing remote sensing algorithms. In collaboration with the HOT program, we have initiated time-series measurements of particle size distributions, hyperspectral absorbance and attenuation, optical measurements of particle and pigment concentrations, and CDOM profiles which are being merged with hyperspectral irradiance/radiance to generate PP models for the region. We will present results from these time-series analyses along with flow-thru bio-optical measurements and proxies for PP from a series of cruises of opportunity in the region.

Session 3. Land-ocean transport and linkages with global change

Coastal carbon fluxes along the U.S. eastern continental shelf derived from a coupled biogeochemical-circulation model

The U.S.ECoS Team

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The role of coastal margins in regional and global carbon budgets is not well understood, primarily because many key shelf fluxes are not yet well quantified over annual time scales, e.g. the exchange of carbon across the land-ocean and shelf-slope interfaces, air-sea exchange of CO_2, burial, and biological processes including productivity. Because of the temporal and spatial undersampling typically associated with most observational studies, model-derived carbon flux estimates are likely to be the only viable approach for defining these fluxes in a consistent manner on annual time scales. However, such models require the interfacing of watershed, estuarine, shelf and oceanic systems, which remains a challenge for the modeling community.

The goal of our USECoS (U.S. Eastern Continental Shelf Carbon Cycling) project is (1) to estimate coastal carbon fluxes along the U.S. east coast using models quantitatively evaluated by comparisons with observations, and (2) to establish a framework for predicting how these fluxes may be modified as a result of climate and land use change. Recent efforts have been geared toward linking our coastal biogeochemical-circulation model with a dynamic land ecosystem model, as well as directed toward refining the role of estuarine processes in linking the riverine and coastal ocean systems. Our preliminary carbon budget for this region suggests that the USECoS region is a sink of atmospheric CO_2. In addition, roughly 10-20% of net community production (NCP) gets buried in shelf sediments in the mid-Atlantic and South Atlantic Bight. Horizontal divergence fluxes of particulate and dissolved organic carbon are of similar magnitude, and are each greater than that of dissolved inorganic carbon by at least a factor of three. Idealized sensitivity experiments indicate that doubling the input of riverine carbon to the shelf has the opposite effect as doubling the freshwater input, and thus as long as both carbon and freshwater inputs are increased proportionately, only minor changes to the shelf carbon cycle will be expected. On the contrary, the carbon cycle is more sensitive to riverine nitrogen input. Doubling nitrate and freshwater inputs without a coincident increase in carbon, yields significant increases in NCP and air-sea CO_2 flux.

Net ecosystem production of U.S. east coast estuaries

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Coastal regions cover a small fraction of the earth's surface and yet play a major role in the global carbon cycle because coastal rates of carbon fixation, remineralization, and burial tend to be much higher than the global averages. The present study is part of a large-scale synthesis effort by the Ocean Carbon and Biogeochemistry Program and the North American Carbon Program to constrain the coastal carbon budget for North America. The objective of our study is to provide quantitative estimates of net ecosystem production (NEP) in the estuaries along the East Coast of the U.S using a method of statistical modeling of NEP based on the riverine loading ratio of dissolved inorganic nitrogen (DIN) to total organic carbon (TOC). NEP is the gross primary production minus community respiration, and thus describes the net metabolic status of a system. Estuarine NEP is an important component of the overall coastal carbon budget because it regulates the fluxes of nutrients and organic carbon to the coastal ocean.

Our analysis relies on NOAA's Coastal Assessment and Data Synthesis framework of Estuarine Drainage Areas (EDAs), with the focus on 64 major EDAs on the U.S. East Coast that have been characterized as part of NOAA's estuarine eutrophication survey. We use the output of the U.S. Geological Survey SPARROW water quality model (Spatially Referenced Regression on Watershed Attributes) to constrain riverine inputs of nutrients and carbon to the 64 estuaries. We are conducting an extensive literature search to assemble a database of existing NEP estimates, riverine loading ratios, and various ancillary data. These existing data are used to develop a statistical relationship between NEP and DIN:TOC loadings for the U.S. East Coast, which will allow us to use the SPARROW-derived DIN:TOC loading ratios to calculate NEP for all 64 estuaries and to obtain an integrated estimate for the entire U.S. East Coast. Preliminary results show that NEP increases with the loading ratio, consistent with an earlier synthesis.

Implications of climate-driven freshwater inflow changes to ecosystem responses in lagoonal estuaries of western Gulf of Mexico

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Texas lagoonal estuaries lie in a climatic gradient along the western Gulf of Mexico (WGOM). Estuaries located in the northeastern part of WGOM, such as Lavaca Colorado (LCE) and Guadalupe Estuary (GE), receive more rainfall than Nueces Estuary (NE) in the southwest. The drying tendency peaks at the Laguna Madre Estuary (LME) located in the southernmost part of the United States territory in the WGOM. This climatic alignment is, in general, reflected in freshwater inflow patterns and salinity of each bay. Extreme inter-annual variability of precipitation is another characteristic of WGOM, which is associated with El Niño Southern Oscillation (ENSO) events. During El Niño events, salinities in Texas estuaries decrease because of increased precipitation and subsequently increased freshwater inflow to the coast. During La Niña periods, salinities increase due to drier climatic conditions than normal years. The combination of the climatic gradient and temporal variability can be used to identify the effects of inflow variability on estuarine productivity because changes in frequency, timing, duration, and magnitude of river inflows to coastal waters lead to dramatic changes in salinity and dynamics of environmental stressors (nutrient, organic matter and sediment) in estuaries of the western Gulf. We developed a multi-component ecosystem model embedded in a box model in order to investigate effects of changing environmental conditions on water quality and ecosystem dynamics. Preliminary results imply that freshwater inflow is an important driver in maintaining productivities and ecosystem functions of estuaries, and is required to maintain estuarine health and sustainability.

Quantifying net transport of river nutrients and organic carbon to the Columbia River estuary using in situ sensors

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The Columbia River is a dominant geographic and ecological feature of the Pacific Northwest and a significant freshwater input to the California Current ecosystem. Over the last century, humans have altered the seasonal pattern in river discharge through the construction of an international network of hydroelectric dams. A likely consequence for river biogeochemistry was the decrease in turbidity and alleviation of light limitation for phytoplankton, which may have altered the flux of nutrients and organic matter to the coastal zone. To determine the contemporary state of the river we investigated the role of pelagic primary production on biogeochemical fluxes during a two-year study at a sampling location in the Lower Columbia River. Our primary approach was to use high resolution in situ sensors that allow for the capture of many different scales of variability in biogeochemical cycles. During fall and winter, chlorophyll was low and biogeochemical parameters including nitrate, CDOM, and turbidity increased during episodic storm events, snowmelt, and hydroelectric management activities. During spring and summer, increases in chlorophyll, primary productivity, and nitrate utilization demonstrated that phytoplankton significantly altered the flux of organic carbon to the estuary and coastal ocean.

A global perspective on the distribution of the lanthanides in the ocean: influence of boundary sources and role of the internal particle field

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The lanthanides, or rare earth elements (REE), consist of 15 economically important elements with atomic numbers between 57 and 71. The filling of the 4f electron shell with increasing atomic number produces a progressive reduction of their ionic radii (lanthanide contraction). This effect results in relative fractionation

patterns across the REE sequence. Patterns depend on the geochemical environments. Characteristic patterns and their spatio-temporal evolution can be used to probe geochemical processes (metal-particle interactions, estuarine mixing, metal cycling, redox state) and have been suggested to be useful paleo-proxies of past oceanic conditions, notably for the oxidation state of seawater (Ce), circulation (Nd) and particle export to the seafloor.

Aside from transport, the oceanic REE distribution depends on the location and intensity of the REE sources (rivers, dust, submarine groundwater discharge, sediment fluxes). Their magnitude and variability remains poorly characterized. Secondly, since REE scavenge onto particles, their relative distribution depends on the density, type and dynamics of the particulate field. Finally, since scavenging rates and partition coefficients are affected by complexation with organic and inorganic (mostly carbonate) ligands, the distribution of REE also depends on the physico-chemical environment (temperature, pH, ionic strength).

We present preliminary results from a data measurement, synthesis, and modeling study, performed under the umbrella of the GEOTRACES program, that aims to reduce uncertainties about the sources of REE to the ocean and to better characterize internal cycling processes. Although few full vertical profiles of the complete REE pattern exist, this situation is now rapidly changing through measurement of full sections of REE concentrations during the GEOTRACES program. Available data consistently show characteristic distribution with a relative depletion of the dissolved light REE and an enrichment of the heavy REE. Conversely, light REE are enriched in the particulate phase and particulate heavy REE are relatively depleted. The degree of light-to-heavy fractionation increases with depth and with time and varies across water masses. Initial results from a global model, based on the transport matrix formalism and using specifically developed river and dust REE-flux boundary conditions, indicate that experiments using a reversible scavenging parameterization fit observed profiles better than when irreversible scavenging or linear decay parameterizations are used. Boundary conditions for groundwater, exchange on margins, and parameterizations incorporating complexation theory are being developed.

Temporal and spatial variability of the riverine inorganic carbon system in the Mackenzie River and beyond

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The inorganic carbon system of the Mackenzie River (MR) was measured monthly in the delta as well as across the basin. Total dissolved inorganic carbon (DIC), total alkalinity (TA), pH, and $p\mathrm{CO_2}$ showed strong seasonal and diel variations. River discharge has a dilution effect on DIC and TA year-round except near the freshet. DIC and TA also increase significantly along the main channel downstream, consistent with the distribution of bedrock geology. Annual DIC flux was estimated to be 5.41×10^{11} mol C yr^{-1}. Speciation of the carbonate system indicates that on average, bicarbonate (HCO_3^-) accounts for ~95% of the DIC flux, while dissolved CO_2 (CO_2*) represents a small but significant (~5%) and previously unaccounted for component of the total DIC flux. Temperature exerts a significantly positive control on the DIC yield in the basin. The first-order estimate suggests that the DIC flux from the MR could increase by 20% at the end of century due to warming alone. The finding of the inorganic carbon system in the MR may also have global implications based on recent measurements from other river basins.

Session 4. Integrating measurements across multiple time and space scales

Optimization of a global biogeochemical model using in-situ observations

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Comparing model results to observations is challenging due to the sparseness and irregular distribution of in situ data, the fact that measurement "snapshots" are compared to instantaneous or mean model results that may reflect different small scale structures at the time of sampling, and to deficiencies in model physics, chemistry, or biology. Here, we present a proof-of-concept study that applies a Green's functions approach to a high resolution, full-depth, global-ocean configuration of the Massachusetts Institute of Technology general circulation model (MITgcm), in particular eddying estimates of ocean circulation from the Estimating the Circulation and Climate of the Ocean, Phase II (ECCO2) project, coupled to the MIT ecosystem model (Darwin), and a marine carbon chemistry model. We use observational data for the partial pressure of carbon dioxide (pCO_2) from the years 2009 through 2010, global air-sea CO_2 flux estimates and the seasonal cycle of the Takahashi et al. (2009) climatology to constrain the model and to obtain initial fields of dissolved inorganic carbon, alkalinity, and oxygen that allow us to improve estimates of air-sea carbon fluxes at high spatial and temporal resolution. We have performed a variety of sensitivity experiments starting from climatological conditions and results from model runs from two different ocean biogeochemistry models, as well as runs reflecting different approaches to the parameterization of air-sea gas exchange and the ratio of particulate inorganic to organic carbon. The Green's functions approach yields an optimized linear combination of the different initial conditions that represent a first step towards a more realistic representation of the oceans' role in the global carbon cycle. Comparisons with particular observational time-series help identify critical regions for improvement, for instance, in the Southern Ocean.

The organic complexation of dissolved iron in NE Atlantic depth profiles: Preliminary results from the first leg of the U.S. GEOTRACES North Atlantic Section

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Iron-binding ligands play an important role in the biogeochemical cycling of iron, influencing iron solubility, reactivity and bioavailability in the oceans. As part of the U.S. GEOTRACES North Atlantic Section, the organic complexation of dissolved (< 0.2 μm) iron was measured in full depth profile samples using competitive ligand exchange-adsorptive cathodic stripping voltammetry (CLE-ACSV) with salicylaldoxime as the added competing ligand. Strong iron-binding ligands (log $K_1 > 11$) were found in excess of dissolved iron at all depths in the profiles, and were more variable in deep water concentrations than dissolved iron alone. A subset of profile samples was analyzed both at sea and back in the lab onshore after freezing and thawing. Results from these analyses were in good agreement and indicate that freezing at -20º C was a suitable technique for storing these samples.

Porewater temporal variability in a wave-impacted permeable sediment

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Porewater samples were collected from a nearshore permeable sediment at the Kilo Nalu Nearshore Observatory, Oahu, Hawaii over a variety of surface gravity conditions to evaluate the effect of ocean swells and their corresponding bottom currents on dissolved oxygen and nutrient dynamics in the porewater. Swells with significant wave heights of greater than ~1.3 m, with resulting nearbed velocities reaching at least >0.30 m/s, affected porewater constituents to a depth

of ~7.5 cm by enhancing exchange between the porewater in the uppermost sediment and the overlying water column. This diel-scale process is associated with a fluorescence response in the bottom of the overlying water column, suggesting that sediment flushing and subsequent nutrient input to the water column may be important to nutrient budgets in nearshore oligotrophic waters. Depth-integrated O_2 concentrations were positively correlated with nearbed velocities, suggesting that increasing oxygenation of the sediment occurs with larger significant wave heights and correspondingly larger nearbed velocities. The observed ratios of regenerated nutrients suggest that the majority of organic matter undergoing remineralization is planktonic in origin. However, a shift in source matter undergoing remineralization coincided with a late-summer swell event, suggesting that swells events and/or seasonality may be important factors in controlling the organic matter supplied to these sediments.

Strategies for autonomous sensors

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The growing application of autonomous platforms to the study of biogeochemical processes demands new approaches for calibration and interpretation. Direct calibration and cross-calibration against known reference sensors are required to determine uncertainties and to support quantitative analysis across arrays of sensors. For many biogeochemical sensors, pre- and post-deployment laboratory calibration is insufficient, and should be augmented with other approaches, including direct in situ calibration, cross calibration against well-characterized references and the use of redundant and/or related sensors. Laboratory characterization and in situ calibration are also required to develop the biogeochemical proxies for optical and acoustic measurements. The 2008 North Atlantic Bloom (NAB08) experiment characterized patch-scale evolution of the spring phytoplankton bloom using four gliders, a Lagrangian float and intensive ship-based sampling, underpinned by an aggressive calibration effort. Proxy sensors were used for carbon cycle components, with ship-based efforts providing direct calibration and data for constructing proxy relationships. Direct calibrations were propagated to other autonomous sensors through deliberate intercallibration profiles. NAB08 illustrates an effective approach for implementing process-scale calibration of autonomous sensors and provides guidance for the design of larger-scale efforts.

Modeling dissolved gas tracers of primary productivity

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Dissolved gas tracers can be used to estimate rates of gross photosynthetic production (GPP) from the triple oxygen isotopic abundance (TOI, ^{18}O, ^{17}O, ^{16}O) and net community production (NCP) from the O_2/Ar ratio. By combining field observations with global ocean and marine ecosystem models (BEC - CCSM-3), we are improving our understanding of tracers of whole-ecosystem metabolic rates and their implications in the climate system. Seasonal and spatial biases due to non-steady state conditions and physical transport are evaluated for GPP and NCP.

An autonomous underwater vehicle for shelf, coastal, and estuarine oceanography

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Autonomous underwater vehicles will play a leading role in coastal and estuarine oceanography in the next decade. The University of Maryland Center for Environmental Science Autonomous Marine Research Facility, based at Horn Point Laboratory, will commence operation of a Kongsberg-Hydroid REMUS 600 in Spring 2013, and will make this vehicle available for charter by oceanographers.

The HPL AUV's capabilities include the endurance, navigational equipment, and modular instrument configurations necessary for basic and applied research on the continental shelf, coastal ocean, and estuaries. As presently equipped, the AUV is optimized for water column research. Research-specific acquisitions can improve the benthic (acoustic and optical) sampling capabilities of the vehicle. Advanced features and equipment include:

-Forward and aft thruster modules, which allow for hovering, station-keeping, pivoting, strafing, and vertical profiling
-On-board payload computer for implementing algorithms for adaptive autonomous data collection
-Shore-to-vehicle communications buoy for redirection of vehicle via Iridium or VHF while submerged
-Fully portable shipboard communications package
-Surface communications include Iridium satellite and WiFi

- -inertial navigation system
- -Modular payload that can be fitted with a variety of sensors or expanded for instrument development
- -Large battery capacity to enable missions not suitable for smaller AUVs or gliders.

Delivery is scheduled for March 2013, at which point sea trials will commence. This AUV may be included in research proposals for work beginning in Fall 2013. Further information can be found at: http://www.umces.edu/hpl/autonomous-underwater-vehicle-specs

Estimates of potential new production (PNP) for the waters off the Western Antarctic Peninsula (WAP) region

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Potential new production (PNP) can be used as a proxy for new primary production (NPP) and sets the upper bound limit of newly available production. For this study, we estimate PNP by employing a one-dimensional analytical model using in situ and model data for waters off the Western Antarctica Peninsula (WAP) for January (mid summer). The WAP region is further subdivided into three sub-regions i.e. coastal, shelf and slope. Coastal region includes waters with bathymetric depths < 450 m, slope covers the oceanic region > 750 m water depth, and the shelf region occupies the area from 450-750 m. Field observations obtained during the Palmer Long Term Ecological Research (PAL LTER) and U.S. Global Ocean Ecosystems Dynamics (US GLOBEC) programs consisting of a decade long time-series (1998-2007) are used for our PNP computations. Mean PNP estimates are computed to be 2531.0 ± 197.5, 355.4 ± 61.7, and 886.2 ± 81.8 mg C m^{-2} d^{-1} for the coastal, shelf, and slope sub-regions, respectively. The calculated overall mean PNP rate for the whole PALMER LTER WAP region for mid summer is 1257.5 ± 113.6 mg C m^{-2} d^{-1}. Mean PP for the coastal, shelf and slope subregions are computed to be 1080.6 ± 1026.3, 799.7 ± 827.3, and 359.6 ± 274.8 mg C m^{-2} d^{-1}, respectively. The calculated potential f-ratios are 2.34, 0.44, and 2.46 for the coastal, shelf and slope subregions, respectively.

New views of the subpolar North Atlantic Spring Bloom, from NAB 2008

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The subpolar North Atlantic is responsible for more than 20 percent of the ocean's uptake of atmospheric CO_2, with its spring bloom contributing substantially to CO_2 drawdown. While well studied for decades, the spring bloom still holds some surprises. The 2008 autonomous North Atlantic Spring Bloom experiment (NAB 2008) provided a number of new insights into the initiation, evolution and demise of this bloom, and additionally provided a testing ground for a new way to study ocean biogeochemistry.

<u>Spring bloom initiation</u> – Mahadevan et al., July 6 issue of Science:

Classically, spring stratification that leads to the development of the bloom is ascribed to solar warming of the sea surface. Autonomous observations from the subpolar North Atlantic, coupled with a three-dimensional biophysical model, show that the initial stratification and the resulting bloom are the result of eddy-driven slumping of the basin-scale north-south density gradient. This mechanism leads to bloom initiation 20-30 days earlier than would otherwise occur by warming, and also helps create the patchiness characteristic of this bloom.

<u>Productivity</u> – from a Lagrangian float and gliders:

Net Primary Productivity (NPP) and Net Community Productivity (NCP) are rarely measured on identical space and time scales; NPP is typically measured with tracers in bottles for <1 day while NCP is derived from changes in biogeochemical inventories over submeso- to mesoscales for days to months. For 2 months, NPP was computed from ship-measured P-vs-E curves and float optics, and NCP was measured independently from float budgets of O_2 and NO_3^- (Alkire at al., 2012, DSR). Early in the bloom, NPP and NCP were very similar, suggesting mostly new production. During the main diatom bloom, NPP exceeded NCP by ~25%, suggesting increased importance of nutrient recycling. The majority of apparent POC export occurred continuously during this period. A large respiration event occurred at bloom termination, with minimal NCP but with continuing high NPP.

Glider surveys in June, after termination of the diatom bloom, showed that NCP and POC export from the mixed layer was comparable to that of the shorter diatom spring bloom, drawing down an additional 8 μM NO_3^-.

Carbon export during the diatom bloom – from traps and other observations:

Floating sediment traps captured a rapid carbon export 'event' to the meso-pelagic (Martin et al., 2011, DRS). Carbon flux was dominated by resting spores of *Chaetoceros spp*., structures resistant to microbial degradation. Gliders observed the export event optically over larger spatial scales (Briggs et al., 2011).

Calibration protocols – Rigorous calibration on shore and cross-calibration at sea produce high quality biogeochemical data – see poster by Lee et al.

Connecting seasonal and spatial trends in plankton community structure with POC export using the Po-210/Pb-210 isotope pair along Line P, Subarctic Pacific

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The ^{210}Po and ^{210}Pb radionuclide pair has been increasingly applied as a tracer for particulate organic carbon (POC) export from the surface ocean due to the preferential sorption of ^{210}Po by biota relative to its grandparent ^{210}Pb. In this study, we investigated the seasonal and spatial distribution of dissolved ^{210}Po and ^{210}Pb in the upper 500 m of the North Pacific Subarctic Ocean in relation to plankton community using data from Niskin bottles, sediment traps, in situ pumps, and plankton nets. This is the first ^{210}Po/^{210}Pb data set presented for Line P and Ocean Station Papa. Preliminary results show that dissolved polonium activity profiles reflect changes in size and species distribution of dominant zooplankton and phytoplankton groups. Radionuclide profiles are unexpectedly similar from the highly productive coast of Vancouver to the HNLC area near Ocean Station Papa throughout spring, summer, and winter. The highest deficits of ^{210}Po occur when copepods dominate the zooplankton community and

approximately 40% of the phytoplankton community is < 5 µm in diameter. We will present POC export estimates along the Line P transect in the context of plankton community structure and provide possible mechanisms that link the species composition to the rate and magnitude of carbon flux.

Session 5. New observations from an Arctic Ocean in rapid transition

Contrasting responses to ocean acidification of DMS and its precursor DMSP in Arctic waters

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Increasing atmospheric CO_2 is decreasing ocean pH most rapidly in cold regions such as the Arctic. As a component of the EPOCA pelagic mesocosms experiment off Spitzbergen in 2010, we examined the consequences of decreased pH on the emission of dimethylsulfide (DMS), an important reactant and contributor to aerosol formation and growth in the Arctic troposphere. In the nine mesocosms of initial pH 8.3 to 7.5, highly significant responses to acidity occurred following nutrient addition, with a decrease in DMS relative to H+ concentration. This was despite increased concentrations of the precursor dimethylsulphoniopropionate (DMSP) at reduced pH. Measurements of the specific rate of synthesis of DMSP by phytoplankton indicate increased production at high H+ concentration but reduced turnover rates, partially explaining the reduced DMS concentrations. We explore the taxonomic and physiological basis of the response of DMSP production and the apparent reduced conversion of DMSP to DMS with increased acidity.

A narrow enzymatic gateway into the Arctic carbon cycle: Implications for DOC cycling in changing oceans

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Surface ocean microbial communities differ in a systematic manner in their abilities to enzymatically hydrolyze high molecular weight organic matter: pelagic microbial communities at high latitude hydrolyze a much narrower spectrum of soluble substrates than their temperate counterparts (Arnosti et al., 2011). Our investigation of 32 stations from the Atlantic, Pacific, Southern, and Arctic Oceans as well as the Gulf of Mexico showed that the rates and spectra of polysaccharide substrates hydrolyzed in surface ocean waters decreases from temperate to high latitudes, paralleling decreases in microbial community diversity (Pommier et al., 2007; Fuhrman et al., 2008). Since extracellular enzymatic hydrolysis is the initial step in microbial remineralization of high molecular weight dissolved organic carbon (DOC), the structural specificities and activities of extracellular enzymes thus determine which fraction of DOC can be metabolized and respired, and which fraction remains untouched and may be transported to other regions of the ocean.

Recently we have found that the limited spectrum of enzyme activities in Arctic waters extends to hydrolysis of peptides, as well as to polysaccharides. Activities of leucine aminopeptidase, trypsin, and chymotrypsin enzymes were measured with five different substrates in surface and bottom waters of two fjords of Svalbard. In surface waters of both fjords, 4 of 5 substrates were hydrolyzed; in bottom waters, only 3 of 5 substrates were hydrolyzed. In both fjords, leucine aminopeptidase activites were quite high and were comparable to rates reported from more temperate environments (Balter et al., 2010; Piontek et al., 2011), trypsin activities were in the same range as leucine aminopeptidase activities, and chymotrypsin activities were low to undetectable. These results contrast strongly with previous investigations in temperate waters, where trypsin and chymotrypsin activities were high, considerably higher than leucine aminopeptidase activities (Obayashi & Suzuki, 2005; 2008). Compared to their temperate counterparts, Arctic pelagic microbial communities thus exhibit a far narrower spectrum of enzyme activities for hydrolysis of peptides as well as polysaccharide-containing substrates.

Since polysaccharides and proteins together constitute the majority of marine organic matter, these data suggest that Arctic pelagic microbial communities currently focus on a subfraction of marine organic matter as their substrates. At high latitudes, changes in microbial community composition facilitated by changes in ocean temperature, circulation, and/or biogeochemical parameters (Kirchman et al., 2009) may lead to a broader spectrum and higher rates of extracellular enzyme activities, and consequently greater respiration of DOC. Since the inventory of DOC in the ocean is comparable in magnitude to the atmospheric CO_2 reservoir (Hedges, 2002), such a change could greatly accelerate the increase in atmospheric CO_2.

Increased biological CO_2 uptake following sea-ice retreat in the Western Arctic Ocean

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The retreat of sea-ice into the Arctic Ocean basins in recent summers may have increased ocean biological production and uptake of atmospheric CO_2. Reports of high pCO_2 and decreased nutrient availability in the southern Canada Basin, however, suggested that marine productivity may have decreased and any enhancement of the Arctic Ocean CO_2 sink was short-lived. Contributing to this important debate, we report results from summer 2008 and 2010 during the Chinese Arctic Research Expeditions to the western Arctic Ocean basins up to 88ºN. Our results revealed that a low pCO_2 zone had formed in the rapid sea-ice melting areas at ~80ºN but high pCO_2 existed in the nearly ice-free southern basins, which were in contrast to the more uniform distribution observed under ice-covered waters in 1994. Evidence also suggested that high biological production and CO_2 removal rates had followed the retreat of sea-ice, advancing from ~74ºN in the 1990's and early 2000's to ~80ºN in recent summers. These findings provide a more complete basis for predicting the Arctic Ocean's response to future climate change.

Carbonate mineral suppression and ocean acidification in the eastern Bering Sea

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Increasing CO_2 concentrations in the atmosphere and ocean have induced an anthropogenic acidification phenomenon particularly in high latitude seas, commonly resulting in suppression of carbonate mineral saturation states. On the Eastern Bering Sea shelf, several natural mechanisms of carbonate mineral saturation state suppression have been observed, including the upwelling of low pH deep water onto the shelf; the influx of low pH river water to the coastal margin; and a highly productive biological pump, which seasonally lowers pH in bottom waters and increases atmospheric CO_2 absorption in surface waters particularly over the middle shelf. Despite the presence of these various naturally occurring mechanisms of carbonate mineral suppression, we show that it is ultimately the addition of anthropogenic CO_2 that results in seasonal undersaturation of carbonate minerals in this system. Further, recent analysis has shown the first definitive evidence of shallow-water carbonate mineral dissolution as a result of carbonate mineral undersaturation, which caused TA concentrations to increase by ~40 μmoles kg^{-1} in some locations. This dissolution was distinct from net chemical erosion affecting terrestrial discharge, as well as the upwelling of deep basin waters onto the shelf. The presence of this dissolution indicates that anthropogenic acidification processes are already affecting the environment of the Bering Sea, well ahead of model projections.

The Arctic-Boreal Vulnerability Experiment: A proposed NASA Terrestrial Ecology Field Campaign

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Climate change in the Arctic and Boreal Region (ABR) is unfolding faster than anywhere else on Earth, resulting in receding glaciers, a longer ice-free Arctic Ocean during summer, warming and thawing of permafrost, increases in the frequency and severity of climate-driven disturbances, and widespread changes to surface water extent and vegetation structure and function. To more fully understand the evolving ABR environment and provide the information required to develop options for societal responses to the impacts of ABR climate change, the Arctic-Boreal Vulnerability Experiment (ABoVE) has been proposed as a NASA Terrestrial Ecology Program field campaign. Remotely-sensed data products would be created to address scaling issues that are inherent in linking process-based research conducted at local scales over short time periods to modeling research that addresses a variety of spatial and temporal scales. Research carried out as part of ABoVE would provide the opportunity to not only focus on key process associated with the land surface, but on key interfaces between the land and the coastal ocean and atmospheric boundary layer as they interact with climate-mediated terrestrial processes.

Proposed Scientific Scope:

1. What processes, interactions, and feedbacks control the vulnerability of Arctic and boreal ecosystems and landscapes to structural and functional changes in a changing Earth system?

2. How are people at local, regional, national, and global scales being affected by and responding to these changes?

3. How do changes to terrestrial processes in the ABR alter inputs to the adjacent ocean?

4. How do changes to terrestrial processes in the ABR provide feedbacks to regional and global climate through exchanges of energy, water, gases, and particulate matter between the land surface and troposphere?

A NASA-sponsored workshop to further develop and evaluate the scientific scope for the Arctic-Boreal Vulnerability Experiment (ABoVE) was held in Boulder, CO June 13–15, 2012. The workshop report, due in August, will guide NASA in determining the next steps for the project including the selection of a Science Definition Team charged with drafting a concise experiment plan.

The effect of sea ice on gross primary production and net community production: A study in the Canada Basin

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In recent years, the Beaufort Gyre of the Canada Basin has experienced a decrease in sea ice extent and thickness and has experienced increases in freshwater accumulation, melt season length, and water temperature – all factors that are likely to affect the biological productivity of the basin. The freshening of the gyre and related deepening of the nitracline and deep chlorophyll maximum have been accompanied by a shift in community composition from nanoplankton to picoplankton. How will these changes affect the rates of net community production and gross primary production? The triple isotope composition of dissolved oxygen in seawater is a measure of gross primary production (GPP) and the ratio of O_2/Ar is a measure of net community production (NCP). Here we present triple oxygen isotopes and O_2/Ar data collected in the Canada Basin in the summer of 2011 during mid-season ice melt conditions. Estimates of gas exchange are used to convert the tracer data to rates of GPP and NCP. We find a significant correlation between rates of GPP and ice cover as well as between the NCP:GPP ratio and ice cover. However, there is no significant relationship between rates of NCP and ice cover. This suggests that the melting ice is stimulating photosynthesis but is also stimulating respiration. Hence the ice melting is having an effect on the ecosystem dynamics but not on net carbon cycling.

Understanding continental shelf carbon dynamics: Recent patterns of carbon drawdown and export on the Chukchi Sea shelf

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Carbon flux balances between ocean and atmosphere and the net export of carbon from continental shelf waters result from the complex interactions of nutrient availability, temperature, seawater density, phytoplankton and zooplankton ecology, terrestrial carbon inputs, bathymetry, benthic-pelagic coupling, and physical oceanographic processes. Some continental marginal seas have been identified as perennial net carbon sources to the atmosphere, others as perennial net carbon sinks, and others as seasonally dynamic sources and sinks (Chen and Borges, 2009). The shallow Chukchi Sea shelf, which is adjacent to the Canada Basin, has been identified as a perennial net sink and a significant component of the global carbon budget, operating through a ‘continental shelf pump’ mechanism (Bates, 2006). Organic carbon is exported off the shallow shelf into the basin, where it contributes to the net heterotrophy of that system (Mathis et al., 2007a). Here, we report new estimates of the net carbon drawdown and mass-balance carbon export from the Chukchi shelf based on measurements taken during the summer 2010 and 2011 ICESCAPE cruises.

General OCB Session

POC provenance insights from ramped thermal degradation and ^{14}C analyses

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Vertical transit times of sinking particulate organic carbon (POC) in the open ocean based on decreasing $\Delta^{14}C$ values with depth significantly exceed estimates based on particle sinking velocities. Neither radioactive decay nor isotopic fractionation can account for this discrepancy. Rather, it has been hypothesized to arise from incorporation of constituents at depth from the comparatively $\Delta^{14}C$-depleted pools of dissolved organic carbon (DOC), dissolved inorganic carbon (DIC), and laterally transported resuspended sediments. To constrain this provenance, $\Delta^{14}C$ values were measured on CO_2 generated from the oxidation of sinking POC during a 5°C/min ramp from room temperature to 1000°C. This method produces coarse spectra of concentrations and $\Delta^{14}C$ values as functions of temperature that i) are representative of bulk POC based on mass balance, and ii) reveal the abundance of underlying populations of carbon and their estimated $\Delta^{14}C$ values. The utility of this method as applied to POC and potential constraints on $\Delta^{14}C$-depleted carbon sources are discussed.

Compensating responses of the ocean carbon pumps to ocean circulation changes over the 21st century

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Under increasing atmospheric CO_2 concentrations the changing Earth's radiative balance will influence the atmospheric and oceanic circulation. One of the consequences will be a modification of the ability of the ocean to absorb and store CO_2. The ocean's carbon uptake can be separated between solubility-driven and biologically-driven pumps. The separate impact of the changing ocean circulation on these two pumps is still unclear, though a partial compensation between opposite responses is expected. We design a suite of model

experiments to quantify the impacts of winds and buoyancy forcing on these ocean carbon pumps and on anthropogenic CO_2 uptake. We analyze a control preindustrial run, a wind-perturbation experiment and a climate change simulation with atmospheric carbon concentrations rising according to historical (1880-2009) and projected IPCC scenarios. All experiments are carried out in CM2Mc, a coarse version of one of the climate models (the GFDL CM2) used in the IPCC Fourth Assessment report. The ocean biogeochemical component is solved by the Biology-Light-Iron-Nutrients-Gas (BLING) model, which allows a separation between biological and solubility carbon pump components.

Response of phytoplankton to climate change in the northern vs. southern hemisphere: An IPCC AR5 Earth System Model intercomparison

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We assess the response of ocean ecology to 21st century climate change across some of the new IPCC AR5 Earth System Models. These models have very different ocean ecology modules, resulting in different phytoplankton community structures and complexities, different surface chlorophyll and productivity, and ultimately different ecological responses to climate change. Here we provide an assessment of climate driven changes in the extent, productivity, community composition and organic matter export across the major biogeochemical provinces in the ocean in our model suite. We notice fundamentally different phytoplankton behavior in the northern vs. southern hemisphere subpolar and subtropical gyres; we hypothesize that this hemispheric asymmetry is driven by different shifts in the mid-latitude westerlies in the northern and southern hemispheres. We relate trends in stratification, mixing and wind patterns to changes in phytoplankton ecology and biogeochemistry under climate change.

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

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Woods Hole Oceanographic Institution

Biological and Chemical Oceanography Data Management Office (BCO-DMO) staff members work with investigators to publish data from research projects funded by the Biological and Chemical Oceanography Sections (OCE) and the Office of Polar Programs Antarctic Organisms & Ecosystems Program (OPP ANT) at the U.S. National Science Foundation. Data management services are provided at no additional cost to investigators funded by those offices. The main goals of BCO-DMO are to preserve NSF-funded project data and to provide open access to those data.

BCO-DMO was created in late 2006, by combining the formerly independent data management offices for the U.S. GLOBEC and U.S. JGOFS programs. Since 2006, researchers have been contributing data to the BCO-DMO data system, and the database has developed into a rich repository of data from open ocean, coastal and Great Lakes research programs, including the data collected by U.S. GLOBEC and U.S. JGOFS investigators.

BCO-DMO has developed an end-to-end data stewardship process that includes: (1) working with investigators at the proposal stage to write their two-page NSF data management plan; (2) registering their funded project at BCO-DMO; (3) adding data and supporting documentation to the BCO-DMO database; (4) designing geospatial and text-based data access systems that support data discovery, access, display, assessment, integration, and export of data resources; (5) submission of final data sets to the appropriate long-term data archive; and (6) publication of data sets to provide publishers of the peer-reviewed literature with citable references (Digital Object Identifiers) and to encourage proper citation and attribution of data sets in the future.

Trace-metal clean automated culture system for ocean acidification experiments

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The interactive effects of trace-metal speciation and changing ocean pH on marine primary producers are largely unknown. Research indicates the bioavailability of trace metals may change substantially with ocean acidification, due to changes in speciation of metals in seawater. In addition, for open ocean studies and laboratory experiments that are designed to mimic the natural low trace metal environment, it is essential to work under trace metal clean conditions. In response, a trace-metal clean culture system was developed that controls pH levels in 12 culture tanks. Automated pH measurements were obtained through computer-controlled fluidic and spectrophotometric systems. The shipboard system has been used to study nitrogen fixers and bacterial processes in sub-tropical oligotrophic waters and calcifying phytoplankton in the Southern Ocean. However, the system and trace-metal clean methodology are easily adapted to a range of marine organisms.