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Session: Carbon fluxes in coastal wetlands

Particulate organic carbon composition at the marsh-estuary interface in Chesapeake Bay

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Aquatic exchange of carbon between wetlands and estuaries is one of the least-constrained fluxes in carbon budgets for the coastal margin. The aim of this study was to measure the concentrations, fluxes and composition of particulate organic carbon (POC) at the marsh-estuary interface. The study was conducted in two temperate marshes associated with Chesapeake Bay: Taskinas Creek VA, which drains into the York River VA and Kirkpatrick Marsh, draining into the Rhode River MD. Water samples were collected monthly from Taskinas Creek over a tidal cycle for ~2 years. The samples were filtered and the particulate fraction was analyzed for POC concentration and composition. POC concentrations and water quality data were analyzed by structural equation modeling (SEM) to identify the key drivers of POC. In addition, larger volume samples were collected at high and low tide and lipid biomarker compounds were used to evaluate the sources and reactivity of the POC.

Generally, the marsh at Taskinas was a sink for POC from the adjacent York River Estuary. Results from the SEM analysis showed that four variables control POC concentration at Taskinas; chlorophyll, phaeopigments, and TSS had a positive direct effect on POC and temperature had a negative direct effect. Tide also had a positive, but indirect, effect on POC as mediated through chlorophyll and TSS. To evaluate the sources of POC, we analyzed two classes of lipid biomarker compounds: *n*-alkanes and fatty acids (FA). FA generally reflected labile POM (microalgae and marsh sources) while n-alkanes derived primarily from soils and high plant vegetation. The biomarker composition was similar at both marshes. FA were an order of magnitude more abundant than n-alkanes and dominated by short-chain (C12-C16) and C18 FA, which derive from microalgae and marsh sources. In contrast, *n*-alkanes were derived primarily from soils and higher plants.

Assessing inorganic carbon export from intertidal salt marshes using direct, high-frequency measurements

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The lateral export of carbon from coastal marshes via tidal exchange is potentially a major term in the marsh and coastal carbon cycles. However, this export has been difficult to accurately

quantify due to the large variability at this interface. This is the first study to use direct, high-frequency measurements of dissolved inorganic carbon (DIC) and water fluxes to estimate lateral DIC fluxes from a U.S. northeast salt marsh. DIC was measured by a CHANnelized Optical Sensor (CHANOS) during summer (July-August) and fall (December) periods. Tidal and spring-neap cycles are fundamental drivers of marsh carbon export, yet episodic events such as rain and changes in water elevation as well as groundwater input can significantly affect both DIC concentrations and fluxes. Variability between individual tides within each sampling period was comparable to variability between the periods. In addition, net DIC fluxes calculated using water fluxes and a simple multiple linear regression (MLR) to estimate DIC concentrations agreed reasonably well with DIC fluxes derived from CHANOS DIC concentrations. During episodic events, there were discrepancies between DIC concentrations from the MLR model and the CHANOS. However, net DIC fluxes were relatively insensitive to these differences, resulting in comparable DIC fluxes between the modeled MLR and directly measured CHANOS methods. This study demonstrates that highly variable lateral carbon exports from dynamic coastal marshes can be well-constrained with a simple model using high-frequency measurements of in situ water chemistry, physics, and water fluxes.

Insights gained from a wetland-estuary dissolved organic matter modeling system

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A recent estimate of wetland dissolved organic carbon (DOC) export to the coastal ocean of 174-400 Tg C yr^{-1} [*Cai,* 2011] indicates that coastal marshes are important in the organic carbon cycle. This wetland-derived DOC is optically and chemically diverse, with chromophoric dissolved organic matter (CDOM) undergoing an array of photochemical and microbial degradation pathways as it is transported away from marshes through estuarine and coastal waters. In order to better quantify carbon export from terrestrial ecosystems, efforts to explicitly represent wetlands, CDOM and CDOM degradation pathways in regional carbon cycle models are just now being undertaken. This study describes a three-dimensional carbon cycle model developed in the well-studied, small-scale Kirkpatrick Marsh and Rhode River, MD. Numerical experiments with and without a newly developed explicit photodegradation module show that photochemical degradation of DOM both directly and indirectly influences many biogeochemical pathways in the estuary. When photodegradation is turned off, summertime net primary production at a station 1.3 km away from the marsh decreased by 36% from 31.5 to 20.1 mmol C m^{-2} d^{-1}, on average. The degradation of wetland derived CDOM can act as a control on phytoplankton productivity in nutrient rich, light limited estuarine waters. Insights from the Rhode River modeling effort are being used to scale up to a regionally significant wetland, the Blackwater-Nanticoke River wetland-estuary ecosystem on the Eastern Shore of Chesapeake Bay, MD.

Carbon dynamics at the land-ocean interface through a subterranean estuary

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Submarine groundwater discharge (SGD) transports nutrients, carbon and traces elements and contributes to the chemistry of coastal waters. However, transports and transformations from coastal aquifers to the ocean are still poorly constrained, particularly in permeable sandy beaches which are recognized as significant biogeochemical reactive zones. In boreal regions, where hydrology and organic carbon dynamic of wetlands are changing rapidly in response to global warming, little is known about biogeochemical transformations of terrestrial organic carbon that transfer through sandy beaches. Here, we investigated the biogeochemical behavior of groundwater-borne carbon in a boreal subterranean estuary (Magdalen Island, Qc, Canada), from fresh inland groundwater to the discharge zone of the beach. Since micro-organisms play a key role in biogeochemical processes, the links between bacteria distribution and dissolved organic matter were also explored in the discharge zone of the beach. Vertical and horizontal profiles of dissolved organic carbon (DOC), δ^{13}C-DOC, and the optical properties of colored dissolved organic matter (CDOM; SUVA, a_{375}, S_R, BIX, FI) were analyzed in relation to the abundance and phylogenetic clades of total and free bacteria. Since heterogeneous conditions in carbon concentrations, origin and molecular composition were encountered, terrestrial carbon dominated at the discharge zone and marine organic matter was very limited to the surface. Multivariate analyses (PCA, RDA) showed that both the molecular composition and origin of organic carbon controlled the diversity of bacteria. Terrestrial organic carbon inputs likely modified biogeochemical processes and ecosystems functions of the sandy beach.

Salt marsh metabolism and carbon accumulation: effects of location and fertilization

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Salt marshes are thought to have high carbon (C) sequestration rates and store a globally significant pool of C. However, C sequestration rates are heterogeneous, changing with elevation, dominant plant species, and distance from channel as well as external forcing such as anthropogenic nitrogen (N) loading. In net autotrophic marshes gross primary production (GPP) of the dominant macrophyte exceeds community (plant and microbe) respiration (R). When R exceeds GPP, marshes are a source of C to the atmosphere (i.e. net heterotrophic). Net heterotrophic marshes generally require input of sediment C in order to accumulate C; however, lateral export of C as dissolved inorganic or organic C (DIC, DOC) to adjacent creeks may represent a significant loss. Location may be an important factor affecting C sequestration as flushing by creek water and prolonged inundation may influence the accumulation of dissolved pore-water compounds such as sulfide (H_2S), known to interact with C cycling. Anthropogenic N

loading to marshes has been observed to increase above-ground biomass and rates of sediment C trapping; however, it may also increase net heterotrophy by stimulating plant and microbial R. We performed an experiment in polyhaline *S. alterniflora* marshes near Camp Lejeune, NC, USA C cycling rates in triplicate unfertilized and fertilized (30 moles N/year and 15 moles P/year) plots across three different *Spartina* marsh locations: Freeman marsh edge and interior with shorter inundation time, Traps interior with longer inundation time. Pore-water H_2S, NH_4^+, DIC and DOC were measured at 5 and 15 cm depths. R, GPP, and net community production (NCP) were measured seasonally for a year using static chambers. Sediment C input was quantified based on marker horizon data and a predictive model. For determination of lateral C export, DIC (calculated based on pCO_2 and pH) and DOC were measured in overlying water at flood tide and in groundwater wells at the edge of the marshes. Pore-water analytes were lower on the edge than interior and higher at Traps than Freeman marsh. Freeman marsh was net heterotrophic in both edge and interior, but Traps marsh was net autotrophic. Fertilization increased net heterotrophy in Freeman marsh, particularly on the edge, and decreased net autotrophy in Traps marsh. Allochthonous sediment deposition increased with fertilization, and the associated sediment C was enough to result in a net accumulation of C in the net heterotrophic marsh. DIC and DOC exports were negligible compared to sediment C input and NCP. We concluded that: 1) location is an important driver determining pore water chemistry and resulting C sequestration potential of salt marshes, 2) fertilization tends to increase net heterotrophy or decrease net autotrophy, and 3) sediment input is vital to C accumulation and sustainability in net heterotrophic marshes.

Air-sea CO_2 variability in the Chesapeake Bay

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Increasing urbanization and eutrophication of coastal regions, together with increasing atmospheric CO_2 concentrations, are significantly affecting estuarine air-sea CO_2 fluxes. To better understand changing air-sea CO_2 fluxes in the Chesapeake Bay, we use a linked land-estuarine-ocean modeling system that includes both inorganic and organic carbon cycling, and compare two simulations: one from the first decade of the 1900s and one from the first decade of the 2000s. In the present day simulation, annual inputs of riverine dissolved inorganic carbon (DIC) are much greater than the annual export of DIC to the shelf, with the difference explained by positive net ecosystem production (net autotrophy) and net outgassing of CO_2. Seasonal variability in these fluxes is controlled primarily by biological processes: high productivity drives atmospheric CO_2 uptake in the spring, while respiration during the rest of the year results in CO_2 outgassing. In contrast, interannual variability is driven mainly by changes in precipitation. In wet years, riverine input of DIC and outgassing of CO_2 are both relatively high; however in dry years riverine DIC input is low, and there is very little if any net CO_2 outgassing. A comparison of the present day simulation with the early 1900s simulation highlights that over the past century changes in land cover/land use in the Chesapeake Bay watershed have caused the Bay to become increasingly net autotrophic in the spring season, driving decreases in both the net outgassing of CO_2 to the atmosphere and the export of dissolved inorganic carbon to the shelf.

Variation in salt marsh CO_2 fluxes across a latitudinal gradient along the US Atlantic coast

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Salt marshes occur at the dynamic interface of land and ocean, where they play an important role as sink and source of carbon (C) and sediment. They continuously accumulate soil organic matter and sediment to keep their position relative to sea level. Decadal average C sequestration rates can be inferred from soil carbon density and mass accumulation rates, but cannot provide detailed information about biological and climatic controls on C cycling in these systems.

In this study, we report field measurements from salt marshes along the US Atlantic coast made at two coastal Long-Term Ecological Research (LTER) sites in Massachusetts (PIE) and Georgia (GCE). Here, we focus on atmospheric measurements of carbon dioxide (CO_2) exchange between marshes and the atmosphere that have been made for several years in areas dominated by the grass *Spartina alterniflora*. To constrain lateral fluxes, atmospheric flux rates will be compared to soil accumulation rates estimated from sediment cores and/or surface elevation tables. At the northernmost LTER, measurements over four years (2013-2016) indicate the marsh to be a substantial C sink of varying magnitude depending on soil salinity levels during the growing season. Overall, the atmospheric measurements indicate a larger C sequestration potential ($-170 gCm^{-2}a^{-1}$) than derived from dated sediment cores ($110 gCm^{-2}a^{-1}$). Net CO_2 exchange at the Georgia LTER, it is an order of magnitude larger than published estimates for soil C sequestration rates. This suggests that tidal loss of C is larger in the southern marshes than at PIE. We will discuss possible factors, e.g. higher soil temperatures and a longer growing season in the southern marshes or different flooding frequency and duration at the sites.

Biophysical controls on ecosystem-scale CO_2 exchange in a tidal marsh in northern California

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Carbon (C) cycling in coastal wetlands is difficult to measure and model due to dynamic atmospheric (vertical) and hydrologic (lateral) fluxes, as well as sensitivities to dynamic land- and ocean-based drivers. To date, few studies have reported on continuous measurements of vertical and/or lateral C exchanges in these systems and as such, our understanding of the key drivers of carbon cycling in coastal wetlands including inundation, temperature, radiation, and

salinity remains limited. Increasing the number of direct measurements of vertical and lateral C fluxes is a critical first step to developing a better understanding of the drivers and sensitivities of C sequestration and greenhouse gas (GHG) mitigation potential of coastal wetlands. Here we present 2.5 years of near-continuous eddy covariance measurements of CO_2 and CH_4 fluxes from a brackish tidal marsh in Northern California. We used a combination of wavelet analysis and information theory to analyze the interactions between whole ecosystem CO_2 flux and biophysical drivers. CO_2 fluxes showed significant interannual variability, with low net CO_2 uptake in the first year of the study (67 g C m^{-2} yr^{-1} ; March 2014 – March 2015), and considerably higher uptake the following year (295 g C m^{-2} yr^{-1} ; March 2015 – March 2016). Conversely, annual CH_4 fluxes were similar between years (1.2 and 1.3 g C m^{-2} yr^{-1} in the first and second year, respectively). With respect to the net atmospheric GHG budget (assuming a sustained global warming potential of 45), the wetland was a net GHG sink of 172 g CO_2eq m^{-2} yr^{-1} in 2014–2015, and a sink of 1004 g CO_2eq m^{-2} yr^{-1} in 2015–2016. Our results also showed that tides significantly influenced CO2 fluxes across multiple timescales; ecosystem respiration was approximately 25% lower during spring tides relative to neap tides, and flooding resulted in an overall increase in photosynthesis by 9 to 27%. While there are several mechanisms that can potentially contribute to the suppression of respiration following flooding, our results suggest tidal effects may largely be due to the suppression of CO_2 efflux from the soil as the water creates a physical barrier to gas diffusion. In this case, it is critical to consider lateral fluxes as flooding may also coincide with increased dissolved inorganic carbon loss from the marsh. Further research on lateral C transport is key to investigating the influence of tides on the role of coastal wetlands as C sinks or sources.

Characterizing climate and human influences on coastal margin carbon dynamics using integrated land-ocean modeling approaches

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Changing climate and land use practices have the potential to dramatically alter coupled hydrologic-biogeochemical processes and associated movement of water, carbon and nutrients through various terrestrial reservoirs into rivers, estuaries, and coastal ocean waters. Consequences of climate– and land use–related changes will be particularly evident in large river basins and their associated coastal outflow regions. Here, we describe a NASA Carbon Monitoring System project that employs an integrated suite of models in conjunction with remotely sensed as well as targeted in situ observations with the objectives of describing processes controlling fluxes on land and their coupling to riverine, estuarine and ocean ecosystems. The nature of our approach, coupling models of terrestrial and ocean ecosystem dynamics and associated carbon processes, allows for assessment of how societal and human-related land use, land use change and forestry (LULUCF) and climate-related change affect terrestrial carbon transport as well as export of materials through watersheds to the coastal margins. The objectives of this effort include the following: 1) Provide representation of carbon processes in the terrestrial ecosystem to understand how changes in land use and climatic conditions influence the export of materials to the coastal ocean, 2) Couple the terrestrial exports of carbon, nutrients and freshwater to a coastal biogeochemical model and examine how different climate and land use scenarios influence fluxes across the land-ocean interface, and 3) Project future changes under different scenarios of climate and human impact, and support user needs related to carbon management and other activities (e.g., water quality, hypoxia, ocean acidification). This research is providing information that will contribute to determining an overall carbon balance in North America. Results can also benefit efforts to describe and predict how land use and land cover changes impact coastal water quality including possible effects of coastal eutrophication and hypoxia.

Large-scale, high-resolution wetland mapping with satellites for improved blue carbon estimates

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Global coastal and freshwater wetlands provide ecosystem services valued at over $200,000 USD per hectare per year. Despite their value, wetlands continue to be lost at alarming rates worldwide, with as much as 71% of global wetland extent being converted to other land-cover types since 1900. Targeted conservation and restoration efforts, however, have proven successful, particularly in Europe and North America. Such efforts require accurate protocols to identify, assess, and map wetlands repeatedly to enable detection of change. High-resolution (i.e. 2-meter pixel) satellite imagery has proven effective to map wetlands at higher accuracies than historical 30-meter or coarser satellite data. We describe a method to process and classify high volumes of multispectral high-resolution satellite data to update land cover and land use maps. We show the results of a study conducted with 130 2-meter resolution WorldView-2 satellite images to map forested wetland, upland, water, bare land, and developed lands in a 6,500 km^2 watershed. The processing of the land cover map was completed in under 24 hours and was more accurate at identifying forested wetland (78%) and upland (64%) than three previous, widely used maps of the same area (45–65%, and 49–53%, respectively). This method offers high potential for monitoring change in coastal areas and adjacent watersheds over large geographic regions at fine scales, and for more accurate wetland coverage estimates to be used in blue carbon storage calculations.

Revisiting the blueprints for blue carbon: is salt marsh sediment organic carbon a source of emissions after wetland degradation?

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Salt marshes have enormous potential to bury and store organic carbon in sediment for centuries to millennia. However, little is known about the fate of this carbon pool after degradation events, particularly erosion that would unbury and expose it to aerobic and photo-oxidizing environments in tidal creeks. Currently, estimates in the literature span from 25% to 100% oxidation of preserved organic carbon in wetlands upon degradation (e.g., land-use change or erosion), but few experimental data exist to narrow this potential range. Therefore, we devised an experimental approach to address the following question: are the emissions produced from the oxic decomposition of eroded salt marsh sediment organic carbon a significant source of emissions within the wetland carbon budget? Our approach used sediment collected from shallow (5-10 cm) and deep (35-40 cm) horizons in a North Carolina *Spartina alterniflora* marsh that were incubated at either 20 °C or 30 °C. Incubations lasted for 161 days, which was the time it took for all experimental units to reach at least 4% loss. Sediment from the shallow horizon decomposed faster than deep horizon within their respective temperature treatments, but sediment from both depth horizons incubated at 30 °C decomposed faster than either treatment at 20 °C. The Q_{10} of sediment from the shallow horizon was 2.0, while the decomposition of deeper sediment was slightly more temperature sensitive with a Q_{10} of 2.2. We calculated activation energy (49.7 kJ mol^{-1} and 58.8 kJ mol^{-1} for shallow and deep sediment, respectively) to determine annual decomposition rates using multi-year temperature monitoring data. We estimate that if material from the shallow horizon were exposed to oxic conditions for one year in a typical temperature regime for our study site, 23.0±0.3% of organic carbon would remineralize, whereas deeper sediment would experience only 16.8±0.2% loss. These data are useful in reducing the variation surrounding the estimated potential magnitude of greenhouse gas emissions from degraded wetlands.

The role of particulate resuspension on organic matter, nutrient, and oxygen dynamics in Chesapeake Bay: Preliminary results from a coupled model

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Observations in coastal environments show that seabed resuspension can impact light attenuation and organic matter fate. Yet, models that incorporate both sediment transport and biogeochemical processes are rare, and nearly all neglect the effect of resuspension on oxygen and nutrient dynamics. Accounting for such processes can be important in coastal environments such as the Chesapeake Bay, where sediment resuspension and transport affects development of summertime hypoxia by (1) transferring organic matter from the estuary's shoals to deeper regions; (2) increasing light attenuation, which affects primary productivity; and (3) altering biogeochemical fluxes between the seabed and water column.

This presentation focuses on the implementation of a coupled hydrodynamic-sediment transport-biogeochemistry model for the Chesapeake Bay. Developed within the open-source Regional Ocean Modeling System (ROMS), the coupled model accounts for transport of sediment, organic matter, oxygen, and nutrients, as well as processes including advection, resuspension, diffusion within the seabed and at the sediment-water interface, organic matter remineralization, and oxidation of reduced chemical species. Preliminary model results for the Chesapeake Bay indicate that resuspension increases turbidity, lowering rates of primary productivity and photosynthesis in surface waters of the Bay's oligo- and meso-haline regions. Additionally, resuspension increases concentrations of organic matter in the bottom portion of the water column, which increases remineralization rates in the Bay's meso- and poly-haline regions. These processes both decrease oxygen concentrations while increasing ammonium concentrations over timescales of days to a month. Ongoing work includes quantifying fluxes of material between the shoals and the main channel, and their effect on biogeochemical dynamics.

Nutrient enrichment alters blue carbon pools and processes

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Global change factors are known to feedback on ecosystem processes that influence primary production and coastal blue carbon in tidal salt marshes. Although there has been an emphasis on the inventory of blue carbon pools and processes, very little attention given has been given to the potential role of global change as an environmental filter on foundation species that directly influences carbon cycle processes. In a long-term nitrogen enrichment experiment (TIDE), we have found that nutrient pollution induced and environmental filter that reduced intraspecific genetic diversity and genetic identity of the foundation species, *S. alterniflora.* These genetic changes were also associated with reductions in belowground biomass allocation and altered phenology, which cumulatively reduce long-term carbon sequestration. Furthermore, we also found increased ecosystem respiration with nutrient enrichment, higher rates of decomposition, lower rates of soil organic matter stabilization leading to reduced carbon stocks. These data suggest that changes in plant traits in foundation species altered by global change factors may feedback on ecosystem processes reducing the blue carbon function of wetlands.

Allometric scaling of coastal ecosystem metabolism

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Coastal margins are home to some of the most productive habitats on the planet, yet there is still a great deal of uncertainty about the sources, exchanges, and fates of carbon and nitrogen at the land/ocean interface. Scaling up in situ measurements to estimates of how these habitats contribute to global biogeochemical cycling has been hindered by their apparent heterogeneity, complex circulation, diverse geomorphology, and sizes that range from tens of meters to hundreds of kilometers. Here I present allometric scaling relationships that indicate that ecosystem metabolism varies with ecosystem size to the 3/4 power. This result is consistent with explanations for organismal metabolic scaling and indicate that an underlying transport mechanism controls nutrient delivery across coastal ecosystems. These scaling relationships provide a simple framework for understanding ecosystem response to eutrophication and, possibly, climate change.

The organic geochemistry of Blue Carbon stores in a changing environment: a contemporary and paleo perspective

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Salt marsh, mangrove swamp, and seagrass bed ecosystems, together termed vegetated coastal ecosystems, comprise a global carbon stock known as "blue carbon." While these ecosystems have a small global areal extent, their total carbon burial rates are comparable to global marine carbon burial rates, giving them an important and outsize role in the global carbon cycle that is just beginning to be fully understood. Under various scenarios of environmental change, including climate warming, sea-level rise, and vegetation change, the role of these systems in the global carbon cycle could change significantly, potentially becoming a source of carbon to the atmosphere. It is therefore important to understand the factors controlling carbon storage in various coastal wetland systems in order to better predict their future behavior. Here, we will present data from two present-day study sites in Chesapeake Bay that include both C4 and C3 vegetation regimes and that are undergoing environmental change due to sea-level rise, in addition to cores of Louisiana coastal marshes from ~10,000 ybp, allowing for a comparison between present day and paleo peat deposits. The organic geochemistry of these peats was studied using a variety of both bulk (stable isotope, elemental, NMR, and FTIR analyses), and compound specific methods (lignin-phenol analysis). This provides important insight into the chemical nature of peats under a variety of vegetation and environmental change regimes, and also into the long-term geologic stability of this important organic carbon store. This data set includes some of the first organic geochemistry data of the changes in marsh peats due to rising sea level and vegetation changes.

Gulf of Mexico carbon stock and flux from rivers through estuaries

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This Gulf of Mexico (GOM) integration adds new Mexican mangrove data and new GOM seagrass carbon measurements to the GOM basin's carbon budget. Mangroves bury 386-1356

MgC_{org} m^{-2} stock. The photosynthetic processes remove 1000 gC_{org} $m^{-2}y^{-1}$ from the air. From this photosynthetically-derived amount, the mangroves supply 25% to the shelf, while burying 22%. Mexican mangroves' sedimentary carbon stock were higher than the Florida Everglades' stock. Our methods include measurements of C_{org} sediment/water, flux towers, isotopic flux, use of restoration sites indicating pollution effects plus C_{org} loss and calibration of baseline estuarine carbon, and extent results from remote imagery confirmed by field measurements. Our extent integration demonstrates GOM mangrove extent (USA=255,100 ha, Mexico=283,146 ha, GOM total =538,246 ha) and GOM mangrove carbon stock from 217 Tg C_{org} to 806 TgC_{org} . Seagrass extent was substantial at 947,300 ha USA GOM and 25,000 ha in Mexico. We "customized" the point measurements and extents to a C_{org} stock (20 cm depth of 37.6 Tg equivalent) or estimated 1m depth stock of 174 Tg . GOM marshes of 432, 600 ha occur intensely in the far northwest with GOM C_{org} stock of 115 TgC_{org}. Clearly mangroves, seagrasses and marshes not only create new carbon, but additionally modify substantial riverine carbon influx. All three blue carbon habitats release root exudates into their sediments, and into estuarine water through their detritus, then the detritus is consumed into the food web and moved offshore by animal migration and DOC, POC flux especially during intense storms.

Spatiotemporal dynamics of sea surface pCO_2 and its flux in the East China Sea during warm periods

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The distribution and air-sea exchange flux of pCO_2 with its controlling factors had been investigated in surface waters of the East China Sea (ECS) by an automated underway pCO_2 system during warm periods. The spring-summer pCO_2 distribution in the East China Sea (ECS) was associated with the mixing of varied water masses, which had their own dominant governing factors of pCO_2. pCO_2 changes in the Kuroshio Waters (KW) and Taiwan Current Warm Waters (TCWW) were, for instance, mainly controlled by temperature effect, in the Changjiang Diluted Waters (CDW) by biological activity and in coastal waters (offshore < 100 km) by vertical mixing, respectively. A multivariate regression relationship was then established ($R^2 = 0.86$) according to temperature and chlorophyll-a as major controlling variables. Moreover, model relation as a polynomial of two parameters was applied to the areas of offshore >100 km by using remotely sensed data of temperature and chlorophyll-a (2003 ~ 2010). The model results were comparable to the observed spatiotemporal distribution of pCO_2 in the ECS. The data further showed that the concentration gradients of pCO_{2w} were found i.e., an increasing trend from the CDW to TCWW and KW. The ECS overall acted as an atmospheric CO_2 sink between May and October (-2.8 ~ -0.3 mole C m^{-2} yr^{-1}), except in August as a source (~ 0.1 mole C m^{-2} yr^{-1}). Finally, based on the model pCO_{2w} data, the ECS was capable of absorbing atmospheric CO_2 at a rate of 0.0042 Gt C yr^{-1} about 30% of the total in warm seasons (May ~ October).

Session: Ecological and biogeochemical impacts of natural climate perturbation

Ribosomal RNA and DNA of diverse high light *Prochlorococcus* reveal variable activity and abundance relationships across taxonomic ranks

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Phytoplankton communities in oligotrophic temperate and tropical oceans are numerically dominated by *Prochlorococcus sp.,* a genetically diverse and biogeochemically important marine cyanobacterium. The phylogenetic clades and subgroups of *Prochlorococcus* exhibit niche partitioning based on light, temperature and other resources in the ocean, but it is unknown how these clades/ecotypes, differ in their *in situ* activity across large spatiotemporal environmental gradients. Here in the context of future climate scenarios, we use relative 23S rRNA:rDNA ratios as a proxy for specific activity to examine high light (HL) adapted *Prochlorococcus* across environmental gradients in the surface North Pacific Ocean to (1) determine the coupling between activity and abundance and (2) examine the relative activity among closely related operational taxonomic units (OTUs). We show that activity and abundance are highly correlated for all 97% similarity OTUs of *Prochlorococcus* across all sites in the surface ocean. Rank-ordered rRNA:rDNA ratios reveal differing trends among closely related OTUs with substantially different patterns between high and low abundance taxa. These results suggest that HL *Prochlorococcus* populations respond quickly to (a)biotic changes and the mechanisms that lead to uncoupling between activity and abundance (e.g. density dependent processes) are less important for this community. These findings also suggest that relative *Prochlorococcus* population abundances at a given location can serve as a proxy for activity, providing an important tool for ecosystem model development, but that substantial 'micro' diversity exists.

Characterizing ENSO events in satellite derived ocean phytoplankton biomass

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Observed variations in phytoplankton community structure and biogeochemical processes of the tropics have been linked to the El Niño Southern Oscillation phenomenon (ENSO), a dominant driving force of large-scale natural climate variability on interannual time-scales. ENSO has a warm (El Niño) and a cold (La Niña) phase characterized by anomalous changes in trade wind intensity and sea surface temperature induced through a complex suite of ocean-atmosphere feedbacks, tropical-extratropical interactions and atmospheric teleconnections. Scientists have shown a recent shift in ENSO characteristics and the increased occurrence of a 'new' flavor of El

Niño, known as Warm Pool or Modoki El Niño, different from the classical Cold Tongue El Niño and perhaps linked to the occurrence of the 1998-2011 hiatus period

Significant technical advances have allowed for the retrieval of biological data from optical properties of water via satellite ocean color remote sensing, providing an opportunity for quantifying the relationships between biological and climate indices. Studies have focused in-depth on contrasting flavors of ENSO events for various physical parameters (e.g., sea surface salinity, precipitation) with only a few recent studies focusing on satellite-observed chlorophyll, with none focusing on phytoplankton functional groups (PFT) and biomass itself. Here we review the types of ENSO and their effect on biology by analyzing, using different techniques, the backscattering-based PFT and biomass over the SeaWIFS period (1997-2010), for a PFT product recently refined in *Kostadinov et al. 2016*. We also contrast the responses of biomass with those of chlorophyll and analyze their physical drivers during various types of ENSO events. Possible mechanisms responsible for these signatures will be discussed.

Environmental controls of phytoplankton community size structure

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Phytoplankton play key roles as the base of the marine food web and as a crucial component in the Earth's carbon cycle. Changes to sea temperatures, increased stratification, and decreasing pH are just some environmental stressors that are and will continue to impact plankton communities and productivity. We aim to explore changing patterns in phytoplankton community diversity, specifically as it relates to cell size distribution, on a global scale in response to environmental controls. Using satellite data products and the absorption based approach of Mouw and Yoder (2010), we retrieve the proportional contributions of micro- (>20 µm) and pico-plankton (0.2–2 µm) to the total phytoplankton community across both SeaWiFS and MODIS missions from 1997 to 2015. We characterize spatial and temporal variability and trends in community size structure in relation to satellite-based physical drivers of the system.

Chlorophyll and black carbon: Light absorption on Arctic Sea ice

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The extent of Arctic sea ice has been declining steadily chiefly because of the deposition of black carbon (BC) on the snow and ice pack, and the growth of ice algae in the brine channels and horizontal layers of ice. We present simulations for the contemporary period showing that the optical depth contributed by the chlorophyll in Arctic ice algal is comparable to BC during the Boreal Spring. The bottom ice layer in the Bering Sea and Sea of Okhotsk shows the greatest absorption where the chlorophyll pigment concentration is estimated to be 300 - 1000 mgm^{-3} whereas the ice interior in regions north of 75° N and across the Canadian Archipelago has chlorophyll concentration of less than 0.1 μgm^{-3}. Intermediate level light reduction is observed in the freeboard and infiltration layers. The amount of light penetrates through the ice pack has diverged as a function of varying ice pack thickness, where the ice algae act as a crucial absorber.
Assuming a continuous increase in relative chlorophyll activity and attenuation in the future, as biological activity becomes stronger as the ice thins toward the center of the Arctic basin. A shift in relative importance of the two absorber types could occur as total BC mixing ratios are reduced because of environmental restrictions.

Multi-model analysis of marine biogeochemical feedbacks from regional and global ocean

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Marine phytoplankton plays a significant role in the global carbon cycle as one quarter of anthropogenic CO_2 emissions end up in the ocean. Life in the ocean increases the efficiency of marine environments to take up more CO_2 and reduces the rise in atmospheric concentrations. However, challenges with appropriate representation of physical and biological processes in Earth System Models (ESM) undermines the effort to quantify seasonal to multi-decadal variability in ocean uptake of atmospheric CO_2.

In a bid to improve analyses of marine contributions to climate–carbon cycle feedbacks, the International Land Model Benchmarking (ILAMB) project at ORNL is now expanding to meet the growing benchmarking needs of ocean biogeochemistry models. This expansion includes modification of the ILAMB package to satisfy some intrinsic demands of the Ocean community, and use the generated International Ocean Model Benchmarking (IOMB) package to validate DOE ocean model biogeochemistry results with observation datasets. The IOMB will also be employed to analyze outputs from other international ocean models that contributed results to the fifth and sixth phases of Coupled Model Intercomparison Project (CMIP5 and CMIP6).

Our analyses suggest that biogeochemical processes that determine CO_2 uptake by the global ocean are not well represented in most ESMs. Polar regions continue to show notable biases in biogeochemical and physical oceanographic variables. Some of these disparities could have first order impacts on the conversion of atmospheric CO_2 to organic carbon. In addition, single forcing simulations show that the current state of the global ocean can be partly justified by the deposition and uptake of anthropogenic emissions. Combined effects of two or more of these forcings on ocean biogeochemical cycles and ecosystems are challenging to predict as additive and antagonistic effects may occur. Thus, a benchmarking tool for marine biogeochemical outputs is indispensable as we continue to improve ESM developments and understand climate – carbon cycle feedbacks from the ocean.

Climatic modulation of anthropogenic ocean acidification in the California Current ecosystem

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The oceanic uptake of anthropogenic carbon mitigates climate change, but also results in global ocean acidification (OA). OA corresponds with a reduction in carbonate ion concentration ($[CO_3^{2-}]$), which has been shown to hinder calcification by some marine organisms. Here, we use the calcification history recorded by fossil shells of calcifying zooplankton preserved in marine sediments to reconstruct the progression of OA over the last century in the central California Current Ecosystem (CCE). This record indicates a 20% reduction in calcification translating to a 35% decline in $[CO_3^{2-}]$ over the 20th century. The reconstruction also shows considerable modulation of the anthropogenic ocean acidification signal that is timed with shifts Pacific Decadal Oscillation and correspondingly upwelling strength. The relationship between the shorter-lived climate mode El Niño Southern Oscillation and the state of the marine carbonate system has already been observed in this region but the correlation with PDO has been obscured by the relatively short duration of observational time-series in this region. The observed correlation between PDO and $[CO_3^{2-}]$ indicates that this climate mode will play an important role in the progression of OA in this region. Despite such modulation, the anthropogenic signal is large, with the reconstructed history of OA in the CCE implying very low CO_3^{2-} levels in the near future.

Decadal climate change impacts on carbon cycling in the Gulf of Maine

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Global anthropogenic warming has resulted in a considerable increase in Arctic ice melt and freshwater input to the North Atlantic. As a result, the Gulf of Maine is experiencing substantial decadal changes in water column hydrography, biogeochemistry and planktonic ecosystem structure. Gulf of Maine researchers have documented significant freshening, a nutrient regime shift, changes in production and plankton community composition, decreases in carbon delivery rates, and potential impacts on $CaCO_3$ precipitation/dissolution rates. We summarize multiple

chemical and biological data sets obtained from time-series moorings, research cruises and satellite surveys to examine the linkages between drivers and specific impacts on the biogeochemical system.

Seasons in the ocean: developing phenological indicators for climate assessment

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The timing of seasonal events in the ocean is shifting as a result of climate change. This changing phenology can impact marine ecosystems and their populations, which have evolved to exploit resources or conditions that occur at certain times of year. We are developing phenological indices to concisely capture the dominant modes of variability in the ocean's seasons, and to understand the impact that these changes can have on marine life. Here, we highlight our approach with satellite estimates of chlorophyll *a* in the North Atlantic Basin, from 2003 to 2016. We use empirical orthogonal function (EOF) analysis to identify regions with similar dominant modes of surface chlorophyll variability. This analysis yields four distinct regions with different annual chlorophyll cycles; and the first two modes capture 66.4% and 25.5% of variability, respectively. We extract time series of phenological metrics for each region to compare to biological metrics, including North Atlantic copepod abundances and seasonal cycles. We also generate time series of phenological metrics directly from the chlorophyll dataset, such as annual center of mass, timing of cumulative chlorophyll thresholds, and multiple bloom metrics. We compare time series of these metrics, as well as metrics of temperature phenology across the study region, to time series of higher trophic indicators, such as North Atlantic copepod abundances and seasonal cycles, anadromous fish arrivals to spawning grounds, and their annual mean abundance. These spatial analyses can reveal where in the fishes' ranges the timing of seasonal events has the most impact. Indices that encapsulate most of the variability in a system are useful tools for climate assessment.

Session: General OCB interest

Distribution and variability of total alkalinity in the Cariaco Basin, Venezuela.

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The spatial distribution of total alkalinity (TA) was studied in surface waters (upper 100 m) across the domain of the Cariaco Basin located off Venezuela in the southern Caribbean Sea.

Observations were collected during upwelling (dry season of March 2004 and 2009) and stratification periods (rainy season of September 2006 and 2008). Specifically, 11 stations were occupied in March 2004, 19 in September 2006, 36 in September 2008, and 36 in March 2009. Alkalinity variability responded strongly to changes in salinity in the western sub-basin of the Cariaco Basin ($R^2 = 0.87$ and $R^2 = 0.80$ for September 2008 and March 2009, $p < 0.001$). This relationship was weaker in the eastern sub-basin ($R^2 = 0.20$, $p > 0.01$ for March 2004, and $R^2 = 0.37$ and $R^2 = 0.31$ for September 2008 and March 2009, $p > 0.001$). The TA-salinity relationship is reproducible with a two end-member mixing model (upwelled waters and river input), which appears to be occasionally affected by biological removal of CO_2 via photosynthesis. During upwelling periods, TA and nTA (normalized to a constant salinity of 36.8) did not show significant variability in the eastern sub-basin. During thermal stratification, however, waters with salinities < 36.4 showed a slight increase in nTA, specifically in September 2008. Low salinity waters had higher nTA (> 2425 µmol kg^{-1}) than more saline waters, i.e. Subtropical Underwater (SUW). There was a westward increase of surface nTA values that may suggest additional TA sources such as such as alkalinity input from local rivers.

The role of autotrophic biomass in marine particulate organic carbon

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Global oceanic food web models commonly use chlorophyll estimates, standardized conversions to carbon, and allometric scaling of carbon (C) biomass to model net primary productivity. Estimates of each component (i.e. chlorophyll, particulate organic carbon (POC), and cell volume) and their ratios are subject to pronounced variability, and thus uncertainty. Marine POC is comprised of heterotrophic bacteria, microzooplankton, detritus and phytoplankton, which vary geographically in their relative abundance. The C density of cells and C-to-chlorophyll relationships are confounded by a lack of knowledge of whether chlorophyll concentrations scale with biomass, or are a result of photoacclimation processes. To better constrain the relationships between ecosystem C components, we reanalyzed data from cruise transects to major ocean basins in the North Atlantic, equatorial Pacific, and eastern Indian Oceans, along with the high nutrient Bering Sea and Peruvian upwelling zone. We used flow cytometry to semi-empirically derive C biomass from pico- and nano-plankton (<20 µm cells; C_{nano}) functional groups. We used the POC:Chlorophyll relationship to derive expected total autotrophic biomass (C_{phyto}), and the difference between C_{phyto} and C_{nano} to calculate large (>20 µm) phytoplankton biomass (C_{micro}). Outside of the Bering Sea, the transects were dominated by C_{nano}. Across the entire dataset, the C_{phyto}:POC ratio was 0.41 ± 0.38, and was positively correlated to macronutrient concentration. Higher autotrophic biomass also correlated to lower particulate carbon-to-phosphorus ratios, highlighting the connection of nutrient cycles to C dynamics. Depth profiles comparing POC:Chlorophyll and C_{micro} tend to show that the subsurface chlorophyll maximum generally reflects an increase in autotrophic biomass, but with some influence of photoacclimation. We intend to use this data set to improve satellite retrievals of phytoplankton functional groups, coupled with better constraints on C-to-volume relationships and vertical distribution in the water column.

The North Atlantic Aerosols and Marine Ecosystems Study (NAAMES)

Mike Behrenfeld[1], Mary Kleb[2], Chris Hostetler[2], Rich Moore[2], Chris Proctor[3], Gao Chen[2] and Luke Ziemba[2] Presenter: Susan Menden-Deuer[4],

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This poster will provide an introduction to the North Atlantic Aerosol and Marine Ecosystem Study (NAAMES, a 5-year campaign employing ship, aircraft, float and drifter, and satellite observations to resolve these important processes in the North Atlantic Ocean across the annual plankton seasonal cycle. The North Atlantic plankton bloom is among the most conspicuous biological events that is recorded each year by satellite ocean color measurements. Yet, the scientific underpinning how this bloom comes about remains highly controversial! For example, does the bloom begin in the Spring (traditional view) or does it actually begin in the Autumn (as suggested by an emerging theory based on the satellite record)? Resolving this scientific impasse has profound implications for the carbon cycle, ocean management as well as for quantifying the production of atmospheric aerosols and their impact on clouds and climate.

Sea to space particle investigation

Ivona Cetinić[1,2], Hugo Berthelot [3], Kirsten Carlson[4], Colleen Durkin[5], Margaret Estapa[6], Benjamin Knorlein[7], Zrinka Ljubešić[8], Antonio Mannino[2], Aimee Neeley[2], Melissa M. Omand[9], Wayne Homer Slade[10], Stephanie Schollaert Uz[2], Ryan Vandermeulen[2], Noah Walcutt[9], Seaver Wang[11] and Jeremy Werdell[2]

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Sea to Space Particle investigation took place in January/February 2018, with the idea of linking ocean color, phytoplankton diversity and different aspects of oceanic carbon cycle. Combination of novel techniques and instruments allowed for collection of complex optical, biogeochemical and physical ship-based and autonomous observations along a Hawaii to Pacific Northwest transect. Data collected during this experiment will be used to validate current and future ocean color algorithms targeting phytoplankton diversity and its role in oceanic carbon cycle.

Linking surface phytoplankton with sinking particles

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Phytoplankton growing in the surface ocean fuel the biological pump: the organic carbon produced by phytoplankton can be removed from the atmosphere and naturally sequestered in the deep ocean through complex ecological and physical processes. The mechanisms leading to the transport of phytoplankton and the organic carbon they produce must be better resolved to improve quantification and prediction of the ocean carbon cycle. We deployed a combination of drifting sediment trap platforms (~150 m deep) and sensors at three locations in the open North Pacific Ocean to identify 1) which phytoplankton from the surface were contributing to carbon export and 2) the mechanism leading to their transport. The three sampling locations spanned ecosystems in the oligotrophic subtropical gyre to the coastal upwelling-influenced coast of California. A subset of sediment trap tubes contained a polyacrylamide gel layer, which was imaged and analyzed by microscopy to enumerate individually-resolved particles and organisms. The organismal contents of individual particles isolated from the gel (i.e fecal pellets or aggregates) and from the surface waters will be determined using molecular sequencing tools. Our preliminary data indicate large shifts in the surface community among these locations, corresponding with an order of magnitude difference in particle fluxes and changes in the dominant phytoplankton and particles responsible for carbon export.

Non-uniform ocean acidification and attenuation of the ocean carbon sink

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Surface ocean carbon chemistry is changing rapidly. Partial pressures of carbon dioxide gas (pCO_2) are rising, pH levels are declining, and the ocean's buffer capacity is eroding. Regional differences in short-term pH trends primarily have been attributed to physical and biological processes; however, heterogeneous seawater carbonate chemistry may also be playing an important role. Here we use Surface Ocean CO_2 Atlas (SOCAT) Version 4 data to develop 12-month gridded climatologies of carbonate system variables and explore the coherent spatial patterns of ocean acidification and attenuation in the ocean carbon sink caused by rising

atmospheric pCO_2. High-latitude regions exhibit the highest pH and buffer capacity sensitivities to pCO_2 increases, while the equatorial Pacific is uniquely insensitive due to a newly defined *concentration* effect. Importantly, dissimilar regional pH trends do not necessarily equate to dissimilar acidity ($[H^+]$) trends, indicating that $[H^+]$ is a more useful metric of acidification.

Comparison of bacteria recruited by axenic Southern Ocean diatoms under Fe stress

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Diatoms, an important phytoplankton group responsible for 40% of oceanic primary production, have mutually beneficial interactions with bacteria. Marine bacteria consume diatom-derived organic carbon, while providing diatoms with essential vitamins and micronutrients. Diatoms in severely Fe limited regions such as the Southern Ocean (SO) may rely on bacterially-produced siderophores, organic ligands that tightly bind exogenous Fe, as an Fe source via the uptake of siderophore-bound Fe. This putative interaction could provide an ecological advantage for diatoms in Fe limited environments. During a SO cruise in the austral spring of 2016, an experiment was done to determine whether different Fe-stressed diatoms recruit distinct bacterial communities and whether the recruited bacteria have potential to produce siderophores. Experiments were conducted by comparing growth of three axenic diatom species (*Fragilariopsis cylindrus*, *Pseudo-nitzschia arenysensis*, and *Thalassiosira tumida*) in Fe limitation (-Fe) and Fe sufficiency (+Fe), then exposing these cultures to a smaller than 3 μm SO seawater fraction for bacterial recruitment. Growth rates show that the diatoms under -Fe conditions experienced growth limitation compared to +Fe cultures. Twenty siderophore-producing bacterial strains have been isolated from the -Fe *F. cylindrus* cultures and genotyped based on 16S rDNA sequences. These strains match Gammaproteobacteria known to be diatom-associated and include the genera *Pseudoalteromonas* and *Colwellia*. Future work will include measurements of Fe and ligand-bound Fe. The overall bacterial community composition will be assessed via highthroughput sequencing of a 16S rDNA variable region to determine if different diatom species recruited distinct bacterial communities under Fe stress. Expression levels will be compared for putative diatom siderophore uptake genes to see if these are upregulated in the presence of bacteria. Results from this study could provide information on likely SO diatom-bacteria interactions and help pinpoint what role these bacteria have, if any, in alleviating Fe stress in SO diatoms.

Subcellular proteomics for determining Fe-limited remodeling of plastids in the centric diatom *Thalassiosira pseudonana*

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Diatoms are important primary producers in the world's oceans, yet their growth is constrained in large regions by low bioavailable iron (Fe). This low Fe-induced limitation of primary production is due to requirements for Fe in components of essential metabolic pathways, including key plastid functions. During introduction of Fe into low Fe waters, diatoms can bloom and accumulate significant biomass. This bloom response indicates adaptations allowing for survival in Fe-limited waters, and rapid growth when Fe becomes abundant. Studies have shown that under Fe limited stress, diatoms alter plastid-specific processes, including components of electron transport. These physiological changes suggest regulation of protein content within the diatom plastid. While in-silico predictions provide putative plastid-localized proteins, knowledge of diatom plastid proteins remains limited in comparison to model photosynthetic organisms. To characterize proteins enriched in diatom plastids we have used tandem mass spectrometry proteome sequencing to assess the proteome of subcellular plastid-enriched fractions from *Thalassiosira pseudonana.* To improve our understanding of how the plastid proteome is remodeled in response to Fe limitation, sequencing has been performed on *T. pseudonana* grown under Fe replete and limited conditions. These analyses have shown that Fe limitation regulates major metabolic pathways in the plastid, including the Calvin cycle, as well as changes in light harvesting protein expression. Localization prediction of proteins within this plastid-enriched proteome has also provided an in-depth comparison of plastid-localized proteins and their computational predictions. This may provide evidence for the presence of additional import pathways into the diatom plastid.

Optically estimating CDOM composition across diverse spectral ranges

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Colored dissolved organic matter (CDOM) is a significant, optically active component of dissolved organic matter that impacts the underwater light field and ecosystem processes and provides insight into large-scale biogeochemical processes. CDOM spectral slope, S_{CDOM}, has been treated as a constant or semi-constant parameter both in satellite remote sensing and biogeochemical models despite significant regional and temporal variability. S_{CDOM} and other optical metrics provide insights into CDOM composition, processing, food web dynamics, and carbon cycling. To date, much of this work relies on fluorescence techniques or a_{CDOM} in spectral ranges unavailable to current and planned satellite sensors (e.g. <300 nm). Additionally, many global measurements of a_{CDOM} do not extend below 300 nm. Recently, a new method for fitting specific chromophores in a_{CDOM} spectra with Gaussian components was proposed, but the feasibility of adapting this method to wavelengths widely available in public databases of *in situ* spectra and anticipated with future hyperspectral satellite remote sensing (λ > 300 and 350 nm, respectively) has not been addressed. Here, we applied the Gaussian decomposition method to publicly available a_{CDOM} spectra to investigate if the retrieved S_{CDOM} and Gaussian components provide additional insight into CDOM composition and degradative state beyond previously observed relationships with $a_{CDOM}(\lambda)$. We iteratively decreased the spectral range considered and analyzed the number, location and magnitude of fitted Gaussian components to understand if a reduced spectral range impacts information obtained within a common spectral window. We also compared the fitted slope from the Gaussian decomposition approach to absorption-based indices indicating CDOM composition to determine the ability of satellite-derived slope to inform analysis of large-scale biogeochemical processes and modeling of those processes. By analyzing these CDOM metrics across biogeochemical provinces, we present variability and implications for remote sensing and biogeochemical modeling of CDOM composition, diagenetic state and the underwater light field.

Atlantic inflow to the North Sea modulated by the subpolar gyre: A potential oceanic influence on North Sea marine ecosystems?

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The oceanic inflow to the North Sea is known to be mainly forced by winds. Here we show that a part of this inflow, which acquires its properties south of the Rockall Trough, may be influenced by the North Atlantic Subpolar Gyre (SPG). We analyze historical simulation (1850-2005) from the coupled Max Planck Institute Earth System Model (MPI-ESM). In this model, the canonical SPG index, defined as the first principal component of the sea surface elevation, represents decadal variability of both the strength and shape of the gyre, which is key for the redistribution of subpolar and subtropical water masses. Source water masses in the eastern North Atlantic are identified using modelled salinity and oxygen profiles. We find a close connection between the northward penetration of water mass of subtropical origin and the canonical SPG index. A weak SPG results in the westward retreat of the subpolar front allowing saline waters, such as the Eastern North Atlantic Water, to invade most of the eastern North Atlantic. The core of this saline water is seen at depths shallower than 700 meter in the Rockall Trough moving close to the shelf edge, and subsequently crossing over the Greenland-Scotland Ridge into the Faroe Shetland Channel (FSC). In the FSC, even though the properties of the saline core are slightly diluted, the volume transport still follows the SPG variability. There is a close connection between the three regions, the Rockall Trough, the FSC and the northern North Sea; the northern North Sea salinity varies with the other two regions with one year lag. Overall, we find that volume transport of the saline inflow to the North Sea is significantly correlated with the canonical SPG index. In the next step, we will assess to which degree the North Sea marine ecosystem variability is influenced by the SPG dynamics.

A mechanistic model of an upper bound on oceanic carbon export as a function of mixed layer depth and temperature

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Export production reflects the amount of organic matter transferred from the surface ocean to depth through biological processes. This export is in great part controlled by nutrient and light

availability, which are conditioned by mixed layer depth (MLD). In this study, building on Sverdrup's critical depth hypothesis, we derive a mechanistic model of an upper bound on carbon export based on the metabolic balance between photosynthesis and respiration as a function of MLD and temperature. We find that the upper bound is a positively skewed bell-shaped function of MLD. Specifically, the upper bound increases with deepening mixed layers down to a critical depth, beyond which a long tail of decreasing carbon export is associated with increasing heterotrophic activity and decreasing light availability. We also show that in cold regions the upper bound on carbon export decreases with increasing temperature when mixed layers are deep, but increases with temperature when mixed layers are shallow. A metaanalysis shows that our model envelopes field estimates of carbon export from the mixed layer. When compared to satellite export production estimates, our model indicates that export production in some regions of the Southern Ocean, most particularly the Subantarctic Zone, is likely limited by light for a significant portion of the growing season.

Under-ice phytoplankton bloom dynamics controlled by spring convective mixing in refreezing leads of open water

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Spring phytoplankton growth in polar marine ecosystems is limited by light availability beneath ice-covered waters, particularly early in the season prior to snowmelt and pond formation. Leads of open water increase light transmission to the ice-covered ocean and are potentially important sites for enhanced primary production. Here we explore the role of leads in controlling the initiation of phytoplankton blooms within the sea ice zone of the Arctic Ocean. Data are presented from spring measurements in the Chukchi Sea during the Study of Under-ice Blooms In the Chukchi Ecosystem (SUBICE) program in May-June 2014. Observations revealed that while fully consolidated sea ice occasionally supported modest under-ice blooms, sea ice with higher concentrations of leads had significantly lower phytoplankton biomass, despite high nutrient concentrations in surface waters. Through an analysis of hydrographic and biological properties, we attribute this counterintuitive finding to the occurrence of springtime convective mixing in refreezing leads of open water. Our results demonstrate that waters beneath loosely consolidated sea ice (e.g. 85-95% ice concentration) had weak stratification and were frequently mixed below the critical depth (the depth at which depth-integrated production balances depth-integrated respiration). These findings are supported by model calculations of under-ice light, primary production, and critical depth at varied lead fractions. The model demonstrates that under-ice blooms can form in stratified waters even beneath snow-covered sea ice but not in more deeply mixed waters beneath ice with refreezing leads. Future estimates of primary production must account for these phytoplankton dynamics in ice-covered waters.

Estimating particulate inorganic carbon concentrations of the global ocean from ocean color measurements using a reflectance difference approach.

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A new algorithm for estimating particulate inorganic carbon (PIC) concentrations from ocean color measurements is presented. PIC plays an important role in the global carbon cycle through the oceanic carbonate pump, therefore accurate estimations of PIC concentrations from satellite remote sensing are crucial for observing changes on a global scale. An extensive global dataset was created from field and satellite observations for investigating the relationship between PIC concentrations and differences in the remote sensing reflectance (R_{rs}) at green, red and near-infrared (NIR) wavebands. Three color indices were defined: two as the relative height of R_{rs}(667) above a baseline running between R_{rs}(547) and an R_{rs} in the the NIR (either 748 nm or 869 nm), and one as the difference between R_{rs}(547) and R_{rs}(667). All three color indices were found to explain over 90% of the variance in field-measured PIC. But, due to the lack of availability of R_{rs}(NIR) in the standard ocean color data products, most of the further analysis presented here was done using the color index determined from only two bands. The new two-band color index algorithm was found to retrieve PIC concentrations more accurately than the current standard algorithm used in generating global PIC data products. Application of the new algorithm to satellite imagery showed patterns on the global scale as revealed from field measurements. The new algorithm was more resistant to atmospheric correction errors and residual errors in sun glint corrections, as seen by a reduction in the speckling and patchiness in the satellite-derived PIC images.

Validation of dynamic satellite biogeographic seascapes: scaling ocean biodiversity observations in the Florida Keys National Marine Sanctuary

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Coastal and open ocean environments can be conceptualized/visualized as complex mosaics, in which physical, chemical and biological processes interact to shape patterns on multiple spatial and temporal scales and levels of ecological organization. Hierarchical and dynamic seascapes classification allows to study how boundaries, extent, and location of features in these ecosystems change with time. As part of a Marine Biodiversity Observing Network pilot demonstration in the Florida Keys National Marine Sanctuary (FKNMS), we conducted a multivariate classification of dynamic coastal seascapes in surrounding waters of the FKNMS (23-27° N, 79-83° W) during March 11-18, May 9-13, and September 12-19, 2016, using sea surface temperature (SST), chlorophyll-a (Chl-a), and normalized fluorescence line height (nFLH) satellite input data. To validate seascape distributions we compared synoptic patterns to in situ chlorophyll-a concentrations, phytoplankton absorption coefficients (a_{phy}*), and pigment observations collected aboard the *R/V Walton Smith* (U. Miami) as part of the South Florida

Program of the National Oceanic and Atmospheric Administration. Seascape extent and habitat diversity varied throughout the sampling period. Seascape types show relatively unique phytoplankton community structure and allow to predict hydrographic conditions (i.e. salinity and nutrients) using remotely sensed ocean color data. A seascape framework presents an effective tool for translating local biodiversity measurements to broader spatiotemporal scales, enabling whole-ecosystem management in the dynamic ocean.

Investigation of the relationships between phytoplankton community structure and environmental parameters in the Chukchi Sea

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Multiyear ice in the Chukchi Sea is in sharp decline, with summer sea ice predicted to be negligible or completely gone by 2040. Sea surface temperatures and stratification are expected to increase in the Chukchi Sea congruent with the decline in sea ice thickness and persistence. Shifts in phytoplankton communities may include a transition from larger phytoplankton species that prefer colder temperatures, water column mixing, and higher nutrient concentrations to smaller taxa that prevail in conditions of low nutrients and increased stratification. It is imperative to understand how the pelagic and benthic ecosystems and associated food web dynamics will be impacted if these changes occur. We will present an analysis of environmental factors that are currently associated with phytoplankton species dynamics in the Chukchi region. We applied multivariate statistical techniques to explore relationships among sea ice extent, phytoplankton taxonomy and environmental variable data collected during the NASA funded **I**mpacts of **C**limate on **E**co**S**ystems and **C**hemistry of the **A**rctic **P**acific **E**nvironment (ICECAPE) field campaign of 2011. This approach was used to determine the underlying relationships between the observed environment variables and phytoplankton species diversity and abundance. Understanding how community assemblages shift with sea ice extent and associated environmental characteristics allows us to consider implications of warming on the Chukchi Sea ecosystems.

How choice of depth horizon influences estimated spatial patterns and global magnitude of ocean carbon export flux

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Quantifying the global magnitude and spatial patterns of biological carbon export from the surface ocean is important for understanding the influence of this key process in the global carbon cycle. However, different observational, remote sensing, and model based approaches

have led to widely varying estimates. Here we demonstrate that estimates of the rate and efficiency of export are sensitive to differences in the depth horizons used to define export, which often vary across methodological approaches. We evaluate sinking particulate organic carbon (POC) flux rates and efficiency (e-ratios) in a global earth system model, using a range commonly used depth horizons: the seasonal mixed layer depth (MLD), the particle compensation depth, the base of the euphotic zone, a fixed depth horizon of 100 meters, and the maximum annual MLD. Within this single dynamically consistent model framework, global POC flux rates vary by 30% and global e-ratios by 21% across different depth horizon choices for defining export. Spatial variability in POC flux and e-ratio also depends on the depth horizon due to pronounced influence of deep winter mixing in subpolar regions. Estimates of POC flux and e-ratio are more globally uniform when evaluated at the maximum annual MLD or 100 meters, as compared with pronounced zonal variations found when export is evaluated at the euphotic or particle compensation depths. Efforts to reconcile conflicting estimates of export among multiple observational, modeling, and remote sensing approaches need to account for these systematic discrepancies created by differing depth horizon choices for defining export.

The SeaBASS archive and validation system: Data and tools for researchers and ocean color satellite match-ups

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The SeaWiFS Bio-optical Archive and Storage System (SeaBASS; https://seabass.gsfc.nasa.gov) is NASA's repository for *in situ* oceanographic datasets maintained by the Ocean Biology Processing Group (OBPG) at the Goddard Space Flight Center. In addition to SeaBASS serving datasets publicly through web search engines, its data and services support Ocean Color satellite missions with the ongoing ground-truth comparisons needed for the validation of global geophysical measurements. Various updates have been made recently to SeaBASS architecture. The long-used SeaBASS file format has become a NASA Earth Science Data and Information Systems approved standard. FCHECK software, allowing data submitters to scan and fix formatting problems when they create new SeaBASS files, can now be downloaded and run offline. The format itself continues to grow with many new metadata headers and fields added to support the evolving field of instruments and measurement types. Digital Object Identifiers (DOIs) are regularly assigned to SeaBASS submissions to assist with citation and attribution. Website menus and search pages have been streamlined and have new options like being able to search for coincident measurements of different types, or filtering out files containing optically shallow measurements. Updates were made to the validation search engine, which allows users to query the SeaBASS database for coincident satellite-and-*in situ* measurements, or compare satellite-to-satellite points. Such queries can be performed on a list of standard products (including Chl, AOP and IOP products) for ocean color satellite data maintained by NASA including SeaWiFS, MODIS Aqua and Terra, MERIS and VIIRS. Several software tools can be downloaded to assist users in reading SeaBASS files in different software programs like Python,

MATLAB or Perl, converting files to netCDF, or even creating their own match-ups between *in situ* and satellite files.

A synthesis of 20 years of fCO_2 data in the US South Atlantic Bight: Can we see a clear trend through noisy data?

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We analyze spatio-temporal fCO_2 observations that span over 26 years in the South Atlantic Bight (SAB) off the southeast United States. Various cruises and one moored time series are used to determine multi-decadal fCO_2 trends. We compare two statistical methods for resolving trends: 1) deseasonalization (removal of the mean seasonal harmonic) using an ensemble mean reference year with a linear least squares best-fit slope; and 2) a Generalized Additive Mixed Model (GAMM) to identify and remove the seasonal signal, with a non-linear best-fit slope. The results from the two methods are not statistically different; however, the GAMM method calculates narrower 95% confidence intervals. Both methods agree that fCO_2 across the SAB is increasing at a rate greater than that of the atmosphere (~2 μatm y^{-1}). Thermal increases could influence outer portions of the SAB, while there is no evidence for thermal influences on the shallower inner portions of the shelf. Even though the moored fCO_2 time series has just less than 10 years of observations, the linear least squares best-fit slope agrees well with the slopes for only the cruise observations over 26 years. Therefore, we assume that even though the moored fCO_2 time series is less than a decade old, the high observational frequency (three hours averaged to one day) provides an accurate assessment of long-term fCO_2 trends.

Deciphering phytoplankton community dynamics from HPLC pigment variability

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Phytoplankton pigments can provide insight into phytoplankton size classes, functional groups and taxonomy. While there are caveats and exceptions when using HPLC pigment analysis, it remains one of the fastest and easiest ways to characterize community composition. Changes in pigment ratios can be caused by changes in species composition, increased growth of certain groups, or photoacclimation, but this distinction is not always acknowledged. For decades, pigment samples have been collected throughout the world. Since HPLC pigment data is often used to calibrate and validate satellite/optical algorithms and models of phytoplankton community composition, our goal was to characterize ranges of pigment variability and evaluate the role of photoacclimation. We compiled a new dataset of 89117 HPLC pigment records from five publicly available sources (MAREDAT, NASA, HOT, BATS, PALMER LTER), only considering the eight pigments that are most frequently sampled, and focusing on surface samples (<20m, n=43500). We then selected four environmentally different locations of (5x5 degrees) with abundant HPLC data and matched those with the corresponding satellite

Photosynthetic Active Radiation product for those bins. Results show that changes in pigment concentrations may reflect different processes, such as enhanced production of accessory pigments as antennae to harvest more light in low irradiance conditions, or photoprotection in high irradiance conditions, as well as natural succession or biogeographical differences. However, if we only consider the ratio between typical picophytoplankton and microphytoplankton pigments (i.e. zea:fuco and chlb:fuco), there is not a clear relationship between irradiance and pigment fractions. This suggests that pigment ratios might be useful markers of community composition while changes in the concentration of individual pigments may be significantly impacted by photoacclimation.

Direct measurements of seawater carbonate ion concentrations in the Gulf of Mexico: Implications for spatial mapping of $CaCO_3$ saturation states

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The marine CO_2 system has historically been examined through determination of at least two of four measurable parameters — pH, total alkalinity, total dissolved inorganic carbon, and partial pressure of CO_2 — and subsequent calculation of additional parameters. Recently, procedures for direct spectrophotometric determination of carbonate ion concentration ($[CO_3^{2-}]$) have added a fifth measurable parameter. Carbonate ion concentration in marine systems plays a role in biological calcification and inorganic dissolution processes.

At typical marine pH, the major lead species present in seawater are $PbCO_3$ and Pb(II) chloride complexes. These species show distinct absorbance spectra in the ultraviolet. Consequently, with knowledge of chloride concentration (from salinity) and an appropriate model, carbonate ion concentrations can be determined from absorbance measurements in the ultraviolet spectrum.

The model to determine $[CO_3^{2-}]$ from absorbance measurements has recently been amended to account for spectrophotometer wavelength calibration differences and to encompass a more diverse array of seawater conditions. In addition, an empirical model for calculation of in situ carbonate ion concentration and in situ calcium carbonate saturation states has been introduced.

These updated approaches will be used to assess ecosystem health in the Gulf of Mexico on the 2017 Gulf of Mexico Ecosystems and Carbon Cruise. Reoccupations of previously visited transects will allow for evaluation of chemical changes in the region—chiefly, changes in seawater saturation states with respect to both calcite and aragonite—in the context of both natural and anthropogenic influences.

NES-LTER: A New Long Term Ecological Research Site on the Northeast US Shelf

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The northwest Atlantic, renowned for its fisheries, is experiencing faster-than-average warming and other climate-related impacts. To date, lack of systematic and detailed measurements over a sufficient length of time has hampered our ability to observe the responses of pelagic food webs to environmental perturbations and uncover the underlying causes and implications. To address this challenge, a new NSF-supported Long-Term Ecological Research site on the Northeast US Shelf (NES-LTER) will be established later this year. NES-LTER goals are to understand and predict how planktonic food webs change through space and time, and how those changes impact the productivity of higher trophic levels. While patterns of ecosystem change over seasons to decades have already been documented in this region, the key mechanisms linking changes in the physical environment, planktonic food webs, and higher trophic levels remain poorly understood. For this reason, predictive capability is limited and management strategies are largely reactive. To address these needs, the NES-LTER strategy combines observations that provide regional-scale context (NOAA survey cruises), process cruises along a cross-shelf transect, high-frequency time series at inner- and outer-shelf locations (MVCO and OOI Pioneer Array, respectively), coupled biological-physical food web models, and targeted population models. The long-term research plan is guided by an overarching science question: How is climate change impacting the pelagic NES ecosystem and, in particular, affecting the relationship between compositional (e.g., species diversity and size structure) and aggregate (e.g., rates of primary production, and transfer of energy to important forage fish species) variability? By capitalizing on high levels of seasonal and interannual variability in the NES, the PIs will study short-term responses to climate-related variables to a) characterize low and high export food webs, b) understand the linkages and transfer of energy from the phytoplankton to pelagic fish, and c) identify the mechanisms that underlie shifts between high and low export communities. Ultimately, mechanistic knowledge will be scaled up to understand and predict the impacts and feedbacks associated with decadal- to climate-scale forcing in the ecosystem.

The Changing Arctic Ocean: Interannual variability and potential shifts in gross primary production and net community production in the Beaufort Gyre

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Profound changes are occurring in the Arctic Ocean as climate warms. Most dramatically the summer sea ice extent has decreased significantly. How is the carbon cycle changing concurrent with these environmental changes? Biological productivity is one of the main drivers of the carbon cycle in the ocean. Net community production (NCP) reflects the total amount of CO_2 drawn down by the ocean's biological pump. Gross primary production (GPP) is a measure of the photosynthetic flux and thus represents the total amount of CO_2 removed by photosynthesis.

The ratio of NCP to GPP allows quantification of how efficiently an ecosystem is cycling its carbon. Gas tracers – namely O_2/Ar ratios and triple oxygen isotopes – can be used to quantify in situ rates of NCP and GPP. Here we present rates of NCP and GPP from the Beaufort Sea in the Canadian Arctic in late summer and early fall for five years (2011 – 2015). Each year, rates of biological production and the NCP:GPP ratio are calculated at a multitude of stations within the Canada Basin and also for one or two transects from the near-shore coast to the open basin. We explore the relationship between these rates of biological productivity and environmental variables such as ice cover, sea surface temperature and salinity, mixed layer depth, etc. Additionally, several of the cruises were in the fall rather than late summer, allowing investigation of seasonal modulation of productivity in this Arctic coastal ecosystem.

Investigating gas exchange processes using noble gases in the SUSTAIN wind-wave tank

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Air-sea gas exchange is a key part of the biogeochemical cycle of many climatically important gases such as CO_2, DMS, and NO_2. Additionally, a better quantitative understanding of gas exchange, and in particular the role of bubbles, is crucial for calculating rates of biological production from O_2 records derived from floats, gliders, moorings, or other autonomous platforms. In particular, the bubble flux in most areas of the ocean leads to an equilibrium state of O_2 that is supersaturated by a few percent, depending on wind/wave conditions. If the gas exchange flux is represented without explicitly including bubbles (as is common in many gas exchange parameterizations), the equilibrium concentration would be considered to be exactly at saturation. Calculations of rates of net community production made without explicitly including bubbles have been shown to overestimate true rates of biological production by a factor of two. Thus, we will be conducting an experiment later this summer in the SUSTAIN wind-wave tank in order to better quantify and understand the role of bubbles in air-sea gas exchange.
Noble gases are ideal tracers for air-sea gas exchange since they are biologically and chemically inert and thus gas exchange is the major process affecting their concentrations. We thus will use a recently developed noble gas mass spectrometer – a semi-portable mass spectrometer that measures ratios of Ne, Ar, Kr, and Xe continuously with an e-folding response time of 1.5 to 7 minutes – in order to calculate gas fluxes in the tank at a range of wind, wave, and temperature conditions. The fast response time of this instrument will enable study of both the kinetics and the equilibrium supersaturation of gas transfer. Discrete samples of noble gases including helium, measured by traditional techniques, will provide further data on equilibrium supersaturations. Concurrent measurements of O_2 and pCO_2 will enable investigation of gases that are more relevant to biogeochemical processes. Bubbles will be imaged by an underwater shadowgraph system, which will quantify bubble size distributions and void fraction. Wave, wind and thermal conditions will be monitored by infrared imaging and dozens of sensors located throughout the SUSTAIN tank. In this poster, we will describe the noble gas mass spectrometer, present data from lab tests, and discuss the experimental design. The first experiment in the SUSTAIN tank will be in July of this year and we are eager to receive feedback from the OCB community before we conduct the experiment.

Assessing bacteria as potential enhancers of iron availability for Southern Ocean diatoms

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Diatoms act as important food sources, oxygen producers, and carbon sinks. However, they are unable to fill these roles without the essential micronutrient iron (Fe). Fe acquisition by diatoms is especially challenging in the well-known Fe-limited Southern Ocean (SO). Fe stress experienced by diatom communities in this environment may be alleviated through a mutualistic relationship with tightly associated bacteria that produce siderophores. Siderophores are organic ligands that increase Fe bioavailability and are produced by a variety of bacteria across terrestrial and aquatic environments. Using color-changing Chrome Azul S (CAS) plates, diatom-associated and free-living bacteria from the SO were screened for siderophore production while onboard the R/V NB Palmer surrounding the Western Antarctic Peninsula. Over 130 cultured bacteria strains are CAS-positive indicating siderophore production, and over 30 of these purified strains have been identified using the highly variable V3 and V4 regions of the 16S rDNA gene. Cultured siderophore-producing bacteria represent the following genera of Gammaproteobacteria: *Pseudomonas, Colwellia, Moritella,* and *Pseudoalteromonas.* These include known psychrophilic, diatom-associated, and siderophore-producing bacteria. Future work includes identification of the siderophore compounds produced and co-culturing experiments with diatoms from the region. Elucidating diatom-bacteria interactions focuses on previously unknown and overlooked players at the bottom of the food chain and may better inform our understanding of Fe cycling, a challenge for global ocean models.

Impacts of anthropogenic nutrients on primary production and benthic hypoxia in the East China Sea – A Numerical Study

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In recent years, benthic hypoxia has been observed near the mouth of the Changjiang River (aka Yangtze River) in the East China Sea (ECS). Because the nitrogen input to the Changjiang watershed, mainly from human activities, has increased by 3 fold in the last four decades and the nitrogen load had grown exponentially, it is highly speculated that anthropogenic nutrients may have impact for the development of hypoxia in the ECS shelf. Here we conduct a coupled 3D Physical-biogeochemical model to asses such an increase impact on the ECS from 1970 to 2002. The model predicts an average value of 437 $mgCm^{-2}\ d^{-1}$ for primary production and 10.0 mmol $O_2\ m^{-2}\ d^{-1}$ for seafloor oxygen demand (SOD) for the ECS shelf over the entire modeling period. Responding to the increase of the Changjiang DIN loading by a factor of ~2.4 during 1970 to 2002, the modeled primary production in the ECS shelf has increased by 17%, and the modeled SOD by 22%. The maximum area of potential hypoxic region in any month of a year has increased dramatically after 1991; the change appears related to the Changjiang DIN loads from May to July that showed a sudden increase after 1990. The responses in potential hypoxic area are more pronounced than the increases in DIN loads, suggesting strong nonlinear effect in the development of hypoxia, which warrants further investigation. It should be cautioned that the SOD calculation in this study is based on the Redfield ratio, and we plan to improve our biogeochemical model by including different classes of phytoplankton and dissolve oxygen in the near future. Moreover, high-resolution model is required to study fine features of biogeochemical processes in the ECS shelf.

Freshening and stratification in the subpolar North Atlantic: Possible effects on chlorophyll-*a* concentrations and NPP

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This study examines the spatial trends of salinity, temperature, stratification, nitrate, chlorophyll-a and ocean productivity in the the subpolar North Atlantic. Spatial trends of surface salinity reveal large-scale freshening, with the largest trends in western subpolar gyre and Labrador Sea. Analysis of satellite derived productivity, along with maps of chlorophyll-a, reveal a reduction in total production, starting in the mid-2000s in the two regions experiencing freshening. Additionally, analysis of a model-derived biogeochemistry reanalysis outputs suggests an overall negative trend in sea surface nitrate over the same time period. Overall, these results suggest that the freshening trends in the subpolar region, and associated changes to stratification, are leading to a reduction in vertical advection of nutrient inputs, thereby limiting productivity.

Impact of circulation, transport, and exchange variability in the Northern Gulf of Mexico on shelf ecosystem dynamics

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A circulation model based on the Regional Ocean Modeling System/Coupled-Ocean-Atmosphere-Wave-Sediment Transport Modeling System, with coupled biogeochemical and sediment transport modules, has been implemented for Mississippi Sound and the adjacent continental shelf region. The model uses 400-m horizontal resolution, 24 vertical layers, and includes wetting/drying capability to resolve shallow inshore regions. The circulation model was spun-up using oceanographic initial and lateral boundary conditions provided by the Navy Coastal Ocean Model (NCOM) 1-km Gulf of Mexico model. Two atmospheric forcing products are applied: 1) North American Regional Reanalysis; and 2) CONCORDE Meteorological

Analysis (CMA). The latter synthesis product is regionally specific and provides significantly improved spatial and temporal resolution, including the diurnal sea breeze impacts. These high-resolution atmospheric forcing fields are used in experiments focused on particular time periods when comprehensive ship-based sampling was deployed as part of CONCORDE (Consortium for Coastal River-Dominated Ecosystems). The simulations show exchange between Mississippi Sound and the MS Bight. To quantify this exchange, Lagrangian drifters were embedded in the circulation fields and tracked. The simulated drifters provide estimates of primary transport pathways, residence times and their variability. Additional simulations that include a tracer provide quantitative estimates of exchange between the Sound, innershelf and shelf waters. These estuarine – inner shelf exchanges in the model have been validated with in situ mixing studies, moored arrays and surface drifters focused on the Mobile Bay plume. The biophysical interactions and biogeochemical variability associated with these exchange patterns have implications for planktonic interactions, hypoxia onset and persistence, pollution pathways, and oyster spat transport and recruitment.

Session: Mesoscale and submesoscale physical-biological-biogeochemical interactions

Diatom community composition shifts in the nitrogen-limited Mid-Atlantic Bight

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Diatoms are unicellular, photosynthetic eukaryotes with high sensitivities to nutrient availability, often leading to rapid shifts in community composition. This characteristic makes diatoms a strong bioindicator for environmental change. The Mid-Atlantic Bight (MAB), located off the eastern U.S., is an ecosystem predominantly limited by nitrogen. In the summer, waters are strongly stratified and phytoplankton communities are dominated by diatoms. Rivers and estuaries in this region can deliver nitrogen pulses, which can lead to community shifts in response to nutrient availability. Previous studies have produced overall phytoplankton composition for this region, naming the top few diatoms present, though have not provided an in-depth species-level diatom community composition analysis for the MAB. We completed a comprehensive diatom species-level assemblage analysis along the MAB to help elucidate the coastal-driven effects on the ecosystem as a function of distance from the coast. In order to obtain the species-level resolution, high-throughput sequencing techniques were used on the V4 region of the 18S rDNA marker gene. Most abundant diatom species in this region include *Leptocylindrus convexus*, *Nitzshcia longissima*, and a *Fragilariopsis sp*. Nutrient analyses were completed using PRIMER to assess shifts in community composition with fluctuations in nitrate.

Biogeochemical effects of ringwater influence on the Mid-Atlantic Bight shelf: differences in microbially-driven carbon cycling along a shelf transect

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The shelf waters of the Mid-Atlantic Bight (MAB) are affected by interactions with offshore waters of the Gulf Stream; these interactions are driven by a variety of exchange processes (e.g. Zhang & Gawarkiewicz 2015). In addition to affecting the physical characteristics of the water in the MAB, exchange with offshore waters can bring different organisms – including different microbial communities – to the MAB. Although microbial communities play a key role in driving biogeochemical cycles in the ocean, studies to date have not explicitly investigated microbially-driven biogeochemical processes in conjunction with characterization of water masses in the MAB. In order to compare the carbon-cycling capabilities of the microbial communities at distinct depths and locations in the MAB, we sampled surface and bottom waters at four stations along a shelf transect at 71 W. The four comparatively closely-spaced stations (bottom depths of 60m, 80 m, 100m, and 200 m) showed strong density stratification between surface and bottom waters, as well as contrasts in temperature and salinity characteristics, especially of the bottom waters along the transect. Bottom waters of Stns. 1 and 2 were characteristic of shelf water, while the bottom water of Stn. 3 showed features characteristic of a mixture of slope and shelf water, and the bottom water of Stn. 4 was characteristic of ring water. Since microbial processing of much organic matter is initiated by the activities of extracellular enzymes, we measured hydrolysis rates and substrate specificities of extracellular enzymes responsible for hydrolyzing a range of polysaccharides and peptides, representing two major classes of organic matter. The sites differed notably in terms of hydrolysis rates and substrate specificities, with the most distinct differences between Stns. 1/2 and Stns. 3/4. Notably, hydrolysis patterns in Stn. 4 bottom water were distinct from all other depths and stations, indicating that the microbial communities in bottom water of Stn. 4 had the enzymatic capabilities to access a specific range of substrates. The differences in enzymatic capabilities among heterotrophic microbial communities did not correlate with cell counts or bacterial productivity, demonstrating that patterns of substrate selectivity and rates of enzymatic activities are not simply a reflection of bulk measures of microbial communities such as population size or protein production. Offshore waters that exchange into the MAB likely bring distinct microbial communities with carbon-cycling capabilities that differ from their inshore counterparts. Such exchanges also affect the nature and rates at which organic matter is cycled within the water column.

Interactions between submesoscale dynamics and sinking particles: a pre-EXPORT study

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Submesoscale dynamics (O(0.1-10 km)) have been recognized to have major implications on the production of phytoplankton and the downward export of Particulate Organic Matter (POM). In the horizontal, submesoscale features are associated with strong vorticity and strain rates that enhance mixing and stirring in the mixed layer, generating "hot spots" of POM. In the vertical, submesoscale features are associated with large vertical velocities (O(10^{-3} m/s or 100 m/day)) capable of subducting patches of POM below the mixed layer. This subducting mechanism competes with the gravitational sinking of POM and is expected to have a greater impact on smaller particles with slower sinking velocities than on larger particles that sink out of the mixed layer over shorter timescales. To investigate the effects of submesoscale features on the downward flux of POM, numerical simulations were conducted in a model configured to represent conditions in the North Pacific. Model fields were statistically compared to oceanographic observations collected from underwater gliders, to assess the model's capability to generate a realistic submesoscale field. Particle tracking experiments were completed using a spectrum of particle size and sinking velocities. Early results from those numerical experiments are presented, along with a discussion on future milestones and the potential implications for the NASA EXPORTS field campaigns.

Diatom community composition through upwelling over thin and broad continental shelves

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Climate predictions indicate that upwelling events will become less frequent, longer in duration, and stronger. Upwelling waters differ in composition from the surface water usually having higher nutrient concentrations and lower temperatures. Upwelling events support seasonal blooms of phytoplankton, which are important primary producers at the base of the oceanic food web. Diatoms are unicellular phytoplankton known for an ability to respond quickly to nutrient pulses, allowing them to bloom in upwelling environments. Along the California coast, upwelling occurring over a thin continental shelf has been associated with iron limitation, while upwelling over a broad continental shelf has been found to be iron replete. Diatom community analysis was done on two transects, one transect following upwelling waters over a broad continental shelf and one transect following upwelling waters over a thin continental shelf. Differences between these two transects have highlighted the susceptibility of diatom communities to macro- and micro-nutrient changes.

A seasonal cycle of surface instabilities and physically-driven export from gliders in the northeast Atlantic Ocean

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Export of biologically-fixed carbon out of the euphotic zone is mediated by both biological (aggregation and sinking) and physical (vertical transport) processes. Recent studies have shown that a variety of small-scale instabilities can cause large vertical velocities of O(100 m/day), leading to a potentially large, but still ill-defined, physical transport of physiologically active phytoplankton out of the surface ocean. Here we use a full year's worth of in situ hydrographic and optical measurements, obtained from ocean gliders within a 20 x 20 km region in the subtropical northeast Atlantic Ocean, to investigate the seasonal cycle of gravitational, mixed layer, and symmetric instabilities, and the extent to which each of these contributes to the physical export of fixed carbon out of the surface ocean. The observations were collected as part of the OSMOSIS (Ocean Surface Mixing Ocean Submesoscale Interaction Study) project. We use data from seven distinct Seaglider deployments, which were staggered such that for 92% (58%) of the year at least one (two) Seagliders were sampling the region. Regions of low potential vorticity and apparent oxygen utilization are observed below the mixed layer, suggesting subduction of surface waters with increasing frequency during the winter months. However, fluorescence and optical backscatter show less prevalent anomalies at depth, suggesting a decoupling between the physics and biology in this region.

Modeling the sympagic-pelagic-benthic coupling processes in the St. Lawrence Island Polynya region, northern Bering Sea

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The Pacific Arctic Ocean is experiencing significant changes in atmosphere, sea ice, and ocean that may alter the marine ecosystem. The St. Lawrence Island Polynya (SLIP) region in the northern Bering Sea is one of the major biological hotspots. The highly productive benthic communities provide abundant prey for benthic-feeding mammals and seabirds, particularly the endangered spectacled eiders. Yet, major ecosystem shifts are occurring in the SLIP region, such as the observed declining trend in the percent biomass of the medium-sized nuculanid bivalves. Historical hydrographic and biogeochemical measurements and ice-ocean-ecosystem model outcomes are synthesized to elucidate the relationships between wind, sea ice, hydrography, nutrients, and production processes in this high-latitude continental shelf system. The model captures the annual cycles and seasonal patterns of the water column physical structure, nutrients, and primary production, and export production. In the wintertime, the mixing process brings high nutrients from the bottom water to the surface. A spring bloom occurs when light becomes available for photosynthesis and is typically associated with the formation of wind-driven polynyas. In the summertime, a two-layered water column is built up mainly due to thermal stratification. Nitrate and ammonium are gradually depleted in the surface water and concurrent high zooplankton grazing results in low phytoplankton standing stock. Meanwhile, nutrients are accumulated in the bottom water due to benthic remineralization. With later ice advance in recent years, a fall bloom may become more prevalent. The analyses of bottom-up

forcing and sympagic-pelagic-pelagic coupling will facilitate the prediction of the persistence or relocation of benthic hotspots and also the development of management strategies to mitigate detrimental effects from climate change in the Pacific Arctic Ocean.

What components of vertical velocity contribute to nutrient transport?

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Advective exchange of nutrients and biomass between the ocean surface and the permanent thermocline is an important process for both new biological production at the surface and particle export from the surface to the deep ocean, processes which could be enhanced by intense submesoscale circulation. Using a model based on oceanographic conditions near Bermuda, I explore vertical motion at a front and in an eddy dipole in the Lagrangian framework to examine how the evolution of the strain and vorticity fields of frontal meanders and eddies relate to vertical motion of water parcels in a non-hydrostatic ocean model. In doing so, I present a method for decomposing vertical velocity into the two components of Lagrangian vertical motion: vertical transport along sloping isopycnal surfaces and vertical motion of isopycnal surfaces. I conclude that nutrient transport along sloping isopycnal surfaces as important as vertical motion of isopycnal surfaces for supplying nutrients to a deep chlorophyll maximum. Frontogenesis is an important process for vertical transport, particularly for upward transport along isopycnal surfaces.

Interactions between mesoscale eddies and the bottom bathymetry in the southern Florida Straits and the biogeochemical impacts

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Abundant and diverse deep corals and associated fish communities reside in the deep waters of the Florida Straits. Here Florida Current drive ubiquitous meso- and submeso-scale eddies, which move along the shelf slope from Dry Tortugas to Florida Keys. Using a coupled physical-biogeochemical model, we show strong interactions between these eddies and the bottom bathymetry over Pourtalès Terrace (200-450 m) where deep coral reefs can be found. As the Florida Current is forced to follow the lower slope, eddies can propagate over the terrace with upwelled cold deep waters rich in nutrients and CO_2. Some eddies can also lift the thermocline to directly drive deep waters from lower slope onto the platform. These waters may be left on top of the platform after these eddies pass through the area, therefore strongly affecting the near bottom carbonate chemistry including pH and alkalinity over the reefs. Eddy-driven upwelling also drives strong phytoplankton blooms, mostly along the eddy perimeter, which lead to high chlorophyll concentrations often visible from satellite images. The associated biological export from these blooms can be an important food source for the coral reef communities.

Submesoscale fronts in Northwest Atlantic and implications for particulate organic carbon export

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Submesoscale mixed layer fronts in the Gulf Stream region are often characterized by warm and salty filaments compensated by cold and fresh water. These compensated fronts are associated with small density gradients and are not as dynamically important to vertical eddy driven fluxes as uncompensated fronts. Here, we analyze the degree of compensation and the seasonal and spatial variability of horizontal mixed layer fronts in the Northwest Atlantic. Shipboard observations made by the cargo ship, MV *Oleander*, provides a continuous 5 year record of surface temperature and salinity along a transect between New Jersey and Bermuda, spanning shore, shelf, slope, Gulf Stream and Sargasso Sea water masses. The density ratio reveals a high degree of salinity dominated compensation on the shelf and slope indicating that satellite derived sea surface temperature data may not always provide sufficient evidence to locate dynamically important fronts. Eddy driven particulate organic carbon (POC) flux is parameterized based on the measured density gradients (M^2), surface POC concentration, and the climatological stratification and mixed layer depth, implicating the year round importance of the Gulf Stream, and a winter-time intensification of vertical transport of POC rich waters to depth.

Modeling the impact of submesoscale physical dynamics on phytoplankton community composition and carbon cycling in the North Pacific subtropical gyre

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In the subtropical gyres, spatial and temporal patchiness exists across a wide range of scales. As ocean surface temperatures continue to rise, global climate models suggest that the strength of these gyres as a biological carbon pump may diminish due to increased stratification and depleted nutrients over large scales. However, such predictions often ignore climate-physical-ecosystem interactions on much finer scales due to computational constraints and a lack of observational evidence. In order to assess the ecosystem responses to fine-scale patchiness in the physical and biogeochemical environment, we introduced a new and computationally tractable modeling approach, the Spatially Heterogeneous Dynamic Plankton (SHiP) model, which allows for subgrid-scale heterogeneities in the resource environment through a probabilistic representation of fine-scale disturbances. We applied the SHiP model to the Hawaii Ocean Time-series (HOT) site (Station ALOHA) in the North Pacific Subtropical Gyre, and compared the model output against high-resolution observations from satellite, automatous sampling platforms, and ship-based field campaigns. We show that the model successfully captured both the mean dynamics and the full range of variability observed at Station ALOHA. The model

also yielded a substantially different phytoplankton community composition and carbon cycling when run in a temporally and spatially heterogeneous mode relative to the traditional homogeneous approach. In general, subgrid-scale heterogeneities in the nutrient field favors the growth of large phytoplankton and enhances organic carbon production and export under oligotrophic conditions. Our findings also suggest that both the temporal scale (i.e. duration) and the intensity (i.e. magnitude) of fine-scale disturbances are critical for determining the response of oligotrophic ecosystems to fine-scale processes. This indicates that future changes in both large and fine-scale dynamics may significantly impact marine ecosystem structures and global carbon cycling, and both should be accounted for in the next-generation global climate models.

Biogeochemical fronts: gateways to exchange

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Fronts in the oceans, including the Gulf Stream and Kuroshio Currents, have lateral property gradients at least a factor of fifty higher than subtropical gyres they border. More than a decade of work has revealed that transport across such fronts provides a critical nutrient supply pathway that fuels subtropical gyre productivity, yet the spatial distribution of this flux and the mechanisms governing this exchange – including the role of eddies – has yet to be quantified. Here, we use a strongly eddying ocean component of a climate model to suggest that lateral transport across the Gulf Stream and Kuroshio provides the majority of new nutrients to the subtropical gyres, and that this lateral transport is tied to mesoscale eddies. We further hypothesize that ring shedding from these strong currents might be an important mechanism providing this flux of nutrients. Blending satellite and in situ measurements, we provide a quantification of the flux of nutrients into the subtropical gyre by rings shed from the Gulf Stream. Finally, we explore the ecological and biogeochemical implications of this cross-frontal transport.

Particle cycling in the Sargasso Sea water column revealed by lipid biomarkers in suspended particles: Seasonality and physical forcing

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Lipid biomarkers elucidate OM sources and cycling within the water column. Lipid biomarkers (*n*-fatty acids, *n*-alcohols and sterols) and bulk properties (organic carbon (OC), nitrogen (N), OC/N ratio, $CaCO_3$ and stable isotopes $\delta^{13}C$ and $\delta^{15}N$) were determined in suspended particles at Oceanic Flux Program (OFP) site offshore Bermuda. Profiles (30-4400 m, 100 mab) were collected in April/November 2015 and October 2016, three periods of contrasting weather patterns. Key lipid biomarkers, were used to evaluate the relative importance of phytoplankton, bacterial and zooplankton OM sources and diagenetic processes, as well as the impact of upper ocean environmental forcing in the dynamics of the carbon pump. Additionally, we assessed benthic remineralization by comparing particles above and within the nepheloid layer.

N-fatty acids, *n*-alcohols and sterols comprise up to 76%, 11% and 5%, respectively, of total extractable OM. Higher lipid concentrations in April *vs* November 2015 mirror seasonality in primary production, while change in C_{27} and C_{28} sterol composition reflect shifts in phytoplankton community structure. In the mesopelagic zone increased cholesterol/phytosterol ratios and percentages of C_{16} and C_{18} *n*-alcohols, odd-chain and branched *n*-fatty acids document a transition from algal to animal OM sources as well as a bacterial reprocessing of labile OM. The impact of Hurricane Nicole (October 2016) on the mixed layer and subsequent increases in production/flux was evident in higher concentrations as well as greater depth penetration of particulate N and fresh/labile algal biomarkers (e.g. 18:5 ω3 and 22:6 ω3 polyunsaturated fatty acids) in the upper 1000 m. The nepheloid layer had higher concentrations of OC and N and more depleted $\delta^{13}C$ values than at 4200 m for all dates. While biomarker composition was similar, lipid concentration in April 2015 (seasonal production peak) and October 2016 (hurricane physical forcing) was higher than in November 2015, consistent with the increases observed in the water column. Our results highlight that episodic physical forcing of the upper ocean, such as was the Hurricane Nicole, can have a large effect on the OM composition through the water column, triggering an episodic pulse of labile materials and OM-associated trace elements to the deep ocean.

Submesoscale export of particulate and dissolved organic carbon

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Observations support the importance of submesoscale motions in exporting non-sinking particulate organic carbon (POC) out of the euphotic zone in phytoplankton patches. However, the contribution of submesoscale transport to the export of dissolved organic material (DOM) and how the submesoscale export of POC and DOM contribute to the carbon budget on annual time-scales and at the basin scale are still unknown. Here, we examine the export of POC and DOM by submesoscale motions, large-scale circulation and sinking of aggregates, using a high-resolution (1/54°) coupled physical-biological model of the North Atlantic. We show that the export of DOM is a major contributor to the total carbon export and that the impact of submesoscale is mostly local, with challenging implications for in-situ measurements of export.

From the oligotrophic ocean gyres to coastal upwelling systems: Simulating the dynamic range of chlorophyll concentration

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The measured concentration of chlorophyll *a* in the surface ocean spans four orders of magnitude, from ~0.01 mg m^{-3} in the oligotrophic gyres to >10 mg m^{-3} in coastal zones. Productive areas with annual mean chlorophyll *a* concentrations >3 mg m^{-3} account for only ~2% of global ocean area yet they contribute disproportionately to marine resources and biogeochemical processes, such as fish catch and oxygen depletion. These areas are often poorly represented in biogeochemical models, and we test the hypothesis that this is partly because of the very coarse representation of phytoplankton size classes in ecosystem models, which often include only one or two groups to represent the entirety of ocean phytoplankton communities. We find that the addition of a third phytoplankton size class representing a large, chain-forming coastal diatom yields a major improvement over the baseline two-phytoplankton size class model in capturing the full range of chlorophyll *a* observed in the California Current System. This improvement was accomplished by representing two mechanisms: i) including the third size class expanded the sequential invasion of phytoplankton groups of incremental cell size along a gradient of increasing autotrophic biomass, and ii) weaker 'top-down' control on large coastal diatoms increased phytoplankton biomass in areas of high resource supply. The enhanced representation of near-shore chlorophyll maxima also allows the model to better capture coastal hypoxia along the continental shelf of the North American west coast with important implications for improved representation of living marine resources.

Trait composition of the plankton community across environmental gradients.

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Contrasts in the community composition are usually attributed to differences in the underlying environment; however, predator-prey interactions often play an equally important role in structuring communities. Systematic differences observed between nutrient-rich and poor environments, cascade further up the food chain, which is particularly evident in planktonic systems. We analyse plankton communities across the southern California Current, which span multiple trophic levels, from bacteria to meso-zooplankton, and experience contrasting environmental conditions, from nutrient-rich upwelling to oligotrophic oceanic environments. We focus on traits related to resource acquisition that affect predator-prey interactions. The level of biomass varies 5-fold across environmental regions, yet, size distributions remain similar. The relative trait composition remains comparable between regions, with significant differences being confined to a small range of size or trait groups. Our trait-based analysis demonstrates that the relative trait distribution is remarkably conserved across the environmental gradient, even in the face of large differences in biomass.

Influences of water masses on the distribution of phytoplankton communities derived by pigment analysis in the mid-shelf East China Sea in summer

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Distribution of phytoplankton communities were investigated in July 2009 -2011 and 2013 in the mid-shelf East China Sea where received influences from both fresh water of Changjiang Diluted Water and oceanic Kuroshio current. The result of CHEMTAX analysis showed cyanobacteria as well as prochlorophytes dominated in Kuroshio surface water across the four years. Out of Kuroshio region, interannual variations of phytoplankton composition were found corresponding to the nutrient variability: diatoms showed strong correlation with the increased phosphate, and dominated in 2009 and 2013, whereas cyanobacteria and cryptophytes increased in high nitrate years of 2010 and 2011. Cluster analysis confirmed the relationship between the dominated phytoplankton communities and nutrient condition, and further identified the controlling factors of other phytoplankton groups in the mid-shelf ECS; dinoflagellates showed similar distribution pattern as diatoms that increased in high phosphate water, prochlorophytes associated with the high temperature of Kuroshio surface water, prymnesiophytes existed in the shelf mixed water between Changjiang Diluted Water and Kuroshio region. It is concluded that phytoplankton composition shifted from mixed population to diatom domination in responses to phosphate elevation. This variation is probably related to Kuroshio incursion in summer East China Sea which was expected to be the potential nutrient source for phytoplankton growth.

Impacts of mesoscale eddies on the vertical nitrate flux in the Gulf Stream region

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The Gulf Stream (GS) region has intense mesoscale variability that can affect the supply of nutrients to the euphotic zone (Z_{eu}). In this study, a recently developed high-resolution coupled physical-biological model is used to conduct a 25-year simulation in the GS region. By applying an eddy detection and tracking algorithm, we create eddy-centric composites and quantify the long-term contributions of cyclonic eddies (CEs) and anticyclonic eddies (ACEs) to the vertical nitrate flux into Z_{eu} over the GS region. The eddy composite structures indicate that, below 100m depth, an upward transport of nitrate associated with the doming of isopycnals occurs in CE, while the isopycnals and nitrate isopleths form a concave shape in ACE due to downwelling. Notably, above Z_{eu}, the upward doming of nitrate isopleths occurs in both types of eddies, and the positive nitrate anomalies are even more pronounced in the ACE. Overall, the net vertical

fluxes of nitrate upwelled into Z_{eu} by CE are comparable with that upwelled by ACE. Furthermore, this study reveals that the ACE in the GS region have positive net vertical fluxes of nitrate into Z_{eu} based on a large sample of eddies detected from the long-term simulation. The possible mechanisms leading to the positive nitrate anomalies in ACE are discussed.

Session: Our autonomous future

Engineering a Smartfin for surf-zone oceanography

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We are developing the Smartfin, a surfboard fin capable of measuring geolocated ocean chemistry data, to enable surf-zone observations via a new citizen/surfer science initiative. The Smartfin collects GPS, temperature, and motion data; modules for measurement of pH, dissolved oxygen, and chlorophyll fluorescence are in development. The fin is used by citizen/surfer scientists with a goal of distributing several hundred Smartfins in California in 2017 and rapidly expanding across the country and world in the coming years. Taking advantage of the resource that the surf community offers will provide unique insight into changing patterns in the near-shore environment. Furthermore, once the Smartfin concept has been proven on surfboard fins, it will be readily adaptable to larger “vessels of opportunity” such as stand-up paddleboards, kayaks, and sailboats on the surface and eventually SCUBA divers, marine mammals, and miniature drifters under the ocean’s surface.

In addition to the contributions that Smartfin will make to coastal oceanography, it is a uniquely powerful communication and education tool. The Smartfin project equips local surf communities with the tools necessary to talk about changes to ocean health, including sea level rise (and associated shifting or complete destruction of surf breaks) and coral bleaching and ocean acidification (which could have dramatic effects on reef breaks). Smartfin allows surfers, frequently among the strongest groups of ocean health advocates, to become more informed and proactive stewards of the marine environment.

Remote sensing of optical characteristics and particle distributions of the upper ocean using shipboard lidar

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Passive ocean color remote sensing has revolutionized our ability to quantify the horizontal distribution of phytoplankton in the surface ocean. Lidar technology, which has already proven its utility in a variety of geoscience applications, can provide remotely sensed estimates of the vertical distribution of optical properties and suspended particles in natural waters, significantly improving our ability to model biogeochemical processes in the upper ocean. In this study, we constructed and deployed a shipboard lidar system to measure laser backscattering and linear depolarization profiles in the coastal Mid-Atlantic ranging from estuarine to oceanic conditions, and across the Gulf of Maine. The instrument identified layers with different backscattering intensity in stratified waters of the coastal Mid-Atlantic, and produced system attenuation coefficients (K_{sys}) approximating the absorption coefficient [$a_{pg}(532)$] of suspended particles and CDOM. The linear depolarization ratio was strongly related to the ratio of backscattering to total scattering (b_b/b). These relations were used to generate a section map of K_{sys} and b_b/b across the Gulf of Maine that corresponded well with simultaneous *in situ* observations performed aboard the M/V Nova Star and by an autonomous glider deployed along the ship track. These results support the idea that oceanographic lidar can provide a powerful tool for measuring and monitoring optical properties and particle distributions in the upper ocean at a relatively high spatial resolution. As a next step, we will be investigating the use of multiple field-of-views to retrieve information regarding the composition and size distribution of particles in the water column.

Deep-water benthic nepheloid layers: A global synthesis

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Understanding the distribution and underlying causes of both intense and weak benthic nepheloid layers helps in understanding benthic sediment resuspension and in assessing the potential for scavenging of adsorption-prone elements in the deep ocean as measured in the GEOTRACES program. Our global maps provide a baseline of particle concentrations occurring due to natural oceanic processes and could be useful in quantifying the impact of future deep-sea mining. We mapped benthic nepheloid layers (increased particulate matter concentration) using >9000 profiles taken during >75 cruises using transmissometers on CTDs in programs such as WOCE, SAVE, JGOFS, CLIVAR-Repeat Hydrography, GO-SHIP and other programs during the last four decades.

In the Western North Atlantic, particle mass and bottom concentrations are greater in areas beneath the Gulf Stream where eddy kinetic energy is high due to the meandering and formation of rings and the generation of deep cyclonic and anticyclonic eddies that accelerate currents near the seafloor and resuspend sediment (Benthic storms, nepheloid layers, and linkage with upper ocean dynamics in the western North Atlantic https://dx.doi.org/10.1016/j.margeo.2016.12.012). The Argentine Basin is another area of known high eddy kinetic energy and strong nepheloid layers. The Agulhas Current retroflection sheds rings, generating deep eddies which resuspend sediment from the continental slope of South Africa. Areas of the Southern Ocean and around

Madagascar have moderate to strong nepheloid layers. Most of the Pacific, Indian, and tropical/subtropical Atlantic away from margins have minimal nepheloid layers.

Combining bio-optical glider observations and biogeochemical modeling to examine potential Ross Sea phytoplankton changes in the 21st century

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The Ross Sea is characterized by high primary productivity in comparison to other Antarctic coastal regions and, over the next century, is expected to experience changes including warmer temperatures, reduced summer sea ice concentrations, and shallower mixed layers. To investigate the future impacts of these climatic changes on Ross Sea phytoplankton, glider observations were used in conjunction with the Model of Ecosystem Dynamics, nutrient Utilisation, Sequestration and Acidification, which was adapted for use in the Ross Sea (MEDUSA-RS) to include both solitary and colonial forms of *Phaeocystis antarctica*. Biogeochemical model parameters were explored and constrained by assimilating bio-optical glider observations with the Marine Model Optimization Testbed (MarMOT), a one-dimensional model analysis and assimilation framework. Scenario experiments were carried out using projected physical drivers for mid- and late-21st century. These future scenarios project an increase in primary productivity and proportional increase in carbon export flux over the next century. In addition, these scenarios demonstrate increases of diatom biomass with decreases of *P. antarctica* biomass in the first half of the 21st century, whereas *P. antarctica* biomass increases and diatom biomass remains relatively constant in the second half of the century. Scenarios examining the independent contributions and uncertainties of expected future changes (temperature, mixed layer depth, irradiance, and surface iron inputs from melting ice) indicate that earlier availability of low light due to reduction of sea ice early in the growing season is the primary driver of productivity increases over the next century; shallower mixed layer depths additionally contribute to changes of assemblage composition and export. This study demonstrates the effectiveness of using bio-optical observations from autonomous gliders for the development and constraint of biogeochemical model projections in the context of climate change.

Determination of carbonate chemistry parameters using 'Lab-on-Chip' sensors: developments and future direction

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Anthropegnic activities, primarily through the combustion of fossil fuels, release approximately10 petagrams of carbon per year into the Earth's atmosphere. Almost half of this additional atmospheric carbon is subsequently absorbed into the surface ocean which ultimately

lowers the seawater's pH. This process, defined as ocean acidification (OA) has attracted much attention from reseachers and legistators and has been proven to have adverse consequences on marine ecosystems thus profoundly impacting the marine economy. Our ability to fully understand the changing chemistry associated with OA is limited due to the lengthy and costly nature of sample collection and analysis. To overcome this limitation in essential OA data, development is required in the production of in situ high performance low cost carbonate sensors. In situ sensors offer the potential for sustained long term monitoring in remote locations, and eliminating the need for sample handling. In addition sensors can be clustered into multi-parameter observatories, and networked to provide both spatial and time series coverage. At the Ocean Technology and Engineering Group (OTEG) of the National Oceanography Centre (NOC), UK, we are addressing these needs through the development of in situ sensors for the measurement of dissolved inorganic carbon, total alkalinity and pH. The approach being taken incorporates microfluidic technology whereby common bench-top assays are miniaturised into portaable devices known as 'lab on chip', which will be capable of performing in situ measurments at full ocean depths. This presentation will provide on overview of the technology and its current state of development.

Towards sustained autonomous measurements of coral reef metabolism and health

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Coral reefs are a highly dynamic system, where large variability in environmental conditions (e.g. pH, light) occurs on timescales of minutes to hours. Yet, techniques that are capable of monitoring reef calcification rates without artificial confinement on the same frequency are scarce. We have developed the Benthic Ecosystem and Acidification Measurement System (BEAMS) which is capable of simultaneously measuring benthic net community production (ncp) and net community calcification (ncc) under natural conditions without any alteration to the environment. The BEAMS measures the chemical gradient and the current velocity profile in the benthic boundary layer using autonomous sensors to calculate the chemical flux (thus metabolism) from the benthos. We have successfully deployed BEAMS in multiple reefs around the world, and currently is capable of continuously measuring metabolic rates at 15 minute intervals for a month. In this poster, we highlight deployments from Palmyra Atoll, and the potential use of BEAMS to monitor reef health as they transition from a healthy coral dominated state to a degraded algae-dominated state.

Assessment of holographic microscopy for quantifying marine particles

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Characterizing marine snow and phytoplankton communities in sparse, highly variable oceanic environments remains a methodological challenge. In situ holography may help to address this challenge by sampling 100x larger volumes than comparable objective lens-based systems, and is easily deployable on CTD-rosette, flow-through, and autonomous systems. Qualitatively, detected particle counts show good agreement with beam attenuation down to depths of 1000m (the depth rating of our autonomous system). Here, the quantitative capability of a digital in-line holographic microscope to evaluate abundance, size and type of particles ranging from 5 to 1000 micron equivalent spherical diameter, is assessed. Over one million particles are analyzed using a custom image processing pipeline, which allows a precise definition of the three-dimensional volume sampled. Experiments were performed on dilutions of *Dunaliella* culture and with environmental samples collected from the North Pacific in February 2017 and compared with concentration estimates from an Imaging FlowCytobot, FlowCam, and manual light microscope counts. The good correlation ($r^2 = 0.92$, $P < 0.05$) with these other detection methods suggests that digital holography is a promising tool for in situ and autonomous studies of ocean biogeochemical cycling and phytoplankton ecology.

Observing the Southern Ocean carbon cycle using biogeochemical profiling floats equipped with pH

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Abstract: More than 74 biogeochemical profiling floats that measure water column pH, oxygen, nitrate, fluorescence, and backscattering at 10 day intervals have been deployed throughout the Southern Ocean. Calculating the surface ocean partial pressure of carbon dioxide (pCO_{2sw}) from float pH has uncertainty contributions from the pH sensor, the alkalinity estimate, and carbonate system equilibrium constants, resulting in a relative standard uncertainty in pCO_{2sw} of 2.7% (or 11μatm at pCO_{2sw} of 400 μatm). The calculated pCO_{2sw} from several floats spanning a range of oceanographic regimes are compared to existing climatologies. In some locations, such as the subantarctic zone, the float data closely match the climatologies, but in the polar Antarctic zone significantly higher pCO_{2sw} are calculated in the wintertime implying a greater air-sea CO_2 efflux estimate. Our results based on four representative floats suggest that despite their uncertainty relative to direct measurements, the float data can be used to improve estimates of air-sea carbon flux, as well as to increase knowledge of spatial, seasonal, and interannual variability in this flux.

Session: Stoichiometry and higher trophic levels

Will invertebrates require increasingly carbon-rich food in a warming world?

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We hypothesise that invertebrate consumers, including copepods and insects, will require increasingly C-rich diets in a warming world because of increasing C in metabolism. The hypothesis was tested using a new stoichiometric model with C and N as currencies. Results did not support the hypothesis for two reasons: (1) many consumers are N-limited in which case the excess of C can be used to meet increasing metabolic requirements, and (2) increasing food intake at elevated temperature compensates for the extra demands of C and N in metabolism. The analysis indicates that future climate-driven increases in the C:N ratios of autotroph biomass will likely exacerbate the stoichiometric mismatch between nutrient-limited invertebrate grazers and their food, with important consequences for C sequestration and nutrient cycling in ecosystems.

Estimating the influences of flexible POC: POP stoichiometry on future carbon export

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Export production of particulate organic matter (POM) from the surface to the deep ocean is a key driver of global carbon cycle. The amount of carbon (C) removed from the surface ocean by this export depends critically on the elemental ratios in POM of C to nitrogen (N) and phosphorus (P), two essential nutrients that limit productivity. Here we developed a simple power law model with a stoichiometry sensitivity factor, which is able to relate a fractional increase in C:P of POM to a fractional decrease in ambient phosphate concentration. We believe that the new factor is robust, measurable, and biogeochemically meaningful. Using the stoichiometry sensitivity factor, we estimate that any future compensation of carbon export by the expected increase in C:P as nutrient supply decreases under global warming will be modest (~1-4% under a future IPCC RCP8.5 scenario). Further, we demonstrate that our new power law model of flexible stoichiometry can be implemented successfully and easily in a global model to reproduce the large scale C:P variability in the ocean.

Theoretical study on the effects of flexible grazing preference of zooplankton on regulating the C:N:P ratio of marine ecosystem

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The C:N:P ratios of zooplankton are dependent on their internal regulatory mechanisms, grazing preference, and the C:N:P ratios of their preys. How zooplankton's internal stoichiometry affects the bulk C:N:P ratios of exported organic matter is currently poorly understood, especially when there are multiple preys and predators each with varying internal stoichiometry. The aim of this research is to show how the changes in grazing preference of zooplankton as a function of internal stoichiometry of their prey affects the marine ecosystem dynamics within a simple NPZD type model with multiple prey and predator functional groups. We hypothesize that the increase in the flexibility of zooplankton grazing preference transforms the ecosystem from a bottom-up system, where biomass is dominated by phytoplankton, to a stable top-down ecosystem, where both biomass and C:N:P ratios are regulated by zooplankton. Our results suggest that the grazing preference of zooplankton, which is currently fixed *a priori* in most models, can quite variable and thus have significant impacts on the food-web and carbon cycle.

Phytoplankton community metallomes vary across environmental gradients in the global ocean

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Trace metal micronutrients are required for many processes in phytoplankton, including photosynthesis, nitrogen and phosphorus acquisition, and DNA replication and repair. In many of these processes metals play catalytic rather than structural roles, and metal contents (and cellular metal stoichiometries) can vary to a greater degree than the stoichiometries of C, N and P. Metal contents also vary with ambient availability, but an incomplete understanding of chemical speciation of dissolved trace metals precludes us from fully predicting metal availability in natural systems. Measurements of trace metal contents in individual cells collected from several natural systems that span a range of dissolved Fe, Zn, Mn, Co, and Ni concentrations have been compiled to investigate the response of metal stoichiometries of natural phytoplankton communities to these gradients. Data are from the Southern Ocean, equatorial and sub-Arctic Pacific Ocean, sub-tropical North Atlantic, as well as several near-shore areas. Across all regions, dissolved concentration gradients range from 2-fold for Ni to 300-fold for Zn. Ranges of cellular Fe, Co, and Zn stoichiometries are approximately 2-fold smaller than dissolved ranges, while community Mn/C ratios vary to a similar extend as dissolved concentrations. Relationships between community Fe/C ratios and ambient dissolved Fe overlap with data collected for phytoplankton cultures in EDTA-buffered media, indicating that

organically-bound forms of Fe are available for use by phytoplankton in natural systems. Community Co/C ratios were essentially insensitive to total dissolved Co concentration. Averaged over ocean basins, the phytoplankton from the Atlantic and Arctic are shown to be relatively Fe-rich and Zn- and Ni-poor, while Pacific phytoplankton are Fe-poor but relatively Zn- and Ni-rich. In contrast, phytoplankton Mn contents are remarkably constant across the global ocean. Community metallomes appear to respond to large-scale gradients in both micro- and macronutrients.