POSTER ABSTRACTS

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Session: A tale of two poles: Arctic and Antarctic responses to global change

CO_2 System Dynamics in the Dalton Polynya, East Antarctica

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We present new high-frequency underway and discrete water column observations of the CO_2 system from Dalton Polynya on the Sabrina Coast (115 – 123 °E), East Antarctica in summer 2014/2015. Seasonal changes were partitioned into physical and biological components, quantifying the contributions from air-sea CO_2 exchange, sea ice melt/formation, and biological activity on mixed-layer dissolved inorganic carbon (TCO_2) concentrations. Surface waters were on average supersaturated in pCO_2 (ΔpCO_2 = +10 µatm), with the greatest degree of supersaturation found near ice-covered Totten Ice Shelf (TIS). This region acted as a weak net source of CO_2 to the atmosphere (0.7 mmol C m^{-2} d^{-1}) during the period of observation. Estimates of seasonal net community production (NCP), derived from seasonal mixed-layer TCO_2 deficits, reveal net autotrophy in the ice-free Dalton Polynya (NCP = 5 – 20 mmol C m^{-2} d^{-1}) and weakly heterotrophic waters near the ice-covered TIS (NCP = - 4 – 0 mmol C m^{-2} d^{-1}). Satellite chlorophyll-a (Chl-a) and sea ice coverage data suggest that the early summer season was anomalous relative to the long-term (1997-2017) record, with lower surface Chl-a concentrations and a greater degree of sea ice cover during the period of observations; the implications for seasonal primary production and air-sea CO_2 fluxes are presented. This study highlights the significant seasonality and interannual variability in the CO_2 system in Antarctic coastal waters.

Both dissolved iron and coastal water additions to Southern Drake Passage waters stimulate similar growth responses and shifts in diatom community composition.

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The potential for iron (Fe) to limit primary productivity in the major high nutrient, low chlorophyll (HNLC) regions of the ocean has been well established, with the Southern Ocean being the largest HNLC region. In early Spring 2016, we performed two sets of incubation experiments at the southern boundary of the Drake Passage, near the Western Antarctic Peninsula. One experiment involved five amended treatments and a control. The amended treatments included three different additions of Fe ranging from 1-10 nM, a vitamin B_{12} (600 pM) addition, and vitamin B_{12} (600 pM)/Fe (4nM) co-addition. A second incubation at this location two weeks later tested whether additions of high Fe water sourced from a coastal region could alleviate Fe stress. Extracted chlorophyll measurements were used to track phytoplankton growth in incubated waters. In addition, we assessed shifts in diatom community composition using high throughput Illumina sequencing of the diatom 18S rDNA. In spite of the two-week separation of the two incubations, the starting diatom community composition in both sets of incubated waters was similar and they shifted in similar ways between the initial and final time points in the control treatments. Iron additions of 4 nM and 10 nM resulted in significant increases in chlorophyll compared to the control and $+B_{12}$ treatments, and shifted diatom community composition from that observed in treatments with less than 4 nM Fe additions. Addition of filtered coastal waters also led to a significant increase in chlorophyll over control treatments and resulted in diatom communities similar to those where > 4 nM Fe was added. Unlike other Southern Ocean HNLC areas that have been found to be Fe/vitamin B_{12} co-limited in summer, vitamin B_{12} additions in this early austral spring season had no impact on diatom community composition or in phytoplankton biomass. These results confirm hypotheses that Fe is the important limiting nutrient in the Southern Drake Passage and that coastal Fe advected offshore has the potential to alleviate Fe stress.

Benthic Biological Hotspots in the Northern Bering and Chukchi Seas: Spatial Distributions and Environmental Drivers

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Benthic biological hotspots with persistently high macroinfaunal biomass exist on the continental shelves from northern Bering to Chukchi Seas, despite recent sea ice diminishing and ocean warming in the Pacific Arctic region. Large data sets of benthic observations and environmental parameters were analyzed using generalized additive models to understand the relationships between benthic community and dominant environmental drivers. Model-predicted benthic

macroinfaunal biomass recaptured four known hotspots and revealed the presence of a putative massive hotspot in the Gulf of Anadyr where observations were scarce in the Russian water. The combinations of environmental drivers suggested two general types of pelagic-benthic coupling regimes among five hotspots: pulsed phytoplankton bloom with low water column consumption (high export efficiency) versus prolonged phytoplankton production (high carbon supply). Those hotspots that require pulsed supply may be negatively impacted as warming Arctic waters may reduce the export efficiency and shift the ecosystem from a benthic- to pelagic-dominated system.

Data assimilative ecosystem modeling of bacterial dynamics and upper-ocean carbon cycling in the coastal West Antarctic Peninsula

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The West Antarctic Peninsula (WAP) is a climatically sensitive region where periods of warming have caused significant changes in the marine ecosystem and biogeochemical processes over the past decades. As a long-term monitoring effort, the Palmer Long-Term Ecological Research (LTER) program has spanned over 25 years of observations (1991-2018) of key biogeochemical variables to better understand how ecosystem functions have responded to the variability of climate and physical forcing in the WAP. Here, we developed a marine ecosystem model that provides built-in capabilities for assimilating physical forcing data and optimizing biological model parameters based on a variational adjoint scheme. We simulated the flexible stoichiometric C, N, and P stocks and flows of the WAP food-web components at seven different depths for three different Palmer LTER field seasons, including the moderate (2003-2004), high (2005-2006), and low (2009-2010) ice years. Depending on the degree of sea ice extent in each field season, there are different patterns of bacterial-phytoplankton coupling and bacterial grazing by microzooplankton. With optimized model parameters for each simulation year, the model was rerun with varying temperature forcing fields to explore the responses of marine heterotrophic bacteria and bacteria-mediated carbon flows to increasing temperatures. The model experiments with varying temperature forcing highlight that there are inconsistent responses of carbon export and primary production to increasing temperatures. In contrast, bacterial production, bacterial biomass, and bacterial carbon demand consistently increase in response to increasing temperatures. Furthermore, with increasing temperatures the rate of an increase in bacterial carbon demand supported by semi-labile dissolved organic carbon (DOC) is always higher than that supported by labile DOC. Overall, our findings imply that in the coastal WAP temperature plays a significant role in shaping bacterial dynamics with more active bacterial processes at warmer temperatures. With the possibility of increasing semi-labile DOC from retreating glaciers in the future, our findings suggest an increasingly important role of heterotrophic bacteria in the microbial food-web with ocean warming along the coastal WAP.

Arctic-COLORS (Arctic-COastal Land Ocean inteRactionS)

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The realization that changes within the Arctic have profound impacts on ecosystems and human populations across the globe has motivated greater attention by researchers, funding agencies, governmental policy makers, and non-governmental organizations. Yet major gaps remain in our understanding of the feedbacks, response, and resilience of coastal Arctic ecosystems, communities, and natural resources to current and future pressures. Most importantly, the Arctic coastal zone, a vulnerable and complex contiguous landscape of lakes, streams, wetlands, permafrost, rivers, lagoons, estuaries, and coastal seas—all modified by snow and ice—remains poorly understood. To improve our mechanistic understanding and prediction capabilities of land-ice-ocean interactions in the rapidly changing Arctic coastal zone, our team proposed a Field Campaign Scoping Study called Arctic-COLORS (Arctic-COastal Land Ocean inteRactionS) to NASA's Ocean Biology and Biogeochemistry (OBB) Program. Arctic-COLORS aims to quantify the response of the Arctic coastal environment to global change and anthropogenic disturbances – an imperative for developing mitigation and adaptation strategies for the region. The Arctic-COLORS field campaign is unprecedented, as it represents the first attempt to study the nearshore coastal Arctic (from riverine deltas and estuaries out to the coastal sea) as an integrated land-ocean atmosphere-biosphere system. The overarching objective of Arctic-COLORS is to quantify the coupled biogeochemical/ecological response of the Arctic nearshore system to rapidly changing terrestrial fluxes and ice conditions, in the context of environmental (short-term) and climate (long-term) change. This focus on land-ocean interactions in the nearshore coastal zone is a unique contribution of Arctic-COLORS compared to other NASA field campaigns in polar regions. The science of our field campaign will focus on three key science themes and several overarching science questions per theme:

(1) Effect of land on nearshore Arctic biogeochemistry
(2) Effect of ice on nearshore Arctic biogeochemistry
(3) Effects of future change (warming land and melting ice) on nearshore Arctic biogeochemistry

This field campaign will be composed of an integrative measurement approach utilizing a broad range of proven sampling approaches from a multitude of platforms including autonomous vehicles to achieve sufficient seasonal and spatial coverage to resolve the science questions proposed by the Arctic-COLORS team as well as remote sensing and development of coupled physical-biogeochemical models.

Assessing Phytoplankton Activities in the Seasonal Ice Zone of the Greenland Sea over an Annual Cycle

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In Seasonal Ice Zones (SIZ), such as the one of the Greenland Sea, the sea ice growth in winter and subsequent melting in summer influence the phytoplankton activity. However, studies assessing phytoplankton activities over complete annual cycles and at a fine temporal resolution are lacking in this environment. Biogeochemical-Argo floats (hereafter BGC-Argo floats), able to sample under the ice, have been used to collects physical and biogeochemical data along vertical profiles and at five-day resolution during two complete annual cycles in the Greenland Sea SIZ. A pre-bloom under-ice phase was followed by an ice-edge bloom phase, and a post-bloom Subsurface Chlorophyll Maximum (SCM) phase. As expected, the light and nitrate availabilities controlled the phytoplankton activity and the establishment of these phases. On average, most of the annual Net Community Production (NCP) occurred equally during the pre-bloom under-ice and the ice-edge bloom phases. The post-bloom phase contribution, on the other hand, is much smaller. Phytoplankton biomass accumulation and production thus occur during a long period of time including under sea ice. Satellite-based estimates of phytoplankton biomass and production in this SIZ are thus affected. Simulations with the Arctic-based physical-biologically coupled SINMOD model suggest that most of the annual NCP in this SIZ results from local processes rather than by being influenced by advection of nitrate from the East Greenland and Jan Mayen Currents.

Organic periostracum protects pteropod shells from dissolution in aragonite undersaturated waters

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Pteropods are a group of planktonic gastropods that form aragonitic shells. Pteropods play a vital role at the base of the marine food chain, particularly in polar regions, however, their shell mineralogy puts them at high risk from ocean acidification. Early work suggested that pteropod shells will dissolve when waters become undersaturated with respect to aragonite, however, recent field observations have found that one species of pteropod, Limacina helicina helicina, are protected from undersaturated seawater by an ultra-thin external organic layer called the periostracum. Here we conduct incubation experiments where Limacina helicina antarctica are exposed to three different levels of aragonite saturation to test the protective role of the periostracum in this species. Using a combination of light and scanning electron microscopy, and micro-CT scanning we find that dissolution only occurs when both the periostracum is breached and the seawater is undersaturated with respect to aragonite. The extent and intensity of shell dissolution increases with the degree of undersaturation, although this varies greatly between specimens based on the degree to which the periostracum has been damaged. The findings of this experiment demonstrate that the periostracum of Limacina helicina antarctica is effective at protecting the underlying shell from dissolution in undersaturated waters adding to the view that pteropods may be more resilient to ocean acidification than previously thought.

Projected Increases in Arctic Freshwater Export Reduce the North Atlantic Anthropogenic Carbon Sink

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The subpolar North Atlantic covers only 2.3% of the global ocean area but plays an important role in the global carbon cycle. As the most intense carbon sink per unit area, the subpolar North Atlantic accounts for 12% of the 1.7 Pg C yr^{-1} of global ocean carbon uptake. We consider the future evolution of this critical anthropogenic carbon (C_{ant}) sink using the physical and biogeochemistry output from the CESM Large Ensemble Community Project (CESM-LENS). After the region reaches a peak uptake of 0.24 Pg C yr^{-1} in 2049, the sink of anthropogenic carbon begins to decrease at an increasing rate, and is reduced by 53% in 2100 to only 0.11 Pg C yr^{-1}. The global C_{ant} flux grows from 1.7 Pg C yr^{-1} to 4.9 Pg C yr^{-1}. The subpolar North Atlantic C_{ant} flux decreases from 8% of the total ocean C_{ant} flux, to 2% of the total ocean C_{ant} flux. There is no Northern Hemisphere region where sink growth compensates for this reduction. The mechanism of decline in subpolar North Atlantic C_{ant} flux is export of Arctic surface freshwater that leads to stratification. Reduced ventilation increases storage of anthropogenic DIC in the surface ocean, and elevates surface ocean pCO_2. The patterns of change in salinity and air-sea CO_2 flux are consistent across the CMIP5 archive. This Arctic climate-carbon feedback leads to a significantly reduced role for the North Atlantic in global anthropogenic carbon uptake.

Report of the Ross Sea Working Group Meeting

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The Ross Sea is an important sector of the Southern Ocean and a necessary focus of the Southern Ocean Observing System (SOOS). The first SOOS Ross Sea Working Group workshop was held in September, 2017 in Shanghai to identify the current and planned observations in the Ross Sea. These include the polynyas, boundaries of the Ross Sea, the under sampled eastern Ross Sea, and the Ross Gyre. While a single comprehensive observing system would be ideal, hypothesis driven research is more likely to contribute components to an observing system, and free and open international exchange of data will be required to achieve integration among observing system components. The Marine Protected Area in the Ross Sea and its associated Research and Monitoring Plan also provide a collaborative opportunity to support an ocean observing system in the Ross Sea, and collaborations between SOOS and Commission for the Conservation of Antarctica Marine Living Resources (CCAMLR) should be continued and expanded. Recommendations from the workshop include the need 1) to observe at all temporal and spatial scales in the Ross Sea and 2) to understand the linkages among physical processes, biogeochemical cycles, and biological processes. Achieving these objectives should provide the data to assess the expected changes and the rates of change to provide credible projections for future states in the Ross Sea.

Nutrient maxima along the East Siberian Sea

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The continental shelf seas of Siberia are a productive area of organic matter transformation resulting in high nutrient and low oxygen concentrations. The process is influenced by brine production during sea-ice formation and the prevalent ventilation processes on the shelf and along the slope. Both processes are directly responding to the climate change due to changes in the heat budget and sea-ice coverage of the Arctic Ocean.
Field data from the SWERUS-C3 expedition in 2014 shows that a patch of high nutrient water extents from 140-180°E along the continental margin and intensifies further east, spreading over a wider depth range. The nutrient maximum east of 170°E is characterized by a high salinity of up to 34.5 and a minimum in SF_6 partial pressure suggesting that the water mass is isolated from the boundary current. This water mass shows a nutrient signature of hypoxic conditions, which can be explained by the low ventilation and thus long interaction times at the sediment-water interface.

Session: Evolutionary insights on marine organism response to climate change: How past and contemporary evolution are shaping the future

Rapid Adaptation of a Marine Copepod to a Greenhouse World

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A fundamental challenge to ocean scientists is predicting the response of the biota to climate change. A worst-case scenario (full greenhouse conditions) for climate change would mean a drop in pH to ~ 7.5 and an increase in temperature of 4-5°C by the year 2300.Yet, the fitness consequences of combined warming and acidification for copepods, the most abundant

metazoans in the oceans and the basis of pelagic fisheries, are not well characterized or understood. We use the ubiquitous copepod Acartia tonsa as a model system to understand the consequences of a greenhouse world on copepod fitness. Using a factorial design, we characterized functional life-history traits for 15 generations under ambient (18°C, 400 ppm pCO_2), elevated temperature (22°C, 400 ppm pCO_2), elevated CO_2 (2000 ppm pCO_2, 18°C) conditions, and greenhouse (22°C and 4000 ppm pCO_2) conditions. We compared survival from juvenile to adult stages, development time, egg production rate, egg hatching frequency, and body size among all four conditions of temperature and CO_2. Results indicate reduction in performance under the three experimental treatment relative to the ambient conditions (control). However, rapid adaptation (as demonstrated by improved egg production rate and hatching success) became evident after a few generations under elevated temperature and full greenhouse conditions. Thus, for this species there appears to be sufficient extant genetic variation to cope with the direst projections for climate change. Future work will link functional traits to genomic and transcriptomic markers, and address possible costs of adaptation.

Physiological Plasticity and Potential Adaptive Responses of Two Diazotrophs after Long-term Growth at Three Different Temperatures

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Trichodesmium and *Crocosphaera* are two key groups of diazotrophs that contribute significantly to global nitrogen fixation and carbon cycling. We investigated the roles of plasticity and adaptation in the responses of these two groups to experimental thermal selection. Experiments examined changes in thermal reaction norms in *Trichodesmium erythraeum* IMS 101 and *Crocosphaera* WH0005 during nearly two years of growth at three temperatures (22°C, 27°C and 32°C) spanning most of their natural thermal ranges.

After 8 months of culturing, full thermal reaction norms were determined for *T. erythraeum* IMS101 conditioned at each temperature. Cell lines selected at different temperatures showed initially slightly improved growth rates at temperatures near their respective selection temperatures, but these small differences disappeared after a week. Reciprocal switch experiments between three selection temperatures conducted in the twelfth month showed that all the temperature-selected IMS101 cell lines could fully acclimate to new temperatures within 4-8 days (1-2 generations), based on growth rate and nitrogen fixation measurements.

In contrast to *Trichodesmium*, after 18 months of temperature selection the thermal curves of *Crocosphaera* WH0005 cell lines showed an obvious shift of the optimum temperature and thermal niche towards their respective selection temperatures. This shift pattern persisted steadily for 16 days (6-8 generations), thus suggesting the possibility of true thermal adaptation. Longer term experiments are currently underway with *Crocosphaera* to test this possibility.

In conclusion, our early results suggest that *T. erythraeum* IMS101 did not adapt to the three temperature regimes. It appears to instead to possess a considerable amount of inherent thermal plasticity, allowing it to quickly acclimate to temperature shifts from 22-32°C. True thermal adaptation may possibly have occurred in *Crocosphaera* WH0005 cell after 18 months of temperature selection, although these results need verification in long-term reciprocal switch experiments. Alternately, the selected cell lines of the unicellular cyanobacterium may re-acclimate as well, but at a much slower rate than *Trichodesmium*. To provide mechanistic information about both acclimation and possible adaptive responses, genome and transcriptome samples are being collected for future sequencing and analysis.

Exploring the impacts of Proteorhodopsin phototrophy in the expanding oligotrophic ocean

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Sunlight drives virtually all life on the Earth's surface, with about 50% of primary productivity occurring in marine systems. However, before the year 2000, all known phototrophic metabolisms in the ocean were based on chlorophyll-like molecules. This traditional view of phototrophy changed radically with the discovery of marine bacterial proteorhodopsins (PR). Since then, PR genes and transcripts have repeatedly been found in extremely high abundances in all sunlit environments, particularly in the surface ocean. PRs are simple light driven proton pumps that allow microbes to transform light into chemical energy. Combining physiology studies, with omics and environmental quantifications we are starting to understand the role of PR light harvesting in marine microbial communities. Our research shows that the solar energy captured by PR-photoheterotrophy can promote bacterial growth, substrate uptake and survival to starvation under organic matter limitation. Also outside the prokaryotic domains, there's growing evidence that eukaryotic phytoplankton can produce large amounts of PR in response to nutrient limitation. This strongly suggests a critical role for PR in bacterial and algal carbon processing that remains largely unexplored. Given the expansion of oligotrophic environments in response to global warming, the importance of PR-photoheterotrophy is expected to increase in the future oceans. Understanding the fate of carbon under this climate change scenario will be essential to obtain more accurate predictive models.

Tales of the cryptophytes: acclimation to variations in underwater spectral irradiance

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Cryptophytes are a ubiquitous but relatively understudied group of phytoplankton found in environments ranging from tea-colored ponds to blue-water open oceans. Our work explores the genetic, phylogenetic, and functional diversity of cryptophytes in relation to the spectral quality of light in these diverse environments. For this poster, we will focus on the phenotypic plasticity of light capture. Cultures of 8 differently pigmented cryptophytes were grown in full spectrum, red light, blue light or green light environments at an intensity of ~ 30 μmol m^{-2} s^{-1}. We measured spectral absorption, phycobiliprotein (PBP) type and concentration, non-PBP

pigments, cell volumes and growth rates for each species. Cryptophytes that contained phycoerythrin grew fastest under the blue light treatment (~0.4 to 0.6 d^{-1}) due to the absorption of the abundant blue wavelengths by phycoerythrin, chl-a, alloxanthin, chl-c2, and α-carotene. Phycocyanin-containing cryptophytes grew slowest under green light (0.3 d^{-1}), but the light treatment at which cells grew best varied with species. Maximum growth rates ranged from 0.5 - 0.8 d^{-1}. These experiments investigated short-term (weeks) acclimation of cryptophytes to a shift from full spectrum to blue, green, or red light dominated light fields. Experiments are currently underway to determine whether, over longer timescales (years), cryptophytes can adapt to novel light environments through changes in gene sequence, gene expression, and/or post-transcriptional regulation.

Following diatom response to ocean acidification in mesocosm experiments with metatranscriptome sequencing indicates contrasting CO_2 responses in *Skeletonema* and *Thalassiosira* diatoms

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Fossil fuel combustion has raised atmospheric pCO_2 from ~277 ppm in 1750 to the present level of ~400 ppm. The ocean sequesters ~30% of that CO_2, decreasing its buffering capacity and pH (ocean acidification). Diatoms are responsible for ~40% of oceanic primary production based upon photosynthetic fixation of CO_2, which is aided by a carbon-concentrating mechanism (CCM), which uses bicarbonate transporters (BCTs) to take up HCO_{3-} and carbonic anhydrases (CAs) to interconvert HCO_3- and CO_2. There are several distinct classes of BCTs and CAs found in diatoms, including the substrate-specific SLC4 and non-specific SLC26 BCTs, as well as the α, β, δ, γ, ζ, and θ CAs. The ability to regulate and conserve energetic costs associated with the CCM may influence diatom community composition in a higher CO_2 future.
This study used mesocosm CO_2 manipulation incubations to examine the diatom community response to changes in pCO_2. Seawater from Vineyard Sound, MA was collected in March of 2014, pre-filtered to remove large grazers, and amended with nutrients. The pCO_2 levels were manipulated to approximate pre-industrial conditions (< 215 ppm pCO_2), present-day pCO_2 in the open ocean (330-390 ppm pCO_2), and future pCO_2 projections (>780 ppm pCO_2). After 20 days, metatranscriptomes were sequenced (>3-µm size fraction); the majority of reads were attributed to *Skeletonema* and *Thalassiosira* diatoms.
We show evidence of differing CCM strategies: *Thalassiosira* diatoms regulate the α, δ, and ζ CAs and the SLC4 and SLC26 BCTs; whereas, *Skeletonema* regulates the γ and ζ CAs and the SLC26 BCTs. The CCM of these two diatoms require different metal cofactors: CAs generally use zinc as a cofactor, but the γ CAs can substitute with iron and are CO_2-sensitive only in *Skeletonema*. Conversely, the δ CAs can substitute with cobalt and are CO_2-sensitive only in *Thalassioira*. *Thalassiosira's* ability to down-regulate the HCO_3—specific SLC4 BCTs in high CO2 may afford this organism some energetic savings in high CO_2.

Simulating marine microbial metabolism using genome-scale models

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Genome-scale models (GEMs) of metabolism are in silico representations of biological systems that can be used to simulate genotype-phenotype associations. In this study GEMs were used to investigate evolution and energy conservation in the ubiquitous *Shewanella* genus under different temperature regimes. Two model species were selected, *S. piezotolerans* WP3 and S. oneidensis MR-1, which represent the two major i lineages adapted to cold and moderate temperatures, respectively. Through the development of a new modeling approach, connections between diverse carbon sources and mechanisms of energy conservation were investigated, and the analysis revealed differences in the organisms' redox state during anaerobic respiration. Currently, more advanced models are being developed for simulating metabolic fluxes subjected to the thermodynamic constraints under different temperature conditions. These developments will enable the simulation of temperature adaptations in the metabolism of *Shewanella* species, and the same approaches can be applied broadly to study other marine microbes.

Session: It's about time: Insights from long-term marine ecological monitoring programs

Using cruises and Bio-Argo floats data to estimate dissolved organic carbon in the Northeast Pacific Ocean

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Here, data accessed from seasonal cruises along the NE Pacific Ocean were used in order to (1) observe the accumulation of dissolved organic carbon; (2) estimate net community production (NCP); and (3) establish relationships between NCP and DOC in the upper layer. The fraction of DOC that accumulated as a result of positive NCP, hereafter defined as net dissolved production ratio (NDPr), was calculated for several stations during spring and summer in relation to winter conditions. The DOC/NCP relationship was a constant of 0.26 in the most oceanic station, named Station Papa, during different seasons and years. Using nitrate profiles obtained from Bio-Argo floats during 2009-2018 nearby the station, we estimated high-resolution NCP and then applied the 0.26 constant in order to (4) estimate DOC concentrations for the extended period. Main results indicate a strong seasonality in NCP, with maxima occurring during summers ranging from 0.3-2.9 mol C m^{-2}. The accumulation of DOC varied between 65 and 72 µmol kg-1 depending on the year, and Bio-Argo floats showed consistency with cruise observations. This study reinforces the importance of deploying floats equipped with chemical sensors to better understand marine biogeochemical cycles, especially when fine data cannot be obtained solely from cruises.

Initial DECK analysis of the carbon cycle in GFDL's CM4 contribution to CMIP6

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As part of the currently ongoing sixth Coupled Model Intercomparison Project (CMIP6), modeling centers have focussed on improving the resolution from nominally 2 degree atmospheres and 1 degree oceans in CMIP5 to nominally 1 degree atmospheres and 1 to 1/4 degree oceans in CMIP6. Similarly, they have made great strides in comprehensiveness, and fidelity including improving surface temperature, wind patterns and variability, and ocean boundary currents in of these physical models which will allow for more accurate and robust determination of ocean biogeochemical interactions. The experimental design of CMIP6 (Eyring et al., 2016) includes not only a standard set of Design, Evaluation, and Characterization of Klima (DECK) experiments, but includes two dedicated Intercomparison efforts of ocean biogeochemical cycling through the Ocean Model Intercomparison Project (OMIP; Griffies et al., 2016; Orr et al., 2016) and experiments with fully coupled ESMs through the Coupled Climate-Carbon Cycle Model Intercomparison Project (C4MIP; Jones et al., 2016). These sets of experiments will provide an unparalleled comprehensiveness in terms of historical experiments of ocean heat, carbon and transient tracer uptake in the historical context with ocean only and fully coupled models as well as experiments designed to improve the mechanistic attribution of climate and chemistry driven changes. GFDL's CM4 contribution to CMIP6 includes a 1/4 degree MOM6 ocean with 75 hybrid layers and a second generation Biogeochemistry with Light, Iron, Nutrients and Gas (BLINGv2). As an initial analysis, we compare the GFDL CM4 ocean carbon results with advanced observations, syntheses, and inverse modeling products including GLODAPv2 effort to synthesize shipboard ocean carbon observations, the SOCAT effort to supply updated climatologies and time dependent analysis of ocean pCO_2 and air-sea CO_2 fluxes from surface underway sampling, individual inverse modeling studies and larger, programmatic efforts like the Global Carbon Project.

Variability in oceanic CO_2 parameters in the North Atlantic Subtropical gyre: a neural network approach

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The North Atlantic Subtropical gyre (NAST) consists of a recirculation regime with significant transports towards the equator in both the western and eastern basins (NAST-W and NAST-E). In this region, CO_2 uptake is most sensitive to climate forcing (changes in sea surface temperature (SST) and wind speed), and the sea-air CO_2 exchange is mainly controlled by SST changes due to the oligotrophic conditions outside upwelling areas, thus presenting the highest variability in the sea-air CO_2 exchange and the CO_2 parameters of the North Atlantic [1, 2]. Recent warming identified in the region, partially linked to anthropogenic forcing, is already reducing its CO_2 uptake [3].
A neural network-based method was developed to estimate the relevant variables of the CO_2 system in the NAST during Spring 2016 at high spatial resolution (0.25° x 0.25°). The variables are the concentrations of four CO_2 parameters [total alkalinity (AT), dissolved inorganic carbon (DIC), pH (pH_T), and partial pressure of CO_2 (pCO_2)], which are estimated from concurrent remotely sensed oceanic daily observations of wind stress (IFREMER, L3-ASCAT) [4], SSS (BEC Spain, L4-SMOS) [5], SST (NCEI OISST-V2-AVHRR) [6], and their respective latitude and longitude [7].
For each CO_2 variable, the best architecture and performance of the neural network was selected on the basis of algorithm training and validation [7] using the datasets from two cruises participating in the Ocean Carbon Data System (OCADS). The average Pearson correlation between co-temporal and co-located cruise and remotely-sensed SSS and SST were 0.9 and 0.8 respectively, testifying the high quality of the input data. Overall, the best results were obtained with a multi-layer perceptron architecture of 3 input (ASCAT-SSS-SST) and 4 output neurons (DIC-AT-pH_T-pCO_2); the neural network retrieved the CO_2 variables with high accuracies (model BIAS observed-predicted): -19 μmol kg^{-1} (DIC), 10 μmol kg^{-1} (AT), 0.04 (pH_T), and 12 μatm (pCO_2).
The average predicted surface seawater pCO_2 for Spring 2016 was fairly constant in the NAST-W (372 μatm, σ = 1.2) and the NAST-E (373 μatm, σ = 2.2), and resulted unsaturated with

respect to mean atmospheric CO_2 (406.4 ppm) in Spring 2016. Surface seawater pCO_2 showed a latitudinal decreasing trend from the northern (41°N) to the southern boundaries (8o°N) of the NAST-W (386 µatm to 372 µatm) compared to latitudinal variability in pCO_2 in the NAST-E (373 µatm to 375 µatm). The spatial variability of pCO_2 at upwelling regions was well captured, especially on the NAST-E near the Azores, the Canary Islands, as well as along the Atlantic Moroccan coast, where a pCO_2 maximum of 375 µatm was observed.

The neural network approach is a promising method to make an accurate evaluation of the ocean surface CO_2 distribution. The architecture of our neural network can be further improved and trained to achieve a higher performance in its temporal and spatial prediction not just for the ocean surface but also for deeper layers.

Acknowledgements: The authors would like to acknowledge networking support by the EU COST Action "Ocean Governance for Sustainability - challenges, options and the role of science", CA15217. This work was supported by STSM Grants 39764 and 40699 from COST Action CA15217 within the Ocean Climate and Acidification Internal group activities.

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Decadal comparisons of Particulate Matter in Repeat Transects in the Atlantic, Pacific and Indian Ocean Basins

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Basin-wide sections of beam cp (proxy for particulate matter concentration - PM) in ocean basins collected during numerous oceanographic programs over the last four decades (WOCE, SAVE, JGOFS, CLIVAR, GO-SHIP, etc.) record variable concentrations in euphotic surface waters, very low concentrations through most of the water column, and very low to very high concentrations near the seafloor. Sections re-sampled at decadal intervals show that sub-surface particle distributions are very similar over these time spans: areas of high eddy kinetic energy (EKE) are more likely to have high bottom PM concentrations, whereas areas of low EKE (most of the ocean) are very likely to have low PM concentrations. Quantifying the temporal and spatial distribution of particles in the ocean helps in identifying and understanding mechanisms affecting the sources and sinks of particles. We added O_2 contours to sections to track relationships between PM and oxygen concentration, which sometimes seem correlated and sometimes not. The general O_2 distribution decades apart between these sections is very similar. Mapping the intensity of PM in benthic nepheloid layers aids in understanding deep ocean sediment dynamics, linkage with upper ocean dynamics, and in assessing the potential for scavenging of adsorption-prone elements near the deep ocean seafloor, as investigated in the GEOTRACES program.

A 3-year time series of downward particle fluxes and carbon export in Southern Adriatic (Mediterranean Sea)

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Downward particle fluxes have been measured at the E2M3A site (41°30' N, 018° 0.5' E), located in the centre of the Southern Adriatic Pit from December 2013 to October 2016. In addition, continuous measurements were collected at the mooring station to assess the interannual variability of the thermohaline circulation as well as the properties of the water masses.
Sediment trap samples were collected below the photic layer (125 m) and near the bottom (1160 m), and analysed for total mass flux, contents of total and organic carbon, total nitrogen, carbonates, biogenic silica, and stable isotopes of organic carbon (δ13Corg) in order to elucidate main processes driving the amount, composition and temporal variability of particle fluxes. Total mass fluxes (TMF) measured at the shallower trap were generally lower that those measured at the bottom trap, ranging from 35.6 to 412.4 mg m^{-2} d^{-1}, with a time-weighted average of 93.6 mg m^{-2} d^{-1}, whereas at the bottom trap TMF varied from 33.0 to 885.4 mg m^{-2} d^{-1}, with a time-weighted average of 231.5 mg m^{-2} d^{-1}. The TMF showed a high temporal variability, with maximum values observed in late winter-spring in 2014 and 2015 at both depths.
The mean lithogenic flux measured at the bottom trap was three times higher than that measured below the photic layer, highlighting advective processes that appear particularly active in the area. These processes can be correlated to the near-bottom spreading of dense shelf waters coming from the north and central Adriatic, generally observed in Spring.
The organic carbon fluxes presented a similar temporal trend at the two depths with higher values during March 2014 and April 2015. Values ranged from 2.5 to 22.2 mg m^{-2} d^{-1}, with a time-weighted average of 5.9 mg m^{-2} d^{-1} at the shallow trap, whilst in the bottom one ranged from 1.2 to 18.6 mg m^{-2} d^{-1}, with a time-weighted average 5.3 mg m^{-2} d^{-1}. The organic carbon flux peaks occurring in spring 2014 and 2015 were related to phytoplankton blooms triggered by

nutrient input into the euphotic zone due to the vertical mixing by open ocean convection, which affects timing and size of the new and exported production.

TMF and organic carbon fluxes are integrated and compared with averaged monthly data obtained from previous research projects, carried out in the Southern Adriatic area in 1994-95, 1997-98 and 2007-08 to investigate possible long-term temporal trends.

Fish habitat compression by temperature-dependent hypoxia in the California Current System

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The California Current System (CCS) supports an ecologically and economically important marine ecosystem. Climate trends in deoxygenation are expected to emerge early in the CCS, but both the present and future impacts of hypoxia on species habitat and abundance are difficult to predict. We analyze present variability and future changes in the Metabolic Index, a physiologically-based measure of temperature-dependent hypoxia and a critical threshold for fish habitat availability—the ability to breathe is a strong constraint on where fish can be found. This analysis combines historical ecosystem data and high-resolution earth system models. Changes in the volume of aerobically suitable habitat are quantified based on a global compilation of physiological traits expected to encompass the diversity of CCS species. We find strong seasonal to interannual variations in habitat availability over the range of physiological traits, indicating that species in the CCS are likely to already experience large fluctuations in available habitat. We provide a concrete example of how the Metabolic Index shapes habitat for the northern anchovy (*Engrualis mordax*) using distributions of adults and larvae. Larval anchovy abundance (which correlates with adult fish biomass) appears to be very sensitive to multidecadal changes in the Metabolic Index and associated habitat availability. Projected oxygen and temperature changes with future climate will decrease the annual mean metabolic index below critical levels in some parts of the anchovy's range, seasonally compressing habitat and potentially leading to local exclusion or extirpation of anchovy across parts of the CCS.

Spatial and interannual variability in export efficiency and the biological pump in an eastern boundary current upwelling system with substantial lateral advection

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Estimating interannual variability in carbon export is a key goal of many marine biogeochemical studies. However, due to variations in export mechanisms between regions, generalized models used to estimate global patterns in export often fail when used for intra-regional analysis. We present here a region-specific model of export production for the California Current Ecosystem

(CCE) parameterized using intensive Lagrangian process studies conducted during El Niño-Southern Oscillation (ENSO) warm and neutral phases by the CCE Long-Term Ecological Research (LTER) program. We find that, contrary to expectations from prominent global algorithms, export efficiency (e-ratio = export / primary productivity) is positively correlated with temperature and negatively correlated with net primary productivity (NPP). We attribute these results to the substantial horizontal advection found within the region, and verify this assumption by using a Lagrangian particle tracking model to estimate water mass age. We further suggest that sinking particles in the CCE are comprised of a recently-produced, rapidly-sinking component (likely mesozooplankton fecal pellets) and a longer-lived, slowly-sinking and non-pigmented component that is likely advected long distances prior to export.

Impact of Hurricane Nicole on carbon cycling in the Sargasso Sea water column: Insights from lipid biomarkers in suspended and sinking particles

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To elucidate carbon cycling in the oligotrophic ocean, we have analyzed lipid biomarker composition of suspended and sinking particles at the Oceanic Flux Program (OFP) time series site in the northern Sargasso Sea (75 km SE of Bermuda). In October 2016 Hurricane Nicole (Category 3) passed over Bermuda. Nicole generated currents of up to 10 m s^{-1} at 80 m depth and strong near-inertial waves within the upper 300 m which persisted for >2 weeks. The mixing and nutrient pulse resulting from Nicole caused a strong phytoplankton bloom, with elevated pigments down to 200 m depth. This transient bloom also stimulated zooplankton grazing activity as indicated by increased concentrations of cholesterol and other zooplankton-derived lipids in suspended particles. Concentrations of labile phytoplankton- and zooplankton-derived biomarkers were elevated (relative to typical late fall conditions) down to 1500 m depth and indicated extreme depth penetration of bloom derived materials. Increases in microbially-derived lipids showed active degradation of this material. Additionally, fluxes of labile material in the 1500 m and 3200 m OFP traps increased dramatically following Nicole, indicating rapid sedimentation of hurricane-sourced materials. Our results demonstrate that extreme weather events can result in greatly enhanced export of labile material to the deep ocean, and underscore the sensitivity of the deep ocean to climate forcing. This study highlights the importance of long-term multidisciplinary observatories to assess the impacts of extreme events on the ocean carbon cycle and deep sea ecosystems.

Environmental controls on pteropod phenology along the Western Antarctic Peninsula

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The pteropod (pelagic snail), *Limacina helicina antarctica*, is one of the most abundant zooplankton taxa in the Western Antarctica Peninsula (WAP), a region affected by rapid climate warming. *L. antarctica* is an important grazer of phytoplankton and prey for higher trophic levels in the WAP. However, little is known about *L. antarctica*'s annually occurring life history events (phenology). We determined if shifts in *L. antarctica* phenology have occurred due to warming or other environmental controls– changes that would have important implications for regional food web dynamics. *L. antarctica* shell lengths were analyzed from samples collected in the Palmer, Antarctica Long-Term Ecological Research program (PAL LTER) year-round sediment trap from 2004 to 2016. Sediment traps are used to measure export of sinking particulate matter from the surface to the deep ocean, but live pteropods commonly enter sediment traps due to their sinking behavior to escape predators. There was considerable interannual variability in the time of appearance of a new *L. antarctica* cohort, and no long-term, directional change in time of appearance or growth rate. This study represents the first in the Southern Ocean to illustrate *L. antarctica* actively grows throughout the winter season. However, the most rapid growth occurs in November (austral summer) corresponding to a time of high biological productivity. Earlier *L. antarctica* appearance and faster growth rates corresponded with high sea surface temperature in austral autumn (Apr-May), indicating that long-term regional warming may change phenology with unknown consequences for the food web.

Session: Phytoplankton physiological engines of biogeochemical models

Marine nitrogen fixers crucial for dust-driven strengthening of the biological carbon pump

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Biological uptake and export of carbon dioxide (CO_2) from surface to deep waters is a primary control on Earth's climate, required to explain the recent glacial cycles and to predict carbon-climate feedbacks of coming millennia. The strength of the "biological carbon (C) pump" is in turn dependent on the functioning of the marine ecosystem. We use an ocean model equipped with a prognostic nitrogen (N) cycle to show that dinitrogen (N_2) fixing microbes are crucial for oceanic CO_2 sequestration. N_2 fixers' supply of N, efficient utilisation of phosphorus (P) and C enrichment of exported organic matter contributes 757 Pg C (1 petagram = 10^15 g) or approximately 27% of the biological C store under modern conditions. By emulating variations in aeolian iron (Fe) deposition characteristic of the glacial cycles, we find that these attributes enable gains in the oceanic C inventory that are otherwise not realised when N_2 fixers are absent. The gains in C are magnified by stoichiometric changes in response to P utilisation and are located in the tropical Pacific, where the habitat of N_2 fixers couples strongly to denitrification.

Ultimately, we find that the maximum potential rate of N_2 fixation, and therefore respired C accumulation, is limited by P, the supply of which is determined by the circulation. Even so, an Fe-induced stimulation of N_2 fixers under glacial conditions allows this stratified, P-limited ocean to draw down 100 ppmv of atmospheric CO_2. Our results strongly implicate marine N_2 fixation as a major player in the global carbon cycle on millennial timescales.

A metabolic model of biogeochemistry

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The biogeochemical impact and biogeography of marine microbes can be understood in terms of their metabolism, defined by redox chemistry. Growth efficiencies reflect factors including metabolic capabilities and substrate availability. Growth rates reflect factors including the kinetics of substrate uptake. We describe a generalized framework for marine biogeochemical modeling which exploits mass, energy and electron conservation to describe metabolism and growth efficiency, while the elementary physics of resource encounter and uptake control growth rates. Building on these "first-principle" perspectives, we construct a general model of microbial populations including primary producers, heterotrophs, predators and parasites. Geometric parameterizations of resource acquisition provide boundary conditions for simple stoichiometric network descriptions of physiology. A variety of trophic lifestyles is resolved; the organisms interact directly through predation and parasitism, and indirectly by the exchange of substrates. We describe the modeling framework, demonstrate its ability to simulate diverse model systems, and illustrate its improved ability to differentiate between predation and parasitism in terms of biogeochemical impact.

An Optimality-Based Non-Redfield Ecosystem Model for the UVic-ESCM

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The canonical Redfield ratio in marine phytoplankton and seawater (carbon (C) : nitrogen (N) : phosphorus (P) =106:16:1) applies to today's ocean as a whole, but strong deviations from this ratio occur in many regions, due to mechanisms such as nitrogen fixation, atmospheric N deposition and denitrification. In order to understand how phytoplankton stoichiometry interacts with these mechanisms, capturing the dynamic stoichiometry of C, N and P for phytoplankton in marine ecosystem models is essential. However, most of the models only use a fixed C:N:P ratio up to the present. We have implemented an optimality-based NPZD model with Nutrients (N, P), non-diazotrophic and diazotrophic Phytoplankton, Zooplankton, and Detritus into the University of Victoria Earth System Climate Model (UVic-ESCM). The new optimality-based phytoplankton compartments utilize ambient nutrients in different C:N:P ratios and thus allows for dynamic stoichiometry of C, N and P in phytoplankton, diazotrophs, and detritus.

Organismal contents of sinking particles identify biological source and ecological interactions that lead to carbon export

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Identifying mechanistic relationships between surface plankton and the carbon exported by settling particles will enable better quantify the biological pump. This study identifies these connections through direct observation of settling particles collected in a sediment trap using microscopy, particle imaging, and DNA sequencing of individual particles. Sinking particles and cells were collected in sediment traps containing polyacrylamide gel layers at three locations in the Pacific Ocean in February 2017. Individual cells contributed a small but non-negligible amount to total POC flux (~3-5%). Diatoms and Rhizaria sank consistently in the oligotrophic and coastal locations, with increasing contribution of coccolithophores at the coast. Most POC was exported in the form of organic aggregates and fecal pellets. To identify the organismal composition within these detrital particles, the 18S rRNA gene fragments were sequenced from individually isolated particles. Preliminary results suggest that particles contain different genetic compositions among locations and among different particle types. The DNA sequences identify organisms involved in particle production (e.g. copepods) and degradation (e.g. parasitic and bacterivorous protists) in addition to potential sources of the carbon (e.g. chlorophytes, diatoms, dinoflagellates). Together, these data provide direct observations of the biological source of organic carbon within sinking particles and the ecological mechanisms affecting their production and transport through the water column.

Pico-phytoplankton controls on global ocean carbon export and C:N:P stoichiometry patterns

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Both laboratory and field populations of pico-sized (< 2 µm) marine phytoplankton exhibit plasticity in their cellular phosphorus, nitrogen, and carbon content in response to changing environmental conditions such as light and nutrient supply. Phylogenetic affiliation is an additional control on pico-phytoplankton cellular C:N:P stoichiometry. Variable carbon to nutrient stoichiometry for marine primary production has important implications for the carbon-climate feedback of the ocean's biological pump that remain largely unrepresented and unquantified in Earth System Models. We have implemented three new explicit pico-phytoplankton groups (Prochlorococcus, Synechococcus, and pico-eukaryotes) for a total of six phytoplankton functional types with variable C:P stoichiometry within the CESM-BEC ocean biogeochemistry model. Pico-phytoplankton dominate NPP in the low-nutrient subtropical ocean gyres with their greater cellular C:P plasticity giving them a competitive advantage over larger plankton (nano-plankton, diatoms) with lower C:P stoichiometry. Pico-phytoplankton account

for a third to two-thirds of carbon export in the subtropical gyres with a C:P stoichiometry of exported organic matter approaching 200:1 in the Atlantic basin. The pattern of high C:P plankton within the subtropics and lower C:P plankton in the equatorial and polar latitudes reduces the meridional gradient in carbon export predicted by the standard version of CESM-BEC that assumes a constant Redfield C:N:P stoichiometry. Pico-phytoplankton contribute 10, 4, and 8% to global carbon export for Prochlorococcus, Synechococcus, and pico-eukaryotes, respectively. Future work will add two additional diazotrophic phytoplankton types for a nine phytoplankton group, variable C:P stoichiometry version of the CESM-BEC model, compatible with the E3SM model via the Marine Biogeochemistry Library (MARBL).

Quantifying the Role of River Nutrient Loading in the Global Coastal Ocean

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The coastal ocean is increasingly threatened in a high carbon dioxide, urbanized world. Coastal stressors, such as occurrences of harmful algal blooms and oxygen deprivation, are forecast to intensify over the next century owing to the combined effects of global warming and enhanced nutrient inputs. As a major terrestrial source of nutrients to the ocean, rivers play a significant but poorly quantified role in driving both coastal biogeochemical processes and global carbon cycling. We address this problem by evaluating and applying a state-of-the-art, high-resolution (1/4°) global ocean-ice-ecosystem model (MOM6-SIS2-COBALT) with time varying river nutrient inputs derived from an offline land model (LM3-TAN), both developed at the NOAA's Geophysical Fluid Dynamics Laboratory. Focused on phytoplankton biomass and oxygen, our 52-year simulation depicts a global view of "river impacted zones" with boundaries extended up to 1,000 km from their discharge points. We show that intensity and distribution of coastal extremes (i.e., blooms and hypoxia) in some coastal systems are strongly influenced by interannual variability of river nutrients, while those events in others are driven more by oceanic dynamics. Our results emphasize that future prediction of coastal ecosystem tipping points requires resolution of both oceanic and terrestrial/riverine drivers of coastal change.

Diatom populations in an upwelling environment decrease silica content to avoid growth limitation

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A mix of adaptive strategies enable diatoms to sustain rapid growth in dynamic ocean regions, making diatoms one of the most productive primary producers in the world. We illustrate one

such strategy off coastal California that facilitates continued, high, cell division rates despite silicic acid stress. Using a fluorescent dye to measure single-cell diatom silica production rates, silicification (silica per unit area) and growth rates we show diatoms decrease silicification and maintain growth rate when silicon concentration causes a decrease in silica production. While this physiological response to silicon limitation was similar across taxa, in situ silicic acid concentration limited silica production rates by varying degrees for taxa within the same community. Despite this variability, silicon limitation did not alter the contribution of specific taxa to total community silica production or to community composition. Maintenance of division rate at the expense of frustule thickness favors silica regeneration at shallow depths, possibly altering regional biogeochemistry. The reduction in frustule silicification also creates an ecological tradeoff: thinner frustules increase susceptibility to predation, but reduced Si quotas maximize cell abundance for a given pulse of silicic acid, favoring a larger eventual population size which facilitates diatom persistence in habitats with pulsed resource supplies.

A satellite perspective of 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 temperature and stratification are just some environmental stressors that are and will continue to impact plankton communities. We explore changing patterns in phytoplankton community composition, specifically as they relate to cell size distribution, on a global scale in response to environmental controls. Using a variety of satellite observed ocean color products (percent microplankton, chlorophyll concentration, primary production) and physical properties (photosynthetically available light, euphotic depth, sea surface temperature, sea level anomaly, heat flux, mixed layer depth and stratification) across a variety of missions spanning 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. From a global satellite perspective, the most important driver of phytoplankton size composition is euphotic depth, followed by chlorophyll concentration, net primary production, sea surface temperature, and photosynthetically available light. We further explore the temporal variability of these relationships globally and regionally.

A nitrogen-silicon-iron ROMS biogeochemical model for the Labrador Sea

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Fluxes of glacial meltwater from the Greenland Ice Sheet (GrIS) are linked to summer phytoplankton blooms in the Labrador Sea. To trace the fate of surface runoff around southern Greenland from the GrIS, Luo et al. 2016 used a Regional Ocean Modeling System (ROMS) incorporating time series of runoff rates into the ocean, as determined from regional climate model Modèle Atmosphérique Régional (MAR) coupled to the 1-D Surface Vegetation Atmosphere Transfer scheme Soil Ice Snow Vegetation Transfer (SISVAT). The ROMS model shows that the arrival of meltwater makes little difference to summertime mixed layer depths; therefore meltwater has a minimal effect on relieving light limitation for phytoplankton in summer. We therefore hypothesize that the meltwater-associated blooms in the Labrador Sea may be linked to enhanced nutrients resulting from glacial melt, rather than enhanced light. To test the hypothesis, we have created a biogeochemical model for the meltwater-tracing ROMS. This model has three nutrient budgets: 1) nitrogen, 2) silicon, and 3) iron, in addition to three phytoplankton species (diatoms, phaeocystis, and picoplankton). This model was built drawing upon three previously-published biogeochemical models for ROMS: 1) NEMURO, 2) NPZD_IRON, and 3) Fennel. To assess the quality of our model, we compare the output from our model to those three previously published models, in both 1D and 3D simulations. From this analysis we also determine the biogeochemical parameters to which the new model is most sensitive before its implementation in the southern Greenland ROMS.

Wasteful algae? Turnover of C, N, and P in the chlorophyte Selenastrum minutum

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The growth rate and elemental composition of aquatic primary producers partly depend on local resource supplies. In turn, organismal growth rate and elemental composition modulate ecosystem function and biogeochemical cycles. Here we present a physiological model to describe variations in the algal stoichiometry and growth rate. When constrained by published data from continuous cultures of the chlorophyte Selenastrum minutum, the model suggest that under P limitation the relationship between stoichiometric ratios and growth rate is determined by the dynamics of the limiting nutrient. Under N limitation, this relationship depends more strongly on the turnover of the temporary stores of the non-limiting C and P. We use the model-data synthesis to infer the cellular residence times of different elements in the cell. Our parameter estimate suggests that P is excreted at a high rate under N limitation, especially at high growth rates. We discuss independent evidence for this apparently wasteful behaviour and the potential implications for the functioning of aquatic ecosystems.

Simulated eddy induced bottom-up controls on phytoplankton growth in the Southern Ocean

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Observational and modeling work point to the important role of mesoscale eddy processes in regulating biological productivity and ecosystem dynamics, but the relationship is subject to a great deal of regional and mechanistic variability which is of yet poorly constrained, particularly in the Southern Ocean. We consider the effect of coherent mesoscale features on the bottom-up controls that regulate depth integrated phytoplankton populations within eddies with a particular focus on light availability and iron supply. We use an explicit, eddy-centric framework to analyze variability in the mechanisms that modify light and iron limitation and ultimately lead to anomalous division rates, a direct reflection of bottom-up growth conditions. We find that mixed layer depths are anomalously shallow (deep) in only 50% (51%) of cyclones (anticyclones), but that the prevalence of shallow (deep) cyclones (anticyclones) increases to 80% (82%) when only considering large eddies with deep background mixing. Within this subset, phytoplankton populations in turn experience reduced (exacerbated) light limitation in 88% (89%) of cyclones (anticyclones). Iron concentrations are anomalously low (high) in 73% (71%) of all cyclones (anticyclones) and are fueled primarily by a combination of horizontal advection, mixed layer modification, and Ekman pumping, but not eddy pumping. Ekman pumping appears more important than previously suggested in the Southern Ocean. Together, population specific division rates are depressed (elevated) in 80% (77%) of cyclones (anticyclones), however, this distribution is subject to some seasonal variability. Due to variability in the relative contribution of light and iron limitation anomalies 25% (29%) more cyclones (anticyclones) suppress (stimulate) division rates in the summer than in the winter.

Best Practices for Data Sharing of Ocean Metaproteomic Data Workshop Results

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Participants in the Ocean Metaproteomic Data Sharing Workshop

Ocean metaproteomics is an exciting new datatype that has the potential to provide a myriad of valuable new insights into the biogeochemical functions of marine microbes throughout the oceans and their impact on ecological and chemical processes. A community workshop was organized to discuss and explore solutions to the challenges specific to data sharing of these ocean metaproteomic datasets. This workshop was held in May of 2017 with a diverse group of proteomic scientists, data scientists, and computer programmers, the latter groups associated with the Biological and Chemical Data Management Office and the development team of the EarthCube Ocean Protein Portal. The group identified areas that present challenges to data quality control and intercompatability, including diverse data types and diversity and lack of standard approaches to informatic data processing. The group also recognized the important need for a metaproteomic intercalibration effort and demonstrated a willingness to organize and participate in a future intercalibration and in the development of intercalibration standards. The value of the future ocean protein portal, and the sustainability considerations in balancing capabilities with managing costs were also discussed. Finally, given that many participants had never met before, this workshop served as an important community-building effort for this nascent scientific community.

A New Method to Measure Inter- and Intra-Specific Variability in Primary Productivity: Stable Isotope Probing and Single-Cell Resonance Raman Microspectrometry

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Understanding processes driving variability in phytoplankton productivity among cohabiting populations is fundamental to explaining the "paradox of the plankton" and to predicting overall ecosystem responses to episodic, seasonal and supra-annual environmental perturbations. In complex plankton communities, however, current oceanographic tools are rarely capable of addressing germane questions such as:

(i) Are dominant taxa necessarily the fastest growing taxa of the moment?
(ii) Does relaxed top-down control (predation & viral lysis) explain numerical dominance of specific taxa within the community?
(iii) How does resource availability (light, N, P, Si, Fe, B_{12}) shape growth responses of specific taxa within the community?
(iv) Is variability in single-cell growth rates necessarily greater between taxa than within individual taxa?
(v) How variable are intra-population single-cell growth rates among different phytoplankton taxa (e.g., rare vs common)?

To address such questions, we developed a new method to measure growth rates of individual photoautotrophic cells by combining stable isotope probing (SIP) and single-cell resonance Raman microspectrometry (Taylor et al. 2017; doi: 10.3389/fmicb.2017.01449). As proof-of-concept, we grew isogenic cultures of the cyanobacterium, *Synechococcus* sp., in seawater amended with 13C-bicarbonate. Time course sampling demonstrated linear covariance between cellular 13C fractional isotopic abundance and wavenumber (cm-1) shifts in carotenoid Raman peaks from individual cells. Single-cell growth rates were calculated from spectra-derived isotopic content and empirical relationships. Growth rates among any 25 Synechococcus cells in a sample varied considerably; mean coefficient of variation, CV, was 29±3% (SD/mean), of which only ~2% was analytical error. Daily population growth rates measured by in vivo fluorescence also varied (CV = 53%) and were statistically indistinguishable from single-cell growth rates at all but the lowest levels of cell labeling. Single-cell censuses of mixtures of *Synechococcus* sp. and *T. pseudonana* populations with varying 13C-content and growth rates closely matched predicted spectral responses and fractional labeling of cells. Our approach enables direct interrogation of isotopically- and phylogenetically-labeled cells (FISH) and detects as little as 3% changes in cellular fractional labeling, which equates to growth rates < 0.01 doublings d^{-1}. This is the first non-destructive technique to measure single-cell photoautotrophic growth rates based on Raman spectroscopy and requires few ancillary measurements. It is amenable to field experiments in which selective pressures are manipulated and single-cell growth rates are measured through time.

Phytoplankton production from community to cell-specific rates

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Phytoplankton groups drive the global cycle of elements in specific ways depending on their abundance, cell size, metabolic repertoire and physiological status. We investigated phytoplankton activities on ecological scales from the whole community to the taxon- and cell-specific level in the temperate and subpolar North Atlantic Ocean. Whole-community primary production rates (specific uptake rates) were higher during summertime compared to the spring. These higher rates are attributed to nano- and picophytoplankton-dominated communities thriving at higher temperature and light levels in the summer, despite low nutrient levels. Specific carbon fixation and nitrate uptake rates by microphytoplankton during summertime, on the other hand, were always lower than the whole community rates. This is consistent with larger cells being less competitive at the low nutrient levels prevalent during summertime. Specific nitrate uptake rates by *Synechococcus* cells measured on flow cytometry-sorted populations were always lower than nanophytoplankton uptake rates in spring but not consistently so in summer, highlighting the different roles of these two phytoplankton groups in terms of new production. Growth rate estimates of *Synechococcus* obtained for the first time by applying the index of replication (iRep), a taxon-specific genome-based method, to culture experiments adds a new tool for assessing the growth of cyanobacteria. While whole-community production rates provide an essential measure of biological response to environmental conditions, phytoplankton group-specific rates offer mechanistic insights into the functioning of the base of the foodweb and the biogeochemical impact of phytoplankton community members.

Concentrations of multiple phytoplankton pigments in the global oceans obtained from MERIS

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The remote sensing of chlorophyll a concentration from ocean color satellites has been an essential variable quantifying phytoplankton in the past decades, yet estimation of accessory pigments from ocean color remote sensing data has remained largely elusive. In this study, we validated the concentrations of multiple pigments (Cpigs) retrieved from in situ and MEdium Resolution Imaging Spectrometer (MERIS) measured remote sensing reflectance ($Rrs(\lambda)$) in the global oceans. A multi-pigment inversion model (MuPI) was used to semi-analytically retrieve Cpigs from $Rrs(\lambda)$. With a set of globally optimized parameters, the accuracy of the retrievals obtained with MuPI is quite promising. Compared with High-performance liquid chromatography (HPLC) measurements near Bermuda, the concentrations of chlorophyll a, b, c ([Chl-a], [Chl-b], [Chl-c]), photoprotective carotenoids ([PPC]) and photosynthetic carotenoids ([PSC]) can be retrieved from MERIS data with a mean unbiased absolute percentage difference

of 38%, 78%, 65%, 36%, and 47%, respectively. The advantage of the MuPI approach is the simultaneous retrievals of [Chl-a] and the accessory pigments [Chl-b], [Chl-c], [PPC], [PSC] from MERIS Rrs(λ) based on a closure between the input and output Rrs(λ) spectra. These results can greatly expand scientific studies of ocean biology and biogeochemistry of the global oceans that is not possible when the only available information is [Chl-a].

Diel patterns of variable fluorescence and carbon fixation of picocyanobacteria Prochlorococcus-dominated phytoplankton in the South China Sea basin

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A variety of photosynthetic architectures and light utilization strategies are the critical factors regulating the distribution and primary productivity of phytoplankton. Active chlorophyll fluorescence has been a powerful technique for the assessment of nutritional status of phytoplankton through the study of photosynthetic dynamics. Further study on carbon fixation in light of the energetic stoichiometry between light absorption and carbon production was required to understand the ways phytoplankton adapt to their niches. To explore the ecophysiology of Prochlorococcus-dominated phytoplankton assemblage, we conducted studies of the diel patterns of variable fluorescence and carbon fixation by phytoplankton in the oligotrophic South China Sea (SCS) basin in June 2017. We found that phytoplankton photosynthetic performance at stations SEATS and SS1 were characterized by a nocturnal decrease, dawn maximum, and midday decrease of the maximum quantum yield of PSII (Fv(')/Fm('), which denoted both Fv/Fm and Fv'/Fm') in the nutrient-depleted surface layer. That these diel patterns of Fv(')/Fm(') were similar to those in the tropical Pacific Ocean suggests macro-nutrient and potentially micro-nutrient stress. However, the fact that variations were larger in the central basin than at the basin's edge implied variability in the degree of nutrient limitation in the basin. The estimated GOP:NPC ratio (gross oxygen production to net carbon production ratio) of 4.9:1 was similar with the reported ratios across the world's oceans. The narrow range of the GOP:NPC ratios is profound to the theory of common strategy of phytoplankton for photosynthetic energy allocation. That the large extent of photoinactivation and nonphotochemical quenching accounts for most of the total phytoplankton absorption which do not go to GOP explains why the maximum quantum yield of carbon fixation is substantially low in the oligotrophic basin. This analysis may provide insight into a better structure of absorption-based primary production model.

Session: The world of microzooplankton: Ocean carbon movers and shakers

Net carbon remineralization (defined here as CO_2 release) of stable isotope-labeled phytoplankton measured in the mesopelagic environment with a newly designed deep-sea incubator

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To determine the efficiency of the biological pump, and to supply models with accurate degradation rate parameters, it is necessary to better understand the processes of degradation and remineralization of organic carbon under true mesopelagic and bathypelagic conditions. As simulation of such conditions in the laboratory or in shipboard experiments is exceedingly difficult, we built a device that autonomously incubates labeled samples in situ and exposes them to natural microbial communities. In the first course of experiments, $13CO_2$ release from fresh phytoplankton cultures (a diatom and a cyanobacterium) was measured over incubation periods of 2 and 3 weeks. Carbon dioxide release rates translated into degradation rates that were at the lower range of previous estimates based on oxygen consumption. One of the reasons for a low degradation rate is that phytoplankton are well adapted to survive long exposures in cold and dark environments. Secondly, phytoplankton carbon from exudation and death is incorporated into the biomass of a diverse microbial community and not immediately respired. Long-term survival also explains the large numbers of intact phytoplankton cells observed in the deep sea by holographic in-situ microscopy and by direct sampling. After the incubation period, water in the incubator was highly enriched with both prokaryotes and eukaryotes in comparison to the original mesopelagic water. Two eukaryotic groups stood out to be even more highly enriched than both the average prokaryote and eukaryote cell: kinetoplastids and fungi, a fact that reveals their role as early colonizers of fresh phytoplankton carbon arriving at depth. More detailed results from these field incubations underscore the need (1) to study the mechanics of microbial degradation of organic carbon in more detail, (2) to investigate the biochemical transformation of organic material during degradation (from live cells to freshly dead cells to refractory organic carbon), and (3) to determine the variety of factors that modify degradation rates (i.e., environmental conditions and resident microbial communities). The deep-sea incubator presented here is a useful tool for addressing these topics.

Mesozooplankton are not herbivores: The importance of microzooplankton in mesozooplankton diets and in arctic and sub-arctic trophic linkages

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Large copepods, such as *Calanus* spp., in Arctic regions typically are described as herbivores, although it has been hypothesized that microzooplankton could constitute a significant component of their diet. Nonetheless, the concept of *Calanus* spp. as herbivores persists in the literature. Grazing experiments conducted in the Bering and Chukchi Seas over several years demonstrated that microzooplankton are important prey for both copepods and euphausiids, with

the relative importance of microzooplankton in the diet varying between species and seasons. Microzooplankton were a greater proportion of the copepod diet during summer relative to spring, coincident with a greater proportion of microzooplankton in the available prey field. Microzooplankton were more important prey for the large shelf-slope *C. glacialis* than to the basin species *C. hyperboreus* and were greatly preferred over phytoplankton by the strongly omnivorous *Metridia* spp. at all times of the year. Trophic cascades during grazing experiments could result in significant underestimates of chlorophyll grazing rates by mesozooplankton, especially for those taxa that showed strong preference for microzooplankkon prey. These results further support the growing evidence that most mesozooplankton are not herbivorous, but are omnivorous even during periods of high primary productivity.

Nitrate, iron and B_{12} metabolism in eukaryotic phytoplankton across a geochemical gradient in the central Pacific Ocean

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A natural geochemical gradient exists in the equatorial and tropical Pacific Ocean in which the tropical regions are deficient in nitrate (NO_3) yet iron (Fe)-replete, while the equatorial upwelling region is NO_3-rich and low in dissolved Fe, cobalt (Co) and nickel (Ni). These contrasting nutrient regimes provide a unique opportunity to match eukaryotic phytoplankton NO_3, Fe, Co-dependent vitamin B_{12} and other metalloprotein metabolism with regional geochemistry to determine how macronutrient and trace metal availability influence major biochemical processes. We integrated metatranscriptomes, metaproteomes and 18S rRNA gene sequences with physiological and physiochemical parameters and report the metabolic profiles of protists across seven stations collected from multiple depths spanning the surface to the mesopelagic. Our findings suggest that dinoflagellates – the most abundant eukaryotic taxonomic group based on 18S community analysis and relative gene expression and protein abundance – are well-adapted to both tropical and equatorial regions with NO_3 transporters more abundant in the NO_3-deficient tropical zones, while Fe and urea transporters, carbonic anhydrase, ATP-generating rhodopsin, and Fe-independent alternative proteins involved in photosynthesis were more abundant in the low-Fe equatorial upwelling waters. Differences in gene expression across depths was apparent with deeper water (>200 meters) higher in dissolved Co, NO_3 and phosphate (PO_4) supporting dinoflagellates with a distinct metabolic profile compared to surface communities exposed to higher dissolved oxygen and ammonium (NH_4). These differences include photosynthetic genes being more highly expressed in surface waters, and lysosome and cytoskeleton-related genes being more highly expressed below 200 meters, perhaps indicative of heterotrophy. We additionally observed high dissolved Co and oxygen minimum zones (OMZ) coinciding with peaks in diatom B_{12}-dependent methionine synthase (*METH*) gene expression. Collectively our study provides insight into the geochemical drivers of phytoplankton growth dynamics and nutrient-specific adaptations of dinoflagellates to contrasting oceanic regimes.

Quantifying Temperature Dependence of the Growth Rates of Planktonic Grazers

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Herbivorous protists (HP) are the major consumers of primary production in the ocean and key mediators of biogeochemical cycles. Temperature is a fundamental driver of biological rates. Lack of knowledge of the temperature sensitivity of HP physiological rates can preclude insights into cross-ecosystem and future net primary production trends. Remarkably, data for HP growth rates at temperatures <5°C are virtually non-existent, despite the importance of cold temperatures for global oceans. To address this critical knowledge gap, we measured heterotrophic dinoflagellates and ciliates growth rates over a temperature range reflective of the surface ocean as well as seasonal cycles (-1 to 22°C). Experiments used both established laboratory cultures of *Oxyrrhis marina*, *Gyrodinium dominans* and *Protoperidinium bipes* and new isolates derived from Narragansett Bay, a temperate estuary that annually fluctuates from polar to tropical temperature. Growth rates of the three cultured organisms increased with increasing temperature. *O. marina* also grew at the lowest temperature (0.03±0.08 and 0.20±0.08 d^{-1} at 0 and 2°C, respectively), indicating that this species is able to grow in polar or wintertime conditions. We observed significant differences between rates based on cell numbers and on biomass (0.03±0.08 d^{-1} to 1.19±0.17 d^{-1} and 0.21±0.03 and 1.45±0.05 d^{-1}, respectively). Results from the new isolates show an increase in growth rate whenever protists were exposed to temperature increases, irrespective if these were cold or warm adapted species. The sensitivity of the response to changes in temperature appeared to be strongly specie-specific. Our study suggest that increase in temperature results in increased HP growth rates and likely in higher proportion of primary production lost to protistan herbivory. These experimental data are essential for our understanding of microbial processes and to build accurate models of future ocean scenarios.

Non-linearity required to model wintertime phytoplankton growth

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Recent autonomous biogeochemical observations have revealed increases in phytoplankton biomass during the wintertime, a process that has yet to be incorporated into theories of phytoplankton bloom dynamics. Current hypotheses ("dilution-recoupling") suggest that a release from grazing causes the wintertime biomass accumulation. We demonstrate that the assumption that a release from grazing occurs with a deeper mixed layer restricts the class of potential models that should be used to study North Atlantic plankton community dynamics. Modes are often used to supplement sparse data and better constraints on the range of possible

model functional forms allows inferences about zooplankton community dynamics in the absence of autonomous measurements of grazing.

Constraining biological rates governing the North Atlantic annual cycle in phytoplankton biomass.

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A major goal of the North Atlantic Aerosol and Marine Ecosystem Study (NAAMES) was to "define environmental and ecological controls on plankton communities" to build a predictive understanding of the structure and function of plankton systems. During the four NAAMES field campaigns, we measured phytoplankton growth and grazer-induced mortality rates in 145 two-point dilution experiments. The NAAMES sampling region in the Western North Atlantic (38-48 W, 40-55 N) was influenced by the Gulf Stream and often characterized by a complex eddy field. Chlorophyll concentration varied from 0.2 µg L^{-1} to 7 µg L^{-1}, with lowest values measured in September 2017 and highest values in May 2016. Phytoplankton communities were largely dominated by <5 µm cells including Synechococcus and pico- and nano-eukaryotes. Diatoms were rarely abundant. From the perspective of the entire NAAMES region, rates obtained from surface water incubated at a gradient of light levels showed a seasonal pattern of decreasing biomass accumulation in September (median= -0.03 d^{-1}) and increasing biomass accumulation starting in November (median= 0.3 d^{-1}) climaxing in March (0.6 d^{-1}). Nevertheless rates varied among sampling stations and depths sampled, illustrating environmental patchiness. These data imply a prolonged growth period and a relatively shorter period of net biomass loss. Consequently seasonal biogeochemical fluxes and the transfer of matter and energy through the North Atlantic food web may be quite prolonged rather than defined by short 'bloom' events.

Large *Phaeodaria* in the Twilight Zone: Their Roles in the Carbon and Silica Cycles

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Advances in in situ imaging allow enumeration of abundant populations of large rhizarians that compose a substantial proportion of total mesozooplankton biovolume. Using a quasi-Lagrangian sampling scheme, we quantified the abundance, vertical distributions, silica content, and sinking-related mortality of *Phaeodaria* in the California Current Ecosystem. Inter-cruise variability was high, with average concentrations at the depth of maximum abundance ranging from <10 to >300 cells m^{-3}. Vertical profiles showed that these organisms were consistently most abundant at 100-150 m depth. Average turnover times with respect to sinking were 4.7 to 10.9 d, equating to minimum in situ population growth rates of ~0.1 to 0.2 d^{-1}. Using simultaneous measurements of sinking organic carbon, we find that these organisms could only meet their

carbon demand if their carbon:volume ratio were ~1 μg C mm^{-3}. This value is substantially lower than previously used in global estimates of rhizarian biomass, but is reasonable for organisms that use large siliceous tests to inflate their cross-sectional area without a concomitant increase in biomass. Despite this reduced carbon biomass estimate, *Phaeodaria* were important contributors to the carbon and silica cycles. Two families (Aulosphaeridae and Castanellidae) contributed on average 10% of total $bSiO_2$ export from the euphotic zone. Their proportional contributions increased in oligotrophic regions and at deeper depths, where they could at times dominate $bSiO_2$ flux. We also found that Aulosphaeridae alone can intercept >20% of sinking particles produced in the euphotic zone before these particles reach a depth of 300 m.

Speciation of iron regenerated through grazing

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Iron availability controls primary production and community composition in large regions of the global ocean. Like nitrogen, iron is readily regenerated following ingestion of phytoplankton by protistan and mesozooplankton grazers. In fact, in most systems a majority of the iron taken-up by phytoplankton has been regenerated, passing through a grazer digestive system en route to the phytoplankton. Laboratory and field studies have shown regenerated iron to be highly bioavailable. Despite this importance, only a handful of studies have documented the chemical speciation of iron regenerated by grazing. We conducted laboratory grazing incubations with the heterotrophic dinoflagellate *Oxyrrhis marina* and the calanoid copepod *Acartia tonsa*. Phytoplankton prey used were the diatom *Thalassiosira pseudonana*, the coccolithophore *Emiliania huxleyii*, or the cyanobacterium *Synechococcus*. Ingestion of diatoms by either the protist or copepod, or *Synechococcus* by the protist, resulted in higher Fe(II) concentrations compared to prey-free controls. In contrast, ingesting of *E. huxleyii* by either grazer did not produce elevated Fe(II). Regenerated Fe(II) was more stable than inorganic Fe(II), suggesting stabilization by Fe(II)-binding ligands. Increased concentrations of Fe(III)-binding organic ligands were also measured in grazing experiments. Observations of vacuole pH in protist grazers suggest that *E. huxleyii* buffered pH changes, resulting in reduced acidification. Protist grazing experiments with natural plankton communities in the southern Indian Ocean also demonstrated elevated Fe(II) production via grazing. These results demonstrate the important impact of grazing processes on Fe speciation in the surface ocean.

General OCB topic posters

Modeling the impact of zooplankton diel vertical migration on the carbon export flux of the biological pump

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One pathway of the biological pump that remains largely unquantified in many export models is the active transport of carbon from the surface ocean to the mesopelagic by zooplankton diel vertical migration (DVM). Here, we investigate the effect of DVM on export and mesopelagic biogeochemistry with a global model of the biological pump. The model describes export out of the euphotic zone and the fate of exported carbon in the twilight zone using a surface food web model driven by diagnostic satellite measurements of net primary production, algal biomass, and size structure. The modeled global export flux from the base of the euphotic zone was 6.7 PgC/yr, which represents an 18% increase over the export flux in model runs without DVM. The annual mean (± standard deviation) export ratio, calculated over space and time, was 0.12 ± 0.05. DVM activity accounted for about one-fifth of both total carbon export and total respiration within the twilight zone. DVM also pushes dissolved inorganic carbon production and oxygen utilization deeper into the thermocline and creates a deep local maximum in the oxygen utilization profile. The effect of DVM on export was most sensitive to the assumptions for the fraction of fecal pellets produced in the euphotic zone, the fraction of individuals participating in DVM, and the fraction of grazed carbon that is metabolized. The model indicates that DVM is an important export pathway in the biological pump that also significantly influences mesopelagic biogeochemistry.

A web-based Best Practice Guide to design marine multiple driver experiments

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Marine ecosystems are being subjected to a complex matrix of change across a range of scales, from local to regional and global. Understanding the cumulative effects of multiple drivers (e.g. warming, oxygen, nutrients, prey) represents a formidable challenge: as the number of drivers increases, the number of permutations that could be tested grows exponentially. Here, we introduce an open access SCOR (Scientific Committee on Oceanic Research) web-based Best Practice Guide (BPG) to help researchers design and carry out these experiments. The BPG is currently under development and will be launched in mid 2018. The highly successful Ocean Acidification BPG significantly improved the consistency of single driver (i.e. ocean acidification, OA) experiments. Tools were presented in a 200+ page book (Riebesell et al., 2011, ISBN 9789279206504; doi 10.2777/66906). OA topics include carbon chemistry, selection of controls and treatment levels, and biostatistics.
Multiple driver studies involve too many permutations for a single book. A new SCOR web-based guide will step you through the planning stages using open access online decision support tools, interactive simulations, and video tutorials. The three tiers of the BPG are designed to guide, stimulate and enhance your learning experience by:

> *Guide* - Identify how drivers will vary with region and season; Make decisions in a stepwise manner using the decision support tool; Select the best design for your project/question(s)/study site.
> *Stimulate* - Roadtest the design in our webbased simulation lab, without getting your hands wet or costing resources; Use the results to refine your design and your skill set.

Enhance - Short video tutorials will help you make the most of your learning adventure. A 40 page pdf booklet guides you through these three linked tiers and will provide links to additional resources. See https://scor149ocean.com/ for updates on the release date and the launch of the BPG nationally, regionally, internationally.

How important are forced changes in the equatorial current system for the extent of tropical oxygen minimum zones?

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Oxygen Minimum Zones (OMZs) in the tropics are maintained by a delicate balance between two large and opposing processes: Biological consumption due to respiration of sinking organic material and ventilation by physical processes like advection and diffusion. Uncertainties in projecting both processes for a warming climate amplify the uncertainty in projections for the extent of tropical OMZs, which have broad implications for ecosystems (in particular for fishery industries) and global biogeochemical cycles.
Estimates from global earth system show no consistent projection, not even of the sign of OMZ volume change. Moreover, while observational estimates suggest an expansion, it remains unclear whether this is attributable to a long-term trend or part of decadal-centennial variability, as other proxy studies suggest.
Previous studies point out the sensitivity of OMZ extent to the strength of the Equatorial Undercurrent (EUC) within the CMIP5 model suite. This class of models lacks a realistic representation of the narrow jets, comprising the Equatorial current system, which is thought to be essential for oxygen ventilation in the tropical Pacific and Atlantic. We compare the sensitivity of the tropical oxygen budget (and in turn the OMZ volume) to forced changes in the Equatorial current system.
Using a suite of fully coupled climate models (GFDL CM2 and ESM2.6) with varying horizontal resolution and biogeochemical models we investigate the importance of changes in the physical transport of the equatorial current system, in particular the EUC, for the tropical OMZs.

The EXPORTS (EXport Processes in the Ocean from Remote Sensing) Project – Unique Challenges for Data Management and Synthesis

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EXport Processes in the Ocean from Remote Sensing (EXPORTS) is a large-scale NASA campaign designed to develop a predictive understanding of the export and fate of global ocean net primary production (NPP) and its implications for present and future climates. The achievement of this goal requires quantification of the mechanisms that control export of carbon from the euphotic zone and its subsequent fate in the underlying ‘twilight zone’ where some fraction of exported carbon will be sequestered in the ocean's interior on time scales of months to millennia. The first field campaign will take place in August 2018 near the long-term monitoring site of Ocean Station Papa and its associated Line P in the Northwest Pacific. EXPORTS is a truly unprecedented in terms of its inter- and multidisciplinary approach. Measurements will be made from several platforms – satellite, autonomous gliders and floats, and a process and survey ship – which will generate a dataset that includes traditional hydrographic measurements, discrete water samples, satellite ocean color data products, high resolution imagery of single plankton cells, and cutting edge 'omic' assays. Additionally, these data will be used to constrain and inform extensive physical and biogeochemical models. The data repositories for both measured and modeled EXPORTS data are NASA's SeaBASS and NSF's BCO-DMO. However, the collection of such a dataset presents unique challenges in terms of archiving, analyzing, and ultimately, synthesizing the data to form a holistic understanding of the numerous processes at play in the biological carbon pump. Here, we present the EXPORTS data management approach, along with examples of unique tools that have been developed to allow visualization of the linkages and interdependencies of the >350 measured, modeled or derived parameters.

Molecular and microscopic characterization of sinking particles at the Bermuda-Atlantic Time Series Study station (BATS)

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"Marine snow" particles are detritus aggregates that are considered to be the major constituents to downward particle flux. Understanding the contribution of different plankton taxa to these particles would help elucidate their predominant method of transport to depth, either through direct formation of aggregates, or by grazing and formation of sinking fecal pellets. In this study, we deployed traps with tubes containing polyacrylamide gels at the Bermuda Atlantic Time-series Study station (BATS) at 150 m, 200 m, and 300 m depth to investigate individual particles in the context of the vertical flux of organic carbon. We will describe the relative contribution of different particle categories to flux and show the composition of these particles using epifluorescence and confocal microscopy. In addition, we will show results of the resident bacterial and protistan community on individual marine snow particles (such as types of phytoplankton aggregates and fecal pellet-nucleated particles) using next-generation sequence amplification of the 16S and 18S rRNA genes. Preliminary results suggest a significant contribution of pico-phytoplankton, especially the pico-cyanobacterium *Synechococcus*, to the communities associated with the isolated particles.

Seasonal cycle of variability, instabilities, and subduction at submesoscales

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Submesoscale dynamics at scales of 1-100 km evolve on a timescale of hours to days and are difficult to observe in the ocean. Dynamics at submesoscales can induce a range of instabilities that lead to large vertical velocities, which may induce substantial vertical transport of physical and biological tracers. Recent studies have found the strong influence of a seasonal cycle in the strength of submesoscale motions, meaning studies at a particular time may miss important processes active in a different season. Here we use ocean glider measurements of physical and biological variables at submesoscale resolution in the northeast Atlantic Ocean. Five gliders were deployed at staggered times and piloted within a 20 x 20 km region, such that two gliders were always present throughout a full year. We compute horizontal structure functions of potential energy and passive tracers from simultaneous measurements between glider pairs. An important result is that tracer variance is enhanced during winter at depths which substantially exceed that of the mixed layer depth, suggesting that the mixed layer base is permeable during wintertime. A key factor is the stratification at the base of the mixed layer, which is dramatically reduced during winter, allowing the wintertime mixed layer to act as a window to the interior ocean. The mixed layer water column is also sporadically baroclinically and symmetrically unstable throughout the winter, and we find clear subductive features below the mixed layer following instances of strong baroclinic or symmetric instabilities. In this particular location and year, a temporal offset in these instabilities and the seasonal cycle of biological production limits the ability of submesoscale instabilities to export fixed carbon out of the surface ocean. However, the combination of an unstable mixed layer and a weakly stratified mixed layer base presents a clear physical mechanism for carbon export that has not yet been well explored, and will lead to enhanced knowledge about the uptake of carbon in the ocean.

Geostatistical analysis of North Atlantic mesoscale biophysical variability in an eddy resolving CESM run

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The North Atlantic Ocean is home to one of the largest, most reliable phytoplankton blooms each year and as such plays a role in global climate. The mechanisms driving the start and end of the bloom each spring/summer are still debated. As the resolution of our tools enhances, such as from autonomous observations, remote sensing advances, and higher-resolution models, we have become more aware of the role of biological patchiness and the responsible (sub)mesoscale physical processes. In a sense, the observed variability could be closely tied to the bloom's annual reliability. In this study we build off of remote sensing-based investigations (Glover et al., 2018, Doney et al., 2003), to address how the magnitude and spatial scale of biological patchiness varies in time and space in the North Atlantic using a 0.1° eddy-resolving coupled Community Earth System Model (CESM) simulation. We use the geostatistical semi-variogram approach to quantify the magnitude and spatial scale of mesoscale variability of surface Chlorophyll concentration in 2-D across the Western North Atlantic. This approach exposes a pronounced seasonal cycle in resolved variability in the subpolar gyre with a lagging, though less defined, minimum in spatial range. When compared to satellite data, the two display similar regional patterns in resolved variability, though the model expresses a greater magnitude of

variability (and coefficient of variation) overall in the subpolar gyre than SeaWiFS and MODIS. Ongoing work investigates the physical mechanism driving model patchiness.

Seasonal asymmetry in the evolution of surface ocean pCO2 drivers

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Recent modeling and observational studies have confirmed the long-held hypothesis that seasonal cycle amplitudes of carbonate system parameters change as the ocean absorbs anthropogenic carbon dioxide (CO_2). What remains unclear is whether the altered seasonal cycles of CO_2 partial pressure (pCO_2) influence the annual mean air-sea CO_2 flux. To evaluate the driving mechanisms of pCO_2 seasonal cycle amplification, we use numerical models and observations to test how the surface ocean may respond to continued "business-as-usual" atmospheric pCO_2 concentrations through 2100. We do this while holding the seasonal cycle amplitudes of dissolved inorganic carbon, total alkalinity, salinity, and temperature at 2010 levels. Our results indicate that, between 1861 and 2100, changes in seawater chemistry cause asymmetric amplification of pCO_2 seasonal cycles by a factor of two or more relative to pre-industrial levels. These changes are relevant to climate feedbacks associated with the Revelle Factor and indicate that significant alteration of sea surface pCO_2 can occur without modifying the physical or biological ocean state. The mechanisms identified using this theoretical approach may help to better characterize air-sea CO_2 flux responses in fully-coupled model simulations and improve the understanding of carbon cycle feedbacks.

Evaluating pCO_2 interpolation methods using large ensembles

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The Surface Ocean CO_2 Atlas (SOCAT) is a synthesis of quality-controlled surface ocean pCO_2 (partial pressure of CO_2) observations from volunteer observing ships. A monthly averaged product on a regularly spaced grid is available for the entire SOCAT record, 1957 to 2017. This synthesis is laudable but the number of observations within any given month is sparse, which makes an accurate assessment of the global ocean carbon sink difficult. Various methods have been proposed to interpolate these observations to create a time history of monthly estimates with full global coverage. Methods using neural networks, mixed layer budgets, and statistical techniques have been used. It is unclear how well these approaches are able to capture the actual pCO_2 variability on a monthly scale. Here, we present as testbed using large ensembles suitable for evaluating pCO_2 interpolation methods. The basic strategy is to sample each member from various large ensembles at the SOCAT locations and then use various methods to reconstruct the modeled data. Lastly, we evaluate using a suite of statistical tests how well each method is able to reconstruct the modeled pCO_2. We present preliminary results where we evaluate a neural network based approach against two independent large ensembles.

Seeing molecules from space: Tools for optically estimating CDOM composition

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Colored dissolved organic matter (CDOM) absorption varies significantly across the global oceans, a feature presumably linked to differences in source material, degradation pathways and in situ production. Tracking this variability on a global, or even regional, scale requires broad temporal and spatial sampling at high frequency. Satellite remote sensing provides this platform; however, current and near future sensors are/will be limited to measurements within the UV and visible wavelengths (> 350 nm) while most optical proxies estimating CDOM composition use wavelengths < 350 nm. Here, we assess absorption-based optical proxies for estimating CDOM composition using in situ CDOM absorption and fluorescence with special attention paid to proxies derived from CDOM absorption at wavelengths > 350 nm. In anticipation of hyperspectral satellite remote sensing, we utilize radiative transfer software to determine what absorption features are viewable at wavelengths > 350 nm considering the anticipated signal-to-noise ratio of NASA's proposed hyperspectral sensor and varying in-water optical conditions (e.g. coastal to open ocean waters). From this, we present what spectral features of CDOM absorption are viewable from a hyperspectral satellite, including sensitivity to changes in spectral slope and the ability to detect secondary CDOM absorption spectral features, and how this can be related to optical estimates of CDOM composition.

Mesoscale effects on carbon export: a global perspective

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Carbon export from the surface to the deep ocean is a primary control on global carbon budgets, and is mediated by plankton that are sensitive to physical forcing. Earth system models generally do not resolve ocean mesoscale circulation (O (10–100) km), scales that strongly affect transport of nutrients and plankton. The role of mesoscale circulation in modulating export is evaluated by comparing global ocean simulations conducted at 1º and 0.1º horizontal resolution. Mesoscale resolution produces a small reduction in globally-integrated export production (< 2%); however, the impact on local export production can be large (+/-50%), with compensating effects in different ocean basins. With mesoscale resolution, improved representation of coastal jets block off-shelf transport, leading to lower export in regions where shelf-derived nutrients fuel production. Export is further reduced in these regions by resolution of mesoscale turbulence, which restricts the spatial area of production. Maximum mixed layer depths are narrower and deeper across the Subantarctic at higher resolution, driving locally stronger nutrient entrainment and enhanced summer export production. In energetic regions with seasonal blooms, such as the

Subantarctic and North Pacific, internally generated mesoscale variability drives substantial interannual variation in local export production. These results suggest that biogeochemical tracer dynamics show different sensitivities to transport biases than temperature and salinity, which should be considered in the formulation and validation of physical parameterizations. Efforts to compare estimates of export production from observations and models should account for large variability in space and time expected for regions strongly affected by mesoscale circulation.

Random forests and a potential function for the Chesapeake Bay

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Machine learning presents a unique opportunity for oceanography and estuarine science, in that it can uncover previously unknown relationships between chemical and physical parameters. A common criticism of this approach is its supposed "black-box" methodology, because it can be difficult to ascertain how specific results were acquired. However, we show that thorough experience and knowledge of a system can yield noteworthy results. Here, we applied the machine learning algorithm known as random forest (RF) analysis, which is an ensemble learning method that uses multiple decision trees seeking to minimize error for a given dataset. We used model output from a biogeochemistry model in which the interactions between biomass, nutrients, light, and temperature are known. The RF model was trained on 60% of the data and tested on the remaining 40%. The algorithm was able to produce a R^2 value between the observations and predictions of 0.97, showing its ability to capture the variability in the dataset. However, to discover the original known relationships between the predictor variables and biomass, it was necessary to observe the data with more than just standard partial dependence plots. Using maximum and minimum values for the predictors was required to find the expected relationships. Following this success, we began a preliminary inquiry to examine the ability of the RF algorithm to predict dissolved oxygen concentrations for subsequent months in the Chesapeake Bay using information from prior month's observations.

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

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Diatoms are an important phytoplankton group responsible for 40% of oceanic primary production. They have mutually beneficial interactions with bacteria, which consume diatom-derived carbon while providing diatoms with essential vitamins and micronutrients. Diatoms in severely iron (Fe) limited regions 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 could provide an ecological advantage for diatoms in Fe limited environments such as the Southern Ocean (SO). During an austral spring 2016 SO cruise, an experiment was done to determine whether different Fe-stressed diatoms recruit distinct bacterial communities and whether the recruited bacteria have the potential to produce siderophores. Axenic diatom species (Fragilariopsis cylindrus, Pseudo-nitzschia arenysensis, and Thalassiosira tumida) were grown in low Fe (-Fe) and Fe replete (+Fe) conditions, and then exposed to a < 3 µm SO seawater fraction for bacterial recruitment. Growth rates based on chlorophyll a measurements show that the diatoms under -Fe conditions experienced growth limitation compared to +Fe cultures. The overall bacterial community composition was assessed via highthroughput sequencing of the 16S rDNA V4 region and the bacterial communities recruited to different diatoms are not influenced by Fe status, but are distinct across diatom species. Regardless of the diatom tested, the bacterial communities included members of the genera Pseudoalteromonas and Colwellia, Gammaproteobacteria that are known to be diatom-associated siderophore producers. All incubations also saw an increase in Polaribacter, a Flavobacteriia often found in response to diatom blooms. Future studies should include addressing the molecular mechanisms that underpin the establishment of diatom species-specific bacterial communities and determining whether or not these bacteria play a role in alleviating Fe stress in SO diatoms.

Mechanisms of low-frequency oxygen variability in the North Pacific

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This study investigates the mechanisms of interannual and decadal variability of dissolved oxygen (O_2) in the North Pacific using historical observations and a hindcast simulation using the Community Earth System Model (CESM). The simulated variability of upper ocean (200~m) O_2 is broadly consistent with observations in the western and eastern Pacific where sampling density is relatively high. The dominant mode of O_2 variability explains 24.8% of the variance and is significantly correlated with the Pacific Decadal Oscillation (PDO) index (r=0.68). Two primary mechanisms are hypothesized by which the PDO controls upper-ocean O_2 variability. Vertical movement of isopycnals (``heave'') drives O_2 variations in the deep tropics; isopycnal surfaces are depressed in the eastern tropics under the positive (El Nino-like) phase of PDO, leading to O_2 increases in the upper water column. In contrast to the tropics, changes in subduction are the primary control on extra-tropical O_2 variability. These hypotheses are tested by contrasting O_2 anomalies with the heave-induced component of variability calculated from potential density anomalies. Isopycnal heave is the leading control on O_2 variability in the tropics, but heave alone cannot fully explain the amplitude of tropical O_2 variability, likely indicating reinforcing changes from the biological O_2 consumption. Mid-latitude O_2 variability indeed reflects ocean ventilation downstream of the subduction region where O_2 anomalies are correlated with the depth of winter mixed layer.
These mechanisms, synchronized with the PDO, yield a basin-scale pattern of O_2 variability that are comparable in magnitude to the projected rates of ocean deoxygenation in this century.

BCO-DMO Data Stewardship Support Throughout the Research Data Life Cycle

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Oceanographic data, when well-documented and stewarded toward preservation, have the potential to accelerate new science and facilitate our understanding of complex natural systems. The Biological and Chemical Oceanography Data Management Office (BCO-DMO) is funded by the NSF to document and manage marine ecosystem data, ensuring its discovery and access, and facilitating its reuse.
The task of curating and providing open access to research data is a collaborative process. This process may be thought of as a life cycle with data passing through various phases. Each phase has its own associated actors and critical activities, and good data management practices are necessary for all phases, from proposal to preservation. BCO-DMO supports all phases of the this cycle and works closely with investigators through certain phases to ensure open access of well-curated project data and information. The result is a rich repository of marine, coastal and limnological data ready for reuse and reanalysis. This poster describes some of the critical points along the data life cycle where BCO-DMO staff engage with researchers to offer data management services. We invite you to think about your project data's life cycle and where BCO-DMO can help provide support for your project output.

Ocean Carbon States based on k-means cluster analysis

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Advanced data mining techniques are rapidly becoming widely used in Climate and Earth Sciences with the purpose of extracting new meaningful information from big data. This is particularly important for studies of the global carbon cycle, where lack of understanding of the interacting physical and biogeochemical drivers confounds our ability to accurately describe, understand, and predict CO_2 concentrations and their changes in the major planetary carbon reservoirs. Here we describe the use of a specific data-mining technique, cluster analysis, as a means of identifying and comparing spatial and temporal patterns of pCO_2 (Landschuetzer product) and temperature at 10m (ARGO Coriolis product) for 2000-2015. As the observation-based data is organized into various regimes, which we will call "ocean carbon states", we gain insight into the physical and/or biogeochemical processes controlling the ocean carbon cycle. Preliminary results demonstrate that this technique effectively produces realistic, dynamic regimes that we can study in order to gain insight into the complex interannual and spatial variability of relevant climate indices (ENSO, AO, NAO) and other physical fields like salinity and chlorophyll.

Theoretical considerations on factors confounding the interpretation of the oceanic carbon export ratio

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The fraction of primary production exported out of the surface ocean, known as the export ratio (ef-ratio), is often used to assess how various factors, including temperature, primary production, phytoplankton size and community structure, affect the export efficiency of an ecosystem. To investigate possible causes for reported discrepancies in the dominant factors influencing the export efficiency, we develop a metabolism-based mechanistic model of the ef-ratio. Consistent with earlier studies, we find based on theoretical considerations that the ef-ratio is a negative function of temperature. We show that the ef-ratio depends on the optical depth, defined as the physical depth times the light attenuation coefficient. As a result, varying light attenuation may confound the interpretation of ef-ratio when measured at a fixed depth (e.g., 100 m) or at the base of the mixed layer. Finally, we decompose the contribution of individual factors on the seasonality of the ef-ratio. Our results show that at high latitudes, the ef-ratio at the base of mixed layer is strongly influenced by mixed layer depth and surface irradiation on seasonal timescales. Future studies should report the ef-ratio at the base of euphotic layer, or account for the effect of varying light attenuation if measured at a different depth. Overall, our modeling study highlights the large number of factors confounding the interpretation of field observations of the ef-ratio.

Ocean carbon sink response to ENSO and impacts on atmospheric CO_2

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ENSO is the main source of inter-annual fluctuations in atmospheric CO_2. During the 2015/2016 El Niño event, satellite OCO-2 data detected a strong decrease of 1 ppm in column CO_2 over the central Equatorial Pacific, which has been attributed to an increase in the ocean sink. However, the magnitude and the processes controlling this increase in the ocean sink are poorly constrained, with far reaching implications for our understanding of the land carbon sink estimation.The aim of this project is to constrain the ocean carbon sink response to ENSO by combining an ocean model coupled to a biogeochemistry module (GFDL- MOM6-COBALT) with atmospheric and oceanic observational constraints. Preliminary model simulations indicate an anomalous ocean uptake of CO_2 during El Niño. The contributions from thermal, biological, and ventilation processes are examined and discussed.

Circadian Physiology in Zooplankton

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The diel vertical migration of zooplankton is a process where individuals spend the night in surface waters and retreat to depth during the daytime, with substantial implications for carbon transport and the ecology of midwater ecosystems. The physiological consequences of this daily pattern have, however, been poorly studied beyond investigations of speed and the energetic cost of swimming. Many other processes are likely influenced, such as fuel use, energetic trade-offs, underlying diel (circadian) rhythms and antioxidant responses. Using a new reference transcriptome, proteomic analyses were applied to compare the physiological state of a migratory copepod, *Pleuromamma xiphias*, immediately after arriving to the surface at night and six hours later. Oxygen consumption was monitored semi-continuously to explore underlying cyclical patterns in metabolic rate under dark/dark conditions. The proteomic analysis suggests a distinct shift in physiology that reflects migratory exertion and changes in metabolism. These proteomic analyses are supported by the respiration experiments, which show an underlying cycle in metabolic rate with a peak at dawn. These studies suggest that *P. xiphias* is a tractable model for continuing investigations of circadian and DVM influences on plankton physiology. Previous studies did not account for this cyclic pattern of respiration, and may therefore have unrepresented respiratory carbon fluxes from copepods by ~24%.

Parameterizing Multiple Ligand Classes Improves the Simulation of Dissolved Iron in the Subtropical North Atlantic

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Recent observations of dissolved iron (dFe) in the subtropical North Atlantic (GEOTRACES GA03) revealed remarkable features: while this region receives a high level of atmospheric dust, the near-surface dFe is relatively low (0.3 – 0.5 nM). In the main thermocline, the dFe concentration increases to 1.4 – 1.6nM, forming a subsurface maximum. These features are not well captured by the current generation of ocean biogeochemistry models, which generally overestimate the surface dFe and underestimate the mid-depth dFe concentrations, causing the mid-depth maximum to be shallower than observed. Ye and Völker (2017) suggested that a stronger scavenging by lithogenic particles can decrease surface dFe under the high dust plume. While it provides a plausible mechanism for low surface dFe under high dust deposition, its efficiency to remove dFe depends on the concentrations and strengths of organic ligands. In this study, we perform a suite of numerical sensitivity experiments to examine the role of organic ligands in regulating the scavenging of dFe in the high dust region of the subtropical North Atlantic. The model includes three classes of organic ligands, representing biologically produced siderophores (L1), dissolved organics released from particle remineralization (L2), and the background, refractory organic matter (L3). In the sensitivity experiments, lithogenic scavenging rates, as well as the ligand conditional stability constants are perturbed in order to assess their control over the dFe distribution in the subtropical North Atlantic. These experiments show that a 10-fold decrease of the conditional stability constant for L3 causes a stronger surface dFe decrease (~ -0.8 nM) and deepens the mid-depth dFe maximum, significantly improving the

pattern correlation between modeled and observed dFe along the GA03 transect (r=0.86). In contrast, a 1,000-fold increase of the lithogenic scavenging rate causes a moderate reduction in the surface dFe (~ -0.3nM) and a slight increase in the pattern correlation (r=0.55). Parameterizations of ligands can play a crucial role in modulating the Fe cycling of the North Atlantic with implications to the regional ecosystem dynamics, including a potentially Fe-limited growth for the nitrogen-fixing cyanobacteria.

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 continuous ground-truth comparisons necessary to ensure and improve the accuracy 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.

Which future would you like? Biogeochemical model sensitivity to temperature dependent plankton processes

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Global ocean biogeochemical and earth system models are commonly being used to predict ocean responses and functioning in a future climate.
These models are often based on established parameterizations of processes and interactions of plankton, which fail to resolve both physiology and diversity. Moreover, different models predict (un)surprisingly different behavior in terms of future ecosystem functions, dominating functional types or biogeography. We are starting to systematically analyze model sensitivity to commonly employed formulations in an idealized warming scenario. As a basis, we use the simple and thoroughly assessed global ocean biogeochemical model MOPS. We compare different configurations of temperature dependence of biogeochemical fluxes like phytoplankton growth and zooplankton grazing spanning the range found in IPCC-class and model inter-comparison studies. The fixed physical environment reveals biogeochemical model uncertainty already with such basic parameter changes. In a next step, we will extend our preliminary findings with a sensitivity study and address implicit assumptions about future export production inherent in earth system models. Our study ultimately aims to approach the question how much plankton ecology matters for ocean biogeochemical modeling on scales of future climate change.

Benthic Oxygen Respiration Rates on the Oregon Shelf in Winter and Spring

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New winter and spring measurements of benthic oxygen consumption derived using eddy covariance (EC) methods indicate intensified benthic respiration driven by high energy wave conditions and an over-winter retention of organic matter in the Oregon shelf bottom boundary layer. These EC measurements were made in December 2017 and January, February and early May 2018 at ~30 m and 80 m stations adjacent to inshore and mid-shelf moorings of the Ocean Observatories Initiative (OOI) Endurance Array. Six more 2-5 day cruises will extend this seasonal study into 2019.
Two landers equipped with Rockland Scientific MicroSquid-FireSting O_2 (MS-FS-O_2) modules that interface PyroScience fiber optic oxygen sensors with a Nortek Vector Acoustic Doppler Velocimeter were used for the collection of simultaneous velocity and dissolved oxygen time series at fixed points 15-30 cm above the seafloor. During some deployments a Rockland FP07 micro-thermistor was also used to collect high resolution temperature records for heat flux estimates. Wave-generated velocity artifacts do not appear in the MS-FS-O_2 time series (as has been observed with microelectrodes), but changes in temperature and salinity must be included when converting the fiber optic sensor records to dissolved oxygen concentrations. In the process of analyzing our EC time-series we are using, validating, and sometimes finding issues with OOI Benthic Experimental Package sensor data. We are also finding variable amounts of calibration drift with the FireSting O_2 sensors.
Although still preliminary, our EC-derived estimates of benthic respiration run contrary to many coastal-upwelling shelf ecosystem models that assume significant respiration occurs only as a rapid response to new production and fresh particulate detritus sinking to the benthos during summer upwelling.

SOCON: SUSTAINED OCEAN COLOR OBSERVATIONS USING NANOSATELLITES

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SOCON – Sustained Ocean Color Observations Using Nanosatellite (http://www.uncw.edu/socon): University of North Carolina at Wilmington (UNCW) has entered into a PUBLIC/PRIVATE/FEDERAL partnership funded by Gordon and Betty Moore Foundation for development and "proof-of-concept" for a low-cost, miniaturized multispectral ocean color imager (HawkEye) capable of flight on a CubeSat (SeaHawk). UNCW has contracted with Cloudland Instrument, LLC (http://cloudlandinstruments.com), of Santa Barbara, CA, to construct the HawkEye Coastal Ocean Color Imager and Clyde Space, Ltd. (http://www.clyde.space), Glasgow, Scotland, UK, to build the SeaHawk satellite bus. This "Game Changer" satellite is 130-times smaller, 4-times lighter, 8+ times better resolution (120-m vs 1-km) at 10% of development time/construction costs as SeaWiFS (the most successful color sensor flown to date). The Hawkeye instrument measures ocean color in 8 spectral bands, similar to the SeaWiFS bands, with the exception of Band 7, which is shifted slightly lower in wavelength to avoid the oxygen absorption feature that a wider band overlapped on SeaWiFS. UNCW and NASA have entered into a U. S. Space Act Agreement to expand free access to the data. The data from SOCON will have direct and significant relevance to many international programs and in helping meet many of international science objectives and could have a large impact in helping address a number of critical societal needs, especially in the highly variable coastal regions of the world. SeaHawk-1 is currently scheduled to be launched into a 575km LEO orbit 3rd Q 1018 with SeaHawk-2 scheduled to be launched into an 525km LEO orbit 2nd Q 2019, allowing for a 6-8 month overlap when both will be in orbit. Data will become available as the satellites finish their commissioning phases and enter their operational phases with data available internationally via the NASA Ocean Biology Distributed Active Archive Center (OB.DAAC - https://oceancolor.gsfc.nasa.gov/). Under our Intellectual Property and Data Sharing Agreement with the Moore Foundation, the data will publicly available as soon as possible at no cost, and all reasonable actions will be taken necessary to ensure the details of the sensor design are made freely available in a manner that is sufficient to enable another competent individual or organization to replicate the HawkEye Ocean Color Sensor and Seahawk CubeSat.

The EXPORTS NE Pacific Field Program

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The goal of the EXport Processes in the Ocean from RemoTe Sensing (EXPORTS) field campaign is to develop a predictive understanding of the export and fate of global ocean primary production and its implications for the Earth's carbon cycle in present and future climates. EXPORTS builds upon decades of NASA-supported research assessing global net primary production from space and is designed to deliver science of significant societal relevance by better characterizing the fate of organic carbon in the ocean from future satellite ocean color instruments. The first EXPORTS field deployment was conducted in August-September 2018 near Station P in the Northeast Pacific Ocean. This poster presentation will present the Northeast Pacific field deployment focusing on the coordinated deployment of multiple ships and robots to understand and quantify the multiple pathways by which fixed organic carbon is exported into the ocean interior.

Dark carbon fixation in the pelagic zones of the Southwestern Atlantic Ocean

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Increasing efforts are being made to investigate the role of microbes in the pelagic realm, including the chemoautotrophic primary productivity. Microbes may take advantage of the oxidation of a variety of reduced inorganic compounds as energy sources to produce new organic matter, even in the oxygenated waters. The aim of our study was to investigate chemoautotrophic primary production in the waters around Vitória-Trindade seamount chain (Southwestern Atlantic) by determining the in situ rates of prokaryotic dark carbon fixation. Samples were collected at four oceanographic stations located across Vitória-Trindade seamount chain in the epipelagic, mesopelagic and bathypelagic zones. Incubations were performed by measuring the incorporation of 14C-bicarbonate in the dark at approximate in situ temperatures. The average rates varied from 0.001-1.99 $\propto g.L^{-1}.h^{-1}$, and rates higher than 1 $\propto g.L^{-1}.h^{-1}$ were observed at stations #327 e #328 at 1250 and 2800 m depth, respectively. The reasons for these higher rates, as well as the influence of environmental factors on microbes at the sampling points, are still under investigation. Regarding the vertically integrated chemoautotrophic prokaryotic production in the water column, our results showed that the bathy-, meso-, and epipelagic zones contributed with 63%, 33% and 4%, respectively, to the total organic matter production via chemosynthesis. Ongoing molecular analyses using RNA-based approaches, combined with the chemosynthetic rates, will give us more clues on the role of chemosynthesis in the pelagic zones of the Southwestern Atlantic Ocean.

Remobilized volcanic ash may support autotrophic production in the oligotrophic subarctic Pacific Ocean

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Autotrophic production is limited in the subarctic Pacific Ocean in part by insufficient micronutrient concentrations. However, fresh volcanic ash and terrigenous dust deposition are known to support episodic phytoplankton blooms in this oligotrophic region. Remobilized volcanic ash, which is aged ash blown from the flanks of volcanoes after sufficient drying, is

another potential source of micronutrients, including iron. We used data from NASA's Multi-angle Imaging Spectroradiometer (MISR) satellite to identify remobilized ash plumes, and from the Moderate Resolution Imaging Spectroradiometer (MODIS) aqua satellite for surface chlorophyll a concentrations. We examined chlorophyll a anomalies associated with five remobilization events from the flanks of the volcano Shiveluch, on the Kamchatka Peninsula. We found that in four of the five events, chlorophyll a concentrations were above average during the week following the event; however these results are preliminary. We propose a series of experiments to further address the hypothesis that remobilized ash is indeed a unique source of otherwise limiting nutrients in the subarctic Pacific.

Where and when to apply the $^{210}Po/^{210}Pb$ method to calculate particle export; lessons learned from the results of 3 GEOTRACES cruises and historical measurements in the global ocean

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The deviation from secular equilibrium between the natural radionuclide ^{210}Po (half-life 138.4 days) and its radioactive grandparent ^{210}Pb (half-life 22.3 years) has been used to examine particle export from the surface ocean. Here we present ^{210}Po and ^{210}Pb activity results from three GEOTRACES cruises: two transects of the North Atlantic Ocean (NAZT: 15-40 ºN, and GEOVIDE: 40-60 ºN) and one transect of the South Pacific Ocean (EPZT: 10-15 ºS), and estimate ^{210}Po export fluxes at ~ 100 m (FPo100m) by assuming steady state without advection or diffusion of the isotopes. Despite expectations, we found that FPo100m was sometimes lower at basin margins than at the open-ocean stations along the transects, and also discovered a low ($\leq$ 1) ratio of ^{210}Po to ^{210}Pb activity on the large ("sinking") particles collected in the upper 200 m at 9 of our 22 stations. These results contradict our understanding of the steady-state model, which assumes that ^{210}Po is more effectively removed from the surface ocean via sinking particles than ^{210}Pb.
Within this context, we will compare our dissolved and particulate ^{210}Po and ^{210}Pb results (~750 samples), as well as calculations of partitioning coefficients (Kds), to previous reported values from the global ocean and discuss observed trends such as lower $^{210}Po/^{210}Pb$ ratios in nearshore particles and in samples from high latitudes. We will discuss where and when it may (or may not) be appropriate to apply the $^{210}Po/^{210}Pb$ method to calculate particle export, and suggest modifications to the method which may make it more universal and robust. Emphasis will be placed on the effects of particle composition and biogeochemical conditions on the fractionation between total ^{210}Po and ^{210}Pb.

Evidence for Shallow Respiration-Driven Carbonate Dissolution in the North Pacific Ocean

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Calcium carbonate cycling is an important part of the marine carbon cycle. Much of the carbonate produced in the surface ocean dissolves either in the water column or sediments, a process which both sets the alkalinity content of seawater and balances the long-term ocean alkalinity input from continental weathering. The drivers of carbonate dissolution in the ocean have been debated for decades. Laboratory studies show strongly nonlinear, but relatively slow, dissolution rates. In contrast, water column data appears to necessitate rapid addition of alkalinity into shallow waters at or near the calcite saturation horizon. Here we present laboratory evidence for a link between carbon dioxide production and fast carbonate dissolution rates, and we corroborate these findings with evidence for a strong coupling between oxic respiration and carbonate dissolution in the water column. These results imply that alkalinity is quickly regenerated in the intermediate waters of the North Pacific, that it is coupled to the oxidation of organic matter, and that there is a significant excess of uncompensated carbon dioxide in the deep North Pacific.

A simulation of phytoplankton bloom in the Labrador Sea

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The objective of this study is to simulate the observed phytoplankton bloom in the Labrador Sea and to understand the mechanisms controlling its timing and intensity. A relatively simple nutrient-phytoplankton-zooplankton-detritus (NPZD) model is coupled to the MIT General Circulation Model (MITgcm) configured for the regional Labrador Sea domain at 7km resolution. The regional simulation is initialized with climatology in 1994 and is integrated for 15 years. Model output from 2003 to 2008 is compared to the ocean productivity derived from the satellite ocean color data. The model shows the ability to reproduce the observed features of phytoplankton bloom, especially in the northern Labrador Sea. The timing of the simulated bloom is sensitive to the shallowing of mixed layer depth (MLD) as suggested by the Sverdrup hypothesis. The intensity of the surface turbulent mixing is also coupled to the shoaling of MLD, potentially contributing to the bloom in the Northern Labrador Sea. Regarding the bloom intensity, the winter-time nutrient supply strongly controls the productivity in the spring for the whole basin and the central Labrador Sea. Interannual variability of MLD controls the peak bloom intensity in the Northern Labrador Sea but the central Labrador Sea bloom tends to be more related with the nutrient supply. Stronger surface eddy kinetic energy also supports more intense bloom in all regions. Our results show different regimes of the spring blooms in the Labrador Sea with linkages to climate variability through deep convection, ocean eddies and stratification.

Machine learning estimates of biological nitrogen fixation in the world's oceans and comparison to other models

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Marine nitrogen (N_2) fixation supplies "new" nitrogen to the global ocean, supporting oceanic uptake and sequestration of carbon. Despite its central role, marine N_2 fixation and its controlling factors remain elusive. In this study, we identify strong predictors of N_2 fixation by compiling over 900 observations, collocated with sampling coordinates, month, solar radiation, wind speed, sea surface temperature, sea surface salinity, surface nitrate, surface phosphate, surface excess phosphorus, minimum oxygen in upper 500 m, photosynthetically available radiation (PAR), mixed layer depth, averaged PAR in the mixed layer, and chlorophyll-a concentration. However, we find that no single environmental property predicts N_2 fixation at global scales. Therefore, we derive global N_2 fixation estimates using compiled properties and machine learning algorithms of random forest (RF) and support vector regression (SVR). Our algorithms predict global estimates of marine N_2 fixation ranging from 59 to 82 Tg N yr^{-1} between latitudes 50ºS-50ºN. Comparison of our machine learning predictions and 11 other model outputs currently available in literature shows substantial discrepancies in the global magnitude and spatial distribution of marine N_2 fixation, especially in the tropics and in high latitudes. The large uncertainties highlighted in our study argue for increased and more coordinated efforts to explore oceanic N_2 fixation using geochemical tracers, modeling, and observations over broad oceanic regions.

Quantifying controls on sea surface pCO2 dynamics in the East China Sea: the role of bio-uptake effect

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The quantification of controls on the seasonal alternation and dynamics of sea surface CO_2 uptake in coastal oceans, especially for the monsoon-influenced and large river- dominated marginal seas, has not yet been revealed. The study is to de-convolute quantitatively controlling processes on the spatiotemporal CO_2 dynamics in the East China Sea (ECS) by use of the river-ocean mixing method. The field partial pressure data of CO_2 (pCO_2) collected from 2003 to 2011 during the 8 different-month cruises were analyzed. Quantification from the mixing analysis found that in the summer, there was the strongest bio-uptake (ΔpCO_2_Bio, mean -24.6 μatm), and in the winter the strongest temperature effect (ΔpCO_2_Temp, -144.3 μatm) and subsurface vertical mixing effect (ΔpCO_2_Vmix, 93.1 μatm). These three effects have significant correlations with the temperature change, Changjiang discharge, and mixed layer depth (R2 = 0.99, 0.73, 0.88, n = 8), respectively. Overall, the annual CO_2 uptake averaged -1.6 ± 1.6 mol C m^{-2} yr^{-1} with a strong sink in spring (-3.0 ± 0.6) and winter of cold season (-3.0 ± 0.7), a weak sink in summer (-0.5 ± 1.2), instead of a weak source in autumn (0.2 ± 0.4). If the bio-uptake

mechanism in the ECS was shut down, the annual flux will be reduced from the normal -1.6 mol C m^{-2} yr^{-1} to -1.3, the ability of the ECS absorbing atmosphere CO_2 will hence decrease ~20%. This result was also consistent with the annual -1.3 mol C m^{-2} yr^{-1} calculated after the CDW was replaced with the KW during the algae-bloom warm season. This indicates that the change in sea surface pCO_2 in the ECS is mainly governed by the seasonally physical effects related to monsoon alternation, while the biological effect on the pCO_2 uptake contributed from riverine nutrients by the Changjiang is merely 20%.

Variability in North Atlantic marine microbial communities in relation to patterns of nutrient availability, nitrogen fixation, and net community production

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Nutrient availability to marine microorganisms moderates the productivity of ocean ecosystems. Assessing the response of microplankton communities across diverse marine biomes to different nutrient inputs will improve our understanding of microbially-driven cycling of carbon and nutrients in the surface oceans. From samples collected in August 2015, 2016, and 2017 across the Western North Atlantic, we determined quantitative abundances of eukaryotic and prokaryotic microplankton using an internal standard rRNA amplicon sequencing approach. We examine relationships between microplankton community structure and nutrient concentrations, daily nitrogen fixation rates, net community production (NCP) rates, and measured respiration. Eukaryotic diversity is negatively related to phosphate, NCP, and both whole-community and particle-associated respiration. Productive coastal samples with high observed nitrogen fixation rates are dominated by Chrysophytes, Gonyaulacales, and *Aureococcus anophagefferens*. Nitrogen fixation rates were not strongly associated with most prokaryotic and eukaryotic taxa, but were correlated with the abundance of Haptophytes, which may be eukaryotic hosts for diazotrophic UCYN-A. These preliminary findings provide intriguing insights into how marine microbial communities, productivity, and nutrient cycling may be linked in this region.

Overview of the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission

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The Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission will continue NASA's multi-decadal record of satellite ocean color, clouds, and aerosol particle observations. PACE's primary instrument will be a global spectrometer (hyperspectral from 350 to 900 nm, with seven