

mixing rates. These simulations suggest that strongly bottom intensified mixing captured by the new scheme is an essential component of the balances required for the maintenance of the deep stratification. New insight has been provided into the contribution of baroclinic tides to the dynamics of the deep ocean.

OS220-09 1610h

The eddy-driven thermocline

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The nonlinear equilibration of a rapidly rotating fluid differentially heated from above is examined. In a periodic geometry, a zonally symmetric steady state exists which is weakly stratified in the small Rossby number limit. Such steady state is linearly unstable to transverse time-dependent baroclinic waves very similar to non-geostrophic Eady modes. The finite amplitude equilibration of these baroclinic disturbances maintains a well-defined deep stratification which depends very weakly on the explicit vertical diffusion.

OS220-10 1625h

The Effects of Mesoscale Eddies on the Thermal Structure of an Ocean With a Circumpolar Channel

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We investigate the affect of mesoscale eddies on the stratification of the oceanic thermocline and abyss. Motivated by the potentially large dynamical importance of the Southern Ocean on the ocean as a whole, we integrate a primitive-equations ocean model with an idealized domain containing a box bordered by a circumpolar channel to the south, forced both mechanically and thermally.

Because of the surface forcing, certain isopycnals outcrop in the channel. We ask: a) Under what circumstances do these isopycnals enter the box region, and b) when they do enter, what determines their depth? When mesoscale eddies are absent from the simulation, the lack of a zonal pressure gradient in the channel prohibits meridional transport, the outcropping isopycnals are trapped in the latitudes of the channel, and the abyss has a very small vertical temperature gradient. When a mountain barrier that partially blocks the channel is included, meridional transport is supported and abyssal thermal gradients are produced, even in cases with small vertical diffusivity.

Mesoscale eddies appear to have a significant affect on this picture. Much of the non-eddy channel has temperature fronts which are baroclinically unstable. As the eddies form they act to decrease the available potential energy of the system, relax the fronts, and transport the water from the channel into the abyss. We are able to run the eddy resolving model for approximately 85 years, which is sufficient to achieve near-equilibration in the abyss, and investigate the processes determining the stratification of the polar channel. When we increase the vertical diffusion, we find that the isopycnals are deeper, consistent with a net storage of more available potential energy in the system. Typically, the eddy simulations are much less sensitive to topographic effects in producing stratification than are non-eddy runs. In all eddy cases the main stratification remains in the upper ocean. We conclude that mesoscale eddies are playing an important role in determining the stratification of the (model) Southern Ocean, but that they alone cannot produce deep stratification.

OS220-11 1640h

Role of Cross-Isopycnal Mixing in the Thermohaline Circulation

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This study seeks to improve understanding of the role of cross-isopycnal mixing in the dynamics of the NADW circulation. Most of the previous studies considered only vertical mixing at the low latitudes in the Atlantic. This study includes all cross-isopycnal eddy transports, horizontal as well as vertical, and considers

a role of the mixing in both the Atlantic and the Southern Ocean. A set of numerical experiments in a coarse-resolution OGCM and an output of an eddy-permitting simulation are combined with an analytical model of the main dynamical processes that set the deep density structure in the Atlantic. The analytical model does not assume a local balance between the vertical diffusion and upwelling, which has been shown to be invalid in several of studies, but rather represents 3D buoyancy balances in the deep ocean. Coarse-resolution numerical experiments explore dependence of the circulation on the distribution and magnitude of mixing. The output from an eddy-permitting OGCM is used to verify the main balances in the heat and salt equations.

It is demonstrated that the NADW circulation is highly sensitive to the amount and type of the cross-isopycnal mixing in the Southern Ocean. In particular, noticeable differences between a simulation with the Gent-McWilliams mixing scheme and the one with the horizontal diffusion are almost entirely explained by the differences in the mixing in the Southern Ocean. Low-latitude horizontal eddy transports change deep horizontal density gradients but have a limited effect on the strength of NADW flow. The attempt is also made to separate a role of the air-sea fluxes in the Southern Ocean from direct effects of the internal mixing.

OS22P HC: 315 Tuesday 1330h

Oceanic Time-Series Measurements: Assessment of the Past and Planning for the Future III

Presiding: J E Corredor, UPR-Dept. of Marine Sciences; G A Cutter, Old Dominion University

OS22P-01 1330h

Interannual to decadal variability in the carbon cycle of the subtropical gyres: A comparative study between Station 'S'/BATS and HOT

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We examine interannual to decadal variability in the ocean carbon cycle in the subtropical gyres on the basis of three long-term upper ocean time-series records. The longest record exists from Station 'S' near Bermuda (32°10'N, 64°30'W), where the Carbon Dioxide Research Group (CDRG) at Scripps Institution of Oceanography started sampling in late 1983. In 1988, as the Bermuda Atlantic Time-series Station (BATS) (31°50'N, 64°10'W) and the Hawaii Ocean Time-series (HOT) program (22°45'N, 158°W) were established, CDRG extended its sampling to both these sites. At the same time, independent sampling and analysis of inorganic carbon properties started at Bermuda and Hawaii (e.g. Bates, 2001; Winn *et al.*, 1994; Dore *et al.*, 2001). As differences between the laboratories and between the two Bermuda sites are small, these records can be combined into the two longest existing records of inorganic carbon variability in the ocean. Both sites exhibit substantial interannual variability in all measured and computed carbon properties (dissolved inorganic carbon (DIC), total alkalinity (Alk), computed ocean surface partial pressure of CO₂ (pCO₂), and the ¹³C/¹²C ratio of DIC). We also find at both sites strong anti-correlation between sea-surface temperature (SST) anomalies and DIC anomalies, which lead to a suppression of the correlation of either of these properties with pCO₂. We employ a simple diagnostic box model, a modification of (Gruber *et al.*, 1998) to quantify the contribution of the processes controlling this variability. Near Bermuda, the variability in the carbon dynamics is largely driven by variations in winter mixed layer depths, which impact both the amount of DIC that gets entrained into the mixed layer and the magnitude of net community production. The variability of air-sea CO₂ fluxes tends to be controlled by

sea-surface temperature (SST) anomalies with larger CO uptake from the atmosphere during years of deeper than normal mixed layers. We find significant correlation of the magnitude of net community production and air-sea CO₂ fluxes with the North Atlantic Oscillation (NAO), attributed to a strong influence of the NAO on convection and SST during winter. Preliminary analyses of the HOT data indicate a much weaker role of mixed layer depth variability, and a much stronger role of SST and windspeed anomalies driving air-sea CO₂ flux variations, and hence driving DIC variability. Interannual variations in net community production and air-sea CO fluxes tend to be correlated, as was the case near Bermuda. Results of a more refined analysis and comparison between the two sites will be presented and discussed.

OS22P-02 1345h

The Atlantic Meridional Transect Programme

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The biota of the surface ocean has a profound influence on the global budgets of climatically-active trace constituents in the atmosphere (CO₂, DMS, N₂O, CH₄ and aerosols) and hence climate. For this reason attempts to predict the future global environment depend on an improved knowledge of how biogeochemical cycling in the oceans affects the climate system, and of how changes in climate influence the structure and functional properties of oceanic ecosystems.

The Atlantic Meridional Transect (AMT) Programme (1995-2006) [http://www.pml.ac.uk/amt/index.html] aims to quantify the nature and causes of ecological and biogeochemical variability in the planktonic ecosystems of the tropical and temperate Atlantic Ocean, and the effects of this variability on biological C cycling and on air-sea exchange of radiatively active gases and aerosols. Marine and atmospheric data are collected from more than 14 biogeochemical provinces during the bi-annual passage of RRS James Clark Ross between the UK (50°N) and the Falkland Islands (52°S) including the undersampled subtropical gyres and the NW African upwelling.

These data represent the most coherent set of repeated biogeochemical observations over ocean basin scales and have led to several important discoveries concerning the validation of ocean colour algorithms, distributions of picoplankton, and variability in rates of primary production and respiration.

This presentation will summarise the data collected thus far and describe the additional hypotheses to be tested in the future.

URL: http://www.pml.ac.uk/amt/index.html

OS22P-03 1400h

Mesoscale Variability of pCO₂ at the Sea Surface in the North East Atlantic Ocean as Measured by Ship and CARIOCA Drifters

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An important French oceanographic program POMME was conducted in the North East Atlantic in 2001. A major objective of the project was to investigate the coupling of mesoscale dynamical and

biological processes. Three intensive field campaigns were conducted in late Winter, Spring and Fall. During the first 20 days of each seasonal campaign, an intensive survey of the central POMME area, limited in latitude between 38°N and 45°N and 12°W and 20°W in longitude was made. Ship's data: The distribution of hydrographic and carbon chemistry properties, pCO₂ and pH, were measured at 80 stations in the water column and continuously at the water surface. Buoy's data: Four CARIOCA drifters were deployed between February 9 and 17, 2001. Time series of the evolution of wind speed, SST, salinity, surface pCO₂, fluorescence, were measured, at an hourly frequency, in order to determine the evolution of pCO₂ at the air-sea interface and to understand the mechanisms which control its spatial and temporal variability. Data are transmitted in real time by Argos telemetry. Globally, the 4 buoys have stayed in the main POMME area. As each buoy is equipped with a drogue anchored at a depth of 15 meters, their displacement is mainly controlled by the mesoscale processes, eddies and fronts, which control the water masses circulation. Hourly values of the CO₂ air-sea fluxes have been computed taking into account the pCO₂ and wind speed measurements made with the same frequency by the buoys. The main observations over a period of five months are: -the Atlantic ocean was a sink for atmospheric CO₂ over the whole period, including February-March, as the mean pCO₂ air-sea difference was close to +30 micro-atm under winter conditions. -monthly mean values of the CO₂ air-sea fluxes increased from February to May and then decreased in June. Large differences are observed, up to a factor 2, between the measurements made in area located within two degrees of latitude. These large spatial differences between air-sea fluxes values were mainly controlled by the distribution of pCO₂ at the sea surface. In the beginning, the processes which control the distribution of surface pCO₂ were mixing with deeper enriched waters in response to wind forcing and the occurrence of biological production on a scale of a few days. The first primary production events were clearly associated with the presence of fronts which were identified by their temperature-salinity signature. The main primary production events, revealed by the fluorometers measurements were observed everywhere between the end of march and the end of may. The signals were much less intense after mid-June, when oligotrophic conditions are prevailing. This study demonstrates that it is crucial to make in situ observations during the period end of winter-beginning of spring in order to be able to derive a reasonable value of an annual CO₂ air-sea flux in a given oceanic province.

OS22P-04 1415h

Cycling of Dissolved Organic Sulfur in the Sargasso Sea

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Unlike DOC or DON, the distribution and behavior of dissolved organic sulfur (DOS) in the ocean are poorly known. This is in spite of the fact that DOS is the likely precursor of the radiatively important gas carbonyl sulfide through photolysis, probably includes many of the strong ligands that affect trace metal speciation and cycling, and is a poorly constrained component in the global sulfur cycle. Thus, a reconnaissance of DOS in coastal and open ocean waters has been undertaken using a newly developed analytical method. The determination of DOS includes selective removal of sulfate via barium sulfate precipitation and ion exchange, determination of the residual (nanomolar) sulfate, and subsequent measurement of the total dissolved sulfur (TS) by reductive pyrolysis to hydrogen sulfide and gas chromatography/flame photometric detection; DOS = TS - sulfate. Filtered seawater samples were stored like those for DOC, placed in solvent-cleaned, glass vials and quick frozen, but careful sample storage experiments are still underway. In the Sargasso Sea at the Bermuda Atlantic Time Series Station, DOS concentrations in surface waters (upper 100 m) ranged from 80-200 nmol/L in July-August 1999, increased to ca. 700 nmol/L in the major thermocline (700-1000 m), and decreased to 180 nmol/L in deep waters. In contrast, there was a surface maximum of 420 nmol/L DOS in March 2000, with a rapid decrease to ca. 100 nmol/L in the upper thermocline. This winter/spring profile is similar to those of DOC at BATS, with the DOC/DOS value of 158 (atomic) being similar to the POC/POS ratio of 100 for particulate organic matter in surface waters. However, DOS values decrease much more rapidly with depth than DOC. Additionally, the low surface water concentrations in the summer suggest that DOS may be photodegraded like colored dissolved organic material (CDOM) in the Sargasso Sea displays higher surface water concentrations in the winter compared to very low values in the summer). Thus, DOS is far more reactive than its cousins, DOC and DON, and may have a surface water residence time on

the order of weeks to months due to photolysis and a deep water residence time of several years.

OS22P-05 1430h

Quantum Yield of Dimethylsulfide Photo-Oxidation in the Sargasso Sea

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Rates of dimethylsulfide (DMS) photo-oxidation were determined using samples collected from two depths (15 and 80 meters) during July 2001 in the Sargasso Sea. Broadband solar incubation experiments indicate that the UV wavebands are responsible for most of the DMS photolysis and that the rate is a function of quantity and quality of colored dissolved organic material (CDOM). The mixed layer sample from the Sargasso Sea with bleached CDOM has a larger UVB component as compared to the deeper sample with more freshly created CDOM. Wavelength resolved apparent quantum yields were determined monochromatically demonstrating that DMS photolysis is driven entirely by UVB and UVA wavelengths in open ocean sites. In contrast to this, a crude action spectrum from Mobile Bay, Alabama shows a significant contribution from visible wavelengths (>20%). In the Sargasso Sea samples, DMS photolysis follows first order kinetics and is proportional to the radiant flux although the relationship with CDOM is more complex. The temperature dependence of this process indicates that photo-oxidation rates will double with a 20 C increase in temperature. These results are consistent with the quasi-inverse relationship between DMS and concentrations of CDOM observed at the Bermuda Atlantic Time-Series (BATS) site. The seasonality of this process is explored using the multiyear Dacey-Michaels-Wakeham DMS dataset (1992-1994) and the extensive time-series data sets collected in conjunction with the BATS and Hydrostation S sampling programs. This research provides for the first time an apparent quantum yield for DMS photolysis in open ocean regions and clearly indicates that there is a relationship between quantity and quality of CDOM and DMS photo-oxidation rates.

OS22P-06 1445h

Temporal and Spatial Variability of Cobalt in the Atlantic Ocean

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The spatial and temporal variability of cobalt in the Atlantic Ocean was investigated using adsorptive cathodic stripping voltammetry. Total dissolved cobalt measurements were made on a time-series samples near Bermuda from MITESS, (Moored in-situ Trace Element Serial Sampler), on a surface transect from the Sargasso Sea to coastal Massachusetts, and on a depth profile to 3000m at the Bermuda Atlantic Time Series Station (BATS). The biweekly time-series samples from 1999 did not show an obvious response to the summer maximum in aeolian dust deposition, with an annual average of 20pM ± 10pM at 40-47m depth. Several sharp decreases in cobalt were observed in the time series that occur simultaneously with a shallowing of the thermocline depth. These decreases could be caused by nutrient drawdown associated with higher productivity cold core eddy events. Using the annual average cobalt concentration and literature particulate cobalt data, we calculate 100m surface water residence times as low as 0.32y for cobalt. Dissolved cobalt on the surface transect correlated strongly with salinity ($r^2=0.93$) and ranged from 19pM to 133pM, indicating mixing of cobalt from shelf waters into the Sargasso Sea. The vertical profile of total dissolved cobalt at the BATS station ranged from 17-73pM and displayed surface depletion indicative of biological utilization. This profile when compared to a cobalt profile from the

northeast Pacific shows no increase in deep water concentrations with thermohaline circulation through the deep ocean basins. Previous estimates of cobalt residence times and our current understanding of the biogeochemistry of cobalt will be discussed.

OS22P-07 1520h

Seasonal and Interannual Variability in the Biological Pump at Station ALOHA

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Since Oct 1988, measurements have been made of the rates of primary production (*in situ* ¹⁴C method) and particulate matter export from the euphotic zone (free drifting sediment traps at 150 m) at Station ALOHA (22°45'N, 158°W). Contrary to *a priori* expectation, these two processes were not well correlated at this open ocean site. The export ratio (e-ratio), defined as particulate C flux / primary production, varied nearly an order of magnitude from 0.02 to 0.15 with overall mean and standard deviation values of 0.062 and 0.026, respectively (n=89). The e-ratio displayed temporal variability with sustained higher than average e-ratios for a two-year period from 1989 to 1990 and again in 1997, and sustained lower than average e-ratios during 1991-1992 and 1994-1996. These variations in e-ratio were caused almost exclusively by changes in C export; annually integrated rates of primary production were nearly invariant over the 11-year observation period. From Oct 1988 to May 1995, free-drifting sediment traps were also deployed at 300 and 500 m to measure the net loss of biogenic materials in the upper mesopelagic zone. While the average particulate matter attrition between 150 and 500 m during the 7-year observation period was not significantly different from that predicted by the Martin et al. C flux model (1987, Deep-Sea Res. 34: 267) with an average 60-65% loss over this depth interval, there were also significant deviations from the mean. Changes in the remineralization length scale imply variations in particulate matter composition affecting the lability of the exported organic matter, variations in sinking rates or other non steady-state mesopelagic zone processes. Bottom-moored sequencing sediment traps deployed at reference depths of 2800 and 4000 m confirmed these dynamical patterns and also revealed a sustained decade-long increase in organic C export to depth. Because the patterns and dynamics of C export from the euphotic zone (150 m) were different from those observed in the dark abyss, it is likely that processes in the "twilight zone" are ultimately responsible for controlling the overall efficiency of the biological C pump and, therefore, the C sequestration potential of the intermediate and deep water reservoirs.

OS22P-08 1535h

Rates and Patterns of Nitrogen Fixation by Unicellular Cyanobacteria in Pelagic Waters

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The role of large, colonial cyanobacteria in pelagic nitrogen fixation is well established, but the contribution of smaller, dispersed nitrogen fixers to the oceanic nitrogen budget is not well known. During recent cruises to the Sargasso Sea, the Western North Atlantic, and the Southwest Pacific, we carried out direct, simultaneous tracer measurements of ¹⁵N₂- and ¹³CO₂-fixation by suspended particles in bulk water samples from the mixed layer. The specific rate of N₂-fixation in these bulk water experiments ranged from below the limit of detection to values above 1 × 10⁻³ h⁻¹, with the highest rates occurring in the waters north of Australia and generally low to undetectable

rates in the Sargasso Sea. We have further investigated the timing and potential controls on N_2 -fixation by picocyanobacteria in several focused time-series experiments carried out ashore using water collected at the Hawaii Ocean Timeseries station (ALOHA). $^{15}N_2$ -fixation by particles smaller than $10 \mu m$ in size occurs primarily at night with specific rates ranging above $5 \times 10^{-4} h^{-1}$. The ratio of C and N specific uptake rates is typically much greater than 1 in our experimental incubations, which implies that only a small fraction of the population of autotrophic cells in the water column are actively fixing N_2 .

OS22P-09 1550h

Nitrate-Based and Nitrogen Fixation-Based Support of Export Production at Station ALOHA: 1989-2001

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Over timescales of months to years, the export of organic nitrogen from the oceanic euphotic zone (principally as sinking particulate nitrogen, PN) is believed to closely balance the input of exogenous combined inorganic nitrogen, i.e., export production is balanced by new production. In the oligotrophic waters of the North Pacific subtropical gyre, there are two significant sources of new nitrogen to the euphotic zone: the upward flux of nitrate from deep water and the fixation of dissolved nitrogen gas by diazotrophic microorganisms in near-surface waters. These N sources have distinct stable isotopic signatures ($\delta^{15}N \approx 6.5$ for the nitrate flux, $\delta^{15}N \approx 0$ for nitrogen fixation), therefore the $\delta^{15}N$ of exported PN is constrained between these two extremes. We utilize total PN and $\delta^{15}N$ measurements of sinking particles (captured at 150 m in free-drifting sediment traps) and a simple isotopic mass balance model to deconvolute the relative and absolute contributions of the nitrate flux and nitrogen fixation to the gravitational export of PN at Station ALOHA ($22^{\circ}45' N$, $158^{\circ} W$). We find that the sinking flux of PN and its isotopic composition have both varied widely over month-to-month, seasonal, and interannual timescales between 1989-2001. On a seasonal basis, nitrogen fixation correlates inversely with mixed-layer depth, reaching a maximum in Jun-Aug, while nitrate-supported export correlates inversely with sea surface temperature, reaching a maximum in Feb-Mar. These patterns are consistent with summertime increases in diazotroph biomass as indicated by phycoerythrin concentrations. On an annual basis the relative contribution of nitrogen fixation to N export has varied from a low of 36% in 1993 to a high of 69% in 1999, with an overall flux-weighted mean contribution of 48%. This fraction demonstrated a significant increasing trend over the twelve-year period of observation. While total PN export seems to correlate well with the Southern Oscillation Index, the nitrate-based and nitrogen fixation-based components appear to respond to tropical climate forcing in different ways.

OS22P-10 1605h

Elevated Phosphorus in Surface Waters of the Intra-Americas Sea: Results of the CaTS Program

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N-fixation in North Atlantic (NA) surface waters is a function of phosphorus availability (1). Surface waters flowing through the Intra-Americas Sea (IAS) constitute the major source of warm surface water to the NA providing an input of ca. 30 Sv to the NA gyre; enough to totally replace surface waters in the tropical and subtropical NA to a depth of 50 m in about 1.5 years. The multi-year database on dissolved inorganic nutrient distribution from the Caribbean Time Series Station (CaTS) at $17^{\circ}36' N$ $67^{\circ} W$ in the NE Caribbean and cruises throughout the Eastern Caribbean are here used to assess the potential contribution of dissolved inorganic phosphorus (DIP) from the IAS to surface waters of the NA.

Average DIP (31 nM) in the mixed layer at CaTS is 65 times that of the NA gyre (0.48 nM) (2) but average dissolved inorganic nitrogen (DIN) (40 nM; n=159) is

indistinguishable from that at BATS (46 nM; 0 - 100 m; 1997-1998) leading to low DIN:DIP ratios (2.7); ca 10 times lower than those in the mixed layer of the NA gyre (20-32)(2). Regression of DIN vs DIP (n = 82; r² = 0.89) for samples above 200 m yields a high slope (24.5) but a negative intercept (-0.5) indicating total DIN depletion at DIP concentrations below 50 nM; well above the average mixed-layer DIP concentration at CaTS. South American rivers plumes and upwelling along the northern borders of South America and the Yucatan Peninsula influence surface waters of the entire IAS providing large input of DIP to IAS and adjacent NA surface waters. Concurrent near-Redfield DIN inputs occur but this DIN appears to be preferentially lost. The nature of the N-sink remains troublesome. Rapid N derivatization to unavailable organic compounds (1) is unlikely; experimental exposure of Orinoco River plume water to solar UV leads to photobleaching of dissolved humic matter and concomitant DIN release (3) rather than to DIN loss. Substantial denitrification in the water column is also unlikely as oxygen depletion is only apparent in the core upwelling regions, but sediment denitrification along the continental margins may remove fixed N from the water column. Preferential N depletion in recently upwelled waters along the northern coast of S. America (4), presumably through consumption by N-starved phytoplankton, serves also to reduce N:P ratios.

Large-scale optical fronts are apparent in ocean color imagery separating high chlorophyll Caribbean waters from oligotrophic plankton-poor waters of the NA. Analysis of DIP across such a front shows substantial depletion in the oligotrophic NA waters. Average mixed layer DIP concentration in Caribbean waters exceeded that in NA waters by a factor of 15 but N:P ratios were 7 times greater in NA waters. Seasonal expansion of these Caribbean fronts limits N fixation over wide areas of the Caribbean as *Trichodesmium*, the principal N-fixer, is largely excluded from waters under continental influence. DIP drawdown or N:P reduction to levels at which *Trichodesmium* displays a competitive advantage may be a prerequisite to vigorous *Trichodesmium* growth. We propose that given the apparent, but as yet unexplained loss of DIN from surface waters, this large DIP source can serve to enhance N-fixation in the NA. The area extent and temporal patterns of the influence of the DIP source remain to be established.

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OS22P-11 1620h

The Oxygen Isotope Composition of Phosphate in the Pacific and Atlantic Oceans

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We have developed a technique to measure the oxygen isotope composition of dissolved inorganic phosphate in sea water on as little as one micromole of phosphate with a precision of 0.2-0.3 permil (1 s.d.). This measurement can be a sensitive indicator of the balance between transport and reaction of nutrients in both marine and freshwater domains. Biochemical cycling of phosphate facilitates the exchange of oxygen between phosphate and ambient water, an exchange that would not occur at appreciable rates in the absence of enzyme-mediated formation and subsequent destruction of organophosphorus compounds and cellular inorganic phosphate derivatives. The resultant thorough exchange of phosphate and water oxygen results in a temperature dependent equilibrium offset between the phosphate and water oxygen isotope compositions. In the absence of active biological phosphate cycling, isotopic disequilibrium may prevail.

Using the method referred to above, we have measured the oxygen isotope composition of dissolved inorganic phosphate at a variety of depths in the Pacific (Sta. ALOHA, Hawaii Ocean Time-series) and in the Atlantic (Bermuda Atlantic Time Series). Although the oxygen isotope composition in phosphate in both oceans is close to the equilibrium values, there appears to be a slight offset towards lower $\delta^{18}O$ than expected from the temperature profiles. The cause of this apparent offset is ascribable to incomplete exchange of the oxygen in phosphate with ambient seawater at depth in the oceans.

OS22P-12 1635h

Phosphorus Uptake Rates and Phosphorus Pool Dynamics in the North Pacific Subtropical Gyre

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Phosphorus (P) pool dynamics were studied at Sta. ALOHA ($22.75^{\circ}N$, $158^{\circ}W$) from March 2000 to July 2001 (n=16). The soluble reactive phosphorus (SRP) pool (integrated 0-45 m) was highly dynamic and ranged from 0.1 to 5.0 mmol m⁻² with a mean of 2.6 mmol m⁻² (s.e. 0.3). P uptake rates, based on *in situ* ³²P₄ addition experiments, ranged from 1.7±0.8 to 10.4±0.3 with a mean rate of 6.3 μmol P m⁻² h⁻¹ (s.e. 0.5). P uptake rates were poorly correlated to ambient SRP concentrations (r²=0.2, n=14), implying that factors other than P may control microbial production rates, or that P requirements were met through dissolved organic P (DOP) utilization. The bioavailable P pool (BAP), based on the specific labeling of ATP, was on average twice the concentration of SRP, indicating that the extant microbial community utilized DOP for its P nutrition to a similar extent as SRP.

A phytoplankton bloom developed in June 2000, dominated by the diatom *Hemiaulus* sp., and manifested by changes in several ecological variables (integrated 0-45 m); chlorophyll a increased 5-fold from May to June, primary production increased 3-4 fold, ATP concentrations doubled as did P uptake rates (May to July). Silica was drawn down from 70 mmol m⁻² to 35 mmol m⁻² (May to July) and SRP inventories declined from 3.9 mmol m⁻² to 0.1 mmol m⁻² (May to August), remaining low into October. There was a net loss of P from the upper water column that was not accounted for in the particulate pool, and only partially recovered as DOP. This missing P is equivalent to 30-50% of the annual P export for this site and was likely lost in rapidly sedimenting particles.

These abrupt increases in P uptake and primary production rates were associated with a shift in the phytoplankton community structure lasting for a few months, after which it returned to the long term mean observed at Sta. ALOHA with the prokaryote *Prochlorococcus* sp. as the most abundant photoautotroph. However, even though the diatom bloom was relatively short-lived the impact on the SRP inventory was longer lasting. The supply of readily available P may have reached concentrations too low to sustain the eukaryotic phytoplankton community and hence P depletion may have contributed to their demise.

OS22Q HC: 316 B Tuesday 1330h

The North Atlantic Ocean and Its Changing Climate IV

OS22Q-01 1330h

What are "heat content" and "heat flux" in the ocean?

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Potential temperature is used in oceanography as though it is a conservative variable like salinity, however turbulent mixing processes conserve enthalpy and mostly destroy potential temperature in a similar fashion to how entropy is universally produced by mixing processes. This talk will show that potential enthalpy - the enthalpy that a water parcel would have if raised adiabatically and without exchange of salt to the sea surface - is more conservative than potential temperature by two orders of magnitude. Furthermore, it will be shown that a flux of potential enthalpy can be called "the heat flux" even though potential enthalpy is undefined up to a linear function of salinity. The exchange of heat across the sea surface is identically the flux of potential enthalpy. This same flux is not proportional to the flux of potential temperature because of variations in heat capacity of up to 5%. The geothermal heat across the ocean floor is also approximately the flux of potential enthalpy with an error of no more than 0.15%. These results prove that potential enthalpy is the quantity whose advection and diffusion encapsulates the physical meaning of the First Law of Thermodynamics in the ocean.