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 μm in size occurs primarily at night with specific rates ranging above 5×10^{-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°45' N, 158° 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 17o36' N 67o 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.

1. Saudo-Wilhelmy, et al. 2001. Nature. 411: 66. 2. Wu, J., et al. 2000. Science. 289: 759. 3. Morell J.M. and J. E. Corredor. 2001. J. Geophys. Res. 106(C8): 16,807. 4. Corredor, J.E. 1979. Deep-Sea Res: 26A: 731.

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°N, 158°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* $^{32}PO_4$ 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 (r^2=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 be 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 of 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 that 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.

OS22Q-02 1345h

Excitation of Ocean Basin Modes by the Mean Circulation

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Linear stability analysis of the large scale ocean circulation (filtered through planetary geostrophic equations) for realistic basin and forcing is performed and linear unstable modes with decadal to interdecadal time scales are found and described.

Surface boundary conditions have a tremendous influence for the positiveness of the modes growth rate, which is generally weak (of the order of cycles per year), although atmospheric stochastic forcing can easily excite the modes even if weakly damped.

Some "basin modes" are based on planetary waves "slow" propagation across the basin, resonating through "fast" boundary adjustment by Kelvin waves. Their physics can be tracked back and better understood through simplified quasigeostrophic and shallow-water dynamics.

Their relevance for explaining interannual to interdecadal climate variability found in observations and realistic models is discussed.

URL: http://www.ifremer.fr/lpo/thuck

OS22Q-03 1400h

Reading the Dynamics of the Atlantic Ocean in the Stable Isotopic Composition of Corals from the Island of Tobago

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Scleractinian corals growing around the island of Tobago in the Southern Caribbean exhibit a large inter and intra annual variation (1 to 1.25 per mille) in the oxygen isotopic composition of their skeletons despite the presence of only a small change in the sea surface temperature (1 to 2^{o}C). Although it is evident that the large inter annual variation in the oxygen isotopic composition is related to salinity variations caused by outflow from the Orinoco, the absolute magnitude of annual discharge from the Orinoco is not correlated directly with the annual oxygen isotopic signature in the coral skeletons of Montastraea complex and Siderastrea siderea corals growing around the island. An explanation for the failure of the coral skeletons to record the Orinoco signal is linked to oceanic temperatures in the northern and southern sub-tropical Atlantic Ocean which govern the position of the Inter tropical Convergence Zone (ITCZ). The ITCZ in turn controls the degree to which water from the Amazon and Orinoco influences the island of Tobago as well as other atmospheric dynamics such as wind velocity and precipitation. Although the oxygen isotopic composition of the coral skeletons is inversely related to temperature, as would be expected, the slope of the relationship is much greater than can be explained as a result of temperature alone. The extra change in the oxygen isotopic composition is related to lower salinities during periods of higher temperatures. As the lower oxygen isotopic values are not directly related to increased outflow from the Orinoco, it is suggested that these are related to the position of the ITCZ which is controlled by difference in the temperature of the northern subtropical Atlantic Ocean and the southern sub-tropical Atlantic Ocean. Although the precise mechanism is unknown, preliminary data suggest a positive correlation lagged by one year between the mean latitude of the ITCZ and the annual oxygen isotopic composition of the corals from Tobago.

OS22Q-04 1415h

Chlorofluorocarbon Constraints on North Atlantic Ocean Ventilation

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The North Atlantic Ocean vigorously ventilates the ocean interior. Thermocline and deep water masses are exposed to atmospheric contact there and sequestered in two principal classes: Sub-Tropical Mode Water (STMW) and Sub-Polar Mode Water (SPMW). Non-eddy-resolving general circulation models (GCMs) capture aspects of this ventilation but show sensitive dependence to poorly-known lateral mixing parameters. Here we ask if chlorofluorocarbon (CFC) measurements can discriminate between these ventilation changes. First, we use synthetic CFC data from the GCM at the locations of CFC determinations from the real North Atlantic. These synthetic data can distinguish between the different ventilation patterns and rates. Next, we compare the real North Atlantic CFC data to the different model simulations. Each GCM solution is close to being statistically consistent with the CFC observations and likely sources of error. But the results show that the case with lowest diffusivity gives the closest match to data. The preferred ventilation patterns show SPMW ventilation in the Irminger Sea in addition to the Labrador Sea and STMW ventilation in the central North Atlantic rather than in the eastern basin. We are now including more CFC observations to refine the model/data comparison.

OS22Q-05 1430h

NAO-related differential cooling of the subpolar and subtropical gyres: what role for the North Atlantic Ocean meridional heat transport?

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Interannual to interdecadal fluctuations in the heat balance of the subpolar and subtropical gyres of the North Atlantic are studied using simple models, hydrographic sections at 24N and 48N, indirect estimates of Ekman heat transport and net surface heat flux from da Silva et al. (1994). Emphasis is put on the differential heat content fluctuations between the subpolar and subtropical gyres, as part of the ocean - atmosphere heat balance changes associated with the North Atlantic Oscillation (NAO).

It is shown that, on monthly to interannual timescales, heat storage in the upper layers balance the differential net heat input at the surface (DHIS) and Ekman heat transport fluctuations. On interdecadal timescales, it is found that Ekman heat transport changes are small compared to DHIS changes. The latter are, however, consistent with the enhanced geostrophic northward heat transport across the intergyre boundary (48N) hinted at in the hydrographic observations (0.2 PW) from 1958 to the 1980s and 1990s. No such changes can be detected at 24N.

Analysis of a simple stochastic model shows that the amplitude of observed interdecadal DHIS changes can not be accounted for by ocean heat storage, nor can it result from atmospheric intrinsic variability. It is thus suggested that interdecadal DHIS changes are a consequence, rather than a cause, of the enhanced northward geostrophic heat transport across the inter-gyre boundary.

OS22Q-06 1445h

Heat Transport and Overturning Circulation in 0.1° , 0.2° and 0.4° simulations of the North Atlantic Ocean

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A suite of simulations of the North Atlantic Ocean has been conducted at horizontal resolutions of 0.1° , 0.2° and 0.4° with the aim of understanding the effects of resolution on eddy variability and on the mean wind-driven and thermohaline circulation. The model configuration, initial condition, and surface forcing were identical in the three runs. As reported in Smith et al. 2000 (JPO **30** 1532-1561) the 0.1° case shows remarkable improvements in both the eddy variability and wind-driven circulation relative to eddy-permitting simulations in the range of 1/2° to 1/6° . In this study we focus on aspects of the thermohaline circulation, including meridional heat transport, overturning circulation, and the formation and pathways of deep water at high latitudes, in order to elucidate some of the mechanisms responsible for the increase in meridional heat transport with increasing model resolution. This increase is primarily due to a stronger meridional overturning circulation with a colder deep branch in the higher resolution simulations. This in turn is associated with a shift in the partitioning of water flowing over the sills west and east of Iceland, and in the subsequent pathways and entrainment acting on the deep currents in the Irminger and Labrador Seas. Only in the highest resolution simulation do the deep currents qualitatively and quantitatively resemble the observed flows.

OS22Q-07 1500h

Recirculation and diapycnal transformation in the North Atlantic Ocean

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Mass, heat and salt transports are inferred from hydrographic sections and in-situ observations of currents and surface heat and freshwater fluxes, using a box inverse model. The model explicitly includes air-sea transformation of outcropping layers, and solves for reference velocities, corrections to the surface flux fields, and internal mixing in order to conserve volume, salt anomaly and potential temperate in neutral density layers.

By dividing the Atlantic into regional boxes, meridional overturning is estimated across several latitudes, and regional corrections to the UWM/COADS air-sea heat and freshwater fluxes are obtained. Transport divergences are also inferred, and the distribution of diapycnal mixing is found to be strongly inhomogeneous. In subtropical latitudes, diapycnal fluxes are largest in outcropping layers. Throughout much of the Atlantic, water in the Antarctic Bottom Water density range is converted into lower North Atlantic Deep Water. Immediately south of the Denmark Strait and Iceland-Scotland ridges, dense overflow water is converted into deep water, and intermediate water is converted into denser, upper deep water. These diapycnal transfers are consistent with entrainment of Nordic Sea Overflow Water as it enters the North Atlantic through the Denmark Strait and Faroe Bank Channels.

OS22Q-08 1515h

Changes in the Volumetric Census of the North Atlantic

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Using historical hydrographic data from the National Oceanic Data Center, we identify the depth, temperature and salinity on neutral density surfaces that span the entire water column in the North Atlantic. The properties on these surfaces are interpolated to 1 x 1 spatial bins and are averaged over two time periods: 1950-1975 and 1976-2000. By determining the thickness between the successive neutral density surfaces for each bin, we calculate the volumetric differences between the two time periods for a range of density classes. Additionally, we use the temperature and density differences to calculate temporal changes in the heat content of the North Atlantic. In addition to gross changes in density classes and heat content, our approach also illuminates the regional variability associated with these changes.

OS22Q-09 1550h

North Atlantic Variability In A Global Isopycnal Model Driven by Anomalous Surface Forcing

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Preliminary results from a multidecadal simulation of a global isopycnal model driven by anomalous surface forcing are presented. The model is the Miami Isopycnic Coordinate Ocean Model (MICOM) with a simple thermodynamic sea ice component, a 1-dimensional description of ice forming/melting cycle and associated effects on surface heat and salinity fluxes. Surface forcing for the ocean-ice model is taken from the NCAR/NCEP reanalysis products for the past 40 years. The overall goal of this study is to understand changes in the deep water formation rate and location in the North Atlantic in response to varying atmospheric forcing. We will describe pathways of North Atlantic deep water simulated by surface-injected tracers and its variability on interannual and longer time scales. Because isopycnal models can simulate near-adiabatic transport processes in the ocean interior more accurately, they are particularly suitable for this study. Possible mechanisms responsible for the changes in deep water formation and its relationship to the overturning circulation will be discussed.

OS22Q-10 1605h

Prospects for decadal prediction of the North Atlantic Oscillation (NAO)

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For certain, but realizable, states of the thermohaline and wind driven circulation of the North Atlantic Ocean, we demonstrate the possibility of making statements regarding the likely range of values to be taken by the annual average of the NAO–index on time scales out to a decade. Given that the North Atlantic is currently in such a predictable state, a simple surrogate model yields a prediction that the NAO index is more likely to be positive than negative for the next couple of years, followed by several years in which the NAO index is more likely to be negative.

OS22Q-11 1620h

Interannual to Decadal Variability in the Ocean Near Bermuda From Observations and a Global Ocean Model

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Few observational records are of sufficient duration to resolve oceanic variability out to decadal scales. A notable exception is the *Panulirus* data from Bermuda Station "S" in the North Atlantic Ocean, which has full-depth sampling over the period 1954 to the present. We use the *Panulirus* data to validate the NCAR Climate Ocean Model (NCOM) in terms of its representation of North Atlantic Subtropical Mode Water variability and of the variability at deeper levels at Bermuda. Hindcasts of ocean conditions for the period 1958–1997 have been produced by forcing the NCOM $\times 2'$ version with historical atmospheric data from the NCEP-NCAR atmospheric reanalyses. Good agreement between the model and observations would justify studies of low-frequency oceanic variability at locations where observations are not available.

Forty year average maps of model potential vorticity (PV) on potential density surfaces show a well defined mode water bowl in the model. The formation region is further east than observed, is more distributed zonally and is shallower (150 m rather than 300 m), but the strength of the PV minimum is comparable with that observed. Moreover, the interannual variability of PV, temperature and salinity in the model's mode water bowl shows good correlation with the variability in observations from Bermuda Station "S". Model salinity tracks observed salinity particularly closely.

Vertical profiles of the variance of temperature and salinity at Bermuda, in the observations and in the model, show that below the mode water the model underestimates the observed temporal variability. We explore this variability deficit in terms of baroclinic Rossby wave dynamics. The baroclinic response is composed of Rossby waves propagating from the eastern boundary and a local forced response. Baroclinic radii of deformation have been calculated by normal mode decomposition for stratification appropriate to Bermuda in the model. Using quasi-geostrophic theory and a value for horizontal viscosity equal to that in the model, we estimate that propagating first mode baroclinic Rossby waves of period three years and less, and second mode baroclinic Rossby waves of period ten years and less, are damped at Bermuda. We believe that the model's variability at Bermuda is primarily due to the baroclinic response to the local atmospheric forcing.

OS22Q-12 1635h

Meddy-Seamount Interaction: Implications for the Mediterranean Salt Tongue

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A quasi-geostrophic point vortex numerical model is developed and used to explore interactions of eddies and seamounts.The ultimate objective of this study is to assess the role of Meddy-seamount interaction as an input to Mediterranean salt tongue maintenance. Secondary objectives are to clarify the dynamics of Meddy-seamount interaction, which is a commonly observed event. The results suggest Meddies survive seamount collisions with 60-70% of their initial cores remaining intact as coherent vortices. Given Meddy formation rates, it appears Meddies supply between one quarter and one half the global rate necessary to sustain the Mediterranean salt tongue against mean advection, although other considerations suggest the observationally determined effect of mean advection is underestimated. Meddies are of considerable local importance near the Horseshoe seamounts, but less significant near the Azores plateau. These local results are consistent with maps of salt tongue concentration. In summary, while Meddies are important in the maintenance of the salt tongue, other mechanisms are required as well. Thus, the survival by Meddies of collisions with seamounts emerges as a potentially important limiting effect on the Mediterranean salt tongue. This has climatically significant implications for ocean simulations.

OS22R HC: 323 C Tuesday 1330h

Modeling: Planktonic and Biogeochemical Processes

Presiding: **R A Armstrong,** SUNY Stony Brook

OS22R-01 1330h

Beyond Moloney and Fields: A Continuous Size-spectral Plankton Model with Parameterized Zooplankton

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For many applications, there is need for a general plankton model that reflects both size structure and taxonomic structure of both phytoplankton and zooplankton. Until now, the leading candidate for these applications has been the size-structured model of Moloney and Fields (1991). That model has several deficiencies. First, it allows only rigidly defined size classes, so that continuously-graded differences in size (and associated physiological and ecological properties) are difficult to reflect. Second, that model has several dynamically independent zooplankton size classes, leading to dynamical behaviors that are complex, and probably often chaotic. Here I present a new model, where the zooplankton community is represented by a single state variable, while phytoplankton species can be represented individually. The representation of zooplankton differs from that of a previous attempt (Armstrong 1999) in that the size of the largest zooplankton size class increases or decreases with increasing (decreasing) total zooplankton biomass, much as the largest phytoplankton size class tracks biomass in the models of Hurtt and Armstrong (1996, 1999). Applications to specific test cases will also be discussed.

OS22R-02 1345h

Response of Ocean Biology to Future Climate Change

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We examine six different coupled climate model simulations of future climate change to determine the range of behavior of those physical properties of global warming simulations that are relevant to the ocean biological response. The overall response we infer from examining the physical response of the ocean to global warming varies widely in magnitude, but shows a tendency towards decreased biological production in low latitude upwelling regions and the poleward half of the subtropical gyres, and increased production in the polar regions. The nature of the response, with variable magnitude but similar qualitative patterns, is broadly consistent with more traditional measures of climate response. We have used satellite color and ocean climatological observations to develop an empirical model for predicting chlorophyll from the physical properties predicted by the global warming simulations. Application of this empirical model to the climate model simulations yields results that agree with the inferences drawn from analysis of the physical properties. A dominant mechanism for nutrient supply in the subtropical gyres poleward of the subtropical convergence zone is wintertime convection. These regions tend to become more stratified with future climate change, which reduces the depth of wintertime mixing in most models. The expectation, supported by model predictions, is that this would result in reduced biological production. The polar regions generally have a high supply of nutrients due to upwelling and convection, but can suffer from low productivity due to low light supply in deep mixed layers. Increased stratification, which occurs in most models, though with a complex pattern, would thus tend to increase biological production. Exceptions to this would be where low levels of micronutrient supply by dust limit the production, such as is thought to be the case in the Southern Ocean and North Pacific, or where the decreased mixing reduced the nutrient supply to less than the potential biological uptake. The mechanism of nutrient supply to regions between the equatorial upwelling bands and subtropical convergence is poorly understood and poorly simulated in most models. It is difficult to determine how these regions will respond to future climate change.

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A Novel Approach to Estimate the Export of Biogenic Carbon From the Euphotic Zone. 1. Conceptual Development.

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The usual approach to estimate the export of organic matter from the euphotic zone (E) assumes that E is quantitatively equivalent to the fraction of long-term phytoplankton net production (P) that is fuelled by the allochthonous supply of the limiting (L) element (i.e. new production, Pnew). Two often neglected assumptions of this approach are that (1) community respiration in the euphotic zone (R) is quantitatively equivalent to the part of P that is supported by the autochthonous supply of L (regenerated production, Preg), and (2) the ratio of carbon (C) to L (C:L) is the same in both the exported material and P. Empirical evidence is consistent with our prediction that these two assumptions are incorrect. Because the C:L ratio of the exported material generally exceeds that in phytoplankton, we predict that generally Preg > R. We describe a new, general approach to estimate E that

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