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.

OS22R-03 1400h

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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does not require assumptions (1) and (2) above. Our approach estimates E directly from P and R (i.e. E = P - R), thus the assumption about the C:L ratio is unnecessary. Moreover, since Pnew (expressed in the L currency) is quantitatively equivalent to the amount of L exported, our approach permits the independent computation of the C:L ratio in the exported material (as E/Pnew).

OS22R-04 1415h

A Novel Approach to Estimate the Export of Biogenic Carbon From the Euphotic Zone. 2. Model Implementation

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Over the past decade, various food web and biogeochemical models have been developed to predict the biological and biogeochemical responses of the upper ocean to a variety of environmental forcings, including those due to global climate change. Many of the models use estimates of f-ratio or new production (Pnew) to compute the export (E) of biogenic carbon (BC) from the upper ocean. The estimates of E from Pnew assume that (1) community respiration in the euphotic zone (R) is quantitatively equivalent to the part of phytoplankton net production (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. We present empirical evidence that is consistent with our prediction that these two assumptions are incorrect. For major ocean regions, we show that Preg is systematically greater than R, and the C:L ratio in the dissolved and particulate biogenic material is greater at depth than in phytoplankton within the euphotic zone. We propose an approach to compute both E (as E = P - R) and the C:L ratio in the exported material from P, R and Pnew, variables which are available for most ocean basins.

OS22R-05 1430h

Stirring and Mixing - Their Effect on the Marine Ecosystem

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The biology of the oceans plays a fundamental role in the carbon cycle. Ecosystem models of the ocean are required in climate models used to predict future levels of atmospheric CO_2 and its effect on global warming. The ecosystem models themselves need to be a fair reflection of the dynamics of the ecological system, which may vary in both space and time. The underlying theme of the present talk is that stirring and mixing of biologically active constituents cannot be ignored in the overall dynamics of the system, and that the 'tuning' of one-dimensional models to fit observations can often produce erroneous results.

Here we give an overview of recent research on the effects of fluid dynamical processes, in particular lateral stirring and mixing, on biological productivity. It is found that from the diffusive scale to supra-mesoscale, diffusion and straining by the flow can have an impact on the dynamics of the biology. The biological response is affected by not only the fluid dynamics but also the dynamics of the ecosystem itself. In certain cases the biology can evolve to a completely different state given heterogeneity in the system.

OS22R-06 1445h

Complexity in the Self-Organized Pelagic Marine Biological System

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The pelagic marine biological system (MBS) is considered here to be self-organized. This in turn encourages new conceptual and research approaches. The system is characterized by power-law and other nonlinear interactions between its components and processes in space and time. The MBS is driven by the physical and chemical processes of the ocean and its interfaces, and the organisms have evolved to take advantage of those processes. A major driving factor of the system is that of the power-law ocean turbulent processes of large to small scale, having a fractal dimension of D = 1.67. All scales have biological significance. The consequences are illustrated by three examples involving the food web. (1) The patchiness of northwestern Atlantic phytoplankton has a similar power-law fractal dimension to that of turbulence, being passively distributed by the turbulence. (2) Northwestern Pacific herbivore copepods graze on phytoplankton and have a patchiness with a higher fractal dimension near D = 1.8, the result of turbulence and swimming by random walk. (3) Eddies can be considered to be semi-contained ecosystems, in essence self-organized; Antarctic krill swarms are inferred to be partially organized by ocean eddies (D = 1.67), upon which is superimposed feeding behavior involving swarming, with the swarm sizes having a fractal dimension near D = 1.9. Present numerical and box modelling approaches give significant insights into many aspects of the functioning of the MBS. But these approaches are hampered by their necessarily specialized conceptual frameworks, the need to use linear approximations of the non-linear processes and relationships, and limitations in available computer power. The present stepwise progress is one necessary approach to dealing with the inherent complexity of the MBS, but an overall strategy has not yet evolved and gaps exist. For example, the models need to be developed to reflect adequately the self-organizing nature of the system, and the size-scaling and energy/mass budgeting in the food web; also the gelatinous organism component of the food web is inadequately understood and modelled. Nevertheless important progress is being made, though stepwise, and the paradigm change is moving swiftly.

OS22S HC: 319 A Tuesday 1330h

Biogeochemical Linkages Between Rapidly Urbanizing Coastal Watersheds and the Coastal Ocean II

Presiding: **E H De Carlo,** University of Hawaii at Manoa**; K J Spencer,** Los Alamos National Laboratory**; F T Mackenzie,** University of Hawaii

OS22S-01 1330h INVITED

Diurnal to Decadal Variations of Trace Element Concentrations in San Francisco Bay: The Urban Estuary

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A systematic investigation of contaminants in San Francisco Bay over the past decade has revealed pronounced spatial and temporal variations in its trace element concentrations in this, the "urban", estuary. Historic inputs of industrial lead over the past 150 years now account for most of the lead within the estuary, based on stable lead isotopic composition and mass balance calculations. The resultant model for the biogeochemical cycle of lead in the Bay is consistent with Turekian's original model for trace elements in estuaries, which was primarily derived from Pb-210 analyses in other embayments a quarter of a century ago. While we have not been able to definitively identify the origins of other trace elements within San Francisco Bay, using similar isotopic composition analyses, we have been able to resolve subtle decreases in some of their concentrations over the past decade, in spite of their much larger seasonal and episodic short term variations, using time series models. These models have also independently corroborated the results of our stable lead isotopic composition measurements. In toto, these analyses demonstrate that both systematic, long term data sets and rigorous geostatistical analyses are required to accurately quantify anthropogenic perturbations of natural biogeochemical cycles in estuaruies and other, highly dynamic, coastal waters.

OS22S-02 1345h INVITED

Boron Isotopes as Tracers of Groundwater Sustainability and Anthropogenic Contamination in the Urbanizing Coastal Corridor

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The sustainability of groundwater resources and the discharge of anthropogenic contaminants to estuaries and the ocean are arguably the most important issues facing policy makers along rapidly developing coastlines. For example, groundwater salinization is rapidly becoming the common result of excessive drawdown of fresh water reserves from coastal aquifers. Potential sources of saline water include intrusion of present-day seawater, infiltration of agricultural effluents, and upwelling of brines of both marine and non-marine origin. Distinguishing between these sources of saline water is complicated, yet early detection and characterization of the salinization process is critical for the development of proper remediative aquifer management strategies. Similarly, contamination of estuaries and the adjacent ocean through discharge of agricultural effluents and "urban runoff" is essentially an unavoidable consequence of coastline development, although quantifying the extent of the anthropogenic impact is problematic at best. Boron isotopes can provide a unique and especially powerful tracer of these important processes at the ocean-coastline interface, precisely due to the juxtaposition of marine and non-marine environments in this setting and the conservative geochemical behavior of boron. The nearly 60 per mil difference in $^{11}B/^{10}B$ ratio between relatively light non-marine evaporites, the typical source of anthropogenic boron in detergents and fertilizers, and relatively heavy marine brines provides the broad context for distinguishing contributions from potential end-members in both groundwater and surface water systems. Numerous examples from our current ongoing work demonstrate that boron isotope tracer techniques provide an exceptional tool for monitoring the impact of development on the urbanizing coastal corridor, particularly when used in a multi-tracer approach that incorporates other isotope and geochemical parameters.

OS22S-03 1400h

Variability of heavy metal concentrations during storm-events in streams of a subtropical watershed

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Storm-generated freshwater pulses, or freshets, represent one of the primary mechanisms by which terrestrial material can be transferred from the land to the coastal ocean in a subtropical environment. As urbanization broadens its reach, freshets can become very important in the transport of anthropogenic material, especially with respect to non-point source pollution (i.e., street runoff). Typically elevated in concentrations of heavy metals such as Pb, Zn, and Cu, this anthropogenic input may have a deleterious effect upon estuarine and near-shore biological communities, as well as degrade the quality of stormwater.

The presence of steeply sloped watersheds and intense and episodic rainfall in the Hawaiian Islands creates an ideal scenario for the study of event-based transport of terrestrial mass. Moreover, the intersection of watersheds with increasingly urbanized areas, particularly in Honolulu, provides the opportunity to examine the effects of anthropogenic activity upon heavy metal concentrations during storm-events. Spanning both conservation and urban areas, a network of stations has been established in streams of the Ala Wai Canal Watershed on southern Oahu and in streams of the Kaneohe Watershed on eastern Oahu to examine short-term and annual variability in terrestrial mass transfer. The presentation will largely focus on data collected during 9 storm-events in the Ala Wai Canal Watershed with preliminary data from 1 storm-event in the Kaneohe Watershed also discussed.

Though both dissolved and particulate phases show variability in heavy metal concentrations during storm-events, particulate concentrations in the watershed, as expected, are much larger than that observed for the dissolved phase. Particulate Pb, Zn, Cu, Ba, and Co display patterns of elevated concentrations in the lower, more urbanized, watershed, while solid phase As exhibits higher values in the conservation areas of the upper watershed. Concentrations of Ni, V, and Cr in suspended particulate matter show a relative invariance throughout the watershed with similar values observed in both urban and conservation areas. Examination of a "Kona" storm (offshore low-pressure system) reveals