across the heat boundary layer was estimated from a surface renewal model. Estimates of the net heat flux were determined from direct measurement of latent and sensible heat fluxes and longwave emission. Heat transfer velocities were computed and scaled to gas transfer velocities using appropriate Schmidt numbers for heat and gas. Frequency-wavenumber slope spectra of small-scale waves (25-800 rad/m) were measured with a scanning laser slope gauge. Surface films were measured using a surface microlayer skimmer and fluorometry package. The field data show a strong correlation between gas transfer velocity and mean square slope, including observations made in areas with significant surface films. Comparison of transfer velocities with wavenumber-binned slope data indicate that the correlation becomes increasingly linear and statistically significant for wavenumbers above 100 rad/m; a poor correlation is observed for wavenumbers below 50 rad/m. Notable exceptions were observations made during rain events, when mean square slope at higher wavenumbers increased significantly without a concomitant increase in transfer velocity as measured using thermal imaging. Wave slope was generally negatively correlated with surface film enrichment, as measured by microlayer-subsurface differences in CDOM fluorescence. At low winds, wave slope was reduced 1-2 orders of magnitude by the presence of surfactant films and gas transfer velocity was poorly correlated with wind speed. The potential applicability of a robust transfer velocity-mean square slope relationship to remote sensing of transfer velocity fields will be discussed.

OS32I HC: 319 A Wednesday 1330h

Synthesis of Pacific Ocean Carbon Cycle Research II

Presiding: **R Feely,** NOAA/Pacific Marine Environmental Laboratory; **F Chai,** University of Maine

OS32I-01 1330h

Distribution of Anthropogenic CO_2 in the Pacific Ocean

Christopher L. Sabine[1] ((206) 526-4809; sabine@pmel.noaa.gov); Richard A. Feely[2] (feely@pmel.noaa.gov); Robert M. Key[3] (key@princeton.edu); John L. Bullister[2] (bullister@pmel.noaa.gov); Frank J. Millero[4] (fmillero@rsmas.miami.edu); Kitack Lee[5,6] (ktl@postech.ac.kr); Tsung-Hung Peng[5] (peng@aoml.noaa.gov); Bronte Tilbrook[7] (Bronte.Tilbrook@marine.csiro.au); Tsuneo Ono[8] (onot@frontier.esto.or.jp); Chi-Shing Wong[9] (wongc@dfo-mpo.gc.ca)

[1]University of Washington, C/O NOAA-PMEL 7600 Sand Point Way NE, Seattle, WA 98115, United States

[2]NOAA/Pacific Marine Environmental Laboratory, 7600 Sand Point Way NE, Seattle, WA 98115, United States

[3]Princeton University, AOS Program Forrestal Campus/Sayre Hall, Princeton, NJ 08544, United States

[4]University of Miami, RSMAS 4600 Rickenbacker Causeway, Miami, FL 33149, United States

[5]NOAA/Atlantic Oceanographic and Meteorological Laboratory, 4301 Rickenbacker Causeway, Miami, FL 33149, United States

[6]Pohang University of Science and Technology, School of Environmental Science and Engineering San 31, Nam-gu, Hyoja-dong, Pohang 790-784, Korea, Democratic People's Republic of

[7]CSIRO, Division of Oceanography GPO Box 1538, Hobart, Tasmania 7001, Australia

[8]FRSGC/IGCR, Ecosystem Change Research Program 3173-25 Showa-machi, Kanazawa-ku, Yokohama 236-0001, Japan

[9]Institute of Ocean Sciences, 9860 W. Saanich Road, Sidney,, BC V8L 4B2, Canada

This work presents an estimate of anthropogenic CO_2 in the Pacific Ocean based on measurements from the WOCE/JGOFS/OACES global CO_2 survey. These estimates used a modified version of the ΔC^* technique originally proposed by Gruber et al. [1996]. Modifications include a revised preformed alkalinity term based on Pacific surface data, a correction for denitrification based on N* estimates, and an evaluation of the disequilibrium terms using an optimum multiparameter (OMP) analysis. The total anthropogenic CO_2 inventory over an area from 120°E to 70°W and 70°S to 65°N (excluding the South China Sea, the Yellow Sea, the Japan/East Sea, and the Sea of Okhotsk) was 44.5±5 Pg C in 1994. Approximately 28 Pg C was located in the Southern Hemisphere and 16.5 Pg C was located north of the Equator. The deepest penetration of anthropogenic CO_2 is found at about 50°S associated with the Subtropical Convergence. The shallowest penetration is found just north of the equator. Very shallow anthropogenic CO_2 penetration is also generally observed in the high latitude Southern Ocean. One exception to this is found in the far southwestern Pacific where there is evidence of anthropogenic CO_2 in the northward moving bottom waters. In the North Pacific, deep ventilation within the Kuroshio Extension and the subsequent circulation in the subtropical gyre generates a strong zonal gradient in the anthropogenic CO_2 penetration depth with the deepest penetration in the western Pacific. Relative to the Atlantic and Indian Oceans, the Pacific has the largest total inventory in all of the southern latitudes despite the fact that it generally has the lowest average inventory when normalized to a unit area. The lack of deep and bottom water formation in the North Pacific means that the North Pacific inventories are smaller than the North Atlantic despite the larger area in the Pacific.

URL: http://cdiac.esd.ornl.gov/oceans/glodap/index.html

OS32I-02 1345h

Ocean Transport and Storage of Carbon in the South Pacific

Paul E Robbins[1] (858-534-6366; probbins@ucsd.edu)

Gregory C Johnson[2] (206-526-6806; gjohnson@pmel.noaa.gov)

Christopher L Sabine[3] (206-526-4809; sabine@pmel.noaa.gov)

Richard A Feely[2] (206-526-6214; feely@pmel.noaa.gov)

[1]Scripps Institution of Oceanography, Mail Stop 0230 SIO/UCSD 9500 Gilman Dr., La Jolla, CA 92093-0230, United States

[2]Pacific Marine Environmental Laboratory, NOAA, 7600 Sand Point Way NE, Bldg. 3, Seattle, WA 98115, United States

[3]Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, 7600 Sand Point Way NE, Bldg. 3, Seattle, WA 98115, United States

The WOCE/JGOFS hydrographic survey in the South Pacific Ocean is used as the basis for estimating the advective transport and storage of both natural and anthropogenic carbon. The mass transport fields are determined from a box-inverse model which adjusts an a priori estimate of the flow field in order to satisfy imposed constraints for selected geographic regions. The a priori estimate of the geostrophic velocity is based on the observed density distribution and carefully selected initial reference levels. A priori estimates of the surface Ekman transports are determined from annual climatological wind fields. A solution is found which is consistent with both the expected error in the initial transport fields and the uncertainty of the imposed constraints.

The observed carbon distribution is partitioned into natural and anthropogenic components based on analysis incorporating oxygen, nutrient and transient tracer observations. Rates of local oceanic anthropogenic carbon accumulation are estimated from a simple model assuming exponential growth of the perturbation. The South Pacific Basin is found to be a moderate sink of anthropogenic carbon, storing approximately 0.4 PG C/yr. Both air/sea flux and advective convergence are important components of the overall balance. A significant portion of the convergence is due to southward Ekman transport of tropical waters rich in anthropogenic carbon.

OS32I-03 1400h

The Distribution and Inventory of Bomb Produced Radiocarbon in the Pacific Ocean

Robert M. Key (609-258-3595; key@princeton.edu)

AOS Program, Sayre Hall Princeton University, Princeton, NJ 08544-0001, United States

The World Ocean Circulation Experiment provided the first three-dimensional description of the Pacific Ocean radiocarbon distribution. Measurement of the U.S. samples has been completed. Estimates of the bomb produced component were made using a new algorithm based on the strong linear correlation between natural radiocarbon and potential alkalinity. Unlike previous methods, the new algorithm works at all latitudes and can be used to approximate pre-bomb surface values.

The meridional distribution of bomb radiocarbon is similar that found for both chlorofluorocarbon and anthropogenic CO_2, however, notable differences exist, particularly at high southern latitudes. The differences are indicative of the fact that radiocarbon has a much longer air-sea equilibration time than either CO_2 or CFC. Measurable levels are generally restricted to the upper kilometer of the water column with deepest penetration found near 40 North and South and the highest concentrations somewhat equator-ward of that latitude. Unlike GEOSECS, the highest concentrations were frequently found in the upper thermocline rather than at the ocean surface. For the first time, evidence was found of slight bomb contamination in newly formed bottom waters adjacent to Antarctica.

The bomb produced radiocarbon inventory is minimal at high latitudes and has a relative minimum near the Equator. Maximum inventory values occur around 30 North and South latitudes with the north showing somewhat higher values at individual stations. On depth or density surfaces the bomb distribution is consistent with generally accepted flow patterns and is strongly influenced by convection and/or convection of mode and intermediate waters.

OS32I-04 1415h

Bomb Radiocarbon and Anthropogenic CO2 in Ocean Biogeochemical Models

Katsumi Matsumoto[1] (kmatsumo@splash.princeton.edu)

Jorge Sarmiento[1] (jls@princeton.edu)

Robert Key[1] (key@princeton.edu)

Richard Slater[1] (rdslater@splash.princeton.edu)

Christopher Sabine[2] (sabine@pmel.noaa.gov)

[1]Princeton University, Atmospheric and Oceanic Sciences Program, Princeton, NJ 08544, United States

[2]PMEL/NOAA, US Department of Commerce, Seattle, WA 98115, United States

The testing of thermonuclear bombs in the late 1950's and in the following decade has produced vast amounts of radiocarbon (14C), which was released to the atmosphere. Subsequently, this "bomb 14C" has entered the natural reservoirs of carbon, including the ocean. Measurements of 14C in the ocean show clear evidence of elevated 14C content that can be attributed to bomb testing, and this tracer offers a unique opportunity to study how carbon is taken up by the ocean. However, the distributions of bomb 14C and anthropogenic CO2 are not related in any simple way, because their atmospheric time-histories and gas exchange equilibration times are very different.

Here we investigate how bomb 14C and anthropogenic CO2 in the ocean are related to each other with the use of a suite of 3-dimensional ocean circulation models (GCMs) participating in the Ocean Carbon Model Intercomparison Project (OCMIP), which mandates the use of a standardized marine biogeochemistry model. A topic of interest is how the simulated distributions of bomb 14C and anthropogenic CO2 are affected by the relative strengths of parameterized vertical and horizontal mixing. The contrast in the distributions of the two tracers can be accentuated by the different model circulations. Preliminary analysis indicates that mixing in the Southern Ocean in particular plays an important role in their distributions. Another topic of interest is whether the penetration depth of bomb 14C is a good indicator of anthropogenic CO2 invasion for this decade. This expectation is borne out from the rough equivalence between the time since the injection of bomb 14C into the ocean until the recent large scale field surveys (Joint Global Ocean Flux Study and World Ocean Circulation Experiment) and the characteristic time constant of the atmospheric CO2 growth rate. As a result, the penetration depth of bomb 14C may intersect the more or less constant penetration depth of anthropogenic CO2 in this decade. If the ratio of the two penetration depths is demonstrated to be relatively robust amongst the different OCMIP models, the penetration depth of anthropogenic CO2 and thus its inventory can be estimated from the penetration depth of bomb 14C determined from observation.

The investigation of both of these topics illustrates significant model differences. We expect these differences to provide useful insights into the strengths and weaknesses of the GCMs, which will aid our ongoing efforts to improve these models and their predictive capabilities with regard to anthropogenic CO2 uptake by the ocean.

OS32I-05 1430h

Inferring the Concentration of Anthropogenic Carbon in the Ocean from Tracers

Timothy M Hall[1] (212-678-5652; thall@giss.nasa.gov)

Thomas W N Haine[2] (410-516-7048; twnh@stommel.eps.jhu.edu)

Darryn W Waugh[2] (410-516-8344; waugh@rua.eps.jhu.edu)

[1]NASA Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025, United States

[2]Earth and Planetary Sciences, Johns Hopkins University 3400 N. Charles St., Baltimore, MD 21218, United States

We present a new technique to infer concentrations of anthropogenic carbon in the ocean from observable tracers and illustrate the technique using synthetic data from a simple model. In constrast to several recent studies the technique makes no assumptions about transport being dominated by bulk advection and does not require separation of the small anthropogenic signal from the large and variable natural carbon cycle. Mixing is included naturally and implicitly by using observable tracers in combination to estimate "age spectra," the distributions of transit times from the surface to interior points. The time-varying signal of anthropogenic carbon in surface waters is propagated directly into the interior by the age spectrum without having to consider background natural carbon. The age spectrum technique provides estimates of anthropogenic carbon, as simulated directly in the model, that are more accurate than techniques relying on single tracer "ages" (e.g., CFC age) to represent transport. In general, the age spectrum technique works best when at least two tracers are used in combination, and the tracers have significantly different timescales in either their surface temporal variation or radioactive decay. Possibilities are a CFC or CCl_4 in combination with natural $\Delta^{14}C$ or ^{39}Ar. Even for a CFC alone, however, the age spectrum technique results in less bias for anthropogenic carbon estimates than use of a CFC age.

OS32I-06 1445h

Turnover Times of the North Pacific Subtropical Thermocline Based on Chlorofluorocarbons

John L. Bullister[1] (206-526-6741; bullister@pmel.noaa.gov); Rolf E. Sonnerup[2] (206-526-6748; sonnerup@pmel.noaa.gov); Rana A. Fine[3] (305-361-4722; rfine@rsmas.miami.edu); DongHa Min[4] (206-221-6741; dongha@ocean.washington.edu); William M. Smethie[5] (845-365-8566; bsmeth@lamont.ldgo.columbia.edu); Mark J. Warner[4] (206-543-0765; mwarner@ocean.washington.edu); Ray F. Weiss[6] (858-534-2598; rfw@siorfw.ucsd.edu)

[1]NOAA-PMEL, 7600 Sand Point Way NE, Seattle, WA 98115, United States

[2]University of Washington-JISAO, Box 354235, Seattle, WA 98195, United States

[3]University of Miami- RSMAS, 4600 Rickenbacher Causeway, Miami, FL 33149, United States

[4]University of Washington, School of Oceanography Box 357940, Seattle, WA 98195, United States

[5]Columbia University, LDEO, Palisades, NY 10964, United States

[6]University of California, San Diego, Scripps Institution of Oceanography, La Jolla, CA 92093, United States

Dissolved Chlorofluorocarbons (CFCs) were measured on hydrographic sections in the Pacific Ocean in the 1990's as part of World Ocean Circulation Experiment (WOCE) Hydrographic Program. This program has provided a time-dependent tracer data set of unprecedented size and quality. These data are being utilized to examine the pathways of ventilated waters into the interior of the ocean, to estimate the rates of ocean circulation and mixing processes, to estimate the uptake of anthropogenic carbon dioxide and to help validate numerical ocean models. In this study, CFC inventories in selected isopycnal layers in the North Pacific Subtropical Thermocline are determined using the WOCE data set. A turnover time for each layer is derived using these inventories and models of the time-dependence concentrations of CFCs in the corresponding winter outcrop region. These results are compared with turnover times derived using mean CFC 'apparent ages' in the layers, and with estimates of renewal times based on subduction rates derived using climatological data. The turnover times calculated using CFC inventories and mean CFC apparent ages in general are substantially faster than those calculated from subduction rate estimates. The inherent assumptions for each method of estimating turnover times will be presented along with efforts to utilize the differences to better understand the circulation in the North Pacific Subtropical Thermocline.

OS32I-07 1520h INVITED

Decadal Variability of Modeled Carbon Cycle and Ecosystem Dynamics in the Pacific Ocean

Fei Chai[1] (207-581-4317; fchai@maine.edu); Richard T. Barber[2] (rbarber@duke.edu); Mingshun Jiang[1] (jiang@athena.umeoce.maine.edu); Richard C. Dugdale[3] (rdugdale@sfsu.edu); Tsung-Hung Peng[4] (tsung-hung.peng@noaa.gov); Yi Chao[5] (yi.chao@jpl.nasa.gov)

[1]University of Maine, School of Marine Science, 5741 Libby Hall, Orono, ME 04469, United States

[2]Duke University, NSOE Marine Laboratory, 135 Duke Marine Lab Road, Beaufort, NC 28516, United States

[3]San Francisco State University, Romberg Tiburon Centers, PO Box 855, Tiburon, CA 95920, United States

[4]San Francisco State NOAA/AOML, 4301 Rickenbacker Causeway, Miami, FL 33149, United States

[5]Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA 91109, United States

The Pacific Ocean exhibits strong variations at seasonal to decadal time scales, and the changing Pacific climate has direct impacts on marine ecosystems and carbon cycle. A physical-biogeochemical model has been developed and used to investigate physical variations, ecosystem responses, and biogeochemical consequences. The lower trophic level ecosystem model with multiple nutrients and plankton groups, embedded into a three-dimensional circulation model, is forced with observed the air-sea fluxes between 1950 and 1998. The physical-biogeochemical model is capable of reproducing many observed features and their variability in the Pacific Ocean. Linkage of the ecosystem components to the carbon system provides a model estimated air-sea flux of carbon dioxide that is comparable with the observations. Analyses of the modeled results for the North Pacific will be presented with focus on the variability at decadal time scale. The abrupt shift in the Pacific climate system occurred during the mid 1970s, the modeled responses to such climate shift will be discussed. The model exhibits some different behaviors between the North Pacific and the equatorial region, and the modeled results from these two regions will be presented with emphases on comparison before and after the mid 1970s climatic shift.

OS32I-08 1540h

Comparison of one- and three-Dimensional Simulations of the Oligotrophic Ecosystem in the North Pacific

Yvette H. Spitz[1] (541-737-3227; yvette@coas.oregonstate.edu)

James G. Richman[1] (541-737-3328; jr@coas.oregonstate.edu)

Mark R. Abbott[1] (541-737-4045; mark@coas.oregonstate.edu)

Katja Fennel[1] (541-737-3281; kfennel@coas.oregonstate.edu)

[1]Oregon State University, COAS, Ocean Admin. Bldg., 104, Corvallis, OR 97331, United States

Ecosystem models are often coupled to one-dimensional physical models to simulate the key processes that take place at specific areas of the Ocean. With the availability of long-term time series observations at stations such as the Hawaiian Ocean Time series (HOT) station in the North Pacific, the one-dimensional ecosystem modeling became very appealing. These observations are one-dimensional with high vertical resolution that allows a thorough comparison with the model outputs. Furthermore, it is computationally inexpensive and therefore it allows the researchers to test very quickly some given hypothesis. On the other hand, these one-dimensional models do not permit to take into account horizontal advection and diffusion that can be important even for the oligotrophic part of the North Pacific. We analyze the differences in the behavior of an eleven component ecosystem model for HOT when coupled to a one-dimensional and a three-dimensional circulation model between 1989 and 1993. The 1D physical model with restoration to the observed temperature profiles agrees well with the 3D model driven by NCEP flux data. Preliminary results of the ecosystem model reveal that the 1D modeled deep-chlorophyll maximum (DCM) agree very well with the observed DCM except for 1991 when the modeled DCM is much larger than the observed DCM. On the contrary, the 3D results agree very well with the observations and show a decrease of DCM in 1991. Similar results are found for the primary productivity. We are analyzing the 3D nitrogen/carbon budget around HOT to determine the causes of these differences.

OS32I-09 1555h

Simulated Air-Sea CO_2 Fluxes in the Pacific: Multidimensional Statistical Analysis of Model Performance

James C. Orr[1,2] (33-1-69-08-77-23; orr@cea.fr)

Kenneth G. Caldeira[2] (1-925-423-4191; kenc@llnl.gov)

Karl E. Taylor[3] (1-925-423-3623; ktaylor@pcmdi.llnl.gov)

OCMIP Group

[1]Laboratoire des Sciences du Climat et de l'Environnement (LSCE), CEA Saclay Bat. 709 - Orme, Gif-sur-Yvette F-91191, France

[2]Lawrence Livermore National Laboratory (LLNL), Mail Stop L-103 7000 East Avenue, Livermore, CA 94550, United States

[3]PCMDI, P.O. Box 808, L-264, Livermore, CA 94551-0808, United States

As part of the the Ocean Carbon-Cycle Model Intercomparison Project (OCMIP) thirteen groups have used climatologically forced, global ocean models to simulate preindustrial, modern, and future air-sea CO2 fluxes. These same groups have also made tracer simulations of CFC's, C-14, and He-3 to provide a means to evaluate modeled circulation. We have quantitatively analyzed model performance relative to the observed climatology of air-sea fluxes. For this analysis we have used a new type of diagram, recently developed for atmospheric model intercomparisons, to summarize the contributions of the different spatial and temporal components to the overall error. This "Taylor" diagram is based on the geometric relationship between the correlation coefficient, simulated and observed variances, and the centered pattern RMS difference. In the Pacific basin, models are more satisfactory in the the tropics and subtropics than they are in the higher latitudes. Similar analysis of the OCMIP-2 tracer results, which is ongoing, should help place upper and lower limits on modern air-sea CO2 fluxes particularly where spatial and temporal data coverage is poor.

URL: http://www.ipsl.jussieu.fr/OCMIP

OS32I-10 1610h

ENSO and Diatoms: Implications for the Eastern Equatorial Pacific from a 3-D model – an Analogue for the Last Glacial Maximum?

Andre G Wischmeyer[1] (+49 (0) 471 4831 1852; awischme@awi-bremerhaven.de)

Richard Dugdale[2] ((415)338-3518; rdugdale@sfsu.edu)

Mingshun Jiang[3] (jiang@athena.umeoce.maine.edu)

Fei Chai[3] ((207) 581-4317; fchai@maine.edu)

Frances Wilkerson[2] ((415) 338 3519; fwilkers@sfsu.edu)

[1]Alfred Wegener Institute for Polar and Marine Research, PO box 120161, Bremerhaven D 27515, Germany

[2]Romberg Tiburon Centers San Francisco State University, 152 Paradise Drive, Tiburon, CA 94920-0855, United States

[3]School of Marine Sciences University of Maine, 5741 Libby Hall, Orono, ME 04469-5741, United States

A significant strengthening of the trade winds over the tropical Pacific ocean as an El Niño fades is a sign of a La Niña period. As a consequence upwelling along the equator increases and the thermocline in the eastern part of the tropical Pacific shifts upwards bringing more nutrients into the surface layer. We investigated two extreme thermocline settings in the eastern equatorial Pacific with a 10 compartment biological model embedded in a 3-D ocean general circulation model. The minimum and maximum depths of the thermocline match with observed La Niña and El Niño situations in 1988/89 and 1992. Those ENSO events have a significant effect on the silicic acid supply of the open ocean upwelling zone in the equatorial Pacific. Enhanced silicic acid availability during the modelled La Niña situation leads to elevated diatom productivity. Changes in biological productivity due to a thermocline shift could be used as an analogue for productivity changes between the last glacial maximum and today.

OS32I-11 1625h

Global Estimates of Carbon Export in the Nitrate-Depleted Tropical and Subtropical Oceans

KITACK LEE[1] (82-054-279-2285; ktl@postech.ac.kr)

David Karl[2] (808-956-8964; dkarl@iniki.soest.hawaii.edu)

Jia-Zhong Zhang[3] (305-361-4397; jia-zhong.zhang@noaa.gov)

Rik Wanninkhof[3] (305-361-4379; rik.wanninkhof@noaa.gov)

[1]Pohang University of Science and Technology School of Environmental Science and Engineering, San 31, Hyoja-dong, Nam-gu, Pohang 790-784, Korea, Republic of

[2]University of Hawaii Department of Oceanography, 1000 Pope Road, Honolulu, HI 96822, United States

[3]Atlantic Oceanographic and Meteorological Laboratory, 4301 Rickenbacker Causeway, Miami, FL 33149, United States

Nitrate availability is generally considered to be the limiting factor for oceanic new and export production and this concept is central in our observational and modeling efforts. However, recent time-series observations off Bermuda and Hawaii indicate a significant new production in the absence of measurable nitrate. Here we estimate global new production in nitrate-depleted tropical and subtropical waters with temperatures higher than 20 degree (Celsius) from the decrease in the salinity normalized total dissolved inorganic carbon inventory within the surface mixed layer corrected for changes due to net air-sea carbon exchange. This method yields a global new production of 0.8 giga ton carbon per year, which accounts for a significant fraction of the recent total new production estimates in the tropical and subtropical oceans, with the remainder being supported by upward nutrients into the euphotic zone through eddy diffusion and turbulent mixing processes. Our modeled value is the first global-scale estimate of new production in the absence of measurable nitrate. We hypothesize that it is attributable to nitrogen fixing microorganisms, which can utilize the nonlimiting nitrogen and thereby bypass nitrate limitation. This reported new production is significantly higher than published global nitrogen fixation estimates based on extrapolation of sparse measurements of nitrogen fixation.

OS32I-12 1640h

The Influence of the Subtropical Oceans on Atmospheric Carbon Dioxide.

Michael J Follows[1] (617 253 5939; mick@plume.mit.edu)

Takamitsu Ito[1] (617 253 9345,; ito5@mit.edu)

Jochem Marotzke[2] (023 80593755; Jochem.Marotzke@soc.soton.ac.uk)

[1]Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, United States

[2]Southampton Oceanography Centre, University of Southampton, Southampton SO14 3ZH, United Kingdom

Ocean general circulation and biogeochemistry models exhibit a much enhanced sensitivity of atmospheric carbon dioxide to perturbations of the warm surface water properties when compared to classical box models (Broecker et al., Global Biogeochemical Cycles, 13, 817-820, 1999). We demonstrate that this is attributable to the action of the wind-driven circulation and prescence of the ventilated thermocline in the circulation models.

We use an ocean circulation and abiotic carbon cycle model configured in an idealized sector with a coupled atmospheric reservoir of carbon. We compare solutions where the circulation model is driven purely by buoyancy forcing against those with both buoyancy and wind forcing. The model with wind forcing develops subpolar and subtropical gyres and a ventilated subtropical thermocline. The warm lens of the ventilated thermocline is depleted in carbon relative to the surrounding, cooler waters and inherits its properties from the mid-latitude surface ocean at the point of subduction. It is several hundred metres thick and represents a significant ocean carbon reservoir. The sensitivity of atmospheric carbon dioxide to perturbations of low and mid-latitude surface water properties is significantly enhanced in the model with wind forcing, relative to the model with only buoyancy forcing, facilitated by modulation of the carbon budget of the ventilated thermocline. Many highly idealized box models are analagous to the sector model with only buoyancy forcing, having no representation of the ventilated thermocline or its influence on atmospheric carbon dioxide. On the other hand, the wind-driven gyres are partially resolved in global general circulation models leading to their enhanced their sensitivity to subtropical surface perturbations.

The results of these models may be extrapolated to speculate that a global-scale cooling of the ventilated thermocline by 4 degrees during glaciation could reduce atmospheric carbon dioxide on the order of 15 ppmv by this mechanism. Thus, excluding possible changes in the biological pumps, the subtropical thermocline might exert a significant, but not dominant, influence on changes in atmospheric carbon dioxide.

OS32J HC: 323 C Wednesday 1330h

Biogeoinformatics: Challenges at the Intersection of Biological, Biogeochemical, and Physical Data Over Multiple Scales of Space and Time I

Presiding: **R W Buddemeier,** University of Kansas; **R Luettich,** Department of Marine Sciences

OS32J-01 1330h

Non-electronic Sources of Biogeographical Data

Daphne G. Fautin (1-785-864-3062; fautin@ku.edu)

Ecology and Evolutionary Biology, Natural History Museum, and Kansas Geological Survey, University of Kansas, Lawrence, KS 66045, United States

Most historical data and many data currently being collected that are relevant to marine biogeography are unavailable electronically. Putting them into a form that can be stored and used electronically is time-consuming but essential for many purposes. Historical data provide a time dimension of centuries, producing a baseline obtainable in no other way when environmental change is occurring on a scale of decades. Even point measurements of environmental variables can be informative. Taxonomic identification of very few kinds of organisms is possible by remote sensing. Assembling information from museum catalogs – even electronic ones – cannot produce comprehensive taxon lists except, perhaps, for taxa with few members. The presumed difficulties of capturing non-electronic data are primarily those of entry. The human effort involved in entering these data is not so different from that needed to manipulate electronic data (by converting, editing, parsing, etc.) to make them useful for particular purposes.

URL: http://www.kgs.ukans.edu/Hexacoral/

OS32J-02 1355h

Data Assimilation for Modeling and Predicting Multiscale Coupled Physical-Biological Interactions in the Sea

Allan R. Robinson[1] (617-495-2819; robinson@pacific.deas.harvard.edu)

Pierre Lermusiaux[1] (617-495-0378; pierrel@pacific.deas.harvard.edu)

[1]Harvard University, 29 Oxford Street, Cambridge, MA 02138, United States

Data assimilation is now being extended to interdisciplinary oceanography from physical oceanography which has derived and extended methodologies from meteorology and engineering for over a decade and a half. There is considerable potential for data assimilation to contribute powerfully to understanding, modeling and predicting biological-physical interactions in the sea over the multiple scales in time and space involved. However, the complexity and scope of the problem will require substantial computational resources, adequate data sets, biological model developments and dedicated novel assimilation algorithms.

Interdisciplinary interactive processes, multiple temporal and spatial scales, data and models of varied accuracies and simple to complex methods are discussed. The powerful potential of dedicated compatible data sets is emphasized. Assimilation concepts and research issues are overviewed and illustrated for both deep sea and coastal regions. Progress and prospectus in the areas of parameter estimation, field estimation, models, data, errors and system evaluation are also summarized.

OS32J-03 1410h

The Use of Near Real Time, High Resolution Fish and Environment Data in an Aedvanced Fisheries Management Information System

Wendell S. Brown[1] (508-910-6395; wbrown@umassd.edu); Frank L. Bub[1] (508-910-6307; fbub@umassd.edu); Brian J. Rothschild[1] (508-910-8193; brothschild@umassd.edu); Miles Sundermeyer[1] (508-910-8892; msundermeyer@umassd.edu); Avijit Gangopadhyay[1] (508-910-6330; avijit@umassd.edu); Robert Lane[2] (508-539-4241); Allan R. Robinson[3] (617-495-2819; robinson@pacific.harvard.edu); Patrick J. Haley[3] (617-495-2827; haley@pacific.deas.harvard.edu)

[1]School for Marine Science and Technology, University of Massachusetts Dartmouth, 706 S. Rodney French Blvd., New Bedford, MA 02744-1221, United States

[2]New Bedford Trawler Survival Fund, F/V Isabelle S., 113 MacArthur Dr., New Bedford, MA 02740, United States

[3]Division of Applied Sciences, Harvard University, 29 Oxford St., Cambridge, MA 02138, United States

Working under the hypothesis that more frequent information would help to improve science and management practice, we have built a prototype operational advanced fisheries management information system (AFMIS). AFMIS, which consists of ocean data, a suite of coupled data assimilation models, and a data and information management system, is designed to be operated in near real time and is able to provide frequent (hourly to weekly), high resolution (1-10km), multi-species fisheries nowcast and forecast information. In this implementation the Harvard Ocean Prediction System (HOPS) ocean circulation model is linked with a highly simplified fish model that simulates fish movement as a combination of swimming toward a preferred temperature–"advection"–and a background random searching–"diffusion." To obtain some of the data needed by AFMIS, we have partnered with a fleet of 20 commercial ground fishing vessels, from which selected fishermen obtain the in situ ocean environment and fisheries (up to 50 species) data. The fleet observations, as well as Fleet Numerical Meteorological and Oceanographic Center model meteorological forcing data and satellite imagery, are being assimilated into an ongoing weekly series of prototype AFMIS nowcasts and forecasts. Since November 2000, coincident bottom temperature and fish catch data have been collected during about 4700 separate trawls. This unique data set provides fish abundance estimates and associated environmental data for up to 50 species, with the target species of primarily yellowtail flounder during winter and codfish and/or haddock during spring/summer. The fish abundance estimates exhibit the typical three orders of magnitude range with a significant number of zero catches. Our efforts to explain these large variances in terms of physical environment and fish behavior will be discussed.

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The Partnership for Interdisciplinary Studies of Coastal Oceans: Enabling Flexible Data Management Within a Long-Term, Large-Scale Consortium

Christopher S Jones[1] (805-893-5144; cjones@lifesci.ucsb.edu); Steven D Gaines[1] (805-893-5145; gaines@lifesci.ucsb.edu); Matthew B Jones[2] (805-892-2531; jones@nceas.ucsb.edu); Chad Berkley[2] (805-892-2531; berkley@nceas.ucsb.edu); Jivka Bojilova[2] (805-892-2531; bojilova@nceas.ucsb.edu); Daniel Higgins[2] (805-892-2531; higgins@nceas.ucsb.edu)

[1]Marine Science Institute, University of California, Santa Barbara, Santa Barbara, CA 93106, United States

[2]National Center for Ecological Analysis and Synthesis, University of California, Santa Barbara, Santa Barbara, CA 93106, United States

The Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) is investigating how physical oceanographic phenomena influence near-shore community structure over large geographic scales. Many of the important questions about the near-shore ocean environment remain unanswered and require data drawn from both oceanographic and biological sciences. Integrating these types of data presents an information management challenge, because each discipline produces inherently different types of data. PISCO generates two broad and disparate types of data: physical oceanographic data that are high volume, homogenous measurements (e.g., current velocity and direction), and biological data are often low volume, heterogeneous