generally correlate with the benthic foraminiferal isotopic record. To determine paleotemperatures, we estimated seawater $\delta^{18}O$ from Lear et al. (2000, Science, 287: 269-272) using the latitudinal correction of Zachos et al. (1994, Paleoceanography 9:353-387). The isotopic records show a warm early Eocene tropical climate (mean annual temperature = 26-27 ^{o}C) with a seasonal temperature range (seasonality) of about 6 ^{o}C, followed by cooling and an Oligocene paratropical climate (22-23 ^{o}C) with a seasonality of about 8 ^{o}C. These results are generally consistent with paleobotanical data, but suggest that seasonality increased at least sporadically prior to the Eocene-Oligocene boundary. The warm Eocene temperatures and cooling trends, with more significant winter cooling (5 ^{o}C) than summer cooling (3 ^{o}C), support the contention that atmospheric CO2 change was a major factor controlling Paleogene climate change.

OS31I-07 1035h INVITED

Influence of Ocean-Atmosphere Feedbacks on Warm Climates

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The role of ocean circulation in maintaining warm climates remains one of the outstanding questions in paleoclimatology. This debate has focused largely on the mode of the deep circulation during warm climates. However, feedbacks between the surface ocean and atmosphere cannot be overlooked. As exemplified by the modern ENSO phenomenon, relatively small surface ocean perturbations can have a powerful influence on atmospheric circulation and the transports of sensible and latent heat. The narrowing of the Pacific Ocean over the last 100 million years almost certainly yielded much larger changes in the surface climate of the ocean than that caused by ENSO variability.

To explore this topic, a series of Cretaceous simulations has been completed using the Fast Ocean Atmosphere Model, a fully coupled general circulation model. The Cretaceous simulations include paleogeography for 100 Ma, elevated atmospheric CO_2 concentrations (1380 ppm), and a reduced solar luminosity (99% of modern). The Cretaceous experiments were run in fully coupled and uncoupled modes. (In the uncoupled mode, a simple slab ocean model is used as the lower boundary condition to the atmospheric model.) These experiments will be compared to demonstrate the effect of dynamic oceanic circulation on the Cretaceous atmospheric circulation. Preliminary results indicate that feedbacks between the ocean and atmosphere play an important role in the maintenance of a warm Cretaceous climate. It is hypothesized that changes in the ocean-atmosphere feedbacks may have contributed to the Cenozoic cooling trend of the last 55 million years.

OS31I-08 1050h

Glacial-to-interglacial-to-glacial climate change inferred from subarctic deep water $\delta^{18}O$ records

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Benthic foraminiferal $\delta^{18}O$ data from sediment cores of the deep Nordic seas were investigated, in combination with proxy records of carbonate content, iceberg-rafted debris (IRD), and planktic foraminiferal $\delta^{18}O$, to reconstruct and interpret some major ocean changes in this climatically sensitive region over the last 5 climate cycles. In particular, complete interglacial cycles were studied in more detail, i.e., time intervals that always include a glacial maximum, the ensuing peak warm period, and the inception of glacial conditions. Marine isotope stages (MIS) 11, 5e, and 1 have been identified as the three most pronounced interglacial periods. Of the three glaciations (MIS 12, 6, 2) that preceded these warm climate intervals, MIS 12 is recognized as the one when ice volume was largest and, consequently, sea level lowest. Of all peak interglacial periods studied, MIS 5e had the smallest ice volume whereas interglacial intervals MIS 11 and 1 show similar $\delta^{18}O$ values, indicating ice volumes and sea levels of comparable magnitude. The early parts of the interglacial-to-glacial transitions, which followed upon the peak interglacial interval in MIS 11 and 5e, show the first significant increase in benthic $\delta^{18}O$ almost time-coeval with a recurrence of IRD. A similar finding is noted in the proxy records from the youngest Holocene sediments. From this it may be concluded that the present oceanic conditions in the Nordic seas are in such a critical state that significant effects on the thermohaline system cannot be precluded for the time to come.

OS31I-09 1105h

Low and High Latitude Linkages During the Transition From Early Pliocene Warmth to Northern Hemisphere Glaciation

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Continuous well-dated records of oceanic change over the last 5 Ma have been generated from cores recovered by the Ocean Drilling Program from many locations around the globe. Although a large-scale picture of conditions of some intervals within the Early Pliocene warm period (from about 4.6 - 3.1 Ma) exists, the transitions into and then out of this period to the colder period of the Late Pliocene and Pleistocene have only partially been described. The mechanisms of these climate transitions can only be derived from comparing records from high and low latitudes, and from shallow and deep water. In this study we present new data (mostly oxygen isotopes of foraminifera) from tropical and sub-tropical regions in the context of data from other regions. We find that the transition from cooler conditions into the Pliocene warm period (at 4.6 Ma) is marked by an increase in North Atlantic Deep Water (NADW) formation and a reorganization of tropical conditions (the initiation of an El Nino like state). The transition out of the Pliocene warm period is marked by an increase in global ice volume, a reduction in NADW, and an increase in stratification of the North Pacific Ocean. While the thermohaline circulation adjusts in concert with ice sheet development, there is no significant change in low latitude conditions. The increase in the amplitude of ice volume variability at this time is linearly related to the insolation changes. Therefore, the end of the warm period and the onset of larger Northern Hemisphere glaciation at around 3.0 Ma appears to be part of a gradual trend rather than a pronounced change in climate sensitivity. The most dramatic increase in the sensitivity of ice sheet response to insolation forcing actually occurs at around 2.0 Ma when a new state in the sub-tropics and in the tropics is established. For example, Walker Circulation and subtropical circulation that determines California margin dynamics are intensified. These observations suggest that low latitude conditions, with a marked change at 2.0 Ma, play a critical role in shaping climate sensitivity to insolation changes and thus, high frequency variability through the Plio-Pleistocene. The only way to connect the events at the end of the Pliocene warm period at 3.0 Ma to the pronounced change in low latitude conditions at 2.0 Ma is to invoke a non-linear process that links distant regions. We explore the idea that a gradual change in the thermocline, and its non-linear relationship to tropical SSTs, can explain the global array of Pliocene observations.

OS31I-10 1120h

Did an open Panama isthmus prevent the establishment of a meridional overturning cell in the Atlantic Ocean?

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Existing general circulation modeling studies suggest that, prior to the closure of the Panama isthmus, low salinity Pacific ocean water invaded the Atlantic Ocean via the associated gap between North and South America. According to this scenario, the invasion decreased the Atlantic Ocean salinity to the point where deep water formation was impossible and, consequently, no conveyer belt movement was in action.

Using simple dynamical principles, analytical modeling and process-oriented numerical experiments, it is shown that one would normally expect a flow from the Atlantic to the Pacific Ocean (rather than from the Pacific to the Atlantic) through an open Panama isthmus. An analogous present-day situation is that of the Indonesian Throughflow which brings Pacific water to the Indian Ocean rather than the other way around. The direction of the flow in both situations is primarily determined by the wind field to the east of the gaps.

On this basis it is suggested that if low salinity Pacific water did in fact invade the Atlantic Ocean prior to the closure of the Panama isthmus, then this invasion took place via the Bering Strait rather than through the open Panama Isthmus.

OS31I-11 1135h

Blackbody Temperature in Terms of Orbital Elements and the Milankovitch Precession Index Cycle

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The temperature T of a black or gray body orbiting the Sun can be expressed in terms of spherical harmonics in latitude and longitude, its Keplerian orbital elements, and a variable describing rotation about its axis. Assuming that the Earth is a gray body, the resulting equation for T exhibits previously unrecognized odd-degree zonal terms dubbed Seversmith psychroterms. They cause a hemispheric temperature gradient which depends upon e sin w, where e is the orbital eccentricity and w is the Suns argument of perihelion. The hemisphere containing perihelion is the cooler. For a gray body with the Earths average albedo of 0.3, an emissivity of unity, and an obliquity of 23.5 degrees, the pole-to-pole temperature difference for the combined first and third degree spherical harmonic psychroterms can reach 3.4 K for the present eccentricity of 0.016, and 12.9 K for the maximum eccentricity of 0.06. While a black body with its boiling hot subsolar point and nights at absolute zero is a poor model for the Earth, the Seversmith psychroterms survive in more realistic models (although with smaller amplitudes) because the Earth radiates nonlinearly in T. The psychroterms acts in the direction opposite to the Milankovitch precession index, which also depends on e sin w: by warming the cool northern summers, the psychroterms make it harder for the traditional Milankovitch mechanism to operate. It may in fact be the Seversmith psychroterms which are actually responsible for the ice sheets which cycle with e sin w, instead of the Milankovitch mechanism. By cooling the southern hemisphere when perihelion is in the south, the psychroterms may somehow cause the southern hemisphere to control the northern ice sheets associated with the 19 kyr and 23 kyr periods (kyr = kiloyear), possibly through ice-albedo feedback in the sea-ice surrouding Antarctica.

W E D

OS31J HC: 319 A Wednesday 0830h

Synthesis of Pacific Ocean Carbon Cycle Research I

Presiding: **C Sabine,** University of Washington**; F P Chavez,** MBARI

OS31J-01 0830h INVITED

Recent Changes in the AOU of the Upper Thermocline in the North Pacific Ocean

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In the year 2001 there were three papers published that reported an increase in the AOU in the upper thermocline of the North Pacific Ocean between the 1980s and 1990s (Watanabe, 2001; Ono, 2001; and Emerson et al., 2001). I use a simple model of the atmosphere and the upper equatorial - subtropical North Pacific Ocean to demonstrate the sensitivity of the ocean and atmosphere reservoirs of oxygen to changes in carbon export or ocean circulation. The model cannot distinguish between an increase in carbon export and a slow down in circulation as the cause of the increase in AOU. Increases in the CFC-determined water mass age on some of the reported transect reoccupations indicate that the circulation has slowed between the 1980s and 1990s. Increases in the primary production and chlorophyll in the subtropical North Pacific suggest the carbon export may also have increased in this time interval. While it is not presently possible to determine the roles of changes in circulation and the biological pump in causing the increase in AOU in the upper thermocline, we know that the nutrient-depleted subtropical upper ocean does not respond as a simple system in which carbon export is limited by nutrient flux from below. An increase in AOU in response to either a slow down in circulation or an increase in the biological carbon pump suggests that circulation and carbon export are uncoupled. The mechanisms causing the change in

AOU in the upper ocean are likely decadal-scale oscillatory forcing or global warming, but the processes controlling carbon export are presently not well enough understood to predict its response to these changes.

Emerson, S. , S. Mecking and J. Abell (2001) Glob. Biogeochem. Cycles, 15, 535-554

Watanabe, Y. et al. (2001) Geophys. Res. Letts. , 28, 3289-3292.

Ono, T. et al. (2001) Geophys. Res. Letts., 28, 3285-3288.

OS31J-02 0850h

Possible Biological or Physical Explanations for Decadal Scale Trends in North Pacific Nutrient Concentrations and Oxygen Utilization

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We analyze North Pacific GEOSECS (1970s) and WOCE (1990s) observations to examine potential decadal trends of the marine biological carbon pump. Nitrate concentrations ($[NO_3^-]$) and apparent oxygen utilization (AOU) decreased significantly in intermediate waters (by -0.6 and -2.9 μmol kg^{-1}, respectively at σ_θ =27.4 kg m^{-3}, corresponding to an average depth of $\approx$ 1050 m). In shallow waters (above roughly 750 m) $[NO_3^-]$ and AOU increased, though the changes are not statistically significant. A sensitivity study with an ocean general circulation model indicates that reasonable perturbations of the biological carbon pump due to changes in export production or remineralization efficiency are insufficient to account for the intermediate water tracer trends. However, changes in water ventilation rates could explain the intermediate water tracer trends and would be consistent with trends of water age derived from radiocarbon observations. Trends in AOU and $[NO_3^-]$ provide relatively poor constraints on decadal scale trends in the marine biological carbon pump for two reasons. First, most of the expected changes due to decadal scale perturbations of the marine biota occur in shallow waters, where the available data are typically too sparse to account for the strong spatial and temporal variability. Second, alternative explanations for the observed tracer trends (e.g., changes in the water ventilation rates) cannot be firmly rejected. Our data analysis does not disprove the null-hypothesis of an unchanged biological carbon pump in the North Pacific.

OS31J-03 0905h

Analysis of New Production Variability in the High-Nitrate-Low-Chlorophyll Regions

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The High-Nitrate-Low-Chlorophyll (HNLC) regions in the Subarctic, Equatorial and Antarctic Pacific are characterized by phytoplankton biomass that is low year-round, and by primary production that is lower than expected from the ambient nutrient levels. The similarity of the plankton cycles in these three locales is striking given the large differences between their physical environments (e.g. temperature, light, mixing and upwelling/downwelling). Understanding what controls new production variability within and between the three HNLC regions is important because these areas comprise some of the largest CO_2 fluxes to and from the atmosphere, and are potential zones where the biological pump may be enhanced. Toward that end, we performed regression analyses on a synthesis of data from JGOFS and other programs, to assess the extent to which observed variability in new production in the HNLC regions was explained by other physical and biochemical variables.

Significantly different f-ratios were observed in the different HNLC regions, with such large dynamic ranges within each one that estimates of new production made using mean values have associated errors of 50%. The observed variability is not explained by historical regressions of f-ratios versus primary production, dissolved nitrogen or temperature, or by correlations of f-ratios with any other single environmental variable. This points to multivariate control of new production, as has recently been shown for the Tropical Pacific by a multiple linear regression (MLR) of new production versus primary production (or chlorophyll), nitrogen, ammonium and temperature. When examined for the Equatorial Pacific, the fit of this MLR is slightly degraded, but still captures most of the observed variability. However, the same MLR systematically underestimates new production in the Subarctic Pacific, and results in very poor R-squared values. Further analyses revealed major differences in the simple correlations of variables between the HNLC regions. We present a new MLR using different variables, that is capable of estimating new production within the Subarctic Pacific HNLC, and discuss how the different correlations point to different controlling mechanisms between these HNLC regions.

OS31J-04 0920h

Latitudinal Change of Remineralization Ratios in the Oceans and Its Implication for Nutrient Cycles

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A new three-end-member mixing model is introduced to obtain the remineralization ratios of organic matter in the water column. The remineralization ratios ($P/N/C_{org}/-O_2$) of organic matter in the deep water column change systematically from the northern Atlantic to the Southern Oceans, then to the equatorial Indian and the northern Pacific oceans, more or less along the global ocean circulation route of deep water. The average remineralization ratios for the northern Atlantic are $P/N/C_{org}/-O_2 = 1/(16\pm1)/(73\pm8)/(137\pm7)$, and for the Southern Oceans $P/N/C_{org}/-O_2 = 1/(15\pm1)/(80\pm3)/(133\pm5)$. Those values are similar to the traditional Redfield ratios of $P/N/C_{org}/-O_2 = 1/16/106/138$ for marine plankton, except for the low C_{org}/P ratio. Conversion of organic nitrogen into gaseous N_2O and N_2 in a low-oxygen or reducing micro-environment of organic matter and/or bacteria is an important process throughout the oxygenated water column of the equatorial Indian and the northern Pacific oceans. If one adopts an N/P ratio of 15$\pm$1, the average remineralization ratios for the equatorial Indian Ocean are $P/N/C_{org}/-O_2 = 1/(15\pm1)/(92\pm5)/(130\pm7)$, which are closest to the traditional Redfield ratios. The average remineralization ratios for the northern Pacific Ocean are $P/N/C_{org}/-O_2 = 1/(15\pm1)/(123\pm11)/(162\pm11)$, indicating high organic carbon content in remineralized organic matter. No temporal trends of the remineralization ratios are detected when comparing the results obtained by the GEOSECS and WOCE data sets.

OS31J-05 0935h INVITED

Temporal and spatial variability in the air-sea flux of carbon dioxide in coastal and open ocean upwelling systems

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In this contribution we present biological and chemical observations from coastal and open ocean upwelling regions in the Pacific Ocean and explore with a very simple model the processes that regulate the concentration of inorganic carbon in surface waters and its exchange with the atmosphere. Our focus is on short term degassing effects, biological drawdown and the long term effects of variable C:N ratios. The most striking difference between the two systems is the rate of biological uptake of carbon. The rate of biological drawdown of CO2 is a product of the plant biomass (typically reported as chlorophyll a), and the specific rate of nutrient uptake (V nutrient). Chlorophyll concentration in the ocean can vary by several orders of magnitude while the specific uptake rate of nitrate is reported to vary by less than order of magnitude. The general pattern of plant biomass distribution in the ocean is for higher concentrations close to continents and lower biomass in offshore waters. This spatial distribution is accompanied by changes in species composition and in specific nitrate uptake rate. Coastal upwelling regions typically are dominated by larger organisms, primarily diatoms and may have higher specific nitrate uptake rates. Open ocean upwelling systems are dominated by small cyanobacteria and may have lower specific nitrate uptake rates. These ecosystem differences lead directly to the observed temporal and spatial variations in the air-sea flux of carbon dioxide in coastal and open ocean upwelling systems.

OS31J-06 1015h

Biogeochemical Processes During the Subarctic Pacific Iron Experiment for Ecosystem Dynamics Study (SEEDS)

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Iron limitation has been proposed as the reason for the existence of surface waters rich in macro-nutrients but low in phytoplankton biomass in the subarctic Pacific, the equatorial Pacific and the Southern Ocean. Recent *in situ* iron enrichment experiments confirmed this in the equatorial Pacific and the Southern Ocean. In the Subarctic Pacific, with biology and water structure different from the other two regions, strong zonal gradients in atmospheric iron deposition existing between the eastern and western gyres, may give rise to distinct phytoplankton communities that characterize these biogeochemical provinces. Here we present an overview of SEEDS (Subarctic Pacific Iron Experiment for Ecosystem Dynamics Study), the first *in situ* test of the iron limitation hypothesis on natural ecosystem and geochemical cycles in the subarctic Pacific. An *in situ* iron enrichment experiment was conducted in the western subarctic gyre of the North Pacific (48.5°N, 165°E) from 18 July to 1 August 2001. The experiment consisted of a single addition of 350 kg iron as $FeSO_4$ with an inert tracer gas sulphur hexafluoride, over an 8 × 10 km patch with a mixed layer depth of 10 m. Initial concentration of dissolved iron in the patch was ca. 1.9 nM (mean value of Day 1 underway transect; maximum recorded was 6.0 nM). During this experiment, we observed unambiguous and massive biogeochemical responses to the iron addition, which resulted in an increase in chlorophyll *a* concentrations to as high as 20 $\mu g\ l^{-1}$ and large drawdowns in carbon dioxide and nutrients. In addition, iron supply led to floristic shifts that resulted in the dominance of chain-forming large centric diatoms, unlike the equatorial Pacific and the Southern Ocean where iron stimulated the growth of pennate diatoms. These results clearly demonstrate that iron availability fundamentally controls the magnitude of phytoplankton response thereby regulating the biogeochemical processes in high nutrient areas of the western subarctic Pacific.

OS31J-07 1030h

Dynamics of Iron During the Subarctic Pacific Iron Experiment for Ecosystem Dynamics Study (SEEDS)

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An Iron enrichment experiment was carried out in the western subarctic Pacific Ocean during the 2001 summer. A patch of water in western subarctic gyre was fertilized with 1740kg of $FeSO_4 7H_2O$.

In order to understand the changes in iron distribution throughout the evolution of the phytoplankton bloom, iron concentrations were measured underway transects throughout the patch and in vertical profiles of the upper water column (5 - 70 m) of In- and Out-patch station. The physical speciation of iron was also investigated in several size-fractionated pools, as defined as: particulate (> 0.2 μm), dissolved (< 0.2 μm), colloids (200kDa - 0.2 μm) and soluble ($<$ 200 kDa), using ultrafiltration technique. Unfiltered and filtered samples were analyzed for Fe (III) in near real time by onboard flow injection chemiluminecence systems.

Prior to release of iron, dissolved iron concentrations in the ambient surface seawater were extremely low ($< 0.05 \pm 0.02$ nM). At the first underway transects throughout the patch after the iron release (within 4.5 - 11.5 h from the iron release), we observed significant increase of dissolved iron. Mean value calculated using all measurements of first underway transect in the patch was 1.88 nM (n=28) and maximum concentration was 6.02nM. At the first vertical observation in the patch (D2), more than 75 % of dissolved iron was in the colloidal (200 kDa - 0.2 μm) fraction in surface layer. Dissolved iron concentrations subsequently decreased rapidly (0.99 nM, D3), and loss rate gradually decreased. Dissolved iron concentrations did not decrease below about 0.15 nM even after phytoplankton bloom development. While, more than 1 nM particulate (> 0.2 μm) iron concentrations were observed throughout the experiment and the portion of this fraction in total dissolvable iron (unfiltered fraction) elevated with decrease of concentration of colloidal iron fraction in surface layer. The processes resulting in the high particulate iron in surface layer and the changes of the portion between soluble and colloidal fraction are discussed.

OS31J-08 1045h

Primary Production and N Assimilation during the Subarctic Pacific Iron Experiment for Ecosystem Dynamics Study (SEEDS 2001).

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Primary production and N assimilation rates were measured in the SEEDS 2001 cruise. Bottle incubation experiments on board were also conducted to elucidate the effects of Fe concentration and temperature on the growth of phytoplankton and nutrient utilization. Primary production was measured using ^{13}C method and nitrate, ammonium and urea uptake rates were measured using ^{15}N method with simulated on board incubation for 24 hr. For bottle incubation, subsurface seawater samples spiked with $FeCl_3$ ranging from 0-2 nM were incubated at 5, 9, 13 and 18?C for 14 days. Nutrients, size-fractionated chlorophyll a and phytoplankton species composition were measured. Nitrate was abundant at 17 μM before the iron enrichment as well as phosphate and silicate. Absolute nitrate uptake rate at 5 m depth was 0.2 μmol l^{-1} d^{-1} on Day 0 and the same as ammonium uptake rate. This rate sharply increased 20 times after Day 7. The maximum rate was observed on Day 9 at 4.2 μ mol l^{-1} d^{-1}. The day integrated nitrate uptake rate between Day 4 and 9 was 10.8 μM, which was consisted with the amount of nitrate distinction in situ at 8.5 μM. Absolute uptake rate of ammonium increased from 0.2 to 1.3 μmol l^{-1} d^{-1} on Day 4, but stayed a constant level afterwards. The ratio of new production to total production (f-ratio) was low at 0.2 before Day 4, but increased to 0.7 on Day 7 and maintained high ratio at 0.8 until Day 13. These results suggested that nitrate assimilation pathway was woken up by the Fe enrichment to meet a high N demand required for a high growth rate of dominant phytoplankter *Chaetoceros debile*. The deck incubation of subsurface seawater samples taken on Day 2 revealed that the increase in chl a was almost the same between in situ and in vitro, but the draw-down of nutrients was much faster in vitro than in situ. The specific growth rate increased with the amount of spiked $FeCl_3$ and was also the function of incubation temperatures. The results from on board incubation indicated that community growth rate, nutrient utilization and species composition were highly dependent on Fe concentration and growth temperature.

OS31J-09 1100h

Export flux and carbon system changes in the Subarctic Pacific Iron Experiment for Ecosystem Dynamics Study (SEEDS)

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The Subarctic Pacific Iron Experiment for Ecosystem Dynamics Study (SEEDS) in July 2001 was carried out in the western subarctic gyre having high surplus of macro-nutrients during summer season. The underway pCO_2 system with high measurement frequency (1 minute interval data logging) with real time monitor facilitated to trace the enrichment patch with biological draw down of pCO_2 after the pCO_2 decrease inside was observed. The pre-experiment condition of the iron enriched area showed uniform pCO_2 of 379-391 μatm. The change of pCO_2 inside the iron patch was observed after 5 days of the iron enrichment, when 20 μatm of pCO_2 decrease was observed from the outside of the iron patch associating surface chlorophyll-a increasing. The draw down of pCO_2 expanded up to 146 μatm after 11 days of the iron enrichment.

Export flux was measured using drifting sediment traps (Knauer type). Trap has eight tubes for each depth and organic carbon, silica and metallic elements in the trapped material were analyzed or now being analyzed. The depths of the traps were 20, 40, 60, 100 and 200 m from the sea surface. The trap inside iron patch was applied and recovered at about 2 days of interval. The reference trap outside iron patch was applied and recovered at about 4 days of interval. The trap tubes were filled by brine with formaldehyde. Enormous amount of swimmers was trapped, but removed under microscope. The majority of the trapped material was fecal pellet of zooplankton with green color.

Increase of export flux was observed after 7 days from the enrichment. It was approximately doubled from the reference trap outside iron patch. SiO_2 concentrations in the trapped material were about 30-45% for the outside but 40-55% for the inside traps after phytoplankton blooming started. This indicates diatom dominance both inside and outside of the patch. The export flux inside of the patch increased until 12 days after the enrichment and then slightly decreased. Wind driven deviation of the patch inside trap was occasionally occurred, which made it difficult to estimate the export flux accurately, however, the increasing of the export flux inside the trap was apparent.

The dissolved inorganic carbon (DIC) decrease inside the patch was nearly equivalent to the POC content in the surface mixed layer. The export carbon flux was about one tenth of the DIC decrease. This suggests that the carbon export should be succeeded after we left the experiment site after 14 days of enrichment.

OS31J-10 1115h

Identifying the Mechanisms Likely Responsible for Changes in Bulk Bacterioplankton Stocks and Processes in the Subarctic NE Pacific.

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Mixed-layer bacterial abundance, productivity, and growth rates were measured in the subarctic NE Pacific along the line-P transect westward from slope waters off Juan de Fuca Strait to open-ocean waters at ocean station Papa. Sampling was done during winter, spring, and late summer between 1993 and 1999. Slope waters in this region typically exhibit spring bloom and summer nutrient depletion, whereas the oceanic waters exhibit no spring bloom, consistently replete macronutrients, and iron limitation of primary productivity. The measured bacterial properties were compared to concurrently measured temperature, salinity, mixed-layer depth, macro-nutrient concentrations, chlorophyll concentrations (total and size fractionated), primary productivity (total and size fractionated), and heterotrophic flagellate abundance. Positive correlations between bacterial properties and both chlorophyll and primary productivity were dominated by only a few data points (outliers) associated with identifiable physical fronts. Aside from the outliers, bacterial properties were typically negatively correlated with chlorophyll and either not, or only weakly positively correlated with primary productivity. Bacterial properties increased in association with indicators of past algal production and/or current algal nutrient stress in conjunction with high light (low macro-nutrients, low chlorophyll, shallow mixed-layer). Bacterial properties decreased with increased dilution processes (increased salinity and mixed-layer depth, decreased temperature). Dilution processes were prominent in the winter when growth rates were low, and over the annual cycle in association with the fall deepening of the mixed-layer from ~20 to 120 m. Past algal production and/or current algal nutrient stress appeared to drive seasonal increases in bacterial abundance and productivity. However, at times, direct mineral nutrient stress also limited bacteria in the spring and summer. These data suggest that bacterial abundance and productivity are often decoupled from phytoplankton productivity either because of physical processes (dilution) acting differently on bacteria and phytoplankton, or due to increased algal DOM excretion associated with high light and nutrient stress (i.e., primary production did not contribute to phytoplankton biomass production). These data also suggest that significant regressions between bacterial properties and phytoplankton properties over a large range of values may offer little insight into the causes of change over the typical ranges of values encountered.

OS31J-11 1130h

Suspended and settling particles in the northern and southern hemispheres of the Pacific

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In order to understand the vertical transport of particulate matter, suspended and settling particles were collected along a meridional transect between 46N and 35S and an equatorial longitudinal transect between 135E and 175E in the Pacific. The low Corganic/N atomic ratios (less than 8.2) of suspended particulate organic matter (OM) and good correlation between particulate organic carbon (OC) and chlorophyll-a confirmed that the suspended particulate OM in the surface water was mainly produced by phytoplankton. Only 0.1% to 3.2 % of primary production was transported to 1.3 km water depth in the boreal central Pacific. All data on settling particles (excluding deep trap data) showed strongly positive correlation between total mass and OM fluxes with high correlation factor of 0.93. Biogenic opal-producing plankton, mainly diatom, was responsible for most of the vertical transport of particulate OM in association with higher Corganic/Ccarbonate ratios in the subarctic and equatorial hemipelagic regions in the Pacific. This vertical transport of settling particles potentially works as a sink of CO2. In the transition zone during the May 1993, large difference between PCO2 (less than 300 micro-atm) in the surface water and pCO2 (340 micro-atm) in the atmosphere was actually due to enhanced particulate OM flux. Since the deep water of the Pacific is enriched in CO2 and nutrients, upwelled seawater may tend to release CO2 to the atmosphere. However, higher production of particulate matter could reduce the partial pressure of CO2 in the surface water. Also terrestrial nutrients' inputs in the western equatorial Pacific have potential for the reduction of CO2 in the surface water.

OS31J-12 1145h

Carbon Isotope Ratios of Organic Compound Fractions Separated From Sinking Particulate Organic Matter at a Deep Sea Station in the Northeast Pacific

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Carbon isotope ratios ($\Delta^{14}C$, $\delta^{13}C$) were measured on organic fractions separated from sinking particulate organic matter (POM) collected at station M in the Northeast Pacific (a 3450m depth, 650 m above bottom, 34^{o}50'N, 123^{o}00'W). To study the variability of the carbon isotope ratios with the flux of POM, 13 samples were chosen from low flux to high flux (1-27 mgC/m^2/d) periods (10 day period samples were combined if needed). Four classes of organic fractions (lipids, total hydrolyzable amino acids (THAA), total hydrolyzable carbohydrates (TCHO) and acid insoluble fractions) were separated by extraction with organic solvents, and elution through ion-exchange resin column after hydrolysis by strong acids (Wang et al, 1996).

Percent dry weight of the refractory (acid insoluble) fraction is inversely correlated with organic carbon flux, while those of the labile fractions (lipids, THAA, and TCHO) are directly correlated. $\delta^{13}C$ values of bulk organic matter show a positive correlation with organic carbon flux suggesting that the properties at the surface ocean such as primary productivity, pCO_2, and change of plankton communities may be responsible. $\delta^{13}C$ values of each fraction show the same trend as the bulk organic matter. $\delta^{13}C$ values for THAA and TCHO fractions are higher than those for lipids and the acid insoluble fractions. Bulk POM samples have lower $\Delta^{14}C$ values than those of dissolved inorganic carbon in the surface water, but they do contain bomb ^{14}C (>-50 $^o/_{oo}$). $\Delta^{14}C$ values of THAA and TCHO fractions are higher than those for lipids and acid insoluble fractions. The range of $\Delta^{14}C$ values for organic fractions from a single sample is larger during low flux periods than those during high flux periods. These trends will be discussed in terms of degradation, remineralization, bacterial heterotrophy and the exchange of carbon with other carbon pools such as dissolved organic carbon (DOC).

Wang, X-C, E.R.M. Druffel and C. Lee, 1996. Geophysical Research Letters, 23, 3586.

OS31K HC: 323 B Wednesday 0830h

Biophysical Factors Affecting the Growth and Survival of Aquatic Organisms I

Presiding: **J Ackerman,** University of Northern British Colombia

OS31K-01 0830h INVITED

Lost History of Unsteady Flows at Low Reynolds Numbers

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Small-scale flow dynamics are important to plankton in delivery of nutrients, sensory detection by and physical encounter with predators, accumulation of bacterial populations in the phycosphere or region immediately surrounding phytoplankton cells and coagulation of cells themselves as a mechanism terminating blooms. In nature, most organisms in upper mixed layers and bottom boundary layers experience unsteady flows. Velocities near the individual vary with time due to the intermittency of turbulence, to discontinuous, spatially distributed pumping by suspension feeders or to the organism's own unsteady swimming behavior, yet most laboratory mathematical and laboratory models at low Reynolds numbers (Re) have used steady flows. Moreover, despite the fact that accurate derivations for simple geometries date back to Boussinesq in 1885, models of unsteady flows at low Re have largely been ignored in biological applications. Objects at very low Re perturb the flow large distances away (of order 100 object radii). A consequence for an object in the range of 0.1 to 1 mm in diameter, shortly after an acceleration begins, is that accelerations are substantially resisted by a so-called "history" term that accounts for the need to change this spatially extensive flow field or "wake." For this size range (a common one for plankton, including many larvae and most species of phytoplankton) and the normal density (specific gravity) range of organisms, the effect is generally larger in magnitude and longer lasting than the more familiar "acceleration-reaction" or "added-mass" term. New singularity solutions from mechanical engineering make calculations for realistic organism shapes feasible, and PIV methods allow experiments in unsteady flows.

OS31K-02 0915h

Filter-Feeding in Daphnia? 1) Flow of Water Through Daphnia

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The feeding current of Daphnia enters the carapace and only algae entrained in this feeding current may be captured by the animal. The question was: where will the particles separate from the water? We investigated the flow of water from entering the carapace to leaving it. We used India ink to trace the flow while observing with high-speed video equipment. We also used fluoresceine dye as a tracer and a macro-epi-fluorescence illumination in conjunction with high-speed and normal speed video.

Our results show that the path of a water parcel through the carapace depends on the point of entering the carapace. Water parcels entering mid-ventral and in the plane of symmetry can reach the food groove directly depending on its temporal position within the timing of the motion by the feeding appendages. Water parcels entering at other positions will flow through the carapace differently; some will be discarded within one, some within two cycles.

We will show the flow system of Daphnia in a video and discuss its spatial structure and the temporal character of the speeds involved in mosaic graphs.

URL: http://www.uwm.edu/~jrs/research_topics.htm

OS31K-03 0930h

Filter-Feeding in Daphnia? 2) Capture of Particles

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Particles entrained within the feeding current may end up in front of the mandibles. The question we investigated is what track will particles take to get there after entering the carapace. We observed the fate of particles entrained in the feeding current with high-speed video and epi-fluorescence optics.

Our results show that the point of entering the carapace determines the track a particle will take within the feeding O'machineOL of Daphnia. The particles will be accelerated and decelerated several times before hitting the food groove. Once in the food groove they will be transported to the spot in front of the mandibles. The path of an alga will not follow the path of the water originally surround it. However their paths are predictable given the points of spatial and temporal entrance into the carapace.

We will show the tracks of particles in a video and discuss the spatial and temporal character of particle captures in Daphnia.

URL: http://www.uwm.edu/~jrs/reserch_topics.htm

OS31K-04 0945h

Filter-Feeding in Daphnia? 3) Questioning the Filter Hypothesis

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For over 100 years researcher wondered how Daphnia captures its food. The feeding appendages and their motions challenged all techniques used to demystify the way Daphnia feeds. Heated debates, orally, as well as in print, replaced concepts based on physics.

We used the latest techniques, such as high-speed video recording and epi-fluorescent illumination, to observe the fate of water parcels and suspended particles. We may have shed enough light on the problem to allow a synthesis explaining the underlying principles. We will show that the repeated acceleration and deceleration of parcels of water and their entrained particles separates the particles from the water. We will also show that only a very small percentage of water passes through the filtering structures. Our observations contradict the assumptions of so many researchers of the past 100 years while enhancing statements of a few others.

We will show in a video the results of observations made with the specific objective to visualize possible flow through the filtering structures. We will also explain our interpretation of all results obtained to date.

URL: http://www.uwm.edu/~jrs/research_topics.htm

OS31K-05 1020h

Swimming, Sinking, and the Feeding Current Flow Field: Prey Detection and Capture by Calanoid Copepods

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Calanoid copepods exhibit complex swimming behaviors that help determine feeding current geometry and velocity. Because motile prey may escape from hydrodynamic disturbances of the feeding current, a