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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 (Δ^{14}C, δ^{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. δ^{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. δ^{13}C values of each fraction show the same trend as the bulk organic matter. δ^{13}C values for THAA and TCHO fractions are higher than those for lipids and the acid insoluble fractions. Bulk POM samples have lower Δ^{14}C values than those of dissolved inorganic carbon in the surface water, but they do contain bomb ^{14}C (>-50 $^{o}/_{oo}$). Δ^{14}C values of THAA and TCHO fractions are higher than those for lipids and acid insoluble fractions. The range of Δ^{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 predatory copepod must tailor its feeding current to minimize the perceptible fluid disturbance, while maximizing its encounter rate with prey. In this study, we document the use of mechanoreception by the calanoid *Skistodiaptomus oregonensis* as it attacks and captures remotely located artificial prey entrained in the feeding current. Published hydrodynamic models are utilized to support the hypotheses that these calanoids utilize an expansive feeding current and directed swimming to reduce risk of detection by prey, and use wake capture while sinking to increase the volume searched.

Mechanoperception of remotely located prey entrained in a far-reaching feeding current is an energy efficient strategy compared to chemoperception. However, while an expansive feeding current is effective in non-turbulent regimes, in turbulent environments, a far-reaching, low velocity feeding current should be effective only if coupled with behaviors that quickly minimize separation distances once prey is detected. The results of this study show how copepod swimming and sinking behavior, coupled with a low velocity feeding current, not only can increase copepod encounter rates by increasing direct contact rates, but also can increase the probability of detecting and capturing prey in turbulent and non-turbulent environments.

OS31K-06 1035h

The Effect of Autotroph Geometry on C:N Ratios.

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Perhaps the simplest biophysical factor affecting an autotrophs is its dimensionality i.e. whether it is a 3-D particle, or forms a 2-D surface. The C:N ratio of unicellular algae is consistently 6.625 (the Redfield ratio), while macroalgae and seagrass (which obtain nutrients through a 2-D surface) have a C:N ratio which is 1 to 9 times the Redfield ratio, with a median of 2.8. Simple calculations are presented of the physically-limited supply rates under highly light- and N-limiting conditions of light and N to unicellular algae and benthic plants. These calculations predict that the light:N supply rate ratio to benthic plants is $\sim$ 4 times that to unicellular algae. More thorough calculations shed light on the variability of C:N ratios of macroalgae. Contrasting geometric properties may exert a significant evolutionary pressure on the elemental composition of unicellular algae and benthic plants.

OS31K-07 1050h

Fluid Mechanics Produces Conflicting Constraints During Olfactory Navigation: The Effect of Drag

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Animals foraging in turbulent odor plumes not only must acquire appropriate information from the chemical signal, but must respond to fluid forces imposed on their body. Drag forces experienced by animals will affect the cost of locomotion, but magnitude of this effect varies with both fluid velocity and the drag coefficient. We measured the drag on blue crab specimens oriented at angles ranging from 0 deg (facing the flow) to 90 deg (facing to the side) using a simple force transducer. At 0 deg. the long axis of the animal is normal to the flow resulting in a large drag coefficient (Cd =1.1). As the body angle rotates to a position of 90 deg, the drag coefficient decreases by a factor of 2. Blue crabs attempting to minimize drag during locomotion therefore would be expected to adopt a body angle of 90 deg. This was tested by examining the body angle of animals navigating in a chemical plume of metabolites released from freshly dead flesh. At low flow speeds (ca. 5 cm/s) crabs searching for odor sources orient at an angle of roughly 45 deg relative to the flow direction. However, at higher flow speeds (ca. 10 cm/s) animals assume the drag minimizing posture of 90 deg. Animals also may alter their body posture with distance to the source, and this will be discussed as well. The failure of blue crabs to adopt a drag-minimizing posture in slow flows suggests an additional constraint that also mediates their response to flow, but which opposes the drag effect, i.e. the deleterious consequences are maximal at 90 deg and minimal at 0 deg. The fact that crabs do indeed orient at 90 deg when flows are swift, and hence the overall drag force is increased, suggests that they tradeoff these two constraints to strike an optimal balance between the positive and negative consequences inherent in assuming a particular body angle. Our hypothesis is that postures that result in drag minimization are accompanied by a decrease in the ability to effectively acquire chemosensory information necessary to navigate in chemical plumes. The companion abstract by Webster et al. details the chemical signal structure impinging on olfactory appendages as a function of body angle. Quantification of chemical signals using a variety of techniques suggests that drag minimization is indeed inversely related to the ability to extract chemical information from turbulent plumes.

OS31K-08 1105h

Fluid Mechanics Produces Conflicting Constraints During Olfactory Navigation: Effects on Chemical Signal Acquisition

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In the companion abstract, Weissburg et al. document that for blue crabs, a body angle of 90 deg results in the lowest drag coefficient (Cd). However, crabs searching in chemical plumes only orient at this angle when flows are rapid, and in slow flows show an angle of ca. 45 deg. Our working hypothesis is that differing body angles have dramatic consequences for the chemical signal impinging on the sensory organs, and that drag minimization has the consequence of decreasing the ability to acquire chemical signals necessary for olfactory navigation. Flow visualization and laser-induced fluorescence measurements revealed variation in odor plume dynamics around the crab body for different orientations. When the appendages are in the turbulent wake of the claw or body, the plume is mixed and homogeneous relative to the unobstructed plume. This arrangement commonly occurs at higher body angles, where the cephalic appendages and the legs on the downstream side receive signals within the turbulent wake of the claw or body. The effect of postural angle was investigated further using a minute (10 mm dia) chemical microprobe positioned close to the sensory appendages. When at 0 deg, the antennae and legs experience a virtually unobstructed plume composed of intense peaks of odor concentration, which are intermittent at the antennae and much more uniform at the legs (which are lower in the boundary layer). Signal strength declines with increasing angle, and at 90 deg the antennules receive only very dilute odor. At the legs, intermittence increases with increasing angle and is greatest at 90 deg. Additionally, at this angle the downstream legs receive only dilute odor concentrations. The reduction of peak concentration at the antennae may inhibit identification of appropriate odors, whereas the increase in intermittence at the legs, and the reduced concentrations impinging on the downstream side, make bilateral comparisons difficult. Since efficient plume tracking depends on both of these factors, a drag-minimizing posture (i.e. 90 deg) will inhibit olfactory navigation. Blue crabs respond to these conflicting demands by weighting the degree of drag minimization in proportion to the potential magnitude of the drag effect. Increased flow velocity magnifies the locomotory cost of a high drag posture, thus in swift flows crabs turn to the side in order to minimize drag and sacrifice their ability to acquire olfactory cues.

OS31K-09 1120h

Modeling of Nutrient Uptake and Signal Release by Benthic Bacteria

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Substantial theoretical efforts have argued that unattached bacteria are too small to improve nutrient uptake directly by moving through fluid or from turbulence because their low Reynolds numbers preclude a thinning of the diffusive boundary layer. Conversely, plush biofilms comprised of many layers of bacteria attached to a surface have been shown theoretically and empirically to increase nutrient uptake with flow over the surface. Comparatively little work has focused on interactions between solitary or sparsely populated attached bacteria and the fluid environment. Furthermore, scant theory has addressed the diffusive release of compounds from bacteria, a topic of increasing relevance due to recent discoveries of 'quorum sensing,' or chemical communication among microbes. This work uses a theoretical electrical analog for diffusive mass transfer to model nutrient uptake by bacteria attached to surfaces, showing that sparse populations of bacteria (less than a monolayer coverage) can benefit from flow over the surface. Signal release from single cells is modeled with published reaction kinetcs, standard diffusion equations, and careful consideration of boundary conditions and their physiological interpretation. Premliminary models suggest that signal dynamics are dependent on the proximity of cells to one another, a result that supports published observations.

OS31K-10 1135h

Flow sensing in dinoflagellates at small temporal scales: Studies in developing Couette flow reveal sensory tuning.

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Many marine dinoflagellates are bioluminescent, emitting bright flashes of light from single cells in response to mechanical stimulation. This extremely rapid behavior is believed to serve a defensive function by deterring grazing. The time scale of the response is much faster than the time scale at which macroscopic flows can be fully developed. Therefore it is appropriate to characterize the time-dependent response to quantifiable developing flow. In order to study what parameters of flow development are important in determining the bioluminescent response of dinoflagellates we have constructed small-scale Couette (concentric cylinder) flow chambers to allow measurement of the full response over time of a defined population of cells during flow development. The gap between the outer and inner cylinders of the Couette devices was kept small so that the flow could develop rapidly across the gap. The bioluminescent response of the dinoflagellate *Lingulodinium polyedrum* was observed while the outer cylinder was accelerated using a computer-controlled servo-motor at a rate proportional to the time scale for diffusion of the velocity gradient across the gap. The developing phase of the flow was numerically modeled to determine velocity and shear versus radial position in the gap over time. There were surprising differences in the sensitivity and kinetics of flow-stimulated bioluminescence between different strains of *L. polyedrum*. For a given strain the response threshold measured in developing Couette flow was very similar to that observed in converging flow (another developing flow) and to that previously reported in fully developed Couette and pipe flows. However, at above threshold shear levels the response was strongly dependent on the rate of flow development. This indicates that dinoflagellate mechanotransduction may display rapid adaptation similar to that observed in known mechanosensory cells of many metazoans.

OS31L HC: 314 Wednesday 0830h

Coupling of Biogeochemical Processes Between the Upper and Mesopelagic Ocean I

Presiding: **R B Rivkin,** Memorial University of Newfoundland**; L Legendre,** Laboratoire d"Ocanographie de Villefranche

OS31L-01 0830h INVITED

Maximum Resiliency as a Food web Organizing Construct: Export Production and Microbial Composition of a Pelagic Ecosystem

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A pelagic food web model was formulated with the goal of developing a quantitative understanding of the relationship between total production, export production, and environmental variables in marine ecosystems. The model assumes that primary production is partitioned through both large and small phytoplankton and that the food web adjusts to changes in the rate of allochthonous nutrient inputs in a way that maximizes resiliency, i.e., the ability of the system to return to steady state following a perturbation. The results of the modeling exercise indicate that ef ratios, defined as new production/total production = export production/total production, are relatively insensitive to total production rates at temperatures greater than 25^{o}C and lie in the range 0.1-0.2. At moderate to high