OS22K-11 1635h

Observing and Modelling Suspended Sediment Transport Over Ripples in Combined Wave-Current Flow

Jon J Williams[1] (++441516538633; jjw@pol.ac.uk)

Paul S Bell[1] (++441516538633; psb@pol.ac.uk)

[1]Proudman Oceanographic Laboratory, Bidston Observatory, Bidston Hill, Prenton CH43 7RA, United Kingdom

Detailed measurements of hydrodynamic conditions, bedforms and suspended sediments have been obtained using the multi-sensor PIP (POL Instrument Package) deployed from a small jack-up barge in a small tidal inlet in Portugal. Detailed measurements of bed morphology, turbulence and suspended sediment obtained over highly mobile bedforms are used to investigate vertical flow structure and the processes of sediment entrainment and bedform migration in combined wave-current flows. Comparisons are made between measured rates of sediment transport and a number of existing sediment transport expressions frequently used in marine applications. Based upon the present data, a new semi-empirical model of has been developed that simulates the measured instantaneous re-suspension events and time-average suspended sediment concentration profiles. Together the field observations and the numerical model contribute to the understanding of the physical mechanisms driving sediment transport in the marine environment.

OS22K-12 1650h

An Evaluation of the Mass-Balance Equation for Suspended Sediments Using an Eddy Diffusivity Parameterization

Richard Styles[1] (732-932-3692; styles@imcs.rutgers.edu)

Scott M. Glenn[2] (glenn@imcs.rutgers.edu)

Peter Traykovski[3]

[1]Department of Geological Sciences, University of South Carolina, Columbia, SC 29208, United States

[2]Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, NJ 08901, United States

[3]Woods Hole Oceanographic Institution, MS 11, Woods Hole, MA 02543, United States

A statistical average of the continuity equation for suspended sediments leads to a simple balance between upward turbulent diffusion and gravitational settling. This result has formed the basis of sediment transport studies for nearly a century and, with an appropriate turbulent closure scheme, it is routinely used to model vertical distributions. Despite its widespread use, it is almost never evaluated, unlike the momentum equation, to determine the conditions for which the simple balance holds. The present study focuses on a depth-integrated form of the mass-balance equation in the context of predicting suspended sand concentrations over ripples in a wave-dominated continental shelf environment. The results indicate that for two widely used eddy diffusivity closures the depth-integrated sediment concentration is strongly correlated with the turbulent sediment flux. The results show further that the balance holds for heights above the predicted wave boundary layer thickness only when the closure scheme is formulated in terms of the combined stress. This has implications for modeling sediment transport in wave-dominated environments over ripples, in which the present state-of-the-art bottom boundary layer models may be significantly under predicting the spatially averaged thickness of the wave boundary layer.

OS22K-13 1705h

Modelling Water Column Structure and Suspended Particulate Matter on the Middle Atlantic Continental Shelf During The Passages of Hurricanes Edouard and Hortense

Alejandro J Souza[1] (+44-151-6531590; ajso@pol.ac.uk)

Tommy D Dickey[2] ((805) 8937354; tommy.dickey@opl.ucsb.edu)

Grace C Chang[2] ((805) 6818207; grace.chang@opl.ucsb.edu)

[1]Proudman Oceanographic Laboratory, Bidston Observatory Bidston Hill, Prenton CH43 7RA, United Kingdom

[2]Ocean Physics Laboratory University of California Santa Barbara, 6487 Calle Real Unit A, Santa Barbara, CA 93117, United States

The present contribution is motivated by the desire to elucidate the processes that contributed to the evolution of observed thermal structure and resuspension of particulate matter during and after the passages of two hurricanes, Edouard and Hortense, within a two week period in late-summer 1996. A unique set of high temporal frequency measurements of the vertical structures of physical and optical properties was obtained at a mooring site near the Middle Atlantic Bight continental shelf-break (70 m water depth). These data provided insight and initial conditions for the physical model used for this study. The model accounted for wind and bottom current generated turbulence, surface waves, wave-current interactions, tides, and depth-dependent density driven circulation. We find that the most important process controlling the thermal water column structure during and following the passage of Hurricane Edouard was the wind stirring. Differences between the model results and the observations of thermal structure may have been caused by advection, which is not included in this one-dimensional model. There is also clear evidence of internal tides in the observations, whereas the model could not reproduce this effect. A suspended particulate matter (SPM) model is included as a module of the physical model to examine sediment resuspension processes. It is concluded that wave-current bottom shear stress was clearly the most important process for sediment resuspension during and following both hurricanes. Discrepancies between modelled and observed SPM are attributed to the presence of biological material in the surface waters and changes in sediment properties (flocculation and de-flocculation) during and following the passages of the hurricanes.

OS22L HC: 316 C Tuesday 1330h

Coupled Biophysical Processes, Fisheries Resources, and Climate Variability in Coastal Ecosystems of the Northeast Pacific Ocean IV

Presiding: **W Crawford,** Fisheries and Oceans Canada**; A J Hermann,** Joint Istitute for the Study of the Atmospere and the Oceans

OS22L-01 1330h

Water-Column Stability, Phytoplankton Distribution and Zooplankton Abundance During Summer in Prince William Sound, Alaska

Lewis Haldorson[1] (907 465-6441; lew.haldorson@uaf.edu)

Thomas Shirley[1]

Jennifer E. Purcell[2]

Jennifer Boldt[1]

Jill Snyder[1]

[1]School of Fisheries and Ocean Sciences University of Alaska, 11120 Glacier Highway, Juneau, AK 99801, United States

[2]Shannon Point Marine Center Western Washington University, 1900 Shannon Point Rd, Anacortes, WA 98221, United States

During summer of 1997 and 1998 we measured stability in the upper water column (rate of change in sigma -t in upper 20 m), fluorescence profiles, and abundance of herbivorous and carnivorous zooplankton in four study areas of Prince William Sound (PWS). In 1998 the upper water column was more stable than in 1997. Stability also differed among areas, with the same pattern both years, probably due to consistent sources of fresh water around PWS. Mean depth of the chlorophyll maximum (DCM) was shallower in 1998, and areas with higher stability had shallower DCM. Herbivorous zooplankton were more abundant in 1998, and occurred in higher numbers where DCM was shallower. Abundance of carnivorous zooplankton was unrelated to numbers of herbivores. These relationships suggest that increased stability during summer in the northern Gulf of Alaska leads to higher production of zooplankton, as proposed in the Optimal Stability Hypothesis. There are indications that variation in the planktonic ecosystem propagated through the food web, affecting planktivorous fishes and piscivorous seabirds.

OS22L-02 1345h

Satellite-measured Seasonal and Interannual Variability of Chlorophyll in the Gulf of Alaska

Peter Brickley[1] (207 581 4334; peter@grampus.umeoce.maine.edu)

Andrew Thomas[1] (207 581 4335; thomas@maine.edu)

P. Ted Strub[2] (541 737 3015; tstrub@coas.oregonstate.edu)

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

[2]College of Oceanic and Atmospheric Sciences, Oregon State University 104 Ocean Administration Bldg., Corvallis, OR 97331, United States

We present a synoptic summary of chlorophyll variability on seasonal and interannual timescales for the Gulf of Alaska (GOA) as observed in four years (1997-2001) of SeaWiFS ocean color data. Low light levels and/or cloud during November January prevent examination of winter patterns. EOF analysis of the climatological annual cycle shows a dominant pattern (88%) of shelf-intensified chlorophyll (a factor of 3 or more) around the entire basin with peaks in May and again (but more weakly) in August and September. The second and third modes (4 and 2%) capture April-June chlorophyll peaks on the shelf and most importantly, patterns strongly related to bathymetry (the 500m isobath) west of Kayak Island (144W). Interannual variability is examined using an EOF decomposition of the 48 month time series. A gulf-wide amplification (mode 1, 77%) of the annual cycle occurred during 1999 and 2000. The second and third modes (4 and 3%) show chlorophyll peaks obviously linked to bathymetry in the western GOA and a more diffuse enhancement on and off the shelf in the eastern GOA during April-May of 1999-2000. Cross-shelf chlorophyll variability (0-400 km offshore) is more closely examined in five locations relevant to ongoing GLOBEC research. Chlorophyll is typically shelf-intensified and decays offshore, but becomes strongly enhanced over the shelf break in the western GOA (off Seward and Kodiak Island). During 1999 and 2000 the spring blooms extended farther offshelf in all locations and were enhanced by a factor of 3 over spring 1998. A portion of the observed variability results from recurring eddies (100-300 km scales) evident in the imagery immediately seaward of the 500m isobath west of 144W. Results are examined in relation to the annual cycle of wind forcing, gyre-scale circulation and larger scale signals emanating from the Northeast Pacific and ENSO.

OS22L-03 1400h INVITED

The Gulf of Alaska Ecosystem: An Interdisciplinary View After Four Years

Terry E Whitledge[1] (907-474-7229; terry@ims.uaf.edu); Tom Weingartner[1] (907-474-7993; weingart@ims.uaf.edu); Ken Coyle[1] (907-474-7705; coyle@ims.uaf.edu); Tom Royer[2] (757-683-5547; royer@ccpo.odu.edu); Dean Stockwell[1] (907-474-5556; dean@ims.uaf.edu); Lew Haldorson[3] (907-465-6446; Lew.Haldorson@uaf.edu); Bob Day[4] (907-455-6777; bday@arbinc.com); Dave Musgrave[1] (907-474-7837; musgrave@ims.uaf.edu); Susan Henrichs[1] (907-474-7807; henrichs@ims.uaf.edu); Russ Hopcroft[1] (907-474-7842; hopcroft@ims.uaf.edu); Tom Kline[5] (tkline@pwssc.gen.ak.us); Evelyn Lessard[6] (206-543-7895; elessard@u.washington.edu)

[1]School of Fisheries and Ocean Sciences, University of Alaska Fairbanks PO Box 757220, Fairbanks, AK 99775-7220, United States

[2]Center for Coastal Physical Oceanography, Old Dominion University, Norfolk, VA 23508-5290, United States

[3]School of Fisheries and Ocean Sciences, Juneau Center, University of Alaska Fairbanks, Juneau, AK 99801, United States

[4]ABR, Inc, PO Box 80410, Fairbanks, AK 99708-0410, United States

[5]Prince William Sound Science Center, 1, Cordova, AK 99574, United States

[6]School of Fisheries and Oceanography, University of Washington, Seattle, WA 98195, United States

The results from four years of sampling under the Long-Term Observation Program (LTOP) in Gulf of Alaska GLOBEC, combined with measurements from a biophysical mooring in the North Pacific Marine Research (NPMR) program show a complex and highly variable water circulation pattern that greatly affects

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the chemical and biological patterns of this highly productive down-welling coastal ecosystem. Six or seven sampling cruises each year at approximately monthly intervals plus data from biophysical moorings indicate that mesoscale variability dominates the distribution of properties and organisms. Seasonal and interannual variations have also been observed in the water properties and organisms that could be related to large scale processes such climate variability, precipitation patterns and unusual weather patterns.

OS22L-04 1425h

Observations of a New Circulation Feature on the Gulf of Alaska Shelf: The Seward Eddy

David L Musgrave[1] (907) 474-7837; musgrave@ims.uaf.edu)

Hank Statscewich[1] (stats@ims.uaf.edu)

Terry Whitledge[1] (terry@ims.uaf.edu)

Tom Weingartner[1] (weingart@ims.uaf.edu)

[1]University of Alaska Fairbanks School of Fisheries and Ocean Sciences, PO Box 757220, Fairbanks, AK 99775-7220, United States

Observations of a new Circulation Feature on the Gulf of Alaska Shelf: The Seward Eddy

A biophysical mooring was deployed for one year beginning March 2000 at 200 m depth, 60 km from shore along the Seward Line on the shelf in the Gulf of Alaska. The mooring included measurements of full water column velocities from ADCPs, temperature, salinity, nitrate, fluorescence, transmissivity, and PAR. The results show that abrupt changes in upper water column salinity, temperature, fluorescence and nitrate are due to advection of two kinds of water masses within the Alaska Coastal Current (ACC): one that has passed through Prince William Sound (PWSCC) and one that has bypassed Prince William Sound by flowing seaward of Montague Island (MICC). The PWSCC water has low salinity and nitrate and high fluorescence and the MICC has the opposite characteristics. The ACC near Seward organizes into the cyclonic Seward Eddy due to interaction with a bathymetric ridge just west of Seward. Satellite images of chlorophyll support the high fluorescence in the ACC and its recirculation in the Seward Eddy. The mean barotropic current over the year was 1.6 cm/s, 306, which is orthogonal to the coastline, but parallel to the bottom topography.

URL: http://blackburn.ims.uaf.edu:8000/~musgrave/SewardEddy

OS22L-05 1440h

Offshore Transport of Heat, Nutrients and Larvae by Haida Eddies from British Columbia Coastal Waters.

William Crawford[1] (1-250-363-6369; crawfordb@pac.dfo-mpo.gc.ca)

Frank Whitney[1]

Alan Sinclair[2]

[1]Fisheries and Oceans Canada, Institute of Ocean Sciences P.O. Box 6000, Sidney, BC V8L 4B2, Canada

[2]Fisheries and Oceans Canada, Pacific Biological Station 3190 Hammond Bay Road, Nanaimo, BC V9R 5K6, Canada

Haida Eddies are anti-cyclonic features that form in winter along the eastern continental margin of the Gulf of Alaska, west of the Canadian Queen Charlotte Islands. Their number and size vary with winter sea levels, currents and temperatures along the coast. Extreme El Nino winters, with warmer waters and higher sea levels, generally set up bigger eddies that carry more coastal water into the Gulf of Alaska. We describe physical processes that set up eddies and examine their offshore transport of heat, nutrients and larvae.

The largest eddy observed to date, Haida-1998, carried offshore about 5,000 cubic kilometers of coastal water, a volume comparable to that of Queen Charlotte Sound and Hecate Strait combined. These two seas are the main source basins for eddies. The offshore heat flux by this eddy may be one-quarter to one-half the northward heat transported along the Canadian continental margin west of Vancouver Island during the winter of 1997/98. Offshore eddy heat flux in other years may be a similar fraction of northward flux. Through its natal summer, Haida-1998 lost nitrate from core waters at 3 times the rate we have historically observed in the Gulf of Alaska (at stations P16 or Papa.) Nitrate supports new production, which is the portion of primary production that results in biomass increases.

Eddies may also carry Pacific cod larvae offshore in winter, away from spawning and rearing grounds in Hecate Strait. We investigate this hypothesis by using winter, pressure-adjusted sea level at Prince Rupert, in northern British Columbia, as a proxy for offshore transport of Hecate Strait waters in winter. Pacific cod are recruited into fisheries at age three. Correlation between fisheries catch and winter adjusted sea levels at -3 years are consistently high over 40 years of data, and provide good support for this hypothesis.

OS22L-06 1455h

Juvenile Pink Salmon Feeding and Consumption in the North Gulf of Alaska

Jennifer L Boldt[1] (907-465-6441; fsjlb3@uaf.edu)

Lewis J Haldorson[1] (907-465-6441; ffljh@uaf.edu)

[1]Juneau Center School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, 11120 Glacier Hwy, JUNEAU, AK 99801, United States

Large numbers of wild and hatchery juvenile pink salmon enter coastal waters of the northern Gulf of Alaska every summer. To assess the effects of their planktivory, we describe seasonal changes in juvenile pink salmon diet in their first six months of ocean residence in 1998, and estimate their consumption of zooplankton in PWS using a bioenergetics model. There was a trend of increasing prey sizes consumed over the four sampling periods. Pink salmon in PWS (July) generally consumed small prey items, such as gastropods, cladocerans, small calanoid copepods, and bivalves along with some large prey items, large calanoid copepods and larvaceans. In August, juvenile pink salmon sampled in the GOA were consuming fewer small prey items and most of their prey biomass consisted of pteropods (*Limacina* sp.), larvaceans, hyperiid amphipods, and euphausiids. Prey items consumed by fish sampled in October were larger. The prey items that comprised the largest biomass were large pteropods (*Clio* sp.), large hyperiid amphipods, euphausiids, crab megalopae, and fish. During their residence in PWS, the 1998 cohort of pink salmon was estimated to consume less than 1% of the zooplankton production, but potentially a large proportion of the available standing stock of their prey.

OS22L-07 1530h

Growth Rates of *Neocalanus* Species in the Northern Gulf of Alaska

Russell R Hopcroft[1] (907-474-7842; hopcroft@ims.uaf.edu)

Alexei I Pinchuk[1] (907-224-6441; ftaip1@uaf.edu)

Cheryl Clarke[1] (907-474-7842; choproft@ims.uaf.edu)

[1]University of Alaska Fairbanks, Institute of Marine Science, Fairbanks, AK 99775, United States

Growth and molting rates for copepodites of *Neocalanus* species were estimated monthly in coastal and offshore waters of the northern Gulf of Alaska during 2001. Incubations of 4 or 5 days duration were executed in waters from 5 to 10°C employing both single 'picked' stages and artificial cohorts. Both methods appeared to yield similar data on molting rates and growth increment. For *N. flemingeri*, duration of the first 4 copepodite stages appears similar, approximately 10 days at 5-6°C. Corresponding growth rate appears to decline with stage, from approximately 0.13 to 0.07 per day. Animals that molted were often smaller at stage than animals freshly collected, possibly due to increased temperature during incubation, reduced food concentration, or damage during collection/handling. Ongoing research will quantify the relationship to, and impact of, these factors on stage duration and growth rate.

OS22L-08 1545h

Spatial and temporal structure of shelf circulation in the Northern Gulf of Alaska

Albert J Hermann[1] (206-526-6495; hermann@pmel.noaa.gov)

Phyllis J Stabeno[2] (206-526-6453; stabeno@pmel.noaa.gov)

Dale B Haidvogel[3] (732-932-6555; dale@imcs.rutgers.edu)

Nancy Kachel[2] (206-526-6780; nkachel@pmel.noaa.gov)

Elizabeth L Dobbins[1] (206-526-4581; dobbins@pmel.noaa.gov)

[1]Joint Istitute for the Study of the Atmospere and the Oceans, University of Washington, Seattle, WA 98195, United States

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

[3]Institute of Marine and Coastal Sciences, Rutgers University, 71 Dudley Road, New Brunswick, NJ 08901, United States

Shelf circulation in the northern Coastal Gulf of Alaska (CGOA) is driven by wind and runoff patterns with pronounced seasonal and interannual variability. Mean winds are downwelling-favorable, yet the shelf is highly productive. New Eulerian and Lagrangian datasets emerging from GLOBEC field work have clarified several aspects of the spatial and temporal structure of the circulation. Complementing these efforts, a new primitive-equation circulation model, spanning the west coast of North America from Baja California through the Bering Sea at 10 km resolution, is being used to investigate the covariance of circulation and biology across a broad range of spatial scales for GLOBEC. The new datasets include 13 moorings and 40 satellite-tracked drifters deployed in May-September 2001. Observed features from Eulerian data collected thus far include: spatial decorrelation scales less than 10 km, episodic freshwater events nearshore, episodic onshelf intrusions of warm saline water, and moderate upwelling events in the summer. The drifter paths were generally disorganized in the summer, becoming more coherent after intensification of the Alaska Coastal Current in September. Here we compare the observed patterns and coherence scales of salinity, temperature, and currents with corresponding model output, and suggest possible sources of nutrients for this highly productive, yet typically downwelling, continental shelf.

OS22L-09 1600h

Stability Analysis of a Six Component Ecosystem Model for the Coastal Gulf of Alaska

Georgina A Blamey[1] (907-474-5184; george@ims.uaf.edu)

David L Musgrave[1] (907-474-7837; musgrave@ims.uaf.edu)

Sarah Hinckley[2] (206-526-4109; Sarah.Hinckley.noaa.gov)

[1]Institute of Marine Science, University of Alaska Fairbanks P.O. Box 757220, Fairbanks, AK 99775, United States

[2]Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, United States

It has been hypothesized that ocean survival of salmon is determined primarily by survival of juvenile salmon in coastal regions, and is affected by interannual and interdecadal changes in physical forcing in the Gulf of Alaska (US GLOBEC, 1996). The link between physical forcing and salmon survival is through the lower trophic levels: nutrient supply, phytoplankton and zooplankton production. To assist interpretation of the observational data gathered under the GLOBEC program we have developed a ecosystem model for the Coastal Gulf of Alaska. Through theoretical modeling studies this model has provided an insight into bio-physical interactions. Due to the importance of microzooplankton grazers in the Gulf of Alaska, the model of the lower trophic levels includes both small and large phytoplankton, macro and microzooplankton, nitrate and ammonium. By forcing biological models with some prescribed physical data researchers attempt to simulate ocean productivity. However, a formal analysis of the stability of the biological model in the absence of physical forcing is an essential prerequisite in order to gain a more complete understanding of the models fundamental dynamics. Such analysis is seldom performed, but contributes greatly to understanding the model dynamics that occur when biological models are coupled to physical models. Here we present the results of a formal stability analysis for our six component biological model developed for the Coastal Gulf of Alaska.

OS22L-10 1615h

Deep Water Exchange and Renewal within Small Fjords of Prince William sound, Alaska in Relation to Large Scale Advective Processes

Shelton M Gay (907-424-5800; shelton@pwssc.gen.ak.us)

Prince William Sound Science Center, P.O. Box 705 300 Breakwater Ave., Cordova, AK 99574, United States

Exchange of both intermediate (100-200m) and deep (> 200m) water between the Gulf of Alaska (GOA) and Prince William Sound (PWS) occurs annually at Hinchinbrook Entrance (HE) from late spring to early fall. The Sound is considered to be a large fjord complex with basin depths ranging from 300 to nearly 900m and it is silled at HE due to the 180m depth of the Continental Shelf. Therefore, annual exchange of GOA water may play a vital role in the influx of both nutrients and large zooplankton species that provide a prey base for pelagic fish and sea-birds. Some exchange between

the GOA and PWS may also occur at Montague Strait. However, due to the shallower depths over the Continental Shelf in this region it is less likely to occur there. Although the frequency and magnitude of deep water exchange vary from year to year, past measurements of currents at HE indicate that a complete flushing of the bottom water (> 250m) can occur within one months time due to intrusions from the GOA. Broad-scale advection of GOA water around PWS has also been inferred from stable isotope data (del 13C).

Although surface water from the GOA could potentially reach many fjords in PWS, hydrographic data collected from 1994 to 1997 indicate that deep water intrusions potentially reach only basins that lack entrance sills. Deep advection into these fjords was evident from increases in both temperature and salinity (hence density) at intermediate depths (100-300 m) from late spring to early fall that were correlated with similar temporal changes in the deep T/S properties of +1 to 2 (C and psu) within nearby passes. The changes in deep density within the smaller fjords indicated that deep water exchange is potentially linked to large scale circulation processes in PWS. In contrast, fjords with intermediate to shallow depth sills exhibited either very minor changes or none at all in deep T/S properties during the same time period. Exchange within these basins appears to occur in the late winter, similar to renewal of the deep water within Unakwik Inlet and other shallow silled fjords around the GOA. This renewal process prevents stagnation and anoxic conditions from developing within the inner basins of all shallow-silled fjords in PWS. Also, the seasonal variation in the timing of deep advection among fjords in conjunction with differences in freshwater content may influence the species composition of zooplankton available to juvenile fish within these nursery habitats; in particular Calenoid copepods and other oceanic holoplankton species.

OS22L-11 1630h

Mechanisms Affecting Spring Zooplankton and Pink Salmon Fry in Prince William Sound

Richard E. Thorne[1] (907 424 5800; thorne@pwssc.gen.ak.us)

Gary L. Thomas[1] (907 424 5800; loon@pwssc.gen.ak.us)

Shelton M Gay[1] (907 424 5800; shelton@pwssc.gen.ak.us)

[1]Prince William Sound Science Center, P.O. Box 705, Cordova, AK 99574, United States

The distribution and abundance of zooplankton and fish have been monitored for several years in Prince William Sound, first through the efforts of the Sound Ecosystem Assessment (SEA) program (1994-98), and more recently as part of the Nowcast/Forecast Information System (NFIS) program of the Oil Spill Recovery Institute (OSRI). The SEA program documented the importance of large-bodied copepods, mainly Neocalanus, as prey, and walleye pollock (Theragra chalcogramma) and Pacific herring (Clupea pallasi) as the numerically most abundant competitors and predators of juvenile pink salmon in the early spring. We conducted eight acoustical- net sampling surveys in the Sound during the spring bloom periods of 2000-01 to document the physical and biological conditions in the Sound that influence juvenile pink salmon growth and survival. A five-fold difference in zooplankton biomass was observed between the two years. Dense schools of herring were observed to reduce nearby zooplankton abundance, but in general fish abundance in the zooplankton layer was low. It appears possible to explain the spatial distributions from the deep-water sources of Neocalanus combined with physical features. However, more information is needed to understand the substantial interannual differences.

OS22L-12 1645h

Climate, Chaetognaths, and Copepods: Interactions on the Southeast Bering Sea Shelf

Christine T. Baier[1] (206-526-4112; Christine.Baier@noaa.gov)

Makoto Terazaki[2] (terazaki@ori.u-tokyo.ac.jp)

[1]NOAA/NMFS/Alaska Fisheries Science Center, 7600 Sand Point Way NE, Seattle, WA 98115, United States

[2]Ocean Research Institute, University of Tokyo, Tokyo, Japan

During 1995-99, the abundance and community structure of zooplankton on the southeast Bering Sea Shelf reflected interannual variability in climate conditions. We examined the interactions of an invertebrate predator, the chaetognath *Sagitta elegans*, and its copepod prey, by comparing chaetognath and copepod abundances during 1995-1999, and evaluating effects of chaetognath predation on copepods during spring of 1995 and 1997. The percent of prey standing stock consumed was estimated from ambient chaetognath and prey concentrations, gut content analysis, and experimentally-determined digestion rates. Chaetognaths consumed a range of prey sizes that encompassed all local copepod species and stages. The mean feeding rate was 0.7 prey chaetognath^{-1} day^{-1}, and the copepod standing stock removed daily was more than 0.4%. The most frequently consumed prey types were the copepods *Calanus marshallae* and *Pseudocalanus* spp. *Pseudocalanus* abundances were relatively low in cool years, while spring *C. marshallae* abundances appeared to be related to the timing of the spring phytoplankton bloom, which was influenced by ice cover. Chaetognath concentrations did not covary with climate indices, but increased from 1995-99. *C. marshallae* generally produces only one generation a year, and is more vulnerable to cumulative predation effects than *Pseudocalanus*, which has multiple generations within a year. In 1997, an average spring in terms of temperature and ice, when copepod abundances were low and chaetognath abundances were high, predation effects were much greater than in 1995, a cold year in which chaetognath abundances were relatively low and copepod abundances high. Low abundances of *C. marshallae* in 1997 may have resulted in part from heavy predation by chaetognaths.

OS22M HC: 317 B Tuesday 1330h

Linking Modern and Past Biogenic Fluxes II

Presiding: **R Francois,** Woods Hole Oceanographic Institution**; R A Jahnke,** Skidaway Institute of Oceanography

OS22M-01 1330h

Can the Al/Ti ratio be used as a tracer of export production in biogenic marine sediment? An examination of the compositional associations of excess metals in biogenic sediment.

K A Kryc[1] ((617) 353-4085; kkryc@bu.edu)

R W Murray[1] ((617) 353-6532; rickm@bu.edu)

D W Murray[2] (401-863-3531; david_murray@brown.edu)

[1]Boston University, Department of Earth Sciences 685 Commonwealth Ave, Boston, MA 02135, United States

[2]Brown University, Center for Environmental Studies, Providence, RI 02912, United States

Many studies have focused on interpreting the record of biological productivity in the oceans using a variety of chemical and sedimentological tracers preserved in marine sediments. Murray et al. (1993) and Murray and Leinen (1996) showed that changes in Al/Ti in bulk carbonate sediment from the equatorial Pacific coincide with changes in the bulk accumulation rate, and proposed that the high ratios (∼3 times higher than average shale values) are caused by scavenging of dissoloved Al. Because the excess Al component accounts for up to 50% of the total sedimentary Al, the Al/Ti may be a sensitive tracer of particle flux and/or export production. As interest in this potential tracer evolved (i.e. Dymond et al., 1997; Banakar et al., 1998; Timothy and Calvert, 1998), the question progressed from Does it occur? to What is it recording? To address this question, we performed sequential extractions targeting the chemical signatures of the loosely-bound, carbonate, oxide, organic, opal, and residual fraction of surface samples along the JGOFS cross-Equator transect at 140W, and from downcore samples at critical glacial/interglacial intervals. While Al was detected in all extracts, Ti was only detected in extracts of the oxide, organic, opal, and residual phases. The greatest percent of Al (in samples with >75% CaCO3) was tied to the oxide (∼30-70%) and organic fractions (∼5-40%). Only 10% of the Al was associated with the opal phase and 20% with the residual phase. The results for Ti indicate that between 30-70% of the Ti in high-carbonate samples is in the organic phase, 2-8% is in the opal phase, and 20-30% is in the residual phase. All of the Ti in low-carbonate, high-terrigenous samples is associated with the residual fraction. Although the percentages of Al and Ti in the opal phases are lower than in other phases, the correlation between Al and Ti is strongest (r2=0.97) in this phase. The Al/Ti of the total excess components shows an equatorial maximum not only confirming the importance of the excess phases, but also highlighting the possible role of an excess Ti component in the system.

OS22M-02 1345h

A Proxy for Benthic Carbon Oxidation Rate Reconstructions

Lowell D. Stott[1] (213-740-5120; stott@usc.edu)

William Berelson[1] (213-740-5828; berelson@earth.usc.edu)

[1]Dept. Earth Sciences, University of Southern California, 3651 Trousdale Pkwy, Los Angeles, CA 90089, United States

We present a new geochemical proxy for determination of past changes in organic carbon (C-org) oxidation rates (C-ox) on the sea floor. The method employs the δ^{13}C of two co-existing benthic foraminifers; Bolivina argentea, a near-surface dwelling species and Buliminella tenuata, a species that calcifies at between 4 and 6 mm below the sediment-water interface in suboxic, laminated sediments in the North Pacific. The δ^{13}C values of their tests accurately record pore water δ^{13}C values at their respective habitat depths. Paired analyses of these two species allows us to reconstruct the magnitude of the pore water δ^{13}C gradient from sediment samples representing near annual resolution for the past few hundred years. Because the pore water isotopic gradient is directly proportional to the TCO_2 pore water gradient, it is possible to relate the magnitude of the δ^{13}C gradient to values of C-ox. On the sea floor of Santa Monica Basin, C-ox has fluctuated between 0.6 - 2.5 mmmolC m^{-2} d^{-1} and generally increased from 1600 to 1980 AD. Between 1920-1970, C-ox increased from 1 to 2 mmmolC m^{-2} d^{-1} and then decreased into the 1980's. By adding C-ox to a high resolution record of C-org burial rate we have derived the pattern of C-org rain to the sea floor; it fluctuated between 3 and 4 mmolC m^{-2} d^{-1} over the last 80 years. Estimates of primary productivity at this location for the past 80 years reconstructed from SST measurements are compared to our estimates of C-org rain derived from the isotopic proxy measurements. The ratio of C-org rain at 900m to primary carbon production has remained constant at 10±1% despite a 40% change in mean annual primary productivity. Of the 10% of the carbon reaching the sea floor in Santa Monica Basin ∼50% accumulates as buried organic carbon. However, there is a trend toward lower burial efficiency with higher productivity and rain rate.

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Paleo-Sediment Trap Insights into the Significance of Subsurface Production for Ocean Flux

Alan E S Kemp[1] (44 2380 592788; aesk@soc.soton.ac.uk)

Richard B Pearce[1] (44 2380 592788; rp1@soc.soton.ac.uk)

Jennifer Pike[2] (44 29 2087 4830; pikej@cardiff.ac.uk)

Patrick G Quilty[3] (03 6226 2814; P.Quilty@utas.edu.au)

Ivo Grigorov[1] (44 2380 592788; ivogrigorov@hotmail.com)

[1]School of Ocean and Earth Science, University of Southampton, Southampton Oceanography Centre, Southampton SO14 3ZH, United Kingdom

[2]Department of Earth Sciences Cardiff University, Department of Earth Sciences Cardiff University P.O. Box 914, Cardiff CF10 3YE, United Kingdom

[3]School of Earth Sciences University of Tasmania, University of Tasmania GPO Box 252-79, Tasmania 7001, Australia

The emerging mismatch between satellite-derived surface water productivity and benthic fluxes highlights the current lack of understanding of the contribution of sub-surface production to export flux. Although oceanographic sampling with closing nets employed as early as the 1898-1899 Valdivia cruise led to suggestions of the existence of a shade flora, very few experiments have targeted subsurface phytoplankton. Recent SEM-led research on laminated diatomaceous sediments from a wide range of deep-sea and marginal settings has focussed on a species-based interpretation of the annual cycle of diatom production and export. Reinforced by examination of selected sediment trap data, these studies demonstrate that a number of diatom species, hitherto regarded as a typical sparse flora of oligotrophic settings are capable of major carbon export forming organic-carbon rich sediments such as the Mediterranean sapropels (1,2). The styles of production and mechanisms of export undergone by these diatoms contrast with the received spring bloom or upwelling scenario. Rather, these diatoms appear to have a number of adaptations which allow them to exploit a deep nutrient source including a) the adaptation to grow rapidly in low light conditions; b) the ability

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