OS22D-234 1330h POSTER

Chromium Immobilization in Harbor Sediment Mesocosms

Carlos R. Green-Ruiz[1,2] (52-69-85-28-45; cgreen@ola.icmyl.unam.mx)

Y. Meriah Arias[1] (858-534-0638; meriah@ucsd.edu)

Anna Ya Obraztsova[1] (858-534-0638; annao@ucsd.edu)

Bradley M. Tebo[1] (858-534-0638; btebo@ucsd.edu)

[1]University of CA, San Diego, Scripps Institution of Oceanography, 9500 Gilman Drive- 0202, La Jolla, CA 92093-0202, United States

[2]Marine Science and Limnology Institute National University of Mexico, PO Box 80011, Mazatlan, SIN 8200, Mexico

In the environment Cr exists primarily as Cr(VI), the soluble and carcinogenic form, and Cr (III), which is less soluble and non-toxic. Cr(VI) is widely used as an antifouling and anticorrosive agent and some harbor sites have up to 12 mM of total Cr. To determine the fate of Cr(VI) entering marine sediments from the water column, we performed mesocosm experiments with 37.85 L aquaria containing sediment, seawater, and paddles to simulate modest wave action. Sediment was collected from San Diego Bay, homogenized and put into five aquaria with 20 L of overlying seawater. Two aquaria were used as controls without Cr(VI), two with 0.25 mM Cr(VI) (low- Cr), and one with 1.5 mM Cr(VI) (high- Cr). Cr(VI) levels were maintained by adding Na2CrO4 as needed. After two months, two 10 cm cores from each aquarium were taken, sliced at 5 mm intervals, and total Cr, Fe, and Mn concentrations measured by ICP-OES. Organic carbon content was determined by the ignition method. We also investigated the role of the bacteria for Cr(VI) reduction, examining the microbial community structure using denaturing gradient gel electrophoresis (DGGE).

The profiles of metals and organic carbon with depth in the sediment were investigated. Concentrations of total Cr (1 mM) were found in the control aquaria throughout depth and considered as a background. Concentrations up to 9 mM and up to 14 mM of Cr were found in the low- and high- Cr aquaria, respectively. Most of the chromium was immobilized within the first 2-3 cm. The concentrations of Fe, Mn, and organic carbon in sediment cores did not indicate significant stratification in most mesocosms. We attempted to find correlations between Cr and investigated parameters. For example, Cr correlated with Fe in the control and low-Cr aquaria ($r = 0.74$ to 0.80; $p < 0.01$) and with Mn in all three sets of aquaria ($r = 0.57$ to 0.65; $p < 0.05$). The correlation between organic carbon distribution and Cr was not very clear. However, there was a correlation between Cr and organic carbon ($r = 0.90$, $p < 0.01$) in one core from a low- Cr aquarium, that had the highest concentrations of Cr and organic carbon (18 mM and 7.34 %, respectively) in the surface sediment layer. These observations suggest that when Cr concentrations are high (12 to 14 mM), neither organic carbon or solid Fe phases have sufficient capacity to adsorb or react with Cr(VI).

The DGGE profile showed that the bacterial community was similar at all depths in all conditions except the first cm of sediment where Cr was significantly accumulated. This result showed that Cr affected the microbial community and enriched for bacteria that might be key players in the immobilization and detoxification of Cr(VI). Our findings indicate that Cr(VI) reduction and precipitation take place in the surface layers of sediments where complex interactions between geochemical factors and microbial populations occur. The contribution of bacteria to Cr immobilization and the natural attenuation of Cr(VI) pollution is currently being investigated.

OS22D-235 1330h POSTER

Examination of Molecular Markers Specific to Urban Stormwater Runoff

Diana Young[1] ((714)372-9213; dianay@sccwrp.org)

Eddy Y. Zeng[1] ((714)372-9214; eddy@sccwrp.org)

Kim Tran[2] (klt@san.ci.ca.us)

[1]Southern California Coastal Water Research Project, 7171 Fenwick Lane, Westminster, CA 92683, United States

[2]City of Los Anegels, 12000 Vista del Mar, Playa del Rey, CA 90893, United States

Tracing pollutants in coastal marine sediments is a challenging task, since inputs from various sources may have undergone heavy mixing before deposition. One approach is to employ molecular markers that are abundant in the environment, specific to an input source, and resistant to physical, chemical, and biological modifications. In southern California, municipal wastewater outfalls and stormwater runoff have been the major sources of contaminant inputs to the coastal ocean. While sewage markers have been widely utilized, no viable stormwater runoff markers are known in spite of a few previous efforts.

In this study, we focused on potential marker compounds of urban surface runoff. Source specificity and persistence of several sulfur-polycyclic aromatic hydrocarbons (S-PAHs), nitro-PAHs (N-PAHs), and triphenylene, which are associated with automobile tires, engine exhausts, and break liners, were examined via analyses of stormwater runoff and wastewater effluent samples and spiked samples upon exposure to sunlight. Samples were collected during the 1997/1998 wet weather season from two major storm channels and four major wastewater treatment plants in southern California. Among the target compounds examined, 2-(4-morpholinyl)benzothiazole, dibenzothiophene, and triphenylene were detected in storm runoff only. However, 2-(4-morpholinyl)benzothiazole appeared to degrade rapidly in seawater and sediment after sunlight exposure, which might impede its use as a runoff indicator. Dibenzothiophene and triphenylene also degraded quickly in sunlight-exposed seawater samples, but remained fairly abundant in sediments after six months of exposure to sunlight. They are by far the most promising candidates of urban runoff markers based on the criteria of abundance, source specificity, and persistence, although more research efforts are needed to ensure that no other sources would also contribute significantly to their presence in the aquatic environment.

OS22E HC: Hall III Tuesday 1330h

Stratified Coastal and Estuarine Circulation I

Presiding: **J A Whitehead,** Department of Physical Oceanography; **M A Sundermeyer,** University of Massachusetts Dartmouth

OS22E-236 1330h POSTER

On Small-Scale Instability in the Topographic Flow in Knight Inlet

Yakov Afanassiev (709 737 2500; yakov@physics.mun.ca)

Memorial University of Newfoundland, Department of Physics and Physical Oceanography, St John's, NF A1B 3X7, Canada

Recent observations by Farmer and Armi (1999) of a topographic flow in Knight Inlet (British Columbia) provide an example of a phenomenon that is very rich in the fundamental hydrodynamic interactions. In its fully developed form this flow constitutes a high velocity jet at the lee slope of the topography and include a hydraulic jump of the kind that may be generated in one-layer unstratified flow over an isolated obstacle. This flow also bears a striking resemblance to severe downslope atmospheric windstorms that are often observed in the lee of major mountain ranges. An important condition, namely the existence of mixed intermediate layer is required for the existence of such a flow. The dynamical sequence which leads to the formation of the mixed layer, however is not completely understood. Our concern in the present study will be to address the hydrodynamical issue of the development of the small scale shear instability in the flow. For this purpose very high resolution simulations were performed to reproduce explicitly the small scale instability.

URL: http://www.physics.mun.ca/~yakov

OS22E-237 1330h POSTER

Internal solitons in Knight Inlet, British Columbia

Svein Vagle[1] (vagles@dfo-mpo.gc.ca)

Patrick F. Cummins[1] (cumminsp@dfo-mpo.gc.ca)

Laurence Armi[2] (larmi@ucsd.edu)

David M. Farmer[3] (farmerd@gso.uri.edu)

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

[2]Scripps Institution of Oceanography, University of California at San Diego

[3]Graduate School of Oceanography, University of Rhode Island

Knight Inlet, British Columbia provides a natural laboratory for the study of a variety of geophysical flows involving the interaction of stratified fluid with topography. Results are presented from a recent experiment conducted in Knight Inlet, focusing on the generation and propagation of internal solitons near the sill during ebb tide. High quality echo-sounder and ADCP measurements were obtained in a novel fashion, using instrumentation carried aboard an inflatable Zodiac. A set of photographic images of the surface expression of the internal waves were also acquired and these serve to situate the acoustic data within the larger scale structure of the internal response within the inlet. Also discussed are fully nonlinear numerical simulations illustrating the generation mechanism and propagation of the internal solitons.

OS22E-238 1330h POSTER

Generation of Intense Internal Waves by Surface Intrusions on Shelf

Qiao He[1] (202-319-6142; 03he@cua.edu)

Andrey N Serebryany[2] (095-126-98-64; aserebr@dataforce.net)

Hsien P Pao[1] (202-319-6142; pao@cua.edu)

Timothy W Kao[1] (202-319-5164; kao@cua.edu)

[1]The Catholic University of America, Department of Civil Engineering, The Catholic University of America, Washington, DC 20064, United States

[2]N.N. Andreyev Acoustic Institute, Shvernik Str., 4, Moscow 11036, Russian Federation

An evidence of internal wave generation by moving surface intrusion of warmer and fresher water was obtained during long-term observations of internal waves on a shelf. Observations were made from stationary pile-supported platform in the Northwest part of the Black Sea, located 60 km from the nearest shore. A change of water masses occurred in the study area, leading to an appropriate change in the thermocline structure of the upper layer of the sea. At this time a long-term train of intense internal waves was recorded. All data indicated the passage of a local front: a mass of freshened warm water intruded into the portion of the sea having salinity that is uniform with depth. The intrusion occurred at the surface and lasted several days; the salinity during this time fell by 2.1 promille. The freshened waters moved in the direction from the shore regions outward toward the sea. The process of surface intrusion propagating above sharp thermocline was also investigated by numerical modeling. The numerical model is based on solving full Navier-Stokes and diffusion equations. Results from numerical modeling are in a good agreement with observed data. The research work described in this publication was made possible in part by a grant of Award No. RP2-2255 of the U.S. Civilian Research and Development Foundation (CRDF).

OS22E-239 1330h POSTER

Scattering of semidiurnal internal tide observed in Uchiura Bay

Yujiro Kitade[1] (81-3-5463-0447; ykitade@tokyo-u-fish.ac.jp)

Yuji Kawamura[1] (od01102@cc.tokyo-u-fish.ac.jp)

Masaji Matsuyama[1] (masaji@tokyo-u-fish.ac.jp)

[1]Department of Ocean Sciences, Tokyo University of Fisheries, Konan 4-5-7, Minato-ku, Tokyo 108-8477, Japan

Large amplitude of semidiurnal internal tide is frequently observed in Uchiura Bay at the head of Suruga Bay in Japan (Matsuyama, 1991, Tidal Hydrodynamics, p.449-468). To clarify vertical structure of internal tide in the bay, mooring observation, using memorable thermometer and workhorse ADCP, was performed in the bay from July 25 to August 8, 2000. Vertical displacement and along-bay current for semidiurnal internal tide were mainly represented by the first mode, and their phase relation indicated the property of standing wave. However, the second and third modes for the across-bay current with semidiurnal period were predominant. The difference of vertical structure between the along-bay and across-bay currents suggested that the across-bay current for the higher mode internal wave have been generated in the bay. Detailed analysis for the across-bay current with the semidiurnal period revealed vertical phase propagation with wavelengths of 50 120 m in vertical and about 13 km in horizontal. The generation mechanism of the across-bay current was investigated by using a 3D numerical model with simple topography. The model result well represented the observed structure of across-bay current. From the numerical model, the across-bay current was found to be caused at the shallow region along the south coast of Uchiura Bay by the scattering of the along-bay current associated with standing wave in the bay.

OS22E-240 1330h POSTER

Evolution of Shoreward-Propagating Internal Solitary Waves over the Continental Shelf: Energy Losses and Turbulent Processes

James N Moum[1] (541-737-2553; moum@coas.oregonstate.edu)

David M Farmer[2] (dfarmer@gso.uri.edu)

William D Smyth[1] (smyth@coas.oregonstate.edu)

[1]College of Oceanic Atmospheric Sciences, Oregon State University, Corvallis, OR 97331-5503, United States

[2]Graduate School of Oceanography, University of Rhode Island, Naragansett, RI, United States

Recent experimental investigations into the characteristics of internal solitary waves over Oregons continental shelf focused on their evolution as they propagated shoreward. Individual waves were tracked significant distances (40 km) across the shelf using continuous acoustic imaging and velocity profiling interspersed with sequences of intensive turbulence profiling. These observations permit quantification of the proportion of wave energy lost to turbulence. Acoustic images vividly reveal large (10 m vertical scale) Kelvin-Helmholtz billows. Turbulence signals on smaller scales are consistent features of the trailing edge of solitary waves; these are advected within the rollups of large-scale Kelvin-Helmholtz billows and may result from shear layers too thin to be resolved by ADCP. The potential for shear instability on centimeter scales is under investigation.

URL: http://mixing.coas.oregonstate.edu/research/solitons/solitons.htm

OS22E-241 1330h POSTER

Multiple Mixing States Around An Isolated Bank on the Continental Shelf

William D Smyth[1] ((541) 737-3029; smyth@coas.oregonstate.edu)

James N Moum[1] (moum@coas.oregonstate.edu)

[1]College of Oceanic and Atmospheric Sciences, Oregon State University, Corvallis, OR 97330, United States

Stonewall Bank is an isolated topographic feature located on the continental shelf about 10km off the Oregon shore. Previous studies have shown this to be the site of strongly turbulent, hydraulically controlled flows. Mixing by such flows represents an important factor in shelf dynamics that is not accounted for in present models. An extensive survey of currents, hydrography and microstructure around Stonewall Bank was conducted in June, 2000. Along with the previously observed hydraulically controlled flows, two significant new features were observed.

(1) Strongly turbulent hydraulic flows associated with baroclinically reversing currents. This flow regime was characterized by an intense near-bottom jets directed oppositely to the surface current.

(2) Turbulent wake structures. Far from the bank, quasiperiodic structures were observed exhibiting mixing rates comparable to those in the hydraulic flows near the bank crest.

OS22E-242 1330h POSTER

Variable Mixing Near the Head of Monterey Submarine Canyon

Glenn S Carter[1] (206 685 9080; carter@apl.washington.edu)

Michael C Gregg[1] (206 543 1353; gregg@apl.washington.edu)

[1]Applied Physics Laboratory - University of Washington, 1013 NE 40th Street, Seattle, WA 98105-6698, United States

A microstructure survey near the head of Monterey Submarine Canyon, the first in a canyon, confirmed eariler inferences that coastal submarine canyons contain intense mixing. The data, collected during two weeks in August 1997 with Deep Advanced Microstructure Profilers, showed turbulent kinetic energy dissipation and diapycnal diffusivity up to 1000× higher than open-ocean levels. The diapycnal diffusivity within 10 km of the canyon head is amongst the highest observed anywhere. The average value ($\overline{K_\rho} = 1.3 \times 10^{-2}$ m^2 s^{-1}) is compariable to observations in upper-ocean hotspots such as Carminal Sill, Gibraltar and inferences at abyssal constrictions such as the Samoan Passage, both of which have $\overline{K_\rho} \approx 5.5 \times 10^{-2}$ m^2 s^{-1}.

The turbulence occurred in a stratified layer up to 200 m thick. The thickness and turbulent intensity of this stratified layer increased from neap to spring tide. Locations of the most intense mixing changed from ebb to flood, but we could not identify the processes responsible. Coastal submarine canyons may account for a small but significant fraction of the global energy budgets. A crude estimate gives the global dissipation in canyons to be 58 GW or approximately 15% of the global internal tide estimate.

OS22E-243 1330h POSTER

Toward a Two-Equation Turbulence Closure Without Adjustable Parameters

Helmut Baumert[1] (+49 4103 91223 0; baumert@hydromod.de)

Hartmut Peters[2] ((305) 361-4032; hpeters@rsmas.miami.edu)

[1]Hydromod Scientific Consulting GbR, Bahnhofstr. 52, Wedel D-22880, Germany

[2]RSMAS/MPO, University of Miami, 4600 Rickenbacker Cswy, Miami, FL 33149, United States

Commonly the length scale equation of turbulence closure is considered the source of trouble, while the turbulent kinetic energy (TKE, k) equation is considered sound. In a possibly radical step, we reconsider the TKE equation and modify it. Our quest for a simple, physically sound two-equation closure continues previous efforts, in which we showed how closures can be, and need to be, constructed such as to reproduce the most basic features of homogeneous stratified shears flows from laboratory and DNS experiments: exponential growth at suffienciently low gradient Richardson number R_g, steady state at some value $R_g^s \lesssim 1/4$, and exponential decay at $R_g \gtrsim 1/4$. We term such states of exponential evolution, $\dot{k}/k = \text{const}$ and $\dot{\varepsilon}/\varepsilon = \text{const}$, "structural equilibrium." Here, ε is the dissipation rate of TKE.

We gain further guidance from considering the collapse of turbulence. We hypothesize that there is an extra energy sink in the TKE equation that represents the transfer of energy from k to internal waves and other non-turbulent motions which do not contribute to the buoyancy flux, to $\overline{w'\rho'}$. This extra sink scales 'energetically' with the squared ratio between the turbulent time scale and the minimum period of internal waves, $T = 2\,\pi/N$.

Technically, turbulence is described by a new two-equation model for the master length scale $L \sim k^{3/2}/\varepsilon$ and the master time scale $\tau \sim k/\varepsilon$. We assume that the onset of the collapse of turbulence occurs at $\tau = T$. The new theory is almost free of empirical parameters and compares well with published data from laboratory, DNS and field experiments for sheared and shear-free flows. Most remarkably, our model predicts the turbulent Prandtl number, which is generally $\sigma = \sigma_0/(1-(\tau/T)^2)$ with $\sigma_0 = 1/2$, and, in structural equilibrium, $\sigma = \sigma_0/(1 - 2\,R_g)$. Full equilibrium occurs at $R_g^s = 1/4$, and turbulence collapses into waves at $R_g = 1/2$.

OS22E-244 1330h POSTER

Impact of the boundary turbulence on a large scale coastal flows

David Smith[1] (480-727-6659; dcsiv@asu.edu)

William Lavelle[2] (206-526-6182; lavelle@pmel.noaa.gov)

Andjelka Srdic-Mitrovic[1] (srdic@asu.edu)

Don Boyer[1] (don.boyer@asu.edu)

[1]Arizona State University, MAE Department, Tempe, AZ 85287-6106

[2]NOAA-PMEL, 7600 Sand Point Way NE, Seattle, WA 98115-0070

Results presented herein are part of an research effort aimed at understanding to what extent laboratory experiments can be used as benchmarks for the development of numerical models (in the present context, models of coastal currents). Recent laboratory studies of laminar flows along model coastal regions have proven useful in the development and testing of associated numerical models. Recognizing, however, that the oceanic environment is by nature turbulent, it is important that these studies be extended to include turbulence. To initiate this line of inquiry, the present study introduces turbulence by mechanical means along a laboratory model ocean floor.

New experiments were conducted on the 14 m diameter turntable of the Laboratoire des Ecoulements Gophysiques et Industriels (LEGI) in Grenoble, France. The experiments considered both oscillatory and impulsively started flows of a rotating, linearly stratified fluid along a continental shelfslope. Four different geometrical configurations were considered: viz., a smooth continuous topography, a smooth topography interrupted by a single isolated canyon, a rough continuous topography, and a rough topography interrupted by a canyon. In the experiments with rough topography, the entire shelf and continental slope were covered by cubic roughness elements of dimension 3 cm.

Preliminary finding indicate several significant differences between the new laboratory results with roughness elements and our previous laminar experiments. The main conclusion is that boundary turbulence leads to significantly different interior flows (i.e., away from the system boundaries) than those observed for laminar flows under otherwise similar parameter values. In particular, laminar flows lead to quite regular large-scale eddy patterns which advect around the tank and are akin to the classic dishpan experiments of Fultz and Hide. In fact, the same physical mechanism of baroclinic instability is most likely at work here, as it is in the dishpan experiments. These advecting eddy structures are evidenced in the experiments by flow visualization and by monitoring the kinetic energy in a finite horizontal region of space above the continental slope and extending over the shelf break. While some eddies are formed along the shelf break level for the turbulent cases, their horizontal extent is significantly less than their laminar counterparts, indicating the different relative role of the Ekman boundary layer in turbulent versus laminar experiments.

In our previous efforts (Perenne et al. 2001), we have achieved a high level of agreement between impulsively started flows obtained in physical experiments and those produced by numerical simulations, for the smooth topography interrupted by canyon, and our goal is to achieve the similar level of agreement for the rough topography case. Then the numerical model can be used to explore hypothetical cases not considered in the laboratory.

OS22E-245 1330h POSTER

Lateral Reynolds Stress in a Coastal Strait

Keir M Colbo ((250) 472-4010; keir@uvic.ca)

University of Victoria, SEOS, P.O. Box 3055, Victoria, BC V8W 3P6, Canada

The velocity along a channel is often reduced near the lateral boundaries. This may be the result of bottom friction in the shallow water near the sides. However stratification can suppress vertical motions allowing horizontal mixing to become important.

We deployed an array of acoustic doppler current profilers in Juan de Fuca Strait, at distances from 350 m to 2 km away from the side, to directly measure the lateral Reynolds stress, $\overline{u'v'}$, as well as the large scale shear. The ratio of these gives the local eddy viscosity which is often modelled as either a constant value or a law of the wall parameterization which depends on a roughness length.

The Reynolds stress associated with high frequency internal waves and vortical modes acting on the tide is reasonably consistent with a constant eddy viscosity of about 15 m^{2}s^{-1}. A law of the wall parameterization does not properly account for the observations. The interaction between the tide and mean flow is more complex and not well reproduced by either simple parameterization.

We will also address the statistical reliability of our results, particularly the sensitivity of the Reynolds stress to the choice of axis orientation.

OS22E-246 1330h POSTER

Intense Mixing and air Entrainment in a Controlled Sill Flow, With Implications for Air-sea gas Exchange

Burkard Baschek[1] ((250) 363-6587; burkard@uvic.ca)

David M Farmer[2] ((401) 874-6176; dfarmer@gso.uri.edu)

[1]Institute of Ocean Sciences, C.P. 6000, Sidney, BC V8L 4B2, Canada

[2]Graduate School of Oceanography, University of Rhode Island, Narragansett, RI 02882-1197, United States

Haro Strait, British Columbia provides an example of estuarine circulation in which flow past sharp topography can result in energetic entrainment of gas bubbles with implications for air-sea gas exchange in coastal environments.

The exchange flow consists of saline water from the Pacific advancing along the sea floor towards the Strait of Georgia, beneath a brackish outflow from the Fraser River. The flow is strongly modulated by the tide, resulting in transports over a sill that can be great enough to override the internal control, producing a single layer flow of the deeper layer. Downstream of the sill, a downslope flow develops, bounded at the surface by a front separating the descending saline layer from the brackish water. The downslope flow interacts strongly with the nearly stagnant water above it and approximately one half of the transport is lost through upwards entrainment.

Local convergence causes extensive wave breaking and bubble formation; the bubbles move downwards in the supercritical lower layer with a vertical speed of

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up to $1\,ms^{-1}$ and may be carried to depths of $180\,m$ before dissolution. These violent processes may play an important role in the aeration of water moving into the Strait of Georgia, and at other similar locations. We model the process with a hydraulic analysis which includes mass and momentum transport across the interface and the consequences of the changing interfacial density step. Air-sea gas flux in the tidal front is calculated using the hydraulically determined flow field combined with a model describing the behaviour of gas bubbles as they are subducted and ultimately dissolve. The model results are compared with observations of the flow structure and bubble distributions acquired with a vessel mounted ADCP, an echo sounder, a CTD and an acoustical bubble sensor.

URL: http://pulson.seos.uvic.ca/people/burkard/haro_e.html

OS22E-247 1330h POSTER

Deep Water Renewal in the Strait of Georgia

Diane Masson (1-250-363-6521; massond@pac.dfo-mpo.gc.ca)

Institute of Ocean Sciences, P.O. Box 6000, Sidney, BC V8L 4B2, Canada

The Strait of Georgia is a semi-enclosed basin on the Canadian west coast in which exchange with the shelf is restricted by narrow constrictions and shallow sills. The local dynamics is mostly dominated by the mixed tides and by the estuarine circulation that is forced mainly by discharge of fresh water from the Fraser River. The intermediate and deep water of the Strait are renewed through discrete deep water renewal events during which dense water flows over the sills and into the interior basin. Several data sets are closely examined to better understand the nature and variability of the deep water renewal process over a wide range of time scales. Measured deep water renewal (DWR) events are clearly identified, as well as their effects on the water properties in the deep basin. It is found that the events can be classified into two categories: late winter intrusions bring cold, oxygen rich water, and late summer events bring warm, saline, low oxygen water. These two DWR seasons determine the annual cycle of the deep water properties in the Strait of Georgia.

For both seasons, the DWR events always occur following a neap tide, at which time the density of bottom water in the sill area peaks. However, not all neap tides are followed by a DWR event. During the DWR seasons, discrete events are found to occur every second neap tide. It is believed that this monthly periodicity is required to allow enough time for the salinity (density) of the deep water near the sill to increase sufficiently following the flushing of dense local water by the previous DWR event. Also, the timing of the two DWR seasons is explained in terms of the yearly cycle of the surface and bottom water density in the estuary: DWR events are more likely to happen at the beginning (spring) and end (fall) of the coastal upwelling season, when the Fraser River discharge is not too large. Finally, it is shown that, during El Nino years, unfavorable conditions develop that can shut down the late winter DWR season, leading to much warmer deep water during the following winter.

OS22E-248 1330h POSTER

Interaction Between Wind-Induced and Density-Driven Flow in a Coastal Plain Estuary

Rosario Sanay[1] ((757) 683 3234; sanay@ccpo.odu.edu)

Arnoldo Valle-Levinson[1] ((757) 683 5578; arnoldo@ccpo.odu.edu)

[1]Old Dominion University, 768 52nd ST Crittetion Hall-ODU, Norfolk, VA 23508, United States

A series of numerical experiments were carried out to study the effects of wind forcing on a stratified system with lateral depth variation. In particular, the study focused on the transverse variability of salinity and along-channel flow. The transverse variation of the along channel flow and salinity were sensitive to bathymetry shape and to the magnitude and direction of the wind. For narrow channels (narrower than one internal radius of deformation), the inflow reached the surface over the deepest part of the cross section. For wide channels (wider than one internal radius of deformation), the inflow was restricted to a lower layer. The circulation pattern and salinity distribution induced by the wind over a stratified system showed that wind forcing dominated over buoyancy influences when the Wedderburn number (W), which compares wind stress to baroclinic pressure gradient, is near 1. For example, for weak up-estuary wind (W<<1), the gravitational circulation remained almost unaltered, only a thin third layer developed at the surface (the wind only influenced the upper part of the water column). Under strong winds (W near 1), the wind-induced pattern of down-wind flow over shoals and up-wind flow in the channels masked any effect of the gravitational circulation as the water column remained vertically homogeneous.

OS22E-249 1330h POSTER

Tidal Current and Stratification Profiles on the Inner Continental Shelf at the Mouth of an Estuary

Laura V Rear[1] (laura.rear@uconn.edu)

Daniel L Codiga[1] (d.codiga@uconn.edu)

[1]The University of Connecticut, Department of Marine Sciences 1084 Shennecossett Lane, Groton, CT 06340, United States

We present the vertical structure of tidal currents and stratification profiles observed in 20-50 m water depth on the inner continental shelf outside Block Island Sound (BIS). Water velocities are measured for several months during fall/winter and spring deployments of an array of upward-looking bottom-mounted acoustic Doppler current profilers (ADCPs) having nominal 20-minute and 1 m temporal and depth resolutions respectively. Hydrographic data with vertical resolution of several cm are collected with two-hour sampling intervals by moored profiling conductivity-temperature-depth instruments (CTDs) co-located with selected current meters during spring. The barotropic (vertical-mean) component of currents accounts for nearly all of the kinetic energy variance in winter and fall, while in spring there is a larger baroclinic component. This is consistent with the higher likelihood of internal tides associated with spring stratification in contrast to the weaker fall and winter stratification. Harmonic fits to M_2, N_2, S_2, O_1, and K_1 constituents account for substantially more of the variance during the spring than during the fall and winter, as may be expected due to strengthened wind-driven motions during the latter. M_2 is dominant, has tidal current ellipses generally oriented with major axis directed toward the mouth of BIS, and falls off in amplitude from ∼15 cm/s at ∼8 km away from the estuary mouth to ∼8 cm/s at ∼12 km farther offshore. Spring stratification profiles at a site with water depth 43 m reveal a pycnocline spanning 15-20 m depths across which the density changes by about 0.75 kg/m^3. Maximal isopycnal displacements occur within the pycnocline and reach 10 m. The harmonic fit indicates 58 % of the density variance is tidal. Depth dependence of tidal ellipse parameters (semi-major axis length and azimuth angle relative to east, eccentricity, and instantaneous phase) is modest but shows a slight increase with depth of the semi-major axis in the upper water column and a more pronounced decrease in the deepest several m as expected due to friction. Phasing of vertical displacements relative to tidal currents along the major axis is consistent with an internal tide propagating onshore phase-locked to the barotropic tide. Time-series gradient Richardson number profiles are presented and patterns in the temporal and depth structure identified.

OS22E-250 1330h POSTER

Flow, Salinity and Bottom Turbulence Characteristics in the Altamaha Estuarine Channel

Daniela Di Iorio[1] (706 542 7020; daniela@uga.edu)

Ki Ryong Kang[1] (706 542 3731; krkang@uga.edu)

[1]University of Georgia , Dept of Marine Sciences 230 Marine Sciences Building, Athens, GA 30602, United States

A directed studies research project has been carried out as part of the Georgia Coastal Ecosystems Long Term Ecological Research (GCE-LTER) project. In this study we analyze the flow and salinity characteristics in the Altamaha Estuarine Channel which has a periodic component of stratification that interacts with turbulent mixing to control water column structure and flow. Tidally driven flows classifies the estuary as well mixed with increasing salinites during flood and decreasing salinities during ebb. There is a contrast between ebb and flood phases of the tide showing that during ebb the gradient Richardson number is $Ri < 0.25$ indicating that shear instabilities give rise to turbulent mixing and that during the flood $Ri > 0.25$ indicating that the density gradient stabilizes the variations caused by the current shear. This is contrary to most estuarine environments and allows us to investigate how tidal straining acts to reduce water column stability. Bottom turbulence measurements of Reynolds stress and kinetic energy dissipation also show differences between flood and ebb regimes and will discussed over a spring/neap cycle.

URL: http://gce-lter.marsci.uga.edu/lter/

OS22E-251 1330h POSTER

Estuarine Modification of Tidal Flow in Juan de Fuca Strait

Steven F Mihaly[1] (mihalys@pac.dfo-mpo.gc.ca)

Richard E Thomson[1] (thomsonr@pac.dfo-mpo.gc.ca)

Alexander B Rabinovich[2]

[1]Department of Fisheries and Oceans, Institute of Ocean Sciences, 9860 West Saanich Road, Sidney, BC V8L 4B2, Canada

[2]Russian Academy of Sciences, P. P. Shirshov Institute of Oceanology, 36 Nakhimovsky Prosp., Moscow 117851, Russian Federation

Juan de Fuca Strait separates Vancouver Island from Washington State and connects the Strait of Georgia and Puget Sound with the Pacific Ocean. The main portion of the channel is 100 km long, 22-28 km wide and 150-250m deep. It is the most heavily used commercial waterway on the west coast of Canada and the US. Pacific Northwest. The dynamics of the Strait are dominated by along channel barotropic tidal currents that are mixed, predominantly M_2 semidiurnal and which account for over 90% of the along channel current variance at all depths. The Strait is classified as a partially-mixed estuary, with freshwater input from the Fraser River of > 6000 m^3 s^{-1} at peak summer flows. In summer, the brackish near-surface outflow reaches 40 cm/s and is compensated by a 20 cm/s salty inflow. Two years of continuous observations near the centre of the Strait have been made by a bottom-mounted, upward looking 150 kHz ADCP. Forty bins span the water column from 12 m above bottom to 12 m below surface. These observations are used to examine the temporal variability in the vertical structure of the tidal currents. The variation with depth of the seasonally steady tidal currents indicates internal motions which are mainly phase-locked to the barotropic tide. After separation of the baroclinic tide from the barotropic tide, the inter-seasonal variability of the baroclinic motions are shown to have a direct relationship to estuarine flow variability. For the M_2 tidal constituent, this nonlinear interaction between the depth-varying mean flow and the barotropic tidal currents is responsible for deviations in the predicted current magnitude of up to 10% in the winter and 20% in the summer. Detailed analyses of the tidal ellipses of five major constitutents (K_1, O_1, M_2, N_2, S_2) reveal significant changes in the ellipse parameters for the baroclinic tide. These changes are apparently forced by the estuarine circulation. The coupling varies with constituent and is evident in the magnitudes of both major and minor axes, the phases, and the direction of rotation of the ellipses. The complex interaction between the tidal currents and estuarine circulation is remarkably consistent between seasons and can be used to enhance prediction of the currents in Juan de Fuca Strait.

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Effects of Mixing and Entrainment on a two-layer Exchange Flow in a Strait

Frank Gerdes[1] (1-250-363-6587; gerdesf@dfo-mpo.gc.ca)

David Farmer[2] (1-401-874-6176; dfarmer@gso.uri.edu)

[1]School of Earth and Ocean Sciences, University of Victoria, P.O.Box 3055, Victoria, BC V8W 3P6, Canada

[2]Graduate School of Oceanography, University of Rhode Island, Narragansett, RI 02882-1197, United States

In contrast to two-way exchange flows in broad and deep straits, a narrow and relatively shallow strait may exhibit effects due to mixing of mass and momentum between the layers and from sidewall and bottom friction. Observations acquired in the Bosphorus through a collaboration with colleagues at the Turkish Department of Navigation, Hydrography, and Oceanography, using moored and vessel mounted ADCPs, CTD profiles and acoustic imaging, illustrate some of the implications of these effects. Our observations show that substantial changes occur in the density structure of the water masses as they move through the strait. Moreover the interface between the layers has an appreciable slope, even within the subcritical portion which is well away from the controls. Mass and momentum flux between the layers, together with friction along the boundaries, contribute to the balance of forces within the strait. Mixing between the layers is derived from cross-channel ADCP/CTD transects and the vertical fluxes calculated on the basis of volume and salt conservation for comparison with commonly used entrainment laws. The observations are analyzed with a two-layer mathematical model that includes the effects of friction and entrainment. We show that in the central and southern portion of the Bosphorus the effects of friction and entrainment on the flow can be of equal importance.

URL: http://pulson.seos.uvic.ca/people/gerdi/bosphorus/bosphorus.html

OS22E-253 1330h POSTER

Seasonally Varying Controls on Flushing and Oceanic Exchange in Willapa Bay, Wash.

Neil S Banas[1] (206-543-0599; neil@ocean.washington.edu)

Barbara M Hickey[1] (bhickey@u.washington.edu)

[1]Univ. of Washington, Oceanography, Box 355351, Seattle, WA 98195

Three years of hydrographic time series and transects from Willapa Bay, Washington, largest of the Pacific Northwest coastal-plain estuaries, reveal that the subtidal dynamics which control flushing and oceanic exchange vary strongly–indeed, alternate between control by tidal stirring and control by gravitational circulation–on seasonal and shorter timescales. These dynamics are diagnosed through running estimates of the terms in the time-dependent subtidal salt balance.

During late summer, local riverflows are negligible and stratification weak, while ocean salinity, and thus the along-channel salinity gradient, are highly variable on timescales of 3-10 d because of wind-driven upwelling and downwelling. In these conditions (and in the average over several wind events) diffusive stirring by the bay's strong (4 m) tides is estimated to dominate over buoyancy-driven processes by an order of magnitude. The along-channel profile of horizontal tidal diffusivity is calculated by finding the slope between the rate of change of salt storage and the along-channel density gradient at several time-series stations. Calculated diffusivities are consistent with observed rates of up-estuary propagation of oceanic salinity fluctuations.

In winter and spring, when riverflow is intermittent but high, flushing by the gravitational circulation becomes important. Exchange-flow velocities show a linear correlation with along-channel density gradient, and their magnitude is consistent with a simple dynamical balance between that gradient and vertical mixing. Stratification, in contrast, appears to oscillate between two dynamical regimes and is poorly correlated with along-channel gradient in either of them. In the first regime, stratification follows the 2/3-power-law relationship with riverflow which indicates an exchange flux in balance with down-estuary flushing by riverflow. (Notably, exchange flux and river flushing appear to balance each other even when both are small and tidal stirring dominates.) In the second regime, intrusions of a strong, buoyant plume from the Columbia River, 50 km south, eliminate stratification and flatten the along-channel gradient for days or weeks at a time. These effects undermine density-driven exchange even when local riverflow is substantial; tidal stirring explains the rate of intrusion and replacement of plume water during these events.

OS22E-254 1330h POSTER

Circulation and Mixing in a Complex Estuarine Environment. Effects on the Transport and Fate of Suspended Matter.

Elias Hunter[1] (hunter@imcs.udel.edu); Robert Chant[1] (chant@lucitania.rutgers.edu); Rich Styles[1] (styles@imcs.rutgers.edu); Scott Glenn[1] (glenn@arctic.rutgers.edu); Kelly Rankin[2] (krankin@stevens-tech.edu); Michael Bruno[2] (m1bruno@stevens-tech.edu)

[1]Rutgers University, Inst. of Marine and Coastal sciences, 71 Dudley Rd, New Brunswick, NJ 08901

[2]Stevens Institute of Technology, Department of Environmental and Ocean Engineering, 711 Hudson St, Hoboken, NJ 07030

As part of the New Jersey Department of Environmental Protections Toxics Reduction Program, we are conducting hydrographic surveys of the Newark Bay complex to characterize physical processes within this estuarine system. The observations include shipboard and moored current observations and salinity, temperature and turbidity measurements. A major objective of these surveys is to provide a dynamical framework that will aid in the interpretation of chemical data, as well as to provide insights into the transport and fate of dissolved and suspended material. This framework is particularly needed because of the complex nature of this estuarine system that is comprised of multiple sources of fresh water that feed several semi-enclosed bays that are interconnected by a pair of tidal straights. This poster will focus on exchange processes in the two tidal straights. The Kill van Kull tidal straight runs east-west connecting New York Harbor to Newark Bay and the Arthur Kill tidal straight runs north-south connecting Newark Bay to Raritan Bay. Observations emphasize that while buoyancy effects, meteorological forcing and tidal processes drive exchange in these straights the relative importance of these processes varies in both space and time. In the Kill van Kull a classic estuarine two-layer buoyancy driven flow is evident, with eastward flowing surface layer over a westward flowing bottom layer. This two layer circulation, however, vanishes during spring tide conditions and during times of low river discharge. Wind forced motions appear to dominate exchange through the Arthur Kill. Examples of these processes will be presented as will their effect on the transport of suspended matter.

OS22E-255 1330h POSTER

Validation and Application of a Near Real Time Nowcast System of Salinity and Temperature in Chesapeake Bay

Zhen Li[1] (zhen.li@noaa.gov)

Tom Gross[1] (tom.gross@noaa.gov)

Harry Wang[2] (wang@vims.edu)

Christopher Brown[3] (christopher.w.brown@noaa.gov)

Rayleigh Hood[4] (raleigh@hpl.umces.edu)

[1]NOAA/NOS/CSDL, 1315 East West Hwy, Silver Spring, MD 20910

[2]NOAA/NESDIS, Office of Research and Applications

[3]Virginia Institute of Marine Sciences, Glouster Point

[4]Horn Point Laboratory, University of Maryland Center for Environmental Sciences

A near real time nowcast system of salinity and tempearture in Chesapeake Bay has been developed to help estimate the habitat and probable location of sea nettles (Chrysaora quinquecirrha), a stinging jelly fish, in Chesapeake Bay. The nettle habitat is primarily determined by salinity and temperature in the Bay, therefore, the accuracy of nowcasting the distribution of sea nettles depends upon the validity of model simulated salinity and temperature. Simulated salinity from retrospective runs of CH3D from 1996 to 2001 are compared against observations obtained from the Water Quality Monitoring Program database (http://www.chesapeakebay.net/wquality.htm) at about 49 stations in the mainstem of the Bay. The stations are sampled once each month during the winter months and twice each month during the warmer months. At each station, there are typically 10 to 30 data points over a year. The hydrodynamic model CH3D (Curvilinear Hydrodynamics in 3 Dimensions), developed at the U.S. Army Corps of Engineers Waterways Experiment Station for Chesapeake Bay, was adapted to run in near real time.

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Volume Fluxes Throughout One Year In The Chesapeake Bay Derived Volume Fluxes Throughout One Year In The Chesapeake Bay Derived From Sea Level Slope

David Salas-Monreal[1] ((757) 683 3357; salas@ccpo.odu.edu)

Arnoldo Valle-Levinson[1] ((757) 683 5578; arnoldo@ccpo.odu.edu)

[1]Old Dominion University, Center for Coastal Physical Oceanography, Department of Ocean, Earth and Atmospheric Sciences, Old Dominion Univesity, Norfolk, VA 23529, United States

Time series data for the year of 2000 at eight stations inside and outside the Chesapeake Bay are used to determine the relative influence of wind, barometric pressure and thermosteric effects on sea level variability and sea level slope.

Special emphasis is placed in the lower Chesapeake Bay. Inverse barometer effects may account for up to 30% of the variations of sea level in the Bay. Its greatest influence was noted at the northernmost, freshest and shallowest location. Thesmosteric effects accounts amount for less than 10% of the variability and wind forcing accounts for most of the variability.

The sea level slopes respond to the wind as expected: in the southwestern corner of the Bay, northerly winds cause water pile ups and southerly winds produce water level depressions. The slopes across the bay were used to estimate geostrophic volume fluxes trough the mouth. These were different from the fluxes calculated through continuity by using the time rate of change of sea level. However the addition of wind stresses to the geostrophic flux estimates compared more favorably. Both, the continuity constrained fluxes and the frictional dynamics estimates of the volume fluxes indicated drainage of the bay with northwesterly winds and full up of the Bay with northeasterly winds. These responses compared reasonably well with the flow measured at one point at the entrance to the bay.

OS22E-257 1330h POSTER

Mixing and Structure in Double-Diffusive Density Currents

Jin H Hwang[1] (217-333-6183; jinhwang@uiuc.edu)

Patrick R Jackson[1] (217-333-6183; prjackso@uiuc.edu)

Chris R Rehmann[1] (217-333-9077; rehmann@uiuc.edu)

[1]Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, 205 N. Mathews Ave., Urbana, IL 61801, United States

Laboratory experiments on warm, salty arrested currents injected beneath a cold, fresh opposing flow were performed to examine the contributions of mechanical and double diffusive processes to vertical mixing. Comparing the time scale of the double diffusive instability to the eddy turnover time indicates when interfacial scouring by turbulent eddies should be important. The ratio of the discharges of dense and light water decreases by a factor of 4 as the density ratio increases, but no systematic effect of the stratification strength was observed. Temperature and salinity profiles measured along the length of the current have several features observed in previous experiments on salt wedges and double diffusive flows. Profiles near the outlet show multiple layers for low density ratios and high Richardson numbers. The flux ratio is inferred from the changes of the temperature and salinity differences along the length of the current. Two main regions are identified: Near the tail, the flux ratio is larger than that in double diffusion experiments without shear but still less than one. Near the nose, mechanical entrainment can make the flux ratio much greater than one. Results on preliminary experiments on fingering currents (cold, fresh water injected beneath a warm, salty opposing flow) will also be presented.

URL: http://www.staff.uiuc.edu/∼rehmann

OS22E-258 1330h POSTER

Turbulent Mixing in the Thermocline of Lake Superior

Brian D May (218-726-8773; bmay@d.umn.edu)

University of Minnesota Duluth , Large Lakes Observatory 10 University Drive, Duluth, MN 55812, United States

Temperature microstructure profiles obtained in Lake Superior are used to estimate levels of turbulent mixing in the thermocline. The data collected represent the first direct measurements of turbulence in Lake Superior. A wide variety of regimes is sampled, ranging spatially from coastal to open waters and temporally from spring through late fall. Mixing intensities (characterized by dissipation rate of turbulent kinetic energy ϵ and vertical eddy diffusivity K) vary significantly. Spatially, the data indicate enhanced levels of turbulent mixing near topography, e.g., where the thermocline intersects the bottom. Temporally, the data show a clear seasonal cycle with high rates of mixing during the spring and fall overturns and much weaker mixing during the stratified summer period.

OS22E-259 1330h POSTER

Eastern-Boundary Intensification of Flow in Lake Vostok

David Walsh (907 474 2677; dwalsh@iarc.uaf.edu)

International Arctic Research Center & University of Alaska Fairbanks, 930 Koyukuk Drive P.O. Box 75-7335, Fairbanks, AK 99775, United States

Located in Antarctica and buried under several kilometers of ice, estimates suggest Lake Vostok has been isolated from the outside world for 10-20 million years. As a result of its prolonged isolation, the ecosystem of the lake may have evolved differently from other terrestrial ecosystems, and there is considerable interest in investigating its character. In order to plan future field studies it is important to have a basic knowledge of the circulation in the lake.

Based on the predictions of a simple hypothetical model it is proposed that the geothermally driven circulation in Lake Vostok is asymmetric, with a narrow boundary layer along the eastern wall and a diffuse counter-clockwise recirculation in the interior. The predicted boundary layer thickness is roughly 0.5 km, much less than the 60-km width of the lake. Our results differ from recent work by Wüest and Carmack (2000), who predicted a symmetric, clockwise circulation in the lake. The predicted boundary-layer intensification is due to variation in the depth of the lake, which creates a dynamically important topographic β effect. Eastward intensification may have significant implications for future studies attempting to characterize the ecosystem of the lake, since organisms may tend to concentrate within particular flow regimes.

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