C-DOGS 2006

Conference of Dalhousie Oceanography Graduate Students

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$9am$ - $5pm$, University Hall
Dalhousie University, Halifax, Nova Scotia

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Discrepancies between NCEP/NCAR and ERA-40 reanalysis products

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Global, atmospheric data from the NCEP/NCAR and ERA-40 reanalyses are compared with each other and with observations. Especially in the early reanalysis period, large sea level pressure and 500 hPa geopotential height discrepancies between the two reanalyses are present year round over North Africa, the Middle East and Asia, and other discrepancies exist particularly over the Southern Ocean and Antarctica. Low surface air temperature correlation values between the two reanalyses are found over the tropical and subtropical land areas of South America, Africa and southern Asia, even in the period when satellite data were available. Moreover, there is worse agreement between the two reanalyses in upper tropospheric temperature variability over the entire tropical band in the satellite era than there was before.

Surface wind retrieval over Lunenburg Bay

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The Radarsat-1 synthetic aperture radar (SAR) is one of few remote sensing instruments that is capable of resolving the roughness of the ocean surface at O(100m) resolution. Nonlinear scattering models that relate surface roughness to wind speed have been constructed for scatterometers, which operate at much lower resolution and are therefore unable to image most coastal inlets and bays. Here, we examine the feasibility of employing SAR data at near-full resolution and an operational C-band scattering model (CMOD, which was originally developed for scatterometers on board the ERS-1,2 satellites). Wind retrieval is performed with the aid of numerical model wind forecasts and validation is performed using wind observations in Lunenburg Bay.

Waves and Flows Over a Bedrock Shoal

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Wave forcing and response over a rough rocky shoal are investigated through analysis of field data and numerical simulation. The field site, Lunenburg Bay, is a coastal embayment on the southern shore of Nova Scotia approximately 8 km long and 4 km wide. It has irregular bathymetry characterized by a typical depth of 10 m and is exposed to wave energy from the North Atlantic Ocean. A 2 to 5 m deep shoal exists near the mouth of the bay, composed of long, narrow and steep-walled bedrock ridges that are separated by deeper channels infilled with gravel-sized sediments. Based on observations and model predictions, this site was chosen for investigation of energy dissipation through wave breaking and bottom friction, and momentum exchange to mean flows and pressure gradients.

Large offshore wave forcing conditions, including wave events driven by hurricanes, create the largest gradients of wave energy in the bay and induce strong currents. Observations made from an array of wave and current instruments on and around a shoal are presented for a 50-day deployment. The observations are compared with predicted wave spectra and current velocities made by numerical simulations of wave conditions using a nearshore wave model (SWAN) and coupled circulation model (DELFT3D) for several events. Wave breaking and frictional dissipation are shown to be significant and wave-driven currents around the shoal can be strong, O(1 m/s), an order of magnitude greater than tidal currents, O(0.1 m/s). Temporal and spatial scales for wave energy dissipation and generation of wave-driven flows are considered for a range of conditions and the importance of including wave forcing in coastal circulation models is addressed.

Numerical study of the baroclinic response of Lunenburg Bay and Mahone Bay to local wind forcing in summer 2003

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Baroclinic response of Lunenburg Bay (LB) and Mahone Bay (MB) to wind forcing in August 2003 is examined using numerical models. Significant spatial and temperal variations of temperature and salinity were evident from the observations in Lunenburg Bay during this period. A linear reduced gravity model is first used to study the response of the first baroclinic mode to wind forcing in a flat-bottom coastal embayment. The model results demonstrate that internal Kelvin waves are generated and propagate around the bay. A linear multi-mode shallow-water model suggested by McCreary (1981) is then used to examine the generation and propagation of baroclinic waves in LB and MB with a realistic coastline but with a flat bottom and linear stratification. Finally, the primitive-equation ocean circulation model known as CANDIE is used to examine the interaction of the baroclinic waves with bottom topography and nonlinear effects in the study region.

Implementation of a simple 3D ecosystem box model for Lunenburg Bay, NS.

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Coastal planktonic ecosystem dynamics is the result of a complex set of interactions by many variables. Lunenburg Bay, the study site, is a dynamic environment where local circulation, forced by tides and wind, is thought to have a key role on the local plankton dynamics. Besides, CDOM load, Scotian Shelf forcing and benthic-pelagic coupling are among many other parameters that could contribute to the variability of the planktonic ecosystem.
In order to reach a satisfactory understanding on the causes of these dynamics, a 3D ecosystem model has been implemented. Its physical framework was reduced using the *box model* technique. It allows to focus on the ecosystem dynamics in a particular set of conditions. For that, modelled diffusion and advection data were used. A description of the model implementation will be presented, among with a first series of results and a discussion of difficulties and further model development.

The influence of habitat on the reproduction of a Northeast Pacific hydrothermal vent gastropod, *Lepetodrilus fucensis*

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The ephemeral nature of hydrothermal vents is expected to favour species that have evolved *r*-type life history strategies that include fast growth, early reproduction, and wide-spread larval dispersal. *Lepetodrilus fucensis* is the numerically dominant macrofaunal species in the NE Pacific hydrothermal vent ecosystem. It spans a wide range of vent habitats with physico-chemical conditions that are highly variable over short temporal scales. Thus, habitat selection by *L. fucensis* may have important consequences in impacting its reproductive output, as different flow regimes may reflect different nutrient resources, which would affect energy allocation to reproductive efforts. Histological techniques were used to determine size at first reproduction, reproductive output, and fecundity, through examination of the gonads of male and female *L. fucensis* collected from four different habitat types. For females, feret diameter was calculated for all oocytes that had been sectioned through the nucleus and then classed as mature or immature. For males, the abundance of spermatozoa within the gonad was quantified as a percentage of the total gonad cross-sectional area occupied by spermatozoa. Both males and females exhibited early maturity, with the first reproductive event occurring at one-sixth of their maximum size. There was no difference in spermatozoa cover, indicating male reproductive condition is not affected by habitat. However, females within actively venting habitats had a larger percentage of mature oocytes and greater actual fecundity than those from habitats further from vent influence. Thus, selection of actively venting habitats appears to maximize female reproduction. This difference between genders may be the result of the relatively greater energetic cost associated with producing large, yolky oocytes, than small, inexpensive spermatozoa. Early maturity, high fecundity, and continuous production of gametes suggests a reproductive strategy characteristic of an opportunistic species, and may be contributing to the extremely abundant populations of *L. fucensis* observed in the NE Pacific vent ecosystem.

Environmental influence on consumption rates of juvenile native and non-native decapods from the Bras d'Or Lakes, Nova Scotia

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Interspecific interactions between juvenile stages of native and non-native decapod species have received little attention. In the semi-enclosed, brackish Bras d'Or Lakes three decapods are found: the non-native green crab (Carcinus maenas) and the natives rock crab (Cancer irroratus) and mud crab (Dyspanopeus sayi). Consumption rates of each species were measured, in both laboratory and field settings, under manipulated physical conditions (temperature, salinity, flow and food presentation). In the laboratory, we manipulated temperature (17°C, 13°C) and salinity (17, 26) in an orthogonal design and measured consumption rates of Mytilus sp. by each decapod species. Consumption rates of green crabs varied only with temperature and those of rock crabs only with salinity. Mud crab consumption was not significantly effected by either factor. We examined the effect of flow (flow through, bubbling) and prey size distribution (representative of the field, preferred) on each decapod also in an orthogonal design in the laboratory. The only significant effect on consumption was between prey size distributions for rock crabs. There were no significant effects of prey size distribution in experiments done concurrently in the field. However, for both green crabs and rock crabs consumption rates were significantly higher in the laboratory than the field consumption rates. Based on these experiments there is evidence to suggest that consumption rates of native and non-native decapods do vary under different environmental conditions and settings, although this variation is not necessarily consistent among species.

Determining larval supply mechanisms of an invasive invertebrate

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*Membranipora membranacea*is an encrusting epiphytic bryozoan introduced to the Atlantic coast of North America that causes defoliation of kelp beds. We investigated spatial and temporal patterns in larval settlement and colony abundance of *M. membranacea* with respect to oceanographic conditions on the southwest shore of Atlantic Nova Scotia. Abundance, size, and percent cover of *M. membranacea* colonies (settlers to adults) on the kelp *Laminaria longicruris* were measured at 2 sites located near the northeast and southwest ends of St. Margaret's Bay, Nova Scotia, respectively. Three depths (4, 8, and 12 m) were sampled from June 2005 to February 2006, on weekly (summer and early fall) or monthly (late fall and winter) time scales. *M. membranacea* settled in low abundance throughout July and August. The abundance of settlers increased dramatically through September, peaked in October/November, and subsequently declined. In fall, settler abundance was consistently greater at depth than in the shallows, at both sites. Patterns in settler abundance were similar between sites within the bay, and settlement time series suggest that both advective and diffusive mechanisms are involved in larval delivery to the shore. Compared to the west coast of North America, a region to which *M. membranacea*is native, settlement occurred much later in the season in Nova Scotia. As for the west coast, however, there is some evidence to suggest that strong temperature fluctuations are implicated in the delivery of *M. membranacea* larvae to the shallow rocky subtidal in Atlantic Nova Scotia.

Chemotaxis: the search continues

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Chemotaxis, the directed movement of an organism in response to a chemical gradient, may be an important mechanism for aggregation of microalgal flagellates in the water column. Recently, there has been renewed interest in the aggregation of microalgae, both in the context of colonization and collection around marine snow, and with respect to "thin layers" (meter-scale vertical aggregations). Understanding the mechanisms of aggregation is important for a number of reasons. Aggregation creates spatial relationships between flagellates and other organisms in the water column, and also between flagellates and their environment. This structure affects the ecology of the system by influencing factors such as predator-prey relationships and sexual interactions. Meter-scale aggregations like thin layers are important to oceanographers in the context of sampling regimes, because high concentrations of flagellates may remain in the water column undetected at typical (meter-scale) sampling resolutions. Many layer-forming flagellates are harmful algal bloom species (HABs), and improving our ability to predict their behaviour is of considerable interest. Chemotaxis may also play a significant role in the successful acquisition of nutrients in a heterogeneous water column environment, and therefore influence carbon cycling. My research aims to identify oceanographically relevant substances to which selected flagellates exhibit a chemotactic response, and to identify the ecological context(s) which favour the existence of these response(s).

VERTICAL DISTRIBUTION OF SEA STAR LARVAE AROUND SHARP HALOCLINES: SALINITY AVOIDANCE BEHAVIOUR

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For many marine benthic invertebrates, the dynamics of adult populations are tightly coupled with the successful recruitment of larvae. However, the relative importance of larval behavior at small scales (cm's to m's) in determining larval survival and dispersal is poorly understood. Larval aggregations at haloclines have been observed in the field and laboratory. One potential mechanism for the formation of these aggregations is larval avoidance of physiologically stressful salinities. Reductions in salinity can have adverse effects on many taxa of meroplankton, in particular, echinoderms. Echinoderm larvae are stenohaline and have poor ion regulation. Consequently, these larvae may avoid salinity layers that adversely affect their development and survival. We examined larval response of the sea star Asterias rubens to a range of sharp ($\sim$ 2 cm) haloclines in the laboratory. The vertical distribution of bipinnaria larvae was examined in Plexiglas columns with experimentally constructed haloclines. In four treatments, the salinity of the bottom layer was 35 and that of the top layer was 21, 24, 27 and 30, respectively. In two other treatments, salinity in the bottom layer was 32 and in the top layer was 24 and 27, respectively. Vertical distributions of larvae indicate that larval position relative to a halocline is related to the salinity of the top layer and is not a result of the relative salinity difference between two layers. Subsequent short term and long term salinity tolerance experiments indicate that changes observed in larval vertical distribution in the halocline trials may be associated with a salinity avoidance behavior.

Growing-degree days and fish growth

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The growth rate of ectotherms, including most fish, is governed by temperature. For over 270 years, agriculturalist have recognized the thermal integral, known as the growing degree-day (GDD,°C·d), to be a strong predictor of plant growth and development. For over 60 years, entomologists have equally employed GDD as a strong predictor of insect growth and development. Fish researchers have yet to widely acknowledge the explanatory power of the growing degree day in addressing growth and development in fish. To paraphrase Reaumur (1735): *"The same [fish] are harvested in very different climates; it would be interesting to compare the sums of heat degrees over the months during which the [fish] does most of its growing and reaches complete maturity in hot countries, like Spain or Africa... in temperate countries like France and in the colder countries of the North."* Here we demonstrate that fish length-at-day, prior to maturation, is a strong and linear function of GDD capable of explaining 85 to 99% of the variation among 78 unique datasets representing 11 fish species drawn from marine and freshwater environments, temperate and tropical climes, and laboratory-control and field studies. Moreover, the GDD method demonstrates explanatory power across large spatial scales; e.g. 93% of the variation in length-at-age, for age-2 to -4 Atlantic cod (*Gadus morhua*) across their entire range (17 different stocks) is explained by one simple GDD function. As well, we show that the GDD method accounts for the temperature variation in growth of Scotian Shelf haddock (*Melanogrammus aeglefinus*) from 1966 to 1993 thereby identifying residual variation in growth likely attributable to fishing pressure. Our analysis extends the well-established and physiologically-based GDD method to fish and, relative to conventional calendar-time methods, offers a significant improvement in predictive skill.

Cross Ripples and Wave Directional Spectra

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Wave formed sand ripples are created through interaction of the surface gravity wave field and the bottom sediments. Water motion is induced by the passage of waves and can cause sediment to become organized into rippled beds. Which ripple type develops depends on the wave energy. At intermediate wave energies, one possible bed state is cross ripples. Cross ripples are a double crested feature that may be caused by the existence of a bi-directional wave field. To investigate any correlation between cross ripple occurrence and a bi-directional wave field, the directional spectra are calculated from point measurements of the wave orbital velocities. Directional spectra will be calculated through a maximum likelihood estimate and a simpler Fourier expansion estimation. These estimates are then compared with numerical predictions using the Simulating WAves Nearshore (SWAN) model.

Reconstructing Dynamically Consistent Hydrographic Climatology for the Northwestern Atlantic Ocean by using a Three-dimensional Ocean Circulation Model

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A three-dimensional ocean circulation model is used to reconstruct monthly mean climatology of temperature and salinity (TS) for the northwestern Atlantic Ocean. The model domain covers the region between 261E and 321.96E and between 8N and 51.96N, with a horizontal resolution of 1/3 deg in longitude. Different model runs are conducted to generate monthly mean TS climatology for 12 months. The model in each run is initialized with input density taken from the monthly mean TS climatology constructed by Geshelin et al. (1999), and forced by the corresponding monthly mean wind stress and surface heat freshwater fluxes. The model in each run is integrated for 90 days in diagnostic mode and then for another 90 days in prognostic mode. The prognostic model results from days 30 to 60 are used to reconstruct the new monthly mean TS climatology for the region. In comparison with the climatology of Geshelin et al (1999), the new TS climatology is more dynamically consistent since the prognostic calculation eliminates the misalignment of the input density field and bathymetry.

Closing the Oceanic Heat Budget

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The transport of heat by the ocean plays a major role in the global heat balance, and its variability is often thought to have important consequences for climate change. The traditional point of view is that in the ocean, the meridional transport of heat is achieved by the wind-driven and meridional overturning circulations. Furthermore, it is only in the Southern Ocean that eddies are believed to play a fundamental role in the heat balance. Here we examine the zonally-averaged oceanic heat budget. We argue that eddy-induced diapycnal fluxes are required to balance the surface heat input, a result that is not confined to the Southern Ocean, but applies throughout the global ocean. We further argue that eddy-induced mixing, especially in the surface mixed layer, can provide the so-called "missing mixing" required to close the oceanic heat budget.

A laboratory experiment on internal solitary waves for senior undergraduate students

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I will introduce a new laboratory experiment for senior undergraduate students dealing with aspects of internal solitary waves. In the experiment the students will examine the propagation of internal solitary waves in a two-layer stratified fluid. They will learn the basic techniques to create two-layer stratified systems with miscible fluids (e.g. fresh and saltwater) and to generate internal solitary waves. Measurements will be made of the amplitude, wavelength and phase speed of the waves and will be compared to a weakly nonlinear theory. Some results from our experimental runs will also be presented.

Impact of an internal solitary wave upon a natural sloping boundary

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We present observations of an internal solitary wave propagating towards an island in the Saint Lawrence Estuary. Towed echosounder and transects document the development and decay of a trapped core below the shoaling solitary wave. The trapped core propagates upslope across the pycnocline, detraining material from depth into the surface layer as it decays. Curiously, it maintains a constant aspect ratio as it decays. This is consistent with numerical simulations of the process as well as laboratory experiments found in the literature. A simple model describing the trapped core's detrainment is also presented.

Resonant Triad Interactions

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Internal waves exist between fluids of different densities. Since world's oceans are stratified in density, it is not surprising that internal waves are found almost everywhere. However, what may be surprising is that internal wave spectra from two mutually exclusive areas of the ocean (far from any wave source) are nearly identical; a model of which has been called the Garrett-Munk spectrum. With different overall depths, underlying topography, temperature and salinity structures, surface weather patterns, etc., this may seem surprising. The Garrett-Munk spectrum can be explained by resonant triad interactions; a process where energy from a low wavenumber internal wave is transferred to internal waves of higher wavenumber. Resonant triad interactions will be introduced and it will be shown that this process is responsible for the majority of the mixing that occurs in the interior of the ocean.

Comparing and contrasting mixed layer depth detection schemes on the Scotian Shelf

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The ocean is separated from the atmosphere through a surface boundary layer. Many processes of interest occur in this layer including heat, mass and momentum exchange with the atmosphere, biological primary production, particle flux, gas exchange, shipping and macro biological activity to name a few. A persistant characteristic of this surface layer is nearest the surface where properties of interest do not vary with depth or the mixed layer. The deepest point of homogeneous properties is called the mixed layer depth (MLD). The actual definition of interest may vary depending on the study. Climatological data sets have been used to estimate MLD however their vertical resolution is sparse compared to the instrumentation that is available to the modern oceanographer. Two methods or definitions have been proposed recently to detect this mixed layer depth. These methods are compared and contrasted to the two classes of traditional mixed layer depth criteria with regards to 15 days of Seahorse CTD profiles with a 30 minute profile rate from Station 2 of the Halifax Section of the Atlantic Zonal Monitoring Program. One method illustrated a clear superiority in detecting the MLD in density or temperature. However, the research was performed to study the evolution of the MLD as predicted by a turbulence model and the best MLD predictor detected diurnal MLD changes that were not detected by the model. A fifth criteria for detecting changes in the surface layer is presented and recommended for model - data comparison. With the advent of the ARGO floats and other permanent monitoring stations, an argument can be made for an efficient MLD detection scheme be applied in situ to the profile data to calculate the MLD value prior to storing the climatological depth data. This research suggests a particular method for such an application and a method for surface layer depth model-data comparisons.

Of rules, and ships, and whales all black - and collisions of these things

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Historical records demonstrate the highest per capita ocean going vessel-strike recorded among large-whale species accrues to the North Atlantic right whale. As vessel speed restrictions are being considered to reduce the chances of vessels killing right whales, we used all of the published historical data on vessels striking large whales to examine the influence of vessel speed on the fate of the stricken whale. Simple logistic regression and boot-strapped models fitted to the data show that the probability of a lethal injury to a large whale ranges from 0.2 at 9 knots to 0.8 at 15 knots and asymptotically approaches 1 at speeds of 21 knots. At lower speeds the uncertainties around the estimates increase markedly (e.g. at 8 knots the probability is ∼0.2 with CI of 0.03 to 0.6) because there are few data on low-speed collisions; presumedly because there are relatively few slow-moving vessels. The results we provide here can be used to directly assess the utility of vessel speed-limits that have been proposed, and are likely to be proposed in the future, to reduce the lethality of vessels striking the critically endangered North Atlantic right whale and other large whales that are also frequent victims of vessel strikes.

SEDTRANS96: a modified sediment-transport model for heterogeneous sediment

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We use the modified SEDTRANS96 model to simulate the net sediment transport on the upper Scotian Slope in 2003, based on near bed velocity and suspended sediment concentration (SSC) observations. For given inputs of wave, current and seabed conditions, the model predicts the bed shear stress, near bed velocity profile, and SSC profiles for each size class of surficial sediment by imposing a limitation on the available depth of erosion. The net sediment transport is then calculated by summation of the total sediment transport in the bottom boundary layer through time. The simulated SSC is close to observations. The observed offshore net sediment transport is consistent with that estimated by Hill and Bowen (1983).

Environmental effects of oyster aquaculture: Sediment dynamics

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Suspension-feeding bivalves serve as key agents in benthic-pelagic coupling by filtering particles from the water column and transferring material to the sediment surface. The Eastern oyster (*Crassostrea virginica*) maintains relatively high clearance rates, even as seston concentrations increase, in comparison with other suspension feeding bivalve species (e.g., clams and scallops). Hence, oysters are particularly efficient when it comes to influencing benthic-pelagic coupling in systems of high turbidity, as the maintenance of high clearance rates can result in the rejection of large numbers of particles as pseudofeces, including phytoplankton cells. A key question we are attempting to answer is whether biodeposits alter the physical properties of sediment such that the likelihood of a resuspension event is changed in the vicinity of culture operations as compared with the surrounding environment. Resuspension may be an important factor in both increasing the food supply to the oysters and in dispersing biodeposits over a wider area, which may lessen the impact of culture activities.

EROSION RATES OF BOTTOM SEDIMENTS AND SUSPENDED PARTICULATE MATTER IN KUGMALLIT BAY AND BEAUFORT SEA DURING ICE-FREE CONDITIONS

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In this study we describe sediment erosion rates and horizontal fluxes of suspended sediment in Kugmallit Bay and Beaufort Sea by measuring sediment resuspension, sedimentation rates, suspended particulate matter (SPM), particle size and settling rates during ice-free conditions. Sediment erosion rates were measured using a portable erosion device called, "Benthic erosion assessment sediment tool" (BEAST) at depths ranging from the 33 m shelf region of the Kugmallit trough to 523 m on the slope of the Amundsen Gulf. Sediment erosion rates varied between 11 to 54 g m^2 min^{-1} with corresponding critical erosion thresholds (u^*) between 1.3 to 1.8 cm s^{-1}. Sediment concentration at these critical erosion thresholds ranged from 1590 up to 4271 mg L^{-1}.

Kugmallit Bay is shallow and under open-water conditions, turbidity appears to be wind driven, with SPM reaching over 90 mg L^{-1}. The organic content was fairly high in SPM residues and surface sediments. Sediment turbidity showed a strong relationship with wind speed ($R^2 = 0.71$). Deployments of sediment traps during storm events produced sedimentation rates up to 5400 g m^{-2} d^{-1}. The large freshwater input into Kugmallit Bay produces a freshwater lens creating pronounced stratification with horizontal gradients in salinity, temperature and suspended sediment. Increased salinity was strongly related to a drop in water temperature ($R^2 = 0.97$). Settling rates and sizes of particles were measured before and after storm events, and a strong relationship between equivalent spherical diameter (ESD) and settling rate exists ($R^2 = 0.91$), mean floc settling rates were 0.72 cm s^{-1} with mean ESD values of 0.9 mm at wind speeds between 11-16 km h^{-1}.