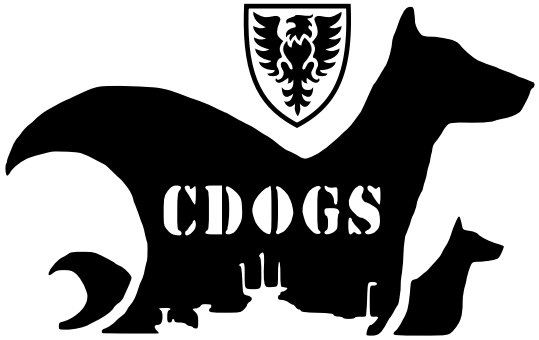

C-DOGS 2010

Conference of Dalhousie Oceanography Graduate Students

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Dalhousie University, Halifax, Nova Scotia

Contents

Cross Border Signals: Comparing Canadian and US Ecosystems in the Northwest Atlantic

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We investigated whether there were common broad-scale biological responses to climate and fishing across seven Northwest Atlantic ecosystems using a suite of biological, climate and fishing indicators. A minimum / maximum autocorrelation analysis (MAFA) of the biological indicators produced a common primary trend for all regions, which changed rapidly during the 1980s through to the early 1990s, after which it abated in some regions. There was a strong common pattern in the biological indicators responsible for the primary temporal trend in the five more northerly regions: an increase in phytoplankton, an increase in mid-trophic levels, and a decline in the average size of predatory groundfish. Two warmer southerly regions did not exhibit the increase in planktivore biomass but did experience a decline in predatory groundfish biomass and size. These common patterns were correlated with fishing (total landings) and with large-scale environmental forcing (AMO). Our results are consistent with intense fishing (decline in biomass and/or size). In areas where predatory groundfish size declined, the abundance of their prey increased, further supporting the hypothesis that larger predators regulate their prey more efficiently. Bottom-up forcing, originating in the AMO may also be occurring, although the mechanism is still unknown. This is the first broad-scale comparative analysis of both US and Canadian Northwest Atlantic ecosystems and allowed us to identify research questions that will provide further insight. Specifically, the interaction between climate/fishing will require a mechanistic approach to reveal the role of local climate in heavily fished ecosystems where fishing effects dominate.

One system, three models

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If scientific results are to be applied to serve humans fruitfully, then it is not enough just to understand the relevant processes, but to be able to 1) predict their effects and 2) communicate these effects efficiently. In computational models, there is frequently a trade-off between achieving an accurate, high-resolution representation of the system, and achieving one that can be represented in a computer. Though computing power is still growing quickly, reality will always be more complex. But it is not enough to make a computer model. A scientific result becomes much more useful when it can be effectively communicated to non-experts and this typically requires further simplification of the model.Here, I outline and discuss three different mathematical models of the scallop (*Placopecten magellanicus*) population residing on Georges Bank. Each one becomes simpler than the last, and we will see that each one may be useful for different purposes. I show how these three models will be used to design the next phase of my thesis work. We will see that the selection of a "best" model depends on the question being asked, as well as the audience that it is designed for.

The mean surface circulation of the western North Atlantic subpolar gyre from a new geodetically-determined mean sea surface topography

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The currents of the North Atlantic subpolar gyre provide an important pathway for the transport of cold, fresh water from high latitudes towards the equator. Melting of the Greenland ice sheet will increase the volume of fresh water entering the gyre and understanding the circulation will be important in projecting the regional and global effects of climate change. In this study we use a new estimate of the mean sea surface topography (MSST), derived from satellite and terrestrial gravity measurements and satellite altimeter measurements, to estimate the mean surface circulation of the subpolar gyre. We compare this estimate with previous geodetic estimates of MSST, with direct oceanographic estimates of the circulation derived from the movement of surface drifters over more than 20 years and with results from the NEMO ocean model. We show that the new MSST gives improved resolution of the currents along the coasts of Greenland and Labrador compared with earlier geodetic MSSTs. We also find good agreement with the oceanographic observations and model results.

Numerical Study of Three-Dimensional Circulation and Hydrography in Halifax Harbour Using a Nested-Grid Ocean Circulation Model

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Halifax Harbour is a multi-use estuary with great environmental and economic values. Raw sewage and wastewater had been dumped directly into Halifax Harbour for centuries, leading to poor water quality of this critical coastal system. Better understanding of oceanographic processes is required for pollution control and sustainable development in the harbour. A three-dimensional nested-grid coastal ocean circulation model, known as NCOPS-HFX (Nested Coastal Ocean Prediction System for Halifax Harbour), has recently been developed for investigating circulation and hydrography and associated temporal and spatial variability in Halifax Harbour. The NCOPS-HFX is driven by tides, meteorological forcing and buoyancy forcing associated with freshwater discharges. We assess the model performance by comparing model results with observations including tide gauges and monthly mean climatology of temperature and salinity, which was newly constructed from historical hydrographic observations in the harbour. Model results demonstrate that currents in the harbour are significantly affected by tides and wind forcing with an intense tidal jet in the Narrows and a weak salinity front in the Bedford Basin. The time-mean circulation produced by the model is characterized by a typical two-layer estuarine circulation.

Lateral transport of carbon on the Scotian Shelf: A preliminary overview

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While the open ocean carbon system is relatively well understood, coastal environments remain a significant area of uncertainty in global ocean carbon budgets. In general, coastal seas are thought to transfer atmospheric CO2 from the atmosphere into the deeper ocean using "continental shelf pump" mechanisms. However, recent observational studies on the Scotian Shelf reveal the area is a net source of CO2 to the atmosphere. In order to better understand both the mechanisms responsible for this outgassing and general coastal carbon cycling, my proposed research investigates the lateral carbon flux from the Scotian Shelf to the adjacent open ocean. First, transport of water at constant depths along the Halifax line cross-shelf section will be quantified using a Radium isotopic method. Combined with vertical profiles of dissolved inorganic carbon species these estimates yield a lateral flux of carbon either on or off the shelf. One important preliminary step of this project involves designing a sampling strategy for both chemical analyses. While methods for DIC sampling and analysis are well developed from previous cruises, devising a method for Radium collection on the Hudson is the primary focus of my current research.

Fluorescence and phytoplankton, a new interpretation

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Chlorophyll *a* fluorescence, emitted by phytoplankton, can be used to improve satellite estimates of chlorophyll *a* concentration, in areas where traditional techniques break down. Caution must be used however since, chlorophyll *a* fluorescence varies not only with phytoplankton biomass, but with their health, species composition and light exposure. Understanding the effects environmental conditions have on fluorescence will help its use in assessing chlorophyll a concentrations.
Chlorophyll *a* fluorescence measurements were gathered from the Seahorse and examined as a function of irradiance. A parameter was obtained from these fluorescence vs. irradiance curves that is linked with the saturation irradiance of photosynthesis. This parameter showed strong within day, and daily variability that could not be explained by several measured environmental variables. Further work is needed to explain the unknown sources of variability.

Vertical distribution of marine invertebrate larvae in response to thermal stratification

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The purpose of this experiment was to determine the effect of thermal stratification of the water column on the vertical distribution of the common starfish (*Asterias rubens*), the green sea urchin (*Strongylocentrotus droebachiensis*), and the Atlantic bay scallop (*Argopecten irradians*). Thermoclines were generated in the laboratory using plexiglass thermocline chambers. Laboratory reared larvae were introduced at the bottom of the chambers and their vertical distributions were recorded through time by visual observation. Urchin and starfish larvae were found to migrate to the surface regardless of stratification, but showed some avoidance to temperature extremes. In contrast, scallops were evenly distributed throughout the water column in the absence of stratification. Additionally, scallops remained below the thermocline in the presence of stratification. Since the vertical position in the water column can ultimately affect the transport of these organisms in the ocean, the behavioural differences between taxa shown here are pertinent to dispersal and connectivity of marine invertebrate larvae.

Inter-annual variation in right whale feeding habitat occupancy explained using prey abundance and physical oceanography

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The number of right whales that return each year to two critical late-summer feeding habitats of Grand Manan and Roseway Basins is highly variable. In these regions right whales are known to feed on highly concentrated patches of diapausing calanoid copepods located at depths >100 m. We test the hypothesis that inter-annual variability in feeding habitat occupancy of right whales in the Roseway and Grand Manan basin regions can be explained by variability in the regionally-scaled average concentrations of their zooplankton prey located at depths >100m where the whales normally feed. We also test whether variation in the mean zooplankton concentration is a function of variation in regional water mass characteristics. This is achieved through analyses of a unique 30-year set of historical and contemporary zooplankton net samples coupled with historical measures of the regional water mass characteristics (salinity, temperature and density) and whale occupancy.

Characterizing Arctic intertidal landscape features

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Intertidal habitat in the Canadian Arctic is subject to strong pressures such as ice scour, glacial outwash, low temperatures and increasing human activities. Rising sea level and temperatures associated with climate change will cause additional stress on intertidal ecosystems. A study was carried out in August 2009 to sampl e the Arctic benthos and to quantify the landscape structure at two sites on Baffin Island, Nunavut, in order to examine the relationship between habitat landscape structure and biodiversity. Benthic core samples were collected, and aerial photography was captured using a helium balloon-mounted camera platform. Initial results and aer ial imagery will be presented.

A relaxation technique for computing nonlinear internal-wave streamfunctions

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Measuring the energy flux of nonlinear internal waves requires detailed knowledge of the wave structure, in order to accurately measure the kinetic and available potential energies. In the absence of high temporal resolution profiles to map isopycnal displacement, streamlines determined from an acoustic Doppler current profiler (ADCP) can be used instead. For 2D flow, in a frame of reference moving at the wave speed, isopycnals will be parallel to streamlines. In this talk, direct integration techniques currently in use in the literature are compared against a relaxation scheme which solves a Poisson equation. Using synthetic fields and field data from the St. Lawrence Estuary, the relaxation method is shown to be more robust to noise and vertical shear, and produces more sensible streamlines.

The Madden-Julian Oscillation and the Coastal Ocean: The Gulf of Carpentaria

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The Madden-Julian Oscillation (MJO) is a significant contributing factor to intraseasonal variability in both the tropical and extratropical oceans. It is evident as regional standing modes in coastal waters and as propagating modes along the major coastal and equatorial waveguides. Sea level variations in the Gulf of Carpentaria (northern Australia) and the coastal regions of the northeastern Indian Ocean and eastern Pacific are related to the MJO [Oliver and Thompson, 2010, JGR, 115, C01003]. In this presentation, we focus on the the Gulf of Carpentaria. Using a three-dimensional, nonlinear, barotropic, numerical model validated with local tide gauge data we show that sea level variations in this region are driven by surface wind stress. This wind stress is, in turn, highly dependent on the MJO and is also seasonally modulated. The response of both sea level to MJO forcing is quantified. The model is next used to remove the local wind effect from the tide gauge data resulting in a low frequency residual signal which is interpreted in terms of larger scale modes of variability of the adjacent shelf seas and deep ocean.

Vertical migration of larvae of benthic invertebrates

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The objective of this study was to investigate whether the vertical distribution and abundance of different functional groups of meroplankton, with contrasting life history strategies and swimming mechanisms, vary periodically on lunar or diel cycles. For marine benthic invertebrates with a meroplanktonic larval phase, dispersal can be an important process in regulating population dynamics. Meroplanktonic larvae are small and weak swimmers and consequently thought to be incapable of sustained horizontal movement. It is well accepted that meroplankton are capable of vertical movement against weak vertical currents. The vertical distribution of meroplankton in the water column can be related to physical and biological discontinuities, some even appear to respond to cues linked to predictable cycles such as tidal and diel cycles. Plankton samples were collected at 3 depths (3 m, 8 m, 18 m), using horizontal tows at each tidal phase over a 16 hours period. Hydrological measurements were taken at the beginning and end of each sampling period. The abundance and distribution of gastropods and bivalves varied with tidal cycle and bryozoans varied with diel cycle. Gastropods and bivalves were more abundant at depth during the flood tide and at surface during the high tide. Generally, bryozoans are more abundant at the surface during the day and deeper at night.

Foucault's Pendulum

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In 1851 Leon Foucault used a pendulum to prove the Earth rotates. This talk will be a discussion of the historical significance and context of Foucault's Pendulum as well as a description of the experiment.

Exploring biogenic turbulence : turbulence and zooplankton meausrements on Canada's coasts

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For decades, oceanic turbulence and mixing has been considered solely as a function of physical factors such as wind and waves. In recent years, it has been found that microorganisms swimming through the water can create comparable levels of turbulence. This is a remarkable result because turbulence caused by organisms on this scale was previously considered negligible. We investigate these ideas further with co-incident observations of plankton and turbulence. These data are the first to be collected with a new instrument that combines a Vertical Microstructure Profiler with a Video Plankton Recorder and thus are the first data with the necessary resolution in both parameters to study the potential relationship between zooplankton and turbulence in-situ.

The radiance field under wavy sea surface

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The underwater light field varies, temporally and spatially, in relation to the dynamic air-sea interface, the sky radiance distribution, the optical properties of water itself and even the sea bottom reflectance. Among them, the wind-induced sea surface waves usually cause a fast fluctuating light field, in order of less than one second. Knowledge on the light field variability of this kind has been of great interest in many fields, such as biology, remote sensing and underwater imaging, etc. In this study we present the underwater angular radiance field, $L(\theta, \phi)$, which was measured along the horizontal tracks with a radiance camera (RadCam). The wavenumber spectral analysis indicates that the radiance variability is a function of the wavenumber as well as the direction and it only weakly depends on the water depth. The relationship between the sea wave field and the (refracted) radiance field is further discussed.

Seasonal Variability of the Inorganic Carbon System in the Amundsen Gulf Region of the Southeastern Beaufort Sea

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High latitude oceans are ecologically sensitive areas where the early detection of climactic changes will most likely be possible. Polar oceans are also chemically sensitive due to the relatively high Revelle factor and correspondingly weaker buffer capacity of these waters. Dissolved inorganic carbon (DIC), total alkalinity (TA) and partial pressure of CO_2 (pCO_2) measurements covering a full annual cycle were collected in the Amundsen Gulf region of the Southeastern Beaufort Sea as part of the Canadian International Polar Year initiatives, between October 2007 and September 2008. The annual cycles of inorganic carbon system parameters (DIC, TA, pCO_2, pH, and aragonite saturation (Ω_{ar})) are presented, and seasonal variations examined. The physical and biological processes responsible for the seasonal variations in water column DIC are identified. The study area is divided into a surface and deep box and monthly changes in DIC due to horizontal and vertical advection between the boxes, air-sea exchange of CO_2, freshwater input from river runoff and sea-ice melt, and biological processes are computed. The assessment of these governing processes allows an estimate of net community production for Amundsen Gulf to be computed on the basis of the inorganic carbon data collected in the region.

Parameter Optimization of a Two-Layered Sediment Model Through Variational Assimilation

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Diagenetic processes make considerable contributions to elemental cycling in coastal ecosystems through their role in the regeneration of nutrients, denitrification, and the consumption of oxygen. Elemental fluxes between the sediments and the overlying water column can be estimated using diagenetic models that simulate the complex interactions of physical and chemical processes. Parameters of diagenetic models are often poorly known, as it can be difficult or even impossible to independently measure them. The challenge is then to constrain these parameters by optimizing a model s ability to reproduce empirical data. This can be achieved through variational assimilation, a systematic and quantitative method for minimizing the misfit of model and empirical data through variation of model parameters. In this study, we assess the performance of a two-layered sediment model in light of nutrient and oxygen flux data from mesocosms of the University of Rhode Island s MERL experiments. Through the use of variational assimilation, it is possible to optimize unknown inputs to the model, such as parameterizations of the depositional flux of organic matter, as well as selected model parameters.

Assessing the performance of a Northwest Atlantic ocean circulation model using the spectral nudging and the semi-prognostic methods

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The spectral nudging method (Thompson et al. 2006) and the semi-prognostic method (Sheng et al. 2001) were developed to reduce errors in ocean circulation models. In this study we assess the performance of these two methods using a (1/4°) resolution ocean model constructed from OPA (Océan PArallélisé). The model domain covers the region between 32°W and 81°W and between 33°N and 57°N. The model is forced by atmospheric reanalysis fields produced by Large and Yeager (2004) and monthly mean climatologies of temperature and salinity produced by Geshelin et al. (1999). Four different numerical experiments are conducted, which are: a) a fully prognostic run; b) a run using the spectral nudging method; c) a run using the smoothed semi-prognostic method (Eden et al. 2001); and d) a run using a combination of the spectral nudging and the smoothed semi-prognostic methods with weaker nudging coefficients. We demonstrate that the model run with the combined approach reproduces the general circulation and associated mesoscale variability reasonably well. The model results in the fourth experiment are used to examine the interannual to decadal variabilities of the Sea Surface Temperature (SST) over the area of the Scotian Shelf and Slope during the 17-year period of 1988-2004. Over this area, similar variabilities can also be found from model results throughout the entire water column and particularly in the upper (∼0-50 m) and middle (∼50-1000 m) water columns. We discuss the role of the local heat flux, the Gulf Stream and the Labrador Current in affecting the low frequency temperature variability over this study area.

A short introduction to SIR data assimilation

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Numerical models have become important tools in modern oceanography. At same time, an incredible amount of ocean data is available today, with great potential to continuously increase our understanding of the world's oceans. Data assimilation techniques, which improve models by incorporating data, offer a way to tap this potential. Sequential Importance Resampling (SIR) is a sequential data assimilation technique that is very flexible in its applications. We give a brief overview of model ensembles and other key concepts that form the basis of sequential data assimilation and SIR. We also present a practical application of SIR to a 3D ocean model and ocean color data from satellites. Our results show that SIR can be applied successfully for oceanographic problems and high-dimensional models.

Diatom-driven carbon export during the North Atlantic Spring Bloom: coupled physical-biological modelling and variational data assimilation

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The North Atlantic spring bloom is one of the main events that lead to carbon export to the deep ocean and drive oceanic uptake of CO_2 from the atmosphere. During the North Atlantic Spring Bloom experiment (carried out south of Iceland in 2008), autonomous platforms followed the evolution of a phytoplankton patch during the spring bloom and provided a high-resolution coverage over time. A Lagrangian float and four seagliders measured physical, chemical and bio-optical data that were calibrated with *in situ* samples from three supporting cruises. During the experiment we observed a major export event of diatom cysts. We have implemented this behavior in an ecosystem model that describes the bloom. Specifically, a 1-D physical model was coupled to three biological model variants of different complexity. We applied variational data assimilation to optimize the models and compared them based on their performance in replicating the bloom and its associated carbon export. This study demonstrated the power of autonomous platforms for studying the oceans and showed silica-controlled diatom cyst formation as an important process controlling carbon export during the North Atlantic spring bloom.

Implementation of the two-scale approximation for increased accuracy in the wave energy balance equation.

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Accurate evaluation of the non-linear wave-wave energy transfer represents a significant proportion of the computation time of ocean wave models. The Discrete Interaction Approximation (DIA) developed within the first version of the WAM model (WAMDI, 1988) is still the only algorithm to be used today in operational wave modeling as it is the only way to calculate the wave-wave interactions rapidly enough. The goal of this study is to complete the first implementation of the Two-Scale Approximation (TSA), a successor method to the DIA in an operational model. Preliminary results (Perrie et al., 2009) have shown that it offers improved accuracy, while the theory behind the TSA should allow for a computation time similar to the DIA. After implementing the TSA in a modern third generation wave model, WAVEWATCH III (WW3), a complete tuning of the other source terms (wind input and wave dissipation) will be done to ensure optimal results for fetch-growth curves and SWAMP-type tests. The implementation of the TSA in an operational wave model should demonstrate the possibility of having an accurate representation of the spectral distribution of wave energy in wave models.