Environmental and Geophysical Fluid Mechanics
Mécanique environnementale et géophysique des fluides
(Org: **Marek Stastna** and/et **Michael Waite** (Waterloo))

JORDAN FAZIO, University of Toronto
Differential Geometric Formalism for GFD Coordinate Transformation Applications

This talk will focus on the use and importance of the methods and formalism of differential geometry in geophysical fluid dynamical settings. There are specific applications to work done on residual flows by Young (2012) and some extensions to other systems. The purpose of this is to elucidate the applicability of a more formal and complete use of differential geometric methods in GFD contexts, and particularly in coordinate transformations widely used throughout applications of GFD. Though coordinate transformations are explicitly geometric in nature, the full power of differential geometry is often skimmed over or altogether left out of discussion on the topic. However, to paint a more complete picture of applications of GFD involving coordinate transformations, the formalism can be useful.

In this talk, we go over the common basic ideas and structures in differential geometry such as the metric tensor and derivative operators such as the gradient curl and divergence, and by applying these ideas formally we find a more general framework for changing between various coordinate systems commonly used in literature. To demonstrate our ideas, we extend residual flow work done by Young (2012) both by extending this work to use the full formalism of differential geometry as well as applying Young's thickness-weighted averaging (TWA) formalism to other simple systems in the ocean and atmosphere, all involving coordinate transformations to common GFD quantities. In particular, Young's work depends on the use of a vertical buoyancy coordinate, while our applications replace the horizontal coordinate with potential vorticity.

ANDREW GRACE, University of Waterloo
Gravity Currents in the Cabbeling Regime

Recently, the dynamics of flows beneath ice cover in lakes has garnered much interest in the GFD community. Much focus has gone into characterizing vertical flows beneath ice, while less has gone into characterizing the impact of horizontal flows beneath ice. We know that horizontal flows play a major role in the transport of nutrients, as well as impacting CML temperature. In this talk, we describe one such example of the interactions of horizontal flows and vertical flows induced from freshwater cabbeling (the mixing of parcels with equal density but different temperature). This talk presents numerical simulations of the evolution of freshwater gravity currents where intruding and ambient temperatures are on different sides of the temperature of maximum density. A setup like this might occur in the springtime from a riverine inflow. We will highlight how the initial intrusion flows along the upper surface of the domain and mixes with ambient water, and due to cabbeling, generates a coherent bottom current. We will introduce a control parameter (essentially the inverse of the non-dimensional temperature of maximum density), which is key to the evolution of the system, and we will show how the maximum horizontal extent of the initial intrusion varies with it. We show that for some cases, the maximum extent of the initial intrusion controls some of the important characteristics of the coherent bottom current. Finally, we will highlight some of the key characteristics (head height and temperature distribution) of the bottom current.

NICOLAS GRISOUARD, University of Toronto
Causes and diagnostics of internal tide scattering by balanced vortices

Internal tides are oceanic internal waves that oscillate approximately at tidal frequencies. However, their scattering by the turbulent oceanic eddy field leads to a modulation in amplitude and frequency. Satellite altimeters, which are our most reliable measurements to track internal tides globally, suffer from a sampling that is too coarse in time to capture the tidal oscillations when these modulations are important. This talk will describe our attempts to shed light on these processes from two complementary approaches: one idealized and one data-driven. I will first present numerical experiments of tidal wave scattering by isolated barotropic balanced vortices and propose a scaling law for how much scattering happens for a given wave/vortex pair. In a second part, I will describe how our group trained and tested a deep-learning algorithm to produce snapshots of the tidal wave's signature based on raw snapshots of synthetic sea surface heights containing both eddies and waves.

NICHOLAS KEVLAHAN, McMaster University
Realistic Modelling of the Gulf Stream Using Brinkman Penalization

The advantage of a smooth representation of bathymetry in terrain-following σ-coordinate ocean models is compromised by the need to avoid numerical errors on steep slopes associated with horizontal pressure gradient discretization. Geopotential z-coordinate models avoid these errors, but greatly underrepresent the interaction of flow with a topographic slope, especially when the bathymetry is underresolved. Hybrid coordinate models are also deficient because it is difficult to find a satisfactory compromise between z and σ coordinates. With volume penalization, we do not seek a compromise, but rather a correction to the usual coordinate systems that realistically recovers continuous and steep bathymetry. We derive and apply a new volume penalization method to the Gulf Stream separation problem that has puzzled modellers for decades. The method improves the representation of the flow-topography interaction and achieves realistic separation of the Gulf Stream at resolutions as coarse as 1/8 degrees. In addition, it provides a tool to separate the effect of eddy activity and topographic slope when changing grid resolution. Our results show that realistic bathymetry is more important than eddy activity in ensuring realistic Gulf Stream separation. We anticipate that a successful topographic slope correction will be valuable to climate models, as their current resolution is far from sufficient to represent western boundary currents (WBCs) using traditional coordinate systems. Our results suggest that a climate model using penalization with 1/4 degree resolution would represent ocean circulation much more realistically.

GREG LEWIS, Ontario Tech University
Numerical continuation of amplitude-modulated rotating waves in sheared annular electroconvection

We investigate amplitude-modulated rotating waves (often referred to as amplitude vacillating flow) using numerical bifurcation methods based on time-integration. In particular, we study these flows as they occur in a model that simulates the flow of a liquid crystal film suspended between two annular electrodes, and subjected to an electric potential difference and a radial shear. This system is a close analogue of some laboratory-scale geophysical flow experiments (e.g. the differentially-heated rotating annulus), and to simplified models of the rotating equatorial regions of planetary atmospheres and planetary interiors. Although sheared annular electroconvection shares many characteristics with its geophysical counterparts, including their SO(2) symmetry, a crucial difference is in the two-dimensional nature of electroconvection. In particular, because the liquid crystal that is employed is in smectic A phase, its motion can be effectively modelled using the 2-D incompressible Navier-Stokes equations coupled with an equation for charge continuity.

The numerical method uses a Newton-Krylov approach for the continuation of solutions, and linear stability analysis of a flow map is used to identify the flow transitions that result due to changes in the model parameters. The amplitude-modulated waves equilibrate via a transition from rotating waves, and lose stability via a symmetry-breaking bifurcation. An appropriate choice of preconditioner enables the computation of the solution branch of modulated waves through a large range of parameter values regardless of the stability of the solutions.

KELLY OGDEN, Western University
Mixing and Structure of Internal Hydraulic Jumps

Internal hydraulic jumps result in localized, intense mixing, affecting water properties and nutrient distributions. In some locations, the distribution of water properties can have severe negative effects on the local ecosystem; for example, in Hood Canal, low levels of dissolved oxygen result in periodic fish kills. To better understand how to mitigate these events, and how they might change in response to climate change, a better understanding of the behaviour of internal hydraulic jumps is required. Internal hydraulic jumps in the environment are complicated by many details, such as topographic variation, continuously varying velocity and density profiles, and Earth's rotation. This work describes the results of idealized simulations that show how the structure and mixing of internal hydraulic jumps varies with upstream shear in a straight channel, with

channel width variations, and with rotation. Idealized simulations are employed to isolate individual effects. Large Eddy Simulations are conducted using the CFD code Gerris, allowing turbulence statistics to be calculated. The scalar variance production from the turbulent scalar variance equation is used to quantify and compare mixing between simulations.

JASON OLSTHOORN, Queen's University
Optimal Heat Flux Estimates

Temperature-chain data provide a lot of information about the physical processes occurring in lakes. These measurements characterise the thermal stratification, which has important consequences for the vertical transport of tracers. The evolution of the thermal stratification $T(z,t)$ is often modelled as a one-dimensional process obeying a diffusion equation,

$$\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(\kappa_e \frac{\partial T}{\partial z}\right),$$

for an eddy diffusivity κ_e, assuming a fixed cross-sectional area. The value of κ_e is estimated through an empirical formal.

We propose a new way to determine the optimal κ_e directly from the temperature profile data. Using an adjoint-loop, we can determine the best coefficient that minimizes the error between the diffusion equation and the observed data. Preliminary results show that the method is robust to low-level noise in the temperature record. Our hope is that this optimal method may help to quantify and clarify the physical processes occurring in lakes.

FRANCIS POULIN, University of Waterloo
The Dynamics of Magnetic Vortices

The solar tachocline is a thin layer of the sun that is located between the radiative interior and the convective exterior. The dynamics is nearly two-dimensional and dominated by strong vorticity and shear. In this talk, we present recent investigations that use the Quasi-Geostrophic Magnetohydrodynamic (QG MHD) model to describe the dynamics of the solar tachocline since the deformations in the layer depth are small and the ambient rotation is strong compared to the local rotation rates. In particular, we revisit the classical test problems of Weiss (1966) to study the dynamics of magnetic vortices in the context of QG MHD that allows for an evolving magnetic field and weak deformations in the layer depth. It is determined that increasing magnetic fields tends to disrupt coherent vortices and forces energy to travel more to smaller scales.

ERICA ROSENBLUM, University of Manitoba
Observed and simulated surface salinity under transitioning ice cover in the Canada Basin

Climate models, which have been analyzed extensively to assess and predict current and future climate change and to inform policy, struggle to accurately simulate the rapid decline in Arctic sea ice. One possible source of this bias could be related to the vertical distribution of salt in the ocean, which controls the exchange of heat between the surface and deeper ocean. We compare simulations from two climate models to ocean observations collected below sea ice in the Canada Basin. In 1975, observations were collected by scientists living in ice camps, and in 2006–2012, they were obtained by automated instruments attached to sea ice. The observations indicate as much as six times greater surface freshening than the models between 1975 and 2006–2012. We show that the salt bias can be partly attributed to the models' tendency to mix fresh water from the surface deeper than in observations, resulting in a saltier ocean surface. The results may provide insight for climate model improvement that could have wide-reaching implications because the vertical distribution of salt in the ocean directly impacts the vertical transport of heat and nutrients.

MAREK STASTNA, University of Waterloo
Rotation effects in long-thin lakes

While the effect of rotation on linear propagating waves and modes in closed basins (e.g. lakes) has a clear theory, the picture for nonlinear, dispersive waves is far from clear. After reviewing the effects of rotation on linear waves, I will use the example of

Cayuga Lake, NY, USA during the temperature stratified season as a motivator for discussing nonlinear adjustment problems in long thin lakes. Here the idea is that the narrow dimension of the lake is smaller than than the internal Rossby deformation radius, but the long dimension of the lake is far larger compared to the internal Rossby deformation radius,. Wave trains formed by stratified adjustment thus have time for all of nonlinear steepening, short-wave dispersion and rotation to play a role in their evolution. I will discuss the results of pseudospectral simulations of an idealized lake to discuss what kinds of wave forms are spontaneously generated. I will then put these into context with respect to existing literature on stratified and geostrophic adjustment. Time permitting I will speculate on the effects of departures from an idealized geometry.

MICHAEL WAITE, University of Waterloo

Viscous generation of potential enstrophy in breaking gravity waves

Ertel's potential vorticity (PV) is an important quantity in the study of stratified flows in environmental and geophysical fluid dynamics. In the absence of viscosity, diffusion, and forcing, PV is materially conserved. In the quasi-geostrophic regime, the entire flow can be found by inverting the PV. But even for unbalanced flows at higher Rossby numbers, PV is useful for identifying vortical motions and distinguishing them from gravity waves. In turbulence, viscous effects are generally dissipative and restricted to small length scales. But because PV is quadratic in the flow variables, viscosity and diffusion can affect it in unexpected ways. Herring, Kerr and Rotunno (1994) showed that viscous and diffusive effects are not necessarily dissipative or restricted to small scales; instead, they can generate large-scale PV. In this work, we revisit this problem in high-resolution direct numerical simulations of stratified turbulence. The initial condition is a standing internal gravity wave, which is a linear solution to the equations of motion that notably has zero PV. However, the wave eventually breaks, generating small-scale stratified turbulence. We explore the growth of potential enstrophy (squared PV) and its dependence on Froude and Reynolds numbers. Results are interpreted using scale analysis and cascade theories for stratified turbulence. Implications for the use of PV to identify vortices in stratified turbulence are discussed.