Fluid Dynamics
Dynamique des fluids
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JAHRUL ALAM, Memorial University of Newfoundland
A multi-scale methodology for simulating the atmospheric boundary layer.

The study of turbulence in the atmospheric boundary layer (ABL) is an important topic to the field of weather forecasting or projecting climate change. In a large eddy simulation (LES) model of the turbulent ABL, one calculates "grid scale" large eddies, where "sub-grid scale" small eddies are parameterized. Evidences from physical and numerical models indicate that the LES model does not address fully the multi-scale and intermittent character of the turbulent ABL. In this talk, I will present a novel "multi-scale computational methodology" for modelling the full range of turbulent eddies, where a sub-range of large significant eddies are calculated on a multi-scale grid, and that of small non-significant eddies are parameterized. First, to model the full range of eddies, a multi-scale representation of the mean conservation laws are derived, taking into account the surface roughness. Second, two stages of multi-scale computational methods are developed. I will explain recent progresses for addressing some of the challenges that must be overcome, and will discuss possible ways for addressing other challenges, which is an ongoing research topic. I will present validation results for simulating a neutrally stable turbulent ABL using only about $41\,131$ grid points at a resolution $2\,048^3$.

DAVID AMUNDSEN, Carleton University
Asymptotic Solutions for Resonant Acoustic Oscillations in Cylindrical and Spherical Geometries

The propagation of acoustic waves in closed containers provides a natural context in which to study the mechanisms of shock formation and their dependence upon underlying geometry. As is well known, for the case of a gas in a straight tube with a closed end, shocks form and all harmonics are generated, see Chester (JFM 1964). Recent studies have shown that in more general axisymmetric geometries the flow can be continuous or shocked depending on the input Mach number and the details of the geometric configuration. A nonlinear geometric acoustics approach is used to analyse the shocked motion of the gas and provide an approximation with respect to a geometric parameter associated with the ratio of the inner radius to gap width. Based on comparisons with full numerical solutions it is seen that the approximation remains valid for a surprisingly wide parameter regime. This provides insight into the nature of the interplay between geometric and nonlinear effects and in particular the transition between shocked and continuous flows. The effect of density variation will also be discussed. This is joint work with Brian R. Seymour(UBC) and Michael P. Mortell (UC Cork).

JOHN BOWMAN, University of Alberta
Pseudospectral Reduction of Incompressible Two-Dimensional Turbulence

Spectral reduction was originally formulated entirely in the wavenumber domain as a bin-averaged wavenumber convolution in which bins of modes interact with enhanced coupling coefficients. A Liouville theorem leads to inviscid equipartition solutions when each bin contain the same number of modes. We describe a pseudospectral implementation of spectral reduction which enjoys the efficiency of the fast Fourier transform. The model compares well with full pseudospectral simulations of the two-dimensional forced-dissipative energy and enstrophy cascades.

LUCY CAMPBELL, Carleton University
Generation of internal gravity waves by convection

Internal gravity waves affect the general circulation of the atmosphere and hence it is important to understand their generation, propagation and interactions in order to represent them correctly in weather prediction and climate models. The primary mechanisms for gravity wave generation are convection in the lower atmosphere and topography. Convection is the movement of fluid particles from one location to another and it occurs in the atmosphere when the rate at which the temperature decreases with height exceeds a certain value. The mechanisms for the generation of internal gravity waves by convection are not fully understood. Investigations into these mechanisms generally involve large-scale simulations using general circulation models and gravity wave drag parameterizations. However, the high level of complexity of general circulation models and the large number of degrees of freedom involved make it complicated to identify and quantify relationships between the gravity waves and the convection. A mathematical study based on relatively simple equations that can be solved either analytically or numerically would allow us to investigate these relationships directly. In this study we develop a two-layer model of internal gravity waves over convective vortices and use weakly-nonlinear analyses and numerical simulations to obtain approximate solutions and investigate some of the current hypotheses for convective generation mechanisms.

GEORGES DJOUMNA, University of Waterloo
Comparison of a range of turbulence schemes for thermally stratified lakes

In stratified lakes the vertical mixing processes are small, as evidenced by the small seasonal change in the hypolimnion temperature found in mid- and high-latitude lakes like the Great Lakes. The basin-scale internal wave field appears to be the fundamental control mechanism for the cascade of energy from the wind into mixing and benthic boundary layer (BBL) transport. Mixing in the metalimnion and the BBL is crucial to the vertical flux of nutrients and oxygen. In this talk a comparison of the Massachusetts Institute of Technology General Circulation Model (MITgcm) and the General Estuarine Transport Model (GETM) to an extensive set of time series and spatially resolved measurements of Lake Erie, with particular emphasis on appropriate parametrization schemes for the vertical mixing is discussed. The two approaches for the parametrization of vertical mixing include the K profile parametrization and the Generic Length Scale (GLS) closures. The GLS turbulence closures used for the Lake Erie setup are: the Mellor and Yamada level 2.5, $k-\epsilon$ and, gen a new closure scheme developed by Umlauf and Burchard [2003]. Comparison with observations shows that the models can reproduce the time evolution of the lake temperature reasonably well. This is a joint work with Dr. K. G. Lamb.

JERZY FLORYAN, University of Western Ontario
Super-Hydrophobic-Like Effect Created by Surface Corrugations

Drag reduction can result from the use of surfaces with micro-features where trapped gas bubbles reduce shear stress over part of the surface exposed to a moving liquid. This is the so-called super-hydrophobic effect. The best surface topography for such effect is yet to be determined and is subject to an active search. In the current implementation this effect can be taken advantage of only in the case of liquids and requires presence of a gas phase. We are looking for creation of a similar effect using surface grooves that reduce shear either through the local flow separation or through the fluid squeezing. The available results show that the shear drag can be reduced but this effect can become practical only if the associated pressure drag can be controlled. Current understanding of this effect will be discussed.

GREG LEWIS, UOIT
Secondary flow transitions in the differentially heated rotating annulus

We present some results on the secondary flow transitions that occur in the differentially heated rotating annulus. In particular, we seek secondary bifurcations in a model of the annulus that uses the three dimensional Navier-Stokes equations in the Boussinesq approximation. The flows that may be observed after transition can be quasi-periodic, and include flows such as mixed-mode and amplitude vacillating solutions. We discuss the nature of these flows and the bifurcations that lead to them. In particular, the quasi-periodic flows correspond to 2-tori in phase-space and result from a bifurcation from a periodic orbit, which corresponds to a rotating wave in the annulus. We also discuss the numerical techniques used to compute the flows and bifurcations.

This is joint work with Nicolas Perinet and Lennaert van Veen.

FRANCIS POULIN, University of Waterloo
Analyzing Spectral Fluxes in Wind-Driven Gyres using Wavelets

The dynamics of wind-driven gyres are complex. Energy is input at the planetary scales, it cascades downwards to smaller length scales and eventually dissipates at molecular scales. Many models have been used to study this physical problem. Recently, we have performed a series of numerical simulations of a Rotating Shallow Water model (RSW) that resolves a wider range of scales than have been previously performed (the planetary scales, the mesoscales and some aspects of the sub-mesoscale.)

For periodic domains, computing the energy spectra and spectral fluxes is relatively straight forward using Fourier methods. This is more complicated for flows in a basin that are inherently inhomogeneous in nature. Here, we present a Wavelet based method that is advantageous over Fourier methods in that it allows for both better resolution of the large scales and furthermore provides spatially localized spectral information. These techniques show great promise and could readily be applied to better understand the dynamics of inhomogeneous flows in the world's oceans.

MARY PUGH, University of Toronto
Coating flows on slowly rotating cylinders

We consider a horizontal cylinder, rotating about its center. A viscous fluid is on the outside of the cylinder, coating the cylinder as it rotates. We consider a lubrication approximation of the Navier Stokes equations for the regime in which the fluid film is relatively thin and the surface tension is relatively large. The resulting lubrication model may have no steady state, a unique steady state, or more than one steady state. Using both numerics and analysis, we consider the dynamics of this flow, including whether or not solutions can become singular in finite time. This is joint work with Marina Chugunova (University of Toronto) and Roman Taranets (University of Nottingham).

MALCOLM ROBERTS, University of Alberta
On the Calculation of Higher-Order Convolutions

The quadratic nonlinearity of the incompressible Navier–Stokes equations is transformed into a binary convolution in Fourier space. The compressible Navier–Stokes equations and equations with higher-order nonlinear terms exhibit ternary or other high-order convolutions when transformed into Fourier space.

If the input vectors are periodic or of infinite length, then an n-ary convolution is equal to $n-1$ binary convolutions. However, we show that this does not hold for the case of fixed-length vectors. While the full n-ary convolution for fixed-length vectors is more computationally complex and requires more memory than computing $n-1$ binary convolutions, we demonstrate that this can be cost can be greatly reduced by making use of implicitly padded convolutions.

MAREK STASTNA, University of Waterloo
Numerical Simulation of Confined Shear Instability

The transition from laminar to turbulent flow via shear instability is one of the most widely studied problems in fluid mechanics. Beginning with the linear stability theory as encapsulated in the Taylor Goldstein equation, through analysis of secondary instability in the resulting billows and finishing in simulations of the complex, turbulent flow that results, the basic scenario is well understood. Experimentally, the classical tilted tube experiments due to Thorpe have demonstrated both the general validity of the theory and the rich, and complex phenomenology the physical world exhibits. In this talk I will revisit the shear transition using a pseudospectral numerical methodology that allows for the resolution of both the primary shear instability and the boundary layers on the confining walls. I will demonstrate how, and in what parameter regime, the presence of walls quenches three-dimensionalization. In cases where three dimensionalization does occur I will discuss how vorticity is removed from the boundary layer, and during which portion of the instability the shear stresses on the wall reach their maximum value. Finally, I will briefly speculate on the implications of these simulations for the issue of sediment resuspension by boundary layer instabilities.

BRUCE SUTHERLAND, University of Alberta

The Growth and Rise of Anelastic Internal Waves

The diagnoses of internal wave propagation, anelastic growth and breaking in the middle atmosphere are assessed in general circulation models through heuristics based upon observations and the predictions of linear theory. Before wave breaking occurs, however, internal waves grow to moderately large amplitude and so the predictions of linear theory are drawn into question. In this talk weakly nonlinear theory is used to derive the nonlinear Schrodinger equation, which reveals that the dominant weakly nonlinear dynamics are determined by interactions between internal waves and the mean flow that they induce (their "Stokes drift"). In particular, this predicts that hydrostatic internal waves are modulationally stable, meaning that their anelastic amplitude growth is retarded as the wavepacket nonlinearly disperses. Fully nonlinear simulations show, as a consequence, that hydrostatic waves can overturn tens of kilometers higher in the atmosphere than predicted by linear theory.

MICHAEL WAITE, University of Waterloo

Non-cascade effects in atmospheric turbulence

The kinetic energy spectrum of the atmospheric mesoscale (scales of 10-1000 km) is an approximately -5/3 power law, which is remarkably similar to the spectrum of three-dimension isotropic turbulence. As a result, attempts to explain this spectral range have been based on the notion of a turbulent cascade. Different cascade mechanisms have been proposed, including inertia-gravity waves, stratified turbulence, and surface quasi-geostrophic turbulence. In this talk, I will present numerical simulations of two non-cascade mechanisms that may contribute significantly to the flux of energy through the mesoscale. The first is a highly non-local transfer of energy from large scales to the buoyancy scale due to the instability of strongly stratified shear layers. The second is the direct forcing of the mesoscale by heating from moist convection. Implications for existing theories of the mesoscale spectrum will be discussed.