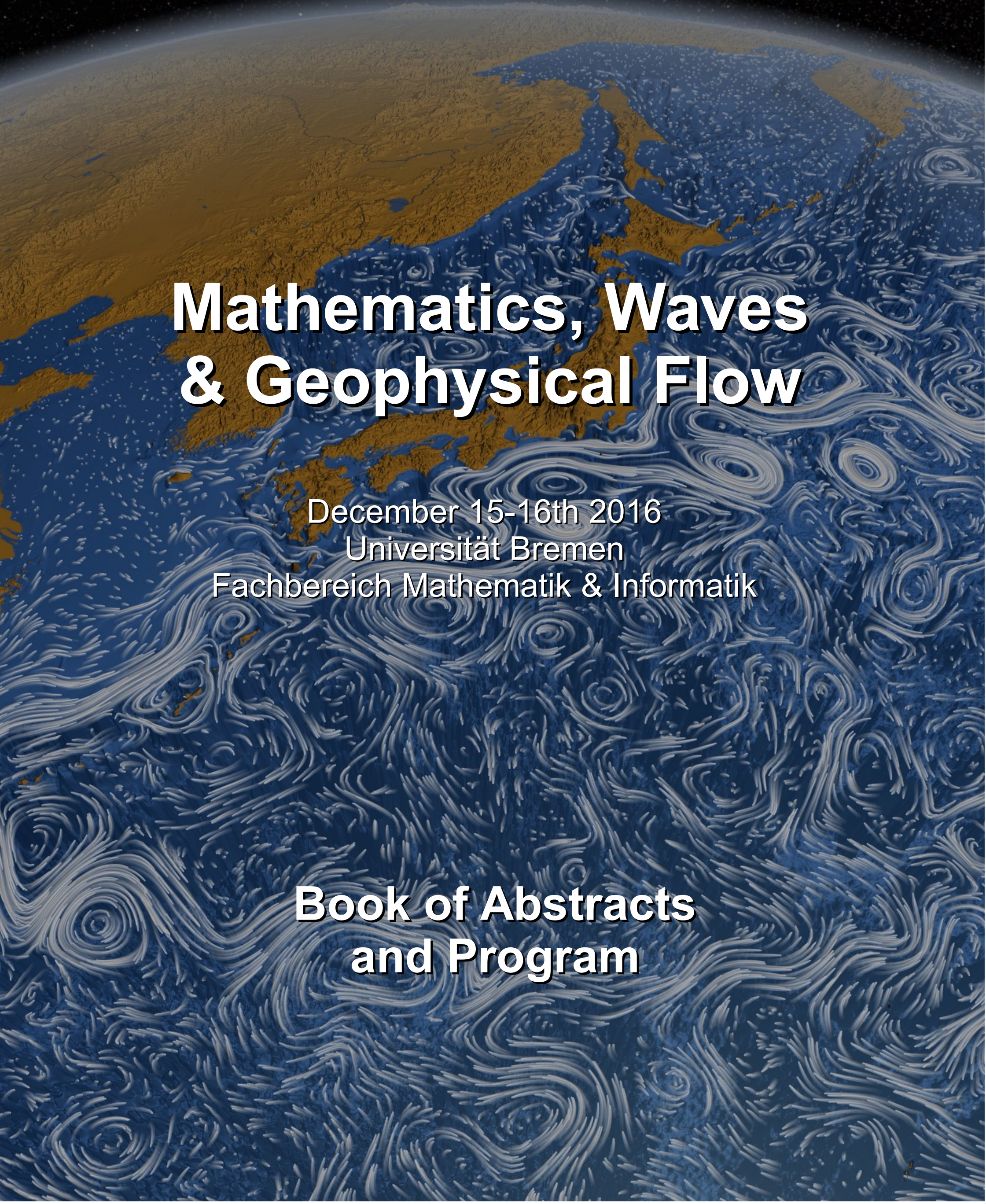

Mathematics, Waves & Geophysical Flow

December 15-16th 2016
Universität Bremen
Fachbereich Mathematik & Informatik

Book of Abstracts and Program

Universität Bremen*

TRR181

Symposium

Mathematics, waves and geophysical flow

December 15-16th
Fachbereich Mathematik & Informatik
Universität Bremen

Funded by German Research
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Center TRR 181

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Program

Thursday 15.12

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Abstracts

Talk 1

When oceanographers cannot neglect viscosity

Nicolas Grisouard*

Armed with only a basic understanding of fluid dynamics, one can easily understand why viscosity matters in a coffee cup, and not for the much larger ocean waves, vortices and currents. But is our intuition always correct? I will review three examples of when viscosity (or a parameterized representation thereof), no matter the magnitude, is the driver of some oceanic flow features. In each case, viscosity breaks the orthogonality between the geostrophically balanced and unbalanced eigenmodes of the linear oceanic fluid equations (for our purposes, unbalanced modes are internal inertia-gravity waves, which I will simply refer to as waves). I will describe three very different scenarios of irreversible balanced-unbalanced interactions, in an attempt to paint an impressionistic picture of when viscosity matters. Be it when (1) stationary dissipating waves resonantly force balanced vortices, (2) balanced density fronts lose energy to viscously-dissipating waves that viscously dissipate within them, or (3) random dissipating waves disperse Lagrangian tracers much more efficiently than random inviscid waves, the same viscous effects act as key enablers, regardless of the magnitude of the viscosity. In all cases, I expect these effects to matter most in the so-called ‘sub-mesoscale’ range of oceanic motions (~ 10 km wide at mid-latitudes), which are believed to control much of the air-sea exchanges as well as being a significant global sink for the ocean’s kinetic energy.

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Talk 2

Transport and mixing by viscous vortex rings

Jean-Luc Thiffeault*

Biomixing is the study of fluid mixing caused by swimming organisms. The swimming of large organisms can lead to mixing by the turbulent flows in their wakes, but the wakes created by small swimming organisms are less turbulent. Instead, the main mechanism of mixing by smaller organisms is the net particle displacement (drift) induced by the swimmer. Several experiments have been performed to examine this drift for small jellyfish; these produce vortex rings that trap and transport a fair amount of fluid. However, since inviscid theory implies infinite particle displacements, the effects of viscosity must be included to understand the damping of real vortex motion. We use a model viscous vortex to compute particle displacements and other relevant quantities, such as the mean kinetic energy fluctuations. (Joint work with Thomas Morrell and Saverio Spagnolie)

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Talk 3

Multiple scale regimes for internal waves in the atmosphere

Rupert Klein*

The first part of this lecture summarizes a large-amplitude WKB-theory for internal wave packets under the pseudo-incompressible flow equations (with U. Achatz and F. Senf) and describes new exact analytical solutions to the nonlinear WKB-evolution equations (by M. Schlutow). Comparison with numerical simulations based on the full pseudo-incompressible model corroborate their existence.

The second part of the lecture will describe asymptotic models for the (nonlinear) interaction of internal waves with an ensemble of narrow deep convective clouds (with A.J. Majda and D. Ruprecht). An interesting prediction from the theory is a new LONG-wave cut-off for internal wave radiation from bottom orography.

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Talk 4

Passive tracer spectra in Navier-Stokes turbulence

Djoko Wirosoetisno*

We review a few rigorous partial results on energy spectra of generic solutions of Navier-Stokes equations for large Grashof number. We then discuss some analogous results for spectra of a passive tracer in such flows, and how these could help us better understand turbulent flows. (Joint work with M.S. Jolly)

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Talk 5

The Dynamics of Meddy-type Vortices

Francis Poulin*

Mediterranean Eddies (Meddies) are a type of mesoscale vortices that play an important role in the transport and distribution of fluid and biogeochemical properties. Using the stratified Quasi-Geostrophyic (QG) dynamics, we study the linear stability and subsequent nonlinear equilibration of Meddy-type vorticies. By solving the linear problem for the two-dimensional eigenvalue problem, we determine the structure of various unstable modes and find that there are different parameter regimes of interest depending on the Burger number of the Meddy. Then, high-resolution numerical simulations with a newly developed spectral QG model of the nonlinear equations reveal the spatial structures that develop after destabilization as well as the spectral fluxes between the different length scales. Larger Meddies tend to split to yield smaller vortices that have length scales more comparable to the Rossby radius of deformation.

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Talk 6

Spontaneous generation of gravity waves from atmospheric jets

RIwal Plougonven*

The generation of gravity waves from atmospheric jets and fronts has been studied for a number of years. An important motivation has been that these waves are an important contribution to the momentum transfers between the troposphere and the middle atmosphere (stratosphere and mesosphere). Emission of gravity waves from steadily propagating dipoles have become one paradigm to understand these waves. Idealized simulations with several models have shown that the emission is robust, but that the wave characteristics remain sensitive to resolution. Recent simulations with Norihiko Sugimoto, which extend longer in time, have shown that the sensitivity to resolution affects affects the details of the wave packet, but not the emission itself. A more robust estimate of the emission ensues. Similarities and differences with gravity waves near real jets and fronts will be discussed, as well as implications for the ocean's energy budget.

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Talk 7

Error Estimates and 2nd Order Corrections to Approximate Fluid Models

Bin Cheng*

In weather and climate studies/predictions, geophysical fluid dynamics (GFD) plays a central role across a wide range of temporal and spatial scales. Various constraints in multiscale simulation and observation make it necessary to enlist approximate fluid models which are typically “easier” to study and simulate and thus have long attracted the attention of theoretical and applied scientists alike. Notable examples include the incompressible approximation and quasi-geostrophic approximation. Part of this talk is proof-based analysis in getting sharp error estimates of some approximate models which essentially filters out the majority of fast waves. In this analysis, an important and difficult aspect is the physically relevant solid-wall boundary. Another part of this talk tries to establish connections to numerical analysis and geophysical studies. Approximate fluid models and their error estimates can make fundamental contribution to the development and refinement of next-generation weather/climate codes. These codes are essentially multiscale and ultimately aim at capturing GFD at regional scales, but such attempt is only meaningful if their performance at larger and longer scales are sufficiently close to the prediction of “easier” approximate models.

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Talk 8

Water waves with rough vorticity

Bogdan Matioc*

We discuss the existence of traveling water waves with rough vorticity, when accounting for surface tension effects at the wave surface. A rough - that is discontinuous or unbounded - vorticity is quite common in geophysical flows and it can appear as a result of the interaction of currents with different properties, or it can be induced by external factors such as the wind. The regularity properties of such waves are also discussed. (Joint work with Joachim Escher, Calin Martin, and Anca Matioc)

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Talk 9

Nonlinear equatorial dynamics: A Kymologist's Theory of Everything

John P. Boyd*

The variation of the Coriolis parameter with latitude refracts large-scale waves in the air and sea. Some modes are trapped within a waveguide centered on the equator which is created by total internal reflection. If a continuously stratified fluid is linearized about a state of rest, separation of variables yields the normal modes as the products of four one-dimensional factors. The time and longtitude factors are sines or cosines, the depth dependence is the solution to the vertical structure, a Sturm-Liouville eigenproblem yielding for the ocean a barotropic mode plus a countable infinity of baroclinic modes. The latitudinal factors, known as “Hough functions”, simplify to Hermite functions when spherical geometry is approximated by the “equatorial beta-plane”. When weak nonlinearity is allowed, the modal structure in latitude and depth is preserved to lowest order, but the time and longitude dependence is altered to a bivariate function that satisfies a nonlinear evolution equation derived by multiple scales perturbation theory.

We give an overview of nonlinear dynamics in the equatorial waveguide. Almost every species of behavior known to kymology, which is the science of waves, occurs in equatorial dynamics. Perturbation theory predicts KdV-type Rossby solitons, modon-like dipoles with closed regions of recirculation, frontogenesis and breaking in large amplitude Kelvin waves, round Kelvin solitons of small amplitude in strong mean curents, nonlinear wavepackets whose envelopes evolve according to the Cubic Schroedinger equation with sideband instability, breathers and envelope solitary waves. Spatial periodicity adds to the fun: solitary waves become cnoidal waves [elliptic functions] and N-soliton solutions become N-polycnoidal waves [hyperelliiptic functions]. Resonant triad interactions, long wave-short resonance, and second harmonic resonance add to the confusion.

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Tropical Instability Vortices are stable, quasi-steady anticyclones embedded between two alternating jets, similar to the Great Red Spot of Jupiter.

The theory is largely in place. The challenge is the sheer number and diversity of nonlinear behaviors.

Talk 10

Weak-Strong Uniqueness in Fluid Dynamics

Emil Wiedemann*

Various concepts of weak solution have been suggested for the fundamental equations of fluid dynamics over the last few decades. However, such weak solutions may be non-unique, or at least their uniqueness is unknown. Nevertheless, a conditional notion of uniqueness, the so-called weak-strong uniqueness, can be established in various situations. We present some recent results, both positive and negative, on weak-strong uniqueness in the realm of incompressible and compressible fluid dynamics. Applications to the convergence of numerical schemes will be indicated.

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Talk 11

Geometric generalised Lagrangian mean theories

Jacques Vanneste*

The interactions between waves, or more broadly fluctuations, and mean flows in geophysical fluids can be analysed effectively using the generalised Lagrangian mean (GLM) theory of Andrews & McIntyre. This non-perturbative theory relies on particle-following averaging to incorporate the constraints imposed by the material conservation of potential vorticity. As formulated, however, it suffers from drawbacks that can be traced back to an implicit reliance on Cartesian coordinates. To remedy this, we develop a geometric generalisation of GLM that we formulate intrinsically, using coordinate-free notation. This shows that the Lagrangian mean momentum (defined as the average of the pull-back of the momentum one-form) obeys a simple equation which guarantees the conservation of Kelvin's circulation, irrespective of the mean-flow definition. We discuss four possible definitions for the mean flow: a direct extension of GLM, a definition based on optimal transportation, a definition based on a geodesic distance in the group of volume-preserving diffeomorphisms, and the glm definition proposed by Soward & Roberts (2010). (Joint work with A D Gilbert, Exeter)

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Poster Abstracts

Poster 1

On the Detection of Hyperbolic Coherent Structures using Covariant Lyapunov Vectors in 2D Flows

Giovanni Conti*

A new method to find hyperbolic coherent structure, emerging from the tracers dynamics in 2D flows, based on the Covariant Lyapunov Vectors (CLVs) is proposed. CLVs have the interesting properties to be covariant with the dynamics, norm independent, and invariant under time reversal. Thanks to these properties these vectors, that can be not orthonormal, can probe the spatial structure of the space. In particular CLVs are able to detect the direction of the stable and unstable manifold of the system through the scalar map representing the angles between the vectors in every point of the space. With these intrinsic properties of the system we investigate three models, a simple Hamiltonian system, a "double gyre" and the Bickley jet, to see how well this angle is able to describe these particular patterns of the nature and we compare the results with other well known methods in the literature. In particular, we try to compare this method with the Finite Time Lyapunov Exponents (FTLEs) and with the variational theory for the Lagrangian Coherent Structures (LCSs). We show that there is a simple relation between the angle of CLVs and the LCSs computed with the variational theory.

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Poster 2

Internal wave emission from baroclinic jets: experimental results

Uwe Harlander*

Large-scale balanced flows can spontaneously radiate meso-scale inertia-gravity waves (IGWs) and are thus in fact unbalanced. While flow-dependent parameterizations for the radiation of IGWs from orographic and convective sources do exist, the situation is less developed for spontaneously emitted IGWs. Observations identify increased IGW activity in the vicinity of jet exit regions. Examining spontaneous IGW emission in the atmosphere and validating parameterization schemes confronts the scientist with particular challenges. Due to its extreme complexity, GW emission will always be embedded in the interaction of a multitude of interdependent processes, many of which are hardly detectable from analysis or campaign data. The benefits of repeated and more detailed measurements, while representing the only source of information about the real atmosphere, are limited by the non-repeatability of an atmospheric situation. This argues for complementary laboratory experiments, which can provide a more focused dialogue between experiment and theory. Indeed, life cycles are also examined in rotating annulus laboratory experiments. Thus, these experiments might form a useful empirical benchmark for theoretical and modelling work that is independent of any sort of subgrid model. In addition, the more direct correspondence between experimental and model data and the data reproducibility makes lab experiments a powerful test bed for parameterizations. (Joint work with Costanza Rodda and Ion Borcia)

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Poster 3

Stochastic Filtering for Rotating Shallow Water Equations

Oana Lang*

The aim of the poster is to present a stochastic filtering problem consisting of a signal that models the motion of an incompressible fluid below a free surface when the vertical length scale is much smaller than the horizontal one. The evolution of the two-dimensional rotating system is represented by an infinite dimensional stochastic PDE and observed via a finite dimensional observation process. The deterministic part of the SPDE consists of a classical shallow water equation (with an added viscosity term) and a new type of noise. Although this is a single layer model, therefore it does not completely reflect the complex stratification of the real atmosphere, it allows for important geophysical phenomena such as gravity and Rossby waves, eddy formation and geophysical turbulence.

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Poster 4

Linear and nonlinear waves in a damped-driven shallow water equation

Artur Prugger*

As a mathematical case study we consider the rotating shallow water equations in an unbounded domain damped by diffusion and driven by linear terms. Our interest lies in the effect of damping and driving on the linear waves and we find various possibilities for finite wave number instabilities. Preliminary results show the bifurcation of nonlinear waves as parameters vary.

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Poster 5

The Dynamic Smagorinsky Modell for Stratified Macro-turbulence

Urs Schaefer-Rolffs*

Turbulent kinetic energy cascades in fluid dynamical systems are usually characterized by scale invariance. However, subgrid-scale (SGS) parametrizations of in large eddy simulations do not necessarily fulfill this constraint. Up to now, scale invariance has been considered only in the context of isotropic, incompressible, and three-dimensional turbulence. Here we extend the theory to anisotropic turbulence in compressible flows that obey the hydrostatic approximation. We present a criterion to check if the symmetries of the governing equations are correctly translated into the equations used in a numerical model including the corresponding SGS parametrizations (model equations).

We validate the criterion by recovering the breakdown of scale invariance in the classical Smagorinsky model and by confirming scale invariance for the Dynamic Smagorinsky Model. We further apply the criterion to the primitive equations completed by horizontal and vertical diffusion as used in a GCM. Our assumption is that the numerical resolution extends into the macroturbulent inertial range of the mesoscales, which is governed by a forward energy cascade. The aforementioned criterion then allows us to formulate both the horizontal and vertical mixing lengths for the free atmosphere in accordance with scale invariance. High-resolution runs with the Kühlungsborn Mechanistic General Circulation Model (KMCM) using triangular spectral truncation at wavenumber 330 are presented, being the first simulations of a -5/3 slope of the kinetic energy spectrum in the upper troposphere and lower stratosphere without numerical dissipation or hyperdiffusion. In particular, a dynamic vertical mixing length leads to a steepening of the spectrum in the synoptic scales and a shallowing in the mesoscales.

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Poster 6

Havelock's theory for acoustic-gravity waves in deep water

Raphael Stuhlmeier*

We investigate the linearized theory of waves generated by a wave-maker in compressible flow. In addition to the propagating and evanescent waves found in the incompressible case, new modes then appear which incorporate both the effects of gravity and compressibility - called acoustic-gravity waves. The treatment of this problem in infinite depth is an exercise in classical analysis, and leads to a version of Havelock's wave-maker theorem for compressible flows. The asymptotic behavior of these new waves is investigated, and some simple examples for line wave-makers are given.

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Poster 7

Generalized large-scale semigeostrophic approximations for the f-plane primitive equations

Sergiy Vasylkevych*

We derive a family of balance models for rotating stratified flow in the primitive equation (PE) setting. By construction, the models possess conservation laws for energy and potential vorticity and are formally of the same order of accuracy as Hoskins' semigeostrophic equations. Our construction is based on choosing a new coordinate frame for the PE variational principle in such a way that the consistently truncated Lagrangian degenerates. The balance relations so obtained are elliptic when the fluid is stably stratified and certain smallness assumptions are satisfied. Moreover, the potential temperature can be recovered from the potential vorticity via inversion of a non-standard Monge-Ampère problem which is subject to the same ellipticity condition. (Joint work with Marcel Oliver)

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