Surface and Internal Waves

SIG meeting

University of East Anglia
Norwich
17 -18 December 2018

Programme of the meeting

17/12 **Monday**

12-1 Lunch (SCI0.31)

1st session: 1.10- 3.00 pm (SCI0.31)

1.10-1.50 *Internal wave impacts on offshore industry*. Gus Jeans (Oceanalaysis)

1.50-2.20 *Ring waves in a stratified fluid over a depth-dependent parallel shear flow.* Karima Khusnutdinova (Loughborough)

2.20-2.50 *Nonlinear Stability of Two-layer Flows with a Free Surface.* Francisco de Melo Virissimo (NOC)

3.00-3.40 Coffee break

2nd session: 3.40-5.30 pm (SCI0.31)

3.40-4.20 *Internal Solitary Waves and their interaction with Sea-Ice.* Magda Carr (Newcastle)

4.20-4.50 *Surface wave energy in sea ice covered regions: where does it go and does it matter?* Stefanie Rynders, Yevgeny Aksenov (Southampton)

4.50-5.20 *Arctic Ocean internal tides*. Thomas Rippeth (Bangor)

5.20-5.50 Discussions

6.00-9.00 Dinner in SCVA

18/12 T**uesday**

1st session 9.10-10.40 am (SCI0.31)

9.10-9.40 *Deep ocean circulation: variations in internal wave energy distribution and mixing efficiency.* Laura Cimoli (Oxford)

9.40-10.10 *Goldilocks mixing in wave-induced turbulence*. Ali Mashayekhi (Imperial)

10.10-10.40 *Scattering of Internal Gravity Waves by Rough Topography*. Stuart Dalziel (Cambridge)

10.40-11.10 Coffee Break

2nd session 11.00-12.20 (SCI0.31)

11.10-11.*30 Can Triadic Resonance Instability be ignited by the interaction between an internal wave field and a vortex ring?* Katherine Grayson (Cambridge)

11.30-11.50 *Internal tide energy flux over a ridge measured by a co-located ocean glider and moored ADCP*. Robert Hall (UEA)

11.50-12.20 Closing discussions

12.30-1.30 Lunch

Titles and Abstracts in the order of appearance

Title: **Internal wave impacts on offshore industry** (30 min +10 for discussions)

Gus Jeans, Oceanalysis Ltd, gus.jeans@oceanalysis.com

Abstract

A summary of internal wave impacts on offshore industry will be provided. Large amplitude internal waves, or solitons, are important to offshore industry if they are associated with strong orbital velocities. They are a hazard to operations and critical to engineering design in many offshore developments. Some specific impact cases will be described. In deepwater, the main impacts are due to rapidly varying surface currents and complex current profiles through the vertical. Large vertical motions within the water column can also impact some subsurface structures. Very different impacts are important in relatively shallow water, where the associated currents become strongest close to the seabed. Highlights from several recent projects to quantify solitons for offshore industry applications will be provided. These have all considered various challenges associated with the reliable quantitation of soliton currents from measurements or models. Rapidly sampled site specific measurement of velocity and temperature throughout the water column are usually required for soliton quantification. In several cases, quantification has proved more reliable via temperature measurement and appropriate theory than direct velocity measurement. This has highlighted industry benefits from oceanographic measurement strategies that have been more widely adopted in academia.

Title: **Ring waves in a stratified fluid over a depth-dependent parallel shear flow** (30 min)

Karima Khusnutdinova, Department of Mathematical Sciences, Loughborough University, Loughborough LE11 3TU, UK, k.khusnutdinova@lboro.ac.uk

Abstract

We study long weakly-nonlinear ring waves in a stratified fluid in the presence of a depth-dependent parallel shear flow (e.g., oceanic internal waves generated in narrow straits and river-sea interaction zones) within the scope of the full set of Euler equations with the boundary conditions appropriate for oceanographic applications. Our results generalise the results obtained by Johnson (1980, 1990) and Lipovskii (1985). We show that despite the clashing geometries of the waves and the shear flow, there exists a linear modal decomposition (separation of variables) in the set of Euler equations describing the waves, more complicated than the known decomposition for the plane waves. We use it to describe the wavefronts of surface and internal waves, and to derive a 2+1D weakly-nonlinear model for the amplitudes of the waves. The general theory is applied to a two-layer fluid with a piecewise-constant current. The distortion of the wavefronts is described by two branches of the singular solution (envelope of the general solution) of a nonlinear first-order differential equation. The wavefronts of surface and interfacial waves propagating over the same piecewise-constant current look strikingly different. This is a joint work with Xizheng Zhang.

References

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Title**: Nonlinear Stability of Two-layer Flows with a Free Surface** [20 min + 5 for discussions]

Francisco de Melo Virissimo and Paul A. Milewski, Department of Mathematical Sciences, University of Bath, F.de.Melo.Virissimo@bath.ac.uk

Abstract

In this talk, we will formulate and discuss the problem of density stratified interfacial flows in the shallow water limit. This type of flow occurs in nature with the atmosphere and ocean as prime examples [8], [3].

Mathematical studies of these are particularly important, since wave motion tend not to be resolved by most numerical climate models due to their fast scales, and thus need to be understood and parameterised [7]. For example waves may break and dissipate energy or mix the underlying fluids and affect the medium in which they are propagating [9], [6]. Consequently, studies in this area not only increase the understanding of internal waves but may also have an impact on future climate models.

We will focus our attention on two-layer flows with a free surface, without the so-called *Boussinesq approximation* which requires small density differences. This is a simplified model for geophysical situations, but it is not too simplified: the model has both *barotropic* (fast waves affecting the whole fluid uniformly) and *baroclinic* modes (slower waves with more internal structure) [2].

The governing equations will be derived and the dynamics of their solutions will be studied from both analytical and numerical points of view, particularly the issue of whether the solutions maintain hyperbolicity (i.e. wave-like behaviour) [5], [1].

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References

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Title: **Internal Solitary Waves and their interaction with Sea-Ice** (30 min +10 for discussions)

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Prof P A Davies (Department of Civil Engineering, University of Dundee, Scotland).

Abstract

Internal solitary waves (ISWs) propagating in a stably-stratified two layer fluid in which the upper boundary condition changes from open water to ice are studied in the laboratory. The waves are generated by a lock-release mechanism and different ice types are considered, namely, grease ice, level ice and nilas ice. It is shown that the ISW-induced current at the surface is capable of transporting the ice in the horizontal direction if the ice is free to move. In the level ice case, the transport speed of the ice is shown to be dependent on the length but not the thickness of the ice floe. Moreover, in cases where the ice floe protrudes into the pycncoline it is shown that interaction with the ice edge can cause the ISW to break or even be destroyed by the process. In cases where the underside of the ice is rough, small vortices are generated there due to the ISW induced flow. The results suggest that interaction between ISWs and sea ice are an important mechanism for dissipation of internal wave energy in the Arctic Ocean.

Acknowledgements. This work was funded through the EU Horizon 2020 Research and Innovation Programme Hydralab+.

Title: **Surface wave energy in sea ice covered regions: where does it go and does it matter?** [20 mins+ 10 discussion]

Stefanie Rynders[1]*, Yevgeny Aksenov*[1]*, Lucia Hosekova*[2]*, Danny Feltham*[2]*, George Nurser*[1]
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Abstract

Surface waves are an important phenomenon in the ice covered regions. Because of climate change waves are becoming more prevalent in the Arctic and possibly also in the Southern Ocean. Through modification of energy and momentum transfers between the atmosphere, sea ice and ocean waves can influence climate feedbacks and potentially accelerate sea ice retreat. We discuss different mechanisms of wave momentum transfer into the ocean and demonstrate how waves affect sea ice.

Title: **Deep ocean circulation: variations in internal wave energy distribution and mixing efficiency**

[30 min]

Laura Cimoli, Department of Physics, University of Oxford, laura.cimoli@physics.ox.ac.uk

Abstract

In the deep ocean, turbulent (diapycnal) mixing is crucial for the closure of the deep ocean overturning circulation, i.e. working to raise dense waters back to shallower depths. In the ocean interior, turbulent mixing is largely driven by the breaking of internal waves, which in the deep ocean are generated mainly through the interaction of tides, jets and eddies with bottom topography. To quantify the role of turbulent mixing in the upwelling of dense waters, it is necessary to know: (I) the fraction of the internal waves that breaks locally, q, against how much radiate away from the local source, and (ii) how much of the turbulence generated through a wave-breaking event is translated into mixing (M) against how much is lost into heat dissipation (ε) ; the ratio of such mixing to local dissipation is referred to as flux coefficient $\Gamma=M/\varepsilon$. For practical reasons, it is customary to assume $q=0.3$ and $\Gamma=0.2$ in the parametrization of deep ocean mixing in coarse resolution ocean and climate models. Here, we analyze the sensitivity of mixing to spatially variable q and Γ to make three important points: (I) global variations of either of these parameters is significant for ocean circulation and their combined variations are highly intertwined; (II) the combined variations of these two parameters significantly modifies the global patterns of upwelling and downwelling of dense waters; (III) the impacts of such variations vary across ocean basins, implying an influence on inter-basin exchanges of water masses through the Southern Ocean pathways. All of these points have implications for the ocean tracers' budgets as their uptake, sequestration and ventilation depend on the global patterns of upwelling and downwelling of deep and abyssal waters.

Title: **Goldilocks mixing in wave-induced turbulence** (30 min)

Ali Mashayekhi, Imperial College, mashayek@imperial.ac.uk

Abstract

Turbulence induced by breaking internal waves is an abundant feature in nature occurring over a wide range of scales. I will argue that recent advances in ocean observations and computational resources have put us in a position to gain new insight into the nature of wave-induced turbulent mixing. I will show that the very existence of natural overturns associated with the turbulence-inducing waves acts so as to optimize the efficiency of turbulent mixing, defined as the percentage of energy available to turbulence which contributes to irreversible mixing. I will show that this optimal mixing, identified based on high resolution numerical simulation of waves, also manifests itself in a diverse range of oceanic datasets.

Title: **Scattering of Internal Gravity Waves by Rough Topography** [20 mins+10 discussions]

Stuart Dalziel, Department of Applied Mathematics and Theoretical Physics, University of Cambridge, s.dalziel@damtp.cam.ac.uk

Abstract

While there has been substantial progress in our understanding of internal gravity waves, key questions such as the detail to which we need to know bathymetry in order to adequately capture reflections remains an open question. When the topography has length scales comparable to the wavelength of an incoming wave beam, it has long been known that there is a transfer of energy between wavenumbers and, in many cases, the possibility of back reflection. Unfortunately, this has been the subject of only a small number of experimental studies, and not all of those have ever been published. This presentation will explore some of this (historical) unpublished work to see what lessons have been learnt.

Title: **Can Triadic Resonance Instability be ignited by the interaction between an internal wave field and a vortex ring?**

Katherine Grayson (Univ of Cambridge), Stuart Dalziel (Univ of Cambridge), Andrew Lawrie (University of Bristol), kmg43@cam.ac.uk

Abstract

The role played by Triadic Resonance Instability (TRI) in transferring energy across the wavenumber and frequency spectra for internal waves is becoming increasingly recognised. However, much of the experimental work to date has considered the development of this crucial mechanism in the idealised conditions of monochromatic plane waves or wave beams. Here we present novel experimental results exploring whether TRI can be ignited in a pre-existing wave beam by the passage of a vortex ring. In this study, the internal wave field is generated from the motion of a flexible horizontal boundary condition, driven by an array of independently controlled actuators. This allows for varying amplitude, frequency and wavelength in both the spatial and temporal domain. We therefore examine the effect of varying the wave input parameters on the generation of this instability and determine if, under certain conditions, the presence of the vortex ring can ignite the TRI.

Title: **Observing internal waves using autonomous ocean gliders (**20 min not 2-4 pm on 17th)

Internal tide energy flux over a ridge measured by a co-located ocean glider and moored ADCP

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Abstract

Internal tide energy flux is an important diagnostic for the study of energy pathways in the ocean, from large-scale input by the surface tide, to small-scale dissipation by turbulent mixing. Accurate calculation of energy flux requires requires repeated full-depth measurements of both potential density (ρ) and horizontal current velocity (u) over at least a tidal cycle and over several weeks to resolve the internal spring-neap cycle. Typically, these observations are made using near-full-depth oceanographic moorings that are are vulnerable to being 'fished-out' by commercial trawlers when deployed on continental shelves and slopes. Here we describe and test an alternative approach too minimise these risks, with u measured by a low- frequency ADCP moored near the seabed and ρ measured by an autonomous ocean glider holding station over the ADCP. The method is used to measure the M2 internal tide radiating from the Wyville Thompson Ridge in the North Atlantic. The observed energy flux (3.9±0.2 kW m−1) compares favourably with a previous numerical modelling study and historic observations. Error in the calculation due to imperfect co-location of the glider and ADCP is estimated by sub-sampling potential density in an idealised internal tide field along pseudorandomly distributed glider paths. The error is considered acceptable (<10%) if all the glider data is contained within a 'watch circle' with a diameter smaller than 1/8 of the mode-1 horizontal wavelength of the internal tide. Observed energy flux is biased low because phase shifts in sub-sampled potential density result in underestimation of vertical isopycnal displacement and available potential energy; this bias increases with increasing watch circle diameter. If watch circle diameter is larger than 1/8 of the horizontal wavelength, the bias is greater than 3% and all observed energy fluxes within the 95% confidence limit are underestimates. For the Wyville Thompson Ridge, where the M2 mode-1 horizontal wavelength is ≈100 km and all the glider dives are within a 5 km diameter watch circle, the bias is only 0.5% and the error is less than 4% at the 99% confidence limit.

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1. Alexander Korobkin (UEA)

2. Emilian Parau (UEA)

3. Rob Hall (UEA)

4. David Stevens (UEA)

5. K. Grayson (Cambridge)

6. Tatyana Khabakhpasheva (UEA)

7. Mark Blyth (UEA)

8. Mark Cooker (UEA)

9. Magda Carr (Newcastle)

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19. Alireza Mashayekhi (Imperial)

20. Laura Cimoli (Oxford)

21. Andrew Lawrie (Bristol)

22. Evgeny Buldakov (UCL)

23. Gillian Damerell (UEA)

24. Callum Rollo (UEA)

25. Ted Johnson (UCL)