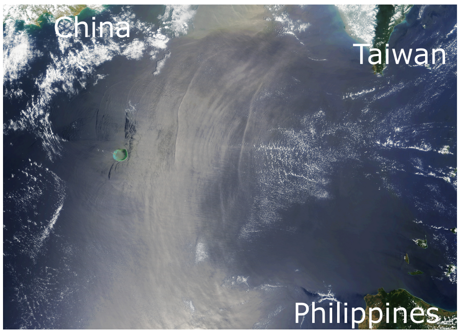
PhD Proposal

Rim Currents Induced by Internal Waves Attractor in Enclosed Basins

Fluids stratified in density develop waves beneath the surface and therefore in their bulk. Nowadays these so-called internal gravity waves whose origin comes from the simple Archimedes law are the center of many theoretical or numerical studies, but also of major scientific cruises through oceans. Recently, for example, a significant effort has been performed in the South China Sea, well-known to host underwater tsunamis up to 200 m with surface signatures visible from satellites. Their generation through the interaction between tides and bathymetry, their propagation and sometimes instability, or the interaction properties with oceanic currents or the Coriolis force are already relevant questions. Moreover, their consequences on the biological activity by providing planktons from deep water to gourmet whales or by regenerating the coral reef of Dongsha island are also of notorious interest, that includes also classified military objectives...

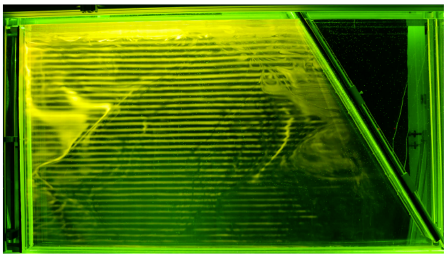


Satellite image of surface signature of large internal waves propagating in the South China Sea. (NASA ©).

From the physicist's point of view, internal gravity waves are particularly interesting. They are transverse waves that do not respond to our classical perception of wave phenomena. Their group and phase velocities are perpendicular, their reflection laws are completely different from the usual Snell-Descartes laws, the wavelength is not controlled be the frequency, the Huyghens-Fresnel diffraction laws are not valid anymore, ... All these properties lead to paradoxes that are of high interest from the 'fundamental physics' point of view. Moreover, part of the above properties, which are consequences of an anisotropic dispersion relation due to gravity, are also encountered for inertial waves (in presence of rotation) or plasma waves (in presence of a magnetic field), but also in the astrophysical context, a domain where interest for internal waves is developing very fast.

The main topic of the PhD will be to study the **flow of a rotating stratified fluid in a parabolic basin in response to a tidal forcing**. According to recent numerical simulations, nonlinearities in the near-shore internal tide produce an azimuthally independent 'set-up' of the isopycnals that in turn drives an approximately geostrophically balanced, cyclonic, near-shore, sub-surface jet. The latter, also called rim currents, rely neither on the wind nor on local topographic features yet provide a simple mechanism for driving cyclonic subsurface currents at continental slopes that is dynamically consistent with observations.

The Ph-D student will **develop the experimental set-up**, and study such a baroclinic flow, in the laboratory using different kinds of forcing. The stratification will be reproduced using *salt water* in a relatively large tank ($\sim$ 2 m wide and 0.5 m high), since we want to reduce viscous effects by attaining a rather large Reynolds number. Internal wave fields will be visualized using Particle Image Velocimetry (PIV), the well-established experimental technique that determines velocity field data through cross correlation investigations of trajectories of glass microspheres seeding the flow. Post-processing of field measurements with high spatial and temporal resolution over long durations is central. One will take advantage of elaborated signal processing analysis (Hilbert transform, bicoherence, time-frequency analysis, ...).



In a confined domain with an inclined slope, internal waves generated at a given frequency reflect on the different walls before eventually converging towards a closed loop that concentrate all the energy. See the Video.

Within the linear regime, the formation of a nice axy-symmetric internal wave attractor is expected. Its destabilization when nonlinearities become important and the possible generation of an associated mean-flow should lead to the appearance to a rim current. The possible subsequent destabilization of this current will also be studied. The role of the different boundary conditions will finally be explored. We expect to consider also the possible connections with enclosed basins such as the Baltic, Black and Caspian seas.

In addition, when becoming nonlinear, such a fluid is expected to develop wave turbulence, a really open domain for internal waves. Wave turbulence describes physical systems with a large number of dispersive and weakly interacting waves and has been successfully applied to describe gravity, capillary and inertial waves, waves in magnetized fluids, elastic plates,... We would like to explore wave-turbulence with this experimental set-up.

An **Internship** during the spring 2020 on this topic is possible and would be an excellent preparation.

PhD advisors:
Thierry DAUXOIS (http://perso.ens-lyon.fr/thierry.dauxois). Thierry.Dauxois@ens-lyon.fr
Sylvain JOUBAUD (http://perso.ens-lyon.fr/sylvain.joubaud). Sylvain.Joubaud@ens-lyon.fr

Laboratoire de Physique, CNRS and ENS de Lyon (http://www.ens-lyon.fr/PHYSIQUE)

Collaborations:
The PhD will be performed within the internal waves group of the Physics laboratory at ENS de Lyon and in close collaboration with Evgeny Ermanyuk, from the Lavrentyev Institute of Hydrodynamics in Novosibirsk (Russian Federation).
This work will be part of the Simons Collaboration on Wave Turbulence (https://cims.nyu.edu/wave-turbulence/).

References:
T. Dauxois, S. Joubaud, P. Odier, A. Venaille, *Instabilities of internal wave beams*, Annual Review of Fluid Mechanics 50, 131-156 (2018).
G. Pillet, E.V. Ermanyuk, L. Maas, I.N. Sibgatullin, T. Dauxois, *Internal Wave Attractors in 3D Geometries : trapping by oblique reflection* , Journal of Fluid Mechanics, 845, 203-225 (2018).
P. Maurer, S.J. Ghaemsaidi, S. Joubaud, T. Peacock, P. Odier, *An axisymmetric inertia-gravity wave generator*, Experiments in Fluids 58, 143 (2017)
C. Brouzet, I.N. Sibgatullin, E.V. Ermanyuk, S. Joubaud, T. Dauxois, *Scale effects in internal wave attractors*, Physical Review Fluids 2, 114803 (2017).
C. Brouzet, E.V. Ermanyuk, S. Joubaud, I. Sibgatullin, T. Dauxois, *Energy cascade in internal wave attractors*, Europhysics Letters 113, 44001 (2016).