Wave Attractors Report Summary

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Final Report Summary - WAVE ATTRACTORS (Internal and inertial wave focusing and instability in closed fluid domains)

One of the important questions in the dynamics of the oceans is related to the cascade of mechanical energy in the abyss and its contribution to mixing. We have proposed a unique self-consistent experimental and numerical set up that models a cascade of triadic interactions transferring energy from large-scale monochromatic input to multi-scale internal wave motion. We have shows how this set-up can be used to tackle the open question of studying internal wave turbulence in a laboratory, by providing, for the first time, explicit evidence of a wave turbulence framework for internal waves. Finally, beyond this regime, we have highlighted a clear transition to a cascade of small-scale overturning events that induce mixing.

The continuous energy input to the ocean interior comes from the interaction of global tides with the bottom topography yielding a global rate of energy conversion to internal tides of the order of 1TW. The subsequent mechanical energy cascade to small-scale internal-wave motion and mixing is a subject of active debate in view of the important role played by abyssal mixing in existing models of ocean dynamics. The oceanographic data support the important role of internal waves in mixing, at least locally: increased rates of diapycnal mixing are reported in the bulk of abyssal regions over rough topography in contrast to regions with smooth bottom topography. A question remains: how does energy injected through internal waves at large vertical scales induce the mixing of the fluid?

The anisotropic dispersion relation for linear waves in a stratified fluid requires preservation of the slope of the internal wave beam upon reflection at a rigid boundary. In the case of a sloping boundary, this property gives a purely geometric reason for a strong variation of the width of internal wave beams (focusing or defocusing) upon reflection. Internal wave focusing provides a necessary condition for large shear and overturning, as well as shear and bottom layer instabilities at slopes.

In a confined fluid domain, focusing usually prevails, leading to a concentration of wave energy on a closed loop, the internal wave attractor. At the level of linear mechanisms, the width of the attractor branches is set by the competition between geometric focusing and viscous broadening. High concentration of energy at attractors make them prone to triadic resonance instability (TRI) which sets in as the energy injected into the system increases.

The onset of instability in this case is similar to the classic concept of triadic resonance, which is best studied for the idealized case, with monochromatic in time and space carrier wave as a basic state that feeds two secondary waves via nonlinear resonant interactions. The resonance occurs when temporal ω₀=ω₁+ω₂ and spatial k₀=k₁+k₂ conditions are satisfied (ω is the frequency, k the wave vector while subscripts 0, 1 and 2 refer to the primary, and two secondary waves, respectively). In a wave attractor, the wave beams serve as a primary wave, and the resonance conditions are satisfied with good accuracy providing a consistent physical framework for the short-term behavior of the instability.

We have carefully studied and reported this novel experimental and numerical set up, an "internal wave mixing box", which presents a complete cascade of triadic interactions transferring energy from large-scale monochromatic input to multi-scale
internal wave motion, and subsequent cascade to mixing. We have reported interesting signatures of discrete wave turbulence in a stratified idealized fluid problem. Moreover, we shown how statistics of extreme vorticity events leads to mixing that occurs in the bulk of the fluid.

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