Global instability of mixing layers created by confinement

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Abstract

Our research problem is concerned with the inviscid linear stability of parallel stratified shear layer. Most flows do not form well-defined layers, but have density and/or velocity that varies smoothly and continuously with a spatial coordinate. Even in these cases, dividing the flow into layers may be a useful modelling strategy to simplify the equations of motion. A parallel stratified shear layer is where layers of fluid of different density parallel to one another are moving with different speeds creating shear in between them. If the fluid has constant density then we say it is unstratified or homogeneous. Stratified shear layers can arise in the upper oceans, and this motivates our work. We investigate the temporal, absolute and global stability properties of model stratified flows. In temporal instability the disturbances are assumed to be periodic in the streamwise direction, and propagation properties are not determined, it does determine if a flow is stable or unstable. Absolute instability considers propagation of a spatially localized disturbance and determines whether there is a growth in the rest frame or not. Both temporal and absolute instability assume parallel flow. Global instability takes account of variation of the basic flow in the streamwise direction, and determines if there is a growth in the rest frame when the flow is not parallel. Often shear layers develop slowly in the streamwise direction which justifies a local stability approach, i.e. obtaining dispersion relations based on velocity and density profiles found at particular streamwise positions. Streamwise variation of the basic flow is neglected in the local theory, i.e. the flow is assumed to be parallel.

A mixing layer is the region of high shear between two layers of uniform, but different, velocity. The existence of a mixing layer also

implies the presence of surrounding uniform (or nearly uniform) flows. Huerre and Monkewitz (1985) showed that mixing layers become locally absolutely unstable if there is a sufficiently strong reverse flow in one of the two streams, and then, disturbances spread and grow both upstream and downstream. Healey (2009) showed that the presence of boundaries parallel to the shear layer can increase the absolute instability so that even mixing layers without reverse flow can become absolutely unstable. We show that for weakly stratified mixing layers typical of the upper ocean, the sea surface and the sea bed can provide the necessary confinement for the creation of local absolute instability. We also show that absolute instability is sometimes increased by stable stratification. Furthermore, typical bed topographies can create zones of absolute instability parallel to the shoreline that have the potential to act as wavemaker regions for global instability. This mechanism could operate in coastal areas with wind blowing offshore. Results are presented for global instabilities of mixing layers where one layer is essentially stationary, a common scenario in geophysical flows. We consider flows where the distance from mixing layer to a boundary varies slowly with the streamwise coordinate, which can create a pocket of absolute instability, and which in turn can produce global instability. Flows of this type can arise, for example, when wind blows over the sea leading to an upper layer moving at nearly uniform velocity lying above an essentially stationary lower layer, with a relatively thin mixing layer between them. We have identified flows that become globally unstable and on the other hand we have found flows that have a region of absolute instability and yet remain globally stable. It is shown here that typical sea bed topographies can generate global instabilities even when stabilizing stratification is included. It is expected that the appearance of global instability would significantly enhance mixing.