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On the role of nonnormality in the overreflection of gravity waves

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Shear instability of stably stratified fluids is a common feature of atmospheric and oceanic flows. One of the conceptual frameworks that have been advanced for a physical, mechanistic basis for stratified shear instability is the overreflection theory, describing the instability in terms of continuous overreflection of gravity waves. Overreflection occurs as gravity waves extract energy from a mean, shear flow in a transient process. It has been hypothesized that the Orr mechanism, in which a perturbation leaning against the shear intensifies transiently as it is sheared over, provides the necessary energy extraction mechanism from the mean flow. Our purpose is to clarify the role of the Orr mechanism and non-normal growth in the overreflection process. The scattering of a gravity wave packet by a finite stably stratified shear layer was investigated focusing on the transient growth characteristics of the overreflection process. This process was found to occur in three stages: first the incoming wave enters the shear layer and excites non propagating perturbations leaning with and against the shear. The excitation is non-local as a result of the tunnelling of the wave. Subsequently, the energy of perturbations leaning against the shear grows in a manner similar to energy growth of perturbations in constant shear flows. Finally, the amplified perturbations excite propagating waves originating from the vicinity of the shear layer boundary. These results therefore were found to support the conclusion that the Orr mechanism that is slightly modified by stratification produces the observed growth during the overreflection process. The role of non normality in this process is also investigated from the perspective of the associated non orthogonality of the modes of the dynamical system. It is found that the incident wave packet projects on non-orthogonal analytic modes having the structure of a downward propagating wave in the far field below the shear layer and overreflection results from the interaction among these non-orthogonal modes.