Rethinking the gradient Richardson number

J. L. Pelegrí and P. Sangrà

Institut de Ciències del Mar, CSIC, 08003 Barcelona; Instituto Universitario de Oceanografía y Cambio Global, Universidad de Las Palmas de G. C., 35017 Las Palmas de Gran Canaria, Spain.

Abstract

The gradient Richardson number, Ri, is the classical index for dynamic vertical instability. It is generally viewed as a ratio between the stabilizing effects of buoyancy versus the destabilizing role of the (squared) vertical shear. The gradient Richardson number is small (subcritical when its value is less than one) when stratification is small enough and/or vertical shear is sufficiently large; under these circumstances the flow becomes unstable, prone to mixing. In this communication we carefully explore an alternative perspective, which arises in isopycnic coordinates: the gradient Richardson number is now a ratio between the inverse of vertical stratification and the (squared) shear in density coordinates (named the diapycnal shear). From this point of view the flow becomes unstable in well stratified conditions as long as the diapycnal shear remains moderately large (Pelegrí and Csanady, 1994; Pelegrí and Sangrà, 1998; Pelegrí et al., 1998).

One important limitation of Ri, as an indicator of mixing, is that it cannot differentiate between mixing in stratified regions versus flow instability in already well-mixed waters. The isopycnic approach suggests that diapycnal shear is a most relevant variable for flow stability, yet it alone cannot assess the existence of unstable conditions. Therefore, we rewrite the instability condition as a reduced squared diapycnal shear, which is a function of both Ri and the stratification, and decreases monotonically with stratification.

The above concepts are illustrated using data from three distinct regions: the shelf break south of Gran Canaria, the Gulf Stream and the Mediterranean outflow. It turns out that very often for Gran Canaria and the Mediterranean outflow, and only very rarely for the Gulf Stream, the conditions are subcritical. The variables are non-dimensionalized by means of the background stratification. The vertical shear, diapycnal shear and the reduced squared diapycnal shear are then plotted, as cloud points, as a function of stratification. The results confirm a dependence of the squared reduced diapycnal on stratification, which is characteristic for each particular flow dynamics.

References

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