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Shear instability at marginally subcritical Ri

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Shear instabilities are readily observed in the Connecticut River estuary using a high-frequency echo sounder. The instabilities have distinctive braids that extend across the pycnocline, with vertical scales of 2-3 m and horizontal scales of 10-20 m. While the primary instabilities have low slopes, they are populated with numerous secondary instabilities with slopes O(1). One of the most distinct differences between these shear instabilities and those typically observed in laboratory or numerical simulations is that the vertical scale of the overturns in these observations are much smaller than the vertical scale of the primary braids. The overturns are only associated with secondary instabilities, comparable to the width of the primary braids but about 1/5 of their vertical extent. Likewise the magnitude of the density anomalies associated with the overturns is much smaller than the overall density difference. Thus these shear instabilities do not exhibit the familiar “jelly-roll” structure of fully developed shear instabilities often described in laboratory and numerical experiments.

The explanation for this difference is the consideration of how the flow becomes unstable. I suggest that in the estuarine observations, Ri drops below 0.25 so gradually that the instabilities develop in marginally unstable conditions. This explains the low slope of the primary instabilities. Within the braids, Ri drops much lower due to strain and baroclinicity, so vigorous secondary instabilities develop rapidly within the braids, extracting energy from the shear and maintaining marginally critical conditions in the presence of persistent forcing by the large-scale hydraulics. This regime can only occur at high Re, because the scale of the flow has to be large enough for fully turbulent secondary instabilities to develop.