Reply

DAN E. KELLEY

Department of Oceanography, Dalhousie University, Halifax, N.S., Canada

18 April 1990 and 24 April 1990

The laboratory experiments described by Fernando confirm my (Kelley 1987) prediction of the speed of interface migration in double-diffusive layered systems. Fernando's Fig. 1 illustrates the factor of 2 agreement, over two decades of variation, between his new measurements and the prediction [Eq. (9) in Kelley (1987), repeated by Fernando as Eq. (2)]. The results of Fernando's experiments are important because they release us from a critical assumption of the Kelley (1987) formulation, namely, that measurements of interface migration in layer-gradient systems (i.e., linearly stratified fluids heated from below) can be extrapolated to two-layer double-diffusive systems of the "diffusive" variety (in which a layer of cool, fresh water lies above a warm, salty layer).

The factor of 2 scatter of Fernando's measurements about the predicted value is similar to the scatter in the layer-gradient systems upon which my formulation was based. Scatter of this magnitude is typical in turbulent convective systems; the cause is not known. Fernando suggests that the scatter increases at small values of $\mathrm{Ri}^{-1}(1 - J_2/J_1)$ and that therefore the Kelley (1987) formulation breaks down in that limit. This qualitative statement is hard to verify visually in Fernando's Fig. 1—the scatter at the left of the plot is not much larger than at the right—but it would be an important limitation if it could be justified quantitatively.

In summary, then, Fernando's two-layer laboratory experiments verify the formula for interfacial migration put forward by Kelley (1987), while raising the potential issue of inapplicability at high Richardson numbers. This leaves unaltered the central point I put forward, that the vertical fluxes of salt and heat effected by interface migration in thermohaline staircases are small (<20%) compared with the double-diffusive fluxes through the interfaces. Interestingly, though, this does not necessarily mean that interface migration is irrelevant. McDougall (personal communication) has suggested that even though these vertical migration fluxes are weak, they might be important in controlling T–S variability along the layers of the staircase. His calculations suggest that water-mass conversion caused by interface migration may be large enough to explain the strikingly systematic along-layer T–S variation observed in the C-SALT (Caribbean Sheets and Layers Transects) experiment (Schmitt et al. 1987). This new theoretical suggestion of the (subtle and somewhat surprising) importance of interface migration raises new observational challenges and opportunities. Can we use such indirect signals to gauge the strength of interface migration, which is too small [vertical motions $< 10^{-8}$ m s^{-1} (Kelley 1987)] to observe directly? On the other hand, can we turn the reasoning around, and use what we know about interface migration to close conservation budgets tightly enough to infer advective stirring across thermohaline staircases?

Corresponding author address: Dr. Dan Kelley, Dalhousie University, Department of Oceanography, Halifax, N.S., Canada B3H 4J1.

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