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Reply

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Introduction

We are glad that *Colomer et al.* [this issue] found *Whitehead et al.* [1996] of interest, and we agree with them that the study of the penetration of localized convection into a stratified fluid has many aspects yet to be resolved. The scaling argument in *Whitehead et al.* [1996] should be attributed to *Visbeck et al.* [1996], who originated the argument. Their article postdates *Whitehead et al.* [1996] simply by editorial accident.

Colomer et al. [this issue] correctly point out that the equation by *Whitehead et al.* [1996, equation (32)] is incorrect and their equation *Colomer et al.*, [this issue, equation (3)] should be used instead. Our corrected calculation evaluating quantities for a Mediterranean convection event now indicate that a mistral must blow for 15 to 26 days for the mixed layer to penetrate to equilibrium depth. This is far longer than an individual storm, so more than one cold event is required for convection to be deep enough for baroclinic eddies to remove the dense fluid. The progressive increase of the mixed layer over the winter from many storms is well documented. An estimate for the Labrador Sea now has a minimum formation time of 89 days rather than 33.5 days using a cooling of 100 W/m^2. For the greater heat flux value of 600W/m^2 the estimate is 50 days rather than 18.5 days. There is no way to cool thermally stratified water to such depths any more rapidly than this. It is not clear that observations of sufficient frequency have been made for comparison of field data with these estimates of times.

Colomer et al.'s [this issue] logarithmic Figures 1 and 2 have a slope of 1 or more. This indicates that there is a range at early times in which stratification is not yet dynamically important, but such a fact does not clearly resolve whether one or another scaling argument is the only correct one. Note, for example, that there is a later time when the slope is less than the one half given by *Colomer et al.* [this issue]. We do agree that no range with such a slope is visible. Their measurements show that the *Visbeck et al.* [1996] scaling seems to hold for vanishing values of f, which is a new and important result. Such a result is incidentally consistent with our observations for larger stratification ($N/f > 1$). The three parameters B_0, R_s, and N could be combined to forecast the depth of the convection h in many ways. However, velocity clearly scales with Nh if it is produced by the conversion of potential energy to kinetic energy. Moreover, the other two parameters can only combine as $(BR)^{\frac{1}{3}}$ for a matching velocity scale, and this leads to the *Visbeck et al.* [1996] depth as *Colomer et al.* [this issue] point out. We agree that balancing these two scales is also equivalent to a simple balance of heat if Nh is the velocity scale. As long as buoyancy difference between the mixed region and the stratified fluid is the only source of kinetic energy for the eddies that remove the heat, it is difficult to see what other scale the mixed layer could adopt. Since the focus of our research was on convection in the ocean, the regime for vanishing f was not explored. If rotation is included, the velocity scale could be found by multiplying Nh by any power of N/f. The fact that the baroclinic eddies in a rotating fluid adopt a radius that produces the same scaling is striking. Nonetheless, it seems that the scaling (in retrospect) is inevitable in the absence of frame rotation, and it is useful to see their development of the argument along with data which verified this.

References

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