# Direct measurements of turbulent buoyancy fluxes in the nearshore coastal ocean

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## Introduction

Written in terms of the balance of turbulent kinetic energy (TKE), the efficiency of mixing produced by turbulence in stratified fluids is usually given in terms of the flux Richardson number:

$$Ri_f = \frac{B}{B+\varepsilon} \tag{1}$$

where $B$ is the turbulent buoyancy flux and $\varepsilon$ is turbulence dissipation rate. If $Ri_f$ is known then $B$ can be computed from $\varepsilon$, as is often done with turbulence profiler data acquired in the ocean. While it is commonly assumed that (e.g., [1]) $Ri_f \approx 0.2$, using Direct Numerical Simulations (DNS) to study sheared stratified turbulence, [2] found that

$$Ri_f = C\left(\varepsilon/\nu N^2\right)^{-1/2} = CA^{-1/2} \tag{2}$$

where $N$ is the buoyancy frequency, $A$ is the turbulence activity number, and $C$ = 1.5. Eq. 2 predicts values of $Ri_f$ that are much smaller than 0.2 when $A$ is large, implying that energetic mixing events may produce much less mixing than would be the case if $Ri_f \approx 0.2$.

## Methods

Between 2010 and 2013 we carried out measurements of stratified turbulence at three shallow (15 to 25 m of water) nearshore coastal ocean sites: the coral reef at Eilat, Israel; the relict coral reef in Mamala Bay, Hawaii; and, a sandy area of Monterey Bay, California. At all three sites we deployed a tower to which were attached a set of Acoustic Doppler Velocimeters (ADVs) with co-located fast C-T sensors to measure fluxes of heat and salt. In all cases, these instruments were cabled to shore, enabling us to sample turbulent fluctuations continuously for weeks at a time. After correction for surface wave effects, these measurements produced time series of TKE, Reynolds stresses, TKE production and TKE dissipation (via inertial sub-range fitting),and turbulent buoyancy fluxes (direct covariance) for a wide range of values of $A$ and of mean flow conditions (e.g. gradient Richardson number).

## Results

During the tower deployments, all three sites experienced tidally periodic internal wave/bore events that stratified the water column and produced strong shears and turbulence. Observations from all three sites with $10^2 < A < 10^7$, confirm the functional relationship given by eq. 2, with values of $C$ from the three sites as follows: Eilat $C$ = 2.7 ($r^2$=0.82); Mamala Bay $C \approx 1.5$ ($r^2$=0.99) and Monterey Bay $C \approx 2.4$ ($r^2$=0.94). Likewise similar measurements reported in [3] gave $C \approx 4.5$. One common feature to all three data sets is that during stratified periods, TKE production was significantly less than TKE dissipation, suggesting that TKE transport may play a significant role in the TKE balance.

## References

[1] Kunze et al., *J. Phys. Ocean*, **42**:910-927, 2012.
[2] Shi et al., *J. Fluid Mech.*, **525** :193-214, 2005.
[3] Davis and Monismith, *J. Phys. Ocean*, **41**:2223-2241**,** 2011.