How Should Entrainment be Parameterized?

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Definitions:

We're talking about entrainment at the top of convective boundary layers without active moist convection.

Emphasis is on buoyancy flux, but some concepts apply to scalars, moisture, etc. as well.

$$A_R = -\frac{\overline{(w'\theta_v')_i}}{\overline{(w'\theta_v')_0}}$$

$A_R \neq 0.2$

(well, hardly ever)

What controls entrainment?

-- Impinging thermals
-- Inversion characteristics (strength and depth)
-- Shear across the inversion

The simple notion of an entrainment flux ratio only addresses the first of these.

Effects of inversion characteristics seem to be highly non-linear.

Issues

Simple parameterizations underestimate entrainment at the top of convective boundary layers.

The underestimation is worse when:
-- Convection is weaker
-- Inversion is weaker
-- Shear is stronger

Pure surface-driven free convection is rare (in a global sense, at least).

The mixed layer is often in free convection, but the entrainment zone rarely is.

A ratio can definitely not be applied to potential temperature, moisture, or any other quantity. Only virtual potential temperature can be used with any sort of ratio argument!

LES, theory, laboratory experiments, and observations are thought to disagree about how much entrainment occurs.

Observations show large entrainment (A~=0.4-0.5) even in cases that might be thought of as free-convective.

LES with finer resolution seem to show a bigger influence of shear.

Tank experiments were at fairly low Reynolds number, and may not represent entrainment structure correctly.

Theoretical expressions for influence of shear give very different results.

Entrainment dominates the morning transition and is at least 20% of the heat budget at all times.

The entrainment ratio has a very large magnitude during the early phases of transition.

Suggestions for improvement:

TKE schemes can handle weakly convective and transitional BLs without "switches," but fine vertical resolution may be necessary.

Entrainment flux can be parameterized as a function of surface flux and entrainment zone Richardson number.

$$R_{ibEZ} = \frac{g(\Delta\theta_v/\theta_{v0})d_{EZ}}{\Delta u_i^2}$$

Stratification by Entrainment Zone Richardson Number (from Angevine 1999)

	$R_{ibEZ}<0.5$	$0.5<R_{ibEZ}<1.5$	$R_{ibEZ}>1.5$
A_R	0.86 ±0.18 (0.92)	0.28±0.20 (0.35)	0.32±0.19 (0.20)
N, hours	28	29	34

(A few) References:

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