Evaluation of entrainment velocity from a Zero-order model and a First-order model with Large-eddy simulations and observations

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By definition the entrainment velocity estimates the engulfment within the atmospheric boundary layer (ABL) of air from the free troposphere. Several parameterizations are described in the literature to estimate this entrainment process. Measurements made by research aircraft and large eddy simulations based on different field campaigns enable us in a complementary way to compare two existing jump-models parameterization for various types of boundary layers.

Estimates of the entrainment velocity

$$w_e = \frac{\partial Z_i}{\partial t} - w_h$$

The boundary layer growth can be described as the sum of the entrainment velocity, w_e, and large-scale vertical motion at the ABL top, w_h. **The entrainment velocity quantifies the incorporation of air into the boundary layer from aloft. Its parameterization is important to quantify the exchanges of humidity or other scalars between the ABL and free troposphere.**

Two different approaches

Zero-order model (ZOM) | First-order model (FOM)

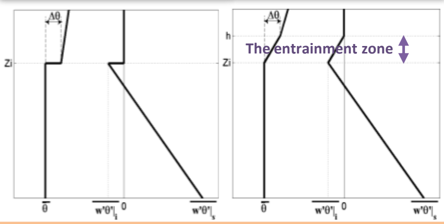


Figure 1: *Schematic profiles of the potential temperature and the buoyancy flux by (right) a ZOM and (left) a FOM approach.*

The difference between the two models mainly lays in the consideration of **the depth of the entrainment zone (δ)**: the ZOM jump model assumes a sharp discontinuity and the FOM considers a finite depth.

Parameterizations:

$$w_e \simeq -\frac{\overline{w'\theta'_v}|_i}{\Delta\theta_v}$$

ZOM

FOM

$$w_e \simeq -\frac{\overline{w'\theta'_v}|_i}{\Delta\theta_v} + \frac{\delta}{\Delta\theta_v}\frac{\partial\theta_v}{\partial t}$$

✓First study: Sahelian convective Boundary Layer

Zero-order model (ZOM) | First-order model (FOM)

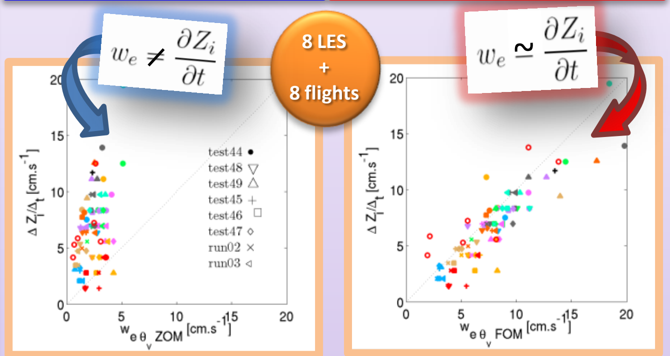


Figure 2: *Comparison between the growth of the ABL and the entrainment velocity calculated by using the virtual potential temperature based on (right) a ZOM and (left) a FOM. Each symbol represents a LES simulation at different time of the day and the red circles represent the aircraft observations made during the AMMA campaign at midday.*

Necessity, for the convective Sahelian Boundary Layer, to consider the first order model (FOM) to estimate the entrainment processes (Canut et al. 2012).

QUESTIONS: After this study of the sahelian convective boundary layer, we ask the following question: **is the FOM parameterization better for different types of atmospheric boundary layer? What is the behaviour of the entrainment velocity estimate with the FOM parameterization when the depth of the entrainment zone is thinner than observed in the sahelian region?**

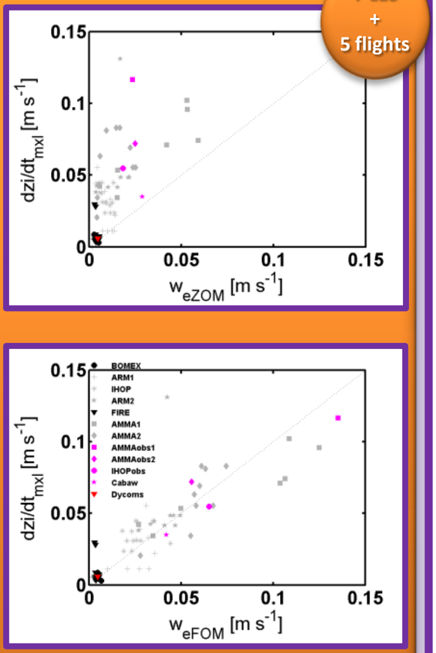
✓Follow-up study: approach & results

Aircraft Observations		δ
AMMA **West African monsoon**	• 5 June 2006: **dry convective** boundary layer (Canut et al. 2012) • 10 July 2006: **initiation of deep convection** (Couvreux et al. 2012)	**300 m**
IHOP **Great plains in North America**	• 30 May 2002: **dry convective** boundary layer (Gorska et al. 2008)	**200 m**
DYCOMS **Northeast Pacific Ocean**	• 10 July 2001: **nocturnal stratocumulus** regime over Pacific ocean (Stevens et al. 2003; Faloona et al. 2005)	**50 m**
CABAUW **Netherland**	• 27 July 2002: **convective boundary layer** (De Arellano et al. 2004)	**100 m**

Large Eddy Simulations (meso-NH, Meteo-France)		δ
AMMA	2 LES : same cases as for the aircraft observations (Canut et al. 2012; Couvreux et al. 2012).	**300 – 600 m**
IHOP	1 LES: a case evaluated by Couvreux et al. (2005).	**50 - 200 m**
ARM	2 LES: one case of **continental shallow convection** and one case of **continental deep convection** (Guichard et al. 2004)	**100 – 500 m**
FIRE	1 LES: a case of **marine stratocumulus** (Duynkerke et al. 2004; Sandu et al. 2008).	**≤ 50 m**
BOMEX **Barbados island**	1 LES: an idealized stationary case of **shallow cumulus convection over ocean** (Siebesma et al. 2003)	**constant 600 m**

Figure 3: *Comparison between the growth of the ABL and the entrainment velocity calculated by using the virtual or liquid potential temperature based on (top) a ZOM and (bottom) a FOM. Each grey symbol represents a LES run and each pink symbol represents an estimate from one observed case made during the different campaigns.*

7 LES + 5 flights



When we consider a ZOM model we find a large difference for 9 over 12 cases between w_e and boundary-layer growth estimated with the potential temperature profile. Only two LES simulations and one observation have a correct correlation. They correspond to the smallest estimates of entrainment rate close to 0.01 ms^{-1}. These three cases, FIRE BOMEX and DYCOMS, are characterised by quasi-stationary boundary layer during the time of the simulation, with a very sharp discontinuity between the PBL (FIRE and DYCOMS) and the free troposphere or very weak surface fluxes (BOMEX). For all other experiments, which show larger entrainment depth, the FOM jump model significantly improves the comparison between w_e and the depth of the ABL.

Observations and numerical simulations have been used to study different mixed layer model approximations to estimate the entrainment velocity, considering various types of boundary layers. The result of this investigation is that the FOM jump model is appropriate for all convective boundary layers while the ZOM model is only relevant for cases of sharp inversion, like those found in stratocumulus-topped boundary layers. The choice of the appropriate model is also important for the attempt of estimating entrainment fluxes of scalars themselves deduced from the entrainment velocities that are calculated from another scalar.

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Boston (USA) 9-13 July 2012 -20th Symposium Boundary Layer and Turbulence-