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Atmospheric Chemistry and Physics
Discussions
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Interactive comment on "Basic convective element: bubble or plume? A historical review" *by* J.-I. Yano

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Reply to the Referee 1:

Summary:

The present referee well summarizes the basic spirit of the present review: a short story on simplified models of convective elements in application to formulation of mass–flux parameterization of moist convection. At the same time, the referee thinks the review is "too compact" to be useful for many readers.

In order to amend this shortcoming, the manuscript will be extensively expanded in revision. Especially, the concepts of "plume" and "entrainment" are introduced in the

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beginning of the revised Sect. 3 in the following manner:

“The idea of plume can most vividly be seen by a water–tank experiment originally performed by Morton et al. (1956). They placed a constant buoyant–mass source at a bottom of a water tank (with dyed alcohol as a marker), and examined the resulting motion. The result was a plume gradually growing upwards, which may be considered steady after a substantial time (Fig. 1).

In general, the plume refers to convective flows resulting from a continuous source of buoyancy. They tend to be quasi–steady in contrast to the inherently transient nature of bubbles.

In case of the original experiment by Morton et al. (1956), the plume grows upwards by sucking the surrounding water with a constant rate, and as a result it also increases its radius with a constant rate with height. Such a ‘sucking’ process is commonly referred as *entrainment*. A particular plume solution obtained by them is called *entraining plume*, because it is driven under a constant fractional entrainment rate (cf., Eq. 3 below).

Importantly, the obtained laboratory result is consistent with a theoretical result predicted by Batchelor (1954) using a similarity theory. Here, a similarity theory seeks a form of a solution of a given system that is determined solely by examining the dimensionality of the variables and the parameters in concern."

The notion of detrainment will be introduced in discussing the concept of “starting plume" towards the end of this section.

Many of the responses to the Major Comments below also constitute proposed text segments for the revised manuscript.

Major Comments:

Abstract:

The adjective “moist" will be added to convection throughout the abstract in order to make it clear that the present review is dealing with “moist atmospheric convection".

2. Bubble:

Sect. 2 will be modified as follows:

“Atmospheric moist convection may be considered consisting of a series of warm bubbles released from a surface level. A cauliflower–like structure seen in clouds may be considered a visualization of an ensemble of bubbles. Existence of these warm bubbles (or thermals as called by them) was known for glider pilots for years. By riding over such a thermal, they could substantially boost their gliders.

A good laboratory analogue could be a series of air bubbles released from a bottom of a water tank. Such an experiment is originally performed by Davies and Taylor (1950) from fluid–mechanical interests. Their experiment, in turn, induced interests of an Imperial College group for studying atmospheric moist convection as an ensemble of bubbles.

A major difference from the atmospheric bubbles to air bubbles used in the experiments by Davies and Taylor (1950) is that the former gradually mix with the environment as they ascent, whereas the latter are immiscible. In order to introduce such mixing tendency, the salt water was taken, instead of air, as source of bubbles within a water tank (Scorer and Ronne 1956, Scorer 1957, Woodward 1959).

In their experiments, a hemispheric copper cup was filled with dense salt water, which was turned over quickly by hand into a water tank in order to generate a bubble, but in an upside-down manner. The focus of the study was time evolution of a single bubble. Thus only a single bubble is released at one time in all the experiments reported.

An example of such an experiment is shown in Fig. 2: highly transient nature of the bubble dynamics may be noted.

Detailed measurements of the velocity around a bubble (Woodward 1959) revealed that a doughnut–shaped vortex ring was formed inside the bubble (Fig. 3).

. . .

Levine (1959) was one of the firsts to consider an idealized bubble model for atmospheric convection in self-contained manner. More specifically, he considered a vertical motion of an isolated bubble in an infinite domain under a quiescent state at infinity. Under this condition, the most remarkable conclusion is that the dynamic pressure trivially vanishes at the center of the bubble. Thus no effect of the dynamic pressure is found in the total vertical momentum equation.

More precisely, Levine (1959) considered a spherical bubble. Hill's vortex solution (Lamb 1932) is adopted inside the bubble in order to describe a vortex ring structure. The flow outside the spherical bubble is constructed by an irrotational flow assuming a continuity of the tangential velocity at the surface. This inviscid–flow solution is explicitly exploited by Levine in order to derive a drag force acting on the bubble. In order to obtain a drag force, it is assumed that a bottom part of the bubble is open to outside air, where a drag force is inserted.

Turner (1964) expanded Levine's work to the case when the bubble increased in size with time, and examined more detailed structure of flows inside the bubble.

. . .

The drag force derived under an elaborated effort by Levine (1959) also becomes rather irrelevant in applying his formulation to the plume dynamics. In the latter case, it can easily be shown that the drag coefficient simply be equal to the fractional entrainment rate of a given plume."

3. Plume:

The following sentence is moved to the end of Sect. 3 in revision: "In spite of the fact that the original entraining plume model has been much criticized, the notions of the entrainment and the detrainment are hardly given up in current convection parameteri-

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zations (cf., de Rooy 2013).”

The “completely new model" in quotation of Morton (1957) has rather been exaggerated. A key point here is that by performing an analysis under a relatively limited setting with a constant potential–temperature profile and no density stratification, he found a tendency of plume to grow to infinity both in size and height when a bottom plume size is above a critical value: See his Fig. 6 and compare it with the case below this critical value shown in his Fig. 5. Unfortunately, no careful followup study exists to investigate how this explosive tendency of plume under water condensation can be tamed under a presence of stratifications. In other words, an emergence of a new theory is still awaited.

Sects. 4 and 5:

Stommel did not examine whether convection observed by him was maintained by a continuing buoyancy source as a condition for constituting a “plume". Thus, a link of his “entrainment" to entrainment observed in water tank is not straight. Here, we also emphasize that by “entrainment" Stommel merely referred to a lateral mixing of the convective cloudy air with an immediate surrounding even without specifying how to define this “immediate surrounding".

A schematic (Fig. 4 based on Raymond 1993) that summarizes three different theories for the atmospheric convective entrainment–detrainment processes will be added in Sect. 5 in revision.

Morton (1997b): The notion of the “jet" will be introduced here in revision.

6. Buoyancy Parameter

Sànchez et al. (1989) will be added in revision as a reference addressing issues of initial momentum in thermal experiments.

The initial velocity of the plume: the discussion here simply points out that non–convective momentum source in the atmospheric boundary layer is small in the nondi-

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mensional unit. I would suggest to the reviewer to substitute the values she or he would think more appropriate. My best expectation is that we will still get the buoyancy parameter substantially smaller than unity.

One may argue that at the cloud base, we may have larger values such as $d \sim 10^3$ m and $w \sim 1$ m/s. However this still merely gives the buoyancy parameter, $B \sim 0.1$.

Minor Remarks:

3338–10: parapetization → parameterization

3342–4: plume theories were steady with time → plume theories were developed under a steady framework

References:

Lamb, H., 1932: Hydrodynamics, 6th Ed., Cambridge University Press, 738pp.

Raymond, D. J., 1993: Observational constraints on cumulus parameterizations. *The Representation of Cumulus Convection in Numerical Models. Meteor. Mono.,* No. 46, Amer. Meteor. Soc., 17–28.

Sànchez, O., D. J. Raymond, L. Libersky, A. G. Petschek, 1989: The development of thermals from rest. J. Atmos. Sci., 46, 2280–2292.

Interactive comment on Atmos. Chem. Phys. Discuss., 14, 3337, 2014.

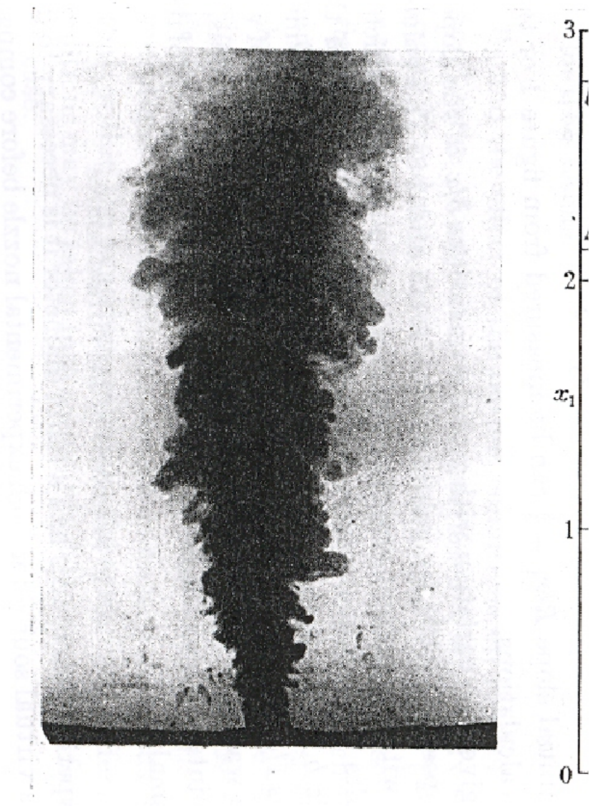

Fig. 1. The entraining plume generated by an original water–tank experiment by Morton et al. (1956).

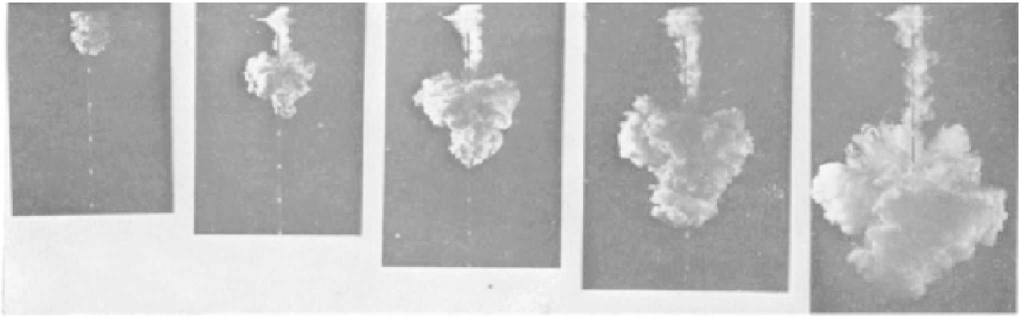

Fig. 2. Example of the bubble experiment: Photos of a sequence from left to right [Reproduced from Scorer 1957]

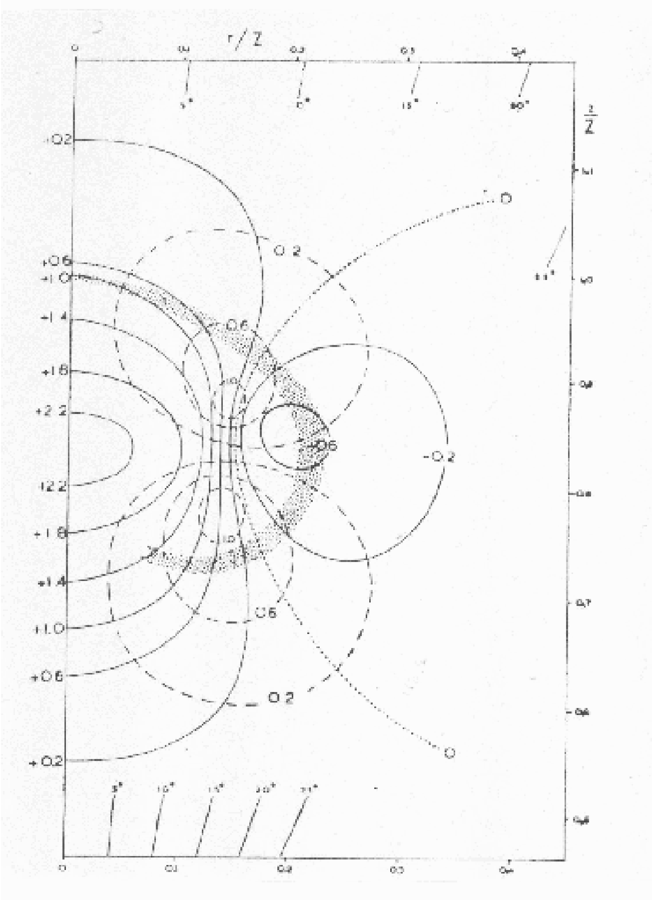

Fig. 3. The distribution of velocity in and around an isolated thermal. Only the right–hand side of the thermal is shown. The outline of the buoyant fluid is shaded. [Reproduced from Fig. 2 of Woodward 1959]

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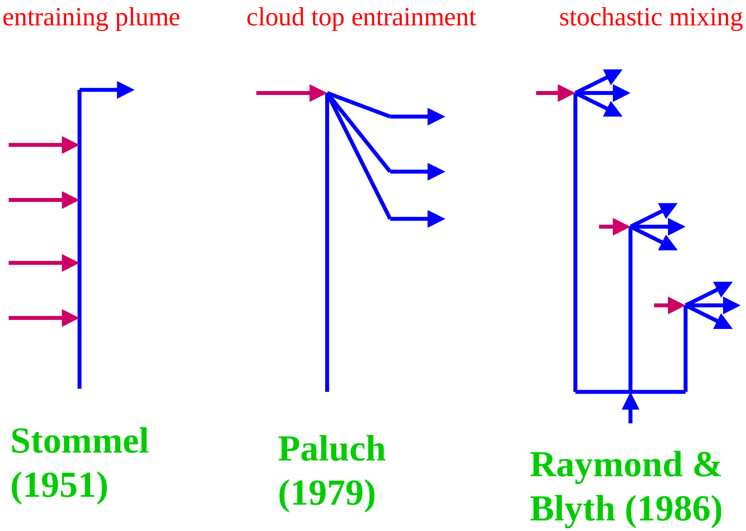

Fig. 4. A schematic summary of the three different theories for the atmospheric convective entrainment–detrainment processes. [Based on Raymond 1993]