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A core-cloak representation of convection

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Introduction

Conventional convection schemes usually use a 'top-hat' assumption or 'segmentally constant approximation', which neglects the variability within the plume. We show the vertical transport of different variables is substantially under estimated by up to 30%-50% for both shallow and deep convection using this assumption. Better representations of entrainment, detrainment and cloud processes may require a good estimation of sub-plume variability so that the updraft dynamics could be well parameterized.

Sub-plume variability representation

Down-gradient method:

- Lappen and Randall (2001) parameterized the sub-plume fluxes as a down-gradient effect. This assumes that these sub-plume fluxes result from small scale eddies, which may not be the case.

Joint-PDF method:

- Assumed joint PDF of vertical motion and transported variables could be used to recover the sub-plume variability (Larson et al. 2002). But it introduces high-order moments that need to be estimated through high-order closures.

Can we have a simple but physically plausible method ?

- **Yes!**
- **Need to first examine how the sub-plume variability is controlled within the plumes.**

Dataset – Large eddy simulations

- **BOMEX:** Unified Model, 100 m resolution, 25.6 km X 25.6 km, similar configurations as Siebesma et al. (2003);
- **Radiative-Convective Equilibrium (RCE)** simulations with and without shear are also analysed but not shown here.

Drafts Definition

Drafts are defined based on the distribution of vertical velocity (top 5%-2%-1%) across the domain at each vertical level and at each time. Take three-partition for example:

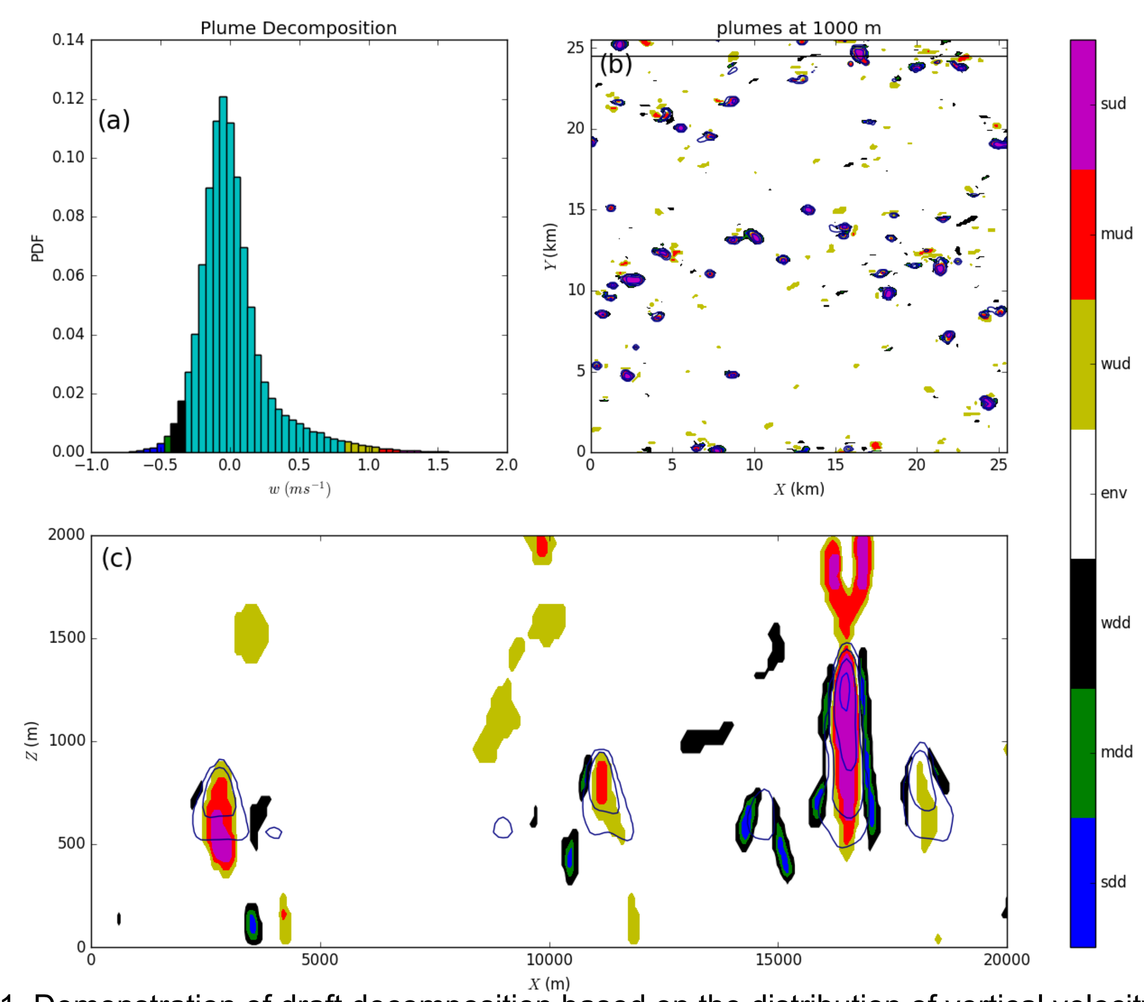

Fig. 1. Demonstration of draft decomposition based on the distribution of vertical velocity. (a). Probability density function of vertical velocity near cloud base (520 m). (b) Horizontal distribution of different types of drafts at 1000 m (shading) and cloud liquid water. The horizontal line represents the position (y=24.5 km) of vertical cross section for (c). (c) Vertical cross section of identified drafts (shading) and cloud liquid water (contour lines). In the colorbar, sud, mud, wud, wdd, mdd, sdd and env represent 'strong updraft', 'medium updraft', 'weak updraft', 'weak downdraft', 'medium downdraft', 'strong downdraft' and 'environment', respectively.

A core-cloak representation

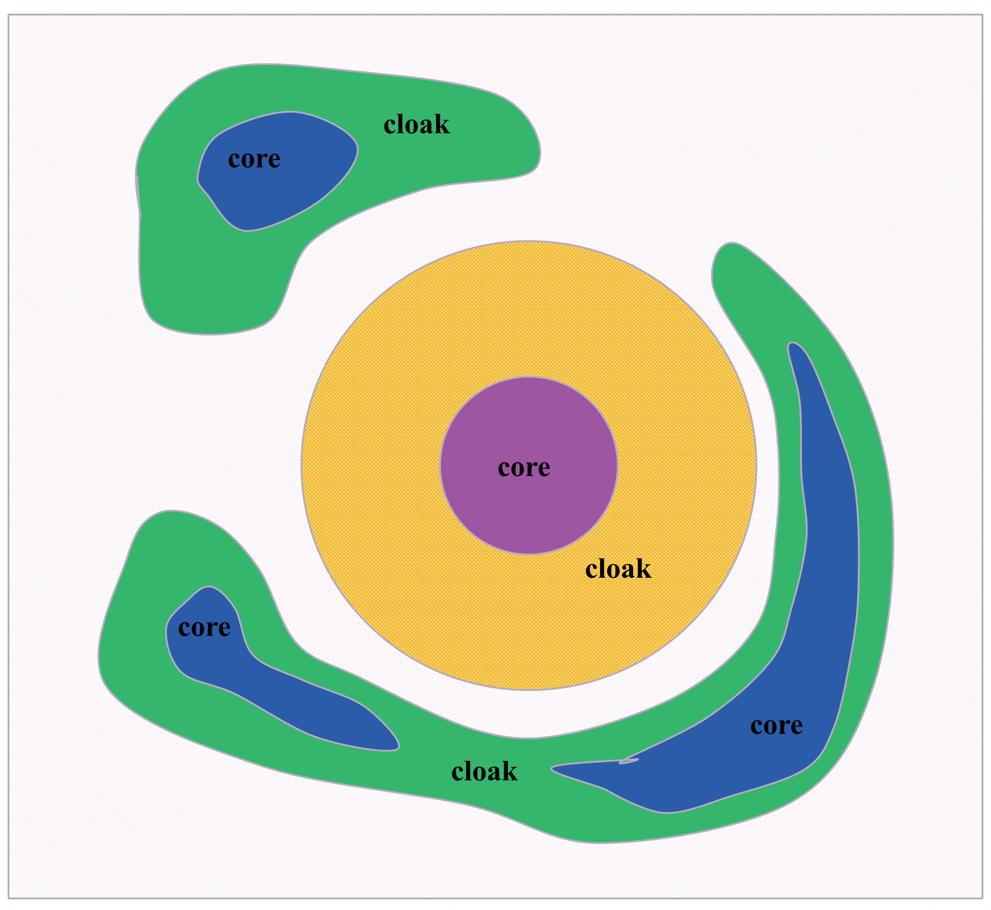

Fig. 2. The schematic diagram of our core-cloak representation of convection. Both downdrafts and updrafts are represented as a combination of core (strong draft) at centre and cloak (weak draft) around the centre.

Decomposition of vertical flux

Area fraction of draft *i*: a_i

Variable within the draft *i*: ϕ_i

Average over the draft *i*: $\overline{\phi_i}$

Domain averaged mean: $<\phi> = \sum_i a_i \overline{\phi_i}$

Perturbation with respect to draft average: $\phi_i' = \phi_i - \overline{\phi_i}$

Difference between draft average and domain average: $\overline{\phi_i}^* = \overline{\phi_i} - <\phi>$

$$<w^*\phi^*> = \sum_i a_i(\overline{w_i^*}\,\overline{\phi_i^*} + \overline{w_i'\phi_i'})$$

Mass-flux contribution ① **Sub-plume variability** ②

Results

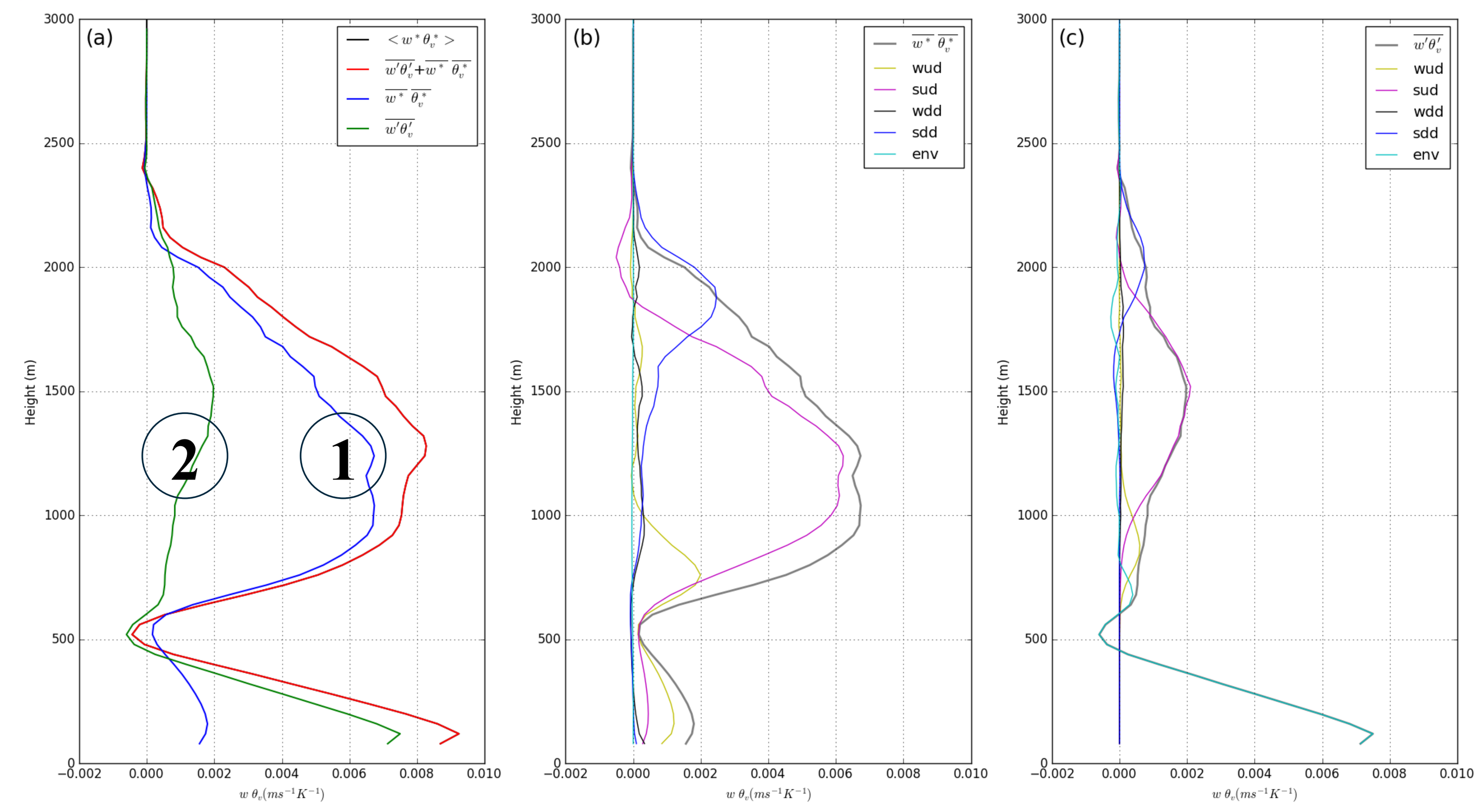

Fig. 3. Vertical profile of time- (last 1 h) and domain-averaged buoyancy flux and its different components in BOMEX simulation: (a). Total buoyancy flux (red solid lines), mass-flux contribution (blue line) and sub-plume variability (green line); (b). Mass-flux contribution (grey line) of total buoyancy flux and its components from different types of drafts; (c). Contribution from sub-plume variability (grey line) to the total buoyancy flux and its components from different types of drafts.

- The mass-flux contribution in a core-cloak representation could recover most of the total vertical flux within the cloud layer
- Weak updraft dominates the vertical transport in the lower part of the cloud
- Strong updraft dominates the vertical transport across most of the cloud layer
- Strong downdraft has non-negligible contribution to the total vertical flux at cloud top
- The vertical transport within sub-cloud layer is controlled by less extreme (top 40%-30%) updrafts
- A large part of sub-plume flux is contributed by strong drafts rather than small eddies

Summary

1. Sub-plume variability is not only contributed by small scale eddies but also controlled by non-local strong drafts.
2. A core-cloak representation of both updrafts and downdrafts captures most of the vertical fluxes and has the potential for implication in the parameterization. Future work will focus on the representation of exchanges between core, cloak and the environment.
3. Downdrafts near cloud top should be considered properly.
4. Consistent results have also been obtained from the large eddy simulation of RCE case.

References

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