Parameterizing the sub-grid vertical fluxes with composited distributions of variables within the cloud

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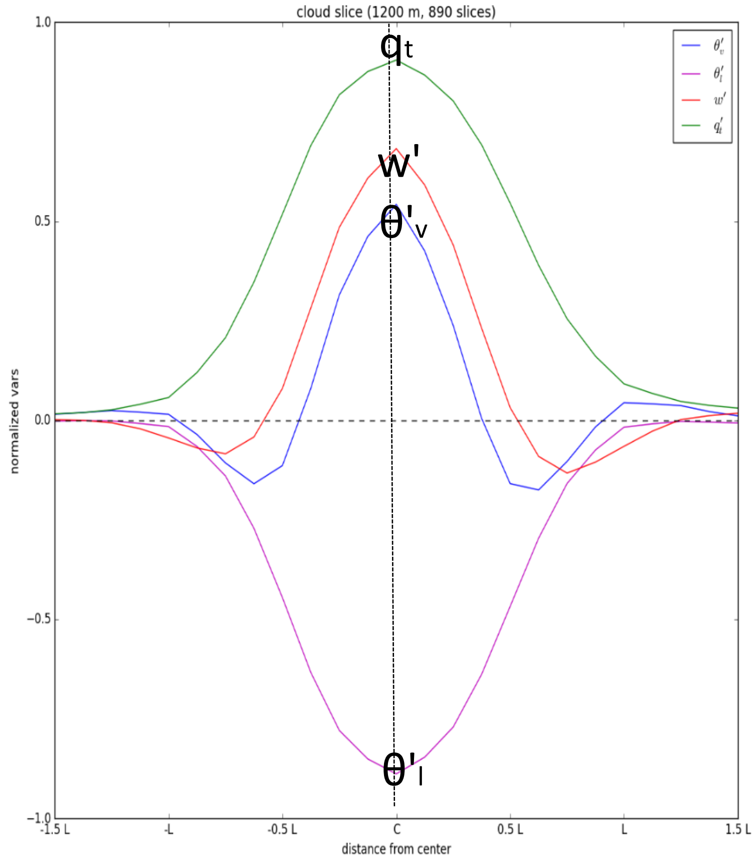
BOMEX (@100m)

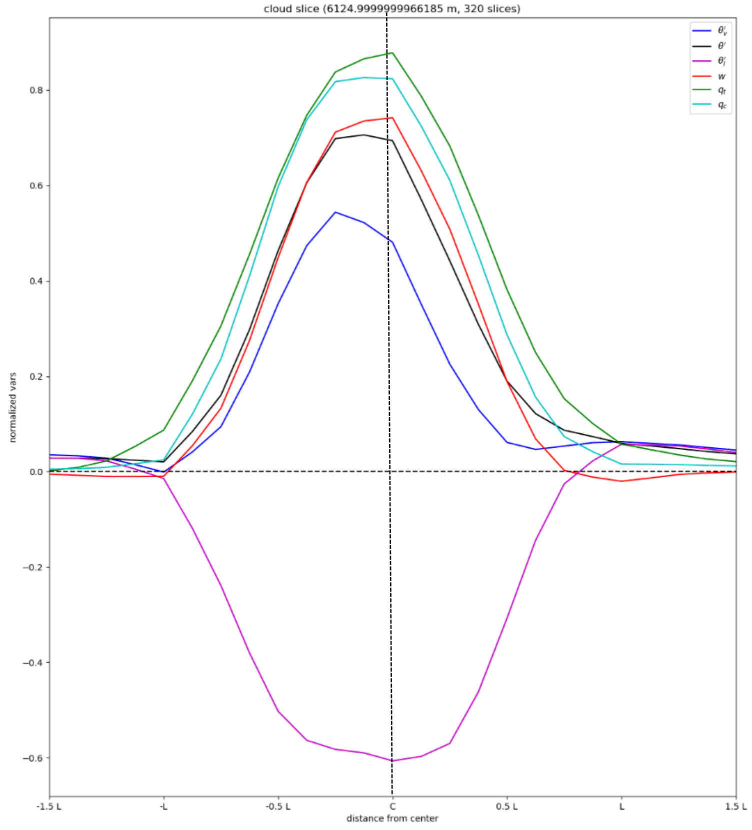
$q_l > 1e\text{-}5$



1200 m

RCE (@400m)

$q_l + q_i > 1e\text{-}4$



6100 m

To some extent, distributions of different variables agree better in deep clouds because the shell structure is not obvious.

Several points to clarify

- Can the total fluxes across the domain be approximated by the vertical fluxes within the cloud objects?

- Can our parameterization reproduce the vertical fluxes within the cloud objects?

- How to simplify the parameterization of vertical fluxes with this approach?

- Data:
- LES simulation of BOMEX case with UM (@100m)
- LES simulation of RCE case with MONC (@400m, -1.5K forcing)

Flux estimation

$$\langle w^* f^* \rangle = \sum_i \frac{\iint_{S_i} w^* f^* \, dS_i}{S_{total}} = \sum_i \frac{\int_0^{2p}\int_0^{r_i} w^*_{mi} f^*_{mi} f_w(\frac{r}{r_i}) f_f(\frac{r}{r_i}) r \, dr \, dj}{S_{total}}$$

- Assumptions:
- 1. The cloud objects all have round shapes
- 2. The cloud object has enough in-cloud points so that the composited distribution is robust

- Disadvantage:
- Information (etc. maximum perturbations, normalized distribution) of each cloud object is necessary

Shallow cumulus clouds

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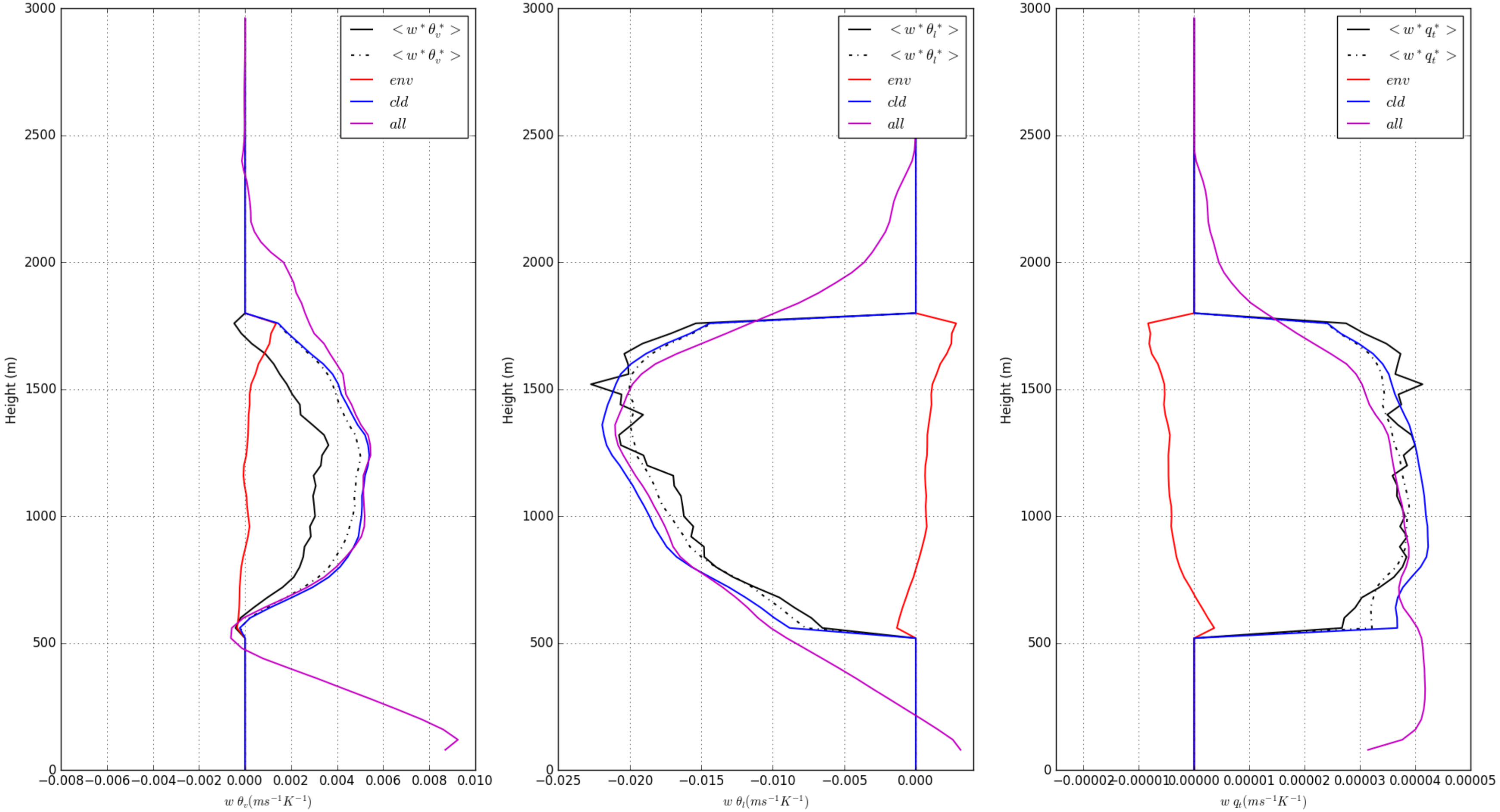
Red line: total vertical flux
Blue line: vertical flux within cloud
Magenta line: vertical flux in the environment
Dash-dotted line: vertical flux within cloud objects
Black line: estimated flux with composited distribution



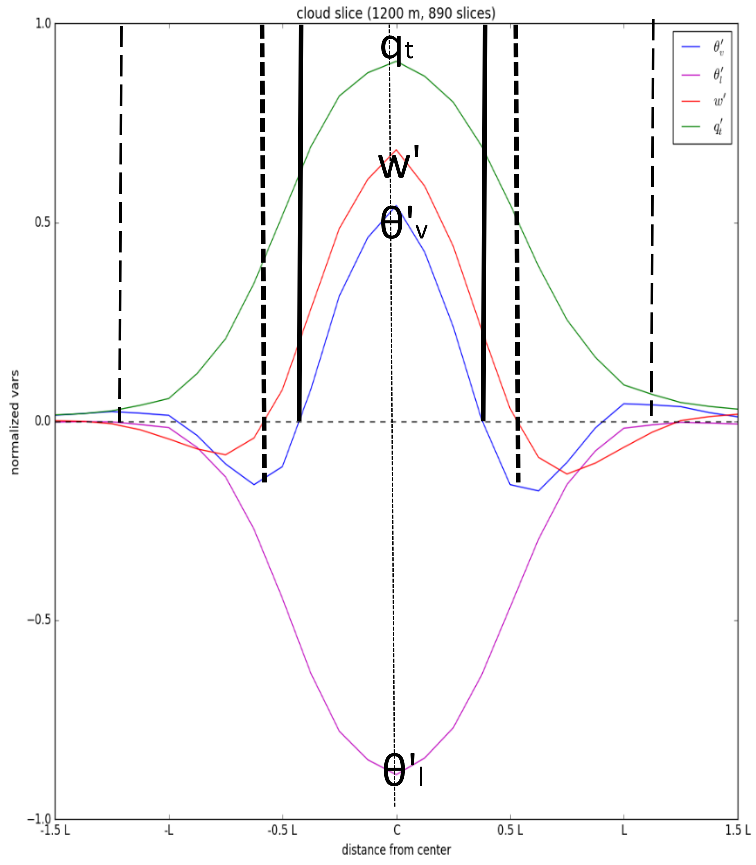
The total flux of cloud objects (dash-dotted line) that are involved in the calculation is close to the total flux of all the cloudy points (blue line).

The total flux of all the cloudy points (blue line) is also close to the total flux across the whole domain (purple line).

Estimation of theta_l and qt fluxes (black line) matches well with the accurate flux (dash-dotted line)

Estimated buoyancy flux is about 30% less than the accurate buoyancy flux

Contributions from cloud boundary



1200 m

$$w^* f^* = w_+^* f_+^* + w_+^* f_-^* + w_-^* f_+^* + w_-^* f_-^*$$

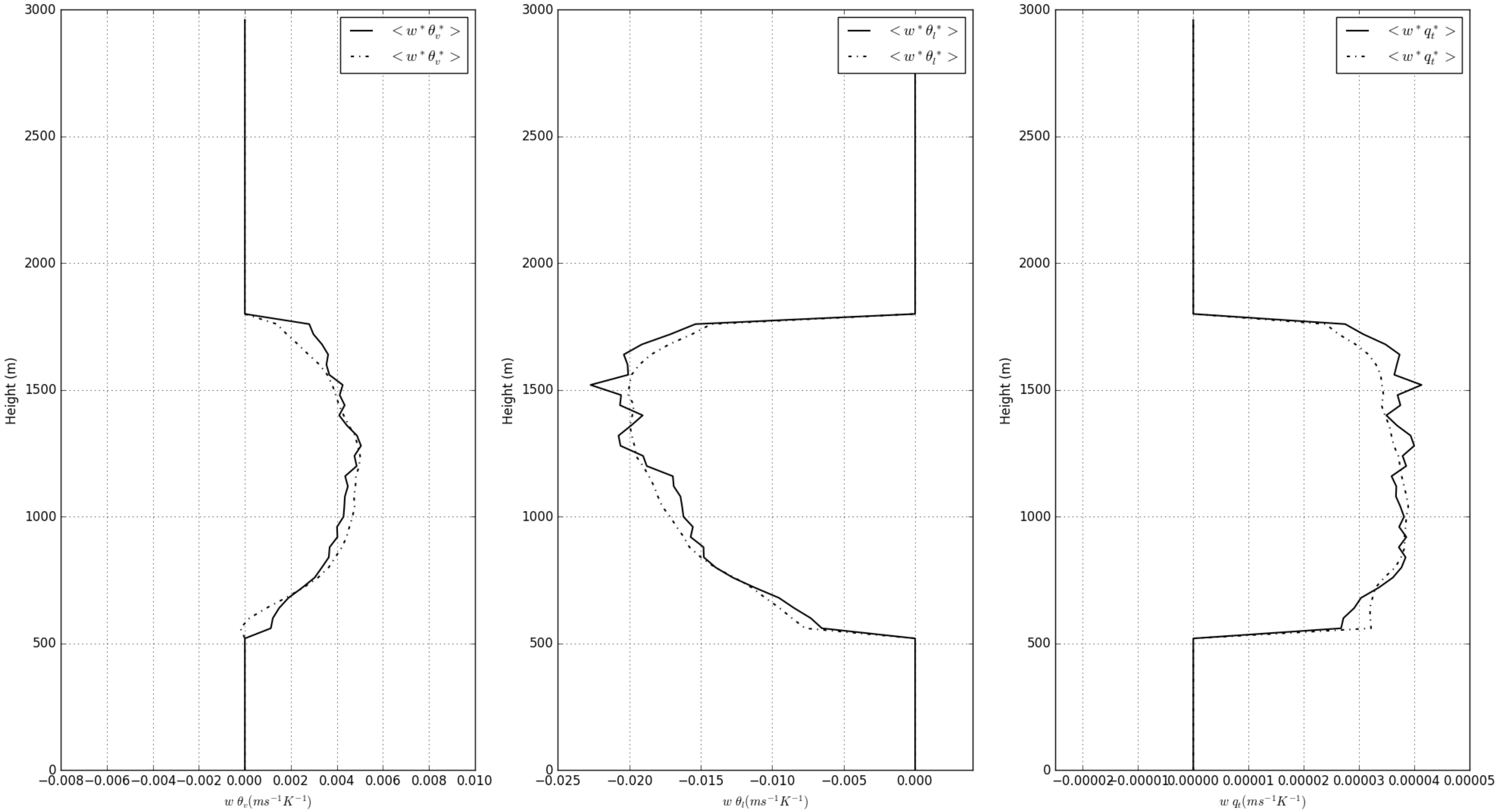
(+) (-) (-) (+)

Vertical flux of a cloud object= flux (buoyant updraft) + flux (negative buoyant updraft) + flux(shell) + flux (buoyant downdraft)

A small shift of the distribution of vertical velocity relative to that of buoyancy is inevitable due to the assumption of round shape.

This small shift will result in large error due to the transition zone and the shell structure near cloud boundaries.

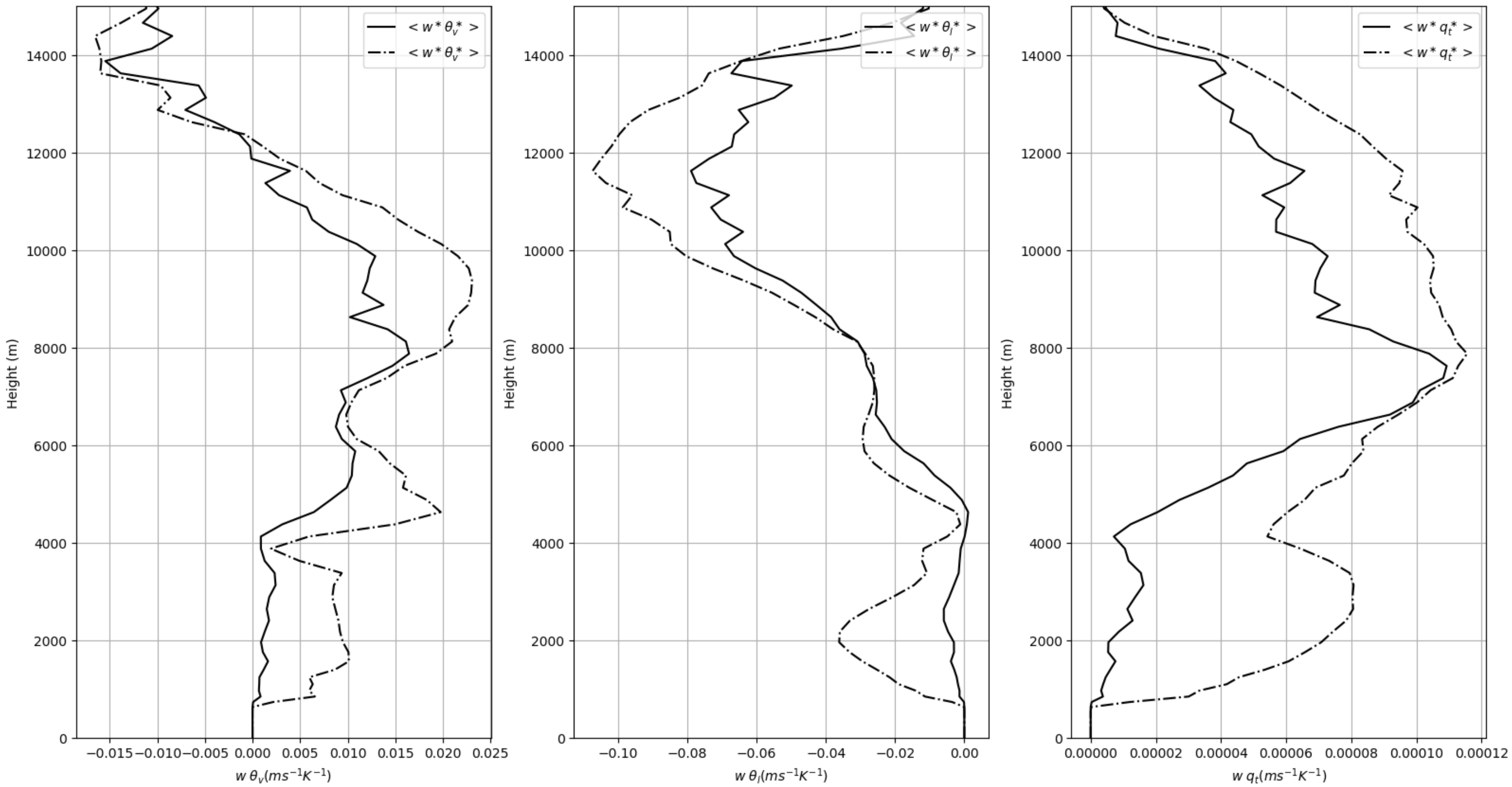
Correction



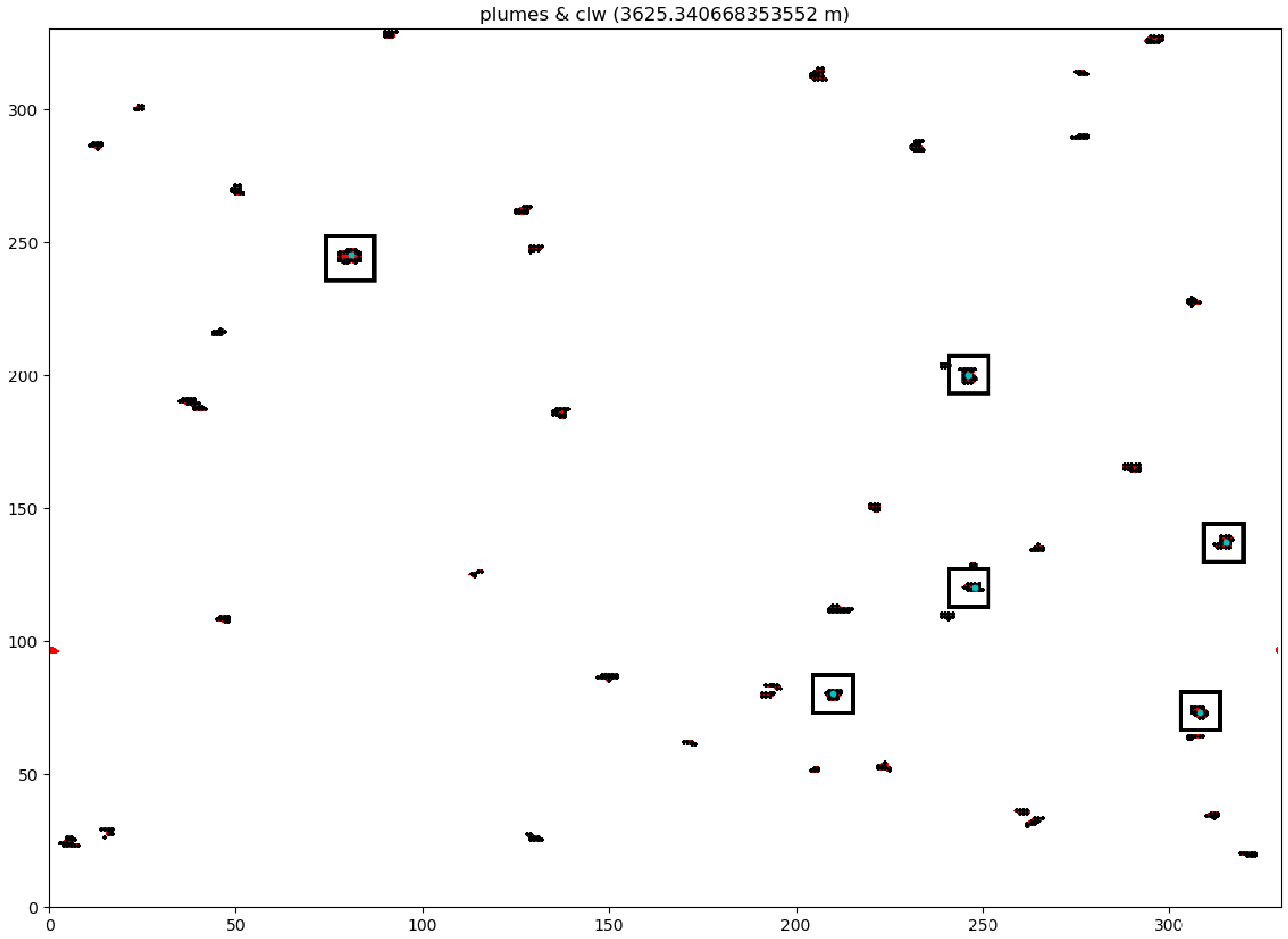
Correcting method: using the same normalized distribution of vertical velocity and buoyancy.

This correction is not physically consistent, but partly compensate the errors due to the possible shift of vertical velocity distribution relative to the buoyancy

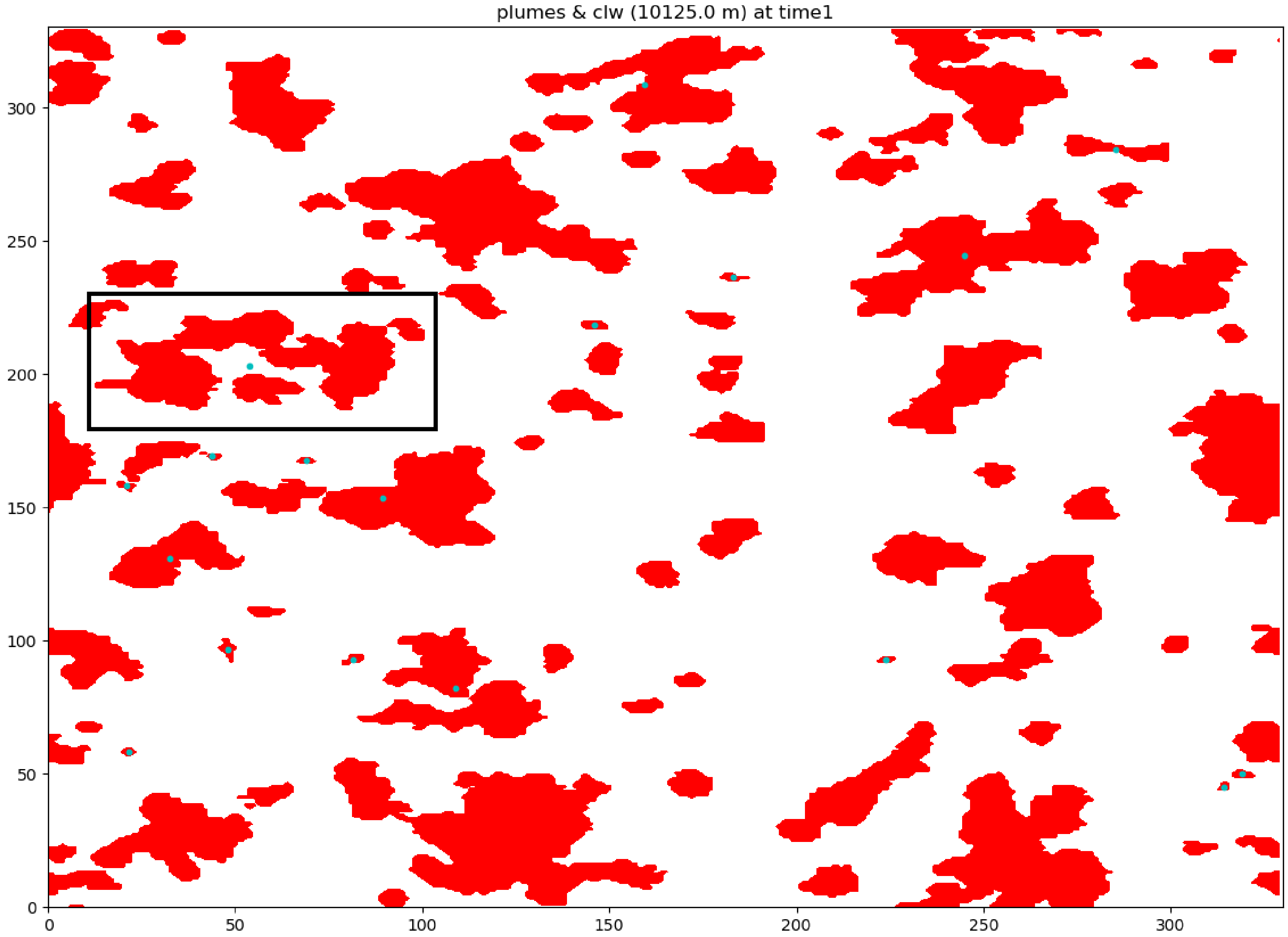
Deep clouds



Significant underestimation at both low and high levels.

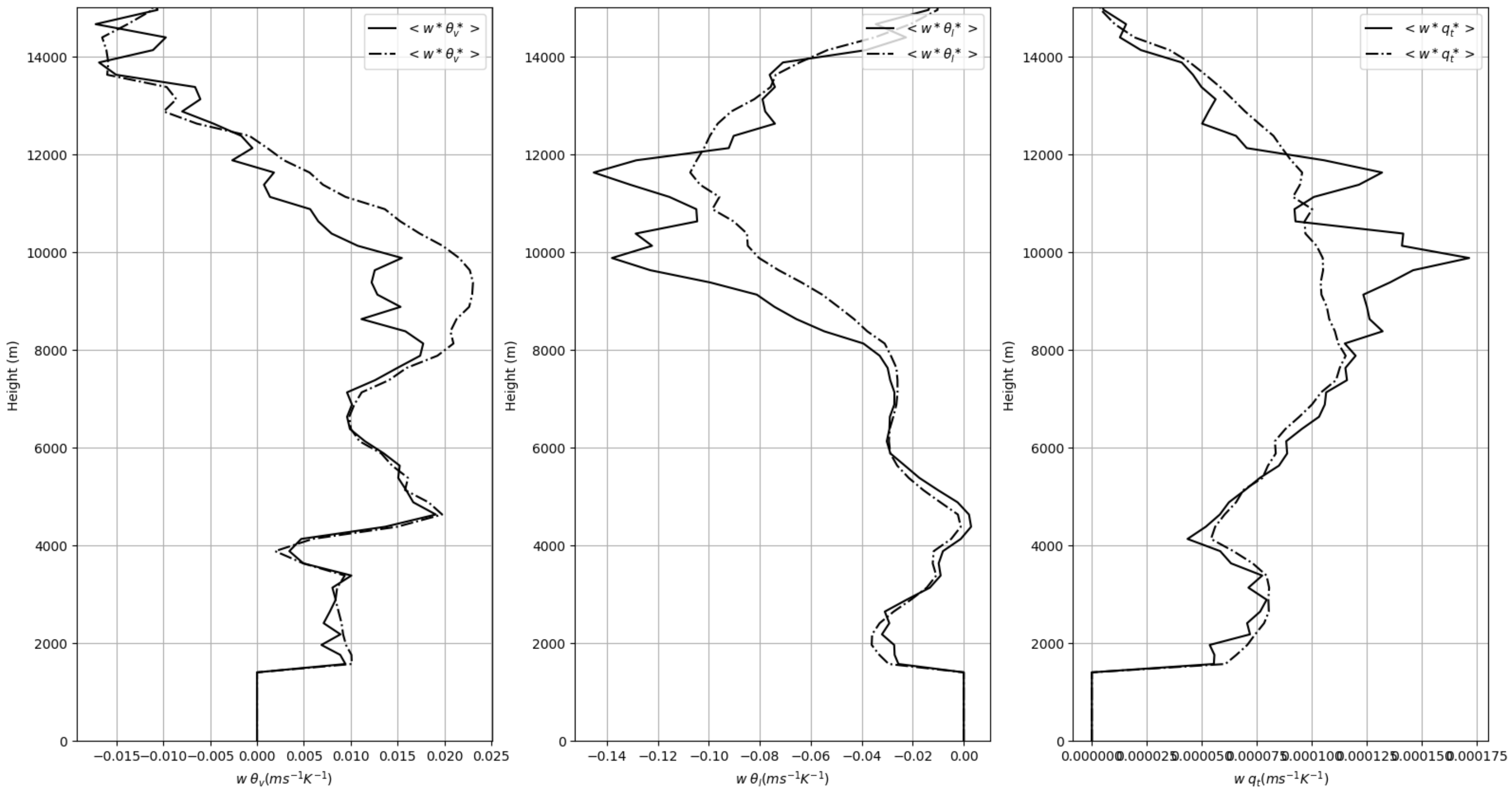


Many cloud objects do not have enough in-cloud points



Complicated shapes for some anvil clouds

At each time and each level, for each object, use individual maximums. If the cloud object has a distribution, then use its own distribution. Otherwise, use the averaged distribution of cloud objects that are large and have regular shapes.



Deep strong updraft cloud

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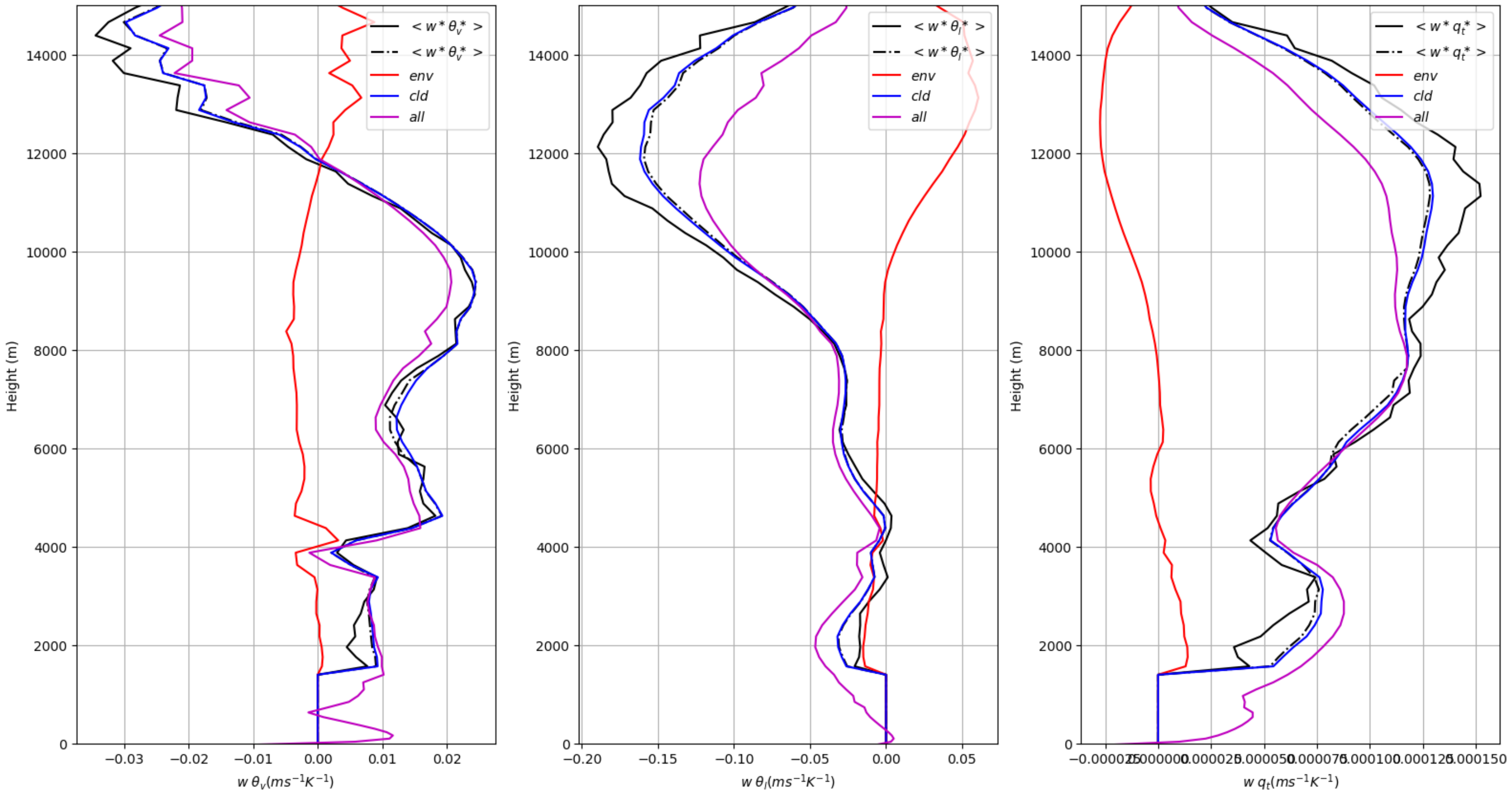
RCE



Using cloud water and w (>1 m/s) to define cloud object

The estimated fluxes are close to the total fluxes within the cloud objects, especially for buoyancy flux. But the total fluxes for theta_l and qt within the cloud objects clearly deviate from the total fluxes across the domain at upper levels. This is because the neglected anvil clouds are also important for vertical transport of water.

Simplification

Simplification	Formulations	Work or not
Averaged distribution for all cloud objects	$\sum_i \frac{\int_0^{2\pi}\int_0^{r_i} w^*_{mi} f^*_{mi} \overline{f_w(\frac{\rho}{r_i})}\,\overline{f_f(\frac{\rho}{r_i})}\rho\, d\rho\, d\varphi}{S_{total}}$	√
Averaged maximum perturbation	$\sum_i \frac{\int_0^{2\pi}\int_0^{r_i} \overline{w^*_{m}}\,\overline{f^*_{m}}\,\overline{f_w(\frac{\rho}{r_i})}\,\overline{f_f(\frac{\rho}{r_i})}\rho\, d\rho\, d\varphi}{S_{total}}$	× (underestimation)
Spectral calculation	$\frac{\int_0^{\infty} N(r_c) \int_0^{2\pi}\int_0^{r_c} \overline{w^*_{mc}}\,\overline{f^*_{mc}}\,\overline{f_w(\frac{\rho}{r_c})}\,\overline{f_f(\frac{\rho}{r_c})}\rho\, d\rho\, d\varphi\, dr_c}{S_{total}}$	√ for water fluxes × for buoyancy flux

- Need careful treatment of maximum perturbations
- Instead of calculating explicitly, maximum perturbations could be randomly drawn from its conditional probability distribution at given cloud sizes.

$$P(f^*_m \mid r_c)$$

Summary

- **Can the total fluxes across the domain be approximated by the vertical fluxes within the cloud objects?**
- Yes, if the cloud objects include the major part of updrafts and downdrafts

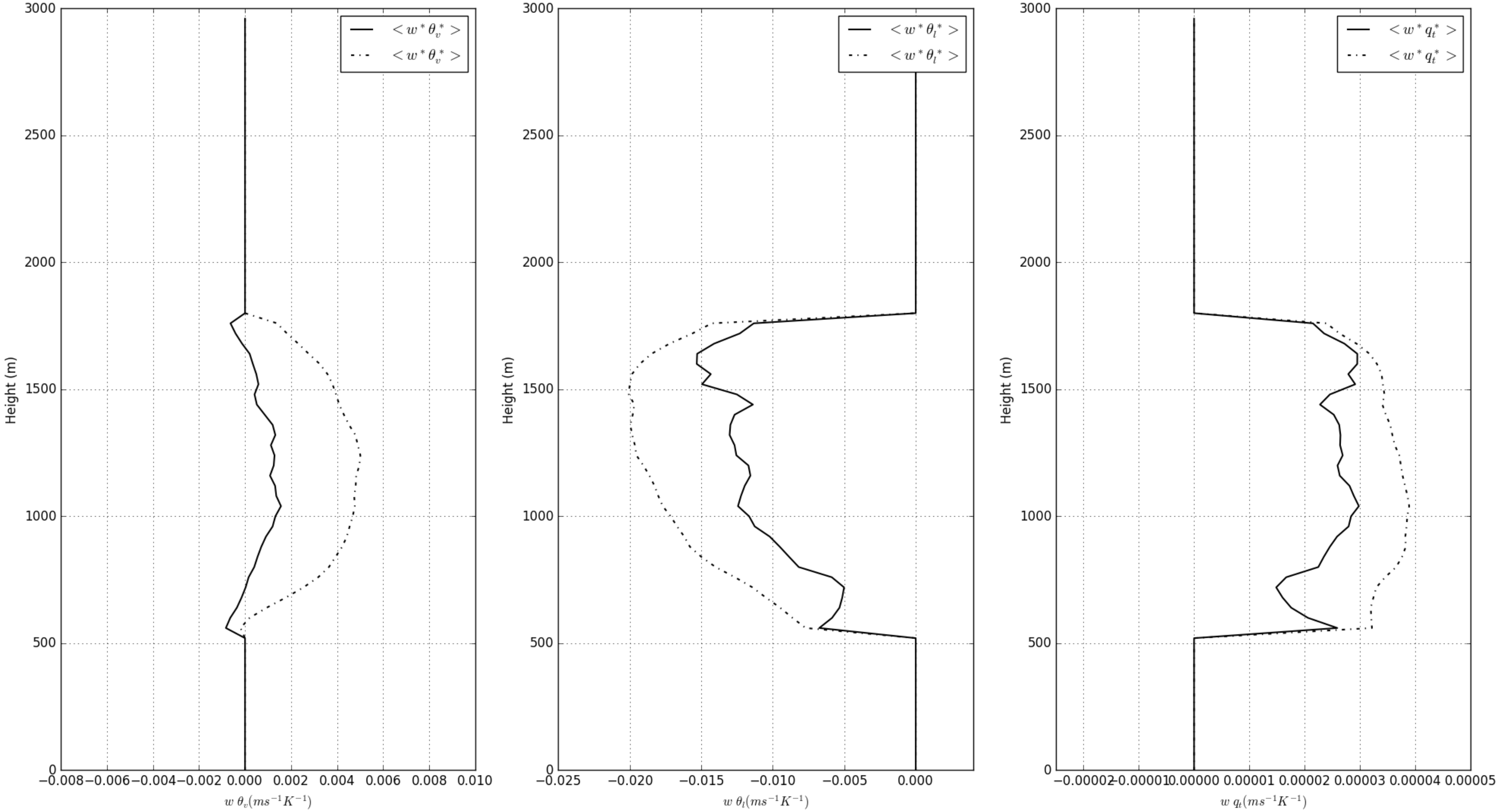
- **Can our parameterization reproduce the vertical fluxes within the cloud objects?**
- Estimation using composited distribution could well capture the vertical fluxes in the cloud layer, both in magnitude and the vertical profiles.

- For shallow cumulus clouds, the transition zone and the cloud shell structure are important for the estimation of vertical buoyancy flux.

- For deep clouds, this method may have some errors due to the complex shapes of anvil clouds at high levels. This could be solved by just parameterizing the strong updraft part but may need a fallback structure to account for the vertical water transport in anvil clouds.

- **How to simplify the parameterization of vertical fluxes with this approach?**
- Simplification of this parameterization is possible (averaged internal distributions could be used) but need some knowledge maximum perturbations.

Simplification

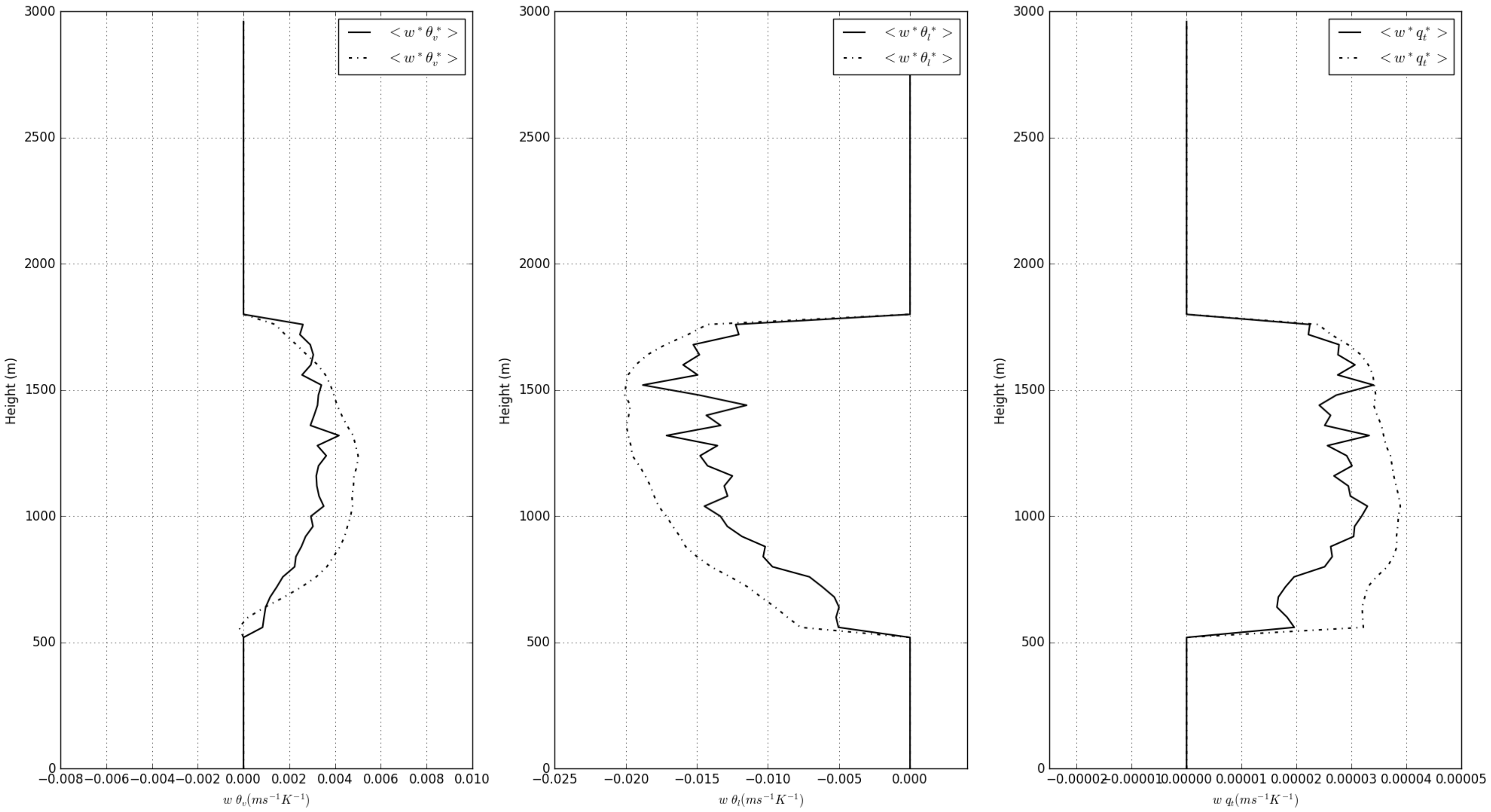


In practice, it's not possible to get the maximum perturbation and distribution for each cloud object.

It's better to use the averaged distribution and the averaged maximum perturbations to simplify the parameterization.

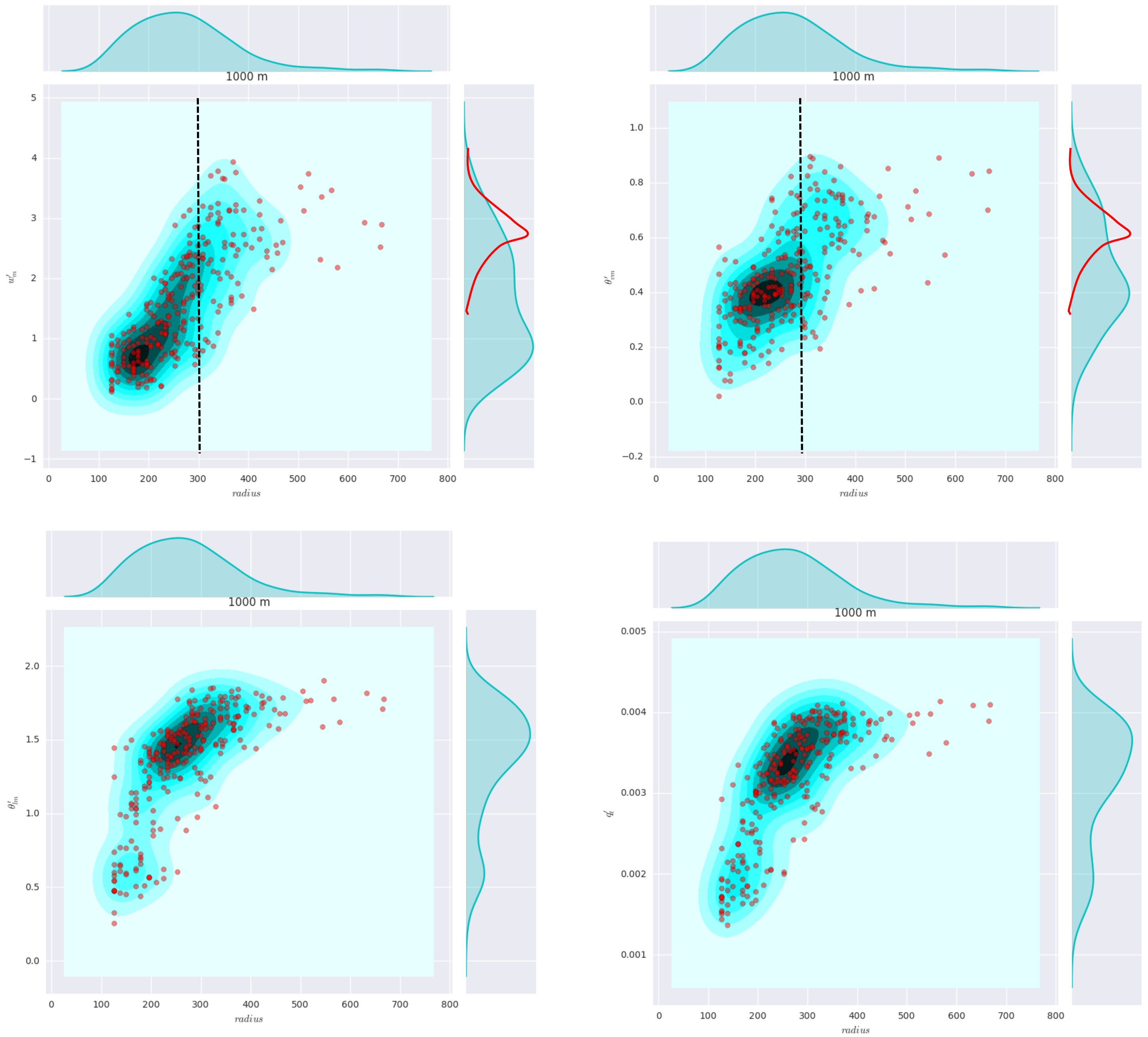
Maximum perturbations have dependency on cloud size. Averaged maximum perturbations will underestimate the vertical fluxes.

Can we randomly draw the maximum perturbations from its distribution?



Also underestimate the vertical fluxes. What’s wrong?

Joint PDFs of max perturbations and object size (1000 m)



w_m'

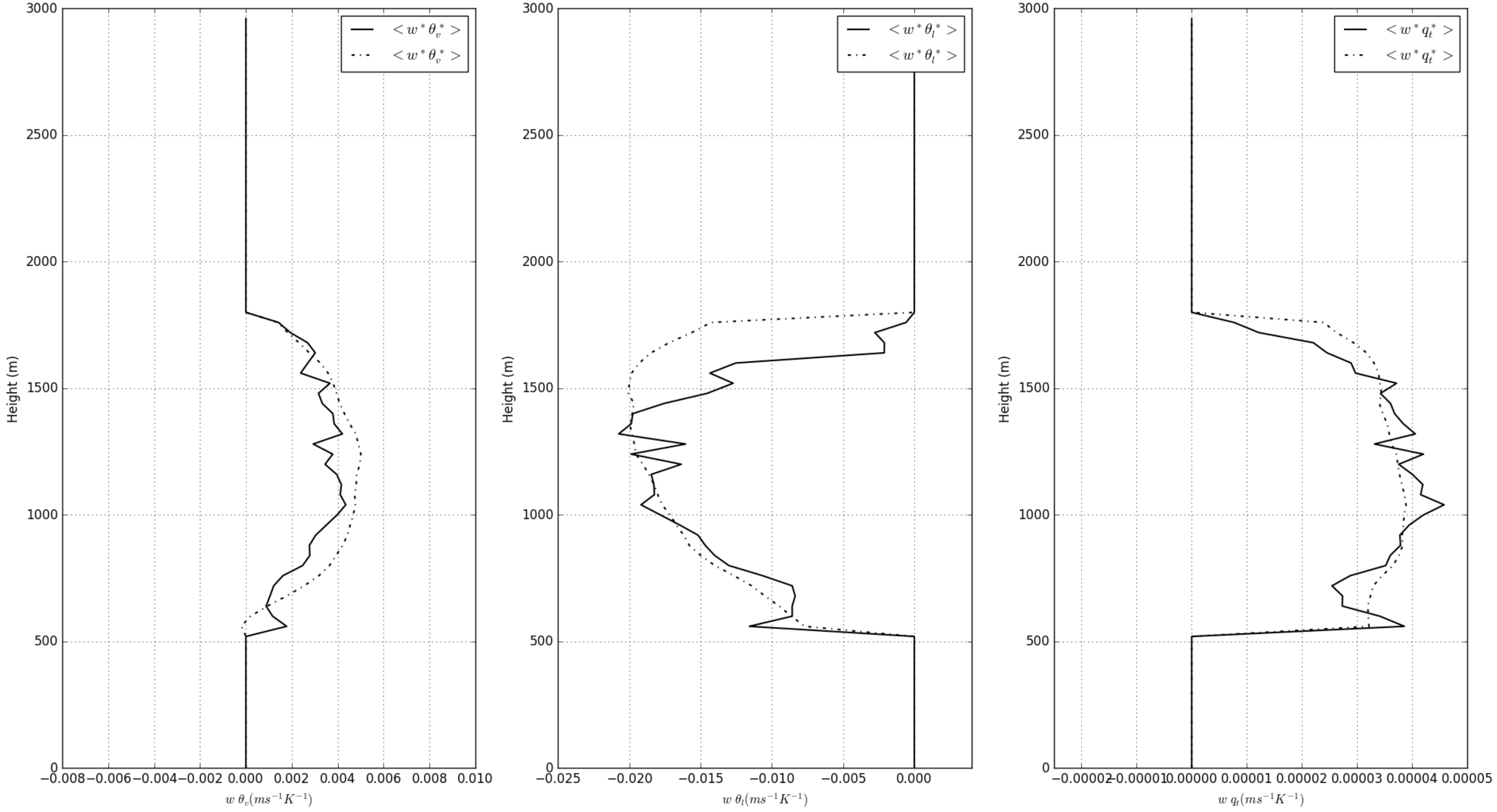
θ_{vm}'

θ_{lm}'

q_{tm}'

Randomly draw the maximum perturbations using conditional probability

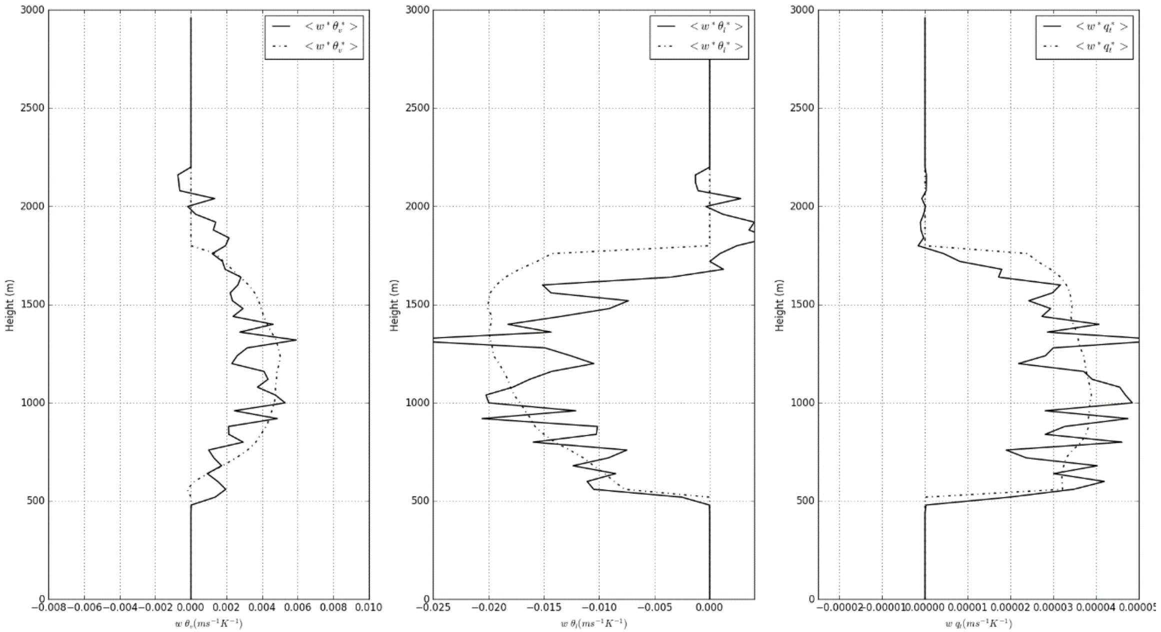
$P(f_m^* | r_c)$



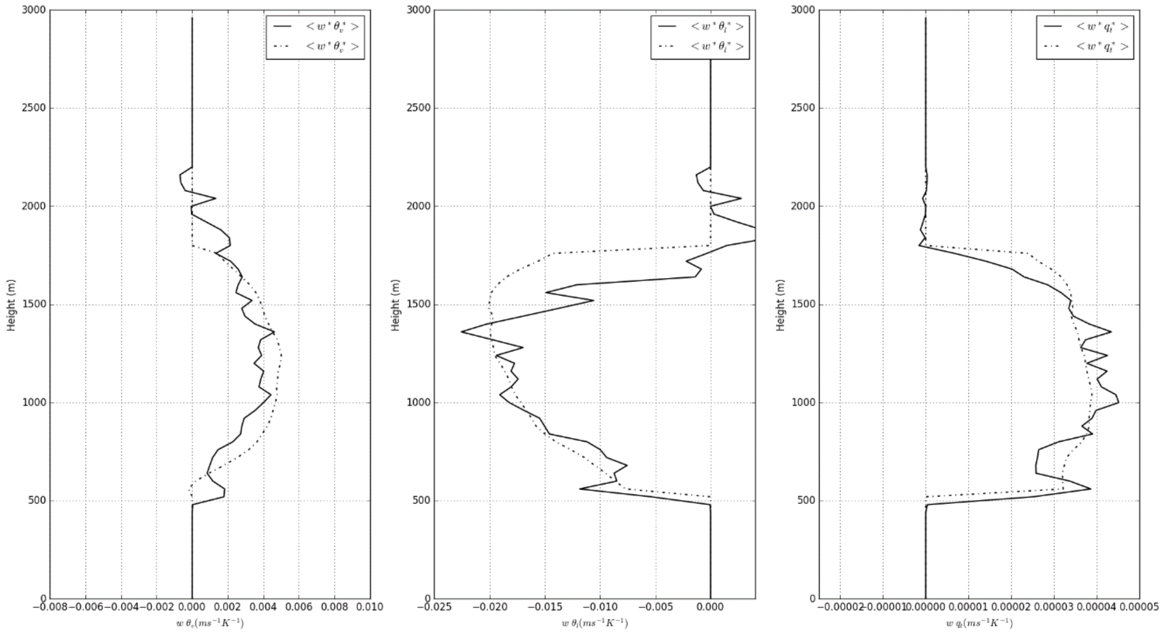
In practice, we may not know the exact values of maximum perturbations of each cloud object.

It's better to randomly draw the maximum perturbations from different bins, so a spectral model would be better

Spectral calculation



No ensemble, too many pluses



Ensemble (10 times)

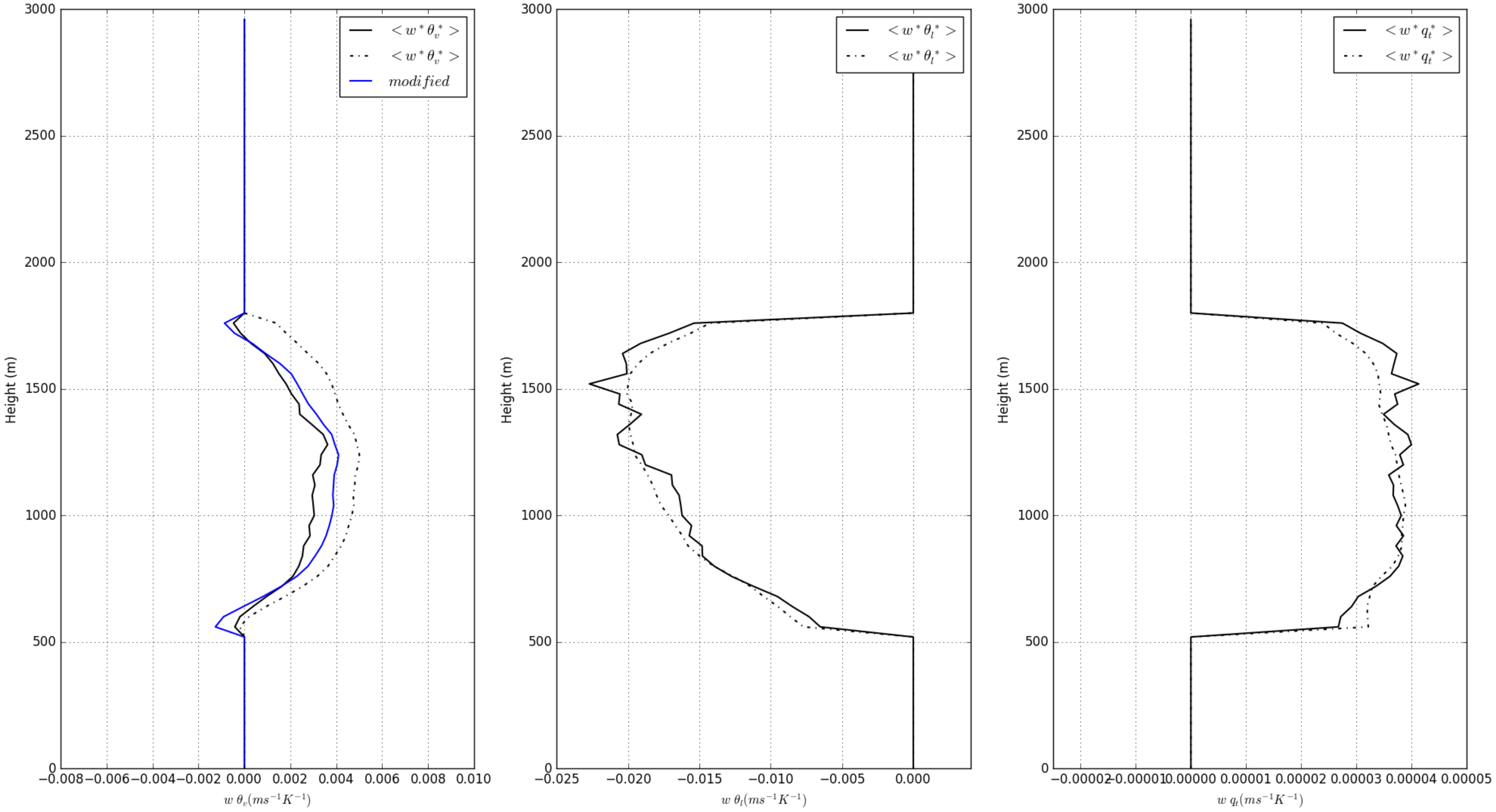
- Now the problem is converted to find the conditional probability $P(f_m^* \mid r_c)$

- Bayesian rule: $$P(f_m^* \mid r_c) = \frac{P(f_m^*, r_c)}{P(r_c)}$$

- $P(r_c)$ could be estimated from statistical equilibrium theory (assuming some relationships between mass-flux and cloud area)

- How to estimate $P(w'_m, r_c)$? Maybe do some Monte Carlo simulations? Using a plume model with different cloud base perturbations and a range of entrainment rates at each bin to generate a dataset that gives $P(w'_m, r_c)$. This will need some knowledge of dependence of entrainment rates on cloud size.

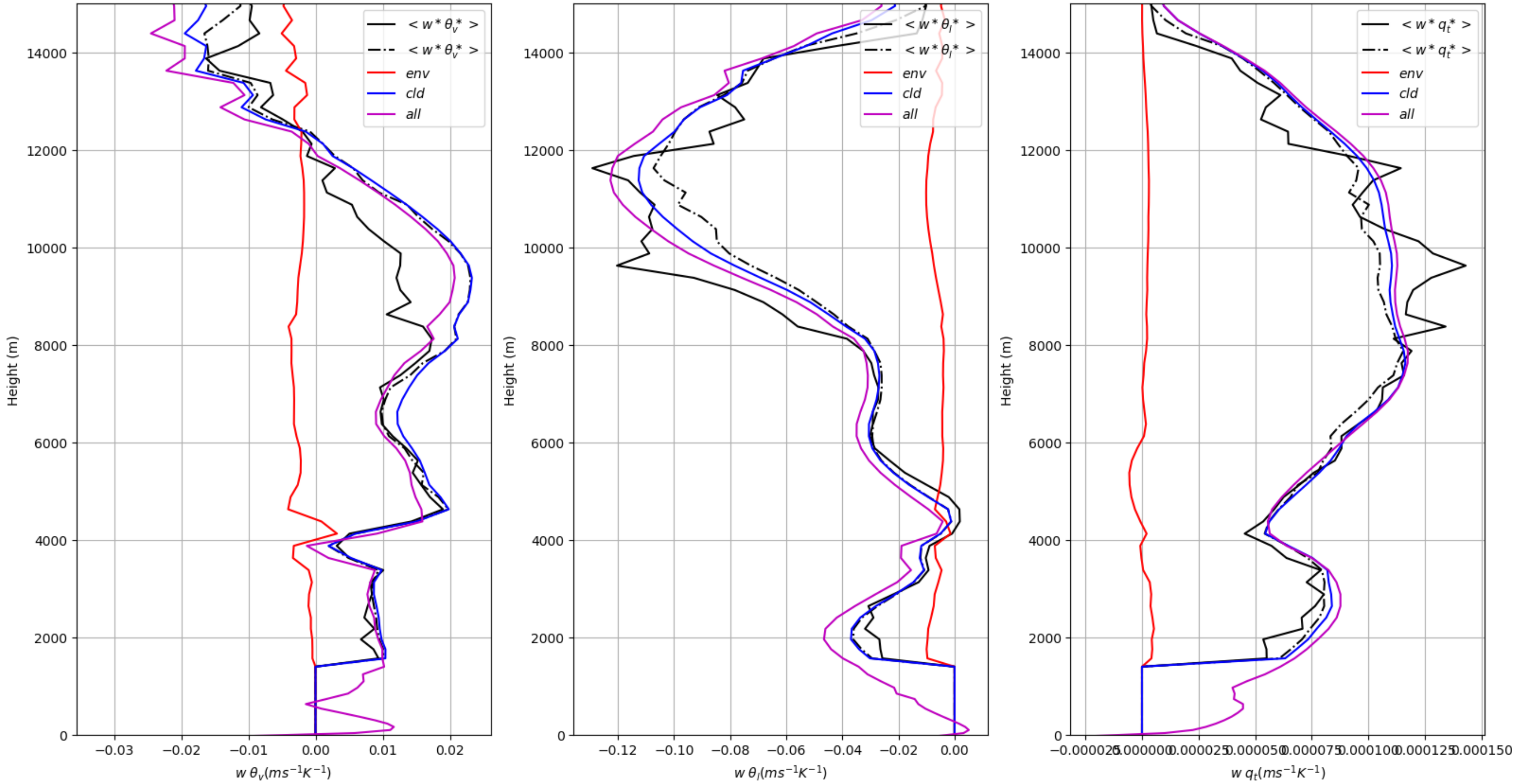
- Other thoughts?



Removing the contribution near the cloud edge give similar results as our estimation, suggesting the importance of transition zone and cloud shell structure.

At each time and each level, for each object, use individual maximums. If the cloud object has a distribution, then use its own distribution. Otherwise, use the averaged distribution of cloud objects that are large and have regular shapes.

RCE



Using single cloud model gives consistent result

Generally, the estimated fluxes are close to the total fluxes within the cloud objects and also the total fluxes across the domain. But the errors at upper levels are larger than at low levels because of the large objects with strange shapes. The distribution within these objects could not simply replaced with the averaged distribution of all other objects.

$$\langle w^* \phi^* \rangle \simeq \sum_i \frac{\int_0^{2\pi}\int_0^{r_e} w_m^* \phi_m^* f_w(\frac{r}{r_i}) f_\phi(\frac{r}{r_i}) r\, dr\, d\varphi}{S_{total}} \frac{S_i}{S_{cld}}$$

$$S_{cld} = \sum_i S_i = \sum_i \int_0^{2\pi}\int_0^{r_i} r\, dr\, d\varphi$$