Comparing shallow cumulus mass flux and convective velocity scale measurements with LES

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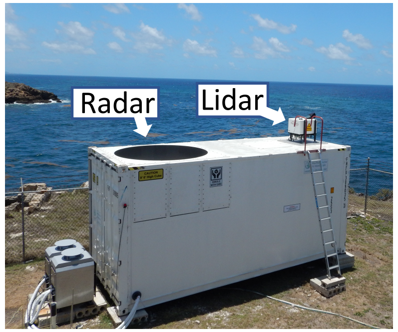
1. Summary

In this study we compare shallow cumulus mass flux and convective velocity scale measurements, taken at the Barbados Cloud Observatory (BCO), with Large Eddy Simulations (LES) from *Grant (2001).*

The convective velocity scale measurements are similar to LES regarding the tropical region. Nevertheless, the mass flux measurements at BCO show a stronger variation than the simulations. We assume that this is caused by different large-scale conditions, which might influence the shallow convective mass flux more than assumend by current LES studies.

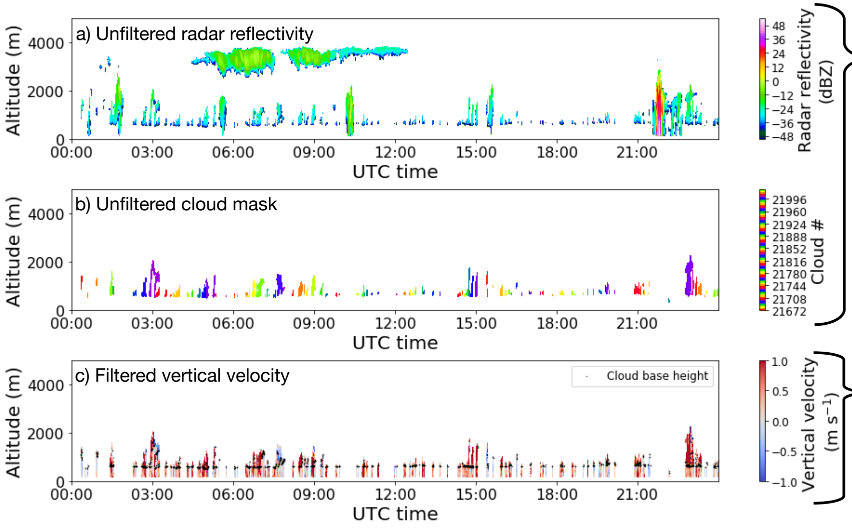
2. Instruments



Stream Line Pro Doppler lidar to identify the vertical air motion in the sub-cloud layer with a temporal resolution of 1.3s. The Doppler resolution is < 0.2 m s^{-1} between ± 20 m s^{-1} .

35 GHz Ka-Band cloud Doppler radar is used to measure the vertical velocity of the cloud droplets. It has a sensitivity of -52 dBZ at 5 km and a temporal resolution of 10 s. The Doppler resolution is < 0.02 m s^{-1} between ±10 m s^{-1}.

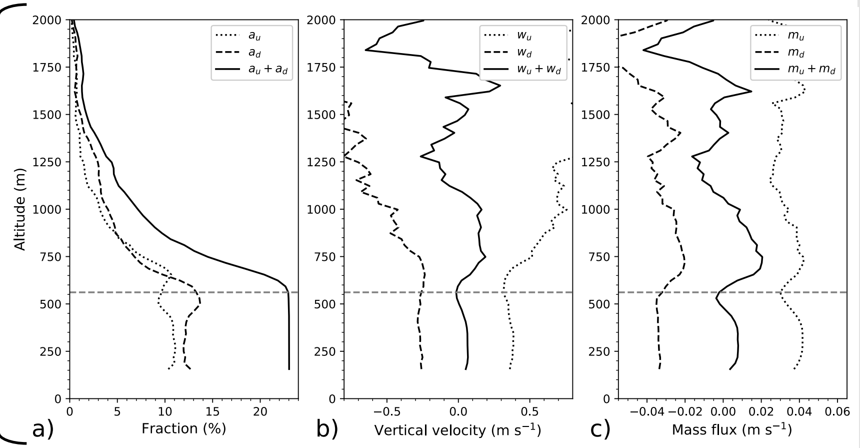
3. Mass flux estimation



Applying the Konow cloud-mask to the radar reflectivity data from the 28. March 2018 to identifiy every single cloud with associated parameters (e.g. cloud base and cloud top height). Clouds other than shallow cumulus are removed by neglecting all clouds with a cloud base height lower than 300 m (precipitation) and higher than 1 km.

Using the Doppler velocity measurements from the radar and adding the vertical velocity measurements from the Doppler lidar below the cloud base.

Calculating cloud fraction (a) and mean vertical velocity (b) of shallow cumulus clouds, seperated into up- and downward motion. The mass flux (c) is the product of cloud fraction and vertical velocity. For convenience, the mass flux is devided by the air density which results to the units m s^{-1}, where the true mass flux has the units kg m^{-2} s^{-1}.



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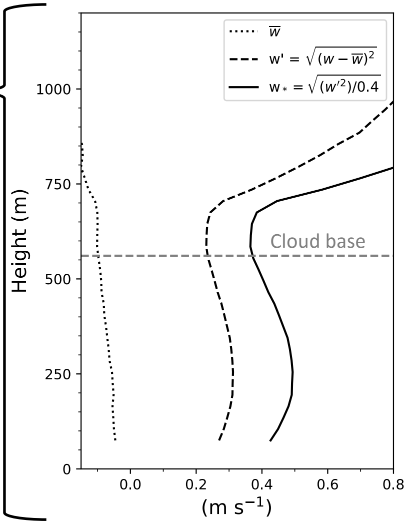
4. Convective velocity scale w_*

Estimating the convective velocity scale w_* is challenging because there is no instrument at the BCO to measure surface fluxes directly.
Therefore, we are going to estimate w_* from w‘ measurements and the well known profiles w'^2/w_*^2 (*van Heerwarden and Mellado, 2016*), which we assume to be constant with a maximum value in the sub-cloud layer of 0.4. Based on this assumption we calculate w_* by:

$$w_* = \sqrt{\frac{w'^2}{0.4}} \qquad \text{with} \qquad w' = \sqrt{(w - \overline{w})^2}\ .$$

Vertical profiles of $\overline{w}$, w‘ and w_* for the 28. March 2018 (same day as in section 3).

Only vertical velocities below shallow cumulus clouds were considered.

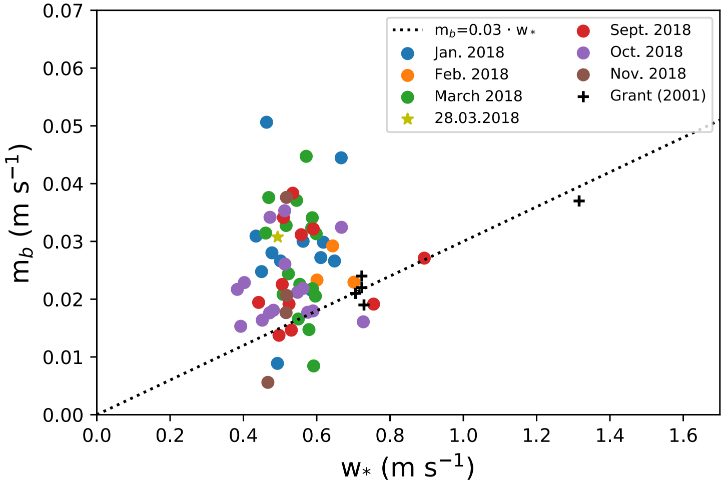


5. Comparison with Grant (2001)

Grant (2001) showed with Large Eddy Simulations (LES) that the cloud base mass flux is proportional to the sub-cloud convective velocity scale w_*:

$$m_b = 0.03 \cdot w_*.$$

This hypothesis is based on the assumption that the Turbulent Kinetic Energy (TKE) flux is associated with the kinetic energy that forms the roots of the cumulus clouds *(LeMone and Pennell 1976)*.



To compare the BCO measurements with the simulations we plot the maximum value of w_* in the sub-cloud layer (see section 4) against the upward directed cloud base mass flux (see section 3). The result for the 28. March 2018 is represented by the star in the right figure. The dots in the plot show 60 more days from 2018 with a distinct mass flux profile.

The majority of the analyzed BCO days show a w_* between 0.4 and 0.8 m s^{-1} and are close to the tropical simulations from *Grant (2001)*, which are around 0.7 m s^{-1}. Nevertheless, the mass flux at cloud base measurements from the BCO show a stronger variation than for the LES. This difference could be caused by the large-scale conditions. While the BCO measurents are always influenced by changing large-scale conditions, the LES studies use prescribed or constant settings (*Grant and Brown, 1999).*

In conclusion, this might indicate that the large scale conditions influence the shallow convective mass flux more than assumed by current LES studies.

References

Grant, A. L. M., 2001: Cloud-base fluxes in the cumulus-capped boundary layer. *Quarterly Journal of the Royal Meteorological Society*, **127 (572)**, 407–421

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