Effects of Vertical Shear on Cloud Field Organization and Variability

M.R. Muetzelfeldt[1] | R.S. Plant[1] | P.A. Clark[1] | S.J. Woolnough[1] | A. Stirling[2]

1. University of Reading 2. UK Met Office

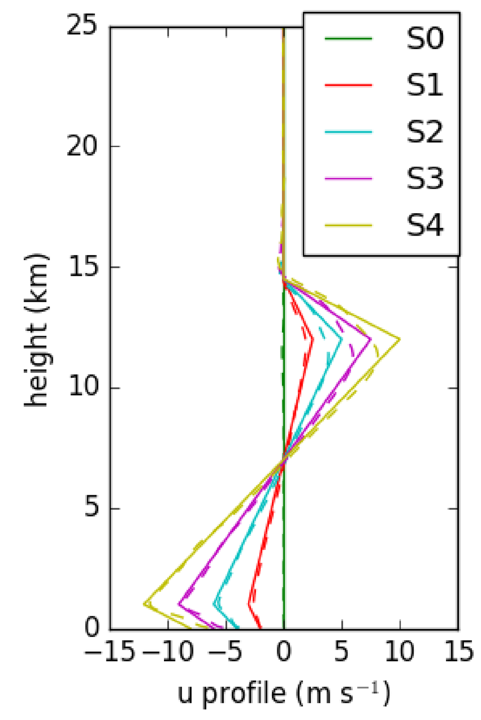
Introduction

Upscale organization of convection is currently not well represented in deep cumulus parametrization schemes. Vertical wind shear can cause one form of upscale organization: squall lines. Cloud Resolving Models (CRMs) can be used to investigate this form of organization. By analysing the statistical distributions of mass flux, we hope to be able to include some of the effects of organization into a stochastic deep cumulus parametrization scheme [1]. We will do this by modifying the distributions of mass flux that the scheme uses to determine the amount of convective heating and moistening. Here we present results from a CRM under different shear profiles, showing that organization is present and that the shear has clear effects on the distribution of mass flux.

Model setup

- Idealized UK Met Office Unified Model 10.7
- Biperiodic domain of 256x256 km^2
- 2 km horizontal resolution
- Variable vertical resolution with 98 levels
- 2 K day^{-1} prescribed cooling – typical of tropical radiative cooling
- No Coriolis force or geostrophic forcing
- 5 experiments, S0-S4, no shear to strong shear (Fig. 1)

Figure 1: shear profiles (solid) and domain mean wind (dashed)



Cloud field organization

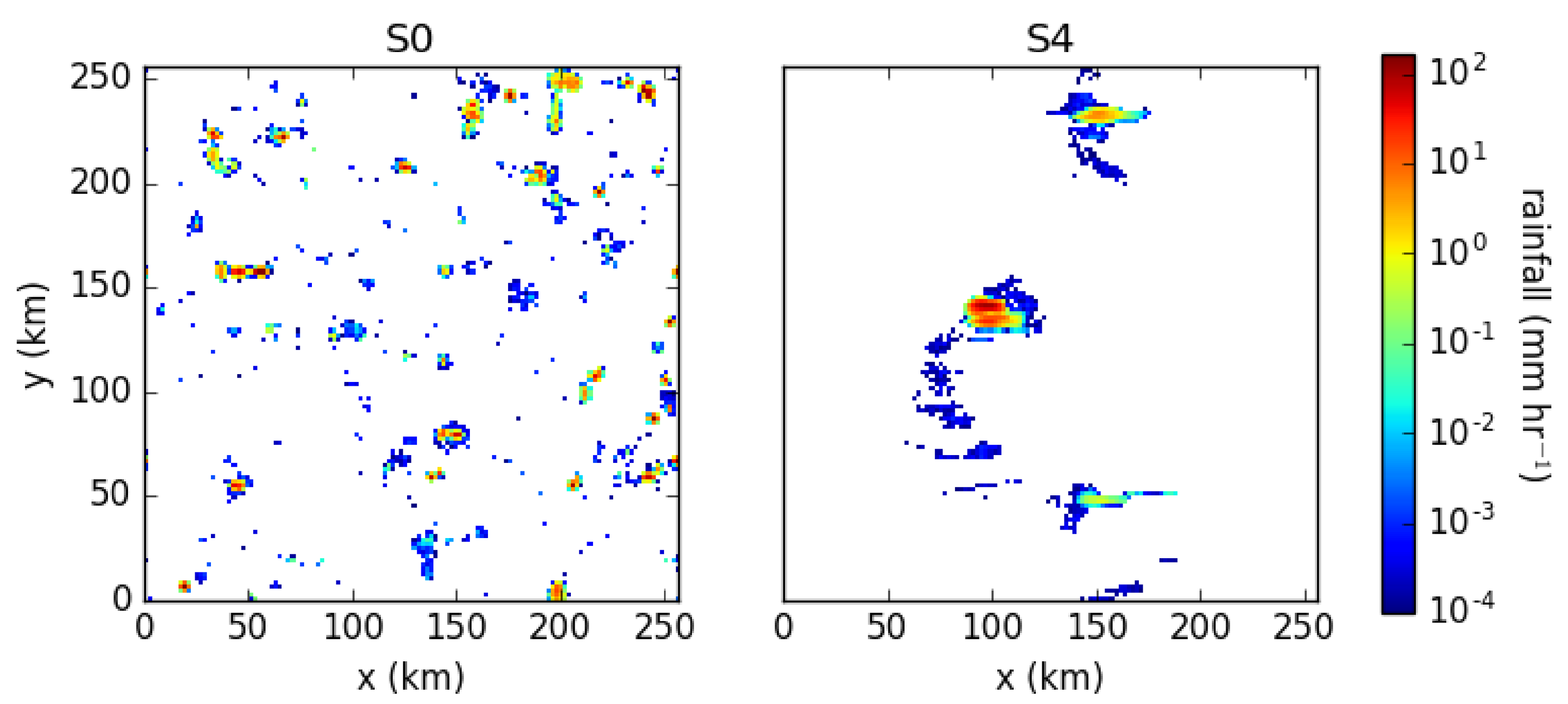


Figure 2: snapshots of 15 minute mean rainfall for S0 and S4 taken from the equilibrium state.

In Fig. 2, the difference between the no shear, S0, and the strong shear, S4, experiments is clear. S0 exhibits a random or 'popcorn' distribution of convection, whereas S4 shows a linear feature identified as a squall line, that is broadly perpendicular to the applied shear.

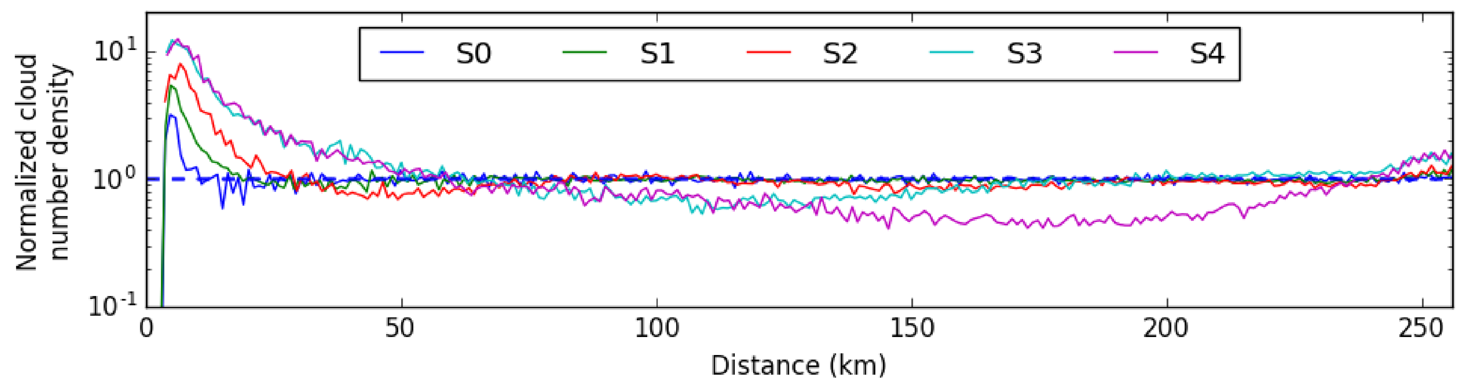


Figure 3: spatial clustering for all shear profiles, based on a diagnosis of clouds at 2063 m.

Fig. 3 shows a measure of the spatial scale of clustering [2]. Any value above one shows preferential clustering of convection at the given scale, and any value below one shows repression. The no shear and weak shear profiles show weak clustering over short spatial scales of less than 15 km. The stronger shear profiles, S3 and S4, are seen to show strong clustering, over spatial scales of up to 50 km, as well as significant repression over larger spatial scales. S2 sits in between: it shows significant clustering on short spatial scales, but the magnitude and scale is less than for the strong shear profiles.

Mass flux variability

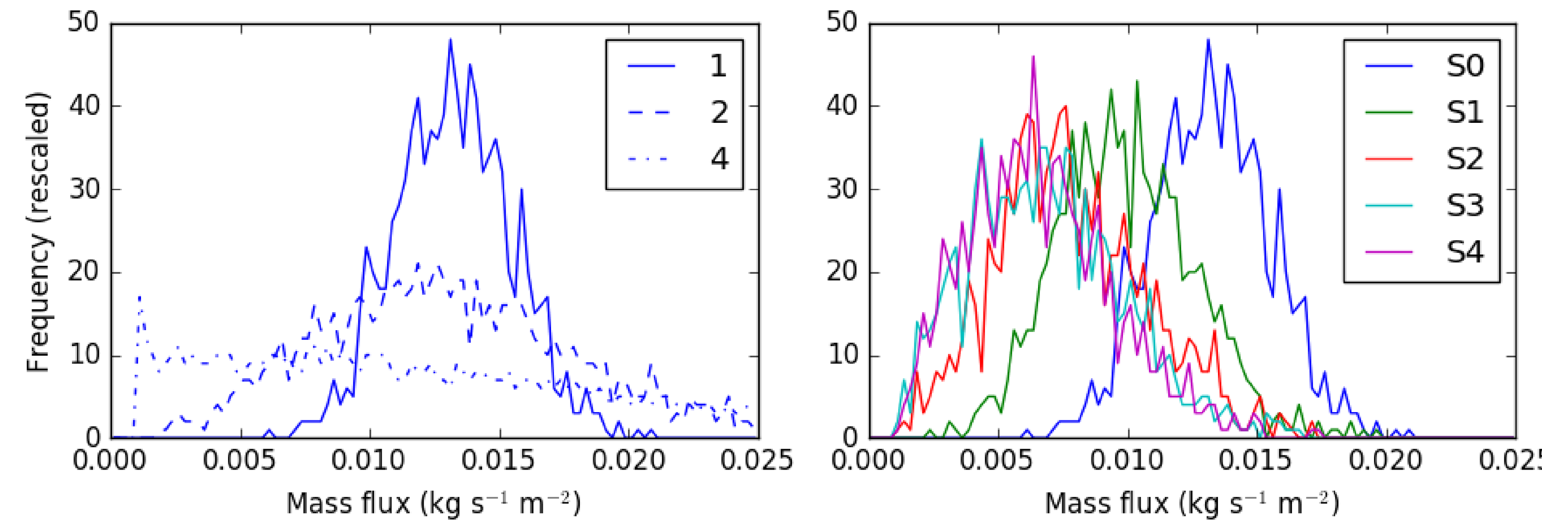


Figure 4: Left: mass flux variability at different spatial scales for S0. 1 is over the entire domain, 2 is over 4 squares with sides half as long as the domain, 4 is over 16 squares. Right: variability of the shear profiles over the spatial scale of the entire domain. Both figures are from a height of 2063 m.

Fig. 4 (left) shows a broadening of the distribution of total mass flux as the spatial scale over which it is calculated is reduced. This can be interpreted as showing the need for a stochastic convection parametrization scheme in order to represent the greater variability as the resolution of a model is reduced. Fig. 4 (right) shows the difference in mass flux distribution as the shear profile is changed, hinting that we may need to modify our representation of convective variability in parametrization schemes as shear increases.

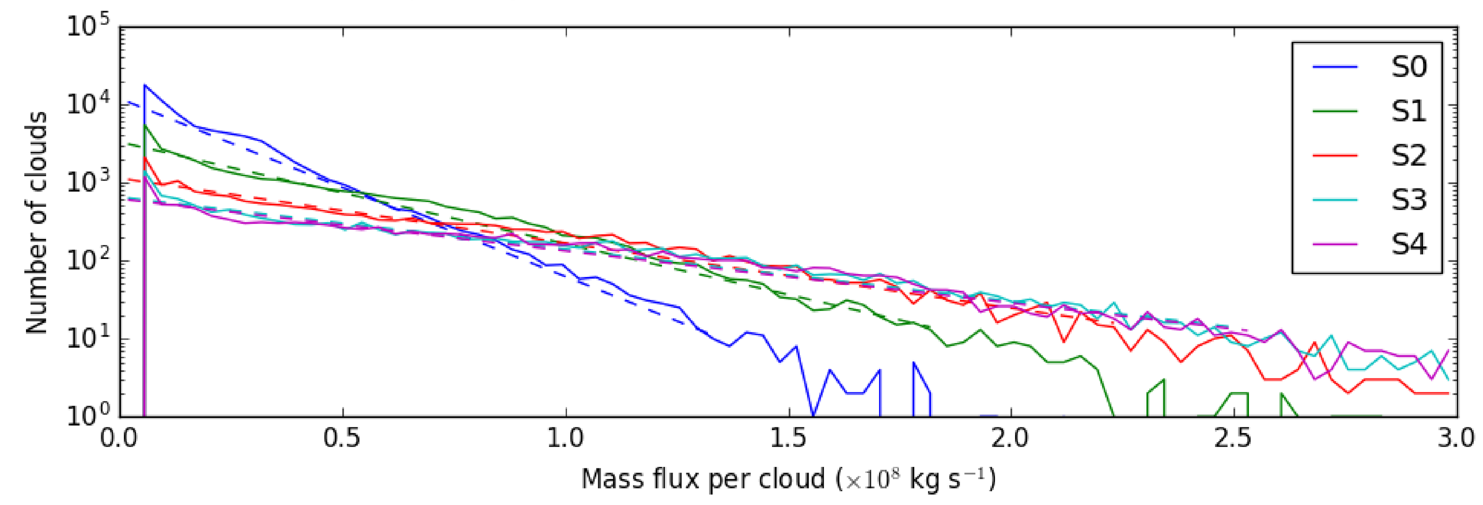


Figure 5: mass flux per cloud for the different shear profiles. Linear regressions (dashed lines) have been fitted to each profile, using only the values of mass flux where there are 10 or more clouds.

In Fig. 5, the mass flux per cloud is seen to be well represented by an exponential decrease, in accordance with theory [2]. As shear increases, the number of clouds with low mass fluxes decreases, and the maximum mass flux per cloud increases.

Summary

- Increasing shear increases the measured degree of organization
- Clustering occurs over up to 50 km for strong shear profiles
- Distributions of mass flux show clear trends with increasing shear

References

1. Plant, R. S., & Craig, G. C. (2008). A stochastic parameterization for deep convection based on equilibrium statistics. *Journal of the Atmospheric Sciences*, 65(1), 87-105.
2. Cohen, B. G., & Craig, G. C. (2006). Fluctuations in an equilibrium convective ensemble. Part II: Numerical experiments. *Journal of the Atmospheric Sciences*, 63(8), 2005-2015.

Acknowledgements: Met Office CASE Studentship
Contact details: Mark Muetzelfeldt – m.muetzelfeldt@pgr.reading.ac.uk