The Contributions of Shear and Turbulence to Cloud Overlap for Cumulus Clouds

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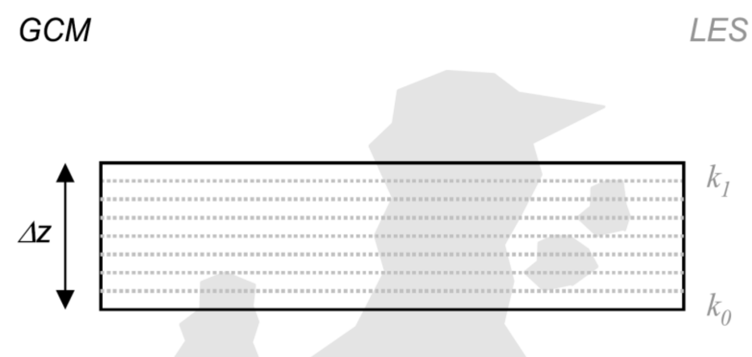
(with Anthony Sulak, William Calabrase, Shawn Ryan, Roel Neggers)

Background

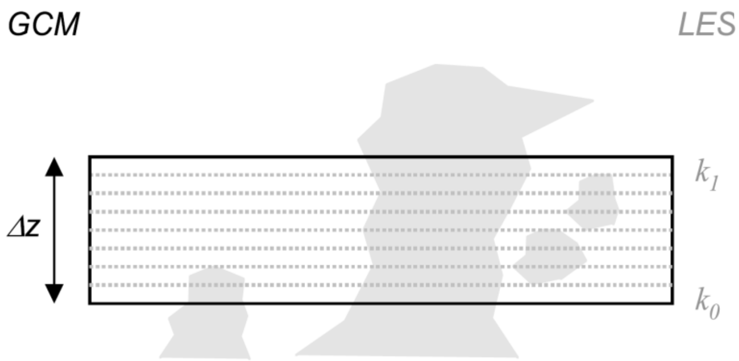
- How clouds are layered is a long standing issue in determining the cloud radiative forcing of a cloud field
- Traditionally cloud layers would be either correlated (with maximum overlap), decorrelated (random overlap), or something in between
- With finer resolutions for GCMs, **what about the overlap efficiencies within a cloud field?**

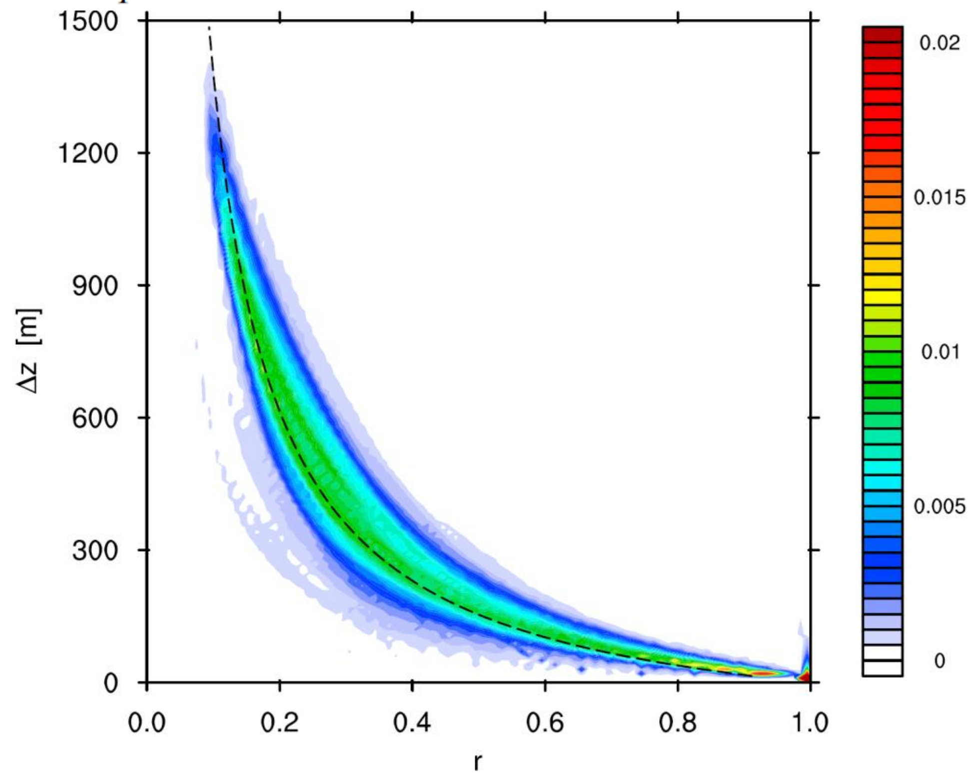
Cloud Overlap

- Neggers et al (JGR, 2011) used LES to determine the cloud overlap ratio $r = \frac{c_v}{c_p} = \frac{V}{H\ c_p}$ for shallow cumulus
- Found faster decorrelation than previously thought (300m)
- Corbetta et al (GRL 2015) saw similar results
- **Can we move beyond empirical values?**



Cloud Overlap $r = \frac{C_v}{C_p}$





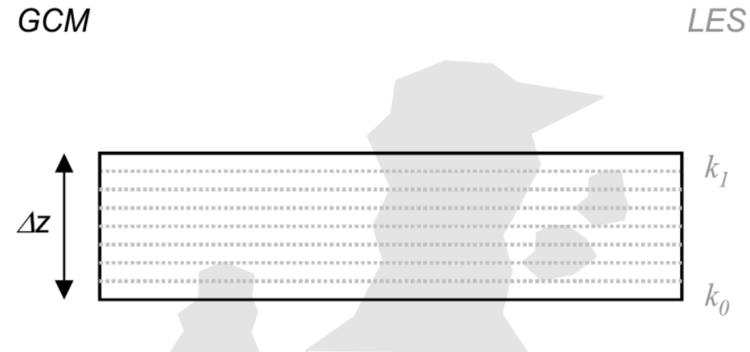
- Overlap depends of course on layer width ("GCM resolution")
- Decorrelates faster than typically suggested
- Best fitted as an inverse linear fit

Name	Function	Constants	RMS
Exponential	$r = \exp(-\frac{\Delta z}{\Delta z_0})$	$\Delta z_0 = 310$ m	0.10105
Powerlaw	$r = a\Delta z^b$	$a = 2.8$ $b = -0.36$	0.08053
Inverse linear	$r = \frac{1}{1+\beta\Delta z}$	$\beta = 0.0064\ \mathrm{m}^{-1}$	0.04229

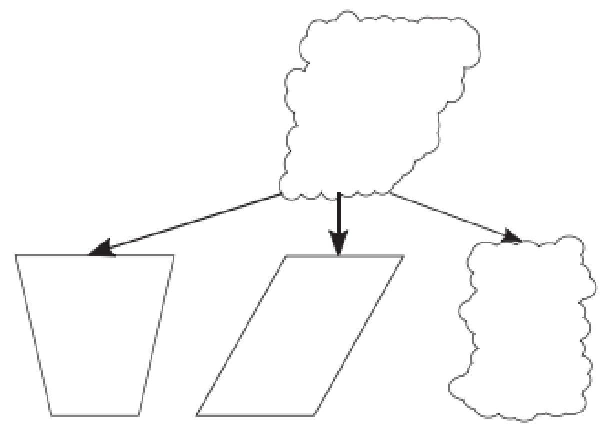
Approach

- LES at 25m/25km of BOMEX, RICO, ARM, 20 LASSO cases, using MicroHH (van Heerwaarden et al, 2017)
- Explore the overlap ratio for individual clouds
- Step 1: Empirical exploration
- Step 2: Parameterize individual terms
- Step 3: Compare parameterized with actual overlap

Driving factors of overlap



1) Inter-cloud Overlap
   - (small effect, not shown)
2) Intra Cloud Overlap:
   - Shape
   - Shear
   - Turbulence

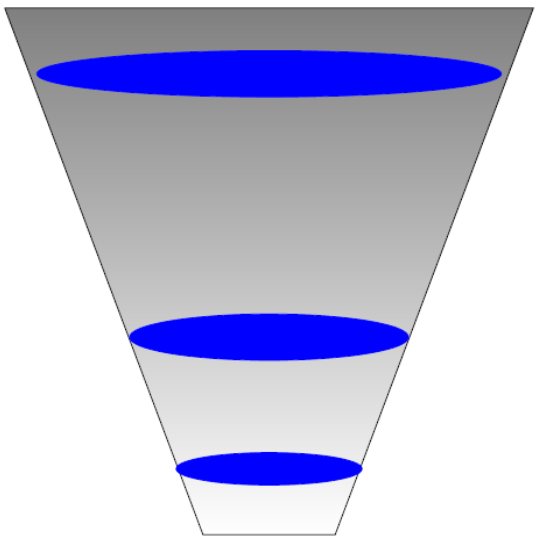


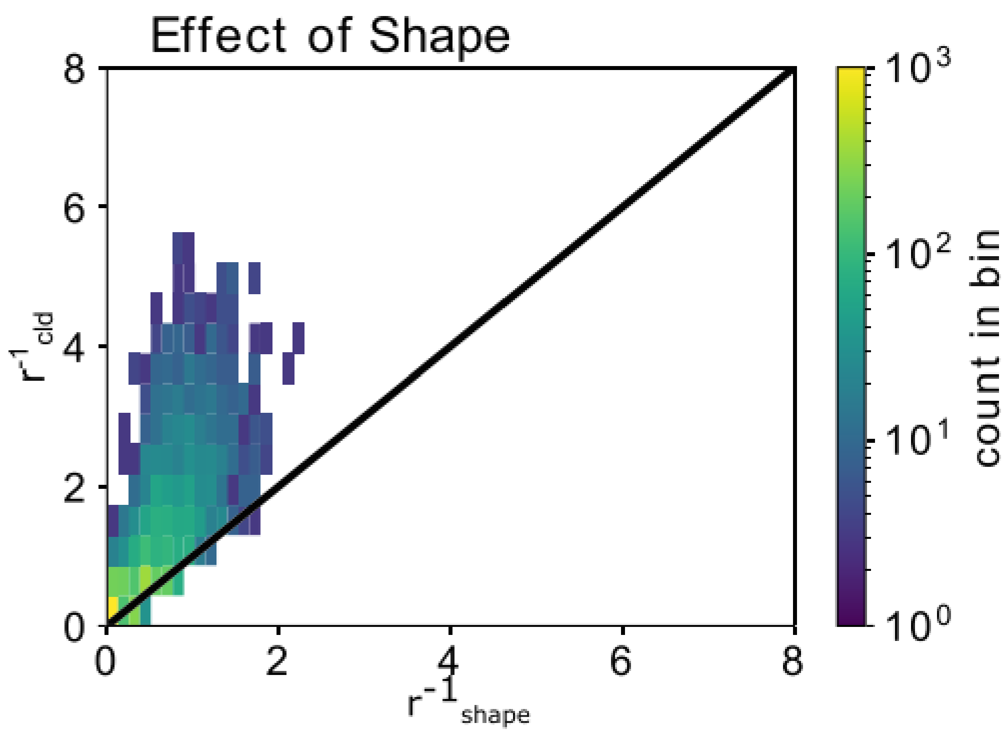
- Easier to describe as inverse overlap:

$$r^{-1} = 1 + r_{fld}^{-1} + r_{shape}^{-1} + r_{shear}^{-1} + r_{turbulence}^{-1}$$

Driving factors of overlap: Shape

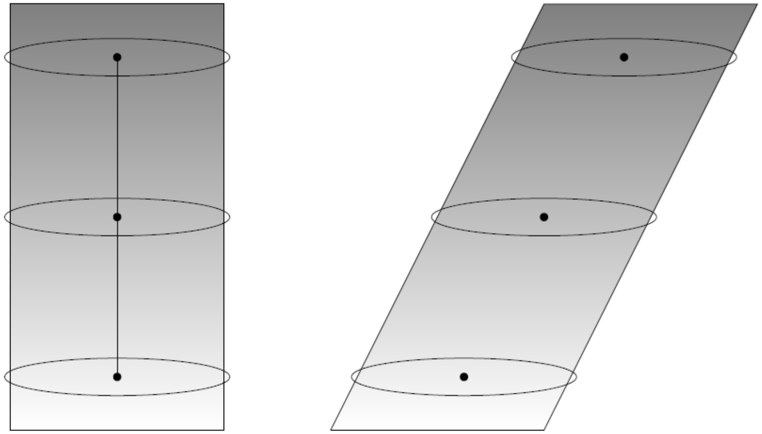
Maximum overlap vastly underestimates overlap!!

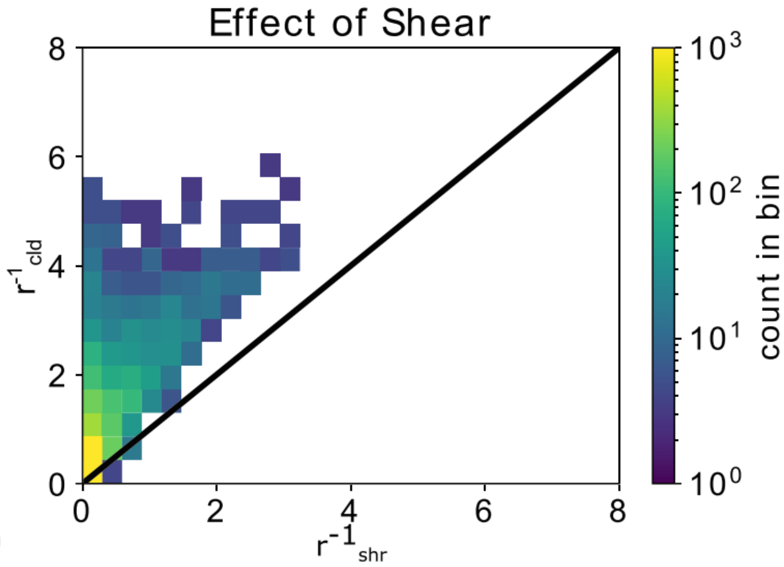




$$r_{shape}^{-1}(n) = \frac{A(n)_{max}}{A(n)_{avg}} - 1$$

Driving factors of overlap: Shear



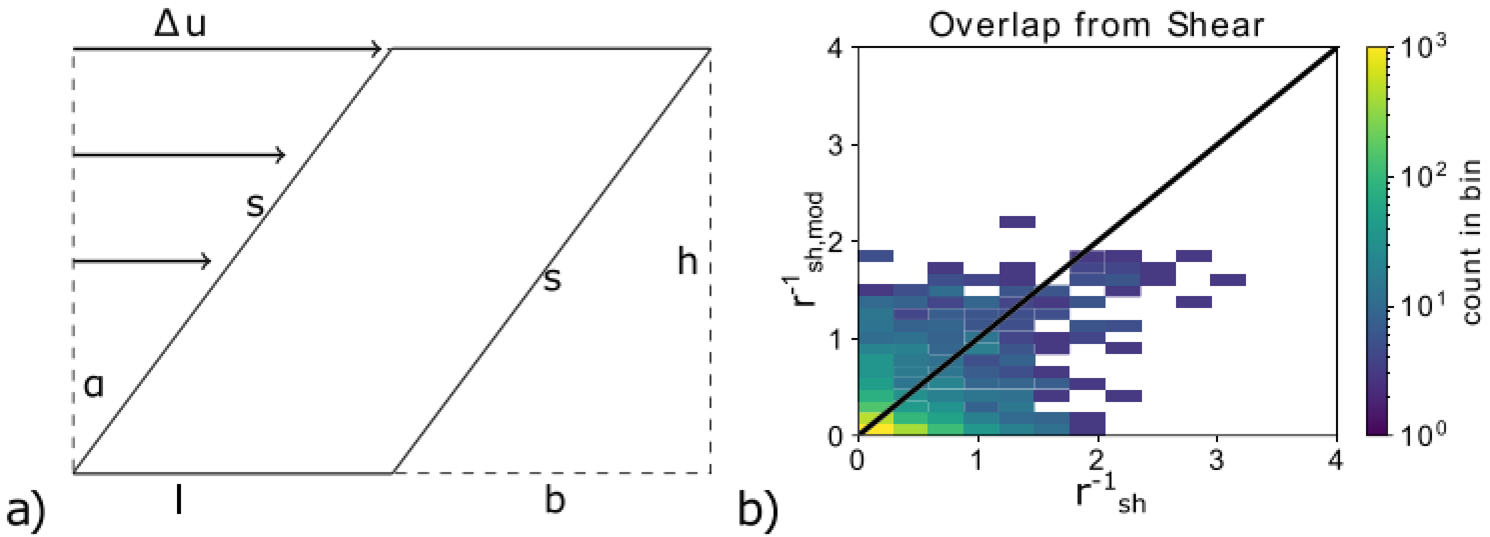


Shear effect calculated by realigning centers of mass

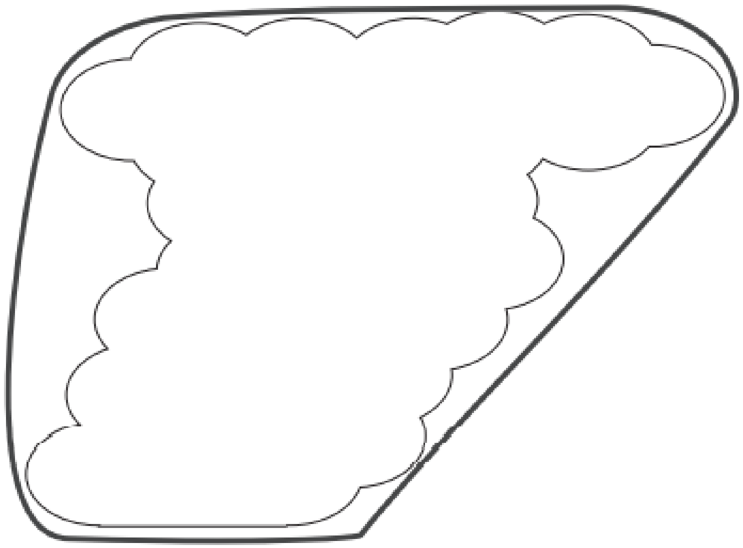
Significant effect on some, but not all clouds

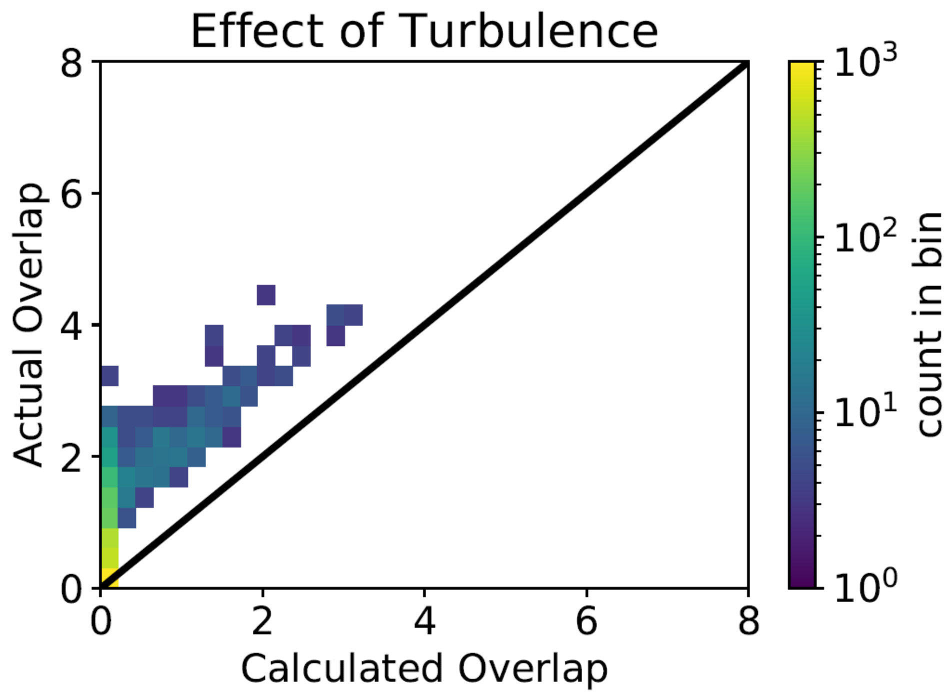
Shear model

- Assume a tilted cloud due to shear: $r^{-1}_{shr,mod} = \frac{b}{l} = \frac{h\Delta u}{lw}$,
- Infinte spread in mapping real shear onto modeled shear, but on average (for large inv. overlap) reasonable



Driving factors of overlap: Turbulence

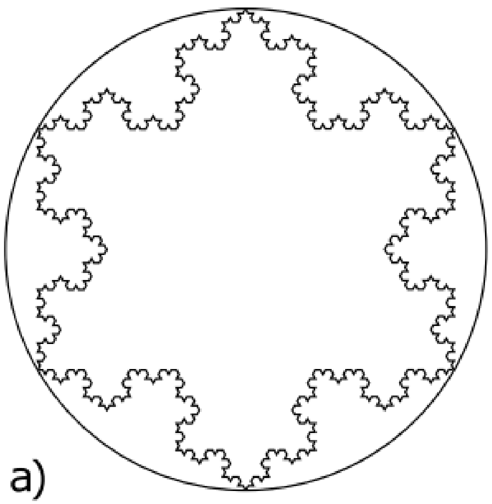


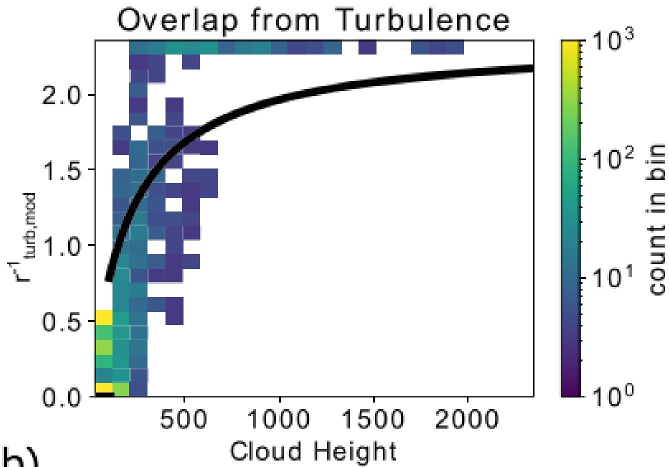


- Calculating effect of small scale turbulence by subtracting the overlap of a convex hull
- Strong effect across the board

Turbulence model

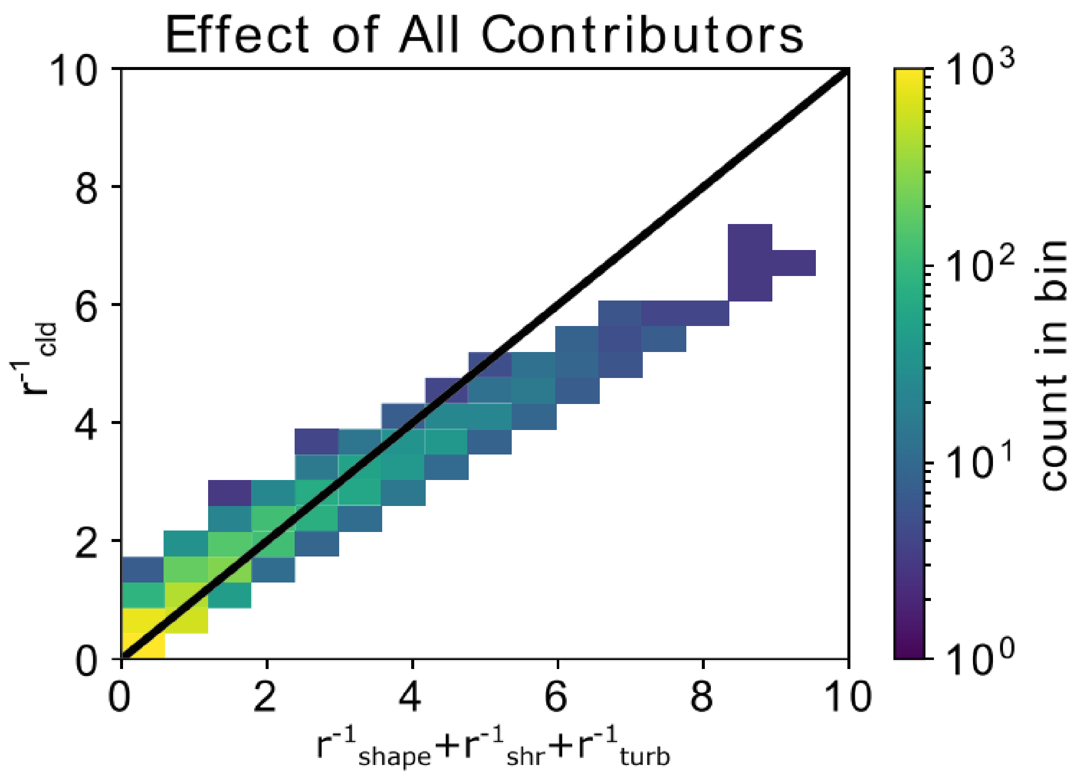
- Assume a Fractal that further fills up when stacking layers: $r^{-1}_{turb,mod}(h) = \frac{\sqrt{3}\pi}{2} \cdot \frac{h}{h_0 + h},$
- Fit 'decorrelation length' to 200m (following Corbetta, Neggers)


a)



b)

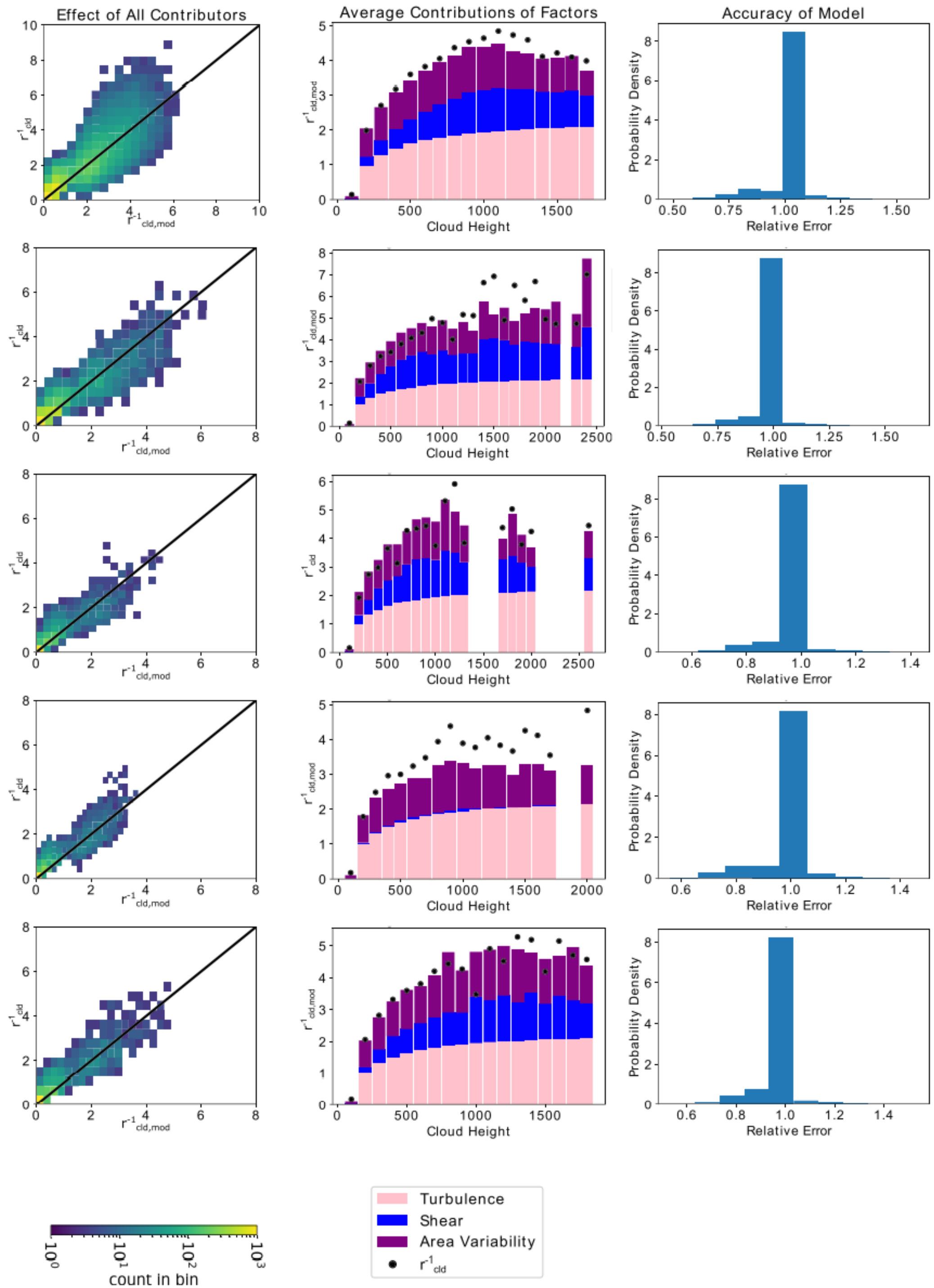
Sum of all effects (observed)



- Slight overcount for large clouds, probably because turbulence + shape double counting

Overall model

- Overall, good match for most cloud fields with considerable spread between clouds
- Turbulence tends to dominate, though n factor can be excluded



Conclusions

*) LES to understand (intra-)cloud overlap

*) Maximum overlap explains < 50% of the cloud cover

*) Turbulence effect particularly significant

*) A simple model of each effect works well across different cases of shallow Cu

Papers:

*) Sulak, Calabrase, Ryan, Heus JGR 2020

*) Corbetta et al GRL 2015

*) Neggers, Heus, Siebesma, JGR 2011

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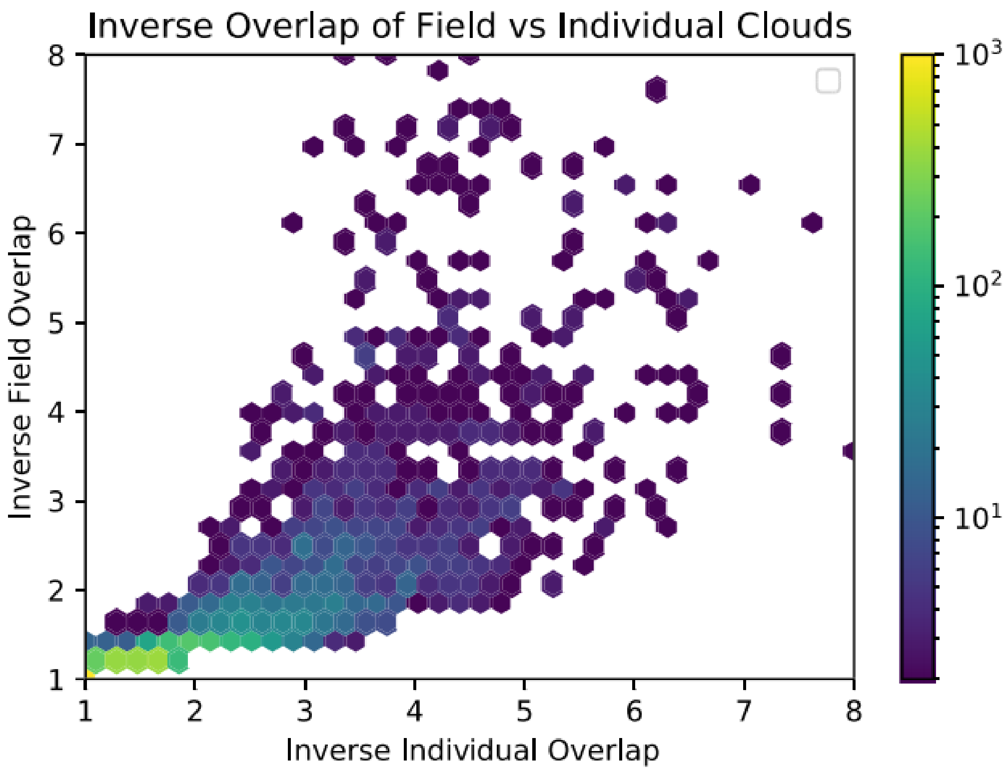
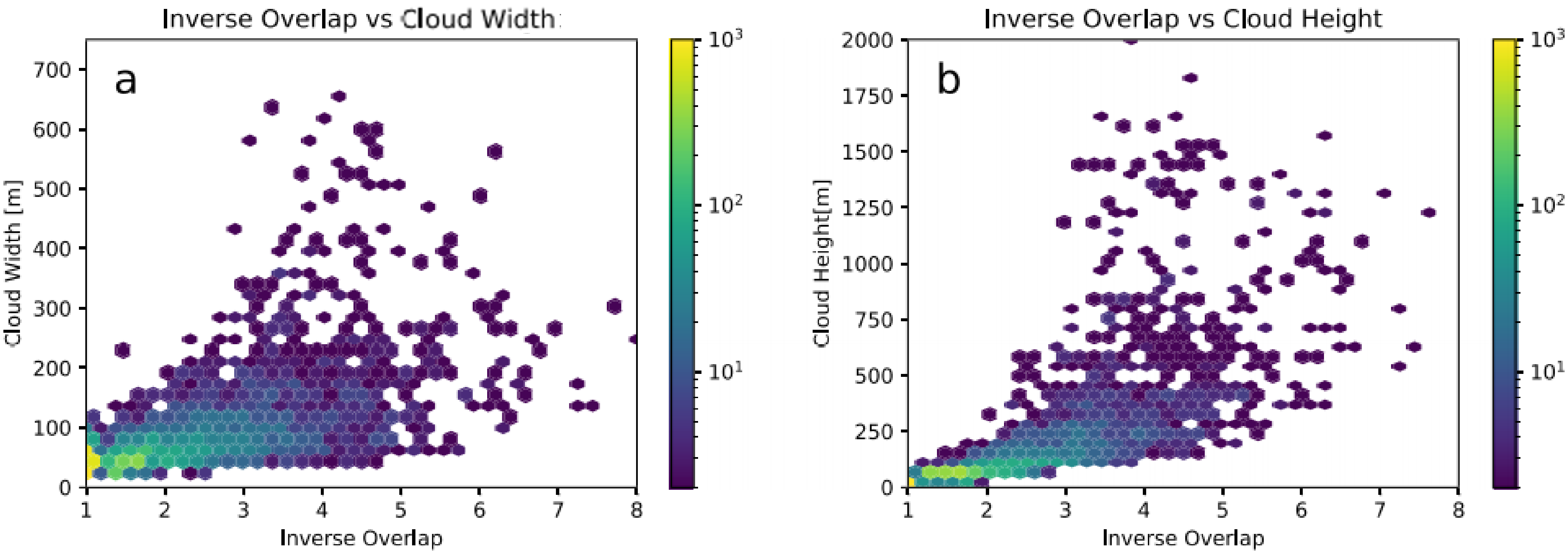
Inter cloud overlap



Considerable spread, but on average

Field overlap = Individual Overlap



- Overlap somewhat better modeled vs Cloud Height