

Entrainment in deep convection

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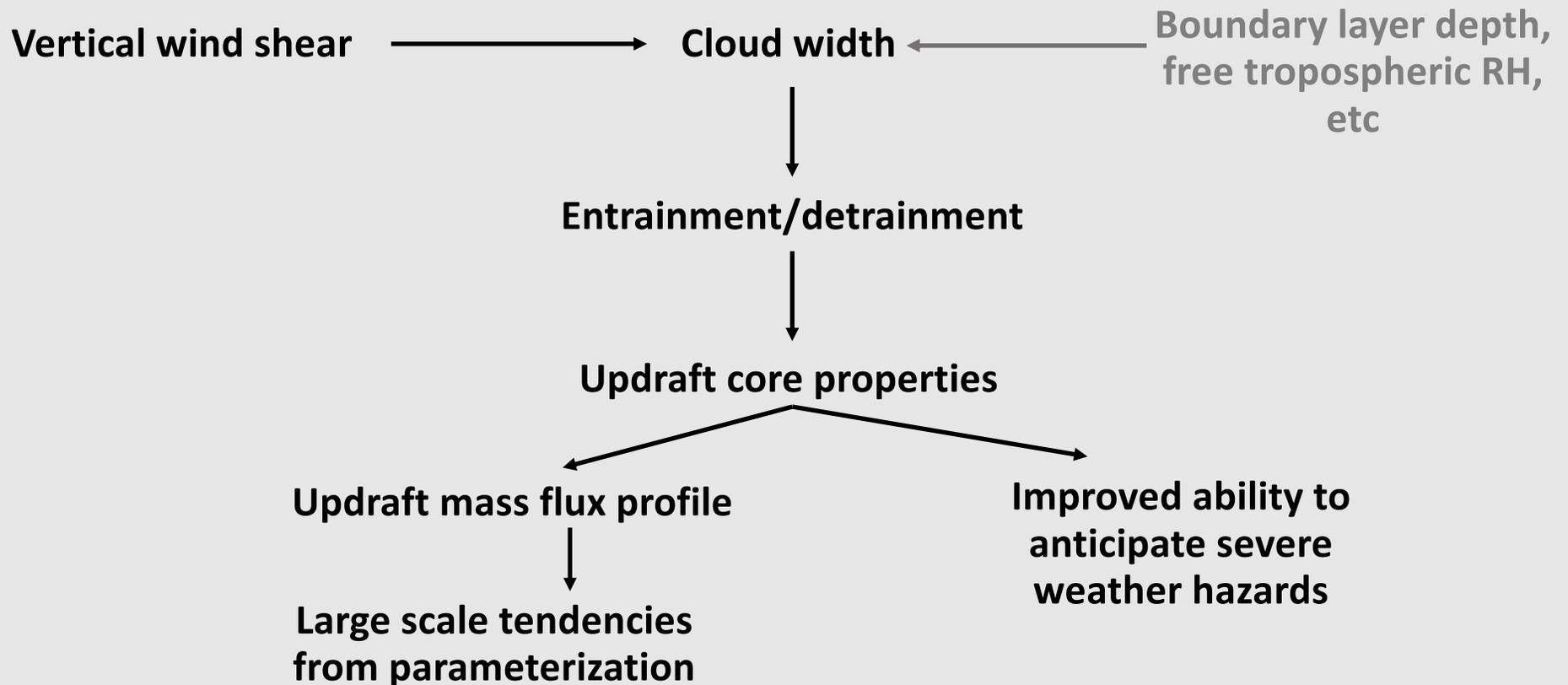
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Importance of entrainment



*Vertical mass flux scales as **radius squared***

$$M \sim \rho w R^2$$

*Horizontal mass uptake e rate with height scales as **radius***

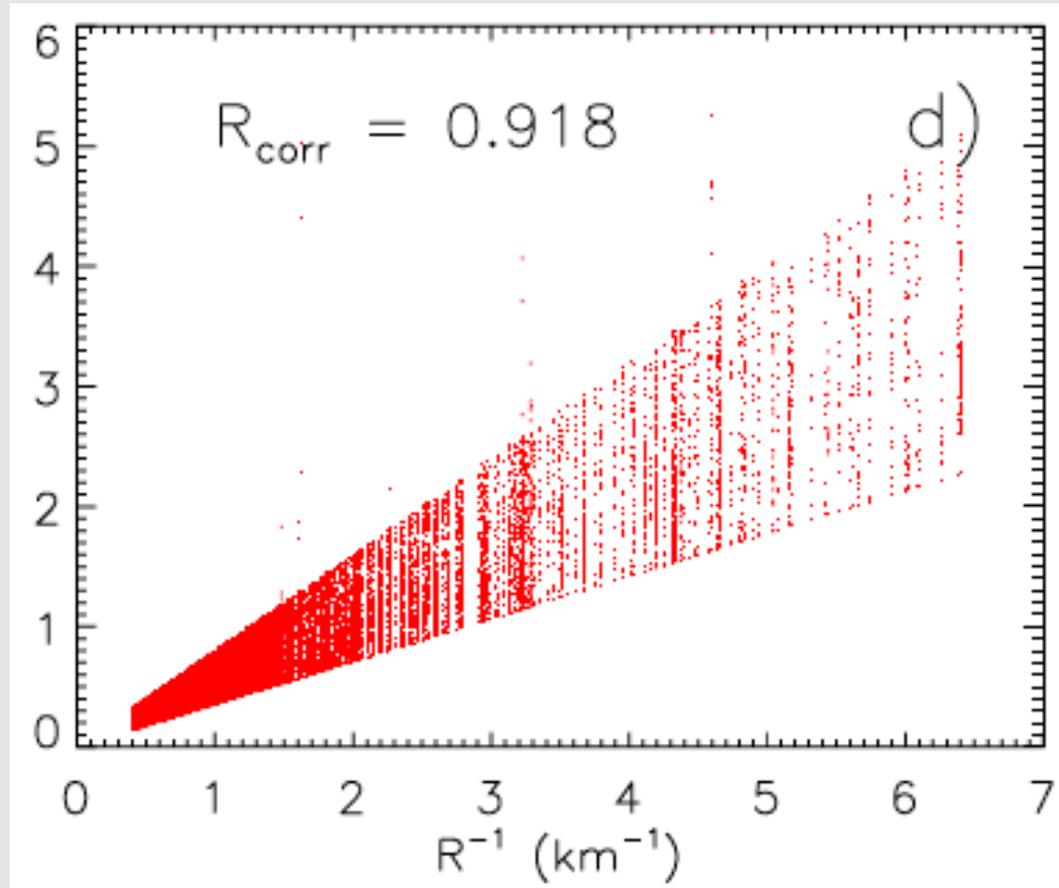
$$e \sim \rho u R$$

Fractional entrainment ε scales e/M , and therefore inverse radius

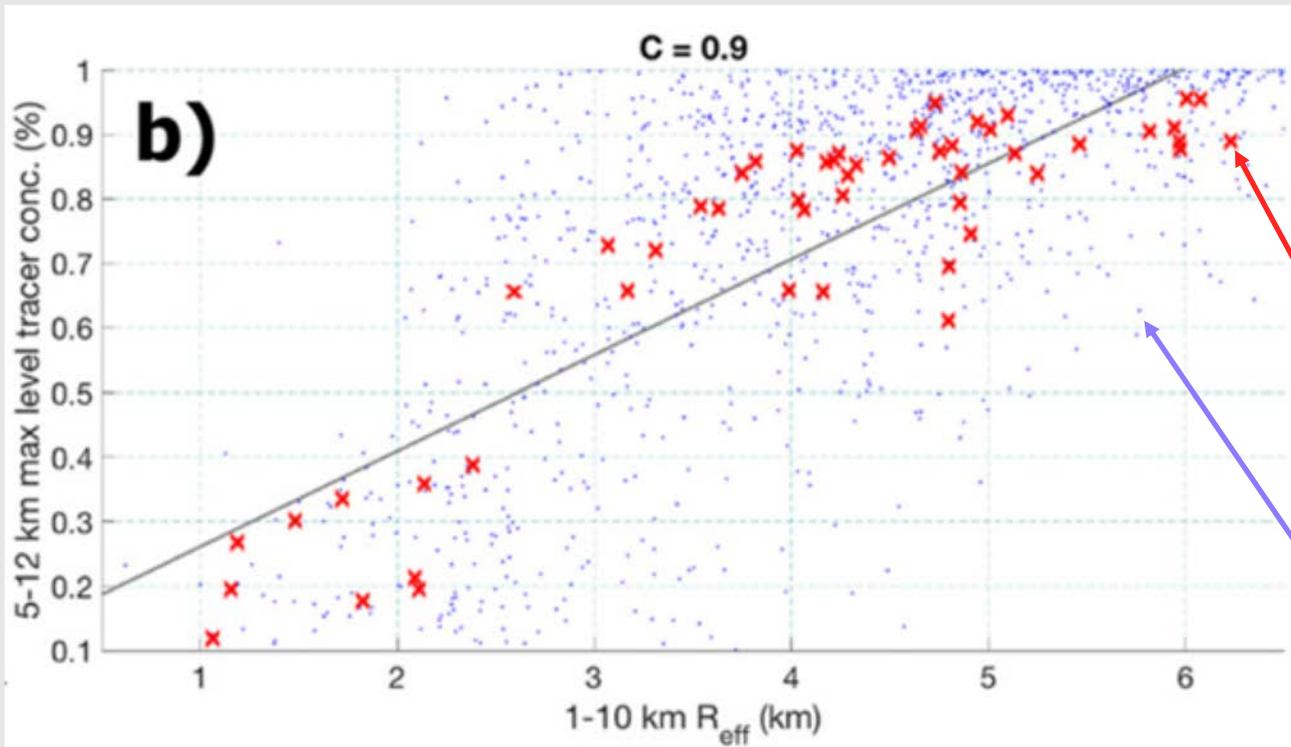
$$\varepsilon \sim e / M \sim R^{-1}$$

From Morrison et al.
(2020), JAS

ε (km^{-1})



Theoretical relationship

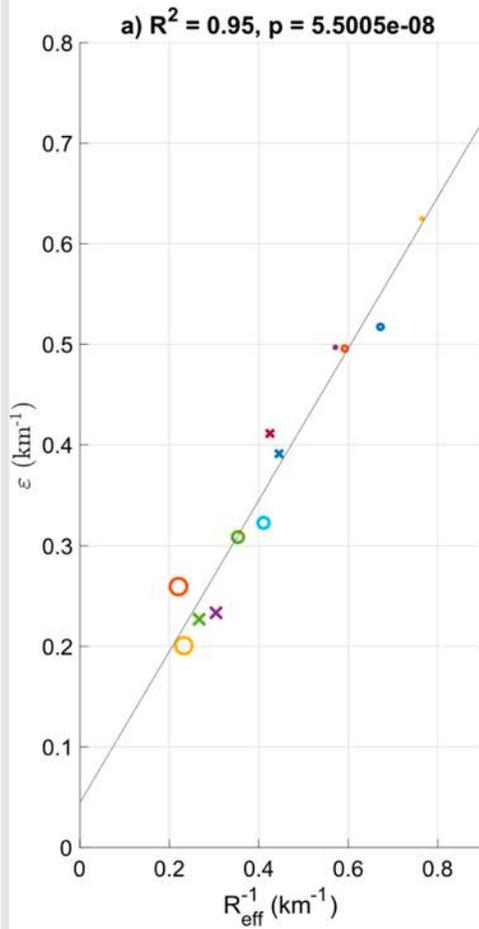


From Peters et al.
(2019), JAS

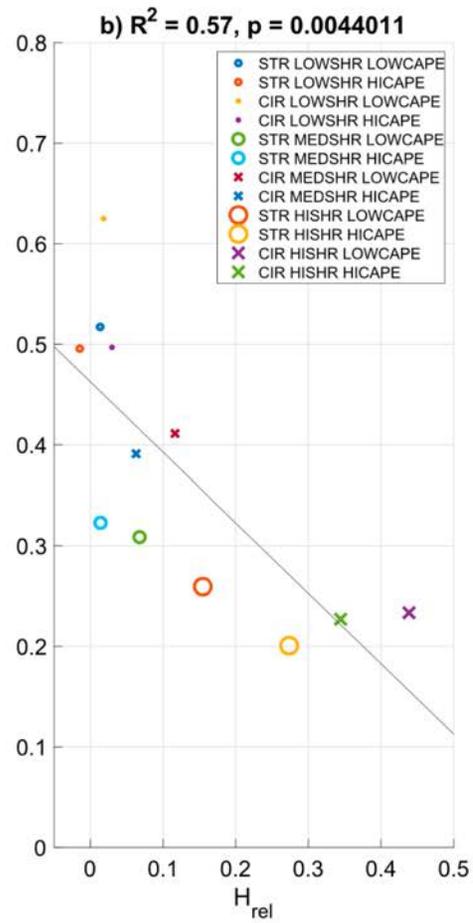
Whole
model run
averages

Individual 5-
minute time
snapshots

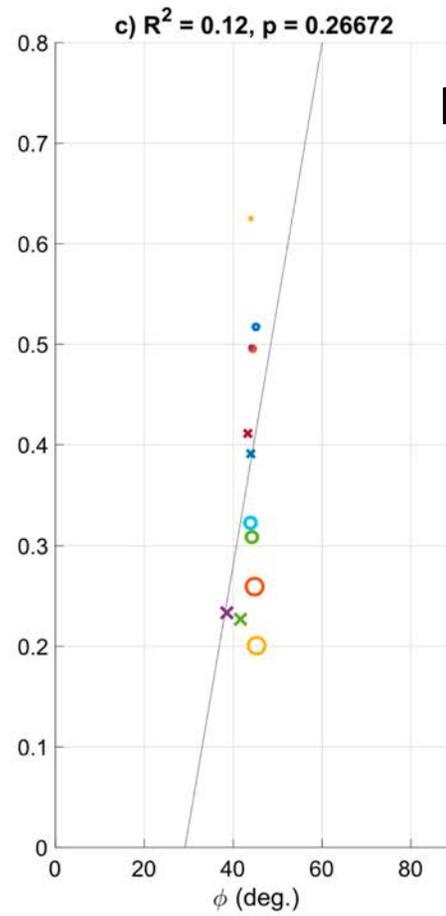
As radius increases (to the right), dilution decreases (upward)



Strong correlations with inverse radius

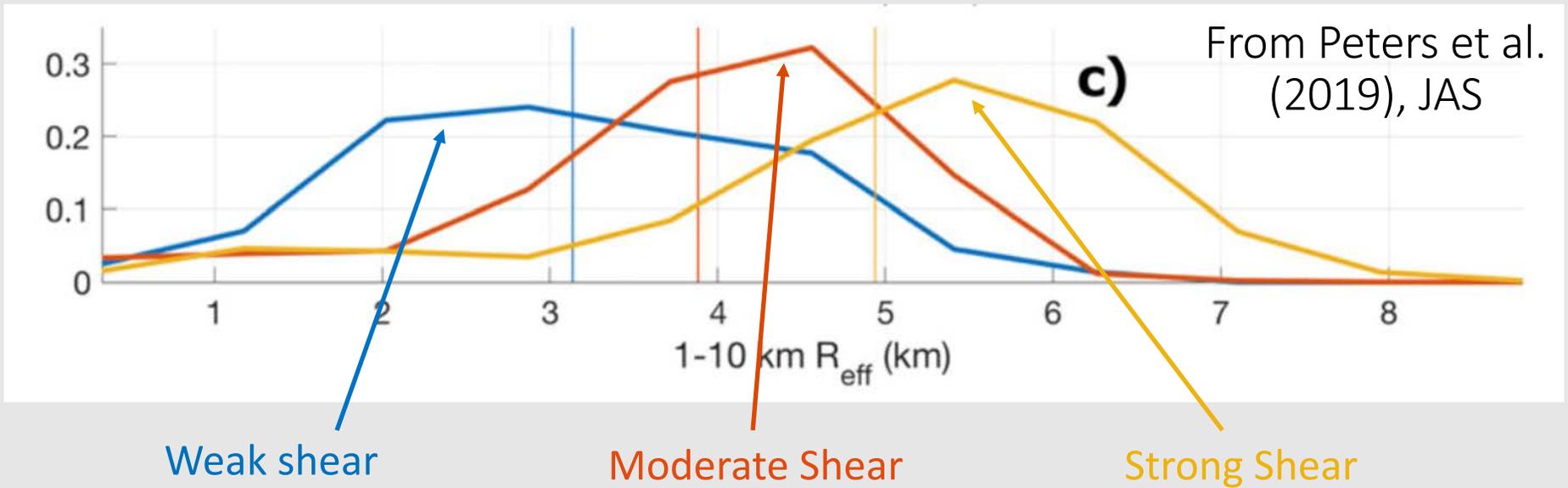


Weaker correlations with rotational characteristics

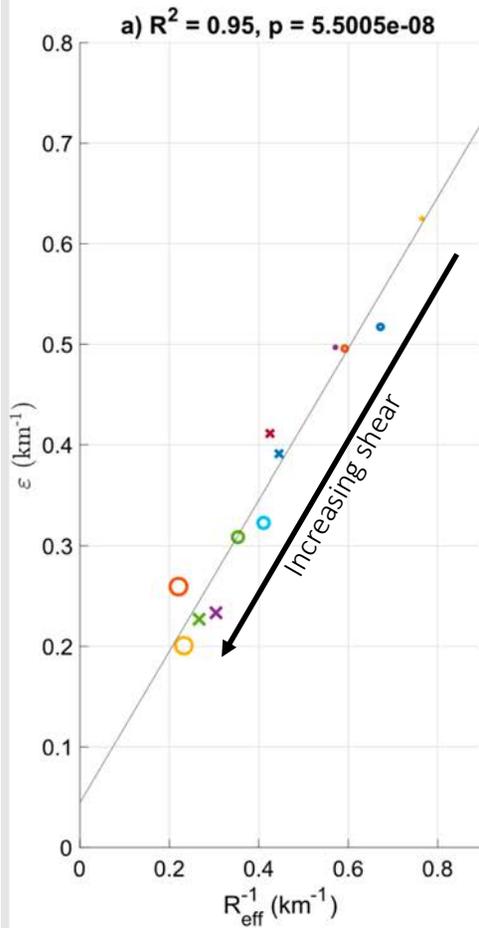


From Peters et al. (2020a), JAS

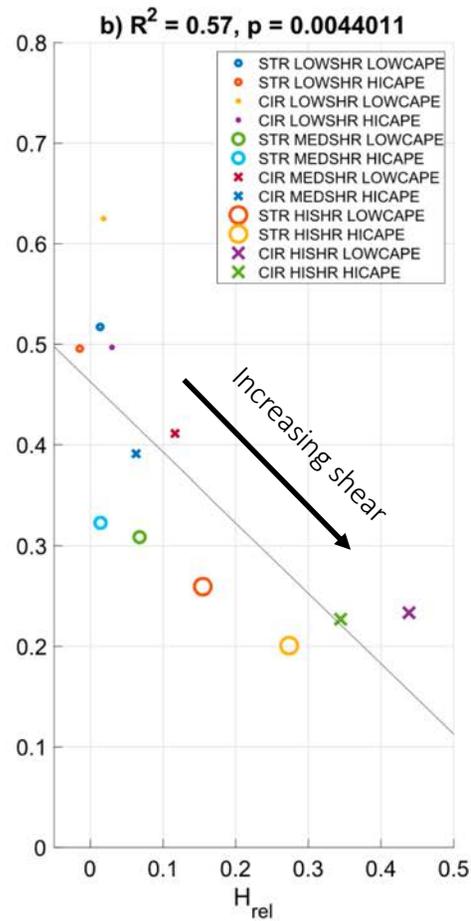
How does vertical wind shear
influence cloud width?



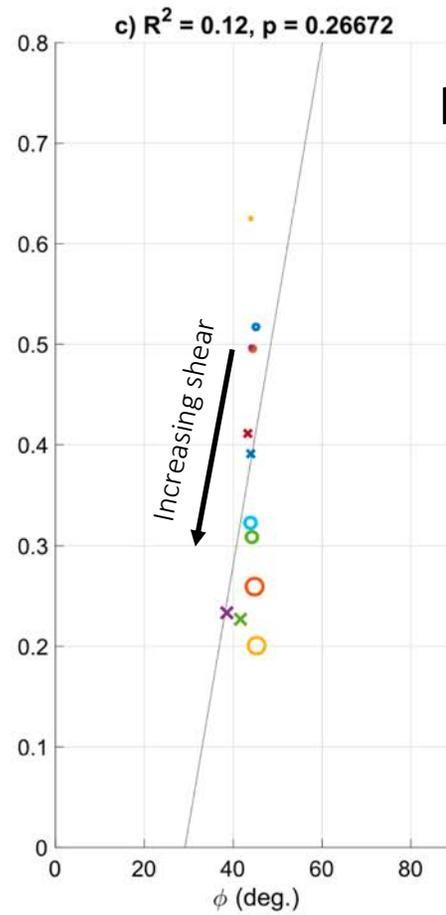
Distribution of updraft radii among CRM simulations



Strong correlations with inverse radius



Weaker correlations with rotational characteristics



From Peters et al. (2020a), JAS

Using vertical wind shear to
predict updraft width,
entrainment, in a “smart
entraining CAPE” calculation

Tradition entraining CAPE

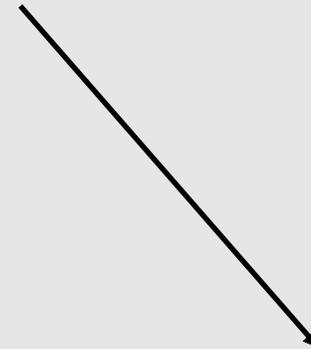
Background sounding: T,
RH, wind, etc

CAPE (for undilute parcel)

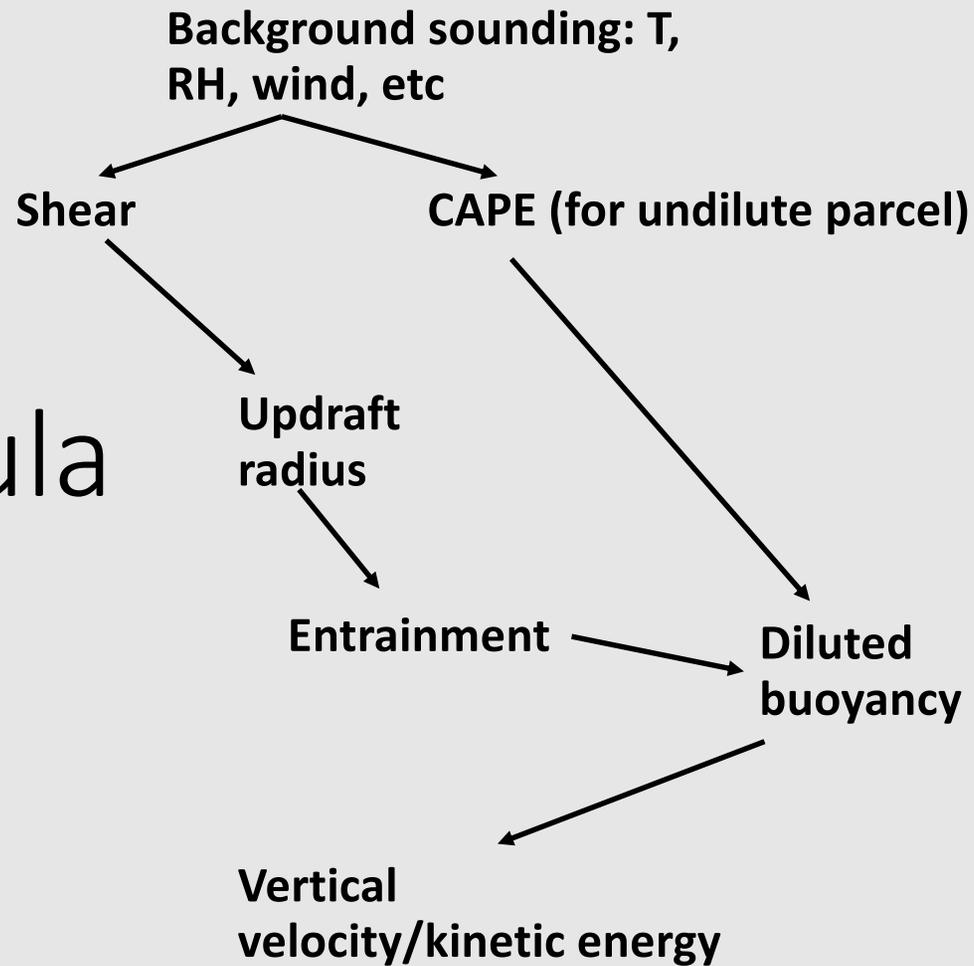
Entrainment

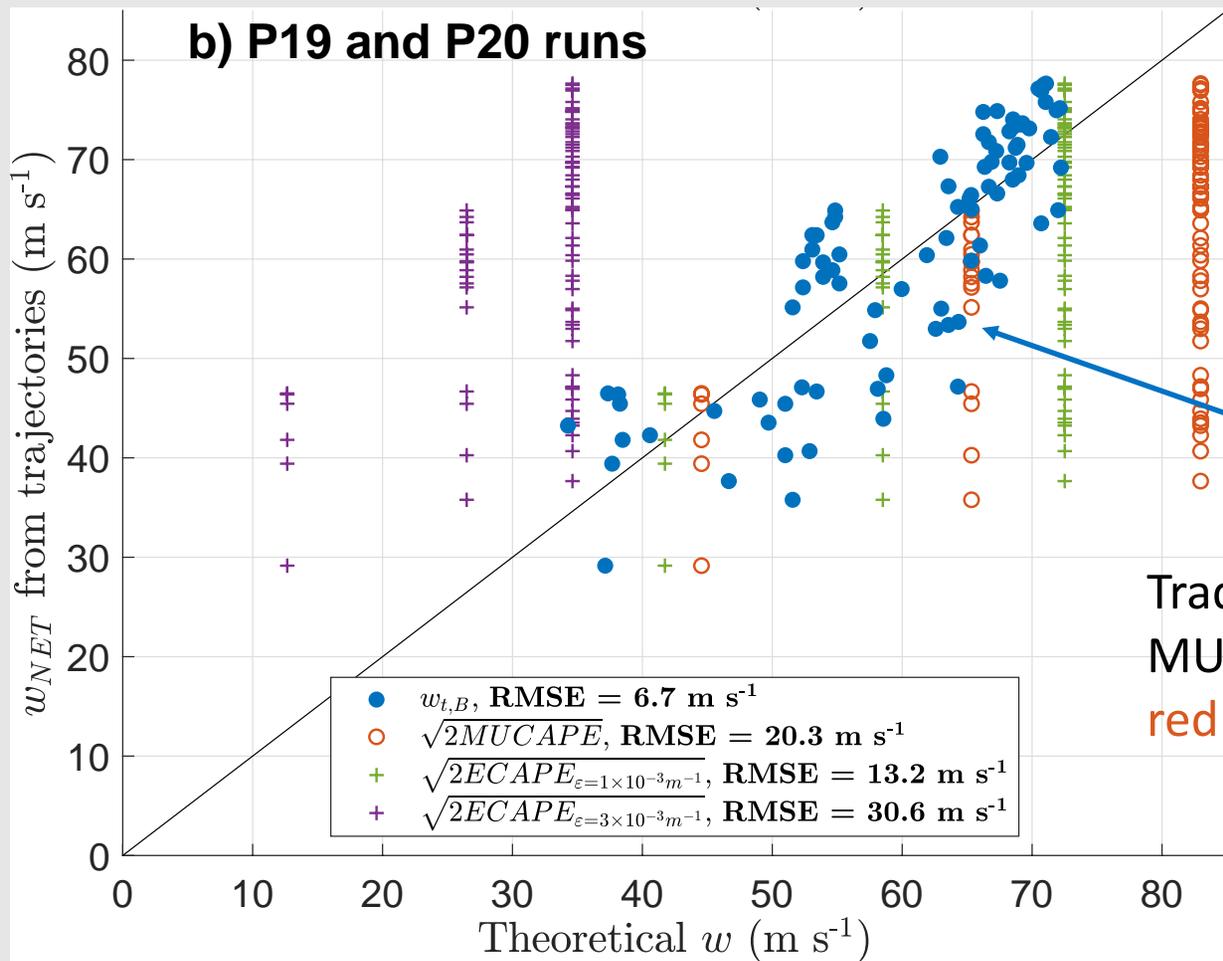
Diluted
buoyancy

Vertical
velocity/kinetic energy



New formula





ECAPE with two different entrainment rates: green and purple

New formula (blue dots)

Traditional MUCAPE: red

Outstanding problems

- How do assumptions about updraft structure (i.e. plumes vs thermals) affect entrainment?
- What environmental factors other than vertical wind shear control updraft radius, particularly when shear is weak?
- Entrainment is a notoriously nebulous process – how do we reconcile the various methods for defining and measuring these quantities? Is there an obvious method that is optimal?
- How do we improve the treatment of entrainment in cumulus parameterizations based on the fundamental knowledge we have gained?