Entrainment in deep convection

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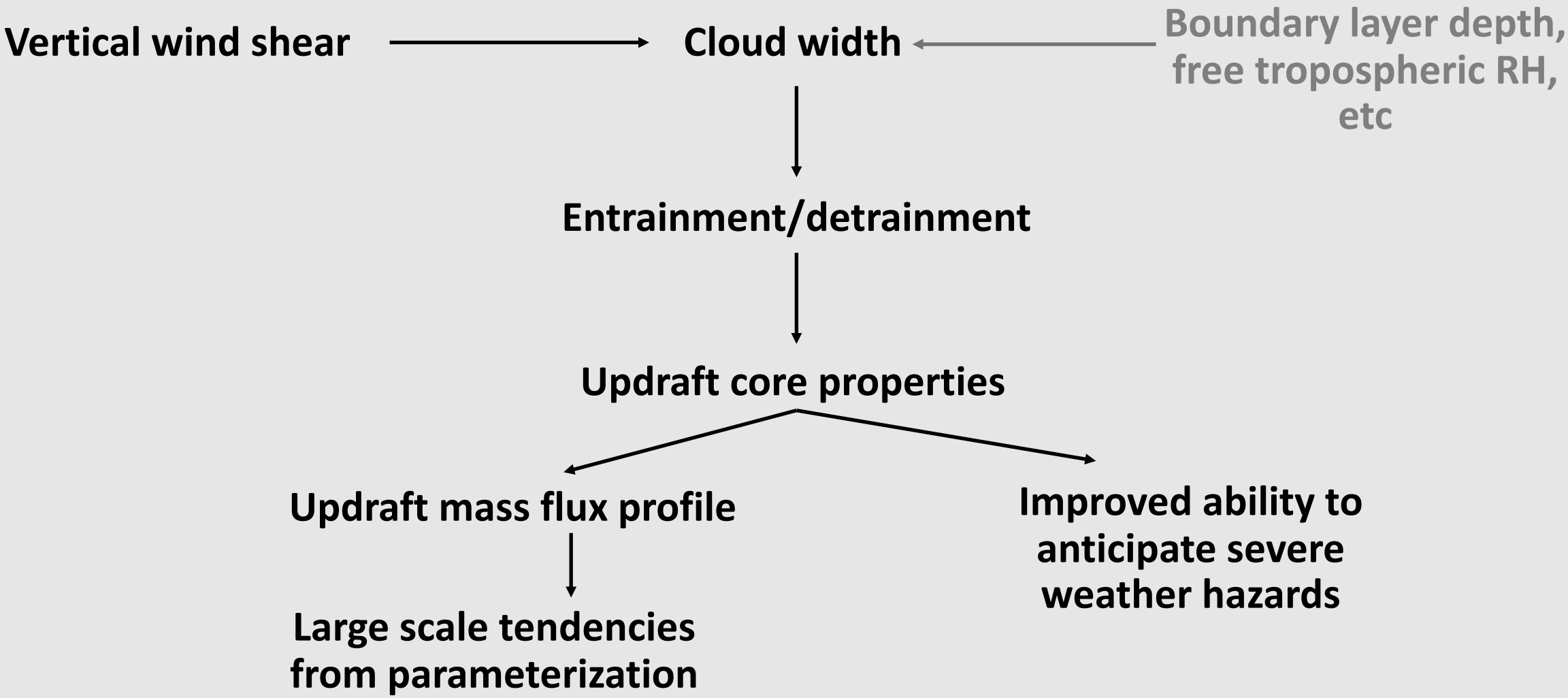
Importance of entrainment



Vertical mass flux scales as **radius squared**

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

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

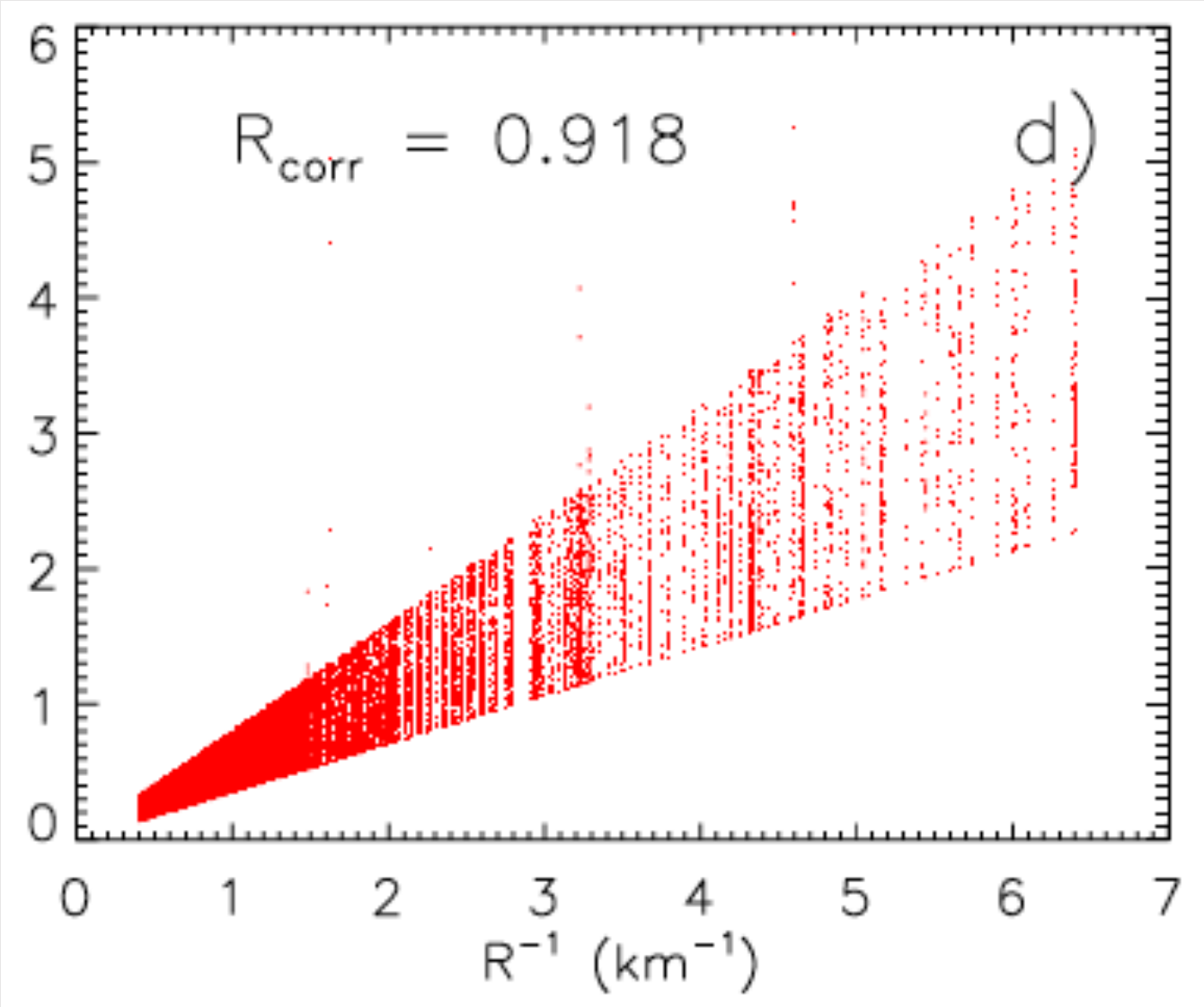
$$e \sim \rho u R$$

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

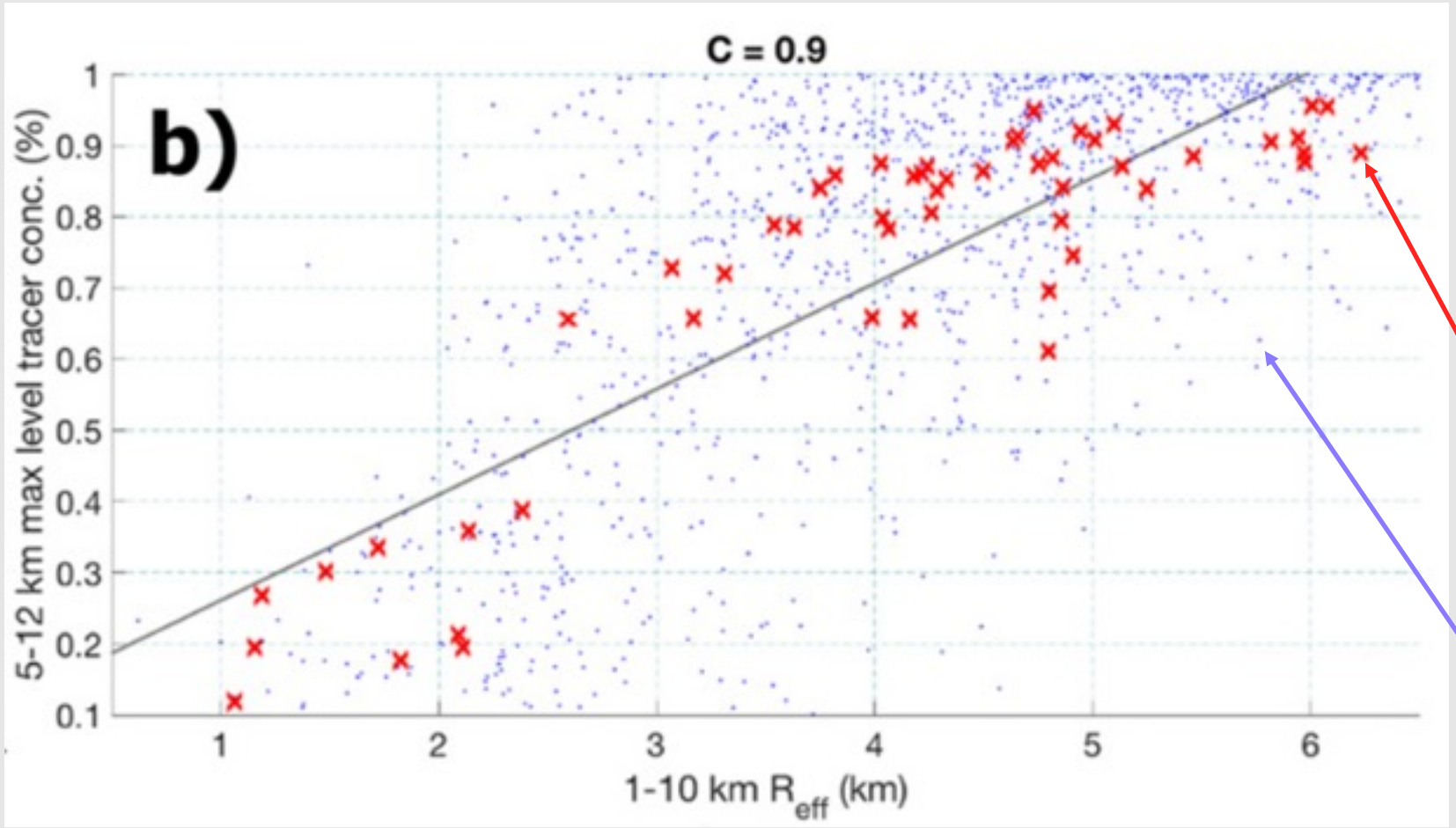
$$\varepsilon \sim {}^{e}/_{M} \sim R^{-1}$$

From Morrison et al. (2020), JAS

$\varepsilon\ (km^{-1})$



Theoretical relationship

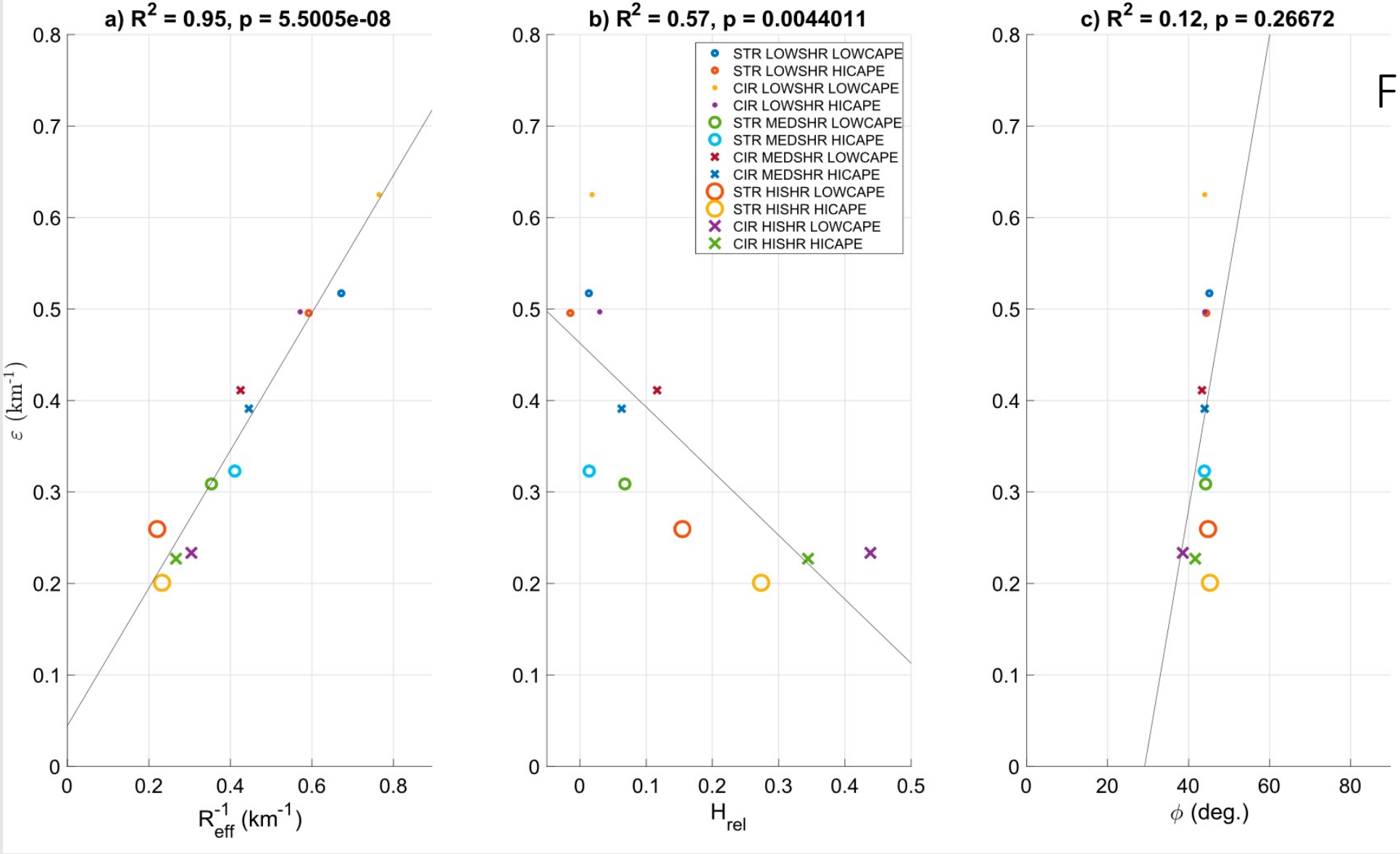


From Peters et al. (2019), JAS

Whole model run averages

Individual 5-minute time snapshots

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

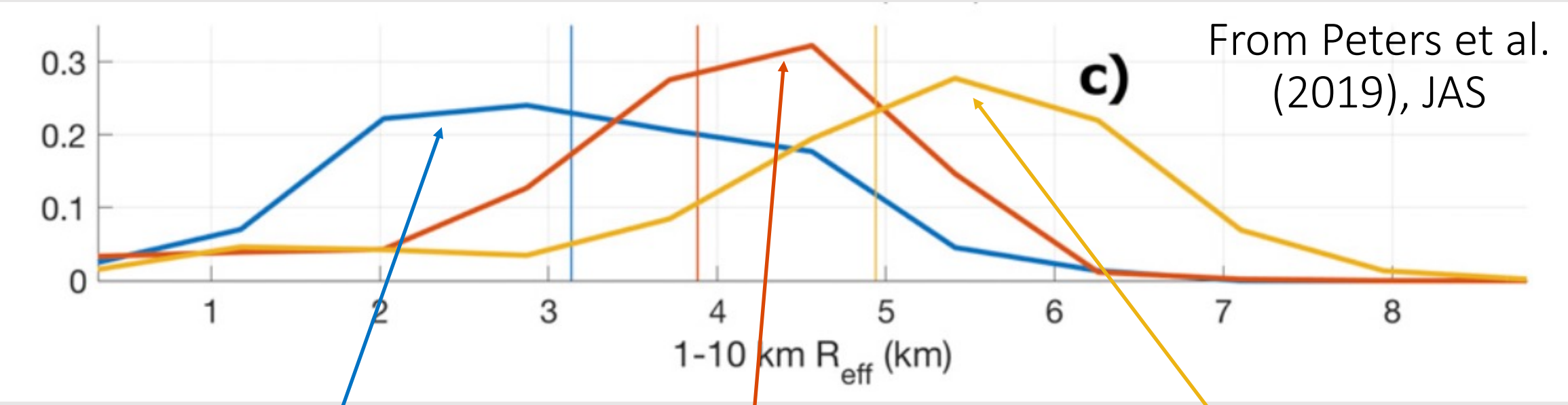


From Peters et al. (2020a), JAS

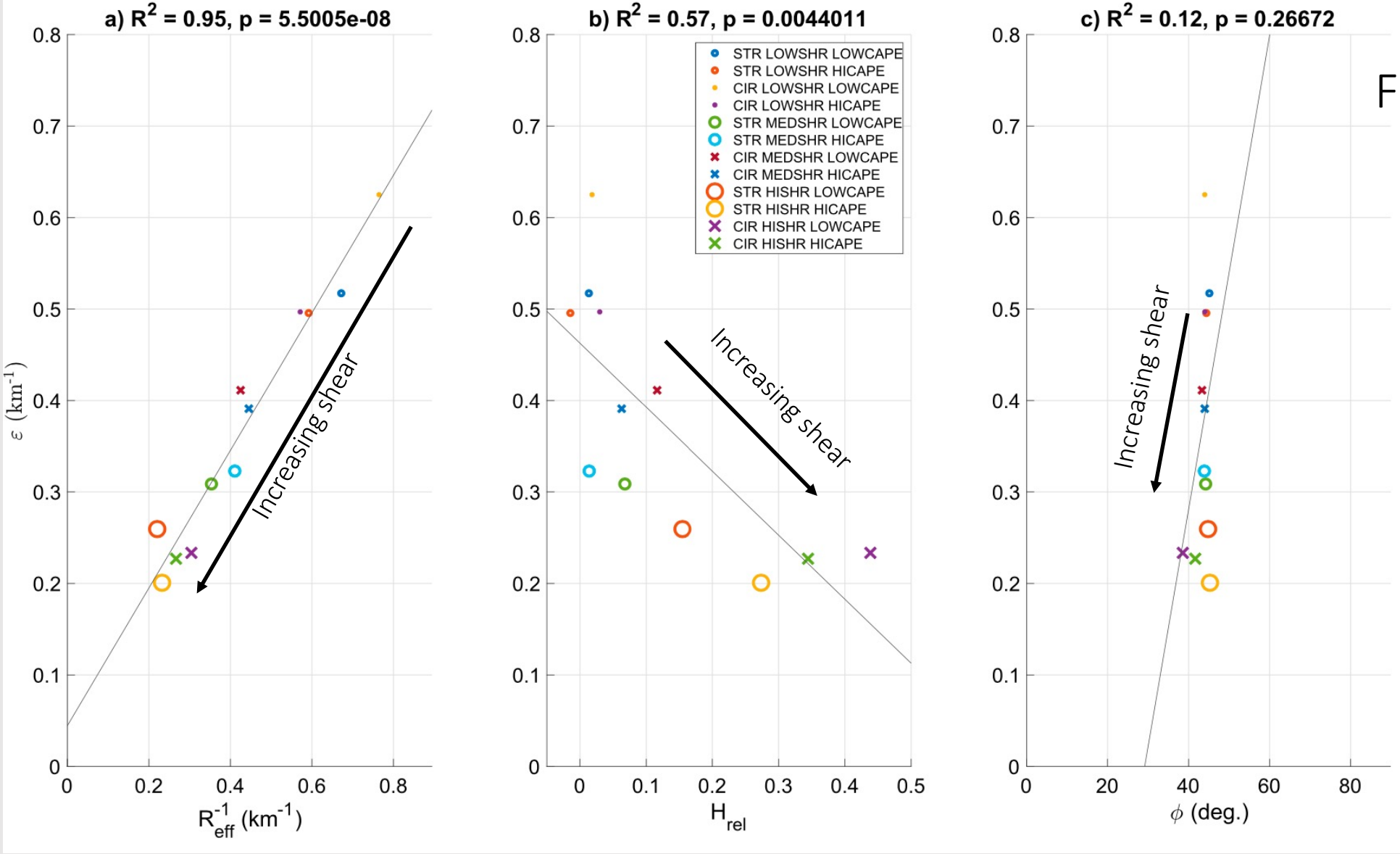
Strong correlations with inverse radius

Weaker correlations with rotational characteristics

How does vertical wind shear influence cloud width?



Distribution of updraft radii among CRM simulations



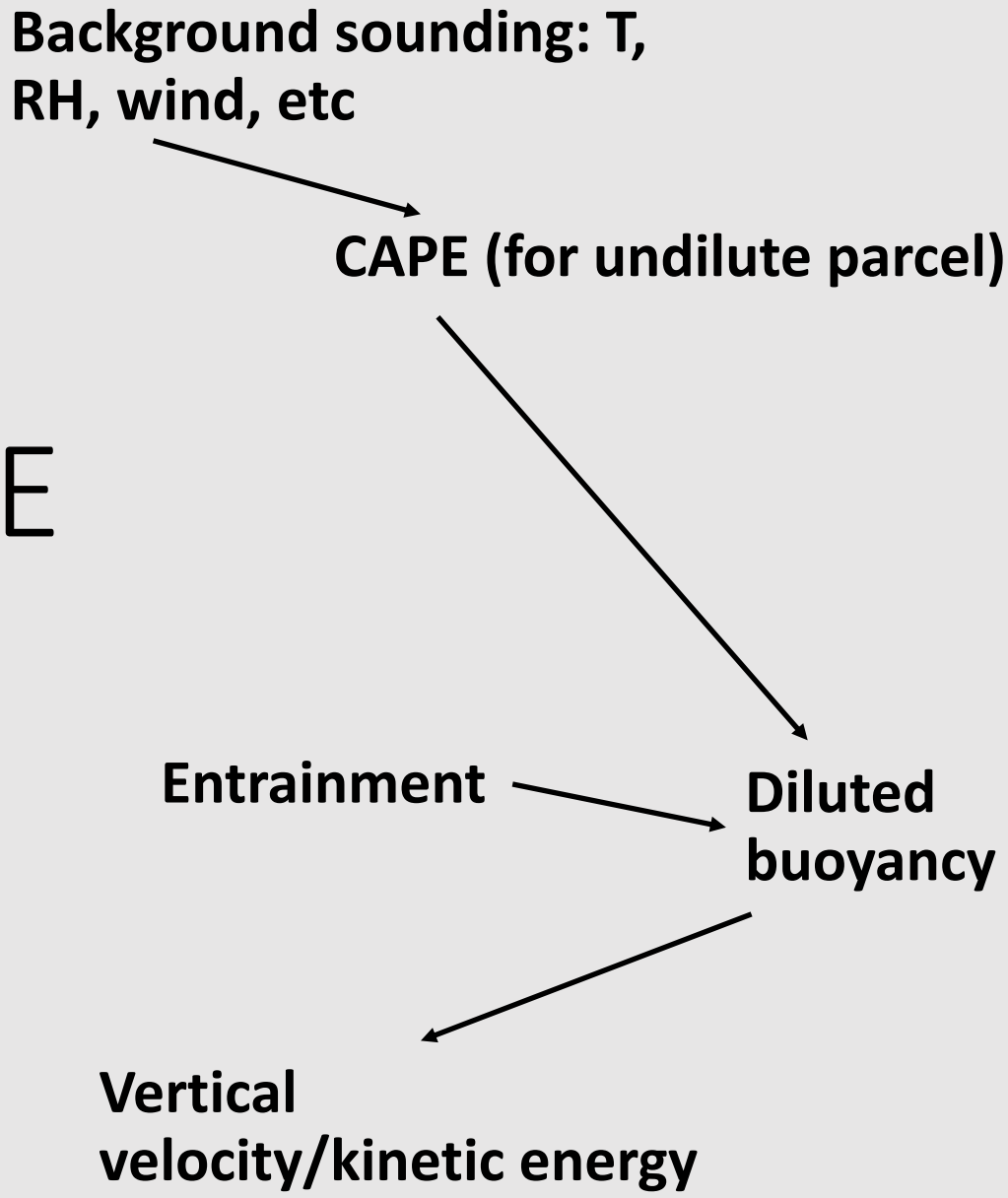
From Peters et al. (2020a), JAS

Strong correlations with inverse radius

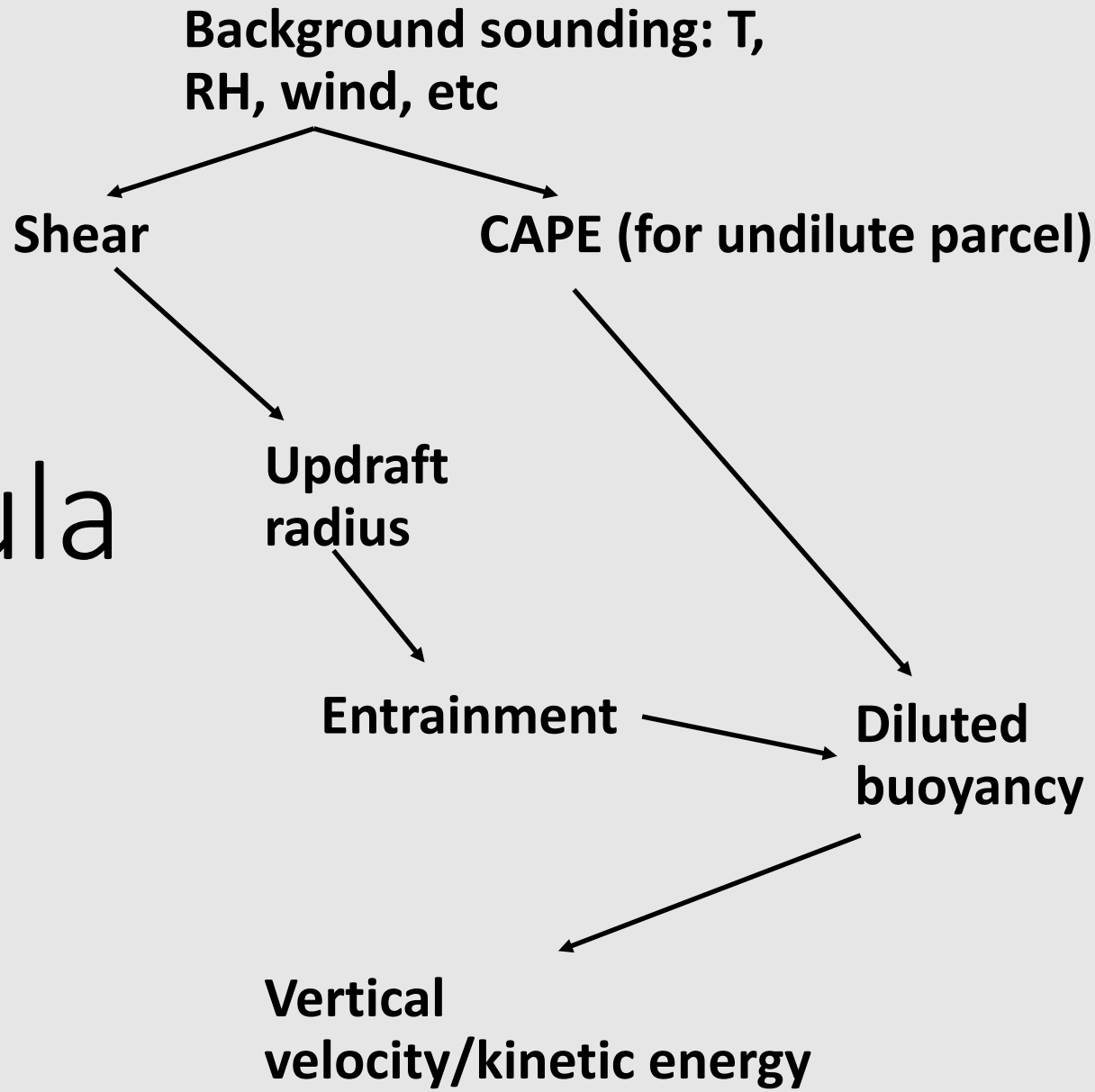
Weaker correlations with rotational characteristics

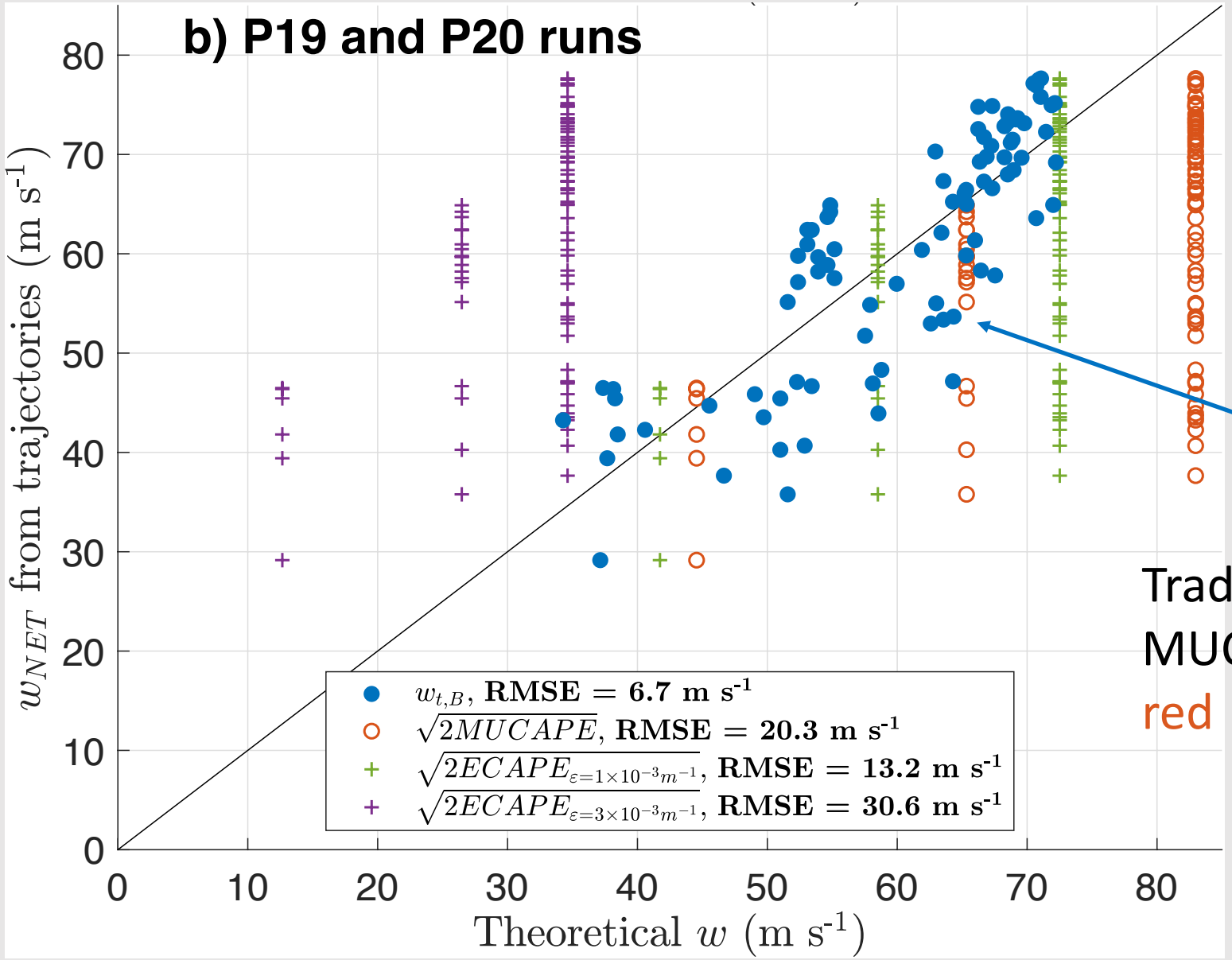
Using vertical wind shear to predict updraft width, entrainment, in a “smart entraining CAPE” calculation

Tradition entraining CAPE



New formula


Background sounding: T, RH, wind, etc
Shear
CAPE (for undilute parcel)
Updraft radius
Entrainment
Diluted buoyancy
Vertical velocity/kinetic energy



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 week?
- Entrainment is a notoriously nebulas 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?