A New Parameterization for Entrainment Rate of Shallow Cumulus Based on SGP Observations

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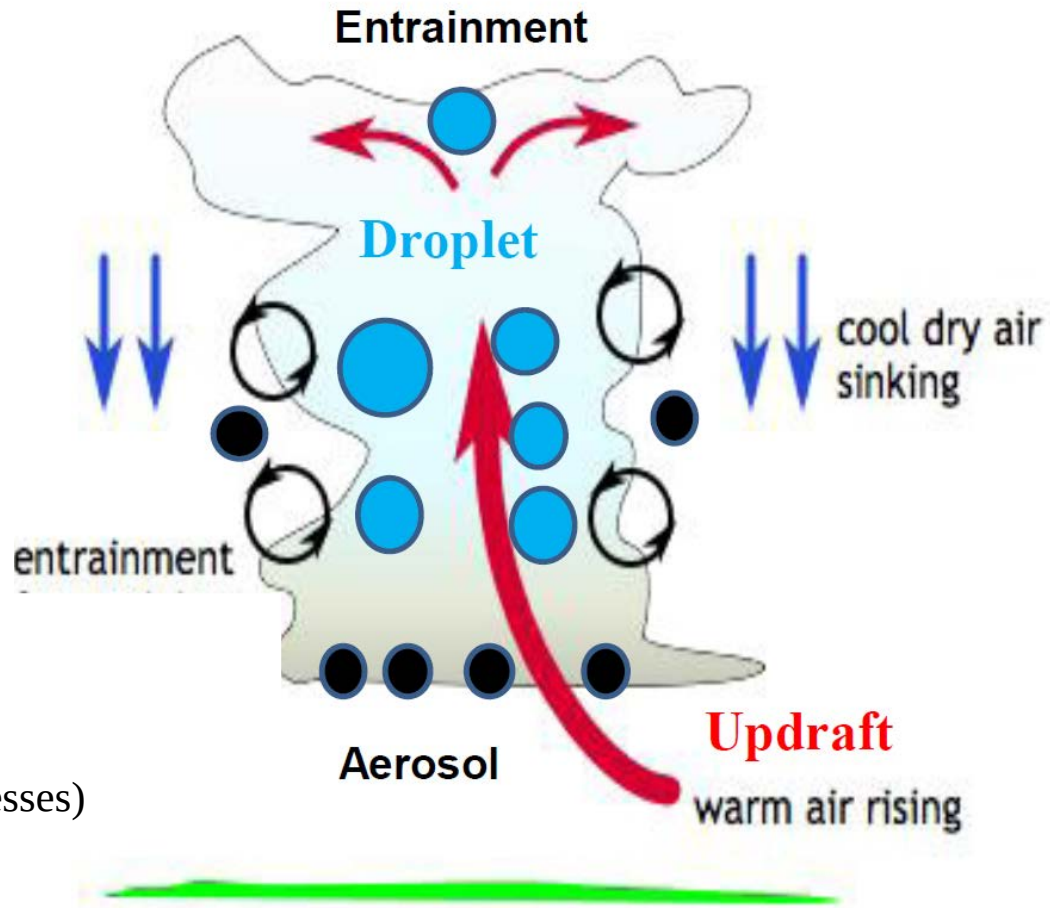
Shallow Cumuli as Open Multi-Physics System

- **Entrainment Rate**
- **Vertical velocity**
- **Buoyancy**
- **Dissipation**
- **Environment RH**
- **Aerosol**
- **Turbulent mixing**
- **Microphysics**

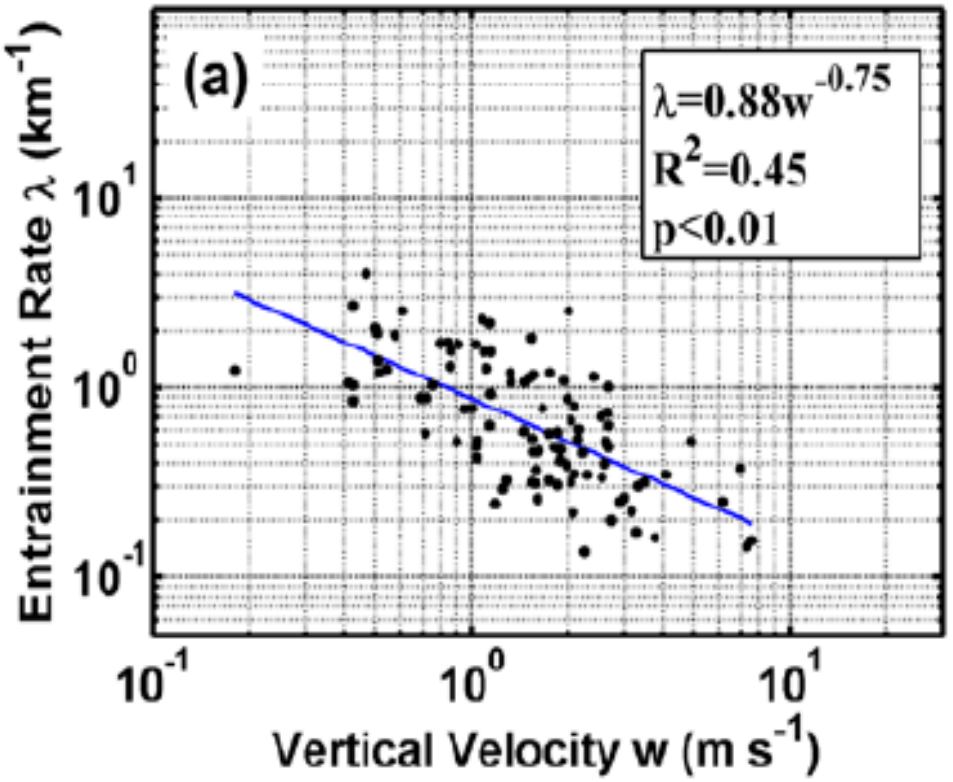
(See Lu et al, 2011, 2012, 2013 and 2014 for entrainment method, and mixing processes)



Approach: examine the relationship of entrainment rate to the other key variables in growing shallow cumuli.

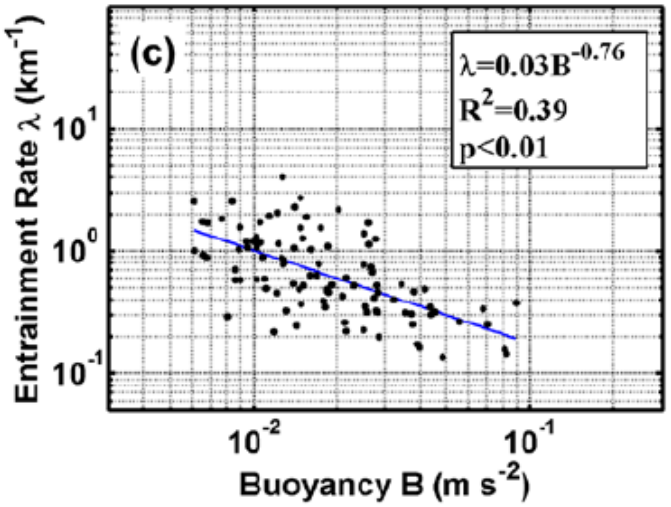
Relationship between Entrainment Rate and Vertical Velocity

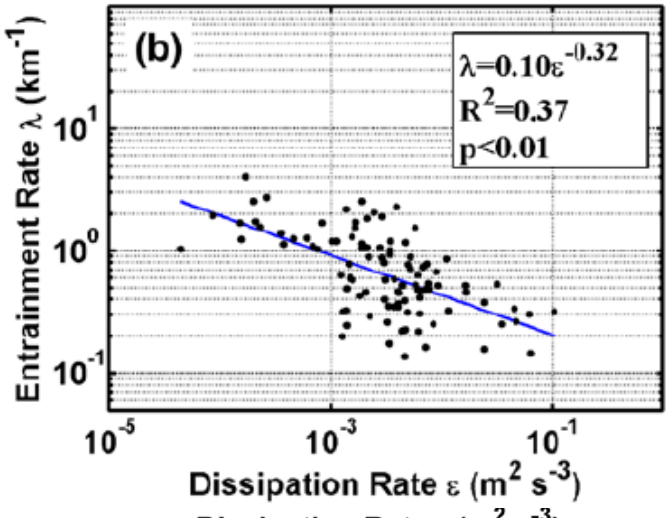
- 102 RACORO cumul
- Aircraft measurement
- Method for estimating entrainment rate (Lu et al., GRL, 2012)

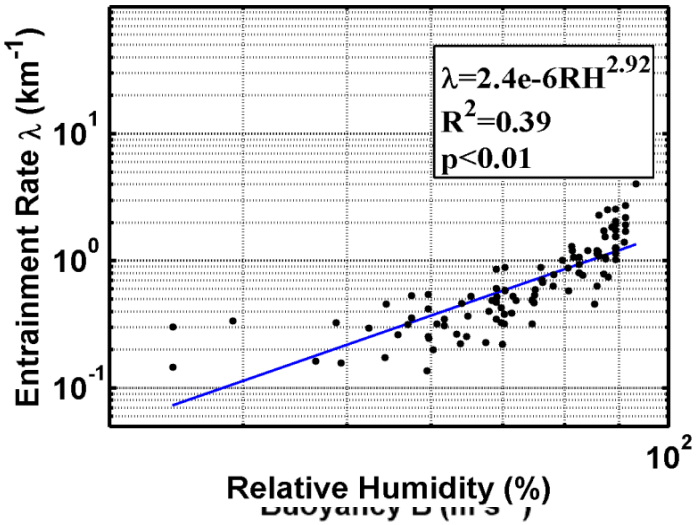


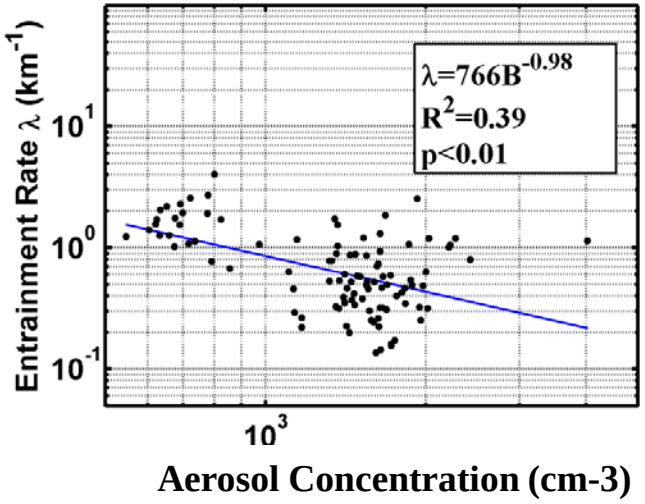
The negative correlation provides observational evidence for Parameterizing entrainment rate as a function of updraft velocity. But ….

More Pairwise Relationships







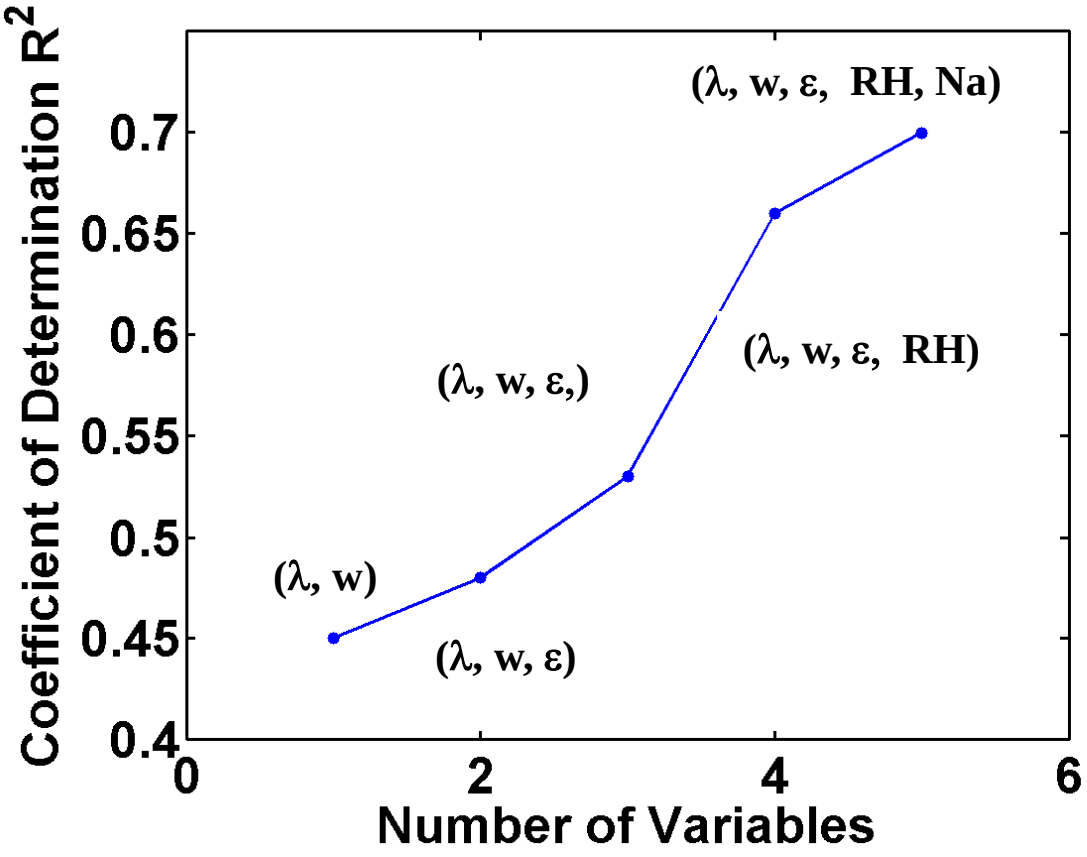


These results suggest shallow cumulus is a system in which many variables are related to one another but only with partial correlations around 0.5.

Q: How to develop parameterization for a system with a number of partially correlated relationships?

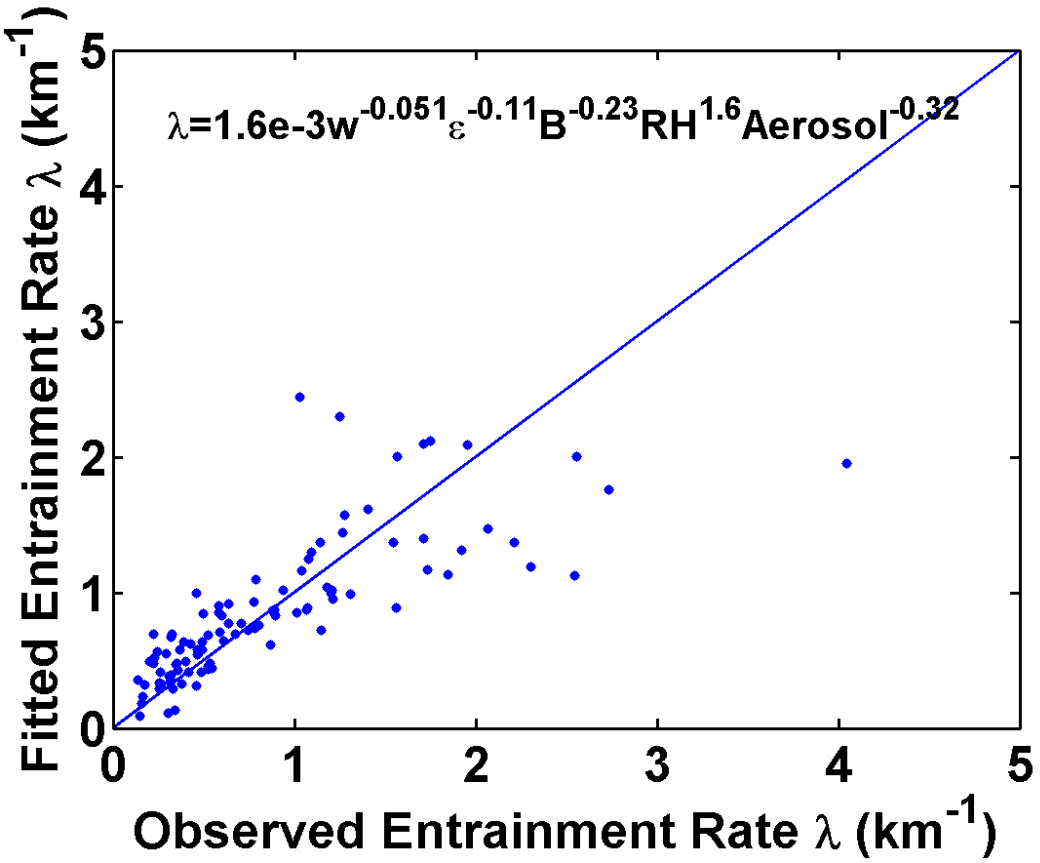
A: Use stepwise multi-variate PCA regression.

Regression Improves with Adding Variables



Vertical velocity, buoyancy, dissipitation rate, RH and aerosol concentration each carry similar significance in representing entrainment rate; the best parameterization considers them all.

The Best Parameterization



Future Work:

1) **Validation against independent obs, e.g., at ENA site**
2) **Advanced cause-effect-feedback analysis**

Deeper Physical Question:

How to address such a multi-physics system with multiple "grey" cause-effect-feedbacks?

Thanks for your attention and comments!

Parameterization