Subcloud controls on shallow-cumulus dilution

Daniel Kirshbaum[1], K. Lamer[2], S. Drueke[1]

[1]McGill University, Montreal, Quebec

[2]Brookhaven National Laboratory, Upton, NY, USA

Motivation and Objectives

- Cumuli are diluted by entrainment of surrounding air
  - Modifies internal cloud properties and cloud life cycle

- Factors regulating dilution are poorly understood and parameterized
  - Dilution is a flow-dependent process (e.g., Kirshbaum and Lamer, 2021), but underlying mechanisms are uncertain

- **Question**: how do subcloud processes influence cloud-layer dilution?

- **Objectives**: synthesize ARM observations and LES to investigate impacts of two subcloud parameters
  - Mean wind speed (V_{sc}), cloud-base mass flux (M_b)

Experiment Plan

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- ARM observations: two bulk-entrainment (i.e. dilution) retrievals
  - Jensen and Del Genio (2006; JD06): entraining parcel model to match ELNB to observed cloud-top height
  - Drueke et al. (2019; D19): analytic scaling based on TKE similarity theory
  - Apply at both continental SGP (638 clouds) and maritime ENA (1,920 clouds) over 4+ year period (2015-2019)

- Large-eddy simulation (LES): cm1 model (Bryan and Fritsch, 2002)
  - Consistent results with past model inter-comparison studies (D19)
  - 5th-order WENO nonoscillatory momentum and scalar advection
  - 32 m horizontal, 40 m vertical grid spacing
  - Configurations based on continental ARM-SGP (Brown et al. 2002) and maritime BOMEX (Siebesma et al. 2003) cases

ARM dilution retrievals

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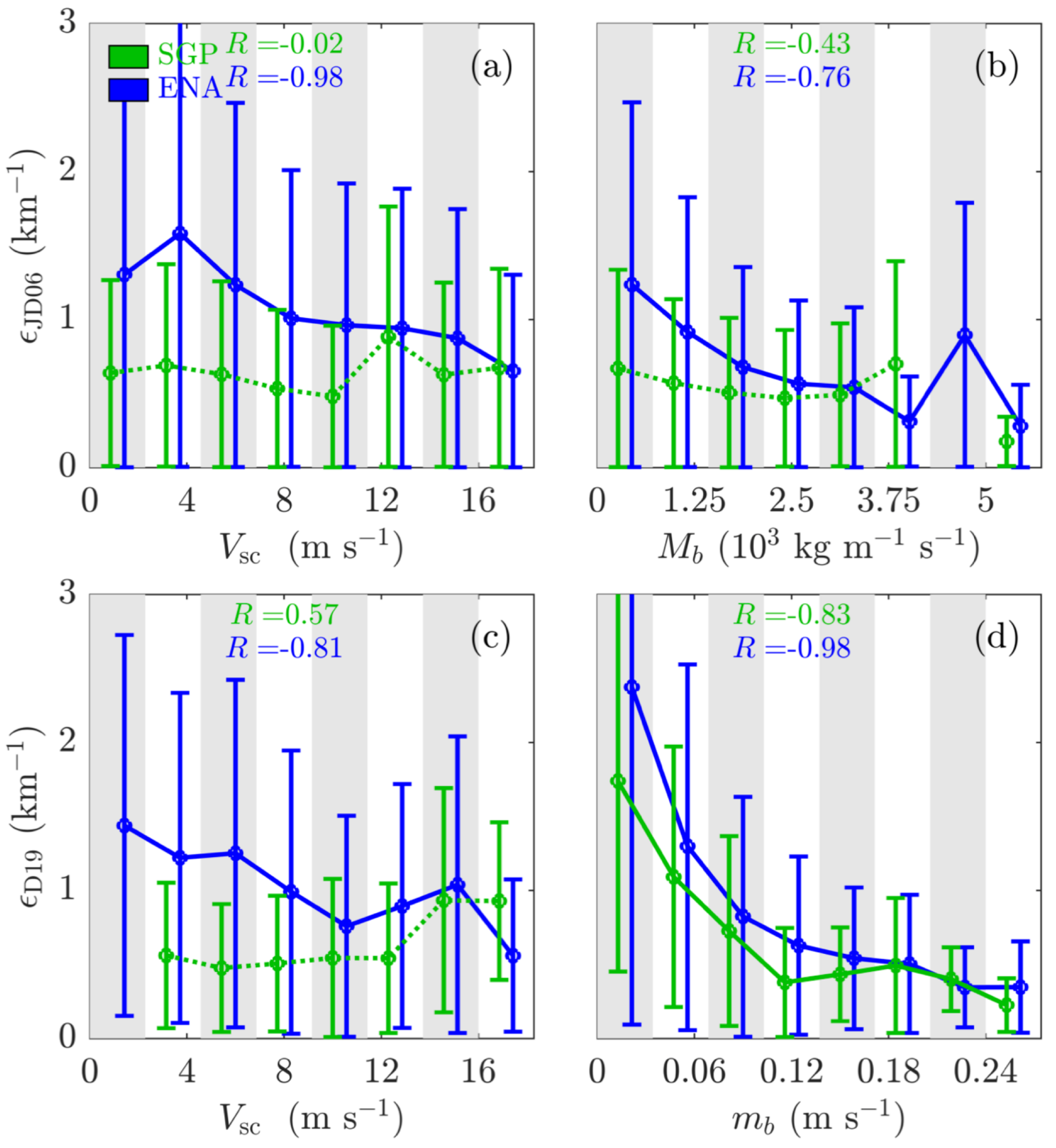
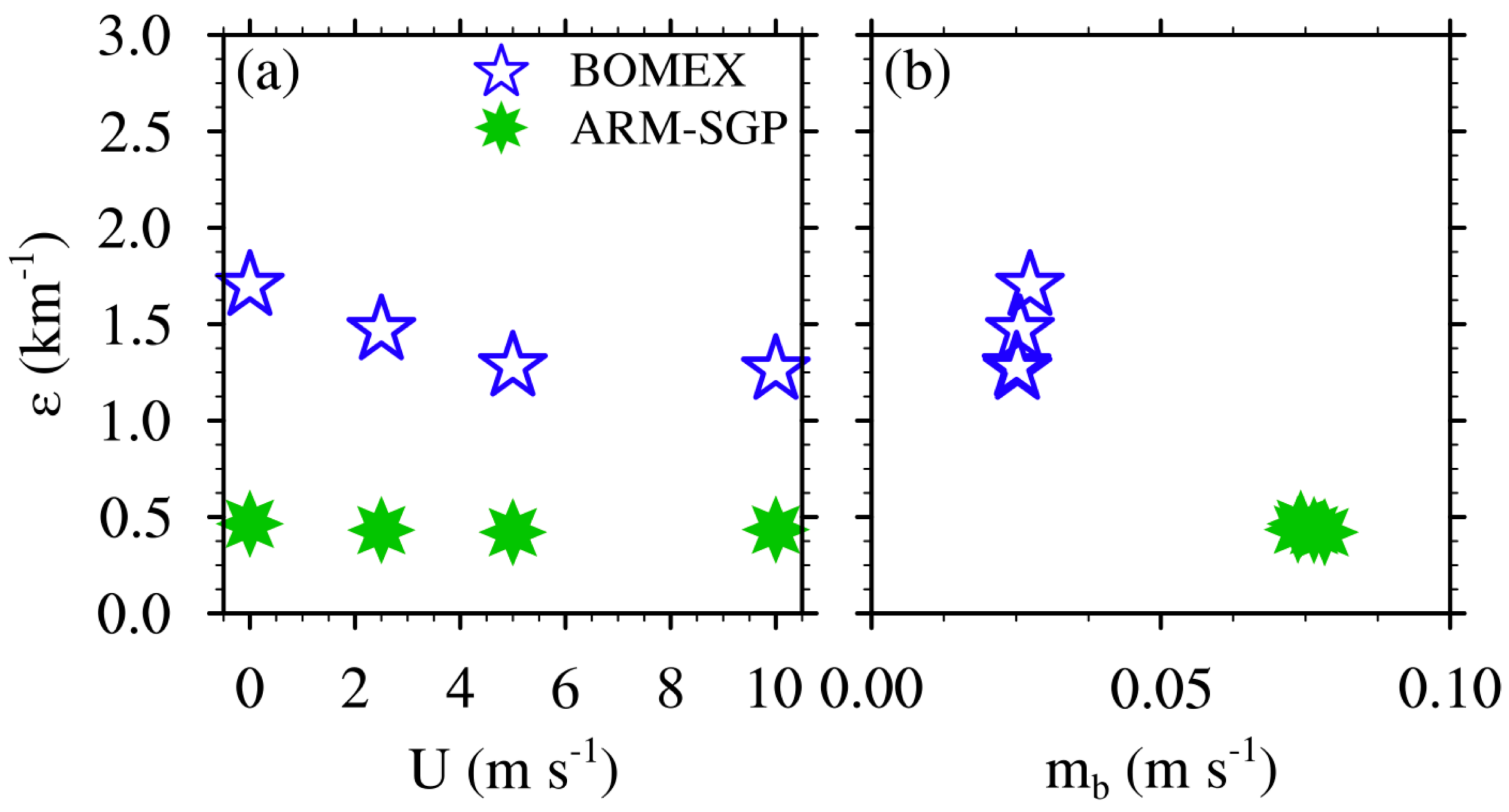
- V_{sc}: mean subcloud wind speed from sounding
- M_b: cloud-base mass flux along cloud chord (JD06)
- m_b: time-averaged vertical velocity at cloud base (D19)

- Two retrievals give consistent results:
  - ϵ depends inversely on V_{sc} at ENA, not at SGP
  - ϵ depends inversely on both M_b and m_b



LES experiments

- Simulated cloud-core ϵ consistent with retrievals
  - ϵ depends inversely on mean geostrophic subcloud wind (U) at ENA but not at SGP
  - ϵ depends inversely on m_b (m_b is much larger at SGP)



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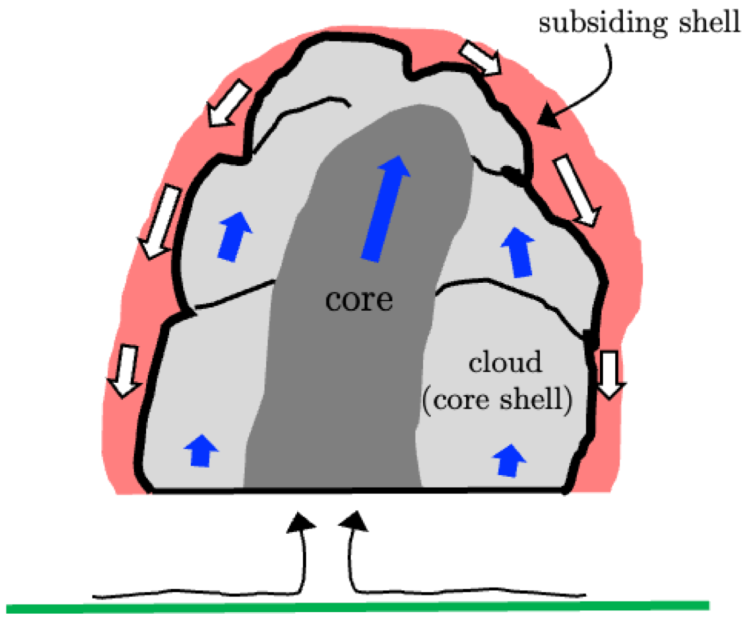
Interpretation

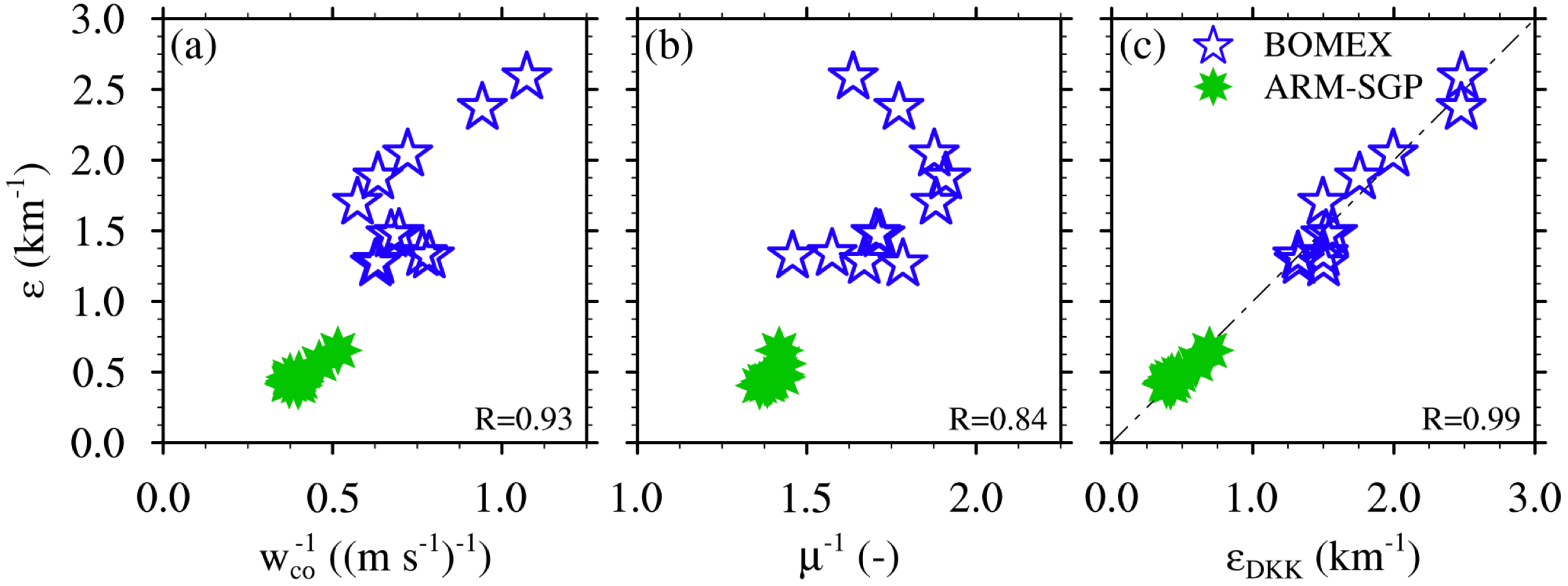
- Interpretive framework based on conceptual model of a cumulus

- Two main control parameters:
  - Core updraft velocity w_{co}: regulates exposure time of cloud to environment
  - Core-exterior mixing fraction μ: regulates dilution induced by a given entrainment flux
  - Empirical function explains most variability:

$$\epsilon_{\mathrm{DKK}} = w_{\mathrm{co}}^{-1.14}\mu^{-1.84} - 0.2$$



$$\mu = \frac{(q_t)_{\mathrm{co}}}{(q_t)_{\mathrm{co}} + (q_t)_{\mathrm{sh}}}$$



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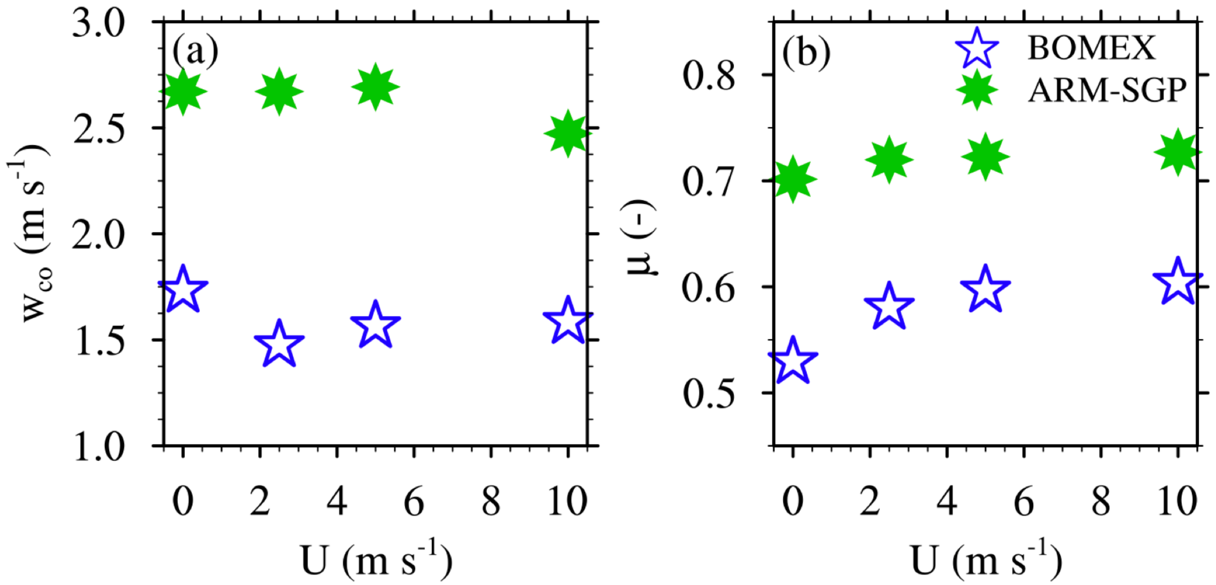
Interpretation

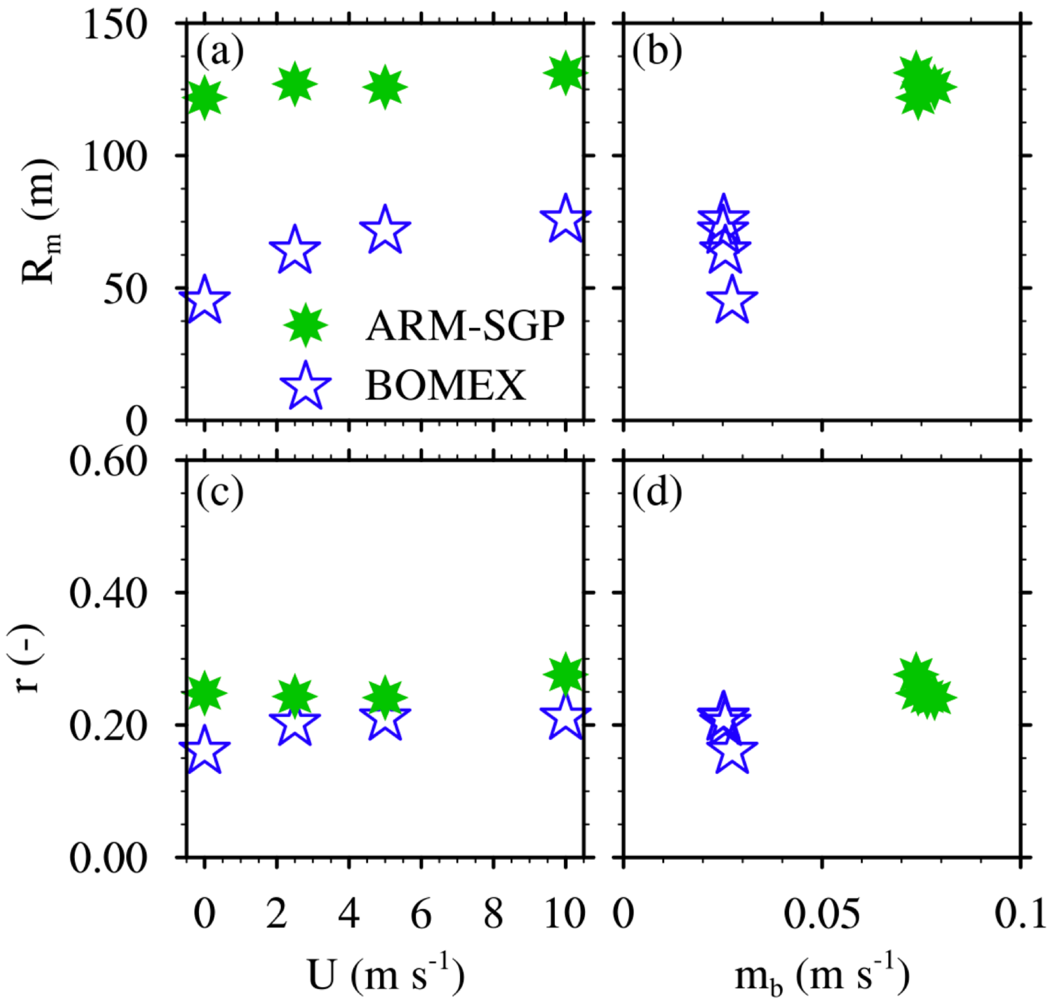
- As U increases,
  - w_{co} decreases due to enhanced shear and updraft suppression in lower cloud layer
  - μ increases, particularly in BOMEX

- Trends in μ related to core-shell width (R_m)
  - Wider core shells: moister core exterior, larger μ
  - Core-shell width depends on ratio $r = \frac{\sqrt{\mathrm{TKE_{cl}}}}{w_{co}}$

  where $\sqrt{\mathrm{TKE_{cl}}}$ is cloud-layer TKE

- Trends in μ largely a function of $\sqrt{\mathrm{TKE_{cl}}}$:
  - Larger m_b and/or U: larger $\sqrt{\mathrm{TKE_{cl}}}$, larger μ





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Conclusions

- In observations and LES, subcloud wind speed and cloud-base mass flux correlate robustly negatively with ϵ
- Trends in ϵ may be explained on the basis of cloud-core updraft speed (w_{co}) and core-exterior mixing fraction (μ)
- Dominant effect here (but not always) is μ, which increases with $\sqrt{\mathrm{TKE}_{\mathrm{cl}}}$
  - Stronger turbulence → wider core shells → moister entrained air → less dilute cores