Are long-term measurements at the ARM Southern Great Plains site adequate for detecting aerosol invigoration of deep convection?

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INTRODUCTION

Many studies conclude that increasing aerosol concentration tends to invigorate convection and lead to increased cloud top height with more extensive and thinner anvils. A few of these studies have used data from the ARM SGP site to reach this conclusion (e.g., Li et al., 2011), while also concluding that meteorological effects on cloud top height are negligible for different aerosol regimes.

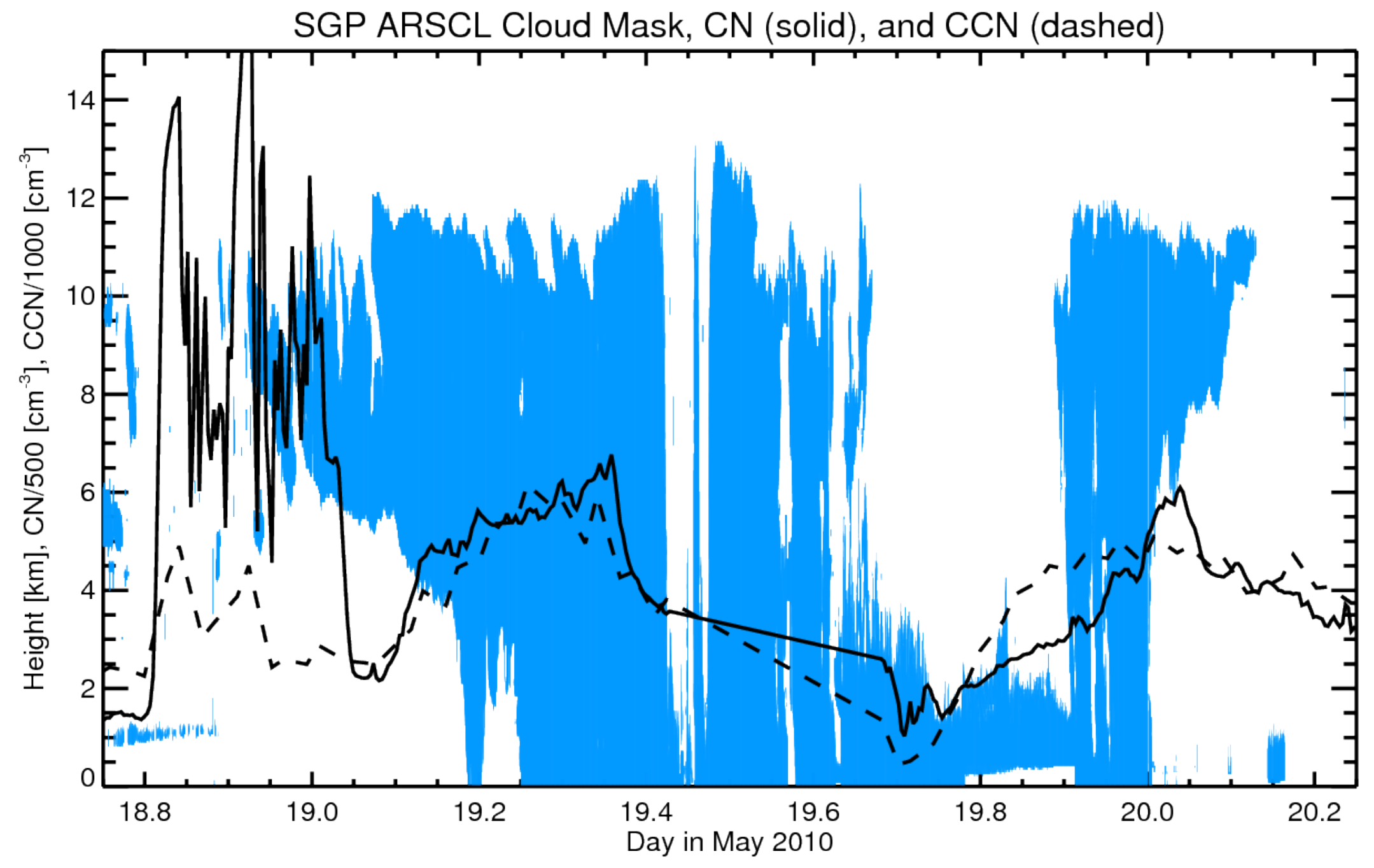
This study is intended to rigorously test these conclusions at the ARM SGP site and to determine, through combined observations and idealized modeling, the necessary measurements to isolate and quantify an aerosol convective invigoration effect.

METHODS AND MODELS

We are using 14 years (1997-2010) of April-October CN, ARSCL, MERGESONDE, and sounding retrievals from the ARM SGP site. The methodology is as follows:

1. Define contiguous time-height ARSCL cloud objects with each object representing an independent sample rather than each time of single-layer clouds because single-layer clouds are often measurements of the same cloud and miss large portions of the cloud in which layers overlap.
2. Use MERGESONDE to determine cloud base (CBT) and cloud top temperatures (CTT) and only use clouds with CBT > 15°C and CTT < -4°C following Li et al. (2010).
3. Use the median surface CN concentration between the start time of the cloud object (at any altitude) and the start time of the lowest cloud base height.
4. Use Mike Jensen's calculations from soundings between April and October 1997-2010 with CAPE > 0, LCL > 15°C, and LNB < -4°C to examine CAPE, LNB, and wind shear as a function of surface CN.
5. Run idealized 2D WRF simulations (500 km long, 1 km grid spacing, 92 vertical levels, open boundaries, warm bubble initialization) with the simplified Hebrew University bin scheme (Khain et al., 2009) and the Weisman/Klemp sounding (1982) to analyze the relative impacts of CCN, humidity, and vertical wind shear on convective system properties.

SGP ARSCL Cloud Mask, CN (solid), and CCN (dashed)



REFERENCES

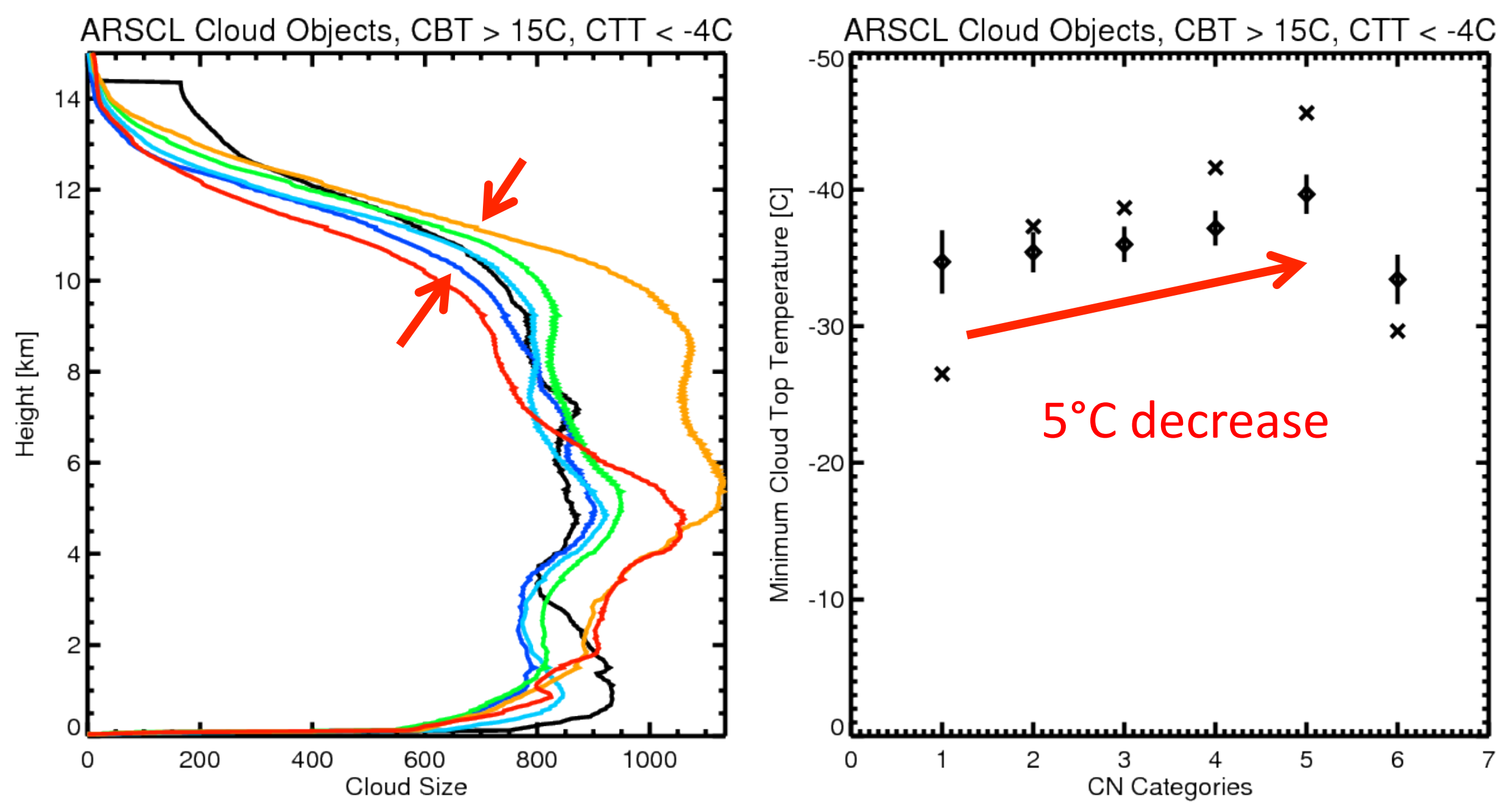
Khain, A., et al. (2009), Effects of aerosols on the dynamics and microphysics of squall lines simulated by spectral bin and bulk parameterization schemes, *J. Geophys. Res.*, 114, D22203.

Li, Z., et al. (2011), Long-term impact of aerosols on the vertical development of cloud and precipitation, *Nat. Geosci.*, 4, 888-894.

Weisman, M. L. and J. Klemp (1982), The dependence of numerically simulated convective storms on vertical wind shear and buoyancy, *Mon. Wea. Rev.*, 110, 504-520.

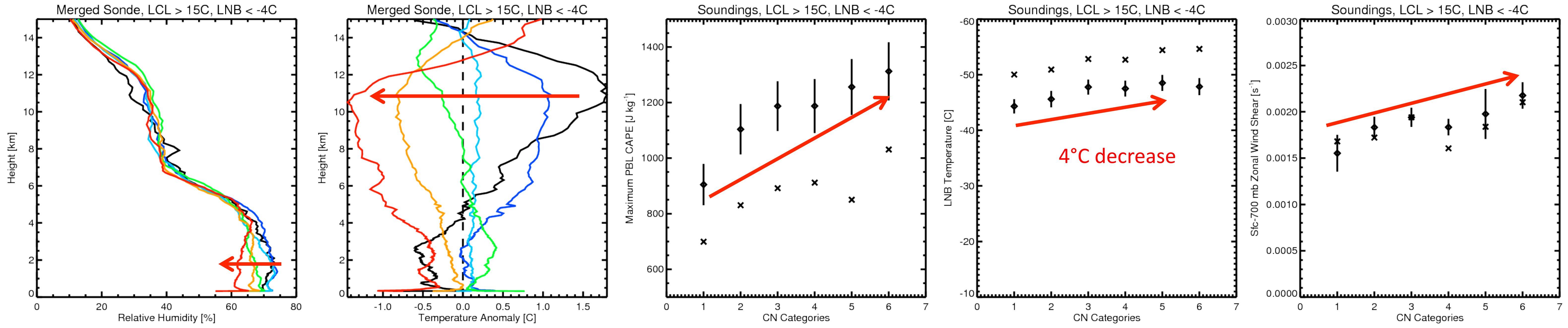
Relating Convective Clouds, Condensation Nuclei, and Meteorology with ARM SGP Observations

Cat. 1: CN < 1000	Samples: 91
Cat. 2: 1000 < CN < 2000	Samples: 229
Cat. 3: 2000 < CN < 3000	Samples: 308
Cat. 4: 3000 < CN < 4000	Samples: 309
Cat. 5: 4000 < CN < 5000	Samples: 235
Cat. 6: 5000 < CN < 6000	Samples: 139



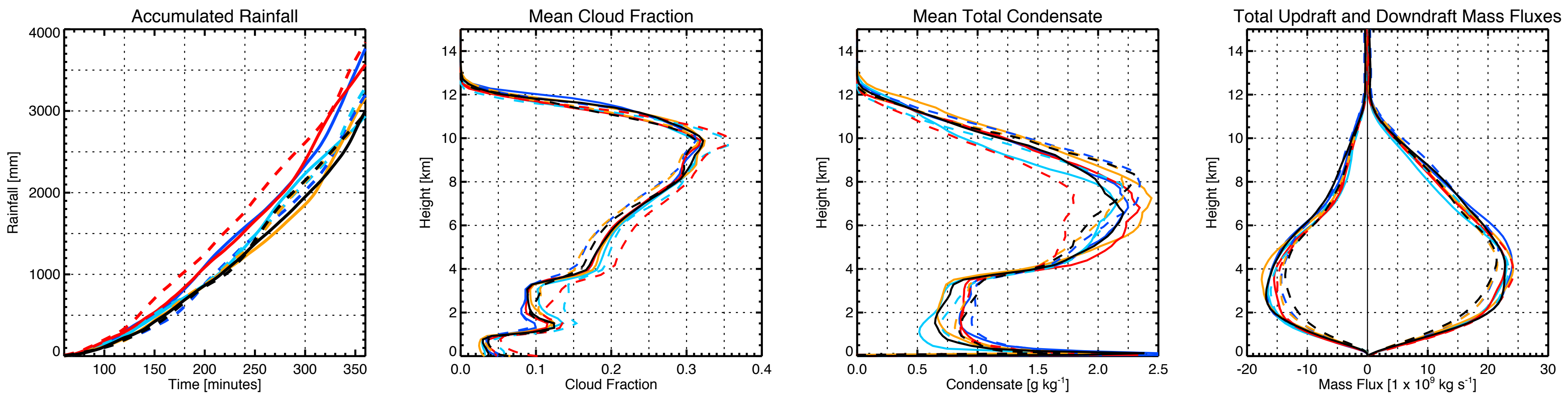
For warm cloud base and cold cloud top systems, the lowest and highest CN categories suffer from low sample sizes, but there is a decrease in minimum CTT and mean anvil CTT with increasing CN for the intermediate categories. However, temperature lapse rates steepen and lower tropospheric humidity decreases as a function of CN during times when the systems considered are present.

Instability, LNB, and wind shear also increase with increasing CN, which could explain much of the decrease in CTT with increasing CN.



Sensitivity of Convective Systems to Environmental Factors in Idealized Simulations

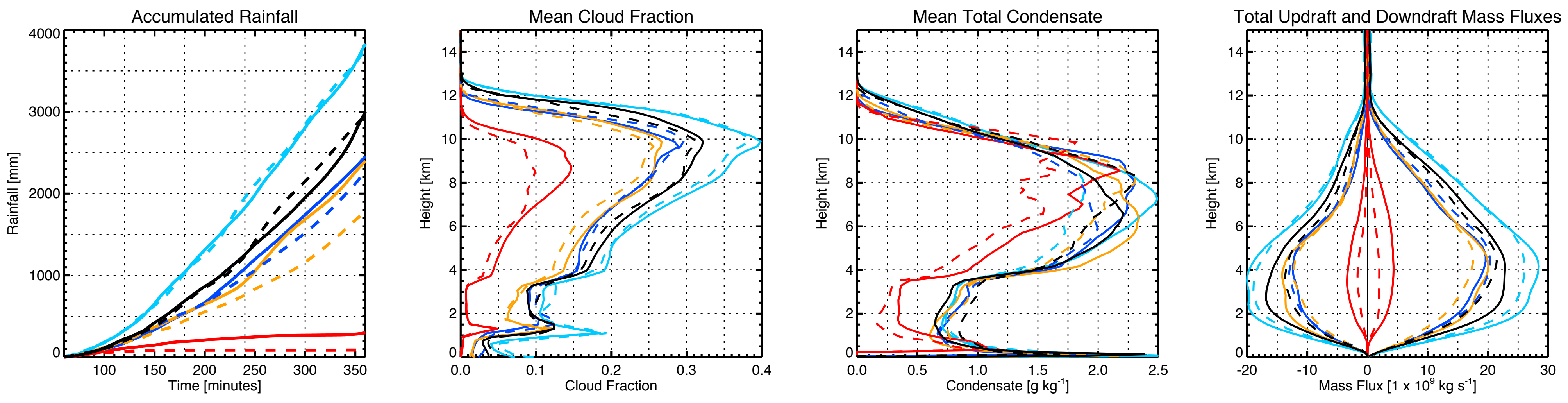
- Weisman/Klemp (1982) Sounding
- Add 3 m s^{-1} vertical wind shear over 2.5 km
- Subtract 3 m s^{-1} vertical wind shear over 2.5km
- Decrease vertical wind shear depth by 500 m
- Increase vertical wind shear depth by 500 m



Dashed lines: PBL $CCN_{0.4}$ = 425 cm^{-3}
Solid lines: PBL $CCN_{0.4}$ = 1700 cm^{-3}

CCN drops off exponentially with height in free troposphere

- Weisman/Klemp (1982) Sounding
- Decrease PBL Qv by 1 g kg^{-1}
- Increase PBL Qv by 1 g kg^{-1}
- Decrease free tropospheric water vapor mixing ratio by 10%
- Decrease free tropospheric water vapor mixing ratio by 20%



CONCLUSIONS AND FUTURE WORK

CTT generally decreases with increasing CN for warm CBT and cold CTT, but the decrease and correlation are weaker than in past studies due to our different methodology. Surface CN concentration is positively correlated with CAPE, LNB, and wind shear for situations with warm LCL, cold LNB, and CAPE > 0, which could plausibly explain much of the CTT-CN correlation, however more work needs to be done correlating specific convective systems to their large-scale environment. Further work will also concentrate on relating CN and CCN (which have different diurnal cycles at the SGP), examining sensitivity to the CN measurement used, removing precipitation-affected CN measurements, and using regional satellite, rainfall, and atmospheric analyses to place SGP measurements into context.

Idealized 2D simulations with bin microphysics show that changing water vapor mixing ratios in the free troposphere or PBL by 5-10% can easily outweigh effects on clouds and precipitation from a four-fold increase in CCN, while changes in vertical wind shear of a few m s^{-1} can result in comparable effects. More simulations will be performed to better quantify changes in clouds, precipitation, and mass fluxes to changes in CCN, humidity, vertical wind shear, and model resolution.

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