Shallow Cumuli at the SGP Site: Macrophysical and Environmental Properties

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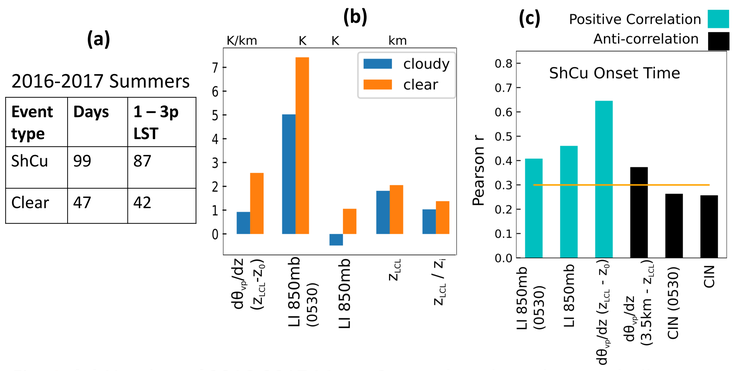
1. Motivation

- A new method has been developed for estimation of shallow cumuli (ShCu) horizontal size from wide field-of-view (FOV) observations (*Kleiss et al*., 2018).
- Horizontal size distributions of ShCu observed at the ARM SGP site have been generated with high temporal resolution for almost two decades.
- *What environmental parameters covary with **cloud effective diameter** (**CED**) of ShCu?*



Event type	Days	1 – 3p LST
ShCu	99	87
Clear	47	42

*Fig. 1. **(a)** Number of 2016-2017 May – September clear-sky and shallow cumulus events. **(b)** Clear-sky and ShCu events between 1-3 LST differ ($p < 0.01$) for five variables: environmental lapse rate $d\theta_{vp}/dz$, Lifting Index (LI) at 850mb from the dawn (0530) and morning (1130) sondes, and the lifted condensation level (z_{LCL}), and ratio of z_{LCL} to mixed height (z_i). **(c)** Correlation of ShCu onset time with morning sonde stability indexes. Sonde is 1130 LST unless noted otherwise.*

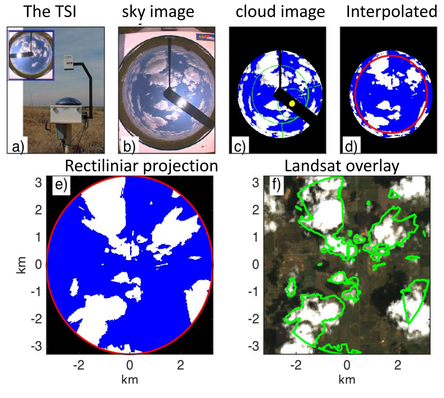


*Fig. 2. (**a**) Ground-based Total Sky Imager (**TSI**). (**b**)Sky image, (**c**) cloud mask (**d**) cloud mask without sky obstructions, (**e**) projection to rectilinear coordinates, and (**f**) Landsat color image for May 15, 2006. Red circle (**d**,**e**) defines 130°FOV. Projection:*

$$\begin{Bmatrix} x \\ y \end{Bmatrix} = CBH \tan\theta_p \begin{Bmatrix} \cos\phi_p \\ \sin\phi_p \end{Bmatrix}$$

***CBH** is **cloud base height**, θ_p is pixel zenith angle, and ϕ_p is pixel azimuth angle*

2. Data

- ***Total Sky Imager*** (**TSI**): wide-FOV images (Fig. **2**).
- ***Ceilometer*** (ShCu CBH, CF), ***lidar-radar*** (Cloud top height, high cloud CF,).
- ***Radar Wind Profiler***: winds at altitude
- ***Surface meteorology***: wind, RH, temperature, z_{LCL}
- ***Sonde***: synoptic indexes
- ***ECOR***: Sensible heat flux, w_*, u_*
- ***Doppler Lidar***: Mixed layer height (z_i)

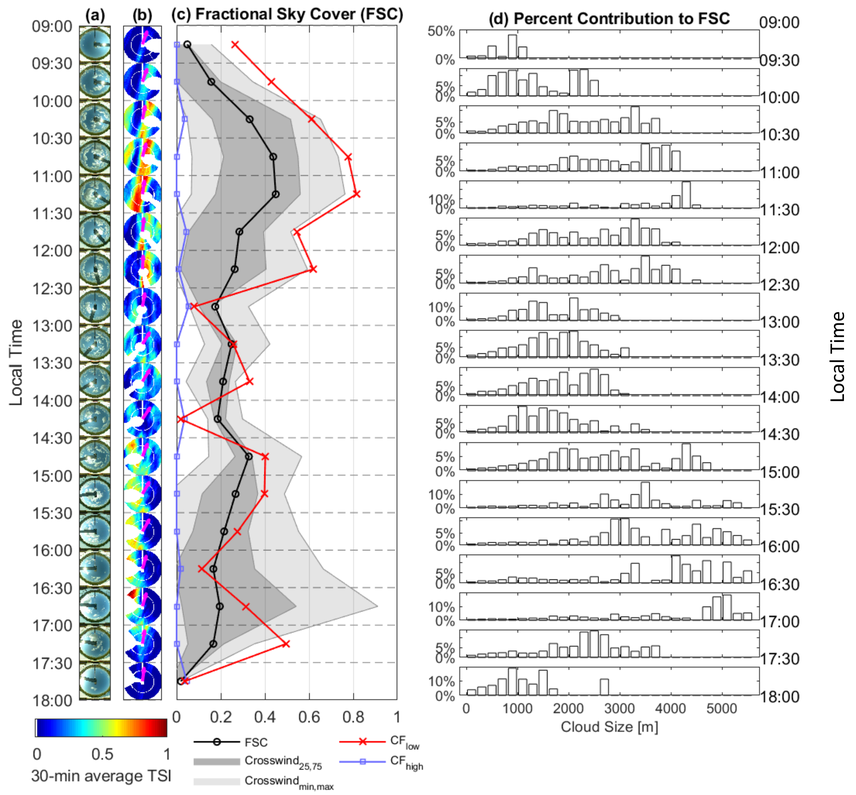


*Fig. 3. Cloud cover conditions on **11-June, 2016**. **(a)**: sample sky image **(b)** 30 min mean TSI cloud cover in rectilinear coordinates. **(c)** Fractional Sky Cover (FSC) and cross-wind spatial variability (gray areas), cloud fraction 0.3-3km (CF_{low}), and above 3km (CF_{high}). **(d)** 30-min percent contribution to FSC by cloud-size histograms.*

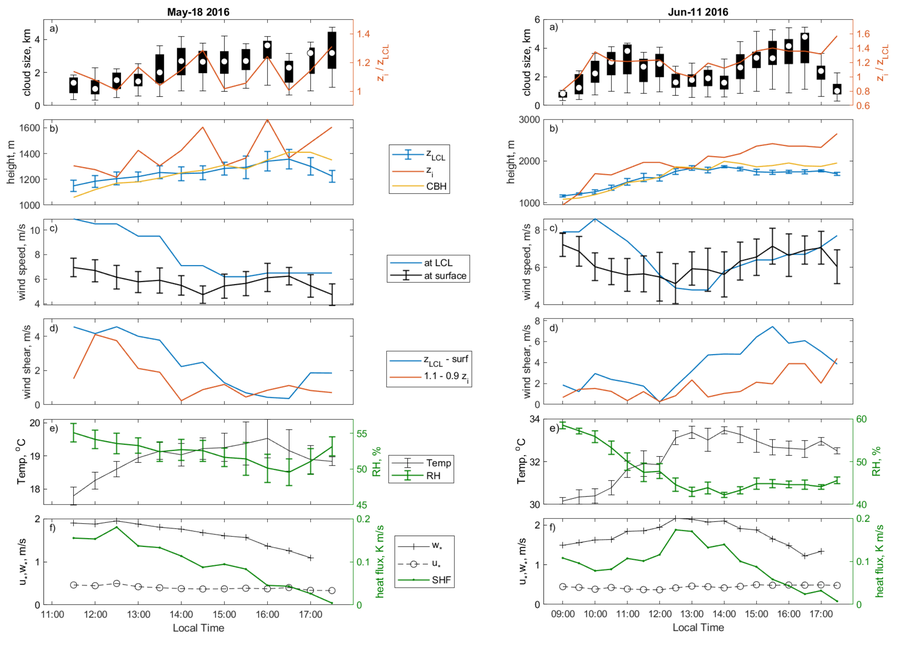


*Fig. 4. Environmental conditions for two days. **(a)** box plots of 25th – 75th percentiles and 5th-95th whiskers (e.g. Figure 3d). **(b)** height of cloud base (CBH), z_{LCL}, and z_i. **(c)** wind speed at z_{LCL} and surface **(d)** wind shear bulk and at boundary layer top **(e)** Surface temperature and humidity **(f)** sensible heat flux and turbulent velocities.*

4. Summary

- High spatial-temporal resolution **CED** distributions are estimated from ground-based TSI images of ShCu.
- Larger cloud areas in comparison with smaller cloud areas have higher correlation to environmental variables.
- Cloud thickness is correlated with bulk wind shear in the boundary layer and convective inhibition (CIN)
- CED covaries with z_{LCLI}/z_i, $d\theta_{vp}/dz$, and sensible heat flux variability. CED is larger on days with earlier onset time.
- CBH is lower during easterly flow, and correlated to w_*

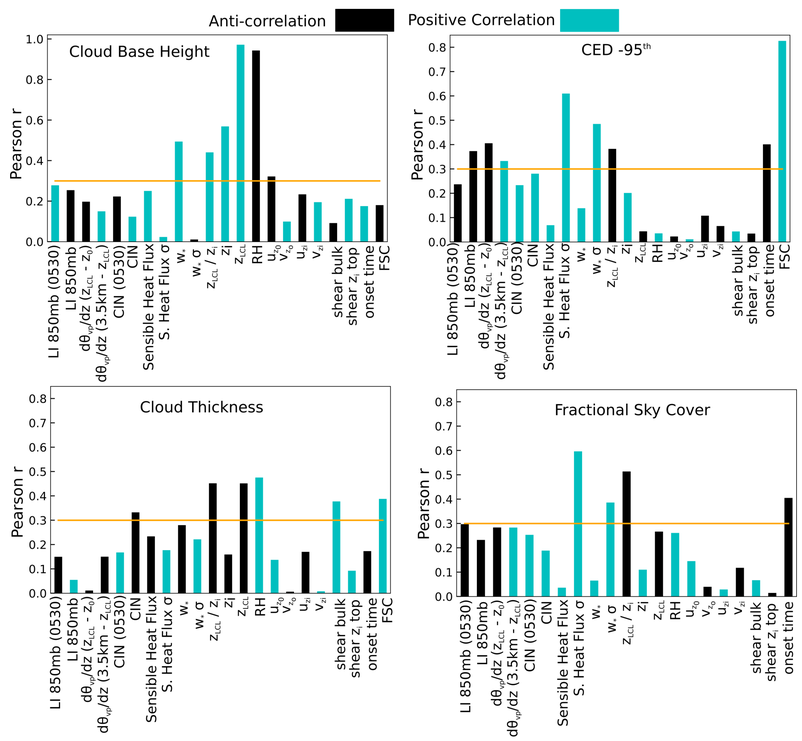


Fig. 5. Pearson correlation coefficient between cloud macrophysical properties and environmental variables for 2 h (1-3 pm) across 87 days with ShCu clouds. Stability indexes are from 1130 LST sonde unless noted as 0530 sonde.

3. Approach

- Identify single-layer shallow cumulus (ShCu) and clear-sky events for summers 2016-17 and find synoptic differences related to ShCu formation and onset time (Fig. **1**)
- Compute cloud area distributions (Fig. **2a -f**).
- Use new TSI quick look tool (*Riley et al*., 2019) to illustrate temporal changes of cloud properties (Fig. **3**)
- Examine relationship between cloud macrophysical properties (CED, cloud thickness, fractional sky cover, and cloud base height) and environmental variables (Figs. **4,5**).

Kleiss, et al., Atmosphere, 9(7), 258, doi:10.3390/atmos9070258, 2018.
Riley, et al., Atmos. Meas. Tech. Disc., doi:https://doi.org/10.5194/amt-2019-155, 2019.

Acronyms:
ShCu: Shallow cumulus.
CED: Cloud effective diameter
TSI: Total Sky Imager
FSC: Fractional Sky Cover
CF: Cloud fraction
CBH: Cloud base height, m
LI 850mb: Lifted index at 850 mb, K
$d\theta_{vp}/dz$: Environmental lapse rate from regression slope of virtual potential temperature. K/km
z_{LCL} : Lifted condensation level AGL., m
Z_0: surface, 0 m AGL
RH: Surface relative humidity
CIN: Convective Inhibition, J/kg (negative)
w_* : Convective velocity scale m/s
u_*: Frictional velocity, m/s
σ: standard deviation.
ECOR: Eddy correlation flux measurement system

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