Macro-physical Properties of Shallow Cumulus Clouds at the ARM SGP Site: Enhanced Ground-Based Observations from the Total Sky Imager

Jessica Kleiss[1], Erin Riley[1], Charles N. Long[3], Laura Riihimaki[2], Larry K. Berg[2], Victor Morris[2], Evgueni Kassianov[2]

[1]Lewis and Clark College [2]Pacific Northwest National Laboratory, [3]Cooperative Institute for Research in Environmental Sciences

1. Motivation

- Wide field-of-view (FOV) observations have been used for almost two decades to document temporal changes of shallow cumulus at the ARM Southern Great Plains (SGP) site. These observations offer fractional sky cover.
- Information on **cloud horizontal size** is required to improve Large Eddy Simulation models.
- *Can wide-FOV sky images provide **cloud effective diameter** (**CED**) of shallow cumulus clouds with high temporal resolution?*

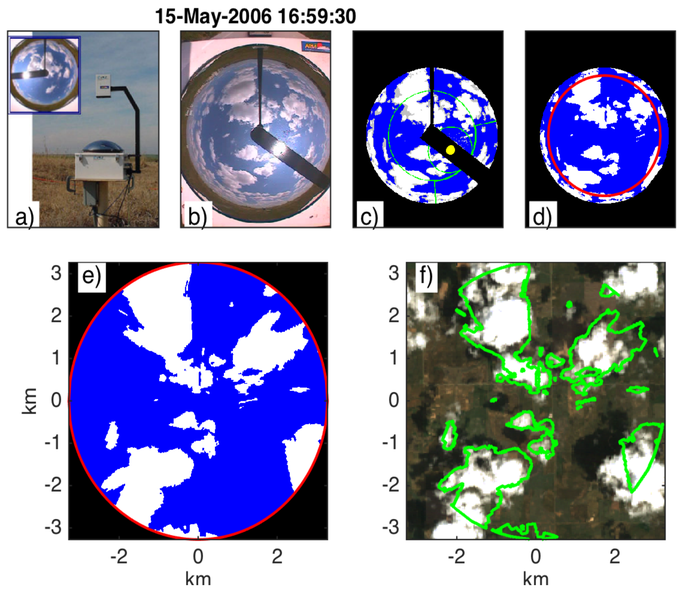

***Fig. 1**. Ground-based Total Sky Imager (**TSI**) (**a**). Examples of original sky image (**b**) , cloud mask (**c**), cloud mask without sky obstructions (**d**) , earth-projected image (see Eq. 1) (**e**) and Landsat color image (**f**) for May 15, 2006. Red circle (**d**,**e**) defines 130° FOV.*

$$\begin{Bmatrix} x \\ y \end{Bmatrix} = CBH \tan\theta_p \begin{Bmatrix} \cos\phi_p \\ \sin\phi_p \end{Bmatrix} \qquad (1)$$

***Projection of TSI image to earth coordinates**. **CBH** is **cloud base height**, θ_p is pixel zenith angle, and ϕ_p is pixel azimuth angle [1]*

2. Data

- *Total Sky Imager* (**TSI**): wide-FOV images (Fig. 1).
- *Active Remote Sensing of Clouds* (**ARSCL**): CBH
- *Radar Wind Profiler* (**RWP**): wind speed/direction at CBH.
- *Landsat:* satellite images (30 m/pixel) (Fig. 2).
- Consider 5 days with integrated data.

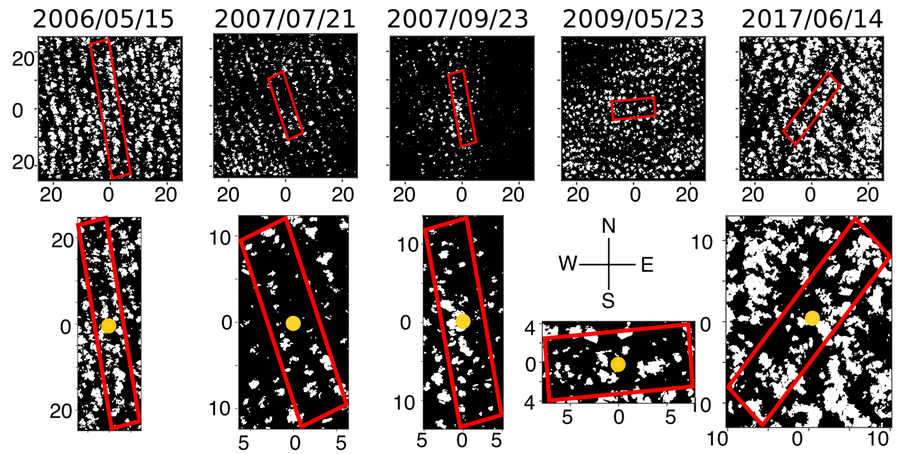

***Fig. 2**. Landsat cloud mask images for selected 5 days: large area (50x50 km²) (top panel) and smaller sub-area with swath (red rectangle) surrounding the ARM SGP site (yellow dot at origin) (bottom panel).*

Date	wind speed m/s	wind dir.	CBH (km)	Swath Width (km)	Swath Length (km)	N TSI	N Landsat	N TSI-like
2006/05/15	13	348	1.53	6.6	47	2445	260	3943
2007/07/21	6.5	159	1.3	5.6	23.4	1483	71	1868
2007/09/23	7.2	167	1.24	5.3	26	1700	79	1824
2009/05/23	5	85	1.21	5.2	18	2017	64	2103
2017/06/14	7.9	222	1.31	5.6	28.4	4093	77	1878

***Table. 1**. Parameters (first three columns) for estimation of swath's **size** (forth/fifth columns) and **orientation**. These parameters are also used to simulate 1-h TSI-like observations with 30s temporal resolution and 130° FOV. Number of counted clouds (last three columns).*

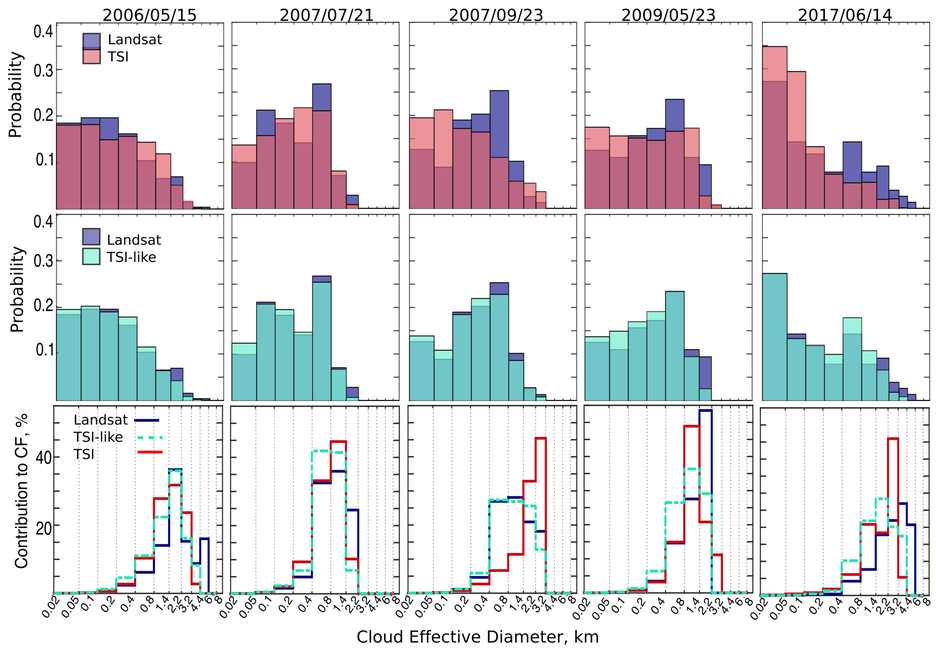

***Fig. 3**. Swath-related histograms of CED from Landsat (navy), TSI-like (turquoise) and TSI (red) images (top and middle panels) for clouds with CED ≥ 0.03 km. Landsat histograms include clouds touching/extending outside of swath boundaries (**Fig. 2**) to preserve true size distributions. Purple (top panel) and cyan (middle panel) colors define overlapping sections of histograms. Cloud area contribution to **cloud fraction** (**CF**) from clouds within CED bins (bottom panel) [2].*

4. Summary

- We introduce a new approach to obtain **CED** from ground-based TSI images of single-layer shallow cumulus clouds.
- There are two main advantages of our approach: (1) *high temporal resolution* (30 sec) and (2) *wide range* (~0.03-3km) of estimated **CEDs**.
- Difference in CED (TSI vs Landsat) corresponding to 50% contribution to CF tends to be small (~20%) for sufficiently large sampling areas with comparable TSI- and Landsat-derived CFs.

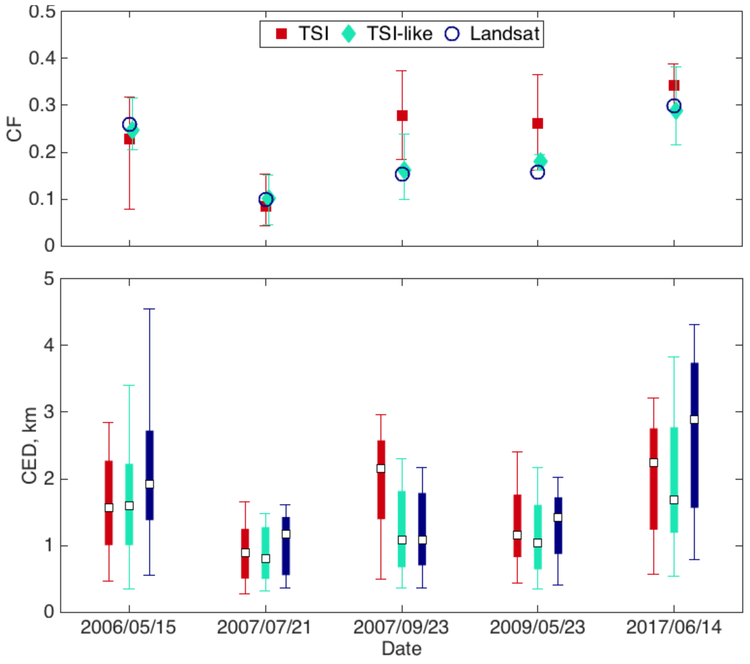

***Fig. 4**. **Top:** Mean and min/max values of TSI earth projected CF (130-deg) (red) and TSI-like CF (turquoise) from four 15-min intervals; CF from Landsat swath (blue). **Bottom:** 5-95th percentiles of CED contribution to CF; box is 25-75th percentiles, white square is median.*

3. Approach

- Apply cloud mask for opaque cloud pixels (Fig. 1c).
- Interpolate cloud mask over sky obstructions (Fig. 1d).
- Provide **earth-projected image** at CBH (Figs. 1e-f).
- Select Landsat sub-area similar to 1-hr TSI (Fig. 2).
- Simulate TSI sampling within sub-area (Table 1).
- Estimate **CEDs** obtained from earth-projected and satellite images and **CED** contributions to CF (Fig. 3).
- Compare distribution of **CEDs** obtained from earth-projected and satellite images (Fig. 4).

Contact Information: jkleiss@lclark.edu.

References:

1. Chow, C. W. *et al.* Intra-hour forecasting with a total sky imager at the UC San Diego solar energy testbed. *Solar Energy* **85,** 2881–2893 (2011).
2. Rodts, S. M. A., et al. Size Distributions and Dynamical Properties of Shallow Cumulus Clouds from Aircraft Observations and Satellite Data. *J. Atmos. Sci.* **60,** 1895–1912 (2003).

Acknowledgement: U.S. Department of Energy's Atmospheric System Research Grant No. DE-SC0016084.