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DOE/SC-ARM-16-041

Determination of Cloud Base Height, Wind Velocity, and Short-Range Cloud Structure Using Multiple Sky Imagers Field Campaign Report

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ARM CLIMATE RESEARCH FACILITY

DISCLAIMER

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Acronyms and Abbreviations

ARM	Atmospheric Radiation Measurement Climate Research Facility
ASR	Atmospheric System Research
BNL	Brookhaven National Laboratory
3D	three-dimensional
DOE	U.S. Department of Energy
HD	high-definition
Hz	hertz
km	kilometer
LES	large-eddy simulation
m	meter
NASA	National Aeronautics and Space Administration
PI	Principal Investigator
TSI	Total Sky Imager
UTC	Coordinated Universal Time

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1.0 Summary

Clouds are a central focus of the U.S. Department of Energy (DOE)'s Atmospheric System Research (ASR) program and Atmospheric Radiation Measurement (ARM) Climate Research Facility, and more broadly are the subject of much investigation because of their important effects on atmospheric radiation and, through feedbacks, on climate sensitivity. Significant progress has been made by moving from a vertically pointing ("soda-straw") to a three-dimensional (3D) view of clouds by investing in scanning cloud radars through the American Recovery and Reinvestment Act of 2009. Yet, because of the physical nature of radars, there are key gaps in ARM's cloud observational capabilities. For example, cloud radars often fail to detect small shallow cumulus and thin cirrus clouds that are nonetheless radiatively important. Furthermore, it takes five to twenty minutes for a cloud radar to complete a 3D volume scan and clouds can evolve substantially during this period.

Ground-based stereo-imaging is a promising technique to complement existing ARM cloud observation capabilities. It enables the estimation of cloud coverage, height, horizontal motion, morphology, and spatial arrangement over an extended area of *up to 30 by 30 km* at refresh rates greater than 1 Hz (Peng et al. 2015). With fine spatial and temporal resolution of modern sky cameras, the stereo-imaging technique allows for the tracking of a small cumulus cloud or a thin cirrus cloud that cannot be detected by a cloud radar.

With support from the DOE SunShot Initiative, the Principal Investigator (PI)'s team at Brookhaven National Laboratory (BNL) has developed some initial capability for cloud tracking using multiple distinctly located hemispheric cameras (Peng et al. 2015). To validate the ground-based cloud stereo-imaging technique, the cloud stereo-imaging field campaign was conducted at the ARM Facility's Southern Great Plains (SGP) site in Oklahoma from July 15 to December 24. As shown in Figure 1, the cloud stereo-imaging system consisted of two inexpensive high-definition (HD) hemispheric cameras (each cost less than $1,500) and ARM's Total Sky Imager (TSI). Together with other co-located ARM instrumentation, the campaign provides a promising opportunity to validate stereo-imaging-based cloud base height and, more importantly, to examine the feasibility of cloud thickness retrieval for low-view-angle clouds.

Figure 1. The spatial arrangement of three imagers in the cloud stereo-imaging field campaign.

2.0 Results

During the five-month period, we collected about one terabytes of sky images from the cameras. The data covered almost all types of sky and cloud conditions. Figure 2 shows an example of the images by the two HD cameras.

(a) (b)

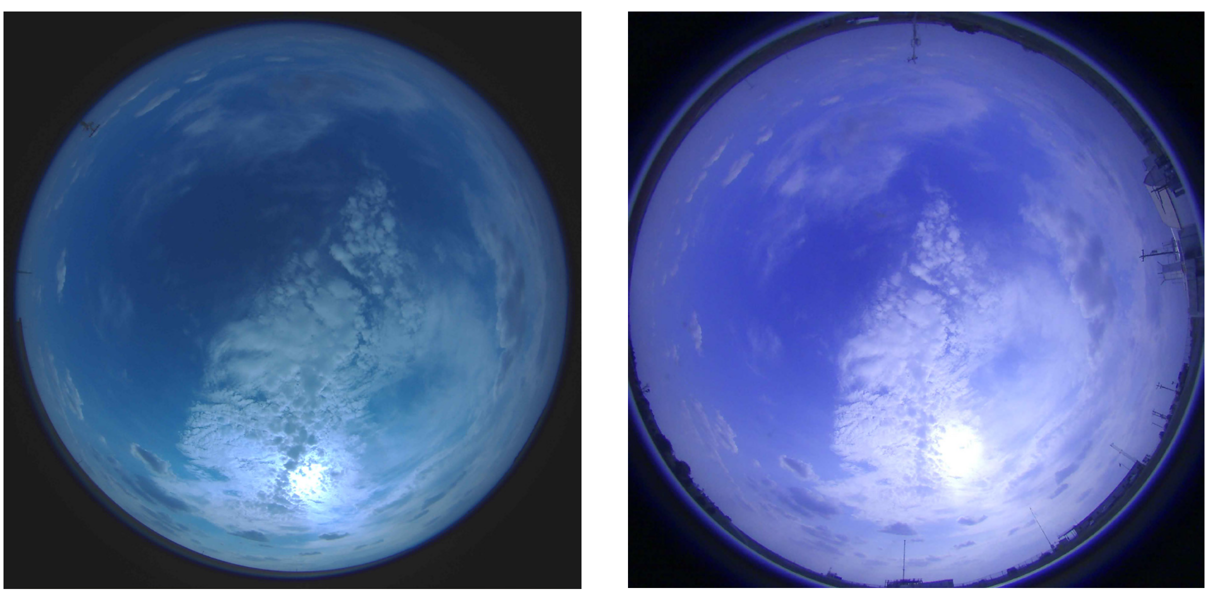

Figure 2. Examples of images collected by the BNL HD sky cameras. The images were collected by the two cameras separated by approximately 980 m at 21:04 UTC, September 29, 2015. Multi-layer clouds were evident from the images and the cloud base height is inversely proportional to the displacement of the cloud in the two images.

The main research and development task following the field campaign is to develop a suite of fully automated algorithms for cloud base height (for clouds with high view angles) and cloud thickness (for clouds with low view angles) retrievals. The suite will consist of tools for automated color balance and geometry undistortion, multi-camera co-registration, cloud base height/cloud thickness retrieval, cloud base wind speed retrieval, and cloud horizontal size determination.

Based on our preliminary analysis, the cameras often view a mixture of cloud base and side for intermediate view angles. It is therefore important to examine the validity of the above algorithms under such conditions. This resultant retrieval data will not only fill a gap in ARM's small-cloud observing capability but also be highly valuable for evaluating the skills of high-resolution numerical models such as a Large Eddy Simulation (LES) model for simulating cloud spatial variability and structure.

3.0 Publications and References

Peng Z, D Yu, D Huang, J Heiser, S Yoo, and P Kalb. 2015. "3D cloud detection and tracking system for solar forecast using multiple sky imagers." *Solar Energy* 118: 496-519, doi:10.1016/j.solener.2015.05.037.

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