U.S. DEPARTMENT OF ENERGY | Office of Science

DOE/SC-ARM-20-011

Measuring Clouds at the Southern Great Plains with Stereo Photogrammetry Field Campaign Report

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ARM

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Work supported by the U.S. Department of Energy,
Office of Science, Office of Biological and Environmental Research

Acronyms and Abbreviations

3D	three-dimensional
ARM	Atmospheric Radiation Measurement
CF	Central Facility
MPL	micropulse lidar
SGP	Southern Great Plains
SR	stereo reconstruction

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1.0 Summary

The U.S. Department of Energy's Measuring Clouds at the Southern Great Plains (SGP) with Stereo Photogrammetry Atmospheric Radiation Measurement (ARM) user facility campaign started with the deployment of two over-the-counter outdoor surveillance cameras at the SGP Central Facility (CF) on April 18, 2014. The deployment aimed to collect three-dimensional (3D) measurements related to macrophysical cloud features such as the structure of cloud boundaries, cloud-base and cloud-top heights, cloud life cycles, etc. by using stereo-photogrammetric principles. The 3D position of an object can be estimated by stereo photogrammetry if it is captured synchronously at two distinct angles. For a scene as far as tens of kilometers deep, two separate cameras are required to be placed about 1 km apart and precisely calibrated for their locations and orientations.

The campaign cameras were positioned roughly in a north-south direction facing west at 36.6078N, 97.4884W and 36.6013N, 97.4868W coordinates as shown in Figure 1. They were separated with a baseline of 733 meters and they covered an approximately 75°-wide overlapping field of view. A steady stream of 2592x1944-pixel-resolution images were captured synchronously at 30-s intervals and were recorded in JPEG format by a common server connected to the cameras. The camera calibration problem, which is particularly challenging for outdoor settings, was solved by implementing an algorithm that used the positions of the brightest celestial objects observed by the cameras. Next, image processing algorithms were developed to detect cloud features and stereo reconstruction (SR) was used to compute their 3D positions.

Figure 1. The locations of both cameras at the SGP CF and sample views from the northern (upper right) and southern (lower right) cameras.

The campaign cameras collected images from April 2014 through September 2018 with occasional server connection issues prompted by various factors. The connection issues resulted in data loss until the connection could be reestablished by an onsite staff member.

2.0 Results

Automatic feature extraction refers to detecting distinctive pixels that can be distinguished from their surroundings using a quantitative measure. A feature-extraction algorithm was developed that identified distinctive cloud features in the common field of view of the stereo-calibrated cameras and retrieved their 3D positions by using stereo reconstruction (Oktem et. al. 2014, 2015). Automatic feature extraction enabled the detection of thousands of cloud points at an instant from a region that is tens of square kilometers wide.

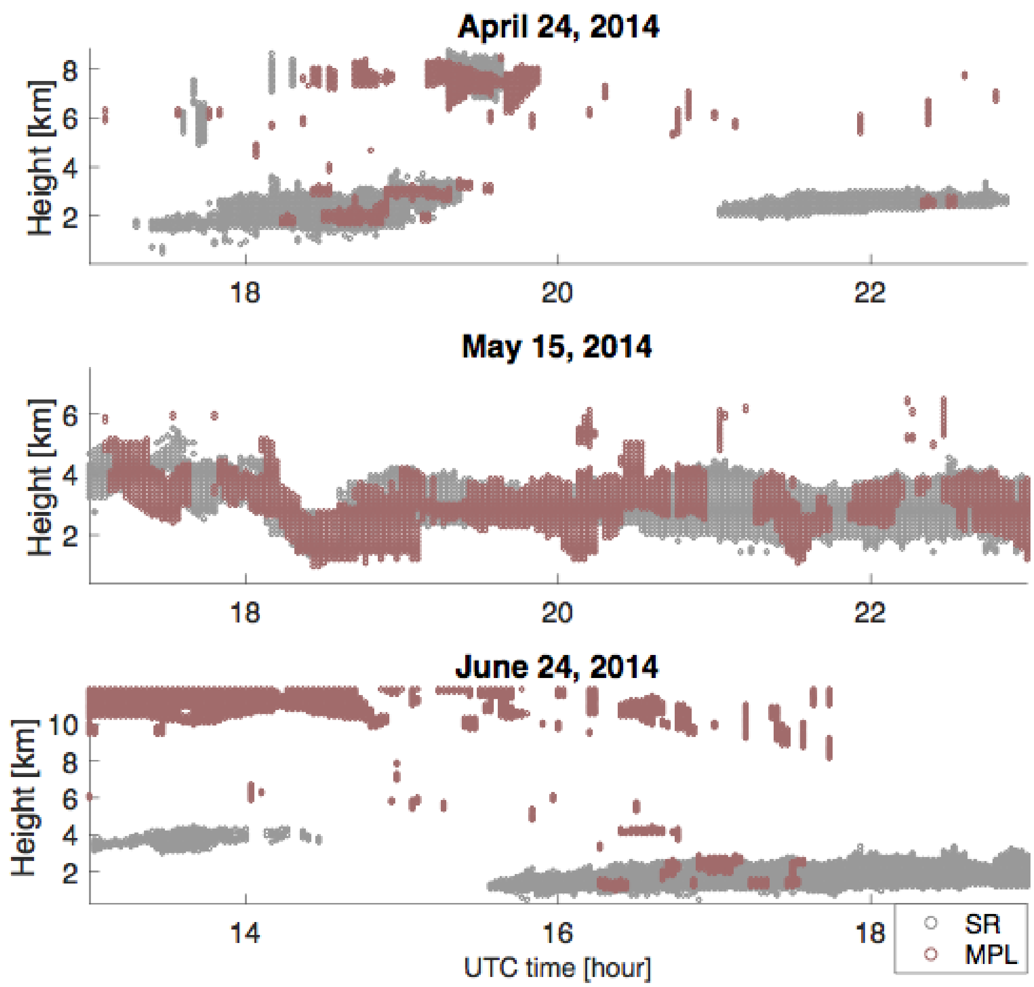

Figure 2. Cloud-point heights detected by SR (gray circles) and MPL (red circles) on different days.

Figure 2 displays cloud-point heights detected by stereo reconstruction (gray circles) for selected time intervals representing various cloud conditions. Micropulse lidar (MPL)-detected heights extracted from the mplcmask1zwang datastream in the ARM Data Center are also included for comparison (red circles). Due to its ability to scan a wide horizontal region and altitude range at a time, SR is particularly useful in capturing shallow cumulus clouds (low-altitude clouds on April 24, 2014 and June 24, 2014 — top and bottom panels) that may often be missed by vertically pointing instruments such as the MPL. SR captures the same low- to middle-altitude stratocumulus layers as the MPL on May 15, 2014 (middle panel) and high-altitude clouds on April 24, 2014 (upper panel, high-altitude clouds), but misses optically thin high-altitude clouds on June 24, 2014 (bottom panel, high-altitude clouds) due to lack of distinctive features exhibited in that case.

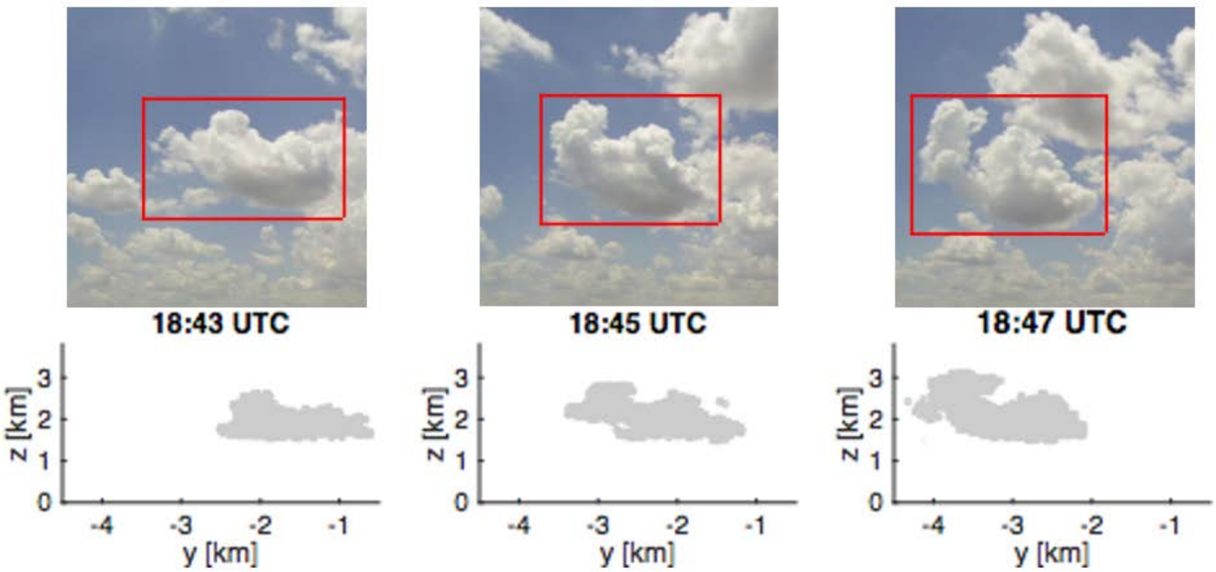

Figure 3. The bottom panels display the northward distance from the northern camera and the altitude above the ground of the cloud points associated with the cloud enclosed by the red rectangle shown in the top panels. The evolution of the cloud boundaries and the cloud-top heights are observed from left to right for four minutes.

Figure 3 presents another example where SR provides a unique opportunity to observe shallow cumulus clouds by tracking the evolution of an individual cloud in high-space-and-time resolution.

This campaign helped us to gain experience and knowledge related to stereo camera deployment and to test the capability of this setup in providing measurements of macrophysical cloud features. We found that this stereo setup provides a unique set of data, particularly on shallow cumulus clouds that are only partially sampled by vertically pointing instruments.

3.0 Publications and References

Oktem, R, JL Prabhat, A Thomas, P Zuidema, and DM Romps. 2014. "Stereophotogrammetry of oceanic clouds." *Journal of Atmospheric and Oceanic Technology* 31(7):1482–1501, https://doi.org/10.1175/JTECH-D-13-00224.1

Oktem, R, and DM Romps. 2015. "Observing atmospheric clouds through stereo reconstruction." *Proceedings of SPIE* 9393, https://doi.org/10.1117/12.2083395

4.0 Lessons Learned

The major and most common technical problem during this campaign was connection loss between the camera and the server. This experience helped us design our standalone stereo camera setups that were later deployed at the SGP site.