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# DACCIWA Cloud-Aerosol Observations in West Africa Field Campaign Report

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ARM CLIMATE RESEARCH FACILITY

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# DACCIWA Cloud-Aerosol Observations in West Africa Field Campaign Report

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# Acronyms and Abbreviations

| | |
|---|---|
| ARM | Atmospheric Radiation Measurement |
| CDP | cloud droplet probe |
| DACCIWA | Dynamics-Aerosol-Chemistry-Cloud Interactions in West Africa |
| DOE | U.S. Department of Energy |
| g | gram |
| km | kilometer |
| LWP | liquid water path |
| m | meter |
| MWR | microwave radiometer |
| nm | nanometer |
| PI | principal investigator |
| sec | second |
| UK | United Kingdom |
| µm | micrometer |
| UTC | Coordinated Universal Time |

# Contents



# Figures

# 1.0 Summary

Interactions between aerosols and clouds, and their effects on radiation, precipitation, and regional circulations, are one of the largest uncertainties in understanding climate. With reducing uncertainties in predictions of weather, climate, and climate impacts in mind, the Dynamics-Aerosol-Chemistry-Cloud Interactions in West Africa (DACCIWA) project, funded by the European Commission, set out to improve our understanding of cloud-aerosol interactions in southern West Africa. This region is ideal for studying cloud-aerosol interactions because of its rich mix of natural and anthropogenic aerosols and diverse clouds, and because of the strong dependence on the regional and global climate of the sensitive West African monsoon. The overview of DACCIWA is described in Knippertz et al. 2015.

The interdisciplinary DACCIWA team includes not only several European and African universities, but also Met Centres in the United Kingdom (UK), France, Germany, Switzerland, Benin, Ghana, and Nigeria. One of the crucial research activities in DACCIWA is the major field campaign in southern West Africa from June to July 2016, comprising a benchmark data set for assessing detailed processes on natural and anthropogenic emissions; atmospheric composition; air pollution and its impacts on human and ecosystem health; boundary layer processes; couplings between aerosols, clouds, and rainfall; weather systems; radiation; and the monsoon circulation. Details and highlights of the campaign can be found in Flamant et al. 2017.

To provide aerosol/cloud microphysical and optical properties that are essential for model evaluations and for the linkage between ground-based, airborne, and spaceborne observations, the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) Climate Research Facility loaned two sun photometers to the DACCWIA team for the campaign from June 8 to July 29, 2016. The first sun photometer was deployed at Kumasi, Ghana (6.67962°N, 1.56019°W) by the University of Leeds (UK). The instrument was supposed to operate in normal aerosol mode in clear-sky conditions for aerosol monitoring, and operate in cloud mode for measuring cloud properties when clouds block the sun. Unfortunately, the robot of the sun photometer did not work properly from the beginning of the deployment, and remained problematic throughout the campaign. No useful data was recovered.

The second sun photometer was deployed at Savé, Benin (8.000842°N, 2.413115°E), set up and maintained by the Karlsruher Institut fuer Technologie, Germany. Unlike most sun photometers that are designed to monitor aerosol properties and thus operated in normal aerosol mode, this sun photometer at Savé was operated in a special cloud mode, pointing vertically and measuring zenith radiance continuously at wavelengths of 440, 500, 675, 870, 1020, and 1640 nm with 10-sec temporal resolution. Zenith radiances at 440, 870, and 1640 nm alone can be used to retrieve cloud optical depth and column-mean effective radius (Chiu et al. 2010, 2012).

The following section takes 6 and 7 July as an example to highlight a typical diurnal cycle of clouds observed during the campaign. Cloud properties retrieved from zenith radiance are compared against those retrieved from microwave radiometer (MWR) measurements, and against in situ measurements collected from the Twin Otter aircraft.

# 2.0 Results

## 2.1 Case 1: Overcast-to-Cumulus Transition on 6 July

Clouds on 6 July, 2016 represent a typical case during the campaign: low clouds were observed at nighttime and started breaking up in the afternoon, as indicated in ceilometer backscatter signals (Fig. 1). Compared to other days during the campaign, this case has much fewer mid- and high-level clouds during 8:00-18:00 UTC. Since we focus on low-cloud retrieval, the lack of higher-level clouds helps ensure the retrieval performance of low clouds. This case also provides an opportunity to observe small, scattered cumulus clouds in the afternoon.

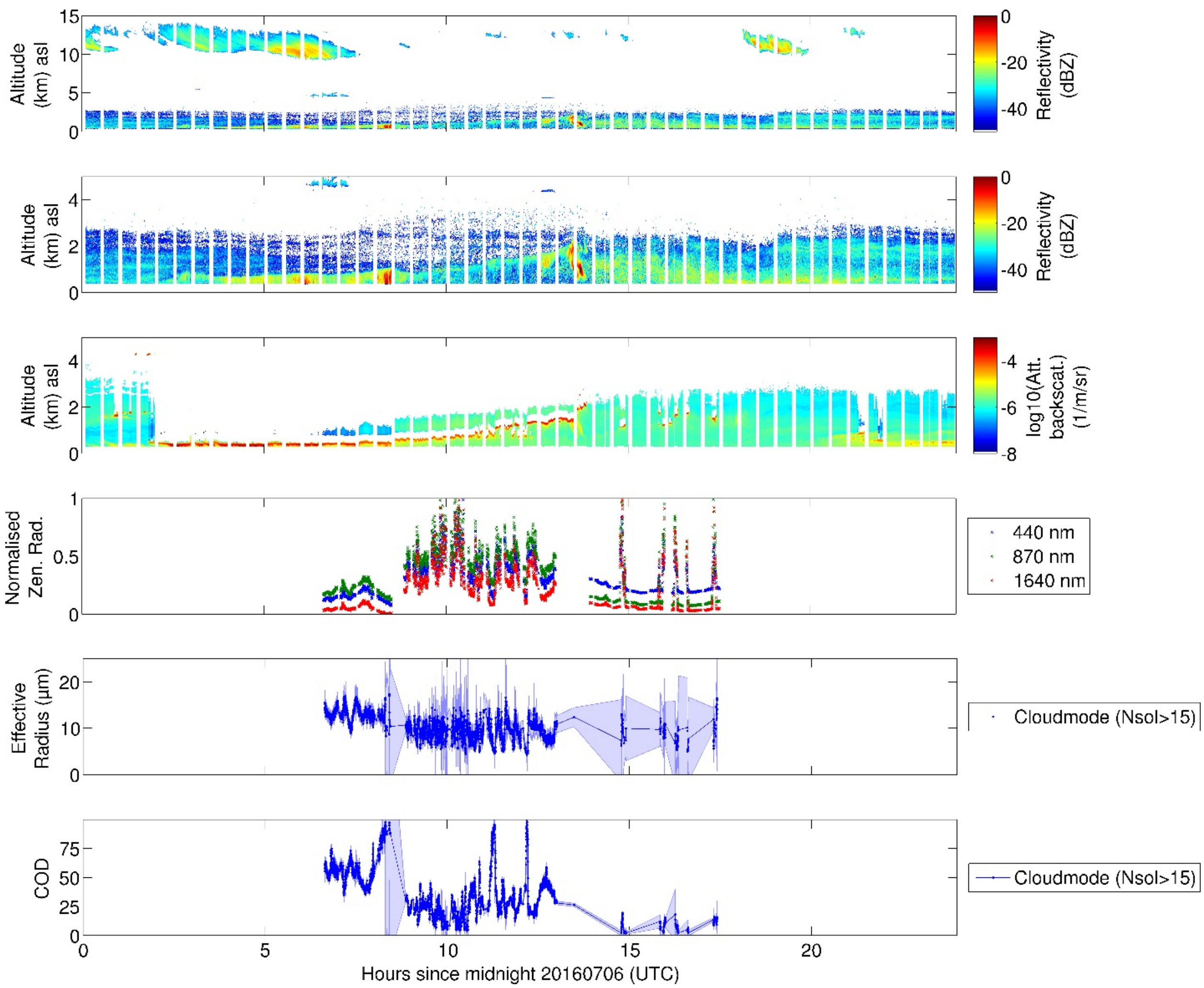


**Figure 1**. Retrieved cloud properties on 6 July, 2016 during the DACCIWA campaign. Panels from top to bottom show time series of observed cloud radar reflectivity factor (for 0–15 km and a zoom-in for 0–5 km), ceilometer backscatter, and zenith radiances; and retrieved column-mean effective radius, and column-integrated cloud optical depth. The blue shading in the bottom two panels represents one standard deviation uncertainty in the retrieval.

In general, cloud optical depths vary significantly during daytime. Prior to precipitating clouds at 8:30 UTC, clouds are optically thick; after precipitation, cloud optical depth decreases to around 25. For the scattered cumulus during 14:00-18:00 UTC, the optical depths are relatively small (~5–10). The retrieved cloud effective radius is about 15 μm and 10 μm before and after precipitation, respectively. Assuming liquid water content increases linearly with height, liquid water path (LWP) can be derived from the retrieved cloud optical depth and effective radius. We found that the derived LWPs have similar variations to those retrieved from MWR (figure not shown), but tend to be larger by ~130 g $m^{-2}$. It is unclear yet what causes such a large discrepancy between two data sets. Further investigations on both MWR and sun photometer calibrations are needed to identify the sources of the errors. Users of this data set are strongly recommended to contact the PI for further updates.

## 2.2 Case 2: 7 July

Similar to the previous case, low clouds persist on 7 July from nighttime to daytime, with increasing cloud base height, as shown in Fig. 2. Cloud optical depths were thick before the major precipitating event at 9:00–11:00 UTC, and were reduced afterwards. The retrieved LWPs continued to be larger than those from MWR by ~100 g $m^{-2}$, which required further evaluations.

The Twin Otter flew over Savé on 7 July, providing just enough samples for us to evaluate cloud retrieval. During 10:39–11:07, the aircraft was within the circle of a 50-km radius from the site at altitudes of ~0.4–1.5 km. Measurements from the cloud droplet probe (CDP) showed that the mean cloud effective radii increased with height, ranging from 3 μm at 0.5 km altitude to 9 μm at 1.5 km altitude (Fig. 3). Compared to the in situ measurements, we found that the mean cloud effective radius from cloud mode observations during 10:39–11:07 was about 10±2 μm (Fig. 4), which is slightly larger than the range found in CDP measurements. Since clouds were drizzling during the aircraft flight over Savé, the difference in the mean cloud effective radius may have been because some drizzle particles are outside the range that CDP can measure.

## 2.3 Future Work

As shown in the examples above, high clouds occur frequently over this region, making it challenging to observe low-level clouds properly from satellite observations. Cloud retrieval from this campaign provides statistics and evolutions of cloud optical depth, droplet effective radius, and liquid water path, which can be used to investigate the interactions of clouds with aerosol, precipitation and radiation. Combining radar and lidar measurements, cloud mode observations also make it possible to retrieve cloud droplet number concentration, detailed profiles of water content and droplet size for clouds and precipitation (*Fielding et al.* 2014, 2015), critical for understanding cloud processes and evaluating models and satellite products.

Cloud retrieval from zenith radiance is available in the ARM Data Archive. The release of synergetic retrieval and in situ measurements follows the data policy of DACCIWA.

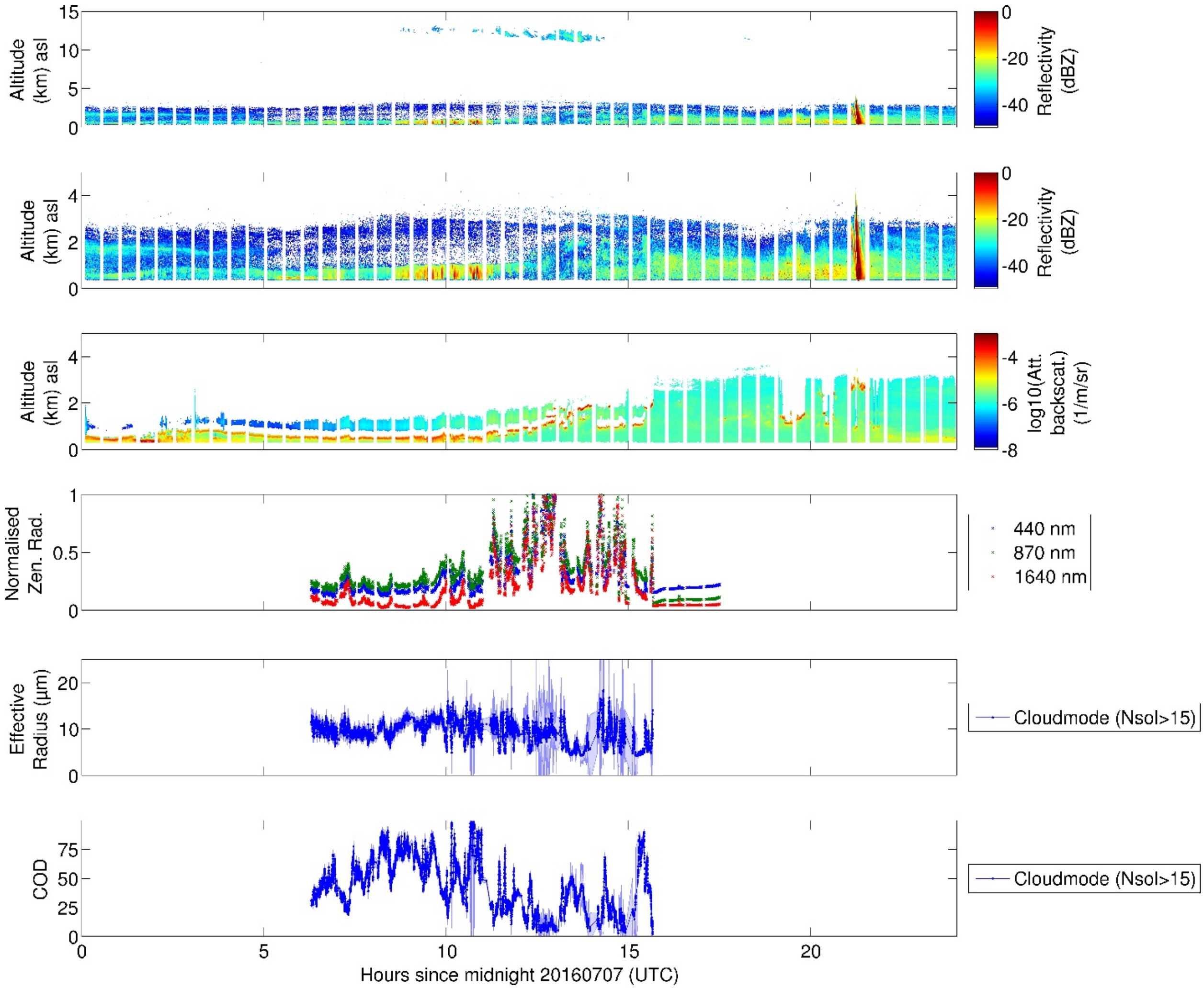


**Figure 2**. Same as Figure 1, but for 7 July, 2016.

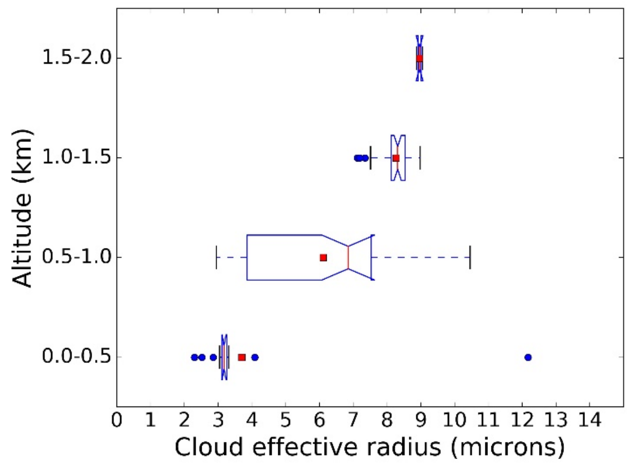


**Figure 3**. Box plots of cloud effective radius at various altitudes near Savé, measured from the cloud droplet probe (CDP) on the Twin Otter during 10:39-11:07 UTC on 7 July, 2016. The blue box extends from the lower to upper quartile values of the data. The whiskers mark points within 1.5 times the interquartile distance, while blue dots represent outliers. The red dots and red lines represent the mean and the median, respectively. The notches show the 95% confidence interval for the median. (CDP measurements were collected by the DACCIWA team from University of Manchester. Data used here were provided by Johnathan Taylor, University of Manchester.)

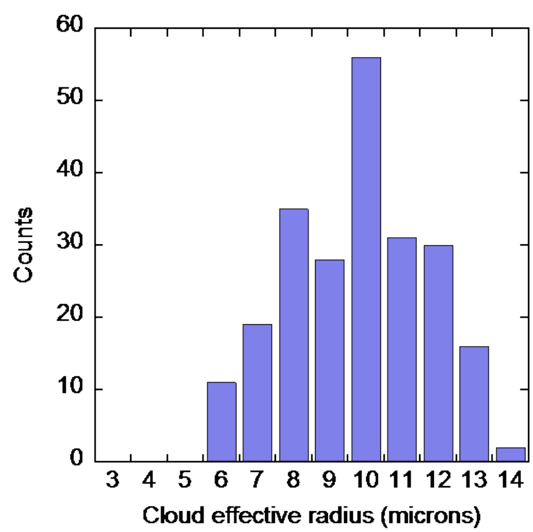


**Figure 4**. Histogram of cloud droplet effective radius retrieved from cloud mode observations during 10:39-11:07 UTC on 7 July, 2016.

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