Evaluating Microphysical Cloud Properties from ARM's Cimel Sunphotometer Cloud Mode

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Abstract

Observations of boundary layer clouds are critical to advancing Earth system modeling. These clouds exhibit extensive coverage and controls on boundary layer dynamics, as well as on the global radiative energy balance. Improving understanding of these cloud conditions is key, as small changes in cloud coverage, thickness and/or droplet properties can impart significant net radiative changes. For over two decades, the Atmospheric Radiation Measurement (ARM) user facility has deployed sunphotometers. Originally designed to retrieve aerosol optical properties, these instruments recently implemented a "cloud mode" strategy. Performed during sequences where clouds completely block the sun, this mode enables estimates of key cloud properties. As a narrow-beam instrument, these passive retrievals are potentially viable over a wide range of conditions. During the previous year, ARM has completed an operational implementation for a Value-Added-Product that estimates cloud optical depth (COD), cloud droplet effective radius (Re), and liquid water path (LWP) -- including associated uncertainties. These products adopt a three-channel (440, 870, and 1640 nm) retrieval, building on current Aerosol Robotic Network (AERONET) two-channel methods applicable only over vegetated surfaces. We present results from operational outputs, focused on overcast warm, low cloud conditions at the ARM Southern Great Plains (SGP) and Eastern North Atlantic (ENA) sites. We offer retrieval performance comparisons for the LWP, COD, and Re by evaluating these new VAP quantities against existing ARM retrieval VAPs (MWRRET, MFRSR, KAZR/ARSCL/MICROBASE).

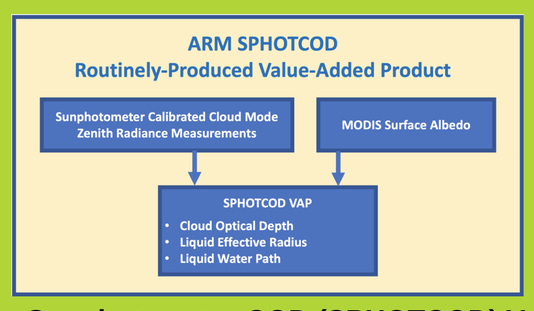
Instruments and Retrieval/VAP Methods

ARM's Sunphotometer

The CIMEL Sunphotometer (SPHOT) is the primary instrument of this effort. It is an automated ground-based sun/sky scanning photometer featuring a narrow field of view (1.2°). NASA AERONET calibrates & maintains the instruments and processes certain levels of data as part of their global data archive. This study also utilizes the MICROBASE VAP (Re, LWP from MWRRET VAP), and the MFRSRCLDOD VAP (COD, Re, LWP also from MWRRET).

The Sunphotometer and its "Cloud Mode" Operations:

- Marshak et al. (2004) suggested COD could be derived from ground-based zenith radiance measurements. Chiu et al. (2010) worked with AERONET to alter the observing strategy to include a number of zenith radiance observations during previously idle periods.
- This "cloud mode" measures zenith radiance when routine aerosol measurements are unavailable.
- When the sun is blocked by clouds, the instrument points zenith and obtains high gain sky mode observations in seven channels: 380, 440, 500, 675, 870, 1020 and 1640 nm.
- The photometer allows for ~10 individual 10-sec retrievals every 15-min (more frequent at higher solar zenith angles). A direct sun acquisition is taken every 3 minutes, and cloud mode retrievals can be taken at that frequency.



MICROBASEKAPLUS

Liquid Water Content [gm-3]	Liquid Effective Radius [microns]
$LWC = (N_0 Z_e/3.6)^{1/1.8}$ Scaled by MWR LWP (Liao and Sassen 1994)	$R_{el}=\exp(2.5\sigma^2)/[3*LWC/4\pi N\rho_l \exp(9\sigma^2/2)]^{1/3}$ (Frisch et al. 1995)

N_0 = Reference Cloud particle Number Concentration = 100 cm^{-3}
Ze = equivalent radar reflectivity (35 GHz), in unit ($mm^6 m^{-3}$)
N = cloud particle number concentration (CDNC) = 200cm^{-3}
ρ_l = density of water
σ = width of a log-normal droplet distribution (0.35)

Sunphotometer COD (SPHOTCOD) Value-Added Product (VAP):

- Chiu et al. (2012) developed an improvement to AERONET's two-channel (440nm, 870nm) COD retrieval with a three-channel (440, 870, and 1640 nm) algorithm.
- ARM has operationalized this algorithm in its first ever sunphotometer-based SPHOTCOD VAP. The VAP simultaneously retrieves COD and Re. COD and Re are used to compute LWP.
- Associated uncertainties for these quantities are estimated.
- This differs from MFRSR and MICROBASE VAPs that use LWP from MWRRET in estimating Re.

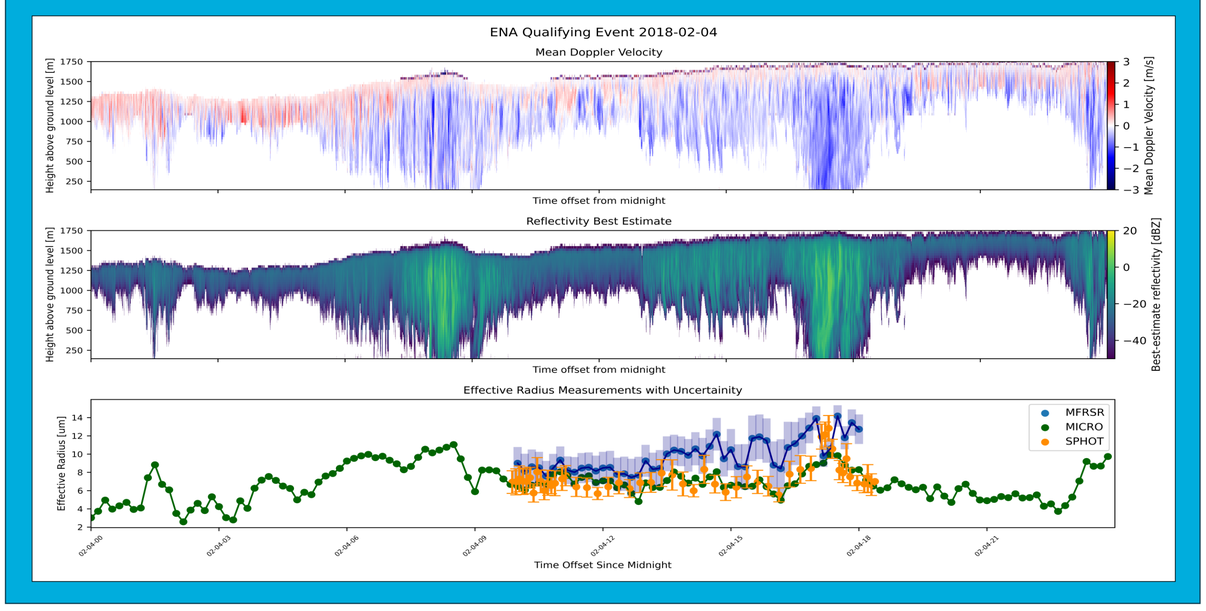
Adjustments to MICROBASE for ENA:

- The MICROBASE VAP was developed for SGP, and assumes a fixed number concentration of N = 200 cm^{-3}. For ENA, this fixed value has been lowered to N = 50 cm^{-3}.

Stratocumulus (StCu) Case Selection

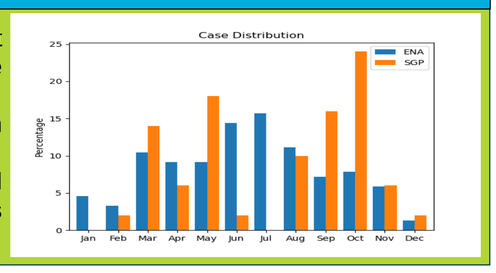
Our study takes advantage of a multi-year dataset (2014-2019) from the ARM ENA and SGP fixed sites. Events were designated as stratocumulus (StCu) using the below criteria. The criteria must be met for **2 consecutive hours**. Added inspection was used to remove outlier events.

1. MFRSR available (implies 85% cloud cover).
2. A lowest cloud echo top height < 4 km, and a cloud echo base above 500 m.
3. No presence of rainfall heavier than drizzle (e.g., surface R < 1 mm hr^{-1}) at the surface.

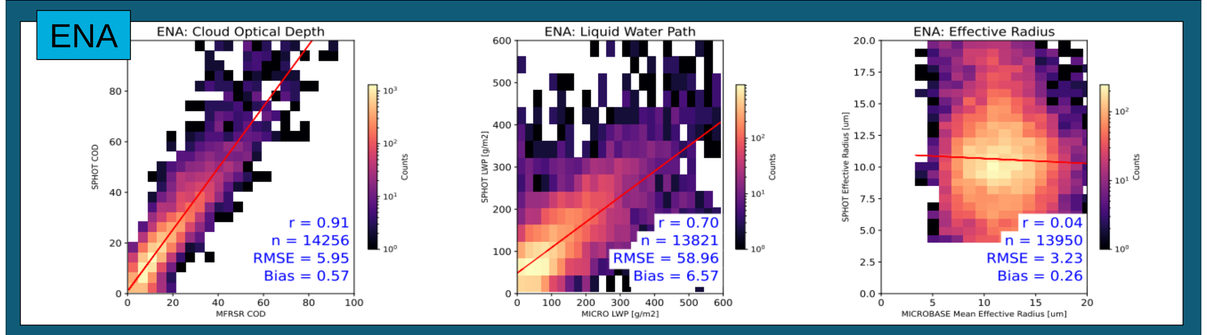


Distribution of Stratocumulus Cloud Events

- The monthly distribution of ENA events (right) indicates most daytime StCu events were observed during the summertime months under dominant Azores High conditions.
- The daytime SGP events illustrate a bimodal distribution, with frequent StCu observed during the shoulder seasons.
- In total, 152 ENA events accounted for 15915 collocated (MICROBASE) daytime samples. We sampled 49 events having 6912 collocated samples at SGP.



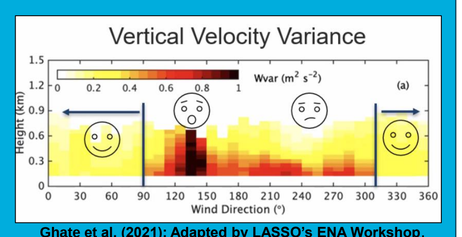
Retrieval Intercomparisons



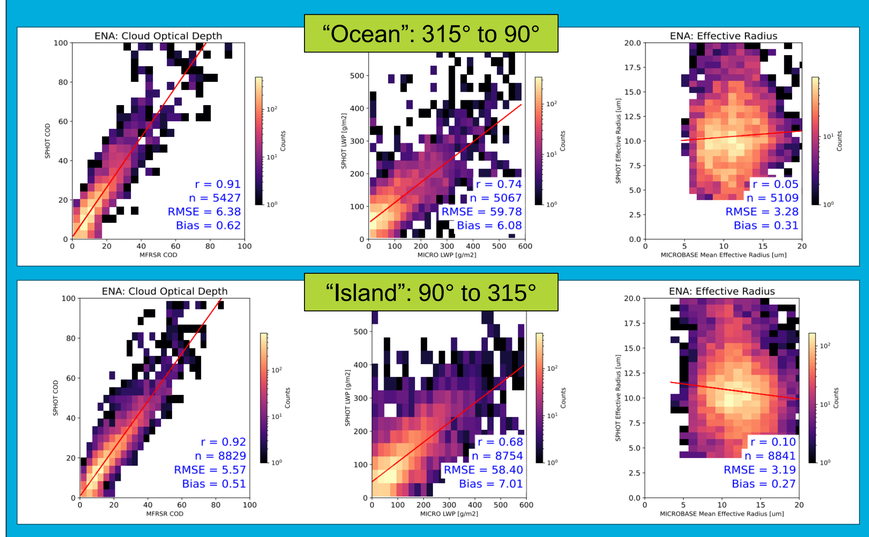
- (Above) Scatterplots for these 5-year datasets from ENA, SGP locations (not all VAPs need to be available).
- Comparisons between independent estimates for COD, LWP are highly correlated, with low Bias and RMSE.
- MFRSR Re estimates (not shown) suggest the largest values, least agreement with the other methods (i.e., MFRSR retrievals further dominated by error propagation, MWRRET LWP uncertainty).
- The poorest relative performances are found for Re. To compare bulk (column-cloud) SPHOT retrievals with MICROBASE values, an *average* in-cloud value was adopted.
- For ENA, our fix for a lower value for the MICROBASE-assumed number concentration improved the overall relative bias between the retrievals, but did not dramatically improve the correlation or RMSE.

Connections to Other ARM, ENA Observations

As noted by recent ENA publications (e.g., Giangrande et al. 2019; Ghate et al. 2021), cloud/precipitation properties and their attendant conditions may be influenced by frontal proximity, flows associated with directions that pass over Graciosa Island and/or surrounding Azores islands (e.g., right). It is often suggested that southerly flow or island-influenced days may exhibit enhanced cloud motions, thickness observable by ARM sensors/radars.



Ghate et al. (2021); Adapted by LASSO's ENA Workshop.

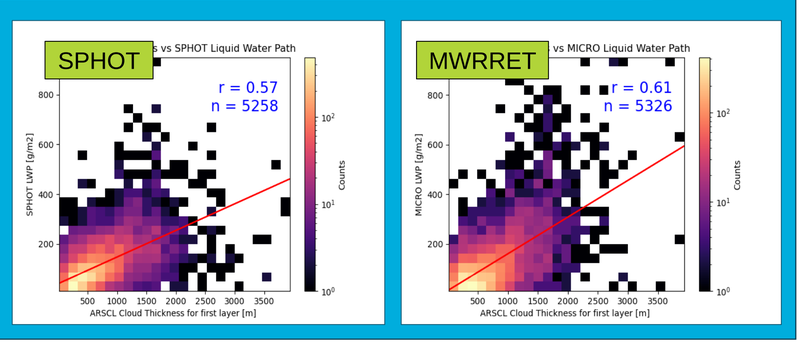


The range of StCu properties under both ambient wind regimes were similar (Island/Ocean counts have 60:40 split).

"Island" events from our parent case selection largely excludes StCu associated with frontal passage.

Interestingly, "Island" StCu events for this dataset carried higher LWP & COD values.

Combining these retrievals with ARSCL-based cloud properties such as Cloud Thickness (right) allows for additional checks. Initial images show an expected nonlinear behavior with possible sensitivity from the SPHOT (as compared to MWRRET) into lower LWP / thinner clouds.



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