ARM data as a resource for validation of NASA PACE cloud retrievals

Andrew M. Sayer[1,2] (andrew.sayer@nasa.gov), Chamara Rajapakshe[1,3], Kirk D. Knobelspiesse[2], Brian Cairns[4], P. Jeremy Werdell[2]
1: GESTAR II, University of Maryland Baltimore County, MD, USA 2: NASA GSFC, Greenbelt, MD USA
3: SSAI, Lanham, MD USA 4: NASA GISS, New York City, NY, USA

NASA's **Plankton, Aerosol, Cloud, ocean Ecosystem** (PACE) mission will launch in January 2024 and continue and improve upon satellite data records in its eponymous domains. PACE will carry a broad-swath hyperspectral imager, OCI, which will provide MODIS/VIIRS-type cloud data products (i.e. a **cloud mask, top height, visible optical thickness, droplet effective radius, phase, and derived water path**). It will also carry two multi-angle polarimeters (HARP2 and SPEXone) which will not only provide the above but also enable retrievals of additional cloud properties (e.g. **droplet effective variance, ice crystal asymmetry parameter**).

Validating satellite-based cloud retrievals is challenging. We plan to use several ARM data streams to evaluate PACE cloud data products and are prototyping our analyses using retrievals from MODIS on the Aqua satellite and OLCI on the Sentinel-3A satellite. This poster shows how we plan to use ARM data to evaluate liquid water path (via MWRRET) and cloud top height retrievals (via KARZASRCL), with example results from these proxy sensors and ARM data from the SGP, ENA, and NSA sites. **We seek comments from and collaborations with the ARM community to get the most out of our respective data streams.**

Data sets and matchup methods

We draw on ARM data from the three permanent sites: Southern Great Plains (SGP); East North Atlantic (ENA), and North Slope of Alaska (NSA). We average satellite retrievals within 1 km of the ARM site and ARM retrievals within 2 minutes of the satellite overpass. We make a parallax correction to apparent latitude and longitude based on the satellite-retrieved cloud-top height (CTH).

For LWP we filter out points with error more than 1.5 times the interquartile range from the center of each data set, which are often due to sampling differences.

PACE's validation error goals are defined for single-layer clouds with COT>3 (to be achieved for >65% of matchups).

Cloud top height (CTH)

OCI's goal uncertainty is expressed in terms of cloud-top pressure **(CTP): ±60 mb**. We transform this to CTH using MERRA2 profiles for each matchup.

- Sentinel 3A OLCI retrievals from the CHROMA algorithm (Sayer *et al.*, 2023), which will be applied to PACE OCI, for 2016-2020.
- CTH from the KAZRARSCL product (Kollias *et al.*, 2016).

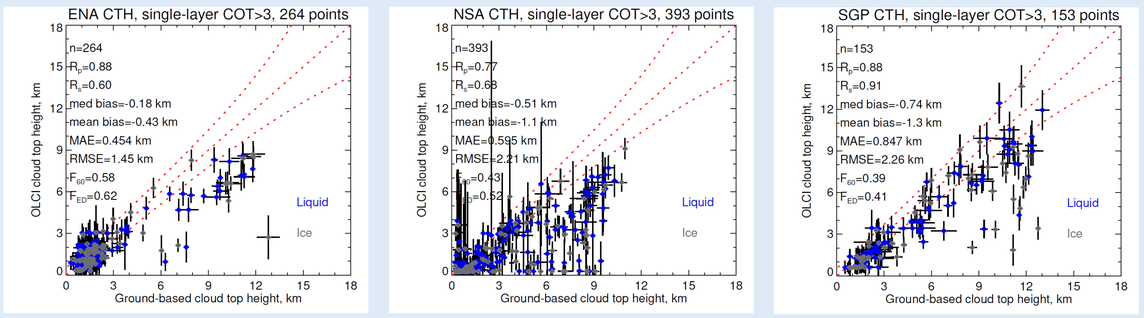
Liquid water path (LWP)

LWP validation is informative on the quality of the COT and CER used to derive it. OCI's uncertainty goal for liquid COT and CER are 25%. As LWP is proportional to the product of those, if their uncertainties are independent, adding in quadrature our goal is to obtain **LWP with 35% uncertainty**.

- Collection 6.1 MYD06 (Aqua) single-layer LWP (Wind *et al.*, 2020) for 2018-2020, applying provided quality flags (derived from COT and CER from the 2.1 μm band).
- LWP from the MWRRET1LILJCLOU product at SGP and NSA, and (due to instrumentation differences) MWRRET2TURN at ENA (Turner *et al.*, 2007).

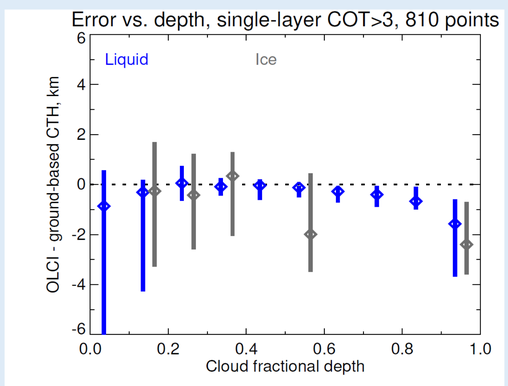
Cloud top height comparisons

We focus on the subset of points where KAZRARSCL identified a single-layer cloud, and OLCI retrieved COT>3.



- Red lines indicate 1:1 and the ±60 mb envelope in height space (for a US Standard Atmosphere).
- Horizontal bars are the ARM standard deviation in the time window; vertical bars are the forward-propagated CHROMA 1σ uncertainty estimate.
- Colours indicate OLCI retrieved the cloud as liquid (blue) or ice (grey) phase. **Is there an ARM product we can use for phase assessment?**
- Statistics include the number of matchups; Pearson and Spearman correlation coefficients, median and mean OLCI-ARM biases, median absolute and root mean square error. F_{60} and F_{EE} indicate the the fraction of matchups within 60 mb difference and within the retrieval's uncertainty estimate, respectively.

There is a negative bias for higher clouds. This is suspected to be due to the assumptions of cloud fractional geometric thickness in the retrieval (0.25 for ice clouds and 0.5 for liquid); an underestimate would be expected where clouds are deeper than this. This is somewhat consistent with an analysis of binned results from all sites (right).



Some more extreme outliers appear related to sampling differences, and we will evaluate our criteria. A cluster of low-biased points at NSA are likely due to 3D effects at high solar zenith angles, together with frequent snow cover.

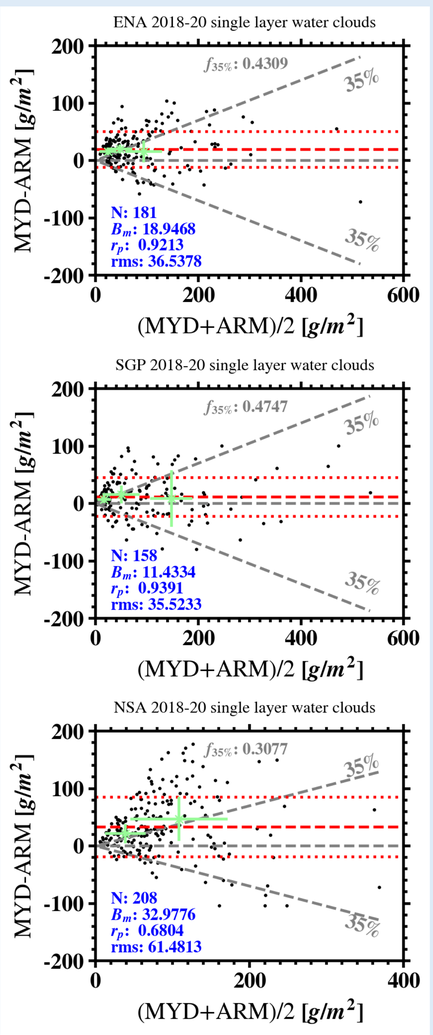
Liquid water path comparisons

We focus on single-layer liquid clouds and visualise results as "mean vs. difference" plots (aka "Bland-Altman") as these are useful for assessing the presence of scale-dependent bias.

- Grey lines indicate zero and ±35% difference.
- Red lines indicate the mean difference and 2σ limits of agreement.
- Green symbols indicate the mean and standard deviation of differences binned by LWP.
- Statistics include the number of matchups; MODIS-ARM bias; Pearson's correlation coefficient, and root mean square (RMS) difference. The symbol *f* indicates the fraction of matchups within 35% difference.

The comparison is poorest at NSA, likely due to 3D effects at high solar zenith angles, together with frequent snow cover. Bias and error magnitude appear fairly independent of LWP at SGP and ENA. No site meets the PACE goal of 65% of opaque cloud matchups agreeing within ±35%. We are investigating:

- **How significant and how well-characterized Is the uncertainty on ARM LWP** (e.g. retrieval error, drizzle sensitivity), so we can include it when calculating apparent agreement?
- Are there additional matchup-related uncertainties to take into account, and how does changing our colocation criteria affect the comparison?



https://pace.gsfc.nasa.gov

Thanks to the MODIS and VIIRS cloud teams for providing your algorithm to PACE project science, LAADS for hosting the MODIS retrieval products used, and ESA/EUMETSAT for the OLCI level 1 data. Thanks ARM for provision of the ground-based data.

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