Validation of MODIS cloud liquid water path to prepare for PACE evaluation efforts

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The **Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission** will launch in January 2024, extending and improving NASA's global satellite observations in its eponymous domains. PACE's hyperspectral Ocean Color Instrument (OCI) will offer daily near-global spatial coverage with a 1.2 km horizontal pixel size at the sub-satellite point. PACE will also have two multi-angle polarimeters (HARP2 and SPEXone) capable of advanced atmospheric characterization.

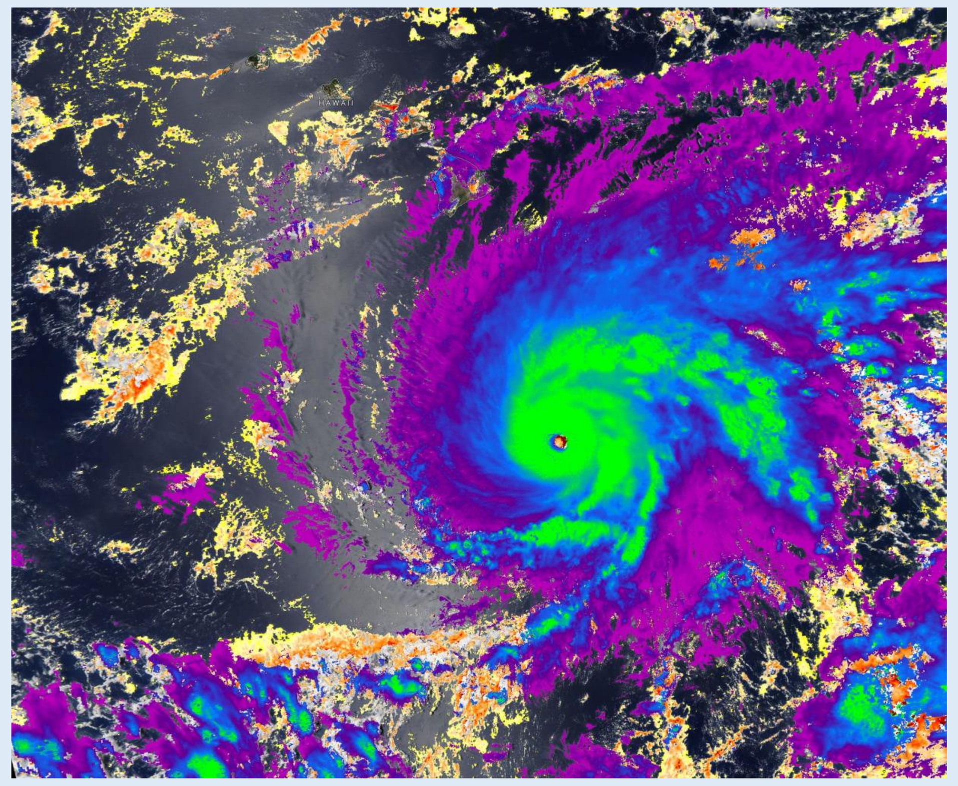
Validation of cloud retrievals is challenging. Here **we evaluate liquid water path (LWP) from MODIS** from the standard (MOD06) product. The same cloud optical properties retrieval algorithm will be applied to OCI data. This will allow us to **understand the expected performance of this algorithm** and to **develop the processing and analysis code needed to evaluate PACE data**.

Please tell us what you think and if we should be doing something differently!

What cloud products will PACE provide?

OCI cloud data will include the CHIMAERA cloud optical properties algorithm developed by MODIS/VIIRS science team members (Wind *et al.*, 2020). This provides cloud optical thickness (**COT**), cloud effective radius (**CER**), and **phase**, from which **LWP** (or ice water path, **IWP**) are derived. We hope this will make use of PACE cloud retrievals easy for MODIS/VIIRS data users. We will also be providing a **cloud mask** and cloud top pressure/height (**CTP**/**CTH**). Since OCI has no thermal bands, the CTP algorithm uses O_2 A-band measurements (Sayer *et al.*, 2023).

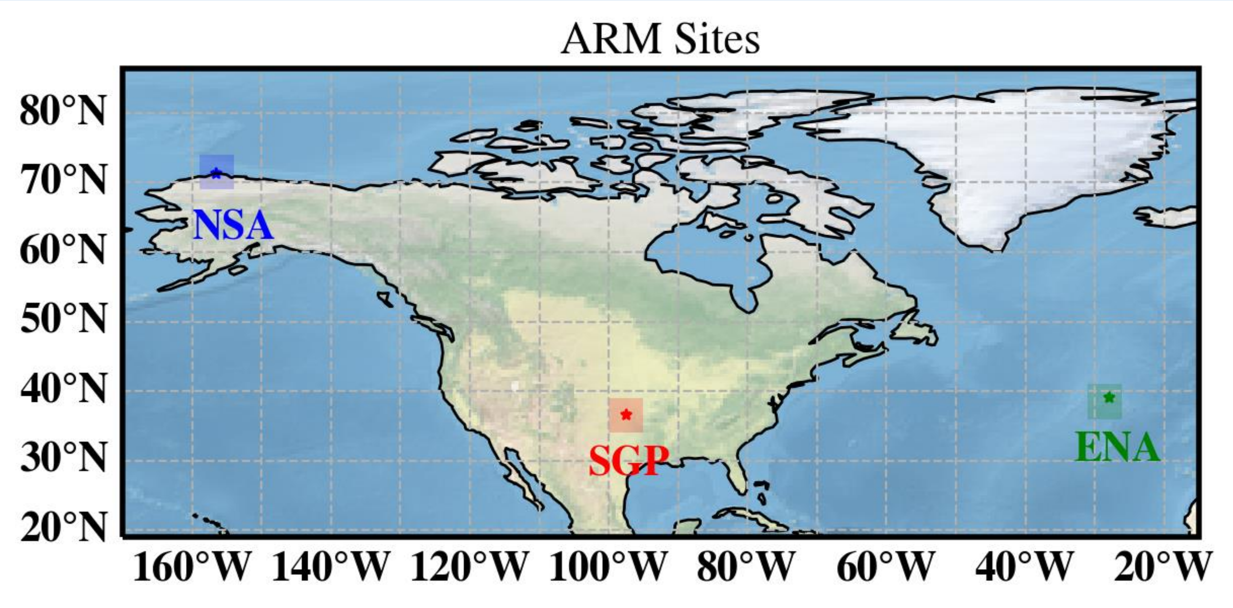
MODIS midvisible COT during Typhoon Soulik from Aug 21, 2018. Over a true-colour background, cool colours indicate ice phase COT from 1-100 and warm colours liquid phase COT from 1-100. Image from NASA Worldview, https://worldview.earthdata.nasa.gov



Several algorithms are being developed by science team members to retrieve cloud properties from the multi-angle polarimeters. As well as alternative approaches to the above heritage-type products, these will include cloud droplet size distribution **effective variance** and ice crystal **asymmetry factor**.

Why and how are we validating LWP?

LWP can be determined reasonably well from ground-based microwave sensors and its validation is informative on the quality of the COT and CER used to derive it. OCI's goal uncertainties for liquid COT and CER are 25% (to be achieved for >65% of opaque clouds). As LWP is proportional to the product of those, if their uncertainties are independent, adding in quadrature it follows that our goal is to **obtain LWP with 35% uncertainty**. We use:



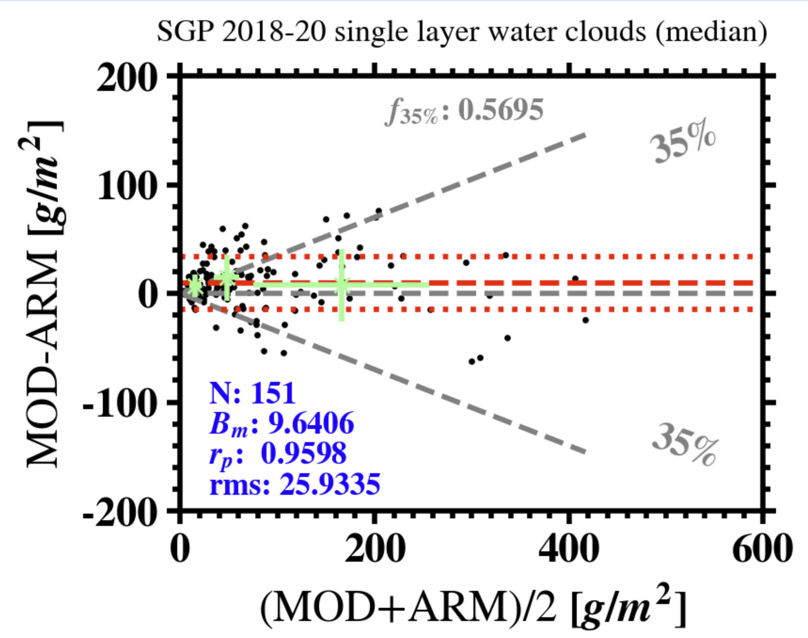
- Collection 6.1 MOD06 (Terra) single-layer LWP from 2018-2020, applying provided quality flags (derived from COT and CER from the 2.1 µm band), and make a parallax correction to latitude and longitude based on the MODIS-retrieved CTH.
- LWP from three DOE ARM sites: Southern Great Plains (SGP); East North Atlantic (ENA), and North Slope of Alaska (NSA). Due to instrumentation differences this is the MWRRET1LILJCLOU product at SGP and NSA, and MWRRET2TURN at ENA (Turner *et al.*, 2007).

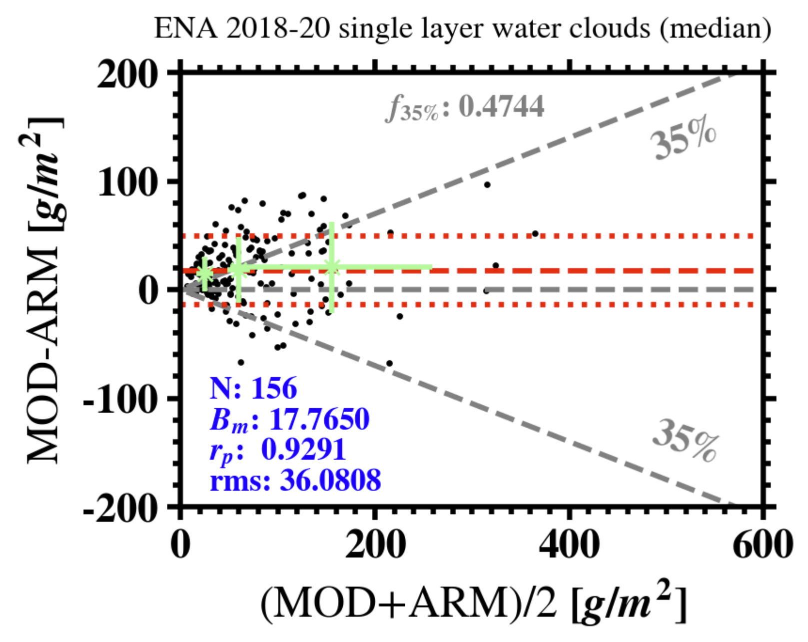
We average satellite retrievals within 1 km of the ARM site and ARM retrievals within 2 minutes of the satellite overpass. We filter out points with error more than 1.5 times the interquartile range from the center of each data set, which are often due to sampling differences.

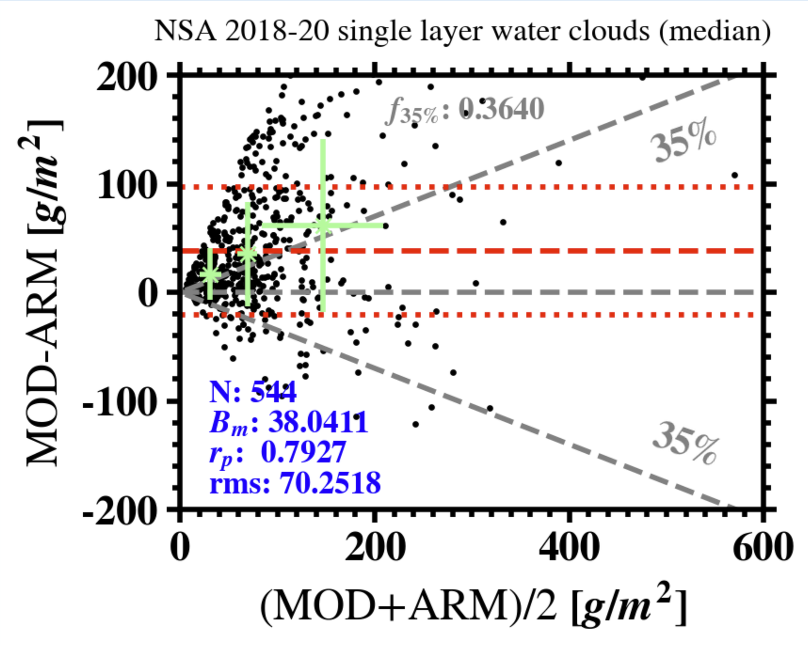
What do the results look like?

We visualise results as "mean vs. difference" plots (aka "Bland-Altman") as these are useful for assessing the presence of scale-dependent bias. We look site-by-site due to their individual distinct atmospheric and surface regimes. In these plots:

- 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.







As expected, the comparison is poorest at NSA. This is likely due to 3D effects at high solar zenith angles, together with frequent snow cover, leading to an overestimate of LWP by MODIS. 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:

- Is the uncertainty on ARM data (e.g. retrieval error, drizzle sensitivity) significant such that we should 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?

We are keen to talk with users of MODIS and/or ARM LWP data to hear your experiences with these data products and understand how we might most appropriately evaluate them (and PACE).

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

- Sayer, A. M. *et al.* (2023), The CHROMA cloud-top pressure retrieval algorithm for the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) satellite mission, *Atmos. Meas. Tech.*, 16, doi:10.5194/amt-16-969-2023
- Turner, D. D. (2007), Improved ground-based liquid water path retrievals using a combined infrared and microwave approach, *J. Geophys. Res.*, 112, doi:10.1029/2007JD008530.
- Wind, G. *et al.* (2020), The CHIMAERA system for retrievals of cloud top, optical and microphysical properties from imaging sensors, *Computers & Geosciences*, 134, doi:10.1016/j.cageo.2019.104345

Learn more about PACE at https://pace.gsfc.nasa.gov !