# Improvements to CloudSat warm cloud retrievals using combined CloudSat/CALIPSO observations

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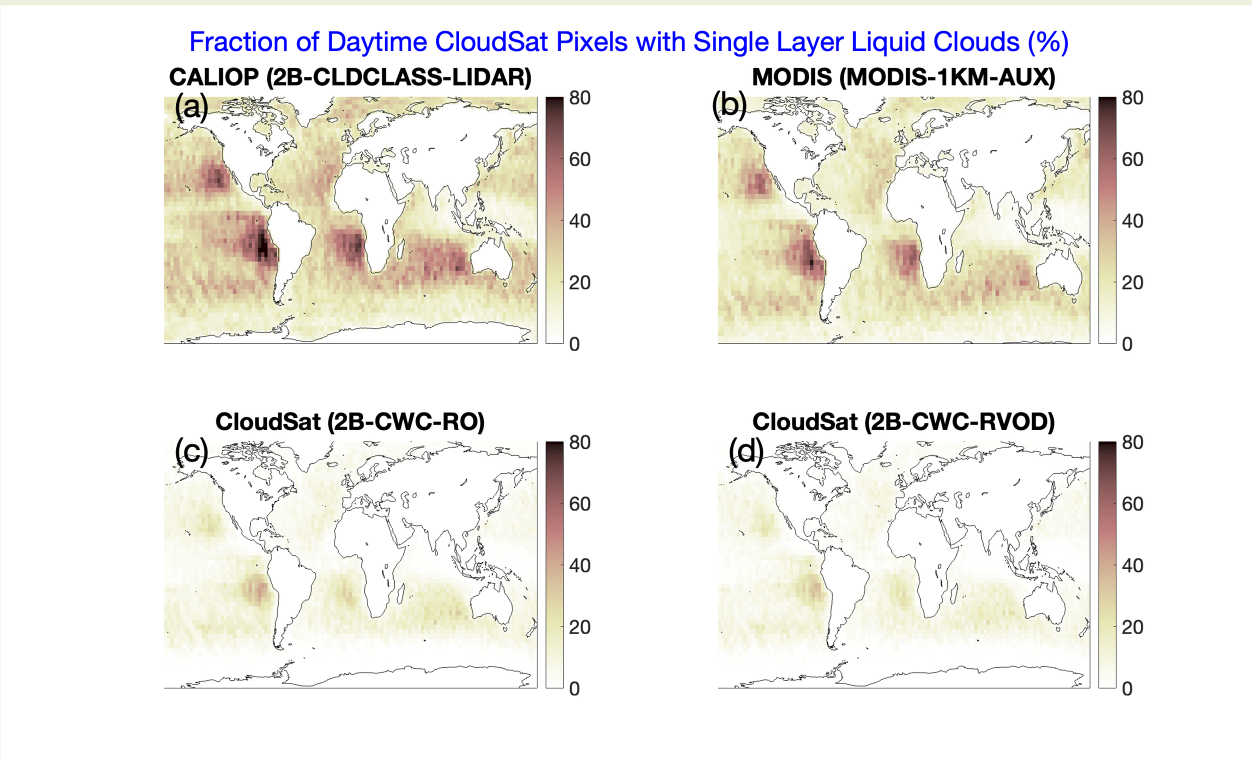
## Motivation

- Many thin liquid clouds that are detected by the CALIOP lidar and MODIS spectroradiometer are missed by the CloudSat Cloud Profiling Radar (CPR), either because they do not generate reflectivities above the noise level of ~-30 dBZ or because they are masked by surface clutter.




## Methods

- We train a random forest model to retrieve the cloud optical depth ($\tau$) and cloud top effective radius ($r_e$) based on other A-train measurements. We train on data from 2008 and test on data from 2009 (ocean pixels only).
- From $\tau$ and $r_e$, we can estimate profiles of cloud water using the same subadiabatic model developed in Schulte et al. (2023).

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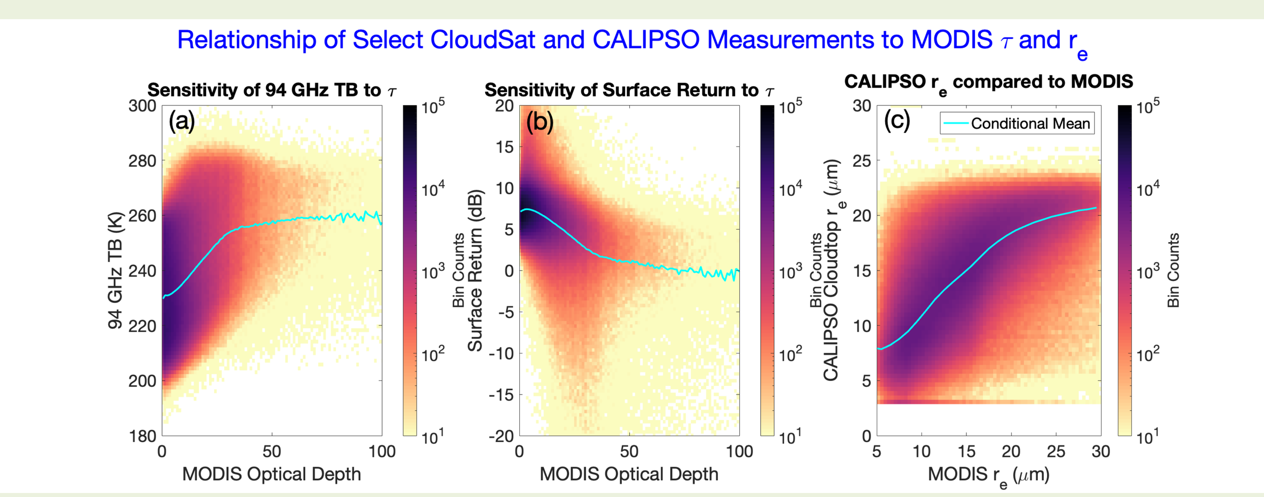
## Why Does This Work?

- $TB_{94}$ and $\sigma_0$ are correlated with MODIS $\tau$, especially when controlling for total column water vapor (TCWV) and SST (for $TB_{94}$) and wind (for $\sigma_0$).
- The CALIPSO-based estimate of cloud top $r_e$ from Hu et al. (2021) is highly correlated with MODIS 3.7 micron $r_e$.




## References

Hu, Y., and coauthors, 2021: Liquid phase cloud microphysical property estimates from CALIPSO measurements. *Front. Remote Sens.*, **2**, https://doi.org/10.3389/frsen.2021.724615.

Schulte, R. M., M. D. Lebsock, and J. M. Haynes, 2023: What CloudSat cannot see: liquid water content profiles inferred from MODIS and CALIOP observations. *Atmos. Meas. Tech.*, **16**, 3531-3546, https://doi.org/10.5194/amt-16-3531-2023.

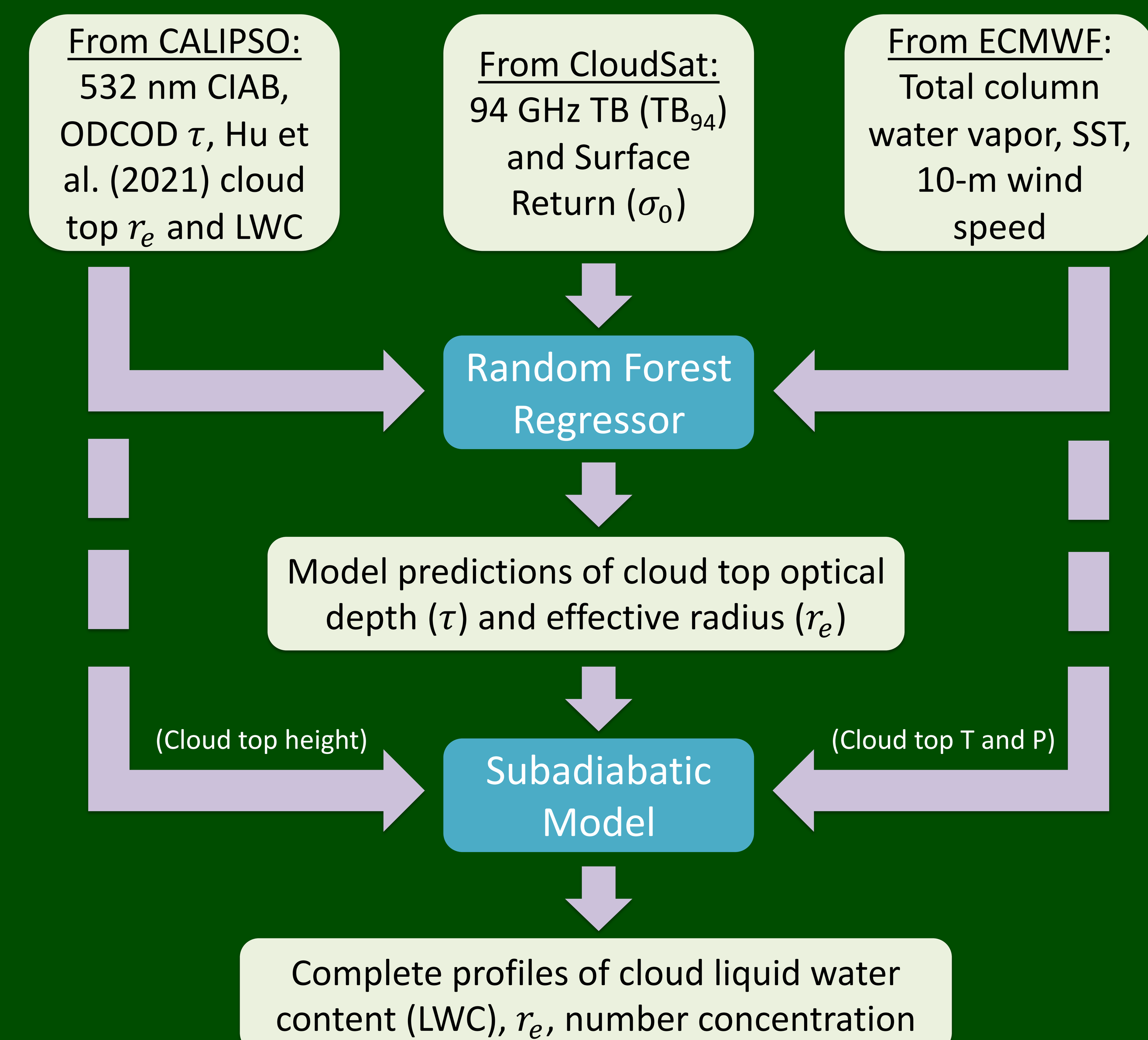
## Many **low liquid clouds** are missed by the CloudSat radar, but we can **infer their properties** using coincident measurements from CALIPSO, *non-reflectivity* measurements from CloudSat, and environmental conditions.

## Key Points

- About 80% of single layer liquid clouds that are detected by the CALIOP lidar are not detectable from CPR radar reflectivities.

- By training a machine learning model to predict cloud microphysical properties, and then assuming a subadiabatic cloud model, we can estimate vertical profiles of cloud water for clouds detected by CALIOP but missed by CPR (including nighttime clouds).

- 94 GHz TB and CPR surface return are useful predictors of cloud optical depth, while CALIOP measurements can be used to reliably estimate cloud top effective radius.

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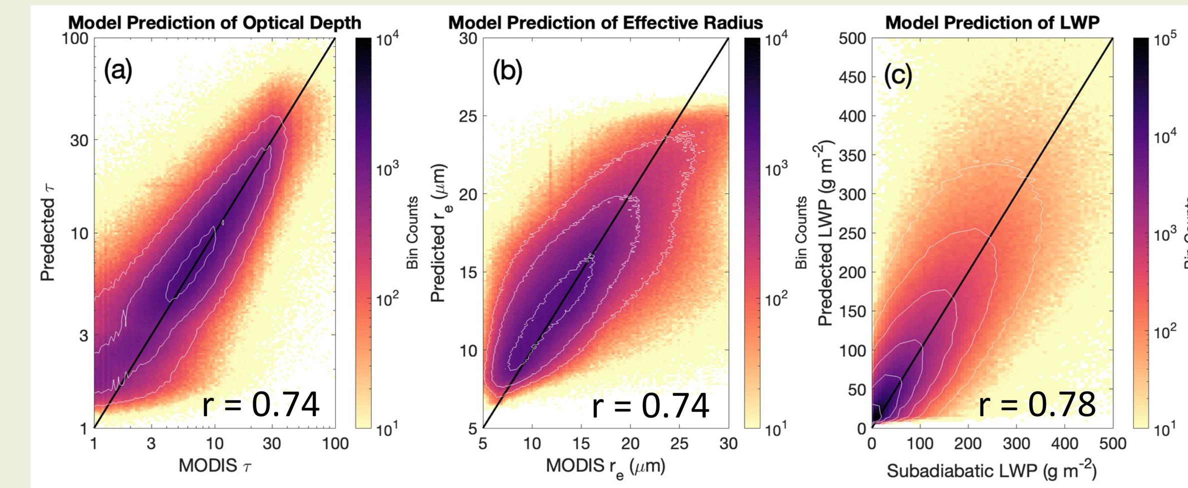
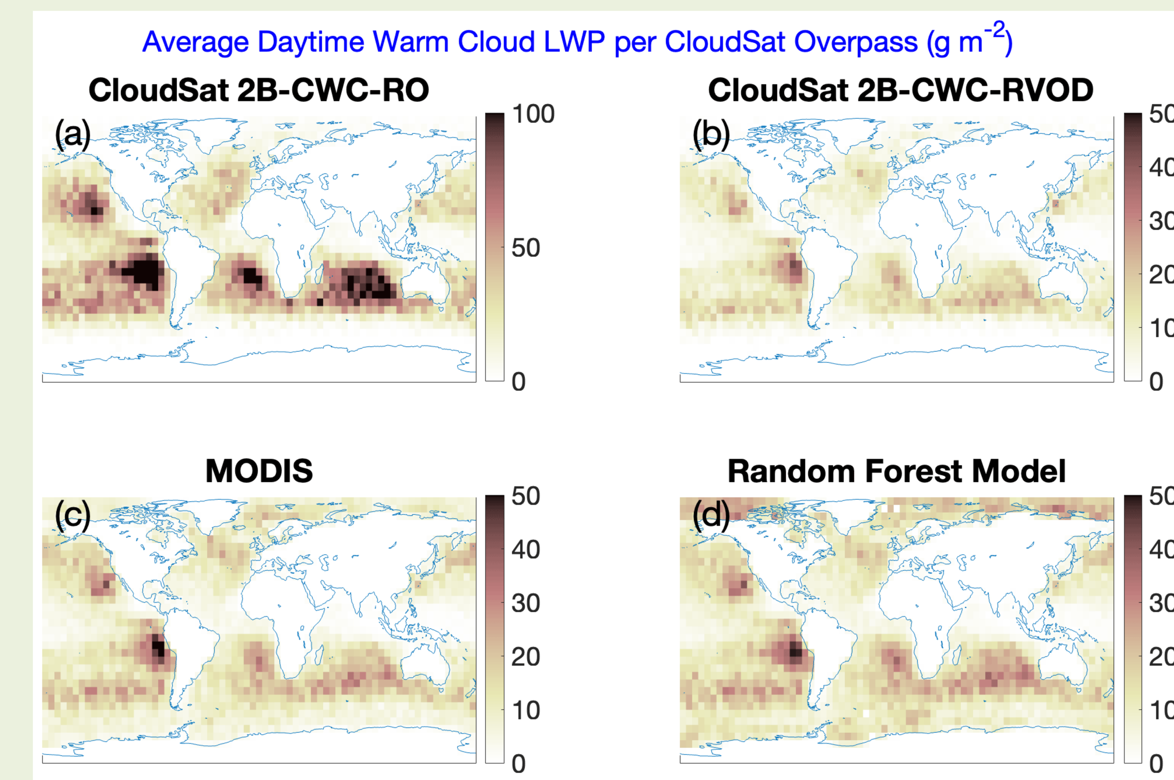
## Results

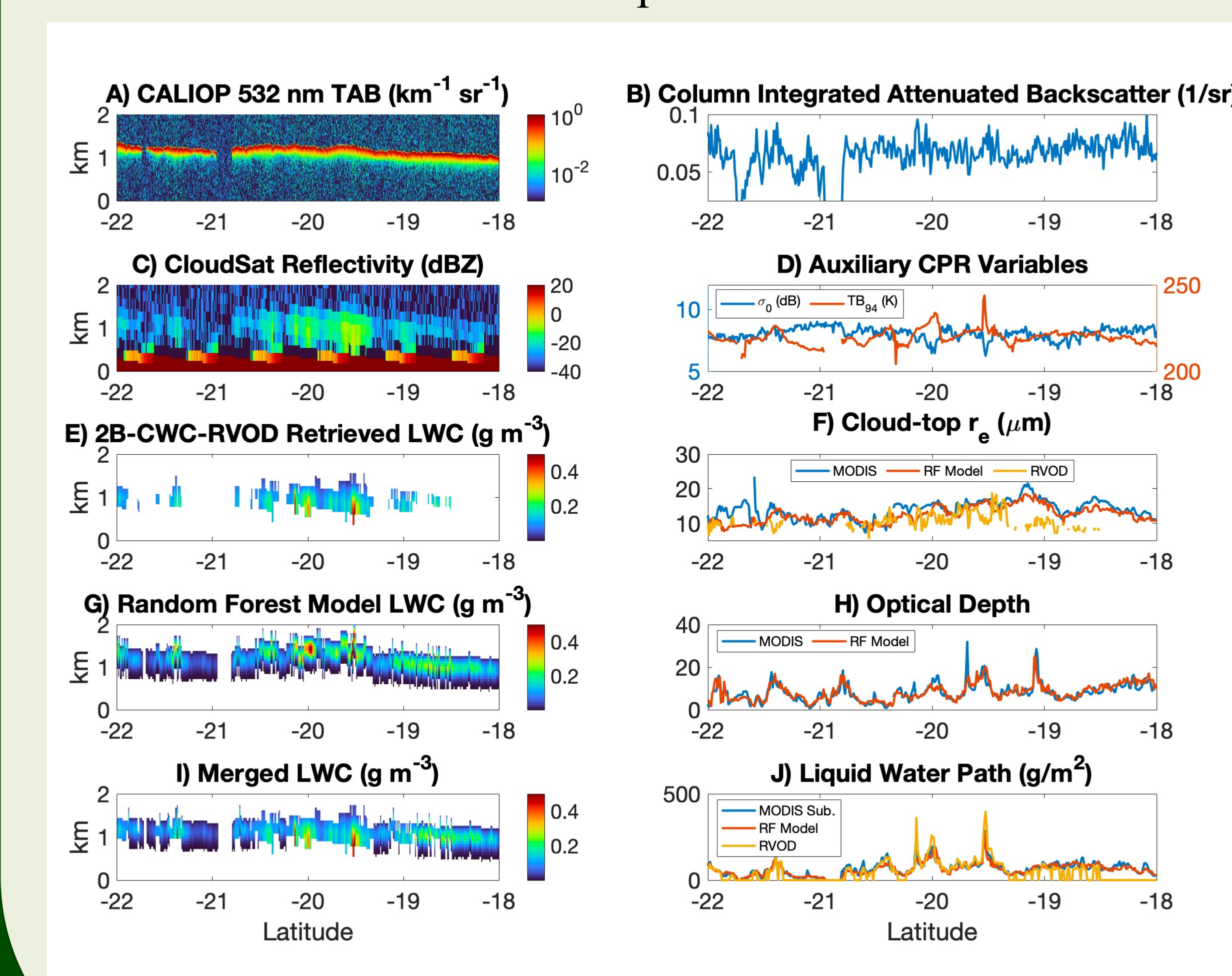
- Model predictions of $\tau$, $r_e$, and liquid water path (LWP) are well-correlated with MODIS estimates for daytime observations.




- With our model, the unconditional average warm cloud LWP increases from 6.4 g m$^{-2}$ in the operational 2B-CWC-RVOD algorithm to 10.2 g m$^{-2}$.




- When we merge the random forest LWC profiles with profiles from 2B-CWC-RVOD, we get reasonable-looking cross sections without sharp discontinuities.




Case study from 2 September 2009 over the southeastern Pacific Ocean