# Validation of Cloud Fraction Estimates from Passive Imagers Using CALIOP Observations with Attention to the Effects of Spatial Resolution

Chris Yost, Bill Smith, Jr., Qing Trepte, and Rabindra Palikonda

Special Thanks to CALIPSO Science Team:

Dave Winker, Chip Trepte, Mark Vaughan, Xia Cai, Roman Kowch

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# Motivation for Study

- NASA LaRC Cloud Working group uses SatCORPS algorithms to retrieve cloud physical and optical properties from polar-orbiting and geostationary passive sensors (e.g., MODIS, GOES, AHI) for Earth radiation budget and other applications

- CALIOP (Cloud-Aerosol Lidar with Orthogonal Polarization) observations used to validate and check consistency of retrievals amongst the various passive sensors

- CALIOP products are very complex and require careful consideration of horizontal averaging (HA) and quality flags

- Low-level marine cumulus and stratocumulus are an important part of the Earth radiation budget, but it can it can be difficult to accurately characterize their abundance, i.e., cloud fraction

# Collocated CALIOP/MODIS Dataset

- Collocated CALIOP/MODIS from June 2006, August 2015, and July 2016 "golden months"
  - CALIOP V4.10 products
  - NASA LaRC CERES-MODIS cloud mask and cloud property retrievals

- CALIPSO ground track broken into 5-km segments
  - 5-km spatial scale is the fundamental scale used by the CALIOP feature-finding algorithm

- Nearest MODIS pixel matched to the midpoint of each track segment

- CALIPSO products used:
  - Vertical Feature Mask (VFM): provides details about detected "features", i.e., clouds and aerosols
  - 5-km Cloud Layers product: cloud top heights

- Some 5-km track segments are only partially cloud-filled. Single-shot detections provide "sub-segment" cloud fraction, or an estimate of cloud fraction

# CALIPSO VFM and Horizontal Averaging Summary
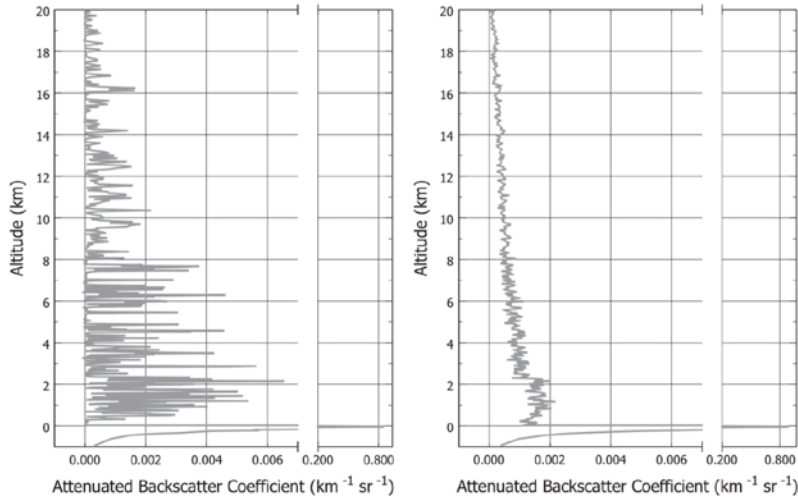
Fig. 2 from Vaughan et al. (2009, JAOT)



FIG. 2. (left) An example of the native SNR of the CALIOP data shown by a single, full-resolution 532-nm attenuated backscatter profile acquired 13 Aug 2006 at 19.2°S, 113.9°E; (right) the same data incorporated into a 20-km (60 profile) horizontal average. The aerosol layer at ~2.2 km is present in both profiles, but its presence only becomes apparent in the averaged data.

**Single lidar shots have a footprint size of ~100m at the surface and are spaced 333 m apart.**

**Strongly scattering features (e.g., water clouds) are typically detectable with a single shot**
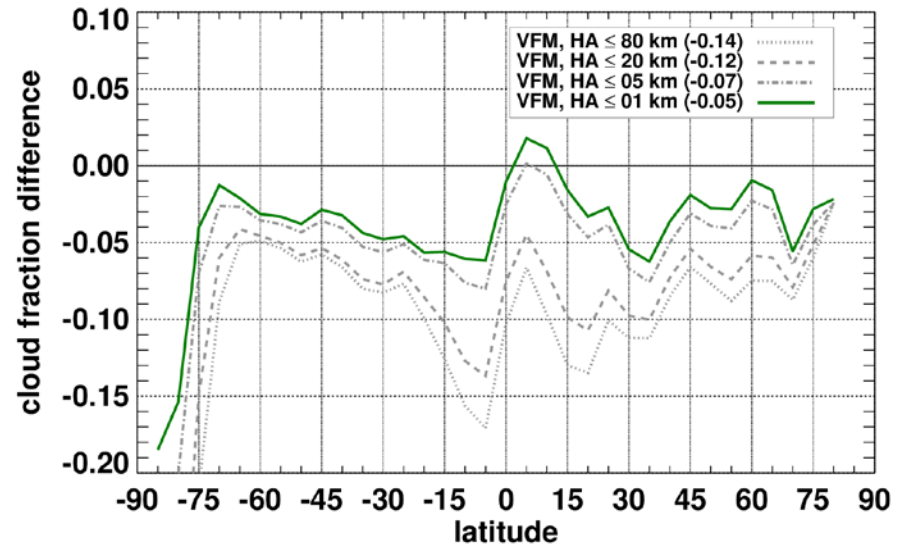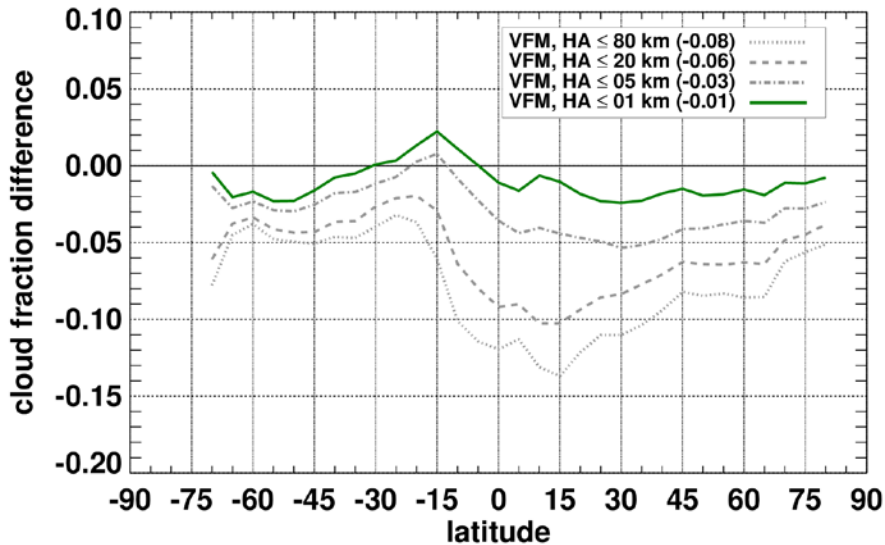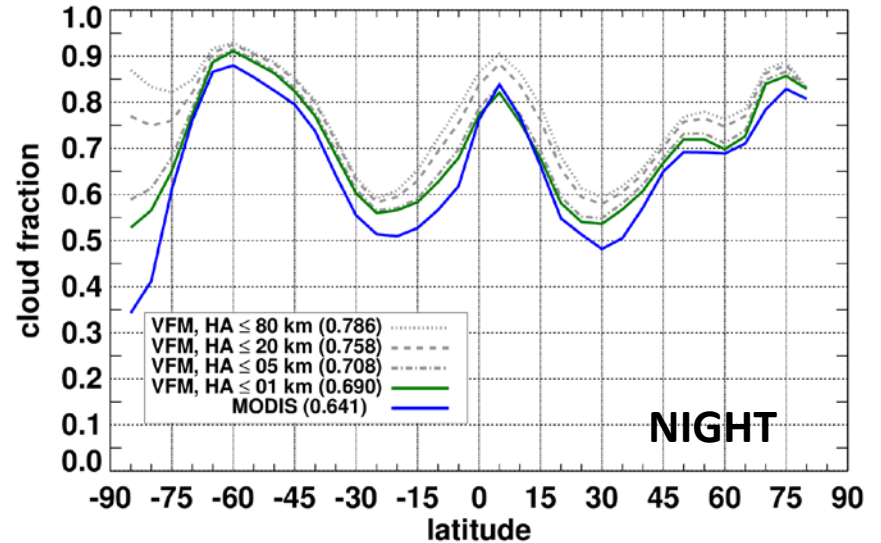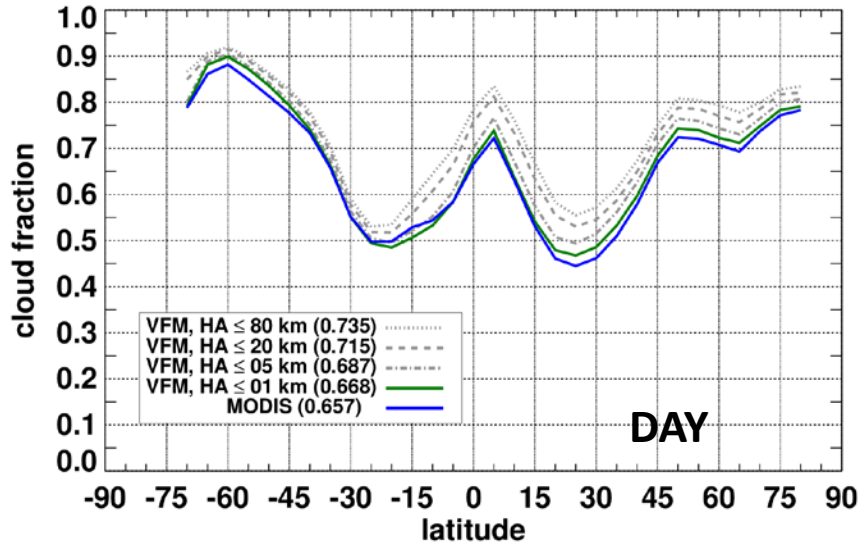
**Weak features (e.g., thin cirrus, aerosol layers) usually require some amount of horizontal averaging (HA) to detect**
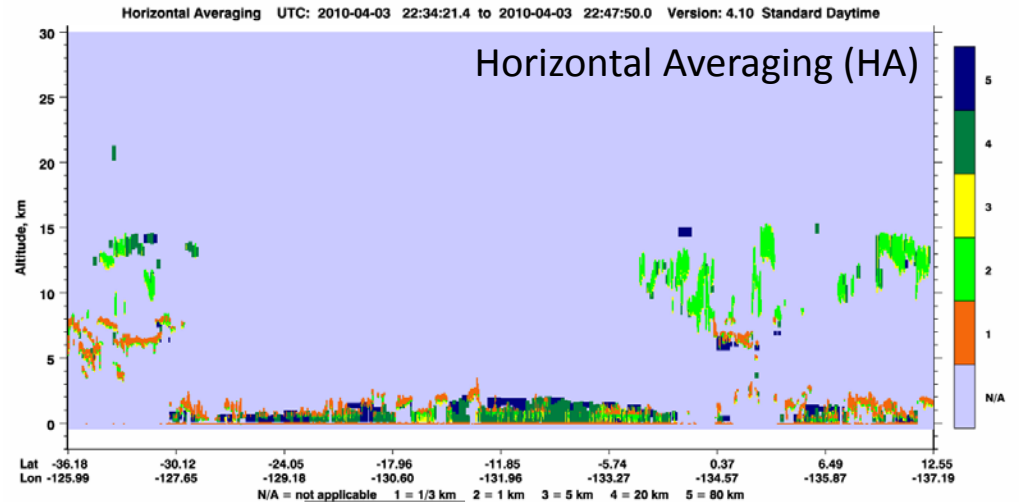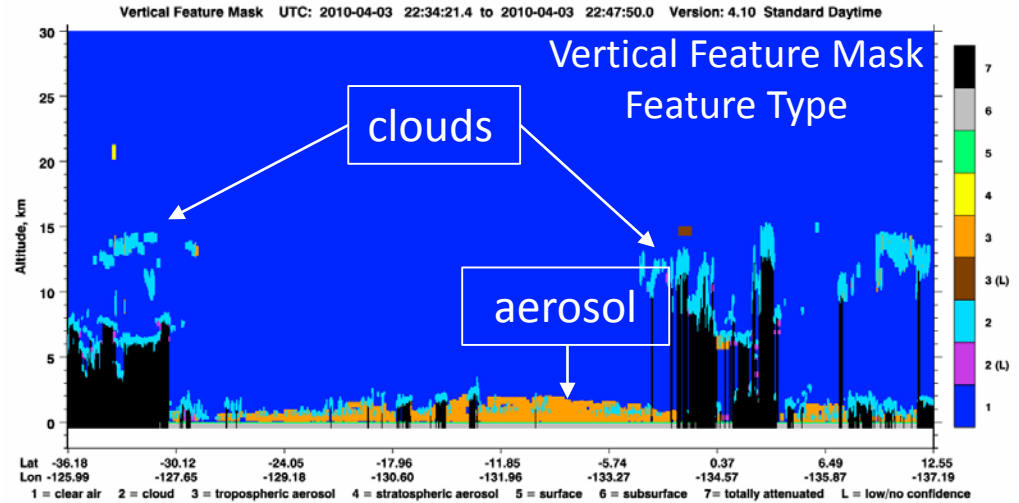


N/A = not applicable    1 = 1/3 km    2 = 1 km    3 = 5 km    4 = 20 km    5 = 80 km

aka, "single-shot"

# VFM/MODIS Zonal Cloud Fraction Comparisons



**Cloud fraction estimated from VFM can vary by up to 10% depending on horizontal averaging criteria**
**MODIS has good agreement with VFM using 1-km and single-shot detections**
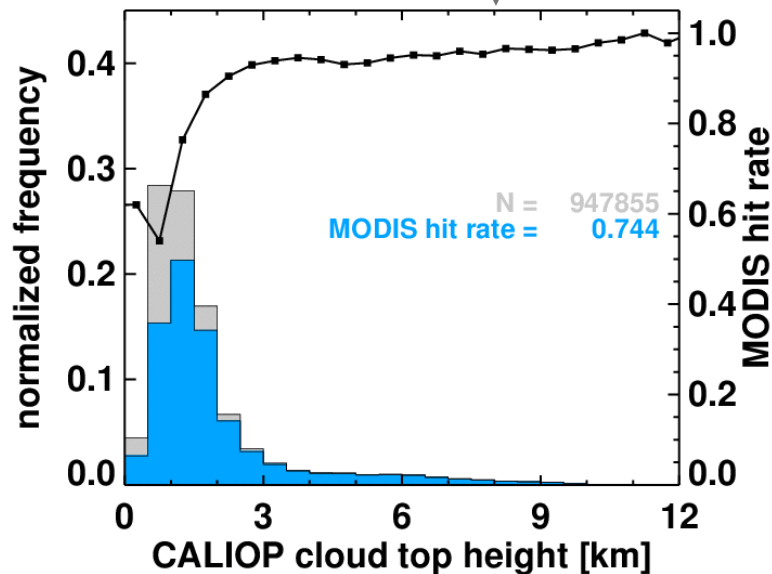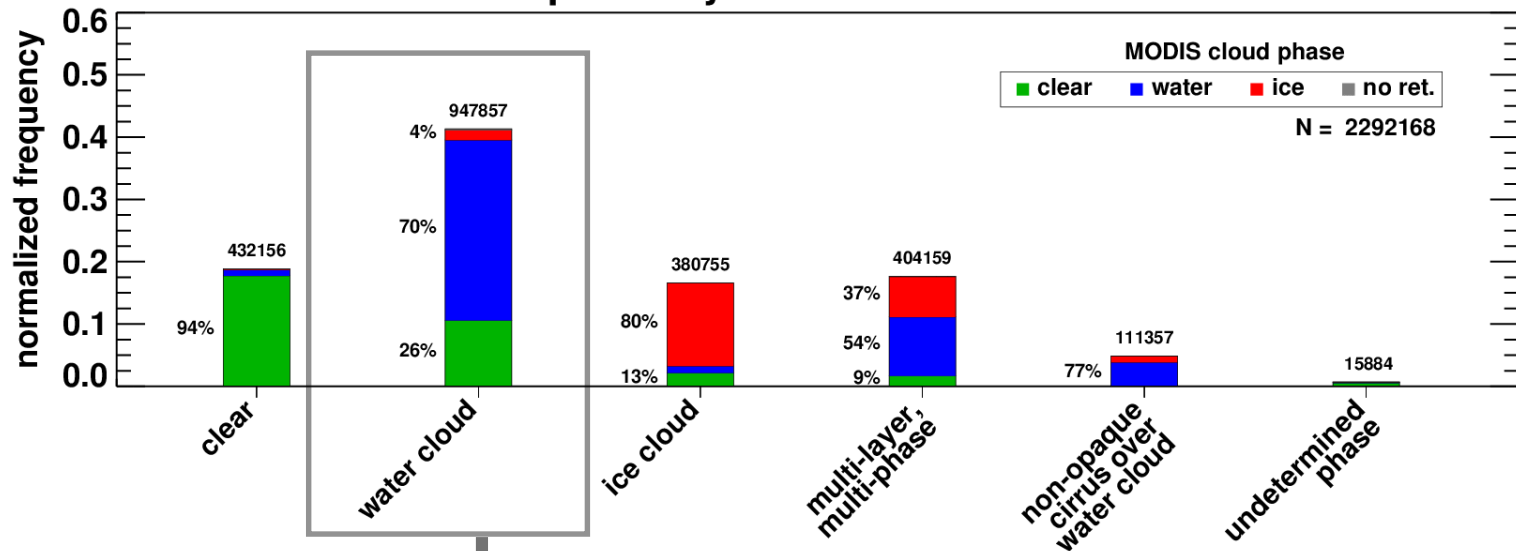
# Cloud Mask/Phase Summary: Golden Months

## MODIS cloud phase by VFM-based scene classification
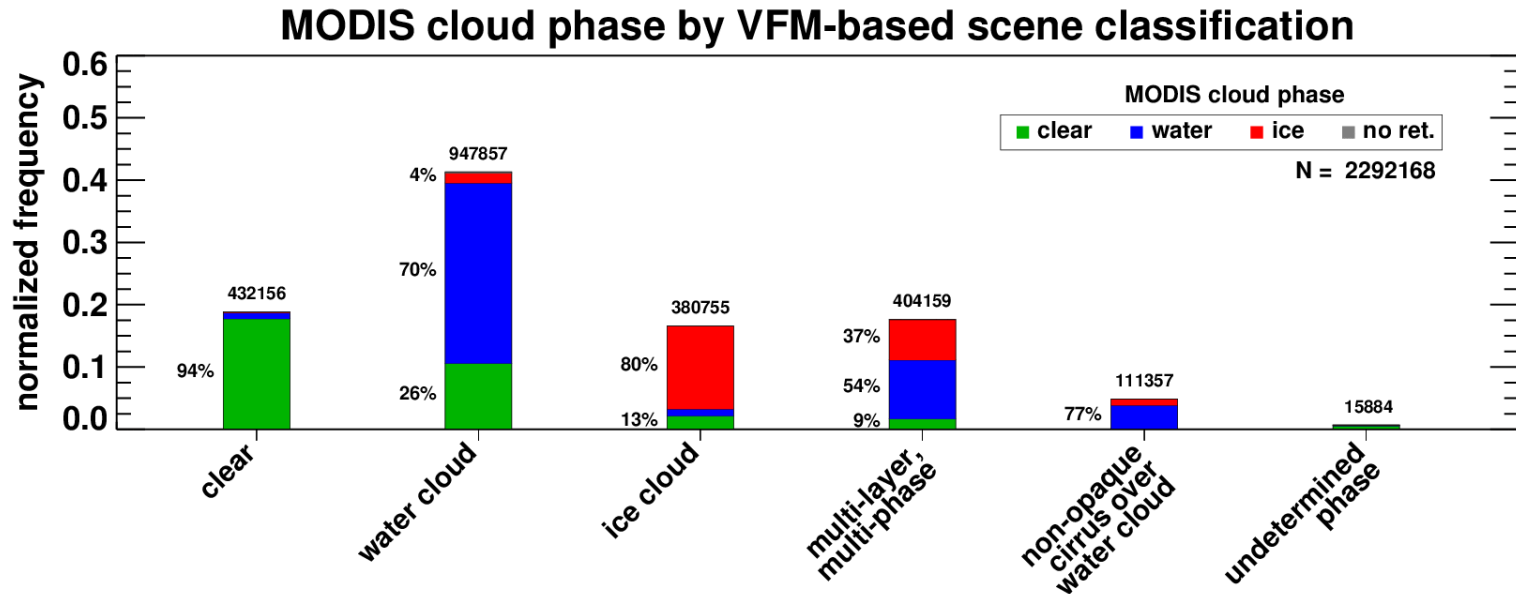


- Collocated CALIOP/MODIS data from ICWG golden months (non-polar, daytime, ocean surface)
- Scene classification determined from VFM product (x-axis labels) based on number of cloud layers and cloud phase
- MODIS cloud phase represented by colors indicated in the legend
- MODIS false detections comprise < 6% of the "clear" category and only ~1% of the entire 3-month dataset

# Cloud Mask/Phase Summary: Golden Months

## MODIS cloud phase by VFM-based scene classification



Blue PDF represents fraction of CALIOP clouds that MODIS detected

Black line: MODIS hit rate as a function of cloud top height (see right y-axis)

Undetected clouds have top heights < 2 km, characteristic of marine boundary layer clouds
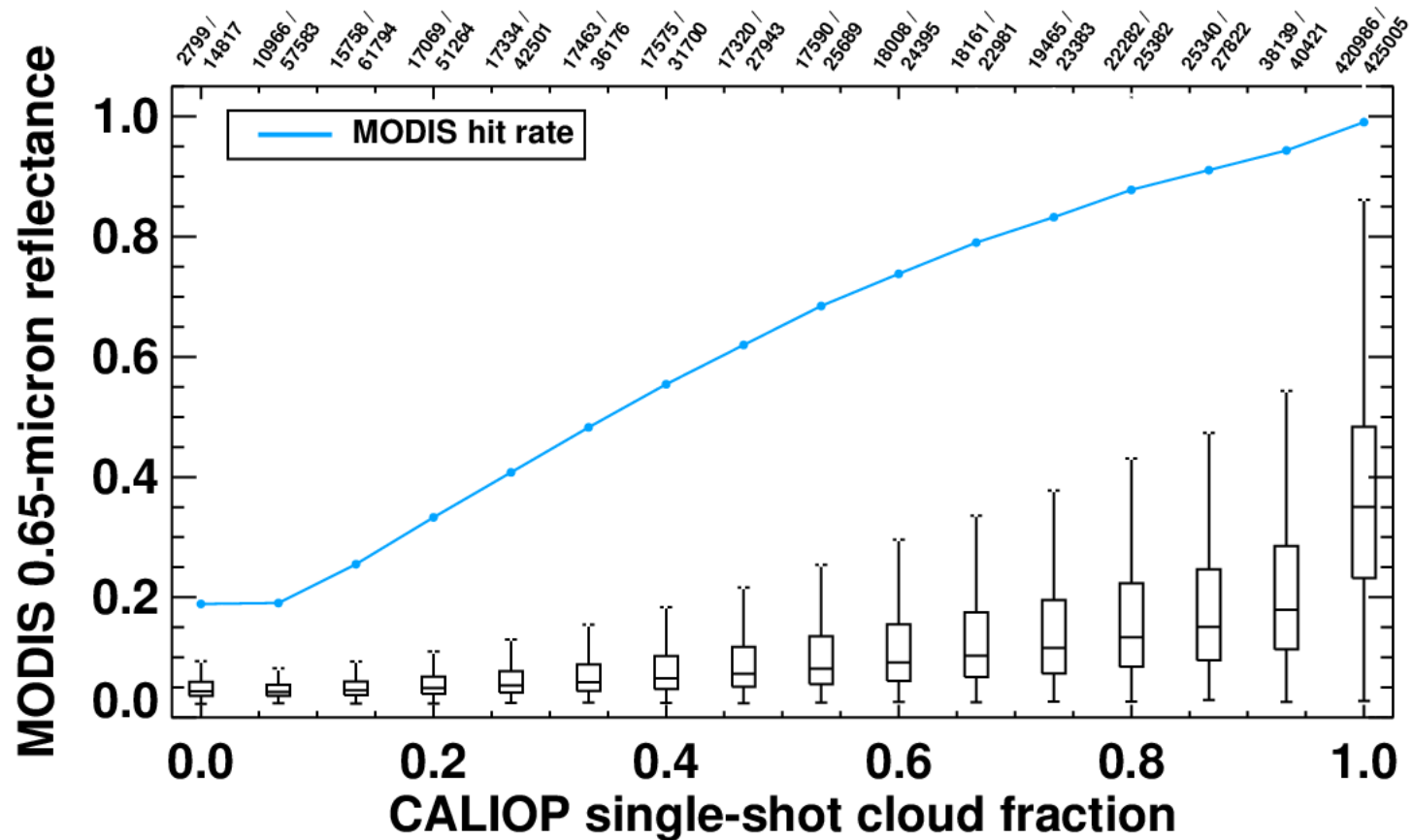
# Cloud Mask/Phase Summary: Golden Months

## MODIS cloud phase by VFM-based scene classification
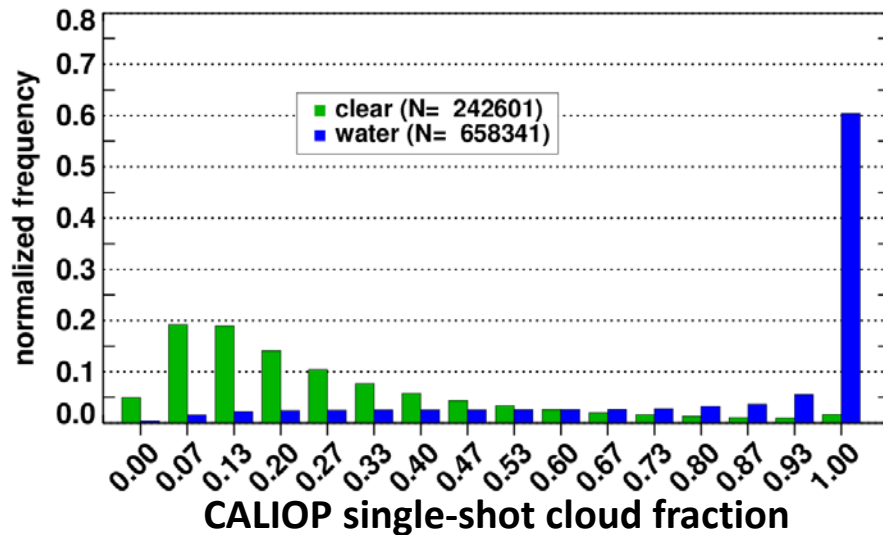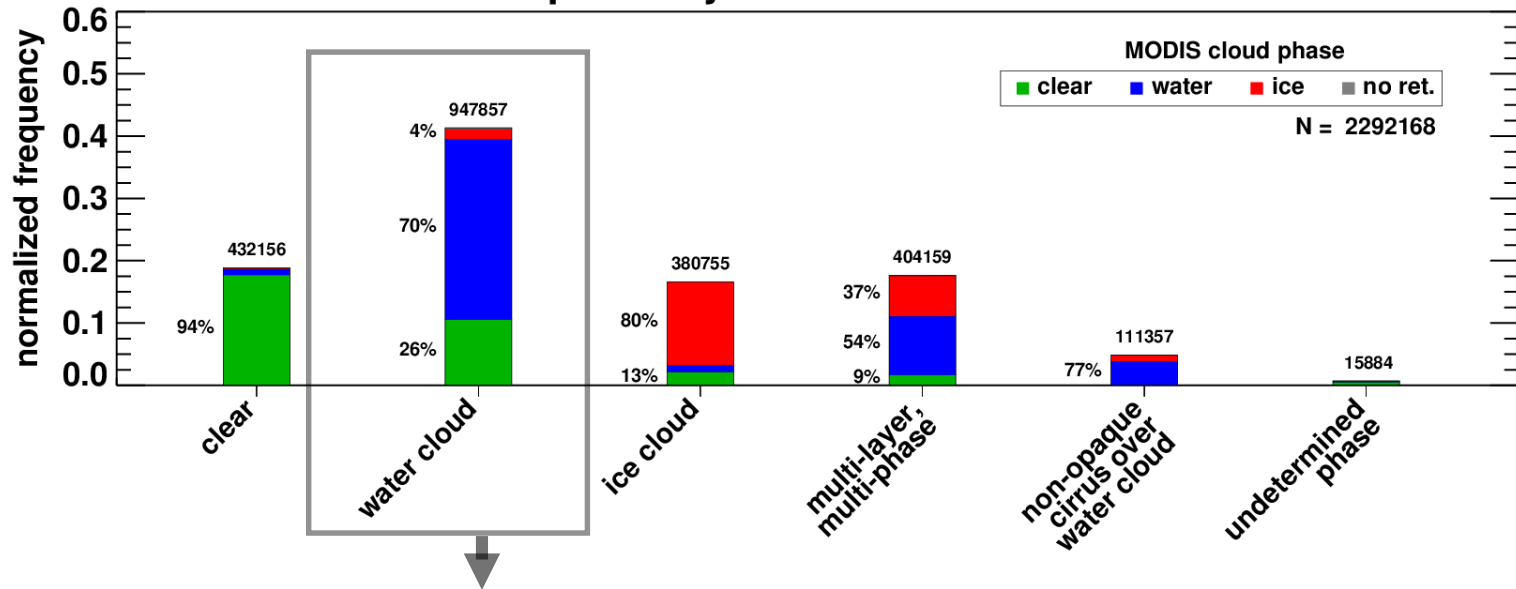


Most (~60%) of the detected water clouds (blue bars) were overcast scenes
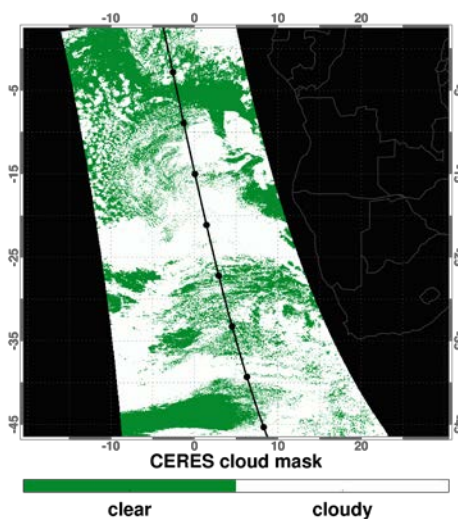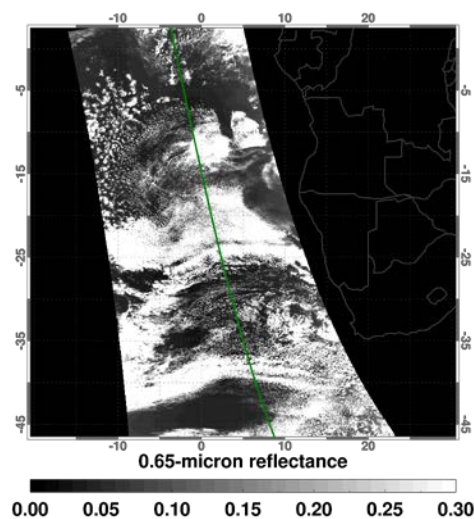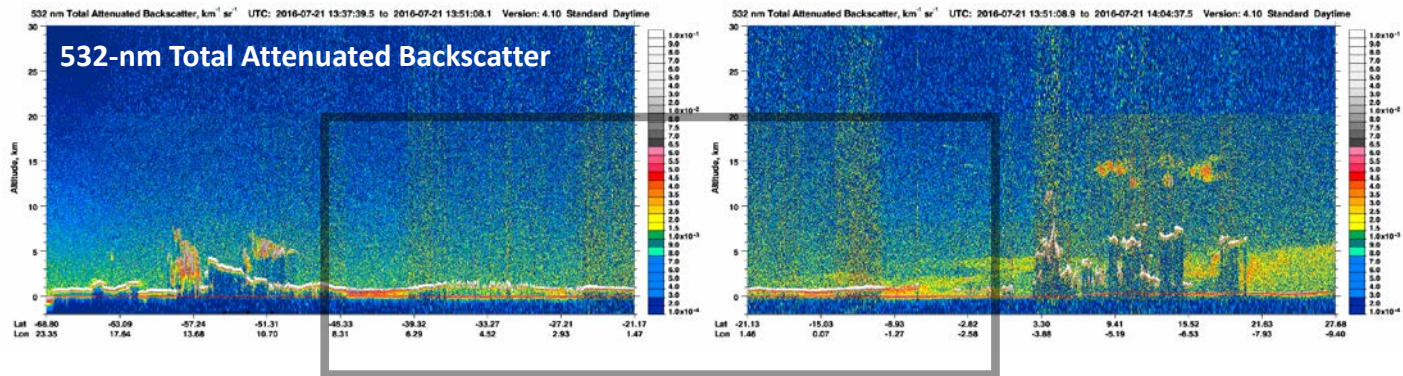
A significant portion of the undetected water clouds (green bars) were partially cloud-filled scenes

# MODIS VIS Reflectance and Hit Rate as Function of Single-Shot Cloud Fraction



- MODIS has hit rates > 70% for mostly cloudy scenes
- MODIS VIS reflectance very small for CALIOP CF < 0.4 and often not high enough to trigger detection

# Example Case Study:
# 7 July, 2018



532-nm Total Attenuated Backscatter



0.65-micron reflectance

0.00   0.05   0.10   0.15   0.20   0.25   0.30



CERES cloud mask

clear        cloudy

### CALIOP

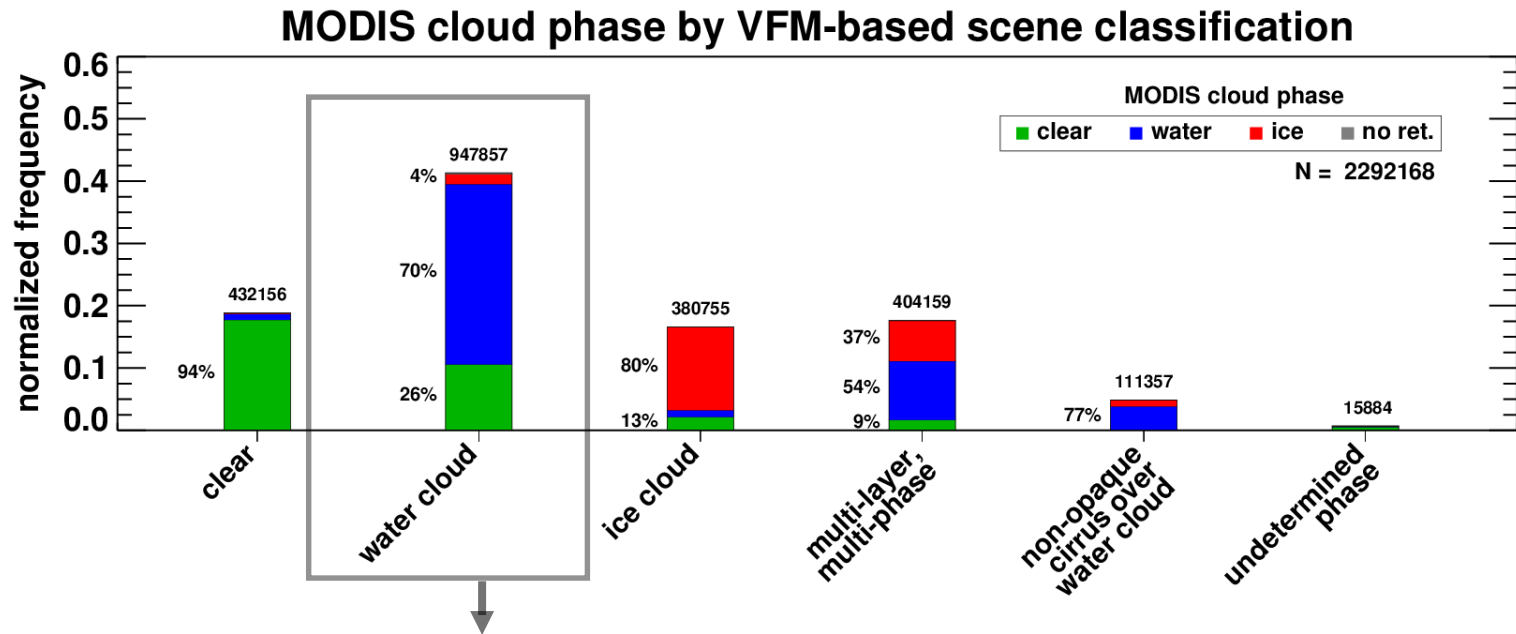|  | | CLEAR | CLOUD |
|---|---|---|---|
| **MODIS** | CLEAR | 45 | 106 |
| | CLOUD | 3 | 512 |

Fraction correct* = 0.84

Hit rate** = 0.83

*FC = (45+512) / 666

**HR = 512 / (106+512)

| | CAL HA ≤ 80 km | CAL HA ≤ 20 km | CAL HA ≤ 5 km | CAL HA ≤ 1 km | CAL single-shot only | MODIS |
|---|---|---|---|---|---|---|
| **cloud fraction** | 0.78 | 0.78 | 0.78 | 0.77 | 0.68 | 0.77 |

# Cloud Fraction in Low-Level Water Cloud Scenes: Golden Months

## MODIS cloud phase by VFM-based scene classification



|  | CAL HA ≤ 80 km | CAL HA ≤ 20 km | CAL HA ≤ 5 km | CAL HA ≤ 1 km | CAL single-shot only | MODIS |
|---|---|---|---|---|---|---|
| cloud fraction | 0.82 | 0.81 | 0.81 | 0.80 | 0.68 | 0.74 |

- Again, MODIS cloud fraction is high only relative to single-shot cloud fraction
- MODIS and CALIOP cloud fraction are in better agreement when 1-km and 5-km detections are included

# Summary

- Does MODIS detect too many low-level clouds?
  - no, not at the native pixel resolution
  - CALIOP cloud fraction computed with 333-m, 1-km, and 5-km HA detections yield results similar to MODIS for low water clouds

- Does MODIS overestimate low cloud fraction?
  - Generally yes, when the cloud elements are smaller than the pixel resolution (1 km)
  - However, this is a known issue documented in the literature and not unique to MODIS
  - CALIOP single-shot cloud fraction is smaller than MODIS due to CALIOP spatial resolution/sampling (333-m spatial resolution)

- For water clouds, CALIOP 333-m (single-shot) detections probably yield the best estimate of the true cloud fraction for low-level water clouds (top altitudes < 8.2 km)

- Validation metrics such as fraction correct, hit rate, etc., may be insufficient for assessing cloud mask performance in broken cloud systems

- CALIOP overestimation of high clouds detected at 20- and 80-km horizontal averaging?