A41L-2804: Progress Towards a Common CERES Cloud Mask Algorithm for MODIS and VIIRS: Evaluation Using CALIOP Data

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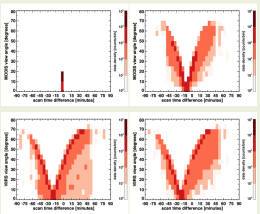
1. Introduction

- The Cloud's and the Earth's Radiant Energy System Cloud Working Group (CERES CWG) derives cloud properties from MODIS and VIIRS in order to study the role of clouds in Earth's energy budget.
- MODIS and VIIRS serve similar purposes but there are some notable differences:
  - VIIRS has higher spatial resolution than MODIS
  - MODIS pixel size increases with view angle while VIIRS pixel size stays approximately constant
  - Different spectral characteristics, i.e., similar bands but with different spectral widths and responses
- There is an ever-increasing need for cloud retrieval algorithms to have cross-platform consistency as new sensors replace aging ones.
- A unified MODIS and VIIRS cloud mask algorithm is under development for the next CERES Edition (Edition 5) that uses only those spectral bands which are common to both instruments (see poster A41L-2797, Trepte et al.).
- The CWG uses CALIOP data to assess global and regional cloud fraction estimates from MODIS and VIIRS.

2. Data, Methodology, and Satellite Data Colocation Details

- The CALIOP Vertical Feature Mask (VFM) Version 4.20 product is used primarily as "ground truth" with which to compare MODIS and VIIRS estimates of total cloud fraction.
- A nearest-neighbor spatial colocation scheme is used to match MODIS/VIIRS pixels to 5-km CALIOP ground track segments (pixel distance not to exceed 8 km).
- CALIOP data is used in addition to the MODIS/VIIRS cloud masks to identify clear fields of view (FOV) with greater confidence and assess the accuracy of computations of top-of-atmosphere (TOA) brightness temperatures (BTs).
- During the A-Train era prior to September 2018, Aqua-MODIS had near-nadir views of the CALIPSO ground track.
- During the C-Train era (post Sep 2018) MODIS views of the CALIPSO ground track are generally off-nadir.
- NOAA-20 VIIRS views of the CALIOP ground track were not as significantly affected by CALIPSO's orbit change.

A-TRAIN ERA, JULY 2018 | C-TRAIN ERA, JANUARY 2019



Summary and Concluding Remarks

- CALIOP data was used to screen for clear FOVs and compare computed TOA BTs to actual MODIS and VIIRS observations.
- Improved radiative transfer parameterizations resulted in more accurate computations of clear-sky TOA brightness temperatures which the CERES cloud mask utilizes for cloud identification.
- Results thus far indicate that the unified CERES MODIS/VIIRS cloud mask currently under development yields better regional accuracy compared to the previous Editions.
- CALIPSO's orbit change from A-Train to C-Train had a significant impact on comparisons of CALIOP and Aqua-MODIS total cloud fraction due to the drastic change in Aqua-MODIS viewing geometry of the CALIPSO ground track.
- The impact of CALIPSO's orbit change on NOAA-20 VIIRS comparisons is much less drastic since VIIRS view of the CALIOP track changed very little.
- Overall, cloud fraction estimates from the unified cloud mask appear to be at least as accurate as those from the previous MODIS/VIIRS Editions compared to CALIOP.
- New surface emissivity maps have been developed for land surfaces (see poster A41L-2805, Chen et al.). Future clear-sky radiance and cloud fraction evaluations will include land surfaces.

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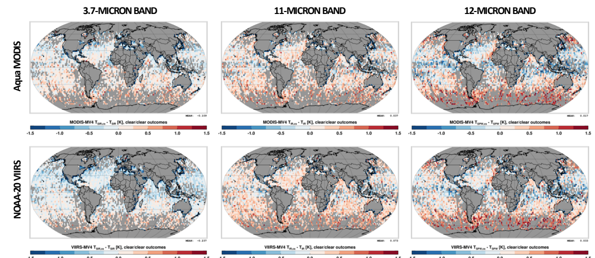
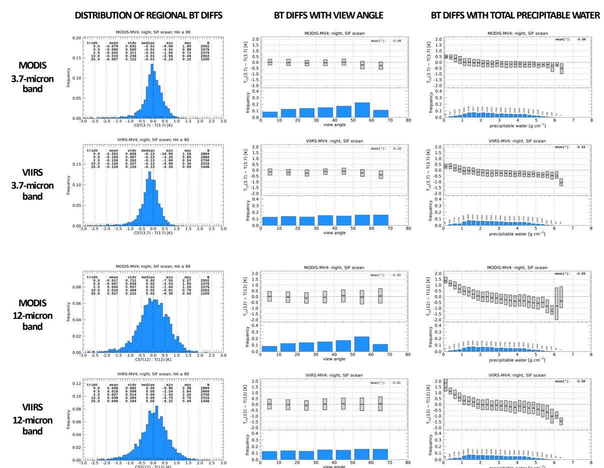
3. Evaluation of Clear-Sky Brightness Temperature Computations

- The CERES cloud mask algorithms compare observed radiances to simulations of the expected clear sky values to determine which pixels are clear and cloudy. Clear sky simulation errors due to the radiative transfer model or the inputs (e.g., surface skin temperature, water vapor loading, etc.) can lead to regional errors in cloud properties.
- CALIOP provides independent confirmation of cloud-free FOVs so that the accuracy of computed BTs can be assessed with minimal cloud contamination.
- In order to minimize biases due to cloud contamination, only those FOVs deemed cloud-free by both CALIOP and MODIS/VIIRS are used for assessing clear-sky BT computations.
- Regional differences of simulated and observed BTs over snow/ice-free (SIF) open ocean surfaces are shown below.

DIFFERENCES OF SIMULATED AND OBSERVED CLEAR-SKY BRIGHTNESS TEMPERATURES FOR CLEAR FOV, JANUARY + JULY 2019



- Differences in simulated and observed BTs are analyzed by MODIS/VIIRS view angle and by column total precipitable water (TPW). TPW data were obtained from the CERES MOA (Meteorological, Ozone, and Aerosol) product. MOA incorporates meteorological data from various sources and re-grids and interpolates the data to meet CERES requirements. Figures below show data for July 2019.

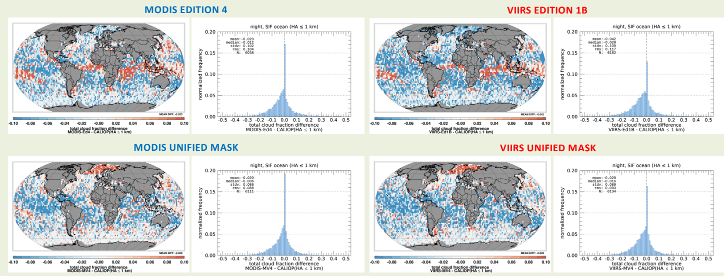


- Large positive BT differences for TPW < 1 g m^{2} have been linked to strong gradients in sea surface temperature that are not resolved well by the ancillary surface temperature data.
- Large negative BT differences for TPW > 3 g m^{2} may be due to clouds in the reanalysis data that are not representative of observed cloud-free conditions, but more investigation is needed.
- Trends with TPW are weaker for cleaner window channels (e.g., near 3.7 microns) and more pronounced for spectral bands with more water vapor absorption (12 microns).
- The radiative transfer computations account for path length through the atmosphere, and BT differences show no monotonic trend with MODIS/VIIRS view angle.

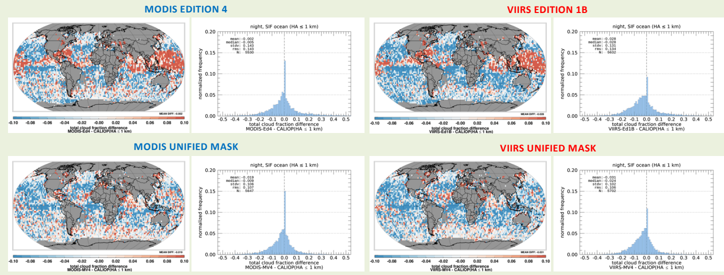
4. Evaluation of Total Cloud Fraction

- Total cloud fraction was computed from the CALIOP VFM product using 1-km and single-shot cloud detections. Detections made using coarser spatial averaging (≥ 5 km) were treated as clear sky.
- Regional differences in MODIS/VIIRS and CALIOP nighttime total cloud fraction are shown below for snow/ice-free (SIF) open ocean surfaces.
- MODIS Edition 4 and VIIRS Ed1B overestimated cloud fraction over the tropical oceans, but the unified cloud mask shows much more uniformity across the globe.
- Regional differences significantly improved with the unified cloud mask (reduced RMS differences).

JANUARY 2019

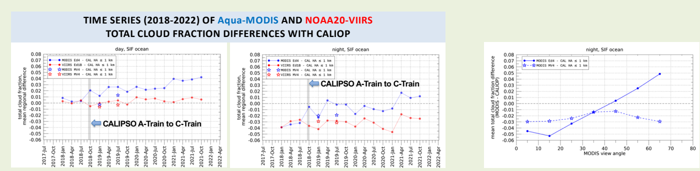


JULY 2019



- For broader context, MODIS Ed4 and VIIRS Ed1B results are shown below for the months of January, April, July, and October 2018-2021 along with results thus far (January and July 2019) from the unified cloud mask. Results from the unified mask are denoted by star icons ☆.

TIME SERIES (2018-2022) OF Aqua-MODIS AND NOAA20-VIIRS TOTAL CLOUD FRACTION DIFFERENCES WITH CALIOP



- Aqua-MODIS Edition 4 differences with CALIOP increased markedly after CALIPSO's orbit change from the A-Train to the C-Train. This is likely due to a shift in near-nadir to off-nadir views of the CALIPSO ground track (see Section 2).
- VIIRS differences are fairly stable during this period. CALIPSO's orbit change had little impact on VIIRS views of CALIPSO's ground track.
- The accuracy of the unified cloud mask is similar to the predecessor algorithms (Edition 4 and Edition 1B). The differences between MODIS and VIIRS are also reduced (better cross-platform consistency).
- Nighttime cloud fraction is generally underestimated because CALIOP has increased sensitivity to clouds due to increased signal-to-noise during nighttime conditions.
- MODIS Edition 4 cloud fraction shows a pronounced trend with view angle (above right). Cloud fraction from the unified cloud mask shows little trend with view angle due to more accurate simulated clear-sky BTs and greater reliance on these computations to better account for the impact of regional variations in water vapor on the cloud mask.