Cloud Properties from MODIS and VIIRS for CERES: Intercomparison and Validation with CALIOP

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Abstract

The Clouds and the Earth's Radiant Energy System (CERES) project monitors Earth's long-term energy balance and produces data products which have improved our understanding of the role clouds and aerosols play in that balance. Cloud property retrievals from the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Visible Infrared Imaging Radiometer Suite (VIIRS) are a major component of many of these data products. It is important for cloud property retrievals to be consistent over the course of the record so that artificial discontinuities are not introduced into the Earth radiation budget record. In practice, the MODIS and VIIRS instruments have different characteristics and different sets of spectral bands so deriving completely consistent cloud properties from the two instruments is a complex task. This paper investigates differences in the cloud properties retrieved from MODIS and VIIRS using the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument as an independent validation source. Particular consideration is given to CALIOP's sensitivity to optically thin clouds and the effect these clouds have on the retrieved cloud properties, especially cloud thermodynamic phase. Differences in cloud phase and cloud optical depth from MODIS and VIIRS are characterized by different cloud types including multi-layer scenarios. Characterizing these retrieval differences will help understand and mitigate artifacts in the long-term record.

A43K-3064. Cloud Properties from MODIS and VIIRS for CERES: Intercomparison and Validation with CALIOP

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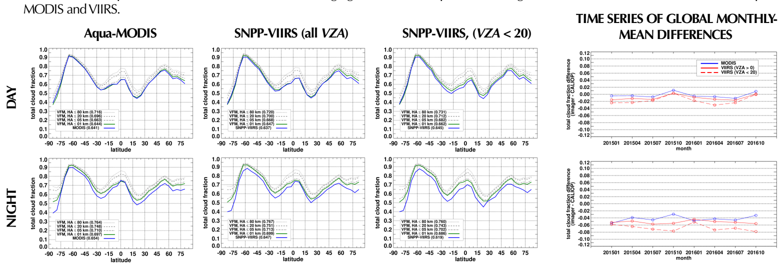
INTRODUCTION

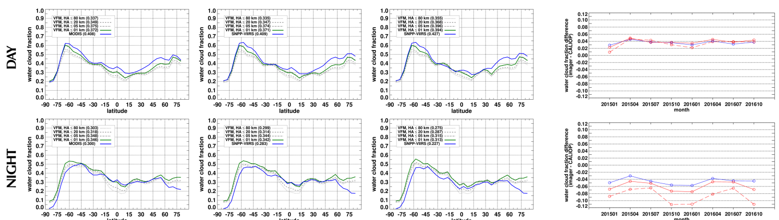
The Clouds and the Earth's Radiant Energy System (CERES) project monitors Earth's long-term energy balance and produces data products which have improved our understanding of the role clouds and aerosols play in that balance. Cloud property retrievals from the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Visible Infrared Imaging Radiometer Suite (VIIRS) are a major component of many of these data products. It is important for cloud property retrievals to be consistent over the course of the record so that artificial discontinuities are not introduced into the Earth radiation budget record. In practice, the MODIS and VIIRS instruments have different characteristics and different sets of spectral bands so deriving completely consistent cloud properties from the two instruments is a complex task. This paper investigates differences in the cloud properties retrieved from MODIS and VIIRS (Edition 4 and Edition 1 cloud products, respectively) using the Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) instrument as an independent validation source. Particular consideration is given to CALIOP's sensitivity to optically thin clouds and the effect these clouds have on the retrieved cloud properties, especially cloud thermodynamic phase. Differences in cloud phase and cloud optical depth from MODIS and VIIRS are characterized by different cloud types including multi-layer scenarios. Characterizing these retrieval differences will help understand and mitigate artifacts in the long-term record.

TOTAL CLOUD FRACTION

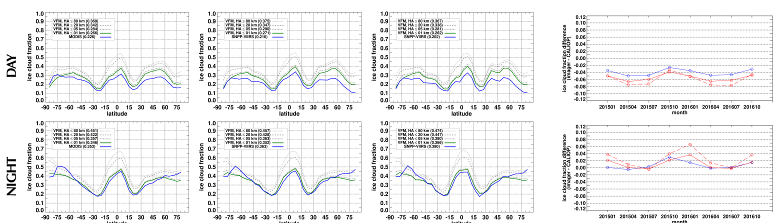
- The CALIOP Vertical Feature Mask (VFM) product is widely used to validate cloud fraction estimates from passive instruments.
- Aqua-MODIS and CALIOP orbit in close coordination in the A-Train Constellation. Overpass times are within 2 minutes of each other and MODIS views CALIOP footprints near nadir. SNPP-VIIRS is not as closely coordinated with CALIOP, but overpass time differences were restricted to less than 15 minutes for these analyses. View angle differences were also considered since cloud fraction generally increases with view angle.
- It is commonly assumed that passive imagers cannot detect the faintest of clouds, i.e., 80-km and 20-km cloud detections. CALIOP cloud fraction was computed as a function of horizontal averaging (HA) scales to produce a range of reasonable values with which to compare MODIS and VIIRS.



WATER CLOUD FRACTION



ICE CLOUD FRACTION



- Differences in cloud fraction between CALIOP and the passive instruments are typically smallest for HA ≤ 1 km. CALIOP cloud detections at coarse resolutions, e.g., 80 km, are too thin for the passive instruments to detect or may be significantly overrepresented.
- MODIS and VIIRS both have smaller total cloud fraction than CALIOP, but differences are typically less than 2% for HA ≤ 1 km. VIIRS total cloud fraction is smaller than MODIS, even more so for nadir observations.
- For daytime observations, total cloud fraction compares well with CALIOP, but water cloud fraction and ice cloud fraction are overestimated and underestimated, respectively.
- For nighttime observations, total and water cloud fractions are underestimated to a greater degree than for daytime. Global and non-polar ice cloud fractions compare well with CALIOP, but overestimation is seen in the polar regions.

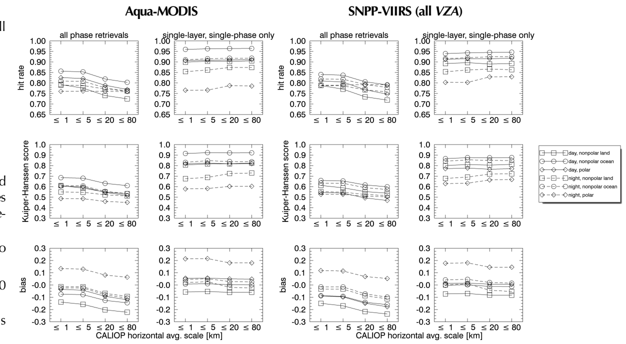
PIXEL-SCALE CLOUD PHASE VALIDATION METRICS

- Contingency tables and the associated statistical metrics, e.g., hit rate (H), and Kuiper-Hanssen skill score (KHS), were used to quantify the accuracy of MODIS and VIIRS cloud phase identification.

Sample contingency table for MODIS "day, non-polar ocean" conditions

		CALIOP (HA ≤ 1 km)		
MODIS		WATER	ICE	TOTALS
	WATER	(*a*) 2,133,443 (53.6%)	(*b*) 434,485 (10.9%)	2,567,928 (64.5%)
	ICE	(*c*) 137,948 (3.5%)	(*d*) 1,273,956 (32.0%)	1,411,904 (35.5%)
	TOTALS	2,271,391 (57.1%)	1,708,441 (42.9%)	3,979,832 (100.0%)

- Perfect accuracy is all but impossible to achieve due to differences in senor spatial resolution and slight spatial and temporal mismatches, but accuracy is expected to be high for overcast scenes involving only one cloud phase. Validation metrics are indeed much higher for "single-layer, single-phase" scenarios.
- Metrics are also dependent on the CALIOP horizontal averaging scales considered and tend to improve when coarse-resolution detections are discounted.
- MODIS performs better than VIIRS. VIIRS is slightly more biased towards water than MODIS ($B < 0$ indicates water-phase bias).
- Cloud phase accuracy is best over ocean surfaces during daytime conditions. Daytime accuracy is better overall than for nighttime.
- Retrievals in polar nighttime conditions are the least accurate and are more biased towards ice than for the other conditions considered here. Daytime land retrievals are biased towards water phase.

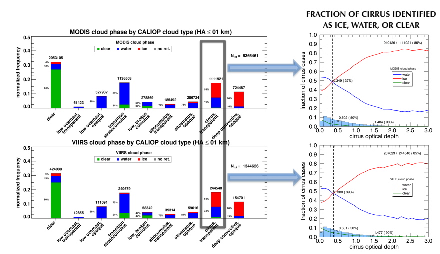


$$H = \frac{a+d}{a+b+c+d} \qquad KHS = \frac{(a*d - b*c)}{(d+b)*(c+a)} \qquad B = \frac{c-b}{a+b+c+d}$$

CLOUD PHASE DISTRIBUTIONS BY CLOUD TYPE

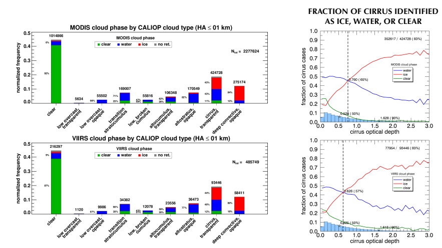
- Partially cloudy scenes cause some mismatches between "clear" and "cloudy" outcomes. Here, CALIOP footprints with cloud fraction < 0.50 were considered "clear". These pixel-level mismatches partially offset each other in cloud fraction computations.
- Low-level water clouds are correctly identified in most cases. Partial cloudiness results in some apparent "missed detections".
- A large portion of phase mismatches can be attributed to cirrus clouds. Cirrus with optical depth < 0.3 are more often classified as water than ice phase.

DAY, NON-POLAR OCEAN

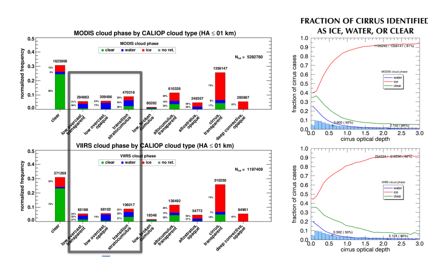


- Cloud type distributions for land are different than for ocean, but phase identification results are similar.
- Over land, MODIS and VIIRS have more difficulty correctly identifying thin cirrus than over ocean. Cirrus with optical depths < 0.6 may be classified as water or may go undetected.

DAY, NON-POLAR LAND

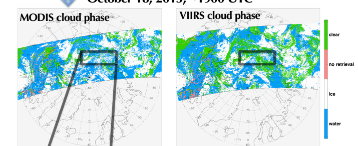


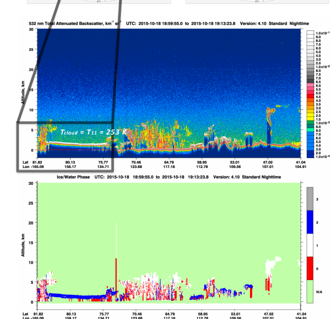
POLAR NIGHT



Water cloud misclassified as ice more common in polar night

October 18, 2015, ~1900 UTC





CALIPSO browse images obtained from: https://www-calipso.larc.nasa.gov/products/lidar/browse_images/production/

SUMMARY

- CALIOP observations were used to evaluate MODIS and VIIRS cloud phase identification at global, zonal, and pixel-level scales. CALIOP cloud fraction was computed as a function of the spatial scales used to detect clouds, providing reasonable upper and lower bounds to give context to cloud fraction comparisons.
- MODIS and VIIRS both underestimate total cloud fraction and differences vary by < 3% during the 2-year dataset used in this study. VIIRS absolute differences are slightly larger than MODIS differences.
- Daytime water cloud fraction is overestimated, largely due to the challenge of detecting optically thin cirrus clouds overlying highly reflective low-level liquid-phase clouds. Cirrus with optical depths < 0.3 may be mischaracterized as water clouds.
- Differences in nighttime ice cloud fraction are small in the tropics and mid-latitudes, but differences are much larger in the polar regions. Polar night conditions yield the poorest validation metrics and the highest bias towards ice-phase clouds.
- Commonly used statistical validation metrics, such as hit rate and Kuiper-Hanssen score, vary significantly depending on the CALIOP horizontal averaging scales considered. Caution should be exercised when comparing results from different studies as CALIOP data is often treated differently by different researchers.