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Development of a Consistent MODIS and VIIRS Cloud Detection Approach for CERES

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INTRODUCTION

A consistent cloud fraction record across various satellite platforms is essential for maintaining a long-term and stable climate data record of Earth's energy budget. With the Aqua satellite approaching the end of its operational lifetime, the continuation of this record relies on utilizing VIIRS observations from NOAA20 for cloud detection in NASA's Clouds and Earth's Radiant Energy System (CERES) project.

This paper reports on progress towards developing a unified MODIS and VIIRS cloud mask using common channels to produce consistent cloud properties for CERES next edition (Ed5) Earth radiation budget data products. Pixel level cloud mask results and global cloud fraction comparisons between MODIS and VIIRS are presented to evaluate their consistency, and initial validation using CALIPSO data to improve cloud mask accuracy.

METHODOLOGY

Several versions of cloud mask are evaluated here:

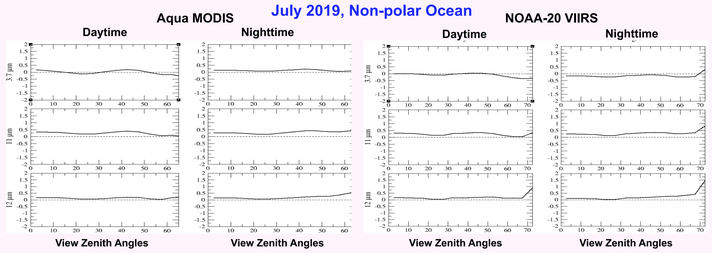
1. The CERES MODIS Edition 4 (CM Ed4) cloud mask (Trepte & Minnis, IEEE, 2019) that uses 12 MODIS channels: 0.47, 0.64, 0.86, 1.24, 1.37, **2.1**, 3.8, **6.7**, 8.5, 11, 12, and **13.3** µm.

2. The NOAA20 VIIRS Ed1B (CV Ed1B) cloud mask:
   - Based on CM Ed4 cloud mask, but uses 10 VIIRS channels: 0.47, 0.64, 0.86, 1.24, 1.37, **1.6**, 3.8, 8.5, 11, and 12 µm. Incorporates Cross-track Infrared Sounder (CrIS) water vapor (6.7 µm) and CO_2 channel (13.3 µm) for polar cloud detection.
   - Serves as a temporary continuity algorithm until Ed5 is released.

3. Ongoing CERES Ed5 cloud mask, a unified MODIS and VIIRS cloud mask using 10 common channels to produce consistent cloud products. The fundamental approach in the CERES cloud mask is to compare the observed radiances to the expected background clear sky radiances. Accurately predicted clear sky background radiances is critical to achieve accuracy and consistency.

   Progress made for Ed5 cloud detection:
   - Revised radiative transfer model to better account for satellite-specific, spectrally dependent surface reflectance, surface emission, and atmospheric absorptions.

Predicted Clear Sky Temperature – Observed Brightness Temperature for Clear Pixels
July 2019, Non-polar Ocean



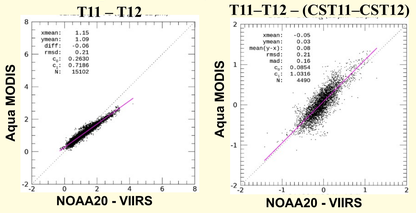
- Updated ancillary data input:
  - Replaced NASA Global Modeling and Assimilation Office (GMAO) GEOS-541 with GEOS-IT skin temperature and atmospheric profiles
  - New MODIS composite IGBP ecosystem map
  - Improved daily snow and ice maps that eliminated TBD along the coasts.
  - Revised surface emissivity maps for 3.7, 11, and 12 µm (see Yan Chen's poster, A41L-2805).
- Improved Ed5 cloud mask based on new clear sky predictions and ancillary inputs.
  - Revised nighttime low cloud and thin Cirrus detection tests
  - Reduced frequency of nighttime land and desert false clouds

RESULTS

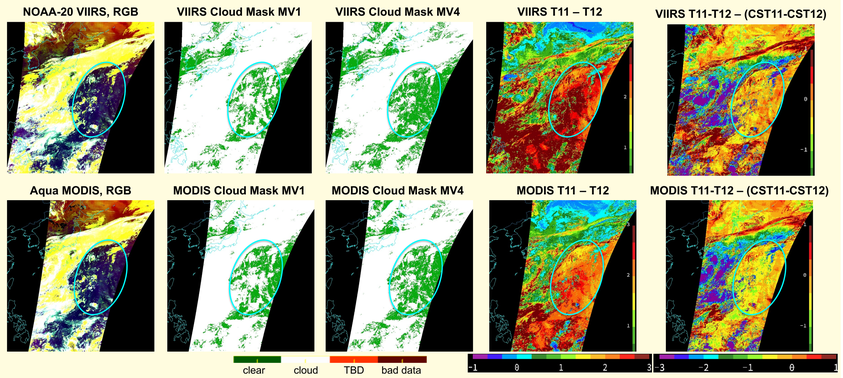
Improvements in Cloud Fraction Consistency

In CM Ed4 and CV Ed1B cloud masks, some cloud detection tests compared various radiance combinations with fine-tuned constant thresholds which do not account for regional variations in atmospheric absorption due to water vapor. In Ed5 MV4 (Mask Version 4), these tests were modified to include comparisons with theoretical simulations of clear sky radiances for each satellite leading to improved regional accuracies as well as improved cross-platform consistency since the satellite-specific spectral dependence of water vapor absorption is better accounted for. Example of Brightness Temperature Differences (BTD) 11-12 µm is shown on the right.

Nighttime Ocean, January + July 2019

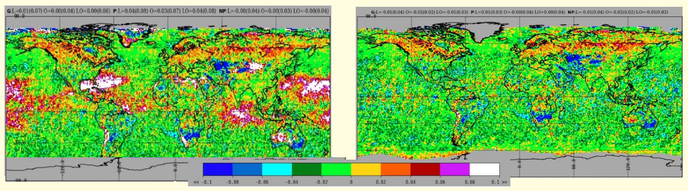


Below is a nighttime matched Aqua MODIS and NOAA-20 VIIRS case on July 05, 2019, UTC16 over Western Pacific. Ed5 MV1 is the baseline version of the common cloud mask that included hardcoded test thresholds of BTDs.



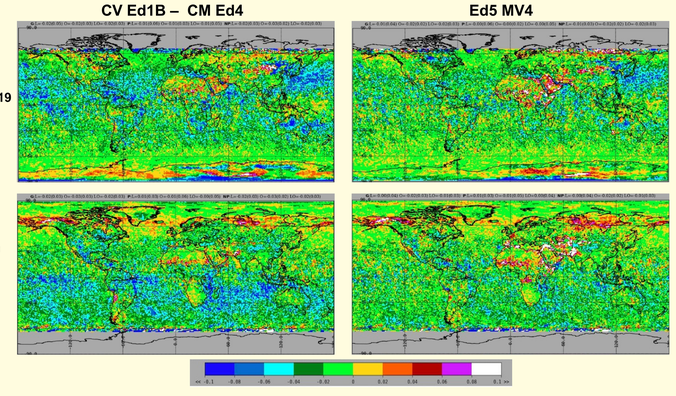
In MV1 cloud mask, VIIRS detected more thin Cirrus than MODIS due to its higher observed T11-T12 values. VIIRS T11-T12 – (CST11-CST12) values are closer to MODIS, so MV4 cloud mask between MODIS and VIIRS is more consistent although VIIRS has slightly less clouds.

Nighttime Cloud Fraction Difference (NOAA20 VIIRS - Aqua MODIS) July 2019



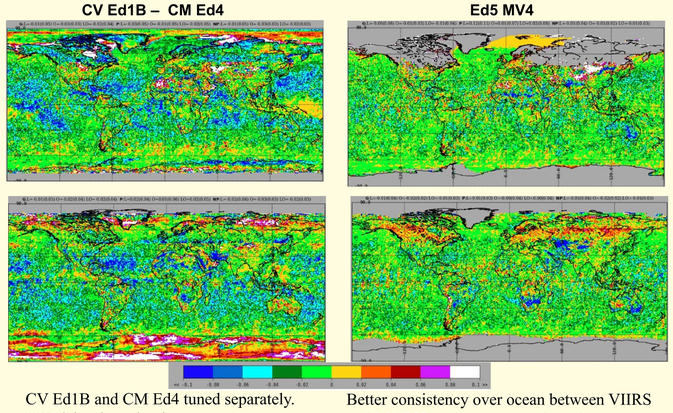
In tropical oceans, better cloud fraction consistency between MODIS and VIIRS in MV4 after replacing constant test thresholds with clear sky predictions in the thin Cirrus tests using T11-T12. Nighttime ocean VIIRS cloud fraction is still up to 2% lower than MODIS, could be differences in BTD (3.7-11).

Daytime Cloud Fraction Difference: NOAA20-VIIRS minus AQUA-MODIS



VIIRS has less clouds over oceans. Better consistency over ocean

Nighttime Cloud Fraction Difference: NOAA20-VIIRS minus AQUA-MODIS

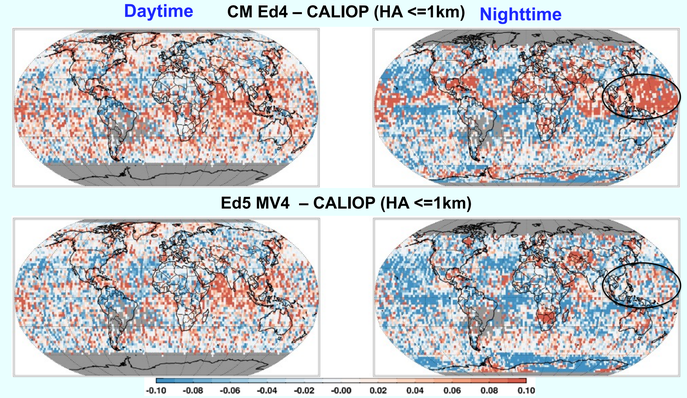


CV Ed1B and CM Ed4 tuned separately. VIIRS has less clouds over oceans. Better consistency over ocean between VIIRS and MODIS using common algorithm

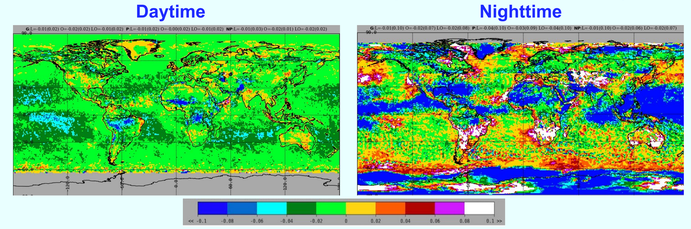
Improvements in Cloud Detection Accuracy

Spatially and temporally matched CALIPSO (Version 4.20) cloud products provided validation for VIIRS and MODIS cloud detection accuracy. See details in Chris Yost poster A41L-2804.

Cloud Fraction Differences between Aqua MODIS and CALIPSO (HA <= 1km)
July 2019



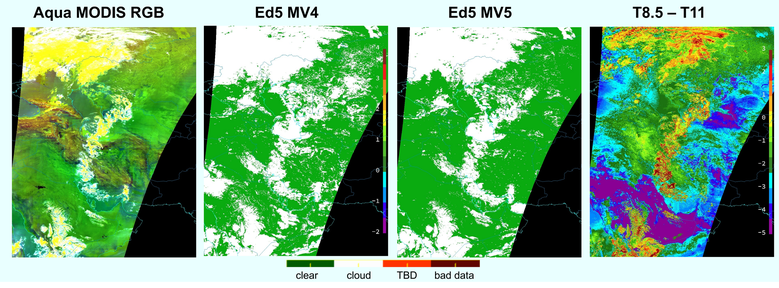
Cloud Fraction Differences between Aqua MODIS (Ed5 MV4 – Ed4)



- Daytime, Ed4 and Ed5 MV4 have similar accuracy compared with CALIPSO.
- Ed4 has slightly more clouds in oceans. These clouds were reduced in Ed5 MV4.
- Nighttime, Ed4 over detected thin Cirrus clouds in tropical ocean. In Ed5 MV4, these clouds were reduced, made it closer to CALIPSO.
- Ed5 MV4 under-detected clouds in Eastern Pacific and Atlantic, and over-detected clouds In West Asia and South Africa. Improvements were made in MV5.

Reduced False Clouds over Nighttime Land and Desert

Below is a nighttime Aqua MODIS case on July 16, 2019, UTC04 over West and Central Asia. Over-detected clouds in MV4 were reduced in MV5 by using T8.5-T11 tests.



CONCLUSION

- Comparisons of pixel-level and monthly global cloud fraction show CERES Ed5 MV4 cloud mask, the common algorithm, produced more consistent cloud fraction between MODIS and VIIRS than CM Ed4 and CV Ed1B.
- Cloud mask modifications that compare observed radiance combinations with clear sky predictions (theoretical simulations) rather than with fixed global thresholds yields improved accuracy and cross-platform consistency by better accounting for the spectral dependence and regional variations of water vapor absorption.
- Spatially and temporally matched MODIS cloud mask results with CALIPSO data show similar accuracy of CM Ed4 and Ed5 MV4 during the day and better agreement in Ed5 MV4 over nighttime tropical ocean.
- False clouds over land and deserts in MV4 are reduced by using T8.5-T11 tests. More tuning will be needed after improved ancillary inputs over land are incorporated.

Future work:
- The neural-network based skin temperature correction for GEOS-IT reanalysis and revised 3.7 µm surface emissivity over land and desert are under testing. These corrections will better capture the diurnal cycle and improve TOA clear sky temperature prediction to further improve Ed5 cloud detection for land and desert.
- Continue to develop and test the nighttime Antarctica cloud detection using neural-network approach.