An Investigation of the Failed Retrievals in the MODIS Cloud Product: Frequency and Potential Causes

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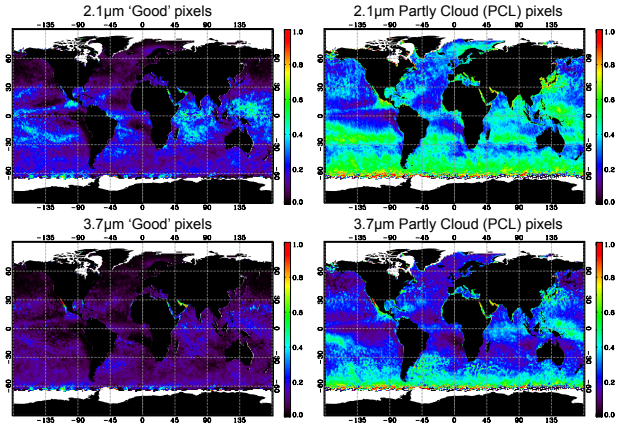
I. Introduction

This study investigates the frequency of occurrence of the failed optical thickness and effective radius retrievals and their causes for Moderate Resolution Imaging Spectroradiometer (MODIS) onboard *Aqua* satellite together with Cloud Profiling Radar (CPR) observations on *CloudSat* satellite. In satellite-based passive remote sensing, the cloud optical thickness (τ) and droplet effective radius (r_e), which has a strong influence on cloud radiative effects, are derived simultaneously from reflectance measurements at two wavelengths, the so called bi-spectral method. Since biases in the τ and r_e of marine water clouds can lead errors in estimates of global radiative forcing, it is critical to identify the sources and magnitudes of errors in the retrieval. The look-up tables (LUTs) used in the bi-spectral method have upper and lower limits to τ and r_e. These limitations might be problematic for clouds having very large or very small radius droplets, and may be even worse for optically very thin clouds. Alternatively, retrievals near or outside the LUTs boundary might be indicative of retrieval artifacts.

II. Failure rate of MODIS τ and r_e retrieval for MBL clouds

- Data: One month (May 2007) of MODIS/Aqua (MYD06), Collection 6
- MBL clouds: Confident or probably water clouds over ocean, no snow/ice surface

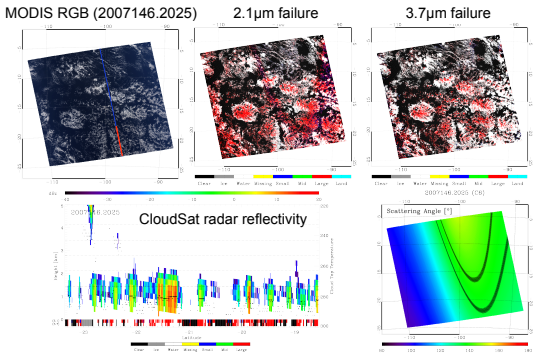


Global map of failure rates.

- Statistics of level-2 failed τ and r_e retrieval pixels

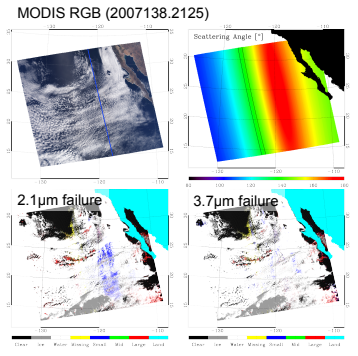
			Both successful	Only 3.7μm failed	Only 2.1μm failed	Both failed	Sum
Clear Sky Restoral (CSR) Flag	PCL pixels	Good Pixels	1,622,320,412 (60.91%) 86.38%	21,661,614 (0.81%) 1.15%	128,140,055 (4.81%) 6.82%	105,975,892 (3.98%) 5.64%	1,878,097,973 (70.52%)
		Cloud Edge	336,183,097 (12.62%) 57.87%	32,680,922 (1.23%) 5.63%	96,004,190 (3.60%) 16.53%	116,058,640 (4.36%) 19.98%	580,926,849 (21.81%)
		Inhomogeneous Clouds	112,942,900 (4.24%) 55.28%	10,583,600 (0.40%) 5.18%	44,519,446 (1.67%) 21.79%	36,266,762 (1.36%) 17.75%	204,312,708 (7.67%)
	Sum		2,071,446,409 (77.78%)	64,926,136 (2.44%)	268,663,691 (10.09%)	258,301,294 (9.70%)	2,663,337,530

2.1μm failure rate: 19.79%, 3.7μm failure rate: 12.14%



III. Cases

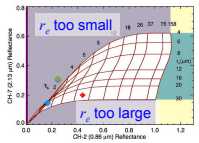
- The left case shows that both bands(2.1μm and 3.7μm) have high failure rate at the center of broken clouds, where heavy precipitation occurs. And the retrieval at 2.1μm often fails along the scattering angles between 135 and 140°, which is the rainbow angle.
- The right case shows that cloud edge (optically thin or inhomogeneous clouds) over sunglint area tends to fail as missing due to too bright in visible band, and the backscattering region (i.e. glory) of stratocumulus cloud tends to fail due to too small particle size.



IV. Analysis of Potential Causes

■ Analysis of technical causes

Collection 6: Retreival_Failure_Metric(τ_{RFM}, $r_{e,RFM}$, cost function)

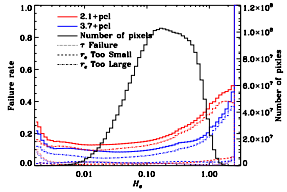


yellow, green, purple: τ failure

		2.1μm failure			3.7μm failure		
		τ Failure: $\tau_{e,RFM}$ = -9999	r_e Too Small: $r_{e,RFM}$ = 4μm	r_e Too Large: $r_{e,RFM}$ =30μm	τ Failure: $\tau_{e,RFM}$ = -9999	r_e Too Small: $r_{e,RFM}$ = 4μm	r_e Too Large: $r_{e,RFM}$ =30μm
CSR flag	Good pixels	2.59%	1.77%	40.04%	3.91%	4.54%	31.00%
	Cloud edge	3.97%	4.37%	31.82%	6.46%	10.82%	28.54%
	Inhomogeneous Clouds	0.19%	1.49%	13.61%	0.31%	2.34%	11.74%
	Combined	6.76%	7.63%	85.46%	10.69%	17.70%	71.28%

■ Analysis of potential physical causes

◆ Connection with cloud horizontal heterogeneity (H_σ: Cloud_Mask_SPI)

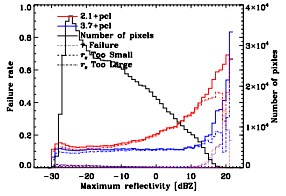


$$H_\sigma = \frac{\text{stdev}[R_i(0.86\mu m, 250m)]}{\text{mean}[R_i(0.86\mu m, 250m)]}$$

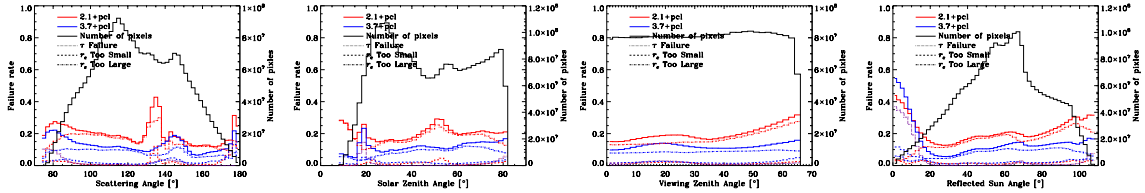
where $\text{stdev}[R_i(0.86\mu m, 250m)]$ and $\text{mean}[R_i(0.86\mu m, 250m)]$ indicate the standard deviation and mean of the measured reflectances, respectively, for the principle sixteen 250m-resolution sub-pixels within the 1-km MODIS retrieval footprint.

◆ Connection with radar reflectivity from analysis of one months (May 2007) data along collocated CloudSat track

Clouds detected by CloudSat (52.33%)
Failure rate: 16.96%(2.1μm)
11.33%(3.7μm)
Clouds not detected by CloudSat (47.67%)
Failure rate: 14.86%(2.1μm)
10.56%(3.7μm)



◆ Connection with sun and satellite geometry



V. Summary

We investigate the frequency of occurrence and their causes of τ and r_e retrievals for MODIS Collection 6 cloud product. Over all, the failure rate at 2.1μm(3.7μm) of MBL clouds is 19.79%(12.14%). The retrievals at both wavelengths are more often failed by too large size in LUT spaces. We investigate whether and how failure is connected to several key cloud parameters, such as cloud horizontal heterogeneity, and sun and satellite geometry. We found that the retrievals tend to fail more often in inhomogeneous clouds and at some specific angles in geometry. For example, failure rate is increasing at the rainbow and glory scattering angles and exact sun reflected angle. The MODIS granule side edge also have high failure rate.