Differentiating Between Clouds and Aerosol During the NPOESS Era

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Introduction

Abstract:
The VIIRS Cloud Mask (VCM) algorithm identifies cloud-contaminated pixels that are essential to produce a number of NPOESS cloud products in addition to other products that are created under cloud-free conditions. The performance of algorithms that expect cloud-free conditions, e.g. sea surface temperature, can be severely degraded when undetected clouds "leak" into the analysis. Therefore, the VCM has been designed to detect all cloudy pixels, including edge effects, while simultaneously ensuring cloud-free pixels are not "falsely" flagged as cloud-contaminated, which would impact the performance of other VIIRS cloud algorithms, e.g. used to retrieve the cloud optical property products. In addition, the VCM algorithm must also differentiate between clouds and atmospheric aerosols, which may have similar spectral characteristics in most VIIRS bands. This poster highlights the NPOESS requirements for automated cloud detection and the approaches used in the VCM algorithm to minimize both leakage and false alarm rates while differentiating between clouds and a variety of atmospheric aerosols, e.g. smoke, volcanic ash, and blowing sand. The presentation shows that the goal of creating a single cloud mask for use in products needed by the entire NPOESS user community can be satisfied by the VCM algorithm.

VCM Requirements:
The VCM will be used to produce 22 EDRs including: seven cloud products (gridded field of cloud optical thickness and effective particle size; cloud top pressure, height, and temperature; cloud base height; and cloud cover/layers at a near constant 6-km resolution), three ocean products (sea surface temperature, ocean color, and net heat flux), five land products (surface temperature, normalized difference vegetation index and enhance vegetation index, albedo, soil moisture, and surface type), three snow/ice products (a sub-pixel snow mask, ice surface temperature, and ice age), and three atmospheric aerosol products (optical thickness, particle size parameter, and suspended matter). VIIRS imagery is a separate EDR product.

Derived Aerosol Requirements:
The VCM must also satisfy other derived requirements including those shown here for the aerosol optical thickness product, which has a measurement range of 0-2 τ.

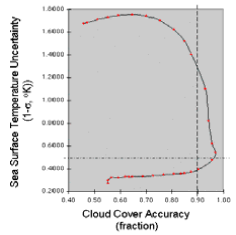
Paragraph	Attribute	Value
	a. Horizontal Cell Size	
40.3.1.1-1a	1. Over Ocean	1.6 km
40.3.1.1-1b	2. Over Land	9.6 km
40.3.1.1-2	**b. Horizontal Reporting Interval**	HCS
40.3.1.1-3	**c. Vertical Cell Size**	Total Column
40.3.1.1-7	**d. Vertical Reporting Interval**	Vertical Cell Size
40.3.1.1-8	**e. Horizontal Coverage**	Global
40.3.1.1-9	**f. Vertical Coverage**	0 – 50 km
	g. Measurement Range	
40.3.1.1-10	1. Operational	0 .0 to 2.0 τ
	h. Measurement Accuracy	
40.3.1.1-11a	1. Operational, Over Ocean, τ < 0.5	0.02
40.3.1.1-11b	2. Operational, Over Ocean, τ > 0.5	0.07 * τ - 0.015
40.3.1.1-12a	4. Operational, Over Land, τ < 1.0	0.1
40.3.1.1-12b	5. Operational, Over Land, τ > 1.0	0.15
	i. Measurement Precision	
40.3.1.1-13a	1. Operational, Over Ocean, τ ≤ 0.6	0.02
40.3.1.1-13b	2. Operational, Over Ocean, τ > 0.6	0.03
40.3.1.1-13c	3. Operational, Over Land	0.1

VCM Requirements Analysis and Aerosol Detection Approach

VCM Requirements Analysis:
The performance of algorithms that expect cloud-free conditions, e.g. sea surface temperature, can be severely degraded when undetected clouds "leak" into the analysis as shown by simulations (from Figure 1.4 in Hutchison and Cracknell, 2005). Thus, the VCM uses spatial tests to detect cloud edges using the four imagery resolution pixels nested in each moderate resolution pixel.

Cloud products are retrieved for all pixels classified by the VCM as confidently cloudy. Thus, cloud tests in the VCM are designed to minimize false alarms, e.g. calling a pixel confidently cloudy when it is cloud-free.

Finally, the derived requirement for the VCM algorithm is to discriminate between clouds and non-cloudy obscurations with sufficient accuracy that aerosol products can be retrieved for optical depths in the measurement range.



Simulations show the impact of an imperfect cloud mask on the SST EDR, retrieved with the MCSST algorithm in the presence of a stratocumulus cloud (Figure 1.4 in Hutchison and Cracknell, 2005)

What is an Aerosol:
Aerosols are defined by the NPOESS program as "suspensions of liquid droplets or solid particles in the atmosphere and include, but are not limited to, **smoke**, **dust, sand, volcanic ash**, sea spray, polar stratospheric clouds, and **smog**. Water and ice clouds are also aerosols, but because of the frequency of their occurrence and their importance to military operations, they are addressed separately in another EDR.

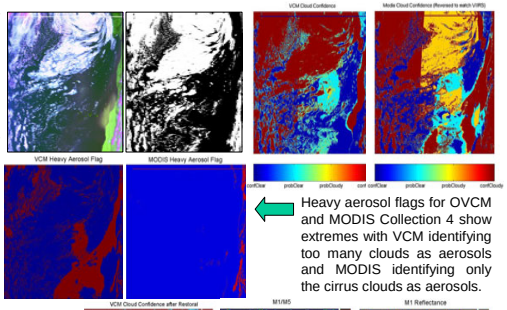
Aerosol Classification Procedure:
Pixels are tested using "aerosol restoral tests" after the VCM determines cloud confidence AND cloud top phase. Pixels identified with these aerosol tests are identified with the "heavy aerosol flag" but cloud confidence is unchanged. Therefore, it is necessary to read both the cloud confidence and the heavy aerosol quality flag to identify the type of aerosols reported (i.e. clouds vs. dust, sand, smoke, smog, etc.) in the VCM.

Detection of Dust and Sand in the VCM

The original VCM (OVCM), based on an early version of the MODIS cloud mask, used three tests to detect heavy aerosols, including:

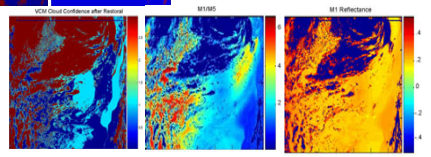
1. A reflectance test based upon concepts discussed by Kaufman et al., (2000),
   RM11(2.2-μm) * 100 < 20 and RM5 (0.67-μm) *100 > [7+ (RM11 * 50)] .
2. Volcanic ash test based upon Prata et al (1998; 2001),
   M15(11.0-μm) – M16 (12.0-μm) < -1.0
3. Fire flag based
   BTM12(3.7-μm) > 350.0 K and BTM12 - BTM15 > 10

The effectiveness of the OVCM in identifying heavy aerosols is shown through the analysis of MODIS granule MOD.2001.213.1210. Top panels show color composite of MODIS imagery, manually-generated cloud mask, VIIRS cloud confidence and MODIS cloud confidence (left to right).



Heavy aerosol flags for OVCM and MODIS Collection 4 show extremes with VCM identifying too many clouds as aerosols and MODIS identifying only the cirrus clouds as aerosols.

The Enhanced VCM (EVCM) provides improved aerosol detection through the use of the M1(0.412-μm) band which has been shown valuable for cloud detection over desert regions (Hutchison and Jackson, 2003) and now is used to accurately identify dust and airborne sand.

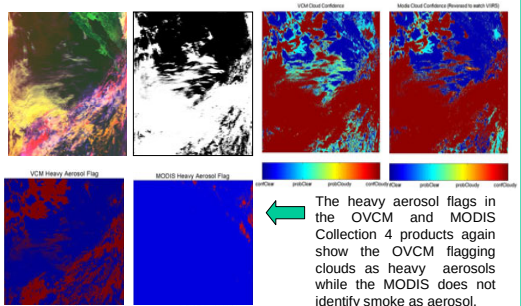


Detection of Smoke in the VCM

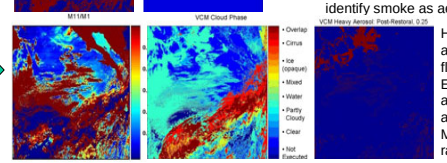
It is important that restoral tests do not identify clouds as aerosols; however, heavy aerosol tests used in the original VCM (OVCM) delivered to NGST did not distinguished between these types of obscurants as shown in MODIS granule MOD.2003.299.1840 that contains extensive areas of smoke associated with fires across Southern California during late October 2003.

The Enhanced VCM (EVCM) again exploits the M1(0.412-μm) band to differentiate between smoke and clouds. However, in this instance the band is used in conjunction with the 2.2-μm band. As noted by Kaufman (2000) most aerosols are highly transmissive in the longer wavelength making it ideal for use with the M1 band, where smoke is highly reflective, making the M11/M1 ratio an extremely small.

The M11/M1 ratio test is applied only to water clouds (green in the cloud phase analysis) since ice clouds can be identified as smoke also.



The heavy aerosol flags in the OVCM and MODIS Collection 4 products again show the OVCM flagging clouds as heavy aerosols while the MODIS does not identify smoke as aerosol.



Heavy aerosol flag in EVCM after applying M11/M1 ratio test

Detection of Volcanic Ash

The original VCM algorithm (OVCM) applied the "reverse absorption" method as noted above.

The enhanced VCM (EVCM) algorithm uses the approach of Pavolonis et al. (2006), which combines reflectances in the 0.672-μm and 3.75-μm bands with the reverse absorption temperature differences (M15-M16) through a series of tests, referred to as "tiers."

Only the Tier I test is applied for the following reasons:

1) The false alarm rate with the Tier I test was reported to be nearly zero when tested against global satellite data know to contain no volcanic ash.

2) Tier II-IV tests, were developed specifically to detect volcanic ash clouds in under specialized conditions that are less important for users of the VCM.

Pollution over Land Surfaces

The challenge of identifying aerosols becomes significantly greater as the reflectance of the surface background becomes larger and more variable than the ocean surface. However, the VCM is not required to identify pixels that contain non-cloud obscurations; it must only ensure these pixels are not classified as confidently cloudy for further processing by the aerosol module. Thus, pixels not classified as cloudy by the VCM will not be examined further.

The EVCM uses restoral tests to identify heavy aerosols. These tests are confined to pixels classified in the cloud phase analysis to be water clouds. The complete algorithm for use over land surfaces follows in another publication.

The EVCM algorithm also uses a nadir BRDF-adjusted reflectance (NBAR) TOC NDVI field to identify dark surfaces and vary cloud detection thresholds as a function of vegetation cover and sun-Earth-sensor scattering geometry (Hutchison et al., 2005).

The EVCM will use the TOC NDVI database to identify "darker surfaces" (e.g. NDVI > threshold) and apply logic similar to that used to detect smoke and dust over the ocean for heavy aerosol identification over land.

Over "brighter surfaces" (e.g. NDVI < threshold) the approach includes switching to bands that have a lower reflectance, e.g. M1 at low NDVI values, and using the M9 (1.38-μm) band in regions of low total atmospheric water content. NPOESS will continue to monitor the successes of the NASA Aerosol Team (Remer et al., 2005; 2006).

Summary

The task of distinguishing between heavy atmospheric aerosols and clouds can be daunting since the spectral signatures of both are often very similar (Martins et al., 2002).

While the MODIS cloud mask algorithm includes many tests and procedures to both detect clouds and distinguish between them from aerosols (Ackerman et al., 2002), studies have shown that it frequently classifies as cloudy many pixels with aerosol optical depths of 0.6 τ or greater (Brennan et al., 2005).

This difficulty in accurately discriminating between clouds and cloud-free obscurations led to multiple approaches to cloud screening being used in the MODIS program (Remer et al., 2005) with each approach having limited value to other applications (Martins et al., 2002).

The VCM algorithm employs a mixture of new approaches plus procedures that have proven useful with MODIS to obtain improved cloud/aerosol discrimination for all users across the NPOESS community.