Cloud Top Temperatures of Cirrus Clouds Retrieved from Radiances in the NPOESS/VIIRS 8.55-μm and 12.0-μm Bandpasses

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Introduction

Abstract:

This poster describes a new approach to retrieve a pixel-level, cirrus cloud top temperature (CTT) product for NPOESS/VIIRS from radiances observed in the 8.55-μm and 12.0-μm bandpasses. The CTT is retrieved based on the numerical solution of two nonlinear algebraic equations derived from the theory of radiative transfer in these two bandpassess. The retrievals are further refined by using cloud effective particle size determined either from the VIIRS solar retrieval algorithms or from parameterizations of the cloud emissivity in the 3.7 and 10.76 μm bandpasses for night conditions. This new VIIRS approach has been demonstrated using a number of MODIS scenes that cover a wide range of geophysical conditions including single and multi-layered cirrus cloud with diverse backgrounds and seasons. For single-layer clouds, the new approach compares favorably with the MODIS cloud products; while the mean CTT for both methods are close, with the standard deviation for the new VIIRS approach being smaller. However, In multi-layered cloud situations, the mean CTT with the new VIIRS approach appears to be colder than that of MODIS, which are acknowledged to be too warm. Finally, partly because the VIIRS approach is applied at the pixel level, CTTs do not increase toward cloud edges as are frequently seen in the MODIS products which apply to a 5-by-5 pixel aggregation.

Based upon these initial encouraging results, the new approach to retrieve VIIRS cloud top temperatures has been incorporated into the ground-based data processing segment of the NPOESS system. Pre-launch testing of this new VIIRS CTT algorithm is continuing and the performance of the algorithm will be established with synthetic data to be generated in the NGST IWPTB.

CTT APU:

The CTT EDR product **a**ccuracy, **p**recision, and **u**ncertainty requirements vary with cloud optical thickness, cloud top phase, and solar illumination conditions.

For ice clouds, the accuracy requirement ranges from 3-6 K while the measurement uncertainty is 5 K.

Paragraph	Attribute	Value
	a. Horizontal Cell Size	
40.4.5-1	1. Edge of Swath	25 km
40.4.5-1-2	2. Nadir	6 km
40.4.9-2	**b. Horizontal Reporting Interval**	HCS
40.4.9-3	**c. Horizontal Coverage**	Global
40.4.9-4	**d. Measurement Range**	180 to 310 K
	e. Measurement Accuracy	
40.4.9-5-a	1. Cloud Layer Optical Thickness >1, Water Cloud, Day	2 K
40.4.9-5-b	2. Cloud Layer Optical Thickness >1, Water Cloud, Night	3 K
40.4.9-5-c	3. Cloud Layer Optical Thickness >1, Ice Cloud	3 K
40.4.9-6	4. Cloud Layer Optical Thickness < 1	6 K
40.4.9-7	**f. Measurement Precision**	1.5 K
40.4.9-8	g. Long Term Stability	1 K
40.4.9-9	h. Mapping Uncertainty, 3 Sigma	1.5 km
40.4.9-10	i. Maximum Local Average Revisit Time	3.9 hrs
40.4.9-13	j. Latency	See App. E
	k. Nadir Measurement Uncertainty	
40.4.9-14-a	1. Water	3 K
40.4.9-14-b	2. Ice	5 K
40.4.9-15	l. Degraded Condition: Sun Glint < 36 deg	Same as night
40.4.9-16	m. Excluded Condition: Aerosol Optical Thickness > 1.0	

Cloud Top Temperature Requirements and Analysis Approach

CTT Requirements Analysis:

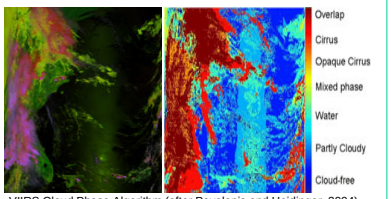
A cloud top temperature is retrieved for all pixels classified by the VIIRS Cloud Mask (VCM) to be confidently cloudy. The VCM also specifies the cloud top phase of the highest cloud in a VIIRS pixel. Seven cloud phase classes are possible, including ice, water, mixed-phase and overlap, i.e. ice clouds over lower-level water clouds.

Mixed-phase clouds are currently treated as water clouds. However, a new approach has been demonstrated by UCLA for NGST and NPOESS to retrieve the optical properties of both the ice and water phase components of mixed-phase clouds simultaneously (Ou et al., 2006).

Different approaches are used to retrieve CTT for ice and water clouds. The CTT for water clouds are retrieved using the 10.76 μm band alone for daytime and 3.7 and 10.76 μm bands for nighttime conditions. The CTT retrieval algorithm for use with ice cloud top phase is presented in this poster.

What is the Cloud Top Temperature:

CTT is defined for each cloud-covered earth location as the set of atmospheric temperatures at the tops of the cloud layers overlying the location. The reported temperatures are horizontal spatial averages over a cell, i.e., a square region of the earth's surface. If a cloud layer does not extend over an entire cell, the spatial average is limited to the portion of the cell that is covered by the layer.



VIIRS Cloud Phase Algorithm (after Pavolonis and Heidinger, 2004)

The enhanced VIIRS Cloud Mask (EVCM) algorithm identifies regions of overlap and single-layered clouds systems in MODIS granule MOD2002.032.1750 to help establish APU for complex cloud patterns.

Cloud Retrieval Approaches:

The EVCM determines cloud confidence and cloud top phase. Separate algorithms are then used to retrieve cloud optical properties (COP). The daytime COP algorithms are based on Look-Up Tables of reflectances generated for ice and water clouds in the 0.67 and 1.61 μm bands. For nighttime water clouds, however, the CTT and COP are retrieved using the 3.7 and 10.76 μm bands. The algorithms used to retrieve CTT for both daytime and nighttime ice clouds are described in the following panels.

Theoretical Basis for Ice Cloud Cloud Top Temperature Retrieval

Background:

Results from the original NPOESS/VIIRS CTT algorithms displayed blockiness artifact due to closure problems. To remove this undesirable feature, NGST and UCLA developed a new approach which allows the retrieval of CTT on a pixel level.

The approach applies the radiative transfer theory to the TOA radiances of the M14 (8.55 μm) and M16 (12.01μm) bands as:

$$R_i = (1 - \varepsilon_i)\, R_{ai} + \varepsilon_i\, B_i(T_c), \quad i = 14, 16$$

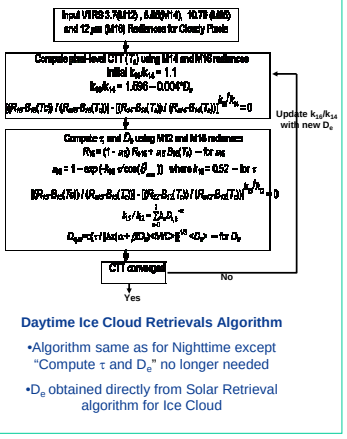
where R_i are TOA radiances, T_c is the cirrus cloud top temperature, $B_i(T_c)$ is the Planck function at T_c, ε_i are spectral emissivities, which are functions of optical depth and effective extinction coefficients, k_i (Ou *et al.* 1993):

$$\varepsilon_i = 1 - \exp(-k_i \tau), \qquad i = 14, 16$$

and R_{ai} are clear sky radiances The parameter k_i does account for multiple scattering effects, and its value can be obtained based on radiative transfer simulations that include scattering. Combining the above equations for the two bandpasses and eliminate ε_i yields

$$[(R_{16} - B_{16}(T_c))/(R_{a16} - B_{16}(T_c))] - [(R_{14} - B_{14}(T_c))/(R_{a14} - B_{14}(T_c))]^{k_{16}/k_{14}} = 0$$

Nighttime Ice Cloud Retrievals Algorithm

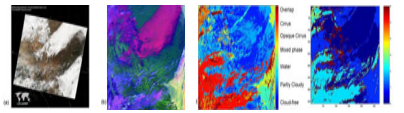


Daytime Ice Cloud Retrievals Algorithm

- Algorithm same as for Nighttime except "Compute τ and D_e" no longer needed
- D_e obtained directly from Solar Retrieval algorithm for Ice Cloud

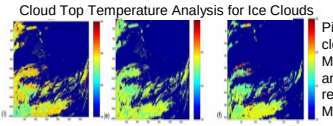
Case Studies – Daytime Data

Single Layer Ice Cloud – MOD2002.032.1750



True color False color VIIRS Phase MODIS phase

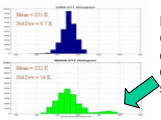
Cloud Top Temperature Analysis for Ice Clouds



Pixels classified as ice cloud in VIIRS and MODIS phase analysis are shown. VIIRS 1-km results are displayed at MODIS 5-km resolution.

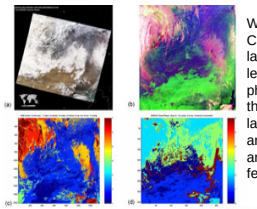
Original VIIRS Enhanced VIIRS MODIS

Original VIIRS product shows blockiness; MODIS product shows unrealistic high temperatures at cloud edges as compare to enhanced VIIRS algorithm



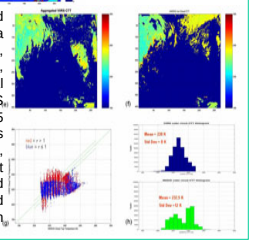
Histograms of ice cloud CTTs show that mean CTT for VIIRS (231K) and for MODIS (232K) differ by less than 1K, respectively. Standard deviations are 6.7K and 14K respectively. MODIS shows CTT tails that are too warm.

Overlap (Ice + Water) Clouds – MOD2002.001.0340



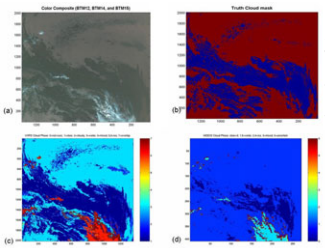
Winter scene over NW China shows multiple layers of clouds in upper left corner. VIIRS cloud phase detects correctly the multiple and single layered clouds, which are evident by noting areas where surface features can be seen.

Histograms of retrieved ice cloud CTT show a single mode for VIIRS, with mean CTT = 228K, and a bi-modal distribution for MODIS, with mean CTT = 232.5 K. Standard deviations are 8K and 12K, respectively. Note that VIIRS CTT at cloud edges are colder and more uniform than MODIS.



Case Studies – Nighttime Data

Overlap (Ice + Water) Clouds – MOD2002.001.0435

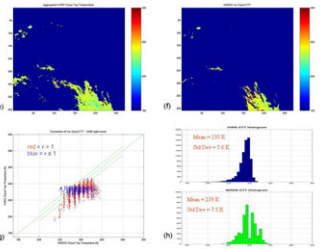


Color composite of MODIS imagery shows water clouds with reddish hue while non-opaque ice clouds have light blue hue in a scene collected off the coast of Chile

VIIRS (left) and MODIS (right) cloud phase analyses show MODIS Collection 4 algorithms detect far too many water clouds compared to VIIRS cloud mask and manually-generate cloud mask (upper right image). Testing suggests VIIRS cloud phase algorithm is less reliable for detecting overlap during nighttime conditions.

CTT from Enhanced VIIRS (left) and MODIS (right) algorithms for areas classified as ice clouds by both cloud masks. VIIRS results are again shown at 5-km resolution to match those of MODIS.

Histogram comparisons again show VIIRS (unimodal) and MODIS (bi-modal) results with mean CTT values of 235K and 239K, standard deviations of 5.6K and 7.6K, respectively.



Summary

A new approach has been developed for the retrievals of cirrus CTT during the NPOESS era.

This approach uses TOA radiances from the VIIRS M14 (8.55-μm) and M16 (12.0-μm) bands to retrieve directly the CTT during daytime conditions with cloud particle size directly input from COP products. During nighttime conditions, however, the new approach needs to iterate to a solution since the cloud particle size is not known a priori.

Comparisons with earlier versions of the VIIRS algorithm and the MODIS MOD06 cloud product show highly encouraging results with the new CTT algorithm. Blockiness has been eliminated in the new, pixel-level analyses and deficiencies in the MODIS product (bi-modal cloud top temperature distributions and unrealistically warm cloud edges) are not observed in the new products. In addition, results from the new VIIRS algorithm have a smaller standard deviation than those found in the MODIS product. Testing of this new and enhanced VIIRS algorithm is continuing at NGST.