Early Performance Predictions of Cloud Environmental Data Records for the NPOESS Preparatory Project VIIRS Sensor

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Overview

The VIIRS flight sensor for the NPOESS Preparatory Project (NPP) is now undergoing its final pre-launch characterization and calibration. The NPOESS Integrated Program Office (IPO) Data Products Division (NDPD) has generated the performance assessments for the Cloud Environmental Data Records (EDRs) of the Visible/Infrared Imaging Radiometer Suite (VIIRS). The VIIRS Cloud EDRs include the Cloud Optical Thickness (COT), Cloud Effective Particle Size Parameter (CEPS), Cloud Top Pressure (CTP), Cloud Top Height (CTH), Cloud Top Temperature (CTT), Cloud Cover/Layers (CCL), and Cloud Base Height (CBH).

The EDR Assessments were developed by the NDPD in consultation with subject matter experts from government labs and universities to collect and track algorithm development status and expected performance against contractual specifications and applicability to user missions.

This poster summarizes the cloud assessments and provides an overview of the NPP cloud data products and predicted performance for each cloud EDR.

The NPP EDR Assessments are used to capture and communicate algorithm issues and expected performance to the Program stakeholders and will be updated as sensor testing and algorithm development continue.

We predict that the VIIRS cloud products will approach equivalent quality as is currently obtained with the MODIS cloud products since the spectral, spatial, and radiometric characteristics of the VIIRS and MODIS are similar. Some of the variations arise from the different Radiative Transfer Models (RTMs) used for the two algorithmic approaches.

Cloud Top Parameters

Algorithm Overview

Cloud Top Temperature (CTT), Cloud Top Height (CTH), and **Cloud Top Pressure (CTP),** are the temperature, height, and pressure values at the tops of cloud layers overlying the location. The VIIRS Cloud Top Parameters are determined using assumption of radiative transfer in plane parallel clouds. VIIRS Cloud Mask information is used to determine the presence and phase of a cloud within a pixel. Cloud top parameters are determined using assumptions of radiative transfer in plane parallel clouds. Retrieval strategies differ for both day and night time retrievals of water and ice (Cirrus) clouds.

- **CTT**
  - Water Clouds (Day)
    - Window IR algorithm based on ISCCP heritage
    - Iterative physical retrieval using radiance in M15 (10.763 microns) used in fast forward RTM, using AER developed Optical Spectral Sampling (OSS) technique; numerical model data and CEPS and COT determines CTP, from which CTT and CTH computed using the Interpolation algorithm, described below, based on the hydrostatic equation
  - Water Clouds (Night)
    - Window IR algorithm can be used to quality check the preferred method of the UCLA IR Water Cloud Retrieval. This method is summarized in the COT and CEPS Performance Summary
  - Ice Clouds
    - UCLA IR Cirrus cloud retrieval algorithm is used. This method is summarized in the COT and CEPS
- **CTH and CTP**
  - Ancillary data used to interpolate CTH and CTP
    - Interpolation between atmospheric levels used to determine CTH
    - CTP Interpolation Algorithm, essentially the hypsometric equation, can be used to determine other parameter, n designates the sounding value, p is pressure, z is height, g is the gravity constant at 0.00981 km/s2, R is the gas constant for dry air, and Tv is the average virtual temperature between the sounding level and the cloud top

$$p_{cld} = p_n \exp\left(\frac{g(z_n - CTH)}{RT_v}\right) \qquad T_v = T/[1-((0.379 * e)/p)]$$

Predicted Performance

All specifications for the Cloud Top Parameter EDRs are not expected to be met for NPP. It is more difficult to meet specification at nadir viewing for optically thin clouds (<1), which has been designated a degraded condition. The precision spec for low water clouds is difficult to obtain in the presence of a low-level temperature inversion and sub-pixel scale convective clouds. Conversely, the Horizontal Cell Size (HCS) for CTP, CTH, and CTT is 4 times better than the government requirement.

The performance of the Cloud Top EDRs is reliant on successful retrieval of Cloud Optical Property data products. As shown above, the temperature is retrieved within the COP algorithm. CTT is most sensitive to radiometric calibration, and the Window IR algorithm used to derive CTT requires the radiometric accuracy of the 10.73 µm band to be less than 0.1% to meet accuracy specification for optically think clouds with small particles.

Additional analyses are needed to fully characterize performance. It is anticipated that CrIS data may be needed to meet spec and achieve day/night consistency. An alternative approach for retrieving clear-sky radiances may be necessary to fully meet specifications.

EDR/Attribute	Appendix D Cloud Top Pressure EDR Requirements	Appendix D Cloud Top Temperature EDR Requirements	Appendix D Cloud Top Height EDR Requirements
Horizontal Cell Size			
1. Entire Swath	6 a 1 km	6 a 1 km	6 a 1 km
Horizontal Reporting Interval	HCS	HCS	HCS
Horizontal Coverage	Global	Global	Global
Measurement Range	50 to 1050 mb	180 to 310 K	0 - 20 km
Measurement Accuracy			
1. Surface - 3 km, Cloud Layer Optical Thickness * 1	100 mb (TBR)	2 K (TBR)	1 km (SYS-TBR-012)
2. Altitude 3 - 7 km, Cloud Layer Optical Thickness * 1	75 mb (TBR)	2 K (TBR)	1 km (SYS-TBR-012)
3. Altitude > 7 km, Cloud Layer Optical Thickness * 1	50 mb (TBR)	2 K (TBR)	1 km (SYS-TBR-012)
Measurement Precision			
1. Surface - 3 km, Cloud Layer Optical Thickness * 1	50 mb (TBR)	1.5 K	0.3 km
2. Altitude 3 - 7 km, Cloud Layer Optical Thickness * 1	38 mb (TBR)	1.5 K	0.3 km
3. Altitude > 7 km, Cloud Layer Optical Thickness * 1	25 mb (TBR)	1.5 K	0.3 km
Long Term Stability			
1. Surface - 3 km	10 mb	1 K	0.2 km
2. Altitude 3 - 7 km	7 mb	1 K	0.2 km
3. Altitude > 7 km	5 mb	1 K	0.2 km
Mapping Uncertainty, 3 Sigma	1.5 km	1.5 km	1.5 km
Maximum Local Average Revisit Time	6 hrs	6 hrs	6 hrs
Latency	NPP - 140 min.	NPP - 140 min.	NPP - 140 min.
	NPOESS - 28 min.	NPOESS - 28 min.	NPOESS - 28 min.
Degraded Daytime Measurement Condition: Sun Glint < 36 deg			
1. Measurement Accuracy for CLOT ≥ 1			
a. Surface - 3 km,	150 mb (TBR)	4.5 K (TBR)	1.5 km (SYS-TBR-013)
b. 3 km - 7 km	110 mb (TBR)	4.5 K (TBR)	1.5 km (SYS-TBR-013)
c. Altitude > 7 km	75 mb (TBR)	4.5 K (TBR)	1.5 km (SYS-TBR-013)
2. Measurement Accuracy for CLOT < 1			
a. Surface - 3 km,	330 mb (TBR)	9 K (TBR)	3.0 km (SYS-TBR-013)
b. 3 km - 7 km	240 mb (TBR)	9 K (TBR)	3.0 km (SYS-TBR-013)
c. Altitude > 7 km	150 mb (TBR)	9 K (TBR)	3.0 km (SYS-TBR-013)
3. Measurement Precision			
a. Surface - 3 km	75 mb (TBR)	2.3 K (TBR)	0.5 km (SYS-TBR-013)
b. 3 km - 7 km	55 mb (TBR)	2.3 K (TBR)	0.5 km (SYS-TBR-013)
c. Altitude > 7 km	38 mb (TBR)	2.3 K (TBR)	0.5 km (SYS-TBR-013)
Degraded Measurement Condition			
1. Measurement Accuracy for CLOT < 1			
a. Surface - 3 km	220 mb (TBR)	N/A	N/A
b. Altitude 3 - 7 km	160 mb (TBR)	N/A	N/A
c. Altitude > 7 km	100 mb (TBR)	N/A	N/A

Cloud Base Height

Algorithm Overview

Cloud Base Height (CBH) is defined as the height above sea level where cloud bases occur. More precisely, for a cloud covered earth location, cloud base height is the set of altitudes of the bases of the clouds that intersect the local vertical at this location.

CBH = (CTH)-(Cloud Thickness)

- CTH (Cloud Top Height) is a VIIRS EDR
- Cloud Thickness (CT) is derived from the VIIRS Cloud Effective Particle Size (ref) and Cloud Optical Thickness (t) EDRs and the VIIRS Cloud Type IP as follows:
  - Water Clouds: CT=Liquid Water Path (LWP) over Liquid Water Content (LWC); where Ψ is determined by cloud type, and is 0.293g/m3 for stratus, 0.455g/m3 for altocumulus and altostratus, and 0.588g/m3 for cumulus clouds

$$IWP = \frac{\tau}{\left[\frac{(a+b)}{2r_{ef}}\right]}$$

  - Ice Clouds: CT=Ice Water Path (IWP)/Ice Water Content (IWC); where |T| is the cloud temperature

$$\frac{LWP}{LWC} = \frac{\frac{[2\tau_{ef}]}{3}}{\psi} \qquad \ln(IWC) = -7.6 + 4\exp\left[-0.2443e^{-3}(|T|-20)^{2.455}\right]$$

EDR/Attribute	Appendix D EDR Requirements
Horizontal Cell Size	
1. Edge of Swath	6 a 1 km
Horizontal Reporting Interval	HCS
Horizontal Coverage	Global
Vertical Reporting Interval	Base of Highest Cloud and Lowest Cloud
Measurement Range	0 - 20 km
Measurement Uncertainty	2 km
Long Term Stability	2.0 km
Mapping Uncertainty, 3 Sigma	1.5 km
Max Local Average Revisit Time	12 hrs
Latency	NPP - 140 min.
	NPOESS - 28 min.
Measurement Degradation Conditions	Derived from Cloud Effective Particle Size, Cloud Optical, Thickness, and Cloud TopHeight EDR's degradation conditions
1. Regions of mixed phase / multiple cloud layers	
Excluded Measurement Conditions	
1. Sun Glint < 36 deg	

Predicted Performance

Analyses indicate that the specifications for CBH will be met for NPP in most conditions. This includes the 2 km uncertainty specification for single-layer cloud systems. NGST analyses predict uncertainty to be 1.4 km for ice clouds and 0.8 km for water clouds. The Horizontal cell size (HCS) is 4 times better than Government requirement.

Degraded conditions include multiple cloud layers, sun glint, and highly reflective surfaces (e.g. snow, sparse vegetation). Mean cloud temperature must be used for approximation, and this is problematic in multiple cloud layers with highly variable temperatures. Instances where the algorithm is limited at the cold end by extreme mean ice cloud temperatures (<-60 deg C) are expected to be rare. Due to external limitations, the cloud thickness cannot exceed 4 km. This can lead to large errors in CBH for mature convective clouds (state-of-science issue). Therefore, performance for convective clouds needs additional analysis. Comparison to CALIPSO/CloudSat cloud boundary data using MODIS data is needed.

Cloud Cover/Layers

Algorithm Overview

Cloud Cover is defined as the fraction of a given area on the Earth's surface for which a locally normal line segment, extending between two given altitudes, intersects a cloud. Cloud Cover is reported as 0.0 for a horizontal cell that has no cloud and 1.0 for a horizontal cell that is completely cloud covered.

- **Group pixels based on vertical location, cloud phase, and values of CTH, COP, and CEPS.**
  - Cluster pixels within the horizontal cell (~6km) with similar Cloud Top Heights and Phases (up to 9 clusters) and regroup by assigning each pixel to closest cluster center.
  - Adjacent cells used as well to smooth layer analysis.
  - Compute new cluster centers as centroid of the clusters, and repeat assigning of pixels to clusters to minimize distance error.
  - Adjust cluster number by merging or splitting clusters as necessary and removing outlier clusters.
- **Determine cloud type of cluster**
  - Evaluate Cloud Top Height, Effective Particle Size, and Optical Thickness values against pre-determined cloud type definitions
- **Determine cloud fraction**
  - Compute ratio of number of cloudy pixels of that cluster/layer to total number of all pixels within the horizontal cell

Predicted Performance

The specifications for the Cloud Cover Layers EDR are expected to be met under most conditions The HCS is 4 times better than Government requirement. The algorithm derives heritage from the SERCAA cloud products that have proven useful for the U.S. Air Force.

The quality of the retrieval is dependent on COP and CTH retrieval quality, and cloud identification by the VIIRS Cloud Mask. The methodology is an extension of the clustering technique used in the heritage SERCAA approach, but uses CEPS for retrieval of layers. CTT, upon which CTH is dependent, is used in the current clustering technique at AFWA. Any problems with the CC/L predecessor products will affect the layering results, but not the total cloud cover amount.

Additional analyses are needed for a complete performance verification. Performance comparisons with heritage algorithm implemented in AFWA Cloud Depiction and Forecasting System II are planned, as well as testing with MODIS data. Comparison to CALIPSO/CloudSat is needed to fully establish performance and credibility.

EDR/Attribute	Appendix D EDR Requirements
Horizontal Cell Size (HCS)	
1. Entire Swath	6 a 1 km
Horizontal Reporting Interval	HCS
Vertical Reporting Interval	4 Layers
Horizontal Coverage	Global
Vertical Coverage	0 - 20 km
Measurement Range	0 - 1.0 HCS Area
Measurement Accuracy	
1. At Nadir	0.07 of HCS Area
2. At Edge of Swath	0.4 of HCS Area
Measurement Precision	
1. At Nadir	0.07 of HCS Area
2. At Edge of Swath	0.4 of HCS Area
Mapping Uncertainty, 3 Sigma	1.5 km
Max Local Average Revisit Time	12 hrs
Latency	NPP - 140 min.
	NPOESS - 28 min.
Binary Map HCS	0.8 km @ Nadir
Binary Map Horizontal Reporting Interval	Binary Map HCS
Binary Map Measurement Range	Cloudy/Not Cloudy
Binary Map Probability of Correct Typing	
1. Ocean, Day, COT > 1.0	94%
2. Day, Land, COT > 1	90%
3. Ocean, Night, COT > 1	85%
Cloud Leakage Rate	
1. Ocean, Day, COT > 1.0, outside Sun Glint region	1%
2. Land, Day, COT > 1.0	3%
3. Land, Ocean, Night, COT > 1.0	5%
False Alarm Rate	
1. Ocean, Day, COT > 1.0	5%
2. Land, Day, ToC NDVI < 0.2 or ToC NDVI > 0.4, or Desert, COT > 1.0	7%
3. Land, Ocean, Night, COT > 1.0	8%
Differentiate heavy aerosols from clouds, Day (S < OD < 2), dust/sand, smoke, volcanic ash.	85% (SYS-TBR-002)
Degraded Measurements Conditions	
1. Cloud Leakage Rate	
Land, Ocean outside Sun Glint Region, Day, COT ≤ 1.0	5%
Land, 0.2 ≤ ToC NDVI ≤ 0.4 and COT ≤ 1.0	7%
Land and Ocean Sun Glint Regions	7%
Night, Poleward of 60 deg N or 60 deg S	15%
1. False Alarm Rate	
Land, Ocean, Day, COT ≤ 1.0	8%
Land, 0.2 ≤ ToC NDVI ≤ 0.4 and COT ≤ 1.0	10%
Land and Ocean Sun Glint Regions	10%
Night, Poleward of 60 deg N or 60 deg S	25% (SYS-TBR-003)

Cloud Optical Properties

Algorithm Overview

The VIIRS cloud retrieval algorithm for simultaneously retrieving cloud optical thickness (COT) and cloud effective particle size (CEPS) contains two basic retrieval approaches: solar retrieval and infrared retrieval. In addition, except for daytime water clouds, cloud top temperature (CTT) is retrieved.

- **COP algorithms retrieve COT and CEPS simultaneously using the spectral dependence of the properties and radiative transfer parameterizations.**
  - CTT is retrieved simultaneously, except for optically thick water clouds where a window channel is used to infer CTP.
- **Algorithm was initially similar in theory to heritage MODIS approach, but were enhanced to exploit VIIRS unique data, such as the 0.412 µm band.**
  - Retrieves cloud properties at night, though at a reduced performance level, and MODIS does not retrieve CEPS
  - Uses UCLA Line-by-Line Equivalent to generate LUTs for optically thin clouds and uses Asymptotic Theory for optically thick clouds
  - Incorporates aerosol, surface and atmospheric effects within the LUT while MODIS and AVHRR use a simpler cloud-only LUT and add in effects outside the LUT
  - Differences between retrievals attributed to differences in scatter modeling of RTMs used, not differences in band characteristics
- **Cloud Mask and Cloud Type information used to determine the presence and phase of a cloud within a pixel**
- **Retrieval strategies differ for day and night retrievals of water and ice (Cirrus) clouds**
- **Clear-sky radiance obtained using information from nearby cloud-free pixels; MODIS uses a pre-computed clear-sky reflectance map**

EDR/Attribute	Appendix D Cloud Optical Thickness EDR Requirements	Appendix D Cloud Effective Particle Size EDR Requirements
Horizontal Cell Size		
1. Edge of Swath	6 a 1 km	6 a 1 km
Horizontal Reporting Interval	HCS	HCS
Horizontal Coverage	Global	Global
Vertical Cell Size	N/A	Vertical Reporting Interval
Vertical Reporting Interval	N/A	Up to 4 layers
Measurement Range	0.1 to 30 (Tau units)	0-50 micrometer
Measurement Accuracy		
1. Water	10% or 0.05 (TBR), whichever is greater	2 micrometer or 10%, whichever is larger (SYS-TBR-004)
2. Ice	10% or 0.05 (TBR), whichever is greater	3.5 micrometer or 10%, whichever is larger (SYS-TBR-005)
Measurement Precision	5% or 0.025 (TBR), whichever is greater	5% or 2 micrometers, whichever is larger (SYS-TBR-006)
Long Term Stability	2%	2%
Mapping Uncertainty, 3 Sigma	1.5 km	1.5 km
Max Local Average Revisit Time	12 hrs	12 hrs
Latency	NPP - 140 min.	NPP - 140 min.
	NPOESS - 28 min.	NPOESS - 28 min.
Measurement Degradation Conditions		
1. COT for Tau < 1	(TBR)	(SYS-TBR-007)
2. COT for Tau > 10 (ice cloud)	(TBR)	N/A
Excluded Measurement Conditions:		
1. Sun Glint < 36 deg		

Predicted Performance

COT is expected to meet specifications, but the CEPS will need additional analysis to meet specifications in all conditions. Though, in both cases, the Horizontal cell size (HCS), 6 km, is 4 times better than the Government requirement of 25 km.

Performance is directly related to the ability of the Radiative Transfer Model to accurately characterize cloud particle size, shape and distribution, which is more difficult for ice than water clouds. No IR (ice and water night) algorithms, including the VIIRS and MODIS algorithms, are applicable to areas where clear radiance is less than cloud radiance such as during polar winter. This is state-of-science issue, as well as application to areas of multi layer/mixed phase clouds.

Government Subject Matter Experts are concerned that the VIIRS approach involves items not yet demonstrated in an operational environment. Therefore, global testing is needed. Results will depend critically on LUTs, inference of clear-sky reflectance's and algorithm implementation. Comparison to MODIS data will be useful for characterizing performance. Alternative approaches for determining clear sky radiance may be necessary to fully meet specifications.

Background Images from the "VIIRS Chain Test Report – The VIIRS Cloud Algorithms", 2007