NPOESS/VIIRS Cloud Top Temperature - Algorithm Performance Case Study

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Introduction

Abstract:

This paper describes a comparison study in cloud top temperature (CTT) between measurements and retrieved CTT using the NPOESS/VIIRS Cloud Top Temperature algorithms. The cirrus CTT is obtained from solving two non-linear algebraic equations derived from the radiative transfer equations for the observed radiances in the 8.55 and 12.0 μm bands. In daytime water cloud conditions, however, the single band Window IR method which employs the measured radiance in the 10.7 μm band is used. In this approach, the cloud top temperature is obtained by running the OSS radiative transfer model iteratively to match the measured radiance.

Northrop Grumman Space Technology (NGST) has recently completed functional and initial verification testing of all VIIRS algorithms. Over 40 MODIS 5-minute granules, specifically selected to stress-test the VIIRS algorithms were analyzed along with global synthetic data generated in the NGST Integrated Weather Product Test Bed. Some of the granules were identified to have satellite overpasses over the ARM and the Cloudnet ground sites. The measured cloud top heights (CTH) from the ground sites were then used to compare with those retrieved by the VIIRS algorithms.

Furthermore, comparison was made using cloud top height (CTH) measurements from the Cloud Physics Lidar (CPL) flown on the NASA ER-2 aircraft for the CRYSTAL FACE field campaign on July 9, 2002.

Finally, comparison was made using the Cloudsat radar CTH measurements.

Although the data used in this study cover only a limited range of conditions they nevertheless provide a rough estimate of the performance of the CTT algorithms.

CTT APU:

The CTT EDR product **A**ccuracy, **P**recision, and **U**ncertainty requirements vary with cloud optical thickness and solar illumination conditions. Accuracy is "TBR" for semi-transparent and thick clouds

The accuracy requirement ranges from 3-6 K depending on cloud opacity while precision is 1.5 K.

System Requirements for Cloud Top Height and Temperature (ref. SY15-0007L)

System Requirements for CTH:
Accuracy = 2 km ($\tau < 1$)
Accuracy = TBR ($\tau > 1$) 1 km for IORD threshold
Precision = 0.3 km

System Requirements for CTT
Accuracy = 6 deg K ($\tau < 1$)
Accuracy = TBR ($\tau > 1$) 3 deg K for IORD threshold
Precision = 1.5 deg K

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 parameterizations to the TOA radiances of the M14 (8.55 μm) and M16 (12.01μm) bands as:

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

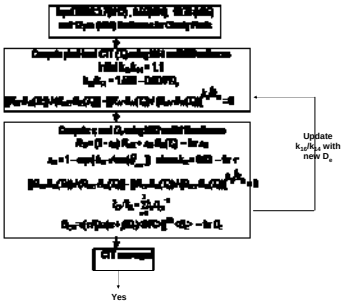
where R_i are TOA radiances, T_c is the cirrus CTT, $B_i(T_c)$ is the Planck function at T_c, ε_i are spectral emissivities, which are functions of optical depth and effective extinction coefficients, k_i (Ou *et al.* 1993):

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

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 CTT Retrieval Algorithm



Daytime Ice Cloud CTT Retrieval Algorithm

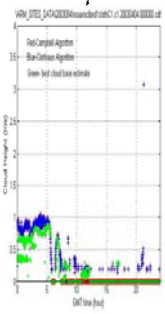
- Identical to Nighttime algorithm without "Compute τ and D_e"
- D_e obtained from Solar Retrieval algorithm for Ice Cloud

Case Studies – Comparisons with ARM & CloudNet Radar Measurements

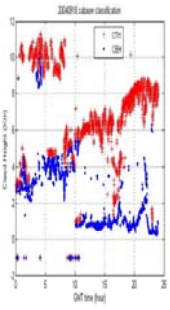
MODIS proxy granules identified to have satellite overpass of the ground sites – covering a range of conditions

Granule ID	Site	Day	Night	Water	Ice
2001114_2305	NSA	X			X
2001164_1800	SGP	X		X	
2003151_1725	SGP	X		X	
2000281_0435	SGP		X	X	
2000320_0440	SGP		X		X
2004262_1250	Cabauw	X			X
2005076_1225	Cabauw	X			X
2005079_1255	Cabauw	X		X	
2003217_1030	Chilbolten	X		X	

ARM VAP Cloud products – "Arslbnd" is used for comparison

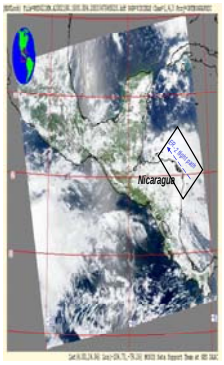


Cloudnet Cloud Products – "Classification" is used for comparison



Case Studies – Comparisons with CRYSTAL FACE CPL Measurements

Aqua/MODIS Image on July 9, 2002 over Central America, South of CRYSTAL – FACE Site

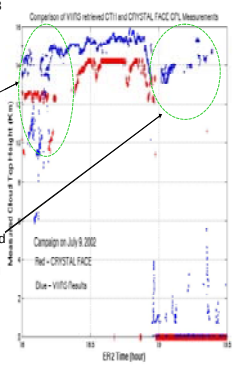


ER – 2 flight occurred approximately 30-80 minutes prior to Aqua overflight

- Aqua overpass at 1930 UTCover the campaign site.
- ER-2 flew over this cirrus cloud patch between 1800 and 1900 UTC – as indicated
- CPL onboard ER – 2 observed variable cloud – top (6km < CTH <15 km) cirrus between 1800 and 1815 UTC, then it observed nearly constant thickness layerof cirrus (CTH ~ 15 km) after 1820 UTC)

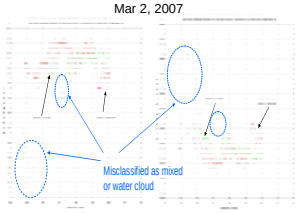
Comparison of VIIRS Retreived CTH with CPL measurements from the CRYSTAL FACE Campaign on July 9, 2002

1. Between 18-18.3 UTC, inspection of MAS imagery from ER – 2 shows sparse very thin cirrus long time delays between ER – 2 and MODIS overpass make location of these cloud highly uncertain
2. Between 19-19.5 UTC, VIIRS cloud mask detect no cloud suggesting cloud may have drifted out of original ER – 2 flight track



Case Studies – Comparisons with Cloudsat Measurements

Comparison of Cloud Top Height and Temperature between VIIRS retrievals and Cloudsat Radar measurements – Mar 2, 2007



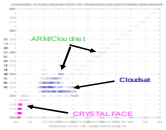
Other than the misclassified pixels the agreements in CTH and CTT are generally good

Comparison in Cloud Top Height between VIIRS retrievals and measurements from Ground/Space – Based Radar and Airborne C PL14

- Based on this limited comparison on the performance of VIIRS CTH algorithm is as follows:
  - -Accuracy = 1.1 km
  - -Precision = 0.3 km
- The estimated performance values are dominated by high clouds –not globally representative
- Estimated performance values are close to meeting the Systems pec and the IORD threshold requirements for CTH

Comparison in Could Top Temperature between VIIRS retrievals and Ground/Space – Based Radar and Airborne CPL measurements (deduced from CTH)

- Based on this limited comparison the performance of VIIRS CT algorithm is as follows:
  - -Accuracy = 3.0 degK
  - -Precision = 2.7 degK
- The precision value is skewed by over sampling of high clouds of high lapse rate



Summary

- **We have conducted limited verification of the VIIRS CTT Algorithms using ground based, airborne and space based radar/lidar CTH measurements**
- **General agreements are observed between the VIIRS retrieved CTH and measurements**
- **The estimated CTH and CTT EDR Performance for τ >1 clouds are as follows:**

  For CTH
  - Accuracy = 1.1 km
  - Precision = 0.3 km-

  For CTT
  - Accuracy = 3.0 deg K
  - Precision = 2.7 deg K
- **VIIRS CTH and CTT EDRs appear to meet most of the System Spec requirements, however, further testing are needed to cover the full range of global conditions**
- **Future Cal/Val Tasks**
  - Pre-launch testing – use Cloudsat and Calipso measurements for the full range of global conditions
  - Long and short term post-launch validation - use measurements from ARM, Cloudnet ground sites, field campaign (if needed) and Cloudsat/Calipso (if still operational) to validate all the cloud EDRs