MISR Cloud-Top-Height (CTH) Optical-Depth (OD) Product Quality Statement (Version 7)

September 19, 2020

The MISR CTH-OD product contains 2D histograms (joint distributions) of retrieved cloud-top-height and cloud-optical-depth on a global 1-degree latitude by 1-degree longitude grid. This quality statement covers Version 7 of the CTH-OD product and describes known problems and limitations of these data. We strongly encourage comparisons of climate model output with MISR data be undertaken using the MISR Simulator contained within the CFMIP Observation Simulator Package (COSP; https://cfmip.github.io/). Details on the MISR simulator are given in Marchand and Ackerman [2010] with evaluation studies given by Marchand et al. [2010] and Hillman et al. [2017, 2018].

Obtaining Data

The MISR CTH-OD data are available in HDF and NetCDF (CMOR compliant) formats. The HDF format data is available from the NASA Langley Atmospheric Science Data Center:

> https://asdc.larc.nasa.gov/project/MISR
> Look for level 3 products MIL3MCOD (monthly) or MIL3YCOD (yearly).
> Data can be obtained through direct download or search tools.

The NetCDF (CMOR) format data is available from Roger Marchand (rojmarch@u.washington.edu):

> https://atmos.uw.edu/~roj/MISR_observations/MISR_CTH_OD_histograms/V7/

and from the CFMIP observational data archive:

> http://climserv.ipsl.polytechnique.fr/cfmip-obs.html.

Data Description

The MISR CTH-OD histograms are conceptually similar to cloud-top-pressure (CTP) and OD histograms being produced by the International Satellite Cloud Climatology Project (ISCCP) and the MODerate resolution Imaging Spectroradiometer (MODIS) project. The MISR CTH-OD product differs from the ISCCP and MODIS products in several ways; most importantly is that the MISR CTH is determined using a stereo-imaging (geometric) retrieval technique which has better vertical resolution for liquid-topped mid- and low-level clouds and is insensitive to image calibration. A lengthy review of the MISR CTH-OD data, including comparisons with MODIS and ISCCP CTH-OD datasets can be found in Marchand et al. [2010], and additional evaluation using CloudSat and Calipso (radar and lidar profiles of cloud occurrence) can be found in Hillman et al. [2017].

In recent years, satellite instrument simulators have been used to make more consistent comparisons between climate models and satellite retrievals. This includes the MISR Simulator, which produces MISR-like CTH-OD histograms from climate model output. We strongly encourage comparisons with climate model output with MISR data be undertaken using the MISR Simulator contained with-in the CFMIP Observation Simulator Package (COSP; https://cfmip.github.io/). Details on the MISR simulator are given in Marchand and Ackerman [2010], and evaluations of the MISR Simulator can be found in Hillman et al. [2017] and [2018].

The primary difference between the Version 7 and previous two versions (Versions 5 and 6) of the MISR CTH-OD product is that Version 7 is:

1) **Based on a new version of the MISR Stereo Retrieval Algorithm**

In all CTH-OD product versions, the product uses MISR stereo heights that are wind-corrected when winds are successfully retrieved, and otherwise uses the uncorrected heights (no adjustment for wind). In V7 the heights are based on the new TC_CLOUD algorithm rather than the older TC_STEREO algorithm. Details on the TC_CLOUD algorithm are given in Mueller et al. [2013a, 2013b]. The cloud wind retrievals in TC_CLOUD are much improved in terms of coverage due to application of a new wind-retrieval algorithm [Mueller et al. 2017].

In V7, there are also tighter quality metrics for the without-wind-corrected height. While use of the quality metrics improves the overall quality of the height algorithm (by rejecting stereo-heights which may not be accurate) this also increased the fraction of pixels for which there is no stereo-height retrieval. The fraction of data where no stereo heights is retrieved, called "No CTH Retrieval" or "NR" for short. NR occurrence is included in the bottom row of the MISR histogram (for example, see Figure 1).

For use of older MISR products, please note that a bug was discovered in the V6 (and earlier) software, which sometimes caused pixels that should have counted as a "No CTH Retrieval", to instead be recorded as having cloud present with a cloud-top-height between 0 and 0.5 km. Overall, while the stereo heights are better, the combination (more restrictive quality thresholds and bug-fix) has resulted in a larger percentage of "No CTH Retrievals". "No CTH Retrieval" conditions now represent approximately 7.5% in the global average, whereas it was 2.5% in V6.

2) **Includes a correction to the MISR NIR calibration**

Studies by Bruegge et al. [2014], Corbett and Loeb [2015], and Limbacher and Kahn [2016] on the MISR calibration found that MISR near-IR radiances (used to obtain MISR optical depths in this product) likely have a small downward calibration drift of about 0.9 to 1.5 % per decade. In the V5 and V6 products, this calibration drift caused a reduction in the retrieved optical depth over time, slightly reducing the occurrence of clouds with large-optical depths in the CTH-OD product (by ~ 0.05 %/year for OD>23) and increasing the occurrences of clouds with lower optical depths by the same amount. This calibration drift did not cause any change in the cloud top altitude but rather caused clouds at a given altitude to shift toward lower optical depths at that same altitude.

A comparison of V7 and V6 CTH-OD datasets, and assessment on the impact of the calibration drift on trends in the MISR CTH-OD dataset is underway. Results of this assessment will be published in the peer-reviewed literature. The impact on the data is small and only matters for trend analysis. Users who are concerned about the impact of the calibration drift (or its correction) are encouraged to contact Dr. Marchand (rojmarch@u.washington.edu).

Know Problems/Limitations:

(1) Ocean only coverage and sea ice

The MISR CTH-OD product is not generated over land surfaces or for solar zenith angles greater than 78.5 degrees. Regions with sea-ice are excluded based on monthly SSMI sea ice maps. The SSMI sea-ice mask does not function well in coastal areas and so coastal areas where ice might be found are also excluded. The identification of sea-ice is not perfect and at times a few grid-cells with patchy sea-ice go undetected.

Sea ice contaminates both the cloud-detection (generating false positives) and optical depth retrievals (which assume a dark-water surface). Typically this appears as an unusually large number of no-CTH-retrieval conditions or an large number of retrieved CTH in the lowest altitude bin (0 to 0.5 km) <u>with a peak in optical depth values between about 4 and 10</u>, as shown below in figure 1. High-latitude regions that display patterns like this should be considered suspect. The CTH retrievals away from the surface (CTH > 1 km) are believed to be good, though the associated OD are very likely to be biased high.

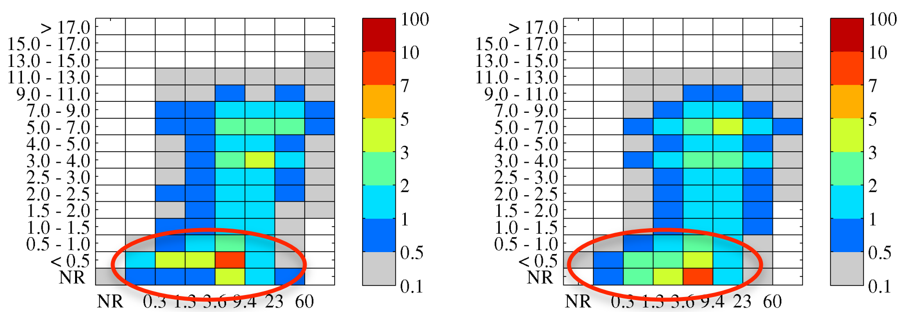

Figure 1 – Examples of CTH-OD results with likely sea-ice contamination

(2) Broken clouds and cloud edges

Because satellite pixels can be partially filled by clouds, the fraction of satellite pixels containing some amount of cloud (what one might call the "imager-retrieved" cloud fraction) will generally be larger than the true fractional area covered by clouds (which one might obtain with a satellite imager with much higher resolution than the 275m used by MISR). This is especially true of the low-altitude-cloud fraction in areas dominated by trade cumulus, where the MISR cloud fraction (derived with an effective pixel size of 1.1 km) is likely 10% larger than would be derived from a much higher resolution imager (Zhao and Di Girolamo 2006). Outside of trade cumulus areas the over-estimate is likely small, perhaps 5%.

This problem is not unique to MISR, all imagers (MODIS and ISCCP included) suffer from this limitation. However, MISR is more aggressive in detecting partially filled pixels with low-clouds than ISSCP and subsequently reports larger low cloud amounts (as much as 10% more than ISCCP in the zonal average, see Marchand et al. 2010).

Small clouds and cloud edges can likewise have a drastic effect on the retrieved optical depth. There has been much discussion in the literature around the subject of error in cloud optical depth retrievals due to three dimensional (3D) effects and the result contained in the MISR histograms are perhaps best considered "1D equivalent optical depths at a scale of 1.1 km". In particular, the preponderance of low-optical depths associated with low-altitude clouds in the tropical and subtropical trade cumulus zones is indicative of the fact that these clouds tend to only partially fill the MISR pixel or otherwise have large 3D scattering effects.

(3) Errors/Uncertainty in retrieved Cloud-Top-Heights

The MISR Cloud-Top-Height retrieval is based on a stereo-imaging technique. A significant advantage of the MISR CTH retrieval is that the technique is geometric and is not sensitive to the actual value of the observed radiances (i.e., the sensor calibration). The MISR CTH retrieval has been the focus of several studies including Hillman et al. [2017], Marchand et al. [2007, 2001], Naud et al. [2002, 2004, and 2005a,b], Seiz et al. [2005]. Error characteristics depend on the cloud-type. The above studies show that cloud top is found with little bias and a standard deviation of about 500 m for liquid-topped clouds. The situation for ice-clouds is more complex, with the retrieved height typically located near the altitude where the cloud opacity reaches about 1, rather than true cloud top as would be observed by a satellite lidar.

The dominant source of uncertainty in the height retrieval comes from errors in the wind-correction (or lack thereof) and is typically less than 1000 m. As a result of CTH retrieval errors, some fraction of the counts in each CTH bin will be placed one bin too low or too high. In principal, this could approach 50% if the actual cloud tops in a given region predominantly occur close to one of the bin-boundaries.

(4) Cloud Phase

Clouds with a CTH below the climatological freezing level are assumed to be composed of water drops with an effective radius of 10 um, while those above the freezing level are treated as ice particles with an effective radius of 50 um and an aggregate-like crystal habit. No formal analysis on the error in the optical depth due to the assumption of a fixed effective radius or cloud phase has been undertaken. Nonetheless, MISR and MODIS retrievals produce very similar OD distributions in mid-latitude mixed phase regions (in spite of the fact that MODIS retrieves the particle size and cloud phase and MISR applies a temperature threshold and climatology) suggesting this is not a large problem, at least in the aggregate [Marchand et al. 2010].

(5) Multiple Cameras

While there has been some research into the potential advantage of using multiple MISR view angles for cloud optical depth retrieval [Evans et al. 2008, McFarlane and Marchand 2008] much more research is needed and no operational multiangle optical depth retrievals yet exist. Only one MISR camera (that is, one view-angle and one radiance measurement) is used in the optical depth retrieval. However, the MISR histograms take advantage of the MISR multi-angle cameras by selecting a ***best camera***, as the camera closest to nadir that has no sun-glint. Most of the time, the best camera is either the nadir viewing camera, or one of the MISR 26^o cameras. There is however, a small region in the tropics (the exact location of which moves with the seasonal cycle) where a 45^o view is used. The MISR operational CTH-OD HDF dataset contains the “best camera” result, as well as histograms for each of the 9 MISR views.

Analysis suggests the sensitivity of the CTH-OD histograms to view angle is modest if the MISR 60^o and 70.5^o views are not considered. This modest sensitivity to view angle should not be taken to mean that the optical depth of individual pixels remains the same regardless of view angle. Rather, it shows that (given the size of the optical depth bins in the histogram) the net change in the optical depth distribution is typically small [Marchand et al. 2010]. This result is consistent with previous studies, such as Varnai and Marshak [2007] who found that mean optical depth retrieved from MODIS shows little sensitivity to view angle for solar zenith angles less than about 50^o, and Horvath and Davies [2004] who found that the percentage of clouds for which MISR observations fit a plane-parallel (1D) model increases dramatically if the MISR 60^o and 70.5^o views are not considered.

References

Bruegge, C., S. Val, D. Diner, V. Jovanovic, E. Gray, L. Girolamo, G. Zhao 2014: Radiometric stability of the Multi-angle Imaging SpectroRadiometer (MISR) following 15 years on-orbit. Proc. SPIE, 9218, 92180N, Earth Observing Systems XIX, doi: 10.1117/12.2062319

Corbett, G., and N. Loeb 2015: On the relative stability of CERES reflected shortwave and MISR and MODIS visible radiance measurements during the terra satellite mission. J. Geophys. Res. Atmos., 120, 11,608–11,616, doi:10.1002/2015JD023484

Limbacher, J. A. and Kahn, R. A., 2016: Updated MISR Dark-Water Research Aerosol Retrieval Algorithm – Part 1: Empirical Calibration Corrections and Coupled 1.1 km Ocean-Surface Chlorophyll-a Retrievals, Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2016-360

Hillman, B. R., R. T. Marchand, T. P. Ackerman, G. G. Mace, and S. Benson (2017), Assessing the accuracy of MISR and MISR-simulated cloud top heights using CloudSat- and CALIPSO-retrieved hydrometeor profiles, J. Geophys. Res. Atmos., 122, 2878–2897, doi:10.1002/2016JD025510.

Hillman, B. R., Marchand, R. T., & Ackerman, T. P. (2018). Sensitivities of simulated satellite views of clouds to subgrid-scale overlap and condensate heterogeneity. Journal of Geophysical Research: Atmospheres, 123, 7506–7529, doi: 10.1029/2017JD027680

Marchand, R., and T. Ackerman (2010), An analysis of cloud cover in multiscale modeling framework global climate model simulations using 4 and 1 km horizontal grids, J. Geophys. Res., 115, D16207, doi:10.1029/2009JD013423.

Marchand, R., T. Ackerman, M. Smyth, and W. B. Rossow (2010), A review of cloud top height and optical depth histograms from MISR, ISCCP, and MODIS, J. Geophys. Res., 115, D16206, doi:10.1029/2009JD013422.

Marchand, R. T., T. P. Ackerman, and C. Moroney (2007) An assessment of Multiangle Imaging Spectroradiometer (MISR) stereo-derived cloud top heights and cloud top winds using ground-based radar, lidar, and microwave radiometers, J. Geophys. Res., 112, D06204, doi:10.1029/2006JD007091.

Marchand, R. T., T. P. Ackerman, M. D. King, C. Moroney, R. Davies, J. P. Muller, and H. Gerber 2001: Multiangle observations of Arctic clouds from FIRE ACE: June 3, 1998, case study. *J. Geophys. Res*. **106** (D14), 15,201.

McFarlane, S. A., and R. T. Marchand (2008), Analysis of ice crystal habits derived from MISR and MODIS observations over the ARM Southern Great Plains site, J. Geophys. Res., 113, D07209, doi:10.1029/2007JD009191.

Mueller, K. J., C. M. Moroney, V. Jovanovic, M. J. Garay, J.-P. Muller, L. Di Girolamo, and R. Davies, 2013a: MISR Level 2 Cloud Product Algorithm Theoretical Basis. Tech. Rep. JPL D-73327, Jet Propulsion Laboratory, 51 pp., https://eospso.gsfc.nasa.gov/sites/default/files/atbd/MISR_L2_CLOUD_ATBD-1.pdf.

Mueller, K. J., C. M. Moroney, and V. Jovanovic, 2013b: MISR level 2 cloud product quality statement, September 14, 2012. Atmospheric Science Data Center, 4 pp., https://eosweb.larc.nasa.gov/sites/default/files/project/misr/quality_summaries/L2TC_Cloud_Product.pdf.

Mueller, K. J., and Coauthors, 2017: Assessment of MISR Cloud Motion Vectors (CMVs) relative to GOES and MODIS Atmospheric Motion Vectors (AMVs). J. Appl. Meteor. Climatol., 56, 555–572, https://doi.org/10.1175/JAMC-D-16-0112.1. Link, Naud, C. M. J.-P. Muller, E. E. Clothiaux, B. A. Baum, and W. P. Menzel 2005: Intercomparison of multiple years of MODIS, MISR and radar cloud-top heights. *Annales Geophysicae*, **23**, p. 1–10, SRef-ID: 1432-0576/ag/2005-23-1

Naud, C., J. Muller, M. Haeffelin, Y. Morille, and A. Delaval 2004: Assessment of MISR and MODIS cloud top heights through inter-comparison with a back-scattering lidar at SIRTA, *Geophys. Res. Lett.*, **31**, L04114, doi:10.1029/2003GL018976.

Naud, C., J-P. Muller, and E.E. Clothiaux 2002: Comparison of cloud top heights derived from MISR stereo and MODIS CO2-slicing. *Geophys. Res. Lett.* **29**, (10),1029/2002 GL015460.

Seiz, G., Davies, R., Gruen, A., 2005: Stereo cloud top height retrieval with ASTER and MISR. *International Journal of Remote Sensing* (accepted September 2005).

Varnai, T., and A. Marshak (2007), View angle dependence of cloud optical thicknesses retrieved by Moderate Resolution Imaging Spectroradiometer (MODIS), J. Geophys. Res., 112, D06203, doi:10.1029/2005JD006912.

Zhao, G., and L. Di Girolamo (2004), A cloud fraction versus view angle technique for automatic in-scene evaluation of the MISR cloud mask, J. Appl. Meteorol., 43, 860 – 869.

Zhao, G., and L. Di Girolamo (2006), Cloud fraction errors for trade wind cumuli from EOS-Terra instruments, Geophys. Res. Lett., 33, L20802, doi:10.1029/2006GL027088