2010

Improving the CALIPSO VFM product with Aqua MODIS measurements

Yong Xie

George Mason University, yxie2@gmu.edu

John J. Qu

George Mason University

Xiaoxiong Xiong

Biospheric Sciences Branch, NASA/GSFC/614.4, Greenbelt, MD

Follow this and additional works at: <http://digitalcommons.unl.edu/nasapub>

Xie, Yong; Qu, John J.; and Xiong, Xiaoxiong, "Improving the CALIPSO VFM product with Aqua MODIS measurements" (2010).
NASA Publications. 203.

<http://digitalcommons.unl.edu/nasapub/203>

This Article is brought to you for free and open access by the National Aeronautics and Space Administration at DigitalCommons@University of Nebraska - Lincoln. It has been accepted for inclusion in NASA Publications by an authorized administrator of DigitalCommons@University of Nebraska - Lincoln.

Improving the CALIPSO VFM product with Aqua MODIS measurements

YONG XIE*[†], JOHN J. QU[†] and XIAOXIONG XIONG[‡]

[†]Environmental Science and Technology Center, College of Science, George Mason University, Fairfax, VA 22030, USA

[‡]Biospheric Sciences Branch, NASA/GSFC/614.4, Greenbelt, MD 20771, USA

(Received 25 November 2009; in final form 22 February 2010)

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) Vertical Feature Mask (VFM) product reports the scene classification globally. However, misclassifications have been observed because of labelling dense dust aerosols as clouds. Both CALIPSO and MODerate resolution Imaging Spectroradiometer (MODIS) aboard the Aqua spacecraft are operating in the A-train orbit with similar local equatorial crossing times. A novel approach to improve the scene classification by integrating the CALIPSO VFM product and measurements of MODIS thermal bands is proposed. According to the infrared (IR) split window technique, the brightness temperature difference (BTD) between MODIS 12 and 11 μm (BTD (12, 11 μm)) is calculated for separating dust aerosol and cloud. Generally, the BTD (12, 11 μm) value is positive for dust aerosol and negative for cloud. After spatial collocation, the comparison between measurements of the two sensors is performed. If a cloud layer in VFM product has positive MODIS BTD (12, 11 μm) value in the same area, the misclassification is identified and thus corrected to improve the VFM product.

1. Introduction

The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) instrument, launched on 28 April 2006, provides measurements for studying the roles of aerosols and clouds in the Earth's climate system (Winker *et al.* 2003). CALIPSO measures the vertical distribution of aerosols and clouds, as well as their optical and physical properties, from a near nadir-viewing geometry, with a two-wavelength (532 and 1064 nm) polarization-sensitive lidar.

The CALIPSO Vertical Feature Mask (VFM) product (Vaughan *et al.* 2004), a level-2 product, classifies aerosols and clouds based on their physical feature differences. With the scene-classification algorithm, the atmospheric features are classified as either clouds or aerosols, and then the clouds and aerosols are separated into different subclasses (Omar *et al.* 2003). Because the intrinsic scattering properties of dust are similar to those of clouds in certain conditions, dense dust aerosols may be misclassified as clouds in the VFM product. This kind of misclassification was reported by Liu *et al.* (2009). Furthermore, misclassifications in the CALIPSO VFM product can be observed by comparing with the MODerate resolution Imaging Spectroradiometer (MODIS) true-colour images, especially over arid and

*Corresponding author. Email: yxie2@gmu.edu

desert areas. The misclassification may reduce the quality of further parameter retrievals and model simulation.

However, successful detection of dust aerosols has been demonstrated using MODIS measurements. Among the various techniques, the infrared split window (Ackerman 1997) is one of the most effective indices for dust aerosol detection. This technique measures the brightness temperature difference (BTD) between two thermal emissive bands with centre wavelength 12 and 11 μm and is termed BTD (12, 11 μm) hereafter. Both Aqua MODIS and CALIPSO are operating in the A-train orbit with only around 1 min difference in local equatorial crossing time. Therefore, the temporal mis-registration between measurements of the two sensors is quite small, and it is not considered in this study. After spatial registration, the CALIPSO VFM product can be improved by combining the MODIS BTD (12, 11 μm) measurements.

2. CALIPSO instrument and measurement

The CALIPSO payload consists of three instruments: a two-wavelength polarization-sensitive lidar (CALIOP), an image infrared radiometer and a wide field camera (Winker *et al.* 2003). CALIPSO can offer such parameters as total attenuated backscatter at 532 and 1064 nm, perpendicular attenuated backscatter, height, elevation, latitude, longitude and so on. Generally, the measurable height relative to sea level is within the range from -2 to 40 km.

Figure 1 shows the CALIPSO attenuated backscattering signal in $\text{km}^{-1}\text{sr}^{-1}$ at 1064 nm across northwest China on 26 July 2006 at Coordinated Universal Time (UTC) time 07:30. In this figure, the red solid line across the lower half of the diagram is the elevation of the ground surface. A heavy dust aerosol over Taklimakan Desert is

Figure 1. The CALIPSO attenuated backscatter signal at 1064 nm on 26 July 2006.

Figure 2. The CALIPSO VFM data product on 26 July 2006. The colours represent scene features (Currey *et al.* 2007): (1) invalid (bad or missing data); (2) 'clear air'; (3) cloud; (4) aerosol; (5) stratospheric feature, polar stratospheric cloud or stratospheric aerosol; (6) surface; (7) no signal. The feature layers enclosed in the rectangle are the misclassification in CALIPSO VFM and identified as dust aerosols after correction.

captured by CALIPSO, at a height of 2–3 km from 38.27° N to 40.3° N. Heavy clouds are present at a height of 7–8 km at the south end of the desert and at a height of 5 km at the north end of the desert. The CALIPSO VFM product can be displayed in a two-dimensional colour-coded image, showing the vertical and horizontal distribution of cloud and aerosol layers (figure 2).

3. Methodology

MODIS is a sensor suitable for separating dust aerosol and cloud with its wide wavelength range. The BTDR (12, 11 μm) can be used to differentiate dust aerosol and cloud in both day and night time based on their physical feature differences in the thermal spectrum. The values of BTDR (12, 11 μm) are positive for dust aerosol and negative for cloud (Inoue 1987, Saunders and Kriebel 1988, Ackerman 1997, Ackerman *et al.* 2002). A total of 54 dust storm events and 66 clouds occurred in China during 2001–2007 which were randomly sampled for analysis (Xie 2009). The dust storm events were selected according to the dust storm calendar (www.duststorm.com.cn) released by China Meteorological Administration, which provides the detailed information (time, location and dust storm intensity) of most dust storm events that occurred in China. A square box is used to cut the MODIS pixels in the middle of each dust storm event. The size of the box is dependent on the coverage of each dust storm, such as 20×20 , 50×50 , 100×100 pixels. The clouds were selected based on the MODIS level-2 cloud product. The statistical distribution

Figure 3. Statistical distribution of BTBD (12, 11 μm) values for 54 randomly selected dust storm events and 66 clouds in China from 2001 to 2007.

of BTBD (12, 11 μm) values for the 54 dust storms and 66 clouds is shown in figure 3. The x -axis is Brightness Temperature of MODIS band 31 (BT31) and the y -axis is BTBD (12, 11 μm) value. The vertical error bar is the standard deviation of BTBD (12, 11 μm) for each case. Figure 3 supports the conclusion that the dust aerosol has positive BTBD (12, 11 μm) value and the cloud has negative BTBD (12, 11 μm) value.

Because of the different field of view, the swath of Aqua MODIS is much larger than that of CALIPSO. The footprint of CALIPSO is generally located near the MODIS swath nadir line. The spatial resolution of Aqua MODIS is 1000 m for its thermal emissive bands and that of CALIPSO is 333 m. Because of the different spatial resolutions between two sensors, the spatial registration is performed first to find the overlapping areas using the provided geolocation data set. Then the overlapping areas are divided into two categories according to MODIS BTBD (12, 11 μm) values: BTBD (12, 11 μm) > 0 and BTBD (12, 11 μm) < 0 . In this way, the MODIS BTBD (12, 11 μm) values are assigned to each corresponding CALIPSO pixel. If a feature layer in VFM product is labelled as cloud, in which 90% or more of the pixels have positive BTBD (12, 11 μm) values, a misclassification is identified. This layer is corrected by designating the feature as dust aerosol in the corrected VFM product.

4. Results

Figure 4 shows the MODIS true-colour image associated with the CALIPSO data shown in figure 2. The MODIS image was generated with measurements extracted

Figure 4. (a) The MODIS true-colour image (bands 1, 4 and 3) of dust storm in Taklimakan Desert on 26 July 2006. The blue solid line is the footprint of CALIPSO. (b) The corresponding BTDR (12, 11 μm) image on 26 July 2006.

partly from two swaths at UTC times 7:25 and 7:30. The dust aerosol is located over the eastern desert. The blue line is the footprint of CALIPSO in this area. It is clear that CALIPSO passes across the dust aerosol. The BTDR (12, 11 μm) values of the same region are given in figure 4(b), and the BTDR (12, 11 μm) values over the CALIPSO footprint are given in figure 5.

The BTDR (12, 11 μm) values are clearly larger than zero in the region between 36.75° and 40.80° N, which suggests that the dust aerosol is dominant in this area. However, the dust aerosol in this region is misclassified as cloud in the VFM product

Figure 5. MODIS BTM (12, 11 μm) values over the CALIPSO footprint on 26 July 2006.

(marked with black rectangle in figure 2) after the spatial match. Hence, the misclassification can be corrected by comparing the CALIPSO VFM product with MODIS BTM (12, 11 μm) measurements.

Figure 6(a) shows the MODIS true-colour image of another case on 30 March 2007. The corresponding MODIS measurements were extracted partly from two swaths at UTC times 05:55 and 06:00. The MODIS BTM (12, 11 μm) image is shown in figure 6(b) and the corresponding BTM (12, 11 μm) over CALIPSO footprint is given in figure 7. From the MODIS true-colour image, the dust aerosol is overlapped with cloud in some areas along the CALIPSO path.

In figure 7, the BTM (12, 11 μm) is positive at three peaks with latitudes 36.59° – 39.79° N, 41.04° – 44.02° N and 44.64° – 45.75° N, which correspond to the dust aerosol areas. Among the three peaks, the BTM (12, 11 μm) is negatively associated with two valleys which correspond to the clouds. According to the MODIS BTM (12, 11 μm) values, four misclassifications, marked with black ellipses in figure 7, are found in the CALIPSO VFM product. A correction can be executed through matching measurements of the two sensors.

From the case study, our method works well if a region has the dust storm only, mixes with cloud partly or presents above cloud. If dense cloud presents above dust storm, both CALIPSO and MODIS can only see cloud, so that no misclassification will be observed. If very thin cloud presents above dust storm, the region is dominated by dust storm. The BTM (12, 11 μm) could still be positive. Thus, using a simple threshold may misclassify thin cloud as dust storm. Future work needs to be done to improve the discrimination of dust storm and cloud. However, because the region is dominated by dust storm, the results still provide important information for further parameter retrieval. Moreover, there is around 1 min difference between the passing

Figure 6. (a) The MODIS true-colour image (bands 1, 4 and 3) of dust storm in northwest China on 30 March 2007. The blue solid line is the footprint of CALIPSO. (b) The corresponding BTDR (12, 11 μm) image on 30 March 2007.

times of CALIPSO and Aqua MODIS. Because of the movement of the dust storm during this time, the temporal mis-registration between the two sensors will produce a small spatial shift. However, as the dust storm usually has very large coverage, the impact from temporal mis-registration is ignored in this study.

5. Conclusion

Misclassification of labelling heavy dust aerosol as cloud has been found in the CALIPSO VFM product by examining MODIS true-colour imagery. A novel

Figure 7. Upper: MODIS BTDR (12, 11 μm) values over the CALIPSO footprint on 30 March 2007; bottom: The CALIPSO VFM product on 30 March 2007. The colours represent scene features (Currey *et al.* 2007): (1) invalid (bad or missing data); (2) 'clear air'; (3) cloud; (4) aerosol; (5) stratospheric feature, polar stratospheric cloud or stratospheric aerosol; (6) surface; (7) no signal. The feature layers enclosed in the ellipses are the misclassification in CALIPSO VFM and identified as dust aerosols after correction.

approach is developed for correcting the misclassification by integrating Aqua MODIS BTDR (12, 11 μm) measurements. The observed area is divided into two different categories with MODIS BTDR (12, 11 μm) values. The comparison between two sensors is performed after spatial registration with the provided geolocation. The misclassification is identified and corrected if a layer labelled as cloud in CALIPSO VFM product while most of pixels have the positive MODIS BTDR (12, 11 μm) values. The impact from temporal difference is also discussed. Because the two sensors have a close passing time over the same area, the influence is small enough to be ignored in the approach. The accurate classification is valuable for the further remote sensing of dust storm by providing both the vertical and the horizontal information.

References

- ACKERMAN, S., 1997, Remote sensing aerosols using satellite infrared observation. *Journal of Geophysical Research*, **102**, pp. 17069–17079.
- ACKERMAN, S., STRABALA, K., MENZEL, P., FREY, R., MOELLER, C., GUMLEY, L., BAUM, B., SEEMAN, S.W. and ZHANG, H., 2002, Discriminating clear-sky from cloud with MODIS. In *MODIS Algorithm Theoretical Basis Document (MOD35)*, Version 5.0 (Washington DC: NASA).

- CURREY, J.C., ANSELMO, T., CLIFTON, R., HUNT, W., LEE, K.P., MURRAY, T., POWELL, K., RODIER, S.D., VAUGHAN, M., CHOMETTE, O., VIOLIER, M., HAGOLLE, O., LIFERMANN, A., GARNIER, A., PELON, J., PITTS, M. and WINKER, D., 2007, Cloud-aerosol LIDAR infrared pathfinder satellite observations-data management system and data products catalog. *CALIPSO Algorithm Theoretical Basis Document*, Document No. PC-SCI-503.
- INOUE, T., 1987, A cloud type classification with NOAA 7 split window measurements. *Journal of Geophysical Research*, **92**, pp. 3991–4000.
- LIU, Z., VAUGHAN, M., WINKER, D., KITAKA, C., GETZEWICH, B., KUEHN, R., OMAR, A., POWELL, K., TREPTE, C. and HOSTETLER, C., 2009, The CALIPSO lidar cloud and aerosol discrimination: version 2 algorithm and initial assessment of performance. *Journal of Atmospheric and Oceanic Technology*, **26**, pp. 1198–1213.
- OMAR, A.H., WINKER, D. and WON, J., 2003, Aerosol models for the CALIPSO lidar inversion algorithms. *Proceedings of SPIE, Laser Radar Technology for Remote Sensing*, **5240**, pp. 153–164.
- SAUNDERS, R.W. and KRIEBEL, K.T., 1988, An improved method for detecting clear sky and cloudy radiances from AVHRR data. *International Journal of Remote Sensing*, **9**, pp. 123–150.
- VAUGHAN, M., YOUNG, S., WINKER, D.M., POWELL, K., OMAR, A., LIU, Z., HU, Y. and HOSTETLER, C., 2004, Fully automated analysis of space-based lidar data: an overview of the CALIPSO retrieval algorithms and data products. *Proceedings of SPIE, Laser Radar Techniques for Atmospheric Sensing*, **5575**, pp. 16–30.
- WINKER, D.M., PELON, J. and McCORMICK, M.P., 2003, The CALIPSO mission: spaceborne lidar for observation of aerosols and clouds. *Proceedings of SPIE*, **4893**, pp. 1–11.
- XIE, Y., 2009, Detection of smoke and dust aerosols using multi-sensor satellite remote sensing measurements. PhD thesis, George Mason University, USA. Available online at: <http://hdl.handle.net/1920/4595> (accessed 25 July 2009).