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Cross-comparison of MODIS and MISR cloud top height retrieval over the Caribbean

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Abstract: - The Moderate Resolution Imaging Spectroradiometer (MODIS) and the Multi-angle Imaging Spectroradiometer (MISR) are two of the instruments onboard the NASA-TERRA platform. The objective of this research is to compare MODIS cloud top pressures and MISR cloud top heights over the Caribbean region to evaluate the retrieval accuracy of both instruments. Variations in cloud top measurements show the ability of MISR to acquire cloud top information at high levels of the atmosphere. MISR cloud top heights can be approximately 2 to 4 kilometers higher than MODIS cloud top heights in most of the situations when MISR cloud top heights are higher. Other variations between MODIS and MISR cloud top heights may indicate the retrieval of two different cloud heights over the same area when highest error between MISR and MODIS high clouds vary between 15 and 19 kilometers. This observation may indicate that one of the instruments was detecting a low cloud. Over 9000 meters, MODIS detects higher cloud tops than MISR in 13.98% of the total observed area. But MISR detects higher cloud tops than MODIS in 26.89% of the total observed area. MISR retrieval performance for high clouds is twice the MODIS retrieval performance. MISR and MODIS cloud values coincide in less than 1% of the total observed area and the cloud height value is 14km. Overall results about the observations between MODIS and MISR show that MISR is a better instrument to measure high clouds including optically thin clouds. Future work will incorporate the use of ICESat multi-cloud layer data to validate MISR and MODIS cloud top heights.

Key-Words: - cloud, top, pressure, height, MODIS, MISR, signal processing.

1 Introduction

In order to monitor cloud development and motion, different instruments have been used such as weather radars, satellite sensors and ground instruments. Satellite-based spectrometers and radiometers data can be used to retrieve cloud top properties such as optical thickness, temperature, pressure and height. Algorithms for the retrieval of cloud-top heights have been implemented in order to get a product that can be applied in climate change studies, climate modeling and atmospheric research.

Cloud top height retrieval techniques can differ in their theoretical basis and accuracy depending on the instrument. Active measurements are provided by lidars and radars onboard satellite platforms. Passive techniques can be based on the information contained in the thermal infrared radiances [Menzel, 2002], the reflected light polarization [Vanbauce, 2003] or the stereophotogrammetric method [Muller, 2002]. Other popular techniques are based on the Semi-Analytical Cloud Retrieval Algorithm (SACURA) applied to the oxygen A-band [Rozanov, 2004].

In this paper the validation process is presented to compare the accuracy of two different satellite-based spectrometers, the Moderate Resolution Imaging Spectroradiometer (MODIS) and the Multi-angle Imaging Spectroradiometer (MISR), over the Caribbean. Instrument validation can assure the quality of available operational cloud products that are used for different applications such as climatic changes over tropical montane cloud forests [Lawton, 2001]. For example, the overestimation or subestimation of a specific type of cloud such as a low or a high cloud may result in a wrong answer to a question concerning tropical lowland deforestation impact over cloud forest.

The NASA EOS TERRA satellite was launched during December 1999. Two of the instruments onboard are MODIS and MISR. MODIS is an imager with 36 channels from the visible to the CO_2 absorption band at 15µm. Two channels are imaged at a nominal resolution of 250 m at nadir, with five channels at 500 m, and the remaining 29 channels at 1 km. MISR has nine pushbroom cameras Df, Cf, Bf, Af, An, Aa, Ba, Ca and Da (from the most forward to the most aftward looking). Each camera is positioned to a different angle (0°, ±26.1°, ±45.6°, ±60°, ±70.5°). A combination of nine cameras and 4 spectral bands (3 visible and one in the near infrared) result in 36 different channels.

MODIS and MISR are used to retrieve cloud properties such as cloud optical depth and cloud top height among others. MODIS cloud top pressures are derived using the CO_2 absorption band, 15µm, by the CO_2 slicing method that is described in [Menzel, 2002]. MISR cloud top heights are derived from the combined 9 cameras-red channel radiances using a stereophotogrammetric technique that is described in [Moroney, 2002], [Muller, 2002] and [Zong,2002].

In related works, inter-comparisons have been made between MISR, MODIS and MERIS [Naud, 2002] and [Naud, 2004]. In this study, assessment was realized over the Atmospheric Radiation Measurement (ARM) program Southern Great Plain (SGP) site near Lamont, OK and the British Isles. MERIS and MISR showed excellent agreement when single opaque clouds were present. In multiple layers conditions, MISR cloud top heights indicate the presence of low clouds and MODIS cloud top heights were too low for low clouds, slightly too high for mid-level clouds and near the top of high clouds. MISR detected higher cloud top height values than MODIS for high clouds. In [Horváth, 2001] retrieved wind was compared with GOES and MISR. Comparisons show good agreement in terms of wind speed, wind direction and pressure height. The comparisons indicate a one-to-one relationship.

In this research, the location to cross-compare both instruments is the Caribbean. The motivation to use cloud top height information over the Caribbean is to analyze the climate, to understand the water cycle on rain forests and urban areas and use input information to predict the climate. Also related work will provide feedback to verify the results.

2 Cross-comparison process

Cloud operational products from MISR and MODIS were obtained from the EOS Data Gateway. Because MODIS operational product MOD06_L2 includes cloud top pressures, these may be transformed to cloud top heights to be compared with stereo MISR cloud top heights from the operational product MISR_AM1_TC_STEREO.

MISR sensor is looking at the same location on Earth every 16 days; it will be looking at the Caribbean at different paths. Because MISR and MODIS sensors are onboard the EOS Terra, MODIS cloud data can be selected at the same dates and similar hours that matched MISR cloud data.

MISR cloud data file contain 144 blocks that covered high and low latitudes. Because the observed region is the Caribbean, MISR_VIEW was used to extract tropical MISR blocks that will be correlated with MODIS cloud data. MISR_VIEW is a module that can be run on the IDL software environment. The module can be ordered through the Open Channel Foundation web site.

Taking selected blocks from MISR data will simplify the data dimensionality. To project MODIS cloud top pressures into a MISR path size, ENVI software can be used to create a new image. Upper left and lower right geographic coordinates from the MISR path must be known to define the new boundaries of MODIS cloud top pressure image. This process will reduce the MODIS data size.

To convert MODIS cloud top pressures into cloud heights, a calculation was performed. The calculation consists of the derivation of the hydrostatic balance equation which is defined as

$\frac{\partial p}{\partial z} = -\frac{\rho}{R'T} g$ (1) where $T=T_{a,s}-\Gamma_s z$ (2) and Γ_s is the tropospheric lapse rate(6.5K km^{-1}). By taking the natural logarithm, the equation can be expressed as $In\left(\frac{p_d}{p_{d,s}}\right) = \frac{g}{\Gamma_s R'} In\left(\frac{T_{a,s}-\Gamma_s z}{T_{a,s}}\right)$ (3).

By solving z, the height can be expressed as follows

$z = \frac{T_{a,s}}{\Gamma_s}\left[1-\left(\frac{p_d}{p_{d,s}}\right)^a\right]$ (4) where $a = \frac{\Gamma_s R'}{g}$ (5).

The height that is derived from the equation is the cloud top height. The cloud top pressure from MODIS will be p_d and the pressure at the surface will be $p_{d,s}$ (1013.25hPa). The surface temperature is $T_{a,s}$, g is the gravitational acceleration and R' is the air constant.

After the conversion of MODIS cloud top pressures into cloud top heights, a pixel difference is made between MODIS cloud top heights and MISR stereo heights. After having errors between both sensors, an analysis about those errors is realized (see Fig.1 showing the logistics of the cross-comparison process). The frequency of MISR and MODIS cloud top differences is also calculated. Cloud top levels are evaluated as follows: low level clouds, for clouds less than 2 km; mid level clouds, for clouds higher than 2 km and lower than 6 km; and high clouds, for clouds higher than 6 km.

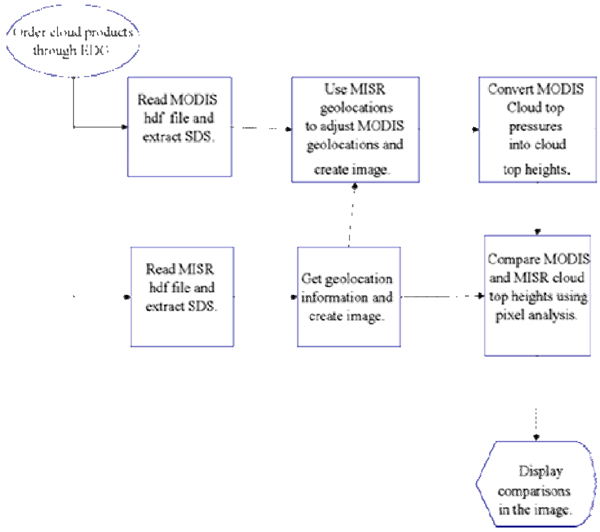

Figure 1 Schematics of cross-comparison process between MODIS and MISR.

3 Results

MODIS cloud top pressures were first subsetted before the transformation of cloud top pressures into cloud top heights (see Fig. 2 left image). The sample images presented in Figure 2 correspond to December 24, 2000: calculated cloud top heights at time: 15:10 – 15:15 UTC from MODIS and MaxStereoHt_WithoutWinds SDS (Blocks 62-80) at time: 14:31:46 GMT, latitude 13.1 N , 35.6 S, longitude -66.2 W, -60.6 E from MISR.

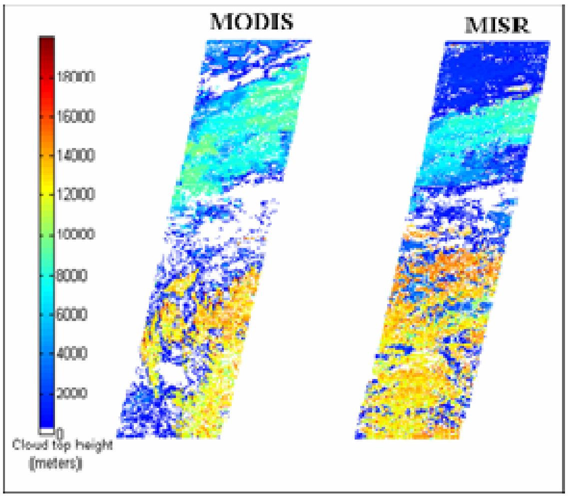

Figure 2 MODIS cloud top heights (left image) and stereo MISR cloud heights (right image).

In Figure 3, the pixel by pixel comparison from the MODIS and MISR sample images is presented. Red and yellow pixels represent higher cloud values for MISR, and blue and cyan pixels represent higher cloud values for MODIS.

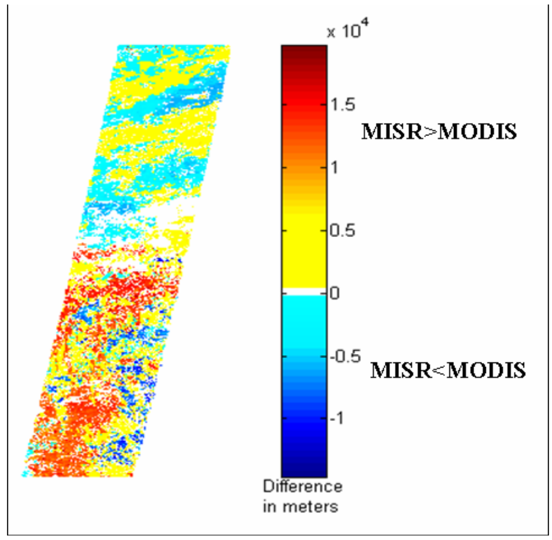

Figure 3 Cloud top height difference. Pixel by pixel comparison between MODIS cloud top heights and stereo MISR cloud top heights.

Higher cloud tops measurements by MISR was 65.3% higher than by MODIS over the same area (see Fig. 4 where height difference is positive). However, MODIS and MISR retrieved the same cloud top heights about 10.32% of the area, over the same location. In 24.4% of the area, MODIS measured higher values than MODIS. MISR show higher percentage retrieval rate for high cloud values (see Table 1). MODIS show higher percentage rate for mid and low cloud values (see Table 1).

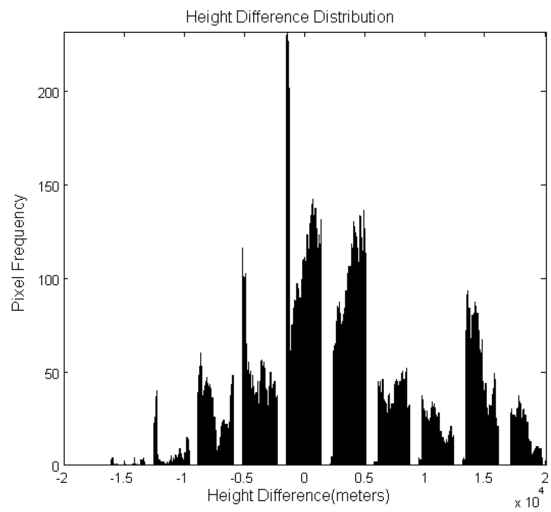

Figure 4 Height difference distribution between MODIS and MISR.

MISR cloud top heights can be approximately 2 to 4 kilometers higher than MODIS cloud top heights. Other variations between MODIS and MISR cloud top heights may indicate the retrieval of two different cloud heights over the same area. Highest errors between MISR and MODIS high clouds is in the region from 15 to 19 kilometers. This observation may indicate that one of the instruments was detecting a low cloud.

Table 1 Percentage rate for MODIS and MISR cloud height retrieval.

Sensor	Retrieval Percentage Rate (%)		
	High clouds	Mid clouds	Low clouds
MODIS	13.98	16.81	12.25
MISR	26.89	8.94	9.05

4 Conclusion

The difference between MODIS and MISR cloud top heights can be as high as 2 to 4 kilometers. Because MODIS CO_2 slicing algorithm is applied to clouds at pressures lower than 700 hPa, low-level cloud heights are based under the assumption that the cloud is optically thick. Multi-layered clouds can't be detected in MODIS because the algorithm also assumes a single cloud layer in the field of view. In consequence, thin cirrus clouds will not be identified due to their lower water content.

MISR stereo height algorithm detects high clouds better. The ability to view at different angles enables the MISR sensor to detect high thin cirrus clouds. MISR will have a better retrieval performance because it will be able to detect thin clouds when multilayer clouds appear and it will detect higher clouds than MODIS.

Results from MISR coincide with related works [3] and [4]. Naud also found that optically thin clouds were found to be accurately characterized by the MISR cloud top height product.

Future work will be directed to the use of lidar instrumentation to validate MODIS cloud top heights. It should be expected to validate MODIS mid and low cloud top heights over a geographic location in Puerto Rico by using available lidar observations from the same time constraints the MODIS instrument overpasses Puerto Rico. Also cross-comparisons with MODIS, MISR and ICESat (Ice, Cloud and Land elevation Satellite) will be done. ICESat data provide cloud altitude and cloud thickness. In the near future, comparisons will be made with preliminary results of the mission CALIPSO (Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observation).

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