A Study on Cloud-Top Height Retrieval by Using MISR and MODIS Data

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***Abstract*- Information about cloud heights can be retrieved by satellite images. Cloud heights can affect total liquid and water content. Cloud heights are needed to determine the reflecting layer reference altitude (RLRA). Multiangle Imaging Spectroradiometer (MISR) and Moderate Resolution Imaging Spectroradiometer (MODIS) can retrieve information about clouds. MISR determines cloud-top height geometrically by a stereophotogrammetric technique. MODIS estimates cloud top pressure by a CO_2 slicing method. To ensure the retrieval of cloud heights, it is important to look for good algorithms that process this kind of information. But the way the instruments process cloud information is different. The objective of this research is to study, analyze and implement the existing algorithms used for the retrieval of cloud-top heights, from both MODIS and MISR instruments. In this paper, the algorithms to retrieve cloud-top heights will be presented. An analysis on cloud information from both techniques will lead to a better understanding of the earth's climate system.**

I. INTRODUCTION

MISR retrieval methods are based on stereo matching algorithms described in [3]. MODIS estimates cloud top pressure by a CO_2 slicing method. There are other methods such as retrieval of cirrus clouds reflectance from aircraft and satellite data described in [2] and measurements of cloud heights by a laser pulse described in [6]. In the first method, they use an algorithm for visible channels and 1.38μm bands. The visible channels are available in AVIRIS (0.66μm) and MODIS has a channel near 1.38μm for remote sensing of high clouds from space (cirrus clouds). With the retrieval of cirrus reflectance, they can remove the scattering cirrus effects in satellite images. In the second method, cloud heights are measured by GLAS. Geoscience Laser Altimeter System (GLAS) is a spaceborne laser that measures vertical distributions of clouds and aerosols and the altitude between the instrument and the Earth's surface by laser pulses. Their objective is to obtain information about changes in the polar ice-sheet topography that contributes to the sea level. Caribbean data will be used to analyze the climate phenomena. To validate the implemented algorithms, processed data will be used to compare the tested ones. To present the methodology of both algorithms, the following sections are organized as follows: in Section 2, MISR stereophotogrammetric technique is described, in Section 3, MODIS cloud-top pressure estimation is described, and finally, in Section 4, future work and the discussion is concluded.

II. MISR STEREOPHOTOGRAMMETRIC TECHNIQUE

MISR has nine 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. A combination of nine cameras and 4 spectral bands will result in 36 different channels. Cloud information can be retrieve from the 0.67μm spectral band. The conceptual methodology of the cloud-top height retrieval using MISR data is described in [3]. In [3] is mentioned that the image data is broken into 144 blocks of equal area. Each block is 140.8 km long and 563.2 km wide and covers the same geographical location for all the nine cameras. It is also mentioned the each block will be subdivided into 16 mesoscale domains (70.4 km on a side) and wind vectors will be retrieved in an independent form for every domain.

After determining the cloud advection field, a stereo-matching algorithm is used in Bf-Df and Bf-An camera pairs. Matched points will be used to solve cloud-motion and cloud-top height. The camera pairs Af-An and Aa-An are used independently in the stereo matcher. The height field will be retrieved for each fourth pixel. Fig. 1 shows the implementation of the MISR cloud-top height retrieval algorithm. The mathematical formulations for this methodology is described in [8].

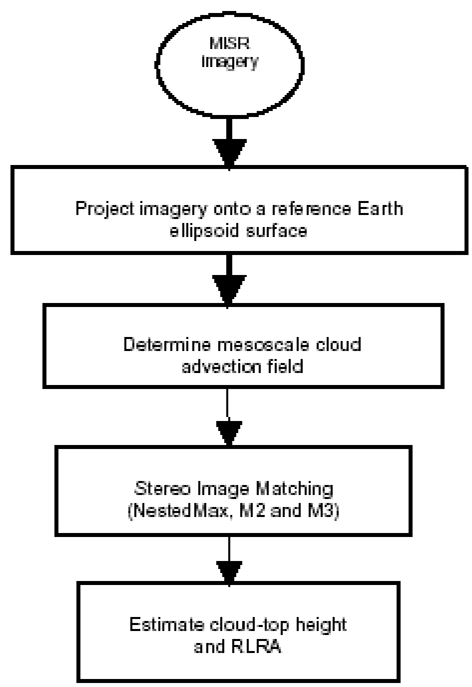

Figure 1. Schematics of MISR cloud-top height retrieval algorithm.

One of the stereo algorithms is NestedMax. It is a feature-matcher used to retrieve wind vectors. The area matchers are M2 and M3. They are used to retrieve cloud height. The metrics for M2 and M3 are computed for each pair, and then the one with the lowest metric value is chosen as the best match. Metric values of 0.75 and 1.0 are used for M2 and M3. The M2 and M3 metrics are defined in [4] as follows:

$$S_{M2} = \frac{\sum_{i,j} \left\| \left[\frac{R(x_i, y_i) - \langle R \rangle}{R_{max} - R_{min}} \right] - \left[\frac{C(x_i, y_i) - \langle C \rangle}{C_{max} - C_{min}} \right] \right\|}{\sigma_{M2}} \quad (1)$$

where $\sigma_{M2} = \sum_{i,j} \left\| \left[\frac{R(x_i, y_i) - \langle R \rangle}{R_{max} - R_{min}} \right] \right\|$

$$S_{M3} = \frac{median_{ij} \left\{ \left| \frac{R(x_i, y_i)}{median\ (R)} - \frac{C(x_i, y_i)}{median\ (C)} \right| \right\}}{\sigma_{M3}} \quad (2)$$

where $\sigma_{M3} = median_{ij} \left\{ \left| \frac{R(x_i, y_i)}{median\ (R)} - 1 \right| \right\}$

The final step will be to compute the RLRA and the cloud-top location.

III. MODIS CLOUD-TOP PRESSURE ESTIMATION

Cloud heights can be derived by using bands located at 15μm CO_2 band. To determine cloud heights, cloud pressures have to be determined numerically. Cloud pressures are calculated by the radiance ratio method. The detailed mathematical formulation is discussed in [9]. Radiative transfer in an atmosphere with a single cloud layer is defined in [9] as radiance observed, R(υ):

$$R(\upsilon) = (1 - NE) R_{cir}(\upsilon) + NE * R_{bcd}(\upsilon, P_c) \quad (3)$$

where υ is an spectral band, Rcir(υ) is the clear sky radiance, Rbcd(υ,Pc) is the radiance if the field of view was covered by a black cloud at a pressure level Pc, N is the fraction of the field of view covered by a cloud and E is the cloud emissivity. The opaque cloud radiance is defined in [9] as follows:

$$R_{bcd}(\upsilon, P_c) = R_{cir}(\upsilon) - \int_{P_c}^{P_s} \tau(\upsilon, p) \frac{dB[\upsilon, T(p)]}{dp} dp \quad (4)$$

where Ps is the surface pressure, t(υ,p) is the fractional transmittance of radiation of frequency υ emitted from the atmospheric pressure level (p) and B[υ,T(p)] is the Planck radiance of frequency υ for temperature T(p). The ratio of the deviations in observed radiances Rmax(υ) and Rmin(υ) and the clear sky radiances, Rcir(υ), for two spectral channels of frequency υ1 and υ2 viewing the same FOV is defined as follows:

$$\frac{R(\upsilon_1) - R_{cir}(\upsilon_1)}{R(\upsilon_2) - R_{cir}(\upsilon_2)} = \frac{NE_1 \int_{P_s}^{P_c} \tau(\upsilon_1, p) \frac{dB[\upsilon_1, T(p)]}{dp} dp}{NE_2 \int_{P_s}^{P_c} \tau(\upsilon_2, p) \frac{dB[\upsilon_2, T(p)]}{dp} dp} \quad (5)$$

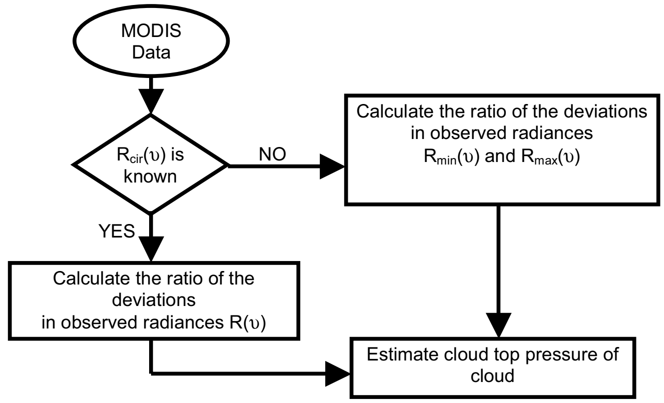

Figure 2. Schematics of MODIS cloud-top pressure retrieval algorithm.

where $NE = \frac{R(w) - R_{cir}(w)}{B[w, T(P_c)] - R_{cir}(w)}$.

N is the fractional cloud cover within the FOV, w is the window channel frequency, $B[w,T(P_c)]$ is the opaque cloud radiance, NE is less than 1, for observing broken cloud, N<1, E=1; for overcast transmissive cloud, N=1, E<1 and for broken transmissive cloud, N<1, E<1. If the frequencies are close, then $E_1 \approx E_2$, and the pressure of the cloud within the FOV can be specified. The atmospheric temperature and transmittance profiles for the two spectral bands have to be estimated. If clear sky radiances are unknown, then the last equation can be modified by inferring the cloud top pressure from the radiance gradients in two CO_2 slicing spectral bands within the area of interest. In [9] is defined as follows:

$$\frac{R_{min}(\upsilon_1) - R_{max}(\upsilon_1)}{R_{min}(\upsilon_2) - R_{max}(\upsilon_2)} = \frac{(NE_{min} - NE_{max}) \int_{P_s}^{P_c} \tau(\upsilon_1, p) \frac{dB[\upsilon_1, T(p)]}{dp} dp}{(NE_{min} - NE_{max}) \int_{P_s}^{P_c} \tau(\upsilon_2, p) \frac{dB[\upsilon_2, T(p)]}{dp} dp} \quad (5)$$

where $R_{min}(R_{max})$ is the cloudiest pixel and $NE_{min}(NE_{max})$ is the associated effective emissivity. The same assumptions as before are taken. It is mentioned that radiance gradients will depend on changes in cloud top pressure. The method can performed accuracies of about 50 hPa for high, thin cirrus. Cloud height accuracy increases while the observed radiance R(υ) increases. Fig. 2 shows the implementation of the MODIS cloud-top pressure retrieval algorithm.

IV. CONCLUSIONS AND FUTURE WORK

Cloud-top heights can be retrieved by stereo matching algorithms as in MISR and by calculating the radiance observed in a cloud element as in MODIS. A feature analysis can help to estimate cloud heights. By estimating the cloud heights in the Caribbean, we can determine how the changes in heights over the years can tell us about cloud forest climate changes. Future work is expected to consist of implementing the MODIS approach using MATLAB as a first step by using data from MODIS. The next step will be the implementation of the MISR algorithm. MISR data isn't available. To obtain MISR data, a study on the Advanced Satellite Products

Team/Cooperative Institute for Meteorological Satellite Studies (CIMSS) in Madison Wisconsin will be done on Summer 2003.

ACKNOWLEDGMENT

Work can't be done without the collaboration of NOAA CREST(National Oceanic and Atmospheric Administration Cooperative Remote Sensing Science and Technology Center (2001-096)), SIL/UPRM (Space Information Laboratory from the University of Puerto Rico at Mayagüez) and the Advanced Satellite Products Team/Cooperative Institute for Meteorological Satellite Studies (CIMSS). Thanks to the people involve in this research: P. van der Meer, F. Holt and J. Key.

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