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Initial investigation on different types of clouds observed by Mars Color Camera (MCC) from India's first Mars Orbiter Mission (MOM)

Jyotirmoy Kalita*[(1)], and Anirban Guha [(1)]
(1)Department of Physics, Tripura University, Suryamaninagar, Tripura - 799022, India
*Email: jyotirmoy.physics@tripurauniv.in; anirban1001@yahoo.com
Phone: +91-757798089

Abstract

In the present work, we analyzed different types of clouds observed at the limb as well as over the surface of the red planet by MCC and estimated the atmospheric parameter associated with it. Our analysis based on the data collected by Mars Colour Camera (MCC) on board Indian Mars Orbiter Mission during orbit number 44,45,48,49, 50,51,179,187,190,191,466 and 474. Estimated height of the high altitude cloud varies from 40 to 76 km and horizontal spreading of 400 to 1100 km. We used ARC-GIS to detect the area over which the high altitude clouds are observed. These detached layers of clouds are found to be formed of Dust and water-ice particle. MRO-MCS and MARCI confirms few dust events during the appearance of the high altitude cloud. Lee-wave cloud images are captured during the MY33 and MY34. Estimated wavelength of the Lee wave cloud varies from 38 to 44 km while wind speed varies from 54 to 64 m/sec. Aerosol Optical Depth (AOD) as a function of altitude varies from 0.6 to 2.4 for red channel and 0.8 to 1.8 for blue channel for the captured events. We consulted Global Circulation Model (GCM) as well as MOLA-DEM to frame the AOD output. Estimated wind speed profile from MCC and MARCI-MGDM suggested the circulation of strong wind across the globe and delivered input to formation of clouds through different processes related to the atmosphere dynamics viz. Deep Convection, Orographic lift, Thermal updraft, etc. In our present study we tried to estimate the parameter related to these processes and tried to correlate them with the observed events.

1. Introduction

During the mission period, MCC captured number of images, where we may observe distinct high altitude cloud and lee wave cloud. A number of studies have already done on the mentioned topic. We primarily select MCC images, because it is India's first Mars Orbiter Mission and also a comprehensive study is needed to validate its observation. We considered 20 limb viewing images with distinct high altitude clouds and 20 images of lee wave clouds near Martian Volcanoes for the present investigation. In the previous literature height of the high altitude cloud was reported and accordingly estimated the cloud content [2]. Previous studies in Lavega et al. 2018 motivated us to proceed with present investigation [1]. Also the thesis work by Väisälä 2005 motivated us to include the lee wave cloud in our present investigation. Initially we focused on the high altitude cloud and estimated the height, horizontal spreading, and properties of the cloud content. ARC-GIS global projection over the images reveals the area where cloud has been observed and we analyses MRO data base to report the climate condition during the observed period [3]. We reported extinction, CBL height as well as vertical mixing for the high altitude cloud based on MRO-MCS data base [4]. Further we analyze the wavelengths of the ripples in the Lee wave clouds and estimate the wind speed over those regions. Formation of water ice cloud and participation of dust particle causes high haze near the Martian Volcanoes e.g. Ascraeus Mons, Tharsis Tholus, etc. [4]

Further we focused on the giant system of canyons in Mare Acidalium and Lunae Palus quadrangles on Mars, which is centered at 24.6° north latitude and 65.0° west longitude. Length of the Kasei Valles is nearly 1,580 km and it is one of the largest outflow channels on Mars. We consulted MOLA-DEM to estimate the altitude and direction of the surface features of the observed images. We tried estimate the atmospheric parameter for the haze and cloud appeared over Mare Acidalium and Lunae Palus quadrangles in our present work. We may see the three different scenarios we considered for our work in figure 1.

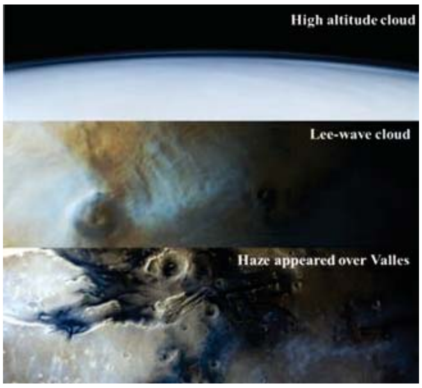

Figure 1. We may see the different types of clouds appear over different are

2. The Mars Color Camera (MCC) and the Archiving of Images:

MCC acquires images in the snap-shot mode with an IGFOV of 20 m at 500 km altitude, with a frame size of around 40 km X 40 km from Periareion and covers the full Martian disc from Apoareion using an area array detector having 2048 X 2048 elements on a pixel pitch of 5.5µm with RGB Bayer pattern. Raw data contains with high-resolution image files in .IMG format, processed low-resolution images in a .jpeg format, and the metadata files corresponding to these images. Raw data files are available in the database and may be downloaded through proper authentication the data in a .zip archived file [3]. (https://mrbrowse.issdc.gov.in/MOMLTA/)

3. Theoretical background and methodology:

3.1 Cloud height of HAC and Wavelength of LWC calculation:

To estimate the height of the cloud, we prepared a luminosity plot against the no of the pixel in the image plane as shown in figure 2. We may see high altitude cloud at the edge of the planet in figure 1. It is not possible to see the end of the Mars surface clearly due to dust storms occurred during the observed period (Ls = 210 to Ls = 260) so we have consider a probable height with least error of ±5 km. We have prepared an algorithm using MATLAB to plot the data, from where we may estimate the cloud height as [1, 3, and 4],

Height of the cloud= (no of pixel contend from surface to the cloud) X (spatial pixel resolution at the center of the image) + scale height factor+ other error

After the angle correction, spatial pixel resolution (m, n) at any given coordinate (i, j) can be expressed as,

(m,n) = (a/2, b/2)*(1/Cos (sat zenith angle at_ (i, j)) (1)

Thus we may correct the error regarding solar zenith angle. Corrected plot is furnished in figure 2.

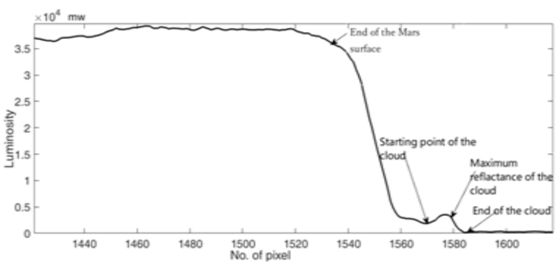

Figure 2. Luminosity plot for the high altitude cloud. The peak shows the maximum reflectance is considered to be the distance of the cloud from the surface of the red planet.

We used the same technique to calculate the wavelength of the lee wave cloud also. We may see the plot for the radiance of lee wave cloud over the surface in figure 3. We may see the peak with maximum radiance value will indicate the consecutive tough to calculate the wavelength.

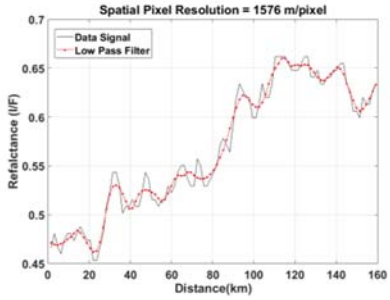

Figure 3. we may see the peak in the plot from which we may easily estimate the value of wavelength of the cloud.

3.2 Calculation for reflectance value on the top of the atmosphere (TOA):

Raw data images are 10-bit images with DN numbers vary from 0 to 1024. DN numbers can be converted in radiance value as,

$$L\lambda = ((L\lambda\ MAX - L\lambda\ MIN)/ (QCALMAX-QCALMIN))^* DN + L\lambda\ MIN \qquad (2)$$

To evaluate reflectance value at the top of the atmosphere (TOA), we converted the visible band's radiance values (Lλ) to the reflectance values (I/Fλ) as,

$$I/F\lambda = \pi^* L\lambda /F(0,\lambda)\cos(i)\cos(\theta^\circ) \qquad (3)$$

Where Lλ, i and θ0 refer to the spectral radiance value, the apparatus incidence angle and the solar zenith angle respectively. Fλ refers to the corrected incoming solar flux per unit of the surface at the top of the atmosphere with respect to Mars-Sun distance 6. The three visible bands of MCC (red, green and blue) are broadband with a spectral width of approximately 0.2 µm. Integrated incoming solar flux F (0, λ) used in equation 3 is computed using the spectral response function for each corresponding band.

3.3 Calculation for Angstrom exponent (α):

Angstrom exponent is a parameter that indicates the mode of the particle. If α is greater than 1, then the effective radius of the particle is less than the respective wavelength (fine mode) whereas if α is less than 1 then the effective radius of the particle is greater than corresponding wavelength value (coarse mode). The relation between the TOA value and α can be expressed as,

$$(\lambda 1 /\lambda 2)^{-\alpha} = (I/F)\,\lambda 1/ (I/F)\,\lambda 2 \qquad (4)$$

Where, λ1 and λ2 are the wavelengths for red and blue color bands [3].

3.4 Wind speed calculation:

The algorithm works based on the gravity wave calculation to estimate the wind speed. After meeting the obstacle, the velocity is perturbed as (ū + u, w). Density and pressure in each point become also perturbed due to air mass movement. We are following the mathematical formulation for the lee-wave cloud developed by Ganna Valeriyivna Portyankina. According to the literature calculated wavelength of the lee-wave cloud is given by

$$G(\lambda) = 2\pi u c_s / g\sqrt{\gamma - 1 - \gamma^2 * u^2 / 4c^2} \quad (5)$$

Where u = wind speed, g= acceleration due to gravity on Mars (3.69 m/s2), G(λ)= wavelength, =Cp/Cv (1.3055), and cs=sound speed for mars~ (226 m/s). Utilizing equation 4, we may evaluate the horizontal wind speeds over Ascraeus Mon. If we consider low wind speed compared to the speed of light (such that $u^2/c^2 \approx 10^{-3}$), then the third term inside the square root will vanish. We have rearranged the equation for the wind speed as,

$$u = gG(\lambda)\sqrt{(\gamma - 1)} / 2\pi c_s \quad (6)$$

3.5 Cloud height calculation for lee wave cloud:

With the wind speed value, we may estimate the approximate height of the cloud. For that, we run the General Circulation Model (GCM). We may collect the required information from the Mars Climate Database link (http://wwwmars.lmd.jussieu.fr/mcd_python/).To estimate the height of the cloud, we have calculated the Scorer parameter. The Scorer parameter [m^{-1}] is used to describe whether gravity waves will develop or not. It combines the Brunt-Väisälä frequency with characteristics of the vertical wind profile and is given by the following equation [4]:

$$l^2(z) = \frac{N^2(z)}{U^2(z)}$$

Where N = N (z) is the Brunt-Väisälä frequency, and U = U (z) is the horizontal wind's vertical profile. Both the quantities are determined using GCM. When l^2 (z) decreases sharply with height, conditions are favorable for trapped lee-waves. At higher levels, the Scorer parameter often shows values of about 0.5/km, rarely exceeding 1/km. In figure 3, we may see a decrement between 25 to 30 km, which supports the required Scorer parameter value and the favorable condition for the formation of lee-waves [4].

However, when l^2 (z) is nearly constant with height, conditions are favorable for vertically propagating mountain waves. We used the GCM model to estimate the scorer parameter and compare it with our estimated wind speed to see the more accurate height of the lee-wave cloud. In figure 4, we presented the wind profile and scorer parameter profile for a particular time as a function of height. Thus, with the model-based scorer parameter calculations, we may evaluate the tentative height of the Lee -wave clouds. S R Lewis et al. (1999) shows an error bar of ±5% in temperature, pressure, and other atmospheric parameters in MCD. If we consider that error, the height of the lee-wave cloud will vary from 27±2 km to 30± 4.2 km. Our estimated wind speed also satisfies that particular height with a low margin of error. Mass movement density and pressure in each point become also perturbed.

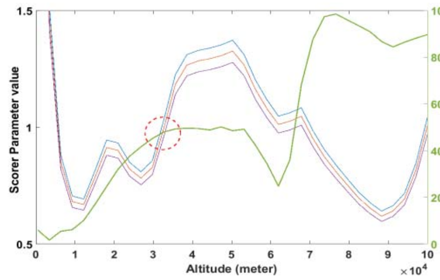

Figure 4. Comparison between scorer parameter and horizontal wind speed as the function of altitude. We may see three different plots of the Scorer parameter with different temperature gradient for three transact of the whole lee-wave cloud. We may also see the red circle indicates an intersection point of scorer parameter 0.965/km, horizontal wind speed 50 m/s, and an altitude of 35 km. Hence, it gives us an idea of forming a lee-wave cloud at an altitude of 35 km, supporting all of our calculated results on different time of the years.

3.6. Calculation for AOD, Albedo, and Temperature: Stereo Method:

Let us assume that μ1 and μ2 be the cosine of emission angles with nadir with different inclined views for the same region on the surface such that μ1 < μ2. This means the view with emission angle μ1 is more inclined than the view with emission angle μ2. Therefore the view with emission angle μ1 has a longer path length through the atmosphere and will thus show a strong atmospheric contribution leading to a decreased contrast as compared to view with emission angle μ2. This difference in contrast can be used to estimate atmospheric optical depth as follows [3],

AOD= [μ1*μ2/ (μ1-μ2)][(contrast I1/I1)/(contrast I2/I2)] here, I stand for contrast of the particular channel of the pixel at different emission angle [4].

3.7. Calculation of scale height:

We have fitted the AOD values as the function of altitude exponentially in Matlab and we find the correlation as AOD=1.08exp (0.0452*Z) for Ascraeus Mon and AOD=1.21exp (-0.0852*Z) for Kasei Valles. After getting the values of AOD we may calculate the scale height. we may see the curve fitting for both Ascraeus Mon and Kasei Valles [3].

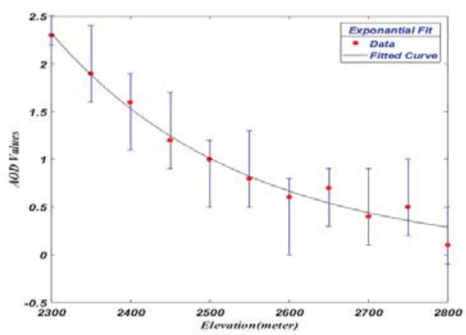

Figure 5: We may see how AOD values are changing with altitude and we may accordingly calculate the scale height.

3.8 Calculation of the temperature (K):

The Stefan–Boltzmann law describes the power radiated from a black body in terms of its temperature. Stefan–Boltzmann law states that the total energy radiated per unit surface area of a black body across all wavelengths per unit time (also known as the black-body radiant remittance) is directly proportional to the fourth power of the black body's thermodynamic temperature T. The radiance value (watts per square meter per steradian) for a black body is given by [4],

$$L = (\sigma / \pi) * T^4$$

$$=> P = \sigma A T^4 \quad (16)$$

Depending on the albedo value we can modify the above equation as follows,

$$=> T = (1-a)^{1/4} \frac{279}{r^{1/2}} K \quad (17)$$

Where L is the radiance value, σ is the Stephen's constant = 5.670367(13) ×10−8 W·m−2·K−4, Where 'T' is the temperature, 'a' denotes albedo value, r is the distance between mars and sun in the atmospheric unit. We took an approach to calculate the temperature using the TOA value evaluated from the radiance value. We have verified our map result with Mars SWIR Albedo map prepared in Ramdayal Singh et al. with an error bar of ±.05. Estimated temperature varies from 160±3 K to 180±4 K. We may see the temperature colour map in figure 6.

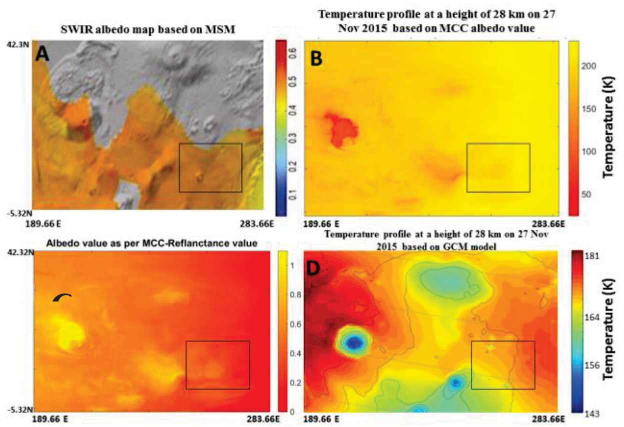

Figure 6. We may see the temperature colour map and Albedo map. We compared our results with the SWIR albedo map.

4. Results and discussion:

In our present analysis we estimated the height of the high altitude cloud varies from 60 to 90 km from the surface of the red planet with a horizontal spreading of 400 to 1100 km. All the events observed during the solar longitude of Ls= 180 to 280, which indicate a dust storm seasons [2]. During the dust storm season due to deep convection process dust has been lifted to a height, hence we may see a detach layer of cloud. All the clouds contain both fine modes as well as fine mode particles and effective radius is found and verified to be 400nm to 3000nm [1]. To estimate the effective radius we used MRO-MCS data. In case of lee wave cloud wind speed varies from 20m/s to 60m/s and height is computed to be 30 to 50 km. Due to updraft of westerly wind water ice cloud and dust has been lifted and interaction with an obstacle of mountain range lee wave cloud has been formed. Formation temperature is calculated and verified (GCM) to be 220K. AOD values vary from 1.2 to 2.4 during the events and albedo is estimated to be 0.9, indicates the reflection of most of the radiation to the space.

Appearance of haze and dust over Valles indicate the occurrence of a local dust storm or a regional dust storm. We estimated a high albedo and ADO values during the period of appearance of haze and Cloud. We confirm our findings with the help of MARCI-MGDM for the local and global dust storm. So further we may focus on the core reason behind the events and the physical process that enhance the event to happen frequently in the red planet.

5. Acknowledgments:

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