STUDY OF CLOUD MICROPHYSICAL PARAMETERS FOR TROPICAL CYCLONE VARDAH USING INSAT-3D DATA

Jinya John and Bipasha Paul Shukla
Atmospheric Sciences Division
Atmospheric and Oceanic Sciences Group,
Earth, Ocean, Atmosphere, Planetary Sciences and Applications Area,
Space Applications Centre (ISRO)
Jodhpur Tekra, Ahmedabad – 380015
Email: jinyajohn@yahoo.in, bipasha@sac.isro.gov.in

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ABSTRACT: The formation and growth of clouds is controlled by several processes occurring at the micro scale which define the cloud microphysical properties (CMP) such as cloud optical thickness (COT) and cloud effective radius (CER). There are several studies showing the effect of CMPs on climate change but there are only very few which show their impact on extreme weather events such as tropical cyclones. Moreover, studies which have been carried out for extreme weather events are limited to oceans in the mid-latitude regions but there are none reporting over the Indian Ocean. Keeping this in mind, we aim to analyze the cloud microphysical properties and investigate its effect over cyclone Vardah. In order to carry out this study, we have used geostationary satellite INSAT-3D retrieved COT and CER data. These parameters are derived every half hourly, using INSAT-3D visible and shortwave infrared (SWIR) radiances. Using this data, we have traced the COT and CER for each stages of cyclone Vardah. It was found that the range of COT varies from 18-75 and the range of CER varies from 15-50 microns. It can also be seen that during the initial stages, cloud droplets are distributed randomly throughout the area covered by the cyclone. But as it reaches its mature stage, due to system organization, droplets of larger sizes are found mainly over the rain bands. The micro-scale characterization of a tropical cyclone helps in identifying potential areas of heavy precipitation.

1. INTRODUCTION

Tropical cyclones are rotating storms that form over the tropical oceans and are associated with strong near surface winds (wind speed > 33 m s^{-1}) and torrential rains (Glossary of Meteorology). The structure and patterns of clouds vary from cyclone to cyclone. In general, cyclones are developed from mesoscale convective systems (MCS) which are cumulonimbus cloud system which produces continuous precipitation over an area of almost 100 km [1]. Since very long, visualization of cloud features in satellite imagery are used to predict the intensity of cyclones [2]. These cloud features mainly correspond to their macrophysical properties. There are also studies which show that tropical cyclones are sensitive to cloud microphysics in addition to cloud dynamics. The microscale structure of clouds is defined by properties such as cloud effective radius (CER), cloud optical thickness (COT), liquid water content, thermodynamic phase, cloud droplet size distribution etc. Cloud optical thickness defines the opacity of clouds and cloud effective radius defines the distribution of cloud droplets within the clouds. Several investigations on the distribution of cloud droplets at different levels for precipitating and non-precipitating clouds have been carried out. But, there are very few studies which demonstrate the nature of cloud microphysical parameters during extreme weather events such as tropical cyclones.

There are evidences which show the influence of average particle fall speed on wind speeds at outer rings of the cyclone as well as on their tracks. The average particle fall speeds are involved in cloud microphysical assumptions for making sensitivity tests [3]. Moreover, simulations carried out for the case of a hurricane Rita show sensitivity of cyclone track to cloud microphysical details which is revealed in the model forecast [4]. There is also a study which reveals the effects of cloud microphysical processes on the hurricane intensity, precipitation, and inner-core structures for a series of 5-day explicit simulations of Hurricane Bonnie. Through this study, it was observed that microphysical processes produced little sensitivity on track but pronounced sensitivity on hurricane intensity and inner-core structures [5]. Also, Black and Hallet studied the distribution of cloud particles during three Atlantic hurricanes and observed that they consist mostly of ice crystals [6]. Moreover, these particles are distributed in the mid and upper level of the troposphere.

All the studies mentioned above shows that characteristics of severe weather cloud systems are highly sensitive to cloud microphysical processes. Hence, it is essential to understand the microscale structure and processes during such events. In view of this, a case of a particular cyclone has been taken for analyzing the nature and variability of cloud microphysical parameters during its course. For this purpose, we have considered cyclone Vardah which hit the Southern India during 2016. Cyclone Vardah was a very severe cyclonic storm that was formed in the Bay of Bengal during December 6, 2016 to December 12, 2016. It developed into a cyclonic storm on December 8 and attained its mature stage (severe cyclonic storm) on December 9. Later on, it weakened and dissipated on December 13 making landfall close to Chennai. In the following sections, this paper describes the data and methodology for carrying out the study. The results are then discussed in the subsequent sections.

2. DATA USED

INSAT-3D imager data have been used to carry out this study. INSAT-3D is a meteorological satellite of India launched on 26 July, 2013. It carries a six channel multi-spectral imager and a 19 channel atmospheric sounder. It images the Earth in six spectral channels from visible to thermal infrared. The six channels include visible, shortwave infrared (SWIR), middle infrared (MIR), water vapor (WV), thermal infrared-1 (TIR-1) and thermal infrared-2 (TIR-2). It offers a higher spatial resolution of 1 km in visible and SWIR bands. It has the advantage of having a higher temporal resolution of 26 minutes providing continuous information of Earth and its atmosphere. In the present work, L2C_CMP products have been used which provides data on a per pixel basis. L2C_CMP consists of Cloud Optical Thickness (COT) and Cloud Effective Radius (CER). These parameters have been derived from L1C_SGP (Standard Sector Product) visible and SWIR radiances at a spatial resolution of 4 km using a look-up-table (LUT) approach [7].

3. METHODOLOGY

As mentioned in the previous section, cloud microphysical properties such as COT and CER have been derived from INSAT-3D visible and SWIR radiances at a spatial resolution of 4 km using a look-up-table (LUT) approach [7]. In this approach, the forward radiative transfer (RT) problem is solved until the solution matches the measured output. The lookup table approach is a computationally efficient technique and can be applied on a per pixel basis of satellite images. The determination of cloud optical thickness and cloud effective radius from spectral reflectance measurements constitutes the inverse problem and is typically solved by comparing the measured reflectances with entries in a lookup table and searching for the combination of τ_c and re that gives the best fit. Using a large set of randomly generated input variables (5000 vectors), a LUT was computed for different bins of satellite geometry. The radiance was convolved with filter functions of INSAT-3D channels. The simulated and observed radiances from satellite were matched to arrive at the best combination of COT and CER. These parameters have been investigated during different stages of the cyclone. For this, CMP data have been extracted for the region covering the cyclone right from its early development to dissipation stage. The extent of the cyclone for the entire duration was from 5^0 N to 20^0 N and 80^0 E to 100^0 E. The extracted parameters have then been used to examine the structure of the cloud systems at successive phases as well as the distribution of the cloud droplets/particles throughout the area covered by the cyclone. In order to analyze the changes in cloud microphysical structure as it progresses, three dimensional plots of COT and CER have been generated for different days of the cyclone. Further, transects along different directions having the maximum coverage of the cyclone have been taken to investigate the variations of the parameters under study.

4. RESULTS AND DISCUSSIONS

Figures 1 and 2 [(a) to (c)] illustrates the 3D plot of cloud optical thickness and cloud effective radius as the cyclone progresses from its initial to mature stage. Figures (1 and 2) [(a)] represents the cloud microphysical parameters (CER and COT) during the time when the system developed into a depression. This is the early development stage of the cyclone where the cloud droplets of all sizes are uniformly distributed throughout the system. The spatial distribution is uniform and no specific structure is observed. Further, as the system becomes more organized, a spiral pattern begins to develop and begins to mature. From figures (1 and 2) [(b)], one can infer that the cyclone is at its fully developed mature stage where the larger droplets/particles have accumulated together towards the centre due to higher wind speed. Also, there are stronger updrafts during this stage which facilitates the formation of larger droplets/particles. The clouds are optically very thick in this region. Later, when the downdrafts dominate the updrafts, the cyclone begins to weaken and becomes disorganized. The cloud droplets are scattered and is no more concentrated at a particular region. This can be observed from the figure (1 & 2) [(c)] where the system weakens. Moreover, the cloud optical thickness ranges from 18-75 and cloud effective radius ranges from 15-50 microns.

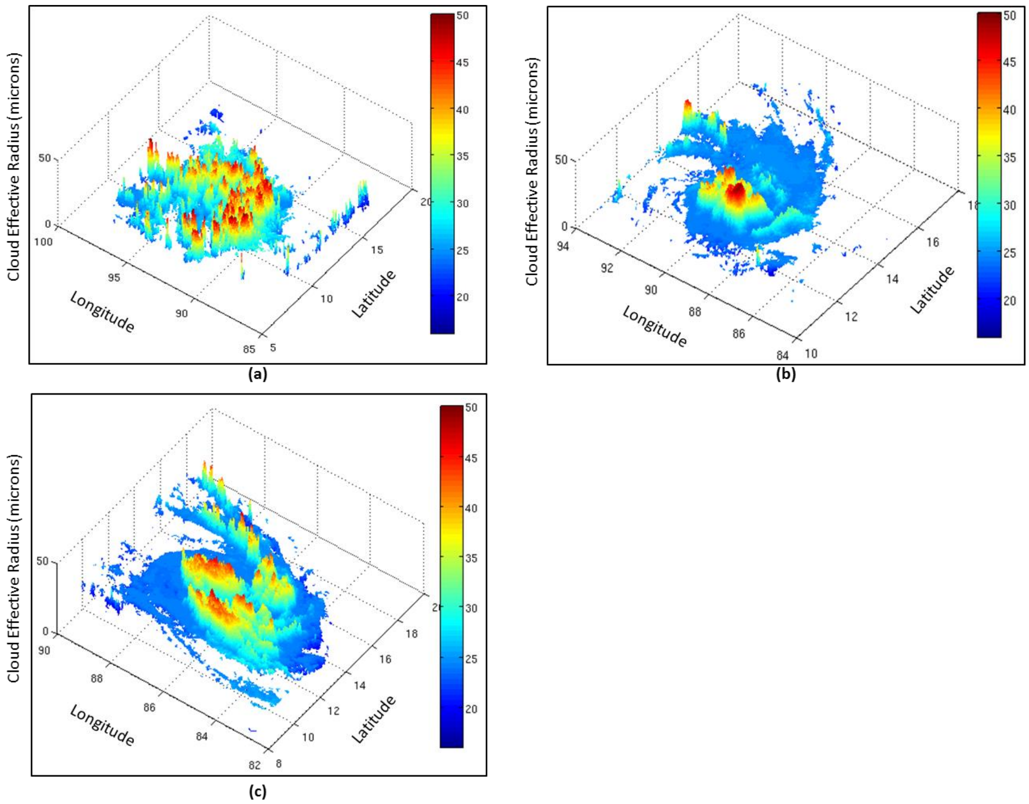


Figure 1: 3D plot of cloud effective radius (CER) for (a) 06 dec (b) 09 dec (c) 10 dec respectively for 0730 UTC.

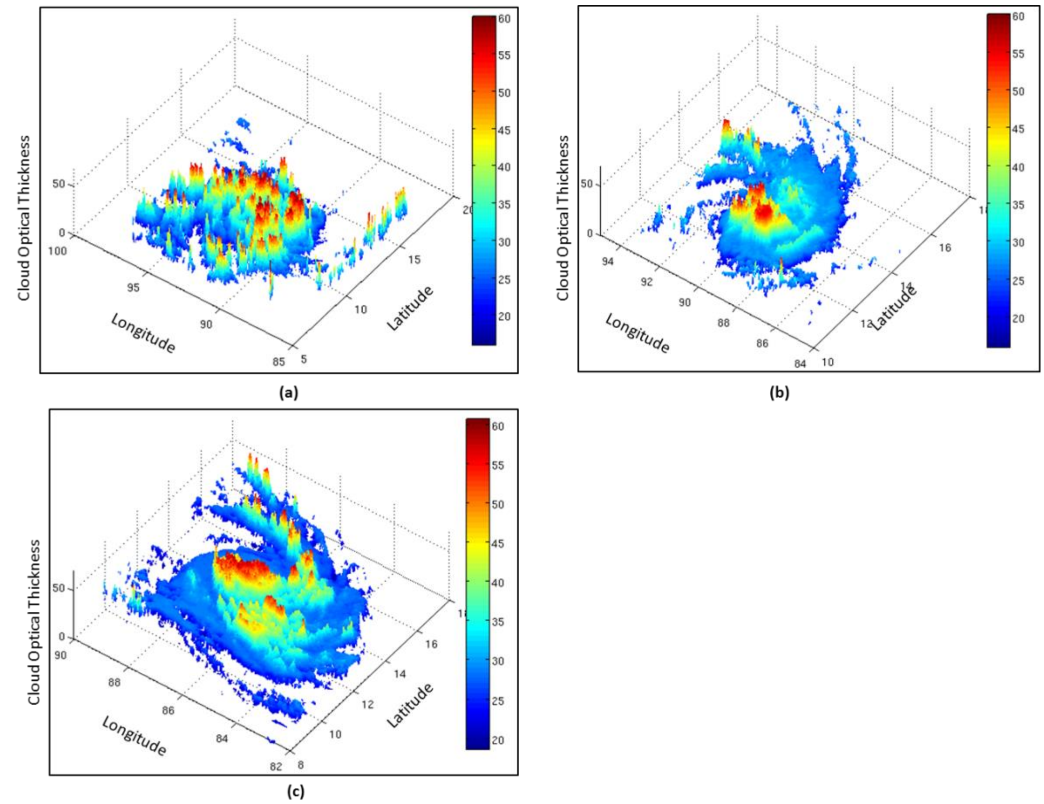
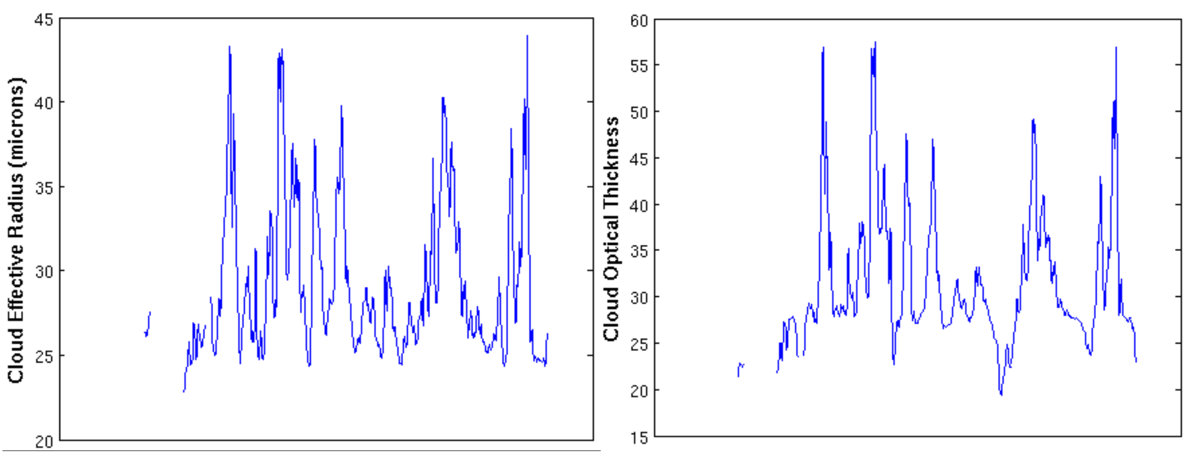


Figure 2: 3D plot of cloud optical thickness (COT) for (a) 06 dec (b) 09 dec (c) 10 dec respectively for 0730 UTC.

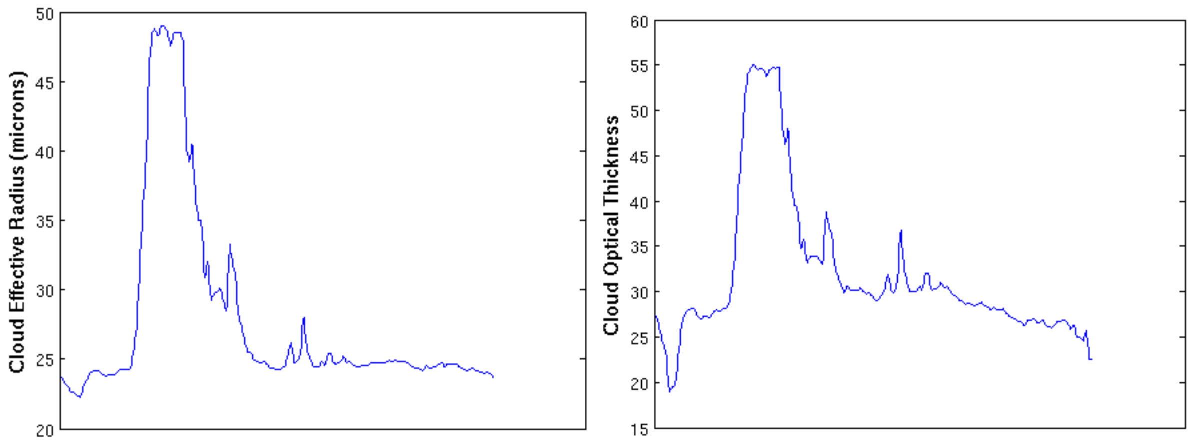
As already mentioned in the previous section, transects along the cyclone have been cut along the direction of maximum coverage for obtaining information regarding the variability of cloud parameters at different regions within the cyclone. Such plots are generated for the successive stages of cyclone as can be seen in figures (3, 4 and 5). Figure 3 represents the transect drawn along the cyclone for 6 December. As mentioned earlier, this marks the initial stage of the cyclone where the particles are uniformly distributed throughout its area. This can be very well seen in the figure 3(a) where multiple peaks denote cloud droplets of larger sizes and cover the whole extent of cyclone. Also, figure 3(b) shows that optically thick clouds (optical thickness ~ 60) are also spread at different locations.



(a) (b)

Figure 3: Plot of transect line for 06 Dec, 2016, 0730 UTC for (a) CER and (b) COT

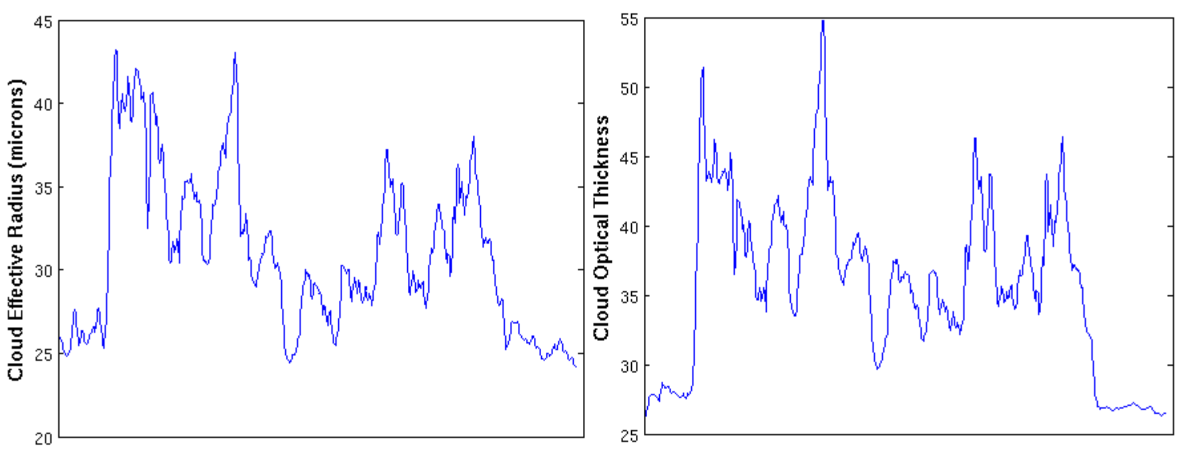
Figure 4 depicts the case for 9 December when the cyclone attained its mature stage. A transect has been cut along a particular direction for evaluating the cloud properties during this stage. Figure 4 (a & b) represents the plot generated for cloud effective radius and cloud optical thickness respectively. One can observe only a single peak in this case as compared to multiple peaks in Figure 3. This clearly denotes the organized structure of cyclone when it has reached its mature stage. Optically thick clouds with larger droplets (CER~50 microns) are concentrated at the centre as is evident from the figure.



(a) (b)

Figure 4: Plot of transect line for 09 Dec, 2016, 0730 UTC for (a) CER and (b) COT

Figure 5 demonstrates the variation of CMPs as the systems weakens and dissipates. The disorganization of the system begins and it is less ordered during this stage. The distribution of cloud droplets takes a random form and is highly variable throughout the cyclone. Several peaks can be observed as can be seen from the figure 5 (a & b) which indicates that cloud droplets are scattered.



(a) (b)

Figure 5: Plot of transect line for 10 Dec, 2016, 0730 UTC for (a) CER and (b) COT

5. CONCLUSIONS

Through this study, we analyzed the cloud microphysical properties and investigated its effect over cyclone Vardah. For this purpose, COT and CER data retrieved from INSAT-3D visible and shortwave infrared (SWIR) radiances respectively have been used. Using this data, we have traced the COT and CER for each stages of cyclone Vardah. The spatial distribution of cloud effective radius and cloud optical thickness was investigated using three dimensional plots. Transects covering the maximum extent of the cyclone was also extracted and plotted. It can be seen that during the initial stages, cloud droplets are distributed uniformly throughout the area covered by the cyclone. But as it reaches its mature stage, we observe alignment of cloud cells due to system organization. It is also seen that droplets of larger sizes are concentrated at the centre. Thus, the micro-scale characterization of a tropical cyclone helps in identifying potential areas of heavy precipitation. Moreover, it was found that the range of COT varies from 18-75 and the range of CER varies from 15-50 microns.

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