CloudSat observations of multi layered clouds across the globe

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Abstract

Detection of multilayered clouds using satellite observations is important for climate-related applications. The present results provide the quantitative information about the percentage of occurrence of one to five-layered clouds across the globe using CloudSat observations. Multilayered clouds occur most frequently in Tropics. Double-layered and triple-layered clouds account for about one-third and one-ninth of the total frequency- of-occurrence respectively. The probability of occurrence of five-layered cloud is high during the period June-July-August over the Asian monsoon region. The present results also quantified the thickness of each cloud layer across the globe by identifying cloud vertical dimensions.

1. Introduction

Knowledge of the presence of multiple cloud layers is important to interpreting satellite data properly and in the ability to compute radiative fluxes. Clouds and the general circulation of earth's atmosphere are linked in an intimate feedback loop, where clouds result from the water vapor transports and cooling by atmospheric motions, but the forcing for the atmospheric circulation is significantly modified by vertical and horizontal gradients in radiative and latent heat fluxes induced by the clouds. To determine the importance of this feedback for climate change, we need quantitative measurements of the geographic distribution and variations of cloud vertical layers to diagnose the processes involved [6]. The detection of multi-layer cloud is the detection of clouds that do not behave radiatively as single layer clouds. General circulation models (GCMs) are major tools for predicting the future climate of the earth. Clouds are fundamental stage of the cycle of water in the atmosphere, condensing water vapor and forming precipitation. However, the cloud precipitation particles are poorly simulated by GCMs .One of the major reasons for the poor representation of hydrometeors in GCMs is a lack of knowledge on the vertical distribution and multiple cloud layers. The surface observer sees only the lowermost cloud layer in a column while the satellite sees only the uppermost cloud layer, requiring so-called overlap assumptions about layers not seen to estimate the complete cloud vertical structure. Little direct information about cloud vertical structure exists [6]. Recent cloud radar and lidar observations collected on a global scale as a part of the A-Train mission [4] represent an unprecedented and unique opportunity to address the multi layers clouds at regional and global scales. In the present study, we focus on multi layered cloud systems and determine the spatial distribution of occurrence of multi-layer clouds over the globe using cloudsat observations.

2. Data and Methodology

For the present study, auxiliary products of CloudSat 2B- GEOPROF-LIDAR [1] data sets are used to construct the vertical structure of clouds. One of the most important parameters provided by GEOPROF-LIDAR product is the location of hydrometeor layers in the vertical column. The maximum number of hydrometeor layers provided by this product is five. One year (January-December, 2007) 2B-GEOPROF-LIDAR data has been collected over the Globe. From 2B- GEOPROF-LIDAR product, seasonal occurrence frequencies of single-, double-, triple-, four-, and five-layer hydrometeors are determined over the globe. In order to determine the occurrence frequencies of single-, double-, triple-, four-, and five-layer hydrometeors, we counted the total occurrence of each hydrometeor layer in a grid (2.5^0 X 2.5^0) and normalized by the total number of profiles collected over the globe within the seasons in each grid.

3. Results and discussion

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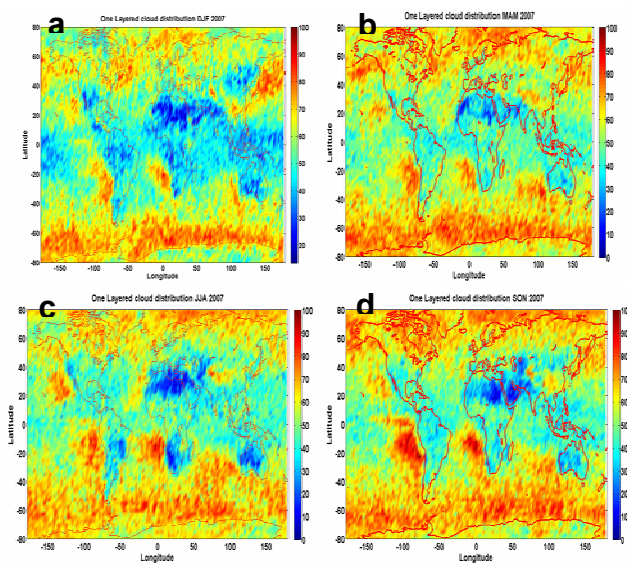

Figure 1: Shows seasonal occurrence frequencies of DJF, MAM, JJA and SON of single-layer hydrometeors over the globe respectively (a) during the DJF season, (b) during the MAM season, (c) during the JJA season and (d) during the SON season

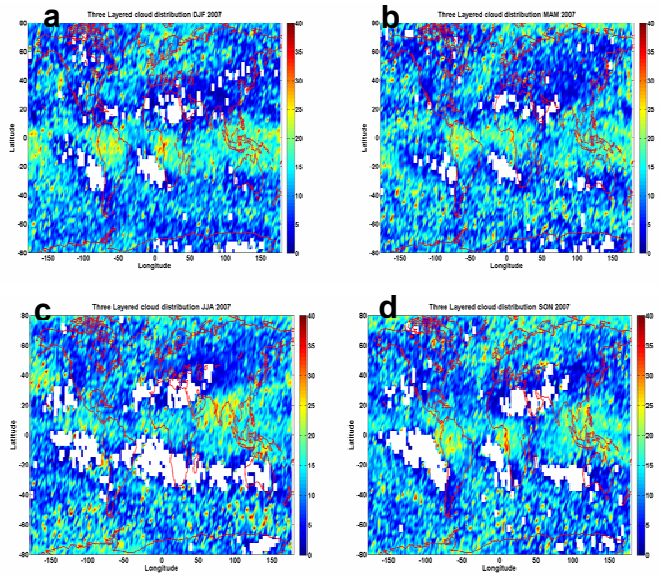

Figure 2: Shows same as in Figure 1 for triple-layer hydrometeors over the globe

The seasonal mean global distribution of single-,double-,triple-,four-and five-layered clouds and their top and base using the CloudSat product is estimated using the above-mentioned procedure. Figures 1-3 (a, b, c, and d) show seasonal occurrence frequencies of single-, triple-, and five-layer hydrometeors over the globe during of DJF, MAM, JJA and SON. The frequencies of occurrence were also computed for double and four layer clouds but figures are not shown. The frequency of occurrence of single-layer hydrometeor is high in the oceans compared to land and particularly in the southern ocean region is more during all periods (Figure 1). Clouds over the ocean occur more frequently at lower levels than over land [6]. During the DJF, the notable feature is the distribution of single-layer hydrometeor in the South Atlantic Ocean (SAO), the South Pacific Ocean (SPO) and in the North Pacific Ocean (NPO) (Figure 1(a)). The percentage of single-layer hydrometeor during the DJF is less as compared to MAM period and the percentage has been increasing towards the seasons from DJF to SON. But, the amount of occurrence of single-layer hydrometeor in the SAO and SPO was considerably high during the period of SON compared to any other period (Figure 1 (d)). Thus Figure 1 shows that the frequency of occurrence of single layered cloud is high over oceans. Figure 2 represents the triple-layer hydrometeor cloud distribution over the globe and we can see migrating of Inter Tropical Convergence Zone (ITCZ) from north to south. The percentage of occurrence of triple–layer, which is shown in figure 2, is more in South America and South Africa regions during all seasons except for JJA. During the period JJA, there was considerable amount of triple layered-clouds in the South Pacific region, which was not seen in the other seasons. And the most notable feature was in the Indian subcontinent and its surrounding ocean during the JJA (Figure 3(c)) and SON (Figure (3(d)), which was not there in the periods of DJF and MAM. The same features were observed in the double- and four-layer distribution (figures not shown). This is due to the onset of the Indian summer monsoon season, which is the major weather system causing heavy rainfall during summer over the Indian sub-continent [5]. We have observed that, in the Indian subcontinent and surrounding oceanic region, the multilayer hydrometeor frequencies exhibit remarkable seasonal variation with a maximum during summer (JJA) and minimum during winter (DJF), similar to that of the total frequency of occurrence.

Figure 3 shows the distribution of five-layered clouds over the glove. These five layered clouds are least occurrence as compared any other category of clouds during JJA period the frequency of occurrence of five-layered cloud is ~

15% (figure 3(c)) over the Asian monsoon region. It is observed that the contribution from four- and five-layer hydrometeors is negligible as compared to other cloud types in the subtropics and midlatitudes. Thus multilayered clouds occur most frequently in the Tropics and least frequently in the subtropics and mid-high latitudes. Also, there are more multilayered clouds in summer (JJA) than in winter (DJF). [2] reported that multilayered clouds with occurrence of 20% over southern Baffin Island during the Strom Studies in the Arctic (STAR) period (i.e., October and November 2007). The author mentioned that the frequency of occurrence of single-, double-, triple- and four-layer hydrometeors was 65, 17, 2.4 and 0.09 respectively during the STAR period. Where as in our analysis shows during the SON period the frequency of occurrence of single-, double-, triple-, four- and five-layer hydrometeor clouds is

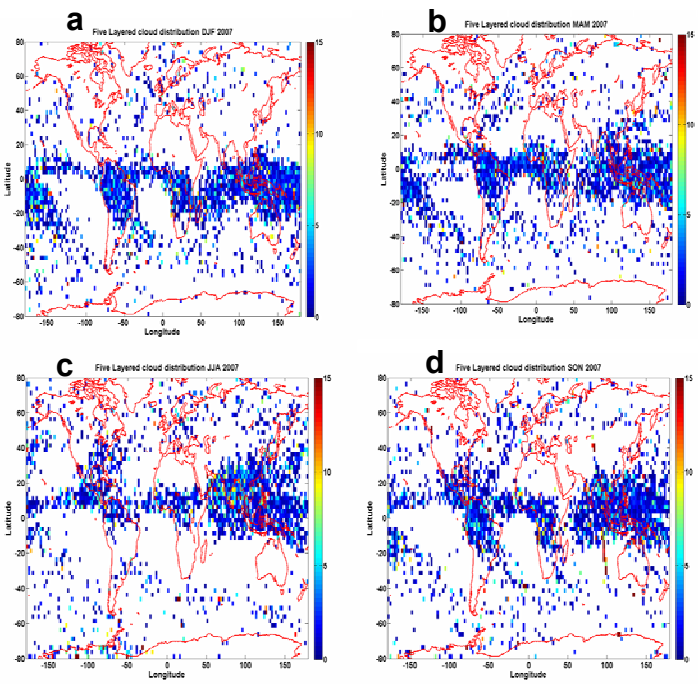

Figure 3: Shows same as in Figure 1 for five-layer hydrometeors over the globe

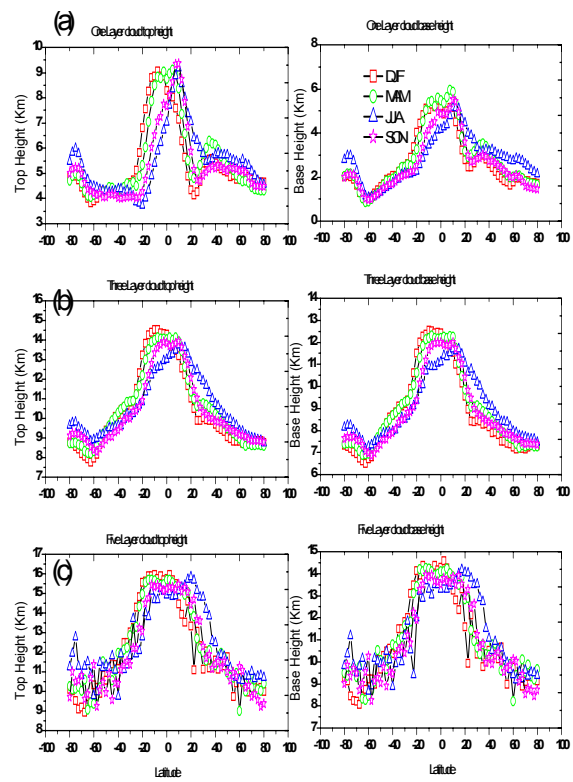

Figure 4 (a-c) shows the latitudinal distribution of top and base of single-, triple-, and five-layer clouds

Table 1: gives a % of the seasonal mean single-, double-, triple-, four-, and five-layer cloud distribution over the Globe, Tropics and Tropics plus subtropics

Globe					
Season	single-	double-	triple-	four-	five-layer
DJF	57.88	26.69	10.90	4.44	2.26
MAM	56.95	30.23	11.23	4.60	2.47
JJA	55.25	28.82	11.32	4.63	2.74
SON	57.29	29.34	11.24	4.7	2.59

67.23, 30.69, 10.62, 3.73 and 3.37 respectively. [6] analyzed the rawinsonde data globally and he found that 58% of clouds are single-layered, 28% are double-layered, 9% are triple-layered and 5% are four (greater than and equal to)-layered; almost 67% of the latter are two-layered clouds. There are about 7% more single-layered clouds over land than ocean. Recently, [7] study shows the single-layer hydrometeor contributes 53% in Indian region and 63% in Eastern China region. Table 1 summarizes the frequency of occurrence of multi layer clouds during all the four seasons over the globe.

Figure 4 (a-c) shows the latitudinal distribution of top and base of single-, triple-, and five-layer clouds. The distribution shows the similar structure for all the multi-layer clouds during respective season. [7] compared cloud fractions of multi layered clouds between two sub regions of the Asian monsoon region. Eastern China (20^0-35^0N,

102.5^0-122.5^0) and mentioned that in the Indian region, the high-, mid-, and low-top clouds have similar distribution in a given season. The single –layered cloud bottoms in all seasons of the year 2007 are in between the altitude of 0.75 – 6 km and its cloud top are in between 3.5 to 9.5 km. But, where as in the ITCZ (Inter Tropical Convergence Zone) from ~10^0S to 10^0N, shows its largest cloud bottoms and cloud tops in all seasons and in all layered clouds. From Figure 6, in the southern hemisphere (55^0S to 65^0S) single-, and multi-layered hydrometeors cloud bottom and cloud top heights were lower than in the northern hemisphere. It shows the northern hemisphere the cloud formation took place at an altitude of ~ 1.5 km, where as in southern hemisphere at an altitude of ~0.75 km in the year of 2007. During the JJA period, hydrometeor cloud bottom and tops were at high heights compared to DJF, MAM and SON seasons, particularly in the southern hemisphere from 60^0S-80^0S and northern hemisphere 60^0N-80^0N. But it shows the similar phase structure with other periods. The most notable feature in Fig 6 is that the crest in the diagram observed during the all seasons around 35^0N-40^0N in the single-layered cloud bottom and top. Apart JJA period, in the double-layered cloud bottom and top, above same crest were seen during the DJF, MAM and SON only. Whereas in the case of triple-, four- and five-layered cloud bottom and top same crest were seen only during the DJF period. And other feature was in figure 6(b), there was small phase shift in JJA and SON when compared to with DJF and MAM periods in the tropical latitude range from -20 – 20 ^{0}N. There are considerable contributions by triple- , four- and five-layer hydrometeors cloud bottom and tops, especially in the summer months shows the peak at between ~15^0N to 20^0N, while other season's shows the peak at between ~5^0S to equator.

4. Concluding remarks

Observations collected by CloudSat during the year 2007 are used to study the frequency of occurrence of single-, double-, triple-, four- and five- layered clouds over the globe. Main focus of this study is the distribution and seasonal variations of multi layered clouds. Multilayered clouds exist most frequently in the Tropics and least frequently in the subtropics; there are more multilayered clouds in summer than in winter and particularly over the Indian subcontinent and its surrounding oceanic region during the JJA period. Also, we found that five-layered cloud occurrence is 15 % over the Indian region, which is highest as compared to any part of the globe. On an average over the globe the % occurrence of single-, double-, triple-, four- and five-layered cloud is 56.84, 28.61, 11.17, 4.6 and 2.5 respectively. Double-layered cloud accounting for about one-third of the total frequency of occurrence and triple-layered cloud accounting for one-ninth of the total frequency of occurrence. We have found that cloud top and bottoms have similar latitudinal structure in a given season. It is envisaged that the present results will have important implications in the GCM simulations of climate prediction as it provides an important information on cloud vertical distribution across the globe.

Acknowledgments

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