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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Cloud vertical structure over a tropical station obtained using long-term high resolution Radiosonde measurements" *by* Nelli Narendra Reddy et al.

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Replies to Reviewer #3 Comments/suggestions

The paper documents the cloud vertical distribution over a tropical Indian station, Gadanki using the long-term radiosonde measurements. The authors classify the clouds based on the occurrence altitude and discuss their variations for different season. Investigating the cloud vertical profile is an interesting research topic due to their role in earth's radiation budget and difficulty in parameterizations of clouds in models. One of my main concern is the cloud height estimation, which is not been compared with any other measurements and lack of discussion on the observed cloud structure

with large-scale environments. The manuscript is publishable, but needs careful consideration of the points listed below.

Reply: First of all we wish to thank the reviewer for going through the manuscript carefully, appreciating actual content of the manuscript and providing constructive comments/suggestions which made us to improve the manuscript content further.

1. The authors mentioned "Cloud Vertical Structure in all the seasons including diurnal variation over Indian region is made for the first time." Is the cloud variability observed over Gadanki can be considered as a representative over the Indian region?

Reply: Diurnal variability in Cloud Vertical Structure of middle and upper layers in multi-layer cloud configuration over Gadanki can be considered as a representative over Indian region. However, the diurnal variability of CVS of single-layer and lower layer of multi-layer configuration might vary from location to location as it depends on topography, land use and land surface and geo-location.

2. Ln 223: Pandit et al. (2015) studied the cirrus clouds climatology over the same station from lidar measurement. Why authors have not compared the cloud height estimated from radiosonde with lidar measurements. The aim of this task is to verify the accuracy in cloud height estimation from radiosonde. What precaution the author has taken to estimate cloud height during the raining condition, especially during monsoon?

Reply: Kindly note that Pandit et al. (2015) used only lidar measurements to investigate cirrus clouds. This lidar can provide measurements between 7 and 30 km only (Mie channel) and we will not get any information below this altitude. However, in the present study, Cloud Vertical Structure is examined only up to 12.5 km altitude as the accuracy in RH measurements is poor at higher altitudes. Note that LIDAR gives the vertical structure of the cirrus clouds (occur at higher altitude). Also, LIDAR is operated mostly during cloud free conditions (cirrus cloud and clear sky conditions). Further, the timings of Radiosonde and LIDAR measurements are different. Hence we did not do inter comparison study with LIDAR observations. In general we will not release the balloon

during moderate to heavy rain conditions. However, we have done visual inspection of each radiosonde profile. RH profiles which show continuous saturation with height were discarded. These aspects are mentioned in the revised manuscript.

3. Ln 227: How many cases do you have CPS measurement with radiosonde? What threshold of cloud number concentration the authors consider to define cloud layer from CPS measurement? The number concentration is higher between 10 and 15 km not for the lower altitude.

Reply: We have only two cases of simultaneous measurements of Radiosonde and CPS Sonde from Gadanki location. Hence, the comparison of cloud number concentration and CVS structure is qualitative. We have not put any threshold on cloud particle concentration. Yes, we agree with the reviewer that the cloud particle number concentration is higher in top layer (10 – 16 km) but not for lower layers. This could be due to relatively smaller thickness of lower layers. We may need more number of simultaneous observations for further study.

4. Ln 240: homogeneous cloudiness..... How the authors defined it.

Reply: Homogeneous cloudiness mean that nearly uniform OLR values occurred for more than 50 km radius around Gadanki location.

5. For Fig.4, please mention the latitude and longitudinal average the authors have considered.

Reply: Figure 4c describe the monthly mean OLR at Gadanki location (KALPANA OLR grid location is 79.125o E, 13.375o N). We have also estimated monthly mean OLR values 0.25o around this grid point and could see results do not change. Please see enclosed Supplementary Figure S1 for this clarification.

6. Ln283: Change to 'between 12 and 15 km'

Reply: Done.

7. Ln 311: Fig 5: Diurnal variability of cloud is difficult to understand as variability of one-, two-, three- and more-layer clouds are different. What could be the possible reason to have maximum occurrence of cloud during mid-night to early morning. Also bit surprising to see afternoon occurrence of cloud is less. Authors considered OLR as a proxy for convection. It will be interesting to see the OLR diurnal variation also.

Reply: As suggested by reviewer we have shown the diurnal variability in OLR at Gadanki location in supplementary Figure S2. From the Figure S2 it is evident that OLR values shows low values from evening to early morning hours with minimum OLR value at 20:30 LT.

8. Ln 371: Fig. 8c, the cloud thickness is up to 12 km for all season (even though the occurrence percentage is less). Under what thermodynamic conditions such tall clouds develop over the measurement site? Why such thick clouds are absent in fig 6 and fig. 7.

Reply: In general, the factors which trigger the deep convection are strong surface heating, moisture availability at the surface and mid troposphere, and some lifting mechanism to lift the surface parcel above the level of free convection. Over the Gadanki location, the different lifting mechanisms are: strong wind shear because of low level jet during monsoon season; strong buoyancy force due to relatively higher surface temperature during pre-monsoon period; orographic lifting as this location is surrounded by hills.

Figure 8c is the cloud thickness observed over Gadanki location with long-term (11 years) radiosonde data at 17:30 LT. Whereas Figure 6 and 7 are diurnal variations in one-layer and two-layer clouds using Tropical Tropopause Dynamics (TTD) campaigns data (2010-2014). During these campaigns, the radiosondes were launched every three hourly for continuous three days in each month during Dec. 2010 to Mar. 2014. Hence deep convective clouds are not seen in Figure 6 and Figure 7.

9. Ln 412: 'The outflow caused by the deep convective systems could be responsible .

. ..' Do authors have any analysis to support their argument?

Reply: In general, after the dissipation of deep convective clouds they spread large anvils and remain persist as high level clouds for longer duration. These high level clouds could be due to in-situ generated Convective Systems or else propagated from the surrounding Oceans. Especially during monsoon season, deep convective clouds embedded in northward propagating convective systems originated over Indian Ocean and westward/northwestward propagating convective systems over the Bay of Bengal, dissipate over Indian land region (e.g. Sikka and Gadgil, 1980; Lawrence and Webster, 2002; Goswami, 2005; Jiang et al., 2011) and they contribute majorly to the high level cloud occurrence. In general, the high level clouds follow background winds at those levels. Due to the strong westerly winds in the upper levels, high level clouds which are originated from MCS over Bay of Bengal advect into the Indian land region and contribute to the high level cloud occurrence. Some of these aspects are included in the revised manuscript.

10. Ln 467: 'This could be due to interactions between the different layers of cloud'. What kind of interaction, authors want to infer? Please demonstrate.

Reply: Interaction we mean here is longwave radiative effects. We have made the following correction (Line 492-496). " This could be due to the exchange of longwave radiation between cloud base of upper layer and cloud top of lower layer. As a result, the strong reduction in longwave radiation cooling at the top of the lower layer of cloud in the presence of upper layers of cloud (Zhang et al., 2010; Wang et al., 1999; Chen and Cotton, 1987)."

11. Ln 502: Please mention the climatological onset date of monsoon over Gadanki. What criteria authors considered to define onset of monsoon.

Reply: Arrival date over Gadanki is picked up manually from the yearly onset date lines over India map given by IMD. The mean arrival of southwest monsoon date for the period of analysis is on 7 June with $\pm$ 4 days.

We once again thank the reviewer for providing detailed comments/suggestions for betterment of the manuscript.

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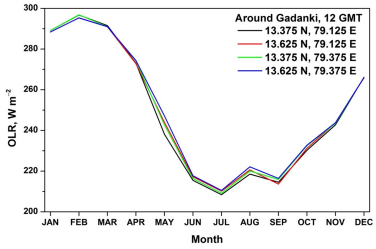

Figure S1. Monthly mean Outgoing Longwave Radiation (OLR) around Gadanki obtained using KALPANA-1 data during Apr. 2006 to May 2017.

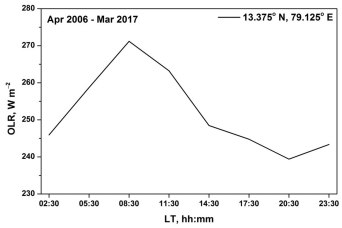

Figure S2. Diurnal variations in Outgoing Longwave Radiation (OLR) over Gadanki obtained using KALPANA-1 data during Apr. 2006 to May 2017.

Fig. 1.