<u>Responses to comments of Anonymous Referee #2</u>

We thank anonymous referee #2 for reviewing our manuscript and emphasising the fact that manuscript is a work based on a unique dataset from a region which is under-represented in terms of long-term cloud observations. We thank referee #2 for considering our manuscript suitable for publication in ACP after minor revision. Please find below our detailed response to the comments.

Specific Comments

1. Abstract and Title: The abstract and title mainly reflect the climatology portion of the work, which is the bulk of what is presented. But the trend analysis is also important and suggest you add specific language in the abstract about the magnitude of the trends and their link to signatures of climate change. Also, you modify the title to draw some attention to the work. Suggest "Long-term trend analysis and climatology of tropical cirrus clouds using 16-yr lidar dataset over southern India" or something similar.

Reply: We thank the referee for suggesting this improvement. In the revised manuscript, we are changing title as suggested by the referee. We have also modified the abstract to give more emphasis on long-term trend analysis.

2. P. 15800, Line 14: "Data product is known as: : :" suggest "We use the feature optical depth data product from the CALIOP level-2 data product."

Reply: As suggested by the referee we have modified the sentence in the revised manuscript.

3. In many places you discuss the differences in cloud thickness or altitude between the two datasets, but you do not consider the differences in vertical resolution of the two lidar systems as a possible source of the discrepancies. This needs to be discussed in many instances. You could start with a discussion in the methodology section about the relative sensitivity of the two lidar systems (i.e. signal to noise ratio) and the vertical resolution differences. You mention a 5 km CALIOP cloud layer product. This is very large! For NARL you state 300 m. This is a big discrepancy. Please address how you handled these differences in your analysis.

Reply: In this context, the 5 km CALIOP cloud layer product implies horizontal resolution of 5 km along the track of satellite. The vertical resolution of CALIOP data is 60 m. The vertical resolution of NARL lidar is 300 m. The details of vertical resolution of both Lidars is provided in Table 1. In the revised manuscript, we include this information in text also.

4. Discussion on P. 15801 and 15802, Frequency and maintenance of tropical tropopause layer (TTL) cirrus clouds: You state that the formation of cirrus clouds in the tropics is due to deep convective clouds. Yes, this is true for some tropical cirrus, but the TTL cirrus is not necessarily formed by deep convection, but can be the result of stratospheric waves (Boehm et al.) or can self maintain for up to 2 days through cloud radiative heating processes (Dinh, et al. 2010). You need to consider these studies in your discussion. TTL cirrus can last for days and has been shown to do so by many.

If there is a discrepancy between day and night time TTL cirrus occurrence, then it is due to instrument sensitivity during the daytime. Please address these issues more quantitatively in the discussion of the results.

Reply: We agree that there are several mechanisms through which TTL cirrus cloud can form. However, other mechanism such as suggested by Boehm et al. (2000) or Dinh et al (2010) cannot account for day and night difference. A related comment is received by referee #1 asking to perform significance test for the monthly differences between day and night percentage of occurrence. We found that the monthly differences are not statistically significant due to small data-set available in the region 50 km around Gadanki. Hence in the revised manuscript we are reducing the discussion about day and night differences particularly which is based on Fig. 3.

5. Last sentence of Sec. 4.1: This statement should be removed because it is not a legitimate physical difference but an artifact of the instrument.

Reply: As mentioned in the previous comment, we are going to reduce all the discussion about day-night difference including the statement mentioned here.

6. Again on p. 15803 Lines 13-15: we can't definitely conclude that the day-night differences are a real atmospheric phenomenon because of the instrument issues.

Reply: Please see our response to previous comment.

7. P. 15804: The tropical tropopause is not well defined. How are you identifying the tropopause?

Reply: We used cold-point tropopause definition to calculate tropopause height from temperature profiles of FNL. However, in the revised manuscript we have decided to use tropopause altitude provided as a part of FNL data which uses lapse rate tropopause definition. We find no significant difference in the percentage of occurrence of cirrus clouds above tropopause in NARL lidar data, nevertheless we made this decision as tropopause height provided part of FNL data is a standard product and its comparisons with similar products from other datasets are available in literature e.g. Pan and Munchak (2011).

8. P. 15805, lines 10-15: Could this discrepancy be the vertical resolution or sensitivity issue?

Reply: We believe that NARL lidar has better sensitivity than CALIOP which is responsible for more detection of sub-visible cirrus than CALIOP. CALIOP has 60 m vertical resolution whereas NARL lidar has 300 m vertical resolution. We carried out sensitivity study to investigate the effects of bin-width on PO distribution by rebining CALIOP data at coarser resolutions and found no significant difference in PO distributions at 60m and 300m resolutions. Though, we found vertical resolution not playing direct role, indirectly high vertical resolution can reduce the signal strength and hence increase the signal to noise ratio. The sensitivity issue of CALIOP lidar is also pointed out by other researchers like Davis et al., 2010, Martins et al., 2011, Thorsen et al., 2013, etc.

9. P. 15806: How accurate are the NARL optical depths <0.01? what is the uncertainty?

Reply: Since no standards are available to compare against, we used estimates of errors in inputs and their propagation to compute cloud optical depth for determining precision and accuracy of NARL lidar. From error analysis, we found that the NARL lidar can estimate cloud optical thickness with precision of the order of 10^{-4}. However, the precision should not be confused with accuracy which is largely determined by accuracy of assumptions as mentioned next. The largest sources of errors are lidar-ratio (extinction to backscatter ratio) and multiple scattering correction factor (η). Effect of lidar-ratio and η on output values (extinction coefficient or optical depth) is similar to scaling the output values with these parameters. The lidar ratio and η values being used in current study are expected to have about 20% error based on the values reported in literature. Both the parameters together will contribute about 40% error in the cloud optical thickness.

10. P. 15807, Lines 20-22: I believe this is an instrument detection issue in daytime coupled with vertical resolution.

Reply: We agree with the referee's suggestion. The statement is changed to reflect this caveat.

11. P. 15808, last paragraph: you should acknowledge the reasons for the differences in cloud properties in these temperature regimes is due different cloud formation mechanisms.
See (4) above.

Reply: As suggested by the reviewer, we included the reasons for the differences in the clouds properties in these temperature regimes in the revised text.

12. P. 15809, line 15-16: Why not use cloud top temperature for this analysis? Midcloud height has thickness and cloud altitude influences. Cloud top altitude would be the trend in altitude alone. Are the trends robust for cloud top temperature? Please add to the discussion.

Reply: After receiving the reviewer's suggestion we analysed trends in temperature at cloud-top and found the trend of 0.02±0.1 ˚C/year (p-value=0.8). This is similar to our earlier results as far as statistical significance of mid-cloud temperature trend is concerned. Since there is no new information is obtained by this exercise we are retaining the trends of mid-cloud temperature in the manuscript.

13. P. 15809 Line 23-25: Do you expect that midlatitude cirrus would have similar trends? I would not expect this because midlatitude clouds are primarily synoptically forced and the dynamic feedbacks might be different in each case. Do you have any thoughts on why optical depth would be decreasing in a warming climate?

Reply: We agree with the referee that the tropical cirrus clouds differ significantly from the mid-latitude cirrus clouds in terms of their formation mechanism and their properties. However, climate warming is a global issue which will have definite impact on cirrus clouds present at different regions of globe with different magnitudes of changes. Recent climate model simulations done by Chepfer et al., 2014 suggest that in a +4K climate there will be an upward shift in the cirrus clouds everywhere (including mid-latitude) with the highest shift in the tropics.

As to the second part of this comment, we do not have definite or conclusive thought about why cirrus cloud optical depth should decrease in warming climate. Warming climate pushes up the tropopause altitude and altitude of occurrence of cirrus clouds. Hence, we speculate that this will reduce the cloud physical and optical thickness. Since this statement is highly speculative we have not mentioned in the manuscript.

14. Figure 1 font sizes are much too small to be legible. Hopefully the final version will be a large portion of the page.

Reply: As the page dimensions are different for ACPD and ACP article, we hope there will be improvement in the figure for ACP format. At the time of proof-reading, we will try to fix this issue.