Norrköping, 2015-09-21

Response to reviewer #1

We would like to thank the reviewer for her/his comments that improved the manuscript. Please find below response to your comments.

There is some interesting material in the response of the authors, but there overall is not too much change in the scientific content of the paper itself. In terms of figures, the main changes appear to be that mean profile sidebars have been added to several of the Figures, and Figure 13 is new.

The paper is also still mainly descriptive, rather than offering a new way of explaining some set of observations. A descriptive paper can be publishable, in my opinion, if the observations are sufficiently novel and/or they are arranged in a particular insightful way. I am not familiar enough with this field to independently determine how novel the observations are. In terms of presentation style, as I mentioned in my previous comment, much of the material is presented in the same manner: e.g. Figs 4, 6, 8, 9, 10, (and all supplementary Figures). These figures comes across more as an "information dump", with too much detail for the reader to assimilate, rather than an attempt by the authors to support some specific argument, or give some explanation for the observed seasonal and latitudinal progression of cloud radiative heating.

Also at times, the paper still suggests it will deliver more mechanistic insight than it actually does, and this creates a confusing impression in the reader. For example, in the abstract, it states: "Profiles of radiative heating inferred from these observations provide insights into the role that different clouds play as regulators of the monsoon. Such information is vital for understanding the relative importance of cloud radiative versus latent heating." However, the paper is essentially a compilation of cloud radiative heating rates over the Indian subcontinent. Due to the complexity of the interactions between cloud radiative heating, convection, and large scale dynamics, it is difficult, without a model, to predict how these heating rates might affect precipitation patterns, TTL dehydration, etc. (And models often are often not that good either). I don't think the paper gives any new specific insights on how clouds regulate the monsoon. The argument that they will affect the monsoonal circulation by warming the atmosphere and cooling the surface seems obvious, and can't be an original insight. The possibility mentioned in the conclusion that the decrease in surface heating from clouds could be responsible for the monsoon "break" periods seems quite speculative, and outside the scope of the paper.

We would like to clarify that it is not our intent in the present study to show how monsoonal circulation is affected by clouds or vice versa. This is a very complex question and, as the reviewer points out, it would require model simulations to fully address it. We think that some of the sentences in the manuscript may have misled the reviewer in believing that we were attempting to address this question. Hopefully, the changes made in the revised version of the abstract and introduction sections would clarify our position.

The main aim of the present study is very straightforward and that is to investigate and document the role of different cloud types in the total radiative heating/cooling and the intraseasonal evolution of their radiative effects. This is very basic (and hence may seem little descriptive at times), but first important step in addressing the eventual impact of clouds on monsoonal circulation.

The first paragraph of the abstract is revised as it may have been misleading. It now reads:

Clouds forming during the summer monsoon over the Indian subcontinent affect its evolution through their radiative impact as well as the release of latent heat. While the latter is previously studied to some extent, comparatively a little is known about the radiative impact of different cloud types and the vertical structure of their radiative heating/cooling effects. Therefore, the main aim of this study is to partly fill this knowledge gap by investigating and documenting the vertical distributions of the different cloud types associated with the Indian monsoon and their radiative heating/cooling using the active radar and lidar sensors onboard CloudSat and CALIPSO. The intraseasonal evolution of clouds from May to October is also investigated to understand pre-to-post monsoon transitioning of their radiative heating/cooling effects.

The last three paragraphs of the Introduction section are also rewritten to bring out the fact that the manuscript provides compilation of observations of cloud radiative heating over the Indian subcontinent. These paragraphs now read:

In spite of their seminal role in influencing the atmospheric dynamics during summer monsoon, the individual contributions from latent and radiative heating components to the total diabatic heating have not been quantified hitherto over the Indian subcontinent. The role of latent heating has been previously investigated in a few studies to some extent (Zuluaga et al., 2010 and references therein), but the radiative component of heating has received very little attention so far due to lack of suitable observations**. This is the knowledge gap that the present study aims to address over the Indian subcontinent by documenting radiative heating/cooling contributions from different cloud types and their intraseasonal evolution from May to October.**

As a result of limited knowledge of radiative heating/cooling potential of different cloud types, currently there exist significant differences in CRH estimates amongst various reanalyses (Ling and Zhang, 2013; Wright and Fueglistaler, 2013), as well as between models and observations (McFarlane et al., 2007). Due to the ability to resolve the detailed vertical structure of clouds in combination with possibility to precisely delineate different types of cloudy layers, the A-Train constellation of satellites is an extremely useful source of information to improve our understanding of the radiative heating/cooling effects (L'Ecuyer and Jiang, 2010; Henderson et al. 2013). Especially the combination of data from CloudSat and CALIPSO satellites can address the inherent limitations of passive imagers that can only provide a 2D image of clouds. Therefore we here exploit the state-of-the-art estimates of CRH for the years 2006-2011 derived from the application of broadband radiative transfer calculations to cloud and aerosol information obtained from space based lidar and radar observations (L'Ecuyer et al., 2008, Henderson et al., 2013) to answer the following scientific questions:

1) How does the vertical distribution of CRH evolve over the Indian continent during pre-monsoon, monsoon and post-monsoon seasons?
2) What is the absolute contribution of different clouds types to the total CRH?
3) How do active and break periods of monsoon affect the distribution of CRH?
4) What are the net radiative effects of different cloud types at surface?

The first three questions are discussed with specific focus on the UTLS region. Addressing these questions in the present study is the first step towards quantifying the role of cloud radiative heating/cooling in shaping the atmospheric dynamics during monsoon.

Furthermore, in the revised version, the last paragraph in the conclusion section is removed as it was speculative in nature (although these speculations were based on the results of investigations presented in the manuscript).

Nevertheless, there appears to be some interesting aspects of the paper in terms of the contributions of various cloud types to the vertical structure of cloud radiative heating over the Indian subcontinent. So my overall recommendation would be potentially publishable with revisions.

Other Comments

From my reading of the paper, I didn't see a definition, or reference, for how the various cloud types, have been defined. I think this is quite central to the paper and should be in there somewhere.

A very good point. We have used the standard 2B-CLDCLASS-LIDAR product to obtain information on cloud types. We have now provided a brief description of cloud typing algorithm. The revised text reads:

" A combination of threshold and fuzzy logic based approaches are used to classify cloud types in the 2B-CLADCLASS-LIDAR product (Wang et al. 2013). A neural network, that is trained based on contextual, spectral and geometrical properties of cloud types, is used in the fuzzy classifier. The classifier first uses combined radar and lidar data to find cloud clusters according to their persistence in horizontal and vertical dimensions. Then cloud physical properties such as temperature, height etc are examined for cloud clusters. Finally, cluster mean properties and spatial inhomogeneities in physical properties are sent to fuzzy classifier to categorize detected cluster into one cloud type and to assign confidence level. Further details of the cloud type algorithm can be seen in Wang et al. (2013). "

lines 296 - 298: "Given the distinct monthly variability in cloud fraction from pre to post monsoon, examining corresponding monthly variations of CRH provides interesting insights that can be directly evaluated in the global climate models." However, the material did not seem to be arranged in a way that would be of direct use to climate models. In general, climate models can not easily attribute the cloud ice in the model to the various cloud types (whose definitions are to some degree intrinsically fuzzy anyway), so segregating the radiative effects in this way does not make for easy comparison with climate models. Also, the latitudonal means in each zone would not provide easy comparison with climate models, since they would likely have errors in their precipitation patterns. I realize that the use of cloud types does help with physical insight at times, and that the mean profiles now given would help with climate model comparisons.

We appreciate that there are few intrinsic differences in the way cloud types are defined in models and observations. One would need to employ satellite simulators to allow direct one-to-one comparison. This in itself is another topic of research. Having said this, we believe that the comparison with climate models is still possible as it is easy to delineate major cloud types (e.g. convective and stratiform cloudiness) including thin cirrus in models. As mentioned in the Introduction, each of these cloud types has a unique role in influencing atmosphere during monsoon. The pdfs, mean vertical profiles and zonal distribution of cloud types and their radiative heating presented in the manuscript would certainly be useful to evaluate models and to check if they can reproduce at least basic description of cloud radiative effects over the monsoon regions. If they successfully can, then the model can be further used to understand dynamical coupling between clouds, radiation and monsoonal circulation.

line 232: "rate parameter" not defined.

The rate parameter is the distribution parameter used to define exponential distribution in statistics (please see the link below). The distributions of ice water paths follow exponential distribution and, by definition, a pdf will be narrower if the rate parameter has higher value and vice versa.

https://www.encyclopediaofmath.org/index.php/Exponential_distribution
https://en.wikipedia.org/wiki/Exponential_distribution

The revised version omits this unnecessary reference to the rate parameter and now reads

“In the case of high clouds, the pdf of ice water path follows a sharp exponential distribution, while for stratiform clouds, the distributions are broader.”

line 260: "effect of melting layer at around 5 km is also visible .."
How?

A narrow band of longwave cooling at the freezing height (between 4.5 and 5.5 km) is visible in the right column plots for Z2 and Z3.

The revised text now reads ”A narrow band of longwave cooling at the freezing height (between 4.5 and 5.5 km) is due to the effect of melting layer. This effect is most visible in Z2 and Z3, extending meridionally over the entire cross section.”

Line 400: There is no explanation here of why the atmospheric warming shown in Figure 13 saturates at a low value of IWP while the surface cooling continues to cool with increasing IWP.

It is physically expected that the rate of atmospheric response would be different. There are few processes often limiting the atmospheric response. Entrainment of air is one such commonly occurring process. Both lateral and cloud top entrainments can have diluting effects on building convection.
(For example: http://onlinelibrary.wiley.com/doi/10.1002/qj.1959/abstract)

line 525: "Deep convection has mean cooling effect in absolute terms above LZRH during both active (- 1.23 K/day) and break periods (-0.36 K/day). However, the active conditions show much wider PDFs of CRH, suggesting that convective clouds do not always cool the TTL." What must be meant here is not "Deep convection" or "convection" but rather the cloud radiative effects of convection (since the paper has no calculations of convective heating). This is a specific example of how the paper at times seems to confuse the cloud radiative effects of convection with convection itself.

Please note that since the manuscript deals exclusively with radiative effects of clouds, the actual cloud type and its radiative effect are referred interchangeably. This is removed in the revised manuscript and CREs are mentioned explicitly.

References:
Wang, Z., D. Vane, G. Stephens, and D. Reinke, Level 2 Combined Radar and Lidar Cloud Scenario Classification Product Process Description and Interface Control Document Version 1.0, JPL/CalTech, NASA, Pasadena, USA, pp. 1-61, 2013.