Response to reviewers

This document details our reply to the reviewer comments and lists how the manuscript has been modified. Original reviewer comments are in italics and our itemized response is in red color.

Reviewer #1:

General comments: This paper is an important contribution, presenting characteristics of three classes of marine low clouds classified by their morphology and type of mesoscale cellular convection (MCC) on a global scale. The classification is based on an artificial neural network scheme developed in a previous study. The physical and radiative properties are presented. Many results are new and important for understanding the cloud and precipitation processes in these types of clouds that are main modulators of cloud radiative forcing with high albedo and cloud coverage. The manuscript is well written and the results are clearly presented. I recommend that this paper is published with minor revisions. There are several suggestions for revisions as described below.

Major points

1. P6986, L12: The retrieved optical thickness and effective radius are not available or not accurate when the sun is low. Therefore, high latitude regions in winter seasons could not be investigated with the method used in this paper. Nevertheless, Fig. 5 present results for global maps including the high latitude regions in winter. I am wondering how reliable these results are.

We agree with the reviewer that MODIS cloud optical depth and effective radius retrievals at high latitudes may be problematic due to the influence of low sun elevation angles and the possible presence of sea ice particularly during the winter months. For this reason, we excluded all low cloud regions beyond about 65^{0} North or South from our statistical analysis. However, in Fig. 5 we still present results for these regions but the results should be taken with caution. We modified the text as follows:

In section 2:

"Also, it is emphasized that cloud retrievals based on MODIS radiances may be problematic at high latitudes due to the effect of low solar zenith angles and the possible presence of sea ice during the winter months. Therefore, low cloud regions above and below about 65^{o} N or S are excluded in the subsequent analysis."

In section 3:

"Closed MCC are also the dominant type of low cloud morphology in the Arctic Ocean east of Greenland (i. e., the Greenland Sea). However, this result should be taken with caution due to the inherent uncertainty in MODIS cloud retrievals (i. e., cloud optical depth and effective radius) at high latitudes mentioned in Section 2."

2. Sect 4: In my view, I do not feel strong necessity to describe technical details in this section to present the case study results that are not very interesting. The results are all reasonable but it seemed to me that there are few new findings. If implications from the case study and association with subsequent sections are clearly described, it may be helpful for readers.

Our study presents a novel concept for analyzing the impact of cloud morphologies on the physical and radiative properties of marine low clouds. As such, we think that a proof of concept as presented in section 4 is adequate. However, we shortened this section to make it more concise and appealing to the reader. In particular, we omitted some technical details as suggested by the reviewer.

3. The mesoscale-domain-mean shortwave reflectance and transmittance are determined primarily by cloud fraction and cloud optical thickness. While the authors present variability of cloud fraction, there is no explanations about the cloud optical thickness. Before an explanation of the variability of mesoscale-domain-mean shortwave reflectance, it would be of interest to see the variability of cloud optical thickness.

We agree with the reviewer and added cloud optical thickness to our analysis in Section 6.

4. Also, results in Figures 14 and 15 seem to be for domain-mean reflectance and transmittance including contributions from cloudy and clear-sky pixels in the domain. Please specify that definitions to avoid misunderstanding. On Page 6999, line 24, I think this sentence is misleading because the mesoscale-domain-mean shortwave reflectance discussed here may be confused with mean reflectance of cloudy pixels excluding contributions from clear-sky pixels.

We rephrased the text in section 6 to be more clear:

"We emphasize that the inferred statistics of radiative properties of MCC types are representative of the cloud field on the scale of several tens of kilometers (including clear-sky pixels) rather than on the scale of individual clouds contributing to the cloud field. This is because the footprint of the CERES instrument is about 20 km and, thus, much larger than the footprint of CloudSat or CALIPSO. Therefore, we are unable to infer the radiative effect of individual Sc clouds but only the radiative effect of the (mesoscale) field of clouds on the scale of a few tens of km."

Minor points

Page 6986, line 9: The MODIS measures the radiances, and "irradiances" should be replaced with "radiances".

Done.

Page 6986, line 10: Please specify a Collection number of the MODIS product.

It's collection 5. We added this information in Section 2.

Page 6987, L9: "The higher horizontal and vertical resolution of the lidar allows. . ." Exact values of the resolutions would be of interest.

The resolution of the lidar is roughly 1 km along track, 300 m across track and 75 m in the vertical. This is now mentioned in the text of Section 2.

Page 6990, line 10: "previous satellite-based estimates (Leon et al., 2008)" Would be interested in some more details of similarity and difference between methodologies used in the present study and that of the previous study.

The similarity is that both studies use a combination of the CALIPSO feature mask and the CloudSat GEOPROF cloud mask for the detection of marine low clouds and drizzle. Also, there are some minor technical differences such as the choice of thresholds used in the CPR cloud mask, the height threshold used for the identification of low clouds, and the Z-R relationship applied for the conversion of radar backscatter to rain rate. The important novel element of this study is the combination and analysis of cloud, precipitation and radiation observations from the A-train within the cloud classification framework, which allows us, for the first time, to analyze the physical properties and radiative impact of low clouds as a function of the cloud morphology on a global scale.

Page 6991, line 11: Please exactly define the "frequency of occurrence of closed MCC". Is this a fraction of frequency of closed MCC occurrence to total frequency of all low cloud regimes?

All MCC observations are binned into $5^0 \times 5^0$ regions. In each grid box, the frequency of occurrence is the fraction of occurrences of a certain MCC type to the total number of all MCC occurrences expressed as a percentage value. We clarified this in section 3 and in the caption of Fig. 5.

Page 6995, line 24: "low cloud fraction determined from the CPR". Why not use the CALIOP here to determine the low cloud fraction?

The detection of low clouds uses a combination of radar and lidar following Marchand et al. (2008) and Mace et al. (2008). Thus, the lidar information is taken into account whenever possible. We rephrased the sentence to avoid confusion.

Page 7002, line 20: "the differences are not found to be statistically significant". If so, I think the first sentence in Conclusion 6 should be just removed from the Conclusions.

Actually, the differences are statistically significant based on the Wilcoxon rank-sum test. We modified our statement accordingly:

In section 5.3: "Based on the nonparametric Wilcoxon rank-sum test (Wilks, 2006), the median cloud top height differences among the MCC categories in the global data set are statistically significant at the 95 % confidence level."

However, we removed the part of the sentence in the conclusions to make it more concise.