Review of Sohn and Choi "A cautionary use of DCC as a solar calibration target: explaining the regional difference in DCC reflectivity ",Atmos. Meas. Tech. Discuss., 8, 2409–2436, April 8, 2015.

The authors attempt to demonstrate why the TWP DCC reflectances are darker than over the Africa and South America during the A-train overpass times in January. Using collocated MODIS, CloudSat, and CALIPSO data they conclude that IWP difference explains the difference of DCC reflectivity. I also find the contradictory MODIS and CloudSat retrieved DCC particle sizes most interesting. I am also pleased to see that the paper does indicate the most difficult part of the DCC calibration approach is selecting the identification thresholds to obtain only the DCC cores.

I believe the paper is worth publishing after the following issues are addressed.

Before responding to each question, I would like to provide how raised important issues will be addressed in the revision. But, before doing that I convey my sincere thanks for reviewer's comments which were taken seriously to fix our mistakes and to make the arguments clear.

Inconsistency of the title with contents (related to #1, #2, #3, #4)

We fully agree that the DCC method has not been much discussed while a main attempt has been made for explaining why deep convective clouds over the Western Pacific are in smaller reflectivity than those over tropical continental regions. In fact, it was the main objective, and the use of the findings for the visible calibration was a secondary issue. As you correctly pointed out, we focused mainly on explaining the contrasting features of reflectivity between land and TWP noted in Doelling et al. (2013).

Recognizing and admitting that the main objective is to explain the geographical difference in DCC reflectivity instead of focusing on the solar calibration, we wish to change the title accordingly fitting to the contents, carrying what we have done and discussing possible implication in the DCC calibration method. We admit that a serious mistake has been made in describing the data processing for selecting the DCC targets. Although we have used the criteria of TB < 205K for defining the DCC, samples were limited with ones showing highly convective single layer cloud whose depth is thicker than 15 km. It is not truly TB_{11} < 205K alone to determine the DCCs. Furthermore, at this time we find no reason why TB_{11} < 205K should be used because a 15 km depth is used as a DCC criterion, excluding the possible mid-identification of cirrus and anvil clouds.

Thus, being consistent with what has been done we propose to change the title and rewrite the introduction. New figures and tables were introduced, with explanation.

Sampling and its associated issues (related to #4, #8, #12)

The DCCs of interest in this study are defined as a single-layer cloud whose depth is greater than 15 km and thus cloud tops reach around the tropopause level. Cirrus and anvil type clouds were effectively removed by selecting only thick convective clouds. The small sample numbers in Table 1 are due to the 15-km depth as a single layer used for defining the DCC and the homogeneity check using 9x9 pixels, which was consider to be one way alleviating the parallaz problem. In the revision, after making the parallax correction, 3x3 MODIS pixels surrounding the collocated CloudSat pixel were averaged. In so doing, new sample numbers are now 980, 2295, 2455, 23836 for Africa, South America, WP-land, WP-ocean (Table 1).

In this new data processing, as the reviewer suggested, we further divided the WP domain into its land and ocean regions (WP-land and WP-ocean). It is indicated that the African and South American domains show much larger IWCs in comparison to that over the WP ocean region. Separation of the western Pacific domain into land and ocean regions reveals that WP land region has larger IWP compared to the ocean region, but smaller than those for other two continental regions. Thus the contrast in reflectivity would be more evident if the WP ocean-only region is compared to continental land regions. New figures were produced with new data.

We give thanks for questioning the sampling number, which led to fixing the serious mistake.

Outline of revising the manuscript

In the revision, instead of bringing in more of the DCC calibration issue, we like to deliver what we have, i.e., explanation why highly deep convective clouds are more reflective over the land than over ocean. In doing so, a new introduction is introduced with a changed title and possible implication of the obtained results in the visible channel calibration of satellite-borne sensor is discussed.

#1. The emphasis of the paper is not the DCC calibration method but explaining the DCC reflectance difference between TWP and South America and Africa. However the title implies that the paper will address the DCC calibration method. However, it seems to be a side topic of this paper. The DCC method is not outlined anywhere in the paper. It simply uses the DCC identification provided in Doelling et al. 2013 to compare the regional DCC characteristics. There needs to be a greater contribution of the DCC method in the paper in order to be consistent with the title.

We fully agree that the DCC method has not been much discussed while an attempt has been made mainly for explaining why deep convective clouds over the western Pacific are less reflective than those over tropical continental regions. In fact, it was the main object, and the use of findings for the calibration purpose was a side issue. In the revision, as you correctly pointed out, we focus mainly on explaining the contrasting features of reflectivity. New title and introduction are as follows:

Title: Explaining darker deep convective clouds over the western Pacific than over tropical continental convective regions

Introduction:

Deep convective clouds (DCCs) associated with strong convection play an important role in the global climate because DCCs can alter the radiation balance not only due to changes in solar reflectivity or infrared emission level but also due to changes in water vapor and hydrometeor profiles associated with deep convection. DCCs are known to be potentially important in the radiation balance (e.g., Soden and Fu 1995; Aumann et al. 2007). DCCs over the Tropics can supply moisture from the lower troposphere to the upper troposphere, enhancing the water-vapor greenhouse effect (Soden and Fu 1995; Sohn and Schmetz 2004; Chung et al. 2007; Sohn et al. 2008). Furthermore, DCCs can be used as calibration targets from which satellite-borne solar channels can be calibrated (Sohn et al. 2009; Ham and Sohn 2010; Doelling et al. 2013; Kim et al. 2013). Thus, it is of interest to examine the optical and physical properties of DCCs to attain a better understanding of their impact on the radiation balance and for better parameterization of their optical properties for radiative transfer simulations.

A recent study by Doelling et al. (2013), based on an analysis of Moderate Resolution Imaging Spectroradiometer (MODIS) solar channel measurements, reported that DCCs over the tropical western Pacific have lower reflectivity (or are darker) than DCCs over continental tropical regions such as Africa and South America. This phenomenon is quite interesting and an immediate attempt to explain the reason for it may be related to different cloud microphysics between land and ocean. The difference in the diurnal cycle of convection and the vertical structure of DCCs between the oceanic western Pacific and tropical South American or African land regions has been well documented (e.g., Liu and Zipser 2005; Nesbitt et al. 2006; Zipser et al. 2006; Liu et al. 2007). Most of these results are based on Tropical Rainfall Measuring Mission (TRMM) measurements. However, considering that TRMM radar signals reflect microwave interactions with raindrops and precipitation-size ice particles, these analyses may be insufficient for explaining the difference in cloud reflectivity. Scattered solar radiation caused by cloud droplets and ice particles should be considered to completely understand the cause of such a difference.

In this study, with the goal of understanding why DCCs over the western Pacific show generally lower reflectivity in comparison with those over tropical African and South American regions, regional differences in optical properties of DCCs are examined using CloudSat Cloud Profile Radar (CPR) and Cloud Aerosol Lidar Infrared Pathfinder Satellite Observation (CALIPSO) measurements. From an intercomparison of the vertical structures of DCC optical properties, important elements causing regional differences in DCC reflectivity are identified. Then, we address the issue of how the obtained results are relevant for the possible use of DCCs as calibration targets from which satellite-borne solar channels can be calibrated. The results obtained from this study will lead to a better understanding of the role of tropical DCCs in influencing radiation budgets and climate feedback and may also improve the performance in the use of DCC targets for solar channel calibration.

#2 and #3:

Page 2411 line 4. "DCC have radiatively similar behaviors" This is a very confusing sentence. It does not clarify the foundation of the DCC calibration. Must each individual DCC have the same reflectivity for DCC calibration to be successful? DCC calibration is a large ensemble statistical method that does not depend on the reflectance of one DCC cell, but relies on the inter-annual consistency of the spatial and seasonal distribution of all identified DCC over a large equatorial domain. This fact was proposed with the seminal Hu et al. 2004 DCC calibration paper.

Y. Hu, B. A. Wielicki, Y. Ping, P. W. Stackhouse, Jr., B. Lin, and D. F. Young, 2004: Application of deep convective cloud albedo observation to satellite-based study of the terrestrial atmosphere: monitoring the stability of spaceborne measurements and assessing absorption anomaly. Geoscience and Remote Sensing, IEEE Transactions on,42, 2594-2599, doi:10.1109/tgrs.2004.834765.

Page 2411 line 10. "simple adaption" I do not know what a simple adoption would consist of, since those are not published. Since the title of this paper mentions DCC as a calibration target, then a brief summary of the DCC calibration method needs to be given in the paper. This way the reader can differentiate between the published DCC calibration methods and a simple adaption. The method of DCC detection is critical to the success of DCC calibration. As mentioned in this paper, it is difficult to differentiate the anvil with the convective core.

Thanks for pointing out confusing description. Hu et al. (2004) and later Doelling et al. (2013) are a different method. Here we tried to explain the method introduced by Sohn et al. (2009) for the use of DCC targets for the visible channel calibration. In Sohn et al., radiances were simulated for DCC targets by using a radiative transfer model under homogeneous overcast ice cloudy conditions for COT = 200 and r_e = 20 μm. Those COT and r_e values are assumed to be typical for DDCs. From the comparison of the simulated radiances with MODIS-measured values it was claimed that visible-channel measurements can be calibrated within an uncertainty range of ±5%, which can be applicable for the calibration of a satellite-based visible-channel sensor.

New discussion has been made in Conclusions and Discussion section, i.e.:
The regional differences in DCC's optical properties noted in this study cast a cautionary warning for the use of DCCs for the solar channel calibration without taking those different factors into account when radiative transfer calculation is involved. Using a radiative transfer model under homogeneous overcast ice cloudy conditions for DCCs with COT = 200 and R_e = 20 μm, Sohn et al. (2009) claimed that simulated radiances at the MODIS 0.646-μm channel are in the agreement with satellite-measured radiances within an uncertainty range of ±5%, which is often a calibration target for the geostationary-based solar sensor. In that paper, a criterion of TB_{11} < 190 K was used for defining DCCs. Sohn et al. method was implemented for examining the calibration performance of the Meteosat-8/9 Spinning Enhanced Visible Infra-Red Imager (SEVIRI) 0.640-μm channel (Ham and Sohn, 201), successfully demonstrating that Meteosat-8/9 0.640-μm channels are underestimated by 6–7%.

This calibration method is particularly useful for calibrating the visible sensor not equipped with the onboard calibration system because the method only requires DCC pixels determined from measurements of window channel brightness temperature, not requiring other information from other satellites. The results obtained in this study suggest a way how the proposed calibration method using DCC samples can be improved. For instance, instead of treating selected DCCs equally to produce the same reflectivity everywhere over the tropics as in Sohn et al. (2009), radiative transfer modeling for DCCs can be done to yield less reflectivity at least over the western Pacific. It is because, as shown in Fig. 2 and Table 2, the DCCs produced over the ocean are generally less reflective than DCCs found over the continental convective regions such as Africa and South America.

Sohn, B.-J., S.-H. Ham, P. Yang, 2009: Possibility of the visible-channel calibration using deep convective clouds overshooting the TTL. *J. Appl. Meteorol. Clim.*, **48**, 2271-2283.
Ham, S.-H., and B. J. Sohn, 2010: Assessment of the calibration performance of satellite visible channels using cloud targets: application to Meteosat-8/9 and MTSAT-1R. *Atmos. Chem. Phys.*, **10**, 11131-11149.

#4. Fig 2b, Fig 2c. Doelling et al. 2013, DCC calibration method uses the mode of the reflectivity PDF to further limit the contribution of anvil reflectances. The mode reflectance in Figure 2b show that there are differences between South America, which has the greatest mode reflectance, and Africa and the TWP. The authors are concentrating on the mean DCC reflectances, which combines both the DCC core and anvil conditions. Over the TWP more anvil conditions are represented than over South America and Africa. If the TWP anvil conditions could be removed from the analysis, would that significantly change any of the CloudSat based conclusions?

In this study, we examine DCC-only targets limited by highly deep convective clouds whose depth is thicker than 15 km as a single layer, effectively excluding cirrus and anvil-type clouds. Thus the mode difference between any two regions shown in Fig. 2b should not be associated with cirrus and anvil conditions.

We again admit our mistake to describe the collocation processing, which caused misleading.

#5 and #6
Abstract. The abstract indicates there is a 5% difference between TWP and the land sites. However, this does not take into account the mode reflectance as described in Doelling et al. 2013 DCC calibration algorithm. It represents the mean DCC reflectance with the sparse sampling of CloudSat during January.
Page 2422 line 25, Page 1416 line 23. A follow up question. A reflectance threshold of 0.95 to capture only the DCC cores, indicates to me that Africa and the TWP are within 1% of South America DCC reflectivity. If that threshold were applied in the CloudSat analysis, would that change any of the CloudSat based conclusions?

The mode difference also indicates that there exists an intrinsic difference even in the mode between land and ocean (see new Figure 2b). It seems that the modes are in good agreement between DCCs over the land (Fig. 2b) although there are clear differences in the mean reflectivity, i.e. 0.939, 0.929, and 0.900 for Africa, South America, and WP-land. The mean reflectivity over WP-ocean is 0.846. Although there should be some useful information which may be used for the calibration of visible sensor, it is not the main issue of this paper, as newly described in Introduction.

#7 Page 2413 line 23. There is no mention what the A-train sun-synchronous satellites local equator crossing time is. This is very important information, since the results in this paper are only valid at this local time.

1:30 p.m. local time is included.

#8 There is another possibility of lower DCC reflectances over the TWP, and that is that the TWP represents all phases of the TWP lifecycle, especially over ocean, whereas over South America and Africa all of the TWP are in the same phase of the diurnal lifecycle, due to the A-train local overpass time of 1:30PM. If the land DCC are in the peak of the convection stage, then there are less anvil conditions and less precipitation, then in the dissipation stage. Are the cloud physics differences more associated with regional atmospheric conditions or dependent on the life-cycle of the DCC?

We understand the reviewer's concern about diurnal variation affecting results here. The life cycle of individual deep convection including the ascent and development of precipitation, and downdrafts lasts for an hour or so, then convection in the decaying stage evolves to the development of long-lived anvil clouds (Mapes et al. 2006) that may last several hours. Even though deep convective clouds are less frequent in both land and ocean at around 1:30 pm, DCCs selected here are likely before evolving into the later stage because they still maintain the layer thicker than 15 km. Thus DCC samples used in this study may be snap shots of the storms at any time in the one hour window of mature stage. Thus results obtained here are largely attributed to cloud's microphysical differences between land and ocean, rather than to the different diurnal variations.

Mapes, B., S. Tulich, J. Lin, P. Zuidema, 2006: The mesoscale convection life cycle: Building block or prototype for large-scale tropical waves? Dyn Atmos Oceans, 42, 3–29.

#9 The TWP also contains land regions yet this paper did not distinguish between ocean and land regions. The TWP domain also has sufficient sampling to stratify between land and ocean. I do agree that the TWP reflectance over ocean and land are darker than over South America and Africa. However, the Doelling et al. 2013 Fig 6 indicates that the TWP land regions have a very different 2.12μm reflectivity than over oceans, which indicate different cloud microphysics over land than oceans. This could be helpful in distinguishing between regional and life-cycle differences adding much value to the paper.

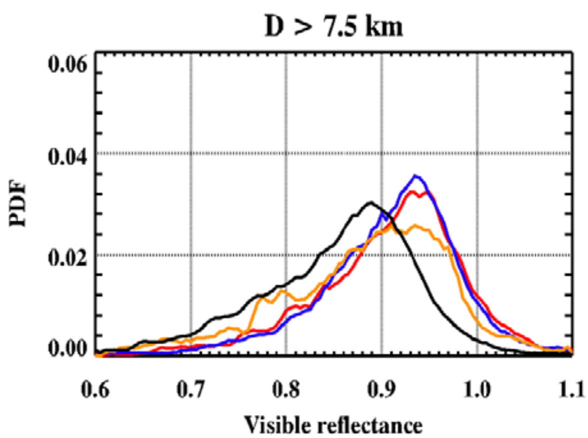
Thanks for the suggestion. In the revision, we presented results after dividing the TWP domain into its land and ocean sub-domains.

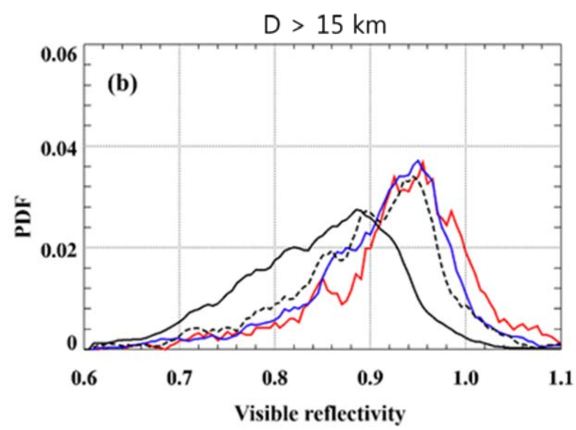
#10 Page 2423 line 18. "regionally different criteria between land and ocean can be introduced". As mentioned in the previous comment, there is also land over the TWP. Doelling et al. 2013 also shows that the TWP ocean is darker compared to the East Pacific and Atlantic ocean regions. This statement cannot be made unless the TWP land regions are evaluated.

This has been removed from the discussion part. Reflectivities of 0.94, 0.93 for Africa and South America are larger than 0.90 over the TWP-land, and far larger than 0.846 for the TWP-ocean. Yes, indeed there is a substantial difference in reflectivity between land and ocean. However, it is also true to say that DCCs over the TWP are less reflective than over continental Africa and South America, considering that the frequency-weighted mean reflectivity over the TWP is 0.85, which is far smaller than continental counterparts.

#11 Page 2423 line 29. "A more stringent criteria of TB = 195K". Since this criterion is just a subset of the TWP in this study, would that change of the CloudSat cloud physics conclusions, such as the IWC and extinction coefficient profile distribution? Would that help isolate only the cores from the anvils? Do the authors believe the colder TWP criteria would make the CloudSat profiles more consistent with Africa and South America? Is the point of the study to say that consistent DCC reflectivity relies on consistent cloud microphysics?

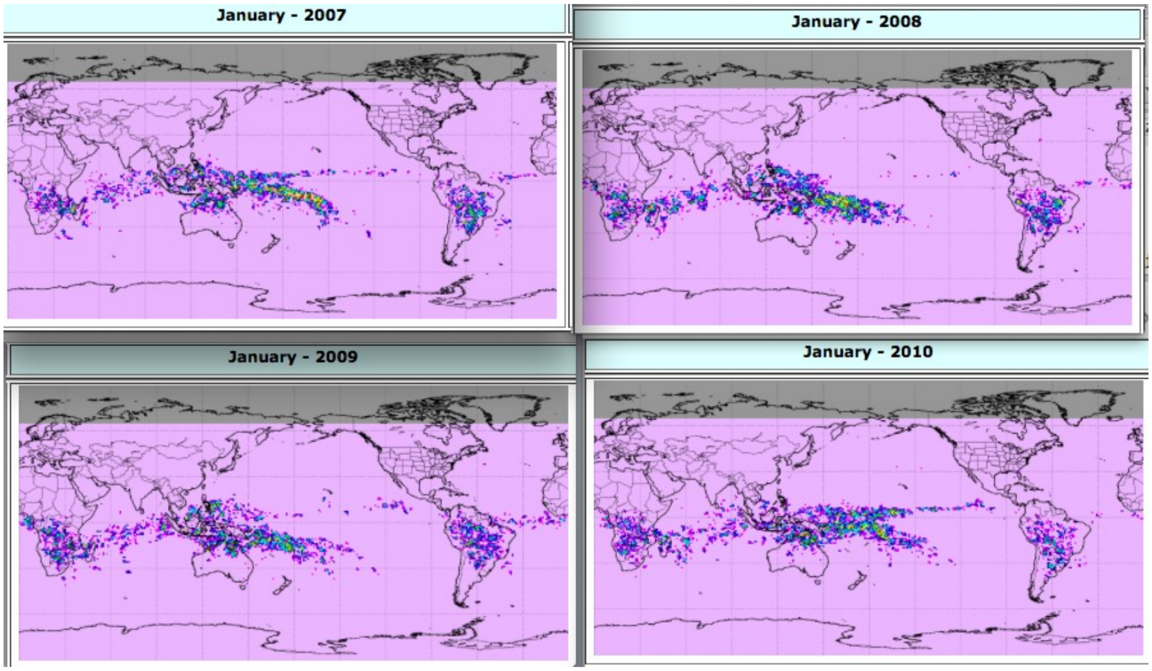
According to the results, we may not have radiatively coherent and consistent DCCs throughout the tropics even if we successfully remove all anvil type clouds. We provide one example. Even for clouds whose depths > 7.5 km (left figure) there appears to be fundamental difference in cloud microphysics between land and ocean. The right-hand side figure is one presented in Fig. 2b of the revised manuscript.





Thus, I would say there is no way to make them consistent between TWP and Africa/South America. This has been discussed in the last section "Conclusion and discussion."

#12 Page 2415 line 7 and Table 1. I am unconvinced that the African domain has the DCC frequency as shown in Table 1. There are 217 observations in 2007 and only 8 in 2008, which is a 96% drop in frequency. I have displayed the CERES ISCCP-D2like cloud product Aqua-MODIS ice cloud frequency for cloud top pressures less than 180mb and optical depths greater than 60.36. (http://ceres-tool.larc.nasa.gov/ord-tool/jsp/ISCCP- D1Selection.jsp). These plots do not indicate any overwhelming sampling in 2007 and sparse sampling in the remaining years.



As mentioned in the beginning of this response, the small sample number especially over Africa is mainly due the definition of the DCC employed in this study.

#13 If I understand correctly, only MODIS pixels along the CloudSat/CALIPSO line of sight were used to identify DCC. No inter-annual comment over Africa can be made until there is sufficient sampling over the 4 years.

That's right. Claims on the interannual variation were removed.

 # 14 Figure 4d. Is the peak at 5-km for the TWP associated with the melting line in Figure 3C? Does this imply that there is more precipitation in the TWP Fig. 3 profile? If the attenuation is great enough that the surface reflection is missing, this implies precipitation. Is this a possible explanation? Would this suggest that the TWP contains more phases of the DCC life-cycle than over Africa or South America?

Sassen, K., S. Matrosov, and J. Campbell (2007), CloudSat spaceborne 94 GHz radar bright bands in the melting layer: An attenuation-driven upside-down lidar analog, Geophys. Res. Lett., 34, L16818, doi:10.1029/2007GL030291.

Following paragraph is now added; "Below the melting layer at about 5 km, there is a bright band caused by more reflection by melting snow flakes (Saseen et al. 2007). But, decreasing reflectivity below the bright band suggests the attenuated reflectivity due to the rain particles. However, since different rain intensity results in different slopes of radar reflectivity profile (Fig. 2(a) of Sassen et al. 2007), the similar slopes found amongst four regions may suggest that precipitation rates are likely similar."

Page 2415 line 19. The word contamination is ambiguous, it could mean that there are optically thinner clouds above the DCC core. Does this term relate to "optically thinner convective/anvil-type clouds."? Please clarify that the DCC identification thresholds were also allowing more optically thinner clouds to be classified as DCC. The word misidentified is more fitting.

Thanks for the suggestion. We tried to avoid ambiguous words like "contamination".

Page 2413 line 18. Have the CloudSat collocations been parallax corrected when they were collocated with MODIS? Yang et al. also used CloudSat, CALIPSO and Aqua- MODIS coincident data to examine DCC.
Young, A. H., J. J. Bates, and J. A. Curry (2012), Complementary use of passive and active remote sensing for detection of penetrating convection from CloudSat, CALIPSO, and Aqua MODIS, J. Geophys. Res., 117, D13205, doi:10.1029/ 2011JD016749.

Wang et al. 2011, "Parallax correction in collocating CloudSat and Moderate Resolution Imaging Spectroradiometer (MODIS) observations: Method and application to convection study", JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, D17201, doi:10.1029/2011JD016097, 2011.

Thanks for the comment on the parallax correction and provided references. In the first version, we alleviated the problem by taking the spatial homogeneity test over 9x9 pixels centered at a CloudSat pixel. But, in the revision, we made the parallax correction.