Anonymous Referee #2

General comments: The authors analysed the impact of fine and coarse dust aerosols on the day-to-day variability of stratiform cloud glaciation occurrence by using 4 years' satellite cloud phase products and MACC aerosol reanalysis. Compared to the previous study, this study mainly focused on the day-to-day variability of cloud phase. The results showed that the phases of stratiform clouds is highly dependent on temperature and latitude, and dust aerosol mixing ratio is anti-correlated with the average occurrence of fully glaciated stratiform clouds. Generally speaking, the paper is interesting, and tables and graphics are well constructed. As a result, I am recommending the paper be accepted with major revisions if the authors response properly my comments. Some main questions and comments I have are listed below in the specific comments to the authors.

We thank Anonymous Referee #2 for his encouraging comments.

Specific Comments:

(1.a) One of my concerns is: The applicability of MACC aerosol reanalysis, especially over the Southern Ocean, where ground-based measurements are sparse. There is no direct observation evidence of dust aerosol to prove the applicability of MACC aerosol reanalysis.

Indeed, all evidence is from northern hemisphere. However, until such studies are available in the southern hemisphere, we assume that the positive past evaluations in the northern hemisphere reflect that the emission, transport and deposition mechanisms should offer a valid estimate in the southern hemisphere.

We have emphasized in the outlook the need of future validations of the MACC aerosol reanalysis in the southern hemisphere.

See also response to Anonymous Referee #3: *"…showing a mean bias of 25% between MACC and LIVAS (dust product based on CALIPSO satellite) over Europe, northern Africa and Middle East. Additionally, the correlation between MACC and AERONET (network of ground-based remote sensing stations) was found in the range of 0.6 over the Sahara and Sahel to 0.8 over dust transport regions."*

(1.b) In addition, the variable used in this study is dust mixing-ratio? Isn't mass concentration? I think that the dust mass concentration should be more proper for this analysis.

The height of the studied isotherms varies from 0 up to 8 km from pole to the equator (See supplement S12). Because the different atmospheric pressure at these levels lead to different molar volumes of air, mixing-ratio (kg/kg) has the advantage of being independent of pressure. However, we believe that both mixing-ratio and dust mass concentrations can be valid parameters. Additionally, mixing-ratio (kg/kg) is the original output of the MACC reanalysis.

(2) One suggestion: The section 3 includes too much information, and it is easy to confuse the readers. May you provide us one table or flow chart? The authors also reconstruct this section to make the method clearer. For example, move the lines 177-195 to the first paragraph, and following sentences interpret these variables.

We have now included a flow chart as suggested. The Methods section has been also reordered to match the diagram.

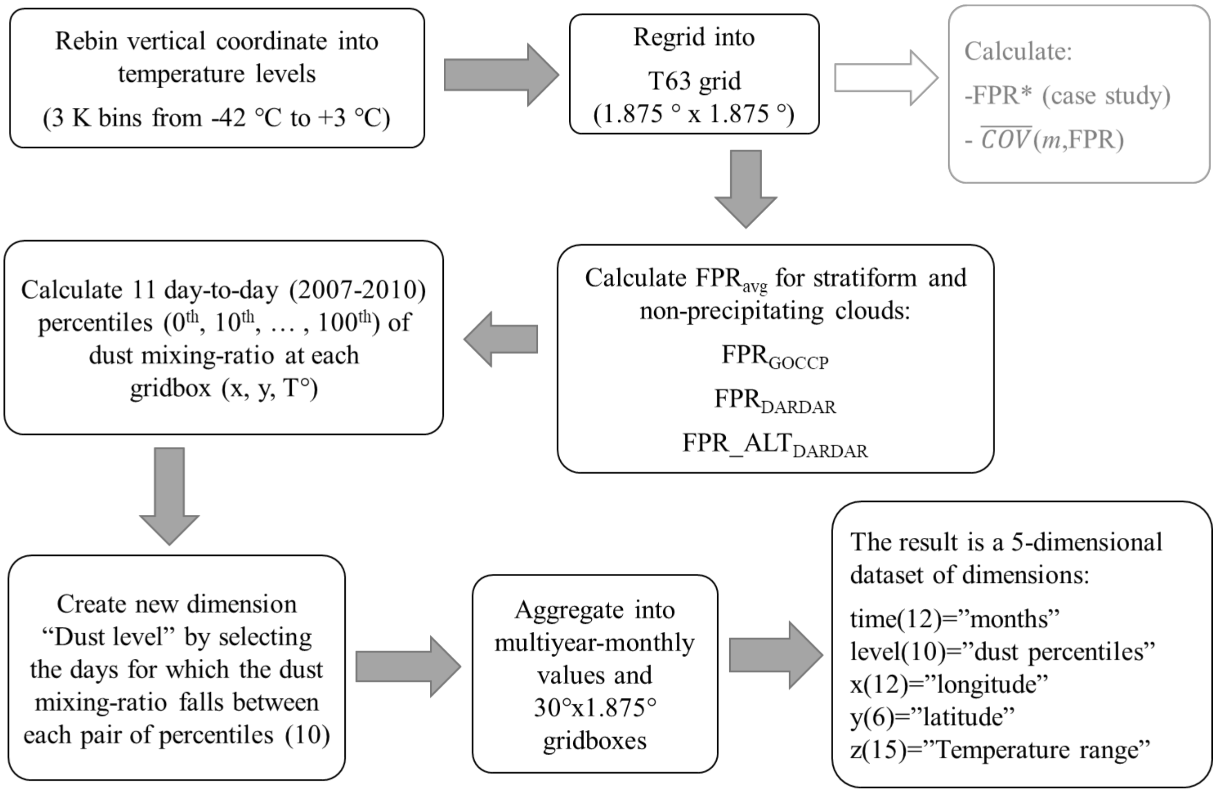

Figure 1. Flow chart of the data processing steps.

(3) Line 125: What is the meaning of the Jan'0?
Jan'09 (January 2009). Corrected and clarified.

(4) Line 140: Please provide the detailed information about the classification of nonprecipitation.

See response to Anonymous Referee #1: "As briefly mentioned in lines 88-89, the 2B-CLDCLASS product uses mainly the radar reflectivity to classify clouds as "precipitating". The radar is sensitive to large particles (e.g., rain drops) and therefore clouds with a reflectivity larger than a given temperature-dependent threshold are defined as "precipitating". The fifth range gate (~1.2 km above ground level) is used for the classification. The threshold is defined between -10 and 0 dBZ for temperatures between -10 °C and 0 °C and constant outside this temperature range (Hudak et al., 2009).

Hudak et al. 2009 offers a validation of the 2B-CLDCLASS precipitation product and a brief description (paragraphs 10-11) of the precipitation algorithm.

References: Hudak, D., Rodriguez, P. and Donaldson, N.: Validation of the CloudSat precipitation occurrence algorithm using the Canadian C band radar network, J. Geophys. Res. Atmos., doi:10.1029/2008JD009992, 2009.

These points have been added to the Methods section."

(5) For the equations 3.2-3.5, FPR or FPR*?
FPR is right. FPR* (Equation 3.1) is only used in Sect 4.1 as stated in text. FPR* is used exclusively to ease the visualization of the thermodynamic phase in the case study (to show only clouds with significant cover).

This has been now clarified in the methods section.

See also the response to Anonymous Referee #3: *"The sole purpose of the definition of FPR* is to plot the cloud phase as a range between LIQUID and ICE while also blending out non-significant clouds (of cvf~0). Here the cloud volume fraction cvf is used merely as a filter to aid the visualization in Fig. 2."*

(6) The main concern is: the authors how to peel off the impact of meteorological condition from dust loading. Because the aerosol and dynamical factor usually are co-variability. Thus, some discussions about dynamical factor are necessary.

See response to Anonymous Referee #1: *"We agree that the constrains on the data are not enough to prove a causal relationship between dust aerosol and cloud phase. Given the limited data available, we found that additional temporal constrains on the dataset (e.g. dynamic regimes) leaded to insufficient sample sizes in the individual regimes. Therefore, we focused in analysing the co-variability between dust aerosol and some key dynamical parameters in Fig 8 (RH, cloud height and updraft) to rule out the possibility of some of these parameters driving the co-variability observed in Fig 6. From this analysis, we concluded that the co-variability between dust mixing-ratio variability and dynamics appears to be too low to support that the observed increases of ice occurrence in Fig. 6 are controlled by dynamics.*

However, we agree that a methodology to isolate the effect of aerosols from the correlated effect of dynamics is still lacking. Therefore, we have now emphasized the need for such a methodology in our outlook: "Additionally, the further development of a methodology to isolate aerosol-cloud interactions from atmospheric dynamics has the potential to lift much of the uncertainty found in this study."

(...)

The correlation between dust mixing-ratio and updraft suggest indeed that (everything else held constant), the ice occurrence should decrease at higher dust mixing-ratios. In fact, larger updrafts favour supersaturation and therefore CCN activation, droplet growth and inhibition of the WBF (Wegener–Bergeron–Findeisen) process. All three process would lead to a lower cloud ice occurrence. One could then argument that the increase in ice occurrence for higher dust mixing-ratio should be even larger if the effect of updrafts is considered. We agree however, that this would rise a larger discussion. Immersion freezing, for example, requires saturation over liquid water. This could result in updrafts promoting heterogeneous nucleation.

The spatial correlations in the study of J. Li et al. 2017 show actually an increase in cloud ice occurrence for higher large-scale updrafts. Although not included in the paper, we also found a day-to-day increase in cloud ice occurrence for higher updrafts. Therefore, the in-depth analysis of the dust-updraft-iceOcurrence co-variability would need a new evaluation of the relationship between large-scale updraft and ice cloud occurrence. As mentioned by

Anonymous Referee #1, this would lead to a large (and necessary) discussion but we think that it lays outside the scope of this study.

This issue has been now commented in the Discussion."

And the response to Anonymous Referee #4 :" *We agree that stability is a useful parameter for separating between aerosol-cloud interaction regimes. However, figure #4.1a shows that we found no significant difference in the day-to-day correlation between dust and ice occurrence for different stability regimes (defined as "unstable", "neutral" and "stable"). Nor were the day-to-day changes in stability associated with changes in ice occurrence. We used lower-tropospheric static stability (LTSS) following Li et al. 2017 (defined in (Klein and Hartmann, 1993))."*