Reviewer's comments in black, replies in blue.

In my opinion, this paper misrepresents the measurements and does not offer any new information. One of the premises stated in the paper is that (e.g. lines 236 – 237): "The ice PSD measured by the Learjet indicates that large frozen drops were observed at colder temperatures than small ice", contradicts the ICE-T measurements shown in Lawson et al. (2015). In the example in Lawson et al. (2015) Fig. 2, there is a clear progression showing that large supercooled drops freeze prior to small drops in the updraft, and the ice PSD shows much higher concentrations of small ice than large frozen drops at the coldest temperatures. These measurements are supported in the mean PSDs shown in Figs. 5 and 9, which are based on all of the cloud penetrations shown in Table 1.

Answer: We appreciate your careful reading of the manuscript and your insightful comments. The purpose of this study is to quantitatively estimate the freezing time of supercooled drops with different sizes, and to show the importance of the drop freezing time in understanding aircraft observations, modeling drop freezing, and evaluating models using aircraft measurements, which are rarely discussed in previous studies. This is important because in models freezing of supercooled drops are assumed instantaneous; this is not true and is an oversight in developing models. Assuming instantaneous freezing may be an important source of uncertainties in modelling convective clouds, for example, instantaneous freezing of supercooled drops results in the sudden release of a large amount of latent heat, which may lead to an overestimation of the vertical velocity in modeled convective clouds.

According to Fig 2, 5 and 9 in Lawson et al. (2015), you suggest that "*large supercooled drops freeze prior to small drops in the updraft, and the ice PSD shows much higher* *concentrations of small ice than large frozen drops at the coldest temperatures*". This does not contradict our study, and we agree that large supercooled drops are likely to start to freeze prior to small drops in the updrafts. As seen in Fig. 2 and 5 in Lawson et al. (2015), the ice observed at about -8 C were small, with larger frozen drops observed at temperatures colder than -8 C. Taking into account the relatively long freezing time for large drops, the observed frozen drops may start freezing at temperatures warmer than observed within the strong updraft core. We are not arguing the drops at the early stage of freezing should be regarded as ice, actually these drops probably contain more liquid mass than ice mass. However, in models any supercooled drop that begins to freeze is regarded as a fully frozen drop; this is why there is large ice at about -8 C in the simulation, inconsistent with airborne observations (Fig. 1). In the revised manuscript *"The ice PSD measured by the Learjet indicates that large frozen drops were observed at colder temperatures than small ice"* is changed to "*The ice PSD measured by the Learjet indicates that ice observed at about -8 C are primarily small, and the larger frozen drops were observed at temperatures colder than -8 C*".

The paper also contains several statements that display a lack of understanding of the literature and the physics of convective clouds.

For example, lines 30 – 31 state: "Observations suggest that ice initiation in convective clouds is strongly related to the freezing of supercooled drops (Rangno and Hobbs, 2005; Lawson et al., 2015). While the statement has validity as written, the main conclusion of both of these studies is that ice initiation and ice production are strongly related to the size of supercooled drops.

Answer: We appreciate the comment. "*Observations suggest that ice initiation in convective clouds is strongly related to the freezing of supercooled drops*" is changed to "*Observations suggest that ice initiation in convective clouds is strongly related to the freezing of supercooled drops and the size of the freezing drops*".

Lines 34 - 35 state: "... during airborne measurements, freezing drops cannot be observed until they have experienced obvious deformation. This generalized statement does not apply in all situations, and perhaps does not apply in most situations. Large drops tend to deform when they freeze so that frozen drops larger than about 300 microns, which are 30 pixels across when viewed with the 2D-S, are most often discernable from supercooled drops of the same size. Smaller drops are readily discernable with the CPI, which has a much smaller sample volume and has poor sampling statistics for drops larger than about 300 microns. That said, there are certainly frozen drops that can be mistaken for supercooled drops, but laboratory experiments and comparisons with other in situ instruments (e.g., LWC and TWC devices), suggest these instances are in the minority.

Answer: We apologize for the unclear statement. We agree large drops tend to deform when they are close to fully frozen, and frozen drops larger than 300 microns are mostly discernable from supercooled drops using 2D-S images, small frozen drops are readily discernable with the CPI. However, it takes time for the drops to freeze and thus deform, so for drops at the early stage of freezing the deformation is slight, so they are generally spherical. In the revised manuscript, "*... during airborne measurements, freezing drops cannot be observed until they have experienced obvious deformation*" is changed to "*drops at the early stage of freezing usually has no or slight deformation*".

Lines 39 – 40 state: “the recalescence stage [of the freezing process of a supercooled drop], during which rapid kinetic ice nucleation occurs, which results in a rapid drop in temperature that is terminated when the drop temperature reaches 0 C.” The temperature of a supercooled drop doesn’t fall during the freezing process, it rises.

Answer: We apologize for the mistake, "*...which results in a rapid drop in temperature...*" is now changed to "*...which results in a rapid rise in temperature...*".

Line 45: Stating the (long) freezing time of a drop in still air (“typical air conditions”) is of no value and misleading, because as stated later in the paper, drop cooling and freezing time is largely a function of the convective heat transfer term, which is a nonlinear function of drop size.

Answer: Thank you for the comment. The sentence: "*In typical air conditions, it takes approximately 400 s for a stationary millimeter-sized drop to completely freeze at -5 °C under a pressure of 1 atm; this freezing time is reduced to approximately 200 s at -10 °C*" is removed in the revised manuscript.

Lines 77 – 78: First ice in cumulus may, or may not be small. First ice can only be reliably identified using high resolution imagery from the CPI or similar instruments, and the CPI and other similar instruments have relatively small sample volumes. This limits the ability to detect first ice, whether it is small or large. There are no conclusive measurements of the size and type of “first ice” in convective updrafts. In my opinion this is not well clarified in Lawson et al. (2015).

Answer: We agree there are no conclusive measurements of the size and type of "first ice" in convective updrafts. In the revised manuscript, "*first ice*" is changed to "*ice at relatively warm temperature (about -8 C)*". *Similar statements elsewhere have* been clarified too.

Line 94: The paper states that coalescence is neglected in the model. Yet, there can be no argument that this is the process that generates the large supercooled drops in tropical convective updrafts. This is a blatant oversight. This alone is grounds for rejection of the paper, unless the authors can definitively show that neglecting coalescence does not affect their results, and explain why this is so.

Answer: We totally agree that coalescence is the key process that generates large supercooled drops in convective clouds. Firstly, we'd like to clarify that coalescence is included in the parcel model to model cloud microphysics, but we neglect the impact of coalescence on the calculation of the freezing time of a single supercooled drop. It is not necessary to include the coalescence process in the calculation of the freezing time of a single supercooled drop, because the freezing time is the shortest assuming that drop size doesn’t increase due to coalescence after freezing begins. The drop size increase due to the coalescence process results in a longer freezing time. In this study, we prefer to examine the shortest freezing time of supercooled drop for a given size. The results indicate that the freezing time of supercooled drops larger than 200 microns in diameter is considerably long even if size increase due to coalescence is not included (longer than the typical time step of cloud resolving models), therefore, freezing of supercooled drop is an important process which should be considered in numerical models, but few models have done so.

Lines 107 – 108: “The primary goal of the Learjet was to make repeated penetrations in fresh developing convective updrafts near the cloud top.” This is incorrect. The primary objective of the Learjet was to make rapid, repeated penetrations of the updrafts of growing turrets at different altitudes. The C-130 was not capable of making rapid, repeated penetrations of growing convective turrets, and was certainly not capable of climbing with the updraft, which is what the Learjet did whenever possible.

Answer: We appreciate for the correction. *“The primary goal of the Learjet was to make repeated penetrations in fresh developing convective updrafts near the cloud top”* is changed to *"The primary objective of the Learjet was to make rapid, repeated penetrations in the updrafts of growing turrets"*.

Line 197: As stated in the paper: “The latent heat released due to freezing leads to a sudden drop in temperature from -8 C to 0 C.” Again, this is incorrect, either a mistake or a fundamental misunderstanding. Going from -8 C to 0 C is obviously a rise in temperature.

Answer:

We apologize for the mistake, "*The latent heat released due to freezing leads to a sudden drop in temperature from -8 C to 0 C*" is now changed to "*The latent heat released due to freezing leads to a sudden rise in temperature from -8 C to 0 C*".

Section 3.3 Discussion: The whole introduction of Hallett-Mossop ice multiplication is off topic and incorrect. H-M did not occur in strong ICE-T updrafts.

Answer: Thank you for the comment, we agree that the H-M process did not occur in strong developing ICE-T updrafts. The discussion about H-M process is removed in the revised manuscript.

The only correct result from this paper that I can find is that large supercooled drops take longer to freeze than small drops. But, this has been known for hundreds of years. I don't see how this paper can be salvaged in its present form. The work needs to be redone and the paper resubmitted.

Answer: We acknowledge your comments and suggestions. The purpose of this study is to show the importance of the freezing time to more fully understand aircraft observations, to model drop freezing, to evaluating models using aircraft measurements, and to note the deficiency of instantaneous drop freezing currently assumed in cloud models. The theory of heat transfer in the calculation of the freezing time of supercooled drops is not new, but the importance of considering the freezing time of large supercooled drops in modeling ice PSDs, in understanding the observed ice PSDs, and effectively using observations to validate and improve simulations has not been appreciated. We try to correct that oversight in our article.

We apologize for the unclear statements. The manuscript has been much improved based on your comments, and unclear statements have been clarified. For example, statements like "*freezing drops cannot be observed until they have obvious shape deformation*" are changed to "*drops at the early stage of freezing usually have a slight deformation*". Please see more revisions in the revised manuscript with track changes.