Anonymous Referee #1

The reviewer's comments are presented in italics, followed by our responses. We thank the reviewer for his comments.

The authors describe cloud microphysical measurements made at Storm Peak Laboratory (SPL) during 2 measurement campaigns during 2011 and 2014. They used in-situ microphysics probes to measure cloud particles including ice crystals and liquid droplets and looked at relationships between the different cloud properties but also with ambient meteorological conditions. They find some already established results, for example an inverse relationship between cloud droplet size and concentration due to CCN availability,

While the relationship between drop size and concentration is expected, the original Fig. 3 presents an added dimension to this relationship, which is found to depend on liquid water content. This demonstrates a unique aspect and a potential drawback to studies at mountaintop laboratories, where the cloud base height may vary below the lab.

and some less well understood results such as a correlation between large drops and small ice crystals and enhancement in ice crystal concentrations in general. The paper has the potential to provide useful results but I suggest major corrections are needed before the paper is considered for publication in ACP.

Major Comments

I found the descriptions of the experimental setup to be confusing, particularly the explanation of how the instruments were aspirated, orientated into the wind and the steps taken to quality control the measurements made by instruments subject to the harsh environmental conditions. Any revision should include a new figure detailing the different instruments and the setup at SPL and a more in depth discussion of how the probes were aspirated.

The probe setup was discussed in lines 104-121. A new figure (Fig. 1 (revised), below) was added showing the probe configuration and a view upwind. The last sentence in this section starting on line 119 was moved to the end of line 104: "The cloud probes were mounted on a rotating wind vane (to orient them into the wind) located on the west (upwind) railing of the roof approximately 6 m above the snow surface. The sentence "The cloud probes were calibrated and serviced at DMT prior to each field campaign." was moved to the end of the section (line 121). The revised sentence notes that calibration and servicing was done at DMT. The discussion of how the probes were "aspirated" pertains only to the FSSP-100, which is fitted with a fan that draws air through the probe's sample volume. The CIP is not aspirated. The CIP sample volume is based on the wind speed measured with a sonic anemometer. This was clearly described in the text.

The most novel measurements relate to the enhanced ice crystal concentrations at a mountain top site like this where the cloud is in contact with the surface and interaction processes are poorly understood. The CIP-25 probe is key to this – there should be presentation of some of the imagery from the instrument and a detailed justification of why using a size threshold >62.5um for ice was appropriate.

Figure 8 (revised), below, which is included in the revised manuscript, shows CIP images from the case study on 9 February 2014 (discussed in section 3.3). The following is inserted into the text on line 252: "Figures 8a and 8b present CIP images from the high and low IWC periods, respectively. Note the relatively higher concentration of "dots" in Fig. 8b (low IWC, high LWC). These represent cloud droplets that occluded a single CIP diode."

and a detailed justification of why using a size threshold >62.5um for ice was appropriate.

This is discussed in the paragraph beginning on line 191. The objective was to exclude cloud droplets from the CIP data. There is no evidence for droplets this large in these shallow, orographic clouds when SPL is close to cloud base. Indeed, Lloyd et al. (2015) concluded that there were no droplets larger than 35 µm in orographic clouds at the Jungfraujoch. The original Fig. 2, which compares the CIP size distributions for wet (LWC>0) and dry (LWC=0) cases during StormVEx and IFRACS, demonstrates that only the first CIP size bin was impacted by droplets.

The data is sometimes presented in a confusing way. There are numerous times the data is compared for warm and cold conditions. Cold is defined as below -12 and warm above -8. What happens in between this range?

The logic was that if a process is temperature-dependent, that process will be observed most readily at extremes in temperature. In this case, 93 and 81% of 1-minute average observations occurred at temperatures lower than -10 ºC during StormVEx and IFRACS, respectively. The relationship between large drops and small crystals is similar at cold temperatures defined as either <-12 ºC or <-8 ºC. In response to this question, "cold" is defined as <-8 ºC in the revised manuscript.

I didn't find the interpretation of some of the results very convincing. It is proposed that the relationship between large drops and small ice crystals could be due to immersion or contact freezing. There is a relationship found between larger supercooled drops and ice crystal concentrations but I'm not sure how the jump is made to the impact of these bigger drops being increased appearance of small ice crystals through primary ice nucleation when it would seem more likely to be a secondary process of some kind. One of the key suspects (but not the only one) for enhanced ice crystal concentrations in supercooled orographic clouds in contact with a frozen surface is some process that provides ice from the surface. The mechanism by which this might happen is still very uncertain but I'd like to see a bit of information about the topography and surfaces around SPL. I think the relevant ideas and literature are generally included but the results are framed poorly. My interpretation is that the main findings surround the enhanced ice crystal concentrations vs what you might expect at these temperatures, but I felt that *although the different potential mechanisms for the production of these were stated, the authors didn't present coherent conclusions.*

The hypothesis that ice crystal production is related to large drops was raised in previous studies, as described in lines 70-74 of the original manuscript. Our analysis shows a relatively strong relationship between large droplet and small ice crystal concentration at low temperatures during IFRACS. This is ***new evidence*** for heterogeneous freezing of large droplets, whether by immersion or contact freezing. We see nothing logically or scientifically incoherent about this conclusion. On the other hand, the reviewer states that "it would seem more likely to be a secondary [ice production] process [SIP] of some kind". Upon what evidence is this belief based? There is a lot of speculation about SIP in the literature but in the absence of direct evidence from our studies, we prefer not to engage in it.

Minor Comments:

1. In the abstract I suggest removing acronyms that don't appear in the abstract again and then defining them in the body of the manuscript. 2. StormVEx and IFRACS should be defined in the abstract.

In the revised manuscript, all acronyms are defined at their first use in both the abstract and main text.

3. P2 L35 is second reference in brackets correct?

Corrected to Peng.

4. P3 L86 I may have missed it earlier but if not please define DRI.

Desert Research Institute inserted on L85.

5. P3 L93 variation over a 3 year period? If the campaign periods are correct it isn't over 3 years but you do compare between the two time periods (Nov 2010 – Apr 2011 and Jan – Feb 2014).

Changed "over a 3-year period" to "over two winters".

6. P3 L106 Add FSSP acronym

7. P3 107 the SPP-100 acronym might refer to the electronics revision of the FSSP. I'd prefer this instrument to be referred to as the Forward Scattering Spectrometer Probe (FSSP)

8. P4 L108 who is the manufacturer?

In all cases, “SPP-100” is replaced by FSSP-100, noting that the electronics were modified by DMT. The aspirator was purchased with the original PMS FSSP-100 probe, as noted in the revised manuscript.

9. P4 L109 What is the face velocity?

It’s the velocity at the center of the inlet.

10. P4 L142 If the TAS vs the OAP set airspeed is not equal you begin to get distortions of aspect ratio that will lead to changes in size. I think it is inaccurate to state that the misshapen particles will not necessarily be sized incorrectly.

There is no “set” air speed for the CIP. The air speed (TAS) is supplied by the sonic anemometer, as described in lines 116-117. As noted in the manuscript, we used the “area equivalent diameter” to size CIP particles. This is the diameter of a sphere with the same projected area of a particle which may be irregular. We intentionally used this method because distortions may arise from incorrect wind speed. The reviewer is correct that aspect ratios would be sensitive to such distortions but our analysis does not include this parameter.

11. P5 L164 I’d be interested to know with these constraints which contributes to the loss of _ 50 % of data. You say the CIP measures particles for 101.4 and 77.2 hours respectively, so condition 1 is met for this number of hours. You are then left with 49.2 and 43 hours of MPC suggesting you were in glaciated for considerable time periods (condition 2 and 3 not met but condition 1 is true).

The data completeness requirement (75%, line 163) accounts for the reduced number of 1-minute averages. LWC was zero during 10 and 4.3% of seconds when Ni was greater than zero during StormVEx and IFRACS, respectively. This is apparent from the numbers given in the original Fig. 2 and the total number of observations given in the text.

12. Section 3.1 header has SPP-100 I might be getting this wrong but I think this should be the FSSP.

Changed to FSSP, as noted above.

13. P5 L178 the nominal size range quotes is below the threshold you stated earlier in the paper.
Interactive comment on Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2018

Optical array probes have been widely used for decades and a detailed explanation of how they work can found in the literature. 12.5-37.5 µm indicates the lower and upper bounds of the first CIP size channel given the 50% reduction of laser energy needed to trigger a diode. The size bins are typically referred to by their midpoints, i.e., the first channel is 25 µm and the 64th channel is 64x25=1600 µm. In presentations of size distributions, the bin boundaries are taken as the midpoint ±12.5 µm. The following sentence was added at line 115: “An array diode is triggered when a particle obscures >50% of the incident laser energy on the diode.”.

References

Lloyd, G., Choularton, T.W., Bower, K.N., Gallagher, M.W., Connolly, P.J., Flynn, M., Farrignton, R., Crosier, J., Schlenczek, O., Fugla, J., and Henneberger, J.: The origins of ice crystals measured in mixed-phase clouds at the high-alpine site Jungfraujoch. Atmos. Chem. Phys., 15, 12953-12969, doi:10.5194/acp-15-12953-2015, 2015.

Figure 1 (revised). Recent picture of SPL probe stand used previously during StormVEx and IFRACS with FSSP-100 and sonic anemometer on top and DMT CIP and PIP (Precipitation Imaging Probe) on left and right sides, respectively. View facing west over the railing (right panel).

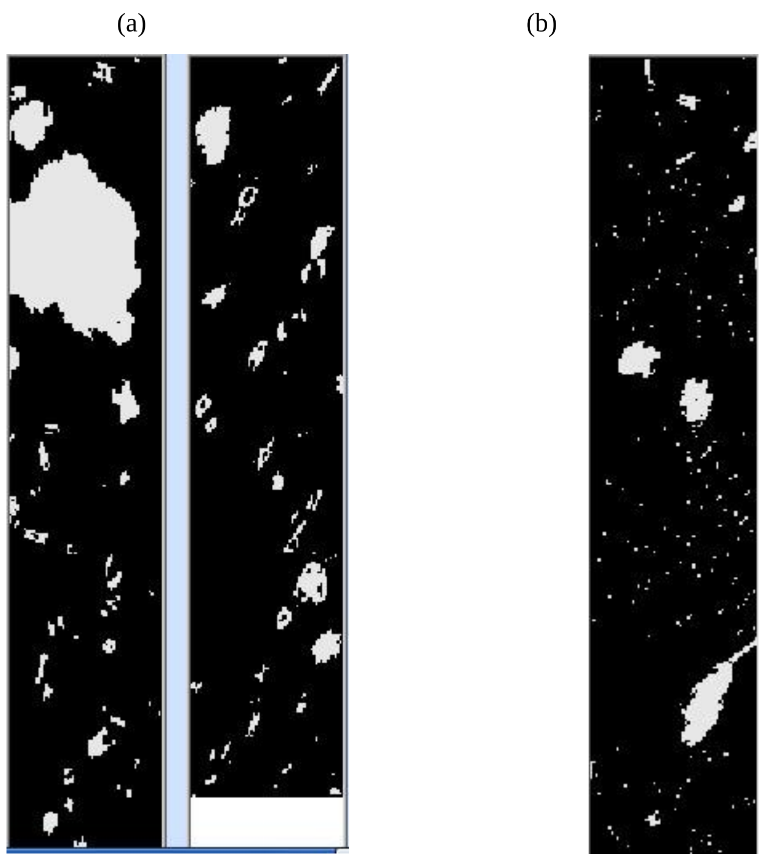

Figure 8 (revised). CIP images from 9 February 2014: (a) 13:12:19 MST, high IWC and low LWC, and (b) 12:29:09 MST, low IWC and high LWC. The vertical bars contain all of the images sampled in 1 second. The width of each bar corresponds to 1600 μm.