We thank reviewers for their important comments to improve our manuscript. We have now addressed all of the comments raised in the revision. The main revisions we made include:

1. We have avoided the discussions about evolution of clouds, and now focus on the discussion and comparison of cloud microphysics at different stages. The ice mass fraction (IWC/TWC) is now used to indicate the different development stages of clouds, by considering a more mature cloud has a more glaciated fraction.
2. We have carefully revised and responded to the related parts which reviewers consider to be speculative.
3. We have added the radar times and the flight time windows for the four stages, and the time windows of targeting analysis periods.
4. We have carefully examined the manuscript for editorial and grammatical errors, addressing them to enhance the overall readability of our work.

In addition, the relative development stages of the clouds are now renamed as P1, P2, P3, and P4 according to the reviewer2's comment. The related descriptions and figures have also been amended in the revised manuscript.

Reviewer #1

It is good to see a set of microphysical measurements being reported. They are difficult measurements to make and are valuable for checking and improving models. Many assertions are made in this paper without evidence. For example it is assumed that there is evolution in time of microphysical characteristics from one cloud region to a different region studied. There is no evidence presented to support this assumption. There are many errors in the written English which need to be corrected. I felt unable to review pp 8-12 of the paper until the comments below are addressed. It is important to state what has been changed on pp 8-12 in response to the above comments if appropriate.

We thank reviewer for the important comments to improve our manuscript. We now avoid discussing the "evolution" from one cloud to another, but using the ice mass fraction (IWC/TWC) to identify the different development stages of clouds and discuss the differences among them. We have also addressed all of the comments raised in the revision.

Detailed comments

Line 13. Are the clouds stratiform with embedded convection?

We thank reviewer to point this out, and the cloud type is now changed to "stratiform clouds with embedded convection".
The title is changed as:

Microphysical view of development and ice production of mid-latitude stratiform clouds with embedded convection during an extratropical cyclone.
The related parts are also revised.

Line 18. Some definitions have graupel only forming when d > 250 um. They are not large at that point.

We agree with the reviewer's comment, and the related discussions are revised:

P1, Line 19: "The N_{ice} was positively associated with the number concentrations of graupel with diameter (d) > 250 μm and large supercooled droplet (d > 50 μm)."

Line 21. Between what?

The sentence is more clearly stated:

P1, Line 22: "The collection efficiency between the graupel and droplet was found to increase when the size of droplet was closer to graupel which may improve the agreement between measurement and model."

Lines 23-26. This is conjecture.

The related discussions are now revised according to reviewer's following comments.

Line 80. As above, stratiform with embedded convection? They are not stratocumulus clouds.

It has been revised in manuscript.

Line 82. Does the temperature probe become wet in cloud? Most temperature probes do suffer from this problem.

Thank reviewer to point this out. We found we have used the temperature measured by Rosemont total temperature probe, not the AIMMS probe. We agree with reviewer that the temperature sensor would become wet in cloud and it might underestimate the ambient temperature when water was evaporated, and the Rosemount temperature probe may be affected when T > 0 °C (Heymsfield et al., 1979; Lawson and Cooper, 1990). However, previous literatures suggested this error is negligible in supercooled cloud (Lawson and Rodi, 1992; Korolev and Isaac, 2006), and in this study, the temperature shift in and out of cloud was not observed. The related description has been corrected:

P3, Line 83: "The air temperature was measured by the Rosemount total-air temperature probe (Lenschow and Pennell, 1974; Lawson and Cooper, 1990). The temperature may be underestimated due to water evaporation however this artifact is negligible for supercooled clouds (Lawson and Rodi, 1992; Korolev and Isaac, 2006), and the temperature shift in and out of clouds was not observed in this study."

Lines 98-99. What is the distance of the radar in Beijing to the cloud system studied?

The distance from the radar (located in the southeast of Beijing) to the observed cloud system in this study was approximately 50-200 km. This is added in the revision:

P4, Line 103: "The distance from the radar to the observed cloud system in this study was approximately 50-200 km."

Lines 114-116. What are the errors of the mass of ice determined in this way?

The error in calculating ice mass according to the mass-dimension relationship from Holroyd (1987) will increase when ice particle is larger and the shape has large irregularity to be classified. More details about the calculation of ice mass from 2DS can be found in Holroyd (1987). The related discussions are added:

P4, Line 121: "It should be noted that the error in calculating ice mass according to the mass-dimension relationship will increase when ice particle is larger and the shape has large irregularity to be classified (Crosier et al., 2013)."

Line 136. It would be helpful to show the location of Beijing in Figure S2. Although the text mentions that Figure S2 shows the movement of the surface cold front, the location of the surface cold and warm air is the same over the 4-hour period for the two flight segments. Is this relevant?

The location of Beijing is now added in Fig.S2. We have now revised Fig. S2 and Fig. S3 to more clearly shows the surface position of front system according to the wind and temperature shear. The southeastward movement is indicated here (green box) to better indicate the position of aircraft relative to the front system:

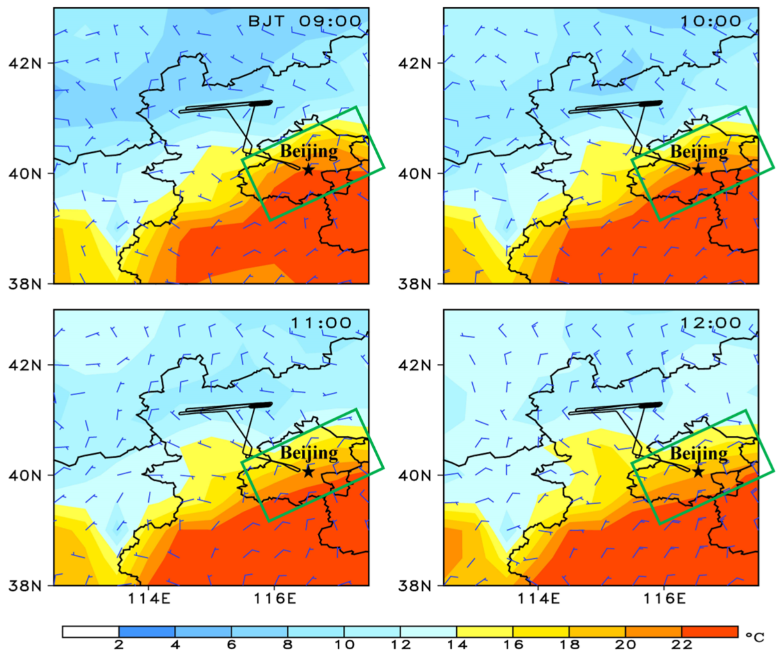

Figure S2: Flight tracks (black line) mapping on the wind field (blue wind shaft) and temperature field (color) observed by ground weather observation station at 09:00-12:00 (BJT) on September 26th, 2017. The location of Beijing is indicated by the black five-pointed star.

Lines 137-140. Is Figure S3 essential? Perhaps add the location of Outer Manchuria and the surface cold front if the figure is kept.

Figure S3 shows the location of extratropical cyclone and indicates the aircraft observation area relative to the position of extratropical cyclone. The location of Outer Manchuria and the surface cold front are added:

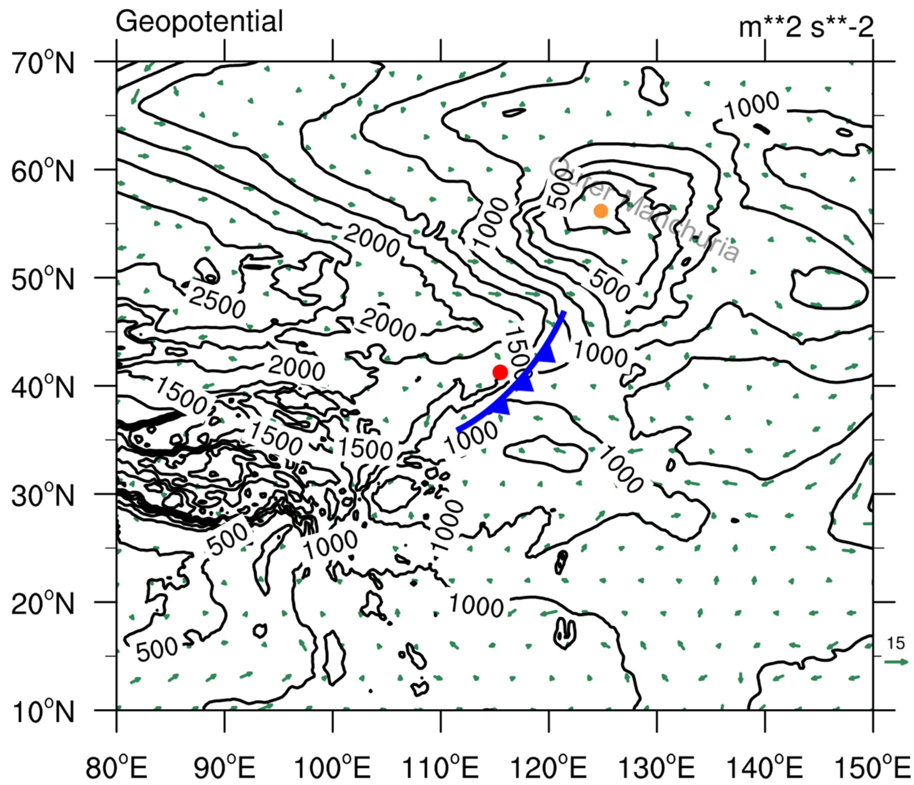

Figure S3: Geopotential height contour map at 1000 hPa at 09:00 (BJT) on September 26th, 2017. The experimental region and the center of the extratropical cyclone are indicated by the red dot and yellow dot respectively, and the surface cold front is indicated by the blue cold front symbol.

Lines 143-144. The sentence is not clear. Where was the aircraft observation area?

This is more clearly stated:

P5, Line 151: "The aircraft sampled the clouds formed in this cyclonic system at this stage, i.e. behind the surface cold front line (Fig. S3) and for the newly formed, developing and matured clouds."

Lines 151-153. It would be helpful to provide the times of the radar plots and indicate key times of the aircraft tracks to show the development of the system. It looks like the developing cells were observed in the southerly part of the system, whereas the mature cells were observed in the northern part. It is assumed, I think, that the clouds have the same dynamical and microphysical properties in the two regions. It would be good to discuss this point in the paper.

We thank reviewer to point this out, the times of the radar plots and the start/end time for each stage are added. The clouds observed were in the same cyclonic system, where the clouds underwent continuous generation, development and dissipation. The microphysical properties under different development stages of clouds are therefore different. However, though in the same synoptic system, it is difficult to explicitly rule out the "evolvement" from the same cloud, because we were measuring different clouds. We therefore now avoid the discussions about evolution of clouds, but using the ice mass fraction (IWC/TWC) to indicate the different development stages of clouds (Fig. 2), by considering a more mature cloud has a more glaciated fraction, for the discussions of cloud microphysics at different stages.

P6, Line 164: "The flight tracks mapping on the composite reflectivity of precipitation radar are shown in Fig. 3, colored by the LWC from FCDP and IWC from 2D-S respectively, the radar times and the flight time windows for the four stages are shown in Table S1."

Newly added Table S1 (Supplement):

Table S1. Radar times in Fig. 3 and the corresponding flight time windows for the four stages (all in UTC+8h).

Stages	Radar time	Flight time window	Targeting periods
Developing cells (P1)	10:06	10:03:35-10:23:55	1.1: 10:09:13-10:10:31 1.2: 10:11:54-10:12:41
Mature cells (P2)	10:42	10:25:35-11:05:17	2.1: 10:42:02-10:42:58 2.2: 10:45:47-10:46:25 2.3: 10:48:38-10:49:33
Dissipating cells (P3)	11:30	11:13:01-11:45:20	\
Young cells (P4)	12:00	11:46:16-12:15:52	4.1: 11:47:16-11:47:35 4.2: 11:51:02-11:51:05 4.3: 11:56:30-11:56:50

Newly added Figure 2:

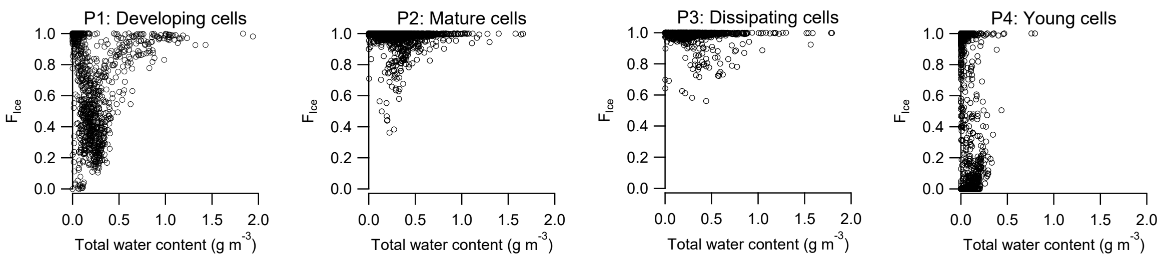

Figure 2: Ice mass fraction (F_{Ice}) as a fuction of total water content at four stages.

Related discussions are added:

P5, Line 156: "Four relative stages during the lifecycle of clouds were identified during experiment, which corresponded to the developing (P1), mature (P2), dissipating (P3) and young cells (P4) in cloud system, according to the different glaciation extents of clouds. The ice mass fraction (F_{Ice}: IWC/TWC) was used to indicate the different development stages of clouds (Fig. 2), by considering a more mature cloud has a more glaciated fraction, for the discussions of cloud microphysics at different stages. The cloud system was formed through the combined effects of dynamic forcing induced by the frontal uplift and the moisture transport provided by the prefrontal southerly air mass. Therefore, this study postulated that the continuous clouds within the cloud system had similar dynamic and thermodynamic properties."

Line 154. I don't think "evolved" is the correct word? Is it the case that the aircraft passed from a region with dominant LWC to one with dominant IWC? It is also curious why the LWC was so low in "developing cells". Is the cloud base altitude known?

We agree with reviewer that we were sampling different clouds and the word "evolve" is removed in the revision. The developing stage has mixed clouds with a range of LWC from 0.002 to 0.31 g m^{-3} but a lower F_{Ice} than mature stage. The cloud base is at about 1 km according to the radiosonde measurement.
Related discussions are revised:

P6, Line 166: "In developing cells, substantial LWC was detected up to 0.3 g m^{-3}, and the aircraft penetrated a high IWC region in this cloud at 10:09-10:11 BJT, with the highest IWC exceeded 2 g m^{-3} (Fig. 3a1, b1), and F_{Ice} at this stage could span from zero (pure water) to unit (pure ice) (Fig. 2)."

Lines 154-155. There is no evidence given that the LWC was "consumed by the growth of ice crystals". Is it the case, from the evidence in Fig 2, that the aircraft made passes through a different region of cloud (at a later time according to Figure 3), and measured higher values of IWC than LWC?

We agree with reviewer that it is difficult to link the clouds from both areas. We have removed this discussion about the evolution of the microphysical processes. The related discussions are revised:

P6, Line 168: "In mature cells, F_{Ice} ranged in 0.36-1 and IWC generally exceeded 0.3 g m^{-3} (Figs. 2 and 3b2), and the maximum radar reflectivity of mature cells was enhanced from 20 dBZ to 27 dBZ at 10:06 to 10:42 BJT (Fig. 3a1, a2)."

Lines 155-156. It isn't clear from Fig 2 that the radar reflectivity was enhanced. Is this enhanced from the same region in Fig 2a1 and 2a2? The values of radar reflectivity would be helpful.

The radar reflectivity of the clouds in mature cells is enhanced compared to the last, and the maximum radar reflectivity increased from 20 dBZ to 27 dBZ at 10:06 to 10:42 BJT. The related discussions are revised:

P6, Line 168: "In mature cells, F_{Ice} ranged in 0.36-1 and IWC generally exceeded 0.3 g m^{-3} (Figs. 2 and 3b2), and the maximum radar reflectivity of mature cells was enhanced from 20 dBZ to 27 dBZ at 10:06 to 10:42 BJT (Fig. 3a1, a2)."

Line 156. How is it known, From Fig 2 that "the ice phase precipitation process occurred"?

The clouds moved eastward over time and the aircraft conducted continuous observations of the cloud. The statement that precipitation has occurred is based on the significant weakening of the radar echoes in dissipating cells compared to the mature cells (Fig. 3 and Fig. 4), indicating a reduction in large particles within the cloud.

Line 159. Figure 3 contains a lot of detailed information. It would be helpful to include shorter time series with the details expanded. For example, what is the structure of the region with a strong downdraft and updraft. It isn't clear where the peaks in LWC and concentration of ice particles occur relative to the updrafts and downdrafts. Also, is the strength of the downdraft real? Have the vertical winds been filtered for aircraft turns? It might be helpful to add vertical dotted lines in Fig 3.

According to reviewer's suggestion, Fig. 3 (Fig. 4 in revised manuscript) is now broken into a few figures with shorter time window showing finer details, as Fig. S4. The vertical wind data during aircraft turns are removed in Fig. 4 and Fig. S4. The AIMMS-20 probe equipped on the aircraft of this experiment is calibrated once every two years according to the procedure and flight scheme provided by the manufacturer, therefore the vertical wind data observed during level flight of aircraft is reliable. The vertical wind data during aircraft turns are not used for data analysis.
Related description is added:

P6, Line 174: "Figure 4 shows the microphysical properties of clouds and meteorological parameters along the flight track, and Figure 4 is broken into four figures according to four stages with shorter time window showing finer details (Fig. S4). The vertical wind data during aircraft turns were excluded from Figs. 4 and S4 and were not used for the analysis."

Newly added Figure S4:

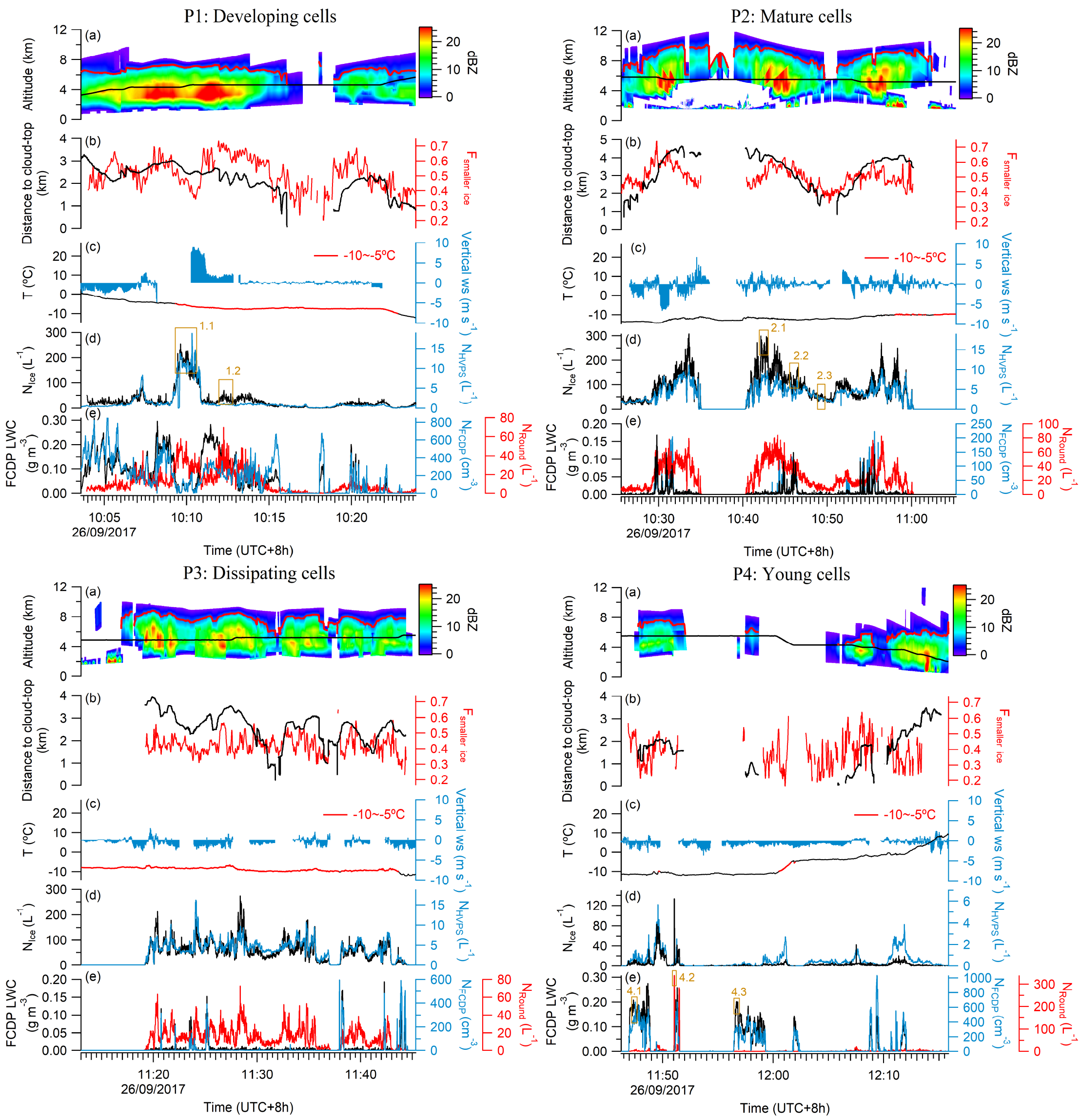

Figure S4: Cloud properties along the flight track at four stages. (a) Vertical profile of radar reflectivity from the ground S-band precipitation radar collocating with the flight path. (b)The distance to cloud-top of aircraft and smaller ice (d < 180 μm) number fraction ($F_{\mathrm{smaller\ ice}}$). (c) Ambient temperature and vertical wind speed. (d) Ice number concentration (N_{Ice}) from the 2D-S and precipitation particle number concentration (N_{HVPS}) from the HVPS. (e) LWC and cloud droplet number concentration (N_{FCDP}) from the FCDP, and the large droplet number concentration (N_{Round}) from the 2D-S. The targeting periods are indexed for further analysis.

Line 160. Is "Developing cells" a relative term since the same strength of radar echoes appear as in the mature cells, and the clouds are already quite deep with the top of the radar echoes at about 8 km. Are there radar echoes from earlier and later times of the cells penetrated in S1 just after 10 local?

We agree with reviewer that the developing cells are relative term. The ice mass fraction (F_{Ice}: IWC/TWC) is used to indicate the different relative development stages of clouds, by considering a more mature cloud has a more glaciated fraction, for the discussions of cloud microphysics at different stages. The developing stage is determined as the F_{Ice} is in the range of 0-1, while the F_{Ice} is in the range of 0.36-1 in mature cells (Fig. 2). The related discussions are revised:

P5, Line 156: "Four relative stages during the lifecycle of clouds were identified during experiment, which corresponded to the developing (P1), mature (P2), dissipating (P3) and young cells (P4) in cloud system, according to the different glaciation extents of clouds."

P6, Line 166: "In developing cells, substantial LWC was detected up to 0.3 g m^{-3}, and the aircraft penetrated a high IWC region in this cloud at 10:09-10:11 BJT, with the highest IWC exceeded 2 g m^{-3} (Fig. 3a1, b1), and F_{Ice} at this stage could span from zero (pure water) to unit (pure ice) (Fig. 2). In mature cells, F_{Ice} ranged in 0.36-1 and IWC generally exceeded 0.3 g m^{-3} (Figs. 2 and 3b2), and the maximum radar reflectivity of mature cells was enhanced from 20 dBZ to 27 dBZ at 10:06 to 10:42 BJT (Fig. 3a1, a2)."

P12, Line 383: "The four relative stages were identified by ice mass fraction, by considering a more mature cloud has a more glaciated fraction."

Line 170. Isn't it the case the S1 and S2 were in different cloud regions? Is it correct to say "developed"?

We agree with the referee's comment, and the P1 and P2 are different cloud regions. It has been corrected:

P7, Line 197: "The cloud-top height in P2 reached 10 km (Fig. 4a), which was the highest cloud-top of clouds observed during experiment."

Line 172. There are still a few cores with reflectivity values close to 30 dBZ.

The area of radar reflectivity exceeding 20 dBZ in dissipating cells significantly decreases compared to mature cells. The dissipating cells is identified due to the clouds have a more glaciated fraction compared to mature cells. The related discussions are added:

P6, Line 170: "At the dissipating stage, the ice phase precipitation process occurred and the radar reflectivity became weaker with narrowed cloud band (Fig. 3a3, b3), and the range of F_{Ice} reached up to 0.56-1 (Fig. 2)."

P7, Line 201: "The cloud-top height in P3 was lower than P2, and the area of stronger echoes (>20 dBZ) was also reduced compared to P2 (Fig. 4a). Similar to P2, the dissipating stage was dominated by ice but only intermittent unglaciated LWC-rich clouds were present (Fig. 4d, e), however, the clouds in P3 had a more glaciated fraction (Fig. 2). All above confirmed the dissipating stage of P3."

Line 173. It is very surprising that the LWC values are so low with vertical winds of +10 m/s. Is it actually the case that the cloud has suffered significant entrainment and conversion to precipitation?

Previous studies also observed low LWC when high updraft when liquid water was considerably consumed by rapid production of ice, such as LWC as low as 0.1 g m^{-3} was observed when updraft up to 8.5 m/s (Lawson et al., 2015). The related discussion has been revised:

P6, Line 190: "P1 was strongly turbulent with vertical wind speed up to 8.9 m/s, and the strong updraft region was dominated by ice particles and precipitation particles (Fig. 4c-e). The low LWC when high vertical updraft may be caused by the rapid production of ice particles, which was also observed in tropical highly convective region (Lawson et al., 2015)."

Lines 174-175. There is no evidence that the liquid was consumed by producing ice. Is it possible that the downdraft is a region affected significantly by entrainment and the ice particles were transported down from above?

We agree with reviewer and the statement about ice consumption is now removed. The downdraft data is observed during aircraft turns and has been removed now (Fig. 4 and Fig. S4), and the related discussion are revised:

P6, Line 192: "The ice number peaked at a valley between two peaks of liquid water, but it was difficult to determine the vertical wind at the peak of ice number due to aircraft turns (Fig. S4). However, in the subsequent level flight, high ice number concentration (> 170 L^{-1}) was also observed in the strong updraft region. After the high ice number region, LWC up to 0.28 g m^{-3} was observed in the region with weaker updraft."

Line 177. There is no evidence that the drops in S1 grew to larger drops and were consumed by ice in S2.

It has been revised:

P7, Line 198: "The LWC in P2 was considerably lower compared to P1, while there were more large droplets and ice particles in clouds (Fig. 4d, e), and the distribution of large droplets and ice particles in P2 showed a bimodal distribution."

Lines 178-179. Is the cloud measured in S4 really stratocumulus cloud?

The stratocumulus (it has been corrected as "stratiform clouds with embedded convection") is an overall description of the cloud system observed in this experiment. The continuous clouds within the cloud system are postulated to have similar dynamic and thermodynamic properties in this study, therefore the clouds are now described as stratiform clouds with embedded convection.

Line 181. Some of the cells at the beginning of S3 do not appear to be dissipating. Cloud tops are still above 8 km and the radar echoes are approaching 30 dBZ (which is not a high value, but similar to the values in S2).

The dissipating is a relative stage, which is identified to have a more glaciated fraction compared to mature cells. Additionally, the area of stronger echoes in dissipating cells is reduce compared to mature cells, and the cloud-top height is also lower. Related discussions are revised:

P7, Line 201: "The cloud-top height in P3 was lower than P2, and the area of stronger echoes (>20 dBZ) was also reduced compared to P2 (Fig. 4a). Similar to P2, the dissipating stage was dominated by ice but only intermittent unglaciated LWC-rich clouds were present (Fig. 4d, e), however, the clouds in P3 had a more glaciated fraction (Fig. 2). All above confirmed the dissipating stage of P3."

Line 181. S4 includes the first region of (weaker) radar echo with a top above 6 km. Why is it treated as a young cell?

The clouds are identified as young cells due to the lower glaciated fraction compared to other stages (Fig. 2). The first region in P4 is rich in LWC, and the overall ice mass fraction is smaller than developing cells. This is now added in the revision:

P7, Line 204: "P4 was likely a newly developed cell with lower F_{Ice} and weak radar reflectivity, and the cloud-top had not reached as high as other stages (Figs. 2 and 4a). This stage was rich of liquid water with LWC up to 0.27 g m^{-3} at a colder temperature (−11 ^{o}C), while there was no appreciable IWC measured in the region (Fig. 4d, e)."

Lines 183-184. The last sentence in this paragraph doesn't make sense.

The sentence is deleted in the revised manuscript.

Lines 188-190. Again, there is no evidence.

It has been revised:

P7, Line 211: "The clouds in P2 were primarily composed of ice water, with the number concentration of cloud droplets significantly lower compared to P1."

Line 195. No evidence of "consumed".

It has been revised:

P7, Line 216: "The lower cloud optical depth and cloud-top temperature in Zhangjiakou area suggested the lower water content and higher cloud-top height of the cloud region."

Lines 195-196. There is no evidence of "vigorous development of the precipitating cloud".

It has been deleted in the revised manuscript.

Lines 209-210. A more accurate statement is that there was an increase in N_round at two levels. Fig 3 suggests one of those might be in a region of low LWC and N_FCDP, and higher concentration of ice particles.

This suggestion is now added:

P8, Line 230: "In developing cells, N_{FCDP} tended to decrease with the increase of height, while the diameter of droplets tended to increase (Fig. 6a1), and there was an increase in N_{Round} at two levels. The broadened droplet spectrum at two levels of developing cells was also observed (Fig. S5)."

Lines 221-222. What is the evidence for the statement.

The evidence is now added:

P8, Line 245: "The ice habits were consistent with the feature of cloud region where SIP is thought to be active (Field et al., 2016), considering the temperature of the environment was within the H–M zone, and the region was rich in supercooled large droplets, the H-M process was most likely active (Crosier et al., 2013; Taylor et al., 2016)."

Lines 222-225. It should be remembered that the pass through the cloud regions are snapshots in time. There is no evidence of "... leading to more small ice through the H-M process...". It is only a suggestion. There is history to consider with vertical and horizontal transport.

We thank reviewer's suggestion and make revision accordingly on this statement:

P8, Line 251: "This might suggest the great number of large ice at P1.1 improved the riming efficiency and increased the riming surface area, leading to more small ice through H-M process and resulting in the consumption of the droplets. However, the dynamic vertical or horizontal transported of produced ice might induce some uncertainty when evaluating the concentration at the supposed same aircraft position."

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