Comment on "Observation-based analysis of horizontally oriented ice crystals using dual-angle polarization lidar and cloud Doppler radar in Beijing" by Wu et al.

This study presents comprehensive case studies and statistical analyses of horizontally oriented ice crystals (HOICs) using a full year (2022) of synergistic observations in Beijing, China, combining a zenith-pointing micropulse lidar, a collocated 15° off-zenith polarization lidar, and a Ka-band cloud Doppler radar. Applying a novel height-resolved classification method based on dual-angle polarization lidars, HOICs are identified with high spatiotemporal resolution. Many novel findings have been found in this study, making it highly worthy for prompt publication. For example, HOICs are found to be common, accounting for 15.0 % of all ice-containing cloud data points annually and peaking at 24.6 % in summer, with maximum occurrence at temperatures from −20 °C to −10 °C. Also, HOICs preferentially occur in stable environments with turbulent eddy dissipation rates below 10^{-2} m^2 s^{-3} and exhibit lower fall velocities than ROICs. The manuscript is generally well written, logically organized, and addresses an important source of uncertainty in cloud remote sensing and radiative-transfer parameterizations. Minor comments have been provided as follows.

Reply: We sincerely thank Referee #2 for reviewing our paper and providing constructive comments for improvement. Responses to these comments are provided below. In this author's comment, we reply (in blue font) to Referee #2's comments (in black font). The relevant part in the revised version is in green font.

General comment

- The retrieval of particle diameter and Reynolds number follows the method introduced in the authors' previous study. However, these calculations are presented only for HOICs and not for randomly oriented ice crystals (ROICs). Is it possible to calculate those for ROICs?

Reply: Thank you for your comment. In principle, the same aerodynamic framework could be applied to ROICs if their particle habit and orientation were known. However, ROICs may include plates, columns, aggregates, and irregular particles with different mass, projected-area, and drag relationships. The need to assume particle habit and orientation makes the retrieval highly model-dependent. Therefore, the radar Doppler velocity alone cannot uniquely determine their diameter and Reynolds number. We have clarified this limitation in the revised manuscript (Section 4.6, Line 761–763):

"The retrieval was not applied to ROICs because their particle habits and orientations are not independently constrained, preventing unique estimates of Reynolds number and diameter from Doppler velocity alone."

- The retrieved median equivalent diameter of HOICs is 1187 μm, which is larger than the sizes commonly reported for pristine plates and dendrites in previous in-situ studies. The authors acknowledge that cloud-radar measurements are strongly weighted toward larger particles and may not detect smaller HOICs in optically thin cirrus. To avoid possible overinterpretation of Table 1 and Figure 14, please state explicitly in the main text or figure/table captions that the retrieved diameters and Reynolds numbers represent radar-reflectivity-weighted estimates for the radar-detectable HOIC population, rather than an unbiased size distribution of all HOICs.

Reply: Thank you for your comment. We have added "radar-reflectivity-weighted diameter and Reynolds-number estimates for the radar-detectable HOIC population" at the Fig. 14 and Table 1 captions as you suggested.

- The HOIC classification and the resulting cloud-phase fractions depend on a fixed combination of thresholds, including a zenith-to-off-zenith attenuated-backscatter ratio of 2 and a depolarization-ratio threshold of 0.6. How will the conclusion of cloud phase fraction change with varying the thresholds? Is the distribution sensitive to the fixed thresholds?

Reply: Thank you for your important comment. To evaluate the robustness of the retrieved cloud-phase fractions, we repeated the annual classification using three combinations of the zenith-to-off-zenith attenuated-backscatter ratio and depolarization-ratio thresholds.
First, the zenith-to-off-zenith attenuated-backscatter ratio of 2 and a depolarization-ratio threshold of 0.6 were used as the baseline, which is the current thresholds used in the manuscript. The results are shown in Fig. S1.

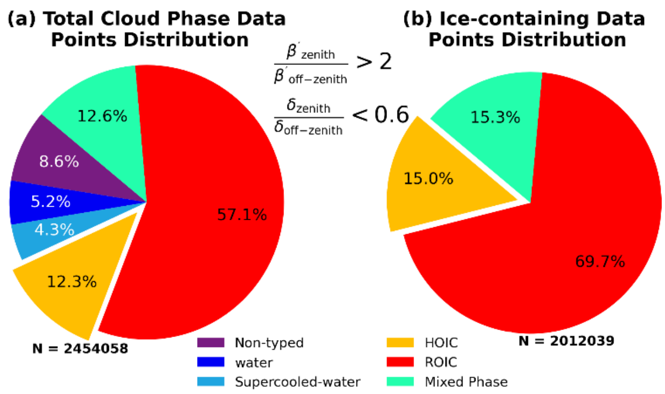

Figure S1. Statistical characteristics of cloud phase distributions in Beijing for 2022: (a) Cloud phase distribution pie charts of all cloud data points annually (b) Cloud phase distribution pie charts of ice containing cloud data points annually. Zenith-to-off-zenith attenuated-backscatter ratio of 2 and a depolarization-ratio threshold of 0.6 are used. Cloud-phase statistics in this figure are based on the relaxed cloud mask. Abbreviations: Water (warm water cloud), SWC (supercooled liquid water cloud), HOIC (horizontally oriented ice crystal), ROIC (randomly oriented ice crystal), MPC (mixed-phase cloud).

The fraction of HOICs among total cloud phase data points and among ice-containing cloud data points is 12.3% and 15.0%, respectively.

We jointly perturbed the two thresholds to construct stricter and more relaxed HOIC criteria. The first extra sensitive experiment was conducted. The zenith-to-off-zenith attenuated-backscatter ratio of 2.2 and a depolarization-ratio threshold of 0.5 were used. This represents a stricter criterion for HOICs, which requires the two lidars have stronger contrast of attenuated backscatter and depolarization ratio. The results are shown in Fig. S2.

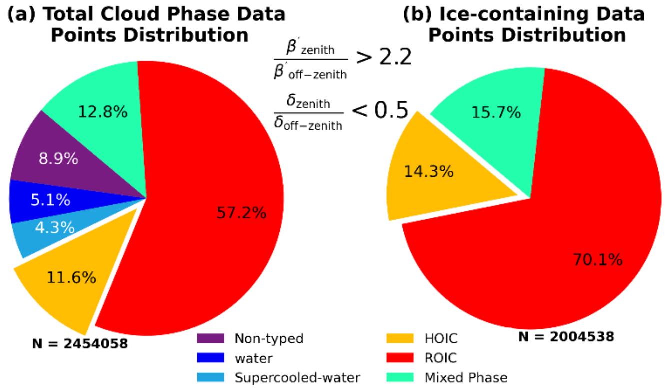

Figure S2. As in Fig. S1, but using Zenith-to-off-zenith attenuated-backscatter ratio of 2.2 and a depolarization-ratio threshold of 0.5.

The fraction of HOICs among total cloud phase data points and among ice-containing cloud data points is 11.6% and 14.3%, respectively.

Then the second extra sensitive experiment were conducted. The zenith-to-off-zenith attenuated-backscatter ratio of 1.8 and a depolarization-ratio threshold of 0.7 were used. This represents a more relaxed criterion for HOICs. The corresponding results are shown in Fig. S3.

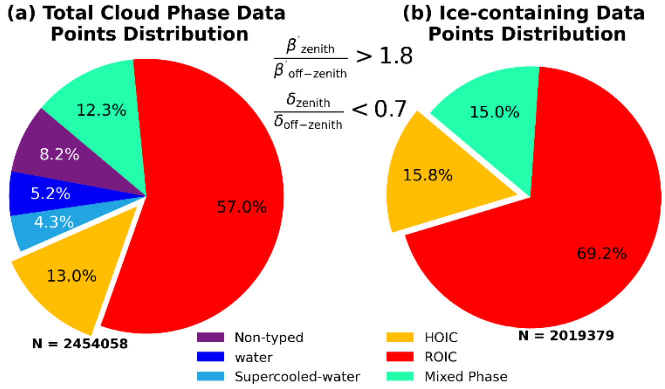

Figure S3. As in Fig. S1, but using Zenith-to-off-zenith attenuated-backscatter ratio of 1.8 and a depolarization-ratio threshold of 0.7.

The fraction of HOICs among total cloud phase data points and among ice-containing cloud data points is 13.0% and 15.8%, respectively.

The three experiments are summarized in Table S1. Under the baseline, stricter, and relaxed criteria, HOICs accounted for 12.3%, 11.6%, and 13.0% of all classified cloud data points, respectively, and for 15.0%, 14.3%, and 15.8% of all ice-containing cloud data points. Relative to the baseline, the maximum change is 0.7 percentage points for all cloud data and 0.8 percentage points for ice-containing cloud data. These results indicate that the inferred cloud-phase fractions show only limited sensitivity to the tested threshold combinations, and the main conclusion remains robust. In general, cloud phase fraction is not sensitive to the fixed thresholds. As the fixed thresholds change, the fraction of HOICs fluctuates slightly. As shown in Fig. 3 of the manuscript. The two baseline thresholds (0.6 and 2) are selected to isolate cases in which the zenith-pointing depolarization ratio is significantly lower than the off-zenith value and the zenith-pointing scatter is significantly higher than the off-zenith one. The majority of conventional cloud data (with a ratio near 1) is excluded from being misidentified.

Table S1. Summary fraction of HOICs using different fixed thresholds for two lidars

Fixed thresholds for two lidars	The fraction of HOICs among total cloud phase data points	The fraction of HOICs among ice-containing cloud data points
$\frac{\beta'_{\mathrm{zenith}}}{\beta'_{\mathrm{off-zenith}}} > 2, \frac{\delta_{\mathrm{zenith}}}{\delta_{\mathrm{off-zenith}}} < 0.6$	12.3%	15.0%
$\frac{\beta'_{\mathrm{zenith}}}{\beta'_{\mathrm{off-zenith}}} > 2.2, \frac{\delta_{\mathrm{zenith}}}{\delta_{\mathrm{off-zenith}}} < 0.5$	11.6%	14.3%
$\frac{\beta'_{\mathrm{zenith}}}{\beta'_{\mathrm{off-zenith}}} > 1.8, \frac{\delta_{\mathrm{zenith}}}{\delta_{\mathrm{off-zenith}}} < 0.7$	13.0%	15.8%

After careful examination, we also corrected the total number of the datapoints used in the manuscript of Fig. 5, which does not change the conclusion.

Minor comments:

Line 71, Actually, the authors did not provide detailed descriptions of previous studies, while they provide descriptions regarding the limitations of observations to HOICs. Thus, I would like to suggest the authors remove "these" in the sentence to say "Most of previous studies did not"

Reply: Thank you! We have removed "these" as you suggested.

Line 78-80, I would suggest the authors do not need to emphasize their previous study. Instead, they can simply say "Wu et al. (2025) introduced a range-bin-resolved method for …".

Reply: Thank you! Done!

Line 144-145, To introduce the method proposed by other studies which the authors select to compare with, I would suggest changing the description as "Griesche et al. (2020) retrieved turbulent dissipation rates from cloud radar observations, which has been validated using tethered-balloon in situ measurements".

Reply: Thank you! Done!

Line 148, Similar as earlier comment, the authors can simply say "in the Appendix of Wu et al. (2025)".

Reply: Done!

Line 171, please keep the citation format the same and correct, such as Wu et al. (2025).

Reply: Done!

Line 173, please indicate the time zone for this study, local time or UTC?

Reply: We have added "local time".

Line 182, "It is highly convincing that HOICs exist above our lidar station" is not necessary to mention, which is a repeat to other information, and I would like to suggest removing it.

Reply: Done!

Line 205, The authors may add “unless an inversion layer exists within clouds”.
Reply: Thank you! Done!

Line 259, No need to explain the median “diamonds” and interquartile range “horizontal lines”, since they have been explained in the figure caption.
Reply: Thank you for the comment. We have removed “diamonds” and “horizontal lines” in the revised text.

Line 305, “introduced in” should be better as “introduced by”
Reply: Thank you! Done!

Line 314-315, I would suggest removing “finally”.
Reply: Done!

Line 319-320, Note that temperature threshold -40 degree C is used earlier, different from the value -38 degree C used here. I would suggest the authors keep using the same value in this study.
Reply: Thank you for pointing out this inconsistency. We agree and have adopted −38 °C consistently as the temperature boundary between the mixed-phase and pure-ice-cloud regimes. The −40 °C value used earlier in the discussion of Fig. 3 as the mixed-phase/pure-ice temperature threshold was a rounded approximation and has now been revised to −38 °C.

Line 502, “generally stronger than that at night”
Reply: Thank you! Done!

Line 520-521, I would suggest combining this sentence into the last paragraph.
Reply: Done!

Line 687-689, “Consistent with our estimates” and “which is in good agreement with the findings in our study” are redundant to each other, please only keep one of them.
Reply: Thank you for the comment. We have removed “which is in good agreement with the findings in our study”.

Line 756, I would suggest changing “:” to “,”
Reply: Done!

Line 813-814, Do the authors mean “it would be desirable if such data sets are available at different sites over several years and to further examine the sensitivity of the inferred HOIC properties to cloud classification strategy, ice-crystal habit assumptions, and environmental variability”?
Reply: Thank you for pointing out this! We have rephrased the sentence as following (Line 844-Line 846):
“In the future, it would be desirable if such datasets were available at different sites over several years to further examine the sensitivity of the inferred HOIC properties to cloud

classification strategy, ice-crystal habit assumptions, and environmental variability.”