Dear Editor,

The authors sincerely appreciate your valuable comments and suggestions to help improve the manuscript. We have revised the manuscript titled “Estimating the Snow Density using Collocated Parsivel and MRR Measurements: A Preliminary Study from ICE-POP 2017/2018”. that was submitted to ACP (Atmospheric Chemistry and Physics) on 3 January 2024. Based on your suggestions, we have added additional discussion to the wind-induced undercatch issue of Pluvio in the revised manuscript.

Other than applying the undercatch correction to single/no-shield Pluvio measurements, all sites were equipped with double windshields and DFIR for the MHS site to mitigate wind-induced undercatch issues during ICE-POP 2017/2018. The Pluvio at YPO was equipped with a Belfort double Alter windshield. The Pluvios at MHS, BKC, and GWU were equipped with a double windshield with inner Tretyakov and outer Alter shields. The Pluvio at the MHS was within the DFIR (double fence intercomparison reference) in addition to the double shield. The studies from Kochendorfer et al. (2017; 2018) have shown that the SDFIR (small DFIR) and the Belfort double-Alter windshield have much smaller uncorrected biases and also smaller adjusted RMSE relative to the corresponding reference.

Even though the double windshields have been applied to each site and DFIR to the MHS site, some Pluvio measurement bias caused by the undercatch issue may remain. Noticeable discrepancies between density-derived and Pluvio-observed SR (liquid-equivalent snowfall rate) can be found in BKC and GWU sites (Figure 4 and Table 3 of the manuscript), which were equipped with ordinary inner Tretyakov and outer Alter shields. On the other hand, the YPO (Belfort double-Alter windshield) and MHS (double windshield with DFIR configuration), which are ideal for reducing wind-induced undercatch issues, have better agreements of density-derived and Pluvio-observed SR (Figure 4 and Table 3 of the manuscript).

The main goal of this study is to propose a robust method to derive bulk density and bulk water fraction of a population of particles from collocated measurements of MRR and Parsivel. Despite wind-induced undercatch issues being mostly mitigated by double windshields and some SR discrepancies remaining noticeable, the density retrieved from the proposed algorithm shows good agreement with PIP retrieval at the MHS site. The MHS site had a double windshield with inner Tretyakov and outer Alter shields. The instruments at the MHS were within the DFIR in addition to the double shields to mitigate the wind-induced undercatch issues. Pluvio's wind-induced undercatch issues are beyond the scope of this study. A discussion of wind-induced undercatch issues has been added to the revised manuscript.

The manuscript has also been revised carefully. The authors would like to express our sincere appreciation for the comments. The added or modified sentences in the revised manuscript are in red for your convenience. We would appreciate any feedback on the revisions.

############ Opening comments ############

I do have a concern that I believe should be more carefully addressed. An issue raised by Reviewer 1 is that there is a tendency for under-catch by the Pluvio precipitation gauge which was used for validation. The reviewer estimated that this issue is relatively minor. I'm not sure I agree. You may wish to consider the paper by Colli et al. 2020 "Adjustments for Wind-Induced Undercatch in Snowfall Measurements Based on Precipitation Intensity". Collection efficiency can drop by at least one half in even modest winds. Currently the article does not address collection efficiency concerns seriously and I believe it should.

Reply:

As the reviewers and the editor indicated, wind plays a dominant role in reducing the gauge collection efficiency (CE) in snowfall measurements. The DFIR (double fence intercomparison reference) has been considered as the manual reference configuration for investigating wind-induced undercatch issues (Kochendorfer et al. 2017; Colli et al. 2020). Studies (Kochendorfer et al. 2017; 2018; 2022; and Colli et al. 2020) have utilized DFIR to obtain the CE under different environmental conditions. The wind-induced undercatch (CE < 1) is most severe under high wind speed and light snow intensity (SI) conditions. Colli et al. (2020) suggest that the wind-induced undercatch is unneglectable for high wind speed > 4 m s^{-1} and SI < 0.6 mm hr^{-1} when a single Alter windshield is equipped.

During ICE-POP 2017/2018, the undercatch issue was mitigated by applying double windshields. All of the Pluvios were equipped with double windshields. The Pluvio at YPO was equipped with a Belfort double Alter windshield. The Pluvios at MHS, BKC, and GWU were equipped with a double windshield with inner Tretyakov and outer Alter shields. The Pluvio at the MHS was within the DFIR (double fence intercomparison reference) in addition to the double shield. The studies from Kochendorfer et al. (2017; 2018) have shown that the SDFIR (small DFIR) and the Belfort double-Alter windshield have much smaller uncorrected biases and also smaller adjusted RMSE relative to the corresponding reference.

Due to unavoidable logistic and maintenance issues, the collocated AWS measurements Pluvio to MRR and Parsivel were only sometimes available for each site (YPO, MHS, BKC, and GWU) during ICE-POP 2017/2018. Therefore, wind-induced undercatch correction cannot be implemented, as Colli et al. (2020) suggested. The closest AWS data of each site is utilized

to characterize the background environmental condition of each site and analyze snow density. However, it's not adequate to be applied for wind-induced undercatch correction. According to the closest AWS data of each site, most SI is about 0.0 to 1.0 mm hr^{-1} during ICE-POP 2017/2018 (Figure 4 of the revised manuscript). 74% of the wind speed is less than 4 m s^{-1} (See Figure R1 of the reply). The Pluvio at the YPO site equipped Belfort double-Alter shield is more effective at mitigating wind-induced undercatch than the standard double-Alter shield (Kochendorfer et al. 2017; 2018;). In addition, the Pluvio at the MHS was within the DFIR.

The BKC and GWU sites, equipped with ordinary inner Tretyakov and outer Alter shields, do exhibit noticeable discrepancies between density-derived and Pluvio-observed SR, as expected (Figure 4 and Table 3 of the manuscript). On the other hand, the YPO and MHS with double windshield configuration, which is ideal for reducing wind-induced undercatch issues, have better agreements between density-derived and Pluvio-observed SR (Figure 4 and Table 3 of the manuscript).

A discussion of wind-induced undercatch issues has been added to the revised manuscript. Please see Lines 242-252 of the revised manuscript. Or see the following.

In addition to MRR attenuation, part of the inconsistency can be attributed to Pluvio-observed SR bias caused by the wind-induced undercatch issues (Kochendorfer et al. 2017; 2018; 2022; and Colli et al. 2020). Kochendorfer et al. (2017) and Colli et al. (2020) have proposed wind-speed-based undercatch correction algorithms for single/no-shield instruments. In this study, instead of applying the undercatch correction to single/no-shield Pluvio measurements, all sites were equipped with double windshields to mitigate wind-induced undercatch issues during ICE-POP 2017/2018 (see section 2). Kochendorfer et al. (2017; 2018;) indicate that the SDFIR (small DFIR) and the Belfort double-Alter windshield have much smaller uncorrected biases and also smaller adjusted RMSE relative to the corresponding reference. Kochendorfer et al. (2018) show that the collection efficiency (CE) for the Belfort double-Alter windshield (YPO site) is about 0.9 at a wind speed of 4 m s^{-1}. On the other hand, the CE of the double-Alter windshield (BKC and GWU sites) is dropped to 0.7 at a wind speed of 4 m s^{-1}. The MHS site with DFIR has fewer undercatch issues. It's postulated that wind-induced undercatch issues partially contribute to the discrepancies between density-derived and measured SR. Further investigation of the wind-induced undercatch issues is needed.

A description of the double windshield and DFIR at the MHS site to mitigate the wind-induced undercatch issues is added in the conclusion section of the revised manuscript. Please see Lines 493-495 of the revised manuscript. Or see the following.

The MHS site had a double windshield with inner Tretyakov and outer Alter shields. The instruments at the MHS were within the DFIR in addition to the double shields to mitigate the wind-induced undercatch issues.

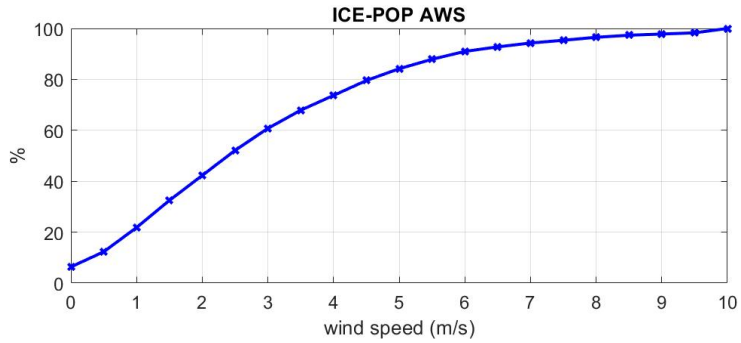

Figure R1: The CFD of wind speed from the closest AWS to YPO, JMS, BKC, and GWU sites. The CFD values of 3 m s^{-1} and 4 m s^{-1} are 60.76% and 73.71%, respectively.