Review of “Light scattering and microphysical properties of atmospheric bullet rosette ice crystals” by Wagner et al.

Summary

The paper provides a detailed analysis of the microphysical and optical properties of bullet rosette ice crystals, a common habit in in-situ generated cirrus. Using data from the CIRRUS-HL airborne campaign, the authors employ the Particle Habit Imaging and Polar Scattering (PHIPS) probe to link microphysical properties (e.g., bullet dimensions, aspect ratios, and hollow structures) with light-scattering characteristics, particularly the asymmetry parameter (g). The g for bullet rosettes was measured to be consistently lower (mean g=0.718) than previous theoretical predictions, which assumed idealized, pristine surfaces. The authors found that surface complexity, such as roughness and stepped hollowness, was the primary factor causing the discrepancy, with minimal impact from microphysical parameters such as maximum dimensions or number of bullets. The findings suggest that theoretical models overestimate g due to oversimplified assumptions about crystal smoothness, leading to inaccuracies in climate simulations of the radiative effects of cirrus. However, theoretical models that assume some representation of surface roughness on the surfaces of bullet rosettes or aggregates of rosettes (which these days would be most models) are more representative of the authors experimental findings.

The manuscript is well-structured, and the presentation of results is thorough, supported by clear figures. The authors have done well in detailing their methods, validating their results, and contextualizing their findings within the existing literature. My comments are minor and overall, this paper is a strong contribution to atmospheric science and should be considered for publication with the following minor revisions.

Specific comments are listed as follows:

1. Abstract. Line 9. ‘…optical…’ -> ‘the optical…’
2. Abstract. Line 10 comment. Most parametrizations of ice optics used in climate models these days include surface roughening effects rather than assuming smooth surfaces. This is done to mimic featureless phase functions which are most often observed. You should acknowledge this in the text of your manuscript. For instance, the ice optical parametrizations of Yang, P., Bi, L., Baum, B. A., Liou, K. N., Kattawar, G. W., Mishchenko, M. I., & Cole, B. (2013). Spectrally consistent scattering, absorption, and polarization properties of atmospheric ice crystals at wavelengths from 0.2 to 100 µm. *Journal of the atmospheric sciences*, 70(1), 330-347; Baran, A. J., Hill P., Furtado K., Field P., and Manners J. (2014). A coupled cloud physics-radiation parameterization of the bulk optical properties of cirrus and its impact on the Met Office Unified Model Global Atmosphere 5.0 Configuration. *J. Climate*, 27, 7725-7752 and Baran, A.J., Hill P., Walters D., Hardiman S. C, Furtado K., Field P. R., and Manners J. (2016). The Impact of Two Coupled Cirrus Microphysics–Radiation Parameterizations on the Temperature and Specific Humidity Biases in the Tropical Tropopause Layer in a Climate Model. *J. Climate*, 29, 5299–5316 – all include surface roughening effects on the surfaces of their ice crystal models to mimic observations to improve radiative simulations in climate and weather models.

3. Introduction. Line 13. On the global percentage distributions of cirrus – there are more updated references. For instance, the well-known works of Stubenrauch, see for instance Stubenrauch, C. J., Feofilov, A. G., Protopapadaki, S. E., and Armante, R.: Cloud climatologies from the infrared sounders AIRS and IASI: strengths and applications, Atmos. Chem. Phys., 17, 13625–13644, https://doi.org/10.5194/acp-17-13625-2017, 2017.
4. Introduction. Line 15. Why are you mentioning 'photons' in the context of atmospheric physics? Since you are applying geometric optics later on in the paper, I suggest you use 'rays'.
5. Introduction. Line 15. Citations of Paltridge and Liou are a bit dated. Suggest you augment these with more updated references such as Yang, P., Liou, K. N., Bi, L., Liu, C., Yi, B., & Baum, B. A. (2015). On the radiative properties of ice clouds: Light scattering, remote sensing, and radiation parameterization. *Advances in Atmospheric Sciences*, 32, 32-63 and Baran, A. J. (2012). From the single-scattering properties of ice crystals to climate prediction: A way forward. *Atmos. Res*., 112, 45-69.
6. Introduction. Line 19. '…at present…' -> '…at the present…'
7. Introduction. Line 31. Readers might not be conversant with the term 'effective density', please explain the term.
8. Introduction. Line 34. Explain how you define 'maximum dimension' in your paper – how do you measure it from your observations?
9. Introduction. Line 35. Did Fridlind et al. (2016) not provide power laws for their mass derivations. If so, why not quote the power laws instead of numbers?
10. Introduction. Line 44. The paper for comparisons with others relies on the works of Iaquinta et al. (1995) and Schmitt et al. (2006). However, the works of Yang and his students have also produced papers on the single-scattering properties of solid and hollow bullet rosettes. Why have the authors not included the latter works? See for instance, Yang et al. (2008) present differing results to those of Schmitt et al. (2006). Yang, P., et al., (2008). Effect of Cavities on the Optical Properties of Bullet Rosettes: Implications for Active and Passive Remote Sensing of Ice Cloud Properties. *J. Appl. Meteor. Climatol.*, **47**, 2311–2330.
11. In the paper, what is your justification for assuming random orientation? Is this because the quoted comparison citations also assume random orientation or is it for experimental reasons such as noise reduction or both?
12. Section 2. Line 66. '…in base..'-> '..in the base..' also
13. Same line. '….required focus…'-> add 'the' after required.
14. Section 2. Line 90. '…depening…'-> '…depending…'
15. Section 2. Line 93. What does a magnification setting of 4 mean?
16. Line 110. On examination of your Fig 1. I am not convinced that the solid bullet rosette shown contains no air cavities – on closer inspection there does appear to be some faint cavity – bottom-left on both solid images. Can you clarify?
17. Line 125 space between '…to L_B ..'
18. Line 136. 'solid ice' preferred as opposed to just 'ice'.
19. Line 140 '…measure…'-> '…measured…'
20. Same line, the projected area A is this assuming random orientation? If so, use <A>.
21. Line 155. Why is Xu et al. (2022) bracketed?

22. Line 165. The numerical simulations applying a large-scale approximation to surface roughness. Is there any work in the literature that compares this large-scale approximation to more accurate representations of surface roughness in calculating optical properties such as the asymmetry parameter?
23. Line 179. Why 10000 orientations? How do you know whether this is a sufficient number of orientations?
24. Line 238. '…calculate the uncertainty bullet length…'->'….calculate the uncertainty in the bullet length….'
25. Line 249. '…..Fridlind et al. (2016) *becomes* slightly higher…'
26. In this section, the derived mass and area power laws please can you state the units of the maximum dimension? Moreover, another mass-D power law that was derived using in-situ observations of cold cirrus and often used has been derived by Cotton et al. (2013), mass=$0.0257D_{max}^2$ (SI units). See, Cotton, R.J., Field, P.R., Ulanowski, Z., Kaye, P.H., Hirst, E., Greenaway, R.S., Crawford, I., Crosier, J. and Dorsey, J. (2013), The effective density of small ice particles obtained from in situ aircraft observations of mid-latitude cirrus. Q.J.R. Meteorol. Soc., 139: 1923-1934.When using the Brown and Francis (1995) relationship did you correct for their definition of mean diameter to maximum dimension following the Hogan et al. (2012) correction factor? See Hogan, R. J., Tian, L., Brown, P. R. A., Westbrook, C. D., Heymsfield, A. J., and Eastment, J. D.: Radar Scattering from Ice Aggregates Using the Horizontally Aligned Oblate Spheroid Approximation, J. Appl. Meteorol. Clim., 51, 655–671, 2012.
27. Line 269. '….indidual..'->'….individual…'
28. Figure 6. Can you please state the percentage of bullet rosettes that comprised of unmeasurable hollowness?
29. Line 325. The work of Baran and Labonnote (2006) is relevant to this paper because they found that by distorting the six-branched bullet rosette using a distortion parameter of 0.4 they were able to replicate the global POLDER measured polarized reflectances fairly well, see Baran, A. J., & Labonnote, L. C. (2006). On the reflection and polarisation properties of ice cloud. Journal of Quantitative Spectroscopy and Radiative Transfer, 100(1-3), 41-54.
30. Line 328. The discussion about column ice crystals being used to represent bullet rosettes. Since this paper uses one single wavelength, we must be careful not to exaggerate the applicability of simple models to other regions of the electromagnetic spectrum. This is shown quite nicely by Baran and Francis (2004) who found that simple hexagonal columns were an inadequate model relative to a complex aggregate model when differing portions of the observed electromagnetic spectrum were used simultaneously to test the models. See Baran, A.J. and Francis, P.N. (2004), On the radiative properties of cirrus cloud at solar and thermal wavelengths: A test of model consistency using high-resolution airborne radiance measurements. Q.J.R. Meteorol. Soc., 130: 763-778.
31. Figure 8 caption. Space between corresponding and H_{FACTOR}.
32. Line 340. '…rougness…'-> '…roughness…'
33. Line 355. In this study,….
34. Line 360. What is 'me'? Seems to be a typo.
35. Line 398. '…caluate..'->'…calculate…'

36. Appendix C. Are the authors aware of the refinements of C_D for bullet rosettes presented by McCorquodale and Westbrook (2021)? See McCorquodale MW, Westbrook CD. TRAIL part 2: A comprehensive assessment of ice particle fall speed parametrisations. *QJR Meteorol Soc*. 2021; 147: 605–626.