Review of "Fragmentation of ice particles: laboratory experiments on graupel-graupel and graupel-snowflake collisions" by Grzegorczyk and colleagues

Verdict

The paper should be published only after major modifications have been made.

Major Comments

The present graupel and snow particles are artificial and limitations of representativeness of the lab data arise. The fact that the snowflakes were created by manually clumping together some dendritic crystals needs to be mentioned in the concluding section and in the abstract.

Although high numbers of fragments are reported for graupel-graupel and graupel-snow collisions, the morphology of the artificial particles observed are extreme. There is a lack of representativeness. For example, the snow particles studied are 1 cm wide. But most snow particles are smaller than this in any size distribution. Also, the fragility of the snow particle and the number of monomers near the collision path of the incident graupel will increase with the snowflake size.

In reality, the proposed parameterization (Eq 3) does not necessarily apply to most snow particles, because a crucial quantity is missing: area of contact. These limitations need to be discussed in the concluding section.

The proposed parameterization should be adapted to apply to a wider range of particle sizes if possible. Area of contact could be introduced as a multiplying factor into Eq (3).

I think the title should be changed to convey the fact that the particles being studied are artificial and this should also be highlighted in the abstract. The abstract and conclusions sections need to state clearly the sizes of particles studied.

It needs to be specified under what conditions of LWC and temperature the vapour growth can prevail such that the dendritic crystal can grow on the graupel, so that the graupel-graupel results are valid.

Detailed Comments

Line 36: Other modeling studies can also be cited that use this breakup scheme: Waman et al. (2022, JAS), Sotiropolou et al. (2021, 2022), Zhao et al..

Line 49: It is not true that Phillips et al. wrote that use of a fixed target could falsify results. In fact, they argued the opposite:

"On the one hand, for head-on collisions the fixing of the target boosted the initial CKE without appreciably altering the energy-based coefficient of restitution q governing fragmentation. In the present paper, the laboratory observations were used only by relating fragment numbers to the initial CKE, so there is no problem in this respect.".

It is important to read the papers that are cited.

Line 76-77: It is not true that *both* colliding spheres were fixed during and after collision. Phillips et al. never wrote that. Only one of the colliding spheres was fixed. Of course, this artificially boosted the CKE. But as noted above, that is not really a problem, if the analysis is done in terms of CKE, relating it to the number of fragments.

Line 282: This Equation (3) is simplistic because it neglects the role of the area of contact during impact, which depends on the particle sizes.

Line 283-284: The maximum emission of fragments beyond a certain CKE was not merely "expected", but rather was observed in Takahashi's published data when analysed by Phillips et al. (2017) in terms of CKE.

Line 304: What is really needed for use of the graupel-graupel results is the critical LWC and temperature range, for which the dendritic growth prevails at the surface. Outside of these conditions, there will be no fragmentation because the surface will be rimed and any depositionally grown ice will be continually buried by fresh rime.

Line 386: There was no intention to "rime" (accretion of supercooled droplets) the ice spheres in the Takahashi et al. lab experiment. The purpose of their controlled supply of supercooled cloud-liquid was to control the time of exposure to high humidities and vapour growth of ice.

Line 375-400: The concluding section needs to discuss the limitations arising from the fact that all particles studied in the present paper are artificial. What conditions of LWC and duration of exposure are needed for graupel in a simulation to be representative of the artificial graupel observed here ? The artificial manner of creation of these particles must be discussed.