Review of "How observations from automatic hail sensors in Switzerland shed light on local hailfall duration and compare with hailpads measurements", by Kopp, Manzato, Hering, Germann and Mar/us, AMT-2023-68.

This is a worthwhile study that reports on data from automatic hail sensors based on the Loffler- Mang et al. (2011) instrument. There were 80 of these automatic hail sensors operational in Switzerland, some of which acquired data from 2018-2022. The observations were compared with data from a hailpad network in northern Italy. Some interesting aspects of the hail sensor data were examined, including the duration of hail, when the largest hail was observed relative to the beginning of the hail event, etc. My comments appear below. I recommend that the revision considers my comments below.

We thank the referee for its revision and both supporting and pertinent comments.

Main Comments

This article has many similarities to the Kopp et al. (2022) article that you cite. You do mention that in the text. Perhaps you could add a sentence on some of the results from that article.

Kopp et al. (2022, Weather) describe the weather situations that let to severe hailstorms in summer 2022 and contains a qualitative description of the hail sensor measurements and comparison to crowd source data gathered on 8. July 2021. The present article presents a detailed discussion of the entire hail sensor data set and a detailed comparison with hail pad measurement. Hence the research questions of Kopp et al. (2022) differ from those of the present article. We agree with the referee that we should include some of the conclusions of Kopp et al. (2022) regarding automatic hail sensors:

Line 44: Some observations recorded during the particularly active hail season of 2021 were presented in Kopp et al. (2022) **where it was shown that automatic hail sensors could successfully capture precise time series of individual hailstone impacts.**

Line 230: The highest number of yearly impacts **(6'400)** was recorded in summer 2021, during a particularly active hail season (Kopp et al., 2022).

I tried to find the Wetzel (2018) article in MTI but couldn't. You may want to add references to the instrument that appeared in the Kopp et al. (2022) article.

We agree with the referee that the access of the reference is not straightforward. The references of Kopp et al. 2022 related to the hail sensor are the same as those of the present article. The reference Wetzel, 2018 can be found here: https://www.innetag.ch/wp-content/uploads/2020/10/HailSens-MTI_2018_09.pdf

We made the following change:

Url added to the reference in the bibliography

Eq. (1). A square root sign when a variable is taken to the ¼ power. Please convert it to $[\ ]^{0.25}$

We modified accordingly with $[]^{0.25}$.

When a comma, should be used, for example 10,200 you have 10’200. There are many places where this needs correction. For example, line 43: 12’300

We agree with the referee that this notation is not an official one.

Change: We replaced the symbol ‘ by a space, following guidelines from the International System of Units (SI).

Using the values you provided for the variables in Eq. (1), I did a curve fit that relates diameter to kinetic energy. The goodness of fit is almost 1.00. I did the same thing using the values presented in Heymsfield et al. (2018). As you can see from the figure below, the spherical assumption results in hailstone diameters that are perhaps 30% *smaller*. It took me a while to figure out why but after thinking about it is definitely the case. In Figure 12 of the Kopp et al. 2022) article, there are good examples of why you should consider non-spherical particles. I feel extremely strongly that we need to move forward acknowledging that the assumption of spherical hailstones needs to be replaced with current knowledge-not citing studies from the 1970’s. I suggest that you include both spherical and the “nonspherical” hailstone assumptions in your discussion (lines 98-100, etc.)

We agree with the referee that considering hailstones to be spherical is an approximation, which we explicitly acknowledge on lines 91 to 96. We used the output diameters of the instrument as provided by the manufacturer (ie. Using the spherical approximation), and changing this internal estimation is beyond the scope of this work. Moreover, applying non-spherical approaches would require further steps to be properly conducted. First, it would require information on the aspect ratios or sphericity of the measured hailstones, which unfortunately is not given by the hail sensors. Using hailpad and hail sensor in pairs could help fill this gap. Second, both automatic hail sensors and hailpads are calibrated using spherical masses. The calibration process would need to be conducted using masses of different shapes to properly assess the impact of the non-sphericity on the output of both devices (electric signal and dents).

Besides, we note that the hailstones shown on Figure 12 of Kopp et al. (2022) have (largest) diameters between 4cm and 10cm, which are larger than the largest hailstone measured by the automatic hail sensors (3.3cm).

We made the following changes in our conclusion:

Line 100: **We discuss this point further in the conclusion.**

Line 435 (new paragraph). **We used the output diameters of the hail sensor as provided by the manufacturer in the present study. Such diameters were estimated using the approximation that hailstones are spherical, which is not always the case, especially for large hailstones. Pairs of hailpad and hail sensor could be used to investigate more**

advanced non-spherical approaches \citep[eg.][]{Heymsfield2018, Shedd2021}. For example, the distribution of aspect ratios could be inferred from the hailpad measurements and used as an input when estimating the hailstone dimensions from the kinetic energy measurements of the hail sensors.

Section 2.1.6. What if the hailstones 5 to 7 mm are non-spherical. They could be considered raindrops?

We agree with the referee that there is an overlap between the range of kinetic energies of small hailstones and very large rain drops. Consequently, we cannot exclude that some of the recorded impacts were caused by large rain drops and not by hailstones. However, we believe this effect to be limited because the non-spherical hailstones should be the largest and not those of 5-7mm. Then, if we consider all (or a large fraction of) hailstones from 5 to 7 mm as raindrops, then our hail size distribution would become very different from the size distribution measured by hailpads (for small sizes) as hailpads do not record raindrops. While the two distributions may differ due to several factors, we think as rather unlikely that the number of hailstones between 6mm and 7mm is much lower in Switzerland than in Italy.

Could you add nonspherical hailstone diameters to Fig. 6a. Would this improve the agreement between the hail sensors and hailpads?

As mentioned in our answer above, we believe that using non-spherical assumptions is a valuable research avenue but that it requires a more detailed analysis which is beyond the scope of the present paper. We mention in our conclusion how this could be further conducted.

As you know, probability is not concentration. The concentration is the number per cubic volume (meters). Could you estimate the terminal velocity to get the concentration? That would be useful information. In fact, in this way you could compare your hail size distributions to the article by Federer and Waldvogel, and others from the 1970s.

We agree with the referee that we limited our study to the hail size distribution measured at the ground, because our objective was the comparison of the measurements of hailpads and hail sensors and for that the hailstone concentration was not needed. We are not sure which publication of Federer and Waldvogel the referee is mentioning. If such references analyse the hailstone concentration within the cloud, then assumptions on the melting rate and hailstone drifting would have to be made. This is another interesting research question which could be treated in another publication but is beyond the initial scope of the present paper.

Also, the impacts on the hailpads are not likely to be spherical because of the non-spherical shape of large hailstones. In fact, the shape of the impacts could be examined for non-sphericity. This has been done in the past.

A discussion on the aspect ratios of the impacts on the hailpads is available in Manzato et al., 2022. They found that the median aspect ratio for hailstones larger than 6mm is approx. 1.25. The distribution of the aspect ratios is available in their figure 3.

Manzato, A., Cicogna, A., Centore, M., Battistutta, P., and Trevisan, M.: Hailstone characteristics in NE Italy from 29 years of hailpad data,
Journal of Applied Meteorology and Climatology, https://doi.org/10.1175/JAMC-D-21-0251.1, 2022.

I like the idea of characterizing the duration of the hailstorm events at the ground and its distribution with time. Could you possibly link radar data to your hail impact data and then in the future be able to use radar data to refine the estimates of hail duration?

We thank the referee for this suggestion. Using radar data to refine the estimates of the hail duration would not be feasible due to the current spatial (1 km^2) and temporal (5 minutes) of the Switzerland radar network. We mention at line 419-420 that the local duration of most hailfalls is less than this temporal resolution.

3.3.3 Timing of the largest hailstone. Just a thought. Prior to the largest hailstone, what do you observe in the rain category? Perhaps the smaller hailstones melt prior to reaching the surface and only the larger ones survive the melting process.

It would be interesting to analyse this point in more details. Melting certainly affected the hailstone sizes during the events. However, no rain disdrometer was installed next to the hail sensors to measure the rain drop size distribution. Moreover, the time (5 min) and space (1km) resolution of radar-based estimates of the rain rate would also be too coarse to make a proper estimation at the sensor location. Therefore, we are not able to answer this question.

Minor Comments
Title. Hailpads should be singular, Hailpad.

We changed accordingly.

Lines 1, 15. Measuring the properties of hailstorms

We changed accordingly.

28. "cheap" to "low cost"

We replaced cheap with affordable.

160-161. I very much like the idea of using radar to identify when hailstorms are in close proximity to your sensors.

175. Canada or the United States? I didn’t have access to the Brimelow study

We thank the referee for pointing this out. Brimelow (2018) refers to the following studies which analysed hailstorms in various countries:

Admirat, P., Goyer, G. G., Wojtiw, L., Carte, E. A., Roos, D., & Lozowski, E. P. (1985). A comparative study of hail in **Switzerland, Canada and South Africa**. Journal of Climatology, 5, 35–51.

Frisby, E. M. (1963). Hailstorms of **the Upper Great Plains of the United States**. Journal of Applied Meteorology, 2, 759766.

Nelson, S. P., & Young, S. K. (1979). Characteristics of **Oklahoma** hailfalls and hailstorms. Journal of Atmospheric Sciences, 18, 339–347.

Paul, A. H. (1980). Hailstorms in southern **Saskatchewan**. Journal of applied Meteorology, 19, 305–314.

Webb, J. D. C., Elsom, D. M., & Meaden, G. T. (2009). Severe hailstorms in **Britain and Ireland**, a climatological survey and hazard assessment. Atmospheric Research, 93, 587–606.

We made the following change:

Line 175: **Based on studies from various countries, Brimelow (2018) found** that the majority of hailstreaks are less than 5 km wide, increasing to 10 to 15 km for more organized hailstorms, with maximum widths ranging from 25 to 30 km

205. Good idea to look at a range of time intervals

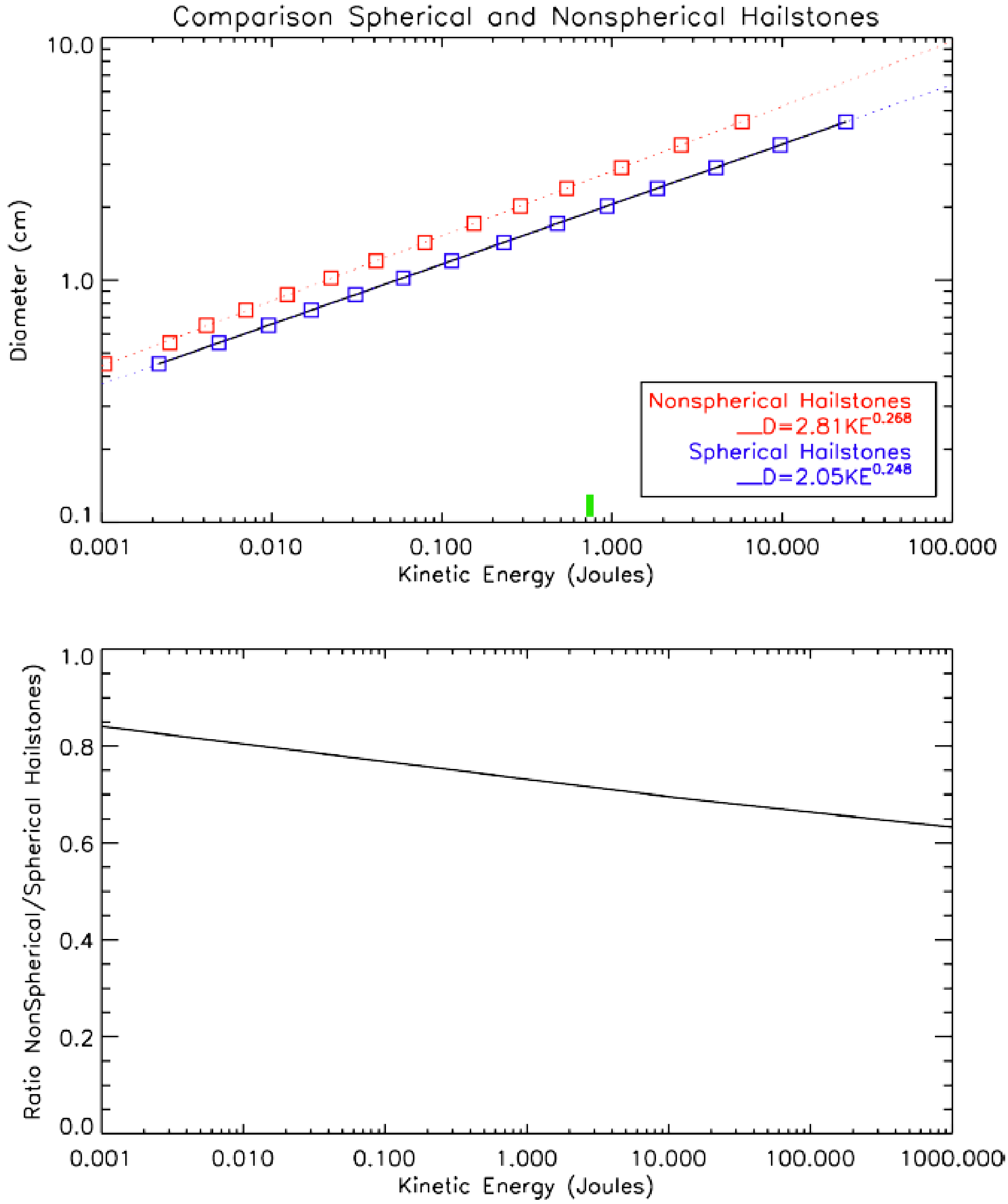
Figure 5a. Put in the alternate diameter. This would be very useful here.

We refer to our comment on non-spherical hailstones above.

437-438. Could there be video cameras that are turned on and off by the hail sensors when they detect hail? That might provide another means of characterizing the hail events.

This is an interesting idea, provided that the camera is properly shielded from the hailstones. The associated cost of adding, setting up and maintaining the cameras would also need to be considered.

More of my comments will be given in a revision.
Andy Heymsfield, NCAR



Comparison Spherical and Nonspherical Hailstones
Diameter (cm)
10.0
1.0
0.1
0.001
0.010
0.100
1.000
10.000
100.000
Kinetic Energy (Joules)
Nonspherical Hailstones
D=2.81KE^0.268
Spherical Hailstones
D=2.05KE^0.248
Ratio NonSpherical/Spherical Hailstones)
1.0
0.8
0.6
0.4
0.2
0.0
0.001
0.010
0.100
1.000
10.000
100.000
1000.000
Kinetic Energy (Joules)

Fig. 1