Advances in Geometrical Classification of Snowflakes Using AI and Images Collected by the Multi-Angle Snowflake Camera

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Developments in artificial intelligence (AI) and machine learning have introduced improved supervised image classification techniques in convolutional neural networks such as Inception, ResNet and EfficientNets or more recent transformer based networks such as Vision Transformers and Swin Transformers. However, these methods, when observing complex shapes from a single angle/view could lead to misleading shape recognition even for the trained expert eye. In observations of snowfall and snowflakes for atmospheric science and meteorology purposes, an important analysis outcome is classification of precipitation, namely, deciding to which of the several typical classes of winter hydrometeors the observed particles belong. With the use of AI and neural networks, we can classify snowflakes into a number of geometrical categories, as well as degrees of riming.

As image classification techniques of complex shapes have improved, researchers have made substantial advances relying on multi-view imaging systems (M. Seeland, P. Mader, "Multi-view classification with convolutional neural networks," *PLoS ONE,* vol. 16, issue 1, 2021). This classification technique suggests the use of concatenating features from multiple views after they are extracted using parallel instances of convolutional neural network of our choice. MASCDB (J. Grazioli, G. Ghiggi, A. C. Billault-Roux, A. Berne, "MASCDB, a database of images, descriptors and microphyscial properties of individual snowflakes in free fall," *Sci Data*, vol. 9, 2022) is a database of snowflakes that has multi-view images of snowflakes collected using the Multi-Angle Snowflake Camera (MASC) in the Alps, Antarctica and Korea. The database has snowflake images that are categorized into six geometrical classes, Small Particle, Aggregate, Planar Crystal, Columnar Crystal, Graupel and Columnar and Planar Combination, alongside other features such as riming, melt/dry state, and fall speed.

This paper presents our novel snowflake classification methodology based on a neural network consisting of parallel instances of Inception-v3 network for feature extraction from each view, which are then concatenated after feature extraction before being fed into our custom classification head. We show results of the geometrical classification of snowflakes using machine learning and MASC images, with the neural network classifier trained on the MASCDB Database. The results we achieved constitute a record high of 98.11% in snowflake geometric classification, surpassing a single view instance of the same network at 94.38%. With the snowflake geometric classification performing at such high confidence, we can perform detailed analyses of categories and subcategories of snowflakes and snowfall.