Understanding PIP Measurements of Particle Shape via Image Analysis

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1. Background and Motivation

Importance of Particle Characteristics

- Understanding microphysical processes
- Improving radar and satellite snow microphysics retrievals

Research Goals

- Understand PIP measurements of particle size and shape in terms of the particle long and short dimensions
- Improve the PIP image analysis techniques to produce more accurate particle shape estimates

2. Data and Instrumentation

Precipitation Imaging Package (PIP)

- Two components: a camera and a light source, which back lights the precipitation particles (Fig. 1; Pettersen et al., 2020)
- Makes measurements of particles as small as 0.1 mm within a 64 mm x 48 mm field of view at 380 frames per second
- Examine ICE-POP (South Korea) data from 7–8 March 2018 event

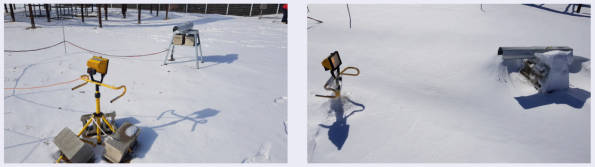

Fig. 1. Photos of the PIP setup during the 2018 ICE-POP field campaign in South Korea that coincided with the Winter Olympics. PIP is composed of a camera, which is shielded by a visor in the pictured setup, and a lamp, which is used to back light the precipitation particles.

PIP Shape-fitting Method

- PIP uses the proprietary IMAQ Visual software package
- An ellipse and a rectangle are fitted to each particle to determine the particle dimensions (ellipse major and minor axis and rectangle base and side) and orientation angle
  - Both the fitted ellipse and rectangle are defined as having the same area and perimeter as the actual particle

Custom-fitted Ellipse Method

- We perform our own ellipse fitting on .avi files depicting the PIP view scenes for the first 2000 populated frames every 10 minutes
- The custom-fitting function uses the "mass distribution" tensor eigenvalues to determine the fitted ellipse properties
- Our analysis indicates that the custom-fitted ellipses provide similar accuracy to the ellipse-fitting employed by MASC

Emulated MASC-fitted Ellipse Method

- We also replicated the ellipse-fitting method used by the MASC instruments at ARM sites
  - MASC employs a best fit method that minimizes the algebraic distance between the particle outline and the fitted ellipse

3. Comparison of Size and Aspect Ratio Estimates

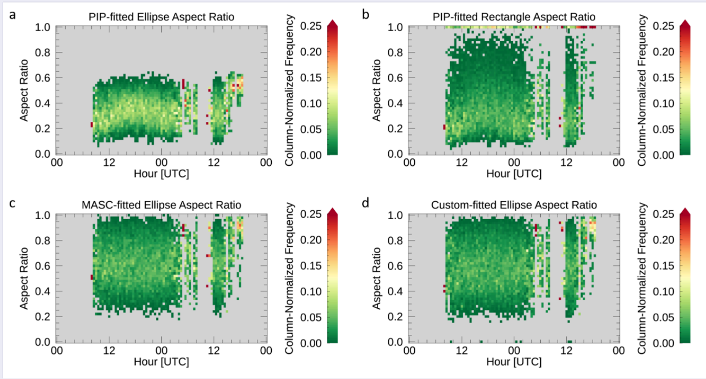

Fig. 2. Time series of (a) PIP-fitted ellipse, (b) PIP-fitted rectangle, (c) emulated MASC-fitted ellipse, and (d) custom-fitted ellipse aspect ratio for the 7–8 March 2018 ICE-POP snow event at the May Hills Supersite.

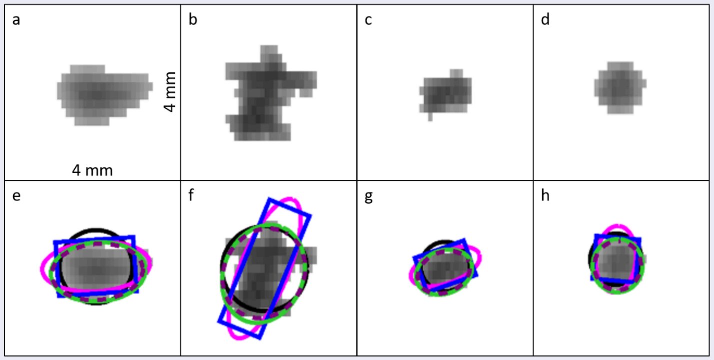

Fig. 3. (a-d) PIP views of particles with (e-h) the fitted shapes annotated as follows: area-equivalent circle in black, PIP-fitted ellipse in magenta, PIP-fitted rectangle in blue, emulated MASC-fitted ellipse in dashed purple, and custom-fitted ellipse in green. Each panel represents a 4 mm by 4 mm area. Particles (a) and (b) are from around 1904 UTC 7 March and particles (c) and (d) are from around 1756 UTC 8 March.

4. Evaluation of Size and Aspect Ratio Estimates

- PIP-fitted shapes typically overestimate the long dimension and underestimates the short dimension
  - Results in underestimation of aspect ratio
  - More severe for PIP-fitted ellipses than rectangles
  - PIP-fitted ellipses have an artificial aspect ratio cap of $\sim$0.6
- The emulated MASC-fitted ellipse and custom-fitted ellipse methods appear to produce reliable representations of particle dimensions

Acknowledgments

Dr. Helms' work was supported by an appointment to the NASA Postdoctoral Program (NPP) at the NASA Goddard Space Flight Center, administered by Universities Space Research Association under contract with NASA. The authors would like to thank the ICE-POP team for their efforts in the field. Finally, the IDL code used to produce the custom-fitted ellipses was provided to the community by David Fanning.

5. The Artificial PIP Aspect Ratio Cap

Fitting a Hypothetical Circular Particle

- Imagine a circular particle with a mean radius of 0.5 mm that always has an aspect ratio of 1.0 regardless of perimeter length
  - Longer perimeters are accommodated by an undulating edge
- We prescribe the perimeter as a multiple of the perimeter of a circle of radius 0.5 mm, hereafter the perimeter stretching factor (PSF)
- We can perform PIP shape fitting to this hypothetical particle because PIP fits shapes based purely on the area and perimeter

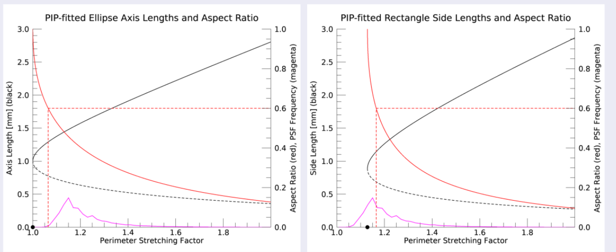

Fig. 4. Long (black solid) and short (black dashed) dimension lengths of a hypothetical circular particle with an undulating edge fitted using the PIP fitting equations for (left) ellipses and (right) rectangles as a function of the perimeter stretching factor (PSF). The resulting aspect ratio is overlaid in solid red with the PSF for an aspect ratio of 0.6 highlighted by the red dashed lines. The black dot is the smallest PSF for which a physically meaningful shape can be fitted and the PSF distribution for 7–8 March 2018 is plotted in magenta.

- PIP-fitted ellipses: A slight increase in the perimeter (PSF$\approx$1.065) of our hypothetical circular particle results in an aspect ratio of 0.6
  - Very few observed particles have a PSF smaller than is needed to achieve a PIP-fitted ellipse aspect ratio larger than 0.6
- PIP-fitted rectangles: Small PSF range between aspect ratio of 0.6 (PSF$\approx$1.165) and smallest possible PSF for a rectangle ($\sim$1.128)
  - This PSF range corresponds to the peak in the observed PSF distribution, hence the PIP-fitted rectangles have more aspect ratios above 0.6 than the PIP-fitted ellipses
  - PIP assigns a rectangle aspect ratio of 1.0 for any particle with a perimeter that is too short to permit the construction of a rectangle of equal area (i.e., PSF$\lesssim$1.128)

6. Summary

- Goal: Understand how PIP measures particle dimensions
- Method: Comparison of particle dimensions using PIP, MASC, and custom shape fitting functions applied to PIP images
- Results: PIP-fitted ellipses and rectangles have considerable errors in the particle long and short dimensions
  - Affected variables: Ellip_Maj, Ellip_Min, Rec_BS, Rec_SS
  - Other PIP variables (e.g., D_{eq}) are unaffected

7. References

Pettersen, C., M. S. Kulie, L. F. Bliven, A. J. Merrelli, W. A. Petersen, T. J. Wagner, D. B. Wolff, and N. B. Wood, 2020: A composite analysis of snowfall modes from four winter seasons in Marquette, Michigan. *J. Appl. Meteor. Climatol.*, **59**, 103–124.