Estimates of ice crystal terminal velocity using IPAS

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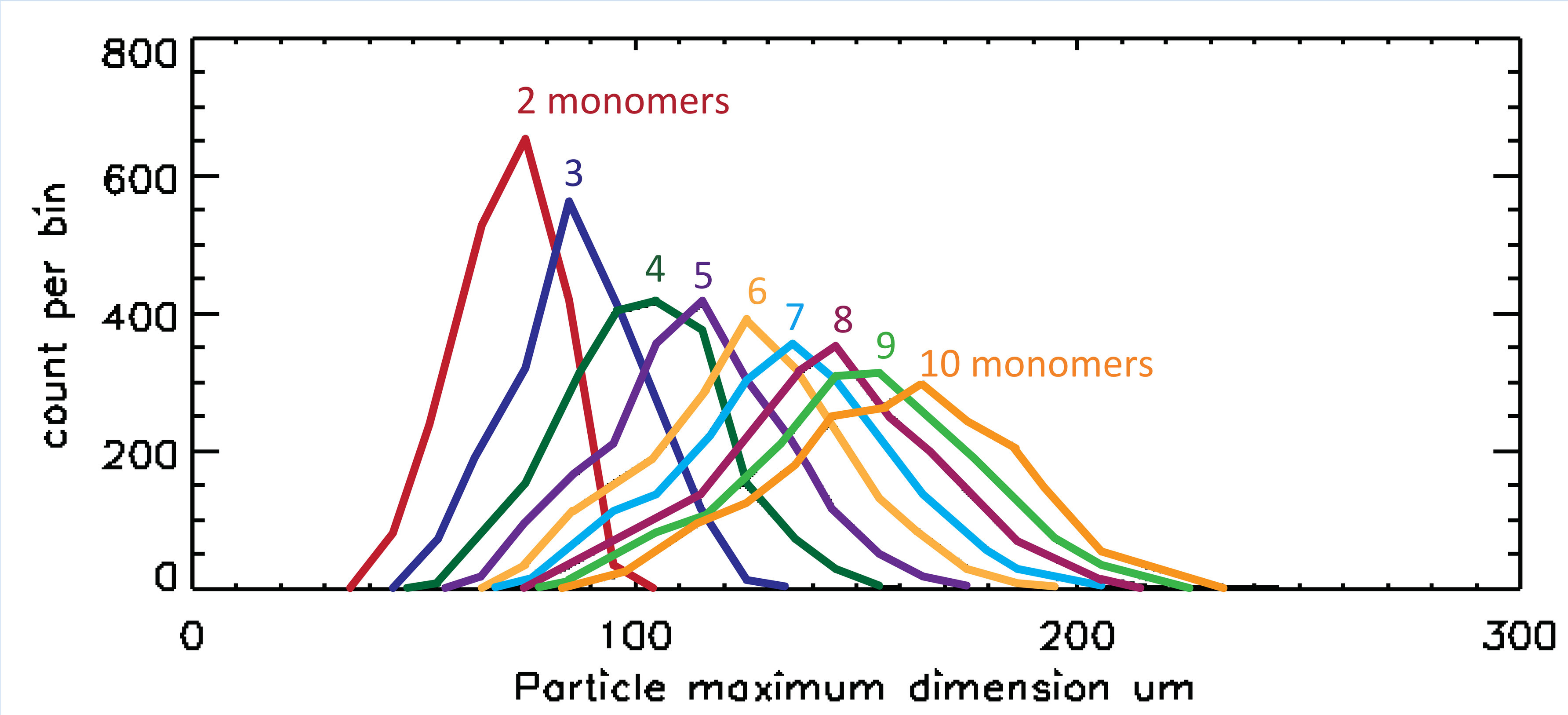
The terminal velocity of hydrometeors is of high importance to atmospheric modeling. For liquid hydrometeors, terminal velocity estimation is simple given their spherical or near spherical shape. For ice hydrometeors, the story is more complicated due to the variety of ice shapes possible in the atmosphere. Because the aggregation of ice crystals relies on the relative terminal velocities of the colliding particles, understanding the particle characteristics that contribute to the distribution of ice particle terminal velocities is crucial. For one particle "size", a variety of terminal velocities are possible. The Ice Particle Aggregate Simulator (IPAS) model is used to create realistic ice particles and ice particle aggregates in order to explore the variability of terminal velocities possible for a given particle maximum dimension. IPAS employs detailed information on ice crystal characteristics to approximate the various aspects of ice particle sedimentation and produces a statistical outline of terminal velocity. Future studies will extend these results to investigate aggregation through the differential sedimentation of ice particles.

The problem

When ice particles aggregate, the resulting particle characteristics are not certain. Imagine that two columnar shaped crystals collided and stuck together. Knowing the original masses, it easy to determine the mass of the new particle, but the projected area, density, maximum dimension (length), and terminal velocity can be quite uncertain. Knowing the "length" of an ice particle does not provide much information on the particle's actual size! Using IPAS, we created 200 aggregates of from 2 to 10 monomers at each of ten different aspect ratios of monomers (ranging from 0.2 to 5.0). We assumed that every monomer had the same maximum dimension (50 microns). Particles were then oriented into their anticipated fall orientation (maximum projected area perpendicular to fall direction). Each curve below represents the particle size distribution for particles of the same number of monomers from 2 (left) to 10 (right). As can be seen, *a 100 micron particle could be composed of anywhere between two and 10 monomers*, a factor of 5 difference.

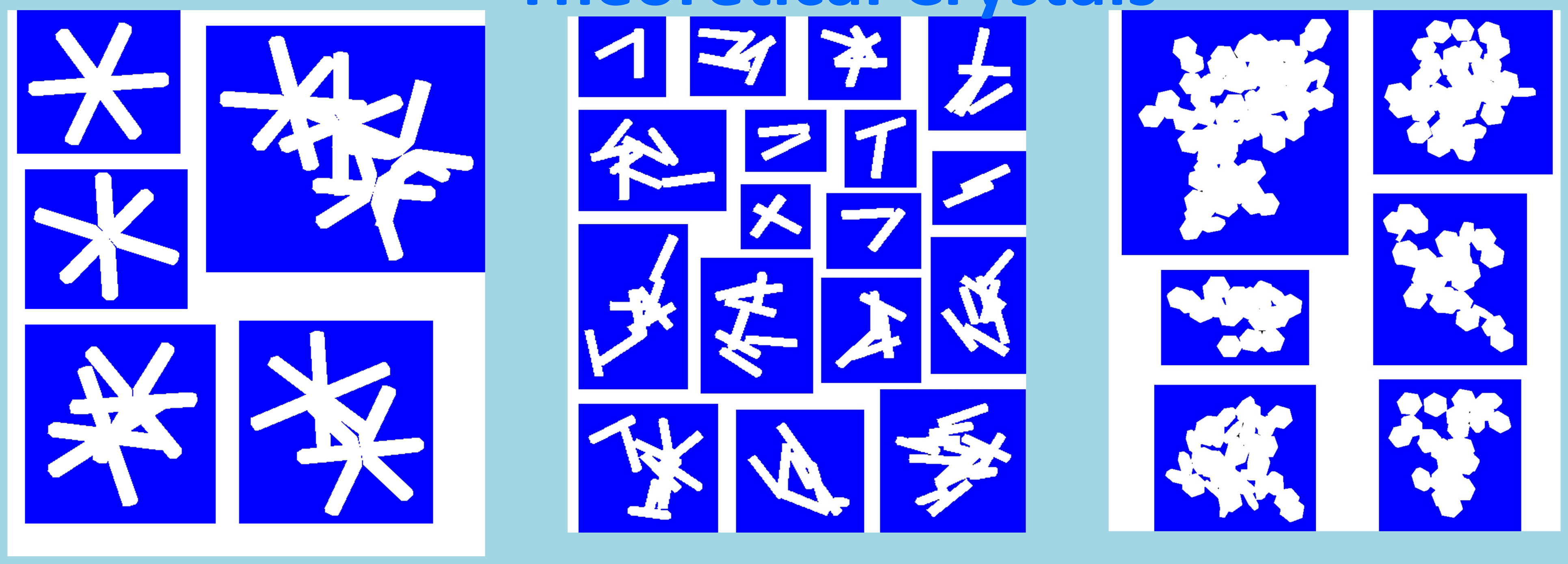


IPAS: the Ice Particle Aggregation Simulator

IPAS was developed initially for the purpose of understanding the three dimensional characteristics of atmospheric ice particles based on two dimensional images. **With IPAS, one can use basic vapor grown crystal shapes and aggregate them into larger aggregates.** Shown below are examples of bullet rosettes, columns, and plates which have been aggregated together as well as Cloud Particle Imager (CPI) images of similar atmospheric crystals and aggregates. From IPAS, the fractal dimension of 2D images of the 3D crystals has been calculated and used to determine mass dimensional relationships (Schmitt and Heymsfield, 2010) and ice particle complexity has been studied (Schmitt and Heymsfield, 2014 and Schmitt et al. 2016).

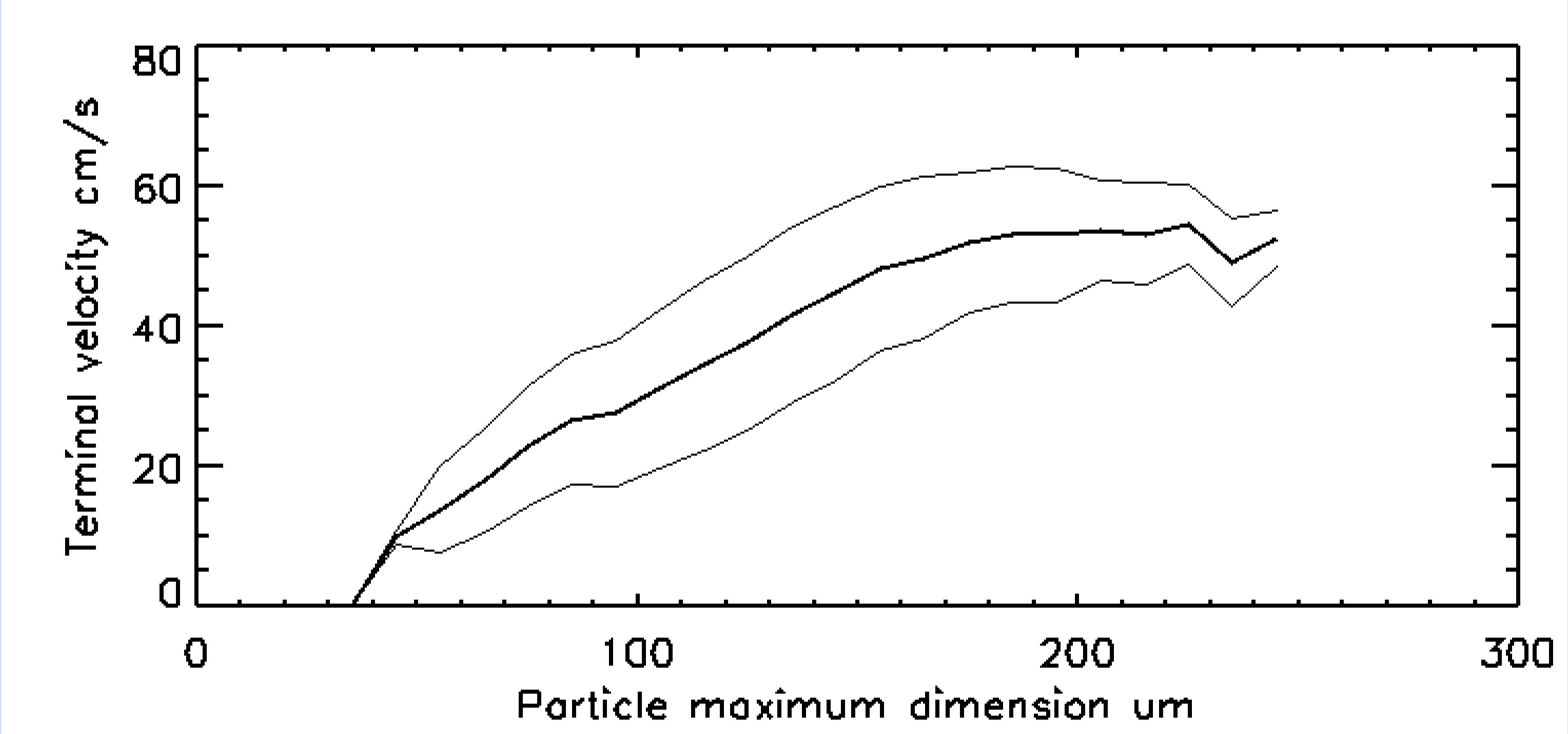
Real Crystals

Theoretical Crystals



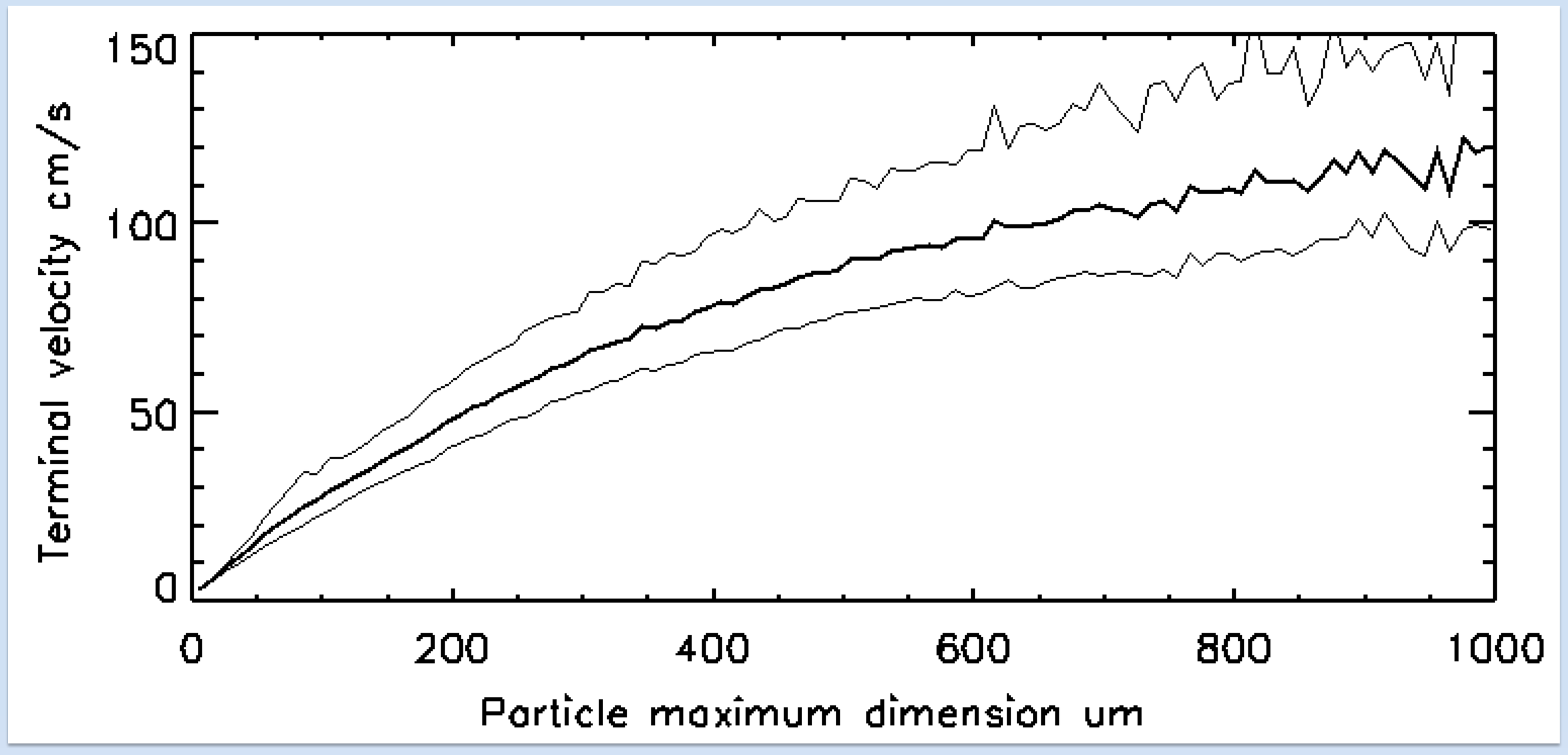
Terminal velocity of IPAS crystals

Using Heymsfield and Westbrook (2010), the terminal velocity of each particle has been determined assuming a temperature of 0ºC and pressure of 1000 hPa for simplicity. The mean terminal velocity for all particles plus and minus the standard deviation are plotted below showing the wide range of particle sizes that can have the same true terminal velocity.



Comparing apples to apples

Unless we can directly measure the mass of individual ice particles, it is difficult to understand the variability with atmospheric ice crystal data. The Heymsfield and Westbrook formulation for calculating terminal velocity requires particle mass, area, and maximum dimension. Obviously, on average, particles with larger projected areas will likely have larger masses, so calculating the terminal velocity for an individual ice crystal using its true area and the mass from a mass dimensional formula isn't satisfactory. For fractal particles (as in Schmitt and Heymsfield, 2010) it can be shown that the mass varies linearly as a function of projected area. With this information, the mass of larger area particles can be scaled leading to more accurate calculations. The plot below shows the mean terminal velocity and plus and minus the standard deviation for Cloud Particle Imager (CPI) data measured during the 2000 ARM IPO campaign.



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