How important is microphysical variability to atmospheric cloud processes? Quantification of variability and impact on forecast model results.

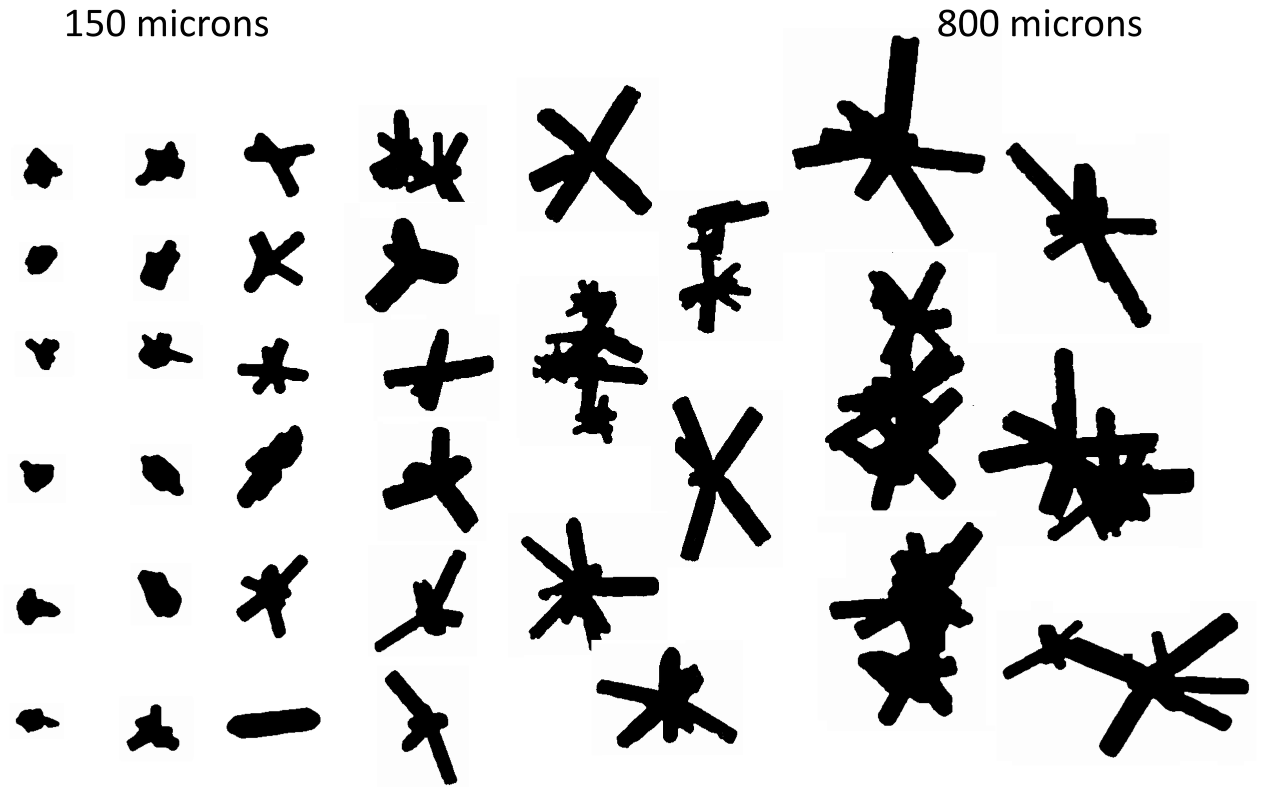
Carl Schmitt, Zach Lebo, Kara Sulia, Vanessa Przybylo

Introduction: To study a multitude of complex interactions between atmospheric ice particles that cannot be physically reproduced in the laboratory, a typical preliminary approach in modeling and experimentation is to reduce the number of variables that affect such interactions.

In an effort to constrain aggregation sticking efficiency estimates, we conduct the following simulations: In cold environments, the time required for particle fusion (the thermodynamic sticking of one particle to another) is long, thus greatly reducing the likelihood for ice crystal aggregation via sintering. This suggests that mechanical interlocking of crystal components could be a dominant form of aggregation in cold conditions. During the March 2000 DOE ARM IOP the University of North Dakota Citation research aircraft made high quality observations with the Cloud Particle Imager (CPI) probe over the Southern Great Plains site. Observations were conducted at multiple altitudes and bullet rosette shaped ice crystals were the dominant habit. We selected 36 crystals from Cloud Particle Imager (CPI) results. Sizes ranged from 130 microns to 920 microns with 6 particles being chosen from 6 different size ranges. The images are below:

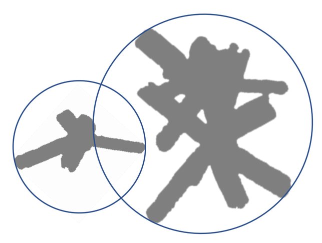
CPI images from 9 March 2000 DOE ARM IOP

150 microns — 800 microns



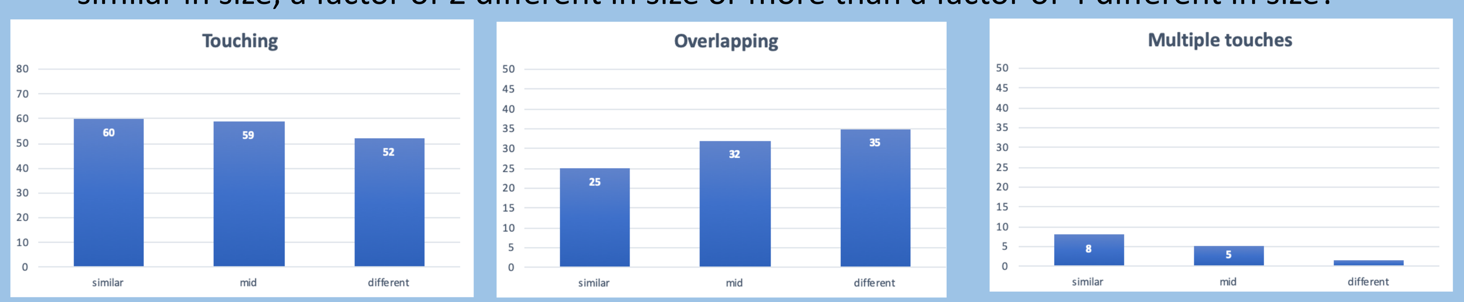
With these crystals, we used a modified version of the Ice Particle Aggregation Simulator (IPAS) to asses different possible aggregation mechanisms. 2D images were randomly rotated, then randomly placed on a 2D plane. 1000 random placements were conducted for each particle pair. Two particles were said to "interact" if their centers were within the sum of their radii (with their radii being defined by the radius of the smallest circle that would completely cover the particle). Of the particles that "interacted", a tally was kept of those that "touched", "overlapped", or "multiply overlapped". "Touching" meant that any part of one particle would touch any part of another. "Overlapping" means that the area of overlap between the two particles was at least 20% of the area of the smaller particle. "Multiple overlapping" means that two areas of overlap occurred with at least 5% of the total area being overlapped. It is expected that the "Multiple overlapping" particles were much more likely to aggregate due to the locking of rosette branches.

When particles interacted:

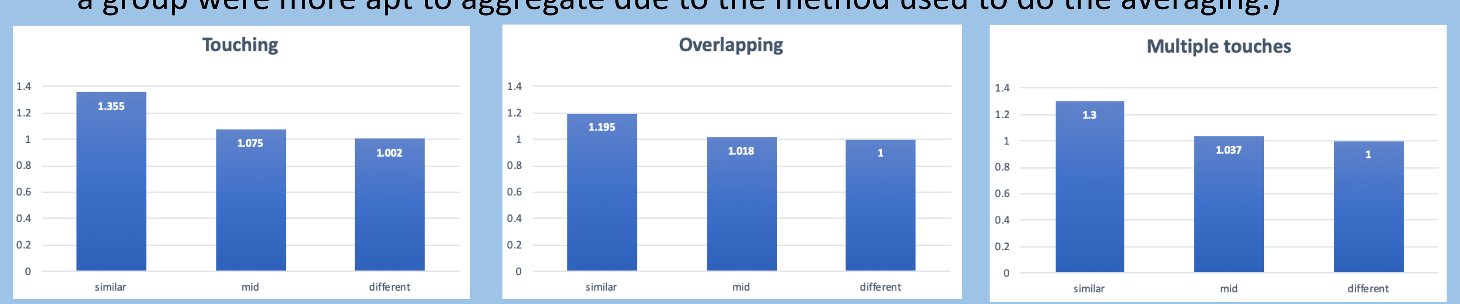


Touching — Overlapping — Multiple Overlap

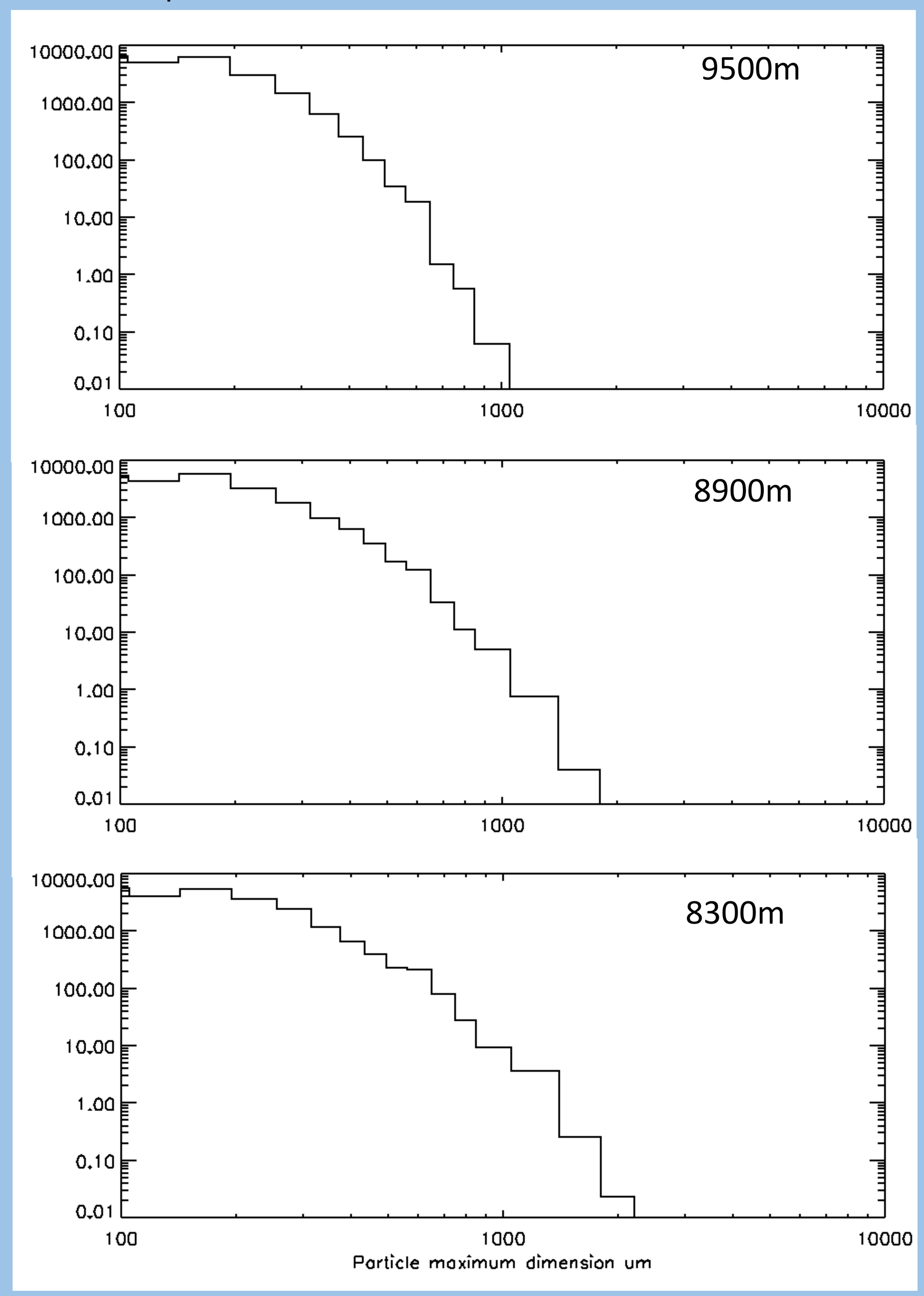
When particles interact, how often do each of these situations occur? When particles are similar in size, a factor of 2 different in size or more than a factor of 4 different in size?



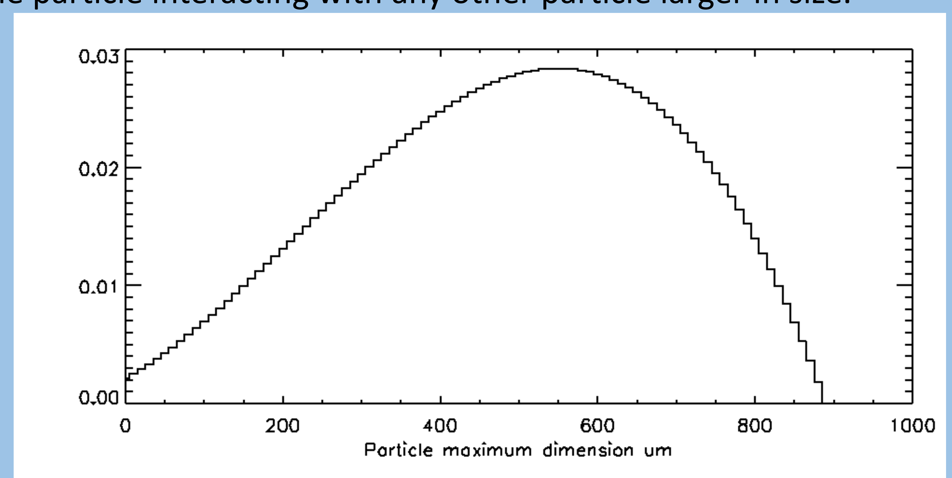
When particles interact in each of these ways, how large is the resulting particle? Results presented as the ratio of the new aggregate size divided by the size of the larger of the two particles to form the aggregate. (Note that zero growth can occur if the smaller particles in a group were more apt to aggregate due to the method used to do the averaging.)



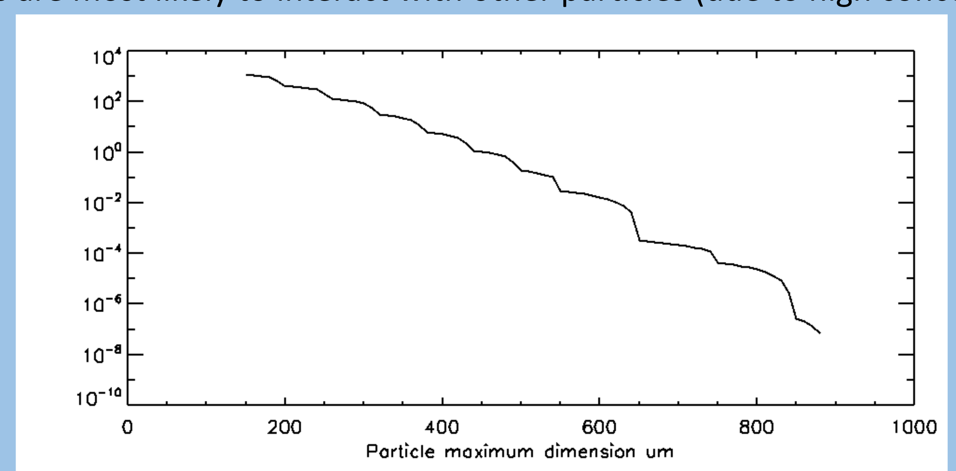
Measured particle size distributions from the 9 March 2000 case.



To estimate the likelihood of interaction between particles, Vt and the area swept out by particles from 100 to 1000 microns was estimated. There is approximately 600 meters between each of the sampled layers above. Based on the differential Vt between sizes, the following interaction curve was estimated. This is the probability of any one particle interacting with any other particle larger in size.



Multiplying the above by the particle size distribution leads to the likelihood of interaction of a particle with any other particle (below). This shows that the smallest particles are most likely to interact with other particles (due to high concentration).



Using this information and analyzing the evolution of the observed size distribution with altitude, the following conclusions can be drawn. First, the smallest particles are the most likely to interact with other particles but, as shown to the left, small particles interacting with larger particles doesn't often lead to substantial particle size increases. Second, the mid size ranges are the active areas, where the concentrations are high enough and the differential Vt are substantial enough for there to be a lot of interactions as well as some particle size increase. Third, based on the randomly selected CPI images, there are a lot of aggregates of multiple medium to large crystals and few obvious aggregates in the mid to small size ranges.

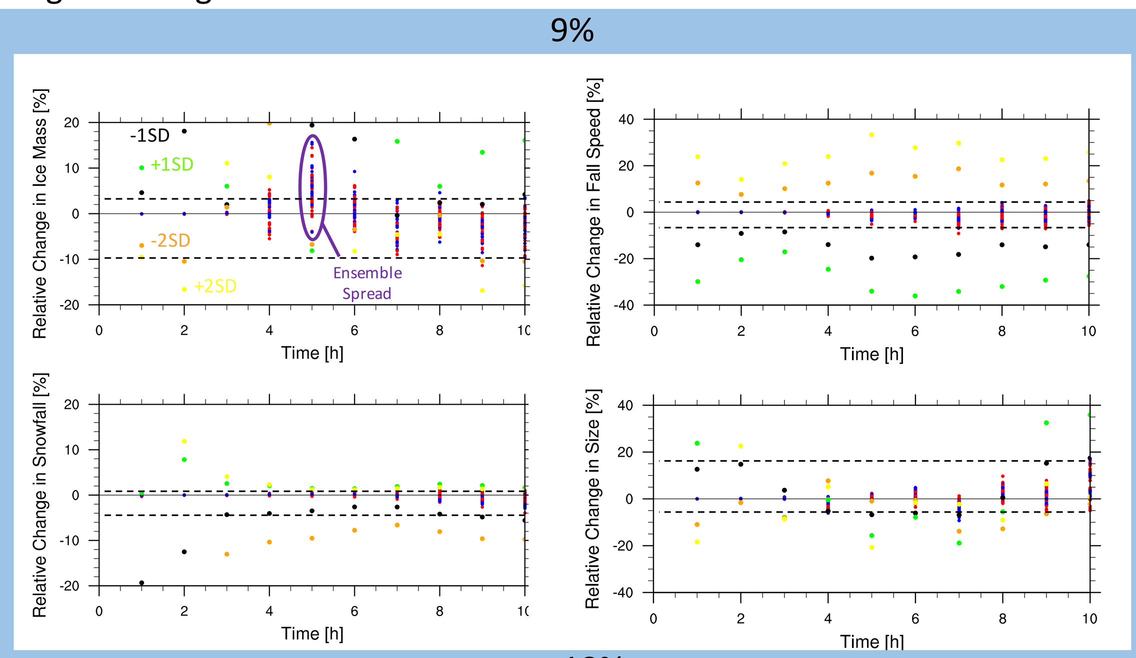
This is likely due to variability in Vt within the size bin. Looking at the individual particles in similar size ranges, it is obvious that there is substantial difference in mass and area even for particles of the same approximate size. Incorporating this idea into the above graphs would raise the interaction and aggregation possibility for the larger sizes thus leading to more increase in the larger sizes of the observed particle size distributions.

The variability in ice particle terminal velocity (Vt) within a size bin has been investigated and the results are in early online release at the Journal of Applied Meteorology and Climatology. Results suggest that typically one can expect approximately 9% deviation above and below the mean value of Vt due to the randomness of particle sizes and shapes within each size bin. The impact of this variability using the Weather Research and Forecasting (WRF) model with the Predicted Particle Properties (P3) microphysics scheme.

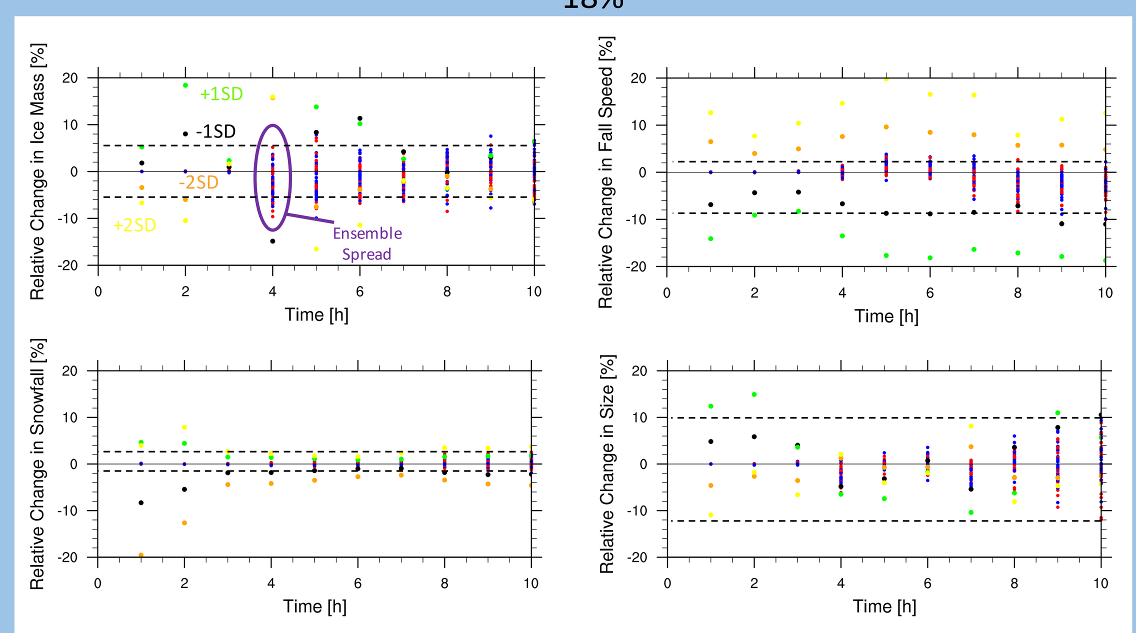
For the simulations, the orographic mixed phase stratiform cloud case from the 2008 International Cloud Modeling Workshop was used (https://ral.ucar.edu/~gthompsn/workshop2008/case1_description.pdf). The simulations are run with 1200 x 60 grid points in the horizontal (1 km resolution) and 60 vertical levels (stretched). P3 microphysics is used, and all other parameters are neglected (i.e., no radiation, boundary layer, convection, surface schemes). Simulations are run with an 800m bell shaped curve in the center of the x-direction of the domain. Time step is 10 s. Boundaries are open in the x direction and periodic in the y. Random theta and qv perturbations are applied to initialize 3D motions.

Two sets of results are shown below, the first with an introduced 9% of random variability in the P3 Vt, and the second with an 18% random variability in Vt. Each panel shows the relative change in the denoted field (y-axis) for simulations with random fall speed fluctuations. The 9% simulation is based on the publication in revisions, and then 18% is used to see how the results scale with increasing variability. The results of the random fluctuations are shown with red and blue dots (colored to show if the mean fall speed differences is negative, blue, or positive, red, relative to the control). The other values show the results from changing the fall speed by ±1 SD and 2 SD (noted those in the figures). The horizontal dashed lines show the range of the results for sampling the fall speed PDFs. Note that the y axis is different in the panels on the left and right owing to the larger range in changes.

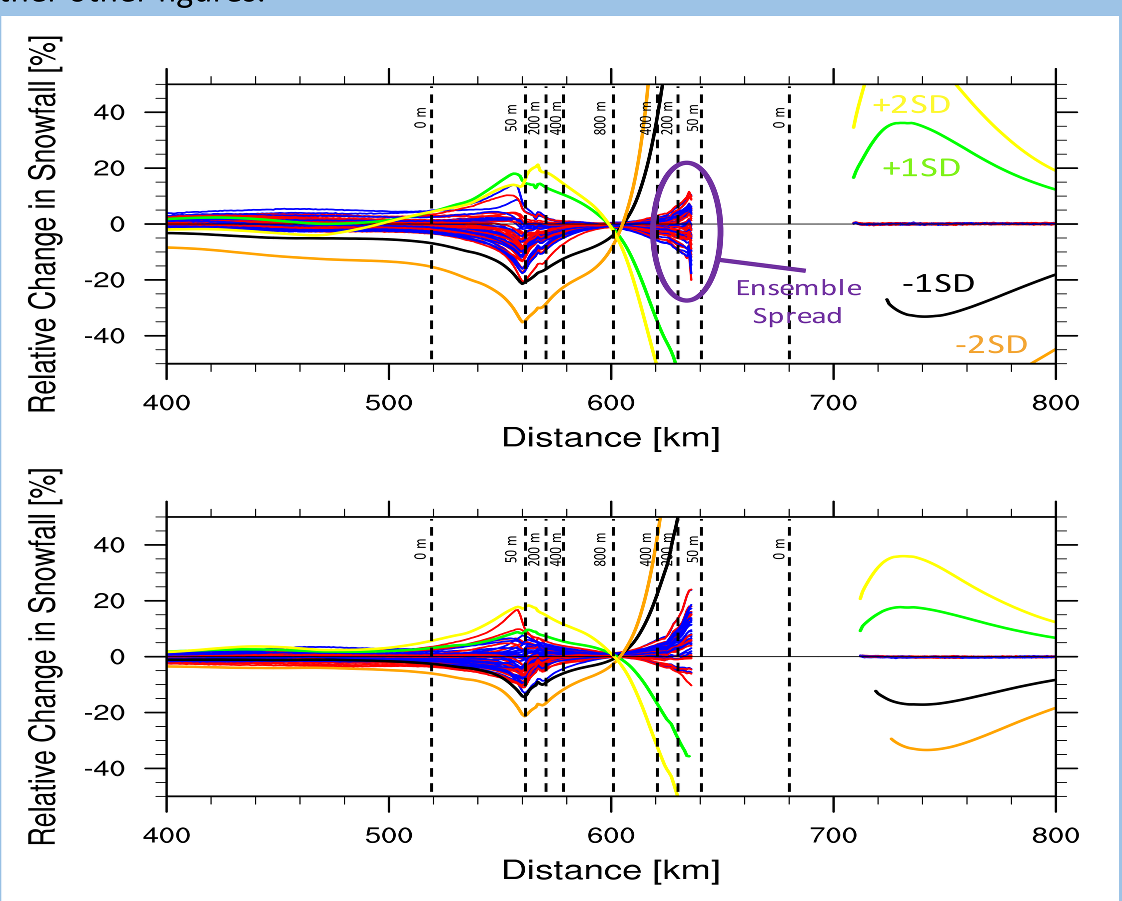
9%



18%



Below, the relative change in snowfall as a function of distance is plotted. Red and blue are for the ensemble simulations as in the other figures, and the other colored lines are also as in the other other figures.



Key findings: Doubling the SD does not double the effect in terms of snowfall.
Even though the total snowfall in a mean sense does not change much, the spatial distribution does change quite significantly. On the windward side of the hill, changes are ±20%, almost regardless of the SD used, with even larger changes see on the lee of the peak. But these changes offset, i.e., decrease in snowfall on the windward side is compensated by an increase in the lee.

U.S. DEPARTMENT OF ENERGY
Office of Science
University at Albany, State University of New York
NCAR
University of Wyoming
NSF
The National Center for Atmospheric Research is operated by the University Corporation for Atmospheric Research under sponsorship of the National Science Foundation.