# A Computational Method for Riming Ice Crystals with Varying Habit

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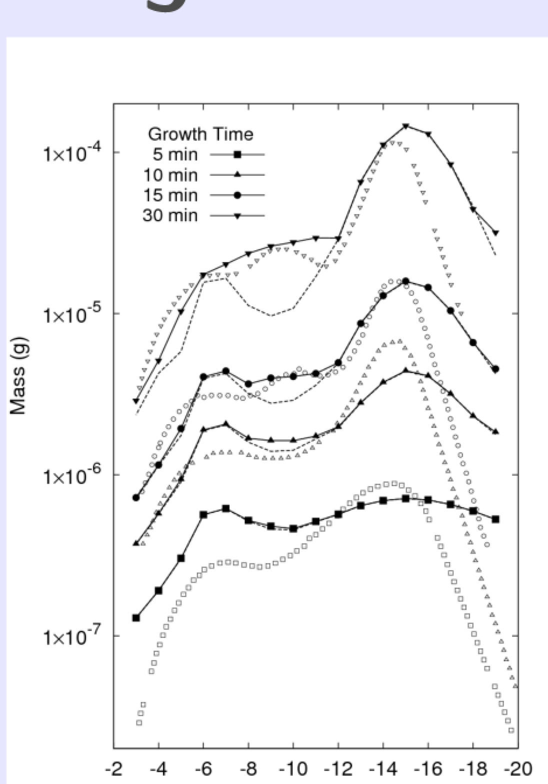
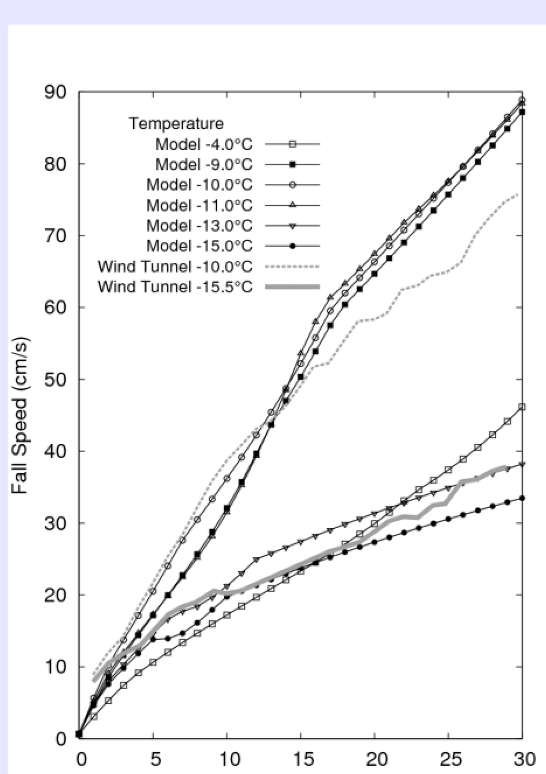
## Motivation

* Phase partitioning is important for understanding mixed-phase clouds.
* Riming (ice collecting liquid) is an important, but understudied process.
* Ice crystal habit should play an important role in riming.

Figs. 1-3 (top left going clockwise). A lightly-rimed crystal, a densely-rimed crystal (5mm diameter), and graupel (paper line spacing is 7mm).

## Single Particle Results



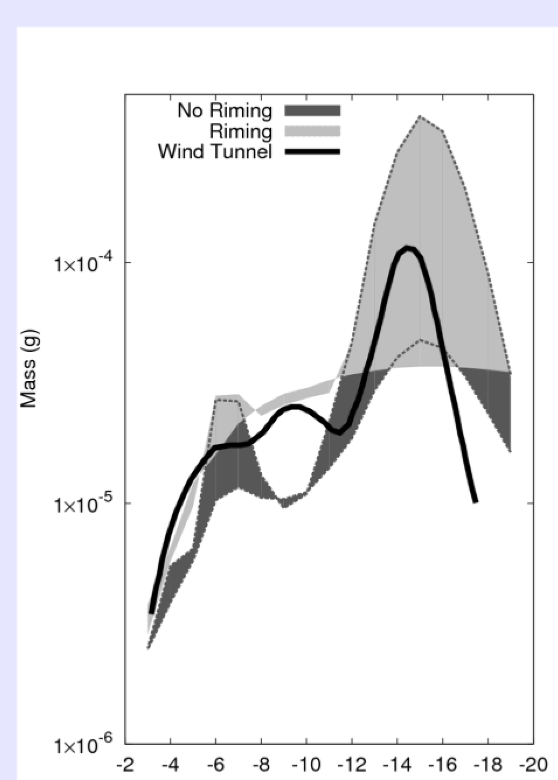




Fig. 4 (left). Mass evolution of single ice crystals grown in a wind tunnel[2] (open points) with 0.4 $gm^{-3}$ liquid and our single particle model (closed connected points). The dashed lines represent our model without riming. Our model is consistent with observations of habit dependent riming.

Fig. 5 (middle). Fall speed evolution as compared to wind tunnel[2] data for isometric ice crystals near -10°C and ice crystals with more extreme aspect ratios. Riming rates impact fall speed which impacts riming rates.

Fig. 6 (right). Model range of ice crystal mass at 30 minutes depending on initial ice crystal size. Smaller initial crystal size leads to larger mass at 30 minutes. Regardless of initial ice crystal size, riming is important from -8 to -11°C and -4 to -5°C which is consistent with wind tunnel[2] data.

## Riming Dendrites

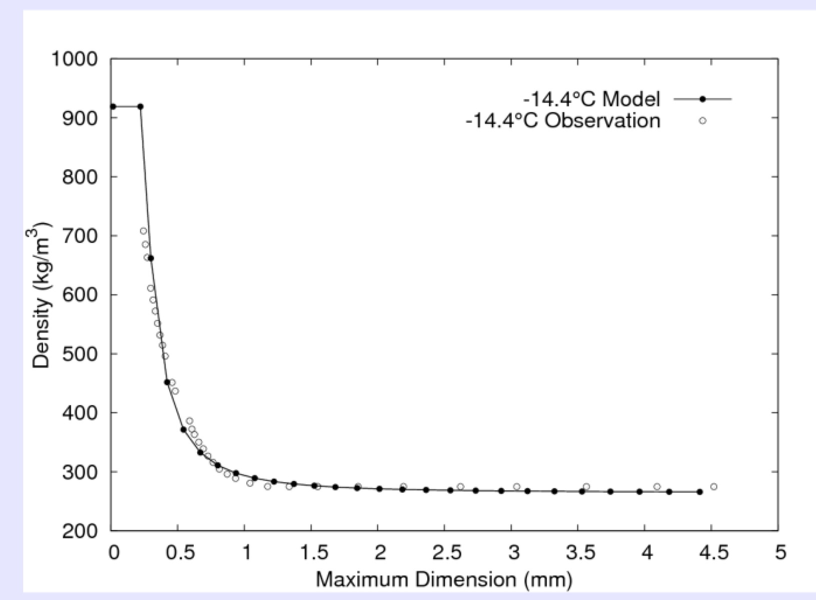



Fig. 7 (left). Effective density evolution of an observed[3] ice crystal grown at -14.4°C and model results. The crystal effective density impacts fall speed and riming processes.

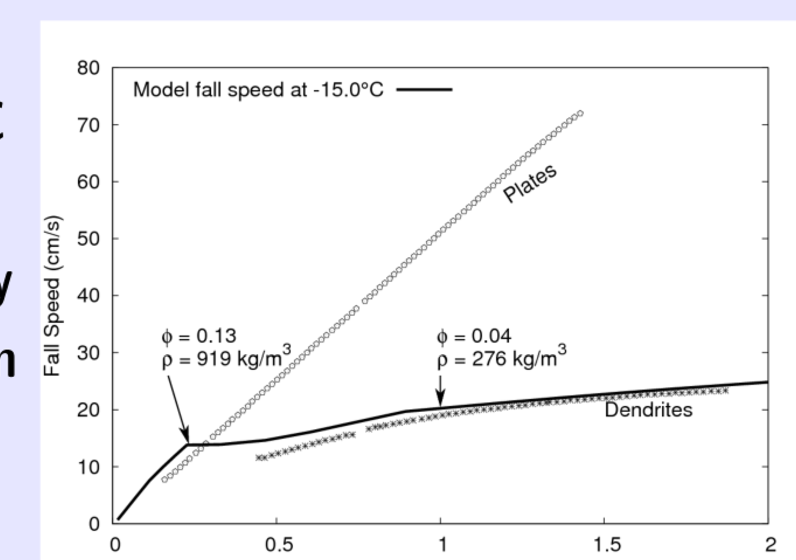
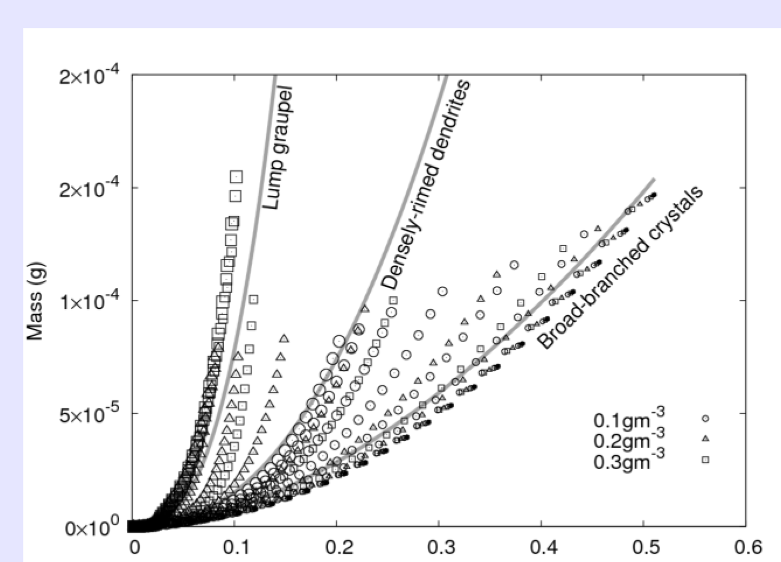
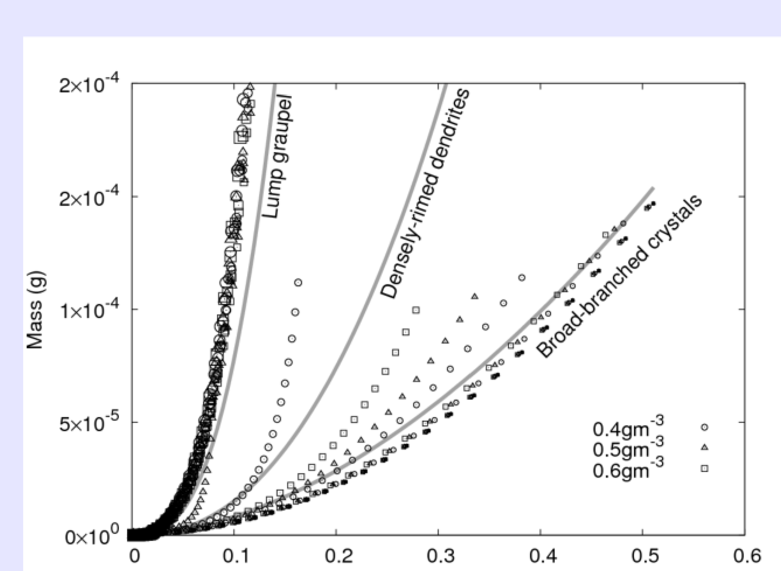



Fig. 8 (right). Fall speed of an ice crystal grown at -15°C compared to observation[1]. Evolving the effective density correctly leads to a change in fall speed from plate-like to dendrite-like when the effective crystal density falls.

* Evolving effective crystal density accurately is important for fall speeds and riming rates.




Figs. 9-10 (left). Mass vs maximum dimension for ice crystals grown and rimed at -15°C using liquid water contents from 0.1 - 0.6 $gm^{-3}$ and mean liquid drop size from 2 - 12 microns. Also plotted are mass-size relationships. The larger the data point the larger mean liquid drop size. The model produces various results that spread the ranges from unrimed crystals to densely-rimed dendrites to lump graupel.

## Graupel Statistics

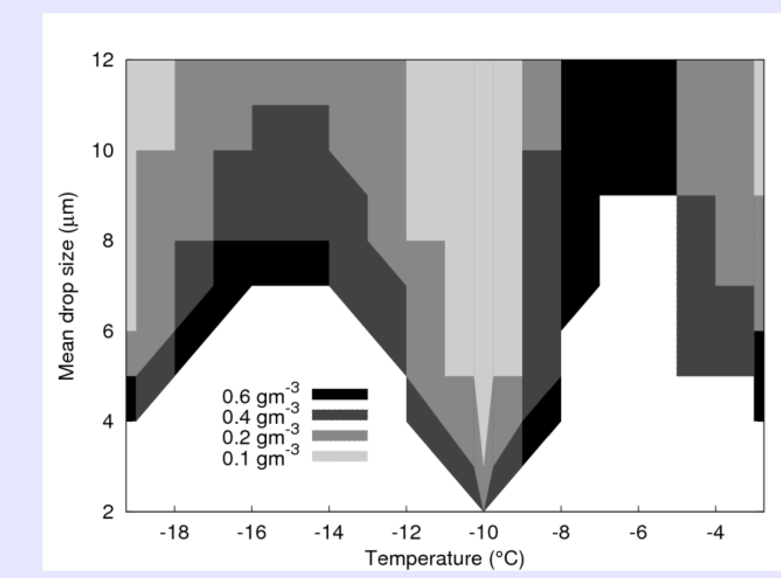



Fig. 11 (left). Model results for spherical graupel at 30 minutes of ice crystal growth and riming for different liquid water contents.

## Bulk Development

* Current adaptive-habit bulk models evolve a distribution of ice with respect to one axis and store the time-average of the inherent growth ratio allowing both axes to evolve.
* Future work involves extending the adaptive-habit model to include riming where temperature dependence of both vapor depositional growth and riming can be captured, leading to more accurate cloud evolution.

## Acknowledgements

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## References

[1]Kajikawa, M. (1972), Measurment of falling velocity of individual snow crystals, *Journal of the Meteorological Society of Japan, 50*, 577 - 584.
[2]Takahashi, T., and N. Fukuta (1988), Supercooled cloud tunnel studies on the growth of snow crystals between -4 and -20°C, *Journal of the Meteorological Society of Japan, 66*, 841 - 855.
[3]Takahashi, T., T. Endoh, G. Wakahama, and N. Fukuta (1991), Vapor diffusional growth of free-falling snow crystals between -3 and -23°C, *Journal of the Meteorological Society of Japan, 69*, 15 - 30.