A Numerical Sensitivity Study of Aerosol Influence on Immersion Freezing in Mixed-Phase Stratiform Clouds

ARM Atmospheric Radiation Measurement

Gijs de Boer, Tempei Hashino, Edwin W. Eloranta and Gregory J. Tripoli

The University of Wisconsin - Madison

THE UNIVERSITY of WISCONSIN MADISON

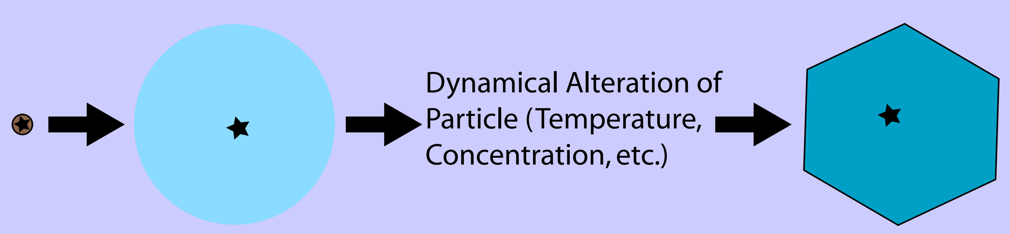
(1) Introduction

Mixed-phase stratiform clouds are commonly observed at high latitudes (Shupe et al., 2006; de Boer et al., 2009a). These clouds significaly impact the atmospheric radiative budget, with reductions in wintertime radiative surface cooling estimated at 40-50 Wm-2 (Curry et al., 1996). Both modeling and observational studies (e.g. Harrington et al., 1999; Jiang et al., 2000; Shupe et al., 2008; Klein et al., 2009) reveal apparent connections between ice nucleation and cloud lifecycle. Unfortunately, mechanisms by which ice is formed in these clouds are not yet fully understood.

Aerosol observations from the Arctic often show mixed aerosol particles containing both soluble and insoluble mass (Leaitch et al., 1984). Soluble mass fractions for these particles have been shown to be high, with estimates of 60-80% and are often made up of sulfates (Zhou et al., 2001; Bigg and Leck, 2001). Since these mixed particles may initially nucleate liquid droplets that contain insoluble mass, immersion freezing has been theorized to contribute to ice nucleation in these clouds (de Boer et al., 2009b).

In this work, we present a numerical sensitivity study investigating effects of aerosol properties on immersion freezing in a mixed-phase stratiform cloud. Immersion freezing is represented using a parameterization from Diehl and Wurzler (2004). Motivation for this work stems from data gathered from the ARM Mixed-Phase Arctic Cloud Experiment (M-PACE, Verlinde et al., 2007) and the ARM/GCSS modeling intercomparison study for single-layer mixed-phase clouds (Klein et al., 2009).

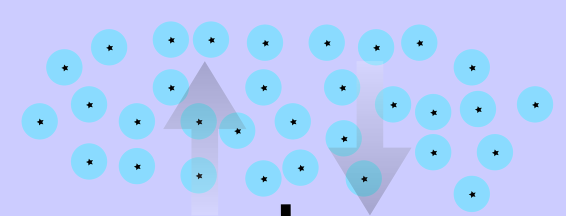
(2) What is Immersion Freezing?



In immersion freezing, a liquid droplet forms on a mixed aerosol particle containing both soluble and insoluble mass fractions. The insoluble mass fraction becomes immersed in the droplet, which consists of a solution of the aerosol soluble mass and water. The droplet then may grow or be exposed to a colder temperature, at which point freezing initiates, and an ice particle is nucleated.

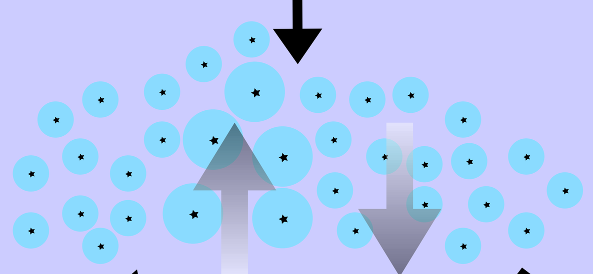
In mixed-phase stratiform clouds:

(1)



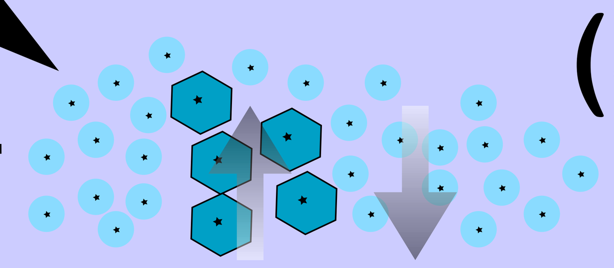
Radiative cooling from the surface leads to the saturation of a moist layer, and a liquid cloud forms. Some of these liquid droplets contain IN that had been coated in soluble material.

(2)



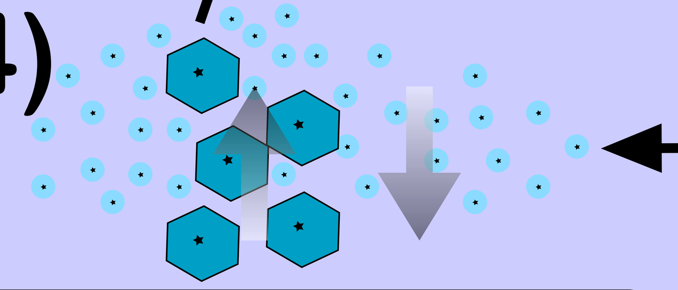
Radiative cooling from cloud top leads to vertical motion within the cloud layer. Droplets in the updrafts cool through expansion and accumulate liquid mass through condensational growth, decreasing droplet soluble mass fraction.

(3)

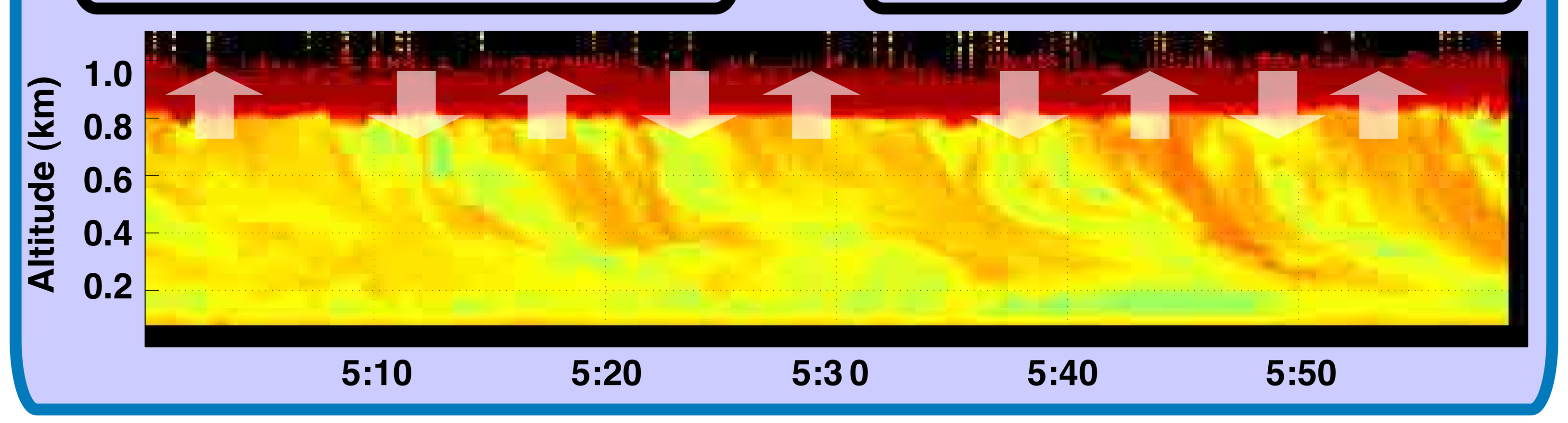


The fraction of soluble mass in the growing drops decreases to the point where freezing is no longer inhibited at the current temperature, and the larger droplets nucleate into ice particles through the immersion freezing process.

(4)

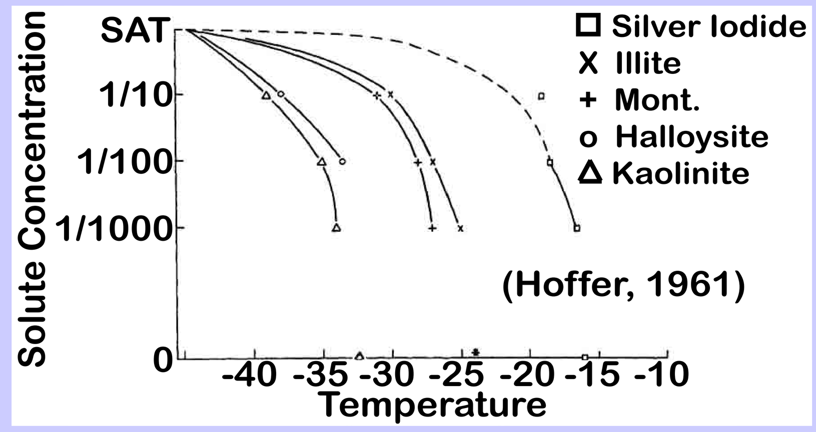


Growth of these ice particles uses up available moisture, and further droplet growth (and therefore ice formation) is limited. The ice particles rapidly grow to a size where they precipitate from the cloud layer, and the cycle starts over.

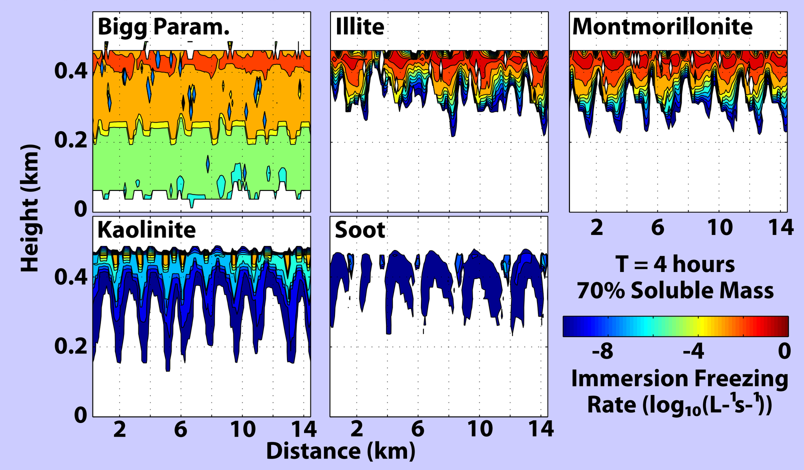


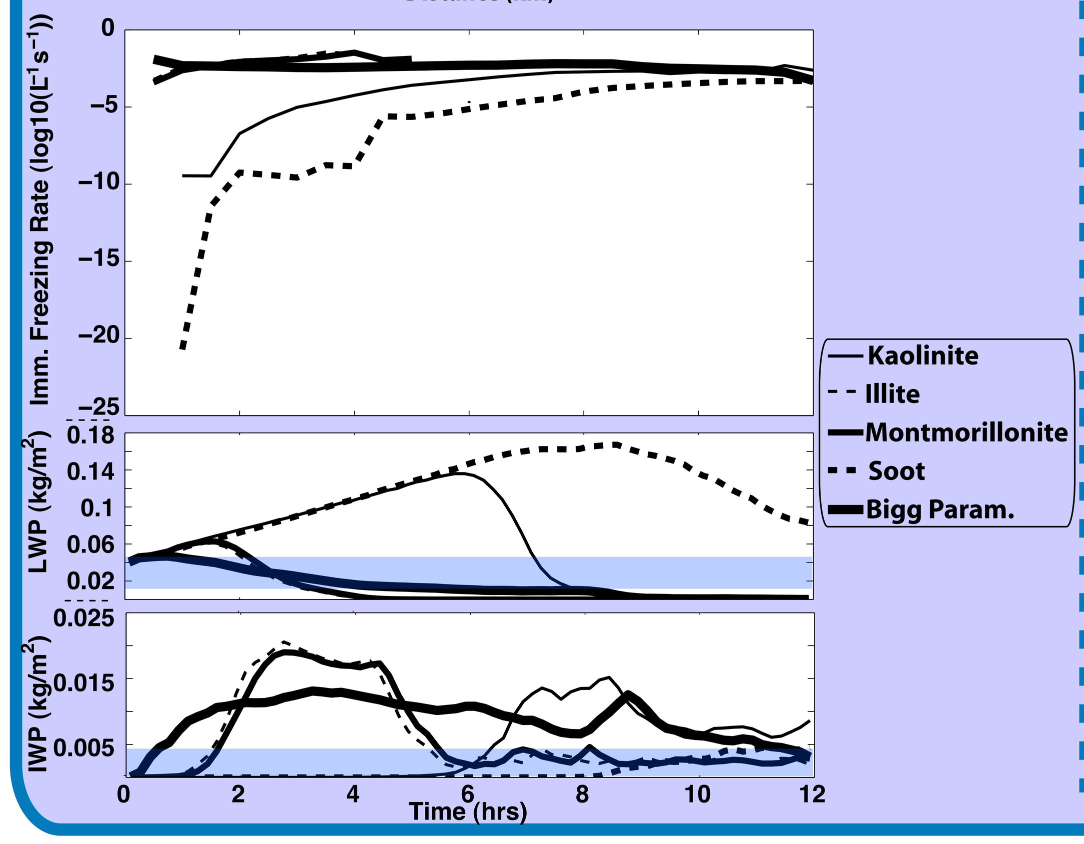
(3) How do Aerosol Properties Affect Immersion Freezing?

Insoluble Mass Type

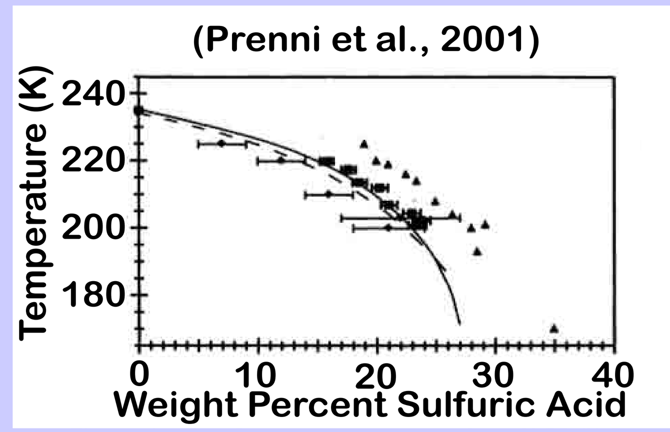


Different materials provide different freezing efficiencies. Therefore, the insoluble mass type is an important regulator of droplet freezing ability.

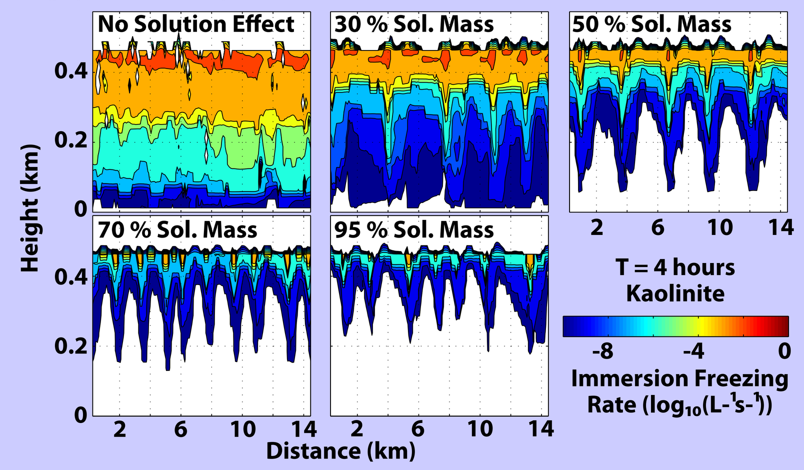


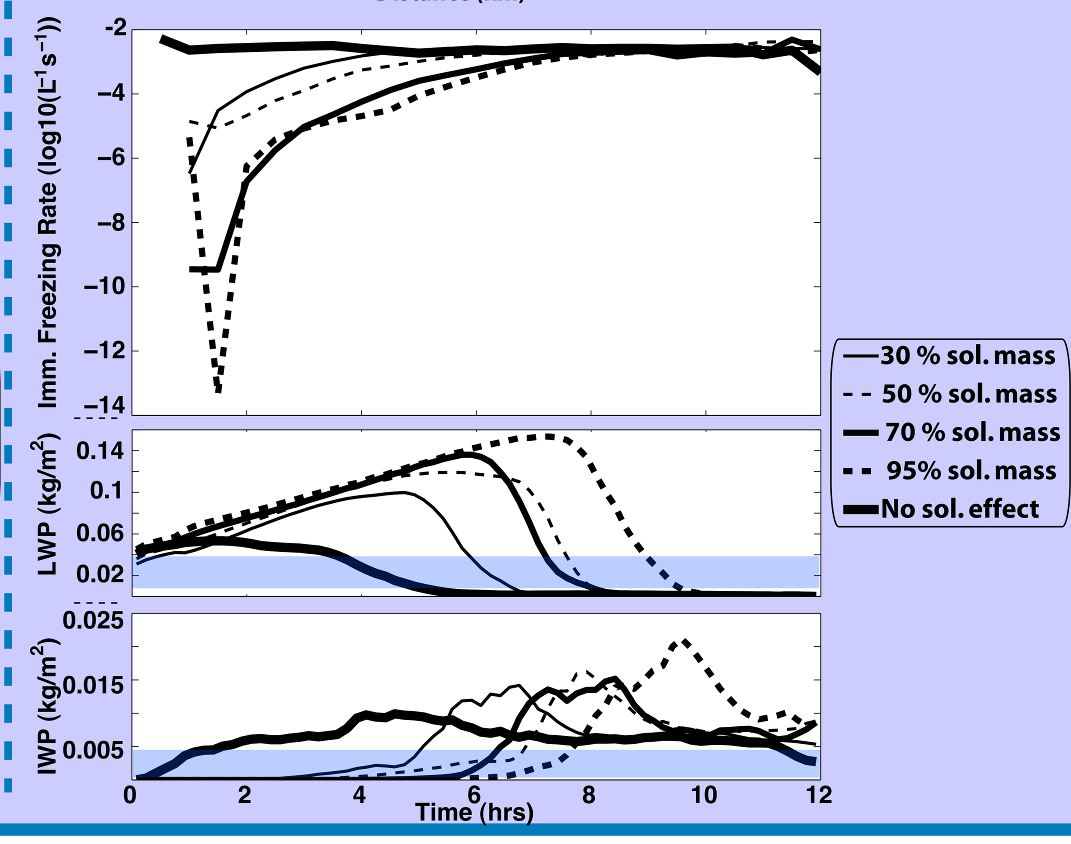


Soluble Mass Fraction



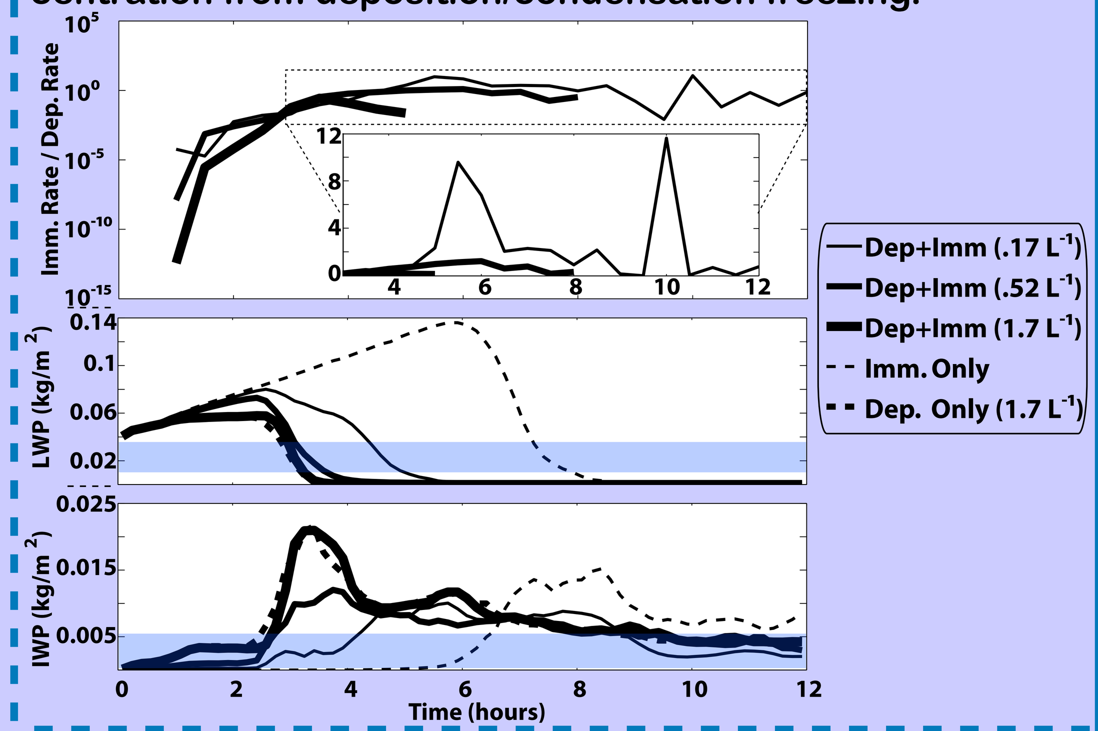
A higher percentage of soluble material associated with the nucleating aerosol will increase the solution effect freezing point depression.





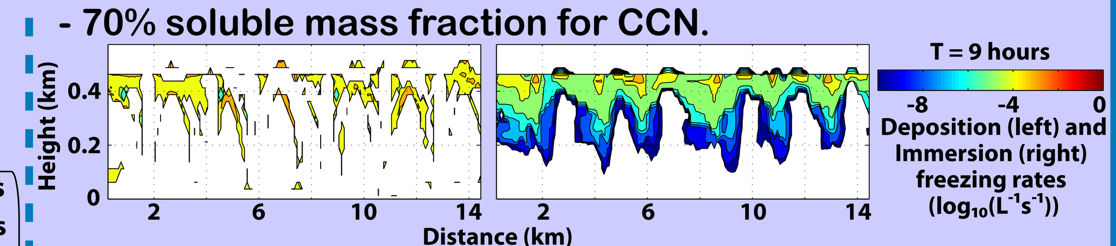
"Free" IN Concentration

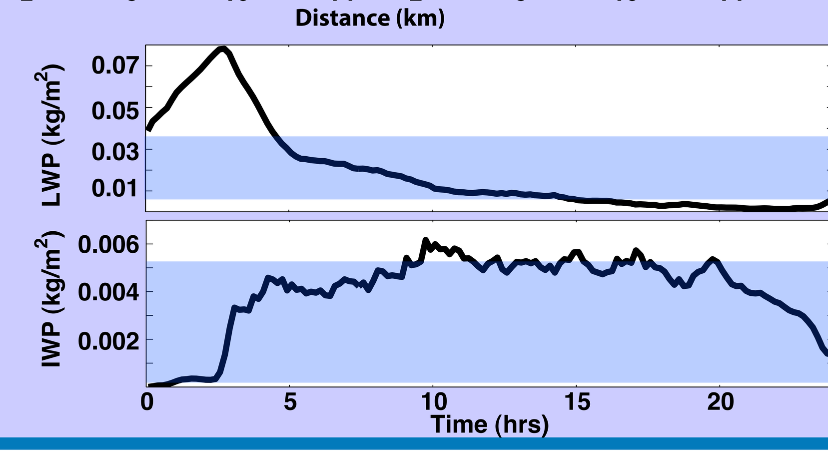
It is unrealistic to believe that immersion freezing is the only active ice nucleation mechanism in these clouds. Here, we run simulations with immersion, deposition and condensation freezing active, with variable contributions to ice concentration from deposition/condensation freezing.



Realistic Simulation

- Immersion and deposition/condensation freezing active
- Reduced IN concentration (0.17 L^{-1}) from CFDC estimates to avoid immersion freezing "double counting".
- A soot insoluble mass fraction for CCN.
- 70% soluble mass fraction for CCN.





(4) Summary

- Immersion freezing contributes significantly to ice formation in simulated clouds

- The freezing efficiencies of droplets containing different insoluble mass types vary widely, and strongly modulate simulated liquid and ice water paths

- Increasing CCN soluble mass fraction increases the freezing point depression, resulting in delayed freezing of droplets

- Inclusion of a freezing point depression calculation results in a reduction of ice formed from haze particles below the liquid cloud base

- A realistic simulation was completed with both deposition/condensation and immersion freezing active

(5) Contact Info. / Acknowledgements

Gijs de Boer (gdeboer@wisc.edu) tel: 608-263-6847

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