**Physically Regularized Machine Learning Emulators of Aerosol Activation**

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**Abstract**

The activation of aerosol into cloud droplets is an important step in the formation of clouds, and strongly influences the radiative budget of the Earth. Directly simulating this process in climate models is challenging due to the computational complexity required to resolve the necessary chemical and physical interactions. As such, various parameterizations have been developed to approximate these detailed interactions at reduced computational cost and accuracy. Here, we explore how machine learning emulators can be used to bridge this gap in computational cost and parameterization accuracy. Specifically, we evaluate a set of emulators of a detailed atmospheric parcel model using physically regularized machine learning regression techniques. We find that the emulators can reproduce the parcel model at higher accuracy than many existing parameterizations. Furthermore, physical regularization tends to improve emulator accuracy, most dramatically when emulating very low activation fractions. That said, this improvement varies with the quality of the regularizing information and the emulator capacity. This work demonstrates the value of physical constraints in machine learning model development and enables the implementation of improved hybrid physical-machine learning models of aerosol activation into next generation climate models.