Enhancing Cloud Seeding Efficiency: Augmentation of Cloud Condensation Nuclei Hygroscopicity and Identification of Optimal Cloud Targets

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Currently, 40% of the world's population is impacted by limited access to water resources, and conditions will only worsen due to climate change. This water scarcity endangers agricultural production, public health, and ecosystems at an unprecedented scale. A potential solution is cloud seeding, a weather modification strategy where particles called Cloud Condensation Nuclei (CCN) are released into the atmosphere, providing a "seed" for water vapor to condense on, accelerating droplet growth. Cloud seeding is promising, but fundamental questions on optimizing CCNs and seeding effectiveness remain unanswered. This project investigates these gaps by, first, enhancing the hygroscopicity of CCNs by decreasing their surface tensions with three types of surfactants: cationic (CTAB), amphoteric (CAPB), and anionic (SLS). The surfactants are mixed with the seeding solution of 1.0M NaCl, which is released via nebulizer into a cloud chamber that simulates atmospheric conditions of supersaturation and sub-dew point temperature. The efficiency of the surfactant-based seeding is determined by measuring the light attenuation of a laser beam. The addition of surfactants, particularly CTAB (due to its higher Critical Micelle Concentration) leads to significantly larger droplets and therefore precipitation yield, a novel finding that has not been experimentally explored. Then, to quantify seeding success, this study merges experimental data with a multi-modal model that analyzes remote sensing data and satellite imagery. By classifying clouds into their microscale categories and measuring how these change due to seeding, the model indicates that surfactant-based seeding is nearly twice as effective as standard seeding, with the cloud microscale classifier achieving an F1-score of 93%.

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