Aerosol-Cloud Interactions during Cloud Seeding

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❖ Introduction

- Cloud seeding is the process of adding substances to clouds to encourage precipitation.
- Cloud seeding is the most common weather modification technique and dates back to 1946.
- As a result of cloud seeding there is between 12% and 16% increase in precipitation (Manton et al. 2011, 2017).
- Cloud seeding can be Hygroscopic or Glaciogenic (warm and cold cloud seeding, respectively).
- A glaciogenic seeding introduces silver iodide (AgI) as ice nucleating particle into the cloud with temperature below freezing to enhance the ice/mixed phase of the cloud.

❖ Goals

- Explore the predictability of cloud seeding effects on climate using machine learning (ML) models as advanced techniques to investigate complex nonlinear relationships.
- Investigate the mechanisms of interactions between aerosol physics and cloud microphysical properties during cloud seeding events is the objective.

❖ Cloud seeding criteria

1. Supercooled Liquid Water,
2. Low temperature; the optimum temperature range is between -5°C to -15°C.
3. Atmospheric instability; there should be no inversion or stable layer between the height of the cloud and the generator.
4. Wind direction and speed.

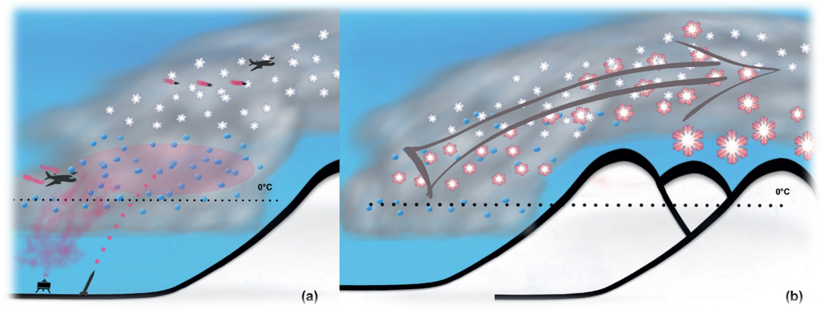

Figure 1. Glaciogenic seeding of an orographic wintertime cloud (Flossmann, 2019).

❖ Key parameters

- **Atmospheric variables**
  Temperature, wind speed & direction, vertical motion, relative humidity, etc.
- **Aerosol physics**
  Aerosol optical depth (AOD) and aerosol radiative forcing
- **Cloud microphysical properties**
  Cloud fraction (CF), cloud top temperature (CTT), cloud effective radius (CER), cloud optical depth, etc.

❖ Previous studies

1. Distinct Change of Supercooled Liquid Cloud Properties by Aerosols From an Aircraft-Based Seeding Experiment

Goal: Investigation of the differences in cloud properties before and after cloud seeding on 22 January 2018 and the possible impacts of cloud seeding on cloud microphysical properties and precipitation (Dong et al., 2020)

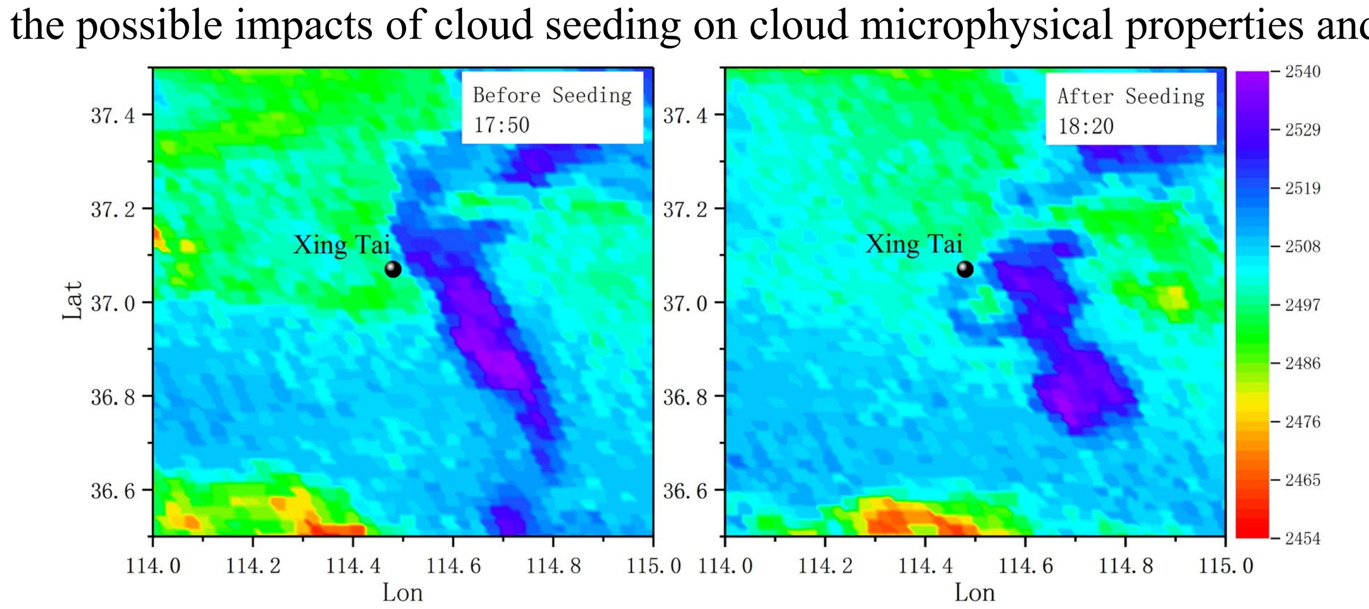

Figure 2. Himawari-8 (geostationary satellite) cloud brightness temperature observation before seeding (17:50 Local Time) and after seeding (18:20 Local Time) on 22 January 2018. Note the unit of cloud temperature in this figure is 0.1 K.

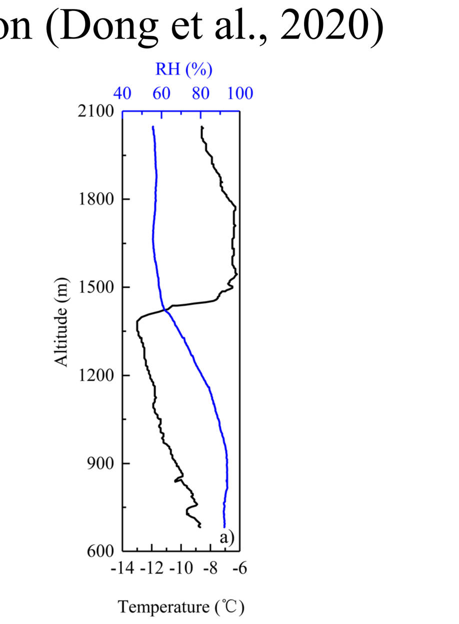

Figure 3. Temperature and relative humidity in the evening of 22 January 2018 over Xingtai, Hebei Province, China

2. Response of Cloud and Precipitation Properties to Seeding at a Supercooled Cloud-Top Layer

Goal: Applications of ground radar, in situ aircraft, and satellite remote sensing observations to gain further insight into the response of cloud properties to inorganic aerosol seeding within supercooled cloud tops (Dejun et al., 2022)

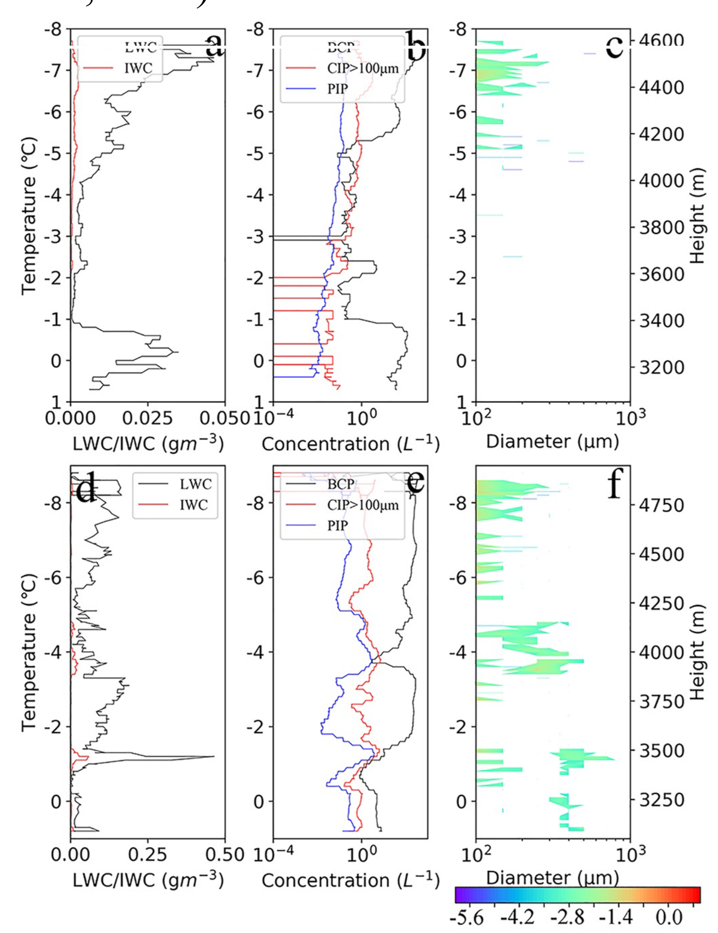

Figure 4. Vertical structure of cloud microphysical properties (a, b, c) before seeding at 12:33–12:39 Local Time and (d, e, f) after seeding at 13:45–13:51 Local Time. Panels (a and d) are the vertical structure of cloud liquid water content and ice water content, (b and e) are the vertical structure of cloud particle concentrations measured by the backscattering cloud particle probe, cloud particle image probe (CIP), and precipitation imaging probe, (c and f) are the vertical structure of cloud particle spectrum with diameters larger than 100 μm measured by the CIP.

3. The Evolution of an AgI Cloud-Seeding Track in Central China as Seen by a Combination of Radar, Satellite, and Disdrometer Observations

Goal: Quantitative analysis of cloud seeding effects on supercooled layer clouds in China (Wang et al., 2021)

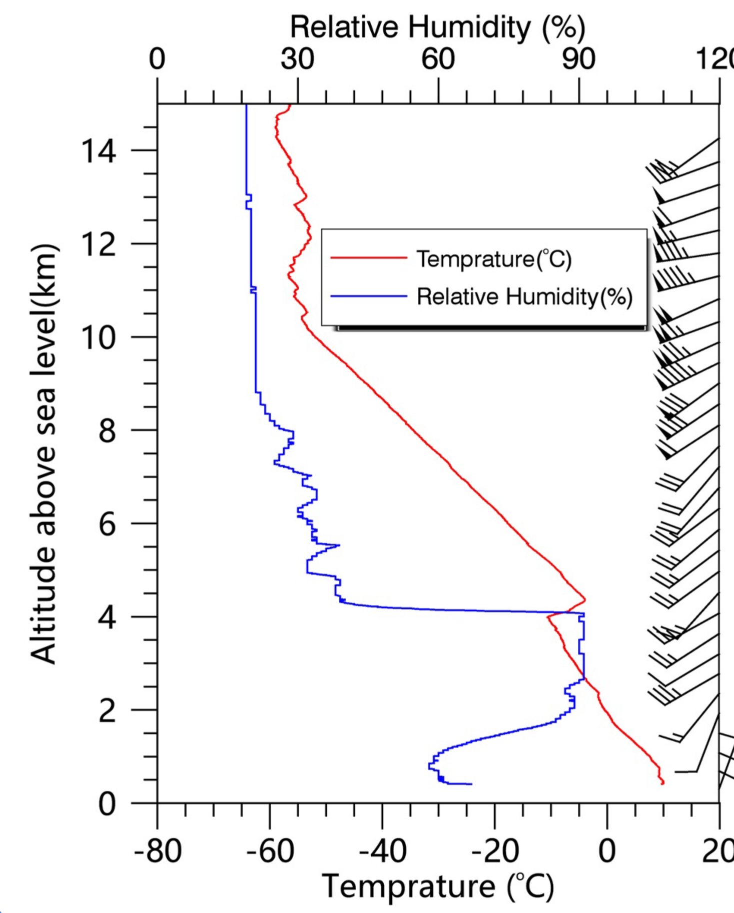

Figure 5. Temperature profile (red solid line), relative humidity profile (blue solid line), and wind speed and direction were determined from soundings at 00:00 UTC on March 19, 2017. The full barb equals 4 m s−1, and the triangular flag equals 20 m s−1.

❖ Research plan

1. Study the climatology of the region.
2. Observe the patterns and trends before, during, and after seeding for each event for the case study.
3. Develop Machine Learning Algorithm:
   - Support Vector Regression (SVR),
   - Deep Neural Network (DNN),
   - Random Forest (RF),
   - Gradient Boost (XGBoost),
   - K-Nearest Neighbors Classifier (KNN),
   - Decision Tree,
   - Least Absolute Shrinkage and Selection Operator (LASSO),
   - Adaptive Boosting (Ada Boost).

1. Conduct Feature Importance study to specify the most important atmospheric variables for cloud seeding.
2. Conduct Statistical Analysis (e.g., R-value and Standard Error) to identify ML model with the highest metrics.
3. Study the sensitivity of ML predictions to temporal and spatial resolution.
4. Investigate the consistency of ML models with previous studies (a comparison with WRF model simulations)

❖ References

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