Removal of Microdust from the Atmosphere

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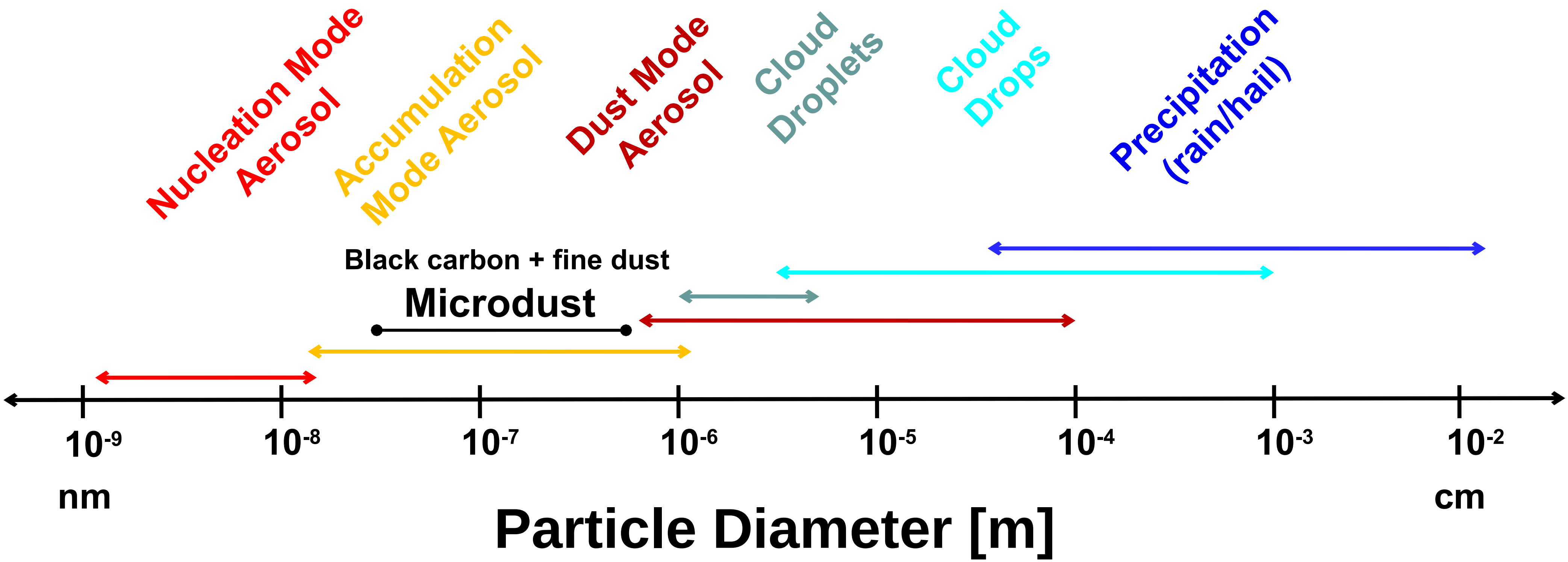
Improve Air Quality for South Korea

- Review our knowledge of microdust, clouds, and precipitation.
- Define how microdust affects precipitation development and how cloud seeding can mitigate high levels of pollution.
- Measurements allow construction of a model of how effective microdust is removed with cloud seeding in South Korea.

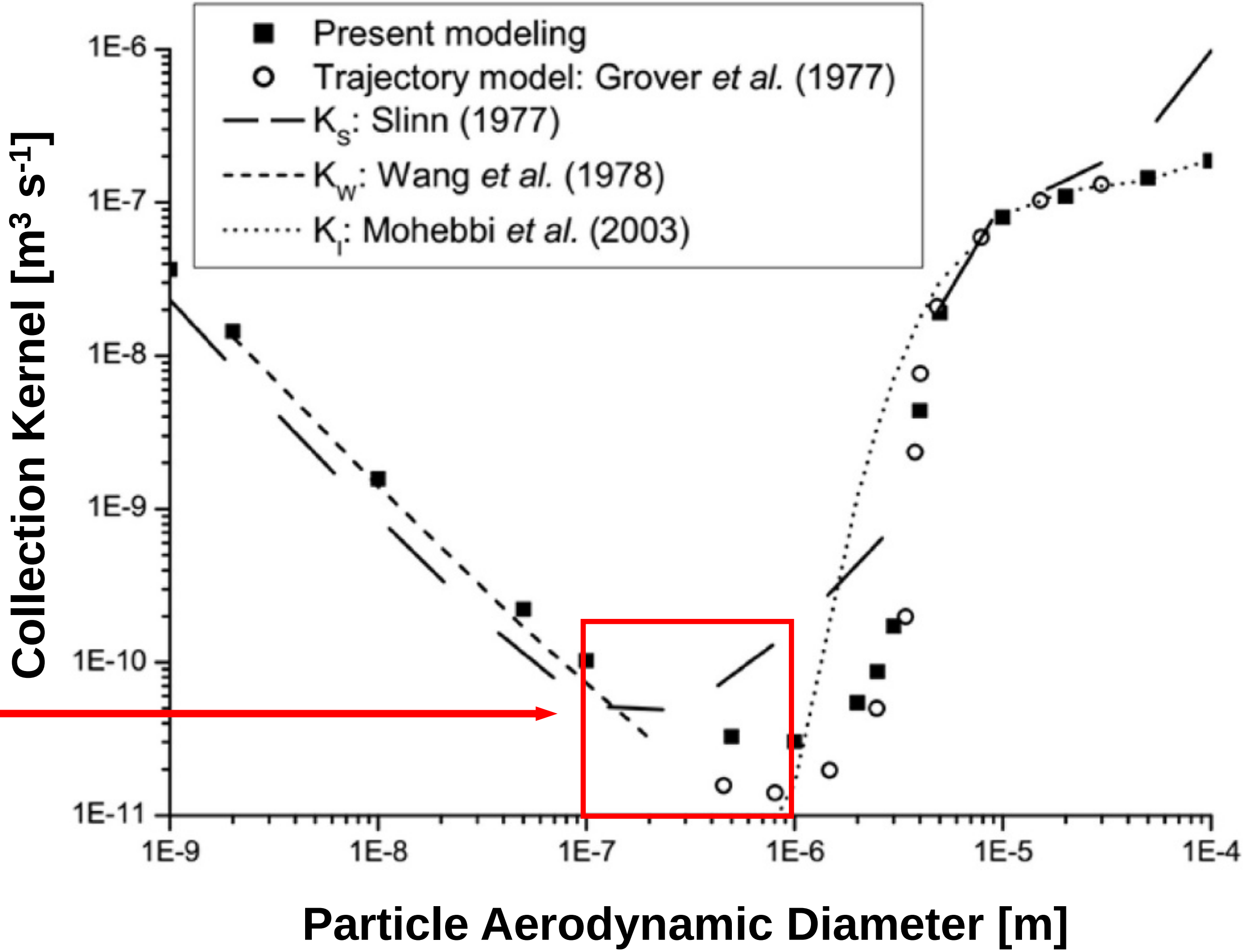
Classification of Particles



- Precipitation and atmospheric mixing reduces particles.

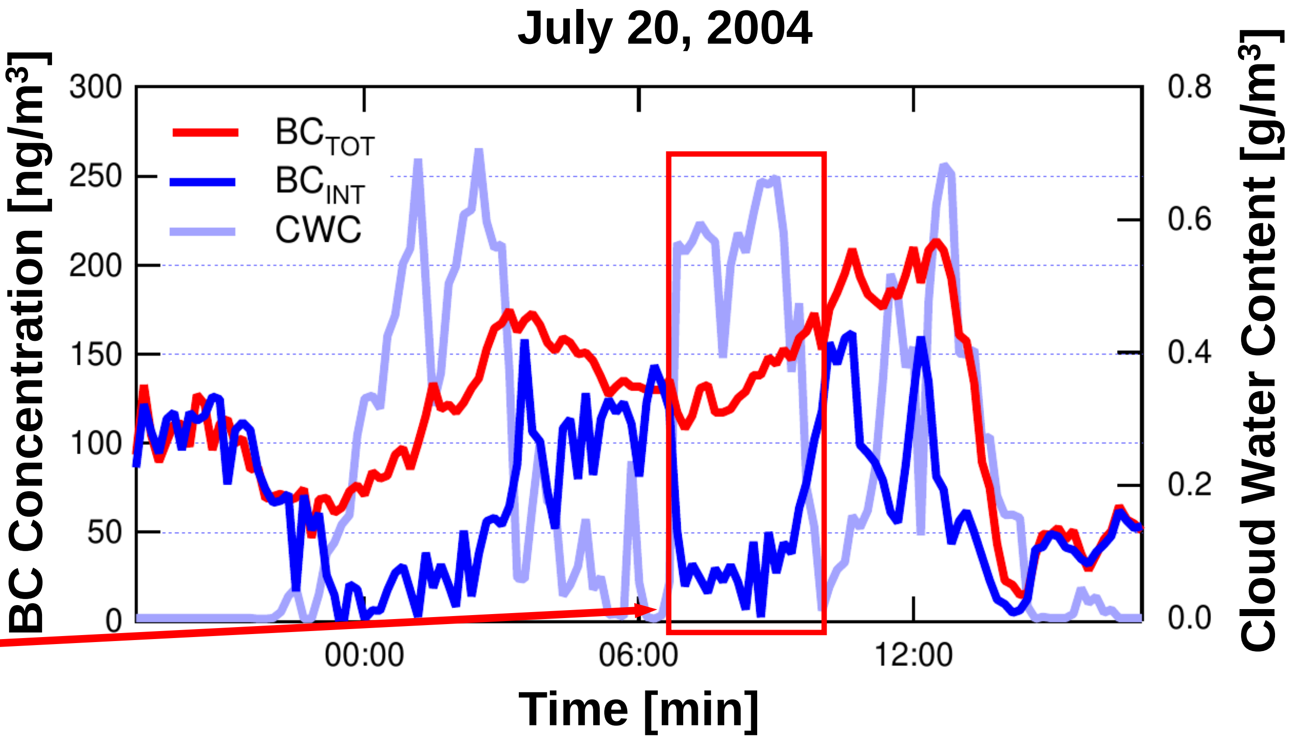
Cherrier, G., E. Belut, F. Gerardin, A. Tanière, and N. Rimbert, 2017: Aerosol particles scavenging by a droplet: Microphysical modeling in the Greenfield gap. Atmospheric Environment, 166, 519–530, doi:10.1016/j.atmosenv.2017.07.052.

- Modeling of droplet scavenging (removal) of aerosols.
- Fig. 6 – Collection kernel values at Re_d = 30 and H = 0 as a function of particle aerodynamic diameter. Here $K_w = K_B$ because of the null value of H.
- **Microdust of 0.1 to 1 μm in diameter are not removed as effectively as larger or smaller sized particles.**



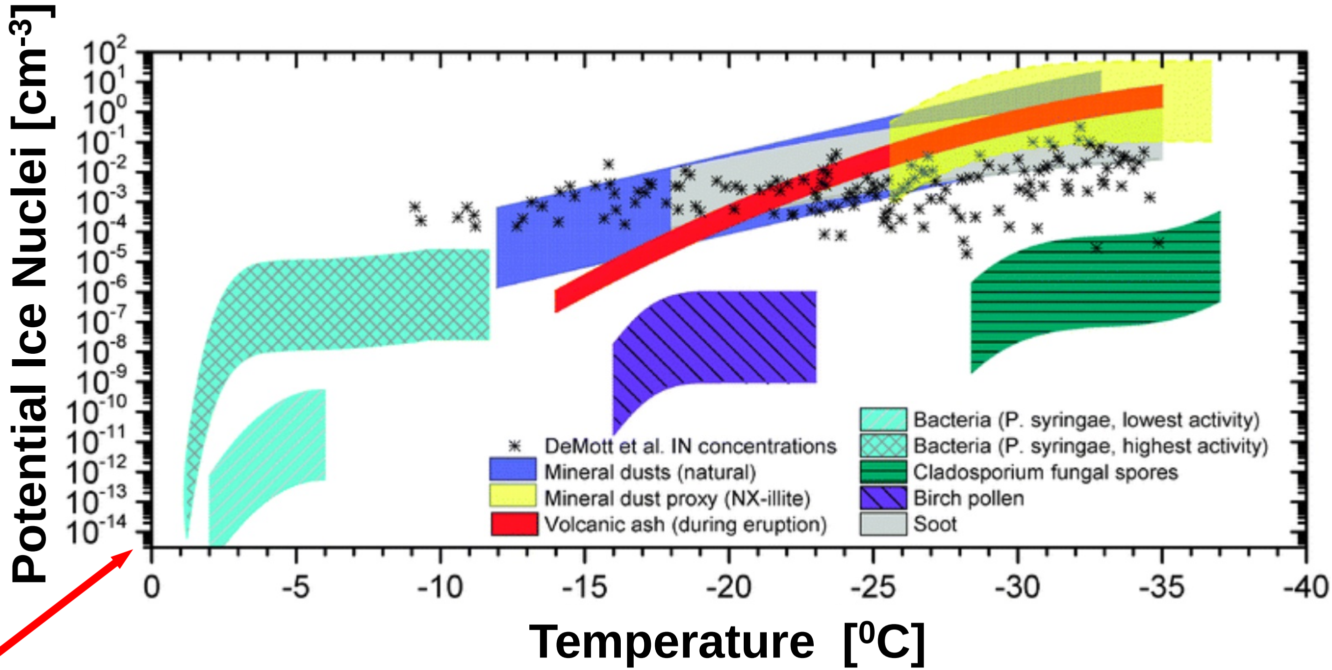
Cozic, J., B. Verheggen, S. Mertes, P. Connolly, K. Bower, A. Petzold, U. Baltensperger, and E. Weingartner, 2007: Scavenging of black carbon in mixed phase clouds at the high alpine site Jungfraujoch. Atmos. Chem. Phys., 7, 1797–1807, doi:10.5194/acp-7-1797-2007.

- Black carbon (BC) microdust is scavenged (removed) as effectively as other microdust, which indicates that black carbon microdust is covered with soluble material.
- Fig. 2 – Temporal evolution of the total and interstitial black carbon concentrations along with the temporal evolution of the cloud water content (CWC) for a liquid cloud (i.e., no ice phase).
- **Microdust, including Black Carbon (pollution), is incorporated into cloud droplets.**



Murray, B. J., D. O'Sullivan, J. D. Atkinson, and M. E. Webb, 2012: Ice nucleation by particles immersed in supercooled cloud droplets. Chem. Soc. Rev., 41, 6519–6554, doi:10.1039/C2CS35200A.

- Mineral dust, biological species, and carbonaceous combustion produced particles immersed within supercooled water droplets nucleate the formation of ice.

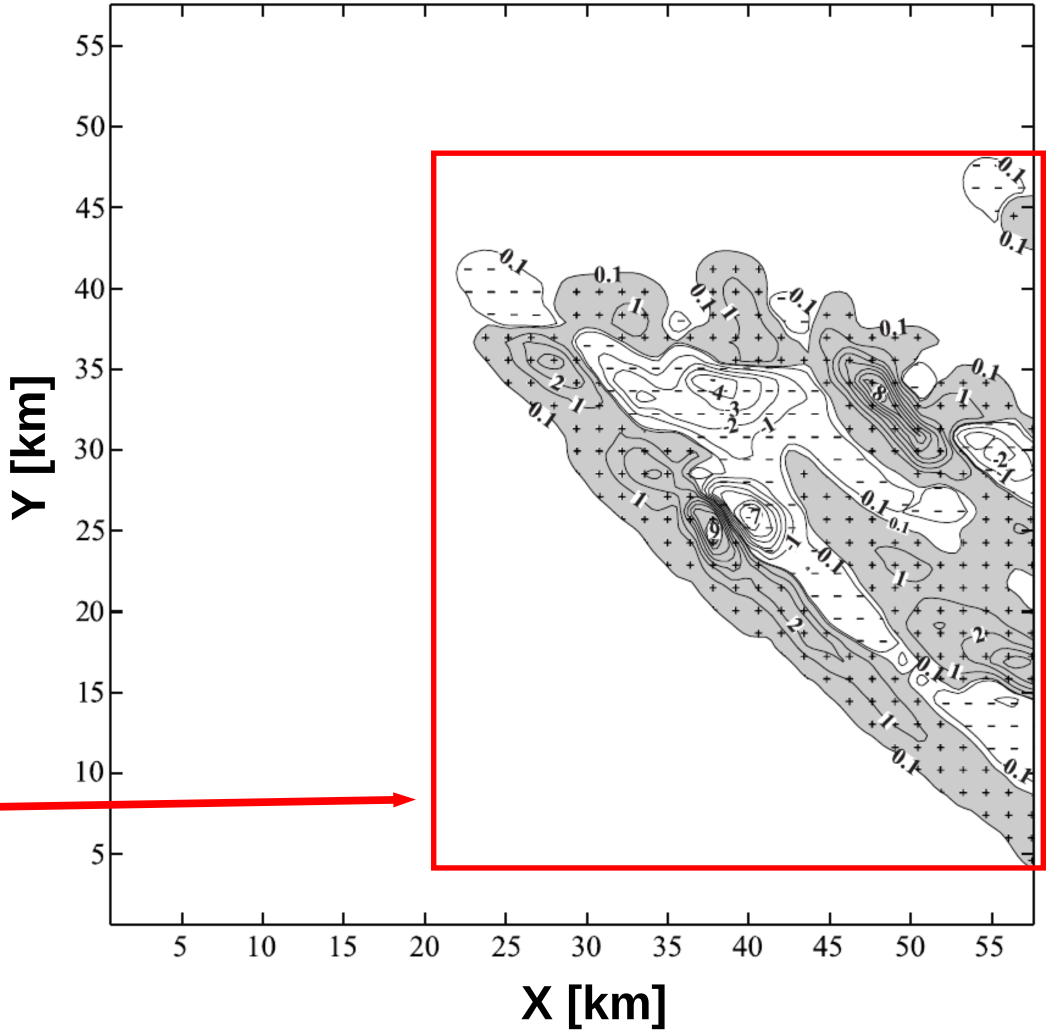


- **The atmosphere lacks microdust that nucleates ice at warm temperatures.**

Fig. 19 – Potential immersion mode ice nuclei concentrations as a function of temperature for a range of atmospheric aerosol species. Calculations performed using concentrations of different particle sizes.

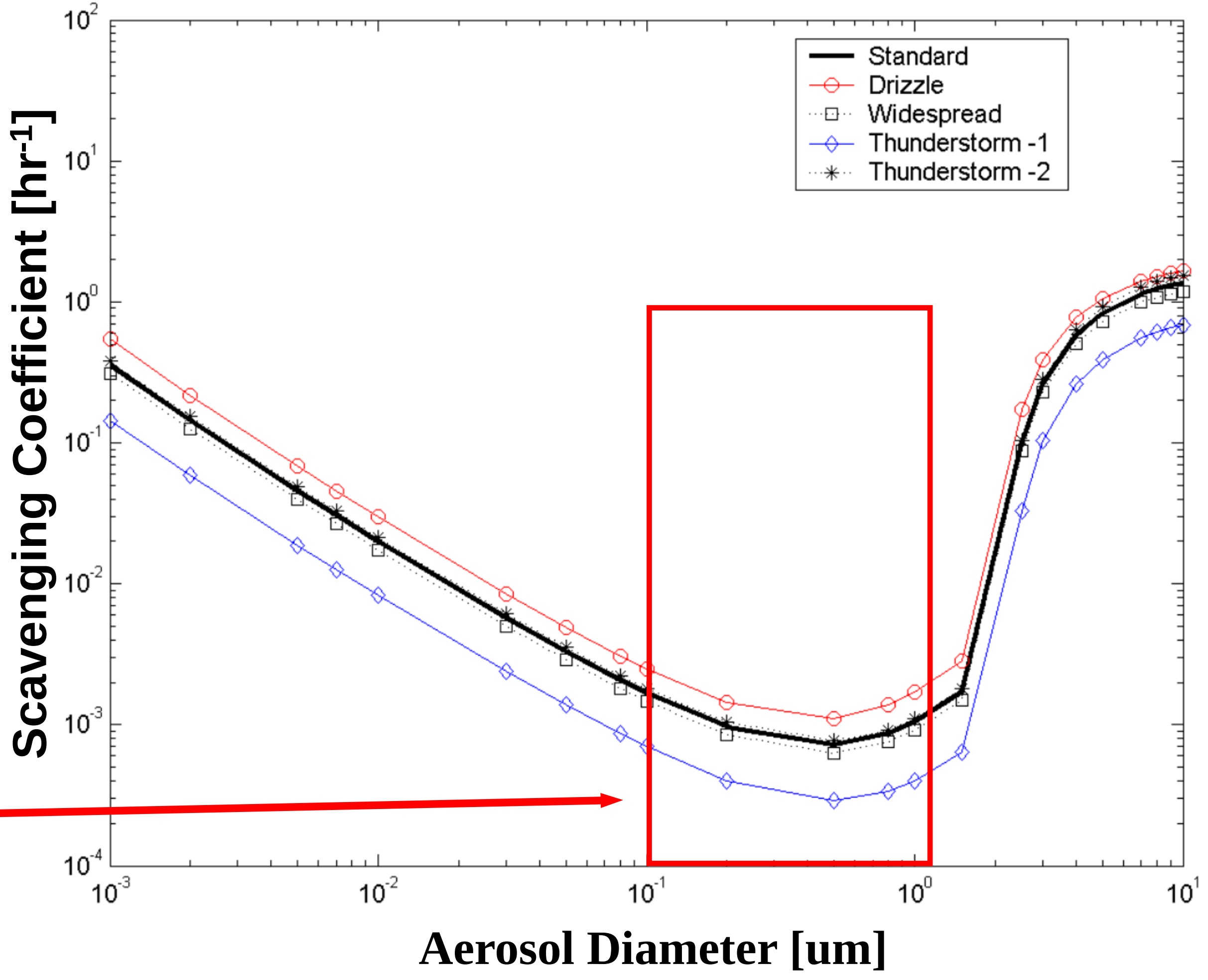
Ćurić, M., D. Janc, and V. Vučković, 2007: Cloud seeding impact on precipitation as revealed by cloud-resolving mesoscale model. Meteorol. Atmos. Phys., 95, 179–193, doi:10.1007/s00703-006-0202-y.

- Cloud-resolving mesoscale model shows cloud seeding increases precipitation.
- Fig. 10 – Differences in cumulative precipitations between test A1 and unseeded case. Contour interval is 1 mm, while isolines of 0.1 and 1.0 mm are also depicted.
- **Cloud seeding with ice nuclei increases precipitation and hence increases the removal of microdust incorporated into cloud particles.**



Andronache, C.: Estimated variability of below-cloud aerosol removal by rainfall for observed aerosol size distributions, Atmos. Chem. Phys., 3, 131-143, https://doi.org/10.5194/acp-3-131-2003, 2003.

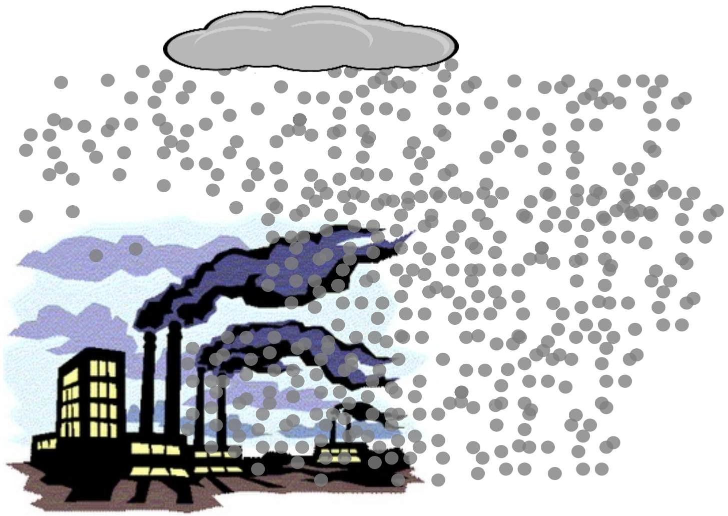
- Below-cloud scavenging (removal) of microdust by rainfall increases with rainfall rate and has a significant dependence on particle size.
- Fig. 3B – Scavenging coefficient L(dp) versus aerosol diameter for the same raindrop size distributions. The plots are for rain rate of (R) of 1 mm hr^{-1}.
- **Microdust of 0.1 to 1.0 µm in diameter are not removed by rainfall as effectively as larger or smaller sized particles.**



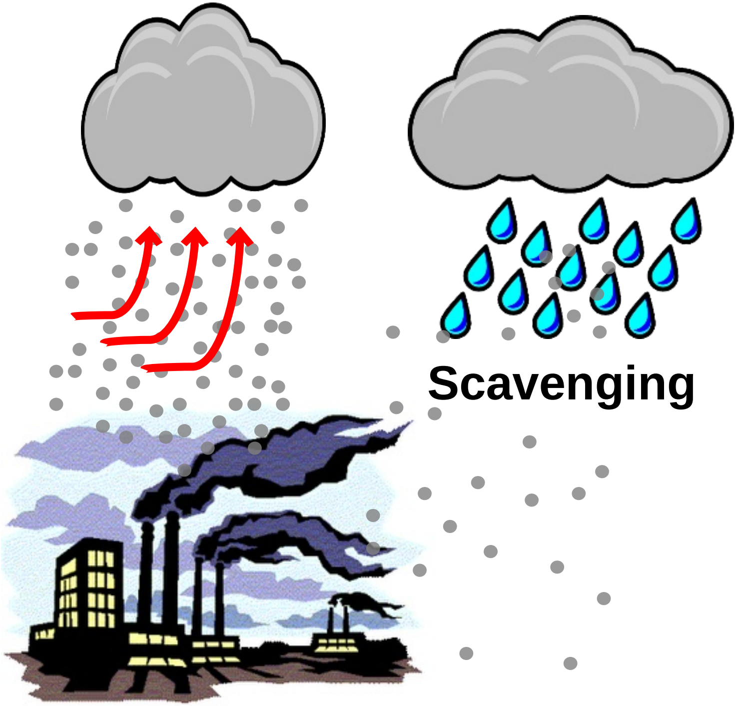
Microdust Levels

Low Precipitation

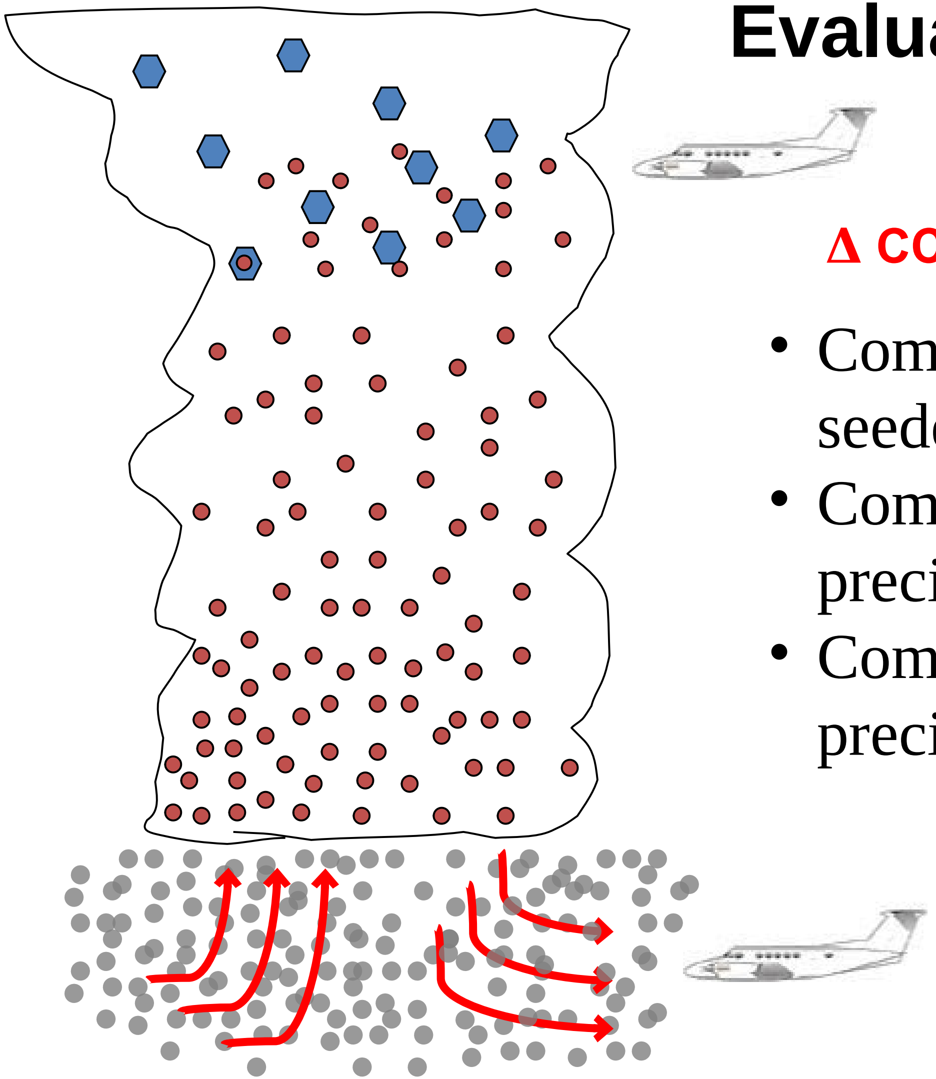
Temperature Inversion
(Traps Pollution)



High Precipitation



Evaluating the Removal of Microdust

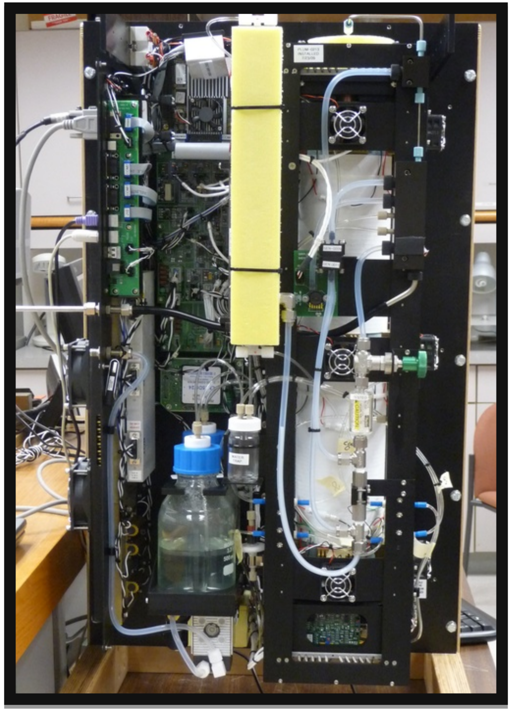


Δ CCN and/or Δ IN -> ↑ Precipitation -> ↓ Microdust

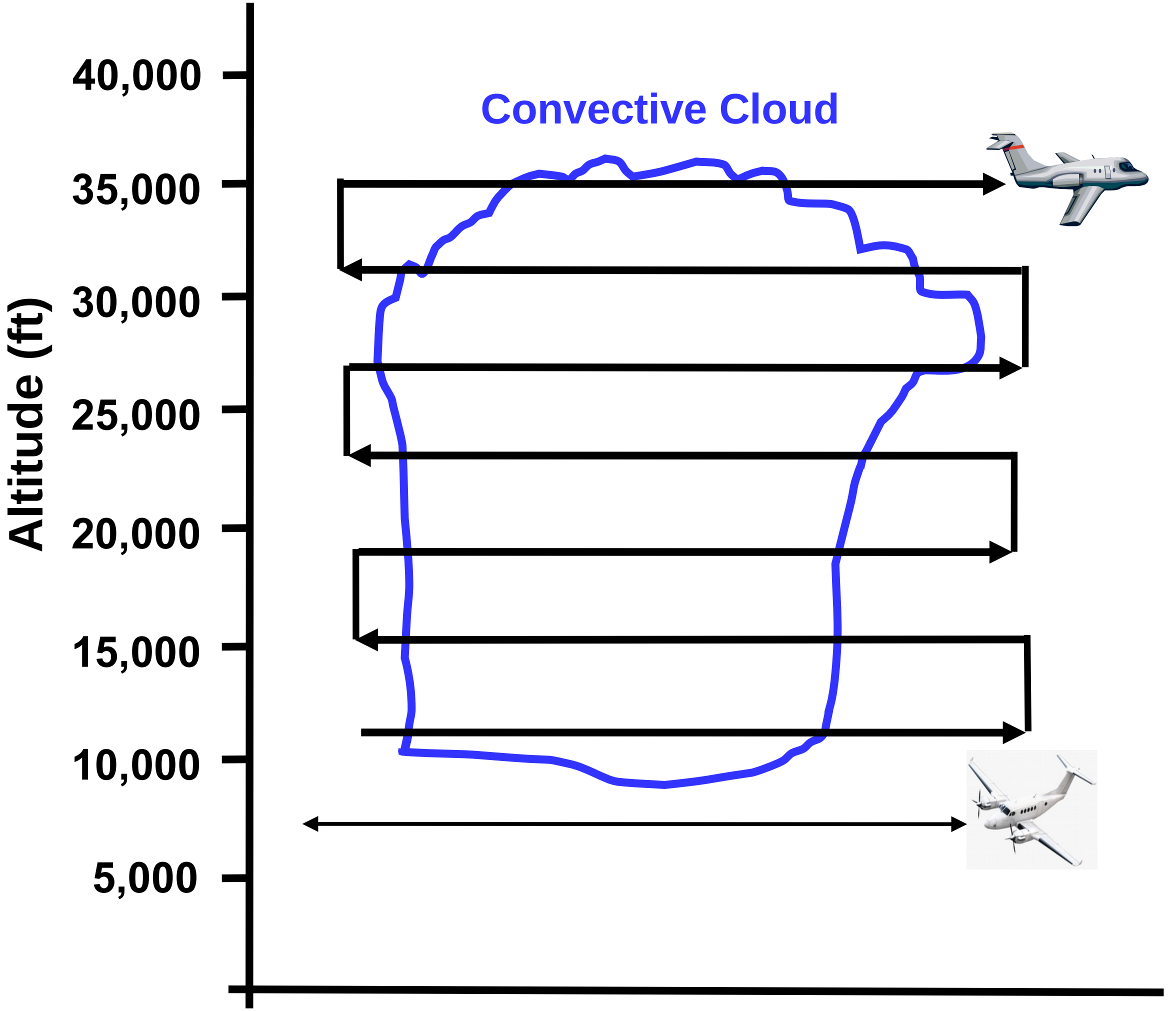
- Comparison of the activated microdust in seeded clouds to that of unseeded clouds.
- Comparison of microdust at cloud base prior to precipitation to after precipitation.
- Compare microdust upwind and downwind of precipitating clouds.

Korean Specific Measurements Required

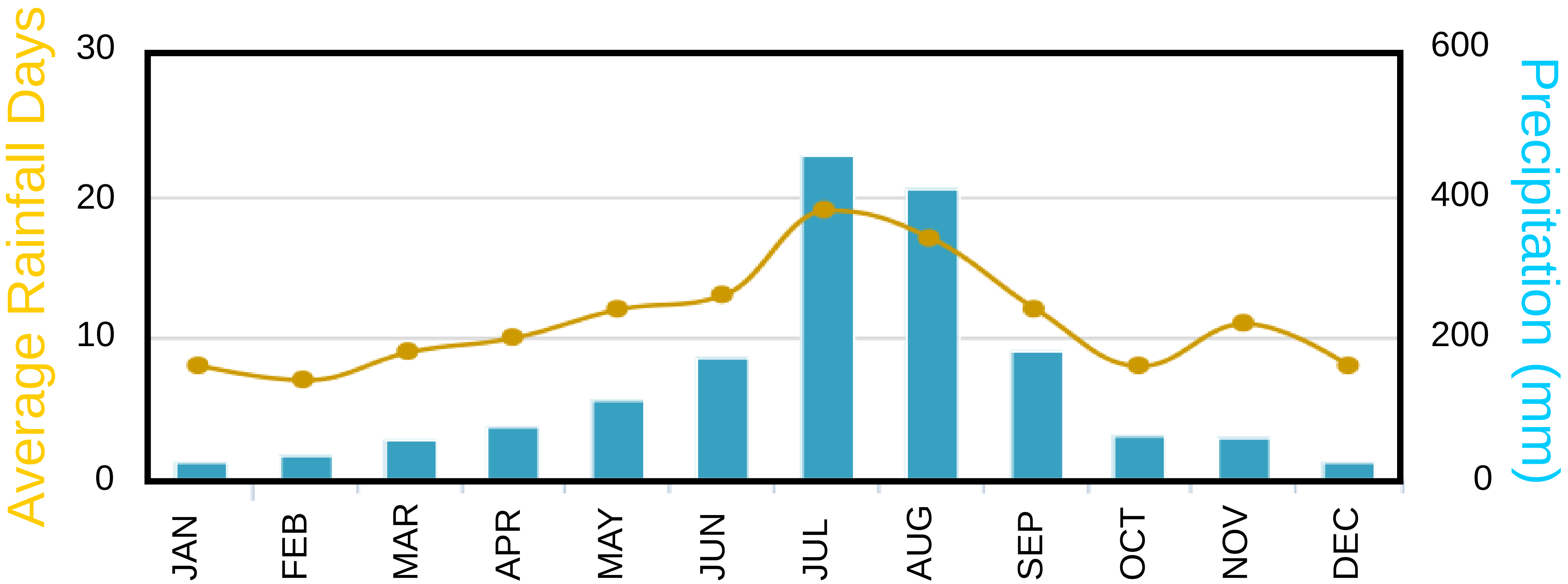
- The concentration of aerosols (cloud condensation nuclei and microdust) related to clouds and precipitation development on the Korean Peninsula.
- Microdust impact on the ability of clouds to produce large drops and ice particles.
- Microdust impact on the temperature of ice formation in seeded and un-seeded clouds.
- What are the commonalities and differences between urban and rural clouds?



Aircraft Observations



Seoul Average Rainfall (mm)



Late Spring (May/June) and Early Fall (Sep/Oct)

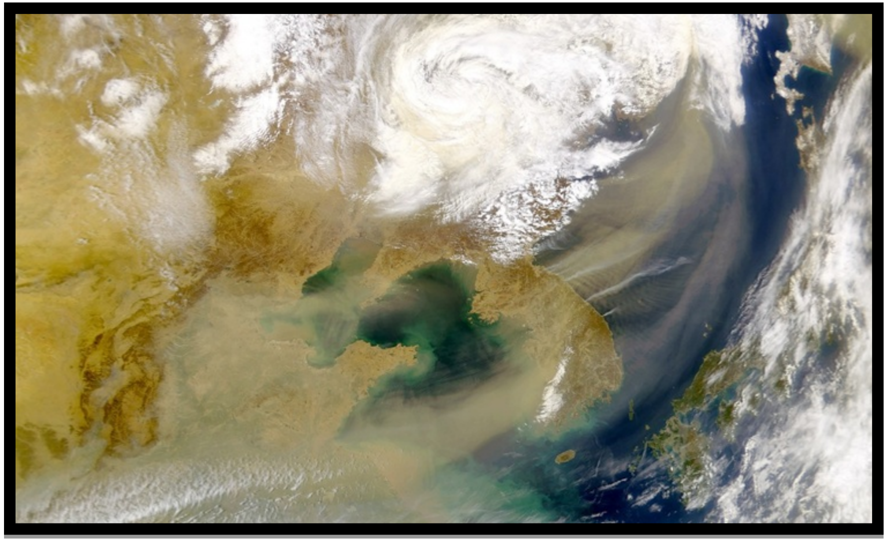
Important Time Periods for Field Measurements.

Summary

- Proven Science, Technology, Equipment, and Operators
- Cloud Seeding Increases Precipitation and Air Mixing
- Precipitation and Air Mixing Reduces Microdust

Cloud Seeding Increases Precipitation/Reduces Microdust

- Multiple Additional Benefits
    - Enhance Understanding of Microdust Origin, Definition, Tracking, and Forecasting



References – Microdust Removal

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