Seeding Is Not Just Believing

More Science is Needed

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Motivated by a United Nations projection that approximately one third of the world population will live under severe water stress by the middle of this century, politicians and water managers have begun to explore precipitation enhancement by cloud seeding as one means to augment water resources. In addition, ample evidence that human activities can alter atmospheric processes on scales ranging from local precipitation patterns to global climate strengthens the physical basis for deliberate attempts to alter the weather.

More than 150 operational weather-modification programs, primarily cloud-seeding activities aimed at enhancing precipitation or mitigating hail fall, take place in 37 countries; at least 66 operational programs are being conducted in 11 states across the United States. Many programs operate without any scientific quantitative assessment or evaluation of the seeding experiments. Although strong evidence exists that cloud seeding could enhance precipitation under certain atmospheric conditions in certain areas, equally strong evidence shows that current cloud seeding technologies do not transfer to other conditions and areas. In fact, glaciogenic seeding may actually reduce precipitation in some situations. Furthermore, some operational cloud seeding programs are ongoing in areas where experiments have shown seeding will not work.

Microphysics and Dynamics Matter

The potential for increases in rainfall using cloud seeding is strongly dependent on the natural aerosols, microphysics, and dynamics of the clouds that are being seeded. Microphysics refers to the size and concentration of water droplets and ice particles inside clouds. Dynamics refers to the forces affecting the movement of air in and around clouds. The microphysics are dependent on background aerosol levels, because it is the aerosol particles that attract water vapor to form cloud droplets, and in cold clouds, ice particles. Furthermore, the types and concentrations of aerosol particles can be influenced by trace gases (i.e., air pollution).

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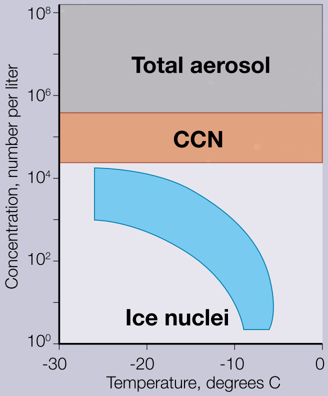
Given these dependencies, the microphysics of clouds and seeding effects can differ significantly from one geographical region to another, and even during and between seasons in the same region. In some instances, clouds may not be suitable for seeding, or the frequency of occurrence of suitable clouds may be too low to warrant the investment in a cloud-seeding program. Both factors need to be evaluated and preliminary studies conducted on atmospheric aerosols and pollution levels, and on the microphysics and dynamics of naturally forming clouds, prior to commencing a larger seeding experiment. In many operational programs these studies are lacking.

If the targeted measurements and additional data show sufficient evidence for clouds to be positively affected by cloud seeding, the seeding techniques should then be evaluated using a randomization procedure to statistically demonstrate that the seeding method works and to quantify any possible increases. This approach is similar, for example, to what is commonly done in medical trials with a new drug.

The dilemma as highlighted in the 2003 report of the National Research Council is that while little funding is available for physical measurements and understanding of weather modification processes, some are willing to spend funds to apply these technologies without knowing the effect it will have in their region. We do know that human activities can affect the weather, and that seeding will cause changes to a cloud. However, in many instances we still are unable to translate these induced changes into verifiable changes in rainfall, hail fall, and snowfall or to employ methods that produce scientifically credible, repeatable changes in precipitation.

Why is Verification Difficult?

Factors that contribute to the difficulty of verifying seeding effects include



The chart at left shows total aerosol concentration in the atmosphere, and subsets cloud condensation nuclei (CCN) and ice nuclei (IN) concentrations, as functions of temperature. Hygroscopic seeding changes the CCN characteristics by adding larger, more hygroscopic (moisture-attracting) aerosols to facilitate the formation of large cloud droplets that convert to rain more quickly. The activation of these particles to cloud droplets is independent of temperature, as is total aerosol concentration, as indicated in the diagram. In contrast, ice particles like to form on hard particles that are not soluble in water, and are strongly dependent on temperature, with particles able to start forming ice crystals in the atmosphere at temperatures around -5 to -10°C, as shown. Glaciogenic seeding with silver iodide, which acts as IN at temperatures warmer than most other IN (such as dry ice or propane), can create more ice crystals at these temperatures, and because ice crystals grow faster than drops, they develop precipitation more efficiently.

uncertainties about the natural variability of precipitation, associated background aerosol and microphysical characteristics of the atmosphere and clouds, inadequate understanding of the interactions between the microphysics and dynamics in clouds, inadequate targeting of seeding material, the inability to measure these variables with the required accuracy or resolution, and the detection of a small induced effect under these conditions.

Quantitative scientific proof is scanty, and the problem is compounded by extravagant claims, growing environmental concerns, and economic and legal factors. Agencies often are under pressure to meet short-term operational needs rather than setting a priority to achieve long-term scientific understanding and assessment. The scientific basis of weather modification concepts is not in question. Rather the absence of adequate understanding of critical atmospheric processes has led to a failure to produce predictable, repeatable, detectable, and verifiable results.

We Have Made Progress

Despite the lack of scientific proof, our scientific understanding has progressed on many fronts in the last twenty years. Recent experiments using hygroscopic seeding particles in mixed-phase (water and ice) clouds have shown encouraging results, with precipitation increases attributed to increasing the lifetime of the rain-producing systems. There are strong suggestions of positive seeding effects in winter orographic cloud systems. Satellite imagery has highlighted the role of high concentrations of aerosols in influencing clouds, rain, and lightning, thus drawing the issues of intentional and inadvertent weather modification closer together.

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unseeded conditions they found that the trend line of Ro shifted upward by 12 to 14 percent for the seeded rain time series compared to the unseeded time series. The sensitivity of Ro to both seeding and pollution effects was greatest in the hilly areas with the greatest natural orographic enhancement factor and practically non-existent in the low-lying areas where no orographic enhancement occurs.

The double-sided sensitivity of clouds to the damaging effects of pollution aerosols and potential corrective effects of cloud seeding provides another powerful tool for assessing the potential for enhancement of orographic precipitation. Areas that have experienced significant reductions in the trends of the orographic enhancement factor are likely manifesting the sensitivity of the clouds to aerosols, and hence could benefit from cloud seeding.

Satellites Offer Great Opportunities

The multispectral capabilities of recently commissioned satellites have provided new insights into the impacts of aerosols in reducing cloud drop size and in slowing the process of precipitation formation. These satellite capabilities can provide further insights into the efficacy of cloud seeding for rain enhancement. They also can be used to direct seeding operations to the clouds that likely will be most responsive to the process. Given the severe shortage of water in the southwestern United States, the time is right to start a new generation of cloud seeding research so the region can benefit from the new methodologies and insights it will produce.

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Yet, changing levels of background aerosols associated with inadvertent weather modification in a region can influence or change the potential for deliberate weather modification and render previous cloud seeding results inapplicable. This finding and other recent work has raised critical questions about the microphysical processes leading to precipitation, the transport and dispersion of seeding material in the cloud volume, the effects of seeding on the dynamical growth of clouds, and the logistics of translating storm-scale effects into an area-wide precipitation effect. Questions such as the transferability of seeding techniques or whether seeding in one location can "steal" rain from other locations can only be addressed through sustained research on the underlying science combined with carefully crafted hypotheses and physical and statistical experiments.

Significant and exciting advances in observational, computational, and statistical technologies have occurred over the past two to three decades. These include capabilities to: 1) detect and quantify relevant variables on temporal and spatial scales not previously possible; 2) acquire, store, and process vast quantities of data; and 3) account for sources of uncertainty and incorporate complex spatial and temporal relationships. Increased computing power has enabled the development of models that range in scale from a single cloud to the global atmosphere. However, because of lack of funding, few of these tools have been applied in any collective and concerted fashion to resolve critical uncertainties in weather modification activities.

Future Directions

Capitalizing on these advances and especially adding new remote and in situ observational tools to existing or new experiments could yield substantial new insights and at last simultaneously provide the necessary physical and statistical data on the efficacy of cloud seeding to enhance precipitation or mitigate hail. Some especially promising areas include:

- *Hygroscopic seeding to enhance rainfall*. The small-scale experiments and larger-scale coordinated field efforts proposed by the WMO (2000) could serve as a starting point for such efforts.
- *Orographic cloud seeding to enhance precipitation*. A randomized program that includes strong modeling and observational components and employs advanced computational and observational tools could substantially enhance our understanding of seeding effects and winter orographic precipitation.
- *Studies of specific seeding effects*. These could include studies of initial droplet broadening, the formation of drizzle and rain associated with natural hygroscopic seeding, and anthropogenic sources of particles.
- *Improving modeling*. Special focus is needed on modeling cloud microphysical processes.

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