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REPORT IN BRIEF

Critical Issues in Weather Modification Research

The impact of human activity on weather and climate has been of increasing national and international concern over the past few decades. In stark contrast, there has been little parallel research directed at understanding the ability of humans to intentionally modify the weather. Yet the fundamental physical principles underlying both inadvertent and advertent weather modification are, in many respects, the same.

In this same timeframe, remarkable progress has been made in our ability to observe atmospheric processes, record this information, and incorporate it into sophisticated mathematical models (see Box 1, p. 2). However, this power has not been collectively applied to the questions that can help us understand how or whether atmospheric systems can be intentionally changed.

We know that we can disperse cold fog, induce changes in clouds and possibly increase snowpack. What we cannot do, with the exception of dispersing cold fog, is provide unequivocal scientific evidence of these changes and demonstrate that the effects are entirely reproducible. Despite this lack of proof, many weather modification programs are operating, spurred by water shortages and increasing weather-related damage and loss of life. People in drought- and hail-prone areas willingly spend significant resources on weather modification programs (see Figure 1), and in 2001 there were at least 66 operational programs being conducted in 10 states across the United States.

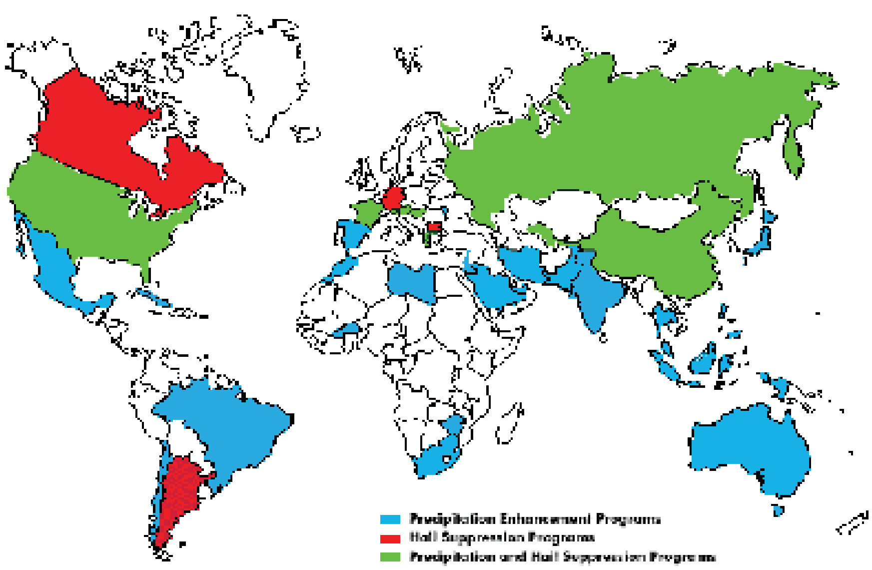

Figure 1. Precipitation and hail suppression programs are conducted in more than 24 countries worldwide. **Source**: Compiled with information from the World Meteorological Organization (1999) by R. Bruintjes.

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At the same time, less than a handful of weather modification research programs are underway worldwide, and related research in the United States has dropped to less than $500,000 per year from a high of $20 million in the late 1970s. Resolving this disparity between our willingness to attempt to modify weather and our willingness to conduct research to understand whether such activities can succeed will occur only if the relevant funding agencies and scientific communities make a commitment to answer some of the fundamental underlying questions. The challenge is to find the right balance between reducing scientific uncertainties and the need for action to address pressing problems.

Box 1. Advances in Observational Technologies

In the past, the only way to measure the moisture content and other characteristics of a cloud was to strap instrumentation onto a plane and fly it into the cloud. Measurements were therefore limited to path of the plane. The newest remote-sensing and *in situ* equipment—advanced by urgent needs in the areas of severe storm warnings, detection of aircraft icing conditions, and climate change—offers higher resolution "pictures" of clouds and cloud systems than ever before possible (see Figure 2).

These tools can now estimate in-cloud particle shapes and sizes, track the dispersion of seeding aerosols, and more accurately estimate precipitation. Millimeter-wave cloud radar can describe non-precipitating clouds. The national Doppler radar network (NEXRAD) provides opportunities for examining the evolution of radar signatures in all regions of the country and for applying cell tracking capabilities in field experiments. Although they have been nominally used in cloud-seeding observations, these tools have not yet been used as integral components of experiments designed to test and evaluate specific scientific hypotheses in weather modification.

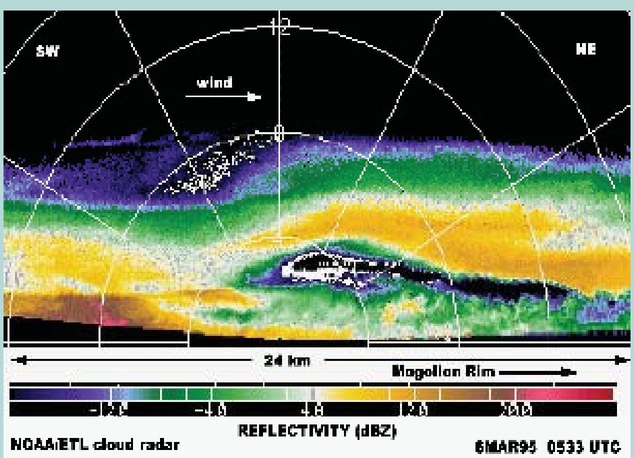

Figure 2. Observations from scanning cloud radar are converted to this "picture" of supercooled liquid in a wave cloud induced by the surrounding mountainous terrain. This is useful for locating good clouds to seed and then to monitor the ensuing changes in the cloud to better understand physical processes. **Source**: Reinking et al. (2000).

Critical Uncertainties Limiting Advancement

If progress in establishing our capability to modify the weather is to be made, intellectual and technical resources must be brought to bear on the key uncertainties (see Box 2) that currently hamper progress. For example, there are critical gaps in our understanding of the complex chain of physical processes that start with condensation of water vapor and end with precipitation. The processes that lead to the formation of a hailstone are equally complex and difficult to understand, especially when placed in the context of the convective field of motion of a violent thunderstorm.

Progress in obtaining answers to such questions depends on sustained and directed research in laboratories, on research centers dedicated to modeling, and on carefully designed and verifiable field experiments equipped with the most advanced observing tools. Identifying and addressing these critical uncertainties will focus future research where it will produce the most useful results.

Call for a Coordinated National Program

A coordinated national program of weather modification research designed to reduce key uncertainties is needed. This program should be the heart of a sustained research effort that uses a balanced approach of modeling, laboratory studies, and field measurements. Instead of focusing on near-term operational applications of weather modification, the program should address fundamental research questions that might include:

- What is the background aerosol concentration in various places, at different times of the year, and during different meteorological conditions? To what extent would weather modification operations be dependent on these background concentrations?

Box 2. Summary of Key Uncertainties

<u>**Cloud/Precipitation Microphysics Issues**</u>

Highest priority: Understand the background concentration, sizes, and chemical composition of aerosols that participate in cloud processes.

Other gaps: How nucleation processes relate to characteristics of aerosol particles; ice nucleation; Evolution of the droplet spectra in clouds; Relative importance of drizzle in precipitation processes.

<u>**Cloud Dynamics Issues**</u>

Highest Priority: Understand cloud-to-cloud and mesoscale interactions as they relate to updraft and downdraft structures and cloud evolution and lifetimes.

Other gaps: Cloud and sub-cloud dynamical interactions as they relate to precipitation amounts and the size spectrum of hydrometeors; Microphysical, thermodynamical, and dynamical interactions within clouds.

<u>**Cloud Modeling Issues**</u>

Highest priority: Combination of the best cloud models with advanced observing systems in carefully designed field tests and experiments.

Other gaps: Application of new cloud-resolving models to weather modification, including short-term predictive models; Predictive models for severe weather events; Cloud models capability to track dispersion of seeding material both within and outside of seeded areas.

<u>**Seeding-Related Issues**</u>

High priority: Targeting of seeding agents, diffusion and transport of seeding material, and spread of seeding effects throughout the cloud volume.

High priority: Measurement capabilities and limitations of cell-tracking software, radar, and technologies to observe seeding effects.

Other gaps: Using observations from new instruments of high concentrations of ice crystals; Interactions between different hydrometeors in clouds and how to best model them; Modeling and prediction of treated and untreated conditions for simulation; Mechanisms of transferring the storm-scale effect into an area-wide precipitation effect and tracking possible downwind changes at the single cell, cloud cluster, and floating target scales.

- What is the variability of cloud and cell properties (including structure, intensity, evolution, and lifetime) within larger clusters, and how do clouds and cells interact with larger-scale systems? What are the effects of localized seeding on the larger systems in which the seeded clouds are embedded?
- How accurate are radar reflectivity measurements in measuring the differences between accumulated rainfall in seeded and unseeded clouds? How does seeding affect the drop-size distribution that determines the relationship between the measured radar parameter and actual rainfall at the surface?

To take advantage of recent related research and advances in observational, computational, and statistical technologies, the program should attempt to:

- Capitalize on new remote and in situ observational tools to carry out exploratory and confirmatory experiments in a variety of cloud and storm systems
- Improve cloud model treatment of cloud and precipitation physics.
- Improve and use current computational and data assimilation capabilities.
- Capitalize on existing field facilities and develop partnerships among research groups and select operational programs.

Thus, the initiation of large-scale operational weather modification programs is premature, but a great opportunity exists to coordinate research efforts to address the fundamental questions that will lead to credible scientific results. It is not enough to expand present efforts that primarily analyze data from largely uncontrolled experiments. Instead, focused investigation of atmospheric processes, coupled with an exploration of the technological applications, will certainly advance understanding and bring many unexpected benefits and results. In time, this research will place us in a position to determine whether, how, and to what extent weather and weather systems can be modified.

Critical Issues in Weather Modification Research is the National Academies latest assessment of weather modification research. The report reviews the current state of the science with particular attention to recent advances, identifies the key scientific uncertainties limiting advances in the science, outlines future directions in weather modification research, and suggests actions to identify the impact of local weather modification on large-scale weather and climate patterns.

This report brief was prepared by the National Research Council based on the committee's report. For more information, contact the National Research Council's Board on Atmospheric Sciences and Climate at 202-334-3512. *Critical Issues in Weather Modification Research* is available from the National Academies Press, 500 Fifth Street, NW, Washington, DC 20001; 800-624-6242 or 202-334-3313 (in the Washington area); www.nap.edu.

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