Precipitation Enhancement: Evaluating Aerosol-Cloud Interactions

NCAR

Research Applications in Weather Modification

Atmospheric water in the form of precipitation is one of the primary sources of fresh water in the world. However, a large amount of water present in clouds is never transformed into precipitation on the ground. This has prompted scientists and engineers to explore the possibility of augmenting water supplies by means of cloud seeding. Although many projects have successfully documented increases in precipitation due to seeding, others have shown a decrease; the majority of projects have thus far yielded inconclusive results. The reason for this inconsistency is that physical mechanisms of aerosol effects on cloud and precipitation development in the atmosphere are much more complex than earlier anticipated. Thus initial optimism about the success of seeding in the 1950-60's has given way to a more cautious approach.

One of the main goals in precipitation enhancement research at NCAR's Research Applications Laboratory (RAL) is to firmly establish the physical chain of events in precipitation development so that perturbations, both intentional and inadvertent, can be understood and quantified. Thus, this research addresses common fundamental questions on aerosol, cloud, and precipitation processes that impede progress in other important research areas including quantitative precipitation forecasting and aerosol-cloud effects on climate. RAL continues to modify and build on earlier research for application in other weather modification field programs and projects throughout the world. The following are some examples of past and current projects.

Mexico

In 1996, concern by representatives of the State of Coahuila and Altos Hornos de México regarding regional pressures on water resources led to the development of the Program for the Augmentation of Rainfall in Coahuila (PARC), which was proposed as a four-year program consisting of physical studies, a randomized seeding experiment, and collaboration with and training of Mexican scientists and students.

The overall objective of PARC was to develop, test, implement, and transfer the technology recently developed in South Africa of hygroscopic cloud seeding in Coahuila. The results of the truncated experiment (only 2 years of seeding) were remarkably similar to those achieved in an earlier program in South Africa – a major achievement in replicating the positive results of one location to another.

United Arab Emirates (UAE)

Encouraged by results from hygroscopic cloud seeding in other parts of the world and by improved measurement systems, the government of the UAE approached RAL about developing and applying the technology of hygroscopic cloud seeding in the UAE. Phase I of the study (2001-2002) was a preliminary assessment aimed at: a) collating existing data and collecting specific data on clouds and rainfall, b) establishing the natural background and variability of aerosols in the region, c) adapting and developing numerical models for simulating UAE clouds, and d) understanding the UAE hydrology sufficiently to assess the impact of rainfall on groundwater resources.

Hygroscopic flare burning during Mexico seeding trials.

Combined radar and satellite image of clouds and storms over eastern UAE and Oman; the radar image in the bottom left corner shows the aircraft tracks during a seeding experiment.
Results from Phase I were encouraging enough to propose a Phase II (summers of 2003-2004) randomized seeding experiment aimed at determining whether there is a quantitative effect on radar-derived storm-based rainfall from hygroscopic seeding at cloud base. Also important was the collection of physical measurements in a subset of the randomized cases to support the statistical results and provide substantiation for the physical hypothesis. Although a fair number of cases (96 out of 134) met the analysis criteria, the results showed no significant differences between seeded and unseeded storms, and it was unlikely that additional cases would change this result. The additional physical measurements were critical in revealing where the hygroscopic seeding model broke down in the UAE clouds.

Saudi Arabia
Similar to the effort in the UAE, RAL scientists, in collaboration with Texas A&M University and Weather Modification Inc. (WMI), conducted field studies on the feasibility of rainfall enhancement via cloud seeding in the north central region of Saudi Arabia during the cool season and in the southwestern region during the summer season. The scientific effort encompassed: cloud and rainfall climatology studies; integration of past studies; airborne chemistry, aerosol, and cloud physics measurements; assessment and enhancement of weather radar capabilities for collection of quantitative data; analyses of field data; and numerical modeling work.

NCAR/RAL has organized and participated in numerous weather modification field projects around the world, supporting the installation and operation of infrastructure and conducting evaluation and assessment studies. Other projects have occurred in Italy, Australia, Indonesia, West Africa, Turkey, and India as well as in the United States.

Wyoming
The Wyoming Weather Modification Pilot Program, funded by the State of Wyoming, is an orographic cloud seeding research program targeting three mountain areas: the Medicine Bow, Sierra Madre, and Wind River Ranges. It is unique among state-sponsored programs in that it includes a substantial independent evaluation component to determine the feasibility of cloud seeding, and to quantify its effectiveness. The operational contract is being fulfilled by WMI, while the evaluation is being conducted by NCAR.

The evaluation is based on two avenues: a) a statistical experiment to collect a randomized set of seeded and unseeded cases, and b) exploratory observations to investigate the different physical processes in cloud seeding to show that the seeding hypothesis is physically-based. One of the main tools in the evaluation effort is the WRF numerical model, which is used to provide storm simulations using nested grids (to <1-km resolution) with detailed microphysics including simulated seeding. WRF is also used with the RT-FDDA system at a more computationally manageable grid resolution (2-km) to provide daily forecast guidance during operations – 15 November through 15 April. The randomized experiment and modeling activities continue through the present.