The History of Cloud Seeding in Arizona

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Cloud condensation nuclei (CCN) are small particles (clay and dust) that water vapor condenses/freezes onto to make up cloud droplets. Cloud droplets are small, typically 3-4 times smaller than the diameter of human hair, but 100 times larger than CCN. Billions of cloud droplets make up a cloud. Cloud is in balance when cloud droplets experience evaporation and condensation at the same rate.
Warm Precipitation Process

- Cloud droplets grow through condensation
- Large cloud droplets fall faster than surrounding cloud droplets
- Large cloud droplets continue to grow as they collide/coalesce with the smaller droplets
- The growing droplets can even break apart when they become very large
- Soon they are too large to evaporate once the drop below the cloud
Cold Precipitation Process

- Cloud droplets (supercooled liquid water (SLW)) and ice nuclei/crystals coexist in clouds with temperatures between 0°C and -40°C
- Supercooled droplets can freeze on contact with ice nuclei/crystals or supercooled water can transfer to the ice nuclei/crystals (much like condensation) due to physical properties of water and ice
- Cold clouds typically have more supercooled droplets compared to ice nuclei/crystals
In 1946 Vincent Schaefer and Irving Langmuir from General Electric began investigating aircraft icing. They lined a freezer with black material and shined a light to visualize SLW (grey cloud) and ice crystals (shiny flashes of light). Wanting to cool the freezer beyond its limit, Schaefer began to add dry ice. The inclusion of dry ice led to a large increase in ice crystals that fell to the bottom of the chest. Schaefer soon found that only small amounts of dry ice were needed to produce large increase in ice crystals.
Modification of Supercooled Clouds

- Vincent Schaefer began testing his ice box results on clouds over New York and Massachusetts

- Theories developed in the ice box translated to the natural environment
Modification of Supercooled Clouds

- Late in 1946 Bernard Vonnegut joined Vincent Schaefer and Irving Langmuir to further their work

- They learned that dry ice only cooled the environment such that SLW would turn to ice crystals

- They soon began to speculate that other substances might convert SLW to ice

- One such substance, silver iodide has a similar crystal-like as ice

- The introduction of silver iodide to a cloud in the ice box had a similar affect as dry ice

- Finally, they discovered that a silver iodide smoke was more effective at creating ice crystals due to an increase in the number of silver iodide particles introduced into the ice chest
Arizona Weather Modification Projects

- In 1947, the Arizona Republic and Phoenix Junior College met with Irving Langmuir at his home and developed a cloud seeding pilot project for Arizona.

- Irving Langmuir suggested a 2 to 3 fold increase in precipitation with hopes of ending a drought which began at the start of the 1940’s.

- The first pilot project took place during July and August, 1947 when the Arizona Republic chartered a DC3 and began dropping dry ice into cumulus clouds on the Salt and Verde watersheds.

- Visual observations indicated that additional rain was being produced, but rainfall measurements and photography failed to validate their claims.
The Arizona Republic continued to sponsor cloud seeding experiments after the summer of 1947.

Wintertime seeding using ground based generators during December of 1948 was claimed to increase snow pack over the mountains.

Airborne seeding of thunderstorms during August of 1949 was claimed to add 12,000 acre feet of additional run-off in SRP’s reservoirs.

However, it was noted that costs were high, but there was great optimism for potential benefits.
The Salt River Project enters the field of cloud seeding with Dr. Irving Krick operating the project in 1949.

Experiments with ground based silver iodide generators over the Verde watershed estimated a 4 fold increase of precipitation over areas not seeded.

Dr. Krick claimed that 1-2 million acre feet of additional run-off could be achieved with 15 ground based generators.

SRP approves the construction of seven new cloud seeding generators.
Arizona Weather Modification Projects

- 1950 SRP begins to utilize airborne seeding and ground based generators during the winter and summer
- Annual report attributes “rainmaking activities” responsible for an estimated 56,000 acre feet of run-off at a cost of $0.23 per acre foot
- However, Dr. Krick’s results were inconclusive, less than advertised, and could not be differentiated from natural occurrences
- The suspect results and questionable salesmanship quickly ended SRP’s relationship with Dr. Krick
SRP contracted with Dr. Paul MacCready of Meteorology Research Inc. and North American Weather Consultants and continued cloud seeding operations.

The early/mid 1950’s SRP builds additional ground based silver iodide generators to accompany airborne seeding operations.
- Up to 23 ground based generators seeded over 9,000 square miles of the Salt and Verde watersheds during the mid-late 1950’s.
- 5 were installed at fire lookout towers over the White Mts.
Arizona Weather Modification Projects

- Dr. Louis Battan from the University of Arizona began seeding summer thunderstorms using aircraft over the Santa Catalina Mountains north of Tucson.

- Summer seeding programs took place from 1957 to 1962 and 1964.

- While results from other convective seeding campaigns outside of AZ seemed encouraging, Dr. Battan found inconclusive results.

- Dr. Battan concluded that rains from summer thunderstorms over the Santa Catalina Mountains were produced from a warm precipitation process where silver iodide would have no effect.
Arizona Weather Modification Projects

- US Army Signal Research and Development Lab and Meteorology Research Inc. seeded thunderstorms over Flagstaff using aircraft during the summer of 1962.

- Time lapse photography, weather radar, lightning detectors, and airborne heat sensors were all used to observe the lifecycle of the seeded thunderstorms.

- One goal was to reduce lightning discharges responsible for forest fires.
Arizona Weather Modification Projects

"Comparison of all methods in A.F."

Highest indicated gain: Jan-Feb 52 --- 344,328
Lowest indicated gain: 3-51 to 3-52 Less Aug. --- 202,557
Avg. indicated gain: All methods --- 260,793

- Cloud seeding projects and experiments over Arizona decreased during the 1960’s
- 1963: SRP’s partnership with Paul MacCready ended along with all cloud seeding operations on the Salt and Verde watershed
- 1966: Dr. Battan released discouraging results from the seeding projects over the Santa Catalina Mountains
- End of drought conditions over Arizona
In the 1970’s US Bureau of Reclamation (USBR) became the Federal government’s primary research entity on cloud seeding

Numerous wintertime scientific research projects over the Colorado Basin were initiated through the USBR

Results from individual projects were transferred to the entire Colorado Basin including the Mogollon Rim of Arizona

SRP joined the North American Interstate Weather Modification Council and began to participate in cloud seeding research with the USBR

- Only four derived variables (2 good, 2 questionable) from weather balloon data were used to assess the potential of cloud seeding.

- Results suggested that the most favorable area for cloud seeding was over the upper Salt River basin (White Mts.).

- However, the simplistic research methods lead to concerns over the results.
During the mid-late 1980’s USBR, ADWR, SRP, North American Weather Consultants, and University of Wyoming performed a feasibility study related to wintertime cloud seeding over the Salt and Verde watersheds (Arizona Snowpack Augmentation Project).

The study utilized instrumented aircraft, radar and other ground instruments to measure quantities of supercooled liquid water (SLW), cloud structure, and atmospheric stability.

Tracer gasses were used to gauge the potential for ground based seeders.

The study focused two locations; Happy Jack in 1986 and 1987 with a full suite of instrumentation and Hannagan Meadows in 1987 with limited resources.
Results indicated SLW was available for seeding with quantities and timing being variable.

Greatest quantities/occurrences of SLW was associated with winds perpendicular to mountain crests.

Seeding material could reach the clouds bases, but temperatures were generally too warm for silver iodide to be effective.

Study suggested that more research needs to be done; however, USBR plans for addition research never materialized.
Arizona Weather Modification Research

- National Oceanic and Atmospheric Administration (NOAA) funding to University of Arizona and the National Center for Atmospheric Research (NCAR) in the early 1990’s lead to the development of high resolution computer weather models

- Modeling indicated that an atmospheric mountain wave develops downwind of Mingus Mt. and is responsible for some of the wintertime precipitation over the western/central Mogollon Rim

- Modeled conditions looked ripe for airborne cloud seeding
Arizona Weather Modification Research

- The Arizona Project was designed with field work in 1995 to verify model results

- The University of Arizona became the sponsor with ADWR, NCAR, NOAA, NASA, Emery-Riddle University, ASU, UoW, NAU, the National Forest Service, SRP, and others contributing

- Further Investigation of findings from USBR 1987-1988 field study

- The field study utilized the latest meteorological instrumentation and sampling such as radar (both ground and aircraft), microwave radiometers, weather balloons, remote weather stations, and snow sampling as well as including the newly developed computer models
- High resolution model performed well and forecast mountain wave induced precipitation up to 12 hours in advance
- Large amounts of SLW exist in the atmospheric mountain wave and in orographic upslope flow
- Radar data showed sizable increases in reflectivity during seeded events; however, increases on the ground (precipitation gauge measurements) were modest
- Increased precipitation would only be enhanced on the windward side and crest of the Mogollon Rim
- Airborne seeding was effective, with ground based generators being effective for a limited number of cases
Conclusions

- The transition from Langmuir and Schaefer’s research to applied science (cloud seeding projects) was too quick.
- Inconsistent and unverifiable results from the late 1940’s to early 1960’s indicate the importance of a properly designed field campaign.
- While the USBR studies during the 1970’s through 1980’s showed the potential, only the last two field projects looked at available SLW and potential application and effectiveness of a cloud seeding agent.
- Studies over the Verde watershed build upon each other and are encouraging, but imply the need of expensive airborne seeding.
- The upper Salt (White Mts.) appears to hold the greatest potential, but it has seen the least amount of research.
- Recent results from ongoing projects in the West US continue to indicate the need for more scientific research and the importance of a proper project design.
Questions

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