

HISTORIC QUOTATIONS ON EVALUATIONS OF CLOUD SEEDING PROGRAMS

A Contribution from Tom Henderson, Atmospherics Incorporated

Cloud seeding programs designed to augment precipitation by enhancing the natural precipitation processes began in the late 1940's following the early discoveries of Drs. Irving Langmuir, Vincent Schaefer and Bernard Vonnegut, a trio of dedicated scientists working at the General Electric Research Laboratory in Schenectady, New York. This past season there were 16 programs active in California, substantial programs in six other states, and a broad range of programs in 60 additional countries. From the serious and extensive evaluations of many cloud seeding programs, a few examples of the conclusions are presented in the following quotations from a cross section of historic publications.

1. **The Effects Produced by Seeding Supercooled Clouds with Dry Ice and Silver Iodide**, Vincent J. Schaefer. Symposium on Physics of Clouds and Precipitation, Centenary Proceedings of the Royal Meteorological Society, 1950. *Enthusiasm, imagination and the other attributes which are essential elements in the carrying out of experiments in a new field are of great importance in the development of experimental meteorology. If carried out in the proper manner I am very sure the results will be most satisfying and I am equally confident that developments of great economic importance will eventually be realized in this important field.*
2. **Australian Experiments on Artificial Stimulation of Rainfall**, E. G. Bowen. Weather, Vol. 7, July 1952. *A final observation, which is contrary to the views of Langmuir, is that in these experiments there was no case with dry ice in which overseeding appeared to occur. The amount of dry ice used varied from ten to 300 pounds on a single cloud cell and the amount of precipitation obtained appeared to increase with increasing quantities of dry ice.*
3. **Cloud Seeding Operations in the Bishop Creek, California, Watershed**, Ferguson Hall (U.S. Weather Bureau), Thomas J. Henderson and Stuart A. Cundiff (California Electric Power Company), Research Paper No 36, U.S. Dept. of Commerce, Washington, DC, Jan. 1953. *Comparison of the annual runoff from the seeded watershed with that from adjacent areas for the three years 1948, 1949 and 1950 showed an average positive departure significant at the 5% level. From the same analysis it is estimated that the average annual flow during the three-year period was augmented by 9%.*
4. **Final report of the National Advisory Committee on Weather Control, Vol., II**, Report prepared for the President of the United States, Howard T. Orville, Chairman, Washington, DC, December 31, 1957. *A major result of all the research by the Advisory Committee's statistical group is the preponderant evidence that cloud seeding has produced an increase in the precipitation from the orographic and West Coast project classes by between 10% and 15%.*

5. **Cloud Physics and Cloud Seeding. Modification of Hail Storms: Seeding with Giant Salt Nuclei**, Louis J. Battan. Introduction to Applied Meteorology, Doubleday and Co. Inc., Garden City, NY, 1962. *There is evidence suggesting that large cloud droplets which freeze are often the embryos on which hailstones grow. If the number of such large droplets were increased, it might be possible to increase the number of stones. In theory one can increase the number of large cloud droplets by seeding the clouds with giant salt nuclei.*
6. **Weather and Climate Modification**, Report of the Special Commission on Weather Modification, National Science Foundation, Washington, DC, Dec. 20, 1965. *For the past 10 years the Kings River Conservation District has supported a cloud seeding program by Atmospherics Incorporated in the Kings River drainage area on the western slopes of the Sierra Nevada Range in California. A grant from the National Science Foundation provided to Thomas J. Henderson for additional measurements and studies of precipitation and cloud physics parameters. Recent analysis of the data indicates an average 6.1% increase in runoff from the drainage area due to seeding for the period. This supports preliminary results of the research study by Colorado State University in the area of Climax, Colorado, and of other commercial seeding operations, extending over shorter periods of time, that seeding can give a moderate increase in precipitation in orographic situations.*
7. **Formation of Precipitation and Modification of Hail Processes**, G. K. Sulakvelidze, N. Sh. Bibilashvili, and V. F. Lapcheva, Leningrad, 1965. *In Italy, Vittori attempted to explain the effect of hail control by explosion of Italarazzi rockets. In 1960 the Vittori effect was tested on artificial hailstones by the explosion of an Italarazzi rocket. It was found that the Vittori effect indeed causes disintegration of hailstones upon the rocket's explosion but the distance at which this effect can be observed does not exceed 5-10 meters from the point of explosion. This method, therefore, can hardly find wide application in hail control."*
8. **Weather and Climate Modification, Vol. II, Research and Development**, Final report of the Panel on Weather and Climate Modification to the National Academy of Sciences, Publication No. 1350, Washington, DC, 1966. *In all evaluations of 41 project-seasons, the test varieties were seasonal watershed runoff values, obtained from U.S. Geological Survey records, with regressions based on nearby control watersheds for which runoff values correlated strongly (order of $r = 0.90$) with the target runoff. Project durations range from 8 to 14 years. The duration-weighted average runoff increase of the four test projects is about 12%, and it is apparent that their combined significance level is such that natural variability is not a likely explanation for these increases.*
9. **Project Sierra Cumulus**, Fresno College Foundation, Atmospheric Water Resources Research, final report to U.S. Department of the Interior, Bureau of Reclamation, Contract #14-06-D-6592, July 1969. *Cumulus clouds over some of the high mountain watersheds of the Sierra Range in California were seeded during the summers of 1966, 1967, and 1968. The experimental design consisted of seeding one*

in a pair of similar, non-precipitating clouds on a random basis. Over three seasons a total of 47 pairs of clouds were examined and yielded the following results: of the 47 seeded clouds 21 yielded rain, 13 yielded virga, and 10 gave neither. Of the 47 non-seeded clouds, only three yielded rain and 44 gave neither rain nor virga. The Chi-square and McNemar statistical tests for significance to the above results indicate that seeding was responsible for producing precipitation from non-precipitating clouds with a significance level of 0.999 (null hypothesis rejected at the point at the .001 level). The evaluation of project activities indicates that increases in runoff of the order of 100% to 250% can be achieved by seeding summertime orographic cumuli.

10. Cloud Seeding with Pyrotechnics in Australia, E. J. Smith, Division of Radio Physics. Paper presented at the AMS Second National Conference on Weather Modification, April 6-9, 1970, Santa Barbara, California. *These notes describe experiments in which pyrotechnic cartridges were fired into large cumulus clouds in Australia. The cartridges were kindly supplied by Dr. P. St.-Amand of the Naval Weapons Center, China Lake, California. These preliminary trials in Australia gave promising results, suggesting that meteorological conditions in this part of Australia are suitable for cloud seeding with pyrotechnics.*
11. Project Skywater in Fiscal Year 1972, Archie M. Kahan, Chief, Division of Atmospheric Water Resources Management, Bureau of Reclamation. Proceedings of the 13th Interagency Conference on Weather Modification, U.S. Department of Commerce, October 12-15, 1972. Skyland, Virginia. *Fiscal year 1972 found Project Skywater with 47 contracts spread among fourteen universities, eight private firms, seven federal agencies, and four state organizations. Twelve field experiments and three pilot projects highlighted the program.*
12. Weather and Climate Modification, Problems and Progress, Committee on Atmospheric Sciences, National Research Council, National Academy of Sciences, Washington, DC, 1973. *Since 1955 there has been a continuing project of cloud seeding over the drainage basin of the Kings River in California that is designed to increase precipitation and runoff. The program has been conducted by Atmospherics Incorporated of Fresno, California, which seeded clouds over a 1,600 mi² target area above Pine Flat Dam. The runoff from the target basin has been compared with runoff predicted from a multiple regression equation depending on the runoff from two control basins. Overall, the runoff during the 17 years of seeding has been about 6% greater than was predicted by the regression equation.*
13. Weather and Climate Modification, Problems and Progress, Committee on Atmospheric Sciences, National Research Council, National Academy of Sciences, Washington DC, 1973. *Cumulus clouds over some of the high mountain watersheds of the Sierra Range in California were seeded during the summers of 1966, 1967 and 1968. The purposes of the program were to establish whether precipitation could be initiated and increased, whether runoff from the watersheds could be increased and identified, and to develop engineering concepts for use in summer cloud-seeding operations. Linear regression equations were devised for predicting target-basin*

runoff knowing the runoff from the four control basins. The actual average runoff for the test cases was 55.7 A.F./sq.mi. compared with a predicted average runoff of 25.8 A.F./sq.mi. For all cases, the application of statistical methods yielded a significance level of 0.005.

14. Weather and Climate Modification, Edited by W. N. Hess, National Oceanic and Atmospheric Administration, Environmental Research Laboratories, John Wiley and Sons, New York, 1974. *A cloud seeding experiment was started in Tasmania in 1964. It was intended to investigate the effects of seeding clouds with silver iodide smoke release from an aircraft on rainfall over a designated area. The first stage of this experiment took place in the four operational years 1964, 1966, 1968 and 1970. The preliminary result was that the rainfall on the target areas was increased by seeding during the autumn and winter, the effect being estimated as 15% to 20% at a satisfactory significance level. The value of this increase is much more than enough to justify the cost of the program.*
15. Weather - Climate Modification, Wendell Mordy, Reviews of Geophysics and Space Physics, Vol. 13, No. 3, July 1975, National Hail Research Experiment. *The project is now in its fourth season. Remarkable progress has been made in depicting the three-dimensional patterns of air flow and hail formation in hail storms, with the combined use of dual-Doppler radar, dual-frequency radar, and color digital computer displays. When this process is perfected, it will provide information which will serve at least two purposes: to show direct physical evidence of the effects of seeding storms and to provide theoreticians with improved information about the phenomena which must be explained by their models."*
16. The Management of Weather Resources. Proposals for a National Policy and Program. Report to the Secretary of Commerce from the Weather Modification Advisory Board, 1978. *All operational cloud seeding projects should have on-site real-time monitoring of meteorological phenomena necessary to recognize seedable opportunities and to recognize severe weather events in sufficient time to avoid contributing to natural calamities. Such devices as meteorological radars or telemetered raingauge networks must be included in the design of precipitation or storm modification projects.*
17. The Israeli Rainfall Enhancement Experiment - a Physical Overview, Dr. Abe Gagin, Head, IREE, Journal of Weather Modification, Vol. 13, No. 1, Fresno, California, April 1981. *The earlier overall results of Experiment I, namely those indicating rainfall increases of the order of 15%, significant at the 2% level, have been confirmed in Experiment II, that is, a 13% increase at a 2.8% significance level.*
18. Weather Modification in Southeast Asia, 1966-1972, E. M. Frisby, The Journal of Weather Modification, Vol. 14, No. 1, Fresno, California, April 1982. *On 9 November 1966, the Commander-in-Chief (CINCPAC) reported that the test was completed. In 56 seedings, 85% of the clouds operated upon had reacted favorably and CINCPAC concluded that "cloud seeding to produce additional rain over*

infiltration routes in Laos could be used as a valuable tactical weapon" (Congress 1974). Since documentation of the Popeye Experiment had been adequate and results sufficiently positive, operations conducted on similar lines could be expected to produce similar results. The actual cloud seeding operation, affecting parts of Laos, North Vietnam, South Vietnam and Cambodia began on 20 May 1967 and continued through the appropriate months of each year (March-November) until 5 July 1972.

19. The 1984-85 National Hail Suppression Program in Greece, A statistical analysis of the randomized exploratory experiment's hailpad network, John A. Flueck, Boulder, Colorado, Report prepared for the Greek National Agricultural Insurance Institute, 31 December 1985. *The visual and algebraic treatment effect results are suggestive of a reduction of hail "activity" due to treatment. The principal reductions are indicated to be in the number of hailstones, the maximum size, and the density of the hailswath. In general, these three characteristics are reduced by about 75%.*
20. Precipitation Enhancement - A Scientific Challenge, Edited by Roscoe Braham, Jr., Meteorological Monograph Vol. 21, No. 43, Published by the American Meteorological Society, December 1986. *The number of commercial cloud seeding operations greatly exceeds the number of research experiments. Typically, these operations were of short duration, had very limited measurement components and lacked randomization. Generally speaking, the results from individual commercial seeding operations could not be rigorously established. A few commercial operations, however, were repeated using the same methods and location over several consecutive seasons, thus contributing to a growing body of experiences. These experiences have led some scientists to believe that, under appropriate conditions, cloud seeding will produce useful effects.*
21. The Bridger Range, Montana, 1986-1987 Snowpack Augmentation Program, James A. Heimbeck and Arlin B. Super. Journal of Weather Modification, April 1988. *A winter orographic snowpack augmentation program was conducted for the benefit of a ski resort near Bozeman, Montana during the winter of 1986-87. Target-control analysis of snow course data suggested 35% to 50% additional seasonal snowpack within the target.*
22. Weather Modification Paradoxes, Joanne Simpson, C.C.M., AMS Symposium on Planned and Inadvertent Weather Modification, Atlanta, Georgia, 5-10 January 1992. *Possibly the greatest paradox about weather modification is the immense cost and labor in demonstrating that a hypothesis will work, compared to the very modest operational costs of a seeding program.*
23. Analysis of Precipitation During Hail Suppression in Mancheng, Wang Yu Zeng, Wang Wenyue, and Yu Qing, Chinese Academy of meteorological Science, Beijing, China, Sixth WMO Conference on Weather Modification, Paestum, Italy, 30 May - 4 June 1994. *Hail suppression for five years has been conducted in Mancheng during which a statistical regression analysis was applied to the effect of the program on*

rainfall. The results suggest increases in rainfall of 7.3% to 9.8% within the affected area.

24. **An Evaluation Trial of the Morocco's "ALGHAIT" Weather Modification Program**, Omar Baddour, Mohamed Benassi, and Abdel-Aziz Ouldbba, Program ALGHAIT, the National Center for Climate and Meteorological Research, Casablanca, Morocco. Sixth WMO Conference on Weather Modification, Pestum, Italy. 30 May - 4 June 1994. *The statistical evaluation which is presented herein is based on the simple statistical tools of double ration and linear regression. These analyses show a streamflow increase of 14% to 17% in the target area reservoir during the 1986-1991 seeding period.*
25. **California Cloud Seeding and Idaho Precipitation**, J. G. MacCracken and J. O'Laughlin, University of Idaho, Moscow, Idaho 83844-1134. *Journal of Weather Modification*, Vol. 28, No. 1, April 1996. *It does not appear from our review of available research and discussions with experts that cloud seeding in California has any effect, negative or positive, on precipitation in Idaho.*