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An Independent Statistical Evaluation of the Vail Operational Cloud Seeding Program

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Abstract: An independent target-control statistical evaluation of the Vail operational cloud seeding program over its period of operations from 1977 to 2005 was conducted using ration statistics and, in particular, the bias-adjusted regression ratio. The water year (October-September) streamflow expressed in Acre-Feet (AF) served as the response variable in the evaluations. The effect of seeding on eight (8), closely-spaced sub-basins in the Vail watershed was evaluated using the controls that give the most precise evaluation results possible with the available data. Evidence for statistically significant seeding effects ranging from +6.3% to 28.8% was found for 5 of the 8 seeding targets. The maximum seeding effect is centered on Bighorn Creek (GBH) and decreases for targets both northwest and southeast of GBH. An analysis of the time evolution of the seeding effect suggests that the percent change in streamflow at each of the target sub-basins was about the same from water year to water year.

An Evaluation of the San Joaquin Operational Cloud Seeding Program Using Monte Carlo Permutation Statistics

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Abstract: An independent target-control statistical evaluation of the Southern California Edison (SCE) Upper San Joaquin River Basin Weather Modification Program, also known as the Big Creek Cloud Seeding Project, was conducted using Monte Carlo permutation statistics. The cumulative effect of seeding over the entire history of the project through water year 2006 was calculated in terms of confidence intervals because they provide information on the strength of the seeding effect and, thereby, allows informed judgments to be made about its cost-effectiveness and societal value. The effect of seeding on several targets in the Upper San Joaquin River Basin was evaluated using the control(s) that gives the most precise evaluation results possible with the available data. Evidence for positive, statistically significant and cost-effective increases in stream flow after 56 years of seeding was found for Mono Creek and Pitman Creek, but the results for Bear Creek were not statistically significant. Physical studies that help explain the statistical results and that cloud lead to more cost-effective seeding operations are suggested.

30+ Winter Seasons of Operational Cloud Seeding in Utah

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Abstract: North American Weather Consultants (NAWC) has conducted operational winter cloud seeding programs in many of the mountainous areas of Utah since 1974. The goal of these programs has been to enhance winter snowpack accumulation in several mountainous target areas throughout the State. Studies have demonstrated that a large majority of the annual runoff in Utah streams and rivers is derived from melting snowpack, which explains the focus on wintertime seeding. Augmented water supplies are typically used for irrigated agriculture or municipal water supplies. Programs and typically funded at the county level with cost-sharing grants from the Utah Division of Water Resources.

Cloud seeding accomplished using networks of ground-based, manually operated silver iodide generators located in valley or foothill locations upwind of the intended target mountain barriers. As such, these programs are classified as orographic winter cloud seeding programs. Orographic winter cloud seeding programs are typically categorized as those with the highest level of scientific support based upon capability statements of such organizations as the American Meteorological Society, the World Meteorological Organization, and the Weather Modification Association.

NAWC historical target/control evaluations of these Utah programs based upon high elevation precipitation and snow water content observations indicated a range of apparent increases in target area average precipitation or April 1st snow water content of 3-21%.

The Utah Division of Water Resources conducted an independent assessment of the

seeding programs in 2000. That assessment confirmed that NAWC indicated increases in snow water content, and then took the additional step of estimating the increases in annual streamflow resulting from the estimated increases in snow water content. Average annual increases from four seeded areas were estimated to total 249,000 acre-feet. Factoring in the cost of conducting these programs resulted in an estimate of the average cost of the augmented runoff to be $1.02 per acre-foot.

Six Hourly Analyses of the Bridger Range Randomized Winter Orographic Cloud Seeding Experiment

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Abstract: The Bridger Range winter orographic cloud seeding experiment was conducted during the early 1970's. Published post hoc exploratory statistical analyses used 24 h experimental units. However, 6 h precipitation observations exist which have not been previously tested with non-parametric statistics. They should be better represented by available 6 h partitioning data. This experiment produced high quality precipitation data and was one of few with associated physical studies adding credibility to statistical suggestions. Use of control gauge data substantially reduces natural variance in target precipitation. Two independent statistical approaches were applied to the 6 h dataset. Results strongly suggest that seeding was effective when conditions were conducive to orographic cloud formation with near crestline temperatures sufficiently cold for adequate nucleation with silver iodide. Specifically, the null hypothesis (seeding had no effect) was rejected with one-tailed P-values near 0.001 for the single partition of seeded zone temperatures less than the median. That subpopulation was further reduced by about 50% with the requirement of rawinsonde observations, launched only when clouds existed near or below crestline elevations. Similar very low P-values resulted from this dual partition with much reduced sample size, and for an even smaller population with 700 mb dew point depressions less than their median values. These results are physically reasonable. Partitioning by cloud-top temperatures and cloud thickness suggested that seeding cloud be effective even when thick clouds with cold tops were present. It is stressed that these results are based on post hoc exploratory analyses so they can only be viewed as suggestive and not conclusive proof. Suggestions are given for future randomized winter orographic experimentation.

Evaluation Plan for a Snow Enhancement Experiment in Australia

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Abstract: A comprehensive suite of tests is developed to evaluate the Snowy Precipitation Enhancement Research Project, a cloud seeding project in south eastern Australia aimed at increasing snow fall. The project will use both physical and chemical observations for its primary evaluation. An analysis of historical data shows that there is an 80% chance that more than 100 five-hour experimental units will occur over the five-year duration of the project. Moreover, although there is a significant amount of natural variability in the properties of experimental units, it is approached to treat all experimental units as members of one class of event. A bootstrap analysis of the historical data shows that there is about a 75% chance that a 20% increase in precipitation will be detected at the 10% significance level. On the basis of bootstrap analysis, the primary analysis for the project is taken to be the identification of a positive seeding impact at the 10% significance level in the primary target area, together with snow chemistry results showing at the 5% significance level that ice nuclei have been activated in the primary target area. A number of secondary analyses are identified to support the results of the primary analysis.

An Assessment of the Environmental Toxicity of Silver Iodide - With Reference to a Cloud Seeding Trial in the Snowy Mountains of Australia

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Abstract: The objectives of the Snowy Precipitation Enhancement Research Project are to determine the technical, economic and environmental feasibility of augmenting snowfalls in the Snowy Mountains region of New South Wales. The project commenced during 2004, following proclamation of special enabling legislation, the *Snowy Mountains Cloud Seeding Trial Act of 2004* (NSW). Amongst other things, the legislation prescribed a target area of approximately 1000 square kilometers (mostly within the Kosciuszko National Park), and scheduled completion date of 2009. The legislation also mandated the use of silver iodide as the seeding agent. The *Snowy Mountains Cloud Seeding Trial Act of 2004* (NSW) was amended in May 2008, expanding the size of the target area to around 2150 square kilometers, and authorising the continuation of cloud seeding activities until April 2015. An extensive review of the literature was undertaken prior to commencement of the project to determine if the use of the silver iodide (AgI) seeding agent would have a adverse impact on the environment. Although silver ions from water-soluble silver salts have been shown to be toxic to aquatic species, this is not the case for the insoluble silver iodide. Many studies have shown that the toxicity of silver ion in water is significantly ameliorated by the presence in water of chloride ion, carbonate ion, sulfide ion and dissolved organic carbon. In addition, silver has been shown to strongly adsorb onto particulate matter in water. Recent research has show that silver ion concentrations in natural waters are negligibly small, and an investigation in the study area has confirmed many of these ameliorating factors to be present. Consequently the

bioavailability of silver is unlikely to change from the current background levels. Extensive investigations undertaken prior to the commencement of the project confirmed background levels of silver, and the presence of many ameliorating factors know to limit toxicity of the silver ion. An analysis of ecotoxicity monitoring data collected over the first four years of the SPERP has shown that the monitoring program has sufficient power to detect any adverse trend in silver concentration well before a level of environmental concern is reached. The SPERP monitoring results to date have all shown mean concentrations of total silver to be well below any level of concern, and we consider the risk of an adverse ecotoxicological impact resulting from the use of silver iodide fro this project to be negligibly small.

An 'Aerosol Effect' Detected in Winter Orographic Clouds but an Effect on Precipitation Could Not be Determined

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Abstract: Analyses of 22-year record (1984/85 - 2005/06) of wintertime (December - February) measurements at Storm Peak Laboratory (SPL) in the northern Colorado Rocky Mountains have shown aerosol particle concentrations were directly related to cloud droplet concentrations, the droplet concentrations were inversely related to mean diameters and the mean diameters were not related to the precipitation rates. A direct relationship between mean diameters and precipitation rates was expected due to the snow crystal riming; the measurements were too variable to establish a relationship. Additionally, no significant trends in precipitation rate and snowfall water content were detected; at least a 40-year record is required. Nevertheless, the record defines average wintertime cloud and precipitation properties at SPL.

Seeding Optimization for Hail Prevention with Ground Generators

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Abstract: An evaluation method of hail prevention by silver iodide ground seeding generators is developed. The method is based on correlations between the point hailfall intensities measured with hailpads and the silver iodide released prior to the hailfalls in the "feeding areas" where the hail cells developed. The time unit for the correlations is the day, but days can be aggregated together after data normalization. Former evaluations have shown that the number of hailstones larger than 0.7 cm is mainly responsive to the amount of seeding material released in a 13-km radius area centered on the place where the storm was developing 80 min before the hailfall, and that the seeding effect can be detected only for the days with at least 15 hailpads.

In this paper, the method is applied to 24 major hail days with seeding recorded in the past 20 years in a hailed region north of the Pyrenees. For each day, 15 to 42 point hailfalls have been recorded, and they are used to compute the best negative daily correlation between hailfall intensity and seeding amount by moving the feeding area around its first approximate position. With this seeding area optimization, all the daily correlations are negative (more seeding, less hail), but they are weak, with a correlation coefficient reaching about about r=-0.3 in only half of the cases. For the whole hailfall sample (561 hailfalls), the correlation computed with the ideal feeding areas determined as indicated above is r = -0.22, significant at the 0.01 level, subject to the data independency hypothesis. In average, the distance from the middle of the feeding area to the hailfall corresponds to a storm travel time of 66 min, but a numerical simulation of the seeding particle trajectories with the Meso-NH model suggests that the generators must be started at least 45 min before the storm travels above them.

An Atmospheric Thermodynamic Model of The Convective Storm Process Types in Mendoza (Argentinta)

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Abstract: The DCPIM (Deep Convection Process Identification Model) index uses only surface meteorology data to forecast the convective storm class of Mendoza (Argeninta). The DCPIM model did not guess right the forecast in about five percent of the studies cases. Then in order to improve the forecast model, we are adding vertical atmospheric information at the index calculation using the radiosonde on Santiago (Chile) and El Plumerillo (Mendoza). This index is calculated by correlating four surface variables: pressure P_s (mb), temperature T_s (°C), dewpoint DP_s (°C) and ground ultraviolet solar radiation index UV. Furthermore, two additional atmospheric variables at the 500 mb level were considered: temperature T_{500} in °C, and dew point DP_{500} in °C at the 500 mb pressure level. The data was taken from radiosonde over Mendoza and Santiago (Chile). We collected 1551 samples, between September 2007 and April 2008. These data were statistically processed, obtaining a multivariate model for each storm convective process class (TPC) in Mendoza. From this correlation, we can observe that the class and severity of the storm convective process do not depend on the dew point at the 500 mb level (DP_{500}), but depend on surface dew point value. This is associated with the fact that the vertical ascendant movement of the circulation air feeds the storm process carrying the water vapor from the ground to upper levels. Moreover,

the class and severity of the convective process depends on the vertical temperatures difference between both levels T_s and T_{500}, and is associated with the heat flux transfer by thermal conductivity and natural convection. We conclude from the above result, that for higher values of the temperature difference and surface dew point, a more complex and severe storm convective process in Mendoza is expected. The thermodynamic calculations performed by the multivariate model were consistently compared with GOES satellite image, the C and S band radar, and its TITAN system.