The Use of Ice Detectors in Assessing the Presence of Supercooled Liquid Water for Winter Seeding

David Yorty, Stephanie Beall, and Mark Solak

North American Weather Consultants, Inc.

Icing rate meters have been utilized in Utah and Colorado to infer the presence of supercooled liquid water in support of cloud seeding programs. They have been situated on a ridge top or summit between about 9,000 and 12,000 feet MSL. These sensors provide point measurements of riming occurrence, usually paired with other meteorological data at the site including winds, temperatures, and precipitation. Some of the currently existing sites in Utah have provided as much as seven seasons of data (as of 2016) which has been analyzed in a meteorological context. Icing occurrence has been examined regarding synoptic weather patterns, precipitation, temperatures, site winds, seasonality, and associated low-level thermodynamic stability.

Sierra Nevada Winter Storm 700 hPa Temperature Trends and Implications for the Future of High Elevation Ground-Based Cloud Seeding with Silver Iodide

Kacie N. Shourd; Desert Research Institute and University of Nevada, Reno Frank McDonough; Desert Research Institute

Climate models for a whole range of global emissions scenarios indicate noticeable changes in temperatures and precipitation across the all parts of the globe over the next 75-100 years. Recent studies focusing on the Sierra Nevada specifically have demonstrated that climate change will impact the Sierras with increasing temperatures and increased winter precipitation, however much more of the wintertime precipitation is expected to fall as rain versus snow by the end of the 21st century. This will ultimately lead to a decrease in annual snowpack and, consequently, April 1 snow water equivalent (SWE) and seasonal/annual average streamflow. These changes will have a direct impact on California/Nevada water supply, hydroelectric power generation, and the ecosystem as a whole. With an expected decrease in annual snow accumulation in the Sierra Nevada, cloud seeding to increase potential snowpack could become an even more important tool for water resource management. The increase in average temperatures will increase the average altitude of the -5°C isotherm, an important indicator of potential silver iodide (AgI) seeding conditions. Using historic SNOTEL precipitation data, rawinsonde temperature profiles, and other available weather station data, this study examines trends in the -5°C isotherm height during wintertime precipitation events over the last 30+ years. Are storms trending warmer as suggested by a number of studies, or just the average temperature? If storm temperatures are in fact warming, how significantly, and what are the implications of these changes on the future of high-elevation ground based cloud seeding? This study aims to answer these questions and others regarding past and predicted future trends in winter storm temperatures and the continued effectiveness of ground based generators for cloud seeding.

Winter Cloud Seeding Operations over the Cachapoal River Basin in Chile:

Summary and Preliminary Evaluations

Robert Hilliard Zarella Bustamante Rodrigo Pérez Arquimedes Ruiz-Columbié

Cachapoal River Oversight Board, Chile Texas Tech University

Winter cloud seeding operations for snow augmentation over the Cachapoal River Basin in Chile have been done since 2000 using automatic ground-based silver iodide generators located in locations upwind of the target area. For that seeding period, a target/control evaluation was used to estimate possible increases in precipitation over the target area versus the control area by comparing streamflow values of the Cachapoal River (target), and the Maipo and Tinguiririca Rivers (controls). Different statistical tests indicated the presence of modification signals associated with positive increases in a range between 6 and 10 % presumably due to the seeding operations. Such signals show the existence of modifiable cloud resources, and also suggest that more intense operations may lead to even stronger increases.

Supercooled Liquid Water Observations within Storms over the Sierra Nevada Mountains

Frank McDonough, Desert Research Institute

The presence of clouds containing supercooled liquid water (SLW) is required for successful glaciogenic cloud seeding. Observing time periods when SLW is part of the cloud microstructure is a difficult task, since no operational observational networks routinely and directly measure this field. Novel, low-cost, approaches can be used by cloud seeding operators to directly observe time periods when SLW is present. These include using mountain top webcams to directly observe riming on structures, using icing reported by air traffic, and using rimed ice crystal morphology observations.

In this talk the novel SLW observing methods are used to identify time periods during the winter 2015-2016 (WY2016) when SLW was present in storms over the Lake Tahoe area of the Sierra Nevada. These time periods are then compared to other remote sensing and observational data sets such as; cloud top properties from the GOES imager; reflectivity from the closest NEXRAD radars; precipitation and temperatures from surface observations. Finally the cloud seeding methodology for a case study from the Desert Research Institute's cloud seeding program in the Lake Tahoe-Truckee Basin from WY2016 is evaluated using the in-situ observations, remote sensing data, and numerical model output.

Investigating the Feasibility of Cloud Seeding in the Bighorn Mountains

Sarah Tessendorf, National Center for Atmospheric Research

A study was conducted to assess the feasibility of an operational weather modification program targeting the Bighorn Mountains in Wyoming. The primary goal of the program would be to augment water in the adjacent river basins. The study included a variety of tasks, including: climatological analysis of the project area; development of a project design; model evaluation of the project design; field surveys of potential ground generator locations; and cost and potential streamflow benefits analysis. This paper focuses on the climatological analysis performed in this study to highlight how to identify the potential for cloud seeding over a given mountain range and use the results to design a cloud seeding program. The climatological analysis utilized output from a multi-year high-resolution model simulation to determine the average frequency of seeding opportunities in the region. Based on the results of the climatological analysis, preliminary project designs were developed and their effectiveness was tested using the Weather Research and Forecasting (WRF) model with a cloud seeding parameterization. Results of the climatological analysis of cloud seeding potential, along with how the results informed the cloud seeding program design, will be presented for the Bighorn Mountains.

Aerosols 102

Tom DeFelice, ASCE/EWRI AWM SC

This talk expands upon the overview of aerosol characteristics, their role in the efficiency of the hydrologic cycle and potential effect on environment (Aerosols 101). It begins with a quick summary of Aerosol 101 main points. Then, provides an overview of aerosol-cloud interactions, of new aerosol technologies/techniques, and challenges to obtain measurements at temporal/spatial frequencies to adequately reproduce the aerosol-cloud interactions throughout a seeding event.

Title: Setup of the Pi Cloud Chamber for Cloud Seeding Flare Testing

Authors: David Delene[1], Alexa Otto[1], and Bruce Boe[2]

[1]Department of Atmospheric Sciences, University of North Dakota

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Abstract: The Pi Cloud Chamber at Michigan Technological University will be used to test Silver Iodide (AgI) cloud seeding flares. Before the first experiments can be conducted, preliminary work is required to define cloud conditions for the simulates and cleaning methods for the chamber. To ensure there is no contamination present after conclusion of the flare testing experiments, it is important to thoroughly clean the chamber walls with the appropriate solvents. The Pi Cloud Chamber is equipped with a large door that provides easy access for cleaning. To avoid contamination and simulate aircraft based cloud seeding, a flare burning and dilution system is required. The system needs to enable burning of flares within a laboratory environment, reproduce the air flow over flares at aircraft speeds, and provide particle concentrations similar to actual seeding conditions. A safety office approved system has been built that uses a 3 inch diameter metal tube to house the burning AgI flare with air flow supplied by two large blowers. Multiple

sampling ports down stream of the burning flare enables measurements of aerosol size distribution from the seeding plume as it is diluted and cooled. Temperature conditions for the flare testing experiments range from 0 to -20 ^{0}C, with a focus on the -4 to -12 ^{0}C range. A high (1.0 g/m^3) and low (0.5 g/m^3) cloud liquid water content (LWC) will be tested. At each LWC, a high and low cloud droplet concentration / mean diameter pair will be simulated. The simulated pair values are determined using cloud microphysical observations obtained during weather modification projects in Mali, Saudi Arabia, and Wyoming. Mali, West Africa is a low aerosol concentration location that has cloud droplet concentrations of 140 cm^{-3} and 19.6 um diameters when the LWC is between 0.45 and 0.55 g/m^3. In contrast, Saudi Arabia is a high aerosol concentration location that has cloud droplet concentrations of 220 cm^{-3} and 15.6 um diameters when the LWC is between 0.45 and 0.55 g/m^3. Future work includes experiments where AgI particles are inject at realistic concentration into the Pi Cloud Chamber which is setup to simulate prescribed cloud conditions.

Technology Innovations Wx Mod – XVII

Tom DeFelice, ASCE/EWRI AWM SC

(Technological advances and applications to weather modification—as an introductory talk to the others that will hopefully be submitted for this area.) Presenter: Tom DeFelice, ASCE/EWRI AWM SC Abstract: Our continuing series focused on highlighting newer technologies and techniques that might have an application to weather modification operations. The development and ultimate application of these technologies could improve forecasts, evaluation, and confidence that these technologies and techniques might help us resolve relevant socio-economic issues. This presentation digs deeper into the use of unmanned systems to carry out cloud seeding operations and evaluations. How the onboard information and other information might be used to support autonomous flight and decision support aid during flight.

Prototype methodology for obtaining cloud seeding guidance from HRRR model data

Nicholas Dawson, D.B., M.K., B.W., and J.C.

Weather model data, along with real time observations, are critical to determine whether atmospheric conditions are prime for super-cooled liquid water during cloud seeding operations. Cloud seeding groups can either use operational forecast models, or run their own model on a computer cluster. A custom weather model provides the most flexibility, but is also expensive. For programs with smaller budgets, openly-available operational forecasting models are the de facto method for obtaining forecast data. The new High-Resolution Rapid Refresh (HRRR) model (3 x 3 km grid size), developed by the Earth System Research Laboratory (ESRL), provides hourly model runs with 18 forecast hours per run. While the model cannot be fine-tuned for a specific area or edited to provide cloud-seeding-specific output, model output is openly available on a near-real-time basis. This presentation focuses on a prototype methodology for using HRRR model data to create maps which aid in near-real-time cloud seeding decision making. The R programming language is utilized to run a script on a Windows® desktop/laptop computer either on a schedule (such as every half hour) or manually. The latest HRRR model run is downloaded from NOAA's Operational Model Archive and Distribution System (NOMADS). A GRIB-filter service, provided by NOMADS, is used to obtain surface and mandatory pressure level data for a subset domain which greatly cuts down on the amount of data transfer. Then, a set of criteria, identified by the Idaho Power Atmospheric Science Group, is used to create guidance maps. These criteria include atmospheric stability (lapse rates), dew point depression, air temperature, and wet bulb temperature. The maps highlight potential areas where super-cooled liquid water may exist, reasons as to why cloud seeding should not be attempted, and wind speed at flight level.

Title: Calibration Uncertainties in the Droplet Measurement Technologies Cloud Condensation Nuclei Counter

Author: Kurt Hibert[1] and David Delene[1]

[1]Department of Atmospheric Sciences, University of North Dakota

Abstract: Cloud condensation nuclei (CCN) serve as the nucleation sites for condensation of water vapor in Earth's atmosphere. CCN are important for their affect on global climate and weather. The influence of CCN on cloud radiative properties is important since the aerosol indirect effect is the most uncertain of quantified radiative forcing changes since pre-industrial times. The influence of CCN on weather is studied since intrinsic and extrinsic aerosol properties affect cloud formation and precipitation. To quantify these effects, it is necessary to accurately measure CCN in the atmosphere, which requires accurate calibrations using a consistent methodology. However, an understanding of the calibration uncertainties is necessary when combining measurements from different field projects. Knowledge of the uncertainties aids in integration of CCN measurements from different instruments into modeling and model/observational comparisons. Since many groups make CCN measurements with the commercially available Droplet Measurement Technologies CCN Counter, it is important to quantify its calibration uncertainty.

The concentration calibration of the DMT CCN counter depends on the accuracy of the flow rate calibration, which does not have a large uncertainty. The supersaturation calibration depends on chamber pressure and is a complex process since the chamber's supersaturation must be inferred from a temperature difference measurement. Large calibration errors can result from the Kohler theory calculations, fitting methods utilized, and the influence of multiply charged particles. In order to investigate the calibration uncertainties and the pressure dependence of the supersaturation calibration, three calibrations are done at each pressure level: 700, 840, and 980 mb. Typically 700 mb is the pressure used for aircraft measurements in the boundary layer, 840 mb is the calibration pressure at DMT in Boulder, CO, and 980 mb is the average surface pressure at Grand Forks, ND. The relative error of each set of three calibrations for each pressure level is

used as the uncertainty for those calibrations and the pressure dependence is calculated from the difference in calculated supersaturation percentage at a given temperature gradient. In addition, comparisons are made between calibrations performed at the University of North Dakota (UND) and calibrations performed at DMT.

A supersaturation calibration uncertainty of 2.3, 3.1, and 4.4 % has been found for calibrations done at 700, 840, and 980 mb respectively. The supersaturation calibration change with pressure is found to be on average 0.047 % supersaturation per 100 mb. The supersaturation calibrations done at UND are 42-45 % lower than supersaturation calibrations done at DMT approximately 1 year previously. Performance checks confirmed that all major leaks developed during shipping were fixed before conducting the supersaturation calibrations. Multiply charged particles getting through the Electrostatic Classifier can influence DMT's activation curves which could be a large part of the supersaturation calibration difference. Furthermore, the fitting method used to calculate the activation size is a significant source of error in DMT's supersaturation calibration. While the DMT CCN counter’s calibration uncertainties are relatively small, and pressure dependence is easily accounted for, the calibration methodology used by different groups can be very important. The insights gained from the careful calibration of the DMT CCN counter indicate that calibration of scientific instruments using complex methodology is not trivial.

An Airborne Narrow-Beam Side-Scanning G-Band Radiometer

R. Stone1, E. Fisher1, J. Henrie2, K. Reed3,4, L. Sankey2 and R. Ware3,4

1RHS Consulting, Ltd. (Sparks, NV) 2First RF Corp., 3Radiometrics Corp., 4NCAR (Boulder, CO)

A narrow-beam side-scanning radiometer was installed in a cloud seeding aircraft to develop supercooled liquid water detection and avoidance capability. The multifrequency instrument operates between 170-183 GHz allowing detection of liquid and vapor at variable ranges up to 50 km. The radiometer scans vertically from -15° to 45° above and below the horizon with a port side field of view. Complimentary instrumentation installed on the aircraft includes a cloud droplet probe and hot wire liquid and temperature sensors making the aircraft a unique cloud liquid measurement platform.

Three critical issues determine the potential for success of a cloud seeding program. These include opportunity recognition, accurate delivery of seeding materials and evaluation of the results. Area-wide real-time detection and location of supercooled liquid water is critical for the detection of seeding opportunities and optimization of seeding effects. Applied to winter seeding vertical scanning allows rapid detection of the top of the supercooled cloud layer. Potential changes in liquid up and downwind of a seed track offer the chance to observe microphysical seeding effects from a unique perspective. No longer will airborne liquid measurements be restricted to thin ribbons of the sky that an aircraft has passed.

The current combination of airborne sensors offers the potential for making major advances in the effectiveness of cloud seeding programs and how they are operated. Two other broad applications this airborne platform can address include icing detection and avoidance as they relate to aircraft flight safety and weather forecast model validation.

This presentation will provide an overview of the aircraft, sensors and preliminary results from initial testing as they relate to proof of concept.

WMI Modeling Update: Utilization of 3km WRF and HYSPLIT for Wintertime Project Forecasting

Adam Brainard and Dan Gilbert

Weather Modification International (WMI) conducts wintertime cloud seeding in multiple states across the Western US. These projects include the Wind River Mountains of western Wyoming and several watersheds in the central Sierra Nevada Mountains of California. In an effort to improve forecasting of suitable seeding conditions for these projects, WMI is pursuing the use of high resolution forecasting models to provide project-specific products. These models include a 3km Weather Research and Forecasting Model (WRF) and the NOAA Air Resource Laboratory HYSPLIT model. Products derived from the WRF output are designed exclusively with cloud seeding operations in mind, and they provide unique targeted guidance to project meteorologists, pilots, and clients. HYSPLIT is being used primarily for plume trajectory modeling in Wyoming where ground based seeding is conducted. This presentation outlines the framework of numerical weather prediction activities being developed at WMI, and illustrates a sample of the model products designed to support cloud seeding operations.

Summary of the performance of the NCAR Wintertime AgI Seeding Case-calling Algorithm: 2012 to 2017

Lulin Xue[1], Sarah Tessendorf[1], Roy Rasmussen[1], Pat Holbrook[2,3], Derek Blestrud[3], Mel Kunkel[3], and Shaun Parkinson[3]

[1] National Center for Atmospheric Research, Boulder, CO

[2] Palo Verde High Magnet School, Tucson, AZ

[3] Idaho Power Company, Boise, ID

The National Center for Atmospheric Research (NCAR) started to develop a real-time cloud seeding modeling capability for Idaho Power Company (IPC) beginning in 2010. A real-time cloud seeding forecast system based on the Wintertime AgI Seeding Parameterization coupled with the Thompson microphysics scheme within the Weather Research and Forecasting (WRF) model has been developed during the last 5 years. The real-time cloud seeding forecast system has three components: 1) a "control" (no seeding is simulated) forecast is run that forecasts the weather conditions over the next 48 hours, 2) a case-calling algorithm is run that automatically identifies opportunities for cloud seeding using the control forecast model output, and 3) a cloud seeding forecast simulation is then run that simulates seeding at times, basins, and methods as identified by the case-calling algorithm. The results of the case-calling algorithm can be utilized by operational IPC forecaster to determine cases to be seeded in the operational program. In addition, the precipitation simulated in the seeding forecast can be compared to the control forecast to estimate the seeding impact from that particular forecast period. Over the last few years, the case-calling algorithm has gone through a series of modifications to improve its performance in terms of identifying the best seeding cases based on the weather forecast.

This work summarizes the development history and rationale for which changes were implemented in the algorithm. An summary of the performance of the algorithm over the seasons is provided. A new algorithm incorporating fuzzy logic methods is under development and some preliminary comparisons between the original and this new version of the algorithm are presented as well.

WRF Model Case Studies of Cloud Seeding over the Bighorn Mountains in Wyoming

Roy Rasmussen, National Center for Atmospheric Research

Lulin Xue and Sarah Tessendorf, NCAR

The Wyoming Water Development Commission funded NCAR to perform an evaluation of the potential for cloud seeding over the Bighorn Mountains in north-central Wyoming. Part of this evaluation involved model simulations on storm cases identified as having high amounts of supercooled liquid water for an extended period. The modeling was performed using a high resolution version of the Weather Research and Forecast (WRF) model into which we have implemented a cloud seeding module. The seeding module simulates cloud seeding by releasing AgI from ground generators or from aircraft. This study will present the results of this modeling effort to understand the type of storms that are seedable and the relative effectiveness of ground versus airborne seeding.

Evaluating the dispersion of AgI in WRF cloud seeding simulations using silver-in-snow samples collected downwind of the Payette Basin

Lulin Xue[1], James Fisher[2], Shawn Benner[2], Mel Kunkel[3], Derek Blestrud[3], Brandal Glenn[3], Sarah Tessendorf[1], Roy Rasmussen[1], and Shaun Parkinson[3]

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Boise State University scientists collected snow samples in the area downwind of the Payette Basin in the Lost River Range at the end of the 2015-2016 winter season under the support of Idaho Power Company. Nine downwind sites were sampled to analyze the silver (Ag) concentration and the downwind seeding signal associated with cloud seeding operations in Payette. The preliminary results indicated that downwind seeding signals were very weak from Payette ground seeding cases while a few seeding signals were picked up for some airborne seeding cases.

This study presents the comparisons of Ag concentration between snow samples collected in the Lost River Range and Weather Research and Forecasting (WRF) model simulation results using the Wintertime AgI Seeding Parameterization for two scenarios. One scenario contains airborne seeding cases on Jan. 28 and 29, 2016, which resulted in detectable Ag signals in 5 out of 9 downwind sites. The other scenario is a ground seeding case on Feb. 18, 2016, which also showed downwind signals in 4 out of 9 sites. The WRF simulations will be driven by ERA-Interim reanalysis data. Different AgI scavenging parameterizations in the model will be tested to determine which results in the best comparison with the Ag samples. The detailed analysis of the model results and comparisons between model and observations will be presented.

Hygroscopic Seeding in Texas: Building a Conceptual Model and Evaluation of Seeding

Jonathan A. Jennings, *West Texas Weather Modification Association, San Angelo, TX*

Hygroscopic seeding in Texas has been ongoing since 2010. It was decided that hygroscopic seeding could help maximize the efficiency of the warm rain process while working in conjunction with glaciogenic seeding. Therefore, randomized seeding took place in the 2010 season with results suggesting more aggressive hygroscopic seeding take place in 2011. Consequently, hygroscopic seeding became operational in 2011 and has continued to be a large part of convective cloud base seeding in Texas.

Despite the positive results, it was suggested that a more in-depth consideration into hygroscopic seeding take place. A cloud climatology was created to see how clouds differ seasonally and by geography. The results of this cloud climatology showed signs of changes in cloud efficiency both seasonally and by geography. Using this data, Texas now has a new process both pre-flight, and intra-flight, to decide when it is best to utilize hygroscopic seeding. Although there is still much to be learned about hygroscopic seeding, the researchers and operational meteorologist in Texas hope to close the gap on building a connective cloud base conceptual model for hygroscopic seeding and dual seeding alike.

An Overview of the 2016 Rainfall Enhancement Activities in Texas: A More Intensive Use of Hygroscopic Material

Kendell LaRoche, South Texas Weather Modification Association

The Texas Weather Modification Association oversees four rainfall enhancement projects which combined have completed their 21st season in 2016. These projects include the Panhandle Groundwater Conservation District, the South Texas Weather Modification Association, the Trans-Pecos Weather Modification Association, and the West Texas Weather Modification Association. Classic Thunderstorm Identification, Tracking, Analysis and Nowcasting evaluation of seeded and control clouds for each project are analyzed to determine the effect seeding operations had on different cloud variables. Two more recent additions to the analysis package are micro-regionalization, is used to analyze precipitation increases county-by-county within each project, and the effect of hygroscopic flares. Excellent results were achieved during the 2016 season with average precipitation increases of 1.34 inches above seasonal value, and over 2 million acre-feet of addition precipitation from cloud seeding activities. An analysis of hygroscopic seeding continues to show its importance for effective seeding operations. Clouds seeded with both glaciogenic and hygroscopic material lasted longer and produced more precipitation than similar clouds seeded with only glaciogenic material.

Rocketry versus Hail: Comments on the Jujuy Battle in Northern Argentina

Franco Ballari, LATSER, S.A. , Jujuy, Argentina
Arquímedes Ruiz-Columbié, Active Influence & Scientific Management, Texas

For the summer 1997-1998, a hail suppression system was created by LATSER, S.A., in order to protect tobacco plantations in the Jujuy Province of Northern Argentina. Since then, cloud seeding operations for hail mitigation using rockets had been developed every summer. Originally conceived as a direct injection method, rocket explosions allow the dispersal of seeding material near the - 5 °C in relatively high doses. Comparative studies of time series for the provinces of Jujuy (target) and Salta (control) appear to show that the pattern of hail damages over the seeded area has favorable changed since the seeding operations took place. Furthermore, for the 2015-2016 campaign, a cell-based evaluation using TITAN data was used as a quality control tool of the operations. Results of the aforementioned evaluations are presented here as well as details on the design and implementation of those rocket operations.

Targeting the critical window of opportunity during hygroscopic seeding

Roelof Burger, North-West University

North-West University

The rationale behind ongoing cloud seeding projects includes positive results from statistical experiments. While they do not add to the fundamental understanding of the physical mechanisms by which seeding material change cloud and precipitation processes, they do provide justification to ongoing operational and scientific efforts. Statistical evidence about the cumulative effect of many seeding experiments is important to show that rainfall can be enhanced using a specific methodology. Some experiments, like the South Africa Rainfall Enhancement Project, have shown statistically significant differences between seeded and unseeded storms. Many others have failed to collect enough cases to achieve significance. The cost, complexity and time needed for these randomized trials depend on the climate and logistical constraints of the seeding area and frequently exceed the funds available. The hygroscopic seeding model relies on the delivery of the seeding material to the right place and time in the updraft of developing convective storms. Manned aircraft with pyrogenic flares are one of the most trusted methods for this task, but suffer from three constraints. Firstly, the logistics of operating expensive turboprop aircraft from commercial and even military airports add to the difficulty of designing field experiments that can effectively target seedable storms early in their lifetimes. Secondly, challenges in communicating seeding information derived from ground-based radars to pilots in a timely way further decrease the effectiveness of current seeding operations. Thirdly, the pilot has to subjectively choose the seeding area by flying through the updraft zone which further delays the onset of seeding and the overall efficiency of the technology. This paper presents aims to characterize the critical window of opportunity by using weather radar data from two different climate zones. It discusses operational approaches that would help to effectively target the seeding window. Ultimately, this could lead to seeding more storms in a shorter period at a reduced cost.

West Texas Numb3rs Revisited: Looking for long term modification patterns

Arquimedes Ruiz-Columbié — Texas Tech University

Craig Funke, Jonathan Jennings — Texas Weather Modification Association

Since 2001, Texas Weather Modification Programs adopted the so called TITAN evaluation as a tool for operation quality control purposes and, by extension, annual evaluations. Based on radar data, those cell-based evaluations have helped to quantitatively estimate the seeding impacts on

seeded units by comparison with unseeded similar control units. After more than 15 operational years, relative long term rainfall modification patterns appear to be also noticeable when rain gage data in and out the target area are used.

Cloud Seeding Increased Runoff/Cost Analysis in Utah

Ashley Nay and Candice Hasenyager, Utah Division of Water Resources

In 1973 the legislature passed the Utah Cloud Seeding Act, although cloud seeding had originally started in the early 1950's. The current five projects sponsored are the Central & Southern Utah project areas, the Northern Utah project areas, the Western Uintas project area, the High Uintas project area, and the Emery propane project area. Cloud seeding is a viable way to augment the natural water supply and the purpose of this study is to estimate how much of an increase in runoff should be expected and how much it costs per acre-foot of water. Estimates are based on the total average runoff from the seeded areas and the increase in snow water content due to cloud seeding. The increase in the snow water content are then used to determine the relationship between annual runoff and snow water content for major gaged rivers in the target areas. The resulting estimated increase in annual runoff is then used to compute the cost per acre-foot. The cost for the 2014-2015 cloud seeding project is $440,086; the preliminary estimated increase in runoff is 198,549 acre-feet and the resulting cost per acre-foot is $2.11.

Does the 2016 gap in San Joaquin River runoff show Cloud Seeding Works?

Maurie Roos, California Department of Water Resources

The San Joaquin River basin in the southern Sierra has had cloud seeding programs for over 60 years, mostly funded by Southern CA Edison Co. In2016, no funds were available for the project, so seeding stopped. Water year runoff was near normal in the Central Sierra, but fell off progressively to the south to only about 50 percent on the Kern. However, there was an additional dip in San Joaquin River water year runoff. Could the dip of 8 or 9 percent be due to the lack of cloud seeding in WY 2016?

Title: Statistical Analysis of the Polarimetric Cloud Analysis and Seeding Test (POLCAST) Field Projects

Authors: Jamie Ekness[1] and David Delene[1], [1]Department of Atmospheric Sciences, University of North Dakota

Abstract: North Dakota relies heavily on agriculture, as farming is the number one industry of the state bringing in more than $4.1 billion annually in cash receipts. Unfortunately, agriculture sales from crops produced vary significantly from year to year, depending on crop loss due to weather events such as hail storms and droughts. One possible solution to a lack of precipitation is to increase the precipitation efficiency of clouds using hygroscopic seeding. Since the effectiveness of hygroscopic seeding on increasing North Dakota precipitation is unknown, the North Dakota Atmospheric Research Board (NDARB) has supported the Polarimetric Cloud Analysis and Seeding Test (POLCAST) research project. POLCAST field projects that obtained airborne and radar observations were conducted in the summers of 2006, 2008, 2010, and 2012, with randomized seeding conducted in the last three summers. Results show that the cumulative rainfall measured in eastern North Dakota at North Dakota Atmospheric Weather Network (NDAWN) stations during POLCAST years is typical. The POLCAST randomized seeding data set is composed of 44 cases, of which 37 cases are statistically analyzed. The seven cases not included in the statistical analysis are days in which test flights or instrument issues occurred. Results from statistical analysis of environmental factor measurements (cloud base temperature, cloud base pressure altitude, and cloud base cloud condensation nuclei (CCN) concentration) using the Mann-Whitney Test show a similarity between seeded and non-seeded cases in all three POLCAST years. Radar analysis using Thunderstorm Identification Tracking and Nowcasting (TITAN) determines differences in polarimetric observables such as reflectivity, differential reflectivity, and radar derived rain rate between seeded and non-seeded clouds. Statistical analysis of the POLCAST data set indicates a positive seeding effect; however, with a limited number of cases, the results are not statistically significant. To determine the number of cases for different levels of significance, the Bootstrap statistical method is applied to the POLCAST data set. Preliminary analysis of the POLCAST data suggest an indication of a positive seeding effect.

An Assessment of HAILCAST Performance in Western North Dakota

Shawn Wagner, University of North Dakota

Gretchen Mullendore, University of North Dakota; Mariusz Starzec, University of North Dakota

The North Dakota Cloud Modification Project (NDCMP) uses the Weather Research and Forecasting (WRF) model coupled with HAILCAST to help generate their daily summer forecasts. HAILCAST is a one-dimensional hail growth model included in the Air Force Weather Agency's Mesoscale Ensemble Prediction Suite. If HAILCAST is activated, any location within the domain which has a 10 ms-1 updraft for over 15 minutes will have five embryos inserted into the updraft which are allowed to propagate, experience wet and dry growth, melting, breakup, and fallout. The mean and standard deviation of the maximum diameter of the embryos between output times is then calculated. With a proper understanding of HAILCAST's performance, NDCMP will be able to more confidently plan seeding operations in anticipation of hail events. The focus of this research is to assess HAILCAST's ability to correctly predict the occurrence of hail and to identify any biases. WRF with HAILCAST was run operationally from 1 June 2015 to 31 August 2015 for the North Dakota Cloud Modification Project. To evaluate HAILCAST performance, model data is compared to corresponding hourly Level-3 Hydrometeor Classification Algorithm (HCA) data derived from Bismarck, ND radar observations. A binary contingency table is established to determine if a hit, miss, false alarm, or correct negative took place. Results show a strong bias towards forecast misses, and further discussion into the cause of this bias will be presented.