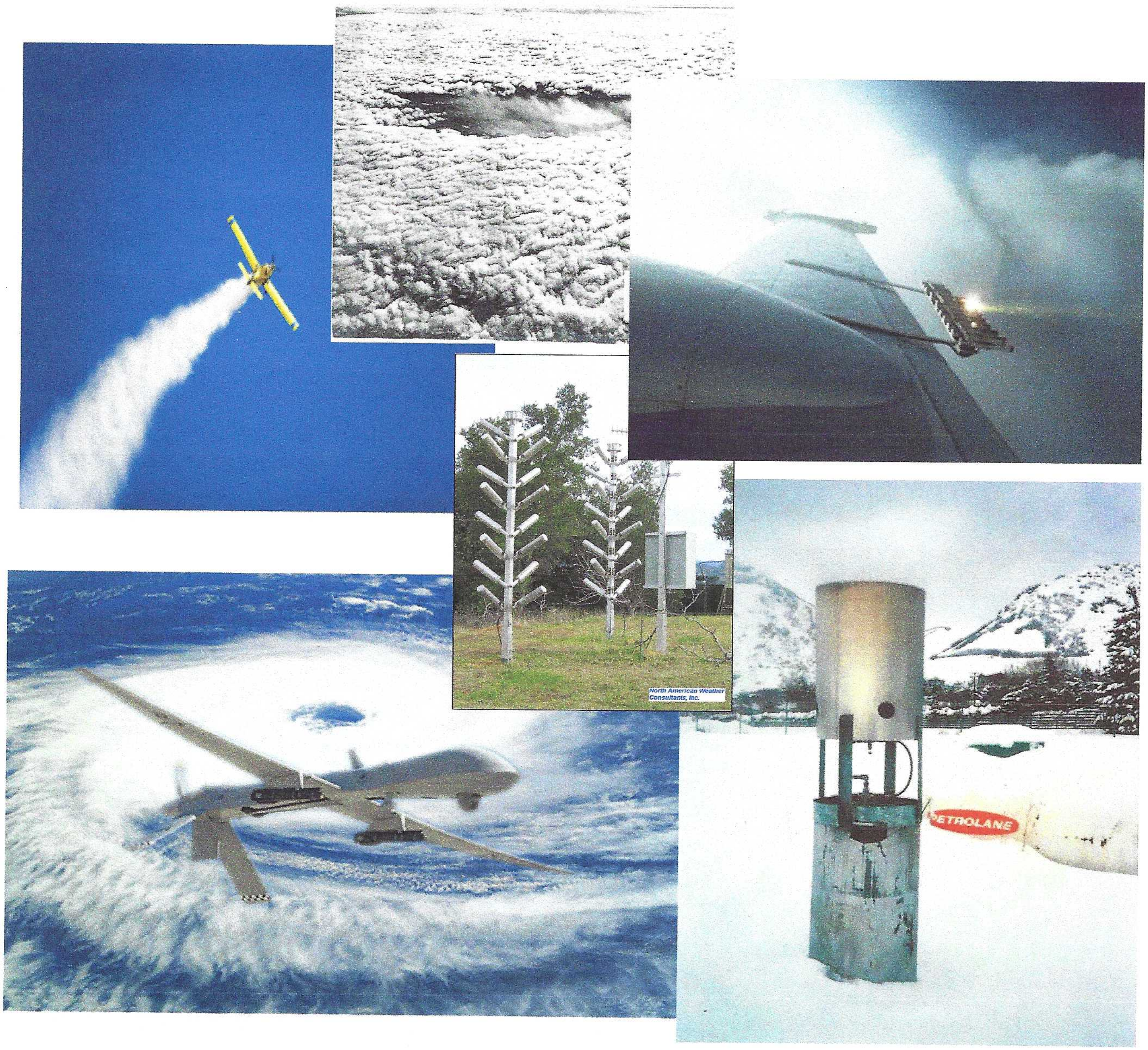
WEATHER MODIFICATION ASSOCIATION

Annual Meeting Webinar Program April 28-29, 2021



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WEATHER MODIFICATION ASSOCIATION

2021 Annual Meeting Webinar

April 28-29, 2021

Technical Program

Times are USA Mountain Time- please add or subtract as needed

Wednesday, April 28, 2021

9:00 am	Welcome and Opening Remarks from Mark Schneider and Derek Blestrud
9:20am	Developing an Unmanned System for Autonomous Rain Enhancement Operations-Tom DeFelice
9:40am	Intelligent Systems in Rain Enhancement Technology- Duncan Axisa
10:00am	Aerosol, Cloud, Precipitation and Rain Enhancement in The Gulf- An Overview of the UAE-NATURE Research- Lulin Xue
10:20am	Coffee Break
10:40am	The Influence of Hygroscopic Flare Seeding on the Droplet Size Distribution in Southeast Queensland- Sisi Chen
11:00am	Measuring the Response of Seeding in Clouds during SNOWIE Project- Sarah Tessendorf
11:20am	Quantifying the Impacts of Cloud Seeding using WRF-Wxmod Ensemble Simulations and SNOWIE Observations- Lulin Xue

11:40am Quantifying Snowfall from Orographic Cloud Seeding- Katja Friedrich

Lunch Break

1:00pm Can a High-Resolution Model Simulate Supercooled Liquid Water over the mountains of Utah?- Binod Pokharel

1:20pm Potential for Ground Based Glaciogenic Cloud Seeding over Mountains in the Interior Western United States, and Anticipated Changes in a Warmer Climate- Thomas Mazzetti

1:40pm Quantifying Event Driven Agl Release from Remote Ground-Based Cloud Seeding Generators during Orographic Winter Operations- Jesse Jutzcher

2:00pm Assessing the Feasibility of Ground Based Cloud Seeding Targeting the Continental Divide in Northern Colorado- Frank McDonough

2:20pm Cloud Seeding Feasibility Study for the Yadkin River Basin in North Carolina- David Yorty

2:40pm Overview of a Feasibility Study Conducted in the Uinta Range of Northeast Utah- Stephanie Beall

3:00pm Coffee Break

3:20pm Precipitation Evaluation for the North Dakota Cloud Modification Project- Matthew Tuftedal

3:40pm An Update on Operational Cloud Seeding Projects in the State of Wyoming- Bruce Boe/ Julie Gondzar

4:00pm Standard Practice for Weather Modification Operations- An Update- Tom DeFelice

4:20pm Close of Technical Session

Thursday, April 29, 2021

9:00-10:30am Business Meeting through Go to Meeting

Developing an unmanned system for autonomous rain enhancement operations. By; **T.P. DeFelice (CU), E. Frew (CU), D. Axisa (DMT), R. Burger (N-WU), C. Dixon (CU), D. Baumgardner (DMT), Steve Borenstein (CU)**

Operational weather modification activities have been taking place in more than 50 countries over nearly 7 decades. Operational weather modification techniques, equipment and sensing technology have predictively evolved during this period. However, there is still a need to more precisely apply seeding materials to improve upon seeding activity effectiveness. We are at an exciting nexus between that predictable path and one that incorporates new technologies and techniques that could provide an operator with enhanced cloud system precipitation efficiency and targeting accuracy at less cost than currently obtained.

This presentation will describe progress made towards applying a science and engineering- based framework for developing and 'intelligently' using new sensing technologies; to create new data assimilation tools, to design novel targeted sampling and delivery strategies, and to integrate them into an unmanned aircraft system (UAS) for real-time, autonomous guidance of rainfall enhancement operations with the goal at optimizing the effectiveness of targeting.

Intelligent systems in rain enhancement technology - *D Axisa (Scripps Institution of Oceanography at UC San Diego) and TP DeFelice (CU Boulder)*

Present-day weather modification technologies are scientifically based and have made controlled technological advances. The technological advances directly related to weather modification have primarily been in the decision support and evaluation based software and modeling areas. Artificial intelligence (AI) techniques have been applied in design and manufacturing engineering for decades. In weather modification humans have conducted operations using cloud seeding vehicles where the real-time decision to seed is by intuition. Applying AI in this process is difficult as the process of identifying cloud seedability must be described mathematically. In recent years the concept of incorporating real-time observational data with simple rule based models has been used to improve the efficiency of rain enhancement operations. In this presentation we consider the programmatic aspects underlying the development of intelligent systems in rain enhancement activities, identifying their potential benefits in improving their success and effectiveness.

Aerosol, cloud, precipitation, and rain enhancement in the Gulf – An overview of the UAE-NATURE research

Lulin Xue on behalf of the UAE-NATURE team

The Arabian Gulf region is a unique place to study aerosol-cloud-precipitation interactions. The high terrain of the Zagros Mountains in the north, the arid land and sand dunes in the west and south, the complex terrain of the Al Hajar Mountains in the east, and the surrounding ocean all work together to influence the dynamic and thermodynamic conditions for cloud and rain formation. In addition, the local heavy dust loading, sea salt particles and pollution from the oil industry provide a complicated aerosol background for the cloud and rain development.

This talk will walk you through the UAE-NATURE (Using Advanced Experimental – Numerical Approaches To Untangle Rain Enhancement) research that have been conducted to study different aspects of the aerosol, cloud, precipitation, and rain enhancement in the Gulf region, and UAE in particular. The cloud and rainfall climatology and the dust impact on storm and cloud at the regional scale, the sea salt emission and potential impact on clouds at the mesoscale, the observation analysis from a field campaign and associated high resolution numerical simulation at the local scale, the single congestus cloud simulation at the cloud scale, and detailed microphysics-parcel simulations of seeding impacts on clouds by different hygroscopic seeding materials will be covered.

Implications of new modeling techniques that can help to untangle and quantify the cloud seeding impact will be discussed at the end.

The influence of hygroscopic flare seeding on the droplet size distribution in southeast Queensland

Sisi Chen (sisichen@ucar.edu)[1], Sarah A. Tessendorf (saraht@ucar.edu) [1], Courtney Weeks (cweeks@ucar.edu)[1], Roelof Bruintjes (roelof@ucar.edu)[1], Roy M. Rasmussen (rasmus@ucar.edu)[1], Lulin Xue (lulin.xue@gmail.com)[1,2]

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[2]Hua Xin Chuang Zhi Sci. & Tech. LLC, Beijing, China

During the Queensland Cloud Seeding Research Program (QCSRP) in 2008-2009, a randomized hygroscopic seeding trial was conducted and microphysical data were collected during the campaign. These measurements provided the background aerosol size distribution and initial cloud drop size distribution (DSD) both in clouds seeded with hygroscopic flares and those that were not seeded. These data were used to investigate the measured impacts of hygroscopic flare seeding on the initial DSD, which showed a statistically significant impact of seeding broadening the DSD in clouds that formed in a continental-influenced aerosol regime.

To complement the observational analysis, a parcel model was utilized to separate the seeding signal from natural cloud processes and to improve the process-level understanding of the seeding effects on the evolution of DSD in clouds formed in maritime-influenced and continental-influenced aerosol regimes. The model was initialized with the background aerosol observations during the QCSRP for these two aerosol regimes. The simulated results qualitatively agree with the observations and show that the effect of hygroscopic seeding broadens the initial DSD, and that this effect is more prominent in clouds within the continental-influenced aerosol regime.

"Measuring the response of seeding in clouds during SNOWIE project"

Sarah Tessendorf[1], Katja Friedrich[2], Kyoko Ikeda[1], Jeff French[3], Courtney Weeks[1], Lulin Xue[1], Roy Rasmussen[1], Bart Geerts[3], Bob Rauber[4], Derek Blestrud[5], Mel Kunkel[5], Nick Dawson[5], Melinda Hatt[5], and Shaun Parkinson[5]

[1] Research Applications Laboratory, NCAR, Boulder, CO
[2] University of Colorado, Boulder, CO
[3] University of Wyoming, Laramie, WY
[4] University of Illinois, Urbana-Champaign, IL
[5] Idaho Power Company, Boise, ID

Abstract

The SNOWIE (Seeded and Natural Orographic Wintertime clouds: the Idaho Experiment) project deployed Doppler on Wheels (DOW) mobile radars into the mountains north of Boise, Idaho to study the impacts of AgI seeding on orographic clouds. The University of Wyoming King Air (UWKA) also flew research flights in the seeded and natural clouds. During the 10-week campaign that ran between January-March 2017, unambiguous seeding signatures were observed by both the DOWs and UWKA in at least three cases. The UWKA flew inside the seeded clouds in these cases measuring the amounts and habits of ice being formed from AgI seeding, and the remote sensing data from the W-band Cloud Radar (WCR) and DOW radars observed the newly formed snow falling to the ground.

The UWKA flew back-and-forth flight legs collecting in situ data that documents the temporal evolution of the cloud microphysical properties prior to seeding as well as during seeding. These data have been analyzed to characterize the cloud microphysical characteristics and impacts from cloud seeding on supercooled liquid water content, ice concentration, and particle size distributions. In addition, the DOW and UWKA radar data tracked the seeding signatures from initiation in the cloud to fallout on the ground. Combined with snow gauge data, the DOW radar data has been used to quantify the amount of snowfall generated by cloud seeding in these cases.

This presentation will share observations of the seeded clouds with unambiguous seeding signatures and results of analyses that estimated the amount of snowfall that fell due to cloud seeding.

Quantifying the impacts of cloud seeding using WRF-WxMod ensemble simulations and SNOWIE observations

Lulin Xue, Courtney Weeks, Sarah Tessendorf, Roy Rasmussen, Jeff French, Katja Friedrich, Kyoko Ikeda, Branko Kosovic, Dalton Behringer, Bob Rauber, Bart Geerts, Derek Blestrud, Melvin Kunkel, Nick Dawson, and Shaun Parkinson

Understanding how aerosol, such as ice nucleating particles (INPs), influence precipitation is a principle question in aerosol-cloud-climate interactions research. This question is addressed in cloud-seeding research experimentally by advertently seeding clouds with INPs, such as silver iodide (AgI). This study examines the impact of AgI cloud seeding on winter orographic clouds. By combining the detailed observations collected from the SNOWIE field campaign and the ensemble WRF-WxMod seeding simulations, the glaciogenic seeding effects on precipitation from the IOP5 can be quantified with constrained uncertainties. The presentation at the conference will describe the approach and show how the observations are used to constrain the simulated seeding effects.

Quantifying snowfall from orographic cloud seeding

Katja Friedrich[1], Kyoko Ikeda[2], Sarah A. Tessendorf[2], Jeffrey French[3], Robert M. Rauber[4], Bart Geerts[3], Lulin Xue[2], Roy M. Rasmussen[2], Derek R. Blestrud[5], Melvin L. Kunkel[5], Nick Dawson[5], and Shaun Parkinson[5]

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[5]Idaho Power Company, Boise, Idaho

Cloud seeding has been used as one water management strategy to overcome the increasing demand for water despite decades of inconclusive results on the efficacy of cloud seeding. In this study snowfall accumulation from glaciogenic cloud seeding is quantified based on snow gauge and radar observations from three days in January 2017, when orographic clouds in the absence of natural precipitation were seeded with silver iodide (AgI) in the Payette Basin of Idaho during the Seeded and Natural Orographic Wintertime Clouds: The Idaho Experiment (SNOWIE). On each day, a seeding aircraft equipped with AgI flares flew back and forth on a straight-line flight track producing a zig-zag pattern representing two to eight lines of clouds visible through enhancements in radar reflectivity. As these seeding lines started to form precipitation, they passed over several snow gauges and through the radar observational domain. For the three cases presented here, precipitation gauges measured increases between 0.05-0.3 mm as precipitation generated by cloud seeding passed over the instruments. A variety of relationships between radar reflectivity factor and liquid equivalent snowfall rate were used to quantify snowfall within the radar observation domain. For the three cases, snowfall occurred within the radar observational domain between 25 -160 min producing a total amount of water generated by cloud seeding ranging from 123,220 to 339,540 m3 (100 - 275 acre feet) using the best-match Ze-S relationship. Uncertainties in radar reflectivity estimated snowfall are provided by considering not only the best-match Ze-S relationship but also an ensemble of Ze-S relationships based on the range of coefficients published from previous studies and then examining the percentile of snowfall estimates based on all of the Ze-S relationships within the ensemble. Considering the interquartile range and $5^{th}/95^{th}$ percentiles, uncertainties in total amount of water generated by cloud seeding can range between 20-45% compared to the best-math estimates. These results provide new insights towards understanding how cloud seeding impacts precipitation and its distribution across a region.

Can a high-resolution model simulate supercooled liquid water over the mountains of Utah?

Binod Pokharel[1], and Stephanie Beall[2]

[1]*Utah Climate Center, Utah State University, Logan, UT*

[2]*North American Weather Consultants, Sandy, UT*

The effectiveness of wintertime orographic cloud seeding operations is largely dependent on the seeding conditions that are guided by numerical modeling when limited atmospheric measurements are available over the target mountains. The Weather Research and Forecasting (WRF) model was simulated for the Uinta Mountains in Utah along with radiometer measurements during the 2018-19 winter season. The objective of the WRF simulation was to evaluate the model performance on liquid water and overall weather parameters. Two nested domains were used for the WRF simulation: an outer domain that covered Utah with 2-km horizontal resolution and an inner domain that covered the Uinta Mountains with 1-km horizontal resolution.

The model performed better for temperature and wind, while it overestimated the dewpoint temperature. The model also generally showed a dry bias in precipitation simulation; however, it did capture the precipitation (snowfall) events in the Uinta Mountains. The model also underestimated the LW compared to radiometer data, but was able to show the significant LW during seeding events that occurred in the 2018-2019 winter season. Lastly, the model captured the low-level inversion that is shown by the observational data. The season long high-resolution model provides useful guidance for the Uinta Mountains and this should be helpful for future operational seeding guidance, particularly for the best array of seeding generators.

Potential for Ground-Based Glaciogenic Cloud Seeding over Mountains in the Interior Western United States, and Anticipated Changes in a Warmer Climate

Thomas O. Mazzetti1, Bart Geerts1, Lulin Xue2, Sarah Tessendorf2, and Yonggang Wang3

1. University of Wyoming

2. National Center for Atmospheric Research

3. State University of New York at Oswego

Abstract

Glaciogenic cloud seeding has long been practiced as a way to increase water availability in arid regions, such as the interior western United States. Many seeding programs in this region target cold-season orographic clouds with ground-based silver iodide generators. Here, the "seedability" (defined as the fraction of time conditions are suitable for ground-based seeding) is evaluated in this region, based on 10 years of hourly output from a regional climate model with a horizontal resolution of 4 km. Seedability criteria are based on temperature, presence of supercooled liquid water, and Froude number, which is computed here as a continuous field relative to the downwind terrain. The model's supercooled liquid water is validated with microwave radiometer observations.

Seedability peaks at 20-30% for many mountain ranges in the cold season, with the best locations just upwind of the crest, over the highest terrain in Colorado and Wyoming, as well as over ranges in the Northwest Interior. Mountains further south are less frequently seedable, but when they are, cloud supercooled liquid water content tends to be relatively high. Seedability is fairly uniform during the cold season, but generally peaks in the middle of the winter.

This analysis is extended into a future climate, anticipated for later this century, with a mean temperature 2.0 K warmer than the historical climate. Seedability generally will be ~3-12% lower in this future warmer climate, especially in the Northwest Interior, but when seedable, clouds tend to contain more supercooled liquid water.

"Quantifying Event Driven AgI Release

from Remote Ground-Based Cloud Seeding Generators During Orographic Winter Operations"

Jesse Juchtzer – Principal Research Technician

Desert Research Institute

Abstract:

As with all glaciogenic cloud seeding operations, the overall goal is to introduce additional ice nuclei into orographic clouds containing supercooled liquid water to increase snowfall on the ground at designated target areas. However, the quantity and release rate of these additional nuclei particles are a crucial variable to the overall production of this augmented precipitation. In this discussion, we will provide a technical overview of how we have developed and currently use automated technologies to quantify event driven Silver Iodide (AgI) release from remote ground-based cloud seeding generators. This topic will include the research and experimental efforts to identify generator nuclei yields, the implementation of automated systems for the regulation of seeding agent release rates, the field calibration procedures for atomized solution nozzles, the measurement and tracking of these seeding consumables throughout an operational season, as well as the integration of real-time data analytics for annual reporting and cooperator water resource needs.

Assessing the Feasibility of Ground Based Cloud Seeding Targeting the Continental Divide in Northern Colorado

Frank McDonough and John Mejia

Desert Research Institute

The Colorado River serves the water needs of nearly 40 million people and drives a $1.4 trillion dollar economy. Runoff from the winter snowpack in the headwaters area of the Colorado River Basin in north-central Colorado contributes more than 1/5th (21.6%) of the total river flows reaching the Imperial Dam, along the Arizona/California border. In addition to being an important source to the Colorado River, snowfall over this area is also critical to water supplies serving the 3 million residents living along the eastern slopes of the Colorado Front Range. Previous climatological modeling studies have suggested that this area may often have seeding conditions present during winter storms.

In this talk an observational cloud seeding feasibility study is presented. The study was conducted across two specific adjacent drainages over the northern CO Continental Divide. One drainage is on the eastern slopes and one is on the western slopes of the Continental Divide. The results of this observational feasibility study were followed by a cloud seeding project design study using a high-resolution numerical weather model (WRF) combined with a numerical plume dispersion model.

Five years of winter storm data from three NRCS SNOTEL sites within the specific drainages were analyzed and storm start and end times were identified using hourly snow water equivalent measurements. 117 storms were identified covering 1853 storm hours. The large-scale weather features for each storm were analyzed and the 650-mb temperatures and winds were determined. In addition, the atmospheric stability, cloud heights, and likely microphysical cloud structures were inferred. The results of this analysis allowed preliminary estimates of additional potential snowfall from orographic cloud seeding to be calculated.

With the primary weather patterns associated with the majority of seedable precipitation over the area defined by the observational study, two multi-day case studies were run using a 1-km WRF simulation. A detailed analysis of these storms' seeding potential is presented followed by simulated plume releases during the storms from potential generator sites. The relative success of seeding over the area from each generator site is shown.

Cloud Seeding Feasibility Study for the Yadkin River Basin in North Carolina

(David Yorty)

North American Weather Consultants conducted a feasibility study for the Yakin River Basin, located primarily in North Carolina, on the southeastern side of the Appalachian Range. The basin includes lower elevation areas (below 1,000 feet MSL) in roughly the southeastern half, and foothill areas rising from 1,000 feet in the central portion to around 3,000 feet MSL along the northwestern edge of the basin. The study was conducted to assess the feasibility of cloud seeding in support of increased hydroelectric power production. This region is substantially different in terms of its meteorology, topography, and vegetation, from most watersheds in the United States where cloud seeding has been conducted. The study analyzed seasonal precipitation versus streamflow relationships, as well as storm period meteorological characteristics, to determine the technical and economic feasibility of seeding for the watershed. The meteorological portion of the study included temperature profile and cloud layer characteristics, winds, and inferred presence of supercooled liquid water in cool-season storm events. The study also identified target and control streamflow gauges in the region that could be used in subsequent evaluations of a seeding program.

Overview of a Feasibility Study Conducted in the Uinta Range of Northeast Utah

Stephanie Beall

The Uinta Range of Utah has long been a subject of cloud seeding operations and feasibility studies in the Western U.S. Cloud seeding has been conducted in this range nearly continuously since the 1980's, with a variety of field studies supporting the operational programs. Previous feasibility studies have estimated the potential benefits of wintertime cloud seeding over this unique mountain range, the only major west-east running range in the state of Utah. The third feasibility study, conducted in 2020, introduced an additional element that had not been previously used, a microwave radiometer which was able to observe a number of different parameters, most importantly, supercooled liquid water occurrence. The microwave radiometer provided validation of some previous feasibility study findings, as well as making new measurements which have helped to optimize the operational program. This presentation highlights some of the older research in this region, as well as some new insights gained with the aid of analyzed radiometer data and modeling techniques of supercooled liquid water.

Precipitation Evaluation of the North Dakota Cloud Modification Project

Matthew Tuftedal, David J. Delene, Andrew Detwiler

ABSTRACT

The North Dakota Cloud Modification Project (NDCMP) is a state-managed cost-sharing program with the primary goal of reducing crop hail damage and a secondary goal of increasing rainfall in western North Dakota that began in 1976 and continues to the present. The impact of NDCMP cloud seeding operations on precipitation in the project area over the period 1977 through 2018 is studied using rain gauge observations and an exploratory historical target/control statistical analysis. Three counties where seeding was conducted each year are designated as target areas and paired with control areas that encompass neighboring counties where little or no seeding has occurred. Monthly and seasonal (June-August) area precipitation amounts for targets and controls is obtained from averages of available daily rain gauge measurements. The relationship between target and control precipitation is compared for the era 1950-1975, before the NDCMP began, and the NDCMP era from 1977-2018. Two target areas, McKenzie, and Bowman are paired with four control regions and Ward is paired with one. Six of eight McKenzie and Bowman target/control pairs have target/control ratios indicating higher precipitation in target areas during the NDCMP. Additionally, 2 of the 8 indicated enhancements have a 95% statistical chance of being greater than 1.0. The Ward target/control comparison indicates no enhancement. The average of all nine target/control enhancements is 1.03.

An Update on Operational Cloud Seeding Projects in the State of Wyoming

BRUCE A. BOE
Weather Modification International
Fargo, North Dakota
JULIE GONDZAR
Wyoming Water Development Office
Cheyenne, Wyoming

Operational ground-based seeding using a glaciogenic agent which functions in the condensation-freezing mode has been conducted in the Wind River Mountains of Wyoming each winter. The 2020-2021 season, just completed, was the eighth season of such seeding. Since the fall of 2018, winter-season airborne seeding operations have been conducted for the Medicine Bow and Sierra Madre Ranges of Wyoming. In this presentation the 2020-2021 operations are reviewed for both projects, and the seasons-to-date for each summarized. Challenges and suspensions are discussed, and an outlook presented for operations in the winter of 2021-2022.

Standard Practice for Weather Modification Operations-An Update. By; C.G. Keyes, Todd Flannigan, Tom DeFelice, Darin Langerud, George Bomar, Don Griffith.

This interactive talk updates the WMA community on the ASCE/EWRI Atmospheric Water Management Standards Committee activities for this past year, including the need for WMA members to help and/or join the ASCE/EWRI standards committee. It also sets the discussion stage for some pressing topics affecting the community, such as, the need for a Standard Practice dedicated to warm cloud seeding, Weather Modification community ice forming nuclei chamber, as well as for the future of ASCE/EWRI - WMA partnerships for example.