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ANNUAL
REPORT

WYOMING • WIND RIVER RANGE
WEATHER MODIFICATION PROGRAM

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Wind
River

Mountain
Range

WEATHER MODIFICATION INTERNATIONAL

3802 20th Street N.
Fargo, ND 58102

WYOMING WATER DEVELOPMENT COMMISSION

6920 Yellowtail Road
Cheyenne, WY 82002

Cloud Seeding Operations in the Wind River Range of Wyoming 2017-2018 Season

ANNUAL REPORT

prepared by

Weather Modification International
3802 20th Street North
Fargo, North Dakota 58102 USA

for the

Wyoming Water Development Office
6920 Yellowtail Road
Cheyenne, Wyoming 82002

July 2018

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EXECUTIVE SUMMARY

Funding for cloud seeding operations in the Wind River Range for the winter of 2017-2018 was provided in part by the 2017 Wyoming State Legislature's "Omnibus Water Bill – Construction". The Wyoming State Legislature has mandated that the funding rate for the State will not exceed 25% of total project costs, leaving 75% of the project costs to be split among other Colorado River Basin water users or interested parties. Funding partners in support of continued weather modification activities in the Wind River Mountains during the winter of 2017-2018 include the Southern Nevada Water Authority, the Central Arizona Project (CAP), and the Colorado River Board of California - Six Agency Committee.

The same ten ground-based ice nucleus generators (ground generators) that were employed during the preceding season were deployed for the two previous operational seasons. The Pocket Creek generator is shown in Figure 1. Nine generators were sited on the west, southwest, and southern flanks of the range. The tenth was sited on the southeastern flank, southwest of Lander.

The 2017-2018 season was intended to begin on 1 December 2017, and conclude after 31 March 2018, but contract finalization did not occur until 9 December 2017. Thus the project did not become operational until December 9th. The first seeding event occurred on 20 December 2017.

The weather pattern produced near-normal storm frequency, with five seeding events occurring in December 2017, three in January 2018, five in February 2018, and five more in March 2018, for a project total of eighteen storms. Seasonal snowpack varied over the target areas, but at season end ranged from a minimum of about 80% of normal median values at the Townsend Creek and South Pass SNOTEL sites to over 125% at the Hobbs Park site. No suspensions occurred during the 2017-2018 season.

The eighteen seeded storms accrued 192 hours and 34 minutes in which one or more generators was seeding during the winter. The fewest number of generators that operated during any one storm was one (twice), the most, nine. The Enterprise generator, sited on the eastern slope of the range near Lander, was used only early and late during the 2017-2018 season, not during the heart of winter, which is typical. Had the field season began in mid-November or even on the first of December as originally intended, or had it continued into April, it may have seen more use.

The total number of "generator hours", defined as the sum of times each generator was operated during a storm, was 1,231 hours. For seeding to have been conducted the wind direction had to be such that seeding agent released from each specific generator would carry seeding aerosol particles (silver iodide, AgI) upslope into cold but yet-unfrozen clouds at speeds sufficient to ensure that transport would occur. The seeding rate is approximately 25 grams of silver iodide per generator, per hour. The results discussed in this report show a variance in the number of generators used from seeding event to seeding event. This variance is due to situations when the wind direction favored the activation of specific generators. The two other requisite conditions needed to initiate seeding were the presence of liquid water clouds, and suitable cloud temperatures. The temperature of the clouds aloft had to be cold enough (-6°C or colder) to ensure that the seeding agent would nucleate ice, thus starting precipitation development. This is discussed in greater detail in the body of the full report.

The requisite temperature and wind criteria were primarily determined through the release of weather balloons. A total of 19 weather balloons were released during the 3.7 months (113 days) of operations. The presence of liquid water clouds over the range was established by the WWDO radiometer sited near Boulder, WY.

Figure 1. The ice nucleus generator sited at Big Pocket Creek on the west flank of the Wind River Range (WMI photograph). For the locations of all the generators, see Figure 5.

The bulk of the weather information used for forecasting and weather monitoring was obtained from the internet. In the 2017-2018 season WMI ran advanced numerical models specific for the project to provide additional cloud seeding-specific information on a 24-hour basis. In the 2017-2018 season WMI had, especially in complex flow circumstances, run the Hybrid Single-Particle Lagrangian Intergrated Trajectory (HYSPLIT) plume dispersion model to establish a better idea of seeding agent plume behavior. This season, the HYSPLIT was re-initialized and run with every run of the Weather Research and Forecasting (WRF) model. More about these models are presented in the body of this report.

The 2017-2018 winter offered several extended, precipitation-producing storms. Nine of the eighteen seeded storms saw seeding continue for ten or more hours, all of these using at least six generators. Three of the nine lasted at least 20 hours. One lasted for over 30 hours!

Additional and more detailed information is provided in the pages that follow, and the attached appendices.

ACKNOWLEDGMENTS

Weather Modification International (WMI) is pleased to acknowledge the following persons and entities which made the 2017-2018 operations possible.

The Wyoming Water Development Commission (WWDC) and Select Water Committee (SWC) contributed 25% of the costs, while the Wyoming Water Development Office (WWDO), especially Julie Gondzar, who coordinated the entire effort. The WWDO also acquired major funding from the Colorado River Board of California – Six Agency Committee, the Central Arizona Project, and the Southern Nevada Water Authority.

Ms. Kathy Raper of the Sublette County Conservation District arranged for local students to visit the WMI facilities in Pinedale, WY to learn about the program and observe weather balloon launches. WMI greatly appreciates the opportunity to provide educational training and community outreach.

WMI also acknowledges all the WMI staff who contributed to the success of the program, specifically meteorologists Dan Gilbert, Jason Goehring, and Adam Brainard, technicians Michael Paul, Ryan Hudson, Pat Trujillo, and Steven Heinitz, and all the additional support provided by Erin Fischer, Ryan Richter, Dennis Afseth, Amber Ottis, and other Fargo-based WMI staff.

1. BACKGROUND AND OVERVIEW

1.1 Background

Atmospheric water transformed to precipitation is one of the primary sources of fresh water in the world. However, a large amount of water present in clouds never is converted into precipitation that makes it to the ground. This has prompted scientists and engineers to explore the possibility of augmenting water supplies by means of cloud seeding.

From 2006 through the spring of 2014, cloud seeding operations in the Wind River Range were conducted within the context of the Wyoming Weather Modification Pilot Project (WWMPP). Eight of the ten ground-based cloud seeding generators used in that project were funded by the Wyoming State Legislature through the Wyoming Water Development Commission (WWDC). The two additional generators were funded by the Lower Colorado River Basin States.

Though the WWMPP concluded in the spring of 2014, local and regional interest in continuing operations remained. In recognizing this interest, the WWDC obtained legislative support and the funding for a 2014-2015 operational cloud seeding program in the Wind River Range. This interest remains, and operations have continued through this mechanism during subsequent winters. Funding provided by the 2017 Wyoming Legislature enabled the State of Wyoming, through the WWDO, to again provide 25% of the operational cost. Additional funding came from other sources as discussed in Section 1.4.

1.2 Scientific Basis

Clouds in the lower troposphere form when, in cooling air, water vapor condenses upon cloud condensation nuclei (CCN), forming cloud droplets. The size of the droplets produced depends on the amount of water vapor present, and the character of the CCN. When the CCN are large or have properties that attract water (such as salt), the resulting droplets will be larger. The formation of cloud droplets happens on a very small scale, as illustrated in Figure 2. About one million (10^6) typical cloud droplets are required to produce a single, 1 millimeter (mm) raindrop.

Precipitation forms in two ways. The simpler process involves the collision and coalescence of cloud droplets until the droplet becomes large enough to fall as precipitation. Thus, the initially-tiny cloud droplets grow in size, becoming drizzle, and with continued growth, rain. This process is known as the *collision-coalescence* or *warm rain* process.

The alternative path to precipitation development is through the formation of ice instead of raindrops, and it is this process that plays a significant role in winter clouds in Wyoming. For ice to exist, the cloud must be colder than 32°F (0°C). However, ice does not *form* spontaneously at temperatures colder than 32°F (0°C). In the absence of ice nuclei, water can become "supercooled", meaning the water in the cloud remains in liquid form at temperatures well below zero Celsius. To most persons this is surprising, as we are accustomed to seeing water (at the surface) freeze whenever temperatures fall "below freezing." Freezing happens at the surface because there are lots of substrates (substances or materials) present that encourage nucleation of the ice phase (freezing), and these substrates are largely absent in the free atmosphere.

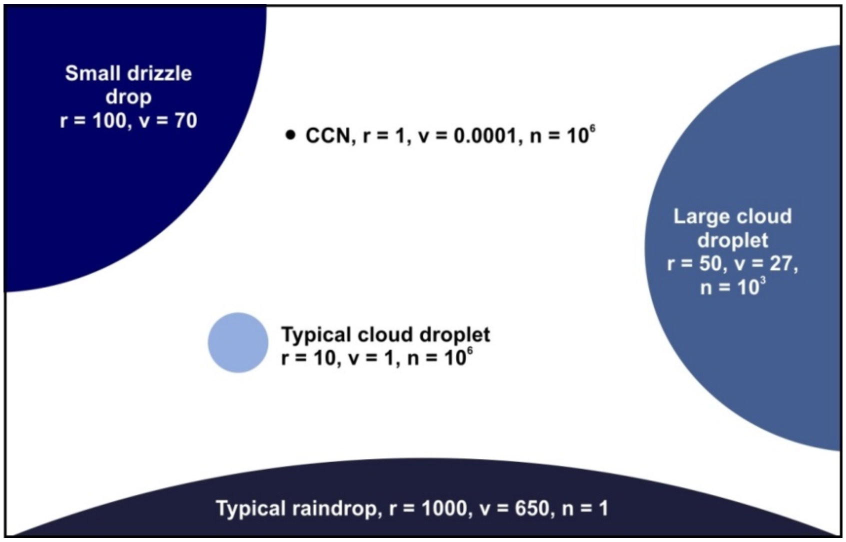

Figure 2. Relative characteristics of particles involved in cloud processes. For each, the radius (r, microns), fall velocity (v, cm per second), and number concentration (n, per liter) are given (after Wallace and Hobbs 1977). The raindrop shown (radius = 1000) is a 2 mm diameter raindrop.

Nature's solution to the lack of substrates available to encourage the freezing process in clouds comes in in the form of tiny particles called *ice nuclei.* Ice nuclei provide microscopic, crystalline "templates" for supercooled liquid water (SLW) to follow, and become the solid form known as ice. The shape of an ice nucleus plays an important role in determining which atmospheric conditions will be better suited for the formation of ice crystals in clouds.

Once ice forms in a cloud, the crystals grow quickly. Initially, growth occurs through water vapor deposition directly on the nascent ice crystal, producing six-sided crystals. Within five minutes, these tiny ice crystals grow large enough to begin to fall. As they fall, growth by deposition continues, but because the ice crystals are heavier than the nearby SLW droplets they collect them as they fall. Upon contact with the ice crystals, the SLW droplets freeze. As they grow ever larger, the ice crystals may encounter each other and become tangled, forming aggregates known as snowflakes.

When clouds grow colder than about -5°C but do not immediately form ice crystals (which is common), they can be treated with silver iodide-based ice nuclei which immediately initiate ice crystal formation, thus starting the ice-phase precipitation process. Ground-based seeding is commonly used in orographic applications, especially when the prevailing wind flow is roughly perpendicular to the mountain range, so that seeding agent is lofted immediately upward into the targeted clouds. This orographic seeding technique was the prime strategy used to seed winter clouds throughout the WWMPP, and continued to be the main approach utilized in the Wind River Range during the operational seeding seasons in the winters since.

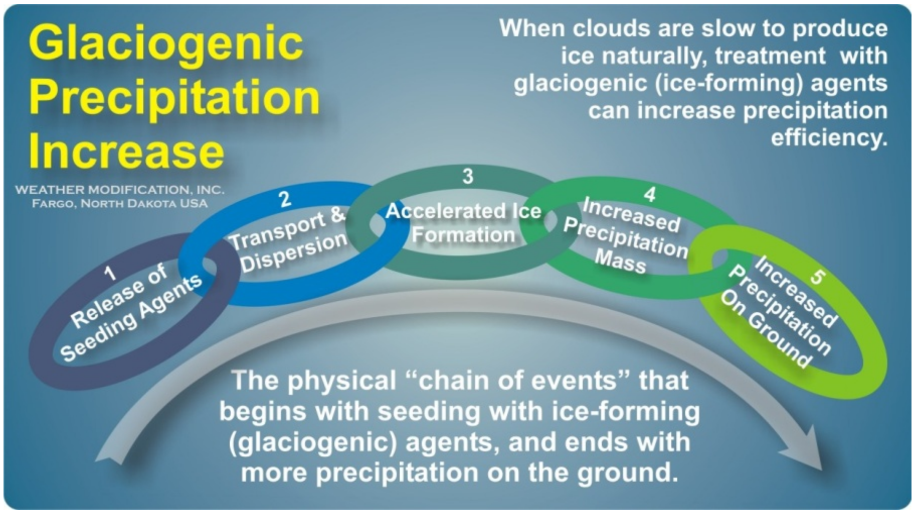

Figure 3. The physical chain-of-events that begins with release of ice-forming seeding agents, and culminates with increased precipitation.

Given the chain-of-events illustrated in Figure 3, effectiveness of seeding operations depends upon three things:

- The clouds of interest must contain liquid water.
- The cloud temperature at the level where liquid water is present, typically in the neighborhood of 10,000 feet MSL, must be colder than +23°F (-5°C). Natural ice nuclei, such as crystalline soil particles, do not act to form ice crystals until the cloud is much colder, +5°F (-15°C) at the warmest. The AgI seeding agent, by virtue of its crystalline shape being very close to that of ice, begins to form ice crystals much sooner, at about +23°F (-5°C). As a result, precipitation formation within the cloud starts significantly sooner, allowing more time for the ice crystals to grow and transform into snow.
- The wind direction and speed must be such that the seeding agent released from the ground-based generators will be transported up the mountain slope and into the target clouds.

1.3 Operations

The three criteria above were the same as those used in the WWMPP research, except the temperature criterion for seeding during the WWMPP was slightly colder (+17.6°F / -8°C). A colder temperature threshold was used in the research to ensure that more of the seeding agent would activate in the cloud and produce a stronger seeding signature.

In operational seeding, the temperature criterion can be met in warmer conditions as long as some of the ice nuclei still produce ice crystals. This being said, it must be noted that the magnitude of the seeding effectiveness will diminish as temperatures warm. Seeding should not occur when temperatures aloft are warmer than +23°F (-5°C). Widening the temperature window for seeding increases the number of seeding opportunities. Most operational (vs. research) seeding programs use this warmer temperature criterion.

1.4 2017-2018 Funding

In addition to the 25% of funding costs provided by the State of Wyoming, funding for the 2017-2018 operations was also provided by the following organizations/agencies.

Southern Nevada Water Authority. The Southern Nevada Water Authority (SNWA) is a cooperative agency formed in 1991 to address Southern Nevada's unique water needs on a regional basis. SNWA officials are charged with managing the region's water resources and providing for Las Vegas Valley residents' and businesses' present and future water needs. With Colorado River water currently representing 90% of SNWA's water supply, the SNWA partners with other Colorado River Basin states to optimize and enhance Colorado River water supplies.

The Central Arizona Project. The Central Arizona Project (CAP) delivers Colorado River water via a 335-aqueduct system to customers in Maricopa, Pinal, and Pima Counties in Arizona, home to 80% of Arizona's population. The CAP diverts more than 1.6 million acre-feet annually, providing water to cities, towns, irrigation districts, Native American communities, and stores water underground for future use during times of drought or shortage. The CAP manages its Colorado River resources for current and future residents in central Arizona, and continuously seeks collaborative approaches with partners in the Colorado River Basin to protect and augment the water supplies in the Colorado River System.

Colorado River Board of California - Six Agency Committee. The Six Agency Committee was created in 1950 through an agreement among Palo Verde Irrigation District, Coachella Valley Water District, San Diego County Water Authority, Imperial Irrigation District, the Metropolitan Water District of Southern California and the City of Los Angeles Department of Water and Power. The Six Agency Committee provides funding to support actions to safeguard the members' rights and interests in the Colorado River system and for the Colorado River Board of California.

2. STAFF AND FACILITIES

2.1 Personnel

The primary project personnel were the project forecasters who monitored the weather and made the decisions regarding which ice nucleus generators should be used, and when each should be turned on and off, and the project technicians who supplied, maintained, and operated the generators.

Meteorologists. Three meteorologists staffed the 2017-2018 operations season. Mr. Daniel Gilbert was located on site in Pinedale, WY through the majority of the project. In addition to coordinating data collection for the project, he also operated the weather balloons (the upper air sounding system). When Dan was not on-site, he was replaced by Mr. Adam Brainard. The other meteorologist was Mr. Jason Goehring, who worked off-site, using weather resources available via the Internet and directly from WMI. Both Gilbert and Goehring are Weather Modification Association Certified Operators. Between the three of them, Gilbert, Goehring, and Brainard completed all the daily forecasting, weather monitoring, and implementation of seeding operations.

Technicians. Four technicians participated in the 2017-2018 operations. On-site technical work was conducted primarily by Mr. Michael Paul, Mr. Steven Heinitz, and Mr. Ryan Hudson, who were occasionally assisted by Mr. Pat Trujillo. Mr. Ryan Richter was available to provide counsel and direction from the WMI home office in Fargo. Since maintenance and servicing of generator sites could only occur when storms were not expected, field days were long as technicians tried to get to as many sites as possible. Safety guidelines require that no fewer than two technicians travel into the field together, largely in the event of equipment failure (i.e., a snowmobile breaking down or getting badly stuck), but also because two persons are required to complete tasks such as adding seeding solution to a generator (Figure 4). Safety is always of paramount importance, but even more so during heavy-snow winters such as the 2016-2017 season, when sleds sink more deeply into the always-fresh snow, and avalanche risk is often heightened.

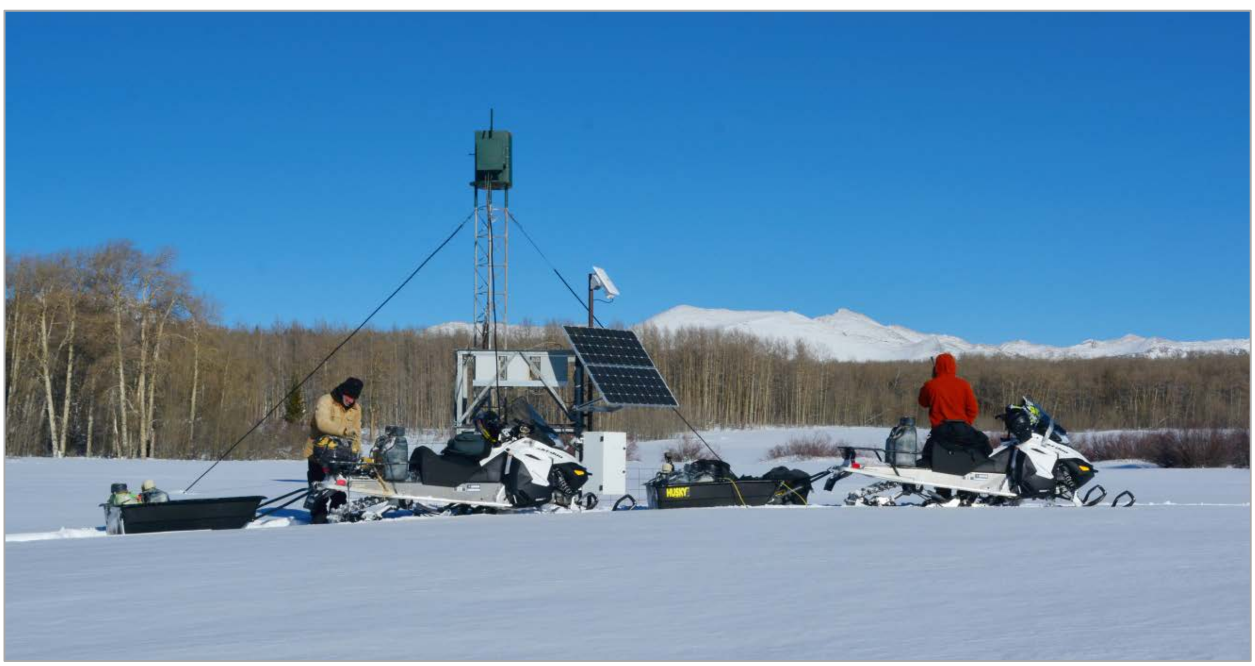

Figure 4. The technician team services the Block and Tackle generator site on a brilliantly-clear day after a nice snowfall. (WMI photograph by Michael Paul.)

2.2 Siting of Seeding Equipment

Figure 5 displays the ten seeding equipment sites used for the 2017-2018 project. These sites were unchanged from those utilized in the WWMPP and the previous operational seeding seasons in the Wind River Range.

The generator placement was such that individual generators could be activated according to wind direction, and as storms passed and conditions changed. As shown in Figure 5, nine of the ten generator sites wrapped around the western to southwestern side of the mountain range, beginning with the Green River site on the west and ending with the Anderson Ridge site at the extreme southern end. These locations allowed targeting of the range when wind directions were within the southwestern quadrant. The tenth site, Enterprise, allowed targeting when winds were easterly. All sites were on state-owned or private lands. Permissions were established through the Wyoming Office of State Lands and Investments or private memoranda of understanding, accordingly.

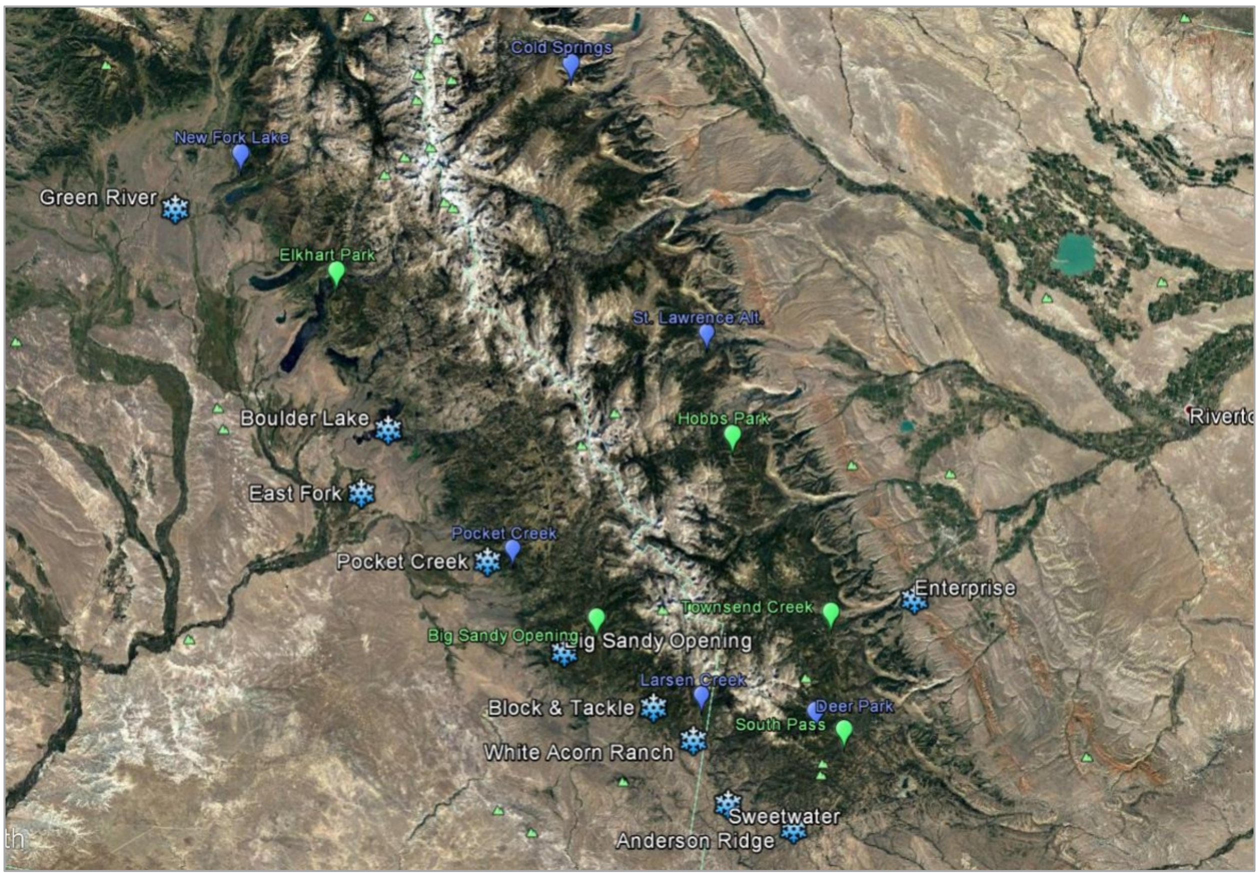

Figure 5. The locations of the ground-based ice nucleus generators are indicated by the snow crystal symbols. The green "balloons" indicate the locations of Natural Resources and Conservation Service (NRCS) snow telemetry (SNOTEL) sites used in monitoring snowpack during the 2017-2018 season. The blue balloons show the locations of additional SNOTELs that were not used because of proximity to sites that were used, or a short period of record (they were relatively new sites).

2.3 Ice Nucleus Generators

The ice nucleus generators were designed, fabricated, deployed, operated, and serviced by WMI. The primary components are shown in Figure 6.

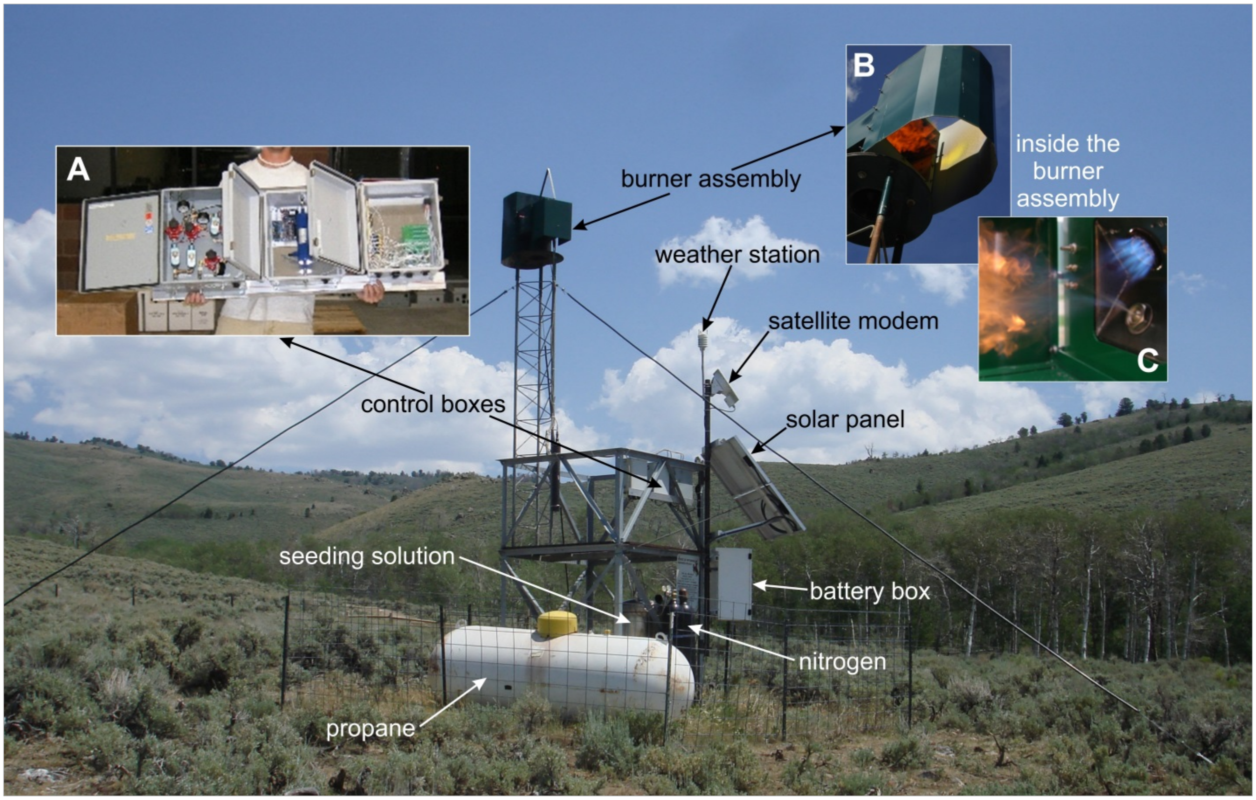

Figure 6. The primary components of the WMI remotely-controlled ground-based ice nucleus generator are illustrated. Inset A, shows the contents of the control boxes. From left to right, these are: solenoids (electronic valves) to turn flows on and off, seeding solution flow rate regulation and measurement, and computer interface with the satellite modem. Inset B, provides a view up and into an ignited generator, and Inset C, shows how the seeding solution is atomized through a nozzle (silver disk, lower right) and into the burning propane (blue flame) and ignited (bright orange flame). The Enterprise and White Acorn Ranch generator sites also had weather stations in 2017-2018.

The Wind River Range generators are fully independent, controlled via satellite, and powered by batteries charged by solar power. This provides the ability to site generators at higher elevations, significantly improving delivery of seeding agent to the clouds. Remotely-controlled generators can be activated and deactivated as weather conditions warrant. This allows less seeding agent to be dispersed unnecessarily (operators are not needed to visit sites), as often occurs with manually-operated generators. All of the generator lines and fittings are made of corrosion-resistant stainless steel, to accommodate the high-performance seeding solution. The generators are robust; designed to function in extreme temperatures, winds, and precipitation.

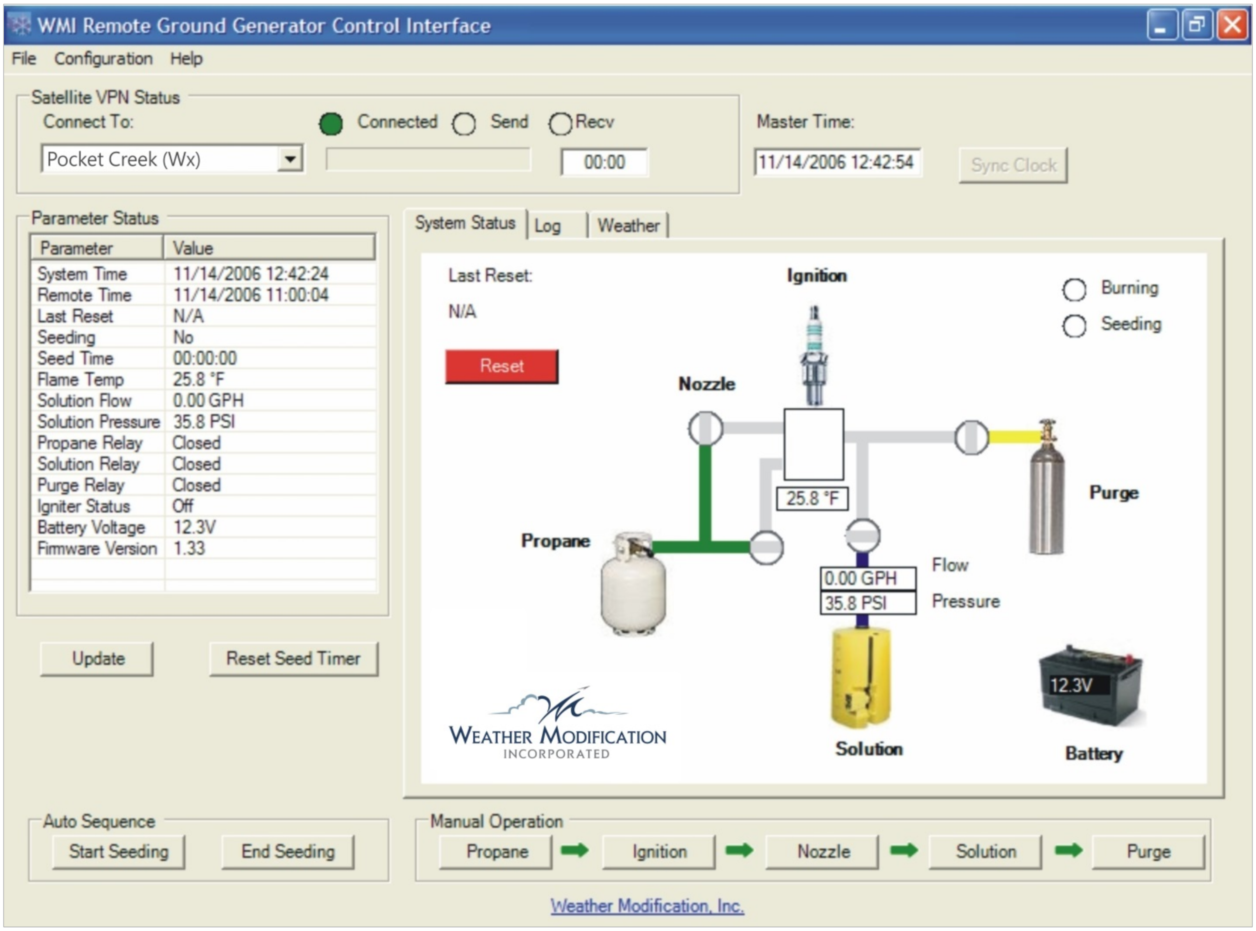

Figure 7. The control interface for the WMI remotely-controlled ground-based ice nucleus generator is shown, after connection is established via satellite, but before the generator is turned on. All flow valves are off, seeding solution flow is zero, but system status is fully reported.

The computer interface used to control the generators is shown in Figure 7. The status of the entire generator system (voltage, pressure, relay (valve) status, and flame temperature) is available for inspection by the technician immediately upon connection to the satellite.

Clicking the Start Seeding button (lower left on the interface, Figures 7 and 8) automatically sequences the generator start-up. At the generator, a valve will open to allow propane to flow. Ignition of the propane is confirmed on the interface by a rapid increase in indicated flame temperature. When the generator is not burning, the “flame temperature” is actually that of the ambient air. Once the generator is burning, the seeding solution is atomized by the nozzle and sprayed as an aerosol into the propane flame (Figure 6, Inset C). As the solution burns, particles of silver iodide are transported by the wind into the clouds over the mountains. Several of these steps, such as the flow rate of the seeding agent, can be confirmed by the technician utilizing the WMI remote-controlled ice nucleus generator interface, as shown in Figure 8.

In the 2017-2018 two significant upgrades were made to the seeding system. New modems for satellite connectivity replaced the older modems in place since 2005. The new modems ran effectively on less power, meaning site connectivity and thus generator operations were improved. The second change was that with the new modems it became possible to connect with multiple generators (all, if we wanted to) at the same time, so monitoring generator performance became easier and more efficient.

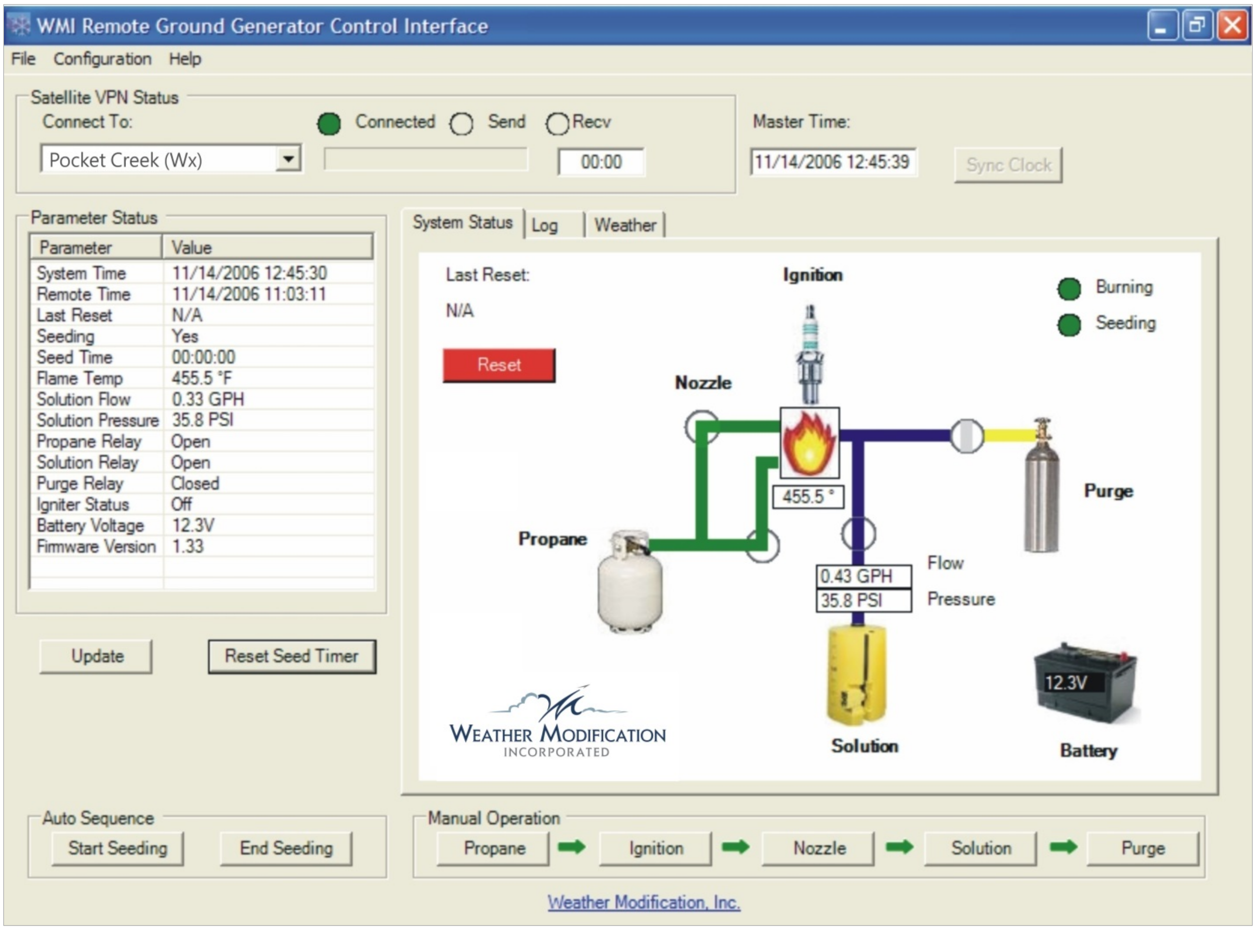

Figure 8. The WMI remote-controlled ice nucleus generator interface is shown, as it appears during seeding operations. Valves are open, the flame is known to be burning, and the seeding solution flow rate is also known. Seeding is certain.

2.4 Seeding Solution

The high performance seeding solution itself was tested at the Colorado State University Cloud Simulation and Aerosol Laboratory by DeMott (1997). Those tests determined that colder cloud temperatures produce a bigger yield of active ice nuclei per gram of AgI burned. As shown in Figure 9, the yield increases markedly from -6°C (+21.2°F) to -8°C (+17.6°F), and even more at -10°C (+14°F). At a cloud temperature of -6°C, 3 x 10^{11} nuclei are active per gram of AgI burned. This is 300,000,000,000, or 300 billion. Operational programs in the western United States commonly commence seeding operations at -5 or -6°C. As in the previous three seasons, the 2017-2018 Wind River operations used a temperature criterion of -6°C at 700 hPa, which is about 10,000 feet above sea level.

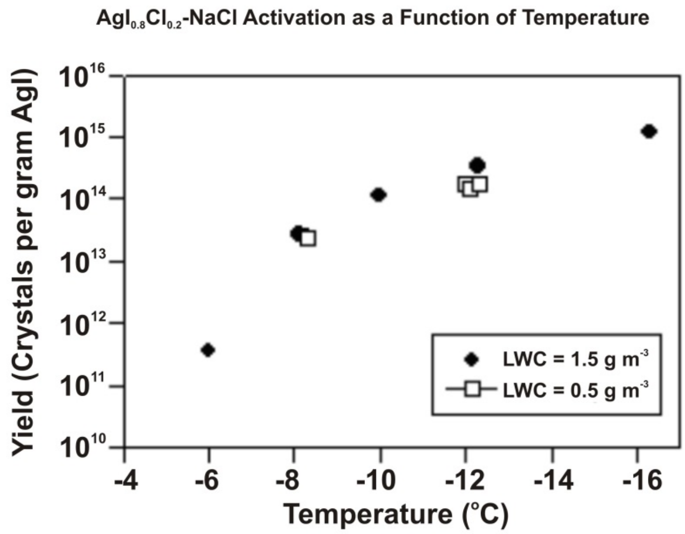

Figure 9. Yield as measured by the number of active ice nuclei per gram of silver iodide (AgI) burned, is shown as a function of temperature (DeMott 1997). These nuclei are comprised of silver iodide, silver chloride, and salt (NaCl).

It was previously mentioned that this seeding solution is "high-performance". This means that unlike simpler solutions that produce a simple AgI nucleus, this high performance solution produces nuclei that contain salt, which enables them to function by the condensation-freezing mechanism. The non-salty, simple AgI nucleus functions by the contact-freezing mechanism. The differences between the two are as follows:

Contact-freezing. For this freezing process to occur, the ice nucleus must come into contact with a supercooled cloud droplet (≤ -5°C). The speed at which this type of nucleation occurs depends upon the density of the water droplets in the cloud. Clouds with a lesser liquid water content contain fewer droplets, so it takes much longer for the chance collisions between the AgI nuclei and water droplets to occur, resulting in slower nucleation of the cloud. In clouds with greater liquid water content cloud droplets are plentiful, so nucleation occurs more quickly. After the ice nucleus and supercooled water droplets make contact, the droplets freeze and can continue to grow by other ice-phase growth processes: deposition, accretion, and aggregation.

Condensation-freezing. Nuclei of this type attract water vapor and immediately form water droplets, eliminating the requirement for collisions between ice nuclei and cloud droplets. As soon as the droplets containing these nuclei cool to at least -5°C, freezing results. Unlike the contact-freezing process, the speed at which this type of nucleation occurs does not depend upon the density of the water in the cloud. As soon as freezing occurs, the new ice particle can grow by other ice-phase growth processes.

The nucleation advantage of the more complex solution used in the Wind River operations is considerable, especially in clouds having lesser liquid water. The sole disadvantage of the complex seeding solution is that, containing salt, it is more corrosive than the simpler solution. Using the more complex seeding solution requires generators designed to burn it. The generators must be equipped with corrosion-resistant stainless steel tanks, lines, and fittings to avoid operational failure, and require more frequent maintenance.

2.5 Atmospheric Soundings (Weather Balloons/Rawinsondes)

Weather balloons were released from the WMI shop, in Pinedale, WY to help determine whether or not weather conditions were suitable for seeding, e.g.; Figure 10. Each balloon carried a miniaturized weather probe that measured temperature, humidity, and pressure. In addition, the GPS position of the balloon was also recorded. The atmospheric sounding data were recorded and compared to the operating criteria to verify that observed weather conditions were sufficient to initiate cloud seeding procedures.

Each sounding required approximately one hour to travel from the surface to the 100 hPa level (an altitude of about 53,000 feet). Upon completion, the sounding data were immediately shared via e-mail with the National Weather Service Offices in Riverton and Cheyenne, and the State of Wyoming's Water Resources Data System (WRDS). All of the soundings were archived, and are available for any post-analysis efforts that might be undertaken.

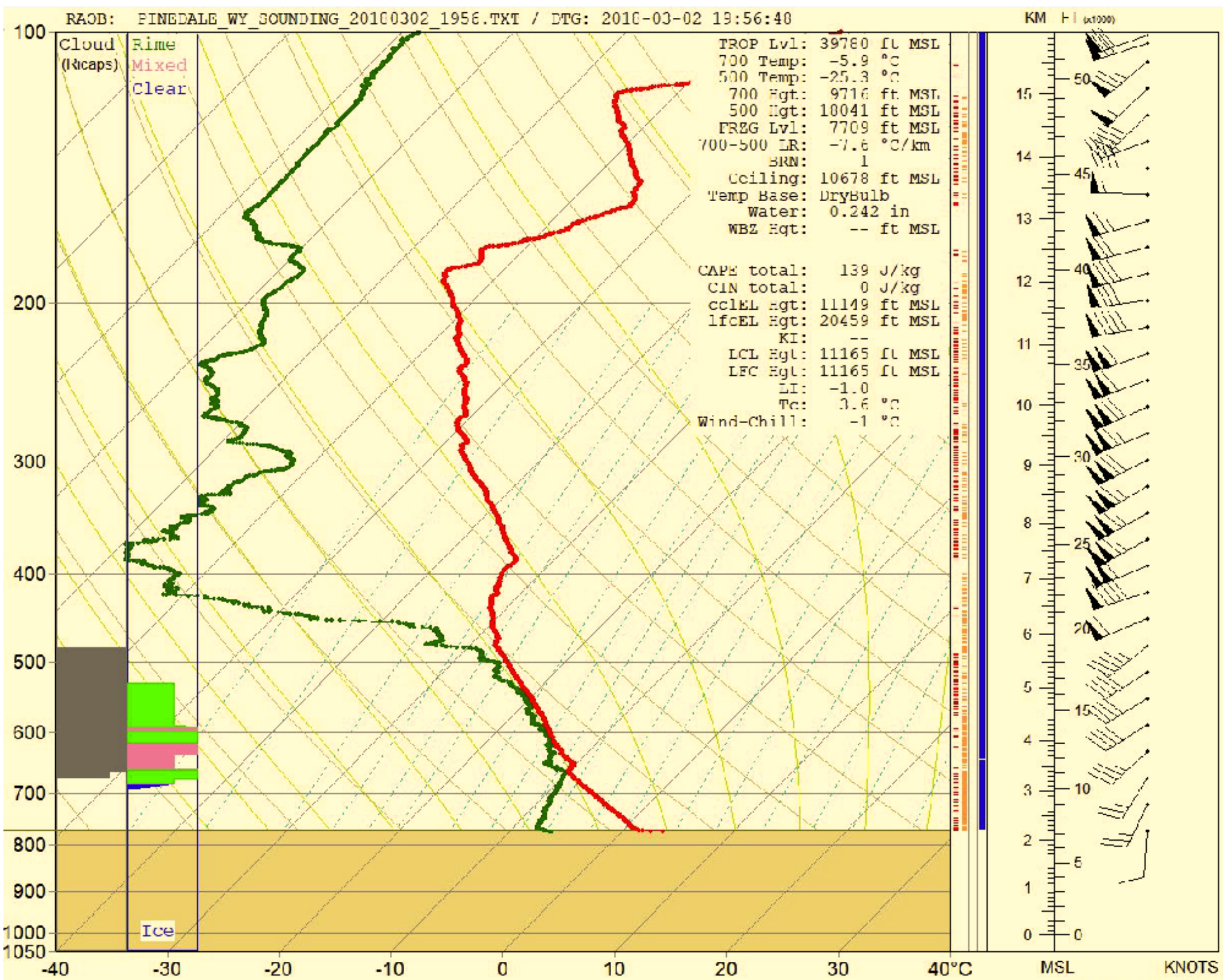

Figure 10. A plot of the upper-air sounding obtained from the weather balloon released from Pinedale, WY at 12:56 pm MST (19:56 am UTC) on 2 March 2018. The temperature at 700 hPa level (approximately 10,000 feet) was -6°C (+21°F), and the wind speed was from 255° (westerly) at 30 knots (~35 miles per hour), both within the acceptable range for seeding.

2.6 Weather Stations

Two generator sites were equipped with Vaisala WXT-510 weather stations, Enterprise and White Acorn Ranch. These compact, tower-mounted instruments measured temperature, humidity, pressure, and wind speed and direction. Data storage of each station was limited to 8 hours; therefore technicians downloaded the data at regular intervals during seeding events, using the connection afforded by the generator satellite modem.

2.7 Shop and Site Servicing

Throughout the season WMI maintained a shop in Pinedale that provided storage and served as a staging area for generator service and the preparation and release of weather balloons. The shop housed WMI's 4x4 truck, snowmobiles/trailers, spare generator parts, trouble-shooting equipment, and replacement nitrogen tanks. The Vaisala MW41 rawinsonde system used for the calibration and tracking of the weather balloons was also at the shop, as well as all the upper air consumables: helium, balloons, and rawinsondes. Internet service was available, allowing immediate sharing of upper air data with other interested parties (NWS, WRDS).

3. FORECASTING AND OPERATIONAL DECISION-MAKING

3.1 Meteorological Data Sources

The bulk of the weather information used for forecasting and weather monitoring was obtained from the Internet. Among these sites were those of RAP Real-Time Weather, the National Center for Environmental Prediction (NCEP), the College of DuPage, European Community satellite imagery, Northern Illinois University, and Unisys. While many of the web-based weather products (i.e., National Weather Service (NWS) products) were publicly available, some data sources were project-specific. This year WMI also implemented a fully-operational numerical model for the project; this is discussed in detail later in this section.

Radiometer. The WWDO radiometer was deployed at a residence near Boulder, WY. Since the presence of liquid water in the clouds over the target area is essential for successful seeding, this measurement was most helpful. The radiometer location for this winter season was the same as was used during the Wyoming Weather Modification Pilot Project, and also the same as the previous season.

Atmospheric Soundings. Weather balloons were released from WMI's Pinedale shop whenever there was doubt about the 700 hPa temperature, that is, if it was cold enough to seeding to be effective (Figure 11). The atmospheric soundings (weather balloons/rawinsondes) were discussed in Section 2.5. Data from the soundings were immediately shared with the NWS and WRDS.

Figure 11. Meteorologist Dan Gilbert checks a weather balloon to verify that it has enough lift, prior to tying it off and attaching the meteorological instrument package. Sensors measured temperature, humidity, pressure, and position. Minute-to-minute changes in position were used to calculate wind speed and direction. (WMI photograph by Bruce Boe.)

3.2 Numerical Modeling

WRF Modeling. For the 2017-2018 season, WMI added runs of the Weather Research and Forecasting (WRF) model specifically tailored to the Wind River seeding program, running a 2.5 km resolution grid initialized with the High Resolution Rapid Refresh (HRRR) model and using the North American Model (NAM) for boundary conditions at 3-hour intervals. A large number of graphical outputs were developed specifically to aid the cloud seeding decision-making. Examples of some of the most unique, the meteorologists' favorites, are shown in the figures that follow. Figure 12 shows forecast cloud water colder than -5°C over the Wind River Range.

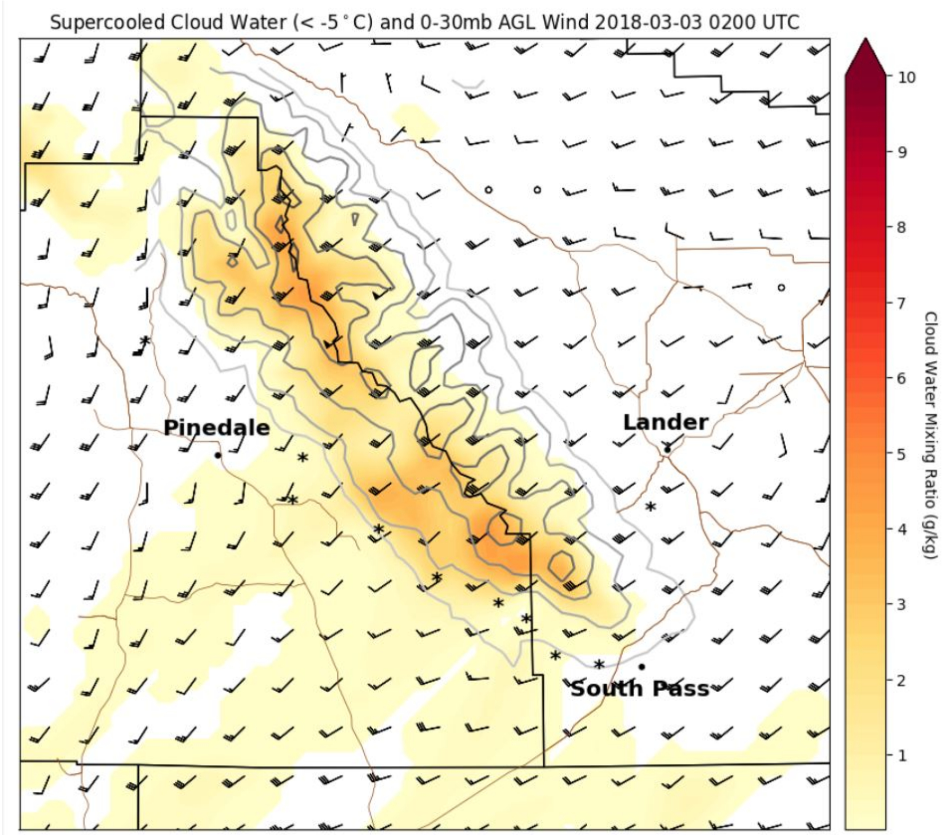

Figure 12. Wind barbs are shown with cloud water mixing ratio on this panel from the WMI WRF model, valid on 3 March 2018, at 02:00 UTC. Since the water shown is only that occurring at -5°C and colder, it is supercooled sufficiently for seeding. The WMI WRF was initialized and run every six hours; output (plots such as this) were created for hourly intervals. Contours are elevation at 1,000 foot intervals.

Though knowing the SLW distribution shown in Figure 12 is very helpful in determining which of the 10 ground-based generators should be activated, it is also very helpful to know the vertical distribution of SLW and cloud ice, as well as the height of the -10°C isotherm. This information was also available to the project meteorologists in the form of vertical cross-sections (Figure 13).

The meteorologist could examine the evolution of SLW and cloud ice along four different cross sections. One was along the continental divide, northwest to southeast. Another was from the Green River generator site, approximately perpendicular to the orientation of the Wind River Mountains. A third was from the Pocket Creek generator site, perpendicular to the range, and the fourth was west-to-east through the central portion of the range.

The example shown in Figure 13 for March 2nd and 3rd is for the Pocket Creek cross section, illustrated in Figure 14. In the upper panel, at 16:00 UTC (9:00 AM MST), a very nice region of cloud water is shown. Note that the region lies entirely above the -10°C isotherm, so all of the SLW is supercooled—perfect for seeding. The position is also very favorable, being to the left (upwind) of the range. This allowed the seeding agent to initiate the development of ice—and thus precipitation—in time for it to fall on the target.

In the lower panel, ten hours later (at 02:00 UTC, or 7:00 PM MST) some SLW still remains, but the amount is considerably diminished. Originally, the SLW content was greater than 0.5 g kg^{-1}. In the lower, later panel, the content had dropped to less than half that, and considerable cloud ice was predicted to have formed over the crest and well-upwind of the range. With real-time web access the images shown in Figures 12-14 can be animated in 1-hour time steps, providing an understanding of expected storm evolution.

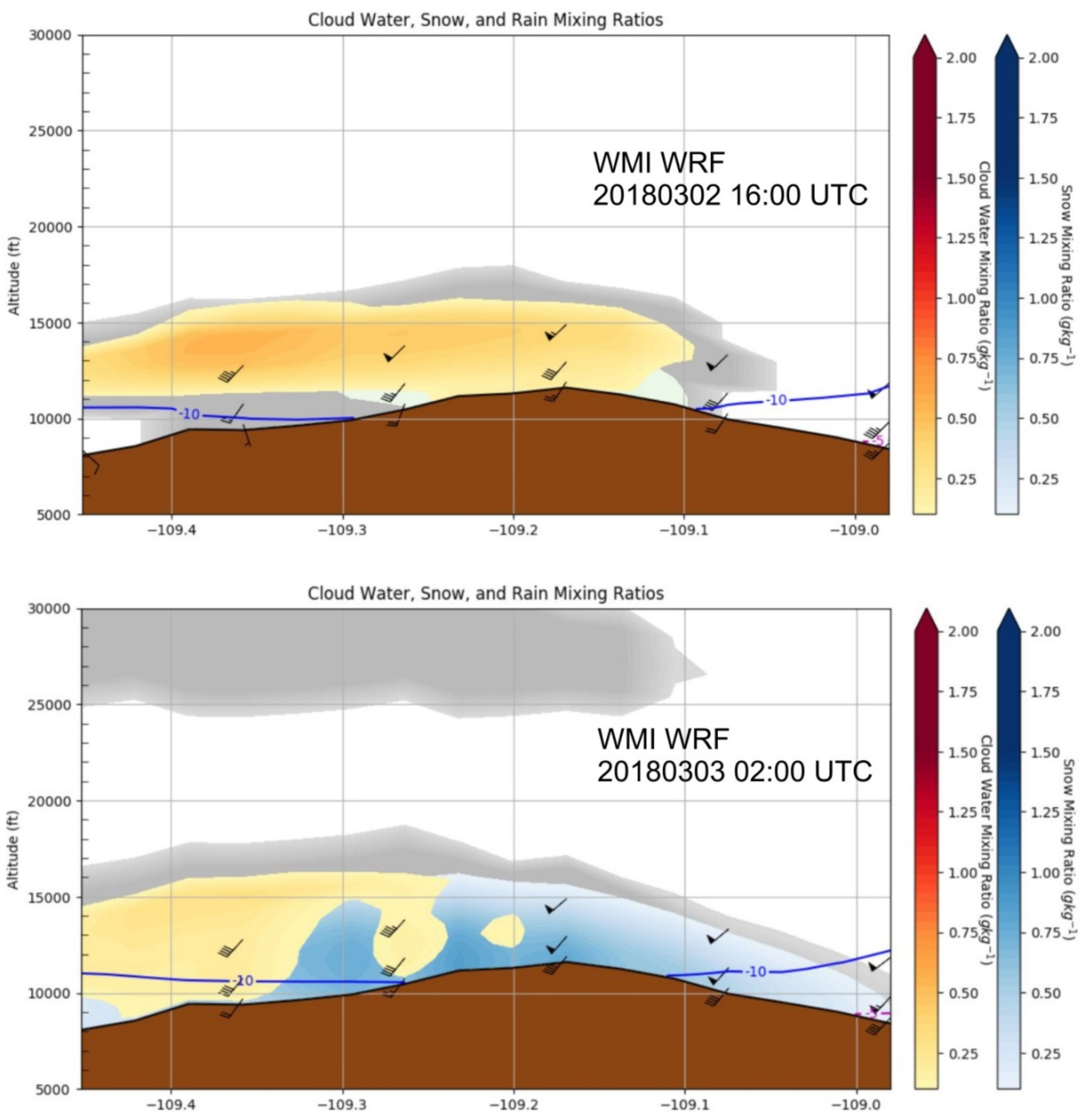

Figure 13. Vertical cross sections through the Pocket Creek generator site, approximately perpendicular to the axis of the Wind River Mountains. The top panel represents 16:00 UTC on March 2nd, or 9 AM MST, the bottom is ten hours later at 02:00 UTC March 3rd, or 7 PM MST on March 2nd. See text for interpretation and discussion.

Simulated radar reflectivities are shown in Figure 14, along with the location of the Pocket Creek vertical cross section. These simulated "echoes" help the meteorologist anticipate the spatial development of cloud and precipitation.

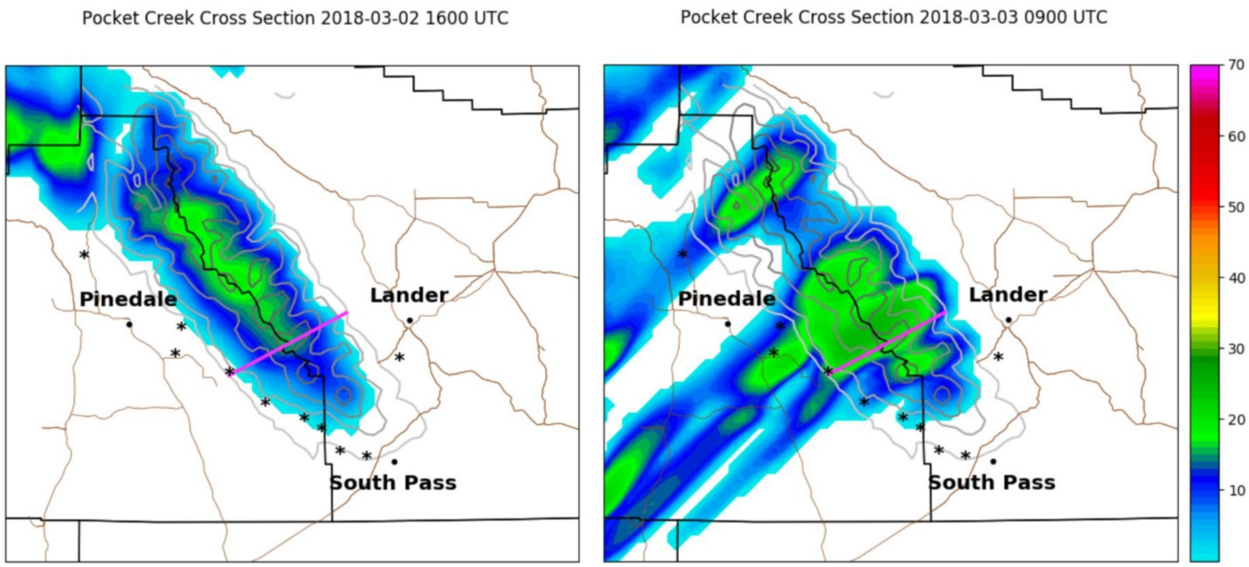

Figure 14. Simulated radar reflectivity (dBZ) is shown for 16:00 UTC (9:00 AM MST) on March 2nd, left, and 09:00 UTC (02:00 AM MST) March 3rd, right. The position of the Pocket Creek cross sections depicted in Figure 14 is depicted by the pink line. The radar reflectivity does not differentiate between cloud water and cloud ice. Most often, the best seeding conditions are found when cloud (and echo) are limited to the range (left). When winter systems become widespread or "deep", natural ice becomes more prevalent and seeding conditions deteriorate.

HYSPLIT Modeling.

During the 2016-2017 season, WMI ran the Hybrid Single-Point Lagrangian Integrated Trajectory (HYSPLIT) plume dispersion model to establish a better idea of seeding agent plume behavior. On days when seeding was thought likely, the plume trajectory model was initialized with WRF data and used as a tool to help make better-informed seeding decisions.

For the 2017-2018 season, the process was automated, and run daily with each update of the WRF, providing a complete record of predicted plume trajectories for the seasons. These HYSPLIT plots were output in one-hour increments, with each plot showing forecast locations of plume centerline (the most dense portions of the plumes) for four hours. A series of such plots is provided as Figure 15, for the March 2nd-3rd seeding event. In the plots, each hour is shown by a "dot" on the plume centerline.

Stability throughout the Wind River domain was made part of the suite of products created during the WMI WRF model runs, as depicted in Figure 16. The meteorologists also considered Froude Number to determine if the plume(s) would go over the range or be blocked by it, and consulted the HYSPLIT plots, which reinforced the other indications. Thus, if cloud and temperature conditions were favorable, seeding would occur only if the seeding agent was likely to reach its intended destinations!

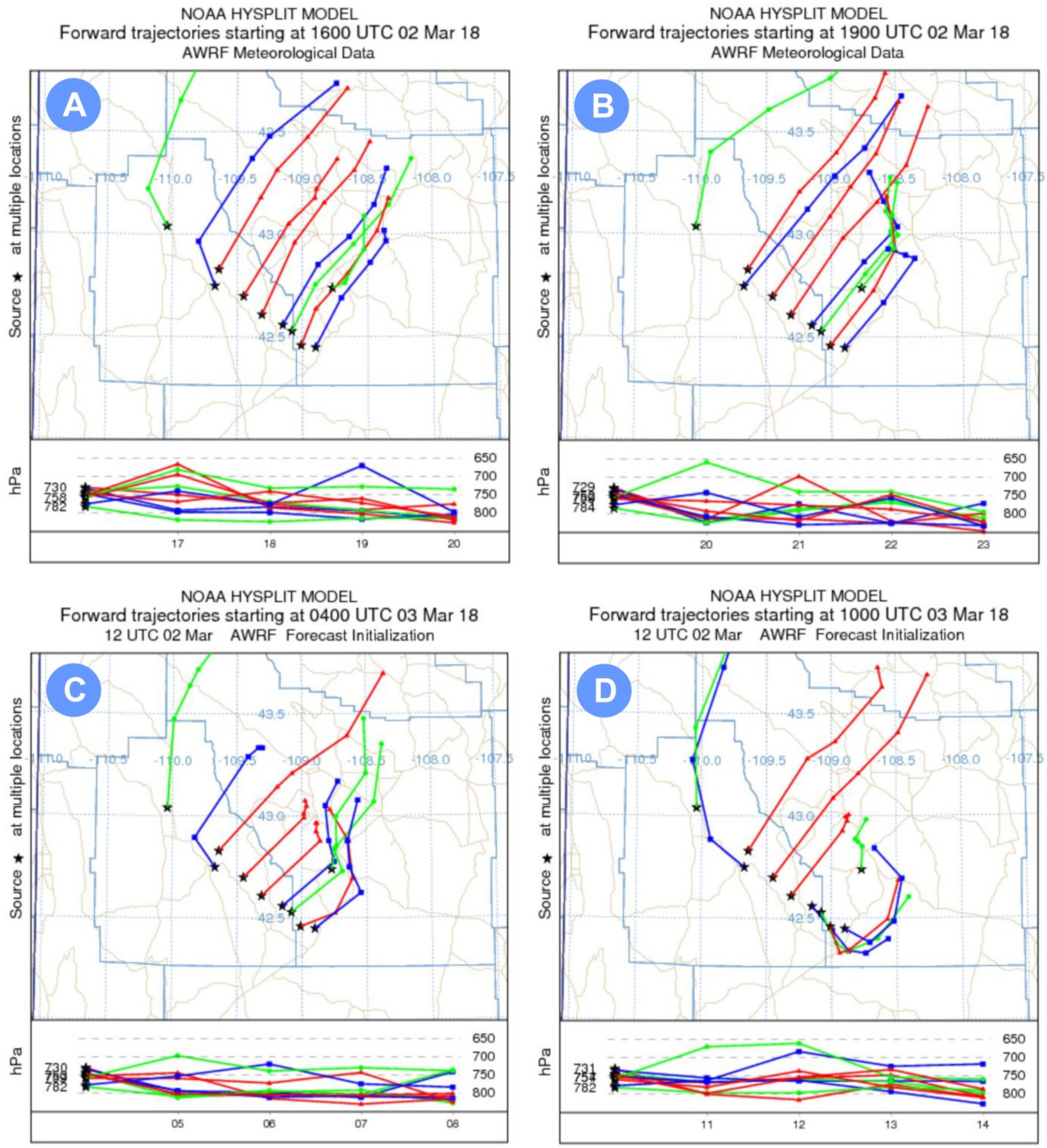

Figure 15. The evolution of the centers of plume trajectories is shown for the seeding event on March 2nd-3rd, 2018. Times (UTC) are as follows: (A) 16:00 March 2nd, (B) 19:00 March 2nd, (C) 04:00 March 3rd, and (D) 10:00 March 3rd. Each "dot" on each plume line shows the projected position at one-hour intervals, so for each plume, a total of four hours is shown. As the seeding began (A), most plumes were projected to flow directly over the Wind River Mountains, the exception being Green River (green line, farthest north and west), and East Fork (blue line, second-closest to Green River). In (B) winds have strengthened enough that all plume go directly over the crest, except for Green River, but even Green River has turned south enough to pass over the range. By 04:00 UTC (C), flow has weakened enough that Green River and East Fork have turned northerly, and plumes from Sweetwater and Anderson Ridge (red and blue, southernmost generators) are starting to flow more easterly, around the range, not over it. By (D) at 10:00 UTC, only plumes from the Big Sandy Opening, Pocket Creek, and Boulder Lake generators would flow over the crest. Cloud conditions had deteriorated well prior, however, so seeding was no longer in progress by that time.

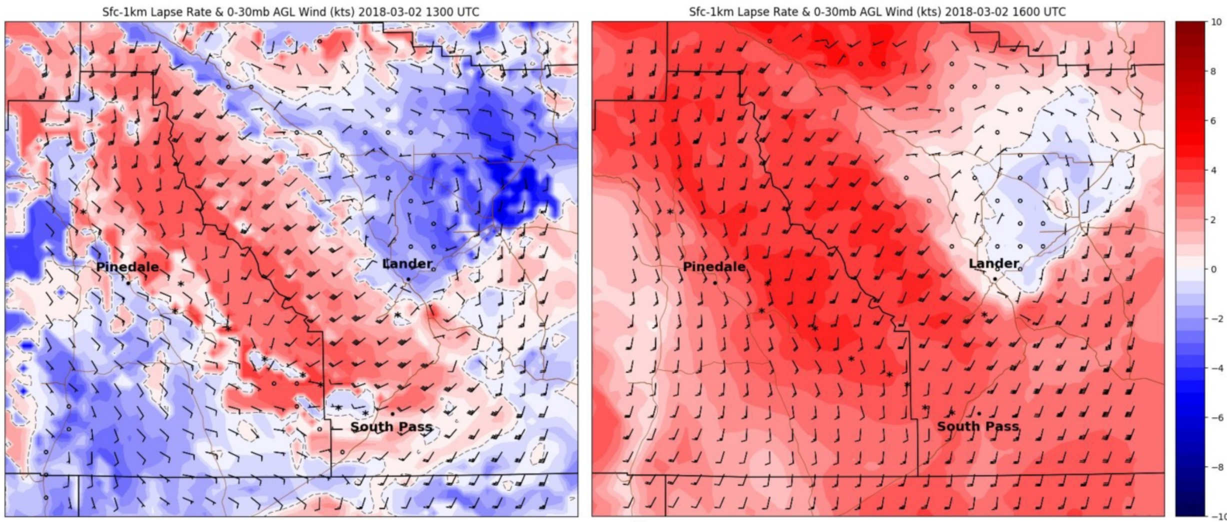

Figure 16. Another product developed specifically for winter orographic seeding is the vertical temperature lapse rate plot of the lowest 1 km (~3,000 feet), shown here. In these graphics, a negative change (blue) indicates increasing temperature with height (warming), while reds and pinks indicate cooling. Thus, the redder the area, the more easily air (seeding plumes) is mixed from below. The left panel shows lapse rates at 13:00 UTC, several hours before seeding began. More than half of the generators were within stable air at the time. The right plot shows how conditions had become more favorable (less stable) by 16:00 UTC, when seeding began.

3.3 Timetables and Routines

If seeding was not underway at dawn, the following daily routine ensued.

WMI furnished a daily "first glance" update that provided an outlook into the probability of seeding operations taking place that day. This very simple form, sent to all project personnel, provided an early look at the weather expected each day. Four time periods were specified, from issuance until noon, from noon until sunset, from sunset until midnight, and from midnight until dawn the next day. The probability of seeding operations occurring in each of these time periods was rated by the forecaster as no chance, unlikely, possible, or probable. Technicians used this outlook to help inform equipment operation and maintenance decisions. In instances when seeding operations were already active in the morning, the "first glance" outlook would still be issued, reflecting the status of current operations.

The "first glance" update was followed by a much more detailed forecast and weather briefing, typically disseminated to the WWDO and all funding partners by late morning via email. These daily briefings included a summary of the preceding day's weather and seeding activities, a summary of the current synoptic-scale weather pattern, and conditions likely to exist for the next 24 hours in the Wind River Range. Oftentimes weather conditions would vary sufficiently during the day that evening forecast updates were warranted and provided. The Daily Wyoming Wintertime Scale (DWWS), shown in Table 1, numerically categorized the probability of seeding operations occurring.

The seeding criteria were straightforward. First, 700 hPa temperature, meaning temperature near the cloud elevation at about 10,000 feet, had to be equal to, or less than -6°C (+21.2°F). Secondly, there had to be SLW present in the clouds. Finally, wind speeds needed to be strong enough to transport seeding agent from the generator upward into the mountains. Wind direction was also taken into account, as it helped inform which generators would be activated.

The first criterion, temperature, was first determined by consulting the most recent prognostic numerical modeling runs. When such consultation yielded uncertain results, that is, temperatures at 700 hPa not clearly -6°C or colder, a weather balloon sounding was released from Pinedale, WY (Section 2.5, Figure 10).

TABLE 1. The Daily Wyoming Wintertime Scale

DWWS	SEEDING	METEOROLOGICAL DESCRIPTION
-3	*No*	Clear skies, or clear with isolated upper-level cloudiness.
-2	*No*	Occasionally clear, with cirrus, cirrostratus; or altostratus with bases above
-1	*No*	Limited coverage or short-lived orographic clouds, not enough temporal or spatial
0	*Possible*	Some orographic clouds or stratiform cloud deck(s) over mountain tops. SLW likely
+1	*Yes*	Orographic clouds and/or stratiform cloud deck(s) enshrouding mountain tops, winds
+2	*Yes*	Persistent orographic clouds and/or stratiform cloud deck(s) enshrouding mountain

The presence of SLW was confirmed by the real-time data from the radiometer (Section 3.1) located near Boulder, WY. The wind speed and direction were obtained from the numerical models, except when atmospheric soundings were done.

When all three conditions were satisfied, seeding was initiated by the meteorologist and the generator technician. The meteorologist would communicate to the technician which generators should be activated, when, and for how long. The length of time a generator was activated depended upon how long weather conditions remained favorable. Once seeding was initiated, the meteorologist would begin tracking the real-time weather conditions that would impact seeding duration. If wind direction changed, some generators could be deactivated while others would be turned on. When favorable weather conditions ended, the technician would be directed to shut down all remaining active generators.

4. OPERATIONS

4.1 2017-2018 Season

The 2017-2018 cloud seeding season again encountered an administrative hurdle. Though operations were schedule to begin on December 1, 2017, delays in finalizing the contract pushed that back to December 9th. Thus, the 2017-2018 season was only active for 95 days. During those days that operations were possible, seeding was conducted on eighteen occasions, as enumerated in Table 2.

December, February, and March each had five seeding events, while January had three. The east-slope Enterprise generator was used twice, once in December, and once in March. Table 3 summarizes operations by month and provides season totals. In total, 32.189 kg of seeding agent were released. Generators were operated for a total of 192:34 hours during the season, accruing a total of 1,231:34 generator hours. [Generator hours are calculated by summing the number of hours each generator was operated. For example, six generators operated for five hours yields thirty generator hours.] Twelve of the eighteen seeding events were quality opportunities in which seven or more generators were operated.

TABLE 2. 2017-2018 Seeding Events						
Date	*Number of Generators Utilized*	*Length of Seeding (hours)*	*Total Seeding (hours)*	*AgI Released This Date (kg)*	*AgI Monthly Total (kg)*	*AgI Season Total (kg)*
20-Dec-17	7	4:25	30:46	0.845	8.468	0.845
21-Dec-17	1	3:36	3:36	0.077		0.922
23-Dec-17	7	24:00	167:23	4.539		5.460
25-Dec-17	7	11:14	77:33	2.299		7.760
27-Dec-17	4	6:24	25:35	0.708		8.468
12-Jan-18	7	11:03	77:17	1.955	4.002	10.423
25-Jan-18	9	5:46	45:57	1.199		11.622
26-Jan-18	5	6:35	32:52	0.848		12.470
8-Feb-18	6	5:44	33:33	0.881	10.414	13.351
15-Feb-18	6	12:00	71:49	1.908		15.259
17-Feb-18	7	5:01	34:39	0.921		16.179
18-Feb-18	9	21:44	179:53	4.766		20.945
26-Feb-18	9	12:56	77:37	1.939		22.884
2-Mar-18	9	30:20	173:01	4.197	9.305	27.080
4-Mar-18	9	12:14	70:42	1.756		28.837
9-Mar-18	7	4:12	29:24	0.779		29.616
17-Mar-18	9	10:37	95:14	2.446		32.063
26-Mar-18	1	4:43	4:43	0.127		32.189

TABLE 3. Summary of Seeding Events During the 2017-2018 Winter Season					
Month	*Events ( ) denotes easterly flow*	*Event Averages*		*Seeding Agent (kg)*	
		Number of Generators	*Generator Hours**	*Average Released per Event*	*Total Released*
December	5 (1)	5.2	60.98	1.69	8.468
January	3	7.0	52.03	1.33	4.002
February	5	7.4	79.50	2.08	10.414
March	5 (1)	7.0	74.61	1.86	9.305
Totals/Averages	*18 (2)*	*6.6*	*68.42*	*1.79*	*32.189*
**generator hours = sum of the hours each generator was run for each event, e.g., 4 generators each operated for 3.5 hours = 14 generator hours.*					

Table 4 shows the activity of each of the ten generators on a case-by-case basis. Each seeding event has two rows, the top indicates whether or not each generator was requested (REQ), and the bottom whether or not the generator ran (RAN). Ideally, every time a generator was requested it would run for the entire duration of the event. If a generator was requested to operate, a "Yes", "No", or "Partial" comment would be denoted in the appropriate (RAN) row.

This season was characterized by the best performance on record, with only two generator failures, and no "partial" runs! Not once did more than one generator fail in the same event. Eight generators ran perfectly all season, only East Fork and Green River had any problems, and then, just once, each.

The generator performance for the season was excellent, at 98.3% functionality.

TABLE 4. Ice nucleus generator operations are shown for each of the eighteen seeding events.

Wind River Range			WR01 Big Sandy	WR02 Block & Tackle	WR03 White Acorn	WR04 Sweetwater	WR05 Anderson	WR07 Enterprise	WR09 Boulder Lake	WR10 East Fork	WR12 Pocket Creek	WR13 Green River	#Ggens Called	#Ggens Active
20171220	WRR0063	REQ	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
20171221	WRR0064	REQ	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	1	
		RAN	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO		1
20171223	WRR0065	REQ	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
20171225	WRR0066	REQ	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
20171227	WRR0067	REQ	YES	NO	NO	NO	NO	NO	YES	NO	YES	YES	4	
		RAN	YES	NO	NO	NO	NO	NO	YES	NO	YES	YES		4
20180112	WRR0068	REQ	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
20180125	WRR0069	REQ	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	YES	YES	YES	YES	YES	NO	YES	YES	YES	NO		8
20180126	WRR0070	REQ	YES	NO	NO	NO	NO	NO	YES	YES	YES	YES	5	
		RAN	YES	NO	NO	NO	NO	NO	YES	YES	YES	YES		5
20180208	WRR0071	REQ	YES	YES	NO	NO	NO	NO	YES	YES	YES	YES	6	
		RAN	YES	YES	NO	NO	NO	NO	YES	YES	YES	YES		6
20180215	WRR0072	REQ	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	NO	YES	YES		6
20180217	WRR0073	REQ	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
20180218	WRR0074	REQ	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES		9
20180226	WRR0075	REQ	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES		9
20180302	WRR0076	REQ	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES		9
20180304	WRR0077	REQ	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
20180309	WRR0078	REQ	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
20180317	WRR0079	REQ	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES		9
20180326	WRR0080	REQ	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	1	
		RAN	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO		1
												TOTALS	118	116
													RUN =	98.3%
													FAIL =	1.7%

ZULU DATES ONLY
PARTIAL = > 25% of Expected Runtime

4.2 Comparisons with Previous Seasons

Comparisons of the three seasons of operational cloud seeding are provided in Tables 5 and 6. In Table 5, the lengths of seeding operations in each month are provided. Each season was different. In terms of actual number of hours with seeding operations, the 2015-2016 season tops the list. However, when one compares the hours of seeding conducted each season (Table 6), the 2016-2017 season was far above the others, 400 hours more than the 2015-2016 season.

TABLE 5. Hours of Seeding

	Nov	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*Season*
2014-2015	10:13	83:45	24:08	36:47	25:21	20:12	200:26
2015-2016	41:28	66:07	49:56	60:30	62:00	9:54	289:55
2016-2017	NA	120:22	63:12	58:53*	SUSP	NA	242:27
2017-2018	NA	49:37**	23:24	57:25	62:06	NA	192:54
Mean	25:50	79:57	40:18	58:09	49:49	15:03	231:26

**Project was suspended on February 11th, 2017.*
***Project started on December 9th, 2017, not December 1st.*

The 2017-2018 season had the fewest hours during which seeding has been conducted during a season (Table 5), but more seeding hours, that is, more generators were operated during those opportunities (Table 6) than either of the first two seasons. Viewed another way, it can be said that full advantage is being taken of those opportunities that present themselves.

TABLE 6. Hours of Ice Nucleus Generator Operation

	Nov	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*Season*
2014-2015	71:43	377:52	125:51	36:47	219:54	20:12	852:19
2015-2016	86:21	375:03	328:57	180:56	191:31	9:54	1172:42
2016-2017	NA	815:05	396:22	406:57*	SUSP	NA	1618:24
2017-2018	NA	304:53**	156:06	397:31	373:04	NA	1231:34
Mean	79:02	468:13	251:49	246:21	255:33	15:03	1218:45

**Project was suspended on February 11th, 2017.*
***Project started on December 9th, 2017, not December 1st.*

It is here noted that since the inception of operational seeding in the Wind River Mountains in the winter of 2014-2015 WMI has significantly improved the guidance available to its meteorological team, especially through numerical modeling products specifically-tailored to assist winter orographic cloud seeding. With these tools, we believe we are now more selective in our operational decision-making. We are also likely more responsive to shorter-term opportunities, and to changing conditions as storms pass.

5. OUTREACH

Whenever possible WMI likes to be receptive to requests to educate those showing an interest in our field efforts. As with previous seasons, WMI was approached by the Sublette County Conservation District (SCCD) during the 2017-2018 season to provide outreach regarding meteorological aspects of cloud seeding in the Wind River Range. WMI meteorologist Dan Gilbert, and the SCCD arranged for local students to visit the WMI shop in Pinedale and learn about the project and upper air soundings, and even to participate in the release of a weather balloon. This event was planned with and coordinated through the WWDO. WMI appreciates being asked to take part in this type of educational outreach, and has gladly conducted such events. It is important to WMI to be receptive to requests to educate those showing an interest in our weather modification efforts.

WMI also presented an update on the 2017-2018 Wind River operational seeding efforts at the Wyoming Weather Modification Technical Advisory Team (TAT) meeting held in Cheyenne, WY on February 6th, 2018. The TAT, initially organized by the WWDO to provide technical advice and support for the WWMPP, is largely comprised of representatives of interested State and Federal agencies. Wyoming agencies include the State Engineer's Office, the Department of Environmental Quality, the Department of Transportation, the University Office of Water Programs, and the Game and Fish Department. Federal agency representation includes several different forests (Bridger-Teton, Shoshone, and Medicine Bow), the U.S. Geological Service, the NWS Riverton and Cheyenne offices, the Bureau of Land Management, and the Natural Resources Conservation Service.

6. SUMMARY

The 2017-2018 cloud seeding effort in the Wind River Range began on December 9th, 2017, and officially concluded on 31 March 2018, a duration of nearly 4 months. The season started eight days later than intended due to a delay in finalizing the collaborative weather modification agreements. The conclusion date of 31 March 2018 was planned as a measure to address funding constraints and keep the Wind River Range cloud seeding program up and running during the heart of the 2017-2018 winter season.

There were no seeding suspensions during the season.

Eighteen seeding events were conducted between December 9th, 2017, and March 31st, 2018. All but two events involved the use of four or more generators, seeding in westerly or southwesterly flow. Twelve of the events utilized seven or more generators. A total of 32.19 kg of silver iodide was released in the course of 1,231 hours of generator operations.

The ice nucleus generators operated reliably, seeding as intended over 98% of the time. Only two generators experienced any performance issues, and each of those, only once.

In terms of hours of seeding generator operations, the winter was about average. In spite of a slow January, the season ranked second (out of four) in terms of total hours of generator operations.

7. LIST OF TERMS AND ACRONYMS

Where applicable, definitions are those provided by the *Glossary of Meteorology*, published by the American Meteorological Society (2000), and are used by permission.

Accretion	See ***riming***.
Aerosol	A system in which particles, either solid or liquid, are dispersed in within a gas, usually air.
Ag	The chemical notation for silver.
AgI	See ***silver iodide***.
Aggregation	The process of clumping together of snow crystals following collision as they fall, to form snowflakes.
AGL	Above ground level
ASCE	American Society of Civil Engineers
BTAC	Bridger-Teton Avalanche Center
CAP	Central Arizona Project
CCN	Cloud condensation nucleus
CSU	Colorado State University
DWWS	Daily Wyoming Wintertime Scale, a number from -3 to +2 indicating the likelihood of seeding operations.
GPS	Global Positioning System
Glaciogenic seeding	Cloud seeding with ice-forming aerosols
Ground generator	See ***ice nucleus generator***.
hPa	Hectopascal, equivalent to one millibar, the common unit used to measure atmospheric pressure. Pressure decreases as altitude increases; standard sea level pressure is 1,013.25 hPa, 850 hPa equates to approximately 5,000 feet (1,500 m) elevation, and 700 hPa, about 10,000 feet (3,000 m) above mean sea level.
Ice nucleus	Any particle that serves as a nucleus leading to the formation of ice crystals, without regard to the particular physical processes involved in the nucleation.
Ice nucleus generator	The remotely-controlled machines that burn a silver iodide solution to produce the ice nuclei that "seed" clouds containing ***supercooled liquid water***.
IN	See ***ice nucleus***.
mb	Millibar, same as hectopascal (***hPa***)
MOU	Memorandum of Understanding
MSL	Above mean sea level
NaCl	The chemical notation for sodium chloride, common table salt
NCAR	National Center for Atmospheric Research, Boulder, CO

NCEP	National Centers for Environmental Prediction, a set of NOAA research centers.
NOAA	National Oceanic and Atmospheric Administration, U.S. Department of Commerce
NRCS	Natural Resource Conservation Service, an agency of the U.S. Department of Agriculture
NWS	National Weather Service, U.S. Department of Commerce
OSLI	Office of State Lands and Investments
PNA	The airport and meteorological station identifier for Pinedale, Wyoming.
Precipitation efficiency	Expressed as a percentage, the ratio of the quantity of precipitation produced by a cloud to the total water condensate produced by the cloud.
Prognostic	A model used to predict future weather conditions. For example, model output showing the expected conditions over a specific area at a specified future time. The *RT-FDDA* model was run in a predictive mode.
Radiometer	A passive (non-transmitting) instrument that measures liquid water and water vaper in the atmosphere.
RAL	Research Applications Laboratory, NCAR, P.O. Box 3000, Boulder, CO 80307
Rawinsonde	Commonly called a ***weather balloon***, the rawinsonde is a small package of weather instruments carried aloft by balloon. Vertical profiles of temperature, humidity, and winds are obtained as a function of pressure.
Riming	The growth of an ice particle by the collision with ***supercooled*** cloud droplets that freeze wholly or partially upon contact.
RIW	The airport and meteorological station identifier for Riverton, Wyoming.
RT-FDDA	Real-time Four Dimensional Data Assimilation, a version of the WRF model run by NCAR
Silver iodide	An inorganic chemical compound, AgI, that has a crystalline structure (symmetry, lattice spacing) similar to ice and a very low solubility in water, and can be easily generated as an aerosol.
SLW	See ***supercooled liquid water.***
SNOTEL	Sites instrumented, operated, and maintained by the ***NRCS***, to measure precipitation, ***SWE*** and other related parameters in the mountains.
SCCD	Sublette County Conservation District, Pinedale, WY
Supercooled liquid water	Liquid water at a temperature below the freezing point.
SWE	Snow water equivalent, the water content of snow, commonly expressed in depth (inches)
TAT	The Wyoming Weather Modification Pilot Project ***Technical Advisory Team***, comprised of representatives of federal, state, and local agencies interested in or affected by the project.
Upslope	A term describing flow from a direction other than the climatological norm that produces orographic cloudiness and precipitation. In this report, the term refers to easterly flow against the Wind River Mountains, contrary to the westerly flow that generates the majority of the range's precipitation.

USDA	U.S. Department of Agriculture
USFS	U.S. Forest Service
UTC	Universal Time Coordinates, formerly known as Greenwich Mean Time, and Zulu time.
UW	The University of Wyoming
WMI	Weather Modification, Inc., 3802 20th Street North, Fargo, ND 58102
WR	Wind River Mountain Range
WRDS	Water Resources Data System, University of Wyoming, Dept. 3943, 1000 E. University Ave., Laramie, WY 82071
WRF	The Weather Research and Forecasting numerical model
WRR	Wind River Range, Wyoming
WSEO	Wyoming State Engineer's Office, responsible for the issuance of Wyoming cloud seeding permits
WWDC	Wyoming Water Development Commission, the state body directing the WWDO
WWDO	Wyoming Water Development Office, 6920 Yellowtail Road, Cheyenne, WY 82002
WWMPP	Wyoming Weather Modification Pilot Project

8. REFERENCES

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Appendix A. Daily Operations Summaries

Wyoming Weather Modification Wind River Mountains *2017-18 Season – WMI Daily Project Summary*	
08 December 2017, Friday	
The range was mostly clear throughout the period with the only exceptions being some very isolated wispy cirrus passing through during the afternoon and a small wave of high clouds that moved through around midnight. Max/Min temperatures PNA: 45/5 RKS: 41/21 LND: 46/17 Observed DWWS: -3	No ground-based seeding was conducted.
09 December 2017, Saturday	
The region was mainly clear throughout the day with some small isolated cirrus clouds during the afternoon. Cirrus coverage increased in the evening and overnight hours. Some elevated arch clouds formed over the central and southern range overnight with bases far above the peaks, and then skies were totally clear again by morning. No precipitation occurred. Max/Min temperatures PNA: 48/21 RKS: 45/20 LND: 43/18 Observed DWWS: -2	No ground-based seeding was conducted.
10 December 2017, Sunday	
Skies were clear throughout the afternoon, and then broken cirrus clouds moved through in the evening starting around sunset. Skies cleared again by midnight and remained mostly clear overnight. There were no orographic clouds observed. Max/Min temperatures PNA: 50/14 RKS: 46/20 LND: 38/15 Observed DWWS: -3	No ground-based seeding was conducted.
11 December 2017, Monday	
Skies were mainly clear during the day with thin wisps of cirrus clouds. In the evening hours, some broken high clouds pushed through briefly with some very brief arch clouds forming as well for an hour or two. Skies cleared	No ground-based seeding was conducted.

again overnight. No precipitation was observed. Warm temps were observed in the lowlands around the range, but the light snow cover prevented temps from climbing above 52 F. Max/Min temperatures PNA: 52/18 RKS: 49/22 LND: 41/11 Observed DWWS: -2	
12 December 2017, Tuesday	
Clear skies during the daylight hours. Multiple cloud layers moved into the area from the north during the early evening hours and continued through the night. Thin, low clouds remained over the range Wednesday morning. Max/Min temperatures PNA: 54/14 RKS: 50/21 LND: 44/16 FWZ: 52/39 Observed DWWS: -1	No ground-based seeding was conducted.
13 December 2017, Wednesday	
Light snowfall began over the region shortly after noon, with some snowfall continuing until close to midnight. The temperature was too warm for seeding operations in the afternoon and the wind flow was not favorable for seeding plume transport. The temperature cooled in the evening but the wind flow was still not favorable for seeding. The clouds cleared during the night with fog forming around the range during the night. Max/Min temperatures PNA: 41/18 RKS: 44/24 LND: 41/27 FWZ: 43/23 Observed DWWS: 0	No ground-based seeding was conducted.
14 December 2017, Thursday	
Fog around the range diminished in the morning. The sky was clear until some high clouds moved in shortly after sunset. High and mid level clouds then continued through the night. Max/Min temperatures PNA: 28/9 RKS: 35/17 LND: 35/16	No ground-based seeding was conducted.

FWZ: 36/16 Observed DWWS: -2	
15 December 2017, Friday	
Waves of high and midlevel clouds passed through during the day with minimal low level clouds and some intervals of clearing. Cloud coverage increased and became lower/thicker during the evening. A cold front pushed through in the late evening. Thick low clouds blanketed the range after midnight with low stratus enshrouding/surrounding the range. Winds were generally very light in the low levels, unfavorable for thick low orographic clouds and seeding. Snowfall began around 8Z, but was mostly over the lowlands surrounding the range rather than over the mountains. Almost no SLW was observed by the radiometer overnight. No seeding occurred. Max/Min temperatures PNA: 39/9 RKS: 44/25 LND: 37/13 Observed DWWS: 0	No ground-based seeding was conducted.
16 December 2017, Saturday	
Low stratus and thick mid/high clouds were present around the range throughout the day with very weak winds and poor orographic lift. Winds shifted to the east (somewhat) around 00z becoming slightly stronger, and orographic clouds developed. However, plume trajectories from Enterprise were indicated to be flowing southward around the range. Winds shifted back to the west around 8z, but then the cloud cover diminished, and coverage was not suitable for operations. Winds and cloud coverage did not line up for a suitable seeding scenario. Light snow was observed off and on through the early morning hours with the best accumulation in the lowlands surrounding the range. Max/Min temperatures PNA: 32/19 RKS: 38/25 LND: 34/24 Observed DWWS: 0	No ground-based seeding was conducted.
17 December 2017, Sunday	
The range was mostly clear in the morning, and then waves of upper level clouds pushed through during the afternoon. High and midlevel clouds increased during the evening and overnight hours, and a few thin, high based orographic clouds were observed late in the period. There were no clouds remotely suitable for	No ground-based seeding was conducted.

seeding operations. Max/Min temperatures PNA: 25/9 RKS: 28/18 LND: 33/16 Observed DWWS: -1	
18 December 2017, Monday	
During the day, a few high and midlevel clouds passed through while orographic clouds formed over the range. These orographic clouds had bases above the peaks and were not quite suitable for seeding with regard to thickness and coverage. Winds remained parallel to the range, and not suitable for seeding throughout the period. Marginal orographic clouds and low/midlevel clouds continued through the night. No seeding occurred. Max/Min temperatures PNA: 32/19 RKS: 37/20 LND: 41/10 Observed DWWS: 0	No ground-based seeding was conducted.
19 December 2018, Tuesday	
Mid level clouds moved in from the west during the afternoon and continued most of the day. There were periods of low clouds at times with some flurries but the temperature was too warm for seeding operations. Orograhic cloud formed over the range early Wednesday morning. Max/Min temperatures PNA: 34/14 RKS: 46/26 LND: 42/22 FWZ: 34/23 Observed DWWS: 0	No ground-based seeding was conducted.
20 December 2017, Wednesday	
Orographic cloud had formed over the range in the morning with light snowfall but the temperature was warmer than the seeding threshold. Cooler air arrived in the afternoon with favorable wind flow allowing for seeding with the western GGEN. Just before sunset, the wind began to change to NE. Favorable seeding conditions for the Enterprise GGEN developed in the early evening until near midnight. Light snowfall continued through the night until after sunrise, mainly over the low lands on the NE side of the range.	Seeding event WRR0063 was called at 1255 MST on 12/20/2017 and began at 1310 MST. <u>Case WRR0063</u> Generators: WR01, WR02, WR03, WR09, WR10, WR12, WR13 Time: 13:10 (12/20) to 17:30 (12/20) MST 20:10 (12/20) to 00:30 (12/21) UTC Duration: 4:25, 30:46 Total Time Seeding: 769.17g silver (13.89 gallons)

Max/Min temperatures PNA: 37/14 RKS: 48/19 LND: 49/17 FWZ: 36/12 Observed DWWS: +2	Seeding event WRR0064 was called at 1854 MST on 12/20/2017 and began at 1857 MST. <u>Case WRR0064</u> Generators: WR07 Time: 18:57 (12/20) to 22:33 (12/20) MST 01:57 (12/21) to 05:33 (12/21) UTC Duration: 3:36, 3:36 Total Time Seeding: 90g silver (1.26 gallons)
21 December 2017, Thursday	
Clear during the afternoon. High clouds moved in after sunset with some around through the night. A few areas of shallow low clouds existed around the range during the night. Max/Min temperatures PNA: 28/5 RKS: 19/10 LND: 16/-2 FWZ: 27/5 Observed DWWS: -1	No ground-based seeding was conducted.
22 December 2017, Friday	
Orographic clouds slowly formed over the range during the morning and early afternoon. The wind flow was a little questionable, but good enough for seeding beginning in the mid afternoon. A high amount of LWP was detected by the radiometer during the afternoon, then mid level clouds moved over and SLW was less but snowfall over the range was heavier. Favorable seeding conditions continued through the night into Saturday morning. Max/Min temperatures PNA: 23/0 RKS: 29/12 LND: 15/-2 FWZ: 27/12 Observed DWWS: +2	Seeding event WRR0065 was called at 1420 MST on 12/22/2017 and began at 1431 MST. <u>Case WRR0065</u> Generators: WR01, WR02, WR03, WR09, WR10, WR12, WR13 Time: 14:31 (12/22) to 14:31 (12/23) MST 21:31 (12/23) to 21:31 (12/24) UTC Duration: 24:00, 167:23 Total Time Seeding: 4184.5g silver (74.6 gallons)
23 December 2017, Saturday	
Continued favorable seeding conditions in the morning and early afternoon. A front moved through causing the wind to shift and be no longer suitable for plume transport over the range. Light snowfall continued over the range until around sunset. The clouds cleared during the evening. Max/Min temperatures PNA: 27/-15 RKS: 30/5	Seeding event WRR0065 continued until 1431 MST on 12/23/2017.

LND: 12/-6 FWZ: 21/-2 Observed DWWS: +1	
24 December 2017, Sunday	
Clear skies gave way to mid and upper level clouds in the evening. Light snow began over the mountains after dusk with low quantities of SLW on the radiometer, but northwest low-level flow was not conducive for seeding operations. Max/Min temperatures PNA: 12/-20 RKS: 23/6 LND: 7/-10 Observed DWWS: 0	No ground-based seeding was conducted.
25 December 2017, Monday	
Snow produced by both mid-level synoptic lift and westerly upslope flow fell across the region. Low level wind direction was the crux of seeding potential with the system. Flow was too northerly in the morning, but turned more westerly in the afternoon. Seeding occurred with the 7 more northerly GGENs on the west side of the range until the winds turned back to the northwest overnight. Max/Min temperatures PNA: 28/5 RKS: 35/22 LND: 10/-5 Observed DWWS: +2	Seeding event WRR0066 was called at 1150 MST on 12/25/2017 and began at 1212 MST. <u>Case WRR0066</u> Generators: WR01, WR02, WR03, WR09, WR10, WR12, WR13 Time: 12:12 (12/25) to 13:20 (12/25) MST 19:12 (12/25) to 06:20 (12/26) UTC Duration: 11:14, 77:33 Total Time Seeding:1938.75g silver (34.79 gallons)
26 December 2017, Tuesday	
Mostly clear skies were observed across the valley while broken low clouds clung to the mountains through the afternoon. Little to no liquid water was observed by the radiometer, and northwest flow did not support seeding activity. Broad mid and upper-level clouds moved into the region from the west after midnight, and flurries were observed in the morning. Max/Min temperatures PNA: 23/-6 RKS: 31/19 LND: 7/-9 Observed DWWS: 0	No ground-based seeding was conducted.
27 December 2017, Wednesday	
Synoptic and orographically enhanced snowfall was experienced in the Wind River range from the morning into the evening, diminishing overnight. A surface layer	Seeding event WRR0067 was called at 1403 MST on 12/27/2017 and began at 1407 MST.

cold pool was observed in the valley, with light east winds observed below 740mb in the 19Z radiosonde sounding. Moisture rich westerly upslope flow was observed above this inversion. Seeding opportunities at several GGEN sites were inhibited by the weak surface inversion and easterly flow, though seeding was warranted for the higher northwestern GGEN sites (WR01, WR09, WR12, and WR13). Max/Min temperatures PNA: 28/-6 RKS: 40/19 LND: 35/-8 Observed DWWS: +1	Case WRR0067 Generators: WR01, WR09, WR12, WR13 Time: 14:07 (12/27) to 20:31 (12/27) MST 21:07 (12/27) to 03:31 (12/28) UTC Duration: 6:24, 25:35 Total Time Seeding: 639.58g silver (11.64 gallons)
28 December 2017, Thursday	
Mostly clear during the morning through the mid afternoon hours. Low clouds with light snowfall started forming over the NW part of the range before sunset and continued through the evening then covering the rest of the range during the night. The temperature was too warm for seeding operations and the wind flow was not favorable for plume transport. Max/Min temperatures PNA: 34/9 RKS: 39/27 LND: 31/14 FWZ: 32/23 Observed DWWS: 0	No ground-based seeding was conducted.
29 December 2017, Friday	
There was light snowfall over the range in the morning and early afternoon, that had ended before mid afternoon. The temperature was too warm for seeding and the wind flow was not favorable. Mid level cloud coverage continued the rest of the period. Low clouds with light snowfall developed again during the night, just before sunrise, but the temperature was still warmer than the seeding threshold. Max/Min temperatures PNA: 41/18 RKS: 47/32 LND: 42/7 FWZ: 39/30 Observed DWWS: 0	No ground-based seeding was conducted.
30 December 2017, Saturday	
Light snowfall over the range increased through the morning, with continuous snowfall through most of the afternoon. The snowfall was diminishing before sunset	No ground-based seeding was conducted.

but some areas of snowfall lasted until after sunset. The temperature was too warm for seeding operations until the mid afternoon when the wind was beginning to shift to NW. The clouds diminished in the evening and it was clear overnight. Max/Min temperatures PNA: 43/7 RKS: 50/22 LND: 47/-2 FWZ: 36/19 Observed DWWS: 0	
31 December 2017, Sunday	
The sky was clear during the daylight hours. A few mid level clouds existed for a short time in the evening. More mid level clouds moved in during the middle of the night. LND had fog most of the day, only a few hours in the afternoon without it. Max/Min temperatures PNA: 28/-4 RKS: 32/13 LND: 19/6 FWZ: 28/14 Observed DWWS: -2	No ground-based seeding was conducted.
01 January 2018, Monday	
Clear skies were observed throughout the forecast period aside a few basins (e.g. Lander) where shallow fog persisted into the early afternoon, and redeveloped again Tuesday morning. Max/Min temperatures PNA: 32/-6 RKS: 36/12 LND: 13/-2 Observed DWWS: -3	No ground-based seeding was conducted.
02 January 2018, Tuesday	
Clear skies were observed throughout the day, followed by mid and upper level cloudiness after 11Z. Bases remained above the mountains, and no precipitation occurred. Max/Min temperatures PNA: 28/-9 RKS: 32/8 LND: 11/-11 Observed DWWS: -2	No ground-based seeding was conducted.
03 January 2018, Wednesday	

Periods of mid-level clouds, with bases above the mountains, were observed in the region during the afternoon and evening. Skies cleared overnight, and were completely clear by morning. No precipitation was observed. Max/Min temperatures PNA: 34/-2 RKS: 36/10 LND: 18/-3 Observed DWWS: -2	No ground-based seeding was conducted.
04 January 2018, Thursday	
Clear skies eventually yielded to mid and upper level clouds moving in from the west late in the afternoon and into the evening. These clouds largely persisted through the night, dropping into mid-level stratus this morning. Liquid water was detected with this mid-level stratus, but bases held above the mountains, and no precipitation aside from brief flurries was observed. Max/Min temperatures PNA: 39/1 RKS: 41/12 LND: 25/6 Observed DWWS: -2	No ground-based seeding was conducted.
05 January 2018, Friday	
During the day, some thin high based orographic clouds were observed along with low and midlevel clouds, particularly along the western side of the range. Stratus lingered through the night. There was a break in the higher clouds during the late afternoon and evening, and then overcast upper layers moved in from the southwest around midnight. It remained too warm for seeding, and clouds/winds were not suitable either. No seeding occurred. Max/Min temperatures PNA: 37/12 RKS: 46/26 LND: 32/12 Observed DWWS: 0	No ground-based seeding was conducted.
06 January 2018, Saturday	
Low clouds were present in the morning, and then mid to high level layers increased throughout the afternoon. Thick overcast was observed late in the day with a few hours of snowfall. Cloud cover diminished rapidly by 03Z and snow ended. Some scattered to broken low stratus and passing midlevel clouds were observed overnight. Winds, temps, and cloud coverage did not line up to	No ground-based seeding was conducted.

create suitable seeding conditions, and no seeding occurred. Max/Min temperatures PNA: 36/14 RKS: 43/25 LND: 34/16 Observed DWWS: 0	
07 January 2018, Sunday	
Skies were mostly clear during the day with a few thin small orographic clouds above the peaks. Low, mid, and high level cloud layers were observed during the overnight hours. There were no clouds suitable for seeding, and it was too warm for operations as well. Max/Min temperatures PNA: 32/12 RKS: 35/25 LND: 43/19 Observed DWWS: -1	No ground-based seeding was conducted.
08 January 2018, Monday	
Cloud cover increased throughout most of the period. Thick low and orographic clouds were present during the evening and overnight hours along with overcast mid and high cloud layers, and light snowfall was observed. It remained too warm for operations, and no seeding occurred. Max/Min temperatures PNA: 32/9 RKS: 35/20 LND: 34/17 Observed DWWS: 0	No ground-based seeding was conducted.
09 January 2018, Tuesday	
Thick low and orographic clouds continued over the range along with other cloud layers through the day and night. Light snowfall occurred but was not continuous during the afternoon and evening. The snowfall was more continuous from the late evening through the night. Liquid water was detected by the radiometer most of the period. The temperature was much warmer than the seeding threshold and precluded seeding operations. No seeding occurred. Max/Min temperatures PNA: 34/21 RKS: 41/24 LND: 39/20 FWZ: 34/30	No ground-based seeding was conducted.

Observed DWWS: 0	
10 January 2018, Wednesday	
The wind flow shifted from SW to NW throughout the morning as the temperature cooled. The orographic cloud coverage and snowfall over the range diminished due to the wind shift. But low clouds and periods of light snowfall continued through the afternoon and evening. No LW was detected after noon. The cloud coverage decreased overnight, with only small, low clouds hanging over mountains by morning. Max/Min temperatures PNA: 32/16 RKS: 38/21 LND: 43/19 FWZ: 32/14 Observed DWWS: 0	No ground-based seeding was conducted.
11 January 2018, Thursday	
Scattered areas of light snowfall began over the range during the early afternoon. After sunset the wind flow became more favorable for orographic forcing and the snowfall increased in coverage. Widespread snowfall with favorable seeding conditions then continued through most of the night. The wind shifted to parallel to the range a little before sunrise, putting an end to the snowfall and seeding operations. Max/Min temperatures PNA: 30/5 RKS: 36/17 LND: 33/10 FWZ: 27/14 Observed DWWS: +2	Seeding event WRR0068 was called at 1825 MST on 01/11/2018 and began at 1841 MST. <u>Case WRR0068</u> Generators: WR01, WR02, WR03, WR09, WR10, WR12, WR13 Time: 18:41 (01/11) to 05:43 (01/12) MST 01:41 (01/12) to 12:43 (01/12) UTC Duration: 11:02, 77:17 Total Time Seeding: 1932.08g silver (32.13 gallons)
12 January 2018, Friday	
There were small low clouds left from the previous storm over the range during the morning along with mid level clouds around the area. The clouds over the range increased by mid afternoon with a few small areas of light snowfall but not enough for seeding. There was less cloud coverage during the evening but then some stratus developed over the range and to the SW overnight. A few small areas of light snowfall occurred again too. The wind flow remained mainly parallel to the range all day. Max/Min temperatures PNA: 32/9 RKS: 38/27 LND: 44/20	No ground-based seeding was conducted.

FWZ: 32/23 Observed DWWS: 0	
13 January 2018, Saturday	
Thin low clouds were in place over the range during the day, but there was nothing remotely suitable for seeding. Clouds diminished throughout the afternoon. Skies cleared in the evening and overnight hours. Max/Min temperatures PNA: 34/18 RKS: 39/26 LND: 46/21 Observed DWWS: -1	No ground-based seeding was conducted.
14 January 2018, Sunday	
The range was mostly clear during the day. Cloud cover increased during the late night hours, mainly on the eastern side of the range. Some low clouds were banked up against the slopes in the early morning along with some flurries (on the eastern slopes). The range itself was not obscured in cloud as the low cloud surrounded the range. There were no clouds suitable for seeding. Max/Min temperatures PNA: 36/16 RKS: 44/21 LND: 38/19 Observed DWWS: -1	No ground-based seeding was conducted.
15 January 2018, Monday	
Low stratus surrounded the range through the evening, and then gradually cleared in the evening. Some upper level clouds passed through overnight, and then skies cleared by morning. No seeding occurred. Max/Min temperatures PNA: 32/10 RKS: 29/13 LND: 31/21 Observed DWWS: -1	No ground-based seeding was conducted.
16 January 2018, Tuesday	
Low stratus was observed surrounding the range while the range itself was mostly clear. A wave of high and midlevel clouds moved through in the evening hours. More upper level clouds passed through during the late night as well. There were no significant orographic clouds. No seeding occurred. Max/Min temperatures PNA: 27/1	No ground-based seeding was conducted.

RKS: 31/4 LND: 24/6 Observed DWWS: -1	
17 January 2018, Wednesday	
Thin high clouds covered the area during the afternoon. Mid level clouds moved in during the evening and continued through the night. Some virga was detected over the far SE corner of the range early Thursday morning. Max/Min temperatures PNA: 34/0 RKS: 41/19 LND: 30/7 FWZ: 37/27 Observed DWWS: -1	No ground-based seeding was conducted.
18 January 2018, Thursday	
High clouds were over the area during the afternoon with a few other cloud layers at times. An arch cloud developed on the east side of the range during the evening. Overnight, thin orographic cloud coverage developed and mid level clouds moved in a little before sunrise; creating a few areas of light snowfall. The temperature was much warmer than the seeding threshold. Max/Min temperatures PNA: 36/9 RKS: 50/25 LND: 33/15 FWZ: 43/30 Observed DWWS: 0	No ground-based seeding was conducted.
19 January 2018, Friday	
Snowfall and orographic cloud coverage began increasing during the morning hours and continued through the afternoon. The temperature was warmer than the seeding threshold until the late afternoon. The wind was shifting to the NW and was no longer favorable for orographic forcing or seeding. The snowfall became more widespread over the region after sunset. Widespread snowfall then continued through the night. Max/Min temperatures PNA: 39/12 RKS: 52/27 LND: 51/28 FWZ: 37/27 Observed DWWS: 0	No ground-based seeding was conducted.

20 January 2018, Saturday	
Widespread snow developed over most of WY during the morning and persisted through most of the day. The low level wind flow was north to NE over the project area giving more snowfall on the NE side of the range. The wind flow was never quite right for seeding operations. The snowfall over the range began diminishing during the night and ended after sunrise. Max/Min temperatures PNA: 28/18 RKS: 27/19 LND: 35/22 FWZ: 25/18 Observed DWWS: 0	No ground-based seeding was conducted.
21 January 2018, Sunday	
A few low clouds were in place early in the period, but they cleared out by early afternoon. The range was mostly clear during the day and through the late night hours with the exception of a few low clouds over the far south end in the afternoon. During the early morning hours, orographic clouds developed with limited coverage. Arch clouds were observed. Midlevel and high cloud layers moved in by morning as well. Max/Min temperatures PNA: 27/1 RKS: 20/11 LND: 29/9 Observed DWWS: 0	No ground-based seeding was conducted.
22 January 2018, Monday	
Low stratus surrounded the range throughout the day and evening. Some thin orographic clouds were present without fully covering the range. Waves of thin upper level clouds also passed through overnight, and cloud cover gradually cleared by morning. Due to unfavorable northwest wind direction, thick orographic clouds were not observed, and seeding plume trajectories were not right for seeding. Max/Min temperatures PNA: 23/1 RKS: 21/6 LND: 15/0 Observed DWWS: 0	No ground-based seeding was conducted.
23 January 2018, Tuesday	
The range was mostly clear during the day except for some very thin low orographic clouds in the late	No ground-based seeding was conducted.

afternoon and early evening. Scattered midlevel clouds passed through during the late night hours. There were no clouds remotely suitable for seeding. Max/Min temperatures PNA: 27/-2 RKS: 26/10 LND: 24/5 Observed DWWS: -1	
24 January 2018, Wednesday	
The range was mostly clear in the morning. Scattered high clouds and a few midlevel clouds passed through during the afternoon. Overcast layers overspread the region overnight. By dawn, a few thin orographic and low clouds were present along with the upper level overcast layers. There were no clouds suitable for seeding throughout the period. Max/Min temperatures PNA: 27/-2 RKS: 32/8 LND: 24/4 Observed DWWS: -1	No ground-based seeding was conducted.
25 January 2018, Thursday	
The wind flow became favorable for orographic forcing in the early afternoon and moisture began increasing after. An orographic cloud and light snowfall developed by the mid afternoon, allowing for seeding operations to begin. A cold front moved through during the evening, creating a wind shift and putting an end to the snowfall and seeding. The orographic cloud quickly diminished with only scattered clouds overnight. Max/Min temperatures PNA: 30/1 RKS: 36/18 LND: 41/9 FWZ: 30/19 Observed DWWS: +1	Seeding event WRR0069 was called at 1515 MST on 01/25/2018 and began at 1526 MST. <u>Case WRR0069</u> Generators: WR01, WR02, WR03, WR04, WR05, WR09, WR10, WR12, WR13 Time: 15:26 (01/25) to 21:09 (01/25) MST 22:26 (01/25) to 04:09 (01/26) UTC Duration: 5:46, 45:57 Total Time Seeding: 1148.75g silver (19.71 gallons)
26 January 2018, Friday	
Small, shallow low clouds were over the range during the morning. The clouds increased to more continuous orographic coverage in the early afternoon, with light snowfall. Favorable seeding conditions then continued into the evening before the wind shifted and moisture dropped off. Midlevel cloud increased during the night. Max/Min temperatures PNA: 27/0	Seeding event WRR0070 was called at 1305 MST on 01/26/2018 and began at 1312 MST. <u>Case WRR0070</u> Generators: WR01, WR09, WR10, WR12, WR13 Time: 13:12 (01/26) to 19:46 (1/26) MST 20:12 (01/26) to 02:46 (1/27) UTC Duration: 6:35, 32:52 Total Time Seeding: 821.67g silver (13.94 gallons)

RKS: 27/12 LND: 35/12 FWZ: 21/14 Observed DWWS: +1	
27 January 2018, Saturday	
Small, low clouds developed around the range in the early afternoon. Shallow, low clouds sat over the range throughout the evening and overnight hours. The clouds didn't fully cover the range and only flurries were observed. Scattered to broken midlevel clouds were around most of the period, with less coverage by Sunday morning. Max/Min temperatures PNA: 30/3 RKS: 30/17 LND: 33/10 FWZ: 25/10 Observed DWWS: -1	No ground-based seeding was conducted.
28 January 2018, Sunday	
There were only scattered, small low clouds around the range during the daylight hours, with minimal coverage. Only flurries existed. There were a few brief periods of low clouds over the range overnight, but snowfall was again very limited. Some areas of midlevel clouds also existed overnight. Max/Min temperatures PNA: 37/14 RKS: 38/23 LND: 41/12 FWZ: 34/21 Observed DWWS: -1	No ground-based seeding was conducted.
29 January 2018, Monday	
Shallow low clouds were in place in the morning and afternoon, not suitable for seeding. Waves of midlevel cloud passed over during the afternoon, and then broken to overcast high and midlevel clouds overspread the region beginning around sunset. Marginal low level clouds and arch clouds increased in coverage throughout the night. It remained too warm for seeding. Max/Min temperatures PNA: 37/12 RKS: 43/27 LND: 46/17 Observed DWWS: -1	No ground-based seeding was conducted.
30 January 2018, Tuesday	

Low stratus, marginal high based orographic clouds, and overcast mid to upper level cloud layers blanked the range throughout the period. Light snowfall occurred over the northern half of the range early in the period, and then spread southward to the entire range late in the day. Light snow and flurries continued through the night. Temperatures and wind direction did not line up for a suitable seeding window, and no seeding occurred. Max/Min temperatures PNA: 43/12 RKS: 49/33 LND: 52/26 Observed DWWS: 0	No ground-based seeding was conducted.
31 January 2018, Wednesday	
Thick overcast cloud layers were observed throughout most of the period with only some brief intervals of broken cloud. Low stratus and thin low orographic clouds were present as well, and light snowfall occurred off and on throughout the period with the heaviest accumulation during the evening. The low level clouds diminished late in the period, and orographic clouds were almost gone by morning. The best snowfall rates occurred over the northwest and northern parts of the range. Winds remained northwesterly and unfavorable for seeding operations. Max/Min temperatures PNA: 32/18 RKS: 38/29 LND: 33/21 Observed DWWS: 0	No ground-based seeding was conducted.
01 February 2018, Thursday	
High and midlevel clouds were present for most of the day with only minor low and orographic clouds. Overnight, thicker low cloud cover developed with some light snow observed, particularly over the northwest part of the range. Winds remained northwesterly with unfavorable plume trajectories parallel to the range. No seeding occurred. Max/Min temperatures PNA: 30/10 RKS: 38/28 LND: 33/17 Observed DWWS: 0	No ground-based seeding was conducted.
02 February 2018, Friday	
There was light snowfall over the NW part of the range in the morning. The snowfall ended during the afternoon	No ground-based seeding was conducted.

but shallow clouds continued around the range until the late afternoon. Midlevel clouds moved in during the evening with orographic snowfall over the range from the late evening until the middle of the night. The temperature remained warmer than the seeding threshold. Max/Min temperatures PNA: 37/19 RKS: 44/32 LND: 47/14 FWZ: 36/25 Observed DWWS: 0	
03 February 2018, Saturday	
Light snowfall over the NW part of the range in the morning spread to cover most of the range for a few hours in the afternoon. The snowfall and thickest cloud coverage was again limited to the NW by sunset and continued through most of the night. Light snowfall again developed over most of the range a little before sunrise Sunday morning but then was diminishing throughout the morning. The temperature was warmer than the seeding threshold and the wind flow was parallel to the range. Max/Min temperatures PNA: 37/27 RKS: 45/34 LND: 50/30 FWZ: 39/28 Observed DWWS: 0	No ground-based seeding was conducted.
04 February 2018, Sunday	
There was light snowfall over the NW part of the range through the morning and afternoon with only shallow, thin clouds over the rest of the range. Widespread snowfall began during the evening as the wind became westerly and continued into the middle of the night, when the wind shifted back to NW. The temperature was warmer than the seeding threshold. Light snowfall continued over the NW part of the range into Monday morning. Max/Min temperatures PNA: 37/28 RKS: 44/34 LND: 46/10 FWZ: 41/32 Observed DWWS: 0	No ground-based seeding was conducted.
05 February 2018, Monday	

Areas of light snowfall developed over the range during the morning from shallow clouds with high bases and continued through the afternoon. A period of more continuous snowfall over the range occurred from the mid evening until midnight. The wind flow was not right for proper seeding plume transport. Thundersnow was observed in RKS during the afternoon. Max/Min temperatures PNA: 36/21 RKS: 43/29 LND: 41/20 FWZ: 32/23 Observed DWWS: 0	No ground-based seeding was conducted.
06 February 2018, Tuesday	
Marginal stratus and orographic clouds were in place throughout the entire period with periods of light snowfall. Waves of high and midlevel clouds passed over during the day and evening, and then diminished for much of the overnight hours. More high and midlevel cloud cover moved in during the early morning. Northwest winds remained unfavorable for thick orographic clouds and seeding plume transport. No seeding occurred. Max/Min temperatures PNA: 32/14 RKS: 39/25 LND: 44/18 Observed DWWS: 0	No ground-based seeding was conducted.
07 February 2018, Wednesday	
Marginal orographic clouds were present through most of the afternoon, and then clouds and SLW improved by around sunset. Plume trajectories became unfavorable in the late evening, and no seeding occurred during the late night hours, although marginal cloud cover persisted. Only light snowfall was observed on radar, but SLW content was good. Max/Min temperatures PNA: 34/12 RKS: 45/27 LND: 49/19 Observed DWWS: +1	Seeding event WRR0071 was called at 1710 MST on 02/07/2018 and began at 1724 MST. Case WRR0071 Generators: WR01, WR02, WR09, WR10, WR12, WR13 Time: 17:24 (02/07) to 23:08 (02/07) MST 00:24 (02/08) to 06:08 (02/08) UTC Duration: 5:44, 33:33 Total Time Seeding: 838.75g silver (14.48 gallons)
08 February 2018, Thursday	
Orographic clouds and SLW were present throughout the period along with waves of high and midlevel overcast. Snowfall was observed, particularly in the late-night hours. It remained too warm for seeding all day	No ground-based seeding was conducted.

and all night. Max/Min temperatures PNA: 43/19 RKS: 50/36 LND: 54/36 Observed DWWS: 0	
09 February 2018, Friday	
Low orographic clouds were present throughout most of the period, diminishing overnight. Low, midlevel, and high level clouds blanketed the region through most of the period as well, and then diminished in the late night hours. Snow bands continued dropping moderate snowfall over the region into the late evening, and then snow ended overnight. Cloud cover diminished in the early morning hours, and skies were nearly clear by morning. Winds and temperatures did not align to provide a seeding window, and no seeding occurred. Max/Min temperatures PNA: 36/21 RKS: 51/21 LND: 46/8 Observed DWWS: 0	No ground-based seeding was conducted.
10 February 2018, Saturday	
There were thin low clouds over parts of the range during the morning and most of the afternoon. No precipitation occurred and overall coverage was low. A few midlevel clouds existed into the early evening then the sky was clear until midlevel clouds moved in Sunday morning. Max/Min temperatures PNA: 25/3 RKS: 35/18 LND: 22/4 FWZ: 21/12 Observed DWWS: -1	No ground-based seeding was conducted.
11 February 2018, Sunday	
Areas of mid level cloud coverage during the morning and early afternoon with widespread mid and upper level clouds moving in during the late afternoon. Areas of light snowfall began during the evening and continued through the night. The wind flow was not favorable for seeding operations. Max/Min temperatures PNA: 30/-4 RKS: 38/17	No ground-based seeding was conducted.

LND: 23/1 FWZ: 23/10 Observed DWWS: 0	
12 February 2018, Monday	
Areas of light snowfall over the range during the morning and afternoon. Overall cloud coverage was minimal during the afternoon. All clouds diminished in the early evening and the sky was clear overnight. Max/Min temperatures PNA: 30/9 RKS: 33/15 LND: 15/2 FWZ: 23/7 Observed DWWS: -1	No ground-based seeding was conducted.
13 February 2018, Tuesday	
The sky was clear. Max/Min temperatures PNA: 45/28 RKS: 43/32 LND: 46/33 Observed DWWS: -3	No ground-based seeding was conducted.
14 February 2018, Wednesday	
Marginal orographic clouds were present on the west slopes throughout the afternoon with some patchy snowfall. Clouds did not fully cover the range until the evening hours. Clouds became suitable for seeding during the evening and overnight hours. Seeding occurred with seven of the western generators through the night and ended after the winds became unfavorable. Max/Min temperatures PNA: 34/0 RKS: 46/21 LND: 43/17 Observed DWWS: +2	Seeding event WRR0072 was called at 1820 MST on 02/14/2018 and began at 1843 MST. Case WRR0072 Generators: WR01, WR02, WR03, WR09, WR10, WR12, WR13 Time: 18:43 (02/14) to 06:40 (02/15) MST 01:43 (02/15) to 13:40 (02/15) UTC Duration: 12:00, 71:49 Total Time Seeding: 1795.42g silver (31.36 gallons)
15 February 2018, Thursday	
Orographic clouds were present through the late evening and then slowly diminished through the night. Light snowfall was observed during the day and into the late evening. Waves of midlevel and high clouds passed over the region throughout the period. Cumulus was observed over the lowlands surrounding the range during the afternoon. By morning, the range was nearly clear. Wind direction and SLW were not suitable for seeding throughout the period, and no seeding	No ground-based seeding was conducted.

occurred. Max/Min temperatures PNA: 28/3 RKS: 34/16 LND: 33/5 Observed DWWS: 0	
16 February 2018, Friday	
The range was nearly clear in the morning hours, and then low stratus with overcast high and midlevel layers overspread the range in the afternoon bringing light snowfall but unsuitable winds for operations. By late evening, winds shifted, becoming favorable for seeding. Thick orographic cloud and snowfall were observed in the evening into the late night hours with periods of good SLW. Seeding occurred with seven western generators until a little after midnight. Precipitation tapered off after seeding ended as moisture diminished and wind flow shifted back to the northwest. Marginal low clouds then lingered through morning but were not suitable for seeding. Max/Min temperatures PNA: 23/1 RKS: 35/13 LND: 32/2 Observed DWWS: +1	Seeding event WRR0073 was called at 2030 MST on 02/16/2018 and began at 2038 MST. <u>Case WRR0073</u> Generators: WR01, WR02, WR03, WR09, WR10, WR12, WR13 Time: 20:38 (02/16) to 01:38 (02/17) MST 03:38 (02/17) to 08:38 (02/17) UTC Duration: 5:01, 34:39 Total Time Seeding: 866.25g silver (15.13 gallons)
17 February 2018, Saturday	
Marginal orographic clouds were present in the morning through early afternoon hours, and then thick orographic clouds developed in the late afternoon becoming suitable for seeding just before sunset. Seeding began with all nine western generators and continued through the night. Excellent liquid water was observed by the radiometer from 00z through 11:30Z, and then SLW amounts decreased a bit in the few hours before dawn. Heavy snowfall was observed in the mountains during the evening through morning. Max/Min temperatures PNA: 34/5 RKS: 46/26 LND: 47/22 Observed DWWS: +2	Seeding event WRR0074 was called at 1710 MST on 02/17/2018 and began at 1719 MST. <u>Case WRR0074</u> Generators: WR01, WR02, WR03, WR04, WR05, WR12 Time: 17:19 (02/17) to 12:35 (02/18) MST 00:19 (02/18) to 19:35 (02/18) UTC WR10 Time: 17:18 (02/17) to 14:04 (02/18) MST 00:18 (02/18) to 21:04 (02/18) UTC WR09, WR13 Time: 17:19 (02/17) to 15:02 (02/18) MST 00:19 (02/18) to 22:02 (02/18) UTC Duration: 179:53 Total Time Seeding: 4497.08g silver (78.33 gallons)
18 February 2018, Sunday	
Continued snowfall over the range with favorable seeding conditions. The wind flow started becoming less favorable for the southern GGEN after noon and then no	Seeding event WRR0074 continued until 1500 MST.

long favorable for any seeding operations by the mid afternoon. Widespread snowfall developed over western WY by the late afternoon and continued into Monday morning. The wind was not favorable for seeding operations and no SLW was expected during the widespread snow event. Max/Min temperatures PNA: 34/19 RKS: 48/11 LND: 47/4 FWZ: 30/3 Observed DWWS: +1	
19 February 2018, Monday	
Widespread snowfall continued over westerly WY until after sunset, but it had ended over the range a few hours earlier. The clouds slowly diminished overnight. This was a very cold air mass and no SLW existed. Max/Min temperatures PNA: 19/0 RKS: 11/-3 LND: 4/-5 FWZ: 3/-8 Observed DWWS: 0	No ground-based seeding was conducted.
20 February 2018, Tuesday	
Scattered, shallow low clouds existed over and around the range from the late morning into the evening hours. There were some periods of light snowfall but no continuous coverage. Midlevel clouds moved in from the SW overnight. Cold air mass continued over the area. Max/Min temperatures PNA: 12/-22 RKS: 14/-8 LND: 6/-15 FWZ: 3/-9 Observed DWWS: -1	No ground-based seeding was conducted.
21 February 2018, Wednesday	
Continued cold air. Areas of midlevel cloud coverage in the morning gave way to clear skies until the late afternoon. Midlevel clouds existed from the late afternoon through the night into Thursday morning. There were a very few low clouds during the evening, then shallow clouds developing overnight. Max/Min temperatures PNA: 16/-20 RKS: 17/-10	No ground-based seeding was conducted.

LND: 14/-13 FWZ: 10/-4 Observed DWWS: -1	
22 February 2018, Thursday	
Shallow low clouds were present for most of the day with no SLW observed on the radiometer. Broken to overcast mid and upper level layers also obscured the range through the late evening. Cloud cover gradually diminished during the night, and skies were mostly clear by morning. There were no clouds remotely suitable for seeding. Overnight low temperatures were quite cold in the low lying areas once again. Max/Min temperatures PNA: 19/-17 RKS: 19/0 LND: 15/-7 Observed DWWS: 0	No ground-based seeding was conducted.
23 February 2018, Friday	
Some very thin orographic clouds were observed during the day along with some passing mid and upper level clouds. Cloud cover diminished in the late afternoon and evening. During the late night hours, more thin orographic clouds developed and overcast upper clouds passed through. By morning the upper clouds moved away while some thin low clouds persisted after dawn. There were no clouds remotely suitable for seeding, and no SLW was detected by the radiometer throughout the period. Max/Min temperatures PNA: 23/-6 RKS: 21/3 LND: 19/-5 Observed DWWS: -1	No ground-based seeding was conducted.
24 February 2018, Saturday	
Low stratus and marginal orographic clouds were observed throughout much of the period, but no SLW was detected by the radiometer. Cloud thickness and spatial coverage was not suitable for seeding. High and midlevel clouds increased in the early afternoon. Waves of high and midlevel clouds continued to pass through all afternoon and evening before diminishing overnight. By morning, the range was mostly clear except for low stratus banked along the western slopes. Max/Min temperatures PNA: 21/-9 RKS: 18/4	No ground-based seeding was conducted.

LND: 28/-2 Observed DWWS: 0	
25 February 2018, Sunday	
Shallow low stratus and thin orographic clouds were present throughout the day with very limited SLW. In the evening, marginal orographic clouds began to improve as moisture improved. Mid and upper level cloud cover increased throughout the afternoon and into the late night. By the late night hours, snowfall was occurring over much of the range. Decent SLW was observed throughout the night. Winds did not become favorable for operations until this morning after sunrise. Max/Min temperatures PNA: 21/-13 RKS: 22/10 LND: 35/8 Observed DWWS: 0	No ground-based seeding was conducted.
26 February 2018, Monday	
Snowfall over the range from thick orographic clouds continued through the afternoon and early evening. The wind flow had become favorable for a few GGEN sites in the early morning then improved for the rest of the western GGEN in the afternoon. Widespread snowfall around the region began in the evening but the wind flow was no longer favorable for seeding. Widespread snowfall continued most of the night but was diminishing by Tuesday morning. Max/Min temperatures PNA: 30/12 RKS: 36/8 LND: 37/15 FWZ: 23/12 Observed DWWS: +2	Seeding event WRR0075 was called at 0730 MST on 02/26/2018 and began at 0740 MST. <u>Case WRR0075</u> Generators: WR01, WR02, WR03, WR12 Time: 07:37 (02/26) to 20:32 (02/26) MST 14:37 (02/26) to 03:32 (02/27) UTC WR05 Time: 13:56 (02/26) to 15:50 (02/26) MST 20:56 (02/26) to 22:50 (02/26) UTC WR04, WR09, WR10 Time: 13:56 (02/26) to 20:32 (02/26) MST 20:56 (02/26) to 03:32 (02/27) UTC WR13 Time: 13:57 (02/26) to 18:43 (02/26) MST 20:57 (02/26) to 01:43 (02/27) UTC Duration: 77:37 Total Time Seeding: 1940.42g silver (31.87 gallons)
27 February 2018, Tuesday	
There was thin low cloud coverage over the range during the morning and early afternoon. By mid afternoon, thicker but shallow clouds formed over the range. There were areas of light snowfall but no SLW existed. The low clouds diminishing in the early evening then a band of	No ground-based seeding was conducted.

mid level clouds passed through during the night. Max/Min temperatures PNA: 32/5 RKS: 36/14 LND: 40/14 FWZ: 25/19 Observed DWWS: 0	
28 February 2018, Wednesday	
Minimal cloud coverage during the daylight hours with only a few upper level clouds. There were more clouds during the evening and overnight as midlevel clouds moved through the area. Max/Min temperatures PNA: 27/-2 RKS: 30/16 LND: 34/17 FWZ: 21/10 Observed DWWS: -2	No ground-based seeding was conducted.
01 March 2018, Thursday	
Low clouds slowly developed over the range during the morning. Continuous snowfall developed by midafternoon and persisted through the evening. The wind flow was not favorable for plume transport from any GGEN site during the storm so no seeding occurred. The snowfall diminished during the night but was increasing again Friday morning. Max/Min temperatures PNA: 32/-4 RKS: 40/12 LND: 38/12 FWZ: 30/9 Observed DWWS: 0	No ground-based seeding was conducted.
02 March 2018, Friday	
Thick seedable orographic clouds were present throughout the period. Seeding began at 1552 UTC with six western generators. By late morning, winds improved and all nine western generators were ignited which ran through the afternoon and evening. A shallow low level inversion developed after sunset on the west side of the range, and some of the lower elevation and far end generators were extinguished due to unfavorable plume trajectories. Four generators ran through the rest of the night. Another adjustment was made Saturday morning. Continuous mountain snowfall was observed throughout the period.	Seeding event WRR0076 was called at 0840 MST on 03/02/2018 and began at 0852 MST. Case WRR0076 Generators: WR02 Time: 08:51 (03/02) to 10:21 (03/03) MST 15:51 (03/02) to 17:21 (03/03) UTC WR01 Time: 08:51 (03/02) to 12:52 (03/03) MST 15:51 (03/02) to 19:52 (03/03) UTC

Max/Min temperatures PNA: 41/12 RKS: 46/28 LND: 49/18 Observed DWWS: +2	WR10* Time: 08:51 (03/02) to 20:31 (03/02) MST 15:51 (03/02) to 03:31 (03/03) UTC 10:22 (03/03) to 15:24 (03/03) MST 17:22 (03/03) to 22:24 (03/03) UTC WR09, WR12 Time: 08:51 (03/02) to 15:25 (03/03) MST 15:51 (03/02) to 22:25 (03/03) UTC WR03 Time: 08:52 (03/02) to 00:20 (03/03) MST 15:52 (03/02) to 07:20 (03/03) UTC WR04, WR05, WR13 Time: 11:23 (03/02) to 20:30 (03/02) MST 18:23 (03/02) to 03:30 (03/03) UTC Duration: 173:18 Total Time Seeding: 4325.5g silver (68.98 gallons) *Generator turned on/off at request of meteorologist due to seeding conditions during the event.
03 March 2018, Saturday	
Seeding was ongoing from the previous day as the period began. During the daytime hours, seedable orographic clouds were in place over the northern end of the range while only thin clouds were observed in the south. Seeding continued through the morning and early afternoon with a few generators to target the northern range. Seeding ended at 2225Z when winds and clouds became unfavorable. Plume trajectories were not right for operations overnight, but marginal clouds lingered through dawn. After dawn Sunday morning, clouds and winds began to improve again. Max/Min temperatures PNA: 41/14 RKS: 46/33 LND: 53/25 Observed DWWS: +2	Seeding event WRR0076 continued until 1520 MST.
04 March 2018, Sunday	
Seeding began in the morning and continued through the mid evening. Thick orographic clouds and passing upper to midlevel cloud layers were present through the evening. The winds became gradually more northwesterly through the afternoon, and some of the more southern generators were shut down at 2152Z. A	Seeding event WRR0077 was called at 0730 MST on 03/04/2018 and began at 0740 MST. <u>Case WRR0077</u> Generators:

handful of northern generators stayed running into the evening until seeding ended at 0249Z when clouds became too sparse and all precipitation ended due to parallel wind flow. Marginal orographic clouds continued through the night, but thickness was not sufficient for seeding due to poor orographic winds. Max/Min temperatures PNA: 27/5 RKS: 39/16 LND: 32/18 Observed DWWS: +2	WR01, WR02, WR03 Time: 07:35 (03/04) to 14:52 (03/04) MST 14:35 (03/04) to 21:52 (03/04) UTC WR09, WR10, WR12, WR13 Time: 07:35 (03/04) to 19:49 (03/04) MST 14:35 (03/04) to 02:49 (03/05) UTC Duration: 70:42 Total Time Seeding: 1767.50g silver (28.87 gallons)
05 March 2018, Monday	
Waves of mid to high level clouds passed through during the day. Thin low clouds covered parts of the range through the late evening, and then diminished through the night. Skies were clear by morning. There were no clouds suitable for seeding. Max/Min temperatures PNA: 25/0 RKS: 29/14 LND: 33/16 Observed DWWS: 0	No ground-based seeding was conducted.
06 March 2018, Tuesday	
Some thin low clouds were observed over the peaks for a few hours during the afternoon. Skies were otherwise mostly clear throughout the period. Clouds were not remotely suitable for seeding. Max/Min temperatures PNA: 30/-4 RKS: 34/15 LND: 39/13 Observed DWWS: -1	No ground-based seeding was conducted.
07 March 2018, Wednesday	
The sky was clear until a very few high clouds moved in just before sunset. Multiple cloud layers existed across the area during the evening and most of the night, with most of the clouds clearing before sunrise. Max/Min temperatures PNA: 36/0 RKS: 41/13 LND: 45/17 FWZ: 32/19 Observed DWWS: -2	No ground-based seeding was conducted.
08 March 2018, Thursday	

Low clouds slowly developed over the range beginning in the early afternoon. Areas of light snowfall existed over the range from the mid afternoon, through the night and into Friday morning. The temperature was too warm for seeding operations until the late evening hours and the wind was unfavorable for seeding during the evening and overnight. Max/Min temperatures PNA: 41/5 RKS: 50/23 LND: 54/27 FWZ: 36/23 Observed DWWS: 0	No ground-based seeding was conducted.
09 March 2018, Friday	
Light snowfall occurred over the range from the morning through the evening hours, ending a little after midnight. The temperature and wind flow became favorable for seeding operations in the early afternoon until the wind shifted to parallel to the range in the evening. The cloud coverage slowly diminished overnight becoming clear around sunrise. Max/Min temperatures PNA: 39/21 RKS: 48/27 LND: 51/31 FWZ: 34/27 Observed DWWS: +1	Seeding event WRR0078 was called at 1443 MST on 03/09/2018 and began at 1450 MST. <u>Case WRR0078</u> Generators: WR01, WR02, WR03, WR09, WR10, WR12, WR13 Time: 14:50 (03/09) to 19:02 (03/09) MST 21:50 (03/09) to 02:02 (03/10) UTC Duration: 4:12, 29:24 Total Time Seeding: 735.00g (12.81 gallons)
10 March 2018, Saturday	
Early in the morning, a layer of low clouds was dissipating and cleared out shortly after dawn. A few isolated fair weather cumulus were observed over the western slopes through the early afternoon, and then skies were mostly clear for the remainder of the period. Some thin wispy high clouds were moving in from the west during the late night Sunday morning. There were no clouds remotely suitable for seeding. Max/Min temperatures PNA: 36/14 RKS: 44/27 LND: 45/26 Observed DWWS: -2	No ground-based seeding was conducted.
11 March 2018, Sunday	
Skies were mostly clear in the morning. High and midlevel clouds slowly increased throughout the afternoon and evening. Overcast layers obscured the range in the late evening into the night with some	No ground-based seeding was conducted.

marginal orographic clouds and low stratus observed. Clouds, temps, and winds were not suitable for seeding. Clouds diminished in the early morning, and skies cleared by morning. No seeding occurred. Max/Min temperatures PNA: 41/9 RKS: 50/21 LND: 47/20 Observed DWWS: 0	
12 March 2018, Monday	
Skies were mostly clear throughout the period except for some very small fair weather cumulus over the range during the mid afternoon hours. Max/Min temperatures PNA: 43/18 RKS: 50/28 LND: 52/27 Observed DWWS: -1	No ground-based seeding was conducted.
13 March 2018, Tuesday	
Skies were mostly clear during the day, and then clouds increased through the night. Orographic clouds were present during the late night and early morning hours. Wind direction and warm temperatures precluded seeding operations. Max/Min temperatures PNA: 46/14 RKS: 55/25 LND: 54/23 Observed DWWS: 0	No ground-based seeding was conducted.
14 March 2018, Wednesday	
Warm temperatures with increasing cloud coverage during the morning and early afternoon. Areas of rain occurred during the mid and late afternoon, even at South Pass. Continuous snowfall existed over the range during the evening and nighttime, while rain fell in PNA. By the time the temperature cooled Thursday morning, the snowfall was diminishing and the wind becoming unfavorable for seeding. Max/Min temperatures PNA: 50/23 RKS: 56/33 LND: 59/28 FWZ: 46/36 Observed DWWS: 0	No ground-based seeding was conducted.

15 March 2018, Thursday	
Small, shallow low clouds lingered over the range from the morning through the afternoon. Light snowfall existed but accumulation was minimal and the clouds did not fully cover the range. The wind flow was also not favorable for seeding. Some mid level clouds passed through during the afternoon, then widespread mid and upper level cloud coverage during the evening and most of the night. Max/Min temperatures PNA: 37/25 RKS: 43/29 LND: 57/36 FWZ: 36/28 Observed DWWS: 0	No ground-based seeding was conducted.

16 March 2018, Friday	
Scattered, small low clouds were over the range most of the daylight hours with minimal coverage and no measurable precipitation occurred. The sky was clear until mid level clouds moved in around midnight. Widespread snowfall began over the range and lowlands a little before sunrise, but the wind flow was not favorable for seeding until after sunrise. Max/Min temperatures PNA: 36/21 RKS: 43/27 LND: 50/28 FWZ: 32/21 Observed DWWS: 0	No ground-based seeding was conducted.

17 March 2018, Saturday	
Favorable seeding conditions developed early in the morning and continued through the afternoon. By sunset, the wind shifted and was no longer favorable for plume transport over the range but light snowfall continued until near midnight. During the night, thick cloud layers moved in from the south, bringing light snowfall mainly east of the range but some snowfall occurred over the far SE part of the range. Max/Min temperatures PNA: 37/27 RKS: 47/22 LND: 52/23 FWZ: 32/23 Observed DWWS: +2	Seeding event WRR0079 was called at 0825 MDT on 03/17/2018 and began at 0836 MDT. Case WRR0079 Generators: WR01, WR02, WR03, WR04, WR05, WR09, WR10, WR12, WR13 Time: 08:36 (03/17) to 19:08 (03/17) MDT 14:36 (03/17) to 01:08 (03/18) UTC Duration: 10:32, 95:15 Total Time Seeding: 2381.25g silver (40.21 gallons)

18 March 2018, Sunday	
There were multiple cloud layers over the area throughout most of the day. Areas of light snowfall occurred from the morning through the evening. The wind was not favorable for seeding operations and no SLW existed. The clouds began moving away to the east during the night. Max/Min temperatures PNA: 32/21 RKS: 29/21 LND: 46/26 FWZ: 30/21 Observed DWWS: 0	No ground-based seeding was conducted.
19 March 2018, Monday	
Mostly clear skies during the morning yielded to broken mid-level clouds in the afternoon, followed by scattered low clouds hugging the range after dusk. Marginal SLW may have occurred, but nothing remotely suitable for seeding. Surface flow remained northwesterly at KPNA. Max/Min temperatures PNA: 34/18 RKS: 38/20 LND: 46/26 FWZ: 30/18 Observed DWWS: -1	No ground-based seeding was conducted.
20 March 2018, Tuesday	
Webcams showed low clouds along the Wind River range much of the afternoon. Deeper clouds moved across the region between 04Z and 10Z, but only a short spike of liquid water was detected on the East Fork radiometer. No precipitation was observed at the AWOS at KPNA. Max/Min temperatures PNA: 36/18 RKS: 42/23 LND: 50/21 FWZ: 32/18 Observed DWWS: 0	No ground-based seeding was conducted.
21 March 2018, Wednesday	
Alternating periods of thick overcast and scattered upper level cloud cover were observed throughout the period. Thick low clouds with high liquid water content persisted over the range throughout most of the period with rain/snow mix. It remained too warm for seeding throughout the period.	No ground-based seeding was conducted.

Max/Min temperatures PNA: 39/23 RKS: 52/28 LND: 57/26 Observed DWWS: 0	
22 March 2018, Thursday	
Continued widespread mixed precipitation across the region through the evening. Rain was reported at South Pass during the afternoon and evening. Rain in PNA changed to snow after midnight. The precipitation was slowly diminishing during the night, mostly ending by sunrise. The temperature was much too warm for seeding operations. Max/Min temperatures PNA: 45/27 RKS: 58/29 LND: 64/33 FWZ: 43/32 Observed DWWS: 0	No ground-based seeding was conducted.
23 March 2018, Friday	
Thin clouds in the morning gave way to thicker, broken clouds for a short time in the early afternoon, with minimal precipitation. The clouds cleared to the east by the mid afternoon. Thin clouds moved in during the night with a few areas of flurries over the NW part of the range. Max/Min temperatures PNA: 41/27 RKS: 50/29 LND: 59/30 FWZ: 41/30 Observed DWWS: -1	No ground-based seeding was conducted.
24 March 2018, Saturday	
Clouds developed over the range during the morning and continued into the evening hours. Light snowfall occurred at times but was inconsistent and the temperature and wind were not favorable for seeding. Cloud coverage developed again overnight with areas of light snowfall, but the wind was not favorable for seeding operations again. Max/Min temperatures PNA: 43/21 RKS: 55/24 LND: 59/27 FWZ: 41/27	No ground-based seeding was conducted.

Observed DWWS: 0	
25 March 2018, Sunday	
Thick midlevel cloud layers obscured the range throughout most of the period. Orographic clouds were marginal due to unfavorable wind direction. Parallel winds precluded any seeding operations, but snowfall was observed throughout much of the period. Max/Min temperatures PNA: 34/21 RKS: 50/23 LND: 55/24 Observed DWWS: 0	No ground-based seeding was conducted.
26 March 2018, Monday	
Orographic clouds and snowfall were observed over the southern half of the range throughout the afternoon. Seeding occurred utilizing the Enterprise generator between 1855Z and 2337Z. In the evening hours, cloud cover diminished, and winds became unfavorable shifting toward the north. Skies were mostly clear overnight. Max/Min temperatures PNA: 34/21 RKS: 35/19 LND: 34/23 Observed DWWS: +1	Seeding event WRR0080 was called at 1251 MDT on 03/26/2018 and began at 1255 MDT. <u>Case WRR0080</u> Generators: WR07 Time: 12:54 (03/26) to 17:37 (03/26) MDT 18:54 (03/26) to 23:37 (03/26) UTC Duration: 4:43 Seeding:117.92g silver (2.08 gallons)
27 March 2018, Tuesday	
Skies were mostly clear during the afternoon. Overcast layers overspread the region in the evening, and scattered snowfall occurred in the evening through the late night hours from midlevel and low clouds passing over the range. Winds remained northwesterly. Orographic clouds remained thin and unsuitable for seeding while plume trajectories were parallel to the range. No seeding occurred. Max/Min temperatures PNA: 41/19 RKS: 46/20 LND: 44/17 Observed DWWS: 0	No ground-based seeding was conducted.
28 March 2018, Wednesday	
Low, mid and high level clouds passed through the region throughout the day with light snowfall over parts of the range. Winds were not favorable for seeding or for thick orographic cloud development. No seeding occurred. Clouds diminished in the evening, and skies	No ground-based seeding was conducted.

gradually cleared overnight. Max/Min temperatures PNA: 39/25 RKS: 45/29 LND: 45/29 Observed DWWS: 0	
29 March 2018, Thursday	
Skies remained mostly clear throughout the day. Some upper level clouds moved in during the evening and overnight hours. Thin, low clouds were observed over the range during the early morning, but nothing remotely suitable for seeding. No seeding occurred. Max/Min temperatures PNA: 39/18 RKS: 47/27 LND: 48/21 Observed DWWS: 0	No ground-based seeding was conducted.
30 March 2018, Friday	
Low clouds were over the range during the daylight hours and then diminished during the evening hours. Coverage was inconsistent and precipitation was minimal. The temperature was warmer than the seeding threshold. Multiple cloud layers moved through during the night with some thin low clouds remaining Saturday morning. Max/Min temperatures PNA: 46/19 RKS: 54/30 LND: 57/27 FWZ: 39/21 Observed DWWS: -1	No ground-based seeding was conducted.
31 March 2018, Saturday	
There were low clouds with a few areas of flurries in the morning. The clouds expanded in coverage after noon with more areas of snowfall. The snowfall became more widespread after midnight then was diminishing by Sunday morning. Warm temps and unfavorable wind flow precluded seeding operations. Max/Min temperatures PNA: 43/23 RKS: 58/38 LND: 37/20 FWZ: 37/21 Observed DWWS: 0	No ground-based seeding was conducted.

Appendix B. National Oceanic and Atmospheric Administration Final Operations Report

Silver iodide seeding agent amounts are stated in grams.

NOAA FORM 17-4A
(4-81)

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Form Approved OMB No. 0648-0025
Expires 03/31/08

INTERIM ACTIVITY REPORTS AND FINAL REPORT

This report is required by Public Law 92-205; 85 Stat. 735; 145 U.S.C. 330b. Knowing and willful violation of any rule adopted under the authority of Section 2 of Public Law 92-205 shall subject the person violating such rule to a fine of not more than $10,000, upon conviction thereof.

NOAA FILE NUMBER: 17-1736

[ ] INTERIM REPORT [X] FINAL REPORT

Complete in accordance with instructions on reverse and forward one copy to:
National Oceanic and Atmospheric Administration
Office of Oceanic and Atmospheric Research
1315 East-West Highway SSMC-3 Room 11216
Silver Spring, MD 20910

REPORTING PERIOD
FROM 12/09/2017 TO 03/31/2018

MONTH	(a) NUMBER OF MODIFICATION DAYS	(b) NUMBER OF MODIFICATION DAYS PER MAJOR PURPOSE				(c) HOURS OF APPARATUS OPERATION BY TYPE		(d) TYPE AND AMOUNT OF AGENT USED				
		INCREASE PRECIPITATION	ALLEVIATE: HAIL	ALLEVIATE: FOG	OTHER	AIRBORNE	GROUND	SILVER IODIDE	CARBON DIOXIDE	UREA	SODIUM CHLORIDE	OTHER
JANUARY	3	3					23	4,002				
FEBRUARY	5	5					57	10,414				
MARCH	5	5					62	9,305				
APRIL												
MAY												
JUNE												
JULY												
AUGUST												
SEPTEMBER												
OCTOBER												
NOVEMBER												
DECEMBER	5	5					50	8,468				
TOTAL	18	18	0	0	0	0	193	32,189	0	0	0	0
TOTALS FOR FINAL REPORT	18	18	0	0	0	0	193	32,189	0	0	0	0

DATE ON WHICH FINAL WEATHER MODIFICATION ACTIVITY OCCURRED *(For Final Report only.)* 03/26/2018

CERTIFICATION: I certify that all statements in this report on this weather modification project are complete and correct to the best of my knowledge and are made in good faith.

NAME OF REPORTING PERSON: Bruce A. Boe

AFFILIATION: Weather Modification International

SIGNATURE: Bruce A. Boe

STREET ADDRESS: 3802 20th Street North

OFFICIAL TITLE: Vice President - Meteorology

CITY: Fargo STATE: ND ZIP CODE: 58102

DATE: 04/12/2018