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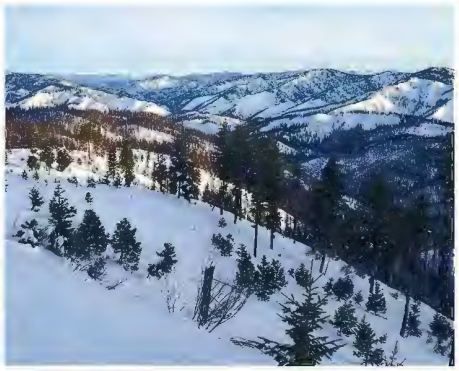
ANNUAL
REPORT

WYOMING • WIND RIVER RANGE
WEATHER MODIFICATION PROGRAM



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Wind
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Cloud Seeding Operations in the Wind River Range of Wyoming 2016-2017 Season

ANNUAL REPORT

prepared by

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August 2017

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EXECUTIVE SUMMARY

Funding for cloud seeding operations in the Wind River Range for the winter of 2016-2017 was provided in part by the 2016 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 2016-2017 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 Big Sandy Opening 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.

Though the 2016-2017 season was intended to begin on 15 November 2016, and conclude after 31 March 2017, contract finalization did not occur until 30 November 2016. The final signature was affixed on 30 November 2016. The first seeding event occurred on 4 December 2016.

The weather pattern was very active, with six seeding events occurring in December 2016, five in January 2017, and three more in February 2017, before the snow water equivalent (SWE) suspension threshold was exceeded at 07:15 AM MST on 10 February 2017, and operations were suspended.

Fourteen storms were seeded, resulting in 242 hours and 27 minutes of actual seeding time. The fewest number of generators that operated during any one storm was four, the most, nine. Interestingly, the Enterprise generator, sited on the eastern slope of the range near Lander, was not used during the 2016-2017 season, a significant anomaly. This was anomalous in that during previous seasons, operation of the Enterprise generator accounted for approximately one-third of all seeding events. Such being the case, those previous operations occurred primarily early and late in the season, whereas this season started two weeks late, and effectively ended (due to suspension) on 10 February. Thus the opportunity for early- and late-season operations was absent. The total number of "generator hours", defined as the sum of times each generator was operated during a storm, was 1,618 hours. The suspension-abbreviated season turned out to be one of the most active since operational seeding began in the Wind River Range.

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

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 27 weather balloons were released during the 2.3 months (73 days) of operations. The presence of liquid water clouds over the range was established by the WWDO radiometer sited near Boulder, WY.

The bulk of the weather information used for forecasting and weather monitoring was obtained from the internet. In the 2016-2017 season, in especially complex flow circumstances, WMI ran the Hybrid Single-Particle Lagrangian Intergrated Trajectory (HYSPLIT) plume dispersion model to establish a better idea of seeding agent plume behavior. More about this is presented in the full report.

Overall, the 2016-2017 winter offered more extended, precipitation-producing storms than any recent season, which led to the suspension in mid-February. The 73 days of the 2016-2017 seeding season were rich with seeding opportunities. Snowpack accumulated during this time would have been very significant even when unseeded, but seeding very likely accelerated the accumulation of the snowpack up until suspension.

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 who made the 2016-2017 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) coordinated the entire effort. The WWDO also acquired additional 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 and Jason Goehring, technicians Michael Paul, Ryan Hudson, Steven Heinitz, Rich Keely, and Ryan Richter, and all the administrative support provided by Erin Fischer, Thuy Tran, Dennis Afseth, 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 2016 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. If the CCN are large or have properties that attract water (such as salt), the resulting droplets will be of increased size. All this 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 versus raindrops, and it is this process that plays a significant role in winter clouds in Wyoming. For ice to form, 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" (SLW); 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.

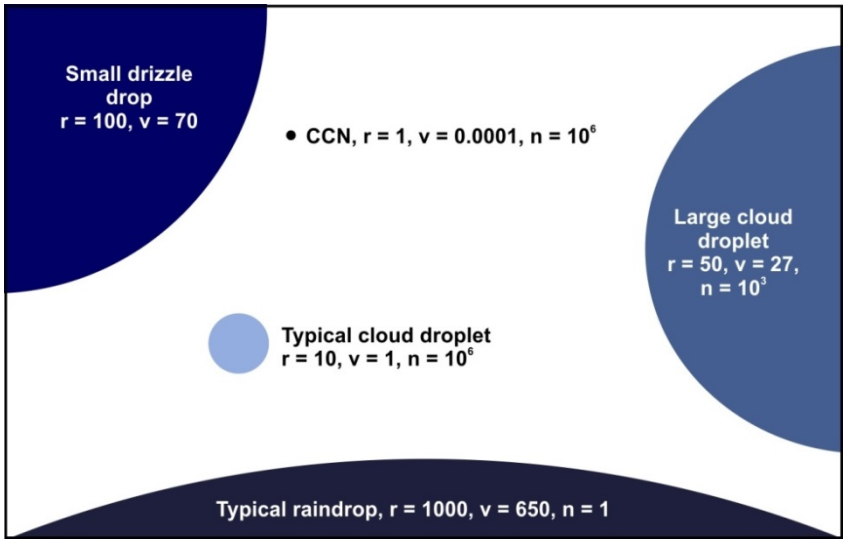

Figure 2. Relative characteristics of particles involved in cloud processes. For each, the radius (r, microns), fall velocity (v, cm per second), and number concentration (n, per liter) are given (after Wallace and Hobbs 1977). The raindrop shown (radius = 1000) is a 2 mm diameter raindrop.

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 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, 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.

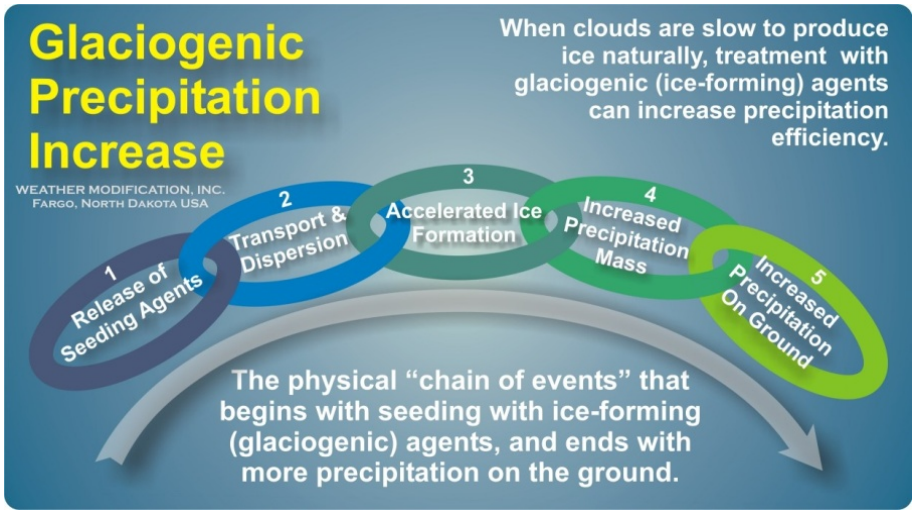

Figure 3. The physical chain-of-events that begins with release of ice-forming seeding agents, and culminates with increased precipitation.

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. Natural ice nuclei, such as crystalline soil particles, do not act to form ice crystals until the cloud is much colder (at least as cold as +5°F). 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. As a result, precipitation formation within the cloud starts 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 2016-2017 Funding

In addition to the 25% of funding costs provided by the State of Wyoming, funding for the 2016-2017 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. Two meteorologists staffed the 2016-2017 operations season. Mr. Daniel Gilbert was located on site in Pinedale, WY throughout the project. In addition to coordinating data collection for the project, he also operated the weather balloons (the upper air sounding system). The second meteorologist was Mr. Jason Goehring, who worked off-site from his home, using weather resources available via the Internet and directly from WMI. Both Gilbert and Goehring are Weather Modification Association Certified Operators. Between the two of them, Gilbert and Goehring completed all the daily forecasting, weather monitoring, and implementation of seeding operations.

Technicians. Four technicians participated in the 2016-2017 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. Rich Keely. 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. Safety is always of paramount importance, but never less than during heavy-snow winters such as that of 2016-2017, when sleds sink more deeply into the always-fresh snow, and avalanche risk is often heightened.

Figure 4. The technician team pauses to discuss travel to the next site during generator servicing in light snow on 15 December 2016. (WMI photograph by Michael Paul.)

2.2 Siting of Seeding Equipment

Figure 5 displays the ten seeding equipment sites used for the 2016-2017 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.

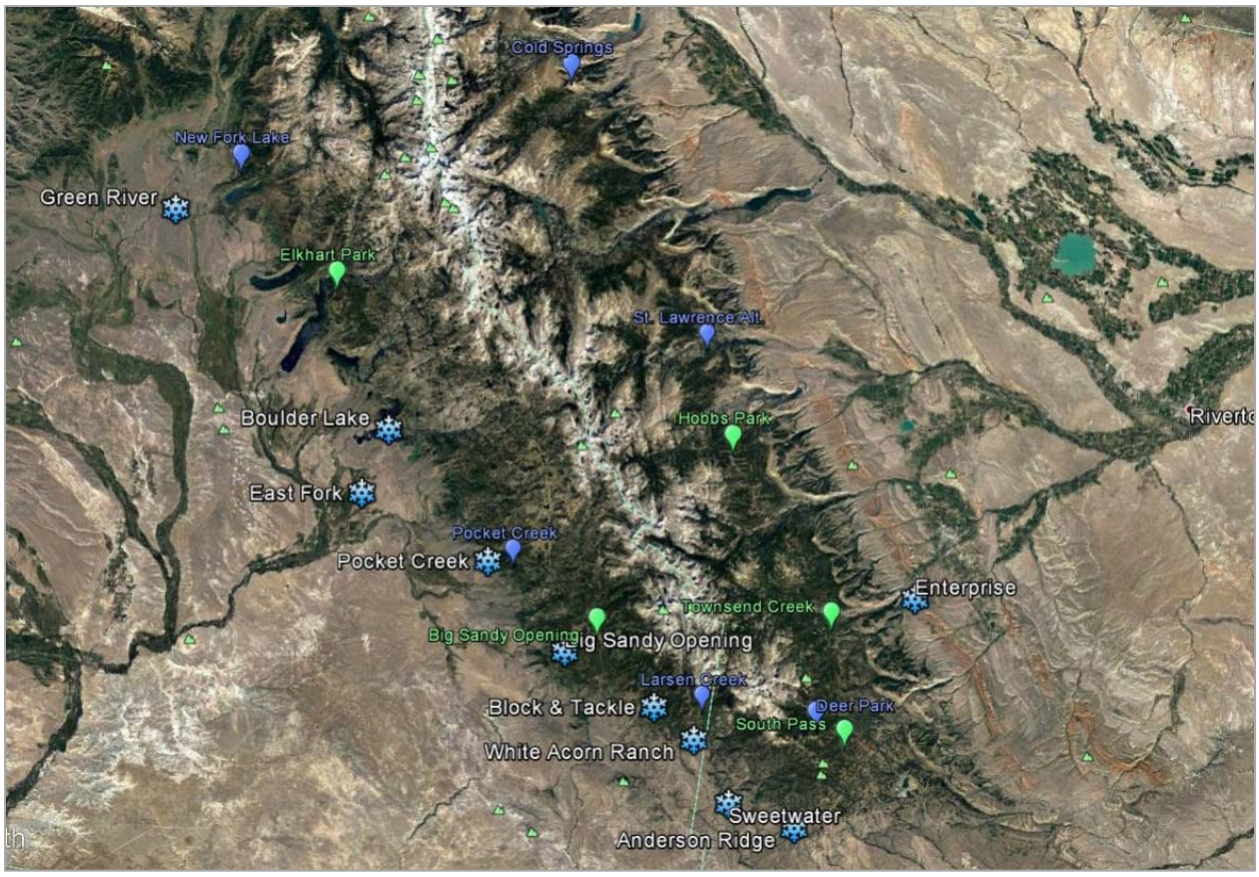

Figure 5. The locations of the ground-based ice nucleus generators are indicated by the snow crystal symbols. The green "balloons" indicate the locations of Natural Resources and Conservation Service (NRCS) snow telemetry (SNOTEL) sites used in monitoring snowpack during the 2016-2017 season. The blue 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 and fabricated by WMI. The primary components are shown in Figure 6.

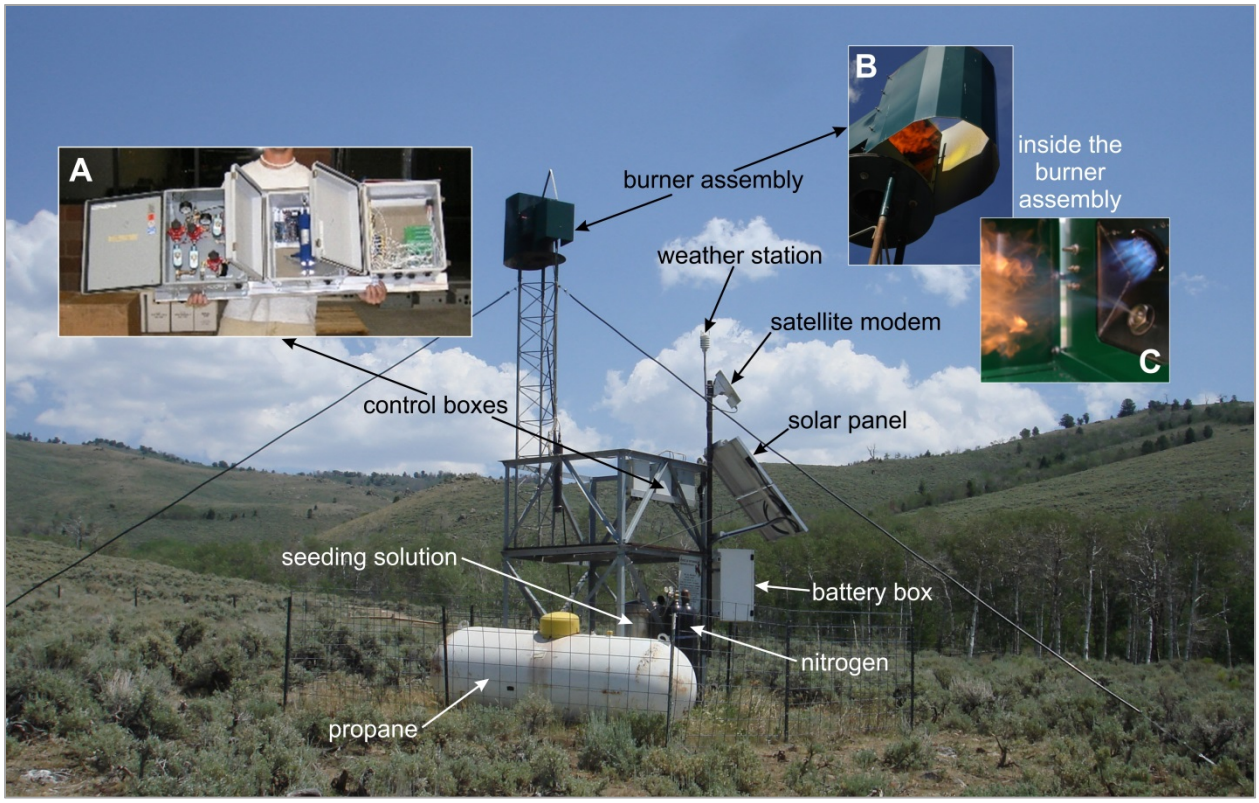

Figure 6. The primary components of the WMI remotely-controlled ground-based ice nucleus generator are illustrated. Inset A, shows the contents of the control boxes. From left to right, these are: solenoids (electronic valves) to turn flows on and off, seeding solution flow rate regulation and measurement, 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 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. Being remotely-controlled means that the generators can be activated and deactivated as weather conditions warrant. This results in less seeding agent being dispersed unnecessarily, as can occur with manually operated generators. All of the generator lines and fittings are made of corrosion-resistant stainless steel, necessary when high-performance seeding solutions, which contain oxidizers, are used. The generators are robust; designed to function in extreme temperatures, winds and precipitation.

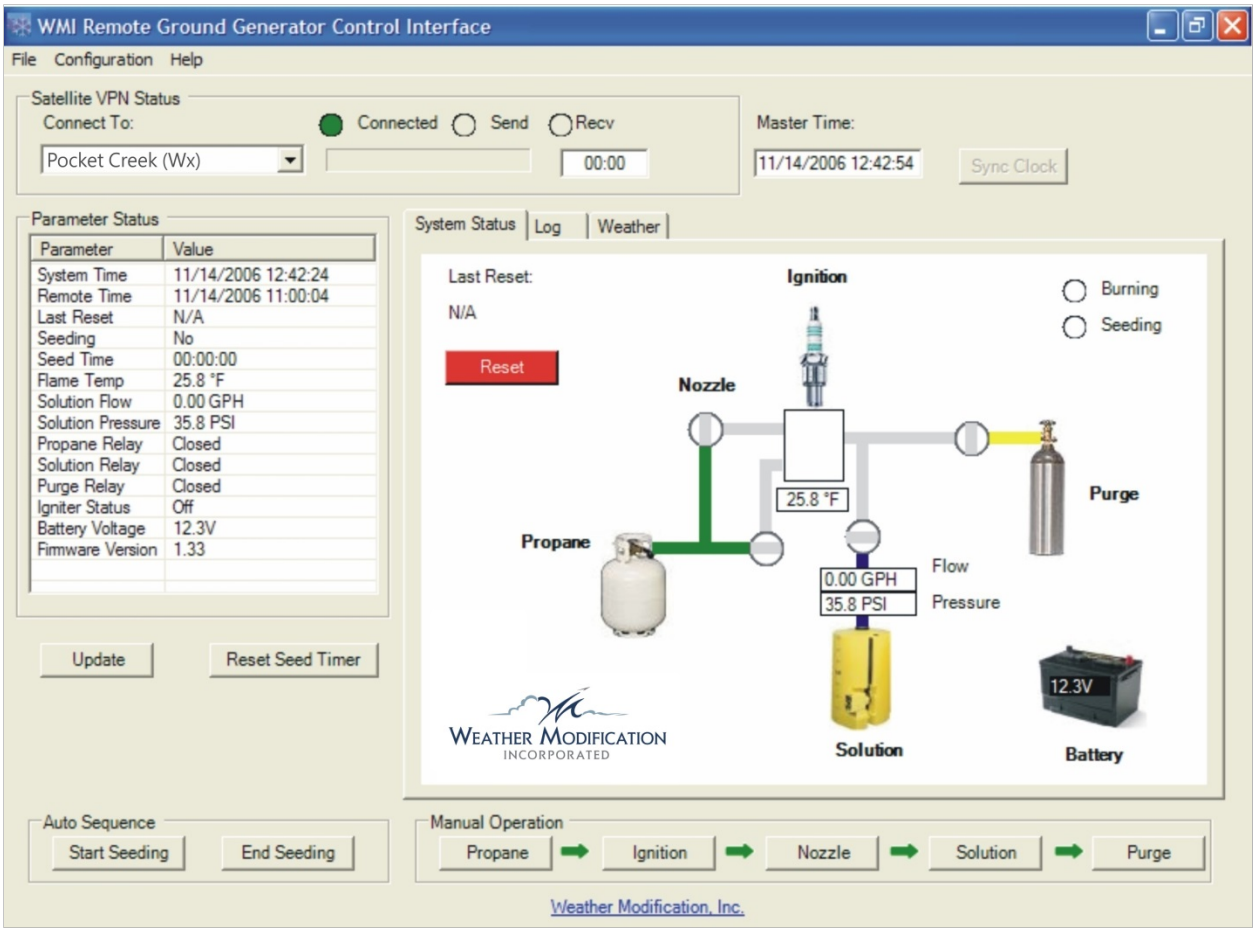

Figure 7. The control interface for the WMI remotely-controlled ground-based ice nucleus generator is shown, after connection is established via satellite, but before the generator is turned on. All flow valves are off, seeding solution flow is zero, but system status is fully reported.

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.

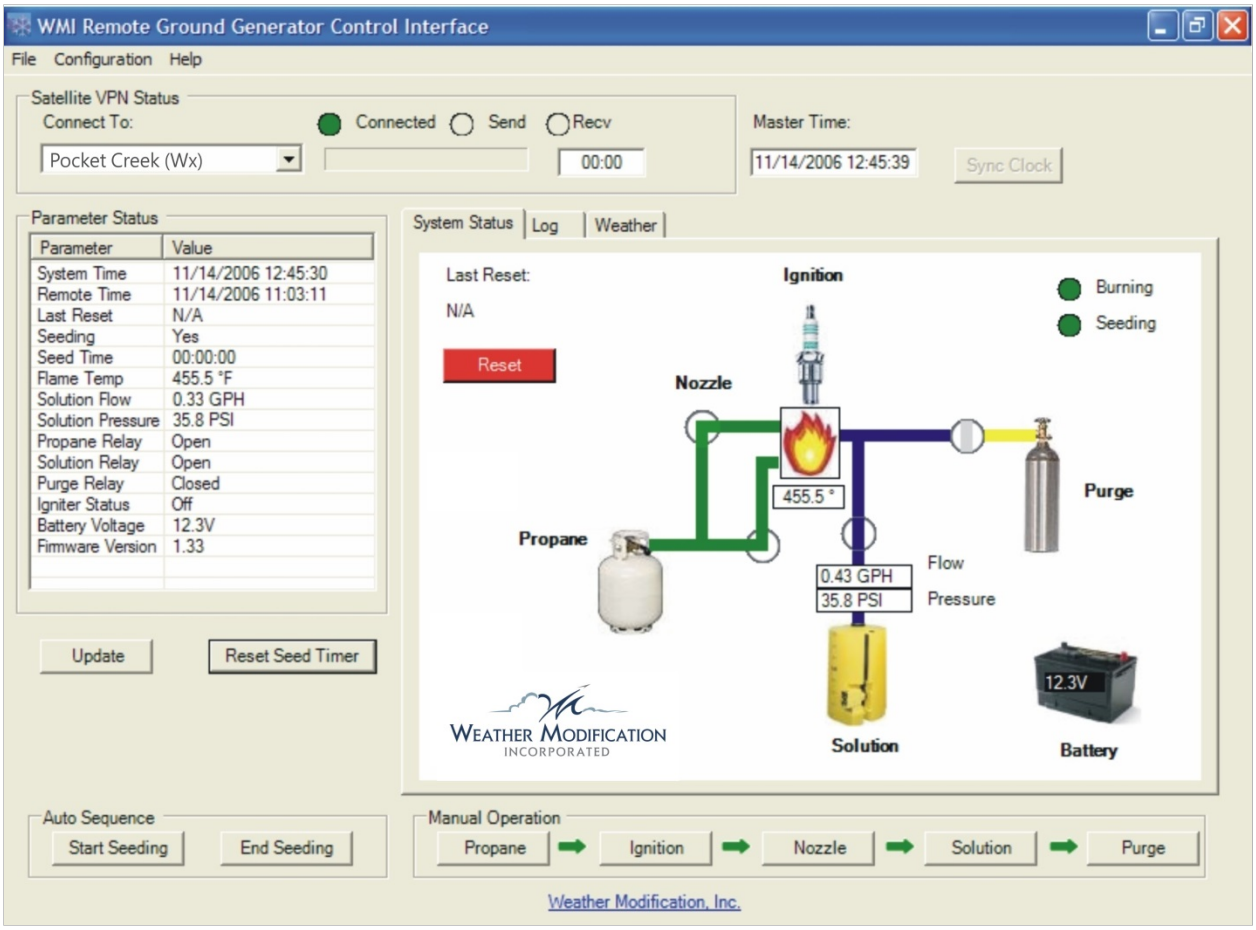

Figure 8. The WMI remote-controlled ice nucleus generator interface is shown, as it appears during seeding operations. Valves are open, the flame is known to be burning, and the seeding solution flow rate is also known. Seeding is certain.

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 (+17.6F), and even more at -10°C (+14°F). In the course of the WWMPP, a -8°C temperature at the 700 hPa altitude (about 10,000 ft, approximate mountain top) was used as the threshold for seeding. At that temperature about 2 x 1013 ice nuclei are active for each gram of AgI burned. In English, this is 20,000,000,000,000, or 20 trillion nuclei. At -6°C, only 3 x 1011 nuclei are active, just 300,000,000,000, or 300 billion. Although the results indicate that cloud seeding efficiency decreases with warmer temperatures, the temperature criteria used in an operational program is typically warmer than those used in research based applications. Research studies provide the foundation for the design of operational programs. Operational programs in the western United States commonly commence seeding operations at -5 or -6°C. As in the previous two seasons, the 2016-2017 Wind River operations used a temperature criterion of -6°C at 700 hPa (about 10,000 feet above sea level).

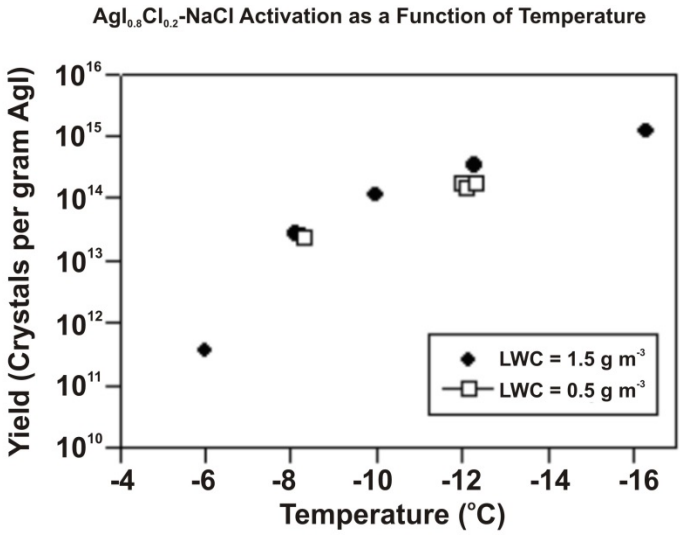

Figure 9. Yield as measured by the number of active ice nuclei per gram of silver iodide (AgI) burned, is shown as a function of temperature (DeMott 1997). These nuclei are comprised of silver iodide, silver chloride, and salt (NaCl).

It was previously mentioned that this seeding solution is "high-performance". This means that unlike simpler solutions that produce a pure AgI nucleus, this "high performance" solution also contains salt, which enables it 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 NCAR, 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.

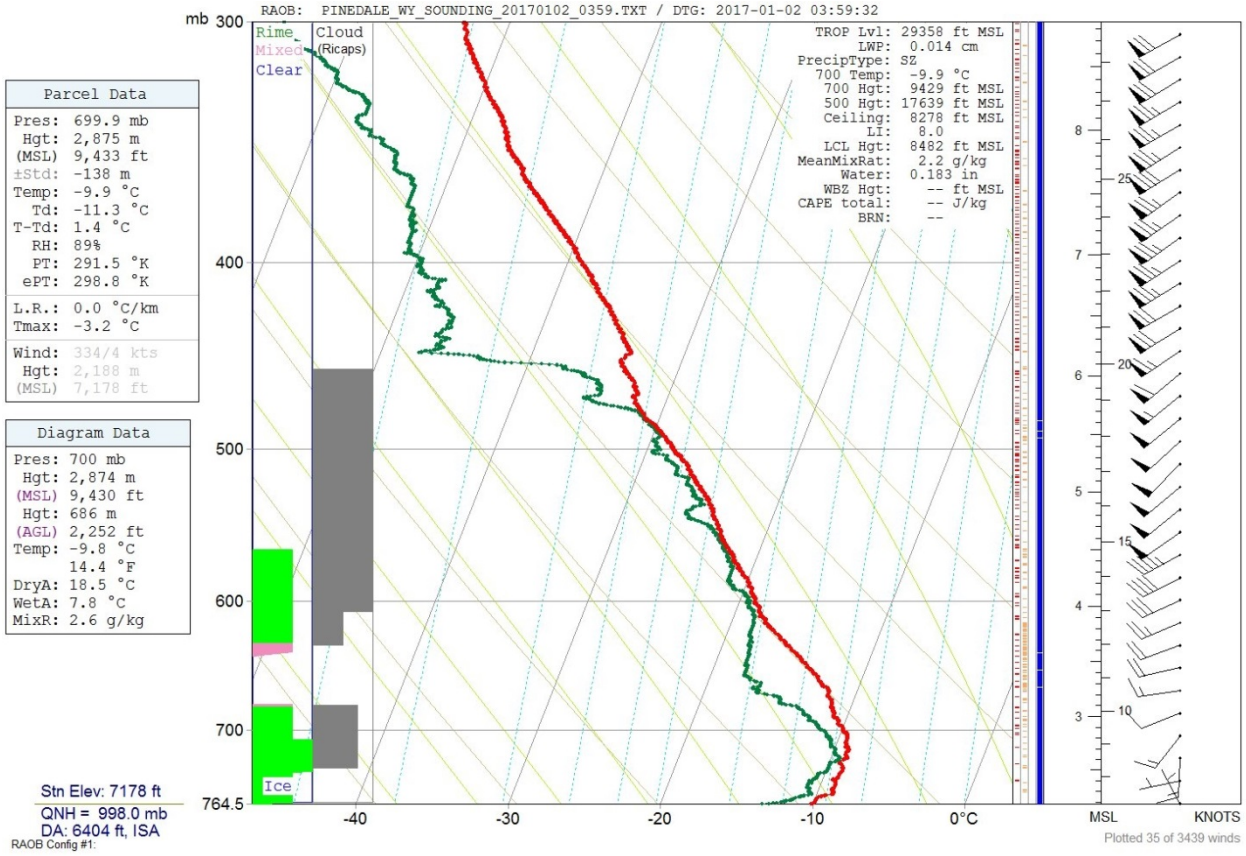

Figure 10. A plot of the upper-air sounding obtained from the weather balloon released from Pinedale, WY at 9:00 pm MST (04:00 am UTC 2 January 2017) on 1 January 2017. The temperature at 700 hPa level (approximately 10,000 feet) was -10°C (+14°F), and the wind speed was from 260° (westerly) at 10-15 knots (11-17 miles per hour), both within the acceptable range for seeding.

2.6 Weather Stations

Five of the ten generator sites were equipped with Vaisala WXT-510 weather stations. These generators were: Big Sandy Opening, Boulder Lake, Enterprise, Pocket Creek, 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, WY that provided storage and served as a staging area for generator service and the preparation and release of weather balloons. The shop remains in Pinedale, but was moved to a new, slightly smaller, but very functional location in 2016.

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.

Radiometer. The WWDO radiometer was deployed at a residence near Boulder, WY (Figure 11). 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.

Figure 11. The radiometer sited near Boulder, WY. The instrument does not transmit, but passively measures the atmospheric liquid water and water vapor. (WMI photograph by Daniel Gilbert.)

Atmospheric Soundings. The atmospheric soundings (weather balloons/rawinsondes) were discussed in Section 2.5. Data from the soundings were immediately shared with the NWS and WRDS.

HYSPLIT Modeling. WMI ran the HYSPLIT plume dispersion model to establish a better idea of seeding agent plume behavior. During the 2016-2017 season, meteorologist Dan Gilbert configured HYSPLIT for the Wind River Range. The plume trajectory model was used as tool to help make better-informed seeding decisions. More about this is presented in Section 4.3.

3.2 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.

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 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).

The presence of SLW was confirmed by the real-time data from the radiometer (Section 3.1, Figure 11) 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 would be activated, when, and for how long. The length of time a generator was activated depended upon how long weather conditions were expected to remain 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 2016-2017 Season

Compared to previous operational seasons, the 2016-2017 cloud seeding season encountered several administrative and operational hurdles. In previous years, project funding was available for approximately 5.5 months of operations. However, in order to address budgetary constraints and keep the program up and running, this past season was contracted to operate under an abbreviated timeline. The new operational timeline was expected to run from 15 November 2016 to 31 March 2017 (no seeding in April). However, due to contractual delays, the start of the seeding season was setback from the 15th to the 30th of November. As mentioned, in previous years, the length of an operational season typically ran for 163 to 167 days, whereas the 2016-2017 season was only 73 days in duration. The 2016-2017 season was abbreviated even further than planned due to above average snowfall amounts. Seeding operations were officially suspended on 10 February 2017 as snow water equivalent (SWE) suspension criteria were met at 07:15 AM MST. The WWDO released a press release discussing the suspension on 14 February 2017.

For the first few weeks after the suspension, snowfall rates decreased and it appeared that the SWE might fall below the suspension threshold allowing operations to resume; however, such was not the case. Figure 12 illustrates the evolution of SWE during the season, with respect to the specific suspension criterion.

During the 73 days that operations were possible, seeding was conducted on fourteen occasions, as enumerated in Table 2. December had the most opportunities (six), and the highest amount of seeding agent released (20.4 kg). January was the second most active month with five events, and a total of 9.9 kg of seeding agent released. Table 3 summarizes operations by month and provides season totals. November went unseeded, as the contract was not finalized until the 30th. Whereas, three seeding events took place in February even though operations were suspended early on, and remained in suspension through the month of March. Note that easterly flow seeding events did not occur in the abbreviated 2016-2017 operational season. In previous seasons it has been used fairly often, but an opportunity to target easterly flow never presented itself. In total, 40.5 kg of seeding agent were released. Generators were operated for a total of 242:25 hours during the season, accruing a total of 1,618 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.] Despite the shortened season, all fourteen seeding events were quality opportunities in which for majority of the seeding events, at least seven of the ten generators were utilized.

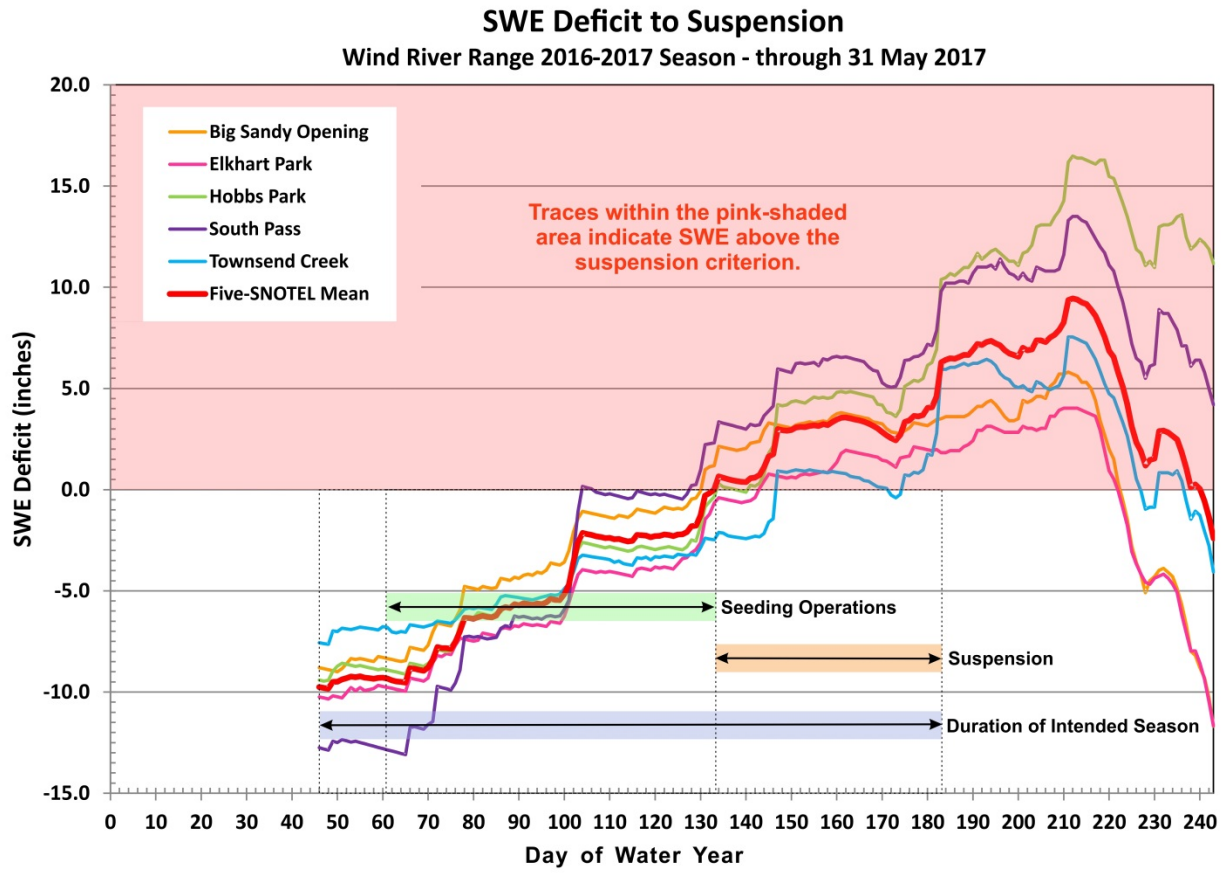

Figure 12. The accumulations of SWE at each of the five SNOTEL sites used (collectively) to determine when snowpack sufficient to warrant suspension of seeding operations are shown. Also shown is the five-SNOTEL mean (bold red), that serves as the actual determinant as to when to cease operations. The double-ended arrow highlighted in blue depicts the duration of the seeding season originally planned, from 15 November 2016 through 31 March 2017. The green-highlighted arrow shows the period of the season during which operations were conducted, from 30 November 2016 through 10 February 2017. Finally, the peach-highlighted arrow indicates the period of the season during which operations were suspended.

TABLE 2. Wyoming Weather Modification Operations, 2016-2017 Season Wind River Mountains						
Date	***Number of Generators Utilized***	***Length of Seeding (hours)***	***Total Generator Hours***	***AgI Released This Date (kg)***	***AgI Monthly Total (kg)***	***AgI Season Total (kg)***
4-Dec-16	9	20:10	117:52	2.946	20.379	2.946
9-Dec-16	7	35:09	245:52	6.147		9.093
11-Dec-16	7	26:40	188:34	4.714		13.807
14-Dec-16	7	9:22	51:00	1.275		15.082
23-Dec-16	9	5:41	52:11	1.307		16.389
27-Dec-16	7	23:20	159:36	3.990		20.379
1-Jan-17	9	7:55	70:57	1.774	9.906	22.153
2-Jan-17	9	7:00	62:24	1.560		23.713
3-Jan-17	6	5:30	27:48	0.695		24.408
9-Jan-17	4	5:02	27:56	0.698		25.106
10-Jan-17	9	37:45	207:17	5.179		30.285
1-Feb-17	7	11:05	77:38	1.941	10.174	32.226
3-Feb-17	9	36:00	246:49	6.170		38.396
6-Feb-17	7	11:48	82:30	2.063		40.459
10-Feb-17	SWE suspension threshold exceeded, seeding suspended at 07:15 MST					

TABLE 3. Summary of Seeding Events During the 2016-2017 Winter Season					
Month	*Events ( ) denotes easterly flow*	*Event Averages*		*Seeding Agent (kg)*	
		Number of Generators	*Generator Hours**	*Average Released per Event*	*Total Released*
November	0	--	--	--	0.000
December	6	7.7	135.9	3.26	10.187
January	5	7.4	79.3	4.00	8.762
February	3	7.7	135.6	2.75	4.808
March	0	--	--	--	0.000
Totals/Averages	*14 (0)*	*7.6*	*257.8 / 42.9*	*1.012*	*31.553*
**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.

As expected, the complexity of the generators and the extreme weather played a role in precluding perfection this season, as seen in Table 4, five red "NO"s, and five yellow "PARTIAL"s are documented.

Only once did more than one generator fail completely in the same event; that occurred on 10 January 2017. Four generators ran perfectly all season: Block and Tackle, Boulder Lake, East Fork, and Pocket Creek. Sweetwater, White Acorn, and Anderson Ridge are located at the southern end of the range and were used less frequently than some of the others. Nevertheless, except for minor glitches experienced during the first seeding event of the season (4 December 2016), these generators also ran flawlessly through the season.

Of the remaining three, the Big Sandy Opening generator was the season's "problem child". Of the 13 times that generator was selected for operations, it failed on four occasions, despite the best efforts of the technicians. The technicians deduced that the heavy snowfall amounts piling up on the solar panels was reducing the recharge of the generator, and on 18 January 2017 they installed a thermoelectric generator, which provides a constant trickle charge by burning a very small amount of propane. The generator ran effectively for all three seeding events after that date.

It is noteworthy that the Enterprise generator, sited on the eastern flank of the Wind River Range near Lander, was never used during the 2016-2017 season. The non-use of the Enterprise generator during the 2016-2017 season is in part attributed to the upper level weather pattern not being supportive of easterly upslope storm development. In previous seasons it has been used fairly often, but most commonly in early- and late-season weather conditions, when flow having a significant easterly component is more common. With the delayed start and early suspension, no opportunity to target easterly flow presented itself.

The generator performance for the season was very good, at 92.9% functionality, a decrease of only 0.4% from the previous season. This high percentage level of performance was attained in spite of a 37% increase in generator hours. This is testimony to the diligence and skill of the technicians. During the 2016-2017 season, generators ran for a record 1,618 hours, whereas during the previous 2014-2015, and the 2015-2016 seasons the total was 852, and 1,173 hours respectively. For additional details of the three recent operational seasons, see Table 5 and 6, in the Section 4.2.

TABLE 4. Ice nucleus generator operations are shown for each of the fourteen 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
20161204	*WRR0049*	*REQ*	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	NO	YES	PARTIAL	PARTIAL	PARTIAL	NO	YES	YES	YES	YES		6.5
20161209	*WRR0050*	*REQ*	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
20161212	*WRR0051*	*REQ*	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
20161214	*WRR0052*	*REQ*	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	NO	YES	YES	NO	NO	NO	YES	YES	YES	PARTIAL		5.5
20161224	*WRR0053*	*REQ*	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES		9
20161227	*WRR0054*	*REQ*	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
20170102	*WRR0055*	*REQ*	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES		9
20170102	*WRR0056*	*REQ*	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES		9
20170103	*WRR0057*	*REQ*	YES	YES	YES	NO	NO	NO	YES	NO	YES	YES	6	
		RAN	NO	YES	YES	NO	NO	NO	YES	NO	YES	YES		5
20170110	*WRR0058*	*REQ*	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES	4	
		RAN	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES		4
20170110	*WRR0059*	*REQ*	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	NO	YES	YES	YES	YES	NO	YES	YES	YES	NO		7
20170201	*WRR0060*	*REQ*	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
20170204	*WRR0061*	*REQ*	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	YES	YES	YES	YES	YES	NO	YES	YES	YES	PARTIAL		8.5
20170207	*WRR0062*	*REQ*	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
												TOTALS	106	98.5
													RUN =	92.9%
													FAIL =	7.1%

ALL DATES ARE IN UNIVERSAL TIME COORDINATES (UTC). UTC = MST + 7 HOURS.

PARTIAL indicates that the generator was inoperative for 25% or less of the expected runtime. If inoperative for more, the indicator NO is used.

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, and no trends or tendencies can be identified. In terms of actual number of hours with seeding operations, the 2015-2016 season tops the list. However, if you were to compare the hours of seeding executed in each season, for only the three months that seeding was conducted in the 2016-2017 season, the results would show that the 2016-2017 season is far above the others, 74 hours more than the2015-2016 season. A very large difference, and that, with two-thirds of February 2017 in suspension!

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
Mean	25:50	90:04	45:45	52:03	43:40	15:03	244:16

The difference in the number of ice nucleus generators operation presents an even more striking result (Table 6). The abbreviated2016-2017 season was 400 hours higher than either of the others, without even considering the differences in season lengths.

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
Mean	79:02	522:40	283:43	208:13	205:42	15:03	1214:28

Thus, even though shortened, the 2016-2017 season was very active and productive, with ample seeding opportunities. The greatest benefits from seeding are accrued when there are many seedable storms, and that was most certainly the case this past season.

4.3 Numerical Modeling

Project forecasters frequently rely on model output that is publicly available on the internet, however, during the 2014-2015 season, the National Center for Atmospheric Research (NCAR) ran a high-resolution version of the Weather Research and Forecasting (WRF) prognostic numerical weather model for the Wind River Range. NCAR's high resolution model provided site specific predictions of suitable seeding conditions at greater detail than those available from public sources; however, the model is proprietary and not available for public use free of charge. In the absence of NCAR's model, WMI began to investigate the implementation of the HYSPLIT model to gain an improved understanding of seeding agent plume trajectories during the 2015-2016 season.

During the 2016-2017 season, meteorologist Dan Gilbert configured HYSPLIT for the Wind River Range and the generators network. An example of the HYSPLIT output is shown in Figure 13.

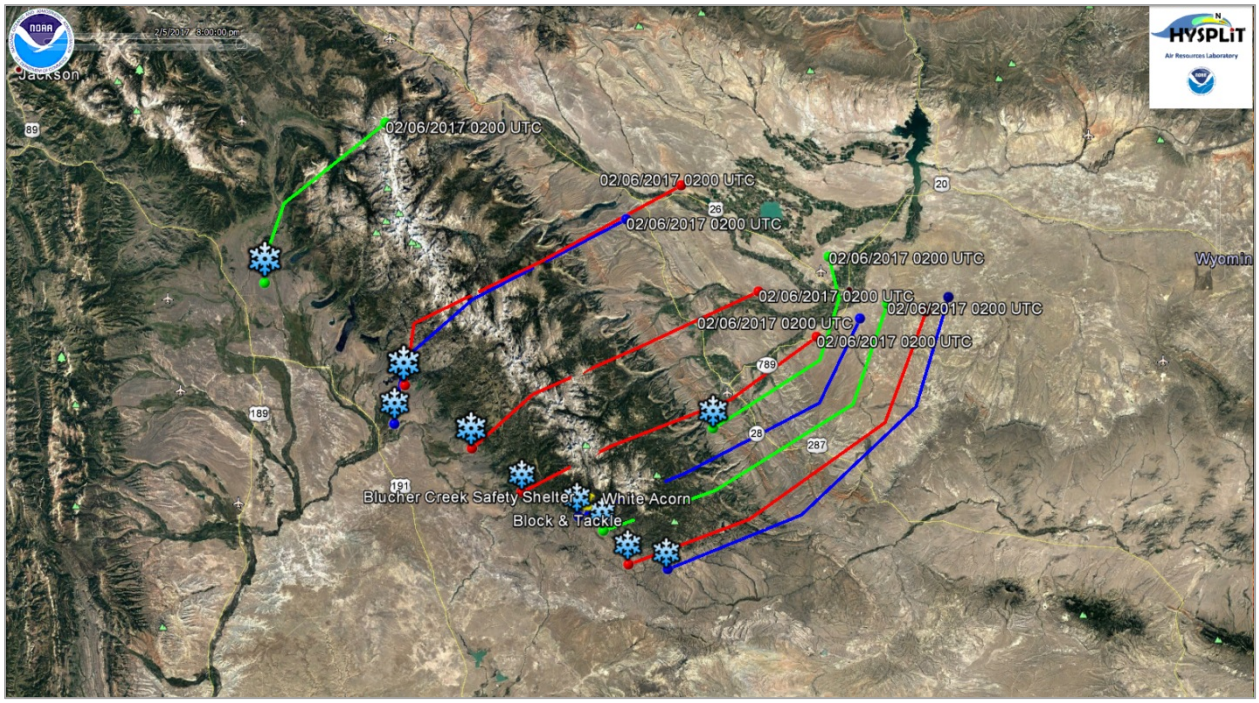

Figure 13. The plume trajectory centerlines over and around the Wind River Range as predicted by HYSPLIT on 5 February 2017 (MST) are shown. Snow crystals denote generator locations. Line colors vary only to aid visual discrimination when plumes from adjacent generators approach each other. From this plot it is apparent that the southernmost generators should not be used, as their plumes would go south of the range rather than over it. (WMI graphic by Dan Gilbert.)

The implementation of the HYSPLIT model was viewed as "another tool in the tool-box" that project forecasters found useful. As shown in Figure 13, seeding agent plumes are predicted to move perpendicular to the range; however, it is apparent that the southernmost generators should not be utilized for this seeding event. The HYSPLIT model predicted that the southernmost plumes would not impact target area. The HYSPLIT model was operated as a surrogate for NCAR's high resolution WRF model, and used when the other available information provided insufficient guidance.

Early in 2017 WMI began investigating the re-introduction of WRF high-resolution numerical modeling, and conducted a number of trial runs. These test runs were very encouraging, and consideration will be given to its implementation in the 2017-2018 season.

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 2016-2017 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, WY and learn about the project and upper air soundings, and even to participate in the release of a weather balloon (Figure 14). 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.

Figure 14. Pinedale pre-school students and parents watch their teacher prepare to release a weather balloon at the WMI shop during a public outreach event on 9 March 2017. Meteorologist Dan Gilbert (left, with orange parachute) assists, while the kids count down to the balloon release. (WMI photograph by Adam Brainard)

WMI also presented an update on the 2016-2017 Wind River operational seeding efforts at the Wyoming Weather Modification Technical Advisory Team (TAT) meeting held in Laramie, WY on 12 July 2017. 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 2016-2017 cloud seeding effort in the Wind River Range began on 30 November 2016, and officially concluded on 31 March 2017, a duration of nearly about 4 months. The season started two weeks later than normal (15 November) due to a delay in finalizing the collaborative weather modification agreements. The conclusion date of 31 March 2017 was planned as a measure to address funding constraints and keep the Wind River Range cloud seeding program up and running for the 2016-2017 winter season.

Seeding operations were suspended on 10 February 2017 because the percent of snow water equivalent had exceeded the pre-established operational cloud seeding suspension criterion. The suspension remained in force for the remainder of the season.

Fourteen seeding events were conducted from 30 November to 10 February 2017. All events involved the use of four or more generators, seeding in westerly or southwesterly flow. A total of 40.46 kg of silver iodide was released in the course of 1,618 hours of generator operations. After the suspension on 10 February 2017, there were four additional situations, all in February, when seeding would have been conducted has operations not been suspended. In two of these, west-slope generators would have been utilized, in the other two, the Enterprise generator on the east slope would have been activated. There were a number of significant precipitation events during March, but all were associated with temperatures too warm for seeding, though some only by small margins.

The ice nucleus generators operated reliably, seeding as intended nearly 93% of the time. Four generators ran perfectly all season: Block and Tackle, Boulder Lake, East Fork, and Pocket Creek. Except for minor glitches experienced during the first seeding event of the season (4 December 2016), Sweetwater, White Acorn, and Anderson Ridge generators also ran flawlessly through the season.

In terms of hours of seeding generator operations, the winter was 37% more active (more hours) than the 2015-2016 season. Even though the season was abbreviated, the generator hours (1,618) exceeded the greatest previous season total by more than 400 hours.

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 *2016-2017 Season – WMI Daily Project Summary*	
29 November 2016, Tuesday	
The range had periods with broken low cloud over parts of the range throughout the afternoon. Some slightly thicker cloud covered the southern end of the range briefly in the evening. Low stratus was banked up against the western side of the range in the late night and early morning hours while the range itself saw clearing. Max/Min temperatures PNA: 28/7 RKS: 29/11 LND: 33/15 Observed DWWS: -1	No ground-based seeding was conducted.
30 November 2016, Wednesday	
There was low stratus along the western slopes in the morning and then waves of midlevel cloud during the day. Overcast layers blanketed the range overnight. Low level winds were light, and orographic clouds were minimal. No seeding occurred. Max/Min temperatures PNA: 28/7 RKS: 29/11 LND: 33/15 Observed DWWS: 0	No ground-based seeding was conducted.
01 December 2016, Thursday	
There were periods of thick stratus and upper level cloud layers off and on throughout the period. Very weak northeast flow developed in the low levels overnight. There was some moderate snowfall, particularly on the eastern slopes late in the period. The light variable winds were not suitable for proper plume transport, and no seeding occurred. Max/Min temperatures PNA: 28/10 RKS: 28/14 LND: 30/14 Observed DWWS: 0	No ground-based seeding was conducted.

02 December 2016, Friday	
An area of thin, low clouds were present over the over the southern tip of the range in the morning, but the wind was light. Scattered, low clouds existed over the range during the afternoon and early evening, but no continuous coverage occurred due to light wind flow. Only high clouds were observed overnight. Max/Min temperatures PNA: 27/0 RKS: 25/7 LND: 31/14 Observed DWWS: 0	No ground-based seeding was conducted.
03 December 2016, Saturday	
There were some shallow, thin, low clouds over the NW part of the range throughout the most of the daylight hours. High and mid level clouds existed overnight with some small low clouds that didn't cover the range. More low clouds developed early Sunday morning. Max/Min temperatures PNA: 27/5 RKS: 26/11 LND: 36/11 Observed DWWS: -1	No ground-based seeding was conducted.
04 December 2016, Sunday	
Thick clouds began developing over the range in the morning and thick clouds with continuous snowfall persisted through the rest of the day. Conditions were favorable for seeding operations with all the southern GGEN. Max/Min temperatures PNA: 30/9 RKS: 37/20 LND: 45/14 Observed DWWS: +2	Seeding event WRR0049 was called at 1010 MST on 12/04/2016 and began at 1015 MST. The seeding event began with only the four northern generators WR13, WR09, WR10, and WR12 due to initial wind direction. WR01, WR02, WR03, WR04 and WR05 were added later in the case at 14:17 MST due to a change in wind direction. Likewise, WR04 and WR05 were shut down early at 23:30 MST due to continued changes in winds. <u>Case WRR0049</u> Generators: WR09, WR10, WR12, WR13 Time: 10:15 (12/04) to 06:25 (12/05) MST 17:15 (12/04) to 13:25 (12/05) UTC WR01, WR02, WR03 Time: 14:17 (12/04) to 06:25 (12/05) MST 21:17 (12/04) to 13:25 (12/05) UTC WR04, WR05 Time: 14:17 (12/04) to 23:30 (12/04) MST

	21:17 (12/04) to 06:30 (12/05) UTC Duration: 117:52 Total Time Seeding: 2,946.67g silver (45.20 gallons)
05 December 2016, Monday	
The clouds from the Sunday seeding event had diminished quickly in the morning hours. More low clouds developed over the range during the afternoon and lasted into the evening. There were some areas of light snowfall, but the wind was not favorable for seeding operations. No significant cloud cover was observed overnight. Max/Min temperatures PNA: 28/-14 RKS: 32/2 LND: 36/3 Observed DWWS: 0	Seeding event WRR0049 continued until 0625 MST 12/05/2016.
06 December 2016, Tuesday	
The range was mostly clear in the morning. Thick overcast layers overspread the region in the late afternoon which remained in place throughout most of the night. The high and midlevel clouds cleared out in the morning, while some thin low cloud lingered over the mountains. Due to lack of SLW, conditions were not suitable for seeding. Max/Min temperatures PNA: 12/-22 RKS: 18/-7 LND: 16/-2 Observed DWWS: 0	No ground-based seeding was conducted.
07 December 2016, Wednesday	
The range was mainly clear in the afternoon with a few low clouds and fog hanging in the valley and between the peaks. Some low overcast thin cloud blanketed parts of the range in the evening and late night hours while other parts were clear. Pinedale was clear and saw lows down to -22F in the early morning while Lander had thin cloud much of the night and lows were about twenty degrees above Pinedale. There was nothing suitable for seeding throughout the period. Max/Min temperatures PNA: 12/-18 RKS: 12/-4 LND: 11/1 Observed DWWS: -1	No ground-based seeding was conducted.

08 December 2016, Thursday	
The range was clear in the morning, and then cloud cover increased throughout the afternoon. Light snow began in the late afternoon and continued through the night. The 02Z Pinedale sounding confirmed the presence of a deep inversion from 9 kft up to 12kft. It was determined that seeding plumes from the GGENS (~7.8-8.5 kft) would be trapped under the strong inversion where winds were not favorable for plume transport toward the mountains. HYSPLIT forward trajectories suggested seeding plumes would travel either toward the northwest or flow around the range all night. Since the sounding confirmed the low level winds were unfavorable below the inversion, no seeding occurred. Max/Min temperatures PNA: 12/-22 RKS: 10/-9 LND: 11/-5 Observed DWWS: 0	No ground-based seeding was conducted.
09 December 2016, Friday	
Light snowfall was observed throughout the morning and early afternoon. The low level inversion became shallow enough for seeding to begin in the midafternoon. Ice nucleus generators ran through the night, and they continue to run Saturday morning. Moderate to heavy snow was observed throughout the evening and overnight hours. Max/Min temperatures PNA: 25/10 RKS: 37/9 LND: 19/-1 Observed DWWS: +2	Seeding event WRR0050 was called at 1425 MST on 12/09/2016 and began at 1446 MST. Seeding ended at 01:55 (12/11) MST <u>Case WRR0050</u> Generators: WR01, WR02, WR03, WR09, WR10, WR12, WR13 Time: 14:46 (12/9) to 01:55 (12/11) MST 21:46 (12/9) to 08:55 (12/11) UTC Duration: 35:09, 245:52 Total Time Seeding: 6,146.67g silver (102.21 gallons)
10 December 2016, Saturday	
Favorable seeding conditions continued from Friday afternoon until after midnight. The precipitation began to weaken in the evening, but it re-developed and then even persisted for a few hours after a cold front passed through just before midnight. By Sunday morning, there were only shallow low clouds over the range. Max/Min temperatures PNA: 36/25 RKS: 40/28 LND: 45/9	Seeding event WRR0050 continued until 0155 MST 12/11/2016.

Observed DWWS: +2	
11 December 2016, Sunday	
Shallow low clouds were over the range in the morning. The clouds thickened in the afternoon but were not consistent enough for seeding and didn't fully cover the range. The clouds developed more after sunset and allowed for seeding. Snowfall remained and somewhat broken in coverage but seeding continued into Monday. Max/Min temperatures PNA: 27/1 RKS: 29/15 LND: 34/17 Observed DWWS: +1	Seeding event WRR0051 was called at 1840 MST on 12/11/2016 and began at 1910 MST. <u>Case WRR0051</u> Generators: WR01, WR02, WR03, WR09, WR10, WR12, WR13 Time: 19:10 (12/11) to 21:50 (12/12) MST 02:10 (12/12) to 04:50 (12/13) UTC Duration: 26:40, 188:34 Total Time Seeding: 4,714.17g silver, (76.01 gallons)
12 December 2016, Monday	
The low clouds over the range were thinning during the morning and snowfall slowly tapering off until after noon when more moisture moved into the area and snowfall increased. Thick clouds and continuous snowfall persisted until mid the evening. The clouds then thinned overnight. Max/Min temperatures PNA: 25/-8 RKS: 28/12 LND: 34/16 Observed DWWS: +2	Seeding event WRR0051 continued until 2154 MST 12/12/2016.
13 December 2016, Tuesday	
Thin, low and mid level clouds were around in the morning. The clouds thickened a little during the afternoon with scattered areas of light snowfall over the range in the late afternoon and evening. Conditions were not continuous enough for seeding operations. Only high clouds and thin low clouds existed overnight. Max/Min temperatures PNA: 25/-15 RKS: 24/11 LND: 33/11 Observed DWWS: 0	No ground-based seeding was conducted.
14 December 2016, Wednesday	
Heavy snowfall was observed from the afternoon through overnight hours. Conditions were favorable for operations through the late night hours, and then it became too warm	Seeding event WRR0052 was called at 1540 MST on 12/14/2016 and began at 1623 MST.

for seeding. Max/Min temperatures PNA: 21/1 RKS: 27/19 LND: 22/9 Observed DWWS: +2	Case WRR0052 Generators: WR01, WR02, WR03, WR09, WR10, WR12, WR13 Time: 16:23 (12/14) to 01:45 (12/15) MST 23:23 (12/14) to 08:45 (12/15) UTC Duration: 9:22, 51:00 Total Time Seeding: 1,275.00 g silver, (19.19 gallons)
15 December 2016, Thursday	
Heavy orographic snowfall continued throughout the period. Low thick cloud clouds enshrouded the mountains, and liquid water content was excellent. However, it remained too warm for seeding operations. No seeding occurred. Max/Min temperatures PNA: 36/18 RKS: 40/18 LND: 49/9 Observed DWWS: 0	No ground-based seeding was conducted.
16 December 2016, Friday	
Snow and even some low elevation rain were observed during the day. Thick orographic clouds will abundant SLW were present all day. Cold air and northwest winds brought an end to the precipitation in the late evening. It was too warm for seeding during the period with decent cloud cover. Winds were unfavorable for ops once the temps dropped to within seeding limits. No seeding occurred. Max/Min temperatures PNA: 37/9 RKS: 42/-1 LND: 26/-4 Observed DWWS: 0	No ground-based seeding was conducted.
17 December 2016, Saturday	
The range was mostly clear during the daytime hours. Late in the day, a large wave of high and midlevel cloud overspread the region along with some thin orographic clouds over the range. The upper level clouds cleared out again around 5z, but some low stratus surrounded parts of the range during the early morning hours. Skies cleared out in the morning. Max/Min temperatures PNA: 9/-18 RKS: 10/-7	No ground-based seeding was conducted.

LND: -4/-21 Observed DWWS: -1	
18 December 2016, Sunday	
Clear skies during the daylight hours until late afternoon when some clouds developed around the range with more coverage for a short time just after sunset. High and mid level clouds moved into the area from the NW by the morning. Max/Min temperatures PNA: 10/-13 RKS: 13/1 LND: 12/-17 Observed DWWS: -1	No ground-based seeding was conducted.
19 December 2016, Monday	
Widespread mid level clouds covered much of WY from the morning through the evening hours, with less coverage overnight. There were periods of light snowfall over the range during the afternoon and evening, but it was not consistent and the wind flow was not favorable for seeding. Max/Min temperatures PNA: 19/-15 RKS: 26/5 LND: 27/-7 Observed DWWS: 0	No ground-based seeding was conducted.
20 December 2016, Tuesday	
Thin, low clouds were over the range in the morning. The clouds became thicker with increasing areas of light snowfall throughout the afternoon. Widespread, continuous snowfall over the range existed from late afternoon through midnight, and then diminished after a cold front moved through. The temperature had been too warm for seeding during the afternoon and evening. Max/Min temperatures PNA: 32/9 RKS: 41/24 LND: 50/18 Observed DWWS: 0	No ground-based seeding was conducted.
21 December 2016, Wednesday	
High clouds were around throughout the day. No other significant cloud coverage appeared.	No ground-based seeding was conducted.

Max/Min temperatures PNA: 28/-6 RKS: 33/17 LND: 45/13 Observed DWWS: -2	
22 December 2016, Thursday	
Thin high clouds were present during the day with otherwise clear skies. Thicker lower cloud layers moved in from the south around sunset. The clouds cleared out overnight and the range was mostly clear until dawn. No seeding occurred. Max/Min temperatures PNA: 14/-13 RKS: 25/13 LND: 21/5 Observed DWWS: -1	No ground-based seeding was conducted.
23 December 2016, Friday	
Skies were clear in the morning hours, and then cloud cover increased steadily through the afternoon and evening. Thick clouds suitable for seeding were present in the late evening into the late night hours, and then clouds and snowfall diminished around 8- 9z. Max/Min temperatures PNA: 19/-11 RKS: 35/13 LND: 22/1 Observed DWWS: +1	Seeding event WRR0053 was called at 1845 MST on 12/23/2016 and began at 1949 MST. <u>Case WRR0053</u> Generators: WR01, WR02, WR03, WR04, WR05, WR09, WR10, WR12, WR13 Time: 19:49 (12/23) to 01:30 (12/24) MST 02:49 to 08:30 (12/24) UTC Duration: 5:41, 52:11 Total Time Seeding: 1,306.58g silver (20.93 gallons)
24 December 2016, Saturday	
Thick clouds and heavy snow persisted throughout the late evening. A midday Pinedale sounding confirmed what the models were showing in that the low level temperatures were slightly too warm for seeding operations. The temps finally dropped to within seeding criteria during the late night hours, but then the winds became unfavorable and cloud/liquid/snowfall diminished. No seeding occurred. Max/Min temperatures PNA: 34/19 RKS: 41/27 LND: 32/10 Observed DWWS: 0	No ground-based seeding was conducted.

25 December 2016, Sunday	
Heavy snowfall was observed throughout the day. Snowfall rates decreased in the evening becoming mainly flurries and light snow after midnight. Snow ended and skies cleared in the early morning. Winds were not suitable for operations, and no seeding occurred. Max/Min temperatures PNA: 32/9 RKS: 34/14 LND: 27/4 Observed DWWS: 0	No ground-based seeding was conducted.
26 December 2016, Monday	
The area was clear until mid level clouds came in around mid afternoon. These clouds continued into the early evening, with some low clouds during that time. It was again clear until just before sunrise when some high clouds moved in from the west. Max/Min temperatures PNA: 14/-9 RKS: 20/9 LND: 24/1 Observed DWWS: -1	No ground-based seeding was conducted.
27 December 2016, Tuesday	
Thick cloud coverage and light snowfall began developing over the range during the morning hours. Favorable seeding conditions developed by late morning and continued for the rest of the period. The wind flow was somewhat marginal at the beginning of the seeding. The heaviest snowfall occurred during the evening hours. The cloud and snowfall slowly diminished Wednesday morning. Max/Min temperatures PNA: 18/-13 RKS: 29/5 LND: 31/2 Observed DWWS: +2	Seeding event WRR0054 was called at 1105 MST on 12/27/2016 and began at 1115 MST. The seeding event began with only the four northern generators WR13, WR12, WR10, and WR09. WR01, WR02 and WR03 were added later in the case at 21:18 due to expanded cloud coverage and precipitation developing further down the range. <u>Case WRR0054</u> Generators: WR09, WR10, WR12, WR13 Time: 11:15 (12/27) to 10:35 (12/28) MST 18:15 (12/27) to 17:35 (12/28) UTC Generators: WR01, WR02, WR03 Time: 14:15 (12/27) to 10:35 (12/28) MST 21:15 (12/27) to 17:35 (12/28) UTC Duration:159:36 Total Time Seeding: 3,990.00g silver (60.18 gallons)
28 December 2016, Wednesday	
The thick clouds from Tuesday had diminished in the	No ground-based seeding was conducted.

morning. Thin clouds lingered over the range through the afternoon with areas of light snowfall, but the wind was no longer favorable for seeding operations. The sky was clear in the evening and overnight. Max/Min temperatures PNA: 21/-4 RKS: 29/16 LND: 31/9 FWZ: 19/9 Observed DWWS: 0	
29 December 2016, Thursday	
The range was clear through the afternoon and evening. High and mid level clouds were around during the night for a few hours. Max/Min temperatures PNA: 14/-17 RKS: 33/11 LND: 20/3 FWZ: 28/9 Observed DWWS: -2	No ground-based seeding was conducted.
30 December 2016, Friday	
The range was mainly clear during the morning and afternoon hours. Thick overcast layers overspread the region from the north starting just before sunset. Marginal orographic clouds were present with a few hours of moderate snowfall during the evening. Wind flow and cloud cover were marginally favorable for an hour or two, but seeding conditions deteriorated quickly in the later evening as winds shifted to NW. The snowfall and cloud cover cleared out completely by midnight, and skies cleared overnight. No seeding occurred. Max/Min temperatures PNA: 25/-9 RKS: 37/7 LND: 43/4 FWZ: 26/-2 Observed DWWS: 0	No ground-based seeding was conducted.
31 December 2016, Saturday	
Skies remained clear throughout the period. Max/Min temperatures PNA: 21/-4 RKS: 32/16	No ground-based seeding was conducted.

LND: 27/8 FWZ: 25/11 Observed DWWS: -3	
01 January 2017, Sunday	
Skies were clear in the morning, and then cloud layers overspread the region and became gradually thicker throughout the day. By late evening, thick low clouds and snowfall were observed, and seeding began. Seeding continued throughout the night, ending in the early morning hours as winds became light and low level clouds diminished. Max/Min temperatures PNA: 18/-15 RKS: 36/15 LND: 29/3 FWZ: 21/7 Observed DWWS: +2	Seeding event WRR0055 was called at 2127 MST on 01/01/2017 and began at 2158 MST. <u>Case WRR0055</u> Generators: WR01, WR02, WR03, WR04, WR05, WR09, WR10, WR12, WR13 Time: 21:50 (01/01) to 05:45 (01/02) MST 04:50 to 12:45 (01/02) UTC Duration: 7:55, 70:57 Total Time Seeding: 1,773.75g silver, (27.12 gallons)
02 January 2017, Monday	
Thick low orographic clouds with very light SLW were observed from late morning through the early evening hours with light snow. Clouds thinned out for the evening and overnight hours as moisture waned slightly. Max/Min temperatures PNA: 18/-13 RKS: 29/15 LND: 13/-3 FWZ: 16/2 Observed DWWS: +1	Seeding event WRR0056 was called at 1025 MST on 01/02/2017 and began at 1056 MST. <u>Case WRR0056</u> Generators: WR01, WR02, WR03, WR04, WR05, WR09, WR10, WR12, WR13 Time: 10:45 to 17: 45 MST 17:45 (01/02) to 00:45 (01/03) UTC Duration: 7:00, 62:24 Total Time Seeding: 1,560.00g silver, (22.63 gallons)
03 January 2017, Tuesday	
Cloud coverage slowly increased and thickened over the WR during the morning. Conditions became favorable for seeding operations shortly after noon but the wind flow weakened after sunset and seeding was ended. Widespread light snowfall continued for most of the evening and overnight, but it was due to mid level forcing with minimal orographic flow. Max/Min temperatures PNA: 14/-15 RKS: 25/12 LND: 4/-2 FWZ: 14/9 Observed DWWS: +1	Seeding event WRR0057 was called at 1300 MST on 01/03/2017 and began at 1312 MST. <u>Case WRR0057</u> Generators: WR01, WR02, WR03, WR09, WR12, WR13 Time: 13:10 to 18:40 MST 20:10 (01/03) to 01:40 (01/04) UTC Duration: *5:30, 27:48 Total Time Seeding: 695.00g silver, (10.13 gallons) *Average time for generators; WR02, WR03, WR09, WR12 and WR13.

04 January 2017, Wednesday	
Widespread thick clouds and light snowfall covered the area from the morning through the evening and then began breaking up and moving away after midnight. The sky was clear by Thursday morning. The wind flow was too light and unfavorable for seeding operations. Max/Min temperatures PNA: 18/5 RKS: 22/0 LND: 6/-2 FWZ: 19/-4 Observed DWWS: 0	No ground-based seeding was conducted.
05 January 2017, Thursday	
Clear and cold! Only exception was a small band of upper level clouds passing through overnight. The daily high temperature in PNA occurred well before sunrise with only a slight warming during the afternoon. Max/Min temperatures PNA: 3/-33 RKS: 1/-20 LND: 3/-17 FWZ: 9/-9 Observed DWWS: -3	No ground-based seeding was conducted.
06 January 2017, Friday	
Continued clear and cold! There was a brief period with arch clouds on the east side of the range during the night and then again around sunrise. Max/Min temperatures PNA: -8/-36 RKS: 5/-24 LND: -4/-25 FWZ: 16/3 Observed DWWS: -3	No ground-based seeding was conducted.
07 January 2017, Saturday	
Thick cloud layers blanketed the range throughout the period. Snowfall occurred from late afternoon through the night. A sounding at 00:44z confirmed the presence of a deep strong inversion layer with easterly winds in the low levels. Although cloud and temperatures were favorable for operations, plume trajectories were unfavorable. No seeding occurred.	No ground-based seeding was conducted.

Max/Min temperatures PNA: 7/-31 RKS: 3/-18 LND: 3/-18 FWZ: 19/-1 Observed DWWS: 0	
08 January 2017, Sunday	
Thick orographic clouds and snowfall were continuous throughout the period. It remained too warm for operations, so no seeding occurred. Max/Min temperatures PNA: 28/5 RKS: 31/1 LND: 22/-6 FWZ: 31/15 Observed DWWS: 0	No ground-based seeding was conducted.
09 January 2017, Monday	
Thick orographic clouds and snowfall were observed through the late evening hours. The temperature cooled to within seeding limits in the early evening. The wind direction was borderline from the WNW, and only favored seeding with four of the northern generators during the evening. Later, winds became NW and parallel to the range. Orographic clouds diminished for the overnight hours. Max/Min temperatures PNA: 34/18 RKS: 38/25 LND: 48/22 FWZ: 31/17 Observed DWWS: +1	Seeding event WRR0058 was called at 1745 MST on 01/09/2017 and began at 1758 MST. <u>Case WRR0058</u> Generators: WR09, WR10, WR12, WR13 Time: 17:58 to 23:00 MST 00:58 to 6:00 (01/10) UTC Duration: *5:02, 27:56 Total Time Seeding: 698.33g silver, (11.15 gallons) *Average time for generators; WR09, WR10 and WR12. An error in satellite communication resulted in an extended runtime for WR13.
10 January 2017, Tuesday	
Once again, thick orographic clouds and snowfall were continuous throughout the period. Seeding began in the early morning hours and continued through the rest of the period. Temperatures stayed just within seeding limits with an evening sounding showing 700mb temps of -6.4C. Max/Min temperatures PNA: 28/14 RKS: 35/21 LND: 42/25 FWZ: 26/11	Seeding event WRR0059 was called at 0645 MST on 01/10/2017 and began at 0710 MST. At the start of the seeding event, seven ggens were requested. In the early evening, winds became more southwesterly and the two southern ggens (WR04 and WR05) were added to the mix. <u>Case WRR0059</u> Generators: WR01, WR02, WR03, WR09, WR10, WR12, WR13

Observed DWWS: +2	Time: 07:10 (01/10) to 20:55 (01/11) MST 14:10 (01/10) to 03:55 (01/12) UTC Generators: WR04, WR05 Time: 19:53 (01/10) to 11:57 (01/11) MST 02:53 (01/11) to 18:57 (01/11) UTC Total Time: 207:10 Seeding: 5,179.17g silver (86.02 gallons)
11 January 2017, Wednesday	
Continued thick, widespread cloud coverage with moderate to heavy snowfall over the region through the morning with less snowfall areas in the afternoon. The widespread clouds were leaving by sunset with orographic clouds continuing over the range for a few more hours but precipitation was tapering off after sunset. The clouds cleared out overnight, with high clouds coming in after sunrise. Max/Min temperatures PNA: 30/3 RKS: 35/22 LND: 40/5 FWZ: 28/19 Observed DWWS: +2	Seeding event WRR0059 continued until 2057 MST 01/11/2017.
12 January 2017, Thursday	
High clouds had moved in during the morning with some mid level coverage during the afternoon. The clouds moved away during the evening and the range was clear overnight. Max/Min temperatures PNA: 9/-15 RKS: 25/16 LND: 16/2 FWZ: 25/14 Observed DWWS: -2	No ground-based seeding was conducted.
13 January 2017, Friday	
The range was clear during the daylight hours but mid level clouds were approaching from the SW by sunset. Periods of mid level clouds passed over the SE half of the range during the evening hours and then a stratus cloud deck existed over the area during the night into Saturday morning, diminishing in the late morning. Max/Min temperatures	No ground-based seeding was conducted.

PNA: 14/-15 RKS: 22/14 LND: 20/1 FWZ: 30/16 Observed DWWS: -1	
14 January 2017, Saturday	
Clear skies over the range for most of the day except for a few mid level clouds for a short period during the evening hours. Some clouds moved into southern WY overnight, but only got to the SE tip of the range Sunday morning. Max/Min temperatures PNA: 21/-15 RKS: 19/11 LND: 22/2 FWZ: 30/19 Observed DWWS: -2	No ground-based seeding was conducted.
15 January 2017, Sunday	
The region had clear skies throughout the entire period. Max/Min temperatures PNA: 7/-22 RKS: 14/1 LND: 15/-1 FWZ: 30/2 Observed DWWS: -3	No ground-based seeding was conducted.
16 January 2017, Monday	
The region had clear skies throughout most of the period. Some thin scattered high level clouds passed through overnight. Max/Min temperatures PNA: 9/-26 RKS: 6/-9 LND: 18/-1 FWZ: 26/10 Observed DWWS: -3	No ground-based seeding was conducted.
17 January 2017, Tuesday	
Aside from a few thin wisps of cirrus clouds, the range was clear throughout the period. Max/Min temperatures PNA: 12/-22	No ground-based seeding was conducted.

RKS: 6/-14 LND: 19/-2 FWZ: 29/10 Observed DWWS: -3	
18 January 2017, Wednesday	
Skies were clear throughout the daylight hours. Around sunset, high level clouds began moving in from the west. By early morning, overcast layers had overspread the region along with some thin high based orographic clouds developing over the range. Max/Min temperatures PNA: 14/-17 RKS: 16/-6 LND: 24/3 FWZ: 31/11 Observed DWWS: -1	No ground-based seeding was conducted.
19 January 2017, Thursday	
Multiple cloud layers moved in from the west during the morning hours and continued through the night, clearing right after sunrise. There was light snowfall around the region, mainly during the afternoon and early evening. The wind flow was not favorable for seeding operations and sufficient SLW was not expected. Max/Min temperatures PNA: 21/-8 RKS: 23/-2 LND: 25/5 FWZ: 32/19 Observed DWWS: 0	No ground-based seeding was conducted.
20 January 2017, Friday	
There were a few low clouds around the range in the morning then clear skies during the afternoon. Multiple cloud layers moved in from the south during the evening and continued through the night. There were periods of light snowfall mainly around midnight. Max/Min temperatures PNA: 16/-8 RKS: 26/17 LND: 35/11 FWZ: 27/16 Observed DWWS: -1	No ground-based seeding was conducted.

21 January 2017, Saturday	
Cloud coverage increased during the afternoon with scattered, areas of light snowfall over the range during the late afternoon and evening. The wind flow was not favorable for seeding. Most of the clouds moved away overnight, but a stratus deck remained on the SW side of the range into Sunday morning. Max/Min temperatures PNA: 25/3 RKS: 26/12 LND: 23/8 FWZ: 27/18 Observed DWWS: -1	No ground-based seeding was conducted.
22 January 2017, Sunday	
There was a short lived period of light snowfall over the range during the middle of the afternoon. Widespread snowfall from a deep system began around sunset and continued through the evening. The snowfall broke up after midnight with only scattered flurries over the range during the night. No seeding occurred due to unfavorable wind flow and lack of SLW. Max/Min temperatures PNA: 19/0 RKS: 28/14 LND: 31/13 FWZ: 23/12 Observed DWWS: 0	No ground-based seeding was conducted.
23 January 2017, Monday	
As a large low pressure circulation moved into WY, the wind direction changed significantly throughout the period. Thick cloud layers blanked the range throughout the period with lots of low stratus enshrouding the range. Wind speeds were generally light, and plume trajectories were not suitable for seeding, mostly flowing around the range. With abundant snowfall from mid-levels, there was very limited liquid water as well. While snowfall was nearly continuous throughout the period, conditions were not suitable for seeding. No seeding occurred. Max/Min temperatures PNA: 27/10 RKS: 23/20 LND: 23/19 FWZ: 27/14 Observed DWWS: 0	No ground-based seeding was conducted.

24 January 2017, Tuesday	
Light to moderate snowfall continued steadily throughout most of the period, gradually diminishing through the overnight hours. Thick overcast cloud cover blanketed the region through the late night, and then diminished in the early morning. By dawn, the range had clear skies, while low stratus hung in the lowlands surrounding the mountains. Low level wind flow remained light throughout the period, and plume trajectories were not favorable for seeding. Therefore, no seeding occurred. Max/Min temperatures PNA: 21/-4 RKS: 22/12 LND: 22/9 FWZ: 15/2 Observed DWWS: 0	No ground-based seeding was conducted.
25 January 2017, Wednesday	
The range was mainly clear in the morning hours with low stratus surrounding the range. By late afternoon, thicker more elevated stratus enshrouded the range with some light snow observed. Low level cloud lingered through the night. Wind flow was parallel to the range throughout most of the period and also light and variable in the low levels. Plume trajectories were not favorable for seeding operations. No seeding occurred. Max/Min temperatures PNA: 7/-15 RKS: 13/0 LND: 22/9 FWZ: 9/-4 Observed DWWS: 0	No ground-based seeding was conducted.
26 January 2017, Thursday	
Low level clouds were present through much of the afternoon and evening with some flurries observed. Cloud cover diminished overnight, and skies became clear by early morning with the exception of some high wispy cirrus. There were no clouds remotely suitable for seeding, and no seeding occurred. Max/Min temperatures PNA: 14/-22 RKS: 12/-2 LND: 21/0 FWZ: 1/-7 Observed DWWS: 0	No ground-based seeding was conducted.

27 January 2017, Friday	
Clear skies during the daylight hours. High and mid level clouds came in from the north during the night. A strong inversion existed over the area, thus the temperature at South Pass was much warmer than Pinedale and Lander. Max/Min temperatures PNA: 1/-26 RKS: 16/-4 LND: 15/-10 FWZ: 34/9 Observed DWWS: -2	No ground-based seeding was conducted.
28 January 2017, Saturday	
High and mid level cloud coverage decreased in the morning, with a small line of low clouds passing through around noon. More high and mid level clouds came in from the NW by sunset and continued through the night. Max/Min temperatures PNA: 30/-8 RKS: 24/10 LND: 15/-7 FWZ: 32/25 Observed DWWS: -1	No ground-based seeding was conducted.
29 January 2017, Sunday	
Periods of high and mid level clouds moved over the area throughout the day. No significant coverage occurred. South Pass was again much warmer than Pinedale and Lander. Max/Min temperatures PNA: 32/5 RKS: 32/14 LND: 30/-1 FWZ: 41/32 Observed DWWS: -2	No ground-based seeding was conducted.
30 January 2017, Monday	
Mid level cloud coverage decreased during the morning, with minimal coverage through the afternoon until just before sunset with clouds moved in from the west. A band of low clouds with light snowfall moved over the range around midnight. The snowfall was short lived and not continuous. Multiple cloud layers existed overnight but no	No ground-based seeding was conducted.

precipitation fell. Max/Min temperatures PNA: 23/0 RKS: 37/19 LND: 46/14 FWZ: 37/19 Observed DWWS: -1	
31 January 2017, Tuesday	
Thick cloud cover blanketed the range throughout the period with snowfall observed in the afternoon through the overnight hours. Plume trajectories were not favorable for seeding as they were from the northwest and parallel to the range. No seeding occurred. Max/Min temperatures PNA: 36/10 RKS: 37/26 LND: 40/18 FWZ: 29/18 Observed DWWS: 0	No ground-based seeding was conducted.
01 February 2017, Wednesday	
Thick low clouds enshrouded the ranged throughout the period. Good orographic cloud coverage was observed from midmorning through the evening hours with moderate SLW. Seeding occurred from 16:37 (Feb 1st) through 3:48 (Feb 2nd) UTC. Severn western generators were utilized throughout the seeding event. Winds became unfavorable for proper targeting for the late evening and overnight hours, although periods of light snow continued through morning. Max/Min temperatures PNA: 32/10 RKS: 39/8 LND: 18/9 FWZ: 28/2 Observed DWWS: +2	Seeding event WRR0060 was called at 0925 MST on 02/01/2017 and began at 0937 MST. <u>Case WRR0060</u> Generators: WR01, WR02, WR03, WR09, WR10, WR12, WR13 Time: 09:35 to 20:40 MST 16:35 (02/01) to 03:40 (02/02) UTC Duration: 11:05, 77:38 Total Time Seeding: 1,940.83g silver (32.60 gallons)
02 February 2017, Thursday	
Thick low stratus surrounded the range throughout the period. However, the cloud coverage over the peaks varied, becoming sparse at times. While HYSPLIT model trajectories appeared favorable, a midday sounding indicated the presence of a strong inversion with southeast winds in the low levels below 10 kft. The inversion was deeper and stronger than anticipated.	No ground-based seeding was conducted.

Contrary to the models, actual trajectories were not favorable for seeding as plumes would be trapped under the inversion and flow away from the mountains. Orographic clouds were marginal as well. No seeding occurred. Max/Min temperatures PNA: 19/10 RKS: 32/5 LND: 10/0 FWZ: 20/-3 Observed DWWS: 0	
03 February 2017, Friday	
Snowfall was continuous throughout the period. Thick low cloud cover was in place along the western slopes early in the period. By midafternoon, thicker orographic clouds developed covering the whole range. An early afternoon sounding indicated low level winds were not favorable for seeding. By the late evening, another sounding showed the low level winds were slightly more westerly allowing for operations. Seeding began with nine western ggens at 6:03 (4th) UTC. The two most southern ggens were turned off at 10:01 UTC due to continued shifting winds. Seeding is still ongoing at the time of this forecast with seven western ggens. Max/Min temperatures PNA: 28/10 RKS: 33/11 LND: 11/-5 Observed DWWS: +2	Seeding event WRR0061 was called at 2250 MST on 02/03/2017 and began at 2303 MST. <u>Case WRR0061</u> Generators: WR01, WR02, WR03, WR09, WR10, WR12, WR13 Time: 23:00 (02/03) to 11:00 (02/05) MST 06:00 (02/04) to 18:00 (02/05) UTC Generators: WR04, WR05 Time: 23:00 (02/03) to 04:00 (02/04) MST 06:00 (02/04) to 11:00 (02/04) UTC WR04 and WR05 shut off early due to a change in weather conditions. Total Time: 246:49 Seeding: 6,170.42g silver (100.51 gallons)
04 February 2017, Saturday	
Thick, orographic cloud continued over the range throughout the day. Light snowfall occurred most of the day except for a few periods of heavier rates. The snowfall became more broken in coverage during the night but SLW with favorable wind flow continued. Max/Min temperatures PNA: 34/19 RKS: 38/25 LND: 46/-1 FWZ: 30/27 Observed DWWS: +2	Seeding event WRR0061 continued throughout the day.
05 February 2017, Sunday	
There was thick cloud coverage and snowfall over the	Seeding event WRR0061 continued until 1806Z.

range in the morning, continued from Saturday. Those clouds had diminished by noon. Low status remained banked up against the western slopes through the afternoon, with areas of light snowfall, mainly over the NW part of the range. Widespread, consistent snowfall began in the late evening but a sounding showed the temperature was too warm for seeding operations. Max/Min temperatures PNA: 32/23 RKS: 39/27 LND: 48/21 FWZ: 32/28 Observed DWWS: +1	
06 February 2017, Monday	
Low and orographic cloud coverage remained over the area throughout the day. The temperature was too warm for seeding operations in the morning, afternoon and evening, then cooled to the seeding threshold a little before midnight. Snowfall rates became moderate to heavy during the evening and through the night, though SLW was fairly minimal. Max/Min temperatures PNA: 34/27 RKS: 41/32 LND: 48/35 FWZ: 32/28 Observed DWWS: +2	Seeding event WRR0062 was called at 2240 MST on 02/06/2017 and began at 2251 MST. <u>Case WRR0062</u> Generators: WR01, WR02, WR03, WR09, WR10, WR12, WR13 Time: 22:45 (02/06) to 10:33 (02/07) MST 05:45 (02/07) to 17:33 (02/07) UTC Duration: 11:48, 82:30 Total Time Seeding: 2062.50g silver (33.12 gallons)
07 February 2017, Tuesday	
Moderate to heavy snowfall over the range and surrounding area during the morning, afternoon and evening. Seeding operations had ended in the morning due to warming temps and lack of SLW and conditions remained as such through the afternoon and evening. The temperature cooled by midnight, but the snowfall was becoming more broken in coverage and the wind flow was less favorable for plume transport. Max/Min temperatures PNA: 36/27 RKS: 42/30 LND: 39/21 FWZ: 32/27 Observed DWWS: 0	No ground-based seeding was conducted.
08 February 2017, Wednesday	
Mountain precipitation was light but nearly continuous	No ground-based seeding was conducted.

throughout the period. Temperatures became too warm for seeding by early afternoon. Low thick orographic clouds enshrouded the range throughout the period, but no seeding occurred. Max/Min temperatures PNA: 32/28 RKS: 38/29 LND: 39/13 Observed DWWS: 0	
09 February 2017, Thursday	
Precipitation was nearly continuous over the range throughout the period. Thick low orographic clouds were present throughout the period along with thick overcast layers above. Rain/snow mix was observed in the lower elevations. Temperatures remained unseasonably warm throughout the period with Lander approaching 60 degrees. Pinedale remained above freezing all day and all night with a high above 40 degrees. Temperatures were much too warm for seeding, and no seeding occurred. Max/Min temperatures PNA: 41/28 RKS: 48/33 LND: 59/19 Observed DWWS: 0	No ground-based seeding was conducted.
10 February 2017, Friday	
Mountain precipitation was continuous throughout the period. Precipitation rates were heaviest during the day, and then diminished overnight. Temperatures remained too warm for seeding throughout the afternoon and evening, finally cooling to within seeding limits during the late night hours. Orographic clouds became marginal overnight, and the radiometer showed no liquid water after midnight. Rain was observed in the lower elevations during the afternoon, and then it transitioned to light snow in the evening. Max/Min temperatures PNA: 39/30 RKS: 48/32 LND: 54/37 Observed DWWS: 0	No ground-based seeding was conducted. Analysis of SWE amounts in the Wind River mountains showed that the combined average SWE at five NRCS SNOTEL sites had exceeded the project suspension criterion. Therefore, seeding was suspended in the Wind River mountains as directed by the WWDO at 0715 MST.
11 February 2017, Saturday	
Upper level clouds were present through early afternoon, and then shifted off the south. Light snowfall and marginal	No ground-based seeding was conducted.

orographic clouds were observed in the morning and early afternoon hours. Cloud cover gradually diminished throughout the day, and the range became mainly clear around sunset. Conditions were not suitable for seeding. Max/Min temperatures PNA: 32/5 RKS: 33/16 LND: 44/23 Observed DWWS: 0	
12 February 2017, Sunday	
Clear skies during the daylight hours and the evening. High and mid level clouds came into the area from the NW during the night. Max/Min temperatures PNA: 25/-4 RKS: 27/9 LND: 37/17 FWZ: 39/23 Observed DWWS: -2	No ground-based seeding was conducted.
13 February 2017, Monday	
Pretty much clear skies except for some isolated high clouds around sunset and then shortly after midnight. Max/Min temperatures PNA: 28/-4 RKS: 27/6 LND: 40/16 FWZ: 39/23 Observed DWWS: -3	No ground-based seeding was conducted.
14 February 2017, Tuesday	
Pretty much clear except for some isolated high clouds during the late morning and early afternoon hours. Max/Min temperatures PNA: 28/0 RKS: 32/9 LND: 44/21 FWZ: 37/23 Observed DWWS: -3	No ground-based seeding was conducted.
15 February 2017, Wednesday	
Clear skies during the daylight hours. A small band of high and mid level clouds moved through during the evening	No ground-based seeding was conducted.

hours, then the sky was clear again overnight. Max/Min temperatures PNA: 28/0 RKS: 39/11 LND: 45/20 FWZ: 45/32 Observed DWWS: -2	
16 February 2017, Thursday	
The range was clear in the morning. Thick overcast layers overspread the region during the afternoon hours. Orographic clouds became thicker overnight, and light snowfall was observed from late afternoon through the late night hours. Low stratus and fog surrounded the range during the overnight hours as well. It remained much too warm for seeding, and operations remained suspended. Max/Min temperatures PNA: 28/-2 RKS: 44/19 LND: 50/24 Observed DWWS: 0	No ground-based seeding was conducted.
17 February 2017, Friday	
Skies were clear in the morning hours, and then thick overcast layers began to overspread the region after 22z. Light snowfall occurred in the evening and overnight hours with thick orographic clouds in place from late afternoon through the morning. It remained too warm for seeding, and operations remained under suspension. Max/Min temperatures PNA: 32/9 RKS: 44/27 LND: 50/31 Observed DWWS: 0	No ground-based seeding was conducted.
18 February 2017, Saturday	
High and mid level clouds continued to flow over the area throughout the day. There was a thick orographic cloud over the range in the morning and early afternoon with light snowfall but coverage diminished by mid afternoon. Only a small orographic cloud existed for the rest of the afternoon and the evening. Overnight, more moisture came and light snowfall developed again. The temperature was warmer than the seeding threshold throughout the day.	No ground-based seeding was conducted.

Max/Min temperatures PNA: 37/30 RKS: 42/35 LND: 47/31 FWZ: 34/30 Observed DWWS: 0	
19 February 2017, Sunday	
Thick overcast layers and low orographic clouds were present throughout the day and into the late night hours with light snow. A few convective clouds were observed during the afternoon, mainly on the east side of the range. Skies cleared for a few hours in the early morning, and then more low level cloud cover moved in during the early morning hours with more snow. Temperatures remained too warm for seeding during the day. Temperatures were likely within seeding limits overnight, but cloud cover was marginal. Seeding operations remained suspended. Max/Min temperatures PNA: 34/18 RKS: 43/28 LND: 56/28 Observed DWWS: 0	No ground-based seeding was conducted. This was the first time that seeding could have been conducted had operations not been suspended.
20 February 2017, Monday	
Light showers existed over the range during the morning and most of the afternoon. Continuous, snowfall developed just before sunset and lasted through the night. The temperature was warmer than the seeding threshold with light rain reported at PNA Monday night. Max/Min temperatures PNA: 34/9 RKS: 46/27 LND: 55/26 FWZ: 34/28 Observed DWWS: 0	No ground-based seeding was conducted.
21 February 2017, Tuesday	
Continuous snowfall over the range during the morning became more broken in coverage by early afternoon. The temperature was warmer than the seeding threshold during this time. A cold front moved through in the late afternoon, bringing widespread snowfall, heavy at times, from a little before sunset through most of the evening. Had seeding not been suspended, a seeding event could have occurred. The snowfall became lighter and more broken during the night.	No ground-based seeding was conducted. This was the second time that seeding could have been conducted had operations not been suspended.

Max/Min temperatures PNA: 37/27 RKS: 53/28 LND: 53/32 FWZ: 36/25 Observed DWWS: +1	
22 February 2017, Wednesday	
Thin mid level clouds were over the area during the daylight hours. A large storm moved into WY during the evening, with the low level winds becoming northerly over the project area during the evening and then NE overnight. Light snowfall began over the range around midnight, then heavy snow developed in the middle of the night. Had operations not been under suspension, seeding with Enterprise GGEN could have occurred during the night. Max/Min temperatures PNA: 30/19 RKS: 31/24 LND: 41/29 FWZ: 27/21 Observed DWWS: +1	No ground-based seeding was conducted. This was the third time that seeding could have been conducted had operations not been suspended, the first for which the Enterprise generator would have been used.
23 February 2017, Thursday	
Large storm passing to the south and then east, affected most of WY. Heavy snowfall was observed over the WR range through the mid afternoon then light snowfall continued through the night. By sunrise, Friday morning, the snowfall was breaking up and scattered in coverage. The wind flow was mainly from the NE, so had operations not been under suspension, seeding with Enterprise GGEN could have occurred most of the day despite limited SLW. Max/Min temperatures PNA: 27/14 RKS: 25/17 LND: 29/19 FWZ: 21/10 Observed DWWS: +2	No ground-based seeding was conducted. This was the fourth time that seeding could have been conducted had operations not been suspended, the second for which the Enterprise generator would have been used.
24 February 2017, Friday	
Low stratus surrounded the range throughout the day while a few thin low clouds were in place. Thicker clouds enshrouded the range in the evening with widespread snowfall. Clouds cleared out for a few hours during the late night, and then thin orographic clouds redeveloped in the early morning. Cloud coverage was not suitable for	No ground-based seeding was conducted.

seeding. Regardless, seeding operations remained under suspension. Max/Min temperatures PNA: 19/-4 RKS: 21/8 LND: 23/7 Observed DWWS: 0	
25 February 2017, Saturday	
Thin low stratus and orographic clouds were in place during the morning. Cloud cover slowly thinned out during the day, and the range became mostly clear by evening. Skies were mainly clear overnight, and then more thin low level clouds started moving in from the northwest around dawn. The cloud cover was not suitable for seeding operations. Seeding remained suspended. Max/Min temperatures PNA: 18/-13 RKS: 20/3 LND: 23/-2 Observed DWWS: 0	No ground-based seeding was conducted.
26 February 2017, Sunday	
Thin low level clouds passed over the range during the morning, and then skies were mainly clear for much of the afternoon. Thick cloud layers overspread the region beginning around sunset. Light intermittent snowfall was observed during the evening and overnight hours. The cloud cover was marginally suitable for seeding. However, the radiometer showed no significant liquid water during the night. For this reason, seeding would not have been likely even if the suspension were not in place. Suspension of operations continued nonetheless. Max/Min temperatures PNA: 14/-15 RKS: 21/3 LND: 24/-2 Observed DWWS: 0	No ground-based seeding was conducted.
27 February 2017, Monday	
Thin low clouds were in place for the morning and afternoon, and then the cloud cover became thicker for a few hours around sunset. Clouds cleared out overnight. Seeding remained suspended, and no seeding occurred. Max/Min temperatures	No ground-based seeding was conducted.

PNA: 19/-8 RKS: 25/10 LND: 29/8 Observed DWWS: 0	
28 February 2017, Tuesday	
Waves of thick clouds moved towards the range beginning around noon. Light snowfall occurred over the range during the afternoon into the early evening hours, with some periods of moderate rates. The wind flow was borderline, and with relativity cold temperatures, SLW was sparse. Conditions were not quite right for seeding operations and seeding probably would not have occurred if there were no suspension. The clouds cleared overnight but then more clouds came in Wednesday morning. Max/Min temperatures PNA: 14/-17 RKS: 22/5 LND: 29/3 FWZ: 12/5 Observed DWWS: 0	No ground-based seeding was conducted.
01 March 2017, Wednesday	
Low cloud coverage was around the area from the late morning through the afternoon into the early evening. Light snowfall was observed during the early afternoon but the clouds never fully covered the range. Some high and mid level clouds existed during the night, but the range was mostly clear. Max/Min temperatures PNA: 19/-6 RKS: 26/15 LND: 31/7 FWZ: 21/9 Observed DWWS: -1	No ground-based seeding was conducted.
02 March 2017, Thursday	
Mid level clouds moved into the area from the west during the afternoon. Shallow, small low clouds developed over the peaks of the range in the late afternoon and only last for a few hours before diminishing. Some light snowfall occurred, but it didn't cover much of the range. High and mid level clouds existed during the night. Max/Min temperatures PNA: 23/-9 RKS: 30/18	No ground-based seeding was conducted.

LND: 39/11 FWZ: 27/14 Observed DWWS: -1	
03 March 2017, Friday	
Mid level clouds around the range had moved away before noon. More mid level clouds had moved in from the west by mid afternoon and scattered to broken cloud coverage then continued through the night. No snowfall occurred. Max/Min temperatures PNA: 25/-9 RKS: 39/11 LND: 45/19 FWZ: 32/12 Observed DWWS: -2	No ground-based seeding was conducted.
04 March 2017, Saturday	
Waves of thin low and midlevel clouds passed through during the day, but there were intervals of clear skies as well. Overnight, marginal orographic clouds were present along with waves of midlevel clouds. Light snowfall occurred throughout the night. The orographic clouds and snowfall diminished in the early morning. Seeding operations remained under suspension. 700mb temperatures remained slightly warmer than the seeding criteria. No seeding occurred. Max/Min temperatures PNA: 30/0 RKS: 46/23 LND: 50/20 Observed DWWS: 0	No ground-based seeding was conducted.
05 March 2017, Sunday	
In the morning and early afternoon, only some sparse very thin low clouds were present over the range. Orographic clouds became thicker covering the entire range by late afternoon. Around sunset, thick overcast layers overspread the region. Snowfall occurred during the evening and overnight hours. Clouds and snowfall diminished around dawn, and skies cleared for a short time over the southern half of the range after dawn. Max/Min temperatures PNA: 36/1 RKS: 44/24 LND: 51/30 Observed DWWS: +1	No ground-based seeding was conducted.

06 March 2017, Monday	
Orographic clouds were in place throughout most of the period with continuous light snowfall. High and midlevel clouds passed through during the day and the late evening. The upper level clouds diminished overnight after 11z. The orographic clouds became thin and sparse around dawn. Max/Min temperatures PNA: 23/8 RKS: 25/15 LND: 33/21 Observed DWWS: +2	No ground-based seeding was conducted.
07 March 2017, Tuesday	
Sparse thin low clouds were in place through the afternoon with light snow, but the range was not full covered. Cloud cover increased around sunset. Overcast cloud layers pushed through during the evening, and then cleared out overnight. Marginal orographic clouds were present throughout the night with light amounts of liquid water observed by the radiometer. Max/Min temperatures PNA: 28/9 RKS: 31/16 LND: 43/23 Observed DWWS: +1	No ground-based seeding was conducted.
08 March 2017, Wednesday	
Orographic clouds persisted over the range throughout the period. Snowfall was light with a limited amount of SLW detected by the radiometer. The temperature was just slightly warmer than the seeding threshold. Max/Min temperatures PNA: 36/18 RKS: 43/25 LND: 53/26 FWZ: 32/21 Observed DWWS: 0	No ground-based seeding was conducted.
09 March 2017, Thursday	
There was light snowfall over most of the range in the morning and lasted into the early afternoon before diminishing. Areas of light snowfall developed over the	No ground-based seeding was conducted.

range again after midnight and continued into Friday morning. The temperature was slightly warmer than the seeding threshold throughout the day. Max/Min temperatures PNA: 43/27 RKS: 46/33 LND: 60/29 FWZ: 41/30 Observed DWWS: 0	
10 March 2017, Friday	
Areas of light snowfall were over the range during the morning and most the afternoon, along with some rain reported at PNA in the afternoon. The temperature was warmer than the seeding threshold. The low clouds diminished shortly after sunset but mid level cloud coverage continued until after midnight. The sky was clear overnight. Max/Min temperatures PNA: 41/28 RKS: 50/35 LND: 61/24 FWZ: 43/30 Observed DWWS: 0	No ground-based seeding was conducted.
11 March 2017, Saturday	
Clear skies until the late afternoon when high and mid level clouds came in from the west. Low clouds developed over the range during the evening hours with small areas of light snowfall during the night, tapering off during the morning. The temperature was warmer than the seeding threshold. Max/Min temperatures PNA: 39/21 RKS: 49/31 LND: 57/33 FWZ: 37/27 Observed DWWS: 0	No ground-based seeding was conducted.
12 March 2017, Sunday	
Thin high based orographic clouds were observed in the morning and afternoon along with thin scattered high and midlevel clouds. Skies cleared during the overnight hours, and then upper level overcast layers overspread the region in the predawn hours. There were no clouds remotely suitable for seeding, and operations remained under	No ground-based seeding was conducted.

suspension. No seeding occurred. Max/Min temperatures PNA: 36/21 RKS: 44/30 LND: 53/32 Observed DWWS: -1	
13 March 2017, Monday	
Marginal orographic clouds were observed during the afternoon and evening hours while thin upper level overcast layers passed through from the northwest. The orographic clouds waned during the night, but broken mid and high level clouds continued pushing through, becoming scattered by morning. Temperatures remained too warm for seeding, and operations remained under suspension. No seeding occurred. Max/Min temperatures PNA: 42/16 RKS: 49/29 LND: 60/25 Observed DWWS: 0	No ground-based seeding was conducted.
14 March 2017, Tuesday	
A few thin orographic clouds were observed in the early afternoon. Scattered mid and upper level clouds increased later in the day and remained through the night. A small band of arch clouds formed over the peaks during the late night hours. There were no clouds remotely suitable for seeding, and operations remained under suspension. Max/Min temperatures PNA: 48/19 RKS: 58/38 LND: 64/33 Observed DWWS: 0	No ground-based seeding was conducted.
15 March 2017, Wednesday	
Skies were mainly clear over the range during the afternoon while arch clouds formed just east of the peaks. Broken high and midlevel clouds overspread the area during the late afternoon through the overnight hours. Thin orographic clouds were observed throughout the night. There were no clouds remotely suitable for seeding, and operations remained suspended. Max/Min temperatures PNA: 43/18	No ground-based seeding was conducted.

RKS: 63/33 LND: 67/36 Observed DWWS: -1	
16 March 2017, Thursday	
Orographic cloud coverage existed during the morning over the range but those clouds had shrunk by noon with only small clouds during the afternoon. More orographic clouds along with mid level clouds existed during the night, with the orographic clouds diminishing before sunrise. The temperature was warmer than the seeding threshold. Max/Min temperatures PNA: 43/27 RKS: 57/38 LND: 62/40 FWZ: 43/32 Observed DWWS: -1	No ground-based seeding was conducted.
17 March 2017, Friday	
Multiple cloud layers existed over the area during the morning but those clouds had thinned by noon. Small, low clouds remained over the peaks of the range during the afternoon but no precipitation occurred and the clouds diminished after sunset. The temperature was much warmer than the seeding threshold. Chinook arc clouds formed on the east side overnight. Max/Min temperatures PNA: 45/23 RKS: 61/35 LND: 63/33 FWZ: 45/34 Observed DWWS: -1	No ground-based seeding was conducted.
18 March 2017, Saturday	
The range was clear of clouds in the early afternoon but mid level clouds moved in by mid afternoon. Mid level cloud coverage continued for the rest of the period. A small area of low clouds with some light snowfall developed over the middle of the range during the night, a little before sunrise Sunday morning and light rain was reported at PNA. The snowfall was short-lived. The temperature was much warmer than the seeding threshold. Max/Min temperatures PNA: 50/21 RKS: 69/36	No ground-based seeding was conducted.

LND: 72/37 FWZ: 52/36 Observed DWWS: -1	
19 March 2017, Sunday	
A few small low clouds existed over the peaks of the range in the early afternoon then mid level clouds had come by late afternoon. Low clouds thickened during the evening with snowfall over the range for a few hours in the late evening and nighttime hours. The temperature was much warmer than the seeding threshold and the clouds were thinning before sunrise. Max/Min temperatures PNA: 46/32 RKS: 61/41 LND: 67/38 FWZ: 46/41 Observed DWWS: 0	No ground-based seeding was conducted.
20 March 2017, Monday	
Overcast cloud layers blanketed the region throughout most of the period. There was a brief break in the upper and midlevel clouds during the evening. However, low clouds remained in place during this time. Some thin orographic clouds were observed, but they were not quite suitable for seeding. It remained too warm for seeding, and operations were under suspension. No seeding occurred. Max/Min temperatures PNA: 50/30 RKS: 63/38 LND: 64/38 Observed DWWS: 0	No ground-based seeding was conducted.
21 March 2017, Tuesday	
Overcast clouds were present throughout the period. The clouds were fairly thin early in the day while mountain wave clouds were observed as well. The overcast layers thickened late in the day. Waves continued to push through overnight. There were isolated showers in the mountains during the day, and then precipitation became more widespread overnight. It remained much too warm for seeding, and operations were under suspension. No seeding occurred. Max/Min temperatures PNA: 50/30	No ground-based seeding was conducted.

RKS: 65/40 LND: 56/34 Observed DWWS: 0	
22 March 2017, Wednesday	
Skies were overcast with deep cloud layers for most of the period. There was some partial clearing in the afternoon hours which allow for a bit of surface heat and some thunderstorms near the south end of the range. Heavy snow occurred in the early afternoon, and then it switched to mostly rain during the later afternoon through the late night hours and back to snow again in the morning. It remained too warm for seeding, and operations remained under suspension. No seeding occurred. Max/Min temperatures PNA: 45/32 RKS: 61/38 LND: 60/34 Observed DWWS: 0	No ground-based seeding was conducted.
23 March 2017, Thursday	
Thick overcast cloud layers blanketed the region through around 6z, and then cloud cover gradually cleared out overnight. Skies were mostly clear by morning. Rain/snow occurred throughout the day and evening and was heavy at times. Temperatures remained too warm for seeding, and operations remained under suspension. No seeding occurred. Max/Min temperatures PNA: 34/30 RKS: 47/35 LND: 45/34 Observed DWWS: 0	No ground-based seeding was conducted.
24 March 2017, Friday	
The WR region was mostly clear with only a few low clouds being the exception during the daylight hours. Cloud coverage began increasing after sunset with periods of light snowfall during the night. The temperature was too warm for seeding operations. Max/Min temperatures PNA: 43/19 RKS: 52/33 LND: 58/31 FWZ: 36/28 Observed DWWS: -1	No ground-based seeding was conducted.

25 March 2017, Saturday	
Cloud coverage thickened during the morning with light snowfall beginning over the range by late morning then widespread precipitation during most of the afternoon. PNA and LND reported rain. The precipitation was breaking up by sunset but light showers continued over the range through the evening. The clouds slowly moved away overnight with only small shallow clouds remaining by Sunday morning. Max/Min temperatures PNA: 36/30 RKS: 52/34 LND: 53/36 FWZ: 39/32 Observed DWWS: 0	No ground-based seeding was conducted.
26 March 2017, Sunday	
A few, shallow low clouds lingered over the range during the morning hours along with some mid level clouds in the late morning for a short time. Widespread high and mid level clouds moved in from the west in the middle of the afternoon. A few low clouds with areas of light snowfall existed during the night along with the mid level clouds. The temperature remained warmer than the seeding threshold. Max/Min temperatures PNA: 39/23 RKS: 48/30 LND: 54/36 FWZ: 34/30 Observed DWWS: -1	No ground-based seeding was conducted.
27 March 2017, Monday	
Mid level cloud coverage increased over the area during the daylight hours. Upslope storm began right around sunset over the range. Light continuous snowfall occurred through the night into Tuesday morning. LND reported rain during the evening and night. The temperature was warmer than the seeding threshold. Max/Min temperatures PNA: 43/25 RKS: 51/34 LND: 55/27 FWZ: 37/27 Observed DWWS: 0	No ground-based seeding was conducted.

28 March 2017, Tuesday	
Thick overcast cloud layers blanketed the area for a few hours in the morning, and then skies became mostly clear for the afternoon with a few shallow cumulus clouds in the lowlands. Skies remained mostly clear through around 9Z, and then broken high level clouds overspread the region for the rest of the night. No precipitation was observed, and operations remained suspended. Max/Min temperatures PNA: 45/28 RKS: 43/32 LND: 46/33 Observed DWWS: -2	No ground-based seeding was conducted.
29 March 2017, Wednesday	
Thin high clouds were present for the afternoon hours with otherwise clear skies. Thicker cloud layers overspread the region in the evening while some marginal orographic clouds developed over the range. Light snow occurred during the late night hours, but it remained warmer than the seeding criteria and orographic cloud coverage was likely not sufficient for seeding operations. Seeding remained suspended. Max/Min temperatures PNA: 48/23 RKS: 52/27 LND: 58/28 Observed DWWS: 0	No ground-based seeding was conducted.
30 March 2017, Thursday	
Overcast layers were present throughout the afternoon with a few brief breaks in the higher level cloud. Light showers were observed during the afternoon, and then heavy precipitation began in the evening which continued through the night. The bulk of the precipitation occurred over the eastern slopes of the range. Rain and snow were both observed with wildly fluctuation snow levels. Wind direction was not favorable for Enterprise as it was a bit too northerly. Temperatures remained warmer than the seeding criteria as well. Operations remained under suspension, and no seeding occurred. Max/Min temperatures PNA: 45/32 RKS: 55/37 LND: 59/36	No ground-based seeding was conducted.

Observed DWWS: 0	
31 March 2017, Friday	
Continued upslope storm. Heavy snowfall was observed over the range during the morning and afternoon, then diminishing during the evening hours. Cloud coverage diminished overnight. The temperature remained warmer than the seeding threshold during the precipitation. Max/Min temperatures PNA: 50/34 RKS: 41/31 LND: 36/32 FWZ: 32/28 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: 16-1704

[ ] 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 11/15/2016 TO 03/31/2017

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	5	5					63	9,906				
FEBRUARY	3	3					59	10,174				
MARCH	0	0					0	0				
APRIL												
MAY												
JUNE												
JULY												
AUGUST												
SEPTEMBER												
OCTOBER												
NOVEMBER	0	0					0	0				
DECEMBER	6	6					120	20,379				
TOTAL	14	14	0	0	0	0	242	40,459	0	0	0	0
TOTALS FOR FINAL REPORT	14	14	0	0	0	0	242	40,459	0	0	0	0

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

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, Inc.

SIGNATURE:

STREET ADDRESS: 3802 20th Street North

OFFICIAL TITLE: Vice President - Meteorology

CITY: Fargo — STATE: ND — ZIP CODE: 58102

DATE: 04/11/2017