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ANNUAL
REPORT

WYOMING • WIND RIVER RANGE
WEATHER MODIFICATION PROGRAM

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Wind
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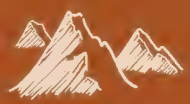

Mountain
Range

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Cloud Seeding Operations in the Wind River Range of Wyoming 2018-2019 Season

ANNUAL REPORT

prepared by

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August 2019

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EXECUTIVE SUMMARY

Funding for cloud seeding operations in the Wind River Range for the winter of 2018-2019 was provided in part by the 2018 Wyoming State Legislature's "Omnibus Water Bill – Construction". The Wyoming State Legislature has mandated that the funding rate for the State will not exceed 20% of total project costs, leaving 80% of the project costs to be split among other Colorado River Basin water users and interested parties. Funding partners in support of continued weather modification activities in the Wind River Mountains during the winter of 2018-2019 included the Southern Nevada Water Authority, the Central Arizona Project (CAP), the Colorado River Board of California - Six Agency Committee, Genesis Alkali, Solvay Minerals, TATA Chemicals, Ciner Wyoming, and Rocky Mountain Power.

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

The 2018-2019 season became operational on 1 December 2018, and concluded after 31 March 2019. The first seeding event occurred on 19 December 2018.

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

The weather pattern produced below-normal storm frequency, with two seeding events occurring in December 2018, three in January 2019, six in February 2019, but only one in March 2019, for a project total of twelve storms. Seasonal snowpack (snow water equivalents, or SWE) at project end (April 1) varied from 88.7% of the median annual value to 107.9%, but the five-site SNOTEL mean was 103.1%, as only South Pass was below the 30-year median value. All the other SWEs ranged from 105.4% to 107.9%. No suspensions occurred during the 2018-2019 season.

The twelve seeded storms accrued 165 hours and 55 minutes during which one or more generators were seeding during the winter. The fewest number of generators that operated during any one storm was one (just once), the most, nine. The Enterprise generator, sited on the eastern slope of the range near Lander, was used only late during the 2018-2019 season, not during the heart of winter, which is typical. Had the field season began in mid-November, or had it continued into April, it may have seen more use.

The total number of "generator hours", defined as the sum of times each generator was operated during a storm, was 951 hours. For seeding to have been conducted the wind direction had to be such that seeding agent released from each specific generator would carry seeding aerosol particles (silver iodide, AgI) upslope into cold but yet-unfrozen clouds at speeds sufficient to ensure that transport would occur. The seeding rate is approximately 25 grams of silver iodide per generator, per hour. The results discussed in this report show a variance in the number of generators used from seeding event to seeding event. This variance is due to situations when the wind direction favored the activation of specific generators. The three other requisite conditions needed to initiate seeding were the presence of liquid water clouds, suitable cloud temperatures, and the absence of a stable layer which would inhibit the transport of the seeding agent up and over the range. 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 later in this report.

The requisite temperature and wind criteria were primarily determined through the release of weather balloons. A total of 15 weather balloons were released during the 4.0 months (121 days) of operations. The presence of liquid water clouds over the range was established by the WWDO radiometer sited near Pinedale, WY.

The bulk of the weather information used for forecasting and weather monitoring was obtained from the internet. In the 2018-2019 season WMI ran advanced numerical models specific for the project to provide additional cloud seeding-specific information on a 24-hour basis. In the 2017-2018 season WMI had, especially in complex flow circumstances, run the Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) plume dispersion model to establish a better idea of seeding agent plume behavior. This season, the HYSPLIT was re-initialized and run with every run of the Weather Research and Forecasting (WRF) model. More about these models are presented in the body of this report.

The 2018-2019 winter offered several extended precipitation-producing storms. Five of the twelve seeded storms saw seeding continue for ten or more hours, all of these using at least six generators. Three of the five lasted ~20 hours or more. One lasted for a project-record of over 54 hours!

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

ACKNOWLEDGMENTS

Weather Modification International (WMI) is pleased to acknowledge the following persons and entities which made the 2018-2019 operations possible.

The Wyoming Water Development Commission (WWDC) and Select Water Committee (SWC) contributed 20% of the costs, while the Wyoming Water Development Office (WWDO), especially Julie Gondzar and Barry Lawrence, who coordinated the entire effort. The WWDO also acquired major funding from the Colorado River Board of California – Six Agency Committee, the Central Arizona Project, and the Southern Nevada Water Authority. For the first time, contributions toward project operations were received from Genesis Alkali, Solvay Minerals, TATA Chemicals, Ciner Wyoming, and Rocky Mountain Power. We appreciate very much the active participation of these stakeholders.

Ms. Allison Long, Director of the Pinedale Children's Discovery Center, arranged for local students to visit the WMI facilities in Pinedale, Wyoming, 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 Adam Brainard, Jason Goehring, and Daniel Gilbert, technicians Michael Paul, Ryan Hudson, and Pat Trujillo, and all the additional support provided by Erin Fischer, Ryan Richter, Dennis Afseth, Amber Ottis, and other Fargo-based WMI staff.

1. BACKGROUND AND OVERVIEW

1.1 Background

Atmospheric water transformed to precipitation is one of the primary sources of fresh water in the world. However, a large amount of water present in clouds never is converted into precipitation that makes it to the ground. This has prompted scientists and engineers to explore the possibility of augmenting water supplies through 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 continues, and operations have continued through this mechanism during subsequent winters. Funding provided by the 2018 Wyoming Legislature enabled the State of Wyoming, through the WWDO, to again provide 20% of the operational cost. Additional funding came from other sources as discussed in Section 1.4.

1.2 Scientific Basis

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

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

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

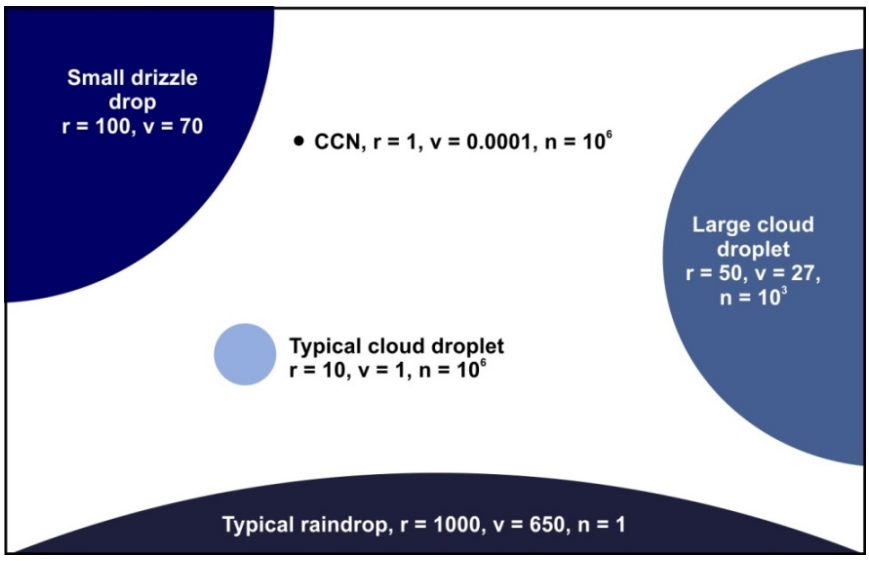

Figure 2. Relative characteristics of particles involved in cloud processes. For each, the radius (r, microns), fall velocity (v, cm per second), and number concentration (n, per liter) are given (after Wallace and Hobbs 1977). The raindrop shown (radius = 1000) is a 2 mm diameter raindrop.

Nature's solution to the lack of substrates available to encourage the freezing process in clouds comes in the form of tiny particles called *ice nuclei.* Ice nuclei provide microscopic, crystalline "templates" for supercooled liquid water (SLW) to follow, and transform to 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 particle, 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 (very common), they can be treated with silver iodide-based ice nuclei which immediately initiate ice crystal formation, thus starting the ice-phase precipitation process. Ground-based seeding is commonly used in orographic applications, especially when the prevailing wind flow is roughly perpendicular to the mountain range, so that seeding agent is lofted immediately upward into the targeted clouds. This orographic seeding technique was the prime strategy used to seed winter clouds throughout the WWMPP, and continued to be the main approach utilized in the Wind River Range during the operational seeding seasons in the winters since.

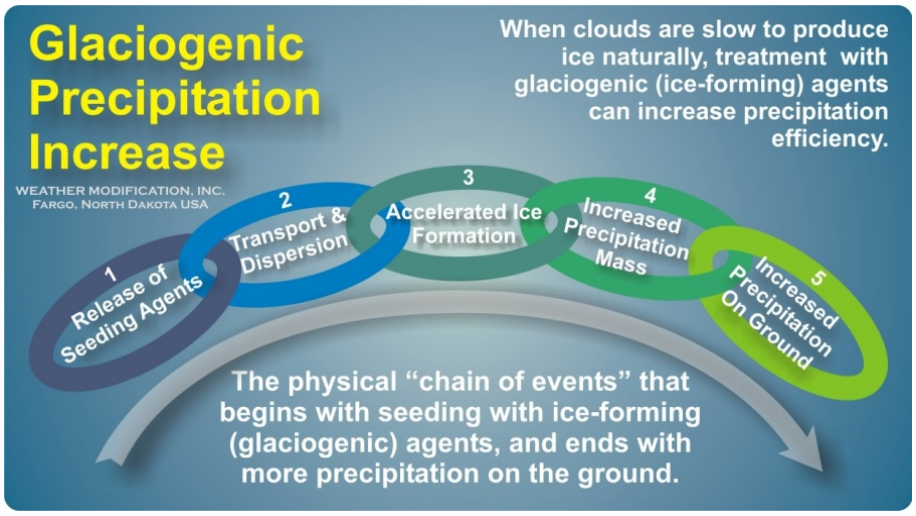

Figure 3. The physical chain-of-events that begins with release of ice-forming seeding agents, and culminates with increased precipitation.

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

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

1.3 Operations

The three criteria above were the same as those used in the WWMPP research, except the temperature criterion for seeding during the WWMPP was slightly colder (+17.6°F or -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). This widening of the temperature window for seeding increases the number of seeding opportunities. Most operational (vs. research) seeding programs use this warmer temperature criterion.

1.4 2018-2019 Funding

In addition to the 20% of funding costs provided by the State of Wyoming, funding for the 2018-2019 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.

For the 2018-2019 winter season, five new project sponsors stepped forward, each having an interest in the water resources within the Green River Basin. Their contributions were modest but meaningful, and very much appreciated. These new supporters were: ***Genesis Alkali***, ***Solvay Minerals***, ***TATA Chemicals***, ***Ciner Wyoming***, and ***Rocky Mountain Power***. Each of these contributed $3,000, except for Rocky Mountain Power, which contributed $5,000.

2. STAFF AND FACILITIES

2.1 Personnel

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

Meteorologists. Three meteorologists staffed the 2018-2019 operations season. Mr. Adam Brainard was located on site in Pinedale, WY through the majority of the project. In addition to coordinating data collection for the project, he also operated the weather balloons (the upper air sounding system). When Adam was not on-site, he was replaced by Mr. Michael Willette. The other meteorologists were Mr. Dan Gilbert, and Mr. Jason Goehring, who worked off-site, using weather resources available via the Internet and directly from WMI. Brainard, Gilbert, and Goehring are all Weather Modification Association Certified Operators. Among the four of them, Brainard, Gilbert, Goehring, and Willette completed all the daily forecasting, weather monitoring, and implementation of seeding operations.

Technicians. Three technicians participated in the 2018-2019 operations. On-site technical work was conducted primarily by Mr. Michael Paul and Mr. Ryan Hudson, who were assisted as needed by Mr. Pat Trujillo. Mr. Ryan Richter was available to provide counsel and direction from the WMI home office in Fargo. Since maintenance and servicing of generator sites could only occur when storms were not expected, field days were long, as technicians tried to get to as many sites as possible. Safety guidelines require that no fewer than two technicians travel into the field together (Figure 4), 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 even more so during heavy-snow winters (such as the 2016-2017 season) when sleds sink more deeply into the always-fresh snow, and avalanche risk is often heightened.

Figure 4. The technician team services the White Acorn Ranch generator site on a sunny day after a nice snowfall. (WMI photograph by Michael Paul.)

2.2 Siting of Seeding Equipment

Figure 5 displays the ten seeding equipment sites used for the 2018-2019 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.

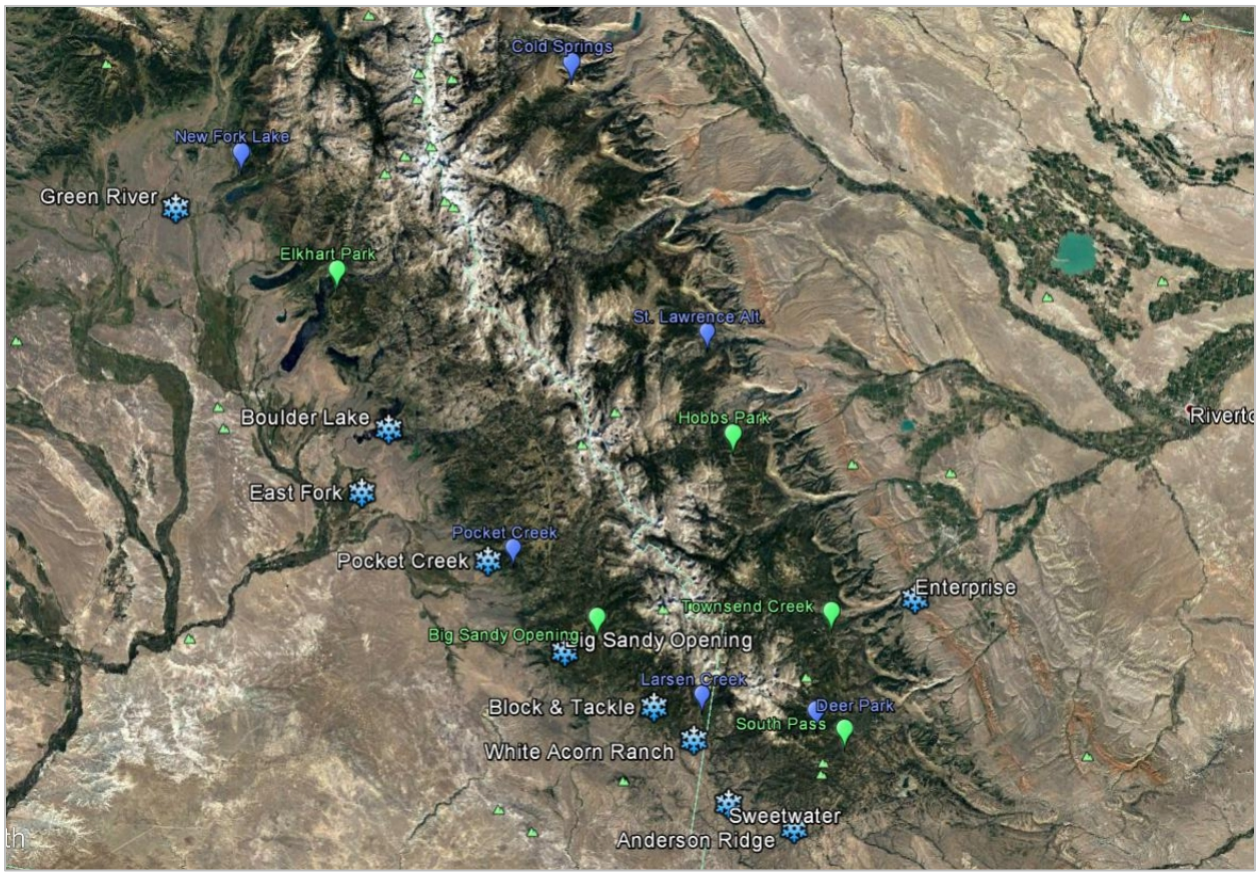

Figure 5. The locations of the ground-based ice nucleus generators are indicated by the snow crystal symbols. The green "balloons" indicate the locations of Natural Resources and Conservation Service (NRCS) snow telemetry (SNOTEL) sites used in monitoring snowpack during the 2018-2019 season. The blue balloons show the locations of additional SNOTELs that were not used because of proximity to sites that were used, or a short period of record (they were relatively new sites).

2.3 Ice Nucleus Generators

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

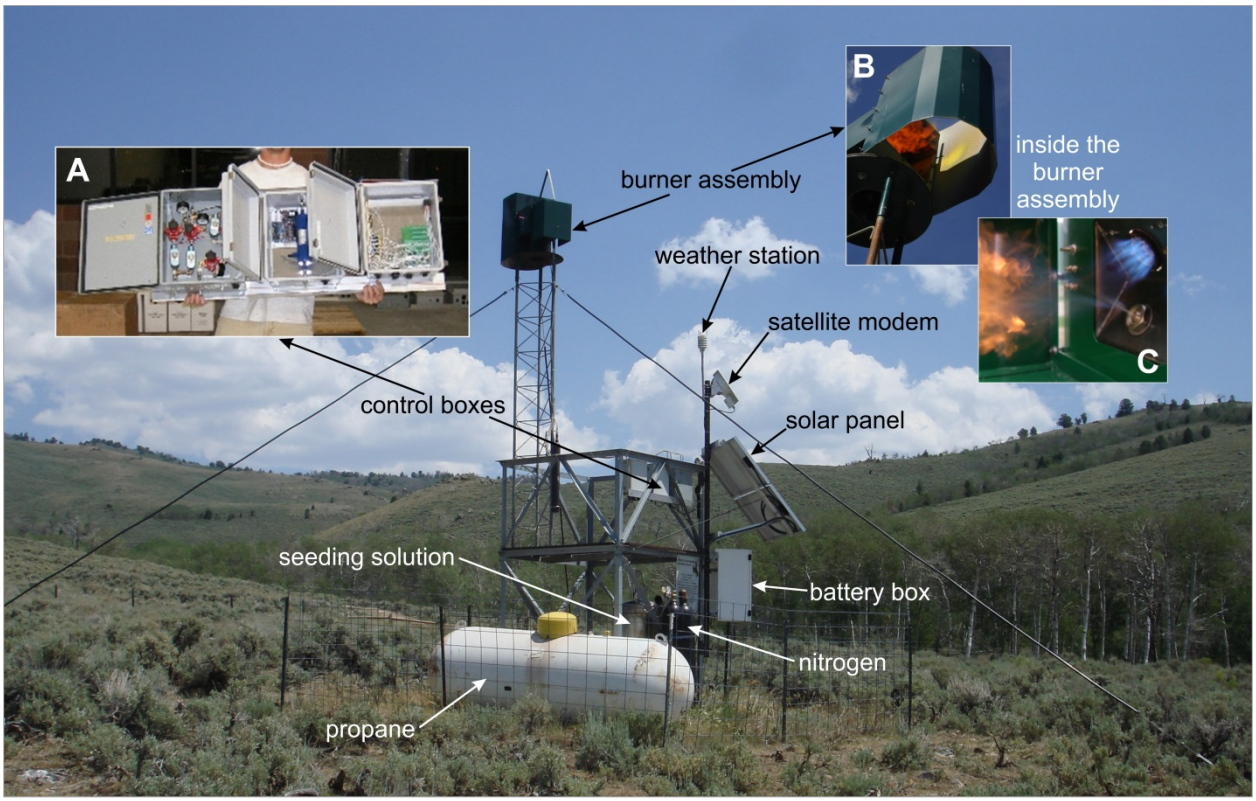

Figure 6. The primary components of the WMI remotely-controlled ground-based ice nucleus generator are illustrated. Inset A, shows the contents of the control boxes. From left to right, these are: solenoids (electronic valves) to turn flows on and off, seeding solution flow rate regulation and measurement,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

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

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.

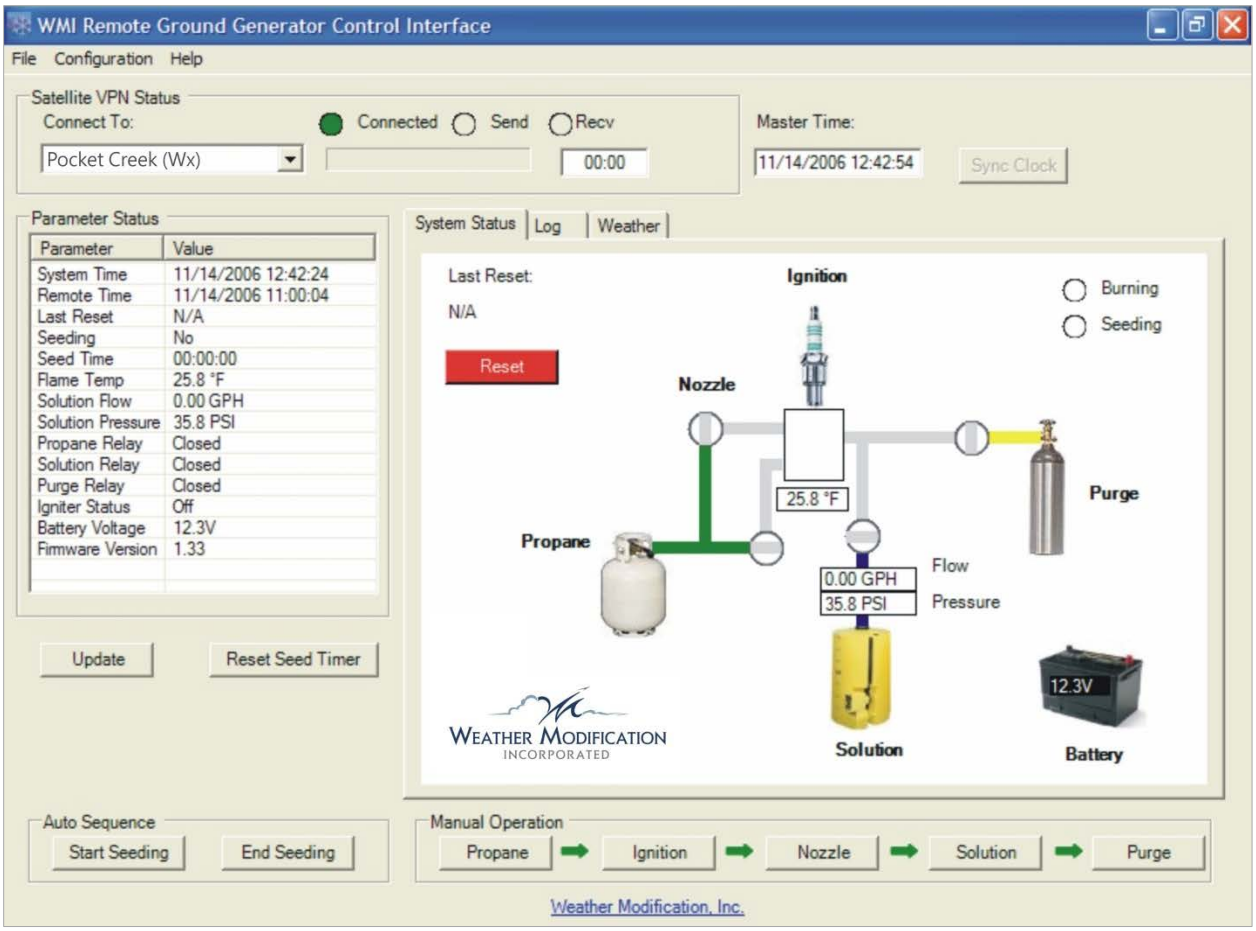

Figure 7. The control interface for the WMI remotely-controlled ground-based ice nucleus generator is shown, after connection is established via satellite, but before the generator is turned on. All flow valves are off, seeding solution flow is zero, but system status is fully reported.

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.

2.4 Seeding Solution

The high performance seeding solution itself was tested at the Colorado State University Cloud Simulation and Aerosol Laboratory by DeMott (1997). Those tests determined that colder cloud temperatures produce a bigger yield of active ice nuclei per gram of AgI burned. As shown in Figure 9, the yield increases markedly from -6°C (+21.2°F) to -8°C (+17.6°F), and even more at -10°C (+14°F). At a cloud temperature of -6°C, 3 x 10^{11} nuclei are active per gram of AgI burned. This is 300,000,000,000, or 300 billion.

Operational programs in the western United States commonly commence seeding operations at -5 or -6°C. As in the previous four seasons, the 2018-2019 Wind River operations used a temperature criterion of -6°C at 700 hPa, which is about 10,000 feet above sea level.

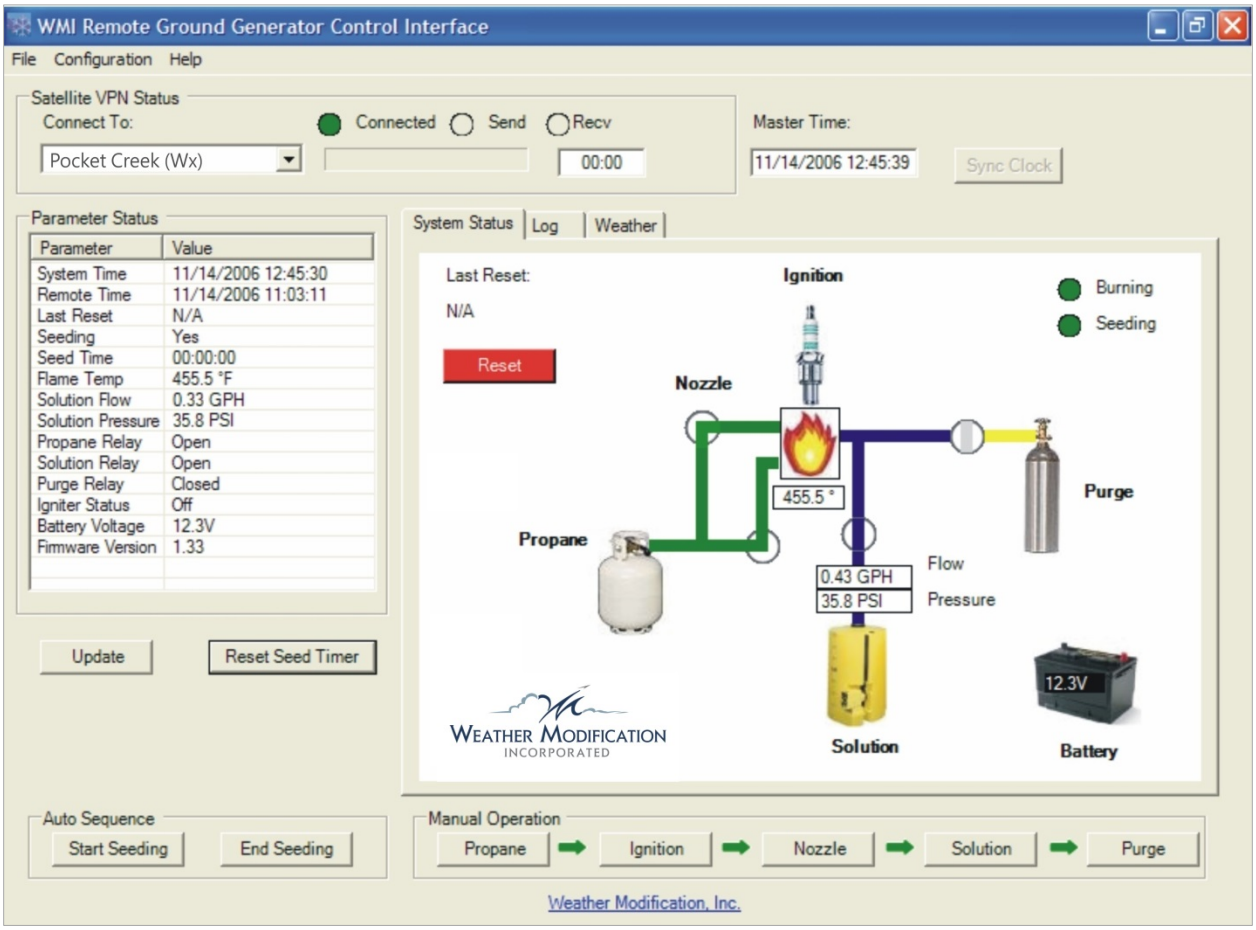

Figure 8. The WMI remote-controlled ice nucleus generator interface is shown, as it appears during seeding operations. Valves are open, the flame is known to be burning, and the seeding solution flow rate is also known. Seeding is certain.

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

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

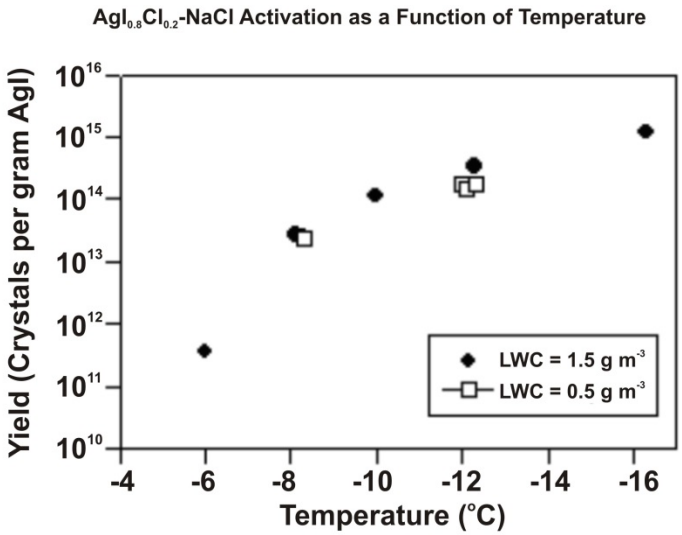

Figure 9. Yield as measured by the number of active ice nuclei per gram of silver iodide (AgI) burned, is shown as a function of temperature (DeMott 1997). These nuclei are comprised of silver iodide, silver chloride, and salt (NaCl).

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

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

2.5 Atmospheric Soundings (Weather Balloons/Rawinsondes)

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

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

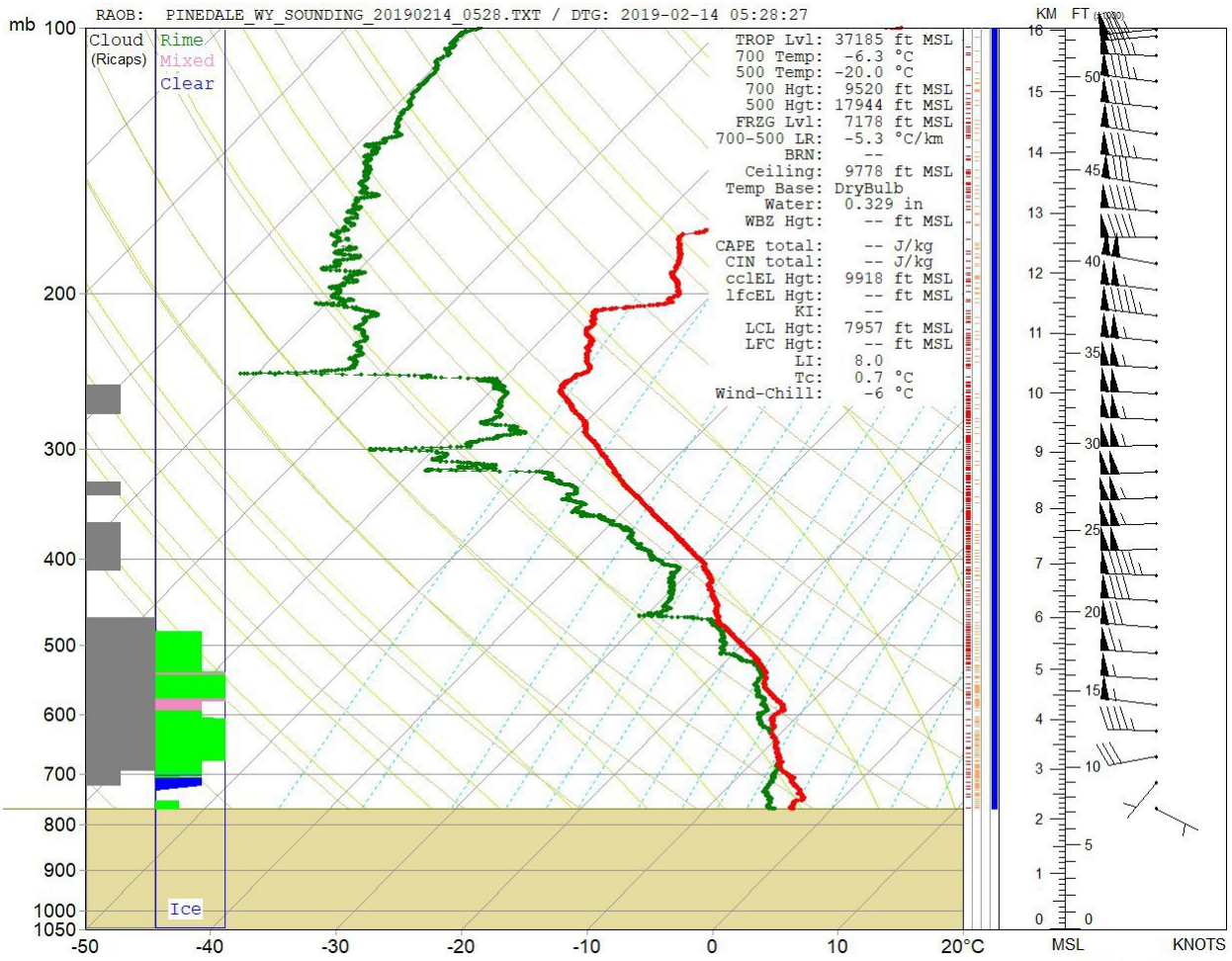

Figure 10. A plot of the upper-air sounding obtained from the weather balloon released from Pinedale, WY at 10:28 pm MST (05:28 am UTC) on 14 February 2019. The temperature at 700 hPa level (approximately 10,000 feet) was -6°C (+21°F), and the wind speed was from 255° (westerly) at about 30 knots (~35 miles per hour), both within the acceptable range for seeding.

2.6 Shop and Site Servicing

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

3. FORECASTING AND OPERATIONAL DECISION-MAKING

3.1 Meteorological Data Sources

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

Radiometer. The WWDO radiometer was deployed at a residence near Pinedale, WY. Since the presence of liquid water in the clouds over the target area is essential for successful seeding, and this radiometer calculates integrated liquid water, its observations can be helpful. This season WMI learned from Radiometrics, the manufacturer of the radiometer, that the configuration files installed on the radiometer were for operation in a vertically-pointing (zenith) mode. While additional scan angles had been sampled in previous project seasons, only data from the zenith scan was processed. Radiometrics was asked to provide new calibration files, appropriate for operation at the desired scan angles, but declined, saying the unit and its software are deprecated, and that contemporary configuration files are not compatible with the unit.

Figure 11. The radiometer is shown here, at the residence of the project meteorologist, near Pinedale. The instrument observes in the direction perpendicular to its axis, so as aligned here, it is configured to take measurements over the Wind River Range in the distance. As utilized in 2018-2019, however, it was zenith-pointing. (WMI photograph by Dan Gilbert.)

Atmospheric Soundings. Weather balloons were released from WMI's Pinedale shop whenever there was ambiguity about the suitability for effective seeding. The data provided from these weather balloon releases help answer questions such as if the low-level wind direction's suitability to effectively transport seeding material transport to the target areas, or if the 700 hPa temperature was cold enough for seeding to be effective (Figure 10).

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

3.2 Numerical Modeling

WRF Modeling. For the 2018-2019 season WMI continued to operate a limited area domain of the Weather Research and Forecasting (WRF) model specifically tailored to the Wind River seeding program. This high-resolution nested domain, with an inner nest grid spacing of 2.5 km, was initialized from the High Resolution Rapid Refresh (HRRR) model and used the North American Model (NAM) for boundary conditions at 3-hour intervals. In contrast from past seasons, a larger parent 7.5 km domain was also operated, along with a second high-resolution nested domain that covered southeast Wyoming and northern Colorado. A large number of graphical outputs were developed specifically to aid the cloud seeding decision-making. Examples of some of the most unique, the meteorologists' favorites, are shown in the following figures. Figure 12 shows forecast integrated cloud water colder than -5°C over the Wind River Range.

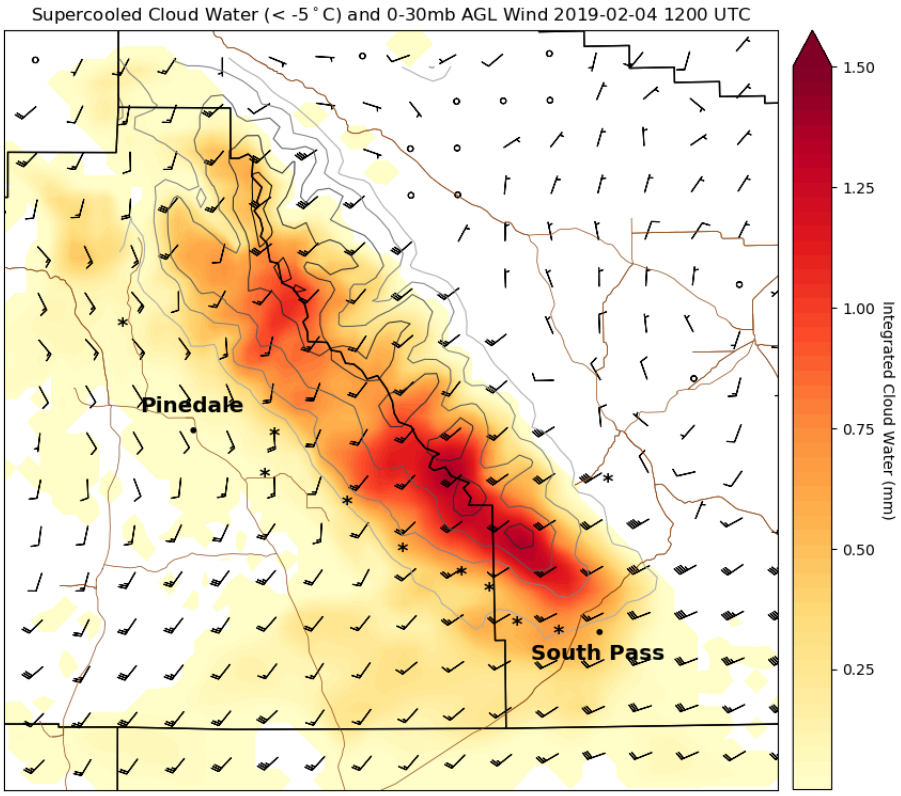

Figure 12. Near surface wind barbs are shown with integrated cloud water on this panel from the WMI WRF model, valid on 4 February 2019, at 12:00 UTC. Since the water shown is only that occurring at -5°C and colder, it is supercooled sufficiently for seeding. The WMI WRF was initialized and run as often as every six hours; plots such as this were created for hourly intervals. Contours show model terrain elevation at 1,000 ft intervals beginning at 8,000 ft.

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

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

The example shown in Figure 13 for February 3rd and 4th is for the Pocket Creek cross section, illustrated in Figure 14. In the upper panel, at 19:00 UTC (12:00 PM MST), a very nice region of cloud water is shown. Note that the region lies entirely above the -5°C isotherm, so all of the SLW is supercooled—perfect for seeding. The position is also very favorable, being to the left (upwind) of the range. This allowed the seeding agent to initiate the development of ice—and thus precipitation—in time for it to fall on the target.

In the lower panel, twenty hours later (at 15:00 UTC, or 8:00 AM MST) significant SLW remains. Deeper cloud cover has moved in, and greater naturally occurring snow is depicted along and downstream of the peak. Plot priority is given to cloud water over snow, so some areas of indicated snow are not visible. With real-time web access the images shown in Figures 12-14 can be animated in 1-hour time steps, providing an understanding of expected storm evolution.

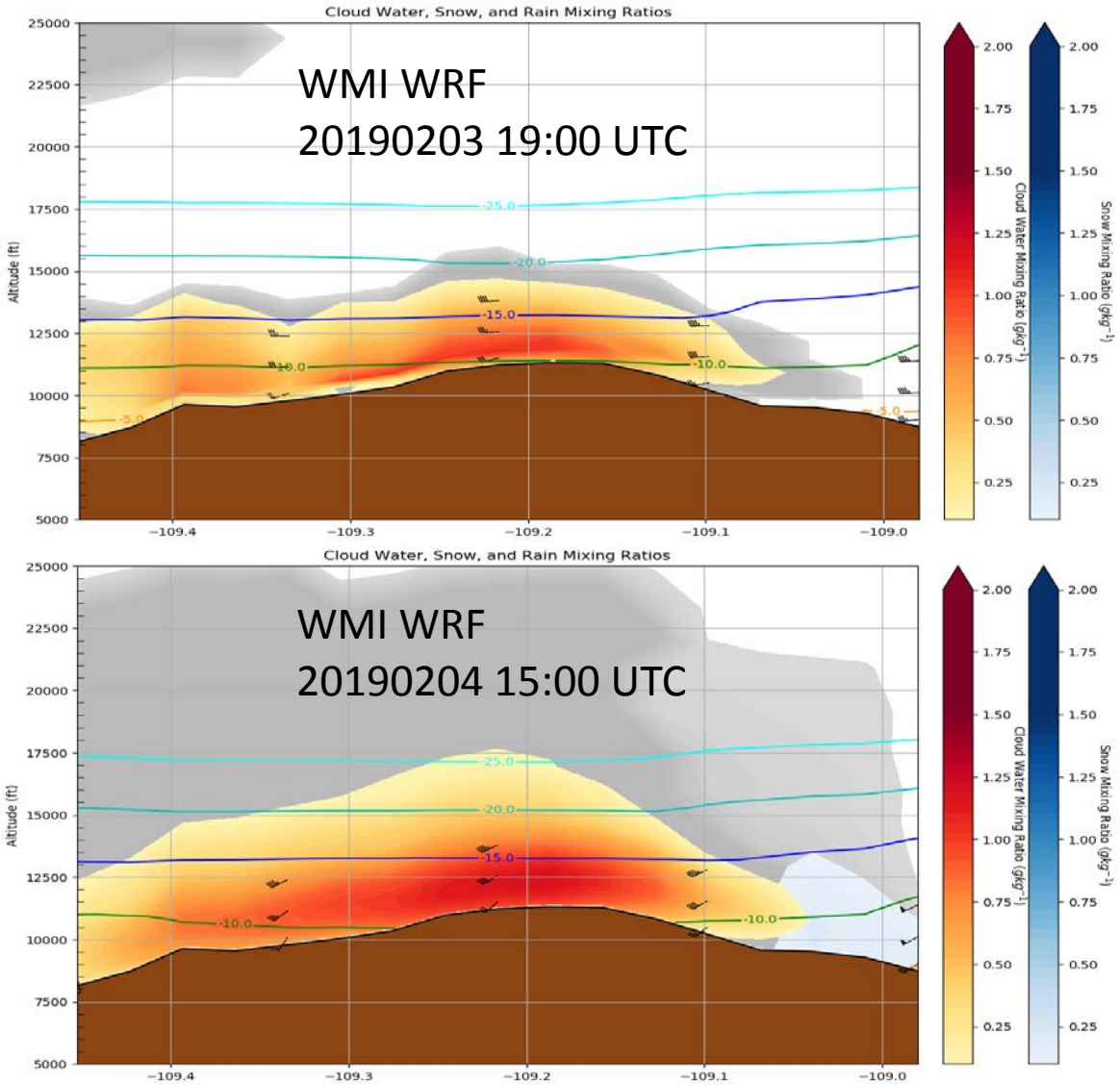

Figure 13. Vertical cross sections through the Pocket Creek generator site, approximately perpendicular to the axis of the Wind River Mountains. The top panel represents 19:00 UTC on February 3rd, or 12 PM MST, the bottom is twenty hours later at 15:00 UTC February 4th, or 8 AM MST. See text for interpretation and discussion.

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

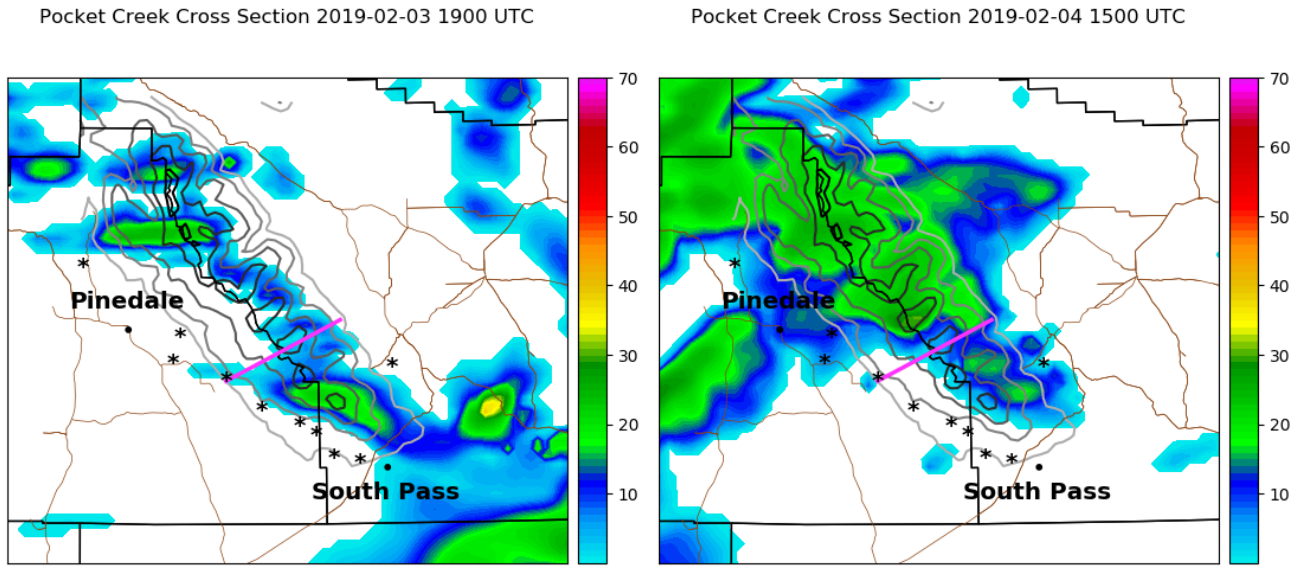

Figure 14. Simulated radar reflectivity (dBZ) is shown for 19:00 UTC (12:00 PM MST) on February 3rd, left, and 15:00 UTC (08:00 AM MST) February 4th, right. The position of the Pocket Creek cross sections depicted in Figure 13 is depicted by the pink line. The radar reflectivity does not differentiate between cloud water and cloud ice. Most often, the best seeding conditions are found when cloud (and echo) are limited to the range. When winter systems become widespread or "deep", natural ice becomes more prevalent and seeding conditions deteriorate.

HYSPLIT Modeling.

During the 2018-2019 season, WMI ran the Hybrid Single-Point Lagrangian Integrated Trajectory (HYSPLIT) plume dispersion model to establish a better idea of seeding agent plume behavior. The process was automated, and run with each update of the WRF, providing a complete record of predicted plume trajectories for the seasons. These HYSPLIT plots were output in one-hour increments, with each plot showing forecast locations of plume centerline (the most-dense portions of the plumes) for four hours. A series of such plots is provided as Figure 15, for the March 2nd-3rd 2018 seeding event. In the plots, each hour is shown by a "dot" on the plume centerline.

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

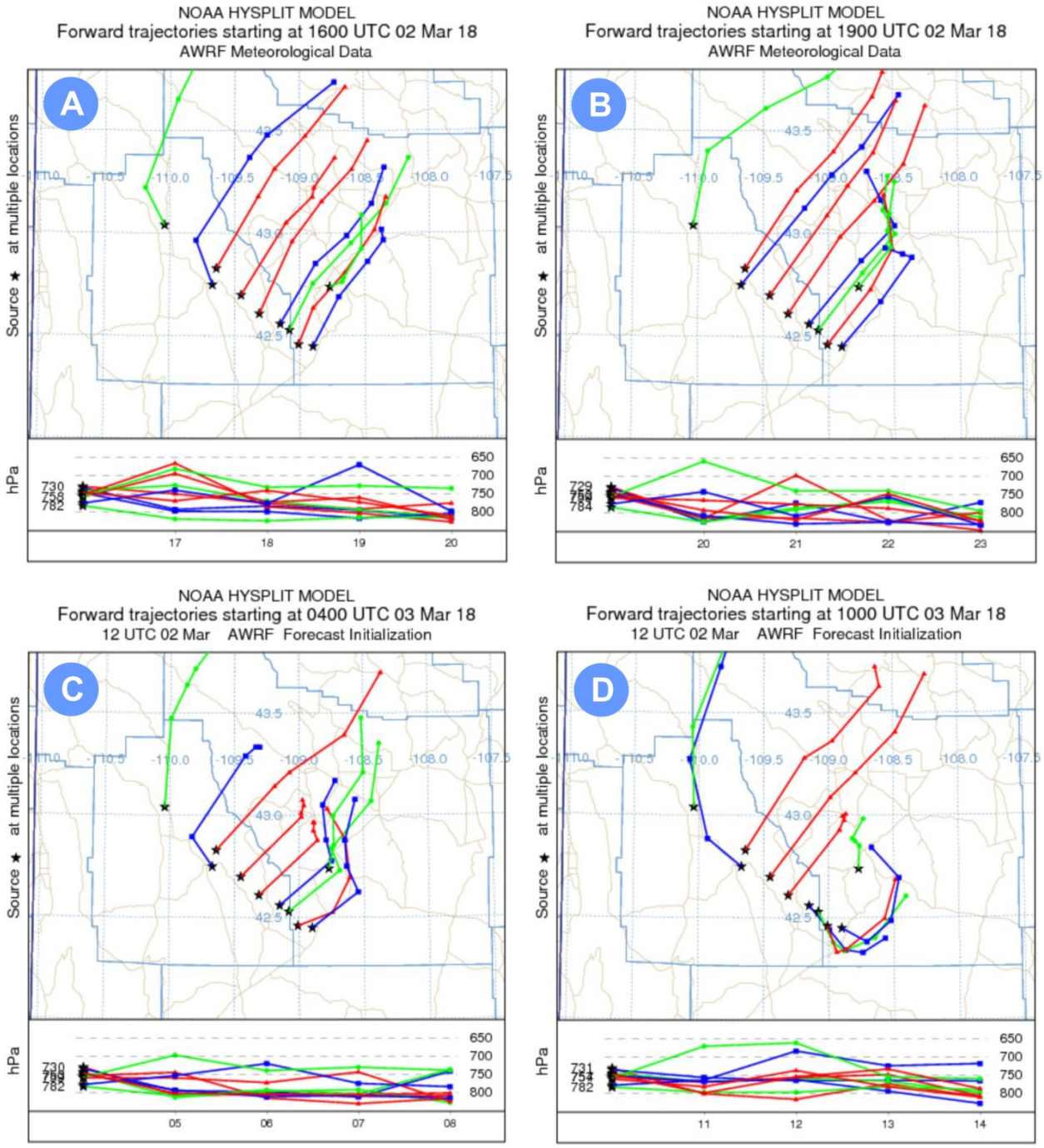

Figure 15. The evolution of the centers of plume trajectories is shown for the seeding event on March 2nd-3rd, 2018. Times (UTC) are as follows: (A) 16:00 March 2nd, (B) 19:00 March 2nd, (C) 04:00 March 3rd, and (D) 10:00 March 3rd. Each "dot" on each plume line shows the projected position at one-hour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

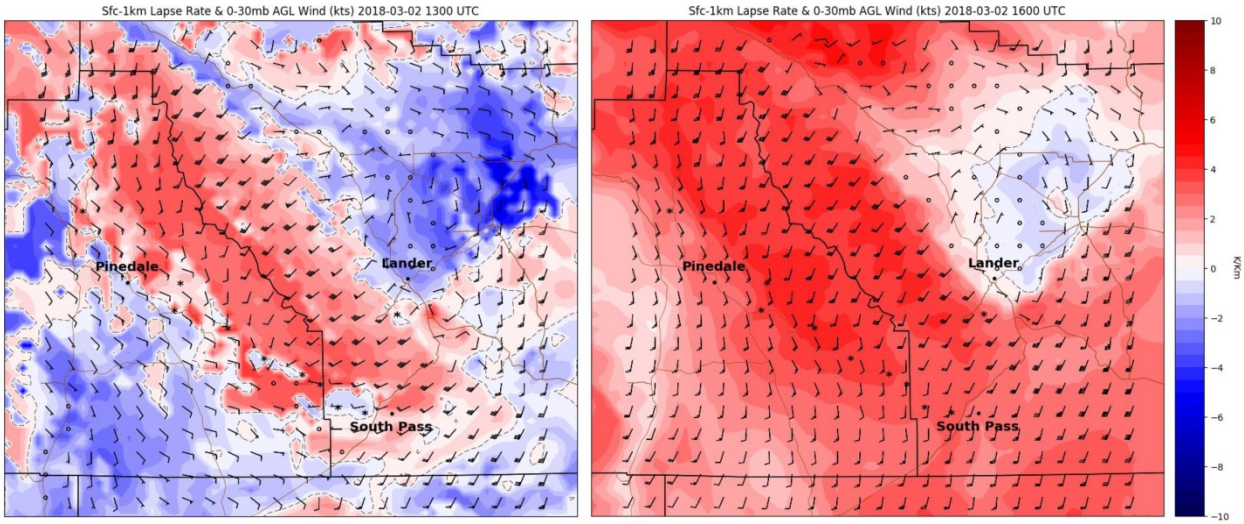

Figure 16. Another product developed specifically for winter orographic seeding is the vertical temperature lapse rate plot of the lowest 1 km (~3,000 feet), shown here. In these graphics, a negative change (blue) indicates increasing temperature with height (warming), while reds and pinks indicate cooling.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

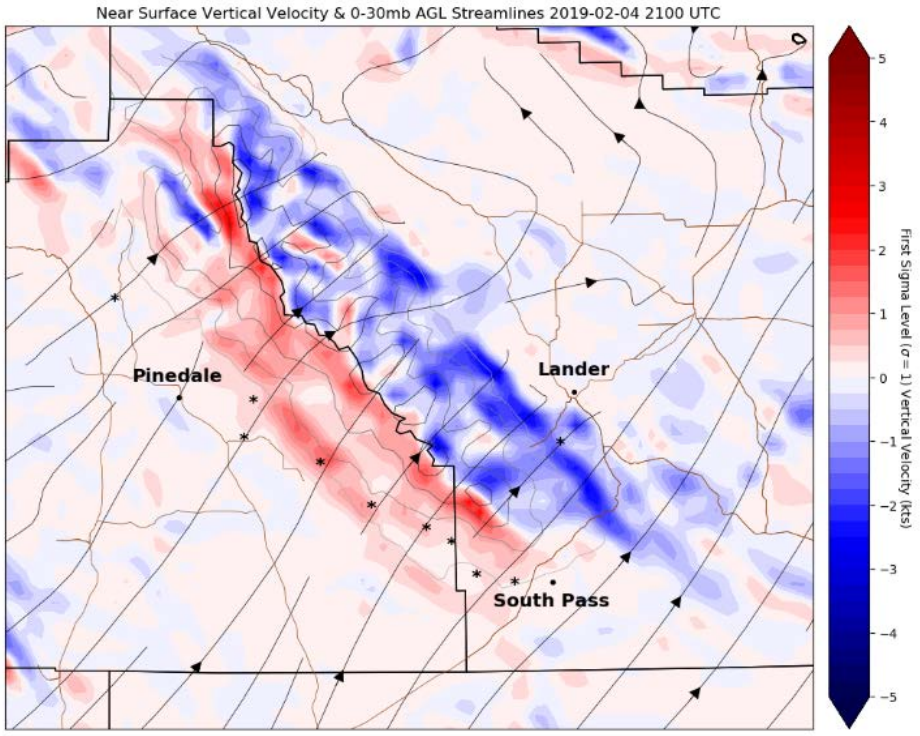

Figure 17. This product, also designed specifically for winter orographic seeding, shows the near surface vertical velocity along with streamlines of the near surface (average 0-30 mb AGL) wind. Here, ascending air is shown in red, with descending air in blue. This plot helps illuminate when sufficient upslope winds exist to transport seeding materials from ground generators up into the target area. This plot shows favorable seeding conditions during a prolonged seeding event in early February 2019.

3.3 Timetables and Routines

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

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

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

The seeding criteria were straightforward. First, 700 hPa temperature, meaning the temperature near the cloud elevation (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 were not clearly -6°C or colder, a weather balloon was released from Pinedale, WY (Section 2.5, Figure 10), to obtain vertical temperature, humidity, and wind profiles.

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

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

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 mountains.
-1	*No*	Limited coverage or short-lived orographic clouds, not enough temporal or spatial extent to warrant seeding activities.
0	*Possible*	Some orographic clouds or stratiform cloud deck(s) over mountain tops. SLW likely insufficient for seeding operations or winds clearly unfavorable.
+1	*Yes*	Orographic clouds and/or stratiform cloud deck(s) enshrouding mountain tops, winds favorable and SLW likely sufficient for seeding operations.
+2	*Yes*	Persistent orographic clouds and/or stratiform cloud deck(s) enshrouding mountain tops, SLW probable, winds favorable. Lengthy operations possible.

4. OPERATIONS

4.1 2018-2019 Season

Project operations began on 1 December 2018, with forecasts and full data collection activities. The first seeding opportunity occurred on 19 December 2018. During the season, seeding was conducted on twelve occasions, as enumerated in Table 2.

December had two seeding events, January three, February six, and March just a single seeding opportunity, that utilizing the east-slope Enterprise generator. Table 3 summarizes operations by month and provides season totals. In total, 23.785 kg of seeding agent were released. Generators were operated for a total of 165:55 hours during the season, accruing a total of 951 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.]

The eleven seeding events that utilized more than one generator were all quality opportunities that used four to nine generators, and were of 3.5 or more hours in duration. Five events were ten hours or longer, and two exceeded twenty hours. One, the storm that began on February 3, set a project record, running for over 54 hours.

TABLE 2. 2018 - 2019 Seeding Events

Date	*Number of Generators Utilized*	*Length of Seeding (hours)*	*Total Generator Hours*	*AgI Released This Date (kg)*	*AgI Monthly Total (Kg)*	*Generator Hours*	*Total Duration of Seeding*
19-Dec-18	7	5:11	36:13	0.948	1.514	39:49	11:15
30-Dec-18	4	6:04	3:36	0.566			
6-Jan-19	6	14:10	84:34	2.178	4.110	159:48	26:46
7-Jan-19	7	9:13	61:44	1.570			
16-Jan-19	4	3:23	13:31	0.362			
3-Feb-19	9	54:40	401:04	10.491	17.978	745:21	121:47
10-Feb-19	6	8:03	43:04	1.113			
13-Feb-19	7	19:38	118:34	3.009			
15-Feb-19	8	4:08	33:03	0.880			
24-Feb-19	6	10:40	53:46	1.460			
25-Feb-19	6	24:38	95:50	2.465			
29-Mar-19	1	6:07	6:07	0.183	0.183	6:07	6:07
Season	12 Events				23.785	951:05	165:55

TABLE 3. Summary of Seeding Events During the 2018 - 2019 Winter Season

Month	*Events* *( ) denotes easterly flow*	*Event Averages*		*Seeding Agent (kg)*	
		Number of Generators	*Generator Hours**	*Average Released per Event*	*Total Released*
December	2	6.5	19.9	0.76	1.514
January	3	5.7	53.3	1.37	4.110
February	6	7.0	124.2	3.24	17.978
March	(1)	1.0	6.1	0.18	0.183
Totals/Averages	*11 (1)*	*5.9*	*80.73*	*2.10*	*23.785*

**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.*

The generator performance for the season was very good, at 93.1% functionality.

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 Table 4 shows, the problems were scattered among the generators. Five of them, Big Sandy, Block & Tackle, Anderson Ridge, Enterprise, and Boulder Lake, ran flawlessly the whole season. White Acorn, East Fork, and Green River each failed once, while Sweetwater and East Fork each experienced problems (less than a complete run) on one occasion. The Pocket Creek generator failed to complete full runs on during two storms.

TABLE 4. Ice nucleus generator operations are shown for each of the twelve seeding events during the 2018-2019 season.

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
20181219	WRR0081	REQ	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
20181230	WRR0082	REQ	YES	YES	YES	NO	NO	NO	NO	NO	YES	NO	4	
		RAN	YES	YES	YES	NO	NO	NO	NO	NO	YES	NO		4
20190106	WRR0083	REQ	YES	YES	YES	NO	NO	NO	YES	YES	YES	NO	6	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	NO		6
20190107	WRR0084	REQ	YES	YES	YES	YES	YES	NO	YES	NO	YES	NO	7	
		RAN	YES	YES	YES	PARTIAL	YES	NO	YES	NO	YES	NO		6.75
20190116	WRR0085	REQ	YES	YES	YES	NO	NO	NO	NO	NO	YES	NO	4	
		RAN	YES	YES	YES	NO	NO	NO	NO	NO	YES	NO		4
20190203	WRR0086	REQ	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	YES	YES	YES	YES	YES	NO	YES	PARTIAL	YES	NO		7.5
20190210	WRR0087	REQ	YES	YES	YES	YES	YES	NO	NO	NO	YES	NO	6	
		RAN	YES	YES	YES	YES	YES	NO	NO	NO	PARTIAL	NO		5.25
20190213	WRR0088	REQ	YES	YES	YES	YES	YES	NO	YES	YES	YES	NO	8	
		RAN	YES	YES	YES	YES	YES	NO	YES	NO	YES	NO		7
20190215	WRR0089	REQ	YES	YES	YES	YES	YES	NO	YES	YES	YES	NO	8	
		RAN	YES	YES	YES	YES	YES	NO	YES	YES	YES	NO		8
20190224	WRR0090	REQ	YES	YES	YES	NO	NO	NO	YES	NO	YES	YES	6	
		RAN	YES	YES	YES	NO	NO	NO	YES	NO	YES	YES		6
20190225	WRR0091	REQ	YES	YES	YES	NO	NO	NO	YES	YES	YES	NO	6	
		RAN	YES	YES	NO	NO	NO	NO	YES	YES	PARTIAL	NO		4.5
20190329	WRR0092	REQ	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	1	
		RAN	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO		1
												TOTALS	72	67
													RUN =	93.1%
													FAIL =	6.9%

ZULU DATES ONLY

PARTIAL = > 25% of Expected Runtime

4.2 Comparisons with Previous Seasons

Comparisons of the five seasons of operational cloud seeding are provided in Tables 5 and 6. In Table 5, the lengths of seeding operations in each month are provided. Each season was different. In terms of actual number of hours with seeding operations, the 2015-2016 season tops the list. However, when one compares the hours of seeding conducted each season (Table 6), the 2016-2017 season was far above the others, 400 hours more than the 2015-2016 season. The 2018-2019 season was the least active, in part due to budget constraints that precluded operations in November and April.

TABLE 5. Hours of Seeding

	Nov	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*Season*
2014-2015	10:13	83:45	24:08	36:47	25:21	20:12	200:26
2015-2016	41:28	66:07	49:56	60:30	62:00	9:54	289:55
2016-2017	NA	120:22	63:12	58:53*	SUSP	NA	242:27
2017-2018	NA	49:37**	23:24	57:25	62:06	NA	192:54
2018-2019	NA	11:15	26:46	121:47	6:07	NA	165:55
Mean	25:50	66:13	37:29	67:04	38:23	15:03	231:26

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

Though the 2017-2018 season had the fewest hours during which seeding has been conducted during a season (Table 5), more seeding hours, that is, more generators were operated during those opportunities (Table 6) than the first season (2014-2015). Viewed another way, it can be said that full advantage is being taken of those opportunities that present themselves. This season saw, by far, the most active February to date.

TABLE 6. Hours of Ice Nucleus Generator Operation

	Nov	***Dec***	***Jan***	***Feb***	***Mar***	***Apr***	***Season***
2014-2015	71:43	377:52	125:51	36:47	219:54	20:12	852:19
2015-2016	86:21	375:03	328:57	180:56	191:31	9:54	1172:42
2016-2017	NA	815:05	396:22	406:57*	SUSP	NA	1618:24
2017-2018	NA	304:53**	156:06	397:31	373:04	NA	1231:34
2018-2019	NA	39:49	159:48	745:21	6:07	NA	951:05
Mean	79:02	382:32	233:25	353:31	197:39	15:03	1218:45

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

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

5. OUTREACH

Whenever possible, WMI likes to be receptive to requests to educate those showing an interest in our field efforts. This season, WMI was approached by the Pinedale Children's Discovery Center regarding general meteorological aspects of cloud seeding in the Wind River Range. WMI meteorologist Adam Brainard and Center Director Allison Long arranged for local students to visit the WMI shop in Pinedale, Wyoming, and learn about the project and upper air soundings, and even to participate in the release of a weather balloon. WMI appreciates being asked to take part in this type of educational outreach, and has gladly conducted such events, which are done with the knowledge and support of the WWDO. It is important to WMI to be receptive to requests to educate those showing an interest in our weather modification efforts.

Figure 18. WMI meteorologist Adam Brainard explains to a group of young students the instrument package (in his hands) that is used on weather balloons. (WMI photograph by Michael Willette.)

WMI also presented an update on the 2018-2019 Wind River operational seeding efforts at the Wyoming Weather Modification Technical Advisory Team (TAT) meeting held in Cheyenne, WY on December 6th, 2018. The TAT, initially organized by the WWDO to provide technical advice and support for the WWMPP, is largely comprised of representatives of interested State and Federal agencies. Wyoming agencies include the State Engineer's Office, the Department of Environmental Quality, the Department of Transportation, the University Office of Water Programs, and the Game and Fish Department. Federal agency representation includes several different forests (Bridger-Teton, Shoshone, and Medicine Bow), the U.S. Geological Service, the NWS Riverton and Cheyenne offices, the Bureau of Land Management, and the Natural Resources Conservation Service.

6. SUMMARY

The 2018-2019 cloud seeding effort in the Wind River Range began on December 1st, 2018, and officially concluded on 31 March 2019, a duration of 121 days (4 months). There were no seeding suspensions during the season.

Twelve seeding events were conducted between December 19th, 2018, and March 29th, 2019. All but one event involved the use of four or more generators, seeding in westerly or southwesterly flow. A total of 23.79 kg of silver iodide was released in the course of 951 hours of generator operations.

The ice nucleus generators operated reliably, seeding as intended over 93% of the time. Five generators operated flawlessly through the season, with the few glitches being more or less spread evenly among the others.

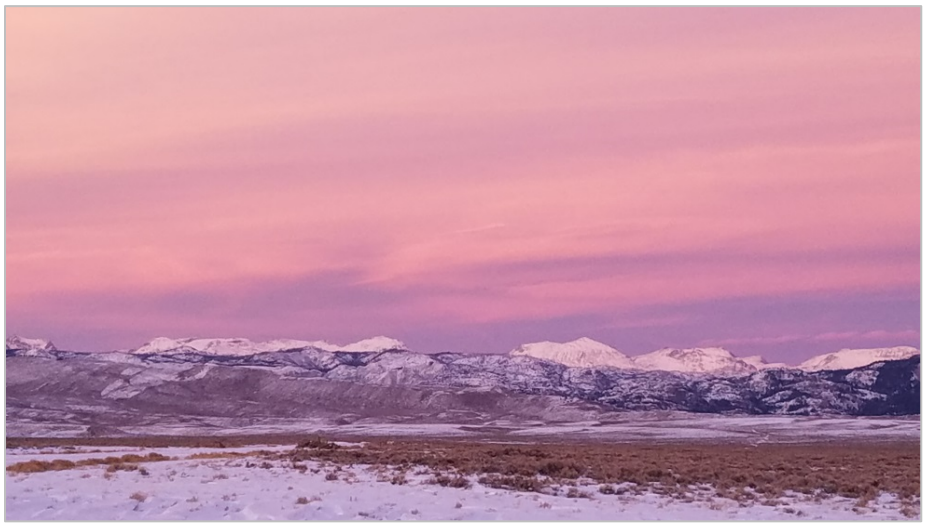

Figure 19. Twilight produced colorful high clouds over the Wind River Mountains on 13 December 2018. Technicians were servicing the Boulder Lake generator site at the time. (WMI photograph by Michael Paul.)

In terms of hours of seeding generator operations, the winter was less active than average. In spite of a very active February, the season ranked last (out of the five seasons) in terms of total hours of generator operations. That being said, the 166 hours during which seeding operations were conducted was but 27 hours less than the 193 hours accrued in the 2017-2018 season. February 2019 was, by a large margin, the busiest February of the five years to date.

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 (mb), 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

DeMott, P.J., 1997: Report to North Dakota Atmospheric Resource Board and Weather Modification Incorporated on tests of the ice nucleating ability of aerosols produced by the Lohse airborne generator. Report from Dept. Atmos. Sci., Colorado State Univ., Fort Collins, CO, 15 pp.

Wallace, J.M., and P.V. Hobbs, 1977: *Atmospheric Science, An Introductory Survey*. Academic Press, 467 pp.

Appendix A. Daily Operations Summaries

Wyoming Weather Modification Program - Wind River Mountains 2018-2019 Season – WMI Daily Project Summary	
01 December 2018, Saturday	
Small, shallow low clouds existed over the SW slopes of the range from the morning through the afternoon hours. No SLW existed and the wind flow was not favorable for seeding operations. Those clouds diminished in the early evening as some mid-level clouds moved in from the west for a short period. A stratus cloud layer developed on the NE side of the range spread over the Sunday morning, but there was no precipitation. Max/Min temperatures Pinedale: 27/-4 Rock Springs: 26/12 Lander: 37/14 South Pass: 27/18 Observed ODC: -1	No ground-based seeding was conducted.
02 December 2018, Sunday	
A stratus cloud layer was over the NE slopes throughout the morning and afternoon hours, but no measurable snowfall occurred. Widespread, thick clouds moved in from the south and covered the area through the night and into Monday morning. Light snowfall occurred but no SLW existed and the wind was not favorable for seeding operations. Max/Min temperatures Pinedale: 23/-9 Rock Springs: 25/7 Lander: 28/16 South Pass: 21/12 Observed ODC: 0	No ground-based seeding was conducted.
03 December 2018, Monday	
The range saw thick cloud layers for most of the day along with some light snowfall. SLW and winds were not suitable for seeding. 500mb temperatures were below -30°C. Clouds diminished through the night, and skies became mostly clear by morning. No seeding occurred. Max/Min temperatures Pinedale: 21/-8 Rock Springs: 22/8 Lander: 27/14 South Pass: 19/12 Observed ODC: 0	No ground-based seeding was conducted.

04 December 2018, Tuesday	
The range was mostly clear through Tuesday evening. Thick high and midlevel cloud layers gradually overspread the region during the night, and these upper clouds were blanketing the region by Wednesday morning with some isolated areas of light snowfall mainly over the southern range. Low and orographic cloud coverage was very limited. SLW, winds, and orographic clouds were not suitable for seeding. Max/Min temperatures Pinedale: 19/-15 Rock Springs: 18/6 Lander: 31/5 South Pass: 27/9 Observed ODC: -1	No ground-based seeding was conducted.
05 December 2018, Wednesday	
High and mid-level clouds passed through the region during the afternoon and early evening before moving away to the SE. Low clouds with light snowfall existed over the southern tip of the range and the basin SW of the range during the evening and overnight hours. Some LW was detected by the radiometer but the wind flow was not favorable for seeding operations. Max/Min temperatures Pinedale: 12/-18 Rock Springs: 18/0 Lander: 21/6 South Pass: 21/9 Observed ODC: -1	No ground-based seeding was conducted.
06 December 2018, Thursday	
Clear skies in the morning through the midafternoon. High and a few mid-level clouds existed for a few hours into the evening. Clear skies again overnight. Max/Min temperatures Pinedale: 23/-11 Rock Springs: 24/9 Lander: 24/5 South Pass: 27/9 Observed ODC: -2	No ground-based seeding was conducted.
07 December 2018, Friday	
Mostly clear skies were observed through the afternoon, with low and mid-level clouds moving in around dusk. These clouds persisted through the night, with broken skies obscuring the range continuing into the morning. Synoptic scale stratus and orographic cloud were observed, but flow was not suitable for seeding activities.	No ground-based seeding was conducted.

Max/Min temperatures Pinedale: 26/-13 Rock Springs: 23/0 Lander: 23/2 South Pass: 27/21 Observed ODC: 0	
08 December 2018, Saturday	
Broken stratus across the valley gradually became more scattered and dissipated by late afternoon. Very menial and short-lived orographic clouds were also observed, though conditions were by and large clear over the peaks. Mostly clear skies were observed overnight, and clear skies have continued into the morning. Max/Min temperatures Pinedale: 30/10 Rock Springs: 33/11 Lander: 34/3 South Pass: 32/21 Observed ODC: -1	No ground-based seeding was conducted.
09 December 2018, Sunday	
Clear skies during the daylight hours. Some high clouds moved in overnight, then mid-level cloud coverage was increasing before sunrise. Arch cloud developed on the NE side of the range a little before sunrise. Max/Min temperatures Pinedale: 25/-9 Rock Springs: 27/10 Lander: 30/6 South Pass: 34/19 Observed ODC: -2	No ground-based seeding was conducted.
10 December 2018, Monday	
Cloud coverage increased during the afternoon as mid-level clouds spread over the region from the west. Snow flurries developed over the range during the evening, but no SLW was present and the wind flow was not favorable for seeding operations. The flurries ended before midnight and the clouds diminished throughout the night, becoming clear by sunrise. Max/Min temperatures Pinedale: 21/-9 Rock Springs: 19/-2 Lander: 24/5 South Pass: 32/21 Observed ODC: 0	No ground-based seeding was conducted.
11 December 2018, Tuesday	
Skies were mostly clear Tuesday afternoon, and then	No ground-based seeding was conducted.

upper level clouds overspread the region during the evening becoming thicker through the night. Orographic and low stratus coverage slowly increased through the night with some light liquid water detected by the radiometer. Light to moderate snow accumulation occurred through the night. Plume trajectories were not favorable for seeding, and several low level inversion layers were noted in the models and confirmed in a PNA sounding early Wednesday morning. Conditions were not suitable for proper targeting with ground generators. No seeding occurred. Max/Min temperatures Pinedale: 28/0 Rock Springs: 27/8 Lander: 38/10 South Pass: 30/12 Observed ODC: 0	
12 December 2018, Wednesday	
Light snowfall occurred in the morning through early afternoon with minimal SLW and poor plume trajectories. Low clouds were mostly stratus, as low level winds were light and orographic lift was poor. Several low level inversions were evident early in the period. Skies gradually cleared throughout the afternoon after the passage of a cold front and trough axis, and then mostly clear skies were observed throughout the remainder of the forecast period. A cold air mass flowed into the region during the evening and night as strong flow aloft shifted to the north behind the trough. Thin upper level cloud waves passed through overnight. No seeding occurred. Max/Min temperatures Pinedale: 27/5 Rock Springs: 28/12 Lander: 41/20 South Pass: 27/12 Observed ODC: 0	No ground-based seeding was conducted.
13 December 2018, Thursday	
Clear skies over the area until the midafternoon, when widespread high and mid-level clouds spread over western WY. Those clouds continued through the evening, then diminished overnight leaving clear skies again by Friday morning. Max/Min temperatures Pinedale: 23/-8 Rock Springs: 25/13 Lander: 39/12	No ground-based seeding was conducted.

South Pass: 32/12 Observed ODC: -2	
14 December 2018, Friday	
Thin, widespread high clouds spread over the area during the afternoon and continued through the evening. A band of low clouds ahead of a cold front moved through during the night. Light snowfall occurred over the range for a few hours, but the temperature and wind flow did not line up to allow for seeding operations. Max/Min temperatures Pinedale: 30/-6 Rock Springs: 30/11 Lander: 33/10 South Pass: 36/23 Observed ODC: 0	No ground-based seeding was conducted.
15 December 2018, Saturday	
Partly cloudy skies become scattered with loose and shallow orographic cloud along the western foothills Friday afternoon. No organized orographic cloud developed, and neither winds nor SLW were favorable for seeding operations. High cirrus drifted across the region into the late evening hours before clearing skies overnight. Very thin cirrus returned to the area Sunday morning. Max/Min temperatures Pinedale: 32/-2 Rock Springs: 37/8 Lander: 45/13 South Pass: 32/21 Observed ODC: -1	No ground-based seeding was conducted.
16 December 2018, Sunday	
Beautiful, mostly clear skies were observed Sunday afternoon and night except for patchy and thin high cirrus. Mid-level stratus and isolated orographic cloud with bases at or above the peaks developed Monday morning. Max/Min temperatures Pinedale: 32/-2 Rock Springs: 33/11 Lander: 43/18 South Pass: 37/21 Observed ODC: -1	No ground-based seeding was conducted.
17 December 2018, Monday	
There were periods of mid-level clouds throughout the daylight hours. Low stratus developed over the valley and southern slopes during the evening and persisted into Tuesday morning. Little to no snowfall occurred	No ground-based seeding was conducted.

and the wind flow was not favorable for seeding operations. Max/Min temperatures Pinedale: 28/0 Rock Springs: 27/6 Lander: 40/18 South Pass: 36/27 Observed ODC: 0	
18 December 2018, Tuesday	
Mostly cloudy skies were observed in Pinedale Tuesday afternoon, with increasingly favorable orographic cloud observed through dusk. Light snow fell at times overnight, though accumulation had been light in the valley. HYSPLIT trajectories consistently identified positive seeding trajectories for seven western GGEN sites overnight, and despite a 700mb temperature of -5.1°C in a 0536Z sounding, seeding was initiated at 0651Z due to model anticipated cooling after 6Z. Trajectories became unfavorable as more northwesterly flow intensified around dawn. Stratus still enshrouded the mountains Wednesday morning. Max/Min temperatures Pinedale: 35/19 Rock Springs: 37/22 Lander: 45/21 South Pass: 36/25 Observed ODC: +1	Seeding event WRR0081 was called at 0041 MST on 12/19/2018 and began at 0047 MST. **WRR0081 Summary:** Generators: WR01, WR02, WR03, WR09, WR10, WR12, WR13 Time: 0047 (12/19) to 0500 (12/19) MST 0747 (12/19) to 1258 (12/19) UTC Duration: 5:11, 36:13 Total Time Seeding Material: 15.58 gallons (905 grams)
19 December 2018, Wednesday	
Light snowfall continued through the morning, but was diminishing by noon, and tapered off in the early afternoon. There were only a few waves of mid-level clouds the rest of the period. Max/Min temperatures Pinedale: 32/14 Rock Springs: 33/22 Lander: 42/22 South Pass: 32/19 Observed ODC: 0	No ground-based seeding was conducted.
20 December 2018, Thursday	
Areas of high and mid-level clouds around during the daylight and evening hours. Then clear sky overnight until small band of precipitation moved in a little before sunrise. Light snowfall began over the range after 12Z, but warm temperature and unfavorable wind flow precluded seeding. Max/Min temperatures Pinedale: 28/0	No ground-based seeding was conducted.

Rock Springs: 38/20 Lander: 35/17 South Pass: 34/18 Observed ODC: 0	
21 December 2018, Friday	
Thin orographic clouds with areas of light snowfall in the morning until the early afternoon. The low clouds had diminished by then, but mid-level clouds had moved in. Areas of mid-level clouds continued to stream across the area the rest of the day. Max/Min temperatures Pinedale: 34/-2 Rock Springs: 36/11 Lander: 48/15 South Pass: 36/18 Observed ODC: 0	No ground-based seeding was conducted.
22 December 2018, Saturday	
Mostly clear skies during the afternoon and evening except for a few mid-level clouds at times. More mid and high clouds passed through during the night. Widespread stratus moved in a little before sunrise but no precipitation occurred. Max/Min temperatures Pinedale: 21/-6 Rock Springs: 27/11 Lander: 32/14 South Pass: 23/10 Observed ODC: -2	No ground-based seeding was conducted.
23 December 2018, Sunday	
Widespread cloud coverage from the morning through the evening hours. There were areas of flurries but no accumulating snowfall. The cloud coverage was less consistent overnight, but periods of flurries still existed. The wind flow was not favorable for seeding operations. Max/Min temperatures Pinedale: 21/-4 Rock Springs: 27/11 Lander: 37/11 South Pass: 27/7 Observed ODC: 0	No ground-based seeding was conducted.
24 December 2018, Monday	
Broken low clouds over the SW slopes during the afternoon and evening with scattered flurries. Thicker, widespread clouds moved in during the night with light snowfall. The radiometer detected LW throughout the night, but the wind was not favorable for seeding operations.	No ground-based seeding was conducted.

Max/Min temperatures Pinedale: 30/7 Rock Springs: 32/19 Lander: 42/14 South Pass: 28/18 Observed ODC: 0	
25 December 2018, Tuesday	
Widespread light snowfall over western WY and a good portion of the entire state from the morning until after midnight. The wind flow was not favorable for seeding operations. Max/Min temperatures Pinedale: 28/10 Rock Springs: 35/20 Lander: 29/18 South Pass: 23/19 Observed ODC: 0	No ground-based seeding was conducted.
26 December 2018, Wednesday	
Shallow low clouds over the SE part of the range for most of the afternoon. The clouds did not fully cover the range. Areas of high and mid-level clouds moved in overnight. Max/Min temperatures Pinedale: 27/-6 Rock Springs: 24/3 Lander: 26/19 South Pass: 21/10 Observed ODC: -1	No ground-based seeding was conducted.
27 December 2018, Thursday	
Low clouds existed over parts of the range from the midafternoon through the evening with areas of light snowfall. Thick stratus moved in from the south during the evening and covered the land around the range with light snowfall in Pinedale through the night; but only minimal cloud coverage was over the range. The wind was not favorable for seeding operations. Max/Min temperatures Pinedale: 18/-6 Rock Springs: 14/-2 Lander: 22/14 South Pass: N/A Observed ODC: 0	No ground-based seeding was conducted.
28 December 2018, Friday	
Thick stratus around the range and the southern edge slowly diminished throughout the afternoon but some areas remained into the evening hours. The top of the range remained clear during this time. High and mid-	No ground-based seeding was conducted.

level clouds began moving into the area during the night. Max/Min temperatures Pinedale: 16/-9 Rock Springs: 16/3 Lander: 20/4 South Pass: 9/1 Observed ODC: -1	
29 December 2018, Saturday	
Morning low-layer stratus mixed out by midday, though broken shallow orographic clouds lingered over the range. Scattered mid and upper level clouds were also observed. Deeper cloud with synoptic scale light snowfall began in the late overnight hours and had persisted into the morning. An inversion developed overnight across the valley and inhibited any seeding opportunities. Max/Min temperatures Pinedale: 23/-15 Rock Springs: 21/0 Lander: 32/-5 South Pass: 28/1 Observed ODC: 0	No ground-based seeding was conducted.
30 December 2018, Sunday	
Thick orographic clouds were present throughout the morning and afternoon hours. A weak low level inversion was present over PNA and for some of the lower elevation generators sites. Cloud conditions were suitable for seeding, but only a handful of generator sites had favorable trajectories due to the presence of the inversion. Seeding begin at 17:25Z with WR01 and WR12, and WR02 and WR03 were added later. Seeding continued until the winds became more northerly and plume trajectories were no longer favorable. Flow shifted to northeasterly late in the period, and widespread snowfall continued through the night, but winds were not favorable for seeding for the remainder of the period. Max/Min temperatures Pinedale: 27/1 Rock Springs: 32/13 Lander: 42/19 South Pass: 25/10 Observed ODC: +1	Seeding event WRR0082 was called at 1022 MST on 12/30/2018 and began at 1025 MST. **WRR0082 Summary:** Generators: WR01, WR02, WR03, WR12 WR01, WR12 Time: 1025 (12/30) to 1629 (12/30) MST 1725 (12/30) to 2329 (12/30) UTC WR02, WR03 Time: 1156 (12/30) to 1629 (12/30) MST 1856 (12/30) to 2329 (12/30) UTC Duration: 21:14 Total Time Seeding Material: 9.3 gallons (531 grams)
31 December 2018, Monday	
Thick clouds with snowfall persisted on the NE side of the range from the morning into the evening hours. There were periods of moderate to heavy snowfall in	No ground-based seeding was conducted.

Lander, while the top of the range had very limited cloud coverage. The sky cleared during the evening allowing for temperatures to get very cold. Max/Min temperatures Pinedale: 19/-18 Rock Springs: 14/-8 Lander: 19/-3 South Pass: 10/-4 Observed ODC: -1	
01 January 2019, Tuesday	
Clear skies except for a few periods of thin high clouds until Wednesday morning when a few mid-level clouds moved into the area. Bitter cold temps over the lowlands with a strong inversion due to warming aloft as seen by the warmer temps at South Pass. Official PNA temperature was not available but the radiometer showed a morning low of -25°F and a high around 0F. Max/Min temperatures Pinedale: N/A Rock Springs: 6/-11 Lander: 4/-15 South Pass: 23/-4 Observed ODC: -2	No ground-based seeding was conducted.
02 January 2019, Wednesday	
A few areas of high and mid-level clouds during the morning gave way to clear skies for the afternoon and evening and most of the night. A few high and mid-level clouds moved in again just before sunrise Thursday morning. Another day with a strong inversion over the area and much warmer temps at South Pass. Max/Min temperatures Pinedale: N/A Rock Springs: 17/-3 Lander: 9/-17 South Pass: 37/19 Observed ODC: -2	No ground-based seeding was conducted.
03 January 2019, Thursday	
Areas of thick mid-level clouds during the morning through the midafternoon. Cloud bases were above the peaks and no low clouds developed. Arch clouds existed for a few hours around sunset and then formed again during the night. The temperatures were warmer over SW WY than the previous days. Max/Min temperatures Pinedale: N/A Rock Springs: 31/12 Lander: 18/-5	No ground-based seeding was conducted.

South Pass: 45/32 Observed ODC: -2	
04 January 2019, Friday	
A few areas of mid-level clouds from the morning to the midafternoon, then widespread clouds spread over the area just before sunset and lasted through the evening. A few clouds lingered for most of the night but it was mostly clear by sunrise. Max/Min temperatures Pinedale: N/A Rock Springs: 33/14 Lander: 26/5 South Pass: 39/23 Observed ODC: -2	No ground-based seeding was conducted.
05 January 2019, Saturday	
Mid-level cloud coverage increased throughout the day, becoming continuous by late afternoon. Widespread cloud coverage continued the rest of the period. Light snowfall began over the range during the evening and continued through the night. The temperature cooled after midnight, and the wind flow was favorable for seeding. Max/Min temperatures Pinedale: N/A Rock Springs: 32/7 Lander: 27/8 South Pass: 36/28 Observed ODC: +1	Seeding event WRR0083 was called at 0140 MST on 1/6/2019 and began at 0147 MST. **WRR0083 Summary:** Generators: WR01, WR02, WR03, WR09, WR10, WR12 Time: 0147 (1/6) to 1557 (1/6) MST 0847 (1/6) to 2257 (1/6) UTC Duration: 14:10, 84:34 Total Time Seeding Material: 35.80 gallons (2114.5 grams)
06 January 2019, Sunday	
Orographic cloud coverage with light snowfall over the range continued from Saturday until the late afternoon, when the wind shifted to the NW. There was minimal cloud coverage during the evening and the night until widespread clouds with light snowfall moved into the area after 09Z. Favorable seeding conditions developed again before 11Z. Max/Min temperatures Pinedale: N/A Rock Springs: 33/16 Lander: 43/18 South Pass: 28/18 Observed ODC: +2	Seeding event WRR0083 continued until 1557 MST on 1/06/2019.
07 January 2019, Monday	
Thick orographic cloud coverage over the range during the morning with favorable seeding conditions. The clouds thinned out quickly after noon as the wind became more NW. A few mid-level clouds were around the late afternoon and early evening then clear skies	Seeding event WRR0084 was called at 0340 MST on 1/07/2019 and began at 0344 MST. **WRR0084 Summary:** Generators: WR01, WR02, WR03, WR04, WR05, WR09,

for the rest of the period. Max/Min temperatures Pinedale: N/A Rock Springs: 32/15 Lander: 39/15 South Pass: 23/12 Observed ODC: +1	WR12 WR01, WR02, WR03, WR04, WR05, WR12 Time: 0344 (1/7) to 1257 (1/7) MST 1044 (1/7) to 1957 (1/7) UTC WR09 Time: 0403 (1/7) to 1256 (1/7) MST 1103 (1/7) to 1956 (1/7) UTC Duration: 61:44 Total Time Seeding Material: 25.81 gallons (1543.25 grams)
08 January 2019, Tuesday	
Clear skies in the morning saw thin high clouds move in during the afternoon. Mid-level clouds came in by the late evening, becoming fairly thick during the nighttime hours for a short period. The clouds were thinning by sunrise Wednesday morning. Max/Min temperatures Pinedale: N/A Rock Springs: 30/17 Lander: 30/5 South Pass: 39/18 Observed ODC: -2	No ground-based seeding was conducted.
09 January 2019, Wednesday	
Thin high clouds were around throughout the afternoon and evening hours. Areas of mid-level clouds moved in during the night and continued into Thursday morning. Max/Min temperatures Pinedale: 30/1 Rock Springs: 29/16 Lander: 31/11 South Pass: 37/25 Observed ODC: -2	No ground-based seeding was conducted.
10 January 2019, Thursday	
Thin low clouds existed over the range and the low lands to the south from the early afternoon into the mid evening hours, with very limited snowfall and unfavorable wind flow. Fog and shallow stratus clouds remained over the lowlands through the night into Friday morning. A band of snowfall moved through north of the range during the night covering the northern slopes as well. The wind was northerly but not favorable for seeding. Max/Min temperatures Pinedale: 27/0	No ground-based seeding was conducted.

Rock Springs: 28/10 Lander: 32/9 South Pass: 36/28 Observed ODC: 0	
11 January 2019, Friday	
Widespread low clouds over the northern slopes and the northern lowlands diminished during the morning hours. Fog was also over the southern lowlands in the morning. A few isolated low clouds existed over the range for a portion of the afternoon, then the sky was clear the rest of the period, except for areas of fog again in the evening and night. Max/Min temperatures Pinedale: 23/-4 Rock Springs: 31/12 Lander: 35/15 South Pass: 30/23 Observed ODC: -1	No ground-based seeding was conducted.
12 January 2019, Saturday	
The range was mostly clear throughout the period. Patches of fog were observed to the south and east of the range overnight, but not over the slopes of the target area. Max/Min temperatures Pinedale: 18/-15 Rock Springs: 17/2 Lander: 21/0 South Pass: 32/23 Observed ODC: -3	No ground-based seeding was conducted.
13 January 2019, Sunday	
Clear skies except for one area of mid-level clouds that moved over the eastern part of the range from the NE around sunset. Those clouds only existed for a short period. Cold temperatures in the low lands as a strong inversion existed over the area, as seen by the significant difference between PNA/LND and South Pass. Max/Min temperatures Pinedale: 10/-18 Rock Springs: 12/1 Lander: 14/-5 South Pass: 34/25 Observed ODC: -2	No ground-based seeding was conducted.
14 January 2019, Monday	
Clear skies during the daylight hours. A few high clouds started coming into the area during the evening and then widespread mid-level clouds pushed in from the south just before sunrise. Strong low level inversion	No ground-based seeding was conducted.

again, with a 49 degree (F) difference between South Pass and Pinedale in the morning. Max/Min temperatures Pinedale: 19/-17 Rock Springs: 7/-6 Lander: 19/-2 South Pass: 36/23 Observed ODC: -2	
15 January 2019, Tuesday	
A band of mid-level clouds passed through during the morning hours. There was a brief period of low clouds over the range during the early afternoon but little to no snowfall occurred. High and mid-level clouds were around during the evening and overnight. Thin, low clouds developed shortly before sunrise Wednesday morning with little to no snowfall again. Max/Min temperatures Pinedale: 18/-18 Rock Springs: 9/-5 Lander: 22/0 South Pass: 32/14 Observed ODC: 0	No ground-based seeding was conducted.
16 January 2019, Wednesday	
Cloud coverage over the range thickened throughout the morning hours, with favorable seeding conditions occurring for a few hours during the afternoon. Thin, low clouds with areas of light snowfall continued over the range during the evening and the night, but the wind was not favorable for seeding. Widespread thick clouds and snowfall moved in during the later nighttime hours, but the wind was unfavorable for seeding. Max/Min temperatures Pinedale: 23/3 Rock Springs: 30/8 Lander: 25/6 South Pass: 32/19 Observed ODC: +1	Seeding event WRR0085 was called at 1240 MST on 1/16/2019 and began at 1244 MST. **WRR0085 Summary:** Generators: WR01, WR02, WR03, WR12 Time: 1243 (1/16) to 1606 (1/16) MST 1943 (1/16) to 2306 (1/17) UTC Duration: 3:23, 13:31 Total Time Seeding Material: 5.95 gallons (337.75 grams)
17 January 2019, Thursday	
Deep cloud layers were observed through the evening with only minimal SLW. Widespread snowfall occurred throughout the day and into the evening hours, and then cloud layers became thinner and broken at times overnight. Plume trajectories, SLW, and temperatures were not favorable for seeding, and a low level inversion was present. Max/Min temperatures Pinedale: 32/14	No ground-based seeding was conducted.

Rock Springs: 35/16 Lander: 37/10 South Pass: 32/19 Observed ODC: 0	
18 January 2019, Friday	
Waves of high and mid-level clouds existed from the morning into the early evening hours. There were some periods of low clouds over the range during the afternoon but no significant coverage. The sky was mostly clear from the mid evening until closer to sunrise, when widespread high clouds moved back into the area. Shallow low clouds developed over the range Saturday morning. Max/Min temperatures Pinedale: 32/9 Rock Springs: 30/20 Lander: 40/20 South Pass: 28/21 Observed ODC: -1	No ground-based seeding was conducted.
19 January 2019, Saturday	
Shallow low clouds over the range during the morning quickly diminished in the early afternoon. Periods of high clouds and a few mid-level existed throughout the period. Shallow, low clouds moved into the area from the west just before sunset, but accumulating snowfall didn't begin until late evening then continued through the night. The temperature and wind flow were not favorable for seeding operations. Max/Min temperatures Pinedale: 32/0 Rock Springs: 32/15 Lander: 42/15 South Pass: 32/16 Observed ODC: 0	No ground-based seeding was conducted.
20 January 2019, Sunday	
Shallow low clouds over the range in the morning mostly diminished in the early afternoon. Multiple cloud layers continued the rest of the afternoon. Widespread, thick clouds moved in by late evening. Light snowfall occurred over the range during the night. The wind flow was not favorable for seeding and with the deep system, little to no SLW existed. Max/Min temperatures Pinedale: 34/19 Rock Springs: 35/21 Lander: 46/19 South Pass: 32/21 Observed ODC: 0	No ground-based seeding was conducted.

21 January 2019, Monday	
Widespread thick clouds over western WY with light to moderate snowfall during the morning and afternoon. The wind was not favorable for seeding and little to no SLW existed. The clouds moved off to the east during the evening but shallow low clouds lingered over part of the range for most of the night. Max/Min temperatures Pinedale: 30/19 Rock Springs: 32/19 Lander: 33/19 South Pass: 30/14 Observed ODC: 0	No ground-based seeding was conducted.
22 January 2019, Tuesday	
A few low clouds lingered over the SE part of the range until a little after noon. High clouds started to move into the area during the midafternoon and continued for the rest of the period. Widespread, deep clouds moved into western WY from the NW during the night with some areas of light snowfall beginning a little before sunrise. The wind was not favorable for seeding operations. Max/Min temperatures Pinedale: 21/3 Rock Springs: 19/12 Lander: 27/11 South Pass: 19/12 Observed ODC: 0	No ground-based seeding was conducted.
23 January 2019, Wednesday	
Periods of low clouds with a few light snow showers were observed across the valley Wednesday afternoon. Stratus clouds, potentially with light orographic enhancement, were also observed in the range, but winds were not remotely suitable for seeding and overall orographic cloud coverage was limited. Skies were mostly clear overnight, with patchy fog developing and persisting into the morning. Max/Min temperatures Pinedale: 24/0 Rock Springs: 24/12 Lander: 34/12 South Pass: 30/5 Observed ODC: -1	No ground-based seeding was conducted.
24 January 2019, Thursday	
Low stratus and orographic clouds developed over much of western WY during the midafternoon and continued for most of the evening. Snowfall was limited and little to no SLW existed. The wind flow was	No ground-based seeding was conducted.

not favorable for seeding operations. Cloud coverage cleared overnight. Max/Min temperatures Pinedale: 27/3 Rock Springs: 28/14 Lander: 27/10 South Pass: 27/10 Observed ODC: 0	
25 January 2019, Friday	
Periods of light snowfall were observed for the first half of the period along with waves of high and midlevel cloud layers. Orographic clouds were marginal with limited SLW due to northwest wind flow parallel to the range. Partial clearing occurred overnight, and then a wave of upper clouds pushed through again Saturday morning, clearing by late morning. Plume trajectories and orographic cloud coverage were unfavorable for operations, and no seeding occurred. Max/Min temperatures Pinedale: 28/1 Rock Springs: 26/17 Lander: 29/7 South Pass: 28/16 Observed ODC: 0	No ground-based seeding was conducted.
26 January 2019, Saturday	
Clear skies during the afternoon. A few high clouds passed through during the evening, then more high cloud coverage overnight. Areas of mid-level clouds began shortly before sunrise and increased Sunday morning. Max/Min temperatures Pinedale: 30/9 Rock Springs: 29/17 Lander: 42/11 South Pass: 30/14 Observed ODC: -2	No ground-based seeding was conducted.
27 January 2019, Sunday	
Scattered, small low clouds were over the peaks of the range for most of the afternoon. Snowfall moved over into the area from the north during the evening hours and continued through the night, tapering off Monday morning. The wind flow was not favorable for seeding operations. Max/Min temperatures Pinedale: 36/10 Rock Springs: 34/23 Lander: 48/19	No ground-based seeding was conducted.

South Pass: 36/19 Observed ODC: 0	
28 January 2019, Monday	
A small area of shallow low clouds lingered over the SE end of the range through the afternoon, diminishing in the early evening. Otherwise the sky was clear until some mid-level clouds passed through during the night. Max/Min temperatures Pinedale: 25/-4 Rock Springs: 27/11 Lander: 27/1 South Pass: 19/10 Observed ODC: -1	No ground-based seeding was conducted.
29 January 2019, Tuesday	
The sky was clear over the area throughout the period except for a wave of high clouds passing through from north to south during the evening. High clouds moved into the area again Wednesday morning. Max/Min temperatures Pinedale: 14/-11 Rock Springs: 24/6 Lander: 19/-3 South Pass: 27/12 Observed ODC: -3	No ground-based seeding was conducted.
30 January 2019, Wednesday	
Areas of high clouds were around until thick mid-level clouds moved through during the afternoon. The sky was clear by sunset. There were only a few periods of high clouds the rest of the period. Max/Min temperatures Pinedale: 27/-15 Rock Springs: 27/5 Lander: 19/-2 South Pass: 32/21 Observed ODC: -2	No ground-based seeding was conducted.
31 January 2019, Thursday	
Mostly clear except for a few periods of high or mid-level clouds. Max/Min temperatures Pinedale: 27/-6 Rock Springs: 33/16 Lander: 28/7 South Pass: 37/23 Observed ODC: -2	No ground-based seeding was conducted.
01 February 2019, Friday	

Skies were clear from afternoon through the evening. High and midlevel broken to overcast cloud layers overspread the region from the west starting around midnight and continued through Saturday morning. Marginal orographic clouds developed around 9z and became gradually thicker through the rest of the morning. Temperatures remained too warm for seeding throughout the period. Max/Min temperatures Pinedale: 27/-4 Rock Springs: 36/14 Lander: 33/12 South Pass: 34/23 Observed ODC: 0	No ground-based seeding was conducted.
02 February 2019, Saturday	
Orographic clouds covered the range throughout the day with waves of thicker mid-level clouds passing through. The snowfall was fairly inconsistent and mainly associated with the mid-level waves until becoming continuous after midnight. The temperature was warmer than the seeding threshold. Max/Min temperatures Pinedale: 30/1 Rock Springs: 39/10 Lander: 40/14 South Pass: 34/28 Observed ODC: 0	No ground-based seeding was conducted.
03 February 2019, Sunday	
Orographic clouds were over the range throughout the entire period. Southwest wind flow was favorable for cross barrier flow throughout the day as well. The heaviest snowfall occurred in the late morning and overnight hours, with some light periods during the afternoon and evening. The temperature was too warm for seeding until the early afternoon, then remained cool enough the rest of the period. Max/Min temperatures Pinedale: 34/12 Rock Springs: 36/21 Lander: 46/24 South Pass: 32/25 Observed ODC: +2	Seeding event WRR0086 was called at 1245 MST on 2/03/2019 and began at 1244 MST. **WRR0086 Summary:** Generators: WR01, WR02, WR03, WR04, WR05, WR09, WR10, WR12, WR13 WR10, WR13 Time: 1247 (02/03) to 2130 (02/04) MST 1947 (02/03) to 0430 (02/05) UTC WR01, WR02, WR03, WR04, WR05, WR09, WR12 Time: 1247 (02/03) to 1927 (02/05) MST 1947 (02/03) to 0227 (02/06) UTC Duration: 401:04 Total Time Seeding Material: 172.44 gallons (10,026.75 grams)
04 February 2019, Monday	
Continued strong SW flow with good moisture allowed for orographic cloud coverage to persist over the range throughout the day. Snowfall was continuous, though	Seeding event WRR0086 continued throughout the day.

there were heavier periods. The temperature was fairly steady just a little cooler than the seeding threshold and a high amount of SLW was expected. Max/Min temperatures Pinedale: 30/14 Rock Springs: 36/22 Lander: 40/12 South Pass: 27/23 Observed ODC: +2	
05 February 2019, Tuesday	
Continued orographic cloud coverage over the range through the afternoon with favorable seeding conditions. The conditions were weakening by late afternoon and the snowfall tapered off in the early evening hours. Widespread, thick cloud coverage moved into the area a little before sunrise with light snowfall increasing in coverage Wednesday morning. Max/Min temperatures Pinedale: 28/1 Rock Springs: 31/18 Lander: 40/15 South Pass: 27/12 Observed ODC: +2	Seeding event WRR0086 continued until 1927 MST on 2/05/2019.
06 February 2019, Wednesday	
Widespread light snowfall spread over the region during the morning and continued through the afternoon. The system pulled away in the early evening with mid-level clouds continuing the rest of the evening and overnight. A few waves of light snowfall passed through during the night. The wind was not favorable for seeding operations and little to no SLW existed. Max/Min temperatures Pinedale: 18/0 Rock Springs: 20/-1 Lander: 15/-4 South Pass: 18/1 Observed ODC: 0	No ground-based seeding was conducted.
07 February 2019, Thursday	
The return of very cold air to the region. Shallow, small low clouds were over the SW slopes of the range slowly decreasing throughout the afternoon. The clouds were mostly gone by sunset. The sky was clear until thin high clouds moved in from the west around sunrise. Max/Min temperatures Pinedale: 10/-24 Rock Springs: 13/-3	No ground-based seeding was conducted.

Lander: 11/-8 South Pass: 9/-2 Observed ODC: -1	
08 February 2019, Friday	
Waves of multiple cloud layers passed through the region throughout the day. There were periods of thicker low clouds with flurries from the late afternoon through the evening, but no continuous coverage. Shallow low clouds existed over the range during the night, but no measurable snowfall occurred from these clouds. The clouds diminished after sunrise. Max/Min temperatures Pinedale: 9/-24 Rock Springs: 11/-4 Lander: 14/-11 South Pass: 21/-4 Observed ODC: -1	No ground-based seeding was conducted.
09 February 2019, Saturday	
High to midlevel clouds increased during the afternoon, and then low level clouds developed for the evening and overnight hours. Wind direction was not suitable, and orographic clouds coverage was not sufficient for seeding operations. Some light snowfall occurred in the evening and overnight, but most of the snow came from midlevel forcing with minimal SLW in the low levels. Max/Min temperatures Pinedale: 16/-18 Rock Springs: 21/-8 Lander: 15/-2 South Pass: 19/9 Observed ODC: 0	No ground-based seeding was conducted.
10 February 2019, Sunday	
Thick orographic graphic clouds with SLW were present during the afternoon and evening. A cold front moved through from west to east during the late evening bringing an end to the favorable wind direction just before midnight. A low level inversion made targeting a big tricky with some of the northern and/or lower elevation generators having poor plume trajectories. These were not ignited. Clouds diminished overnight with only thin spotty orographic clouds over the peaks by morning. Max/Min temperatures Pinedale: 23/-6 Rock Springs: 28/-3 Lander: 14/1 South Pass: 21/14	Seeding event WRR0087 was called at 1400 MST on 2/10/2019 and began at 1410 MST. **WRR0087 Summary:** Generators: WR01, WR02, WR03, WR04, WR05, WR12 Time: 1410 (2/10) to 2212 (2/10) MST 2110 (2/10) to 0512 (2/11) UTC Duration: 8:02, 43:04 Total Time Seeding Material: 18.62 gallons (1,076.5 grams)

Observed ODC: +2	
11 February 2019, Monday	
Thick mid-level clouds spread over the area during the early afternoon with thin, low clouds developing over the range during the afternoon as well. There were some flurries, but no consistent snowfall and the wind was not favorable for seeding operations. These clouds continued until the middle of the night before diminishing. Only a few shallow clouds remained by Tuesday morning. Max/Min temperatures Pinedale: 18/-11 Rock Springs: 16/5 Lander: 29/4 South Pass: 18/1 Observed ODC: 0	No ground-based seeding was conducted.
12 February 2019, Tuesday	
High and mid-level cloud coverage increased during the afternoon and widespread overcast conditions continued until after midnight. Low clouds developed over the range during the night with areas of light snowfall. The wind flow was not favorable for seeding operations. Max/Min temperatures Pinedale: 14/-11 Rock Springs: 24/6 Lander: 34/5 South Pass: 25/1 Observed ODC: 0	No ground-based seeding was conducted.
13 February 2019, Wednesday	
Snowfall over the range increased during the morning hours as the wind became more favorable for seeding operations. Continuous snowfall with favorable seeding conditions continued until Thursday morning. At that time, the wind was becoming west-northwesterly and the temperature was warming above the seeding threshold. Max/Min temperatures Pinedale: 32/7 Rock Springs: 28/13 Lander: 43/19 South Pass: 27/21 Observed ODC: +2	Seeding event WRR0088 was called at 1042 MST on 2/13/2019 and began at 1051 MST. **WRR0088 Summary:** Generators: WR01, WR02, WR03, WR09, WR12 Time: 1051 (2/13) to 0626 (2/14) MST 1751 (2/13) to 1326 (2/14) UTC WR04, WR05, WR10 Time: 1710 (2/14) to 0626 (2/14) MST 0010 (2/14) to 1326 (2/14) UTC Duration: 118:34 Total Time Seeding Material: 49.45 gallons (2,964 grams)
14 February 2019, Thursday	
Thin, shallow low clouds were over the range from the late morning through the midafternoon. Widespread thick clouds with snowfall moved over the area during the later afternoon hours and continued through most	No ground-based seeding was conducted.

of the night. The wind was favorable for seeding but the temperature was warmer than the seeding threshold. The wind shifted to NW a little before sunrise and the snowfall diminished. Max/Min temperatures Pinedale: 34/23 Rock Springs: 38/27 Lander: 42/21 South Pass: 36/27 Observed ODC: 0	
15 February 2019, Friday	
Low clouds began moving towards the range during the early afternoon but didn't cover the range until the late afternoon. Favorable seeding conditions existed for a few hours into the evening until a cold front moved through and the wind shifted to the NW. Widespread thick clouds continued through most of the night with areas of light snowfall. The clouds were moving away and diminishing by sunrise. Max/Min temperatures Pinedale: 32/16 Rock Springs: 37/20 Lander: 44/18 South Pass: 30/21 Observed ODC: +1	Seeding event WRR0089 was called at 1548 MST on 2/15/2019 and began at 1602 MST. **WRR0089 Summary:** Generators: WR01, WR02, WR03, WR04, WR05, WR09, WR10, WR12 Time: 1602 (2/15) to 2009 (2/15) MST 2302 (2/15) to 0309 (2/16) UTC Duration: 4:07, 33:03 Total Time Seeding Material: 14.46 gallons (825.75 grams)
16 February 2019, Saturday	
Scattered thin cloud coverage around the region during the afternoon and evening with some flurries. Areas of mid-level clouds were around during the evening and nighttime hours. Max/Min temperatures Pinedale: 21/-9 Rock Springs: 22/13 Lander: 33/16 South Pass: 21/12 Observed ODC: -1	No ground-based seeding was conducted.
17 February 2019, Sunday	
A cold air mass was in place over the region. Thin orographic and mountain wave clouds were present throughout the day. Overnight, low stratus and freezing fog surrounded the range while the cloud cover over the peaks diminished. By morning, skies became mostly clear. Clouds and temperatures were not suitable for seeding. Max/Min temperatures Pinedale: 18/-15 Rock Springs: 23/5	No ground-based seeding was conducted.

Lander: 21/7 South Pass: 19/5 Observed ODC: -1	
18 February 2019, Monday	
The range had small, thin patchy orographic clouds throughout the period along with some mountain wave clouds extending downwind of the crest at times. During the overnight hours, stratus and freezing fog surrounded the range, particularly on the east side. There were no clouds remotely suitable for seeding. Max/Min temperatures Pinedale: 12/-22 Rock Springs: 12/-1 Lander: 16/7 South Pass: 16/-2 Observed ODC: -1	No ground-based seeding was conducted.
19 February 2019, Tuesday	
Shallow low clouds were over the range throughout the day. Some flurries but no accumulating snowfall. Multiple cloud layers moved in during the evening and continued through the night into Wednesday morning. Max/Min temperatures Pinedale: 9/-27 Rock Springs: 12/-9 Lander: 20/4 South Pass: 12/0 Observed ODC: 0	No ground-based seeding was conducted.
20 February 2019, Wednesday	
Orographic cloud coverage with very limited snowfall over the range during the late morning and early afternoon diminished by late afternoon. However, light snowfall was observed in the lowlands south of the range from the midafternoon through most of the evening. Snow showers existed during the night. By Thursday morning, easterly flow developed snowfall on the north side of the range. Unfavorable wind flow precluded seeding operations throughout the period. Max/Min temperatures Pinedale: 14/-22 Rock Springs: 18/2 Lander: 24/0 South Pass: 12/-4 Observed ODC: 0	No ground-based seeding was conducted.
21 February 2019, Thursday	
Shallow clouds persisted on the north side of the range throughout the period, with LND reporting nearly constant light snowfall. There were waves of light snowfall over the range at times but no significant	No ground-based seeding was conducted.

coverage. Thicker, more widespread clouds moved in during the night with light snowfall in PNA as well during the night, but still only minimal snow over the range. The wind flow was not favorable for seeding operations. Max/Min temperatures Pinedale: 14/-18 Rock Springs: 14/3 Lander: 17/8 South Pass: 10/3 Observed ODC: 0	
22 February 2019, Friday	
The clouds from Thursday diminished during the morning but a very few low clouds existed over the southern portion of the range during the early afternoon hours. A few mid-level clouds passed through during the evening then more clouds come in during the night lasting into Saturday morning. Max/Min temperatures Pinedale: 19/-18 Rock Springs: 14/3 Lander: 21/2 South Pass: 19/3 Observed ODC: -1	No ground-based seeding was conducted.
23 February 2019, Saturday	
Clouds developed over the lowlands on the south side of the range by midafternoon but the range remained fairly clear until clouds moved down the range a little before sunset. Low clouds then remained over the range during the evening and overnight, but snowfall was limited and the wind flow was not favorable for seeding operations. Max/Min temperatures Pinedale: 18/-15 Rock Springs: 20/1 Lander: 31/0 South Pass: 18/9 Observed ODC: 0	No ground-based seeding was conducted.
24 February 2019, Sunday	
Low, orographic cloud coverage was over the range in the morning but snowfall was scattered. Favorable seeding conditions developed during the early afternoon and continued through the evening. After midnight, a low level inversion was forming, making seeding plume trajectories less than ideal. However, light snowfall continued over the range through the night.	Seeding event WRR0090 was called at 1433 MST on 2/24/2019 and began at 1451 MST. **WRR0090 Summary:** Generators: WR01, WR02, WR03 Time: 1438 (02/24) to 0118 (02/25) MST 2138 (02/24) to 0818 (02/25) UTC WR09, WR12

Max/Min temperatures Pinedale: 27/-8 Rock Springs: 31/13 Lander: 39/5 South Pass: 21/10 Observed ODC: +2	Time: 1438 (02/24) to 2347 (02/24) MST 2138 (02/24) to 0647 (02/25) UTC WR13 Time: 1438 (02/24) to 1822 (02/24) MST 2138 (02/24) to 0122 (02/25) UTC Duration: 53:46 Total Time Seeding Material: 23.99 gallons (1,344.25 grams)
25 February 2019, Monday	
Upslope flow with targetable orographic cloud cover was observed by midday Monday with favorable seeding conditions. Seeding continued through the afternoon and overnight hours, though the East Fork generator was shut down in the late evening as a shallow inversion was modeled to set in and inhibit appropriate plume transport. Favorable orographic cloudiness continued into Tuesday morning. Max/Min temperatures Pinedale: 32/21 Rock Springs: 36/17 Lander: 41/15 South Pass: 28/21 Observed ODC: +2	Seeding event WRR0091 was called at 1205 MST on 2/25/2019 and began at 1223 MST. **WRR0091 Summary:** Generators: WR01, WR02, WR03, WR09, WR12 Time: 1211 (02/25) to 1252 (02/26) MST 1911 (02/25) to 1952 (02/26) UTC WR10 Time: 1223 (02/25) to 2154 (02/25) MST 1923 (02/25) to 0454 (02/26) UTC Duration: 95:50 Total Time Seeding Material: 40.52 gallons (2,395.75 grams)
26 February 2019, Tuesday	
Seeding continued into the early afternoon. An early afternoon Pinedale sounding showed that temperatures had warmed beyond seeding limits. Thick orographic clouds with snowfall persisted throughout the entire period. While temperatures were suitable for seeding during the morning, they remained too warm for the afternoon and through the rest of the period. Max/Min temperatures Pinedale: 36/25 Rock Springs: 40/24 Lander: 49/16 South Pass: 32/27 Observed ODC: +1	Seeding event WRR0091 continued until 1252 MST on 2/26/2019.
27 February 2019, Wednesday	
Thick orographic cloud coverage continued over the range with snowfall and favorable wind flow through the afternoon, but the temperature was too warm for seeding operations. The wind became less favorable during the evening and snowfall tapered off. Thicker clouds moved in during the night with some areas of snowfall over the range, but the wind and temperature were not right for seeding operations.	No ground-based seeding was conducted.

Max/Min temperatures Pinedale: 32/21 Rock Springs: 38/22 Lander: 28/10 South Pass: 32/23 Observed ODC: 0	
28 February 2019, Thursday	
Thick orographic cloud coverage with light to moderate snowfall over the range continued through the mid evening hours. The temperature was too warm for seeding operations during that period. The snowfall was tapering off and the clouds thinning by late evening as the wind flow became less favorable. The low lands south of the range had snowfall during the morning and afternoon and at times during the evening. The sky was clear by sunrise Friday morning. Max/Min temperatures Pinedale: 32/18 Rock Springs: 38/27 Lander: 44/16 South Pass: 32/23 Observed ODC: 0	No ground-based seeding was conducted.
01 March 2019, Friday	
Clear skies until high and mid-level clouds moved in from the west during the midafternoon with those clouds continuing through the evening. Low clouds with areas of light snowfall formed around the region during the evening. These clouds existed over the range until the middle of the night, but shallow clouds and snowfall around the range persisted into Saturday morning. The wind was not favorable for seeding operations. Max/Min temperatures Pinedale: 27/3 Rock Springs: 31/21 Lander: 37/17 South Pass: 27/18 Observed ODC: 0	No ground-based seeding was conducted.
02 March 2019, Saturday	
Shallow low clouds were around the southern edge of the range during the morning and early afternoon. Mid-level clouds were over the area from midafternoon through the evening. A few areas of low clouds existed over the range for a short time during the night. A stratus deck developed over the lowlands south of the range during the night and continued into Sunday morning, diminishing by mid-morning. Max/Min temperatures	No ground-based seeding was conducted.

Pinedale: 28/-6 Rock Springs: 28/7 Lander: 27/3 South Pass: 18/-6 Observed ODC: -1	
03 March 2019, Sunday	
A few mid and low level clouds were around during the early afternoon hours, then clear skies until the later evening. Some mid-level clouds were around again in the late evening and most of the night, with some periods of light snowfall reported in PNA, but no significant coverage over the range. The region was clear by sunrise. Max/Min temperatures Pinedale: 12/-17 Rock Springs: 13/-6 Lander: 9/-2 South Pass: 7/-8 Observed ODC: -1	No ground-based seeding was conducted.
04 March 2019, Monday	
Clear skies during the daylight hours and the evening. A few areas of mid-level clouds existed for a short time during the night, then high clouds started coming into the area by sunrise. Max/Min temperatures Pinedale: 12/-18 Rock Springs: 14/-6 Lander: 18/-6 South Pass: 18/1 Observed ODC: -2	No ground-based seeding was conducted.
05 March 2019, Tuesday	
Broken mid-level clouds with bases above the range became scattered in the afternoon before low clouds drifted in around dusk. Light snow began in the late evening and continued until the predawn hours Wednesday. Low-level stability and apathetic upslope flow created inhospitable conditions for seeding for all ggen sites throughout the period. Max/Min temperatures Pinedale: 19/-24 Rock Springs: 25/-1 Lander: 26/-1 South Pass: 25/3 Observed ODC: 0	No ground-based seeding was conducted.
06 March 2019, Wednesday	
Overcast skies lowered with snow beginning in mid-afternoon across the region. Light to moderate snow continued through the evening, becoming more	No ground-based seeding was conducted.

scattered overnight. Temperatures, especially in the low levels above the surface, were mild and not hospitable for ground generator seeding; South Pass had the warmest high temperature in the region at 36 early Thursday afternoon. Low-level winds were also generally weak and variable. Max/Min temperatures Pinedale: 28/17 Rock Springs: 31/17 Lander: 31/15 South Pass: 36/21 Observed ODC: 0	
07 March 2019, Thursday	
Weak orographic flow produced shallow clouds over the range during the afternoon and early evening. Cloud bases were high and snowfall was very limited. Mid-level clouds moved in during the night with areas of snowfall beginning by sunrise but then diminished during the morning hours. PNA reported freezing fog during the night. Max/Min temperatures Pinedale: 36/21 Rock Springs: 37/25 Lander: 38/23 South Pass: 34/23 Observed ODC: 0	No ground-based seeding was conducted.
08 March 2019, Friday	
Widespread, broken cloud layers over the area from the morning through the evening, then the clouds moved away during the night. There was scattered light snowfall around the region with thin orographic clouds over the range during the afternoon. There was a period of thicker cloud coverage and steady snowfall during the midafternoon, but it was short lived with the wind weakening and becoming unfavorable by late afternoon. Max/Min temperatures Pinedale: 30/19 Rock Springs: 37/23 Lander: 33/22 South Pass: 30/21 Observed ODC: 0	No ground-based seeding was conducted.
09 March 2019, Saturday	
Small, shallow orographic clouds were over the peaks of the range during the afternoon but did not fully cover the range. Little to no snowfall occurred. Thin mid-level clouds moved in during the night.	No ground-based seeding was conducted.

Max/Min temperatures Pinedale: 23/-6 Rock Springs: 26/15 Lander: 34/18 South Pass: 19/12 Observed ODC: -1	
10 March 2019, Sunday	
Small, fair weather cumulus clouds scattered over the peaks of the range for most of the afternoon along with a few high clouds in the early afternoon. Clear skies the rest of the period. Max/Min temperatures Pinedale: 28/-8 Rock Springs: 34/13 Lander: 34/13 South Pass: 27/14 Observed ODC: -1	No ground-based seeding was conducted.
11 March 2019, Monday	
Some mid-level clouds moved through during the late afternoon hours and then a few again after midnight for a short time. Otherwise, the sky was clear. Max/Min temperatures Pinedale: 30/-4 Rock Springs: 33/17 Lander: 44/16 South Pass: 32/18 Observed ODC: -2	No ground-based seeding was conducted.
12 March 2019, Tuesday	
Clear skies until some high and mid-level clouds moved in by late afternoon, becoming more widespread during the evening. Thick, low clouds developed during the night with light snowfall beginning over the northern slopes a little before sunrise. The snowfall increased during Wednesday morning but the northerly wind flow was not favorable for seeding. Max/Min temperatures Pinedale: 30/-9 Rock Springs: 37/15 Lander: 48/21 South Pass: 36/23 Observed ODC: 0	No ground-based seeding was conducted.
13 March 2019, Wednesday	
Low overcast skies blanketed the valley the entire forecast period. Snow showers fell in the mountains through the day and into the overnight hours, but low-level winds were not favorable for seeding from any ground generator location. Conditions remained dry in Pinedale through the overnight hours, but light snow	No ground-based seeding was conducted.

began after midnight, with passing flurries continuing into the morning with persistent low stratus. Max/Min temperatures Pinedale: 34/25 Rock Springs: 28/19 Lander: 34/25 South Pass: 32/14 Observed ODC: 0	
14 March 2019, Thursday	
Thin overcast cloud cover was present early in the period with some small orographic clouds. Clouds gradually cleared throughout the afternoon except for some patchy isolated shallow cumulus during the afternoon. Some isolated pockets of stratus were observed overnight with otherwise clear conditions. No significant seedable orographic clouds were observed throughout the period. Max/Min temperatures Pinedale: 23/3 Rock Springs: 26/15 Lander: 34/17 South Pass: 23/10 Observed ODC: -1	No ground-based seeding was conducted.
15 March 2019, Friday	
A few isolated high clouds were around the area during the afternoon and then again during the night. Max/Min temperatures Pinedale: 32/0 Rock Springs: 28/12 Lander: 42/15 South Pass: 32/18 Observed ODC: -3	No ground-based seeding was conducted.
16 March 2019, Saturday	
Mostly clear skies. A few high clouds passed through during the evening, a short lived period of mid-level clouds around midnight, and then more high clouds beginning a little before sunrise continuing Sunday morning. Max/Min temperatures Pinedale: 28/-2 Rock Springs: 35/15 Lander: 44/19 South Pass: 36/21 Observed ODC: -2	No ground-based seeding was conducted.
17 March 2019, Sunday	
Widespread continuous high clouds streamed across the area throughout the period. A few thicker mid-level	No ground-based seeding was conducted.

clouds existed during the evening and nighttime hours. Max/Min temperatures Pinedale: 32/-4 Rock Springs: 37/16 Lander: 47/21 South Pass: 34/25 Observed ODC: -2	
18 March 2019, Monday	
Low clouds formed over the peaks of the range in the early afternoon and continued until after sunset. The clouds did not fully cover the range. A few mid-level clouds also existed during the evening until shortly after midnight. The sky was clear the rest of the night. Max/Min temperatures Pinedale: 32/3 Rock Springs: 35/18 Lander: 46/27 South Pass: 32/21 Observed ODC: -1	No ground-based seeding was conducted.
19 March 2019, Tuesday	
Clear skies with a very few, elevated clouds for a few hours in the early afternoon. There were very few clouds over the entire northern Rockies region under high pressure. Max/Min temperatures Pinedale: 30/-4 Rock Springs: 39/17 Lander: 49/25 South Pass: 32/21 Observed ODC: -2	No ground-based seeding was conducted.
20 March 2019, Wednesday	
Clear skies during the daylight hours. The first wave of upper level clouds moved in from the south during the evening then more after midnight. Some mid-level clouds had moved in just before sunrise. Max/Min temperatures Pinedale: 36/-4 Rock Springs: 43/18 Lander: 57/24 South Pass: 41/27 Observed ODC: -2	No ground-based seeding was conducted.
21 March 2019, Thursday	
Partly sunny skies were observed early in the period. High and midlevel cloud coverage increased throughout the afternoon, evening, and late night hours. Some stratus and patchy fog was observed overnight in the lowlands west of the range. Winds and	No ground-based seeding was conducted.

moisture were not favorable for significant orographic cloud development, and no noteworthy orographic clouds were observed. Temperatures remained too warm for seeding for most of the period. Max/Min temperatures Pinedale: 41/5 Rock Springs: 41/23 Lander: 56/26 South Pass: 41/32 Observed ODC: -1	
22 March 2019, Friday	
Partly cloudy skies were observed during the afternoon with orographic cumulus with bases generally above the peaks. A wave of overcast mid-level cloud moved in around sunset, but mostly clear skies returned by midnight. Clear skies were observed Saturday morning, though a few thin and very shallow stratus were seen hugging the northern end of the range. Max/Min temperatures Pinedale: 36/21 Rock Springs: 43/28 Lander: 50/33 South Pass: 32/27 Observed ODC: -1	No ground-based seeding was conducted.
23 March 2019, Saturday	
Low clouds developed over the range during the afternoon with minimal snowfall. The temperature was too warm for seeding operations. Broken mid-level clouds existed from late afternoon through the night. Low clouds were developing again Sunday morning. Max/Min temperatures Pinedale: 39/14 Rock Springs: 44/27 Lander: 58/28 South Pass: 37/30 Observed ODC: 0	No ground-based seeding was conducted.
24 March 2019, Sunday	
Broken widespread clouds covered the area from the morning through the evening. Thick low clouds existed during the afternoon and evening, with areas of precipitation. Rain was observed in PNA, and South Pass reported some thunder during the afternoon. The temperature was too warm for seeding operations during the afternoon then the wind switched to NW in the evening. The clouds moved away overnight except for a few areas lingering by morning. Max/Min temperatures	No ground-based seeding was conducted.

Pinedale: 36/21 Rock Springs: 46/28 Lander: 53/31 South Pass: 37/28 Observed ODC: 0	
25 March 2019, Monday	
Thin, high clouds moved into the area during the afternoon and periods of high clouds continued the rest of the period. Mid-level clouds existed for a short time around sunset. Arch clouds developed around midnight and persisted through the night. Max/Min temperatures Pinedale: 36/21 Rock Springs: 44/24 Lander: 56/32 South Pass: 36/25 Observed ODC: -2	No ground-based seeding was conducted.
26 March 2019, Tuesday	
Continuous high clouds were over the area from the morning through the afternoon and then cleared away in the early evening hours. More high clouds moved back into the area during the night. Max/Min temperatures Pinedale: 43/12 Rock Springs: 57/23 Lander: 64/31 South Pass: 45/28 Observed ODC: -2	No ground-based seeding was conducted.
27 March 2019, Wednesday	
High clouds from the morning continued into the afternoon. Thick, mid-level clouds with bases above the peaks developed during the afternoon. The overall coverage decreased during the evening, but then more high and mid-level clouds moved in overnight, continuing into Thursday morning. Max/Min temperatures Pinedale: 41/14 Rock Springs: 59/28 Lander: 66/34 South Pass: 45/32 Observed ODC: -2	No ground-based seeding was conducted.
28 March 2019, Thursday	
High based orographic clouds in the morning lowered shortly after noon, with a few areas of showers in the early afternoon hours. The clouds cleared for a few hours in the late afternoon but then more mid-level clouds moved in just before sunset. Coverage increased in the evening as a widespread storm moved	Seeding event WRR0092 was called at 0610 MDT on 2/29/2019 and began at 0614 MDT. **WRR0092 Summary:** Generators: WR07 Time: 0614 (3/29) to 1221 (3/29) MDT

in from the south. Snowfall developed during the night and the wind flow became favorable for seeding shortly before sunrise. Max/Min temperatures Pinedale: 37/27 Rock Springs: 50/31 Lander: 56/35 South Pass: 39/32 Observed ODC: +1	1214 (3/29) to 1821 (3/29) UTC Duration: 6:07 Total Time Seeding Material: 3 gallons (153 grams)
29 March 2019, Friday	
Widespread snowfall occurred throughout the day. Orographic clouds with favorable temperatures and light SLW were present during the morning. Winds and plume trajectories favored the Enterprise generator which was utilized for a few hours during the morning before the winds shifted, bringing an end to seeding. Snow showers continued through the night, but orographic cloud coverage and winds were not suitable for seeding overnight. Max/Min temperatures Pinedale: 34/27 Rock Springs: 33/23 Lander: 38/29 South Pass: 32/21 Observed ODC: +1	Seeding event WRR0092 continued until 1221 MDT on 3/29/2019.
30 March 2019, Saturday	
Skies were mostly clear over the mountains throughout the period except for a small patch of low cloud that was present for a couple hours overnight. Low stratus, fog, and some flurries were present over the lowlands on the west side of the range early in the period. Skies cleared partially during the afternoon, and then the low clouds in this area redeveloped overnight. There were no orographic clouds suitable for seeding. Max/Min temperatures Pinedale: 32/14 Rock Springs: 32/18 Lander: 37/21 South Pass: 28/14 Observed ODC: -1	No ground-based seeding was conducted.
31 March 2019, Sunday	
Clear skies during the afternoon until broken mid-level clouds moved in a little before sunset and continued until the middle of the night. Thin, low clouds developed over the range by late evening and persisted through the night, though they did not fully cover the range and little to no snowfall occurred.	No ground-based seeding was conducted.

Max/Min temperatures Pinedale: 36/7 Rock Springs: 44/16 Lander: 46/18 South Pass: 34/21 Observed ODC: -1	

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: WY201900510

[ ] INTERIM REPORT [X] FINAL REPORT

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

REPORTING PERIOD: FROM 12/01/2018 TO 03/31/2019

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		OTHER	AIRBORNE	GROUND	SILVER IODIDE	CARBON DIOXIDE	UREA	SODIUM CHLORIDE	OTHER
			HAIL	FOG								
JANUARY	3	3					159	4,110				
FEBRUARY	6	6					745	19,437				
MARCH	1	1					6	183				
APRIL												
MAY												
JUNE												
JULY												
AUGUST												
SEPTEMBER												
OCTOBER												
NOVEMBER												
DECEMBER	2	2					57	1,514				
TOTAL	12	12	0	0	0	0	968	25,244	0	0	0	0
TOTALS FOR FINAL REPORT	12	12	0	0	0	0	968	25,244	0	0	0	0

DATE ON WHICH FINAL WEATHER MODIFICATION ACTIVITY OCCURRED *(For Final Report only.)* 03/29/2019

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: Erin Fischer

AFFILIATION: Weather Modification International

SIGNATURE:

STREET ADDRESS: 3802 20th Street North

OFFICIAL TITLE: Client Services

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

DATE: 06/06/2019

Appendix C. Ice Nucleus Generator Operations Summary – 2018-2019

2018-2019 Generator Operations Summary - WIND RIVER RANGE

LAST UPDATED 20190401

GRAND TOTAL OPERATIONAL "SEED" HOURS=	968:44
Total Seeding Solution (Gallons)=	414.92

Monthly Totals	*159:46*	*154:05*	*136:06*	*87:58*	*90:01*	*6:07*	*132:42*	*50:58*	*140:30*	*10:31*	*968:44*	*968.73*
November sub-total											0:00	0.00
December sub-total	11:15	9:44	9:40	0:00	0:00	0:00	5:11	5:11	11:15	5:11	57:27	57.45
January sub-total	26:45	26:22	26:41	6:53	9:13	0:00	23:03	14:10	26:42	0:00	159:49	159.82
February sub-total	121:46	117:59	99:45	81:05	80:48	0:00	104:28	31:37	102:33	5:20	745:21	745.35
March sub-total	0:00	0:00	0:00	0:00	0:00	6:07	0:00	0:00	0:00	0:00	6:07	6.12
April sub-total	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0:00	0.00

UTC DATE	*WR01 Big Sandy*	*WR02 Block & Tackle*	*WR03 White Acorn*	*WR04 Sweetwater*	*WR05 Anderson*	*WR07 Enterprise*	*WR09 Boulder Lake*	*WR10 East Fork*	*WMI-WR12 Pocket Creek*	*WMI-WR13 Green River*	*DAILY TOTAL*		*Operation #*	*Solution Used (gallons)*
12/19/2018	5:11	5:11	5:07				5:11	5:11	5:11	5:11	36:13	36.22	WRR0081	15.58
12/30/2018	6:04	4:33	4:33						6:04		21:14	21.23	WRR0082	9.30
1/6/2019	14:10	13:46	14:08				14:10	14:10	14:10		84:34	84.57	WRR0083	35.80
1/7/2019	9:12	9:13	9:11	6:53	9:13		8:53		9:09		61:44	61.73	WRR0084	25.81
1/16/2019	3:23	3:23	3:22						3:23		13:31	13.52	WRR0085	5.95
2/3/2019	54:39	54:39	53:33	54:40	54:40		54:40	17:58	54:39	1:36	401:04	401.07	WRR0086	172.44
2/10/2019	8:03	8:02	8:00	7:59	8:02				2:58		43:04	43.07	WRR0087	18.62
2/13/2019	19:38	19:36	19:35	14:18	13:58		11:53		19:36		118:34	118.57	WRR0088	49.45
2/15/2019	4:08	4:08	4:07	4:08	4:08		4:08	4:08	4:08		33:03	33.05	WRR0089	14.46
2/24/2019	10:40	10:37	10:40				9:09		8:56	3:44	53:46	53.77	WRR0090	23.99
2/25/2019	24:38	20:57	3:50				24:38	9:31	12:16		95:50	95.83	WRR0091	40.52
3/29/2019						6:07					6:07	6.12	WRR0092	3.00