Mailing Address:
Water Resources Data System
University of Wyoming, Dept 3943
1000 E University Avenue
Laramie, WY 82071

Physical Address:
Wyoming Hall, Room 249
University of Wyoming
Laramie, WY 82071

Phone: (307) 766-6651
Fax: (307) 766-3785

Funding for WRDS and the creation of this electronic document was provided by the Wyoming Water Development Commission (http://wwdc.state.wy.us)

EXECUTIVE
SUMMARY

WYOMING • WIND RIVER RANGE
WEATHER MODIFICATION PROGRAM

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Wind
River

Mountain
Range

WEATHER MODIFICATION INTERNATIONAL

3802 20th Street N.
Fargo, ND 58102

WYOMING WATER DEVELOPMENT
COMMISSION

6920 Yellowtail Road
Cheyenne, WY 82002

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

EXECUTIVE SUMMARY

prepared by

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

for the

Wyoming Water Development Office
6920 Yellowtail Road
Cheyenne, Wyoming 82002

August 2017

BACKGROUND AND OVERVIEW

Atmospheric water transformed to precipitation is one of the primary sources of fresh water in the world. However, a large amount of water present in clouds never is converted into precipitation that makes it to the ground. This has prompted scientists and engineers to explore the possibility of augmenting water supplies by means of cloud seeding. From 2006 through the spring of 2014, cloud seeding operations in the Wind River Range were conducted within the context of the Wyoming Weather Modification Pilot Project (WWMPP). Eight of the ten ground-based cloud seeding generators used in that project were funded by the Wyoming State Legislature through the Wyoming Water Development Commission (WWDC). The two additional generators were funded by the Lower Colorado River Basin States.

Funding for cloud seeding operations in the Wind River Range for the winter of 2016-2017 was provided in part by the 2016 Wyoming State Legislature's "Omnibus Water Bill – Construction." The Wyoming State Legislature has mandated that the funding rate for the State will not exceed 25% of total project costs, leaving 75% of the project costs to be split among other Colorado River Basin water users, or interested parties. Funding partners in support of continued weather modification activities in the Wind River Mountains during the winter of 2016-2017 include the Southern Nevada Water Authority, the Central Arizona Project (CAP), and the Colorado River Board of California - Six Agency Committee.

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

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

Scientific Basis

Clouds in the lower troposphere form when, in cooling air, water vapor condenses upon cloud condensation nuclei (CCN), forming cloud droplets. After the formation of the cloud droplets, precipitation development in Wyoming winter storms occurs through the formation of ice. However, ice does not form spontaneously at temperatures colder than 32°F (0°C). In the absence of ice nuclei, water can become "supercooled" (SLW); meaning the water in the cloud remains in liquid form at temperatures well below 32°F (0°C). 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 freezing, but these substrates are largely absent in the free atmosphere.

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

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

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

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

FIELD RESOURCES

Figure 1 displays the ten seeding equipment sites used for the 2016-2017 project. 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 1, 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.

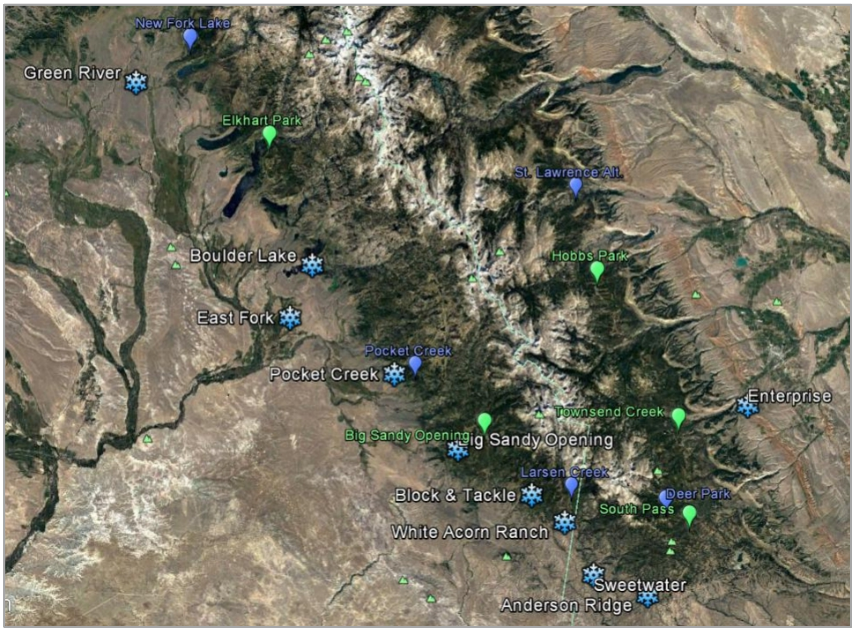

Figure 1. The locations of the ground-based ice nucleus generators are indicated by the snow crystal symbols. The green "balloons" indicate the locations of Natural Resources and Conservation Service (NRCS) snow telemetry (SNOTEL) sites used in monitoring snowpack during the 2016-2017 season. The blue balloons show the locations of additional SNOTELs that were not used because of proximity to sites that were used, or a short period of record (they were relatively new sites).

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.

Ice Nucleus Generators

The ice nucleus generators were designed and fabricated by WMI. The Wind River Range generators are fully independent, controlled via satellite, and powered by batteries charged by solar power. This provides the ability to site generators at higher elevations, significantly improving delivery of seeding agent to the clouds. Being remotely-controlled means that the generators can be activated and deactivated as weather conditions warrant. This results in less seeding agent being dispersed unnecessarily, as can occur with manually operated generators. All of the generator lines and fittings are made of corrosion-resistant stainless steel, necessary when high-performance seeding solutions, which contain oxidizers, are used. The generators are robust; designed to function in extreme temperatures, winds and precipitation.

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. The yield increases markedly from -6°C (+21.2°F) to -8°C (+17.6F), and even more at -10°C (+14°F). At a cloud temperature of -6°C, 3×10^{11} nuclei are active, 300,000,000,000, or 300 billion. Research studies provide the foundation for the design of operational programs. Operational programs in the western United States commonly commence seeding operations at -5 or -6°C. As in the previous two seasons, the 2016-2017 Wind River operations used a temperature criterion of -6°C at 700 hPa (about 10,000 feet above sea level).

Unlike simpler solutions that produce a pure AgI nucleus, this "high performance" solution also contains salt, which enables it to function by the condensation-freezing mechanism. 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.

Soundings

Weather balloons were released from the WMI shop, in Pinedale, WY to help determine whether or not weather conditions were suitable for seeding. 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.

Weather Stations

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

Shop and Field Site Servicing

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

FORECASTING AND OPERATIONAL DECISION-MAKING

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.

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

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

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 temperature seeding criterion was determined by consulting the most recent prognostic numerical modeling runs. When such consultation yielded uncertain results, that is, temperatures at 700 hPa not clearly -6°C or colder, a weather balloon sounding was released from the Pinedale, WY shop. The presence of SLW was confirmed by the real-time data from the radiometer located near Boulder, WY. The wind speed and direction were obtained from the numerical models, except when atmospheric soundings were done. When all three conditions were satisfied, seeding was initiated by the meteorologist and the generator technician. The meteorologist would communicate to the technician which generators would be activated, when, and for how long. The length of time a generator was activated depended upon how long weather conditions were expected to remain favorable. Once seeding was initiated, the meteorologist would begin tracking the real-time weather conditions that would impact seeding duration. If wind direction changed, some generators could be deactivated while others would be turned on. When favorable weather conditions ended, the technician would be directed to shut down all remaining active generators.

SEEDING OPERATIONS

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

For the first few weeks after the suspension, snowfall rates decreased and it appeared that the SWE might fall below the suspension threshold allowing operations to resume; however, such was not the case. Figure 2 illustrates the evolution of SWE during the season, with respect to the specific suspension criterion.

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

Table 3 shows the activity of each of the ten generators on a case-by-case basis. Each seeding event has two rows, the top indicates whether or not each generator was requested (REQ), and the bottom whether or not the generator ran (RAN). Ideally, every time a generator was requested it would run for the entire duration of the event. If a generator was requested to operate, a “Yes”, “No”, or “Partial” comment would be denoted in the appropriate (RAN) row.

As expected, the complexity of the generators and the extreme weather played a role in precluding perfection this season, as seen in Table 3, five red “NO”s, and five yellow “PARTIAL”s are documented. Only once did more than one generator fail completely in the same event; that occurred on 10 January 2017. Four generators ran perfectly all season: Block and Tackle, Boulder Lake, East Fork, and Pocket Creek. Sweetwater, White Acorn, and Anderson Ridge are located at the southern end of the range and were used less frequently than some of the others. Nevertheless, except for minor glitches experienced during the first seeding event of the season (4 December 2016), these generators also ran flawlessly through the season.

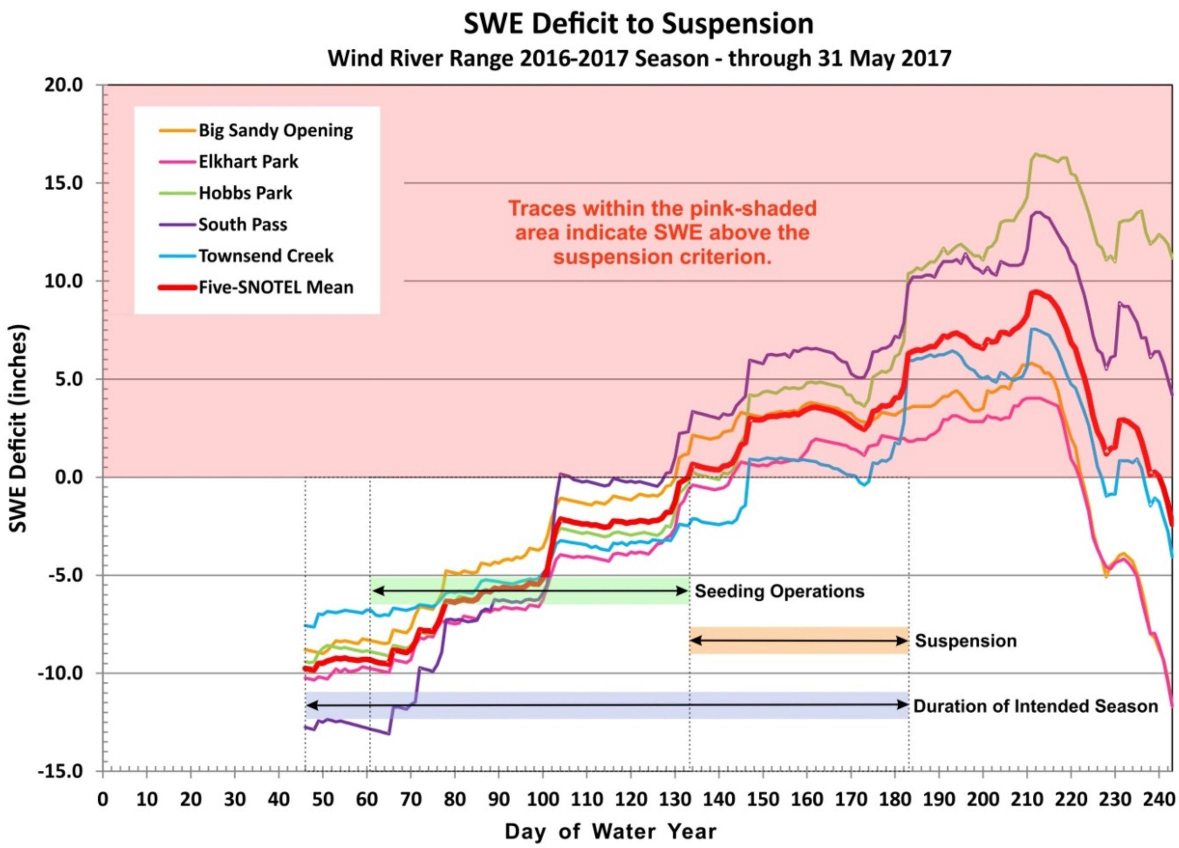

Figure 2. The accumulations of SWE at each of the five SNOTEL sites used (collectively) to determine when snowpack sufficient to warrant suspension of seeding operations are shown. Also shown is the five-SNOTEL mean (bold red), that serves as the actual determinant as to when to cease operations. The double-ended arrow highlighted in blue depicts the duration of the seeding season originally planned, from 15 November 2016 through 31 March 2017. The green-highlighted arrow shows the period of the season during which operations were conducted, from 30 November 2016 through 10 February 2017. Finally, the peach-highlighted arrow indicates the period of the season during which operations were suspended.

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

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

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

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

TABLE 2. Summary of Seeding Events During the 2016-2017 Winter Season					
		Event Averages		*Seeding Agent (kg)*	
Month	*Events ( ) denotes easterly flow*	*Number of Generators*	*Generator Hours**	*Average Released per Event*	*Total Released*
November	0	--	--	--	0.000
December	6	7.7	135.9	3.26	10.187
January	5	7.4	79.3	4.00	8.762
February	3	7.7	135.6	2.75	4.808
March	0	--	--	--	0.000
Totals/Averages	*14 (0)*	*7.6*	*257.8 / 42.9*	*1.012*	*31.553*
**generator hours = sum of the hours each generator was run for each event, e.g., 4 generators each operated for 3.5 hours = 14 generator hours.*					

TABLE 3. Ice nucleus generator operations are shown for each of the fourteen seeding events.

Wind River Range			WR01 Big Sandy	WR02 Block & Tackle	WR03 White Acorn	WR04 Sweetwater	WR05 Anderson	WR07 Enterprise	WR09 Boulder Lake	WR10 East Fork	WR12 Pocket Creek	WR13 Green River	#Ggens Called	#Ggens Active
20161204	*WRR0049*	*REQ*	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	NO	YES	PARTIAL	PARTIAL	PARTIAL	NO	YES	YES	YES	YES		6.5
20161209	*WRR0050*	*REQ*	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
20161212	*WRR0051*	*REQ*	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
20161214	*WRR0052*	*REQ*	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	NO	YES	YES	NO	NO	NO	YES	YES	YES	PARTIAL		5.5
20161224	*WRR0053*	*REQ*	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES		9
20161227	*WRR0054*	*REQ*	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
20170102	*WRR0055*	*REQ*	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES		9
20170102	*WRR0056*	*REQ*	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES		9
20170103	*WRR0057*	*REQ*	YES	YES	YES	NO	NO	NO	YES	NO	YES	YES	6	
		RAN	NO	YES	YES	NO	NO	NO	YES	NO	YES	YES		5
20170110	*WRR0058*	*REQ*	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES	4	
		RAN	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES		4
20170110	*WRR0059*	*REQ*	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	NO	YES	YES	YES	YES	NO	YES	YES	YES	NO		7
20170201	*WRR0060*	*REQ*	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
20170204	*WRR0061*	*REQ*	YES	YES	YES	YES	YES	NO	YES	YES	YES	YES	9	
		RAN	YES	YES	YES	YES	YES	NO	YES	YES	YES	PARTIAL		8.5
20170207	*WRR0062*	*REQ*	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	7	
		RAN	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES		7
												TOTALS	106	98.5
													RUN =	92.9%
													FAIL =	7.1%

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

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

Comparisons with Previous Seasons

Comparisons of the three seasons of operational cloud seeding are provided in Tables 4 and 5. In Table 4, the lengths of seeding operations in each month are provided. Each season was different, and no trends or tendencies can be identified. In terms of actual number of hours with seeding operations, the 2015-2016 season tops the list. However, if you were to compare the hours of seeding executed in each season, for only the three months that seeding was conducted in the 2016-2017 season, the results would show that the 2016-2017 season is far above the others, 74 hours more than the 2015-2016 season. A very large difference, and that, with two-thirds of February 2017 in suspension!

TABLE 4. Hours of Seeding

	Nov	***Dec***	***Jan***	***Feb***	***Mar***	***Apr***	***Season***
2014-2015	10:13	83:45	24:08	36:47	25:21	20:12	200:26
2015-2016	41:28	66:07	49:56	60:30	62:00	9:54	289:55
2016-2017	NA	120:22	63:12	58:53	SUSP	NA	242:27
Mean	25:50	90:04	45:45	52:03	43:40	15:03	244:16

The difference in the number of ice nucleus generators operation presents an even more striking result (Table 5). The abbreviated 2016-2017 season was 400 hours higher than either of the others, without even considering the differences in season lengths.

TABLE 5. Hours of Ice Nucleus Generator Operation

	Nov	***Dec***	***Jan***	***Feb***	***Mar***	***Apr***	***Season***
2014-2015	71:43	377:52	125:51	36:47	219:54	20:12	852:19
2015-2016	86:21	375:03	328:57	180:56	191:31	9:54	1172:42
2016-2017	NA	815:05	396:22	406:57	SUSP	NA	1618:24
Mean	79:02	522:40	283:43	208:13	205:42	15:03	1214:28

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

NUMERICAL MODELING

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

During the 2016-2017 season, meteorologist Dan Gilbert configured HYSPLIT for the Wind River Range and the generators network. The implementation of the HYSPLIT model was viewed as "another tool in the tool-box" that project forecasters found useful. Seeding agent plumes are predicted to move perpendicular to the range; however, it is apparent that the southernmost generators should not be utilized for this seeding event. The HYSPLIT model predicted that the southernmost plumes would not impact target area. The HYSPLIT model was operated as a surrogate for NCAR's high resolution WRF model, and used when the other available information provided insufficient guidance.

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

OUTREACH

Whenever possible, WMI likes to be receptive to requests to educate those showing an interest in our field efforts. As with previous seasons, WMI was approached by the Sublette County Conservation District (SCCD) during the 2016-2017 season to provide outreach regarding meteorological aspects of cloud seeding in the Wind River Range. WMI meteorologist, Dan Gilbert, and the SCCD arranged for local students to visit the WMI shop in Pinedale, WY and learn about the project and upper air soundings, and even to participate in the release of a weather balloon (Figure 3). WMI appreciates being asked to take part in this type of educational outreach, and has gladly conducted such events. It is important to WMI to be receptive to requests to educate those showing an interest in our weather modification efforts.

Figure 3. Pinedale pre-school students and parents watch their teacher prepare to release a weather balloon at the WMI shop during a public outreach event on 9 March 2017. Meteorologist Dan Gilbert (left, with orange parachute) assists, while the kids count down to the balloon release. (WMI photograph by Adam Brainard)

WMI also presented an update on the 2016-2017 Wind River operational seeding efforts at the Wyoming Weather Modification Technical Advisory Team (TAT) meeting held in Laramie, WY on 12 July 2017. The TAT, initially organized by the WWDO to provide technical advice and support for the WWMPP, is largely comprised of representatives of interested State and Federal agencies.

Wyoming agencies include the State Engineer's Office, the Department of Environmental Quality, the Department of Transportation, the University Office of Water Programs, and the Game and Fish Department. Federal agency representation includes several different forests (Bridger-Teton, Shoshone, and Medicine Bow), the U.S. Geological Service, the NWS Riverton and Cheyenne offices, the Bureau of Land Management, and the Natural Resources Conservation Service.

SUMMARY

The 2016-2017 cloud seeding effort in the Wind River Range began on 30 November 2016, and officially concluded on 31 March 2017, a duration of nearly 4 months. The season started two weeks later than normal (15 November) due to a delay in finalizing the collaborative weather modification agreements. The conclusion date of 31 March 2017 was planned as a measure to address funding constraints and keep the Wind River Range cloud seeding program up and running for the 2016-2017 winter season.

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

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

Interestingly, the Enterprise generator, sited on the eastern slope of the range near Lander, was not used during the 2016-2017 season. This was anomalous in that during previous seasons, operation of the Enterprise generator accounted for approximately one-third of all seeding events which occurred primarily early and later in the season. However, being that this season started two weeks late, and effectively ended (due to suspension) on 10 February, the opportunity for early- and late-season operations was absent.

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

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