5.2 OPERATIONAL ASPECTS OF THE WYOMING WEATHER MODIFICATION PILOT PROJECT: AN UPDATE

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1. INTRODUCTION

In the spring of 2005, the Wyoming Water Development Office (WWDO) of the State of Wyoming awarded Weather Modification, Inc. (WMI), a multi-year contract to conduct cloud seeding operations during successive winters in three specific mountainous areas within that state.

Though both airborne and ground-based seeding was specified, the exact design of the seeding operations was left to be determined by the National Center for Atmospheric Research (NCAR), Research Applications Laboratory (RAL), retained by the WWDO under independent contract for the program design and evaluation. The design was to utilize one aircraft, instrumented and equipped for seeding, and twenty-four remote-controlled ground-based ice nucleus generators.

The effort, dubbed the Wyoming Weather Modification Pilot Project (WWMPP) was planned to run for five consecutive winters beginning with the 2005-2006 season. Seeding was to be conducted beginning on 15 November, and ending after 31 March.

1.1 Target Areas

The Medicine Bow and Sierra Madre ranges in south-central Wyoming were specified by the WWDO as areas to be included in the WWMPP target, along with the Wind River Range in west-central Wyoming. The Medicine Bow and Sierra Madre ranges are both largely included in the Medicine Bow-Routt National Forest. The Wind River Range lies within the Bridger-Teton and Shoshone National Forests.

1.2 Involvement of Affected Agencies

From the program outset the WWDO consciously strove to include affected agencies in the program planning. A WWMPP technical advisory team was thus created. Team members include designated staff from the following:

- Bridger-Teton National Forest
- Medicine Bow-Routt National Forest
- Shoshone National Forest Natural Resources Conservation Service
- USDA Rocky Mountain National Forest Research Station, Fort Collins
- National Weather Service, Cheyenne
- National Weather Service, Riverton
- Bureau of Land Management
- U.S. Geological Survey
- University of Wyoming, Department of Atmospheric Science
- Wyoming Department of Environmental Quality
- Wyoming Department of Transportation
- Wyoming Game and Fish Department
- Wyoming State Engineer's Office

The Northern Arapahoe and Eastern Shoshone tribes of the Wind River Indian Reservation have also been invited to participate.

This stakeholder involvement encouraged active dialog from project inception. Though it is perhaps somewhat unusual for projects to actively engage affected agencies at both the State and Federal level, the author believes it has on the whole been very beneficial.

1.3 Project Deployment, 2005-2007

Early in the summer of 2005 efforts to secure sites for ground-based seeding facilities began in earnest, initially focusing on the Medicine Bow and Sierra Madre ranges in south-central Wyoming.

Because many of the most advantageous sites lie on federal lands (within the Medicine Bow-Routt National Forest), compliance with the National Environmental Policy Act (NEPA) was thus required. To facilitate this process, WMI retained the services of Greystone Environmental (now Arcadis, U.S.).

Because permits were not obtained in time for deployment of equipment during the winter of 2005-2006, field activities were limited to data collection efforts with the project aircraft (see Section 3), and very limited airborne seeding on a trial basis.

The ensuing environmental analysis required ten months, at an approximate cost of $150,000, in spite of the cooperation of the Forest Service. The intended project was advertised in the Federal Register and a 45-day public comment period ensued. In addressing the public comments and the concerns of the Forest, a 34-page biological assessment and a 130-page biological evaluation & management indicator species report resulted. The U.S. Fish and Wildlife Service was consulted regarding ten federally-listed threatened and endangered species.

In June of 2006, as the NEPA process was nearing completion for the Medicine Bow-Routt National Forest, an analogous application was submitted by WMI simultaneously to the Bridger-Teton and Shoshone National Forests, and to the Bureau of Indian Affairs (BIA), to initiate the same process for the Wind River Range.

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At the end of August 2006 the Medicine Bow-Routt National Forest issued a categorical exclusion for the project, and issued a permit for sixteen ground generator sites on the forest, any twelve of which could be used during each winter season. Deployment of ground-based seeding equipment in the Medicine Bow and Sierra Madre ranges began immediately in September, but early snows made access difficult. Nevertheless, by mid-December the first twelve ground-based ice nucleus generators had been deployed. An additional five ground-based generators had been deployed on state- and privately-owned lands around the southern perimeter of the Wind River Range.

Ground-based seeding trials were thus able to begin in all three ranges during the winter of 2006-2007 in spite of the late start, but the project statistical design for a randomized seeding program (NCAR) was still evolving.

During the 2006-2007 season, airborne seeding was conducted only over the southern end of the Wind River Range.

2. PERSONNEL & GROUND-BASED FACILITIES

The 2007-2008 field program marked the beginning of full-scale WWMPP operations. The WMI flight crew (pilot, copilot, and data system operator) was based in Rock Springs, Wyoming, as was a team of technicians who serviced ground-based facilities and the aircraft. The project's lead forecaster was also based in Rock Springs.

An additional pair of meteorologists was based between the Medicine Bow and Sierra Madre ranges, in Saratoga, along with one more technician. This crew serviced ground-based facilities sited in the Medicine Bow Range, released rawinsondes (Section 2.3), and serviced a microwave radiometer positioned to observe the atmosphere over and upwind of the Medicine Bow Range.

In addition, a senior meteorologist visited the field frequently, and also served as the aircraft flight scientist during ice nucleus detection flights (see Section 3.3).

Finally, another senior scientist was in the field near Centennial, Wyoming, throughout the month of February 2008, to operate a ground-based acoustical ice nucleus counter (see Section 2.5).

2.1 Ice Nucleus Generators

The ground-based ice nucleus generators deployed by WMI in the WWMPP are all remote-controlled units that utilize satellite communications to ensure reliable operation. In each, a 2% AgI solution is burned at a rate of approximately 1.5L (0.40 gallons) per hour. The solution is comprised of silver iodide, ammonium iodide, sodium perchlorate (monohydrate), para-dichloro-benzene and acetone, as described in DeMott (1997). The resulting aerosol functions by the condensation-freezing mechanism.

One of the generators, a unit deployed in the Medicine Bow Range, is shown in Figure 1.

Figure 1. A WMI remote-controlled generator is shown mid-season, January 2008. Buried beneath the snow are the propane and seeding solution tanks. The "triangle" atop the burner housing is a "perch guard", installed to discourage raptor nesting. Also below the snow is fencing to keep grazing animals away for the unit during the summer months. The total height of the assembly is 7.6 m (25 ft).

As the project statistical design neared completion, some ground-based facilities sited in the Medicine Bow and Sierra Madre ranges were realigned. Two seldom-used generators were relocated to more favorable positions, and four additional ground generators were added to those already deployed in each of the southern ranges, which brought the total number of units to eight for each of the two southern ranges (Figure 2).

In the Wind River Range, one site was also relocated for the 2007-2008 season, and four additional sites were added, bringing the total to nine (Figure 3). All except one are located so as to be functional in the climatologically-favored southwest flow.

This final generator (WR07, Figure 2), was sited on the eastern side of the range to test the feasibility of seeding when upslope easterly flow was present.

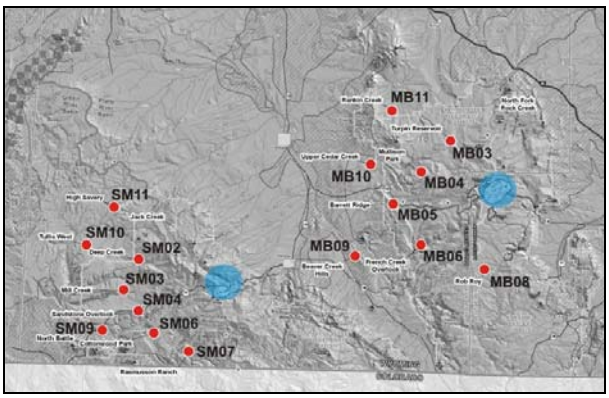

Figure 2. The locations of the ground-based ice nucleus generators for the Sierra Madre (left) and Medicine Bow (right) ranges, used in the 2007-2008 season. The generators are shown by red dots, and the approximate target locations as delineated by the NCAR statistical design by the blue dots.

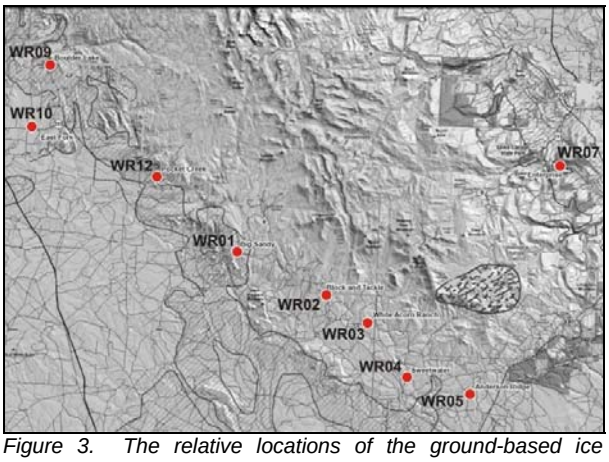

Figure 3. The relative locations of the ground-based ice nucleus generators around the perimeter of the southern end of the Wind River Range are shown, as operated in the 2007-2008 season. These generators were used "operationally", to seed whenever forecasters believed conditions to be favorable.

2.2 Microwave Radiometer

A scanning, dual-channel microwave radiometer was deployed and operated by WMI near the Upper Cedar Creek ground generator (MB10, Figure 1).

This unit measures total integrated atmospheric water vapor and liquid water along its beam path. Such instruments have been widely used to quantify the presence of liquid cloud water in orographic clouds (Boe and Super 1986, Rauber *et al*. 1986, Super and Boe 1988, Super and Holroyd 1989, Huggins 1995).

During the 2007-2008 season the unit was programmed to make measurements at 10, 12, 30, and 90 degrees elevation angles at three pre-determined azimuths that would intersect orographic clouds in southwesterly, westerly, and northwesterly winds.

Additional information about the use and utility of this radiometer is provided by a companion paper in this conference (Paper 6.3).

2.3 Upper Air Soundings

During the winter of 2005-2006, soundings were released by WMI staff from the Saratoga Municipal Airport, Shively Field (KSAA). These initial data provided more detailed information about the atmosphere between the Sierra Madre and Medicine Bow ranges.

In the subsequent winter, the soundings were released from Farson, Wyoming, just southwest (and often upwind) of the southern end on the Wind River Range.

The sounding release point was moved back to Saratoga for the 2007-2008 season. (Saratoga is seen as the light square west-northwest of MB10 in Figure 2.) In this most recent season soundings were taken whenever the project meteorologists believed that conditions came close to satisfying the criteria established by NCAR for declaration of "cases" for the randomized statistical experiment. A full description of the experimental design can be found in other papers by NCAR/RAL scientists (Paper 5.3 and Paper 6.1). This release strategy differed from the previous seasons, when at most one sounding was made in any given day.

Upon completion of the sounding (flight to 100 hPa, about one hour after release), the data were immediately forwarded to the Wyoming Water Resource Data System (WRDS), the National Weather Service offices in Cheyenne and Riverton, the University of Wyoming Atmospheric Science Department, and NCAR/RAL. All sounding data were collected using a Vaisala Digicora receiver and sondes.

2.4 Weather Data Acquisition

During the 2007-2008 season weather stations were co-located with six of the ground-based ice nucleus generators, two in each range. These Vaisala WXT510 weather stations were located at MB03, MB06, SM04, SM10, WR03 and WR12. Each unit recorded temperature, relative humidity, pressure, and wind speed and direction. The WXT510 can measure precipitation in liquid form only, so that function was not utilized. The four units sited in the Medicine Bow and Sierra Madre Ranges were funded by the State of Wyoming, the others by the lower Colorado River Basin States (see Section 5).

2.5 Ice Nucleus Measurements

The ice nuclei produced by the glaciogenic seeding devices being utilized in the WWMPP can be readily detected by acoustical ice nucleus counters (AINC), as described by Heimbach *et al.* (2008).

During the 2006-2007 WWMPP season an AINC owned by WMI was first flown in the project aircraft, a Piper Cheyenne II, which at that time was based on Riverton, Wyoming. That first season served as a shake-down for the instrument, which had not previously been flown. Nevertheless, an initial late-season plume-mapping effort was successful.

The unit was returned to the field for the 2007-2008 season, and operated as opportunities and staffing allowed. No AINC is truly a "turn-key" instrument; as each of the five systems (cooling, humidifying, atomizing, deicing and flow) requires careful monitoring and adjustment.

A second AINC was operated at high elevation on the eastern slope of the Medicine Bow Range near the target area during the month of February 2008.

Additional information about the use and utility of these AINCs is provided by a companion paper in this conference (Paper 6.2).

3. AIRBORNE CAPABILITIES

In the first three seasons the same instrumented aircraft has been deployed for project measurements and (when applicable) airborne seeding.

Documentation of cloud liquid water, ice, and aerosols was the dominant focus of the initial season.

The Piper Cheyenne II (Figure 4) was initially based in Cheyenne, Wyoming and flew primarily over the Medicine Bow and Sierra Madre ranges, though a few missions were flown over the Wind River Range as well. Cheyenne was chosen simply because hangar space was available there, but not at the other comparably-equipped Wyoming airports nearer the target areas.

Figure 4. Piper Cheyenne II N234K, the WWMPP project aircraft, idles on the ramp in Riverton, Wyoming, in late winter 2007. The aircraft was based in Riverton during the 2006-2007 winter, but loss of hangar space forced a move to Rock Springs for the 2007-2008 season.

3.1 Cloud Physics / State Parameters

The project aircraft has been equipped with the following instrumentation:

- temperature, Rosemount total
- temperature, reverse flow
- dew point
- pressure altitude
- liquid water, DMT (seasons 1 and 2)
- liquid water, King (season 3)
- cloud droplet spectrum, SPP
- 2D cloud imaging, 2D-C
- wind vector, Aventech AIMMS-20AQ
- position, GPS

3.2 Aerosols

During the first two winters the aircraft was equipped with the following instrumentation to quantify atmospheric aerosols:

- aerosols from 0.1-3.0 :m, PCASP
- condensation nuclei, TSI (NCAR)
- cloud condensation nuclei, U of Wyoming

In seasons 2 and 3, the aircraft also was equipped with an acoustic ice nucleus counter (AINC). To complement these measurements, in February 2008 a second AINC was operated near the Medicine Bow target area. Again, see conference Paper 6.2 for additional information regarding the sampling of ice nuclei.

3.3 Seeding Equipment

The project aircraft was equipped with two 16-position wing racks, for a total capacity of 32 flares. Pyrotechnics manufactured by Ice Crystal Engineering (ICE) were exclusively used. Each flare contained 150 grams of seeding reagent, and burned for a nominal four minutes after ignition.

These flares produce fast-acting ice nuclei that function by the condensation-freezing mechanism (DeMott 1999).

4. 2007-2008 SUMMARY

The 2007-2008 field season began on 15 November 2007 and concluded after 31 March 2008. In this period a total of 15 cases were called in accordance with the criteria provided by NCAR for the randomized statistical experiment. The early season cases (November and December, and a portion of January) were conducted as “practice”, as the final criteria had not been provided. Nevertheless, a number of these “practice” cases may be included in the formal statistical evaluation if they pass post-hoc screening (by NCAR).

TABLE 1. 2007-2008 WWMPP Operations Summary

	Nov	*Dec*	*Jan*	*Feb*	*Mar*	*Total*
Medicine Bow & Sierra Madre						
*Number of Case Pairs**	(1)	(3)	(7) 3	4	8	(11) 15
Total Generator Hours Seeded	(7)	(28)	(64) 24	31	104	(99) 159
* ”cases” conducted prior to finalization of the seeding criteria for the randomized statistical experiment are shown in parentheses.						
Wind River						
Airborne Seeding Events	2	8	4	3	7	24
Flares Burned (150 g each)	25	116	46	41	119	347
Ground-based Events	4	4	7	6	5	26
Total Ground Seeding Hours+	76	148	180	212	171	787
+sum of hours all generators were operated. For example, three generators each operated for two hours = 6 total ground seeding hours.						

Seeding of the Wind River Range was conducted in a more “operational” mode, wherein seeding was generally conducted whenever the project forecaster believed that conditions were amenable. These conditions were essentially those applied to the randomized statistical experiment, but without quantification.

Airborne seeding was conducted upwind of the Wind River Range only.

In addition to the seeding flights, four flights were conducted to measure ice nuclei plumes released by ground-based project facilities.

Three reconnaissance flights were logged when conditions aloft were found to be lacking for seeding.

5. DOWNSTREAM INTERESTS

Thirsty Colorado River downstream states have for the last two winters taken an active role in assisting ongoing weather modification programs in upstream states. Specifically, Arizona, California, and Nevada have contributed to programs in Utah, Colorado, and Wyoming. This has been done with the belief that additional seeding can mean additional water in the basin, and at least fractionally, additional water downstream.

In the 2006-2007 season, these lower basin states funded the deployment of two additional weather stations in the Wind River Range, and also the deployment of a microwave radiometer in that basin (operated by NCAR/RAL).

These facilities were again funded during the 2007-2008 season, as well as an additional ground-based generator (WR10). The intention of continuing the support of upper basin programs in 2008-2009 has already been expressed.

6. CHANGES FOR THE 2008-2009 SEASON

Possible improvements for the 2008-2009 WWMPP include the following:

- Relocation of the MB08 ground generator. It was not used during the 2007-2008 season, and could be better utilized if relocated to the west of its present position.
- Though the WMI radiometer was on-line during the 2007-2008 season, the data stream will be made more accessible to facilitate real-time decision-making.
- The sounding data will be posted immediately on the project FTP site. This will facilitate ingestion of the data into the NCAR/RAL real-time, four-dimensional data assimilation (RT-FDDA) model, which provides numerical guidance to project forecasters.
- Extending the season(s) into April is presently being explored.

A variety of other program enhancements are also be explored, including boosting power generation at ground generators during periods of extended cloudiness that can significantly limit solar power generation.

7. ACKNOWLEDGEMENTS

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