



WYOMING & COLORADO WEATHER MODIFICATION PROGRAM

WINTER AERIAL CLOUD SEEDING OPERATIONS

Final Operations Report
2018-2019 Winter Season



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Airborne Cloud Seeding Operations 2018-2019 Winter Operations Annual Report

For the

Sierra Madre and Medicine Bow Mountain Ranges, Wyoming
Never Summer Mountain Range, Colorado

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EXECUTIVE SUMMARY

This report summarizes the activities conducted by Weather Modification LLC, dba Weather Modification International (WMI) during the 2018-2019 winter operational season from November 15, 2018¹ – March 31, 2019. The program, facilitated by the Wyoming Water Development Office (WWDO), utilized a WMI seeding aircraft to increase snowfall in the mountains in the Upper North Platte River and Colorado River Basins for additional water runoff. This was the 1st season Weather Modification International has provided pilot and aircraft services to conduct aerial cloud seeding operations for the State of Wyoming and the State of Colorado.

Primary funding for the project was provided by the Wyoming Water Development Commission (WWDC), with funds appropriated by the Wyoming Legislature, in the amount of \$425,273. Additional funding was provided by the Board of Public Utilities (BOPU) of the City of Cheyenne, in the amount of \$45,000. The Jackson County Water Conservancy District (JCWCD) provided an additional \$29,764 for operations conducted within the State of Colorado, primarily through a grant from the Colorado Water Conservation Board (CWCB).

The target area was defined by the client as the Medicine Bow and Sierra Madre mountain ranges (MBSM) located within the Upper North Platte and Colorado River Basins in south-central Wyoming, and the Never Summer Mountain range (NS) located in north-central Colorado. WMI's meteorological team provided operational guidance and was responsible for detailing seeding mission parameters, forecasting, and determining when flights were undertaken. More about these two target areas is provided in Section 1.0 of this report.

A WMI-modified Beechcraft King Air C90A seeding aircraft (US FAA registration N127ZW) was equipped with two wing-mounted burn-in-place flare racks and three belly-mounted ejectable flare racks for glaciogenic seeding. The aircraft also featured data-logging computer system for recording position and seeding events, the capability to receive in-flight weather and radar updates, and satellite phone texting to extend communication ranges.

Experienced WMI flight crewmembers (pilot-in-command and first officer) operated the aircraft during seeding missions, handled the seeding agent, and performed seeding equipment maintenance as needed. The aircraft and crew were based in Cheyenne, Wyoming. This location was selected to expedite safe and speedy aircraft climbs to the seeding tracks, and because it has an instrument approach and adequate hangar and maintenance facilities.

¹ Because the permitting process is lengthy, operation for the Never Summer Range in Colorado did not begin at the same time as the Wyoming operations, but were delayed until after the New Year. The Colorado seeding permit was issued on January 4, 2019, and the agency notifications required by Colorado Water Conservation Board and Department of Natural Resources were completed on January 9th.



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Flight operations were conducted according to basic guidelines established by WMI and the WWDO. The seeding method used on the 2018-2019 project was glaciogenic (or “cold cloud”) seeding - treating clouds with nuclei composed of a silver-iodide (AgI) complex to induce freezing and accelerate precipitation formation. Seeding was conducted when weather conditions were determined to be suitable, employing standard winter storm broadcast seeding track techniques. The WMI personnel discussed relevant weather information on a daily basis, in order to determine the best mission timing, altitudes, and seeding tracks based on the expected winds and temperatures at flight altitudes.

The project aircraft arrived on site November 13, 2018. It was ferried by Captain Kirk Hamilton and WMI Director of Flight Operations, Jody Fischer. The first mission took place in the Medicine Bow range on November 17, 2018. The last seeding event of the 2018-2019 season took place in the Sierra Madre range on March 23, 2019. The program ended on March 31, 2019.



Figure 1. WMI Copilot Jacob Berg snapped this image of the target area on December 30, 2018 after a mission in the Sierra Madre and Medicine Bow target areas. A total of 4.92 flight hours were flown and 4,260 grams of material dispensed on this flight.



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In the Medicine Bow and Sierra Madre mountain ranges, sixteen (16) flights were conducted for a total of 69.25 flight hours, consisting of fifteen (15) seed and one (1) reconnaissance mission. Of the 69.25 flight hours, 33.28 hours were conducted for the Medicine Bow range and 35.97 were conducted for the Sierra Madre range. A total of 76,700 grams of seeding agent were dispensed via 1,210 ejectable flares (20 grams each) and 350 burn-in-place flares (150 grams each).

When seeding opportunities were not present in Wyoming but existed over the Never Summer Range of Colorado, seeding operations were conducted in Colorado on behalf of the Jackson County Water Conservancy District. Additional details regarding seeding priorities were provided in an MOU between the Wyoming Water Development Commission (WWDC) and the Jackson County Water Conservancy District (JCWCD).

In the Never Summer mountain range of Colorado, three (3) flights were conducted for a total of 13.03 flight hours. Seeding was conducted on all three missions. A total of 10,640 grams of seeding agent were dispensed via 517 ejectable flares (20 grams each) and 2 burn-in-place flares (150 grams each).

The WMI team is proud to have been a part of the 2018-2019 Wyoming & Colorado Aerial Weather Modification Program; we look forward to future seasons!



ACKNOWLEDGMENTS

The 2018-2019 project had multiple partners whom WMI here acknowledges. In addition, the project ran smoothly, effectively, and safely because of the diligence of many people, and we appreciate all of them.

Funding for all operations in the Medicine Bow and Sierra Madre target areas within Wyoming was largely made possible by the Legislature of the State of Wyoming, through the Wyoming Water Development Commission. The project budget was significantly enhanced by the Board of Public Utilities, of the City of Cheyenne. Seeding flights that targeted the Never Summer Mountain Range in Colorado were made possible by the Jackson County Water Conservancy District, primarily through a grant from the Colorado Water Conservation Board.

Project guidance and direction on behalf of the State of Wyoming was provided by Ms. Julie Gondzar and Mr. Barry Lawrence of the Wyoming Water Development Office. The WMI seeding aircraft crew was comprised of Captain Kirk Hamilton assisted by co-pilot Jacob Berg. Meteorological services, which included forecasting, weather monitoring (for seeding conditions), and direction of operations were provided primarily by Mr. Daniel Gilbert. Numerical weather prediction services and a meteorological web interface for the project was provided by Mr. Adam Brainard. Additional meteorological support was provided by Mr. Jason Goehring. Bruce Boe, Vice President of Meteorology, provided scientific program oversight.

From the Fargo corporate office, logistical and technical support for the airborne seeding equipment was provided by Mr. Dennis Afseth. Mr. Jake Van Ornum and Ms. Erin Fischer (Client Services), provided administrative and recordkeeping support, with the assistance of Ms. Amber Ottis and Ms. Cindy Dobbs. Aircraft maintenance and servicing were coordinated by Mr. Mike Clancy in cooperation with Mr. Jody Fischer, who managed the flight operations team.

Seeding agent, in the form of glaciogenic pyrotechnics, were provided by Ice Crystal Engineering LLC. We here acknowledge the excellent performance of these flares, and thank ICE Manager, Mr. Charlie Harper, and his entire manufacturing team.

The Jackson County Water Conservancy District board was very supportive and helpful throughout, especially Mr. Kent Crowder and Mr. Ty Wattenberg. The support and assistance of the Colorado Water Conservation Board and the Colorado Department of Natural Resources, in the persons of Mr. Joe Busto and Mr. Andrew Rickert are also greatly appreciated. We here note that the Colorado Water Conservation Board allowed the deployment of its radiometer (used to detect the presence of cloud water) to assist seeding decision-making for the new, Never Summer target area. Thank you!



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1 BACKGROUND & TARGET AREA

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. The Wyoming and Colorado Aerial Weather Modification Program is designed to augment snowfall over select portions of the Upper North Platte River Basin and the Colorado River Basin. By increasing the snowpack and resultant spring runoff, subsequent water supplies downstream are increased. In addition to easing the need for alternative and more costly power supplies, cloud seeding increases the water availability for municipal, recreational, and environmental interests.

The program conducted aerial cloud seeding operations, as described herein. A modified Beechcraft King Air C90A aircraft owned and operated by WMI released silver iodide-based ice nuclei using pyrotechnic flares. The aim is to produce artificial ice nuclei which will cause additional snow crystals to form and precipitate in the target area.

The target area included portions of South Central Wyoming and North Central Colorado, as defined:

- Medicine Bow Range & Sierra Madre Range (MBSM) – Portions of the Medicine Bow and Sierra Madre Mountain Ranges located in Carbon County and Albany County, Wyoming, with much of the area also within the Medicine Bow National Forest. The Continental Divide extends along the high points of the Sierra Madre Mountains, with runoff from the western slopes draining into the Colorado River Basin and the eastern slopes draining to the North Platte River Basin. Run-off from the Medicine Bow Mountains drains into the North Platte Basin.
- Never Summer Range (NS) – Located in north-central Colorado, the Never Summer Mountain Range, lies within the Upper North Platte River Basin and includes Jackson, Grand, and Larimer Counties. Only portions within Jackson County were targeted in the 2018-2019 program.

Standard winter broadcast seeding techniques were employed. Seeding of winter storms was conducted whenever WMI meteorologists determined conditions were suitable. Project meteorologists issued daily forecasts and updated the project pilots on a frequent basis. The wind direction determined which “set” of tracks would be used, the temperature determined the seeding altitude, and the wind speeds at that altitude determined the distance flown upwind from the target. WMI, in cooperation with the WWDO and the CWCB, established the tracks shown (Figure 2) prior to the field program. Generally, the WMI meteorologists attempted to provide the flight crew a 2-hour advance notice prior to the desired commencement of seeding operations.

Table 1, on page 15 lists the exact location of each track’s endpoints and wind speed limits for their use. The WMI crew has the ability to modify the seeding tracks during storms to optimize targeting during seeding flights. This past season, flight tracks were modified on three missions due to weather conditions. These occurred twice on December 19th and once on January 23rd. This illustrates the versatility of the aircraft and crew to ensure proper targeting.

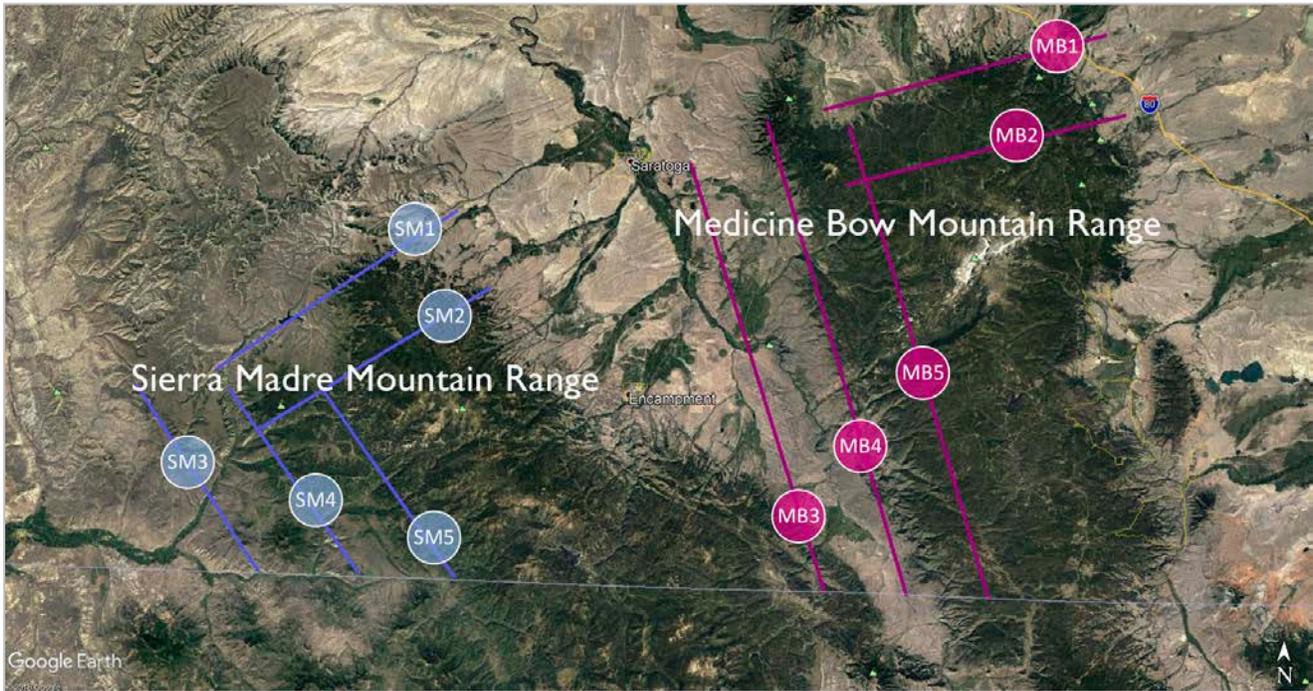


Figure 2. Medicine Bow and Sierra Madre Target Areas located in the State of Wyoming. The predetermined flight tracks are visible in purple (Sierra Madre Mountain Range) and magenta (Medicine Bow Mountain Range).

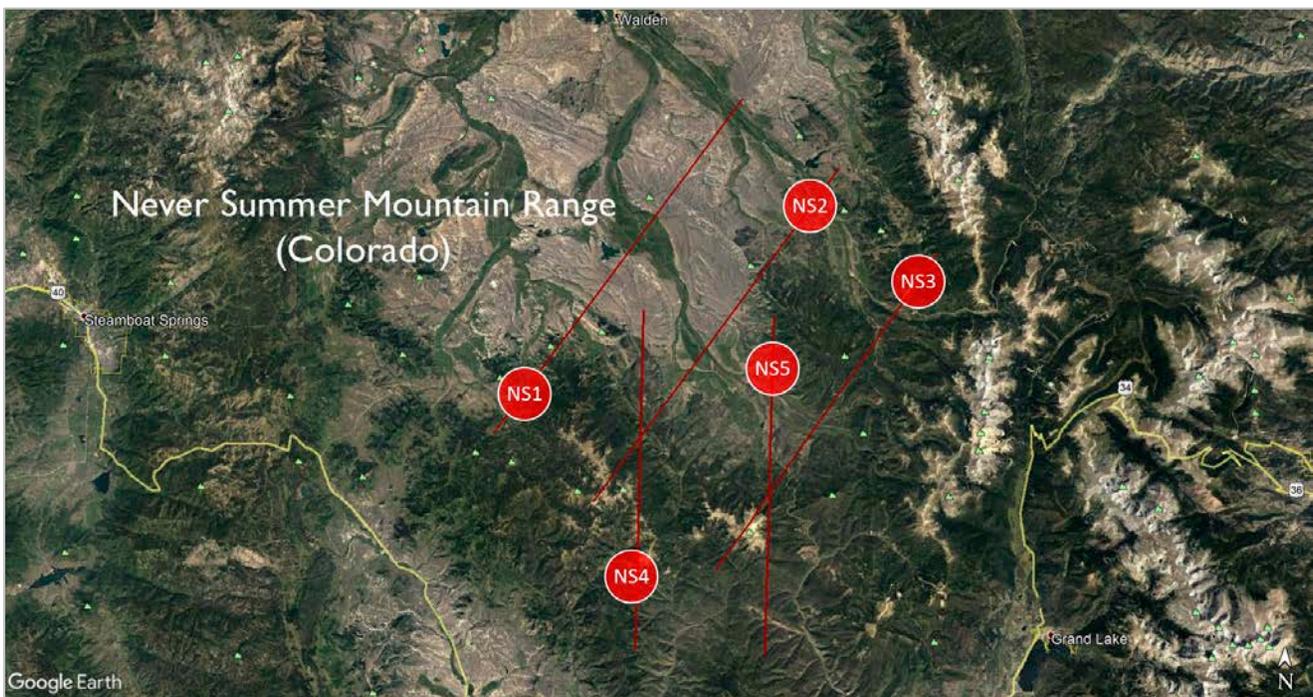


Figure 3. Never Summer Target Area located in the State of Colorado. The predetermined flight tracks are visible in Red.



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Table 1. The locations of each track's endpoints and wind speed (WS) limits are given.

SIERRA MADRE					
	TRACK	LAT	LONG	VOR/RADIAL/DME	WIND SPEED (KTS)
SM1	SM1E	41'24	107'03	CKW/116/032	30-55
	SM1W	41'16	107'17	CKW/150/033	
SM2	SM2E	41'19	107'00	CKW/120/037	<30
	SM2W	41'12	107'14	CKW/147/038	
SM3	SM3N	41'12	107'30	CKW/159/033	55+
	SM3S - WY	41'00	107'19	CKW/151/046	
SM4	SM4N	41'12	107'22	CKW/149/035	30-55
	SM4S -WY	41'00	107'10	CKW/143/048	
SM5	SM5N	41'12	107'14	CKW/139/037	<30
	SM5S -WY	41'00	107'02	CKW/136/051	

MEDICINE BOW					
	TRACK	LAT	LONG	VOR/RADIAL/DME	WIND SPEED (KTS)
MB1	MB1E	41'36	106'08	LAR/296/025	30-55
	MB1W	41'31	106'32	LAR/272/038	
MB2	MB2E	41'31	106'06	LAR/288/021	<30
	MB2W	41'26	106'30	LAR/265/036	
MB3	MB3N	41'27	106'43	LAR/265/046	55+
	MB3S	41'00	106'31	LAR/226/041	
MB4	MB4N	41'30	106'37	LAR/270/041	30-55
	MB4S	41'00	106'24	LAR/222/037	
MB5	MB5N	41'30	106'30	LAR/271/036	<30
	MB5S	41'00	106'17	LAR/217/033	

NEVER SUMMER					
	TRACK	LAT	LONG	VOR/RADIAL/DME	WIND SPEED (KTS)
NS1	NS1N	40'40	106'09	RLG/004/042	30-55
	NS1S	40'24	106'24	RLG/350/024	
NS2	NS2N	40'37	106'03	RLG/012/041	<30
	NS2S	40'21	106'18	RLG/004/022	
NS3	NS3N	40'33	105'57	RLG/020/040	55+
	NS3S	40'18	106'10	RLG/020/022	
NS4	NS4N	40'30	106'15	RLG/002/031	30-55
	NS4S	40'14	106'15	RLG/019/016	
NS5	NS5N	40'30	106'07	RLG/012/033	<30
	NS5S	40'14	106'07	RLG/034/020	



WMI utilizes in-house high-resolution numerical modeling to identify suitable times for seeding. The modeling tools identified periods when seedable clouds were likely (based on winds, temperatures, and liquid water content). When models forecast seedable cloud conditions, project pilots and meteorology staff worked in tandem, continuously monitoring satellite imagery, radiometer data, webcams, pilot reports, and occasionally NEXRAD radar data. When real-time observations indicated the likely presence of suitable targets, a flight was launched. Upon reaching seeding tracks, pilots checked temperatures, winds, and supercooled liquid water content. If conditions were indeed suitable, seeding commenced and continued until conditions deteriorated or the aircraft ran low on fuel or flares. If suitable conditions were not encountered during a flight, no seeding occurred, and the aircraft returned to base having conducted "reconnaissance". After a seeding or reconnaissance flight ended, flight crews and meteorologists immediately prepared for another flight if warranted.

General cloud seeding criteria established for the Wyoming/Colorado project were:

Requirements to initiate a flight:

- WMI models indicate supercooled liquid water (SLW), wind speed and direction, and temperature profiles suitable for targeting clouds in the -4° to -15°C range.
- The range selected is based on which will likely have the greatest SLW. Because the aircraft can be flown lower, down to 13,000 feet, on the Sierra Madre, that range may be chosen in certain temperature profiles or cloud depths.
- Seeding altitude varies between 13,000 to 16,000 feet, depending on temperature profile, cloud depth, and observed supercooled liquid water (icing rate).
- In daytime hours webcams and visible satellite imagery provide information on cloud depth and coverage.
- At night, infrared and water-vapor satellite imagery provide reasonable cloud coverage information.
- The ground conditions at the Cheyenne Airport (KCYS) must be safe for departure and expected to be suitable for return at end of flight. This is mostly taken from the TAFs (Terminal Area Forecasts) and occasionally PIREPS, AIRMETS, and SIGMETS.
- Radar echoes over the Medicine Bow Range (the only range covered by radar, and only partially) are not required. We have observed that cloud SLW is often marginal when echoes are present over the Medicine Bow Range (again, the only range covered by radar).

Procedures en route to seeding track:

- The aircraft will climb above the expected altitude of the icing layer (over the targeted range) while in transit. This avoids beginning seeding with ice already on the airframe. Altitudes are indicated by the model cross-sections of SLW and temperatures.
- Note 0°C , -5°C , and -10°C levels and report to meteorologist, along with overall cloud conditions and winds/icing conditions.
- Communicate with meteorologist to confirm/adjust based on observed conditions.



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Required to begin seeding once on track:

- When the seeding track is approached, the aircraft will carefully descend into target layer from above, to be sure not to accumulate rapid airframe icing. If severe icing is encountered, the aircraft may immediately climb out of it and contact the meteorologist. Depending on temperature and observed cloud conditions, it may be determined that seeding should occur with ejectable flares.
- SLW must be present in the -4°C to -15°C layer at altitude, targetable by ejectable flares, burn-in-place flares, or both. It is preferred that the seeding be conducted below the -10°C level whenever possible, but ejectables may be dropped from as cold as -15°C once SLW is confirmed below. The presence of SLW below should be confirmed before beginning seeding. It should be checked at least hourly.
- The targetable SLW must be present (at seedable temperatures) at reasonable horizontal distance from the target area to allow for fallout of precipitation in the target (20-30 min upwind).



2 PROJECT PERSONNEL

WMI provided an experienced flight crew for the winter cloud seeding season, which consisted of one pilot in-command (PIC) and one copilot (first officer). WMI prefers to utilize a copilot on seeding flights whenever possible to enhance flight safety and targeting, as cockpit workload and recordkeeping responsibilities can be shared.

The Cheyenne team was led by Captain Kirk Hamilton, assisted by first officer Jacob Berg. Hamilton has two aerial winter seasons experience in California. This past summer, Hamilton was a King Air C90 Captain on the North Dakota Cloud Modification Project. Hamilton was accompanied by Jacob Berg. This was Berg's first season as a WMI wintertime copilot. Like Hamilton, Berg was a Captain on the North Dakota Cloud Modification Project, flying a Seneca II aircraft.

Prior to the start of the project, Hamilton conducted ground and flight training in Fargo and Cheyenne with WMI's Director of Operations, Jody Fischer. Fischer is a Weather Modification Association (WMA) Certified Operator. This was his sixteenth winter season and he has over 250 hours of flight experience in Wyoming mountainous terrain.



Figure 4. The 2018-2019 WY/CO crew from left to right – Jacob Berg and Kirk Hamilton stand in front of the WMI C90A seeding aircraft N127ZW outside Legend AeroServ in Cheyenne, WY. Photo submitted by Kirk Hamilton.



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Daniel Gilbert, WMI Chief Meteorologist; Jason Goehring, Field Meteorologist; and Adam Brainard, Meteorologist/Numerical Modeler, formed WMI's meteorology team. This was Gilbert's fifteenth year of winter seeding operations and forecasting. He also has sixteen seasons experience on summer seeding programs. This was Goehring's fourteenth year of WY seeding operations and forecasting in addition to five summers in Alberta. Gilbert and Goehring have worked together for ten seasons on Wyoming programs dating back to the Wyoming Weather Modification Pilot Project. Brainard has been involved with the WY seeding programs since 2016, providing numerical modeling support. This was his first year in the field in Pinedale. Brainard has also completed six years of summer seeding operations in North Dakota and Alberta. Gilbert, Goehring, and Brainard are all Weather Modification Association Certified Operators. Bruce Boe, WMI Vice President of Meteorology, provided overall management of the meteorology team and its day-to-day operations.

Additional project coordination and administrative support was provided by WMI headquarters in Fargo, ND.



Figure 5. The WMI Forecasting team from left to right – Dan Gilbert (Chief Meteorologist), Jason Goehring (Field Meteorologist), and Adam Brainard (Meteorologist/Numerical Modeler). Goehring is based in Long Lake, SD, and Gilbert in Fort Dodge, IA. Brainard resided in Pinedale, WY during the winter season and is pictured next to a microwave radiometer used on the Wyoming Wind River ground operations program. Photos by Gilbert, Goehring, and Brainard.

2.1 Pre-Project Ground School

A pre-project ground school was held in Cheyenne, WY on Wednesday, November 14th for all Wyoming cloud seeding project personnel, both ground-based and aerial. Attendance was mandatory for WMI project employees. The meeting topics included forecasting, media protocol, overview of the project, reporting pre- and post-flight, conducting cloud seeding operations (aerial & ground-based), and winter safety. WMI administrators – Bruce Boe, Vice President of Meteorology; Jody Fischer, Director of Flight Operations; and Erin Fischer, Client Services also attended the kickoff meeting.



3 EQUIPMENT

3.1 Beechcraft King Air C90A

WMI Beechcraft King Air C90A, U.S. FAA registration N127ZW, arrived on site November 13, 2018. It was ferried by Captain Kirk Hamilton and Jody Fischer, WMI Director of Flight Operations. N127ZW was dedicated for full-time use on the program and its crew provided 24 hour a day, 7-day a week support for cloud seeding activities. The aircraft and crews were based at the Cheyenne Regional Airport. Hangar, deicing, maintenance, and fueling services were obtained from Legend Aero at the Cheyenne airport.



Figure 6. WMI Beechcraft King Air C90A, N127ZW rests on the ramp at the Cheyenne Regional Airport. Photo by Kirk Hamilton.

The Beechcraft King Air platform is a high performance twin-engine turboprop aircraft that has proven itself with numerous operators in a wide variety of weather research and cloud seeding operations. Standard equipment includes full dual VFR/IFR instrumentation, an FAA instrument-approach certified GPS navigation system, on board digital weather radar, pressurized cabin, and emergency oxygen.



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The high performance of the turbine-powered King Air provides the power needed to climb safely above the dangerous icing zone (-10°C to -15°C) when required, even after accumulation of significant ice on the airframe. The endurance of this aircraft allowed coverage of the entire project area from the Cheyenne base of operation with a time-on-station of approximately 4+ hours in ideal conditions.

In addition to pressurization, an oxygen system with masks is installed in the event of a loss in cabin pressure. All WMI aircraft are equipped and certified for instrument flight (IFR), day and night. This equipment includes VHF communication and navigation radios, GPS navigation, onboard weather radar system, and an emergency locator beacon system. GPS-based terrain mapping systems provide the crews with increased situational awareness during IFR and nighttime seeding operations, further enhancing safety.

There were 4 crew seats available in the aircraft; however, WMI aircraft are operated in U.S. Federal Aviation Administration “Restricted” category when in seeding configuration and so only project personnel are allowed on board per these regulations.

A total of 4,688 gallons of Jet -A fuel was consumed on the project from November 15 – March 31, an average of 56 gallons per aircraft flight hour. This rate is on par with WMI’s wintertime C90A operations in Idaho at 61 gallons per aircraft flight hour in 2017-2018 and 62 this past winter season. All project fuel was purchased by WMI at the aircraft base location. Fuel costs ranged from \$3.72 to \$4.00 per/gallon with an average of \$3.89 per/gallon.

There were two aircraft issues during the season, neither of which impacted operations.

- 23 November – The aircraft had an avionics issue. It was resolved onsite and no flights were missed.
- 19 February – The crew flew the aircraft to Greeley, CO to have a fuel pump repaired. Maintenance was completed that same day with no impact to operations.

3.1.1 Flight in Known Icing Conditions

The C90A is FAA-certified and equipped for flight into “known icing” conditions with pneumatic deicing boots on the wings, horizontal and vertical stabilizers, exhaust heated engine inlets, electrically heated propeller blades, pitot / static ports, and heated windshield strip. WMI pilots are trained prior to any project on weather recognition, proper seeding procedures, flight operations in icing conditions, crew coordination, flight safety and judgment. Having a two-pilot crew helps ensure that proper attention is paid to changing flight and seeding conditions. WMI has an exemplary safety record, and takes extremely seriously the safety of the general public, WWDO employees, and its company personnel.

Known-icing certification should in no way be interpreted to mean that the aircraft’s manufacturer expected it to fly for extended periods within icing conditions. Such certification means that the FAA has certified that the aircraft is equipped with the necessary deicing equipment and has the required power to safely transit (climb or



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descend through) layers of icing. This constraint will always be kept in mind during operations, ensuring the flight crew will deal safely with winter storm conditions.

In the Wyoming area, there are no lower terrain areas nearby to which the aircraft can escape severe icing encounters and melt of airframe icing, and usually the only option is to return for an instrument approach to the Cheyenne airport. Since this sometimes means icing conditions all the way to the ground, the pilots must have complete discretion in their decisions in dealing with excessive airframe icing; this has always been the policy and practice of WMI.

Generally, about 15-20% of WMI California and Idaho wintertime seeding flights are forced to divert to lower altitudes at some point during winter missions to melt airframe icing. This year, for instance in Wyoming, the crew had to descend or climb for excessive icing conditions on two missions. This was approximately 10% of the missions – less than average for wintertime operations. Additionally, icing forced the crew to end seeding operations prematurely one time or approximately 5% of the time. These statistics are based on 19 missions combined between Wyoming and Colorado.



Figure 7. Images of in-flight airframe icing during WY-CO missions on February 3, 2019 (left) and November 28, 2018 (right). Left – The aircraft nose shown with icing that remained intact upon descend in Cheyenne, WY after a 5.05 hour mission for the Never Summer Mountain Range. Photo by Kirk Hamilton. Right – WMI copilot Jacob Berg captures N127ZW's windshield during a mission over the Medicine Bow Mountain Range on November 28, 2018. A total of 9.25 flight hours were flown and 13,150 grams of seeding material was dispensed during this event on the 28th.



3.1.2 Weather Availability In-Flight

As an enhancement to safety, WMI seeding aircraft were also equipped with a GPS-based terrain mapping and warning system, which displays surrounding terrain features and aviation navigation graphics. The system also provides real-time colored (yellow and red) terrain warnings based upon its database and GPS aircraft position during missions. This system enabled thorough and accurate positional and terrain awareness during instrument and night flights, and allowed decisive action whenever heavy icing conditions dictated flight diversions.

WMI flight crews were also equipped with ADS-B real-time weather and traffic information on a company-issued iPad. The current weather and radar images are displayed on the iPad, overlaid on a moving map of the target area. The pilots can see weather conditions upstream that will allow them to make real-time seeding decisions and optimize use of their fuel and flares.



Figure 8. Image from a WMI iPad showing ADS-B weather information visible to the cloud seeding pilot while conducting operations. Medicine Bow and Sierra Madre target areas in Wyoming overlay shown on the ForeFlight application. The target area at the time of this photo was void of weather.



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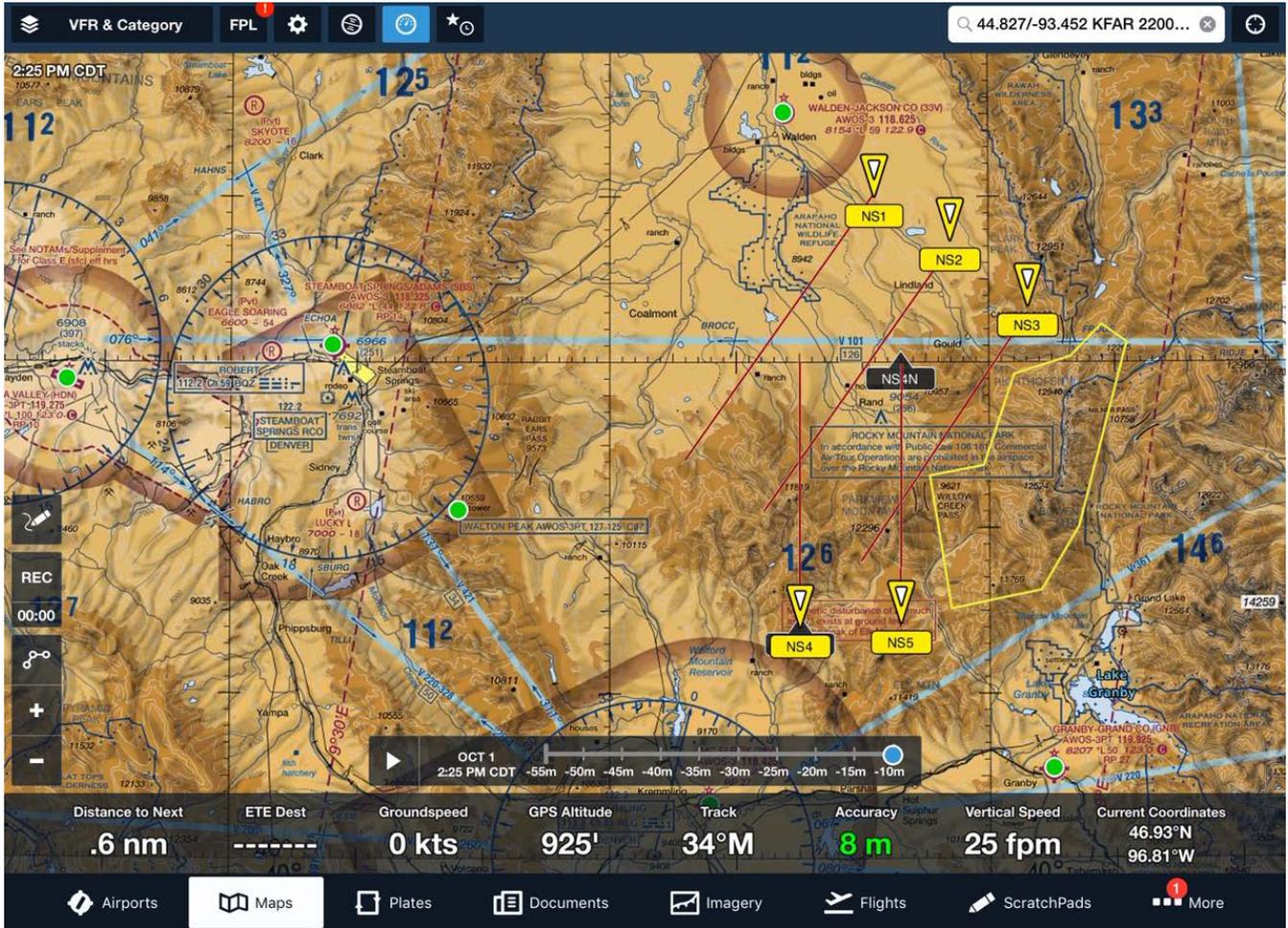


Figure 9. Like Figure 8, the Never Summer Mountain Range target area in Colorado overlay shown on the ForeFlight application. The target area at the time of this photo was void of weather.



3.2 In-Flight Communications

The WMI seeding aircraft were equipped with satellite voice and text messaging service through Iridium GO!®. This is a robust, military-grade device that will withstand turbulence of rugged cloud seeding flights. Its communication features include real-time ability to send texts, weather updates, emergency alerts (SOS), and GPS tracking. It allows for connection to smartphones and tablets compatible with Apple and Android operating systems along with the option to interface with the pilot's headset (hands-free). The remotely-mounted phones were integrated with the aircraft audio systems so that they functioned as a normal aircraft communications system and all units were set up via an app on the pilots mobile phone, or a handset for the pilots to easily speed-dial various project numbers. The system provided adequate long-range communications with the meteorologists directing operations, which was extremely advantageous for the remotely-positioned meteorologists and crew.

3.3 Seeding Equipment and Agents

The project aircraft was modified with two (2) wing-mounted burn-in-place flare racks and three (3) ejectable flare racks. Seeding equipment was fabricated and installed by WMI in accordance with U.S. Federal Aviation Administration approvals (US FAA Form 337), and seeding data were ingested along with GPS position information into a WMI "Datalogger" computer.

3.3.1 Burn-in-place (ICE-BIP™) Flares

Burn-in-place flares were ignited whenever especially large amounts of supercooled liquid water (SLW) or bands of embedded cumuliform clouds were encountered during seeding operations. In wintertime operations, seeding is usually performed using tracks upwind of the target areas, as was done on this program. This is called *broadcast seeding*, with the idea being that the seeding crystals produced by the flares will mix with the available cloud mass and activate when they encounter SLW and thus result in snow downwind in the target area.



Each rack was mounted to the wing such that the flares themselves are positioned aft of the trailing edge. Each rack held 24 flares, for a full capacity of 48. The flares can be burned in any quantity throughout the flight, one at a time or in multiples. These glaciogenic flares yield 150 grams of seeding material and burn for about 4+ minutes each. The flare formulation has been tested for nucleus yield at Colorado State University.

Figure 10. N127ZW aircraft carried two dual burn-in-place flare racks. The flares shown are 150g ICE-EB™ Ice Crystal Engineering LLC glaciogenic flares. Photo by Kirk Hamilton.



3.3.2 Ejectable (ICE-EJ™) Flares

Ejectable flares fall away from the aircraft and drop while burning about 2500 ft (in the absence of up- or down-drafts). These flares are used when there is sufficiently thick cloud mass in the seeding zone, and often as a way of treating storms while allowing the aircraft to remain above icing layers, to increase on-station time. Each of the three belly-mounted ejectable flare racks holds 102 flares, for a full capacity of 306 per aircraft. The racks are designed with removable baskets which hold the 20mm diameter flare cartridges. This allows quick reloading of flares between missions.



Figure 11. Ejectable flare belly racks installed on the project aircraft. Each ejectable flare yields 20g. All three project aircraft were equipped as pictured with 306 ejectable flares. Photo by Kirk Hamilton.

The seeding equipment controls are mounted in the cockpit for pilot or copilot operation, and display the data in real time. WMI owns and manufactures the seeding equipment. All equipment construction is aircraft-quality, and systems are easily accessed for routine maintenance. Equipment installation was completed and flight tested at WMI's maintenance facility in Fargo, North Dakota, prior to project start. The pilots regularly checked all the equipment to ensure functionality. All WMI aircraft modifications and equipment installations are FAA-approved.



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All glaciogenic seeding materials used were manufactured by Ice Crystal Engineering LLC (ICE) of Kindred, North Dakota. ICE pyrotechnic output, as a function of cloud temperature, has been established at the Colorado State University (CSU) Cloud Simulation and Aerosol Laboratory (SimLab), in Fort Collins, Colorado (DeMott 1999). ICE pyrotechnics have established an excellent record in the field and are well known for their extremely low failure rate. All ICE products are ISO9001:2015 certified. This ensures that strict manufacturing processes are followed, including suppliers, customer service, and quality control. For more information on ICE Crystal Engineering please visit: www.iceflares.com.

A total of 350 burn-in-place and 1210 ejectable flares were expended during this winter season for Medicine Bow and Sierra Madre mountain ranges in Wyoming. In Colorado, 2 burn-in-place and 517 ejectable flares were expended for the Never Summer range.

3.3.3 Flight Data and Recording

The aircraft carried a WMI Datalogger system, which recorded and displayed selected flight data. The core of the system is a purpose-built computer that records all parameters during each flight. The Datalogger ingested GPS position, altitude, groundspeed, and track data from an internal GPS receiver. Each seeding event (burn-in-place flares fired and ejectable flares fired) was also recorded. The flight file was then archived and replayed on a ground-based computer using WMI's *AirLink II* software to create a complete flight track of the mission, as shown later in this report. Such plots also contain a basic map of the target area and terrain, see Section 6.0.

The WMI flight crew kept paper records of the flight notes and regular seeding agent inventories. The flight forms were recorded and transmitted to the client, as requested.



4 METEOROLOGICAL SERVICES

WMI meteorologists provided meteorological support for Wyoming & Colorado Aerial Weather Modification Program. Portions of weather systems deemed to have seeding potential were monitored, on a 24-hours-per-day, 7 days-per-week basis (24/7) by WMI meteorological team. This team provided the pilots with forecasts and relevant weather information throughout the season. They would also routinely call the flight crew to discuss the current weather situations as each evolved. In addition to the weather forecasts, these discussions included anticipated cloud conditions, temperatures, upper level winds, and the timing of upcoming opportunities.

Dan Gilbert (WMI Chief Meteorologist), Adam Brainard (WMI Meteorologist/Modeler) and Jason Goehring (WMI Field Meteorologist) alternated duties preparing the project forecasts and, along with the flight crews, monitored opportunities for operations. Gilbert, Brainard, and Goehring are WMA Certified Operators.

The standard reference time chosen for the project field operations was “universal time coordinates” (UTC). This time, also called Greenwich Mean Time (GMT) or Coordinated Universal Time (CUT), is the accepted international standard of time for general aviation and meteorological observations, reporting, and communication. The shorthand notation for UTC is the letter Z, so 1800 UTC can also be written 1800Z.

4.1 Suspension of Cloud Seeding Operations

From time to time, cloud seeding operations may be suspended as part of the standard operating procedures of the program. There are multiple reasons for possible project suspension, including achievement of a snowpack in the target area at a predetermined percentage above “normal”, unusually heavy precipitation, or reservoir capacity issues. In such circumstances, additional precipitation could pose a potential threat to life or property, and in such cases, seeding is not conducted. For these reasons, seeding suspension criteria have been established and strictly adhered to by the operators, in accordance with industry standards.

During the 2018-2019 season, no suspensions occurred. Suspension criteria were monitored by WMI’s meteorology team in close partnership with the WWDO and JCWCD.

4.1.1 2018-2019 Suspension Criteria

Snowfall histories are used to determine the Historic Range of Natural Variability (HRNV) for a given SNOTEL facility. These historic snow-water equivalents are then combined and a ‘median’ is established for a period of time, usually 30 years. This ‘median’ is then used to set the HRNV by the day or month of any recorded year.

Thresholds at which cloud seeding will be suspended for this operation are identified below. These criteria will be implemented to govern all seeding decisions. The criteria for this Wyoming operation were determined using an HRNV at the upper range of 140%, using historic data.



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Cloud seeding will be suspended if any of the criteria listed below are met:

1. Seeding shall be suspended in any target area if and when range-wide snow water equivalents (SWE) indicated by designated NRCS SNOTEL sites exceed a percentage of the long-term median defined by a linear upper limit of 85% of the thirty-year (1981-2010) median April 1 SWE for the site on November 15 (normal program start), and increasing to 140% of the median April 1 SWE as of April 1².
2. Insufficient reservoir storage for flood control, based upon hydrologic estimates of total snowpack using all available data.
3. Potential for significant rain events above 8,500 feet MSL. The area of risk would not be targeted until the risk had passed. This is very rare at the latitude of the target area (rain in winter is uncommon.)
4. Severe winter weather events, as forecast by the National Weather Service office having responsibility for the target. For Never Summer operations, this is the Boulder Weather Service Office. The area forecast to be affected would not be targeted until the risk had passed.
5. Extreme avalanche risk in a specific target area, as indicated by the Colorado Avalanche Information Center (CAIC). The area of risk would not be targeted until the risk had passed.
6. If a significant wildfire occurs within the watersheds of the target area, the Forest Service shall be consulted prior to the next cloud seeding season to determine if there is need for suspension(s) that account(s) for the newly burned areas.
7. Care will be taken to avoid targeting major highways to avoid impact on transportation corridors. In the case of the Never Summer Range, there are no major highways in immediate proximity to the target area.
8. Seeding may be suspended at any time in the Never Summer target area, upon direction from the Colorado Water Conservation Board or the Jackson County Water Conservancy District.
9. Seeding may be suspended at any time in the Medicine Bow and/or Sierra Madre target area, upon direction from the Wyoming Water Development Office.

²During the Wyoming Weather Modification Pilot Project, a research program, the upper limit was conservatively set at 120% of the 1971-2000 mean SWE. However, when the 1981-2010 thirty-year period of record became available, the Natural Resources Conservation Service (NRCS), which operates the SNOTELs, decided to publish (on the NRCS SNOTEL web sites) the long-term median, rather than the mean, as they determined the medians were more indicative of typical values. Thus the operational criteria now use medians rather than means, and also the 1981-2010 period of record. The upper limit was raised from 120% to 140% because this corresponds approximately to one standard deviation above the long-term medians, meaning that snowpack at this level would still be well within the limits of natural variability. We note that the *lowest* SWE suspension threshold currently employed in the western United States is 140%, including programs in Idaho, Utah, Nevada, and California.



4.2 WMI Numerical Model

Almost all weather and forecast data are obtained via the internet, regardless of forecaster location. Data included in real-time monitoring and forecasting this season consisted of: live radar data from the National Weather Service network of WSR-88D radars, lightning data, satellite imagery (NOAA GOES and POES satellites), surface observations, a variety of numerical models (NAM, GFS, HRRR etc.), aviation weather sites (for icing reports), and in-house modeling tools. Visual observations were available from a number of webcams. When weather conditions deviate from those forecast or rapidly changing conditions otherwise warrant, weather updates were initiated by the meteorologist.

For the 2018-2019 season, WMI operated a dual-nest limited area domain of the Weather Research and Forecasting (WRF) model, with high-resolution nests both for the Wind River Range ground generator program and for this MBSMNS aerial project. The high-resolution inner nests, whose boundaries are shown with a thick black border on the plot above, have a grid spacing of 2.5km, were initialized from the High Resolution Rapid Refresh (HRRR) model, and were given the North American Model (NAM) forecast for boundary conditions at 3-hour intervals. The model was routinely run twice per day to a 48-hour forecast duration, but was run four times per day when active weather with potential seeding opportunities was expected or was ongoing. It provided very specific tools that greatly improve targeting and effectiveness of seeding, such as the explicit forecasting of supercooled water content over the flight tracks, and winds/temps aloft at a high temporal resolution. A large number of graphical outputs were developed specifically to aid the cloud seeding decision-making. Examples of some of the meteorologists' favorites are shown in the following figures.



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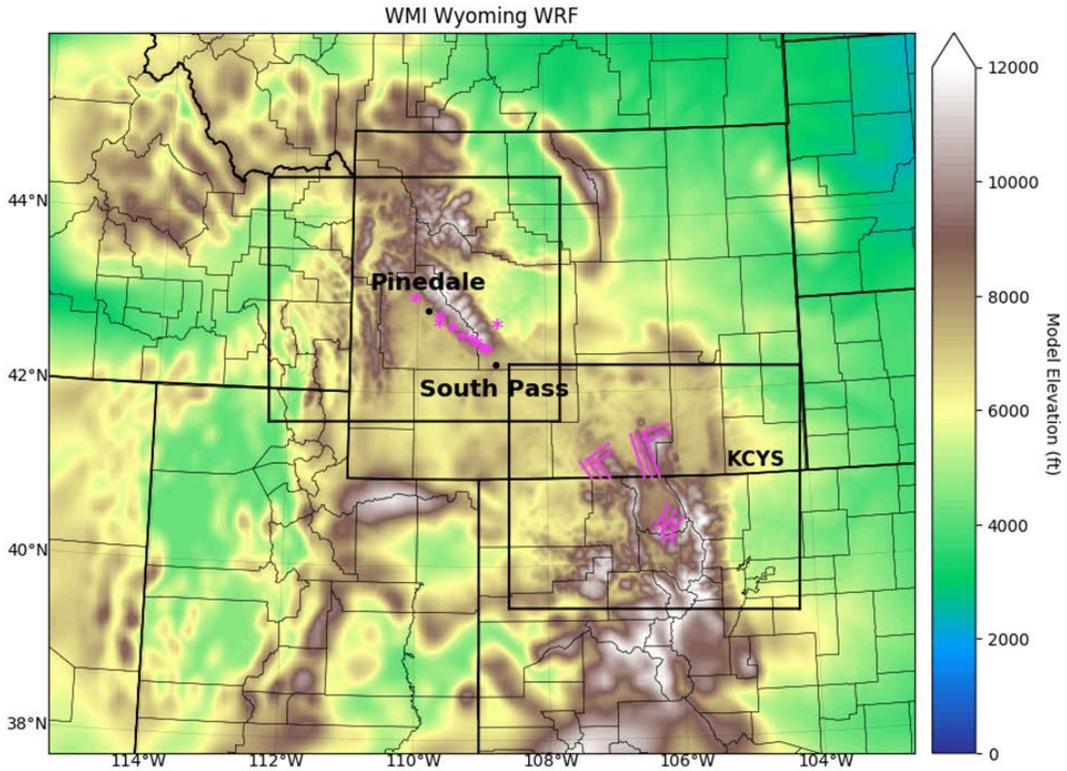


Figure 12. WMI Wyoming Dual Nest 2.5km WRF Domain. Solid pink lines show the established aerial seeding tracks, selected from or modified based on the meteorological conditions present during each seeding event. Graphical output and BUFKIT format model soundings from WMI's Wyoming WRF domain were published to <http://wmiradar.com/wy> as soon as the data was available.



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Sierra Madre - Med Bow Cross Section 2019-02-03 1900 UTC

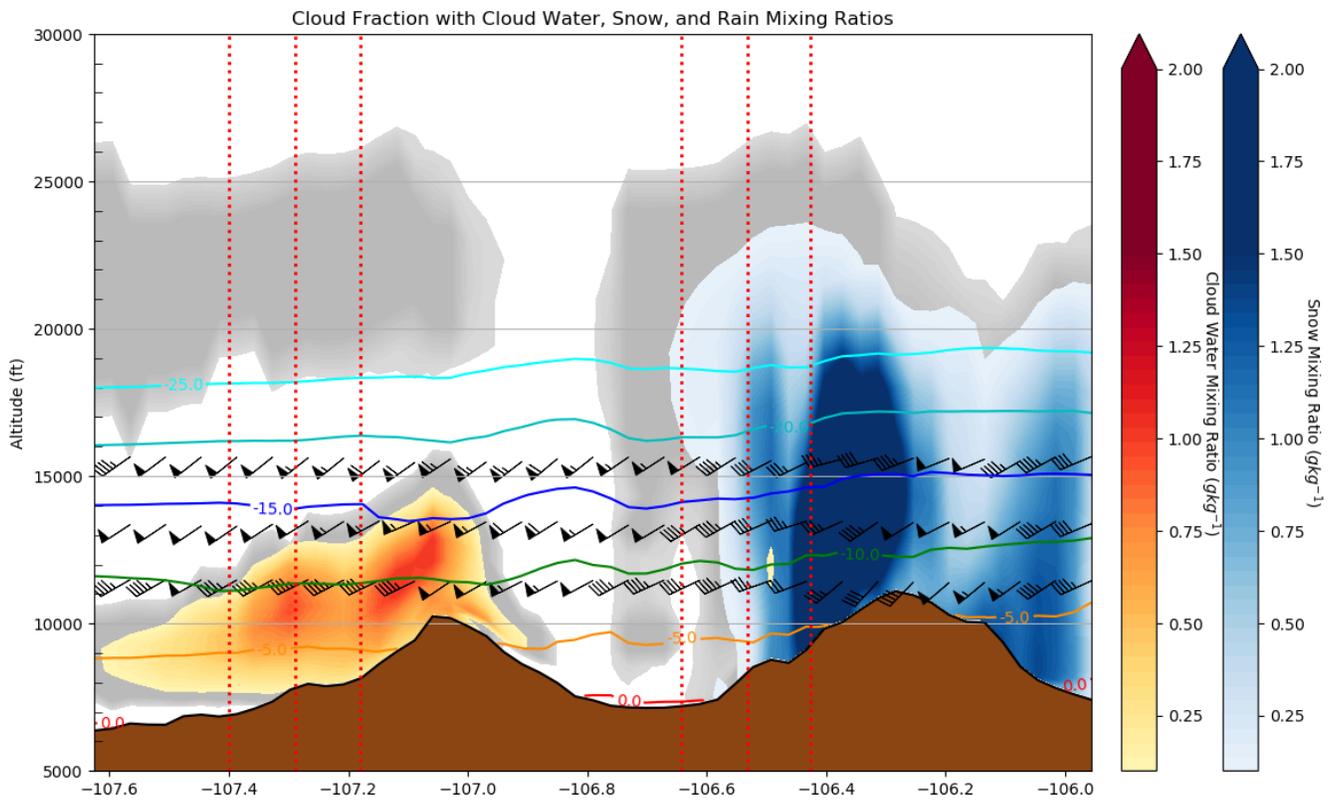
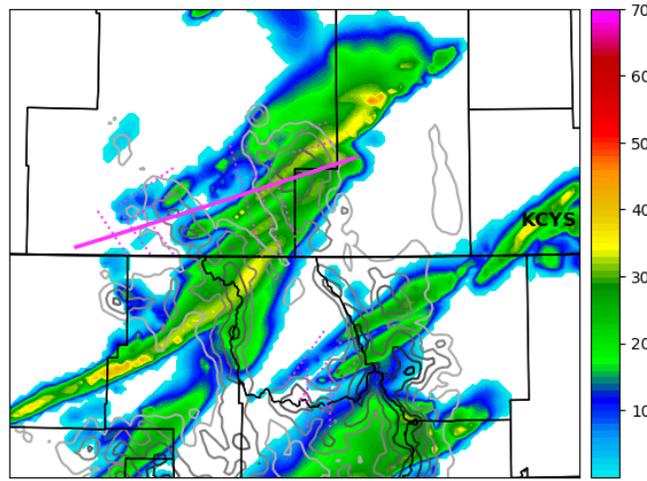


Figure 13. Plot of model simulated composite reflectivity is shown at the top, with a vertical cross section in the bottom half spanning the western flight tracks of the Sierra Madre and Medicine Bow range. The plot is made for 19:00 UTC on February 3rd, or 12 PM MST. See text for interpretation and discussion.



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Figure 13, designed specifically to show an overview of weather in the Sierra Madre and Medicine Bow ranges, shows a vertical cross section from southwest to northeast along the pink track in the composite reflectivity plot above. Horizontal distance, denoted by lines of longitude, is depicted along the x-axis, while vertical depth from the model surface (brown fill) up to 30,000 ft MSL is shown on the y-axis. This cross section intersects six project flight tracks at the vertical red dotted lines. Depicted on the cross section are a number of atmospheric variables. 3-dimensional model-simulated clouds are shown in a gray fill, model-predicted liquid cloud water (SLW when colder than freezing) is shown in warm (orange/red) colors, and model-predicted snow is shown in blue. Plot fill priority is given to cloud water, followed by snow, then cloud fraction. Isotherm contours at -25°C , -20°C , -15°C , -10°C , -5°C , and 0°C are shown in cyan, teal, blue, green, orange, and red respectively, and horizontal wind barbs at various heights at or near common seeding aircraft altitudes are also depicted (strong southwest winds around 50 kts are shown in this example).

Figure 14, much like Figure 13, shows a vertical cross section along the solid pink line in the composite reflectivity plot in the top half of the figure. This cross section, spanning from the western Never Summer flight tracks to the KCYS airport, again shows horizontal distance denoted by lines of longitude on the x-axis and vertical depth from the model surface (brown fill) up to 30,000 ft MSL on the y-axis. The cross section depicts isotherms, cloud fraction, cloud water, and snow in the same manner as Figure 13. In contrast to the previous figure, however, horizontal wind barbs are withheld, and the cross section is drawn over a broader distance from the seeding tracks to the base airport. This cross section is an example of a plot adapted from input from pilots, who appreciated the meteorological-focused meteograms like in Figure 13, but desired a cleaner design, and with the entire flight path between the seeding tracks and KCYS depicted.



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NS1 Cross Section 2019-02-14 1800 UTC

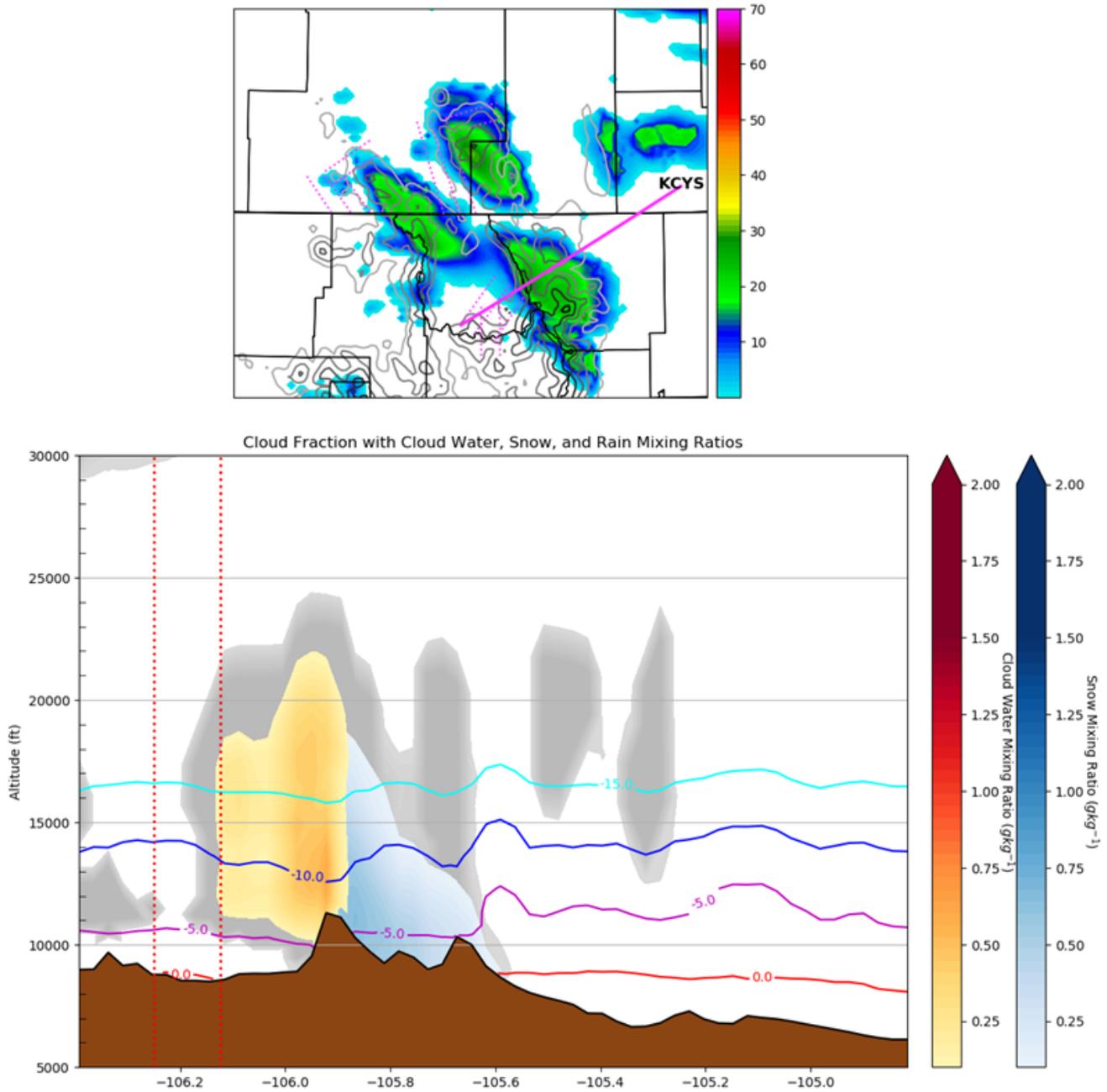


Figure 14. This plot, similar to Figure 13, shows model composite reflectivity in the top portion with a vertical cross section beneath. The cross section is drawn from the western most Never Summer Range flight track to the Cheyenne Airport. The plot is made for 18:00 UTC on February 14th, or 11 AM MST. See text for interpretation and discussion.



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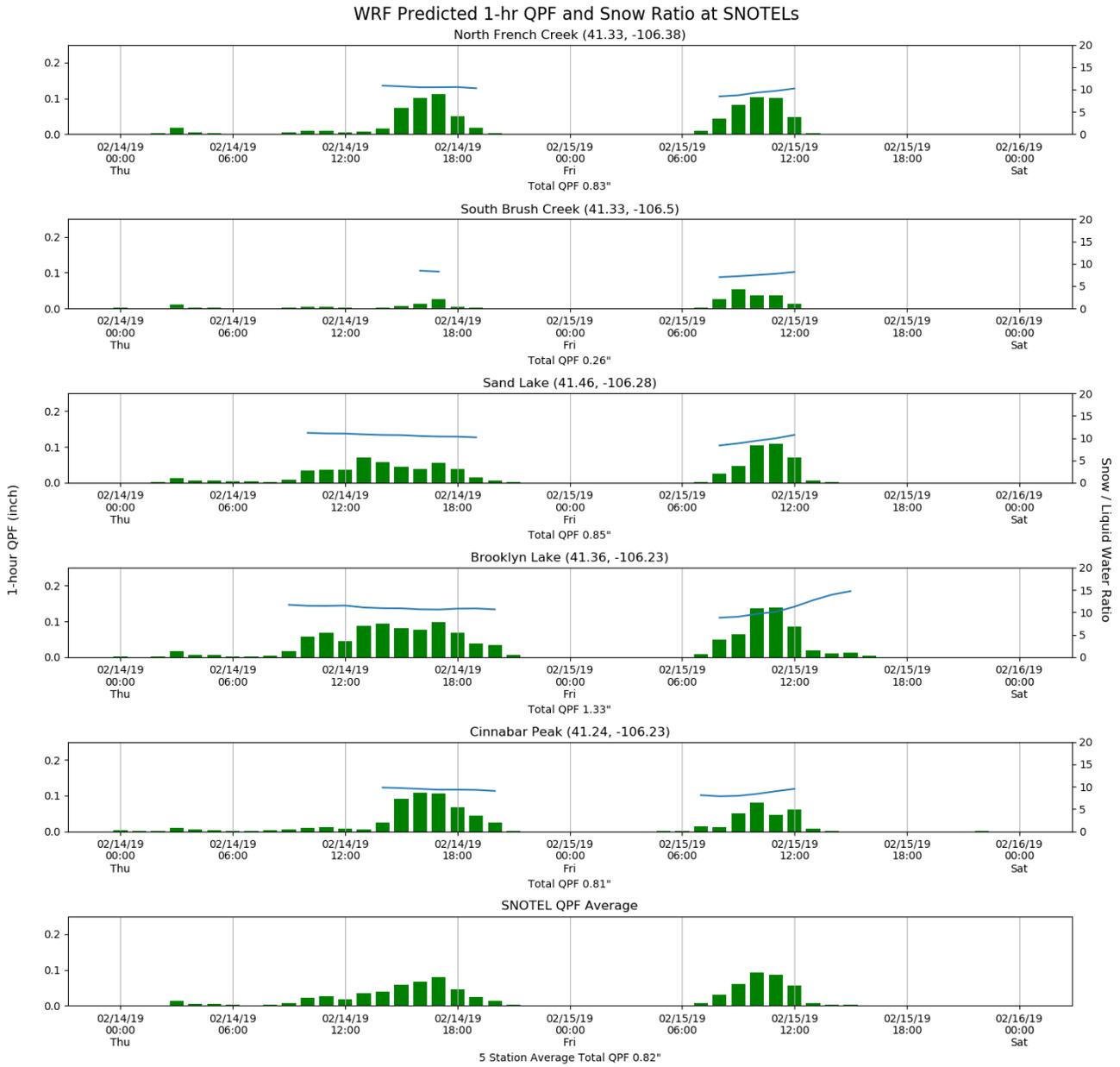


Figure 15. This plot shows hourly quantified precipitation forecast (QPF) outputs for five different SNOTEL locations in the Medicine Bow Range. A five-station average is shown in the bottom plot.

In Figure 15, a meteogram showing hourly model-predicted precipitation (a.k.a quantitative precipitation forecast, or QPF) at predefined locations, outputs are chosen based on the existing locations of SNOTEL sites. This type of meteogram was made for all three target ranges for each model cycle, with this plot showing an example for the Medicine Bow Range from the 00 UTC WRF run on 14 February, 2019. A double y-axis is used to show model predicted snow-liquid water ratios on the right. The meteogram duration is 48-hours, the same as the model duration of the inner high-resolution nests.



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Medicine Bow Peak

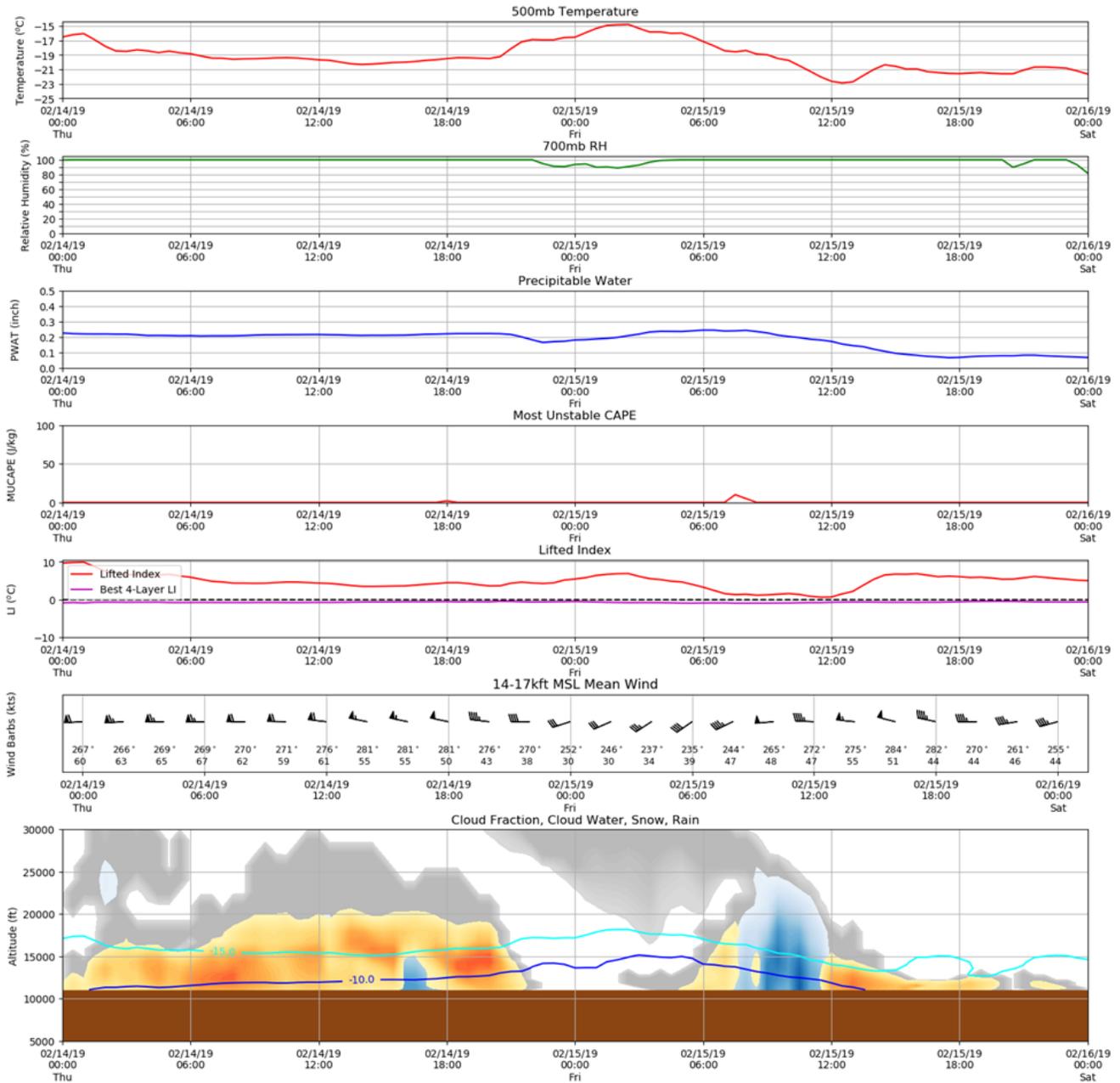


Figure 16. This figure, another meteogram, shows the forecasted evolution of a selection of mid-tropospheric, convective, and precipitation variables through time. The location is fixed at Medicine Bow Peak. Further explanation is provided in the text below.



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One final plot example is Figure 16. This multi-variable meteogram shows the forecasted progression of 700mb temperature, 700mb relative humidity (RH), precipitable water, most unstable convective available potential energy (CAPE), lifted index, 14,000-17,000 foot altitude average wind direction and speed, and a time-height cross section of isotherms, cloud fraction, cloud water, and snow. 700mb temperature and relative humidity are important lower troposphere tracers to monitor for warm/cold air advection and the presence of moisture in the air that can be lifted along the upwind side of the mountains. Precipitable water depicts the overall evolution of tropospheric moisture, while most unstable CAPE and lifted index are used to monitor the potential for convection accompanying precipitation, which may be hazardous to seeding operations. An average 14kft -17kft wind speed and direction is predicted and displayed as a wind barb every two hours, as this block of altitude is frequently utilized by our aircraft during seeding operations. Finally, the time-height cross section shows a breakdown of the model simulated cloud, cloud water, and snow expected throughout the identified time period. Location is held constant, in this case on the Medicine Bow Peak, for all variables, though adjacent valley locations are used for lower tropospheric variables and precipitable water to provide a better free-atmosphere approximation of these model values.



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4.3 WMI Forecast Sheet

AERIAL OPERATIONS DAILY FORECAST
 WYOMING WEATHER MODIFICATION PROGRAM
Medicine Bow, & Sierra Madre Mountain Ranges
 COLORADO WEATHER MODIFICATION PROGRAM
Never Summer Mountain Range
 WEATHER MODIFICATION INTERNATIONAL
 FORECASTER: Adam Brainard
 VALID 2 PM February 13, 2019 THROUGH 2 PM February 14, 2019

	SYNOPSIS Zonal, perturbed flow has developed across a broad swath of the intermountain west as moisture pours in from the Pacific. Although a more pronounced shortwave trough will pass to our north today, smaller scale disturbances in the mid and upper level flow will transit our project area, with the best mid-level forcing occurring during the middle of the night tonight. Surface and low-level moisture, which has been very dry despite extensive mid-level cloudiness, will increase substantially through the remainder of the afternoon, with orographic cloud depth and coverage increasing in kind. A subtle shortwave trough will spread across Wyoming tomorrow afternoon, before an ominous series of troughs blitz the region Thursday night and Friday. 48-hour QPF totals over 2" SWE are expected in the SM range, and over 1" in the MB and NS ranges.
--	--

FORECAST

Mid-level virga will sublimate and saturate the low-levels this afternoon, with widespread snow then likely in the project area this eve. Synoptic scale activity will ebb overnight, though orographic clouds will potentially targetable SLW will persist. A second round of deeper synoptic scale precipitation is prognosticated after midnight, with deep and particularly promising orographic cloud predicted in its wake. This morning's models would suggest operations from an hour around dawn until the early afternoon would capture the best seeding opportunities in the MB and SM range. For the NS range, conditions do not appear quite as favorable overnight and into the morning, but a shorter favorable window is currently identified from around 18z to 22z tomorrow. Flight level winds will be brisk in all regions, especially early, with winds nearly due west at around 50kts. Flight-level temps will creep warmer with time but will remain perfectly suitable for our operations. Morning LLWS with occasional strong surface gusts are the only likely weather threat at KCYS.

ACTION: A seeding flight for the SM/MB range is tentatively scheduled for 630am MST, with a flight for the NS range in the afternoon. Synoptic scale precipitation returns Thursday night, but prolonged seeding opportunities are currently unclear.

Day 2 Outlook ODC: +1

WRF MODEL SOUNDING	
SAA	00Z, 14 February
0 °C level	NA
-5 °C level	8.6 kft
-10 °C level	14.0 kft
-20 °C level	20.0 kft
Precipitable Water	0.38 inches
14 kft T/wind	-10.0°C 269@57 kts
16 kft T/wind	-12.9°C 271@55 kts
700 mb T/wind	-5.8°C 230@59 kts
500 mb T/wind	-16.2°C 272@55 kts

YESTERDAY'S WEATHER **Observed ODC: -1**

Temps Max/Min: Saratoga 33/14 Cheyenne 43/25 Walden 30/14

Weather Summary: High cirrus lowered into fairly thick mid-level cloud in the late afternoon, with this cloud cover persisting overnight. Surface and low-level conditions remained very dry, however, and no precipitation occurred across the project area. Very shallow cap clouds and lenticular clouds have been observed on webcams after dawn this morning, though no orographic clouds remotely suitable for seeding have occurred.

Flights: No seeding flights.

Orographic Day Category (ODC)		
-3	No Seeding	Clear skies, or clear with isolated upper-level cloudiness.
-2	No Seeding	Occasionally clear, with cirrus, cirrostratus, altostratus; cloud bases above mountains.
-1	No Seeding	Limited coverage or short-lived orographic clouds, not enough temporal or spatial extent to warrant seeding activities.
0	Possible Seeding	Some orographic clouds/stratus over mountain tops. SLW/Winds/Temps marginal or uncertain. Operations possible, but not likely.
+1	Seeding Likely	Orographic clouds and/or stratus deck enshrouding mountain tops, Supercooled Liquid Water/Winds/Temps favorable for seeding.
+2	Extensive Seeding	Persistent orographic clouds and/or stratiform cloud deck enshrouding mountain tops, Supercooled Liquid Water/Winds/Temps favorable for extended seeding operations.

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REV 1, 10-2018

Figure 17. A WMI forecast sheet from February 13, 2019; all forecast were submitted to the client via email daily.



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5 PROJECT FLIGHT DATA

The first 2018-2019 winter mission was flown on November 17, 2018 for the Medicine Bow mountain range. A map of each seeding event is provided. The pre-established flight tracks are shown in red and actual aircraft tracks are shown in black. Yellow dots denote where ejectable flares were fired, and light-blue triangles denote where burn-in-place flares were ignited. The table beneath each map details the mission and includes flight data (engine on/off, total time), flares used, pilot(s) observations, a description of observed weather conditions, and area forecast relevant to that mission.

FLIGHT SPECIFICS			WYOMING						
Flight Date (UTC) on Takeoff	Flight Times (UTC)		Medicine Bow		Sierra Madre		Flight Track(s) Flown	Flight Hours	Cumulative Hours
	Engines On	Engines Off	BIP	EJ	BIP	EJ			
17 November 2018	3:07	7:20	28	14			MB4	4.22	4.22
23 November 2018	0:13	2:45					SM4, SM5, MB4	2.53	6.75
23 November 2018	13:32	17:54	16		2	59	SM4, MB4	4.37	11.12
23 November 2018	21:51	1:54			31	12	SM4	4.05	15.17
28 November 2018	13:13	17:43	28	96			MB4, MB3	4.50	19.67
28 November 2018	21:00	1:45	43	29			MB5, MB3	4.75	24.42
19 December 2018	6:00	10:40			27	71	Modified	4.67	29.09
19 December 2018	11:58	17:26	48	100			Modified	5.47	34.56
30 December 2018	19:53	0:48	16	13		80	SM4, MB4	4.92	39.48
7 January 2019	13:14	18:18				191	SM3	5.07	44.55
23 January 2019	19:00	23:35	2	101	1	70	Modified, MB4	4.58	49.13
3 February 2019	6:55	11:27			31	72	SM4	4.53	53.66
14 February 2019	13:14	15:39	10	15			MB4, MB3	2.42	56.08
1 March 2019	8:01	12:41			27	95	SM4	4.67	60.75
6 March 2019	9:25	14:00	39	62			MB3	4.58	65.33
23 March 2019	12:19	16:14			1	130	SM5	3.92	69.25

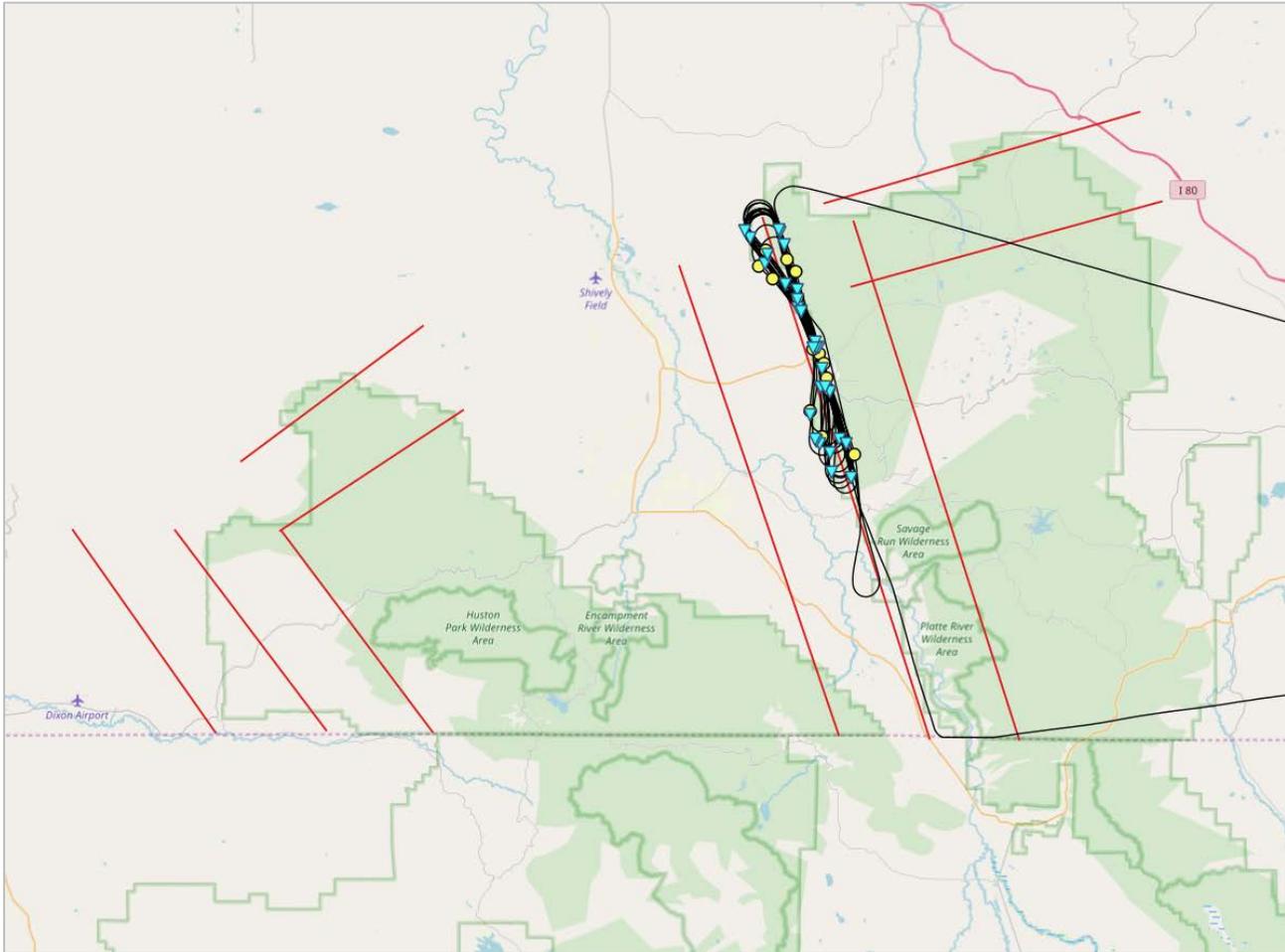
FLIGHT SPECIFICS			COLORADO				
Flight Date (UTC) on Takeoff	Flight Times (UTC)		Never Summer		Flight Track(s) Flown	Flight Hours	Cumulative Hours
	Engines On	Engines Off	BIP	EJ			
3 February 2019	12:02	17:05	2	204	NS4	5.05	5.05
5 February 2019	8:29	12:25		166	NS4	3.93	8.98
14 February 2019	16:01	20:04		147	NS4	4.05	13.03



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5.1 Seeding Mission Flight Tracks – Medicine Bow & Sierra Madre Ranges, WY



N127ZW	FLT. OPS #	01			SEED
UTC Date:	November 17, 2018	MST Date:	November 16, 2018		
UTC Engines ON:	03:07	MST Engines ON:	8:07 pm		
UTC Engines OFF:	07:20	MST Engines OFF:	12:20 am		
Total Time:	4:13	4.22hr	Flares Used:	28 BIP	14 EJECT
Pilot's Flight Summary:	Took off out of CYS headed west towards MB-4. Upon arrival, at 16kft detected no SLW and was above cloud layers. Decided to descend down to 15kft and detected light SLW at the north end of MB-4. The decision was made to use EJs and BIPs. Eventually SLW became spotty and descended to 14kft. At this point we started to broadcast seeding with BIPs. Eventually running low on fuel and by direction of METs, we RTB.				
<i>Flight occurred in the evening hours of the 16th; weather information is from Nov. 16th.</i>					



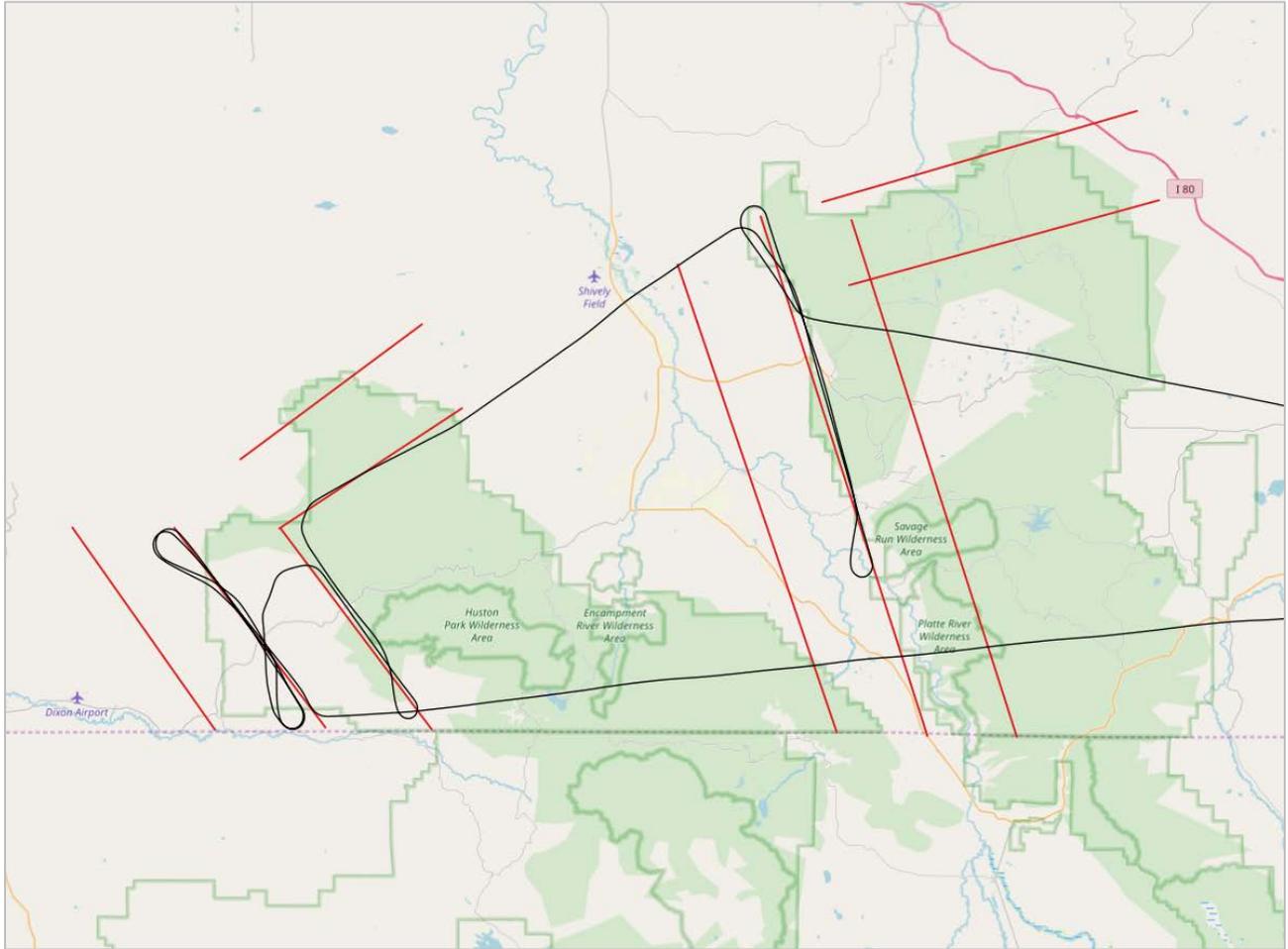
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Synoptic Analysis:	<p>A westerly upper level jet streak will be sagging south into southern WY later today. A midlevel trough is approaching from the northwest and will push through tonight and tomorrow. Upper ridging will return tomorrow evening. Low level moisture is increasing throughout the day, and decent moisture will linger over the region this evening through tomorrow evening. A cold front will push through the project region late this afternoon from the north. Behind the front, a significantly colder air mass will move into the region tonight and tomorrow. As the low level moisture increases this evening, orographic clouds with good liquid water are likely from around sunset to midnight. After midnight, deep midlevel cloud cover will overspread the ranges with abundant natural ice crystals and natural seeder feeder mechanism likely for the rest of the night and through tomorrow.</p>
Area Forecast:	<p>Cloud cover will continue to increase throughout the afternoon and evening hours. Juicy orographic clouds are expected to develop, particularly for the western slopes of the MB, shortly after sunset. The best seeding window looks to be 8pm to midnight local time. Heavy snow accumulation will occur in the MB through tomorrow afternoon while the SM and NS ranges should see only moderate accumulation. In Cheyenne, expect rapidly lowering ceilings after 1am local time with a possibility of freezing fog late tonight and tomorrow morning. With the expected lack of SLW and natural efficiency of the storm after 1am combined with the probability of poor visibility at the airport overnight, late night flights can be ruled out after 1am. The only good seedable period on this system looks to be this evening, ending by around midnight or 1am. Expected flight track for this evening would be MB4 at an altitude of 14 to 15 kft. Winds at flight level will be around 40 kts from the WNW (we could clip off the southern few miles of the track for targeting). Snow will continue throughout the day tomorrow, but the WMI WRF model indicates no significant SLW due to the deep cloud layer. Flights do not look likely tomorrow but cannot be ruled out entirely at this stage. Ridging and dry conditions will return for Sunday and Monday.</p>



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N127ZW	FLT. OPS #	02		RECON	
	Track(s):	SM-4, SM-5, MB-4		Fuel:	143gal.
UTC Date:	November 23, 2018		MST Date:	November 22, 2018	
UTC Engines ON:	00:13		MST Engines ON:	5:13 pm	
UTC Engines OFF:	02:45		MST Engines OFF:	7:45 pm	
Total Time:	2:32	2.53hr	Flares Used:	0 BIP	0 EJECT
Pilot's Flight Summary:	We took off out of CYS, and headed towards the SM-4. Upon arrival we had no SLW on any passes and moved to SM-5. After a couple passes we saw no SLW and moved towards MB-4 per meteorologist's instruction. After finding none, we RTB.				
<i>Flight occurred in the evening hours of the 22nd; weather information is from Nov. 22nd.</i>					
Synoptic Analysis:	A sharp upper level trough with an 180kt jet streak is screaming east across the intermountain west today. Pacific moisture with southwest flow is streaming into our region in the mid and upper levels, though lower altitudes have been slower to saturate. Light rain was observed changing to light snow in Rawlins				



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	<p>midday, but most echoes and taller clouds observed on radar and satellite have been virga. This activity has helped saturate the lower troposphere, however, and is priming the region for an accumulating snow beginning later today into the weekend. The axis of the initial trough will pass through southeast WY / northeast CO in the early overnight hours tonight, and while mid-level conditions will dry out with NVA aloft, low-level moisture with westerly flow will continue into Friday. A new modest shortwave trough will move in from the west-northwest midday Friday bringing deeper moisture and synoptic scale precipitation, followed by an even deeper more powerful trough arriving Saturday morning.</p>
<p>Area Forecast:</p>	<p>Atmospheric conditions favorable for seeding appear promising for several different periods in the coming 48 hours. The first opportunity is in advance of the first shortwave trough this evening. Moderately deep clouds ahead of the trough may be targetable, particularly in the Sierra Madre and Never Summer ranges. Winds turn slightly north of west behind the shortwave trough tonight, and while there is a strong indication upslope flow with appreciable cloud and SLW will be present, it may prove too shallow due to drying mid-level conditions and weak subsidence. Seeding conditions improve in the morning hours Friday, as the mid-levels moisten ahead of the new shortwave trough. Orographic cloud with suitable SLW appears to continue for much of the day Friday, diminishing slightly as NVA behind the second trough again promotes subsidence and drying in the mid-levels. Deep cloud with snow, SLW, and widespread precipitation will arrive late Friday afternoon into the overnight hours as a new surge of moisture spreads in from the west ahead of the larger more powerful trough arriving Saturday.</p>



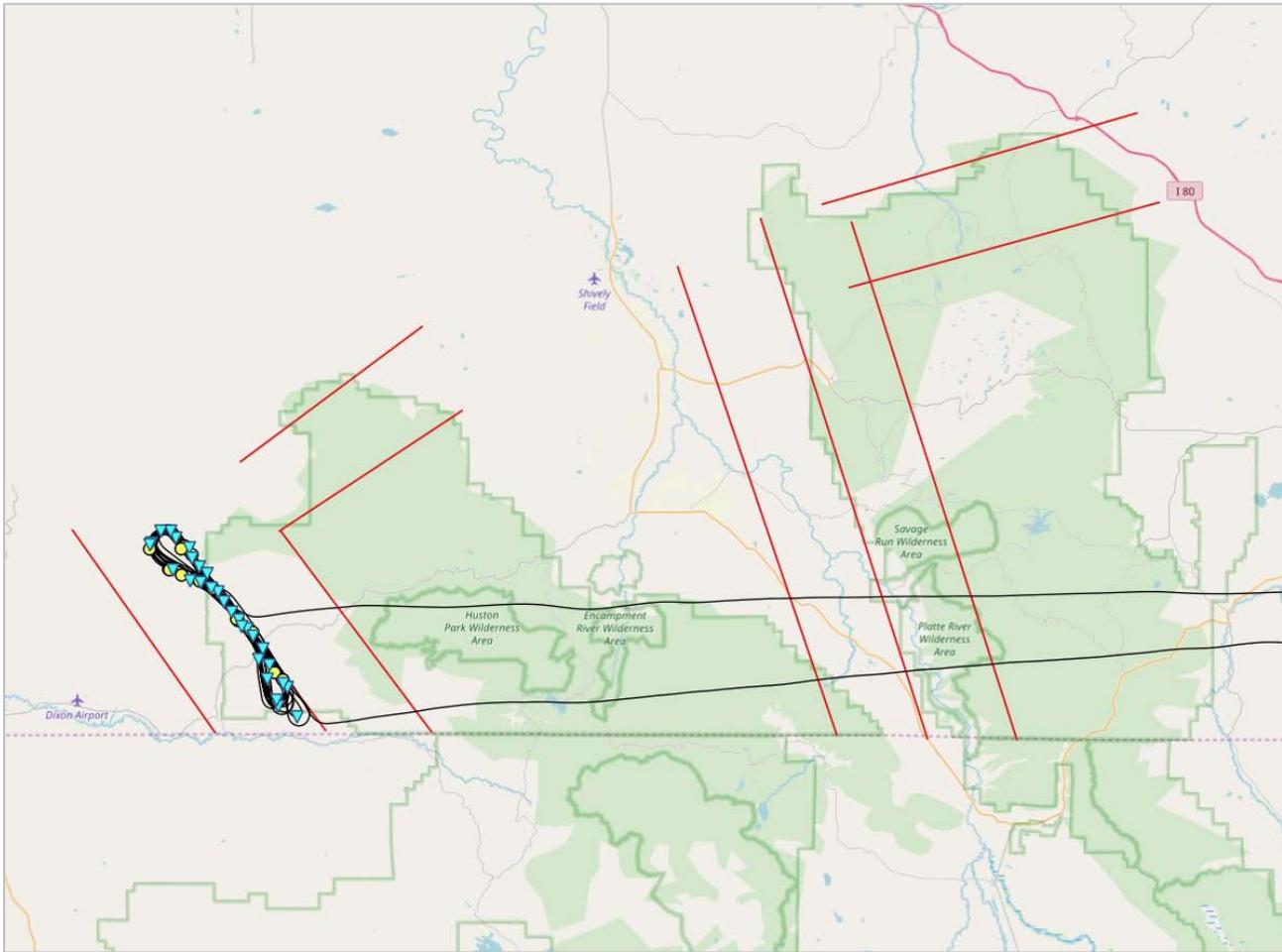
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N127ZW		FLT. OPS #	03	SEED	
Track(s):		SM-4, SM-5, MB-4		Fuel:	246gal.
UTC Date:	November 23, 2018		MST Date:	November 23, 2018	
UTC Engines ON:	13:32		MST Engines ON:	6:32 am	
UTC Engines OFF:	17:54		MST Engines OFF:	10:54 am	
Total Time:	4:22	4.37hr	Flares Used:	18 BIP	59 EJECT
Pilot's Flight Summary:	<p>We took off out of CYS and flew to SM-4. Enroute we encountered pockets of light to moderate SLW. Upon reaching SM-4, we descended to 14kft and picked up moderate SLW. We climbed to 14.9kft and began to eject EJ. At 15:38 we descended down to check for SLW and upon finding a lack of seedable targets we proceeded to MB-4 where we encountered moderate/light SLW at 14.5kft. At 17:22Z we made the decision to RTB due to low fuel.</p>				
<p><i>Flight occurred in the morning hours of the 23rd; weather information remains the same as Flight #2.</i></p>					



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N127ZW		FLT. OPS #	04	SEED	
Track(s):		SM-4		Fuel:	260gal.
UTC Date:	November 23, 2018		MST Date:	November 23, 2018	
UTC Engines ON:	21:51		MST Engines ON:	2:51 pm	
UTC Engines OFF:	01:54		MST Engines OFF:	6:54 pm	
Total Time:	4:03	4.05hr	Flares Used:	31 BIP	12 EJECT
Pilot's Flight Summary:	We took off out of CYS and headed to SM-4. On the way we encountered SLW over the ridge and on the track we encountered light SLW pockets. We lit BIPs and EJs the rest of the time, eventually running low on fuel RTB. After sundown SLW became very minimal.				
<i>Flight occurred in the afternoon hours of the 23rd; weather information is from Nov. 23rd.</i>					
Synoptic Analysis:	A strong northwesterly jet is in place over the region which will become more westerly tomorrow morning as a trough makes its way from the BC coast into the northern Rockies. Midlevel vorticity will impact WY in waves today and				



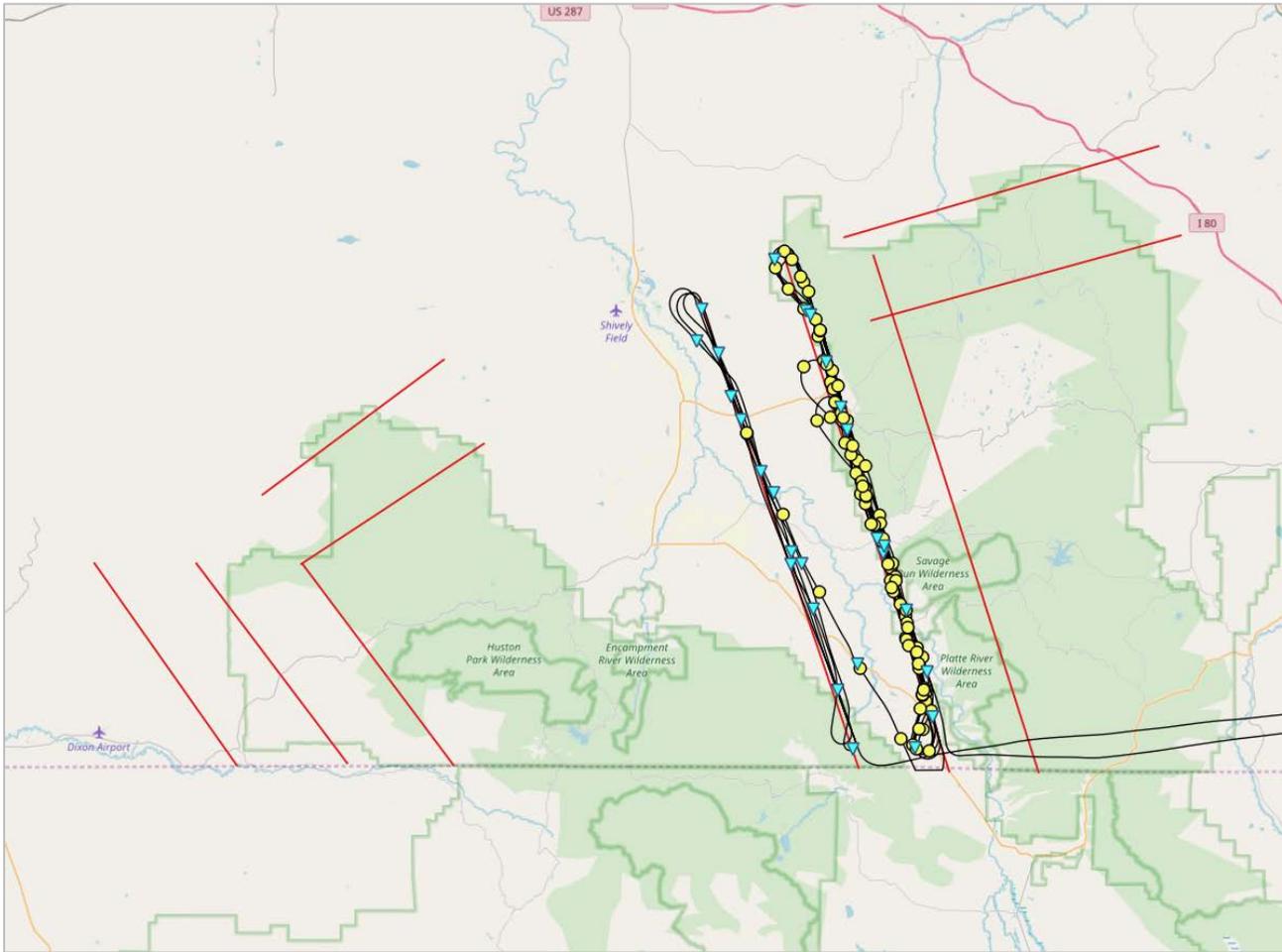
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	<p>tomorrow. The trough axis will pass through around sunset Saturday evening. A significant amount of low level moisture will be pushing through the project areas today and tonight, and then drier cooler air arrives quickly tomorrow afternoon. Midlevels are warming steadily today until around midnight in the warm sector of an approaching frontal system. A cold front will then move through tomorrow morning or early afternoon.</p>
Area Forecast:	<p>There is a bit of a lull in the precipitation and cloud thickness as of forecast time, but conditions will improve in the next hour or two with heavy precipitation and thick juicy orographic clouds starting up again. Heavy orographic mountain snowfall will continue this afternoon through tomorrow morning and then taper off during the early afternoon hours tomorrow. Another brief wave of precipitation will push through tomorrow evening, but this evening system looks to have significant natural ice crystals and will likely not be suitable for operations.</p>



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N127ZW		FLT. OPS #	05	SEED	
Track(s):		MB-4, MB-3		Fuel:	255gal.
UTC Date:	November 28, 2018		MST Date:	November 28, 2018	
UTC Engines ON:	13:13		MST Engines ON:	6:13 am	
UTC Engines OFF:	17:43		MST Engines OFF:	10:43 am	
Total Time:	4:30	4.5hr	Flares Used:	28 BIP	96 EJECT
Pilot's Flight Summary:	Took off out of CYS. Immediately upon entering clouds we pick up SLW. Flying over the ridges we picked up the most SLW. On MB-4 we used BIPs and EJs eventually rising out of the clouds/SLW due to the amount of SLW detected. We flew multiple passes until moving to MB-3, doing multiple passes then RTB due to low fuel. The transition from MB-4 to MB-3 was at radar instruction.				
<i>Flight occurred in the morning hours of the 28th; weather information is from Nov. 27th.</i>					
Synoptic Analysis:	A shortwave upper level ridge over Wyoming is on the move east this afternoon, with unsettled zonal flow taking shape behind it. A significant plume				



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	<p>of Pacific moisture is streaming onshore in California, and pieces of this moisture will move across our region with minor disturbances embedded in the zonal flow. The combination of the Pacific moisture and periods of mid-level dynamic support will create a few opportunities for seeding in the coming days. Although activity will not be as widespread or prolonged as what was observed a few days ago, there will likely be shorter duration periods where favorable SLW and orographic cloud are expected. The first of these opportunities will be in the late overnight hours, when PVA with a small shortwave trough supports upslope flow to create snow showers and some SLW over the target ranges.</p>
<p>Area Forecast:</p>	<p>Expect mid-level cloud cover to continue the rest of the afternoon. Virga is possible with this activity, but significantly dry low-level air should successfully inhibit precipitation the rest of the day. Mid-level moisture will be on the rise, however, with deeper dynamically supported snow showers likely by the late overnight hours. SLW appears somewhat limited at the onset of this activity around midnight, but should improve as the low levels moisten and better, lower based orographic cloud develops. Morning model consensus identifies the 10-18z time frame as the best window for targetable SLW, though this will obviously be reevaluated by observations and subsequent model runs today and tonight. Flight level winds will be brisk throughout the event, around 45kts and nearly due west tonight and tomorrow. By late tomorrow morning, the small shortwave trough exits the area, though modestly moist upslope flow continues. High based orographic cloud may continue across the target ranges, but is expected to be too high above the peaks and too shallow for effective seeding. Another shortwave trough and shot of moisture moves into the region Wednesday night. Another relatively quick opportunity for snow enhancement may be possible in the late overnight hours into Thursday morning.</p>



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N127ZW		FLT. OPS #	06		SEED
		Track(s):	MB-5, MB-3		Fuel: 300gal.
UTC Date:		November 28, 2018		MST Date: November 28, 2018	
UTC Engines ON:		21:00		MST Engines ON: 2:00 pm	
UTC Engines OFF:		01:45		MST Engines OFF: 6:45 pm	
Total Time:		4:45	4.75hr	Flares Used:	43 BIP 29 EJECT
Pilot's Flight Summary:	Departed CYS for MB-3. Picked up SLW (light/moderate) on the north and south ends of the track. As time progressed, SLW decreased so we moved to MB-5. Dropped EJs and burned BIPs until we ran low on fuel and radar requested we RTB.				
<i>Flight occurred in the afternoon hours of the 28th; weather information is from Nov. 28th.</i>					
Synoptic Analysis:	Jet level charts indicate a potent jet streak pushing onshore over California with strong westerly flow also observed over Wyoming. At the midlevels, small lobes of vorticity will push eastward through our region throughout the period. A closed midlevel low is moving inland over California tonight which will pass				



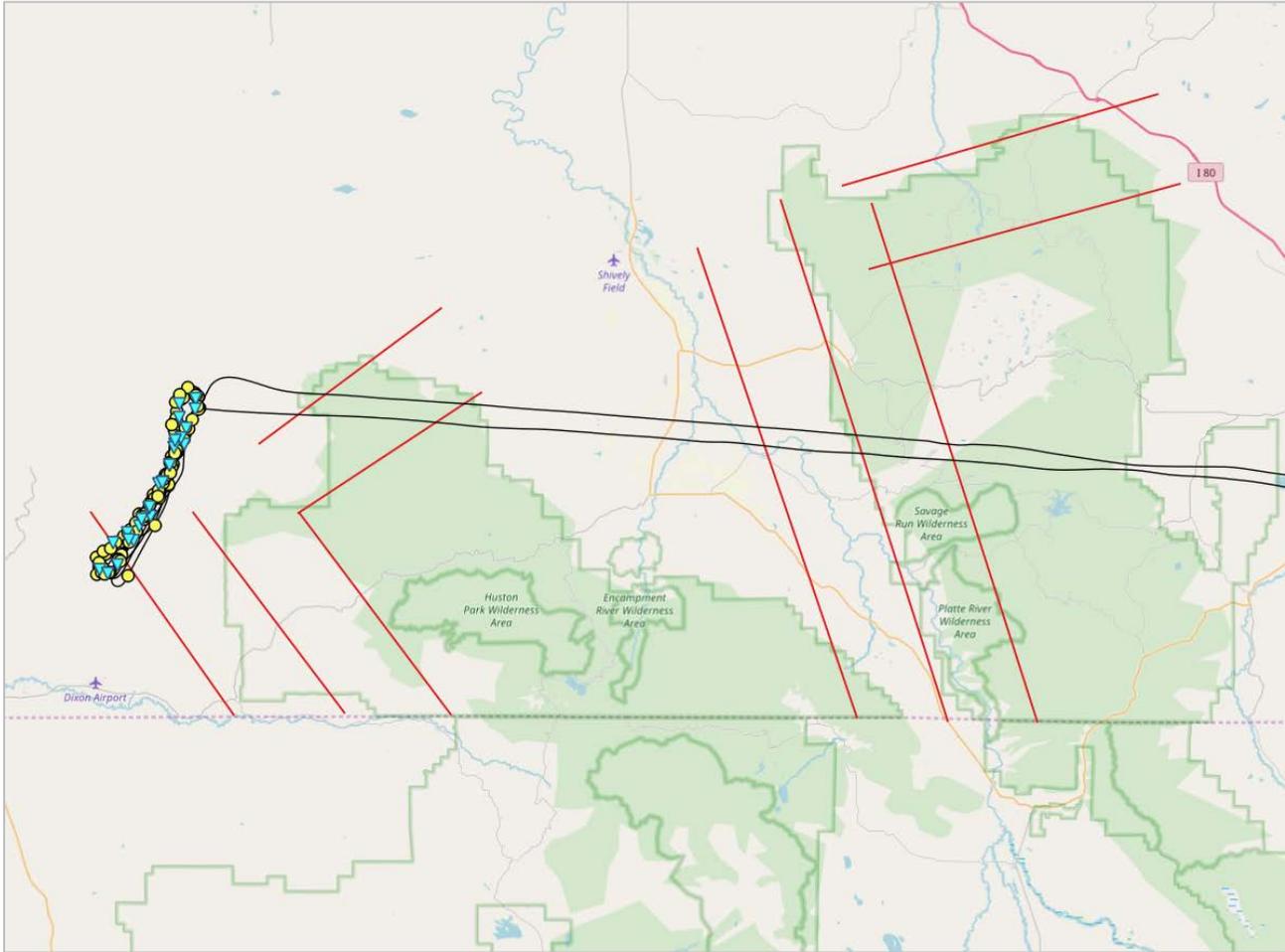
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	<p>through the Rockies tomorrow through Friday morning. Excellent low level moisture continues to flow through WY throughout the period. Precipitable Water will remain high through Friday night. Deep midlevel clouds will move in this evening and tonight with lots of natural seeder/feeder mechanism expected to deplete most of the SLW in the orographic clouds after around sunset. Webcams and satellite imagery indicate thick orographic clouds over the range as of forecast time.</p>
<p>Area Forecast:</p>	<p>Excellent orographic clouds are expected through the rest of the afternoon with high SLW content. A seeding flight will occur this afternoon. While orographic clouds are expected through midday tomorrow, much of this will contain significant ice crystals this evening and tonight. There may be a window for a flight tomorrow morning with better SLW, but it looks marginal and thin at this time. Snowfall and cloud coverage will persist through Friday night. Once the midlevel low moves through, dry conditions are likely for Saturday. Another significant system will push through on Sunday evening into Monday bringing another chance for operations.</p>



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N127ZW		FLT. OPS #	07	SEED	
Track(s):		Modified		Fuel:	292gal.
UTC Date:	December 19, 2018		MST Date:	December 18, 2018	
UTC Engines ON:	06:00		MST Engines ON:	11:00 pm	
UTC Engines OFF:	10:40		MST Engines OFF:	3:40 am	
Total Time:	4:40	4.67hr	Flares Used:	27 BIP	71 EJECT
Pilot's Flight Summary:	We took off out of CYS to the west climbing to 20kft to get above the tops of the clouds. Upon reaching our custom track, due to a northwest wind, we descended down to 14kft and initially picked up heavy SLW. We then climbed to 16kft to get above the heavy SLW and began using EJs. After sometime the tops began to lower and we descended back down to 14kft picking up light to moderate SLW pockets. This whole time we were using EJ and BIPs. Eventually running low on fuel we RTB.				
<i>Flight occurred in the evening hours of the 18th; weather information is from Dec. 18th.</i>					



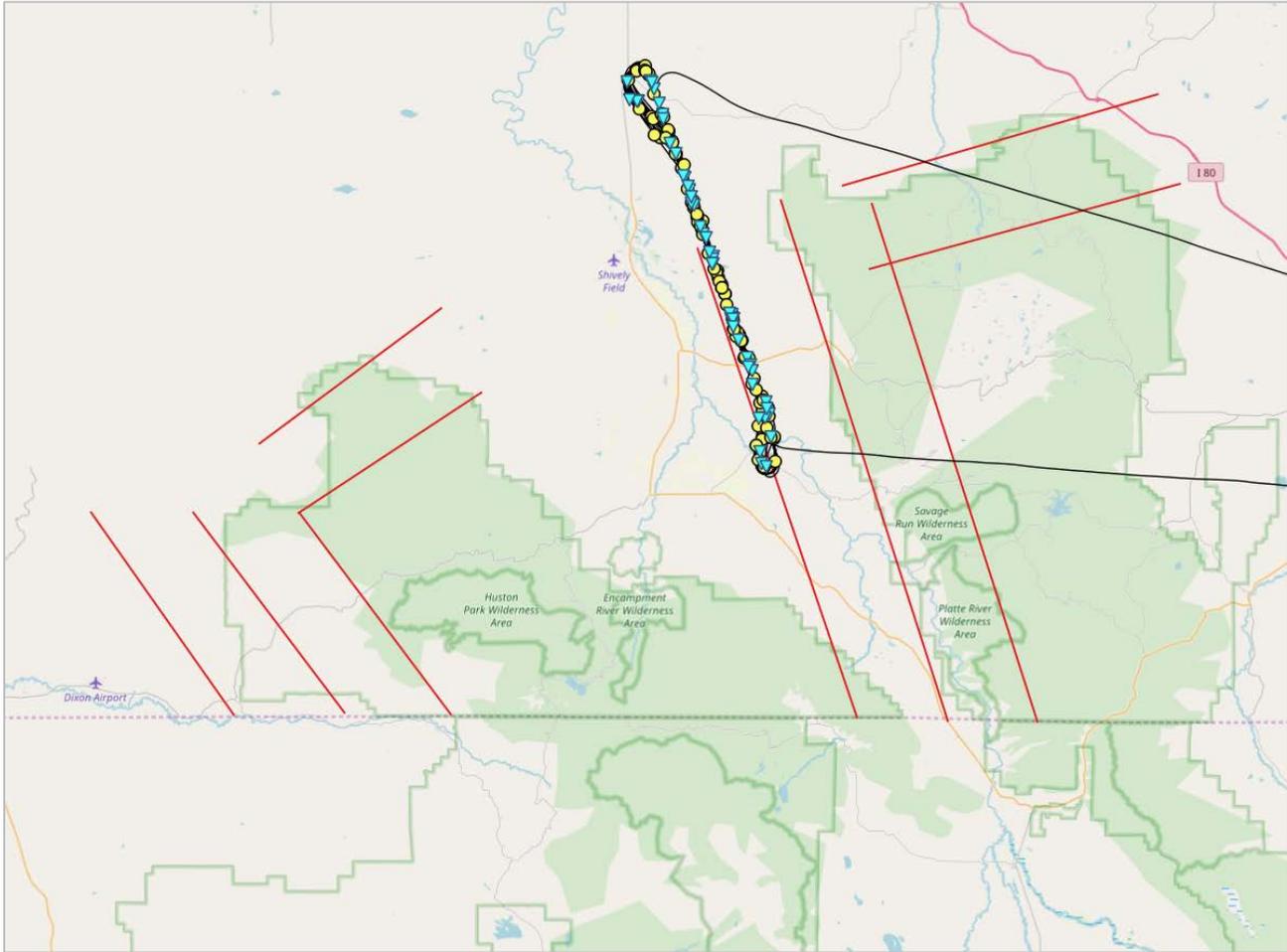
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<p>Synoptic Analysis:</p>	<p>A weak shortwave trough axis is exiting east into Nebraska this afternoon while an upper level jet streak in the Pacific Northwest takes aim for our region. A new modest shortwave trough is expected to develop rapidly this afternoon across Washington state and quickly blitz southeast with the jet streak into Wyoming late tonight into tomorrow. A light push of Pacific moisture will accompany the shortwave trough, though insufficient to inspire meaningful SWE outside of the mountains. In the ranges, however, prolonged and sometimes fierce northwest upslope flow will provide a period of deeper orographic cloud at favorable temperatures for seeding operations. Current model suggestions indicate the best seedable conditions will begin around midnight tonight, continuing intermittently until drier air infiltrates early tomorrow afternoon.</p>
<p>Area Forecast:</p>	<p>Scattered to broken stratus clouds with bases beneath the peaks will continue the rest of the afternoon and evening. Deeper orographically enhanced cloud will develop around and after midnight, with periods of opportune seedable conditions anticipated into Wednesday morning. Flight level winds will increase from around 35kts at midnight to upwards of 60kts by dawn, and will slowly pivot from west-northwest to northwest tomorrow morning. Conditions at KCYS will also become extremely windy tomorrow morning, with strong low-level wind shear and surface gusts as high as 50 kts forecasted in the latest TAF. Winds will continue to pivot more northerly tomorrow afternoon as a ridge begins to build across the western CONUS. This will allow drier air to advect into the area, gradually weakening the orographic cloud. Seeable conditions are not anticipated. Conditions will continue to dry out and warm as the ridge spreads toward Wyoming Thursday, with the next weather system expected behind the ridge Friday.</p>



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N127ZW		FLT. OPS #	08	SEED	
Track(s):		Modified		Fuel:	270gal.
UTC Date:	December 19, 2018		MST Date:	December 19, 2018	
UTC Engines ON:	11:58		MST Engines ON:	4:58 am	
UTC Engines OFF:	17:26		MST Engines OFF:	10:26 am	
Total Time:	5:28	5.47hr	Flares Used:	48 BIP	100 EJECT
Pilot's Flight Summary:	We took off out of CYS and climbed to 14kft. Upon reaching the track, we burned flares and fired EJs, broadcast seeding a majority of the time. We occasionally picked up light SLW but were mostly in the clear. Radar showed continuous echoes the entire time we were seeding.				
<i>Flight occurred in the morning hours of the 19th; weather information remains the same as Flight #7.</i>					



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N127ZW	FLT. OPS #	09		SEED	
	Track(s):	SM4, MB4		Fuel:	261gal.
UTC Date:	December 30, 2018		MST Date:	December 30, 2018	
UTC Engines ON:	19:53		MST Engines ON:	12:53 pm	
UTC Engines OFF:	00:48		MST Engines OFF:	5:48 pm	
Total Time:	4:55	4.92hr	Flares Used:	16 BIP	93 EJECT
Pilot's Flight Summary:	<p>We took off out of CYS to the west climbing to 20kft to get above the tops of the clouds. Upon reaching our custom track, due to a northwest wind, we descended down to 14kft and initially picked up heavy SLW. We then climbed to 16kft to get above the heavy SLW and began using EJs. After sometime the tops began to lower and we descended back down to 14kft picking up light to moderate SLW pockets. This whole time we were using EJ and BIPs. Eventually running low on fuel we RTB.</p>				
<p><i>Flight occurred in the evening hours of the 18th; weather information is from Dec. 18th.</i></p>					



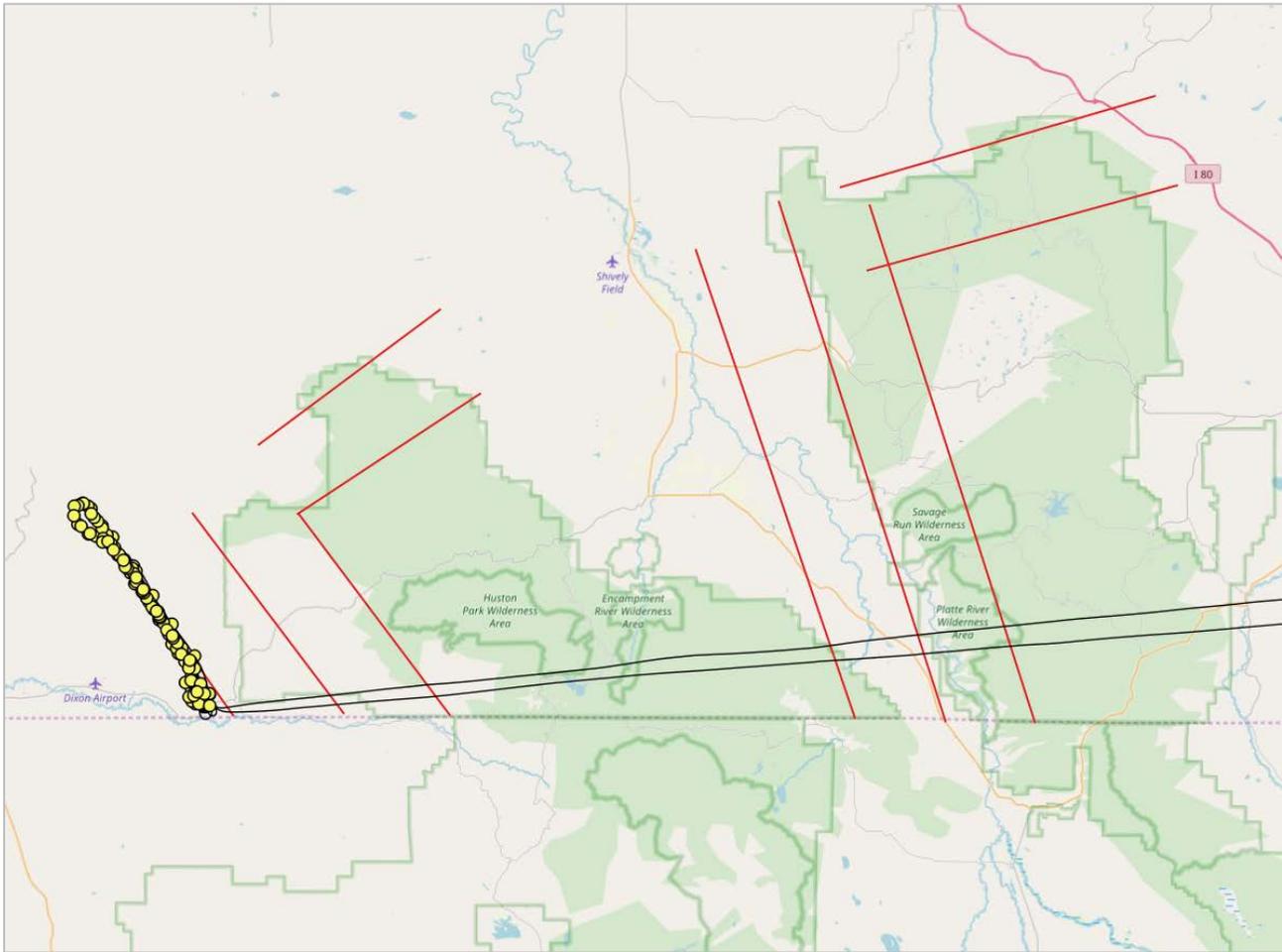
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<p>Synoptic Analysis:</p>	<p>A weak shortwave trough axis is exiting east into Nebraska this afternoon while an upper level jet streak in the Pacific Northwest takes aim for our region. A new modest shortwave trough is expected to develop rapidly this afternoon across Washington state and quickly blitz southeast with the jet streak into Wyoming late tonight into tomorrow. A light push of Pacific moisture will accompany the shortwave trough, though insufficient to inspire meaningful SWE outside of the mountains. In the ranges, however, prolonged and sometimes fierce northwest upslope flow will provide a period of deeper orographic cloud at favorable temperatures for seeding operations. Current model suggestions indicate the best seedable conditions will begin around midnight tonight, continuing intermittently until drier air infiltrates early tomorrow afternoon.</p>
<p>Area Forecast:</p>	<p>Scattered to broken stratus clouds with bases beneath the peaks will continue the rest of the afternoon and evening. Deeper orographically enhanced cloud will develop around and after midnight, with periods of opportune seedable conditions anticipated into Wednesday morning. Flight level winds will increase from around 35kts at midnight to upwards of 60kts by dawn, and will slowly pivot from west-northwest to northwest tomorrow morning. Conditions at KCYS will also become extremely windy tomorrow morning, with strong low-level wind shear and surface gusts as high as 50 kts forecasted in the latest TAF. Winds will continue to pivot more northerly tomorrow afternoon as a ridge begins to build across the western CONUS. This will allow drier air to advect into the area, gradually weakening the orographic cloud. Seeable conditions are not anticipated. Conditions will continue to dry out and warm as the ridge spreads toward Wyoming Thursday, with the next weather system expected behind the ridge Friday.</p>



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N127ZW		FLT. OPS #	10	SEED	
Track(s):		SM3		Fuel:	260gal.
UTC Date:	January 7, 2019		MST Date:	January 7, 2019	
UTC Engines ON:	13:14		MST Engines ON:	6:14 am	
UTC Engines OFF:	18:18		MST Engines OFF:	11:18 am	
Total Time:	5:04	5.07hr	Flares Used:	0 BIP	191 EJECT
Pilot's Flight Summary:	We took off out of CYS and proceed to SM3. Upon crossing the ridge we picked up moderate/heavy SLW. Upon reaching SM3 we were on station for 5+ hours dropping EJ on the layer below that seemed to range from 10-14kft. Eventually we began to run low on fuel and headed back to CYS.				
<i>Flight occurred in the morning hours of the 7th; weather information is from Jan. 6th.</i>					
Synoptic Analysis:	Jet level charts show strong southwest flow over the region as a large scale trough pushes through the Rockies. Flow will become more westerly as the trough axis moves through tonight, and then strong northwest flow is likely				



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	<p>tomorrow morning. A shortwave will be pushing through the region Monday right behind today's system. Excellent moisture will linger over the region through Tuesday. Ridging and dry conditions are likely Tuesday and Wednesday. Some low level moisture is likely to push through Thursday even with the ridge in place due to a massive low pressure system off the CA coast which will be drawing Pacific moisture into the region. The 500mb temps will be dropping steadily through midnight, bottoming late tonight around -26C. Deep SLW is likely this afternoon through late evening, and then SLW layers will become shallow overnight. Impressive SLW is expected to redevelop tomorrow morning and afternoon.</p>
<p>Area Forecast:</p>	<p>Seedable clouds are likely today and tomorrow with a lull in the activity late tonight. With two seeding windows through the next 48 hours, we have the luxury of picking and choosing how we would like to spend our limited remaining flight hours. The most productive option will be to pass on seeding today in favor of the excellent conditions indicated for tomorrow morning through early afternoon. Heavy snowfall is likely throughout most of the next 48 hours, tapering off tomorrow night. There will be a bit of a lull in the activity late tonight, but not for long. The best seeding window will be from around 8am Monday through midafternoon. No seeding is expected Tuesday or Wednesday.</p>



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N127ZW		FLT. OPS #	11	SEED	
Track(s):		SM4/Modified, MB4		Fuel:	273gal.
UTC Date:	January 23, 2019		MST Date:	January 23, 2019	
UTC Engines ON:	19:00		MST Engines ON:	12:00 pm	
UTC Engines OFF:	23:35		MST Engines OFF:	4:35 pm	
Total Time:	4:35	4.58hr	Flares Used:	3 BIP	171 EJECT
Pilot's Flight Summary:	We took off out of CYS and flew to SM4. Upon getting there we started flying a modified track that was about 5 miles north of our usual track due to wind. Upon crossing the ridge we found SLW and upon arriving on track found cloud tops ranged from 12.5kft to 13.1kft. Eventually we moved to the MB4 track, picked up SLW, and cutoff the southern quarter of the track. Eventually running low on fuel we RTB.				
<i>Flight occurred in the afternoon hours of the 23th; weather information is from Jan. 22th.</i>					
Synoptic Analysis:	Jet level charts show a large scale trough exiting the region to the east while a strong northerly jet moves into place over the Rockies. This general pattern				



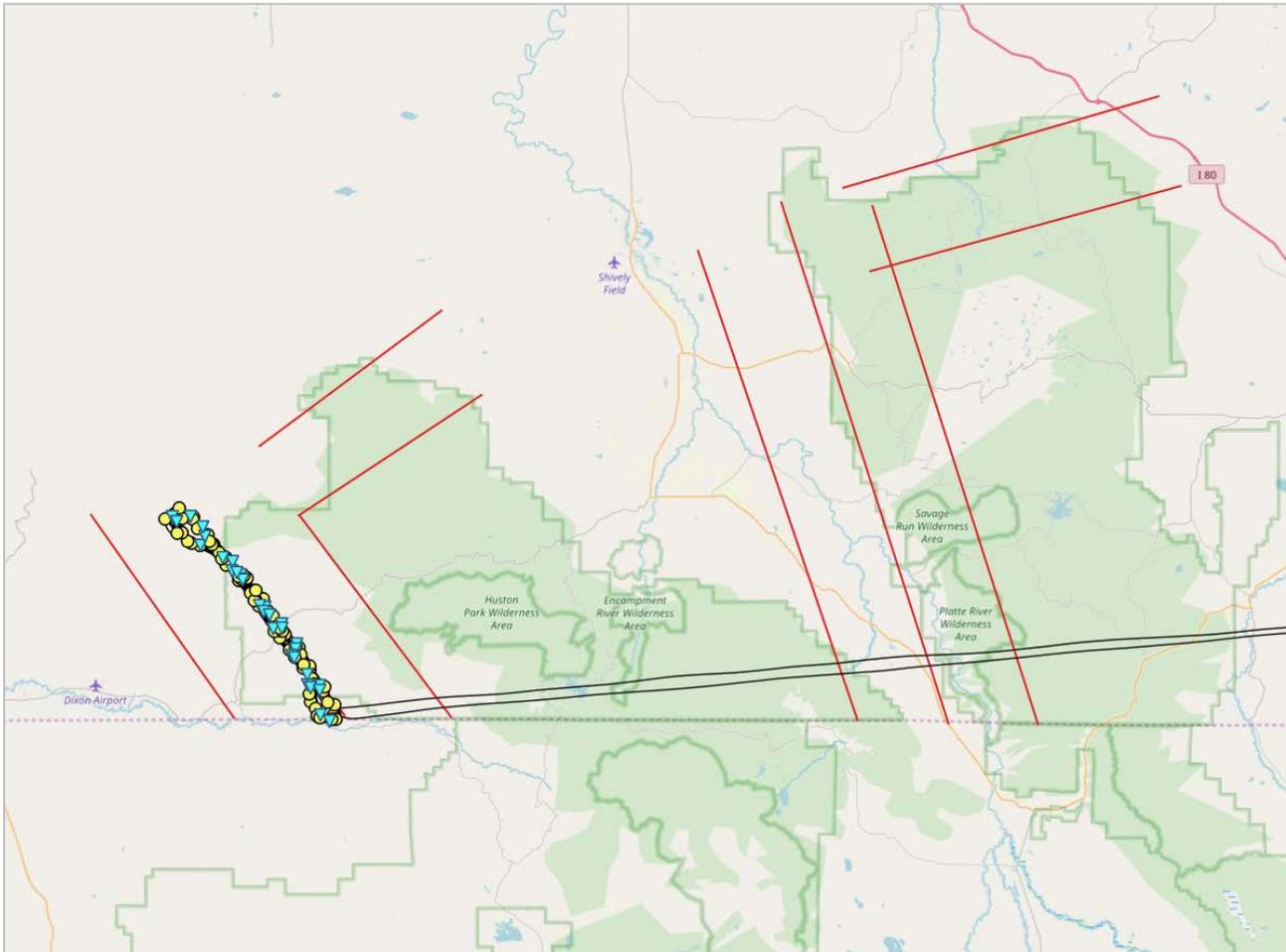
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	<p>with N or NW flow looks to remain in place for the coming week as a large ridge lingers over the eastern Pacific. A dry cool air mass is flowing into the region today, and cloud cover is gradually diminishing as moisture fades. Moisture will begin to return early tomorrow morning through the afternoon with northwesterly and favorable orographic winds. Bits of shortwave vorticity will be pushing through tomorrow afternoon through late night, creating deeper midlevel clouds as well. Models indicate good orographic clouds tomorrow afternoon through late night with only intermittent patchy SLW. The SM and NS ranges look to see mostly ice crystals, while the MB may see somewhat better SLW. Midlevel temperatures will be rising through late tonight and then falling steadily tomorrow starting at 5am.</p>
<p>Area Forecast:</p>	<p>Cloud cover will continue to diminish throughout the afternoon, and partial clearing is expected this evening into the late-night hours. Precipitable Water will increase again starting around 5am, and cloud cover will redevelop through the morning and afternoon tomorrow. Light orographic snowfall is expected to begin around dawn tomorrow for the MB and SM and continue through Thursday morning, spreading to the NS in the afternoon. The SM and NS ranges look to have very minimal SLW tomorrow and tomorrow night. The MB, however, may have a targetable window for operations during the afternoon to early evening before the deepest midlevel clouds and natural seeder/feeder kicks in. Moisture will decrease Thursday into Friday, and then the next small wave of moisture moves in Friday evening with minimal midlevel forcing and strong northwest flow. This may be a decent setup for some good targetable orographic SLW sometime Friday afternoon into Friday night, depending on how much overall moisture is available.</p>



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N127ZW		FLT. OPS #	12	SEED	
Track(s):		SM4		Fuel:	285gal.
UTC Date:	February 3, 2019		MST Date:	February 2, 2019	
UTC Engines ON:	06:55		MST Engines ON:	11:55 pm	
UTC Engines OFF:	11:27		MST Engines OFF:	4:27 am	
Total Time:	4:32	4.53hr	Flares Used:	31 BIP	72 EJECT
Pilot's Flight Summary:	Took off and proceeded to the SM4 range. Initially, at 15kft we picked up light to moderate SLW and began using flares and EJs. Eventually we began running into pockets of light SLW and descended down to 14kft where we found more consistent light SLW. Eventually running low on fuel we RTB.				
<i>Flight occurred in the evening hours of the 2nd; weather information is from Feb. 2nd.</i>					
Synoptic Analysis:	No good ridge goes unpunished. After a number of days with brilliantly clear skies and pleasant temperatures, the trough of reckoning is now marching east toward the central California coast. This is a sizeable disturbance, with flow				



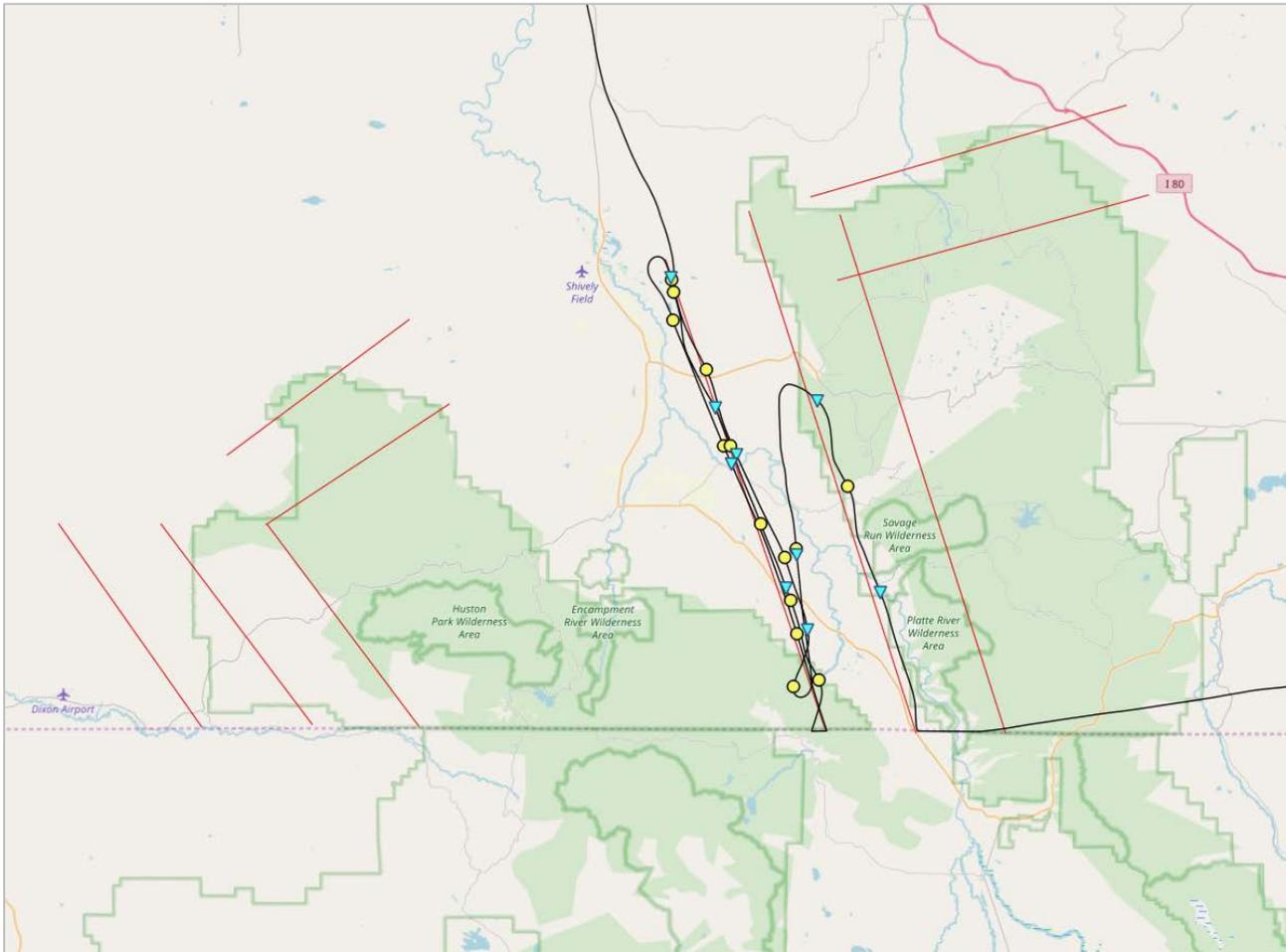
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	<p>already pivoting south-southwest well in advance of its arrival. Substantial moisture accompanies this longwave disturbance, and positive moisture advection is ongoing with PWAT increasing to nearly a half inch by tomorrow morning. Low-level moisture is expected to become sufficient for moderate to deep orographic clouds with targetable SLW after midnight in the SM range, with conditions improving further east through the remainder of the night. PVA will instigate synoptic scale snow showers by dawn Sunday, with orographic enhancement continuing through the rest of the forecast period.</p>
<p>Area Forecast:</p>	<p>Shallow orographic clouds this afternoon will deepen overnight. The Sierra Madre range will be first to develop clouds suitable for seeding, with this timing currently expected around 9Z tonight. Flight level winds at this time will be brisk from the southwest around 50kts. -10C heights will begin around 15kft, but slowly dip toward 13kft by midday Sunday. Further east, in the Never Summer range, suitable seeding conditions will be slower to develop, but improve around dawn Sunday. Winds in that range will similarly be southwest around 50kts. Cooling temperatures will be the predominant concern by Sunday afternoon, with -15C heights falling below optimal levels in all ranges. Conditions at KCYS appear reasonable for operations overnight, with little to no precipitation and 10-15kt winds, but conditions deteriorate through Sunday morning as strong downslope winds mix down to the surface. A high wind watch has been issued for wind gusts exceeding 50mph midday Sunday.</p>



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N127ZW	FLT. OPS #	13		SEED	
	Track(s):	MB4, MB3		Fuel:	180gal.
UTC Date:	February 14, 2019		MST Date:	February 14, 2019	
UTC Engines ON:	13:14		MST Engines ON:	6:14 am	
UTC Engines OFF:	15:39		MST Engines OFF:	8:39 am	
Total Time:	2:25	2.42hr	Flares Used:	10 BIP	15 EJECT
Pilot's Flight Summary:	On climb to 16kft encountered moderate to heavy SLW crossing the ridge. Descended to 14kft on MB4 track. Encountered moderate to heavy SLW and moderate to severe icing. Climbed back up to 16kft and moved to MB3 track. Encountered moderate SLW and seeded with BIPs and EJs until no longer able to sustain flight in icing. RTB.				
<i>Flight occurred in the morning hours of the 14th; weather information is from Feb. 13th.</i>					
Synoptic Analysis:	Zonal, perturbed flow has developed across a broad swath of the intermountain west as moisture pours in from the Pacific. Although a more pronounced shortwave trough will pass to our north today, smaller scale disturbances in the				



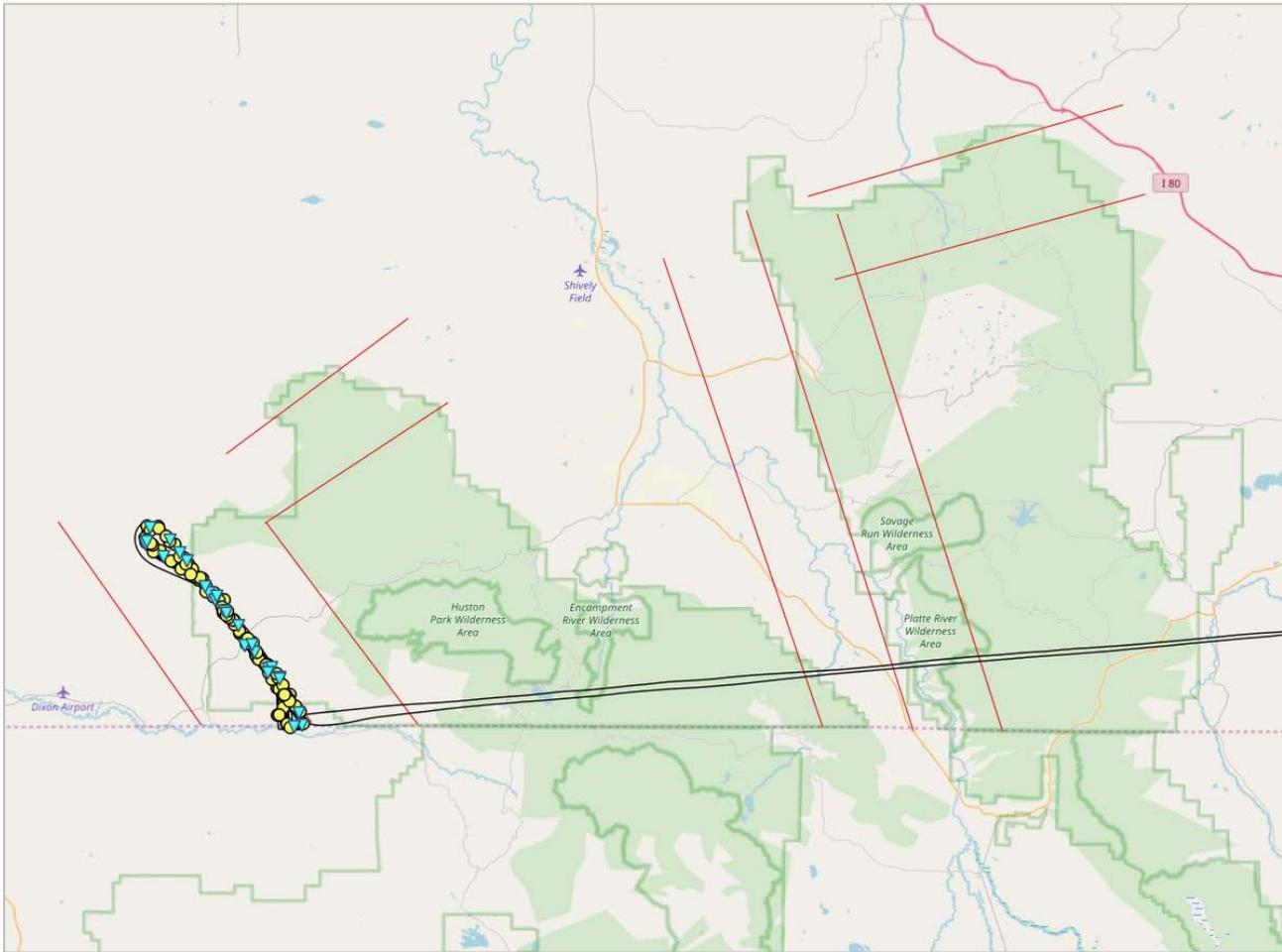
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	<p>mid and upper level flow will transit our project area, with the best mid-level forcing occurring during the middle of the night tonight. Surface and low-level moisture, which has been very dry despite extensive mid-level cloudiness, will increase substantially through the remainder of the afternoon, with orographic cloud depth and coverage increasing in kind. A subtle shortwave trough will spread across Wyoming tomorrow afternoon, before an ominous series of troughs blitz the region Thursday night and Friday. 48-hour QPF totals over 2" SWE are expected in the SM range, and over 1" in the MB and NS ranges.</p>
<p>Area Forecast:</p>	<p>Mid-level virga will sublimate and saturate the low-levels this afternoon, with widespread snow then likely in the project area this eve. Synoptic scale activity will ebb overnight, though orographic clouds will potentially targetable SLW will persist. A second round of deeper synoptic scale precipitation is prognosticated after midnight, with deep and particularly promising orographic cloud predicted in its wake. This morning's models would suggest operations from an hour around dawn until the early afternoon would capture the best seeding opportunities in the MB and SM range. For the NS range, conditions do not appear quite as favorable overnight and into the morning, but a shorter favorable window is currently identified from around 18z to 22z tomorrow. Flight level winds will be brisk in all regions, especially early, with winds nearly due west at around 50kts. Flight-level temps will creep warmer with time but will remain perfectly suitable for our operations. Morning LLWS with occasional strong surface gusts are the only likely weather threat at KCYS.</p>



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N127ZW		FLT. OPS #	14	SEED	
		Track(s):	SM4	Fuel:	255gal.
UTC Date:	March 1, 2019	MST Date:	March 1, 2019		
UTC Engines ON:	08:01	MST Engines ON:	1:01 am		
UTC Engines OFF:	12:41	MST Engines OFF:	5:41 am		
Total Time:	4:40	4.67hr	Flares Used:	27 BIP	95 EJECT
Pilot's Flight Summary:	Took off out of CYS and climbed to 20kft. Cloud tops were between 19kft and 20kft with pockets of light SLW. As we were seeding we kept descending down trying to find better SLW. Usually we found pockets of SLW that lasted at maximum 15 minutes. EJs were lit every one or two minutes depending on conditions. Eventually running low on fuel we RTB.				
<i>Flight occurred in the early morning hours of the 1st; weather information is from Feb. 28th.</i>					
Synoptic Analysis:	A blocking pattern is holding steadfast across North America today with a classic omega block centered over Alaska. An entrenched low-pressure system over				



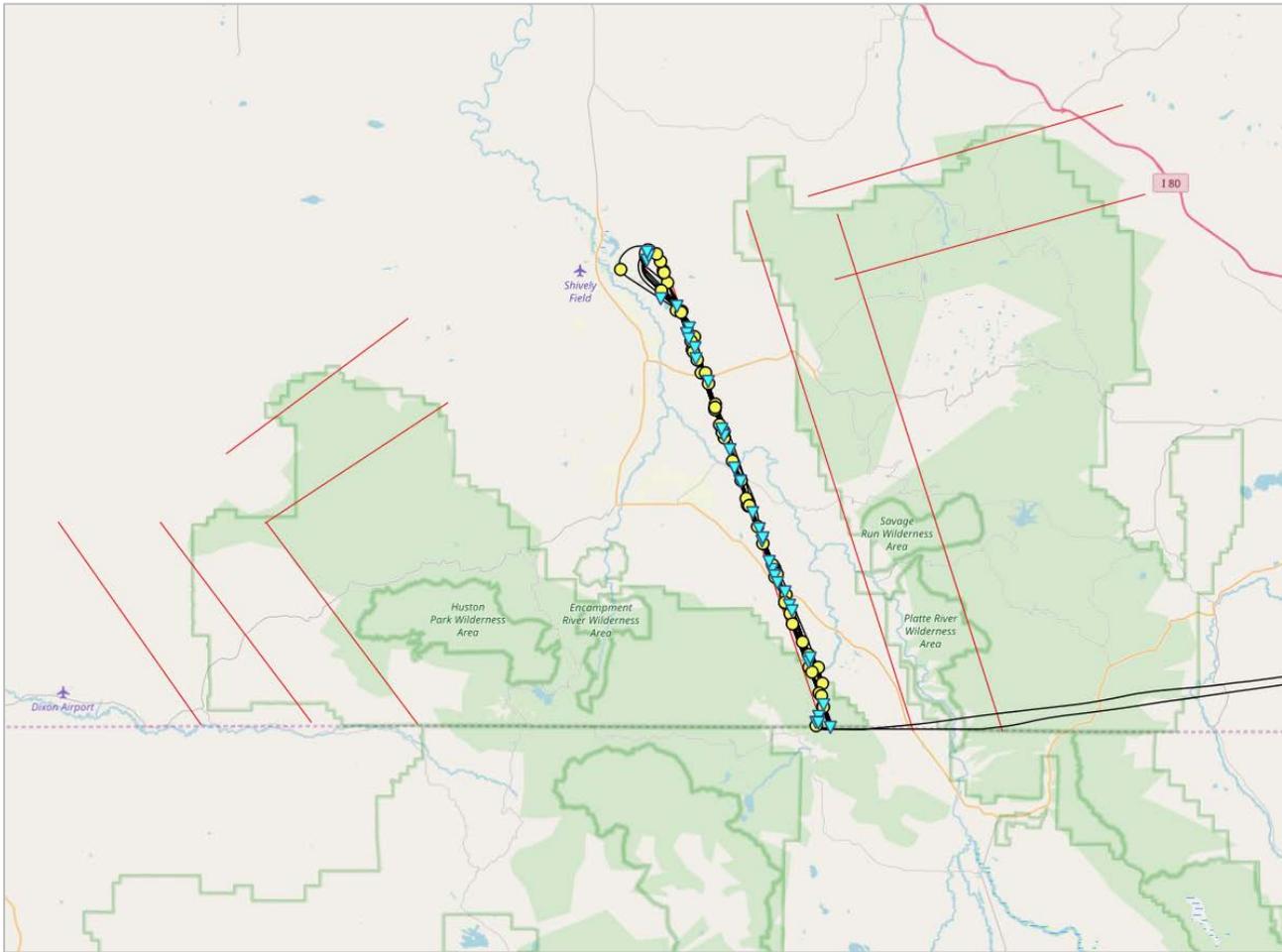
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	<p>the Pacific Northwest continues to drive Pacific moisture onshore, and a variety of small-scale perturbations (low amplitude and small wavelength troughs and ridges) in the flow are instigating areas of precipitation across the intermountain west. A shortwave ridge brought temporary relief from the parade of mid-level disturbances late last night and early this morning, but it has since dissipated and progressed east of our region. Moisture and vorticity advection has increased in its wake, with snow showers beginning around noon in the Sierra Madre range and spreading east in the last couple hours.</p>
<p>Area Forecast:</p>	<p>Upslope flow with orographic cloud cover will continue throughout the forecast period, occasionally accented by deeper synoptic scale snow showers associated with passing disturbances in the mid-level flow. Model prognostications for SLW have been mixed in the last few cycles, with the timing of the best SLW gradually shifting later into Friday instead of in overnight hours tonight. Mid-level temperatures are poised to slowly cool tomorrow as influence from an arctic trough in Central Canada slips south. However, provided temperatures to not drop too cold, a seeding window for at least one flight appears promising in a broad timeframe from Friday morning into the evening. Synoptic scale precipitation coverage increases late Friday as a more formidable shortwave trough axis approaches the region, with significant snow potentially making flight operations in/out of KCYS difficult beginning Friday evening. A winter storm watch has been issued for Cheyenne from 11pm Friday through 11pm Saturday.</p>



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N127ZW	FLT. OPS #		15		SEED	
	Track(s):		MB3		Fuel:	
UTC Date:	March 6, 2019		MST Date:		March 6, 2019	
UTC Engines ON:	09:25		MST Engines ON:		2:25 am	
UTC Engines OFF:	14:00		MST Engines OFF:		7:00 am	
Total Time:	4:35	4.58hr	Flares Used:		39 BIP	62 EJECT
Pilot's Flight Summary:	Took off out of CYS and climbed to 17kft. During climbout we picked up moderate icing and SLW. Upon reaching MB3 we began using BIPs and eventually descended down to 16kft for better SLW conditions. When we began hitting pockets of SLW we descended to 15kft in search of better SLW but found less favorable conditions so climbed back to 16kft. Eventually we started dropping EJs every two minutes and radar indicated echoes from those EJs. Running low on fuel we RTB. As we were enroute back we picked up light/moderate SLW over the ridge.					
<i>Flight occurred in the morning hours of the 6th; weather information is from Mar. 5th.</i>						



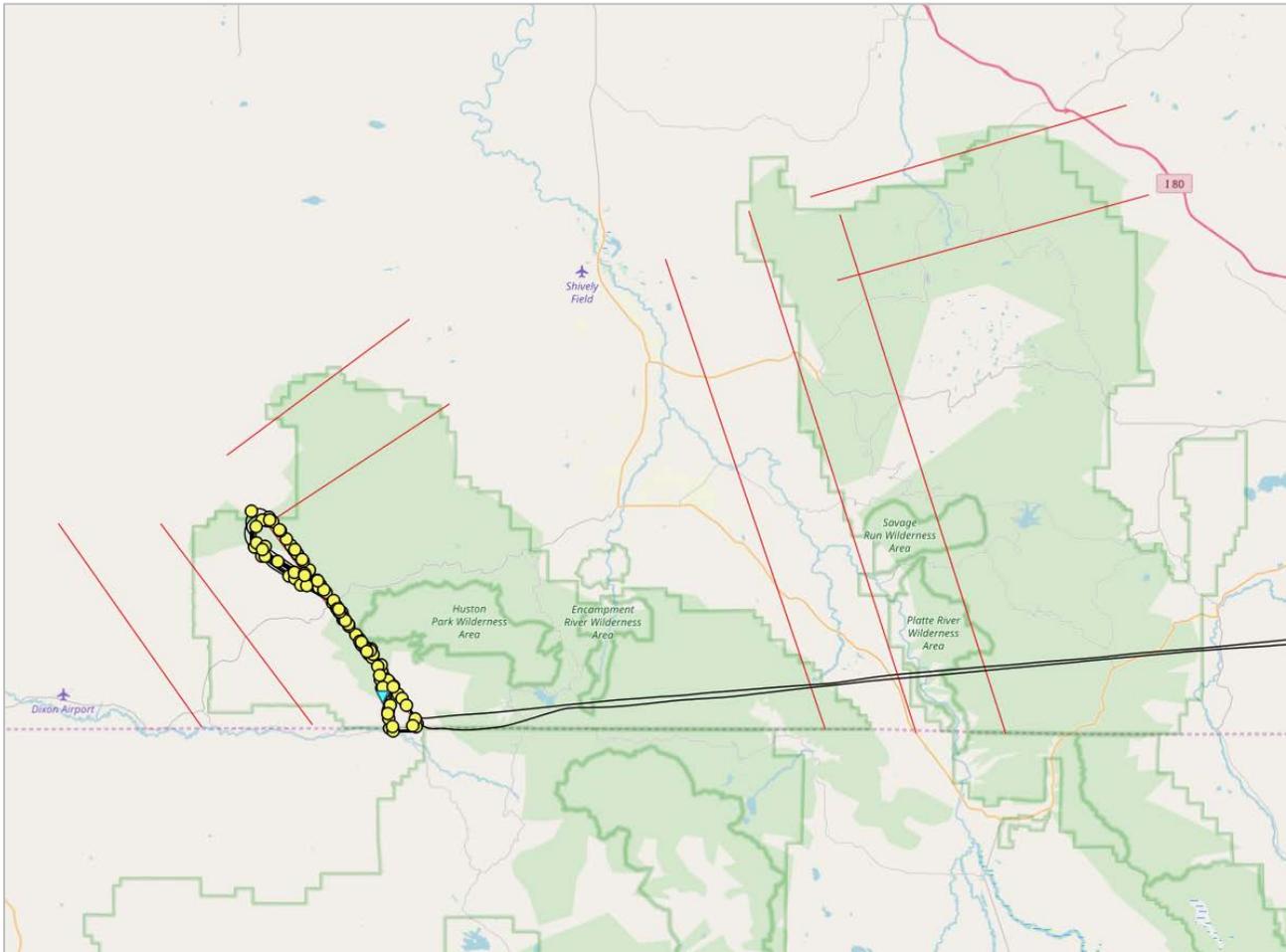
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<p>Synoptic Analysis:</p>	<p>The axis of a broad upper level ridge is sweeping east toward Wyoming this afternoon, pushed aggressively by a series of shortwave troughs along with a longwave trough progressing toward the California coast. The upper level ridge axis will likely crest shortly after dusk, with southwest flow brining PVA and significant moisture transport is occurring immediately behind it. The mid-levels moistening rapidly in response to the synoptic scale lift and Pacific moisture pump, though the low-levels, dry from the bitterly cold airmass in place the last couple days, will need to be primed before precipitation reaches the surface. Once primed, however, waves of orographically enhanced precipitation are likely from late tonight through the day Wednesday.</p>
<p>Area Forecast:</p>	<p>Shallow cap clouds over the higher peaks will be joined by a wall of deep mid and upper level clouds immediately behind the ridge axis in the late evening. Virga will begin falling out of this activity quickly, eventually leading to snow primarily in the mountains and higher terrain overnight. A second push of stronger synoptic scale precipitation will arrive early to mid-morning, with snow showers covering the entire project area. QPF totals through 5pm tomorrow evening will approach an inch SWE in the SM; closer to 0.5" in the MB & NS ranges. In Cheyenne, a mix of light precipitation is possible Wednesday morning, with a low-level downslope inversion complicating the precipitation type. Freezing rain concerns will need to be monitored until surface temperatures moderate into the upper 30s midday. Current model guidance shows limited SLW during the initial shortwave disturbance in the late-night hours tonight, but very strong west-southwest upslope flow with periods of deep rich orographic cloud from just before dawn through much of the day Wednesday.</p>



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N127ZW		FLT. OPS #	16	SEED	
Track(s):		MB3		Fuel:	254gal.
UTC Date:	March 23, 2019		MDT Date:	March 23, 2019	
UTC Engines ON:	12:19		MDT Engines ON:	6:19 am	
UTC Engines OFF:	16:14		MDT Engines OFF:	8:14 am	
Total Time:	3:55	3.92hr	Flares Used:	1 BIP	130 EJECT
Pilot's Flight Summary:	Took off and proceeded to SM5 for a seed mission. When crossing the ridge we picked up light SLW and continuously detected light SLW for a majority of the flight. Cloud tops were 13.2kft and the tops were continually filled with SLW until we were done seeding. As we left SLW became spotty. We RTB due to low fuel and ended up shooting an approach due to worsening weather conditions.				
<i>Flight occurred in the morning hours of the 23rd; weather information is from Mar. 22nd.</i>					
Synoptic Analysis:	A massive and slow-moving closed low is creeping east across the western Rockies this afternoon as a shortwave ridge slides to progress across NV and UT.				



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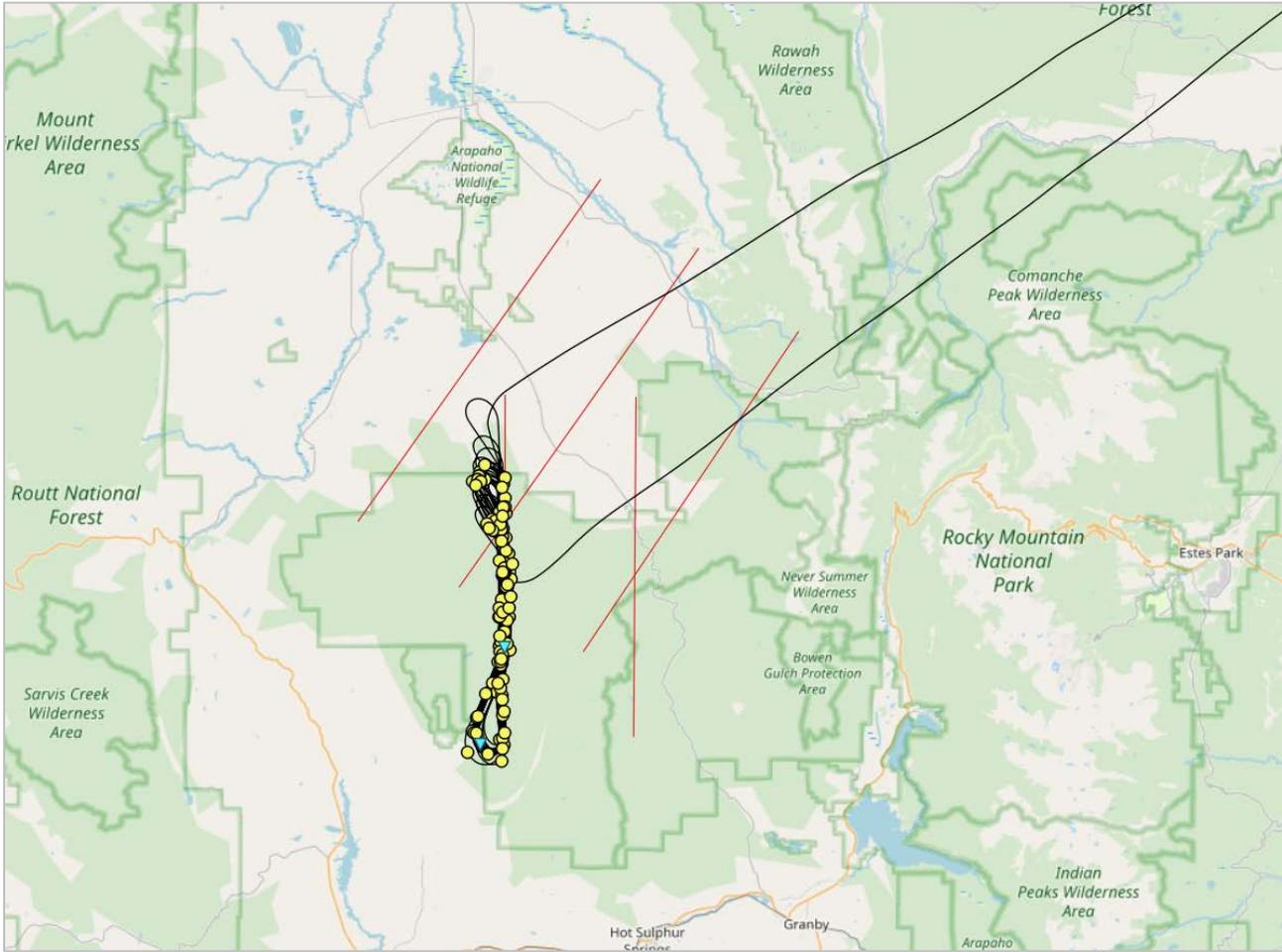
	<p>Copious mid-level moisture has accompanied the low with south to southeast flow aloft, but will subside as the upper-level trough axis clears the area tomorrow. Low to mid-level flow is surprisingly weak in the heart of this broad cyclonic circulation, with flight-level winds expected to be a meager 10kts overnight. They will slowly increase from the west to northwest tomorrow as the height gradient tightens ahead of the incoming ridge. Low-level moisture, which along with light upslope flow has led to meager orographic cloud thus far, will finally be suitable for deeper orographic cloud and SLW late tonight into tomorrow morning.</p>
<p>Area Forecast:</p>	<p>Broken to overcast skies with scattered rain/snow showers will continue through the afternoon. Orographic cloud will remain generally shallow and insignificant into the evening. Low level flow pivots west overnight as the trough continues to progress east, and better low-level moisture and upslope flow should foster better orographic cloud in the late overnight hours into Saturday morning. Cloud and SLW depth appear marginal, but possible, for seeding enhancement in this window. Orographic cloud will likely become higher based Saturday afternoon, with depth remaining marginally suitable. Conditions at KCYS will be challenging this forecast period. Periods of rain will continue this afternoon and change to snow late tonight. This snow will be heavy at times, with embedded convection possible overnight. At the onset of our anticipated seeding window, this precipitation should be much weaker, but rain/snow showers will remain possible through Saturday. Gusty northerly surface winds up to 20-30mph are expected.</p>



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5.2 Seeding Mission Flight Tracks – Never Summer Range, CO



N127ZW	FLT. OPS #	1 – NEVER SUMMER RANGE			SEED
	Track(s):	NS4		Fuel:	265gal.
UTC Date:	February 3, 2019		MST Date:	February 3, 2019	
UTC Engines ON:	12:02		MST Engines ON:	5:02 am	
UTC Engines OFF:	17:05		MST Engines OFF:	10:05 am	
Total Time:	5:03	5.05hr	Flares Used:	2 BIP	204 EJECT
Pilot's Flight Summary:	Took off and flew to NS4 initially starting the track at 16kft. We arrived before any consistent seedable targets so we had time of seeding and recon sporadically. Eventually the clouds began to form a layer below in which we began dropping EJs. SLW was light to moderate while in the clouds and we flew the southern third of the track most of the time due to favorable seeding conditions being on the southern end. After burning through most of our fuel and two racks of EJs we RTB.				
<i>Flight occurred in the morning hours of the 3rd; weather information is from Feb. 2nd.</i>					



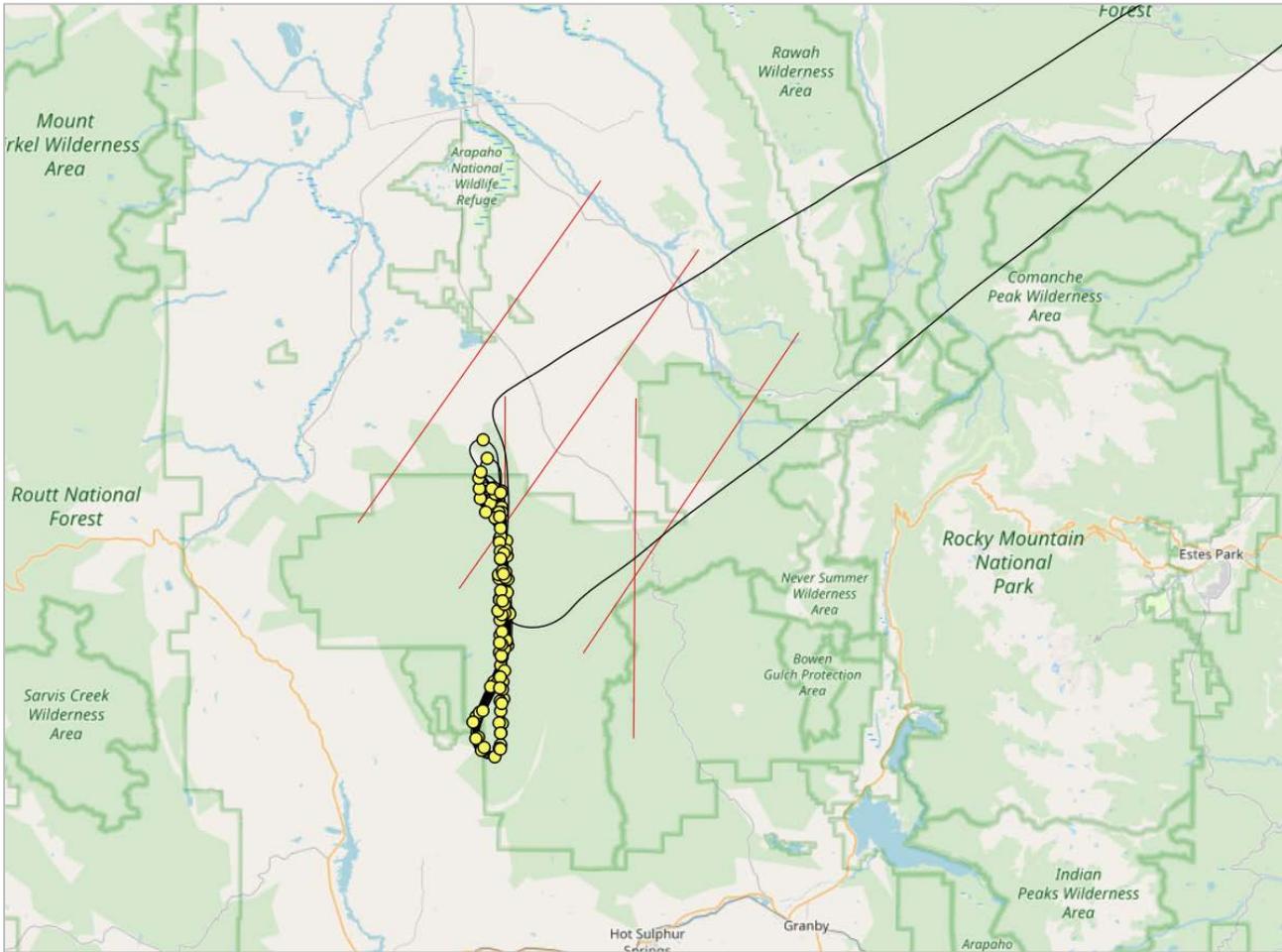
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<p>Synoptic Analysis:</p>	<p>No good ridge goes unpunished. After a number of days with brilliantly clear skies and pleasant temperatures, the trough of reckoning is now marching east toward the central California coast. This is a sizeable disturbance, with flow already pivoting south-southwest well in advance of its arrival. Substantial moisture accompanies this longwave disturbance, and positive moisture advection is ongoing with PWAT increasing to nearly a half inch by tomorrow morning. Low-level moisture is expected to become sufficient for moderate to deep orographic clouds with targetable SLW after midnight in the SM range, with conditions improving further east through the remainder of the night. PVA will instigate synoptic scale snow showers by dawn Sunday, with orographic enhancement continuing through the rest of the forecast period.</p>
<p>Area Forecast:</p>	<p>Shallow orographic clouds this afternoon will deepen overnight. The Sierra Madre range will be first to develop clouds suitable for seeding, with this timing currently expected around 9Z tonight. Flight level winds at this time will be brisk from the southwest around 50kts. -10C heights will begin around 15kft, but slowly dip toward 13kft by midday Sunday. Further east, in the Never Summer range, suitable seeding conditions will be slower to develop, but improve around dawn Sunday. Winds in that range will similarly be southwest around 50kts. Cooling temperatures will be the predominant concern by Sunday afternoon, with -15C heights falling below optimal levels in all ranges. Conditions at KCYS appear reasonable for operations overnight, with little to no precipitation and 10-15kt winds, but conditions deteriorate through Sunday morning as strong downslope winds mix down to the surface. A high wind watch has been issued for wind gusts exceeding 50mph midday Sunday.</p>



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N127ZW		FLT. OPS #		2 – NEVER SUMMER RANGE		SEED	
		Track(s):		NS4		Fuel: 183gal.	
UTC Date:		February 5, 2019		MST Date:		February 5, 2019	
UTC Engines ON:		08:29		MST Engines ON:		1:29 am	
UTC Engines OFF:		12:25		MST Engines OFF:		5:25 am	
Total Time:		3:56		3.93hr		Flares Used: 0 BIP 166 EJECT	
Pilot's Flight Summary:		We took off and flew to NS4 in Colorado. Upon arrival we detected light SLW in the cloud tops at 15kft. We began dropping EJs every minute and as we continued to fly the track the cloud tops begin to descend. By the time we were ready to leave, cloud tops were at 14kft to 14.5kft but due to ATC restrictions we were unable to descend lower than 15kft. Eventually running low on fuel we RTB.					
<i>Flight occurred in the morning hours of the 5th; weather information is from Feb. 4th.</i>							
Synoptic Analysis:		The longwave trough responsible for the active weather the last few days is on a slow march southeast down the West Coast today. It will eventually turn east and accelerate, finally progressing through our project area Wednesday night.					



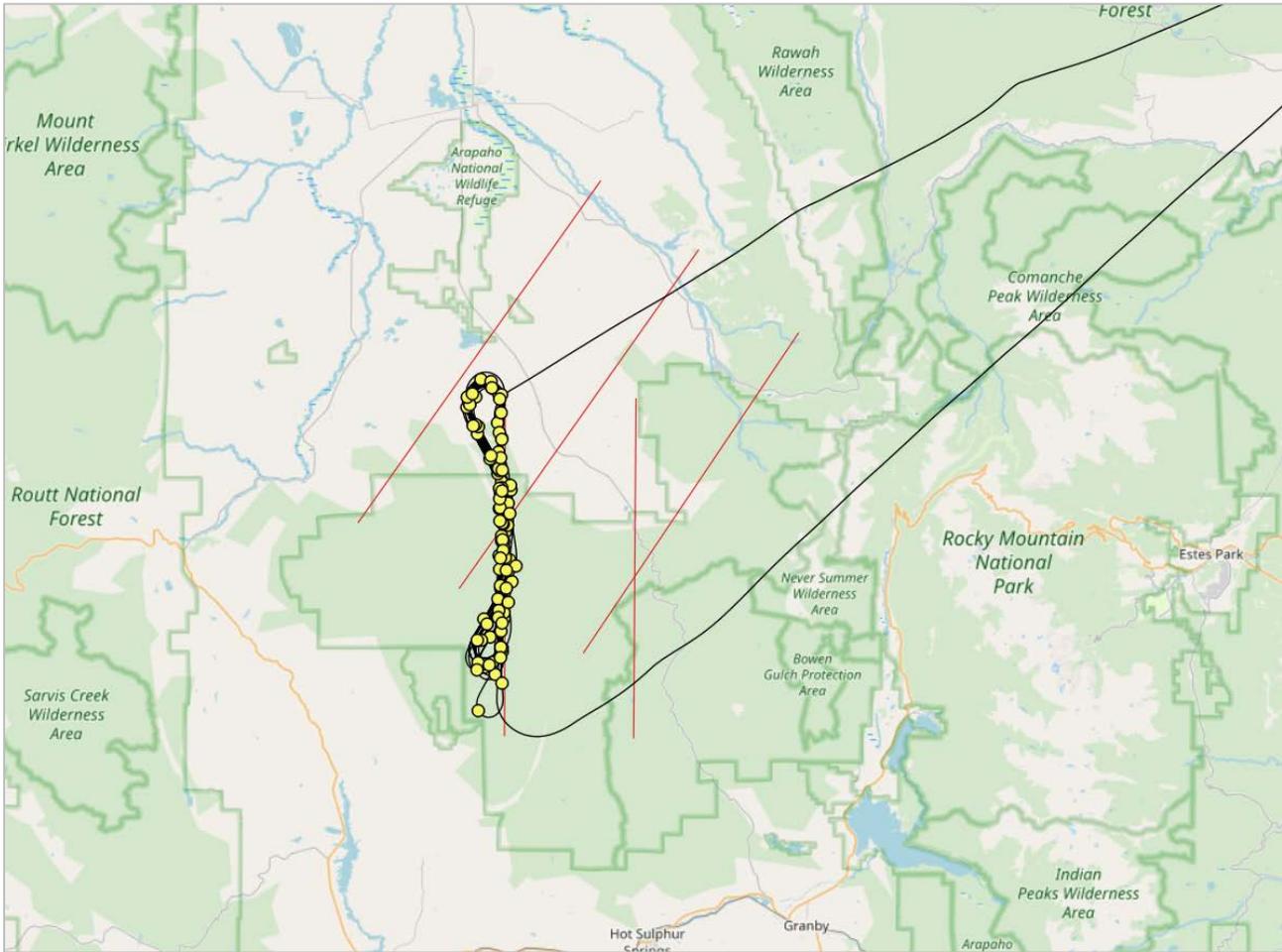
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	<p>In the meantime, moist southwest flow continues to pour across the region, with subtle shortwave disturbances with modest PVA embedded within the flow. While these small-scale disturbances can prove difficult to prognosticate, there appears to be such an atmospheric stimulant moving across the southern half of our project area overnight tonight into early Tuesday morning. A second even more active period is expected as the axis of the longwave trough swings toward our area late tomorrow night into Wednesday, though cooling mid-level temperatures will become a concern.</p>
<p>Area Forecast:</p>	<p>Persistent orographic cloud cover with periods of synoptic scale low and mid-level cloud with snow showers will continue throughout the forecast period. A particularly favorable seeding window is possible in the Never Summer range in the predawn hours Tuesday, though overall confidence in this solution is relatively low. Strong mid-level lapse rates are still evident on all model soundings, and flight-level temperatures remain cooler than ideal values, especially for the SM and MB flight tracks. Model QPF averages indicate around a half inch of additional SWE can be expected by this time tomorrow, with the highest amounts in the Never Summer range and in the southern portion of the Sierra Madre range in Colorado. In Cheyenne, dry and relatively mild conditions are expected with modest southerly warm air advection. Conditions appear too cold for optimal seeding tomorrow afternoon into Wednesday.</p>



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N127ZW		FLT. OPS # 3 – NEVER SUMMER RANGE			SEED	
Track(s):		NS4		Fuel: 205gal.		
UTC Date:	February 14, 2019		MST Date:	February 14, 2019		
UTC Engines ON:	16:01		MST Engines ON:	9:01 am		
UTC Engines OFF:	20:04		MST Engines OFF:	1:04 pm		
Total Time:	4:03	4.05hr	Flares Used:	0 BIP	147 EJECT	
Pilot's Flight Summary:	Departed CYS climbed to 20kft. Was given holding delay by ATC for Denver arrivals. Was told by ATC that altitude changes would not change our hold time. Held for 23 minutes before ATC cleared us to the target area at 17kft. Encountered light SLW when crossing the ridge. Descended to 16kft on track. No SLW on track but models and radiometer indicated good conditions downwind of track. Fired EJs every minute.					
<i>Flight occurred in the morning hours of the 14th; weather information remains the same as MBSM Flight #13.</i>						



5.3 2018-2019 Operational Compression Map

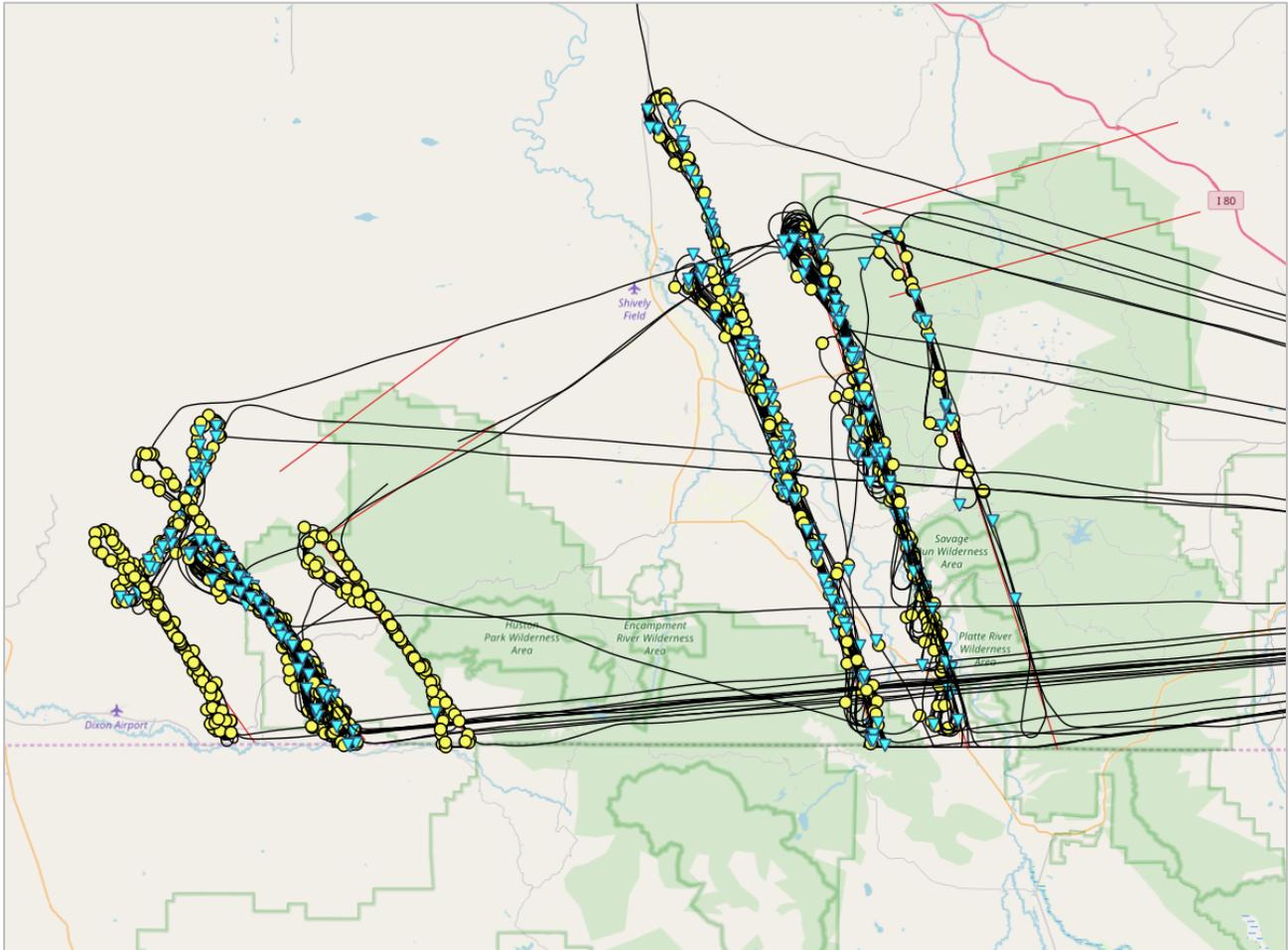


Figure 18. All flights conducted for the 2018-2019 winter season in the Medicine Bow and Sierra Mountain Ranges of Wyoming displayed on AirLink II replay software.



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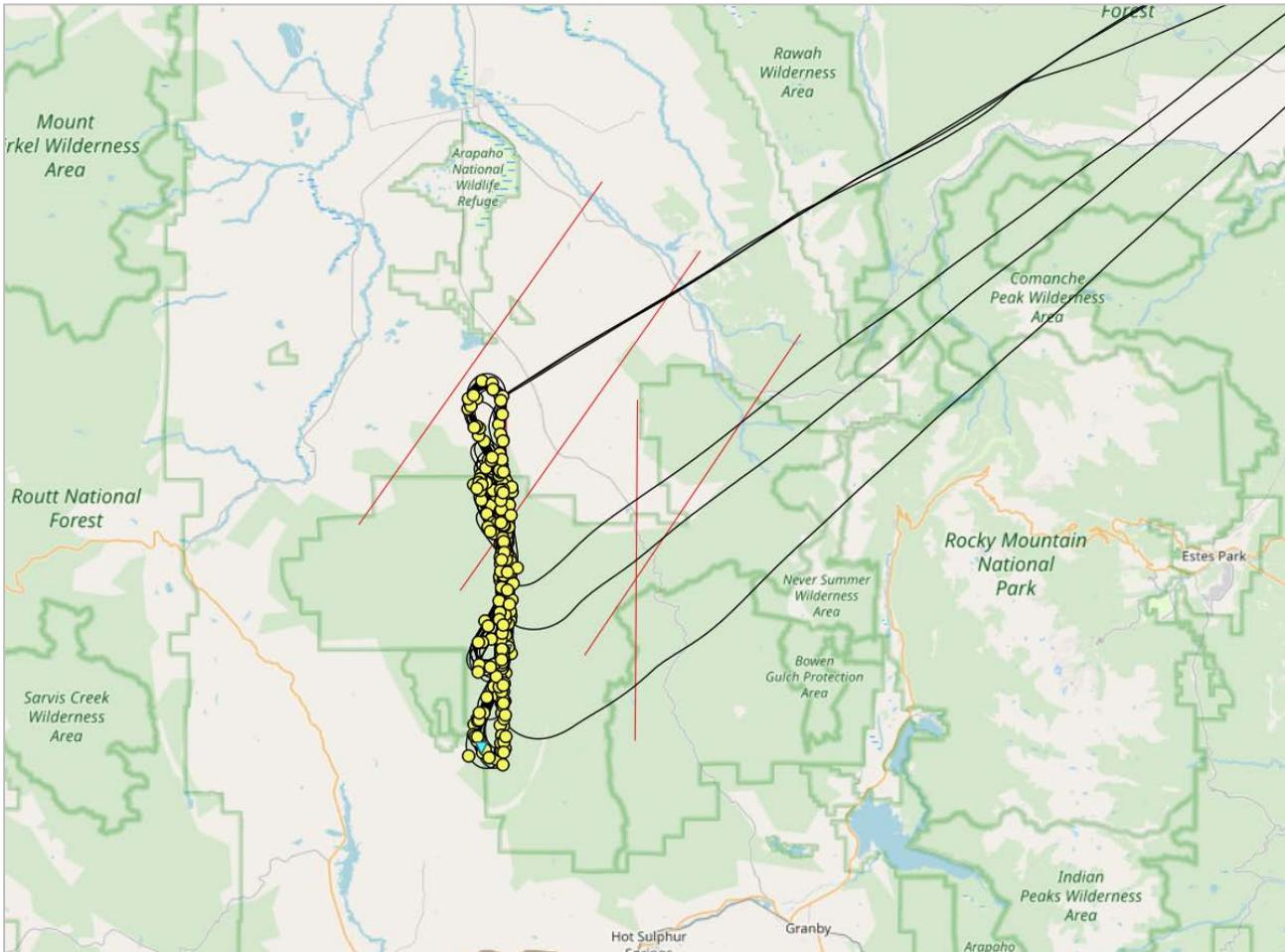


Figure 19. All flights conducted for the 2018-2019 winter season in Colorado's Never Summer Mountain Range displayed on AirLink II replay software.



6 2018-2019 OPERATIONS SUMMARY

**Seeding Start Time of Day (UTC)
MBSMNS Project 2018-2019**

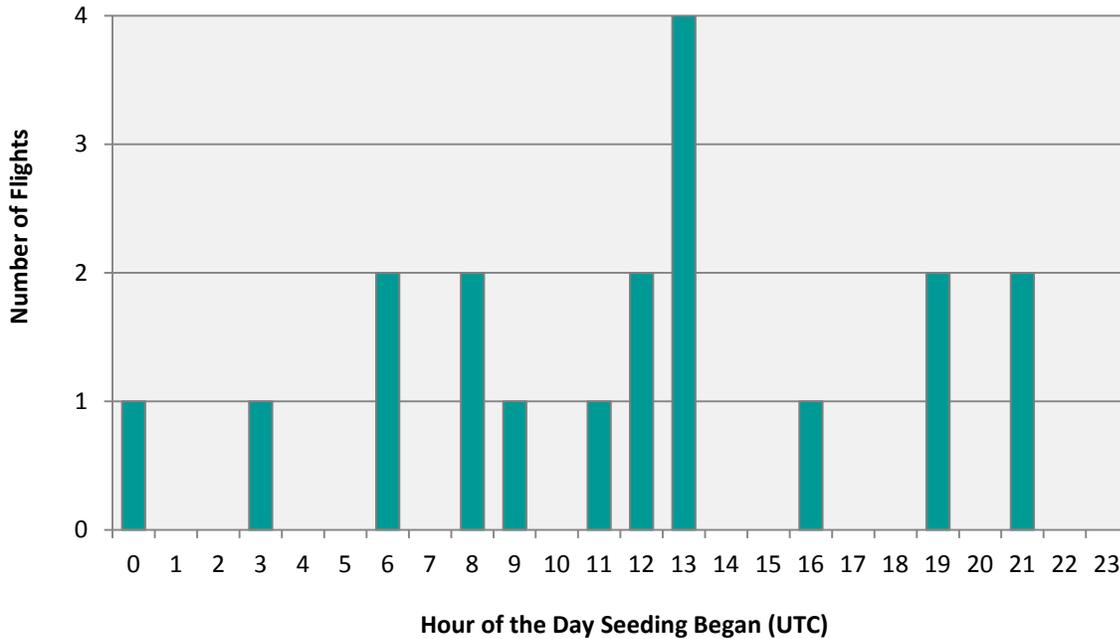


Figure 20. Hour of the day seeding began for each seed mission (in UTC). Subtract 7 hours for Mountain Standard Time.

Season flight operations are summarized in Table 2. Each flight is represented by its own column, so when there are two flights on a single day, for example, November 23rd, there are two columns. Project-billable flights include only seeding and reconnaissance (Recon), but non-billable flights (usually flown for maintenance reasons) are listed in the “WMI” row.

Below the flight times the flare usage, by type, is given. Finally, the bottom row provides the target of the mission if any seeding was conducted. In that row, MB and SM denote the Medicine Bow and Sierra Madre ranges, respectively. An entry of “MBSM” indicates that both the Medicine Bow and Sierra Madre were seeded on that mission. Seeding missions in Colorado are indicated by “NS”, for Never Summer Range.

A total of 19 project-billable (non-WMI) flights were flown. Seeding was conducted on 18 of the 19 missions, the only reconnaissance mission being the first of the three flown on November 23rd. Fifteen seeding missions were flown for Wyoming targets, three more for the Never Summer Range in Colorado.



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November and February were the most active, with six and seven missions flown, respectively. December and March each saw three missions, but January, only two. Nearly 80 hours were flown in the course of the seeding missions, and 2.5 more on the single reconnaissance mission.

It should be noted that of the 19 missions, 15 were of four hours or more duration. Of the other four, the reconnaissance mission was 2.53 hours, the seeding mission for the Medicine Bow Range on February 14th 2.42 hours (the shortest of the season, terminated early because of icing conditions), and the other two 3.92 and 3.93 hours. Three missions were over five hours in duration. The mean duration of seeding missions was over 4.4 hours! The C90's endurance paid off in a big way.

Table 2. Flight operations for the 2018-2019 season are summarized.

	NOV 2018							DEC 2018			JAN 2019		FEB 2019							MAR 2019			Season Totals	
	15	17	23	23	23	28	28	19	19	30	7	23	3	3	5	12	13	14	14	1	6	23	Count	Units
Seeding		4.22		4.37	4.05	4.50	4.75	4.67	5.47	4.92	5.07	4.58	4.53	5.05	3.93			2.42	4.05	4.67	4.58	3.92	79.75	hours
Recon			2.53																				2.53	hours
WMI	1.80															0.65	0.53						2.98	hours
ICE-BIP		28		18	31	28	43	27	48	16	0	3	31	2	0			10	0	27	39	1	352	flares
ICE-EJ		14		59	12	96	29	71	100	93	191	171	72	204	166			15	147	95	62	130	1727	flares
Target		MB		MBSM	SM	MB	MB	SM	MB	MBSM	SM	MBSM	SM	NS	NS			MB	NS	SM	MB	SM	15 / 3	flights



Seeding Material Dispensed per Track Medicine Bow and Sierra Madre Mountain Ranges, WY

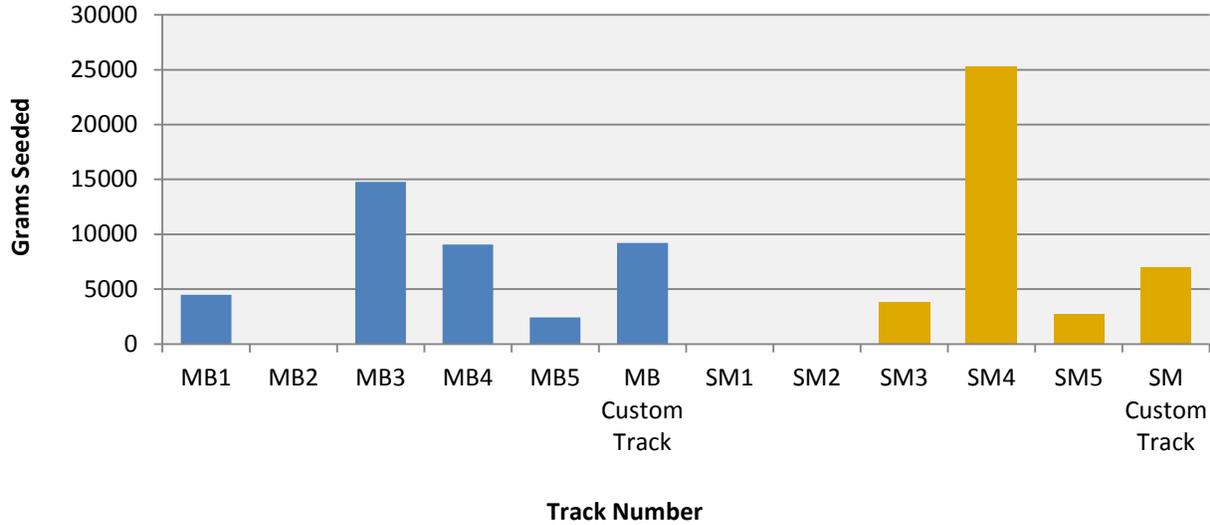


Figure 21. Grams of seeding material dispensed per track over the Medicine Bow and Sierra Madre Mountain Ranges in Wyoming.

Number of Seeding Flights per Track Medicine Bow and Sierra Madre Mountain Ranges, WY

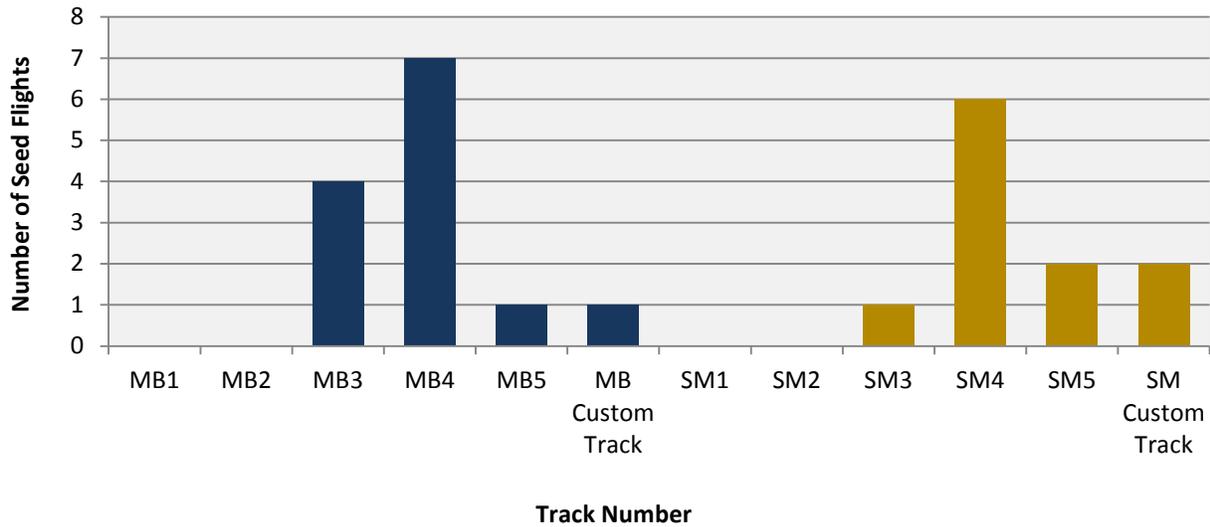


Figure 22. Number of seeding flights per track in the Medicine Bow and Sierra Madre Mountain Ranges, WY. Some flights may utilize multiple tracks.



Seeding Material Dispensed per Track Never Summer Mountain Range, CO

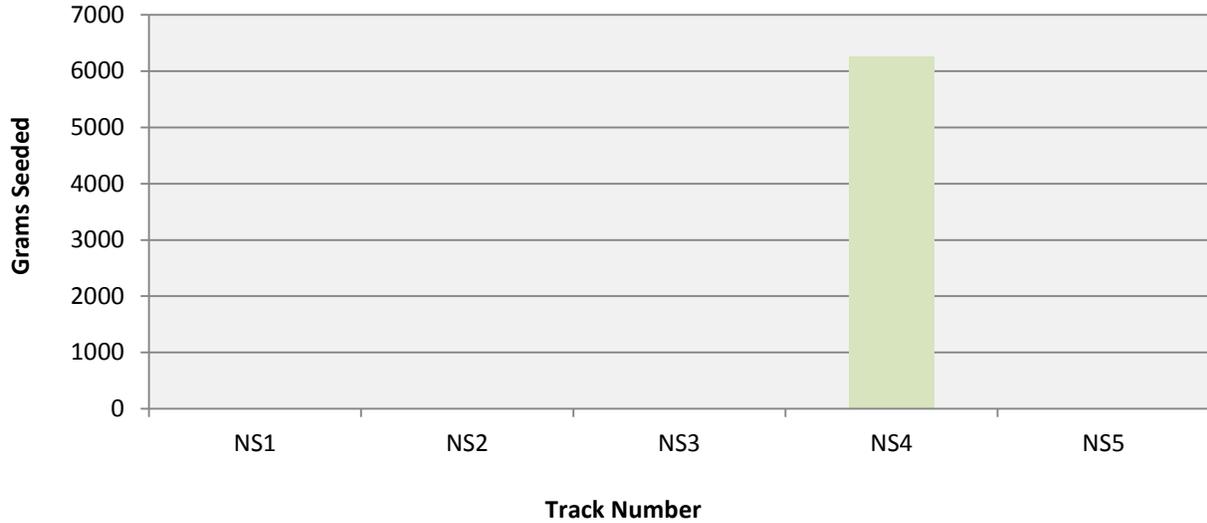


Figure 23. Grams of seeding material dispensed per track over the Never Summer Mountain Ranges in Colorado.

Number of Seeding Flights per Track Never Summer Mountain Range, CO

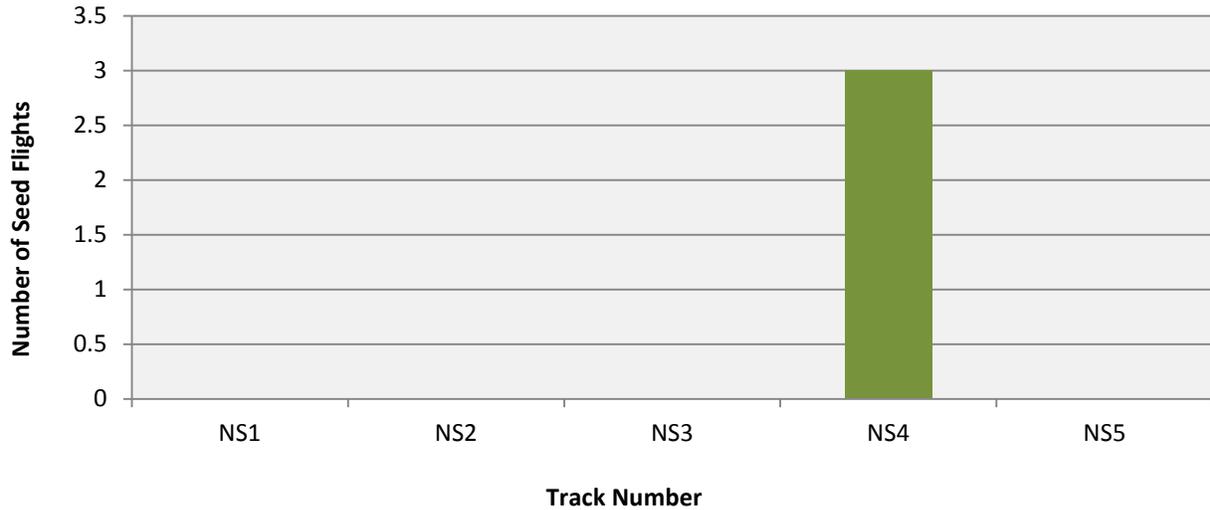


Figure 24. Number of seeding flights per track in the Never Summer Mountain Range, CO.



Percent of Seeding Flights per Month MBSMNS Project 2018-2019

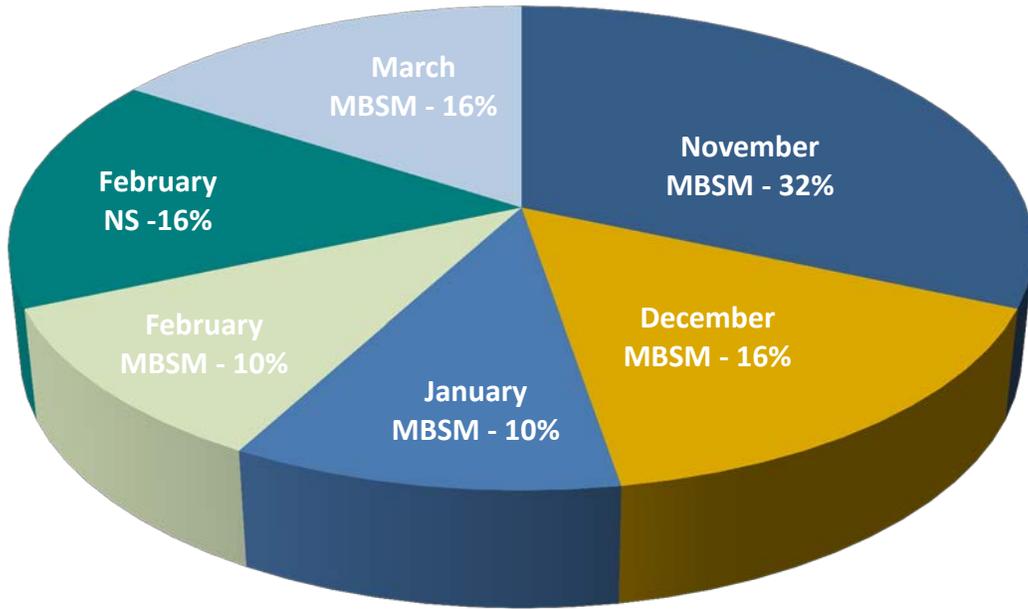


Figure 25. Number of seeding flights by month and per state. No seeding or reconnaissance missions were conducted in April.

6.1 Radar Seeding Signatures

On multiple occasions, the National Weather Service WSR-88D radar located in Cheyenne, Wyoming (KCYS) observed what appear to be linear seeding signatures over the Medicine Bow Range. This was unexpected, as the Medicine Bow target area is 130 km distant from the radar, and blocked at low elevations by the intervening Laramie Range. Radar returns of similar shapes, attributed to seeding, were recently observed during the SNOWIE campaign of 2017 (Tessendorf *et al.* 2019). On November 28th, February 14th, and March 6th, the KCYS radar recorded linear echoes coincident in time, location, and orientation, with the release of glaciogenic seeding material from the seeding aircraft. For each of these cases, the aircraft flight and seeding paths and flight level winds are compared to the radar observation to establish possible cause-and-effect relationships. The pyrotechnics used in this project were of the same formulation as those used in the SNOWIE campaign, the ranges at which the apparent seeding signatures were observed were significantly greater. Figure 26, recorded by the Cheyenne radar on February 14th, provides an example of the apparent seeding signatures observed.



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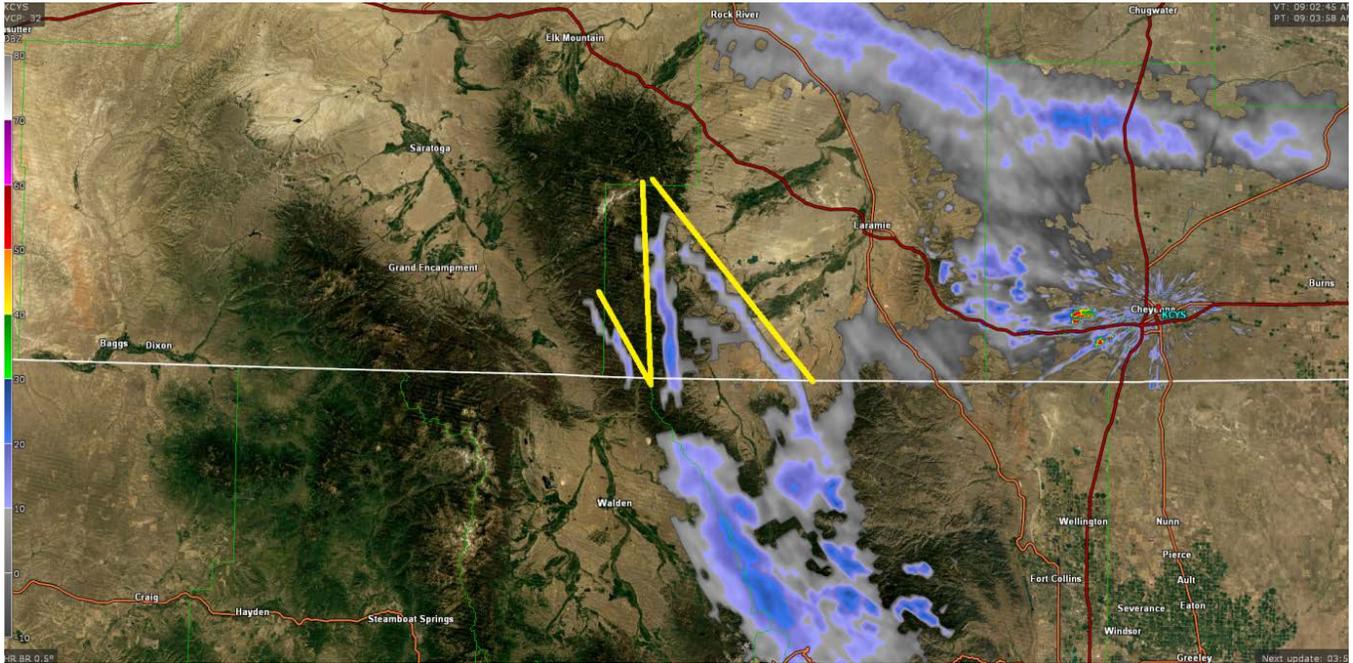


Figure 26. The National Weather Service radar (KCYS), is located in Cheyenne, at the intersection of the two interstate highways (red lines, right), I-80 (east-west), and I-25 (north-south). The linear echoes, in blue hues, mirrored with yellow lines for clarity, match closely the orientation and timing of the project seeding aircraft on this date.

The Cheyenne radar is not part of the planned evaluation of the project, but provides confirmation of the seeding impact. Precipitation has been created—and observed—when none existed naturally. It should be noted, however, that the terrain between Cheyenne and the Medicine Bow Range (the southern portion of the Laramie Range (Sherman Hill)), blocks the radar beam at low elevation angles, so no indication of the spread and expanse of the seeding effects is possible.



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7 CONTRACTOR'S FINAL REMARKS

The 2018-2019 winter season was Weather Modification International's 1st winter season providing operational aerial cloud seeding and meteorological services for the Medicine Bow and Sierra Madre mountain ranges of Wyoming and the Never Summer mountain range in Colorado. The target ranges provided ample suitable seeding targets, and the local terrain, base of operations, and Air Traffic Control restrictions were reasonable for safe effective operations. The King Air C90A Aircraft provided excellent endurance for extended seeding flights, many



of which lasted for four to five hours or more. The satellite communications system onboard the aircraft allowed for real-time coordination between pilots and meteorologists, which optimized the use of project resources and helped keep the pilot crew safe during changing weather conditions. The use of ejectable flares was a critical component to the program's success and should be continued in subsequent seasons.

Figure 27. The Medicine Bow mountain range visible off the aircraft nose during an early morning mission on March 6, 2019. During this mission 39 burn-in-place and 62 ejectable pyrotechnics were expended. Photo by Kirk Hamilton.

Annual snowpack for the region was near normal to slightly above normal. This implies that the number of seeding opportunities observed this season loosely represents what can be expected to occur in an average season. During the 2018-2019 season, meteorology and pilot staff focused efforts on utilizing project resources to target the best, most productive clouds in order to maximize the benefits of the program under the current budget. It should be noted that there were numerous weather periods with suitable cloud conditions for seeding which were not targeted this season due to budgetary constraints. This is promising for future growth of the program, and WMI believes that with similar staffing, an additional ten to fifteen seeding flights may be possible in a future similar "average" season if desired.

On three separate occasions, distinct seeding effects were observed over the Medicine Bow Range utilizing NEXRAD radar from the Cheyenne National Weather Service. This was unexpected due to the distance from the radar and mountainous terrain blocking the lower angle radar beam, but these fortuitous observations are very promising for the future success of the program and provide physical evidence of the program's effectiveness.

WMI invites comments from the WWDO and JCWCD regarding this winter's program. For more information regarding Weather Modification International please visit our website: www.weathermodification.com