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Airborne Cloud Seeding Operations
2020-2021 Winter Operations Report

For the

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

Prepared By

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EXECUTIVE SUMMARY

This report summarizes the aerial cloud seeding activities conducted by Weather Modification LLC, dba Weather Modification International (WMI) during the 2020-2021 winter operational season from 1 November 2020 through 15 April 2021. 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 runoff. This was the 3rd season Weather Modification International has provided pilot and aircraft services to conduct aerial cloud seeding operations for the State of Wyoming and the Jackson County Water Conservancy District. During this time WMI has flown 350 hours over 73 missions for the program!

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 $699,252.51. Additional funding was provided by the Board of Public Utilities (BOPU) of the City of Cheyenne, in the amount of $50,000. The Jackson County Water Conservancy District (JCWCD) provided an additional $70,627 for operations conducted for the Never Summer Mountains 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 North Platte and Little Snake River Basins (western flanks of the Sierra Madre) 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 B200 seeding aircraft (US FAA registration N23MN) 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 a 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 Cheyenne has an instrument approach and adequate hangar and maintenance facilities.

Flight operations were conducted according to basic guidelines established by WMI and the WWDO. The seeding method used on the 2020-2021 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 project personnel discussed relevant weather information daily to determine the best mission timing, altitudes, and seeding tracks based on winds and temperatures at flight altitudes.

The project aircraft arrived on site 23 October 2020. The first mission of the 2020-2021 season took place in the Sierra Madre Range on 8 November 2020. The last seeding event of the 2020-2021 season occurred in the Never Summer Range on 7 April 2021. The program ended on 15 April 2021.

In the Medicine Bow and Sierra Madre Ranges, twenty (20) flights were conducted for a total of 100.52 flight hours, consisting of seventeen (17) seed and three (3) reconnaissance missions. Of the 100.52 flight hours, 22.42 hours were conducted for the Medicine Bow Range and 78.09 were conducted for the Sierra Madre Range. A total of 97,840 grams of seeding agent were dispensed via 3092 ejectable flares (20 grams each) and 240 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, seven (7) flights were conducted for a total of 33.01 flight hours. Seeding was conducted on all seven missions. A total of 29,810 grams of seeding agent were dispensed via 1348 ejectable flares (20 grams each) and 19 burn-in-place flares (150 grams each).

The WMI team is proud to have been a part of the 2020-2021 Wyoming Weather Modification Program with extension over Colorado's Never Summer Mountains; we look forward to future seasons!

Figure 1. WMI Captain Kirk Hamilton takes a picture of the snow-covered terrain during a mission for the Medicine Bow target area on 11 February 2021. A total of 5.35 flight hours were flown and 5,540 grams of seeding material was dispensed on this flight.

ACKNOWLEDGMENTS

The 2020-2021 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 for the Medicine Bow and Sierra Madre target area was enhanced by the City of Cheyenne Board of Public Utilities. 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 Program Manager 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 copilot Nate Engstrom who was replaced by Mattison Davis and later, Brandon Bank. 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. Ramona Adams 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. Jim Baller and Mr. Ty Wattenberg. The support and assistance of the Colorado Water Conservation Board and the Colorado Department of Natural Resources, namely Mr. Andrew Rickert, were also greatly appreciated.

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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 develop the means to augment water supplies through cloud seeding. The Wyoming Weather Modification Program, with extension over Colorado's Never Summer Mountains, is designed to augment snowfall over select portions of the North Platte River Basin and the Little Snake River Basin (western flanks of the Sierra Madres). By increasing the snowpack and resultant spring runoff, subsequent water supplies downstream are increased. In addition to easing the necessity for other more costly means of power generation, 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 B200 aircraft owned and operated by WMI released silver iodide-based ice nuclei using pyrotechnics. These artificial ice nuclei cause additional snow 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 and Sierra Madre (MBSM) – Portions of the Medicine Bow and Sierra Madre, Mountain Ranges located in Carbon and Albany County Wyoming. The ranges run mostly north to south. 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 2020-2021 program.

Standard winter broadcast-seeding techniques were employed. Seeding of winter storms was conducted whenever WMI meteorologists determined conditions were suitable. The meteorology team 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 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 lists the exact location of each track's endpoints and wind speed limits for their use. The WMI crew can modify the seeding tracks in response to actual storm conditions encountered during flight to optimize targeting. This past season flight tracks were shortened and/or extended on multiple missions due to actual weather conditions. This illustrates the versatility of the aircraft and crew in ensuring effective targeting.

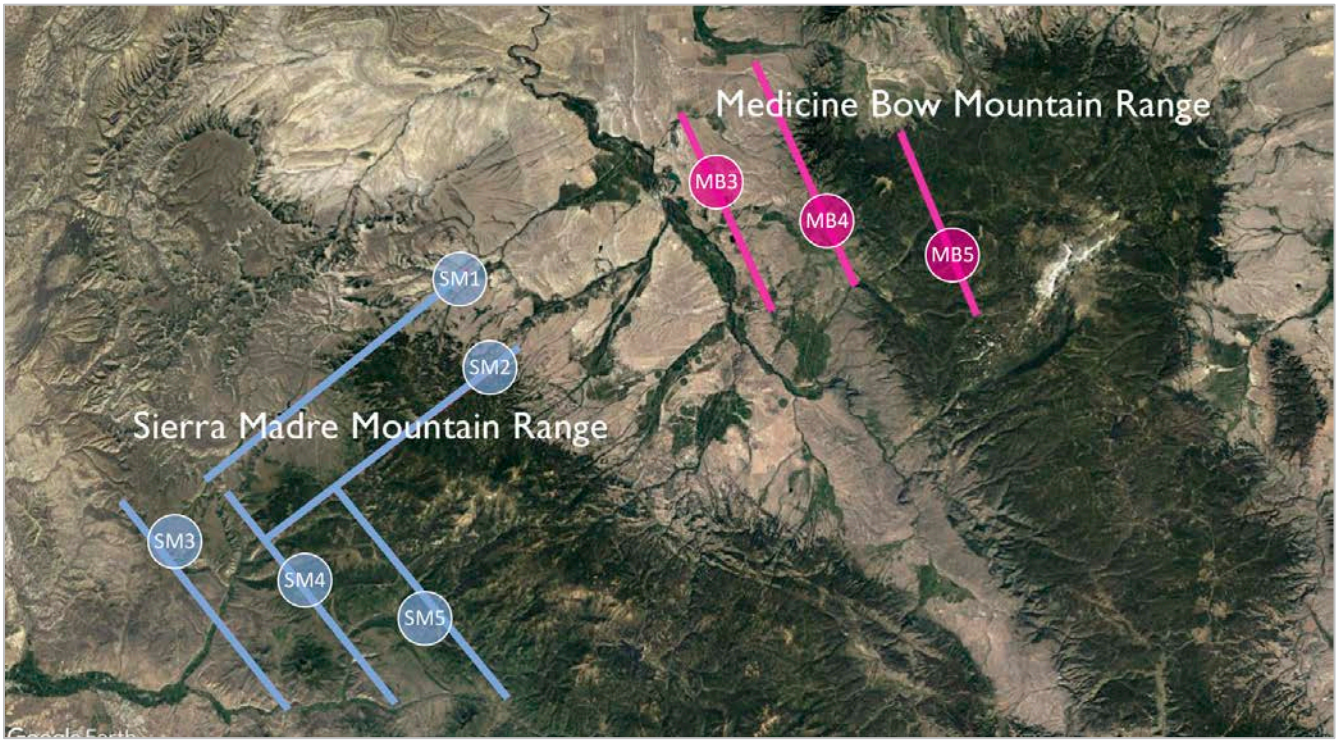


Figure 2. Medicine Bow and Sierra Madre Target Areas located in the State of Wyoming. The predetermined flight tracks are visible in lavender (Sierra Madre Mountain Range) and magenta (Medicine Bow Mountain Range).

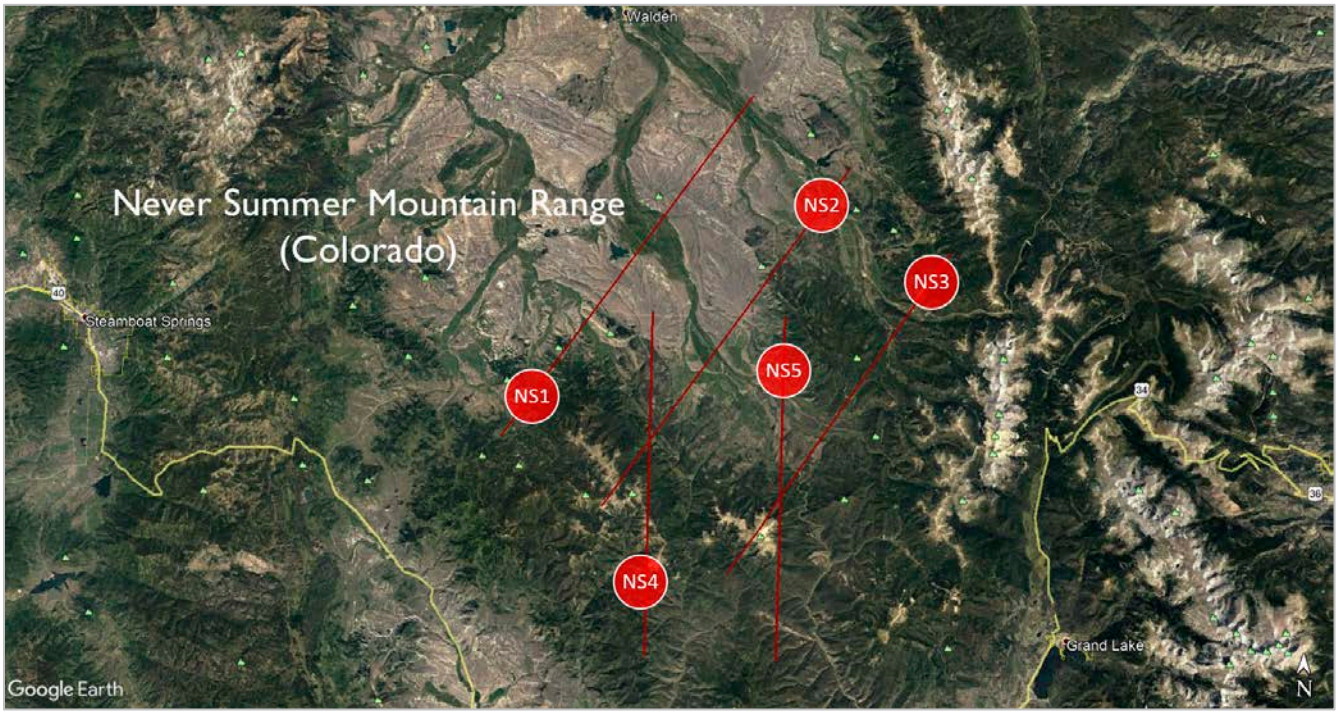


Figure 3. Never Summer Target Area located in the State of Colorado. The predetermined flight tracks are visible in red.

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

SIERRA MADRE			
TRACK	**WAYPOINT**	**VOR/RADIAL/DME**	**WIND SPEED LOWEST ALT**
SM1	SM1E	CKW/116/032	30 - 55 KTS 13,000 ft
	SM1W	CKW/150/033	
SM2	SM2E	CKW/120/037	< 30 KTS 13,000 ft
	SM2W	CKW/147/038	
SM3	SM3N	CKW/159/033	55+ KTS 13,000 ft
	SM3S	CKW/151/046	
SM4	SM4N	CKW/149/035	30 - 55 KTS 13,000 ft
	SM4S	CKW/143/048	
SM5	SM5N	CKW/139/037	< 30 KTS 13,000 ft
	SM5S	CKW/136/051	

MEDICINE BOW			
TRACK	**WAYPOINT**	**VOR/RADIAL/DME**	**WIND SPEED LOWEST ALT**
MB3	MB3N	LAR/269/047	55+ KTS 14,000 ft
	MB3S	LAR/257/043	
MB4	MB4N	LAR/270/041	30 - 55 KTS 14,000 ft
	MB4S	LAR/259/038	
MB5	MB5N	LAR/271/036	< 30 KTS 14,000 ft
	MB5S	LAR/259/032	

NEVER SUMMER			
TRACK	**WAYPOINT**	**VOR/RADIAL/DME**	**WIND SPEED LOWEST ALT**
NS1	NS1N	RLG/004/042	30 - 55 KTS 15,000 ft
	NS1S	RLG/350/024	
NS2	NS2N	RLG/012/041	< 30 KTS 15,000 ft
	NS2S	RLG/004/022	
NS3	NS3N	RLG/020/040	55+ KTS 15,000 ft
	NS3S	RLG/020/022	
NS4	NS4N	RLG/002/031	30 - 55 KTS 15,000 ft
	NS4S	RLG/019/016	
NS5	NS5N	RLG/012/033	< 30 KTS 15,000 ft
	NS5S	RLG/034/020	

WMI utilizes National Weather Service NEXRAD radar data and in-house high-resolution numerical weather prediction to identify suitable times for seeding. The modeling tools identify periods where seedable clouds are likely (based on winds, temperatures, and liquid water content). When models are forecasting seedable cloud conditions, project pilots and meteorology staff work in tandem continuously monitoring radar and cloud conditions. When real-time observations indicate the likely presence of suitable targets, a flight is launched. Upon reaching seeding tracks, pilots check temperatures, winds, and supercooled water content. If conditions are indeed suitable, seeding commences and continues until conditions deteriorate or the aircraft runs low on fuel or flares. If suitable conditions are not encountered during a flight, no seeding will occur, and the aircraft returns to base having conducted "reconnaissance". After a seeding or reconnaissance flight ends, flight crews and meteorologists immediately prepare for another flight if additional flights may be warranted.

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

<u>Requirements to initiate a flight:</u>

- 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 (Pilot Reports), AIRMETS (Airman's Meteorological Information), and SIGMETS (Significant Meteorological Information).
- 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).

<u>Procedures en route to seeding track:</u>

- 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.

Required to begin seeding once on track:

- When the seeding track is approached, the aircraft will carefully descend into the 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 the existence of 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 employs copilots on seeding flights 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 Nate Engstrom, replaced by first officers Mattison Davis and later, Brandon Bank. This was Hamilton's fifth winter season; he completed two seasons on this program and two in California previously. Hamilton also serves as WMI's Chief Pilot. This was Engstrom's first season as a WMI wintertime copilot; he was previously a captain on the North Dakota Cloud Modification Project, flying a Piper Seneca II aircraft. Davis was a local flight instructor in Cheyenne and this was her first season with WMI. Bank is local to northern Colorado and this was also his first season.

Aircrew training was conducted in Fargo, ND prior to the start of the season by Jody Fischer, Director of Flight Operations. Fischer is a Weather Modification Association (WMA) Certified Operator. This was Fischer's eighteenth winter season; he has several hundred hours of flight experience in Wyoming mountainous terrain.

Figure 4. The 2020-2021 flight crew from left to right – Nathan Engstrom and Kirk Hamilton stand in front of the WMI King Air B200 seeding aircraft (N23MN) in the Legend AeroServe hangar in Cheyenne, WY. Photo submitted by Kirk Hamilton.

Figure 5. Kirk Hamilton captures a selfie during the 2020-2021 winter season with copilots Mattison Davis (top left) and Brandon Bank (bottom right). Photo submitted by Kirk Hamilton.

Daniel Gilbert, Chief Meteorologist; Jason Goehring, Field Meteorologist; and Adam Brainard, Meteorological Systems Lead, formed WMI's meteorology team. This was Gilbert's seventeenth year of winter seeding operations and forecasting. He also has eighteen seasons experience on summer seeding programs. This was Goehring's sixteenth year of Wyoming seeding operations and forecasting, in addition to his working five summers of airborne seeding operations in Alberta, Canada. Gilbert and Goehring have worked together for twelve consecutive seasons on Wyoming programs dating back to the Wyoming Weather Modification Pilot Project. Brainard has been involved with the Wyoming seeding programs since 2016, providing numerical modeling support. This was his third year in the field in Pinedale, WY. Brainard has also completed eight years of summer seeding operations in North Dakota and Alberta. Bruce Boe, WMI Vice President of Meteorology, provided overall management of the meteorology team during its day-to-day operations. Gilbert, Goehring, and Brainard are all Weather Modification Association Certified Operators.

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

Figure 6. The WMI Forecasting team from left to right – Dan Gilbert (Chief Meteorologist), Jason Goehring (Field Meteorologist), and Adam Brainard (Meteorological Systems Lead). Goehring is based in Long Lake, SD, and Gilbert in Fort Dodge, IA. Brainard resided in Pinedale, WY during the winter season to forecast and assist with 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 remotely via GoToMeeting with the flight crew, meteorology team, client, and key WMI staff on 28 October 2020. Attendance was mandatory for WMI project employees. The meeting topics included forecasting, modeling, media protocol, overview of the project, reporting pre- and post-flight, aerial cloud seeding operations, and safety. WMI administrators – Bruce Boe, Vice President of Meteorology; Jody Fischer, Director of Flight Operations; and Erin Fischer, Director of Client Services, and Jake Van Ornum, Client Services Assistant, also attended the kickoff meeting. The meeting allowed both groups to share information which improved communication, program efficiency, and contributed to the overall success of the program.

3 EQUIPMENT

3.1 Beechcraft King Air B200

WMI Beechcraft King Air B200, U.S. FAA registration N23MN, arrived on site 23 October 2020. It was ferried by Captain Kirk Hamilton. N23MN was dedicated for full-time use on the program and its crew provided 24 hours-a-day, 7-days-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 AeroServe at the Cheyenne airport.

Figure 7. WMI Beechcraft King Air CB200, N23MN 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.

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 5-6 hours in ideal conditions.

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. In addition to pressurization, an oxygen system is installed in the event of a loss in cabin pressure.

There were multiple 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 FAA regulations.

A total of 9,818 gallons of Jet -A fuel was consumed on the project (7,364 gallons for the MBSM and 2,454 gallons for the NS target area), an average of 73 gallons per aircraft flight hour. All project fuel was purchased by WMI at the aircraft base location. Fuel costs ranged from $3.00 to $3.64 per/gallon with an average of $3.24 per/gallon. This was seventy-one cents lower than during the 2019-2020 winter season.

One aircraft issue was encountered during the season:

- 4 February - The aircraft returned to Fargo for repairs on the ejectable flare racks due to a malfunction. The aircraft returned to Cheyenne on 5 February 2021. No operations were missed.

The WMI flight crew was directed by ATC to change altitude on one mission this year. On 30 January 2021, while seeding on track SM2, ATC directed the crew to climb from 13,000 to 14,000 feet. Seven minutes later descending back to their requested altitude. The aircraft remained on track and seeding was not suspended.

3.1.1 Flight in Known Icing Conditions

The B200 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. 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. Our policy of two-pilot crews helps ensure that proper attention can be paid to sometimes rapidly-changing flight and seeding conditions as they occur. 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 U.S. FAA has certified that the aircraft is equipped with the necessary deicing equipment and has the required power to safely transit (climb or descent through) layers of icing. This capability will always be kept in mind during operations, ensuring the flight crew can 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 off airframe icing, and usually the only option is to return for an instrument approach to the Cheyenne airport. However, with the use of ejectable flares, such descents are even less frequent (Tessendorf *et al.*, 2015).

Occasionally seeding flights are forced to divert at some point during winter missions to handle airframe icing. This year the crew had to descend or climb for excessive icing conditions on only one mission, while conducting a reconnaissance mission over the Sierra Mountain Range on 14 January 2021. This was significantly less than average for wintertime operations. The crew did not suspend seeding or prematurely end any missions due to icing conditions this season. These statistics are based on the 26 combined missions in Wyoming and Colorado.

Figure 8. Images of airframe icing from 2020-2021 winter season. Left – Ice remains on the propeller spinner after the crew's first mission on 18 January 2021 for the Sierra Madre target area. The aircraft refueled and reflared after this photo was taken and departed for the Never Summer target area. Combined the aircraft flew 11 hours and 53 minutes this day. Right – Windshield icing during a night mission over the Medicine Bow target area on 9 February 2021. Photos by Kirk Hamilton.

3.1.2 Weather Availability In-Flight

As an enhancement to safety, all WMI seeding aircraft are 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. Real-time weather and radar data are overlaid on a moving map of the target area. The ability to visualize weather conditions upstream allowed the pilots to make effective real-time seeding decisions and optimize use of their fuel and flares.

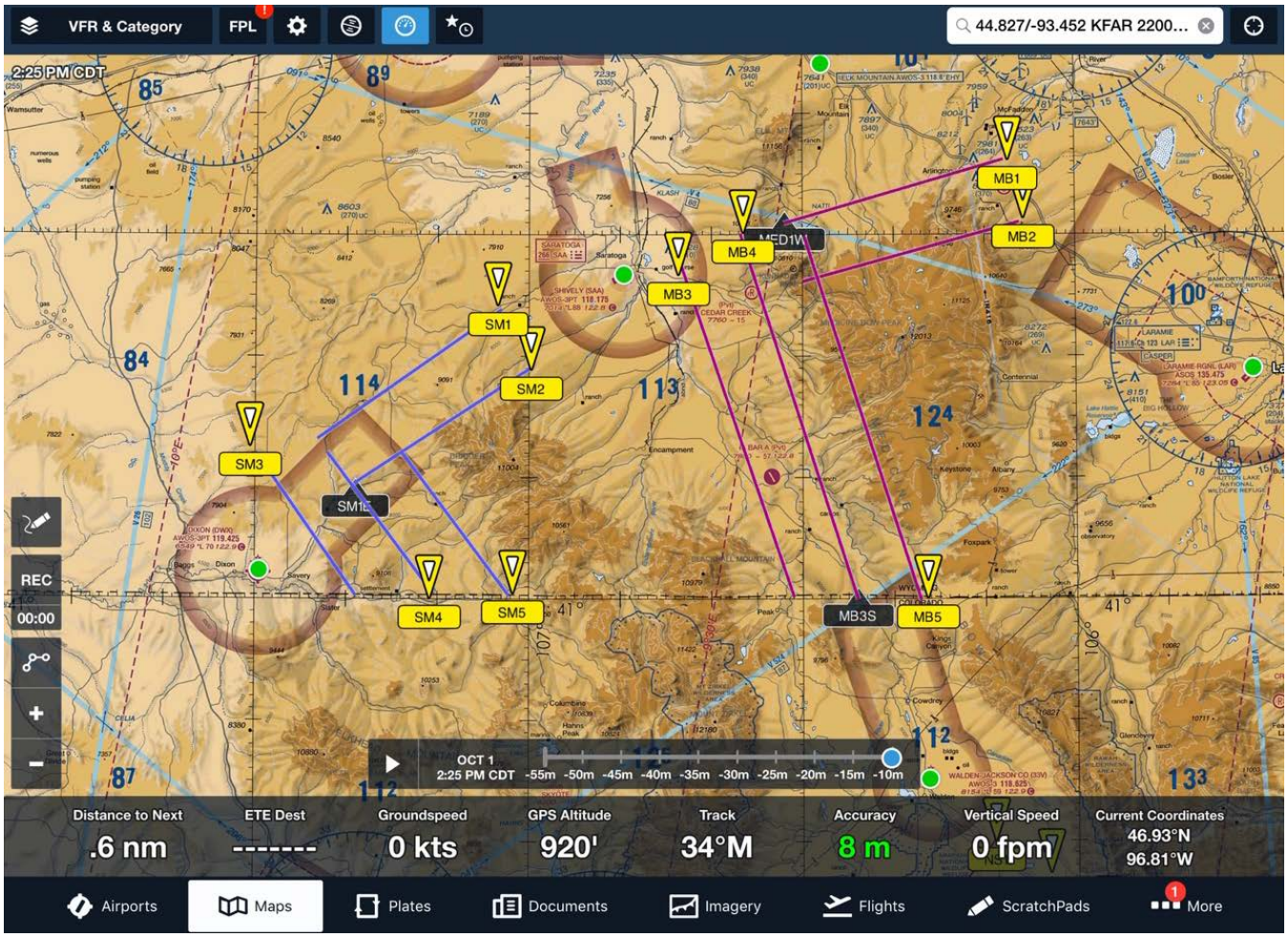


Figure 9. Image from a WMI iPad showing ADS-B weather information visible to the cloud seeding pilot while conducting operations. The Medicine Bow and Sierra Madre target areas in Wyoming overlay is shown on the ForeFlight application. The target area at the time of this photo was void of weather.

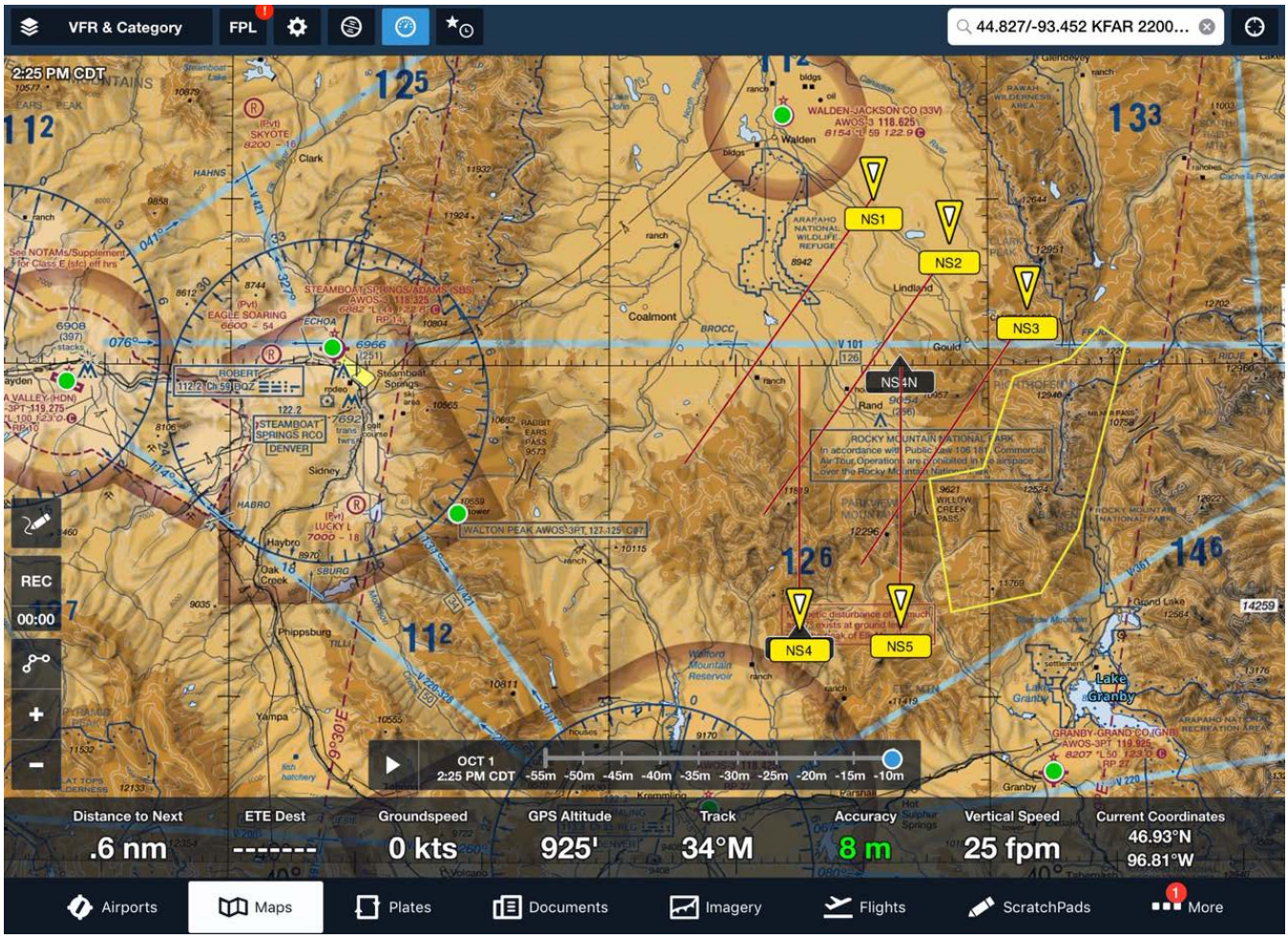


Figure 10. Like Figure 9, the overlay for the Never Summer Mountain Range target area (red tracks) in Colorado is shown on the ForeFlight application. The target area at the time of this photo was void of weather.

3.2 In-Flight Communications

The WMI seeding aircraft was equipped with satellite voice and text messaging service through Iridium GO!®. This is a robust, military-grade device that withstands the 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 system provided reliable long-range communications with the meteorologists directing operations, which was extremely advantageous for the remotely-positioned meteorologists.

3.3 Seeding Equipment and Agents

The project aircraft was modified with two wing-mounted burn-in-place flare racks and three ejectable flare racks. Seeding equipment was fabricated and installed by WMI in accordance with U.S. Federal Aviation Administration approvals (U.S. 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 burned 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, thus resulting in snow downwind in the target area.

Each burn-in-place flare 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 11. N23MN carried two dual burn-in-place flare racks. The flares shown are 150g ICE-EB® Ice Crystal Engineering LLC glaciogenic flares. A total of 259 ICE-EB™ flares were expended during the 2020-2021 season. Photo by Tyler Couch.

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 enable storms to be effectively treated while the aircraft remains above the peak aircraft icing altitude, increasing on-station time. The seeding aircraft were all equipped with three belly-mounted ejectable flare racks. Each rack holds 102 flares, for a full capacity of 306 per aircraft. The rack is designed with removable baskets which hold the 20 mm diameter flare cartridges. This allows quick reloading of flares between missions.

The seeding equipment controls are mounted in the cockpit for pilot or copilot operation. 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 U.S. FAA-approved.

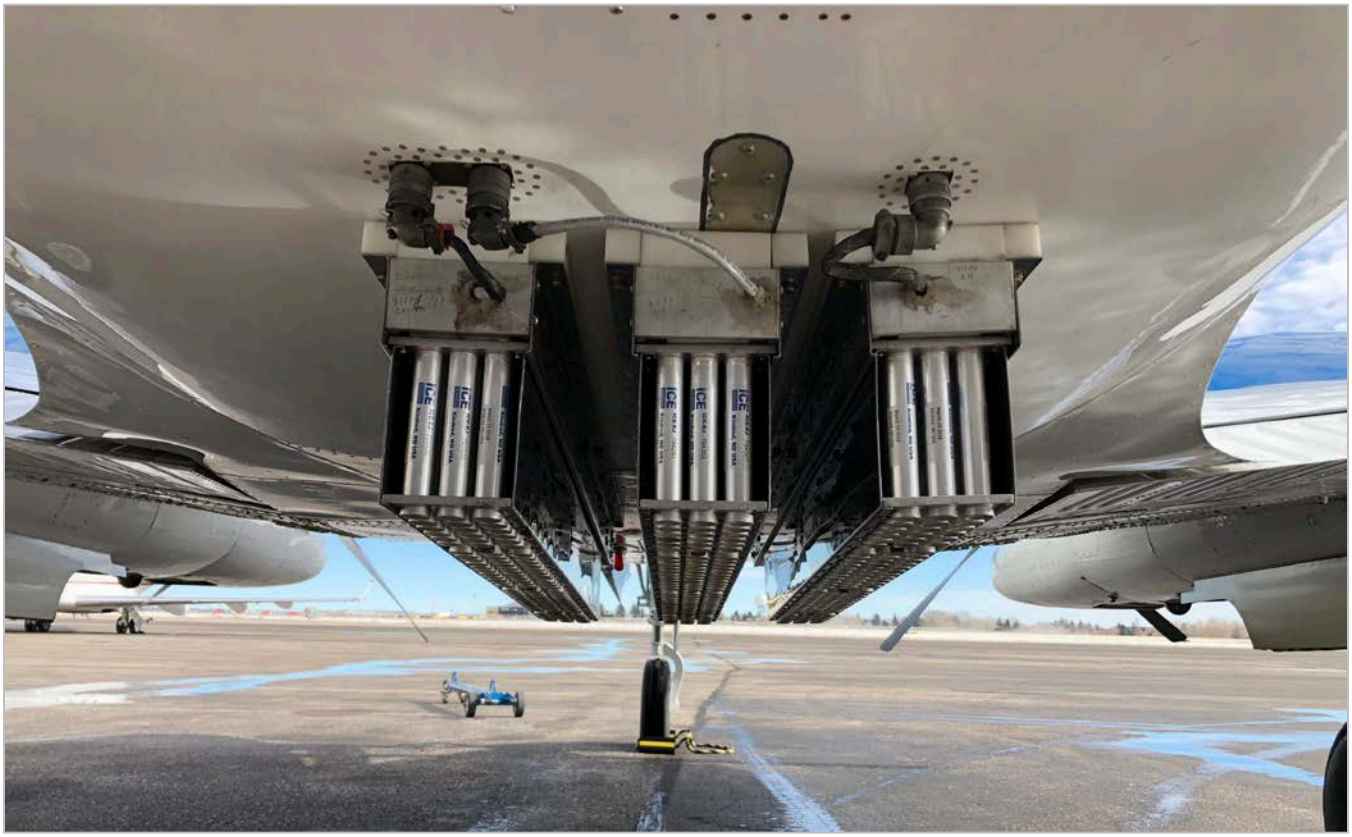


Figure 12. Ejectable flare belly racks installed on the project aircraft. Each ejectable flare yields 20g. The project aircraft was equipped as pictured with 306 ejectable flares. A total of 4,440 ICE-EJ® were expended during the 2020-2021 season. Photo by Kirk Hamilton.

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 standards and 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 240 burn-in-place and 3092 ejectable flares were expended during this winter season for the Medicine Bow and Sierra Madre Mountain Ranges in Wyoming. In the Upper North Platte River Basin of Colorado, 19 burn-in-place and 1348 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 cloud water inertial probe (CWIP, see Sec. 3.3.4) data. Each seeding event (firing of a burn-in-place flare or ejectable flares) 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 also kept paper records of the flight notes and regular seeding agent inventories. The flight forms were recorded and transmitted to the client, as requested.

3.3.4 Cloud Water Inertial Probe (CWIP)

The WMI King Air B200 featured a Cloud Water Inertial Probe (CWIP). The CWIP measured and recorded GPS altitude, wind speed and direction, temperature, humidity, airspeed, angle of attack, updraft speed, and liquid water content. Data from the instrument was displayed on an iPad for cockpit access during operations. Data were reviewed post-mission by WMI's Instrument technicians (Kurt Hibert) and archived for WWDO later use.

Figure 13. Cloud Water Inertial Probe (CWIP) installed under the aircraft wing. Photo by WMI.

4 METEOROLOGICAL SERVICES

WMI meteorologists provided meteorological support for Wyoming 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 the WMI meteorology 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, monitoring opportunities for operations.

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 or 18Z.

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. At times, additional precipitation could pose a potential threat to life or property. At other times, the public may perceive (rightly or wrongly) that seeding activities pose or increase such a threat. For these reasons, seeding suspension criteria have been established and strictly adhered to by the operators in accordance with industry standards. Suspension criteria were monitored by WMI's meteorology team in close partnership with the WWDO and JCWCD.

During the 2019-2020 season, the WWDO suspended seeding operations in the Laramie Range due to concerns with the integrity of the LaPrele Dam. This WWDO decision was a precautionary step determined by the risk associated with the basin hydrology. The Laramie Range target area remained suspended through the 2020-2021 season.

During the summer of 2020, a substantial fraction of the southern portion of the Medicine Bow target area within Wyoming was burned during the course of the Mullen Fire, which in total, consumed about 177,000 acres. Out of an abundance of caution the WWDO elected not to cloud seed in this area in the 2020-2021 season. Thus, two of the usual MB seeding tracks, MB1 and MB2, were not used at all, and the other three, MB3, MB4, and MB5, were shortened, terminating at Wyoming Highway 130. The Mullen fire did not cross HWY 130, so it was deemed safe to seed that portion of the range north of it.

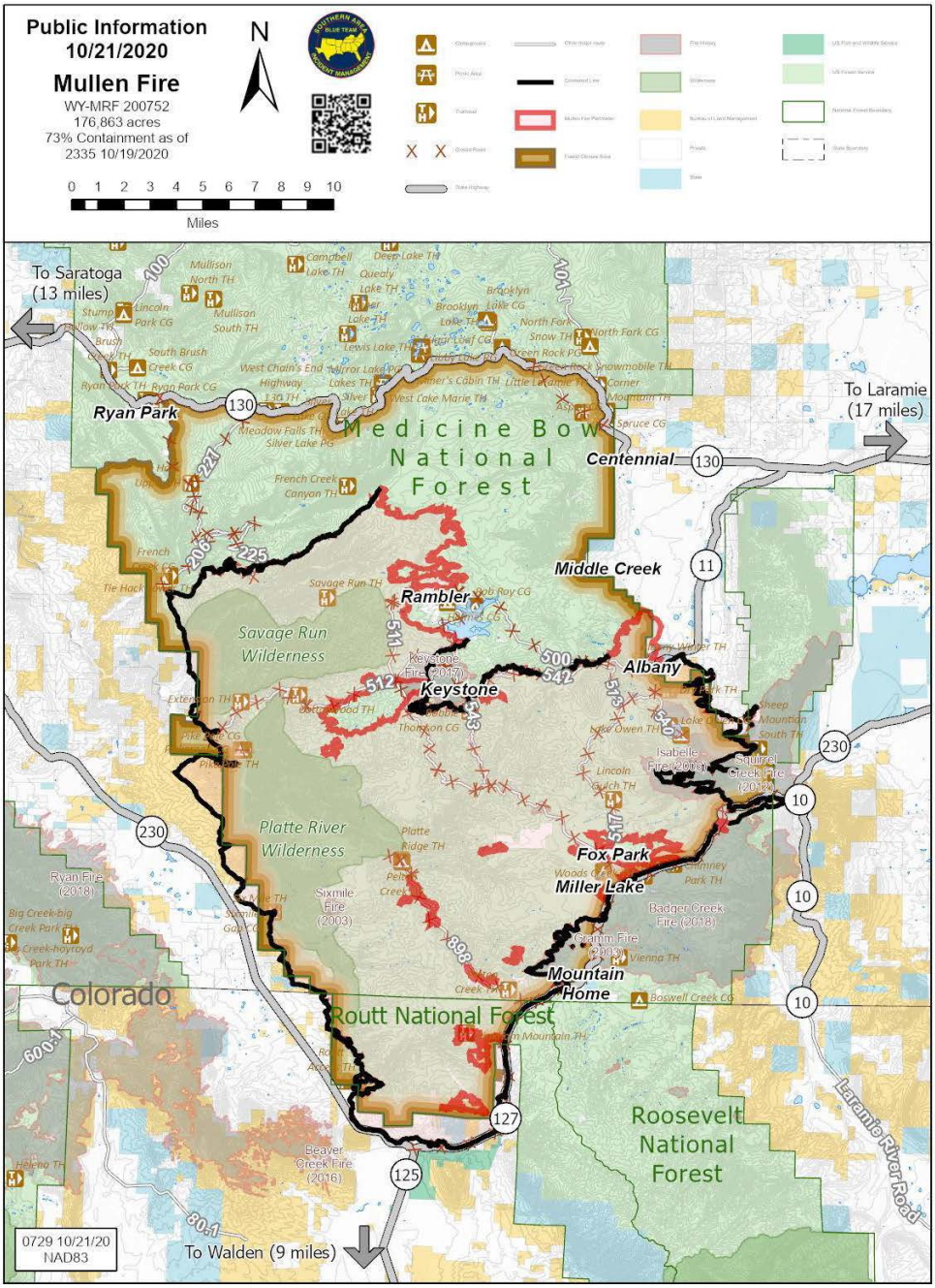


Figure 14. Mullen Fire map published on 21 October 2020.

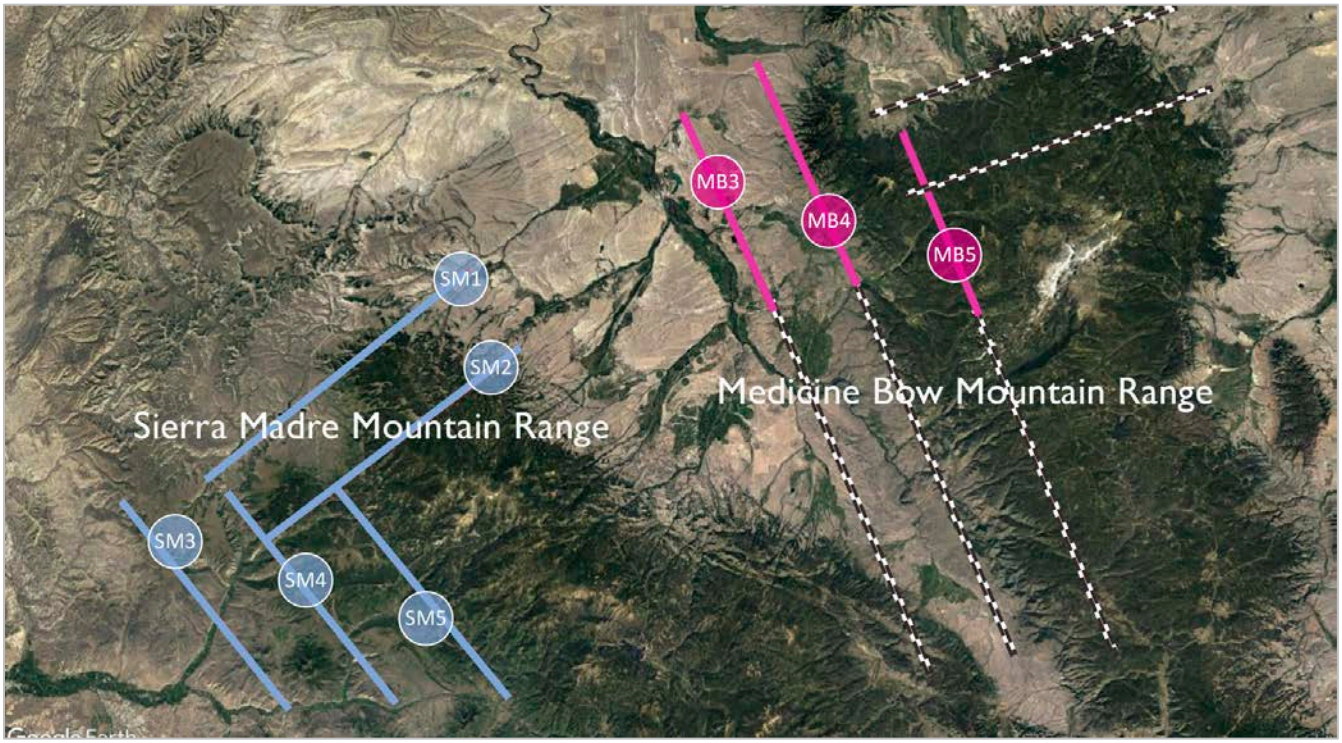


Figure 15. 2019-2020 vs. 2020-2021 Medicine Bow Mountain Range Target Area. The 2020-2021 Medicine Bow tracks are shown in magenta, the 2019-2020 tracks are represented by dashed black and white lines. The top two horizontal (unlabeled) tracks are MB1 and MB2.

4.1.1 2020-2021 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.

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 1[1].
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. This occurred in 2020, and is discussed at the beginning of this section.

[1]During 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.

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.

To facilitate the monitoring of SWE at SNOTELs in and near the project target areas, graphics were generated daily from the on-line SNOTEL data, and made available to project personnel and sponsors. The web link allowed SWE conditions to be assessed with a simple click of a mouse. An example of this graphic is shown below in Fig. 16.

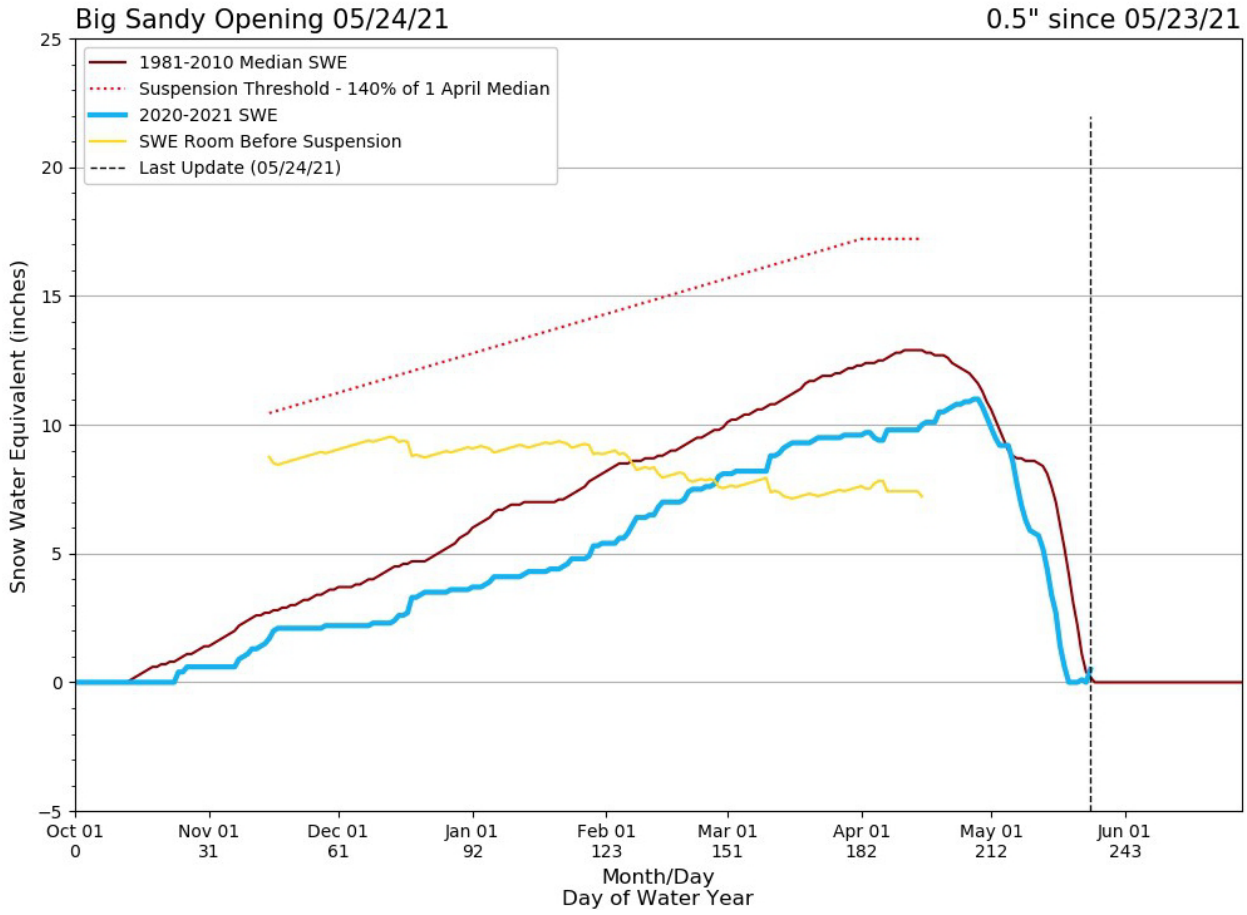


Figure 16. The accumulation of snow water equivalent (SWE, broad blue trace) measured at the Big Sandy Opening SNOTEL within the target area on the western flank of the Wind River Mountains is shown. The thirty-year median is shown in red. The suspension threshold is shown by the fine dotted line. The yellow line indicates the amount of additional SWE needed to reach the suspension threshold, in other words, the difference between the suspension threshold and the 2020-2021 SWE. This graphic is available on the WMI project site for all relevant SNOTELs, throughout the season.

4.2 WMI Numerical Weather Prediction

WMI meteorologists monitor and evaluate a host of real-time and prognostic products to conduct efficient seeding operations. Data included in real-time monitoring and forecasting this season consisted of the following: live radar data from the National Weather Service network of WSR-88D radars, satellite imagery, surface observations, webcam imagery, aviation weather sites (for icing products and observations), a variety of publicly-available numerical models (NAM, GFS, HRRR etc.), and unique in-house modeling tools specially developed for the program. When weather conditions deviate from those forecast or rapidly changing conditions otherwise warrant, weather updates were initiated by the meteorologist.

For the 2020-2021 season, WMI operated a nested limited area domain of the Weather Research and Forecasting (WRF) model, with an inner high-resolution nest covering both the Wind River Range ground-based generator program and this aerial project. The high-resolution inner nest, whose boundaries are shown with a thick black border on the plot below, was initialized from the High Resolution Rapid Refresh (HRRR) model, and was given the North American Model (NAM) forecast for boundary conditions at 3-hour intervals. The outer domain grid spacing was 7.5 km and the inner higher-resolution nest grid spacing was 2.5 km. The model was routinely run twice per day, with a 60-hour forecast duration for the 12 UTC model cycle and a 72-hour forecast duration for the 00 UTC model cycle. When active weather occurred and potential seeding opportunities were expected or ongoing, model integrations from 06 and 18 UTC initial conditions were also performed. Information provided by these customized WRF runs 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 spatiotemporal 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.

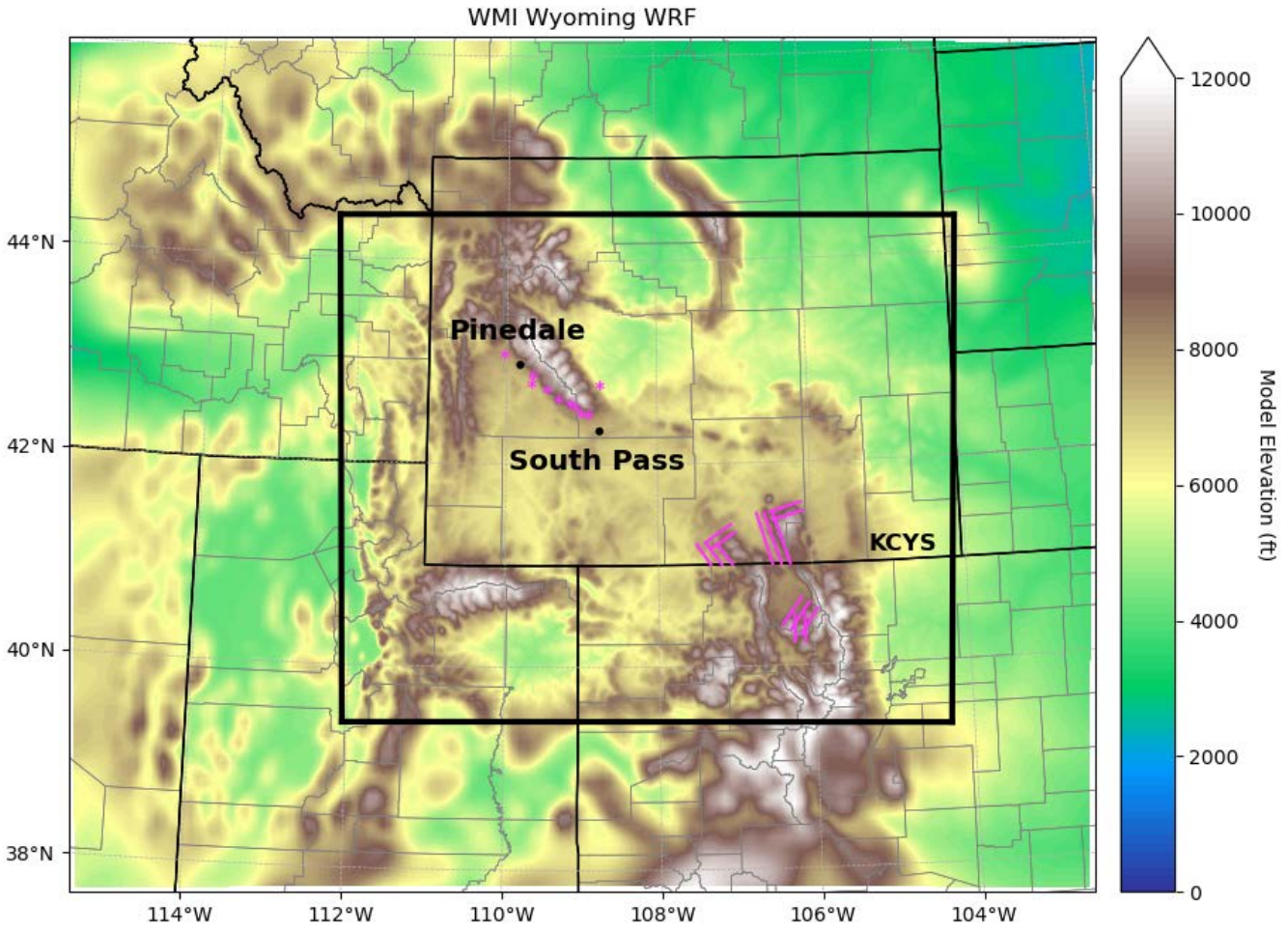


Figure 17. WMI Wyoming Nested 2.5km WRF Domain. Solid pink lines show the established aerial seeding tracks, selected from or modified based on the meteorological conditions present during each seeding event. Graphical output and BUFKIT format model soundings from WMI's Wyoming WRF domain were published to http://wmiradar.com/wy as soon as the data was available.

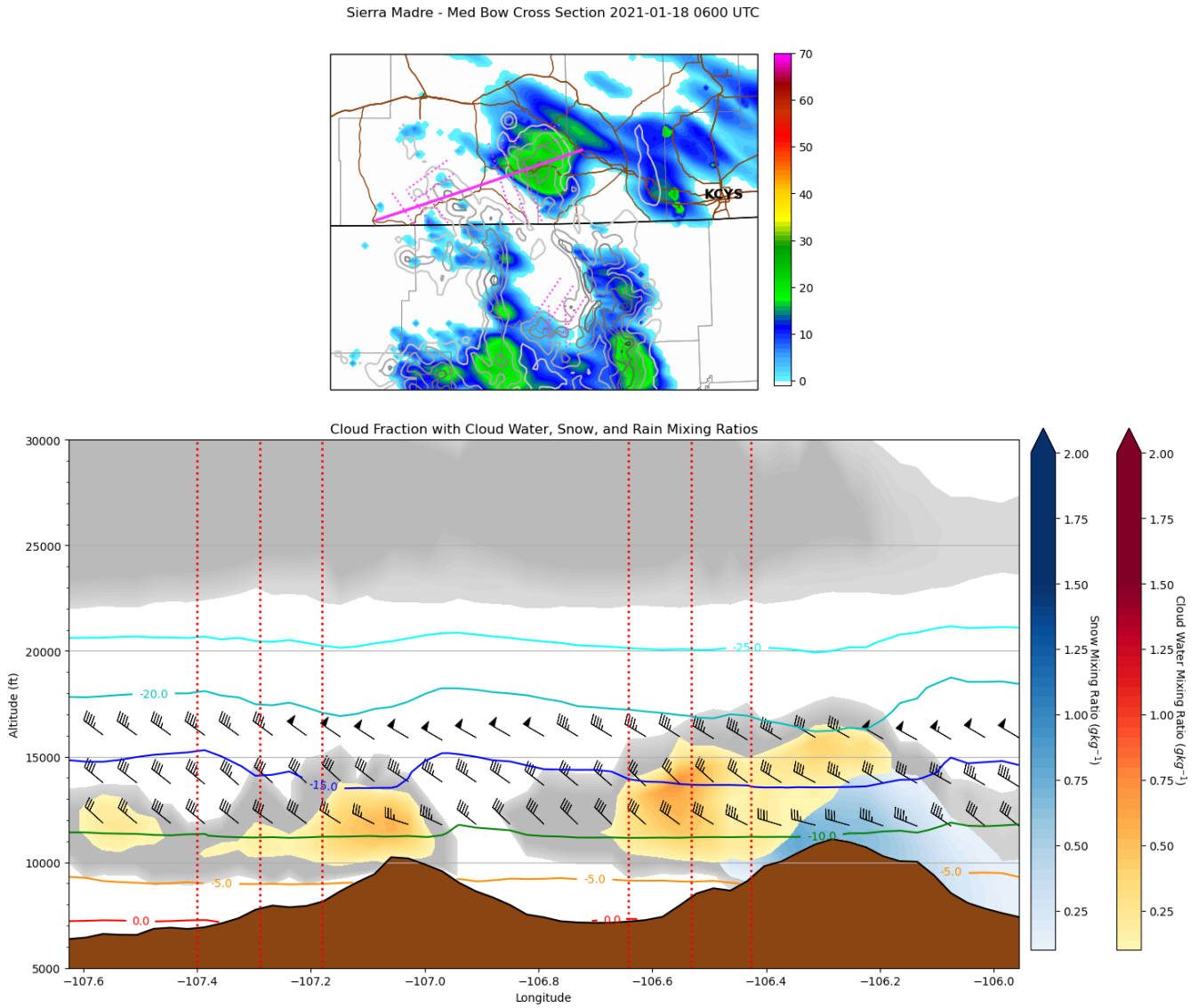


Figure 18. Plot of model simulated composite reflectivity is shown at the top, with a vertical cross section in the bottom half spanning the western flight tracks of the Sierra Madre and Medicine Bow Range. The plot is mode for 06:00 UTC on 18 January 2021, or 11 PM MST. See text for interpretation and discussion.

Figure 18, 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 (northwest winds around 40 kts are shown in this example).

Figure 19, much like Figure 18, 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 40,000 ft MSL on the y-axis. The cross section depicts isotherms, cloud fraction, cloud water, and snow in the same manner as Figure 18. 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 18, but desired a cleaner design, and with the entire flight path between the seeding tracks and KCYS depicted.

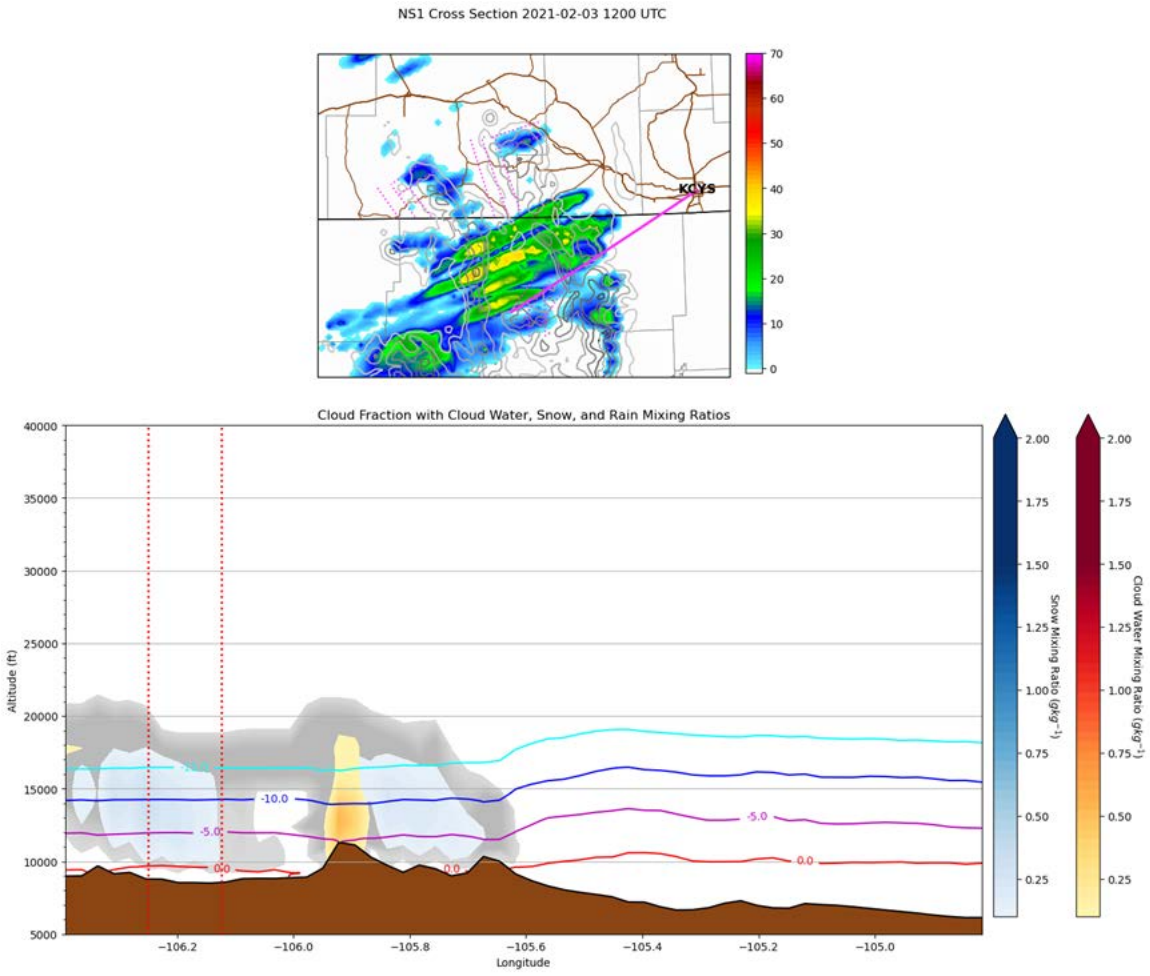


Figure 19. This plot, like Figure 18, shows model composite reflectivity in the top portion with a vertical cross section beneath. The cross section is drawn from the western most Never Summer Range flight track to the Cheyenne Airport. The plot is mode for 23:00 UTC on 7 February 2021, or 4 PM MST. See text for interpretation and discussion.

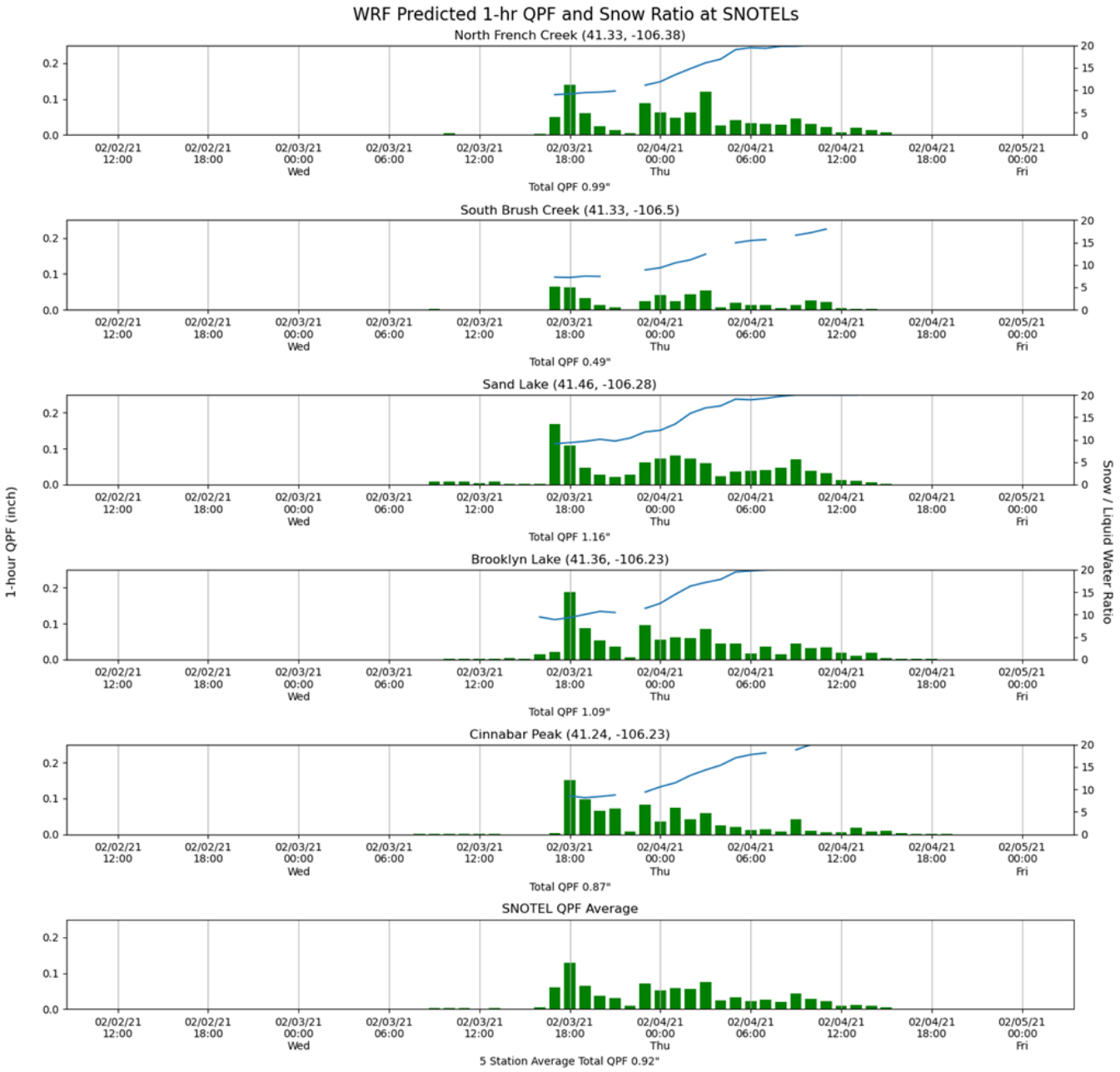


Figure 20. This plot shows hourly quantified precipitation forecast (QPF) outputs for five different SNOTEL locations in the Medicine Bow Range. A five-station average is shown in the bottom plot.

In Figure 20, 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 12 UTC WRF run on 2 February 2021. A double y-axis is used to show model predicted snow-liquid water ratios on the right. The meteogram duration is 60-hours, the same as the model duration of the high-resolution nest.

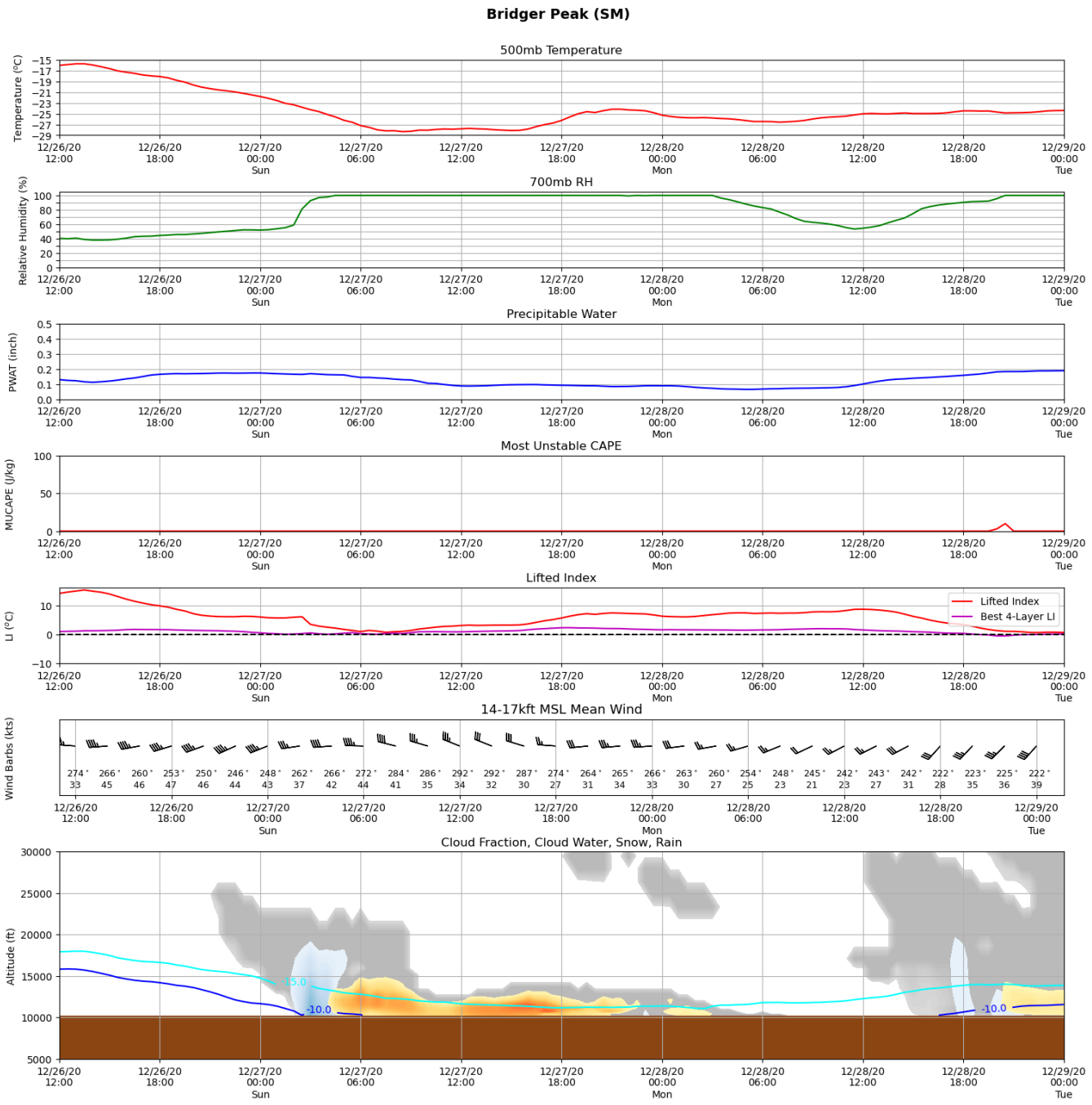


Figure 21. This figure, another meteogram, shows the forecasted evolution of a selection of mid-tropospheric, convective, and precipitation variables through time. The location is fixed at Medicine Bow Peak. Further explanation is provided in the text below.

One final plot example is Figure 21. This multi-variable meteogram shows the forecasted progression of 500 mb temperature, 700 mb 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. 500 mb temperature and 700 mb 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 14 kft -17 kft 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 Bridger Peak in the Sierra Madre range, 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.

4.3 Use of Weather Radar Data

While evaluating timely radar information has always been an aspect of the meteorological services involved in this cloud seeding program, WMI began ingesting live radar data from the nationwide network of NOAA NEXRAD radars this project season. Using radar software called TITAN, Thunderstorm Identification Tracking Analysis and Nowcasting, a mosaic of NEXRAD radars was created, and customizable overlays of aerial flight tracks and select geopolitical features (e.g. counties, interstates) were added for context. Further, timely aircraft position information was added, allowing a real-time fusion of radar information with seeding aircraft position. Web images of both a regional radar mosaic and a closer view of any airborne seeding/patrol operations were created and published in real-time on the project operations webpage when potentially seedable weather occurred.

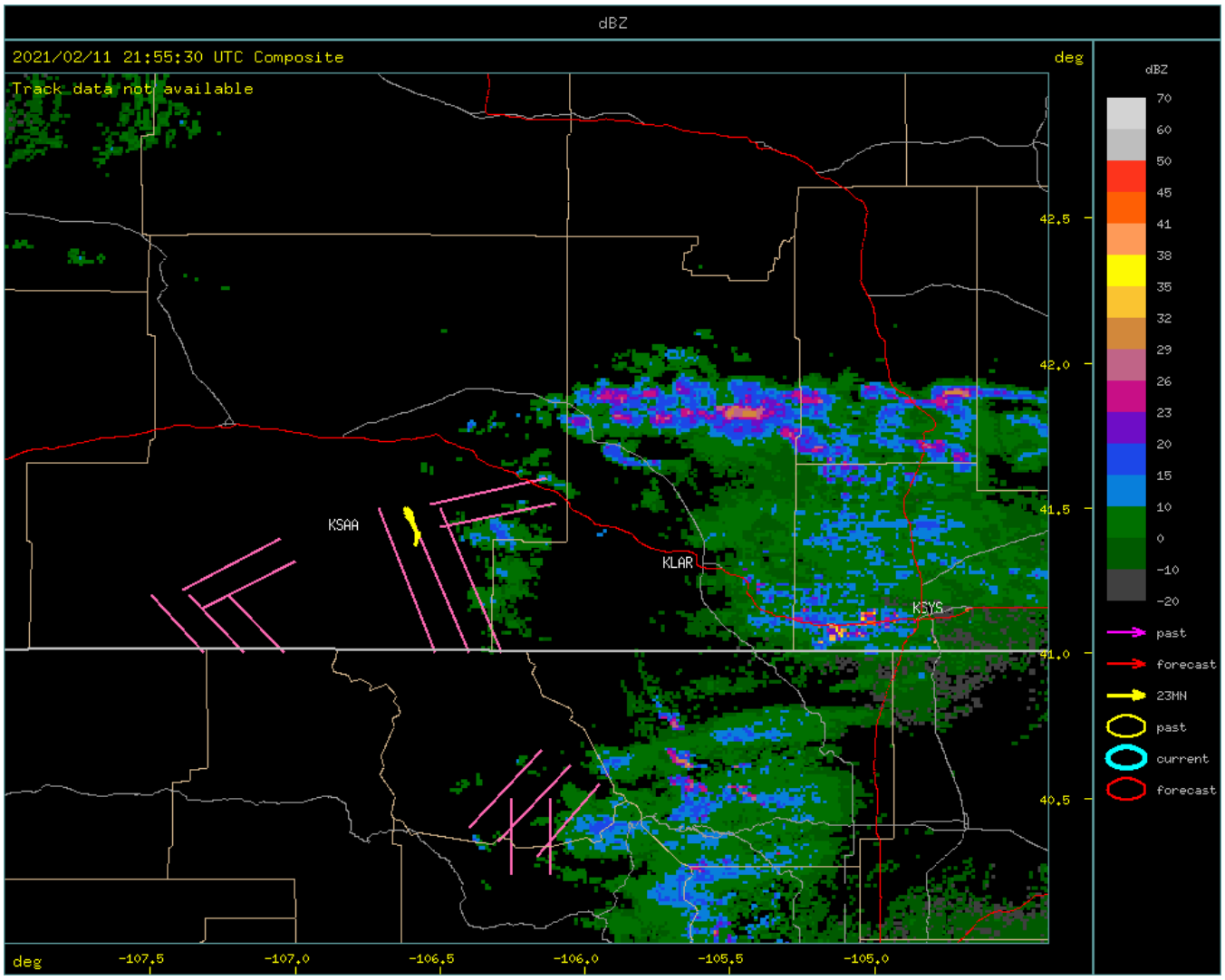
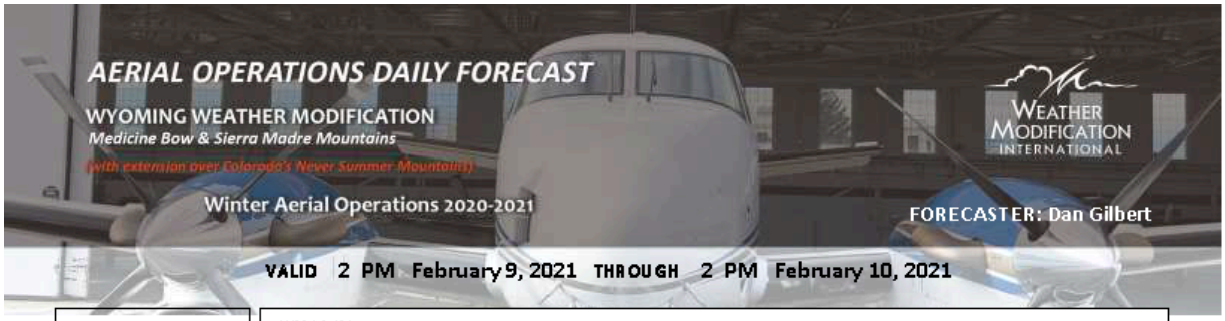


Figure 22. This is a mosaic of composite reflectivity from NOAA NEXRAD radars located in Riverton, WY, Cheyenne, WY, and Denver, CO. Aerial seeding track lines are shown in pink, while the aircraft flight track is shown in yellow.

4.4 WMI Forecast Sheet



Today's ODC: +2

SYNOPSIS

WY has strong zonal flow aloft today as the tail of a jet streak gradually exits the region by tonight. At midlevels, no significant perturbations are expected to pass through the region until Friday and Saturday. A plume of Pacific moisture will continue to flow into our area today through the end of the week keeping 700 mb RH elevated for an extended period. Seeding level winds will remain moderate westerlies favorable for orographic lift throughout the week. A clipper system arrives from the north Friday/Saturday with much colder air invading by Friday night, and moisture will finally plummet at that time. PWAT values will linger around 0.25 inches today and tonight. A shallow layer of dry air in the low levels will keep the PWAT number subdued, but there is a layer of good moisture flowing into the region above 700 mb, and webcams are showing cloud bases are now well-below the peaks, so this should be favorable for seeding. SLW is elevated more than we typically seed, but the temp profile is workable.

FORECAST

Nearly continuous mountain snowfall is expected through Saturday. Intermittent periods of targetable SLW and deep orographic clouds are expected in all ranges through Friday evening with multiple opportunities for seeding. Our challenge will be to select the most productive seeding windows while managing crew duty cycle to maximize our opportunities. A flight has departed CYS at forecast time, en route to the MB tracks where seeding will occur throughout this afternoon into the early evening hours. We will then take a break from seeding overnight before a morning NS flight begins around dawn. Additional seeding could be possible tomorrow afternoon following the NS flight, but we will wait to pin that down tomorrow morning. More seeding is possible Thursday and Friday. Seeding appears unlikely Friday night and Saturday once the Canadian clipper pushes through and temps aloft drop sharply for the weekend.

ACTION: MB seeding has begun on track MB3 utilizing BIPs with light SLW observed. A second flight is expected in the NS around dawn Wednesday morning.

Day 2 Outlook ODC: +2

WRF MODEL SOUNDING	
SAA	00Z, 10 February
0°C level	8.0 kft
-5°C level	9.8 kft
-10°C level	11.5 kft
-20°C level	16.4 kft
Precipitable Water	0.23 inches
14 kft T/wind	-16.0°C 270@44 kts
16 kft T/wind	-19.4°C 274@52 kts
700 mb T/wind	-4.7°C 262@32 kts
500 mb T/wind	-22.4°C 276@58 kts

YESTERDAY'S WEATHER **Observed ODC: 0**

Temps Max/Min: Saratoga 36/21 Cheyenne 28/6 Walden 34/21

Weather Summary: During the day, skies were mostly clear except for mountain wave clouds downwind of the peaks. Scattered high and midlevel clouds passed through overnight. A few hours before dawn, deeper low level cloud developed in the form of high based orographic clouds and stratus with bases mostly above the peaks. Overcast high and midlevel layers overspread the region around dawn. Cloud bases steadily lowered through the rest of the period with snowfall observed Tuesday morning.

Flights: None

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.

Figure 23. A WMI forecast sheet from 9 February 2021; all forecasts were submitted to the client via email daily.

5 PROJECT FLIGHT DATA

The first 2020-2021 winter mission was flown on 8 November 2020 for the Sierra Madre Mountain Range. A map of each seeding event is provided. The pre-established flight tracks are shown in blue and actual aircraft tracks are shown in black. Yellow dots denote where ejectable flares were fired, and blue triangles denote where burn-in-place flares were ignited. The table beneath each map details the mission and includes fight data (engine on/off, total time), flares used, pilot(s) observations, a description of observed weather conditions, and area forecast relevant to that mission. Maintenance and training flights conducted at the contractor's expense are not included in the list.

All flights for the Wyoming target areas are summarized in Table 2. Those flown for the Never Summer Range in Colorado are given in Table 3.

Table 2. Flight operations for the Medicine Bow and Sierra Madre Mountain Ranges are summarized.

2020-21 WYOMING N23MN FLIGHT SUMMARY

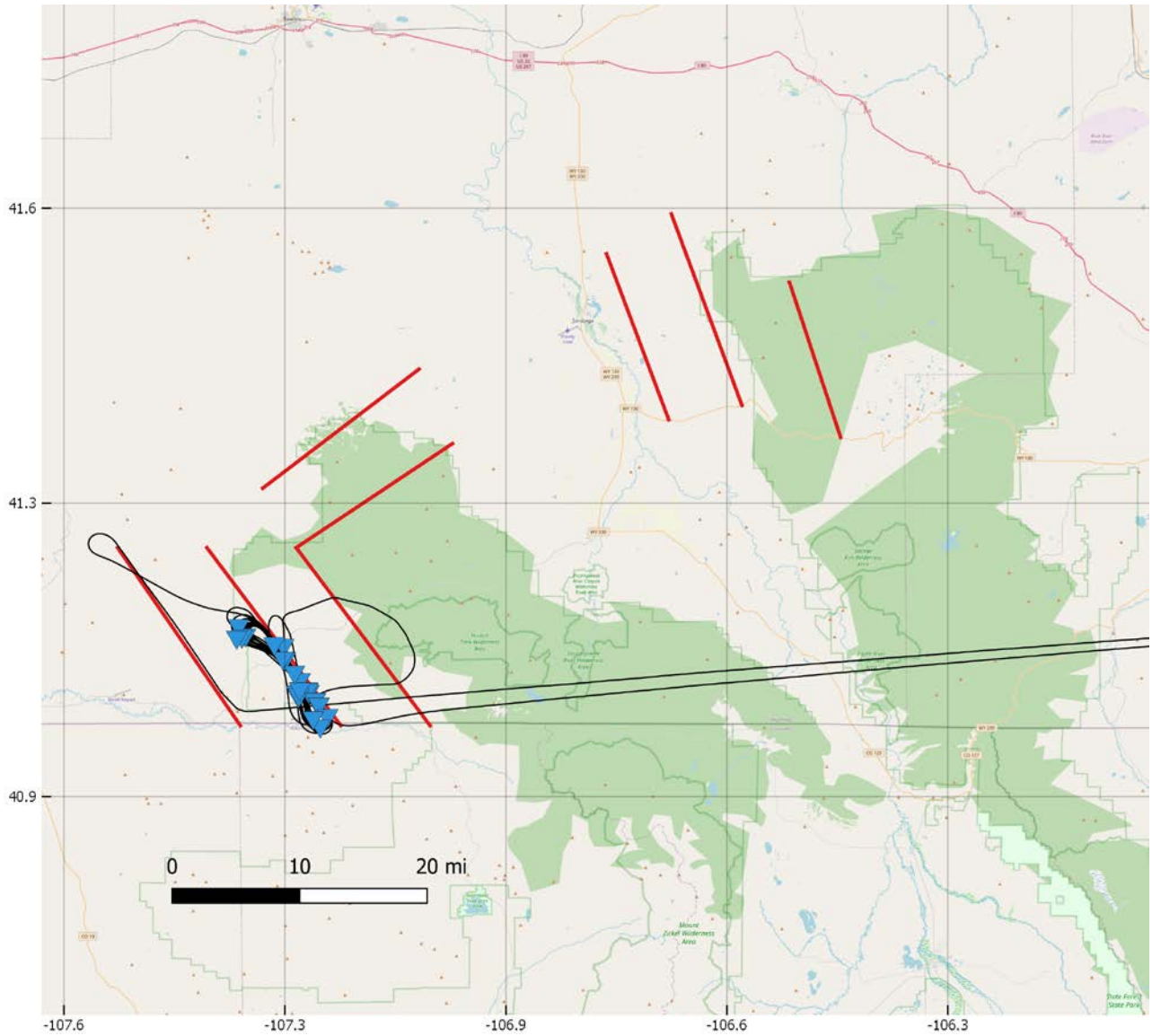
	SNOW	RECON	REPO	WMI OTHER	BILLABLE TOTAL	MX FLIGHTS	BIP	EJ	TRACK(S)	TARGET AREA	CREW	Flight #
DATE	**17**	**3**	**0**									
11/8/2020	4.00				4.00	0.00	27		SM3, SM4, SM5	MBSM	KHNE	1
11/11/2020	6.27				10.27	0.00		305	SM4	MBSM	KHNE	2
11/16/2020	6.30				16.57	0.00		304	SM3	MBSM	KHNE	3
11/19/2020	5.22				21.79	0.00	39	97	SM4, SM3	MBSM	KHNE	4
12/16/2020	6.53				28.32	0.00		303	SM4	MBSM	KHNE	5
12/18/2020	4.20				32.52	0.00	18	22	SM4, SM5, MB5, MB4	MBSM	KHNE	6
12/19/2020	6.23				38.75	0.00		300	MB4, MB5	MBSM	KHNE	7
12/21/2020	5.57				44.32	0.00		244	SM4, SM3, SM1, Modified	MBSM	KHNE	8
12/22/2020	5.32				49.64	0.00	47		SM4	MBSM	KHNE	9
12/27/2020	6.20				55.84	0.00		289	SM4	MBSM	KHNE	10
12/27/2020	6.35				62.19	0.00		284	SM5	MBSM	KHNE	11
1/14/2021		0.93			63.12	0.00			SM1	MBSM	KHNE	12
1/18/2021	5.88				69.00	0.00	26	171	SM1	MBSM	KHNE	13
1/22/2021		1.58			70.58	0.00			MB4, MB5	MBSM	KHNE	14
1/30/2021	6.45				77.03	0.00		252	SM2	MBSM	KHNE	15
2/3/2021	5.85				82.88	0.00	22	127	SM4	MBSM	KHMD	16
2/4/2021				2.33	82.88	2.33						
2/5/2021				2.37	82.88	4.70						
2/9/2021	6.38				89.26	4.70	47	87	MB4, MB3	MBSM	KHMD	17
2/11/2021	5.35				94.61	4.70	14	172	MB4	MBSM	KHMD	18
2/20/2021		2.08			96.69	4.70			MB4, MB5, SM4	MBSM	KHBB	19
3/31/2021				0.60	96.69	5.30						
4/7/2021	3.82				100.51	5.30		135	SM1	MBSM	AWBB	20
TOTALS	**95.92**	**4.59**	**0.00**	**5.30**	**100.51**	**5.30**	**240**	**3092**				

Table 3. Flight operations for the Never Summer Mountain Range are summarized.

2020-21 COLORADO N23MN FLIGHT SUMMARY

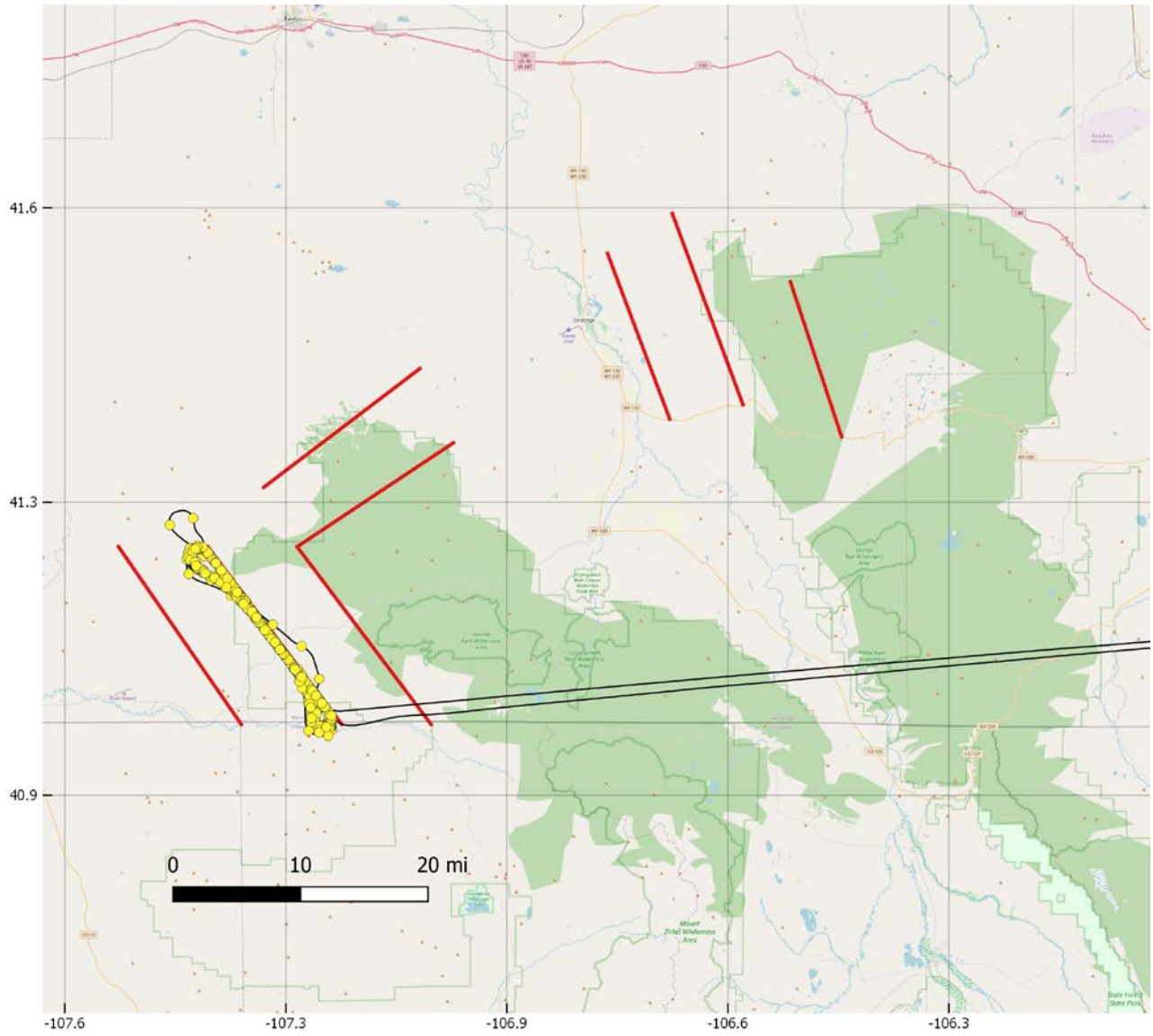
	SNOW	RECON	REPO	WMI OTHER	BILLABLE TOTAL	MX FLIGHTS	BIP	EJ	TRACK(S)	TARGET AREA	CREW	Flight #
DATE	**7**	**0**	**0**									
11/12/2020	2.90				**2.90**	**0.00**		98	NS4, NS5	NS	KHNE	1
12/18/2020	3.95				**6.85**	**0.00**	4	162	NS5	NS	KHNE	2
1/13/2021	3.50				**10.35**	**0.00**	5	154	NS1	NS	KHNE	3
1/18/2021	6.00				**16.35**	**0.00**		261	NS2	NS	KHNE	4
2/3/2021	5.82				**22.17**	**0.00**	10	210	NS4	NS	KHMD	5
2/13/2021	5.87				**28.04**	**0.00**		222	NS2	NS	KHMD	6
4/7/2021	4.97				**33.01**	**0.00**		241	NS2, NS3	NS	AWBB	7
TOTALS	**33.01**	**0.00**	**0.00**	**0.00**	**33.01**	**0.00**	**19**	**1348**				

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



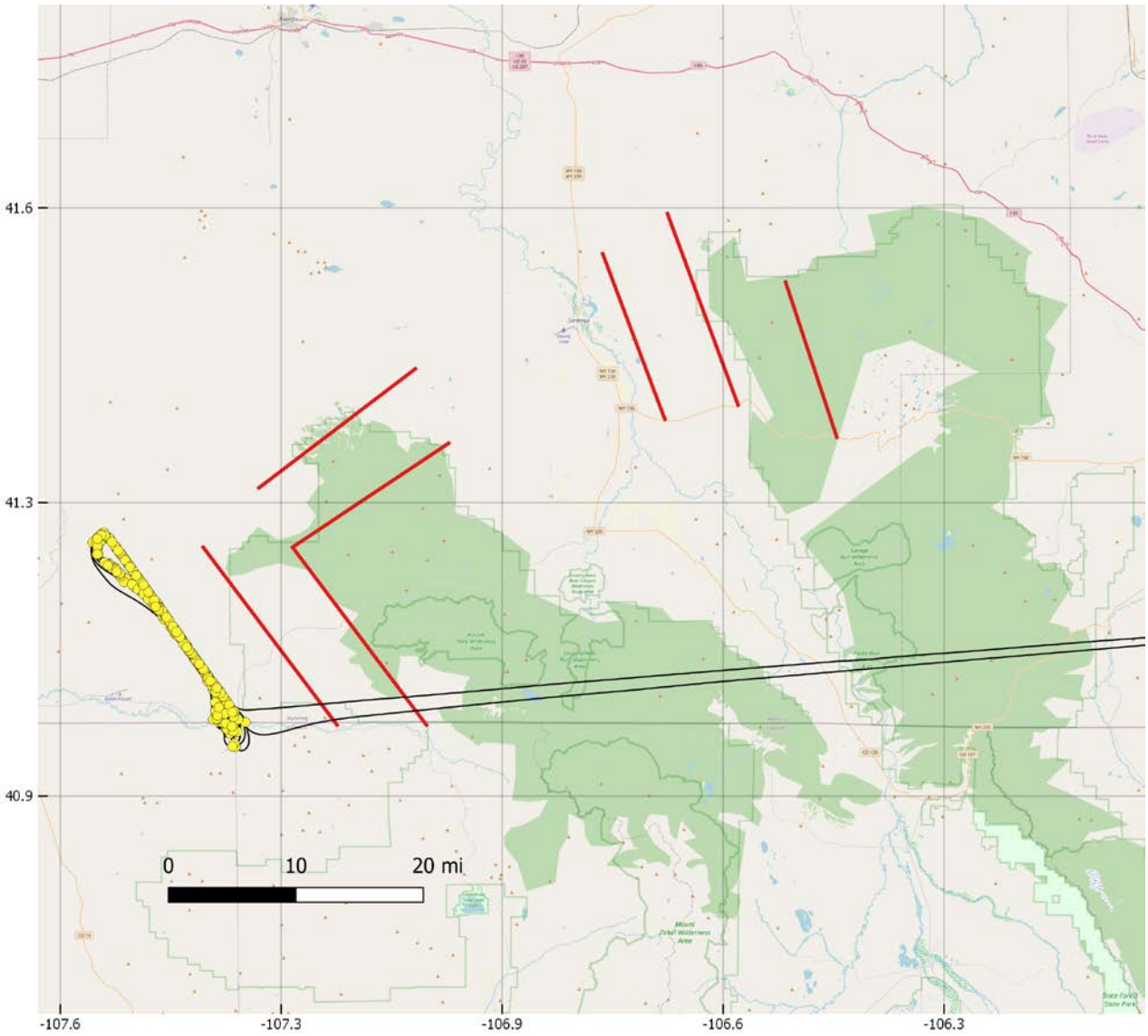
N23MN	OPS #:	01			SEED
	Track(s)/Basin:		SM-3, SM-4, SM-5		
UTC Date:	November 8, 2020		MST Date:	November 7, 2020	
UTC Engines ON:	05:28		MST Engines ON:	10:28 pm	
UTC Engines OFF:	09:28		MST Engines OFF:	2:28 am	
Total Time:	4:00	4hr	Flares Used:	27 BIP	0 EJECT
Pilot's Flight Summary:	Arrived on SM-3 at 16 kft. Found light SLW while crossing the ridge. Moved to SM-4 and began seeding with BIPs at 15 kft and cut off the north half of the track for winds. We continued seeding on SM-4. We left SM-4 to make on pass on SM-5 and found trace SLW. We then returned to SM-4 and descended to 13 kft. We encountered intermittent				

	areas of trace to light SLW and natural ice. Due to lack of seedable targets and direction of radar, RTB.
Synoptic Analysis:	A deep low pressure system centered over California and Nevada will slowly push into the Rockies through the next two days. A strong southwesterly jet is nosing into WY today, and positive vorticity advection will occur today and tonight. Low level RH will increase quickly throughout the day and then drop off tomorrow. A cold front will push eastward through the ranges between 11pm and 3am local time. Warm temps and high snow levels are likely through this evening ahead of the front. Temperatures aloft will drop sharply after midnight along with snow levels, and rain will switch to widespread snow overnight. The low finally meanders east of WY late Monday night, and shortwave ridging is likely Tuesday. The next trough brings another round of active weather to WY Tuesday night and Wednesday from a progressive shortwave trough diving into the region from the NNW.
Area Forecast:	Low level cloud cover will increase through this evening as moisture pours into the region in warm southwest flow. Periods of rain are likely this afternoon and evening with snow levels well above 8,500 feet. This will be too warm for seeding operations during the day, and clouds will be intermittent. As the cold front approaches around midnight, more consistent precipitation is expected to begin and continue through tonight. Winds will become slightly more westerly behind the front as temps plummet. Deep cloud layers from upper level forcing will likely produce significant ice crystals tonight which may limit SLW availability in seedable ranges. According to the latest models, it does not look likely that we will be seeding the frontal passage this evening, though it is possible later model runs could change that. Despite that, latest models do show at least some modest pockets of targetable SLW for the SM later tonight which could warrant a late night or early morning flight. Final decisions about evening or overnight operations will be made after seeing the 00Z model runs, and an evening update will be issued. Seedable clouds appear unlikely tomorrow through Tuesday with snow showers tomorrow and Monday. Seeding could be possible with the next system Tuesday night or Wednesday.
Flight occurred in the evening hours of the 7th; weather information is from Nov. 7th.	



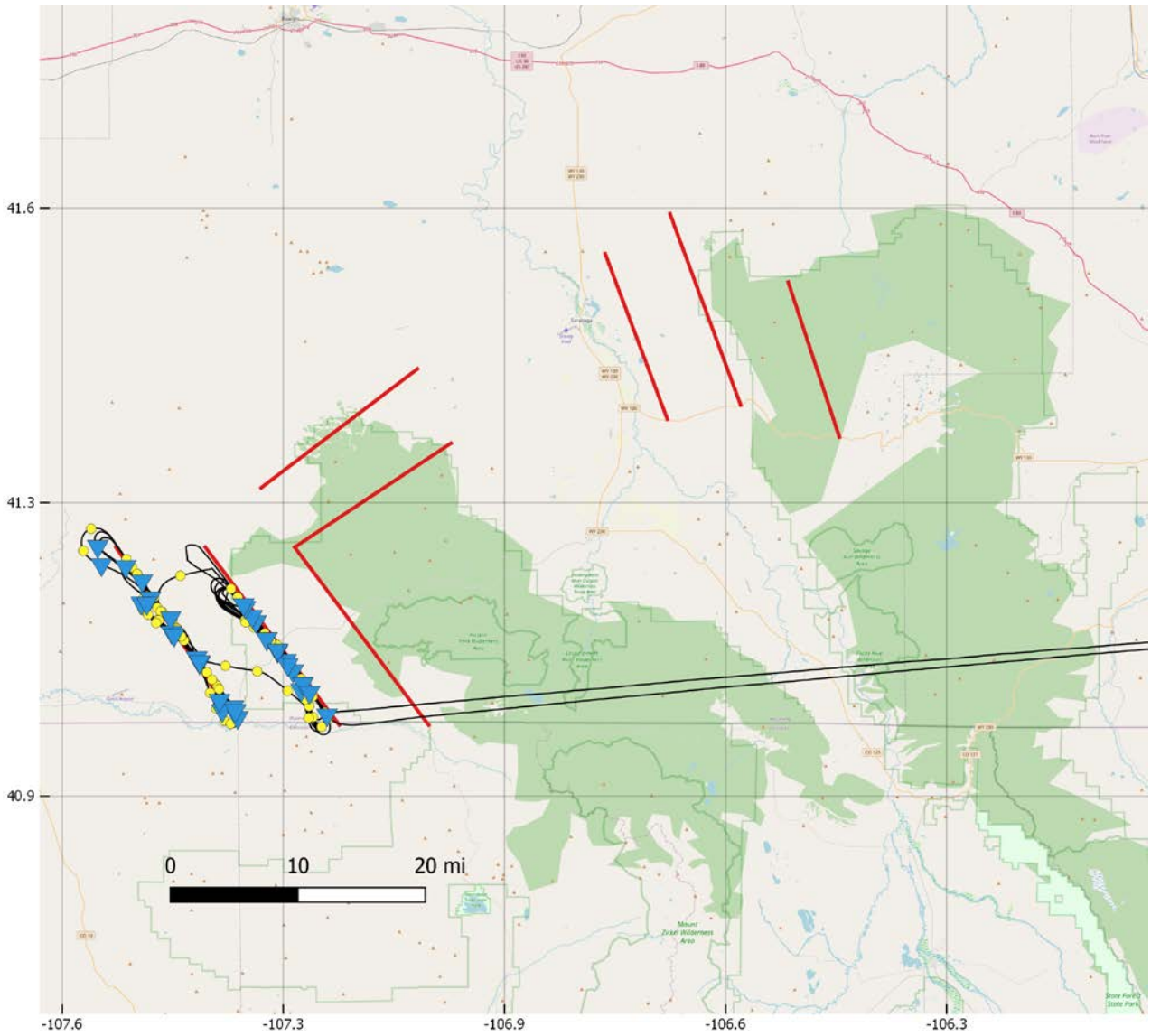
N23MN	OPS #:	02			SEED
	Track(s)/Basin:		SM-4		
UTC Date:	November 11, 2020		MST Date:	November 11, 2020	
UTC Engines ON:	08:06		MST Engines ON:	1:06 am	
UTC Engines OFF:	14:22		MST Engines OFF:	7:22 am	
Total Time:	6:16	6.27hr	Flares Used:	0 BIP	305 EJECT
Pilot's Flight Summary:	Departed Cheyenne. Crossing the ridge we picked up moderate SLW. Began dropping EJs once a minute at 15 kft in moderate SLW at cloud tops. We gradually climbed with the cloud tops up to 16 kft throughout the mission. Cloud tops consistently had moderate SLW. RTB Cheyenne.				
Synoptic Analysis:	The large scale synoptic pattern shows a broad trough over the western US stretching from the eastern Pacific to the Great Lakes. Embedded in the flow, a shortwave ridge				

	over the region exits early in the period followed by a significant shortwave from British Columbia this evening through tomorrow. Low level moisture will remain elevated through tomorrow evening which is allowing for some low stratus and flurries in the SM/MB today. Temps aloft are cooling through morning. PWAT is relatively light with this system, and overall snow totals will be light tonight-tomorrow. Winds at seeding altitudes look to be westerly through tomorrow around 30 knots this evening increasing to around 50 knots overnight. A shortwave ridge pushes through Thursday bringing drier air. Another shortwave trough moves in Friday, and then progressive waves of vorticity look likely in northwest flow through the weekend.
Area Forecast:	Low cloud cover will continue through the afternoon and evening with flurries and insufficient cloud depth for seeding. As moisture and wind speeds increase late tonight, the SM will develop seedable orographic clouds during the late-night hours through dawn. Shallow orographic clouds persist in the SM tomorrow, but seeding looks unlikely there tomorrow. The NS range will see broken low clouds throughout the day becoming overcast this evening and tonight. Seedable orographic clouds look possible in the NS tomorrow afternoon or evening, and then temps aloft will likely become too cold for operations late tomorrow evening. Thursday will see drier conditions with a brief break in cloud cover. Active weather returns with warmer systems moving in Friday through the weekend likely bring more seedable clouds.
Flight occurred in the morning hours of the 11th; weather information is from Nov. 10th.	



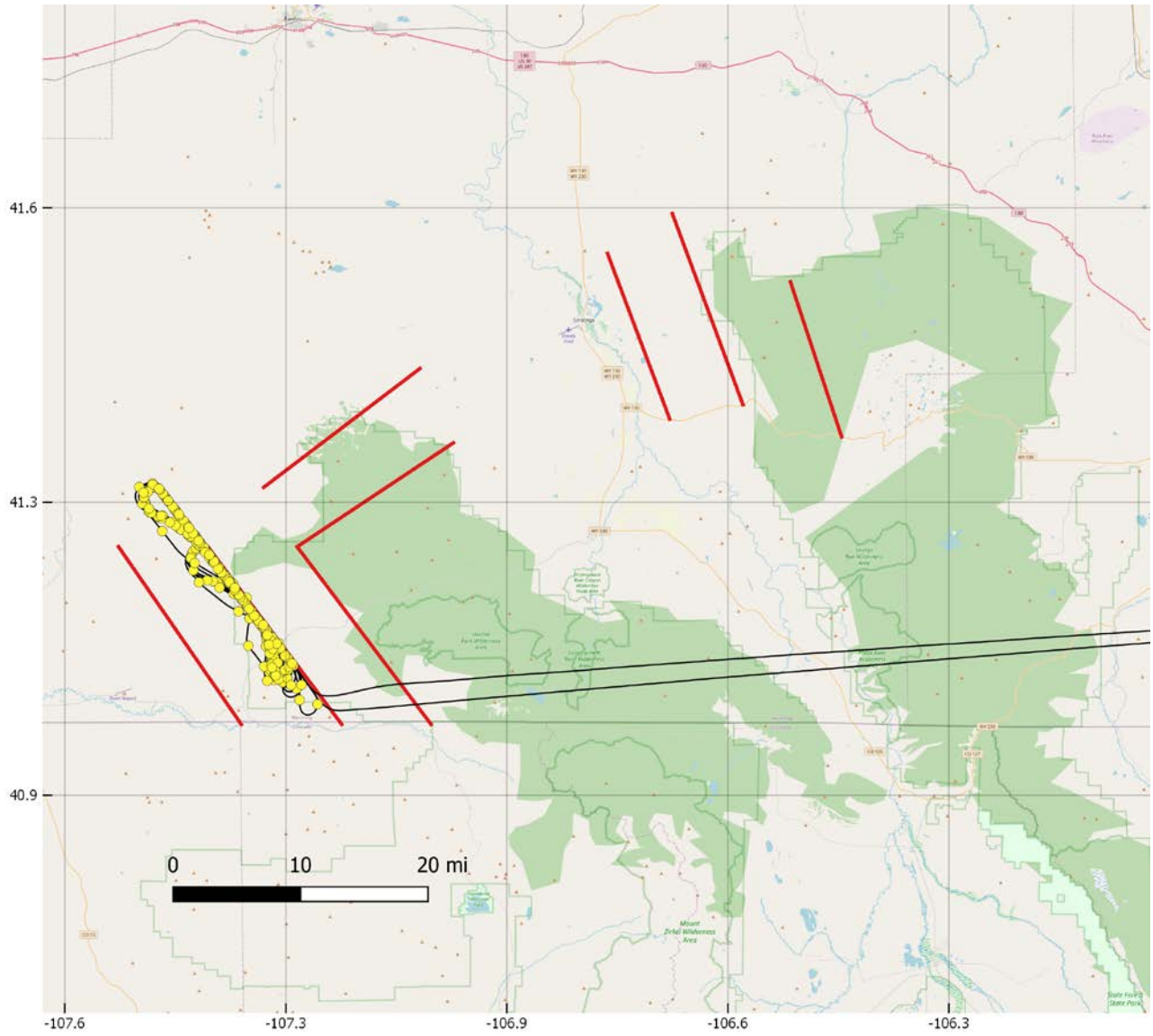
N23MN	OPS #:	03			SEED
	Track(s)/Basin:		SM-3		
UTC Date:	November 16, 2020		MST Date:	November 15, 2020	
UTC Engines ON:	00:54		MST Engines ON:	5:54 pm	
UTC Engines OFF:	07:12		MST Engines OFF:	12:12 am	
Total Time:	6:18	6.3hr	Flares Used:	0 BIP	304 EJECT
Pilot's Flight Summary:	Departed Cheyenne and while enroute over the Medicine Bow range, we encountered moderate mixed ice. We made our first pass on SM-3 at 15 kft and encountered moderate SLW and mixed Icing. Tops 15.8 kft-16.1 kft. We began dropping EJs once per minute at 16.3 kft. We would occasionally descend in altitude to investigate cloud tops and icing, then climb back on top to continue seeding. Cloud tops consistently maintained moderate to heavy SLW and moderate mixed Icing. RTB.				

Synoptic Analysis:	Very strong northwest flow remains in place today and tonight, and then the upper jet shifts north and east of the region tomorrow as a ridge builds over the region Monday and Tuesday. Temps have warmed significantly with 500mb temps now above -18°C, and PWAT will rise above 0.3 inches by this afternoon. Continued very strong seeding level winds are likely through morning, around 60+ kts. With better moisture and warmer temps today, models are now showing deeper more consistent SLW this evening and late tonight. A long steady warming trend continues through Tuesday under the ridge with dwindling moisture Monday-Tuesday. Moisture will start to return slowly Wednesday and Thursday as we shift to southwest flow ahead of the next incoming system. A cold front moves through early Thursday without much impact. A midlevel trough swings through Friday into Saturday bringing widespread moderate snowfall.
Area Forecast:	Models show much better seeding conditions this morning. Seeding is planned for the SM range beginning around 00Z today, likely on the high wind westerly track (SM-3). Models are indicating heavy persistent SLW throughout the evening hours for the SM, and then lighter amounts overnight. The NS range also looks to have periods of seedable conditions overnight if we decide not to do a second flight on the SM. Moderate orographic mountain snowfall will occur this evening and tonight, ending around dawn. Higher elevations will receive 3-6 inches of accumulation. Dry warmer conditions are expected Monday and Tuesday with ridging. Clouds will clear out by midday tomorrow leaving clear skies tomorrow afternoon and Tuesday. Showery activity is possible Wednesday into Thursday with the frontal passage, but seedable conditions appear unlikely due to insufficient moisture. After tonight, the next obvious seeding window appears to be Friday into Saturday after the ridge moves out and the next shortwave trough approaches.
Flight occurred in the evening hours of the 15th; weather information is from Nov. 15th.	



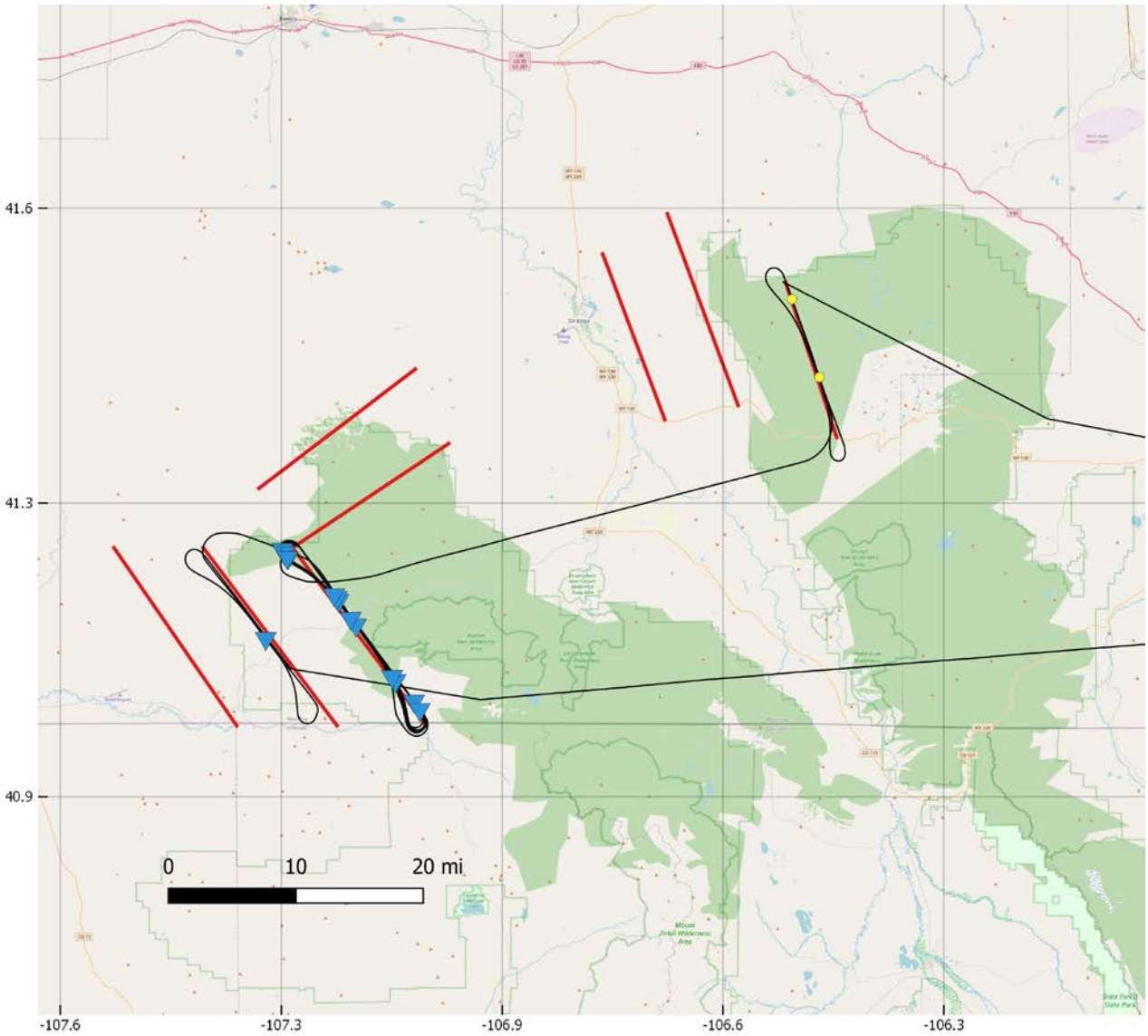
N23MN	OPS #:	04			SEED
	Track(s)/Basin:		SM-4, SM-3		
UTC Date:	November 19, 2020		MST Date:	November 19, 2020	
UTC Engines ON:	17:48		MST Engines ON:	10:48 am	
UTC Engines OFF:	23:01		MST Engines OFF:	4:01 pm	
Total Time:	5:13	5.22hr	Flares Used:	39 BIP	97 EJECT
Pilot's Flight Summary:	Enroute to SM-4, we picked up light SLW in the cloud tops over the Sierra Madre range. After arriving at SM-4, we descended to 17 kft and found light SLW. We climbed up to 18 kft and began dropping EJs once per minute. Due to wind speed, we moved to SM-3 and began dropping EJs once every 2 minutes and continuous BIPs at 14 kft. Moved back to SM-4, found light to moderate SLW. Per request we stopped using EJs and continued with BIPs. RTB.				

Synoptic Analysis:	A southwesterly upper jet is moving into the region today. Temps aloft are cooling gradually through the weekend, and 700mb temps are dropping through tomorrow from around +5°C this morning to -8°C by tomorrow night. PWAT is also on the rise through this evening before tapering off late tomorrow. As temps cool and PWAT increases, the low level RH will be rising throughout the day becoming saturated tonight through tomorrow afternoon. A cold front will push slowly through the region late this evening around midnight. Moderate westerly winds at low levels will favor orographic cloud development late in the period tomorrow morning. Models indicate some decent SLW tomorrow morning through early afternoon for the SM/MB, while the NS has weaker development. A trough moves into the region Friday with cooler temps and decent moisture bringing light snow accumulation. A small ridge pushes through Sunday.
Area Forecast:	Partly cloudy skies are likely this afternoon, and then clouds increase late this evening as the cold front approaches. Seeding appears unlikely with the frontal passage, but light snowfall is expected tonight. Orographic clouds will increase overnight becoming potentially seedable after dawn tomorrow. Seeding appears possible around 8am local time tomorrow morning through the early afternoon hours for the SM range. Seeding looks unlikely in the NS range tomorrow. Only light accumulation is expected in the mountains tomorrow from this orographic-driven event. There will be a break in the weather tomorrow evening and overnight. The next impulse arrives Friday afternoon with the incoming trough from the west. Sunday appears dry with a small transient ridge. The weather pattern appears progressive for next week, however moisture availability over the Rockies is unimpressive in the longer range models. While we may see some shortwaves pushing through the region next week, precipitation looks to be little more than some isolated showers at this point.
Flight occurred in the morning to afternoon hours of the 19th; weather information is from Nov. 18th.	



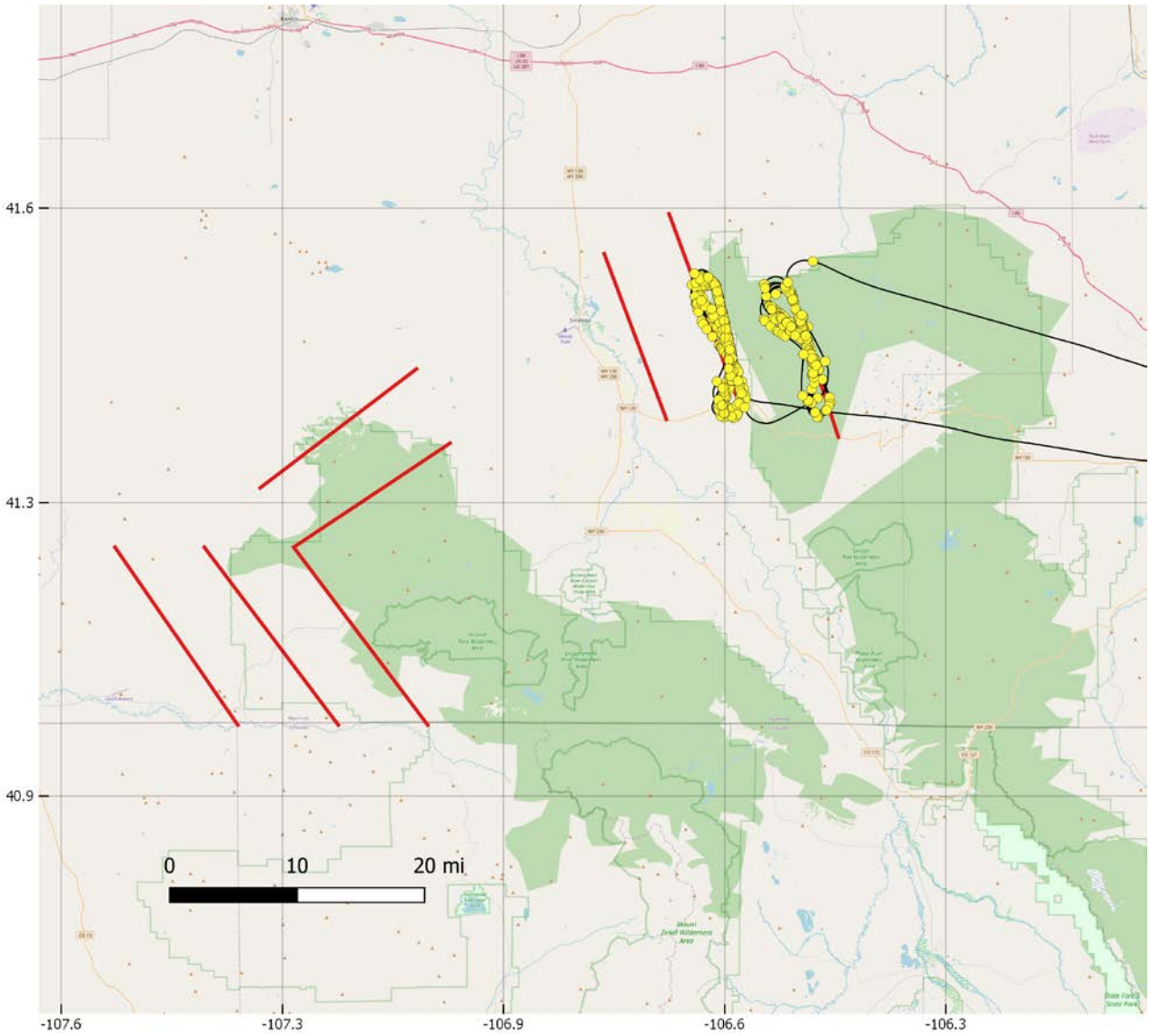
N23MN	OPS #:	05			SEED
	Track(s)/Basin:		SM-4		
UTC Date:	December 16, 2020		MST Date:	December 16, 2020	
UTC Engines ON:	13:30		MST Engines ON:	6:30 am	
UTC Engines OFF:	20:02		MST Engines OFF:	1:02 pm	
Total Time:	6:32	6.53hr	Flares Used:	0 BIP	303 EJECT
Pilot's Flight Summary:	Arrived at SM-4 at 13 kft and began dropping EJs once per minute. We cut 5 miles off the south end of SM-4. Cloud tops continued to rise with light to moderate SLW in the tops. Per meteorologist's request, we extended our northern track by 5 miles. We climbed and descended with the cloud tops throughout the mission. RTB.				
Synoptic Analysis:	A midlevel low to the south continues to push eastward into Texas. Light northerly flow continues over the target ranges this morning. Late in the forecast period, a				

	northwesterly jet streak moves into our region. Low level moisture and PWAT increase overnight, and stronger northwest flow will combine with this moisture to create thick orographic clouds over all ranges just before dawn. Only minor vorticity advection is expected tomorrow which will limit the development of midlevel clouds and snowfall from above the orographic clouds. The 500 mb temps look to remain above -25°C throughout the day tomorrow. Models are indicating SLW as high as 15 kft tomorrow morning and afternoon, and then moisture/cloud diminish tomorrow evening from shortwave ridging. The next trough moves in Thursday afternoon through Friday with decent moisture.
Area Forecast:	Shallow orographic clouds will persist over the ranges through late tonight, but these clouds will not have sufficient depth for seeding. Deeper orographic clouds will form just before sunrise tomorrow. With the lack of natural seeder-feeder mechanism from above and the relatively warm temps aloft, this looks to be a good orographic seeding setup with abundant SLW tomorrow morning and afternoon. One seeding flight looks very likely in the SM or NS range starting around dawn. The NW winds at seeding levels will probably not be favorable for the MB as we avoid seeding the burn scar. A second flight could be possible tomorrow afternoon, although it might not be a full-length long flight before conditions deteriorate. We will pin down timing and plans tonight after the 00z model runs are out, but the tentative plan is for a morning flight on the SM range and then perhaps target the NS in the afternoon seeding until cloud depth becomes too shallow to continue. Clouds will dissipate tomorrow evening with clearing likely overnight. High and midlevel clouds return Thursday afternoon ahead of the next incoming trough. Seeding may be possible Thursday night or Friday with the next trough. Active weather continues through the weekend as well.
Flight occurred in the morning hours of the 16th; weather information is from Dec. 15th.	



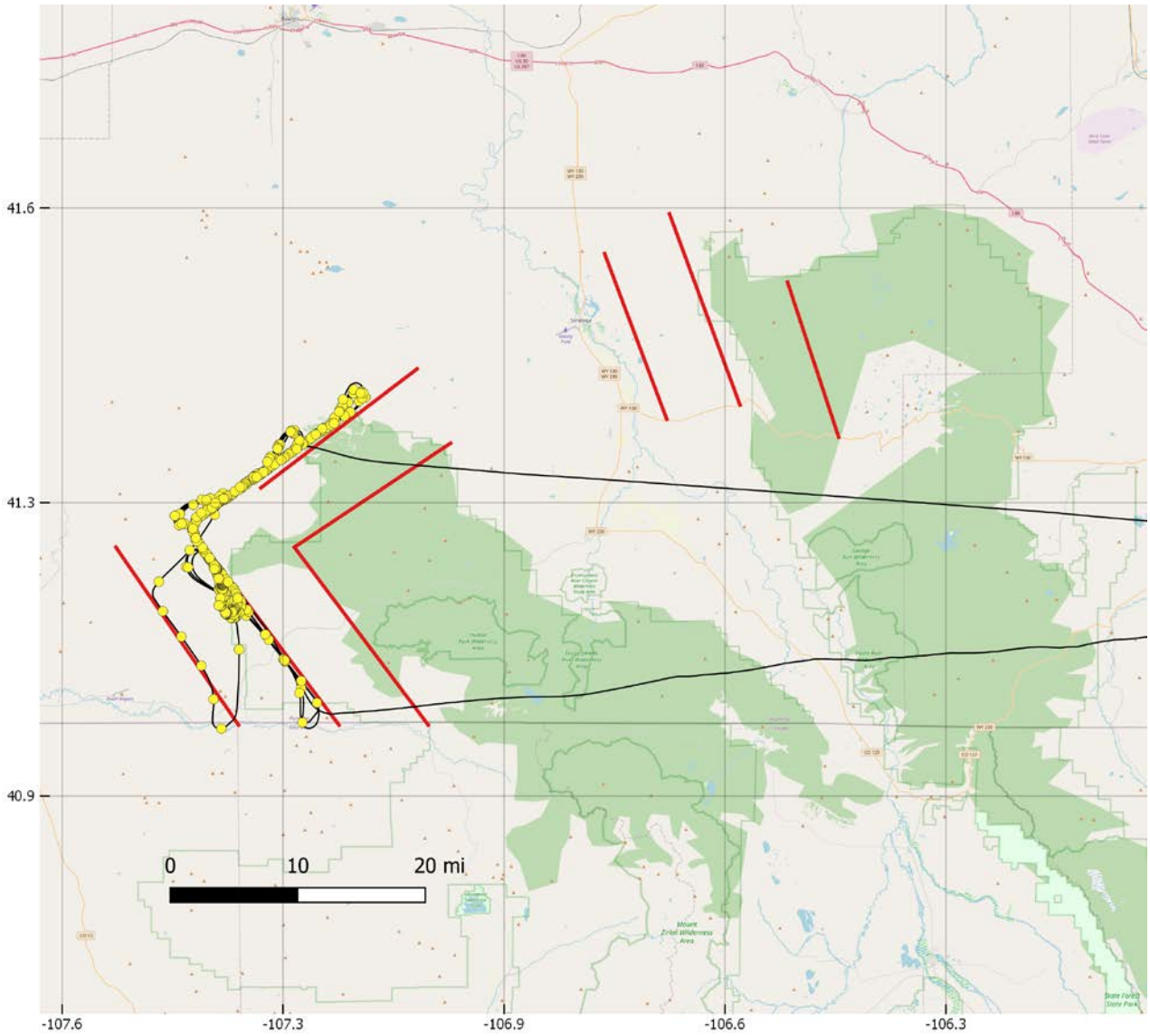
N23MN	OPS #:	06			SEED
	Track(s)/Basin:		SM-4, SM-5, MB-5, MB-4		
UTC Date:	December 18, 2020		MST Date:	December 17, 2020	
UTC Engines ON:	02:13		MST Engines ON:	7:13 pm	
UTC Engines OFF:	06:25		MST Engines OFF:	11:25 pm	
Total Time:	4:12	4.2hr	Flares Used:	18 BIP	22 EJECT
Pilot's Flight Summary:	In route to SM-4, we encountered Moderate SLW crossing both MB and SM ranges. Arriving on SM-4 we found light SLW and began with BIP flares. Per meteorologist's request, we switched to SM-5 and found intermittent light SLW. As SLW became less frequent, we switched to MB-5 per meteorologists request. Arriving on MB-5, we encountered intermittent light SLW mixed with natural ice. We began dropping EJs once per 2 minutes. Per meteorologists request and winds, we switched to MB-4. Due				

	to lack of seedable targets, RTB. On the MB range we seeded the northern most 13 NM.
Synoptic Analysis:	A small ridge is exiting the region at forecast time as the next trough moves into the state from the west. The best dynamics will stay south of our ranges, but moderate PVA is expected this evening and tonight. This is a relatively warm system with fair moisture (mainly in the SM). PWAT will rise to around 0.35 inches today, and 500 mb temps will stay above -25C. The 700 mb RH will be near saturation this evening through tomorrow afternoon. Seeding level winds will be moderate around 35-40 kts from the WSW this evening and tonight creating favorable orographic enhancement, particularly in the SM. Winds shift to NNW around dawn tomorrow behind the trough axis. SLW looks to be light and intermittent this evening and tonight due to the amount of deep midlevel cloud and ice crystals. A shortwave ridge pushes through tomorrow followed by a shortwave on Saturday in stronger NW flow. Another potent trough/low moves through Tuesday and Wednesday bringing another wave of widespread snowfall.
Area Forecast:	The active pattern continues as a trough plows through the region this evening and tonight bringing widespread snowfall. The heaviest snow accumulation will be in the SM where an NWS Advisory is in effect from 5pm MST through tomorrow afternoon with 5-10 inches of snow possible. The MB will also see periods of lighter snow tonight into tomorrow morning while the NS will only see a dusting tomorrow morning. Snow arrives in the SM by late this afternoon with intermittent SLW in both the SM and northern MB ranges. Some models are showing better SLW than others, so we will attempt a seeding flight this evening beginning around 2-3z. Conditions look less favorable in the NS where no flights are expected. Marginal low clouds linger tomorrow with no significant precipitation after noon. No seeding is expected tomorrow. Light mountain snow is expected Saturday with at least marginal SLW, and there looks to be potential for seeding Saturday afternoon/evening.
Flight occurred in the evening hours of the 17th; weather information is from Dec. 17th.	



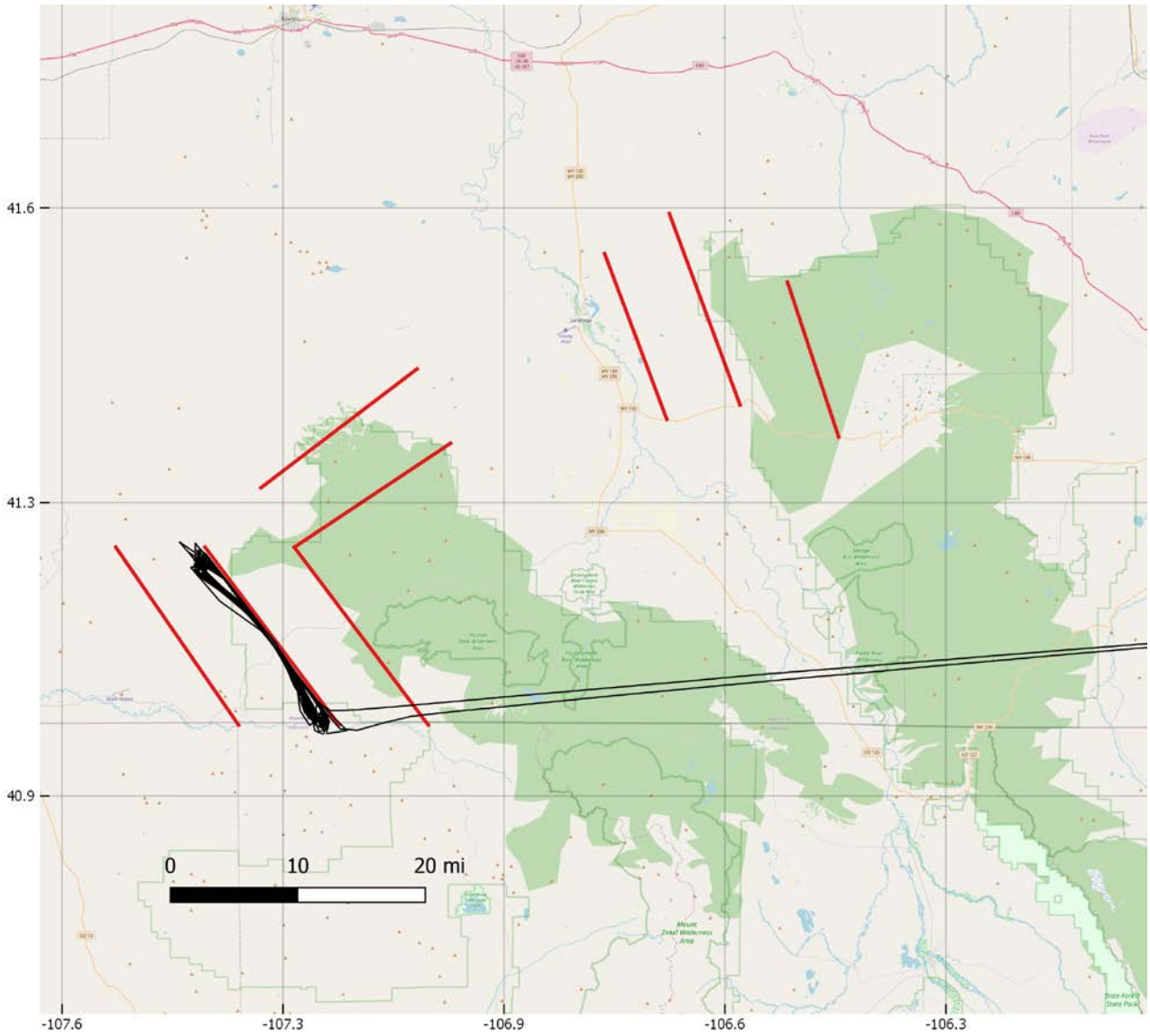
N23MN	OPS #:	07			SEED
	Track(s)/Basin:		MB-4, MB-5		
UTC Date:	December 19, 2020		MST Date:	December 19, 2020	
UTC Engines ON:	21:16		MST Engines ON:	2:16 pm	
UTC Engines OFF:	03:30		MST Engines OFF:	8:30 pm	
Total Time:	6:14	6.23hr	Flares Used:	0 BIP	300 EJECT
Pilot's Flight Summary:	Took off and encountered clear air enroute to MB-4. We used the northern most 8 miles of MB-4 using highway 130 as a turnaround point. We began dropping EJs at 14 kft once a minute, slightly above cloud tops. Clouds slowly dropped but then rose. We began flying in cloud and SLW varied from very light to occasionally moderate. Cloud tops dropped again and meteorologist requested us to move to MB-5. Light to moderate SLW and using the northern most 8 miles of MB5. Out of flares, RTB.				

Synoptic Analysis:	Jet level charts indicate a northwesterly jet streak nosing into our region this evening and tonight. A shortwave trough pushes through WY this afternoon, and then a ridge will build over the region tonight and tomorrow. Temps aloft are cooling through this afternoon, and then a significant warm up is expected tonight and tomorrow morning. 500 mb temps will bottom out around -26C today, climbing to -17C by tomorrow morning. PWAT will be modest through late tonight, and then excellent moisture flows into the region early tomorrow with PWAT climbing to near 0.40 inches in the warmer air mass. The 700 mb RH will linger near saturation for much of the coming 48 hours with a slight lull tonight. Seeding level winds are from the NW to WNW and relatively strong around 45-55 kts. The ridge will remain over our region through Monday, and then the next disturbance in the flow arrives late Tuesday.
Area Forecast:	Marginal orographic clouds are likely over the ranges throughout the afternoon and evening hours. There will be a few hours of deeper SLW over the MB during the late afternoon and early evening. A flight is tentatively planned for the MB range to depart around 22z today. This will be the only potential seeding window of the forecast period. Any snow accumulation looks to be very light today. The low clouds will diminish overnight during a lull in the low-level RH. Thicker orographic clouds and marginal SLW return tomorrow evening through Monday morning. It is uncertain at this time whether the SLW depth will be sufficient for seeding late tomorrow, but it appears at least possible. The best clouds tomorrow will probably be in the SM/MB ranges with less favorable conditions in the NS. We will see another lull in moisture Monday, but then the next trough arrives Tuesday bringing another round of moderate widespread snowfall and much cooler temps. Conditions at CYS are quite gusty today. The NWS has a High Wind Warning in effect until 5pm MST for potential gusts up to 70mph. It is possible this could affect seeding plans this afternoon and evening.
Flight occurred in the afternoon to evening hours of the 19th; weather information is from Dec. 19th.	



N23MN	OPS #:	08			SEED
	Track(s)/Basin:		SM-4, SM-3, SM-1, Modified		
UTC Date:	December 21, 2020		MST Date:	December 20, 2020	
UTC Engines ON:	02:02		MST Engines ON:	7:02 pm	
UTC Engines OFF:	07:36		MST Engines OFF:	12:36 am	
Total Time:	5:34	5.57hr	Flares Used:	0 BIP	244 EJECT
Pilot's Flight Summary:	Enroute to SM-4, we had clear air. Upon arriving at SM-4, we descended down to 13kft and encountered moderate SLW with mixed icing. Tops 13.5 kft – 13.7kft. Began dropping EJs once per minute. Per meteorologist's request, we moved out to SM-3, then moved to SM-1 due to the northerly winds, clipping 5 miles off the east end. We flew above tops at 13.4 kft but descended with tops down to 13kft. Per meteorologist's request, we modified our track. We are flying the western most 9 miles of SM-1 and the				

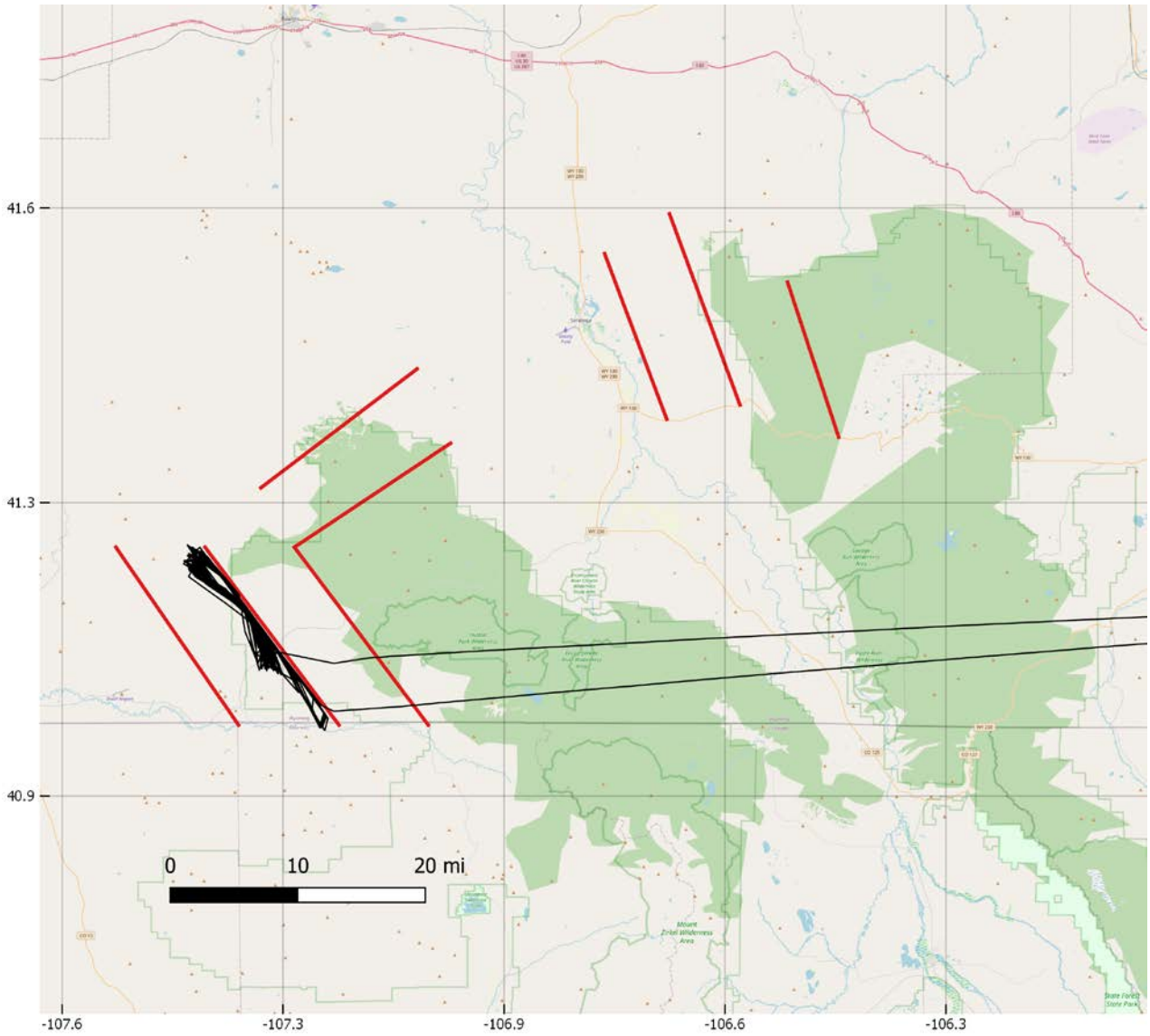
	northern most 4 miles of SM-4. Light SLW on northern section of SM-4. Climbed back up to 13.5 kft, in and out of cloud tops, light to moderate SLW and mixed icing. RTB.
Synoptic Analysis:	Upper level charts indicate strong northwest flow over the region with a broad low-amplitude ridge over the western US and eastern Pacific. Midlevel charts show no major PVA expected throughout the period as a small shortwave passes through Montana well to our north. Low level moisture continues to flow through the region, and PWAT is fair through tomorrow morning. Strong low level winds from the northwest will be favorable for deep orographic development. With the lack of midlevel forcing or deep midlevel clouds to provide ice crystals from above, these deep orographic clouds look to have heavy SLW this evening into the late night hours. Temps aloft remain warm with 500 mb temps lingering around -17C through tomorrow evening before cooler air arrives with the next incoming disturbance Tuesday. A potent trough passes through the Rockies Tuesday into Wednesday.
Area Forecast:	Deep orographic clouds and light orographic snowfall are expected in all ranges. The best clouds for targeting will be in the SM range this evening into the late-night hours. A seeding flight is planned for the SM4 tracks to begin seeding around 3z. The window with the deepest clouds and most favorable SLW does not appear to be of long enough duration for two back-to-back flights. Orographic clouds will slowly diminish tomorrow morning and afternoon with some clearing likely tomorrow night. Another good chance for seeding arrives early Tuesday. Models are again showing excellent deep SLW with strong orographic winds (southwest flow this time). As the trough pushes through later Tuesday into Wednesday, we will see more widespread snowfall and lower SLW amounts Tuesday night into Wednesday. Thursday and Friday will see a much drier air mass and a break in operations for the Christmas holiday, and then another system arrives next weekend with more operations possible. Very gusty winds are forecast for CYS today and tonight with a High Wind Warning in effect until around dawn tomorrow.
Flight occurred in the evening hours of the 20th; weather information is from Dec. 20th.	



Prior to the 12/22 mission a datalogger failure occurred due to icing. Unfortunately, the datalogger wasn't able to be fully repaired until after the two missions on the 27th of December. ADS-B data was retrieved from FlightAware for these missions and the flight track points plotted on AirLink to create a map for each of the three missions. Flare ignition points, however, are unavailable.

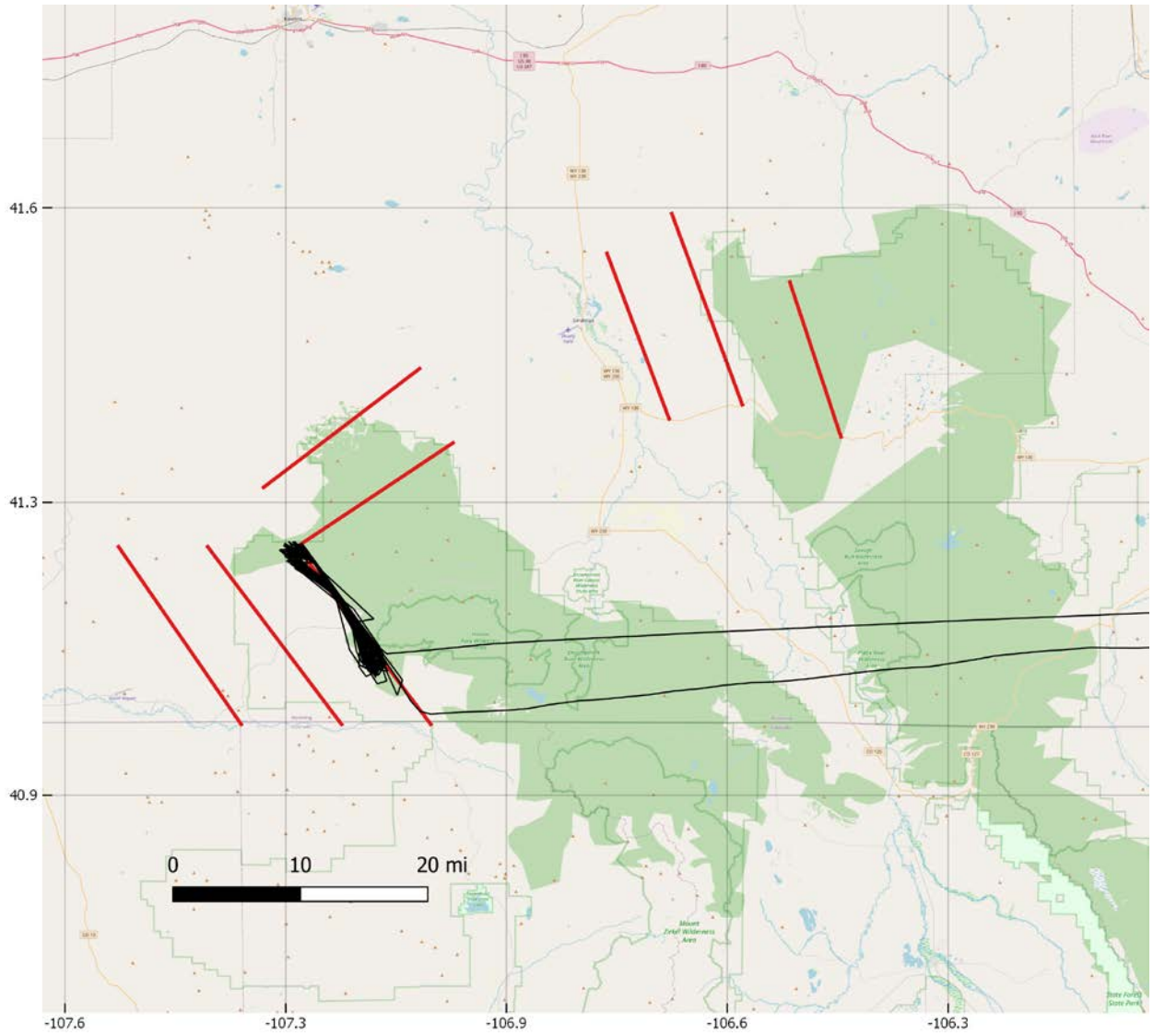
N23MN	OPS #:	09			SEED
	Track(s)/Basin:		SM-4		
UTC Date:	December 22, 2020		MST Date:	December 22, 2020	
UTC Engines ON:	19:05		MST Engines ON:	12:05 pm	
UTC Engines OFF:	00:24		MST Engines OFF:	05:24 pm	
Total Time:	5:19	5.32hr	Flares Used:	47 BIP	0 EJECT

Pilot's Flight Summary:	Enroute to SM-4, we encountered light SLW mixed with natural ice. Descended to 14 kft and had light to moderate SLW mixed with natural ice. Per meteorologists request we descended to 13 kft, continued to find light to moderate SLW mixed with natural ice. After a while, SLW dwindled to light, then to occasional, then to natural ice. RTB.
Synoptic Analysis:	A transient ridge will bring warmer drier air into the region today. The ridge axis passes through late in the day. Flow aloft shifts to the SW tonight ahead of an incoming potent trough from the west. Moisture returns tomorrow morning and lingers through tomorrow night. A powerful cold front moves through tomorrow afternoon. This system will bring bitterly cold temps to the region by tomorrow night, and with gusty surface winds likely, wind chills will dip well below zero in CYS. The best window for seeding tomorrow will be the earliest part of the storm before the coldest air arrives on the back side of the trough. Ridging and warming return Wednesday afternoon through Friday. Another potent trough pushes in from the west on Saturday bringing another shot of widespread light to moderate accumulation. Next week looks to remain active with more powerful wetter systems and potentially a major winter storm midweek.
Area Forecast:	Marginal orographic clouds will be in place early in the period, but they will diminish throughout the day as low level RH wanes. No significant snowfall is expected today. Clearing is expected by this evening, and skies will be mostly clear overnight. Clouds return tomorrow morning as moisture returns ahead of the trough. Deep orographic clouds and light snow are expected tomorrow from late morning through the late afternoon with decent SLW. Seeding appears likely in the SM or MB ranges during the day tomorrow. Temps will be plummeting behind the trough axis tomorrow, which will likely bring an end to seedable conditions by tomorrow evening while light snow continues. Models do indicate some light SLW lingering over the NS range tomorrow evening, so a subsequent flight in the NS cannot be ruled out entirely. However, with 500 mb temps expected to drop to near -37C by tomorrow night, we will likely see natural efficiency early in this storm. Snow ends by midday Wednesday. Thursday and Friday will be dry and warmer, and then the next chance of operations will be the weekend with another Pacific trough from the west.
Flight occurred in the afternoon hours of the 22th; weather information is from Dec. 21st.	



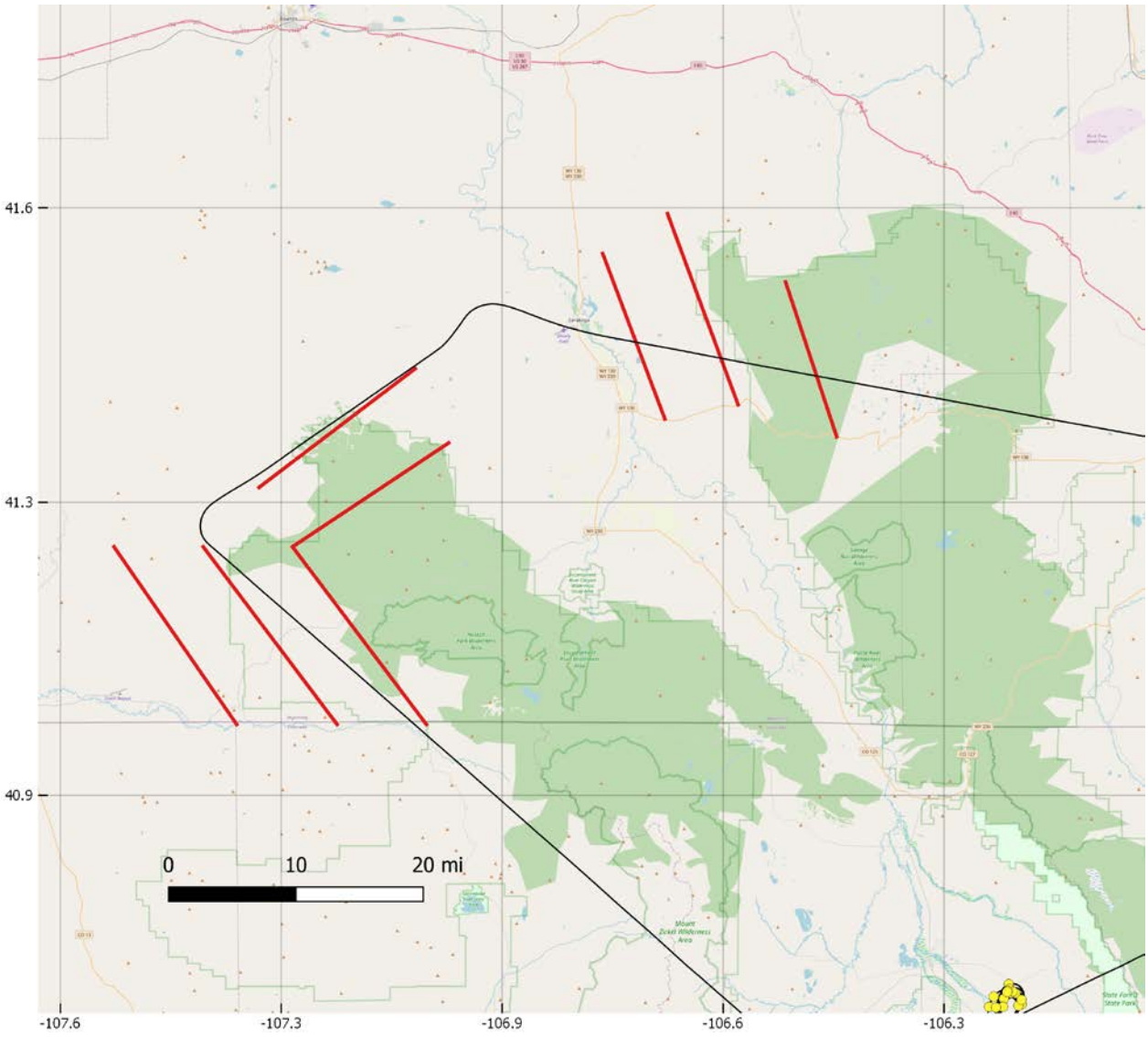
N23MN	OPS #:	10			SEED
	Track(s)/Basin:		SM-4		
UTC Date:	December 27, 2020		MST Date:	December 26, 2020	
UTC Engines ON:	04:48		MST Engines ON:	9:48 pm	
UTC Engines OFF:	11:00		MST Engines OFF:	4:45 am	
Total Time:	6:12	6.2hr	Flares Used:	0 BIP	289 EJECT
Pilot's Flight Summary:	Crossing the Never Summer Ridge, light SLW and natural ice. Descended to 13 kft and began dropping EJs once per minute. In and out of light SLW. Per meteorologists request we cut off the southernmost 5 miles due to winds. Clouds began lowering on the north end of the track over time. Eventually the clouds along the entire route lowered and we were just above the tops at 13 kft. Clouds looked deeper to the south were the winds are blowing. In and out of cloud tops, light SLW. RTB.				

Synoptic Analysis:	Jet level charts show a westerly jet streak nosing into WY and CO today. Midlevel charts show a shortwave pushing through the region this evening and tonight. An associated cold front will sweep through the ranges shortly after sunset. Low level moisture is on the rise through the afternoon becoming saturated this evening through tomorrow afternoon. Seeding level winds will be from the W to WNW around 40 kts this evening, favorable for orographic clouds and mountain snow. Midlevel dynamics are fairly weak with this system, so midlevel cloud will be limited allowing for ample SLW up to around 15 kft. 500 mb temps drop steadily through midnight bottoming near -28C. A more powerful low is still on tap for late Monday and Tuesday tracking through Colorado and expected to bring widespread moderate snowfall to the region. A lull in activity is expected Wednesday with brief ridging, and then another system pushes through late in the week.
Area Forecast:	Low levels remain too dry for significant orographic clouds early this afternoon, but moisture and clouds will be increasing throughout the day. A cold front pushes through shortly after sunset marking the beginning of snowfall. Behind the frontal band, orographic clouds and mountain orographic snow are expected this evening through tomorrow afternoon. The best SLW will be this evening into tonight, and then SLW depth slowly wanes tomorrow morning/afternoon. Seeding is planned for this evening starting around 5z, likely on the SM4 track to start. Additional seeding appears likely overnight, and pilots are prepared for two back-to-back flights. Seedable clouds may persist through midday tomorrow, but seeding is not expected tomorrow due to duty day limitations for crew. Clouds and snowfall taper off tomorrow afternoon/evening. The next wave of precip arrives Monday afternoon with the incoming low through Colorado. This dynamic system will likely have deep midlevel clouds/ice and lighter SLW over the ranges. However, seeding does appear at least possible Monday afternoon or evening. No snow is expected in CYS until Monday, and airport sky conditions should not be a factor for ops tonight.
Flight occurred in the evening hours of the 26th; weather information is from Dec. 26th.	



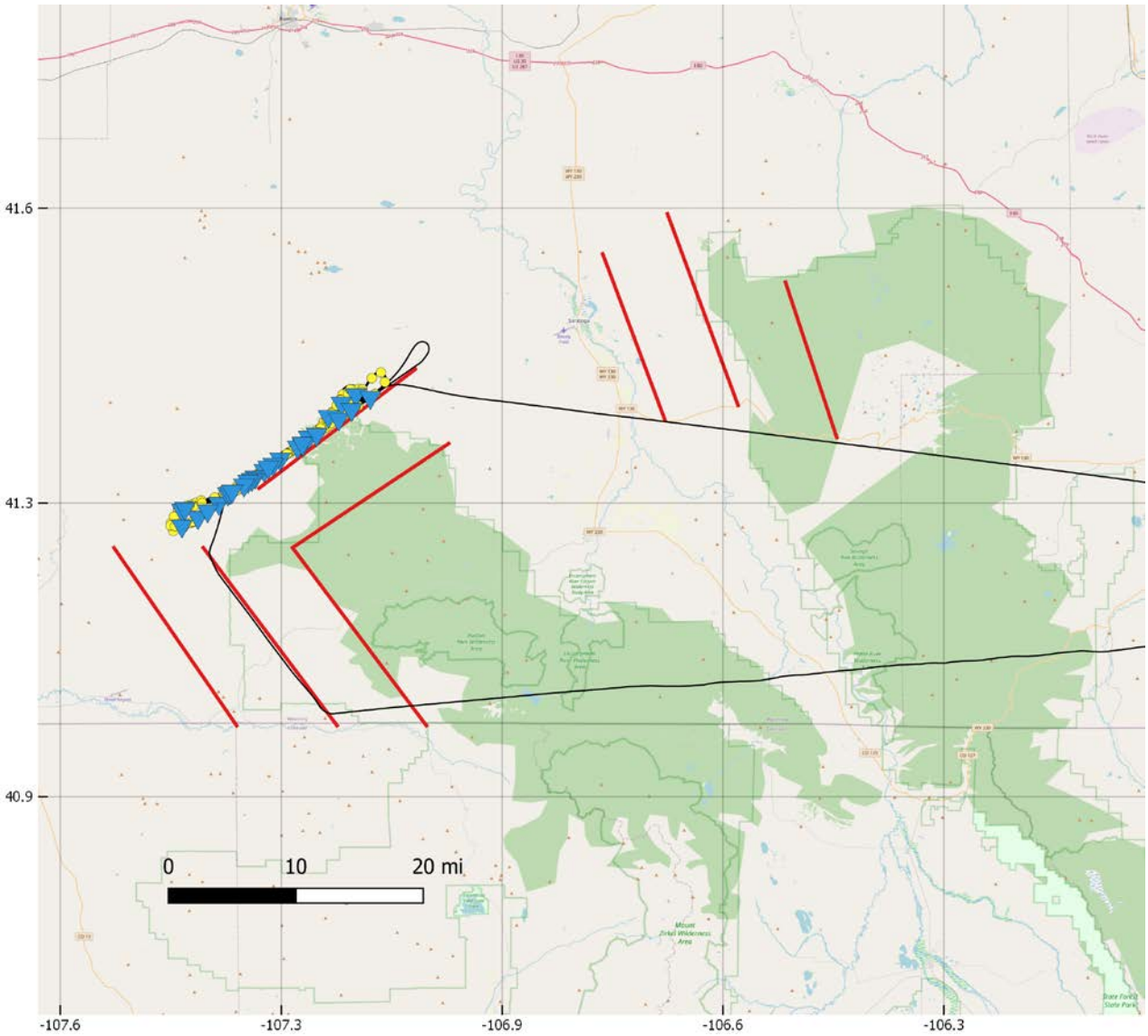
N23MN	OPS #:	11			SEED
	Track(s)/Basin:		SM-5		
UTC Date:	December 27, 2020		MST Date:	December 27, 2020	
UTC Engines ON:	11:45		MST Engines ON:	4:45 am	
UTC Engines OFF:	18:06		MST Engines OFF:	11:06 am	
Total Time:	6:21	6.35hr	Flares Used:	0 BIP	284 EJECT
Pilot's Flight Summary:	Arrived on track and descended to 13,000 ft and began seeding with EJs once per minute. Per meteorologists request we clipped off the southernmost 5 miles. Conditions stayed the same with snow and natural iced mixed with occasional trace SLW. Meteorologists say that models indicate SLW is below and downwind. RTB. Light to moderate SLW crossing ridge on the way home.				

Flight occurred in the morning hours of the 27th; weather information remains the same as MBSM Ops #10.



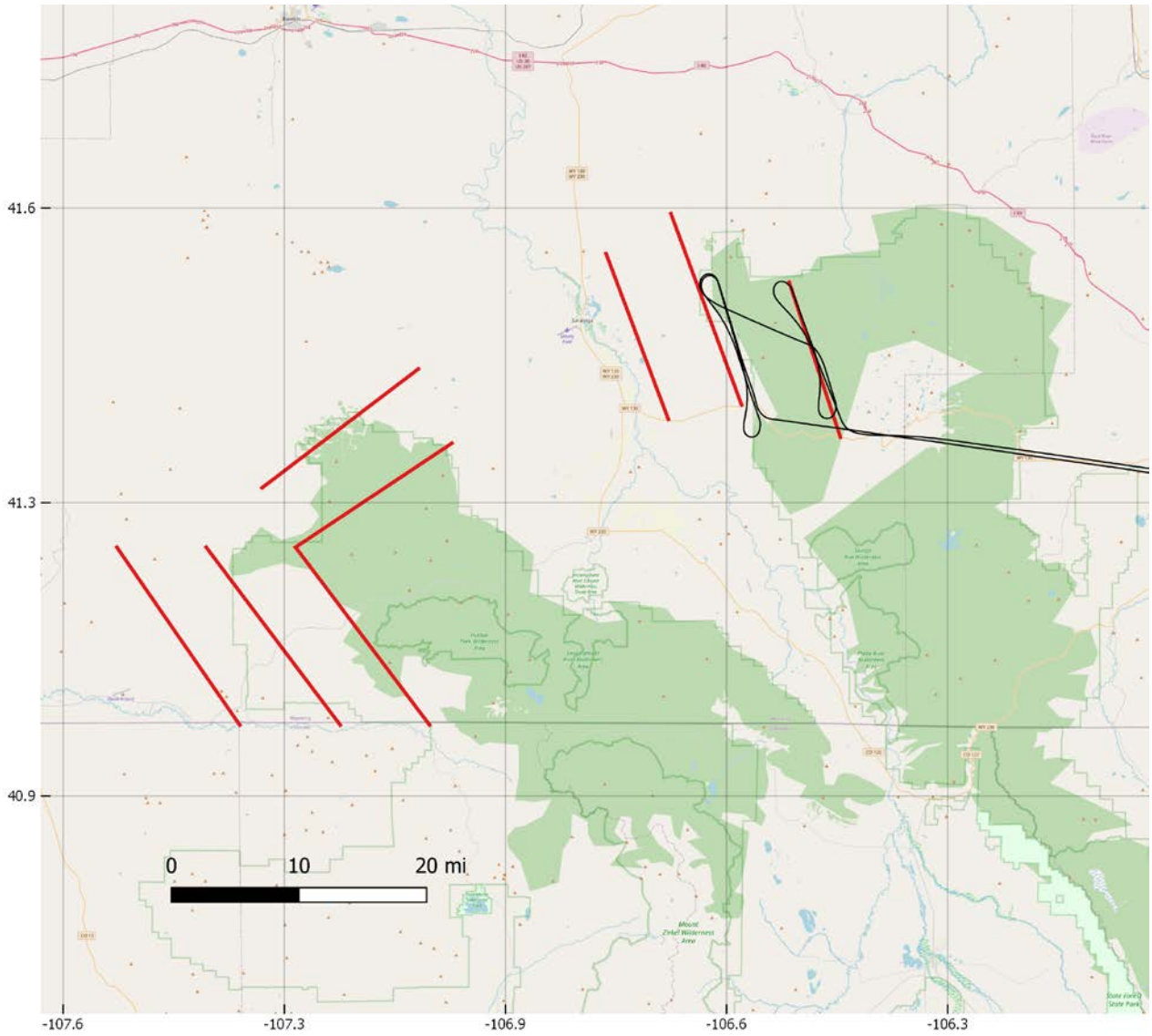
N23MN	OPS #:	12			RECON
	Track(s)/Basin:		SM-1		
UTC Date:	January 14, 2021		MST Date:	January 13, 2021	
UTC Engines ON:	00:46		MST Engines ON:	5:46 pm	
UTC Engines OFF:	01:42		MST Engines OFF:	6:42 pm	
Total Time:	0:56	0.93hr	Flares Used:	0 BIP	0 EJECT
Pilot's Flight Summary:	Enroute to NS-1, we experienced light to moderate SLW crossing the ridges. On track we encountered moderate SLW. Began dropping EJs once per minute *(Shared mission, see NS Summary)*. In and out of cloud tops. We began to experience moderate to heavy SLW and moderate to severe mixed airframe icing. We climbed to 16.5 kft and experience severe Icing and then climbed to 17 kft to stay above cloud tops. We increased the rate of EJs to once per 45 seconds per meteorologists request and favorable conditions. We descended back to 16.5 kft and remained mostly out of tops,				

	still heavy SLW in cloud tops. We cut the southernmost 2 miles off the track. Descended to 15 kft and began broadcast seeding with only BIPs. Descended to 14 kft per meteorologist's request. Cut off northern most mile due to altitude restrictions. Moved to SM-1 due to deteriorating conditions. Enroute to SM-1, mixed natural ice and SLW. Due to lack of seedable conditions, RTB.
Synoptic Analysis:	A powerful jet streak remains in place to the northwest as an Atmospheric River flows onshore. As a ridge amplifies over the PACNW into the Gulf of Alaska, the jet will reach WY late in the period bringing strong NW flow aloft. At mid-levels, tight gradients are present over our region as a trough digs southeastward into WY this afternoon through late evening. A wave of very moist air is pushing through the region this afternoon through this evening with PWAT values currently above 0.40 inches. As the day goes on, significant drying will occur above 600 mb while low levels remain saturated through midnight. Seeding level winds will be from the WNW around 50-60 kts this afternoon and evening. Moisture and winds will be favorable for deep orographic clouds with SLW until midnight. Dry NW flow is likely tomorrow morning followed by ridging later tomorrow into Friday afternoon. A small shortwave then moves through Friday evening through Saturday.
Area Forecast:	Orographic clouds and snowfall will increase throughout the afternoon with periods of deep targetable SLW from late afternoon through the evening. SLW will be intermittent in the MB and SM ranges but more continuous in the NS. A flight is scheduled for the NS1 track for around 22z this afternoon. This will be the only flight for the period. Moisture drops off tonight, and clouds will clear out around midnight. PWAT will fall below 0.10 inches shortly after midnight. As the trough moves through this afternoon and evening, 500 mb temps will bottom out around -27C by midnight, and then rapid warming aloft is expected through tomorrow. Dry conditions are expected tomorrow as the small ridge moves in, but we will see very strong NW flow for the next several days. The next chance for seedable clouds will arrive Friday night into Saturday, but this looks to be a relatively minor system with light QPF. SLW availability may be a limiting factor for any possible operations with that next system.
Flight occurred in the afternoon to evening hours of Jan. 13th; weather information is from Jan. 13th.	



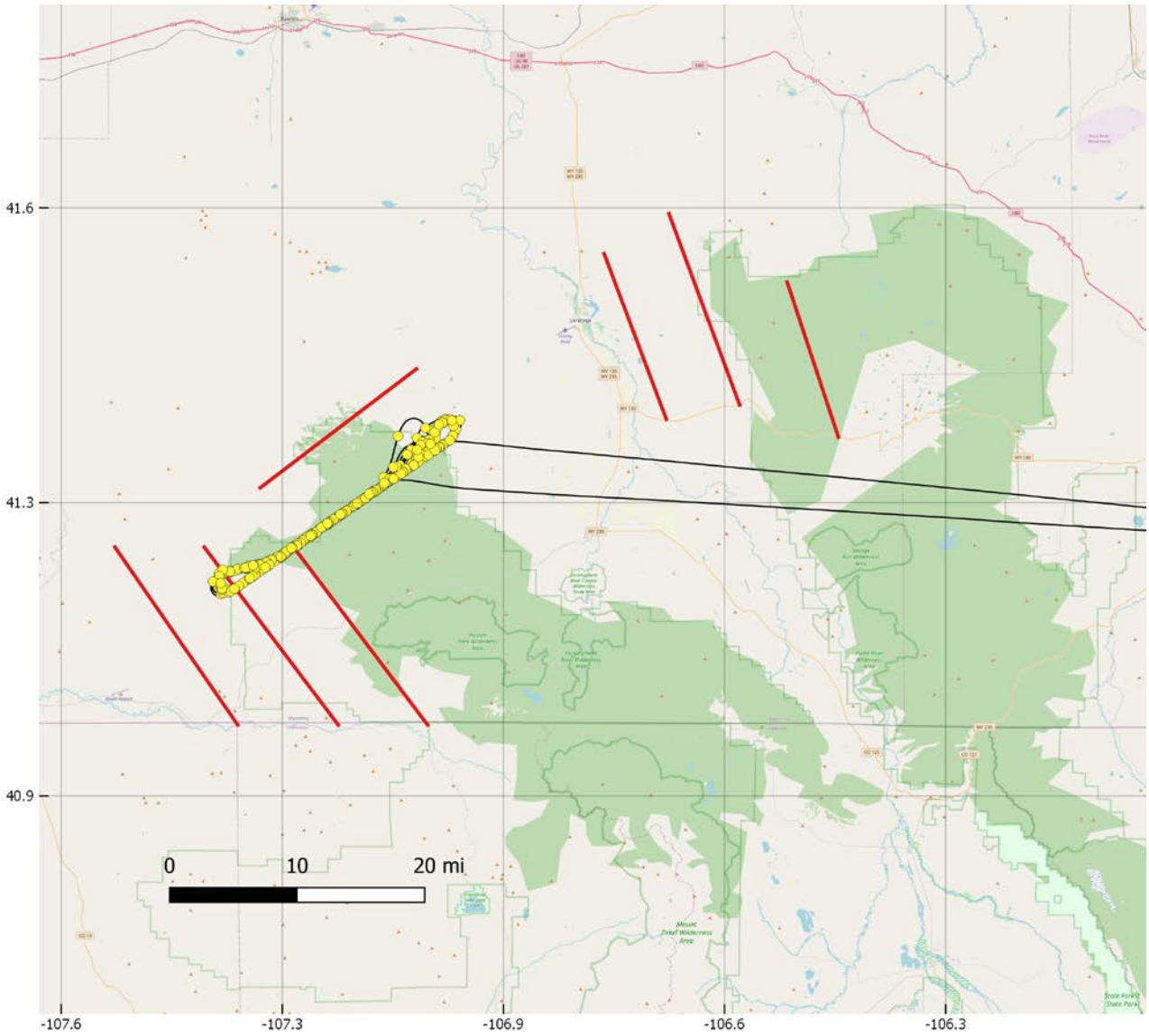
N23MN	OPS #:	13			SEED
	Track(s)/Basin:		SM-1		
UTC Date:	January 18, 2021		MST Date:	January 17, 2021	
UTC Engines ON:	01:10		MST Engines ON:	6:10 pm	
UTC Engines OFF:	07:03		MST Engines OFF:	12:03 am	
Total Time:	5:53	5.88hr	Flares Used:	26 BIP	171 EJECT
Pilot's Flight Summary:	Enroute to SM-4 moderate to heavy SLW crossing the ridge and on track. Switched to SM-1 due to wind direction. Clipping 5 miles off the east end per meteorologist's request. Began dropping EJs once every 45 seconds. Broadcast seeding for SLW downwind. In and out of clouds, light SLW. Descended to 13 kft to burn BIPs only, per meteorologist's request. In and out of clouds, light SLW. Per meteorologist's request, resume seeding the entire track. RTB.				

Synoptic Analysis:	Upper-level charts show a jet streak remains over the region. Jet level flow will be northerly early in the day becoming westerly late in the period. The Pacific ridge has flattened slightly, but it will reamplify tonight and tomorrow. Midlevel charts show strong NW flow over WY with a shortwave moving through our region this evening and tonight. A cold front will sweep southeastward through the target ranges around midnight tonight. PWAT is on the rise and will peak above 0.35 inches during the evening. Low level RH will rise throughout the day, and saturated low level are likely from sunset through tomorrow morning. Seeding level winds will be from the NW around 40-45 kts through midnight, becoming lighter behind the front. Very light low-level flow is expected tomorrow. Moisture tapers off tomorrow morning, and then dry conditions are expected tomorrow afternoon through Wednesday. The next system moves in late in the week.
Area Forecast:	Broken to overcast layers will continue throughout the period. Thick orographic clouds and snow will develop over all ranges around sunset with targetable SLW. The NW flow will favor seeding in the SM and NS ranges. A flight is planned for this evening for the SM range. A cold front pushes through around midnight. There is a slight chance of convective squalls along the cold front again. Behind the front, SLW will be diminished, but seeding appears possible late tonight. Crew should be prepared for a second flight overnight, but we will wait for the 00z model runs to make final decisions about which range and track may be seeded tonight. Orographic lift will weaken by morning, but low stratus and light snow looks to linger over the ranges through tomorrow afternoon. Clearing is expected tomorrow evening. Dry conditions are then likely Tuesday and Wednesday. The next system looks to arrive late in the week, and the best guess on timing for the next operations window is Friday-Saturday. A Winter Weather Advisory is in effect for the project ranges and a Blizzard Warning for the Interstate 80 corridor near Elk Mountain and Arlington
Flight occurred in the evening hours of the 17th; weather information is from Jan. 17th.	



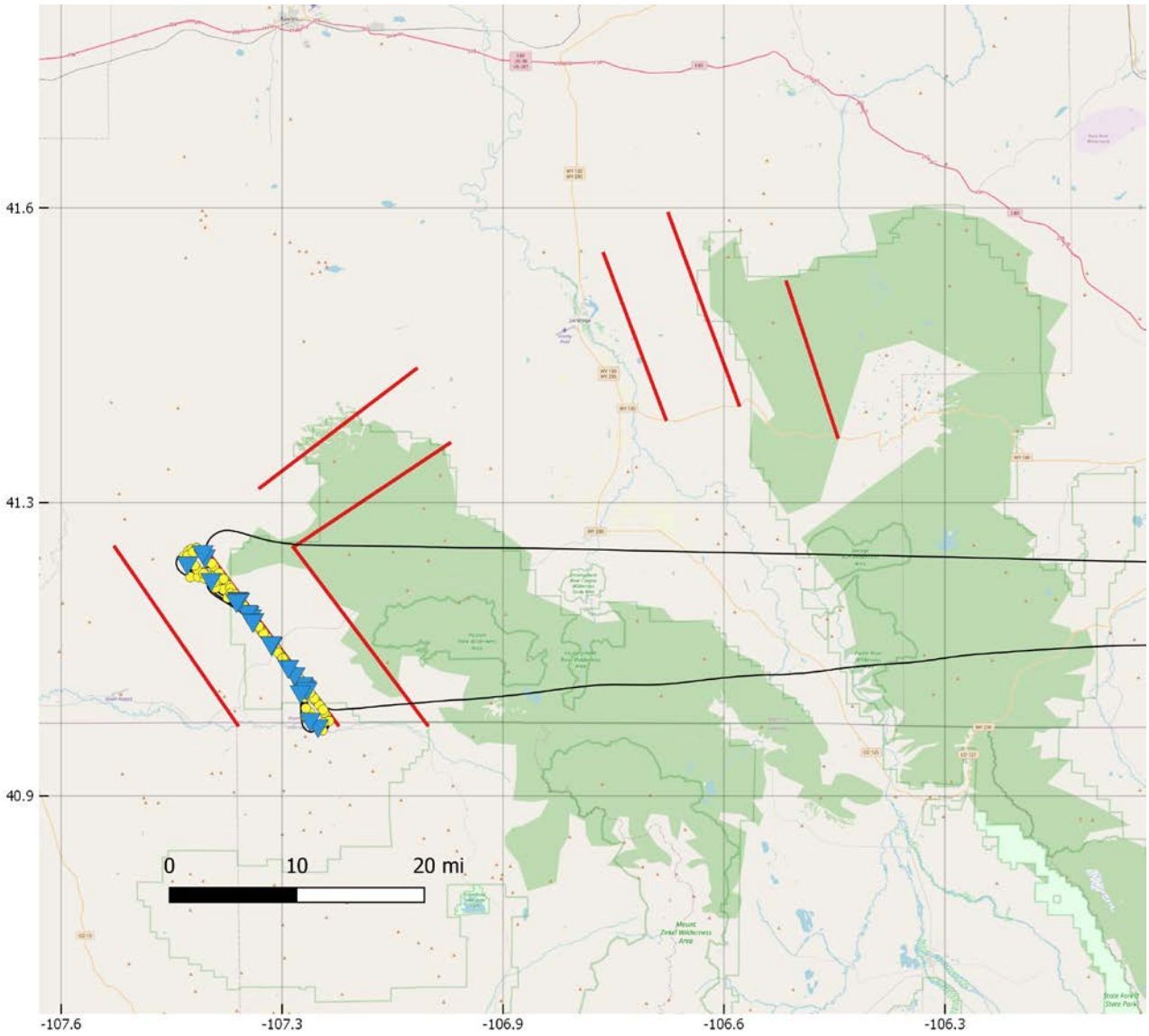
N23MN	OPS #:	14			RECON
	Track(s)/Basin:		MB-4, MB-5		
UTC Date:	January 22, 2021		MST Date:	January 21, 2021	
UTC Engines ON:	02:10		MST Engines ON:	7:10 pm	
UTC Engines OFF:	03:45		MST Engines OFF:	8:45 pm	
Total Time:	1:35	1.58hr	Flares Used:	0 BIP	0 EJECT
Pilot's Flight Summary:	Departed Cheyenne, no SLW crossing the MB ridge, lots of natural ice. Made a pass at 16 kft & 14 kft on MB-4 finding trace SLW at 16 kft, and no SLW at 14 kft. Lots of natural ice. We then moved to MB-5 at 14 kft and found no SLW. RTB.				
Synoptic Analysis:	Upper-level charts show moderate westerly (nearly zonal) flow aloft. At mid-levels, moderate WNW flow is in place. No major midlevel perturbations are expected today, although some weak vorticity will pass through tonight from a small shortwave. A digging trough near Vancouver will move into California tomorrow forming a low. This				

	system will then push east into the southern Rockies. Some lobes of vorticity will impact our region Saturday, but the main low will track through the Four Corners over the weekend. Total moisture will be rising throughout the day with PWAT reaching near 0.30 inches by midnight and remaining elevated through Saturday. Low level moisture increases will lag PWAT today due to a shallow dry layer. Nevertheless, low level RH will become saturated this evening. Seeding level winds will be westerly around 35 kts tonight. Midlevel temps will be dropping through dawn, rebounding slightly tomorrow.
Area Forecast:	Decent moisture lingers over the region through Saturday. Snowfall is expected to begin this evening and continue through morning. A lull in snow rates is likely during the day tomorrow, and then heavier accumulation is likely tomorrow night and Saturday with upwards of 1 inch of SWE likely in parts of the ranges by Saturday night. We will likely see several seeding windows during this multi-day window, and the heaviest snowfall rates will occur Saturday. With intermittent waves of weak PVA and midlevel cloud/snowfall, the periods of targetable SLW in the models are a bit erratic and difficult to time with confidence beyond the near term. The first decent wave of targetable SLW appears to begin tonight around midnight in the MB range. With moderate westerly winds at seeding altitudes, the targeting restrictions should be workable through the night. A seeding flight is planned for MB4 departing around 10:30pm MDT. We will likely have a break from ops tomorrow morning and afternoon, and then we will have potential seeding tomorrow evening and/or overnight. Saturday will see heavier snowfall, but SLW may be lacking. We will not rule out seeding Saturday, but for now it looks less favorable that tonight and Friday evening due to abundant natural snow from mid-levels. Sunday will be dry.
Flight occurred in the evening hours of the 21st; weather information is from Jan. 21st.	



N23MN	OPS #:	15			SEED
	Track(s)/Basin:		SM-2		
UTC Date:	January 30, 2021		MST Date:	January 30, 2021	
UTC Engines ON:	13:16		MST Engines ON:	6:16 am	
UTC Engines OFF:	19:43		MST Engines OFF:	12:43 pm	
Total Time:	6:27	6.45hr	Flares Used:	0 BIP	252 EJECT
Pilot's Flight Summary:	Above cloud tops enroute to SM-2. Skimming cloud tops on track. Began dropping EJs once per minute. In and out of cloud tops, light SLW. In and out of tops, Natural Ice. Per meteorologists request we clipped 2 miles off the east end of the track. Climbed to 14 kft per ATC request. Returned to 13 kft and encountered light SLW in the cloud tops. In and out of clouds. Per meteorologist's request, we resumed flying the entire track. Due to winds, meteorologist requests that we cut 3 miles off the east end. RTB.				

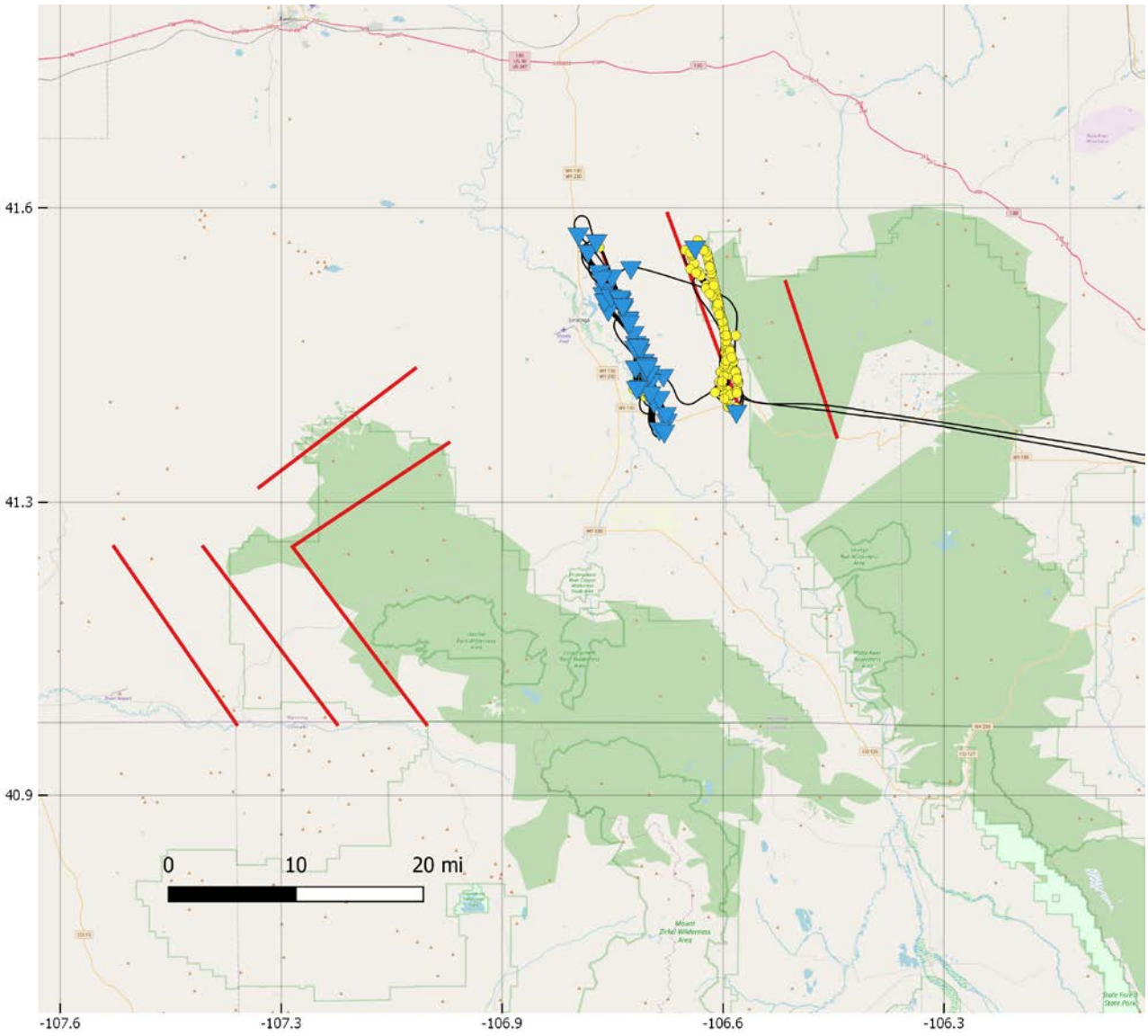
Synoptic Analysis:	Upper-level charts show the ridge over the Rockies exiting the region today as a deep moist trough along the coast moves inland through the Four Corners tonight. The best dynamics will pass far south of us, but fair moisture will move through the target ranges, likely enough for targetable orographic development but QPF will be relatively light. WY has strong southwest flow through midnight, shifting to lighter northwest flow by dawn behind the trough axis. PWAT will rise to around 0.30 inches by tonight, and it holds around 0.25 inches tomorrow morning and afternoon. Low levels look to become fully saturated from around dawn tomorrow morning through sunset tomorrow. Orographic lift will be best in the NS tomorrow morning where wind speeds will be somewhat stronger than the MB/SM. Ridging and dry conditions return Sunday through Tuesday afternoon, and then several wet systems are on tap early Wednesday through next weekend.
Area Forecast:	Deep overcast clouds are likely today through tonight, but low levels remain too dry for significant orographic clouds/snow until later in the period. As low-level RH improves overnight, targetable SLW is expected in the NS range around dawn as upper level clouds diminish. A flight is tentatively planned for the NS range around dawn. Orographic clouds are expected in all ranges, but the stronger winds in the NS region will create the deepest SLW layer in that range. Decent seeding conditions persist through the afternoon tomorrow, and a second seeding flight may be possible in the SM or NS. MB seeding appears unlikely tomorrow due to the NW winds at seeding levels (targeting restrictions). Light snowfall is expected in all ranges from late tonight through around sunset tomorrow evening. Dry conditions are expected tomorrow night through Monday as a ridge amplifies over our region bringing warmer drier air. Moisture returns Tuesday. An active weather period is expected for next week starting early Wednesday when a powerful Pacific trough looks to make a direct impact to WY with ample moisture. This could be a major storm. Several weaker impulses then look to move through later in the week and next weekend embedded in cooler NW flow while a large ridge starts to form again over the eastern Pacific.
Flight occurred in the morning hours of the 30th; weather information is from Jan. 29th.	



N23MN	OPS #:	16			SEED
	Track(s)/Basin:		SM-4		
UTC Date:	February 3, 2021		MST Date:	February 2, 2021	
UTC Engines ON:	06:30		MST Engines ON:	11:30 pm	
UTC Engines OFF:	12:21		MST Engines OFF:	5:21 am	
Total Time:	5:51	5.85hr	Flares Used:	22 BIP	127 EJECT
Pilot's Flight Summary:	Arrived on SM-4 at 16 kft, in and out of cloud tops with light SLW, started with EJ's. Descended to 15 kft and used a combo of EJ's and BIP's. Descended to 14 kft, cut off north two miles of track for winds, and switched to only BIP's with light SLW. Switched back to entire track on event as winds became more favorable and then back to EJ's one per minute per meteorologist request.				

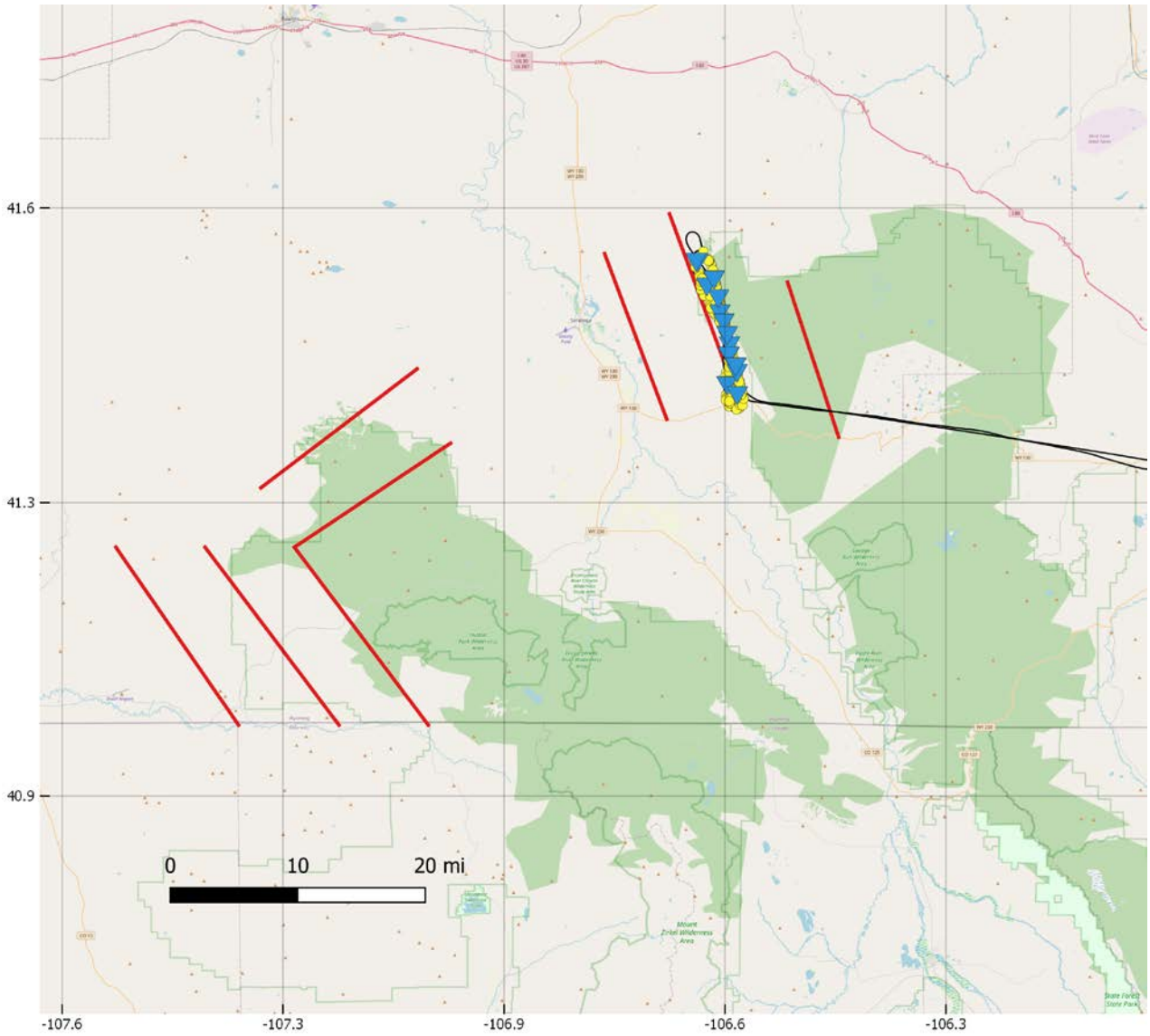
Synoptic Analysis:	The ridge over the Rockies is now shifting off to the east as our region transitions to strong WSW flow. A warm and very moist air mass will be flowing into the region this evening and tonight. Tomorrow, a positively tilted upper trough impacts the ranges bringing significant PVA and a much cooler air mass later tomorrow on the back side of the trough. A cold front passes through the region tomorrow afternoon. WSW orographic winds and moisture will be exceptional tonight through tomorrow morning. Very deep orographic clouds and possibly severe amounts of SLW are likely over all ranges. The most impressive SLW appears to be in the SM tonight. The storm becomes more efficient by midday tomorrow with mostly ice crystals, deeper midlevel clouds, and a shift to NW flow by sunset. A persistent eastern Pacific ridge pattern returns tomorrow, and strong cool NW flow is expected for WY Thursday through early next week with several impulses pushing through with decent moisture.
Area Forecast:	Outstanding seeding conditions are expected tonight starting around midnight. A flight is planned for the SM range to kick things off tonight, but we may also be seeding in the MB and NS ranges later in the night or tomorrow morning. Two back-to-back flights appear likely. Heavy mountain snowfall is expected tonight through tomorrow evening. SLW will taper off by tomorrow afternoon, and although snowfall will continue through tomorrow evening, our best seeding window is the earlier warmer wetter part of this system. We will likely have exhausted the pilot duty day by midday tomorrow, so pilots can sleep through the naturally efficient part of this storm. Thursday looks to have marginal orographic clouds in NW flow which do not look quite good enough for seeding. Another major system arrives Friday and Saturday, but this system will be much colder with lighter SLW. Heavy snow accumulation is likely Friday-Saturday, but the limiting factor for potential seeding will be SLW availability. Another lull is expected Sunday-Monday, and then another round of active weather is likely next Tuesday through the end of next week.

Flight occurred in the morning hours of the 3rd; weather information is from Feb. 2nd.



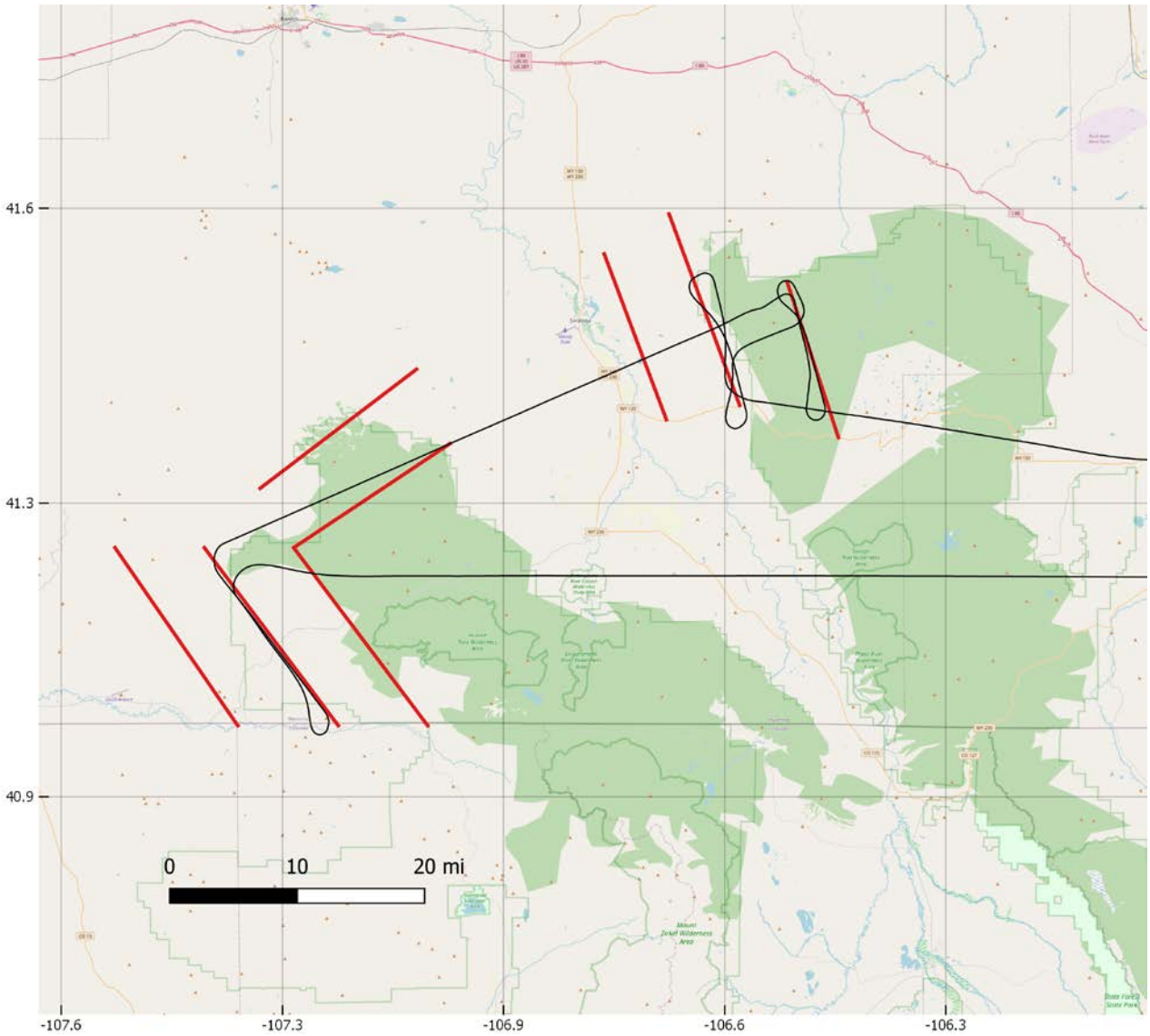
N23MN	OPS #:	17			SEED
	Track(s)/Basin:		MB-4, MB-3		
UTC Date:	February 9, 2021		MST Date:	February 9, 2021	
UTC Engines ON:	20:20		MST Engines ON:	1:20 pm	
UTC Engines OFF:	02:43		MST Engines OFF:	7:43 pm	
Total Time:	6:23	6.38hr	Flares Used:	47 BIP	87 EJECT
Pilot's Flight Summary:	Got on station to MB-4, send conditions to meteorologist and was repositioned to MB-3 for broadcast seeding with BIP's. Majority of events 1-9 were in and out of clouds, while mostly in clear conditions. Extended north end of track 2 miles per meteorologist request. Eventually extended 5 miles north and cut 3 miles off south. Clouds started filling in on the north side of track, and west of the ridge. Near the end of BIP's, switched to MB-4 for more favorable winds and results, and added in EJ's one per two				

	min. After using all BIP's, switched to EJ's one per minute. Initially added 2 miles onto north end of MB-4, then cut off one mile from the south end. Eventually increased EJ's to one per 30 seconds. RTB due to low fuel.
Synoptic Analysis:	Strong NW flow continues for WY today, shifting to W flow tomorrow. The eastern Pacific ridge has flattened along the coast allowing for a more westerly flow which will bring some better Pacific moisture onshore this week along with warmer temps aloft (500 mb temps above -25C at least). A dry air mass remains in place today with PWAT below 0.10 inches. Moisture improves late tonight through tomorrow evening with PWAT reaching above 0.30 inches tomorrow afternoon. Seeding level winds look to be strong westerlies through tomorrow, and orographic lift will be favorable. Low levels will not become saturated in the MB/SM until tomorrow afternoon, but the NS will see good low level RH by tomorrow morning (earlier). Midlevel charts show no major perturbations pushing through until Friday/Saturday when a clipper system dives southeast into WY from Canada bringing bitterly cold temperatures in its wake for next weekend.
Area Forecast:	The ranges will be mostly clear early in the period. High clouds will slowly increase through morning as PWAT improves. Low level RH will lag PWAT, and low clouds will not develop until tomorrow morning. The best setup for orographic clouds and precipitation tomorrow appears to be the NS, but all ranges will see at least marginal orographic clouds and SLW from the morning through the late evening with light snow accumulation. The best chance for seeding is probably in the NS range during the afternoon, but latest models are showing only marginal pockets of SLW. Seeding chances are slim tomorrow, but we will not rule it out yet. Moisture and low clouds will slowly diminish tomorrow night. Thin orographic clouds and flurries are possible Wednesday morning/afternoon. Better orographic development appears possible Wednesday night and Thursday with light mountain snow and another slight chance of seeding. Moderate widespread snow accumulation is expected Friday into Saturday with the incoming trough from the north. Seeding appears likely Friday. By Saturday, temps will likely be too cold for ops and the system will be naturally efficient with waning moisture. Cold dry weather is likely Sunday behind the polar trough, and 500 mb temps may drop to -35C.
Flight occurred in the afternoon to evening hours of the 9th; weather information is from Feb. 8th.	



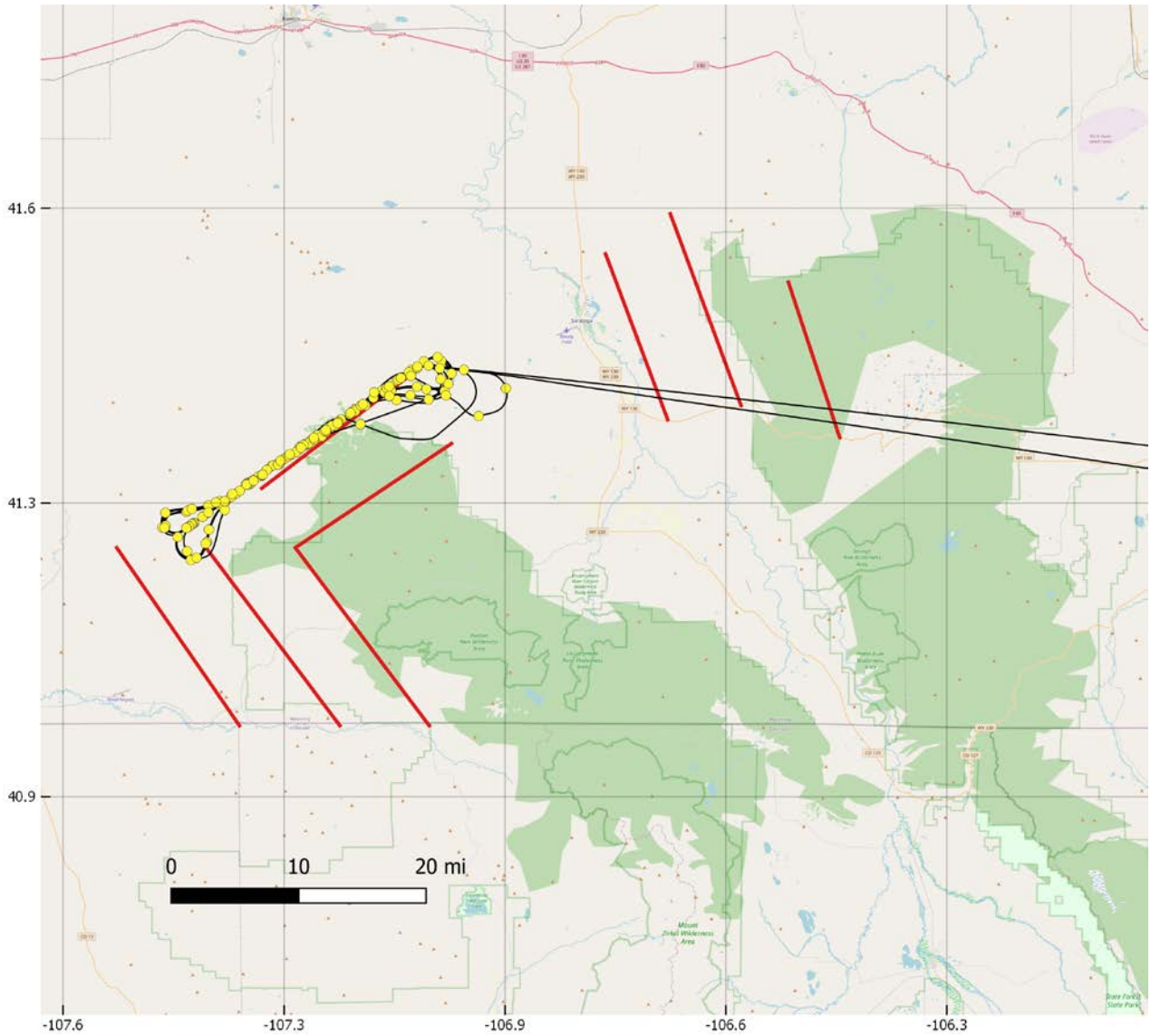
N23MN	OPS #:	18			SEED
	Track(s)/Basin:		MB-4		
UTC Date:	February 11, 2021		MST Date:	February 11, 2021	
UTC Engines ON:	20:03		MST Engines ON:	1:03 pm	
UTC Engines OFF:	01:24		MST Engines OFF:	6:24 pm	
Total Time:	5:21	5.35hr	Flares Used:	14 BIP	172 EJECT
Pilot's Flight Summary:	On way to track there was some light SLW right over the MB ridge. Started EJ's once per minute using the northern most 8nm of track. In and out of clouds throughout the beginning with light SLW mixed with natural ice. We later shifted our track 1nm north. About halfway through the flight, clouds started clearing and we began broadcast seeding with BIP's and EJ's every two min. Switched to only BIP's for remainder of flight.				

Synoptic Analysis:	This morning's upper air analysis shows a bitterly cold longwave trough dominating the CONUS today, accented by a 160kt jet streak over the Midwest and a new jet max developing over the Pacific Northwest. The latter will be a greater interest to us as it propels a shortwave trough from the Pacific onto the California coast, bringing richer moisture inland in the coming days. Midday surface observations show a stationary front hugging the Front Range, encouraging easterly upslope winds and flurries in this area, while clearer and warmer air lies to the west over the mountains this afternoon. Brisk westerly winds aloft continue to encourage patchy orographic cloudiness in our target ranges, but coverage and depth is nowhere near adequate to be seedable.
Area Forecast:	Partly cloudy skies with isolated snow showers will continue across the target ranges this afternoon, especially in the south and west. Precipitation will fade overnight with marginally drier air moving in, but moisture increases again Thursday along with deepening mid- level clouds. A marginal seeding window may develop early Thursday morning in the SM or MB range but is currently expected to be passed for better opportunities later in the week. Deep mid-level cloud cover is likely by the end of the day Thursday. Initial seeding opportunities Thursday evening seem unlikely with low-level moisture lagging behind the mid-levels, but opportunities should improve later Thursday night and Friday as the low levels saturate and deep synoptically driven snowfall fades. SWE predictions through midday Friday show over an inch in the SM and Parker ranges, near an inch in the MB, and closer to 0.5-0.75" in the NS range.
Flight occurred in the afternoon to evening hours of the 11th; weather information is from Feb. 10th.	



N23MN	OPS #:	19			RECON
	Track(s)/Basin:		MB-4, MB-5, SM-4		
UTC Date:	February 20, 2021		MST Date:	February 19, 2021	
UTC Engines ON:	05:50		MST Engines ON:	10:50 pm	
UTC Engines OFF:	07:55		MST Engines OFF:	12:55 am	
Total Time:	2:05	2.08hr	Flares Used:	0 BIP	0 EJECT
Pilot's Flight Summary:	Departed Cheyenne and arrived on MB-4 track. No clouds or SLW on track so we moved to MB-5. No clouds or SLW on track either, so we switched to SM-4 per meteorologist request, and found no seedable conditions there. RTB				
Synoptic Analysis:	Jet level charts show strong westerly flow aloft under a jet streak. Jet level flow will be shifting to WSW overnight ahead of an incoming shortwave. Midlevel charts have shown some weak PVA early in the day today, but we will see very slight ridging during				

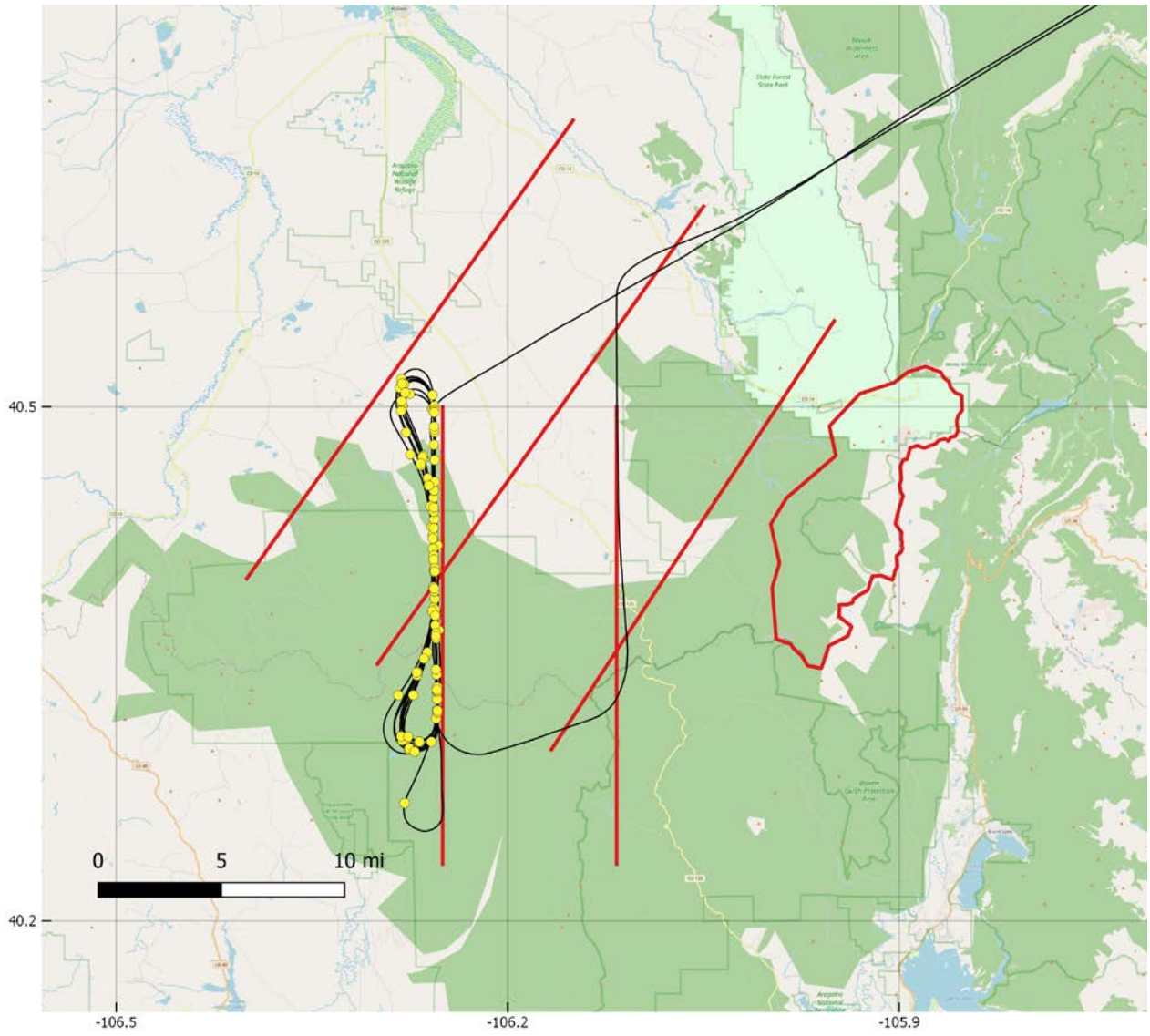
	the afternoon which will bring a bit a brief lull in the cloud depth. The potent shortwave moves in late tonight through tomorrow afternoon. The 500 mb temps will be around -25C through dawn, and then cooling steadily tomorrow. PWAT drops slightly during the afternoon today, climbing back to around 0.25 to 0.30 inches tonight and tomorrow morning. A colder air mass moves in tomorrow along with a cold front and trough axis. Behind tomorrow's shortwave, we will remain in strong but drier NW flow through Monday. Temps aloft will rebound Sunday and Monday. The next cold trough moves in from the NW on Tuesday.
Area Forecast:	Deep orographic clouds will persist through tomorrow evening, but SLW will not be present for this entire time. Mountain snowfall will continue through tomorrow evening, tapering off tomorrow night. The heaviest snowfall rates will occur late tonight through tomorrow afternoon. The heaviest accumulation appears likely in the MB range where 12-15 inches of snow is possible over highest peaks. A window with deep targetable SLW appears likely tonight starting around midnight. By midmorning tomorrow, the system becomes colder more naturally efficient with deeper clouds and midlevel snow providing plenty of natural ice crystals for tomorrow. A seeding flight is planned for the MB range overnight. Seeding level winds will be nearly due west around 45-50 kts tonight, and SLW may be present up to 19 kft. Conditions at CYS look to remain favorable for ops all night as visibility and ceilings will be no factor. Convective showers are possible tomorrow afternoon as temps aloft cool and destabilize the region, but operations appear unlikely tomorrow due to sparse SLW. No seeding is expected Saturday through Monday. The next wave arrives Tuesday. This will be a cold clipper system, but we may have a seeding window early in the storm Tuesday before the temps drop too much.
Flight occurred in the evening hours of the 19th; weather information is from Feb. 19th.	



N23MN	OPS #:	20			SEED
	Track(s)/Basin:		SM-1		
UTC Date:	April 7, 2021		MDT Date:	April 6, 2021	
UTC Engines ON:	03:46		MDT Engines ON:	9:46 pm	
UTC Engines OFF:	07:35		MDT Engines OFF:	1:35 am	
Total Time:	3:49	3.82hr	Flares Used:	0 BIP	135 EJECT
Pilot's Flight Summary:	Departed KCYS and arrived on SM-1 track from the NE. In and out of cloud tops with light icing and intermittent SLW. Started EJs at a rate of one per minute. After one pass we experienced moderate icing and SLW, and increased EJ rate to 1 every 45 seconds, per meteorologist request. This continued for over a half an hour, then conditions changed. In and out of cloud tops with light SLW. Slowed EJ rate to 1/min. Descended to 13 kft due to no real SLW. SLW content improved temporarily at 13 kft, but then				

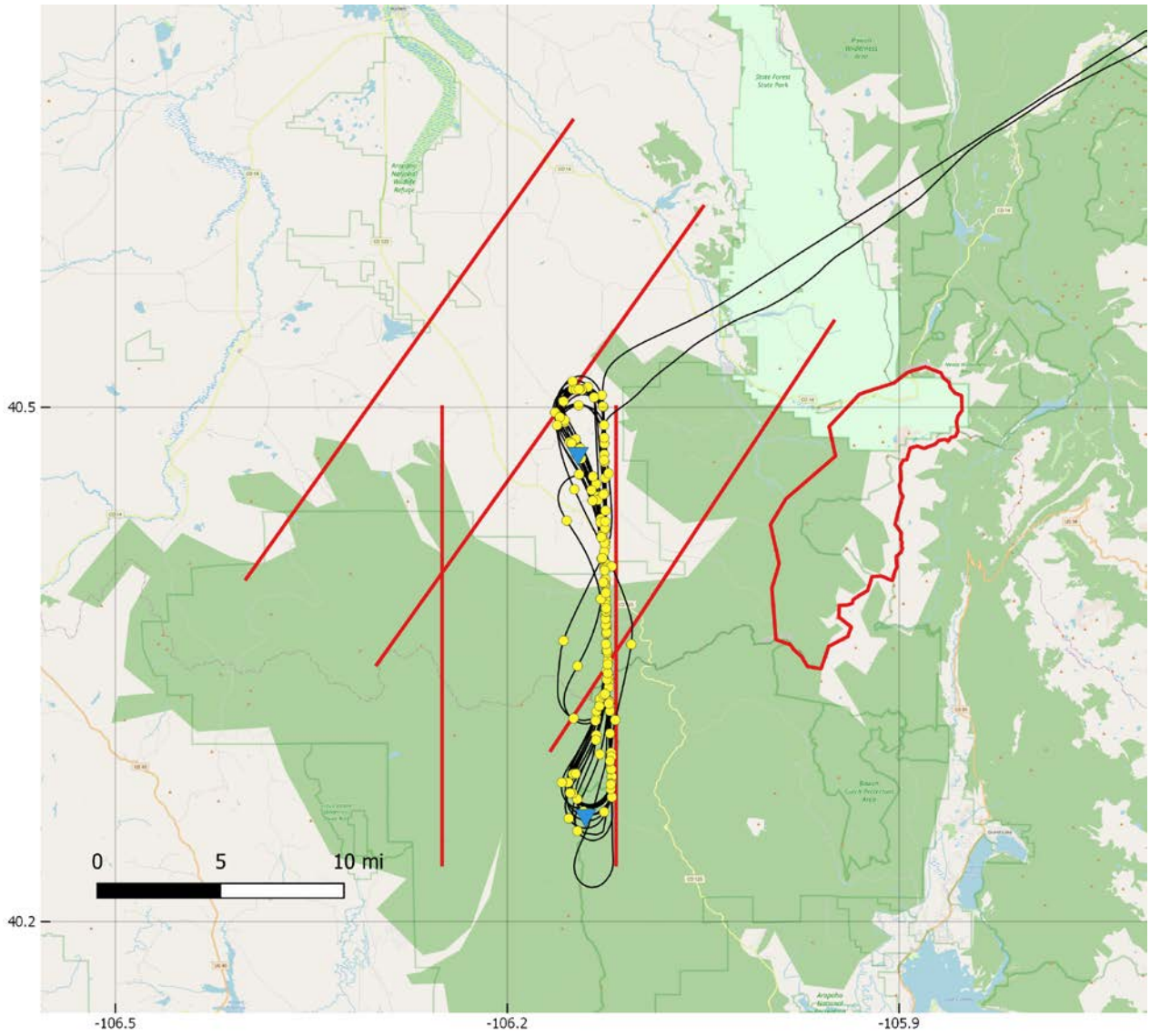
	began to decrease. Decreased EJ rate to 2 per minute, due to light SLW. Eventually only ice crystals and little SLW. Terminated flight per meteorologist request.
Synoptic Analysis:	Upper-level charts show a low approaching from the west. The system will track eastward along the WY/CO border today and tonight reaching Kansas by morning. Low level moisture improves throughout the day, and low levels will be saturated this evening through tomorrow morning. PWAT peaks near 0.40 inches around midnight and then gradually wanes through morning. 700 mb RH drops off sharply in the late morning tomorrow. Seeding level winds will be from the northwest this evening through midday tomorrow (this rules out any MB ops) with speeds around 25-30 kts in the SM and 35-40 kts in the NS. Weak instability is expected this afternoon, but we will stabilize after sunset with stable conditions this evening through the night. Conditions will be favorable for deep orographic cloud tonight through midmorning tomorrow. Shortwave ridging is expected tomorrow and early Thursday. A clipper system dives through WY late Thursday and Friday with light moisture.
Area Forecast:	Broken to overcast cloud layers are expected through midmorning tomorrow. Showery activity is expected this afternoon and evening with a mix of rain and snow. Deep orographic clouds and light mountain snowfall are expected from midnight through tomorrow morning with periods of targetable SLW. NW winds will be workable for flights in both the SM and NS ranges, and both ranges are showing moderate SLW in model cross- sections tonight. We may see a chance for back-to-back flights in both the SM and NS tonight through tomorrow morning. Clouds erode quickly late tomorrow morning, and then clearing is expected by noon. Dry mostly clear conditions are expected tomorrow afternoon through midday Thursday. Another round of light precipitation is likely Thursday evening and overnight with a slight chance of targetable SLW. This is a change from previous forecasts as models have taken a more southerly track with the late-week clipper system. However, moisture is relatively light Thursday night and SLW will be questionable. TAFs are showing CYS ceilings as low as 1500 ft tonight around 12z.
Flight occurred in the evening hours of the 6th to the morning hours of the 7th; weather information is from Apr. 6th.	

5.2 Mission Flight Tracks – Never Summer Range, CO



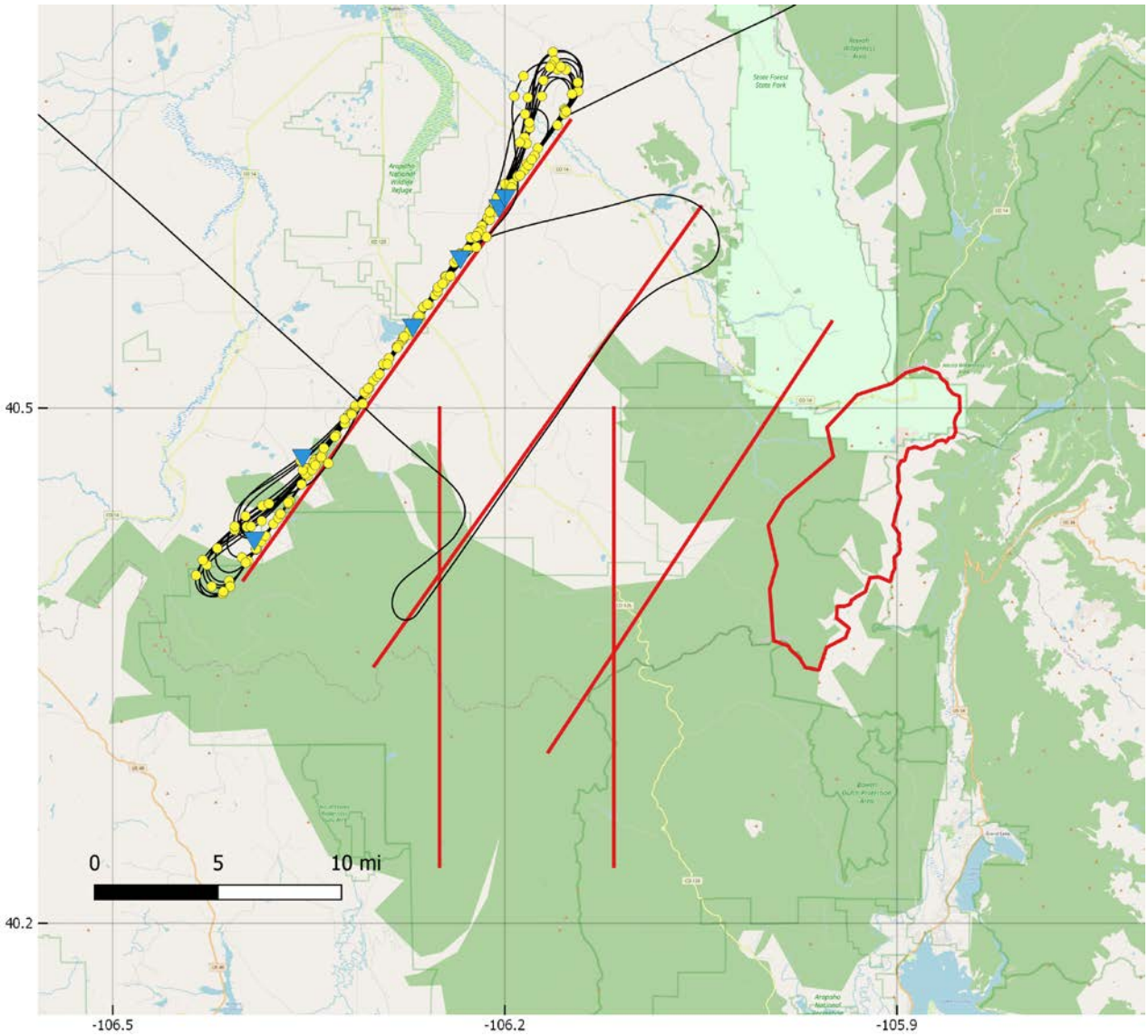
N23MN	OPS #:	01			SEED
	Track(s)/Basin:		NS-4, NS-5		
UTC Date:	November 12, 2020		MST Date:	November 11, 2020	
UTC Engines ON:	03:48		MST Engines ON:	8:48 pm	
UTC Engines OFF:	06:42		MST Engines OFF:	11:42 pm	
Total Time:	2:54	2.9hr	Flares Used:	0 BIP	98 EJECT
Pilot's Flight Summary:	Departed Cheyenne and picked up light SLW while crossing the ridge to NS-4. We began seeding with EJs, once a minute and cut off the last 5 miles on the south end of NS-4. Moved to track NS-5 to check for SLW. Due to lack of seedable conditions we RTB.				

Synoptic Analysis:	A broad arctic upper-level trough is being shunted across the northwest CONUS by a smaller scale trough and ridge traversing the pattern. Well below average temperatures are observed beneath the longwave trough, with the 500mb temperature on the 12Z Riverton sounding registering a frosty -31.5°C. Despite the polar air, low level moisture enhanced by the passing shortwave trough continues to bring snow showers to the region, and another period of enhanced and potentially targetable orographic cloudiness is expected tonight. The best moisture with tonight's shortwave appears to favor the south half of our target area, with the NS range most favored in current model projections. A shortwave ridge builds across the region Thursday morning, diminishing orographic cloudiness and ending seeding conditions.
Area Forecast:	Increasing clouds and snow showers are already evident on radar and satellite moving east from western WY and CO, with activity infiltrating our target ranges this afternoon and evening. Model indicated SLW with this leading wave of activity appears limited, perhaps caused in part by the very cold airmass in place and the more dynamically driven nature of the snow showers. PVA subsides and widespread precipitation diminishes this evening, though modest orographically enhanced cloudiness continues overnight, bringing a better chance of SLW and seedable conditions. The NS range appears most favored by tonight's setup, with more shallow and less consistent orographic cloudiness projected in the more northern ranges. Orographic cloudiness diminishes in all target ranges around dawn, with clear skies in the valley Thursday. No further seeding opportunities are anticipated until a new Pacific trough moves in early Saturday.
Flight occurred in the evening hours of the 11th; weather information is from Nov. 11th.	



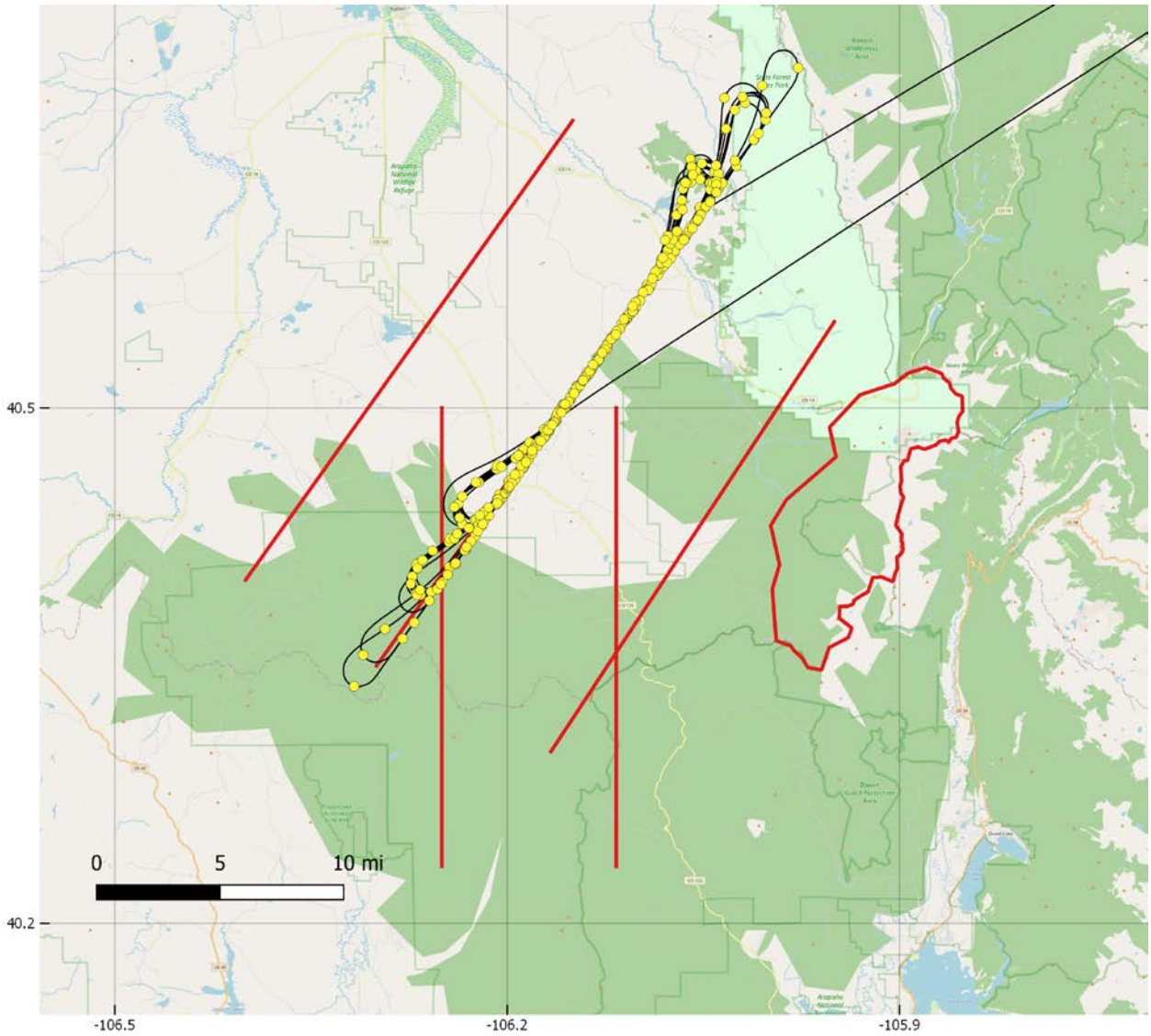
N23MN	OPS #:	02			SEED
	Track(s)/Basin:		NS-5		
UTC Date:	December 18, 2020		MST Date:	December 18, 2020	
UTC Engines ON:	08:32		MST Engines ON:	1:32 am	
UTC Engines OFF:	12:29		MST Engines OFF:	5:29 am	
Total Time:	3:57	3.95hr	Flares Used:	4 BIP	162 EJECT
Pilot's Flight Summary:	Enroute to NS-5 we encountered moderate SLW. After arriving at NS-5, we encountered light SLW. We started burning BIPS and EJs, every 2 minutes. We also cut 3 miles off the south end. We stopped firing BIPs due to in and out of cloud tops, switched to EJs every minute. We continued to find light SLW and continued to fly in and out of cloud tops on NS-5. Towards the end of the flight the cloud tops began to lower and we cut off another 3 miles on the south end of the track, 6 total miles cut off. RTB when conditions deteriorated.				

Flight occurred in the morning hours of the 18th; weather information remains the same as MBSM Ops #6.



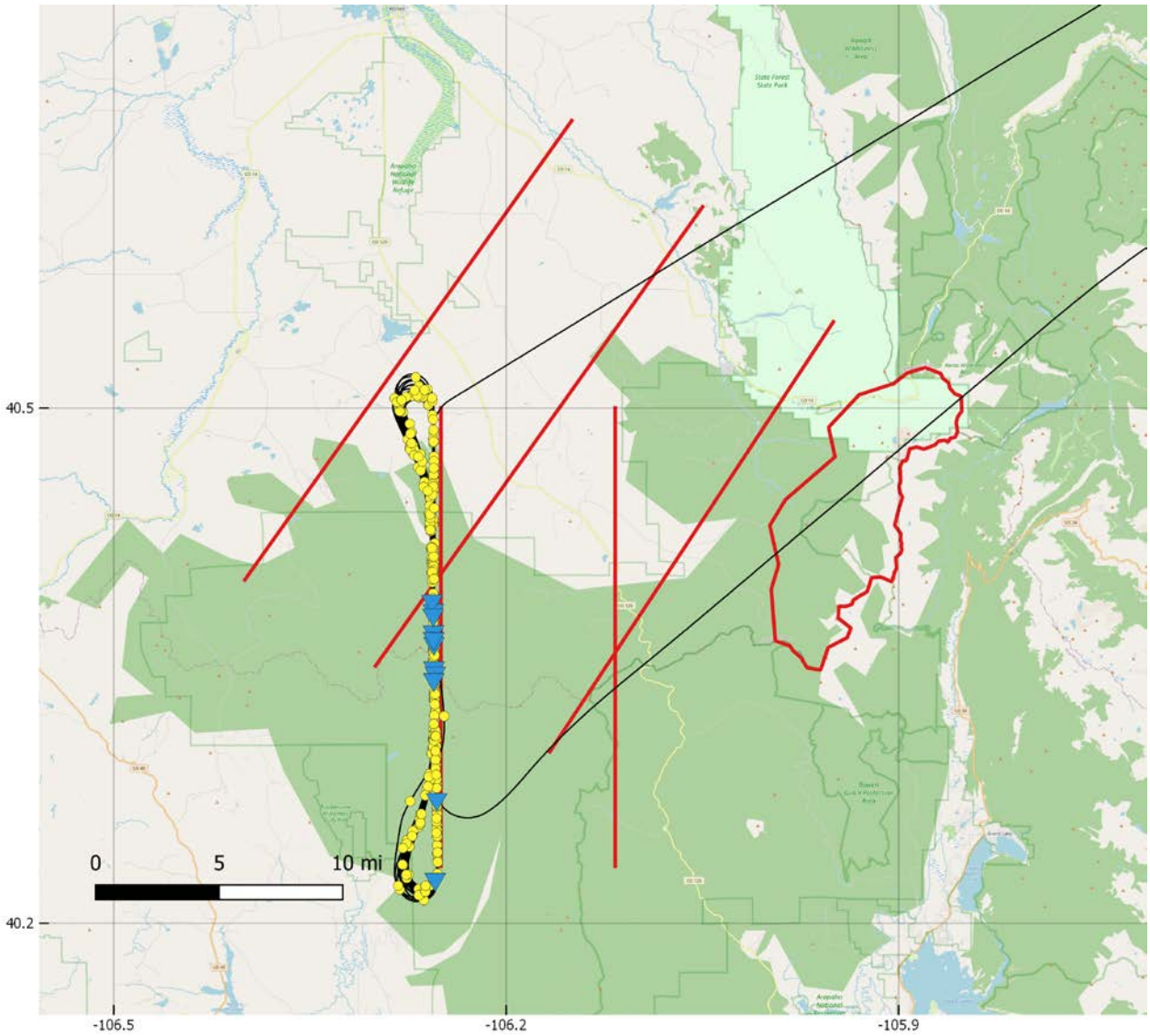
N23MN	OPS #:	03			SEED
	Track(s)/Basin:		NS-1		
UTC Date:	January 13, 2021		MST Date:	January 13, 2021	
UTC Engines ON:	21:16		MST Engines ON:	2:16 pm	
UTC Engines OFF:	00:46		MST Engines OFF:	5:46 pm	
Total Time:	3:30	3.5hr	Flares Used:	5 BIP	154 EJECT

Full flight summary continued in Medicine Bow & Sierra Madre table for Ops #12.



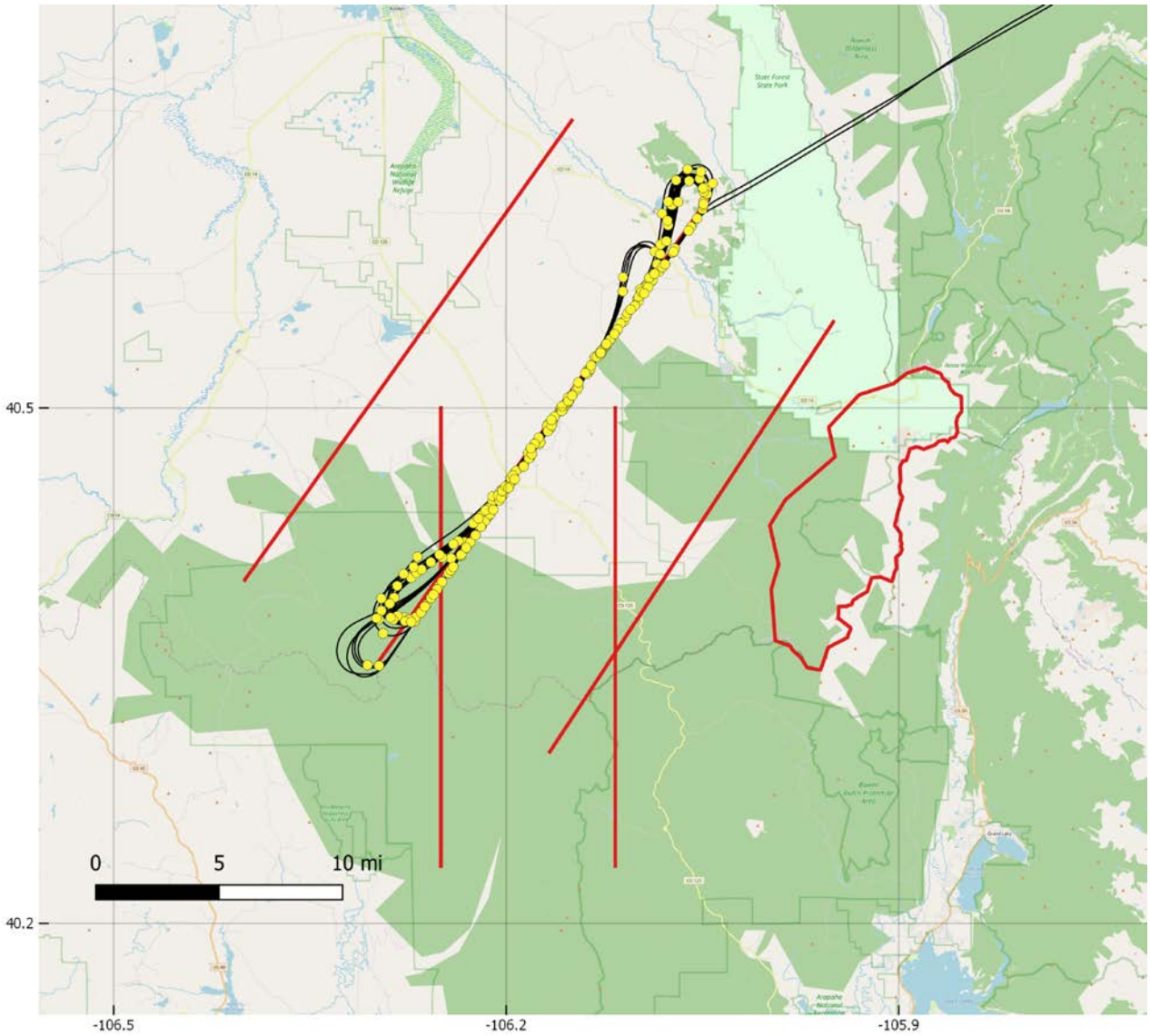
N23MN	OPS #:	04			SEED
	Track(s)/Basin:		NS-2		
UTC Date:	January 18, 2021		MST Date:	January 18, 2021	
UTC Engines ON:	08:47		MST Engines ON:	1:47 am	
UTC Engines OFF:	14:47		MST Engines OFF:	7:47 am	
Total Time:	6:00	6hr	Flares Used:	0 BIP	261 EJECT
Pilot's Flight Summary:	Enroute to NS-2, light SLW crossing the peaks. Began dropping EJs once per minute. Light SLW on track. Per meteorologist's request, we are cutting off 6 miles from the southwest end and adding 3 miles to the northeast. Descended to 15 kft per meteorologist's request. Light SLW mixed with natural Ice. Removed the additional 3 miles to the northeast, returned to normal NE waypoint. Per meteorologist's request, we cut 3 miles off the southwestern portion of the track. Conditions remained constant for the entire flight. RTB.				

Flight occurred in the morning hours of the 18th; weather information remains the same as MBSM Ops #13.



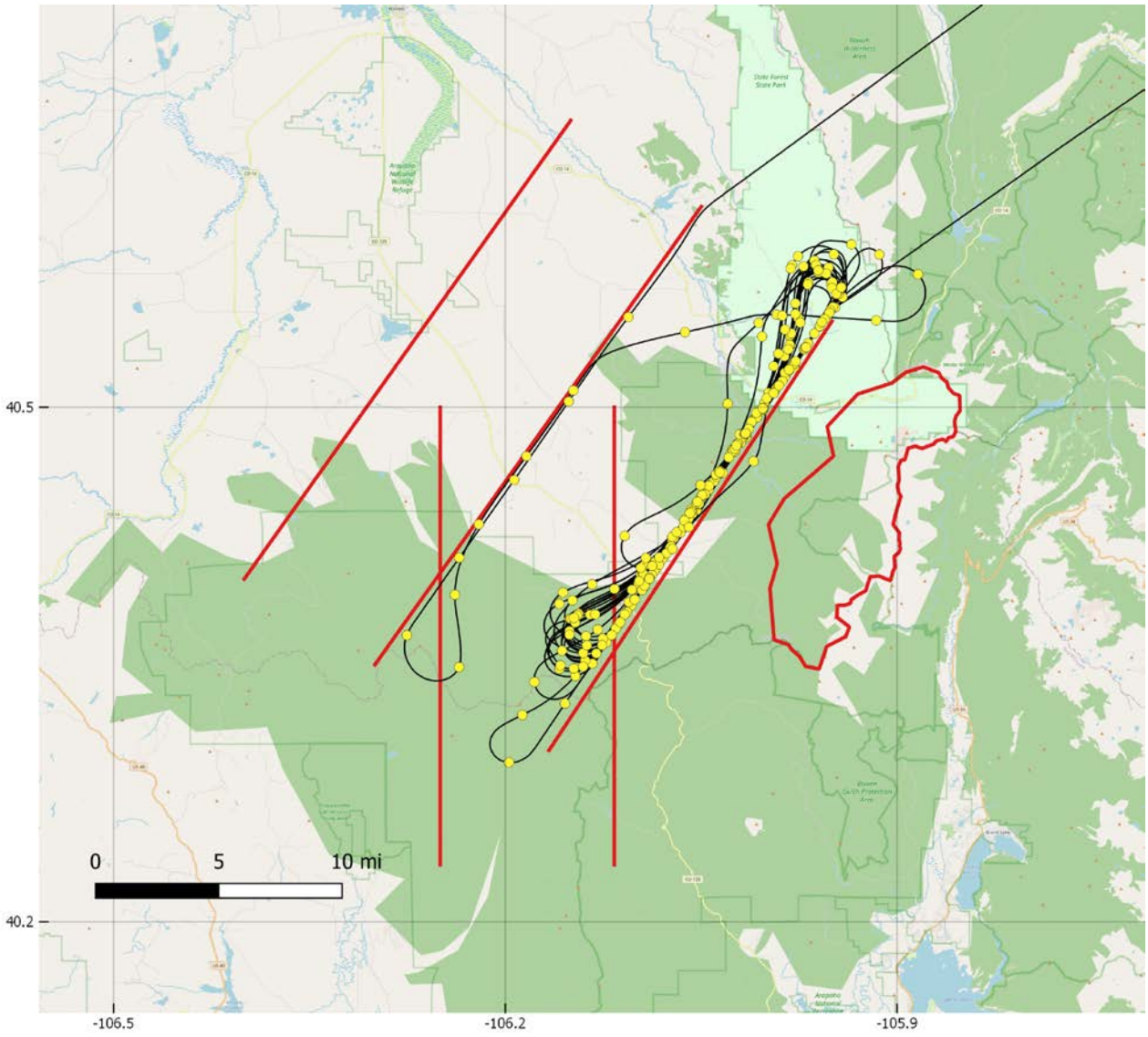
N23MN	OPS #:	5			SEED
	Track(s)/Basin:		NS-4		
UTC Date:	February 3, 2021		MST Date:	February 3, 2021	
UTC Engines ON:	13:10		MST Engines ON:	6:30 pm	
UTC Engines OFF:	18:59		MST Engines OFF:	5:21 am	
Total Time:	5:49	5.82hr	Flares Used:	10 BIP	210 EJECT
Pilot's Flight Summary:	Arrived on track and descended to 15 kft, in and out of clouds for the first two hours. EJ's throughout the flight track, firing one every minute. Clouds started to fill in on the south end of track and continued to fill in more as time passed. Consistently light SLW with a few pockets of moderate at times. As clouds continued to become more dense, we added BIP's per meteorologists request in areas with thicker clouds and higher levels of SLW. Increased EJ's to every 45 seconds during last hour.				

Flight occurred in the morning hours of the 3rd; weather information remains the same as MBSM Ops #16.



N23MN	OPS #:	6			SEED
	Track(s)/Basin:		NS-2		
UTC Date:	February 13, 2021		MST Date:	February 12, 2021	
UTC Engines ON:	02:16		MST Engines ON:	7:16 pm	
UTC Engines OFF:	08:08		MST Engines OFF:	1:08 am	
Total Time:	5:52	5.87hr	Flares Used:	0 BIP	222 EJECT
Pilot's Flight Summary:	When initially on track, there was an abundance of natural ice. With the winds, we cut three miles off most northwestern end of track and started EJ's one per two minutes. Due to slight wind change, we continued to northeastern point of track and cut off south western 2 miles. Intermittent light SLW mixed with natural ice continued until around 04:30, when clouds dropped and we began to go in and out of cloud tops. Per meteorologist request, we increased the EJ rate to every minute. Continued in and out of cloud tops with light SLW. Conditions remained the same until 06:07 when SLW				

	increased some and mixed with natural ice while passing through tops of the clouds. Encountered light SLW crossing ridge after leaving track.
Synoptic Analysis:	Jet level charts indicate moderate westerly flow over WY today as a trough pushes through the Four Corners region. The best midlevel dynamics with this system will stay south of our region today/tonight. Strong NW flow returns tonight behind the trough axis. 700 mb charts continue to show elevated RH over the region until tomorrow evening which will continue to provide ample moisture for widespread snow through tomorrow evening. A drier colder airmass moves in for Sunday, and 500 mb temps will drop well below -25C Sunday through the middle of next week. Low level RH will be elevated for the first half of next week, relative to the cold temps aloft. However, PWAT values and SLW will be marginal at best. Warmer wetter conditions return late in the week. CYS looks to have potential for low IFR and freezing mist through this afternoon. Visibility and ceilings should improve through the evening for a potential ops window, but the threat of freezing mist continues through the night.
Area Forecast:	Waves of deep low and midlevel cloud will be present through tomorrow evening with continuous mountain snow and intermittent pockets of low level SLW between the waves of midlevel snowfall. The biggest challenge for potential seeding appears to be identifying a window of deep continuous SLW that is not interrupted by waves of natural seeder-feeder snow from above. Such a window appears likely in the NS this evening. A flight has been tentatively scheduled for the NS range to depart around 3-4Z. Seeding level winds look to be westerly around 35-40 kts this evening with light, but at times deep SLW. This will probably be the final flight for this weekend. There is some decent SLW overnight in the MB, but it looks to be mostly confined to the peaks which is not workable with the stronger winds. Snow continues Saturday and Saturday night with poor SLW expected. Sunday will see clearing and colder temps. Monday through Wednesday will have a much colder air mass in place, and while some light snowfall and orographic clouds are expected through midweek, temps aloft do not look promising for seeding opportunities. Longer range models indicate the next round of seeding may arrive late next week into next weekend.
Flight occurred in the evening hours of the 12th to the morning hours of the 13th; weather information is from Feb. 12th.	



N23MN	OPS #:	7			SEED
	Track(s)/Basin:		NS-2, NS-3		
UTC Date:	April 7, 2021		MDT Date:	April 7, 2021	
UTC Engines ON:	08:10		MDT Engines ON:	2:10 am	
UTC Engines OFF:	13:08		MDT Engines OFF:	7:08 am	
Total Time:	4:58	4.97hr	Flares Used:	0 BIP	241 EJECT
Pilot's Flight Summary:	Departed KCYS and at about 3 miles out from NS-2 track entered cloud tops. Began EJ fire rate of 1/minute per meteorologist request. No SLW, so we changed to NS-3 track for better targeting. Upon arriving on NS-3 track we encountered light ice and SLW. Winds and temperatures remained fairly constant, and SLW was light and intermittent through the remainder of the flight.				
Flight occurred in the morning hours of the 7th; weather information remains the same as MBSM Ops #20.					

5.3 2020-2021 All Missions Map

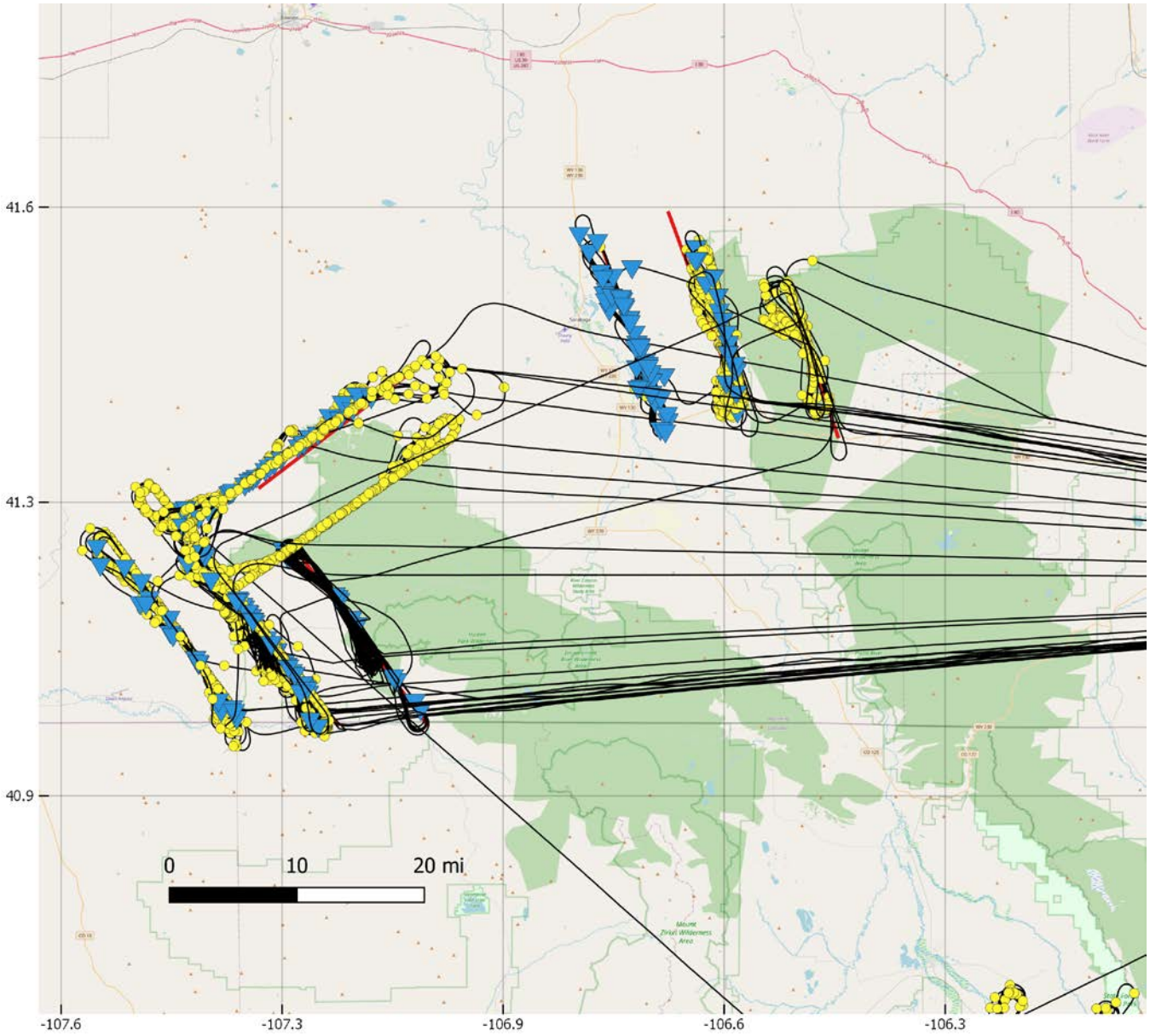


Figure 24. All flights conducted for the 2020-2021 winter season in the Medicine Bow and Sierra Madre Ranges of Wyoming.

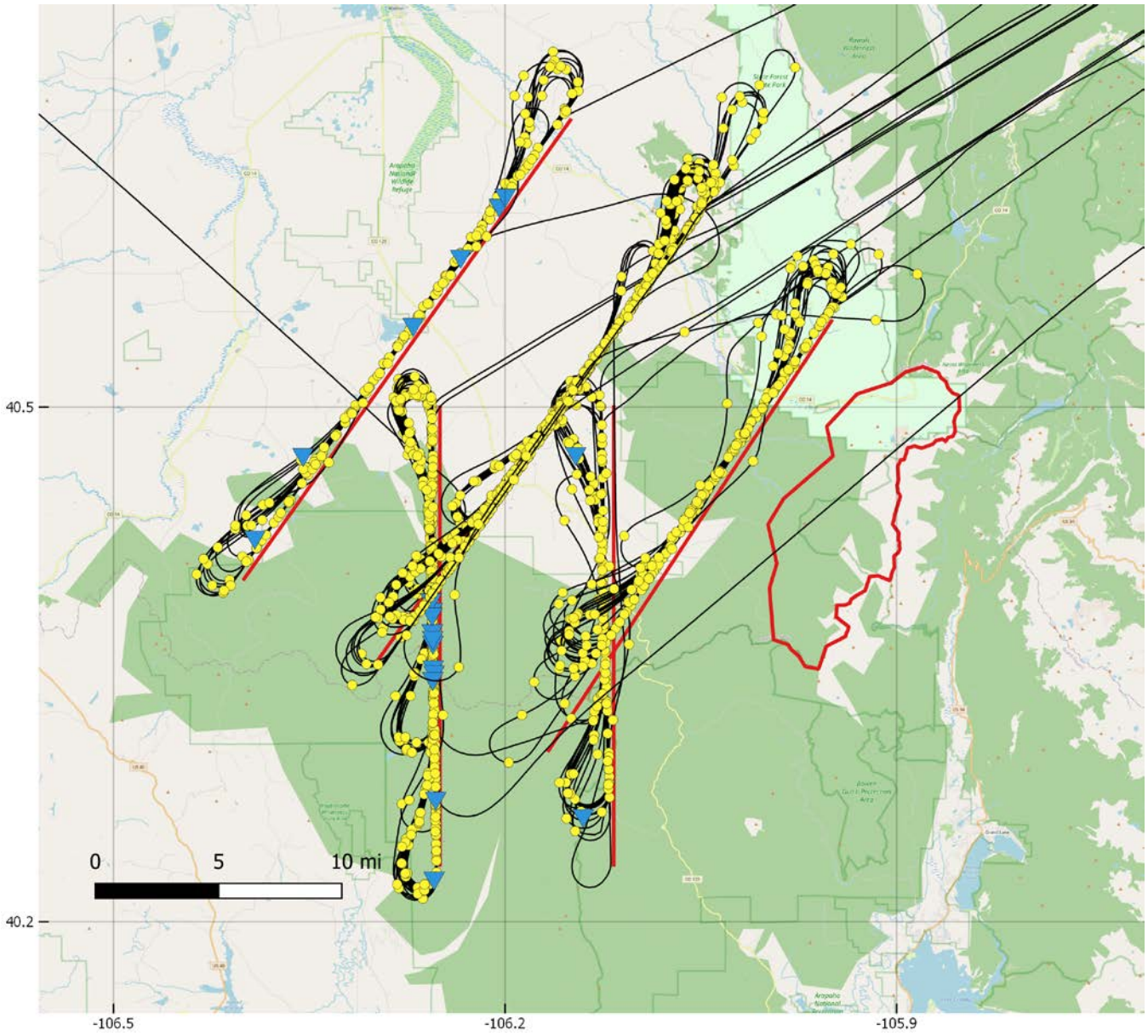


Figure 25. All flights conducted for the 2020-2021 winter season in Colorado's Never Summer Mountain Range.

6 2020-2021 OPERATIONS SUMMARY

Season flight operations are summarized in Table 4. Each flight is represented by its own column, so when there are two flights on a single day, for example, 27 December, there are two columns. Project-billable flights include only seeding and reconnaissance (Recon), but non-billable flights (usually flown for maintenance reasons) are not listed.

A total of 26 project-billable flights were flown. Of these 26 missions, time was split between WY and CO on one flight, 13 January 2021. Seeding was conducted on 24 of the 26 missions, with reconnaissance time flown on 22 January in the Medicine Bow Range and on 20 February for the Medicine Bow and Sierra Madre Ranges. December and February were the most active, with eight and six missions flown, respectively. November and January each saw five missions, April only two missions, and none in March. In comparison, December and January were the busiest months of the 2019-2020 winter season.

A little over 128 hours were flown in the course of the seeding missions and 4.6 on the reconnaissance missions. It should be noted that of the 26 missions, 15 were five hours or more duration. The mean duration of seeding missions was 5.21 hours. The B200's endurance paid off in a big way.

Table 4. Flight operations for the 2020-2021 season are summarized.

Wyoming Operations Summary (MBSMLR)

Date	Engine On (UTC)	Engine Off (UTC)	Duration (hrs)	Monthly Flight Hours	Flight Hours Season Total	Seeding Agent Released (kg)	Seeding Agent Monthly Total	Seeding Agent Season Total
11/8/2020	5:28	9:28	4:00	4:00	4:00	4.05	4.05	4.05
11/11/2020	8:06	14:22	6:16	10:16	10:16	6.10	10.15	10.15
11/12/2020								
11/16/2020	0:54	7:12	6:18	16:34	16:34	6.08	16.23	16.23
11/19/2020	17:48	23:01	5:13	21:47	21:47	7.79	24.02	24.02
12/16/2020	13:30	20:02	6:32	6:32	28:19	6.06	6.06	30.08
12/18/2020	2:13	6:25	4:12	10:44	32:31	3.14	9.20	33.22
12/18/2020								
12/19/2020	21:16	3:30	6:14	16:58	38:45	6.00	15.20	39.22
12/21/2020	2:02	7:36	5:34	22:32	44:19	4.88	20.08	44.10
12/22/2020	19:05	0:24	5:19	27:51	49:38	7.05	27.13	51.15
12/27/2020	4:48	11:00	6:12	34:03	55:50	5.78	32.91	56.93
12/27/2020	11:45	18:06	6:21	40:24	62:11	5.68	38.59	62.61
1/13/2021								
1/14/2021	0:46	1:42	0:56	0:56	63:07	0.00	0.00	62.61
1/18/2021	1:10	7:03	5:53	6:49	69:00	7.32	7.32	69.93
1/18/2021								
1/22/2021	2:10	3:45	1:35	8:24	70:35	0.00	7.32	69.93
1/30/2021	13:16	19:43	6:27	14:51	77:02	5.04	12.36	74.97
2/3/2021	6:30	12:21	5:51	5:51	82:53	5.84	5.84	80.81
2/3/2021								
2/4/2021								
2/5/2021								
2/9/2021	20:20	2:43	6:23	12:14	89:16	8.79	14.63	89.60
2/11/2021	20:03	1:24	5:21	17:35	94:37	5.54	20.17	95.14
2/13/2021								
2/20/2021	5:50	7:55	2:05	19:40	96:42	0.00	20.17	95.14
3/31/2021								
4/7/2021	3:46	7:35	3:49	23:29	100:31	2.70	2.70	97.84
4/7/2021								

Shaded rows indicate days on which flight(s) occurred in Colorado, but not Wyoming

Colorado Operations Summary (NS)

Date	Engine On (UTC)	Engine Off (UTC)	Duration (hrs)	Monthly Flight Hours	Flight Hours Season Total	Seeding Agent Released (kg)	Seeding Agent Monthly Total	Seeding Agent Season Total
11/8/2020								
11/11/2020								
11/12/2020	3:48	6:42	2:54	2:54	2:54	1.96	1.96	1.96
11/16/2020								
11/19/2020								
12/16/2020								
12/18/2020								
12/18/2020	8:32	12:29	3:57	3:57	6:51	3.84	3.84	5.80
12/19/2020								
12/21/2020								
12/22/2020								
12/27/2020								
12/27/2020								
1/13/2021	21:16	0:46	3:30	3:30	10:21	3.83	3.83	9.63
1/14/2021								
1/18/2021								
1/18/2021	8:47	14:47	6:00	9:30	16:21	5.22	9.05	14.85
1/22/2021								
1/30/2021								
2/3/2021								
2/3/2021	13:10	18:59	5:49	5:49	22:10	5.70	5.70	20.55
2/4/2021								
2/5/2021								
2/9/2021								
2/11/2021								
2/13/2021	2:16	8:08	5:52	11:41	28:02	4.44	10.14	24.99
2/20/2021								
3/31/2021								
4/7/2021								
4/7/2021	8:10	13:08	4:58	16:39	33:00	4.82	4.82	29.81

Shaded rows indicate days on which flight(s) occurred in Wyoming, but not Colorado

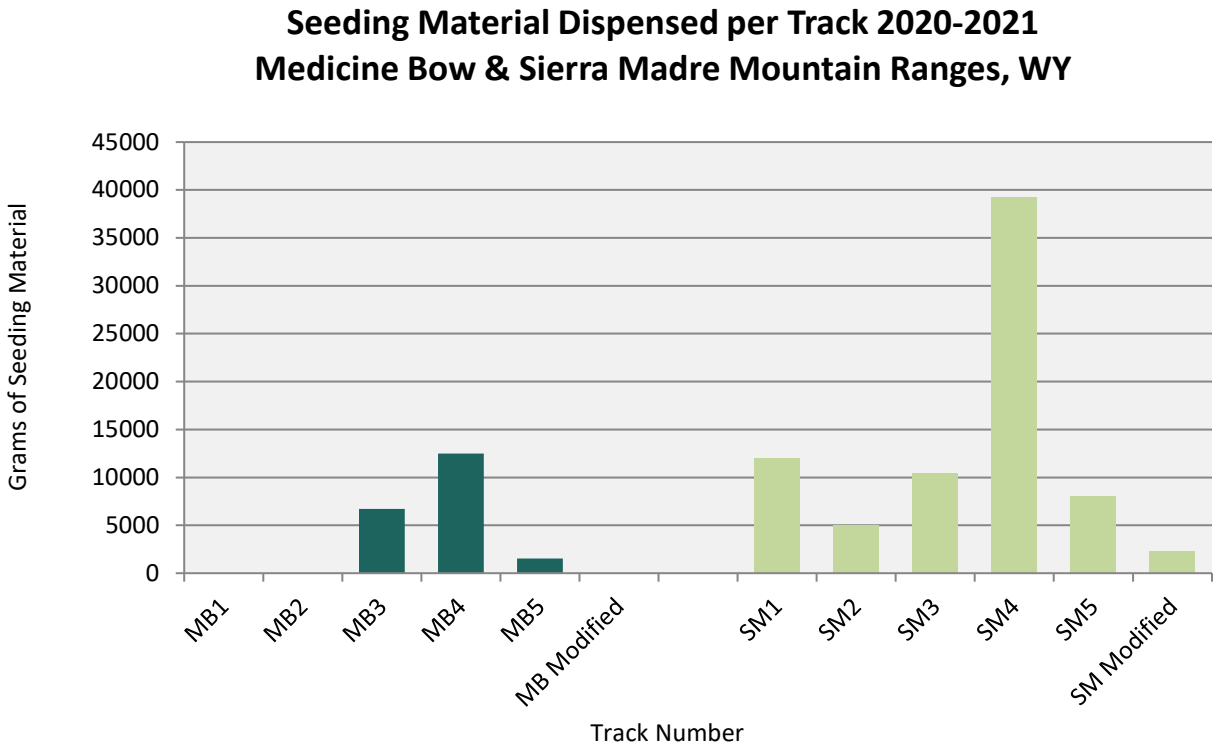


Figure 26. Grams of seeding material dispensed per track over the Medicine Bow, Sierra Madre, and Laramie Mountain Ranges in Wyoming.

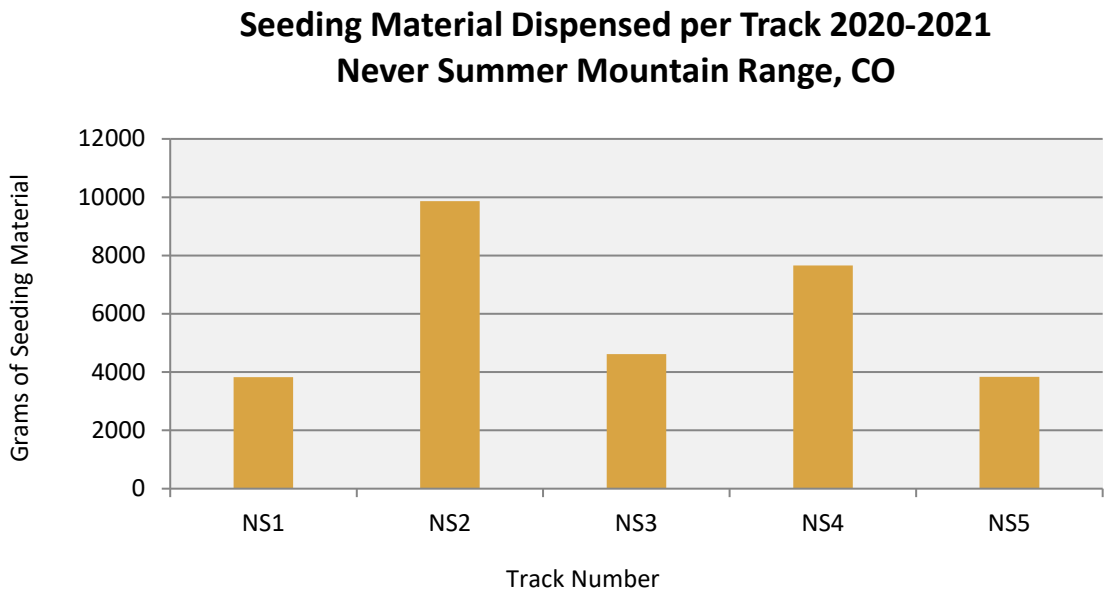


Figure 27. Grams of seeding material dispensed per track over the Never Summer Mountain Range in Colorado during the 2020-2021.

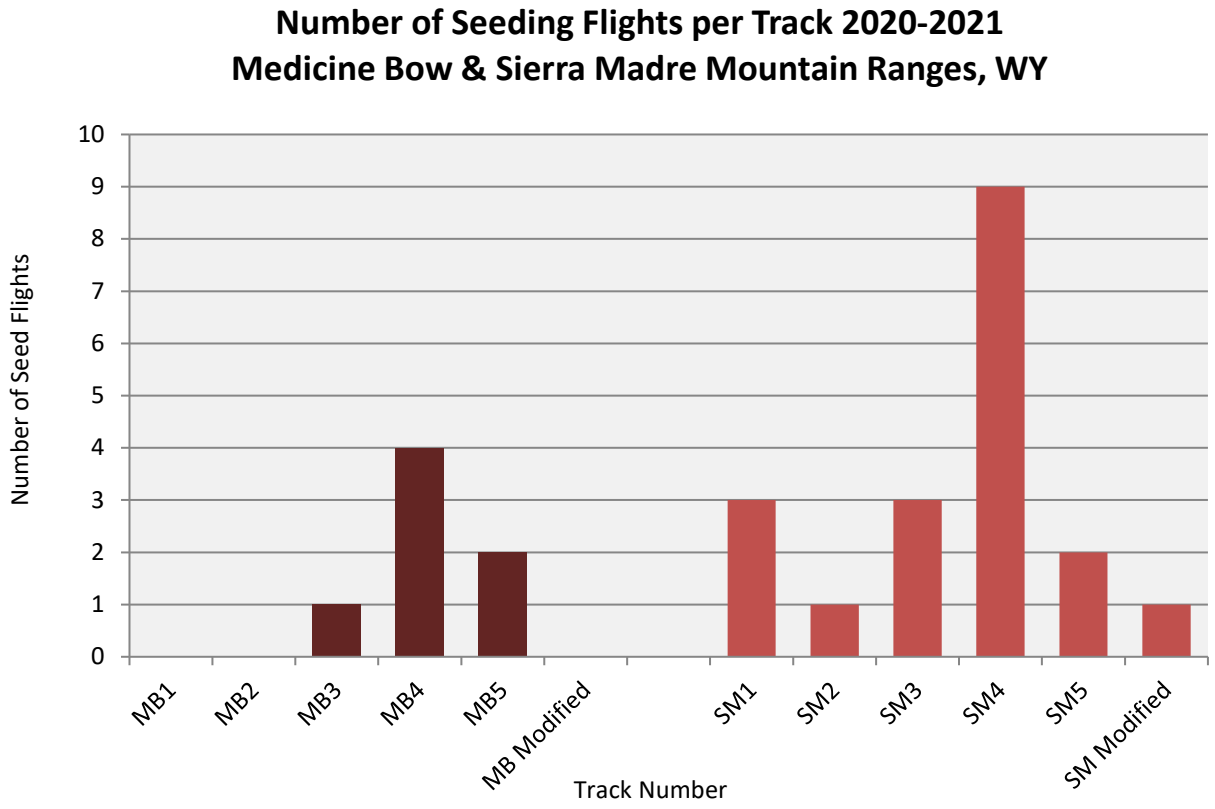


Figure 28. Number of seeding flights per track in the Medicine Bow, Sierra Madre, and Laramie Mountain Ranges in WY. Some flights may utilize multiple tracks.

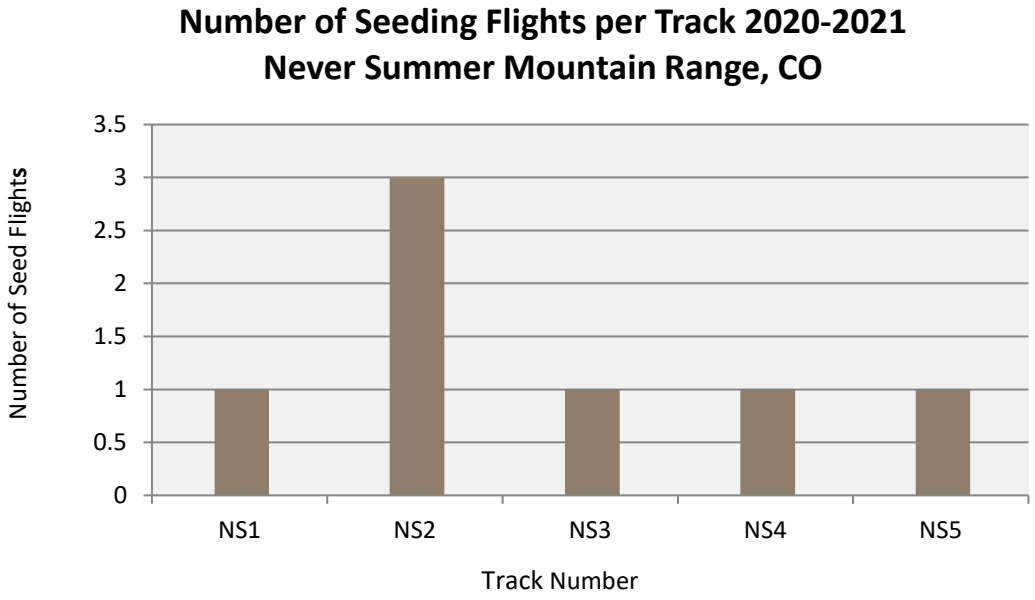


Figure 29. Number of seeding flights per track in the Never Summer Mountain Range in CO. Some flights may utilize multiple tracks.

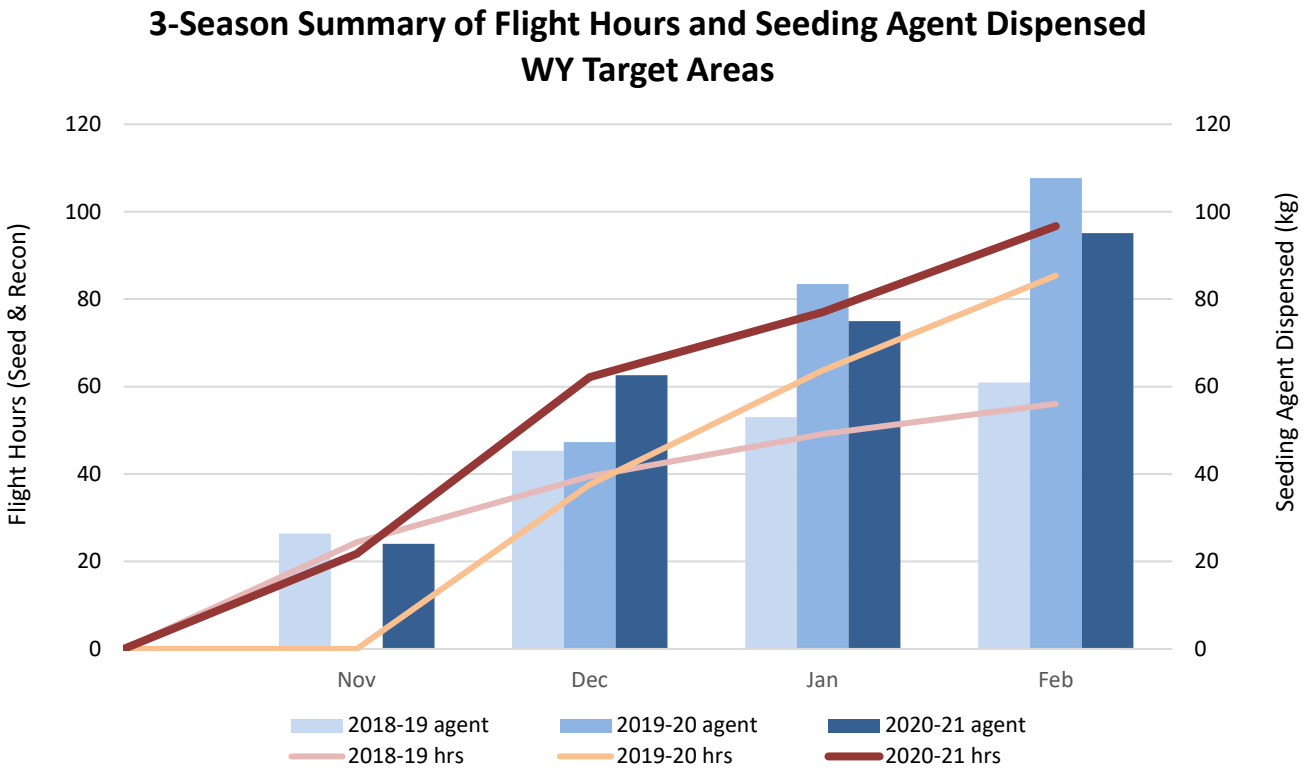


Figure 30. 3-Season Summary of Flight Hours and Seeding Agent Dispensed for the Wyoming Target Areas (Medicine Bow and Sierra Madre Mountain Ranges). Note: Laramie Mountain Range data is included from 15 November 2018 - 20 December 2020.

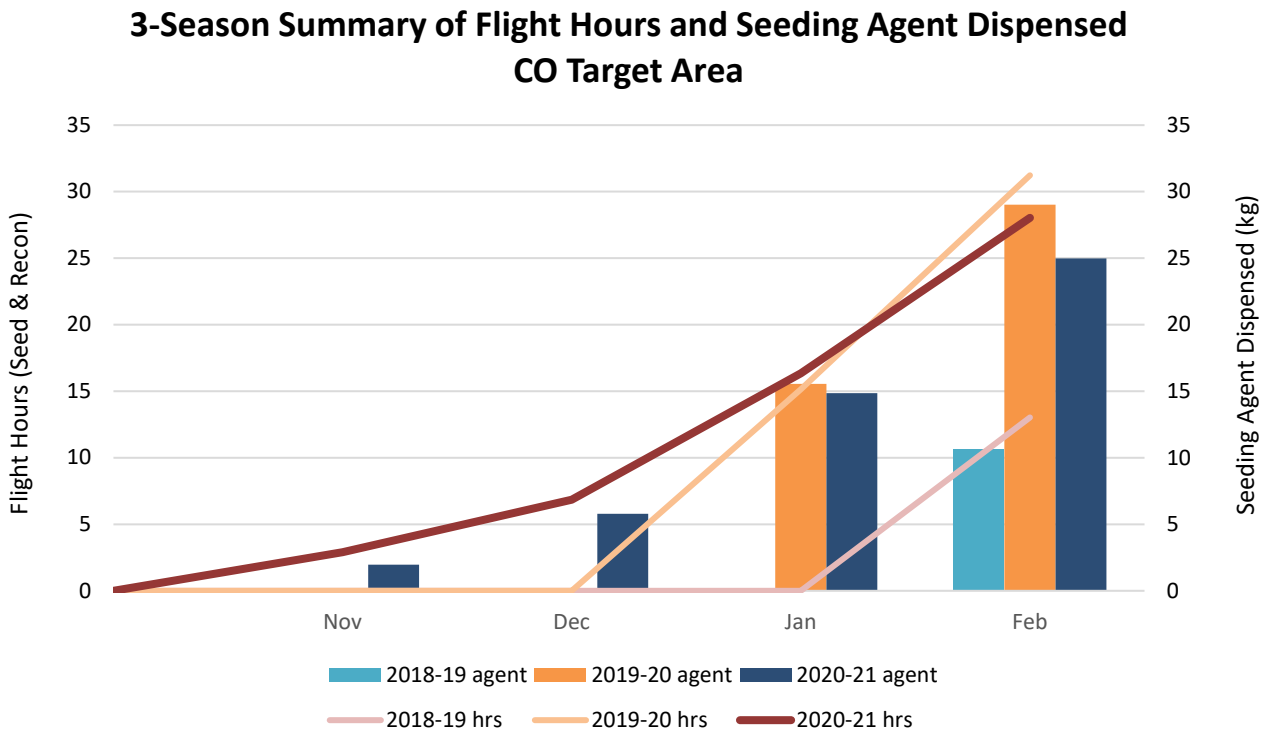


Figure 31. 3-Season Summary of Flight Hours and Seeding Agent Dispensed for the Colorado Target Area (Never Summer Mountain Range).

7 CONTRACTOR'S FINAL REMARKS

The 2020-2021 winter season was Weather Modification International's third 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 terrain, base of operations, and Air Traffic Control allowed safe, effective operations. For the second season in a row, WMI provided a King Air B200 due to aircraft availability. The King Air B200 aircraft provided excellent endurance for extended seeding flights, many of which lasted for five hours or more and some over six hours, due to increased fuel capacity. Airframe icing was also less of a factor due to the greater performance of the B200. 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 crew safe during the ever-changing weather conditions. The use of ejectable flares was a critical component of the program's success, and should be continued in subsequent seasons.

Figure 32. The Sierra Madre terrain below is visible between cloud thin layers on 30 January 2021. Prior to this image, seeding conditions were optimal and 252 ejectables were expended. Photo by Kirk Hamilton.

Annual snowpack for the region was near normal to slightly above normal. This suggests that the number of seeding opportunities observed this season loosely represents what can be expected in a typical season. During the 2020-2021 season, meteorology and pilot staff focused efforts on utilizing project resources to target the most promising clouds in order to maximize the benefits of the program.

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