Annual Cloud Seeding Report

Northern Utah Aerial Program

2023-2024 Winter Season

Prepared For:

State of Utah, Division of Water Resources

Prepared By:

Todd Flanagan

North American Weather Consultants, Inc.

8180 S. Highland Dr., Suite B-2

Sandy, Utah 84093

June 2024

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Northern Utah Aerial Program (NUAP) had its inaugural season during the winter of 2023-24, beginning in early November 2023, and continuing through April 15, 2024. A Cessna Chancellor C414 twin-engine plane was dedicated to the program, equipped with both wing-fixed Burn-In-Place (BIP) flares along with a belly rack for which ejectable flares could also be used. The plane was based at the Logan-Cache Airport in northern Utah and was responsible for aerial-based cloud seeding to complement the various ground-based seeding programs in northern Utah.

The 2023-24 season was active, with twenty-nine (29) storm events occurring in northern Utah during the five-month season. Of these, fourteen (14) flights occurred over ten storm events during the winter. Storms were distributed relatively evenly across the season, with one significant “dry period” during December. A total of 127 silver iodide (AgI) BIP flares were used for seeding, totaling 2540 g of AgI; additionally, 65 AgI ejectable flares were used for seeding, totaling 195g of AgI. Many storm events during the season contained one or more severe hazards (severe turbulence, moderate to severe icing, lightning) that prompted “no-fly” or “temporary no-fly” decisions, which hindered seeding operations. In contrast to the Southern Utah Aerial Program, there were no pre-established flight tracks for the NUAP program, but instead they were developed on a storm-by-storm basis taking various atmospheric parameters into account (e.g., wind flow, moisture availability).

As this was the first year of aerial seeding operations, no statistical or numerical analysis was completed due to lack of data; it is believed that after several years of aerial seeding are completed, initial statistical analysis relating to a target/control comparison and/or streamflow analysis could be undertaken and evaluated to ascertain the prospect of the pilot program becoming operational. Analysis is also complicated by the fact that most of these areas are already included in ground-based seeding programs.

With the conclusion of the season, a look back at all aspects of the program and how well they did or did not work will take place. Recommendations for the program going forward are presented at the end of the report.

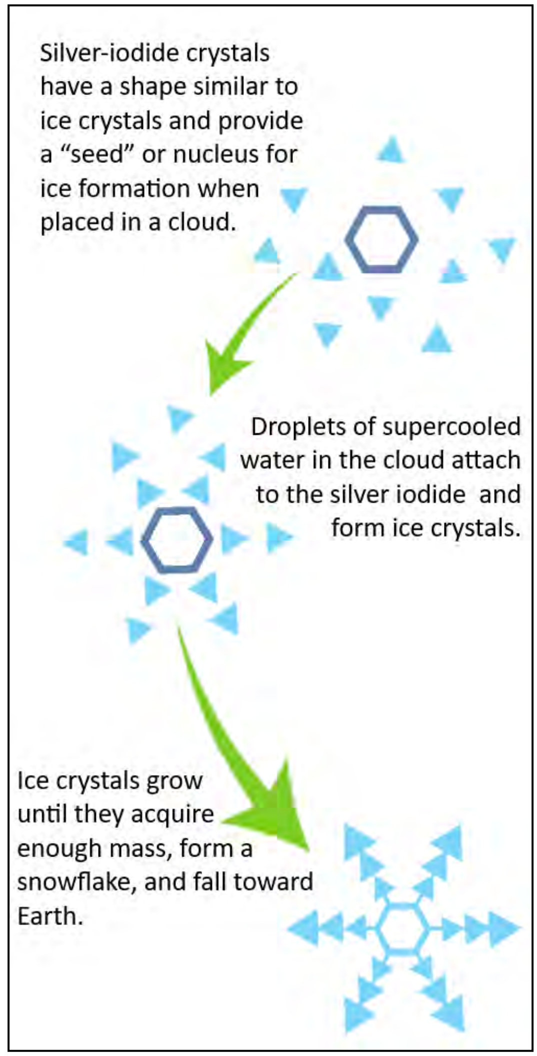
WEATHER MODIFICATION

The Science Behind Cloud Seeding

The Science

The cloud-seeding process aids precipitation formation by enhancing ice crystal production in clouds. When the ice crystals grow sufficiently, they become snowflakes and fall to the ground.

Silver iodide has been selected for its environmental safety and superior efficiency in producing ice in clouds. Silver iodide adds microscopic particles with a structural similarity to natural ice crystals. Ground-based and aircraft-borne technologies can be used to add the particles to the clouds.

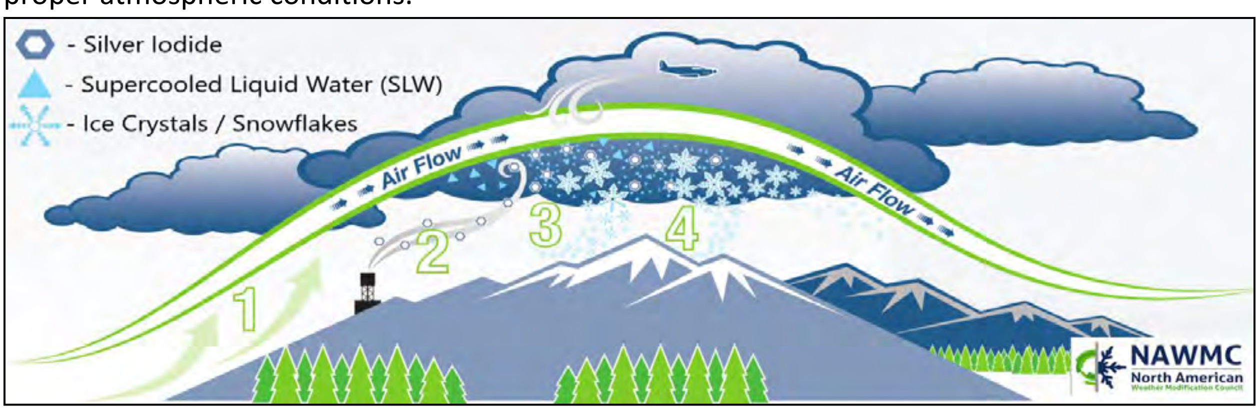


Safety

Research has clearly documented that cloud seeding with silver-iodide aerosols shows no environmentally harmful effect. Iodine is a component of many necessary amino acids. Silver is both quite inert and naturally occurring, the amounts released are far less than background silver already present in unseeded areas.

Effectiveness

Numerous studies performed by universities, professional research organizations, private utility companies and weather modification providers have conclusively demonstrated the ability for Silver Iodide to augment precipitation under the proper atmospheric conditions.



STATE OF THE CLIMATE

Every ten years, the National Oceanic and Atmospheric Association (NOAA) releases a summary of various U.S. weather conditions for the past three decades to determines average values for a variety of conditions, including, temperature and precipitation. This is known as the U.S Climate normal, with a 30-year average, representing the "new normal" for our climate. These 30-year normal values can help to determine a departure from historic norms and identify current weather trends.

The current 30-year average ranges from 1990 – 2020. Images in Figures 1 and 2 show how each 30-year average for the past 120 years compares to the composite 20th century average for temperature and precipitation. For the western U.S., the 1990-2020 average show much warmer than average temperatures, in comparison to the 100-year 20th century average. When comparing precipitation for the past 30 years to both the previous 30-year average and the 1901-2000 average, the American Southwest (including portions of Utah, Arizona, California and Nevada) has seen as much as a 10% decrease in average annual precipitation. Figure 3 shows the mean annual precipitation for the state of Utah based on 30-year period from 1991-2020.

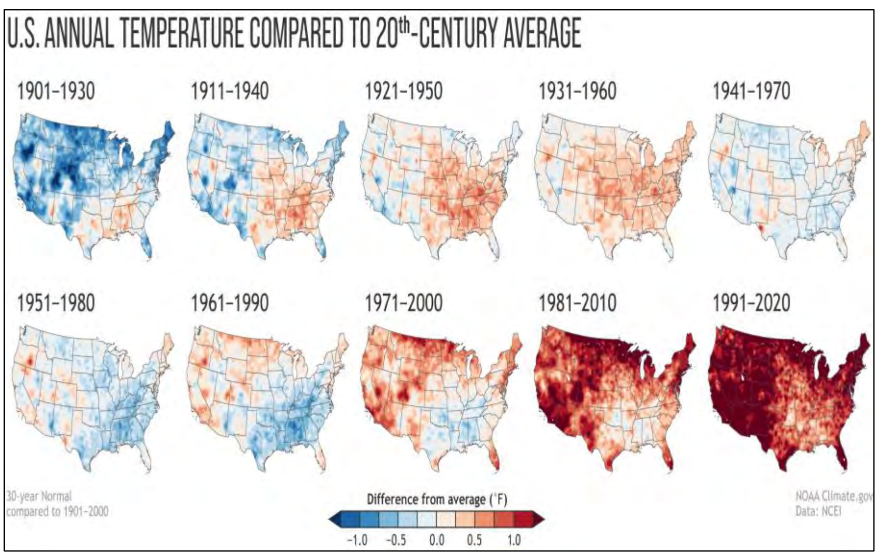


Figure 1. **U.S. Annual Temperature compared to 20th-Century Average**

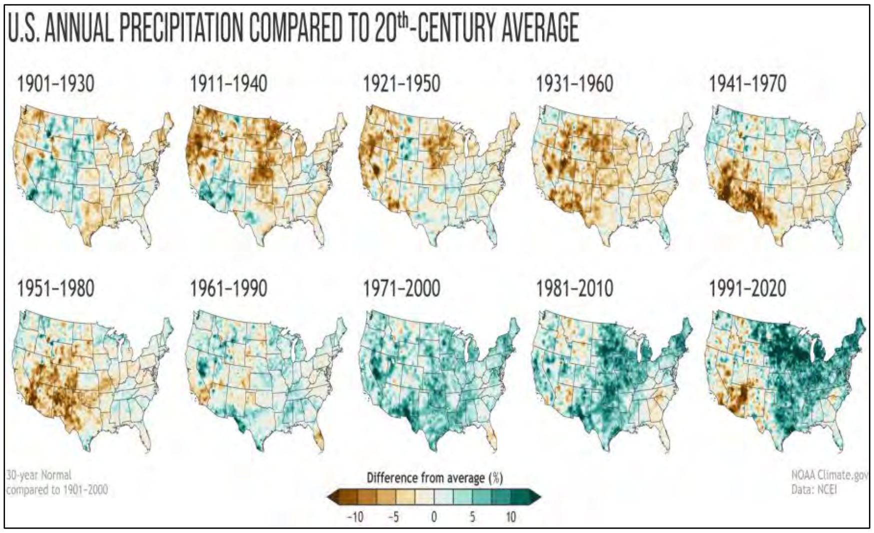


Figure 2. **U.S. Annual Precipitation compared to 20th-Century Average**

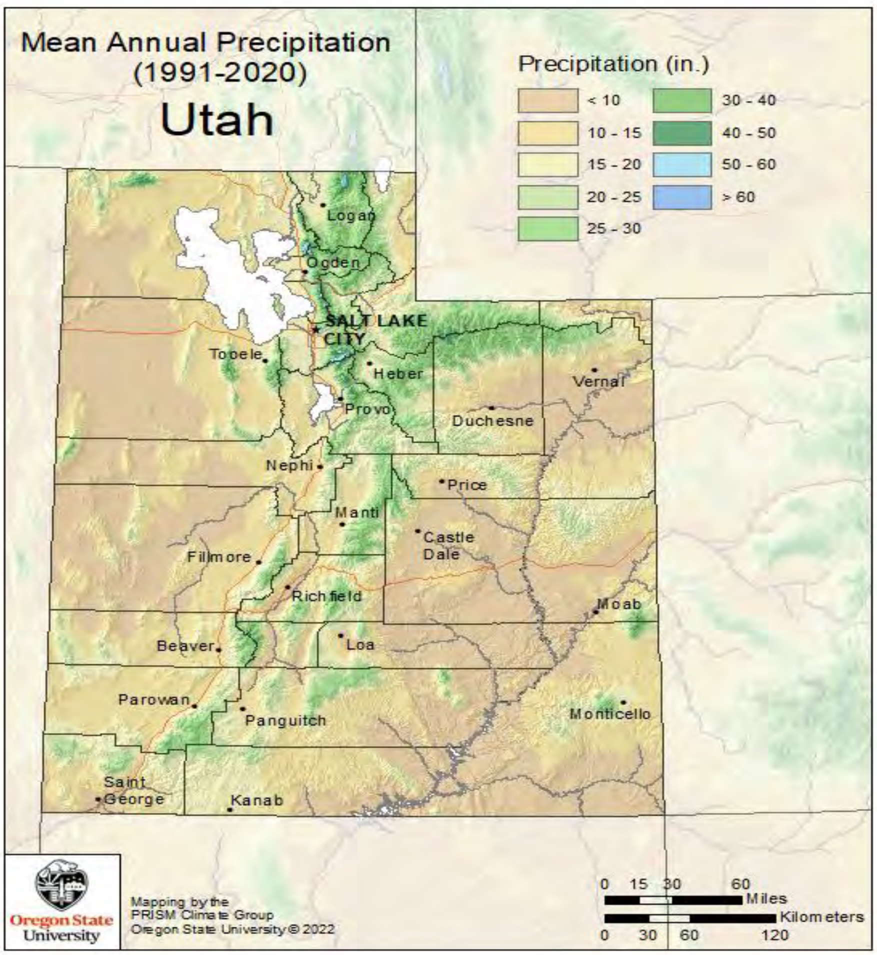


Figure 3. **Mean annual precipitation for the state of Utah based on 30-year period from 1991-2020.**

1.0 INTRODUCTION

Cloud seeding in Utah has a long history, having been conducted in the state since the 1950s. North American Weather Consultants (NAWC) has been running programs to augment snowpack in Utah since the 1970s, primarily through the use of ground generators that disperse silver iodide particles and, utilizing upslope flow along the foothills and higher elevations, are carried into clouds that will ultimately produce ice crystals and snow. This method has worked reasonably well, with estimations of a 5-15% increase in snowpack and precipitation for the various programs in the state.

In 2022 NAWC entered discussions with the State of Utah's Division of Water Resources (Utah DWR) regarding the potential for aerial cloud seeding to be conducted in the state to complement the ground-based seeding efforts. NAWC has conducted aerial programs outside of Utah, in Idaho with the goal of increasing snowpack and snowfall, and in California to promote additional snowfall in the Sierra Nevada range as well as to promote additional rainfall for some coastal regions, primarily in Santa Barbara County. In developing a plan for aerial seeding in Utah, several locations were looked at and their prevailing winter weather conditions were taken into consideration. From this, it was determined that a base in the southern part of the state, which is climatologically warmer than other parts of Utah, would be favorable. St. George was viewed as a good candidate for basing aircraft as snow and ice in this area is uncommon, a decent-sized airport exists there, and it would provide relatively quick access to the target areas already in place for ground-based seeding operations.

After the inaugural season of the Southern Utah Aerial Program, discussions ensued once again with Utah DWR regarding an expansion of the aerial seeding effort, and from this a second program was developed mimicking most of the design of the Southern Utah Aerial Program, with efforts to be focused across several of the northern Utah mountain ranges where ground-based seeding programs are also in place. Flight tracks were suggested, although given some differences between northern and southern Utah, it was determined that flight tracks would not be fixed but rather determined with each storm event that could be successfully and safely seeded.

Through an agreement with Utah DWR wherein cost sharing was enabled, a pilot program was proposed. The 2023-2024 winter season was the first year of this program, beginning in early November 2023, and continuing through April 15, 2024. The pilot and aircraft were based in Logan. This report will discuss the design, implementation and operation of the Northern Utah Aerial Program (NUAP) for the 2023-2024 season.

2.0 PROJECT DESIGN

The Northern Utah Aerial Program is conducted to affect various mountain ranges in northern Utah, among them the Wasatch, Bear River Range and Uintas. The target area along with sample flight tracks is depicted in Figure 2.1. It is important to note that, unlike the Southern Utah Aerial Program, there are no set standard tracks for the Northern Utah Aerial Program, but instead tracks are determined on a storm-by-storm basis. Airborne seeding capabilities were used, with the aircraft operated from the Logan-Cache Airport (LGU) in Logan. The program objective was to seed all suitable storm systems affecting the target area during the period of November 15, 2023, through April 15, 2024, except if precluded on a storm-by-storm basis by established suspension criteria. This section provides an overview of the project design; more information regarding the various project components is provided in Section 3 of this report.

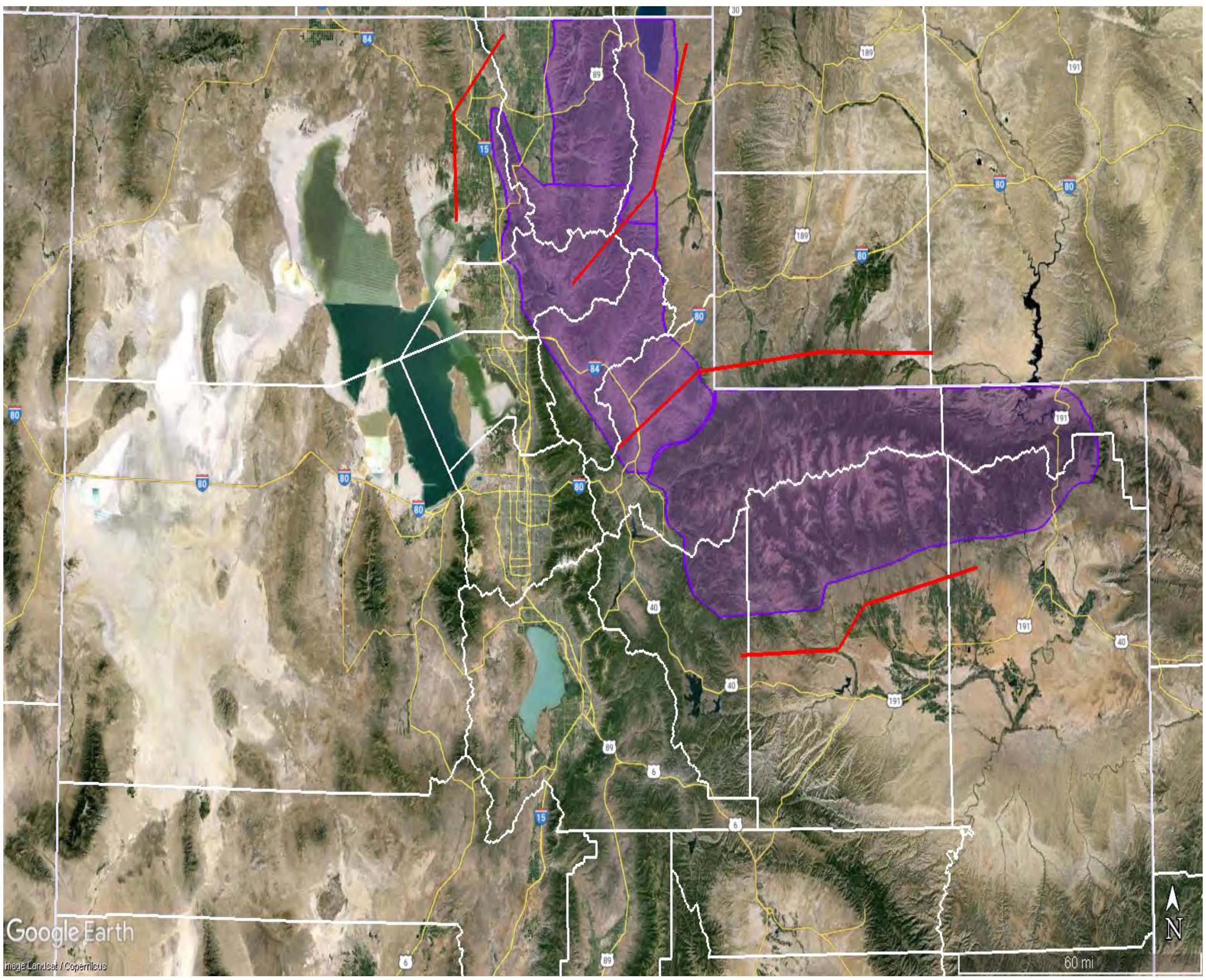


Figure 2.1. Northern Utah Aerial Program target areas, with potential/sample aerial seeding tracks in red.

2.1 Project Design Considerations

Both research and operational programs in weather modification have been conducted in the United States and a number of other countries dating back to the 1950's. This field has experienced its fair share of controversy. The scientific community is still somewhat divided regarding the efficacy of precipitation augmentation because precise quantification of the effects (at least at strict laboratory experimentation levels) is difficult, given that the typical effects are relatively small compared to the natural variability of precipitation. The types of precipitation augmentation programs that find the greatest acceptance are winter orographic (mountainous) programs. NAWC has and continues to operate several of these programs, with a long history of cloud seeding for precipitation augmentation and evaluations of seeding effectiveness.

Several professional societies have adopted capability or position statements regarding weather modification programs. The principal societies or associations that have existing weather modification statements include:

- The Weather Modification Association (WMA)
- The American Meteorological Society (AMS)
- The World Meteorological Organization (WMO)
- The American Society of Civil Engineers (ASCE)

From the organizational statements, the following key points regarding the status of winter orographic seeding emerge:

- Of the primary categories of cloud seeding for precipitation increase, seeding of winter orographic storm systems seems to offer the best prospects for increasing precipitation in an economically viable manner.
- Strong (albeit largely non-randomized) statistical evidence exists for (winter) seasonal increases of the order of 5% to 15%.
- A growing body of evidence from focused physical studies is confirming some key steps in the weather modification process, in support of the statistical evidence.
- Additional research is recommended/encouraged. It is recognized that additional applied research can shed much valuable light on the physical processes involved, leading to improved opportunity recognition and intervention, resulting in more optimum augmentation operations, especially given technological advancements in observational systems and computer modeling.
- Accurately quantifying the effects of cloud seeding programs remains a challenge.

NAWC's philosophy is that the design of our operational programs should be based upon prior research programs that provided positive indications of increases in precipitation, to the extent that the research results are considered to be representative of the operational programs' conditions. We have done so for the Northern Utah Aerial Program. Knowledge gained from other research programs in the West regarding the structure of winter storms and characteristics that are amenable to precipitation enhancement via cloud seeding, has been incorporated into the Northern Utah Aerial Program design. NAWC's extensive previous experience with other seeding project design and operations has also been brought into play.

2.2 Northern Utah Aerial Seeding Project Design

We believe that the best project design for a winter cloud seeding program for the Northern Utah Mountains to be one that incorporates, as much as possible, the core elements of the knowledge gained in earlier research in the mountainous west, plus insights from previous successful operational programs. The combination of ground-based (separate program) and airborne seeding modes should constitute the optimized method for capitalizing on the seeding potential for the area. NAWC operations focus on "selective seeding," i.e., they are focused on the specific storm periods that exhibit the characteristics that present the best potential for precipitation augmentation via cloud seeding. This approach provides the potential for the greatest precipitation augmentation effect at the most reasonable cost, thus constituting an excellent value to the project sponsors. Airborne seeding provides the ability to seed in some situations not favorable for ground-based releases, with guidelines shown below.

Winter Aerial Seeding Criteria

- Storm precipitation of ≥ 0.25 inches (SWE) is anticipated in the Northern Utah Mountains.
- Cloud bases should be below the mountain barrier summit heights of 9-11 kft.
- In stratiform cloud conditions, the -5°C level ideally should be below, but no more than 1-2 kft higher than, the mean barrier height of ~ 9-11 kft.
- Ideally, the cloud top temperature (CTT) of the stratiform clouds producing precipitation should not be significantly colder than -15°C. Higher layered clouds not involved in the precipitation process can be colder. As a rule of thumb, a distance ≥ 2000 feet between cloud layers should provide adequate separation in that determination.
- The aircraft can be flown at ~ -5°C, so that nucleation can be prompt. Flights can be conducted at colder temperatures to maintain safe altitudes and FAA minimum allowable altitudes if the -5°C level is exceedingly low. If heavy airframe icing is experienced, the flight altitude can be lowered to warmer temperatures, but with careful consideration of the underlying terrain and only with ATC approval.
- Use the estimated winds in the layer from the seeding level to the -25°C level as guidance regarding which track or portion of track to use. In stable/stratiform conditions, the goal is to seed about 45-60 minutes upwind of the mountain target areas. In more convective-like situations, the goal is to seed about 40 minutes upwind of the mountains.

The project design, used by NAWC, has aircraft seeding of storms as they approach the Northern Utah mountains, with aircraft flights at the 0°C to -5°C temperature level in-cloud, allowing the seeding material to activate at the warmest possible temperatures and mix and disperse in-cloud. Aerial seeding targets the pool of supercooled liquid water (SLW) that develops in-cloud during stormy periods over the windward slopes of mountain barriers. The SLW is the critical constituent that is converted (by the seeding material) to ice particles that can take on additional moisture and grow to sufficiently large sizes for fallout into the various watersheds. The responsibility of the project meteorologist is to identify the seeding opportunities and then to place the seeding material into the proper cloud regions to achieve the desired augmentation of the precipitation process, all within a variety of evolving temperature, moisture and wind situations during winter storms. This seeding decision-making is dynamic, since cloud, wind, and temperature conditions continually change during the passage of a winter storm over the target area.

The core operational project period will be early to mid-November through mid-April, with the possibility of extension periods at either end of the core period as may be appropriate due to water supply conditions.

3.0 EQUIPMENT, PROCEDURES AND PERSONNEL

Seeding operations during the 2023-24 winter season were conducted using a seeding aircraft during the period from early November 2023 through April 15, 2024. The following sections describe the equipment, procedures and personnel used in the operation of the cloud seeding project.

3.1 Weather Radar

NAWC utilized the National Weather Service (NWS) NEXRAD radar sites at Salt Lake City (KMTX), Pocatello, ID (KSFX) and Grand Junction, CO (KGJX) for the operation of the aerial cloud seeding program as all provide good coverage of the target area. The radars provide valuable information regarding the structure, intensity, movement, and evolution of precipitating cloud systems in addition to wind speed and direction within the precipitating echoes. The radar's dual-polarization capabilities allow the radar to measure targets using both horizontal and vertical waves, providing additional information about hydrometeors and non-weather targets. Real-time radar data are key in operational decision-making for seeding modes and tracks (to help optimize the seeding releases). The NWS is responsible for all the necessary support for the radar: operation, calibration, spare parts, and maintenance.

3.2 Seeding Aircraft and Tracking Systems

NAWC provided a dedicated Cessna Chancellor C414 twin-engine plane as the seeding aircraft for the project. The aircraft was equipped with wing-mounted flare racks to hold burn-in-place flares, and also a belly rack which holds ejectable flares. The plane was housed in a hangar at the Logan-Cache Airport (LGU) at Logan in far northern Utah. Figure 3.1 shows the seeding aircraft used for the program.

Figure 3.1. **NAWC Cessna Chancellor C414 cloud seeding aircraft that was stationed at Logan-Cache Airport in northern Utah.**

For the 2023-24 season, NAWC obtained real-time flight track information from FlightAware, an internet-based aircraft-tracking website for IFR flights; in earlier years, FlightAware had significant problems with occasional long delays in providing information. Over the past couple of years, FlightAware has made substantial improvements to its web service, with position updates occurring every 10-30 seconds. FlightAware also shows a vertical cross-section of the flight path, allowing for a view of the altitude changes during the flight, which are important in times where the plane had to descend to shed ice in times of heavy icing. An example of this type of image is shown in Figure 3.2. During operations, radar and aircraft location data were acquired and archived. The radar-aircraft position-display systems provided useful and reliable information for the conduct of seeding operations. A ForeFlight Sentry Plus ADS-B Receiver was purchased at the start of the season to provide crucial information for the pilot – via an iPad – including current and live weather data such as radar, winds aloft, icing, turbulence and other data transmitted by the NWS and FAA along with GPS and flight data recorder.

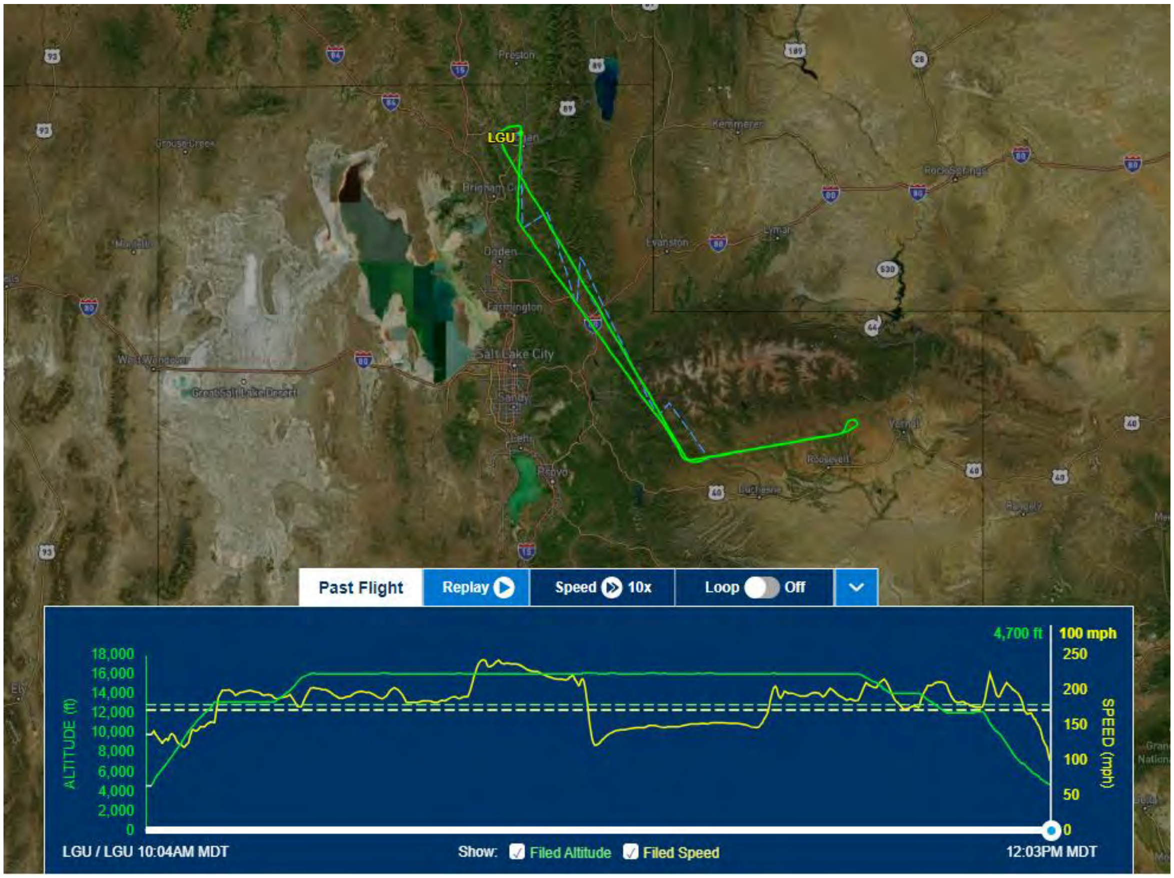


Figure 3.2. Cumulative flight track from FlightAware.com from a seeding flight over northeastern Utah on March 30, 2024. Bottom quarter of image shows altitude (green line) and speed (yellow line) during the flight.

NAWC established set flight tracks for use on the Southern Utah Aerial Program, but with the design for the Northern Utah Aerial Program, a different approach was taken as there are more restrictions in place across northern Utah given the high concentration of the population along the Wasatch Front along with some military airspace restrictions. Suggested flight tracks were developed from looking at past storm events wherein different flow regimes would dictate the location of possible flights; these are shown in Figure 3.3. However, unlike with the design of the Southern Utah Aerial Program, the flight tracks were left as an “open-ended” entity and would be determined on a storm-by-storm basis, with modifications to the suggested tracks allowed as long as safety was not compromised.

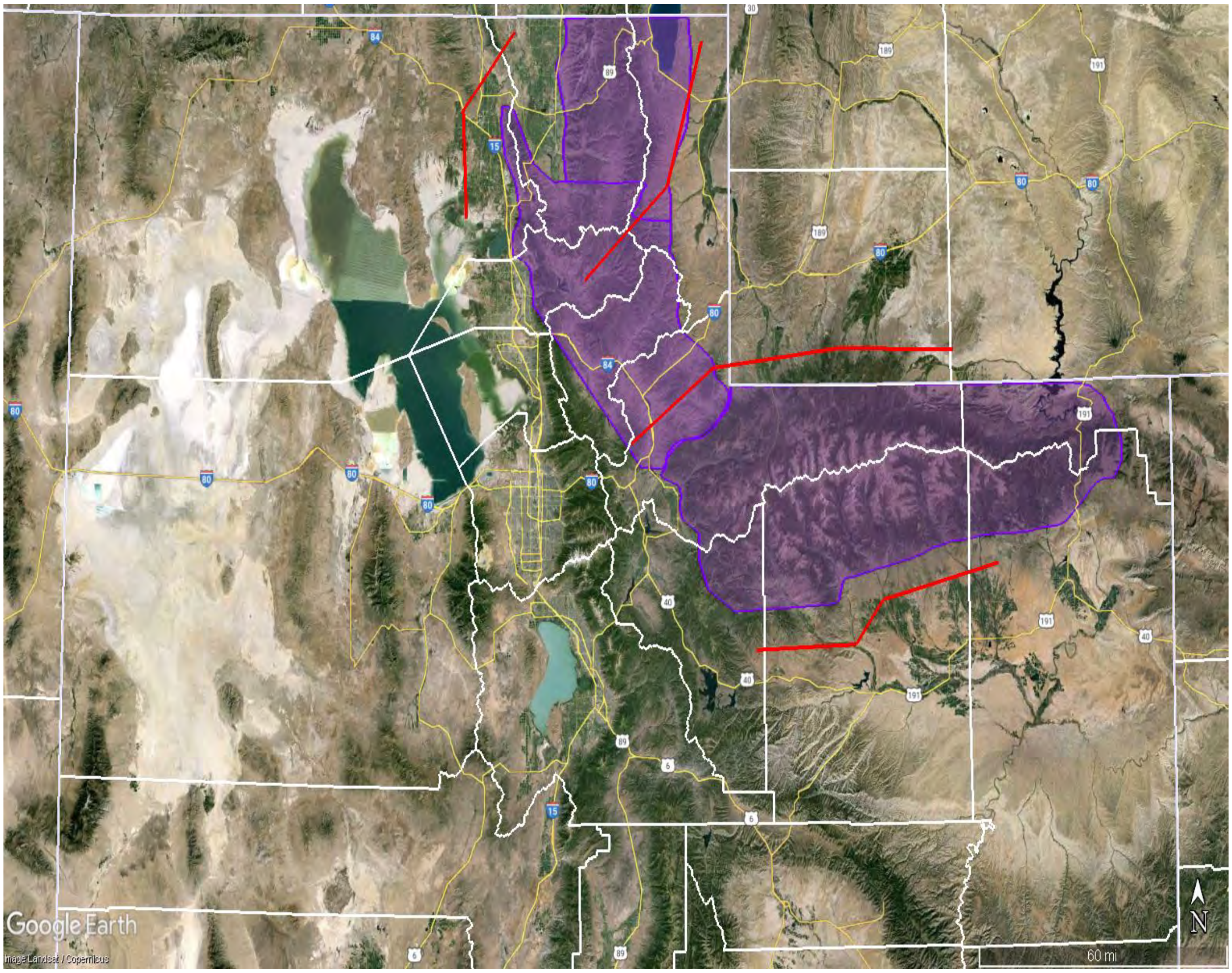


Figure 3.3. **Sample/suggested seeding flight tracks for the Northern Utah Aerial Program. Purple areas indicate the intended target area, covering portions of the Wasatch, Bear River and Uintas mountain ranges.**

3.3 Operations Center

The project meteorologist, working remotely from their residence in St. George utilized a personal computer and internet access to conduct all facets of program operation. Operational support was available from the main office in Sandy. Text messaging and phone calls were the main form of communication between pilot and meteorologist, although unlike with the Southern Utah Aerial Program, texting did not work during flights for the NUAP.

3.4 Weather Forecasts and Meteorological Data Acquisition

Weather forecasting and direction of cloud seeding operations were conducted by the project meteorologist. Project forecast information was communicated to the pilot and other project staff via telephone or e-mail and updated as necessary. Relevant meteorological data/images were captured and archived as needed, for documentation of storm episodes.

3.5 Suspension Criteria

Cloud seeding suspension criteria were implemented by NAWC to serve as safeguards to protect against claims of negligence, and the loss of property and/or life due to the cloud seeding program. Snowpack, streamflow and reservoir conditions are assessed as part of the suspension considerations. Statements issued by the National Weather Service (NWS) can also play an important role in the suspension criteria. NWS public safety notices are issued in the form of advisories or watches, neither of which necessarily restricts program operations. However, any type of NWS "*warning*" issued for the near region, outside of Winter Storm Warnings, results in temporary suspension of seeding operations for the period during which the warning is in effect. The project meteorologist also had the authority to suspend operations in the case of development of weather conditions that were considered dangerous to project personnel or the public, even if an official NWS warning had not yet been issued. Appendix A gives more in-depth information regarding suspension criteria for the program.

3.6 Personnel

The following personnel were involved in the management and conduct of the 2023-24 Northern Utah Aerial Program:

North American Weather Consultants

Mr. Garrett Cammans, President, Project Director
Mr. Todd Flanagan, Project Manager/Meteorologist
Mr. Cole Osborne, Meteorologist
Mr. David Yorty, Meteorologist

Seeding Operations and Atmospheric Research

Mr. Gary Walker, President
Mr. Adam Olsen, On-site Seeding Pilot

4.0 WEATHER DATA AND MODELS USED IN SEEDING OPERATIONS

Meteorological information is acquired online from a wide variety of sources, including some subscriber services. This information includes weather forecast model data, surface observations, rawinsonde (weather balloon) upper-air observations, satellite images, radar information and weather cameras. NAWC's meteorologists have access to all meteorological products from their homes, allowing continued monitoring and conduct of seeding operations outside of regular business hours. This wide variety of available products and information helps NAWC meteorologists to determine when conditions are appropriate for cloud seeding.

Figures 4.1 – 4.6 show examples of some of the available weather information that was used in this decision-making process during the 2023-24 winter season. These include weather radar images, satellite images, upper air wind and temperature maps, rawinsonde/weather balloon soundings and aviation hazards. Global and regional forecast models are a cornerstone of modern weather forecasting, and an important tool for operational meteorologists. These models forecast a variety of parameters at different levels of the atmosphere, including winds, temperatures, moisture, and surface parameters such as accumulated precipitation. An example of a display is shown from the Global Forecast System **(GFS)** model (Figure 4.7). Other models used on a daily basis during the program include but are not limited to the European Center for Medium-Range Weather Forecast **(ECMWF)** model, High-Resolution Rapid Refresh **(HRRR)** model, and North American Model **(NAM)**.

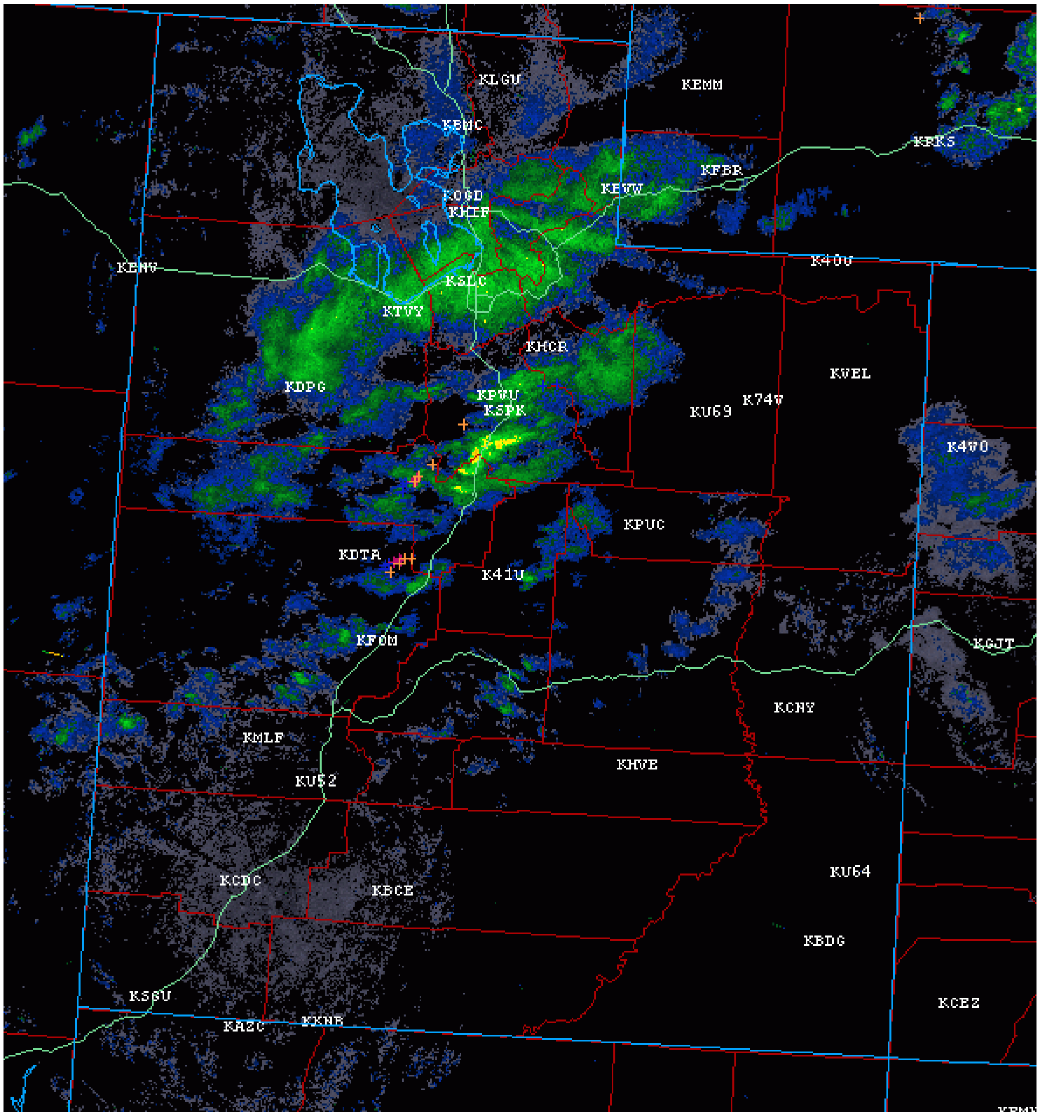


Figure 4.1. **Weather radar image during a storm event/seeding flight over northern Utah on March 28, 2024.**

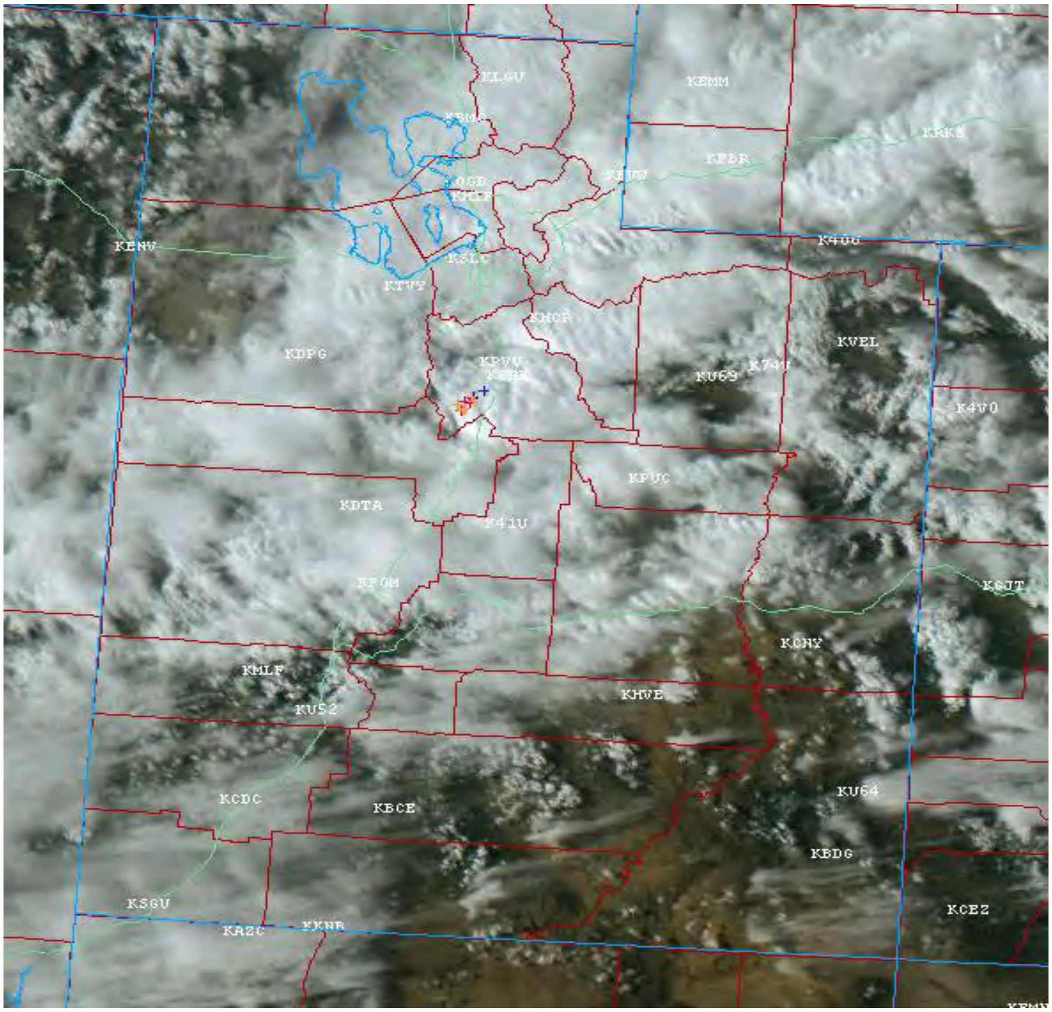


Figure 4.2. **Visible spectrum satellite image on March 28, 2024 at 1631 MDT (2231 UTC).**

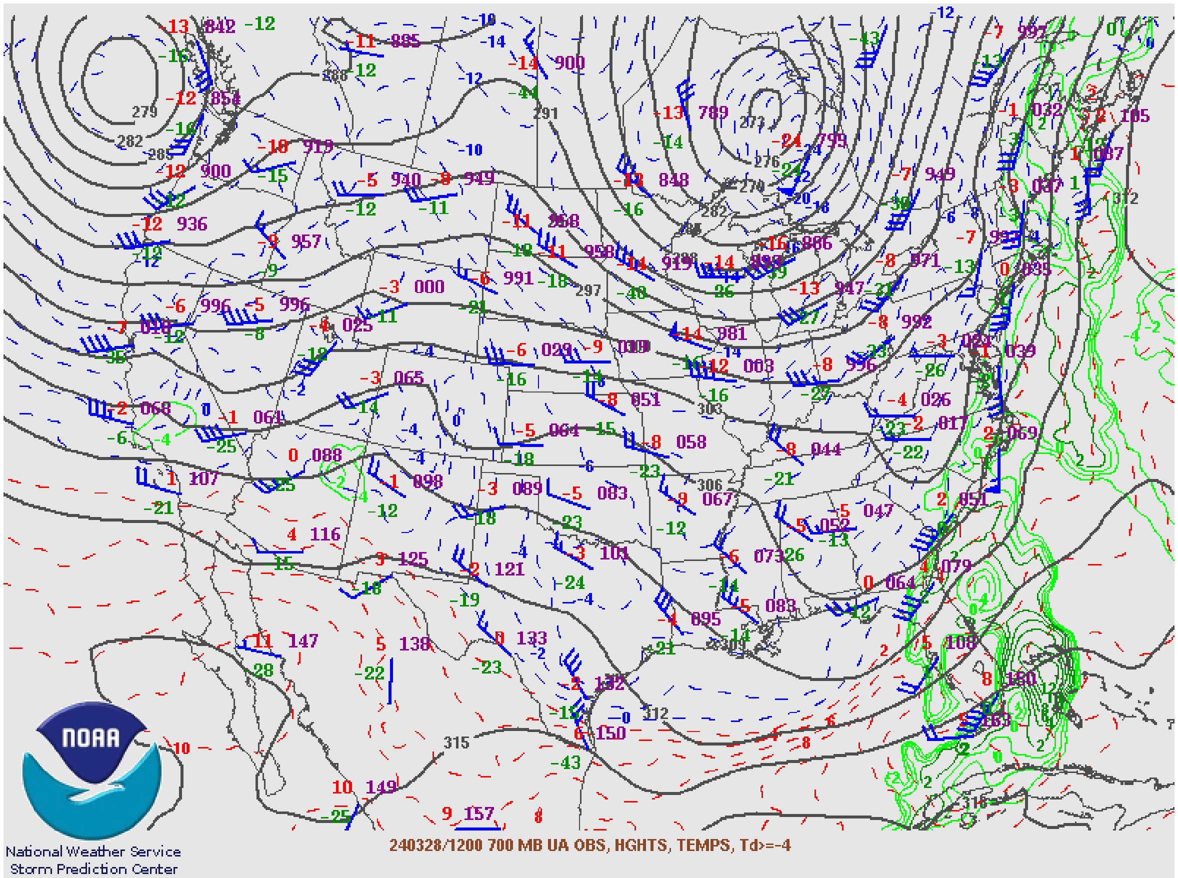


Figure 4.3. **700 mb (approximately 10,000 feet MSL) map valid for 0600 MDT (1200 UTC) on March 28, 2024. Among the more notable map features, contours indicate heights (in decameters) of 700 mb pressure level, red numbers are temperature (°C), green numbers are dewpoints (°C), blue lines with barbs/flags represent wind speed and direction.**

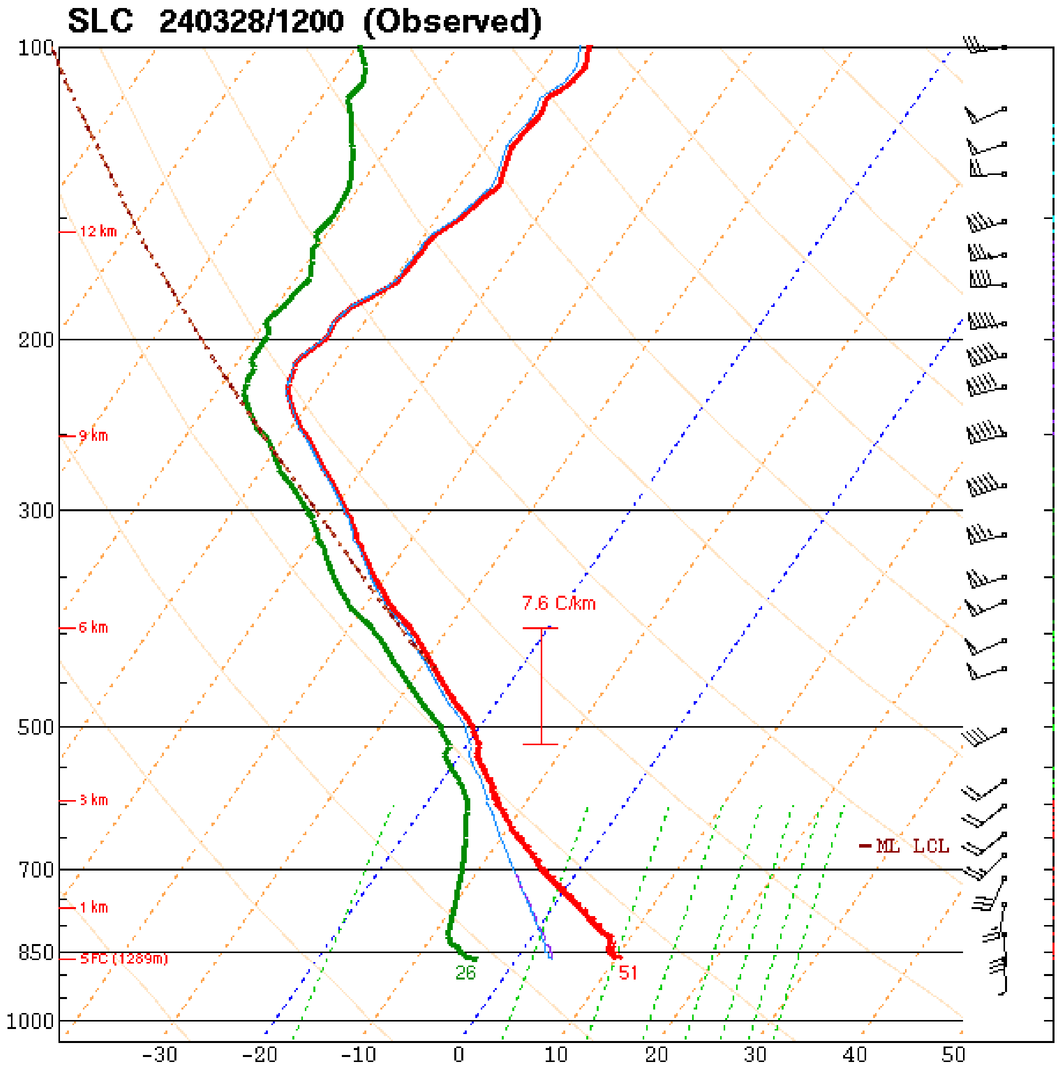


Figure 4.4. **Weather balloon/rawinsonde sounding from Salt Lake City, valid at 12Z/0600 MDT on March 28, 2024 showing temperature (red line), dewpoint (green line) and wind speed/direction (right side barbs) from the surface to 100 mb (approximately 52,000 feet MSL).**

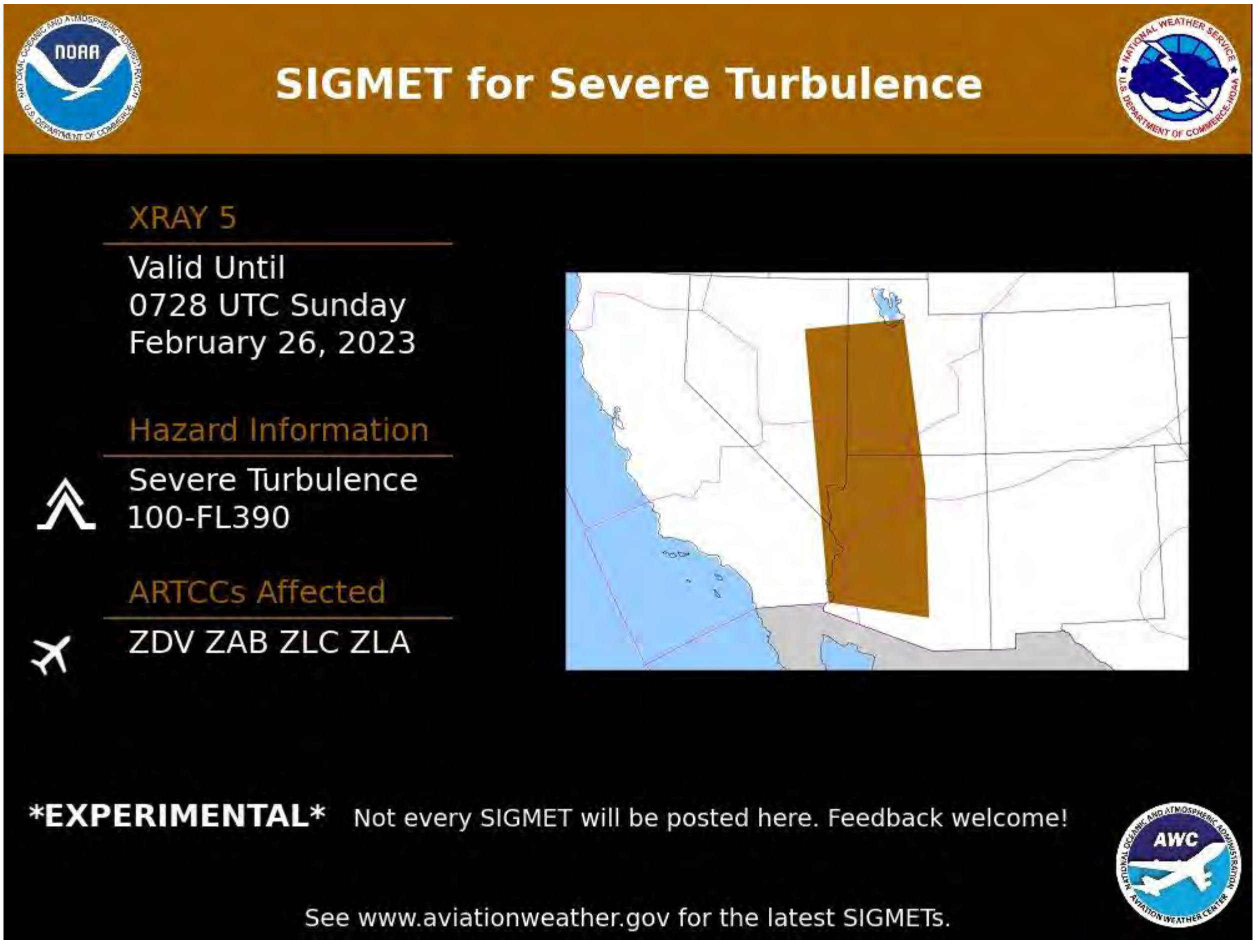


Figure 4.5. **Significant Meteorological (SIGMET) information detailing severe turbulence hazard in the area outlined above on February 26, 2023. Information on SIGMET issuances is available from aviationweather.gov.**

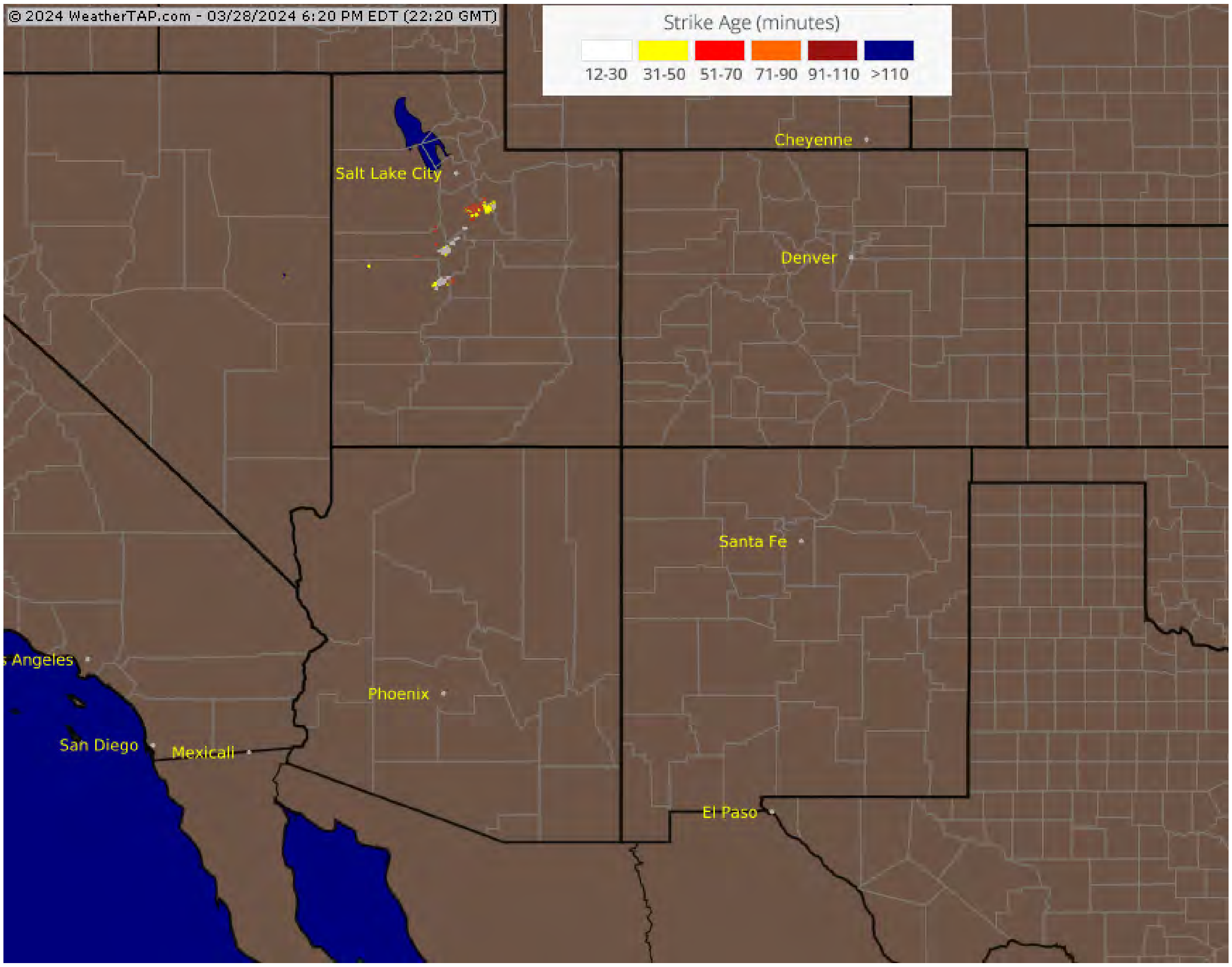


Figure 4.6. **Map showing recent lightning strikes across western United States on March 28, 2024 at 1620 MDT (2220 UTC). Legend shows age of lightning strike via color-coded dots. Courtesy of WeatherTap website, https://www.weathertap.com/ . Lightning is a hazard needing attention with regards to aerial seeding operations.**

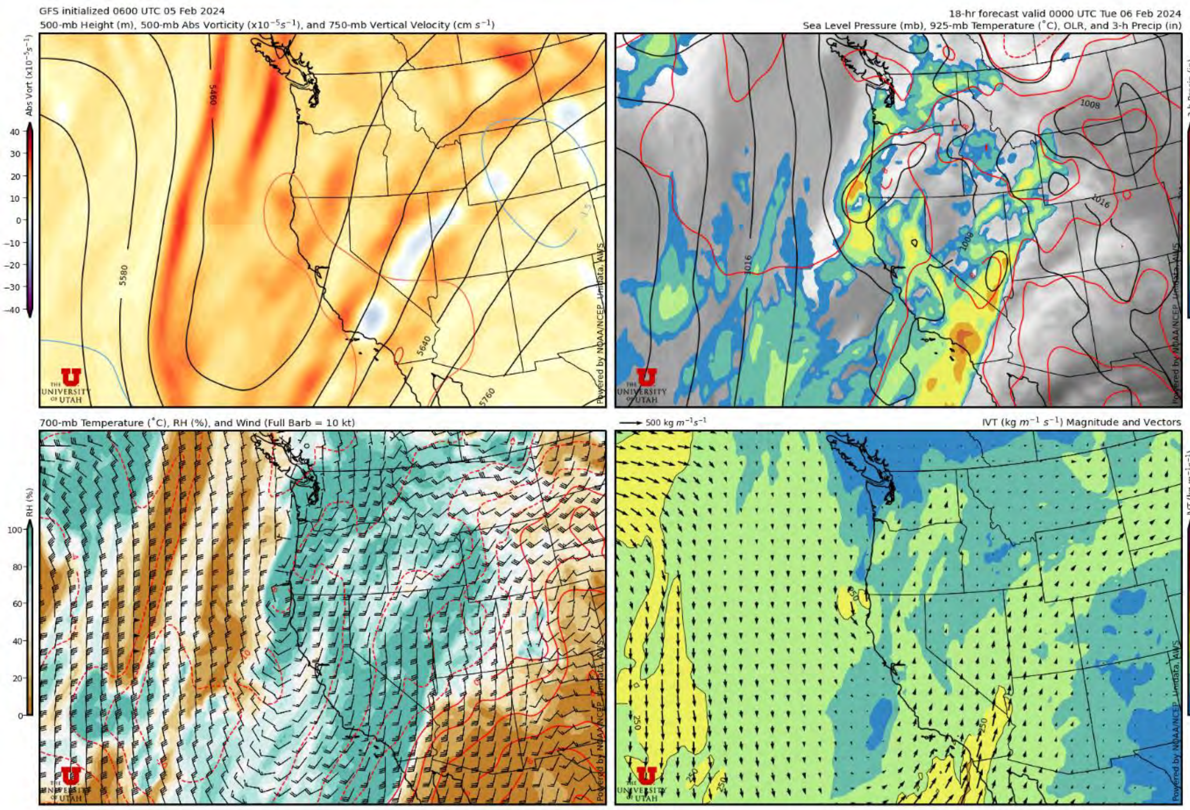


Figure 4.7. **GFS (Global Forecast Systems) forecast data plot for an approaching storm event on February 5, 2024.**

5.0 OPERATIONS

The 2023-24 winter season was fairly busy in terms of the frequency of storm systems that impacted Utah. Near normal to above normal precipitation was recorded statewide. Precipitation in much of the southwestern U.S. was near to above average during the November 2023 – April 2024 period, as shown in Figure 5.1.

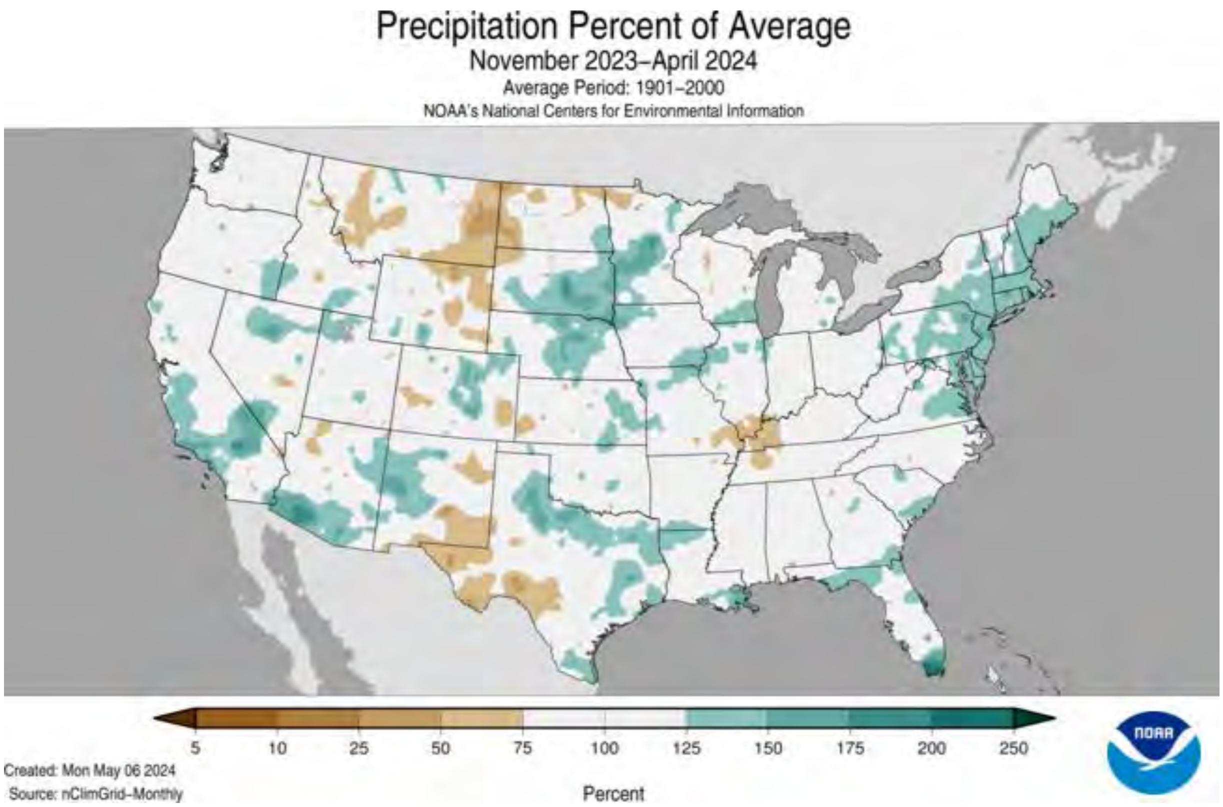


Figure 5.1. November 2023 – April 2024 percent of normal precipitation.

5.1 Operational Procedures

In operational practice, approaching storms were monitored by NAWC utilizing online weather information. If the storm met the seedability criteria presented in Section 2.2, and if no seeding curtailments or suspensions were in effect, a flight was dispatched to fly along a track determined from the prevailing wind flow in place. Seeding continued as long as conditions were favorable and seedable clouds remained over the flight track zones and adjacent target area, albeit with time limits as far as how many flights/total flight hours were allowed per day. Given the orientation and placement of the northern Utah mountain ranges, southwest through northwest wind directions provided the best opportunities to impact larger portions of the target areas.

5.2 Storm Events of the 2023-2024 Winter Season

This section describes the storm events that affected Northern Utah that provided opportunities for aerial seeding operations during the 2023-2024 operational season. Table 5-1 summarizes the flights conducted during the season. A general discussion of the meteorology accompanying each event is given, followed by a description of the seeding operations (if any). Wind directions, when provided, are always reported in the direction from which the wind is blowing (e.g., a southerly wind means the wind is blowing from the south toward the north). Wind speeds are usually reported in nautical miles per hour (knots), with 1 knot equal to 1.15 miles per hour. Figures shown in the storm summaries may include the following:

- Satellite images, including infrared (IR), water vapor (WV), or visible. Infrared images provide information during both the day and night which primarily consists of cloud top temperatures. Water vapor can be useful when determining where mid and upper level dry or moist air exists, and visible satellite images can be helpful for observing cloud structure.
- National Weather Service NEXRAD radar images, showing reflectivity values associated with precipitation near the times when seeding occurred. These images give an indication of the type, intensity, and extent of precipitation during seeding periods. Wind direction and velocity are also observed by the radar through the Doppler feature, which is part of the NEXRAD design. Plots of winds with height in 1000-foot increments are available with a 6-minute time resolution from NEXRAD radars. These displays are called Velocity Azimuth Displays (VAD). Full barbs indicate 10 kt of speed, and half-barbs are 5 kt. A flag indicates 50 kt wind speeds.
- Skew-T upper-air soundings from several locations, including Salt Lake City, UT, Las Vegas, NV and Grand Junction, CO. The skew-T sounding is a plot of temperature, dew point, and winds vs. height, observed by a radiosonde (balloon borne weather instrument). This sounding information is useful for analyzing various parameters of the atmosphere, providing temperature and moisture profiles and convection potential. Soundings are available twice daily at 0500 and 1700 MST. The 700 mb (approximately 10,000 feet) temperatures are frequently reported in the following storm summaries. NAWC typically prefers to see these temperatures at -5°C or colder during seeded periods since silver iodide becomes effective as a seeding agent between -4°C and -5°C.

Table 5-1
Summary of Seeding Flights for 2023-2024

Flight Number	Date	Flares (BIP/Ejec)	Flight Hours
1	November 6	3 / 0	0.80
2	November 19	13 / 0	1.75
3	November 19	8 / 25	1.30
4	January 5	9 / 0	1.23
5	January 6-7	10 / 0	1.25
6	January 13	6 / 0	0.92
7	January 17	15 / 0	2.25
8	February 1	10 / 0	2.57
9	February 5	0 / 0	0.50
10	March 23	10 / 0	1.20
11	March 28	8 / 0	0.98
12	March 28	17 / 15	1.78
13	March 30	18 / 0	1.98
14	March 30	0 / 25	2.02
Totals		**127 / 65**	**20.53**

November 2023

The 2023-24 season for the Northern Utah Aerial Program began in early November. Four storm systems impacted the area during the latter half of the month, two of which saw seeding operations take place with three flights occurring. Figure 5.2 shows precipitation for November expressed as a percentage of normal (based on 1991-2020 normals) for portions of the Four Corners states, including Utah. Most of the state saw below average precipitation, with four exceptions: the central Wasatch Mountains, portions of the Uinta Basin, the Tushar Mountains and the far eastern edge of Zion National Park; these areas saw above normal precipitation.

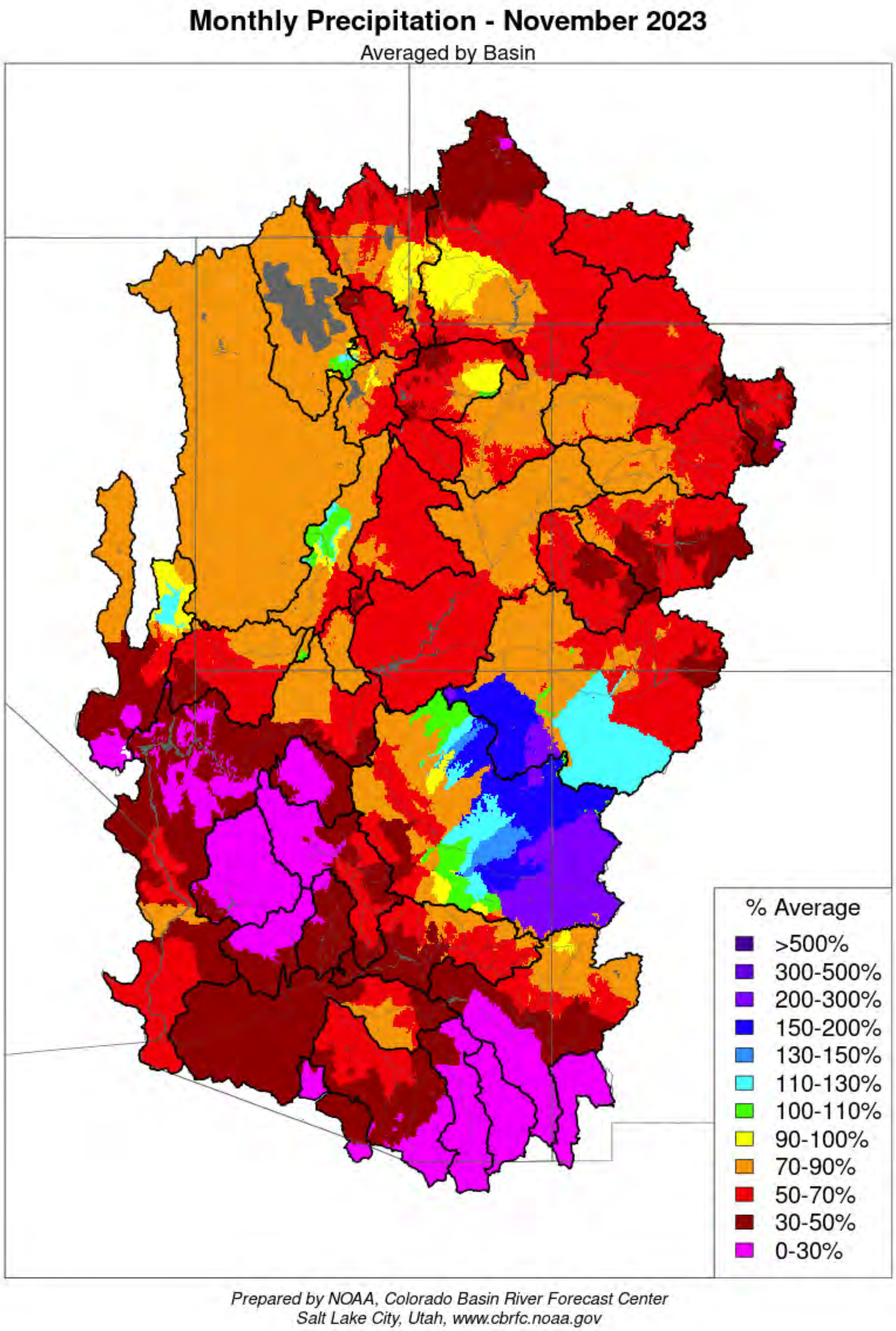


Figure 5.2. **November 2023 precipitation as a percent of average during the month.**

November 6, 2023

An upper level trough of low pressure, with axis oriented from the southern Canadian Prairies southwestward to the central California coast, was approaching from the west during the day. A surface cold front was located from southern Idaho through central Nevada late in the afternoon and was expected to move into northern Utah during the nighttime hours, with frontogenesis expected to increase precip along the front mainly north of Salt Lake City. Warm mid-level temperatures were expected to cool sufficiently behind the front to around -4°C/-5°C, with west to southwest flow 20-35 kt at 700 mb. As the front and associated moisture spread into northern Utah during the evening, a flight plan was developed with a north-south track west of the northern Wasatch Mountains and Bear River Range. Figure 5.3 shows radar imagery across northern Utah at 2205 MST. The plane departed LGU at 2200 MST and arrived at the filed flight altitude of 13,000 feet a short time later. The flight ended up being a short one with a lot of light to moderate turbulence and only pockets of moisture; the pilot reported being in-cloud only a fraction of the time. The plane landed back at LGU at 2249 MST, having flown 0.80 hours and burning 3 burn-in-place (BIP) flares. Figure 5.4 shows the flight data from this event.

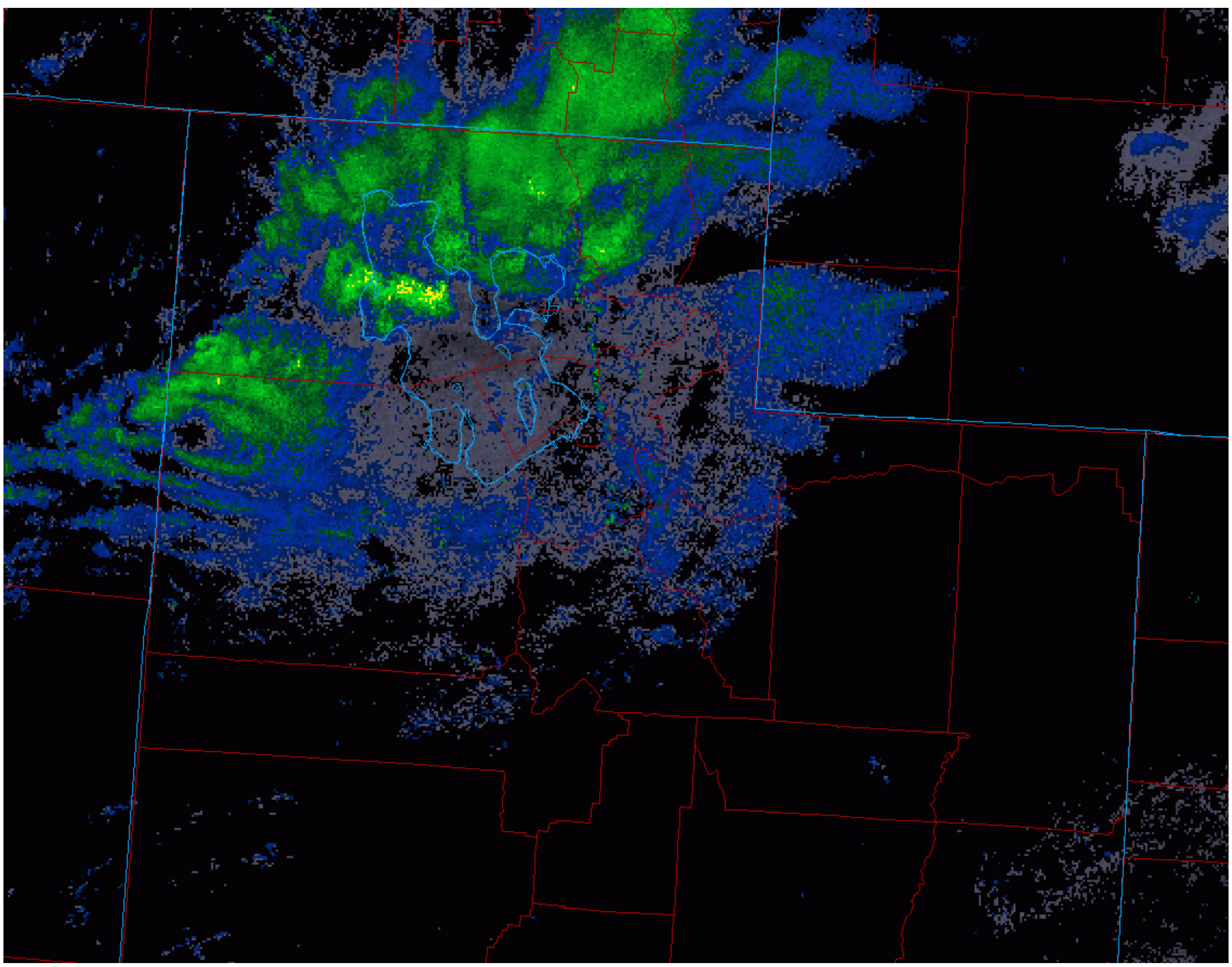


Figure 5.3. Radar imagery from KMTX (Salt Lake City) valid at 2205 MST on November 6, 2023.

Figure 5.4. **Flight track from seeding mission on November 6, 2023. Lower graph indicates altitude of plane (green) and speed of plane (yellow) during flight. Green and blue shading in background is radar image at time of image capture. Courtesy of FlightAware.com website.**

November 19, 2023

A trough of low pressure was approaching Utah from the west and was absorbing energy from a second trough diving southeastward across western Canada. Diffluent flow aloft (e.g., at 500 mb) ahead of the trough was spreading across west-central and southwest Utah, enhancing large-scale lift in those areas. Thunderstorms were occurring in some of these areas but were expected to remain across central and southern Utah. Moisture was spreading across the state with widespread precipitation across the western 2/3 of Utah by early morning. Upper air analysis showed that 700 mb temperatures were around -2°C/-3°C which is a bit warmer than ideal, but mixing within the cloud layer was expected to transport seeding nuclei to colder temperatures. A flight plan was devised, using a track from about the center of the Great Salt Lake northward to the Idaho border, with the northern Wasatch Mountains and possibly Bear River Range as the target area of interest within westerly flow. The plane took off from LGU at 0616 MST and reached altitude a short time later. Radar imagery continued to show plenty of moisture streaming across the area, as shown in Figure 5.5. The pilot flew a couple passes along the flight track before landing back at LGU at 0801 MST, having flown 1.75 hours and burning 13 BIP flares. Figure 5.6 shows the flight track from the first flight. As moisture continued across the area and conditions still appeared favorable for seeding, the plane was refueled, and a second flight was launched using the same track from the first flight. The plane departed LGU at 0958 MST and reached altitude a short time later. Winds aloft at this point had become northwesterly, as shown in the VAD display from the Salt Lake City radar in Figure 5.7. Seeding occurred along the flight track with a few passes being made, before the plane returned to LGU at 1117 MST. A total of 8 BIP flares and 25 ejectables were used for the second flight. The flight track from the second flight is shown in Figure 5.8.

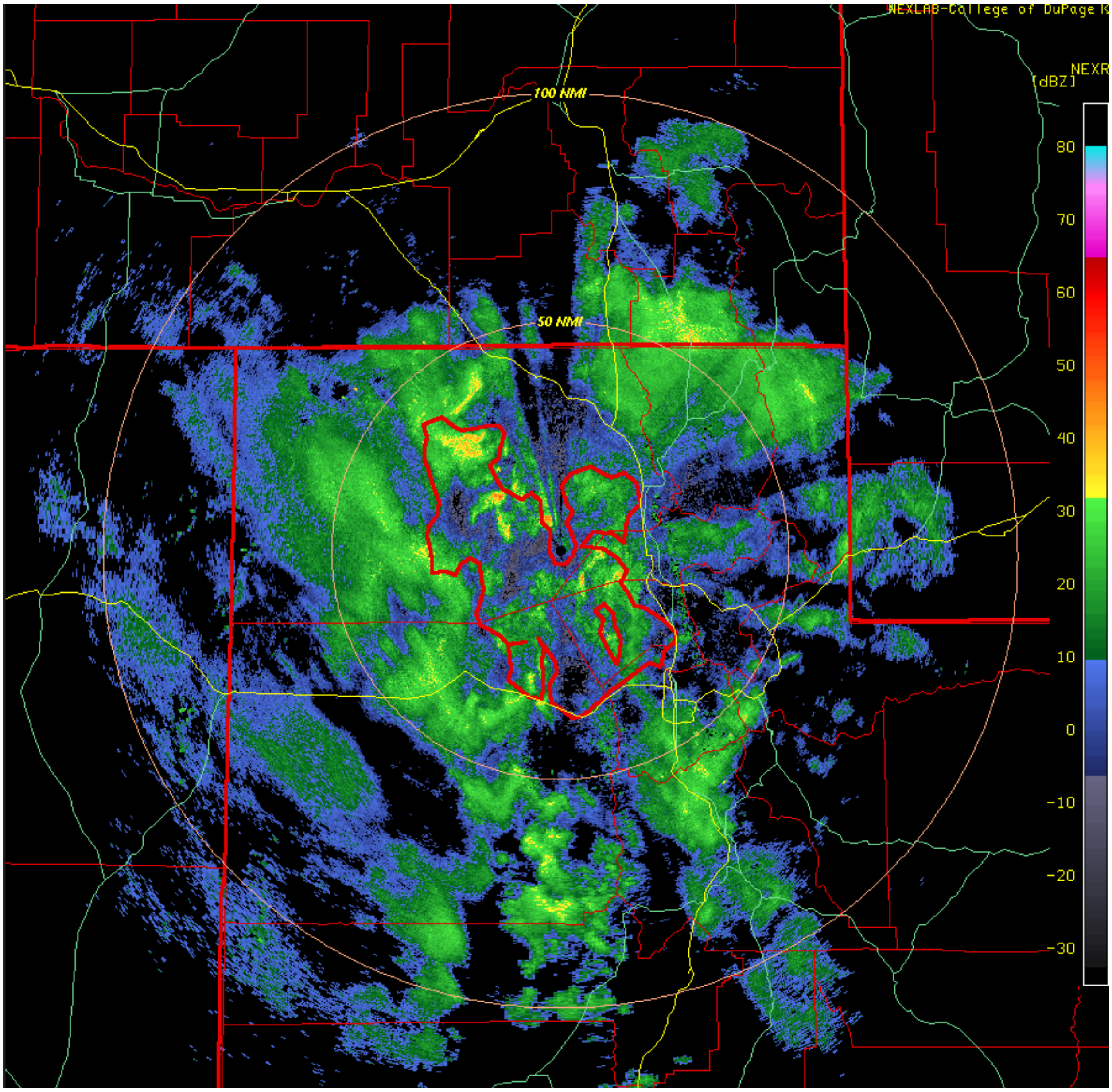


Figure 5.5. **Radar image from KMTX radar valid at 0632 MST on November 19, 2023.**

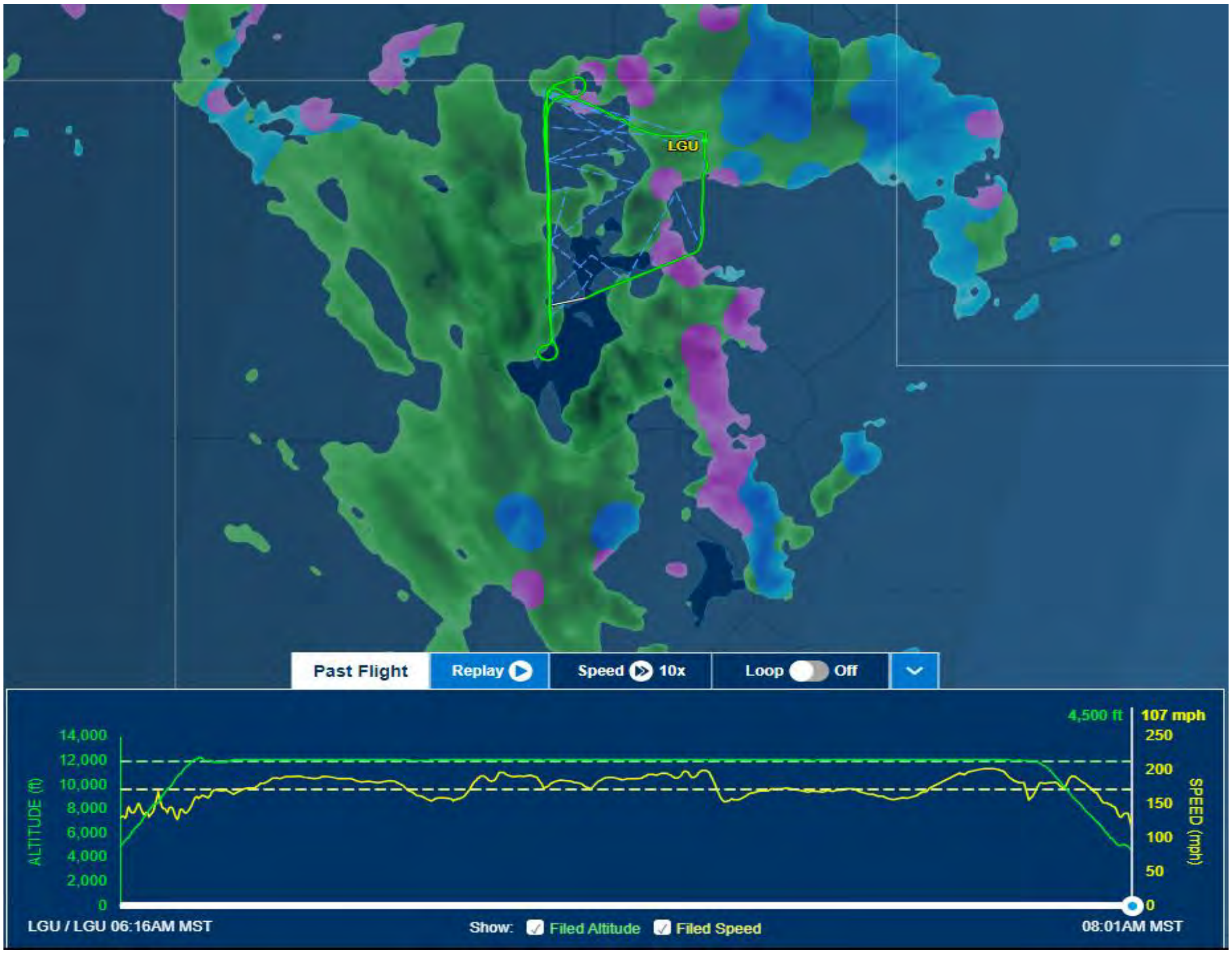


Figure 5.6. Flight track from first flight on November 19, 2023.

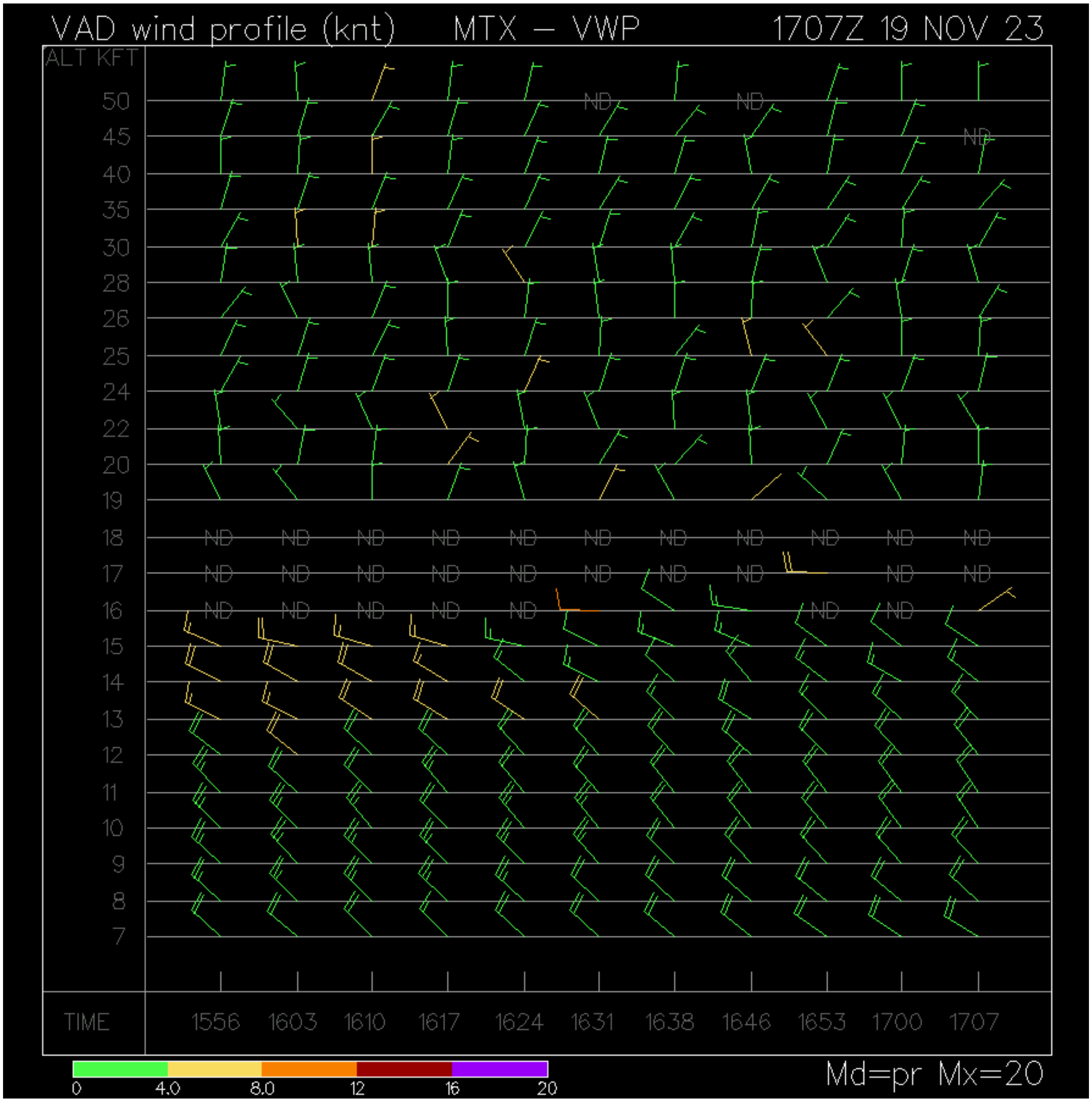


Figure 5.7. **Velocity-Azimuth Display (VAD) from MTX radar showing winds aloft from 7 kft MSL through 50 kft MSL above the radar. Note wind flow below 16 kft is from the NW at 20-30 knots.**

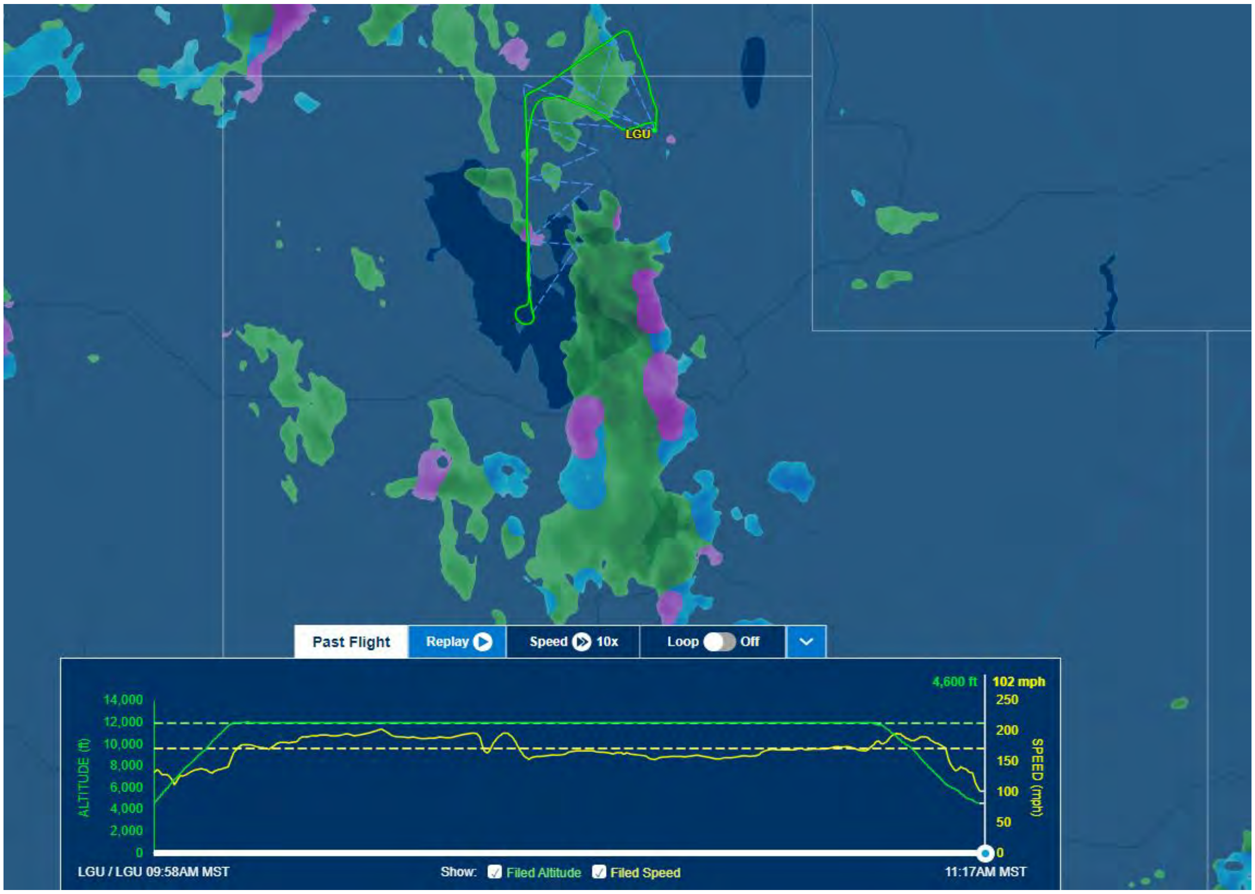


Figure 5.8. Flight track from second flight on November 19, 2023.

November 2023 Suspensions/Missed Flying Opportunities

During the latter half of November, two days saw suspension/no-fly decisions being made with respect to operations. On November 16, thunderstorms resulted in a suspension of operations, and on November 23, weak winds aloft (i.e., 10 knots or less) and warm flight-level temperatures of -1°C precluded seeding operations from taking place.

December 2023

December turned out to be a rather quiet month in terms of storm systems impacting the state. Storm systems affected central and southern Utah on December 1-3 and again December 8. After that time the storm track was removed from Utah for most of the remainder of December, with another storm event affecting mainly northern Utah on December 23. No flights occurred during the month, with the reasoning given in the suspension/missed opportunities section for December. Figure 5.9 shows the monthly precipitation across Utah for December as a percent of normal, averaged by basin.

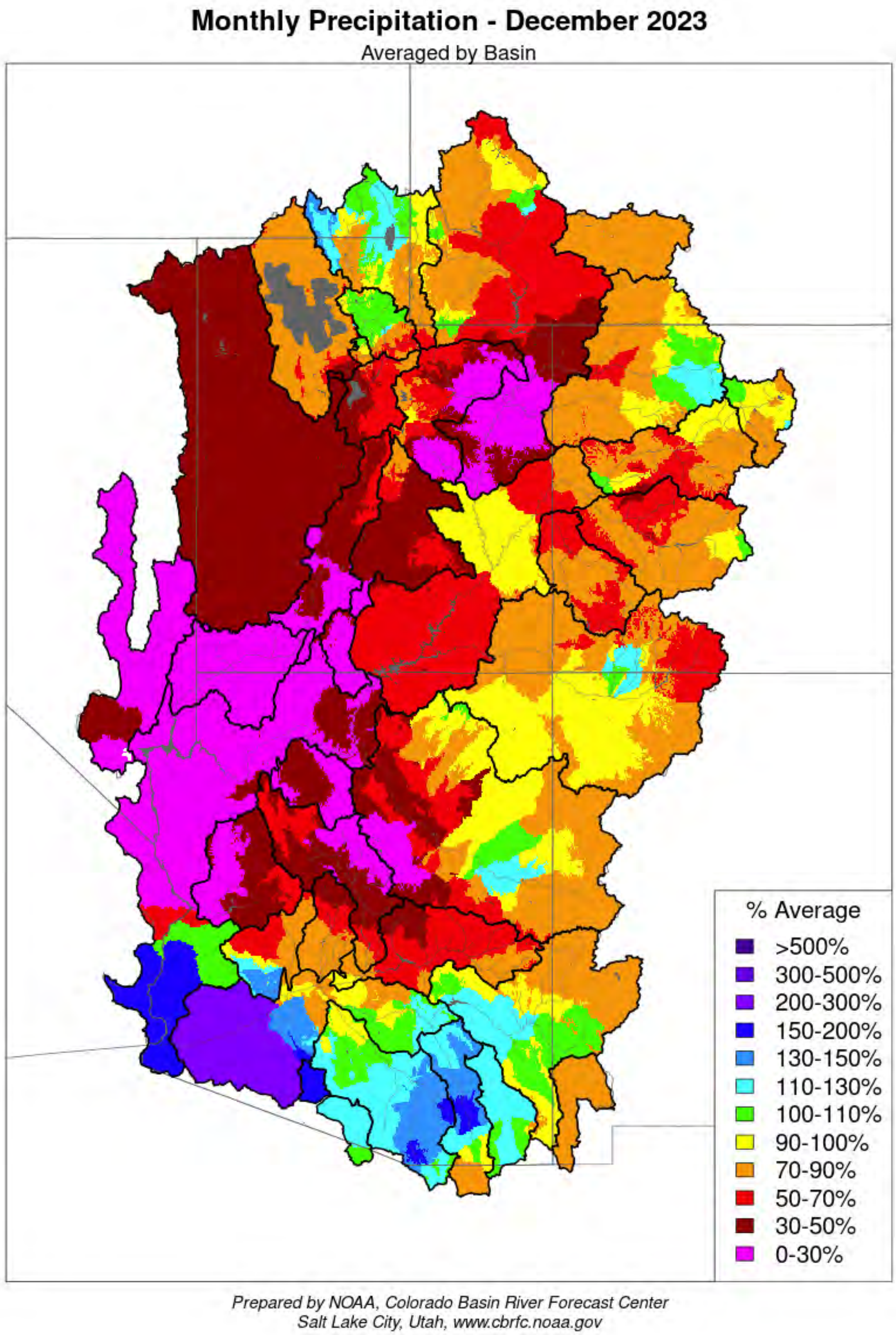


Figure 5.9. **December 2023 precipitation as a percent of average for the month.**

December 2023 Suspensions/Missed Flying Opportunities

On December 3, severe turbulence and associated mountain wave activity due to strong winds aloft was occurring across northern and central Utah, preventing any flights from taking place. On December 8, a flight was filed for a middle-of-the-night departure; the plane, which had been parked outside so a quick departure could take place without a call-out (where airport crew come out during off-hours to tow the plane out of the hangar) ended up getting coated in ice and could not take off.

January 2024

After a quiet December in terms of the frequency of storm events that impacted the state, the pattern in January shifted to one that saw more storms moving across Utah. Nine storm events affected Utah during the month. Four seeding flights occurred during four of these events. Figure 5.10 shows the percent-of-average precipitation for January 2024; most locations within the Northern Utah Aerial Program's area of responsibility saw above average precipitation, with below average amounts over the eastern Uinta Mountains and Book Cliffs area.

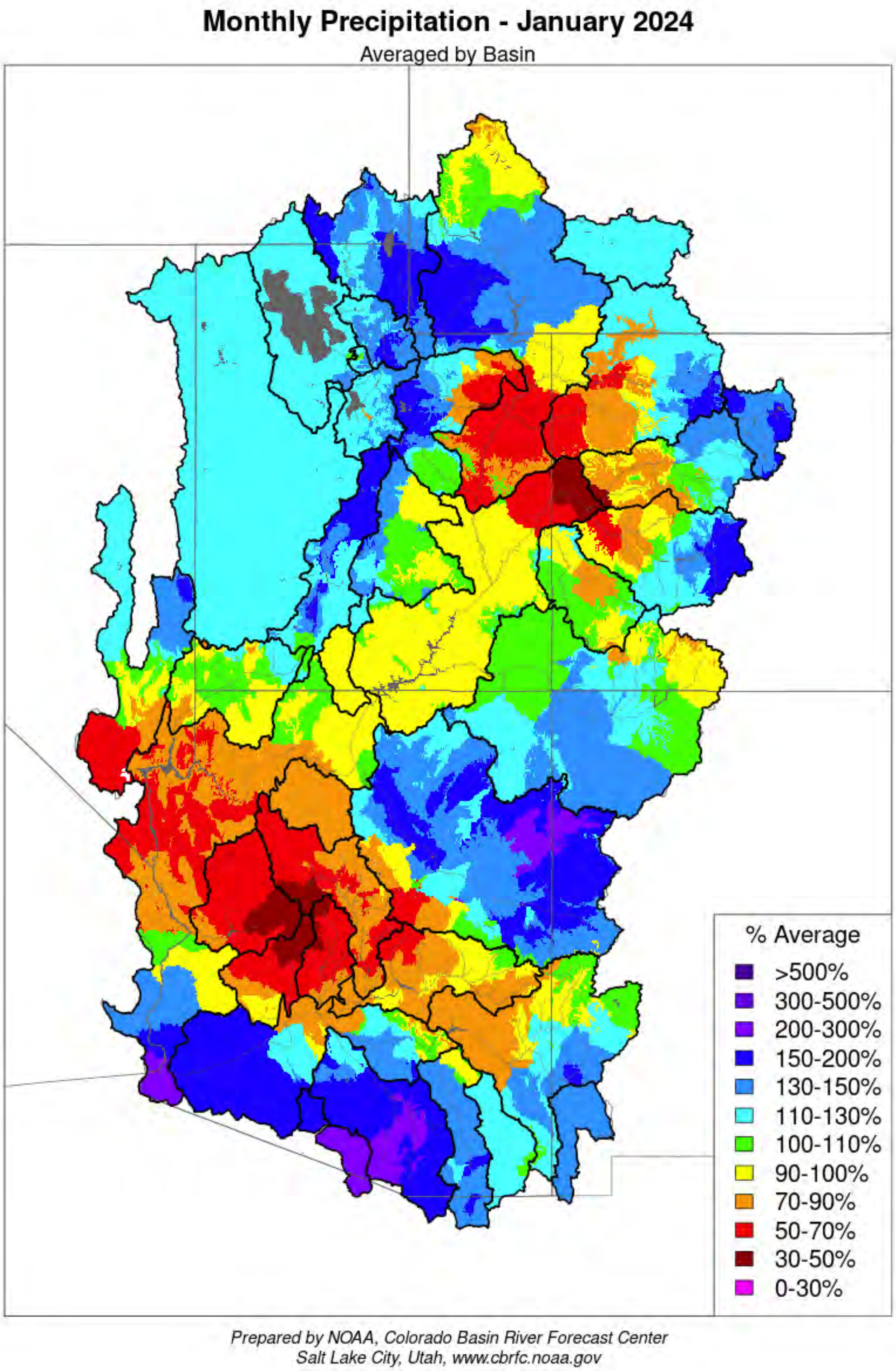


Figure 5.10. January 2024 precipitation as a percent of average for the month.

January 5, 2024

A shortwave trough was located over southern Idaho/northern Nevada early in the morning hours and was expected to shift southeast into northern Utah later in the morning and across the remainder of the state during the afternoon and evening. Moisture associated with the trough was pushing into northern Utah ahead of the trough axis and within a weak warm advection regime; still, 700 mb temperatures were around -12°C as measured on the morning Salt Lake City sounding. Winds were northwesterly ahead of the trough, with a veering to a northerly flow pattern expected behind the trough axis. An initial surge of moisture and associated precipitation moved across portions of northern Utah southwest of the Wasatch Range during the mid-morning hours. Prior to the noon hour, a second slug of moisture tied to the cold front began to push into northern Utah, and this is what the seeding flight was going to target. A flight plan was filed with a northeast-southwest track running from the Idaho border south of Malad to the north-central part of the Great Salt Lake; this track would target the moist, northwest flow as it moved into the northern Wasatch Mountains. The plane departed LGU at 1105 MST and, upon reaching the target altitude of 12 kft, seeding began. Figure 5.11 shows satellite imagery right before the plane took off. Area PIREPs (**PI**lot **REP**orts) indicated light rime icing in the area. The plane returned to LGU at 1219 MST, having flown for 1.23 hours and burning nine BIP flares. Low ceilings and visibilities at LGU prevented a second flight. Figure 5.12 shows the flight track from the mission.

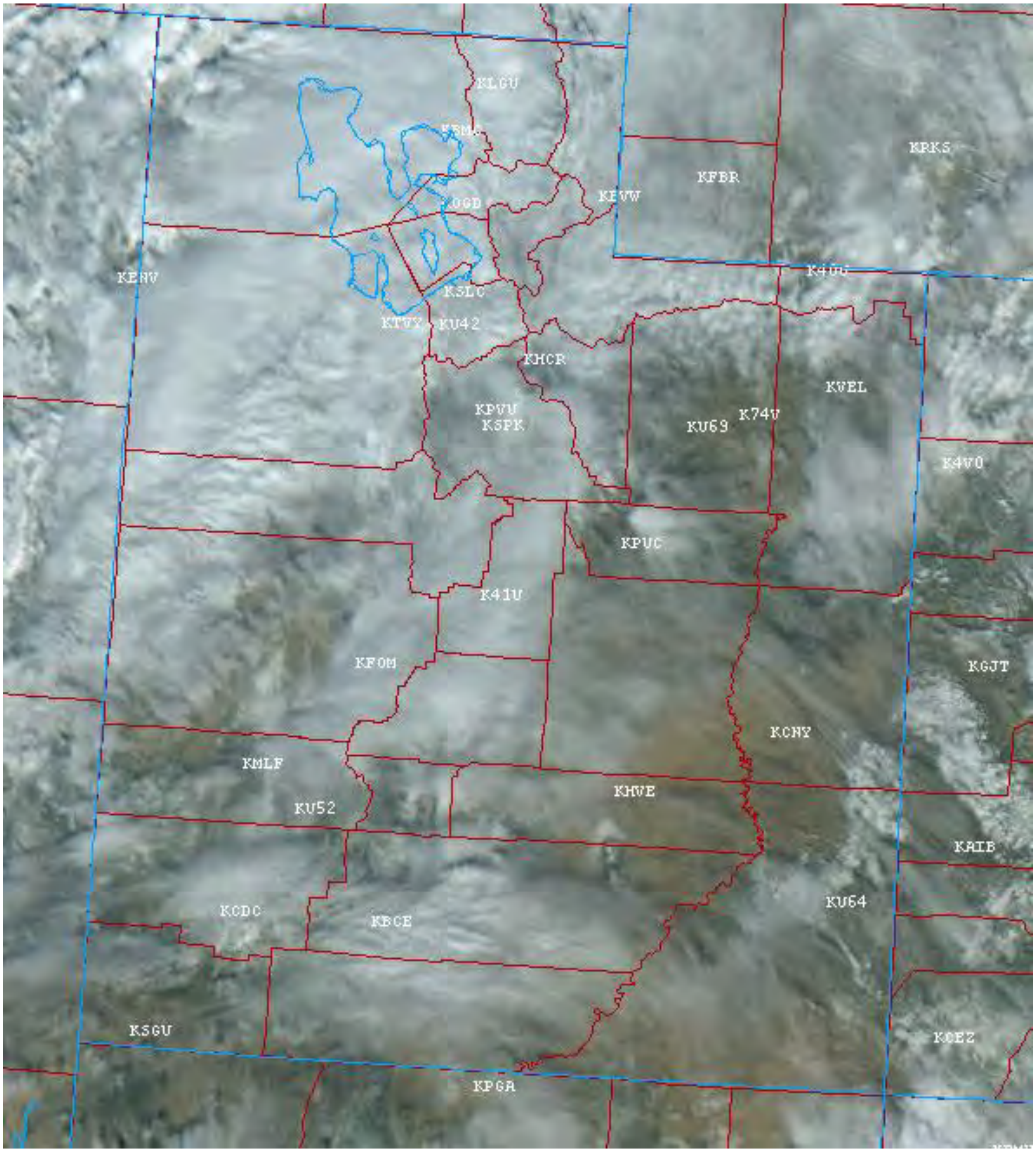


Figure 5.11. **Visible satellite image taken at 1101 MST on January 5, 2024.**

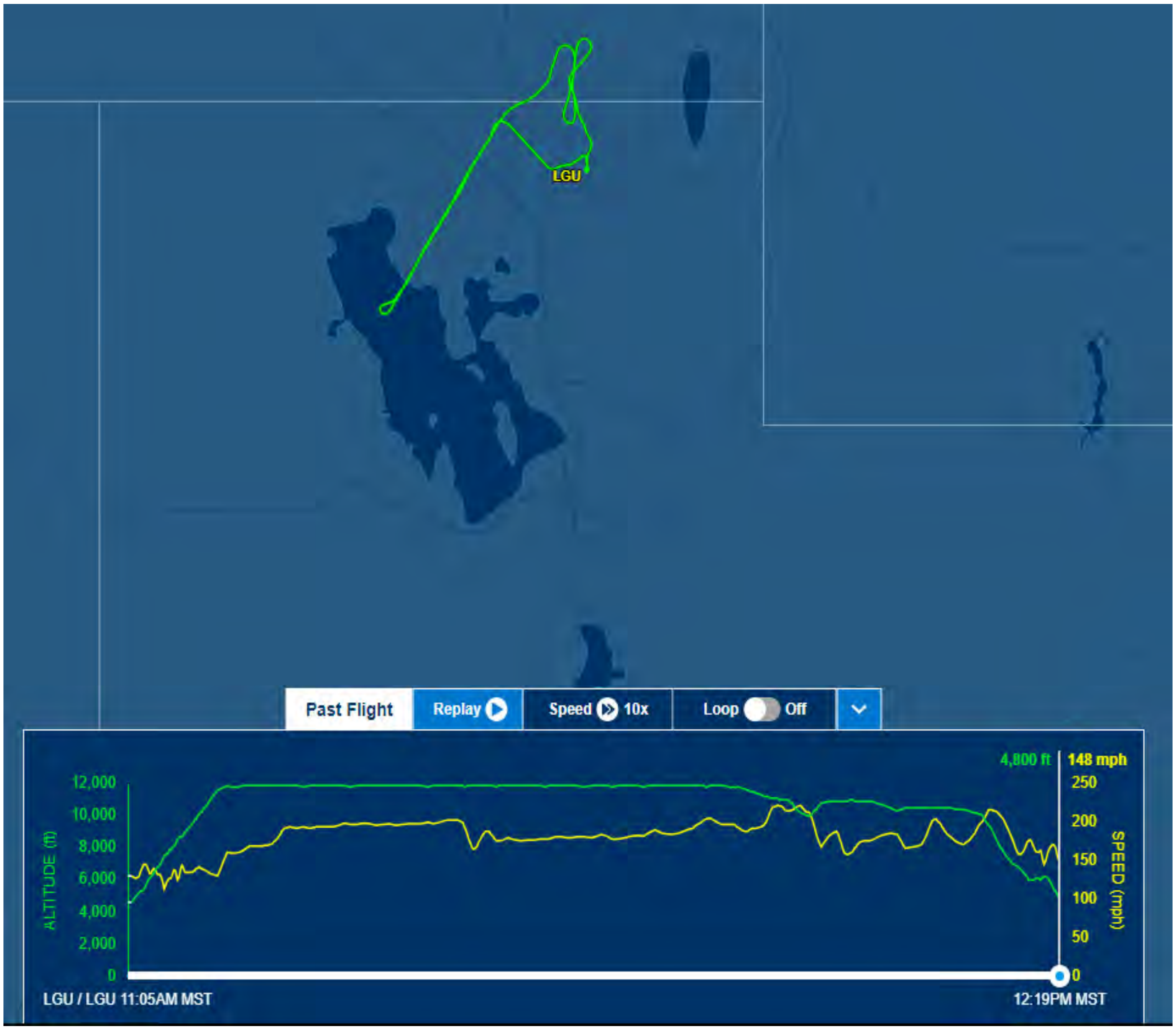


Figure 5.12. **Flight track data from seeding flight on January 5, 2024.**

January 6-7, 2024

A strengthening trough was digging southeast across California and Nevada during the evening of January 6, aided by a jet streak diving southeastward on the backside of the trough. Deep southwest flow was in place across Utah. The upper jet axis was expected to shift to a position across Arizona and the Four Corners area by early morning of January 7 around the same time a cold front associated with the trough was expected to cross northern Utah, with winds veering to northwesterly behind the front. 700 mb temperatures were around -8°C on the Jan 7/00Z sounding and were expected to drop into the -12°C to -15°C range later in the morning on January 7. Although moisture appeared to be of low quality via soundings, satellite analysis and model output, a PIREP on the evening of January 6 indicated moderate rime icing at 13 kft over Ogden. A flight plan was filed using a track from the Idaho border south to the center of the Great Salt Lake, with the Wasatch Mountains the primary target. The plane departed LGU at 2350 MST on January 6 and made a couple of passes along the track, burning 10 BIP flares during the flight. The pilot reported only brief pockets of moisture during the flight, landing back at LGU at 0105 MST on January 7, having flown for 1.25 hours. An infrared satellite image from during the flight is shown in Figure 5.13, and flight track data is shown in Figure 5.14.

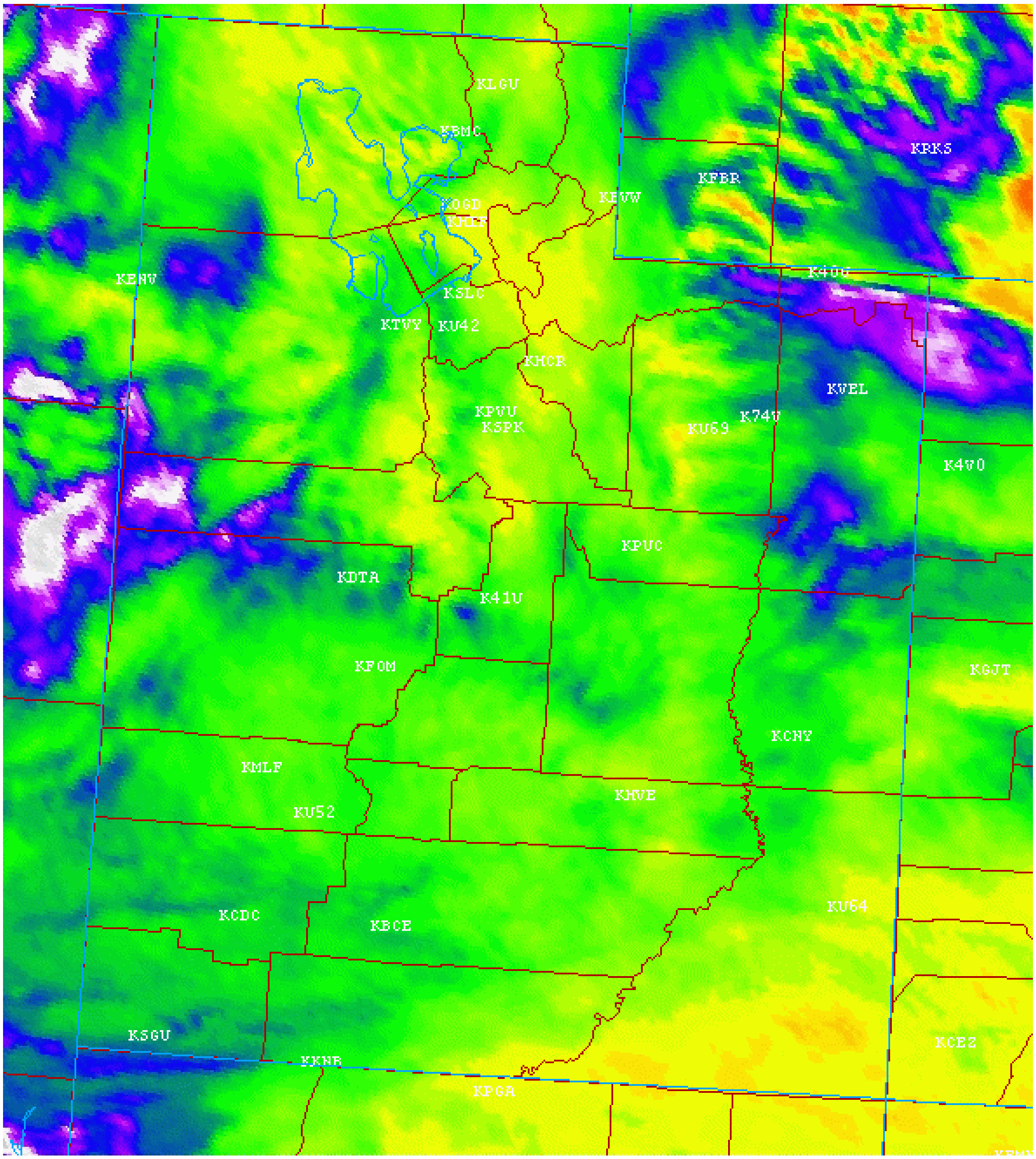


Figure 5.13. **Infrared satellite image from 0011 MST on January 7, 2024. Note the extensive cloud cover across Utah, with yellow and orange colors indicating colder cloud tops with green indicating warmer cloud tops.**

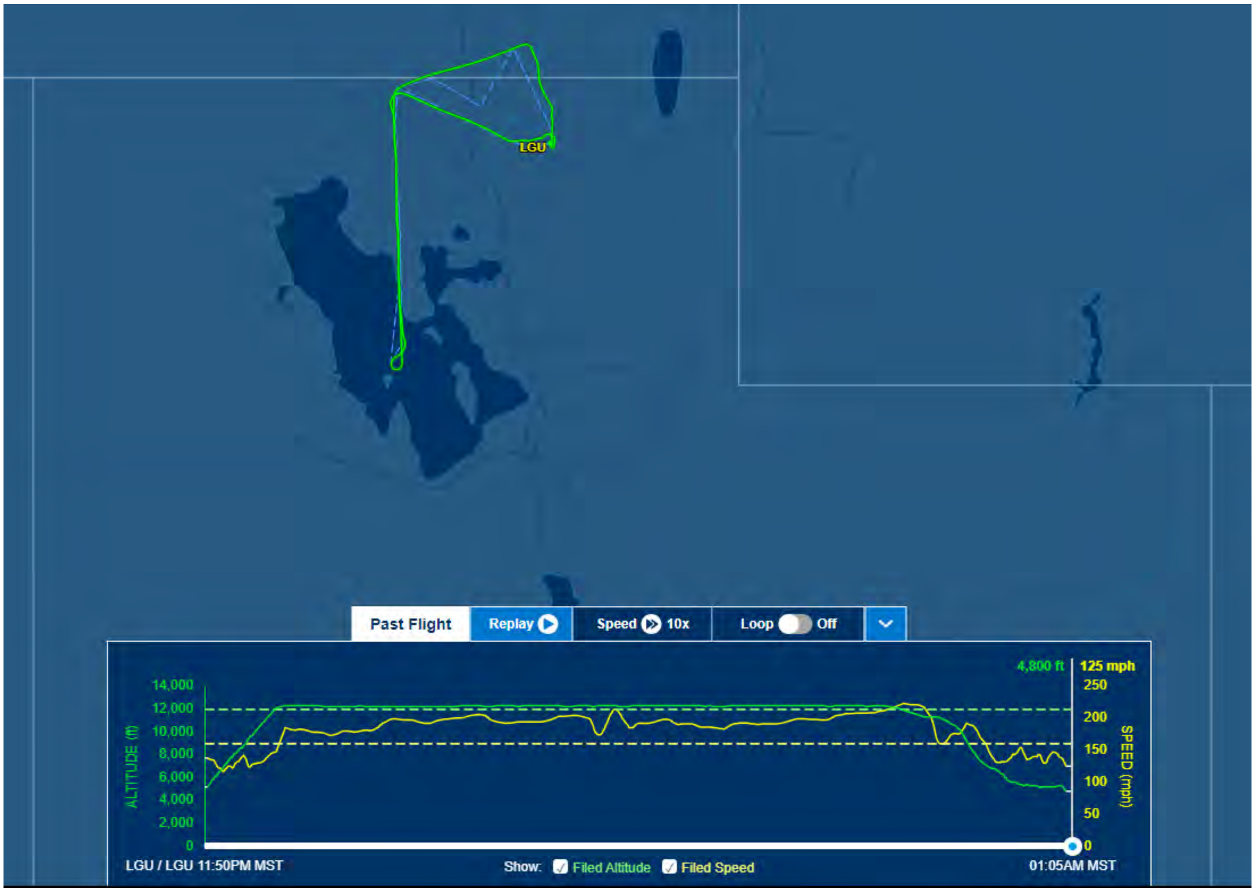


Figure 5.14. **Flight track data from January 6-7, 2024 seeding flight.**

January 13, 2024

A broad trough of low pressure covered much of the United States, with the axis aligned roughly across the central portion of the country, while a highly amplified ridge of high pressure was located off the West Coast; this pattern setup put Utah under general northwest flow aloft. Embedded within the trough were several shortwave disturbances, one of which was located near the Pacific Northwest during the early evening of January 13. The flow ahead of this shortwave disturbance had induced a backing of the winds aloft over Utah to a more westerly direction. Moisture availability was marginal with PWAT values in the 0.35-0.50" range across northern Utah, but sufficient for precipitation across the area. A flight plan was filed using a track from the central Great Salt Lake to the Idaho border, with the Wasatch Mountains the target of seeding operations within westerly flow of 20-30 kt. After some delays related to ceilings and needing to get a helicopter out of the way, the plane departed LGU at 1805 MST. Temperatures at flight level (12 kft) were -9°C. The pilot reported only "sporadic" moisture pockets, enough to burn six BIP flares before having to cut the flight short and return to LGU at 1900 MST as northern Utah airports were all falling below minimums for flights with greater moisture arriving from the south. Radar imagery during the flight is shown in Figure 5.15, while Figure 5.16 shows the flight data/track.

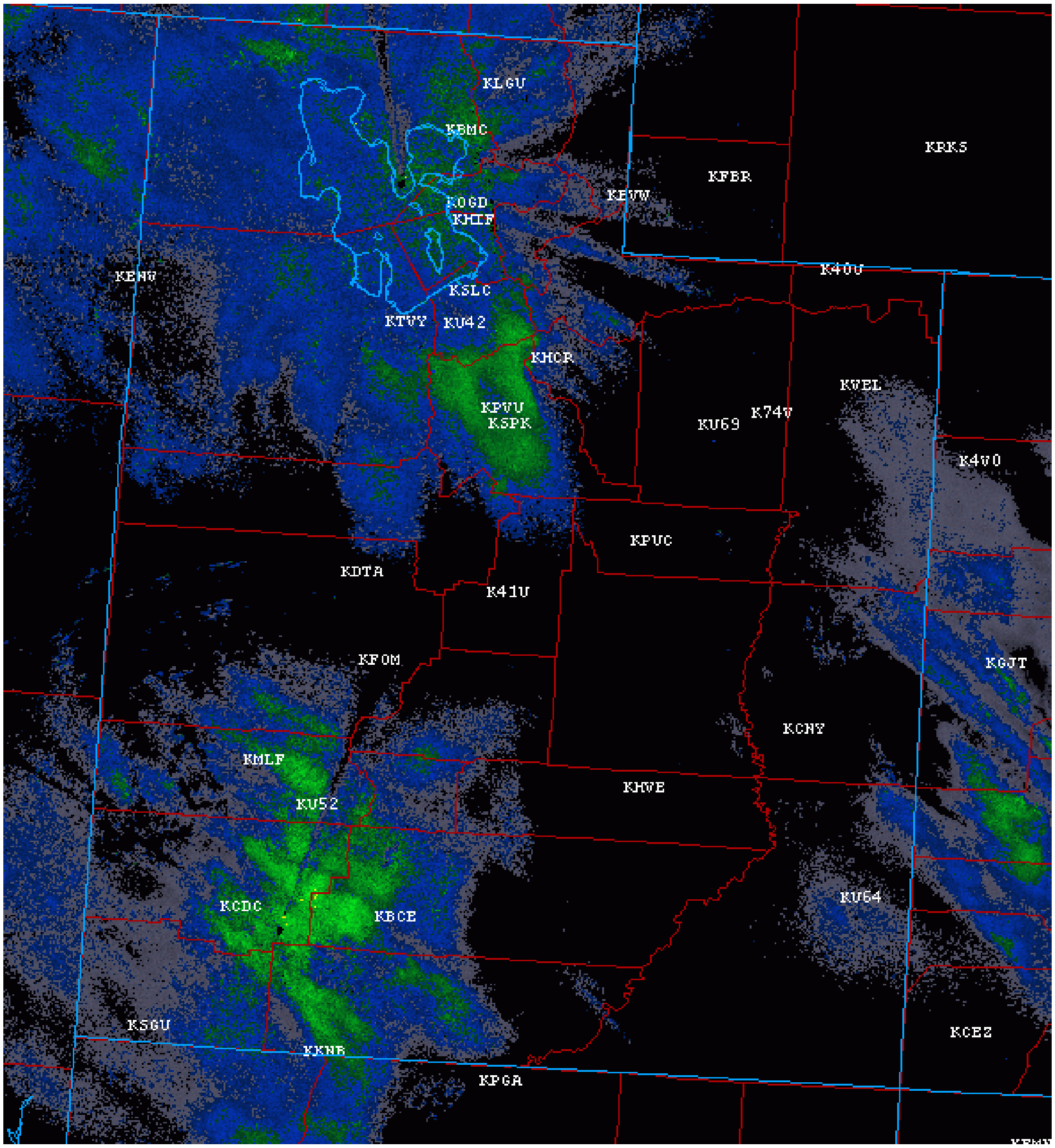


Figure 5.15. Radar imagery from 1830 MST on January 13 showing moisture across the western half of Utah.

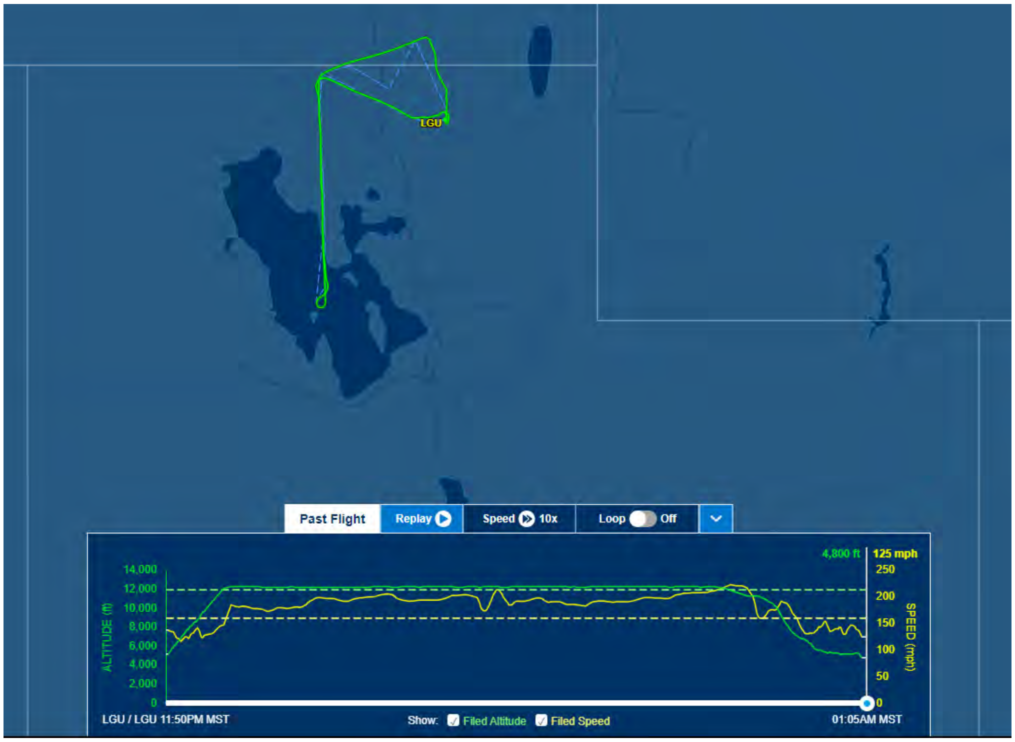


Figure 5.16. Flight track from seeding flight on January 13, 2024.

January 17, 2024

Earlier in the day, a shortwave disturbance moved across northern and central Utah bringing a round of light to moderate snow to the area. Although low levels were stable, moisture was certainly present. However with all area airports in northern Utah below visibility minimums, a flight could not launch. Later in the day, a second impulse of energy over southern Idaho approached northern Utah accompanied by lift and a wave of precipitation. 700 mb temperatures were around -8°C and model data indicated some supercooled liquid water (SLW) present. Figure 5.17 shows the sounding from Salt Lake City at 00Z on January 18 (1700 MST on January 17). With westerly flow in place that was expected to veer to northwesterly, a flight plan was filed with, once again, a north-south track from the Idaho border southward to the central Great Salt Lake targeting the northern Wasatch Mountains and Bear River Range. The plane departed LGU at 2118 MST and, upon reaching altitude, began seeding operations. During the flight, a couple of PIREPs were received indicating light to moderate icing occurring in the 12-14 kft layer. As the pilot was wrapping up the mission and beginning his return to LGU, the airport manager inexplicably closed the airport, and the pilot was left trying to work with the FAA on why that occurred and where to land. After some effort, the pilot was able to land at Brigham City Airport (BMC) at 2333 MST, having burned 15 BIP flares. Figure 5.18 shows the flight track data.

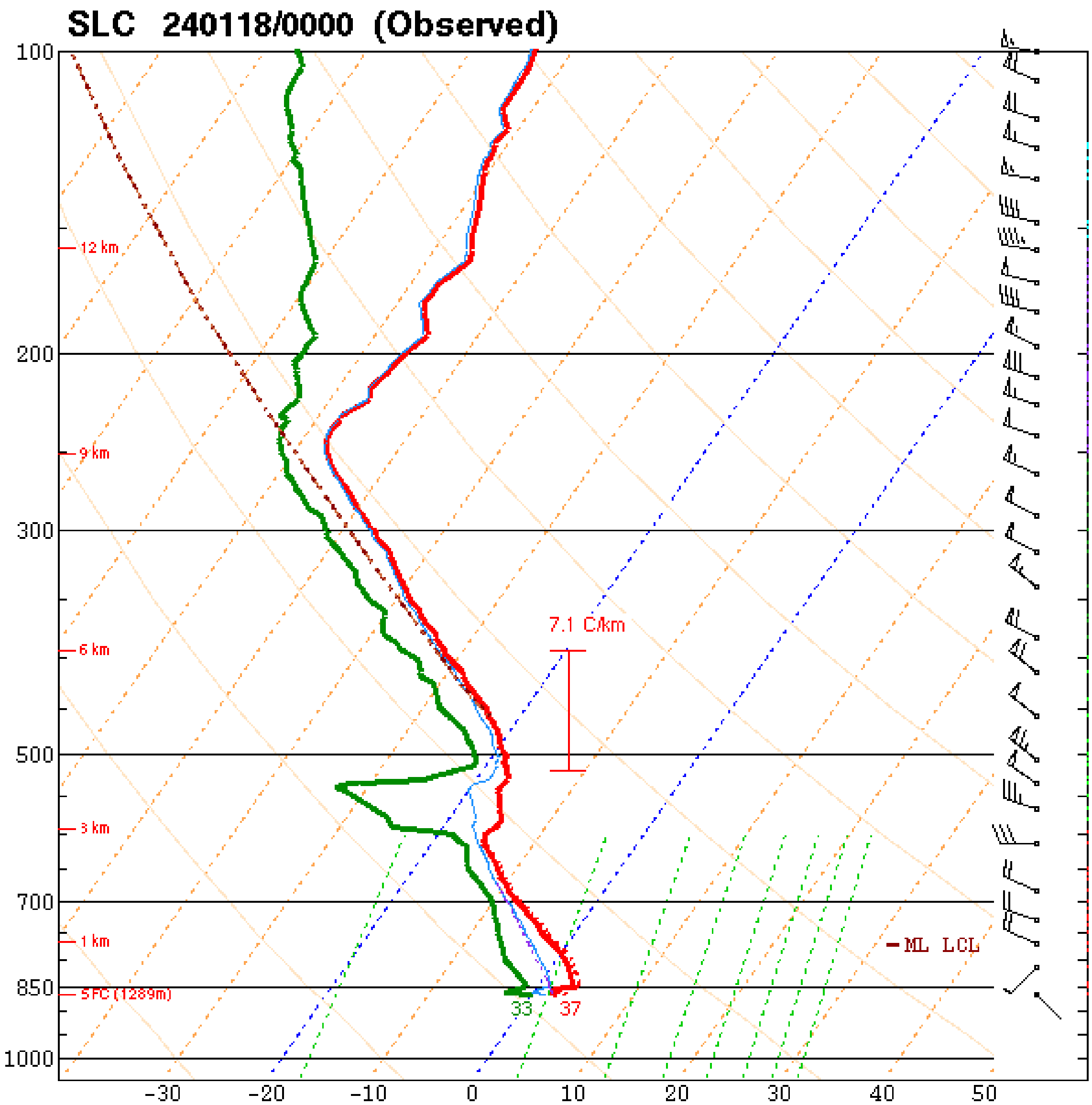


Figure 5.17. **Sounding from Salt Lake City, valid at 0000 UTC January 18 (1700 MST January 17). Note the west to northwest flow in place at and above 700 mb, with a dry pocket around 3 km above ground level (approximately 14 kft MSL).**

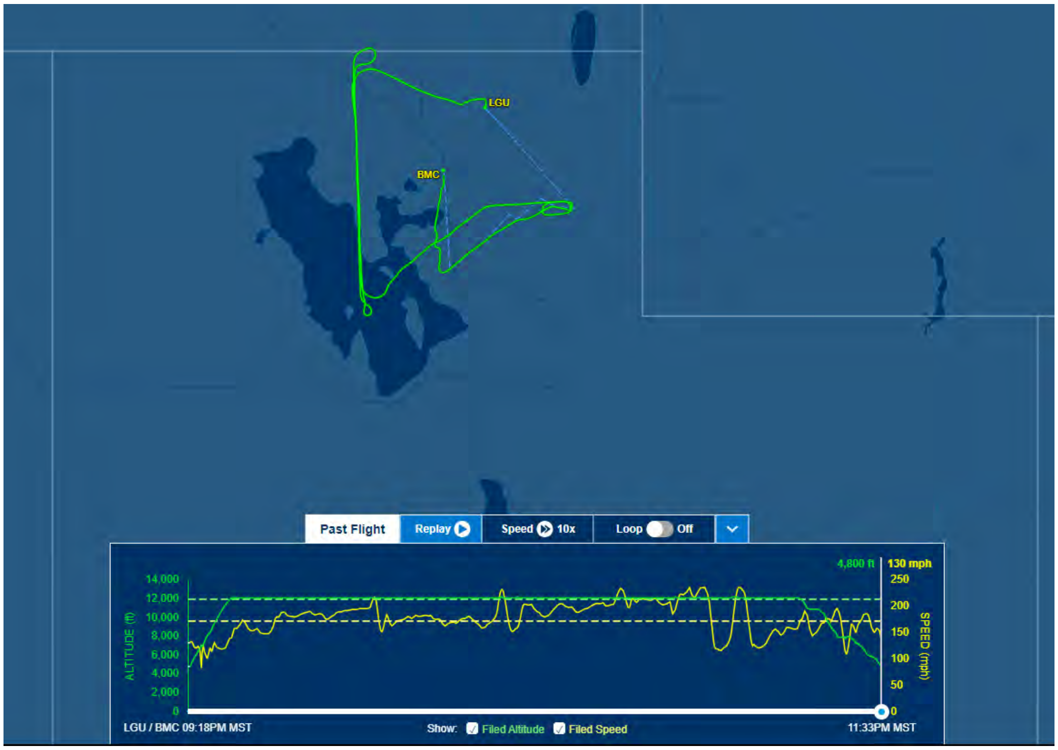


Figure 5.18. Flight track from seeding flight on January 17, 2024.

January 2024 Suspensions/Missed Flying Opportunities

On January 9, the threat (and eventual presence of) scattered thunderstorms prevented any flights from taking place. On January 10-12, during periods of precipitation, pockets of severe turbulence arising from strong winds and resultant mountain waves deemed the area unsafe for flying/seeding. Also, on January 12 into early on January 13, very cold temperatures aloft (-17°C at flight altitude) precluded any seeding operations. On January 25, early in the storm event Logan Airport (LGU) was socked in with low clouds and low visibilities, and then by the time it began to mix out, moisture levels have decreased across northern Utah, and also upper level winds were very weak (< 10 kt).

February 2024

The active weather pattern that was observed in Utah in January continued into February with a number of storm events affecting Utah. Eight storm events impacted the state during the month, yet in spite of the active pattern, only two flights were able to launch early in the month. Further discussion will describe the issues that affected flying during the month in the next sub-section. Figure 5.19 shows the monthly precipitation for February as a percentage of average precipitation for the month. All areas saw above normal precipitation.

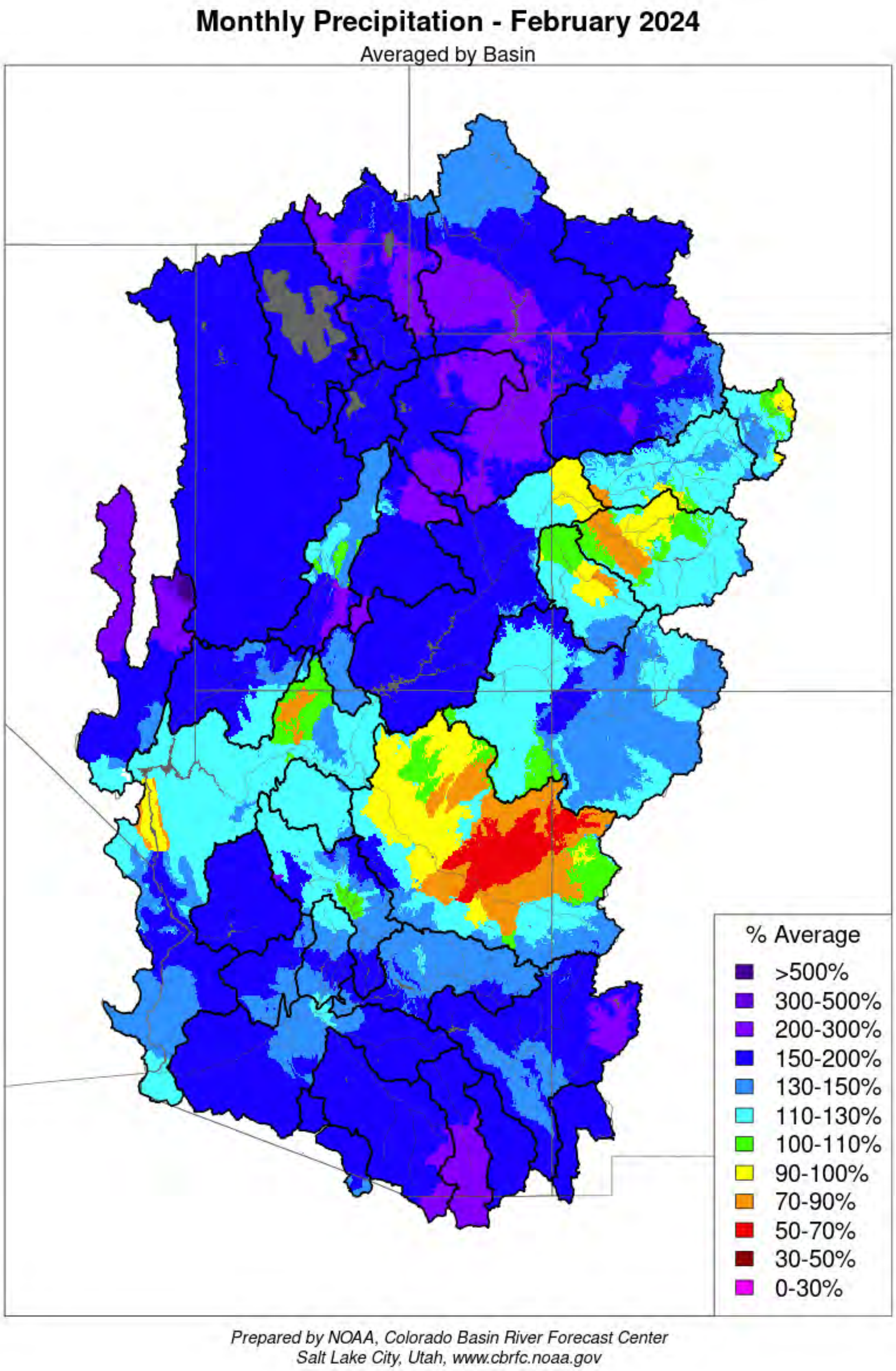


Figure 5.19 February 2024 precipitation as a percent of average for the month.

February 1, 2024

A trough of low pressure pushing into the west coast states was in the process of splitting, with the southern piece of energy expected to move across southern Nevada/northern Arizona/southern Utah during the nighttime hours. Ahead of this system, moist southerly flow and warm advection was pushing into the state from the west. Over northern Utah, a dry sub-cloud layer was in place for much of the day, but as the warm, moist advection ramped up, the sub-cloud layer did moisten up to where precipitation was able to reach the surface. Figure 5.20 shows the 700 mb map valid at 1700 MST. Given the broad southerly flow in place, a seeding flight targeting the Uinta Mountains was planned, with a flight track on the south side of the Uinta Range at 13-14 kft. The plane departed LGU at 1957 MST and headed southeast, reaching the western end of the flight track about an hour later upon which seeding commenced once moisture was observed. The plane flew down the length of the Uinta Range and back, then returning to LGU, landing at 2231 MST. Ten BIP flares were used for seeding, with the pilot reporting only marginal amounts of moisture. Flight track data is shown in Figure 5.21.

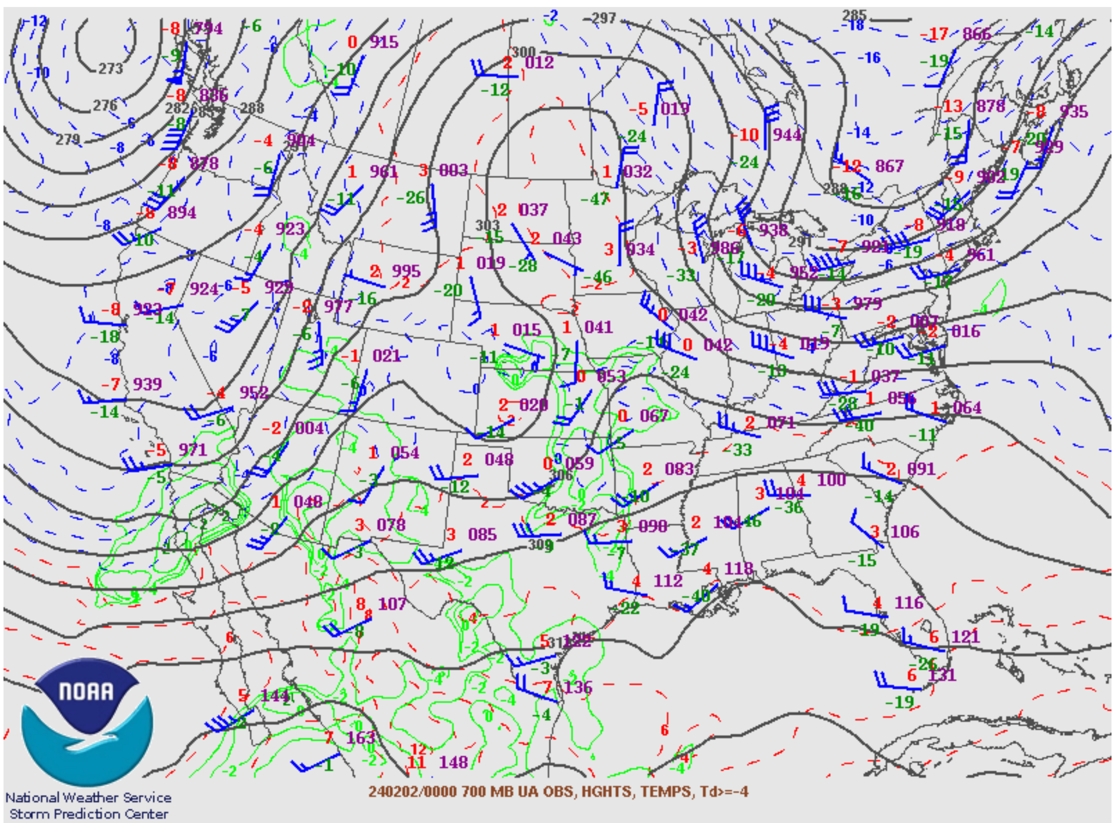


Figure 5.20. 700 mb map valid at 1700 MST on February 1, 2024. Note the trough located over the west coast states with southerly flow across Utah bringing in higher moisture content (green isopleths).

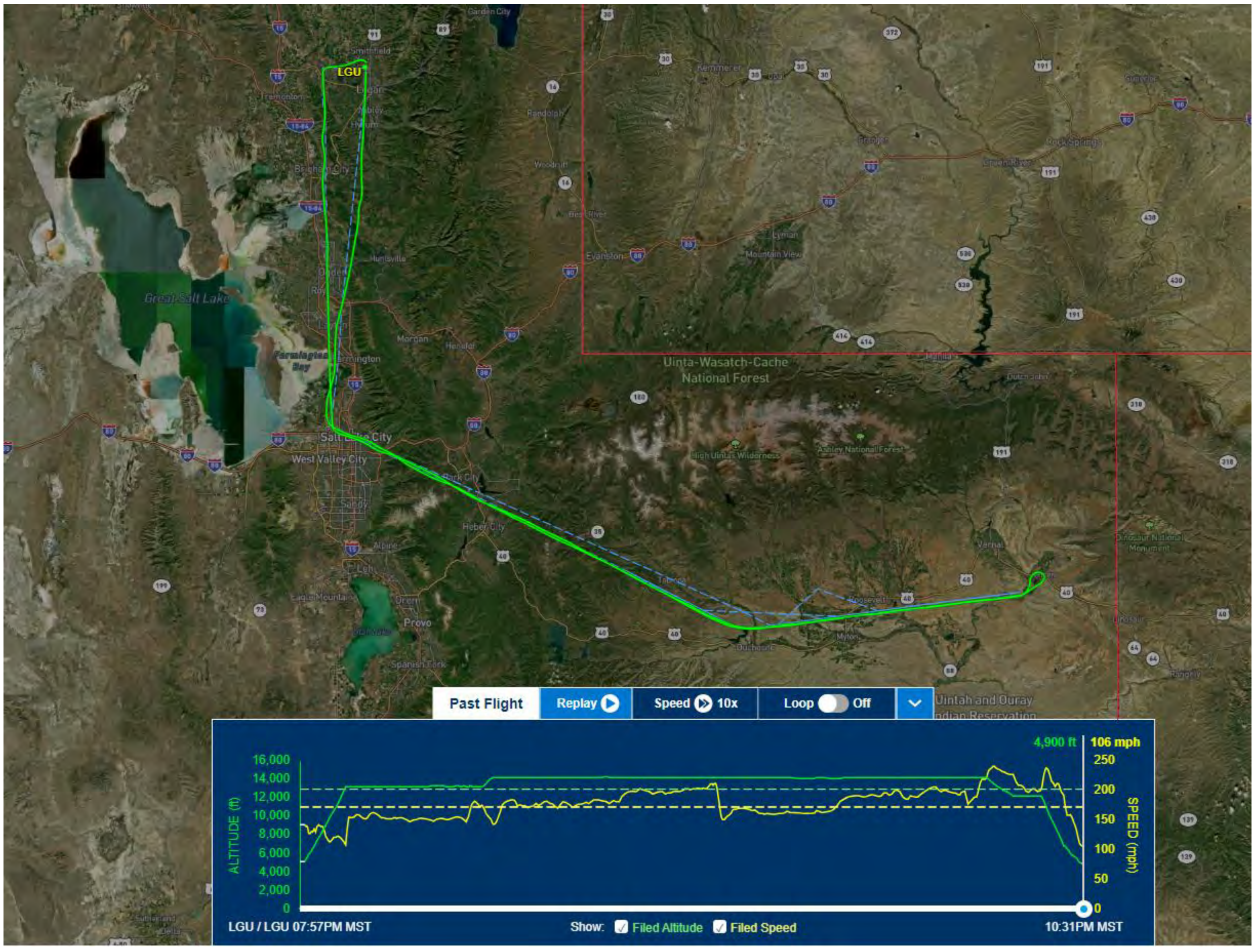


Figure 5.21. Flight track data from seeding flight on February 1, 2024.

February 5, 2024

A large trough, with axis oriented northeast to southwest, was located off the West Coast. An Atmospheric River (AR) extended from east of Hawaii up into the trough and across southern California, Nevada and into Utah; moisture concentration was lower across Utah compared to California, as is typical since much of it gets depleted by major mountain ranges. The trough was forecast to dig southward and elongate near the West Coast which was expected to pivot the moisture band further to the west by nighttime. Rain and snow were falling across northern Utah within this weakened AR, and area PIREPs were mentioning light to occasionally moderate rime icing. With strong southwest winds 35-65 kt between 700 and 500 mb and WAT values of 0.45”, the potential for at least an exploratory flight was there, and a flight plan was crafted with a northwest-southeast orientation extending from near Tremonton to Ogden targeting the northern Wasatch Mountains and Bear River Range. The pilot departed LGU at 1445 MST and, while climbing to flight altitude, encountered a pocket of heavy icing that was not able to be fully shed with the de-icing boots, thus the plane had to abort the mission and make a quick return to LGU, landing at 1515 MST. No seeding was done. Figure 5.22 shows the flight track. No additional flights took place.

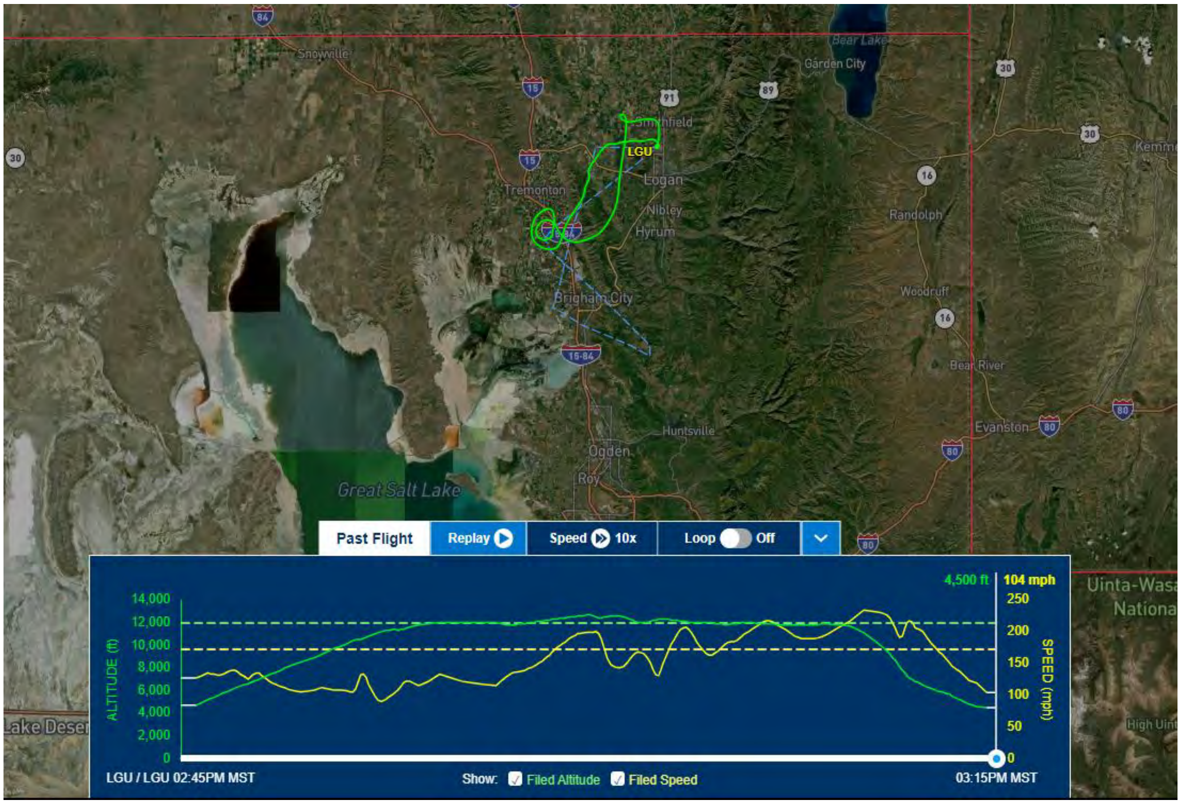


Figure 5.22. Flight track data from flight on February 5, 2024.

February 2024 Suspensions/Missed Flying Opportunities

During the storm event on February 6-8, strong winds aloft (> 50 knots) and the threat of thunderstorms precluded flights from taking place. With the storm on February 15, the FAA debriefer alerted the pilot to the presence of extensive (yet mainly light to occasionally moderate) icing, particularly concentrated near the frontal boundary expected to affect the area and mentioned the difficulty that may be encountered with the de-icing equipment due to icing rates in that area; because of this, the flight was aborted. Temperatures on February 16 were too cold aloft for effective seeding operations (i.e., below -15°C). On February 19, PIREPs indicated light to moderate mixing icing (clear and rime) occurring across northern Utah. With considerations to the difficulty in shedding clear icing compared to rime icing, and with an extended period of this expected to occur, a scheduled flight was aborted. The final storm of the month on February 26-27 brought a myriad of flying conditions, including moderate to occasionally severe icing, strong winds aloft and a thunderstorm threat.

March 2024

The active weather pattern that began in January across much of the western U.S. continued through March, with nine storm events affecting the state, distributed uniformly over the month. The Northern Utah Aerial Program flew five flights over three storm events during the latter part of March. Earlier storms contained hazards that were difficult for flying, which are presented in the Suspensions sub-section. Precipitation for the month was above normal across northern Utah, as were SWE values. Figure 5.23 shows the precipitation for the month across the western U.S. as a percentage of average precipitation for March.

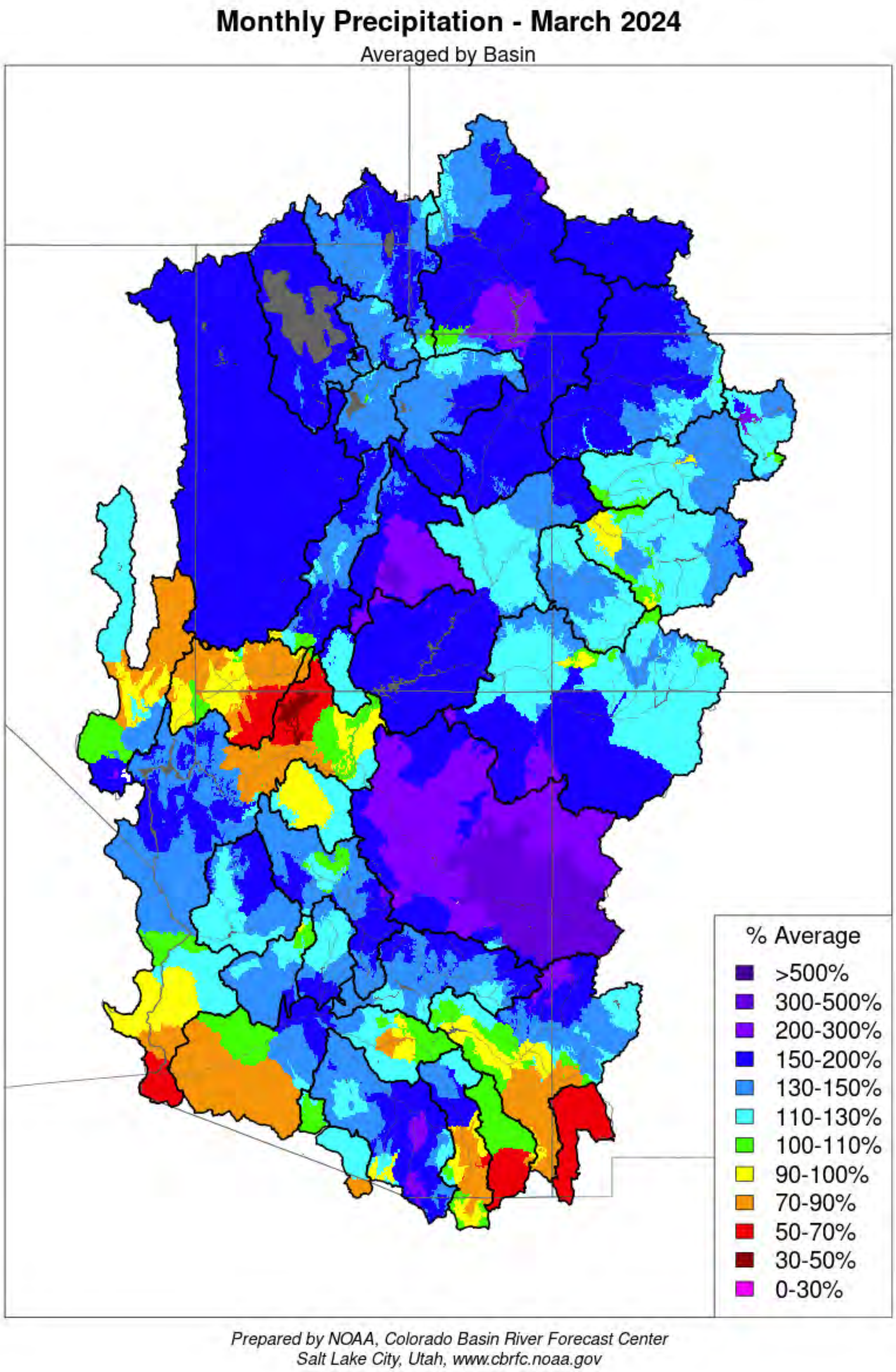


Figure 5.23. March 2024 precipitation as a percent of average for the month.

March 23, 2024

An upper low was located over Oregon with the associated trough extending southward to west of southern California/northern Baja. On the forward/east side of the trough, a strong cold front was located across southern Idaho and eastern Nevada and was forecast to move across Utah during the late afternoon/evening with rain, snow and isolated thunderstorms. Southwest flow was in place ahead of the front with 700 mb winds of 20-40 kt. After some evaluation of the weather and a discussion with the pilot, a flight plan was developed with a north-northwest to south-southeast track from near Tremonton to near Ogden, targeting the northern Wasatch Mountains and Bear River Range. The plane departed LGU at 1444 MDT, reaching the flight altitude of 12 kft a short time later. With moisture being observed, seeding commenced. The plane continued to fly along the track before returning to LGU, landing at 1556 MDT. Ten BIP flares were used for seeding, with the pilot indicating some moisture/ice sticking to the plane during the mission. A second flight was planned for early evening, but lightning concerns and a convective SIGMET for the area resulted in a no-fly decision for the second flight. Figure 5.24 shows a map of lightning strikes during the late afternoon/early evening hours valid at 1810 MDT. Severe turbulence was reported during the evening between Salt Lake City and Provo. Figure 5.25 shows the flight track data from the mission.

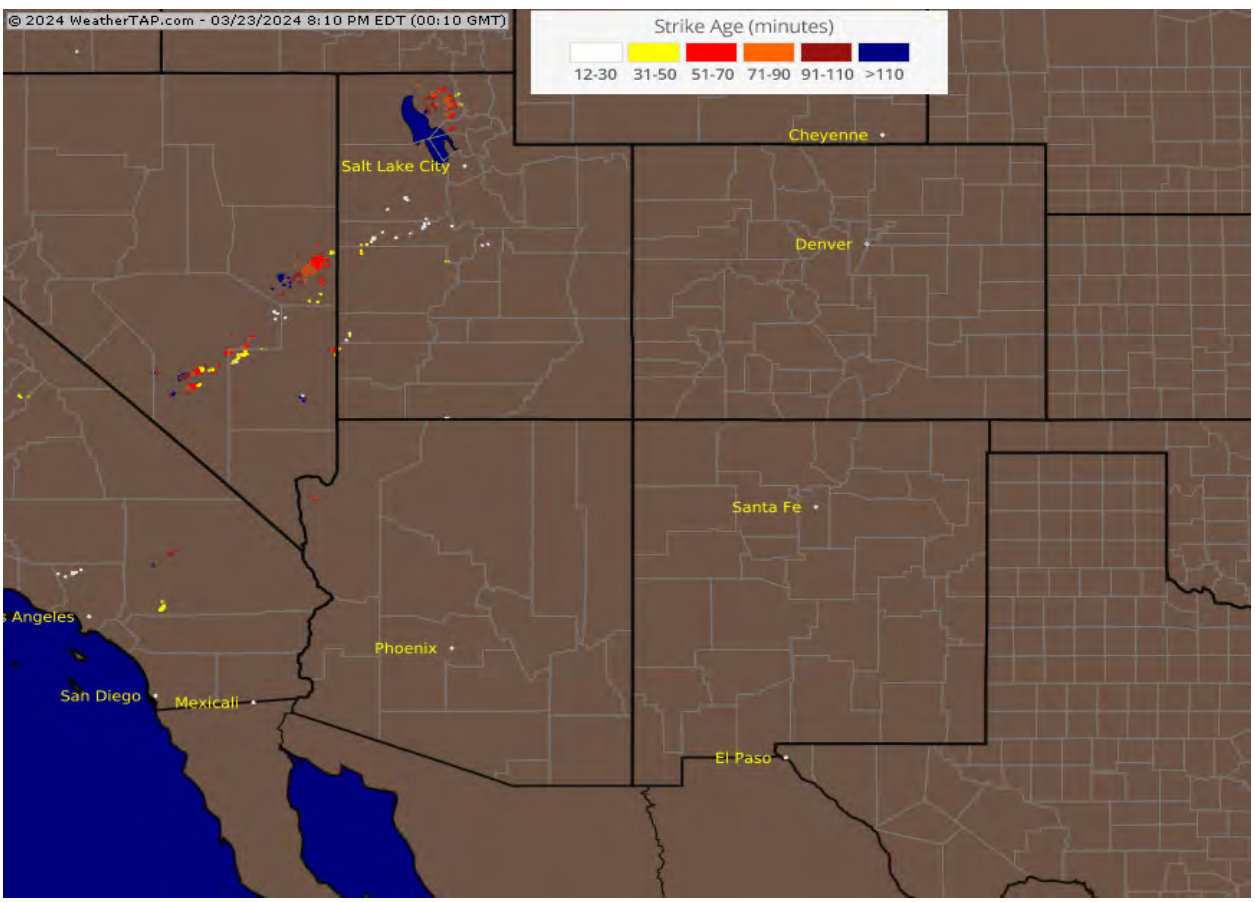


Figure 5.24. **Lightning strike map valid at 1810 MDT on March 23, 2024. Color of dots indicate age, shown in legend. Courtesy of WeatherTap.com .**

Figure 5.25. **Flight track data from seeding flight on March 23, 2024.**

March 28, 2024

An upper low was centered near Vancouver Island with a trough extending southward from the low into the Pacific Northwest and northern California. To the southeast of the trough, diffluent flow aloft was spreading across Nevada and northern Utah which was enhancing large-scale lift and precipitation development. A shortwave disturbance embedded within the trough's flow pattern was expected to move across northern and central Utah during the day with its accompanying cold front expected to move in during the afternoon before stalling across central Utah during the night. Area soundings showed PWAT values around 0.30-0.40" along with 700 mb temperatures around -4°C. The front was expected to undergo frontogenesis (i.e., strengthening) as it moved into northern Utah, with increasing potential for thunderstorms. A flight plan was developed for a flight ahead of the front, with a track similar to the one flown on March 23, extending from near Tremonton to Ogden and targeting mainly the northern Wasatch Mountains. The plane departed at 1126 MDT and reached a cruising altitude of 12 kft a short time later. Seeding soon commenced within the band of moisture, but the band was quickly lifting north and after a short flight, the plane returned to LGU at 1225 having burned 8 BIP flares. Figure 5.26 shows a visible satellite image taken during the flight. Figure 5.27 shows the flight track data from the first flight. With another round of precipitation approaching northern Utah, a second flight was planned, this time targeting the western Uinta Mountains. A flight plan was developed, with a track over the Wasatch Back from near Coalville to Heber City. The plane took off a second time from LGU at 1503 and reached the flight track zone a short time later. During the second flight, a cluster of thunderstorms producing abundant lightning strikes passed just south of Heber City. Figure 5.28 shows radar imagery during the second flight, noting the lightning strikes near HCR (Heber City). The plane returned to LGU at 1650 MDT, having burned 17 BIP flares along with 15 ejectables; the pilot reported plenty of moisture present during the mission. Figure 5.29 shows the flight track data from the second mission.

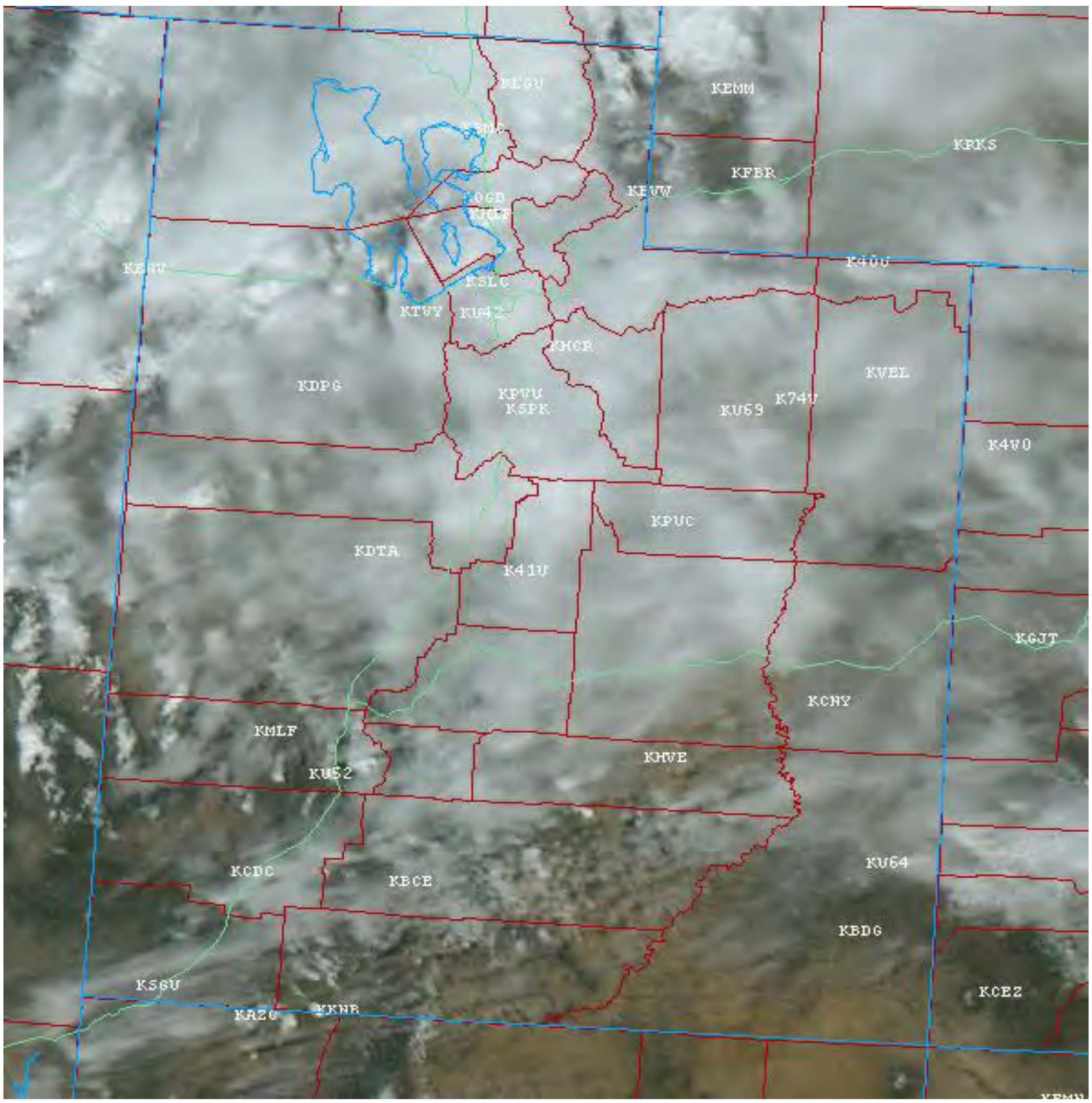


Figure 5.26. **Visible satellite image taken at 1201 MDT on March 28, 2024.**

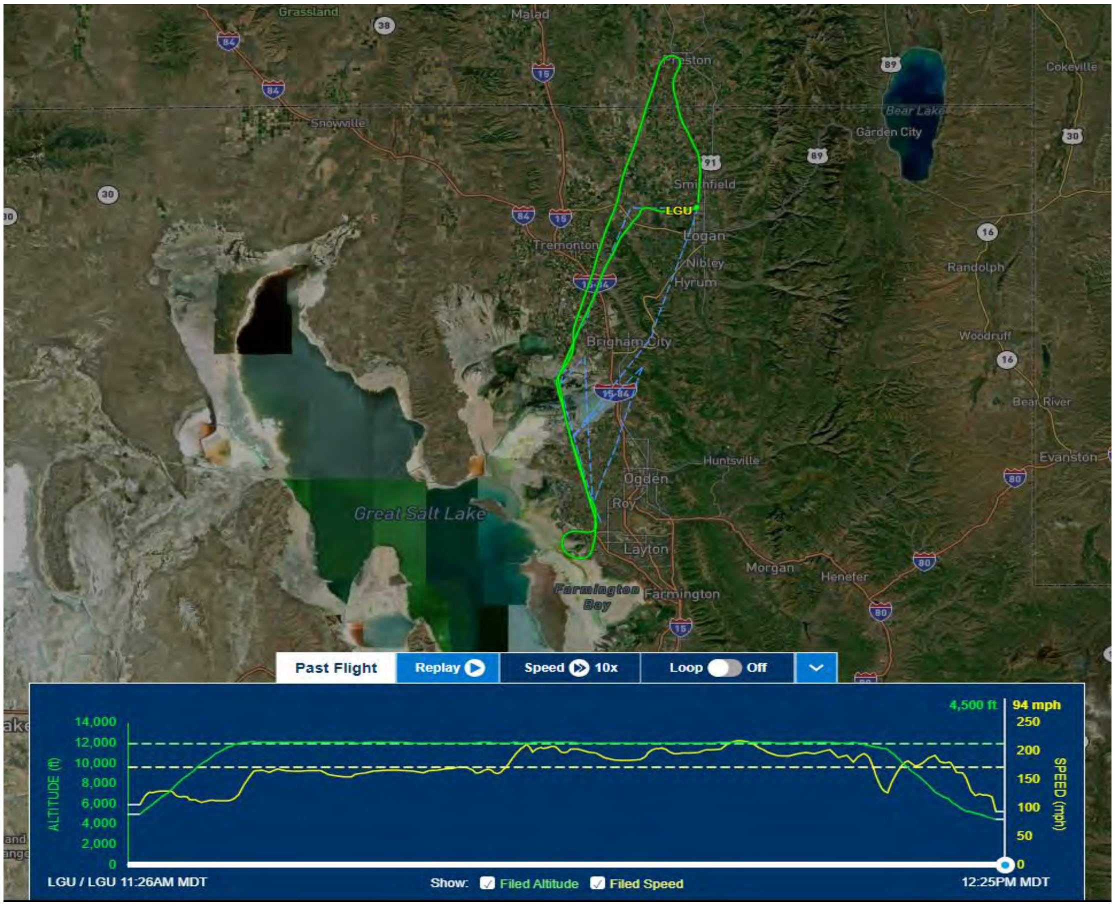


Figure 5.27. **Flight track data from first seeding flight on March 28, 2024.**

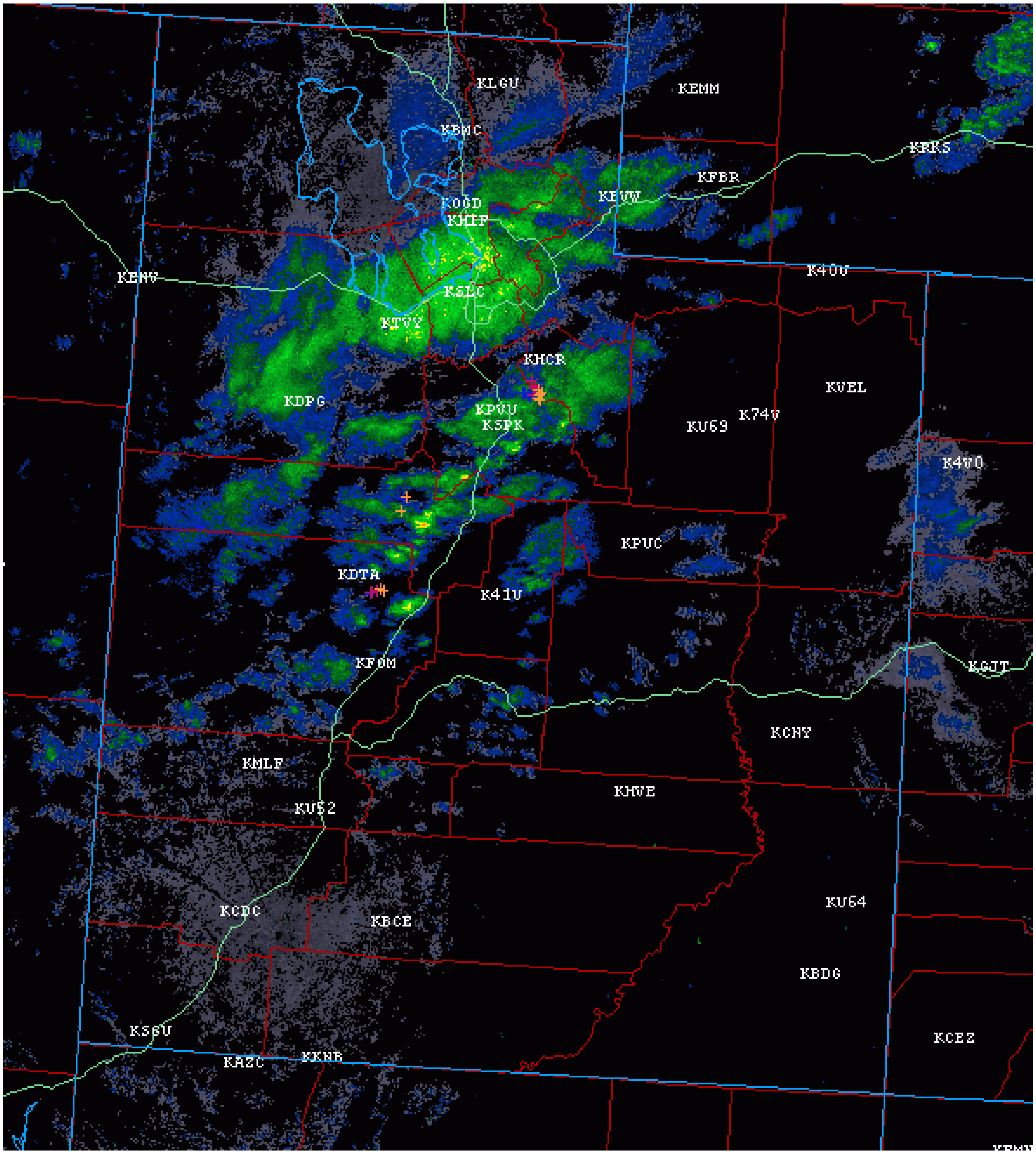


Figure 5.28. **Radar image with lightning strikes superimposed from 1555 MDT on March 28, 2024. Note cluster of strikes south of Heber City (KHCR).**

Figure 5.29. **Flight track data from second flight on March 28, 2024.**

March 30, 2024

A cold closed upper low was located off the northern California coast west of San Francisco and was slowly pushing southward. The associated trough axis, oriented in a northeast-southwest fashion, extended from the central Canadian Prairies through the Great Basin (west of UT) and off the California coast. On the forward side of the trough, diffluent flow aloft was spreading across Utah within a south to southwesterly flow regime. A frontal boundary that had been stretched across central Utah was moving back northward as a warm front. The south/southwesterly flow was expected to increase during the day, with the diffluent pattern aiding in increasing large-scale lift and subsequent development of rain and snow across central and northern Utah. PWAT values were around 0.45" as measured on the morning sounding from Salt Lake City, and a fairly moist atmospheric profile existed up to around 300 mb (approximately 34 kft MSL). 700 mb temperatures were ideal, around -5°C. For this day, seeding for the Uinta Mountains appeared to be the best targeted effort at seeding, and a flight plan was developed with a flight track south of the Uinta range, from roughly Tabiona to Whiterocks. The plane left LGU at 1004

MDT and initially ascended to 12 kft, but after about an hour the pilot was re-positioned up to 16 kft prior to getting to the flight track zone. The pilot began firing flares upon reaching the south side of the Uintas and seeding continued for about an hour before the plane turned to head back to LGU, landing at 1203 MDT, having burned 18 BIP flares with the pilot reporting that there were pockets of “good moisture”. Figure 5.30 shows visible satellite imagery from 1121 MDT, during the flight, and Figure 5.31 shows the flight data from this first flight. As conditions continued to be favorable for seeding, the plane refueled and launched at 1240 MDT, once again heading down to the same flight track zone, only this time the plane’s cruising altitude was 14 kft. Seeding commenced and continued for over an hour with what the pilot again described as “pockets of decent moisture” before the plane headed back to LGU, landing at 1441 MDT and having burned 25 ejectable flares. Figure 5.32 shows a radar image during the second flight, and Figure 5.33 shows the flight data from the second flight.

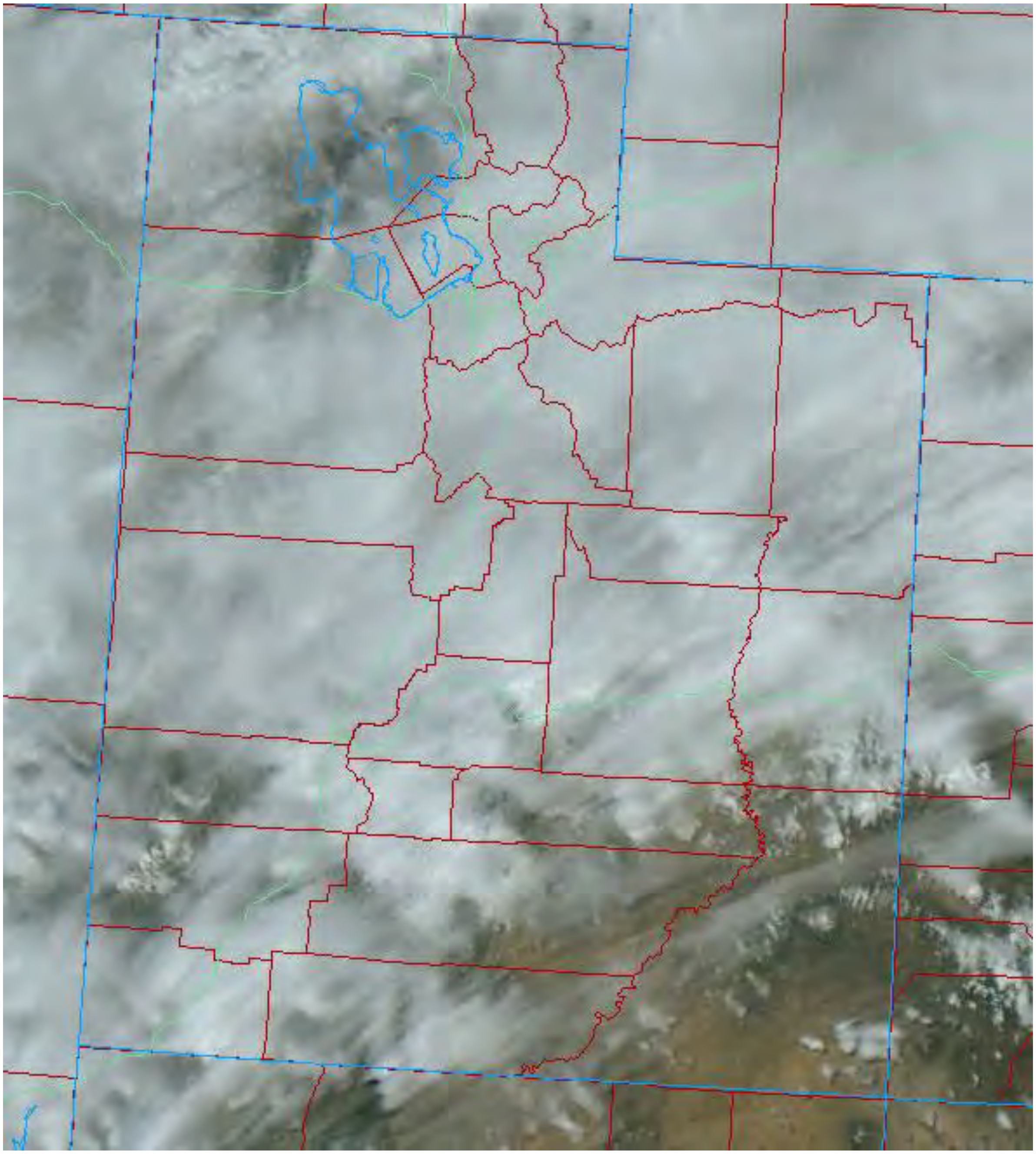


Figure 5.30. **Visible satellite image from 1121 MDT on March 30, 2024.**

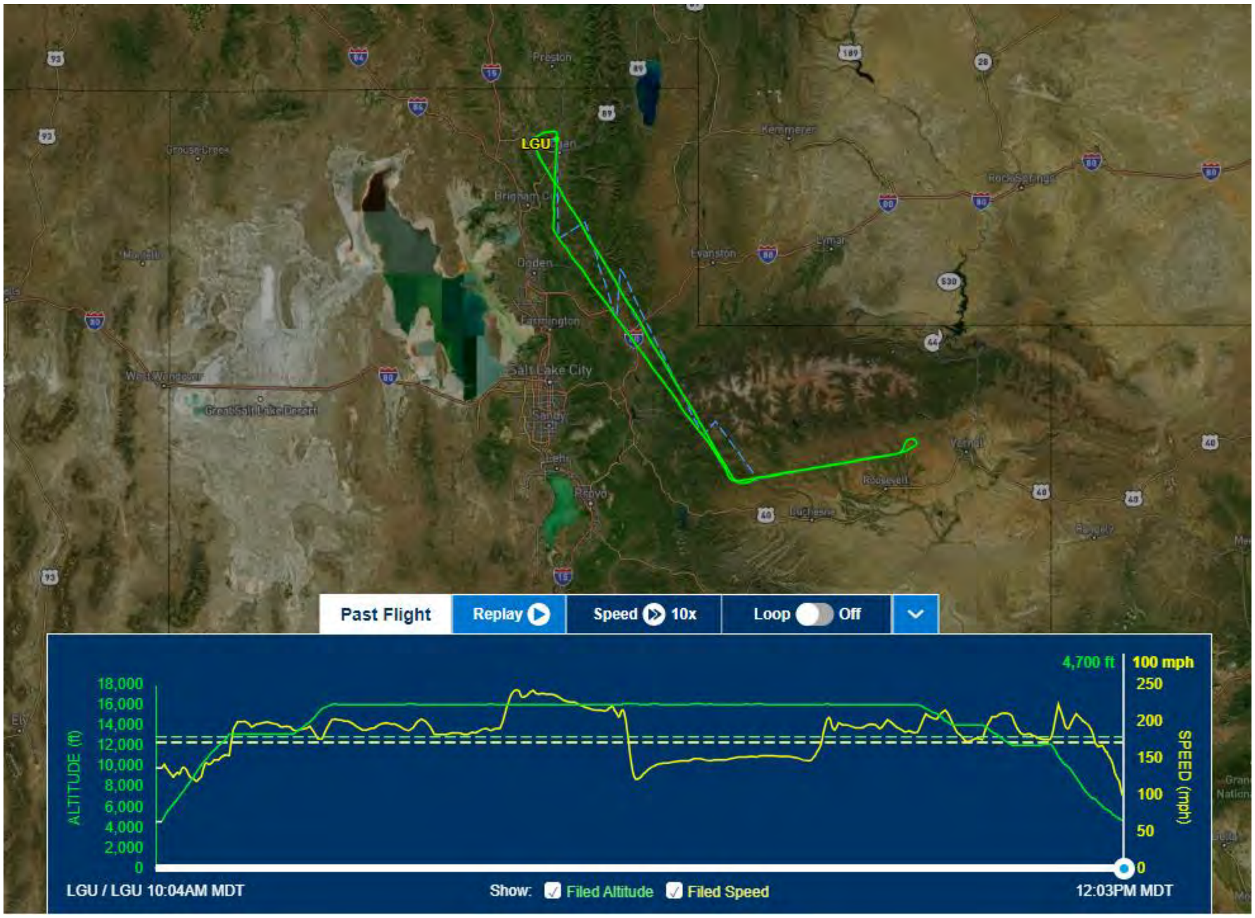


Figure 5.31. Flight track data from first seeding flight on March 30, 2024.

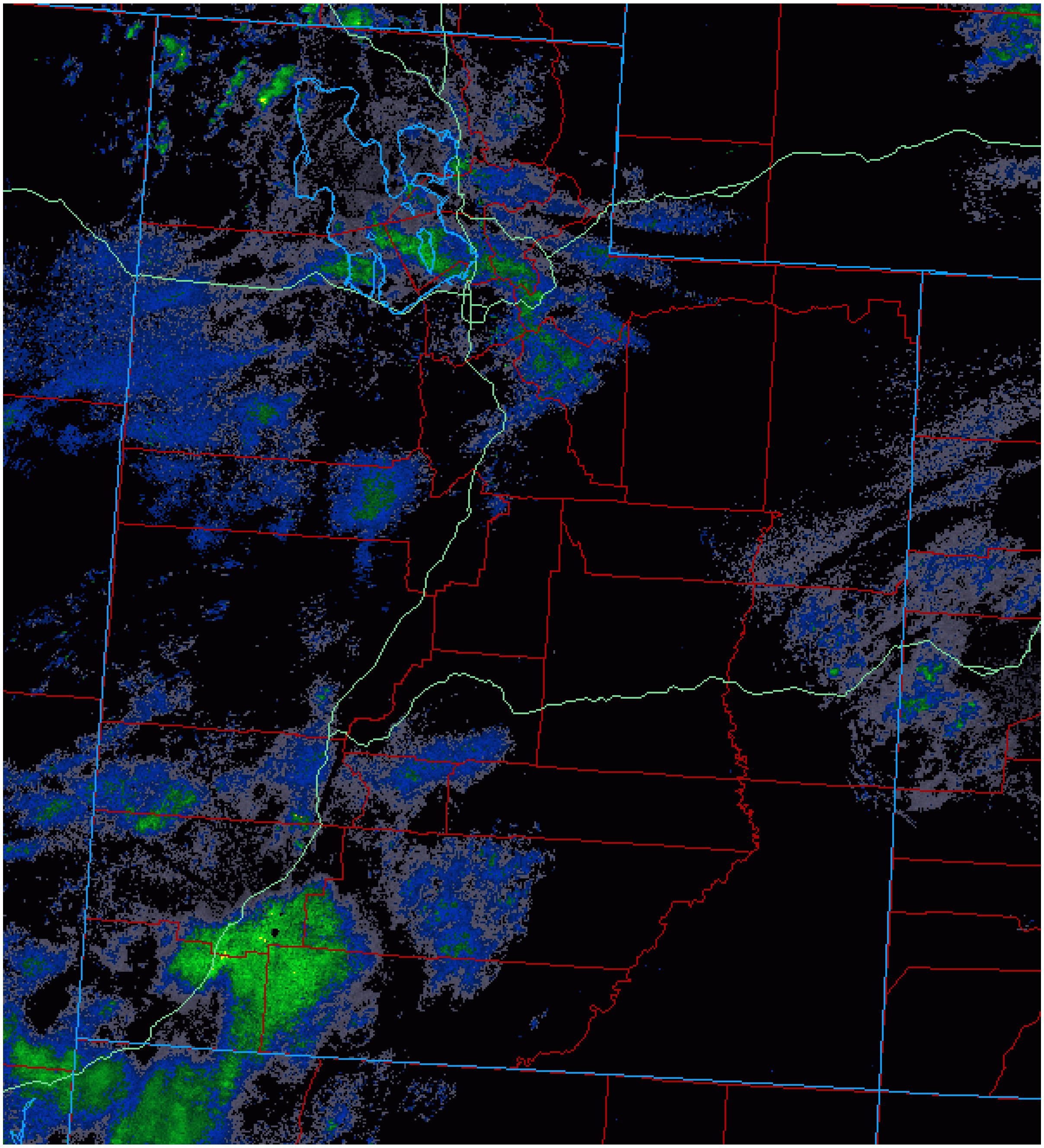


Figure 5.32. Radar image from 1335 MDT on March 30, 2024 during second flight.

Figure 5.33. **Flight track data from second flight on March 30, 2024.**

March 2024 Suspensions/Missed Flying Opportunities

For the storm events in the first half of the month, a combination of scattered thunderstorms (March 2-3, 7, 12), strong winds aloft (March 2-3) and very cold temperatures outside of the desired -5°C to -15°C range (March 2-3) resulted in flying suspensions in place. Thunderstorms during the seeding mission on March 28 occurred after the plane was airborne, but the activity remained just outside of the flight track zone.

April 2024

The busy weather pattern that had been in place for much of the winter began to settle down a bit in April, however there were still two storm events that impacted Utah during the first half of the month. Due to the nature of the storms themselves, no seeding flights took place during the month, with explanations given in the following sub-section. Figure 5.34 shows the precipitation across Utah for April. In spite of the two storm systems that affected Utah, precipitation for the month was well below normal.

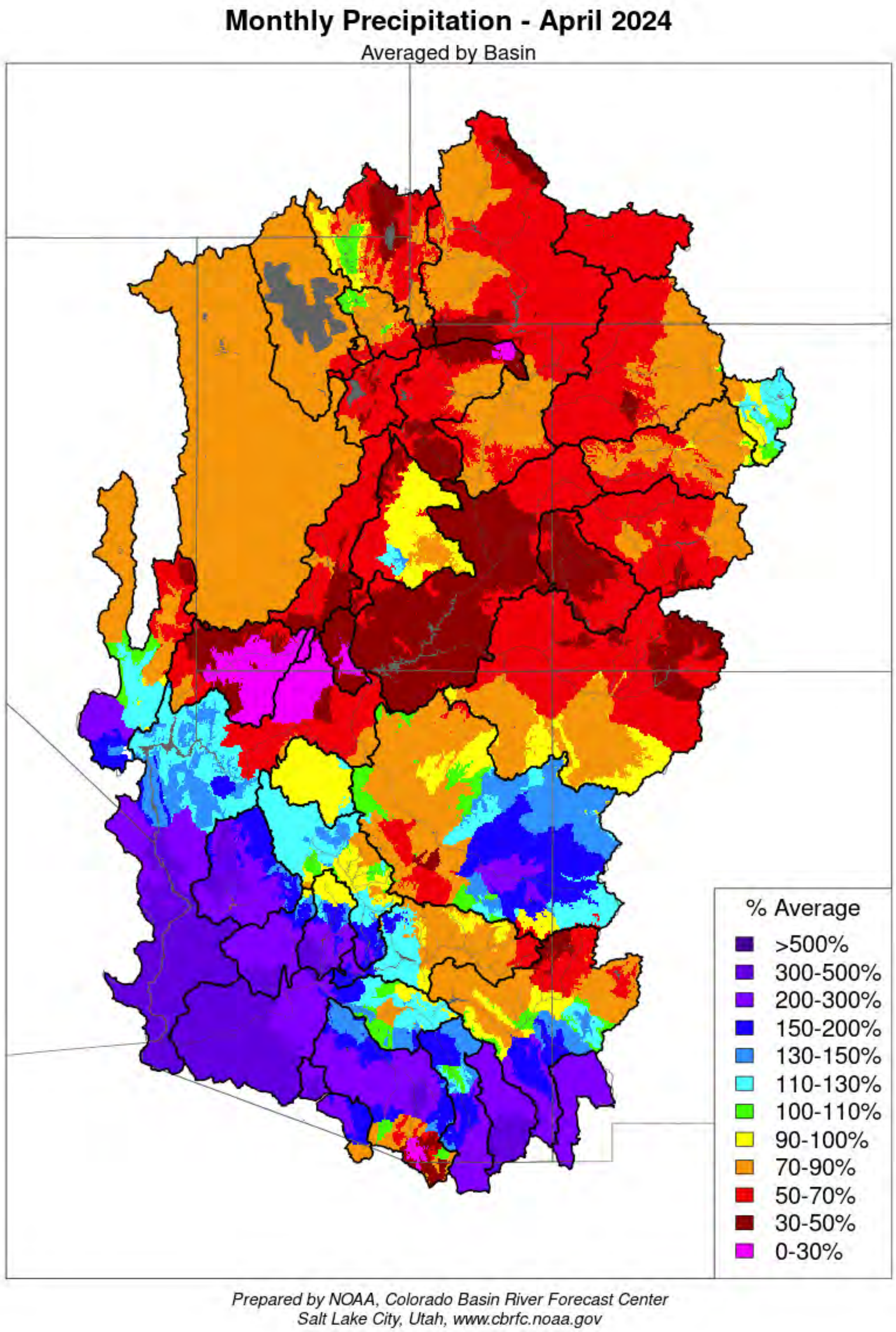


Figure 5.34. April 2024 precipitation as a percent of average for the month.

April 2024 Suspensions/Missed Flying Opportunities

With the storm on April 5-6, strong southerly winds up to 60 knots were observed from the Salt Lake City radar; this was not an ideal setup for aerial seeding in terms of targeting the north-south mountain ranges and the speed with which the wind was blowing. On April 15, an upper low moving across the state resulted in a wind regime across northern Utah that did not allow for proper targeting of the mountain ranges until most of the precipitation had ended.

6.0 SUMMARY AND RECOMMENDATIONS

The 2023-24 winter season marked the inaugural year of operation for the Northern Utah Aerial Program (NUAP) which followed a design similar to the sister project, the Southern Utah Aerial Program (SUAP). An active weather pattern for much of the winter resulted in an above normal snowpack and above normal precipitation for the northern half of Utah. Despite the active weather pattern in place, only 14 flights over 10 storm events were able to launch to conduct seeding operations. Reasons for this are presented below.

In many instances, weather conditions were the reason for suspensions or missed opportunities: lightning, severe turbulence and icing, temperatures too cold or too warm for effective seeding (i.e., outside of the -5°C to -15°C range), ceilings and visibilities below minimums and strong winds at or above 60 kt. These sorts of issues are expected on a seasonal basis and were not entirely surprising, although the frequency with which conditions resulted in "no-fly" decisions were surprising. In one case, a decision that was made in an attempt to expedite an overnight flight turned out to contribute directly to the cancellation of the flight; ahead of one storm event in December, where it was believed that having the plane parked outside for an overnight flight would make for a fast turn-around as it avoided having to make a "call-out", the decision ended up costing a flight as the plane became coated in ice and could not be flown until the ice had melted, a problem that would not have occurred if the plane had remained in the hangar. Furthermore, the Logan-Cache Airport (LGU) sits in the Cache Valley, which frequently is subject to strong inversions and periods of fog/low clouds and low visibility in the December-February period, which can make seeding flights difficult if ceilings and visibilities are below minimum thresholds for taking off/landing.

Unlike with SUAP, no pre-determined fixed tracks were set for NUAP, but instead tracks were chosen on a storm-by-storm case, fitting in with the given atmospheric conditions accompanying each storm. Most of the seeding flights this first season focused on the northern Wasatch Mountains and Bear River Range, with the Uinta Mountains seeing the remainder of the seeding efforts. It is important when discussing the seeding targeting with this program to keep in mind that some areas are/were off-limits for the aircraft tracks, particularly the area west of the central Wasatch Mountains due to the concentration of the population from roughly Ogden southward to Provo. This area also experiences the most amount of air traffic in the state with Salt Lake City International Airport located here. Military airspace is also located nearby, in Tooele County and this area is also off-limits.

With regards to communication with the pilot while airborne, for the 2023-24 season, there was no satellite phone in the plane, and texting did not work with the plane and meteorologist at opposite ends of the state. Although this did not negatively impact seeding operations, going forward, it is strongly advised that there should be a method of communication available to the pilot and meteorologist during flights. A satellite phone or similar device that would, at least allow for texting between pilot and meteorologist should be utilized.

NAWC considers the primary season for NUAP to be more of a learning experience versus a success considering the amount of "no-fly" decisions that were made, particularly given the active weather pattern that was in place for a majority of the season. Decisions regarding the use of a slightly different approach to seeding could be (and could have been) made for certain situations, such as flying near the top of cloud decks given ample moisture and ideal temperatures if in-cloud seeding becomes susceptible to excessive icing, for example. The approach to aerial cloud seeding for NUAP was done in a manner more similar to operations with the Kings Program in central California, which was almost exclusively in-cloud seeding, accounting for excess ice accumulation by descending to a lower, warmer altitude to shed ice before returning to altitude. One stark difference is that most times in Utah in the winter, descending to a lower altitude to shed ice would not be possible given the usual cold airmasses in place, with freezing temperatures all the way to the surface. In these cases, the "on-top" seeding method may have to be used more often.

NAWC believes, for future seasons, that the best approach for aerial seeding in Utah, would be to station a seeding aircraft at St. George in the far southwest part of the state and focus aerial seeding efforts on the central and southern parts of Utah. Ground-based seeding sites in that portion of the state are also less concentrated compared to the network of ground seeding sites across northern Utah. While central and southern Utah would be the main focus for seeding efforts from the air, in the event that an incoming storm might only impact northern Utah, a decision could be made to temporarily position the aircraft in or nearby northern Utah locations and conduct seeding operations as long as safe flying and ideal seeding conditions allow. Perhaps seeding for the NUAP could also be focused on only some portions of the season (e.g. November, plus March – April) with the aircraft stationed elsewhere such as in southern Utah during the December – February period. If it is desired that NUAP continues as is for a second season, it is suggested that a different airport be chosen for stationing the plane, one that does not suffer from inversions in the manner that is seen at LGU. The airport should also have hangar space to house the plane from icing conditions, and ideally might have fuel access 24/7.

APPENDIX A

SUSPENSION CRITERIA

Certain situations require temporary or longer-term suspension of cloud seeding activities, with reference to well-considered criteria for consideration of possible suspensions, to minimize either an actual or apparent contribution of seeding to a potentially hazardous situation. The ability to forecast (anticipate) and judiciously avoid hazardous conditions is very important in limiting any potential liability associated with weather modification and to maintain a positive public image.

There are three primary hazardous situations around which suspension criteria have been developed. These are:

- Excess snowpack accumulation
- Rain-induced winter flooding
- Severe weather

Excess Snowpack Accumulation

Snowpack begins to accumulate in the mountainous areas of Utah in November and continues through April. The heaviest average accumulations normally occur from January through March. Excessive snowpack water content becomes a potential hazard during the resultant snowmelt. The Natural Resources Conservation Service (NRCS) maintains a network of high elevation snowpack measurement sites in the State of Utah, known as the SNOTEL network. SNOTEL automated observations are now readily available, updated as often as hourly. The following set of criteria, based upon observations from these SNOTEL site observations, has been developed as a guide for potential suspension of operations.

Project & Basin	Critical Streamflow Volume (Acft) & USGS Streamgage	SNOTEL Station	SWE Value Corresponding to the Critical Flow								Ranking of SNOTEL Stations
			Jan 1 (in.)	Jan 1 (%)	Feb 1 (in.)	Feb 1 (in %)	March 1 (in.)	March 1 (in %)	April 1 (in.)	April 1 (in %)	
1. Northern Utah	185,208	Franklin Basin, Idaho	19.50	190.84	27.14	165.31	34.35	154.71	41.56	153.60	1
Logan at Logan	USGS 10109000	Tony Grove	28.73	205.94	39.44	175.56	48.06	160.38	56.34	156.56	2
		Bug Lake	17.08	218.82	21.91	180.34	26.72	165.25	31.65	162.70	3
		Average	**21.80**	**205.20**	**29.50**	**173.70**	**36.40**	**160.10**	**43.20**	**157.60**	
Weber near Oakley	176,179	Chalk Creek #1	10.09	173.13	14.73	153.66	28.77	149.85	34.15	143.41	1
	USGS 10128500	Trial Lake	20.15	207.44	26.33	180.55	33.55	173.27	38.54	162.28	2
		Smith Morehouse	10.06	186.34	13.69	137.60	17.36	146.32	21.17	160.26	3
		Hayden Fork	12.19	194.16	16.69	172.11	20.71	158.56	21.79	164.64	4
		Average	**13.10**	**190.30**	**17.90**	**166.00**	**25.10**	**157.10**	**28.90**	**157.70**	
Dunn Creek near	5,733	George Creek	17.84	187.75	18.32	143.81	28.93	163.43	34.61	153.77	1
the Park Valley	USGS 10172952	Howell Canyon, Idaho	28.71	279.96	38	223.24	44.59	205.98	50.46	191.65	2
		Average	**23.30**	**233.90**	**28.20**	**183.60**	**36.80**	**184.70**	**42.60**	**172.70**	
2. Western & High Uintah	166,861	Lily Lake	11.38	202.70	16.40	194.06	17.69	147.37	28.93	139.19	1
Bear River near Utah -	USGS 10011500	Trial Lake	20.07	206.54	26.56	182.26	33.68	173.94	38.49	162.05	2
Wyoming state line		Hayden Fork	12.41	197.65	17.06	175.83	21.03	160.98	20.90	146.02	3
		Average	**14.60**	**202.30**	**20.00**	**184.10**	**24.10**	**160.80**	**29.40**	**149.10**	
Duchesne near Tabiona	140,976	Strawberry Divide	6.92	239.23	10.87	199.25	26.77	178.78	29.75	179.05	1
	USGS 09277500	Daniels-strawberry	16.07	248.12	21.59	202.44	27.82	190.54	29.89	192.75	2
		Smith Morehouse	10.61	196.64	14.95	172.41	18.82	158.83	22.22	168.26	3
		Rock Creek	8.76	230.02	12.31	219.65	15.88	205.68	16.41	209.06	4
		Average	**10.60**	**228.50**	**14.90**	**198.50**	**22.30**	**183.50**	**24.60**	**187.30**	
Provo near woodland	183,845	Trial Lake	22.98	236.53	27.78	190.63	35.23	181.59	31.44	132.39	1
	USGS 09277500	Beaver Divide	10.29	210.39	14.11	179.49	17.45	170.83	20.18	200.3	2
		Average	**16.70**	**223.50**	**20.90**	**185.10**	**26.30**	**176.20**	**25.80**	**166.40**	
3. Central & Southern	120,473	Castle Valley	12.23	244.05	16.96	203.04	22.22	187.68	26.30	180.00	1
Sevier near Hatch	USGS 10174500	Harris Flat	8.71	298.76	15.25	273.59	24.16	222.99	21.15	209.77	2
		Farnsworth Lake	17.25	218.10	20.96	185.95	27.05	182.24	32.93	167.03	3
		Average	**12.80**	**253.70**	**17.70**	**220.90**	**24.50**	**197.70**	**26.80**	**185.60**	
Coal Creek near	38,533	Midway Valley	20.89	215.65	29.12	194.04	35.89	176.99	42.29	167.97	1
Cedar City	USGS 10242000	Webster Flat	13.57	232.46	18.70	197.95	24.30	184.64	24.93	181.12	2
		Average	**17.20**	**224.10**	**23.90**	**196.00**	**30.10**	**180.90**	**33.60**	**174.60**	
South Willow near	5,426	Rocky Basin-settlemnt	19.09	205.33	23.75	174.14	32.11	171.39	40.01	167.51	1
Grantsville	USGS 10172800	Mining Fork	16.31	243.66	20.74	177.04	27.81	171.79	32.19	168.74	2
		Average	**17.70**	**224.50**	**22.30**	**175.60**	**30.00**	**171.60**	**36.10**	**168.10**	
Virgin River at Virgin	151,286	Kolob	23.11	229.25	29.08	220.78	36.51	197.43	43.71	196.21	1
	USGS 09406000	Harris Flat	9.71	377.00	15.69	304.18	21.46	300.00	20.11	370.00	2
		Midway Valley	24.76	256.17	34.56	238.40	41.44	209.68	51.05	211.06	3
		Long Flat	9.38	265.88	13.54	286.16	19.20	286.18	18.91	187.00	4
		Average	**16.70**	**282.10**	**23.20**	**262.40**	**29.70**	**248.40**	**33.40**	**241.10**	
Santa Clare above Baker	11,620	Gardner Peak	13.00	293.90	16.82	172.15	21.70	167.36	24.45	163.95	1
Reservoir	USGS 09409100	**Average**	**13.00**	**293.90**	**16.80**	**172.10**	**21.70**	**167.40**	**24.50**	**164.00**	
		Utah State Average (%)		**230**		**197**		**183**		**178**	
		Standard Deviation		**42**		**38**		**35**		**42**	
		Upper 95%		**248**		**213**		**199**		**196**	
		Lower 95%		**212**		**180**		**168**		**160**	

Snowpack-related suspension considerations will be assessed on a geographical division or sub-division basis. The NRCS has divided the State of Utah into 13 such divisions as follows: Bear River, Weber-Ogden Rivers, Provo River-Utah Lake-Jordan River, Tooele Valley-Vernon Creek, Green River, Duchesne River, Price-San Rafael, Dirty Devil, Southeastern Utah, Sevier River, Beaver River, Escalante River, and Virgin River. Since SNOTEL observations are available on a daily basis, suspensions (and cancellation of suspensions) can be made on a daily basis using linear interpolation of the first of month criteria. There are a number of SNOTEL stations in the various basins of central and southern Utah on which these criteria are based. These include Castle Valley, Harris Flat, and Farnsworth Lake in the Sevier Basin; Midway Valley, Kolob, Harris Flat, Webster Flat, and Long Flat in southwestern Utah; and Rocky Basin Settlement and Mining Fork in eastern Tooele County.

Streamflow forecasts, reservoir storage levels, soil moisture content and amounts of precipitation in prior seasons are other factors which need to be considered when the potential for suspending seeding operations due to excess snowpack water content exists.

Rain-induced Winter Floods

The potential for wintertime flooding from rainfall on low elevation snowpack is fairly high in some (especially the more southern) target areas during the late winter/early spring period. Every precaution must be taken to insure accurate forecasting and timely suspension of operations during these potential flood-producing situations. The objective of suspension under these conditions is to eliminate both the real and/or perceived impact of weather modification when any increase in precipitation has the potential of creating a flood hazard.

Severe Weather

During periods of hazardous weather associated with both winter orographic and convective precipitation systems it is sometimes necessary or advisable for the National Weather Service (NWS) to issue special weather bulletins advising the public of the weather phenomena and the attendant hazards. Each phenomenon is described in terms of criteria used by the NWS in issuing special weather bulletins. Those which may be relevant in the conduct of winter cloud seeding programs include the following:

- **Winter Storm Warning** - This is issued by the NWS when it expects heavy snow warning criteria to be met, along with strong winds/wind chill or freezing precipitation.
- **Flash Flood Warning** - This is issued by the NWS when flash flooding is imminent or in progress. In the Intermountain West, these warnings are generally issued relative to, but are not limited to, fall or spring convective systems.
- **Severe Thunderstorm Warning** – This is issued by the NWS when thunderstorms producing winds of 58 mph or higher and/or 1” or larger hail.
- **SIGMETs** – SIGnificant METeorological Information regarding the presence of convection (thunderstorms), significant icing or turbulence that could be hazardous to aircraft

Seeding operations may be suspended whenever the NWS issues a weather warning for or adjacent to any target area. Since the objective of the cloud seeding program is to increase winter snowfall in the mountainous areas of the state, operations will typically not be suspended when Winter Storm Warnings are issued, unless there are special considerations (e.g., a heavy storm that impacts Christmas Eve travel).

Flash Flood and Severe Thunderstorm Warnings are usually issued when intense convective activity causing heavy rainfall/strong winds/hail is expected or is occurring. Although the probability of this situation occurring during our core operational seeding periods is low, the potential does exist, especially over southern sections of the state during late March and April. The type of storm that may cause problems is one that has the potential of producing 1-2 inches (or greater) of rainfall in approximately a 24-hour period, combined with high freezing levels (e.g., > 8,000 feet MSL). Seeding operations will be suspended for the duration of the warning period in the affected areas.

SIGMETs are crucial to airborne seeding operations, as their issuances relate to the presence of hazardous conditions that may result in temporary suspensions. Convective SIGMETs are issued when thunderstorms are expected to impact a given area, and generally last up to two hours at a time but may be re-issued if the threat continues. Non-convective SIGMETs are issued for hazards such as severe/extreme turbulence or severe icing, and last up to four hours at a time, again, with the potential for extensions if these conditions continue to exist.

NAWC's project meteorologists have the authority to temporarily suspend localized seeding operations due to development of hazardous severe weather conditions even if the NWS has not issued a warning. This would be a rare event, but it is important for the operator to have this latitude.

APPENDIX B

GLOSSARY OF METEOROLOGICAL TERMS

Advection: Movement of an air mass. Cold advection describes a colder air mass moving into the area, and warm advection is used to describe an incoming warmer air mass. Dry and moist advection can be used similarly.

Air Mass/airmass: A term used to describe a region of the atmosphere with certain defining characteristics. For example, a cold or warm air mass, or a wet or dry air mass. It is a fairly subjective term but is usually used in reference to large (synoptic scale) regions of the atmosphere, both near the surface and/or at mid and upper levels of the atmosphere.

Atmospheric River/AR: A long, narrow and transient corridor of strong horizontal water vapor transport that is typically associated with a low level jet stream ahead of the cold front of a low pressure system. The water vapor in ARs is supplied by tropical and subtropical moisture sources and frequently produces heavy precipitation where they are forced upward, e.g., by mountains or dynamic lifting.

Balloon Sounding: see Sounding.

Cell: in radar usage, a local maximum in radar reflectivity that undergoes a life cycle of growth and decay, having both an updraft and a downdraft region.

Cold-core low: A typical mid-latitude type of low pressure system, where the core of the system is colder than its surroundings. This type of system is also defined by the cyclonic circulation being strongest in the upper levels of the atmosphere. The opposite is a warm-core low, which typically occurs in the tropics.

Cold Pool: An air mass that is cold relative to its surroundings and may be confined to a particular basin.

Condensation: Phase change of water vapor into liquid form. This can occur on the surface of objects (such as dew on the grass) or in mid-air (leading to the formation of clouds). Clouds are technically composed of water in liquid form, not water vapor.

Confluent: Wind vectors coming closer together in a two-dimensional frame of reference (opposite of diffluent). The term convergence is also used similarly.

Convective (or convection): Pertains to the development of precipitation areas due to the rising of warmer, moist air through the surrounding air mass. The warmth and moisture contained in a given air mass makes it lighter than colder, dryer air. Convection often leads to small-scale, locally heavy showers or thundershowers. The opposite precipitation type is known as stratiform precipitation.

Convergence: Refers to the converging of wind vectors at a given level of the atmosphere. Low-level convergence (along with upper-level divergence), for instance, is associated with lifting of the air mass which usually leads to development of clouds and precipitation. Low-level divergence (and upper-level convergence) is associated with atmospheric subsidence, which leads to drying and warming.

Cyclonic Flow: Counter-clockwise motion, primarily around low pressure (cyclone).

Deposition: A phase change where water vapor turns directly to solid form (ice). The opposite process is called sublimation.

Dew point: The temperature at which condensation occurs (or would occur) with a given amount of moisture in the air.

Diffluent: Wind vectors spreading further apart in a two-dimensional frame of reference; opposite of confluent.

Disturbance: see Low pressure, shortwave.

Dry slot: A zone of dry (and usually cloud-free) air that wraps into the southern and eastern parts of a low pressure system; easily viewed on satellite imagery.

Entrain: Usually used in reference to the process of a given air mass being ingested into a storm system.

Evaporation: Phase change of liquid water into water vapor. Water vapor is usually invisible to the eye.

El Niño: A reference to a particular phase of oceanic and atmospheric temperature and circulation patterns in the tropical Pacific, where the prevailing easterly trade winds weaken or dissipate. Often has an effect on mid-latitude patterns as well, such as increased precipitation in southern portions of the U.S. and decreased precipitation further north. The opposite phase is called La Nina.

Front (or frontal zone): Reference to a temperature boundary with either incoming colder air (**cold front**) or incoming warmer air (**warm front**); can sometimes be a reference to a stationary temperature boundary line (stationary front) or a more complex type known as an occluded front (where the temperature change across a boundary can vary in type at different elevations).

Frontal band: A band of clouds/precipitation along a cold or warm front.

Glaciogenic: Ice-forming (aiding the process of nucleation); usually used in reference to cloud seeding nuclei.

GMT (or UTC, or Z) time: Greenwich Mean Time, universal time zone corresponding to the time at Greenwich, England. Pacific Standard Time (PST) = GMT – 8 hours; Pacific Daylight Time (PDT) = GMT – 7 hours.

Graupel: A precipitation type that can be described as "soft hail", that develops due to riming (nucleation around a central core). It is composed of opaque (white) ice, not clear hard ice such as that contained in hailstones. It usually indicated the presence of convective clouds and can be associated with electrical charge separation and occasionally lightning activity.

High Pressure (or Ridge): Region of the atmosphere usually accompanied by dry and stable weather. Corresponds to a northward bulge of the jet stream on a weather map, and to an anti-cyclonic (clockwise) circulation pattern.

Infrared (satellite): imagery sensed in the 3-13 μm wavelength region of the electromagnetic spectrum, usually referring to the thermal infrared region.

Inside Slider: A trough or area of low pressure that moves south-southeast along or parallel to the Sierra Nevada mountains before swinging east into the Great Basin or Desert Southwest. These systems typically do not have much moisture with them but can have cold to very cold air accompanying them. The track of these systems typically brings Santa Ana winds as they increase the northeast-southwest pressure gradient.

Inversion: Refers to a layer of the atmosphere in which the temperature increases with elevation, usually associated with stability.

Jet Stream or Upper-Level Jet (sometimes referred to more generally as the storm track): A region of maximum wind speed, usually in the upper atmosphere that usually coincides with the main storm track in the mid-latitudes. This is the area that also typically corresponds to the greatest amount of mid-latitude synoptic-scale storm development.

La Niña: The opposite phase of that known as El Nino in the tropical Pacific. During La Nina the easterly tropical trade winds strengthen and can lead in turn to a strong mid-latitude storm track, which often brings wetter weather to northern portions of the U.S.

Longwave (or longwave pattern): The longer wavelengths, typically on the order of 1,000 – 2,000+ miles of the typical ridge/trough pattern around the northern (or southern) Hemisphere, typically most pronounced in the mid-latitudes.

Low-Level Jet: A zone of maximum wind speed in the lower atmosphere. Can be caused by geographical features or various weather patterns and can influence storm behavior and dispersion of cloud seeding materials.

Low pressure (or low or trough): Region of the atmosphere usually associated with stormy weather. Corresponds to a southward dip to the jet stream on a weather map as well as a cyclonic (counterclockwise) circulation pattern in the Northern Hemisphere.

Mesoscale: Sub-synoptic scale, about 100 miles or less; this is the size scale of more localized weather features (such as thunderstorms or mountain-induced weather processes).

Microphysics: Used in reference to composition and particle types in a cloud.

Mid-level: the layer of the atmosphere from 10-20 kft.

Millibar (mb): a unit of pressure equal to 100 newtons per square meter (N/m^2).

MSL (Mean Sea Level): Elevation height reference in comparison to sea level.

Negative (ly) tilted trough: A low-pressure trough where a portion is undercut, such that a frontal zone can be in a northwest to southeast orientation.

Nucleation: The process of supercooled water droplets in a cloud turning to ice. This is the process that is aided by cloud seeding. For purposes of cloud seeding, there are three possible types of cloud composition: Liquid (temperature above the freezing point), supercooled (below freezing but still in liquid form), and ice crystals.

Nuclei: Small particles that aid water droplet or ice particle formation in a cloud.

Orographic: Terrain-induced weather processes, such as cloud or precipitation development on the upwind side of a mountain range. Orographic lift refers to the lifting of an air mass as it encounters a mountain range.

Precipitable Water, or PWAT: The total atmospheric water vapor contained in a vertical column of unit cross-sectional area extending between the surface and top of the atmosphere, expressed in terms of the depth to which that water substance would be if completely condensed and collected in a vessel of the same unit cross-section.

Pressure Heights (e.g., 700 millibars, or mb): Corresponds to approximately 10,000 feet above sea level (MSL); 850 mb corresponds to about 5,000 feet MSL; and 500 mb corresponds to about 18,000 feet MSL. These are standard height levels that are occasionally referenced, with the 700 mb level most important regarding cloud-seeding potential in most of the western U.S.

Positive (ly) tilted trough: A normal U-shaped trough configuration, where an incoming cold front would generally be in a northeast– southwest orientation.

Reflectivity: The density of returned signal from a radar beam, which is typically bounced back due to interaction with precipitation particles (either frozen or liquid) in the atmosphere. The reflectivity depends on the size, number, and type of particles that the radar beam encounters.

Ridge (or High Pressure System): Region of the atmosphere usually accompanied by dry and stable weather. Corresponds to a northward bulge of the jet stream on a weather map, and to an anti-cyclonic (clockwise) circulation pattern.

Ridge axis: The longitude band corresponding to the high point of a ridge.

Rime (or rime ice): Ice buildup on an object (often on an existing precipitation particle) due to the freezing of supercooled water droplets.

Shortwave (or shortwave disturbance): Smaller-scale wave features of the weather pattern typically seen at mid-latitudes, usually on the order of a few to several hundred miles; these often correspond to individual frontal systems.

Silver iodide: A compound commonly used in cloud seeding because of the similarity of its molecular structure to that of an ice crystal. This structure helps in the process of nucleation, where supercooled cloud water changes to ice crystal form.

Sounding: A measurement of the vertical distribution of physical properties of the atmospheric column such as temperature, dewpoint, pressure, wind speed and direction. Soundings are typically conducted by releasing a balloon filled with hydrogen or helium with instrumentation attached that measures different properties as the balloon rises from the surface until it pops at very high altitudes (80-100 kft).

Stable layer: A layer of given thickness in the atmosphere where temperatures are constant with height or rise with height; this results in little to no vertical movement of the air and little to no turbulence/mixing.

Storm Track (sometimes referenced as the Jet Stream): A zone of maximum storm propagation and development, usually concentrated in the mid-latitudes.

Stratiform: Usually used in reference to precipitation, this implies a large area of precipitation that has a fairly uniform intensity except where influenced by terrain, etc. It is the result of larger-scale (synoptic scale) weather processes, as opposed to convective processes.

Sublimation: The phase change in which water in solid form (ice) turns directly into water vapor. The opposite process is deposition.

Subsidence: The process of a given air mass moving downward in elevation, such as often occurs on the downwind side of a mountain range.

Subtropical/subtropics: Referring to the region of the Earth bordering on the tropics, from the Tropic of Cancer/Capricorn (23.5°N/S) to about 35°N/S. **Subtropical moisture** would refer to moisture whose source region is the subtropics. **Subtropical Jet Stream** would refer to a jet stream within the subtropics.

Supercooled: Liquid water (such as tiny cloud droplets) occurring at temperatures below the freezing point (32°F or 0°C).

Synoptic Scale: A scale of hundreds to perhaps 1,000+ miles, the size scale at which high and low pressure systems develop.

Trough (or low pressure system): Region of the atmosphere usually associated with stormy weather. Corresponds to a southward dip to the jet stream on a weather map as well as a cyclonic (counterclockwise) circulation pattern in the Northern Hemisphere.

Trough axis: The longitude band corresponding to the low point of a trough.

Unstable air mass: an air mass wherein a perturbation (wave) increases in magnitude over time. A parcel of air displaced upward in an unstable airmass will continue to rise until it reaches equilibrium. Regions where, if moisture is sufficient, convection can develop if a mechanism (e.g., heating, frontal boundary) is present to initiate lift.

Upper level: The region of the atmosphere above 20 kft and below the tropopause (approx. 60-80 kft).

Upper-Level Jet or Jet Stream (sometimes referred to more generally as the storm track): A region of maximum wind speed, usually in the upper atmosphere that usually coincides with the main storm track in the mid-latitudes. This is the area that also typically corresponds to the greatest amount of mid-latitude synoptic-scale storm development.

Upper level low/trough/disturbance: an area of low pressure located at higher altitudes, e.g., at 700 mb / 10,000 feet MSL or 500 mb / 18,000 feet MSL.

UTC (or GMT, or Z) time: Greenwich Mean Time, universal time zone corresponding to the time at Greenwich, England. Pacific Standard Time (PST) = GMT – 8 hours; Pacific Daylight Time (PDT) = GMT – 7 hours.

Vector: Term used to represent wind velocity (speed + direction) at a given point.

Velocity: Describes speed of an object, often used in the description of wind intensities.

Vertical Wind Profiler: Ground-based system that measures wind velocity at various levels above the radar site.

Wave clouds: Clouds that form on the rising branches of mountain waves created within a stable airmass in strong flow downwind of mountains. On satellite imagery, they appear as spaced bands of clouds parallel to and downwind of the mountain barrier.