Annual Cloud Seeding Report

Southern Utah Aerial Program

2023-2024 Winter Season

Prepared For:

State of Utah, Division of Water Resources

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EXECUTIVE SUMMARY

The Southern Utah Aerial Program (SUAP), which had its inaugural season during the winter of 2022-23, continued for a second season, which ran from November 15, 2023 through April 15, 2024. Similar to last season, a Cessna 340 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 St. George Regional Airport in southwest Utah and was responsible for aerial-based cloud seeding to complement the Central and Southern Utah ground program from about Nephi southward (i.e., not including the Tooele County portion of the program).

The 2023-24 season was fairly active, with twenty-nine (29) storm events occurring in central and southern Utah during the five-month season. Of these, only six flights occurred over six storm events during the winter. Storms were distributed relatively evenly across the season, with one significant "dry period" during a sizeable portion of December. A total of 28 AgI BIP flares were used for seeding, totaling 560 g of AgI. Many of the 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 greatly hindered seeding operations. Additionally, one brief suspension period occurred near the end of the program, when an elevated risk for a potential dam breach at Panguitch Lake in southwestern Utah resulted in a temporary suspension of both ground and airborne seeding operations that would impact areas in and around that area in early April.

As this was only year two of aerial seeding operations, no statistical or numerical analysis was completed due to lack of data; it is believed that after several years of the program 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.

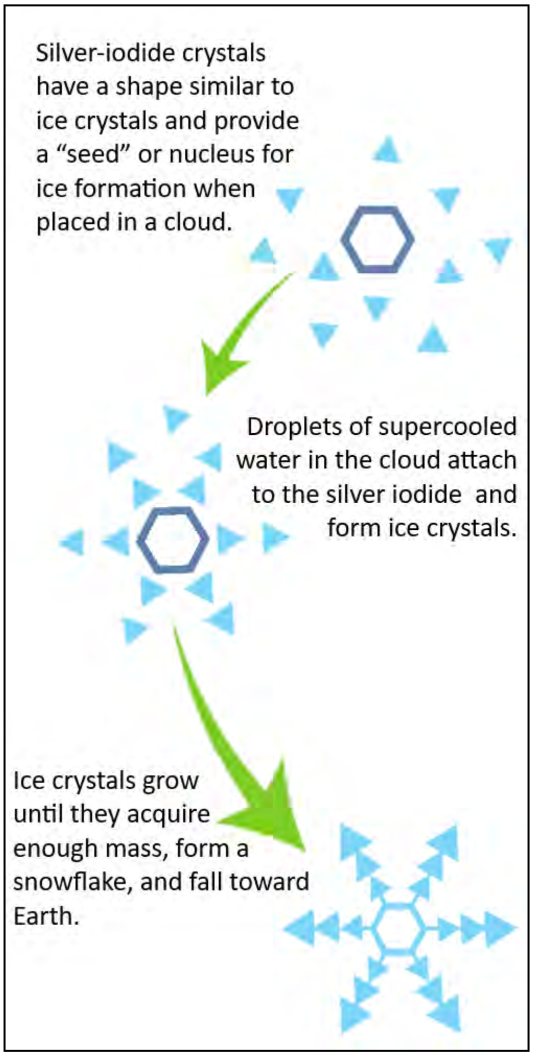
WEATHER MODIFICATION

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.

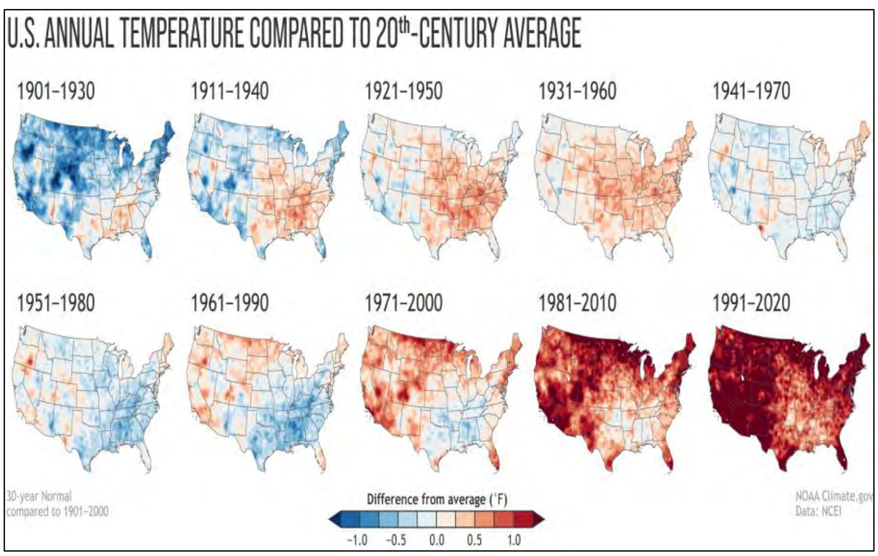


Figure 1. U.S. Annual Temperature compared to 20th-Century Average

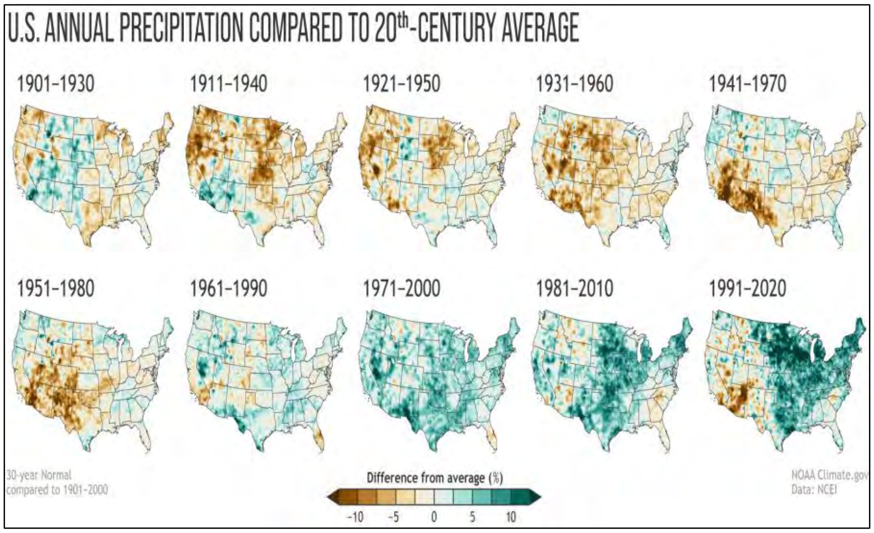


Figure 2. **U.S. Annual Precipitation compared to 20th-Century Average**

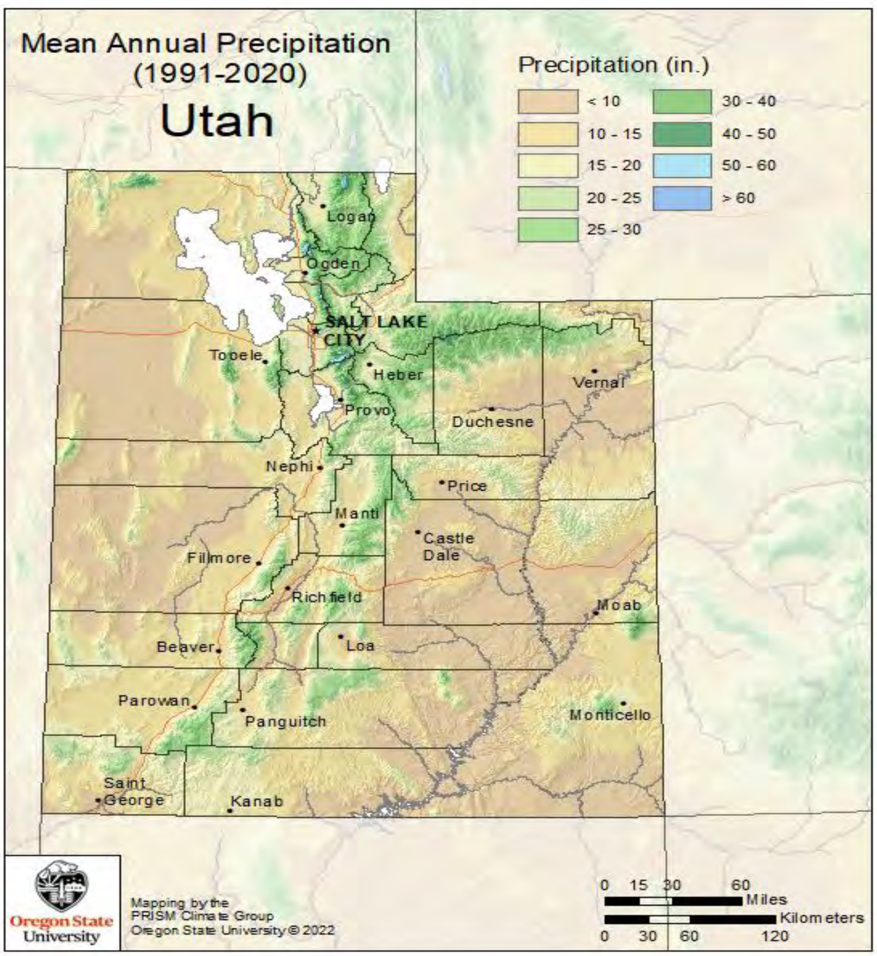


Figure 3. **Mean annual precipitation for the state of Utah based on 30-year period from 1991-2020.**

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 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) to discuss 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.

Through an agreement with Utah DWR wherein cost sharing was enabled, a four-year pilot program was proposed. The 2023-2024 winter season was the second year of this program, beginning on November 15, 2023, and continuing through April 15, 2024. The pilot and aircraft were, once again based in St. George as well as the meteorologist in charge of the program. This report will discuss the design, implementation and operation of the Southern Utah Aerial Program (SUAP) for the 2023-2024 season.

2.0 PROJECT DESIGN

The Southern Utah Aerial Program is conducted to affect the Central and Southern Utah mountains. The full target area is depicted in Figure 2.1. Airborne seeding capabilities were used, with the aircraft operated from the St. George Regional Airport (SGU) in St. George. 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.

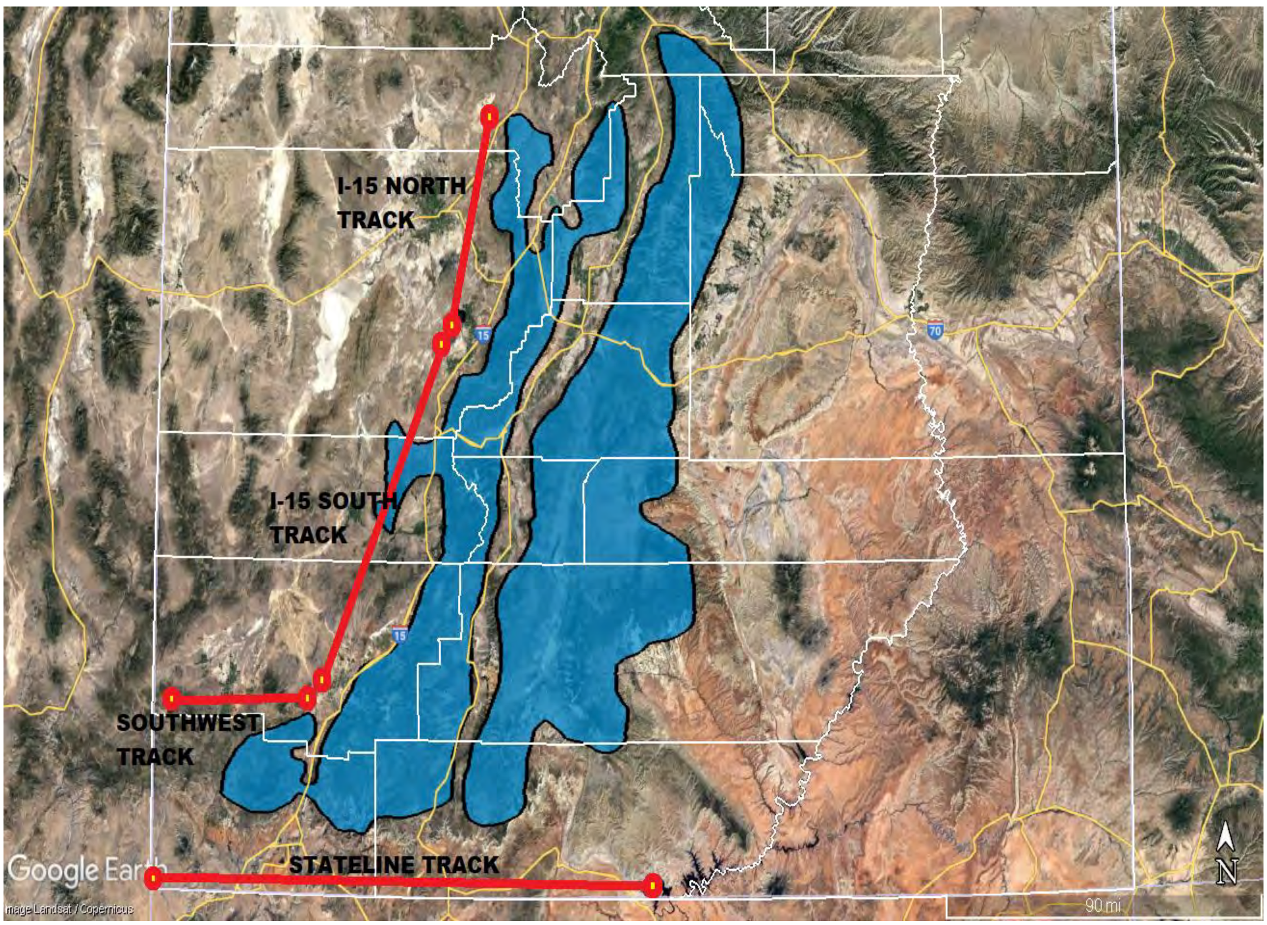


Figure 2.1. Southern Utah Aerial Program target areas, with the aerial seeding tracks in red.

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 Southern 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 Southern Utah Aerial Program design. NAWC's extensive previous experience with other seeding project design and operations has also been brought into play.

2.2 Southern Utah Aerial Seeding Project Design

We believe that the best project design for a winter cloud seeding program for the Central and Southern Utah Mountains to be one that incorporates, as much as possible, the core elements of the knowledge gained in earlier research in the mountainous western U.S., 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 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 Central/Southern 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 Central/Southern 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 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 November 15, 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 Cedar City (KICX) and Salt Lake City (KMTX) for the operation of the aerial cloud seeding program as both 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 340 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 held ejectable flares. Figure 3.1 shows the Cessna 340 seeding aircraft on the ramp at St. George Regional Airport.

Figure 3.1. **NAWC Cessna 340 cloud seeding aircraft on the ramp at St. George Regional Airport.**

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 Garmin GPS system with weather data reception and display capabilities onboard the aircraft provided useful NWS radar information directly to the pilot, along with the aircraft's position.

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

NAWC has established flight tracks for use on the Southern Utah Aerial Program. They are shown in Figure 3.3. The Stateline Track is to be used for storm events with southwesterly, southerly or southeasterly flow; the Southwest Track is to be used with northerly or northwesterly flow affecting the Pine Valley Mountains; the I-15 South/North Tracks are to be used in southwesterly, westerly or northwesterly flow. Table 3-1 shows the GPS coordinates for the end points of the aforementioned tracks and, in some cases, their mid-points.

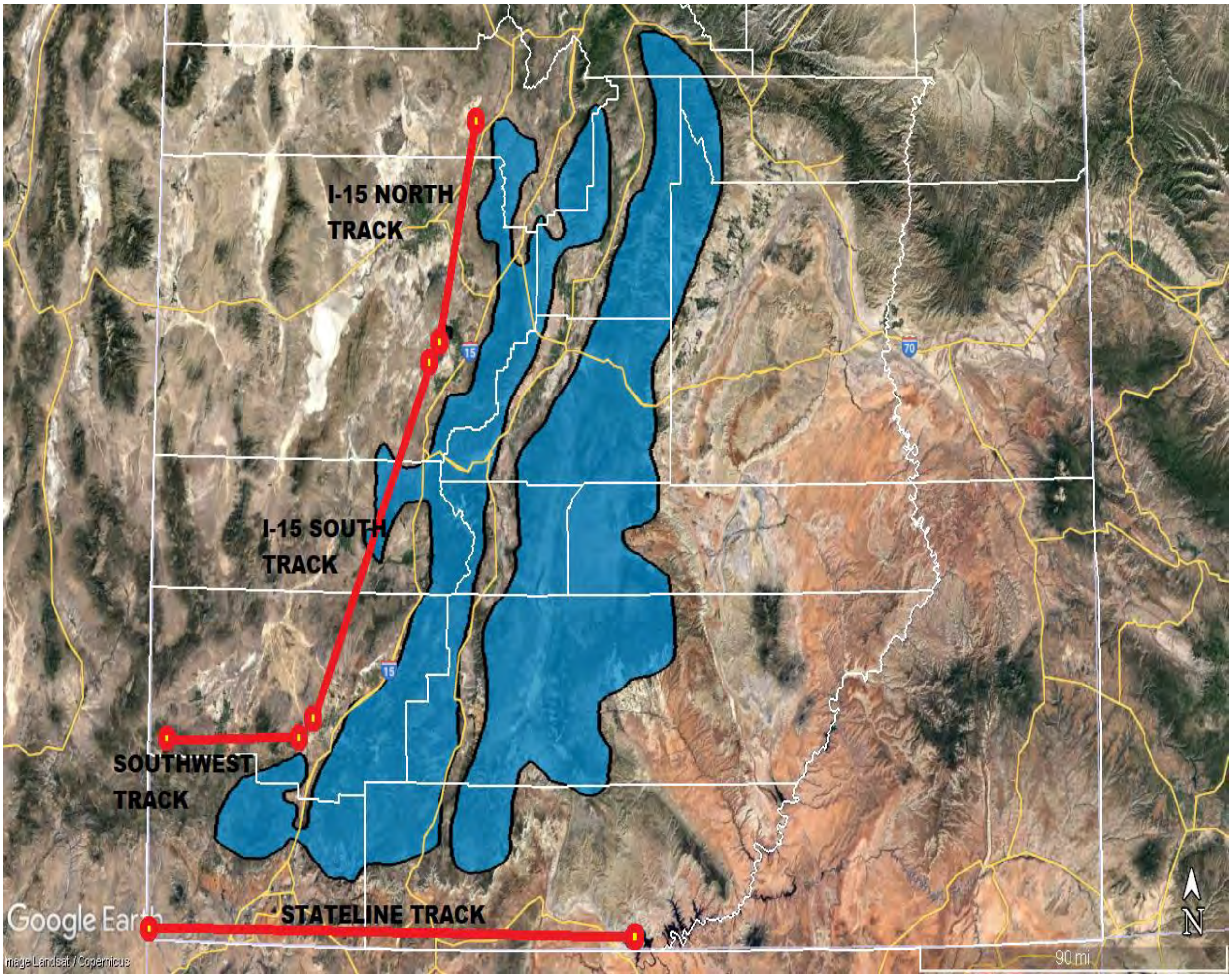


Figure 3.3. Seeding flight tracks for the Southern Utah Aerial Program.

Table 3-1
Airborne Track Points

Track Name	Reference Point	Latitude and Longitude
STATELINE	West Point Center Point East Point	37.03497 °N / -113.97751 °W 37.03497 °N / -112.86620 °W 37.03497 °N / -111.72198 °W
SOUTHWEST	West Point East Point	37.83914 °N / -113.98277 °W 37.86507 °N / -113.32148 °W
I-15 SOUTH	South Point Center Point North Point	37.91948 °N / -113.29446 °W 38.46420 °N / -112.99759 °W 38.99706 °N / -112.70961 °W
I-15 NORTH	South Point North Point	39.04769 °N / -112.70167 °W 39.58313 °N / -112.47388 °W

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. The location was convenient for project personnel as the meteorologist and pilot were both locally situated. The plane was stationed at the St. George Municipal Airport in the far southern edge of the metro area. Although not necessary during this past season, operational support was available from the main office in Sandy. During seeding missions, text messaging was the main form of communication between pilot and meteorologist.

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) also play an important part of 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 Southern 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/Backup Pilot

Mr. Adam Olsen, On-site Seeding Pilot

<u>4.0 WEATHER DATA AND MODELS USED IN SEEDING OPERATIONS</u>

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 home and office locations, 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)**.

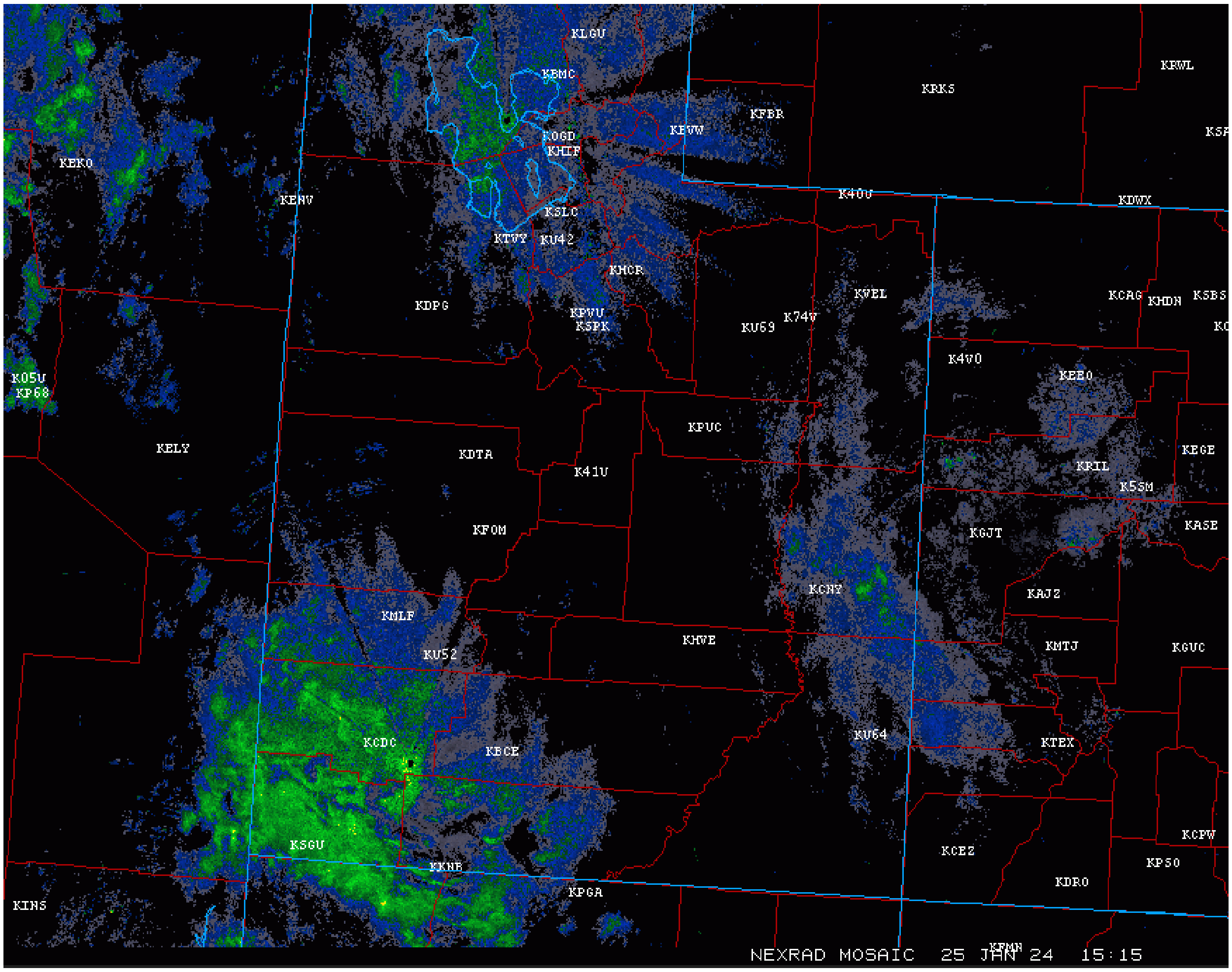


Figure 4.1. **Weather radar image during a storm event/seeding flight over southwestern Utah on January 25, 2024.**

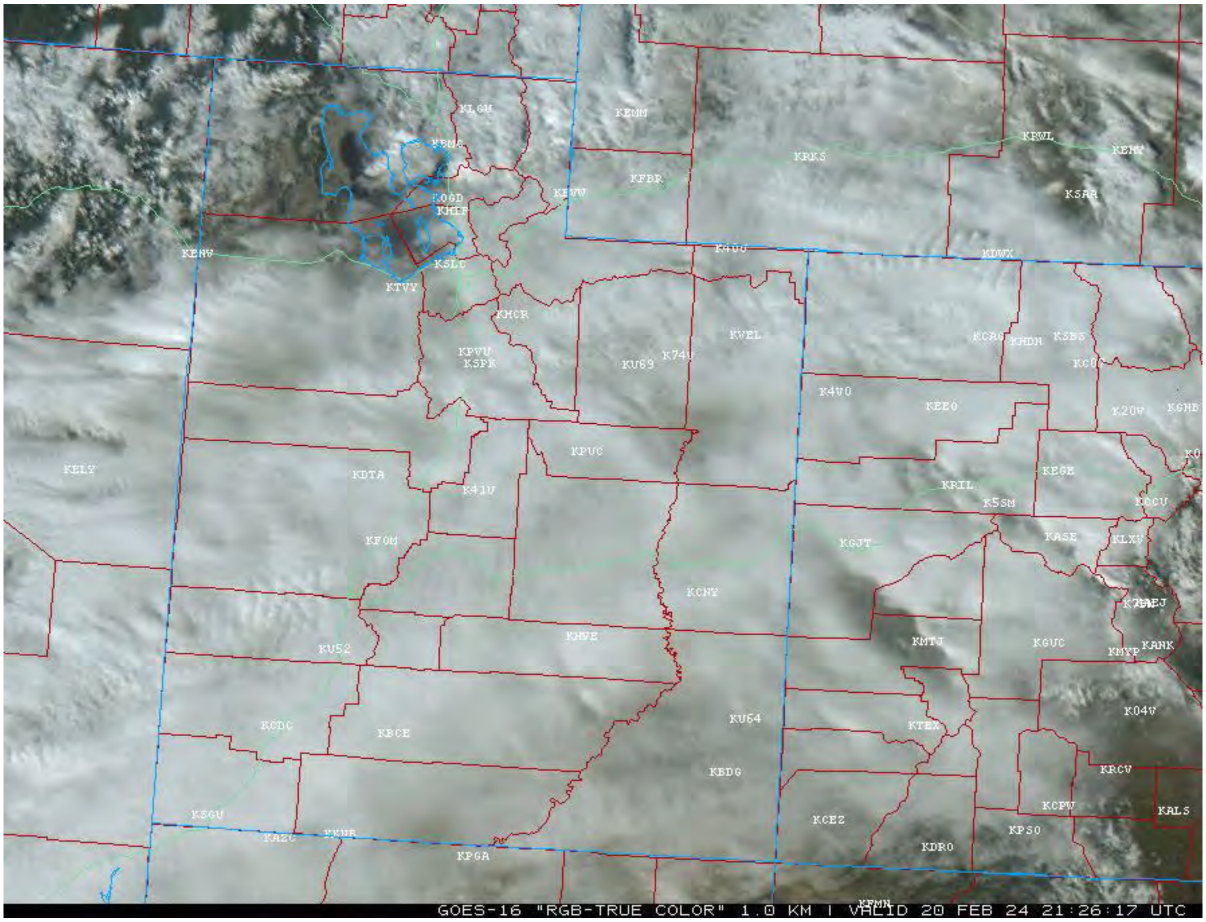


Figure 4.2. Visible spectrum satellite image on February 20, 2024 at 1426 MST (2126 UTC).

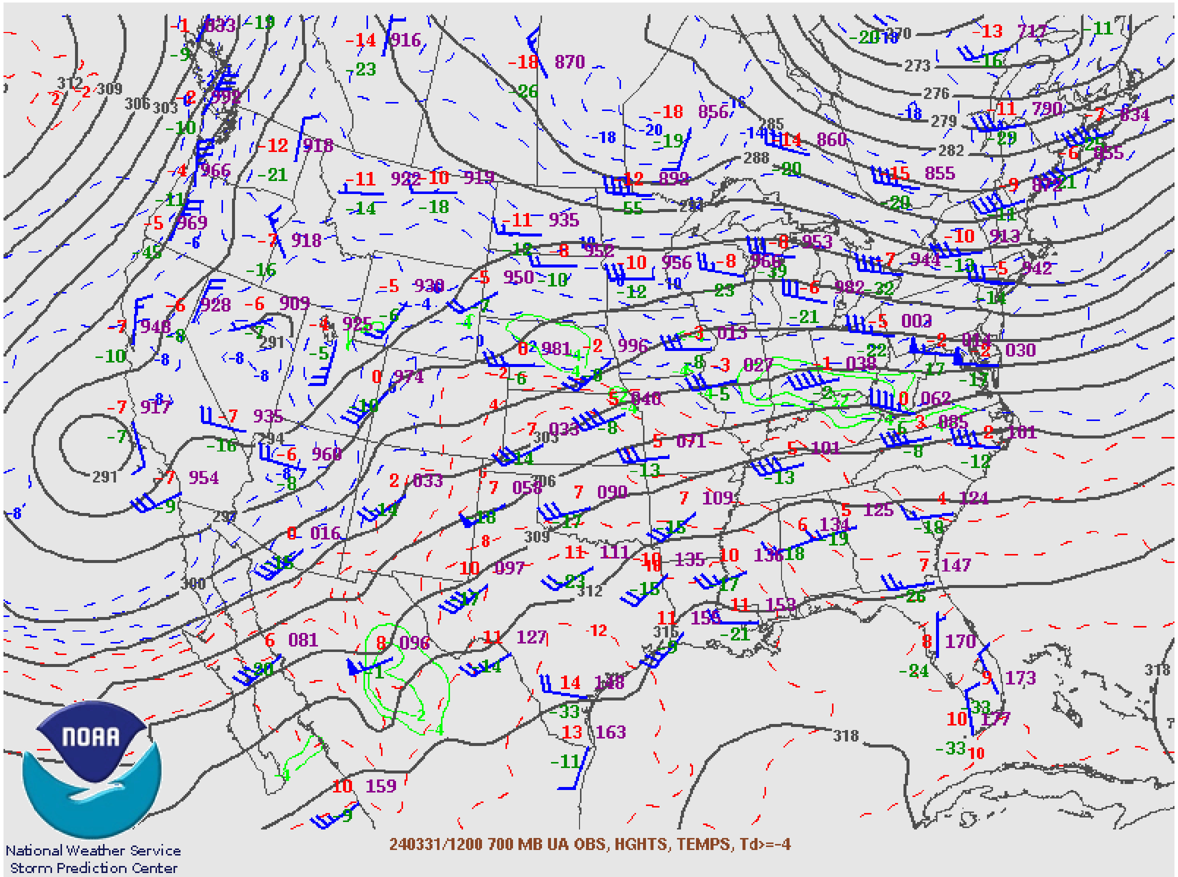


Figure 4.3. **700 mb (approximately 10,000 feet MSL) map valid for 1700 MST (0000 UTC) on March 30, 2024. Among the more notable map features, contours indicate heights (in decameters) of 700 mb pressure level, red numbers are temperature (°C), green numbers are dewpoints (°C), blue lines with barbs/flags represent wind speed and direction.**

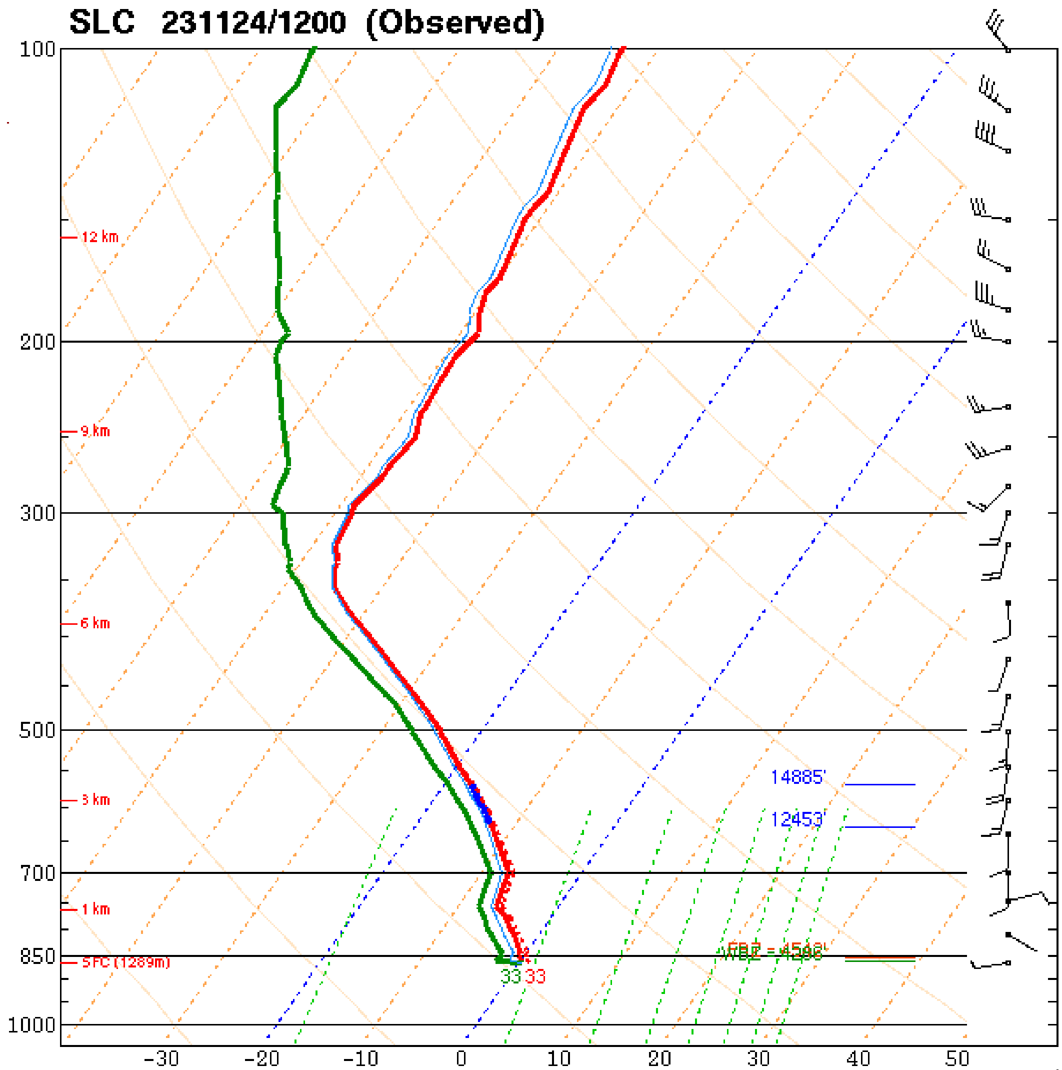


Figure 4.4. **Weather balloon/rawinsonde sounding from Salt Lake City, valid at 12Z/0500 MST on November 24, 2023 showing temperature (red line), dewpoint (green line) and wind speed/direction (right side barbs) from the surface to 100 mb (approximately 52,000 feet MSL).**

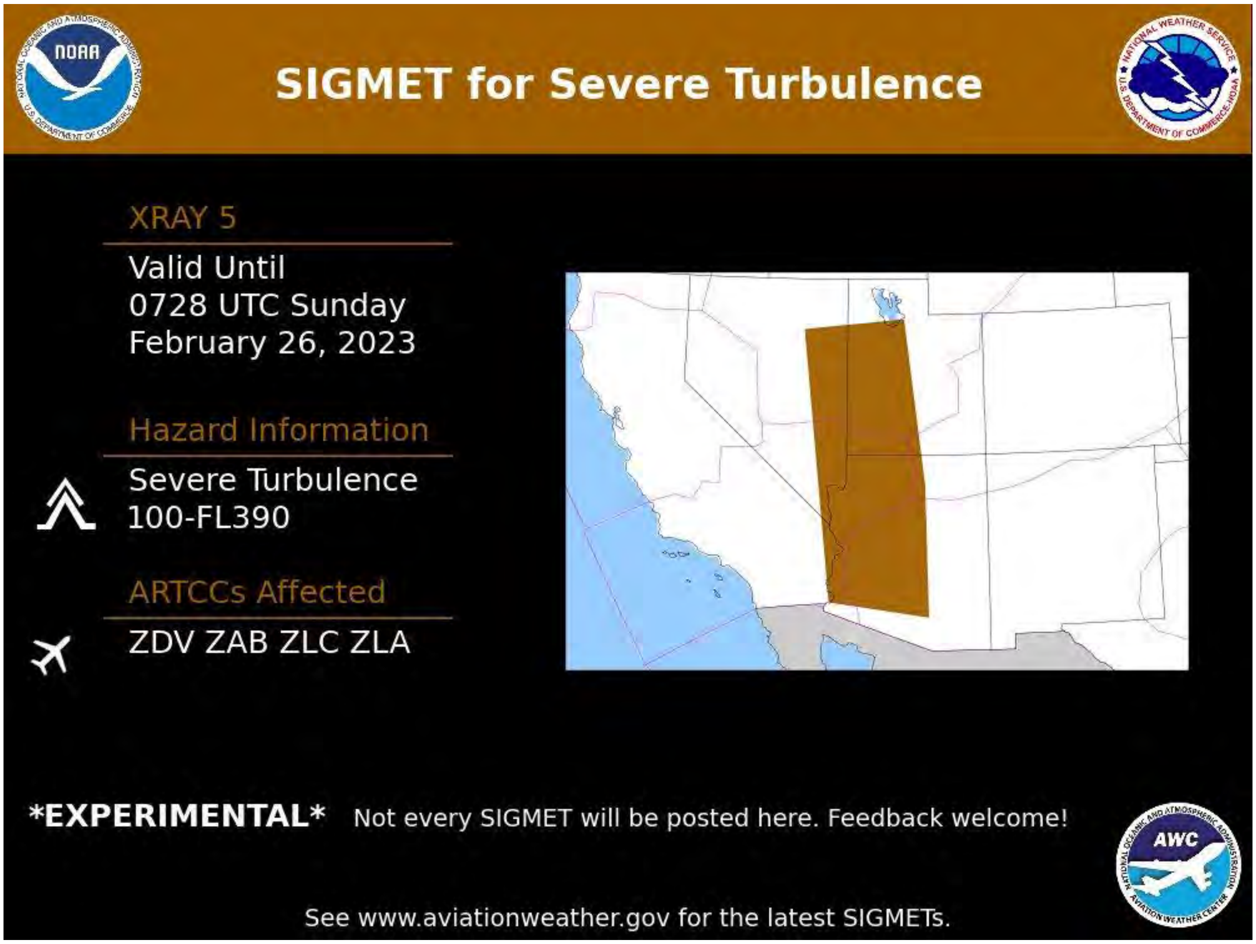


Figure 4.5. **Significant Meteorological (SIGMET) information detailing severe turbulence hazard in the area outlined above on February 26, 2023. Information on SIGMET issuances is available from aviationweather.gov.**

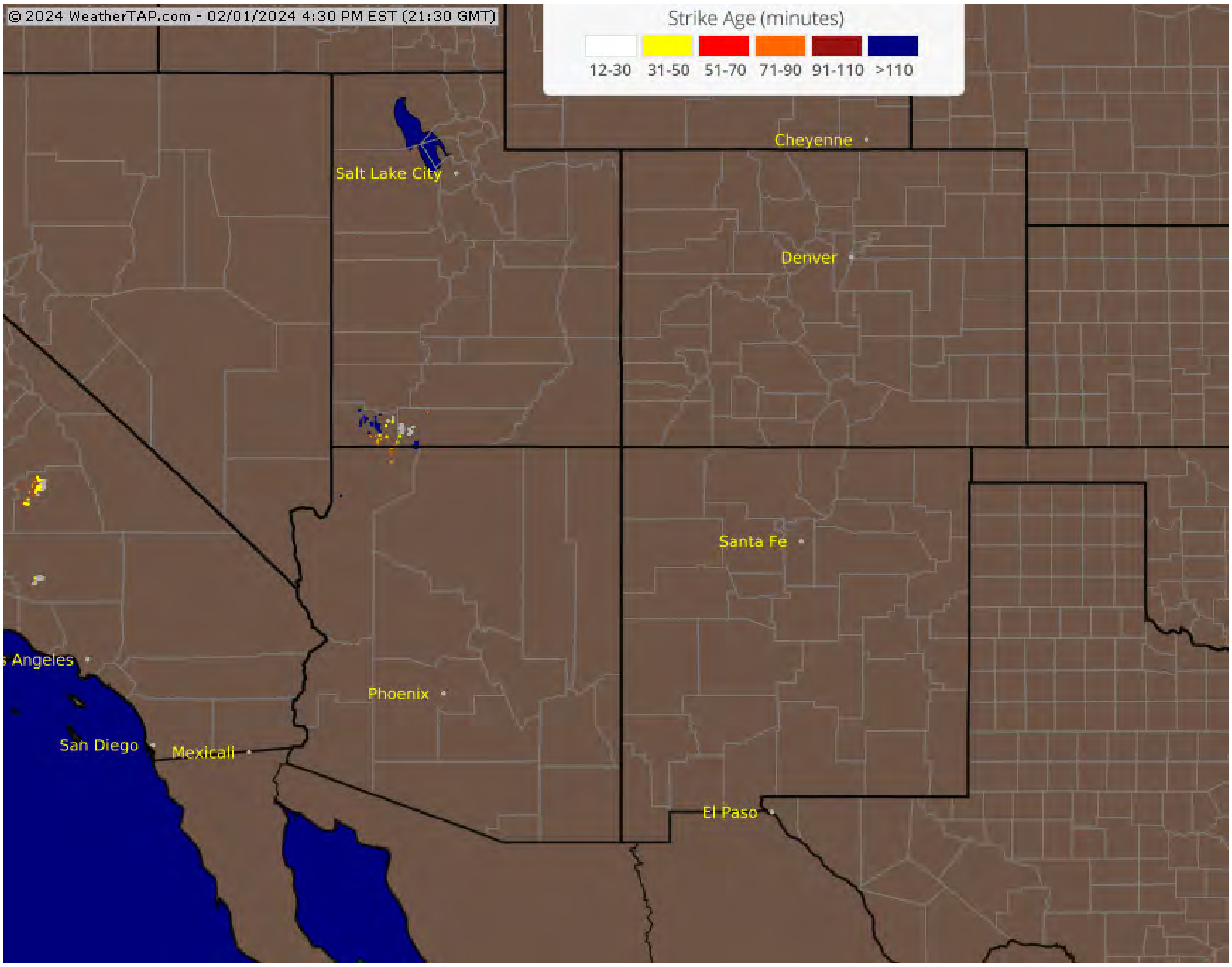


Figure 4.6. **Map showing recent lightning strikes across western United States on February 1, 2024 at 1430 MST. Legend shows age of lightning strike via color-coded dots. Courtesy of WeatherTap website, https://www.weathertap.com/ . Lightning is a hazard needing attention with regards to aerial seeding operations.**

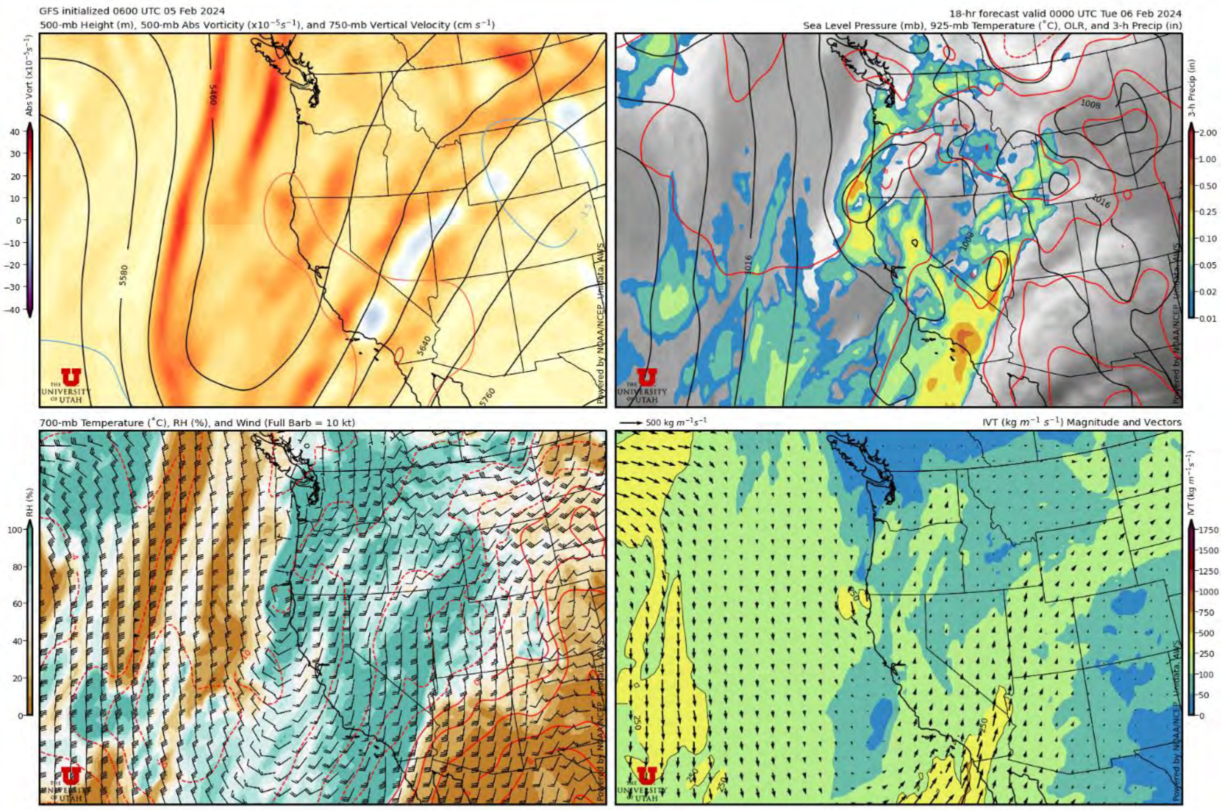


Figure 4.7. **GFS (Global Forecast Systems) forecast data plot for an approaching storm event on February 5, 2024.**

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.

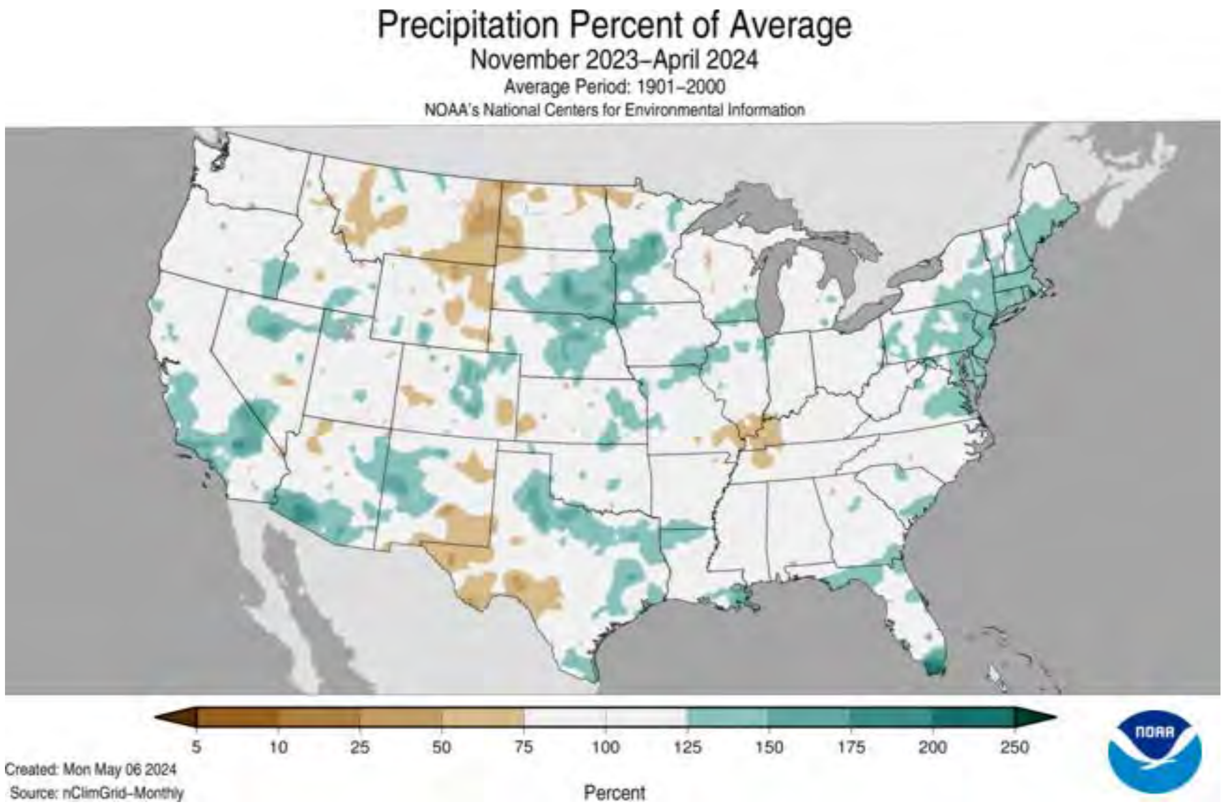


Figure 5.1. November 2023 – April 2024 percent of normal precipitation.

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 one of the pre-determined tracks. 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 flight track zones, 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 the Central and Southern Utah target area 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 Flagstaff, AZ. 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 24	0 / 0	1.50
2	January 7	1 / 0	1.52
3	January 13	3 / 0	1.78
4	January 25	13 / 0	2.00
5	February 20	0 / 0	0.22
6	March 30	11 / 0	2.18
Totals		**28 / 0**	**9.20**

November 2023

The 2023-24 season for the Southern Utah Aerial Program began in mid-November. Three storm systems impacted the area during the latter half of the month, one of which saw seeding operations take place with one flight 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.

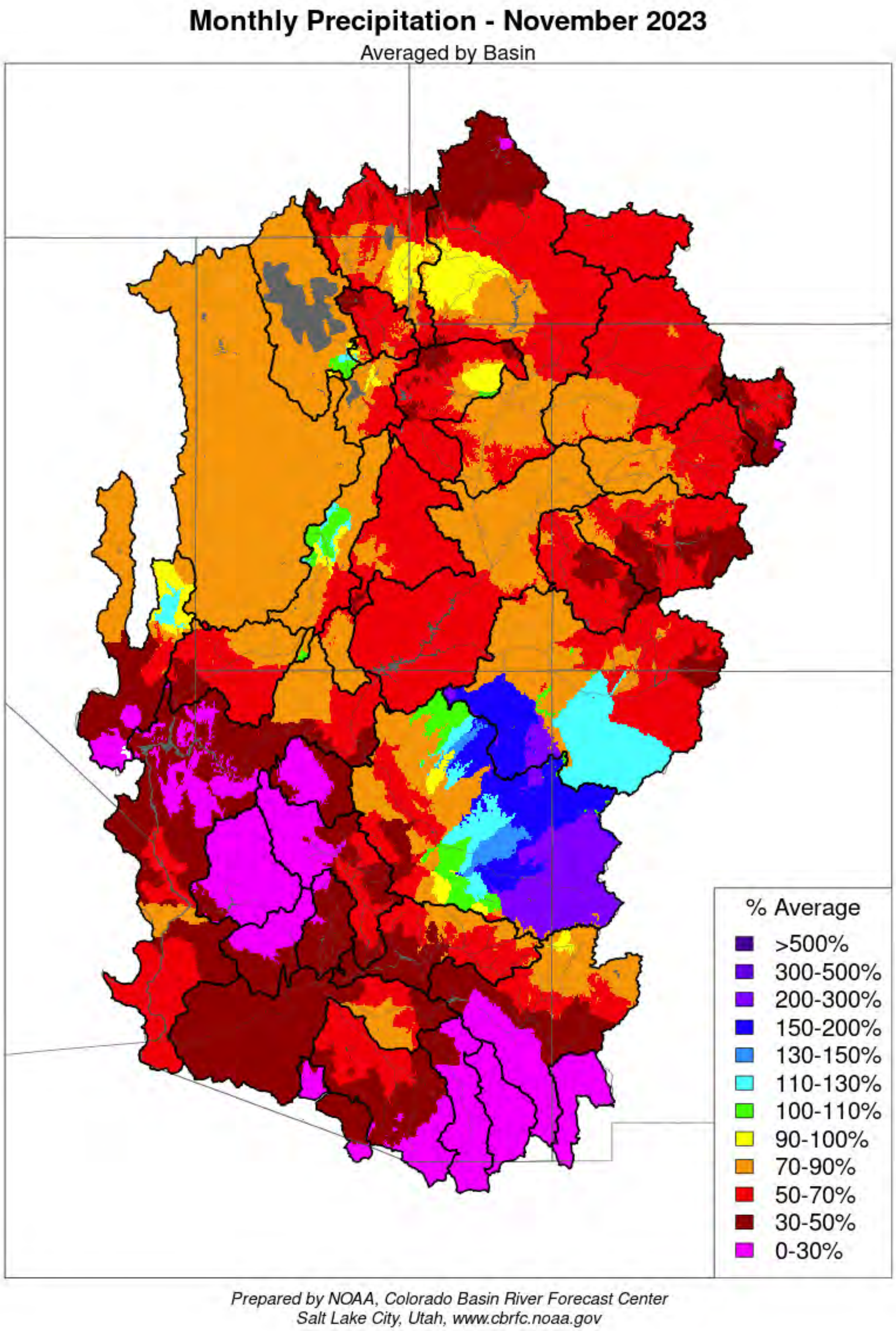


Figure 5.2. November 2023 precipitation as a percent of average during the month.

November 24, 2023

An upper level disturbance approached Utah from the west on November 23 and was accompanied by light precipitation across western portions of the state. Winds aloft were also light with the approaching disturbance. Beginning in the evening hours and continuing into the early morning hours of November 24, the upper level disturbance began to evolve into a closed low across eastern Nevada/western Utah with the center located between Wendover and Delta by daybreak. To the south of the low, a band of moisture was located across southwest Utah within a zone of convergence. Initially the sub-cloud layer was very dry and most, if not all of the precipitation was falling as virga. By daybreak, reports of precipitation were finally being made, and with 700 mb temperatures around -5°C and flight-level (14,000 feet MSL) winds from the west-southwest, a flight plan was filed using the lower half of the I-15 South track. The plane departed SGU at 0847 MST, and upon reaching altitude a short time later, the pilot reported that he was above the clouds (he was at the minimum allowed altitude for the mission). After flying the track for a short time, clouds eventually did cover the track, but the pilot reported little to no moisture and no ice accumulation. The plane was in and out of the clouds over the following 20 minutes, but no visible moisture was ever seen accumulating on the plane and, with satellite imagery showing a clearing line rapidly approaching the flight track zone, the decision was made to terminate the flight and the plane returned to SGU, landing at 1017 MST. Figure 5.3 shows a visible satellite image from 1541 UTC (0841 MST) on November 24, shortly before takeoff. Figure 5.4 shows the flight track from the mission, including flight observational data.

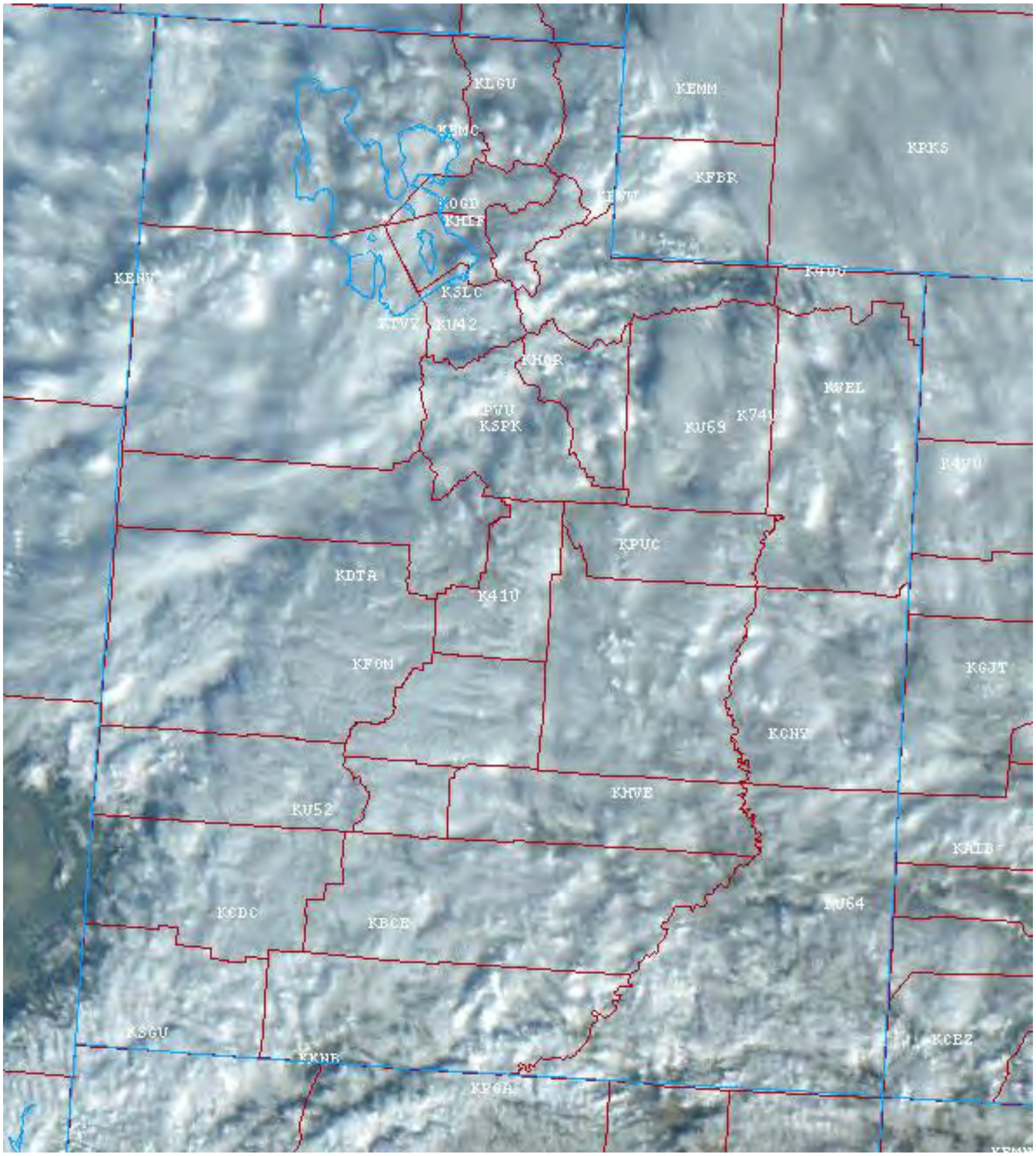


Figure 5.3. **Visible satellite image from 1541 UTC (0841 MST) on November 24. Note area of clearing nosing into far southwestern Utah west of the flight track.**

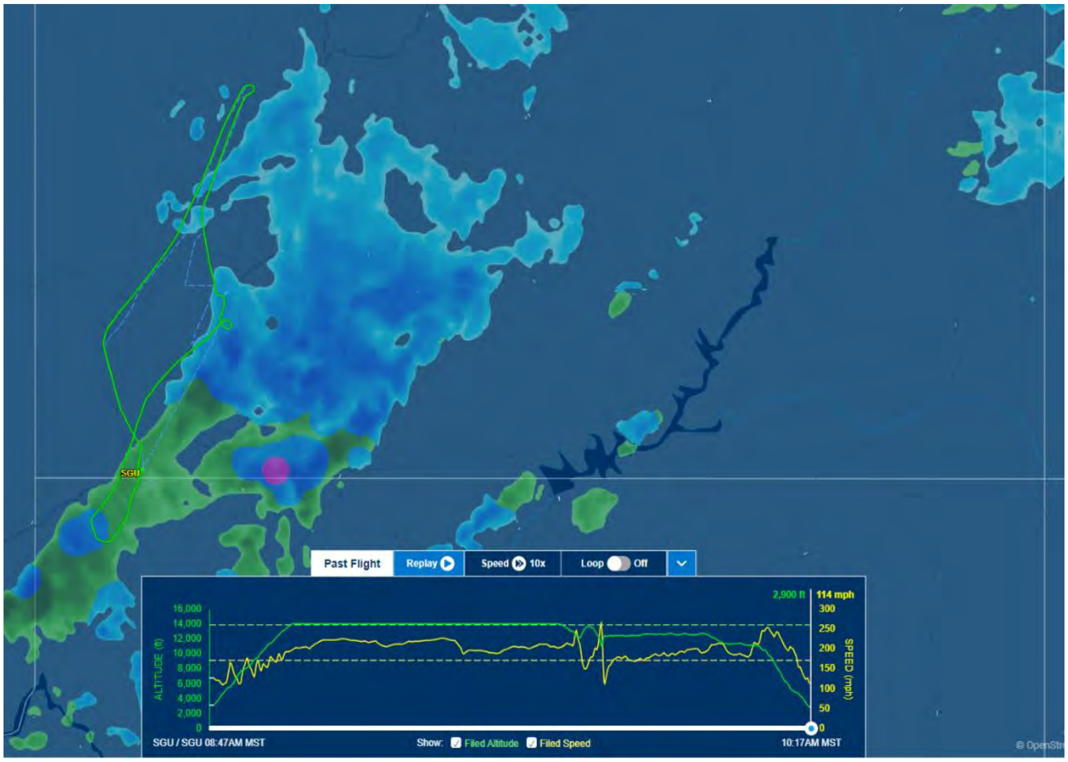


Figure 5.4. **Flight track from investigative flight on November 24, 2023. Lower graph indicates altitude of plane (green) and speed of plane (yellow) during flight. Green and blue shading in background is a radar image at time of image capture.**

November 2023 Suspensions/Missed Flying Opportunities

During the latter part of November, one day saw a suspension of operations. On November 19, thunderstorms producing heavy rainfall and flash flooding across southwest Utah, including Zion National Park, resulted in a suspension of operations until the flooding threat had passed, but by then the flyable portion of the storm had come to an end.

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 5.5 shows the monthly precipitation across Utah for December as a percent of normal, averaged by basin.

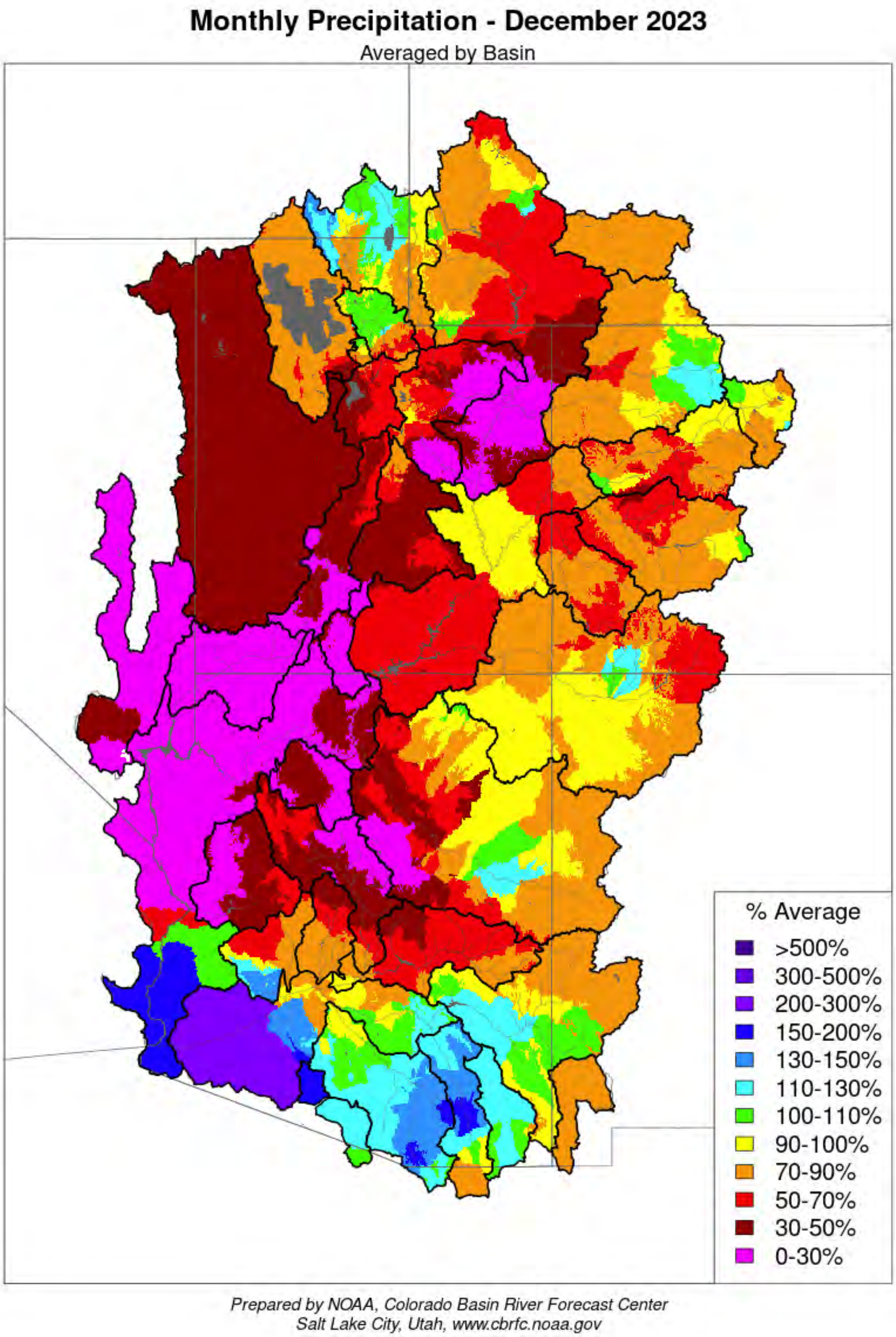


Figure 5.5. **December 2023 precipitation as a percent of average for the month.**

December 2023 Suspensions/Missed Flying Opportunities

On December 1, very cold temperatures aloft (≤ -15°C at flight altitude) prevented a flight from taking place, with most other factors at least marginally ideal for seeding operations. On December 2-3, severe turbulence and associated mountain wave activity due to strong winds aloft was occurring across central Utah, preventing any flights from taking place. On December 8, although some ground seeding took place in the far northern part of the target area, moisture aloft was quite limited across central and southern Utah, with very cold temperatures also in place. For these reasons, no seeding took place.

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. Seeding flights occurred during three of these events. Figure 5.6 shows the percent-of-average precipitation for January 2024; most locations within the Southern Utah Aerial Program's area of responsibility saw above average precipitation, with amounts closer to average for the far south and southwest portions of the state.

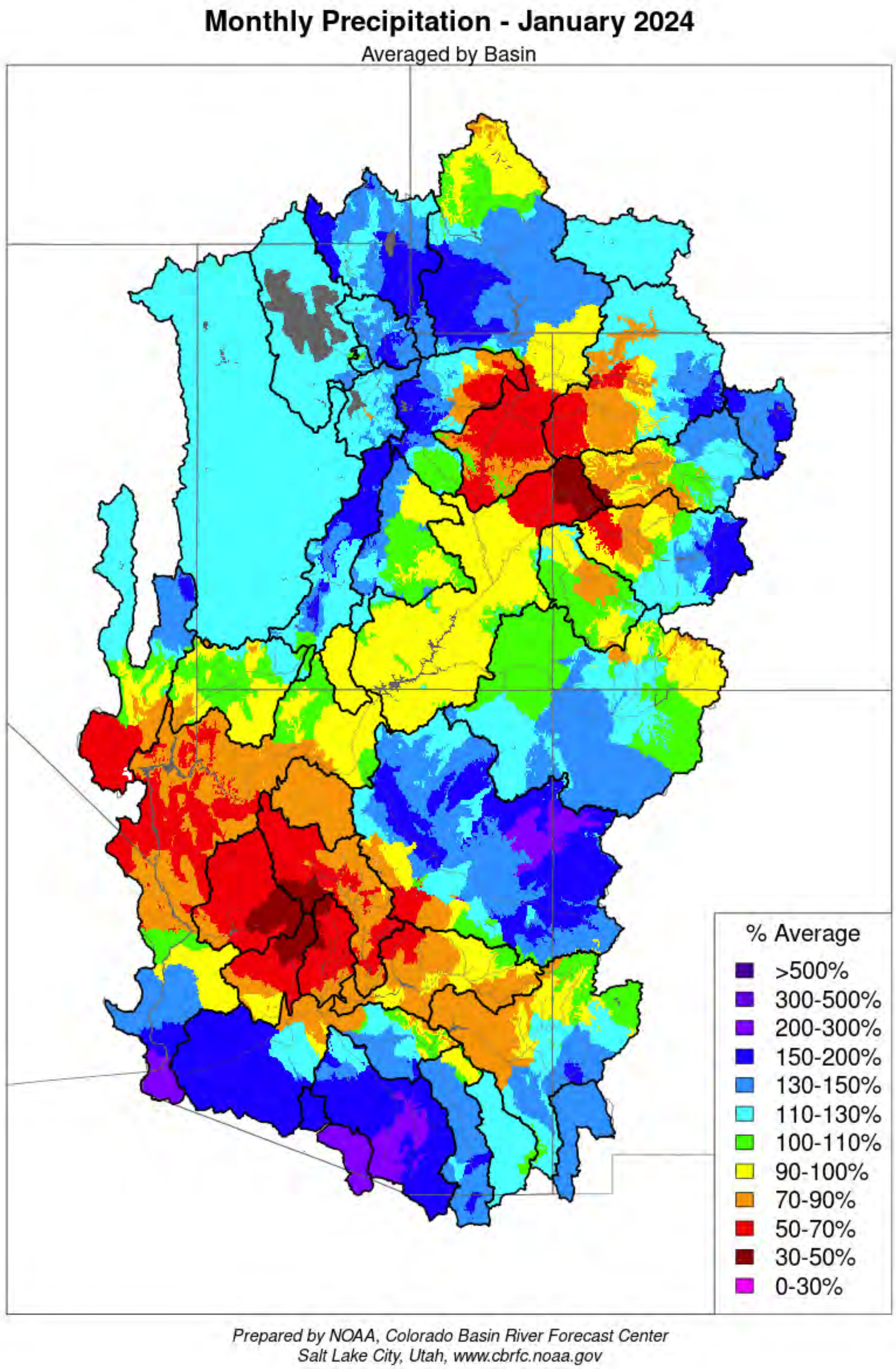


Figure 5.6. January 2024 precipitation as a percent of average for the month.

January 7, 2024

A strengthening trough of low pressure was digging southeast across California and Nevada during the evening of January 6, aided by a jet streak diving southeast on the backside of the trough. Deep west to southwest flow was in place across Utah. An area of enhanced moisture, which really wasn't much as Precipitable Water (PWAT) values were only around 0.20-0.30", moved into southwest Utah late in the evening of January 6 into the early morning hours of January 7. A flight plan was made using the western half of the "Stateline track", and the plane departed SGU at 0006 MST on January 7. Temperatures at flight level (12,000 feet MSL) were -10°C to -12°C and supercooled liquid water was quite limited and confined to a small pocket in the vicinity of St. George. Figure 5.7 shows radar imagery from 0735 UTC (0035 MST) on January 7, during the mission. The aircraft landed back at SGU at 0137 MST, having flown a total of 1.52 hours with only one (1) burn-in-place (BIP) flare used for seeding. Figure 5.8 provides the flight observational data.

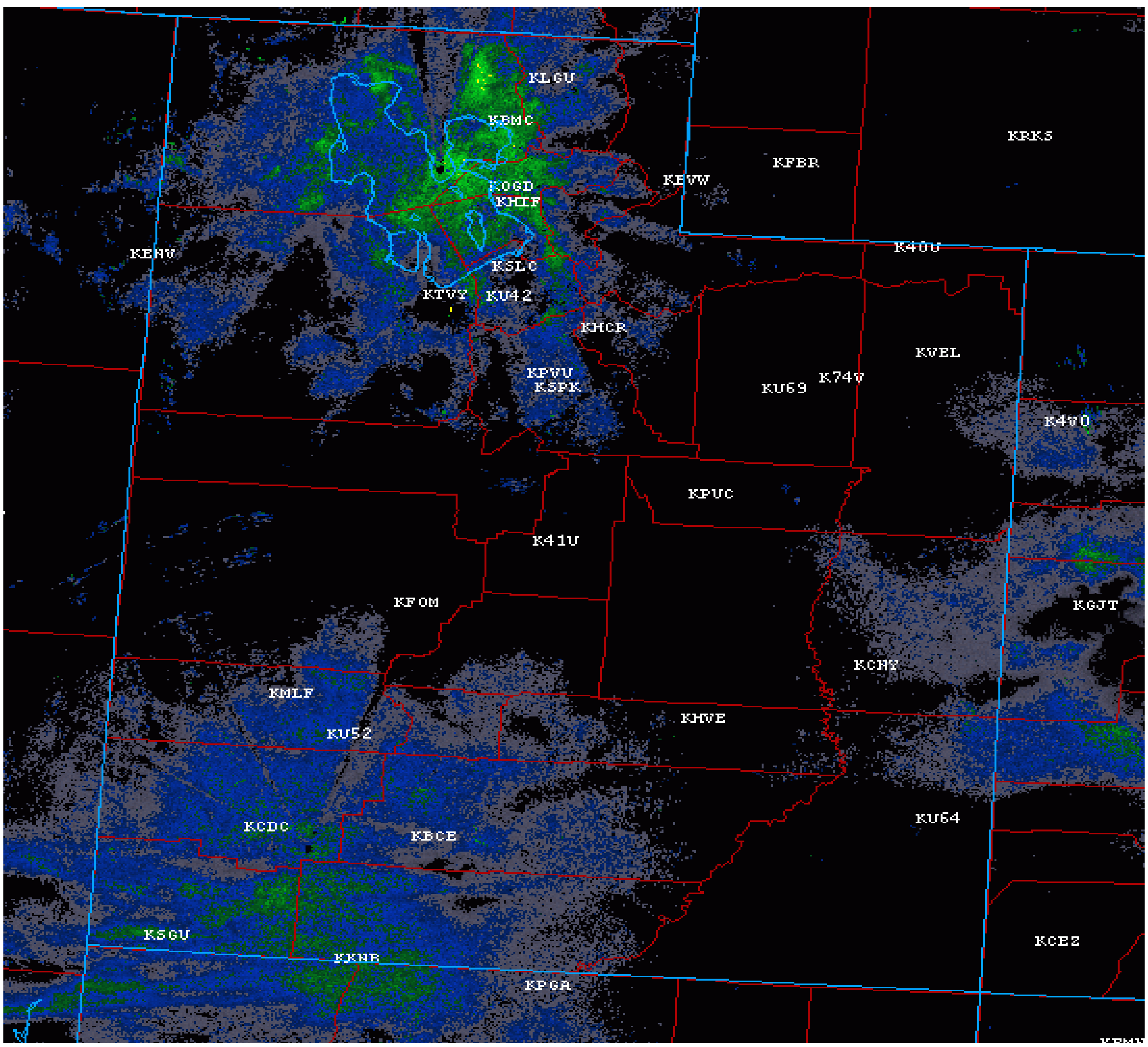


Figure 5.7. **Radar imagery from 0735 UTC (0035 MST) on January 7 showing an area of moisture across south-central and southwest Utah.**

Figure 5.8. Flight track from seeding flight on January 7, 2024. Lower graph indicates altitude of plane (green) and speed of plane (yellow) during 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 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 0.35-0.45" range across central and southern Utah, but sufficient for precipitation across the area. A flight plan was filed using portions of both the I-15 North and I-15 South tracks, or roughly from near Milford up to near Fillmore. The plane departed SGU at 2008 MST. Temperatures at flight level (13,000 feet MSL) were around -9°C which is within the ideal range for seeding, however winds at flight altitude, per Cedar City (ICX) radar's Velocity Azimuth Data (VAD), were 40-50 knots which was at the top end of what would be considered ideal winds for seeding material transport. The pilot did report some visible moisture sticking to the plane (ice), but during the flight the pilot reported VFR while near the northern endpoint of the track. Figure 5.9 shows radar imagery at 2040 MST, during the flight. The aircraft flew for 1.78 hours, landing back at SGU at 2155 MST, having burned three (3) BIP flares. Not long after the flight ended, moisture pushed east of the I-15 corridor. Figure 5.10 shows the flight data/track.

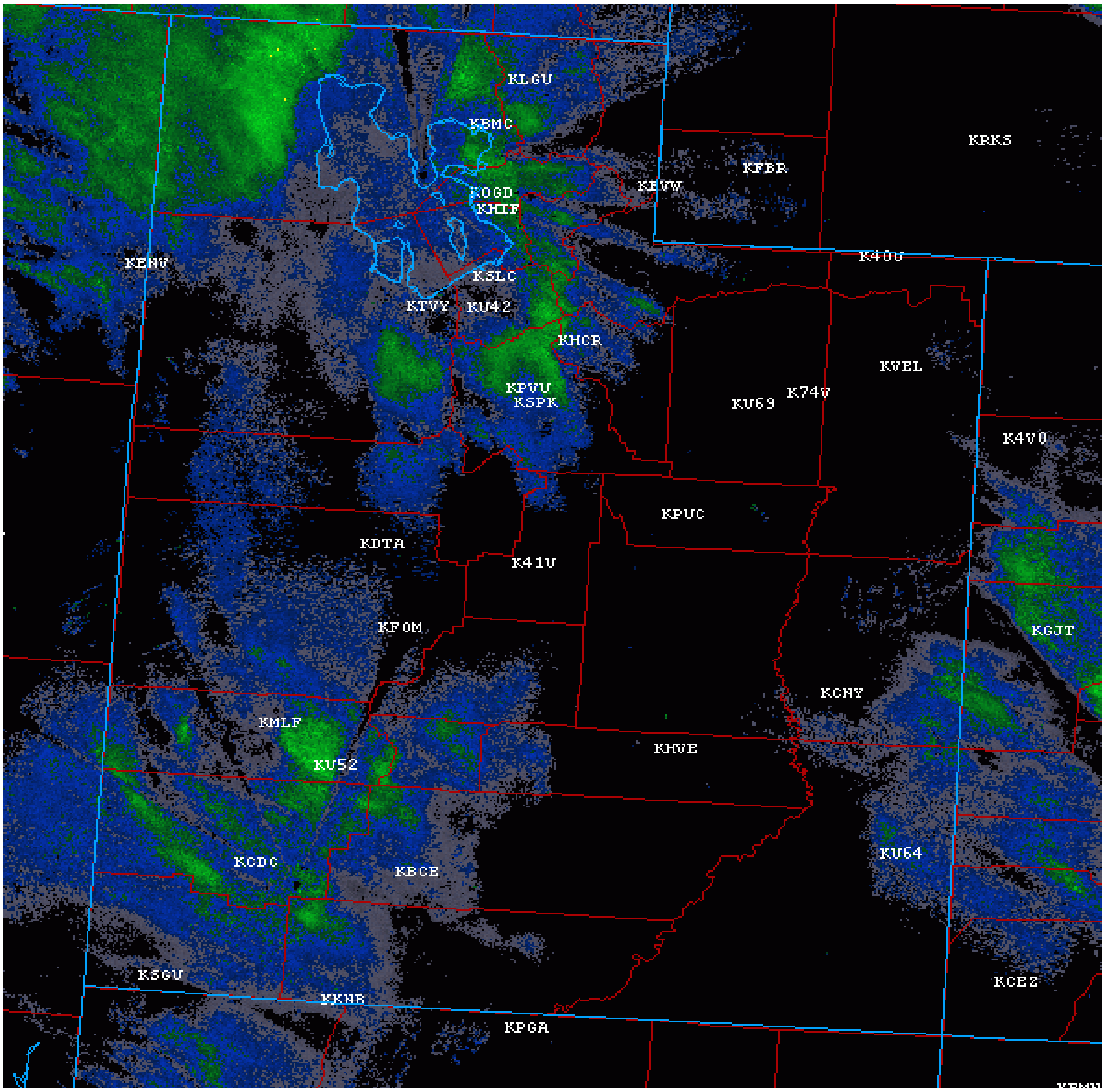


Figure 5.9. **Radar imagery from 0340 UTC (2040 MST) on January 13 showing moisture pushing in from the west and northwest ahead of the approaching shortwave disturbance.**

Figure 5.10. **Flight track from seeding flight on January 13, 2024.**

January 25, 2024

A broad trough of low pressure was in place across the western part of the country, with a shortwave disturbance embedded within the trough poised to move across Utah during the day. A jet streak of 100-130 kt was diving southeastward into northwestern Arizona, where several lightning strikes were noted prior to sunrise. Early morning soundings from around the area indicated PWAT values around 0.50-0.60” across southern areas, drier to the north with PWAT value of 0.30-0.40”. 700 mb temperatures were in the -3°C to -7°C range, with westerly flow around 20-30 kt. Precipitation was spreading across western and southwestern Utah early in the morning. Figure 5.11 shows radar imagery from this time period. A flight plan was filed utilizing a track similar to the “I-15 South” track except shifted further east closer to the mountains from near Cedar City to in between Beaver and Cove Fort. It was determined that the convection producing lighting south of the area prior to the flight would remain there, and there were no indications of thunderstorms upstream of the area that would impact operations. Overall, conditions appeared favorable for seeding, with sufficient supercooled water in the clouds. The plane departed SGU at 0725 MST and, upon reaching the flight track area, the pilot reported decent moisture and began to burn flares. The aircraft flew for 2.00 hours and used 13 BIP flares (plus two more that didn’t burn) for seeding, landing back at SGU at 0925 MST. Figure 5.12 shows the flight data/track.

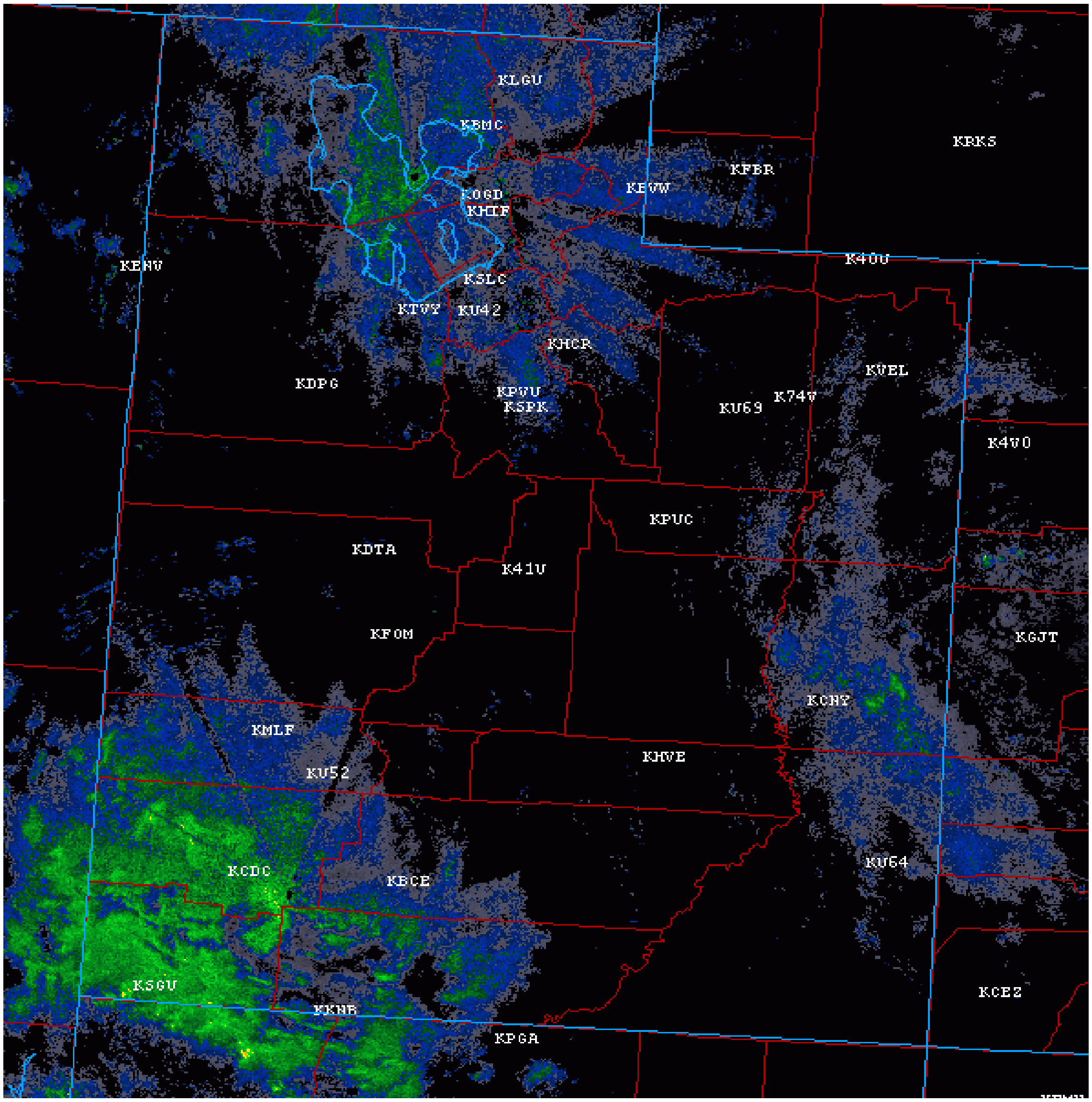


Figure 5.11. **Radar image from 1510 UTC (0810 MST) on January 25, 2024 showing slug of moisture pushing into southwestern Utah.**

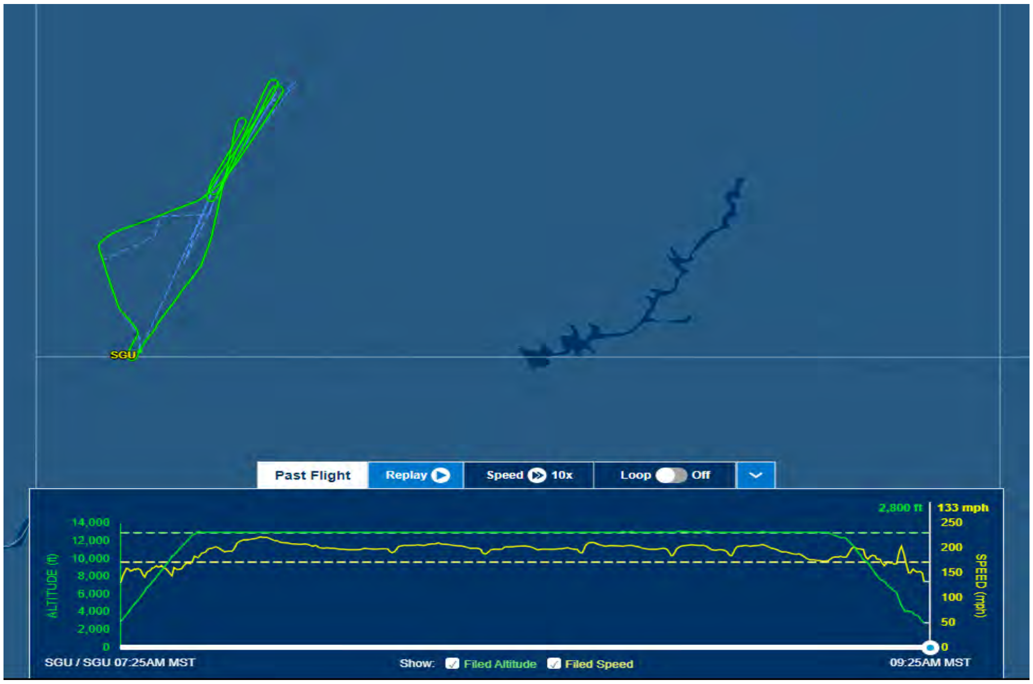


Figure 5.12. Flight track from seeding flight on January 25, 2024.

January 2024 Suspensions/Missed Flying Opportunities

On January 3-4, the aircraft was in the shop to have the attitude indicator repaired after a previous test flight revealed the issue and thus missed seeding opportunities during that specific storm event. On January 9, the threat (and eventual presence of) scattered thunderstorms prevented any flights from taking place. On January 10, 11 and 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 17, 700 mb temperatures across southern Utah were near 0°C which was too warm for seeding operations. This was also a problem on January 20 although temperatures were about a degree cooler in comparison; another factor was the presence of low cloud layers around SGU. Low clouds also hindered flights out of SGU on January 22.

February 2024

The active weather pattern that was observed in Utah in January continued into February with a number of storm events affecting central and southern Utah. Eight storm events impacted the target area during the month, yet in spite of the active pattern, only one flight was able to launch, and it was short-lived due to mechanical issues that developed after takeoff. Further discussion will describe the issues that affected flying during the month in the next sub-section. Figure 5.13 shows the monthly precipitation for February as a percentage of average precipitation for the month. All areas saw above normal precipitation.

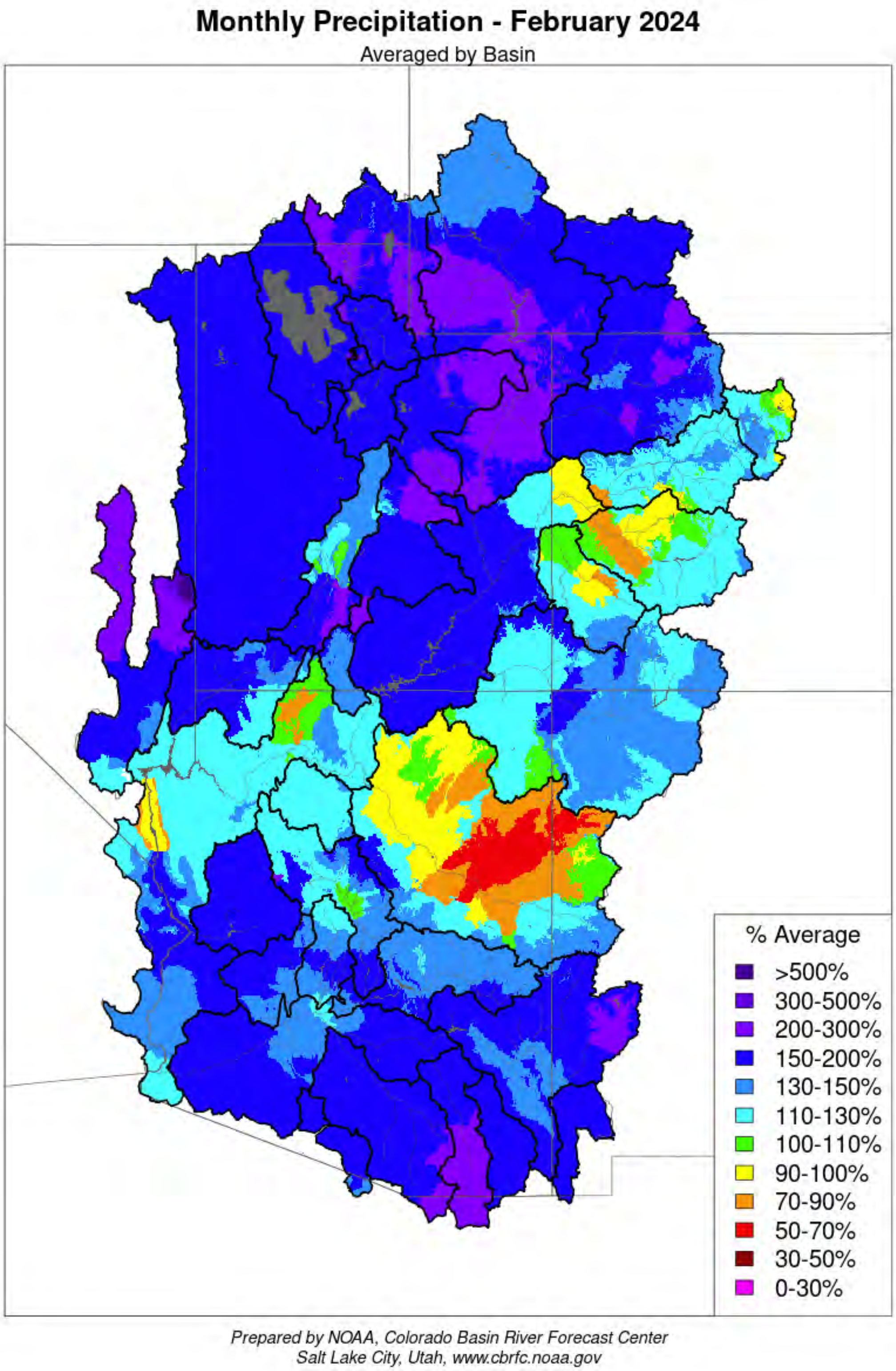


Figure 5.13 February 2024 precipitation as a percent of average for the month.

February 20, 2024

A trough of low pressure was located off the West Coast, with a subtropical plume of moisture streaming from southern California through southern Nevada into southwest Utah. Given the subtropical nature of the incoming moisture, the airmass was on the warm side, with 700 mb temperatures at -1.5°C. A 300 mb jet streak of 125-150 kt was nosing into southwestern Utah aiding in weak diffluent flow aloft over the southern half of Utah (creating weak but broad lift across this area). This same feature was responsible for thunderstorms near Las Vegas in the morning. Later in the afternoon, as greater amounts of moisture arrived from the southwest, a decision was made to conduct a seeding flight, with the Stateline track chosen given the south to southwest flow in place across the area. Moisture availability was good, given the PWAT values from approximately 0.50-0.75" per area soundings. The plane departed SGU at 1542 MST and was climbing past 9000 feet MSL when the left alternator quit, requiring the pilot to return immediately to the airport, landing at 1555 MST. Although this is considered a missed flight opportunity, the conditions were less than ideal given the warmer temperatures aloft, reflected in the fact that most mountain locations were at or above freezing (Brian Head an exception, but even there, temperatures were around -2°C); not long after the plane landed, thunderstorms developed across portions of southwestern Utah but did remain north of the flight track zone. The alternator was repaired the next day, and the plane was test-flown with no issues found. Figure 5.14 shows the brief flight track from the aborted mission.

Figure 5.14. **Flight track from February 20, 2024 with radar data superimposed on background.**

February 2024 Suspensions/Missed Flying Opportunities

On February 1, convection with lightning was scattered across the area which inhibited ops during the "flyable" part of the storm. Figure 5.15 shows a lightning map during the afternoon hours. On February 3, some scattered convective rain/snow showers developed across southwest Utah with cloud tops to 15-16 kft MSL, but moisture content was low with PWAT values at or below 0.30". During the storm event on February 6-8, strong winds aloft (greater than 50 knots) and the threat of thunderstorms prevented flights from taking place. On February 15, warm temperatures aloft (-2°C to -3°C) and scant moisture precluded flights from taking place. On February 26-27, strong winds at flight altitude greater than 50 knots, and the threat of thunderstorms along the cold front precluded any flights from occurring.

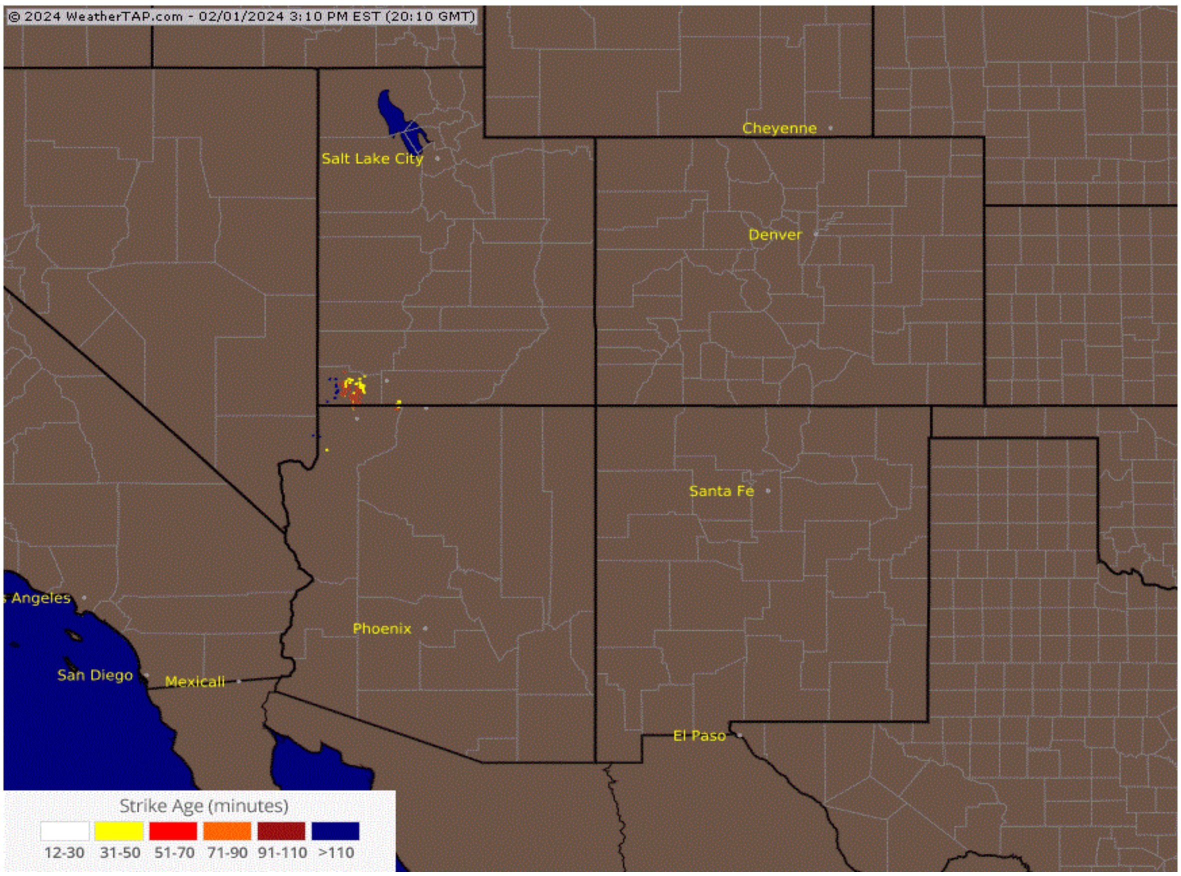


Figure 5.15. **Lightning map from WeatherTap valid at 2010 UTC (1310 MST) on February 1. Legend denotes strike age by color-coding.**

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. In spite of this, the Southern Utah Aerial Program only flew on the final storm event of the month, on March 30. Earlier storms contained hazards that were difficult for flying, which are presented in the Suspensions sub-section. Precipitation for the month was above normal for all but the southwestern portion of Utah, and SWE values were above normal statewide. Figure 5.16 shows the precipitation for the month across the western U.S. as a percentage of average precipitation for March.

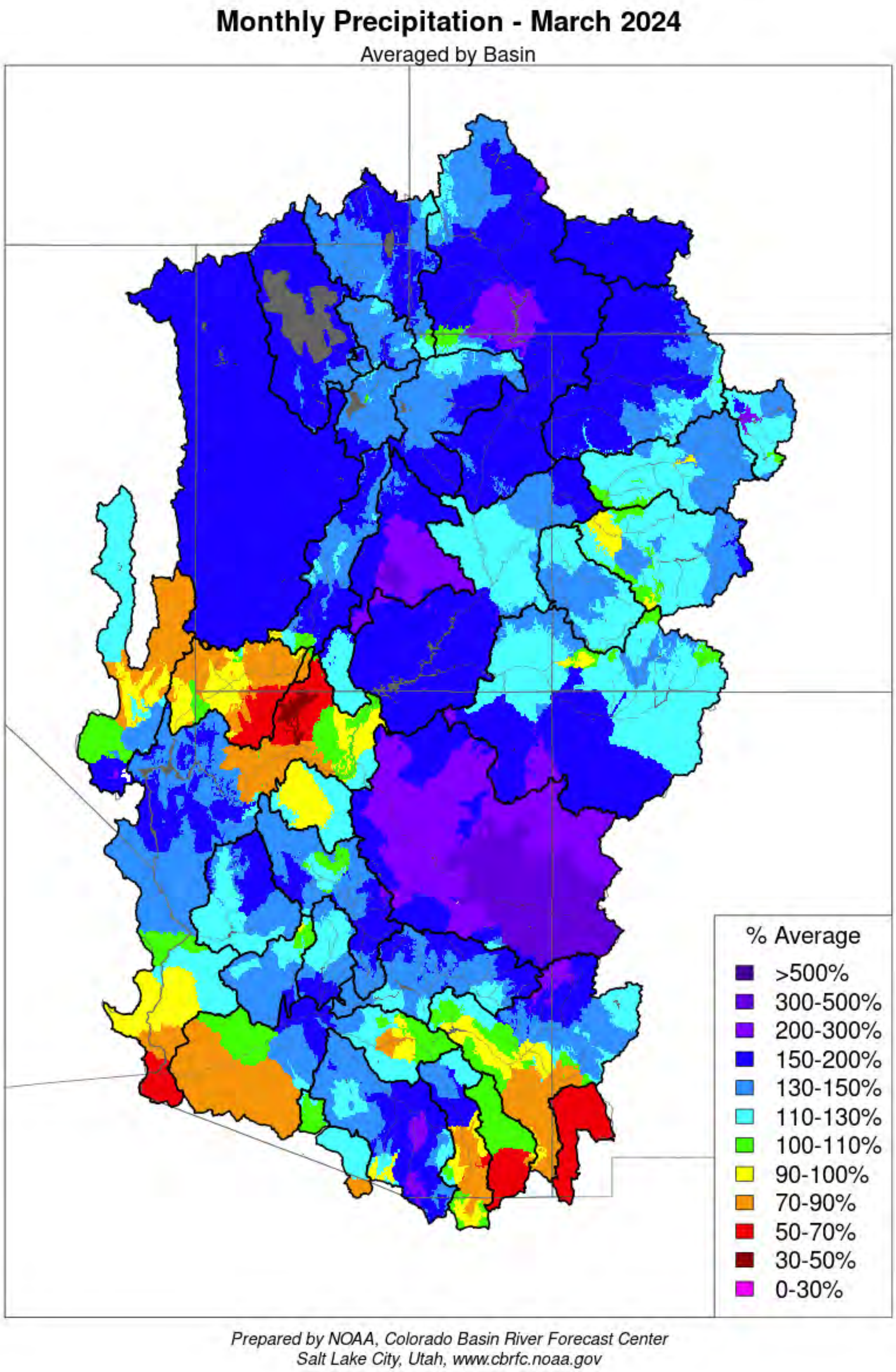


Figure 5.16. March 2024 precipitation as a percent of average for the month.

March 30, 2024

A large, cold upper low (500 mb temperatures of -28°C) was located off the central California coast with the associated trough covering the West Coast into the Great Basin. On the forward/east side of the trough, good diffluent flow aloft was in place across Utah which was promoting synoptic-scale lift. 700 mb temperatures were -3°C to -6°C across southern Utah with southerly flow of 35-50 kt between 700 and 500 mb, respectively. PWAT values were decent, at 0.50" per area soundings. Moisture began streaming into the area during the afternoon hours but the combination of the stronger winds aloft and downsloping effects from the mountains in northern Arizona resulted in pockets of drier air over southwestern Utah. By late in the afternoon, these began to fill in and the pilot was contacted for a flight. Figure 5.17 shows a visible satellite image from 0001 UTC (1801 MDT). A flight plan was made using the Stateline track given the conditions in place. The plane departed SGU at 1813 MDT to investigate and, eventually, conduct seeding operations within the moisture plume spreading into southern Utah. Mid-level temperatures had cooled from earlier values and were ideal for seeding, with values of -6°C to -8°C. The plane returned to SGU at 2024 MDT, having burned 11 BIP flares along the track. Figure 5.18 shows the flight track from the mission.

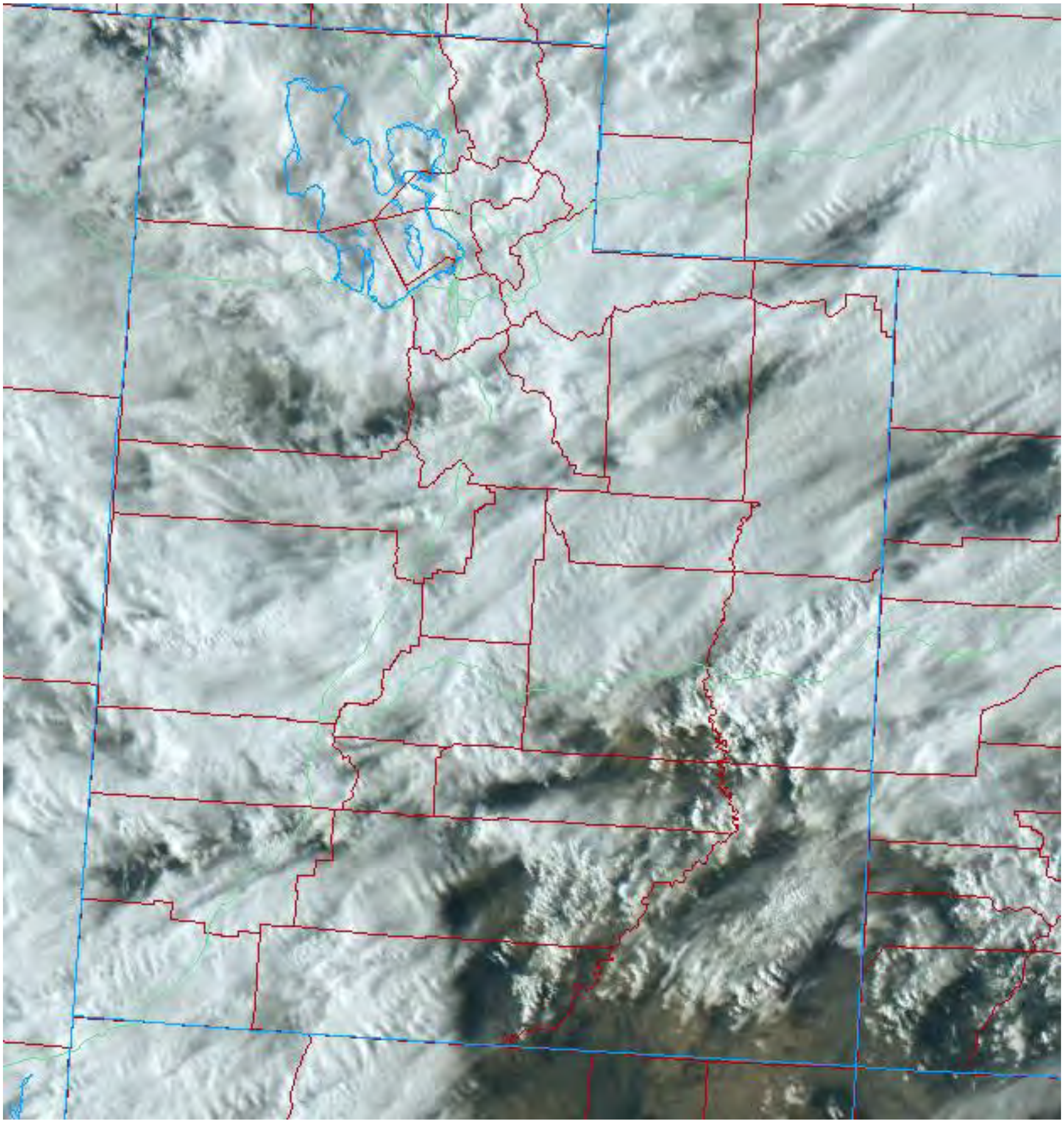


Figure 5.17. **Visible satellite image from 0001 UTC (1801 MDT) on March 30, 2024. Note the ripples on the tops of the clouds, indicative of stronger winds aloft.**

Figure 5.18. **Flight track from seeding 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) and strong winds aloft (March 2-3) resulted in flying suspensions in place. On March 15, an upper low located south of the area had induced a large area of easterly to southeasterly flow across southern Utah, a direction for which flight tracks have not been set up. However, the eastern portion of the Stateline track was deemed ideal for one part of the storm and a flight plan was filed. Prior to departure, thunderstorms approaching from the southeast suspended the flight; once they ended moisture was leaving the flight track zone and the flight was never launched.

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 5.19 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.

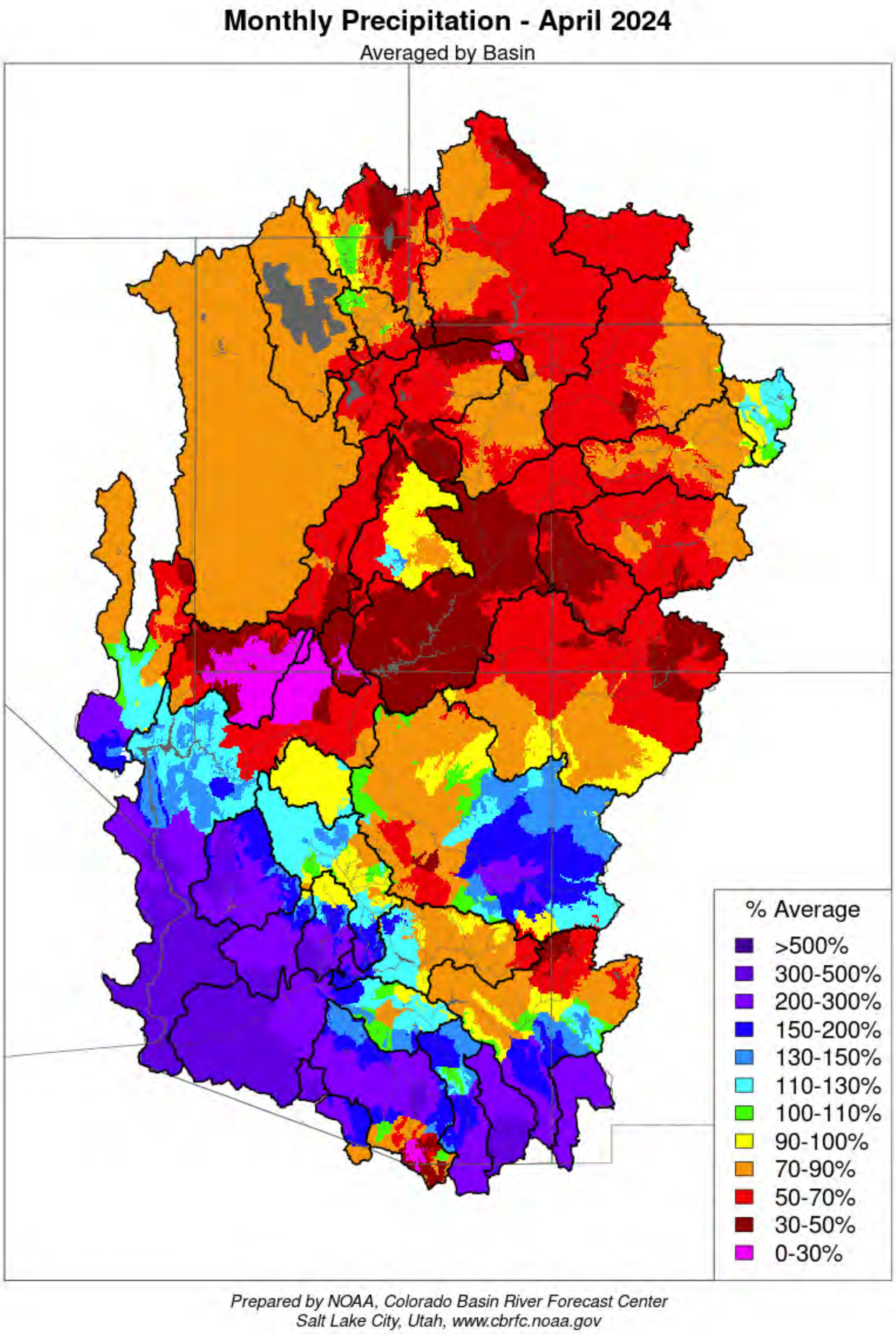


Figure 5.19 April 2024 precipitation as a percent of average for the month.

April 2024 Suspensions/Missed Flying Opportunities

With the storm on April 5-6, strong southerly winds up to 65 knots were observed from the Cedar City radar, with flow largely parallel to the mountain ranges; this was not an ideal setup for aerial seeding. On April 15, an upper low moving across the state resulted in a light yet chaotic upper air wind pattern over central and southern Utah that did not allow for proper targeting of the mountain ranges.

6.0 SUMMARY AND RECOMMENDATIONS

The 2023-24 winter season marked the second year of operation for the Southern Utah Aerial Program. An active weather pattern for much of the winter resulted in an above normal snowpack for all areas, and above normal precipitation for all but the southwestern portion of the state. Despite the active weather pattern in place, only six flights were able to launch to conduct seeding operations. Reasons for this are presented below.

Mechanical issues with the aircraft were few in number, but in both instances, it did result in potential missed flights; an attitude indicator repair on January 3-4 (discovered during a test flight) kept the plane grounded, and on February 20 as the plane was enroute to conduct a seeding mission, the left alternator quit, and the plane returned to the airport. The alternator was subsequently repaired, and a test flight confirmed it to be working properly two days later.

In many instances, weather conditions were the reason for suspensions or missed opportunities: severe turbulence and icing, flash flood warnings, lightning, temperatures too cold or too warm for effective seeding (i.e., outside of the -5°C to -15°C range), 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, particularly for this season. In early April, the Panguitch Lake dam in southwestern Garfield County was found to have significant cracks and was feared to potentially be in danger of failing. During this time period all seeding operations – both ground and air – that would potentially impact Panguitch Lake were suspended until issues with the dam could be resolved, which occurred after the aerial program had concluded for the season.

In terms of the use of the various tracks available for seeding operations, three of the six seeding flights utilized the "Stateline" track this season, which work well with southeast through southwest flow, two flights used the "I-15 South" track, and one flight used a combination of the "I-15 North" and "I-15 South" track; these tracks are favored in southwest through northwest flow regimes. This compares with last season's 13 flights, 11 of which used the "Stateline" track while the remaining two used the "I-15 North/South" tracks. Early expectations, given the pattern of storms in Utah, were for the I-15 flight tracks (North or South) to be the dominant choice for seeding missions, but thus far it is the Stateline track that appears to be more commonly used. As mentioned in last season's report, future seasons will help determine if this should be the standard expectation or if the last two seasons were anomalies.

With regards to communication with the pilot while airborne, for the 2023-24 season, there was no satellite phone in the plane, but instead communication relied on text messaging; this worked reasonably well last season and was replicated again this season with no issues noted. Going forward, while texting does seem to work with the Southern Utah Aerial Program, there should be another method of communication available to the pilot and meteorologist; a satellite phone or similar device should be utilized.

NAWC considers the second season for SUAP 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 using a slightly different approach to seeding could be made for certain situations, such as flying near the top of cloud decks given ample moisture and ideal temperatures if in-cloud seeding results in excessive aircraft icing, for example. The previous two seasons took the approach to aerial cloud seeding 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 difference is that frequently 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 being common for most climate zones in Utah. In these cases, the "on-top" seeding method may have to be used more often.

NAWC looks forward to continuing the program and to learning additional information about aerial seeding operations in Utah over the next few seasons, information that may eventually allow for modifications to the program to increase efficiency.

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 the Park Valley	5,733	George Creek	17.84	187.75	18.32	143.81	28.93	163.43	34.61	153.77	1
	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 - Wyoming state line	USGS 10011500	Trial Lake	20.07	206.54	26.56	182.26	33.68	173.94	38.49	162.05	2
		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 Cedar City	38,533	Midway Valley	20.89	215.65	29.12	194.04	35.89	176.99	42.29	167.97	1
	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 Grantsville	5,426	Rocky Basin-settlemnt	19.09	205.33	23.75	174.14	32.11	171.39	40.01	167.51	1
	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 Reservoir	11,620	Gardner Peak	13.00	293.90	16.82	172.15	21.70	167.36	24.45	163.95	1
	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.