RAINMAKER

# Rainmaker Technology Corporation

## Annual Cloud Seeding Report

## Cache Valley UAV Program

## 2024-2025 Season

## June 2025

NAWC INC

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# 1. Executive Summary

Season one of the Cache Valley UAV cloud seeding program ran from January 27, 2025 through April 30, 2025, marking the inaugural deployment of Rainmaker's first ever drone based cloud seeding platform in the State of Utah. The program was a joint operation effort between Utah State University, recently acquired North American Weather Consultants, and Rainmaker.

Rainmaker successfully delivered and certified ten "Elijah" UAVs for cloud seeding operations in Cache Valley. Four Forward-Deployed Engineers (FDEs) were based in Salt Lake City and deployed to one of two predetermined locations within Utah State University's Certificate of Authorization (COA) area when the project meteorologist deemed conditions favorable for seeding. The COA, located in Northern Utah's Cache Valley region, imposed strict operational guidelines. UAV operations required the presence of a Utah State University-designated Pilot in Command (PIC). Additionally, UAVs were permitted to ascend to within 500 feet of the cloud base, provided cloud bases were between 1,500 and 3,000 feet above ground level. If cloud bases were below 1,500 feet and visibility exceeded 3 miles, UAVs could be flown up to—but not into—the cloud base.

During the 2024–2025 operational period, fourteen cloud seeding flight missions were conducted at varying altitudes, totaling over 80 hours of flight time and resulting in the dispersion of 8,637 grams of silver iodide (AgI).

Concurrently, Rainmaker has significantly advanced the development of its UAVs, meteorological instrumentation, and forecasting and validation software. These advances will bear fruit in Utah, namely by significantly improving and upgrading outdated validation techniques and by enabling Rainmaker to expand UAV seeding opportunities temporally and geographically across the state.

Following a successful inaugural season, Rainmaker's FDEs will return to Utah in November to initiate Season Two with the following objectives completed:

1. Acquire appropriate Federal Aviation Administration (FAA) waivers to be able to fly in-cloud at altitudes greater than 3000 feet above ground level
2. Upgrade meteorological instrumentation infrastructure to increase forecasting accuracy and update validation techniques
3. Expand UAV cloud seeding operations to other regions of the State

# 2. Project Design

## 2.1. Background

Rainmaker in collaboration with Utah State University and recently acquired North American Weather Consultants (NAWC) conducted its first ever drone based cloud seeding platform in the State of Utah from January 27, 2025 through April 30, 2025. Waivers with the FAA to fly in Utah State University's COA were finalized on January 27, 2025 and the projects first seeding mission was flown on February 1, 2025.

## 2.2. Operational Description

It is necessary that the silver iodide crystals become active upwind of the crest of a mountain barrier (i.e., the crest within the target area or defining its downwind boundary) so that the available supercooled liquid water (SLW) in the precipitation formation zone can be effectively converted to ice crystals, with enough time for the crystals to grow to snowflake size and precipitate within the intended target area. If the AgI crystals take too long to become active, or if the temperature upwind of the crest is too warm, the silver iodide crystals will pass from the generator through the precipitation formation zone and over the mountain crest without freezing additional water cloud droplets. Thus, an important task for the project meteorologists is to identify the seedable portions of the cloud systems which traverse the project area.

Rainmaker operated the UAV cloud seeding program in Cache Valley using selective seeding methodology, similarly to how NAWC has been operating ground-based cloud seeding programs in Utah for over forty years. Selective seeding means that seeding is conducted only during specific time periods and in specific locations where it is likely to be most effective. This decision is based on several criteria which determine the seedability of the storm. These criteria deal with characteristics of the atmosphere including temperature, stability, and wind flow, both in and below the clouds. The moisture content of the atmosphere, including cloud types and occurrence of supercooled liquid water (SLW) are important factors during seeding operations. Some heavier storm periods may not be seeded due to factors which make the storm naturally efficient at producing precipitation and bring low visibility. Other storm periods can be deemed unfavorable due to several factors including temperature, stability or wind direction. Additionally, Rainmaker adhered to the strict operational guidelines imposed by Utah State University's COA waiver. The general criteria of selective seeding and the COA wavier are provided below.

- Supercooled clouds are present, and relative humidity is greater than 70%
- Low level wind speed and direction favor the transport of silver iodide seeding material, from its release location into the target area.

- Fly above any low-level inversions or stable layers so that vertical and horizontal transport of silver iodide can reach into the cloud deck.
- Temperatures at the 700-mb level (~10,000 ft) are colder than -5°C.
- Can only fly within Utah State University's COA area
- UAV must stay within visual line of sight and visibility must be greater than 3SM.
- UAVs were permitted to ascend to within 500 feet of the cloud base, provided cloud bases were between 1,500 and 3,000 feet above ground level.
- If cloud bases were below 1,500 feet, UAVs could be flown up to—but not into—the cloud base.

### 2.3. Suspension Criteria

As required in the cloud seeding permit granted by the Utah Department of Water Resources, seeding operations shall not be undertaken, or shall be suspended, if:

- There is an emergency that affects public welfare in the region.
- The National Weather Service (NWS) forecasts a storm to produce unusually heavy precipitation that could contribute to avalanches or unusually severe weather conditions in the project area.
- The Utah Avalanche Center issues an Extreme avalanche forecast warning for avalanche areas located in the target area (note, see modifications to this suspension criterion below).
- The National Weather Service forecasts a warm winter storm (freezing level above 8000 feet) with the possibility of considerable rain at the higher elevations that might lead to local flooding.
    - When potential flood conditions exist in or around any of the project areas the Permit Holder shall consult with the NWS Flood Forecast services. Seeding would be suspended if the NWS determines any of the following warnings or forecasts are in effect:
    - Flash flood warnings by the NWS
    - Forecasts of excessive runoff issued by a river basin forecast center.
    - Quantitative precipitation forecasts issued by the NWS, which would produce excessive runoff.

In addition, seeding is to be suspended at any time the snowpack water equivalents at selected target SNOTEL sites exceed: 175% of average on Jan. 1st, 165% of average on Feb. 1st, 155% of average on Mar. 1st and 145% of average on Apr. 1st when two or more SNOTEL sites located in the target area exceed these amounts. A provision is made where seeding can continue in a portion of the target area that is below the suspension criteria, using generators not expected to impact the SNOTEL sites that exceed the suspension criteria. There are also avalanche suspension criteria developed based on discussions with the Utah Department of Water Resources which focus on avalanche conditions for highways and populated areas.

No seeding suspension occurred during January 27 – April 30 2025.

## 2.4. Equipment and Project Set-up

In December 2024 Rainmaker successfully delivered and certified ten “Elijah” UAVs for the cloud seeding program in Cache Valley. Four Rainmaker Forward-Deployed Engineers (FDEs) were trained and stationed in Salt Lake City and would deployed to one of two predetermined flying locations within Utah State University’s Certificate of Authorization (COA) area when the project meteorologist deemed conditions favorable for seeding. Most winter storms that affect the northern Utah mountains are associated with synoptic weather systems which move into Utah from the southwest, west, or northwest. They often consist of a frontal system and/or an upper trough, with south or southwesterly winds ahead of these features. In meteorology, wind directions are reported as the direction the wind is blowing from, in advance of the system. As the front and/or trough moves through the area, the wind flow typically becomes more northwesterly as time passes. Clouds and precipitation may precede, as well as follow, the front/trough passage, and thus the flying locations were carefully selected to enable seeding operations in southwesterly, westerly, or northwesterly flow situations. The COA area along with the two predetermined flying locations are shown in Figure 2.1. Pertinent flying location information is listed in Table 2-1.

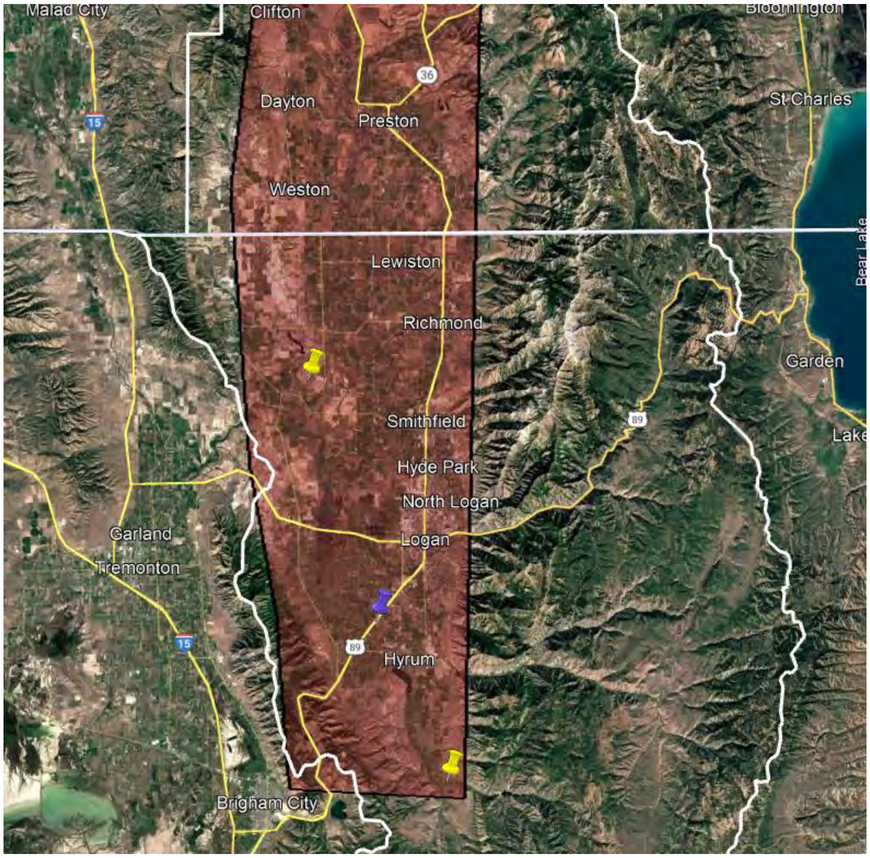


**Figure 2.1** **Utah State University COA area with yellow pins representing flying locations. The purple pin represents the location of a Radiometrics radiometer and purple pins**

**Table 2-1**
**UAV Cloud Seeding Flying Loctions**

| Site Name | Elev (Ft) | Lat (N) | Long (W) |
|---|---|---|---|
| Netwon | 4804 | 41.87285 | -111.96998 |
| Avon | 5017 | 41.52702 | -111.80290 |

Figure 2.2 shows one of the Rainmaker “Elijah” unmanned aerial vehicles (UAVs) utilized in the Cache Valley UAV seeding program. Each UAV is equipped with a suite of meteorological and operational sensors, including temperature, pressure, and relative humidity sensors, along with an aerosol dispersion system (ADS) and anti-collision lighting. The active seeding agent—pure silver iodide (AgI) crystals—is loaded within the ADS and released once the UAV reaches the target altitude. These silver iodide particles function as ice-nucleating agents, with peak effectiveness observed in cloud temperatures between -5 °C

and -10 °C. Each UAV is capable of carrying and dispersing up to 50 grams of silver iodide per flight, with typical mission durations ranging from approximately 25 to 30 minutes.

**Figure 2.2 Rainmaker Elijah UAV**

## 2.5. Operations Center and Personnel

Rainmaker maintains fully equipped operations centers at its headquarters in El Segundo, California and at its newly acquired subsidiary North American Weather Consultants office based in North Salt Lake City, Utah. Real-time weather information is acquired online, supporting decisions regarding where and when to seed. Information used to determine seeding potential includes hourly weather reports, rawinsonde observations, surface and upper-air charts, weather cameras, weather radar, satellite images and computer model forecasts. The project meteorologist in charge of the operations utilizes this information to make informed cloud seeding decisions, as well as for documenting weather information and seeding activities for future reference.

Figures 2.3-2.6 show examples of some of the available weather information that was used in this decision-making process during the operational period that ran from January 27 – April 30, 2025. These include global and regional forecast model data, weather radar images, satellite images, and surface wind and temperature maps.

Figure 2.7 illustrates the predictions of seeding plume dispersion using the HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) model that was developed in-house by Rainmaker. This model provides forecasts of the horizontal and vertical spread of a seeding plume in real-time, based on wind fields contained in the weather forecast models.

Figure 2.8 shows an example of a cross-section plot during a seeded event from this past winter season using the National Oceanic and Atmospheric Administrations 3-km HRRR (High Resolution and Rapid Refresh Model). The user can specify a cross section over any location in the continental U.S. or Canada. This model data was used during cloud seeding operations as a guidance. In these cross sections, liquid water is plotted as a function of distance and height, with temperatures (red dashed lines), wind directions and speed (wind barbs) and potential temperatures (solid black lines) also being displayed.

During the summer of 2024, Utah's Division of Water Resources purchased a Radiometer from Radiometrics. A radiometer is a passive instrument that continuously provides air temperature, humidity and liquid profile products from the surface to 10km above the ground. Figure 2.9 shows a picture of the Radiometer that was deployed in Logan in the fall of 2024 and Figure 2.10 shows an example of the products output by the radiometer during a storm event. The radiometer will continue to be utilized in future winter seasons and possibly lead to further verification techniques.

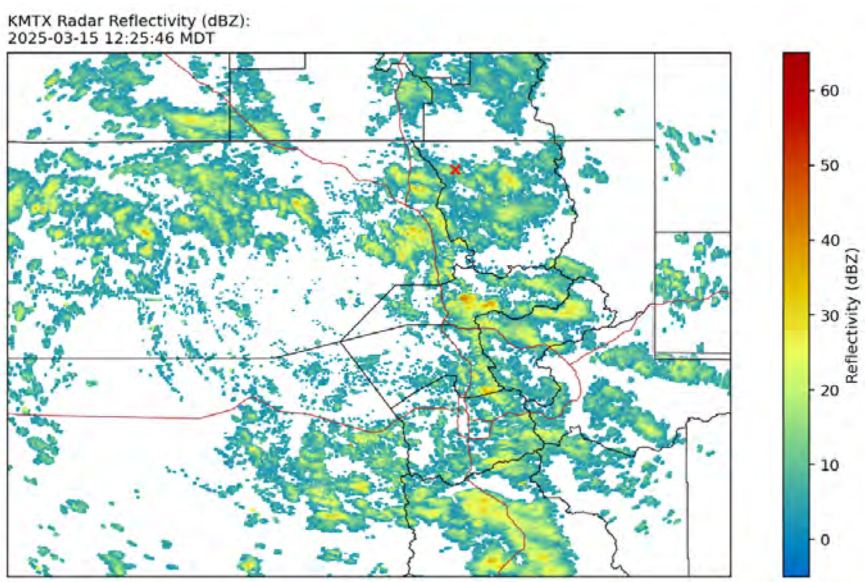


**Figure 2.3** **Captured KMTX radar imagery of northern Utah on March 15, 2025 at 1225 MDT. Red x denotes flying location**

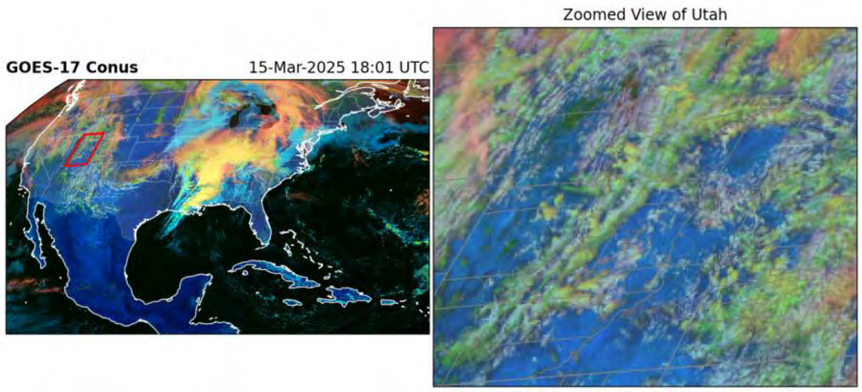


**Figure 2.4** Satellite imagery of northern Utah on March 15, 2025 at 1200 MDT

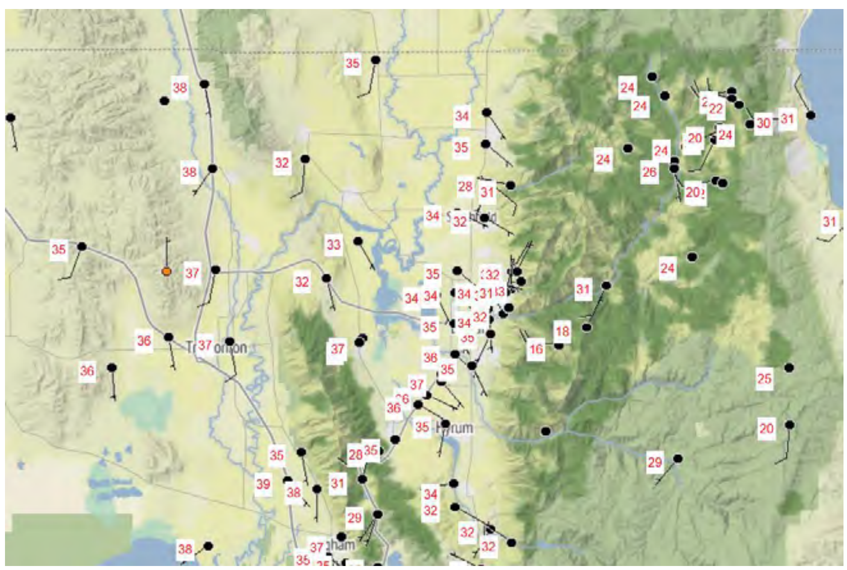

**Figure 2.5** Mesowest surface data map on March 15, 2025. Surface observations are important for diagnosing low-level wind patterns and mixing.

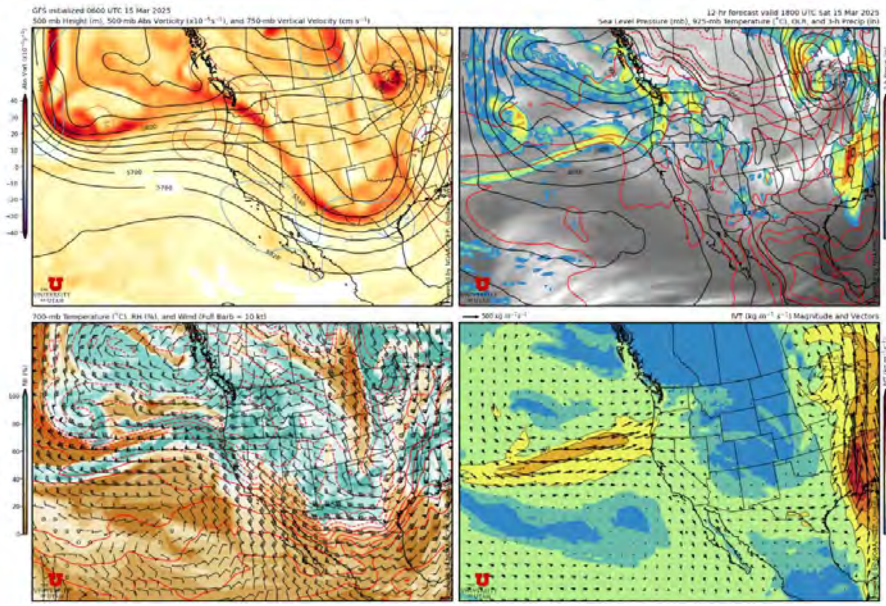

**Figure 2.6** GFS (Global Forecast Systems) forecast data plot for a storm event on March 15, 2025

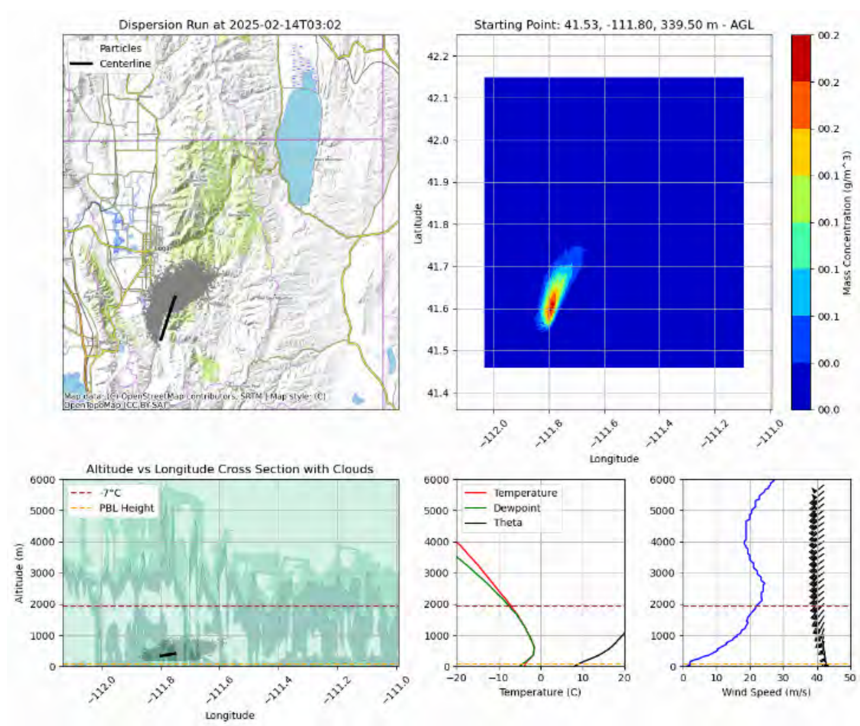


**Figure 2.7** Example of the Rainmaker HYSPLIT tool showing horizontal and vertical plume dispersion of seeding material. Taken during a seeded event on February 14, 2025 at 2000 MST

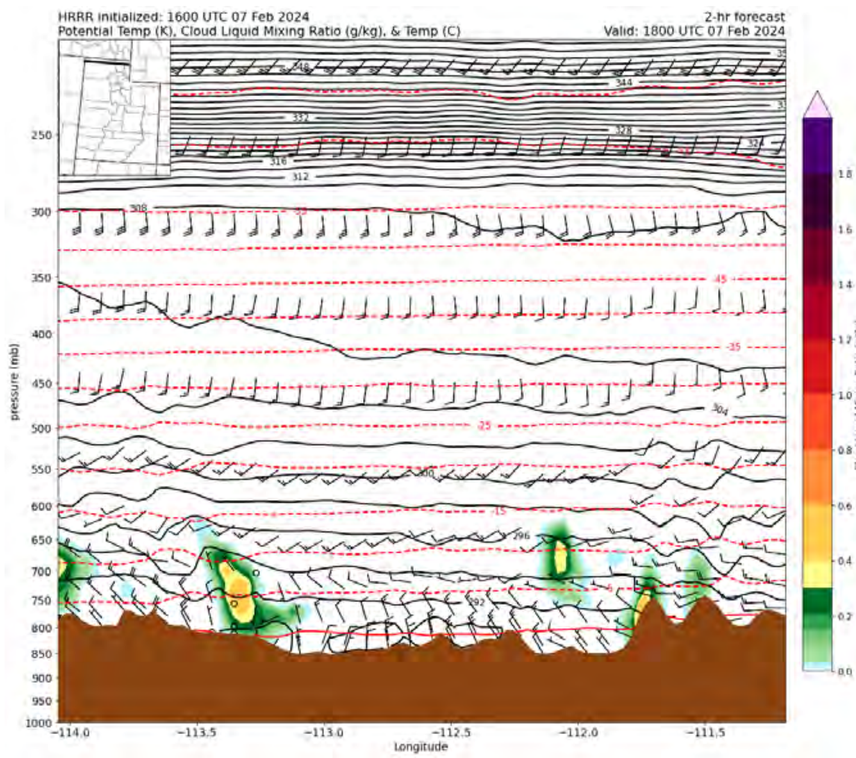


**Figure 2.8 HRRR modeled Cross Section of Liquid Water in Cache Valley on February 7, 2024 – Valid at 1100 MST**

**Figure 2.9** **Picture of the Radiometer that was deployed in Logan in the Fall of 2024**

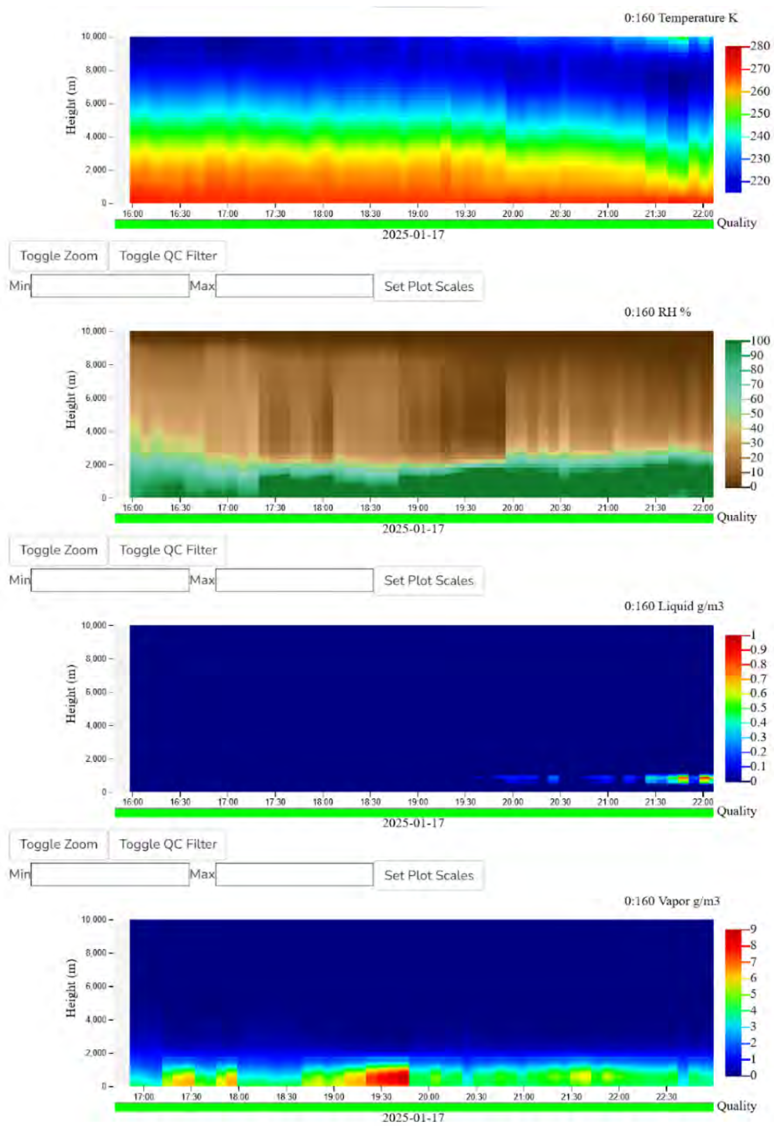


**Figure 2.10** **Example of Radiometer data output from January 17, 2025 showing temperature, RH, Liquid Water and Water Vapor**

# 3. Operations

Season one of the Cache Valley UAV cloud seeding program ran from January 27, 2025 through April 30, 2025, marking the inaugural deployment of Rainmaker's first ever drone based cloud seeding platform in the State of Utah. During the 2024–2025 operational period, fourteen cloud seeding flight missions were conducted at varying altitudes, totaling over 80 hours of flight time and resulting in the dispersion of 8,637 grams of silver iodide (AgI). Table 3-1 shows the dates, flight elevations, total flight times, and total amount of AgI that was dispersed during each storm event.

**Table 3-1**
**Cache Valley UAV Seeding Operations Summary**

| Storm Number | Date | Flight Elevations (ft) | Total Flight Hrs | Total AgI (g) |
|---|---|---|---|---|
| 1 | February 1 | 1998 agl | 3.5 | 350 |
| 2 | February 5 | 1900-2900 agl | 2.5 | 250 |
| 3 | February 7 | 2296-2460 agl | 3.5 | 400 |
| 4 | February 11 | 984 agl | 4 | 400 |
| 5 | February 13-15 | 656-2980 agl | 20 | 1960 |
| 6 | February 16-17 | 1968 agl | 7.75 | 900 |
| 7 | February 20 | 656 agl | .75 | 150 |
| 8 | March 3 | 820 – 2620 AGL | 4 | 550 |
| 9 | March 6 | 410 – 656 AGL | 4 | 200 |
| 10 | March 15 | 328 – 1640 AGL | 10 | 1275 |
| 11 | March 18 | 656 – 984 AGL | 6.75 | 782 |
| 12 | March 22 | 656 – 1640 AGL | 5.5 | 602 |
| 13 | March 29 | 1312 – 1968 AGL | 2.5 | 258 |
| 14 | March 31 – April 1 | 1640 AGL | 5.25 | 560 |
| **Season to Date** | **---** | **—** | **80** | **8637** |

### 3.1. Operational Procedures

During the operational period, the project meteorologist monitored each approaching storm with the aid of continually updated online weather information. If the storm parameters met the seedability criteria presented in Section 2 and if no seeding curtailments or suspensions were in effect, the Forward Deployed Engineers would deploy to one of the seeding locations and begin seeding using the UAVs. Seeding continued as long as conditions were favorable and supercooled clouds remained over the region.

### 3.2. Operational Summary

A synopsis of the atmospheric conditions during operational seeding periods is provided below. All times reported are local, either in MST or MDT. This synopsis describes seeded storm periods, as well as some significant storm periods that were not seeded.

## February 2025

The program officially became active on January 27, 2025 but the first seedable storm did not impact northern Utah until February 1, 2025. February was a fairly wet month across northern Utah, with a couple major storm periods (February 13-15 and February 16-17) bringing substantial snowfall to the area watersheds. In total, there were seven seeded storm periods during the month, all of which are summarized below.

**February 1, 2025**

Westerly flow extended from northern California through the Great Basin and across the central Rockies during the early morning hours, as a landing falling atmospheric river penetrated inland beyond the Sierra Crest and into northern Utah. Ample moisture led to the development of heavy orographic precipitation, which persisted throughout the morning, the afternoon and into the evening hours as well. 700mb level temperatures were around -8 degrees C in the morning, but as the mild subtropical airmass associated with the atmospheric river spread across the state throughout the day, 700mb temperatures warmed to near -5 degrees C by 1800 MST and eventually up to near -3 degrees C late in the evening. Eight flight operations were recorded from approximately 0945 MST through about 1530 MST at an elevation of about 1998 feet agl. Seeding operations ended by 1600 MST after it was determined temperatures were becoming too warm for the altitude at which the drone could fly at.

**February 5, 2025**

A mild airmass within an enhanced southerly flow aloft set up across northern Utah on the morning of February 5, which was ahead of an approaching cold front. A narrow zone of warm advection ahead of the front allowed a burst of convective showers to develop along the terrain east of I-15. As the front grazed northern Utah later in the afternoon, cold advection developed and lowered 700mb temperatures from near –2 degrees C to near –9 degrees C. Convergence along the boundary brought another burst of heavy valley rain/snow and mountain snow to the terrain east of I-15. Showers continued across the region until about 1800 MST after which lift and moisture behind the departing front quickly dissipated and showers dried out. Five flight operations were recorded from approximately 1200 MST through 1347 MST. Recorded flights varied in elevation between about 1900-2900 feet agl.

**February 7, 2025**

A somewhat compact trough embedded within the longwave pattern over the Pacific Northwest grazed by northern Utah during the afternoon and evening hours. A quick moving cold front accompanying this trough pushed through north/central Utah between about 1100-1400 MST. The frontal boundary produced a band of heavy precipitation along its leading edge with a brief period of gusty northwesterly winds. Temperatures dropped rapidly behind the front, falling from near –2 degrees C at 700mb to near –14 degrees C. Winds gradually calmed through the late afternoon but deep instability in the post frontal airmass continued to generate additional showers over the terrain until conditions finally dried out after 2100 MST. Ten flight operations were recorded from approximately 1409 MST through 1653 MST. Recorded flights varied in elevation between about 2296-2460 feet agl.

**February 11, 2025**

The axis of an upper-level trough pivoted overhead northern Utah late in the morning and into the afternoon with a cold frontal boundary following closely behind it. Light snow developed across the terrain of northern Utah after about 1000 MST and continued through the early evening hours before ending by 1800 MST. Moisture was very limited with this cold system given the airmass originated over western Canada. 700mb temperatures hovered around –14/-15 degrees C through the morning but fell to near –20/-21 degrees C later in evening. Even though it was a marginal system for seeding, nine flight operations took place from approximately 0934MST through 1406MST. Flight altitude was recorded at 984 feet agl.

**February 13-15, 2025**

A major atmospheric river system made landfall across the western US and brought well above normal moisture to the state of Utah February 13-15. Heavy precipitation broke out across the state on the morning of the 13$^{th}$ and continued through afternoon and evening. Warm southerly flow aloft allowed 700mb temperatures to climb up to around -5 Degrees C through the day. Precipitation gradually decreased on the morning of February 14$^{th}$ but did not come to a complete end as deep moisture remained and several weak waves rippled across the state. A cold front then crossed Utah from north to south on the evening of February 14$^{th}$, bringing another increase in precipitation along with much cooler temperatures. 700mb temperatures fell to near -11C on the evening of the 14$^{th}$ with snow showers persisting across the terrain of northern Utah. Showers finally came to an end on the morning of February 15$^{th}$ as drier air worked its way in from the northwest and high pressure built across Utah. Approximately 51 flight operations were recorded with the first taking place around 1853 on the 13$^{th}$ and the last around 0545 MST on the 15$^{th}$. Flight elevations varied widely throughout the event, being as low as 656 feet agl and as high as 2560 feet agl.

**February 16-17, 2025**

A shortwave trough ejected eastward into northern Utah through the morning hours, along with some moisture in a warm advection southwesterly flow pattern. Clouds filled in across Northern Utah and a swath of precipitation spread over the Wasatch Front late in the morning through the afternoon. Warm advection allowed this first system quickly exited the region late in the evening and a brief relative lull in showers developed overnight into the morning of February 17. A secondary system or piece of energy then made its way across northern Utah through the early morning hours of the 17th. This second system brought a push of colder temperatures aloft along with increased instability and steepening lapse rates. 700mb temperatures lowered to near -9 degrees C and widespread convective showers developed across the region which continued through about midday before ending. Twelve flight operations occurred on February 16th from approximately 1758 MST through 2330 MST. Flight elevations on the 16th were around 1968 feet agl. Ten additional flights occurred on the 17th, from 1515 MST through 2030 MST. Elevations were generally around 1968 feet agl.

**February 20, 2025**

An upper-level trough located over western Utah on the morning of February 20th was quickly making its way across the state. Within this trough, a closed upper-level circulation developed over northern Utah and was producing a band of heavy precipitation across the Wasatch Front. This area of heavy precipitation continued through the morning hours before tapering off after about 1500 MST. Three flight operations were attempted in the morning between about 0730-0816 MST but poor visibility from ongoing heavy precipitation grounded operations. Flight operations were later cancelled for the remainder of the storm as visibility was forecast to remain poor throughout the afternoon. Flight elevations were around 656 feet agl.

## March 2025

March was an active weather month with seven seeded storm periods, summarized below. Although some of these events were very minor and/or brief in duration, there were also a few larger seeded events and other precipitation periods not favorable to seeding due to various meteorological parameters.

**March 3, 2025**

Upper air and satellite analysis on the afternoon of March 3rd revealed a large upper-level low shifting eastward across the central Rockies with lee cyclogenesis developing across eastern Colorado. Further upstream, the back edge of the aforementioned trough was crossing through Utah. Strong cold advection on the back side of this system combined with deep layer moisture and steepening lapse rates to fuel the development of convective orographic snow showers. 700mb temperatures were around –9 to –10 degrees Celsius and the winds were westerly to northwesterly in direction gusting 10-20 kts. Seeding operations commenced around 1700 MST and continued until showers started tapering off around 0000 MST on March 4. Twelve flight operations were recorded with flight elevations ranging between about 820-2620 feet AGL.

**March 6, 2025**

An active pattern continued throughout the day and into the night as a complex upper-level trough crossed the Great Basin region. Early morning upper-air and satellite analysis indicated a strong upper-level low centered near the San Francisco Bay area. An associated jet max was rounding the base of the trough, spreading broad upper-level diffluence across portions of the Desert Southwest. An embedded shortwave ejected ahead of the parent low, combined with deep moisture, leading to widespread and heavy precipitation across Utah. This first shortwave ejected northward later in the morning and afternoon, with moderate to heavy precipitation gradually turning more showery by late afternoon. Through the morning hours, the flow remained southerly and 700mb temperatures held around –3 to -5°C. As the main trough dug southward into southern California and Arizona later that evening into the early morning hours of March 7th, cold advection increased and drove 700mb temperatures down to near –11°C. The cooling aloft increased instability by steepening lapse rates, which produced some weak CAPE. This brought the potential for a few weak thunderstorms that afternoon and evening, before precipitation tapered further and became more orographic lift-dominant overnight into the early morning hours of March 7th. Seeding operations began around 1700 MST but drones were later ground for the night after 2300 MST due to visibility dropping below a mile. A total of ten flights were recorded with flight elevations ranging between about 410-656 feet AGL.

**March 15, 2025**

A diffuse upper-level diffluent flow pattern was in place across the Intermountain West region early on the morning of March 15, with Utah generally being under a cold but moisture-rich northwesterly mid-level flow pattern. Light snow had developed across northern Utah around 0200/0300 MDT as a weak shortwave trough embedded in the flow traversed the northern half of the state. Snow showers continued through much of the day as the cold and moist northwesterly flow pattern persisted. Instability increased significantly later in the morning into the early afternoon hours as the strong mid-March sun heated the surface. CAPE values increased to near 200–400 J/kg, with lapse rates steepening to near 9.5°C/km. Scattered snow squalls popped up with stronger cells generating graupel and a couple rumbles of thunder. Cloud bases were generally around 1200–1900 feet AGL through the early morning hours but rose to near 2500–3000 feet AGL. Showers quickly diminished with the loss of daytime heating after about 1800–1900 MDT, and a building ridge upstream induced subsidence across Utah. Flying operations started around 0300 MDT and concluded around 1500 MDT. A total of 30 flights were recorded with flight elevations ranging between about 328 – 1640 feet AGL.

**March 18, 2025**

An upper-level trough with its axis located over southeast Idaho through southern Nevada crossed Utah through the day. The associated cold front had already made its way through all but far southeast Utah as of 0600 MDT, with moderate to heavy snow ongoing early that morning. Snow showers decreased in intensity through the morning hours and became more confined to the terrain as a cold and moist northwesterly flow pattern provided favorable ingredients for orographic lift. As the cold core of the trough moved over Utah that afternoon, it combined with daytime heating instability and brought more widespread convective showers. Mesoscale analysis in the afternoon showed CAPE values reaching upwards of 200–300 J/kg with 700mb temperatures hovering around –11/–12°C. Showers quickly tapered off after about 2100 MDT that evening as daytime heating was lost and a ridge building in upstream induced subsidence across the region. Seeding operations began around 0800 MDT and lasted until the flight crew ran out of silver iodide after 1600 MDT. A total of 17 flights were recorded with flight elevations ranging between about 656 – 984 feet AGL.

**March 22, 2025**

Quasi-zonal flow extended from the eastern Pacific inland across northern Utah early on the morning of March 22. An embedded shortwave trough was noted rotating through the northern Great Basin along the nose of a 110 knot jet streak. Broken bands of precipitation had continued overnight into early that morning within this region of forcing and persisted through at least mid-morning, becoming increasingly orographically forced with time as the upper flow veered and the primary forcing moved away from the area. 700mb temperatures lowered to near –8°C that morning and afternoon as slightly cooler temperatures worked in behind the shortwave trough. Cooling temperatures aloft and increased solar heating in the afternoon produced a few weak convective snow squalls. As the trough began to move east later that afternoon, drier air began to spread into northern Utah, with most orographically forced showers quickly tapering off and ending by 1700 MDT. The large-scale pattern then amplified that evening as a broad upper-level ridge built across the Great Basin. Seeding operations were conducted from 0500 MDT until 1230 MDT. Operations ended around midday due to wind gusts exceeding 30 mph at the drone launch site. A total for 14 flights were recorded with flight elevations ranging between 656 – 1640 feet AGL.

**March 29, 2025**

Early morning upper air and satellite analysis on March 29$^{th}$ indicated general troughing across the Western US, with several shortwave troughs rotating around a large upper-level low in the Gulf of Alaska. One of these shortwaves pushed into the western Great Basin early in the morning and later crossed through Utah in the early afternoon. The splitting trough sent a disorganized and weakening cold front across the state, with scattered convective showers developing during the afternoon hours as a result of increased instability from the front and daytime heating. 700mb temperatures lowered to near –6/-7°C late in the afternoon behind the front, with winds generally being 5-15 kts and northwesterly in direction. Shower activity quickly tapered off after sunset, and conditions fully dried out after 23/0000 MDT as a shortwave ridge built in overnight into the following morning. A total of 6 flights were recorded from approximately 1200 MDT until 1600 MDT with flight elevations being around 1312 - 1968 feet AGL.

**March 31 – April 1, 2025**

A large and cold upper-level low was spinning off the coast of the Pacific Northwest early on the morning of March 31. Downstream, broad diffluent flow was noted, with a strong 106-knot polar jet streak producing scattered showers across northern Utah. As the upper low shifted onshore along the Pacific Northwest Coast, southwest flow increased across Utah. By the afternoon of the 31st, southwest wind gusts of 40-50 kts were possible, with strong diabatic heating leading to the development of widespread showers and thunderstorms. An associated cold front then swung through northern Utah on the evening of 31st, reaching the Cache Valley region around 17/1800 MDT. The front was undergoing frontogenesis as it crossed the region and was accompanied by a band of heavy rain changing to snow. Temperatures quickly dropped behind the front, with 700mb temperatures lowering from near –3/-4°C to near –8/-9°C. Gusty southwest winds shifted northwesterly and calmed through the night. Precipitation changed to all snow behind the front, with widespread snow showers lingering in the post-frontal airmass overnight. Scattered snow showers lingered across northern Utah through the morning and afternoon hours of April 1st as a cold, unstable and moist northwesterly flow pattern provided favorable ingredients for orographic lift. Showers then finally tapered off and ended early in the evening of April 1st. A total for 14 flights were recorded from approximately 2100 MDT on March 31st until 0400 MDT on April 1 with flight elevations being around 1640 feet AGL. Operations ended on April 1st at 0400 MDT due to Utah State not having any additional Pilots In Command (PIC's) available for operations beyond that time.

## April 2025

Most of April was dominated by dry weather and above normal temperatures with upper-level ridging situated across the Great Basin region. There were several stormy periods that developed at the beginning of the month, around mid-month and again during the last week of the month. However, none of these storm events provided favorable parameters for seeding with the drone. Temperatures were either too mild, moisture was insufficient, or winds were above the UAV's threshold or blowing from an unfavorable direction.

# 4. Rainmaker Research and Development

Rainmaker's concurrent research and development (R&D) efforts since signing the Cache Valley UAV contract have produced a fully integrated technology platform for cloud seeding, centered on three core products— Elijah V2.0, Eden, and Prophet—that together enable precise prediction, targeting, and validation of precipitation enhancement.

## 4.1. Elijah V 2.0 – Autonomous Cloud Seeding UAV

Rainmaker's Elijah V 2.0 is the world's first purpose-built UAV for in-cloud sensing, targeting, and seeding all on one platform.


**Figure 4.1 Rainmaker Elijah V2.0 UAV**

**Table 5-1**
**Rainmaker Elijah V 2.0 Flight Specifications**

| Specification | Imperial | Metric |
|---|---|---|
| Max Wind Resistance | 50 knots | 92.6 km/h |
| Max Altitude AGL | 16,500 ft | 5000 m |
| Max Flight Time at 10,000 ft | 45 minutes | 45 minutes |
| Max Flight Time in Icing | 45 minutes | 45 minutes |
| Climb Rate | 49 ft/s | 15 m/s |
| Max Radio Range | 12.5 miles | 20 km |
| Weight | 20.3 lbs | 9.2 kgs |
| Max Payload | 6.6lbs | 3 kgs |

### 4.2. Elijah V 2.0 Instrumentation

- Dispersion rate of 3.5 g/min dispersion (210g/hour)
- Dispersion type: Modularity enables solid aerosols, liquid atomization, and flares
- Sensors: Pressure, temperature, relative humidity
- Detection: Wind magnitude, wind vector, and supercooled liquid water detected using algorithms

### 4.3. UAV Weatherization

Rainmaker's anti-icing system, combined with onboard thermal resistors, allows the Elijah V2.0 UAV to remain operational in icing conditions for up to 45 minutes. This capability enables extended in-cloud flight for targeting, dispersion, idling, and atmospheric sensing. With improved performance at higher altitudes, Elijah V2.0 increases the frequency and expands the temporal and geographical windows for cloud seeding operations. Figure 4.2 presents historical radiosonde data from Salt Lake City, showing the percentage of seedable days by month, the average height of the freezing level, and the average wind speed at that level. The data was filtered to reflect conditions favorable for seeding—specifically, where relative humidity exceeded 90%, temperatures ranged from -20°C to 0°C, and cloud depth was less than 2000 meters. The analysis highlights how Elijah V2.0 can extend UAV seeding operations into the warmer spring and fall months, when opportunities have traditionally been more limited.

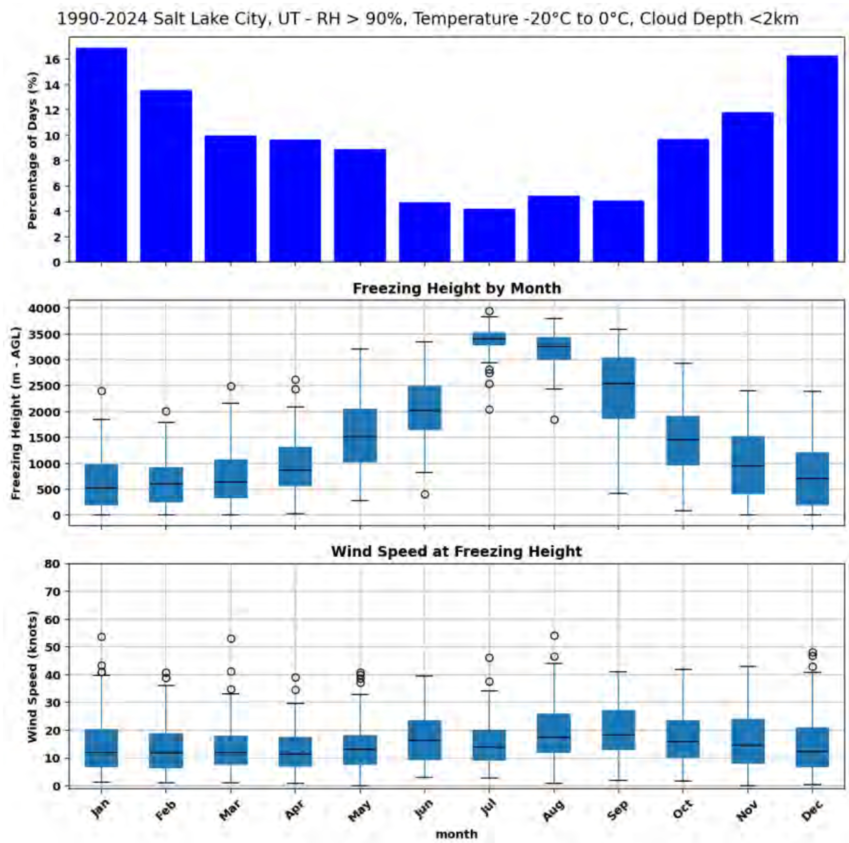


**Figure 4.2** **Salt Lake City Historical Radiosonde data (1990-2024)**

## 4.4. Eden - Remote Ground-Truth Sensing

Eden, shown in Figure 4.3, is a remote sensing platform that delivers hyperlocal cloud and environmental intelligence by combining high-resolution microphysics profiling with ground-based monitoring. A K-band cloud radar continuously captures in-cloud particle size distributions and seeding potential, while a co-located LiDAR ceilometer tracks cloud-base height in real time. Complementing these measurements, an array of surface sensors records temperature, wind speed and direction, barometric pressure, humidity, and $PM_{2.5}$ concentrations—data that feed directly into Peregrine's dynamic mission- calibration algorithms.

**Figure 4.3** **Eden Ground-Truth Sensing**

## 4.5. Prophet - Command, Control, and Intelligence

**Forecasting**

Prophets forecasting engine fuses Elijah's in-cloud measurements, Eden's ground-truth data, satellite imagery, and regional C-band radar into a unified numerical weather-prediction framework. By ingesting real-time microphysical profiles and surface observations, it produces hyperlocal, minute- by-minute maps of supercooled liquid-water content, cloud-top heights, and seeding potential— enabling mission planners to identify optimal launch windows and target areas with unprecedented precision.

**Nowcasting & Remote Control**

Building on its forecasts, Prophet delivers continuous nowcasts via live telemetry from Elijah UAVs and Eden ground stations. Automated dispatch algorithms adjust flight paths on the fly in response to changes in wind shear, cloud-base elevation, and liquid-water availability. Operators can issue real- time commands or rely on pre-authorized decision rules to reroute missions dynamically—maximizing seeding efficiency while ensuring safety and compliance with local aviation constraints.

**Validation & Attribution**

After each operation, Prophet's validation suite applies high-frequency radar-return analysis and comparative quantitative precipitation estimation (QPE) over seeded versus control domains. Sophisticated signal-processing algorithms isolate the anthropogenic precipitation signature, quantify enhancement metrics, and feed into automated dashboards that generate clear time-series graphs and statistical summaries of net water gain. This end-to-end attribution pipeline delivers rigorous proof-of-concept and underpins Rainmaker's performance guarantees. An example of prophets validation suite is shown in Figure 4.4.

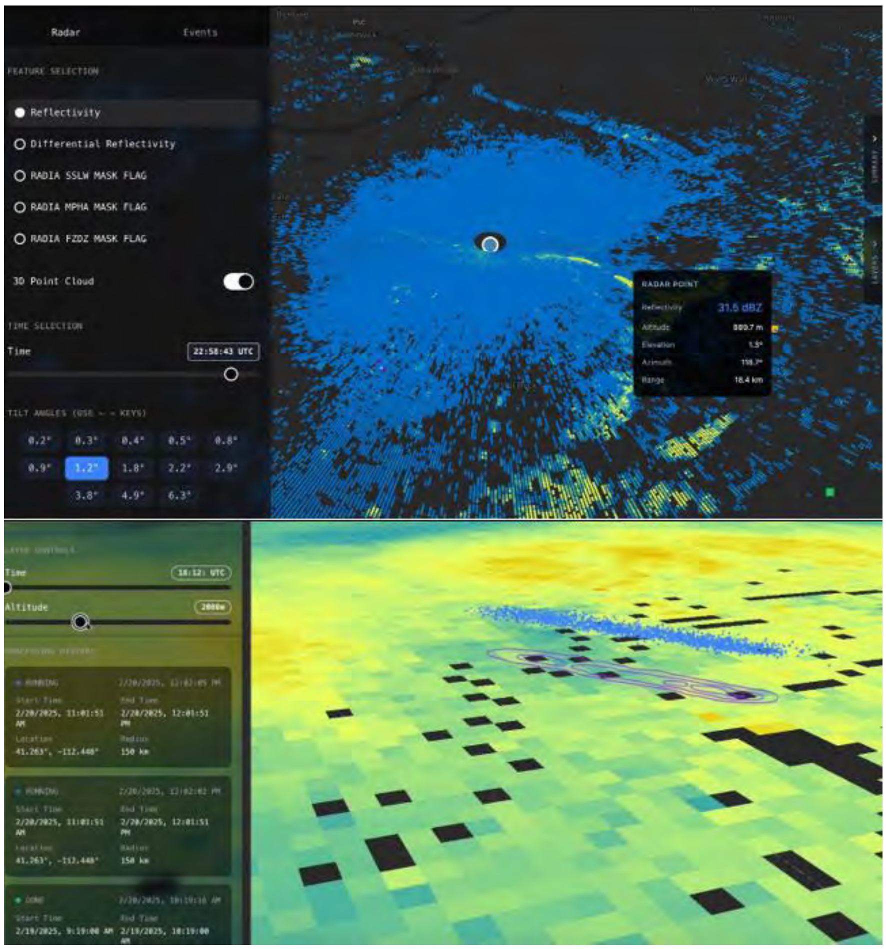


**Figure 4.4** **Prophet SLW detection (Top); Prophet seeding plume visualization (bottom)**

# 5. Conclusions

## 5.1. Season One lessons learned

**Foundation-Setting**

Over the course of Season One, Rainmaker completed the critical groundwork for scalable UAV cloud seeding operations in the state of Utah. All human infrastructures, from logistics coordination teams and local aviation liaisons to maintenance crews—has been recruited and trained under Rainmaker oversight. At the same time, every technical component, including UAVs, weather stations, and the flight dashboard, has been calibrated, stress-tested in situ and now just awaits installation. Standardized processes for mission planning, regulatory compliance, safety checks, and data management are now in place, meaning that once meteorological conditions achieve operational thresholds, seeding missions can commence with minimal lead time. This solid foundation not only accelerates response cadence in Season Two but also de-risks each deployment by embedding lessons learned into repeatable procedures.

## 5.2. Season Two Objectives

**Expand UAV Seeding Programs Across Utah**

During Season One, operations were limited by restrictions within Utah State University's Certificate of Authorization (COA) waiver. UAVs were prohibited from flying in cloud, restricted to visual line of sight operations, and could only be launched under the supervision of a Utah State University Pilot in Command. To overcome these limitations for Season Two, Rainmaker is actively pursuing its own FAA approval for expanded operational waivers for the Logan area and also across the state of Utah. These include authorization to fly beyond visual line of sight and operate at altitudes up to 15,000 feet above ground level.

**Quantitative Precipitation Estimates**

Building on improved seeding coverage and radar instrumentation, Season Two aims to quantify the total volume of artificially induced rainfall precisely. Our target is to verify at least 2 million cubic meters of net precipitation enhancement over the campaign. To achieve this, Prophet's QPE algorithms will fuse data from the MRR-Pro radars, regional C-band networks, and in-situ rain gauges—calibrating volumetric estimates against baseline control areas. Rigorous cross-validation with Eden's ground sensors and post-storm hydrological audits will ensure that all measurements meet independent verification standards. This quantitative milestone will not only demonstrate Rainmaker's effectiveness at scale but also underpin performance-based contracting for future seasons.

# Glossary

**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:** 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.

**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.

**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

**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 Nino:** 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).

**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.

**Inversion:** Refers to a layer of the atmosphere in which the temperature increase with elevation

**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 Nina:** 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 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 (counter-clockwise) 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

**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.

**Pressure Heights:**
(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 pattern):** 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.

**Storm Track** (sometimes reference 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

**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 (counter-clockwise) circulation pattern in the Northern Hemisphere.

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

**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.

**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 site