Liquid Propane Cloud Seeding Pre-experiment Camas Prairie, Idaho, WY2023 Year 1 Report, Contract # CON01631

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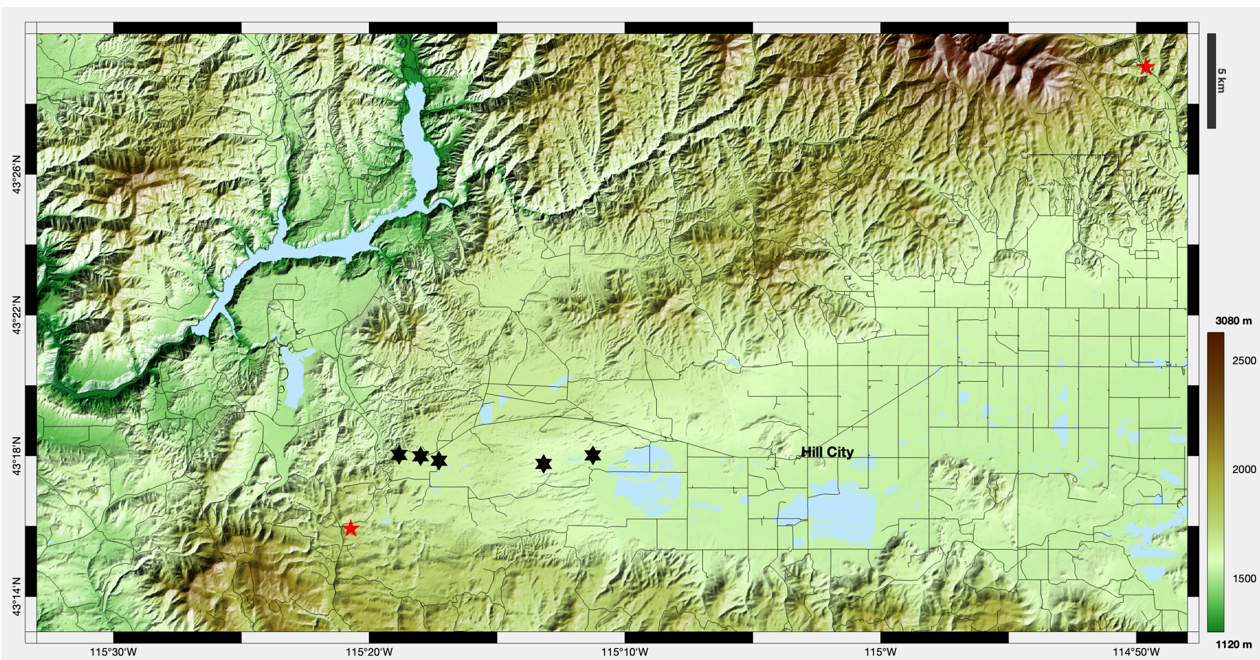


Figure 1: Map of Camas Prairie near Cat Creek Summit, showing 5 weather stations (black stars) and SNOTEL sites in the area (red stars). Proposed generator site is at the Western-most weather station.

1 Abstract

During the Winter 2022-2023 (WY2023), Idaho Power, IDWR, NCAR, and CryoToolbox performed a preliminary investigation of the Camas Prairie, to assess suitability of the site for a future cloud seeding experiment. Idaho Power installed a tower at Cat Creek Summit, where a planned generator will be located this coming winter, and installed some sensors. NCAR performed WRF simulations to determine the number of potential cloud seeding events. IDWR was the project sponsor, and CryoToolbox installed 5 weather stations from the summit to 10km downwind of the proposed generator site. CryoToolbox acquired the hardware for these sites, performed the installation and visited the stations monthly throughout the winter. Two UAV based surveys with lidar and radar were performed, along with a peak SWE survey. We also attended several group meetings where these results were discussed. This report summarizes the results and recommendations for WY2024.

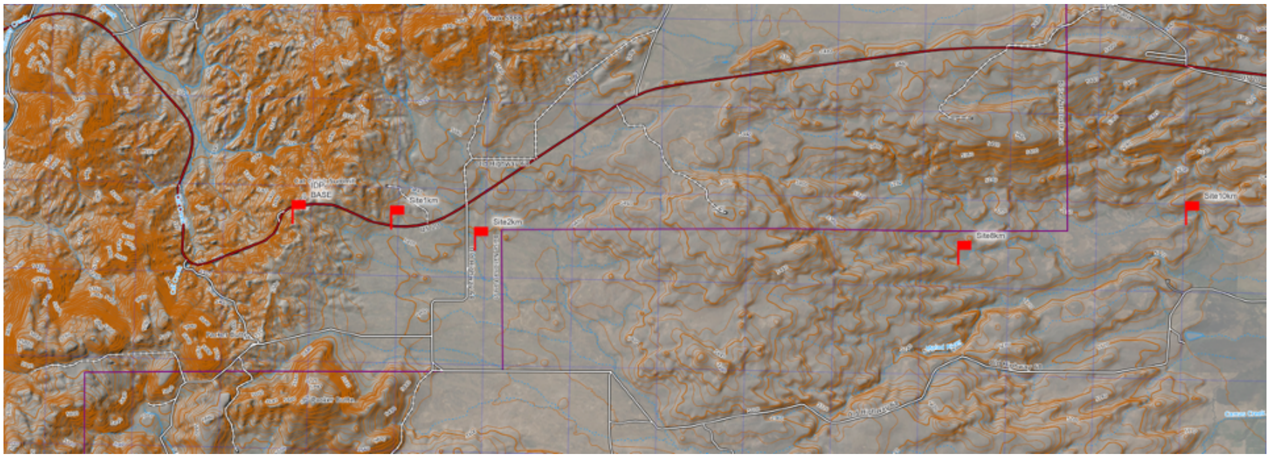


Figure 2: Zoomed in map of the proposed study site, with 10 foot contours. Weather stations are shown as red flags, with the proposed generator site at the Western-most station.

2 Meteorological Stations

CryoToolbox obtained permission from private land owners, and IDWR obtained permission from the State of Idaho, for the locations of the 5 weather stations. We installed the first site in mid-December at the proposed generator site, and the remaining 4 weather stations during the first few weeks of January. Each weather station has a lightweight 3-meter tripod, to allow for deployment by snowmobile, as these sites are not accessible by truck. They each have 15W of solar panels, and a 100A-hr lithium battery bank, rated for -15 C. Each site is measuring air temperature, wind speed, direction, and gust, relative humidity, barometric pressure, and snow depth. The snow depth sensor is laser-based (lidar), which we have recently developed. It is more accurate than the standard acoustic depth sensors, and tracks snow depth through storms and snow saltation/redistribution events, unlike the acoustic sensors.

These weather stations operated continuously, performing 15-minute averages of the meteorological variables, which were recorded every 15 minutes on a logger. Fig. 1 and Fig. 2 show the locations of the weather stations with the surrounding topography. The proposed generator site is at the Western-most weather station, which is at the top of Cat Creek Summit. We hypothesised that there are multiple events per season with winds from the West, which would allow a cloud seeding generator at the summit to increase snowfall to the East, up to 10km away. Figs. 3a and 3b show the weather station at the summit from different directions.

Meteorological observations from WY2023 show that wind directions are predominantly out of the West, as expected, especially during high wind speeds (Fig. 4). The first two sites nearest to Cat Creek Summit (Site 0, Site 1km) WNW predominant direction, likely due to topographic effects near the summit. The site at 8km downwind of the summit also has a WNW general wind direction, likely due to the orientation of the bench just above it (see Fig. 2). The sites at 2km and 10km have mainly due West winds. However, all sites experience winds from the East as well, which is in agreement with both local knowledge and NCAR's modeling results. Locals describe the winds as coming from the East just before snow storms, and then from the West during the storm.

We also partitioned wind during periods when the relative humidity was greater than 75%, however we did not see much difference in the statistics of the wind direction and speed (Fig. 5).

(a) Looking to the West. (b) Looking to the East.

Figure 3: Cat Creek Summit Weather Station

3 Task 1: Degree of wind redistribution of snow

Our first task was to evaluate the degree of wind redistribution of snow at this site. Qualitatively, we did not observe saltation and movement of snow on any of our site visits, even during high wind events. Surface snow densities were around 20% water, and likely temperatures were high enough to produce higher density snow that did not allow for much surface transport by wind. Manual site surveys during peak Snow Water Equivalent (SWE) also showed minimal variation between the weather stations, with SWE varying by less than 15% between Site 1km and Site 10km. The snow depth time series (Fig. 6) also shows a very consistent pattern of snow accumulation, with depth at Sites 1km and 10km being very similar and indicating minimal gradient in the downwind direction. Site 8km shows a similar pattern, albeit lower snow depths, as it is on a small knob and likely experiences some wind scour - this was a trade-off between measuring representative snow information, and representative wind. The site at Cat Creek Summit is very wind exposed and experienced significant wind scouring, and is likely not a useful location for snow observations. Our snow depth sensor at Site 2km failed, and we propose to move the snow depth sensor from Cat Creek Summit to this site for WY2024. The indications of minimal surface snow transport by wind is encouraging, as significant wind redistribution of snow would make evaluation of the impacts of cloud seeding much more challenging.

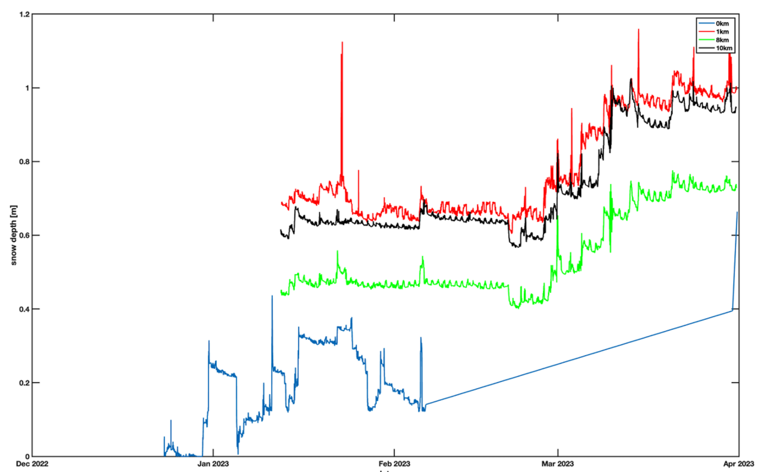


Figure 6: Snow depth time series at 4 of the weather stations. The site at Cat Creek Summit is very wind exposed and experienced significant scouring, while the other three sites show similar snow depth evolution.

UAV radar surveys were challenging, as wind speeds were often too high to fly with our aircraft. We did manage to perform a few surveys, and are confident that we can perform high resolution surveys at this site. However, for the coming winter, we recommend moving to a snowmobile platform for the radar surveys, as

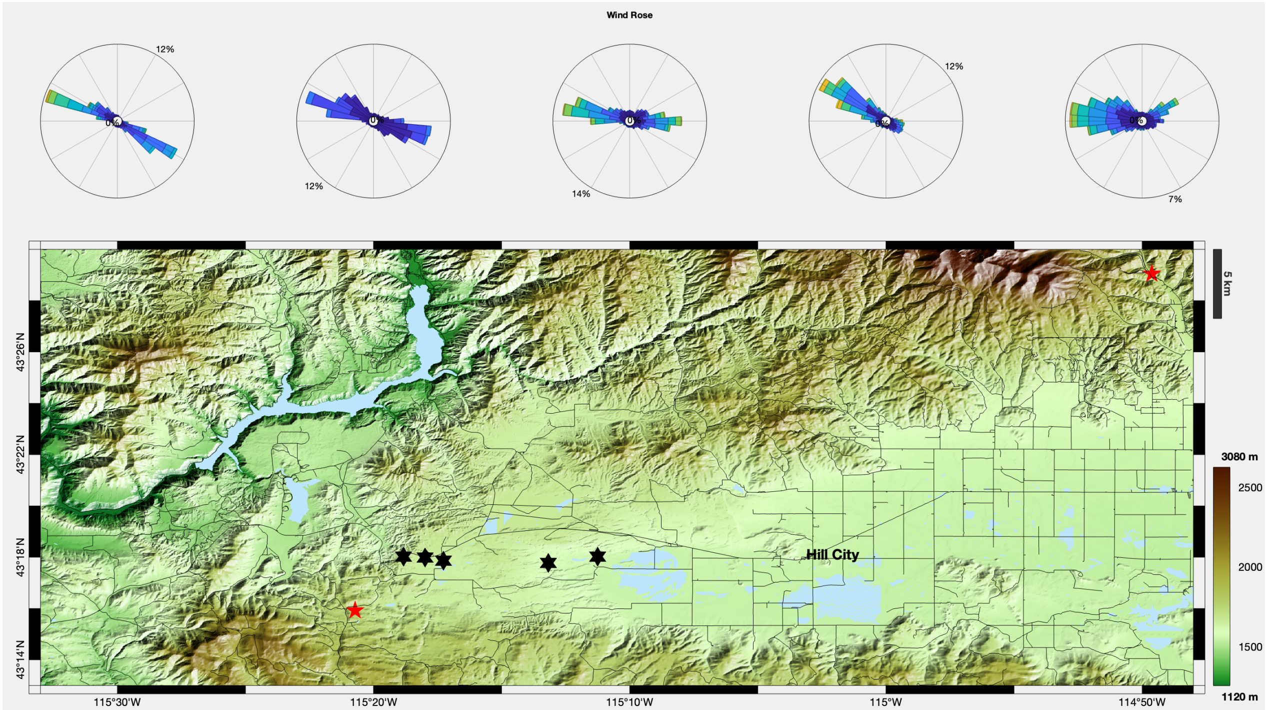


Figure 4: Map of Camas Prairie site, showing locations of weather stations along with summary wind roses for WY2023. Wind roses are shown at the top, in order from West to East.

this will allow sampling in nearly all conditions. An example radar profile is shown in Fig. 7a, and a photo of the UAV radar system is shown in Fig. 7b. Based on feedback from NCAR on the required resolution needed to measure the cloud seeding signal, we suggest a radar redesign for much higher resolution, by increasing the bandwidth. Initial design work has been done to increase the radar resolution, by increasing the bandwidth of the signal.

4 Task 2: Sample during 1-2 cloud seeding test runs

Unfortunately, it was not possible to locate a propane tank onsite, given the timing of the project, and therefore cloud seeding test runs were not possible during Year 1. Cloud seeding is planned during Year 2.

5 Task 3: Collect snow and meteorological data along a downwind transect for a winter

This task was successfully completed, as described above, with 5 weather stations installed and operated along a transect from the proposed generator site, to 10 km downwind (to the East). Data from all 5 sites will be made available to all project participants upon request. Two UAV surveys with airborne lidar and radar were performed, allowing an evaluation of the degree of variability due to wind redistribution. This winter we plan more intensive surveys, but from a snowmobile platform rather than a UAV, due to the challenges of flying small aircraft in high wind conditions.

6 Viability of site

Overall, the Camas Prairie site has some potential as a location for evaluating the effects of cloud seeding. It has gentle topography, low spatial variability of snow, and easy access, making it ideal for characterizing

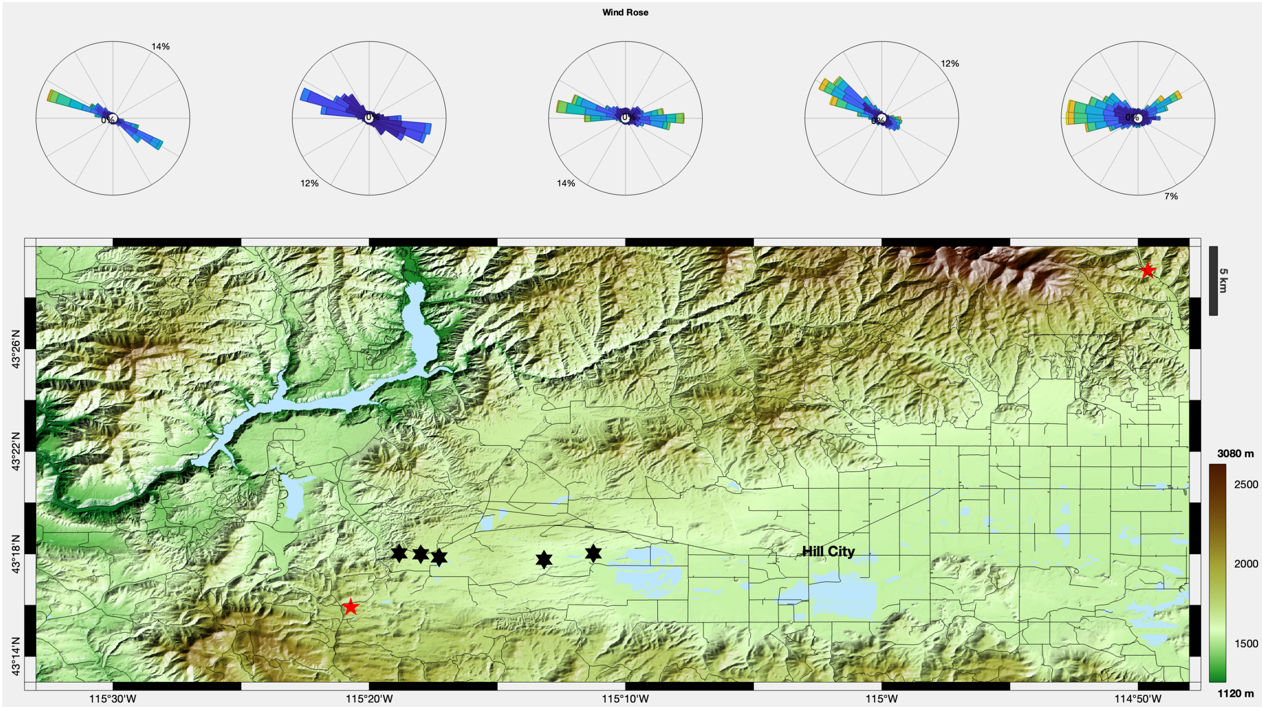


Figure 5: Map of Camas Prairie site, showing locations of weather stations along with summary wind roses for WY2023 during periods with relative humidity greater than 75%.. Wind roses are shown at the top, in order from West to East.

snow spatial patterns and evaluating the differences during cloud seeding events. However, the wind does blow from the East a significant amount of the time, resulting in only a subset of storms being viable for cloud seeding from the summit. In addition, NCAR WRF modeling indicates there are only a limited number of events during each winter that have conditions that are conducive to cloud seeding.

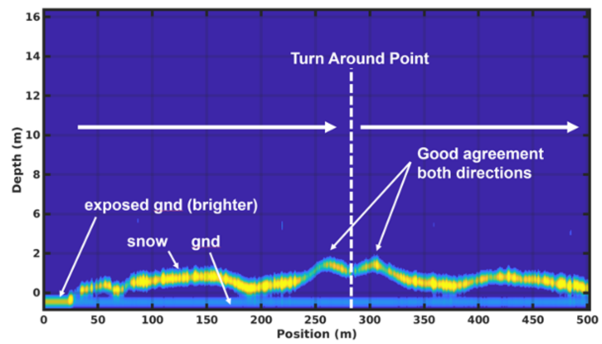
A site farther to the east, near Kilgore, Idaho, is likely to be a better site for the experiment from the perspective of the meteorological conditions, however access is much more difficult, requiring a very long drive from Boise, and a long approach by snowmobile, requiring multi-day field efforts. There are also better options for a precipitation radar that NCAR will deploy in the Camas Prairie. For these reasons, we believe it is useful to perform one more year of observations at the Camas Prairie site, this time with both cloud seeding events and a precipitation radar. This will also give us a chance to refine our sampling strategy.

7 Evaluation of sampling strategy

The locations of our weather stations this season were reasonable, however it has been recommended that we move the furthest stations closer to the proposed generator site. We plan to move the site at 10km to a location between 3-5km from the generator site, and possibly leave the site at 8km where it is, as it is on state land and can remain there long term. We will install another additional site in the 3-5km range, so that we will have two weather stations at this distance from the proposed weather station, all above the larger change in topography at 6-7km.

8 Suitability of generator location

For the Camas Prairie site, the generator location appears to be ideal for storms with wind from the West. The topography will force air masses to lift up and over Cat Creek Summit causing rapid cooling, and this site is at a higher elevation than the rest of the terrain to the East. The location is not ideal for storms with



(a) Example UAV radar transect, with a 15-16 GHz FMCW radar system.

(b) Photo of the UAV radar during a survey at the Camas Prairie site.

Figure 7: UAV radar system used to measure snow spatial variability.

wind from the East, but there is not a good alternative generator location at this site for storms with this wind direction.

9 Recommendations for future work

We recommend one more season of observations at the Camas Prairie site, due to the potential viability of cloud seeding for some of the storms during a given winter, the access for field surveys, and availability of power, a secure location, and orientation for a precipitation radar. We also recommend a smaller preliminary investigation at the proposed Kilgore site, with Idaho Power installing a tower that could be used for a generator with an icing sensor and anemometer, and one of the smaller portable CryoToolbox weather stations at a downwind location. We propose to refine our sampling strategy, moving the location of some of the weather stations at the Camas Prairie and adding an additional station. We also propose increasing the resolution of the radar system to allow detection of small increases in snowfall. We did not run a heater on the laser snow depth sensor, due to power requirements, and this resulted in a small 1cm diurnal variation due to temperature changes. We recommend increasing the battery bank to allow the use of the heater which will alleviate this problem, which we verified in our lab, to improve our ability to detect a cloud seeding signal in the measured snowfall.

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