Utah Prescribed Fire Smoke Study

UTAH DEPARTMENT of ENVIRONMENTAL QUALITY
AIR QUALITY

FOREST SERVICE
DEPARTMENT OF AGRICULTURE

UTAH DNR
50TH ANNIVERSARY
NATURAL RESOURCES

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF LAND MANAGEMENT

2019-2020

Background

Prescribed fire is a key tool for Utah's federal, state, local, and private land managers in their efforts to maintain healthy landscapes. The footprint treated by prescribed fire annually in Utah is between 25,000 and 75,000 acres. An interagency airshed group including the Utah Division of Air Quality (DAQ) and land managers steers the smoke program. Utah's smoke management plan (SMP) specifies the burn procedures for DAQ and land managers, and has been in effect since 1999. The current SMP has the program goal: "To balance the need to minimize smoke impacts on air quality, public safety, and visibility with the need to allow prescribed fires and wildfires to accomplish land management objectives, including catastrophic wildfire risk reduction, hazardous fuel reduction, vegetation management, wildlife habitat improvement, and other ecological functions."

A measure of atmospheric dispersion, the clearing index, is one element of the go/no-go decision for prescribed fires from a smoke standpoint. Until 2020, under the SMP and State Rule R307-204, the same clearing index requirement applied regardless of location and fuel type. In order to address a backlog of hazardous fuels and maximize restoration efforts, land managers in Utah have been asking for flexibility to conduct prescribed burning when dispersion is lower.

Land managers kept records of the barriers to implementing their prescribed fire projects from October 2018 to March 2019. Particular notation was made when the clearing index was the primary impediment. Their results showed 23 out of 77 registered projects were affected, including all six land management agencies that participate in the program.

New smoke management tools are continually being developed. The land managers proposed, through the airshed group, that certain remote burns could be implemented at lower clearing index values than required and still not impair air quality experienced by the general public. To support this they provided BlueSky modeling. To verify the model results, the DAQ and land managers undertook a field monitoring study for prescribed fires.

The study goal was to deploy a variety of monitoring instruments to prescribed burns in the fall/winter 2019/2020, in attainment areas, on days when the clearing index was forecast to be between 100 and 500. If the results were supportive to validate modeling results, the study data could be used to develop an implementation guidance.

Through the smoke coordinator, DAQ reached out to the prescribed fire community asking for volunteers with upcoming burn projects that would meet the criteria. Projects were identified around the state, and six were eventually conducted with monitoring equipment in place.

At the same time in early 2020, a bill passed the Utah legislature making changes to the prescribed fire approval process and codifying options for conducting prescribed fires when the clearing index is under 500 (19-2a-105). Because of this, the study results are not planned to be used directly for building administrative flexibility in burn approvals, but are certainly still of interest in meeting the goals of the smoke management program

Abstract

An interagency study team set up PM2.5 monitoring equipment on six prescribed fire projects around Utah in the fall and winter of 2019-2020. One project was broadcast/landscape burning, three were pile burns with brush piles constructed by hand, and two were biochar kiln burns. Most projects had multiple monitoring sites (fifteen in total across the study). There were sixteen days of active ignition with monitoring equipment in place, and monitors were generally left set up in days following to capture residual effects.

Equipment was provided by DAQ, the US Forest Service, Utah State University, and the US Environmental Protection Agency. Sensor technology included mass filter, beta-attenuation, and light scattering. The cost of the monitoring instruments ranged from $200 to $20,000. The team has included a chapter on instrumentation to discuss findings and future recommendations. The low-cost sensors were found to provide the best value for a project like this one.

Distance from burn site to monitor site had the greatest bearing on measured particulate matter. In all cases, monitor sites farther than one kilometer from the burn site had 24-hour average PM2.5 concentrations indistinguishable from background levels.

The study team primarily used BlueSky to forecast total emissions and smoke dispersion patterns. On 41 of 49 days model results were accurate or slightly overpredicted the monitored concentrations. On 8 days measured concentrations exceeded the model predictions. Recommendations going forward are to use multiple tools for smoke forecasting rather than relying on a single framework, and to consider whether wind or topography will be the more significant factor in smoke movement.

The effect of dispersion, as measured by the clearing index, was inconclusive. As hoped for, the study was able to look at the effects of ignition days with clearing index values in the 100s, 200s, 300s and 400s, but results did not indicate a strong relationship between clearing index and PM2.5 concentration.

Burn size is a factor the team analyzed. The number of piles burned in a given shift ranged between 12 and 400. Even so, none of the pile and biochar burns emitted more than one ton total PM per ignition day. This study found little relationship between burn size (number of piles) and measured particulate matter, with the exception of biochar kilns. Biochar kilns showed quite small impacts, even close to the burn site.

The burns occurred between 1,200 and 2,400 meters elevation (4,000 feet to 7,800 feet), which is a typical range for Utah prescribed fires. The data show no obvious relationship between elevation (either burn site or monitor site) and measured PM2.5 concentration.

Contents

Land managers and study team members discuss the particulars of monitoring a prescribed fire project during a pre-burn field scouting visit

BLACKSMITH FORK

UINTA WASATCH CACHE NATIONAL FOREST

LOGAN RANGER DISTRICT

41.74 N
111.66 W
2300 m / 7545 ft

SUMMARY

A broadcast burn 12 miles East of Logan. 287 acres of timber and brush. Burn days 9/4/19 through 9/6/19.

DESIGN

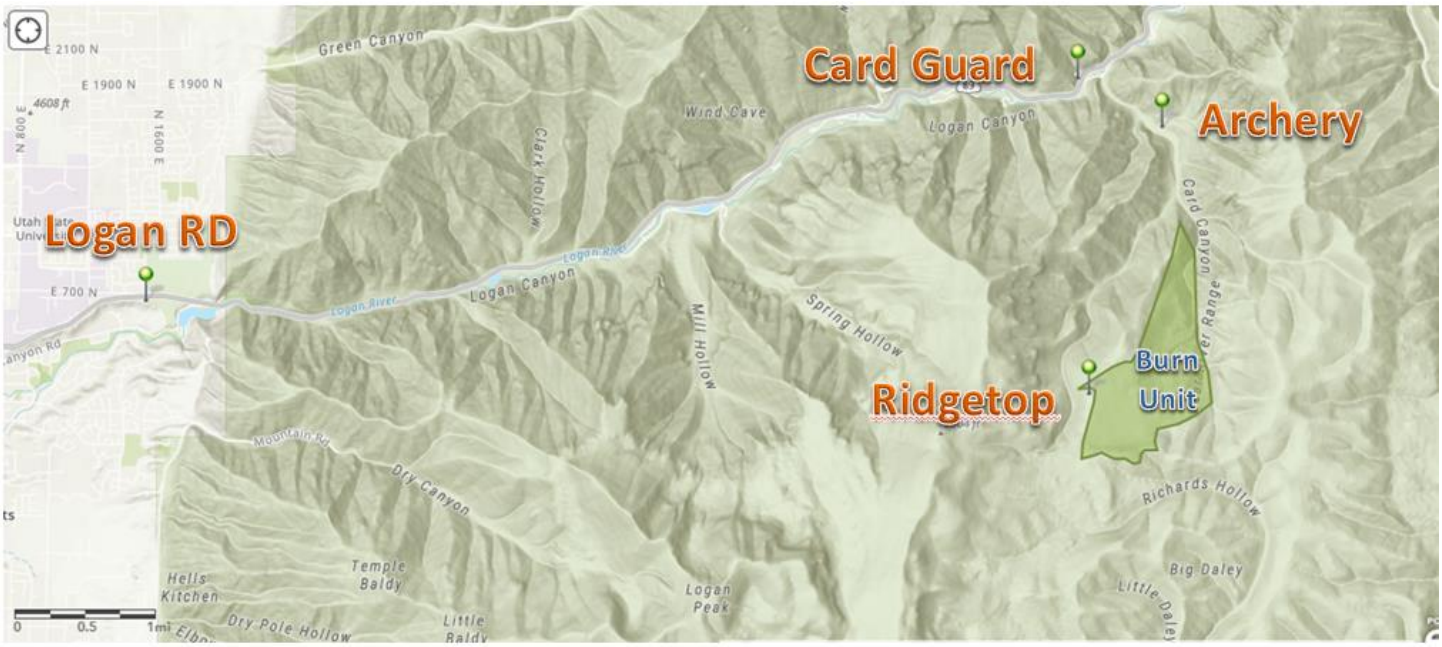
The study team conducted a site visit on 8/20 to select monitoring locations. The team chose four sites.

EQUIPMENT

Logan Ranger District: E-BAM, MiniVol, AirU
Card Guard Station: E-BAM, MiniVol, AirU
Archery Range: MiniVol, AirU
Ridgetop adjacent to burn: MiniVol, AirU

EVENTS

The burn was conducted under excellent dispersion (clearing index 1000+ all days). The project offered the opportunity to field test the equipment and assess data quality.



Pins show the four monitoring sites in relation to the Blacksmith burn unit

MiniVols (left, one with an AirU dangling below it) and E-BAM (right) set up at Card Guard Station, looking West

Looking East from Card Guard Station up Logan Canyon, burn unit is out of view to the right.

Sunset over the burn unit, photo taken near the Ridgetop monitor site, September 4 2019, 1900 hours

Looking up Logan canyon from the Logan Ranger Station, September 5 2019, 0630 hours

Looking towards the burn unit from one ridge the south, September 4 2019, 1300 hours

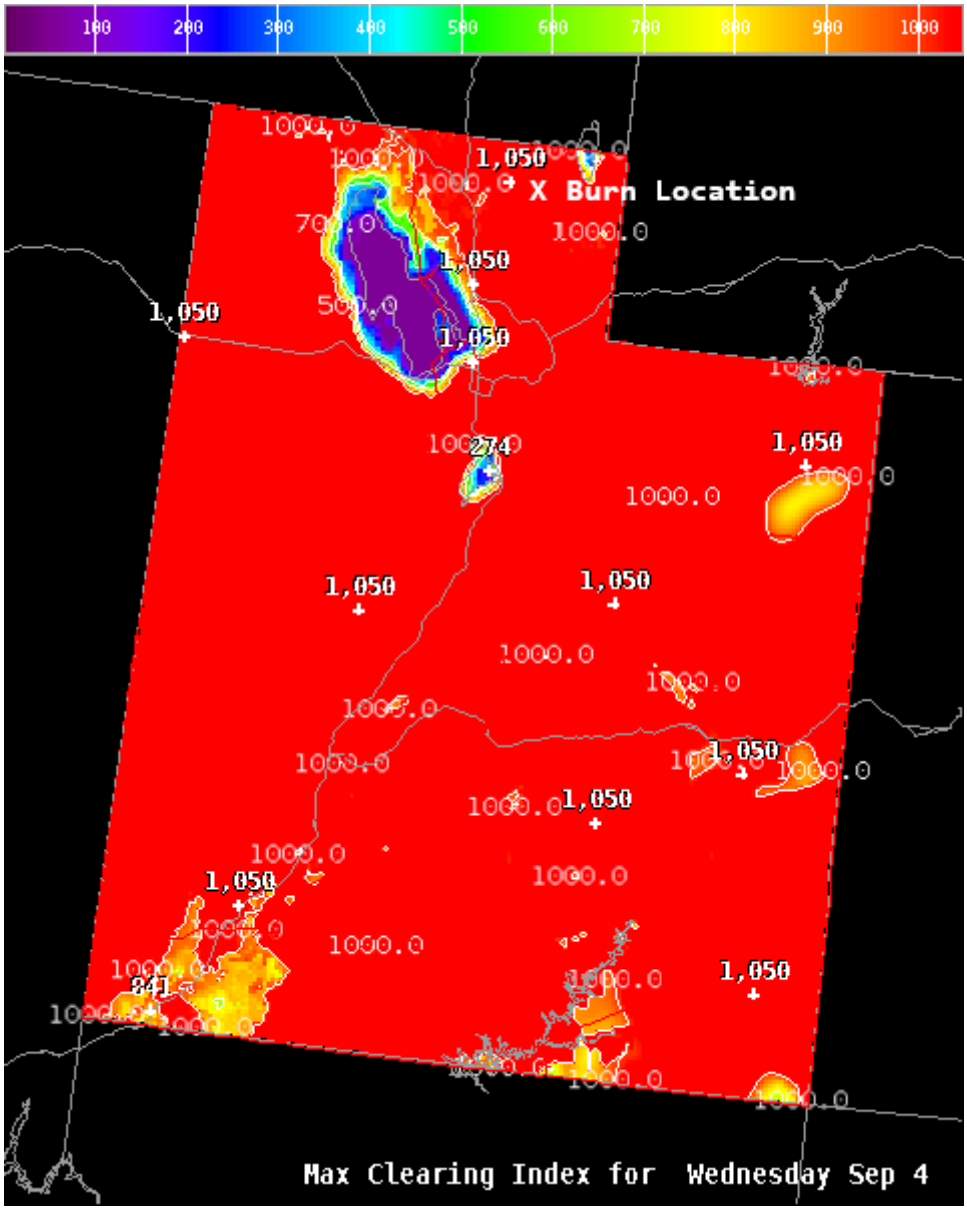
This image from September 7, 2019 shows smoke from a wildfire in another state flowing into the Cache Valley. This was after the burn was complete, but the E-BAMs and two of the AirU's were still running.

Weather

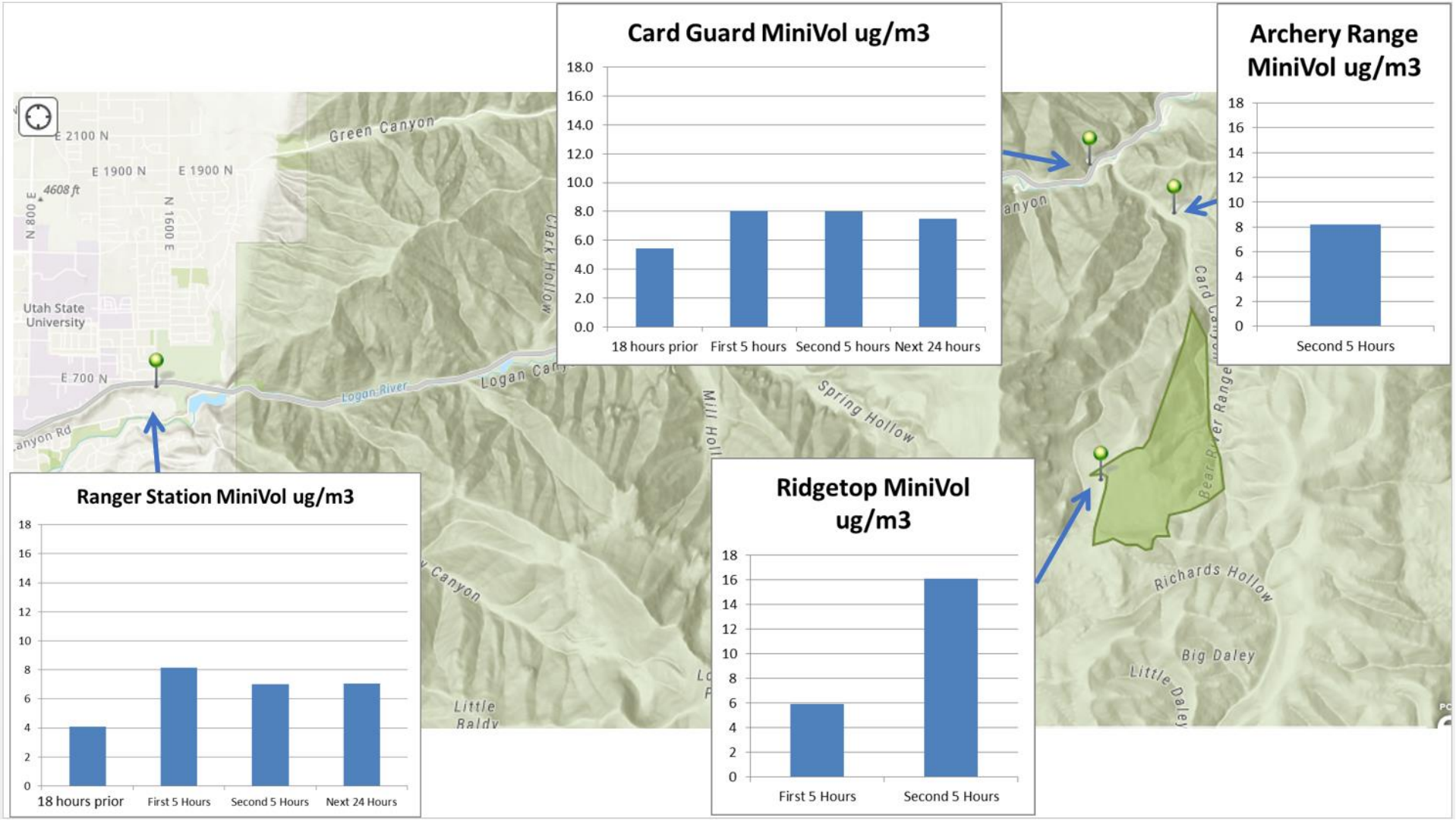
The relatively quiet 2019 wildfire season meant this project could go forward earlier than most fall-season prescribed fires. Early September around Logan Peak is typically pleasant with good dispersion. A US Forest Service remote automated weather station was placed at the Ridgetop monitoring site at 2,300 meters elevation.

Observed Weather at the Ridgetop RAWS	9/3	9/4	9/5	9/6	9/7	9/8	9/9	9/10
Maximum Temperature ◦C	25	28	27	27	23	21	17	16
Minimum Temperature ◦C	16	16	18	14	12	9	6	7
Minimum Daytime Relative Humidity %	15	20	25	51	21	40	36	44
Maximum Nighttime Relative Humidity %	41	43	57	80	66	95	79	85
24 Hour Average Wind Speed m/s	1.2	0.7	1.5	0.9	0.8	1.4	0.7	1.3
Prevailing Wind Direction	SE	W	W	SW	SE	SE	SE	S

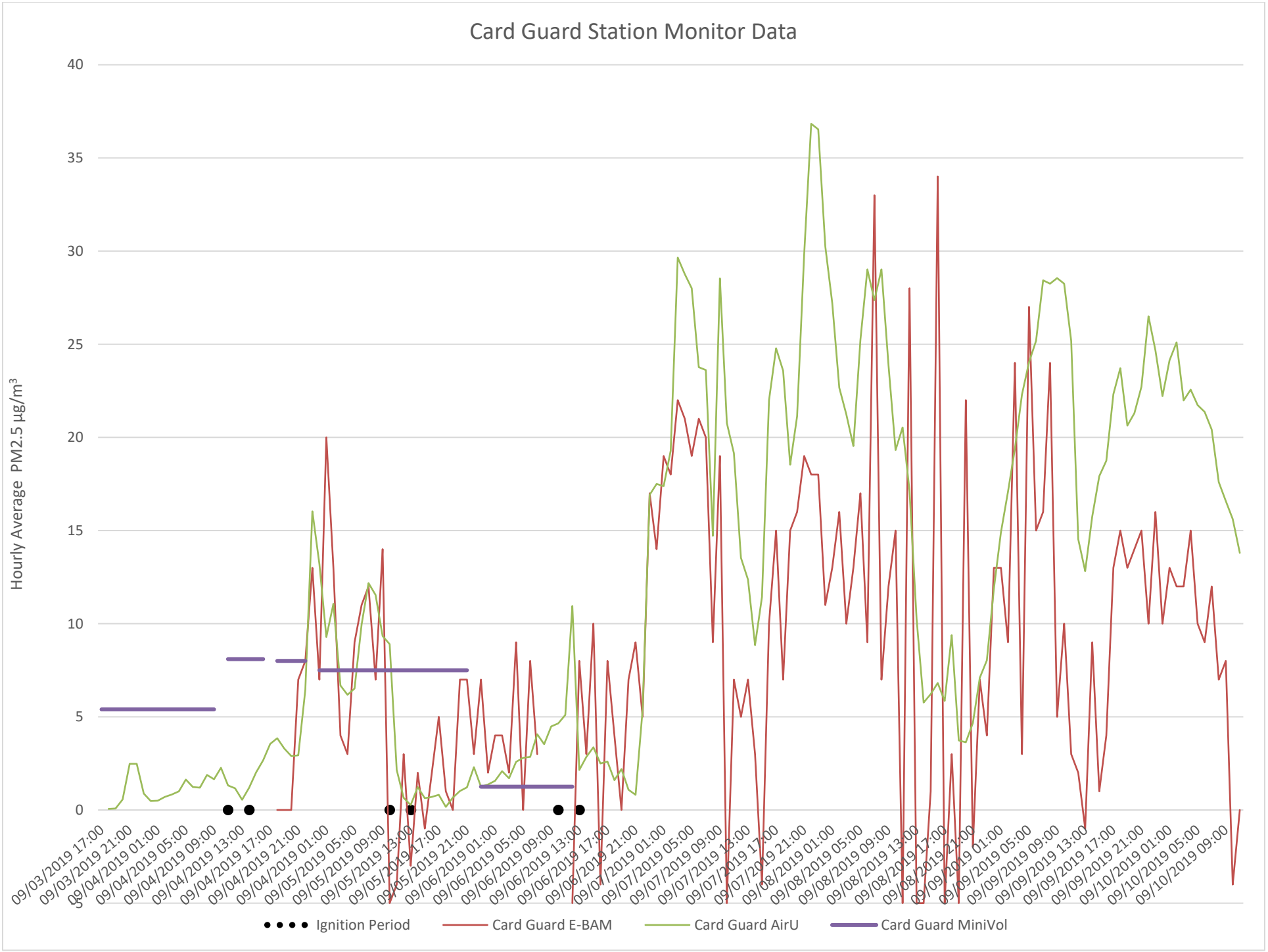
The clearing index forecast map for September 4th shows good dispersion statewide, which remained true throughout the week:



Results-Spatial and Temporal Variation in Concentrations



Results from the MiniVols at Blacksmith Fork, beginning with the pre-burn period on 9/3/2020, and at set intervals following the beginning of ignitions on 9/4/2020. An examination of the temporal variation in the PM2.5 filter concentration data at the Ranger station, Card Guard and Archery Range shows a ~3-4 ug/m3 increase in PM2.5 in the first 5 hours of ignition compared to pre-ignition conditions. Measured concentrations, however, did not exceed safe levels and started decreasing in the following hours. This is also confirmed by measurements collected with the AirU instruments, which show that concentrations returned to background levels within 8-10 hours. Comparing stations shows good agreement for the same time period. On the other hand, greater concentrations were measured at the Ridgetop site, as expected due to its proximity to the burn site. Not all sites captured four sampling periods as scheduled. This was due to the number of sites, equipment available, an untimely slopover of fire across the perimeter, and drive time.


Card Guard Station Monitor Data
Hourly Average PM2.5 µg/m³
40
35
30
25
20
15
10
5
0
09/03/2019 17:00
09/03/2019 21:00
09/04/2019 01:00
09/04/2019 05:00
09/04/2019 09:00
09/04/2019 13:00
09/04/2019 17:00
09/04/2019 21:00
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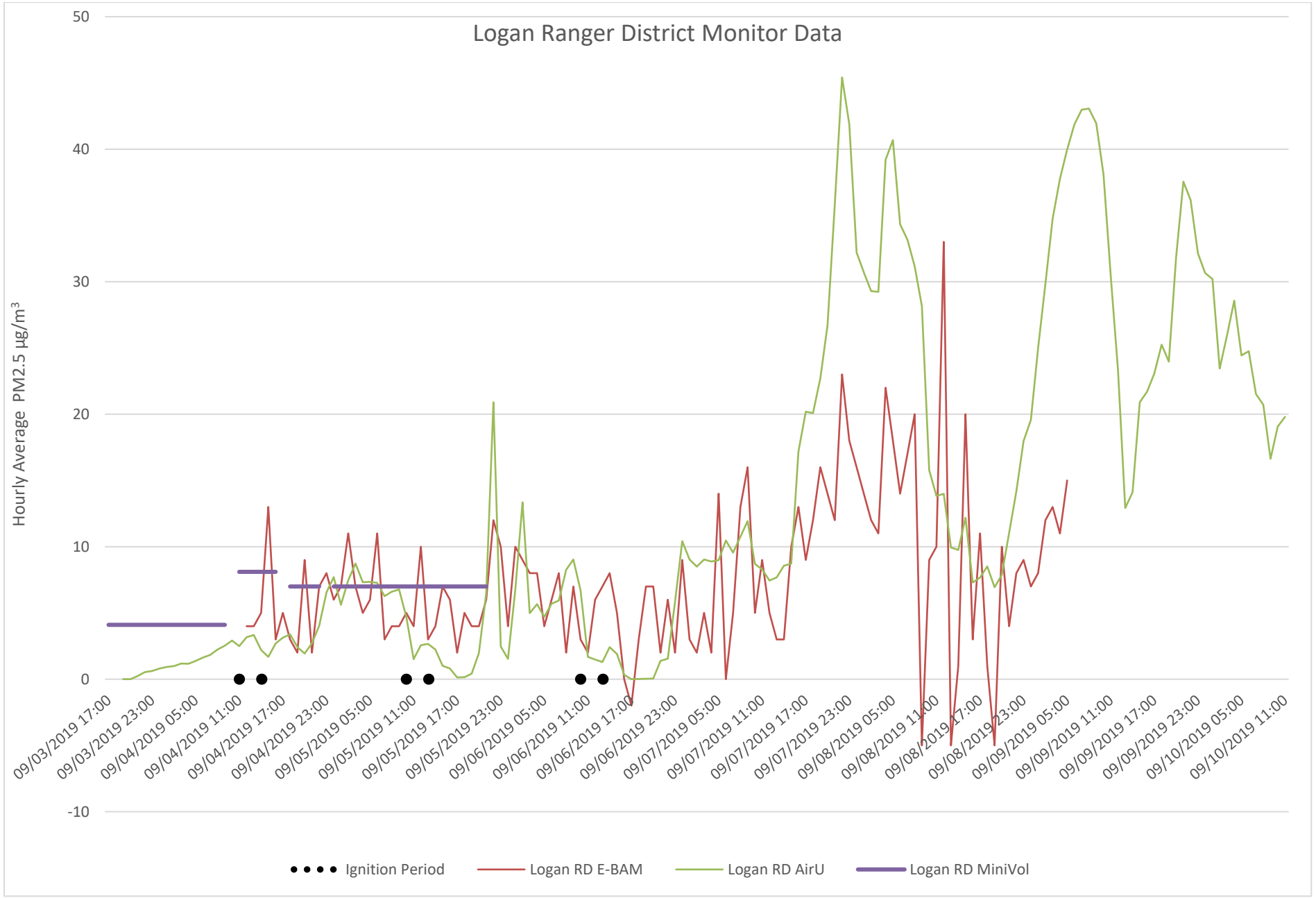
09/09/2019 13:00
09/09/2019 17:00
09/09/2019 21:00
09/10/2019 01:00
09/10/2019 05:00
09/10/2019 09:00
Ignition Period
Card Guard E-BAM
Card Guard AirU
Card Guard MiniVol


Logan Ranger District Monitor Data
Hourly Average PM2.5 µg/m³
50
40
30
20
10
0
-10
09/03/2019 17:00
09/03/2019 23:00
09/04/2019 05:00
09/04/2019 11:00
09/04/2019 17:00
09/04/2019 23:00
09/05/2019 05:00
09/05/2019 11:00
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09/09/2019 11:00
09/09/2019 17:00
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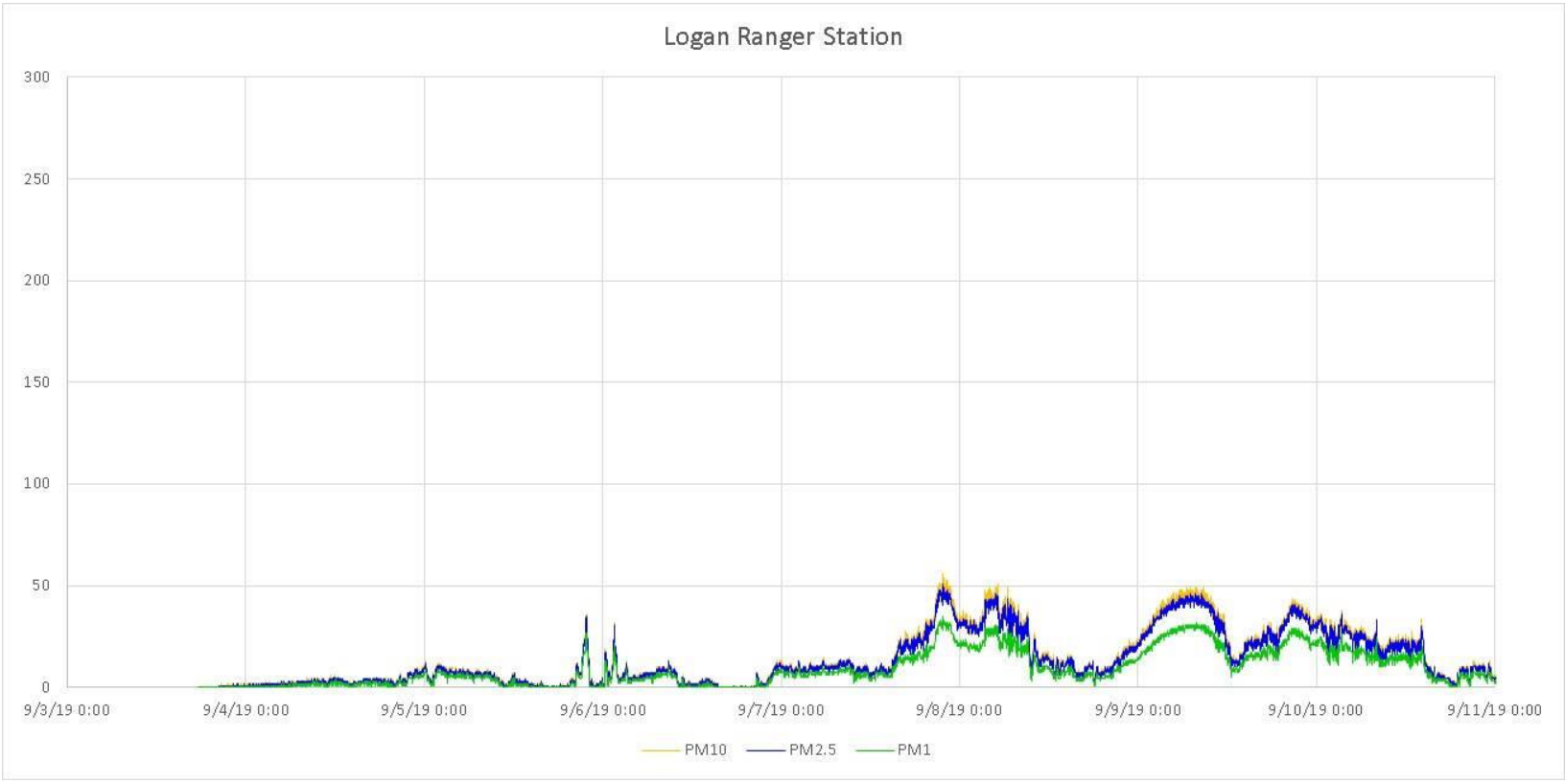
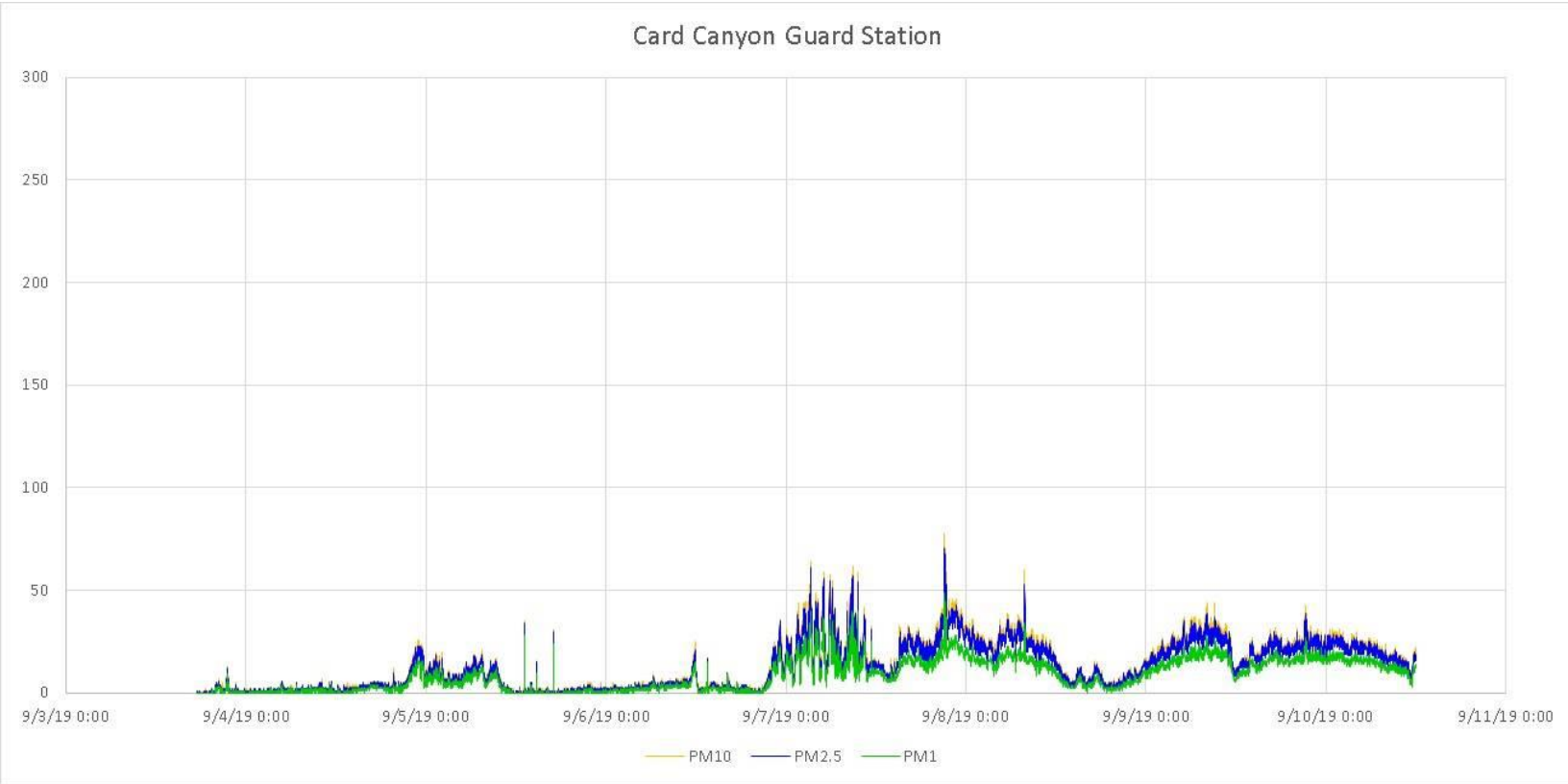
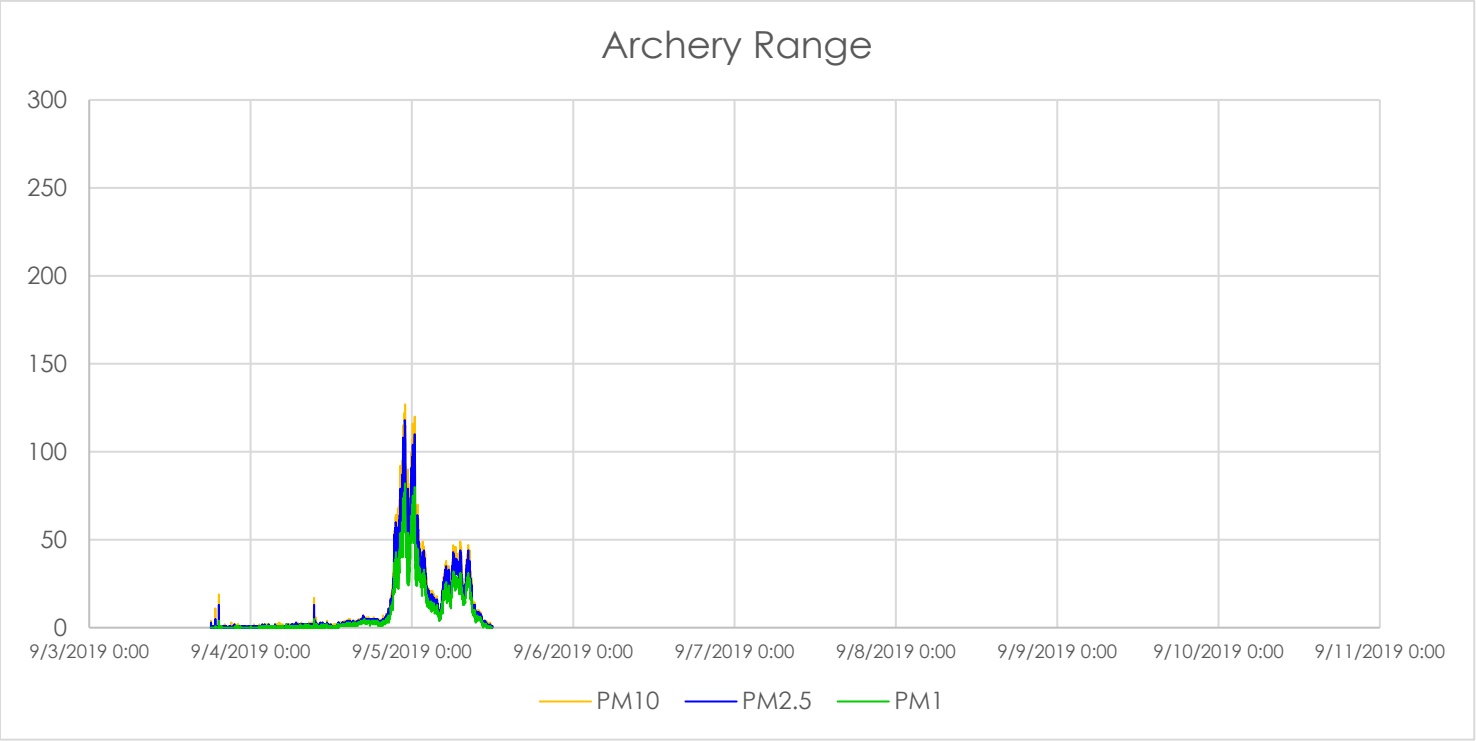
09/10/2019 05:00
09/10/2019 11:00
Ignition Period
Logan RD E-BAM
Logan RD AirU
Logan RD MiniVol



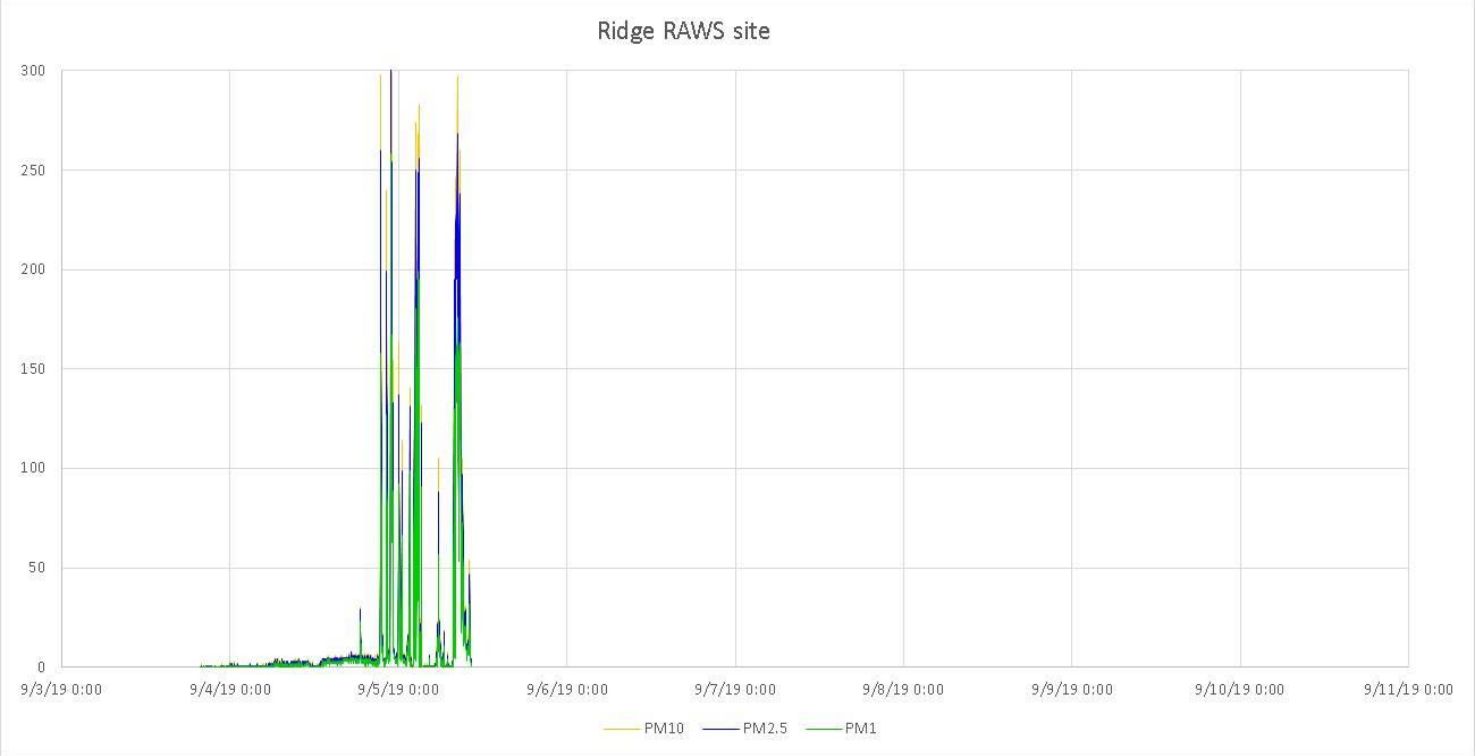
The AirU data trace from Logan Ranger Station



AirU data from Card Guard Station

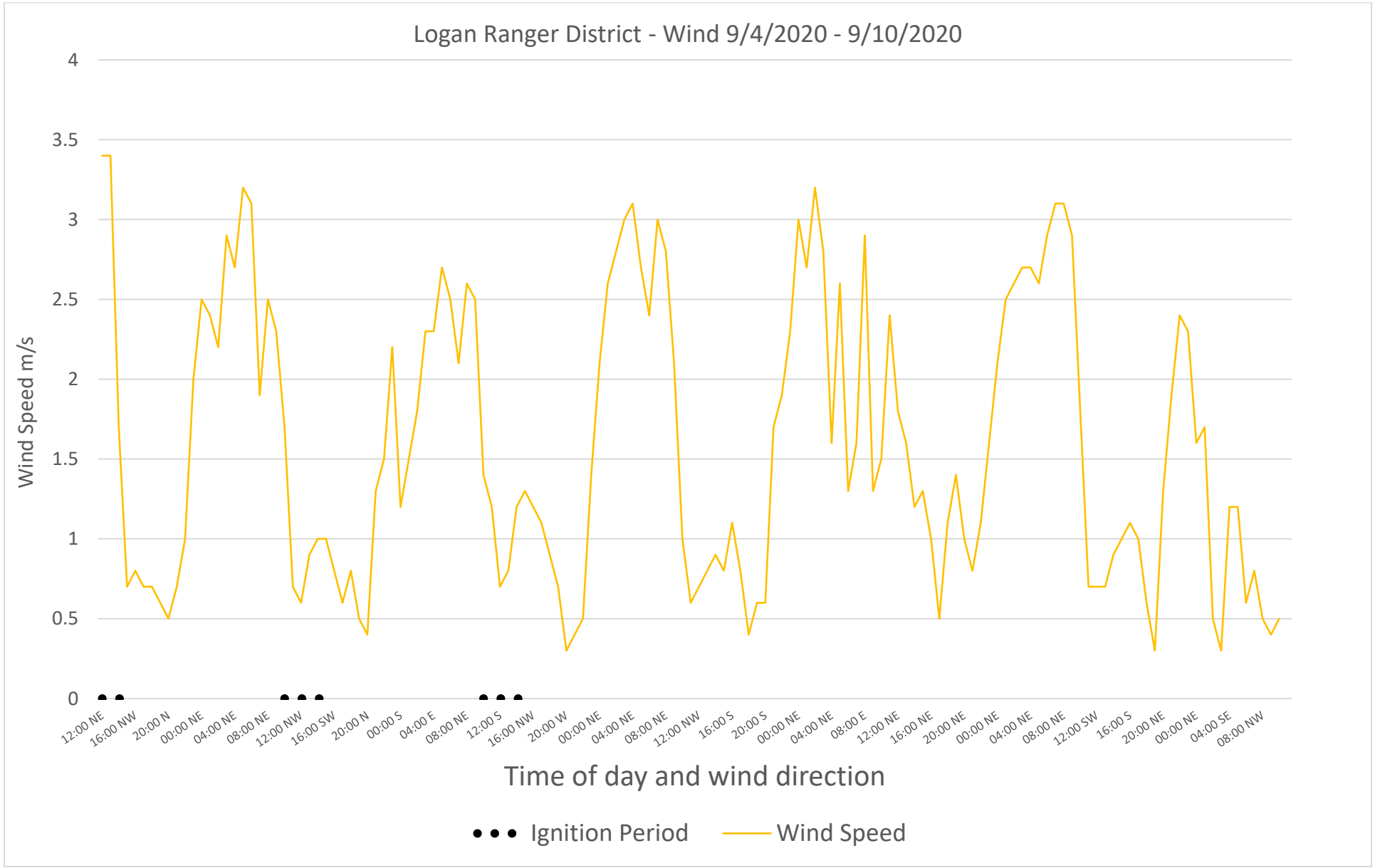


AirU data from the Archery Range appears to show a significant spike on the night after the first burn day



As with the MiniVols, the highest AirU values were recorded at the Ridgetop, adjacent to the burn

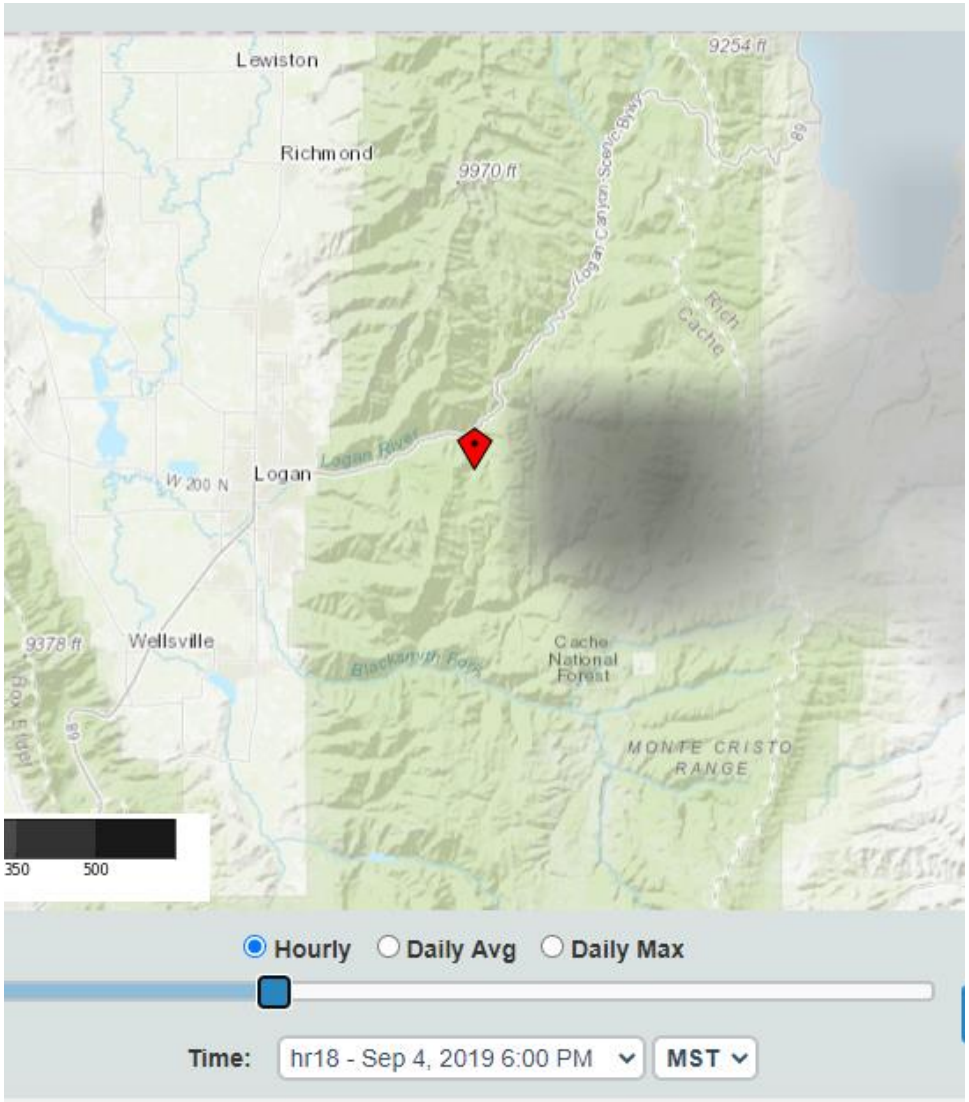
One feature of the AirU monitors is the separate traces for PM10, PM2.5, and PM1. As expected for combustion-derived particles, a comparison of PM10, PM2.5 and PM1 concentrations shows that PM levels were dominated by PM1, which are associated with greater health effects compared to larger-sized particles. Because of their small size, these particles can penetrate deep into the lungs leading to a variety of significant health impacts.



There were distinct diurnal winds at the mouth of Logan Canyon that week, flowing out of the canyon (ENE) overnight and through mid-morning.

Model Prediction

BlueSky modeling indicated the highest 24-hour average would be East of the burn site, in the range of 12-35 µg/m^3 added PM2.5. These screen shots show predicted hourly concentrations, and the model suggests some impact to the Cache Valley in the early morning hours of 9/5, as also indicated by the measurements. A similar pattern held for modeling on the other burn days.



Discussion

Site selection / instrument placement

The Ridgetop monitoring site was within 200 meters of the burn perimeter, on the south side of the unit. The other three monitoring sites are down drainage from the burn unit, at progressively further distances. The fact that AC power was available at the Ranger District and Card Guard station was useful; the team initially set up the Card Guard E-BAM on a solar setup, but eventually switched to AC after the instrument had trouble staying on under solar power.

Filter agreement with continuous monitors

Both E-BAM concentration traces had a noisy signal with a lot of bouncing around. Several times the hourly average was below zero. See the chapter on instrumentation for more discussion of this issue. Some filter time periods did not overlap fully with a co-located continuous monitor. For the MiniVol values which did have co-located continuous data, here are the comparisons. The discrepancy in readings between the MiniVol and AirU is related to a difference in their operating principle. The MiniVol is a gravimetric instrument while the AirU is a light scattering instrument. The performance of the AirU is dependent on the environmental field conditions and properties of the aerosol used for calibration. The AirU data reported here has not been corrected for these differences.

			PM2.5 concentration µg/m^3		
Location	Time Period	Burn Period	Minivol (Filter) Value	E-BAM Average	AirU Average
Logan RD	9/4 1100-1600	Ignition	8.1	n/a*	2.6
Logan RD	9/4 1600-2100	Post-ignition	7.0	4.0	2.7
Logan RD	9/4 2100 – 9/5 2100	Post-ignition+ ignition	7.0	5.8	4.4
Card Guard	9/4 1100-1600	Ignition	8.1	n/a	1.5
Card Guard	9/4 1700-2200	Post-ignition	8.0	3.0	3.9
Card Guard	9/4 2100 – 9/5 2100	Post-ignition + ignition	7.5	5.6	5.8
Card Guard	9/5 2300 – 9/6 1200	Post-ignition+ ignition	1.3	n/a‡	3.5
Archery	9/4 1600-2100	Post-ignition	8.1	n/a	4.6
Ridgetop	9/4 1100-1600	Ignition	5.9	n/a	3.1
Ridgetop	9/4 1600-2100	Post-ignition	16.1	n/a	11.0

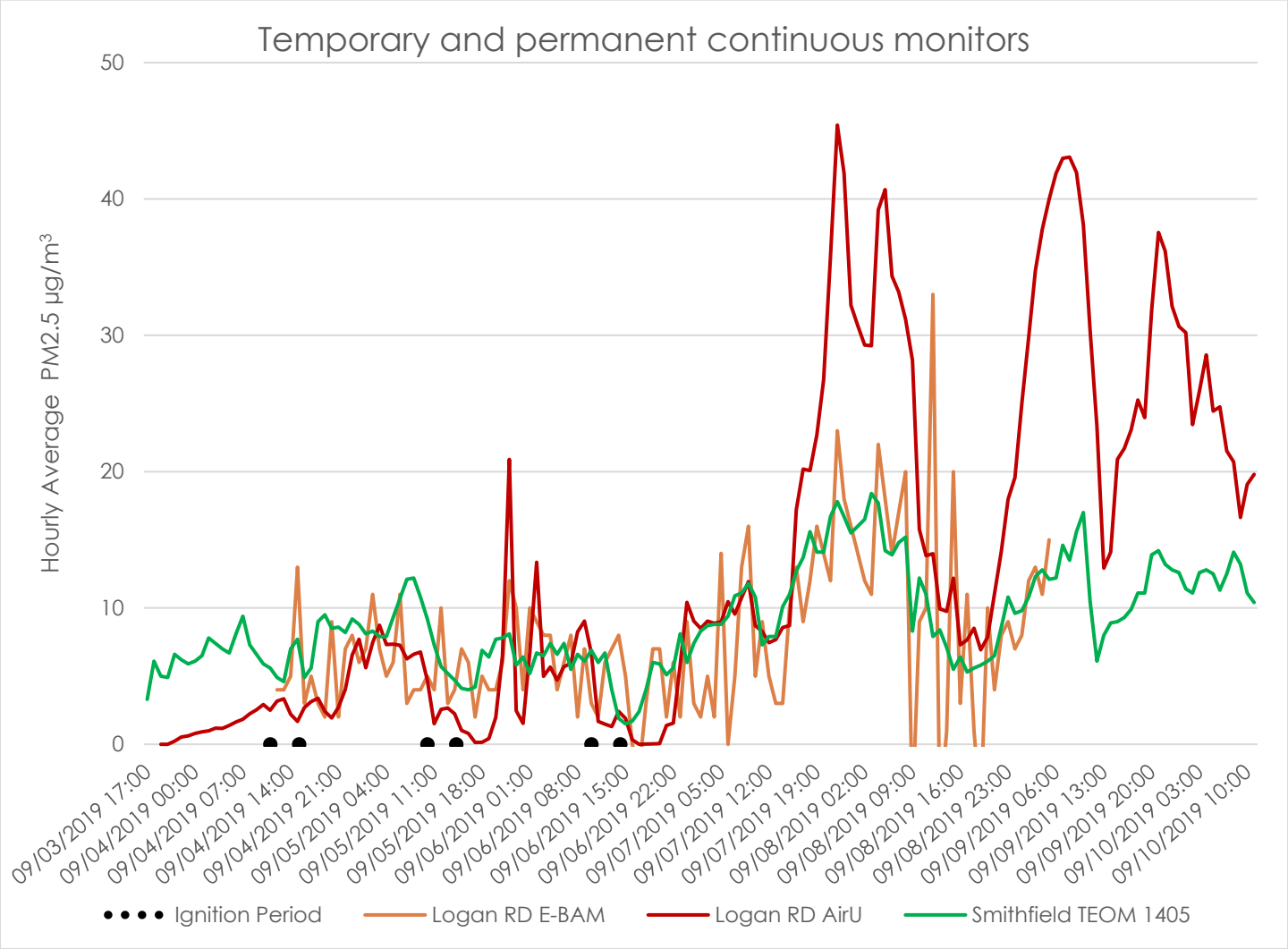
*The E-BAMS both had a lag time following setup before they began transmitting data, hence the n/a's at Logan RD and Card Guard.
‡The AirUs were the only continuous instrument at the Archery Range and Ridgetop.

Looking at Logan RD, there is variation in readings across samplers, but each sampler showed similar values across days, indicating that this site was not impacted by the burn.

There was visible smoke at the Ridgetop on the evening of 9/4, and it is encouraging that in the last two lines of the table, the AirU appears to be responsive to that, just as the MiniVol was. Comparing the single-digit values at the other monitoring sites does not show a clear trend or responsiveness, which could partly be related to their dependency on the properties of the measured aerosol. As aforementioned, reported concentrations have not been corrected for aerosol type.

Other particulate matter sources

An airmass laden with wildfire smoke moved into the Cache Valley on September 7. This gave a good opportunity to look at the instrument response to an extended period of elevated PM. The days of September 7, 8, and 9 certainly show higher PM values than the actual burn days of September 4, 5, and 6. Looking at the satellite imagery from the 7th and other monitors around the region, the team feels confident these higher values are both accurate, and caused by out of state wildfires, rather than the Blacksmith Fork burn. This chart shows the Logan Ranger District E-BAM and AirU values along with Utah DAQ's Smithfield real-time TEOM 1405:



Ignoring the raucous noise, the E-BAM appears to track the TEOM decently on the 7th, 8th, and 9th, while the AirU shows a few spikes significantly higher than the other two instruments on the 8th, 9th, and 10th of September, which is likely related to calibration issues.

Accuracy of model predictions

The monitor data were consistent with model predictions – a negligible 24-hour average impact at the Ranger Station. With the absence of a southeast wind, smoke was unlikely to have traveled from the burn to Smithfield (19 km NW from the burn site). Looking at the chart above which includes the Smithfield monitor, and assuming the Smithfield numbers were unaffected by smoke on the 4th, 5th and 6th of September, it seems appropriate to say that if the burn added any PM above the background at the Logan Ranger Station, it was at most a few µg/m³.

Takeaways

Having four monitoring sites gives good spatial resolution and provides interesting data. One drawback to that was the drive time required to shuttle between all four sites- for setup,

troubleshooting, filter swaps, etc. The team found it difficult to get to all the sites in a timely manner to accomplish those tasks. While four sites were used again at Providence Biochar, they were selected to allow a realistic travel time for a field crew of one or two people.

The study team was concerned about the noisiness of the E-BAM data. Following this event the two E-BAMS, on loan from the US Forest Service in Colorado, were subsequently set up at the UDAQ tech center in Salt Lake City. There the team did additional calibration, observation, and discussion with the manufacturer. An E-BAM was only used one other time during the study; at the Providence Biochar project. Ultimately the team decided the noise from this particular model defeats the purpose of a continuous instrument in a study such as this one: namely, to provide PM2.5 data with fine temporal resolution.

Acknowledgements
The study team would like to thank US Forest Service Fuels Technician Milena Rockwood for an excellent tour of the project area, and Zone Fire Management Officer James Turner for access to the USFS facilities. Prescribed fire burn boss Brandon Everett was amenable to providing access to the burn itself. Thanks also to Utah State University Professor Dr. Randy Martin, for the use of the AirU monitors and consultation on the study design.

146

UINTA WASATCH CACHE NATIONAL FOREST

KAMAS RANGER DISTRICT

40.63 N
111.19 W
2190m / 7185ft

SUMMARY

Pile burn 5 miles up the Mirror Lake Highway East of Kamas. 100 brush piles made of ponderosa pine and rocky mountain juniper. One burn day: 10/22/2019.

DESIGN

The study team conducted a site visit on 10/21/19 to select monitoring locations. The team chose two sites, the Kamas Fish Hatchery 3.7 km down-canyon, and the Upper Setting road 3.2 km up-canyon.

EQUIPMENT

Fish Hatchery: E-Sampler, MiniVol
Upper Setting Road: E-Sampler, MiniVol

EVENTS

The burn was conducted with a clearing index of 320. Ignition began at 1100 and was complete by 1230. The piles burned rapidly and little smoke was left post-burn. Fire crews followed a common procedure and "chunked' the piles- rearranging them to extend the flaming combustion phase and consume more material. It appeared the plume drifted due southeast from the burn and did not pass directly over either monitoring site. Monitoring equipment remained in place overnight.

Pins show the two monitoring sites in relation to the 146 burn unit

Kamas State Fish Hatchery, looking East towards the burn site.

Equipment on the Upper Setting road including solar setup. Looking West towards the burn unit and Kamas. A faint wisp of smoke from the burn is in the midground of the frame, the photo was taken at 1131 hours on October 22.

The burn unit mid-operation, 1123

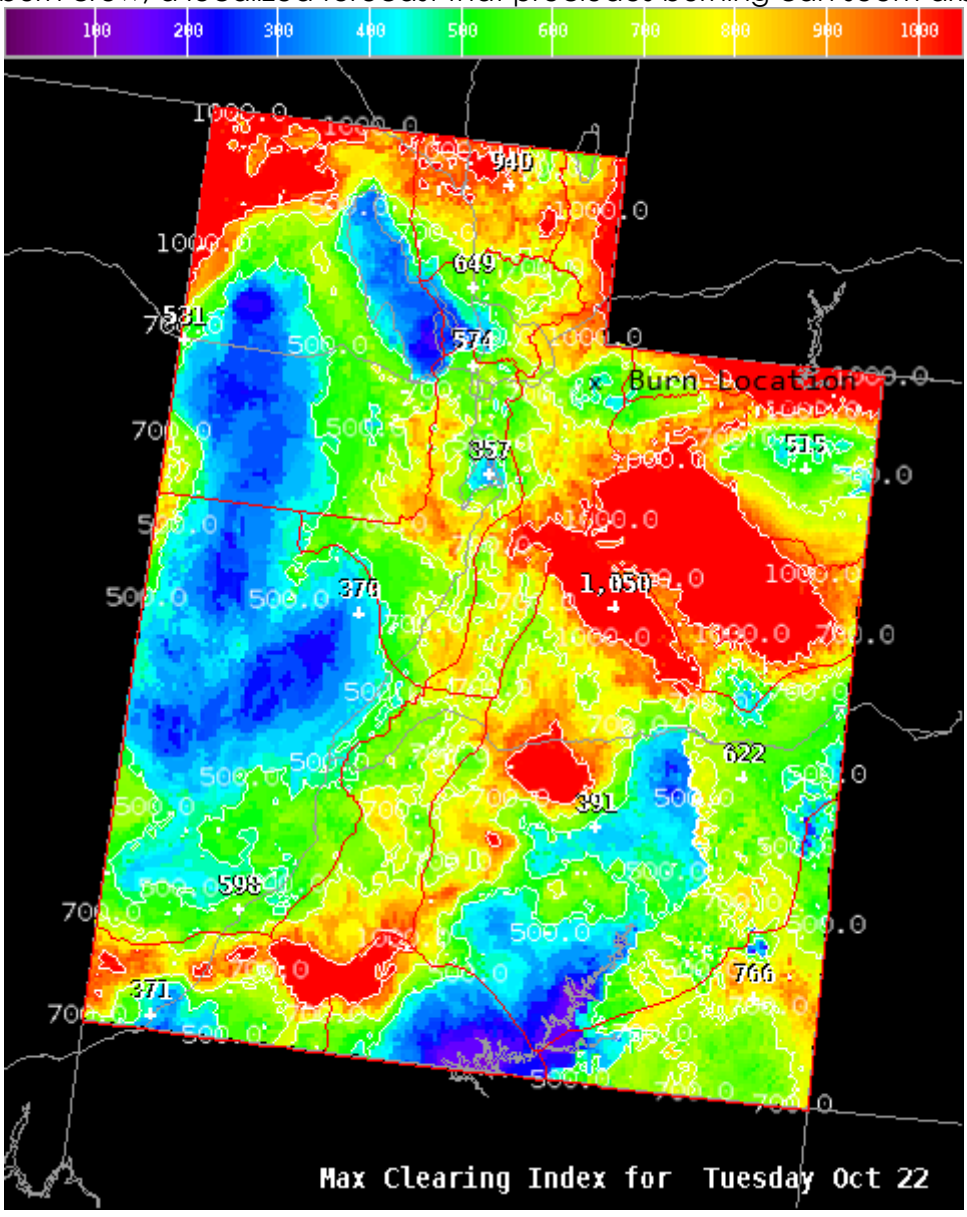
Post-burn, from a slightly different vantage, showing no smoke visible, 1418

Weather

October 22 featured near normal temperatures and a northwest flow aloft, with relatively calm winds at the burn site.

Observed Weather	Upper Setting	Fish Hatchery
Maximum Temperature °C	9	11
Minimum Temperature °C	0	0
24 Hour Average Windspeed m/s	1.8	1.2
Maximum Hourly Average Windspeed m/s	3.4	2.8

The 146 burn unit is in Utah Airshed 6; the Wasatch Back. On the day of the burn, the spot forecast for the burn project gave a clearing index specific to the site of 320. With the exception of western valleys and water-influenced basins like the Great Salt Lake and Lake Powell, most of the state had fair or good dispersion. The burn location itself was in a small area of poor/fair dispersion for October 22. Examining the potential to burn at sites and on days such as this is of great interest to land managers; for a burn crew, a localized forecast that precludes burning can seem arbitrary and fickle.



Results

PM2.5 continuous monitoring was in place for 43 hours beginning 10/21 at 1600 MDT. This time period covers 16 hours pre-burn and 22 hours post-burn. The minivols ran for 24 hours beginning at the initial ignition, 1000 hours on October 22. The continuous monitor at the hatchery recorded a max value of 28 µg/m^3, but this occurred before ignition began and before the minivol was set up, this is believed to be from fireplaces/wood stoves.

24-hour average PM2.5 µg/m^3, beginning 1000 hours on October 22

	Location	
Instrument	Upper Setting	Fish Hatchery
E-Sampler	0.1	0.1
MiniVol	3.2	3.5

Model Prediction

BlueSky modeling indicated both max and 24-hour average added PM2.5 values should be close to zero.

Discussion

Site Selection/Instrument Placement

The two sites were at approximately equal distances from the prescribed fire. The Fish Hatchery site was firmly down-drainage; any smoke following the terrain down Mirror Lake highway should have been recorded on the monitor. The burn site itself was about 400 meters North of the highway, and 40 meters higher in elevation. The Upper Setting monitoring site was 600 meters from the highway and

Filter agreement with continuous monitors

The MiniVols reported higher concentrations than the E-Samplers. The difference is a combination of instrument precision and calibration, with precision being increasingly important at low concentrations. The E-Sampler manual specifies a stated precision of: "Greater of 3 µg/m^3 or 2%". While the discrepancy was greater than 2%, one E-Sampler was 3.1 µg/m^3 off from the co-located MiniVol, and the other was 3.4 µg/m^3 off. Both instruments were tested at the DAQ tech center and found to have decent agreement with other continuous monitors.

Other particulate matter sources

Residences adjacent to the hatchery in the Samak neighborhood certainly use wood for home heating. The study team smelled a faint odor of wood smoke in Samak on the 22nd, before the burn operation began. It was not thick but could certainly explain some or all of the PM2.5 recorded by the E-Sampler and MiniVol there. Bald Mountain pass at the top Mirror Lake Highway was closed for through travel, so the highway had very low traffic volume and is unlikely to affect the results.

Accuracy of model predictions

BlueSky modeling indicated both maximum hourly and 24-hour average added PM2.5 values should be close to zero, and this was consistent with the monitor data.

Takeaways

The 146 project highlighted the fact that it is difficult to "catch" a plume. There is uncertainty before an event about where the smoke plume will go, and physical access to a desired monitoring site may be limited by complex terrain and land ownership.

The fact that smoke dispersed readily from the site and was not influenced by terrain is of interest. Although the Mirror Lake highway at this point is a broad valley, there did not appear to be any retaining or funneling of smoke along the highway corridor through the overnight hours.

Acknowledgements
Thanks go to the Utah Division of Wildlife Resources Kamas Fish Hatchery staff, for the opportunity to set up equipment within their facility, and to prescribed fire burn boss Kyle Yurkovich for providing a site tour and access to the burn.

ALPINE ACRES

UINTA WASATCH CACHE NATIONAL FOREST

KAMAS RANGER DISTRICT

40.77 N
110.99 W
2518 m / 8261 ft

SUMMARY

Pile burn at the headwaters of the Weber River. 50 acres with about 1000 brush piles made of mixed conifer. Burn days 11/1, 11/2, 11/4, and 11/5 2019.

EQUIPMENT

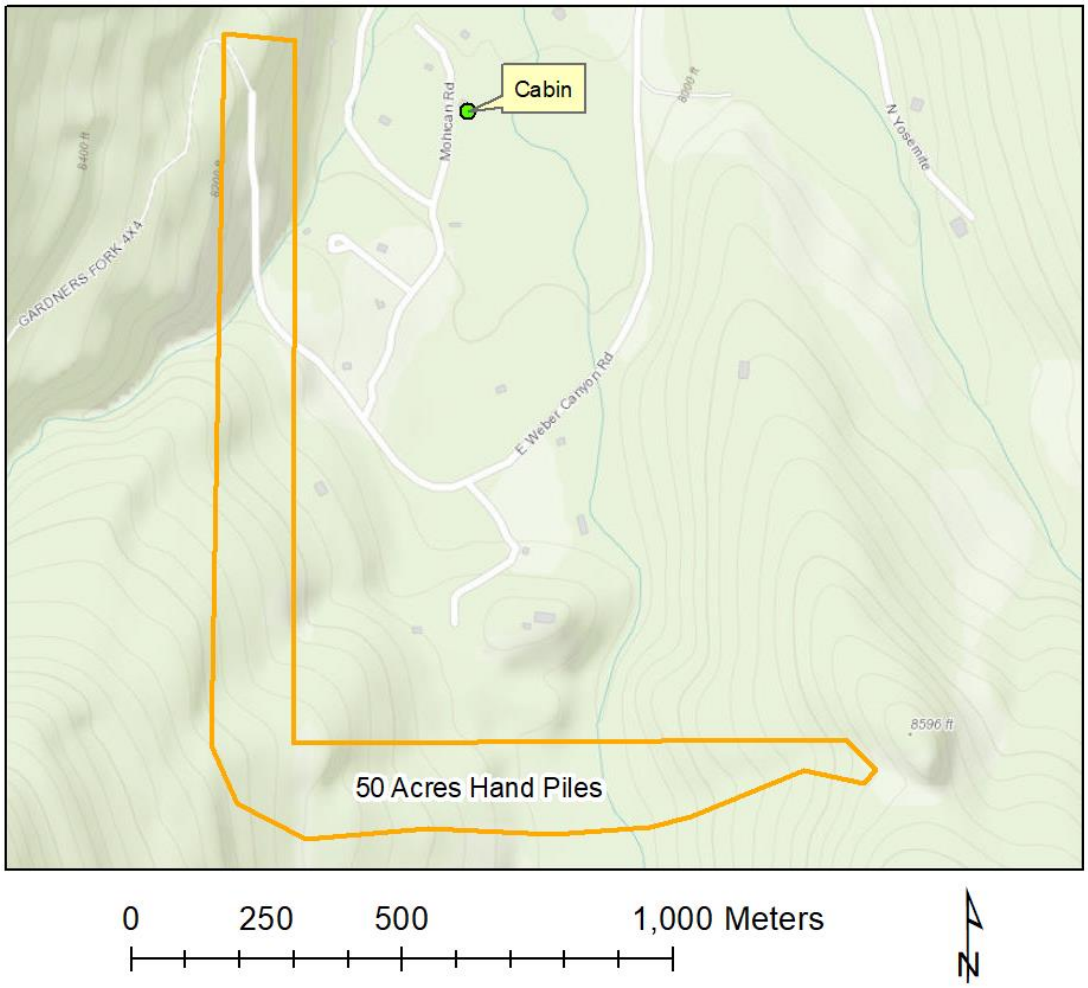
Cabin: E-Sampler, MiniVol, Purple Air

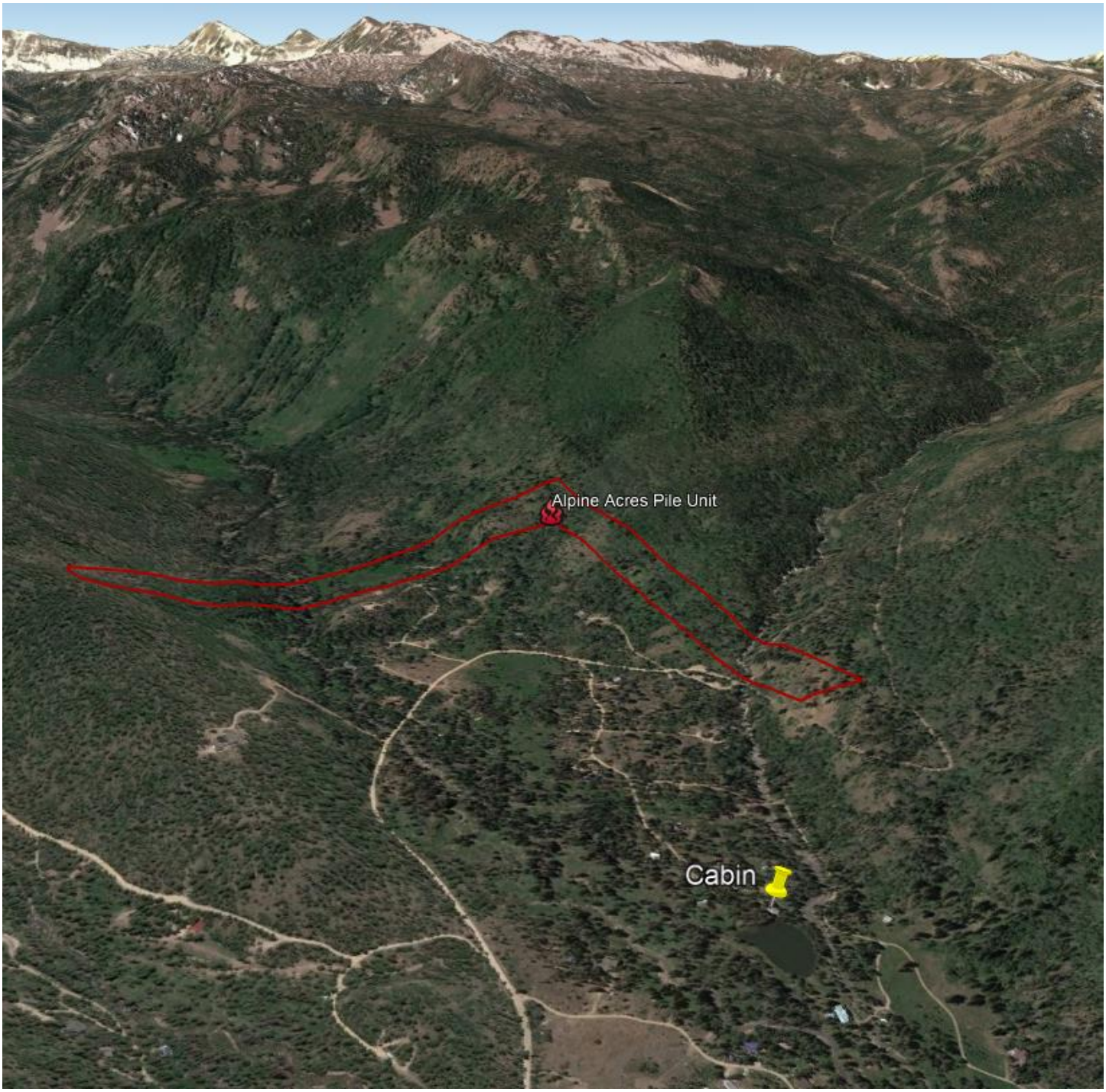
DESIGN

The study team conducted a site visit on 10/31/19 to select monitoring locations. Accessible parts of Weber canyon are private property except in the burn unit itself. Therefore, only one monitoring site was used, by permission of a cabin owner. The burn unit is between 300 and 1000 meters from the cabin, entirely upslope of it.

EVENTS

The burn was conducted with a clearing index between 180 and 680. On burn days ignition began by 1100 and finished by 1600. Fire crews followed a common procedure and "chunked' the piles- rearranging them to extend the flaming phase and consume more material. Monitoring equipment remained in place overnight, and for a week following completion of the project.





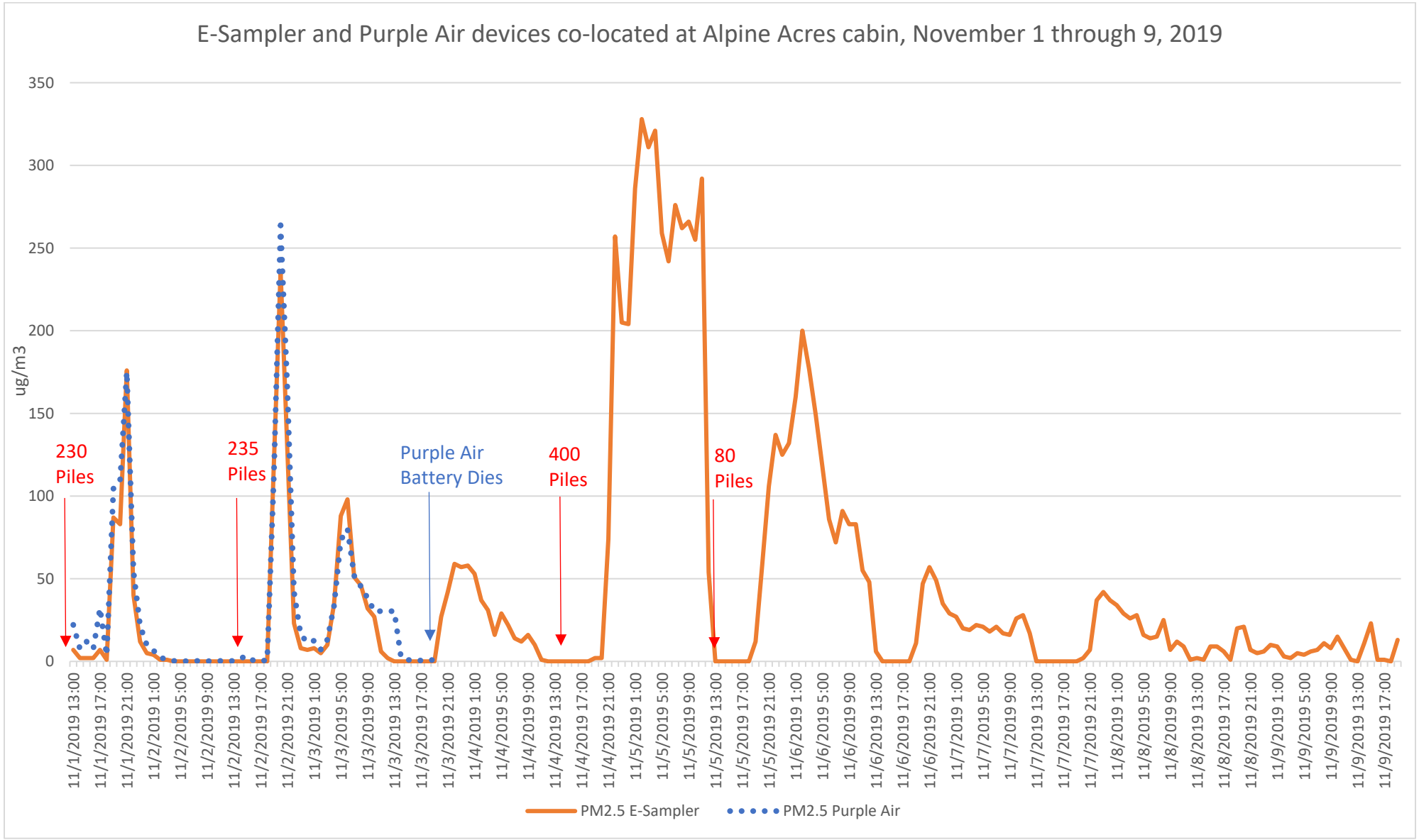
Oblique view of the burn unit and monitoring site near the confluence of two forks of the upper Weber River. The point of view is looking towards the Southwest.

Minivol, Purple Air and E-Sampler at the cabin, looking towards burn unit

Shortly after ignition, day 1 (Nov 1 @ 1000 hours)

Results

The chart below shows the four ignition days and the results from continuous monitoring at Alpine Acres. Unfortunately, the Purple Air solar backpack rolled over and the battery gave out after two days.

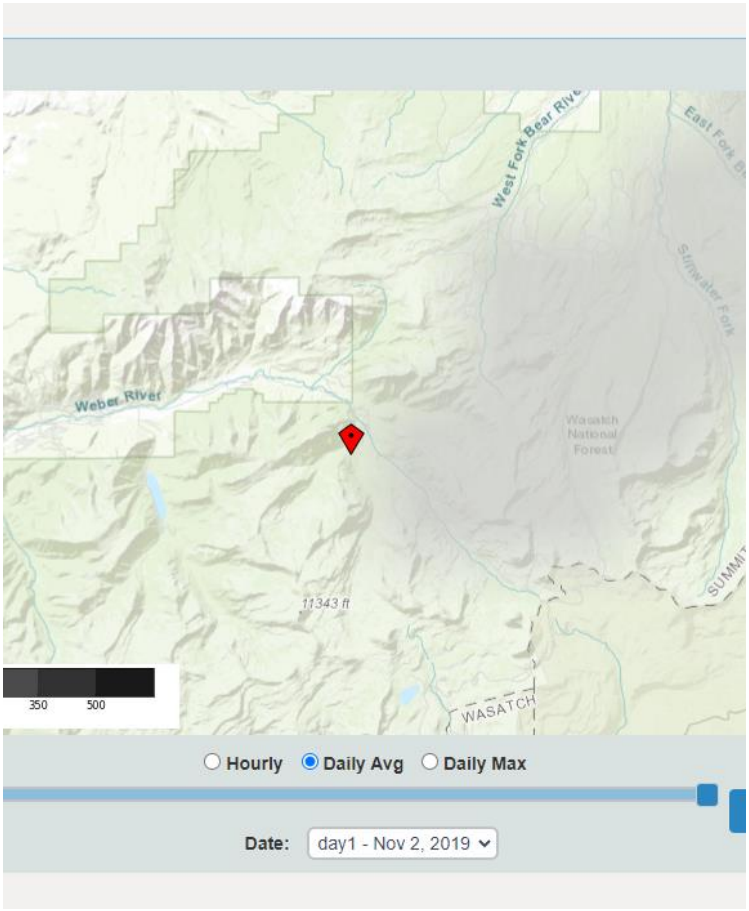


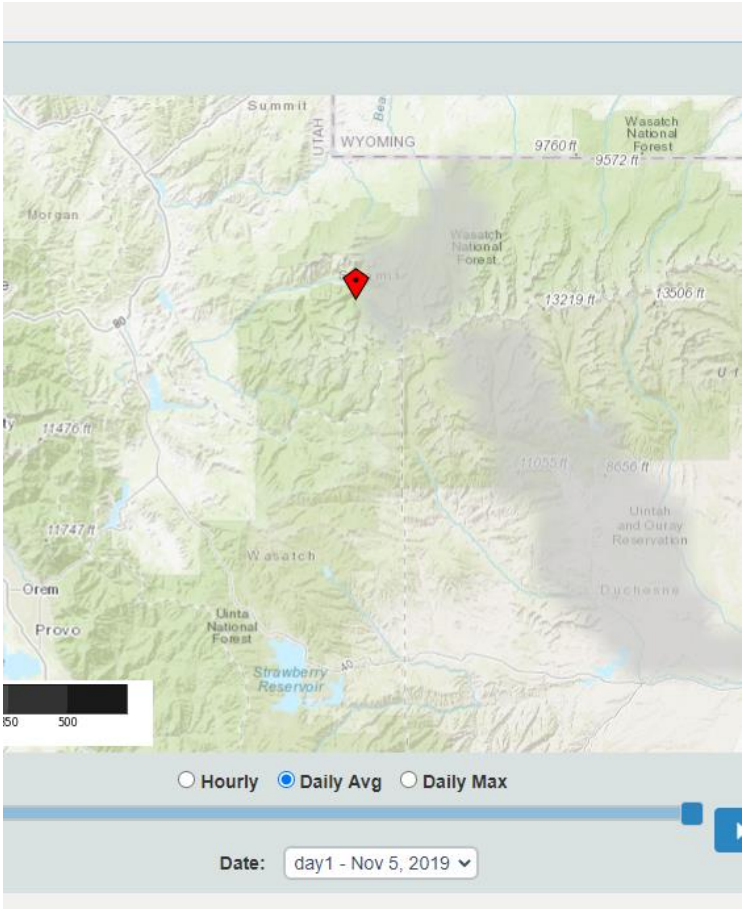
Qualitative Observations

Date	Hour	Location	Wind Direction	Wind MPH	Smoke height feet AGL	Smoke drift direction	Smoke Color	Smoke Volume	Comments
11/01/19	1000	Cabin	N	2	n/a	n/a	n/a	n/a	While setting up the minivol, we noticed that the woodstove was going in the cabin (40 feet away)
11/01/19	1100	On burn	N	2	100	SE	White	Low	
11/01/19	1200	40.788 by -110.990	N	2	300	S	White	Low	
11/01/19	1300	40.775 by -110.995	NE	1	300	SW	White	Low	
11/01/19	1400	40.775 by -110.995	N	2	300	S	White	Low	
11/02/19	1100	N of parking	-	Light	300	W	White	Low	
11/02/19	1200	N of parking	N	2-4	400	W	White	Low	
11/02/19	1300	Parking area	-	Light	400	W	White	Low	Good dispersion
11/02/19	1400	N of parking	Upslope	1-2	400	W	White	Low	Clear skies, good dispersion
11/02/19	1500	Parking area	N	2-4	400	W/SW	White	Low	
11/04/19	1200	Middle Fk. Crk	Variable	Light	200	S	White	Low	
11/04/19	1300	Gardner Fk Trl	S	1-3	600	E	White	Low	
11/04/19	1400	Gardner Fk Trl	N	2-4	600	S	White	Medium	
11/04/19	1500	Middle Fk. Crk	N	1-3	500	E	White	Low	
11/05/19	1200	Top of East Unit	NW	1-3	200	S	White	Low	Upslope/Up-canyon winds
11/05/19	1300	Top of East Unit	NW	2-4	400	S	White/ Brown	Low	Upslope/Up-canyon winds
11/05/19	1400	Top of East Unit	N	1-3	400	S	White/ Brown	Medium	
11/05/19	1500	N. Boundary w/Private Land	N	2-4	300	S	White	Medium	
11/05/19	1600	Weber Canyon Road	Variable	Light	400	SE	White	Low	

Model Prediction

BlueSky runs for the project indicate the area of highest smoke concentration would be East of the burn site. Expected 24-hour average PM2.5 concentrations were no more than 12 µg/m^3. This was true for all modeled burn days. Peak hourly values were predicted to be no more than 35 µg/m^3.



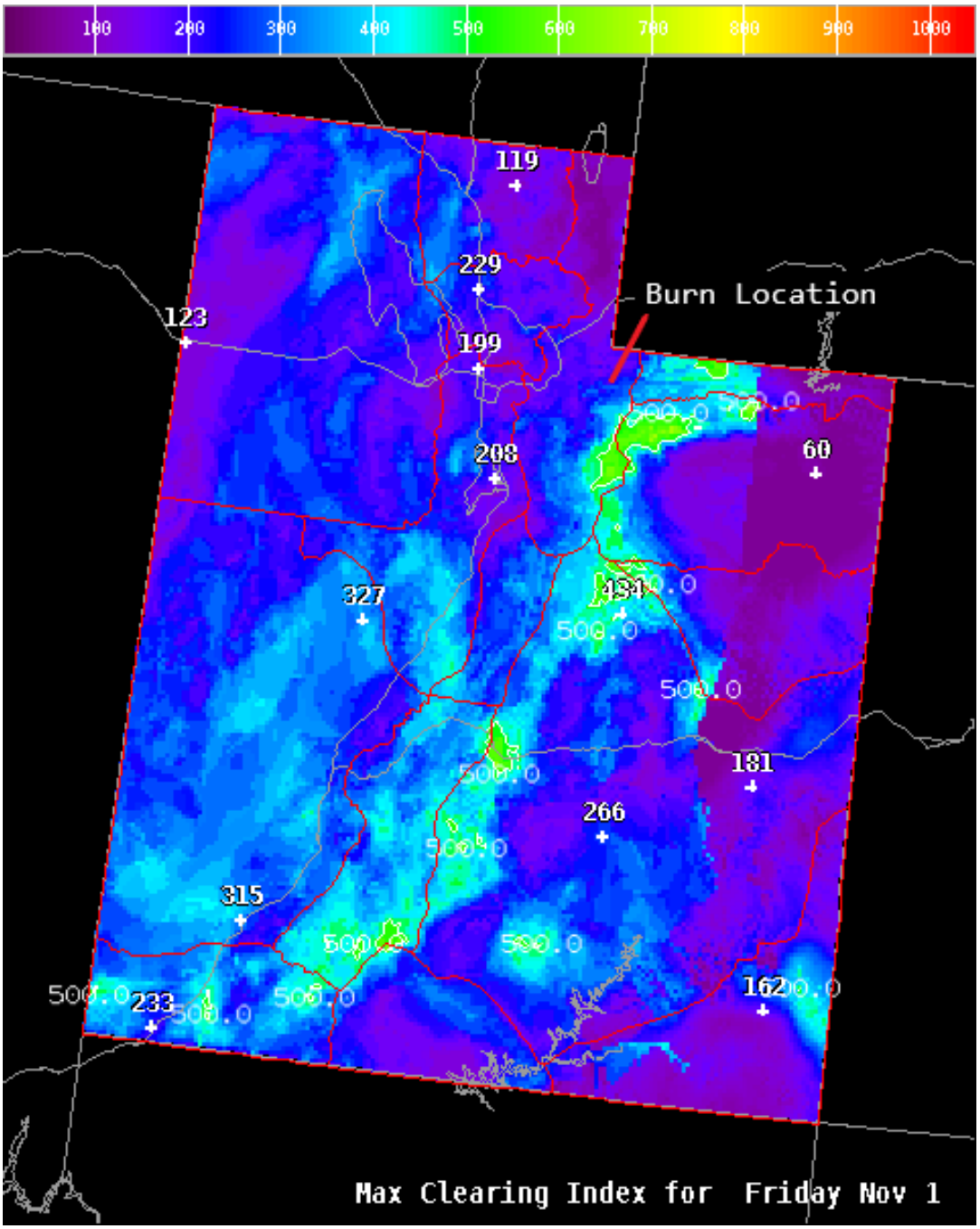


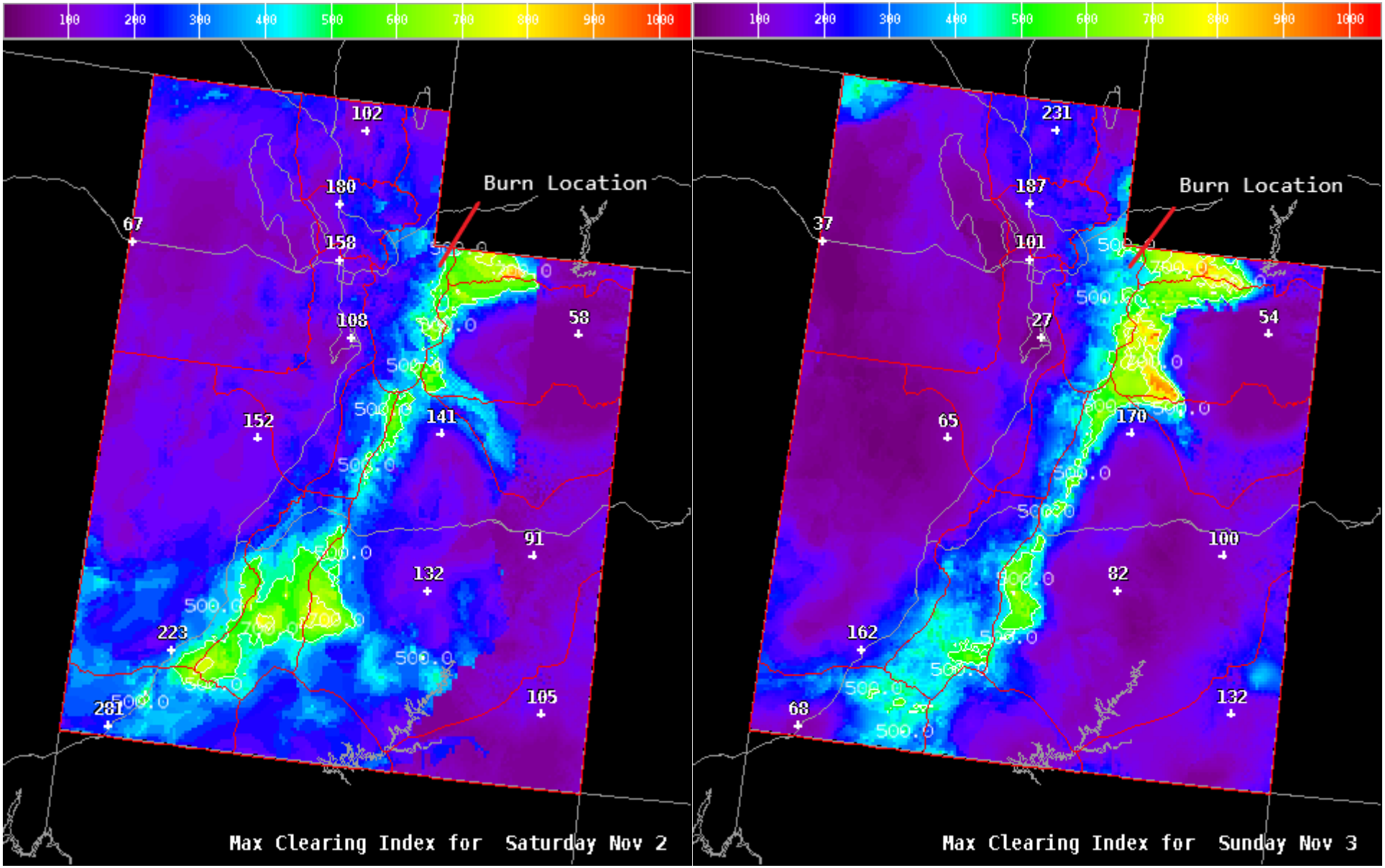
Weather

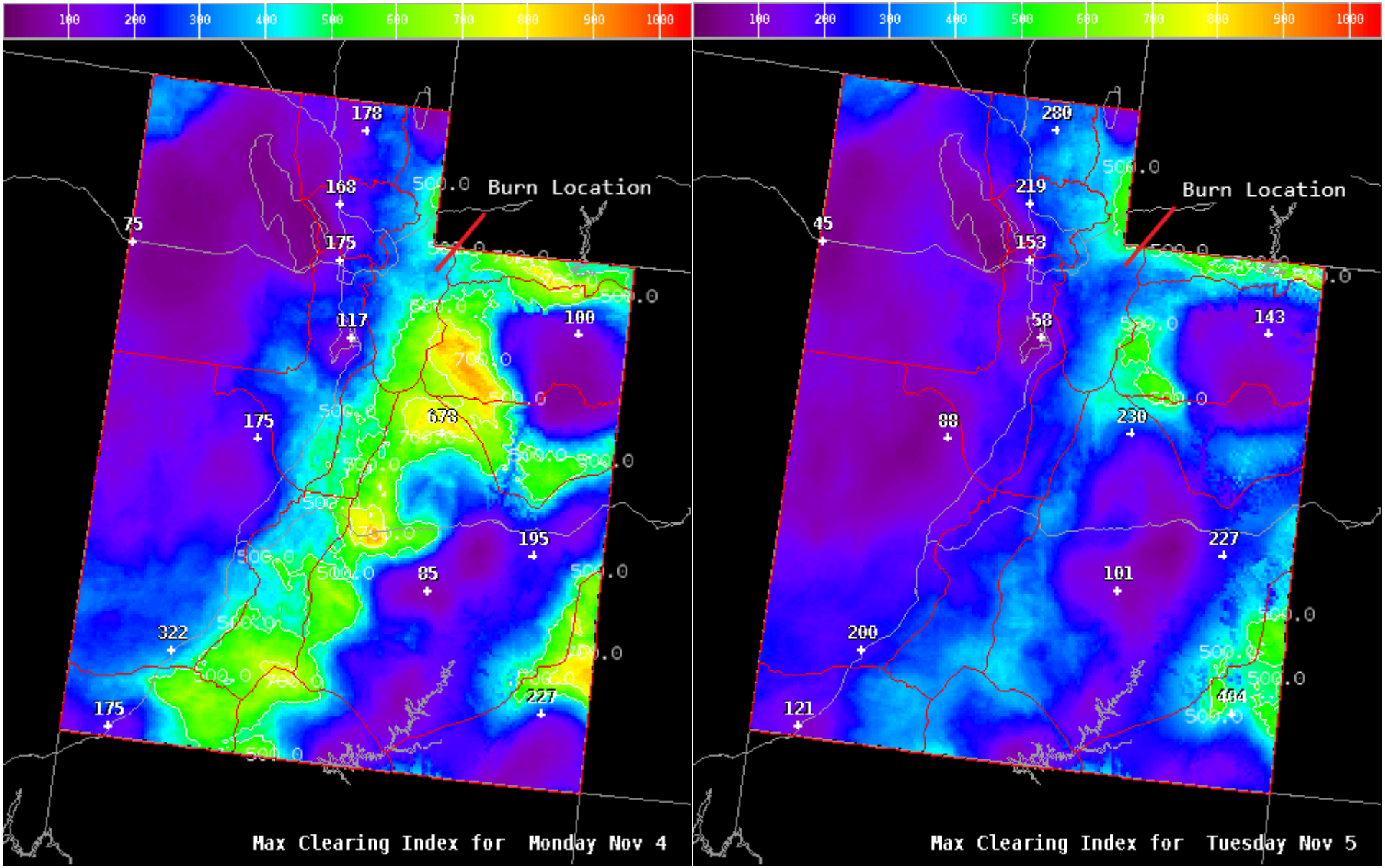
From the National Weather Service forecast discussion on October 30, 2019: "A generally dry and stable northwest flow aloft will persist for the next several days…High pressure is expected to remain centered off the California coast through the entirety of the long term period. This will keep a dry west to northwest flow over Utah…resulting in dry conditions with temperatures near seasonal normals through day seven"

Date	Max Clearing Index From Spot Forecast	Max Clearing Index for Airshed 6 (m)	Mixing Height Airshed 6 (m)	Transport Wind Airshed 6 (m/s)
11/1/2020	540	220	3080	NW4
11/2/2020	180	270	3140	W4
11/3/2020	850	320	3660	W5
11/4/2020	680	410	3510	W5
11/5/2020	300	340	3440	W4

Sky cover was generally clear, with the cold overnight lows typical of November at high elevation. Temperatures at the Cabin E-Sampler ranged from -23 to 3 degrees Celsius during the monitoring period. The E-Sampler was not ideally located to capture wind information, with the anemometer at 2m above ground level and nearby trees 20m tall. The highest hourly average wind speed recorded over 13 days was 1.8 meters/second. Looking at nearby weather stations Windy Peak and Giant Bowl, it appears that a persistent temperature inversion lasted in the upper Weber River drainage from 11/1 through 11/10. Windy Peak, on a ridge 800m above the cabin, reported an average wind speed of 6m/s over the 13 days, always with a westerly component.


100
200
300
400
500
600
700
800
900
1000
119
229
Burn Location
123
199
208
60
327
181
266
315
233
Max Clearing Index for Friday Nov 1


100 200 300 400 500 600 700 800 900 1000
Burn Location
102
180
67
158
108
58
152
141
91
132
223
281
105
500.0
Max Clearing Index for Saturday Nov 2
100 200 300 400 500 600 700 800 900 1000
Burn Location
231
187
37
101
27
54
65
170
100
82
162
68
132
500.0
Max Clearing Index for Sunday Nov 3


100 200 300 400 500 600 700 800 900 1000
178
168
75
175
117
100
175
678
195
85
322
175
227
Burn Location
Max Clearing Index for Monday Nov 4
100 200 300 400 500 600 700 800 900 1000
280
219
45
153
58
143
88
230
227
101
200
121
404
Burn Location
Max Clearing Index for Tuesday Nov 5

Discussion

Site selection and instrument placement

The cabin sits at 2420m, while the pile burn unit ranges from 2450-2550m. The cabin is essentially down-drainage from the entire burn unit. It was expected that during diurnal weather patterns in which cold air flows downhill, smoke from the burn unit would impact the cabin monitors. This appears to have occurred.

In this case the cabin owner was a relative of the burn boss. Nearly all the land along the road leading to Alpine Acres is private property. The study team was not able to make contact with a second landowner in the Weber River corridor. It would have been nice to set up other monitors at greater distances from the burn unit to characterize how PM concentration changed with greater distance from the burn unit.

Filter agreement with continuous

Time Period	Filter Concentration PM2.5 µg/m^3	E-Sampler average PM2.5 µg/m^3	Purple Air average PM2.5 µg/m^3
1 Nov @ 1000- 1 Nov @ 1400	13.2	2.5	n/a
2 Nov @ 1000- 3 Nov @ 2100	22.4	25.8	30.6
31 Oct @ 1300 – 12 Nov @ 1100	21.6	31.3	n/a

The study team had planned to use MiniVol data taken from different time "categories" (background, ignitions, post-burn) to determine a correction factor for the E-Sampler continuous values. Additional burning occurred on Nov 2, 4, and 5, and there was a snafu with programming one MiniVol; this mixed up the time categories and left it impossible to correct the continuous data afterwards.

A filter was scheduled to run during the overnight hours of 11/1-11/2, but it was "overwritten". MiniVols will run their program and flow air again the following week if left undisturbed. The study team was unable to revisit the site to remove the filter before a week had passed, so that filter covers two separate time periods and the value was considered meaningless.

The third line in the table above is from a filter installed in the E-Sampler itself, which has an option to use the same 47mm filter that fits in the MiniVols. This filter was in the E-Sampler for 11 days (265 hours), including both background and burning conditions. The E-Sampler pump flows 2 liters per minute, the MiniVols in this study were set up to run between 4 and 4.5 lpm depending on forecast temperature and pressure. While the calibration for the E-Sampler pump is basic, the process does include temperature and pressure. It is interesting that the numbers on the third line of the table are at least plausible and suggest the E-Sampler hourly and daily averages may be over-reporting actual PM concentrations for this project.

Other particulate matter sources

There are thirteen cabins within 200 meters of the monitoring site, and dozens more within one kilometer. Most if not all of these are secondary residences. Some were certainly occupied during the time of this burn project as indicated by foot and vehicle traffic. In fact the cabin itself where the monitors were located (and the wood-burning stove inside it) were being used at least on the 1st, 2nd and 3rd of November and possibly longer.

Accuracy of model predictions

The BlueSky model suggested 24-hour average PM2.5 values would not exceed 12 µg/m^3. As it turns out, the E-Sampler recorded higher values than this for eight straight days. The E-sampler is a light-scattering instrument and reported concentrations are dependent on the aerosol used for

calibration and environmental conditions. The E-sampler data reported here is uncorrected and should be examined in a relative sense. Absolute concentrations may not be accurate.

Day	Piles Burned	Clearing Index	E-Sampler 24-Hr average PM2.5 µg/m³
10/31	0	260	1
11/1	230	540	14
11/2	235	180	21
11/3	0	850	27
11/4	400	680	41
11/5	80	300	155
11/6	0	450	64
11/7	0	470	15
11/8	0	370	13
11/9	0	310	9

High Values

For the two days in which both the E-Sampler and Purple Air were running, the agreement between the two sensors was close. The Purple Air device ran out of power in the middle of the monitoring period, while the E-Sampler continued running for the duration. There are several impressive "spikes" in PM2.5 concentration, the first two were captured by both continuous instruments, and the rest by the E-Sampler only. The spikes occur at nighttime and morning hours, and afterwards the concentrations go down almost to zero. This is a typical diurnal pattern for smoke and PM in steep terrain during periods of low wind or less than good dispersion.

Looking at the tables and charts of results, it appears the BlueSky model runs for this project significantly under-predicted the daily average concentrations, maximum concentrations, and duration of smoke persistence. This conclusion does assume at least two things:

1) The contribution of other particulate matter sources in the area was not significant, and
2) The E-Sampler values are accurate

While the exact contribution of residential wood burning versus the prescribed fire is impossible to determine, it does seem likely that the major PM source was the prescribed fire. There was wood stove use in the area (and unfortunately even at the Cabin itself where the monitors were located), but even several dozen wood stoves would not consume the amount of material in 1000 piles in a five-day period. Three or four piles on this project could equal a cord of wood in volume and would presumably burn with less efficiency than a wood-burning stove, or perhaps even a fireplace. Contributions from sources other than the prescribed burn, including residential wood-burning, are also accounted for by the background (pre- and post-burn) measurements, which were relatively low, especially compared to peak concentrations measured during burning of the piles.

The E-Sampler did record a short spike for four hours on the evening of November the 10th, after the piles were definitively out. Beginning at 2100, the four consecutive hourly averages reported were 13, 37, 24, and 18 µg/m³. These concentrations are, however, small relative to the peak concentrations recorded by the E-sampler when the piles were burning. If there was a similar contribution to PM from residential wood burning on the burn days, then it is true that the bulk of the PM was from the prescribed fire.

In trying to confirm the E-Sampler values are correct, the close agreement between E-Sampler and Purple Air on Nov 1, 2, and 3 is encouraging, but certainly not definitive. Purple Air sensors have been dogged by the notion that they are inaccurate at high PM concentrations. The two devices are similar in that they both use light-scattering technology. Measurements reported by these samplers are dependent on the aerosol sampled and environmental conditions. Concentration data reported here has not been corrected for these conditions. Absolute concentrations (ug/m3) reported in this

report may not be accurate and should only be examined in a relative sense. E-Samplers are considered to be more robust at high humidity because they have an air inlet heater which limits the internal relative humidity to 50%. Based on the data from the device, that component appears to have been working properly. This particular E-Sampler was set up at the UDAQ technical center and found to have decent agreement with other real-time instruments, although opportunities for comparison were limited to levels of 20 $\mu g/m^3$. For this uncorrected data, any calibration conducted at the technical center may not be representative of field conditions. This was the same E-Sampler (#457) which recorded high numbers at the Devil Canyon project.

While the highest PM spikes on the monitors occurred in the evening through early morning when crews were not present, it is still somewhat surprising that there were no anecdotal reports of thick smoke from the burn crew, either early in the shift when they first arrived or last left the area. There were no known complaints from residents or other members of the public. 150+ $\mu g/m^3$ is really quite high; from biomass burning in the United States, that sort of level is ordinarily associated with wildfires thousands of acres in size, in dense forests.

Takeaways

The team does not have any specific reason to doubt the high measured PM concentrations; this was a significant burn project conducted on days with either poor or fair dispersion, the monitor site was close to the burn, and it was in an area that is topographically constrained. The E-Sampler data is uncorrected so the values cannot be considered definitive- PM2.5 concentrations were probably very high but not necessarily 150 $\mu g/m^3$. The results would have been more robust had there been more filter-based samples, qualitative evidence of heavy smoke such as photographs, or another monitoring site at a greater distance to get a feel for the spatial distribution of PM in the canyon.

If using this Purple Air setup again, the solar panel backpack should be secured so that it remains facing the sun.

Acknowledgements

Thanks to prescribed fire burn bosses Kyle Yurkovich and Dalton Loveless. Kyle's mother-in-law is the owner of the cabin used as a monitoring station. Thanks also to Amara Holder (EPA) for the use of the Purple Air sensor.

PROVIDENCE BIOCHAR

UINTA WASATCH CACHE NATIONAL FOREST

LOGAN RANGER DISTRICT

41.69 N
111.77 W
1713 m / 5620 ft

SUMMARY

This was a public demonstration of a biochar kiln, 2 km up Providence canyon in Cache Valley. Approximately 60 piles of rocky mountain juniper consumed over two days: 11/7 and 11/8/2019.

DESIGN

The study team consulted local forest and fire officials. Based on that discussion and Google Earth the team chose four sites: A friend's house in Providence, the trailhead at the mouth of the canyon, the burn location itself, and a gravel pit 2.4 km up canyon from the burn site.

EQUIPMENT

Friend's House: E-BAM, MiniVol
Trailhead: MiniVol
Burn location: MiniVol
Gravel Pit: E-Sampler, MiniVol

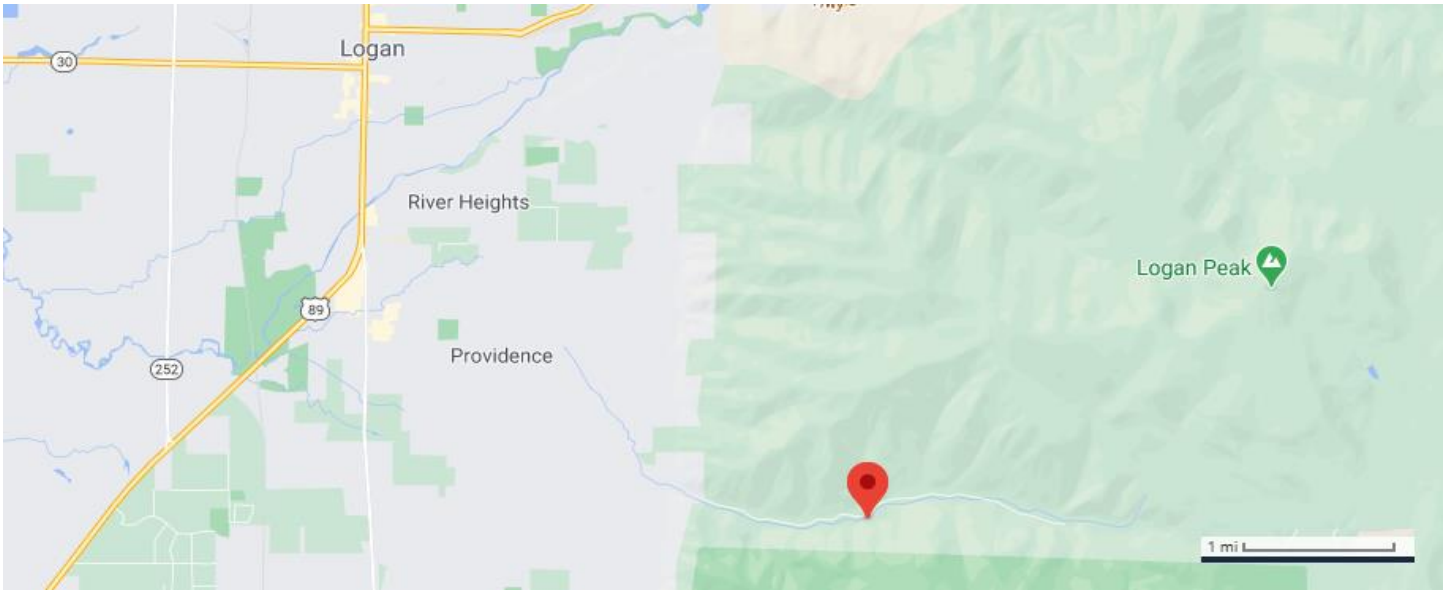
BIOCHAR

Creating Biochar involves burning vegetative material in a specially designed kiln with the goal of controlling the combustion process to produce a carbon-rich soil amendment. The char is produced during pyrolysis: thermal decomposition of biomass in an oxygen-limited environment. Layer upon layer of material is added in sequence to a kiln, and when operators decide it has reached the right point, the material is extinguished rather than allowed to smolder or consume fully. The kiln can then be dumped out and the process repeated. Biochar has been used since prehistoric times.

EVENTS

At Providence Canyon, the biochar kiln used was 4 meters long, 2 meters wide, and 2 meters tall. To manage the kiln and the biomass, a trackhoe with a bucket and thumb was used. A fire engine was on-scene to extinguish the kiln when the time came.

The maximum clearing index on 11/7 was 340 and on 11/8 it was 270. On 11/7 approximately 20 piles of juniper were converted to biochar, and on 11/8 approximately 40 piles were converted. Monitoring equipment remained in place overnight on the 7th but was taken down following extinguishing the kiln on the afternoon of the 8th.



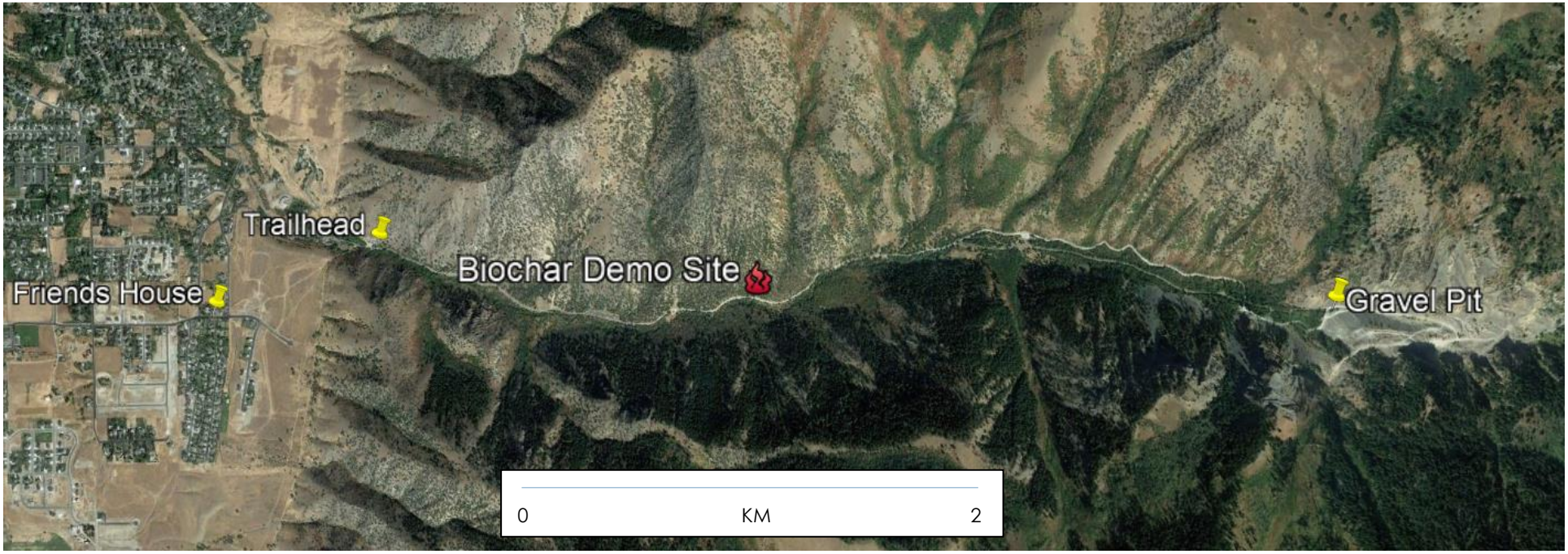
The kiln during initial warm-up, winds are calm or very light, as they were throughout the project.

The kiln mid-process

Quenching the kiln once a full load has been converted to biochar

The monitoring equipment at the gravel pit. (The gravel pit was not operational during the biochar event)

Site selection / instrument placement



Monitoring Site	Elevation (m)	Distance to Kiln
Friend's House	1544	2,490 m
Trailhead	1560	1,750 m
Demo Site	1713	20 m
Gravel Pit	1955	2,440 m

The Friend's House was selected as a monitoring site to provide a background value; it is on a bench, so not directly in line with down-drainage flow from the burn.

The Trailhead is directly down-drainage from the burn location.

At the Demo Site itself, the MiniVol was located about 20 meters from the kiln on the up-canyon side. Photos and observations show the smoke rising more or less vertically from the kiln, and winds were light and variable, so it is likely wind speed and direction played just a small role in values at the Demo Site.

Results

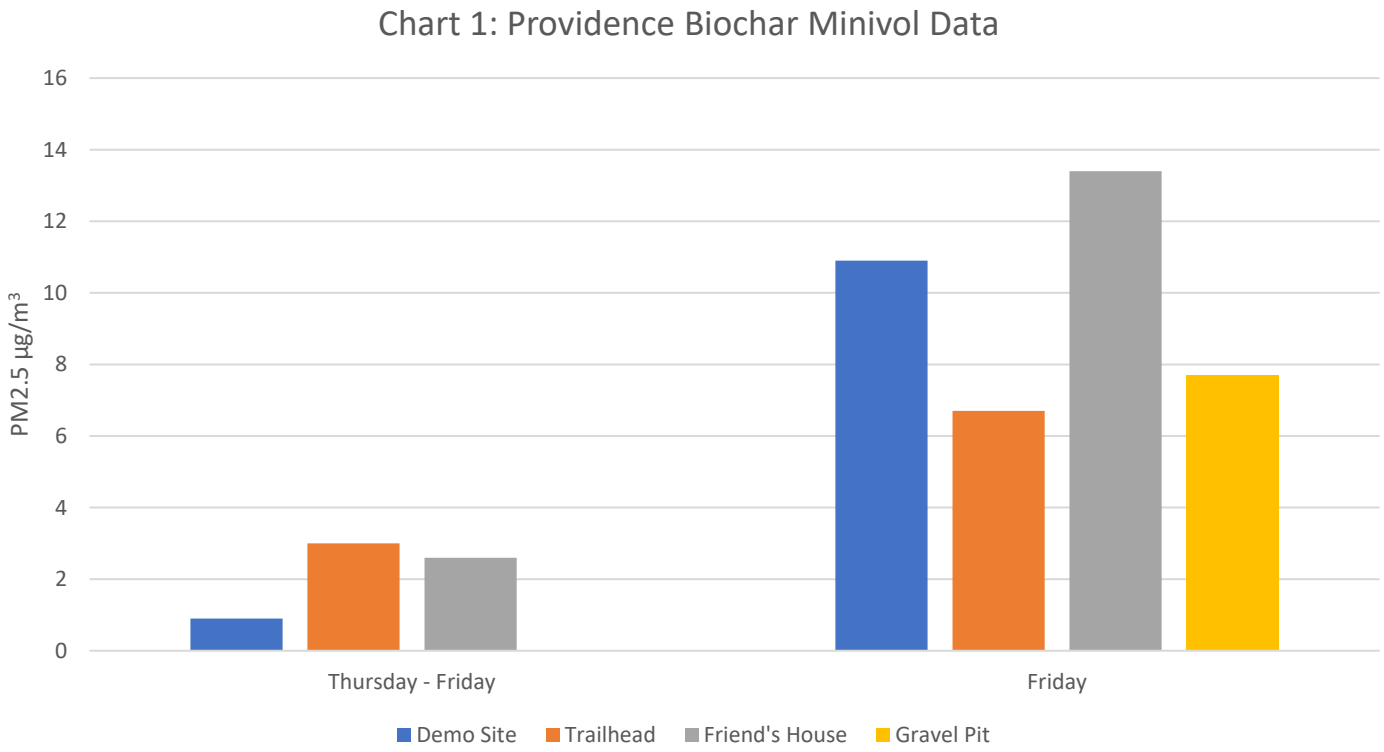


Chart 1: Providence Biochar Minivol Data
PM2.5 µg/m³
16
14
12
10
8
6
4
2
0
Thursday - Friday
Friday
Demo Site
Trailhead
Friend's House
Gravel Pit

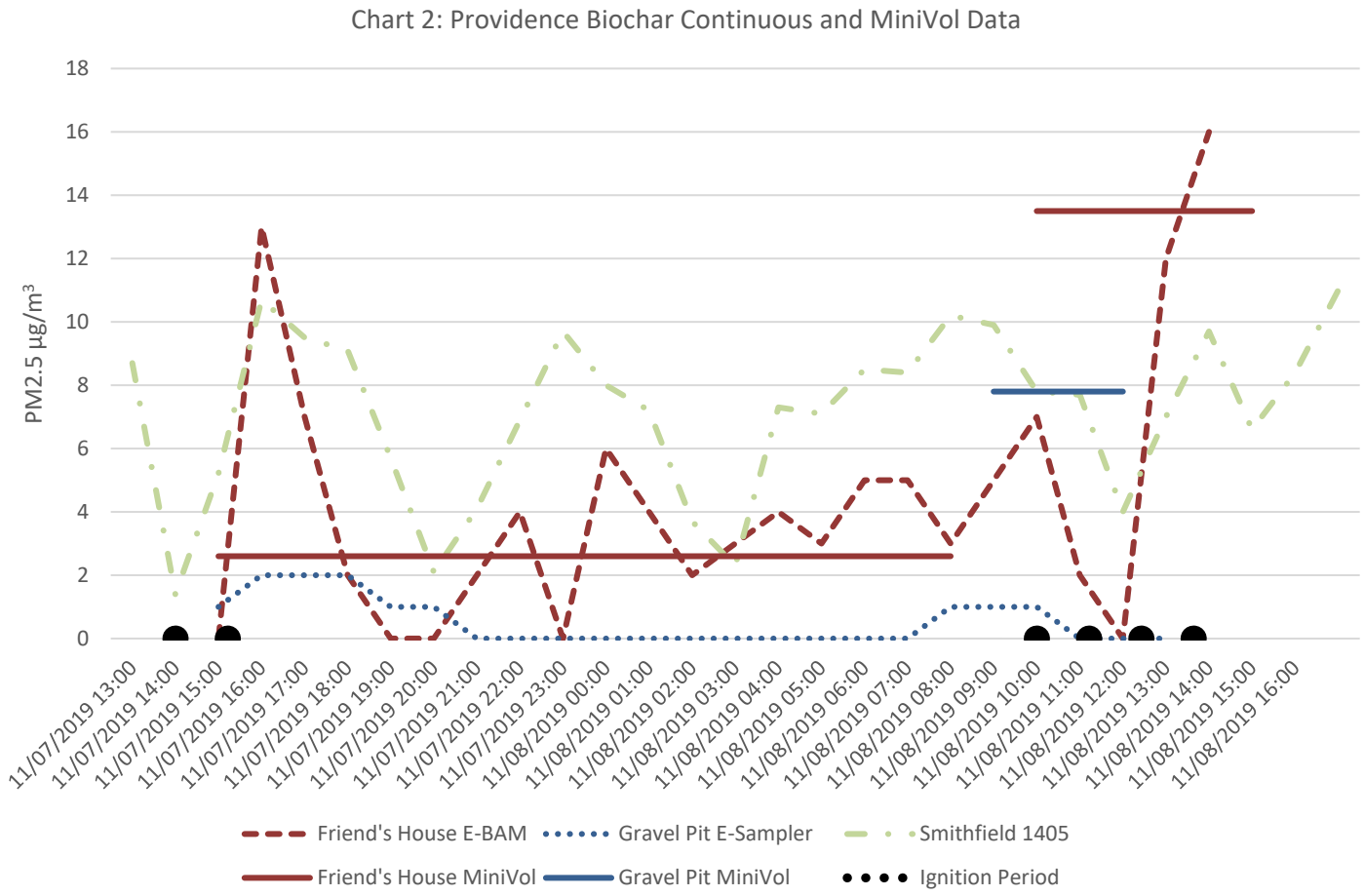


Chart 2: Providence Biochar Continuous and MiniVol Data
PM2.5 µg/m³
18
16
14
12
10
8
6
4
2
0
11/07/2019 13:00
11/07/2019 14:00
11/07/2019 15:00
11/07/2019 16:00
11/07/2019 17:00
11/07/2019 18:00
11/07/2019 19:00
11/07/2019 20:00
11/07/2019 21:00
11/07/2019 22:00
11/07/2019 23:00
11/08/2019 00:00
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11/08/2019 02:00
11/08/2019 03:00
11/08/2019 04:00
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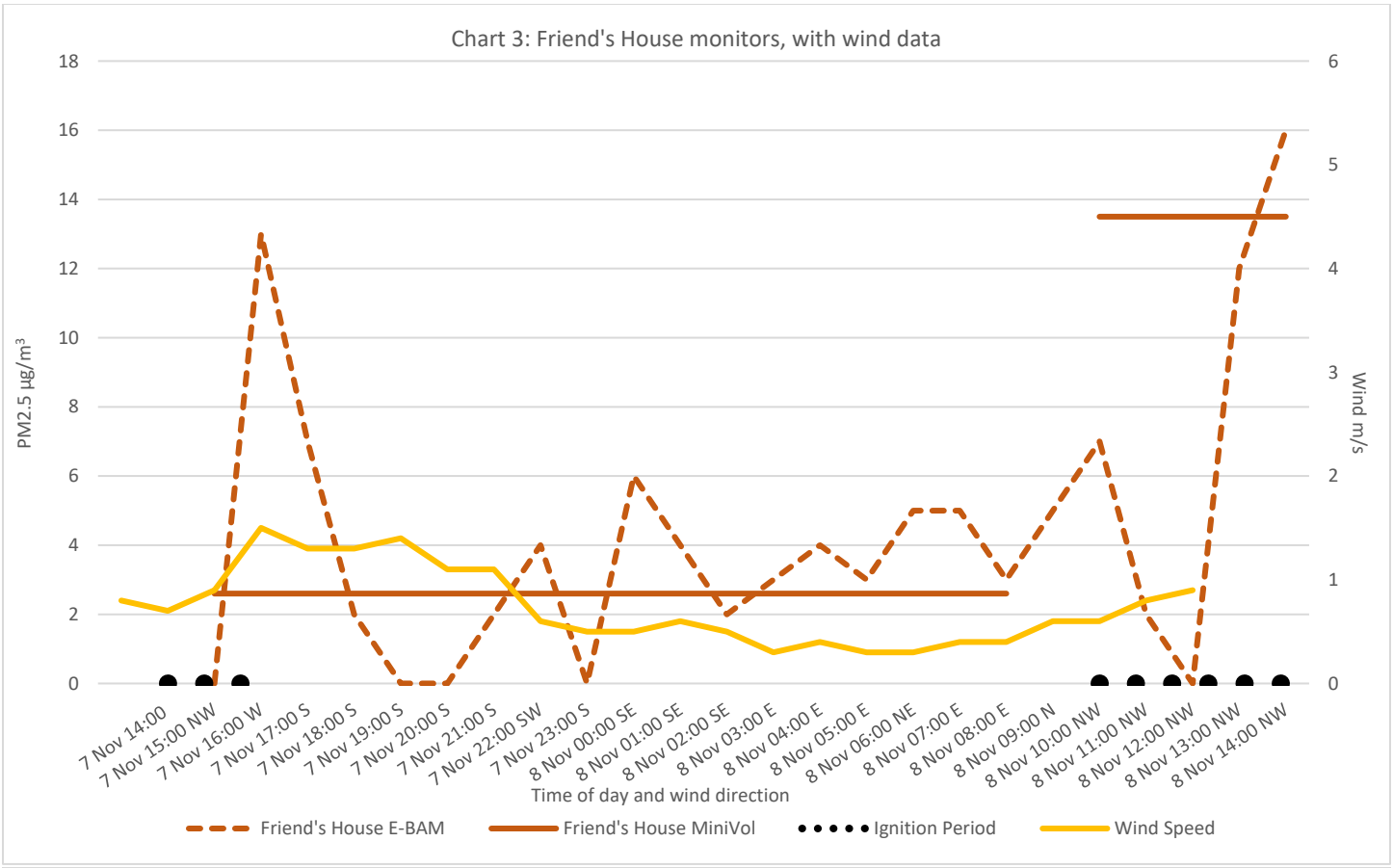
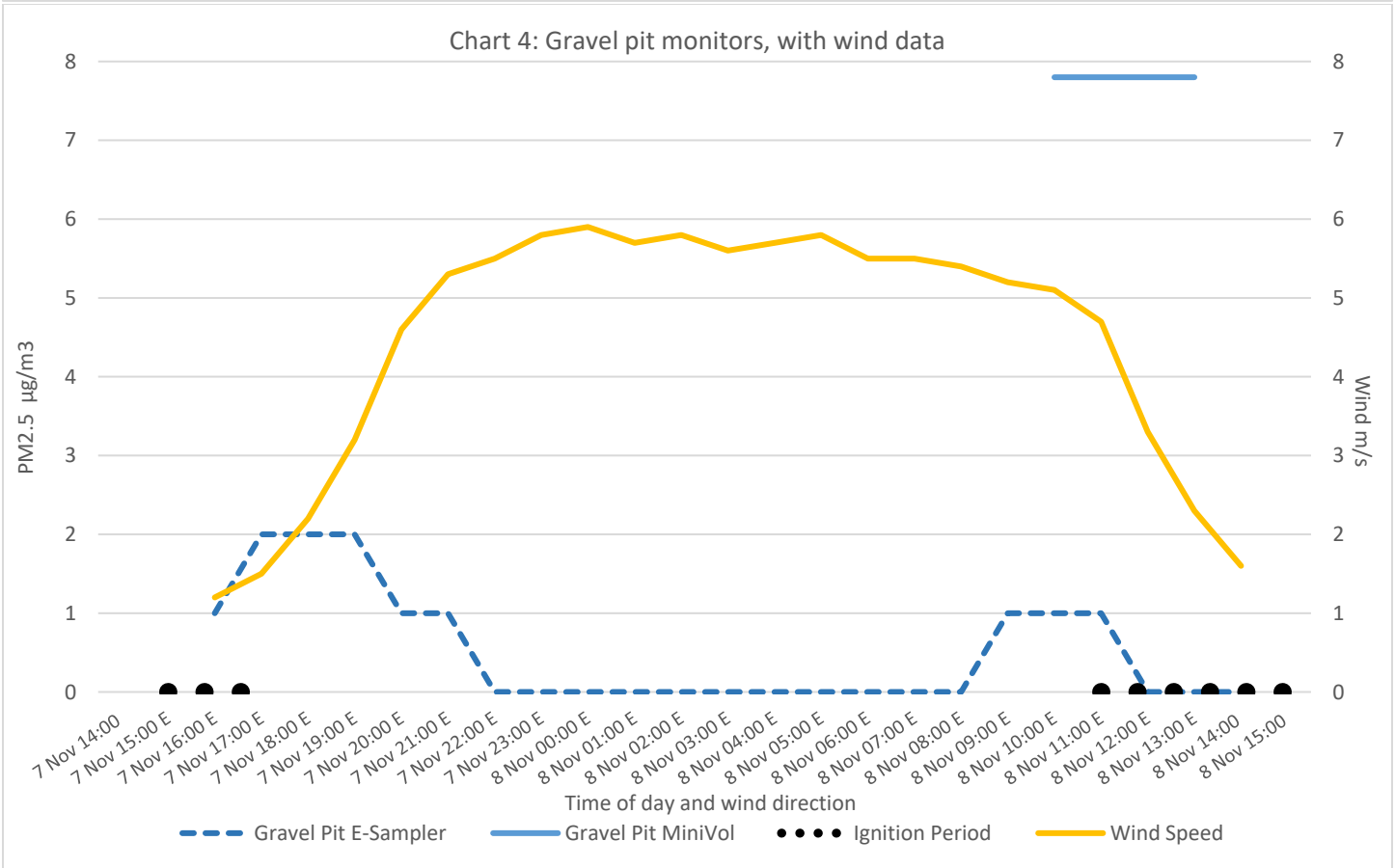
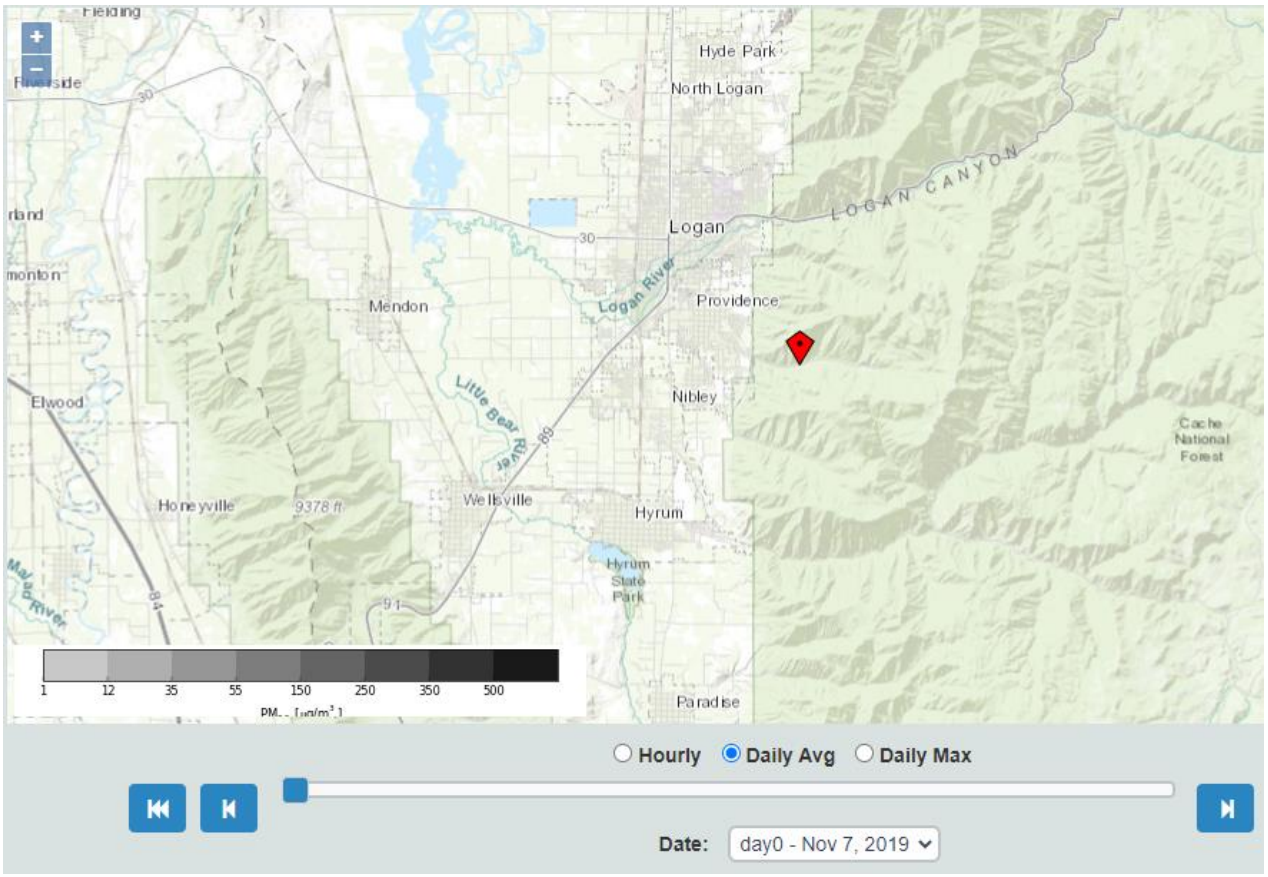
11/08/2019 07:00
11/08/2019 08:00
11/08/2019 09:00
11/08/2019 10:00
11/08/2019 11:00
11/08/2019 12:00
11/08/2019 13:00
11/08/2019 14:00
11/08/2019 15:00
11/08/2019 16:00
Friend's House E-BAM
Gravel Pit E-Sampler
Smithfield 1405
Friend's House MiniVol
Gravel Pit MiniVol
Ignition Period



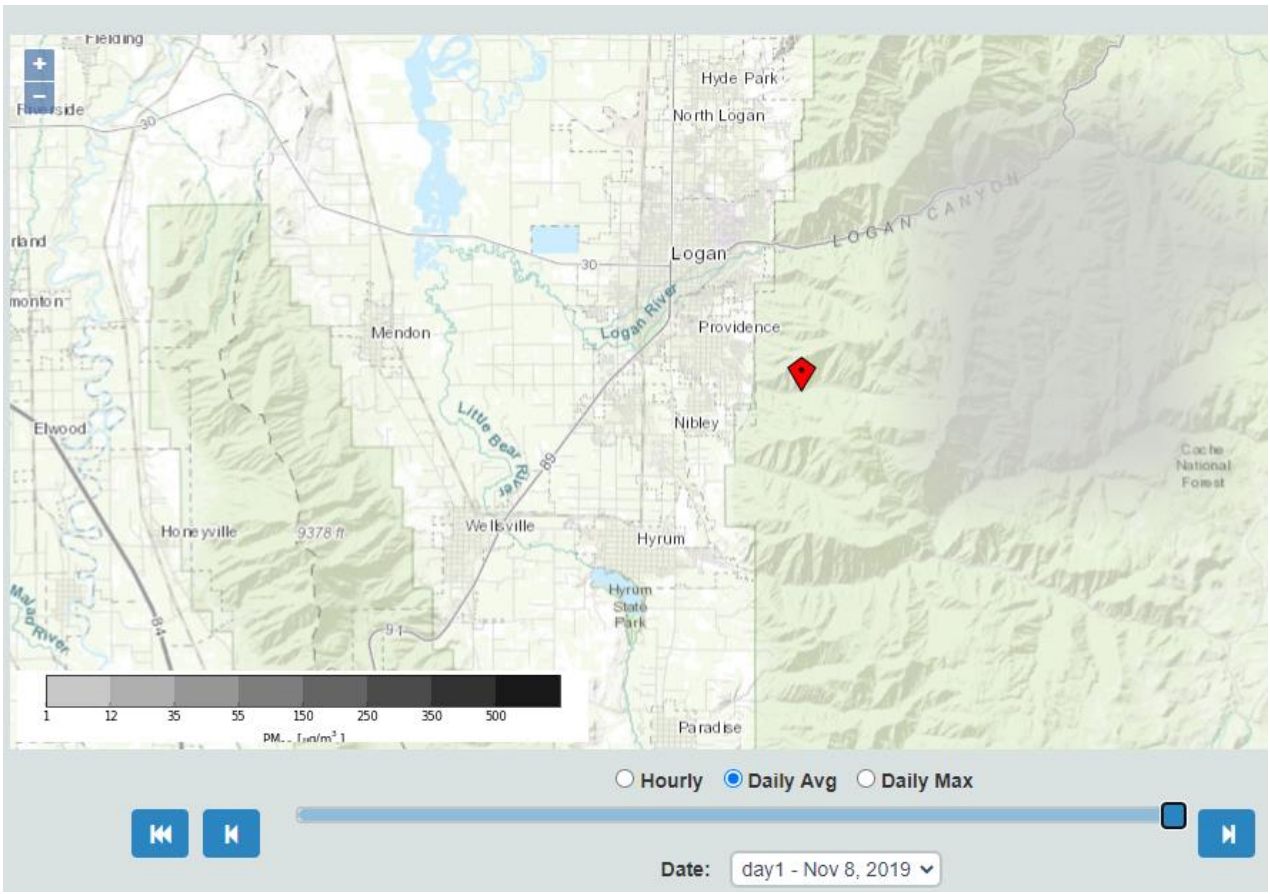


*The wind direction vane on the E-Sampler was likely stuck, these 22 hours all logged within a 5 degree azimuth

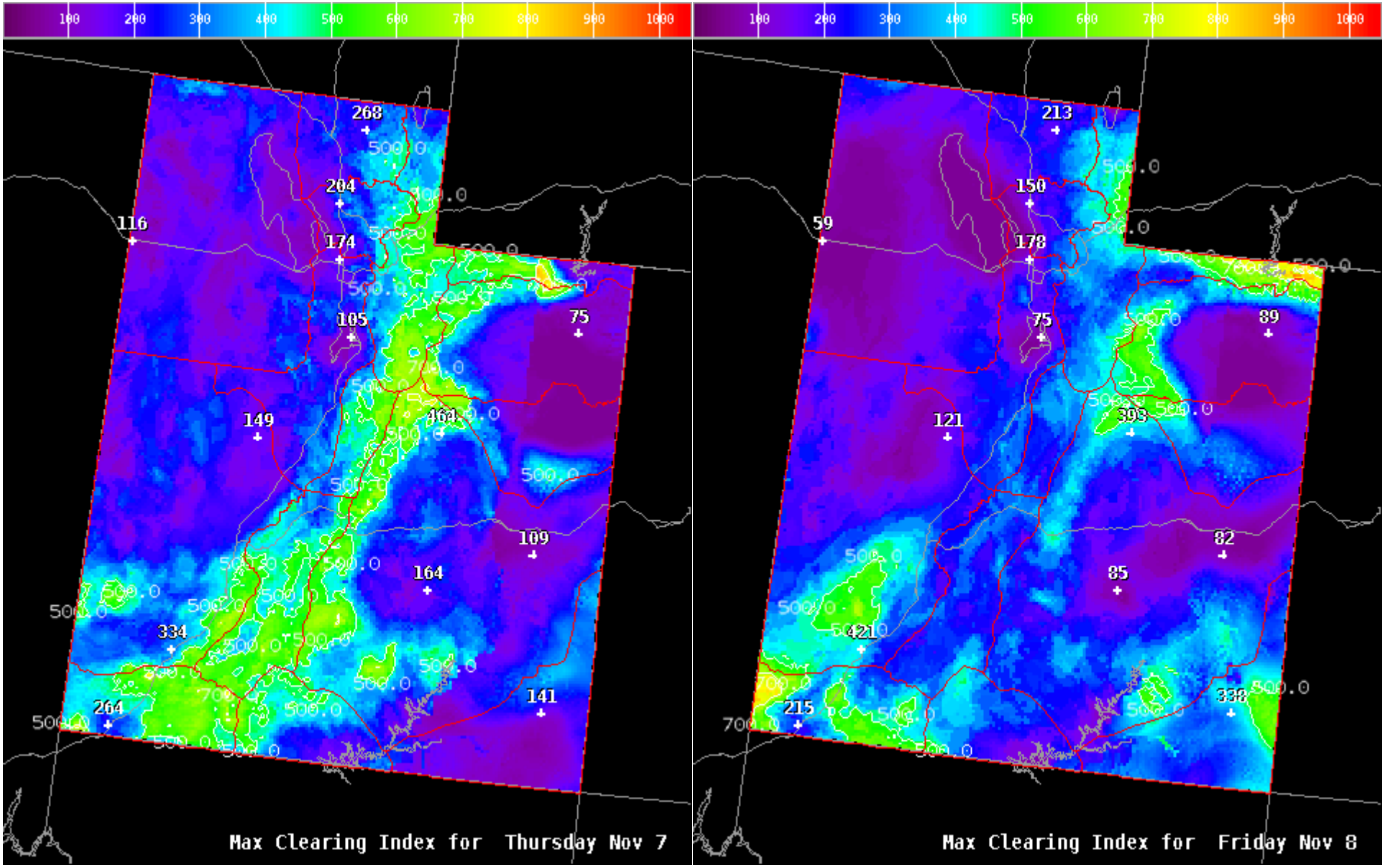
Model Prediction



For the 7th the model predicted no measureable impacts



For the 8th the model predicted light impacts to the East of the burn site



High pressure began building mid-week, causing decreasing clearing index values at the burn location and statewide.

Weather

The sky was clear, calm, and hazy in the Cache Valley on both days of the Providence Biochar project. Comparing weather stations for the 8th of November shows a mild inversion formed overnight, which broke up by the afternoon:

Weather Station/ Site	Elevation (m)	Temp (C) 0600 hours	Temp (C) 1400 hours
Evans Farm*	1382	-5.0	13.8
Friend's House	1544	-1.4	10.2
Gravel Pit	1955	1.9	5.6
Logan Peak	2960	0.5	3.9

*****A nearby weather station on the valley bottom

Discussion

Filter agreement with continuous monitors

Row	Location	Time Period	Burn Category	MiniVol Average µg/m^3	Co-located Continuous Average µg/m^3	Smithfield Continuous Average* µg/m^3
1	Friend's House	Thursday-Friday	Background	2.6	3.75	7.1
2	Friend's House	Friday	Background	13.4	7.0	7.1
3	Trailhead	Thursday-Friday	Burn + Post-Burn	3.0	n/a‡	7.1
4	Trailhead	Friday	Burn	6.7	n/a	6.6
5	Demo Site	Thursday-Friday	Burn + Post-Burn	0.9	n/a	6.7
6	Demo Site	Friday	Burn	10.9	n/a	6.6
7	Gravel Pit	Thursday-Friday	Burn + Post-Burn	n/a†	0.6	7.1
8	Gravel Pit	Friday	Burn	7.7	0.25	7.3

* Because of different start and stop times for the various MiniVols, each value for the Smithfield column is a slightly different

‡ There was no continuous instrument co-located at the trailhead or demo site

† The Thursday-Friday Gravel Pit MiniVol run did not occur due to a setup issue

The Smithfield continuous monitor in this table (a Thermo Scientific 1405) reported hourly values between 2 and 10 µg/m^3 over the two days. When averaged over multiple hours, it showed little variation during the monitoring period (6.6 to 7.3 µg/m^3 depending on the specific hours).

The E-BAM at the Friend's House logged a value 1.15 µg/m^3 higher than the MiniVol in row 1, but 6.4 µg/m^3 lower than the MiniVol at row 2. This particular E-BAM (592) showed significant noise when set up at the DAQ tech center. It was not used again in the field after this project. Data from this instrument should be considered suspicious.

Looking at row 8, the MiniVol at the Gravel Pit and Smithfield report similar concentrations while the E-Sampler reads much lower. The E-sampler data has not been corrected to adjust for properties of the local sampled aerosol, which explains this discrepancy.

Looking just at the MiniVol column, Friday's sampling period had higher concentration than Thursday-Friday at all three sites for which there is a comparison. The Smithfield monitor shows no significant difference between Thursday-Friday and Friday.

Other particulate matter sources

The Cache Valley is a nonattainment area for PM2.5 and a topographically constrained airshed with a sizeable population and accompanying pollution sources. A mild inversion formed the mornings of both the burn days, and it is likely that this project had the highest background PM values in the overall study, with the possible exception of Alpine Acres. The Friend's house was selected as a monitoring site to provide a background value; it is 1.5 miles away from the burn location. Looking both at the DAQ monitoring site in Smithfield, and the various values from the instruments at the

Friend's House, it seems safe to assume a background value around 7 µg/m^3 at the Friend's House. Background at the Demo Site may be lower.

Accuracy of model predictions

Providence Biochar had the smallest volume of material burned out of all six projects. BlueSky playground runs predicted no measureable effect for the 7th, and a small amount of ground level smoke to the east of the incident on the 8th. The highest recorded values on the project were at the Friend's House, rather than at any of the three sites in the canyon. From qualitative observations at the burn demo site, smoke often could not be smelled even 20 meters from the kiln. Given the small amount of total PM emitted it is difficult to say with confidence that any of the monitored values reflect smoke being captured by the instruments.

Takeaways

As with the Moab Biochar project, it appears that this precribed fire did not increase ambient PM concentrations beyond what could be considered acceptable.

It is likely that the set screw fixing the wind direction vane in place was left screwed down on the E-Sampler at the Gravel Pit. A suggestion is to build a checklist for setting up each instrument, with copies to be stored in the instrument case.

Acknowledgements

Thanks go to the prescribed fire burn boss, Garret Pitsenbarger, for allowing access to the kiln site, to fire management officer James Turner for assisting with equipment setup and offering his friend's house as a monitor location, and USU extension forester Darren McAvoy for his efforts in promoting biochar and understanding its effects on air quality.

MOAB BIOCHAR

UTAH DIVISION OF FORESTRY, FIRE AND STATE LANDS

SOUTHEAST AREA

38.54 N
109.59 W
1207 m / 3959 ft

SUMMARY

This was a public demonstration of a biochar kiln, 3 km downriver from Moab on the banks of the Colorado. Approximately 100 piles of Russian Olive consumed over three days: 1/13, 1/14, and 1/15/20.

DESIGN

The study team consulted local fire officials. Based on that discussion and Google Earth the team chose two sites: A vacant BLM campground 1200 meters upriver, and just 200 meters downriver of the kiln site itself.

EQUIPMENT

Campground: E-Sampler, MiniVol
Kiln Site: E-Sampler, MiniVol

BIOCHAR

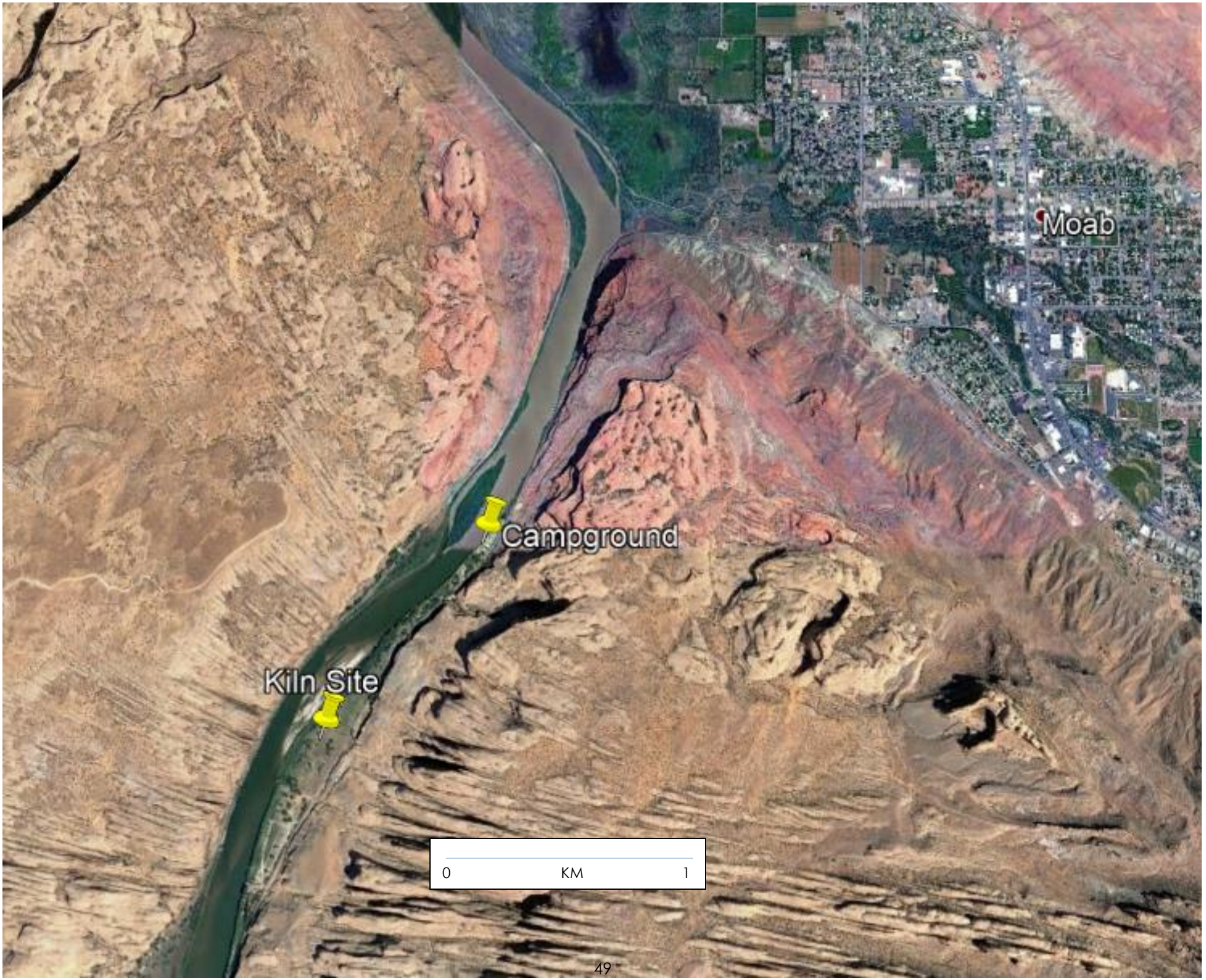
Creating Biochar involves burning vegetative material in a specially designed kiln with the goal of controlling the combustion process to produce a carbon-rich soil amendment. The char is produced during pyrolysis: thermal decomposition of biomass in an oxygen-limited environment. Layer upon layer of material is added in sequence to a kiln, and when operators decide it has reached the right point, the material is extinguished rather than allowed to smolder or consume fully. The kiln can then be dumped out and the process repeated. Biochar has been used since prehistoric times.

EVENTS

This Moab project used a slightly smaller kiln than Providence: 3 meters long, 2 meters wide, and 1.2 meters tall. To manage the kiln and the biomass, a mini excavator with a bucket and thumb was used. A fire engine was on scene to extinguish the kiln when the time came.

The maximum clearing index on 1/13 was 300, on 1/14 it was 110, and on 1/15 it was 50. Approximately 20 piles were converted to biochar on the 13th, and 40 piles on each of the following two days.

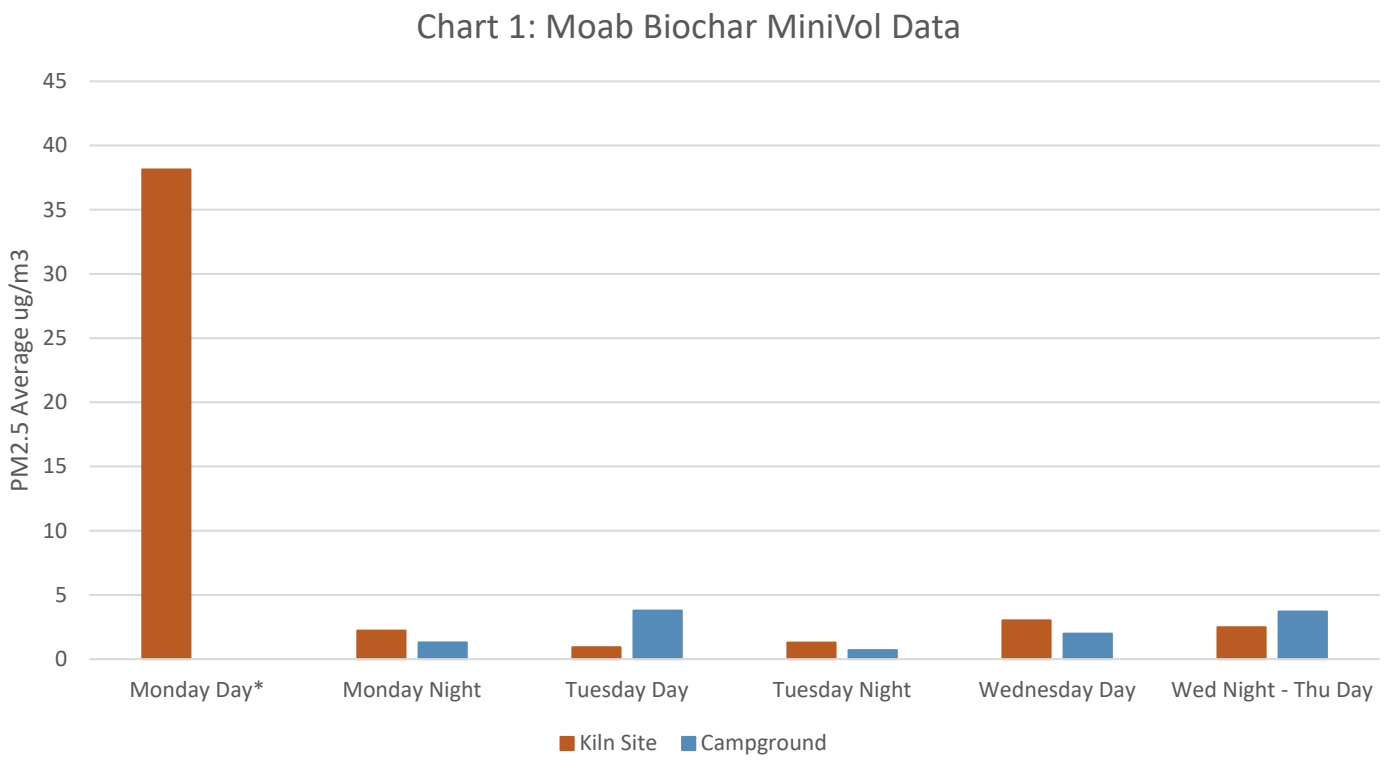
Equipment in place at the campground on the banks of the Colorado River


Moab
Campground
Kiln Site
0
KM
1

The kiln is burning at high efficiency, with another load of material on the way

A grapple full of material has just been added

Results



*During the Monday Day operation, the Kiln Site MiniVol was about 10 meters from the kiln. For operational reasons it had to be moved beginning Monday Night. From then onward the kiln was about 200 meters from the Kiln Site monitors. The Monday Day value is left off Chart 2 for scale purposes:

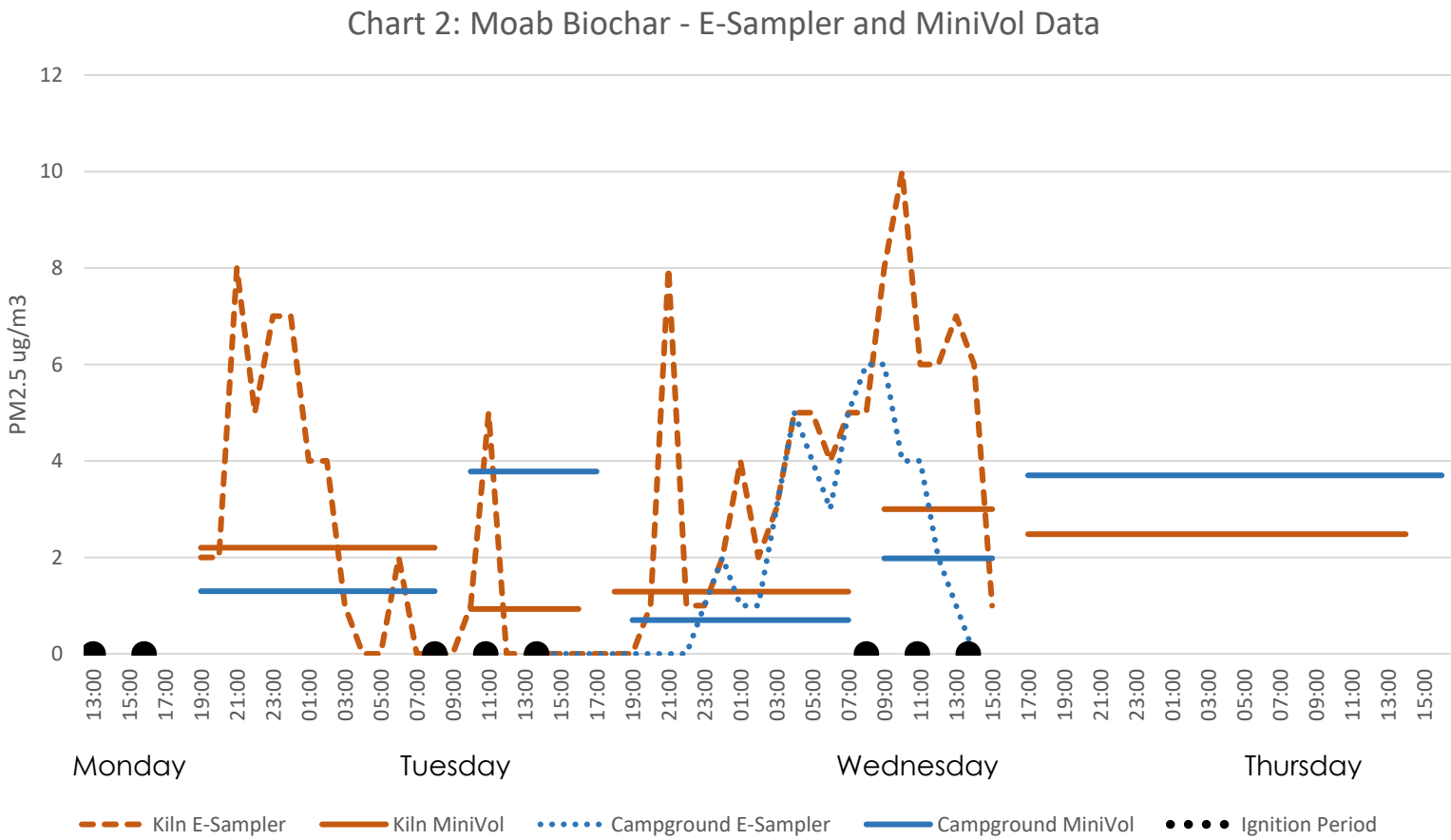
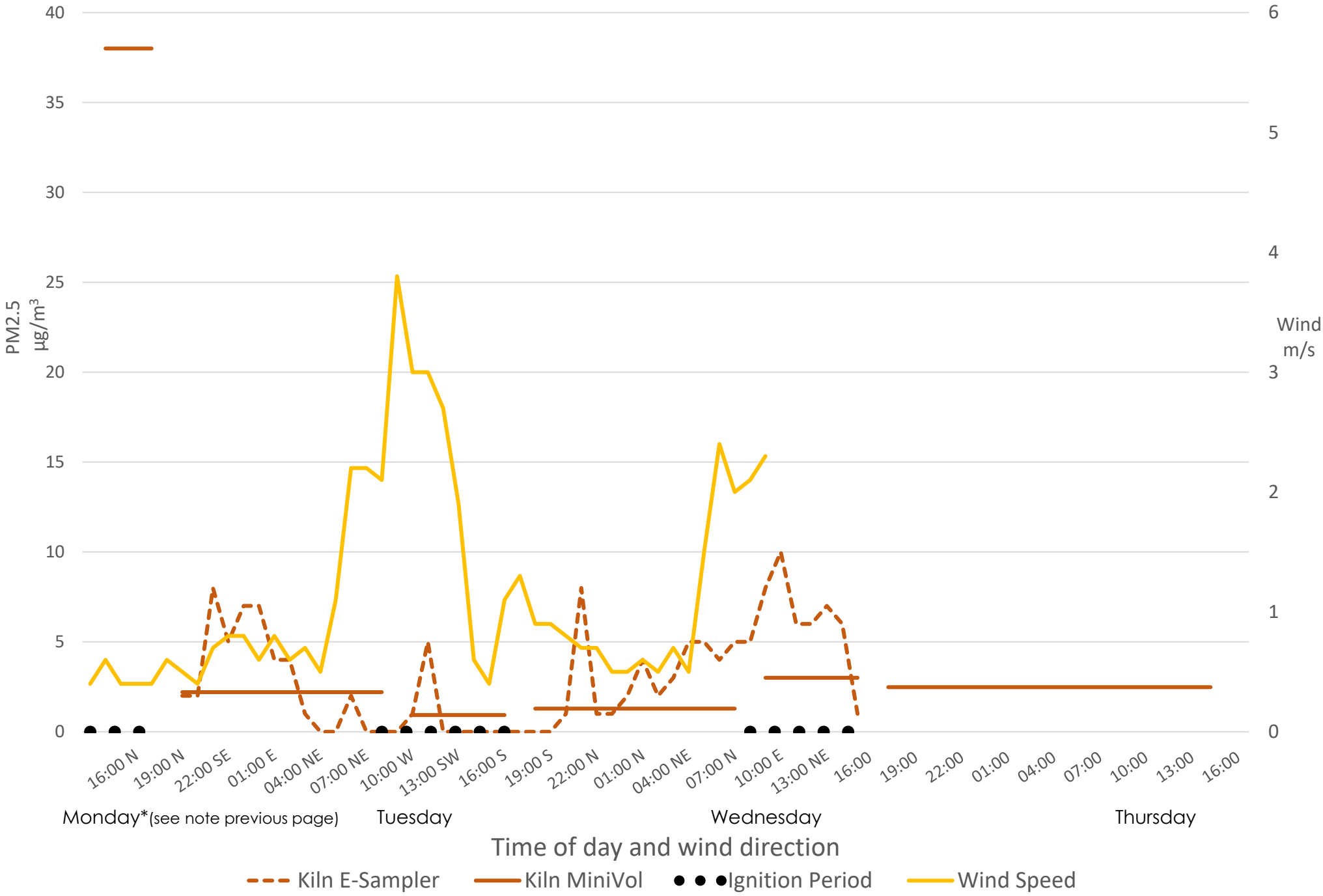


Chart 3: Kiln site monitors, with wind data



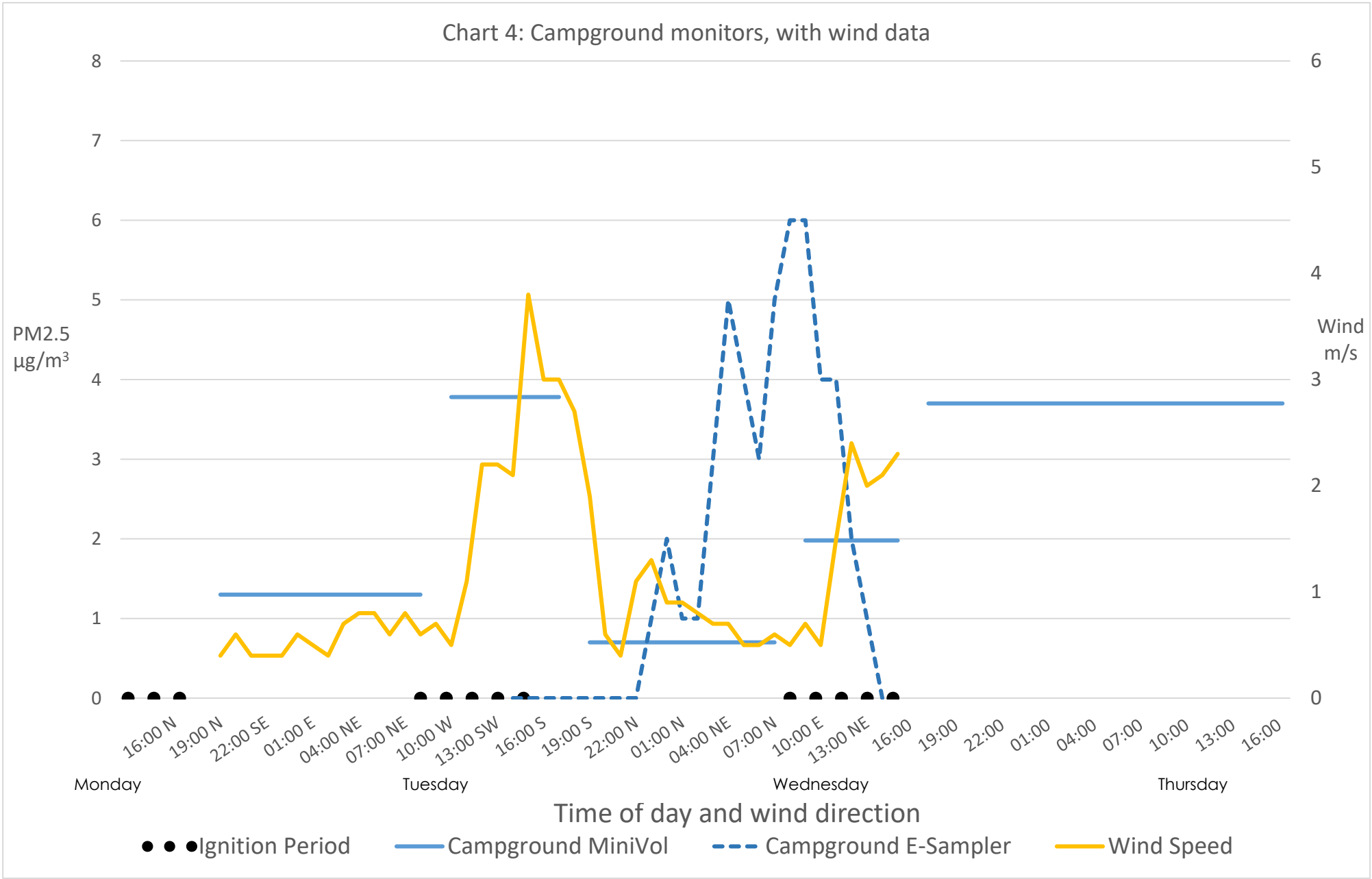
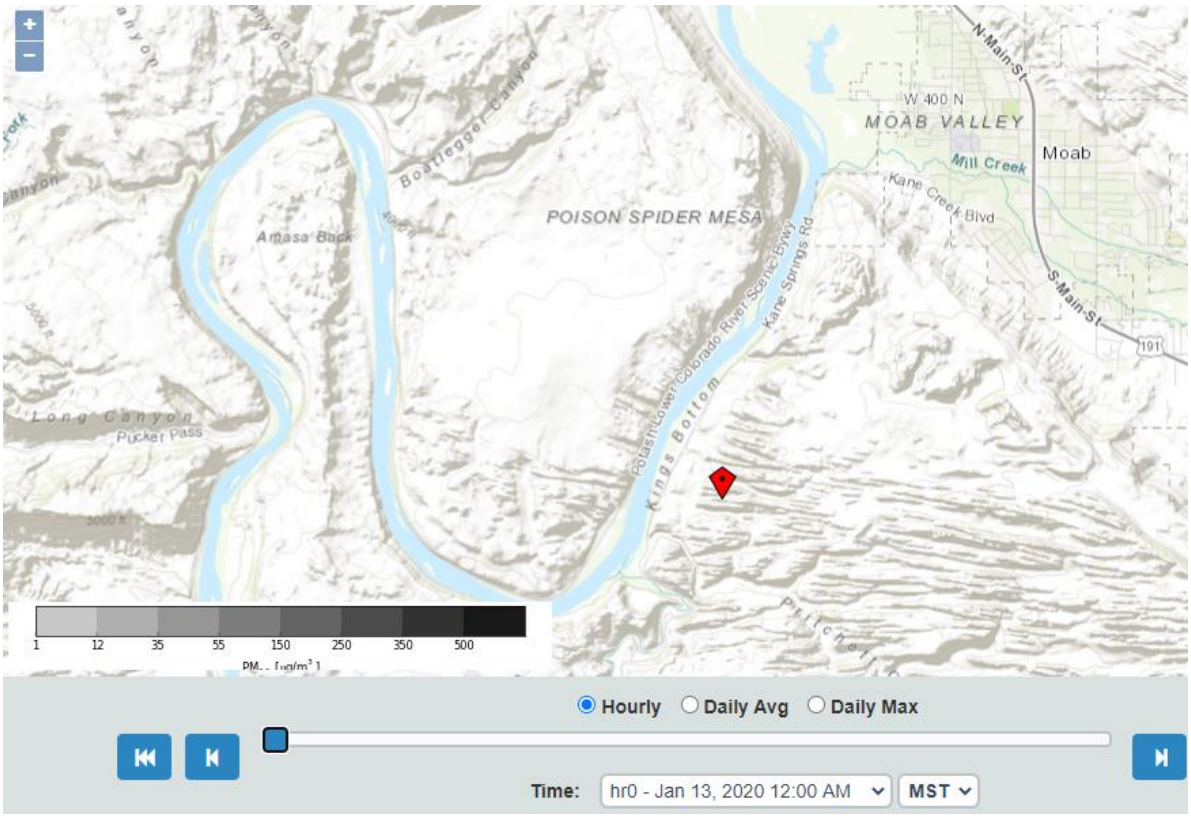
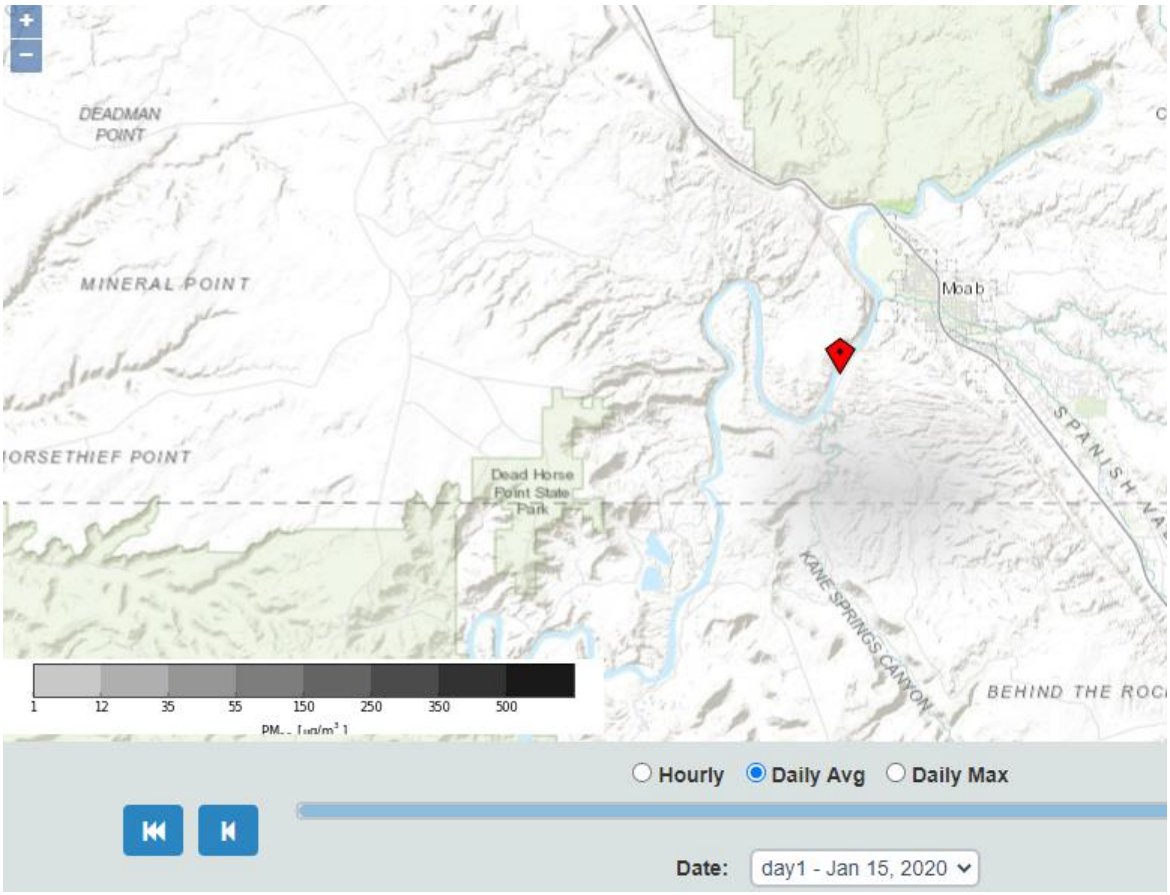


Chart 4: Campground monitors, with wind data
PM2.5 µg/m³
Wind m/s
8
7
6
5
4
3
2
1
0
6
5
4
3
2
1
0
16:00 N
19:00 N
22:00 SE
01:00 E
04:00 NE
07:00 NE
10:00 W
13:00 SW
16:00 S
19:00 S
22:00 N
01:00 N
04:00 NE
07:00 N
10:00 E
13:00 NE
16:00
19:00
22:00
01:00
04:00
07:00
10:00
13:00
16:00
Monday
Tuesday
Wednesday
Thursday
Time of day and wind direction
Ignition Period
Campground MiniVol
Campground E-Sampler
Wind Speed

Model Prediction



For the 13th and 14th the model indicated no impact



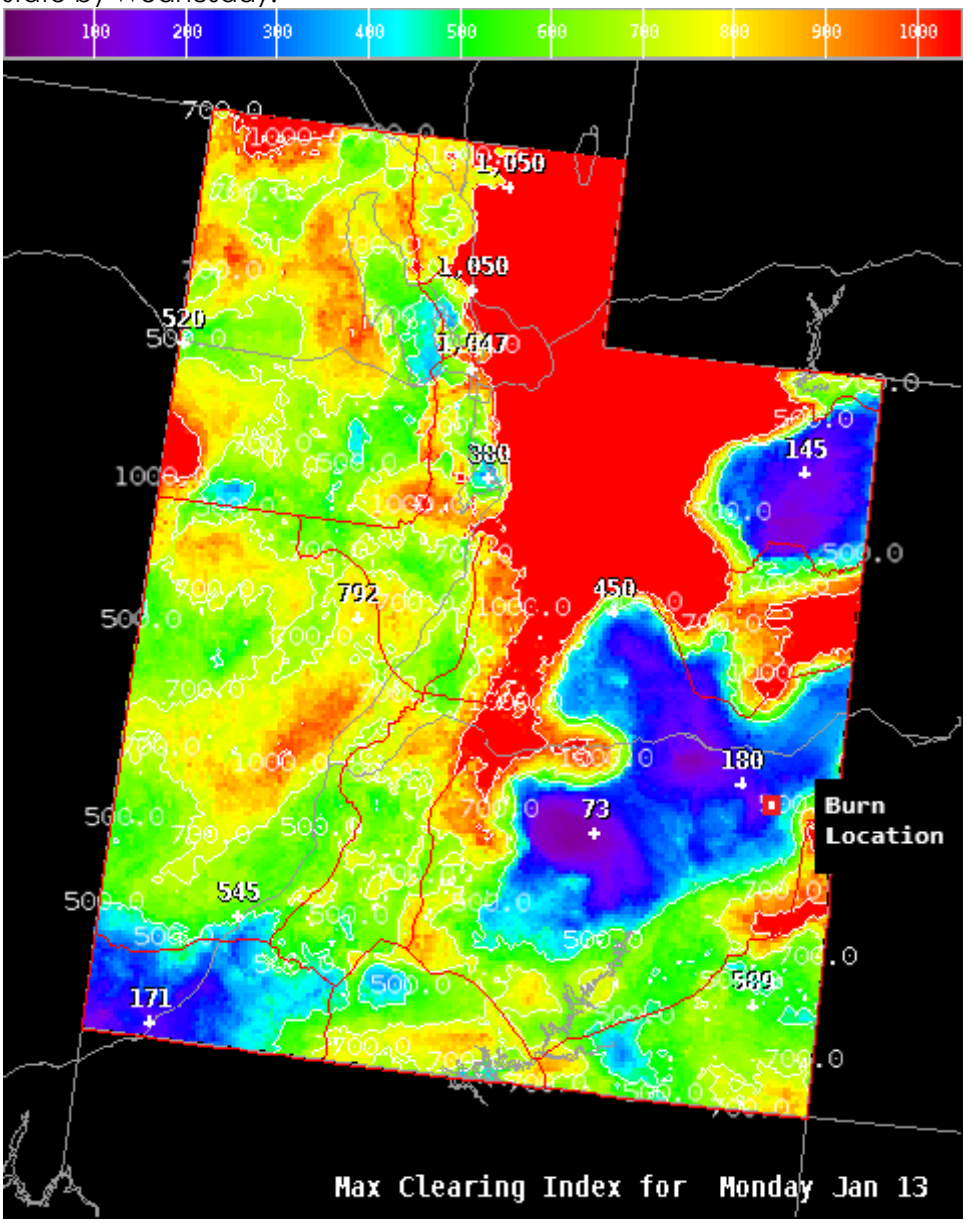
The model indicated light impacts south of the burn on the 15th

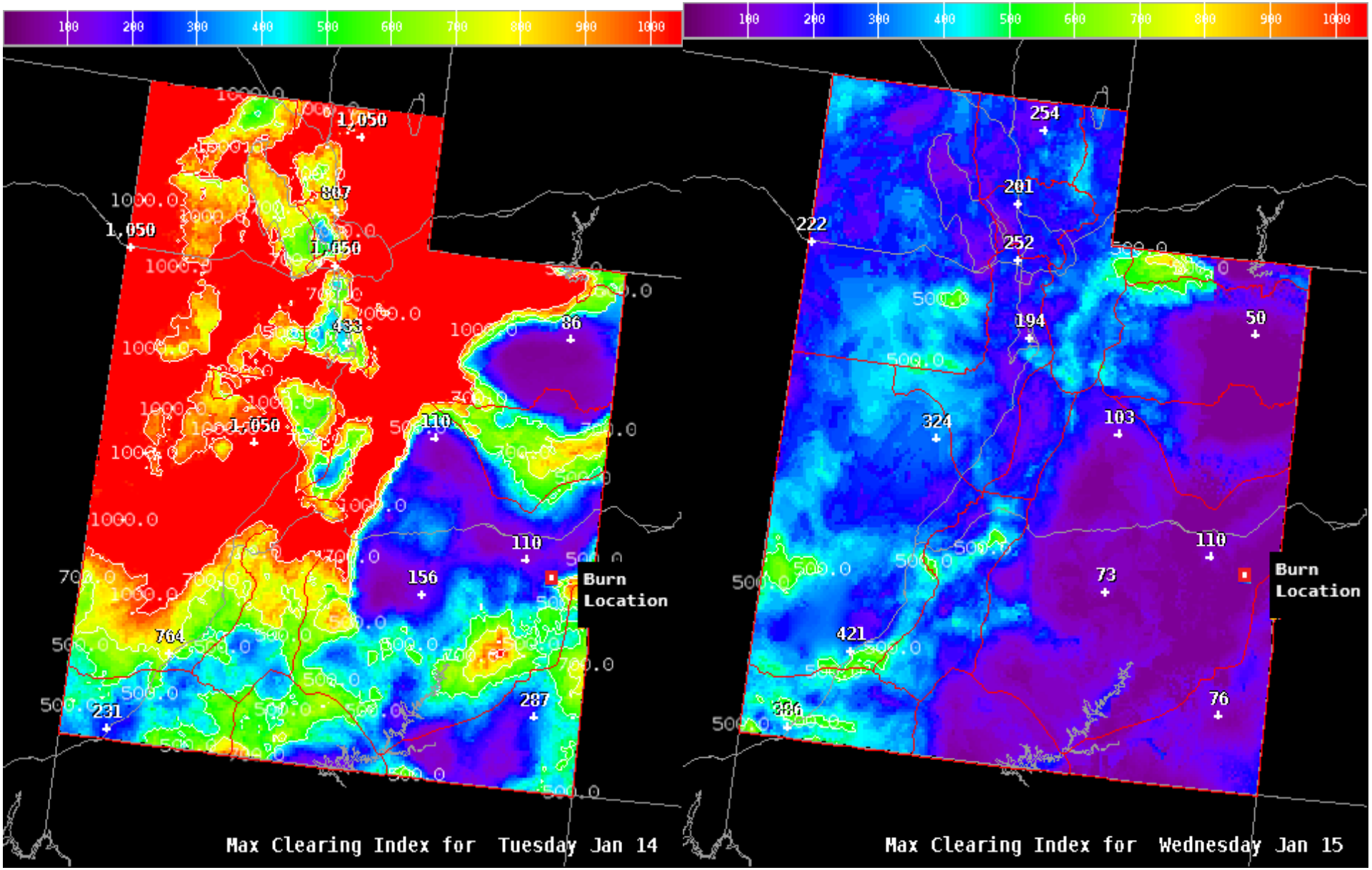
Weather

The week of January 13, 2020 was seasonally typical for a building high pressure system in winter around Moab: clear, fairly calm, and cool. The temperature ranged from -5 to 10 degrees Celsius, with mean of 0.5 degrees. Skies were mostly sunny to sunny in the daytime. Sunrise was at ~0730 and sunset at ~1720. Hourly average wind speed ranged from 0.4 to 3.8 meters/second (0.8 to 8.4 mph). The wind speed average over the entire three days of burning activity was 1.1 meters/second.

Date	Max Clearing Index From Spot Forecast	Max Clearing Index By Airshed (Airshed 12)	Mixing Height By Airshed (Airshed 12) (Meters)	Transport Wind By Airshed (Airshed 12) (m/s)
1/13/2020	300	490	2650	W7
1/14/2020	110	360	2350	SW7
1/15/2020	50	90	2350	S2

The clearing index, a measure of dispersion that is a function of mixing height and transport wind, was only low on Monday near the burn site and other low elevation basins, but high pressure built and spread across the state by Wednesday:




100 200 300 400 500 600 700 800 900 1000
1,050
807
1,050
1,050
483
86
1,050
110
156
110
Burn Location
764
231
287
Max Clearing Index for Tuesday Jan 14
100 200 300 400 500 600 700 800 900 1000
254
201
222
252
194
50
324
103
110
73
Burn Location
421
386
76
Max Clearing Index for Wednesday Jan 15

Discussion

Site selection and instrument placement

The kiln site MiniVol was initially placed about 10 meters from the kiln itself for the Monday afternoon burn operation. Having the sensor this close to the kiln resulted in by far the highest reading from a MiniVol of any of the six projects in this study, 38 µg/m^3 hourly average, over four hours. On Monday afternoon, the study team traveled to Monticello UT to get the E-samplers, therefore co-located continuous data is not available for that time period. That evening, the burn crew explained to the study team that the kiln would need to be moved around a little bit each day to shorten machine tracking time to the sources of burn material, and this would potentially impact the spot where the MiniVol was set up. For this reason and because there was a power outlet available for the continuous instruments about 200 meters away, the study team moved the MiniVol beginning Monday night to a location about 200 meters away from the kiln.

Topography can be an important piece of the puzzle in predicting and monitoring smoke flows from a burn site. While the Colorado River runs in a canyon with walls about 150 meters high, the river corridor itself has a tiny gradient- about a half meter per kilometer. One would expect smoke in the river corridor to be at the mercy of the local wind, which may not routinely be down-gradient. As mentioned in the weather section above, winds were light throughout the week.

Filter agreement with continuous

Due to a software problem the campground E-Sampler was not running until Tuesday night. This table shows results for those time periods which have co-located MiniVol and E-Sampler data:

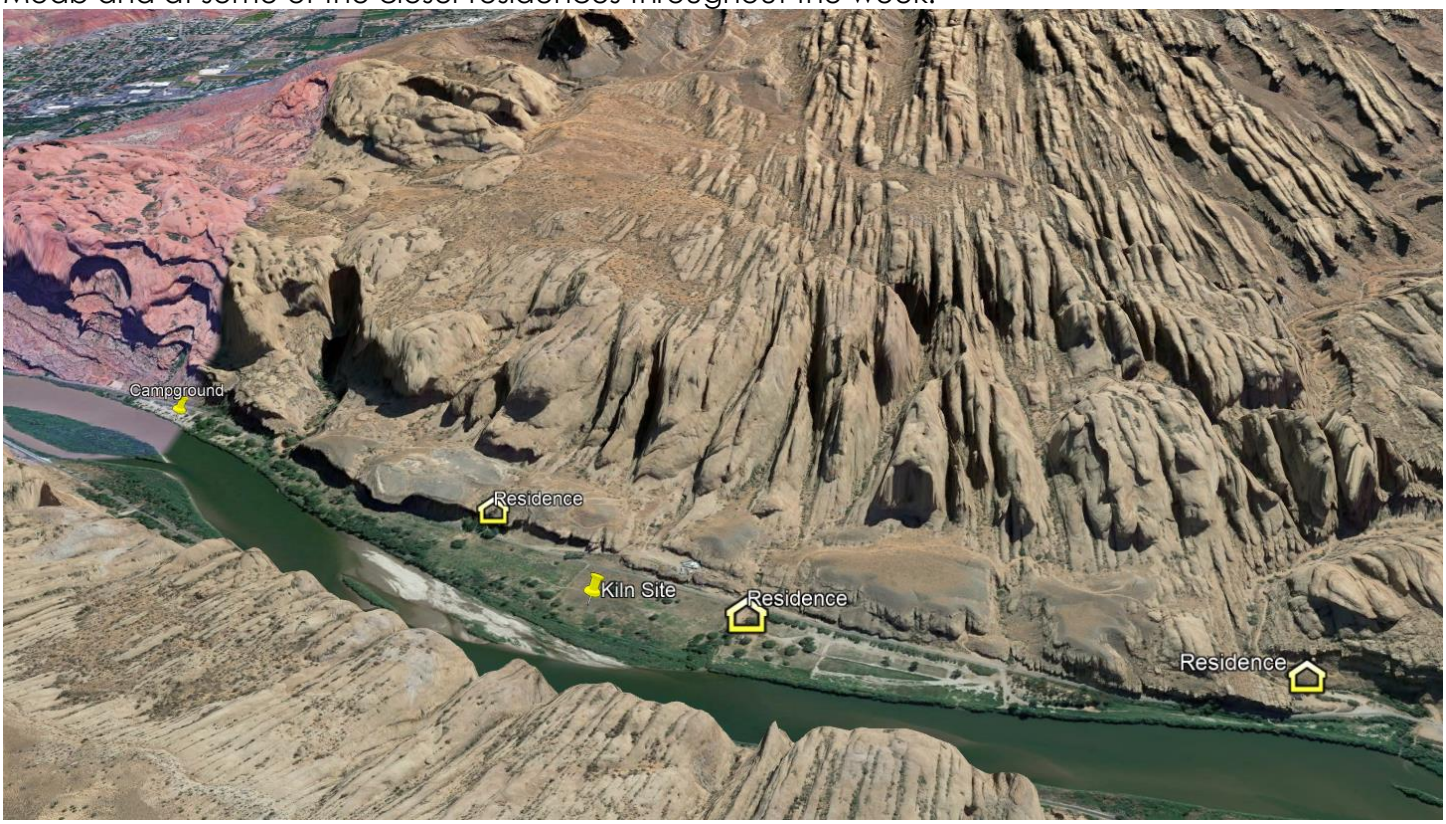
Location	Time Period	Burn period	Minivol Average µg/m^3	E-Sampler Average µg/m^3
Kiln Site	Monday Night	Post-burn	2.23	3.00
Kiln Site	Tuesday Day	Ignition	0.93	0.85
Kiln Site	Tuesday Night	Post-burn	1.29	2.92
Campground	Tuesday Night	Post-burn	0.70	1.92
Kiln Site	Wednesday Day	Ignition	3.01	6.28
Campground	Wednesday Day	Ignition	1.98	2.83

There are no glaring discrepancies. Some of the time periods agree quite closely. The Wednesday Kiln values are off by 3.27 µg/m^3 (3 µg/m^3 is the advertised precision of the E-Sampler).

Accuracy of model predictions

The Minivol runs for Wednesday night through Thursday were intended to capture background PM 2.5 values for the area. They were 2.4 µg/m^3 at the kiln site and 3.7 µg/m^3 at the campground. With the exception of Monday when monitoring the immediate vicinity of the kiln, the values were similar between day and night, and burn/non-burn periods. For this project, it appears the model prediction of little to no impact was accurate. With such a small volume of material being burned (100 piles over three days), the BlueSky tool is possibly too broad scale to confidently predict localized impacts.

Other particulate matter sources
Several residences and a paved road line the canyon corridor. Wood heating was used both in Moab and at some of the closer residences throughout the week.



View of the river corridor looking east back towards Moab

Takeaways

The traces from both continuous monitors appear to show climbing PM concentrations in the overnight and early morning hours on Wednesday. The higest continuous hourly averages were recorded Wednesday the 15th: at the campground at 0900 (6 µg/m^3) and at the Kiln Site at 1000 (10 µg/m^3). The data gathered seem insufficient to answer these questions: whether the higher overnight values include residual smoke off the kiln from the previous day, whether they are a result of ground-based radiation inversion trapping PM from other sources, whether they are a sampling error, or some combination of all of the above.

All monitoring at locations 200 meters or farther from the kiln itself showed modest impacts. Considering a background value of between 2.4 and 3.7 µg/m^3, the peak added PM measured by the filter and continuous instruments would be in the single digits at both sites. With the exception of the immediate vicinity of the biochar kiln, it appears that this precribed fire did not increase ambient PM concentrations beyond what could be considered acceptable.

Acknowledgements

Thanks go to the staff of the Utah Division of Forestry, Fire and State Lands Southeast Area office, including Grand County Fire Warden Bruce Jenkins for his help in troubleshooting, taking down, and storing equipment. Thanks also to USU Forestry Extension Professor Daren McAvoy, and to the Lone Peak Engine Crew for making this biochar demonstration site available as a smoke study project.

DEVIL CANYON

BUREAU OF LAND MANAGEMENT

CANYON COUNTRY DISTRICT, MONTICELLO FIELD OFFICE

37.71 N
109.39 W
2060 m / 6750 ft

SUMMARY

Pile burn between Monticello and Blanding, east of Highway 191. The entire Unit 3 of the project was burned. 425 acres with 2000+ brush piles made of Pinyon and Juniper. Burn days Jan 30, 31, and Feb 1, 2020.

EQUIPMENT

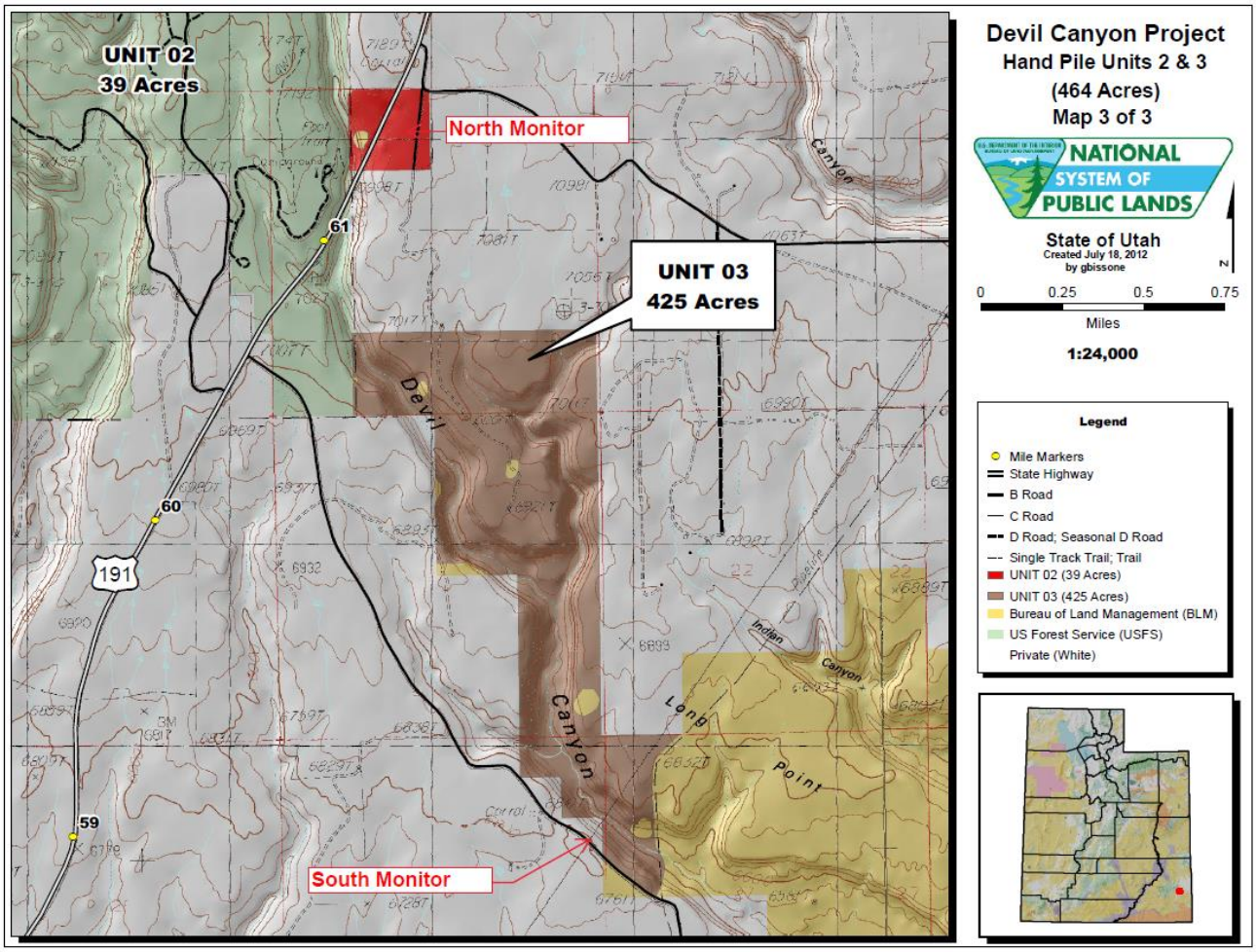
South: E-Sampler, MiniVol
North: E-Sampler, MiniVol

DESIGN

The study team visited the site on October 24, 2019 to select monitoring locations. One site on the south and one on the north side of Devil Canyon were chosen. Initially the team wanted to place equipment in the canyon bottom and a site to the east of the project as well, but with snow expected on the roads during implementation those options were abandoned.

EVENTS

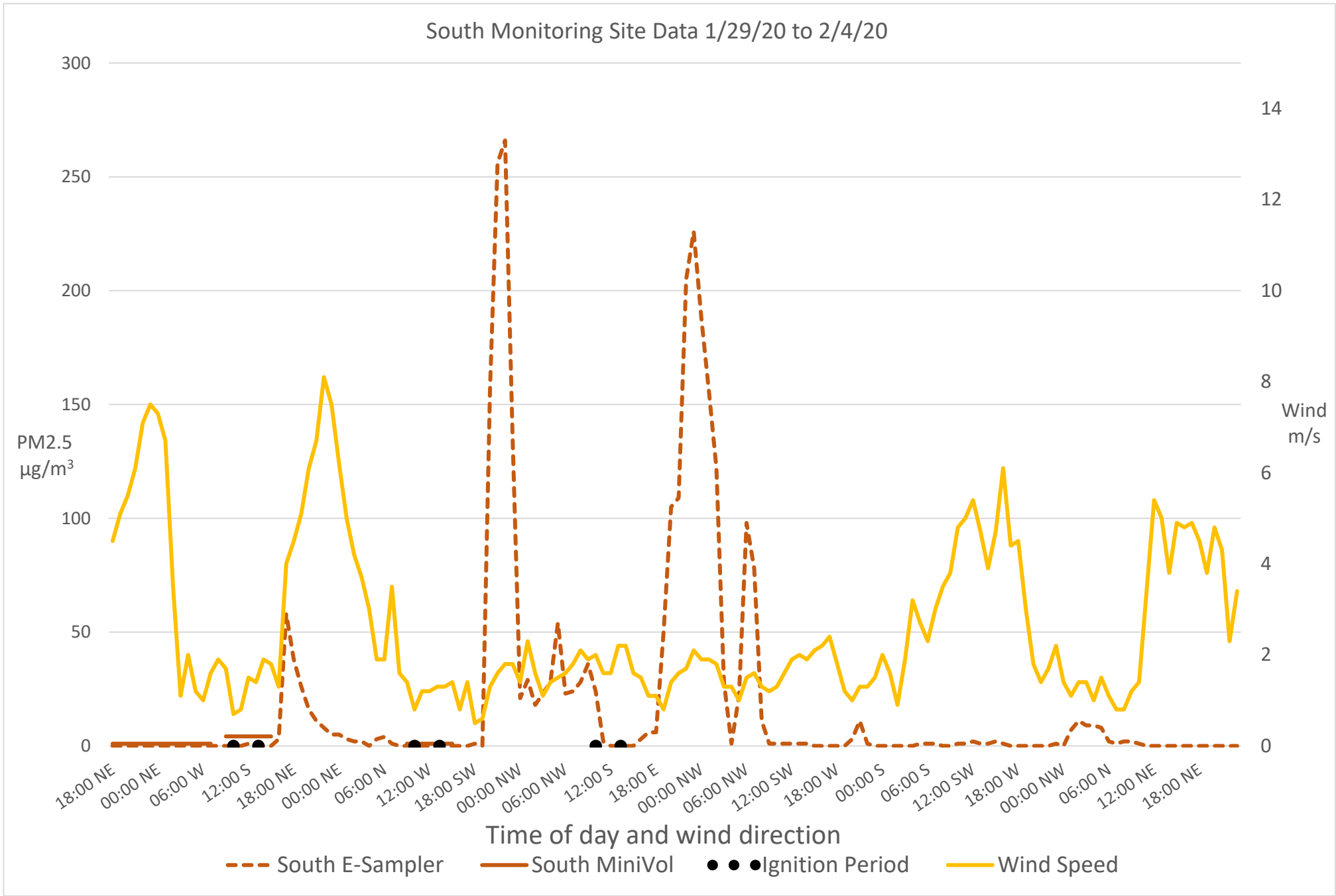
Each day ignition occurred between the hours of 1000 and 1600. The three days the burn was conducted had maximum clearing index values of 470, 220, and 100. Monitoring equipment remained in place for one week following completion of the project.

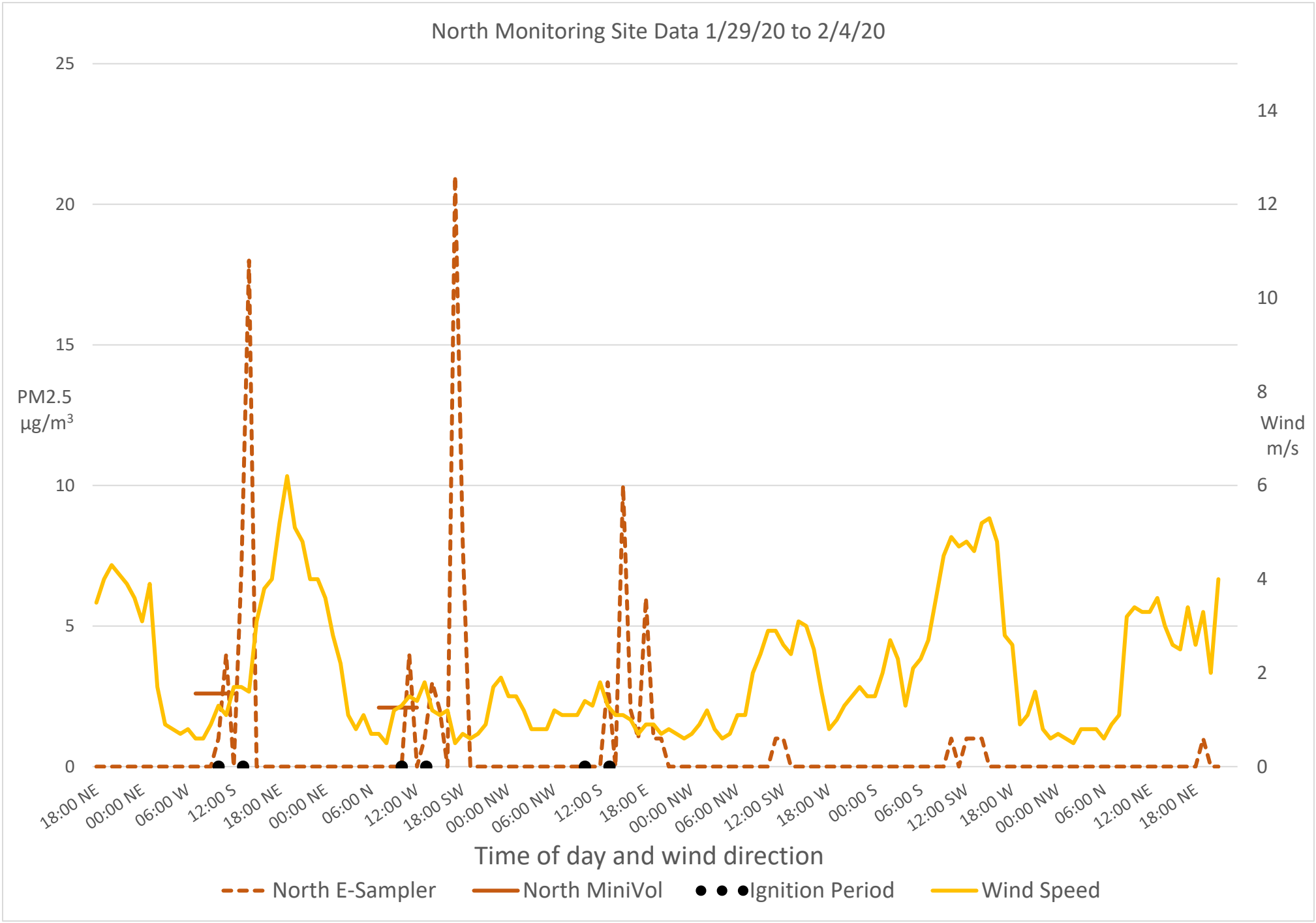


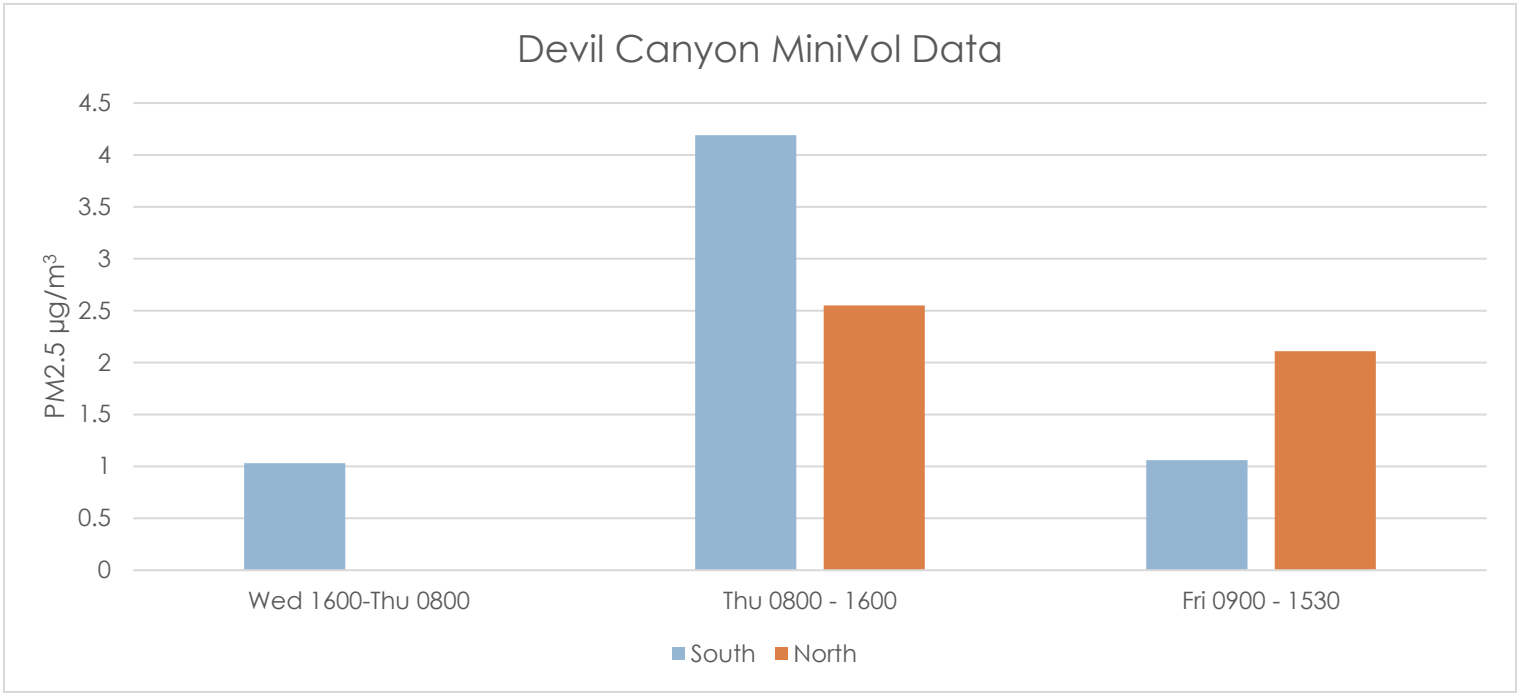
The South monitoring site, looking west towards the burn unit and the Abajo Mountains, Jan 30 2020, 1622 hours.

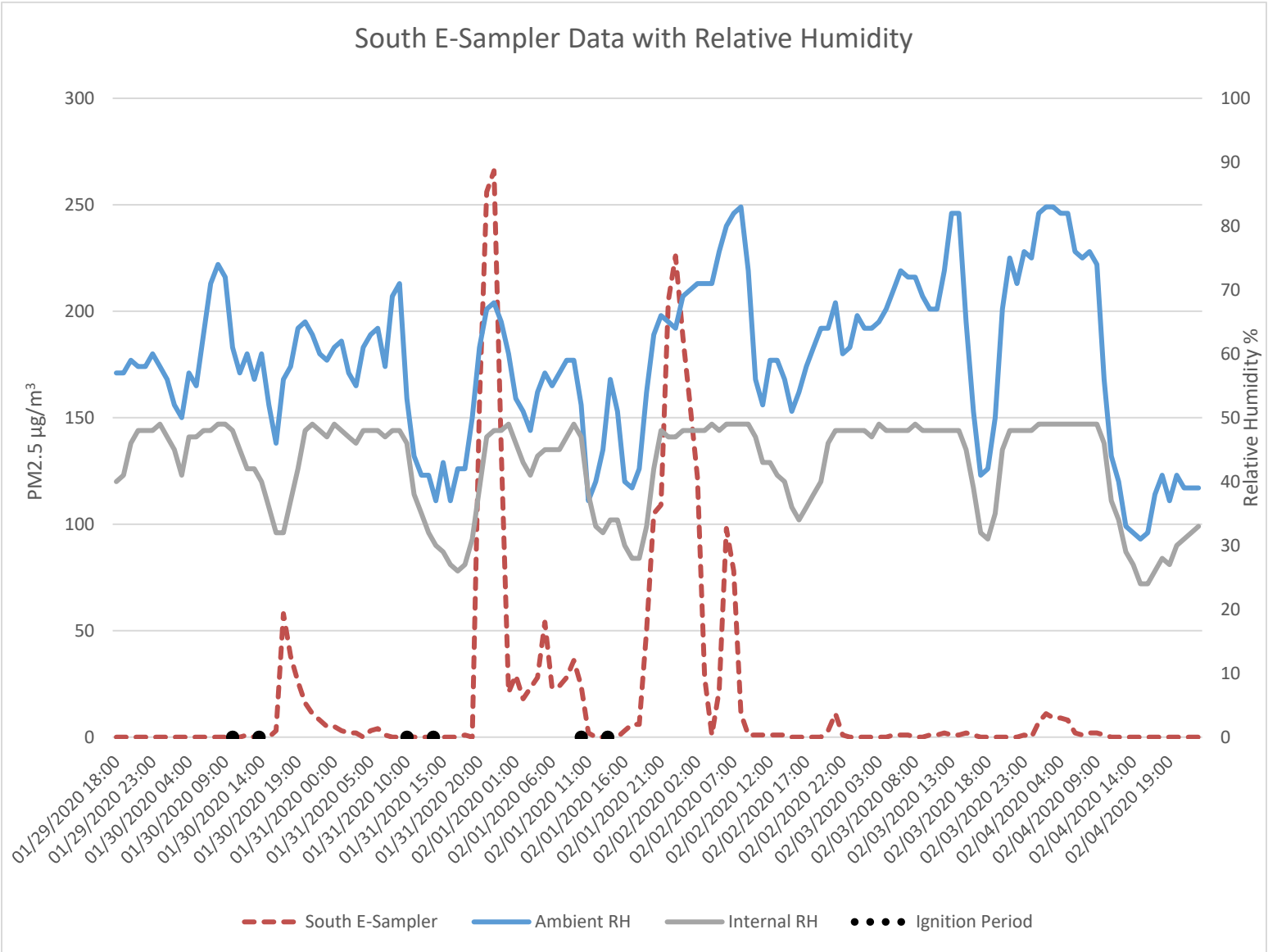
Looking towards the project from the North monitoring site on the afternoon of 1-31-2020, Four Corners in the background.

Piles in various states of consumption, Jan 30 2020, 1130 hours

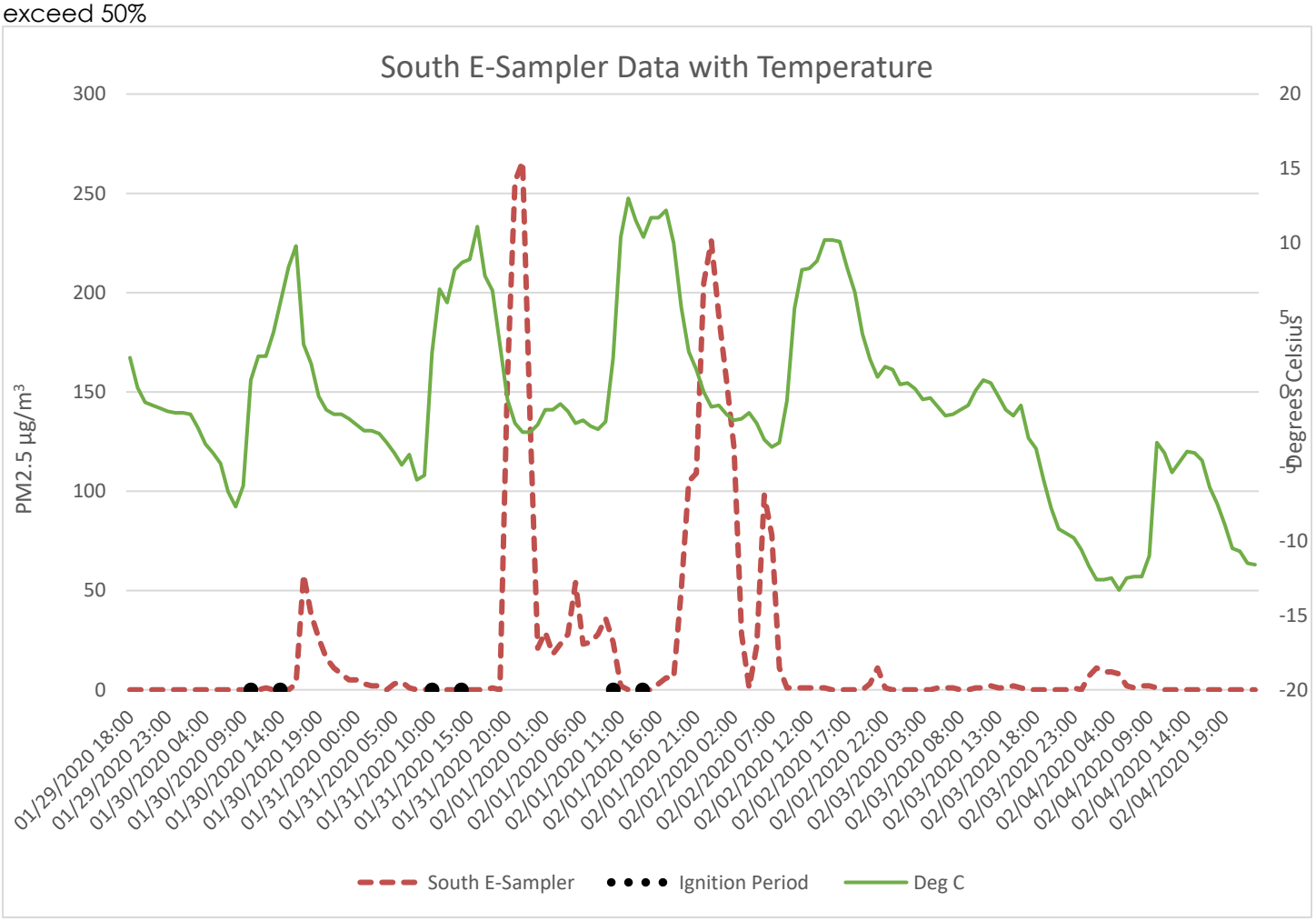

South Monitoring Site Data 1/29/20 to 2/4/20
300
250
200
150
100
50
0
PM2.5
µg/m³
14
12
10
8
6
4
2
0
Wind
m/s
18:00 NE
00:00 NE
06:00 W
12:00 S
18:00 NE
00:00 NE
06:00 N
12:00 W
18:00 SW
00:00 NW
06:00 NW
12:00 S
18:00 E
00:00 NW
06:00 NW
12:00 SW
18:00 W
00:00 S
06:00 S
12:00 SW
18:00 W
00:00 NW
06:00 N
12:00 NE
18:00 NE
Time of day and wind direction
South E-Sampler
South MiniVol
Ignition Period
Wind Speed

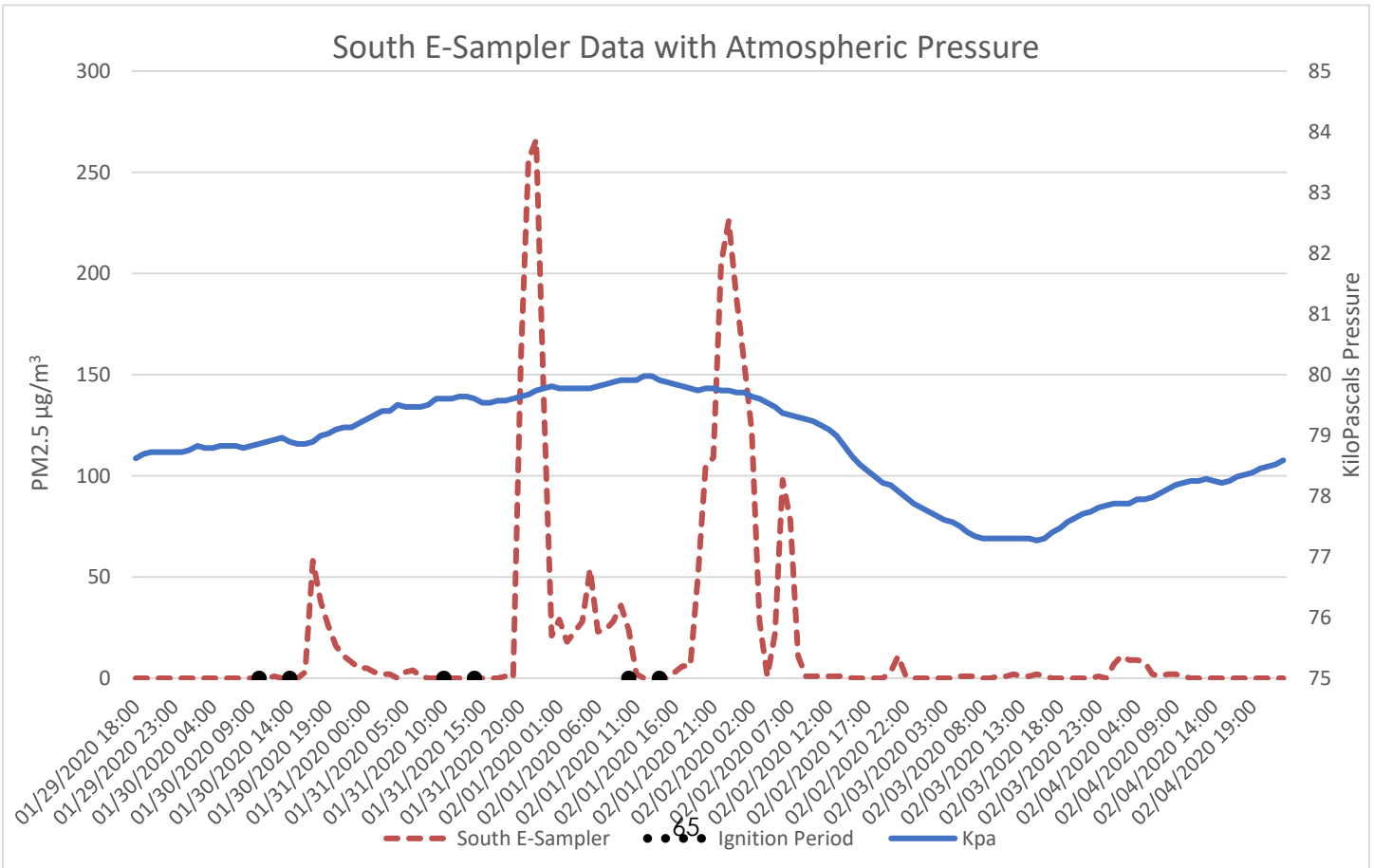

North Monitoring Site Data 1/29/20 to 2/4/20
25
20
15
10
5
0
PM2.5
µg/m3
14
12
10
8
6
4
2
0
Wind
m/s
18:00 NE
00:00 NE
06:00 W
12:00 S
18:00 NE
00:00 NE
06:00 N
12:00 W
18:00 SW
00:00 NW
06:00 NW
12:00 S
18:00 E
00:00 NW
06:00 NW
12:00 SW
18:00 W
00:00 S
06:00 S
12:00 SW
18:00 W
00:00 NW
06:00 N
12:00 NE
18:00 NE
Time of day and wind direction
North E-Sampler
North MiniVol
Ignition Period
Wind Speed


Devil Canyon MiniVol Data
PM2.5 µg/m³
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Wed 1600-Thu 0800
Thu 0800 - 1600
Fri 0900 - 1530
South
North

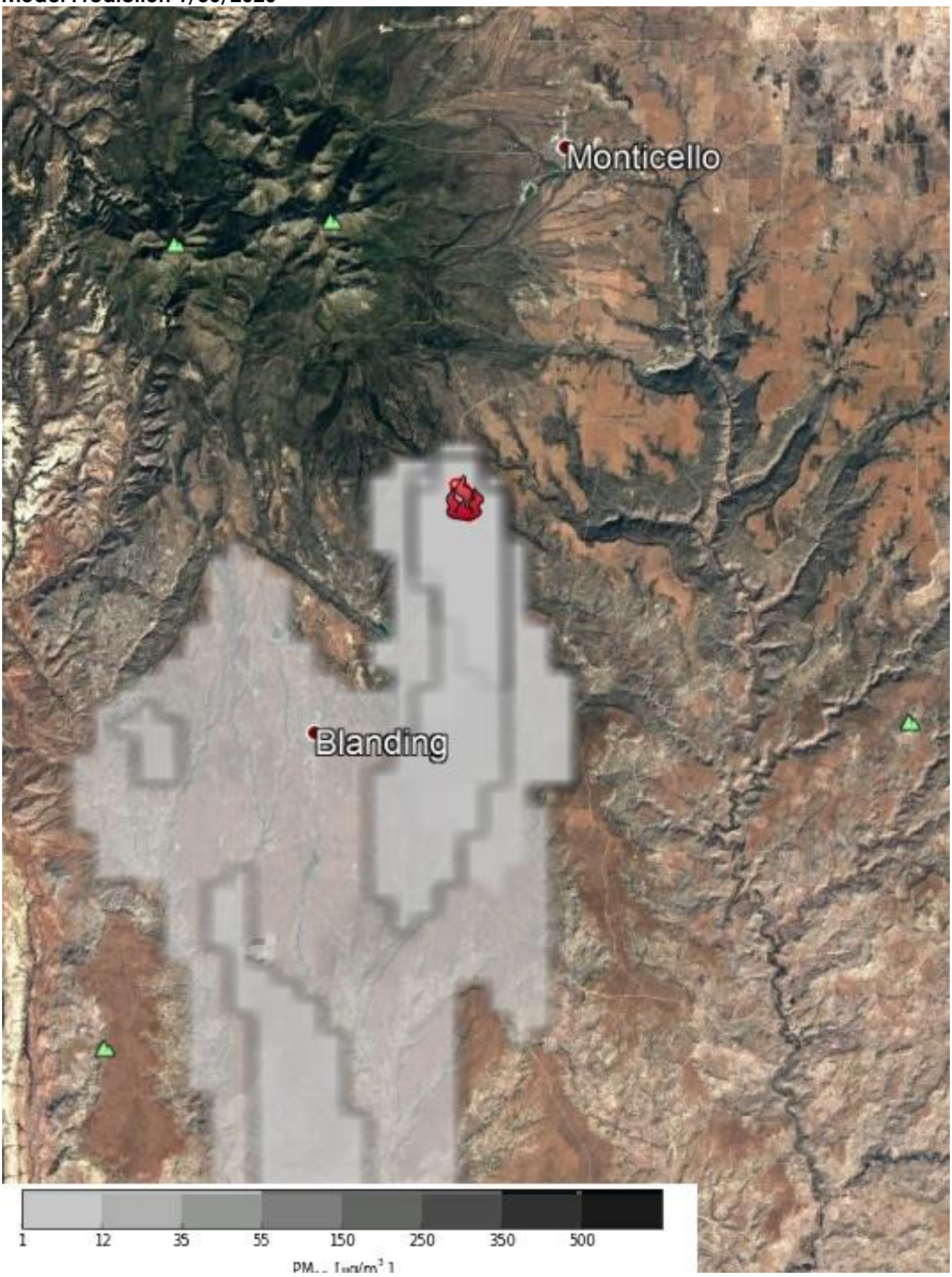

South E-Sampler Data with Relative Humidity
PM2.5 µg/m³
Relative Humidity %
300
250
200
150
100
50
0
100
90
80
70
60
50
40
30
20
10
0
01/29/2020 18:00
01/29/2020 23:00
01/30/2020 04:00
01/30/2020 09:00
01/30/2020 14:00
01/30/2020 19:00
01/31/2020 00:00
01/31/2020 05:00
01/31/2020 10:00
01/31/2020 15:00
01/31/2020 20:00
02/01/2020 01:00
02/01/2020 06:00
02/01/2020 11:00
02/01/2020 16:00
02/01/2020 21:00
02/02/2020 02:00
02/02/2020 07:00
02/02/2020 12:00
02/02/2020 17:00
02/02/2020 22:00
02/03/2020 03:00
02/03/2020 08:00
02/03/2020 13:00
02/03/2020 18:00
02/03/2020 23:00
02/04/2020 04:00
02/04/2020 09:00
02/04/2020 14:00
02/04/2020 19:00
South E-Sampler
Ambient RH
Internal RH
Ignition Period

The E-Samplers have an air inlet heater which appeared to function properly and limit internal RH to not exceed 50%



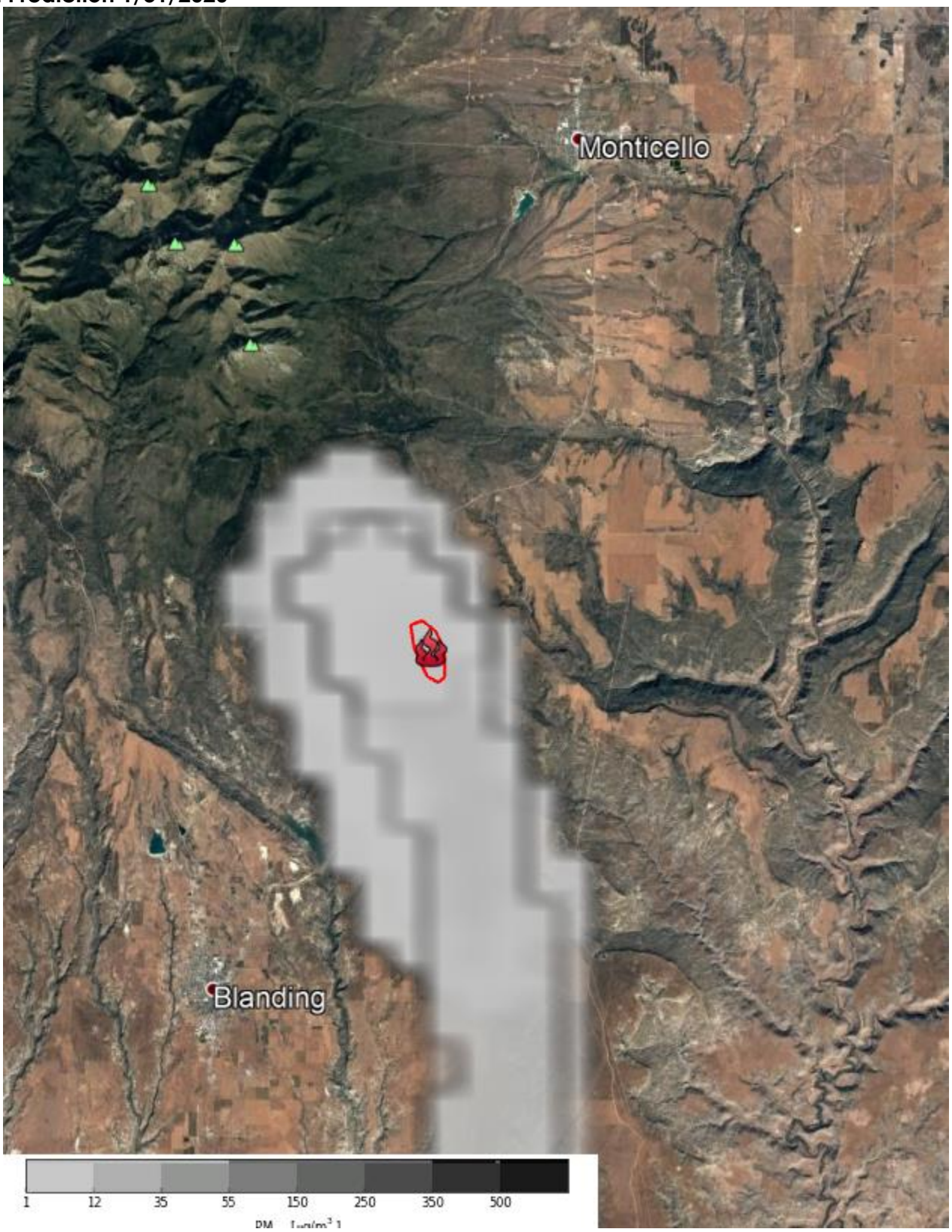


Model Prediction 1/30/2020



Smoke predicted to travel directly south from the fire on Jan 30, with highest impact in the range of 12-35 micrograms.

Model Prediction 1/31/2020



Smoke dispersion prediction trended a little more to the SSE on Jan 31, still 12-35 microgram maximum impacts.

Model Prediction 2/1/2020

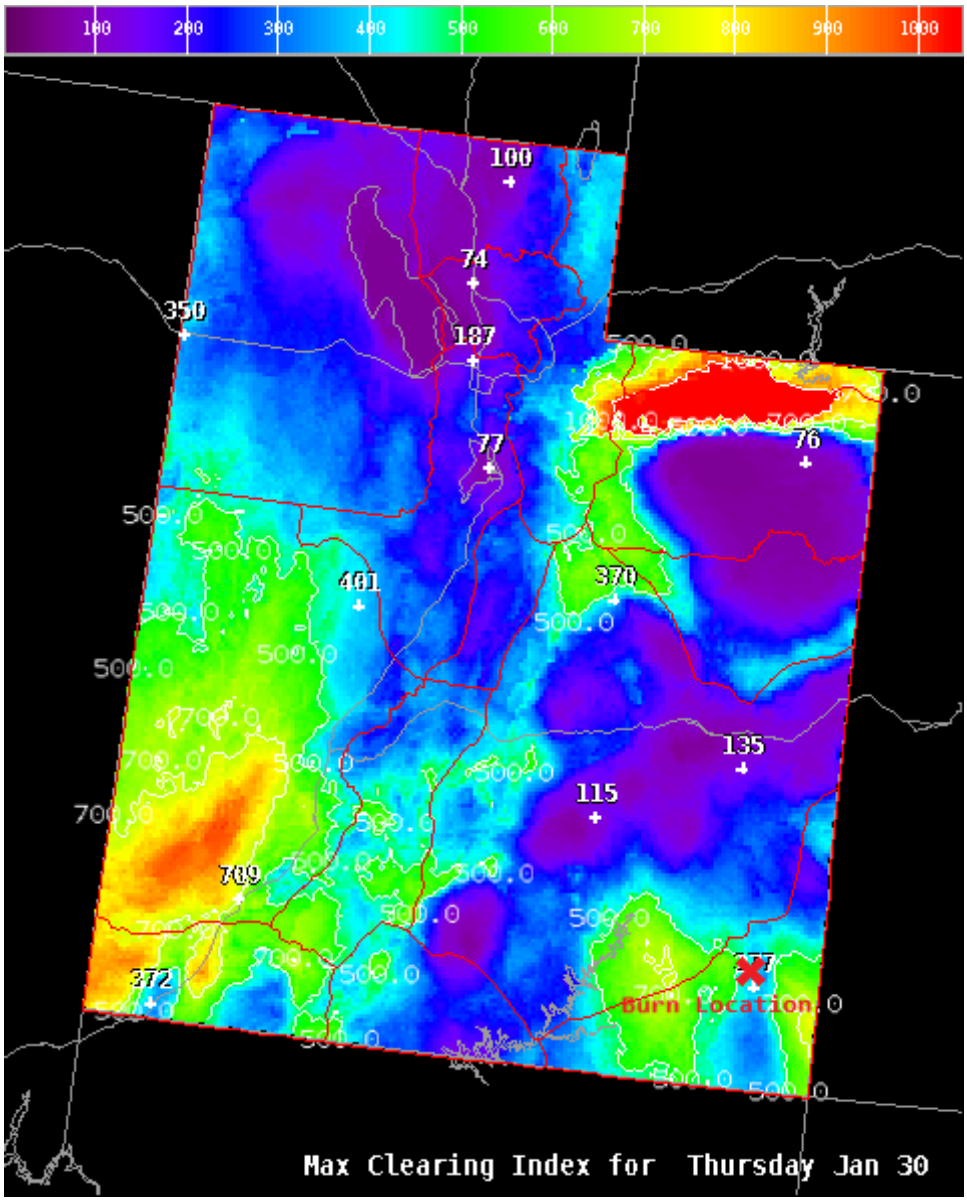
The Feb 1 run predicts similar levels of impact as the previous two days

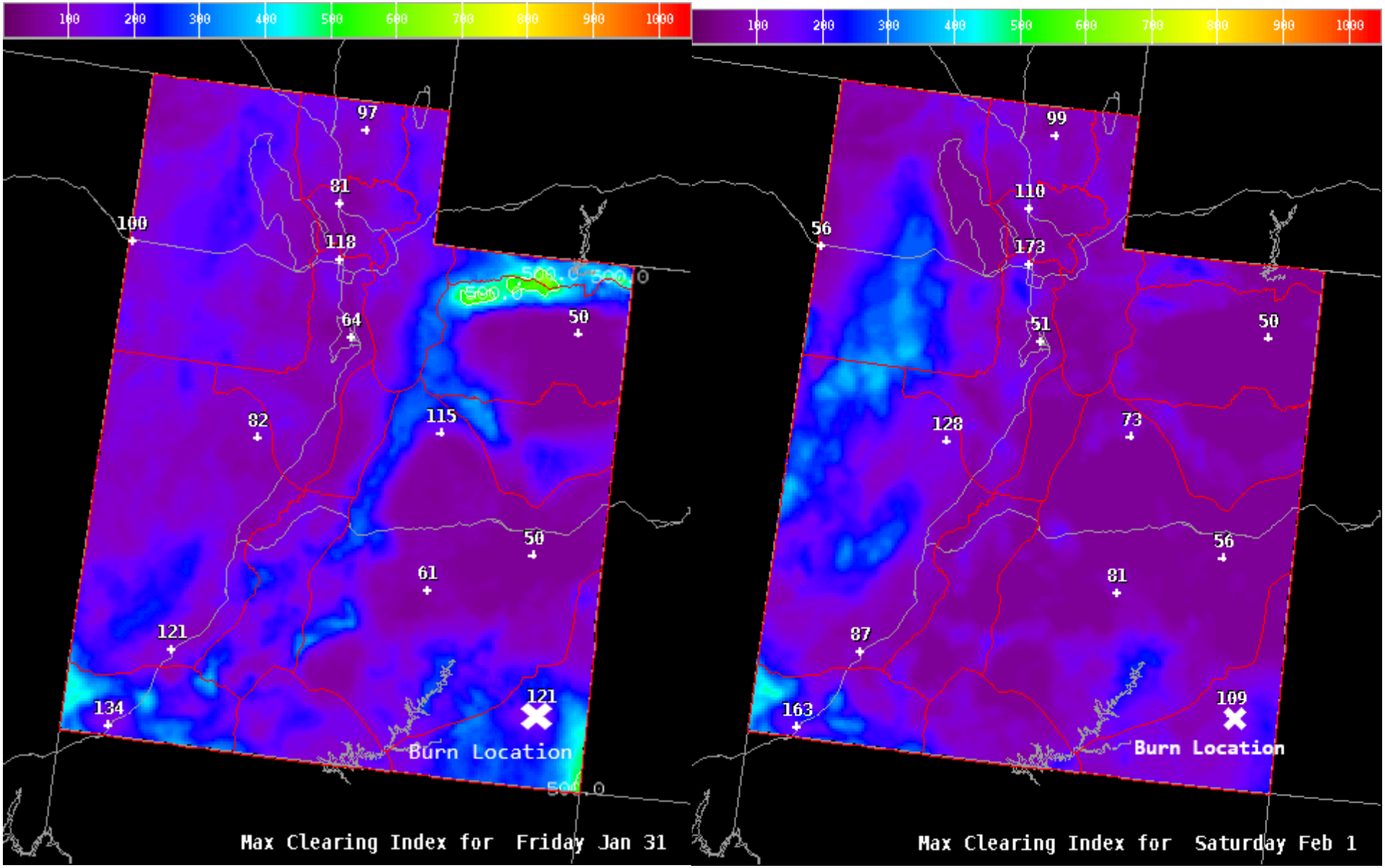
Weather

A light northwest flow was in place over the three days of this burn project, with a high moving into California on Friday night. There were a few high clouds on Thursday, but mostly clear skies on Friday and Saturday. Temperatures ranged from -12 to +12 degrees Celsius, close to average for the time of year.

Date	Max Clearing Index From Spot Forecast	Max Clearing Index for Airshed 15 (m)	Mixing Height Airshed 15 (m)	Transport Wind Airshed 15 (m/s)
1/30/2020	430	470	2800	N6
1/31/2020	220	240	2590	NW4
2/1/2020	100	120	2380	NW3

One defining feature of the Monticello Upland portion of the Colorado Plateau is wind. However the three days of burn activity on this project were characterized by decreasing mixing heights and weakening transport winds. The hourly average surface wind speed at the South monitor was 2.2 m/s (5.1 mph) or less for a surprising 57 straight hours from Jan 31 to Feb 2. This held true for 55 straight hours at the North monitor over a similar time period, and observations from permanent weather stations agree that it was a calm few days.

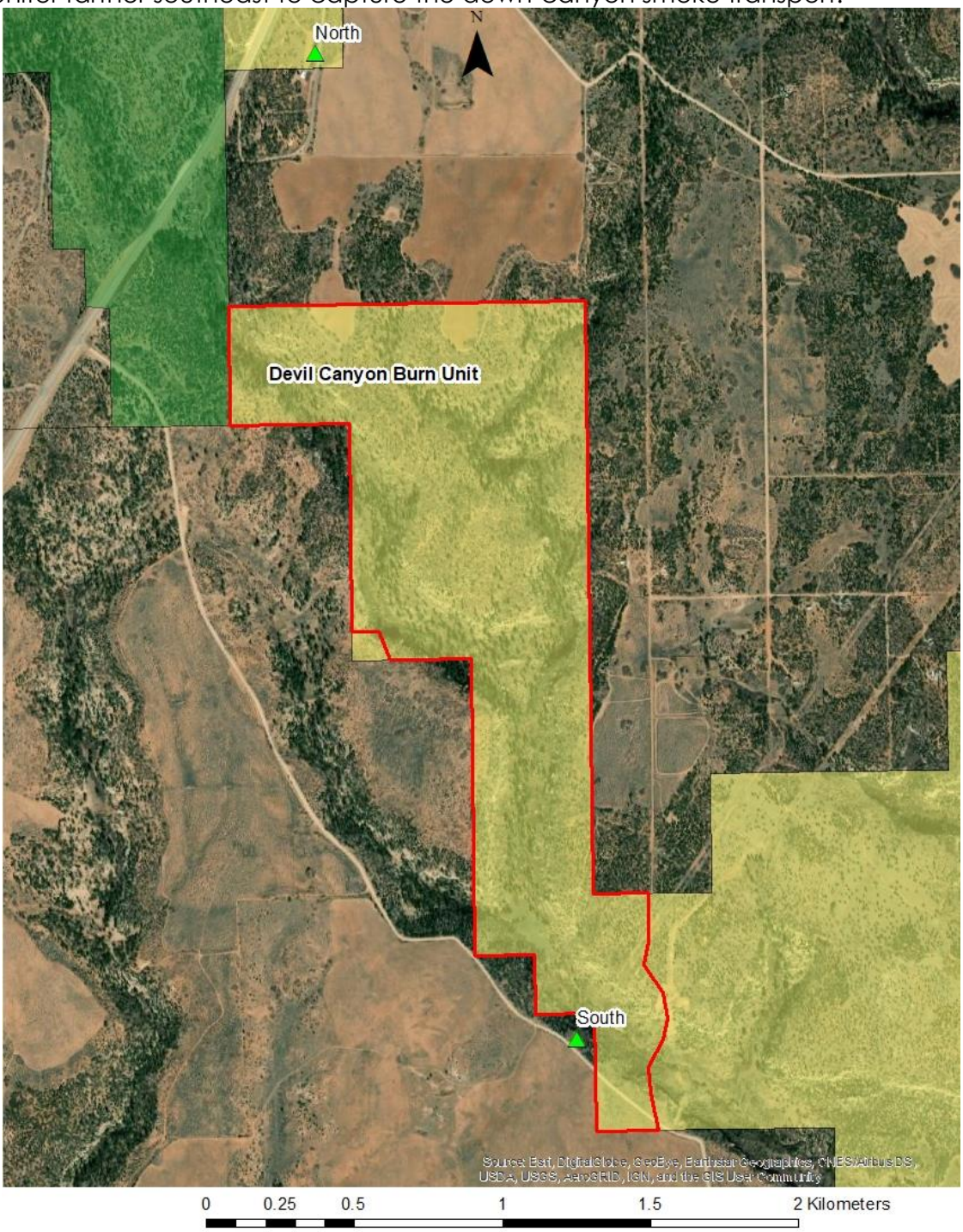



100 200 300 400 500 600 700 800 900 1000
97
81
100
118
64
50
82
115
50
61
121
134
121
Burn Location
Max Clearing Index for Friday Jan 31
100 200 300 400 500 600 700 800 900 1000
99
110
56
173
51
50
128
73
56
81
87
163
109
Burn Location
Max Clearing Index for Saturday Feb 1

Discussion

Site selection / instrument placement

The upper reaches of Devil Canyon are managed by the BLM, but all land on the bench surrounding the canyon is privately owned. The piles were fairly evenly distributed across the 425 acre burn unit. As with all the projects, monitor placement was dictated by the physical site, which did not allow for much separation from the burn unit itself on the south side. The South monitor was located nearly adjacent to the burn unit, within 100 meters of at least a dozen brush piles that were burned. The North monitor was about 800 meters from the boundary of the burn unit and the closest piles. The only access to the canyon bottom was on foot through deep snow, so plans were abandoned to place a monitor farther southeast to capture the down-canyon smoke transport.



BLM managed land is shaded yellow, US Forest Service is green, all else is private property.

Filter agreement with continuous monitors

Filters were in short supply at the time of this project. With only five available, the study team decided to set one to run Wednesday night to assess the background PM2.5 value, and one at each location both Thursday and Friday during the burn period. As at Alpine Acres, these time periods did not overlap with any of the high spikes recorded later on the continuous instruments, which would have been interesting to corroborate with a filter.

Location	Time Period	Minivol Average µg/m^3	E-Sampler Average µg/m^3
South	Wednesday Night	1.03	0.00
South	Thursday Day	4.19	0.50
North	Thursday Day	2.55	3.75
South	Friday Day	1.06	0.13
North	Friday Day	2.11	0.63

Four out of five measurements are within the E-Sampler margin of error of 3 µg/m^3. Because all the concentrations are low, any discrepancy is probably not significant. It is noteworthy that data reported by the E-sampler, which has not been calibrated to the sampled aerosol, is uncorrected and absolute readings may therefore be biased. The relative change in concentrations is, however, representative of true conditions.

Other particulate matter sources

The North monitoring site is about 180 meters off US Highway 191. Traffic volume on US 191 is modest in midwinter, not likely to exceed 1000 vehicles/day. The road running on the south side of Devil Canyon is a well graded dirt/gravel road, and the south monitor site was only 15 meters off that road. Due to wintertime moist/frozen/muddy conditions, it is not expected that dust off the road generated any significant amount of PM2.5 at the south monitor. Vehicle traffic on this gravel road is fairly light, not likely more than a few hundred vehicles a day. Considering the extremely low background PM values gathered on days both before and after the burn event, and that no unusual PM source is known to have been present on the burn days, it seems safe to assume a background value of one or two µg/m^3, and that PM detected above that value was caused by smoke from the burn.

Accuracy of model predictions

Without a suite of devices at multiple distances from the project site, it is difficult to fully characterize the accuracy of model predictions. The Devil Canyon project highlights a difficult aspect of the entire study; placing monitors close to a prescribed fire can give alarmingly high levels. Here are the E-Sampler PM2.5 24-hour average concentrations in µg/m^3 for the duration that monitors were set up:

Date	South	North
1/30/2020	6.9	1.3
1/31/2020	34.8	1.6
2/1/2020	42.5	1.0
2/2/2020	30.2	0.1
2/3/2020	0.5	0.2
2/4/2020	2.1	0.0
2/5/2020	0.0	0.0
2/6/2020	0.3	0.0
2/7/2020	0.0	0.0
2/8/2020	0.2	0.0
2/9/2020	0.1	0.0
2/10/2020	0.0	0.0

The model predicted the direction of smoke travel would be to the south of the burn site, this was definitely borne out by the two monitoring stations. The level of impact predicted by BlueSky was less than 35 µg/m^3 on each calendar day. While that was exceeded on 2/1 at the South site, this site is immediately adjacent to the burn unit, and it seems likely that the concentration did drop off rapidly

with greater distance from the smoke source. Also, the reported concentrations have not been adjusted to the measured aerosol.

High values

As at Alpine Acres, a difficult question for the study team to answer is: are the extremely high hourly readings from the south E-Sampler on the early mornings of Feb 1 and 2 accurate? Unfortunately there was no corroborating filter-based instrument running during those hours. No complaints were received from the public, but no one from the local office or study team was out at those hours of the day to take qualitative observations.

Looking at the possible influence of pressure, temperature and relative humidity, there is no evidence to suggest that any of these factors resulted in erroneous readings. The E-Sampler at the South Site (number 457) was also set up at the DAQ tech center and considered to have decent agreement with other instruments there. An E-sampler is a light scattering instrument and therefore needs to be calibrated to the sampled aerosol. Calibration is largely dependent on aerosol type. Agreement at Tech center may not necessarily reflect agreement under field conditions. Absolute concentrations may very likely be biased but the change in concentrations (trend) is accurate. Temperature inversions formed in the area every night, and those inversions broke up every day, at approximately the same time the PM concentration dropped. E-Sampler 457 was the same instrument that showed high values at the Alpine Acres project site, under similar circumstances.

Takeaways

The model prediction was accurate in terms of the direction of smoke travel, and that was true even though this project occurred during a time of low wind speeds and decreasing dispersion.

Siting a monitor immediately adjacent to a burn project is not ideal when trying to gauge impacts to communities, unless a community is also immediately adjacent. The study team did inquire about the closest landowners and occupied homes but did not find one in the nearby community where a monitor could be sited.

While Devil Canyon is a spectacular location, the distance and time involved with getting there raised some challenges. For example, even if more filters had become available, they would likely be in Salt Lake City, there is in fact no closer Utah PM monitoring station to Monticello. Also the long trip made it difficult to arrive early to collect a background value. Fortunately specialized parts and services were not needed on this project, but in the future there is less risk in a minor problem resulting in missing data if the site is a little closer to the study team, and/or a major community.

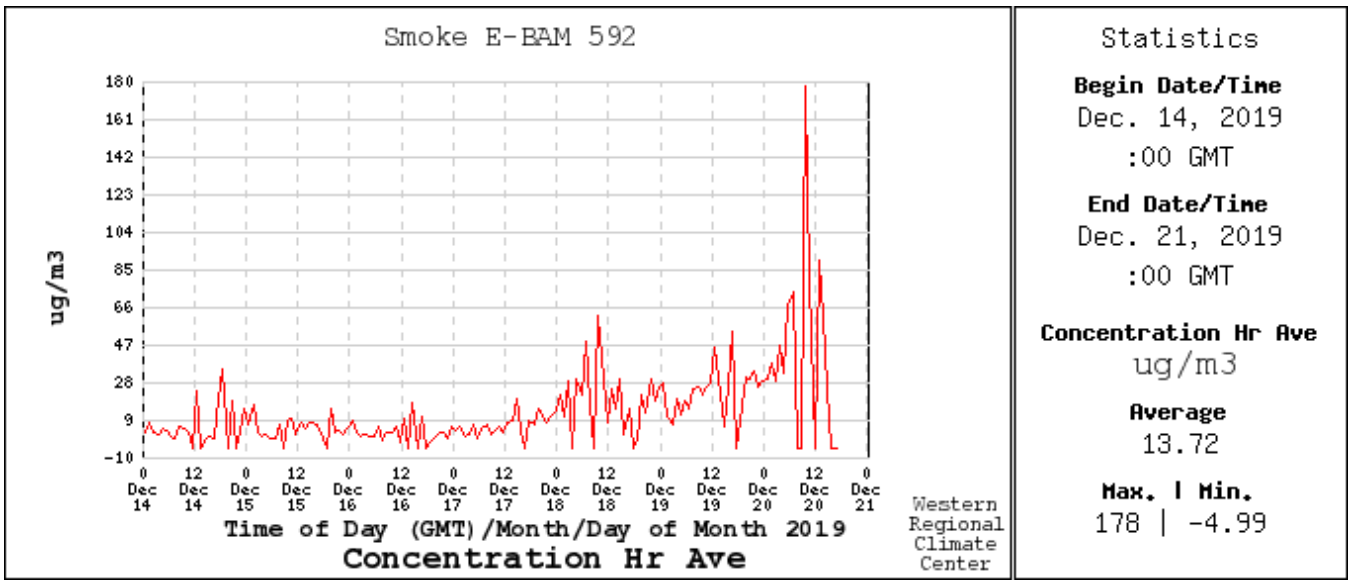
Acknowledgements

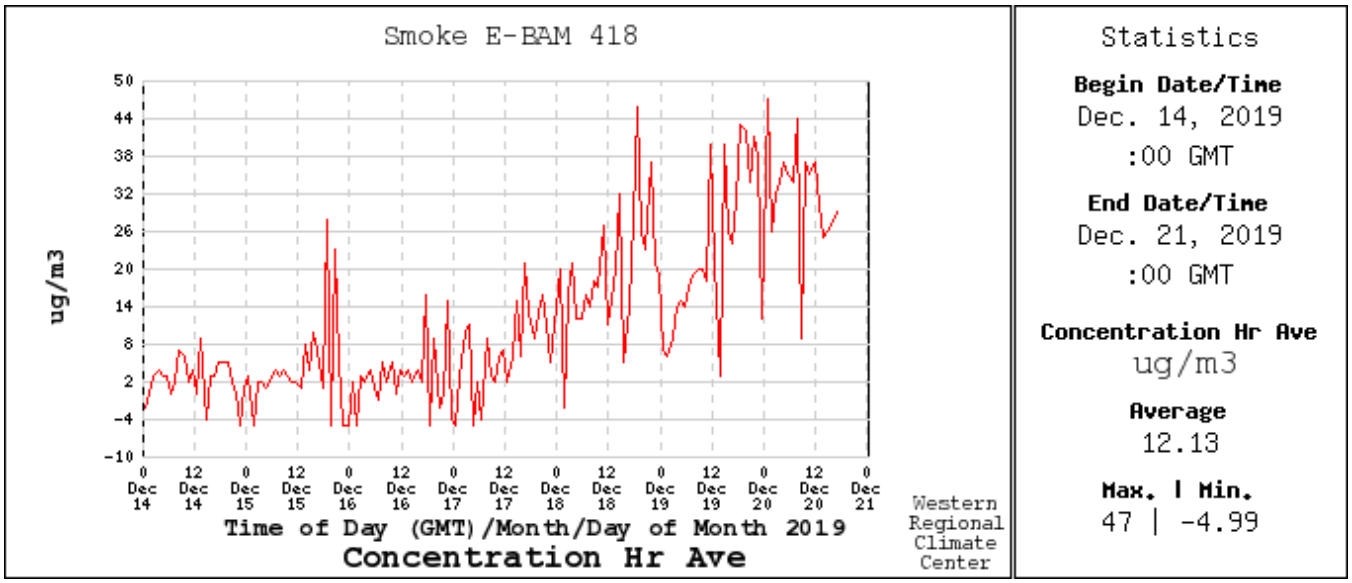
Much thanks goes to Paul Plemons, the local BLM prescribed fire specialist, who was critical in setting up, troubleshooting, maintaining, securing, taking down, and storing the equipment used. Thanks to the USFS Region 4 and Utah DAQ for making funds available in their travel budgets to allow the study team to spend several nights in Grand and San Juan counties.

INSTRUMENTS

Met One E-BAM

Two E-BAMs were on loan to the study from the US Forest Service air monitor cache in Lakewood, CO. These are beta-attenuation instruments that should be calibrated to local temperature and pressure, but the data does not need a correction factor. Transported in three large cases, each E-BAM setup weighs about 45kg (plus solar panel/battery if using off-grid). The E-BAM pump must run at a very specific flow rate, determined by the PM2.5 cyclone, for these instruments that was 16.67 liters per minute. After setting them up on the Blacksmith Fork project, the team noticed the signal was extremely noisy, with some of the highest hourly readings being followed immediately the next hour by negative PM2.5 concentration values. The team set up both instruments at the DAQ tech center in Salt Lake City and compared them with the continuous monitor located nearby at Rose Park, a Thermo 5030i SHARP.

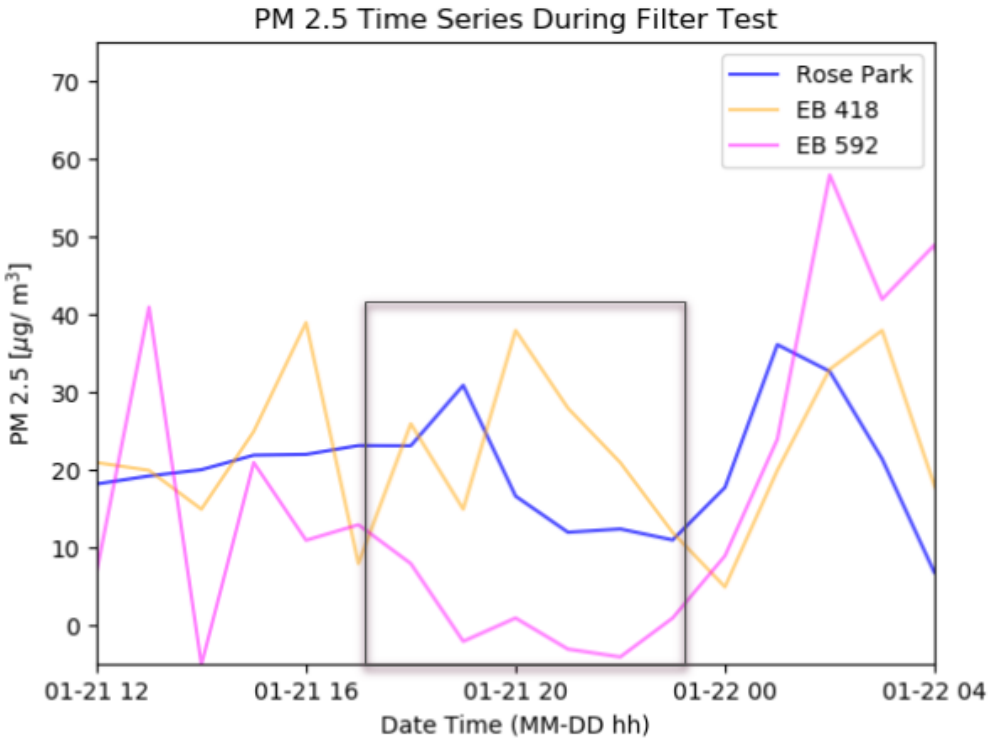




These two traces from an inversion episode in December show the noisiness of the EBAMs.

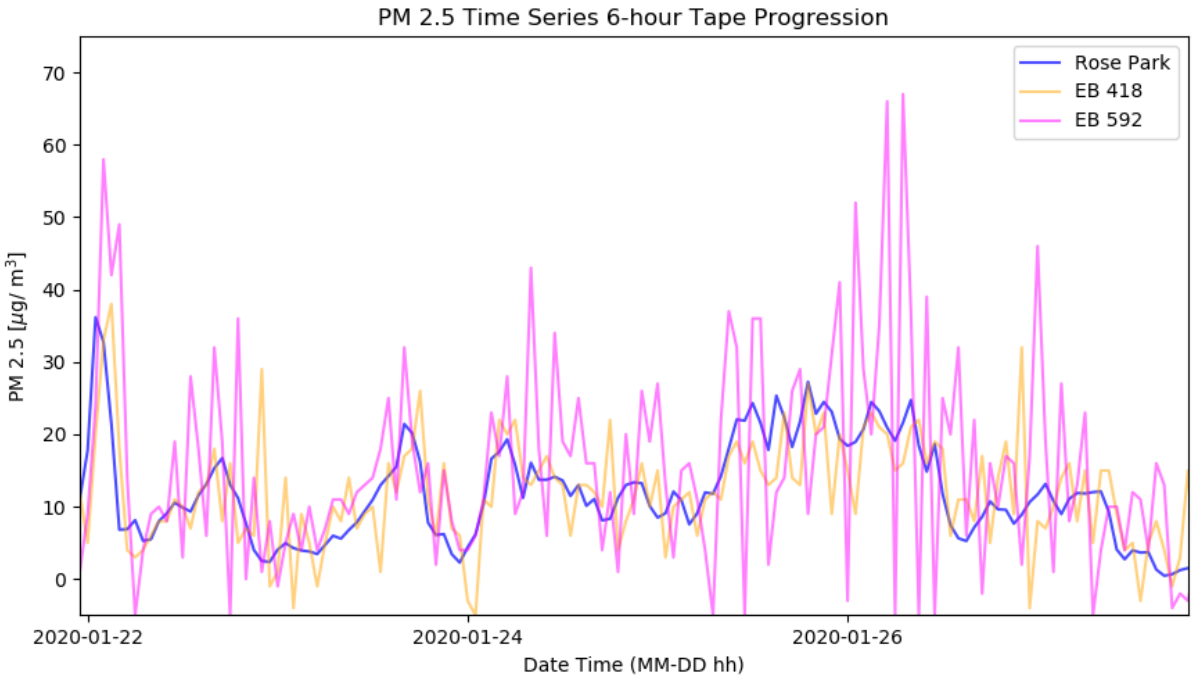
Filter Test

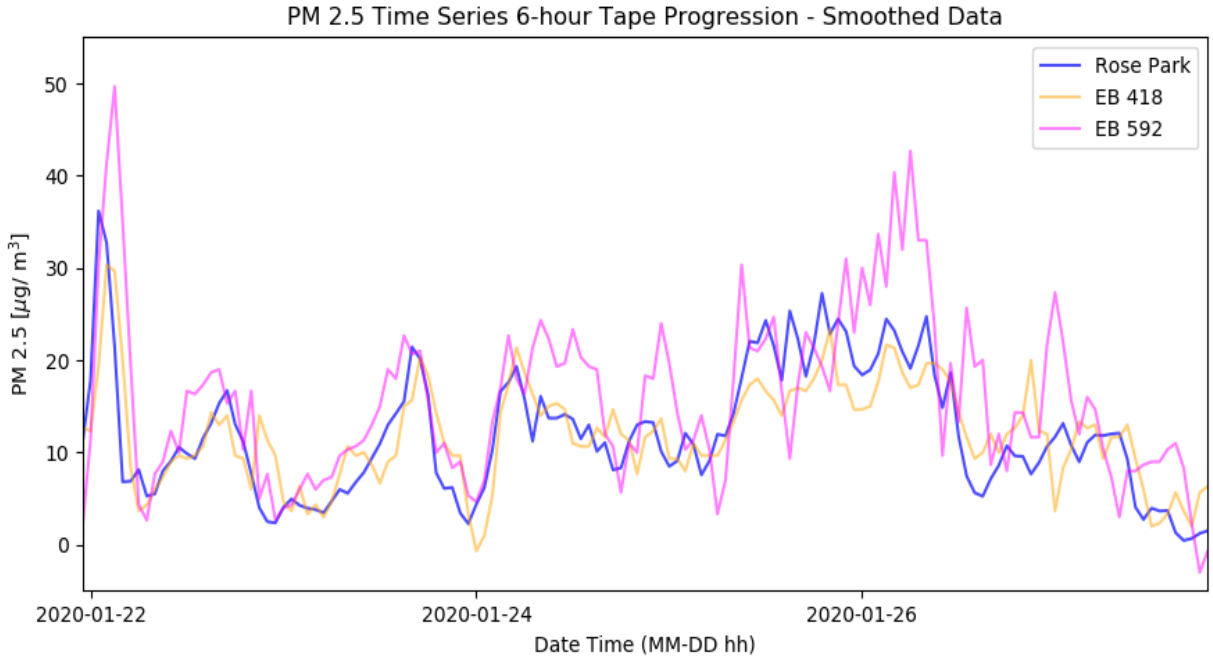
- HEPA filter on EBAM 592 from 1-21 at 16:00 UTC until 23:00 the same day.
- Definitely less noisy, though there might be some breakthrough of the filter. The average for the filter time period is 3.1 ug/m3, with a range of 13 at the beginning to -3.99.
- The mean was 24.3 for EBAM 418 and 18.8 at Rose Park for the same time period



The team conducted a HEPA filter test on one of the EBAMs. This should have the effect of blocking all PM2.5. In fact, the HEPA filter quieted the instrument, but not quite to zero as would be expected.

The team also tried reducing the tape progression time period from every 24 hours to every six hours. There is a cost associated with this as a replacement roll of tape is about $100. Ordinarily a 24-hour tape advance would last several months, but if the time period is shortened to every six hours or less, replacement tape would be needed that much more often.



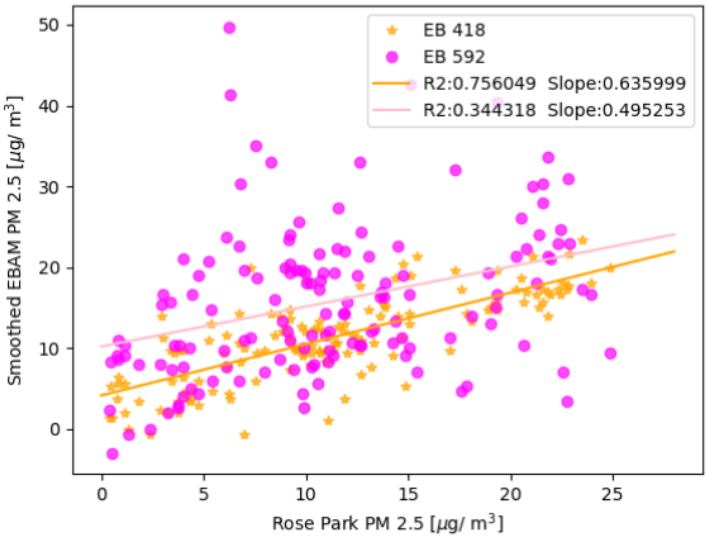


The lower plot is the same data as the upper plot after applying a three hour rolling average to the two E-BAMs for data smoothing.

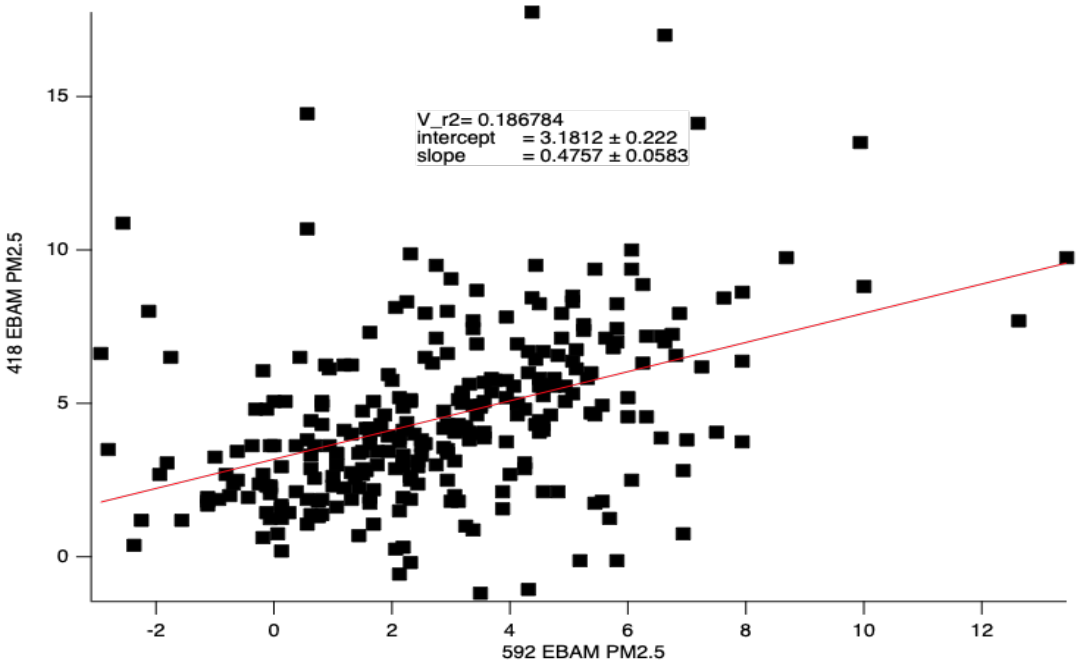
Correlation plots

Correlation of EBAMs and Rose Park during same time period. Smoothed with 3-hour rolling average for all data.

EBAM 418 (orange) is about 40% lower than Rose Park.



Even after smoothing, the correlation between the E-BAMS and the Rose Park Thermo 5030i SHARP was not as good as the team hoped. Additionally, smoothing the data undermines one purpose of the study, namely, understanding hourly fluctuations in smoke concentrations. The team only used the E-BAMs at Blacksmith Fork and at one site on the Providence Biochar project. The team feels this E-BAM model is not well suited for studies that require high temporal resolution.

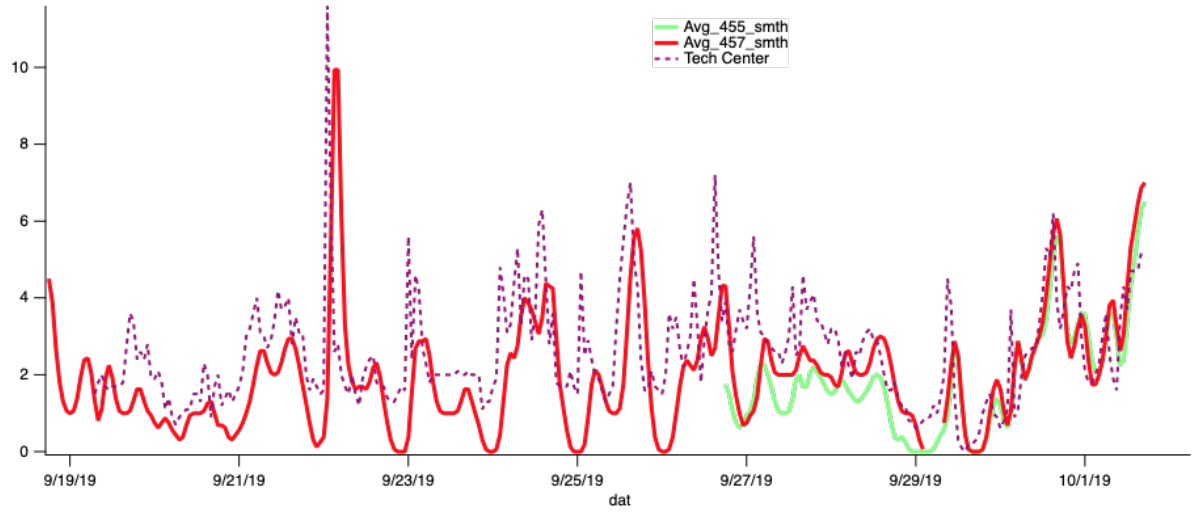


E-BAM to E-BAM correlation was also poor in this test

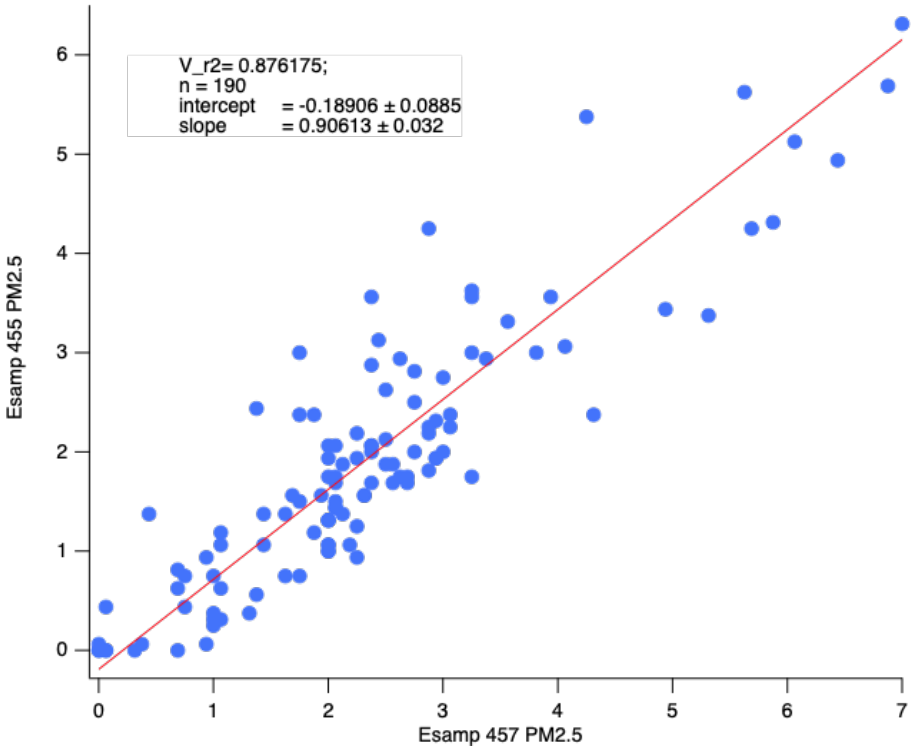
Met One E-Sampler

Two of these instruments were also on loan to the study from the US Forest Service cache in Colorado. E-samplers have a similar footprint to the E-BAM, but use a laser spectrometer. They fit into two large cases plus tripod and are slightly lighter than the E-BAM, but still about 20kg per case. With a lower volume pump than the E-BAM (2 liters per minute vs 16.6), a smaller solar panel and battery bank could meet off-grid needs.

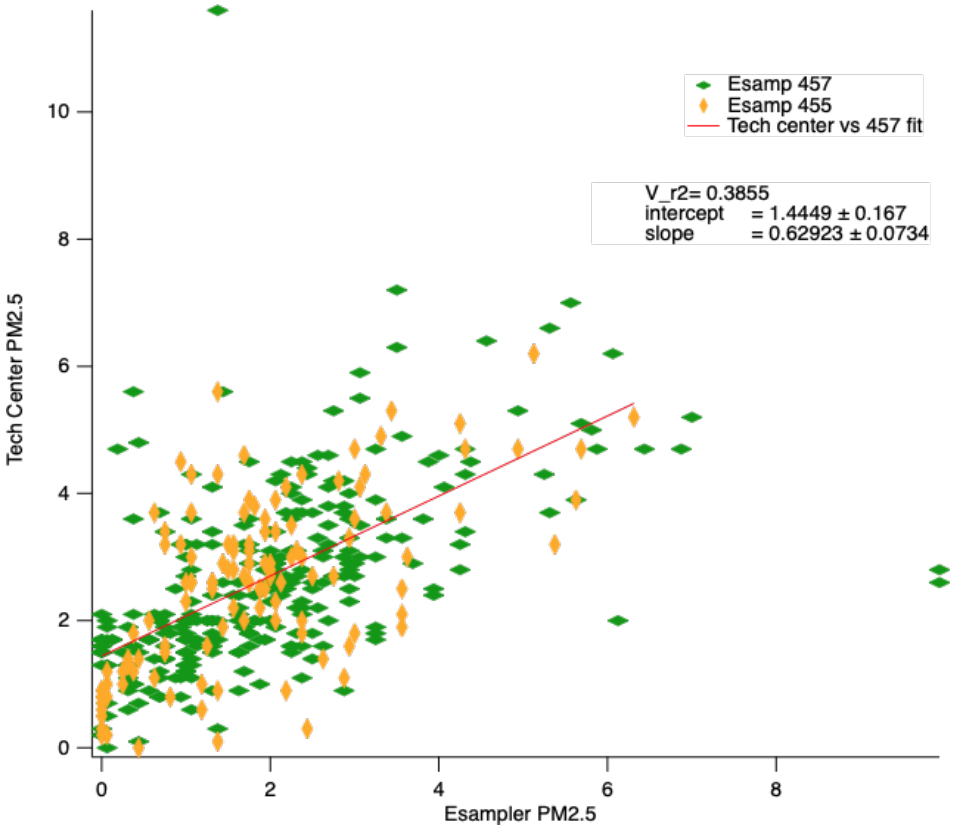
The study team set the two E-Samplers up at the UDAQ tech center to compare with other continuous instruments.



This trace shows the agreement between the continuous instruments at the tech center (again a Thermo 5030i SHARP) and the two E-Samplers.



Comparing the E-samplers to each other gave a decent correlation. The chart below has a correlation line fit between E-Sampler 457 and the tech center instrument and it suggests an offset of ~1.5 µg/m^3.



E-Samplers will read differently depending on the composition of the local aerosol. A correction factor can be derived to apply to the raw data, for example by using a co-located filter-based instrument. The team intended to do this for each of the projects in this study, and for multiple time periods at each project (background, burning, post-burn). It was difficult in practice to stratify filters based on background, burning, and post-burning conditions. In every monitored event, the burning schedule itself was in flux due to factors beyond the control of the study- firefighter resources, weather conditions, fire behavior, etc.

In the end the correction factors suggested by the co-located filters were all over the map. For this reason, E-Sampler data is presented in the study in uncorrected form. The actual values should not be considered accurate, but the trends are very likely correct.

Airmetrics MiniVol

This filter-based instrument takes a 47mm filter, common to many instruments and for which DAQ has standard handling protocols and in-house laboratory service. DAQ owns several MiniVols. They can run on AC power or battery. Battery life was found to be approximately 48 hours, but will vary depending on temperature, flow rate, age of battery, etc. In a previous study, DAQ scientists created adjustment factors for each individual MiniVol. The team was happy with the performance of the MiniVols and considers their data to be quite accurate on this study. There is of course a time lag between the field data collection and the results being available.

One issue that arose with the minivols was a brief filter shortage. Filter preparation and handling is a highly technical skill and at one point the needs of DAQ to meet regulatory requirements meant the study was short of the desired total. This only affected the Devil Canyon project, for which there were still five filters available, so the effect was negligible. If designing a similar study in the future, planning ahead will be important.

Low Cost Sensors – AirU and Purple Air

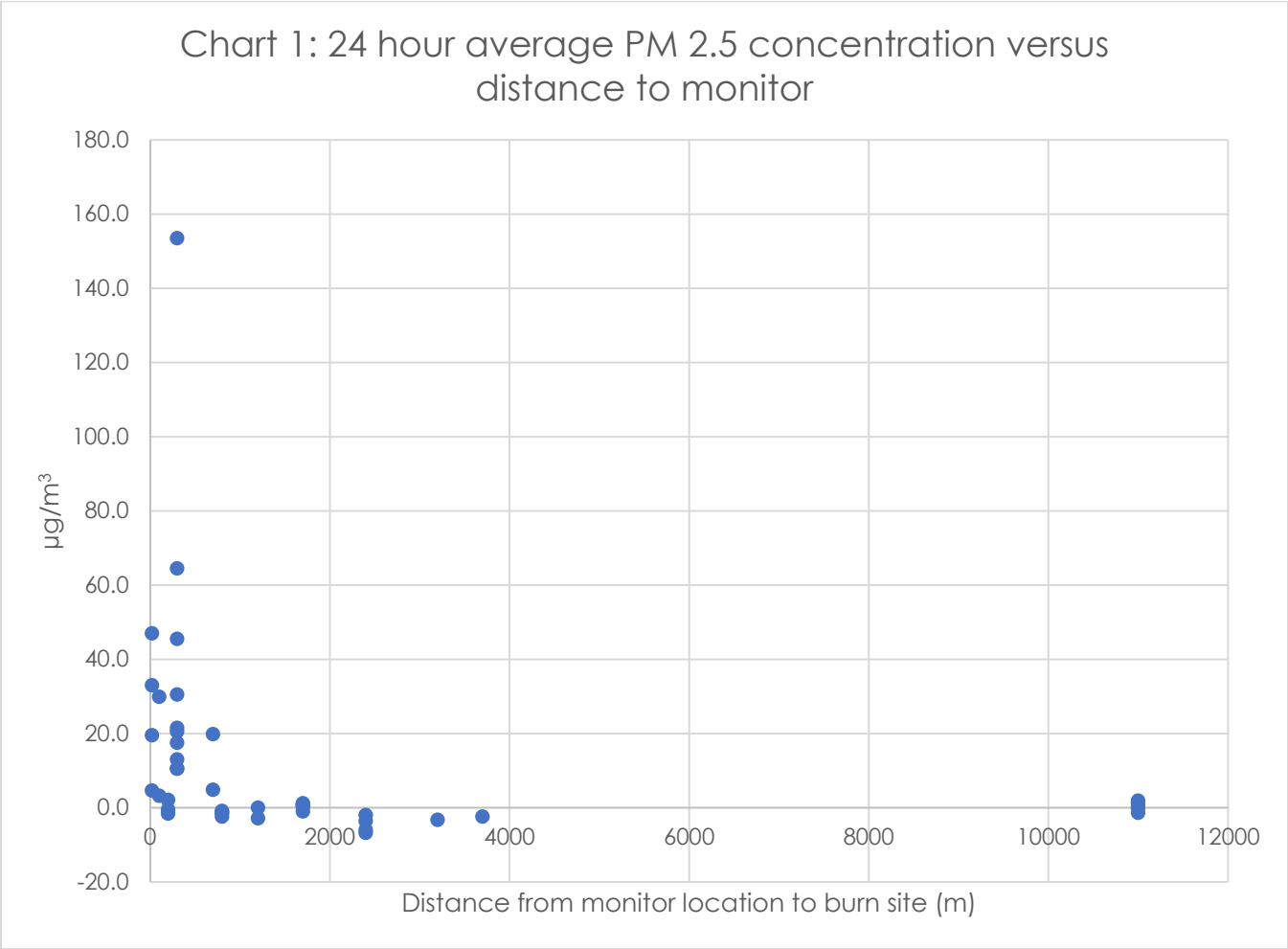
The team used low cost sensors at Blacksmith Fork and at Alpine Acres. Especially for trend purposes, the data showed good agreement with the other instruments in the study, as well as fixed UDAQ monitoring stations. While they have their own technical challenges, and pros and cons, the small form factor and low cost are very attractive for future studies such as this one. Above all, the ability to install more sensors at more locations could be of huge benefit.

Our Utah smoke study team had discussions with a group at US EPA (OAQPS) which tested several low costs sensors. EPA identified several commercial and pre-commercial products which provide more field ruggedness and could be an excellent fit for this type of application. UDAQ contacted one of the manufacturers and offered to field test some of that equipment. As of September 2020, that project is progressing.

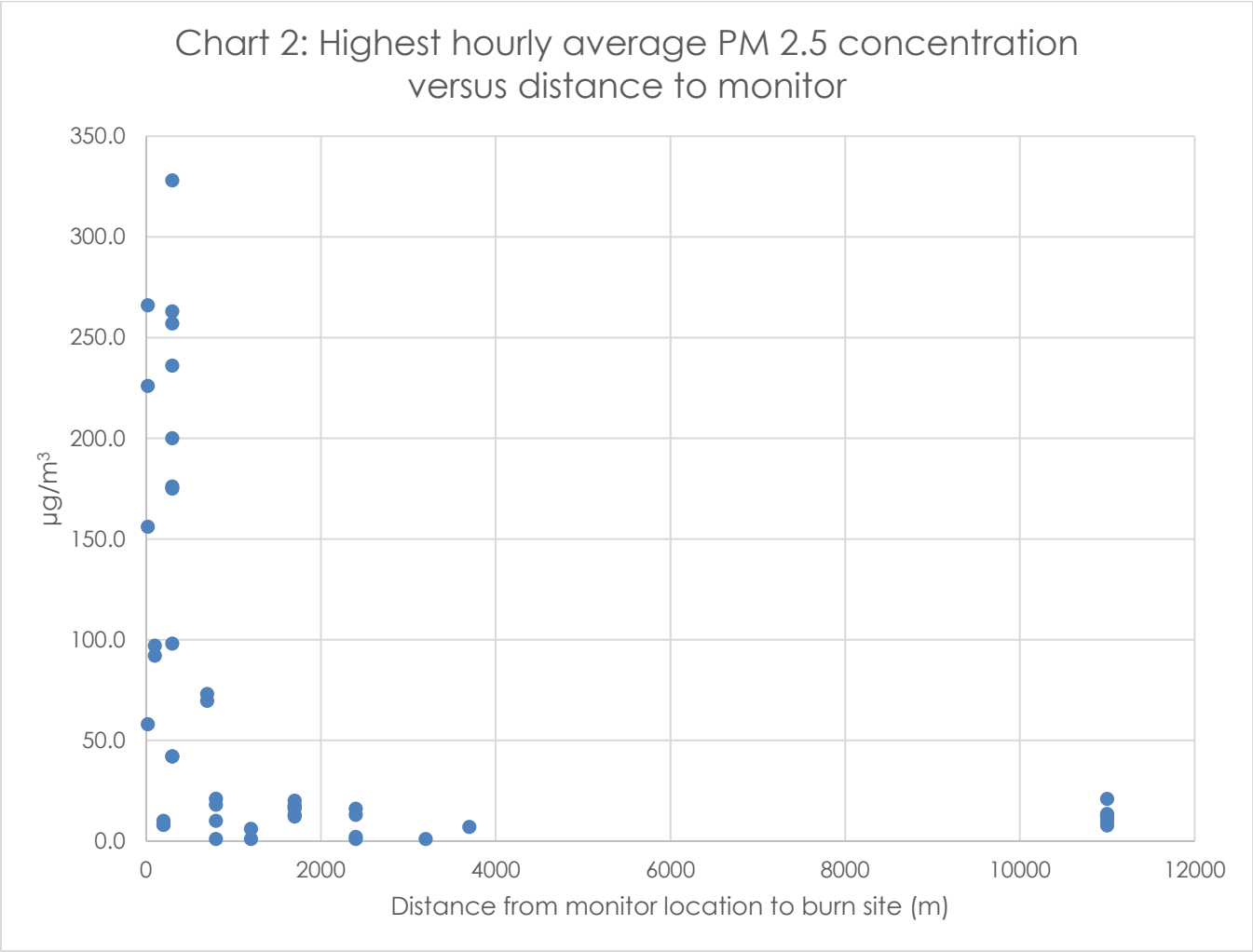
CONCLUSION

Overall analysis of results

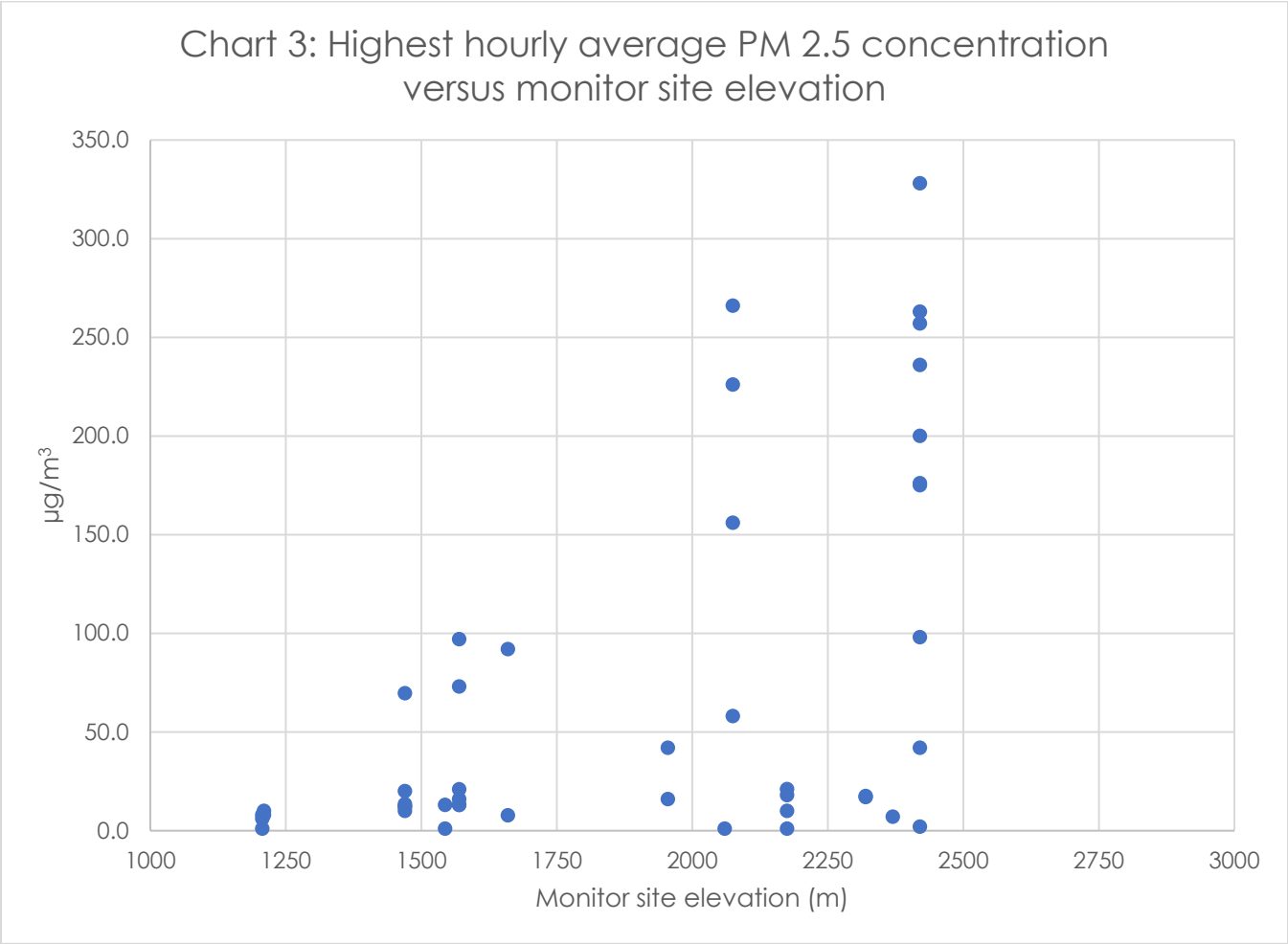
To stratify the data, the study team prepared a table of overall results with 49 rows. Each row represents a 24-hour period at one of the monitoring sites for one continuous instrument. Using a presumed background value unique to each location, the team derived an adjusted PM2.5 concentration that was contributed by the burn. This includes separate columns for the 24-hour average and the maximum hourly concentration. The values in the table are uncorrected for the continuous instruments and should not be considered absolutely accurate, but the trends can still be of interest. The following charts show a variety of ways of looking at those 49 data points.



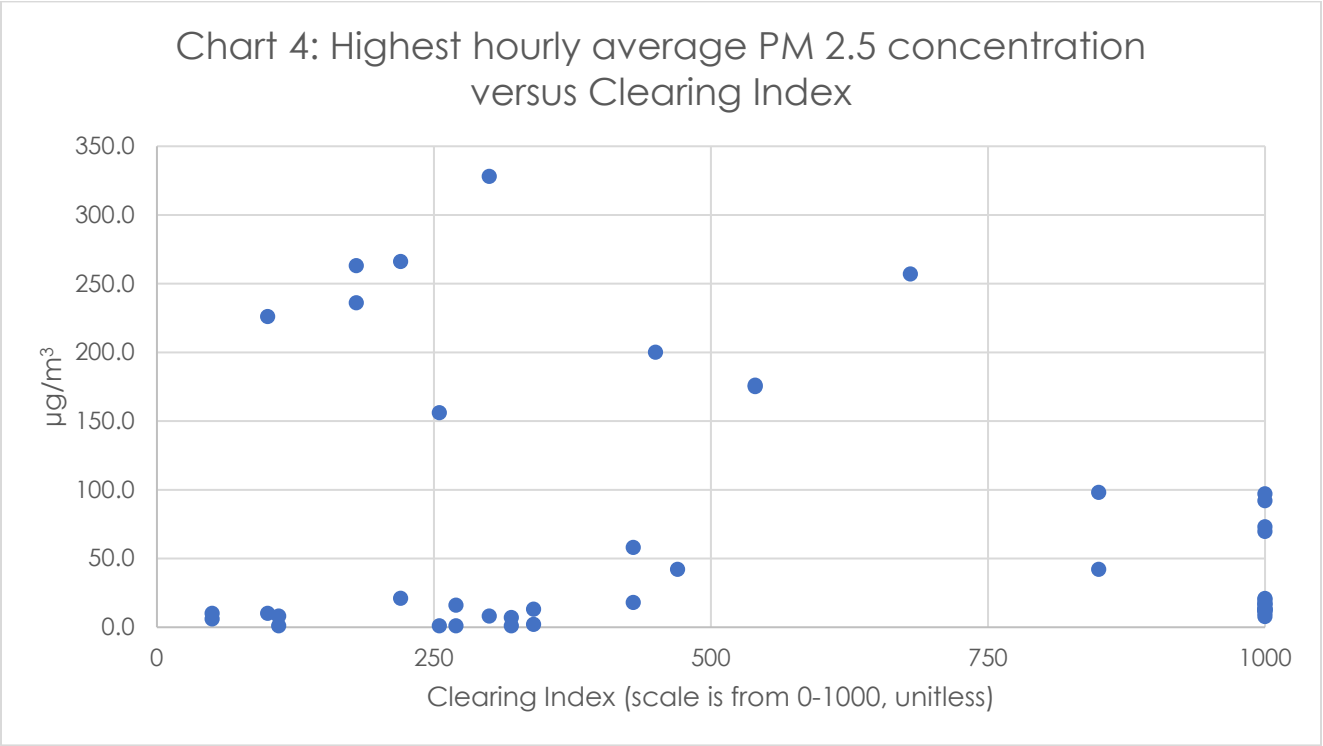
Monitors over 1 kilometer away recorded very little added PM from the prescribed fires. The negative values can be explained because in some cases the background value (taken from MiniVol data) was in fact greater than the continuous instrument 24-hour average. The study team had intended to place monitors at a consistent distance from the burn on all six projects. In reality, available equipment, terrain and access made that impossible. This chart does not take wind direction into account. It would be difficult to characterize each site as either upwind or downwind for an entire 24 hour period.

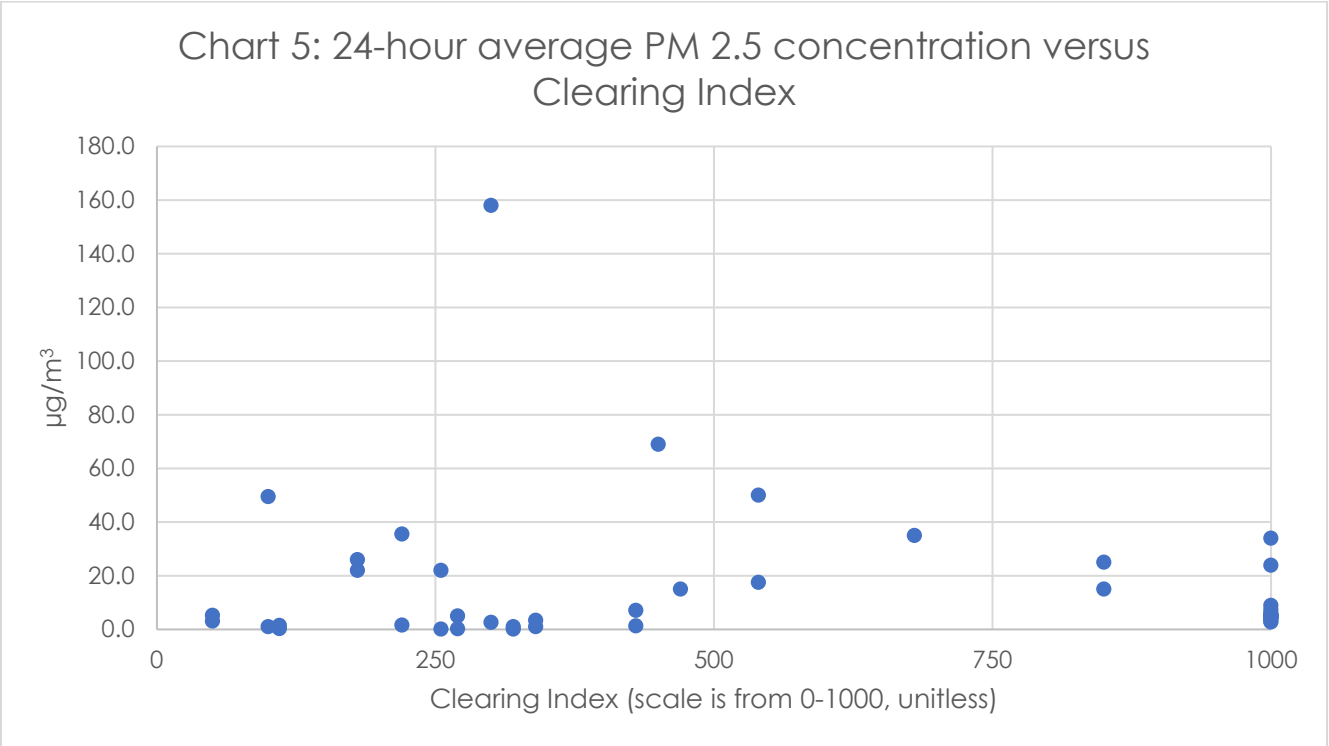


Peak hourly values were highest at Devil Canyon and Alpine Acres, where monitors were sited at a distance of just 20 meters and 300 meters from the burn, respectively. Some monitors that were quite close recorded relatively low values, particularly at the two biochar projects. This is likely because the volume of material burned and therefore total PM produced was small from the biochar kilns.

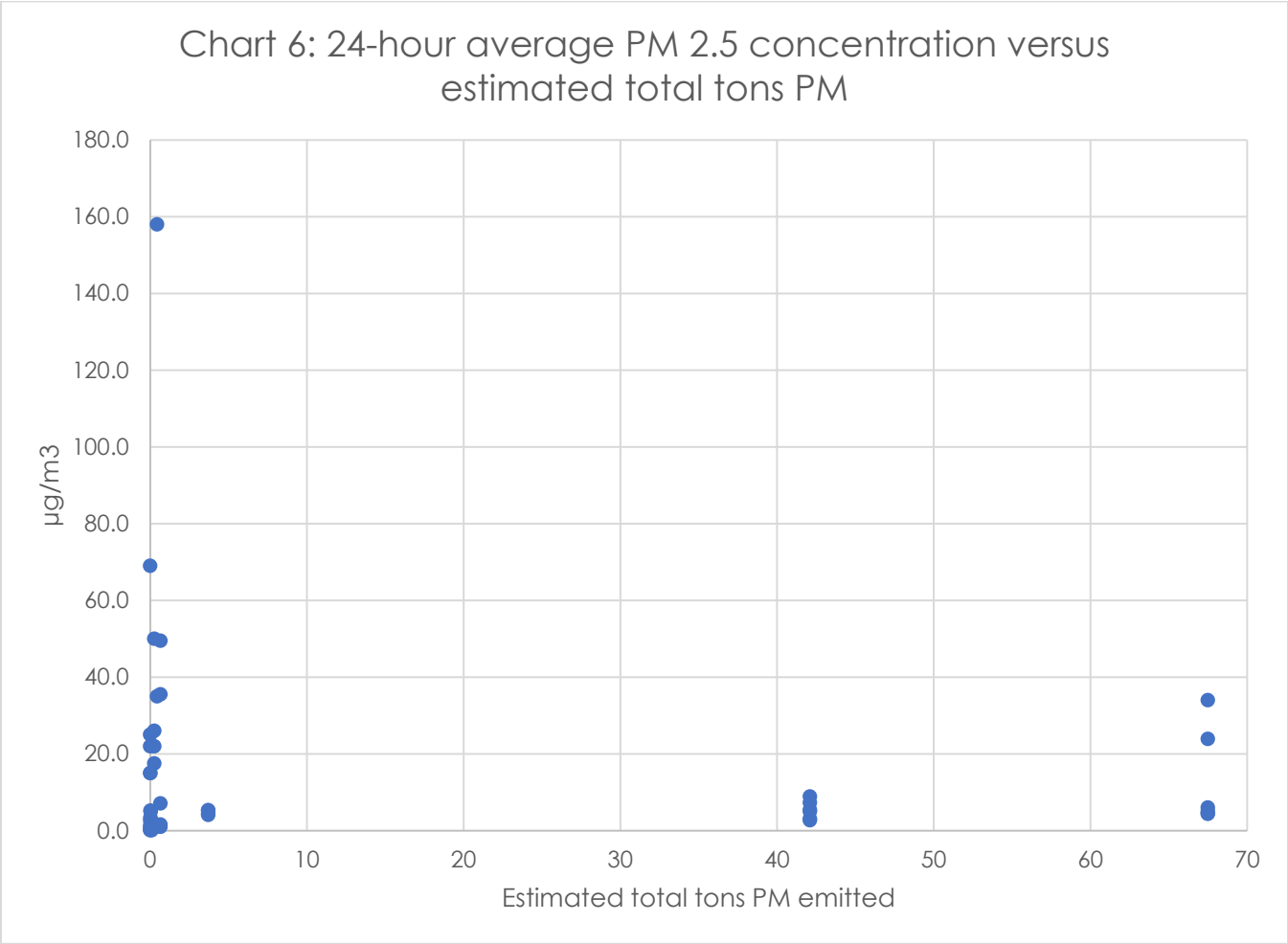


There does not appear to be a strong relationship between elevation of the burn site / monitors and the resulting PM. Again the high values from Devil Canyon and Alpine Acres stand out (2075m and 2420m elevation), but those two sites are so different as to defy a simple comparison. The team believes the lesson is that elevation and topography are certainly important in predicting smoke travel and dispersion, but each site is unique and must be considered individually, rather than applying a formulaic approach.

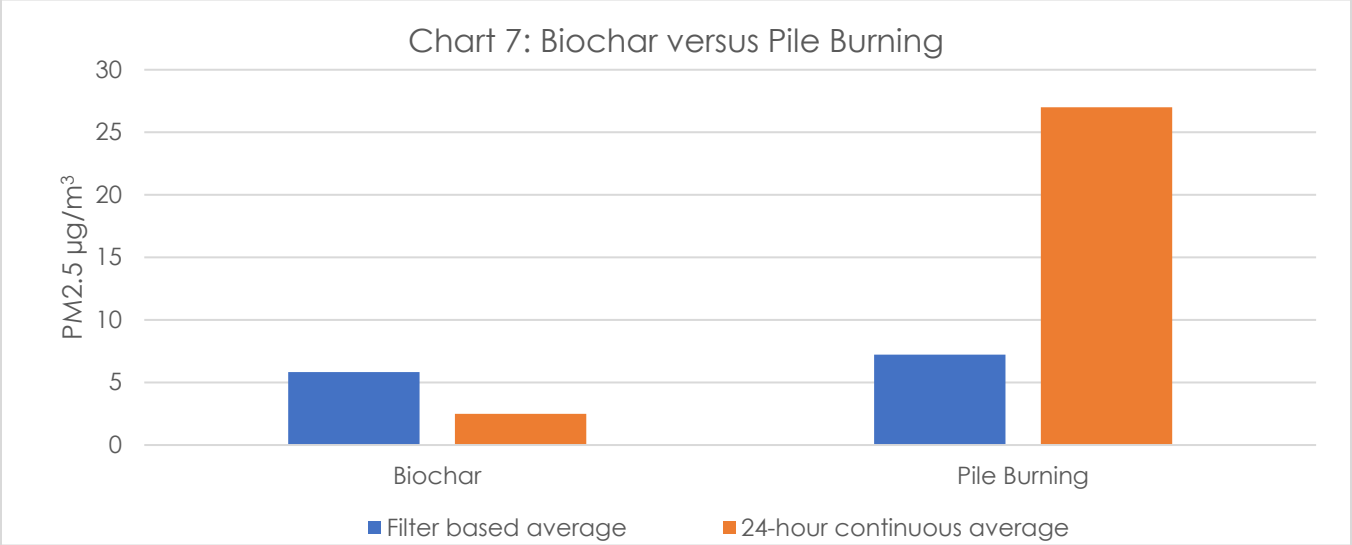




The left half of chart 4 (clearing index < 500, which has in the past been a "no-burn" scenario) shows more hourly spikes over a 100 µg/m³ level, when compared to clearing index > 500 (seven points versus two). Over the time scale of one hour, even burning on a good dispersion day can cause short-term impacts, especially close to the burn site. Chart 5 is encouraging in that there were only two 24-hour levels above 55.5 µg/m³ (red/unhealthy AQI) and those occurred at low clearing index values. Those days were both at Alpine Acres, with a monitor quite close (300m) to the burn itself.



The team expected to see a linear relationship here, with increasing concentrations resulting from larger prescribed fires, but such a relationship is not obvious from chart 6.



Another way to look at this relationship is to separate out the biochar burns, which had far less estimated total PM (0.01 to 0.04 tons PM) compared to the pile burns (0.1 to 0.6 tons). In this case a relationship is suggested; biochar had lower measured concentrations, both for filters and 24-hour continuous average.

Management implications

There appears to be a strong relationship between distance from the burn site, and measured concentration. When considering which criteria are important in approving prescribed fire requests, distance to receptor should probably be one of the most heavily weighed considerations. Dispersion appears to be somewhat important, while burn size and elevation may be less relevant.

Burning with a biochar kiln seems to have small effects, even close to the site, probably due both to increased combustion efficiency and to the small amount of material being combusted.

The study appears to capture effects from burning that lasted for several days post-burn at Alpine Acres and Devil Canyon (i.e. lingering smoke), and long term weather and dispersion forecasts are important for burn decisions in fall and winter months in Utah.

Recommendations for further study

Monitoring Instruments

Two of the continuous samplers used, the E-BAM and E-Sampler, come in multiple large cases, so large that two monitors take up the entire cargo area of a large SUV. A full size pickup could probably carry four of these monitors, but with reduced protection from the elements and the added challenge of securing the load in the bed. In their favor, the E-Sampler and E-BAM include several meteorological instruments (temperature, relative humidity, wind speed and direction). They also broadcast the data through a satellite antenna, so it is available online in close to real time. The team feels that for purposes of a study like this, the meteorological data, the near real time information, and the slightly higher robustness of the E-Sampler did not outweigh the drawbacks of the large form factor. The E-BAM had trouble with accuracy at intervals as short as one hour, and for that reason it is even less useful for this type of project.

If conducting additional monitoring of prescribed burns where real-time data is not necessary, multiple low-cost sensors (currently not in our inventory) could be set up with a lower level of staff time and commitment, providing better spatial resolution, and likely better understanding of impacts and trends.

Site Selection

In an effort to build on this knowledge and improve understanding of trends we identified, the team suggests considering the following when selecting additional prescribed fires for monitoring in the future:

- Access to desirable monitoring locations
- Travel time to the site
- Instruments ready on hand with adequate filters, parts, etc.
- Availability of portable low cost monitors that are not currently available in our inventory

Pre-burn field site visits were incredibly useful for the study team. They allowed assessment of topography, monitoring sites, logistics, and an unhurried opportunity to discuss the project with the local land manager. There was not an opportunity to do pre-burn visits in all cases but the team recommends them in the future whenever possible for similar studies.

Modeling

A main effort of the study was to look at the accuracy of available smoke dispersion models. Each chapter contains an analysis comparing field data to the modeled smoke outputs. BlueSky underpredicted the monitored 24-hour average PM2.5 concentration on two of the projects. This happened on 5 out of 10 days at Alpine Acres and 3 out of 4 days at Devil Canyon. See the Devil Canyon chapter for a discussion of high concentration values and possible confounding factors. For all other days and projects, the model was accurate, or slightly overpredicted, when compared to monitored predictions.

The team feels that the BlueSky playground model framework is useful for understanding wide-scale (airshed or county level) impacts. The BlueSky modeling runs done for this project used a three-kilometer meteorological grid. For certain parts of the state of Utah a finer-scale grid is available but in general the three-kilometer one would be used in the foreseeable future. Many local terrain features are too small to resolve at this scale.

These recommendations may assist with the accuracy of future smoke modeling:

- BlueSky works well to assess smoke dispersal when wind is a dominant factor, and can predict air movement around major topographic features such as mountain ranges.
- For terrain-driven smoke at smaller scales, a tool such as PB Piedmont, or careful use of topographic maps may increase understanding of smoke dispersal.
- For wind-driven smoke at smaller scales, a tool such as Wind Ninja may be useful for identifying and understanding air movement around individual peaks, canyons, valleys, eddy effects, etc.

Acknowledgements

We have included recognition of individuals whose contributions were essential to completing this study in each chapter. Overall, the team would like to thank Luke Leclair-Marzolf, environmental scientist with DAQ, for assembling the solar power systems and otherwise troubleshooting the instruments. Thanks also to Matt Panunto, geospatial analyst with the Salt Lake Bureau of Land Management, for writing a script to capture and archive clearing index values daily, and for his help with geospatial analysis. Lastly, thanks to the various agencies management for their support, the team feels that projects such as this increase understanding and strengthen the working relationship between land managers and Utah DAQ.

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