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Extreme Heat at Outdoor COVID-19 Vaccination Sites

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Abstract

Extreme heat is an increasing climate risk due to climate change and the urban heat island (UHI) effect and can jeopardize points of dispensing (PODs) for COVID-19 vaccination distribution and broader public health emergency preparedness (PHEP) response operations. These PODs were often located on large parking lot sites with high heat severity and did not take heat mitigation or management strategies into account for unacclimated workers and volunteers. To investigate the personal heat exposure of workers, volunteers, and clients at three PODs in Tucson, Arizona, we collected ambient air temperatures, wet bulb globe temperatures (WBGT), surface temperatures, and thermal images. We also made qualitative observations and compared data against daily meteorological records. Ambient air temperatures at all three PODs exceeded the meteorological recorded high. WBGT on average were 8°F (4.4°C) higher in full sun locations than shaded locations such as tents. Evaporative cooling decreased ambient air temperatures by 2°F (1.2°C) when placed one per tent, but decreased ambient air temperatures by 7°F (3.9°C) when placed en masse in a larger tent. Vehicle surface temperatures exceeded recommended safe limits of 140°F (60°C) at all three sites, with a maximum temperature recorded at 170.9°F (77.2°C). Public health professionals should consider heat resilience, including heat mitigation and management measures, in POD and PHEP response operations to reduce exposure. This includes considering the UHI effect in the siting of PODs, applying heat mitigation strategies in the design of PODs such as the adaptive use of solar panels for shading, and improving heat safety guidance for workers and volunteers.

Keywords: climate change, extreme heat, COVID-19, points of dispensing, public health emergency preparedness, heat resilience

1 Introduction

The COVID-19 pandemic coincided with the hottest summer on record in the Northern Hemisphere during 2020 [1]. Heat is the number one weather-related killer in the U.S. [2], causing more deaths and a larger public health burden than all other weather-related disasters combined [3]. Climate change and the urban heat island (UHI) effect are increasing heat risk. Greenhouse gas (GHG) emissions have increased global temperatures by 1.96°F (1.09°C) [4] since the end of the 19th Century with an additional increase of 4.5°F (3°C) by 2100 with current GHG emissions mitigation policies [5]. The UHI effect, caused by the built environment and mechanical waste heat [6], increases the heat severity of urban areas up to 7°F (3.9°C) in the day and up to 5°F (2.8°C) at night [7]. Climate change already accounts for approximately 37 percent of heat-related mortality worldwide [8], and in the U.S., heat-related deaths could increase by almost 100,000 by 2100 under high emissions scenarios [9].

Heat risk compounds other health impacts, such as the COVID-19 pandemic, and requires shifts in response [10]. Many local health departments used points of dispensing (PODs) for mass COVID-19 testing and vaccination operations, also using an informal adaptive management approach [11], where actions are assessed, planned, implemented, monitored,

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evaluated and adjusted, on a weekly or daily basis. Drive-through PODs allowed vaccination clients to remain in vehicles, with workers in ventilated spaces, reducing the need for more COVID-19 infection control measures. Yet without proper training, protocols, and planning, PODs and other field-based incident command posts can become prone to other, compounding health hazards [12].

Consideration of extreme heat is not typical of either PHEP or in the design and operation of PODs. Emergency response and Public Health Emergency Preparedness (PHEP) typically focus on site operations and design that support throughput and efficiency [13,14]. PHEP is “the capability of the public health and health care systems, communities, and individuals, to prevent, protect against, quickly respond to, and recover from health emergencies” [15]. PHEP adopts an all-hazards approach to preparedness using the National Response Framework and U.S. Centers for Disease Control & Prevention (CDC) PHEP Capabilities. Within the heat resilience framing, chronic and acute heat risk requires both heat mitigation and management strategies [16]. Heat mitigation strategies reduce urban heat by decreasing contributors in the built environment, such as roads and parking lot surfaces, and mechanical waste heat, from sources like vehicles and air conditioning. Heat management strategies, more commonly the focus within PHEP and POD operations, prepare and respond to extreme heat events such as emergency planning activities.

Determining appropriate heat mitigation and management strategies requires understanding personal heat exposure. Personal heat exposure, as defined by Kuras et al. [17], is the “realized contact between a human and an indoor or outdoor environment in which the air temperature, radiative load, atmospheric moisture content, and air velocity collectively pose a risk of increase in body core temperature, perceived discomfort, or both.” Outdoor meteorological measurements are often based on a sparse weather station network that do not accurately reflect UHI effect differences across an urban area or specific microclimate conditions at a POD [17], resulting in differences of personal heat exposure [18,19]. The impacts of radiant waste heat from operating machinery is also an underestimated contributor to personal heat exposure [20].

While a variety of methods document personal heat exposure, wet bulb globe temperature (WBGT) is an index used to assess exertion for heat conditions in occupational health settings, including government, military, and sports team organizations [21–23]. These guidance documents set thresholds at which proceed with caution and change behaviors such as reducing intensity, increasing water, and more frequent activity breaks to reduce risk of heat stress. Most guidance recommends reducing the intensity and length of activity when WBGT exceeds 82°F (27.8°C) and to stop activities altogether when WBGT exceeds 92°F (33.3°C). WBGT utilizes ambient air temperature, humidity, airflow, and radiant solar heat to approximate human thermal stress. WBGT and ambient temperature are roughly equal in light cloud environments when humidity is roughly 50 percent. In semi-arid environments, such as Southern Arizona outside of the monsoon, WBGT is numerically lower than ambient air temperature. Still, ambient temperatures above 95°F (35°C) typically translate to WBGT above 82°F (27.8°C) mid-day in direct sunlight even with relative humidity below 20 percent. Another

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challenge is that most guidance documents assume that individuals are already or will become acclimated to outdoor heat over at least a week, which may not be possible given the rapid response required for public health emergencies.

This study documents personal heat exposure at outdoor COVID-19 vaccination PODs in Tucson, Arizona. The mission-driven decision to set up drive-through PODs during the cooler season did not initially prioritize heat risk. Further increasing heat risk, the drive-through PODs were selected for ease of vehicular access and for management of traffic flow, often the highest heat severity locations in the urban area due to the UHI effect and microclimate conditions [16]. As the PODs continued operations into the spring, site managers grew concerned about heat risk on POD operations. This study documents a rapid evaluation of personal heat exposure measurements at the PODs and the strategies that managers adopted in real time to reduce heat risk.

1.1 Case Background

Three drive-through outdoor COVID-19 vaccination sites were set up utilizing the POD model in December 2020 for the Tucson metropolitan area, located within Pima County, Arizona. As temperatures approached 80°F (26.7°C) in March 2021 the Pima County Office of Emergency Management requested assistance to better understand personal heat exposure and recommendations to decrease heat risk to site workers, volunteers, and clients. In Arizona in 2020, heat resulted in more than 3,000 emergency department visits and a record 494 deaths [24]. Pima County anticipated that by May 2021, when temperatures often exceed 90°F (32.2°C), PODs would need enhanced heat education, surveillance, and interventions. The three PODs included the University of Arizona (UArizona) site operated under the State of Arizona; and the Banner South and Tucson Medical Center (TMC) sites operated under Pima County. Each had its own management culture, operation structure, heat stress surveillance systems, microclimate conditions, and site design. With the expectation that, eventually, heat risk would force site closures, managers were hopeful that documenting personal heat exposure patterns could result in simple environmental or operational changes to prolong lengthen the time of operation by days or weeks.

2 Material and methods

To provide a heat risk assessment and recommendations, we developed a quasi-experimental design incorporating personal heat exposure measurements at the three outdoor COVID-19 vaccination PODs in Tucson.

Two expert observers from the research team conducted a walkthrough with each site's manager to determine ideal data collection (Table 1) and note heat mitigation and management considerations. While each study site's operational details varied, they all had a similar task flow (Figure 1): screening; verifying appointments and consents; vaccination administration; and 15-minute observation period. Traffic management was a full sun task, staffed with a mix of acclimated workers and unacclimated volunteers. Almost all other positions were volunteer,

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often unacclimated medical or office workers. Appointments, consents and vaccinations occurred in shade. Observation areas were usually in the sun, with the exception of Banner South, which utilized solar panel structures in the parking lot for shading.

Data collection occurred during the peak heat hours from 12:00 PM to 5:00 PM at UArizona on March 31, 2021, at Banner South on April 1, 2021, and at TMC on April 2, 2021. We utilized Kestrel 5400 instruments to collect ambient air temperature and WBGT readings at each location every 10 seconds. We also utilized Kizen LaserPro LP300 Infrared Thermometers to collect surface temperature readings on several representative surfaces at each location every half hour for the context of radiant temperatures. Example surface temperature readings collected in both sun and shade include grass, road pavement, sidewalk, table, chair, vehicle hood, and vehicle driver-side door. All Kestrel 5400 data was downloaded in CSV form and imported into R for analysis. Ambient air temperature and WBGT readings were averaged at 1-minute intervals and plotted across time for each site. Surface temperatures were entered into REDCap and imported into R for analysis. We also used a FLIR E5-XT thermal camera to visually document temperature differences at various locations. Research team members made qualitative observations and daily debriefings to document observations, best practices, and potential recommendations. Initial reports were given to the site managers within a week.

3 Results

The preliminary meteorological report for Tucson, Arizona (Table 2) indicated daily maximum air temperatures between 88°F (31.1°C) and 90°F (32.2°C). Average humidity was between 10 and 15 percent, typical for spring in the semi-arid desert. The only notable weather condition was high winds averaging 17.3 miles per hour (MPH) with gusts approaching 30 MPH and brief cloud cover on April 1, 2021.

The majority of recorded ambient air temperatures were within the high end of the reported ranges with notable instances of exceeding high temperatures, usually in full sun locations (Figure 2). At UArizona, the full sun control (Location 1) exceeded the reported ambient temperature maximum of 88°F (31.1°C) by 1:45 PM, reaching above 95°F (35°C) three times. The full sun observation area (Location 4) also was generally higher than the reported in the afternoon, exceeding 92°F (33.3°C) at least three times. It is possible that the concentration of vehicles elevated temperatures due to radiant and waste heat. At Banner South, ambient air temperatures increased throughout the day with a noticeable drop during brief cloud cover between 2:30 PM and 3:30 PM. Ambient air temperatures late in the day in the sun and in the 3-sided break tent were closer to 91°F (32.8°C), just above reported maximum temperature for the day. At TMC, ambient air temperatures in the observation area (Location 4) exceeded reported maximum temperature of 91°F (32.8°C) multiple times, reaching a high of above 94°F (34.4°C) just before 2:00 PM.

WBGT data better approximates the personal heat exposure of workers, volunteers, and clients (Figure 3) with some notable patterns in the data. WGBT did not exceed 78°F (25.6°C) at Banner South and 80°F (26.7°C) at UArizona and TMC. This indicates that personal heat

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exposure was approaching but not exceeding the actionable threshold of 82°F (27.8°C) set by most guidance documents for acclimated workers or athletes. Locations tend to cluster into full sun, usually being 8°F (4.4°C) hotter, and those in the shade. This is seen most starkly on the two non-windy days (UArizona and TMC) and by looking at outlier patterns. The cloud cover period at Banner South between 2:30 PM and 3:30 PM depicts a large drop in WBGT at all full sun instrument locations. Another example is a mid-day WBGT decrease at TMC when an instrument (Location 5) was shaded by a tree.

The main vaccination tent (Location 3) at UArizona offers some insight into the use of evaporative cooling. This18 station (3 lanes, 6 stations deep) tent with the pharmacy in a side lane included 20-24 evaporative coolers - one at every station and a few for managers. This resulted in a 5°F (2.8°C) to 7°F (3.9°C) difference in ambient air temperature and a lower WBGT compared to other shaded tent locations from 3:00 PM to 5:00 PM, even with the additional vehicle radiant and waste heat. A more common use of evaporative cooling was a single unit in a tent (Location 6 UArizona; Location 6 TMC). Even with instrumentation within a yard of the direct breeze, ambient temperatures were only lowered by 1°F (0.6°C) to 2°F (1.2°C) and less than 1°F (0.6°C) of WBGT.

Most surface temperatures recorded across all non-vehicle surfaces were within safe thresholds (Table 3). Non-vehicle surface temperatures averaged 96.7°F (35.9°C) and average vehicle surface temperatures were 112.4°F (44.7°C), below the safety threshold of 140°F (60°C) [25]. The safety threshold was exceeded at all three sites by the highest vehicle surface temperatures, at UArizona up to 158.7°F (70.4°C); at Banner South up to 160°F (71.1°C); and at TMC up to 170.9°F (77.2°C).

4 Discussion

With increasing extreme heat risk due to climate change, healthcare professionals should consider chronic and acute heat risk for PODs and broader PHEP response operations. Ambient air temperature and WBGT confirmed large differences of personal heat exposure within each POD and which tasks and locations had greatest heat risk. WBGT were on average 8°F (4.4°C) higher in full sun, consistent with the general rule that full sun adds up to an additional 15°F (8.3°C) of personal heat exposure [26]. Adequate shading via tents and the creative use of existing structures should be part of any POD design. Shade design needs to be modified depending on the season. For example, three-sided tents may provide shelter and retain heat in cooler months, but walls on more than the south and west-facing sides of tents may have the effect of limiting ventilation, trapping heat, and increasing WBGT during warm months. A high density of evaporative coolers can reduce personal heat exposure in large tents, while a single evaporative cooler in a break tent can reduce personal heat exposure in the line of air flow. Water access was a challenge at several of the sites; if evaporative cooling is used, tents need to be placed near water sources.

We recorded enough ambient temperatures above the reported maximums to suggest that management based on the projected high temperature may underestimate heat risk. The WBGT

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approached but did not exceed the 82°F (27.8°C) threshold commonly cited for phasing in reduced activity. Since mass vaccination operations leaned heavily on office-based health care workers and volunteers, the conditions recorded certainly warranted caution. The significant difference between sun and shade WBGT measurements suggests POD managers should manage heat much sooner, especially for those unacclimated during long shifts in the sun. Site managers intuitively understood this but did not always manage heat consistently. When the research team took measurements, all sites had shifted to using acclimated subcontractors instead of volunteers for managing traffic. However, at two sites, volunteers were still staffing the highest heat risk 15-minute observation areas in full sun.

We provided tailored reports within a week of fieldwork to facilitate adaptive management at each site. Major site modifications were difficult, so we focused on practical heat mitigation and management recommendations, including but not limited to adding more tent shade to all traffic management and observation areas; modified break and shift recommendations; increasing access to cool drinks; and the finding that 2-sided tents performed better than 3-sided tents in higher heat due to ventilation. Site managers were responsive to recommendations, consistent with the rapid adaptive management style. Managers added additional educational heat risk signage, created additional break areas using the thermal mass or air conditioned spaces of nearby buildings, and in one case developed a comprehensive Heat Plan and integrated heat safety messages into daily briefings.

We observed and recommended modifications that applied heat risk interventions learned in adaptive ways. For example, in January 2021 at Banner South, the 15-minute observation period was in full sun but by February 2021, managers moved the observation area under the shade of solar panel structures. As temperatures increased, vaccination operations shifted indoors [27], changed their hours of operation [28], and transitioned to mobile community vaccination clinics. In these iterations, heat risk continued for traffic management workers and outdoor client lines. By May 2021, several pop-up outdoor sites had 1-sided tents under solar panel structures for shading. After data collection, TMC shifted its efforts to an indoor site on April 19, 2021; Kino was shut down in favor of smaller pop-up operations on May 10, 2021; and UArizona shifted indoors on May 3, 2021, and closed on June 25, 2021.

One of the paradoxes of drive-through PODs is that sites that accommodate large volumes of traffic are typically areas of higher heat severity. Understanding the UHI heat severity and microclimate conditions of a designated emergency site prior to implementation may help better mitigate heat risk. PODs could be located with consideration of the massing of large buildings on the edges of parking lots to provide respite areas for workers and volunteers while placing tents near buildings and water sources for respite and evaporative cooling during hot weather. The adaptive use of solar panels for shading should be a consideration and incorporated into new or retrofitted site designs based on their performance in reducing personal heat exposure and the co-benefit of renewable energy production. These design considerations are relevant for a variety of scenarios in the future that may utilize pop-up and drive-through models and can ensure the healthcare delivery is safe, efficient, and reduces GHG emissions.

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Several characteristics of POD planning and operations can be leveraged to mitigate and manage heat risk. Multidisciplinary POD planning teams are critical to navigating complex operational and logistical needs to ensure safe and effective delivery. Our experience indicates that PODs may be run by first responders and emergency medical services personnel who may have more direct experience in heat situations, but may be less experienced in managing heat health. As climate change increases heat risk, the inclusion of heat-specific expertise adds a critical component to PHEP. Our research team had prior relationships within and external to UArizona and broad expertise including public health, urban planning, and climate change. This combination of transdisciplinary stakeholders is critical to address public health impacts of climate risks [29]. The team used a task-oriented approach to characterize heat exposure and risk, which informed experimental design and immediately resulted in identifying the highest risk staff and volunteers.

We received consistent feedback from POD managers that an outside expert evaluation of heat risks and recommended mitigation and management strategies was helpful. Study results and recommendations were virtually shared at the 5th Annual Arizona Extreme Heat Planning Workshop on April 19, 2021 with favorable responses from the attendees. Many of the strategies suggested were identifiable without the additional step of heat measurements. Walking the site with a heat expert, thermal camera (Figure 3), and an empowered manager prior to and shortly after setup would likely benefit most sites. In several cases, POD managers began heat interventions even before data collection. A virtual walkthrough or a heat resilience checklist, including heat mitigation and management strategies, for site design and operation, could also be useful.

With climate change increasing the likelihood of extreme heat events, we also recommend future iterations of federal guidance documents and training modules for public health professions explicitly include the mitigation and management of chronic and acute heat risk. Federal emergency management and PHEP guidance and training does not typically include a heat health component in relation to response operations with wildland fire safety as a notable exception [30]. A review of the PHEP Capability 8 (Medical Countermeasures Dispensing and Administration) and CDC POD guidance indicates the lack of heat risk site consideration [31]. Public health professionals should integrate ongoing and adaptive heat awareness education into PODs and broader PHEP response operations.

5 Conclusion

This study demonstrates the need for planning, public health, and emergency management perspectives to consider heat resilience through the mitigation and management of heat risk. We found that the drive-through POD model of mass COVID-19 vaccination increases personal heat exposure for unshaded tasks, increasing heat risk for unacclimated workers and volunteers. Our findings illustrate the value for integrating chronic and acute heat risk into POD planning for continued mass vaccine distribution. The findings also have relevance beyond medical countermeasures dispensing to emergency planning and response such as resource delivery, evacuations, temporary emergency management operations for wildfires, hurricanes,

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flooding, earthquakes, terrorism, and other public health risks. Lessons learned from COVID-19 could lead to an increase in pop-up and drive-through models of medical care for a variety of scenarios. With climate change increasing extreme heat risk, we recommend that public health professionals incorporate heat resilience into POD and PHEP planning guidance and training modules at state and federal levels.

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Author Statement

Ladd Keith: Conceptualization, Resources, Investigation, Analysis, Writing. **Nicole Iroz-Elardo:** Conceptualization, Investigation, Resources, Analysis, Writing. **Erika Austof:** Investigation, Analysis, Writing. **Ida Sami:** Investigation, Analysis, Writing. **Mona Arora:** Analysis, Writing. All authors reviewed the results and approved the final version of the manuscript.

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Tables

Table 1. Vaccination sites and data collection locations

Site	**Location 1 Sun Control, full sun**	**Location 2 Shade Control, full shade**	**Location 3 Main Vaccination Tent, full shade**	**Location 4 Observation Area**	**Location 5**	**Location 6**
UArizona POD	Compacted grass	2-sided tent, no evaporative cooling	Extensive evaporative cooling	Compacted grass, In full sun	Walk-in line under permanent overhang/shade	Break tent in shade with evaporative cooling
Banner South POD	Gravel	3-sided break tent, no evaporative cooling	No evaporative cooling	Asphalt, under solar panels	Initial traffic direction location in full sun	Asphalt parking lot in full sun
Tucson Medical Center (TMC) POD	Asphalt road	3-sided break tent, no evaporative cooling on asphalt	Minor evaporative cooling, on asphalt	Asphalt, in full sun	Asphalt road under a tree	Check-in tent with evaporative cooler in shade on asphalt

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Table 2. Preliminary climatological report

	UArizona POD (March 31, 2021)	Banner South POD (April 1, 2021)	Tucson Medical Center (TMC) POD (April 2, 2021)
Ambient Air Temperature Minimum	49°F (9.4°C) at 6:19 AM	63°F (17.22°C) at 12:20 AM	62°F (16.7°C) at 6:25 AM
Ambient Air Temperature Maximum	88°F (31.1°C) at 4:22 PM	90°F (32.2°C) at 5:20 PM	89°F (31.7°C) at 3:31 PM
Average Humidity	13%	10%	15%
Average Wind Speed (mph)	6.4	17.3	6.2
Max wind speed (mph)	13	32	20
Cloud Cover	Minimal	2:30 - 3:30PM	Minimal

Source: U.S. NOAA National Climatic Data Center

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Table 3. Surface temperature summary statistics

	Average Vehicle Surface Temperature	**Average non-Vehicle Surface Temperature**	**Maximum Surface Temperature**	**Minimum Surface Temperature**
UArizona POD	117.4°F (47.4°C)	90.2°F (32.3°C)	158.7°F (70.4°C)	91°F (32.8°C)
Banner South POD	109.9°F (43.3°C)	96.2°F (35.7°C)	160°F (71.1°C)	78.5°F (25.8°C)
Tucson Medical Center (TMC) POD	112.5°F (44.7°C)	100.7°F (38.2°C)	170.9°F (77.2°C)	91.6°F (33.1°C)
Overall	112.6°F (44.8°C)	-	170.9°F (77.2°C)	78.5°F (25.8°C)
Overall non-Vehicle	-	96.7°F (35.9°C)	166.9°F (74.9°C)	57.2°F (14°C)

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Figure Captions

Figure 1. Configuration of the Banner South POD on April 1, 2021

Caption: Arrows indicate the direction of task flow following the route of clients through the checkin-in tent to the vaccination tent and finally to the observation area before exiting the site.

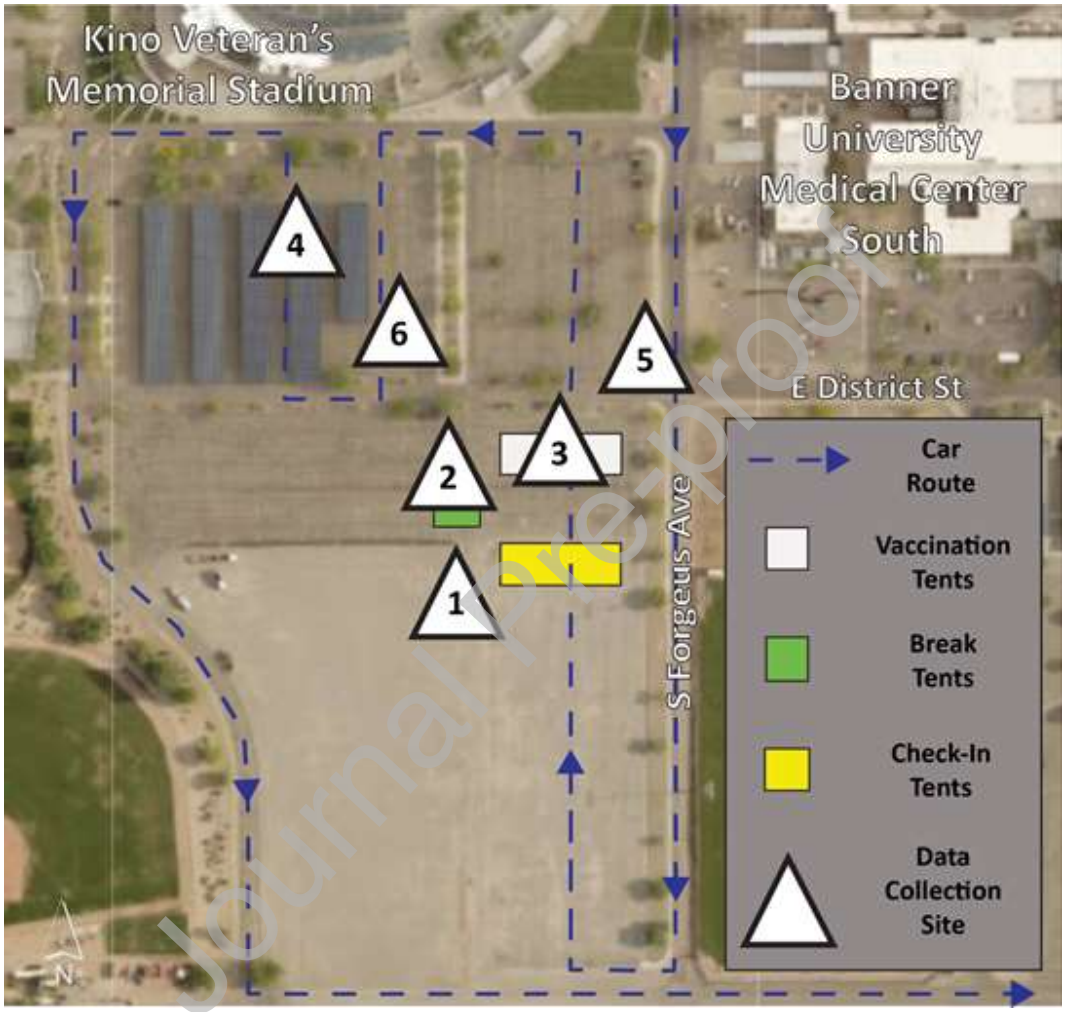

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Figure 2. Ambient Air Temperature and Reported Weather at the PODs

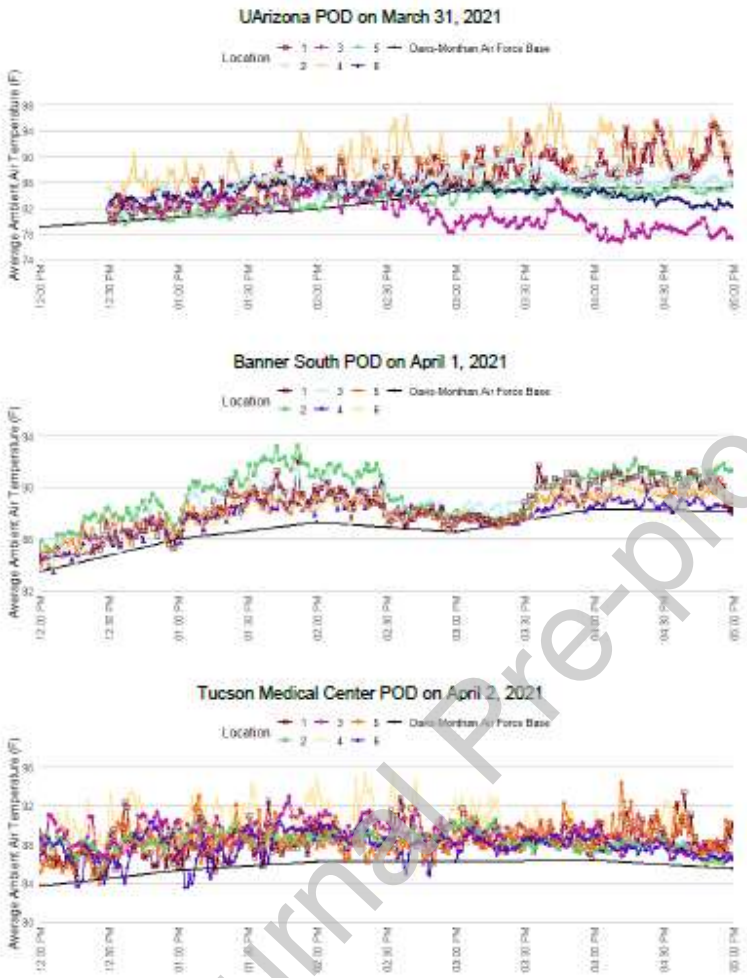

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Figure 3. Wet Bulb Globe Temperature (WBGT) and Reported Weather at the PODs

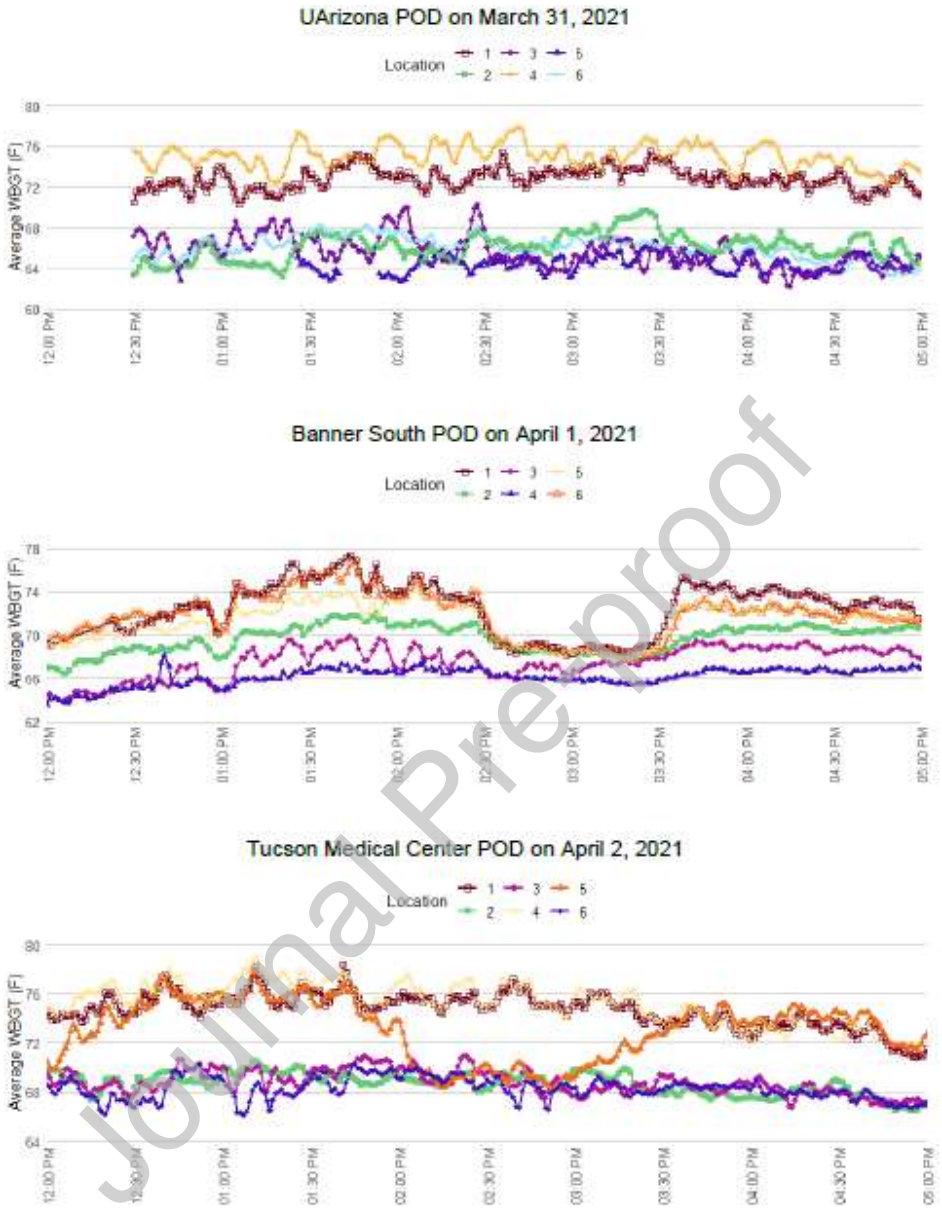

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Figure 4. FLIR Thermal Image at the UArizona POD
Caption: Thermal image showing temperature differentials with evaporative coolers on the left colder (purple) and vehicles hotter on the right hotter (yellow).

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