

Predictors and Strength of Microclimate Buffering in the Gunnison Valley

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Abstract:

Microclimate is an incredibly important factor in understanding how organisms behave and interact with their environment. Microclimate is defined as climate on a very small spatial resolution, referring to areas that may have differing climates than their surrounding macroclimate. Depending on the context, microclimate can refer to areas of many sizes, but in this study, microclimate refers to areas on the order of magnitude of about 1 square kilometer. In order to truly understand the interplay between organisms and climate, accurate climate understanding is necessary. Unfortunately, the majority of climate models are created at coarse spatial resolution, and weather measurements don't typically represent the near-surface environments where most organisms are found. Since an organism depends on the local microclimate in its specific area, understanding of microclimate behavior at small spatial scales is crucial for comprehending the interplay between climate and ecology.

In this study, we explore the buffering capability of four microclimates in the Gunnison Valley against summer season temperature extremes. Buffering is a measure of resistance against extreme temperature change. Buffered microclimates have relatively stable conditions compared to the average climate at large scales, and thus can serve as a barrier against drastic change in macroclimate. We found that near-surface microclimate buffering, measured at 10 cm and compared to a valley wide average temperature measurement, is relatively weak, and in many cases was negative, where near surface microclimate temperatures had more extreme daily minimums and maximums than the reference macroclimate.

This weak buffering is relevant because it represents the fact that the measured microclimate areas had relatively little capacity to prevent extreme temperature fluctuation. The ability of an area to act as a biological refuge against climate stresses, like drought and frost events, depends on its ability to prevent large scale temperature fluctuations. Especially as climate may drastically change in the future, microclimate buffering could become increasingly important for protecting against species extinction.

Introduction:

Understanding the reaction of different organisms to changes in climate is a cornerstone of much of the research done at RMBL. Crucial research is done to understand the interplay between climate and plant growth, and potential effects of future climate change on vital mountain ecosystems (Loik, Redar, & Harte, 2001). At many RMBL research sites, climate sensors are used to measure temperature, humidity, precipitation, etc. However, to truly understand the interplay between microclimate and biological systems, precise understanding of microclimate behavior is necessary.

Microclimatic buffering is the ability of a microclimate to resist change and maintain climatic conditions around some moderate value, even when large, extreme changes in the macroclimate may be occurring (Walther 2002). In order to understand the concept of buffering, one could consider a perfectly buffered system: a house. As outside temperature changes, the temperature inside a house will remain constant, providing a stable environment for life. Ideally, a buffered microclimate acts somewhat like a house for plants and animals. As macroclimate temperature rises and falls, a highly buffered area would have a much more stable temperature.

Buffered areas can provide an important refuge for at-risk species, especially as the risk of climate change increases. Previous studies have found that buffered microrefugia could drastically decrease extinction risk as the climate warms (Maclean 2015). As temperature rises, plants with low-temperature requirements migrate into areas buffered against high temperatures, allowing the species to continue to survive. As the global average temperature increases, wilder fluctuations in temperature are likely to occur. Buffered regions could act as an important refuge for threatened plants, animals, and insects, as temperatures vary erratically. Microrefugia could drastically lower extinction risk as the climate warms (Suggitt 2018). Microclimatic buffering is especially important when considering the effect of long-term climate change on ecosystems.

In this study, we focused on understanding patterns of microclimatic buffering across the Gunnison Valley. The Gunnison Valley is an especially attractive location to study microclimatic buffering because of the drastic variation in elevation across a relatively short

distance, as well as the wide diversity of ecosystems. Buffering can occur on many scales, but this study specifically focuses on the ability of microclimates to buffer maximum and minimum daily temperature against changes in larger-scale macroclimate maximum and minimum daily temperature. These variables were chosen because maximum and minimum daily temperature can be extremely biologically relevant for many species of both plants and animals. While high maximum temperatures can increase drought stress, low minimum temperatures late in the spring can also be devastating for many plant populations, as late frosts can kill buds and inhibit reproduction for the season (Inouye 2000).

However, microclimate behavior is extremely complex. Many variables, such as large and small-scale topography, soil moisture, elevation, vegetation, and vapor pressure deficit, to name a few, can have large effects on temperature (Davis 2018). However, at the most basic level, temperature is determined by net heat flux in and out of the system. The main source of incoming heat is the influx of solar radiation, while outgoing heat is mainly due to latent heat loss, outgoing thermal radiation, and sensible heat loss (Maclean 2018). Therefore, environments that limit solar radiation influx will likely have lower maximum daily temperatures than those with high radiation influx. Thick canopy cover and topographical obstructions are the main limiters of the influx of solar radiation. However, canopy cover likely also has an insulating effect, trapping outgoing thermal radiation. Because of these effects, forested microclimates are expected to have a higher minimum daily temperature than the reference minimum temperature. Therefore, forested microclimates are expected to have a high level of buffering compared to non-forest environments.

Prediction:

Forested sites will have stronger buffering than both ridge sites and cove sites due to the decreased rates of net solar radiation flux.

A positive correlation exists between canopy cover and buffering.

A positive correlation exists between soil moisture and buffering.

Elevation contributes to buffering against high temperatures but detracts from low temperature buffering.

Solar radiation decreases buffering against high temperatures but has no impact on low temperature buffering.

Methods:

I analyzed microclimate sensor data from 12 sensors around the Gunnison Valley. We set up arrays of microclimate sensors at 4 different elevations at the beginning of October 2019 spanning a large elevation range (2456 – 3445m). With daily microclimate sensor data from October to July, the model should have enough data to give a relatively accurate description of microclimate at the 4 locations. The 4 locations are at Almont, Jack's Cabin, Paradise Divide, and Slide Rock Road. Locations are shown on the map (figure 13). At each location, three microclimate sensors are set up: one in a forested site, one in an exposed ridge site, and one in a sheltered, but not forested site. At each site, a TOMST TMS-4 climate logger was installed to take soil moisture and temperature at multiple levels above and below the ground (Wild 2019). These 4 locations at diverse elevations provide a wide enough variety of data to analyze buffering capacity.

At each site, a variety of measurements are taken continuously by the sensors. The sensors record temperature at several heights: 2 m, 10 cm, 1 cm, and -5 cm. The sensors also record soil moisture just below the surface. My project will be using the above-ground 10 cm temperature measurements and soil moisture measurements as continuous data from the microclimate sensors. Measurements are taken every 15 minutes.

Temperature data were compared to other site attributes that might influence microclimatic buffering. Each site was mapped using a GPS unit with an accuracy of

approximately 3m. This gives valuable data regarding a site's location and elevation, but also allowed us to estimate other site attributes like potential solar radiation. Discrete measurements of canopy cover of each microclimate site were also taken. To estimate canopy cover at each site, four photos were taken facing skyward on a clear day, and the average dark pixel percentage was used as the average canopy cover.

To model the impact of the given parameters on temperature, first data are taken from gridMET, which is a high spatial resolution (4 km) macroclimate dataset. Data from gridMET are a good approximation for the external daily maximum and minimum temperatures because the large scale-climate dataset accounts for deviations in microclimate temperature from large-scale climate events. Daily minimum and maximum temperature are then taken from each microclimate sensor.

Analysis:

First, the raw climate data were reprocessed into a more manageable and easily comparable form. The data were sorted so that days where the ground was snow-covered were not considered. A daily maximum and minimum measured temperature were extracted for each sensor location and sensor height in order to compare to the daily maximum and minimum gridMET temperature. Daily minimum and maximum gridMET temperature data were taken as a valley-wide average encompassing all sites, in order to better compare the effects of elevation and other influential factors. Soil moisture, gridMET data, and ground sensor data were then combined into a single data sheet to be easily analyzed.

Discrete measurements were taken as well. Canopy cover was measured by taking the average pixel density of 4 upward facing photos around each forested climate sensor. Cove and ridge sensors were assumed to have 0 canopy cover. Elevation values were measured at each site using GPS. Solar radiation data was taken using the GRASS GIS r.sun package, which estimates solar radiation at each site on a given day of the year based on sun angle, latitude, ground slope, shade from local topography, and day length. Solar radiation is measured in Watts per square meter per day. The discrete measurements for each sensor location serve to give a prediction of buffering capability at each location.

For each site, a maximum and minimum temperature buffering analysis was made. First, plots were made comparing daily measured minima and maxima temperatures with the corresponding valley-wide daily extreme gridMET temperature. A least squares regression was performed on the data and a linear trend was fitted. Because the dataset is relatively small due to the limited timeframe of the study, a bootstrapping method was used to repeatedly sample the existing data and develop a more reliable estimate of fit. The first method of buffering analysis is to take the slope of the relationship between microclimate and macroclimate data. For the second method of buffering analysis for each site, a 1:1 line was added for comparison, and the average area between the 1:1 line and the linear trend was taken (Davis 2018). The 1:1 reference line was used because a 1:1 ratio would represent a site with zero buffering. Both methods of buffering were used because high temperature offsets due to elevation, while important when considering buffering, wash out the effects of other influential variables on buffering capability. For this reason, area buffering is used when considering the effect of elevation on buffering, while the slope measure of buffering is used for all other analyses.

Buffering values for each site are then compared against potential defining characteristics of the site, such as average canopy cover, soil moisture, incoming solar radiation, and elevation. These variables were chosen as they are likely to have the greatest influence on microclimate (Maclean 2018).

Results:

In the study, significantly less buffering was observed than expected. Most sites experienced negative buffering, where measured temperatures near the ground actually experienced higher variation in temperature than the given reference temperature.

This effect was especially pronounced when viewing buffering against daily maximum temperature. The majority of the sites, except the high elevation paradise divide site, had high area buffering values. In this context, when considering buffering against maximum temperatures, a high area buffering value represents a positive temperature increase, and

therefore low buffering. Because of this, many of the sites were actually negatively buffered against high daily maximum temperatures. See table 2 for exact values.

All types of sites were also negatively buffered against daily maximum temperatures when considering the slope measure of buffering. The one exception to the rule there was the Slide Rock Road cove site, which had significant positive buffering against high maximum temperatures. See figures 1,3, and 5 for illustrations of buffering against maximum temperature.

Daily minimum area buffering values were much closer to zero. Daily minimum temperature seemed to correspond more closely with the reference measurement. Cove sites had a lower temperature offset from the reference temperature. Again, in this case, when considering buffering against minimum temperature extremes, a high area buffering measure represents positive buffering against extreme low temperatures. See table 1 for exact values of buffering.

When considering the slope measurement of buffering, the sites had significantly better buffering against minimum temperatures than maximum temperatures. The majority of maximum temperature slopes were above one, while the majority of the minimum temperature slopes were below one, suggesting negative buffering against high extremes, and positive buffering against low extremes.

A 10% increase in canopy cover correlated with a .036-degree slope increase in max temperature buffering (Figure 9). There was no correlation with min temperature buffering (Figure 10).

A 1000 ft increase in elevation correlated with a 3.3-degree area increase in max temperature buffering (Figure 7). A .78-degree area decrease is expected in min temperature buffering (Figure 8).

A 1000 watts/sqm/day increase correlated with a .27-degree slope decrease in max temperature buffering (Figure 11). There was no correlation with min temperature buffering (Figure 12).

Discussion:

Overall, there was significantly less buffering than expected. Compared to the reference extreme temperatures, measured microclimate temperatures would often have higher minimum and lower maximum temperatures. The high daily maximum temperatures could be due to an incoming solar radiation effect that highly affects the surface temperature but has a lesser effect on the macroclimate reference temperature. The low nightly temperatures, especially at the cove sites, could be due to some sort of a small-scale cold air pooling effect near the surface that could overpower potential buffering effects.

Whatever the reason, the fact remains that significantly less buffering was measured at the 12 microclimate sensor locations. This suggests that the Gunnison Valley, while diverse, may have weak biological resistance to extreme macroclimate temperature events. If these microclimates cannot act as refugia for certain at-risk species, risk of extinction and loss of diversity may be higher than expected.

As expected, elevation had a large impact on microclimate buffering. It is well established that high elevations have relatively lower temperatures than low elevations due to higher exposure and increased thermal radiation loss into space. As such, it was not surprising that elevation was well correlated with resistance to high maximum daily temperatures. However, this increased buffering against high maximum temperatures does not come with a comparable weakness to low temperatures. If figures 7 and 8 are compared, it is easily seen that while low temperature buffering decreases with increased elevation, it does not decrease at the same rate as high temperature buffering increases. This suggests that high elevation areas could act as important refugia against future extreme high temperatures, without correspondingly increasing the risk of low temperature events.

Canopy cover weakly correlated with microclimate buffering against maximum temperatures (figure 9). As explained in the introduction, this is likely due to a shade effect, decreasing the incoming solar radiation into the site, and therefore decreasing temperatures during the day, when maximum temperatures are likely to occur. Canopy cover did not correlate with buffering against minimum temperature (figure 10). Previous work suggests that canopies should have an insulating effect against the night sky, keeping forested sites warmer

at night (Davis 2018). However, this work was done in the Northwestern United States, where forests are significantly wetter and thicker than in the Gunnison Valley. Previous work also noted that canopy buffering effects also start to become significant after canopy cover becomes higher than 50%. All 4 forested sites were at or below 50% canopy cover, which suggests that there simply was not enough cover to create any significant insulating effect. In the future, microclimate sensor sites could be set up in thicker and wetter canopies in the Gunnison Valley to capture a more diverse range of forested areas.

Incoming solar radiation correlated highly with reduced buffering capacity against maximum temperatures (figure 11). Logically, this makes sense, as areas with reduced topographical cover from the sun will naturally experience greater near-surface warming. Additionally, incoming solar radiation did not correlate with buffering against minimum temperature (figure 12). This makes sense, as minimum temperatures occur at night, and there is no incoming solar radiation at night.

Unfortunately, soil moisture data returned erratic results, and after further analysis, it seemed that much of the soil moisture data was thrown off by sensor malfunction due to freeze-thaw cycles in the late fall and early spring. There was not enough data to do a comprehensive analysis of the effect of soil moisture on buffering with only a single short incomplete growing season worth of data. Hopefully, with more data in future years, analysis on the effects of soil moisture on near surface microclimate buffering can be done.

Especially as climate change alters the macroclimate in unexpected ways, buffered microclimates will become especially important for maintaining the stability of ecosystems. It is important to continue taking microclimate data across a longer timeframe and across a more diverse variety of site locations to be further able to analyze potential buffering effects. With a greater understanding of buffering, it may be possible to anticipate the severity of consequences of extreme future climate events in the Gunnison Valley. Of course, modeling climate is incredibly complicated, and building a true understanding of microclimate buffering will certainly be a long journey, albeit a worthwhile one. Hopefully this study, while quite limited in its scope, will provide a look into what may be required to build that eventual understanding.

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Table 1: Buffering against minimum temperature for each of the 12 sites

Site	Type	Slope Buffering	Area Buffering	Offset
Almont	Forest	0.90	-0.78	-2.00
	Ridge	0.81	2.90	0.49
	Cove	0.76	3.42	0.46
Jack's Cabin	Forest	0.89	1.79	0.38
	Ridge	0.86	2.10	0.34
	Cove	0.86	-1.41	-3.11
Slide Rock Road	Forest	0.88	0.85	-0.65
	Ridge	0.78	-1.63	-4.35
	Cove	1.05	-4.95	-4.38
Paradise Divide	Forest	0.80	2.36	-0.09
	Ridge	0.89	0.57	-0.86
	Cove	1.05	-4.95	-4.38

Table 2: Buffering against maximum temperature for each of the 12 sites

Site	Type	Slope Buffering	Area Buffering	Offset
Almont	Forest	1.32	6.53	4.15
	Ridge	1.26	9.57	7.61
	Cove	1.39	9.56	6.61
Jack's Cabin	Forest	1.52	3.96	0.08
	Ridge	1.07	8.88	8.37
	Cove	1.32	9.69	7.29
Slide Rock Road	Forest	1.20	-1.02	-2.52
	Ridge	1.33	6.10	3.61
	Cove	0.84	7.57	8.78
Paradise Divide	Forest	1.57	-4.02	-8.27
	Ridge	1.07	2.59	0.21
	Cove	1.23	0.06	-1.65

Figure 1: Buffering against maximum temperature at the 4 Forest sites. Axes give the measured and reference maximum temperature for a given day in degrees celsius.

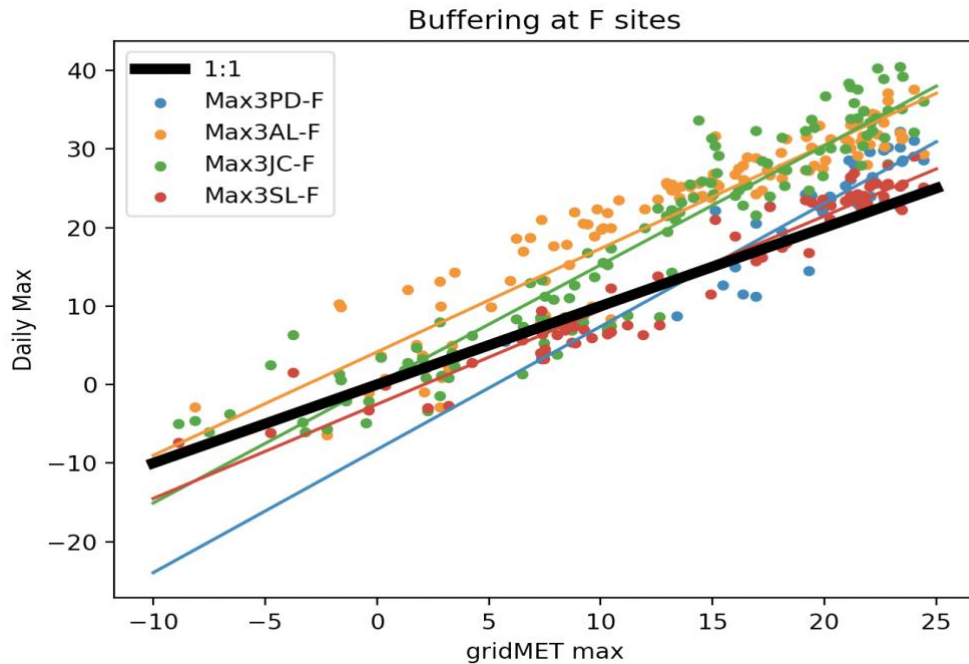


Figure 2: Buffering against minimum temperature at the 4 forest sites. Axes give the measured and reference minimum temperature for a given day in degrees celsius.

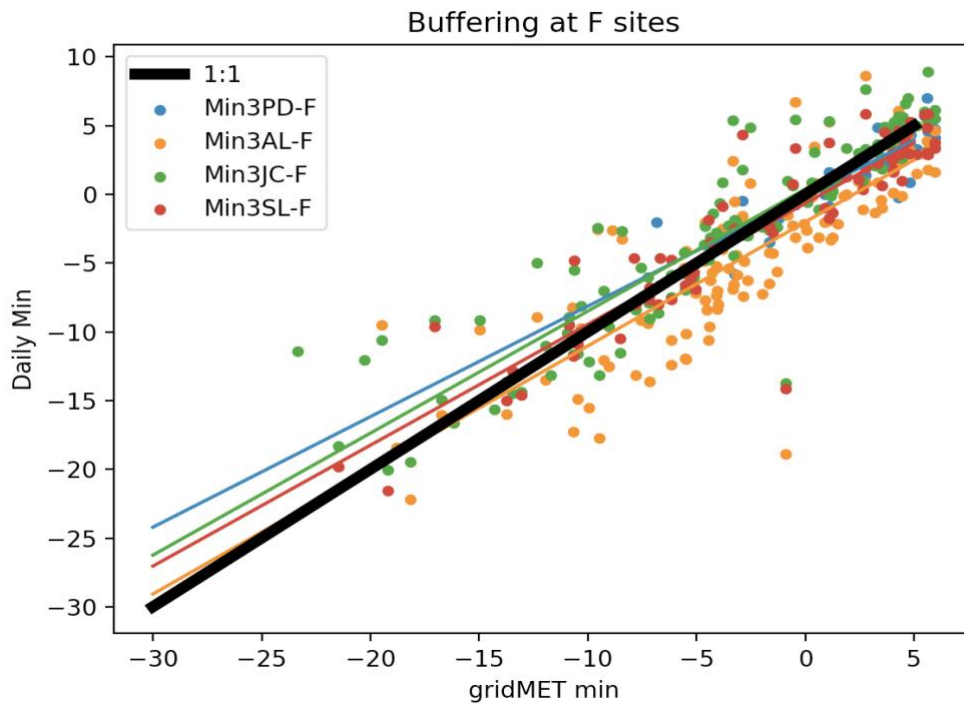


Figure 3: Buffering against maximum temperature at the 4 cove sites. Axes give the measured and reference maximum temperature for a given day in degrees celsius.

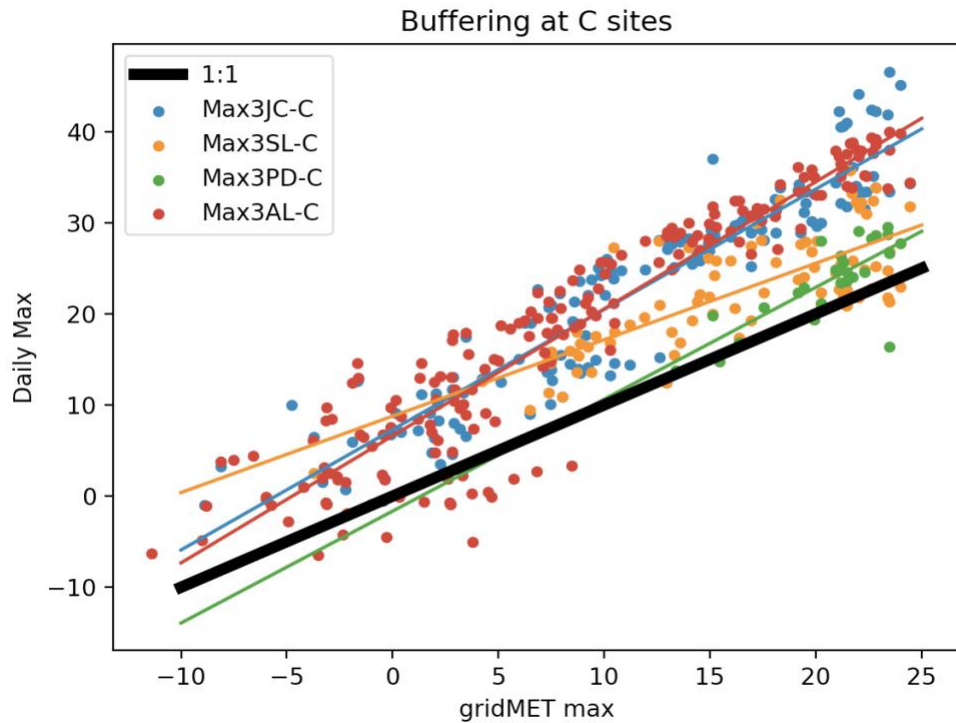


Figure 4: Buffering against minimum temperature at the 4 cove sites. Axes give the measured and reference minimum temperature for a given day in degrees celsius.

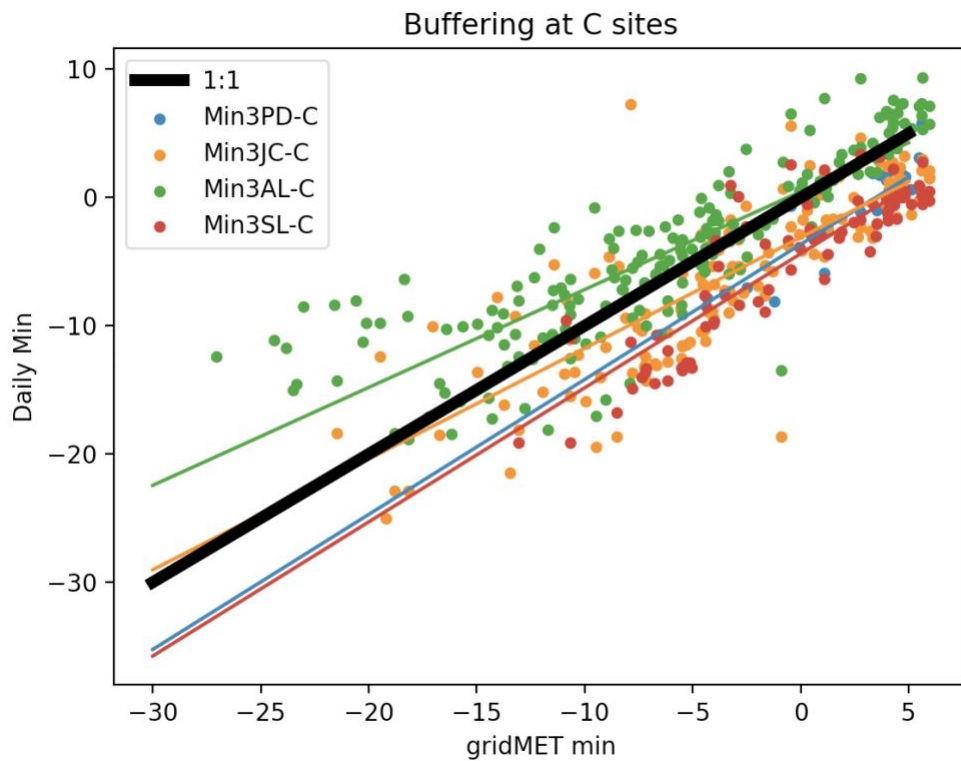


Figure 5: Buffering against maximum temperature at the 4 ridge sites. Axes give the measured and reference maximum temperature for a given day in degrees celsius.

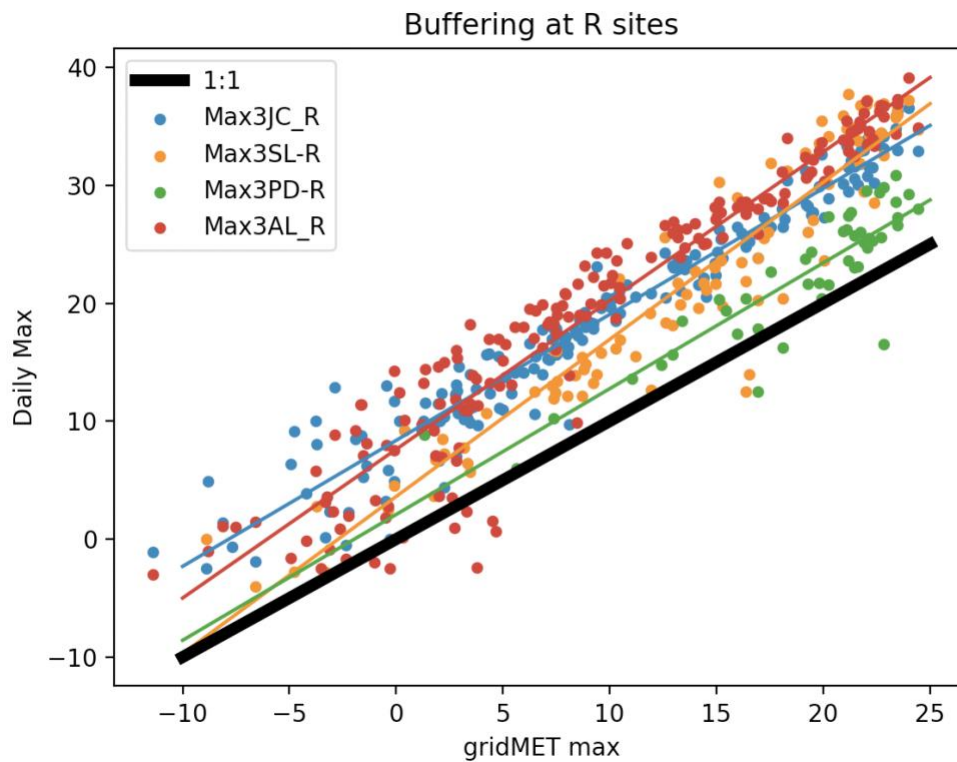


Figure 6: Buffering against minimum temperature at the 4 ridge sites. Axes give the measured and reference minimum temperature for a given day in degrees celsius.

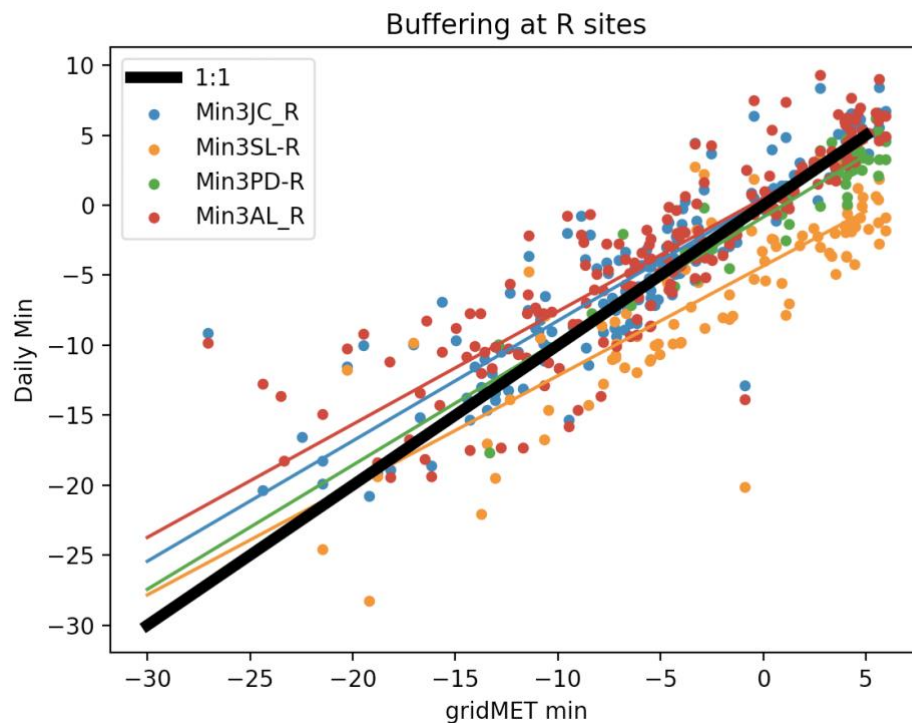


Figure 7: Comparison of elevation and buffering against maximum temperatures. Buffering is here analyzed using the area measure of buffering.

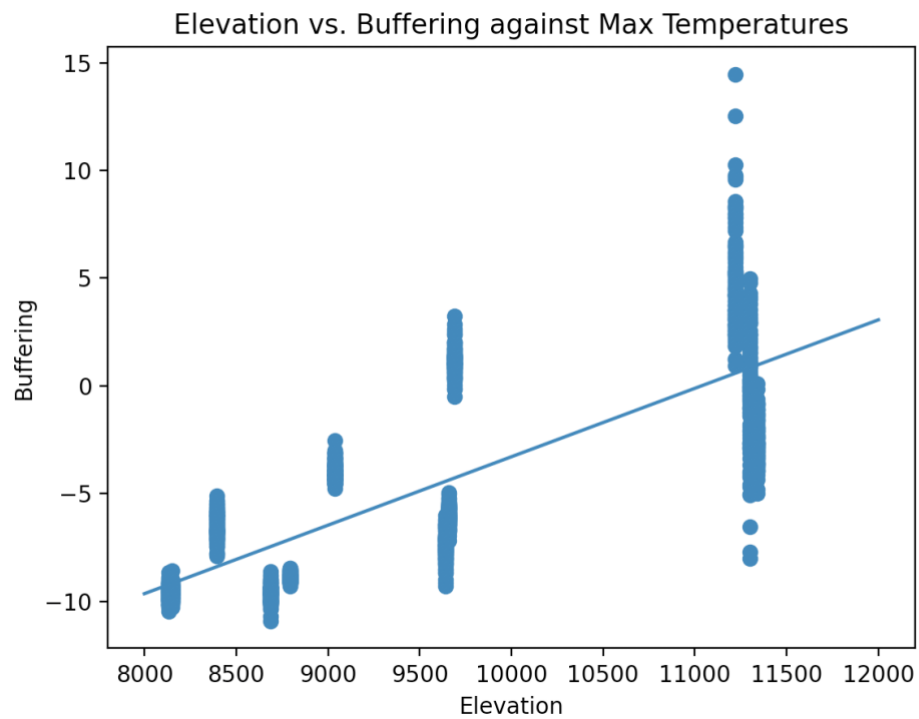


Figure 8: Comparison of elevation and buffering against minimum temperatures. Buffering is here analyzed using the area measure of buffering.

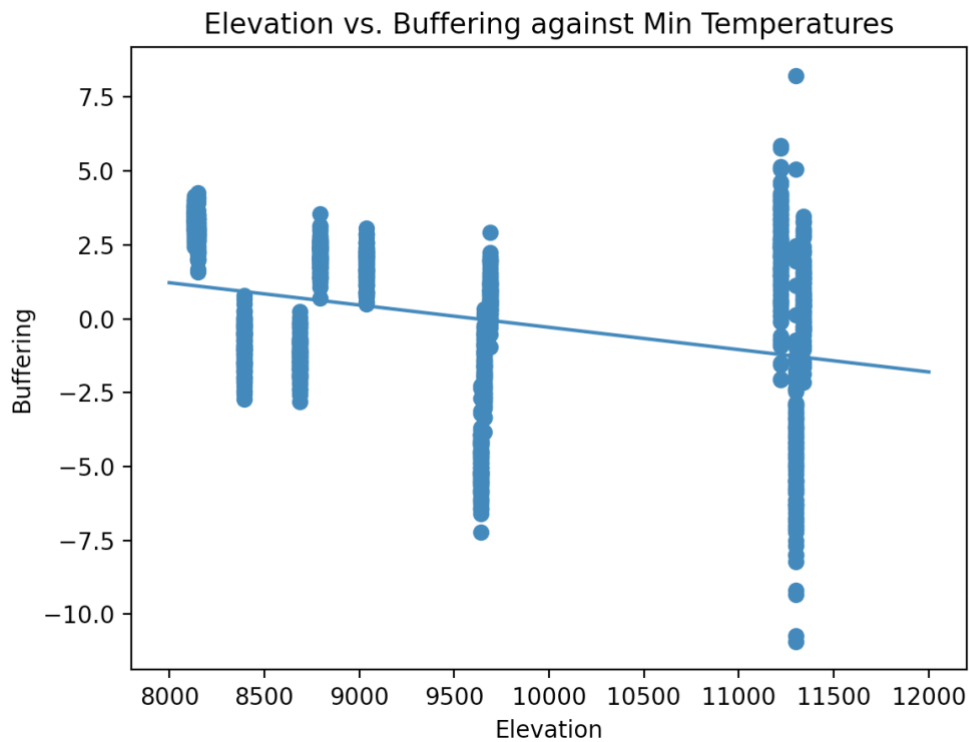


Figure 9: Comparison of canopy cover and buffering against maximum temperatures. Buffering is here analyzed using the slope measure of buffering.

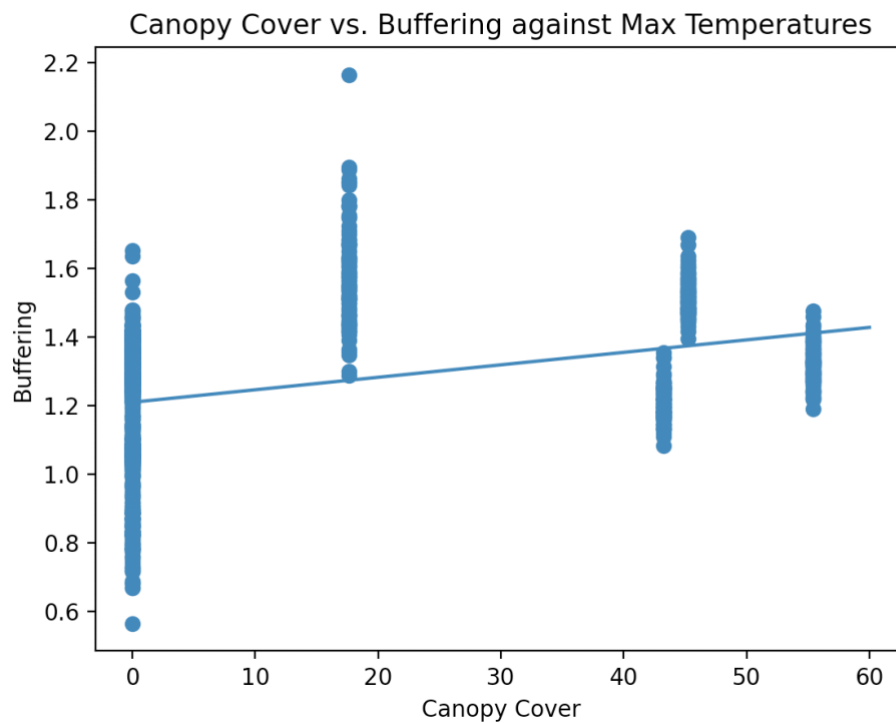


Figure 10: Comparison of canopy cover and buffering against minimum temperatures. Buffering is here analyzed using the slope measure of buffering.

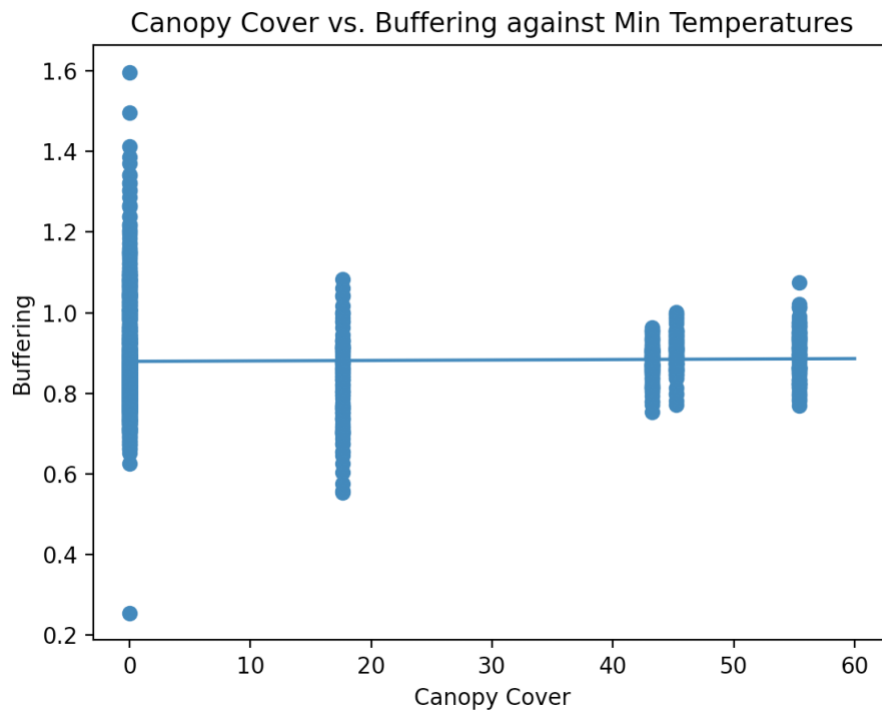


Figure 11: Comparison of expected mean solar radiation and buffering against maximum temperature. Buffering is here analyzed using the slope measure of buffering.

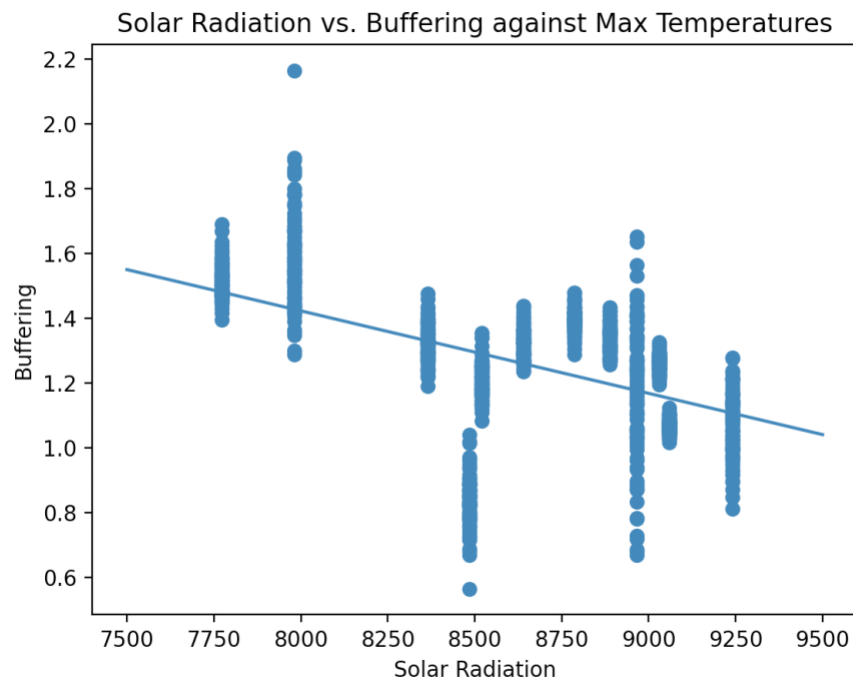


Figure 12: Comparison of expected mean solar radiation and buffering against minimum temperature. Buffering is here analyzed using the slope measure of buffering.

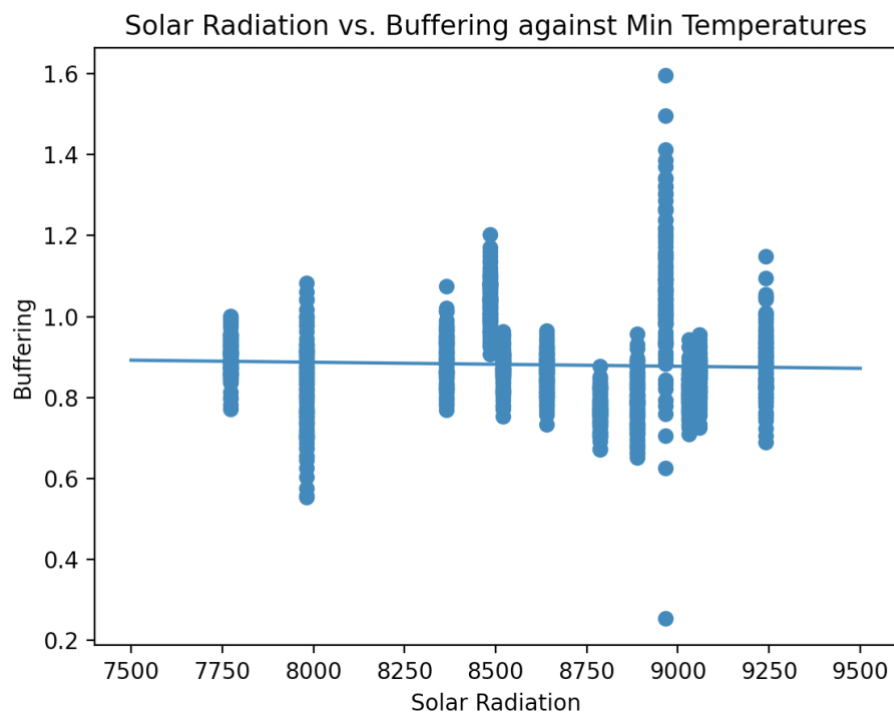


Figure 13: Map of the 12 sensor locations around the Gunnison Valley

