III. Discussion of Results

A. Event Identification

The number of events satisfying the heat wave definition criteria varies widely between stations. For the unfiltered data following the definition requiring at least 3 consecutive days with maximum temperature anomalies greater than or equal to 10, with one of those days having an anomaly greater than or equal to 15, resulted in Red Bluff having the highest number of events for the California Central Valley stations, 31, and Merced having the fewest events for Central Valley stations, 4. Sacramento experienced 24 events. Three of the Central Valley stations had a total of 10 events or less. Among the California coastal cities, seven out of the ten stations had 18 or more heat wave events, with the maximum number, 37, being reached at the Graton station. Crescent City, Eureka, and Santa Barbara all experienced ten or less total events. The stations located in the surrounding states experienced many heat waves under this definition, with Portland, OR, experiencing the maximum number of 40 events. Reno and Tonopah, NV, experienced less than 5 events each. These heat wave events for Sacramento following the initial heat wave definition and using unfiltered data can be seen in Appendix A, Table A.1.

The filtered data resulted in similar results as the unfiltered data, with the total number of events for each station either being the same or a few more or less than the unfiltered total. The only stations that exhibited a difference in the total number of events more than 5 were Sacramento and Pendleton, OR. Sacramento had a decrease of 6 events, going from 24 to 18 events, and Pendleton had an increase of 8 events, going

from 25 to 33 events. The filtered data events for Sacramento can be seen in Appendix A, Table A.2.

Based on the event identifications above, the number of events tends to be least for Central Valley stations near, but south of, San Francisco, stations near the coast, including Santa Barbara, Crescent City, and Eureka, and also the Reno and Tonopah, NV, stations located in the Great Basin desert.

The resulting number of heat wave events based on including the third criterion of requiring the average maximum temperature to be greater than or equal to 100˚F changed slightly for some California Central Valley cities, and not at all for others. For the unfiltered data, all Central Valley cities except for Red Bluff, Merced, and Bakersfield decreased in the number of heat wave events experienced under this definition. The highest and smallest number of events for one city still remained the same with 31 events in Red Bluff and 4 events in Merced. The largest decrease in the number of events was observed for Sacramento, which decreased by 5 events, now with 19 events. Both the California coastal stations and the stations outside of California underwent a drastic change in the number of heat wave events with the inclusion of the new criterion. Five of the 10 coastal stations now resulted in no heat waves experienced. These cities were Crescent City, Eureka, San Francisco, Monterey, and Santa Barbara; note that San Francisco had 32 heat waves by the anomaly criteria alone. Simply put, it never reaches 100˚F (38ºC) at these coastal stations. However, Covelo experienced 15 events, and Graton, the coastal station in closest proximity to Sacramento, experienced 13 heat wave events. Two of the 10 stations in the surrounding states, Seattle, WA, and Tonopah, NV, also had no heat waves according to these criteria and Medford, OR, had the highest

amount of heat waves, 15, in these surrounding states. The heat wave events and information for Sacramento for the unfiltered data for this definition can be seen in Appendix A, Table A.3.

For the filtered data, similar decreases were seen with the average maximum temperature threshold put into place. Fourteen heat waves occurred in Sacramento. The California coastal and surrounding states' stations again exhibited similar decreases in the number of events, with 8 of the 20 stations now experiencing no heat waves. The number of events at 8 of the 10 valley stations decreased. The events and information for Sacramento using filtered data and this definition can be seen in Appendix A, Table A.4.

From the event identifications above following the definition requiring the event average maximum temperature to be greater than or equal to 100˚F (38ºC), the number of events tends to be least for stations near the coast, Central valley stations south of Modesto, and stations located in the Great Basin desert. The number of events also tends to be small at the inland stations in Washington and Oregon. The number of events tends to be highest for the Central valley stations north of Modesto, and the Graton and Covelo stations.

B. Rankings

Table 3.1. Ranking of Sacramento heat waves based on the highest consecutive 3-day anomaly averages and the highest event maximum temperature. Heat waves were identified using the definition requiring at least 3 consecutive days having temperature anomalies greater than or equal to 10, with one of those days having an anomaly greater than or equal to 15, using unfiltered data. Information also includes the highest 3-day anomaly average during the event, the highest maximum temperature during the event, the start and end date of the event and duration. Note that several events ranked by highest maximum temperature have the same highest event maximum temperature.

Rank (based on highest 3-day average anomaly)	Highest 3-day average anomaly in the event	Rank (based on highest event maximum temperature)	Highest Maximum Temperature in the event, ºF (ºC)	Event Start Date	Event End Date	Duration
1	18.77	1	112 (44)	19910702	19910704	3
2	17.89	17	104 (40)	19960602	19960608	7
3	16.93	19	104 (40)	19790911	19790916	6
4	16.92	3	111 (44)	20060720	20060725	6
5	16.88	14	105 (41)	19850609	19850616	8
6	16.56	2	112 (44)	19880716	19880719	4
7	16.05	4	110 (43)	19960809	19960815	7
8	15.37	7	108 (42)	19880903	19880905	3
9	15.27	16	105 (41)	20000613	20000616	4
10	14.75	18	104 (40)	19830911	19830915	5
11	14.49	5	109 (43)	19900805	19900811	7
12	14.40	12	105 (41)	20030626	20030628	3
13	14.35	9	108 (42)	19970804	19970807	4
14	14.24	21	102 (39)	19910607	19910611	5
15	13.58	6	109 (43)	19900710	19900713	4

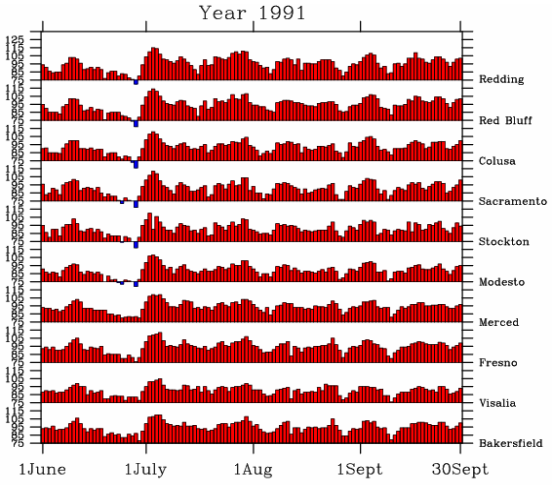
Events were ranked based on the highest temperature reached and by the highest 3-day average anomaly temperature. The two ranking methods generated different orders of the top 15 heat wave events in Sacramento. Some events were present in both top 15 lists, but at different ranks. Some events appeared in one list and not the other. The different orderings for unfiltered data following the first heat wave definition are in Table 3.1 above. When the unfiltered data, according to both heat wave definitions, were ranked by the two methods, five of the top 10 heat wave events were shared by the two

different ranking methods. The 02 July 1991 to 04 July 1991 event was the hottest event when ranked by both methods, meaning this event exhibited both the highest average temperature anomalies and the highest maximum temperature of all the events. An interesting observation for the unfiltered data rankings was that the events that took place from 02 June 1996 to 08 June 1996 and from 11 September 1979 to 16 September 1979 were both in the top three hottest heat wave events according to the ranking based on the 3-day average of temperature anomalies, but were at the bottom of the list when ranked by the highest maximum temperature. This shows that some events that are the most intense based on temperature anomalies might not be so intense when using absolute temperatures only. These two events mentioned above had anomalies of 17.89 and 16.93, respectively, and a maximum temperature of 104ºF (40ºC). There tends to be no relation between the duration and the rankings of the events. For instance, the most intense heat wave according to both rankings is 3 days long. Short events are also seen at lower ranks as well. Longer duration events are also seen throughout the rankings in no particular order.

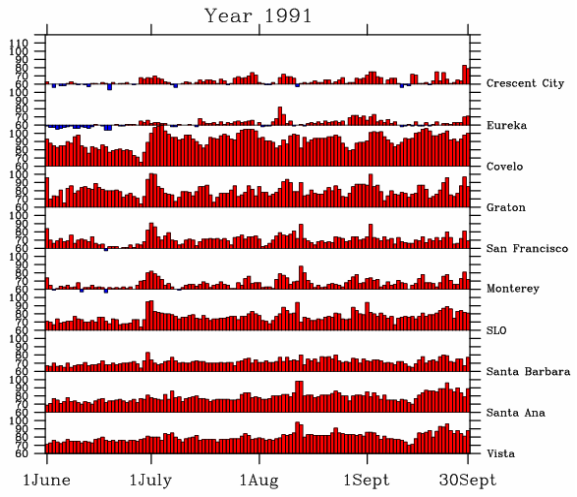
Although most events were ranked in a similar order, there were some differences in the ranking orders between the filtered and unfiltered events. In the 3-day average anomaly ranking the 11 September 1979 event was ranked third for the unfiltered data and sixth for the filtered. This event's 3-day average anomaly value was 16.93 for the unfiltered set and 16.34 for the filtered set. In addition, the 13th and 15th ranked events of the unfiltered data and the 14th and 15th events of the filtered data were not seen on the other's ranking list. A major difference between the filtered and unfiltered event maximum temperature ranking lists was the rank of the 11 September 1979 event. This

event was ranked eighth in the unfiltered ranking and 19th in the filtered ranking, outside of the top 15 events. The filtering causes the maximum temperatures to increase or decrease slightly, which is just enough of a difference to alter some of the rankings. The ranked events for Sacramento for both event definitions and ranking methods for the unfiltered and filtered data can be viewed in Appendix A, Tables A.5 through A.8.

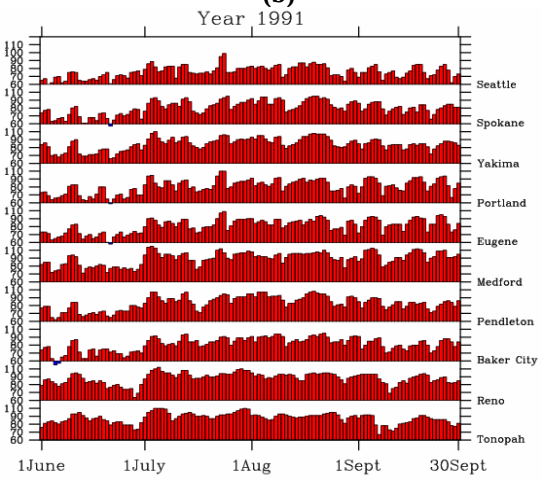
Bar charts that were created from daily maximum temperatures for summers in which Sacramento's top 15 heat waves took place, with events defined by the first heat wave definition and ranked by the highest 3-day anomaly averages, can be seen in Appendix B, Figures B.1 through B.10. These bar charts were made using unfiltered data. The summer in which the top ranked heat wave in Sacramento took place, 1991, is shown below, for all stations, in Figure 3.1. This event occurred from 02 July 1991 to 04 July 1991. The advantages of such bar charts are 1) to show temperature trends, including periods of unusual heat at the different stations, and 2) to show how consistent an event is across the stations.



(a)



(b)



(c)

Figure 3.1. Bar charts of daily maximum temperatures for all 30 stations for the summer of 1991, in which the highest ranked Sacramento heat wave event, ranked according to the highest 3-day anomaly averages, occurred. The dates for this event were 02 July 1991 to 04 July 1991. Charts are divided into the regional areas of a) the central valley, b) the coast, and c) the surrounding states.

C. Matchings and Spatial Extent

Unfiltered dates satisfying the first definition of a heat wave at each station were compared with heat event dates for Sacramento. The dates of the top 15 events only from each station were then compared with Sacramento's top 15 event dates, using both ranking methods (one based on the highest 3-day average anomaly temperature and one based on the highest event maximum temperature). The two ranking methods produced similar numbers of matches. If there was a difference in the number of matches between the two sets, it varied, at the most, by three event matches. The largest number of matches was seen in the California Central Valley stations around the Sacramento area. Redding, Red Bluff, and Colusa to the immediate north of Sacramento, and Stockton and Modesto to the immediate south displayed the largest number of matches for each ranked set. Stockton had the highest number of matches, 9, for the 3-day anomaly average ranked set and Red Bluff had the highest number, 8, for the maximum temperature ranked set, equivalent to the matching of 60% and 53.3% of Sacramento's top events, respectively. The lowest number of matches among the valley stations was seen in Merced, Fresno, and Visalia, with each having 3 matches when ranked by the 3-day anomaly averages, and 1 match when ranked by the maximum temperature. The matches in the surrounding states were small for both rankings, with no more than 3 matching events. The coastal stations of Graton, San Francisco, and Monterey had higher numbers when the matching scheme was performed with the highest 3-day average anomaly ranking method than the method using the highest maximum temperature of each event, showing that the maximum temperature anomalies at these stations and the Sacramento station are comparative. The number of matching heat waves is smaller when matched

based on the highest maximum temperature of each event because the Graton, San Francisco, and Monterey stations do not experience as high of summer temperatures as the Central Valley Sacramento station, and these anomalous events with lower temperatures are not selected by the ranking based on the highest event maximum temperature. Crescent City and Eureka had no matching events when ranked by each method, and Tonopah, NV had no matches when ranked by the maximum temperature method. The number of matches for the unfiltered data according to this definition can be seen in Appendix A, Table A.9.

When the matching scheme was performed on the unfiltered data using the second definition of a heat wave including the average maximum temperature threshold criterion, the number of event overlap matches decreased for most stations compared to the number of matches using the first heat wave definition. It must be remembered however, that the number of identified heat wave events for many of the stations is also smaller using this definition. The highest number of matches for both ranking methods applied to the events identified by the first heat wave definition was again found at the Central Valley stations surrounding Sacramento. Redding, Red Bluff, Colusa, Stockton, and Modesto had the highest numbers of matches among the Central Valley stations, and also among stations elsewhere as well. Red Bluff shared the highest number of matched events, 7, with Stockton when ranked according to the 3-day anomaly averages, and Red Bluff also had the highest number of matches when ranked by the maximum temperature. Fresno and Visalia had the fewest matches within the Central Valley. More than 10 stations along the coast and in the surrounding states had no matching heat wave events when the additional threshold requirement is added, using both rankings. Seven of these stations

that had no event matches had no identified heat wave events. Covelo, Graton, and Medford, however, did have 4 matches each, the most displayed by the other stations when ranked by the anomaly averages. Only Covelo still had 4 matches when ranked by the maximum temperature method. The number of matches for all stations for the unfiltered data with the implemented average temperature criterion can be seen in Appendix A, Table A.10.

For both heat wave definitions and ranking methods, it is observed that the farther away from Sacramento that stations are located to the north and to the south through the Central Valley, the fewer number of matching heat wave events are exhibited by stations, except for Bakersfield, which has more event matches than other Central Valley stations to the north. However, the number of matches cannot be based on distance in every direction. For example, Bakersfield and Seattle are farther than Reno, yet both stations have more event matches than Reno. The pattern of matches is like what one expects from the 850hPa level temperature field chart in Figure 1.1 in the introduction. The long north to south, and short east to west, area of high anomaly values in the figure corresponds to the number of matches at the stations. The higher number of matches at the Central Valley stations would be located in the center of the anomalous temperature area, and the smaller number of event matches would be located towards the edges of this area. Areas of higher and lesser matches also share elements of geography. The stations with the highest number of matches are in the Central Valley. Stations with fewer number of matches are located along the coast and stations with even fewer matches (Reno and Tonopah, NV) are located to the east of the Sierra Nevada mountains in the Great Basin desert. The stations with small numbers of matches in Oregon and

Washington are located close to many mountain ranges in that area. Crescent City and Eureka, with no event matches, are located on the coast, right west of the Klamath Mountains. The geographic spatial orientation of the matches and their respective definitions and ranking systems discussed above can be seen in Figures 3.2 and 3.3 below.

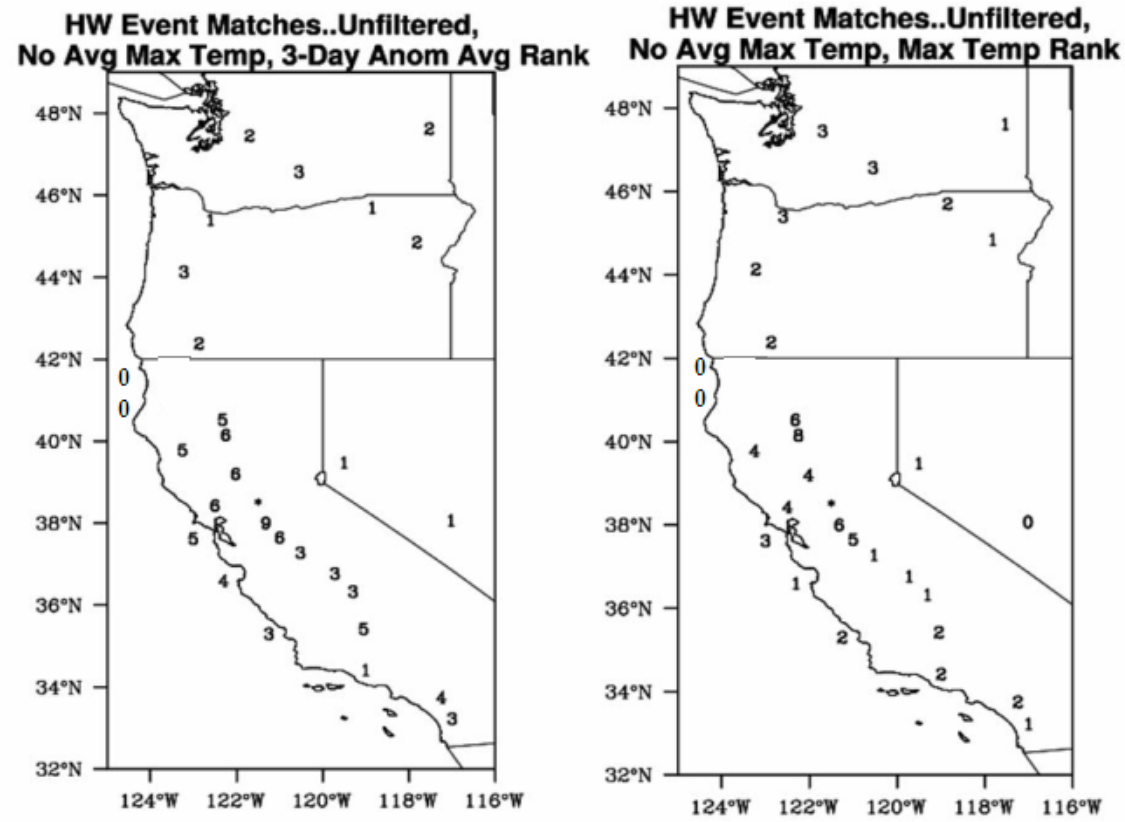


Figure 3.2. Spatial representation of the number of heat wave event matches of the top 15 events using the unfiltered data following the event definition that requires 3 consecutive days with anomalies greater than or equal to 10, with one of those days having an anomaly greater than or equal to 15, and ranked by a) the highest 3-day anomaly average of the events, and b) the highest maximum temperature of the events. Sacramento is represented by the asterisk, and shares 15 of its 15 top events.

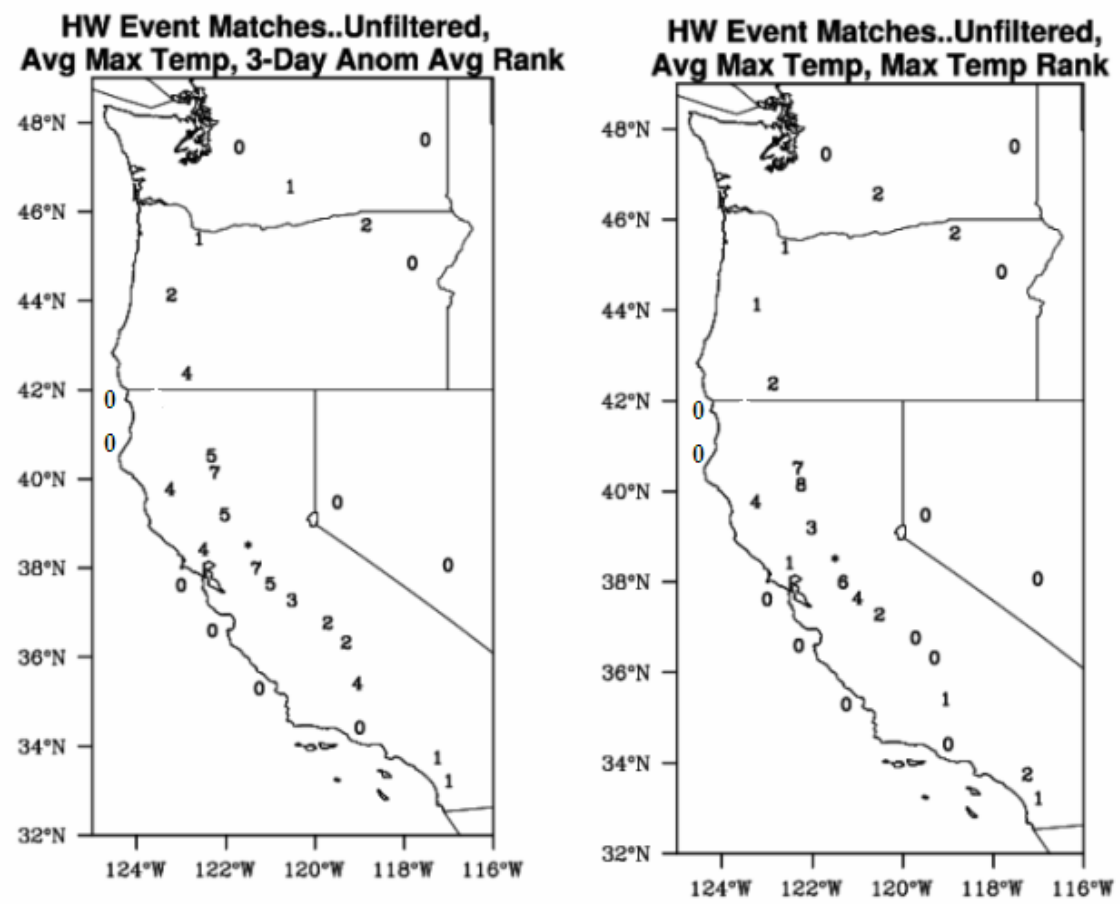


Figure 3.3. Similar to Figure 3.1 above except for heat wave events defined by having 3 consecutive days with anomalies greater than or equal to 10, with one of those days having an anomaly greater than or equal to 15, and having an average maximum temperature greater than or equal to 100ºF (38ºC). Events ranked by a) the highest 3-day anomaly average of the events, and b) the highest maximum temperature of the events. Sacramento is represented by the asterisk, and shares 15 of its 15 top events.

Matching comparisons were also made on the filtered data, once again using both heat wave definitions and both ranking systems. Following the initial heat wave definition requiring anomalies for three consecutive days to be greater than or equal to 10, with one of those days having an anomaly greater than or equal to 15, the number of matches was similar for the two ranking systems. Differences between the two methods did not differ by more than 2 matches. The highest number of matches among the Central Valley stations was observed from Redding south to Modesto for both rankings. Covelo, Graton, and San Francisco also experienced a higher number of matches,

comparable to those observed at the Central Valley stations. The highest number of matches out of all the stations was 7 matches for the ranking based on the highest 3-day anomaly average, seen in Red Bluff, Colusa, Modesto, and San Francisco, and 9 matches for the highest event maximum temperature ranking, seen in Red Bluff. The heat wave definition when the additional average temperature criterion was added yielded very similar results. The number of matches for all stations for the filtered data can be seen in Appendix A, Tables A.11 and A.12.

The number of resulting matches does not vary largely between the two ranking methods in the filtered dataset because many of the stations experience fewer events than the Sacramento station, with Sacramento experiencing 14 events. Therefore, the same top events are being matched again, only the ranking order is different. In the unfiltered datasets, however, the Sacramento station experiences 24 and 19 events under the two definitions, and the top 15 events are different between the two ranking methods.

This study describes the spatial extent of the most intense heat waves in Sacramento's historical record for summertime dates spanning the years 1979 to 2006. The spread of the heat wave events that occurred in Sacramento resulting from the unfiltered data using the first heat wave definition is examined and discussed in further detail here. The top 15 events, in this case, were ranked by the highest consecutive 3-day maximum temperature anomaly average. As seen from Figure 3.2a, there are several noticeable groups of stations that exhibit similar numbers of matches. The first group with the highest number of matches, ranging from 5 to 9, can be seen closest to Sacramento. The northern Central Valley cities of Redding, Red Bluff, Colusa, Stockton, and Modesto, in addition to the coastal stations of Covelo, Graton, and San Francisco,

make up this group of stations that exhibit the most heat wave matches with Sacramento. With matches greater than or equal to five, Sacramento experiences at the least, 1/3, to, at the most, 2/3, of its top 15 heat wave events with the top 15 heat events of these stations. Geographically, this anomalous heat is felt north of Sacramento through the Central Valley to the northern valley cities, south through the valley to Modesto, and westward towards the coast. In addition, Bakersfield in the southern Central Valley is the only station outside of this high-matching group immediately surrounding Sacramento that exhibits this high number of matches with Sacramento, with a total of five matches.

The group of stations that share the next closest number of event matches are Monterey and San Luis Obispo on the central coast, Merced, Fresno, and Visalia in the southern Central Valley, Santa Ana and Vista on the southern coast, Eugene, OR, and Yakima, WA, all having 3 or 4 total matches. The anomalous heat of up to 26.7% of the most intense Sacramento heat waves is felt by these cities to the south and north into Oregon and Washington. Spatially, this anomalous heat is felt south of Sacramento through the rest of the central valley, southwest to the central coast, and southeast to the southern coast of California.

The group of stations only having one or two matches with Sacramento's strongest anomalous heat waves consists of Santa Barbara, Reno and Tonopah, NV, Medford, Portland, Pendleton, and Baker City, OR, and Seattle and Spokane, WA. Of this group, three of the stations experienced fewer than 15 total heat wave events. Tonopah only experienced one, which was matched with a top Sacramento event. Reno experienced four total events, and Santa Barbara experienced nine. Hence, up to 13.3% of Sacramento's most anomalously intense heat events reached southeast to Santa

Barbara, located in between the Pacific Ocean and the Coastal Ranges, east of the Sierra Nevada mountains to Reno and Tonopah, NV, and north through California to stations in Oregon and Washington.

The two stations that did not experience any of the anomalous heat of Sacramento's most intense heat wave events were Crescent City and Eureka, located near the coast in northwest California, west of the Klamath Mountains.

The details of both Sacramento heat events that were felt by stations at substantial distances and the stations that experienced few event matches were looked into further. Tonopah and Reno, NV, and Santa Barbara all experienced only 1 match with Sacramento's most intense heat waves. This one event match for each of these stations was a heat wave in Sacramento's five most anomalously intense events. The two event matches that Baker City, OR, had were also matched with events ranked among the top five experienced by Sacramento. One of the two event matches of both Seattle and Spokane, WA, were also in Sacramento's top five, and the one event match of Portland, OR, was among the top eight events in Sacramento. The one event of Pendleton, OR, however, was Sacramento's 15^{th} most intense event. So, it can be seen that the majority of stations that experienced only one or two event matches, had matches that were among the strongest events in the tested record of Sacramento.

There are advantages and disadvantages to the matching scheme carried out in this project. Of the advantages, it is found what stations share the highest temperature anomaly averages, or maximum temperatures, on the dates when Sacramento experiences its most intense heat events. It is an advantage to find how far the anomalous heat from the same weather pattern can spread. A disadvantage to the matching scheme is not one

of its function, but one of its data. Only 30 stations were selected for use in this project, scattered among California, Oregon, Washington, and western Nevada, and there were only 28 years of data. If data from more stations and a longer time period were available, and the time to test them was ample, the results of the matching scheme could improve. More data provides more reliable statistics. An additional disadvantage to the matching scheme is that one overlapping date in comparing the heat wave event dates between Sacramento and the other stations is considered one entire event that is shared. In reality, only one day might be shared. However, this could be an advantage of the matching scheme if there is a lag between an event that starts in Sacramento before reaching another station. For example, the last day of the anomalous heat felt in Sacramento might be the first day that another city began experiencing that same anomalous heat.

The expected number of matches due to chance of the top 15 Sacramento event dates with the top 15 event dates of each of the other stations was found using unfiltered data, the first heat wave definition, and the 3-day anomaly average ranking method. This information is in Table 3.2 below. Similar tables for all other scenarios are in Appendix A, Tables A.13-A.15.

Table 3.2. The expected number of the top 15 event date matches due to chance for each station, using unfiltered data, the first heat wave definition, and the 3-day anomaly average ranking method. Also listed are the total number of the top 15 event dates and the observed number of matches of the top 15 event dates for each station. Expected number of matches (X) due to chance was estimated by the formula: n2/3416 = X/n1, where n1 is the total number of heat wave dates in the top 15 events at Sacramento, and n2 is the total number of heat wave dates in the top 15 events for each of the other stations, and 3416 is the total number of dates in the 28 years of JJAS.

City	Total # of Days in Top 15 Events (n1=Sacramento, n2=other stations)	Expected # of Top Event Date Matches by Chance (X)	Observed # of Top Event Date Matches (m)
Sacramento	**76**	*	*
Redding	75	1.67	21
Red Bluff	88	1.96	29
Colusa	63	1.40	29
Stockton	65	1.45	43
Modesto	57	1.27	32
Merced	21	0.47	15
Fresno	36	0.80	17
Visalia	42	0.93	20
Bakersfield	48	1.07	23
Crescent City	13	0.29	0
Eureka	3	0.07	0
Covelo	83	1.85	19
Graton	64	1.42	17
San Francisco	51	1.13	13
Monterey	54	1.20	10
San Luis Obispo	65	1.45	9
Santa Barbara	33	0.73	3
Santa Ana	68	1.51	13
Vista	69	1.54	8
Seattle	68	1.51	7
Spokane	75	1.67	5
Yakima	71	1.58	12
Portland	66	1.47	2
Eugene	66	1.47	10
Medford	75	1.67	6
Pendleton	69	1.54	4
Baker City	79	1.76	4
Reno	19	0.43	5
Tonopah	9	0.20	6

It can be seen at all stations, except for Crescent City and Eureka which had no matches, that the number of matches greatly exceeds the number expected by chance. The table shows more than that the number of matches is larger than those expected by chance. It shows that even for those stations that have only a few number of matching events, that the number of matching dates can be up to 10 times greater than due to chance. Tonopah, for instance, has only 9 heat wave dates. Six of these nine days, though, match with Sacramento's top 15 event dates, giving matches almost 30 times that due to chance. Cases such as Fresno and Bakersfield are also of interesting note. Bakersfield has more heat wave event dates than does Fresno, yet both have matches that are nearly 20 times that due to chance for each station, even though the expected number of matches for Bakersfield was higher than that of Fresno. Spokane is another interesting case. It had a very high number of heat wave event dates, 75, and a high number of corresponding matches due to chance, relative to the other stations' values. However, Spokane only had 5 matching event dates, less than 3 times greater than the number of matches due to chance.

D. Correlations and Statistics

The correlation of all unfiltered JJAS Sacramento temperatures with the temperatures on the corresponding dates of the other stations shows the highest JJAS temperature correlations among the Central Valley stations. The highest correlations among all 30 stations tested were found at Stockton (0.91), Modesto (0.91), and Red Bluff (0.87). The smallest temperature correlation was observed at Eureka (0.13). This is of interesting note because even though Eureka is located closer to Sacramento than other stations, for example, Seattle, WA (0.324), it had a lower correlation.

When correlations on the unfiltered JJAS temperature data were calculated at 0, 1, and 2 day lag, five of the nine Central Valley stations (Sacramento excluded) continued to show the strongest correlation at 0 lag time. These cities were Redding, Red Bluff, Colusa, Stockton, and Modesto. However, the Merced, Fresno, Visalia, and Bakersfield valley stations all had the strongest correlation at lag of 1 day. In addition, all the Oregon (Portland, Eugene, Medford, Pendleton, and Baker City) and all the Nevada (Reno and Tonopah) stations also had the highest correlations at lag of 1 day. In addition, the three Washington stations of Seattle, Spokane, and Yakima, had the highest correlation at lag of 2 days. One can see the progression of the strongest temperature correlations from close to Sacramento to farther away, both in the north and south direction, as the lag time advances from 0 to 1 to 2 days. The Central Valley stations closest to Sacramento, and those stations along the California coast correlate highest with Sacramento temperatures on the same day as Sacramento experiences them. Then, the following-day temperatures experienced by the southern Central Valley stations, Oregon stations, and Nevada stations, correlate highest with those of the previous day in Sacramento. Finally, Washington station temperatures correlate the strongest with those Sacramento temperatures experienced two days prior. The 0, 1, and 2-day lag correlations for all JJAS maximum temperatures can be seen in Table 3.3 below.

Table 3.3. Zero-, 1-, and 2-day lag correlations of all JJAS Sacramento maximum temperatures with the maximum temperatures of every other city on the corresponding lag date. Unfiltered data. The lag with the highest correlation for a given station is written in bold.

City	0 Days Lag	1 Day Lag	2 Days Lag
Redding	**0.831**	0.775	0.583
Red Bluff	**0.869**	0.762	0.547
Colusa	**0.865**	0.779	0.559
Sacramento	**1.00**	0.745	0.488
Stockton	**0.912**	0.715	0.474
Modesto	**0.911**	0.780	0.541
Merced	0.771	**0.859**	0.709
Fresno	0.815	**0.831**	0.642
Visalia	0.727	**0.782**	0.631
Bakersfield	0.751	**0.835**	0.673
Crescent City	**0.333**	0.241	0.136
Eureka	**0.128**	0.046	0.012
Covelo	**0.746**	0.714	0.557
Graton	**0.637**	0.354	0.146
San Francisco	**0.511**	0.288	0.116
Monterey	**0.375**	0.207	0.070
San Luis Obispo	**0.545**	0.393	0.234
Santa Barbara	**0.291**	0.198	0.133
Santa Ana	**0.448**	0.384	0.287
Vista	**0.430**	0.382	0.302
Seattle	0.324	0.392	**0.400**
Spokane	0.355	0.420	**0.433**
Yakima	0.387	0.441	**0.442**
Portland	0.384	**0.462**	0.446
Eugene	0.447	**0.524**	0.491
Medford	0.551	**0.633**	0.578
Pendleton	0.415	**0.477**	0.459
Baker City	0.399	**0.481**	0.469
Reno	0.590	**0.704**	0.653
Tonopah	0.538	**0.627**	0.607

The standard deviations of the JJAS maximum temperature data for the unfiltered data produced large values for the California valley stations. Redding had the largest standard deviation among the valley stations with a value of 9.01˚F. However, the largest standard deviations out of all 30 stations were seen at the stations outside of California in

Baker City, OR, Spokane, WA, and Pendleton, OR, with standard deviations of 9.94, 9.83, and 9.63˚F, respectively.

The highest observed normalized anomaly averages on heat event dates of each city, determined by the first heat wave definition, were observed at Eureka, Santa Barbara, and Crescent City, with values of 4.22, 3.41, and 3.28, respectively. However, one must be careful when interpreting these high values for these particular stations, because each has few heat wave events. When only looking at stations with 15 or more events, Monterey, San Francisco, and Santa Ana have the highest averaged normalized anomaly values of 2.63, 2.55, and 2.52, respectively. Among the California Central Valley stations, Merced, Stockton, and Colusa exhibited the highest normalized values of 1.97, 1.95, and 1.94, respectively. If one were to look at only Central Valley stations that experienced at least 15 total heat wave events, then Modesto and Bakersfield would replace Stockton and Colusa with values of 1.87 and 1.80, respectively. Therefore, when considering all stations with 15 or more events, Monterey, San Francisco, and Santa Ana experience the highest values of averaged normalized anomalies. In other words, the average strength of the heat waves experienced by these stations was comparatively more intense than the average strength of the heat waves experienced by all the other tested cities, relative to the long-term climate at each particular station. Overall, the values of the averaged normalized anomalies are small because they are calculated using anomalies of 10 and 15˚F, and therefore, are a measure of how the standard deviation compares with these smaller values. These values can serve as a baseline in comparing the normalized anomaly averages produced for each station using event dates in Sacramento only, discussed next. The filtered data following the same heat event definition produced

similar results. Normalized anomaly averages for all stations can be seen in Table 3.4 and Figure 3.4 below.

Table 3.4. Averaged maximum temperature anomalies of heat wave event dates for each station normalized by the standard deviation of the temperatures at that station. Asterisk (*) represents values of stations that had fewer than 15 heat wave events.

Redding	1.63	**Crescent City**	3.28 *	**Seattle**	2.02
Red Bluff	1.65	**Eureka**	4.23 *	**Spokane**	1.50
Colusa	1.94 *	**Covelo**	1.67	**Yakima**	1.62
Sacramento	1.75	**Graton**	1.97	**Portland**	1.83
Stockton	1.95	**San Francisco**	2.56	**Eugene**	1.71
Modesto	1.87 *	**Monterey**	2.63	**Medford**	1.60
Merced	1.97 *	**San Luis Obispo**	2.27	**Pendleton**	1.52
Fresno	1.75 *	**Santa Barbara**	3.41 *	**Baker City**	1.45
Visalia	1.92 *	**Santa Ana**	2.52	**Reno**	1.66 *
Bakersfield	1.80 *	**Vista**	2.37	**Tonopah**	1.69 *

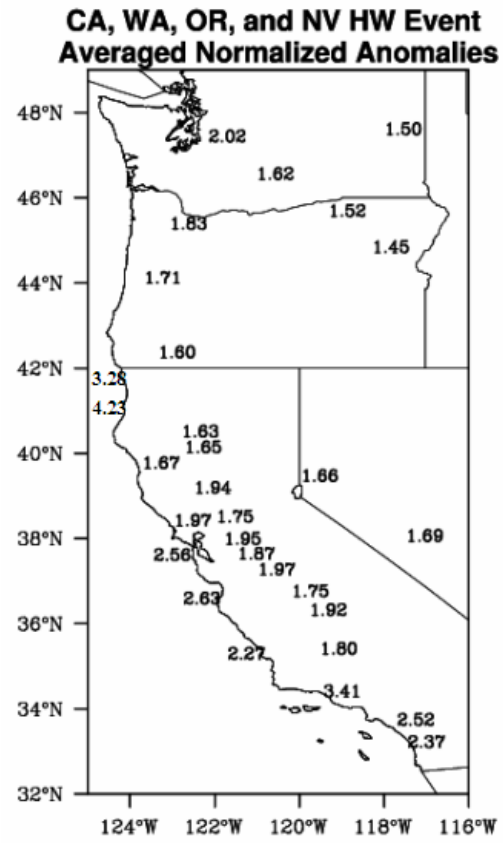


Figure 3.4. Spatial representation of the average maximum temperature anomalies during heat wave event dates for each station. The values are normalized by the standard deviation at each station. Some stations with high values have smaller standard deviations and, hence, have few events meeting the heat wave criteria.

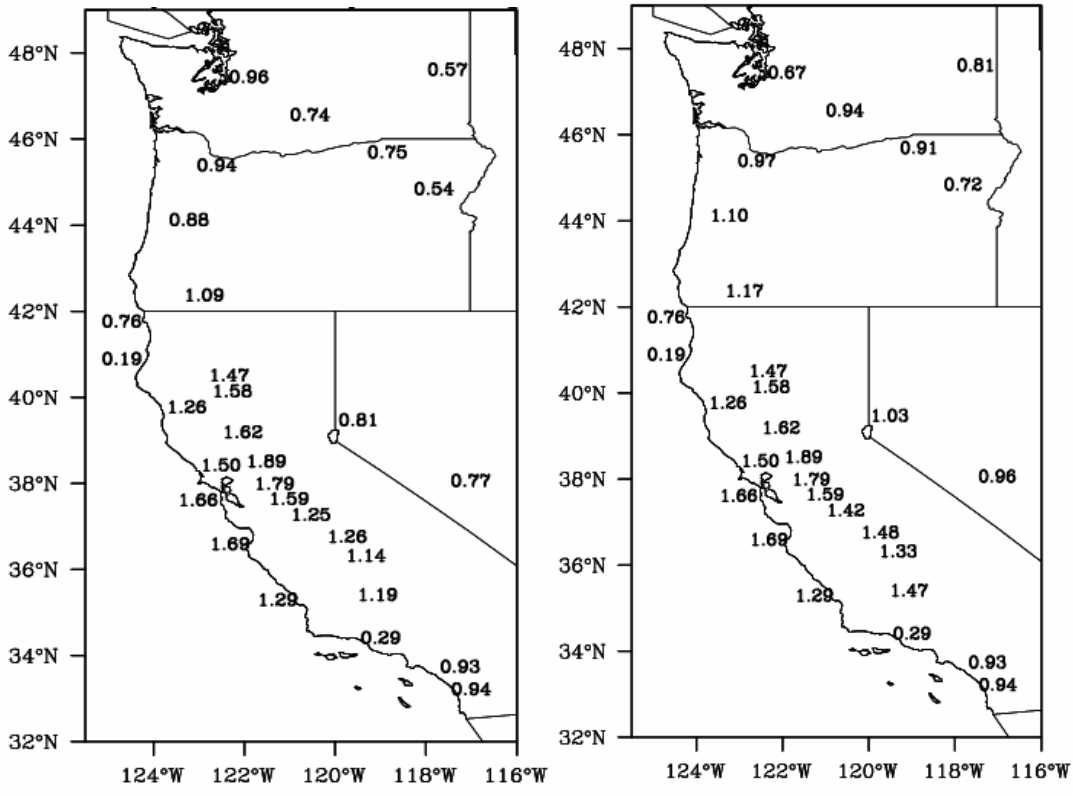
The second set of average normalized anomalies was calculated for each city using the dates of the 15 highest 3-day temperature anomaly averages for Sacramento. These values are the average number of standard deviations that the anomaly is away from the local mean of that particular station on those dates. A value of 1.0 signifies unusually warm temperatures on those dates. The results are shown in Figure 3.5(a). The highest value is observed in Sacramento (1.89). The averaged normalized anomaly values then steadily decrease as one moves away from Sacramento in all directions. The highest values are present in the areas surrounding Sacramento to the immediate north, south, and west to the coast. Stockton has the second highest value (1.79) and the coastal cities of Monterey and San Francisco have the third and fourth highest averaged values, 1.69 and 1.66, respectively. The next set of highest values is observed in the northern end of the Central Valley, followed by smaller-valued stations in the southern end of the Central Valley. Values then fall just below 1.0 in southern California, with Vista and Santa Ana having values of 0.93 and 0.94, respectively. All values in Washington, Oregon, and Nevada are less than one, except that of Medford, OR, with a value of 1.09. Values at Portland, OR (0.94), and Seattle, WA (0.96), fall just below one. These western areas of Oregon and Washington have the next highest values, followed by stations in the central parts of the two states along with the stations located in Nevada, and finally stations in the eastern areas of the states. The lowest observed averaged normalized anomalies are seen in Santa Barbara and Eureka, with values of 0.29 and 0.19, respectively. These values are far from any other observed value on the map.

Averaged normalized temperature anomalies were also computed using the dates corresponding to each station's highest correlation with Sacramento JJAS temperatures,

shown in Table 3.3. For instance, Spokane, WA, had its highest correlation at a lag time of 2 days. So, the date used for Spokane was the date 2 days after that of the date of the highest 3-day anomaly average of each of Sacramento's top 15 heat events. The resulting values for each station are in Figure 3.5(b). All averaged normalized anomaly values using the correlation at one or two days lag time show an increase, except for Seattle. However, if a lag time of 1 day was used for Seattle, instead of a lag time of 2 days, the station would have seen an increase as well (1.00). The southern Central Valley stations of Merced (1.42), Fresno (1.48), Visalia (1.33), and Bakersfield (1.47) had values greater than one previously, but increased even more using a lag time of 1 day. All stations in Oregon increased, with Portland (0.97), Eugene (1.10), and Medford (1.17), along the western side of the state, now being greater than or very close to a value of 1 standard deviation, signifying unusually warm values on those dates. Both the Reno (1.03) and Tonopah (0.96) stations in Nevada increased and exceeded or came very close to 1, using a lag time of 1 day. These high values to the north and into Nevada match well with the anomalous areas in the 850mb temperature plot in Figure 1.1, with the Reno, NV, station being towards the edge of the anomalous area.

In both Figure 3.5 (a) and (b), all values are positive, meaning that, on average, even if a station was not experiencing a heat wave, it still experienced warmer than normal temperatures on those dates. Incorporating the values using the lag times, the stations that experience the most strength of the Sacramento heat events are those in the Central Valley, those near the central California coast, the stations along the western coast of Oregon and Washington, and the stations to the east in Nevada. The northern Central Valley and coastal stations experienced the highest values. The values in Figure

3.5 (b) could be compared to the un-asterisked values in Table 3.4. For some stations, it takes a very large standard deviation value to meet the criteria for a heat wave event (with high standard deviation stations being those with smaller averaged normalized anomalies). However, when examining the how unusual temperatures are at a station, San Francisco (1.66) and Montery Bay (1.69) areas (who have lower standard deviations compared to many other stations), for example, are experiencing just as anomalously warm temperatures, as Sacramento (1.89) during Sacramento heat waves. This is important because it states that even though a station may have a relatively small number of matching heat wave events with Sacramento, that station may still be experiencing the anomalously warm temperatures as Sacramento on those days. The area that is affected by Sacramento heat waves would be more widespread than the number of matches implies, even if the number of matches is greater than that by chance.



(a) **(b)**

Figure 3.5. Spatial representation of the averaged normalized temperature anomalies of each station a) on the dates of the highest consecutive 3-day anomaly averages of the top Sacramento heat wave event dates, and b) on the day of the highest correlation of each station with respect to the date of the highest consecutive 3-day anomaly averages of the top Sacramento heat wave event dates. For example, Spokane, WA had its highest correlation at a lag of 2 days. It's value was calculated using the dates 2 days after the dates of Sacramento's highest event 3-day average anomalies.

E. Bootstrap Resampling

The resulting probability curves from the bootstrap resampling scheme performed on the unfiltered data can be seen in Appendix B, Figures B.11-B.40. A significance threshold of 99.5%, signifying the top half percent of the frequency distribution of 1,000 random samples of 15-member mean ensembles of maximum temperatures, was used in order to test the probability that the mean temperature of the target dates identified for Sacramento heat waves at that station has unusual value, whether it is so high as to be unlikely due to chance. Because it is determined based on the random samples of

averages of temperatures experienced at that particular station, this 99.5% threshold value is different for each station. Twelve of the 30 stations had target mean ensembles that were lower than the value at the 99.5% statistical significance threshold, and 18 of the 30 stations had target ensemble averages that were higher than the 99.5% mark, satisfying the statistical test. The 12 stations that had target mean ensembles that fell beneath the top half percent of the randomly sampled averages on the frequency distribution included all the stations located in the surrounding states of Oregon, Washington, and Nevada, and also the stations in Crescent City and Eureka. The highest 99.5% threshold value for one station was 100.3ºF (37.9ºC) for the Redding station, and the lowest 99.5% threshold value was 66.2ºF (19.0ºC) for the Eureka station. It was shown by this statistical method of bootstrap resampling that for the 18 stations where the target mean ensemble value exceeded that of the statistical threshold value, the probability of experiencing those averaged temperature values that were observed on the dates of Sacramento's most intense heat waves is very small. The 99.5% values and target mean ensemble values for each station can be viewed in Table 3.5 below and in Appendix B, Table B.1.

Table 3.5. The 99.5% values, and target mean ensemble values from the bootstrap resampling frequency distribution. YES signifies that the target mean ensemble average exceeded the 99.5% value, and NO signifies that the target mean ensemble did not exceed the 99.5% threshold value. Temperatures are in degrees Fahrenheit (Celsius).

City	99.5% Value, ºF (ºC)	Target Mean Ensemble Value, ºF (ºC)	YES/NO		City	99.5% Value, ºF (ºC)	Target Mean Ensemble Value, ºF (ºC)	YES/NO
Redding	100.47 (38.04)	104.8 (40.4)	YES		**Monterey**	73.63 (23.13)	80.1 (26.7)	YES
Red Bluff	99.93 (37.74)	104.6 (40.3)	YES		**San Luis Obispo**	83.90 (28.83)	89.9 (32.2)	YES
Colusa	96.20 (35.67)	100.6 (38.1)	YES		**Santa Barbara**	78.17 (25.65)	78.5 (25.8)	YES
Sacramento	95.57 (35.32)	102.5 (39.2)	YES		**Santa Ana**	86.80 (30.44)	86.9 (30.5)	YES
Stockton	96.03 (35.57)	102.3 (39.1)	YES		**Vista**	86.33 (30.18)	86.6 (30.3)	YES
Modesto	96.13 (35.63)	100.8 (38.2)	YES		**Seattle**	80.37 (26.87)	78.7 (25.9)	NO
Merced	98.23 (36.79)	100.3 (37.9)	YES		**Spokane**	86.30 (30.17)	82.5 (28.1)	NO
Fresno	99.93 (37.74)	102.4 (39.1)	YES		**Yakima**	89.58 (31.99)	87.8 (31.0)	NO
Visalia	96.10 (35.61)	97.7 (36.5)	YES		**Portland**	86.44 (30.24)	86.0 (30.0)	NO
Bakersfield	99.23 (37.35)	101.1 (38.4)	YES		**Eugene**	86.87 (30.48)	85.6 (29.8)	NO
Crescent City	68.47 (20.26)	67.7 (19.8)	NO		**Medford**	95.01 (35.01)	94.8 (34.9)	NO
Eureka	66.57 (19.21)	64.1 (17.8)	NO		**Pendleton**	90.30 (32.39)	87.8 (31.0)	NO
Covelo	96.00 (35.56)	98.8 (37.1)	YES		**Baker City**	88.71 (31.51)	84.0 (28.9)	NO
Graton	88.70 (31.50)	96.1 (35.6)	YES		**Reno**	93.13 (33.96)	92.5 (33.6)	NO
San Francisco	77.10 (25.06)	83.6 (28.7)	YES		**Tonopah**	91.88 (33.27)	91.85 (33.25)	NO

When new target ensemble means were calculated for the stations whose initial target ensemble means did not exceed the 99.5% significance threshold (the “NO” stations in Table 3.5 above), using the dates corresponding with that station’s highest lag correlation with Sacramento’s maximum temperatures, all “NO” stations except for

Baker City now had target ensemble mean values greater than the 99.5% value. New target ensemble means were also calculated for "YES" stations who had even higher correlations with Sacramento temperatures at other lag times. The new target ensemble means calculated using the dates of the highest correlations increased for all stations compared with the original mean. Therefore, the target ensemble mean at all stations, except Crescent City, Eureka, and Baker City, exceeded the 99.5% value at that station, using the temperatures corresponding to the dates of the higest correlations with Sacramento temperatures. The stations and results using these new target ensemble means are in Tables 3.6 and 3.7 below.

Table 3.6. New target ensemble means for the stations that did not initially exceed the 99.5% significance threshold value, and whose highest correlation with Sacramento temperatures occurred at a lag time of 1 day. New target ensemble means were created using the dates and temperatures that corresponded with this lag, 1 day after Sacramento experienced its strongest events. Also listed for each station is the 99.5% significance value, the initial target ensemble mean, and YES/NO if the new target ensemble mean exceeded (YES) or did not exceed (NO) the 99.5% significance value. Unfiltered data, the first definition of a heat wave, and the 3-day anomaly average ranking were used.

	City	99.5% Value, ºF (ºC)	Initial Target Ensemble Mean (Lag 0), ºF (ºC)	New Target Ensemble Mean (Lag 1), ºF (ºC)	YES/NO
1	Merced	98.23 (36.79)	100.3 (37.9)	103.33 (39.63)	YES
2	Fresno	99.93 (37.74)	102.4 (39.1)	104.93 (40.52)	YES
3	Visalia	96.10 (35.61)	97.7 (36.5)	99.67 (37.59)	YES
4	Bakersfield	99.23 (37.35)	101.1 (38.4)	104.87 (40.48)	YES
5	Portland	86.44 (30.24)	86.0 (30.0)	87.49 (30.83)	YES
6	Eugene	86.87 (30.48)	85.6 (29.8)	87.87 (31.04)	YES
7	Medford	95.01 (35.01)	94.8 (34.9)	97.46 (36.37)	YES
8	Pendleton	90.30 (32.39)	87.8 (31.0)	91.27 (32.93)	YES
9	Baker City	88.71 (31.51)	84.0 (28.9)	86.87 (30.48)	**NO**
10	Reno	93.13 (33.96)	92.5 (33.6)	95.41 (35.23)	YES
11	Tonopah	91.88 (33.27)	91.85 (33.25)	94.16 (34.53)	YES

Table 3.7. As in Table 3.5 above, except for stations that had the highest correlation with Sacramento temperatures at a lag time of 2 days. New target ensemble means were created using the dates and temperatures that corresponded with this lag, 2 days after Sacramento experienced its strongest events.

	City	99.5% Value, ºF (ºC)	Initial Target Ensemble Mean (Lag 0), ºF (ºC)	New Target Ensemble Mean (Lag 2), ºF (ºC)	YES/NO
1	Seattle	80.37 (26.87)	78.7 (25.9)	81.00 (27.22)	YES
2	Spokane	86.30 (30.17)	82.5 (28.1)	87.24 (30.69)	YES
3	Yakima	89.58 (31.99)	87.8 (31.0)	92.21 (33.45)	YES

F. 850hPa Temperature Plots

Figure 3.6 below are the temperature anomaly fields at the 850hPa level of the top 15 ranked heat wave events (plots b-p) in Sacramento ranked according to the highest 3-day anomaly average of the events, along with the corresponding mean field of those events (plot a). The identified heat wave events were defined as at least 3 consecutive days with maximum temperature anomalies greater than or equal to 10, with one of those days having an anomaly greater than or equal to 15.

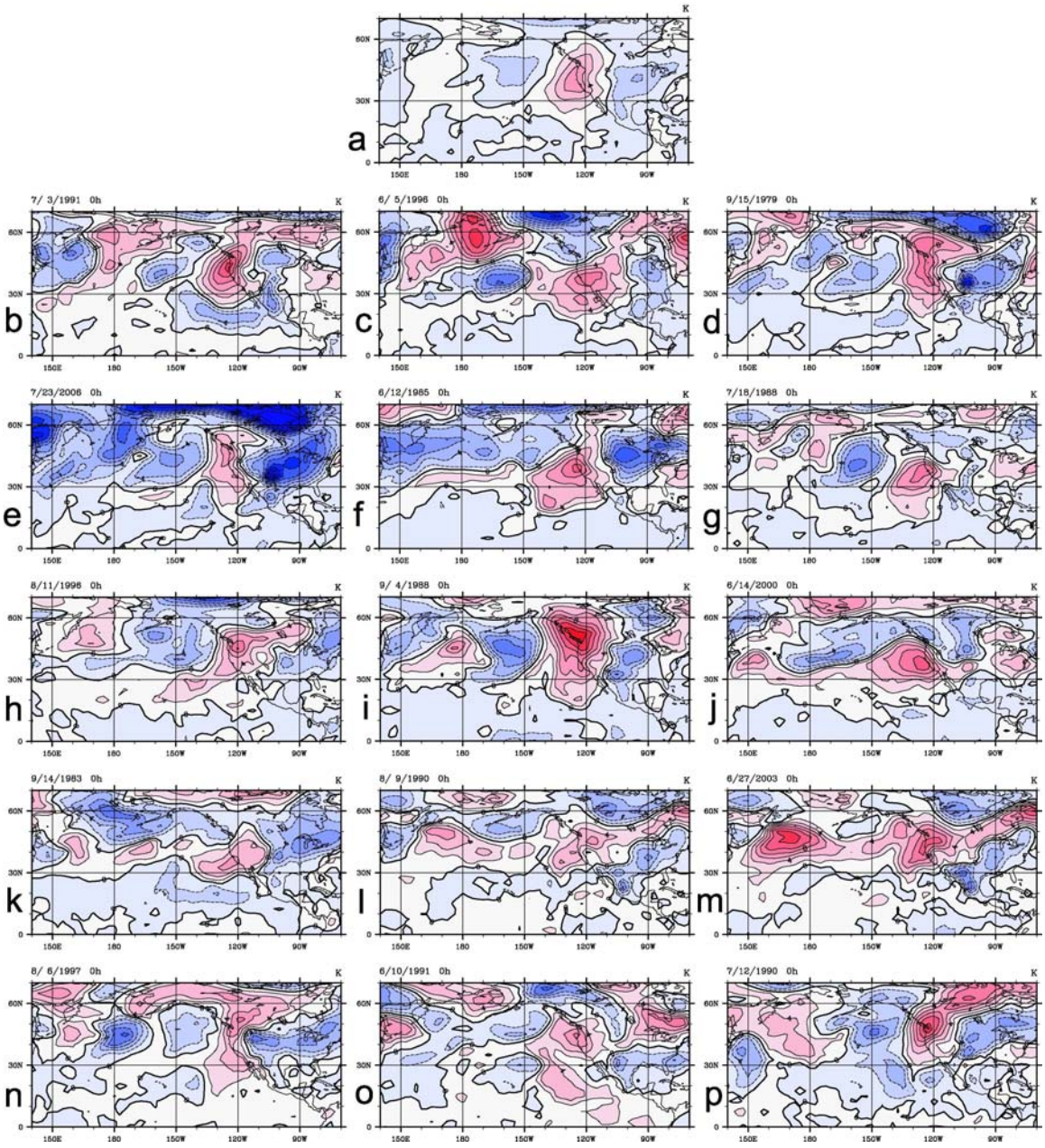


Figure 3.6. (b – p) Plots of the 850hPa temperature anomaly fields for the dates of the highest consecutive 3-day anomaly average of the top 15 heat waves in Sacramento. (a) Plot of the 850hPa mean anomaly field of all anomaly field plots, b-p. Darker shading and dark contours indicate positive temperature anomalies. Lighter shading and dashed contours indicate negative temperature anomalies. Heat wave events were defined as at least 3 consecutive days with maximum temperature anomalies greater than or equal to 10, with one of those days having an anomaly greater than or equal to 15. The events are ranked such that panel (b) is the strongest of the events and panel (p) is the least strong. The contour interval is 2 degrees Fahrenheit.

Similar anomaly patterns are observed in the different figures, with the top 10 events being very similar in the following parts of their patterns. In all of the figures, there is a strongly positive anomalous area centered along the western coast of the United States, and that also covers inland portions of the western United States. There is an area of significant negative anomaly off of the west coast over the Pacific Ocean. In some of the events towards the bottom of the list, this negative area is not as strong. It can also be seen that there is often an alternating pattern of positive and negative temperature anomalies as one moves from the United States westward over the Pacific Ocean. As the events get further down on the ranking list, these primary features of some of the anomaly patterns become less consistent and variable, such as the positive anomaly areas along the coast and their gradients. However, it can be seen that the gradient of the positive anomaly area in panel (p) is stronger than many of the higer ranked events. Looking at the mean anomaly field (plot a), the center of the area of maximum anomalies is located on the northern California coast, with the maximum area extending north into northern Washington and south to the Santa Barbara area. The other anomalous contours cover areas east into Nevada, north into Canada, and south to the Mexico border, but are less strong than the strongest anomalies.

The maximum temperature field plots were also created, but are not shown. The plots resemble similar features throughout the images as well. In the mean temperature field plot, the center of the highest maximum temperature area is located in southeast Nevada with a northwest orientation, with much of the high temperature being over the southwest portion of the United States. A strong temperature gradient is located to the northwest of this area, over the area from northern California to northwestwards over the

ocean. In relation to the mean anomaly field described above, the center of the maximum temperature area is located to the east-southeast of the center of the area of maximum anomalous temperatures.

The plots described above are important in that they display a large-scale pattern that is associated with the highest anomaly averages of the most intense heat wave events in Sacramento, as did the figure by Grotjahn and Faure (2007) displayed in the introduction. The large area of positive anomaly extends more northwards into Washington and Oregon than it does eastwards into Nevada. The majority of the anomalous area encompasses a region that is centered along the western coast of the United States. This coverage is consistent with the earlier findings of averaged normalized temperature anomalies, number of matching events, and resampling values. The area of the strongest anomalies is consistent with the distribution of stations having the highest averaged normalized temperature anomalies on the dates of the top Sacramento heat waves, being highest in the Central Valley, along the central California coast, and northwards into western Oregon and western Washington. The distribution of the number of heat wave event matches also mimic the area covered by the strongest anomalies on the map above, with more matches at stations along the coast, Central Valley, and northwards into Oregon and Washington than seen at the stations eastwards into Nevada. In addition, the distribution of the stations with the highest correlations with Sacramento temperatures, using a lag of zero days, is also similar to the region of the anomalous area, with the northern Central Valley stations, and many of the California coastal stations having the highest correlations. This can be seen in both the 850hPa maximum temperature and anomaly field plots above. Having a large-scale pattern for

such an extreme weather event can be advantageous in that it can be used to better diagnose such impacting events in the future.

G. Overlapping HW dates with G&F

The dates of the top 15 heat wave events in Sacramento found from both the highest 3-day anomaly average ranking and the highest maximum temperature ranking were compared with the list of the 15 heat wave events found in Grotjahn and Faure (2007). It must be noted that three of the top 15 events ranked by the anomalies in this project, and two of the top 15 events ranked by the maximum temperature, occurred outside the 1979-1999 timeframe of Grotjahn and Faure (2007). So, 12 and 13 events from Grotjahn and Faure's (2007) listing are used for the comparison. Seven of the 12 events listed in Grotjahn and Faure (2007) were seen in the top 15 events as ranked by the highest 3-day anomaly average in this project and nine of the 13 events listed in Grotjahn and Faure (2007) were seen in the top 15 events as ranked by the highest maximum temperature.

IV. Summary and Conclusions

The importance of gaining a solid understanding of the characteristics of heat waves is not small. Heat waves deliver extreme discomfort to people, take lives, and cause hardship on communities and economies. For these reasons and others, the understading of heat waves is a valuable tool.

An issues arises when attempting to examine the extent of Sacramento heat waves and how to define such events: does one categorize heat waves based on the highest maximum temperature reached or based on how unusual the temperature is for that date? Each emphasize different, yet necessary characteristics of a heat wave, that must be addressed when confronting the issue. Absolute temperatures signify heat intensity, and when felt, cause hardship and physically impact the surroundings. Anomaly data can be used to help people forecast, or provide guidance to people in identifying events based on past occurrences. One must have knowledge of absolute temperature in order to prepare communities for the extreme heat that they might encounter. One must also have knowledge of the anomalies that accompany heat waves, because it is the anomalies that make it possible to identify the large-scale weather pattern that is associated with the extreme events. Both the 850hPa temperature plot of Grotjahn and Faure (2007) and the 850hPa temperature anomaly plots created as part of this project highlight the large-scale structure of such events. Understanding the anomalies can lead to better identification of events, which can lead to better forecasting in the future. As Lipton et al. (2005) noted, anomaly fields are more successful in identifying heat waves over the absolute fields. Therefore, the two proposed heat wave definitions in this paper capture two important characteristics of the events.

It is seen that the top heat waves experienced in Sacramento are spread across surrounding areas as well. The northern and southern stations of the Central Valley and the coastal stations of San Francisco and Monterey feel substantial anomalous heat on Sacramento heat wave event days. However, it is also seen that this anomalous heat is felt, but not as strongly, east of the Sierra Nevada Mountains into the state of Nevada, even though it is felt by Oregon and Washington stations that are farther away from Sacramento.

It was found from the event identifications that the number of heat wave events varied from station to station, with the highest number of events occurring at the stations in the northern Central Valley, California central coast, Oregon, and Washington, and with the least number of events occurring at the stations in Nevada, the southern Central Valley, and northwest California. It was also found that many of the Sacramento heat waves event dates did not match the event dates at other stations. But, many more matched than were expected to match by chance, except for the Crescent City and Eureka stations, which had no events. The highest number of matches with Sacramento's top heat wave events were at the stations in the Central Valley and along the California central coast, with the least number of matches seen in Nevada and northwest California.

In addition, it was found that the averaged normalized temperature anomalies for many stations on the dates of the highest 3-day anomaly averages of the top Sacramento heat wave events were greater than one standard deviation. These stations included all of the Central Valley and central coast stations, and even north to Medford, OR, but excluded the Nevada, northwest California, southern California, and remaining Washington and Oregon stations. When using the lag dates corresponding to the highest

correlation of the stations, the Reno, NV, and Eugene, OR, stations then had standard deviations greater than one, with the Tonopah, NV, Portland, OR, and Yakima, WA, stations closely following, with values just below one standard deviation. However, it is also found that Reno, NV, even though located more closely to Sacramento than stations throughout California and in surrounding states, continues to exhibit a smaller value than many of these stations. The lag found in the correlations with Sacramento maximum temperatures increases further north into Oregon and Washington, eastward into Nevada, and to the immediate south into the southern Central Valley. When this lag was applied to the heat wave events, it was found from the Bootstrap resampling scheme that these stations also experience rare heat, and more than expected by chance, exceeding the 99.5% threshold value of temperature ensemble averages at each station. Baker City, Crescent City, and Eureka were the only stations that did not exceed their threshold value once applying the dates of the lag correlations.

The 850hPa level temperature anomaly plots help to strengthen the results with the area of strongest temperature anomaly in the large-scale pattern covering the same area as the distribution of the stations exhibiting the results mentioned above. That it, it encompasses the Central Valley and central coast, extending northwards into Oregon and Washington and westwards to just encompass Reno, NV. The consistency of the features of the pattern are seen throughout the plots of the highest ranked events.

When comparing the two approaches of ranking by the highest maximum temperature and the highest consecutive 3-day anomaly average of each event, the order of the stronger events were sometimes reshuffled, but most of the results that establish the spatial extent and timing of the events are seen for both approaches.

Future research will be directed to understand better these large-scale weather patterns that identify the onset of extreme heat wave events and the wide spatial extent that they can cover. Better predictions of heat waves for Sacramento and the surrounding area could save lives and reduce hardship.

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