The Spatial Extent of California Heat Waves

By

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THESIS

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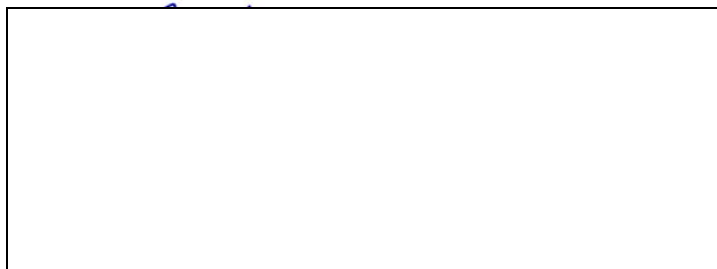
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I. Introduction

Death, record-breaking energy consumption, and economic hardship are impacts felt by society during the event of a heat wave. The weather phenomenon known as the heat wave has been found to be the leading cause of weather-related mortalities among humans in the United States (Lipton, 2005; Davis, 2005). In the California 2006 heat wave alone, near 140 human lives were lost due to the extreme heat (Blier, 2006; Edwards, 2006). However, not only in California are the societal impacts from heat wave events felt, but throughout the rest of the nation and world as well. In the Western European heat wave of August 2003, close to 35,000 deaths were attributed to the heat, along with record-breaking temperatures (Lipton, 2005). Among the many lives that are taken by heat waves, the elderly are the most susceptible age group to losing their life in such an event (World Health Organization, 2003). Death rates aside, individuals are also susceptible to heat-related illnesses such as heat fatigue, heat exhaustion, and heat stroke (World Health Organization, 2003).

Mortality, an important and concerning effect, is not the only impact of heat waves. In the California 2006 heat wave mentioned above, the state of California also set an all-time high energy consumption record on 24 July, with a usage amount of 50,270 Megawatts. Simultaneously, more than one million customers experienced a loss of electrical power (Blier, 2006). These are examples of some of the effects of heat waves that directly impact the communities in which the events occur.

There is no universal definition to classify an event of extreme temperature as a heat wave. In studies that have been carried out concerning the subject, the definition of the weather phenomenon often varies from study to study, resulting in a situation that

makes it difficult to compare the severity of separate events, notably those of the past and present (Robinson, 2001). Being able to define such an event, and therefore make such comparisons, would provide a better understanding of the trends and development of these weather phenomena.

Heat waves have been studied by many scientists and authors who have provided a better understanding on the subject, along with various ways in which to define such an event. Robinson (2001) discusses the need for a definition of a heat wave event and proposes one based on the National Weather Service (NWS) criteria for heat stress watches and warnings. Starting with the NWS criteria that requires the daytime high heat index to be greater than 40.6ºC (105ºF) and nighttime low heat index to be greater than 26.7ºC (80ºF) for 2 consecutive days, he proposes allowing for changes that reflect variations in local climate due to geography and location. In areas where there are many heat wave events taking place, such as the South and Southwest, thresholds are examined using percentile-based values. These values were made by determining the heat index value that was exceeded a specified percent of the time for both overnight low heat index values and daytime high heat index values. If these values are greater than NWS values, then they become candidates for being a heat wave threshold. The goal that was set and achieved by Robinson (2001) was to have a smooth spatial transition between areas using the NWS criteria and those using the percentile-based criteria (Robinson, 2001).

Based on the proposed heat wave definitions in Robinson (2001) and 1951-1990 temperature and humidity data from the Surface Airways dataset of the National Climatic Data Center (NCDC), 1.8 heat waves occur per decade nationwide, with the events displaying a regional pattern. The heat waves were observed to be most common in the

South, and rare in the Northwest and South Florida. The analysis showed that areas of current high heat wave frequency show a decrease in frequency, and those of current low heat wave frequency show an increase in frequency. The completion of the analysis provides a baseline climate description of heat waves for the United States (Robinson, 2001).

The heat index value used by Robinson (2001) takes both temperature and humidity into account and "approximates the environmental aspect of the thermal regime of a human body (Robinson, 2001)." Due to the fact that humidity levels are low in the Sacramento area and throughout California compared to most other regions, humidity is determined to be not as relevant as absolute temperatures for determining a heat wave event in the current thesis study, and therefore, only absolute temperatures are used.

However, temperatures and heat index are not the only measures that scientists have examined in attempting to identify and define heat waves. Lipton et al. (2005) discuss a procedure of forecasting heat waves using climatic anomalies. Their study examines particular anomaly fields of significant mid-latitude heat waves that have taken place in the United States and Western Europe. Upon studying the atmospheric synoptic scale patterns and anomaly variables, they find that similarities exist between the patterns that are characteristic of the extreme heat events in both countries (Lipton et al., 2005).

Lipton et al. (2005) examine the anomaly fields of 500hPa heights, 850hPa temperatures, 700hPa temperatures, and precipitiable water (PW) during the heat wave events. The patterns that were found among all heat wave events were: a 500hPa ridge, a midtropospheric anticyclone associated with a 594dm height contour, and positive 850hPa and 700hPa temperature anomalies. For the most extreme heat wave cases, and

often those with the highest amount of heat-related fatalities, a positive PW anomaly was also present, with the anomalous area of PW being to the north of the ridge and the area with the maximum temperatures. The presence of PW is able to have such an impact on the severity of a heat wave because once humid air is in place, cooling during the night is limited and results in high temperatures at the start of the next day. The definition of a heat wave that was used in the Lipton et al. (2005) analysis to determine the heat wave events required that the daily maximum temperature of June through September months remain 2 standard deviations above normal (based on a 1970-2000, 30-year climatology) for at least 2 consecutive days (Lipton et al., 2005).

Lipton et al. (2005) also emphasize the importance of the use of anomalies. It is explained that while a certain temperature in one area of the United States may be considered normal, a lesser temperature in another area could be considered above-normal. Lipton et al. (2005) conclude that height anomaly fields are more successful in determining heat waves over absolute height fields.

An advantage of having a definition of a heat wave is to better compare the characteristics, structure, development, and changes between past heat waves and the heat waves that occur in the present. Meehl and Tebaldi (2004) investigate the changes in heat waves over the years and into the future with the use of a global coupled climate model and NCEP/NCAR reanalysis data. The 1995 Chicago and the 2003 Paris heat waves are chosen as example cases to examine the changes. The model and reanalysis data show that associated with an increase in the 500hPa heights, both the frequency (number of heat waves per year) and duration of heat waves in the future will increase in Chicago and Paris.

The atmospheric circulation observed during the heat waves examined in Meehl and Tebaldi (2004) is one represented by a semistationary 500hPa positive height anomaly. Subsidence, light winds, clear skies, warm air advection, and sustained high surface temperatures are, in turn, dynamically produced from the height anomaly. Model output shows an increase in the 500hPa height anomaly in the future time period, as well as with an increase in the 500hPa heights (Meehl and Tebaldi, 2004).

Two definitions of a heat wave are presented and explained in the Meehl and Tebaldi (2004) study, one of which is more qualitative, and the second of which uses the exceedence of specific thresholds to determine a heat wave. The first heat wave definition requires "several consecutive nights with no relief from very warm nighttime minimum temperatures (Meehl and Tebaldi, 2004)." The second, quantitative definition states that a heat wave is the longest period of consecutive days that satisfies the following three conditions: 1) The daily maximum temperature is greater than T1 for at least 3 days, where T1 (threshold 1) is equal to the 97.5^{th}-percentile of the distribution of maximum temperatures in the observations and in simulated present day climate, 2) the average daily maximum temperature is greater than T1 for the entire period, where T2 (threshold 2) is equal to the 81st-percentile, and 3) the daily maximum temperature is greater than T2 for every day of the entire period. This definition is useful in determining frequency and duration of current and future heat waves. The model analysis suggests that regions in which current heat waves are very severe and also regions in which heat waves are not as severe will both have an increase in heat wave severity in the future, with the regions of current high severity having the largest increase (Meehl and Tebaldi, 2004).

Accompanying changes in the intensity of heat waves over the years and into the future is the related effect of human mortality. Davis et al. (2005) examine the relationship between heat waves and heat wave-related mortalities, using 1964-1998 mortality records in five United States cities (Davis et al., 2005). The heat event definition that Davis et al. (2005) use to determine significant events requires two or more consecutive day runs of above normal apparent temperatures (with normal defined by the 30-day moving average). In addition to this definition, heat waves are classified into the 4 categories of killer heat waves, non-killer heat waves, high mortality normal heat, and normal mortality normal heat (Davis et al., 2005).

Davis et al. (2007) also discuss and examine this relationship using mortality rates due to heat waves as a response variable, since there is no standard definition for a heat wave. The definition for a "heat event" in this analysis is a liberal one and requires "a maximum apparent temperature that exceeds one standard deviation calculated using a centered moving 5-year window (Davis et al., 2007)." It was shown that 3-4 days is the minimum time that is needed to instigate heat-related deaths. In regard to absolute versus relative heat waves, where absolute heat events are those defined based on absolute conditions and relative heat events are those defined based on deviations from normal, both were present, but absolute heat waves were larger in number than relative. The authors of the analysis suggest that the findings of the study could be involved in city planning and decision-making (Davis et al., 2007).

It can be seen from Table 1.1 below that the number of heat related fatalities in the United States, Puerto Rico, Guam, and the Virgin Islands has increased overall from 1986 to 2006. In addition, the 10-year average number of heat fatalities from 1997-2006

also outnumbers that of the 10-year average number of fatalities for floods, lightening,

tornados, hurricanes, cold, winter storms, or wind (NWS).

Table 1.1. The yearly, total, and 10-year average number of fatalities due to heat, floods, lightening, tornados, hurricanes, cold, winter storms, and wind in the U.S., Puerto Rico, Guam, and Virgin Islands. Dash (-) indicates unavailable yearly data. Data from National Weather Service.

Year	Heat		Floods	Lightening	Tornados	Hurricanes	Cold	Winter Storms	Wind
1986	40		94	68	15	11	-	69	-
1987	38		70	88	59	0	-	30	-
1988	41		31	68	32	9	17	55	-
1989	6		85	67	50	38	121	63	-
1990	32		142	74	53	0	13	48	-
1991	36		61	73	39	19	13	45	-
1992	8		62	41	39	27	14	59	-
1993	20		103	43	33	2	18	66	-
1994	29		91	69	69	9	52	29	-
1995	1021		80	85	30	17	22	17	84
1996	36		131	53	26	37	62	86	54
1997	81		118	42	67	1	51	90	75
1998	173		136	44	130	9	11	68	65
1999	502		68	46	94	19	7	41	52
2000	158		38	51	41	0	26	41	51
2001	166		48	44	40	24	4	18	31
2002	167		49	51	55	53	11	17	45
2003	36		86	43	54	14	20	37	43
2004	6		82	31	34	34	27	28	42
2005	158		43	38	38	1016	24	43	25
2006	253		76	47	67	0	2	28	40
TOTAL	3007		7037	9045	6548	3296	515	978	607
10-year average (1997-2006)	**170**		**74**	**44**	**62**	**117**	**18**	**41**	**47**

In California, with a population of nearly 38 million people, the heat waves that

affect the state, and their notable characteristics, are of much interest and concern. The

residents of the Sacramento and San Joaquin Valleys, in particular, frequently experience

high summer temperatures. Even though residents have learned to adapt to the

uncomfortable conditions over the years, the intensity and effects of the events are still

felt. The July 2006 heat wave that impacted the state in many ways has also been

examined by scientists. Blier (2006) and Edwards et al. (2006) discuss the significance

of the record-breaking heat wave and its synoptic meteorological conditions. Both note

that the July 2006 heat wave in central California was historically significant in that it

broke overnight and daytime high temperatures, most notably of these, the high overnight

temperatures. Other important features of the July 2006 heat wave were the long

duration of extreme heat lasting 11 days, unusually high dewpoints resulting in negative

impacts on humans, and record-breaking energy consumption records (Blier, 2006;

Edwards et al., 2006).

Blier (2006) affirms that a difference in the magnitude of the heat wave was also

observed between the inland, low-level valleys of central California and the higher-

elevation hills and mountains, where the magnitude and intensity was much greater and

more significant in the valleys than at the higher-elevated areas. The large difference in

temperatures between coastal and inland areas over a small spatial extent showed the

existence of a shallow coastal marine layer, with the coastal temperatures not reaching

nearly as high temperatures as inland valley temperatures or previously recorded record-

high coastal temperatures (Blier, 2006).

The meteorological conditions that were representative of the California 2006

heat wave included a retrograding 500hPa height anomaly pattern. The westward shift of

the height anomaly caused a large-scale upper-level high to position itself over the Great

Basin. A shift in mid-level 500hPa winds caused winds to blow from the east-southeast

into California, causing monsoonal moisture from lower latitudes to be transported to

California, resulting in high upper-level moisture over the southwest United States which

allowed higher overnight lows, and, in turn, higher daytime humidity the following day.

The higher overnight lows that were observed resulted in part from the combination of high dewpoint temperatures and calm winds (Blier, 2006; Edwards et al., 2006). No heat wave definition was explained or proposed in Blier (2006) or Edwards et al. (2006).

Moisture is not used as a variable in this thesis study. However, if moisture from southern latitudes moved north into California at any point during a heat wave due to a shift in winds, as was the case in the 2006 heat wave in California, the intensity of the event could potentially increase due to the moister air. Therefore, the addition of moisture as a variable in order to investigate its effect on heat waves could be a worthwhile area to investigate further.

Finally, Grotjahn and Fauare (2007) discuss how to forecast significant weather events in the Sacramento area by using historical analogs. Heat waves are included among the significant weather events covered. Grotjahn and Faure (2007) focus on examining the geopotential, pressure, temperature, and wind fields at the beginning and end times of heat waves in the Sacramento area. Their study builds on the study of Staudenmaier (1995), which attempted to familiarize forecasters with the synoptic patterns of significant weather events in the Sacramento area. Concerning heat waves, Staudenmaier (1995) concluded that high heights measuring above 5920m at the 500hPa level over Nevada, along with a high located off of the coast of California at the 850hPa level with a weak northerly gradient across California, signaled maximum heating in the area. Grotjahn and Faure (2007) improve upon Staudenmaier's study by 1) using data that covers a larger area, 2) looking at the times prior to the event onset, 3) using better data that consisted of NCEP/NCAR Reanalysis data, 4) introducing statistical tests to examine the statistical reliability of the findings, and 5) using more variables at more

levels. Grotjahn and Faure (2007) capture 15 heat wave event occurrences in the June to September months from 1979-1999 by using the definition of a heat wave event to be at least three consecutive days during which the daily maximum temperatures are above 100ºF (38ºC), with the temperature of at least one day being above 105ºF (40.5ºC). Grotjahn and Faure (2007) observe that the end of a heat wave is 1) hard to forecast due to the temperatures that remain elevated until the end of the event, and 2) brought about by the delta breeze, an onshore flow of cool, moist air from the San Francisco Bay area inland towards the Central Valley. Of important note in their study is the fact that both the 300hPa and 850hPa ridges at the west coast of California are linked to larger-scale patterns and cover several southwestern states. This observation is very informative of the nature and structure of heat waves in that it shows heat waves, due to their relationship to larger-scale atmospheric patterns, are in turn, widespread events that are able to affect large areas (Faure and Grotjahn, 2001). The 850hPa temperature field at the event onset is the most relevant synoptic pattern to this thesis study.

In Figure 1.1 below is the 850hPa mean air temperature and significant temperature anomalies, from Grotjahn and Faure (2007), recorded at the onset of the hottest heat waves that occurred in Sacramento. Of important note, and the focus for this project, is the large area of positive anomalies along the western coast of North America. This area of highly significant anomalies, with the majority being greater than 98.5% significant, is centered along the western seaboard and extends as far north to 52.5˚N latitude, north of Washington state, and south to 32.5˚N latitude on the coast to near the California state and Mexico border. The area extends as far west over the Pacific Ocean to 135˚W longitude and east over California to 117.5˚W longitude into western Nevada,

at its middle, and also extends to 112.5˚W longitude into Canada, at its northern points, and to 115˚W longitude at its southern points. These coordinates encompass the majority of the states of California, Oregon, Washington, and western Nevada, therefore, extending more in the north and south directions, than eastwards.

850hPa Mean Air Temperature
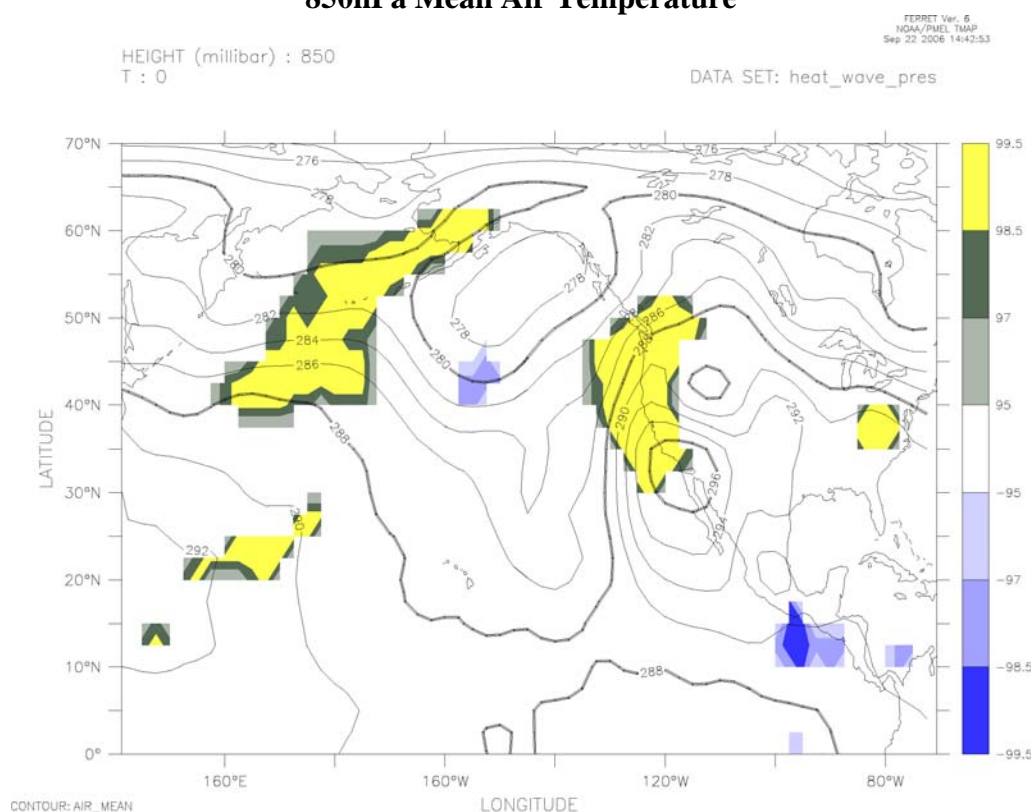
Figure 1.1. 850hPa Mean Air Temperature. Contours represent mean air temperature (Kelvin), and shading represents areas having positive (negative) temperature anomalies with significance greater than (less than) 95% (-95%).   Of important note is the area of positive anomalies centered along the western coast of the United States. Plot produced by Grotjahn and Faure (2007).

Figure 1.1 highlights the important observation that the anomalous temperatures of a heat wave event that takes place in Sacramento spreads across surrounding areas at substantial distances, especially northwards and southwards. The anomaly pattern in the figure shows that these heat waves are not just a local weather event to Sacramento, but are part of a large-scale synoptic pattern.

In Table 1.2 below, the heat wave event definitions and their corresponding sources can be seen for the studies discussed above.

Table 1.2. Heat wave definitions and their sources.

Source	Definition
Robinson (2001)	A period of at least 48 hours during which neither the overnight low nor the daytime heat index (H_i) falls below the NWS heat stress thresholds (80ºF (26.7ºC) and 105ºF (40.5ºC)). At stations where more than 1% of both the high and low H_i observations exceed these thresholds, the 1% values are used as the heat wave thresholds
Lipton et al. (2005)	Daily maximum high temperature remains 2 standard deviations above normal for at least 2 consecutive days
Meehl and Tebaldi (2004)	**1)** *Qualitative*: Several consecutive nights with no relief from very warm nighttime minimum temperatures **2)** *Quantitative*: The longest period of consecutive days satisfying the following 3 conditions: i. Daily maximum temperature > T1 for at least 3 days ii. Average daily maximum temperature > T1 for entire period iii. Daily maximum temperature > T2 for every day of entire period, where T1 (threshold 1) = 97.5$^{\text{th}}$ %-ile of distribution of maximum temperatures in the observations and in simulated present day climate T2 = 81$^{\text{st}}$ %-ile
Davis et al. (2005)	Two or more consecutive day runs of above normal apparent temperatures (with normal defined by the 30-day moving average)
Davis et al. (2007)	A maximum apparent temperature that exceeds one standard deviation, calculated using a centered moving 5-year window
Grotjahn and Faure (2007)	At least 3 consecutive days during which the daily maximum temperatures are above 100ºF (38ºC), with at least one above 105ºF (40.5ºC)

It should be noted that the quantitative definition of Meehl and Tebaldi (2004) in the table above is based on the definition of Huth et al. (2000), in which gridded data is used rather than station data. This is important to point out because when using absolute temperature as a criteria, the source of the data and observations (such as point data or

grid-box averaged data) may be important. The difference in the types and resolutions of the data can possibly result in different values. The qualitative definition of Meehl and Tebaldi (2004) in the table is based on the definition of Karl et al. (1997), which uses station data. Meehl and Tebaldi (2004) also reference Schar et al. (2004) and Palecki et al. (2001) as having alternative definitions of heat waves, where Schar et al. (2004) also uses gridded data.

It can be seen from the above studies that heat waves are a weather phenomenon of importance and concern due to their largely-felt impacts across the state of California. It has been shown that 1) mortality, health related-illnesses, and economic loss have been associated with heat waves, 2) there exists variety in heat wave definitions, and 3) there is a large-scale synoptic pattern associated with heat wave events. This study will focus on the latter two observations by building upon the finding of Grotjahn and Faure (2007) that heat wave events exhibit large-scale synoptic patterns by observing the spread of California heat waves that affect Sacramento. This will be done by identifying heat waves in California and surrounding states by using a specified definition of a heat wave event and performing a matching scheme on the top ranked events. Absolute and anomalous temperature data from 30 stations in California and surrounding states will be used. The goal of the study and its results is to build a better understanding of the extent to which Sacramento heat waves are shared by other regions within and outside of the state. The methodology of data choice, event identification, and station comparisons will be discussed in Section II of the paper. The results of the matching scheme, correlations, and other findings from the study will be discussed in Section III, and the summary and conclusions of the study will be discussed in Section IV.

II. Methodology

A. The Data

Cities were chosen in order to represent spatially the inland Sacramento and San Joaquin valleys, the California coast, and the surrounding states of Washington, Oregon, and Nevada. The 10 cities chosen to represent the Central Valley were Redding, Red Bluff, Colusa, Sacramento, Stockton, Modesto, Merced, Fresno, Visalia, and Bakersfield. The 10 cities selected to represent the coastline were Crescent City, Eureka, Covelo, Graton, San Francisco, Monterey, San Luis Obispo, Santa Barbara, Santa Ana, and Vista. The 10 cities representing the three surrounding states were Seattle, Spokane, and Yakima, Washington; Portland, Eugene, Medford, Pendleton, and Baker City, Oregon; and Reno and Tonopah, Nevada.

The topography of California and the surrounding states is useful to know when the different stations are discussed. California, Oregon, Washington, and Nevada have many mountain ranges, and therefore, some of the stations mentioned above are located close to these ranges. Portland, OR, is nestled in between the Coast and the Central Cascade Ranges; Pendleton, OR, is to the immediate north of the Blue Mountains; Baker City, OR, lies in between the Blue and the Wallowa Mountains; Seattle, WA, is located on the Puget Sound in between the Olympic Mountains and the Northern Cascade Range; Reno, NV, lies directly east of the Northern Sierra Nevada Mountains; and Tonopah, NV, lies to the east of the Central Sierra Nevada Mountains and also among ranges in Nevada. Crescent City and Eureka are located along the Pacific coast at the western edge of the Klamath Mountains. Another characteristic topographic feature of California is the Central Valley, which is approximately 450 miles long and is located in between the

Coast Ranges and the Sierra Nevada Mountains, and is where ten of the 30 stations,

including Sacramento, are located.

The geographic locations and 3 letter codes of the selected stations can be seen in

Figure 2.1 and Table 2.1 below.
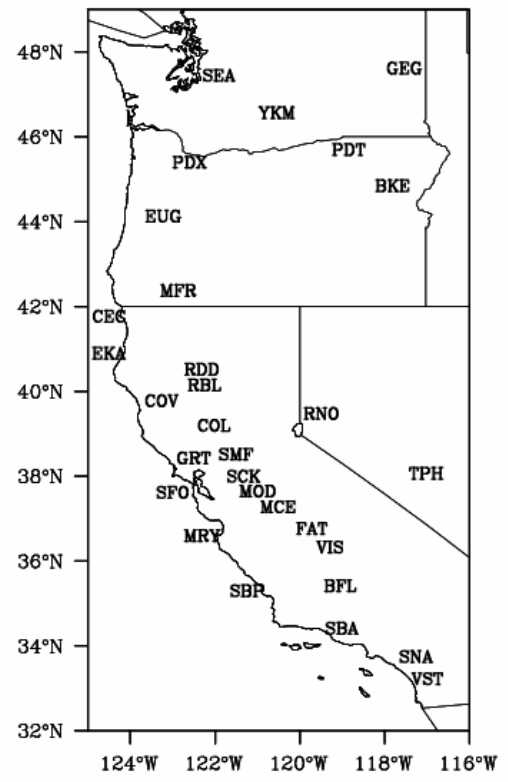
Figure 2.1. The geographic locations of the 30 selected California, Washington, Oregon, and Nevada stations.

Table 2.1. The station codes and names for the selected 30 stations, separated by their geographic regions.

Central Valley Stations		Coastal Stations		Surrounding State Stations	
Redding	RDD	Crescent City	CEC	Seattle	SEA
Red Bluff	RBL	Eureka	EKA	Spokane	GEG
Colusa	COL	Covelo	COV	Yakima	YKM
Sacramento	SMF	Graton	GRT	Portland	PDX
Stockton	SCK	San Francisco	SFO	Eugene	EUG
Modesto	MOD	Monterey	MRY	Medford	MFR
Merced	MCE	San Luis Obispo	SBP	Pendleton	PDT
Fresno	FAT	Santa Barbara	SBA	Baker City	BKE
Visalia	VIS	Santa Ana	SNA	Reno	RNO
Bakersfield	BFL	Vista	VST	Tonopah	TPH

The maximum and minimum daily air temperature data for all California stations used in this project were obtained from the University of California Statewide Integrated Pest Management Program (UC IPM) database of information accessible online (University of California, 2007), which is a provider of weather data and products to the public. Temperature data were chosen by county and specific station site at which the readings took place. Among the data available were current daily and hourly data, and long-term data that were available from climate stations. Climate station data were selected for this project, providing data that spanned a longer time period. For each selected station, the observer, location, recorded variable, sensor height, backup stations, and percentage of values stored for certain time periods were provided.

At the time of data retrieval, the available records for the 10 valley stations contained UC IPM database records spanning 1 January 1950 to about January 2007 and measured temperature data at a sensor height of five feet (1.5 m). The available records for the 10 coastal observation sites contained UC IPM database records that spanned from 1 January 1951 to about January 2007, except for the Graton and Vista observation

sites, whose records spanned from 1 July 1948 to about January 2007, and 1 May 1962 to about January 2007, respectively. Temperature measurements for all coastal stations were measured at a sensor height of five feet (1.5 m).

The data for the Washington, Oregon, and Nevada stations were obtained from the Global Summary of the Day (GSOD) provided by the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center's (NCDC) Climate Data Online (National, 2007). The location, observer, and elevation were provided for all stations. Tables 2.2, 2.3, and 2.4 below list the information for the selected 30 stations.

Table 2.2. California Central Valley Station Information. NWS = National Weather Service, FAA = Federal Aviation Administration, ASOS = Automated Surface Observation Stations

City	Station Site (if known)	County	Latitude	Longitude	Elevation (meters)	Observer (if known)
Redding		Shasta	40º 31´´N	122º 19´´W	153	NWS
Red Bluff	Red Bluff Municipal Airport	Tehama	40º 9´´N	122º 15´´W	106	
Colusa		Colusa	39º 12´´N	122º 1´´W	15	City of Colusa
Sacramento	Sacramento Executive Airport	Sacramento	38º 31´´N	121º 30´´W	5	FAA-Flight Service Station
Stockton	Stockton Fire Station #4	San Joaquin	38º 0´´N	121º 19´´W	4	
Modesto		Stanislaus	37º 39´´N	121º 0´´W	28	Modesto Irrigation District
Merced		Merced	37º 17´´N	120º 31´´W	47	Merced Fire Department
Fresno	Fresno Yosemite International Airport	Fresno	36º 46´´N	119º 43´´W	101	NWS-ASOS
Visalia		Tulare	36º 20´´N	119º 18´´W	99	Visalia Fire Department
Bakersfield	Bakersfield WSO Airport	Kern	35º 25´´N	119º 3´´W	149	NWS-ASOS

Table 2.3. California Coastal Stations Information. NWS = National Weather Service.

City	Station Site (if know)	County	Latitude	Longitude	Elevation (meters)	Observer
Crescent City		Del Norte	41º 46´´N	124º 12´´ W	12	Mrs. Leslie Disrude
Eureka	Eureka WSO, Woodley Island	Humboldt	40º 48´´ N	124º 10´´ W	6	NWS
Covelo	Round Valley Airport	Mendocino	39º 47´´ N	123º 15´´ W	436	William B. Cook
Graton		Sonoma	38º 26´´ N	122º 52´´ W	61	Mrs. Louise Hallberg
San Francisco	San Francisco WSO Airport	San Mateo	37º 37´´ N	122º 23´´ W	2	NWS
Monterey		Monterey	36º 36´´ N	121º 54´´ W	117	Mr. Robert J. Renard
San Luis Obispo		San Luis Obispo	35º 18´´ N	120º 40´´ W	96	California Polytechnic State University
Santa Barbara		Santa Barbara	34º 25´´ N	119º 41´´ W	2	City of Santa Barbara
Santa Ana	Santa Ana Fire Station	Orange	33º 45´´ N	117º 52´´ W	41	Santa Ana Fire Department
Vista	Fire Station #3	San Diego	33º 14´´ N	117º 14´´W	155	Vista Fire Department

Table 2.4. Washington, Oregon, and Nevada Station Information. ASOS = Automated Surface Observation Stations, NWS = National Weather Service, COOP = Cooperation Stations, AC = Cooperative Aviation, NEXRAD = NEXt generation RADar, FAA = Federal Aviation Administration, AAF = Army Air Field.

City	Station Site	County	Latitude	Longitude	Elevation (meters above sea level)	Observer
Seattle, WA	Seattle Tacoma International Airport	King	47º 27´´N	122º 19´´W	113	ASOS-NWS COOP ASOS
Spokane, WA	Spokane International Airport	Spokane	47º 37´´N	117º 32´´ W	717	Air Sampling Station ASOS-NWS ASOS COOP
Yakima, WA	Yakima Air Terminal	Yakima	46º 34´´N	120º 33´´ W	324	ASOS ASOS-NWS COOP
Portland, OR	Portland International Airport	Multnomah	45º 35´´N	122º 36´´ W	6	COOP ASOS ASOS-NWS
Eugene, OR	Eugene Mahlon Sweet Airport	Lane	44º 08´´ N	123º 13´´ W	108	ASOS COOP ASOS-NWS
Medford, OR	Medford Rogue Valley Airport	Jackson	42º 23´´ N	122º 52´´ W	395	ASOS-NWS ASOS COOP
Pendleton, OR	Pendleton E Or Rgnl Airport	Umatilla	45º 42´´ N	118º 51´´ W	453	ASOS-NWS ASOS COOP NEXRAD
Baker City, OR	Baker City Municipal Airport	Baker	44º 51´´ N	117º 49´´ W	1024	ASOS-NWS ASOS ASOS-FAA COOP
Reno, NV	Reno Tahoe International Airport	Washoe	39º 29´´ N	119º 46´´ W	1344	ASOS ASOS-NWS COOP
Tonopah, NV	Tonopah AAF	Nye	38º 04´´ N	117º 01´´ W	1650	AAF

Temperature data were extracted from the websites and put into a comma-delimited data file for the 28-year time period of 01 January 1979 to 30 September 2006, for each station. Due to the utilization of satellites in 1979, dates after 1979 were chosen to assure consistent data when creating the 850mb temperature anomaly field plots discussed later. A 28-year long time period was determined to be a reasonable amount of

time to observe at least a dozen severe heat wave events. The summer months of June, July, August, and September (JJAS) were considered for heat waves because they are the months in which heat waves most frequently occur. These data files were then saved into a Wordpad text file. This external data was imported into Microsoft Excel, and read into the created event identification program, IPM.ncl, of which most parts can be seen in Appendix C. Each station file consisted of 10,135 times, maximum daily temperatures, and minimum daily temperatures which corresponded to one reading for each day between 01 January 1979 and 30 September 2006.

B. Event Identification

NCAR Command Language (NCL), a program language designed for analyzing and graphing scientific data, was used to analyze the data. The programs, which will be individually referenced later, are in Appendix C.

The steps taken to determine the spatial extent of Sacramento heat waves included selecting JJAS dates and temperatures from the entire dataset of maximum and minimum atmospheric temperature data, creating long term daily means and anomalies, selecting heat wave events based on certain criteria, correlating temperature data, ranking heat wave events based on certain criteria, matching the top heat wave event dates between cities, using bootstrap resampling statistical methods to derive certain sample statistics, and creating 850hPa level maximum temperature and anomaly field plots. Other graphs and plots were also created in order to display information about the data. This graphical output aided in identifying and understanding trends, similarities, and differences of the temperatures and heat wave events across the stations. Determination of heat wave events was performed using both unfiltered and filtered temperature data. Filtering was

done in order to smooth the extreme peaks and valleys in the daily raw temperature data so that the lengths of the heat waves could be more reliable. A heat wave event that appears as two separate events due to a low-valued maximum temperature that does not surpass the threshold criteria, could possibly be considered one event after the filtering is performed. Filtering of daily data used a low-pass Lanczos filter with 51 weights and a cut-off period of 3. The filtering program, filter.ncl, is in Appendix C. Each task mentioned above will be explained in further detail.

Once JJAS times and temperature data are selected, long term daily means (LTDM) for maximum and minimum temperatures are computed for each date. For example, the LTDM maximum temperature for 01 June would be equal to that of the sum of the 01 June maximum temperatures from each year divided by the total number of years in the dataset, 28. Therefore, a total of 122 LTDMs, one for each day in JJAS, are computed. The LTDM is then used to compute the maximum and minimum anomalies for each date, for every year, by subtracting the LTDM temperature from the observed temperature recorded on that specific date.

Now that the correct data have been selected, and certain initial calculations made, the heat wave events are now identified based on certain criteria. Therefore, a definition of a heat wave must be created or chosen to implement into the program. It was decided to base the definition of a heat wave on the temperature anomaly data. Using temperature anomalies to define a heat wave would base the event on its deviation from normal on those particular days of the event, rather than absolute temperatures. Using a specified absolute temperature across the board could result in some cities reaching that determined threshold many of the times, because that city frequently

experiences high temperatures, while other cities may never reach the threshold, yet at the same time may be experiencing very high temperatures relative to that city's normal temperatures for that day. A temperature of 100ºF (38ºC)may be a normal occurrence for some cities in the Central Valley, and not anomalous on some dates, while for cities at the coast, a lower temperature would be anomalous and very warm compared to what is normally observed for that region. It was decided to define a heat wave event as at least three consecutive days with temperature anomalies greater than a specified threshold for every day and at least one day where the temperature anomaly exceeded an even higher threshold. The structure of the definition stems from Grotjahn and Faure's (2007) definition, but using temperature anomalies rather than absolute temperatures.

In order to execute such a definition, a maximum and minimum anomaly threshold must be selected. Once thresholds are chosen, all dates in the historical record having anomalous temperatures that exceed the minimum anomaly threshold for three consecutive days are searched for and selected. Once these candidate dates are selected, the historical record is searched again for those dates that satisfy the criteria of at least one of these consecutive dates having a maximum temperature anomaly that exceeds the maximum temperature anomaly threshold. If no dates are found that satisfy this second requirement, then that candidate event is no longer considered.

In order to determine the appropriate minimum and maximum anomaly thresholds, different combinations of thresholds were tested. Threshold pairs 5 degrees apart were chosen, once again mimicking the definition of Grotjahn and Faure (2007). Examples tested included 8 and 13, 9 and 14, 10 and 15, and 11 and 16 degrees Fahrenheit. The anomaly threshold pair was chosen to obtain, at the most, 20 to 30 heat

wave events in Sacramento for the 28 years being reviewed. This would be roughly

equal to about 1 heat wave event per year. It was found that a minimum anomaly

threshold of 10 and a maximum anomaly threshold of 15 was the most suitable pair to

deliver these results. Higher anomaly threshold pairs that were tested resulted in too few

events for some cities, while smaller anomaly threshold pairs resulted in too many events

in other cities. Events would not be considered extreme if a very large number of events

took place at one station. The criteria for this first definition of a heat wave event can be

seen in Table 2.5 below.

Table 2.5. Criteria for the first definition of a heat wave.

	Criteria
1	At least 3 consecutive days where maximum temperature anomaly ≥ 10
2	At least 1 day where maximum temperature anomaly ≥ 15

Once the candidate heat wave events were identified, it was found that some of

the selected heat wave events included maximum temperatures that were perhaps too low

to be considered as a heat wave, despite the fact that they were sufficient in exceeding the

anomaly threshold. For example, a 10ºF anomaly could be as low as 96ºF (36ºC) at some

of the Central Valley cities. Although a warm temperature, it was felt that temperatures

near this range were not hot enough to be included in an extreme event such as a heat

wave in the Central Valley. While anomalies are very important in the examination of

weather patterns and unusual events on weather maps, absolute temperatures are also

important when considering the severity and impacts of a heat wave. It is the heat

intensity that effects the people and economy of a particular community, and therefore, it

is important to also examine the absolute temperatures. Thus, another criterion was

developed to include in the heat wave definition that required the average maximum

temperature of a heat wave event to also equal or exceed 100ºF (38ºC). The criteria for

the second definition of a heat wave event can be seen in Table 2.6 below.

Table 2.6. Criteria for the second definition of a heat wave.

	Criteria
1	At least 3 consecutive days where maximum temperature anomaly ≥ 10
2	At least 1 day where maximum temperature anomaly ≥ 15
3	Average maximum temperature of event ≥ 100ºF (38ºC)

C. Comparing Stations (Rankings and Matchings)

After heat wave events were selected based on the two definitions above, the heat

wave events for each station were ranked, first, based on the maximum temperature of

each event and, second, based on the highest consecutive 3-day average of maximum

temperature anomalies within each event. The top 15 events of each city were selected

for each ranking method. For the first ranking method, the date with the largest daily

maximum temperature within each event was searched for and selected. The heat wave

with the largest maximum temperature was determined to be the "hottest" or "most

intense" heat wave of that city's record and the heat wave with the smallest maximum

temperature was determined to be the "least hot" or "least intense" heat wave of that

city's record.

For the second ranking method based on the highest consecutive 3-day average of

maximum temperature anomalies, three days was chosen as the time interval of which to

take the average because all heat waves, according to the implemented definition, had to

be at least 3 days in duration. All heat waves would have an averaged value. The heat

wave with the highest average was considered the most intense event and the event with

the lowest average was considered the least intense.

The two methods of ranking the hottest heat wave events at each station resulted in differing event lists. The events were ranked according to both maximum temperature and 3-day averages of anomalies because each method highlights different and important features of heat waves. Ranking by the highest maximum temperature of the events highlights the "absolute" or "peak" intensity of the heat wave event. The events that have the highest temperatures will be considered the most intense heat waves. Under this ranking method, coastal stations will not have as many heat events as, say, Central Valley stations, because high temperatures reaching into the 100s do not occur as often at the coast as they do in the Central Valley. Since this ranking scheme identifies areas experiencing the worse "absolute" heat intensity, that knowledge identifies cities whose population and economy might suffer hardship from negative effects of the high temperatures.

When ranked by the highest 3-day average of maximum temperature anomalies, temperature anomalies and anomalous weather patterns are the highlighted features of the events. The latter is highlighted because the event is ranked in part due to the persistence of the high temperatures. Under this ranking method, events are at stations that experience similar anomalous strength of a heat wave relative to the mean local climate of each station, but not necessarily the same high absolute temperatures. Therefore, even if a city does not observe temperatures as high as Sacramento, its anomalous strength and deviation from its local mean can still be compared. For example, because anomalies do not have a seasonal trend, when a heat wave event occurs in September when it is generally cooler, rather than in July, maximum temperatures may not reach the event thresholds, though the large-scale weather pattern may be similar. Once identified, the

anomalous weather pattern can be used in the future to indicate other extreme events such as heat waves. So, another purpose of using anomalies is to even out the season and to create a longer record with which to work, which results in more samples and, thus, better statistics.

Once the top 15 heat wave events for each station were ranked, the heat wave event dates of these events from each valley, coastal, and surrounding state station were compared with the top 15 event dates found in Sacramento using a matching scheme. The matching scheme program, IPM_Stats.ncl, can be seen in Appendix C. If an event date from one of the stations matched the date of a Sacramento heat wave event date, then this date was selected and considered a "match." The number of overlapping heat wave events was then determined and counted. The number of event overlap matches for each station was divided by 15 to obtain the percentage of Sacramento's most intense heat wave events experienced by that station. This matching scheme was performed on both the top heat wave event set ranked by maximum temperature and the set ranked by the highest 3-day average of maximum temperature anomalies, for both unfiltered and filtered data, using both heat wave definitions. This method of matching was developed in order to assess how widespread a heat wave in Sacramento can be by indicating into what surrounding areas it spreads.

The expected number of the top 15 event dates that match by 'chance' is also estimated. Chance is defined as the same frequency as the ratio of the number of total heat wave days in the top 15 events at a particular station to the number of total dates in the period, N. There are JJAS days for 28 years, or $N=122 \times 28=3416$, total dates. The total number of Sacramento heat wave days in the top 15 events is defined as $n1$.

Likewise, the total number of heat wave days in the top 15 events at each other station is defined as n2. The observed number of top event date matches is defined as m. The expected number of matches due to 'chance' would be n2/3416 = X/n1. As an example, for the scenario using filtered data and the first definition of a heat wave ranked by 3-day anomaly averages, n1=76 and n2 (Bakersfield)=50. Therefore, 50/3416 = X/76. This gives X=1.112, or, a little more than 1 match. m=21 top event date matches were observed at the Bakersfield station. This is more than 18 times the expected number of matches due to chance. Similar estimations were made for each station. Since rare weather events such as heat waves are being examined, the total number of observed matches may be small, but might be quite larger than the expected number of matches due to chance.

D. Correlations and Statistics

Correlations were calculated between stations for the temperature data. The first set of correlations performed correlated Sacramento JJAS temperatures with temperatures at the other stations on those corresponding dates. This correlation was performed in order to observe the relationship between daily maximum temperatures within all of JJAS, and not just heat wave events.

The second set of correlations consisted of lag correlations of temperature data. First, correlations of all JJAS Sacramento temperatures with the JJAS temperatures of each of the other cities were performed with lag times of 0 through 10 days (with 0 lag time being equal to the correlations performed above). These lag correlations were calculated in order to identify the relative timing of the temperature data between the

different stations during summer months, and therefore, to better understand the progression of the weather events.

Another comparison was made between stations that used normalized maximum temperature anomalies. The standard deviation of all JJAS maximum temperatures was found for each station. The anomaly value on each date was then divided by this standard deviation value in order to obtain a normalized anomaly, one for each date. The normalized anomalies on all the dates of heat waves identified for that station were then averaged to obtain an average normalized anomaly for each station. This value could then be used to compare the strength of the maximum temperatures on all the identified heat wave dates at each station. The strength of this number represents the average number of standard deviations that the maximum temperature on those particular event dates is away from that station's long-term daily mean. Different stations will have different amounts of variation, and, thus, different standard deviations. This comparison assesses how unusual the temperatures on the target dates are for that particular city, based on that city's local climate, and allows for direct comparison between different stations having this different variability.

A second comparison was made using the normalized maximum temperature anomalies that averaged these values only on the dates that were part of the highest 3-day temperature anomaly averages for each of the top 15 ranked events experienced in Sacramento. The normalized anomalies on those same dates were averaged together for each of the other stations, resulting in one averaged normalized value for each station. These values represent the averaged anomalous temperature strength of each city on the dates that Sacramento experienced its most intense anomaly averages of its 15 most

intense heat events. So, the dates used at the station were not necessarily matching event dates identified for that station. These resulting values give an indication of the sign and size of the maximum temperature anomalies outside of Sacramento on days when Sacramento had its strongest heat waves.

E. Bootstrap Resampling

The statistical significance of the onset dates of the hottest 15 heat wave events in Sacramento was tested using bootstrap resampling. The Bootstrap is a method used for estimating the distribution of a property of groups, or ensembles, drawn from a population. The Bootstrap method used here constructs each ensemble by sampling randomly and with replacement from the days in JJAS for the 28 years. A frequency distribution from the statistical property of each ensemble can then be created and compared to the statistical property of a specified target ensemble. A target ensemble might be the dates satisfying the criteria for a heat wave in Sacramento. The statistical property might be the mean of the maximum temperatures in the ensemble.

For each station, the maximum temperatures at that station on the top 15 onset dates of Sacramento heat waves, ranked according to the highest consecutive 3-day anomaly average, were averaged together and termed the 'target' ensemble average for that station. That ensemble average was then compared with the ensemble averages of 1,000 randomly generated 15-member mean ensembles of maximum temperatures during JJAS at that station. The 1,000 randomly generated ensemble averages and the target mean ensemble were plotted using a histogram in order to see the frequency distribution of the ensemble averages. The 99.5% significance threshold of each station was determined and the target ensemble was compared to that threshold. This procedure

provides another way to assess how unusual the maximum temperatures are at different stations on the same days that Sacramento experiences stronger heat waves, for example, or the onset of a heat wave, for another example. For the stations whose target ensemble mean did not exceed the 99.5% significance threshold, new target ensemble means were created using the dates corresponding with the lag of its highest correlation with Sacramento temperatures. For example, if Seattle has the highest correlation with Sacramento temperatures at a lag time of 2 days, then a new target ensemble mean would be created for Seattle using the dates 2 days after the dates that Sacramento experienced its strongest events. The bootstrap program, rngen.ncl, is in Appendix C.

F. 850hPa Plots

Plots were created for the 850hPa level anomalous temperature and maximum temperature fields on the onset dates of the highest 3-day anomaly averages of the top 15 heat wave events in Sacramento. One plot was created for each event, along with a mean plot of the events for each field, totaling 16 plots. The purpose of the plots was to observe the large-scale structure of the most intense heat waves, and to assess how consistent this pattern is between the mean plot and the individual event plots.

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.
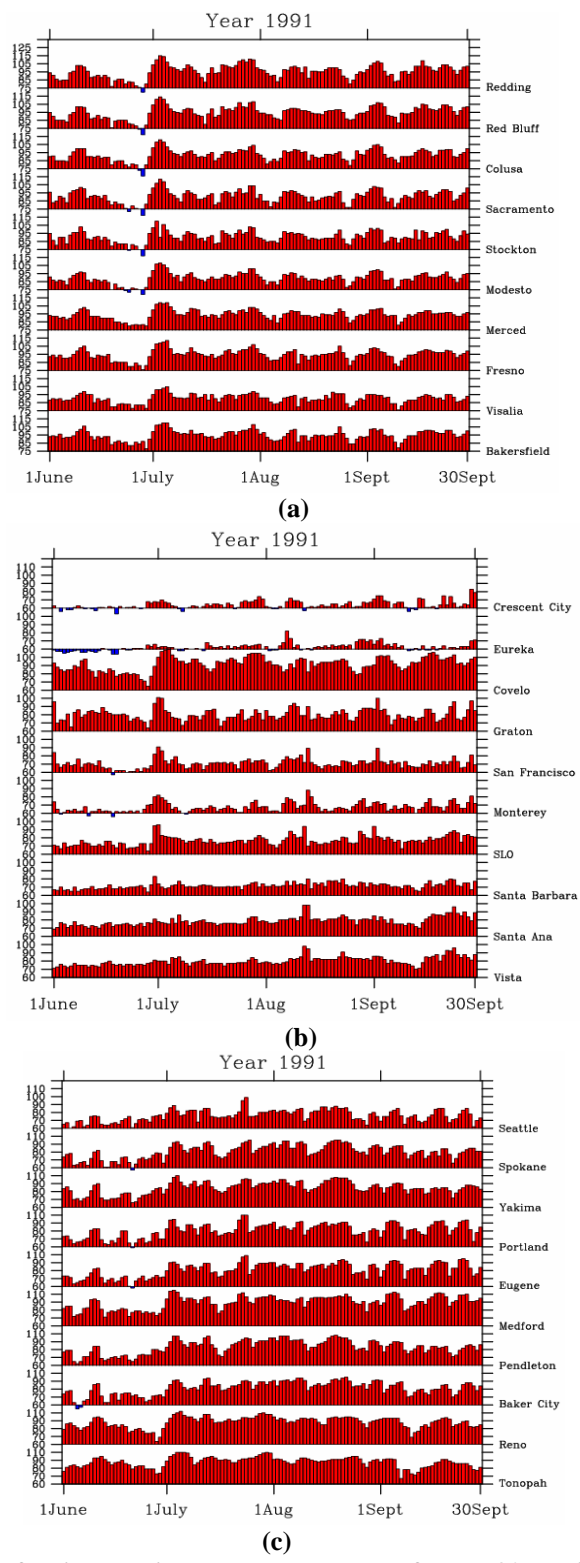
Figure 3.1. Bar charts of daily maximum temperatures for all 30 stations for the summer of 1991, in which the highest ranked Sacramento heat wave event, ranked according to the highest 3-day anomaly averages, occurred. The dates for this event were 02 July 1991 to 04 July 1991. Charts are divided into 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.
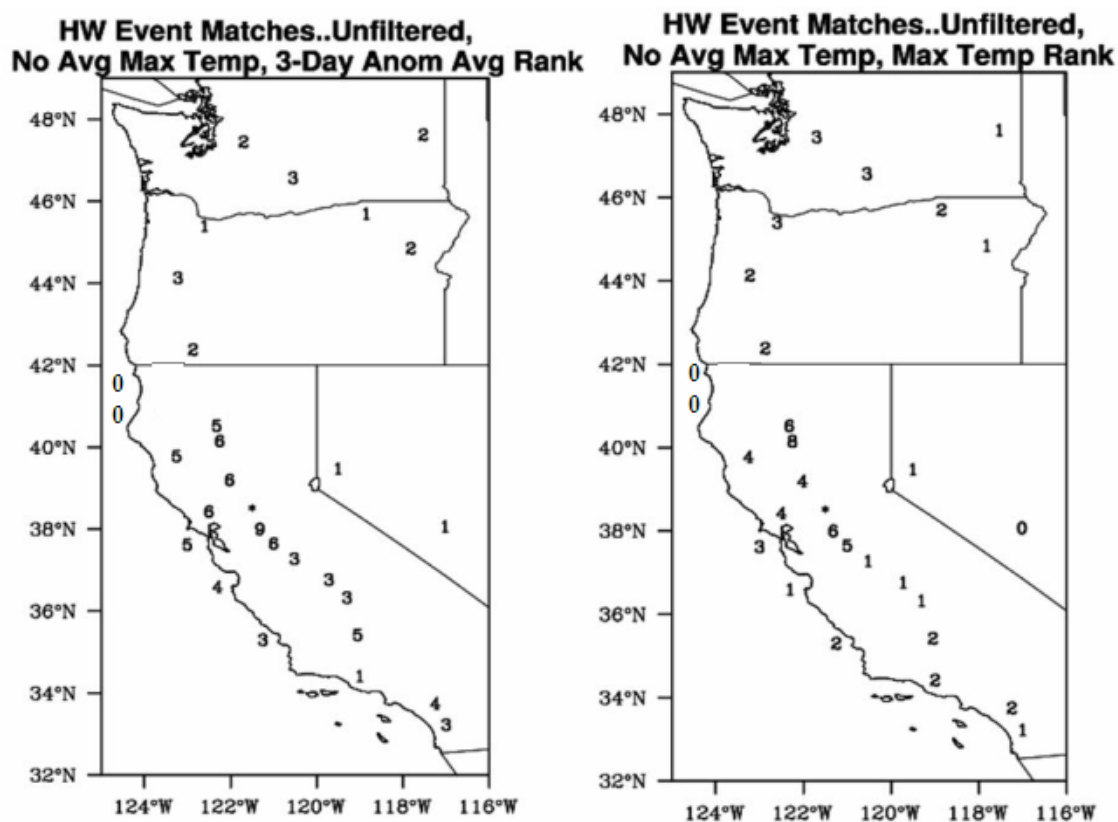
Figure 3.2. Spatial representation of the number of heat wave event matches of the top 15 events using the unfiltered data following the event definition that requires 3 consecutive days with anomalies greater than or equal to 10, with one of those days having an anomaly greater than or equal to 15, 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.
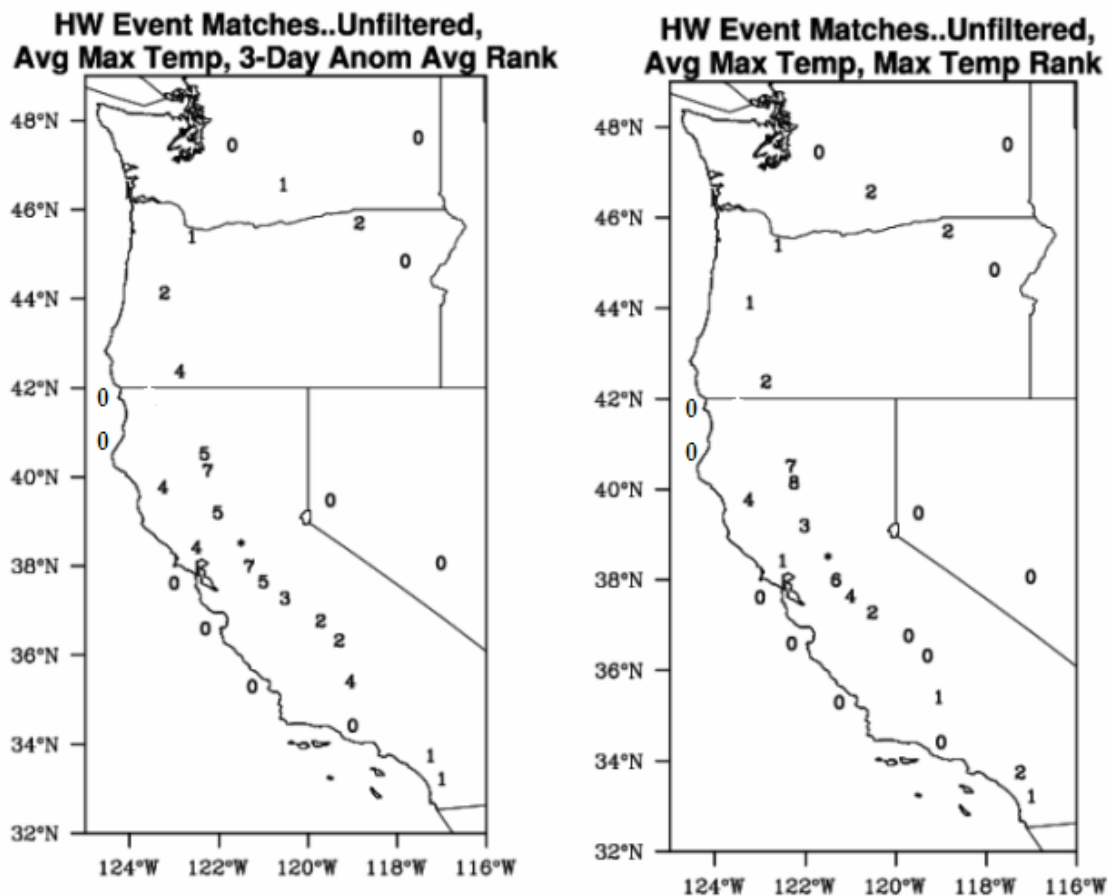
Figure 3.3. Similar to Figure 3.1 above except for heat wave events defined by having 3 consecutive days with anomalies greater than or equal to 10, with one of those days having an anomaly greater than or equal to 15, and having an average maximum temperature greater than or equal to 100ºF (38ºC). Events 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 15th 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 *
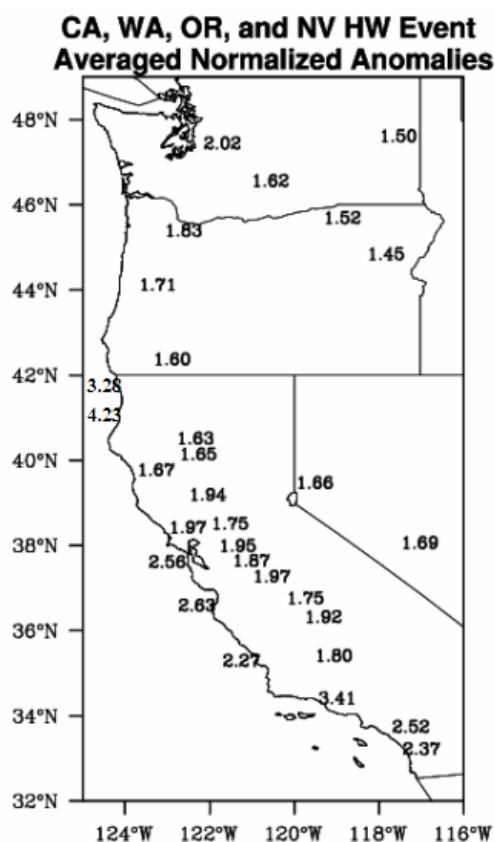
Figure 3.4. Spatial representation of the average maximum temperature anomalies during heat wave event dates for each station. The values are normalized by the standard deviation at each station. Some stations with high values have smaller standard deviations and, hence, have few events meeting the heat 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.
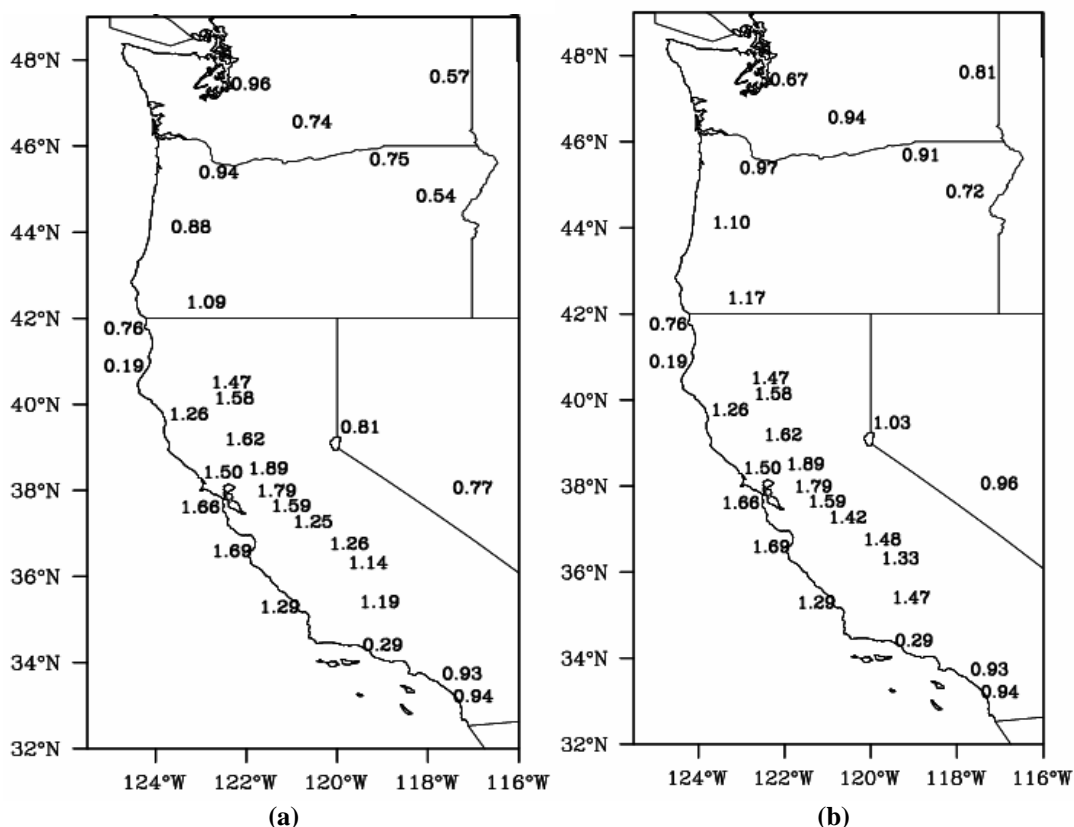
Figure 3.5. Spatial representation of the averaged normalized temperature anomalies of each station a) on the dates of the highest consecutive 3-day anomaly averages of the top Sacramento heat wave event dates, and b) on the day of the highest correlation of each station with respect to the date of the 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.
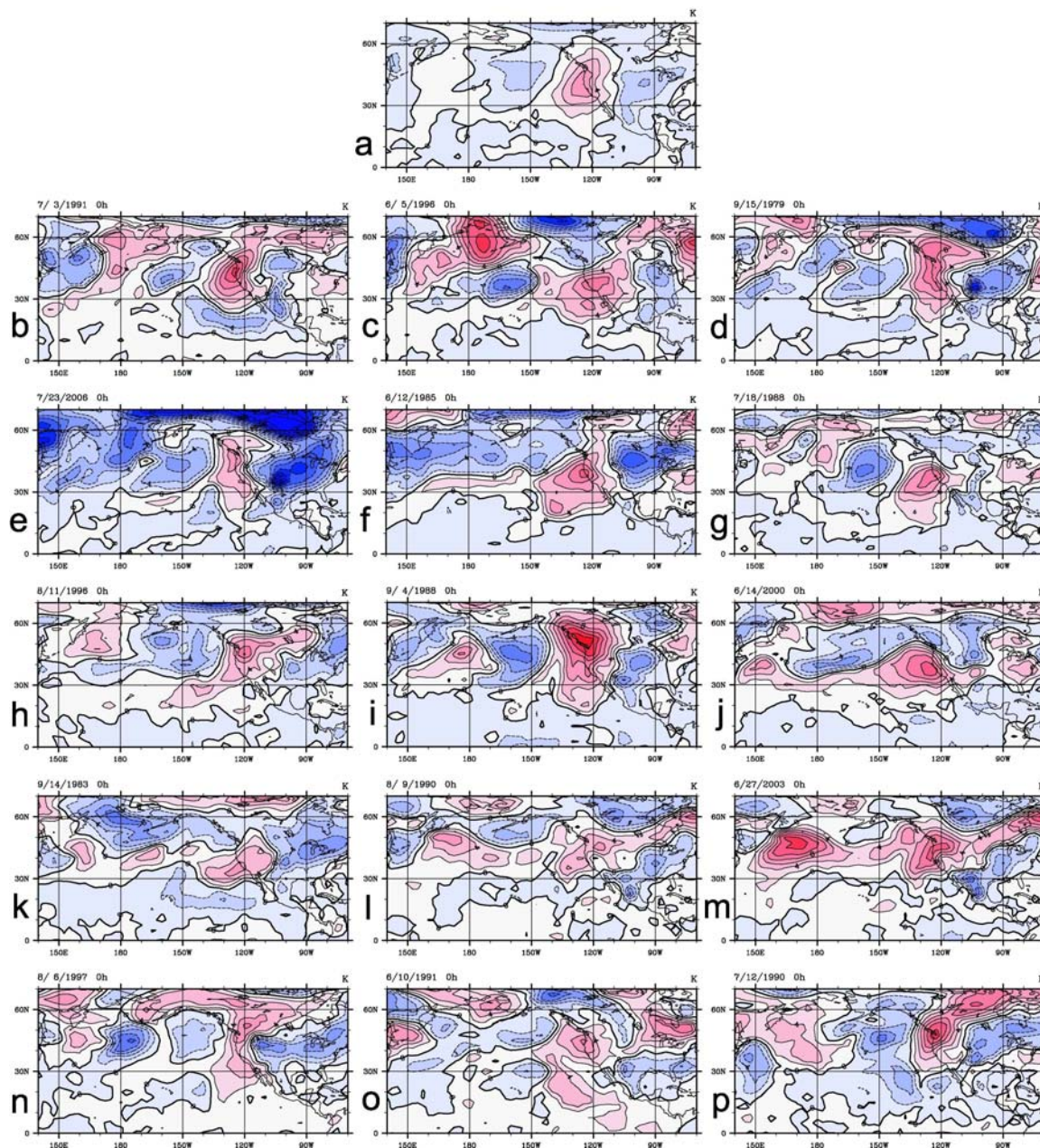
Figure 3.6. (b – p) Plots of the 850hPa temperature anomaly fields for the dates of the highest consecutive 3-day anomaly average of the top 15 heat waves in Sacramento. (a) Plot of the 850hPa mean anomaly field of all anomaly field plots, b-p. Darker shading and dark contours indicate positive temperature 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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Appendix A

<u>**Identified Events**</u>

Table A.1. Chronological ordering of all identified Sacramento heat wave events based on the definition that requires 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. Unfiltered data. Information given includes start and end date, maximum temperature in °F (°C), minimum temperature in °F (°C), average temperature in °F (°C), and duration (in number of days) of the heat event.

Event#	Start	End	MaxT	MinT	AvgT	Duration
1	19790911	19790916	104 (40)	99 (37)	102.17 (38.98)	6
2	19830911	19830915	104 (40)	100 (38)	101.80 (38.78)	5
3	19850609	19850616	105 (41)	99 (37)	102.12 (38.96)	8
4	19880716	19880719	112 (44)	105 (41)	108.00 (42.22)	4
5	19880824	19880826	105 (41)	101 (38)	103.67 (39.82)	3
6	19880903	19880905	108 (42)	105 (41)	107.00 (41.67)	3
7	19900619	19900621	105 (41)	100 (38)	102.00 (38.89)	3
8	19900710	19900713	109 (43)	104 (40)	106.50 (41.39)	4
9	19900805	19900811	109 (43)	104 (40)	106.71 (41.51)	7
10	19900928	19900930	101 (38)	95 (35)	97.33 (36.29)	3
11	19910607	19910611	102 (39)	95 (35)	98.80 (37.11)	5
12	19910702	19910704	112 (44)	107 (42)	109.33 (42.96)	3
13	19920602	19920604	99 (37)	95 (35)	97.00 (36.11)	3
14	19920815	19920820	106 (41)	99 (37)	102.33 (39.07)	6
15	19940609	19940611	103 (39)	95 (35)	98.67 (37.04)	3
16	19960602	19960608	104 (40)	97 (36)	100.71 (38.17)	7
17	19960630	19960702	106 (41)	100 (38)	103.33 (39.63)	3
18	19960809	19960815	110 (43)	103 (39)	107.00 (41.67)	7
19	19970804	19970807	108 (42)	102 (39)	105.75 (40.97)	4
20	19980803	19980805	108 (42)	103 (39)	105.33 (40.74)	3
21	20000613	20000616	105 (41)	99 (37)	101.75 (38.75)	4
22	20020604	20020606	101 (38)	95 (35)	97.00 (36.11)	3
23	20030626	20030628	105 (41)	102 (39)	103.33 (39.63)	3
24	20060720	20060725	111 (44)	103 (39)	106.67 (41.48)	6

Table A.2. Chronological ordering of all identified Sacramento heat wave events based on the definition as in Table A.1, except for filtered data.

Event#	Start	End	MaxT °F(°C)	MinT °F(°C)	AvgT °F(°C)	Duration
1	19790911	19790916	104.99(40.55)	99.23(37.35)	101.93(38.85)	6
2	19830911	19830915	103.45(39.69)	100.48(38.04)	101.68(38.71)	5
3	19840916	19840918	101.59(38.66)	95.71(35.39)	99.23(37.35)	3
4	19850609	19850617	103.63(39.79)	98.30(36.83)	101.51(38.62)	9
5	19880716	19880719	111.09(43.94)	104.00(40.00)	107.85(42.14)	4
6	19880903	19880905	109.90(43.28)	104.10(40.06)	106.48(41.38)	3
7	19900805	19900811	109.87(43.26)	102.72(39.29)	106.51(41.39)	7
8	19910608	19910611	102.38(39.10)	98.67(37.04)	99.74(37.63)	4
9	19910701	19910704	112.27(44.59)	100.94(38.30)	107.25(41.81)	4
10	19910923	19910925	100.22(37.90)	95.19(35.11)	97.94(36.63)	3
11	19920815	19920820	104.57(40.32)	100.02(37.79)	102.46(39.14)	6
12	19940609	19940611	101.76(38.76)	95.60(35.33)	98.87(37.15)	3
13	19960602	19960608	102.63(39.24)	97.96(36.64)	100.73(38.18)	7
14	19960809	19960815	109.71(43.17)	103.31(39.62)	107.11(41.73)	7
15	19980803	19980805	107.66(42.03)	103.33(39.63)	105.31(40.73)	3
16	20000613	20000616	103.87(39.93)	99.08(37.27)	101.90(38.83)	4
17	20030626	20030628	104.82(40.46)	101.55(38.64)	103.32(39.62)	3
18	20060721	20060724	111.15(43.97)	105.03(40.57)	108.43(42.46)	4

Table A.3. Chronological ordering of all identified Sacramento heat wave events based on the definition that requires 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, and an average maximum temperature greater than or equal to 100ºF (38ºC). Unfiltered data.

Event#	Start	End	MaxT °F(°C)	MinT °F(°C)	AvgT °F(°C)	Duration
1	19790911	19790916	104 (40)	99 (37)	102.17 (38.98)	6
2	19830911	19830915	104 (40)	100 (38)	101.80 (38.78)	5
3	19850609	19850616	105 (41)	99 (37)	102.12 (38.96)	8
4	19880716	19880719	112 (44)	105 (41)	108.00 (42.22)	4
5	19880824	19880826	105 (41)	101 (38)	103.67 (39.82)	3
6	19880903	19880905	108 (42)	105 (41)	107.00 (41.67)	3
7	19900619	19900621	105 (41)	100 (38)	102.00 (38.89)	3
8	19900710	19900713	109 (43)	104 (40)	106.50 (41.39)	4
9	19900805	19900811	109 (43)	104 (40)	106.71 (41.51)	7
10	19910702	19910704	112 (44)	107 (42)	109.33 (42.96)	3
11	19920815	19920820	106 (41)	99 (37)	102.33 (39.07)	6
12	19960602	19960608	104 (40)	97 (36)	100.71 (38.17)	7
13	19960630	19960702	106 (41)	100 (38)	103.33 (39.63)	3
14	19960809	19960815	110 (43)	103 (39)	107.00 (41.67)	7
15	19970804	19970807	108 (42)	102 (39)	105.75 (40.97)	4
16	19980803	19980805	108 (42)	103 (39)	105.33 (40.74)	3
17	20000613	20000616	105 (41)	99 (37)	101.75 (38.75)	4
18	20030626	20030628	105 (41)	102 (39)	103.33 (39.63)	3
19	20060720	20060725	111 (44)	103 (39)	106.67 (41.48)	6

Table A.4. Chronological ordering of all identified Sacramento heat wave events based on the definition as in Table A.3, except for filtered data.

Event#	Start	End	MaxT °F(°C)	MinT °F(°C)	AvgT °F(°C)	Duration
1	19790911	19790916	104.99(40.55)	99.23(37.35)	101.93(38.85)	6
2	19830911	19830915	103.45(39.69)	100.48(38.04)	101.68(38.71)	5
3	19850609	19850617	103.63(39.79)	98.30(36.83)	101.51(38.62)	9
4	19880716	19880719	111.09(43.94)	104.00(40.00)	107.85(42.14)	4
5	19880903	19880905	109.90(43.28)	104.10(40.06)	106.48(41.38)	3
6	19900805	19900811	109.87(43.26)	102.72(39.29)	106.51(41.39)	7
7	19910701	19910704	112.27(44.59)	100.94(38.30)	107.25(41.81)	4
8	19920815	19920820	104.57(40.32)	100.02(37.79)	102.46(39.14)	6
9	19960602	19960608	102.63(39.24)	97.96(36.64)	100.73(38.18)	7
10	19960809	19960815	109.71(43.17)	103.31(39.62)	107.11(41.73)	7
11	19980803	19980805	107.66(42.03)	103.33(39.63)	105.31(40.73)	3
12	20000613	20000616	103.87(39.93)	99.08(37.27)	101.90(38.83)	4
13	20030626	20030628	104.82(40.46)	101.55(38.64)	103.32(39.62)	3
14	20060721	20060724	111.15(43.97)	105.03(40.57)	108.43(42.46)	4

Event Rankings

Table A.5 (a). Ranking of Sacramento heat waves based on the highest event maximum temperatures. Heat waves were identified using the definition as in Table A.1, using unfiltered data.   Information includes rank number, start and end dates, and maximum temperature of the events in °F (°C).

Rank	Start	End	Tmax,°F(°C)
1	19910702	19910704	112 (44)
2	19880716	19880719	112 (44)
3	20060720	20060725	111 (44)
4	19960809	19960815	110 (43)
5	19900805	19900811	109 (43)
6	19900710	19900713	109 (43)
7	19880903	19880905	108 (42)
8	19980803	19980805	108 (42)
9	19970804	19970807	108 (42)
10	19920815	19920820	106 (41)
11	19960630	19960702	106 (41)
12	20030626	20030628	105 (41)
13	19900619	19900621	105 (41)
14	19850609	19850616	105 (41)
15	19880824	19880826	105 (41)
16	20000613	20000616	105 (41)
17	19960602	19960608	104 (40)
18	19830911	19830915	104 (40)
19	19790911	19790916	104 (40)
20	19940609	19940611	103 (39)
21	19910607	19910611	102 (39)
22	19900928	19900930	101 (38)
23	20020604	20020606	101 (38)
24	19920602	19920604	99 (37)

Table A.5 (b). Just as in Table A.5 (a), except for filtered data.

Rank	Start	End	Tmax,°F(°C)
1	19910701	19910704	112.27 (44.59)
2	20060721	20060724	111.15 (43.97)
3	19880716	19880719	111.09 (43.94)
4	19880903	19880905	109.90 (43.28)
5	19900805	19900811	109.87 (43.26)
6	19960809	19960815	109.71 (43.17)
7	19980803	19980805	107.66 (42.03)
8	19790911	19790916	104.99 (40.55)
9	20030626	20030628	104.82 (40.46)
10	19920815	19920820	104.57 (40.32)
11	20000613	20000616	103.87 (39.93)
12	19850609	19850617	103.63 (39.79)
13	19830911	19830915	103.45 (39.69)
14	19960602	19960608	102.63 (39.24)
15	19910608	19910611	102.38 (39.10)
16	19940609	19940611	101.76 (38.76)
17	19840916	19840918	101.59 (38.66)
18	19910923	19910925	100.22 (37.90)

Table A.6 (a). Ranking of Sacramento heat waves based on the highest consecutive 3-day anomaly averages. Heat waves were identified using the definition as in Table A.1, using unfiltered data. Information includes start and end date, the date of the start of the highest 3-day anomaly average, and the highest 3-day anomaly average of the event.

Rank	Start	End	Max Anom Date	Max Anom Avg
1	19910702	19910704	19910702	18.77
2	19960602	19960608	19960604	17.89
3	19790911	19790916	19790914	16.93
4	20060720	20060725	20060722	16.92
5	19850609	19850616	19850611	16.88
6	19880716	19880719	19880717	16.56
7	19960809	19960815	19960810	16.05
8	19880903	19880905	19880903	15.37
9	20000613	20000616	20000613	15.27
10	19830911	19830915	19830913	14.75
11	19900805	19900811	19900808	14.49
12	20030626	20030628	20030626	14.40
13	19970804	19970807	19970805	14.35
14	19910607	19910611	19910609	14.24
15	19900710	19900713	19900711	13.58
16	19880824	19880826	19880824	13.42
17	19920815	19920820	19920818	13.42
18	19960630	19960702	19960630	13.39
19	20020604	20020606	20020604	13.23
20	19980803	19980805	19980803	13.18
21	19900619	19900621	19900619	12.96
22	19920602	19920604	19920602	12.69
23	19940609	19940611	19940609	12.57
24	19900928	19900930	19900928	11.79

Table A.6 (b). Just as in Table A.6 (a), except for filtered data.

Rank	Start	End	Max Anomaly Average
1	19910701	19910704	18.69
2	19960602	19960608	17.72
3	20060721	20060724	16.91
4	19850609	19850617	16.82
5	19880716	19880719	16.63
6	19790911	19790916	16.34
7	19960809	19960815	16.11
8	20000613	20000616	15.40
9	19880903	19880905	14.93
10	19830911	19830915	14.63
11	19900805	19900811	14.43
12	20030626	20030628	14.35
13	19910608	19910611	13.98
14	19920815	19920820	13.49
15	19840916	19840918	13.42
16	19980803	19980805	13.11
17	19940609	19940611	12.79
18	19910923	19910925	12.53

Table A.7. Ranking of Sacramento heat waves based on the highest event maximum temperatures. Heat waves were identified using the definition as in Table A.3, using unfiltered data. Information as in Table A.5.

Rank	Start	End	Tmax,°F(°C)
1	19910702	19910704	112 (44)
2	19880716	19880719	112 (44)
3	20060720	20060725	111 (44)
4	19960809	19960815	110 (43)
5	19900805	19900811	109 (43)
6	19900710	19900713	109 (43)
7	19970804	19970807	108 (42)
8	19880903	19880905	108 (42)
9	19980803	19980805	108 (42)
10	19960630	19960702	106 (41)
11	19920815	19920820	106 (41)
12	20030626	20030628	105 (41)
13	20000613	20000616	105 (41)
14	19900619	19900621	105 (41)
15	19880824	19880826	105 (41)
16	19850609	19850616	105 (41)
17	19830911	19830915	104 (40)
18	19790911	19790916	104 (40)
19	19960602	19960608	104 (40)

Table A.8. Ranking of Sacramento heat waves based on the highest consecutive 3-day anomaly averages. Heat waves were identified using the definition as in Table A.3, using unfiltered data. Information includes start and end dates and the highest 3-day anomaly average of the event.

Rank	Start	End	Max Anomaly Average
1	19910702	19910704	18.77
2	19960602	19960608	17.89
3	19790911	19790916	16.93
4	20060720	20060725	16.92
5	19850609	19850616	16.88
6	19880716	19880719	16.56
7	19960809	19960815	16.05
8	19880903	19880905	15.37
9	20000613	20000616	15.27
10	19830911	19830915	14.75
11	19900805	19900811	14.49
12	20030626	20030628	14.40
13	19970804	19970807	14.35
14	19900710	19900713	13.58
15	19920815	19920820	13.42
16	19880824	19880826	13.42
17	19960630	19960702	13.39
18	19980803	19980805	13.18
19	19900619	19900621	12.96

Event Matchings

Table A. 9. The number of total heat wave events and top heat wave matches, according to the rankings based on 1) the highest consecutive 3-day anomaly averages and 2) the highest event maximum temperatures. The percent of the top 15 events that match Sacramento's top 15 heat wave events are also given for each of the ranking methods.   Heat waves are identified by the definition in Table A.1, using unfiltered data.

	City	Total Number of Events at each station	Number of Matching Dates of Top 15 Sac Events, based on 3-Day Anomaly Average Ranking	Top 15 Sac Event Matches, based on 3-Day Anomaly Average Ranking	% of Sac Top 15 Events Matching Top 15 Events at station, based on 3-Day Anomaly Average Ranking	Number of Matching Dates of Top 15 Sac Events, based on Max Temp Ranking	Top 15 Sac Event Matches, based on Max Temp Ranking	% of Sac Top 15 Events Matching Top 15 Events at station, based on Max Temp Rankings
1	Redding	30	21	5	33.3	19	6	40
2	Red Bluff	31	29	6	40	33	8	53.3
3	Colusa	14	29	6	40	17	4	26.7
4	Sacramento	24	76	*	*	67	*	*
5	Stockton	15	43	9	60	29	6	40
6	Modesto	13	32	6	40	23	5	33.3
7	Merced	4	15	3	20	5	1	6.7
8	Fresno	8	17	3	20	8	1	6.7
9	Visalia	7	20	3	20	8	1	6.7
10	Bakersfield	11	23	5	33.3	6	2	13.3
11	Crescent City	4	0	0	0	0	0	0
12	Eureka	1	0	0	0	0	0	0
13	Covelo	20	19	5	33.3	12	4	26.7
14	Graton	37	17	6	40	12	4	26.7
15	San Francisco	32	13	5	33.3	9	3	20
16	Monterey	26	10	4	26.7	3	1	6.7
17	San Luis Obispo	30	9	3	20	5	2	13.3
18	Santa Barbara	9	3	1	6.7	5	2	13.3
19	Santa Ana	18	13	4	26.7	7	2	13.3
20	Vista	22	8	3	20	3	1	6.7
21	Seattle	28	7	2	13.3	8	3	20
22	Spokane	23	5	2	13.3	3	1	6.7
23	Yakima	15	12	3	20	12	3	20
24	Portland	40	2	1	6.7	8	3	20
25	Eugene	35	10	3	20	7	2	13.3
26	Medford	30	6	2	13.3	6	2	13.3
27	Pendleton	25	4	1	6.7	7	2	13.3
28	Baker City	25	4	2	13.3	1	1	6.7
29	Reno	4	5	1	6.7	5	1	6.7
30	Tonopah	1	6	1	6.7	0	0	0

Table A.10. Just as in Table A.9, except with heat waves identified by the definition in Table A.3, using unfiltered data.

	City	Total Number of Events at each station	Number of Matching Dates of Top 15 Sac Events, based on 3-Day Anomaly Average Ranking	Top 15 Sac Event Matches, based on 3-Day Anomaly Average Ranking	% of Sac Top 15 Events Matching Top 15 Events at station, based on 3-Day Anomaly Average Ranking	Number of Matching Dates of Top 15 Sac Events, based on Max Temp Ranking	Top 15 Sac Event Matches, based on Max Temp Ranking	% of Sac Top 15 Events Matching Top 15 Events at station, based on Max Temp Rankings
1	**Redding**	28	21	5	33.3	22	7	46.7
2	**Red Bluff**	31	36	7	46.7	28	8	53.3
3	**Colusa**	11	22	5	33.3	9	3	20
4	**Sacramento**	19	76	*	*	63	*	*
5	**Stockton**	14	33	7	46.7	25	6	40
6	**Modesto**	11	24	5	33.3	15	4	26.7
7	**Merced**	4	14	3	20	8	2	13.3
8	**Fresno**	7	15	2	13.3	0	0	0
9	**Visalia**	5	13	2	13.3	0	0	0
10	**Bakersfield**	11	21	4	26.7	3	1	6.7
11	**Crescent City**	0	0	0	0	0	0	0
12	**Eureka**	0	0	0	0	0	0	0
13	**Covelo**	15	16	4	26.7	12	4	26.7
14	**Graton**	13	11	4	26.7	3	1	6.7
15	**San Francisco**	0	0	0	0	0	0	0
16	**Monterey**	0	0	0	0	0	0	0
17	**San Luis Obispo**	2	0	0	0	0	0	0
18	**Santa Barbara**	0	0	0	0	0	0	0
19	**Santa Ana**	7	3	1	6.7	7	2	13.3
20	**Vista**	4	3	1	6.7	3	1	6.7
21	**Seattle**	0	0	0	0	0	0	0
22	**Spokane**	1	0	0	0	0	0	0
23	**Yakima**	3	3	1	6.7	9	2	13.3
24	**Portland**	4	4	1	6.7	5	1	6.7
25	**Eugene**	6	5	2	13.3	5	1	6.7
26	**Medford**	15	9	4	26.7	8	2	13.3
27	**Pendleton**	6	7	2	13.3	7	2	13.3
28	**Baker City**	1	0	0	0	0	0	0
29	**Reno**	1	0	0	0	0	0	0
30	**Tonopah**	0	0	0	0	0	0	0

Table A.11 Just as in Table A.9, except with heat waves identified by the definition in Table A.1, using filtered data.

	City	Total Number of Events at each station	Number of Matching Dates of Top 15 Sac Events, based on 3-Day Anomaly Average Ranking	Top 15 Sac Event Matches, based on 3-Day Anomaly Average Ranking	% of Sac Top 15 Events Matching Top 15 Events at station, based on 3-Day Anomaly Average Ranking	Number of Matching Dates of Top 15 Sac Events, based on Max Temp Ranking	Top 15 Sac Event Matches, based on Max Temp Ranking	% of Sac Top 15 Events Matching Top 15 Events at station, based on Max Temp Rankings
1	Redding	29	24	6	40	18	6	40
2	Red Bluff	29	36	7	46.7	42	9	60
3	Colusa	15	31	7	46.7	29	6	40
4	Sacramento	18	76	*	*	*	*	*
5	Stockton	14	30	6	40	33	7	46.7
6	Modesto	13	33	7	46.7	30	6	40
7	Merced	5	14	3	20	14	3	20
8	Fresno	6	18	3	20	15	2	13.3
9	Visalia	5	16	2	13.3	13	2	13.3
10	Bakersfield	10	21	4	26.7	21	4	26.7
11	Crescent City	2	3	1	6.7	3	1	6.7
12	Eureka	1	0	0	0	0	0	0
13	Covelo	22	20	5	33.3	20	5	33.3
14	Graton	41	18	6	40	17	6	40
15	San Francisco	29	20	7	46.7	13	5	33.3
16	Monterey	30	10	4	26.7	13	5	33.3
17	San Luis Obispo	29	5	2	13.3	3	1	6.7
18	Santa Barbara	11	8	3	20	5	2	13.3
19	Santa Ana	15	16	5	33.3	13	4	26.7
20	Vista	20	18	6	40	13	4	26.7
21	Seattle	31	6	2	13.3	7	3	20
22	Spokane	27	5	2	13.3	8	2	13.3
23	Yakima	14	6	2	13.3	6	2	13.3
24	Portland	40	3	2	13.3	6	2	13.3
25	Eugene	35	7	3	20	7	3	20
26	Medford	31	7	3	20	13	5	33.3
27	Pendleton	33	0	0	0	7	2	13.3
28	Baker City	22	2	1	6.7	0	0	0
29	Reno	4	6	1	6.7	6	1	6.7
30	Tonopah	0	0	0	0	0	0	0

Table A.12 Just as in Table A.9, except with heat waves identified by the definition in Table A.3, using filtered data.

	City	Total Number of Events at each station	Number of Matching Dates of Top 14 Sac Events, based on 3-Day Anomaly Average Ranking	Top 14 Sac Event Matches, based on 3-Day Anomaly Average Ranking	% of Sac Top 14 Events Matching Top 15 Events at station, based on 3-Day Anomaly Average Ranking	Number of Matching Dates of Top 14 Sac Events, based on Max Temp Ranking	Top 14 Sac Event Matches, based on Max Temp Ranking	% of Sac Top 14 Events Matching Top 15 Events at station, based on Max Temp Rankings
1	Redding	27	21	5	35.7	18	6	42.9
2	Red Bluff	29	36	7	50	42	9	64.3
3	Colusa	12	22	5	35.7	22	5	35.7
4	Sacramento	14	72	*	*	72	*	*
5	Stockton	13	33	7	50	33	7	50
6	Modesto	10	24	5	35.7	24	5	35.7
7	Merced	5	14	3	21.4	14	4	28.6
8	Fresno	6	15	2	14.3	15	2	14.3
9	Visalia	4	13	2	14.3	13	2	14.3
10	Bakersfield	9	21	4	28.6	21	4	28.6
11	Crescent City	0	0	0	0	0	0	0
12	Eureka	0	0	0	0	0	0	0
13	Covelo	15	16	4	28.6	16	4	28.6
14	Graton	14	11	4	28.6	11	4	28.6
15	San Francisco	0	0	0	0	0	0	0
16	Monterey	0	0	0	0	0	0	0
17	San Luis Obispo	1	0	0	0	0	0	0
18	Santa Barbara	0	0	0	0	0	0	0
19	Santa Ana	5	3	1	7.1	3	1	7.1
20	Vista	3	3	1	7.1	3	1	7.1
21	Seattle	0	0	0	0	0	0	0
22	Spokane	0	0	0	0	0	0	0
23	Yakima	3	3	1	7.1	3	1	7.1
24	Portland	4	4	1	7.1	4	1	7.1
25	Eugene	8	5	2	14.3	5	2	14.3
26	Medford	15	9	4	28.6	9	4	28.6
27	Pendleton	7	7	2	14.3	7	2	14.3
28	Baker City	1	0	0	0	0	0	0
29	Reno	1	0	0	0	0	0	0
30	Tonopah	0	0	0	0	0	0	0

Matches Due to Chance

Tables A.13-A.15. The expected number of the top 15 event date matches due to chance for the corresponding identification and ranking methods. 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 due to chance was estimated by the formula: $n2/3416 = X/n1$, where $n1$ was defined as the total number of heat wave dates in the top 15 events at Sacramento, and $n2$ was the total number of heat wave dates in the top 15 events for each of the other stations.

Table A.13. As described above, for unfiltered data, the first definition of a heat wave, and the event maximum temperature ranking method.

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	67	*	*
Redding	63	1.24	19
Red Bluff	80	1.57	33
Colusa	63	1.24	17
Stockton	65	1.27	29
Modesto	57	1.12	23
Merced	21	0.41	5
Fresno	36	0.71	8
Visalia	42	0.82	8
Bakersfield	48	0.94	6
Crescent City	13	0.25	0
Eureka	3	0.06	0
Covelo	77	1.51	12
Graton	60	1.18	12
San Francisco	48	0.94	9
Monterey	54	1.06	3
San Luis Obispo	64	1.26	5
Santa Barbara	33	0.65	5
Santa Ana	64	1.26	7
Vista	68	1.33	3
Seattle	64	1.26	8
Spokane	75	1.47	3
Yakima	71	1.39	12
Portland	64	1.26	8
Eugene	61	1.20	7
Medford	70	1.37	6
Pendleton	69	1.35	7
Baker City	74	1.45	1
Reno	19	0.37	5
Tonopah	9	0.18	0

Table A.14. As described above, for filtered data, the first definition of a heat wave, and the 3-day anomaly average ranking method.

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	76	1.69	24
Red Bluff	90	2.00	36
Colusa	66	1.47	31
Stockton	59	1.31	30
Modesto	58	1.29	33
Merced	24	0.53	14
Fresno	29	0.65	18
Visalia	27	0.60	16
Bakersfield	50	1.11	21
Crescent City	7	0.16	3
Eureka	3	0.07	0
Covelo	87	1.94	20
Graton	64	1.42	18
San Francisco	50	1.11	20
Monterey	51	1.13	10
San Luis Obispo	66	1.47	5
Santa Barbara	42	0.93	8
Santa Ana	66	1.47	16
Vista	73	1.62	18
Seattle	70	1.56	6
Spokane	90	2.00	5
Yakima	65	1.45	6
Portland	67	1.49	3
Eugene	62	1.38	7
Medford	75	1.67	7
Pendleton	72	1.60	0
Baker City	88	1.96	2
Reno	23	0.51	6
Tonopah	0	0	0

Table A.15. As described above, for filtered data, the first definition of a heat wave, and the event maximum temperature ranking method.

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	65	1.45	18
Red Bluff	86	1.91	42
Colusa	66	1.47	29
Stockton	59	1.31	33
Modesto	58	1.29	30
Merced	24	0.53	14
Fresno	29	0.65	15
Visalia	27	0.60	13
Bakersfield	50	1.11	21
Crescent City	7	0.16	3
Eureka	3	0.07	0
Covelo	82	1.82	20
Graton	60	1.33	17
San Francisco	48	1.07	13
Monterey	48	1.07	13
San Luis Obispo	68	1.51	3
Santa Barbara	42	0.93	5
Santa Ana	66	1.47	13
Vista	73	1.62	13
Seattle	65	1.45	7
Spokane	78	1.74	8
Yakima	65	1.45	6
Portland	65	1.45	6
Eugene	58	1.29	7
Medford	66	1.47	13
Pendleton	73	1.62	7
Baker City	84	1.87	0
Reno	23	0.51	6
Tonopah	0	0	0

Appendix B

Figure B.1-B.10. Daily maximum temperatures for summers in which the top 15 heat wave events in Sacramento took place. Events were defined by 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, and ranked by the highest 3-day anomaly averages. Unfiltered data.
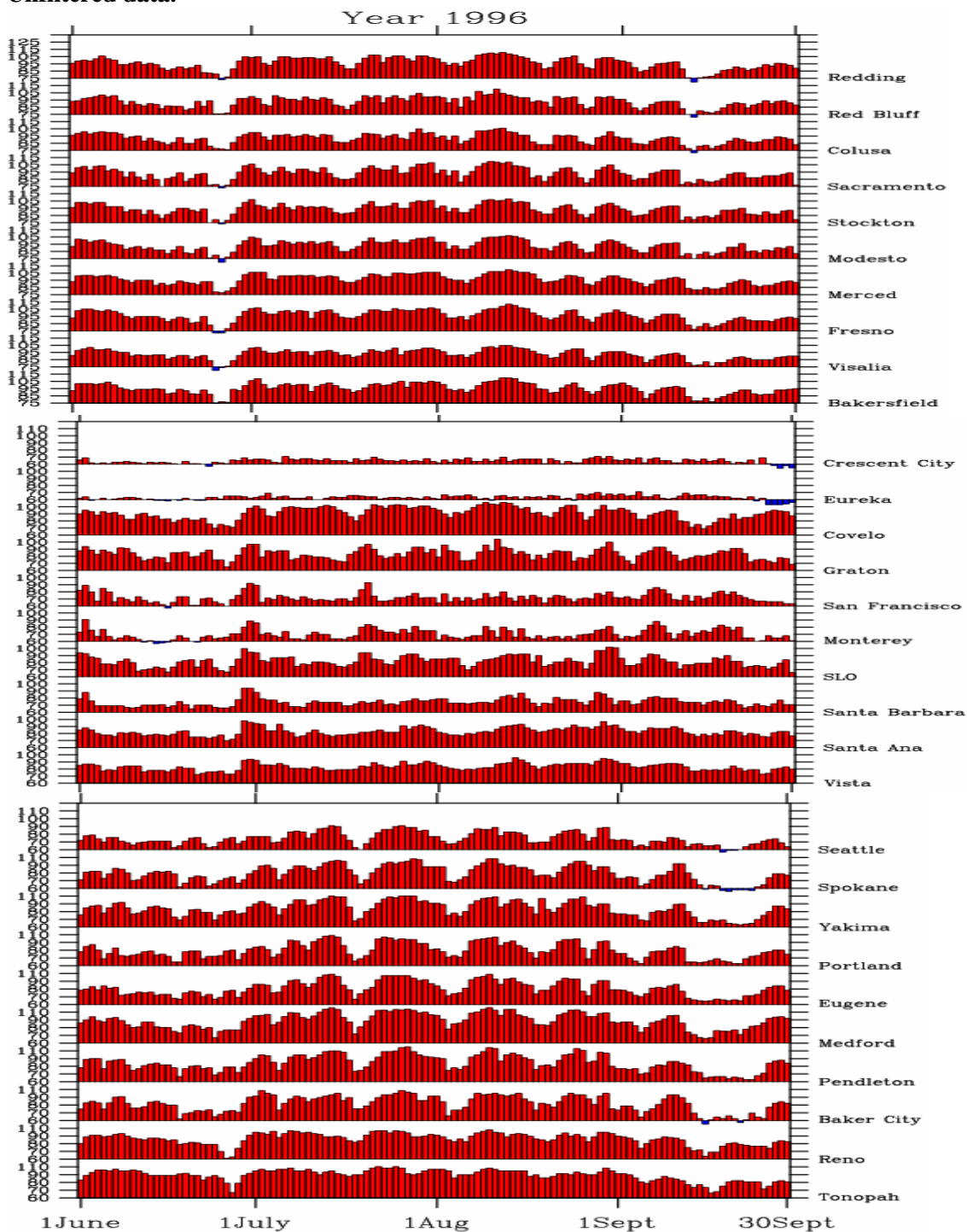
Figure B.1. 1996 Heat Waves: 02 June to 08 June and 09 August to 15 August
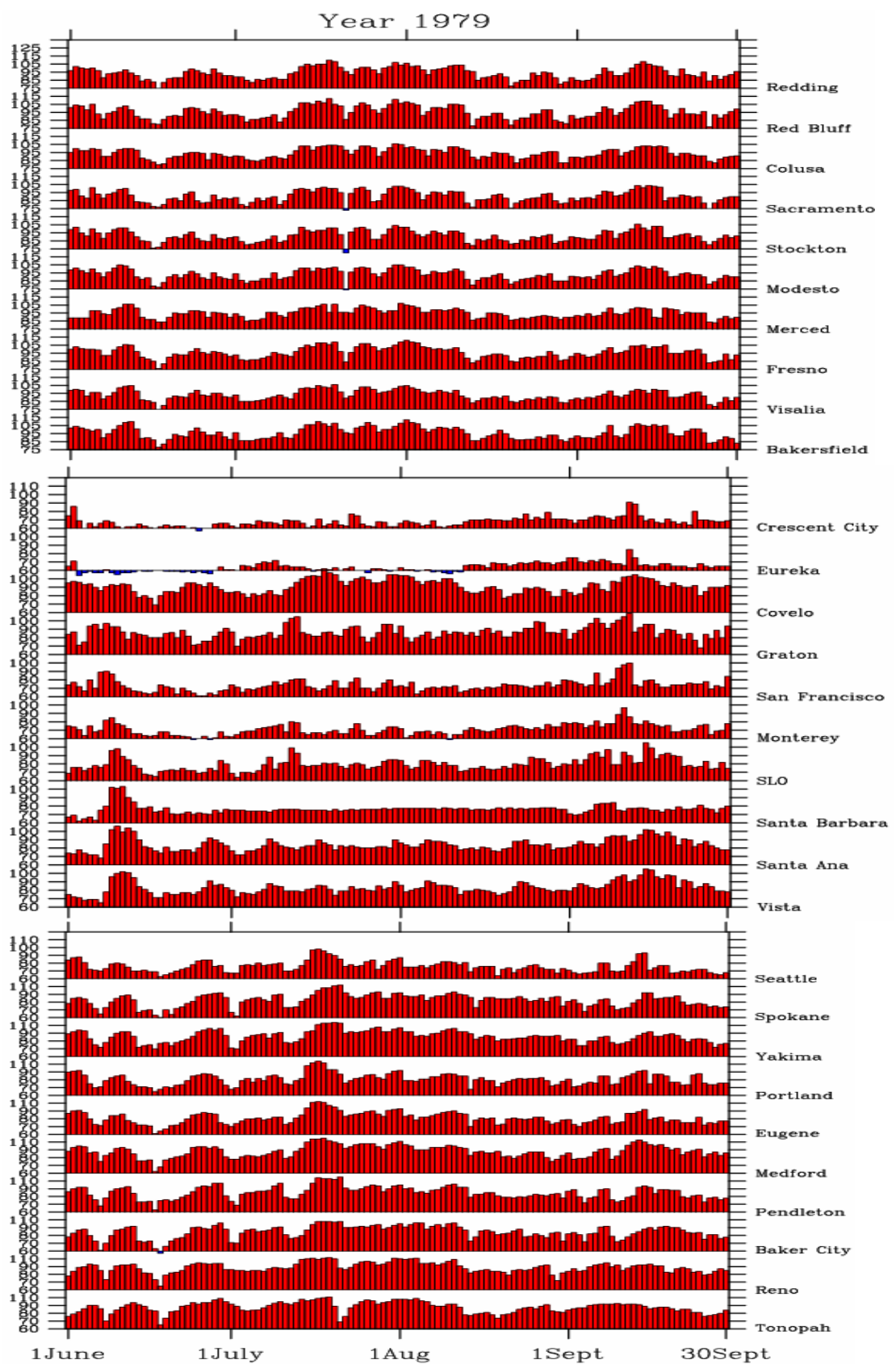
Figure B.2. 1979 Heat Wave: 11 September to 16 September
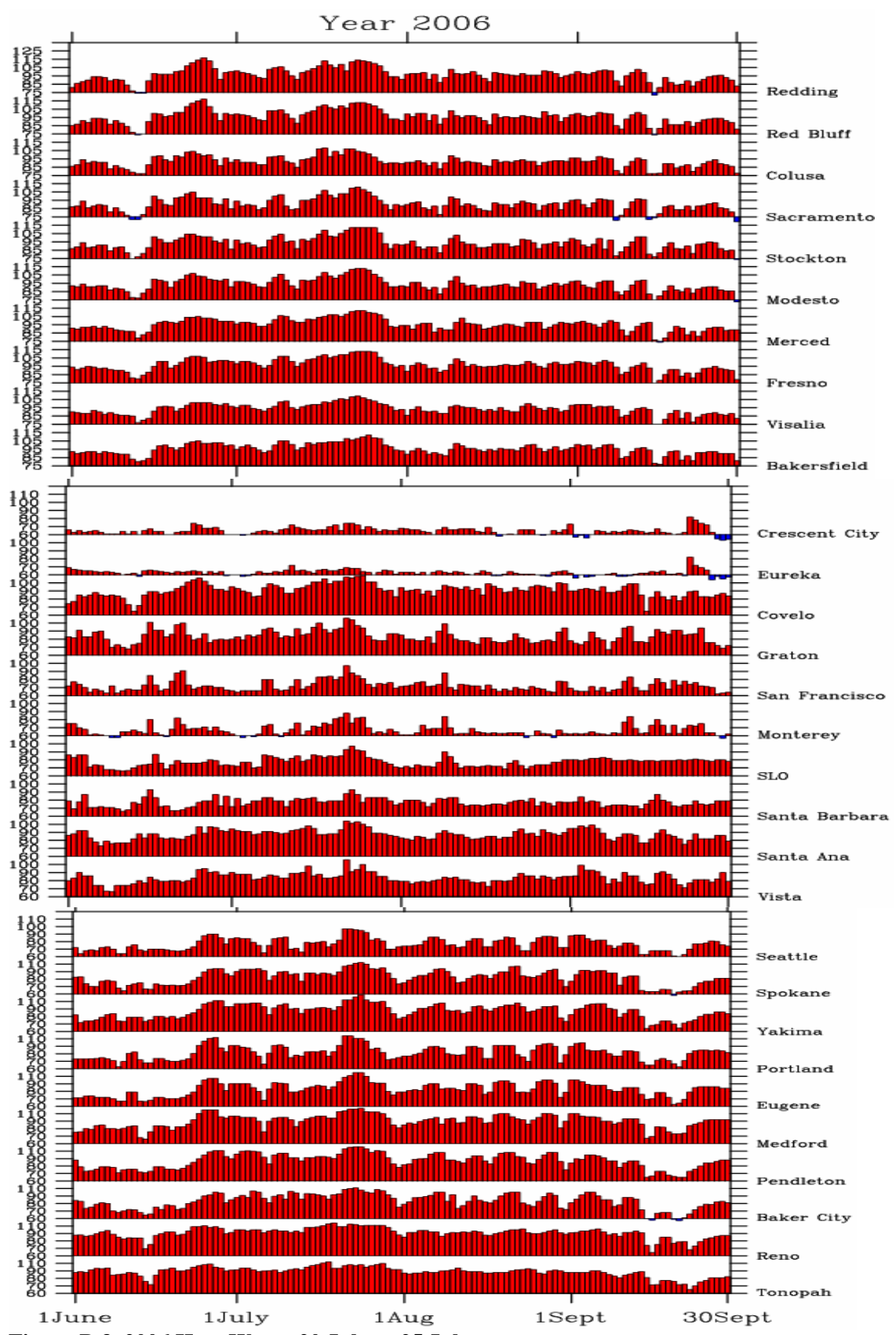
Figure B.3. 2006 Heat Wave: 20 July to 25 July
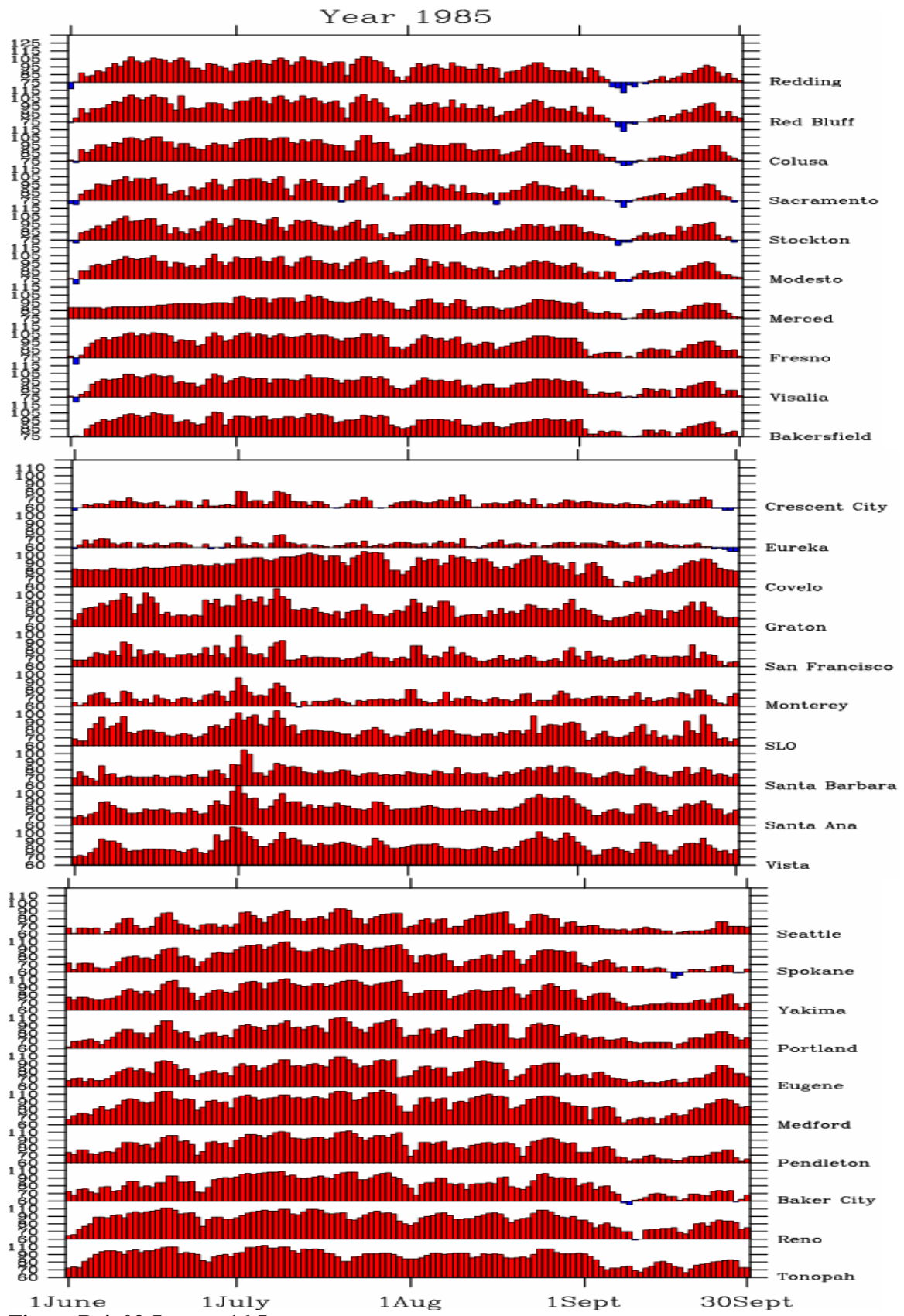
Figure B.4. 09 June to 16 June

Year 1988
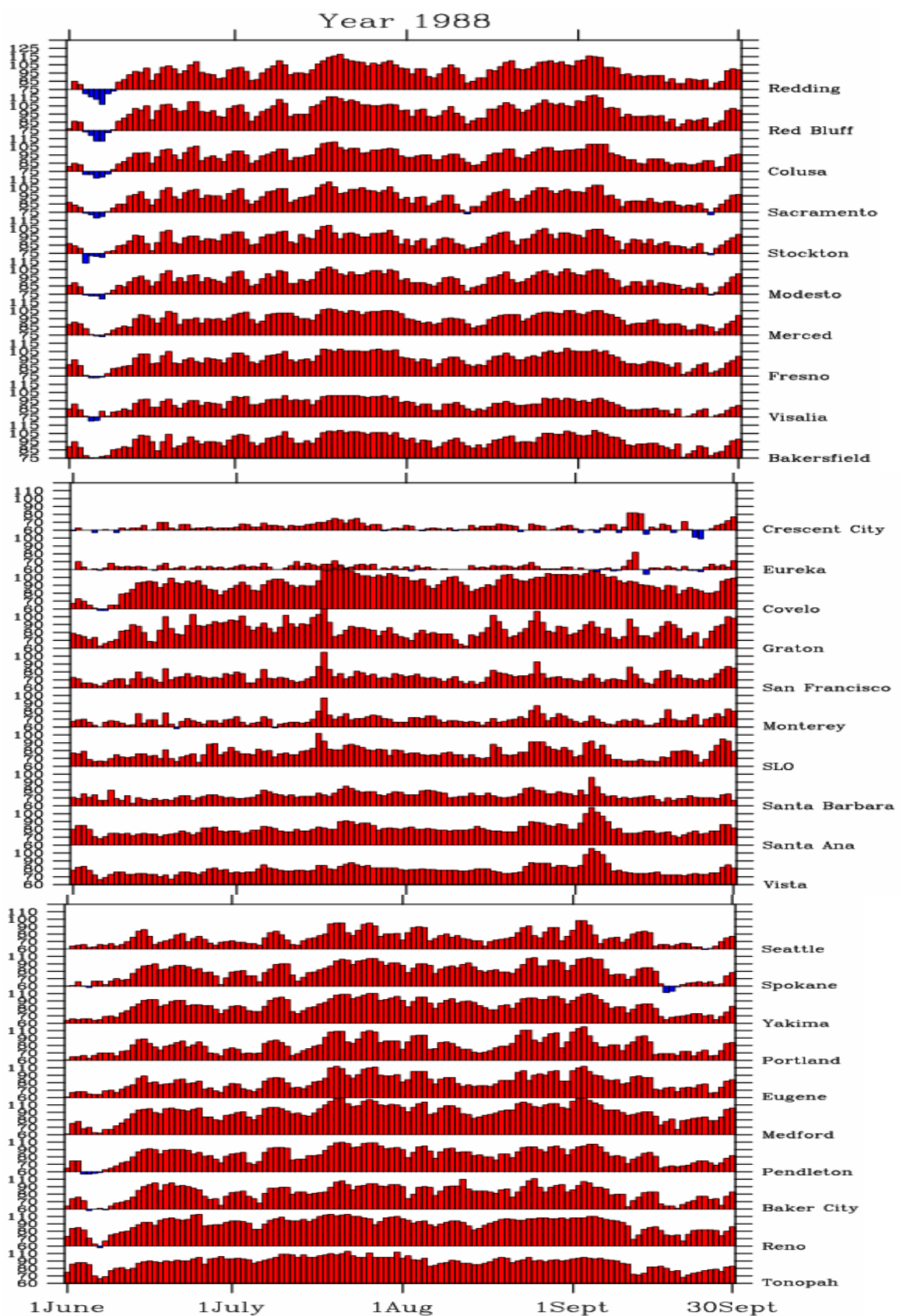
Figure B.5. 1988 Heat Waves: 16 July to 19 July and 03 September to 05 September
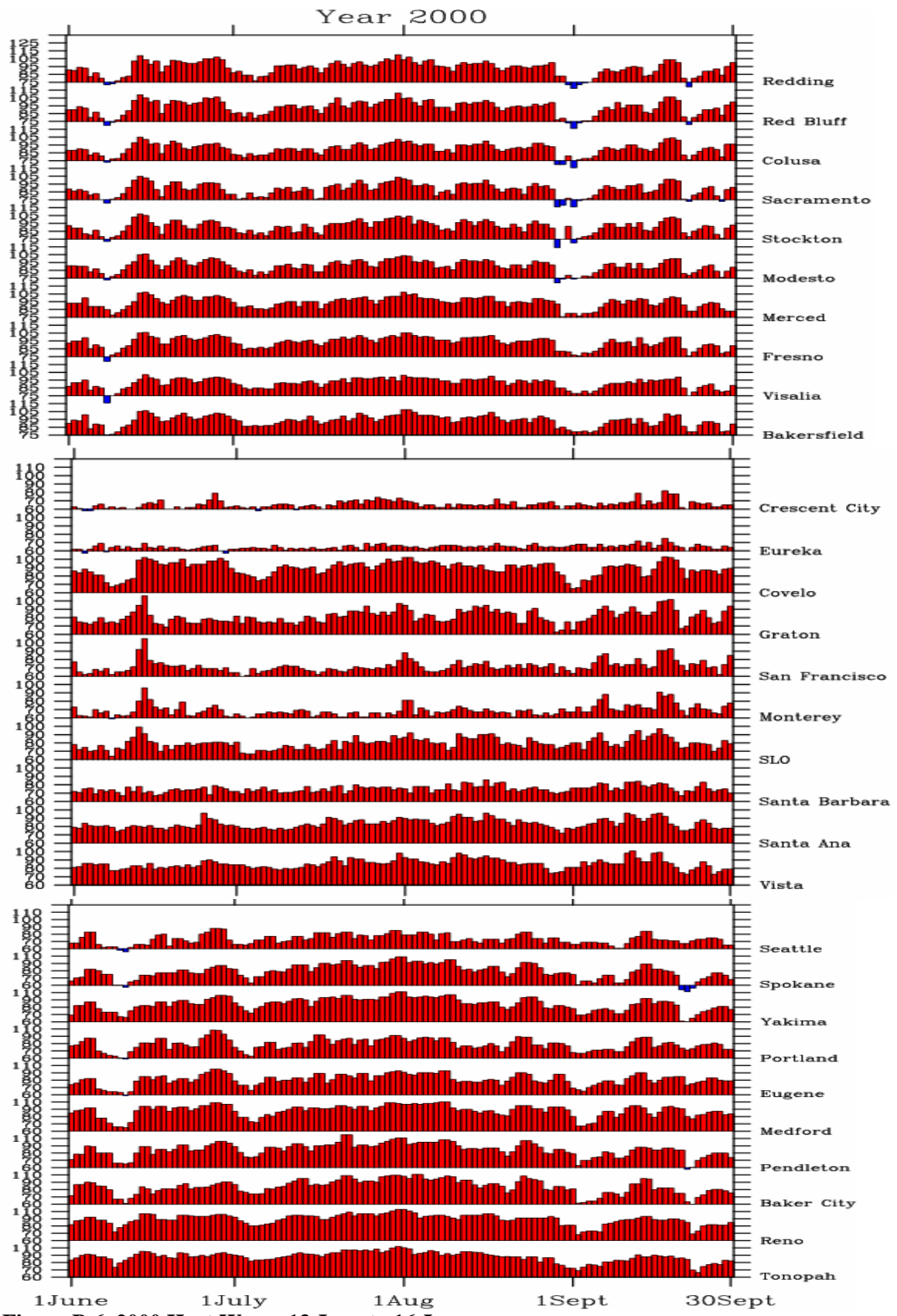
Figure B.6. 2000 Heat Wave: 13 June to 16 June
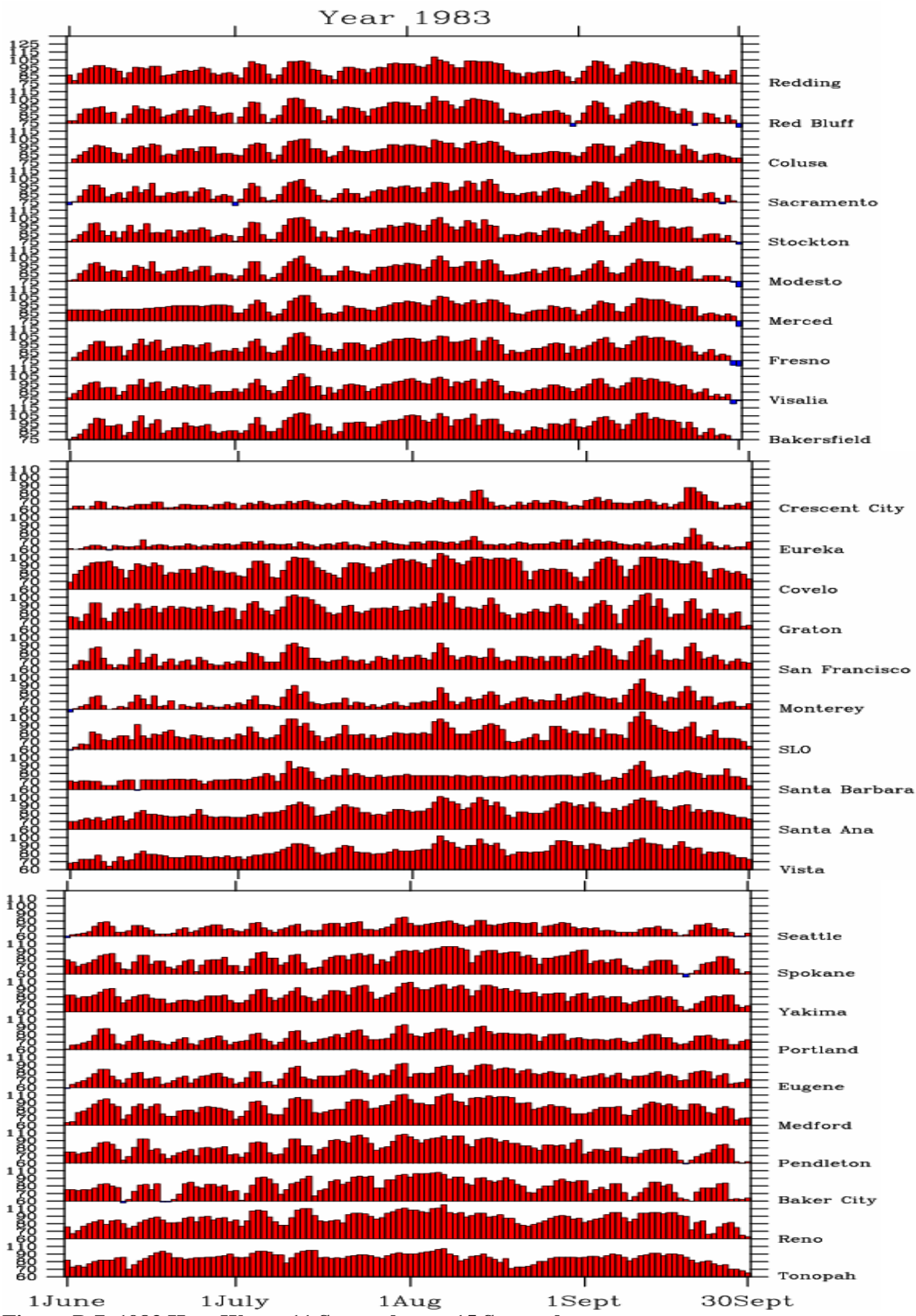
Figure B.7. 1983 Heat Wave: 11 September to 15 September
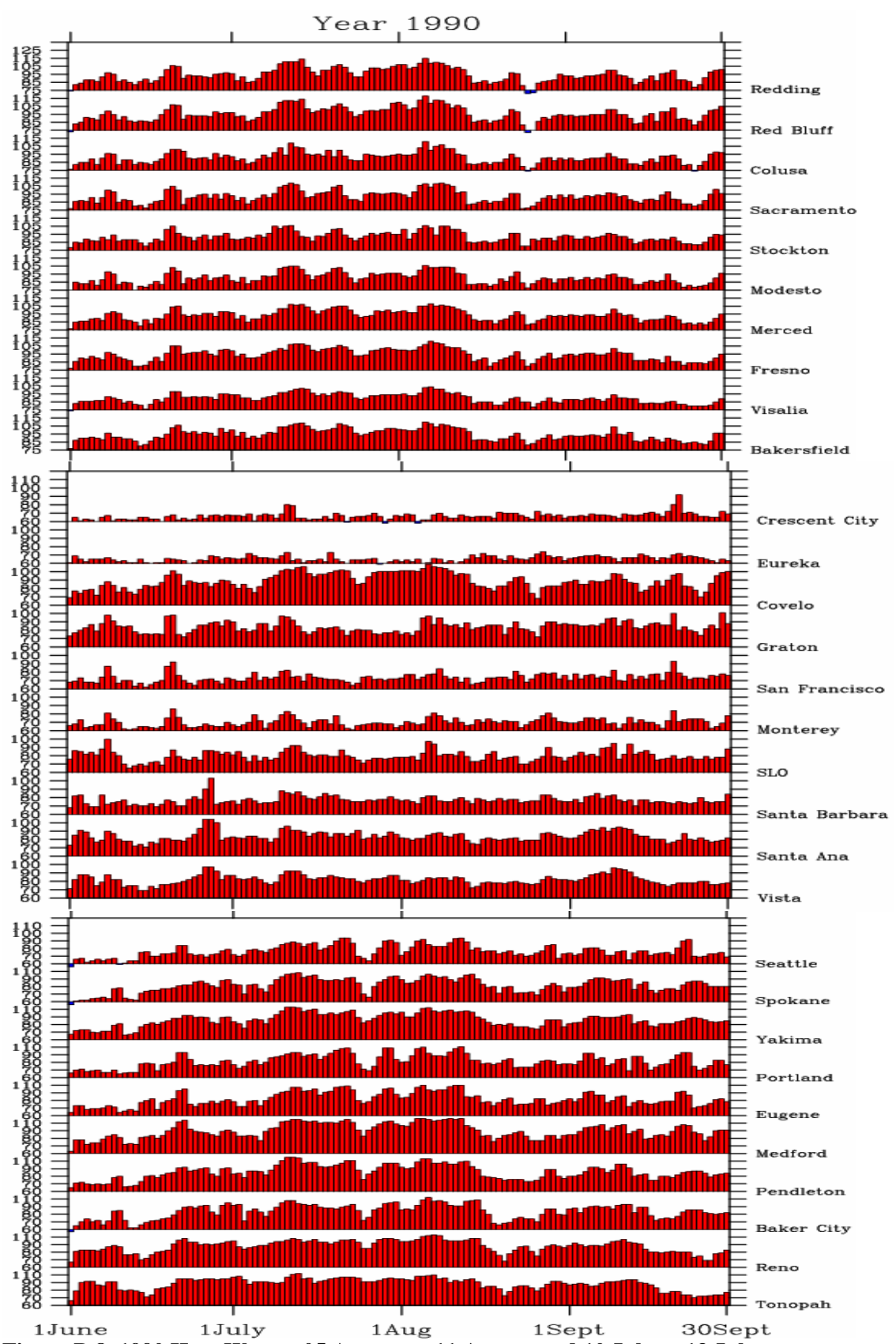
Figure B.8. 1990 Heat Waves: 05 August to 11 August and 10 July to 13 July
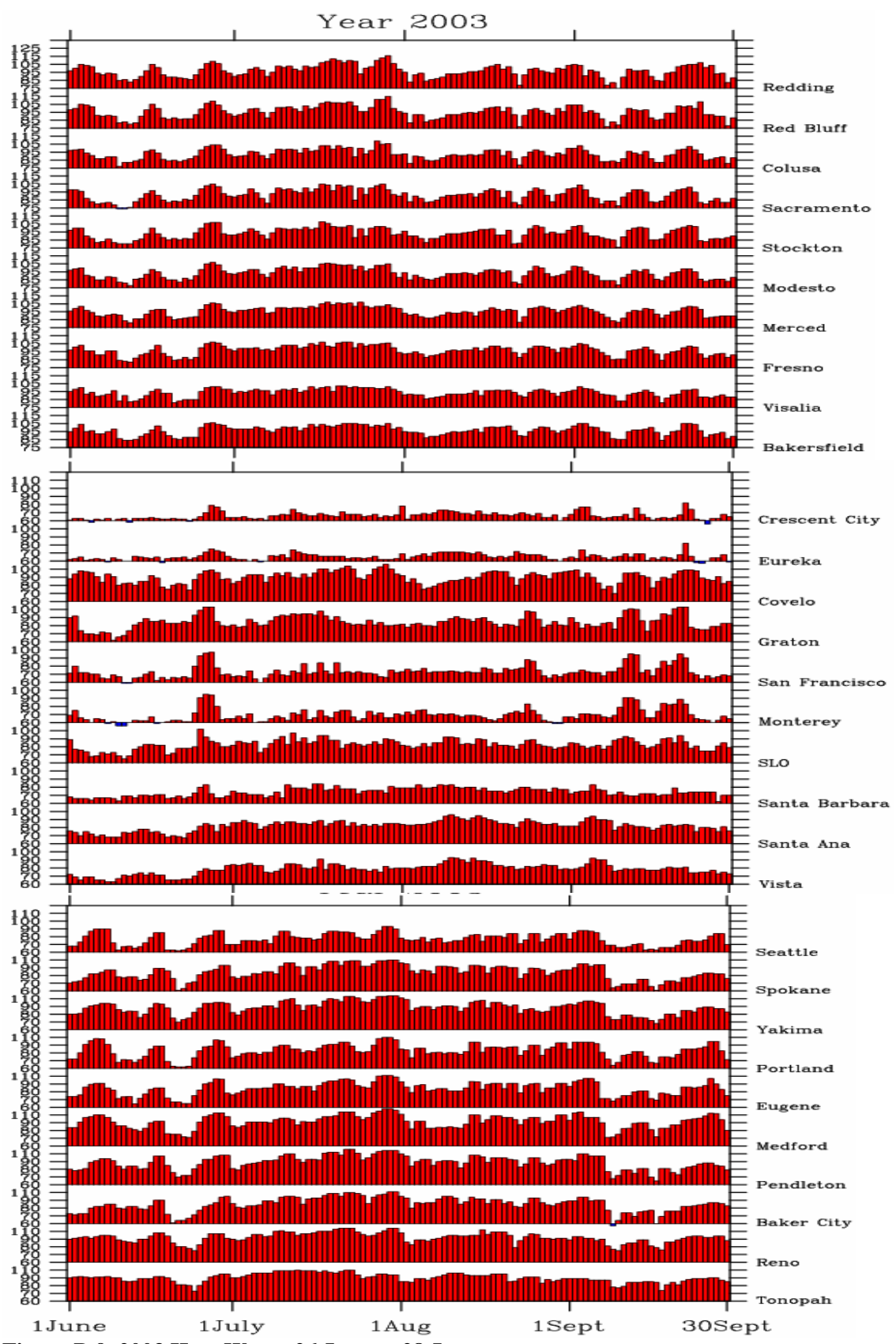
Figure B.9. 2003 Heat Wave: 26 June to 28 June
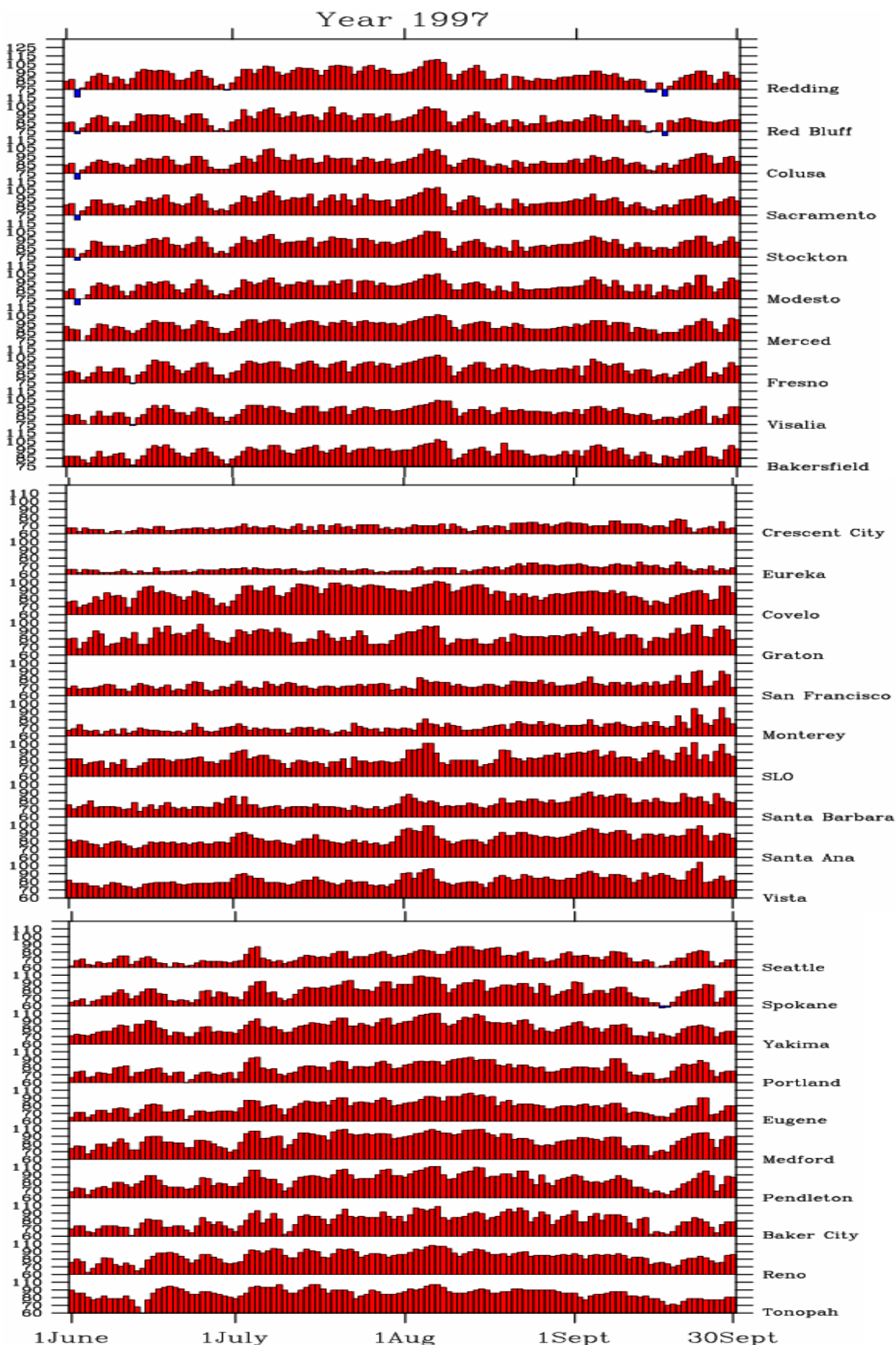
Figure B.10. 1997 Heat Wave: 04 August to 07 August

Figures B.11-B.40. Frequency distributions for each station of the 1,000 randomly generated 15-member ensemble averages of maximum temperatures from that station, plus the 99.5% value and the 'target' ensemble mean of the temperatures from that station on the onset dates of the top-ranked heat wave events in Sacramento, ranked by the highest 3-day anomaly averages. Maximum temperatures on x-axis are in degrees Fahrenheit.
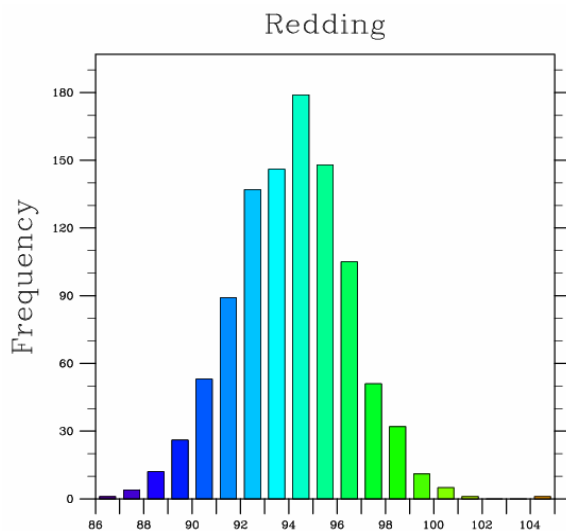
Figure B.11. 99.5% value = 100.47
Target Ensemble Average = 104.8
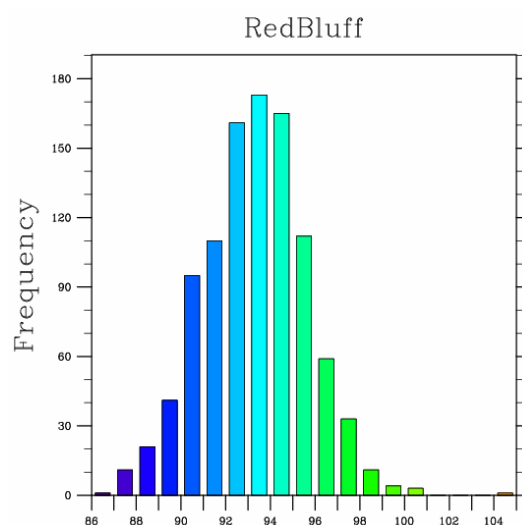
Figure B.12. 99.5% value = 99.93
Target Ensemble Average = 104.6
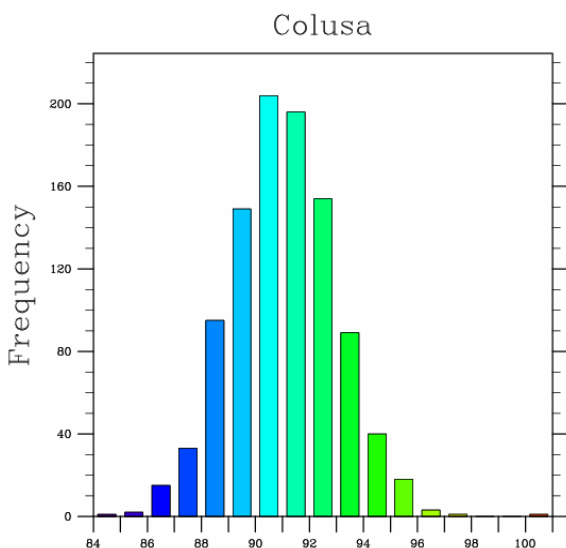
Figure B.13. 99.5% value = 96.20
Target Ensemble Average = 100.6
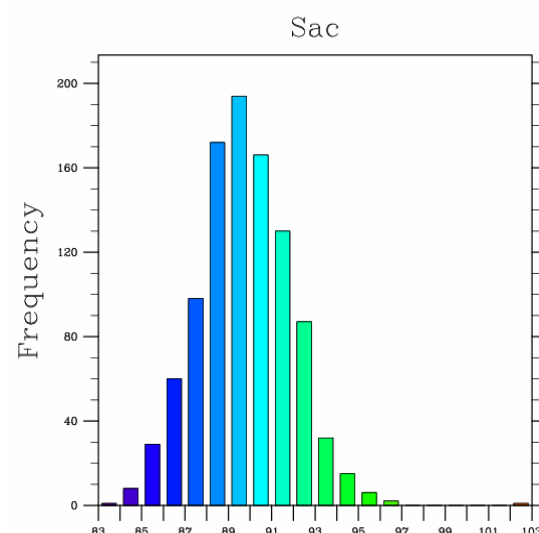
Figure B.14. 99.5% value = 95.57
Target Ensemble Average = 102.5

Stockton

Modesto
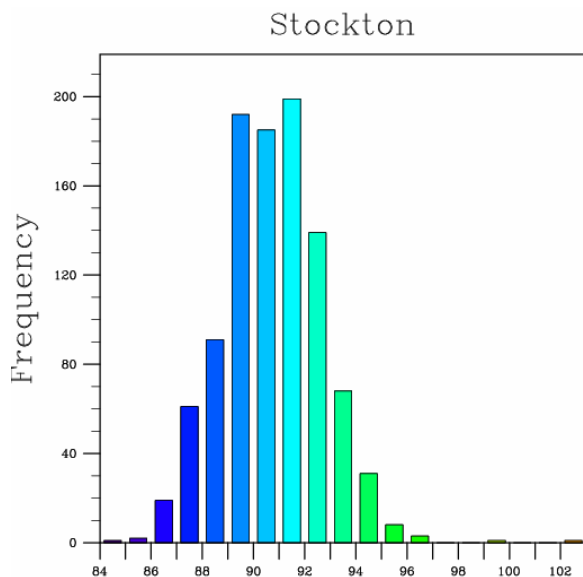
Figure B.15. 99.5% value = 96.03
Target Ensemble Average = 102.3
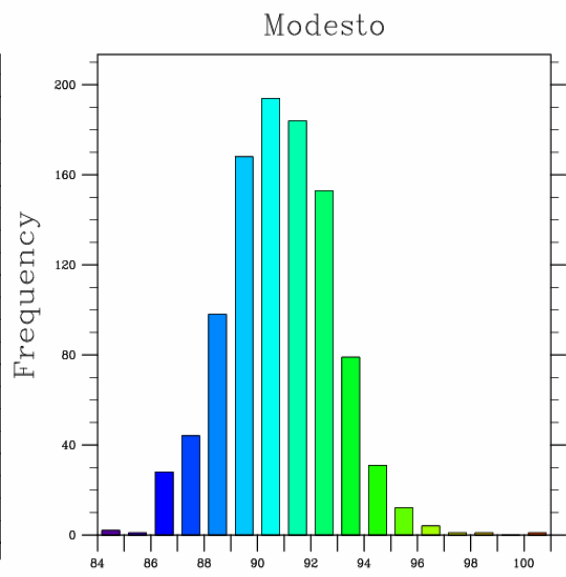
Figure B.16. 99.5% value = 96.13
Target Ensemble Average = 100.8

Merced

Fresno
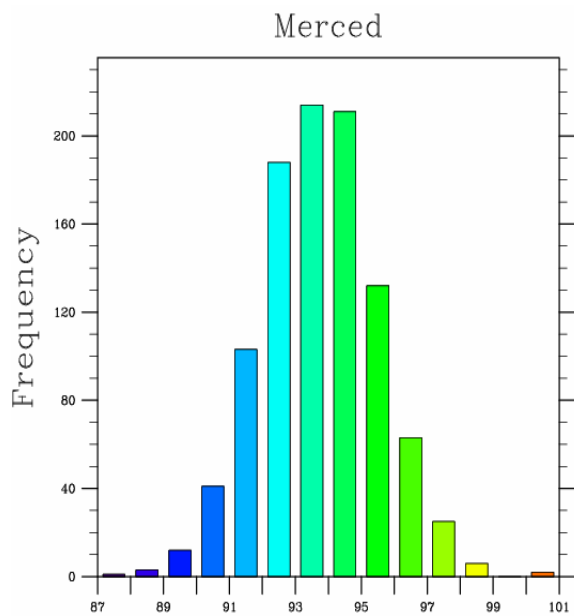
Figure B.17. 99.5% value = 98.23
Target Ensemble Average = 100.3
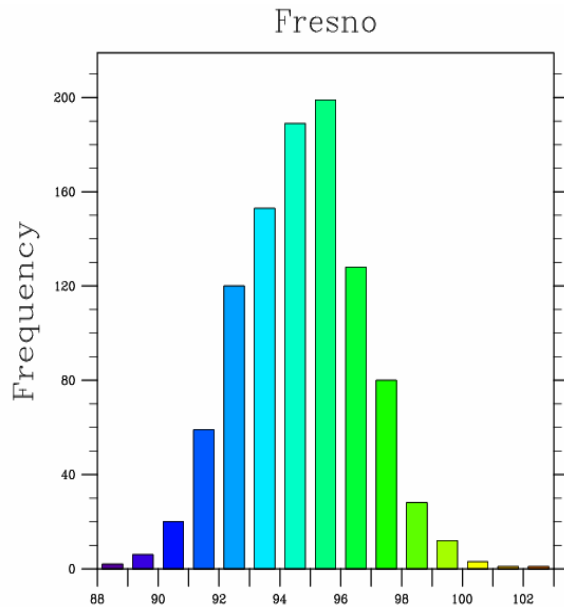
Figure B.18. 99.5% value = 99.93
Target Ensemble Average = 102.4
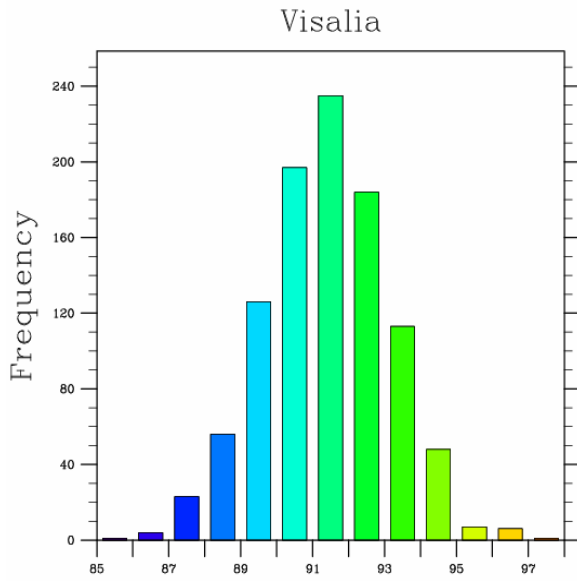
Figure B.19. 99.5% value = 96.10
Target Ensemble Average = 97.7
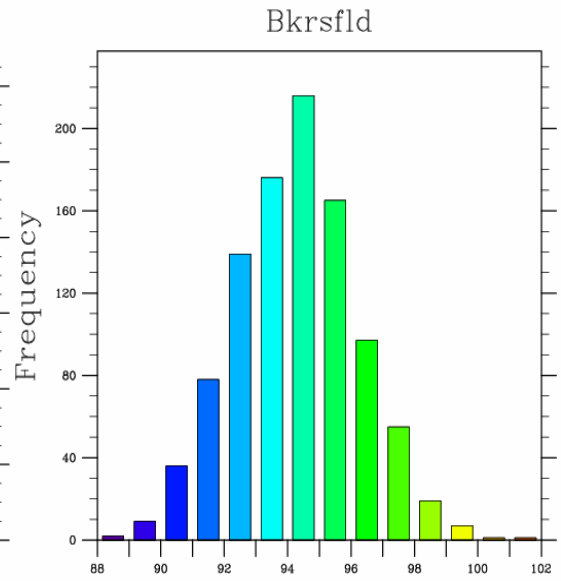
Figure B.20. 99.5% value = 99.23
Target Ensemble Average = 101.1
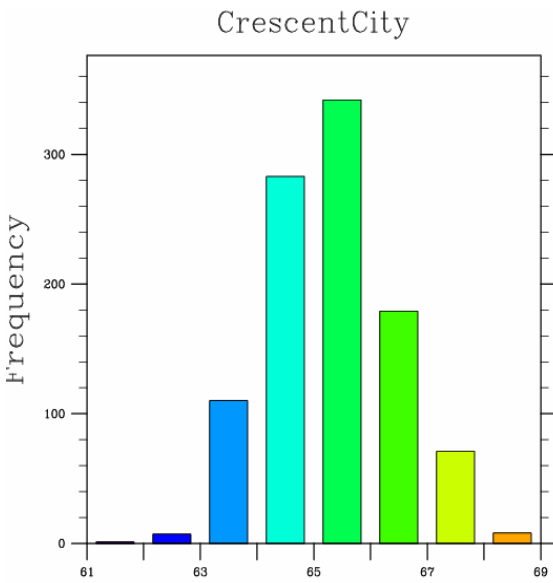
Figure B.21. 99.5% value = 68.47
Target Ensemble Average = 67.7
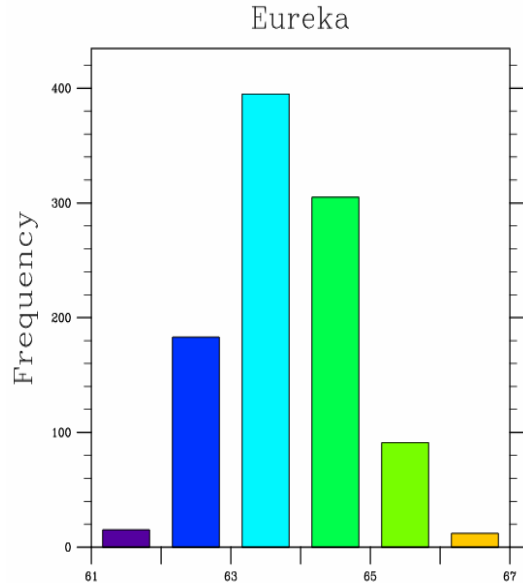
Figure B.22. 99.5% value = 66.57
Target Ensemble Average = 64.1
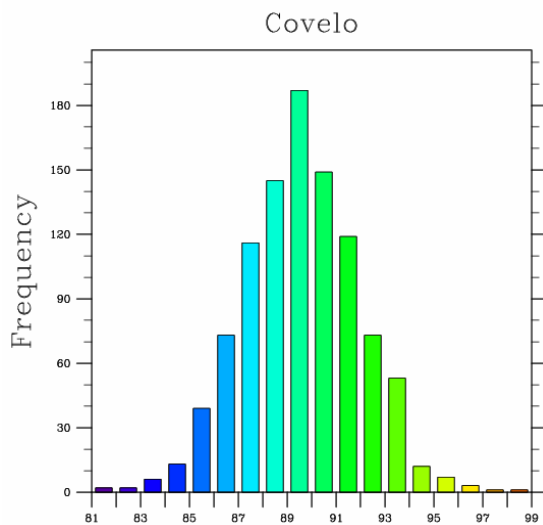
Figure B.23. 99.5% value = 96.00
Target Ensemble Average = 98.8
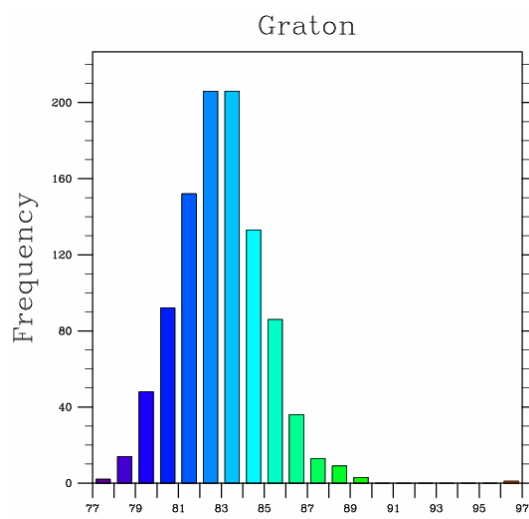
Figure B.24. 99.5% value = 88.70
Target Ensemble Average = 96.1
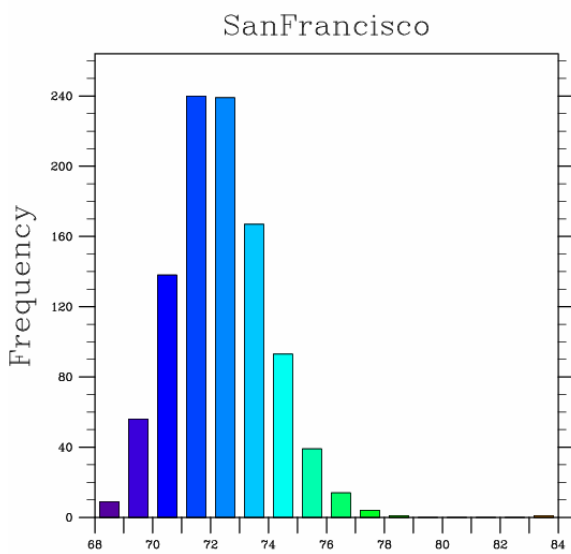
Figure B.25. 99.5% value = 77.10
Target Ensemble Average = 83.6
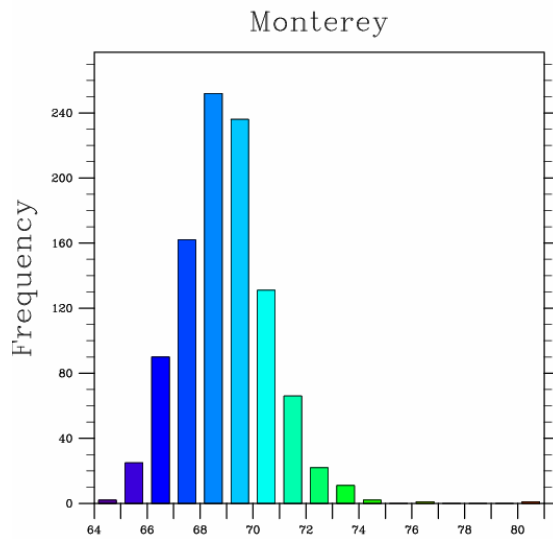
Figure B.26. 99.5% value = 73.63
Target Ensemble Average = 80.1
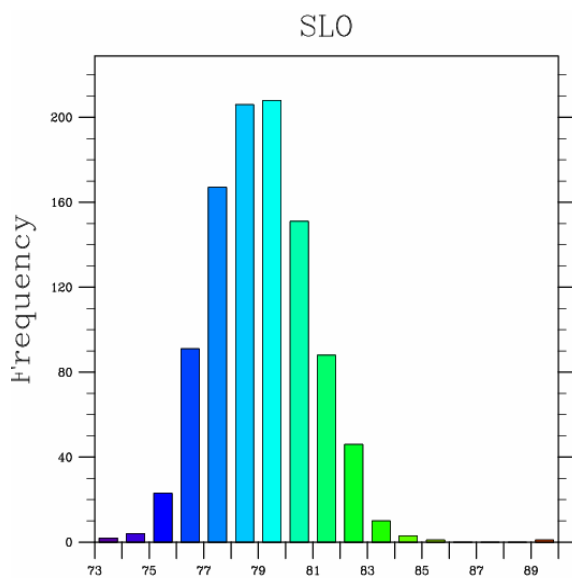
Figure B.27. 99.5% value = 83.90
Target Ensemble Average = 89.9
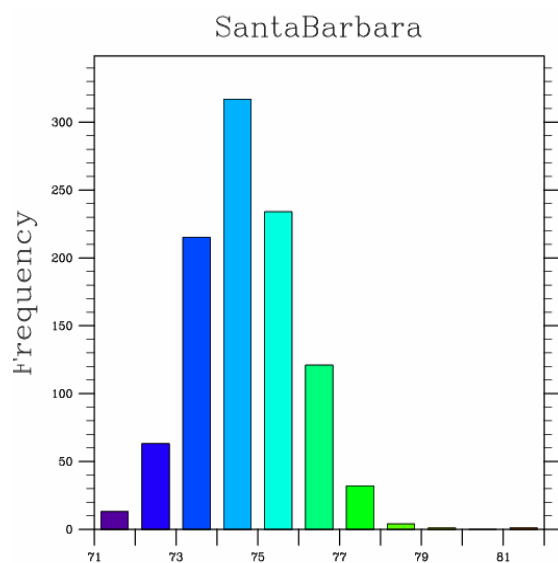
Figure B.28. 99.5% value = 78.17
Target Ensemble Average = 78.5
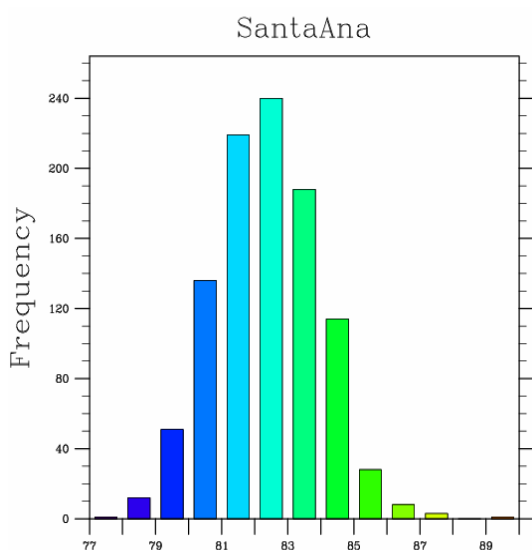
Figure B.29. 99.5% value = 86.80
Target Ensemble Average = 86.9
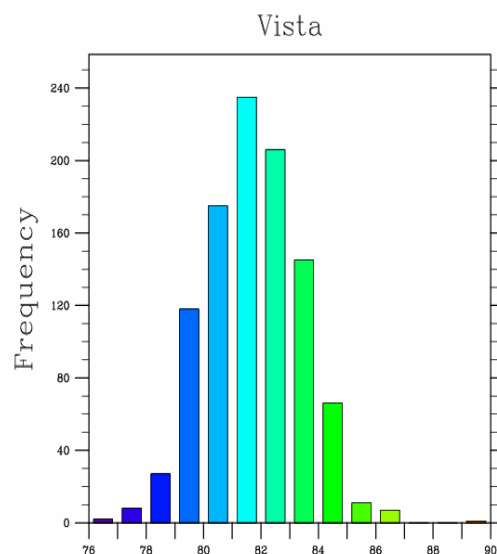
Figure B.30. 99.5% value = 86.33
Target Ensemble Average = 86.6
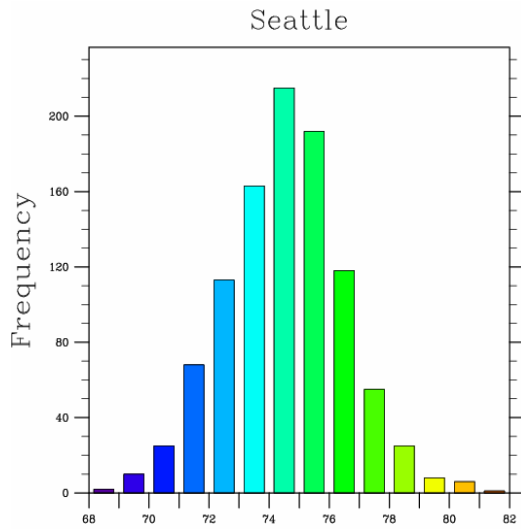
Figure B.31. 99.5% value = 80.37
Target Ensemble Average = 78.7
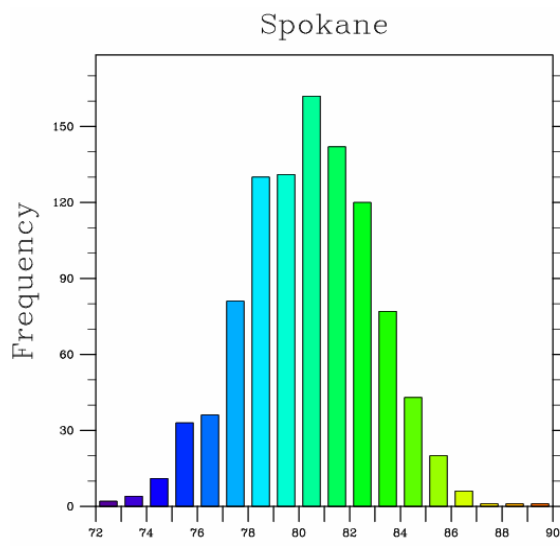
Figure B.32. 99.5% value = 86.30
Target Ensemble Average = 82.5
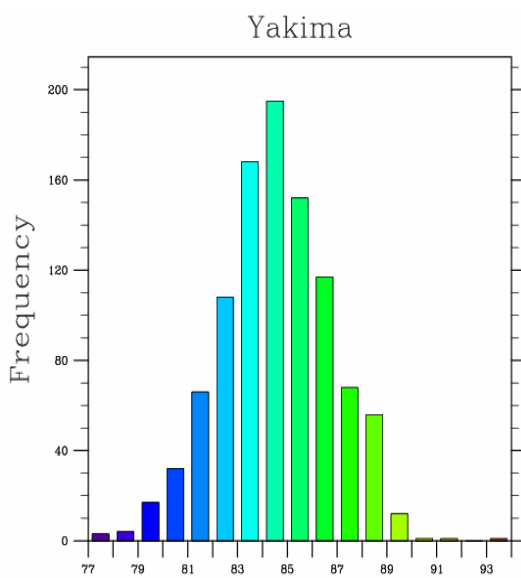
Figure B.33. 99.5% value = 89.58
Target Ensemble Average = 87.8
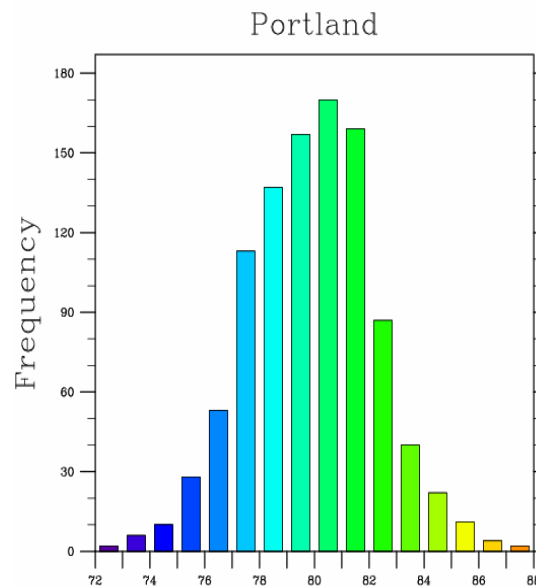
Figure B.34. 99.5% value = 86.44
Target Ensemble Average = 86.0
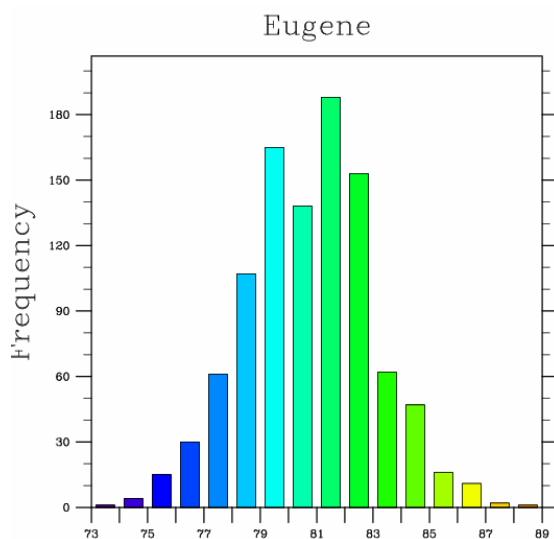
Figure B.35. 99.5% value = 86.87
Target Ensemble Average = 85.6
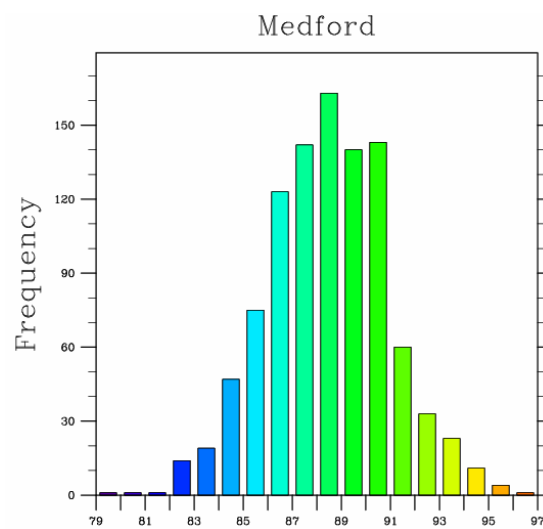
Figure B.36. 99.5% value = 95.01
Target Ensemble Average = 94.8
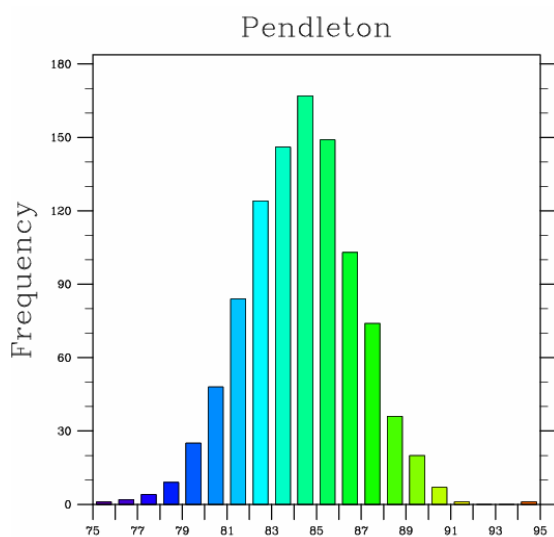
Figure B.37. 99.5% value = 90.30
Target Ensemble Average = 87.8
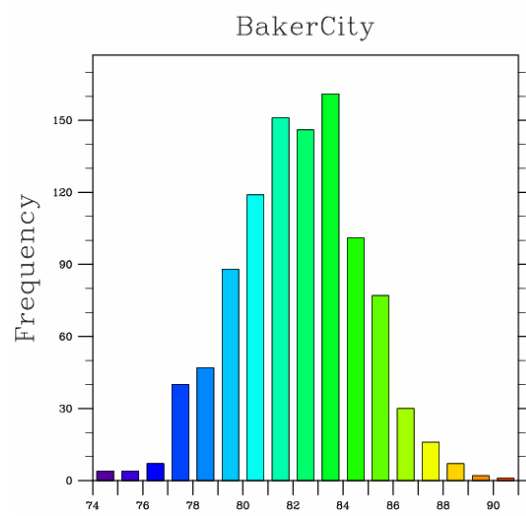
Figure B.38. 99.5% value = 88.71
Target Ensemble Average = 84.0
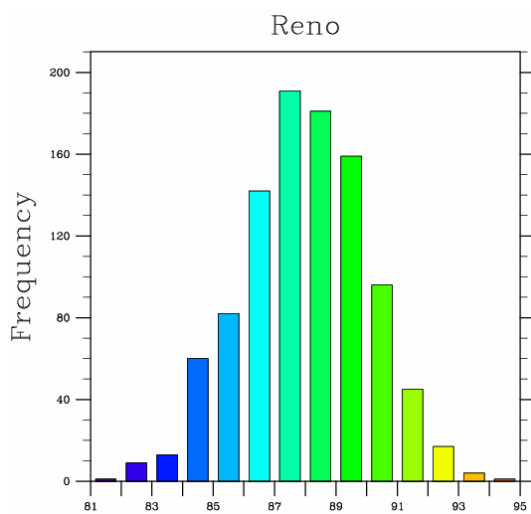
Figure B.39. 99.5% value = 93.13
Target Ensemble Average = 92.5
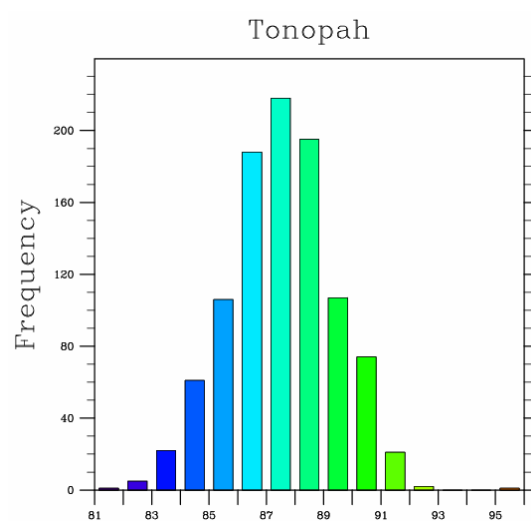
Figure B.40. 99.5% value = 91.88
Target Ensemble Average = 91.85

Table B.1. 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

Appendix C

filter.ncl

```
;***********************************************************************************
*********
; This program uses a Lanczos filter to calculate 1-D filter weights for the raw
temperature data.
; A weighted running average is then calculated using wgt_runave.
;***********************************************************************************
*********

;----------------------------------------------------------------
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/gsn_code.ncl"
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/gsn_csm.ncl"
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/shea_util.ncl"
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/contributed.ncl"
;----------------------------------------------------------------

begin

 files=30                    ; 30 files representing the 30 stations
 num_time=10135              ; 10135 times
 num_col=3                   ; column 1 = time, 2 = maximum, 3 = minimum
 nwt = 51                    ; Total number of weights
 fca = 0.333                 ; Cut-off frequency of the ideal low-pass filter
 ihp = 0                     ; For Low pass filter, ihp = 0
 nsigma = 1.                 ; Power of the sigma factor (nsigma >= 0), nsigma=1
common
 opt = 0                     ; End-point option (opt=0 most common)

 wgt          = new((/files,nwt/),float)              ; filter weights array
 filtered_max = new((/files,num_time/),float)            ; filtered maximum
temperatures array
 filtered_min = new((/files,num_time/),float)            ; filtered minimum
temperatures array
 filtered     = new((/files,num_time,num_col/),float)   ; 3-D filtered array of time,
max, and min filtered temperatures

 datafiles = (/"Redding", "RedBluff", "Colusa", "Sac", "Stockton", "Modesto", "Merced",
"Fresno", "Visalia", "Bkrsfld" \
            , "CrescentCity", "Eureka", "Covelo", "Graton", "SanFrancisco", "Monterey",
"SLO", "SantaBarbara", "SantaAna" \
            , "Vista", "Seattle","Spokane", "Yakima", "Portland", "Eugene", "Medford",
"Pendleton", "BakerCity", "Reno"  \
            , "Tonopah"/)

 do df=0,files-1
  print(df)
  data_filter=asciiread("IPM_"+datafiles(df)+".csv",(/num_time,num_col/),"float") ; Read
in raw temperature data

  time      = data_filter(:,0)                          ; column 0 = time(date)
  maximum   = data_filter(:,1)                          ; column 1 = maximum daily temp
  minimum   = data_filter(:,2)                          ; column 2 = minimum daily temp

  wgt(df,:) = filwgts_lancos (nwt, ihp, fca, -999., nsigma) ; Lanczos filter function,
Calculates 1-D filter weights.

  filtered_max(df,:) = wgt_runave(maximum, wgt(df,:), opt)  ; Wgt_runave function
  filtered_min(df,:) = wgt_runave(minimum, wgt(df,:), opt)  ; Wgt_runave function

                                        ; Loop through to fill in the nwt missing
values with unfiltered raw data
                                        ; These dates will include the first and the
last nwt-1/2 values,
                                        ; which would be January 1979 and September
2007 temperatures
  do i=0,num_time-1
```

```
     if (ismissing(filtered_max(df,i)) .eq. True) then
      filtered_max(df,i) = maximum(i)
     end if
     if (ismissing(filtered_min(df,i)) .eq. True) then
      filtered_min(df,i) = minimum(i)
     end if
   end do

   filtered(df,:,0) = time
   filtered(df,:,1) = filtered_max(df,:)
   filtered(df,:,2) = filtered_min(df,:)

   asciiwrite(datafiles(df)+"_filtered_max", filtered(df,:,1))          ; write out
the filtered max temps to a file
   asciiwrite(datafiles(df)+"_filtered_min", filtered(df,:,2))          ; write out
the filtered min temps to a file

   opt1      = True                        ; File outs arrays to separate files, to
be called in from other programs
   opt1@fout = datafiles(df)+"_filtered"
   write_matrix(filtered(df,:,:), "f8.2", opt1)
   print("opt1 fout done")

 end do

 print(filtered)

 print(filtered_max)
 print(filtered_min)

end
```

IPM.ncl

```
;*******************************************************************************
; This program separates the 01-01-1979 to 09-30-2006 JJAS heat wave months from
; the rest of the data set, creates daily temperature anomalies, and plots various
; statistics concerning the dataset.
;*******************************************************************************

load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/gsn_code.ncl"
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/gsn_csm.ncl"
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/shea_util.ncl"
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/contributed.ncl"


;---------------------------------------------------------------
begin

 num_time=10135                                  ; number of dates from 01-01-1979 to
09-30-2006
 num_col=3                                ; 3 columns: 1)date, 2)maximum daily temp,
3)minimum daily temp
 files=30                                 ; Number of city files, 1 file for each city
 JJAS_days=3416                                  ; Number of days in all JJAS, 1 June
1979 to 30 Sept 2006
 yrs=28                                   ; Number of years
 dys=122                                         ; Number of days in June, July,
August, Sept

 datafiles = (/"Redding", "RedBluff", "Colusa", "Sac", "Stockton", "Modesto", "Merced",
"Fresno", "Visalia", "Bkrsfld" \
              , "CrescentCity", "Eureka", "Covelo", "Graton", "SanFrancisco", "Monterey",
"SLO", "SantaBarbara", "SantaAna" \
              , "Vista", "Seattle", "Spokane", "Yakima", "Portland", "Eugene", "Medford",
"Pendleton", "BakerCity", "Reno" \
              , "Tonopah"/)

 JJAS_time            = new((/files,JJAS_days/),float)   ; 2-D array of all JJAS
times, 3416 days in all JJAS 1979-2006
 JJAS_date_array      = new((/files,JJAS_days/),integer) ; 2-D array of all JJAS dates
 JJAS_max             = new((/files,JJAS_days/),float)   ; 2-D array of all JJAS
maximum temps
 JJAS_min             = new((/files,JJAS_days/),float)   ; 2-D array of all JJAS
minimum temps
 tmin_avg             = new((/files/),float)             ; 1-D array of Minimum
Temperature averages, for ALL JJAS
 tmax_avg             = new((/files/),float)              ; 1-D array of Maximum
Temperature averages, for ALL JJAS
 rc_tmin              = new((/files/),float)              ; 1-D array of Min Temp
regression coefficients
 tmin_reg             = new((/files,JJAS_days/),float)   ; 2-D array of Tmin regression
coefficients
 data_reg             = new((/files,2,num_time/),float)  ; 3-D array of regression
data values
 max_array            = new((/files,yrs,dys/),float)     ; 3-D array of all JJAS
maximum temperatures
 min_array            = new((/files,yrs,dys/),float)     ; 3-D array of all JJAS minimum
temperatures
 max_array_time       = new((/files,yrs,dys/),float)     ; 3-D array of all JJAS times
 max_array_date       = new((/files,yrs,dys/),integer)   ; 3-D array of all JJAS dates
= 28 years,122 days in each yr
 over_max_array       = new((/files,yrs,dys/),float)     ; 3-D array of JJAS max temps
over 100
 LTDM                 = new((/files,dys/),float)         ; The Long Term Daily Mean
for each JJAS day, 1 June-30 Sept
 LTDM_extended        = new((/files,JJAS_days/),integer)
 anomaly              = new((/files,yrs,dys/),float)     ; 3-D array of all JJAS
Anomalies
 over_anom            = new((/files,yrs,dys/),float)     ; 3-D array of anomalies that
exceed the Max anomaly threshold
 over_anom_date       = new((/files,yrs,dys/),integer)   ; 3-D array of dates of anoms
exceeding the Max anom threshold
```

```
 start_date              = new((/files,yrs,dys/),integer)  ; 3-D array of event starting
dates
 end_date                = new((/files,yrs,dys/),integer)  ; 3-D array of event ending
dates
 sum_max                 = new((/files,yrs,dys/),float)    ; 3-D array of the sum of the
event temps
 ave_max                 = new((/files,yrs,dys/),float)    ; 3-D array of the event
average maximum temps
 num_days                = new((/files,yrs,dys/),integer)  ; 3-D array of the # of days
in event with that start date
 indicator               = new((/files,yrs,dys/),float)    ; 3-D array indicates(0/1)
max temp exceeding max anom thrshld
 sum_test                = new((/files,yrs,dys/),float)    ; 3-D array of sums of # days
in event exceeding max anom thrshld
 event_start             = new((/files,yrs,dys/),integer)  ; 3-D array of event starting
dates
 num_days_events         = new((/files,yrs,dys/),integer)  ; 3-D array of the number of
days in each event
 event_max               = new((/files,yrs,dys/),float)    ; 3-D array of event max
Tmaxs
 event_min               = new((/files,yrs,dys/),float)    ; 3-D array of event min
Tmins
 b_max                   = new((/files/),integer)         ; 1-D array of number of events
for each city
 j_max                   = new((/files/),integer)         ; 1-D array of the max number of
event days
 event_num               = new((/files/),integer)         ; 1-D array of number of events
for each city
 days                    = new((/files/),integer)         ; 1-D array of the number of
event days for each city
 g_total                 = new((/files,yrs/),integer)      ; 2-D array of the number
of events each year for each city
 max_anom_ave            = new((/files,yrs,dys/),float)     ; 3-D array of the
maximum N-day anomaly average of each event
 max_anom_ave_date       = new((/files,yrs,dys/),integer)  ; 3-D array of the start date
of the max N-day anom avg
 max_temp                = new((/files,yrs,dys/),float)
 JJAS_SD                 = new((/files/),float)            ; 1-D array of the
standard deviation of JJAS for each city
 norm_anom               = new((/files,yrs,dys/),float)     ; 3-D array of the daily
normalized anomalies
 norm_anom_events        = new((/files,yrs,dys/),float)     ; 3-D array of the
normalized anoms for event days
 norm_anom_avg           = new((/files/),float)           ; 1-D array of the avg of
the norm event anoms for each city
 norm_anom_avg_all       = new((/files/),float)           ; 1-D array of the avg of
all normalized anomalies

;*********************************************************************************
********************************
;*********************************************************************************
********************************

                                        ; THE Do Loop of all cities
; do df=0,files-1                       ; THE Do Loop of all cities, using
UNfiltered temperature data
;  print(df)
;  data=asciiread("IPM_"+datafiles(df)+".csv",(/num_time,num_col/),"float")      ; reads
in .csv file with temp data

 do df=0,files-1                        ; THE Do Loop of all cities, using FILTERED
temperature data
  print(df)
  data=asciiread(datafiles(df)+"_filtered",(/num_time,num_col/),"float")

  time      = data(:,0)                                  ; column 0 = time(date)
  maximum   = data(:,1)                                  ; column 1 = maximum daily temp
  minimum   = data(:,2)                                  ; column 2 = minimum daily temp

printVarSummary(time)
  time!0        = "time"
```

```
  time&time      = time
  time@long_name = "date"
  time@units = "days after 1979-01-01 00:00:00"                      ; for example,
time(1979-01-01) = 0

  utc_date  = ut_calendar(time, 0)                              ; ut_calendar option 0 =
dimsizes(time) x 6:
  JJAS      = ut_calendar(time, 0)                              ; utc_date(:,0) --> years
  JJAS_date = ut_calendar(time, -2)                            ; utc_date(:,1) --> months
                                                               ; utc_date(:,2) --> days
                                                               ; utc_date(:,3) --> hours
                                                               ; utc_date(:,4) --> minutes
                                                               ; utc_date(:,5) --> seconds
                                                  ; ut_calendar option -2 = values returned in
format YYYYMMDD, type integer

  year  = floattointeger(JJAS(:,0))    ; Convert to integer for when using sprinti
  month = floattointeger(JJAS(:,1))
  day   = floattointeger(JJAS(:,2))

  minimum!0    = "time"
  minimum&time = time
  maximum!0    = "time"
  maximum&time = time

  k=0                         ; First do loop cycles through times and picks out JJAS
dates
  j=0                         ; Time, date, max, &  min arrays are deleted then
reinitialized with a dimension size of 'j'
  t=0

  do t=0, num_time-1
    if ((utc_date(t,1)).eq.6) .or. ((utc_date(t,1)).eq.7) .or. ((utc_date(t,1)).eq.8) .or.
((utc_date(t,1)).eq.9) then
     delete(JJAS_time)
     delete(JJAS_date_array)
     delete(JJAS_max)
     delete(JJAS_min)
     k=t
     JJAS(k,:) = utc_date(t,:)
     j=j+1                                  ; j is a counter for JJAS dates
     JJAS_time       = new((/files,j/),float) ; reinitialize arrays with new dimension 'j'
     JJAS_date_array = new((/files,j/),integer)
     JJAS_max        = new((/files,j/),float)
     JJAS_min        = new((/files,j/),float)
    end if
  end do

  print("loop 1 complete")

  k=0                  ; 2nd do loop cycles back through times and fills JJAS time, date,
max, min arrays with appr values
  j=0
  t=0

  do t=0, num_time-1
    if ((utc_date(t,1)).eq.6) .or. ((utc_date(t,1)).eq.7) .or. ((utc_date(t,1)).eq.8) .or.
((utc_date(t,1)).eq.9) then
     JJAS_time(df,j) = time(t)
     JJAS_date_array(df,j) = JJAS_date(t)      ; fill arrays with JJAS time, date, max, min
values
     JJAS_max(df,j) = maximum(t)
     JJAS_min(df,j) = minimum(t)
     j=j+1
    end if
  end do

  tmin_avg(df) = avg(JJAS_min(df,:)) ; average of all JJAS min temps
  tmax_avg(df) = avg(JJAS_max(df,:)) ; average of all JJAS max temps

  print(j)
```

```
   print("loop 2 complete")

   doy = day_of_year(year, month, day)

   y=0                            ; Do Loop to rearrange JJAS times, dates, maxs into 2-D
arrays
  k=0
  do m=6,9
   if (m .eq. 6) .or. (m .eq. 9) then
    do d=1,30
     y=0
     do t=0,num_time-1
      if (month(t) .eq. m) .and. (day(t) .eq. d) then
       max_array(df,y,k) = maximum(t)
       min_array(df,y,k) = minimum(t)
       max_array_time(df,y,k) = time(t)
       max_array_date(df,y,k) = JJAS_date(t)
       y=y+1
      end if
     end do
    k=k+1
    end do
   else
    do d=1,31
     y=0
     do t=0,num_time-1
      if (month(t) .eq. m) .and. (day(t) .eq. d) then
       max_array(df,y,k) = maximum(t)
       min_array(df,y,k) = minimum(t)
       max_array_time(df,y,k) = time(t)
       max_array_date(df,y,k) = JJAS_date(t)
       y=y+1
      end if
     end do
    k=k+1
    end do
   end if
  end do

   print("Max_array done")

   do y=0,yrs-1        ; Do loop to indicate anomalies over 100
    do k=0,dys-1
     if (max_array(df,y,k) .ge. 100.) then
      over_max_array(df,y,k) = max_array(df,y,k) - 100.
     else
      over_max_array(df,y,k) = 0
     end if
    end do
   end do
   print("Over_max_array computed")

   do i=0,dys-1        ; Do loop to find the Long Term Daily Means
    LTDM(df,i) = avg(max_array(df,:,i))
   end do

   do y=0,yrs-1        ; Do Loop to find the daily anomalies
    do k=0,dys-1
     anomaly(df,y,k) = max_array(df,y,k) - LTDM(df,k)          ; Anomaly = Observed - LTDM
    end do
   end do
   print("Anomaly done")

   JJAS_SD(df) = stddev(max_array(df,:,:))     ; Find JJAS standard deviation for each city

   do y=0,yrs-1        ; Do Loop to compute normalized anomalies (anom/SD)
    do k=0,dys-1
     norm_anom(df,y,k) = anomaly(df,y,k) / JJAS_SD(df)
    end do
   end do
```

```
  amin = 10                           ; Minimum anomaly threshold
  amax = 15                           ; Maximum anomaly threshold

  N = num(ismissing(anomaly))        ; Number of anomaly missing values
  print(N)

  a=0                                           ; Counter for number of events that exceed
maximum anomaly threshold
  b=0                                           ; Counter for number of events that do NOT
exceed maximum anomaly threshold
  do y=0,yrs-1                                  ; Do Loop to capture anomalies that exceed
the Maximum anomaly threshold
   do k=0,dys-1
    if (anomaly(df,y,k) .ge. amin) then
     over_anom(df,y,k) = anomaly(df,y,k)
     over_anom_date(df,y,k) = max_array_date(df,y,k)
     a=a+1
    else
     over_anom(df,y,k) = 0
     over_anom_date(df,y,k) = max_array_date(df,y,k)
     b=b+1
    end if
   end do
  end do

  print("Number of Anomalous Dates ="+a)
  print("Number of Non-Anomalous Dates ="+b)
  print("Over_anoms done")

  s=0          ; Do Loop that identifies event starting/ending dates
  d=0          ; Event defined as 3 or more consecutive days with all anoms greater than
or equal to  min anom threshold
               ; and at least 1 day greater than or equal to max anom threshold
  do y=0,yrs-1
   do k=0,dys-1
    if (k .eq. 0) then
     if (over_anom(df,y,k) .ne. 0) .and. (over_anom(df,y,k+1) .ne. 0) .and.
(over_anom(df,y,k+2) .ne. 0) then
       start_date(df,y,k) = over_anom_date(df,y,k)
       s=s+1
      else
       start_date(df,y,k) = 0
      end if
     end if

     if (k .ge. 1) .and. (k .le. dys-3) then
      if (over_anom(df,y,k).ne.0) .and. (over_anom(df,y,k-1).eq.0) .and.
(over_anom(df,y,k+1).ne.0) .and. (over_anom(df,y,k+2).ne.0) then
       start_date(df,y,k) = over_anom_date(df,y,k)
       s=s+1
      else
       start_date(df,y,k) = 0
      end if
     end if

     if (k .eq. dys-2) .or. (k .eq. dys-1) then
      start_date(df,y,k) = 0
     end if

     if (k .eq. 0) .or. (k .eq. 1) then
      end_date(df,y,k) = 0
     end if

     if (k .ge. 2) .and. (k .le. dys-2) then
      if (over_anom(df,y,k).ne.0) .and. (over_anom(df,y,k+1).eq.0) .and.
(over_anom(df,y,k-1).ne.0) .and. (over_anom(df,y,k-2).ne.0) then
       end_date(df,y,k) = over_anom_date(df,y,k)
       d=d+1
      else
       end_date(df,y,k) = 0
      end if
```

```
     end if

     if (k .eq. dys-1) then
      if (over_anom(df,y,k) .ne. 0) .and. (over_anom(df,y,k-1) .ne. 0) .and.
(over_anom(df,y,k-2) .ne. 0) then
       end_date(df,y,k) = over_anom_date(df,y,k)
       d=d+1
      else
       end_date(df,y,k) = 0
      end if
     end if

    end do
   end do

  print("Start/End Dates done")
  print("Number of Starting Dates = "+s)
  print("Number of Ending Dates = "+d)
                              ; Do Loop to find Tmax sums, Tmax averages, and # of days
of each event
  do y=0,yrs-1
   do k=0,dys-1
    if (start_date(df,y,k) .ne. 0) then
     j=1
     sum_max(df,y,k) = max_array(df,y,k)
     do i=1,j
      if (end_date(df,y,k+i) .eq. 0) then
       sum_max(df,y,k) = max_array(df,y,k+i) + sum_max(df,y,k)
       j=j+1
      else
       sum_max(df,y,k)  = sum_max(df,y,k) + max_array(df,y,k+i)
       ave_max(df,y,k)  = ((sum_max(df,y,k))/(i+1))
       num_days(df,y,k) = i+1
      end if
     end do
    else
     sum_max(df,y,k)  = 0
     ave_max(df,y,k)  = 0
     num_days(df,y,k) = 0
    end if
   end do
  end do

  print("Sum,Ave,Num done")
                          ; Do Loop to identify(0/1) event dates that have Tmaxs > the max
                          ; anom threshold.  Sum of the indicators tells how many above
threshold
                          ; Tmaxs each event has.  Only events with at least 1 Tmax > amax
are kept.
  do y=0,yrs-1
   do k=0,dys-1
    if (start_date(df,y,k) .ne. 0) then
     do i=0,num_days(df,y,k)-1
      if (over_anom(df,y,k+i) .lt. amax) then
       indicator(df,y,k+i) = 0
      else
       indicator(df,y,k+i) = 1
      end if
      if (i .eq. 0) then
       sum_test(df,y,k+i) = indicator(df,y,k+i)
      end if
      if (i .ne. 0) then
       sum_test(df,y,k+i) = indicator(df,y,k+i) + sum_test(df,y,k+i-1)
      end if
     end do
     sum_test(df,y,k) = sum_test(df,y,k+(num_days(df,y,k)-1))
    else
     sum_test(df,y,k) = 0
    end if
                         ;******** requires average max temp of event to be >= 100, or
NOT*******
```

```
     ;**********************************************************************
   if (sum_test(df,y,k) .eq. 0) .or. (ave_max(df,y,k) .lt. 100) then
    event_start(df,y,k) = 0
   else
    event_start(df,y,k) = start_date(df,y,k)
   end if

  end do
 end do

 print("Sum_Test done")
 print("Sum/Ave Maxs done")

 do y=0,yrs-1          ; Do Loop to rename the number of event days for each event
  do k=0,dys-1
   if (event_start(df,y,k) .ne. 0) then
    num_days_events(df,y,k) = num_days(df,y,k)
   else
    num_days_events(df,y,k) = 0
   end if
  end do
 end do

 days(df) = sum(num_days_events(df,:,:))            ; Number of events for each city
 print(days(df))

 print("Event,max,min arrays done")

 do y=0,yrs-1          ; Do Loop to find the max temp of events
  do k=0,dys-1
   if (event_start(df,y,k) .ne. 0) then
    temps = new((/num_days_events(df,y,k)/),float)
     do i=0,num_days_events(df,y,k)-1
      norm_anom_events(df,y,k+i) = norm_anom(df,y,k+i)
      temps(i) = max_array(df,y,k+i)
     end do
     print(temps)
     max_temp(df,y,k) = max(temps)
     print(max_temp(df,y,k))
     delete(temps)
    else
     max_temp(df,y,k) = 0
    end if
   end do
  end do
 norm_anom_avg(df) = avg(norm_anom_events(df,:,:))     ; avg of event normalized
anomalies
 norm_anom_avg_all(df) = avg(norm_anom(df,:,:))     ; avg of all normalized anomalies

 N=3                   ; Do Loop to compute 3-day anomaly averages and find the highest
one of the event
  do y=0,yrs-1
   do k=0,dys-1
    if (event_start(df,y,k) .ne. 0) then
     anom_ave = new((/num_days_events(df,y,k)-(N-1)/),float)
     anom_ave_date = new((/num_days_events(df,y,k)-(N-1)/),integer)
     anom_ave_perm = new((/num_days_events(df,y,k)-(N-1)/),integer)
     do i=0,num_days_events(df,y,k)-N
      anom_ave(i) = avg(anomaly(df,y,k+i:k+i+2))
;),anomaly(df,y,k+i+1),anomaly(df,y,k+i+2))
      anom_ave_date(i) = max_array_date(df,y,k+i)
     end do
     print(anom_ave)
     print(anom_ave_date)
     max_anom_ave(df,y,k) = max(anom_ave)
     anom_ave_perm = dim_pqsort(anom_ave, -1)
     max_anom_ave_date(df,y,k) = anom_ave_date(anom_ave_perm(0))
     print(max_anom_ave(df,y,k))
     print(max_anom_ave_date(df,y,k))
```

```
       delete(anom_ave)
       delete(anom_ave_date)
       delete(anom_ave_perm)
      else
       max_anom_ave(df,y,k) = 0
       max_anom_ave_date(df,y,k) = 0
      end if
     end do
    end do

   time_JJAS = new((/JJAS_days/),integer)     ; Do Loop to create timeline for following
 plots
   do i=0,JJAS_days-1
    time_JJAS(i) = i
    end do

   time_anomaly = new((/dys/),integer)        ; Do Loop to create timeline for following
 plots
   do i=0,dys-1
    time_anomaly(i) = i
    end do

 ;****************************************************************
 ; The code below creates an XY plot of the JJAS LTDMs.
 ;****************************************************************

   LTDM_plot = new((/dys/),float)

   LTDM_plot(:) = LTDM(df,:)

   wks1 = gsn_open_wks ("ps","IPM_LTDM_Plot_"+datafiles(df))

   res1                 = True                        ; plot mods desired
   res1@tiMainString    = datafiles(df)+" JJAS LTDMs"         ; add title

   res1@tiXAxisString   = "Date"                              ; xaxis string
   res1@tiYAxisString   = "LTDM"                  ; yaxis string

   res1@xyLineThicknesses = (/1.0,2.0/)                       ; make 2nd lines thicker
   res1@xyDashPattern = 0                                     ; Make curves all solid

   res1@xyLineColors      = (/"red","blue"/)                  ; change line color
   res1@tmXBPrecision = 4                                     ; set the precision to 4
 significant digits
   res1@trXMinF = 1
   res1@trXMaxF = 123

   res1@tmXBMode = "Explicit"
   res1@tmXBValues = (/0,14,30,44,61,75,92,106/)
   res1@tmXBLabels = (/"1 June","15 June","1 July","15 July","1 Aug","15 Aug","1 Sept","15
 Sept"/)
   res1@tmXBMinorValues = ispan(0,121,1)
   res1@tmXBLabelFontHeightF = 0.01

   plot1  = gsn_csm_xy (wks1,ispan(0,dys-1,1),LTDM_plot,res1)           ; create plot
   print("JJAS LTDMs")

 ;****************************************************************
 ; The code below creates an XY plot of the JJAS anomalies.
 ;****************************************************************

   do i=0,yrs-1

   res2                 = True                        ; plot mods desired
   res2@tiMainString    = datafiles(df)+" JJAS Anomalies, Year " + sprinti("%0.4i",
 i+1979)        ; add title

   res2@tiXAxisString   = "Date"                              ; xaxis string
   res2@tiYAxisString   = "Temperature Anomaly"                       ; yaxis string

   res2@xyLineThicknesses = (/1.0,2.0/)                       ; make 2nd lines thicker
```

```
  res2@xyDashPattern = 0                                        ; Make curves all solid

  res2@xyLineColors      = (/"red","blue"/)             ; change line color
  res2@tmXBPrecision = 4                                ; set the precision to 4
significant digits
  res2@trXMinF = 1
  res2@trXMaxF = dys+1
                                                   ; create a reference line and shade
values above and below with
  res2@tmXBMode = "Explicit"
  res2@tmXBValues = (/0,14,30,44,61,75,92,106/)
  res2@tmXBLabels = (/"1 June","15 June","1 July","15 July","1 Aug","15 Aug","1 Sept","15
Sept"/)
  res2@tmXBMinorValues = ispan(0,121,1)
  res2@tmXBLabelFontHeightF = 0.01


                                                   ; selected colors. This is shading
array dsoid.
  res2@gsnYRefLine         = 0.0                        ; create a reference line
  res2@gsnYRefLineThicknessF = 2.0
; res2@gsnAboveYRefLineColor = (/"red"/)
; res2@gsnBelowYRefLineColor = (/"blue"/)
;*******************************
; polyline parameters used on both plots
;*******************************
; polyres2                 = True
; polyres2@gsLineThicknessF = 3.0
 ;*******************************
; res2@gsnAboveYRefLineColor = (/"red"/)                        ; above ref line fill red
; res2@gsnBelowYRefLineColor = (/"blue"/)                       ; below ref line fill blue
; (taken out so other plots could be plotted)  plot2  = gsn_csm_xy(wks2,ispan(0,dys-
1,1),anomaly(df,i,:),res2) ; create plot
; gsn_polyline(wks2,plot2,time_anomaly,(/anomaly_plot/),polyres2)   ; add polyline
; frame(wks)
  end do
;  print("Anomaly")


;*****************************************************************

 asciiwrite(datafiles(df)+"_JJAS_max", JJAS_max(df,:))
 print("asciiwrite JJAS_max done")

  opt1       = True           ; File outs arrays to separate files, to be called in from
other programs
  opt1@title = "JJAS Tmaxs"
  opt1@fout  = datafiles(df)+"_max_array"
  write_matrix(max_array(df,:,:), "I3", opt1)

  print("opt1 fout done")

  opt2       = True
  opt2@title = "JJAS Tmax dates"
  opt2@fout  = datafiles(df)+"_max_array_date"
  write_matrix(max_array_date(df,:,:), "I8.8", opt2)

  print("opt2 fout done")

  opt3       = True
  opt3@title = "Anomalies"
  opt3@fout  = datafiles(df)+"_Anomalies"
  write_matrix(anomaly(df,:,:), "f6.2", opt3)

  print("opt3 fout done")

  opt4       = True
  opt4@title = "Average Tmax"
  opt4@fout  = datafiles(df)+"_ave_max"
  write_matrix(ave_max(df,:,:), "f6.2", opt4)

  print("opt4 fout done")
```

```
 opt5       = True
 opt5@title = "Number of Event Days"
 opt5@fout  = datafiles(df)+"_num_days"
 write_matrix(num_days_events(df,:,:), "I3", opt5)

 print("opt5 fout done")

 opt6       = True
 opt6@title = "Number of Event Days over Maximum Threshold"
 opt6@fout  = datafiles(df)+"_sum_test"
 write_matrix(sum_test(df,:,:), "f2.0", opt6)

 print("opt6 fout done")

 opt7       = True
 opt7@title = "Event Start Date"
 opt7@fout  = datafiles(df)+"_event_start"
 write_matrix(event_start(df,:,:), "I8.8", opt7)

 print("opt7 fout done")

 opt8       = True
 opt8@title = "Event End Date"
 opt8@fout  = datafiles(df)+"_end_date"
 write_matrix(end_date(df,:,:), "I8.8", opt8)

 print("opt8 fout done")

 print(datafiles(df)+" complete")

 if (df .eq. files-1) then
  corr_temp = new((/files/),float)
  do df=0,files-1
   corr_temp(df) = escorc(JJAS_max(3,:),JJAS_max(df,:))
  end do
  print(corr_temp(:))
 end if

 delete(time)
 delete(maximum)
 delete(minimum)

 end do                                ; The End Do of all End Dos

;*********************************************************************************
**************************
;*********************************************************************************
**************************
 print(anomaly)
 print(JJAS_SD)
 print(norm_anom)
 print(norm_anom_events)
 print(norm_anom_avg)
 print(norm_anom_avg_all)
 print(max_array)
 print(max_array_date)
 print(max_anom_ave)

 asciiwrite("JJAS_SD", JJAS_SD(:))
 asciiwrite("norm_anom_avg", norm_anom_avg(:))

 anomave    = new((/files,JJAS_days/),float)
 anomavedate = new((/files,JJAS_days/),integer)
 normanom   = new((/files,JJAS_days/),float)
 anomdate   = new((/files,JJAS_days/),integer)
 max_temp_2 = new((/files,JJAS_days/),float)
 maxarray   = new((/files,JJAS_days/),float)

 do df=0,files-1      ; transform 3-D arrays to 2-D arrays
  anomave(df,:) = ndtooned(max_anom_ave(df,:,:))
```

```
 anomavedate(df,:) = ndtooned(max_anom_ave_date(df,:,:))
 normanom(df,:) = ndtooned(norm_anom(df,:,:))
 anomdate(df,:) = ndtooned(max_array_date(df,:,:))
 max_temp_2(df,:) = ndtooned(max_temp(df,:,:))
 maxarray(df,:) = ndtooned(max_array(df,:,:))

 print(max_temp_2(df,:))

end do

ave_max_long          = new((/files,JJAS_days/),float)
ave_max_long_date     = new((/files,JJAS_days/),integer)
anom_long             = new((/files,JJAS_days/),float)
ave_max_sort          = new((/files,JJAS_days/),integer)
ave_max_sorted        = new((/files,JJAS_days/),float)
ave_max_sorted_date   = new((/files,JJAS_days/),integer)
max_long              = new((/files,JJAS_days/),float)
max_long_date         = new((/files,JJAS_days/),integer)
num_days_long         = new((/files,JJAS_days/),integer)
date_num              = new((/files/),integer)

a=0    ; transform 3-D arrays to 2-D arrays
b=0
d=0
do df=0,files-1
 a=0
 b=0
 d=0
 do y=0,yrs-1
  do k=0,dys-1
   if (event_start(df,y,k) .ne. 0) then
    ave_max_long(df,a) = ave_max(df,y,k)
    ave_max_long_date(df,a) = max_array_date(df,y,k)
    num_days_long(df,a) = num_days_events(df,y,k)
    nd=num_days_events(df,y,k)
    do n=0,nd-1
     max_long(df,b+n) = max_array(df,y,k+n)
     max_long_date(df,b+n) = max_array_date(df,y,k+n)
     anom_long(df,b+n) = anomaly(df,y,k+n)
     d=d+1
     end do
    a=a+1
    b=b+nd
   else
    ave_max_long(df,a) = 0
    ave_max_long_date(df,a) = 0
    num_days_long(df,a) = 0
    a=a+1
   end if
  end do
 end do
 date_num(df) = d
end do

ave_max_date          = new((/files,JJAS_days/),integer)
anomave_perm          = new((/files,JJAS_days/),integer)
max_temp_2_perm       = new((/files,JJAS_days/),integer)
anomave_sorted        = new((/files,JJAS_days/),float)
anomavedate_sorted    = new((/files,JJAS_days/),integer)
anomdate_sorted       = new((/files,JJAS_days/),integer)
max_temp_date_sorted  = new((/files,JJAS_days/),integer)
max_temp_2_sorted = new((/files,JJAS_days/),float)

                      ; reorder arrays in descending order to find
                      ; the max values and their dates

do df=0,files-1
 ave_max_sort(df,:)   = dim_pqsort(ave_max_long(df,:),-1)
 anomave_perm(df,:)   = dim_pqsort(anomave(df,:),-1)
 max_temp_2_perm(df,:) = dim_pqsort(max_temp_2(df,:),-1)
end do
```

```
   print(max_temp_2_perm)

 do df=0,files-1
  do i=0,JJAS_days-1
   anomave_sorted(df,i) = anomave(df,anomave_perm(df,i))
   anomavedate_sorted(df,i) = anomavedate(df,anomave_perm(df,i))
   anomdate_sorted(df,i) = anomdate(df,anomave_perm(df,i))
   max_temp_2_sorted(df,i) = max_temp_2(df,max_temp_2_perm(df,i))
   max_temp_date_sorted(df,i) = anomdate(df,max_temp_2_perm(df,i))
  end do
 end do
 print(max_temp_2_sorted)
 print(max_temp_date_sorted)

;****************
; Print outs for the different Ranking Methods
;****************

 rank_end_date_try = new((/files,JJAS_days/),integer)
 num_days_rank_try = new((/files,JJAS_days/),integer)

 do df=0,files-1
  r=0
  print("HW Ranking by Highest Onset Maximum Temperature")
  print("City = "+datafiles(df))
  print("Ranking StartDate   EndDate  TMax  NumDays")
  do j=0,JJAS_days-1
   if (max_temp_2_sorted(df,j) .ne. 0) then
    r=r+1
    do y=0,yrs-1
     do k=0,dys-1
      if (max_temp_date_sorted(df,j) .eq. event_start(df,y,k)) then
       rank_end_date_try(df,j) = end_date(df,y,k+(num_days(df,y,k)-1))
       num_days_rank_try(df,j) = num_days_events(df,y,k)
      end if
     end do
    end do
    print("  "+r+"     "+sprinti("%8.0i", max_temp_date_sorted(df,j))+"
"+sprinti("%8.0i", rank_end_date_try(df,j))+"   " \
         +sprintf("%6.2f", max_temp_2_sorted(df,j))+"      "+sprinti("%2.0",
num_days_rank_try(df,j)))
   end if
  end do
 end do


 rank_end_date_1 = new((/files,JJAS_days/),integer)
 num_days_rank_1 = new((/files,JJAS_days/),integer)

 do df=0,files-1
  r=0
  print("HW Ranking by Highest "+N+"-day Average Maximum Temperature Anomaly")
  print("City = "+datafiles(df))
  print("Ranking StartDate   EndDate  AnomStartDate Ave TMax Anom  NumDays")
  do j=0,JJAS_days-1
   if (anomave_sorted(df,j) .ne. 0) then
    r=r+1
    do y=0,yrs-1
     do k=0,dys-1
      if (anomdate_sorted(df,j) .eq. event_start(df,y,k)) then
       rank_end_date_1(df,j) = end_date(df,y,k+(num_days(df,y,k)-1))
       num_days_rank_1(df,j) = num_days_events(df,y,k)
      end if
     end do
    end do
    print("  "+r+"     "+sprinti("%8.0i", anomdate_sorted(df,j))+"    "+sprinti("%8.0i",
rank_end_date_1(df,j))+"   " \
         +sprinti("%8.0i", anomavedate_sorted(df,j))+"      "+sprintf("%6.2f",
anomave_sorted(df,j))+"       " \
         +sprinti("%2.0", num_days_rank_1(df,j)))
   end if
```

```
 end do
 end do

 top_rank = 15
 do df=0,files-1
  r=0
  print(datafiles(df)+" Top "+top_rank+" Events")
  print("Ranked by Highest "+N+"-day Average Maximum Temperature Anomaly")
  print("Ranking StartDate   EndDate  AnomStartDate Tmax Average")
  do j=0,top_rank-1                        ; Selecting the top top_rank events
   r=r+1
   if (anomave_sorted(df,j) .ne. 0) then
    print(" "+r+"  "+sprinti("%8.0i", anomdate_sorted(df,j))+"   "+sprinti("%8.0i",
rank_end_date_1(df,j))+"   " \
          +sprinti("%8.0i", anomavedate_sorted(df,j))+"        "+sprintf("%6.2f",
anomave_sorted(df,j))+"       " \
          +sprinti("%2.0", num_days_rank_1(df,j)))
   end if
  end do
 end do

 Sac_norm_anoms = new((/files,top_rank/),float)
 Sac_norm_anoms_avg = new((/files/),float)
 Sacdate_target_3day = new((/files,top_rank/),float)
 Sacdate_target_3day_avg = new((/files/),float)

 do df=0,files-1      ; Find normalized anomalies on Sac Event dates
  do j=0,top_rank-1    ; at all stations
   do k=0,JJAS_days-1
    if (anomavedate_sorted(3,j) .ne. 0) then
     if (anomavedate_sorted(3,j) .eq. anomdate(df,k)) then
      Sac_norm_anoms(df,j) = normanom(df,k)
     end if
    end if
   end do
  end do
  Sac_norm_anoms_avg(df) = avg(Sac_norm_anoms(df,:))
 end do
 print(Sac_norm_anoms)
 print(Sac_norm_anoms_avg)

 do df=0,files-1
  do j=0,top_rank-1
   do k=0,JJAS_days-1
    if (anomdate_sorted(3,j) .ne. 0) then
     if (anomdate_sorted(3,j) .eq. anomdate(df,k)) then
      Sacdate_target_3day(df,j) = maxarray(df,k)
     end if
    end if
   end do
  end do
  Sacdate_target_3day_avg(df) = avg(Sacdate_target_3day(df,:))
 end do
 print(Sacdate_target_3day)
 print(Sacdate_target_3day_avg)

 asciiwrite("Sac_norm_anoms_avg", Sac_norm_anoms_avg(:))
 asciiwrite("Sacdate_target_3day_avg", Sacdate_target_3day_avg(:))

 do df=0,files-1
  qsort(ave_max_long(df,:))
  ave_max_sorted(df,:) = ave_max_long(df,::-1)
 end do

 do df=0,files-1
  do j=0,JJAS_days-1
   ave_max_date(df,j) = ave_max_long_date(df,ave_max_sort(df,j))
  end do
 end do

 ave_max_rank = new((/files,JJAS_days/),integer)
```

```
 b=0
 do df=0,files-1
  b=0
  do j=0,JJAS_days-1
   if (ave_max_sorted(df,j) .ne. 0) then
    ave_max_rank(df,j) = b+1
    b=b+1
   end if
  end do
 end do

;*************
; Print outs of more Ranking Methods
;************

 rank_end_date = new((/files,JJAS_days/),integer)
 num_days_rank = new((/files,JJAS_days/),integer)
 do df=0,files-1
  print("HW Ranking by Highest Average Maximum Temperature")
  print("City = "+datafiles(df))
  print("Ranking StartDate   EndDate  Tmax Average")
  do j=0,JJAS_days-1
   if (ave_max_sorted(df,j) .ne. 0) then
    do y=0,yrs-1
     do k=0,dys-1
      if (ave_max_date(df,j) .eq. event_start(df,y,k)) then
       rank_end_date(df,j) = end_date(df,y,k+(num_days(df,y,k)-1))
       num_days_rank(df,j) = num_days_events(df,y,k)
      end if
     end do
    end do
    print("  "+sprinti("%2.0i", ave_max_rank(df,j))+"   "+sprinti("%8.0i",
ave_max_date(df,j))+"   "+sprinti("%8.0i", rank_end_date(df,j))+"    "+sprintf("%6.2f",
ave_max_sorted(df,j)))
   end if
  end do
 end do

 top_rank = 15
 do df=0,files-1
  print(datafiles(df)+" Top "+top_rank+" Events")
  print("Ranked by Highest Average Maximum Temperature")
  print("Ranking StartDate   EndDate  Tmax Average")
  do j=0,top_rank-1                ; Selecting the top top_rank events
   if (ave_max_sorted(df,j) .ne. 0) then
    print("  "+sprinti("%2.0i", ave_max_rank(df,j))+"   "+sprinti("%8.0i",
ave_max_date(df,j))+"   "+sprinti("%8.0i", rank_end_date(df,j))+"    "+sprintf("%6.2f",
ave_max_sorted(df,j)))
   end if
  end do
 end do

 top_rank_ave      = new((/files,top_rank/),float)
 top_rank_ave_date = new((/files,top_rank/),integer)
 top_rank_anomave  = new((/files,top_rank/),float)
 top_rank_anomdate = new((/files,top_rank/),integer)
 top_rank_max      = new((/files,top_rank/),float)
 top_rank_max_date = new((/files,top_rank/),integer)
 top_temps         = new((/files,JJAS_days/),float)
 top_temps_N       = new((/files,JJAS_days/),float)
 top_temps_max     = new((/files,JJAS_days/),float)
 top_dates         = new((/files,JJAS_days/),integer)
 top_dates_N       = new((/files,JJAS_days/),integer)
 top_dates_max     = new((/files,JJAS_days/),integer)
 top_anoms         = new((/files,JJAS_days/),float)
 top_anoms_N       = new((/files,JJAS_days/),float)
 top_anoms_max     = new((/files,JJAS_days/),float)
 count             = new((/files/),integer)
 count_Nday        = new((/files/),integer)
```

```
counter=0
counter_Nday=0
do df=0,files-1
 counter=0
 counter_Nday=0
 do j=0,JJAS_days-1
  if (ave_max_sorted(df,j) .ne. 0) then
   counter=counter+1
  end if
  if (anomave_sorted(df,j) .ne. 0) then
   counter_Nday=counter_Nday+1
  end if
 end do
 count(df)  = counter
 count_Nday(df) = counter_Nday
end do
print(count)
print(count_Nday)

l=0          ; grab top rank dates of certain max values
i=0
b=0
c=0
do df=0,files-1
 i=0
 b=0
 c=0
 if (count(df) .le. top_rank) then
  do j=0,count(df)-1
   if (ave_max_sorted(df,j) .ne. 0) then
    top_rank_ave(df,i) = ave_max_sorted(df,j)                        ; ONLY top N events,
no holes
    top_rank_ave_date(df,i) = ave_max_date(df,j)
    i=i+1
   end if
   if (anomave_sorted(df,j) .ne. 0) then
    top_rank_anomave(df,b) = anomave_sorted(df,j)
    top_rank_anomdate(df,b) = anomdate_sorted(df,j)
    b=b+1
   end if
   if (max_temp_2_sorted(df,j) .ne. 0) then
    top_rank_max(df,c) = max_temp_2_sorted(df,j)
    top_rank_max_date(df,c) = max_temp_date_sorted(df,j)
    c=c+1
   end if
  end do
 end if

 i=0
 b=0
 c=0
 if (count(df) .gt. top_rank) then
  do j=0,top_rank-1
   if (ave_max_sorted(df,j) .ne. 0) then
    top_rank_ave(df,i) = ave_max_sorted(df,j)
    top_rank_ave_date(df,i) = ave_max_date(df,j)
    i=i+1
   end if
   if (anomave_sorted(df,j) .ne. 0) then
    top_rank_anomave(df,b) = anomave_sorted(df,j)
    top_rank_anomdate(df,b) = anomdate_sorted(df,j)
    b=b+1
   end if
   if (max_temp_2_sorted(df,j) .ne. 0) then
    top_rank_max(df,c) = max_temp_2_sorted(df,j)
    top_rank_max_date(df,c) = max_temp_date_sorted(df,j)
    c=c+1
   end if
  end do
 end if
end do
```

```
top_rank_onset      = new((/files,top_rank/),float)
top_rank_onset_Nday = new((/files,top_rank/),float)
top_rank_onset_max  = new((/files,top_rank/),float)

do df=0,files-1       ; Do Loop to grab the top rank onset dates
 if (count(df) .le. top_rank) then
  do k=0,count(df)-1
   do j=0,date_num(df)-1
    if (top_rank_ave_date(df,k) .eq. max_long_date(df,j)) then
     top_rank_onset(df,k) = max_long(df,j)
    end if
    if (top_rank_anomdate(df,k) .eq. max_long_date(df,j)) then
     top_rank_onset_Nday(df,k) = max_long(df,j)
    end if
    if (top_rank_max_date(df,k) .eq. max_long_date(df,j)) then
     top_rank_onset_max(df,k) = max_long(df,j)
    end if
   end do
  end do
 end if

 if (count(df) .gt. top_rank) then
  do k=0,top_rank-1
   do j=0,date_num(df)-1
    if (top_rank_ave_date(df,k) .eq. max_long_date(df,j)) then
     top_rank_onset(df,k) = max_long(df,j)
    end if
    if (top_rank_anomdate(df,k) .eq. max_long_date(df,j)) then
     top_rank_onset_Nday(df,k) = max_long(df,j)
    end if
    if (top_rank_max_date(df,k) .eq. max_long_date(df,j)) then
     top_rank_onset_max(df,k) = max_long(df,j)
    end if
   end do
  end do
 end if
end do
print(top_rank_onset_max)

target_ave      = new((/files/),float)
target_ave_Nday = new((/files/),float)
target_ave_max  = new((/files/),float)
do df=0,files-1
 target_ave(df)      = avg(top_rank_onset(df,:))
 target_ave_Nday(df) = avg(top_rank_onset_Nday(df,:))
 target_ave_max(df)  = avg(top_rank_onset_max(df,:))
end do

do df=0,files-1
 asciiwrite(datafiles(df)+"_top_rank_onset", top_rank_onset(df,:))
 asciiwrite(datafiles(df)+"_top_rank_onset_Nday", top_rank_onset_Nday(df,:))
 asciiwrite(datafiles(df)+"_top_rank_onset_max", top_rank_onset_max(df,:))
end do
print("asciiwrite top_rank_onsets done")

asciiwrite("target_ave", target_ave(:))
asciiwrite("target_ave_Nday", target_ave_Nday(:))
asciiwrite("target_ave_max", target_ave_max(:))
print("asciiwrite target_aves done")

g=0                                      ; Do Loop to create an array of all events
b=0
f=0
j=0
i=0
jmax=0
do df=0,files-1
 b=0
 do y=0,yrs-1
```

```
   g=0
   do k=0,dys-1
    if (event_start(df,y,k) .ne. 0) then
     j=num_days_events(df,y,k)
     i=i+1                               ; i/ counter for number of events in ALL cities,
ALL years (grand total)
     b=b+1                               ; b/ counter for number of events in each city
file, ALL years
     g=g+1                               ; g/ counter for number of events EACH YEAR in
each city file
     if (j .ge. jmax) then
      jmax = j
      else
      jmax = jmax
     end if
    end if
   end do
   g_total(df,y) = g
  end do
  b_max(df) = b
  print(datafiles(df)+" Number of Events = "+b_max(df))
  j_max(df) = jmax
 end do
 print("Grand Total # of Events, ALL cities, ALL years = "+i)

 total_b = sum(b_max)
 bmax  = max(b_max(:))
 jjmax = max(j_max(:))
 g_total_sum = sum(g_total)

 tmin_year_avg = new((/files,yrs/),float)       ; 2-D array of Yearly Minimum Temp
averages
 tmax_year_avg = new((/files,yrs/),float)
 do df=0,files-1                                ; Do Loop to compute Minimum Temp
average; each year, for every city
  do y=0,yrs-1
   tmin_year_avg(df,y) = avg(min_array(df,y,:))
   tmax_year_avg(df,y) = avg(max_array(df,y,:))
  end do
 end do

 print(tmin_year_avg)
 print(tmax_year_avg)
 print(tmin_avg)
 print(tmax_avg)

 total_days = sum(days)        ; Number of total events, all years, all cities
 print(days)
 print(total_days)
 num_days_sum = sum(num_days_events)
 print(num_days_sum)

 event_array            = new((/files,bmax,jjmax/),float)
 event_dates_array      = new((/files,bmax,jjmax/),integer)
 event_array_all        = new((/num_days_sum/),float)            ; 1-D array of all event
Tmaxs
 event_dates_array_all = new((/num_days_sum/),integer)           ; 1-D array of all
event dates

 b=0            ; Create array of event dates
 f=0
 j=0
 do df=0,files-1
  b=0
  do y=0,yrs-1
   do k=0,dys-1
    if (event_start(df,y,k) .ne. 0) then
     b=b+1                                          ; counter for number of
ALL events
     j=num_days_events(df,y,k)
     do n=0,j-1
```

```
        event_array(df,b-1,n) = max_array(df,y,k+n)
        event_dates_array(df,b-1,n) = max_array_date(df,y,k+n)
        event_array_all(f+n) = event_array(df,b-1,n)
        event_dates_array_all(f+n) = event_dates_array(df,b-1,n)
       end do
      event_max(df,y,k) = max(event_array(df,b-1,:))
      event_min(df,y,k) = min(event_array(df,b-1,:))
      f=f+j
      print(f)
     else
      event_max(df,y,k) = 0
      event_min(df,y,k) = 0
     end if
   end do
  end do
end do
print(event_max)

eventmaxes = new((/files,JJAS_days/),float)
eventdates = new((/files,JJAS_days/),integer)

do df=0,files-1
  eventmaxes(df,:)  = ndtooned(event_max(df,:,:))
  eventdates(df,:)  = ndtooned(max_array_date(df,:,:))
end do

eventmaxes_perm = new((/files,JJAS_days/),integer)
eventmaxes_sorted = new((/files,JJAS_days/),float)
eventdates_sorted = new((/files,JJAS_days/),integer)

do df=0,files-1
  eventmaxes_perm(df,:) = dim_pqsort(eventmaxes(df,:),-1)
end do

do df=0,files-1
 do i=0,JJAS_days-1
   eventmaxes_sorted(df,i) = eventmaxes(df,eventmaxes_perm(df,i))
   eventdates_sorted(df,i) = eventdates(df,eventmaxes_perm(df,i))
 end do
end do

do df=0,files-1
 do j=0,JJAS_days-1
  top_temps(df,j) = 0
  top_temps_N(df,j) = 0
  top_temps_max(df,j) = 0
  top_dates(df,j) = 0
  top_dates_N(df,j) = 0
  top_dates_max(df,j) = 0
 end do
end do

rank_end_date_2 = new((/files,JJAS_days/),integer)
num_days_rank_2 = new((/files,JJAS_days/),integer)

do df=0,files-1
 do j=0,JJAS_days-1
  if (eventmaxes_sorted(df,j) .ne. 0) then
   do y=0,yrs-1
    do k=0,dys-1
     if (eventdates_sorted(df,j) .eq. event_start(df,y,k)) then
      rank_end_date_2(df,j) = end_date(df,y,k+(num_days(df,y,k)-1))
      num_days_rank_2(df,j) = num_days_events(df,y,k)
     end if
    end do
   end do
  end if
 end do
end do

b=0
```

```
do df=0,files-1
 b=0
 if (count(df) .lt. top_rank) then
  do k=0,count(df)-1
   do j=0,date_num(df)-1
    if (ave_max_date(df,k) .eq. max_long_date(df,j)) then
     nd=num_days_rank(df,k)
     do n=0,nd-1
      top_dates(df,b+n) = max_long_date(df,j+n)
      top_temps(df,b+n) = max_long(df,j+n)
      top_anoms(df,b+n) = anom_long(df,j+n)
     end do
     b=b+nd
    end if
   end do
  end do
 end if

 b=0
 if (count(df) .ge. top_rank) then
  do k=0,top_rank-1
   do j=0,date_num(df)-1
    if (ave_max_date(df,k) .eq. max_long_date(df,j)) then
     nd=num_days_rank(df,k)
     do n=0,nd-1
      top_dates(df,b+n) = max_long_date(df,j+n)
      top_temps(df,b+n) = max_long(df,j+n)
      top_anoms(df,b+n) = anom_long(df,j+n)
     end do
     b=b+nd
    end if
   end do
  end do
 end if
end do

b=0                    ; Do Loop to grab top rank dates, temps, and anoms based
do df=0,files-1        ; on Nday ranking
 b=0
 if (count(df) .lt. top_rank) then
  do k=0,count(df)-1
   do j=0,date_num(df)-1
    if (anomdate_sorted(df,k) .eq. max_long_date(df,j)) then
     nd=num_days_rank_1(df,k)
     do n=0,nd-1
      top_dates_N(df,b+n) = max_long_date(df,j+n)
      top_temps_N(df,b+n) = max_long(df,j+n)
      top_anoms_N(df,b+n) = anom_long(df,j+n)
     end do
     b=b+nd
    end if
   end do
  end do
 end if

 b=0
 if (count(df) .ge. top_rank) then
  do k=0,top_rank-1
   do j=0,date_num(df)-1
    if (anomdate_sorted(df,k) .eq. max_long_date(df,j)) then
     nd=num_days_rank_1(df,k)
     do n=0,nd-1
      top_dates_N(df,b+n) = max_long_date(df,j+n)
      top_temps_N(df,b+n) = max_long(df,j+n)
      top_anoms_N(df,b+n) = anom_long(df,j+n)
     end do
     b=b+nd
    end if
   end do
  end do
 end if
```

```
  end do


 b=0              ; Do Loop to grab top rank dates based on max ranking
 do df=0,files-1
  b=0
  if (count(df) .lt. top_rank) then
   do k=0,count(df)-1
    do j=0,date_num(df)-1
     if (max_temp_date_sorted(df,k) .eq. max_long_date(df,j)) then
      nd=num_days_rank_2(df,k)
      do n=0,nd-1
       top_dates_max(df,b+n) = max_long_date(df,j+n)
       top_temps_max(df,b+n) = max_long(df,j+n)
       top_anoms_max(df,b+n) = anom_long(df,j+n)
      end do
      b=b+nd
     end if
    end do
   end do
  end if

  b=0
  if (count(df) .ge. top_rank) then
   do k=0,top_rank-1
    do j=0,date_num(df)-1
     if (max_temp_date_sorted(df,k) .eq. max_long_date(df,j)) then
      nd=num_days_rank_2(df,k)
      do n=0,nd-1
       top_dates_max(df,b+n) = max_long_date(df,j+n)
       top_temps_max(df,b+n) = max_long(df,j+n)
       top_anoms_max(df,b+n) = anom_long(df,j+n)
      end do
      b=b+nd
     end if
    end do
   end do
  end if
 end do

 do df=0,files-1
  asciiwrite(datafiles(df)+"_Top_Event_Dates", top_dates(df,:))
  asciiwrite(datafiles(df)+"_Top_Event_Dates_N", top_dates_N(df,:))
  asciiwrite(datafiles(df)+"_Top_Event_Dates_max", top_dates_max(df,:))
 end do

;***************
; Print outs of more rankings
;***************

 do df=0,files-1
  r=0
  print("HW Ranking by Highest Event Maximum Temperature")
  print("City = "+datafiles(df))
  print("Ranking StartDate   EndDate  Ave TMax Anom  NumDays")
  do j=0,JJAS_days-1
   if (eventmaxes_sorted(df,j) .ne. 0) then
    r=r+1
    print("  "+r+"     "+sprinti("%8.0i", eventdates_sorted(df,j))+"    "+sprinti("%8.0i",
rank_end_date_2(df,j))+"   " \
         +sprintf("%6.2f", eventmaxes_sorted(df,j))+"      "+sprinti("%2.0",
num_days_rank_2(df,j)))
   end if
  end do
 end do

 top_rank = 15
 do df=0,files-1
  r=0
  print(datafiles(df)+" Top "+top_rank+" Events")
  print("Ranked by Highest Event Maximum Temperature")
```

```
  print("Ranking StartDate   EndDate  Tmax Average")
  do j=0,top_rank-1                          ; Selecting the top top_rank events
   r=r+1
   if (eventmaxes_sorted(df,j) .ne. 0) then
    print("  "+r+"  "+sprinti("%8.0i", eventdates_sorted(df,j))+"   "+sprinti("%8.0i",
rank_end_date_2(df,j))+"    " \
         +sprintf("%6.2f", eventmaxes_sorted(df,j))+"      "+sprinti("%2.0",
num_days_rank_2(df,j)))
   end if
  end do
 end do

 Sacdate_target_max     = new((/files,top_rank/),float)
 Sacdate_target_max_avg = new((/files/),float)

 do df=0,files-1
  do j=0,top_rank-1
   do k=0,JJAS_days-1
    if (eventmaxes_sorted(3,j) .ne. 0) then
     if (eventdates_sorted(3,j) .eq. anomdate(df,k)) then
      Sacdate_target_max(df,j) = maxarray(df,k)
     end if
    end if
   end do
  end do
  Sacdate_target_max_avg(df) = avg(Sacdate_target_max(df,:))
 end do
 print(Sacdate_target_max)
 print(Sacdate_target_max_avg)

 asciiwrite("Sacdate_target_max_avg", Sacdate_target_max_avg(:))


 do df=0,files-1
  print(" ")
  print("City="+datafiles(df))
  print("Number of events = "+b_max(df))
  print("Min Anomaly Threshold="+amin)
  print("Max Anomaly Threshold="+amax)
                                         ; Do Loop to print out table of events
and event variables for each city
  i=0
  print("Event# EventStart  EndDate  MaxT MinT AvgTemp NumDays SumTest")
  do y=0,yrs-1
   do k=0,dys-1
    if (event_start(df,y,k) .ne. 0) then
     i=i+1
     print("  "+sprinti("%2.0i", i)+"    "+sprinti("%0.8i", event_start(df,y,k))+"  " \
          +sprinti("%0.8i", end_date(df,y,k+(num_days(df,y,k)-1)))+"
"+sprintf("%6.2f", event_max(df,y,k))+"  " \
          +sprintf("%6.2f", event_min(df,y,k))+"  "+sprintf("%6.2f", ave_max(df,y,k))+"
" \
          +sprinti("%4.0i", num_days(df,y,k))+"       "+sprintf("%2.0f",
sum_test(df,y,k)))
    end if
   end do
  end do
 end do

 do df=0,files-1
  print("City = "+datafiles(df))
  print("Year  # of Events")
  do y=0,yrs-1
   print(sprinti("%2.0i", y)+"        "+sprinti("%2.0i", g_total(df,y)))
  end do
 end do

 do df=0,files-1
  opt10      = True                         ; File outs arrays to separate files, to
be called in from other programs
  opt10@title = "JJAS Event Dates"
```

```
   opt10@fout  = datafiles(df)+"_event_dates_array"
   write_matrix(event_dates_array(df,:,:), "I8.8", opt10)
  end do

;********************
; Create arrays of the top N event based on
; the different ranking methods
;********************

 do df=0,files-1
  if (count(df) .le. top_rank) then

   if (df .eq. 0) then
    if (count(df) .ne. 0) then
    top_0 = new((/count(df)/),float)
    top_0_N = new((/count(df)/),float)
    do d=0,count(df)-1
     top_0(d) = ave_max_sorted(df,d)
     top_0_N(d) = anomave_sorted(df,d)
    end do
    end if
    end if

   if (df .eq. 1) then
    if (count(df) .ne. 0) then
    top_1 = new((/count(df)/),float)
    top_1_N = new((/count(df)/),float)
    do d=0,count(df)-1
     top_1(d) = ave_max_sorted(df,d)
     top_1_N(d) = anomave_sorted(df,d)
    end do
    end if
    end if

   if (df .eq. 2) then
    if (count(df) .ne. 0) then
    top_2 = new((/count(df)/),float)
    top_2_N = new((/count(df)/),float)
    do d=0,count(df)-1
     top_2(d) = ave_max_sorted(df,d)
     top_2_N(d) = anomave_sorted(df,d)
    end do
    end if
    end if

   if (df .eq. 3) then
    if (count(df) .ne. 0) then
    top_3 = new((/count(df)/),float)
    top_3_N = new((/count(df)/),float)
    do d=0,count(df)-1
     top_3(d) = ave_max_sorted(df,d)
     top_3_N(d) = anomave_sorted(df,d)
    end do
    end if
    end if
*
*
*   ...All cities computed in same way
*
*
   if (df .eq. 27) then
    if (count(df) .ne. 0) then
     top_27 = new((/count(df)/),float)
    top_27_N = new((/count(df)/),float)
     do d=0,count(df)-1
      top_27(d) = ave_max_sorted(df,d)
     top_27_N(d) = anomave_sorted(df,d)
     end do
    end if
    end if
```

```
   if (df .eq. 28) then
    if (count(df) .ne. 0) then
     top_28 = new((/count(df)/),float)
    top_28_N = new((/count(df)/),float)
     do d=0,count(df)-1
      top_28(d) = ave_max_sorted(df,d)
     top_28_N(d) = anomave_sorted(df,d)
     end do
    end if
   end if

   if (df .eq. 29) then
    if (count(df) .ne. 0) then
     top_29 = new((/count(df)/),float)
    top_29_N = new((/count(df)/),float)
     do d=0,count(df)-1
      top_29(d) = ave_max_sorted(df,d)
     top_29_N(d) = anomave_sorted(df,d)
     end do
    end if
   end if

  end if

  if (count(df) .gt. top_rank) then
   if (df .eq. 0) then
    top_0 = new((/top_rank/),float)
    top_0_N = new((/top_rank/),float)
    do d=0,top_rank-1
     top_0(d) = ave_max_sorted(df,d)
     top_0_N(d) = anomave_sorted(df,d)
    end do
   print(dimsizes(top_0))
   print(top_0)
    end if

   if (df .eq. 1) then
    top_1 = new((/top_rank/),float)
    top_1_N = new((/top_rank/),float)
    do d=0,top_rank-1
     top_1(d) = ave_max_sorted(df,d)
     top_1_N(d) = anomave_sorted(df,d)
    end do
   print(top_1)
   print(dimsizes(top_1))
    end if
*
* ...All done in same way...
*
   if (df .eq. 29) then
    top_29 = new((/top_rank/),float)
    top_29_N = new((/top_rank/),float)
    do d=0,top_rank-1
     top_29(d) = ave_max_sorted(df,d)
     top_29_N(d) = anomave_sorted(df,d)
    end do
   end if

  end if
 end do

;************************
; Compute correlations of top temperatures
;************************

 if (dimsizes(top_3) .ge. dimsizes(top_0)) .and. (dimsizes(top_0) .gt. 0) then
  delete(top_3)
  delete(top_3_N)
  top_3 = new((/dimsizes(top_0)/),float)
  top_3_N = new((/dimsizes(top_0)/),float)
  do d=0,dimsizes(top_0)-1
```

```
  top_3(d) = ave_max_sorted(3,d)
  top_3_N(d) = anomave_sorted(3,d)
 end do
 print(top_3)
 print(top_3_N)
 end if

 if (dimsizes(top_3) .lt. dimsizes(top_0)) .and. (dimsizes(top_0) .gt. 0) then
  delete(top_0)
  delete(top_0_N)
  top_0 = new((/dimsizes(top_3)/),float)
  top_0_N = new((/dimsizes(top_3)/),float)
  do d=0,dimsizes(top_3)-1
   top_0(d) = ave_max_sorted(0,d)
   top_0_N(d) = anomave_sorted(0,d)
  end do
  print(top_0)
  print(top_0_N)
 end if

 corr_top_0 = escorc(top_3(:),top_0(:))
 corr_top_0_N = escorc(top_3_N(:),top_0_N(:))
 print(corr_top_0)
 print(corr_top_0_N)
*
* ...All done in same way...
*
 if (dimsizes(top_3) .ge. count(29)) .and. (count(29) .gt. 0) then
  delete(top_3)
  delete(top_3_N)
  top_3 = new((/dimsizes(top_29)/),float)
  top_3_N = new((/dimsizes(top_29)/),float)
  do d=0,dimsizes(top_29)-1
   top_3(d) = ave_max_sorted(3,d)
   top_3_N(d) = anomave_sorted(3,d)
  end do
  print(top_29)
  print(top_29_N)
 corr_top_29 = escorc(top_3(:),top_29(:))
 corr_top_29_N = escorc(top_3_N(:),top_29_N(:))
 print(corr_top_29)
 print(corr_top_29_N)
 end if

 if (dimsizes(top_3) .lt. count(29)) .and. (count(29) .gt. 0) then
  delete(top_29)
  delete(top_29_N)
  top_29 = new((/dimsizes(top_3)/),float)
  top_29_N = new((/dimsizes(top_3)/),float)
  do d=0,dimsizes(top_3)-1
   top_29(d) = ave_max_sorted(29,d)
   top_29_N(d) = anomave_sorted(29,d)
  end do
  print(top_29)
  print(top_29_N)
 corr_top_29 = escorc(top_3(:),top_29(:))
 corr_top_29_N = escorc(top_3_N(:),top_29_N(:))
 print(corr_top_29)
 print(corr_top_29_N)
 end if

;**************************************************************************
; Compute Anomaly correlations
;**************************************************************************

 anom_corr = new((/files,3/),float)
 anom_tmax = new((/files,3/),float)
                                   ; Do Loop to capture dates with Tmaxs above a
certain anomaly, that will be used
                                   ; for computing correlations.
 do r=0,15
```

```
   a=0
  do y=0,yrs-1
   do k=0,dys-1
    if (anomaly(3,y,k) .ge. r) then
     delete(anom_corr)
     delete(anom_tmax)
     a=a+1
     anom_corr = new((/files,a/),float)
     anom_tmax = new((/files,a/),float)
    end if
   end do
  end do

  b=0
  do y=0,yrs-1
   do k=0,dys-1
    if(anomaly(3,y,k) .ge. r) then
     do df=0,files-1
      anom_corr(df,b) = anomaly(df,y,k)
      anom_tmax(df,b) = max_array(df,y,k)
     end do
     b=b+1
    end if
   end do
  end do

  corr_anom = new((/files/),float)
  corr_tmax = new((/files/),float)

  a_corr=16
  corr_anom_r = new((/files,a_corr/),float)
  corr_tmax_r = new((/files,a_corr/),float)

  do df=0,files-1                                ; Do Loop to compute anomaly
and temperature correlations
   corr_anom(df) = escorc(anom_corr(3,:),anom_corr(df,:))
   corr_tmax(df) = escorc(anom_tmax(3,:),anom_tmax(df,:))
   corr_anom_r(df,r) = escorc(anom_corr(3,:),anom_corr(df,:))
   corr_tmax_r(df,r) = escorc(anom_tmax(3,:),anom_tmax(df,:))
  end do

  print("Correlations, Anomaly >= "+r)
  print(corr_anom(:))
  print(corr_tmax(:))
 end do

;***************************************************************************
; Compute Temperature correlations.  All Temps and Temps > a specified temp.
;***************************************************************************

 temp_corr_hi  = new((/files,3/),float)
 temp_corr_all = new((/files,3/),float)
                                    ; Do Loop to capture dates with Tmaxs greater
than a certain temp, that will be used
                                    ; for computing correlations.
  r=100
  s=0
  a=0
  c=0
  do y=0,yrs-1
   do k=0,dys-1
    if (max_array(3,y,k) .ge. r) then
     delete(temp_corr_hi)
     a=a+1
     temp_corr_hi = new((/files,a/),float)
    end if
    if (max_array(3,y,k) .ge. s) then
     delete(temp_corr_all)
     c=c+1
     temp_corr_all = new((/files,c/),float)
    end if
```

```
  end do
 end do
 print(a+" = Number of days above "+r)
 print(c+" = Number of days above "+s)

 b=0
 d=0
 do y=0,yrs-1
  do k=0,dys-1
   if(max_array(3,y,k) .ge. r) then
    do df=0,files-1
     temp_corr_hi(df,b) = max_array(df,y,k)
    end do
    b=b+1
   end if
   if(max_array(3,y,k) .ge. s) then
    do df=0,files-1
     temp_corr_all(df,d) = max_array(df,y,k)
    end do
    d=d+1
   end if
  end do
 end do

 lag=10
 corr_temp_100     = new((/files/),float)
 corr_temp_100_lag = new((/files,lag+1/),float)
 corr_temp_all     = new((/files/),float)
 corr_temp_all_lag = new((/files,lag+1/),float)

 do df=0,files-1
   corr_temp_100(df)       = escorc(temp_corr_hi(3,:),temp_corr_hi(df,:))
   corr_temp_100_lag(df,:) = esccr(temp_corr_hi(3,:),temp_corr_hi(df,:),lag)
   corr_temp_all(df)       = escorc(temp_corr_all(3,:),temp_corr_all(df,:))
   corr_temp_all_lag(df,:) = esccr(temp_corr_all(3,:), temp_corr_all(df,:),lag)
 end do

 print("Correlations, Sacramento Temps >= "+r)
 print(corr_temp_100(:))
 print("Correlations, Sacramento Temps >= "+s)
 print(corr_temp_all(:))
 print("Lag Correlations, Sacramento Temps >= "+r)
 print(corr_temp_100_lag(:,:))
 print("Lag Correlations, Sacramento Temps >= "+s)
 print(corr_temp_all_lag(:,:))

;****************************************************************
; Create an XY plot of Temperature correlations.
;****************************************************************
 wks13  = gsn_open_wks ("ps","Temp_Corrs_xy")              ; open workstation

 res13                = True                        ; plot mods desired
 res13@tiMainString   = "All Max Temperature Correlations"       ; add title
 gsn_define_colormap(wks13,"so4_23")

; res13@xyLineThicknesses = (/1.0,2.0/)             ; make 2nd lines thicker

; res13@xyLineColors      = (/14,13,8,3,2,16,15,11,5,7,1,18,20,22,24,4,6,9,10/)
;
(/"red","orange","green","blue","purple","black","brown","gray","deeppink","aquamarine"/)
;                         ,"","","","","","","","",""/)

 res13@tmXBMode     = "Explicit" ; Define own tick mark labels.
 res13@tmXBValues   =
(/0.,1.,2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,12.,13.,14.,15.,16.,17.,18.,19.,20.,21.,22.,23.,2
4.,25. \
                     ,26.,27.,28.,29./)
 res13@tmXBLabels   = (/"Red","RB","Col","Sac","St","Mod","Mer","Fres","Vis","Bkrs" \
                        ,"CC","Eur","Cov","Gr","SF","Mont","SLO","SB","SA","Vist" \

,"Stl","Spok","Yak","Port","Eug","Med","Pend","BkCity","Reno","Tono"/)
```

```
 plot13  = gsn_csm_xy (wks13,ispan(0,29,1),corr_temp_all(:),res13) ; create plot
;*****************************************************************************************

 do r=0,a_corr-1
 wks15 = gsn_open_wks ("ps","Anom_Temp_Corrs_xy")
 res15 = True
 gsn_define_colormap(wks15,"so4_23")
 res15@tiMainString = "Temp Correlations on Anomalous Dates"
; res15@xyLineColors = (/14,13,8,3,2,16,15,11,5,7,1,18,20,22,24,4,6,9,10/)
;(/"red","orange","green","blue","purple","black","brown","gray","deeppink","aquamarine"/
)
 res15@tmXBMode      = "Explicit" ; Define own tick mark labels.
 res15@tmXBValues    =
(/0.,1.,2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,12.,13.,14.,15.,16.,17.,18.,19.,20.,21.,22.,23.,2
4.,25. \
                     ,26.,27.,28.,29./)
 res15@tmXBLabels    = (/"Red","RB","Col","Sac","St","Mod","Mer","Fres","Vis","Bkrs" \
                        ,"CC","Eur","Cov","Gr","SF","Mont","SLO","SB","SA","Vist" \

,"Stl","Spok","Yak","Port","Eug","Med","Pend","BkCity","Reno","Tono"/)

 plot15  = gsn_csm_xy (wks15,ispan(0,29,1),corr_tmax_r(:,r),res15) ; create plot
 end do
;*********************************************************************
; Create a stacking bar chart of event anomalies, by each year.
; For each year, all city JJAS daily anomalies will be displayed,
; stacked one city on top of the other.
;*********************************************************************

 sets = (/"Redding","Red
Bluff","Colusa","Sacramento","Stockton","Modesto","Merced","Fresno","Visalia","Bakersfiel
d" /)
 sets_2 = (/"Crescent City","Eureka","Covelo","Graton","San
Francisco","Monterey","SLO","Santa Barbara","Santa Ana","Vista"/)
 sets_3 = (/"Seattle", "Spokane", "Yakima", "Portland", "Eugene", "Medford", "Pendleton",
"BakerCity", "Reno", "Tonopah"/)
 subset = dys                              ; Dates, 122 days, June 1 - Aug 31,
y,k=0,121
 plot_years = yrs
 set = dimsizes(sets)
 set_2 = dimsizes(sets_2)
 set_3 = dimsizes(sets_3)
 tick = fspan(0., 121., 122)

 res5        = True
 res5@trYMinF = -30.0             ; bottom of Y-scale                ; minimum
anomaly
 res5@trYMaxF = 30.0              ; nominal top of Y-scale           ; maximum
anomaly
 tickMark    = 10.0               ; tick Mark increment (5 degrees)
 curv_offset = res5@trYMaxF-res5@trYMinF  ; range
 res5@trYMaxF = curv_offset*set + res5@trYMinF + tickMark

 anom_new  = new((/set,plot_years,subset/),float)
 anom_new_new = new((/set,plot_years,subset/),float)

 do df=0,9                 ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   anom_new(df,y,:) = anomaly(df,y,:) + curv_offset*(9-df)
  end do
 end do

 do df=0,9                 ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   anom_new_new(df,y,:) = anom_new((9-df),y,:)
  end do
 end do

;******
```

```
 res51          = True
 res51@trYMinF  = -30.0                 ; bottom of Y-scale                    ; minimum
anomaly
 res51@trYMaxF  =  30.0                 ; nominal top of Y-scale              ; maximum
anomaly
 tickMark       =  10.0                 ; tick Mark increment (5 degrees)
 curv_offset_2  =  res51@trYMaxF-res51@trYMinF   ; range
 res51@trYMaxF  =  curv_offset_2*set_2 + res51@trYMinF + tickMark

 anom_new_2     = new((/set_2,plot_years,subset/),float)
 anom_new_2_new = new((/set_2,plot_years,subset/),float)

 do df=10,19                           ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   anom_new_2((df-10),y,:) = anomaly(df,y,:) + curv_offset_2*(19-df)
  end do
 end do

 do df=10,19                           ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   anom_new_2_new((df-10),y,:) = anom_new_2((19-df),y,:)
  end do
 end do

;************************

 res52          = True
 res52@trYMinF  = -30.0                 ; bottom of Y-scale                    ; minimum
anomaly
 res52@trYMaxF  =  30.0                 ; nominal top of Y-scale              ; maximum
anomaly
 tickMark       =  10.0                 ; tick Mark increment (5 degrees)
 curv_offset_3  =  res52@trYMaxF-res52@trYMinF   ; range
 res52@trYMaxF  =  curv_offset_3*set_3 + res52@trYMinF + tickMark

 anom_new_3     = new((/set_3,plot_years,subset/),float)
 anom_new_3_new = new((/set_3,plot_years,subset/),float)

 do df=20,29                           ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   anom_new_3((df-20),y,:) = anomaly(df,y,:) + curv_offset_3*(29-df)
  end do
 end do

 do df=20,29                           ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   anom_new_3_new((df-20),y,:) = anom_new_3((29-df),y,:)
  end do
 end do

;****************************
; Create the actual plot.
;****************************
 do y=0,yrs-1

 wks5   = gsn_open_wks ("ps", "BarChart_Year"+y)

 res5@xyMonoDashPattern    = True  ; all solid lines
 res5@tmYLLabelFontHeightF = 0.01  ; default is 0.02
 res5@tmYLMode        = "Explicit"  ; Define own left tick mark labels.
 res5@tmYLValues      = fspan(res5@trYMinF,res5@trYMaxF,floattointeger((res5@trYMaxF-
res5@trYMinF)/tickMark)+1 )
 res5@tmYUseLeft      = False
 res5@tmYRLabelsOn    = True

 res5@tmYRMode        = "Explicit"   ; Define own right tick mark labels.
 res5@tmYRValues      = res5@tmYLValues
 res5@tmYRLabelFontHeightF = res5@tmYLLabelFontHeightF
 res5@tmYLLabels      = (/"-30","-20","-10","0","10","20" \     ; left labels
                      ,"-30","-20","-10","0","10","20" \
                      ,"-30","-20","-10","0","10","20" \
```

```
                           ,"-30","-20","-10","0","10","20" \
                           ,"-30","-20","-10","0","10","20" \
                           ,"-30","-20","-10","0","10","20" \
                           ,"-30","-20","-10","0","10","20" \
                           ,"-30","-20","-10","0","10","20" \
                           ,"-30","-20","-10","0","10","20" \
                           ,"-30","-20","-10","0","10","20","30",""/)
     res5@tmYRLabels    = (/"","","","Bakersfield","","" \           ; right labels
                           ,"","","","Visalia","","" \
                           ,"","","","Fresno","","" \
                           ,"","","","Merced","","" \
                           ,"","","","Modesto","","" \
                           ,"","","","Stockton","","" \
                           ,"","","","Sacramento","","" \
                           ,"","","","Colusa","","" \
                           ,"","","","Red Bluff","","" \
                           ,"","","","Redding","","","",""/)

   res5@gsnCenterString = "Year " + sprinti("%0.4i", y+1979)
   res5@tiMainString    = "JJAS Daily Anomalies"
   res5@gsnYRefLine = res5@trYMinF + 0.5*curv_offset + ispan(0,set-1,1)*curv_offset

   res5@gsnAboveYRefLineBarColors = "Red"
   res5@gsnBelowYRefLineBarColors = "Blue"
   res5@tmXBMode        = "Explicit" ; Define own tick mark labels.
   res5@tmXBValues      = (/0.,30.,61.,92.,121./)                       ; in IPM,
(/0.,30.,61.,92.,121./)
   res5@tmXBLabels      = (/"1June","1July","1Aug","1Sept","30Sept"/)

   res5@gsnXYBarChart = True
   plot5  = gsn_csm_xy (wks5,tick,anom_new_new(0:9,y,:),res5)
   print("Bar Chart 5 created")

;**********

 wks51   = gsn_open_wks ("ps", "BarChart_2_Year"+y)

 res51@xyMonoDashPattern    = True  ; all solid lines
 res51@tmYLLabelFontHeightF = 0.01  ; default is 0.02
 res51@tmYLMode       = "Explicit"  ; Define own left tick mark labels.
 res51@tmYLValues     = fspan(res51@trYMinF,res51@trYMaxF,floattointeger((res51@trYMaxF-
res51@trYMinF)/tickMark)+1 )
 res51@tmYUseLeft     = False
 res51@tmYRLabelsOn   = True

 res51@tmYRMode       = "Explicit"   ; Define own right tick mark labels.
 res51@tmYRValues     = res51@tmYLValues
 res51@tmYRLabelFontHeightF = res51@tmYLLabelFontHeightF
 res51@tmYLLabels     = (/"-30","-20","-10","0","10","20" \     ; left labels
                        ,"-30","-20","-10","0","10","20" \
                        ,"-30","-20","-10","0","10","20" \
                        ,"-30","-20","-10","0","10","20" \
                        ,"-30","-20","-10","0","10","20" \
                        ,"-30","-20","-10","0","10","20" \
                        ,"-30","-20","-10","0","10","20" \
                        ,"-30","-20","-10","0","10","20" \
                        ,"-30","-20","-10","0","10","20" \
                        ,"-30","-20","-10","0","10","20","30",""/)
     res51@tmYRLabels    = (/"","","","Vista","","" \           ; right labels
                           ,"","","","Santa Ana","","" \
                           ,"","","","Santa Barbara","","" \
                           ,"","","","SLO","","" \
                           ,"","","","Monterey","","" \
                           ,"","","","San Francisco","","" \
                           ,"","","","Graton","","" \
                           ,"","","","Covelo","","" \
                           ,"","","","Eureka","","" \
                           ,"","","","Crescent City","","","",""/)

   res51@gsnCenterString = "Year " + sprinti("%0.4i", y+1979)
   res51@tiMainString    = "JJAS Daily Anomalies"
```

```
 res51@gsnYRefLine = res51@trYMinF + 0.5*curv_offset + ispan(0,set_2-1,1)*curv_offset_2

 res51@gsnAboveYRefLineBarColors = "Red"
 res51@gsnBelowYRefLineBarColors = "Blue"
 res51@tmXBMode       = "Explicit" ; Define own tick mark labels.
 res51@tmXBValues     = (/0.,30.,61.,92.,121./)                      ; in IPM,
(/0.,30.,61.,92.,121./)
 res51@tmXBLabels     = (/"1June","1July","1Aug","1Sept","30Sept"/)

 res51@gsnXYBarChart = True
 plot51  = gsn_csm_xy (wks51,tick,anom_new_2_new(0:9,y,:),res51)
 print("Bar Chart 51 created")

 print("All Bar Charts created")

;***************************************

 wks52   = gsn_open_wks ("ps", "BarChart_3_Year"+y)

 res52@xyMonoDashPattern    = True  ; all solid lines
 res52@tmYLLabelFontHeightF = 0.01  ; default is 0.02
 res52@tmYLMode       = "Explicit"  ; Define own left tick mark labels.
 res52@tmYLValues     = fspan(res52@trYMinF,res52@trYMaxF,floattointeger((res52@trYMaxF-
res52@trYMinF)/tickMark)+1 )
 res52@tmYUseLeft    = False
 res52@tmYRLabelsOn  = True

 res52@tmYRMode       = "Explicit"  ; Define own right tick mark labels.
 res52@tmYRValues     = res52@tmYLValues
 res52@tmYRLabelFontHeightF = res52@tmYLLabelFontHeightF
 res52@tmYLLabels     = (/"-30","-20","-10","0","10","20" \     ; left labels
                    ,"-30","-20","-10","0","10","20" \
                    ,"-30","-20","-10","0","10","20" \
                    ,"-30","-20","-10","0","10","20" \
                    ,"-30","-20","-10","0","10","20" \
                    ,"-30","-20","-10","0","10","20" \
                    ,"-30","-20","-10","0","10","20" \
                    ,"-30","-20","-10","0","10","20" \
                    ,"-30","-20","-10","0","10","20" \
                    ,"-30","-20","-10","0","10","20","30",""/)
 res52@tmYRLabels     = (/"","","","Tonopah","","" \           ; right labels
                    ,"","","","Reno","","" \
                    ,"","","","Baker City","","" \
                    ,"","","","Pendleton","","" \
                    ,"","","","Medford","","" \
                    ,"","","","Eugene","","" \
                    ,"","","","Portland","","" \
                    ,"","","","Yakima","","" \
                    ,"","","","Spokane","","" \
                    ,"","","","Seattle","","","",""/)

 res52@gsnCenterString = "Year " + sprinti("%0.4i", y+1979)
 res52@tiMainString    = "JJAS Daily Anomalies"
 res52@gsnYRefLine = res52@trYMinF + 0.5*curv_offset + ispan(0,set_3-1,1)*curv_offset_3

 res52@gsnAboveYRefLineBarColors = "Red"
 res52@gsnBelowYRefLineBarColors = "Blue"
 res52@tmXBMode       = "Explicit" ; Define own tick mark labels.
 res52@tmXBValues     = (/0.,30.,61.,92.,121./)                      ; in IPM,
(/0.,30.,61.,92.,121./)
 res52@tmXBLabels     = (/"1June","1July","1Aug","1Sept","30Sept"/)

 res52@gsnXYBarChart = True
 plot52  = gsn_csm_xy (wks52,tick,anom_new_3_new(0:9,y,:),res52)
 print("Bar Chart 52 created")

 end do
 print("All Bar Charts created")

;********************************************************************************************
*******
```

```
; Create a stacking bar chart of the number of events each year for each city.
; Cities will be stacked one on top of the other, with year as x-axis and # of events as
y-axis.
;*************************************************************************************
********

 sets = (/"Redding","Red
Bluff","Colusa","Sacramento","Stockton","Modesto","Merced","Fresno","Visalia","Bakersfiel
d"/)
 sets_2 = (/"Crescent City","Eureka","Covelo","Graton","San
Francisco","Monterey","SLO","Santa Barbara","Santa Ana","Vista"/)
 sets_3 = (/"Seattle", "Spokane", "Yakima", "Portland", "Eugene", "Medford", "Pendleton",
"BakerCity", "Reno", "Tonopah"/)
 subset = yrs                              ; Dates, 122 days, June 1 - Aug 31,
y,k=0,121
 set = dimsizes(sets)
 set_2 = dimsizes(sets_2)
 set_3 = dimsizes(sets_3)
 tick2 = fspan(0., 27., 28)

 res6         = True
 res6@trYMinF = 0.0              ; bottom of Y-scale                 ; minimum anomaly
 res6@trYMaxF = 8.0              ; nominal top of Y-scale            ; maximum anomaly
 tickMark     = 2.0              ; tick Mark increment
 curv_offset  = res6@trYMaxF-res6@trYMinF   ; range
 res6@trYMaxF  = curv_offset*set + res6@trYMinF + tickMark

 g_total_new = new((/set,subset/),float)
 g_total_new_new = new((/set,subset/),float)

 do df=0,9                      ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   g_total_new(df,y) = g_total(df,y) + curv_offset*(9-df)
  end do
 end do

 do df=0,9                      ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   g_total_new_new(df,y) = g_total_new((9-df),y)
  end do
 end do

;*****

 res61        = True
 res61@trYMinF = 0.0             ; bottom of Y-scale                 ; minimum anomaly
 res61@trYMaxF = 8.0             ; nominal top of Y-scale            ; maximum anomaly
 tickMark     = 2.0             ; tick Mark increment
 curv_offset_2  = res61@trYMaxF-res61@trYMinF   ; range
 res61@trYMaxF  = curv_offset_2*set_2 + res61@trYMinF + tickMark

 g_total_new_2 = new((/set_2,subset/),float)
 g_total_new_2_new = new((/set_2,subset/),float)

 do df=10,19                         ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   g_total_new_2((df-10),y) = g_total(df,y) + curv_offset_2*(19-df)
  end do
 end do

 do df=10,19                         ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   g_total_new_2_new((df-10),y) = g_total_new_2((19-df),y)
  end do
 end do

;**************************

 res62        = True
 res62@trYMinF = 0.0             ; bottom of Y-scale                 ; minimum anomaly
 res62@trYMaxF = 8.0             ; nominal top of Y-scale            ; maximum anomaly
```

```
 tickMark       = 2.0                 ; tick Mark increment
 curv_offset_3  =  res62@trYMaxF-res62@trYMinF   ; range
 res62@trYMaxF  =  curv_offset_3*set_3 + res62@trYMinF + tickMark

 g_total_new_3 = new((/set_3,subset/),float)
 g_total_new_3_new = new((/set_3,subset/),float)

 do df=20,29                          ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   g_total_new_3((df-20),y) = g_total(df,y) + curv_offset_3*(29-df)
  end do
 end do

 do df=20,29                          ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   g_total_new_3_new((df-20),y) = g_total_new_3((29-df),y)
  end do
 end do

;****************************
; Create the actual plot.
;****************************
 wks6   = gsn_open_wks ("ps", "BarChart_Events")

 res6@xyMonoDashPattern   = True  ; all solid lines
 res6@tmYLLabelFontHeightF = 0.01  ; default is 0.02
 res6@tmYLMode       = "Explicit"   ; Define own left tick mark labels.
 res6@tmYLValues     = fspan(res6@trYMinF,res6@trYMaxF,floattointeger((res6@trYMaxF-
res6@trYMinF)/tickMark)+1 )
 res6@tmYUseLeft     = False
 res6@tmYRLabelsOn   = True

 res6@tmYRMode       = "Explicit"   ; Define own right tick mark labels.
 res6@tmYRValues     = res6@tmYLValues
 res6@tmYRLabelFontHeightF = res6@tmYLLabelFontHeightF
 res6@tmYLLabels     = (/"0","2","4","6" \     ; left labels
                       ,"0","2","4","6" \
                       ,"0","2","4","6" \
                       ,"0","2","4","6" \
                       ,"0","2","4","6" \
                       ,"0","2","4","6" \
                       ,"0","2","4","6" \
                       ,"0","2","4","6" \
                       ,"0","2","4","6" \
                       ,"0","2","4","6","8",""/)

 res6@tmYRLabels     = (/"","","","Bakersfield","","" \          ; right labels
                       ,"","","","Visalia","","" \
                       ,"","","","Fresno","","" \
                       ,"","","","Merced","","" \
                       ,"","","","Modesto","","" \
                       ,"","","","Stockton","","" \
                       ,"","","","Sacramento","","" \
                       ,"","","","Colusa","","" \
                       ,"","","","Red Bluff","","" \
                       ,"","","","Redding","","","",""/)

 res6@gsnCenterString = "All Cities"
 res6@tiMainString    = "JJAS Yearly Number of Events"
 res6@gsnYRefLine = res6@trYMinF + ispan(0,set-1,1)*curv_offset

; res6@gsnXYBarChartColors = "Red"
 res6@gsnAboveYRefLineBarColors = "Red"
; res6@gsnBelowYRefLineBarColors = "Blue"
 res6@tmXBMode       = "Explicit" ; Define own tick mark labels.
; res6@tmXBValues =
(/0.,1.,2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,12.,13.,14.,15.,16.,17.,18.,19.,20.,21.,22.,23.,2
4.,25.,26.,27./)
; res6@tmXBLabels =
(/"1979","1980","1981","1982","1983","1984","1985","1986","1987","1988","1989","1990","19
```

```
91","1992","1993","1994","1995","1996","1997","1998","1999","2000","2001","2002","2003",""
2004","2005","2006"/)

 res6@tmXBLabelFontHeightF = 0.01
 res6@tmXBValues = (/1.,3.,5.,7.,9.,11.,13.,15.,17.,19.,21.,23.,25.,27./)
 res6@tmXBLabels =
(/"1980","1982","1984","1986","1988","1990","1992","1994","1996","1998","2000","2002","20
04","2006"/)


 res6@gsnXYBarChart = True
 plot6 = gsn_csm_xy (wks6,tick2,g_total_new_new(0:9,:),res6)
 print("Plot 6 created")

;*****

 wks61   = gsn_open_wks ("ps", "BarChart_Events_2")

 res61@xyMonoDashPattern    = True  ; all solid lines
 res61@tmYLLabelFontHeightF = 0.01  ; default is 0.02
 res61@tmYLMode       = "Explicit"   ; Define own left tick mark labels.
 res61@tmYLValues     = fspan(res61@trYMinF,res61@trYMaxF,floattointeger((res61@trYMaxF-
res61@trYMinF)/tickMark)+1 )
 res61@tmYUseLeft    = False
 res61@tmYRLabelsOn   = True

 res61@tmYRMode       = "Explicit"   ; Define own right tick mark labels.
 res61@tmYRValues     = res61@tmYLValues
 res61@tmYRLabelFontHeightF = res61@tmYLLabelFontHeightF
 res61@tmYLLabels     = (/"0","2","4","6" \     ; left labels
                      ,"0","2","4","6" \
                      ,"0","2","4","6" \
                      ,"0","2","4","6" \
                      ,"0","2","4","6" \
                      ,"0","2","4","6" \
                      ,"0","2","4","6" \
                      ,"0","2","4","6" \
                      ,"0","2","4","6" \
                      ,"0","2","4","6","8",""/)

  res61@tmYRLabels     = (/"","","","Vista","","" \            ; right labels
                      ,"","","","Santa Ana","","" \
                      ,"","","","Santa Barbara","","" \
                      ,"","","","SLO","","" \
                      ,"","","","Monterey","","" \
                      ,"","","","San Francisco","","" \
                      ,"","","","Graton","","" \
                      ,"","","","Covelo","","" \
                      ,"","","","Eureka","","" \
                      ,"","","","Crescent City","","","",""/)

 res61@gsnCenterString = "All Cities"
 res61@tiMainString    = "JJAS Yearly Number of Events"
 res61@gsnYRefLine = res61@trYMinF + ispan(0,set_2-1,1)*curv_offset_2

; res6@gsnXYBarChartColors = "Red"
 res61@gsnAboveYRefLineBarColors = "Red"
; res6@gsnBelowYRefLineBarColors = "Blue"
 res61@tmXBMode       = "Explicit" ; Define own tick mark labels.
; res6@tmXBValues =
(/0.,1.,2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,12.,13.,14.,15.,16.,17.,18.,19.,20.,21.,22.,23.,2
4.,25.,26.,27./)
; res6@tmXBLabels =
(/"1979","1980","1981","1982","1983","1984","1985","1986","1987","1988","1989","1990","19
91","1992","1993
;","1994","1995","1996","1997","1998","1999","2000","2001","2002","2003","2004","2005","2
006"/)

 res61@tmXBLabelFontHeightF = 0.01
 res61@tmXBValues = (/1.,3.,5.,7.,9.,11.,13.,15.,17.,19.,21.,23.,25.,27./)
```

```
 res61@tmXBLabels =
(/"1980","1982","1984","1986","1988","1990","1992","1994","1996","1998","2000","2002","20
04","2006"/)

 res61@gsnXYBarChart = True
 plot61 = gsn_csm_xy (wks61,tick2,g_total_new_2_new(0:9,:),res61)

 print("Bar Chart created")
; end do
 print("All Bar Charts created")

;**************************************

 wks62   = gsn_open_wks ("ps", "BarChart_Events_3")

 res62@xyMonoDashPattern    = True  ; all solid lines
 res62@tmYLLabelFontHeightF = 0.01 ; default is 0.02
 res62@tmYLMode        = "Explicit"   ; Define own left tick mark labels.
 res62@tmYLValues      = fspan(res62@trYMinF,res62@trYMaxF,floattointeger((res62@trYMaxF-
res62@trYMinF)/tickMark)+1 )
 res62@tmYUseLeft      = False
 res62@tmYRLabelsOn  = True

 res62@tmYRMode        = "Explicit"   ; Define own right tick mark labels.
 res62@tmYRValues      = res62@tmYLValues
 res62@tmYRLabelFontHeightF = res62@tmYLLabelFontHeightF
 res62@tmYLLabels      = (/"0","2","4","6" \      ; left labels
                      ,"0","2","4","6" \
                      ,"0","2","4","6" \
                      ,"0","2","4","6" \
                      ,"0","2","4","6" \
                      ,"0","2","4","6" \
                      ,"0","2","4","6" \
                      ,"0","2","4","6" \
                      ,"0","2","4","6" \
                      ,"0","2","4","6","8",""/)
  res62@tmYRLabels      = (/"Tonopah","","","" \              ; right labels
                      ,"Reno","","","" \
                      ,"Baker City","","","" \
                      ,"Pendleton","","","" \
                      ,"Medford","","","" \
                      ,"Eugene","","","" \
                      ,"Portland","","","" \
                      ,"Yakima","","","" \
                      ,"Spokane","","","" \
                      ,"Seattle","","","","",""/)

 res62@gsnCenterString = "All Cities"
 res62@tiMainString    = "JJAS Yearly Number of Events"
 res62@gsnYRefLine = res62@trYMinF + ispan(0,set_3-1,1)*curv_offset_3

; res6@gsnXYBarChartColors = "Red"
 res62@gsnAboveYRefLineBarColors = "Red"
; res6@gsnBelowYRefLineBarColors = "Blue"
 res62@tmXBMode       = "Explicit" ; Define own tick mark labels.
; res6@tmXBValues =
(/0.,1.,2.,3.,4.,5.,6.,7.,8.,9.,10.,11.,12.,13.,14.,15.,16.,17.,18.,19.,20.,21.,22.,23.,2
4.,25.,26.,27./)
; res6@tmXBLabels =
(/"1979","1980","1981","1982","1983","1984","1985","1986","1987","1988","1989","1990","19
91","1992","1993
;","1994","1995","1996","1997","1998","1999","2000","2001","2002","2003","2004","2005","2
006"/)

 res62@tmXBLabelFontHeightF = 0.01
 res62@tmXBValues = (/1.,3.,5.,7.,9.,11.,13.,15.,17.,19.,21.,23.,25.,27./)
 res62@tmXBLabels =
(/"1980","1982","1984","1986","1988","1990","1992","1994","1996","1998","2000","2002","20
04","2006"/)

 res62@gsnXYBarChart = True
```

```
  plot62  = gsn_csm_xy (wks62,tick2,g_total_new_3_new(0:9,:),res62)

 print("Bar Chart created")
; end do
 print("All Bar Charts created")

;********************************************************************************
; Create a stacking bar chart of Maximum Temperature of all cities, for each year.
;********************************************************************************

 sets = (/"Redding","Red
Bluff","Colusa","Sacramento","Stockton","Modesto","Merced","Fresno","Visalia","Bakersfiel
d"/)
 sets_2 = (/"Crescent City","Eureka","Covelo","Graton","San
Francisco","Monterey","SLO","Santa Barbara","Santa Ana","Vista"/)
 sets_3 = (/"Seattle", "Spokane", "Yakima", "Portland", "Eugene", "Medford", "Pendleton",
"BakerCity", "Reno", "Tonopah"/)
 subset = dys                               ; Dates, 122 days, June 1 - Aug 31,
y,k=0,121
 plot_years = yrs
 set = dimsizes(sets)
 set_2 = dimsizes(sets_2)
 set_3 = dimsizes(sets_3)
 tick = fspan(0., 121., 122)

 print(set)

 res8         = True
 res8@trYMinF = 75.0                ; bottom of Y-scale                ; minimum anomaly
 res8@trYMaxF = 125.0               ; nominal top of Y-scale           ; maximum
anomaly
 tickMark     = 10.0                ; tick Mark increment
 curv_offset  = res8@trYMaxF-res8@trYMinF   ; range
 res8@trYMaxF = curv_offset*set + res8@trYMinF + tickMark

 res81        = True
 res81@trYMinF = 60.0               ; bottom of Y-scale                ; minimum
anomaly
 res81@trYMaxF = 110.0              ; nominal top of Y-scale           ; maximum
anomaly
 tickMark     = 10.0                ; tick Mark increment
 curv_offset_2  = res81@trYMaxF-res81@trYMinF   ; range
 res81@trYMaxF = curv_offset_2*set_2 + res81@trYMinF + tickMark

 res82        = True
 res82@trYMinF = 60.0               ; bottom of Y-scale                ; minimum
anomaly
 res82@trYMaxF = 110.0              ; nominal top of Y-scale           ; maximum
anomaly
 tickMark     = 10.0                ; tick Mark increment
 curv_offset_3  = res82@trYMaxF-res82@trYMinF   ; range
 res82@trYMaxF = curv_offset_3*set_3 + res82@trYMinF + tickMark

; data_chart8 = new((/plot_years,set,subset/),float)
 tmax_new  = new((/set,plot_years,subset/),float)
 tmax_new_new  = new((/set,plot_years,subset/),float)

 do df=0,9                          ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   tmax_new(df,y,:) = max_array(df,y,:) + curv_offset*(9-df)
  end do
 end do

 do df=0,9                          ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   tmax_new_new(df,y,:) = tmax_new((9-df),y,:)
  end do
 end do

 tmax_new_2  = new((/set_2,plot_years,subset/),float)
 tmax_new_2_new  = new((/set_2,plot_years,subset/),float)
```

```
 do df=10,19                         ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   tmax_new_2((df-10),y,:) = max_array(df,y,:) + curv_offset_2*(19-df)
  end do
 end do

 do df=10,19                         ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   tmax_new_2_new((df-10),y,:) = tmax_new_2((19-df),y,:)
  end do
 end do

 tmax_new_3    = new((/set_3,plot_years,subset/),float)
 tmax_new_3_new    = new((/set_3,plot_years,subset/),float)

 do df=20,29                         ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   tmax_new_3((df-20),y,:) = max_array(df,y,:) + curv_offset_3*(29-df)
  end do
 end do

 do df=20,29                         ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   tmax_new_3_new((df-20),y,:) = tmax_new_3((29-df),y,:)
  end do
 end do

;****************************
; Create the actual plot.
;****************************
 do y=0,yrs-1

 wks8   = gsn_open_wks ("ps", "BarChart_Tmax_Year"+y)

 res8@xyMonoDashPattern    = True  ; all solid lines
 res8@tmYLLabelFontHeightF = 0.01  ; default is 0.02
 res8@tmYLMode        = "Explicit"   ; Define own left tick mark labels.
 res8@tmYLValues       = fspan(res8@trYMinF,res8@trYMaxF,floattointeger((res8@trYMaxF-
res8@trYMinF)/tickMark)+1 )
 res8@tmYUseLeft       = False
 res8@tmYRLabelsOn   = True

 res8@tmYRMode        = "Explicit"   ; Define own right tick mark labels.
 res8@tmYRValues       = res8@tmYLValues
 res8@tmYRLabelFontHeightF = res8@tmYLLabelFontHeightF
 res8@tmYLLabels       = (/"75","85","95","105","115" \      ; left labels
                 ,"75","85","95","105","115" \
                 ,"75","85","95","105","115" \
                 ,"75","85","95","105","115" \
                 ,"75","85","95","105","115" \
                 ,"75","85","95","105","115" \
                 ,"75","85","95","105","115" \
                 ,"75","85","95","105","115" \
                 ,"75","85","95","105","115" \
                 ,"75","85","95","105","115","125",""/)

 res8@tmYRLabels      = (/"Bakersfield","","","","" \           ; right labels
                 ,"Visalia","","","","" \
                 ,"Fresno","","","","" \
                 ,"Merced","","","","" \
                 ,"Modesto","","","","" \
                 ,"Stockton","","","","" \
                 ,"Sacramento","","","","" \
                 ,"Colusa","","","","" \
                 ,"Red Bluff","","","","" \
                 ,"Redding","","","","","",""/)

 res8@gsnCenterString = "Year " + sprinti("%0.4i", y+1979)
 res8@tiMainString    = "JJAS Daily Tmax"
 res8@gsnYRefLine = res8@trYMinF + ispan(0,set-1,1)*curv_offset
```

```
 res8@gsnAboveYRefLineBarColors = "Red"
 res8@gsnBelowYRefLineBarColors = "Blue"
 res8@tmXBMode       = "Explicit" ; Define own tick mark labels.
 res8@tmXBValues     = (/0.,30.,61.,92.,121./)                          ; in IPM,
(/0.,30.,61.,92.,121./)
 res8@tmXBLabels     = (/"1June","1July","1Aug","1Sept","30Sept"/)

 res8@gsnXYBarChart = True
 plot8  = gsn_csm_xy (wks8,tick,tmax_new_new(0:9,y,:),res8)
 print("Bar Chart 8 created")

;*********

 wks81   = gsn_open_wks ("ps", "BarChart_2_Tmax_Year"+y)

 res81@xyMonoDashPattern    = True  ; all solid lines
 res81@tmYLLabelFontHeightF = 0.01  ; default is 0.02
 res81@tmYLMode       = "Explicit"   ; Define own left tick mark labels.
 res81@tmYLValues     = fspan(res81@trYMinF,res81@trYMaxF,floattointeger((res81@trYMaxF-
res81@trYMinF)/tickMark)+1 )
 res81@tmYUseLeft     = False
 res81@tmYRLabelsOn  = True

 res81@tmYRMode       = "Explicit"   ; Define own right tick mark labels.
 res81@tmYRValues     = res81@tmYLValues
 res81@tmYRLabelFontHeightF = res81@tmYLLabelFontHeightF
 res81@tmYLLabels     = (/"60","70","80","90","100" \     ; left labels
                     ,"60","70","80","90","100" \
                     ,"60","70","80","90","100" \
                     ,"60","70","80","90","100" \
                     ,"60","70","80","90","100" \
                     ,"60","70","80","90","100" \
                     ,"60","70","80","90","100" \
                     ,"60","70","80","90","100" \
                     ,"60","70","80","90","100" \
                     ,"60","70","80","90","100","110",""/)

  res81@tmYRLabels    = (/"Vista","","","","" \          ; right labels
                     ,"Santa Ana","","","","" \
                     ,"Santa Barbara","","","","" \
                     ,"SLO","","","","" \
                     ,"Monterey","","","","" \
                     ,"San Francisco","","","","" \
                     ,"Graton","","","","" \
                     ,"Covelo","","","","" \
                     ,"Eureka","","","","" \
                     ,"Crescent City","","","","","",""/)

 res81@gsnCenterString = "Year " + sprinti("%0.4i", y+1979)
 res81@tiMainString    = "JJAS Daily Tmax"
 res81@gsnYRefLine = res81@trYMinF + ispan(0,set_2-1,1)*curv_offset_2

 res81@gsnAboveYRefLineBarColors = "Red"
 res81@gsnBelowYRefLineBarColors = "Blue"
 res81@tmXBMode       = "Explicit" ; Define own tick mark labels.
 res81@tmXBValues     = (/0.,30.,61.,92.,121./)                          ; in IPM,
(/0.,30.,61.,92.,121./)
 res81@tmXBLabels     = (/"1June","1July","1Aug","1Sept","30Sept"/)

 res81@gsnXYBarChart = True
 plot81 = gsn_csm_xy (wks81,tick,tmax_new_2_new(0:9,y,:),res81)
 print("Bar Chart 81 created")

 print("All Bar Charts created")

;***********************************

 wks82   = gsn_open_wks ("ps", "BarChart_3_Tmax_Year"+y)

 res82@xyMonoDashPattern    = True  ; all solid lines
```

```
 res82@tmYLLabelFontHeightF = 0.01  ; default is 0.02
 res82@tmYLMode      = "Explicit"   ; Define own left tick mark labels.
 res82@tmYLValues    = fspan(res82@trYMinF,res82@trYMaxF,floattointeger((res82@trYMaxF-
res82@trYMinF)/tickMark)+1 )
 res82@tmYUseLeft    = False
 res82@tmYRLabelsOn  = True

 res82@tmYRMode      = "Explicit"   ; Define own right tick mark labels.
 res82@tmYRValues    = res82@tmYLValues
 res82@tmYRLabelFontHeightF = res82@tmYLLabelFontHeightF
 res82@tmYLLabels    = (/"60","70","80","90","110" \     ; left labels
                        ,"60","70","80","90","110" \
                        ,"60","70","80","90","110" \
                        ,"60","70","80","90","110" \
                        ,"60","70","80","90","110" \
                        ,"60","70","80","90","110" \
                        ,"60","70","80","90","110" \
                        ,"60","70","80","90","110" \
                        ,"60","70","80","90","110" \
                        ,"60","70","80","90","100","110",""/)

 res82@tmYRLabels      = (/"Tonopah","","","","" \            ; right labels
                        ,"Reno","","","","" \
                        ,"Baker City","","","","" \
                        ,"Pendleton","","","","" \
                        ,"Medford","","","","" \
                        ,"Eugene","","","","" \
                        ,"Portland","","","","" \
                        ,"Yakima","","","","" \
                        ,"Spokane","","","","" \
                        ,"Seattle","","","","","",""/)

 res82@gsnCenterString = "Year " + sprinti("%0.4i", y+1979)
 res82@tiMainString   = "JJAS Daily Tmax"
 res82@gsnYRefLine = res82@trYMinF + ispan(0,set_2-1,1)*curv_offset_3

 res82@gsnAboveYRefLineBarColors = "Red"
 res82@gsnBelowYRefLineBarColors = "Blue"
 res82@tmXBMode      = "Explicit" ; Define own tick mark labels.
 res82@tmXBValues    = (/0.,30.,61.,92.,121./)                         ; in IPM,
(/0.,30.,61.,92.,121./)
 res82@tmXBLabels    = (/"1June","1July","1Aug","1Sept","30Sept"/)

 res82@gsnXYBarChart = True
 plot82 = gsn_csm_xy (wks82,tick,tmax_new_3_new(0:9,y,:),res82)
 print("Bar Chart 82 created")

 end do
 print("All Bar Charts created")

;*********************************************************************************************
*
; Create a stacking bar chart of Minimum Temperatures.
;*********************************************************************************************
*

 tmin_min = min(min_array)
 tmin_max = max(min_array)
 print(tmin_min)
 print(tmin_max)

 sets = (/"Redding","Red
Bluff","Colusa","Sacramento","Stockton","Modesto","Merced","Fresno","Visalia","Bakersfiel
d"/)
 sets_2 = (/"Crescent City","Eureka","Covelo","Graton","San
Francisco","Monterey","SLO","Santa Barbara","Santa Ana","Vista"/)
 sets_3 = (/"Seattle", "Spokane", "Yakima", "Portland", "Eugene", "Medford", "Pendleton",
"BakerCity", "Reno", "Tonopah"/)
 subset = dys                              ; Dates, 122 days, June 1 - Aug 31,
y,k=0,121
 plot_years = yrs
```

```
 set = dimsizes(sets)
 set_2 = dimsizes(sets_2)
 set_3 = dimsizes(sets_3)
 tick = fspan(0., 121., 122)

; print(set)

 res11        = True
 res11@trYMinF = 50.0              ; bottom of Y-scale                  ; minimum
anomaly
 res11@trYMaxF = 90.0              ; nominal top of Y-scale            ; maximum
anomaly
 tickMark     = 10.0              ; tick Mark increment
 curv_offset  = res11@trYMaxF-res11@trYMinF  ; range
 res11@trYMaxF =  curv_offset*set + res11@trYMinF + tickMark

 res111       = True
 res111@trYMinF = 50.0             ; bottom of Y-scale                 ; minimum
anomaly
 res111@trYMaxF = 90.0             ; nominal top of Y-scale           ; maximum
anomaly
 tickMark     = 10.0              ; tick Mark increment
 curv_offset_2  = res111@trYMaxF-res111@trYMinF   ; range
 res111@trYMaxF =  curv_offset_2*set_2 + res111@trYMinF + tickMark

 res112       = True
 res112@trYMinF = 30.0             ; bottom of Y-scale                 ; minimum
anomaly
 res112@trYMaxF = 70.0             ; nominal top of Y-scale           ; maximum
anomaly
 tickMark     = 10.0              ; tick Mark increment
 curv_offset_3  = res112@trYMaxF-res112@trYMinF   ; range
 res112@trYMaxF =  curv_offset_3*set_3 + res112@trYMinF + tickMark

 tmin_new   = new((/set,plot_years,subset/),float)
 tmin_new_new   = new((/set,plot_years,subset/),float)

 do df=0,9                         ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   tmin_new(df,y,:) = min_array(df,y,:) + curv_offset*(9-df)
  end do
 end do

 do df=0,9                         ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   tmin_new_new(df,y,:) = tmin_new((9-df),y,:)
  end do
 end do

 tmin_new_2   = new((/set_2,plot_years,subset/),float)
 tmin_new_2_new   = new((/set_2,plot_years,subset/),float)

 do df=10,19                       ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   tmin_new_2((df-10),y,:) = min_array(df,y,:) + curv_offset_2*(19-df)
  end do
 end do

 do df=10,19                       ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   tmin_new_2_new((df-10),y,:) = tmin_new_2((19-df),y,:)
  end do
 end do

 tmin_new_3   = new((/set_3,plot_years,subset/),float)
 tmin_new_3_new   = new((/set_3,plot_years,subset/),float)

 do df=20,files-1                    ; Manipulates data to work with stacking bar
chart
  do y=0,yrs-1
   tmin_new_3((df-20),y,:) = min_array(df,y,:) + curv_offset_3*(29-df)
```

```
  end do
 end do

 do df=20,files-1                        ; Manipulates data to work with stacking bar
chart
  do y=0,yrs-1
   tmin_new_3_new((df-20),y,:) = tmin_new_3((29-df),y,:)
  end do
 end do

;***************************
; Create the actual plot.
;***************************
 do y=0,yrs-1

 wks11   = gsn_open_wks ("ps", "BarChart_Tmin_Year"+y)

 res11@xyMonoDashPattern    = True  ; all solid lines
 res11@tmYLLabelFontHeightF = 0.01  ; default is 0.02
 res11@tmYLMode       = "Explicit"   ; Define own left tick mark labels.
 res11@tmYLValues     = fspan(res11@trYMinF,res11@trYMaxF,floattointeger((res11@trYMaxF-
res11@trYMinF)/tickMark)+1 )
 res11@tmYUseLeft     = False
 res11@tmYRLabelsOn   = True

 res11@tmYRMode       = "Explicit"   ; Define own right tick mark labels.
 res11@tmYRValues     = res11@tmYLValues
 res11@tmYRLabelFontHeightF = res11@tmYLLabelFontHeightF
 res11@tmYLLabels     = (/"50","60","70","80" \     ; left labels
                    ,"50","60","70","80" \
                    ,"50","60","70","80" \
                    ,"50","60","70","80" \
                    ,"50","60","70","80" \
                    ,"50","60","70","80" \
                    ,"50","60","70","80" \
                    ,"50","60","70","80" \
                    ,"50","60","70","80" \
                    ,"50","60","70","80","90",""/)

  res11@tmYRLabels    = (/"Bakersfield","","","" \          ; right labels
                    ,"Visalia","","","" \
                    ,"Fresno","","","" \
                    ,"Merced","","","" \
                    ,"Modesto","","","" \
                    ,"Stockton","","","" \
                    ,"Sacramento","","","" \
                    ,"Colusa","","","" \
                    ,"Red Bluff","","","" \
                    ,"Redding","","","","",""/)

 res11@gsnCenterString = "Year " + sprinti("%0.4i", y+1979)
 res11@tiMainString    = "JJAS Daily Minimum Temperature"
 res11@gsnYRefLine = res11@trYMinF + ispan(0,set-1,1)*curv_offset

 res11@gsnAboveYRefLineBarColors = "Red"
 res11@gsnBelowYRefLineBarColors = "Blue"
 res11@tmXBMode       = "Explicit" ; Define own tick mark labels.
 res11@tmXBValues     = (/0.,30.,61.,92.,121./)                         ; in IPM,
(/0.,30.,61.,92.,121./)
 res11@tmXBLabels     = (/"1June","1July","1Aug","1Sept","30Sept"/)

 res11@gsnXYBarChart = True
 plot11 = gsn_csm_xy (wks11,tick,tmin_new_new(0:9,y,:),res11)
 print("Bar Chart 11 created")

;*******

 wks111   = gsn_open_wks ("ps", "BarChart_2_Tmin_Year"+y)

 res111@xyMonoDashPattern    = True  ; all solid lines
 res111@tmYLLabelFontHeightF = 0.01  ; default is 0.02
```

```
 res111@tmYLMode        = "Explicit"   ; Define own left tick mark labels.
 res111@tmYLValues      =
fspan(res111@trYMinF,res111@trYMaxF,floattointeger((res111@trYMaxF-
res111@trYMinF)/tickMark)+1 )
 res111@tmYUseLeft      = False
 res111@tmYRLabelsOn    = True

 res111@tmYRMode        = "Explicit"   ; Define own right tick mark labels.
 res111@tmYRValues      = res111@tmYLValues
 res111@tmYRLabelFontHeightF = res111@tmYLLabelFontHeightF
 res111@tmYLLabels      = (/"50","60","70","80" \     ; left labels
                         ,"50","60","70","80" \
                         ,"50","60","70","80" \
                         ,"50","60","70","80" \
                         ,"50","60","70","80" \
                         ,"50","60","70","80" \
                         ,"50","60","70","80" \
                         ,"50","60","70","80" \
                         ,"50","60","70","80" \
                         ,"50","60","70","80","90",""/)

  res111@tmYRLabels     = (/"Vista","","","" \            ; right labels
                         ,"Santa Ana","","","" \
                         ,"Santa Barbara","","","" \
                         ,"SLO","","","" \
                         ,"Monterey","","","" \
                         ,"San Francisco","","","" \
                         ,"Graton","","","" \
                         ,"Covelo","","","" \
                         ,"Eureka","","","" \
                         ,"Crescent City","","","","",""/)

 res111@gsnCenterString = "Year " + sprinti("%0.4i", y+1979)
 res111@tiMainString    = "JJAS Daily Minimum Temperature"
 res111@gsnYRefLine = res111@trYMinF + ispan(0,set_2-1,1)*curv_offset_2

 res111@gsnAboveYRefLineBarColors = "Red"
 res111@gsnBelowYRefLineBarColors = "Blue"
 res111@tmXBMode        = "Explicit" ; Define own tick mark labels.
 res111@tmXBValues      = (/0.,30.,61.,92.,121./)                          ; in IPM,
(/0.,30.,61.,92.,121./)
 res111@tmXBLabels      = (/"1June","1July","1Aug","1Sept","30Sept"/)

 res111@gsnXYBarChart = True
 plot111  = gsn_csm_xy (wks111,tick,tmin_new_2_new(0:9,y,:),res111)
 print("Bar Chart 111 created")

 print("All Bar Charts created")
;*********************************************************

 wks112   = gsn_open_wks ("ps", "BarChart_3_Tmin_Year"+y)

 res112@xyMonoDashPattern   = True ; all solid lines
 res112@tmYLLabelFontHeightF = 0.01 ; default is 0.02
 res112@tmYLMode        = "Explicit"   ; Define own left tick mark labels.
 res112@tmYLValues      =
fspan(res112@trYMinF,res112@trYMaxF,floattointeger((res112@trYMaxF-
res112@trYMinF)/tickMark)+1 )
 res112@tmYUseLeft      = False
 res112@tmYRLabelsOn    = True

 res112@tmYRMode        = "Explicit"   ; Define own right tick mark labels.
 res112@tmYRValues      = res112@tmYLValues
 res112@tmYRLabelFontHeightF = res112@tmYLLabelFontHeightF
 res112@tmYLLabels      = (/"30","40","50","60" \     ; left labels
                         ,"30","40","50","60" \
                         ,"30","40","50","60" \
                         ,"30","40","50","60" \
                         ,"30","40","50","60" \
                         ,"30","40","50","60" \
```

```
                          ,"30","40","50","60" \
                          ,"30","40","50","60" \
                          ,"30","40","50","60","70",""/)

  res112@tmYRLabels    = (/"Tonopah","","","" \           ; right labels
                          ,"Reno","","","" \
                          ,"Baker City","","","" \
                          ,"Pendleton","","","" \
                          ,"Medford","","","" \
                          ,"Eugene","","","" \
                          ,"Portland","","","" \
                          ,"Yakima","","","" \
                          ,"Spokane","","","" \
                          ,"Seattle","","","","",""/)

  res112@gsnCenterString = "Year " + sprinti("%0.4i", y+1979)
  res112@tiMainString    = "JJAS Daily Minimum Temperature"
  res112@gsnYRefLine = res112@trYMinF + ispan(0,set_3-1,1)*curv_offset_3

  res112@gsnAboveYRefLineBarColors = "Red"
  res112@gsnBelowYRefLineBarColors = "Blue"
  res112@tmXBMode      = "Explicit" ; Define own tick mark labels.
  res112@tmXBValues    = (/0.,30.,61.,92.,121./)                     ; in IPM,
(/0.,30.,61.,92.,121./)
  res112@tmXBLabels    = (/"1June","1July","1Aug","1Sept","30Sept"/)

  res112@gsnXYBarChart = True
  plot112  = gsn_csm_xy (wks112,tick,tmin_new_3_new(0:9,y,:),res112)
  print("Bar Chart 112 created")

 end do
 print("All Bar Charts created")


;**********************************************************************************
; Create a stacked bar chart of the DURATION of each event.
;**********************************************************************************

 sets = (/"Redding","Red
Bluff","Colusa","Sacramento","Stockton","Modesto","Merced","Fresno","Visalia","Bakersfiel
d"/)
 sets_2 = (/"Crescent City","Eureka","Covelo","Graton","San
Francisco","Monterey","SLO","Santa Barbara","Santa Ana","Vista"/)
 sets_3 = (/"Seattle", "Spokane", "Yakima", "Portland", "Eugene", "Medford", "Pendleton",
"BakerCity", "Reno", "Tonopah"/)
 subset = dys                             ; Dates, 122 days, June 1 - Aug 31,
y,k=0,121
 plot_years = yrs
 set = dimsizes(sets)
 set_2 = dimsizes(sets_2)
 set_3 = dimsizes(sets_3)
 tick = fspan(0., 121., 122)

; print(set)

 res10        = True
 res10@trYMinF = 0.0              ; bottom of Y-scale                ; minimum anomaly
 res10@trYMaxF = 10.0             ; nominal top of Y-scale           ; maximum
anomaly
 tickMark     = 2.0               ; tick Mark increment
 curv_offset  =  res10@trYMaxF-res10@trYMinF   ; range
 res10@trYMaxF =  curv_offset*set + res10@trYMinF + tickMark

 res101       = True
 res101@trYMinF = 0.0             ; bottom of Y-scale                ; minimum
anomaly
 res101@trYMaxF = 10.0            ; nominal top of Y-scale           ; maximum
anomaly
 tickMark     = 2.0               ; tick Mark increment
 curv_offset_2   =  res101@trYMaxF-res101@trYMinF   ; range
 res101@trYMaxF =  curv_offset_2*set_2 + res101@trYMinF + tickMark
```

```
 res102         = True
 res102@trYMinF  = 0.0                   ; bottom of Y-scale                     ; minimum
anomaly
 res102@trYMaxF  = 10.0                    ; nominal top of Y-scale             ; maximum
anomaly
 tickMark       = 2.0                 ; tick Mark increment
 curv_offset_3   =  res102@trYMaxF-res102@trYMinF   ; range
 res102@trYMaxF  =  curv_offset_3*set_3 + res102@trYMinF + tickMark

 num_days_new    = new((/set,plot_years,subset/),float)
 num_days_new_new   = new((/set,plot_years,subset/),float)

 do df=0,9                       ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   num_days_new(df,y,:) = num_days_events(df,y,:) + curv_offset*(9-df)
  end do
 end do

 do df=0,9                       ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   num_days_new_new(df,y,:) = num_days_new((9-df),y,:)
  end do
 end do

 num_days_new_2   = new((/set_2,plot_years,subset/),float)
 num_days_new_2_new   = new((/set_2,plot_years,subset/),float)

 do df=10,19                      ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   num_days_new_2((df-10),y,:) = num_days_events(df,y,:) + curv_offset_2*(19-df)
  end do
 end do

 do df=10,19                      ; Manipulates data to work with stacking bar chart
  do y=0,yrs-1
   num_days_new_2_new((df-10),y,:) = num_days_new_2((19-df),y,:)
  end do
 end do

 num_days_new_3   = new((/set_3,plot_years,subset/),float)
 num_days_new_3_new   = new((/set_3,plot_years,subset/),float)

 do df=20,files-1                        ; Manipulates data to work with stacking bar
chart
  do y=0,yrs-1
   num_days_new_3((df-20),y,:) = num_days_events(df,y,:) + curv_offset_3*(29-df)
  end do
 end do

 do df=20,files-1                        ; Manipulates data to work with stacking bar
chart
  do y=0,yrs-1
   num_days_new_3_new((df-20),y,:) = num_days_new_3((29-df),y,:)
  end do
 end do

;****************************
; Create the actual plot.
;****************************
 do y=0,yrs-1

  wks10   = gsn_open_wks ("ps", "BarChart_Duration_"+y)

  res10@xyMonoDashPattern    = True  ; all solid lines
  res10@tmYLLabelFontHeightF = 0.01  ; default is 0.02
  res10@tmYLMode       = "Explicit"   ; Define own left tick mark labels.
  res10@tmYLValues     = fspan(res10@trYMinF,res10@trYMaxF,floattointeger((res10@trYMaxF-
res10@trYMinF)/tickMark)+1 )
  res10@tmYUseLeft     = False
  res10@tmYRLabelsOn   = True
```

```
  res10@tmYRMode       = "Explicit"   ; Define own right tick mark labels.
  res10@tmYRValues     = res10@tmYLValues
  res10@tmYRLabelFontHeightF = res10@tmYLLabelFontHeightF

  res10@tmYLLabels     = (/"0","2","4","6","8" \      ; left labels
                       ,"0","2","4","6","8" \
                       ,"0","2","4","6","8" \
                       ,"0","2","4","6","8" \
                       ,"0","2","4","6","8" \
                       ,"0","2","4","6","8" \
                       ,"0","2","4","6","8" \
                       ,"0","2","4","6","8" \
                       ,"0","2","4","6","8" \
                       ,"0","2","4","6","8","10",""/)

  res10@tmYRLabels     = (/"Bakersfield","","","","" \           ; right labels
                       ,"Visalia","","","","" \
                       ,"Fresno","","","","" \
                       ,"Merced","","","","" \
                       ,"Modesto","","","","" \
                       ,"Stockton","","","","" \
                       ,"Sacramento","","","","" \
                       ,"Colusa","","","","" \
                       ,"Red Bluff","","","","" \
                       ,"Redding","","","","","",""/)

  res10@gsnCenterString = "Year " + sprinti("%0.4i", y+1979)
  res10@tiMainString    = "Event Duration: Days"
  res10@gsnYRefLine     = res10@trYMinF + ispan(0,set-1,1)*curv_offset

  res10@gsnAboveYRefLineBarColors = "Red"
  res10@gsnBelowYRefLineBarColors = "Blue"
  res10@tmXBMode        = "Explicit"                              ; Define own tick mark
labels.
  res10@tmXBValues     = (/0.,30.,61.,92.,121./)
  res10@tmXBLabels     = (/"1June","1July","1Aug","1Sept","30Sept"/)

  res10@gsnXYBarChart = True
  plot10  = gsn_csm_xy (wks10,tick,num_days_new_new(0:9,y,:),res10)
  print("Bar Chart created")

;********

  wks101    = gsn_open_wks ("ps", "BarChart_Duration_2_"+y)

  res101@xyMonoDashPattern   = True  ; all solid lines
  res101@tmYLLabelFontHeightF = 0.01  ; default is 0.02
  res101@tmYLMode       = "Explicit"   ; Define own left tick mark labels.
  res101@tmYLValues    =
fspan(res101@trYMinF,res101@trYMaxF,floattointeger((res101@trYMaxF-
res101@trYMinF)/tickMark)+1 )
  res101@tmYUseLeft    = False
  res101@tmYRLabelsOn  = True

  res101@tmYRMode       = "Explicit"   ; Define own right tick mark labels.
  res101@tmYRValues    = res101@tmYLValues
  res101@tmYRLabelFontHeightF = res101@tmYLLabelFontHeightF

  res101@tmYLLabels     = (/"0","2","4","6","8" \     ; left labels
                       ,"0","2","4","6","8" \
                       ,"0","2","4","6","8" \
                       ,"0","2","4","6","8" \
                       ,"0","2","4","6","8" \
                       ,"0","2","4","6","8" \
                       ,"0","2","4","6","8" \
                       ,"0","2","4","6","8" \
                       ,"0","2","4","6","8" \
                       ,"0","2","4","6","8","10",""/)

  res101@tmYRLabels     = (/"Vista","","","","" \          ; right labels
```

```
                         ,"Santa Ana","","","","" \
                         ,"Santa Barbara","","","","" \
                         ,"SLO","","","","" \
                         ,"Monterey","","","","" \
                         ,"San Francisco","","","","" \
                         ,"Graton","","","","" \
                         ,"Covelo","","","","" \
                         ,"Eureka","","","","" \
                         ,"Crescent City","","","","","",""/)

  res101@gsnCenterString = "Year " + sprinti("%0.4i", y+1979)
  res101@tiMainString    = "Event Duration: Days"
  res101@gsnYRefLine     = res101@trYMinF + ispan(0,set_2-1,1)*curv_offset_2

  res101@gsnAboveYRefLineBarColors = "Red"
  res101@gsnBelowYRefLineBarColors = "Blue"
  res101@tmXBMode        = "Explicit"                                ; Define own
tick mark labels.
  res101@tmXBValues      = (/0.,30.,61.,92.,121./)
  res101@tmXBLabels      = (/"1June","1July","1Aug","1Sept","30Sept"/)

  res101@gsnXYBarChart = True
  plot101  = gsn_csm_xy (wks101,tick,num_days_new_2_new(0:9,y,:),res101)
  print("Bar Chart created")

 print("All Bar Charts created")

;**********************************************

  wks102   = gsn_open_wks ("ps", "BarChart_Duration_3_"+y)

  res102@xyMonoDashPattern    = True  ; all solid lines
  res102@tmYLLabelFontHeightF = 0.01  ; default is 0.02
  res102@tmYLMode        = "Explicit"   ; Define own left tick mark labels.
  res102@tmYLValues      =
fspan(res102@trYMinF,res102@trYMaxF,floattointeger((res102@trYMaxF-
res102@trYMinF)/tickMark)+1 )
  res102@tmYUseLeft      = False
  res102@tmYRLabelsOn    = True

  res102@tmYRMode        = "Explicit"   ; Define own right tick mark labels.
  res102@tmYRValues      = res102@tmYLValues
  res102@tmYRLabelFontHeightF = res102@tmYLLabelFontHeightF

  res102@tmYLLabels      = (/"0","2","4","6","8" \     ; left labels
                         ,"0","2","4","6","8" \
                         ,"0","2","4","6","8" \
                         ,"0","2","4","6","8" \
                         ,"0","2","4","6","8" \
                         ,"0","2","4","6","8" \
                         ,"0","2","4","6","8" \
                         ,"0","2","4","6","8" \
                         ,"0","2","4","6","8","10",""/)

  res102@tmYRLabels      = (/"Tonopah","","","","" \           ; right labels
                         ,"Reno","","","","" \
                         ,"Baker City","","","","" \
                         ,"Pendleton","","","","" \
                         ,"Medford","","","","" \
                         ,"Eugene","","","","" \
                         ,"Portland","","","","" \
                         ,"Yakima","","","","" \
                         ,"Spokane","","","","" \
                         ,"Seattle","","","","","",""/)

  res102@gsnCenterString = "Year " + sprinti("%0.4i", y+1979)
  res102@tiMainString    = "Event Duration: Days"
  res102@gsnYRefLine     = res102@trYMinF + ispan(0,set_3-1,1)*curv_offset_3

  res102@gsnAboveYRefLineBarColors = "Red"
```

```
  res102@gsnBelowYRefLineBarColors = "Blue"
  res102@tmXBMode       = "Explicit"                                          ; Define own
tick mark labels.
  res102@tmXBValues     = (/0.,30.,61.,92.,121./)
  res102@tmXBLabels     = (/"1June","1July","1Aug","1Sept","30Sept"/)

  res102@gsnXYBarChart = True
  plot102  = gsn_csm_xy (wks102,tick,num_days_new_3_new(0:9,y,:),res102)
  print("Bar Chart created")

 end do
 print("All Bar Charts created")

;*********************************************************************************

 end
```

IPM_Stats.ncl

```
;*******************************************************************************
; This program determines matches of heat wave event dates between Sacramento
; and the other stations, based on the different ranking methods
; for the HW events in the cities specified in 'datafiles'.
;*******************************************************************************
; CHANGE: Reading in of Top_Event_Dates, Top_Event_Dates_N, or Top_Event_Dates_max
; to correspond with the Top Events ranking based on the highest average maximum
; temperature, the highest 3-day average of maximum temperature anomalies, or the
; highest event maximum temperature.
;*******************************************************************************


load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/gsn_code.ncl"
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/gsn_csm.ncl"
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/shea_util.ncl"
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/contributed.ncl"


 ;--------------------------------------------------------------


begin

 top_rank=15          ; corresponds to the top 15 ranked heat wave events

;**********************************************
; Read in all Event dates arrays for each city.
;**********************************************
 data1=asciiread("Redding_event_dates_array", -1, "integer")
 Redding_date = data1(:)
 print(Redding_date)

 data2=asciiread("RedBluff_event_dates_array", -1, "integer")
 RedBluff_date = data2(:)
 print(RedBluff_date)

*
*
*** This is performed this way for every city *****
*
*

 data30=asciiread("Tonopah_event_dates_array", -1, "integer")
 Tonopah_date = data30(:)
 print(Tonopah_date)

 print("data files read")
;*******************************************************************************
; Read in Top Event Dates based on the HW definition requiring the average
; temperature of the event to be >= 100 degrees
;*******************************************************************************

; top1=asciiread("Redding_Top_Event_Dates", -1, "integer")
; Redding_top = top1(:)
; print(Redding_top)

; top2=asciiread("RedBluff_Top_Event_Dates", -1, "integer")
; RedBluff_top = top2(:)
; print(RedBluff_top)

*
*
*** (This is performed this way for every city) *****
*
*

; top30=asciiread("Tonopah_Top_Event_Dates", -1, "integer")
; Tonopah_top = top30(:)
; print(Tonopah_top)


;*******************************************************************************
```

```
; Read in Top Event Dates based on the highest 3-day anomaly average ranking.
;***************************************************************************

; top1=asciiread("Redding_Top_Event_Dates_N", -1, "integer")
; Redding_top = top1(:)
; print(Redding_top)

; top2=asciiread("RedBluff_Top_Event_Dates_N", -1, "integer")
; RedBluff_top = top2(:)
; print(RedBluff_top)

*
*
*** (This is performed this way for every city) ***
*
*

; top30=asciiread("Tonopah_Top_Event_Dates_N", -1, "integer")
; Tonopah_top = top30(:)
; print(Tonopah_top)

;***************************************************************
; Read in Top Event Dates based on the Maximum Temperature ranking.
;***************************************************************

 top1=asciiread("Redding_Top_Event_Dates_max", -1, "integer")
 Redding_top = top1(:)
 print(Redding_top)

 top2=asciiread("RedBluff_Top_Event_Dates_max", -1, "integer")
 RedBluff_top = top2(:)
 print(RedBluff_top)

*
*
*** (This is performed this way for every city) ***
*
*

 top30=asciiread("Tonopah_Top_Event_Dates_max", -1, "integer")
 Tonopah_top = top30(:)
 print(Tonopah_top)

 print("top files read")

;*******************************************************
; Determine HW Event Matches of all heat wave event dates.
;*******************************************************
; Initialize date array with a random number.
; If the date of Sacramento HW mathces the date of
; another city's HW, then declare that a match.
; Reinitialize array with the number of matching dates.
; Repeat with each city.
;*******************************************************


 Sac_Redding_date = new((/10/),integer)                ; initialize array with random number

 m=0
 do i=0,dimsizes(Sac_date)-1
  do j=0,dimsizes(Redding_date)-1
   if (Sac_date(i) .eq. Redding_date(j)) then        ; if the dates of a Sac HW mathches
the date of
    delete(Sac_Redding_date)
    m=m+1
    Sac_Redding_date = new((/m/),integer)
   end if
  end do
 end do

 m=0
```

```
 do i=0,dimsizes(Sac_date)-1
  do j=0,dimsizes(Redding_date)-1
   if (Sac_date(i) .eq. Redding_date(j)) then
    Sac_Redding_date(m) = Sac_date(i)
    m=m+1
   end if
  end do
 end do
 match = m
 print(Sac_Redding_date(:))
 print("Redding: "+m+" matches")

*
*
**** (This is performed this way for every station)***
*
*

 Sac_Tonopah_date = new((/10/),integer)

 m=0
 do i=0,dimsizes(Sac_date)-1
  do j=0,dimsizes(Tonopah_date)-1
   if (Sac_date(i) .eq. Tonopah_date(j)) then
    delete(Sac_Tonopah_date)
    m=m+1
    Sac_Tonopah_date = new((/m/),integer)
   end if
  end do
 end do

 m=0
 do i=0,dimsizes(Sac_date)-1
  do j=0,dimsizes(Tonopah_date)-1
   if (Sac_date(i) .eq. Tonopah_date(j)) then
    Sac_Tonopah_date(m) = Sac_date(i)
    m=m+1
   end if
  end do
 end do
 match = m
 print(Sac_Tonopah_date(:))
 print("Tonopah: "+m+" matches")

;***********************************************************************
; Determine HW Event Matches of the Top N Events
;***********************************************************************

 print("Top "+top_rank+" Events Matches")

 Sac_Redding_top = new((/10/),integer)

 m=0
 do i=0,dimsizes(Sac_top)-1
  if (Sac_top(i) .ne. 0) then
   do j=0,dimsizes(Redding_top)-1
    if (Redding_top(j) .ne. 0) then
     if (Sac_top(i) .eq. Redding_top(j)) then
      delete(Sac_Redding_top)
      m=m+1
      Sac_Redding_top = new((/m/),integer)
     end if
    end if
   end do
  end if
 end do

 m=0
 do i=0,dimsizes(Sac_top)-1
  if (Sac_top(i) .ne. 0) then
   do j=0,dimsizes(Redding_top)-1
```

```
   if (Redding_top(j) .ne. 0) then
    if (Sac_top(i) .eq. Redding_top(j)) then
     Sac_Redding_top(m) = Sac_top(i)
     m=m+1
    end if
   end if
  end do
 end if
end do
match = m
print(Sac_Redding_top(:))
print("Redding: "+m+" matches")

;**************

*
*** (Performed this way for every state) ***
*

;*****************

 Sac_Tonopah_top = new((/10/),integer)

 m=0
 do i=0,dimsizes(Sac_top)-1
  if (Sac_top(i) .ne. 0) then
  do j=0,dimsizes(Tonopah_top)-1
   if (Tonopah_top(j) .ne. 0) then
    if (Sac_top(i) .eq. Tonopah_top(j)) then
     delete(Sac_Tonopah_top)
     m=m+1
     Sac_Tonopah_top = new((/m/),integer)
    end if
end if
  end do
end if
end do

 m=0
 do i=0,dimsizes(Sac_top)-1
  if (Sac_top(i) .ne. 0) then
  do j=0,dimsizes(Tonopah_top)-1
   if (Tonopah_top(j) .ne. 0) then
    if (Sac_top(i) .eq. Tonopah_top(j)) then
     Sac_Tonopah_top(m) = Sac_top(i)
     m=m+1
    end if
end if
  end do
end if
end do
match = m
print(Sac_Tonopah_top(:))
print("Tonopah: "+m+" matches")

;*****************


end
```

rngen.ncl

```
;****************************************************************************************
******************************
; This program creates 1000 random ensembles, with 15 random members in each ensemble,
; for each station, using rand().
; Each random ensemble member corresponds to a maximum JJAS temperature.
; The averages of the random ensembles are compared to the one 'target' ensemble
; of maximum temperature on the onset dates of Sacreamento's 15 hottest heat wave events.
;****************************************************************************************
******************************
; CHANGE:
; 1) Asciiread statements to read in either top heat wave events ranked by
;    1) highest consecutive 3-day average of max temp anomalies, or by
;    2) highest event maximum temperature.
;
; 2) Histogram Main Title and Center Title to correspond to the data that is read in.
;****************************************************************************************
******************************

load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/gsn_code.ncl"
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/gsn_csm.ncl"
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/shea_util.ncl"
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/contributed.ncl"

 ;----------------------------------------------------------------

begin

 files     = 30                      ; 30 files corresponding to the 30 stations
 yrs       = 28                      ; 28 years in dataset
 dys       = 122             ; 122 day in JJAS
 JJAS_days = 3416            ; 3416 days in 28 years of JJAS
 num_col   = 3               ; column 1 = time, 2 = max temps, 3 = min temps
 num_time  = 10135           ; 10135 total times in 28 full years

 ensembles  = 1000           ; number of random ensembles to be created
 num_in_ens = 15             ; number of random members in random ensembles

 low  = 0                    ; random numbers to be created between 0 and 1
 high = 1
 con = (high - low)/32766    ; note: random number generator [rand()] creates random
number between 0 and 32766

 random = new((/files,ensembles,num_in_ens/),integer)   ; random number array
 Rn = new((/files,ensembles,num_in_ens/),float)              ; array of random numbers
 Rn_2 = new((/files,ensembles,num_in_ens/),float)    ; random number index array
 Rn_Index = new((/files,ensembles,num_in_ens/),float)       ; array of random number
indexes, from 0 to 3416
 Rn_Tmax = new((/files,ensembles,num_in_ens/),float); array of random Tmaxs corresponding
to 0,3416 index
 ens_ave = new((/files,ensembles+1/),float)             ; array of ensemble averages
 ens_ave_min = new((/files/),float)                     ; min value of the 1,000 random
ensembles for each station
 ens_ave_max = new((/files/),float)                     ; max value of the 1,000 random
ensembles for each station
 ens_ave_min_int = new((/files/),integer)               ; array of ensemble mins converted to
integers
 ens_ave_max_int = new((/files/),integer)               ; array of ensemble maxs convereted
to integeres
 ens_ave_perm = new((/files,ensembles+1/),integer)  ; array of ensemble average
permutations
 ens_ave_perm_5 = new((/files/),float)                          ; array of 5th top randomly
created value of each station
 ens_ave_perm_6 = new((/files/),float)                          ; array of 6th top randomly
created value of each station
 ens_ave_995   = new((/files/),float)                           ; array of the 99.5% value
for each station
 target_place   = new((/files/),string)                         ; array of the values at
which the target ensemble means lie
```

```
 datafiles = (/"Redding", "RedBluff", "Colusa", "Sac", "Stockton", "Modesto", "Merced",
"Fresno", "Visalia", "Bkrsfld" \
              , "CrescentCity", "Eureka", "Covelo", "Graton", "SanFrancisco", "Monterey",
"SLO", "SantaBarbara", "SantaAna" \
              , "Vista" , "Seattle", "Spokane", "Yakima", "Portland", "Eugene", "Medford",
"Pendleton", "BakerCity", "Reno" \
              , "Tonopah"/)

;*********************************************************************************
; Read in target ensemble averages of filtered/unfiltered data(fil/UNfil),
; with/without the average max temp requirement in the HW definition (tave/notave),
; and according to the average max temp ranking(ave), the max temp ranking(max),
; or the highest consecutive 3-day anomaly average ranking(Nday).
;*********************************************************************************

; data_target_ave = asciiread("target_ave_UNfil_notave",-1,"float") ; Target Ave based on
average maximum temperature,
; data_target_ave = asciiread("target_ave_Nday_UNfil_notave",-1,"float"); Target Ave
based on 3-day anomaly average ranking
; data_target_ave = asciiread("target_ave_max_UNfil_notave",-1,"float")  ; Target Average
based on max temperature ranking

; data_target_ave = asciiread("target_ave_UNfil_tave",-1,"float")     ; Target Ave based
on average maximum temperature
; data_target_ave = asciiread("target_ave_Nday_UNfil_tave",-1,"float"); Target Ave based
on 3-day anomaly average ranking
; data_target_ave = asciiread("target_ave_max_UNfil_tave",-1,"float")  ; Target Average
based on max temperature ranking

; data_target_ave = asciiread("target_ave_fil_notave",-1,"float")     ; Target Ave based
on average maximum temperature

 data_target_ave = asciiread("Sacdate_target_3day_avg_unfil",-1,"float") ; Target Ave
based on 3-day anomaly average ranking
; data_target_ave = asciiread("Sacdate_target_max_avg_unfil",-1,"float")  ; Target
Average based on max temperature ranking

; data_target_ave = asciiread("Sacdate_target_3day_avg_fil",-1,"float")  ; Target average
based on 3-day anomaly avg ranking
; data_target_ave = asciiread("Sacdate_target_max_avg_fil",-1,"float")

 do df=0,files-1
  print(df)
  data_max        = asciiread(datafiles(df)+"_JJAS_max",-1,"float")              ; read
in UNfiltered temp data
;  data_max        = asciiread(datafiles(df)+"_JJAS_max_fil",-1,"float")     ; read in
FILTERED temp data

  srand(123456789)           ; sets the seed for the random number generator rand()

  do i=0,ensembles-1                                  ; cycles through all ensembles
   do j=0,num_in_ens-1                               ; cycles through all members
    random(df,i,j) = rand()                          ; rand() is random number generator
    Rn(df,i,j) = random(df,i,j) * 3415                    ; random number created
    Rn_2(df,i,j) = Rn(df,i,j)/32766             ; 0,3416 index created
    Rn_Index(df,i,j) = round(Rn_2(df,i,j),3)            ; round index to the nearest
whole number
    Rn_Tmax(df,i,j) = data_max(floattointeger(Rn_Index(df,i,j)))   ; Tmax for particular
index retrieved
   end do
   ens_ave(df,i) = avg(Rn_Tmax(df,i,:))                   ; ensemble average for the
particular ensemble is calculated
  end do
  ens_ave(df,ensembles) = data_target_ave(df)        ; sets the target ensemble average
for each station as the last entry
  print(ens_ave(df,ensembles))
  print("df="+df+" done")

  ens_ave_min(df) = min(ens_ave(df,:))               ; calculates the minimum of the
ensemble averages array
```

```
  ens_ave_max(df) = max(ens_ave(df,:))                    ; calculates the maximum of the
ensemble averages array
  ens_ave_min_int(df) = floattointeger(ens_ave_min(df))
  ens_ave_max_int(df) = round(ens_ave_max(df),3) + 1
  ens_ave_perm(df,:) = dim_pqsort(ens_ave(df,:),-1)         ; arrange ensemble averages
in descending order
  ens_ave_perm_5(df)     = ens_ave(df,ens_ave_perm(df,4))   ; grab the 5th ensemble
average value
  ens_ave_perm_6(df)     = ens_ave(df,ens_ave_perm(df,5))   ; grab the 6th ensemble
average value
  ens_ave_995(df)        = (( (ens_ave_perm_5(df)) + (ens_ave_perm_6(df)) ) / 2)   ; find
the value b/w the 5th and 6th values

                                                     ; Label target ensemble avgerage as
satisfying or not satisfying the 99.5% stat
                                                     ; based on if it falls above or below
the 99.5% value
  if (data_target_ave(df) .ge. ens_ave_995(df)) then
   target_place(df) = "SATISFIES"
  else
   target_place(df) = "DOES NOT SATISFY"
  end if

 end do

 print(data_target_ave)
 print(ens_ave)
 print(ens_ave_min)
 print(ens_ave_max)
 print(ens_ave_min_int)
 print(ens_ave_max_int)
 print(ens_ave_perm)
 print(ens_ave_perm_5)
 print(ens_ave_perm_6)
 print(ens_ave_995)
 print("All done")

 do df=0,files-1
  print(datafiles(df)+": 99.5% of values less than "+ens_ave_995(df)+" degrees")
  print(datafiles(df)+": Target Ensemble Average = "+data_target_ave(df)+" degrees, and
"+target_place(df)+" the 99.5% test")
 end do

;************************************************************************
; Create histogram of random ensembles
;************************************************************************

 do df=0,files-1
  wks = gsn_open_wks("ps","histogram_"+datafiles(df))          ; open workstation
  gsn_define_colormap(wks,"rainbow")                 ; choose colormap

  res                          = True           ; plot mods desired
 res@tiMainString = datafiles(df)
;  res@tiMainString = datafiles(df)+" JJAS Max Temp Ensemble Averages :C: Max Temp
Ranking Scheme, Unfiltered, No Tave"
;   res@tiMainString = datafiles(df)+" JJAS Max Temp Ensemble Averages :C: 3-Day Ranking
Scheme, Unfiltered, No Tave"
;   res@tiMainString = datafiles(df)+" JJAS Max Temp Ensemble Averages :C: 3-Day Ranking
Scheme, Filtered, No Tave"
;  res@tiCenterString = "3-day Ranking Scheme"
;  res@tiCenterString = "Average Max Temp Ranking Scheme"
;  res@tiCenterString = "Max Temp Ranking Scheme, Unfiltered, No Tave"
;  res@tiHistogramSelectNiceIntervals = True
  res@gsnHistogramBinWidth = 0.5
  res@tmXBLabelStride = 2
  res@tmXBLabelFontHeightF = .01

  res@gsnDraw      = False           ; do not draw
  res@gsnFrame     = False           ; do not advance

  plot=gsn_histogram(wks,ens_ave(df,:),res)                    ; create histogram
```

```
  txres              = True
  txres@txFontHeightF = 0.05                ; Set the font height

;   label = "********"

;
text=gsn_add_text(wks,plot,label,tmXBValues(floattoint(ens_ave(df,ensembles))),0.2*(float
toint(tmYLValues(nTmY-1))),txres)
 gsn_text(wks,plot,"*",floattointeger(data_target_ave(df)),5.0,txres)

 draw(plot)
 frame(wks)

 end do

;***************************************************************************

end
```

NCL_mapping.ncl

```
;**********************************************************************
; This program spatially plots station data onto a CA, OR, WA, and NV map,
; according to the latitude/longitude coordinates of each station.
;**********************************************************************
; CHANGE: 1) Title of Map (res@tiMainString), corresponding to data plotted
;         2) Data to be plotted (gsn_text)
;**********************************************************************

load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/gsn_code.ncl"
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/gsn_csm.ncl"
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/shea_util.ncl"
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/contributed.ncl"


;---------------------------------------------------------------

begin

;************************************************
; based on the ncl demo program ce_3.ncl
;************************************************
;************************************************
; create plot
;************************************************
  wks = gsn_open_wks("ps" ,"NCL_CA_map")           ; open a ps file

 res                      = True     ; plot mods desired
 res@gsnFrame             = False        ; Do not advance frome
 res@mpFillOn             = False            ; turn off map fill
 res@mpOutlineDrawOrder   = "PostDraw"      ; draw continental outline last
 res@mpOutlineBoundarySets = "GeophysicalAndUSStates" ; state boundaries

 res@pmTickMarkDisplayMode = "Always"; use NCL default lat/lon labels
 res@tiMainFontHeightF = 0.02

; res@tiMainString          = "California, Washington, Oregon, and Nevada Stations"    ;
plot title
; res@tiMainString = " CA, WA, OR, and NV HW Event:C:Averaged Normalized Anomalies"
 res@tiMainString = " CA, WA, OR, and NV HW Event Averaged Normalized:C:Anomalies on Top
Sac 15 3-Day Anom Avg Dates, Unfil"
; res@tiMainString = "        CA, WA, OR, and NV:C: JJAS Average Maximum Temps"
; res@tiMainString = "      HW Event Matches..Unfiltered,:C:No Avg Max Temp, 3-Day Anom
Avg Rank"
; res@tiMainString="  HW Event Matches..Unfiltered,:C:Avg Max Temp, Max Temp Rank"
; res@tiMainString="      HW Event Matches..Unfiltered,:C:No Avg Max Temp, Max Temp Rank"
; res@tiMainString="      HW Event Matches..Unfiltered,:C:Avg Max Temp, 3-Day Anom Avg
Rank"
; res@tiMainString          = "CA, WA, OR, and NV JJAS Max Temp Standard Deviations"
; res@tiMainString          = "CA, WA, OR, and NV Average Minimum Temperatures"
; res@tiMainString          = "CA, WA, OR, and NV Average Maximum Temperatures"

; note that the gsn_csm_*map_ce templates automatically set
; res@mpLimitMode="LatLon" for you. If you are plotting a different
; projection, you may have to set this resource.

 res@mpMinLatF            = 32        ; Southernmost latitude
 res@mpMaxLatF            = 49.               ; Northernmost latitude
 res@mpMinLonF            = -125.     ; Westernmost longitude
 res@mpMaxLonF            = -116.     ; Easternmost longitude

 plot  = gsn_csm_map_ce(wks,res)

 draw (plot)

;***************Text Resource*********************************

 txres               = True                      ; text mods desired
 txres@txFontHeightF = 0.011                         ; font smaller. default big
 txres@txFontThicknessF = 2.0
```

```
 txres@txFontColor = "black"
 txres@txJust        = "CenterCenter"

; add some text at specific locations can use integer or floating latitudes
;   enter lon,lat of station.
; gsn_text(wks,plot,"+",-121.3,48,txres)
; gsn_text(wks,plot,"*",-121.3,38.5,txres)
; tests of encoding a number:
; sum1 = 101.
; gsn_text (wks,plot,"T="+sum1, -122.0, 41. ,txres)
; sum2 = 105.
; gsn_text (wks,plot,sum2, -120.0, 35. ,txres)
; sum3 = 0.923
; gsn_text (wks,plot,sum3, -118.0, 47. ,txres)

 files=30

 cities = (/"RDD","RBL","COL","SMF","SCK","MOD","MCE","FAT","VIS","BFL" \  ; 3-letter
Station codes
            ,"CEC","EKA","COV","GRT","SFO","MRY","SBP","SBA","SNA","VST" \
            ,"SEA","GEG","YKM","PDX","EUG","MFR","PDT","BKE","RNO","TPH" /)

 norm_anom_avg = (/"1.63","1.65","1.94","1.75","1.95","1.87","1.97","1.75","1.92","1.80"
\       ; Station HW event avg normalized anoms
                 ,"3.28","4.23","1.67","1.97","2.56","2.63","2.27","3.41","2.52","2.37"
\

,"2.02","1.50","1.62","1.83","1.71","1.60","1.52","1.45","1.66","1.69"/)

 Sacdates_norm_anom_avg =
(/"1.47","1.58","1.62","1.89","1.79","1.59","1.25","1.26","1.14","1.19" \  ; avg
normalized anomalies on Sac HW event dates

,"0.76","0.19","1.26","1.50","1.66","1.69","1.29","0.29","0.93","0.94" \

,"0.96","0.57","0.74","0.94","0.88","1.09","0.75","0.54","0.81","0.77"/)

 tmax_avg = (/"94.1","93.3","91.0","89.7","90.7","90.8","93.7","94.7","91.3","94.2" \
         ; average JJAS Tmax
               ,"65.3","63.8","89.6","83.0","72.3","68.9","79.1","74.7","82.3","81.7" \
               ,"74.5","80.3","84.5","79.9","80.7","88.4","84.2","82.1","88.0","87.5"/)

 matches_unfil_notave_3day = (/"5","6","6","*","9","6","3","3","3","5" \  ; # of matches
of HW event based on unfiltered, no avg temp requirement,
                             ,"0","0","5","6","5","4","3","1","4","3" \   ; 3day avg
anom ranking HW events
                             ,"2","2","3","1","3","2","1","2","1","1"/)

 matches_unfil_notave_max = (/"6","8","4","*","6","5","1","1","1","2" \          ; # of
matches of HW events based on unfiltered, no avg temp requirement,
                            ,"0","0","4","4","3","1","2","2","2","1" \          ; max
temp ranking HW events
                            ,"3","1","3","3","2","2","2","1","1","0"/)

 matches_unfil_tave_3day = (/"5","7","5","*","7","5","3","2","2","4" \          ; # of
matches of HW events based on unfiltered, avg temp requirement,
                           ,"0","0","4","4","0","0","0","0","1","1" \          ; 3day
avg anom ranking HW events
                           ,"0","0","1","1","2","4","2","0","0","0"/)

 matches_unfil_tave_max = (/"7","8","3","*","6","4","2","0","0","1" \          ; # of
matches of HW events based on unfiltered, avg temp requirement,
                          ,"0","0","4","1","0","0","0","0","2","1" \          ; max
temp ranking HW events
                          ,"0","0","2","1","1","2","2","0","0","0"/)

 latitude  = (/40.52, 40.15, 39.2, 38.52, 38., 37.65, 37.28, 36.77, 36.33, 35.42 \ ;
latitude coordinates for each station
            , 41.77, 40.9, 39.78, 38.43, 37.62, 36.6, 35.3, 34.42, 33.75, 33.23 \
            , 47.45, 47.62, 46.57, 45.4, 44.13, 42.38, 45.70, 44.85, 39.48, 38.07 /)
```

```
 longitude = (/-122.32, -122.25, -122.02, -121.5, -121.32, -121., -120.52, -119.72, -
119.3, -119.05 \        ; longitude coordinates for each station
           , -124.5, -124.5, -123.25, -122.5, -123.0, -122.3, -121.25, -119.0, -117.25,
-117.0 \
           , -121.9, -117.53, -120.55, -122.60, -123.22, -122.87, -118.85, -117.82, -
119.5, -117.02 /)

 do i=0,files-1
;  gsn_text (wks, plot, cities(i), longitude(i), latitude(i), txres)
;  gsn_text (wks, plot, norm_anom_avg(i), longitude(i), latitude(i), txres)
   gsn_text (wks, plot, Sacdates_norm_anom_avg(i), longitude(i), latitude(i), txres)
;  gsn_text (wks, plot, tmax_avg(i), longitude(i), latitude(i), txres)
;  gsn_text (wks, plot, matches_unfil_notave_3day(i), longitude(i), latitude(i), txres)
;  gsn_text (wks, plot, matches_unfil_tave_max(i), longitude(i), latitude(i), txres)
;  gsn_text (wks, plot, matches_unfil_notave_max(i), longitude(i), latitude(i), txres)
;  gsn_text (wks, plot, matches_unfil_tave_3day(i), longitude(i), latitude(i), txres)
;  gsn_text (wks, plot, " "+JJAS_SD(i)+" ", longitude(i), latitude(i), txres)
;  gsn_text (wks, plot, " "+tmax_avg(i)+" ", longitude(i), latitude(i), txres)
;  gsn_text (wks, plot, " "+tmin_avg(i)+" ", longitude(i), latitude(i), txres)
 end do

 frame(wks)
;***********************************************


end
```