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University of Redlands

**Walking Across Remote Terrain... Analysis of Potential  
Temperature-related Dangers Using GIS Tools**

A Major Individual Project submitted in partial satisfaction of the requirements  
for the degree of Master of Science in Geographic Information Systems

By  
Bess Kotsiras

Committee in charge:  
Sally Westmoreland, Ph.D., Chair  
Mark Kumler, Ph.D.

Walking Across Remote Terrain... Analysis of Potential  
Temperature-related Dangers Using GIS Tools

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Bessie Kotsiras

The report of Bess Kotsiras is approved.

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Mark Kumler, Ph.D.

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Sally Westmoreland, Ph.D., Chair

August 2006



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## ABSTRACT

### Walking Across Remote Terrain... Analysis of Potential Temperature-related Dangers Using GIS Tools

By  
Bess Kotsiras

Due to recent U.S. Border Patrol successes in stopping the flow of illegal migrants in populated areas, migrant attempts to illegally cross into the U.S. have shifted to more remote and more hazardous regions. As such, these have become areas of most concern to Border Patrol search-and-rescue teams, whose mission is to reduce the number of injuries and deaths in the southwest region, and are also of concern to private organizations with similar missions. This masters degree study project uses a scenario of helping estimate areas for rescue teams to focus their efforts in remote areas of San Diego County, California. The analysis utilized GIS tools to model the effects of temperature as a measure of danger to people crossing this region on foot, and who may be exposed to the outdoors for extended periods of time. This project introduces an approach to portraying the phenomenon of temperature in a way that might be considered dangerous to humans. The models developed could be refined with additional data sources, and could also be applied to other locations with some modifications.





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## List of Acronyms

BORSTAR	BSI Search, Trauma & Rescue teams
BSI	Border Safety Initiative
CASIL	California Spatial Information Library
CFCC	Census Feature Class Codes, from U.S. Census Bureau Tiger data
DFC	Departures from Comfortable, degrees departure from room temperature
DEM	Digital Elevation Model data
GA	Geostatistical Analyst extension, ArcGIS software
GIS	Geographic Information System
IDW	Inverse Distance Weighting
MIP	Major Individual Project
SAR	Search and Rescue activities
SCW	South Coast Wildlands
USATEC	U.S. Army Topographic Engineering Center
USBP	United States Border Patrol
USCBP	U.S. Customs and Border Protection
USGS	U.S. Geological Survey
WHR	California Wildlife Habitat Relationships data categorization system
WRCC	Western Regional Climate Center

# **1. Project Background**

## **1.1. Introduction**

The International Master of Science program in Geographic Information Systems (GIS) at the University of Redlands requires that all students undertake a major individual project which is client-based.

The objective of this masters degree major study project is to apply GIS analysis to help support U.S. Border Patrol (USBP) search-and-rescue teams identify potential hazardous areas on which to focus during their planning and operations activities. The project results are intended to augment existing tools the rescue teams use to anticipate areas where migrants may be in need of assistance. The project analysis primarily took into consideration environmental factors such as temperature, terrain, and land cover. It is hoped that the analysis results and tools developed for this project could be offered to search-and-rescue teams for their consideration and further refinement.

## **1.2. Background**

The Border Safety Initiative (BSI) is one of several missions which fall under the responsibility of the U.S. Border Patrol. The U.S. Border Patrol was recently reorganized under the new Department of Homeland Security as the U.S. Customs and Border Protection, Office of the Border Patrol. The U.S. Customs and Border Protection website describes the main objectives of the Border Safety Initiative as "...the reduction of injuries and the prevention of deaths in the southwest border region... the BSI is intended to educate and inform potential migrants of the dangers and hazards of crossing the border illegally and to respond to those who are in life-threatening situations" (U.S. Customs and Border Protection [USCBP], 2005).

Recent successes in border security operations near more populous areas of the southern border has pushed illegal migration flows into more remote and hazardous terrain in attempts to cross the border. Over the past five years, almost 2,000 people have died crossing the U.S.-Mexico border from all causes. Border Patrol agents have also rescued over 7,500 persons from dangerous high-risk areas (USCBP, 2005). Death by dehydration is not uncommon, as it is impossible for migrants to carry enough water during the multi-day trek across desert areas (Aceves, 2005). The Border Safety Initiative was implemented in 1998 in order to help educate potential migrants of the dangers and hazards of crossing the border illegally, and to respond to those who are in life-threatening situations (USCBP, 2005).

The BSI search, trauma & rescue teams (BORSTAR) area of responsibility is the entire U.S.-Mexico border region, which is comprised of approximately 2,000 miles of border area, and several miles north of said border. With such a large area of operation, USBP must carefully manage their search-and-rescue efforts. This analysis project proposes to develop geospatial models to assist BSI refine areas on which to focus BORSTAR resources by suggesting areas where people are most likely to travel through and areas which are also potentially the most dangerous. Deliverables will augment existing

BORSTAR analysis capabilities and will aid in the USBP's mission of reducing the number of illegal migrant deaths (USCBP, 2005).

### **1.3. Theoretical Context**

The theoretical context for this project is twofold: (a) The study will need to analyze optimal routes for routes over open terrain, as opposed to an analysis of routes over a defined network; (b) the study will also need to consider the effects of seasonal or climatic variations on the routes which are determined to be optimal. For an optimal route analysis, this study will need to assess which routes people are able to and also likely to traverse. Secondly, it will need to assess which of the likely routes, when influenced by weather related factors, might be considered the most hazardous.

There are several diverse examples of the general study of movement of populations over open terrain. A common environmental application, for example, would include the study of animal migrations trends. Animals seem to instinctively traverse across "least cost" routes, as determined by their own unique cost variables such as proximity to water sources during the trek, possibly the least difficult route, possibly a route which affords cover from the elements or from predators, possibly following routes herds had traveled before. One such example includes a study in Montana which applied weighted cost analysis to determine potential corridor routes of grizzly bear populations (Walker and Craighead, 1997).

Another example of the general study of movement across open terrain includes suitability analysis of terrain for cross-country movement of troops and military vehicles (U.S. Army Topographic Engineering Center [USATEC], 2005). During times of conflict, it may be necessary for the military to traverse off-road, rather than traverse over existing transportation routes. Each vehicle type and each troop grouping size may need to consider different cost variables for determining routes which are suitable or not suitable for them to traverse (U.S. Marine Corps, 2006). Weather-related variations may also influence which regions are suitable for each to traverse. Variables which would influence trafficability across terrain might include whether the vehicle is tracked or wheeled, the soil type, properties of the soil if precipitation occurs, amount of and types of vegetation (trees, grassland, etc.), drainage patterns in the region (are the banks steep? are the rivers fordable? etc.), elevation slope categories, and similar environmental variables.

The analysis of suitability of terrain for cross-country movement of troops and military vehicles might also consider factors such as height of vegetation, percent tree canopy closure, tree spacing, and similar variables which could influence their concealment and aerial detection. Concealment maps are commonly developed by Army engineers to depict areas for optimal concealment from overhead enemy flights (USATEC, 2005). Natural terrain features and vegetation features might be used by troops similarly to how illegal migrants might seek cover while trying to prevent detection and interdiction by border guards. Concealment factors were not considered as a variable for determining routes people might be inclined to use, though concealment factors may be important to consider in further studies. However, percent canopy closure was considered, along with vegetation type, to help determine the level of difficulty, or time cost, a traveler might expect to encounter walking through an area.

The application of GIS in search-and-rescue (SAR) operations is not new, and numerous examples exist. Erickson, Maggio, and Bednarz (1993) presented a paper discussing the use of GIS for wilderness search-and-rescue and included datasets such as vegetation, terrain, drainage and man-made features for the analysis. The Canadian Air and Marine Search and Rescue employs GIS as part of their activities (Payette and Wood, 1997). The University of Alberta developed a "...mobile GIS application that can serve as a decision support system for search-and-rescue missions in both urban and wilderness settings" (Heth, Cornell, and Dostatni, 2006). The use of GIS for U.S. Coast Guard SAR was presented during the 2004 ESRI User Conference (Netsch, 2004). GIS played a key role in the urban search-and-rescue operations of the World Trade Center disaster (Langhelm, 2002), and more recently, GIS helped to find flood victims of Hurricane Katrina in New Orleans (U.S. Geological Survey, 2006b).

#### **1.4. Project Overview**

This project aims to help estimate areas for search-and-rescue teams to focus their efforts within the vast remote areas north of the U.S.-Mexico border, in California. This study considered temperature as the measure of danger, and it sought to identify areas where temperature might pose the greatest threat to those walking through the remote regions.

Models were created to capture the analysis processes and to document data flows. Two primary models were developed to help answer the corresponding two analysis questions:

- (1) Where are the dangers? and,
- (2) Where do the people walk?

The results of these two analyses were then compared to find areas where they intersect. The intersections suggest areas where search-and-rescue teams may most likely find people who are in need of help.

GIS analysis was conducted using base geospatial data layers such as terrain, vegetation, hydrography, and other natural features to estimate areas where migrants would be most likely to traverse in this remote, largely unpopulated region. Temperature data was then used to determine which areas are the most hazardous based on excessively hot or cold temperatures experienced throughout the year. Average monthly minimum and maximum temperature values were used. The regions most likely to be traversed were then compared against regions with extreme temperatures in order to determine areas where people might be found in need of assistance.

The models could be refined with actual rescue information, to better project areas where people might be found in distress. The models could be expanded to consider effects of shifts from expected temperatures or other weather variables to estimate where people might be in need of assistance.

#### **1.5. The Study Area**

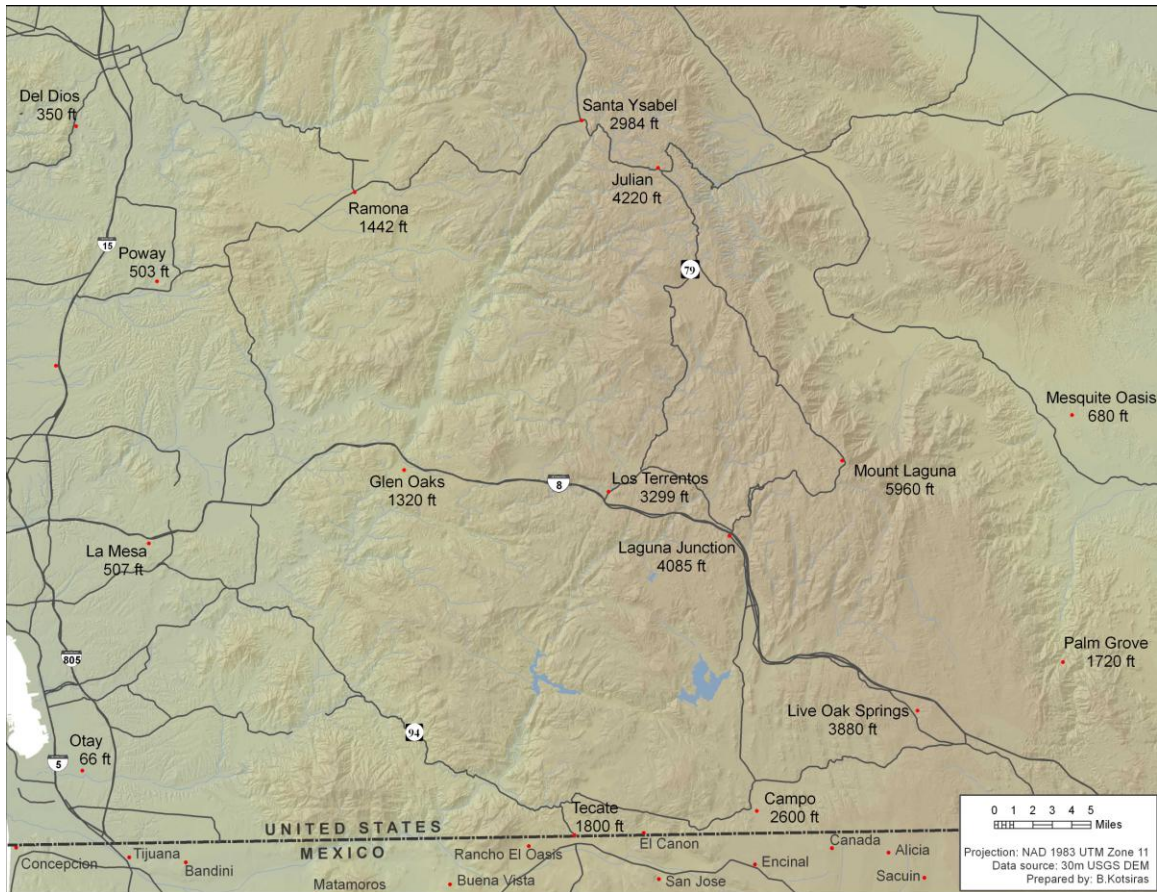
The study area for this masters degree major individual project (Figures 1-1 and 1-2) is approximately a one degree by half degree region north of the U.S.-Mexico border, and includes all of San Diego County, California.





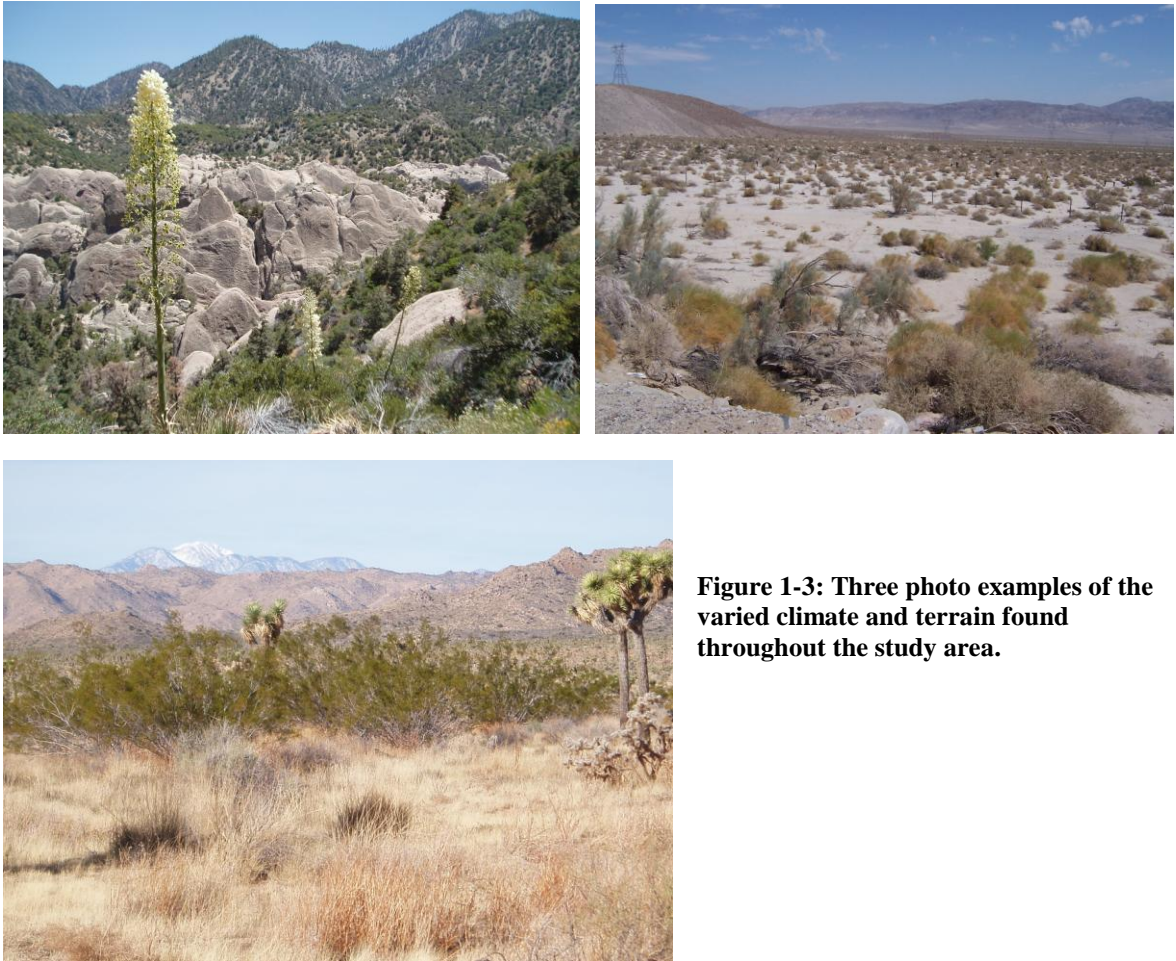
**Figure 1-1: Overview of the study area in southern California, indicated by black box.**

This region of southern California is bordered to the east by the low-lying, hot and arid desert climate of the Imperial Valley and Salton Sea. To the west is milder Mediterranean climate along the Pacific Ocean. The peaks of the San Bernardino and San Gabriel mountains lie to the north, and Mexico lies to the south. The tall peaks of the Laguna and Cuyamaca Mountains stretch north to south through the central portion of this area. These mountains and valleys are subject to extreme temperature fluctuations and sudden shifts in weather conditions, which can be dangerous to those who are not prepared (Smith, Upledger, Cooper, Akers and Murrin, 2001).



**Figure 1-2: Detailed map of the study area.**

Representative place names and their elevations were included in Figure 1-2 to show the broad range of elevations which exist, particularly east-to-west. The following photographs (Figure 1-3) provide ground perspectives of some terrain and climate types which can be found in the study area. They show examples of difficult terrain, such as arid desert climate regions found in the east, and mountainous areas in the central region which can experience snow during winter months.



**Figure 1-3: Three photo examples of the varied climate and terrain found throughout the study area.**

## **1.6. Project Budget**

The guidance received in regards to the scope of this major study project was to plan on a level of effort of approximately 500 total hours of work. This project was estimated to include the following tasks: requirements analysis, conceptual geodatabase design, data acquisition, geodatabase development, development of process flows, data analysis, refining models, and documentation. This project actually exceeded the original cost estimate by a few hundred hours over the course of the year. The overruns can be mostly attributed to refining the problem definition, data acquisition, and scope creep.

All data used in the analysis were available at no cost and were obtained from publicly available sources.



## 2. System and Database Design

### 2.1. System Environment

The process models for this project were developed using commercial ERSI ArcMap version 9.1 software and related software extensions on a Microsoft Windows XP laptop system. The models were developed using the ArcMap Model Builder utility, and they are sharable and transportable in the form of a model embedded inside a toolbox (\*.tbx) file.

### 2.2. Functional Requirements

The requirements identified for this project included the development of (a) diagrams depicting most likely migrant corridor regions, high-hazard border crossing regions, and also diagrams merging both to generate regions where people are most likely to be found in distress; (b) GIS ArcToolbox models to suggest areas for BORSTAR teams to focus search efforts; (c) a visualization of interpolated temperature data over time in their area of interest, along with other feature data in the same display. The development of a personal geodatabase to store all data and custom tools used for the analysis was also identified as a requirement.

### 2.3. System Architecture

#### 2.3.1. Data Summary

Table 2-1 summarizes the data sources used as the basis for this project. Derivatives of these source data are depicted in Figure 3-1, which shows an overview of the analysis approach.

**Table 1: Data summary.**

Data	Description	Source	Data Model	Type of Feature	Attributes
Temperature data archives	Monthly temperature statistics for selected weather collection stations	WRCC website	Data was compiled into tabular format, and converted into point vector	Discrete	Ave. monthly MAX, Ave. monthly MIN temperatures, and station location coordinates
Digital elevation model (DEM)	30 meter post spacing, used to derive % slope	USGS website, and Tijuana River Watershed Study data	Raster	Continuous	All
Digital elevation model (DEM)	10 meter post spacing, used to derive % slope	USGS website	Raster	Continuous	All
Landcover	Used for vegetation type categories for the corridor analysis	CASIL website, and Tijuana River Watershed Study data	Vector, polygon	Continuous	WHR13 values and Density values
Transportation, roads	Selected roads subset for analysis; Others subset for cartographic purposes	CASIL website, Tijuana River Watershed Study data, and ESRI CD	Vector, line	Discrete	4WD, and Major roads
Hydrology,	Used for corridor analysis and for cartographic purposes	CASIL website, and Tijuana River Watershed Study data	Vector, line and polygon	Discrete	All
State & country boundaries	For cartographic purposes	CASIL website, USGS website, ESRI CD	Vector, line and polygon	Discrete	Selected boundaries
Cities, Populated places	Primarily for cartographic purposes	CASIL website, USGS website, ESRI CD	Vector, point	Discrete	Selected place names

### 2.3.2. Data Acquisition

All data used for this project were obtained from open sources and at no cost. Data sources include the U.S. Geological Survey (USGS) website ([www.usgs.gov](http://www.usgs.gov)), the California Spatial Information Library (CASIL) website (<http://gis.ca.gov/data.epl>), the Western Regional Climate Center (WRCC) website ([www.wrcc.dri.edu](http://www.wrcc.dri.edu)), base data from ESRI data CDs, and data which supported the Tijuana River Watershed project (National Ocean Service, 2004) courtesy of University of Redlands MS GIS instructor Clint Cabanero and South Coast Wildlands (2005).

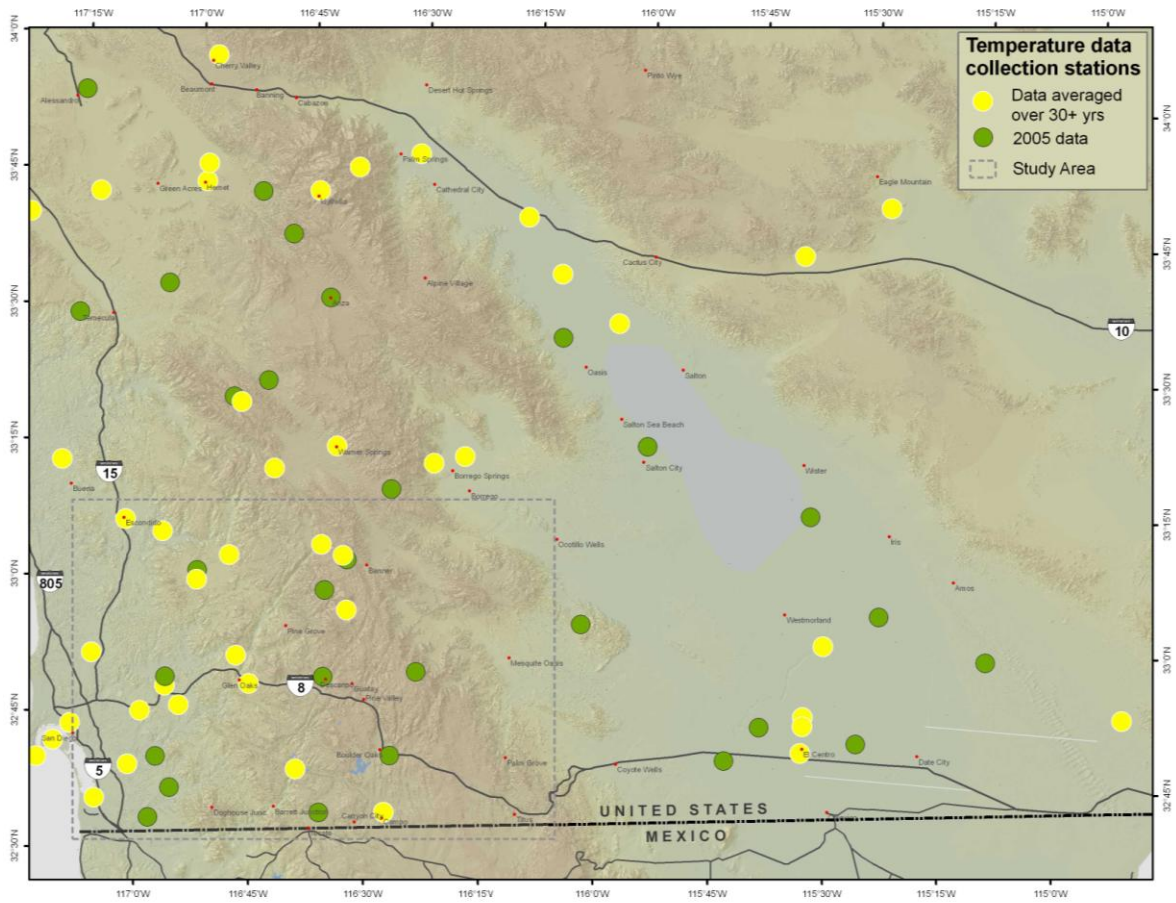
### 2.3.3. Base Data

Base datasets include original data obtained which was later modified to be used as inputs to analysis models developed for this study, such as elevation, vegetation, road and hydrology data. Base GIS datasets also include data which were primarily used for cartographic purposes to display analysis results, for example, place names and boundaries datasets.

### 2.3.4. Temperature Data

Point temperature data were obtained from weather collection station archives available from the Western Regional Climate Center (Western Regional Climate Center [WRCC], 2006a). The point data was the basis for creating interpolated temperature surfaces, which were stored and symbolized into an animated series for display. The interpolated surfaces were then reclassified into departures from room temperature, in order to reveal areas potentially dangerous to people exposed to those temperatures over extended periods of time.

Temperature data from a total of 73 weather collection stations were used for this study (Figure 2-1). Forty-five of the data points were based on data that was averaged over approximately 30 years; those points were then densified with data from additional collection stations which had temperature averages based only on a one-year period, the year 2005.



**Figure 2-1: Temperature data from 73 weather collection stations were used.**

The cokriging method of interpolation was used to generate temperature surfaces from point weather data. An advantage of using the cokriging method is that it allows additional spatial variables to be introduced during the interpolation process in order to produce better estimations of a surface. In order to generate reasonable results, cokriging requires many more input data points than regular kriging or other methods of interpolation. For this study, elevation data was used to influence the results of temperature data surfaces generated from the weather station data. Interpolation methods are discussed in greater detail in Section 3.2.2.

From the temperature data collected, this study used two temperature statistics data values for “average monthly maximum” and “average monthly minimum” temperatures as inputs to the cokriging interpolation processes. Those two statistics were selected so that subsequent analysis could consider the range of temperature highs and lows experienced during different periods, since the range of temperatures experienced may best reflect possible danger to humans.

The temperature data collected from WRCC were not available in a format which could be directly input into the interpolation tools. Formatting the data into tables which were suitable as inputs for the ArcGIS tools required quite a bit of effort. The process of

acquiring point temperature data, putting the data into table formats suitable for input to the cokriging tools, and then converting the data tables into shapefiles required approximately 60 hours of effort for all 73 weather collection station data points.

Monthly average precipitation data were also collected from WRCC, anticipating that precipitation data might also be used as an analysis variable if time permitted. The precipitation data were collected at the same time as the temperature data were collected, and minimally increased the overall time required to capture weather related data. However, it was later determined that the introduction of a third variable increased the processing time required by the cokriging GIS tools, and would demand more time than was available to complete this project in the given timeframe. Precipitation data were subsequently not used.

### 2.3.5. Cost Surface Data

Cost surface data were used to estimate corridors where people would most likely travel through during their journeys northward from the U.S.-Mexico border. The corridors represent areas of least overall cost based on the following primary factors, all of which represent natural phenomena: percent slope, vegetation, proximity to dirt roads, and proximity to water bodies. All data used in this study were available at no charge from public sources. Made-made phenomena which could influence preferred routes were not considered, though a discussion of factors which could have also been considered is included in Section 6, Further Work.

Cost surface data were those which could be directly used as inputs to the Model Builder corridor models which were developed. Cost surface data included base data which were subsequently modified, reclassified or otherwise reformatted for inputs to the cost surface model. For example, the cost surface vegetation data input was derived from base vegetation raster datasets which were edited and then reclassified for use as inputs to the corridor model. As another example, the cost surface data for proximity to dirt roads were derived from base road data. Four-wheel drive (4WD) road category data were subset from base input road data, and then Euclidian distances were determined from the selected road data. The corridor model factor for proximity to dirt roads was estimated using the resulting Euclidian distances values.

California multi-source land cover data were obtained from the CASIL website and used as a surrogate for vegetation data sources for the corridor model (California Spatial Information Library [CASIL], 2006). The CASIL data vegetation type and density values were combined into a new field, which was used as the basis to reclassify vegetation into cost factor categories to indicate the level of difficulty for a person to walk through each type-density combination.

Thirty-meter and ten-meter resolution digital elevation model data (DEM) were retrieved from USGS, and percent slope was derived from the elevation data using spatial analysis tools. The ArcGIS Spatial Analyst Slope function calculates a slope value for every cell in the output raster based on the maximum change in elevation between the cell and its eight surrounding neighbors. The lower the value assigned, the flatter the terrain; the higher the value, the steeper the terrain (McCoy, Johnson, Kopp, Borup, and Willison, 2004).

The resulting slope raster datasets were then reclassified into cost categories to represent estimated time for a person to walk up or down the percent slope category assigned to each raster grid cell. The slope reclassification process used for this analysis is discussed in Section 4.4.2.2.

Though two resolutions of DEM data were obtained, the lower resolution thirty-meter DEM data was used in order to first establish the models and to confirm the analysis proof of concept. If time permitted, higher resolution ten-meter DEM data could be easily substituted into the models to refine the process results. However, the higher resolution DEM data would also increase the overall time required to generate the many interpolated temperature surfaces, and would also increase, to a lesser degree, the time required to generate a more refined percent-slope raster layer.





### 3. Analysis

#### 3.1. Analysis Approach Overview

This project considered *temperature* as the measure of danger for people walking through the remote regions of the study area. The GIS tools and process flows aimed to find where temperature might pose the biggest threat to people. The analysis results could offer search and rescue teams suggestions about where to search the vast remote areas for people who may need aid.

In order to help answer that question, the analysis steps need to include the following two component questions: (a) Where do the dangers exist? and (b) where do the people walk? It is in the intersection of these two areas where search teams would be most likely to find people who might be in distress.

The diagram below (Figure 3-1) provides a graphical description of the primary analysis workflows conducted for this project.

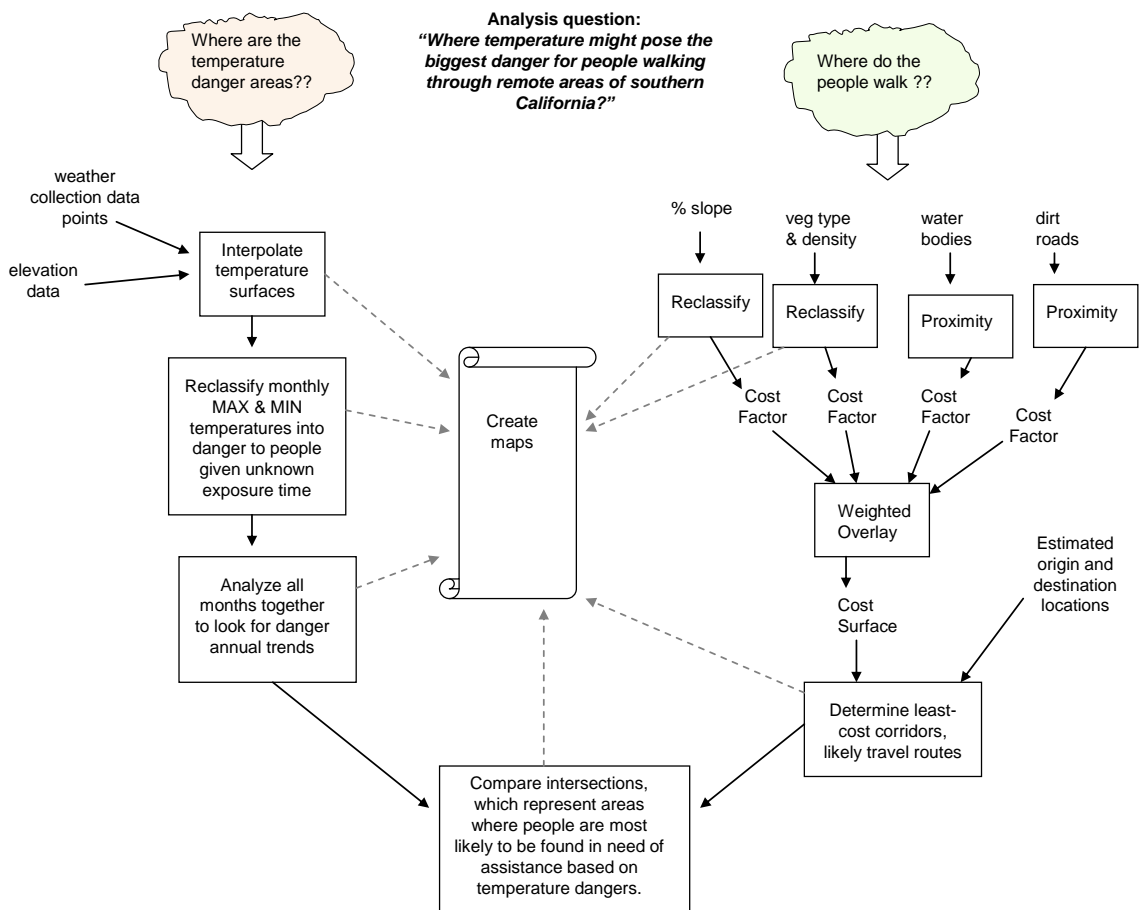


Figure 3-1: Analysis steps overview.

## 3.2. Summary of Analysis Tools and Techniques

### 3.2.1. Model Builder

ESRI ArcMap Model Builder tool was used as much as possible in order to automate some of ArcMap tool interfaces, to document steps used for the analysis, and to facilitate re-running some process with adjustments to parameters or using new input datasets.

### 3.2.2. Interpolating Surfaces

Interpolation is a process of generating a continuous surface by estimating data values for areas that can not be sampled (Fraczek, March 2006). A common GIS example is interpolating surface terrain from digital elevation sample points. “It can be used to predict unknown values for any geographic point data: elevation, rainfall, chemical concentrations, noise levels, and so on” (McCoy et al., 2004, p.135). Several methods, or models, are available to predict surface values. These include deterministic methods which use mathematical functions such as inverse distance weighting (IDW) and spline, and also include geostatistical methods which rely on both statistical and mathematical methods, such as kriging (McCoy et al., 2004, p.96).

Deterministic interpolation techniques, such as inverse distance weighting use a simple spatial autocorrelation algorithm based on distance. With IDW, closer sample point values influence the value at a prediction location more than sample locations further away. Geostatistical interpolation techniques such as kriging and cokriging use more complex spatial autocorrelation algorithms which incorporate spatial statistics about the measured data to create surfaces. Cokriging methods are able to predict surface models based on more than one variable to improve surface results (Johnston, Ver Hoef, Krivoruchko, and Lucas, 2004).

For this study, ESRI Geostatistical Analyst extension (GA) was used to interpolate temperature surfaces from point data obtained from weather collection station data archives (WRCC, 2006). ESRI Spatial Analyst extension also provides tools to generate interpolated surfaces, though cokriging methods are only available in the Geostatistical Analyst extension. Cokriging method was preferred for this study because it allows the inclusion of more than one data set to influence the results of the temperature surfaces generated.

“Surface prediction using cokriging: Cokriging, an advanced surface modeling method included in Geostatistical Analyst, can be used to improve surface prediction of a primary variable by taking into account secondary variables, provided that the primary and secondary variables are spatially correlated....Geostatistical Analyst contains a number of unique tools to improve prediction....” (Johnston et al., 2004, p.7).

To create the predicted temperature surfaces, elevation data was used as an input source in addition to the point temperature data in order to generate better surfaces results. Elevation is a reasonable secondary variable to use in cokriging because it is spatially correlated to temperature. For example, it is reasonable to expect that as one drives up a mountain road, the temperature at higher elevations would, in general, be different than temperatures experienced at lower elevations.

Though the cokriging tools allow several input variables, only temperature and elevation data were used for this study due to time constraints. The use of additional variables, such as precipitation or wind speed and wind direction, may have further refined the temperature surfaces generated.

The Geostatistical Wizard, depicted in Figure 3-2 below, was the primary Geostatistical Analyst extension tool used to interpolate temperature surfaces.

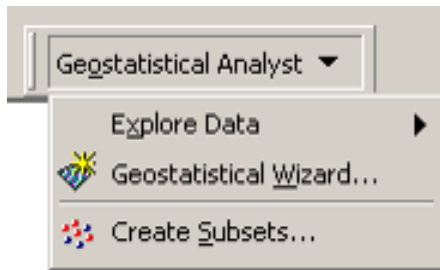


Figure 3-2: Geostatistical Analyst extension toolbar.

The Geostatistical Analyst tool defaults seemed to produce reasonable results for the temperature surfaces. Using default parameters resulted in root mean square standardized values (RMSS) generally fairly close to "1", and mean values generally fairly close to "0", which are indications of reasonable results, as discussed in the ArcGIS 9 Geostatistical Analyst extension tutorial handbook. An RMSS value close to *one* indicates low variability in the predicted values, and a mean prediction error value near *zero* indicates that the prediction errors are unbiased (Johnston et al., 2004, p.190).

The following window (Figure 3-3) shows a cross-validation step example of applying the Geostatistical Wizard against November average maximum point temperature values to create a temperature surface, and accepting most of the default tool values.

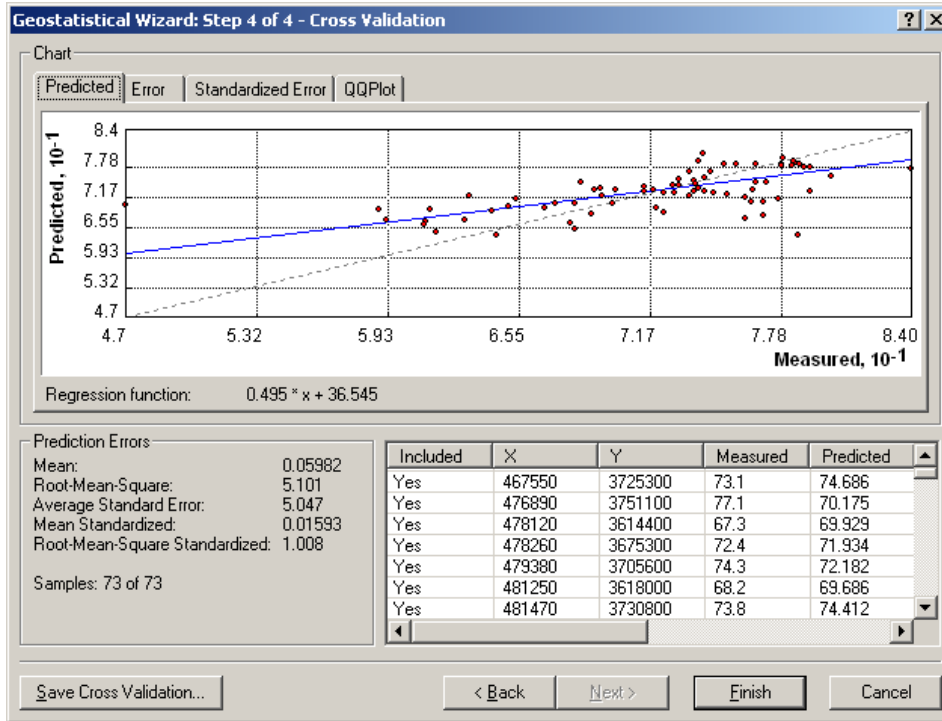


Figure 3-3: Geostatistical Wizard, Cross-Validation step example.

The geostatistical surface results were then converted into raster data types so they could be used as inputs to other processes. Figure 3-4, below, shows an example cokriging interpolation result after the resulting temperature surface was symbolized.

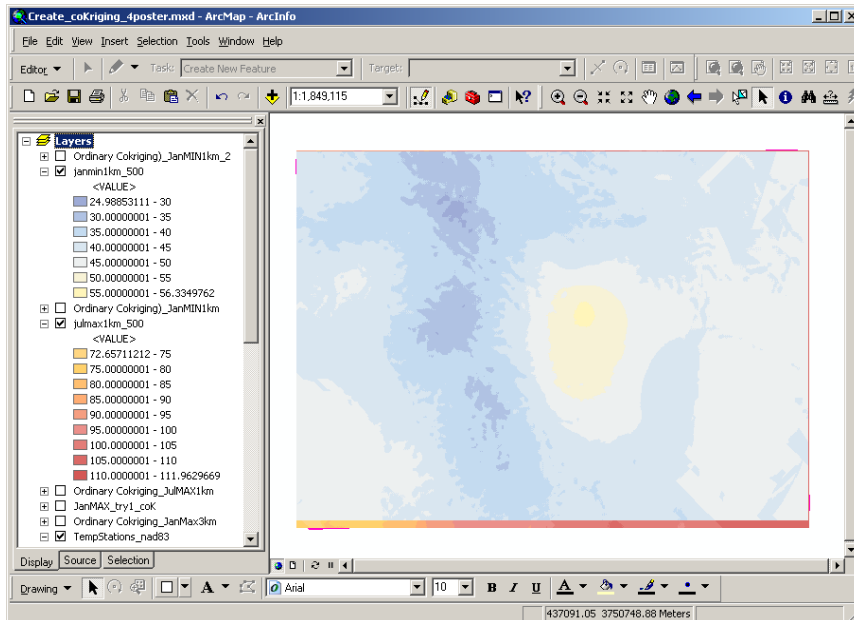
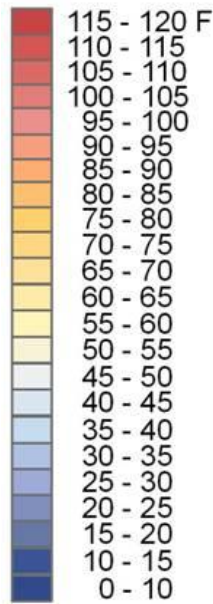


Figure 3-4: Interpolated surface for January minimum average monthly temperatures.



**Figure 3-5: Temperature surface legend.**

The raster temperature surfaces then needed to be symbolized such that the same colors would be applied to the same range of temperature values for all maps produced. In order to do that, a template layer file (\*.lyr) was created which could then be imported into each raster surface's symbol properties. The template layer file consisted of the maximum range of all possible temperature values which existed in this particular data set, representing all months.

The standard tools available in ArcGIS do not offer a straightforward method to create a template color legend which can be applied to several raster datasets. A template \*.lyr file was needed to represent the maximum range of all possible temperature values which might occur over the course of a year for this study area. In order to create a template \*.lyr file which could be used to create a common legend, the following steps describe the workaround which was used.

A template raster dataset was created by running the Euclidean distance tool using an arbitrary feature dataset as input, and setting the maximum distance to 120, using any unit of distance, because 120 is the maximum temperature range value for the entire set of data. The resulting Euclidean distance output raster dataset, which was comprised of raster cells whose data values ranged between 0 and 120, was then symbolized into ranges corresponding to 5-degree temperature increments, as shown in Figure 3-5.

A total of 23 colors were needed for this color ramp, and it required much experimentation in order to get colors which were distinguishable, visually pleasing, and which also relayed a sense of increasing hot and cold temperatures.

Once the color ramp was created, the symbolized template raster dataset was then saved as a layer file (\*.lyr). The resulting \*.lyr file would then be available to import into other raster datasets symbol properties, ensuring that the same colors from the legend are applied to the same range of temperature values, regardless of which range of temperature values actually existed for that particular month's temperatures.

This technique of creating a template layer file was also used for subsequent analysis steps. Specifically, in the next step of analysis, the temperature surfaces were recoded to represent levels of danger to humans when exposed to those temperatures for an unknown length of time. The workaround symbolization technique described above was applied to the recoded temperature surfaces.

Section 4.2 provides more detail about the temperature-related analysis steps used in the model.

### 3.2.3. Corridor Analysis

The corridor portion of the analysis attempted to estimate areas where people would be most inclined to walk based on the minimal time cost to travel from a given source to a

given destination. A detailed discussion about the corridor analysis data and model is included in Section 4.4.

Two ESRI Spatial Analyst “Distance” tools, “Cost Distance” tool and “Corridor” tool, were used to estimate corridors where people would be most likely to travel. The Corridor tool requires two cost distances as inputs; the two cost distances used were created using the Cost Distance tool. The Cost Distance tool requires a cost surface as an input; the cost surface used was created as a result of a model developed using Model Builder. The cost surface model used input datasets for each of the four primary cost factors considered: (a) the estimated cost to travel through percent slope categories, (b) the estimated cost to travel through specific vegetation type and density categories, (c) proximity to dirt roads, and (d) proximity to water bodies such as rivers and lakes.

The following two portions of maps (Figures 3-6 and 3-7) show the results of reclassifying the percent slope data and the vegetation data into cost values as preparation for inputs to the cost surface. Both figures below focus on the map legends to provide more details about the resulting maps. The entire map for each is included in Appendices E and F. Detailed discussions about the corridor analysis used to produce both maps are included in Section 4.4 of this paper.

Figures 3-6 and 3-7 show the results of reclassifying the percent slope data and the vegetation data, correspondingly, into cost values. Both reclassification results were then used as inputs to generate the cost surface. Both figures show only a subset of the entire reclassification results, and zoom in around the map legend areas. The entire map for each of these two examples is included in Appendices E and F.

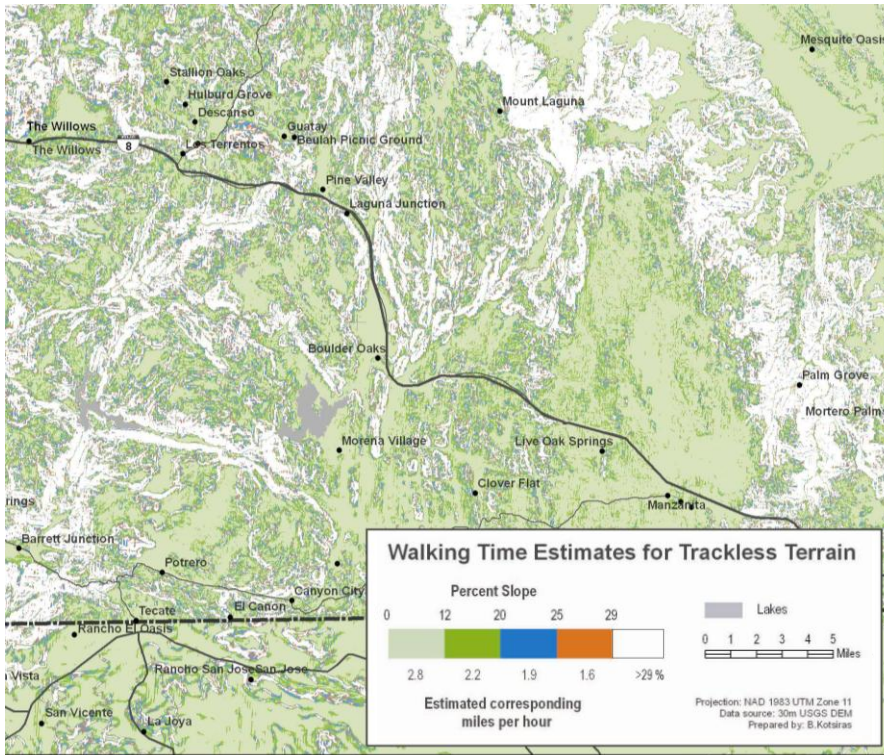


Figure 3-6: A portion of the map resulting from reclassifying percent slope data into cost values.

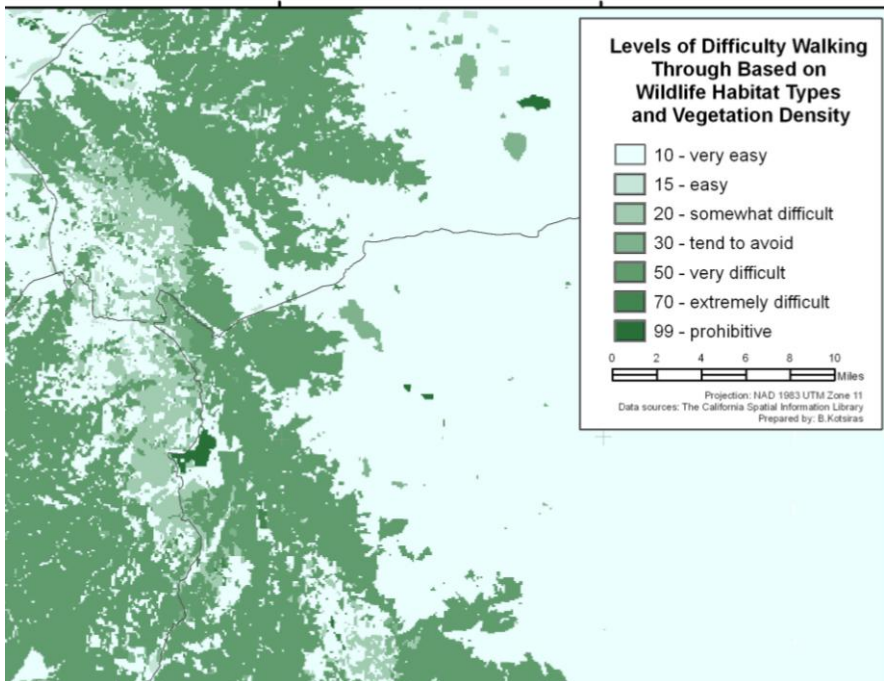


Figure 3-7: A portion of the map resulting from reclassifying vegetation into cost values.





## 4. Process Models

### 4.1. Preprocessing data for input to the temperature model

ArcGIS Model Builder was used as much as possible in order to capture and automate most analysis steps performed. One model was also developed for a portion of the analysis to determine areas considered to be the most consistently dangerous over time, using temperature as the measure of danger (See Appendix A). A second model was developed to estimate areas where people might be most inclined to travel based on least overall costs, and is referred to as the cost surface model (See Appendix B).

For the danger related portion of the analysis, point temperature data were used to interpolate temperature surfaces. Geostatistical Analyst toolbar extension was used to interpolate the surfaces. Because the Geostatistical Analyst interpolation tools are only available as a toolbar, and are not available in the standard toolbox set, a custom script would need to be developed to be able to use the GA interpolation tools inside a Model Builder model. Rather than develop a custom script to model the cokriging steps, the interpolation of surfaces from point data was performed as a preprocessing step outside of the temperature model.

Figure 4-1 shows the first window of the Geostatistical Analyst Wizard tool. This window allows the user to select the input data sources, and also allows the user to select the interpolation method to for the wizard to use. Cokriging method was used to interpolate all 24 temperature surfaces, two for each month, one based on average monthly minimum temperature and the other based on average monthly maximum temperature data values.

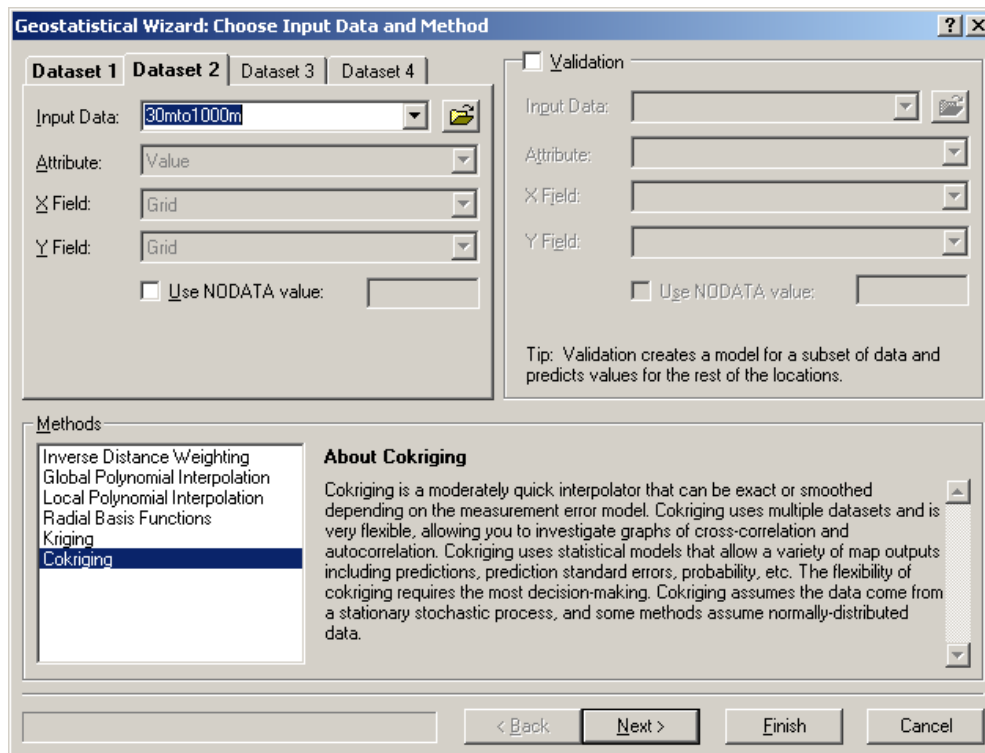


Figure 4-1: Geostatistical Analyst Wizard, defining input data sources and method.

All cokriging processes used the same elevation dataset as a secondary input data source. Initially, 30 meter resolution DEM data (U.S. Geological Survey, 2006a) were used as the elevation dataset. However, using the 30 meter DEM resulted in very long processing times to interpolate temperature surfaces using a laptop computer. The elevation data was then resampled to 300 meter resolution, and then again resampled to 1000 meter resolution, and again tested for the amount of processing time required to generate the cokriging temperature surfaces. It was determined that processing would only be completed in a reasonable amount of time on a laptop computer using the 1000 meter resolution elevation data. Better interpolated temperature surface results could have been achieved by using 300 meter or 30 meter resolution elevation data as the secondary variable, however, the 1000 meter resolution data was sufficient for developing a proof of concept for the overall study approach.

Users of the Geostatistical Analyst (GA) tool should "...be aware that by using (a second input dataset, in this case elevation data, in addition to the temperature point data), you are forcing the GA to analyze trillions and trillions of points (raster cells) to find correlations, errors, and to fit a variogram...." (Fraczek, July 2006). Therefore, the higher the resolution elevation data used, the more amount of processing the GA tool will be required to do, and much longer overall processing times should be anticipated.

Figure 4-2 shows an example cokriging surface result for the month of January, based on average monthly maximum temperatures. The symbol colors and classes shown were automatically generated and are typical of GA tool results.

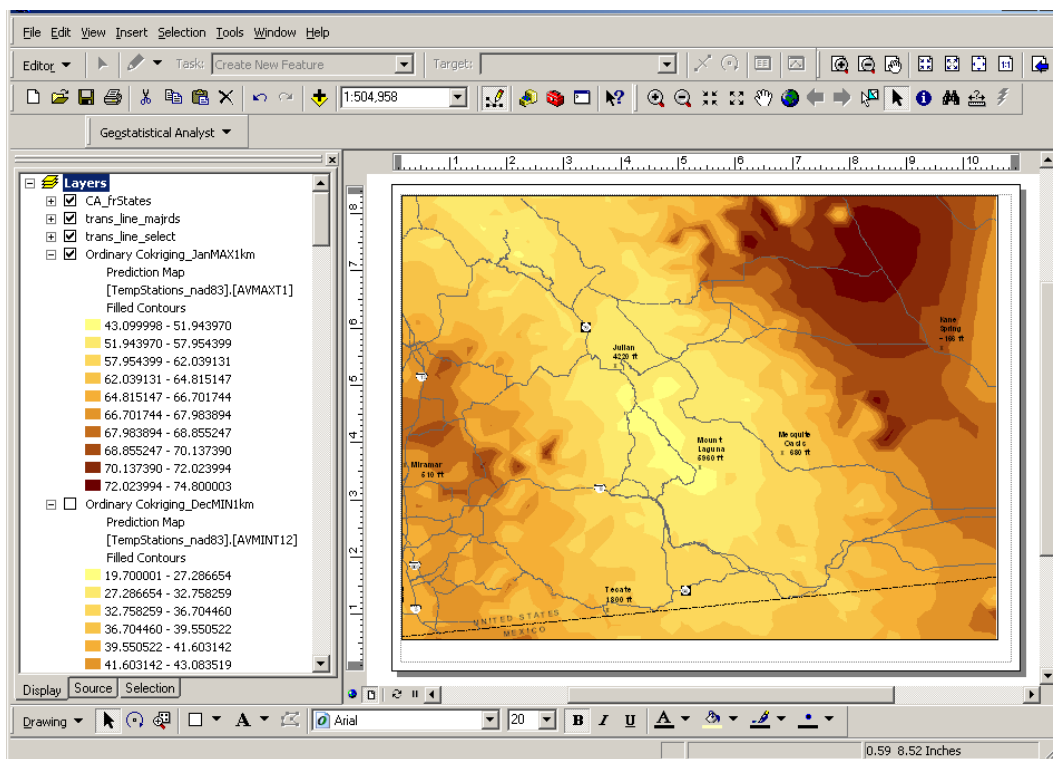


Figure 4-2: Cokriging surface result for January average monthly minimum.

After determining that temperature surfaces interpolated by the GA tool were acceptable, the geostatistical layer results then needed to be converted into standard data formats so that they could be used as inputs to subsequent GIS processing steps. The geostatistical layer data format is discussed in Section 4.2.2. Figure 4-3 shows data export options, available by right-clicking on a geostatistical layer in the ArcGIS layers legend. All cokriging temperature surface results were exported to raster format. Section 4.2.2 discusses the concept of a geostatistical layer in more detail, and also discusses an ArcGIS Toolbox tool available to help automate the conversion of geostatistical layers to standard GIS data formats.

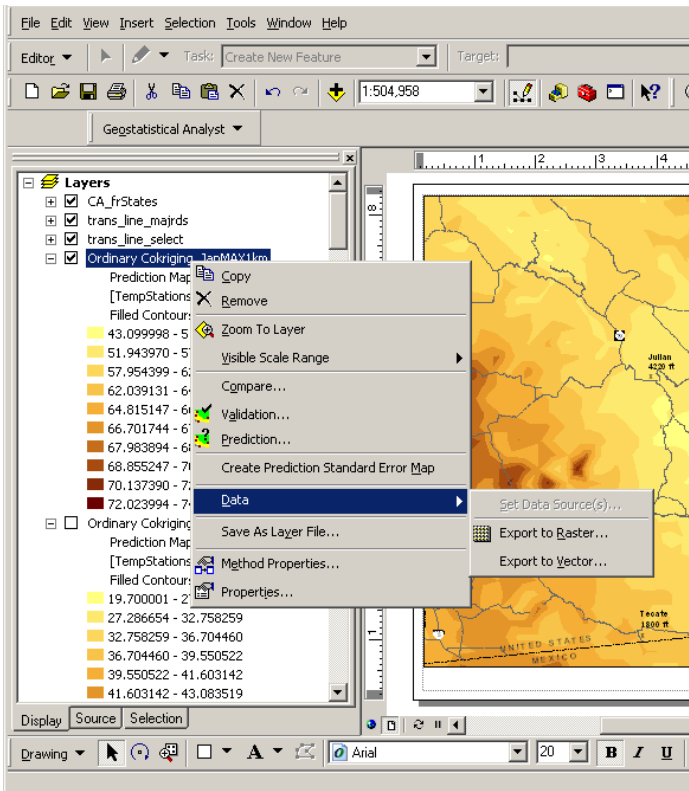


Figure 4-3: Geostatistical Analyst data export options.

## 4.2. Temperature Model

### 4.2.1. Objectives

The first major analysis question was to determine where the danger areas were located, using temperature as the measure of danger. The objectives of the temperature model were to first convert the cokriging surface results into raster grids, and to then reclassify the raster results into categories which would reflect levels of danger to humans when exposed to the various temperatures for unknown lengths of time.

#### 4.2.2. Discussion

The temperature model employed two ArcMap tools available from the standard toolbox: “Geostatistical Layer to Grid” and “Reclassify” tools, as seen in the figure below.

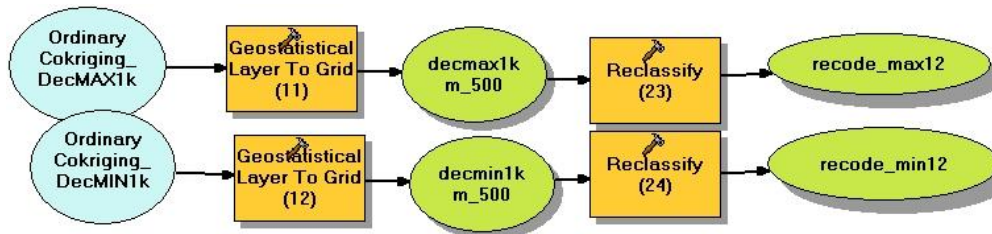


Figure 4-4: Temperature model steps for December.

The “Geostatistical Layer to Grid” tool which was used in the temperature model, depicted in Figure 4-4, is available from the ArcGIS Geostatistical Analyst Tools toolbox, “GA Layer To Grid”, as shown below in Figure 4-5.

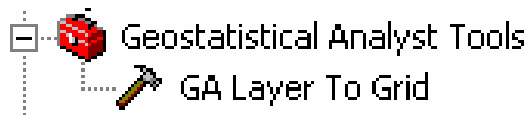


Figure 4-5: GA toolbox tool.

The Geostatistical Analyst tool creates a surface type which is unique to the GA extension, and which allows for exploration of the surface results (Johnston et al., 2004). ArcGIS Desktop Help also explains that data layers created by the Geostatistical Analyst tool differ from raster or vector data formats: “A geostatistical layer can only be created by Geostatistical Analyst. Most ArcGIS layer types store the reference to the data source, the symbology for displaying the layer, and other defining characteristics. A geostatistical layer stores the source of the data from which it was created (usually a point feature layer), the symbology, and other defining characteristics, but it also stores the model parameters from the interpolation. From the Properties dialog box for a geostatistical layer, you can view both the original data source and the model parameters” (ESRI, 2005).

In order to be available as inputs to other analysis steps, the GA tool geostatistical layer results needed to be converted into raster data formats. The “Geostatistical Layer to Grid” tool was used in the temperature model to automate the conversion of each of the twenty four temperature surfaces generated by the GA tool into raster grid format.

For cartographic purposes, each raster grid result was saved and symbolized into a series of map temperature surfaces over time. Appendix G contains all symbolized average monthly maximum and average monthly minimum temperature maps which were created.

While the average monthly minimum and maximum temperature maps provide a general sense of hot areas and cold areas locations, they do not necessarily reveal where danger areas are located. It is not easy to discern from these maps the hot or cold regions that people, many of whom are unprepared, need to be most concerned about if they are going to be walking outside for extended periods of time,.

The next process in the temperature model was to reclassify the temperature surfaces in such a way as to represent danger to people, and more specifically, danger to people who might be exposed to those temperatures for an unknown amount of time.

The reclassification scheme needed to consider that there are a variety of types of people who attempt these journeys - some are old, some are young, some are in good shape, some are in poor shape. The scheme also needed to consider an unknown range of time that people might be exposed to the varying temperatures. Many people who are unprepared may be exposed to the elements for several days.

Hypothermia and hyperthermia, which are respectively a dangerous decrease or increase in body temperature, can occur as a result of many factors (MERCK, 2006). Some environmental factors include the surrounding temperature, wind speed, and the amount of humidity, precipitation or wetness a person is exposed to. Other variables include a person's age, health, clothing (number of layers, type of material, whether it is loose fitting or snug, etc.), amount of food and fluids consumed, amount of alcohol consumed, whether the person is stationary, in motion, or exerting energy strenuously.

Because factors which may cause hypothermia and hyperthermia are so variable, and data difficult to obtain, temperature was the only variable considered as the measure of danger for purposes of this study. Wind speed, wind direction and precipitation were not considered for two primary reasons: (a) data needed to support those additional factors were not consistently available for all weather collection stations, and (b) the scope of the analysis would have extended beyond the total estimated hours allocated for this project.

In general, people are most comfortable over extended periods of time at room temperature. Therefore, deviation from room temperature was used as the basis for the temperature reclassification scheme to indicate a measure of potential danger to humans. The recoded temperatures will reflect degrees departure from comfortable (DFC), using room temperature as the zero-basis, as shown in Figure 4-6. Some literature defines room temperature to be 68-77°F (Houghton Mifflin Company, 2004), or between 69-73 degrees (Wikipedia, 2006). This study defined room temperature to be between 65-70°F.

The recoding scheme reflects deviations from room temperature, or deviation from comfort for each raster cell, for each of the twenty-four periods considered.

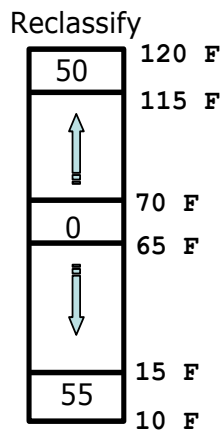


Figure 4-6: Temperature recoding scheme.

A diagram of the complete recoding scheme used for the temperature surfaces is included in Appendix D, Table 6. The reclassified temperature values were categorized into five-degree increment departures from the zero-basis for comfortable (room temperature). For example, 10 degrees warmer departure from comfort (DFC) was recoded to be the same value as 10 degrees cooler departure from comfortable.

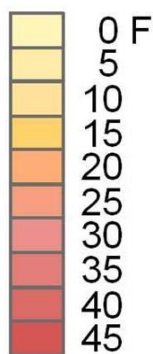
#### 4.2.3. Model diagram and results

A diagram of the complete model used to process the temperature surfaces is included in Appendix A.

Maps were created for all reclassified temperature surface results, using reclassifications based on both the average monthly maximum and the average monthly minimum temperatures. The resulting maps effectively showed where the highest dangers existed during daytime and during nighttime for each month. As with the original temperatures, a total of 24 reclassified temperature maps were created, and are available in Appendix H.

The reclassified degrees departures from comfort (DFC) temperature maps visualize where temperature dangers are most prevalent throughout different times of the year. During January through April, the mountains experience extreme DFC temperatures during nights; In May and June, extreme DFC temperatures appear in the desert during the day and in the mountains during nights; July and August see temperature extremes throughout the study area during days. Starting in September, the most extreme DFC temperatures occur again in the mountains during nights; by December, extreme DFC temperatures occur throughout the study area during nights. The results show where temperature dangers are for any given month, and effectively where dangers are during day or night for each month.

As with the original set of raster temperature surface results, the reclassified temperature surfaces needed to be symbolized such that the same colors would be applied to the same range of DFC danger values for all maps produced, regardless of whether the new danger surface was based on average monthly minimum or on average monthly maximum temperatures.



A method to symbolize the reclassified surfaces was developed similar to the method discussed in Section 3.2.2, in which a generic template layer file (\*.lyr) was created for importation into each raster surface's symbol properties. The template layer file consisted of the maximum range of degrees departure from comfort values which existed across all months. Figure 4-7 shows the color ramp legend used for all surfaces which were reclassified based on DFC values. The color ramp used a total of ten DFC categories, and each category represented a five-degree increment departure from comfort. Figure 4-8 shows an example of the color ramp applied to January minimum DFC temperature values.

**Figure 4-7: Reclassified temperature surface legend.**

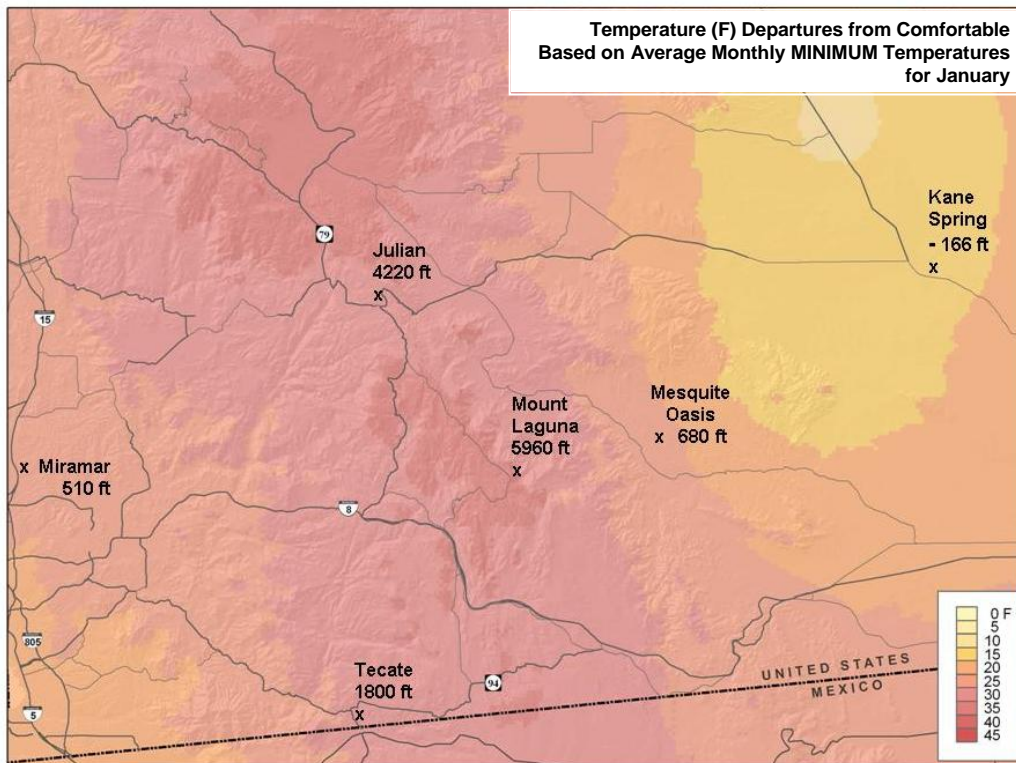


Figure 4-8: Reclassified temperature surface example.

#### 4.2.4. Summarizing the temperature model results over time

The next step in the danger analysis was to summarize where temperature related dangers were most prevalent during a one-year period, and to provide an approximation of duration or frequency of extreme temperature danger periods which could be anticipated at each location across a one-year period.

For example, one location might experience “the most” extreme temperatures, but for only one month out of the year, while another location might experience similarly dangerous temperatures, though slightly below the most extreme temperatures, and for several months of the year. A method was needed to distinguish areas which might be consistently dangerous over time. This could be considered analogous to analyzing the effects of flooding on agricultural crops. Crops may be able to survive some flooding for short periods of time, but are less likely to survive if exposed to flooding over long periods. For this study, it was important to be able to distinguish the intensity, frequency, and duration of the temperature dangers.

Examining frequency and duration of temperature extremes may reveal areas where search-and-rescue team resources should focus their efforts throughout the year, or where they might consider staging emergency equipment and supplies during various parts of the year.



Two methods were used to summarize levels of temperature-danger over time, and both are discussed below. Both methods produced fairly similar estimations of the most hazardous areas where people are likely to traverse over the course of a year.

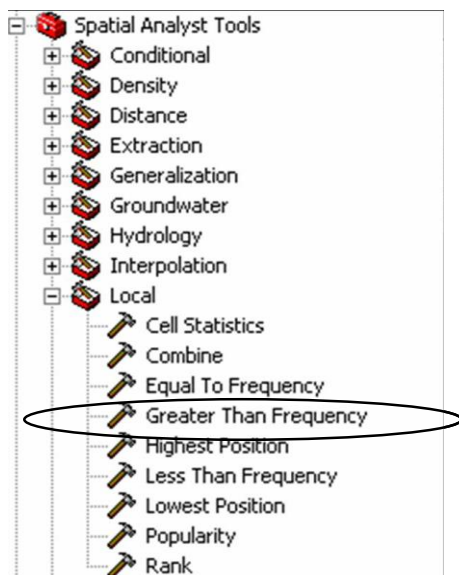
#### 4.2.4.1. Method one

The first method made use of the Greater Than Frequency tool available in the Spatial Analyst toolbox, shown in Figure 4-9. The Greater Than Frequency tool accepts as input any number of raster datasets and returns a grid with counts of occurrences within each cell slide of values which were greater than a specified input threshold value.

For this analysis, all 24 DFC temperature surfaces were used as inputs to the Greater Than Frequency tool, and input threshold values of 10, 20 and 30 degrees departures from comfortable were examined.

In the resulting output raster dataset, each cell represents the number of month periods in a year during which that cell's average monthly maximum or average monthly minimum temperatures exceeded room temperature by a given input threshold value. For example, using an input threshold value of 10 degrees, the value in each output raster cell would represent a count of number of month periods which had DFC values greater than 10, or, in other words, the count of month periods whose average monthly maximum or average monthly minimum temperature was either 10 degrees hotter or 10 degrees colder than room temperature. For any given output raster cell, a maximum count of 24 month periods could exist, one for each DFC surface input.

The following three maps (Figures 4-10 through 4-12) show the results using input threshold values of 10, 20 and 30 degrees departures from comfort and using all 24 DFC temperature surfaces as inputs. The legend used for all three maps below was created using the same cartographic process as described Section 3.2.2 (Figure 3-5) and in Section 4.2.3 (Figure 4-7), and it considered the maximum range of month period counts exceeding all threshold values to incorporate into one common legend.



**Figure 4-9: One tool used to examine duration and frequency of temperature danger areas during all months.**

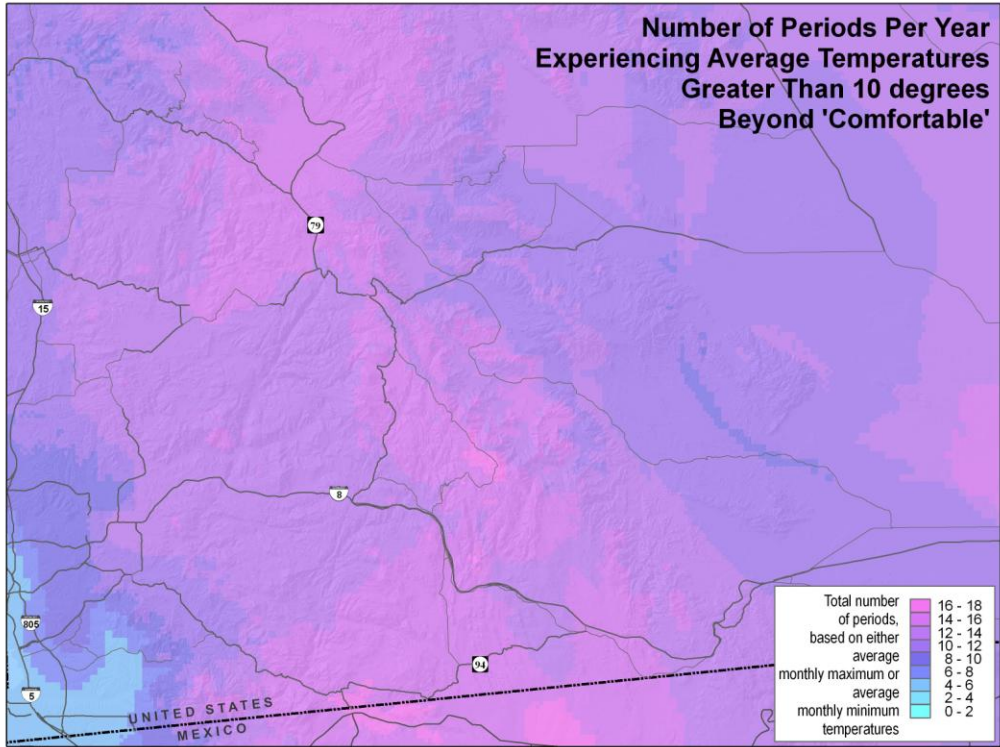


Figure 4-10: Greater Than Frequency tool with 10 degree DFC threshold input value.

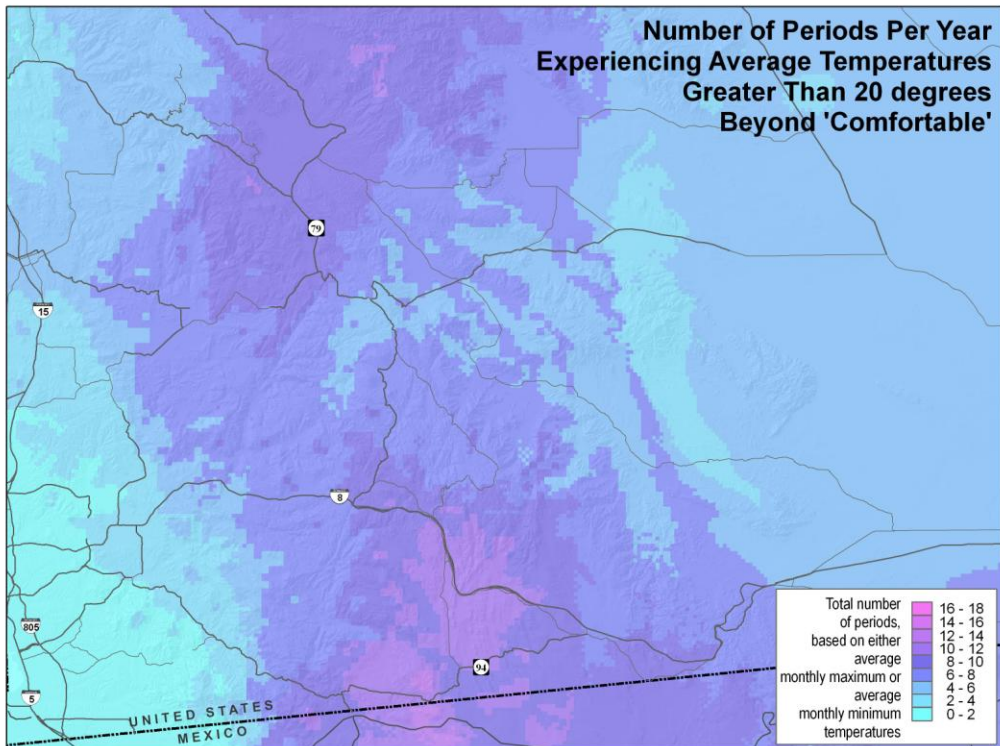
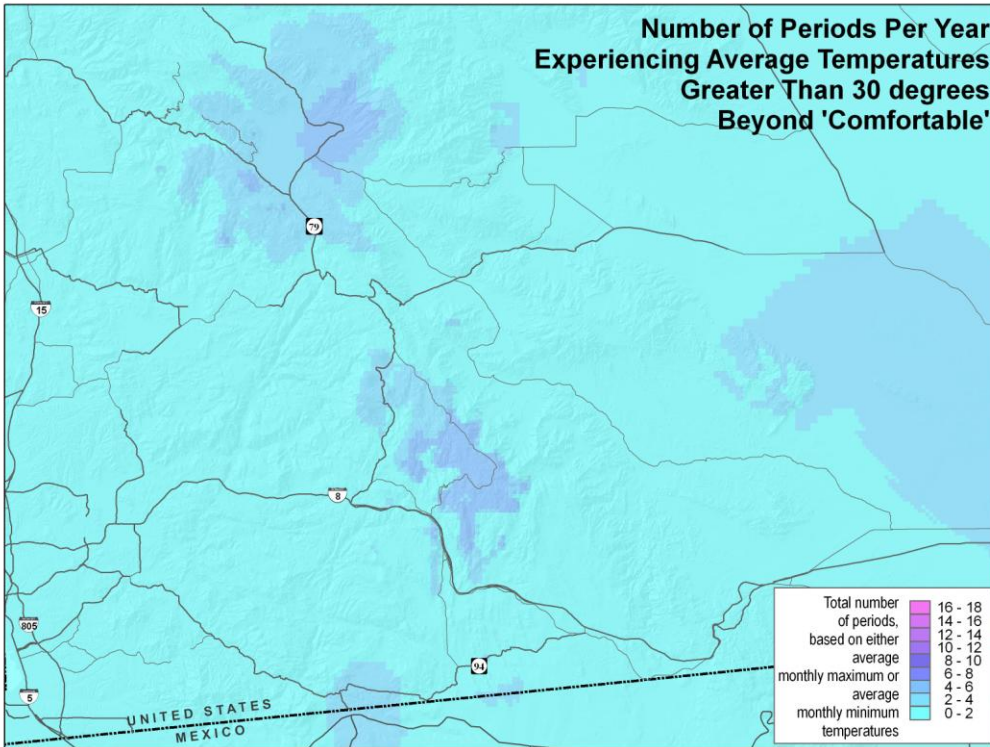


Figure 4-11: Greater Than Frequency tool with 20 degree DFC threshold input value.



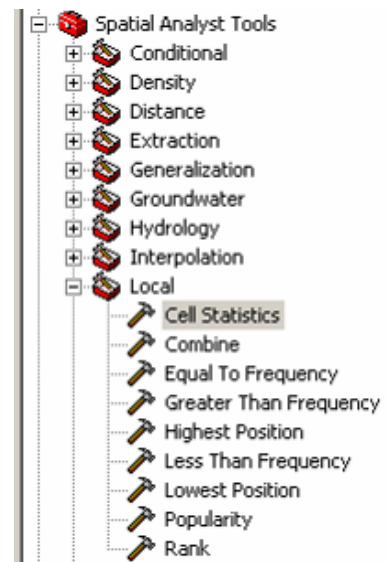
**Figure 4-12: Greater Than Frequency tool with 30 degree DFC threshold input value.**

Examining all three map results above, the mountainous regions seem to experience the most extreme temperatures over the course of a year, and primarily in the regions which follow Highway 79 north to south.

#### 4.2.4.2. Method two

The second method used to provide a sense of duration or frequency of the temperature extremes across all months was to sum all DFC values for each raster cell, and then symbolize the resulting sums into ten equal interval classes for display. The DFC raster datasets were summed using the Cell Statistics tool, which is available in the Spatial Analyst Tools, “Local” standard toolbox (Figure 4-13).

The result of summing all twenty-four DFC periods is shown in Figure 4-14. The areas which experience the most extreme temperature dangers across all months using this method is similar to results using the Greater Than Frequency tool. The highest danger areas primarily fall in the mountainous areas in a north to south angle, following the general trend of the elevation, and along the Highway 79 corridor.



**Figure 4-13: Sum all DFCs with Cell Statistics tool.**

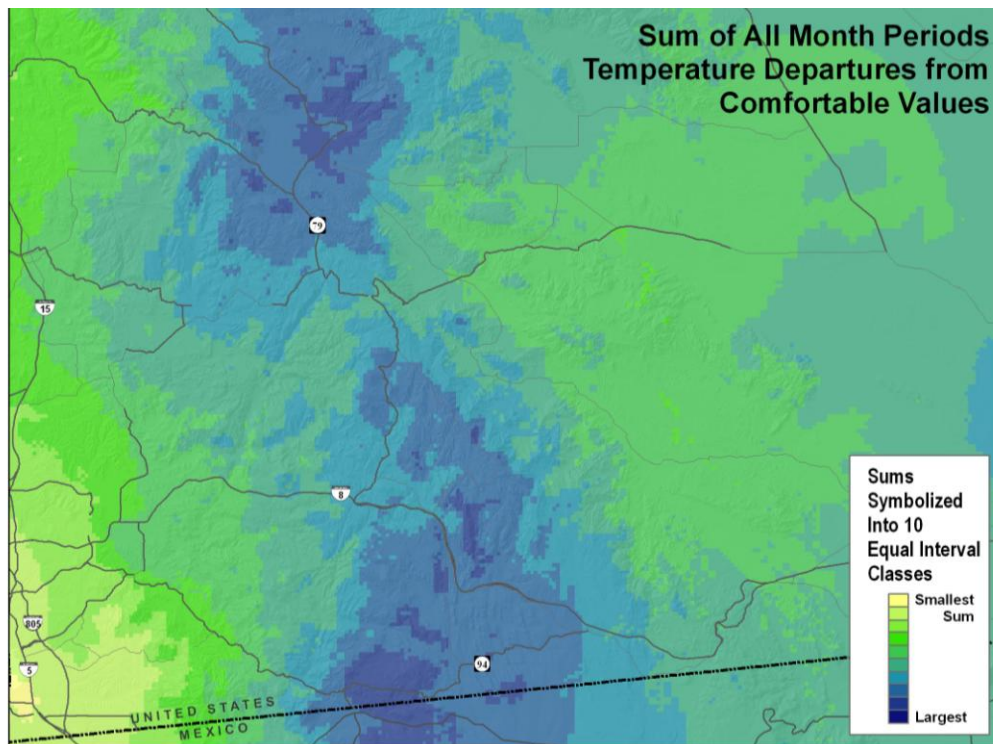


Figure 4-14: Sum of DFC surfaces.

### 4.3. Preprocessing data for input to the corridor model

The preprocessing steps required for data used as inputs to the corridor model mainly consisted of filtering or selecting a subset of the base data based on certain attribute values.

From the road features base datasets, only dirt roads were selected to perform proximity operations on using the model. Dirt roads include all roads having Census Feature Class Codes (CFCC) type values A50, A51, A52, and A53, which are all “Jeep trail, passable only by four-wheel drive (4WD) vehicle...” (TopoDepot, 2006).

From the hydrologic features base datasets, perennial and intermittent water bodies were included in the proximity portion of the corridor analysis; bays and oceans were used to mask out results from other portions of the corridor analysis, as those areas were considered prohibitive to travel through. The hydrologic features types used for this study project included those with the following CFCC type values (TopoDepot, 2006):

- H00 - Water Feature, Classification Unknown or Not Elsewhere Classified
- H11 – Perennial stream or river
- H12 – Intermittent stream, river or wash
- H31 – Perennial lake or pond
- H32 – Intermittent lake or pond
- H41 – Perennial reservoir
- H51 - Bay, estuary, gulf or sound
- H53 - Sea or ocean

## 4.4. Corridor Model

### 4.4.1. Objectives

The second major analysis component of this study needed to estimate regions where people are most inclined to walk through as they journey from anywhere along the border to places north. It is the intersection of these regions and the high-danger areas where Border Patrol search-and-rescue teams would most likely find people who are in need of help.

### 4.4.2. Discussion

The general process used for this part of the analysis is similar to other corridor analysis studies (Walker and Craighead, 1997; Parrish, Parkinson, and Ramseth, 2005). In the ESRI Advanced Spatial Analyst course lecture book, Childs and Kabot (2001) provide discussions about the ArcMap toolbox tools available (Figure 4-15), and a diagram similar to Figure 4-16 outlining the general process flow used to determine least cost corridors.

Model Builder was again used as much as possible in order to capture the process steps performed, and to document parameters used. The primary objective of the corridor model was to develop a cost surface to be used as an input to the Cost Distance tool and subsequently to the Corridor toolbox tool.

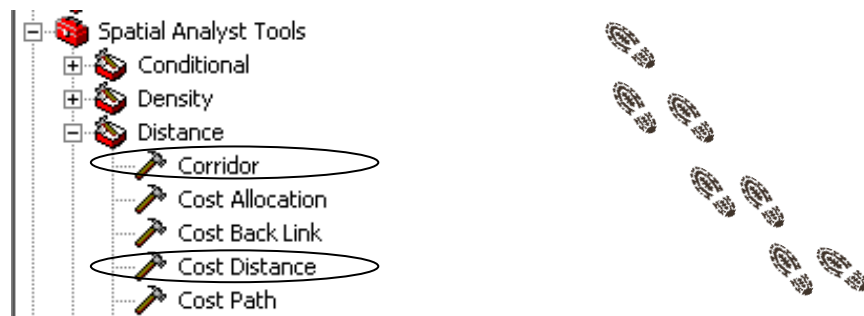


Figure 4-15: Toolbox tools used for to determine least cost routes.

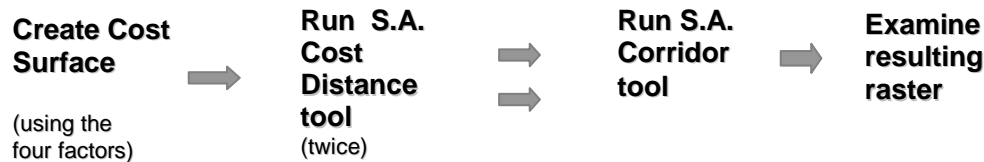


Figure 4-16: Process flow overview to determine least cost corridor regions.

4.4.2.1. Vegetation corridor factor.

“Vegetation” was one of the four factors used to create a cost surface, and reflects a time cost, or difficulty factor, for someone trying to walk through different vegetation types and densities. Figure 4-17 shows some example vegetation types which can be found in the study area. Additional photo examples of the terrain and vegetation are available in Section 1.5, which provides an overview of the study area climate.



Figure 4-17: Vegetation examples include oak woodland, mixed grassland, chaparral, and grassland.

Data used for the vegetation factor were obtained from the California Spatial Information Library. Specifically, landcover datasets “fveg02\_2\_37g” and “fveg02\_2\_13g” for San Diego and Imperial counties, respectively, were used (CASIL, 2006).

Wildlife Habitat Vegetation Type (WHR13) categories from those datasets were used for the vegetation cost factor. The WHR13 categories include thirteen major habitat type classes, which are listed in Table 2 (CASIL, 2006).

Table 2: WHR13 vegetation type categories.

(fveg02_2_metadata.txt)	
FIELD NAME: <b>WHR13NUM, WHR13NAME</b>	
WHR13NUM	WHR13NAME
-----	-----
10	Agriculture
20	Barren/Other
31	Conifer Forest
32	Conifer Woodland
41	Desert Shrub
42	Desert Woodland
51	Hardwood Forest
52	Hardwood Woodland
60	Herbaceous
70	Shrub
80	Urban
90	Water
100	Wetland

Table 3: WHR vegetation density categories.

(fveg02_2_metadata.txt)	
FIELD NAME: <b>WHRDENSITY</b>	
WHRDEN_NUM	DESCRIPTION (WHR_RANGE)
-----	-----
0	None
1	10 to 24%
2	25 to 39%
3	40 to 59%
4	60 to 100%

Density values from the fveg02\_2 datasets were also incorporated into the vegetation cost factor. Metadata describes the California Wildlife Habitat Relationships System (WHR) Density attribute as being “...cross-walked from various sources...” (CASIL, 2006). The density number codes and their corresponding density range values are listed in Table 3.

The two-digit vegetation WHR13NUM “type” values were concatenated with the one-digit vegetation WHRDEN\_NUM “density” values using ERDAS Imagine software. ArcMap version 9.1 software was found to be limited in its ability to edit raster data, whereas ERDAS Imagine software was easier to use and it also preserved all non-edited attribute fields of the raster data.

Using Imagine software, a new “RECODE” field was created for the vegetation raster datasets, and values for the new field were populated with the three-digit concatenated type-density values for each raster grid cell. Figure 4-18 shows window snapshots captured while editing the vegetation raster dataset using ERDAS Imagine software. It shows the Edit drop-down menu, Formula window and the formula which was used to populate new RECODE raster cell field values as follows:

$$(\$\"WHR13NUM\" * 10) + \$\"WHRDEN\_NUM\"$$

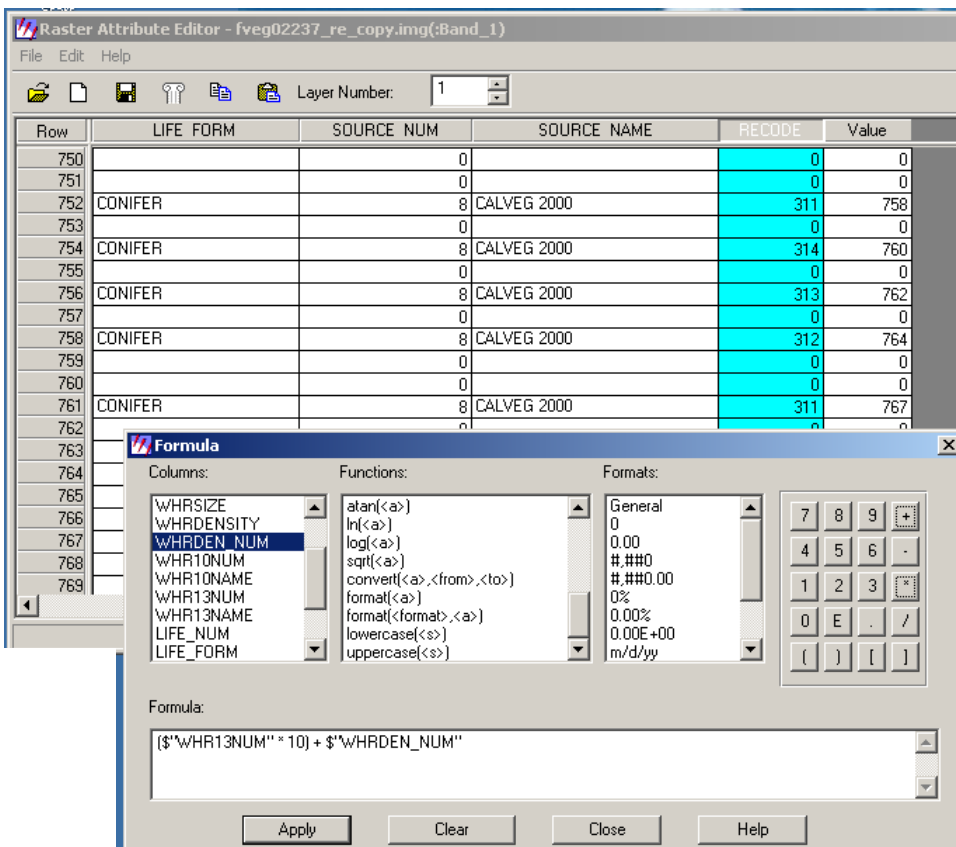


Figure 4-18: Editing WHR vegetation data using ERDAS Imagine software.

The new RECODE field was then used as the basis for reclassifying vegetation into estimated levels of difficulty for someone to walk through it. The reclassification into difficulty levels, or impedance cost factors, was performed using standard ArcMap Toolbox tools, and is captured in the corridor analysis model.

Appendix D, Item 5 lists the complete recoding scheme which was used to convert the concatenated WHR13NUM-WHRDEN\_NUM values into vegetation cost factor values for input to the cost surface. The cost values assigned to each vegetation type-density combination were based on a consensus of available subject experts with field experience. The difficulty ratings were assigned informally though they reflect the knowledge and experiences of people who were familiar with the study region and with the vegetation types found there.

4.4.2.2. Slope corridor factor.

Thirty-meter resolution DEM elevation data were converted into percent slope using Spatial Analyst extension tools, and was done outside the corridor model. The slope conversion process could have alternately been added to the corridor model using the Slope tool available in the Standard Toolbox toolset. The resulting percent slope raster surface represents the maximum change in elevation from each cell to each of its neighboring cells (McCoy et al., 2004).

The percent slope raster dataset then needed to be reclassified into slope cost values for input to the overall cost surface. The reclassification scheme used was based on a study by Thomas Balstrom (2002). The diagram below (Figure 4-19) was taken from Balstrom’s paper, and summarizes his research. In his study, Balstrom tabulated the time it took for subjects to walk up and down trackless mountain terrain of varying slope categories, and each track was consistently measured to be 30 meters in length. The table summarizes the time to walk up or down each percent slope category, and the values were averaged to represent the estimated time to pass through a five-meter cell. The time to walk across a slope, such as along lines of similar elevation, is accounted for by the “0-12%” category in Figure 4-19. Balstrom’s table was used as the basis for reclassifying the percent slope values in the study area.

<b>Table 1. - (Balstrom, 2002)</b>	
<b>Slope in %</b>	<b>* Time in seconds</b>
0-12	4
12-20	5
20-25	6
25-29	7
29-30	8
30+	9999

\* Time spent walking up- or downhill through a 5 metre cell. Please note that an interval of 0-12 means from 0 to just less than 12.

Figure 4-19: Summary of Balstrom's slope cost estimates.

4.4.2.3. Proximity to water bodies factor.

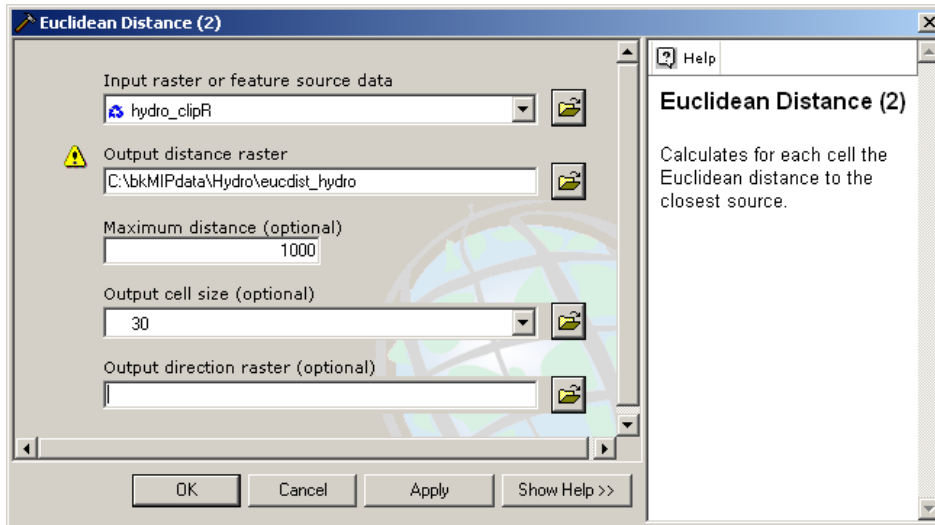
The “hydrology” portion of the corridor model consisted of two parts: (a) The model considered proximity to perennial and intermittent water bodies, and (b) it also added large friction values for water bodies. The model analysis related to hydrology features is shown in the complete Cost Surface model diagram in Appendix B.



Section 4.3 lists the hydrology features which were selected for the proximity portion of the model. The analysis assumed that people would be more inclined to walk near water sources because access to water could assist in their survival, and during dry seasons, areas of intermittent waterways might offer easier routes to walk through.

Proximities to water bodies were assigned cost values as follows:

Line and polygon hydrology feature types for San Diego and Imperial counties were each merged and clipped to the study extents. Euclidian distances from all hydrology features were determined using Spatial Analyst Tools, Distance, Euclidian Distance tool, as shown in Figure 4-20.



**Figure 4-20: Euclidian Distance tool used to determine proximity to water bodies.**

The resulting Euclidian distance raster surface was then reclassified into cost values based on logarithmically increasing costs with increased distance from water bodies. For example, areas within 200 meters distance from a water body were favored as having the lowest friction costs. Areas beyond 1,000 meters distance from water bodies resulted in raster surface values “NoData,” and were weighted with the highest costs. The complete reclassification scheme used is included in Appendix D, Item 2.

Friction, or cost, values were assigned to the water bodies themselves as follows:

Intermittent water (H12, H32) was assigned lower cost values than those assigned to perennial water bodies (H00, H11, H31, H41) using the assumption that intermittent features would generally be less difficult to cross, regardless of time of year.

Though perennial water bodies were assigned high friction values, they were not considered to be impassable. People might be able to cross perennial waterways if they have access to boats, inner-tubes or other floatation devices, or if weather conditions are such that water levels become low enough to successfully cross through.

Bays, estuaries and oceans (H51, H53) were the only water bodies which were considered impassable for purposes of this study, and were assigned extremely large cost factors.

#### 4.4.2.4. Proximity to dirt roads factor.

The portion of the corridor model which considered proximity to dirt roads was similar to that used for proximity to water bodies. The analysis assumed that people would be more inclined to walk near dirt roads because walking near paved roads might prove too risky, and may not offer sufficient concealment from detection. Walking near dirt roads, however, may afford less likelihood of detection while also offering easier paths through rugged terrain.

Dirt roads include roads with CFCC type values A50, A51, A52, and A53 (TopoDepot, 2006). Dirt road features were selected from the roads dataset and clipped to the study area extents. Euclidian distances were then determined using Spatial Analyst Tools, Distance, Euclidian Distance tool. The resulting Euclidian distance raster surface was then reclassified into cost values which increased logarithmically as distance from dirt roads increased, similar to the reclassification scheme used for proximity to water bodies. The scheme used to reclassify the dirt road Euclidian distance values into cost values is included in Appendix D, Item 1. The model steps related to proximity to dirt roads is included in the cost surface model shown in Appendix B.

#### 4.4.3. Model diagram and results.

The cost surface was created using the Spatial Analyst Map Algebra tool to sum up the costs associated with each of the four primary input factors: cost to walk up or down a slope, cost to walk through each vegetation type-density category, proximity to dirt roads, proximity to water bodies. Figure 4-21 shows the Map Algebra tool steps used to sum all cost factors to create an overall cost surface.

The resulting cost surface raster dataset represents the relative cost to travel through each raster cell, based on all the input factors considered.

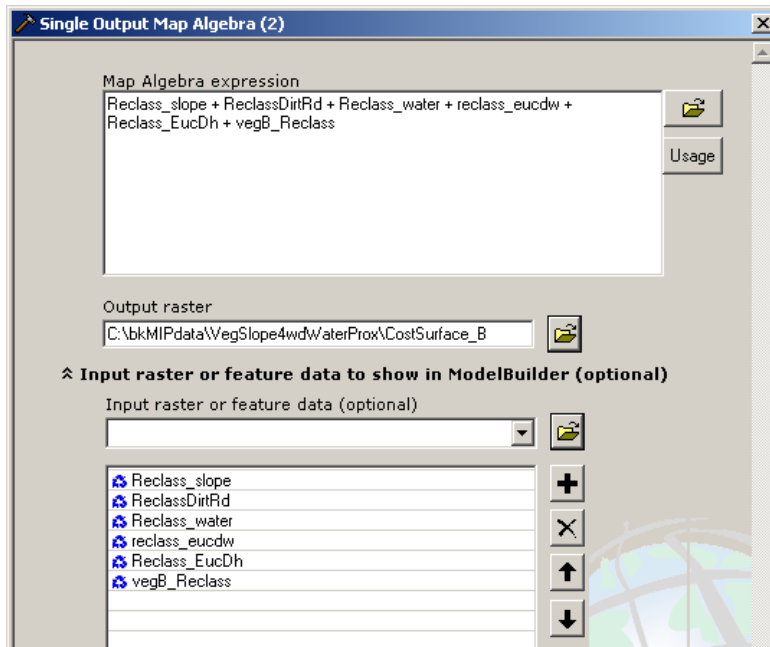


Figure 4-21: Creating the cost surface using Map Algebra tool.

A diagram of the complete Model Builder model used for the corridor portion of this analysis is included in Appendix B.

Figure 4-22 shows the raster dataset output from the Corridor tool and depicts an example corridor. The extents of the example corridor can be modified by manually adjusting the raster data symbol properties to define specific percentiles of the data. In the example shown, a break value was arbitrarily set to 27 percent, though that value is not significant. For corridor analysis related to animal migrations, corridor percentiles are often adjusted to meet minimum width criteria required by various migratory animals. However, no minimum width criteria were associated with people migrating in this region. The corridor examples depicted in this study should only be considered to be general trends of areas where people may be most likely to travel through based on the cost surface factors.

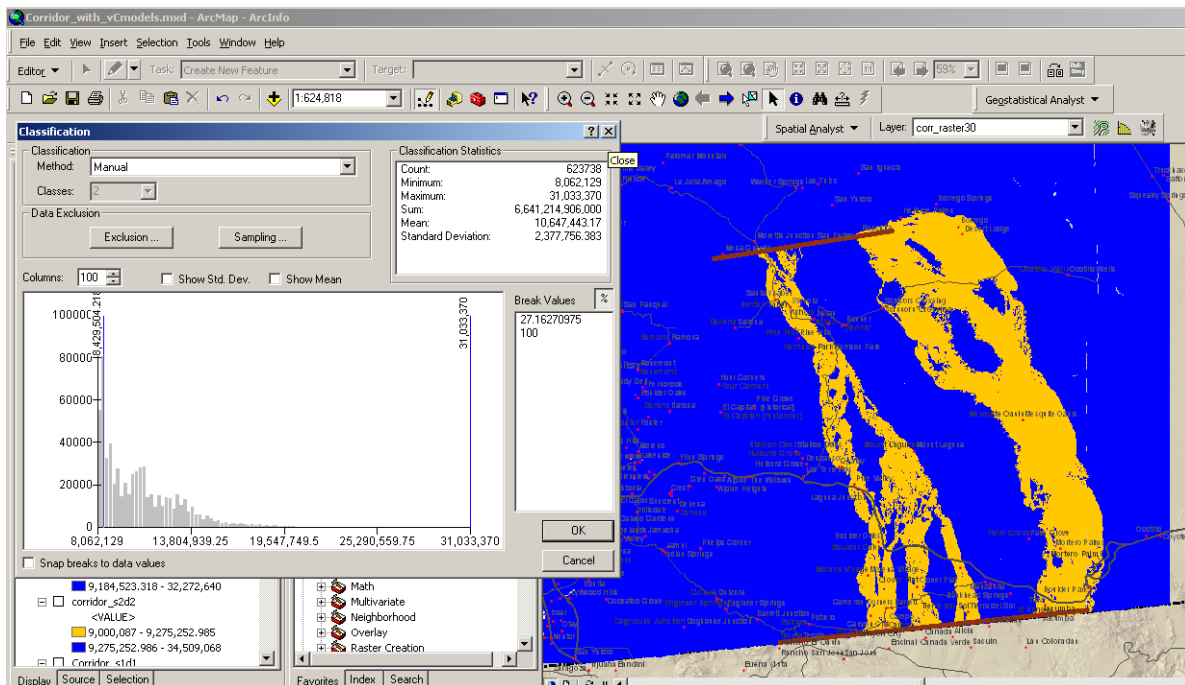


Figure 4-22: Adjusting symbol properties of the corridor raster.

Origin and destination travel locations are required inputs for the ArcMap Cost Distance tool. Two dark brown lines can be seen in the map in Figure 4-22; one runs along the border and one runs parallel to the border and further north. These two lines were used in the model and represent estimated origin and destination locations to which and from which migrants might travel. The origin and destination location estimates used were not meant to infer any known origin or destination locations, nor do they infer that any ancillary information was available to estimate locations. The lines used were intended to indicate the general concept that migrants tend to travel from somewhere along the border to somewhere north of the border.

When using the Cost Distance tool, it was important to ensure that the Environment settings were set to the extents of the cost surface, rather than using the default extents of the input source and destination locations.

The map in Figure 4-23 shows three example corridor results, representing areas of low, lower, and lowest costs to travel from somewhere along the line of origin at the border to somewhere along the destination line north of the border. The areas were created by adjusting the symbol properties of the resulting corridor raster surface, using the same method as described for Figure 4-22 above.

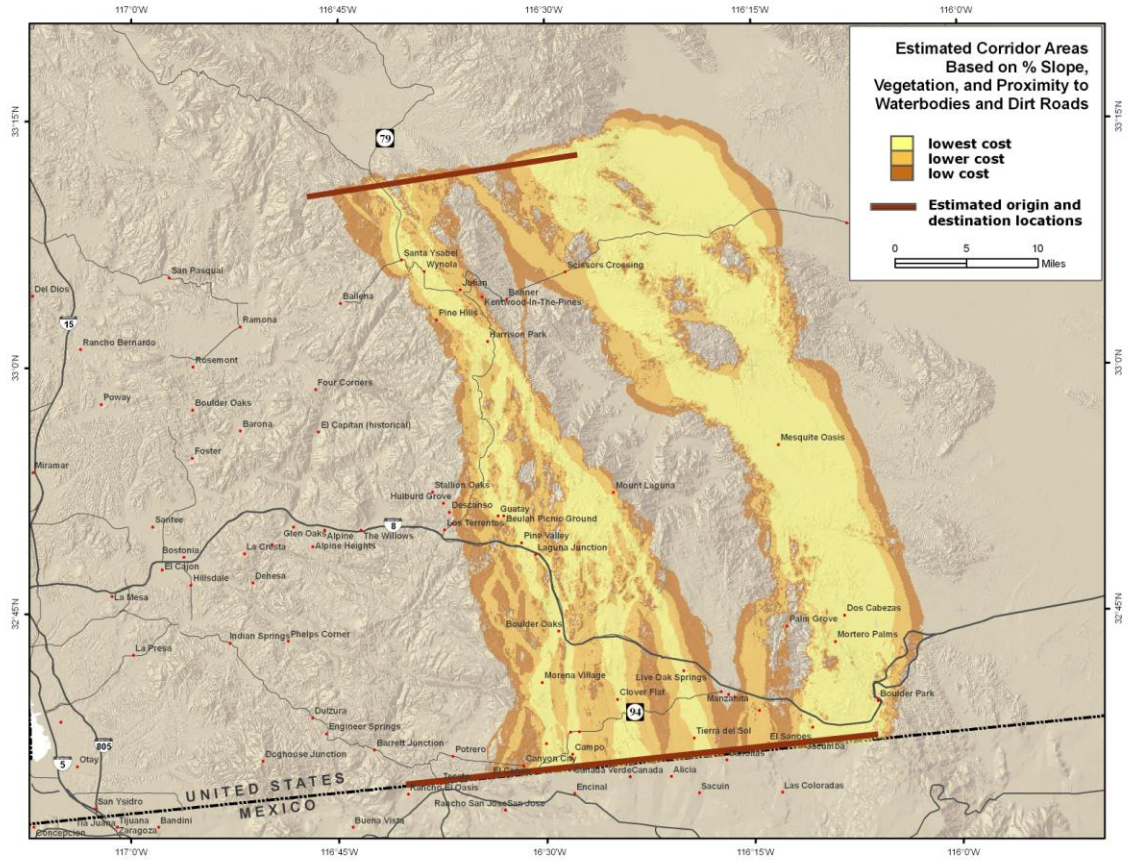


Figure 4-23: Example corridor results.

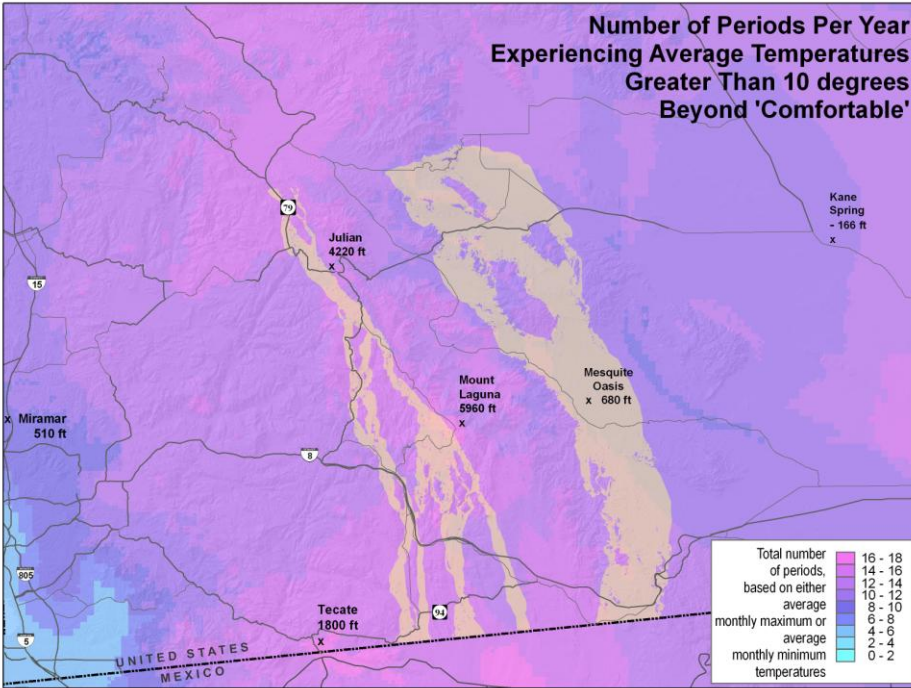


## 5. Analysis Results

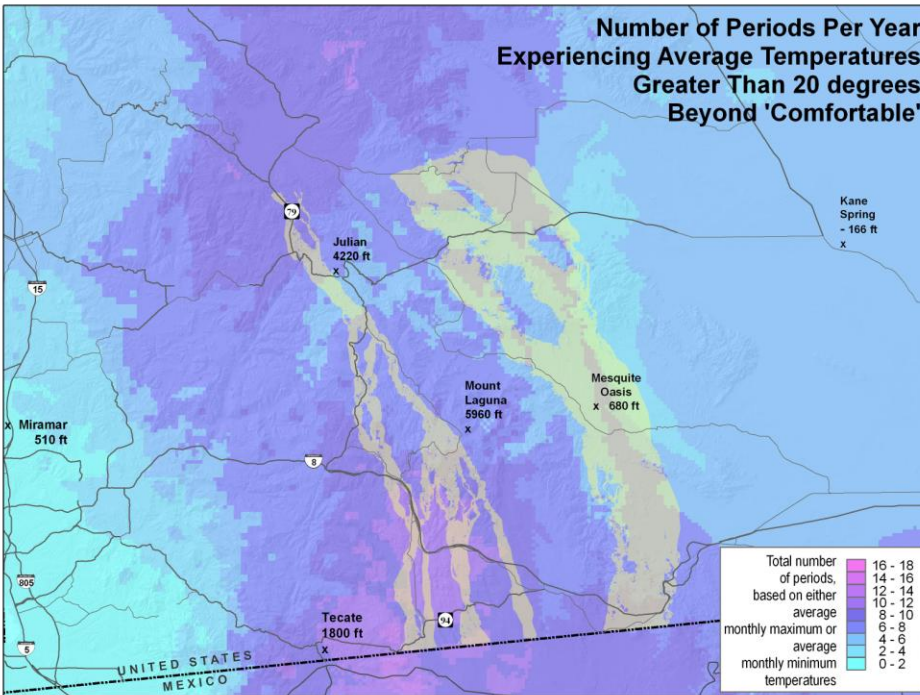
The results of this project suggest areas which could be dangerous to people walking through for extended periods of time, and they also suggest areas where search-and-rescue teams might be most likely to find people in need of assistance. The analysis was based only on publicly available base data, and only natural phenomena were considered. The analysis does not include information about known origin or destination areas, nor does it include information about known travel routes.

The following series of maps (Figures 5-1 through 5-4) show several examples of the analysis results using the two different methods of viewing temperature-related dangers over the course of a year. The first three maps show example results from using the Greater Than Frequency toolbox tool. The last map depicted shows example results from using the method of adding all departures from room temperature surfaces and then symbolizing the results into equal interval classes.

In each map, examples of potential corridor areas were overlaid on top of the temperature danger areas. The corridors, depicted in yellow, are areas of estimated least-cost, and represent just one example of areas where migrants may be most likely to travel through based only on the four natural phenomena factors discussed earlier. In examining the maps below, it is clear to see that there are indeed areas where people are most likely to travel through (the yellow corridors) which overlap areas that experience some of the most extreme temperatures throughout the year. The areas which exhibit the most persistent danger to people appear in the mountain regions from Julian and southward, following the primary road networks north to south near California Highway 79. The high-danger areas are areas where search-and-rescue teams would be most likely to find people in distress and in need of assistance.



**Figure 5-1: Example temperature danger areas based on the Greater Than Frequency tool method with 10 degree DFC threshold, viewed with a least-cost corridor region example of 27 percentile.**



**Figure 5-2: Example temperature danger areas based on the Greater Than Frequency tool method with 20 degree DFC threshold, viewed with a least-cost corridor region example of 27 percentile.**

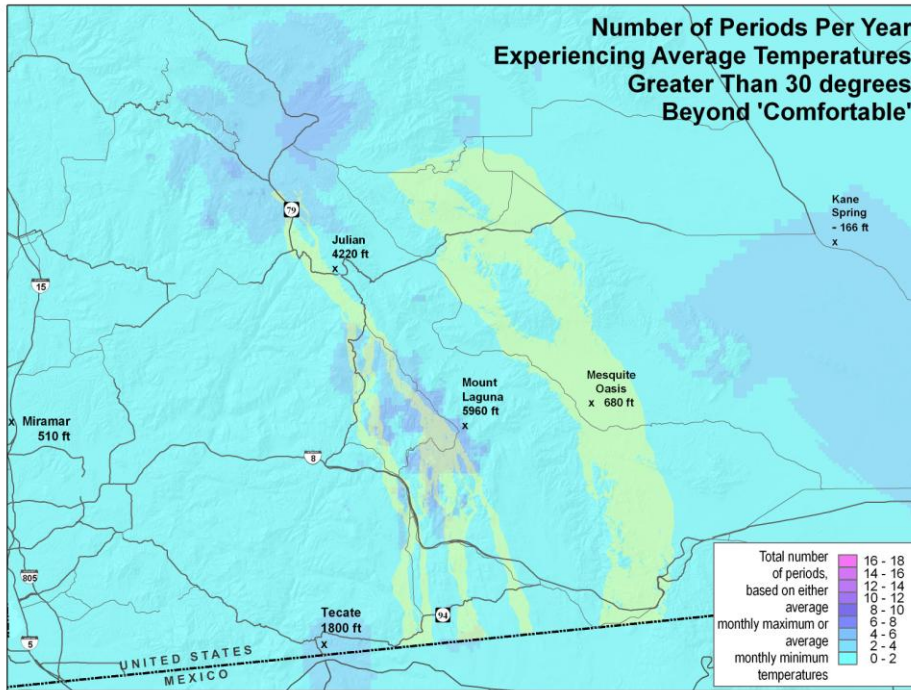


Figure 5-3: Example temperature danger areas based on the Greater Than Frequency tool method with 30 degree DFC threshold, viewed with a least-cost corridor region example of 27 percentile.

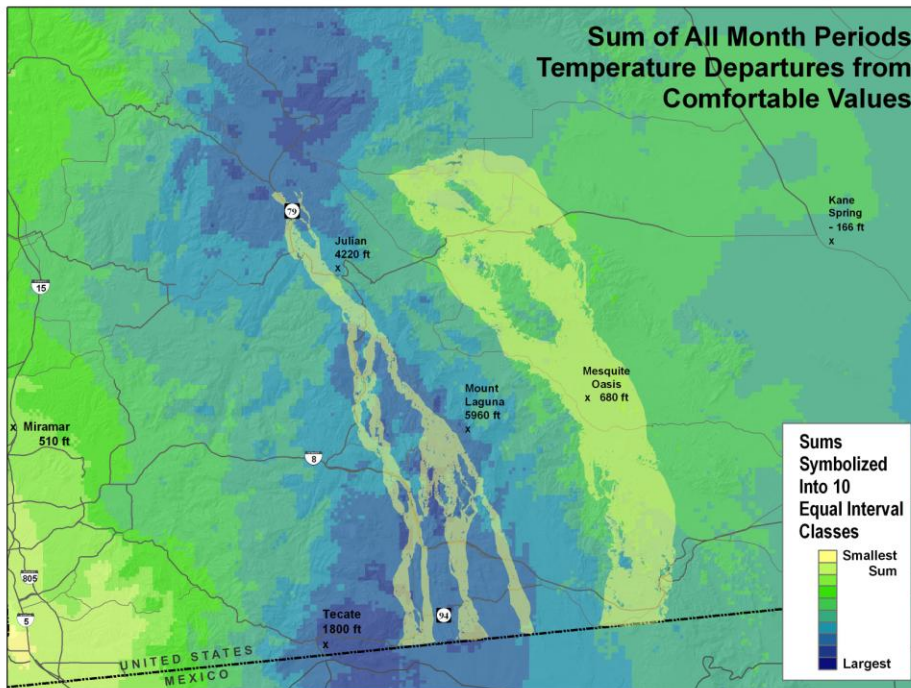


Figure 5-4: Example temperature danger areas based on sum of surfaces method, viewed with a least-cost corridor region example of 27 percentile.





## 6. Further Work

The results achieved by this study demonstrate that the GIS models developed could prove useful with some adjustments, and they also demonstrate that the unique method developed to measure levels of temperature dangers to humans may be useful to U.S. Border Patrol analysts.

Two primary types of adjustments could improve the analysis results: the use of additional datasets, and also the use of higher resolution datasets as inputs to the models which were developed. Suggestions for further work are discussed below.

The corridor model which was developed primarily considered natural phenomena. The corridor model could be improved by also including the influences of man-made factors to estimate where people are inclined to travel through the study area on foot. For example, the models could be refined to include information about actual historical rescue locations, locations of trails which migrants have been known to have used in the past, locations of water drops provided by private aid organizations, or the extents of cell phone reception available in the region. While the inclusion of these types of man-made phenomena might improve predictions of where people are most inclined to walk, datasets for man-made factors were not readily available for this project, and they would have required more time or cost to acquire than was available for this project.

The temperature surfaces created were interpolated using two input data sources: point temperature data and elevation data. Improved temperature surfaces might result with the use of additional variables, such as a terrain aspect, to influence the temperature surfaces generated by the cokriging tool. However, if terrain aspect is used, care must be taken to also consider time-of-day when determining the influence of aspect on temperature at each location. For example, an east-facing slope could be very hot during the early morning hours, whereas the same east-facing slope may be much cooler during times later in the afternoon on the same day.

Temperature surface results might also be enhanced by adjusting the Geostatistical Analyst tool parameters. Through experimentation with the tool parameters, it was determined that the default tool parameters produced acceptable results for this study, as discussed in Section 3.2.2. The assumption was made that it was important to generate all temperature surfaces consistently, using uniform parameter values across all time periods. However, if this assumption were overlooked, additional experimentation with the tool parameters might determine unique parameter values to use for the various time periods.

The temperature surface results might also be improved by using higher resolution elevation data as input to the Geostatistical Analyst tool. For this study, 1000 meter resolution elevation data was used, as discussed in Section 4.1, though the Geostatistical Analyst tool should be able to process 300 meter or even 30 meter post spacing elevation data. However, one should be aware that the tool will require much more time to process higher resolution elevation data, as discussed in Section 4.1, and it may be worthwhile to use a computer more powerful than a laptop to generate higher resolution temperature surfaces.

The temperature surface results could be also refined by including weather-related variables such as wind speed, wind direction, precipitation, snowfall, and flood data as inputs to the cokriging tool. These same types of variable could also be considered to include as independent factors to better determine where the “danger” areas are located, or the regions most hazardous to people who might be exposed to those conditions for extended periods of time. This study only considered one factor, temperature, as the measure of danger.

Another improvement for the interpolated temperature surfaces would be to investigate ways to assign weight factors to the point temperature data based on the number of years the temperature value was averaged. For example, the temperature data points whose values were averaged over long periods of time could be weighted to have more influence on the resulting surface than point data which only reflect values for the year 2005. For this study, it was necessary to include data whose values were averaged over various lengths of time in order to get a sufficient numbers of points as inputs to the cokriging process.

Terrain slope was one of the four factors used in the corridor model, as discussed in Section 2.3.5. For this study, thirty-meter resolution elevation data was used, although with additional time, ten-meter resolution elevation data could have been used to generate an improved percent-slope raster surface.

Vegetation was another factor which was considered in the corridor model. The model used the “WHR13” field from the land-cover data, which categorizes land-cover into thirteen categories, as discussed in Section 4.4.2.1. Alternately, the “WHRTYPE” field categorizes land-cover types into thirty-two distinct categories, and could be used to potentially identify a larger number of vegetation-related friction values as input to the cost surface. However, the ability to assign difficulty values to each combination of “vegetation type and density” is dependent on the availability of knowledgeable subject-matter experts, and the results can be subjective. It was easier and more reasonable to come to a consensus among the subject-matter experts who were available for this study to determine friction values for the sixty-five total number of type-density combinations using the thirteen WHR13 categories than it would have been using the one-hundred-sixty total number of type-density combinations using WHRTYPE categories.

## **7. Conclusion**

This project aimed to help answer the question about what influences weather might have on search-and-rescue locations in the remote areas of southern California, and more specifically, where the most dangerous areas are located. The analysis result examples in Section 5 do suggest areas where rescue teams might focus search efforts for people in distress, and the results can also be used to consider areas to stage equipment used by the search-and-rescue teams. The example results in Section 5 suggest areas which may possess the highest temperature-related dangers throughout the year. A unique method was developed to reclassify temperature data into levels of danger to humans who may be exposed dangerous temperatures for extended periods of time, and who may be unprepared for those conditions. The ArcGIS models developed for this study can be refined with additional variables or with higher resolution datasets, they can be adapted to other study areas, and they may be useful planning tools for Border Patrol search and rescue teams. Some of the lessons learned during this project are discussed below.

### **7.1. GIS analysis techniques.**

This project incorporated a variety of GIS analysis techniques to find a solution to the question of where temperature might pose the biggest danger for people traveling on foot. While the depth of some of the analysis steps could be improved with refined datasets, the study identified and captured a broad range of GIS analysis techniques required to find a solution to the problem statement.

GIS analysis techniques which were exercised in this study include:

- Data acquisition, data preparation
- Data management for analysis and data management for cartographic purposes
- Corridor / least-cost routes analysis
- Surface interpolation techniques
- Temporal-spatial analysis
- Developing data reclassification schemes
- Developing methods to display temporal temperature data statically as well as dynamically
- Cartographic techniques
- Developing Model-Builder models
- Project management

### **7.2. Project risks.**

During a meeting with Border Patrol agents early in the program to discuss projects of possible interest to them, it was determined that the overall success of this project should

be measured more by what it is able to accomplish in regard to the temperature portion of the analysis, and less with being able to accurately predict corridors through which people are likely to travel.

During subsequent project planning activities, and with little more than three months remaining in the program, several project risks were identified, the majority of which involved the temperature-danger portion of analysis. The major project risks identified include:

- How to store temporal temperature data.
- How to display temporal temperature data.
- Acquiring a sufficient number of temperature data point samples.
- Allocating sufficient time to preprocess temperature data into formats usable for GIS analysis.
- Developing a method to preprocess temperature data for inputs to the temperature model.
- Developing a method to convert temperature data into information which represents levels of danger to humans when exposed to those temperatures over extended periods of time.
- Developing good assumptions to apply to the corridor model.
- Acquiring sufficient data for input factors for the corridor model.

The decision was made to focus efforts during the remaining three months of project time on the temperature-danger portion of the analysis, and on developing a method to assess levels of danger. This decision was based on the realization that the majority of risks which were identified were related to the temperature portion of the analysis, and because the client had expressed early in the project that they were most interested in the temperature component. The project focus was to develop a prototype model with the available input datasets, with the understanding that the model process flows developed could still be used with refined input datasets which may become available.

### **7.3. Project management.**

The resources available for this study were measured solely in terms of the time available for one graduate student to perform all analysis using a laptop computer while attending a one-year masters degree program, as noted in Section 1.6. The analysis for this project was conducted during the same timeframe in which other masters degree program requirements were also being met. The significance of this was the recognition of the importance of the role of project management throughout the project timeframe. A project management plan was developed early in the analysis, and timelines were estimated for major product activities. The major activities, or milestones, for this project included the following:

1. Requirements analysis
2. Conceptual geodatabase design
3. Data acquisition
4. Geodatabase development

5. Developing process flows
6. Data analysis
7. Refining the process models
8. Documentation

As project risks became apparent, compromises were required in order to maintain the project within the allocated time constraint. By periodically comparing schedules of completed activities against anticipated completion schedules for those activities, project risks could more easily be identified. Project compromises that were made were generally related to data resolution and number of datasets used as inputs to the models. The time required for data acquisition activities was the most underestimated of the major milestones identified. Also unexpected was that the data acquisition activities extended throughout much of the project timeline, as earlier-collected data were subsequently deemed to be insufficient. That problem could have been minimized if more time were available earlier in the project timeline to carefully examine all datasets, and also if the project problem definition and project scope were both clearly defined very early.

#### **7.4. Project scope.**

Another important lesson recognized during this study was the importance of defining a clear problem statement as the first step in project planning, before proceeding with other project activities; also, it was important to keep project analysis activities within the scope of the defined problem statement.

One problem statement which was initially considered for this project was as follows: “Where are people trying to cross the border illegally?” That project idea was reconsidered after the realization that datasets needed to support the analysis would be too difficult to acquire. However, throughout the remaining project effort, it was sometimes difficult to minimize scope-creep and to keep from migrating back towards that initial problem statement. This project’s defined problem statement, that being to develop a method to locate temperature-related danger areas, differed from early drafts of the problem statement. Also, this project included several analysis components, some of which tended to drift beyond the scope of the stated problem. This was particularly true when searching for datasets to include as inputs for the corridor model; it became apparent that datasets related to man-made features would not only be difficult to obtain, but their use would likely also broaden the scope of the project objectives, issues, and process flows.

The temperature-danger component of the project was considered to be more significant than the corridor analysis component, according to early guidance expressed by the project client, and in terms of prioritizing time resources. It was rationalized that Border Patrol analysts might have access to datasets which could improve the corridor model, such as the man-made features discussed in Section 6. Corridor analysis is a common type of GIS problem, and the approach used in this project was similar to other corridor analysis approaches (Childs and Kabot, 2001). In contrast, the temperature-danger portion of this project presented new challenges; it required the development of a new approach to identify levels of temperature-related danger, it required considering various methods for storing and formatting temporal data, and it required considering new ways

to display levels of danger over time. Therefore, the project budget strived to focus its diminishing resources on the more challenging temperature-danger related activities.

### **7.5. Recommendations.**

This project was conducted using ESRI ArcGIS version 9.1 software. ArcGIS version 9.2 is expected to have much improved capabilities for processing raster data, although version 9.2 of the software would not be available until several months after the analysis for this project was completed ([www.esri.com](http://www.esri.com)). It would be interesting to experiment with the new ArcGIS version to learn if it offers improved solutions for managing, editing and for displaying the temporal raster surface temperature datasets which were used in this project.

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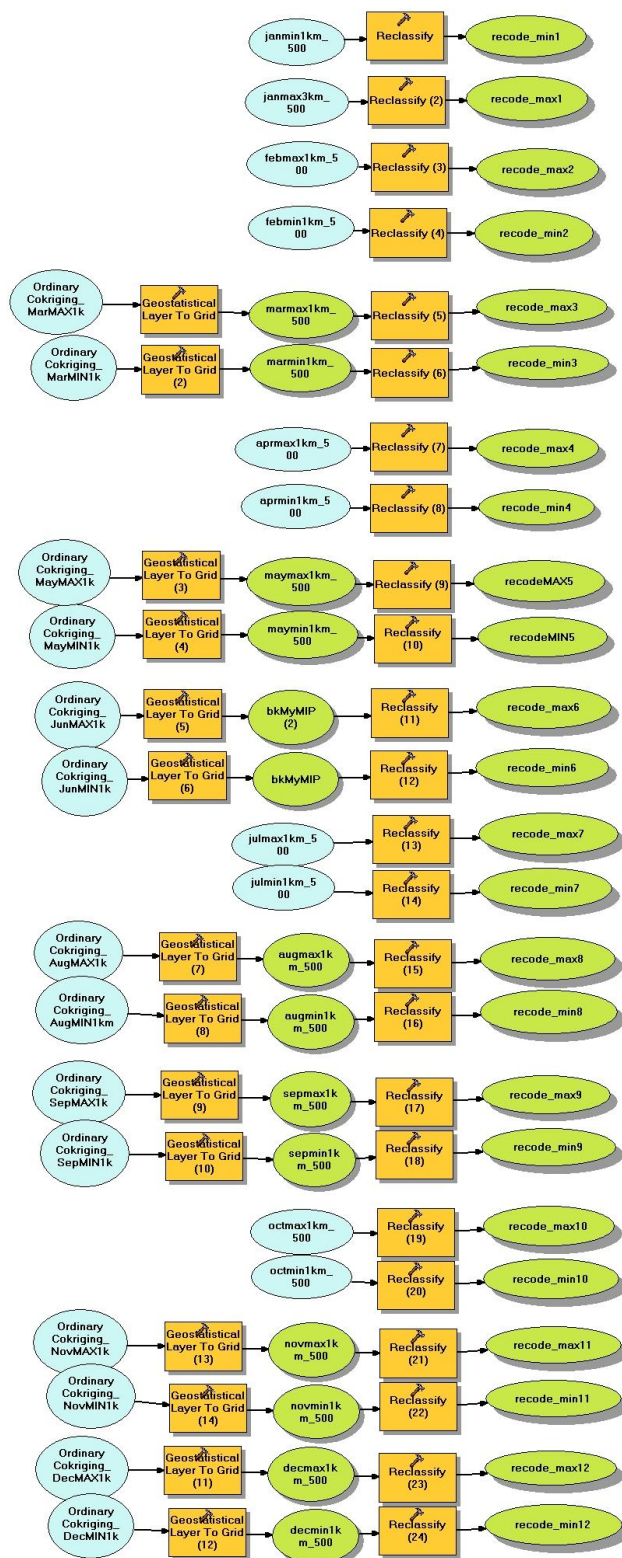


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## Appendix A: Model to convert cokriging temperature surfaces to raster grids and reclassify into degree departures from room temperature.



This temperature model was used to first convert the cokriging surface results into raster grids. Those rasters were then symbolized to create maps outside of the model. The raster temperatures were then reclassified to reflect measures of danger to humans when exposed to the various temperatures for unknown lengths of time. The reclassification scheme used room temperature as the basis, and temperature values were then recoded into degrees departure from comfortable, or from room temperature.

Some “GA to Grid” steps were performed manually, for those months which were created earlier for display on a poster, and were excluded from the model.

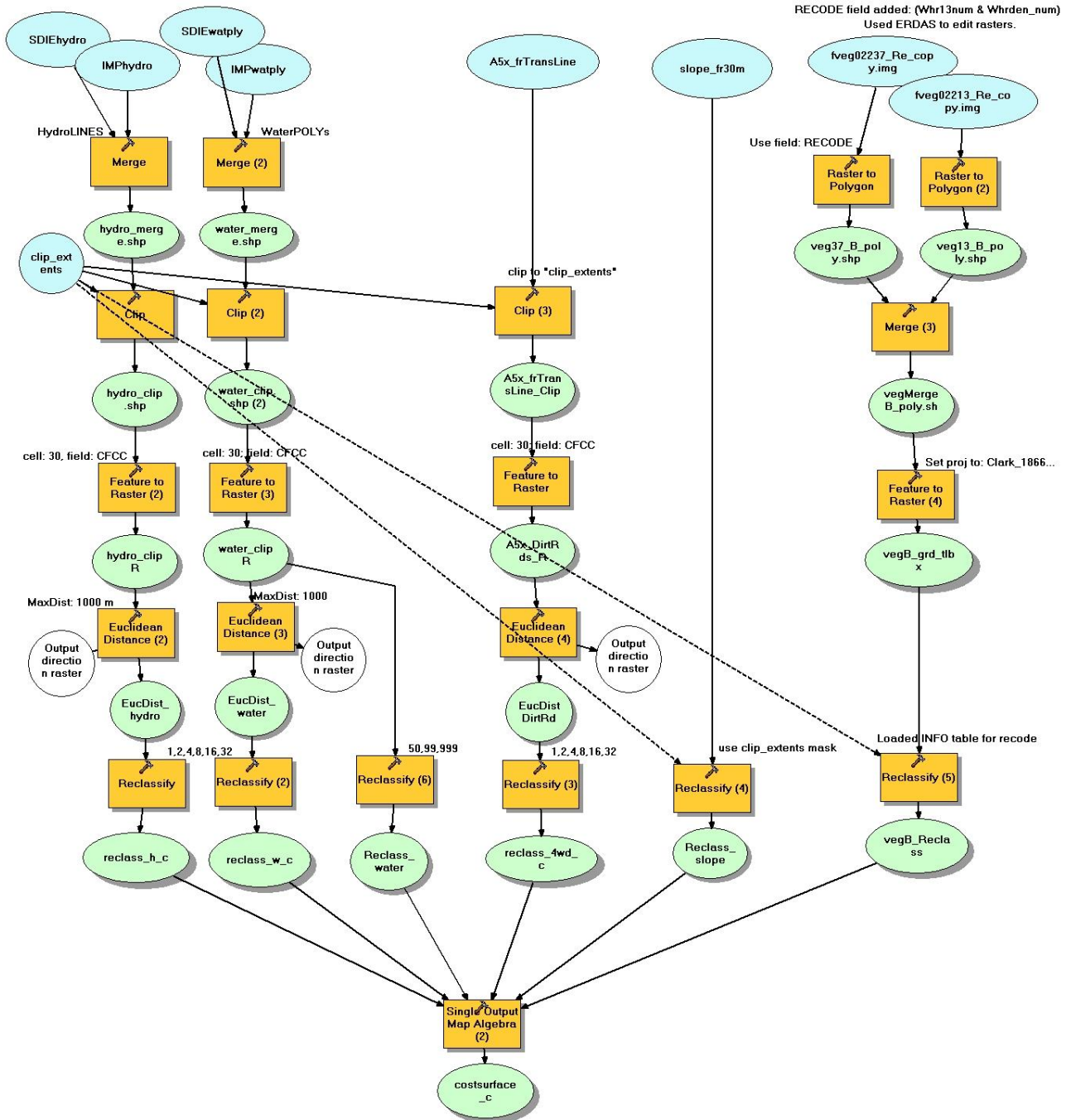
## Appendix B: Model to create cost surface.

### Hydrology

### Dirt Roads

### % Slope

### Vegetation



## Cost Surface

**Appendix C: List of southern California weather collection stations from which data was used to create temperature surfaces for this study.**

NAME	START_DATE	END_DATE	YRS	ELEV_FT
Alpine Coop	1952	2005	54	1700
ANZA	2005	2005	1	3920
Barrett Dam	1971	2000	30	1620
Beaumont Pumping Plant	1971	2000	30	3050
Bonita	1961	1990	30	110
Borrego Desert Park	1948	2005	58	850
Borrego Springs 3NNE	1961	1990	30	630
Brawley 2 SW	1927	2005	79	-120
Cabrillo National Monument	1952	2005	54	410
CAHUILLA	2005	2005	1	278
CALIPATRIA/MULBERRY	2005	2005	1	110
CAMERON FIRE STATION	2005	2005	1	3443
Campo	1948	2005	58	2590
Chula Vista	1948	2005	58	10
Cranston	2005	2005	1	1950
Cuyamaca	1948	2005	58	4670
DESCANSO	2005	2005	1	3480
Eagle Mountain	1948	2005	58	970
El Cajon	1979	2005	27	410
El Cajon Yale Ranch	1948	1959	12	540
El Capitan Dam	1948	2005	58	610
El Centro 2 SSW	1948	2005	58	-50
El Centro NAF	2005	2005	1	45
Elsinore	1948	2005	58	1300
Escondido	1971	2000	30	660
FISH CREEK MTN	2005	2005	1	760
Gold Rock Ranch	1971	2000	30	480
Hayfield Reservoir	1948	2005	58	1370
Hemet	1948	2005	58	1600
Henshaw Dam	1948	2005	58	2700
Idyllwild Fire Dept	1948	2005	58	5400
Imperial (coop)	1948	2005	58	-60
Imperial FAA Airport	1971	2000	30	-60
Indio Fire Station	1927	2005	79	10
JULIAN	2005	2005	1	4240
Julian (coop)	1949	2005	57	4210
Julian Wynola	1971	2000	30	3660
KEENWILD	2005	2005	1	4920
La Mesa	1948	2005	58	580
Mecca 2 SE	1948	2005	58	-180
MELOLAND	2005	2005	1	50
MOUNT LAGUNA	2005	2005	1	5760
Mt San Jacinto	1971	2000	30	8430
OAK GROVE	2005	2005	1	2752
OASIS	2005	2005	1	12
Otay Lake	2005	2005	1	580
Palm Springs	1927	2005	79	420
PALOMAR	2005	2005	1	5530
Palomar Mt Observ	1948	2005	58	5600
Perris	1971	2000	30	1470
Pine Hills	2005	2005	1	0
POTRERO	2005	2005	1	2350
Ramona Airport	2005	2005	1	0
Ramona Fire Dept	1974	2005	32	1450
Ramona Spaulding	1971	2000	30	1480
RANCHITA	2005	2005	1	4180
Riverside March AB	2005	2005	1	1540
SALTON SEA EAST	2005	2005	1	226
SALTON SEA WEST	2005	2005	1	225
San Diego Brown Fld (SAO)	2005	2005	1	540
San Diego Gillespie (SAO)	2005	2005	1	385
San Diego Miramar NAS	1971	2000	30	459
San Diego N Island NAS	1971	2000	30	59
San Diego WSO Airport	1914	2005	92	30
San Jacinto	1971	2000	30	1550
San Miguel	2005	2005	1	425
San Pasqual Animal park	1979	2005	27	420
Seeley	2005	2005	1	40
Sun City Coop	1973	2005	33	1420
Temecula	2005	2005	1	1420
Temecula East II	2005	2005	1	1536
Thermal FAA Airport	1950	2005	56	-110
Vista 1 NE	1957	2005	49	600
Warner Springs	1971	2000	30	3180

The dates and years indicated in this table represent the number of years over which the average monthly minimum and average monthly maximum temperatures are based for each weather collection station. A total of 45 of the 73 weather data collection station temperature data points had data archives which were averaged over about 30 years, more or less. The remaining data points reflect temperature averages for the year 2005.

**Appendix D: Tables used to reclassify feature data values into cost values for inputs to the corridor cost surface.**

1. Reclassification scheme to adjust costs based on proximity to 4WD (dirt) roads. Old values are Euclidean distances, in meters:

Old values	New values
0 - 200	1
200 - 400	2
400 - 600	4
600 - 800	8
800 - 1000	16
NoData	32

2. Reclassification scheme to adjust costs based on proximity to hydrologic features (rivers and lakes). Old values are Euclidean distances, in meters:

Old values	New values
0 - 200	1
200 - 400	2
400 - 600	4
600 - 800	8
800 - 1000	16
NoData	32

3. Reclassification scheme to adjust costs for selected water body features; H00 - Water Feature, Classification Unknown or Not Elsewhere Classified, H11 – Perennial stream or river, H12 – Intermittent stream, river or wash, H31 – Perennial lake or pond, H32 – Intermittent lake or pond, H41 – Perennial reservoir, H51 - Bay, estuary, gulf, or sound, H53 - Sea or ocean:

Old values	New values
H53	999
H00	99
H11	99
H12	50
H31	99
H32	50
H41	99
H51	999

4. Reclassification scheme to convert percent slope into cost values to walk up or down each slope category:

Old values	New values
0 - 7	21
7 - 12	27
12 - 20	30
20 - 25	36
25 - 29	42
29 - 30	48
30 - 40	162
40 - 402.989319	999

5. INFO-format remap file used to reclassify vegetation type x vegetation density values into cost values which represent levels of difficulty to walk through it. The first two digits of input represent the WHR13 type code, the third digit represents the WHR density code:

Rowid	FROM	TO	OUT	MAPPING	Rowid	FROM	TO	OUT	MAPPING
1	100	100	15	ValueToValue	34	513	513	10	ValueToValue
2	101	101	15	ValueToValue	35	514	514	20	ValueToValue
3	102	102	15	ValueToValue	36	520	520	10	ValueToValue
4	103	103	15	ValueToValue	37	521	521	10	ValueToValue
5	104	104	15	ValueToValue	38	522	522	10	ValueToValue
6	200	200	10	ValueToValue	39	523	523	10	ValueToValue
7	201	201	10	ValueToValue	40	524	524	20	ValueToValue
8	202	202	10	ValueToValue	41	600	600	10	ValueToValue
9	203	203	10	ValueToValue	42	601	601	10	ValueToValue
10	204	204	10	ValueToValue	43	602	602	10	ValueToValue
11	310	310	10	ValueToValue	44	603	603	10	ValueToValue
12	311	311	10	ValueToValue	45	604	604	10	ValueToValue
13	312	312	10	ValueToValue	46	700	700	10	ValueToValue
14	313	313	10	ValueToValue	47	701	701	10	ValueToValue
15	314	314	20	ValueToValue	48	702	702	15	ValueToValue
16	320	320	10	ValueToValue	49	703	703	40	ValueToValue
17	321	321	10	ValueToValue	50	704	704	50	ValueToValue
18	322	322	10	ValueToValue	51	800	800	30	ValueToValue
19	323	323	10	ValueToValue	52	801	801	30	ValueToValue
20	324	324	20	ValueToValue	53	802	802	30	ValueToValue
21	410	410	10	ValueToValue	54	803	803	30	ValueToValue
22	411	411	10	ValueToValue	55	804	804	30	ValueToValue
23	412	412	15	ValueToValue	56	900	900	99	ValueToValue
24	413	413	40	ValueToValue	57	901	901	99	ValueToValue
25	414	414	50	ValueToValue	58	902	902	99	ValueToValue
26	420	420	10	ValueToValue	59	903	903	99	ValueToValue
27	421	421	10	ValueToValue	60	904	904	99	ValueToValue
28	422	422	10	ValueToValue	61	1000	1000	70	ValueToValue
29	423	423	10	ValueToValue	62	1001	1001	70	ValueToValue
30	424	424	10	ValueToValue	63	1002	1002	70	ValueToValue
31	510	510	10	ValueToValue	64	1003	1003	70	ValueToValue
32	511	511	10	ValueToValue	65	1004	1004	70	ValueToValue
33	512	512	10	ValueToValue	66	NoData	NoData	NoData	ValueToValue



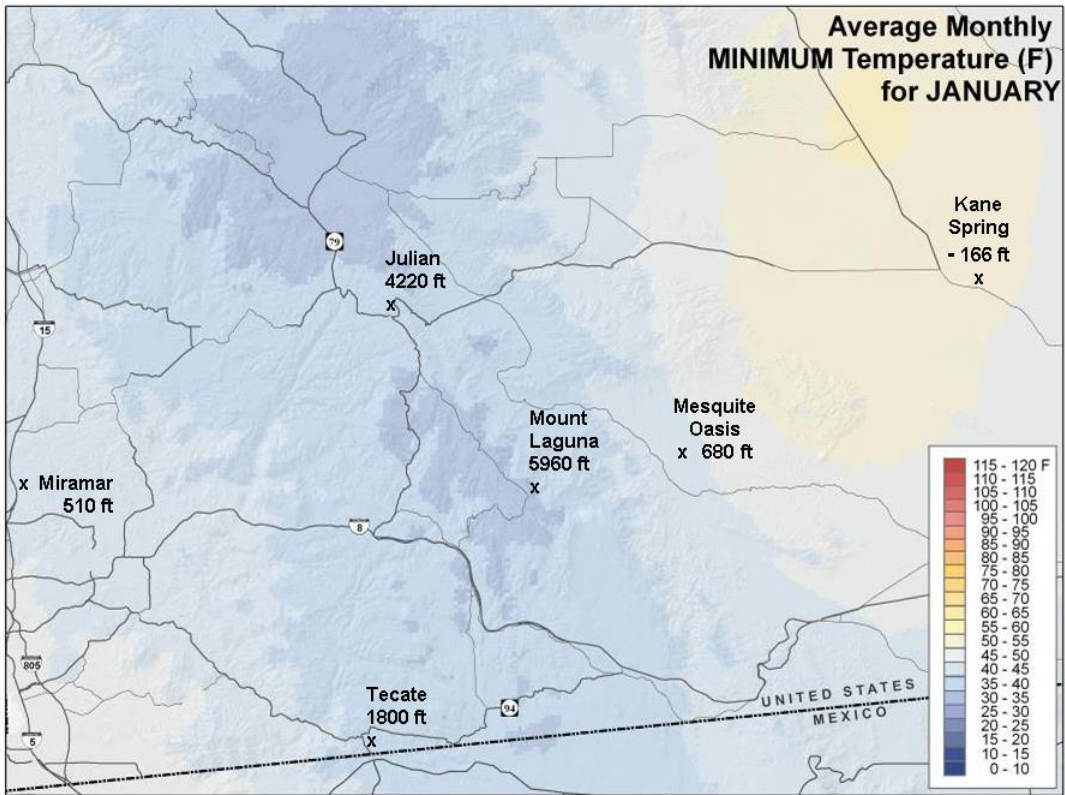
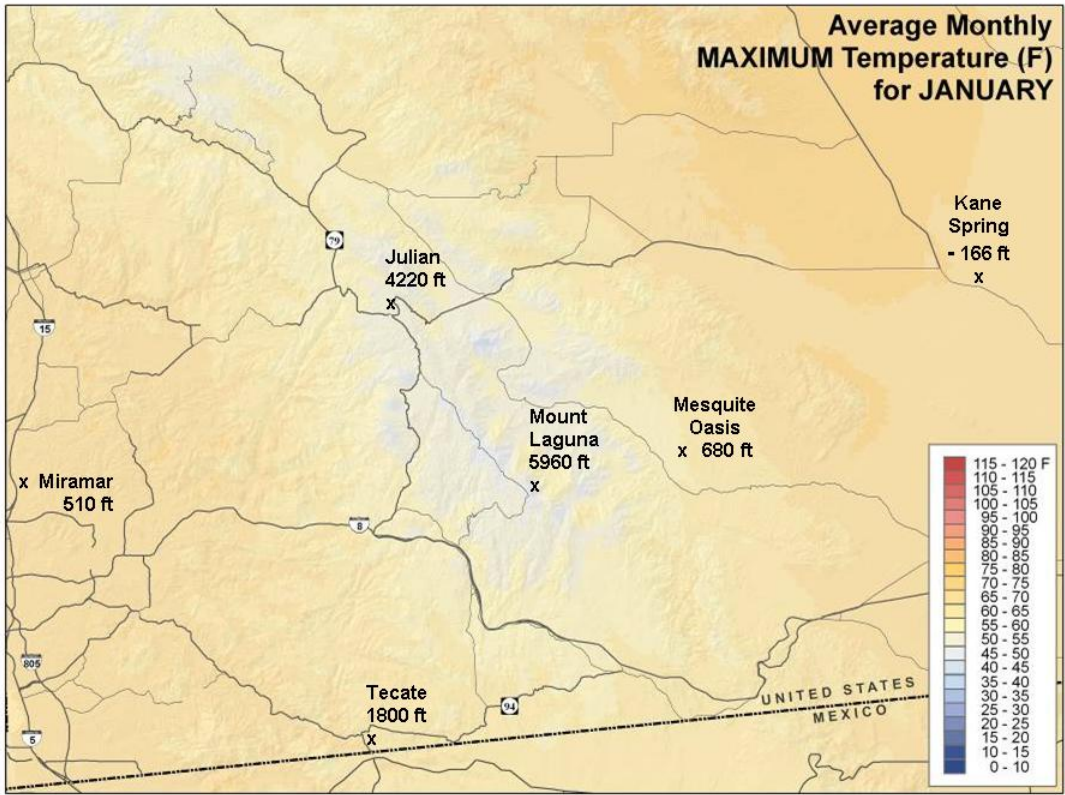
6. INFO-format remap file used to reclassify temperature degrees Fahrenheit values into degrees Fahrenheit Departure from Comfortable (DFC) temperature values. “Comfortable”, or room temperature was considered to be between 65-70 degrees Fahrenheit:

FROM_	TO	OUT	MAPPING
-10	10	60	ValueToValue
10	15	55	ValueToValue
15	20	50	ValueToValue
20	25	45	ValueToValue
25	30	40	ValueToValue
30	35	35	ValueToValue
35	40	30	ValueToValue
40	45	25	ValueToValue
45	50	20	ValueToValue
50	55	15	ValueToValue
55	60	10	ValueToValue
60	65	5	ValueToValue
65	70	0	ValueToValue
70	75	5	ValueToValue
75	80	10	ValueToValue
80	85	15	ValueToValue
85	90	20	ValueToValue
90	95	25	ValueToValue
95	100	30	ValueToValue
100	105	35	ValueToValue
105	110	40	ValueToValue
110	115	45	ValueToValue
115	120	50	ValueToValue
120	140	60	ValueToValue

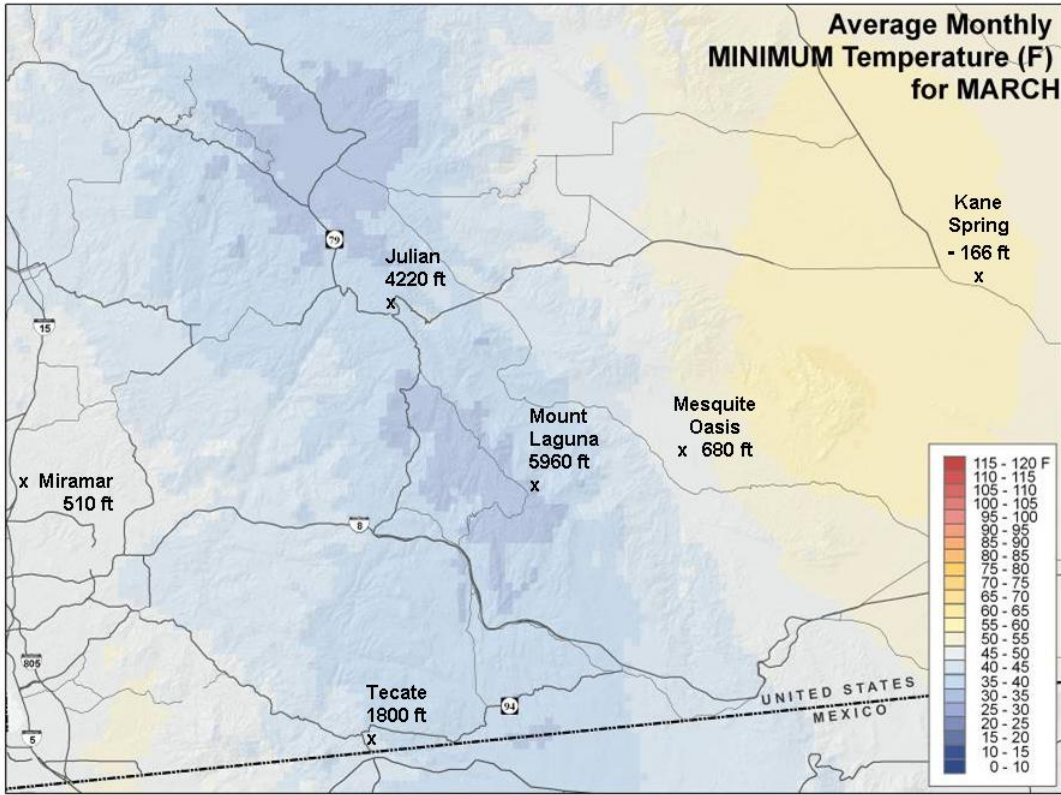
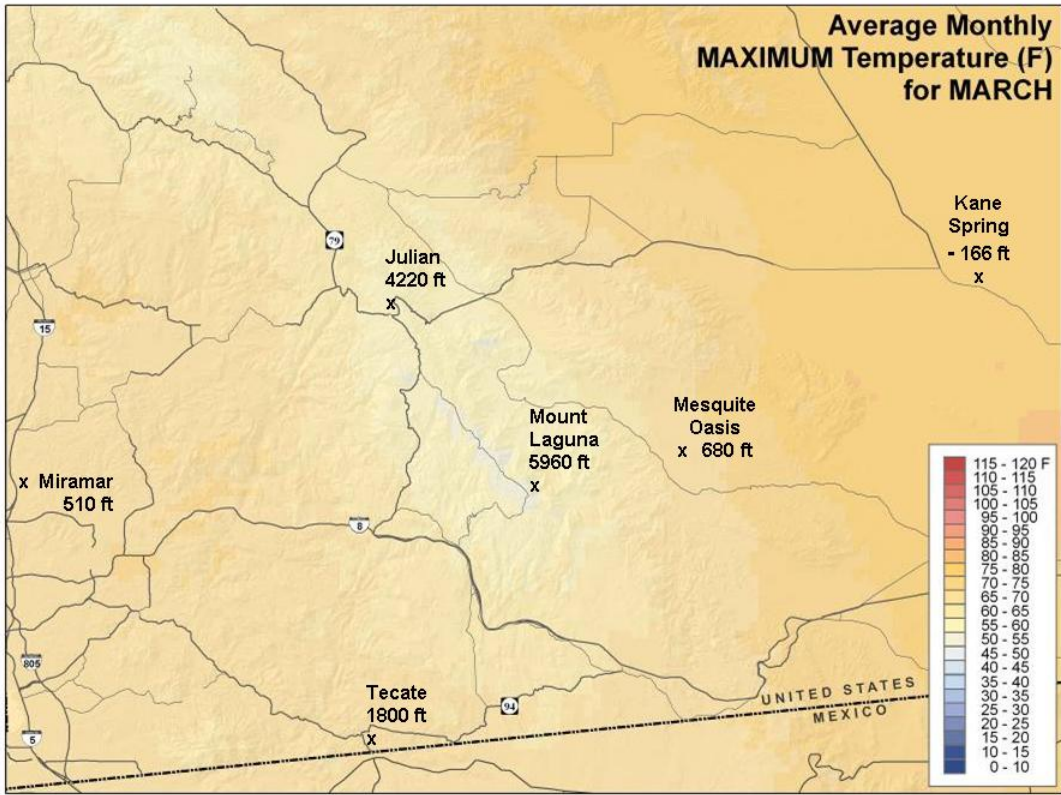




**Appendix G: Maps depicting average monthly maximum and average monthly minimum temperature surfaces interpolated using Geostatistical Analyst cokriging tools.**

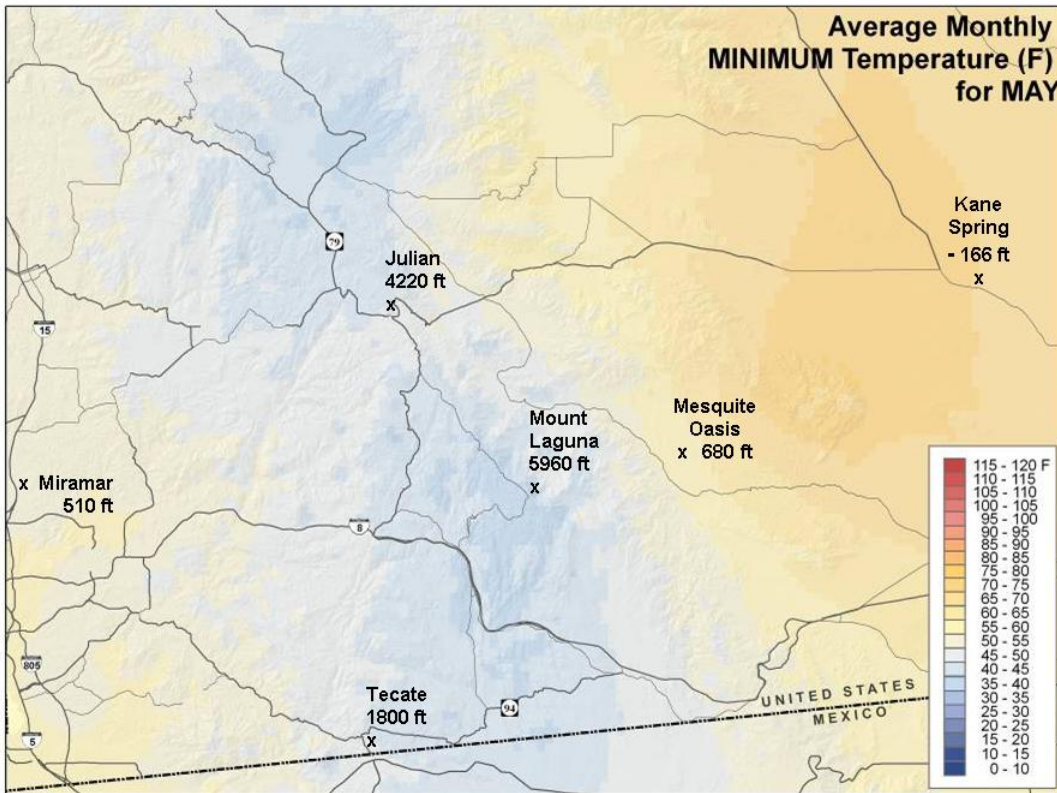
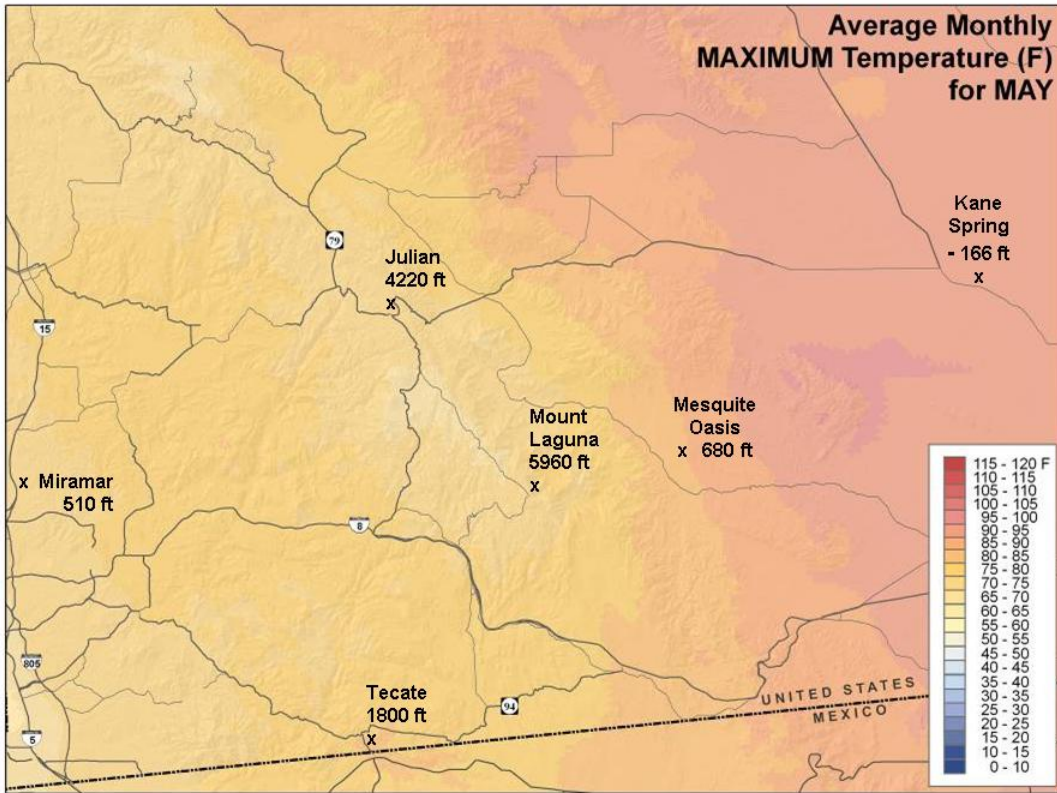


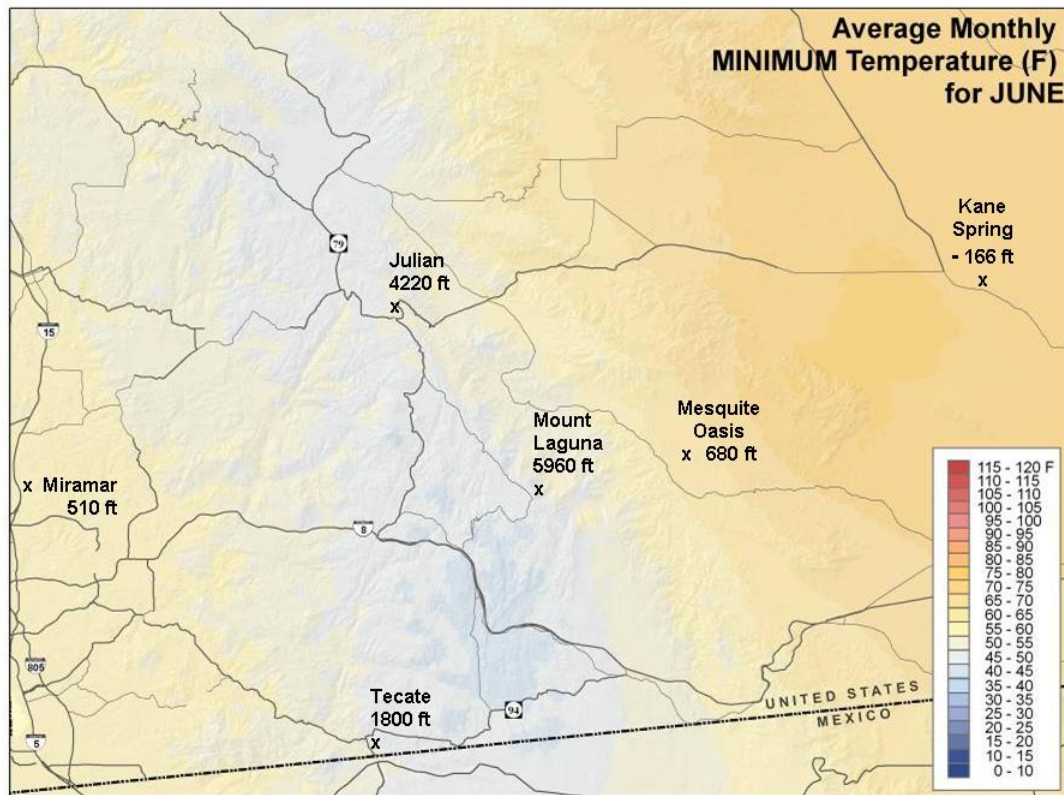
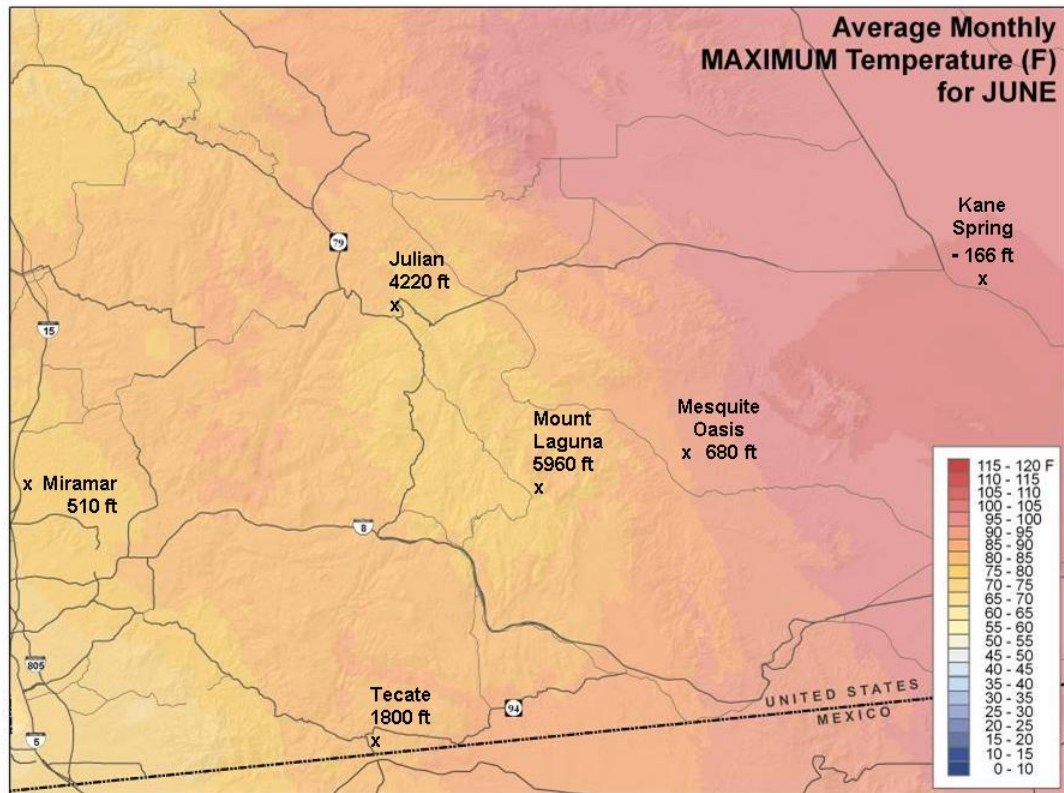


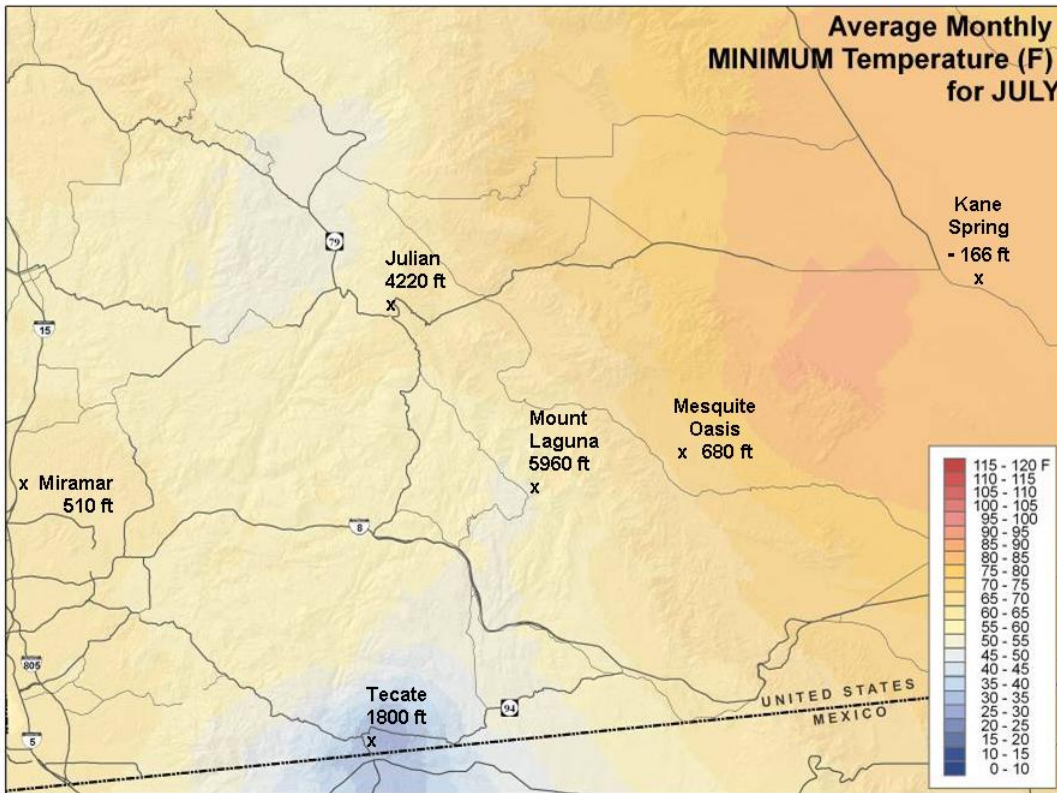
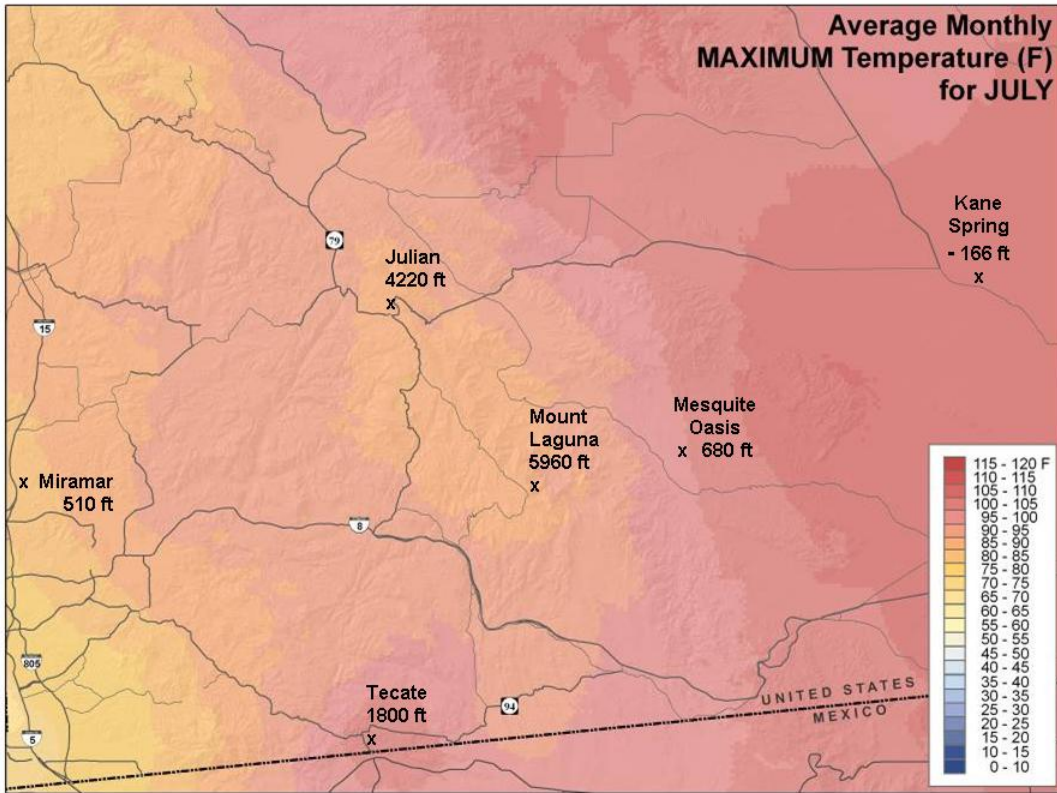


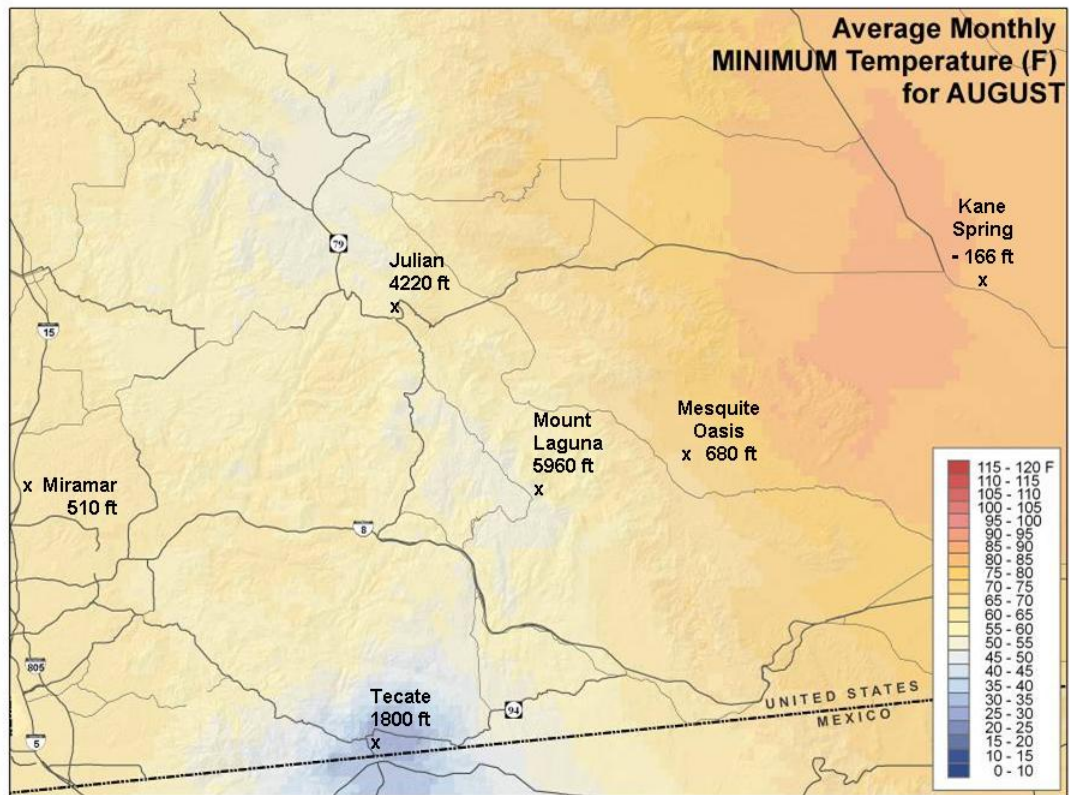
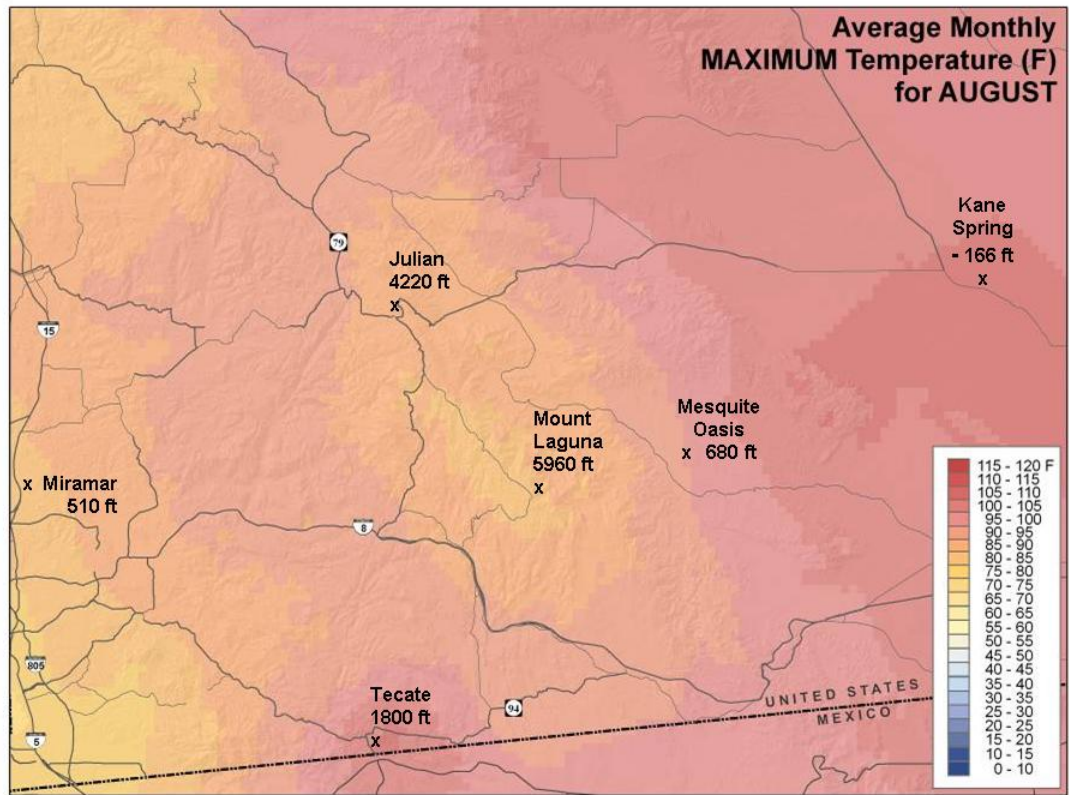


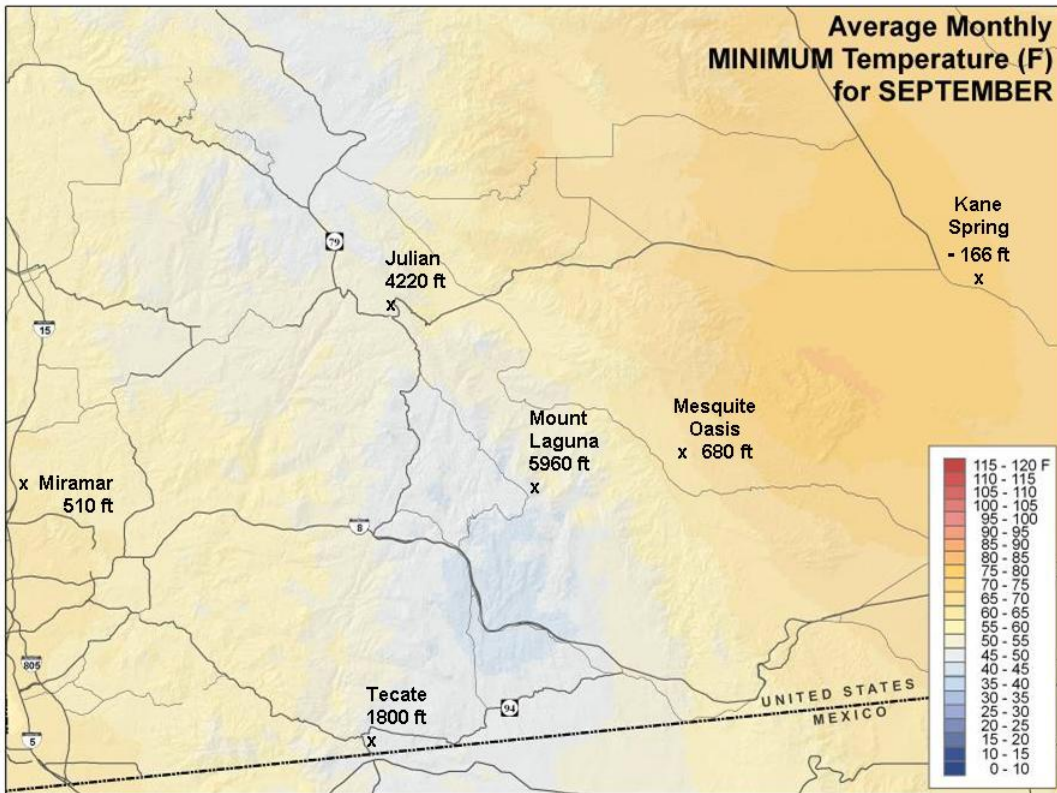
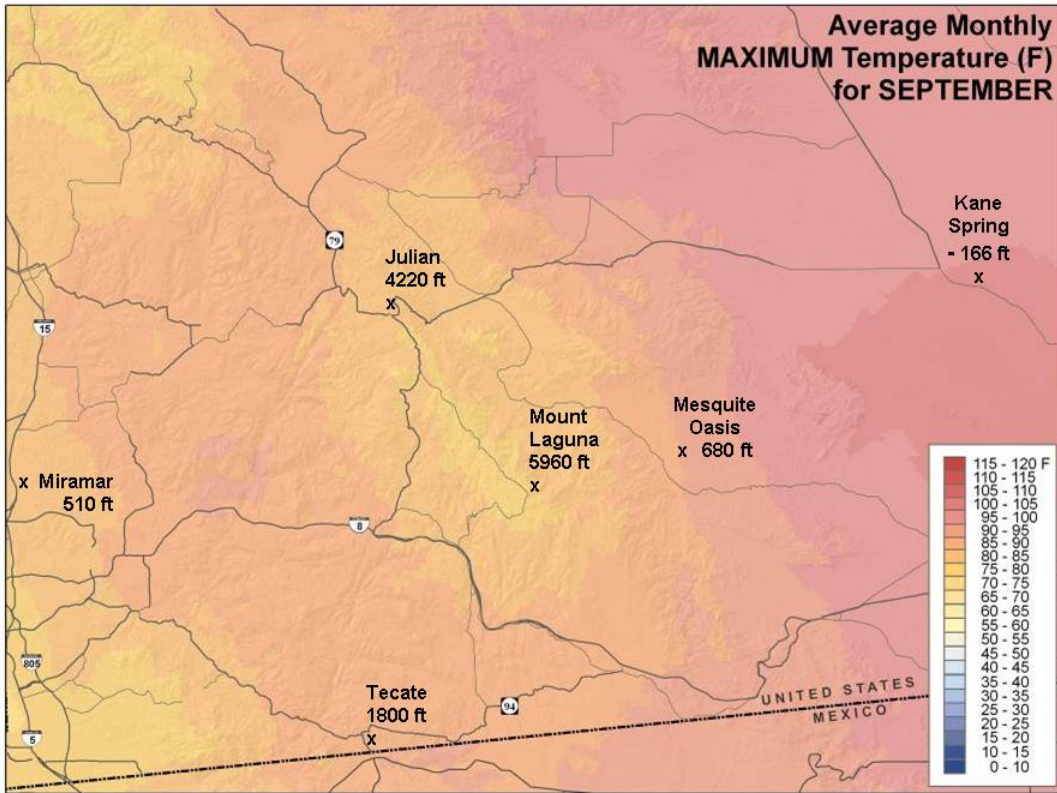


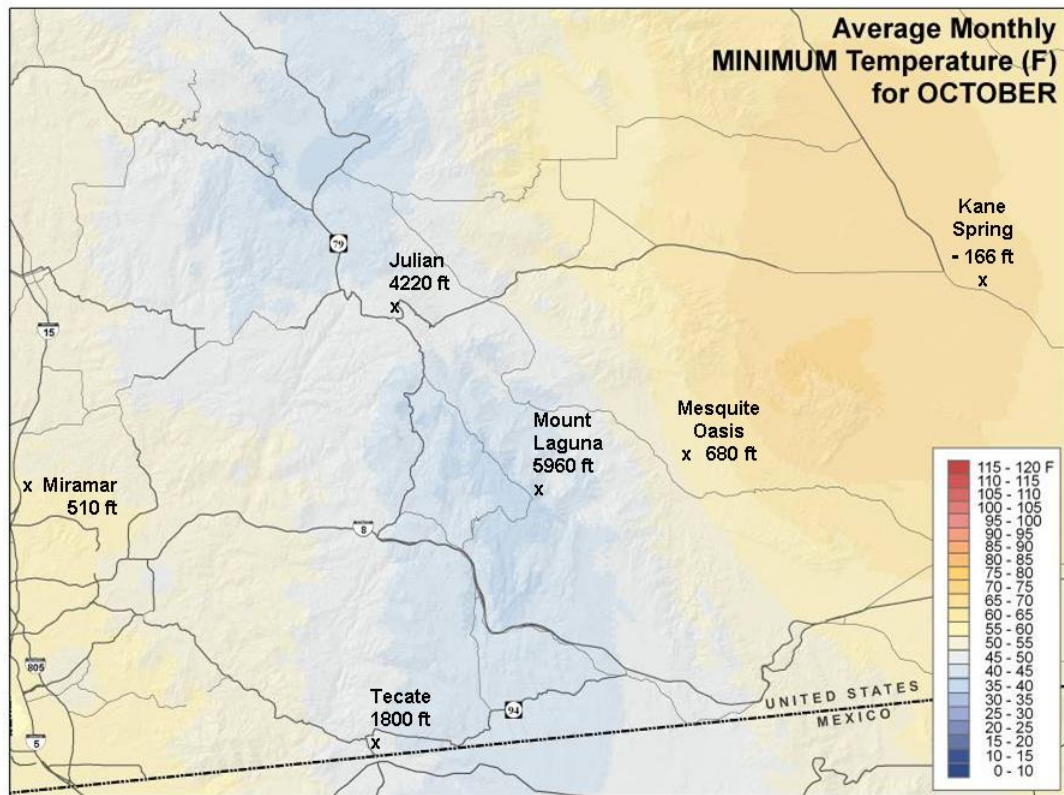
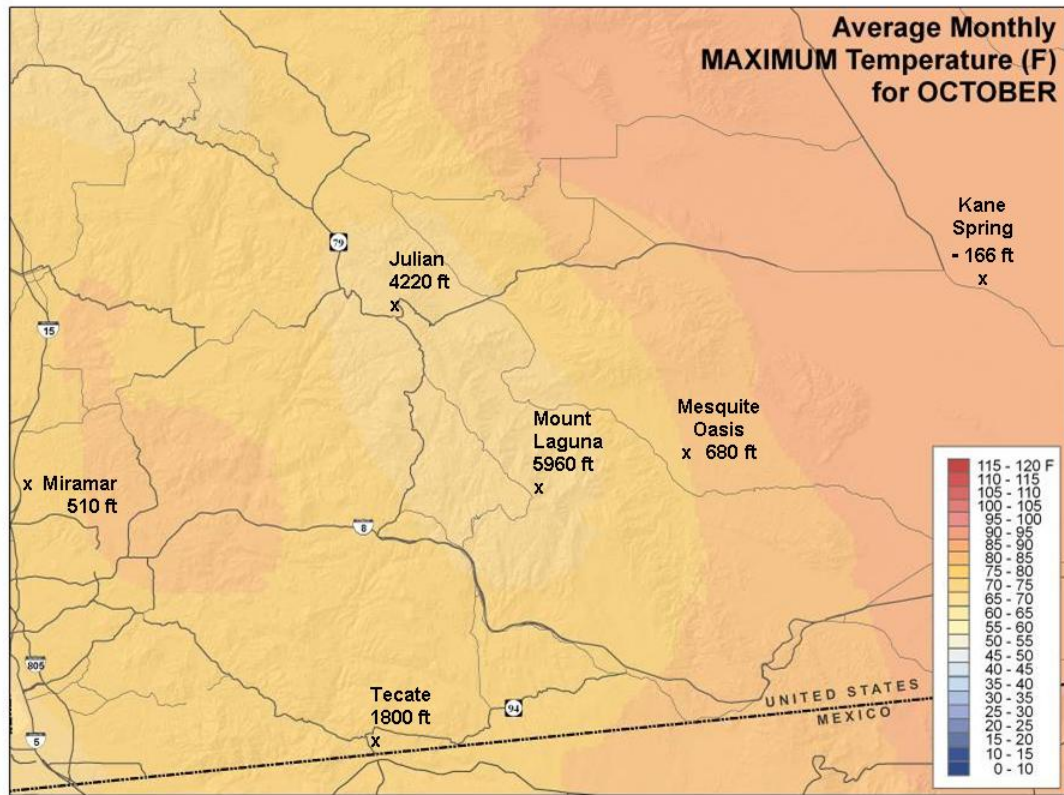


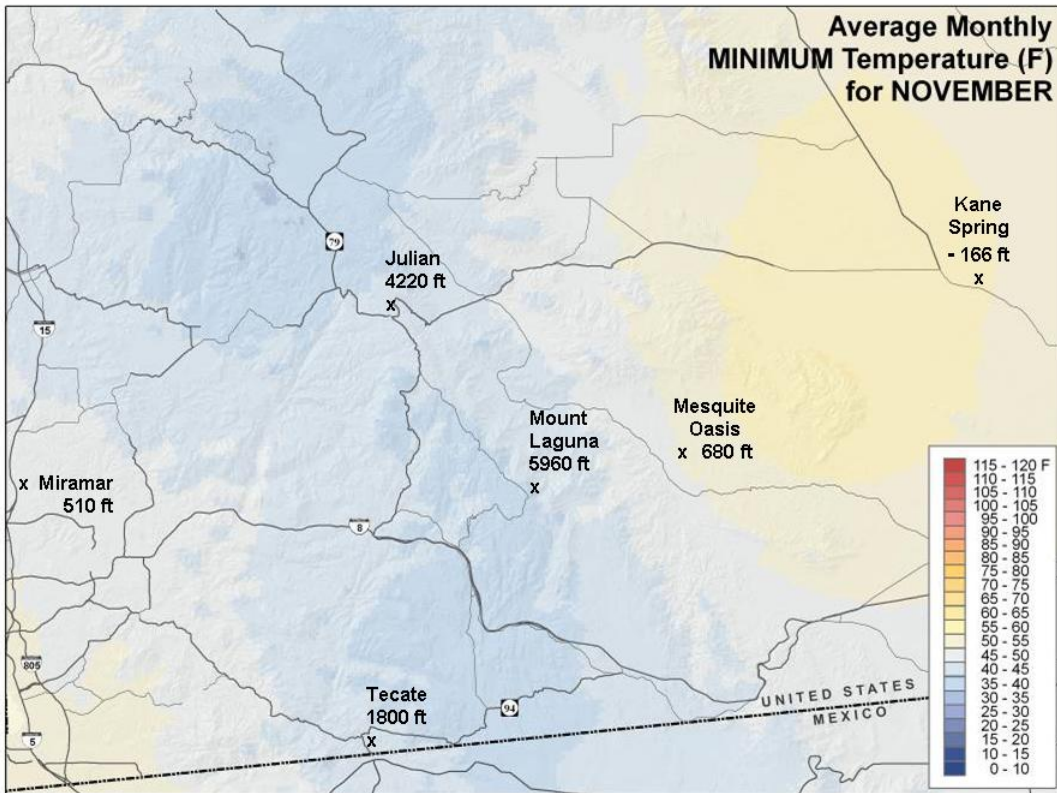
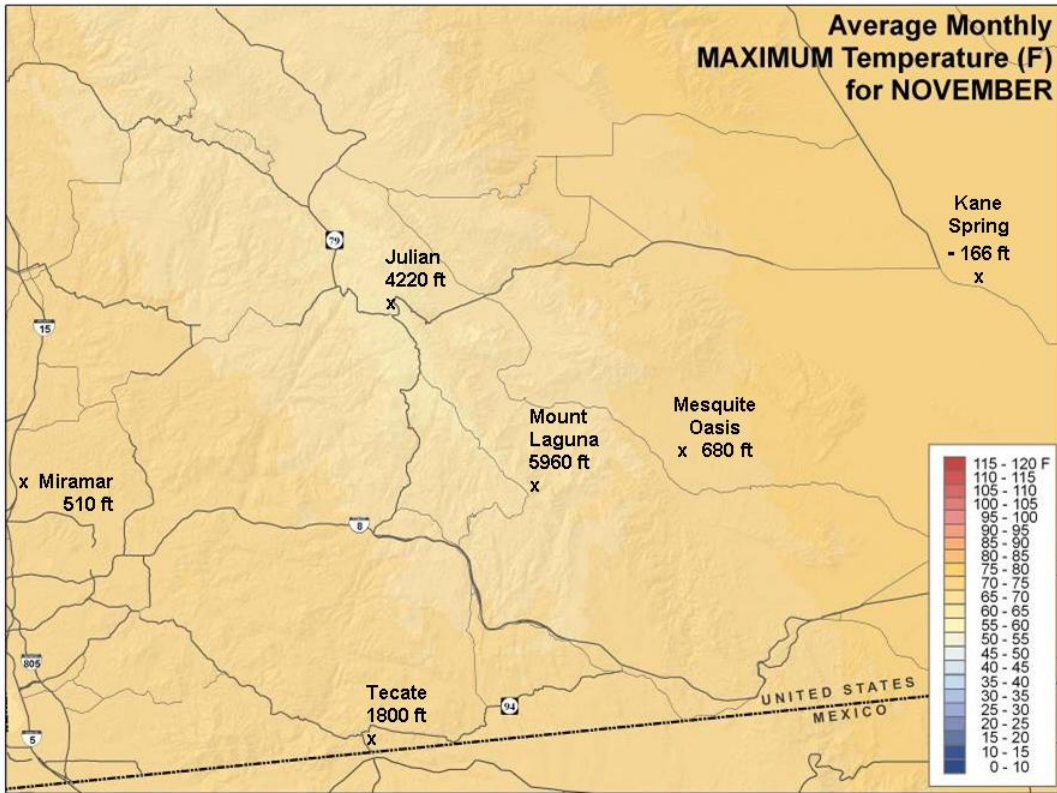


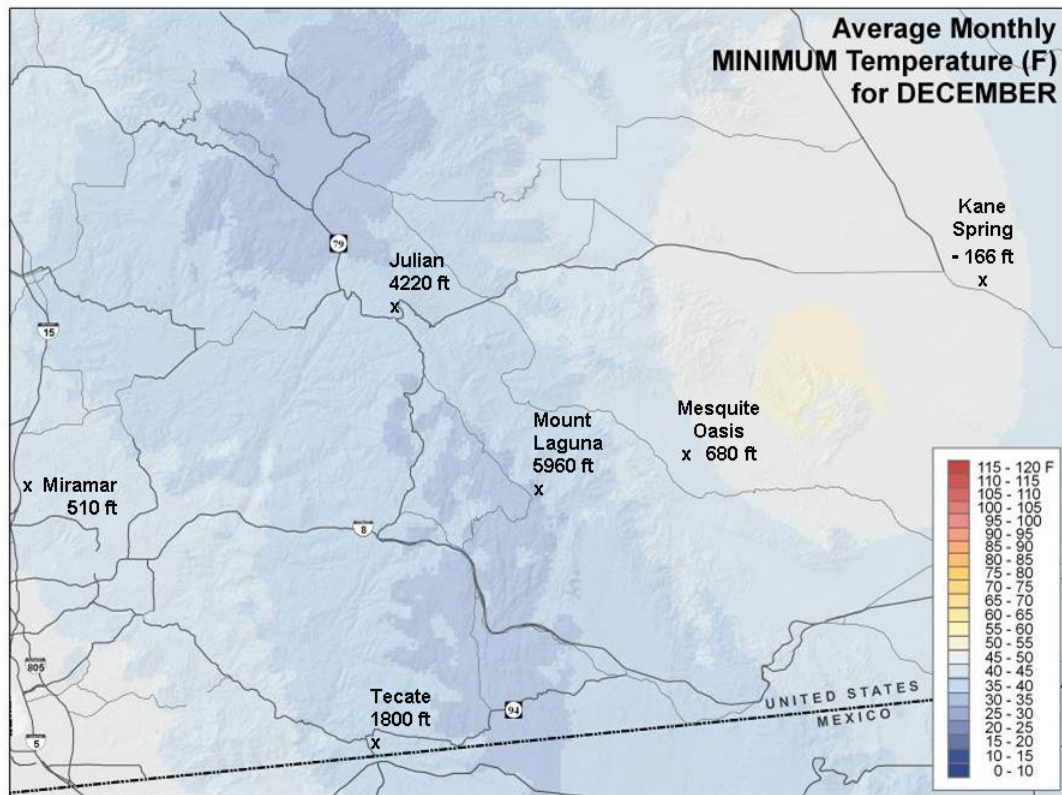
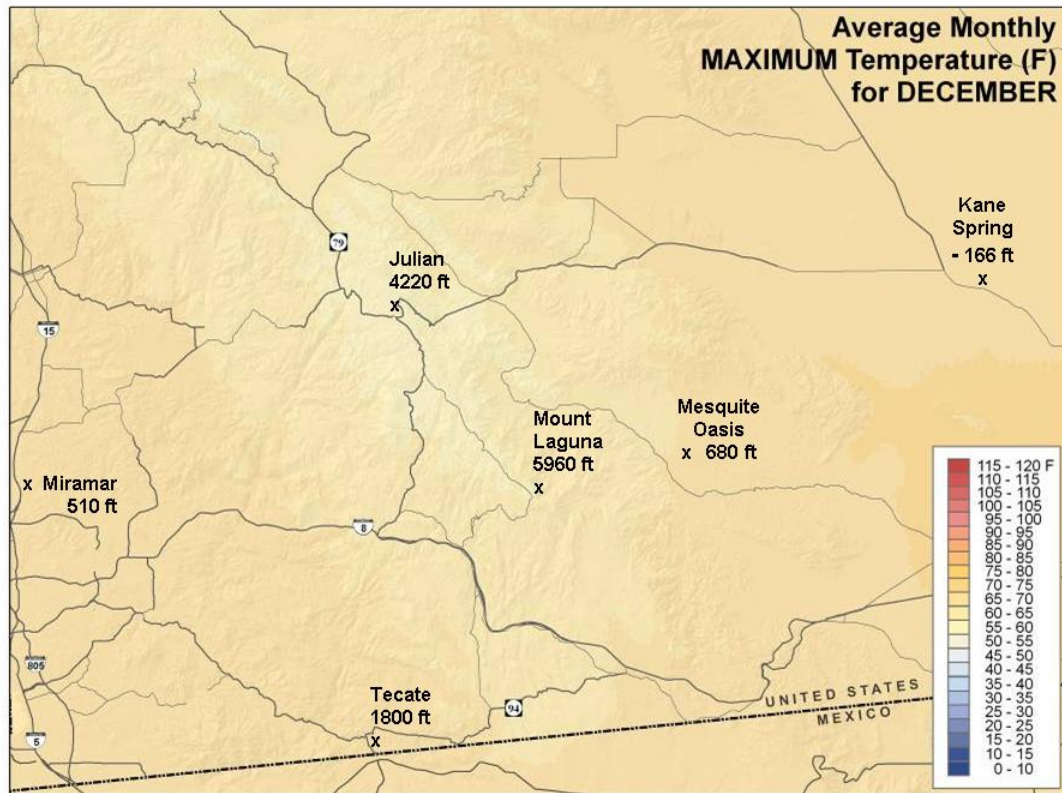
















**Appendix H: Maps depicting temperature surfaces reclassified into degrees departure from comfortable (DFC), based on average monthly maximum and average monthly minimum temperatures, and based on a “comfort” room temperature range of 65-70 degrees Fahrenheit.**

