CLIMATIC DATA REPRESENTATIVENESS IN WESTERN COLORADO

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Climatology Report #90-1

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Bureau of Land Management
Colorado State Office
2850 Youngfield Street
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INTRODUCTION

This project was initiated by the Bureau of Land Management (BLM) Colorado State Office under the direction of Scott Archer during the fall of 1989. It came about as a result of growing recognition of the importance of accurate climate information for appropriate management of Federal lands. The intent of this project was to utilize existing climatic data near Federal rangeland areas of western Colorado to evaluate to what extent these stations provide representative climatic information for surrounding unmonitored areas. In particular, emphasis was directed toward evaluation of data representativeness in a manner that could be adapted to current Geographic Information System (GIS) technology being employed by the BLM.

AREA OF STUDY

A relatively small test area was selected that covered the region from the Utah border eastward to 107 degrees west longitude and from 38 to 39 degrees north latitude. This area is shown in Figure 1 and includes the communities of Montrose, Uravan, Delta, Paonia, Norwood, Paradox, Gateway and Ouray. Grand Junction, Gunnison and Telluride are just outside of the primary area of study on the north, east and south edges, respectively. Twenty-one National Weather Service cooperative weather stations with 8 or more years of record exist within the study area and represent a range of elevation from 4560 feet (Gateway) to 9300 feet (a discontinued mesa-top station west of Sapinero). Eighteen additional data points were used outside the perimeter of the area and included a number of higher elevation sites.

OUTLINE OF ACCOMPLISHMENTS

Task 1: Planning Meeting

At the beginning of this project, a meeting was held at Colorado State University with staff of the Colorado Climate Center and appropriate BLM personnel. The purpose of this meeting was to define, to the extent possible, what aspects of climate are most critical to the BLM. The management of rangeland for animal grazing was determined to be the most important BLM activity with a high degree of climate sensitivity. There was considerable discussion over what climate elements most directly control range production. Precipitation was confidently described as the most critical variable. However, considerable uncertainty remains concerning the most important months or seasons. In general, due to the overall importance of cool season grasses over much of the BLM rangelands, accumulated cool season precipitation appears to correlate best with overall production, with spring precipitation being especially important. However, all precipitation is important. Temperature is also important in that it controls the water demand of plants and the evaporation loss rate of recent precipitation. Any other elements that influence evapotranspiration, such as humidity, solar radiation, wind, slope and aspect, will also play a role. These secondary elements affecting range production were thought to be more consistent from year to year than precipitation and temperature. Also, since much less historic data exist on winds, humidity and solar radiation it was considered less beneficial to attempt to include them in this limited study.

A second purpose for the meeting was to share information on the BLM GIS and to discuss how it could be used as a tool for climate analysis. These discussions provided beneficial information to help develop appropriate climatic analyses that will be adaptable to GIS uses. The meeting outline and list of attendees are found in Appendix 1.

Task 2: Data gathering

Daily and monthly precipitation, maximum, minimum and mean temperatures were assembled for 39 National Weather Service cooperative stations in and adjacent to the area of study. Figure 2 shows the locations of these stations. The stations were distributed by elevation as follows:

Table 1.
Climate stations in BLM study area as function of elevation.

Elevation Range (feet)	Number of stations	
	Within study area	Outside study area
4000-4999	2	3
5000-5999	7	1
6000-6999	3	1
7000-7999	6	1
8000-8999	2	6
9000-9999	1	4
10000-10999	0	2
Total	21	18

A number of descriptive climatic analyses were performed to show the nature of temperature and precipitation characteristics in the region of study that are important to the data representativeness question. The primary descriptor, the map of mean annual precipitation for Colorado is already available digitally in the BLM GIS. A number of map products were generated by BLM personnel identifying spatial precipitation patterns and associated elevation contours throughout the region. Additional analyses were performed to show some of the seasonal and elevational characteristics typical of the region. A set of stations were selected to represent approximate north-south and west-east precipitation profiles across the region of study (Figure 3). Figure 4 shows the seasonal distribution of precipitation based on mean monthly precipitation totals for stations along a north-south and east-west transect crossing the study region. Along the east-west transect, the seasonal distribution of precipitation is quite similar with all stations peaking in August and most stations reaching their minimum in June. Station elevations along this transect range from 5,280 feet at Paradox to 9,200 feet at Pitkin. However, all stations occupy valley locations. Along the north-south transect there is greater diversity of site locations ranging from a mesa-top site at Bonham Reservoir (elev. 9850 ft.) to a low valley site at Delta (elev. 4930 ft.). Significant differences in the seasonality of precipitation are seen on this north-south transect. Only at the highest elevations approaching 10,000 feet do we begin to see the winter precipitation exceeding the late summer maximums that characterize most lower elevation areas. While these figures don't show it clearly, there are several areas in extreme western Colorado where October is the wettest month of the year on average.

Figure 5 shows the relationship between July average precipitation (X-axis) in comparison to January precipitation (Y-axis). This clearly demonstrates some of the significant differences in relative contribution from precipitation in different parts of the year. Two separate relationships appear to exist: locations with relatively more precipitation in January than in July (upper curve) and the larger number of stations which are systematically drier in January than in July. This demonstrates that a simple ratioing method will not work to estimate precipitation from one location to another when the proportions change as a function of time of year.

Precipitation-elevation relationships are shown in Figure 6 for January and April. August and October are displayed in Figure 7 and the combined period June-August is given in Figure 8. There is a systematic increase of average monthly precipitation with elevation during most of the year, although the relationship is somewhat noisy. The cluster of data points that lie above and to the left of most of the other data points in January, April and October are all stations in the upper Gunnison valley. This region is systematically drier for its elevation than other parts of the region. The autumn, and especially October, exhibits some different characteristics with noticeably reduced increases with elevation and an especially clear cluster of upper Gunnison valley stations. In fact, despite its relatively high elevation, the driest part of the entire study region in October is the immediate Gunnison area which averages less than 1" of precipitation.

Temperature behaves with greater consistency. Figure 9 shows the march of mean monthly maximum and minimum temperatures through the year at 6 selected stations. All locations see the same basic annual cycle rising from the lowest temperatures in January to a peak in July. However, local differences in shape are apparent. Wolf Creek Pass and Ouray both experience more moderate temperatures during mid winter (in a relative sense) compared to the other locations. Gunnison experiences a more precipitous drop in temperatures in late autumn and a steeper rise in the spring than the other stations. Note, for example, that Ouray is slightly cooler than Gunnison in terms of average maximum temperatures from April through October. However, in January, Gunnison is more than 10 degrees colder than Ouray. These differences in shape are indicative of the cold air trapping or draining properties that often distinguish one area in the Colorado mountains from another. This becomes very significant in the evaluation of absolute and relative representativeness.

This same characteristic is also evident in Figures 10-12. There is quite a good relationship of mean maximum temperatures with elevation. During the summer, the relationship is so good that you can typically determine the mean monthly maximum temperature to within +/- 1 degree F simply by knowing the elevation. However, elevation is only a secondary control of minimum temperatures, especially during the winter. The relative trapping and draining characteristics of a given site become the primary control of nightime temperatures.

Task 3: Natural variability

If climate were stable from year to year, there would likely be little if any interest in data representativeness. Of course, climate is not stable. It is constantly varying on various time and space scales. These variations are controlled by large scale atmospheric motions, their seasonal cycles and the spatial scales of individual storm systems. These larger scale controls are then perturbed regionally and locally by differences in elevation, topography and exposure that produce the final complex patterns of climate elements that we observe here in Colorado. Figure 13 demonstrates the variability over time of areally averaged temperature, precipitation, and the Palmer Drought Index in west central Colorado. Large variability, especially in precipitation, is a natural and expected part of the climate of arid and semiarid regions.

One of the difficult aspects of variability is that it is a function of many controls which are partially but not totally independent of each other. Figure 14 shows how standard deviations of monthly mean maximum and minimum temperatures vary through the year over the study area. Midwinter sees the greatest natural variations in temperature while July and August are much less variable. Maximum temperatures also exhibit different behavior than minimum temperatures through the year. In the spring and autumn, there is much more variability in maximum temperatures than in minimums. In Figure 15 the standard deviations of monthly mean maximum temperatures are shown over the whole study area for January (Figure 15a) and July (Figure 15b). The region is divided into zones that exhibit more and less variation than the regional average. In winter, high variability characterizes lower elevation valley areas. In summer, the pattern of higher variability is less clearly associated with the topography but could be associated with areas prone to greater year to year fluctuations in cloudiness associated with monsoonal moisture.

Precipitation is much more variable than temperature, at least in a traditional statistical sense. Figure 16 is an attempt to demonstrate differences in natural variability through the year at Montrose. The precipitation amounts associated with a set of nonexceedance probabilities from 0.05 up to 0.95 are shown to give an idea of the range of expected precipitation for any given month. The measure of variability (the difference between the precipitation amounts associated with a 0.80 nonexceedance probability and a 0.20 nonexceedance probability divided by the median (0.50 probability)) is an attempt to remove the dependence of apparent variability on the mean. From this approach, May, June and September exhibit the greatest relative variability while April, July and August are least variable.

Another important component that must be included in the analysis of variability is the length of the sampling period. In general, variability is reduced with longer sampling periods as you go out in time from daily to weekly to monthly to seasonally to annually and eventually to multi-annually.

Task 4: Analysis of data representativeness

Data representativeness is a very complex issue in its purest form. How many weather stations are needed to provide "sufficient" information? This depends both on the climate and on the application. For example, for general resource assessment, data from just a few locations may be sufficient. For air pollution applications and for environmental impact statements, much higher resolution data are normally required. Range management probably lies somewhere in between. Most of what has been written on the subject of data representativeness has been in the context of network design and optimization. Such studies are primarily statistical.

The approach we selected to objectively analyze data representativeness was, to a large part, determined by the limited resources for this project. Only simple associations between distance and elevation using actual measured data were employed. The basic climatic description of the region and the relationships described in the sections above were used to help select groupings of stations that could be used to determine station to station differences and similarities in temperature and precipitation as a function of sampling period, distance between stations and elevation differences. The magnitudes of natural variability were used to determine the significance of correlation statistics that were obtained by linear regression.

The selection of a time scale for representativeness is extremely important. If the primary concern is how similar the average long-term climate of unmonitored locations is in comparison to one or more existing weather stations, then mean climatic statistics can be used and simple spatial patterns and/or elevation relationships can be determined that describe many of the salient features of "representativeness." However, if the primary concern is on how similar the climate is on a daily, weekly, monthly, or seasonal time scale, then time series analyses, comparisons and correlations must be performed to begin to understand representativeness.

a) Climatic representativeness for average seasonal and annual precipitation.

Traditional maps of mean climatic conditions such as those contained in climatic atlases are probably the best way to visualize this type of representativeness. In areas where contours of temperature or precipitation vary smoothly and consistently and few topographic features exist, such as across the U.S. central plains, very few data points are needed to accurately describe the average climate. Mean climatic data for a single station may be valid in an absolute sense for many miles in all directions. In western Colorado, this is certainly not the case. Utilizing the 1951-1980 average annual precipitation map for Colorado, best estimates suggest that average annual precipitation within our study area varies from as little as 8" in the area around Delta to perhaps more than 50" on Uncompahgre Peak near Lake City.

Our descriptions earlier in this report indicated that elevation changes explain the majority of the variations of precipitation within the study region. Figure 17a shows average precipitation as a function of elevation for the cool season (September-May), the precipitation believed to be best related to the growth of cool season grasses. Figure 17b contains the same information for the warm season, May-September. Finally, Figure 18 shows this relationship for the entire water year, October-September. (Note: May and September are included in both the warm and cool season based on suggestions from BLM range experts that those months contribute significantly to the growth of both warm season and cool season grasses.) In all cases, there is a systematic increase of precipitation with elevation in and around the BLM study region. In the 5-month warm season (May-Sept.), precipitation increases with elevation at a rate of approximately 1.7 inches per thousand feet with 64% of the variance in precipitation explained by elevation. For the 9-month cool season (Sept.-May) the rate is 3.6 inches per thousand feet with 50% of the variance explained by elevation. Finally, for the year as a whole the increase is about 4.4 inches per thousand feet with 57% of the variance explained by elevation.

While elevation explains at least half of the variance in mean seasonal or annual precipitation, it is not the only control. At any given elevation, there is considerable spread in total precipitation among our sample points. For example, at 8000 feet for the September through May season, average precipitation ranges from less than 8" to nearly 20". For this reason, we more closely examined the points on the graph to determine their relative locations within the study area. Systematic patterns emerged. The Upper Gunnison Valley was especially prominent in this type of analysis. Upper Gunnison weather stations experienced the same local increases with elevation but were systematically about 8" drier for the September - May period than other stations in the region and formed what appears to be a totally separate population on the graphs. By removing 9 Upper Gunnison Valley precipitation stations from the sample, r-squared values improved from 0.50 to 0.82. The relationships are even better for the other periods. Outside the Upper Gunnison Valley, precipitation exceeded the average for a given elevation on the immediate western side of the Uncompahgre Plateau, near the Grand Mesa and on the west side of the Ruby Range including the Paonia area. This interesting anomaly pattern is shown in

Figure 19. Combining these anomaly patterns with the basic precipitation-elevation association allows for excellent estimates of climatologically averaged precipitation for locations without data.

b) Climatic representativeness of seasonal precipitation including year to year variability.

While precipitation behaves predictably when averaged over many years, its behavior in any individual year or season can be markedly more erratic. To demonstrate this, we compared at least 20 consecutive years of monthly and seasonal precipitation between numerous pairs of weather stations in and near the BLM study region (Figure 20). Correlations were performed to determine how much of the year to year variations in precipitation at one station could be explained by those observed at a second station. Montrose was selected as a central point for comparison. Fort Collins was selected as a control station far from Montrose. The correlation (r-squared) of precipitation for many locations in and near the study area with Montrose is shown in Figures 21-25 for several combinations of months. Contours were drawn for r-squared of 0.25, 0.50 and 0.75. When at least half of the variance in a precipitation time series at a location is explained by the Montrose data, we consider the locations to be well related. A correlation of 0.75 or greater represents excellent similarity from year to year. Less then 0.25 represents very poor representativeness. A value of 0.00 indicates absolutely no similarity between time series.

During the summer (Figure 21) the whole region is relatively well correlated. The worst relationship observed was between Montrose and Lake City with r-squared = 0.25. There was no correlation between Montrose and the control station, Fort Collins. Three separate regions showed good correlation. Correlations with Montrose exceeded 0.50 over extreme western portions of the study area, along the valley bottom from near Grand Junction on up beyond Ouray and with the Upper Gunnison Valley. The best relationship anywhere in the area was between Montrose and Taylor Park — a conclusion that is not easy to explain.

The fall months, Sep.-Oct. (Figure 22) showed strong relationships throughout the region. Only Uravan and Cochetopa Creek had less than 50% of their variance explained by the Montrose precipitation time series. The correlation with Fort Collins was even 0.35 suggesting that fall precipitation has widespread regional year to year relative similarity far beyond the limits of the small study area. The best correlations were found in a band from Paonia southward into the San Juan Mountains where values exceeded 0.75.

Correlations decayed greatly for mid winter (Nov.-Mar.) as shown in Figure 23 and improved in spring (Apr-May), Figure 24. With the exception of the Lake City area, the only correlations in excess of 0.50 were in the valley areas near Montrose. Looking at the entire September-May cool season (Figure 25), the correlations with Montrose were poor in extreme western and eastern parts of the study area, but exceeded 0.50 in the center of the region.

To evaluate if there was any significant association of r-squared values for pairs of stations with their respective horizontal distance or elevation separation, all r-squared values were plotted versus elevation and distance separation. Figure 26a shows that for fall precipitation, distance between stations appears to be the major factor controlling how representative one station may be of another. At a distance of 30 miles, r-squared values are typically about 0.75. Correlations continued at better than 0.50 until distance separation exceeded 80 miles. Elevation difference (Figure 26b) showed no similar association. For the entire cool season (Figure 27) there is only a minor indication that correlations decay with distance and again little interpretable association with elevation difference. Elevation difference, while being the dominant control of mean precipitation, appears by itself to explain little or none of the relative differences in precipitation between stations from one year to the next. If we were to approximate an association between elevation difference and r-squared, it might look similar to the curved line in Figure 27b. Points left of the curve have unusually poor correlations for their elevation difference while those to the right of the curve have unusually good correlations. We examined each combination to see if any significant patterns emerged. What we found was that San Juan Mountain stations were surprisingly well correlated with lower elevation sites north of the mountains. The poorer than expected correlations often were found between stations that lie primarily east and west of each other.

c) Climatic representativeness of mean seasonal temperature data.

As we showed earlier, temperature is greatly influenced by elevation. Elevation can be used, especially during the summer months, to estimate mean temperatures for areas without temperature data. In Figure 28 mean seasonal temperature for the May-September growing season is shown as a function of elevation. This period was chosen due to its association with the growth season for both warm and cool season grasses. Growing season temperatures decrease with elevation at a rate of 4.5 degrees F per thousand feet (r-squared = 0.95). The points which fit this relationship most poorly were plotted on Figure 29 with a "W" for stations which were at least one degree F warmer than the regression line and "C" for those stations that were cooler than the regression relationship. All of the unusually cold stations were in the Upper Gunnison Valley. The unusually warm locations were characterized by well drained exposures such as mesa tops or at ends of canyons. This suggested that improvements in temperature estimates for unmonitored locations could be achieved using additional knowledge about the immediate topography.

Cool season temperatures are not so totally elevation controlled. Upwind and downwind exposure and cold air trapping behavior produce a more complex temperature pattern than is seen in the summer. Since winter temperatures are probably of lesser importance for range management decisions, we did not choose to establish detailed relationships.

d) Climatic representativeness of seasonal temperatures including year to year variability.

Similar analyses to the precipitation data described above were used to show how well temperatures correlated across the region over a period of years. Seasonal temperatures are much more uniformly correlated across the region than precipitation. Most locations within the study area (Figure 30) had at least 50% of the variance in May-Sept. temperatures explained by the Montrose time series, but there were notable exceptions. Nearby Cimmaron showed an r-squared of only 0.16, Gateway was only 0.14 and Lake City showed 0.44. The Montrose-Telluride correlation was a remarkable 0.81. There are no obvious explanations for some of these correlations.

Looking at correlations among numerous station pairs in and around the study area to detect systematic relationships with elevation or distance separation for temperature did not prove fruitful (Figure 31). Distance and elevation obviously do make a difference, but within this relatively small area neither distance nor elevation separately account for year to year differences in growing season temperatures. Spatial correlation patterns appear more promising than composite scatter plots of correlation versus elevation or difference for describing the factors that help determine how climatically similar locations may be with respect to each other.

Note: Many analyses showing relationships and correlations using daily, monthly and seasonal temperature and precipitation data were performed that were not included in this final report. These analyses are filed at the Colorado Climate Center in the BLM project file and are available for inspection.

Task 5: Expression of data representativeness for GIS applications.

The evaluation of data representativeness described in Task 4 resulted in some very clear relationships that can be employed directly within a GIS to extrapolate expected mean climatic conditions to unmonitored locations in and near the study area with considerable reliability. While other factors may be important, elevation differences are the dominant control influencing both average precipitation and temperatures on the scale of this study area.

Precipitation:

May-September:	+1.7 inches / 1000 feet	(r-squared = 0.64)
September-May:	+3.6 inches / 1000 feet	(r-squared = 0.50)
October-September:	+4.4 inches / 1000 feet	(r-squared = 0.57)

Temperature:

May-September T(mean): -4.5 deg. F / 1000 feet (r-squared = 0.95)

Unfortunately, in any individual year, these relationships, especially those for precipitation, may not work as well. Efforts to describe spatial patterns of year to year variability and their relationship to horizontal and vertical distance between measurement points did not provide objective results easily adaptable to GIS applications. Instead, we gathered more subjective information that would require more sophistication in order to apply. For example, our correlation patterns suggest that areas in the same valley, regardless of their distance apart, are more likely to be well correlated than sites on the opposite side of a mountain barrier. Likewise, stations far apart but with similar aspect relative to local terrain, may be better correlated.

Temperature is by far the easier variable to work with, especially when our greatest concern is the growing season. Summer temperatures are typically quite stable from year to year. A very small number of well-distributed stations will generally suffice to describe the basic features of temperature for a region the size of our Montrose study area. The current station density may already be sufficient. Information to allow a determination of the cold air trapping or draining tendencies is very helpful in order to adapt the regional temperature/elevation curve to a particular site.

The range of representativeness is much less for precipitation than for temperature and more factors become significant. Precipitation representativeness is very much a function of the time of year. The different precipitation processes -- convective, orographic and synoptic -- all are event dominated and exhibit their own spatial patterns of representativeness. Excellent spatial correlations are observed during the fall that are little affected by large elevation differences. This changes completely in midwinter as mountains almost totally control the distribution of precipitation. During summer, thunderstorms operating on very small (and probably partially random) scales, produce nearly all of the precipitation. Even if raingages were situated every 5 miles in all directions, some of these storms would elude the network.

Further work is necessary to objectively evaluate precipitation data representativeness. Some of our results point to some interesting and significant characteristics of precipitation patterns. However, the high degree of year to year variability in precipitation and the differences in seasonal precipitation distribution across the study area was not conducive to confident conclusions from a limited study like this.

CONCLUSIONS AND REMARKS

We have shown that existing historical weather records can be very useful in assessing data representativeness and potential requirements for higher resolution data in order to address special climate-sensitive applications such as range management. Several associations, primarily elevation-related, have been identified that should be helpful in monitoring climatic conditions in western Colorado. But most of all, we have shown the marvelous complexity of our climate system. The work represented here should be considered as primarily descriptive in nature. More complex and expensive approaches have been employed in other studies and could assist in this local application. However, the best start in understanding how to use climate information is to understand the climate itself. We hope we have made a contribution in that direction.

APPENDIX 1

Colorado Climate Center - Bureau of Land Management
Miniworkshop:

"Climatic Data Representativeness in Western Colorado
for Range Management Applications"

Department of Atmospheric Science
Colorado State University
Fort Collins, CO 80523

9 AM - Noon 7 December 1989

LIST OF ATTENDEES:

Name	Affiliation
1. John Riel	Bureau of Land Management, Colorado State Office
2. Dennis Murphy	Bureau of Land Management, Montrose District
3. Vocker Steinbeck	Bureau of Land Management, German Exchange Student
4. Bill Kendall	Bureau of Land Management, Colorado State Office
5. Scott Archer	Bureau of Land Management, Colorado State Office
6. Gene Wooldridge	Colorado State University, Dept. of Atmospheric Science
7. Tom McKee	Colorado State University, Dept. of Atmospheric Science
8. Nolan Doesken	Colorado State University, Dept. of Atmospheric Science

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PROPOSED DISCUSSION OUTLINE:

Content	Presenter
Introductions	All
Description of BLM's climate data uses for land management and purpose for investigating climatic data representativeness	Scott Archer
Data -- what do we have to work with	Nolan Doesken
GIS -- how will this tool be used	BLM
Range response to climate -- what aspects of climate are most critical in explaining temporal variations in range production	John Riel & Dennis Murphy
Open discussion to help determine the most significant aspects of climate related to range conditions	All
Other	All
Wrap up	Tom McKee

Lunch: 12:00 - 1:00

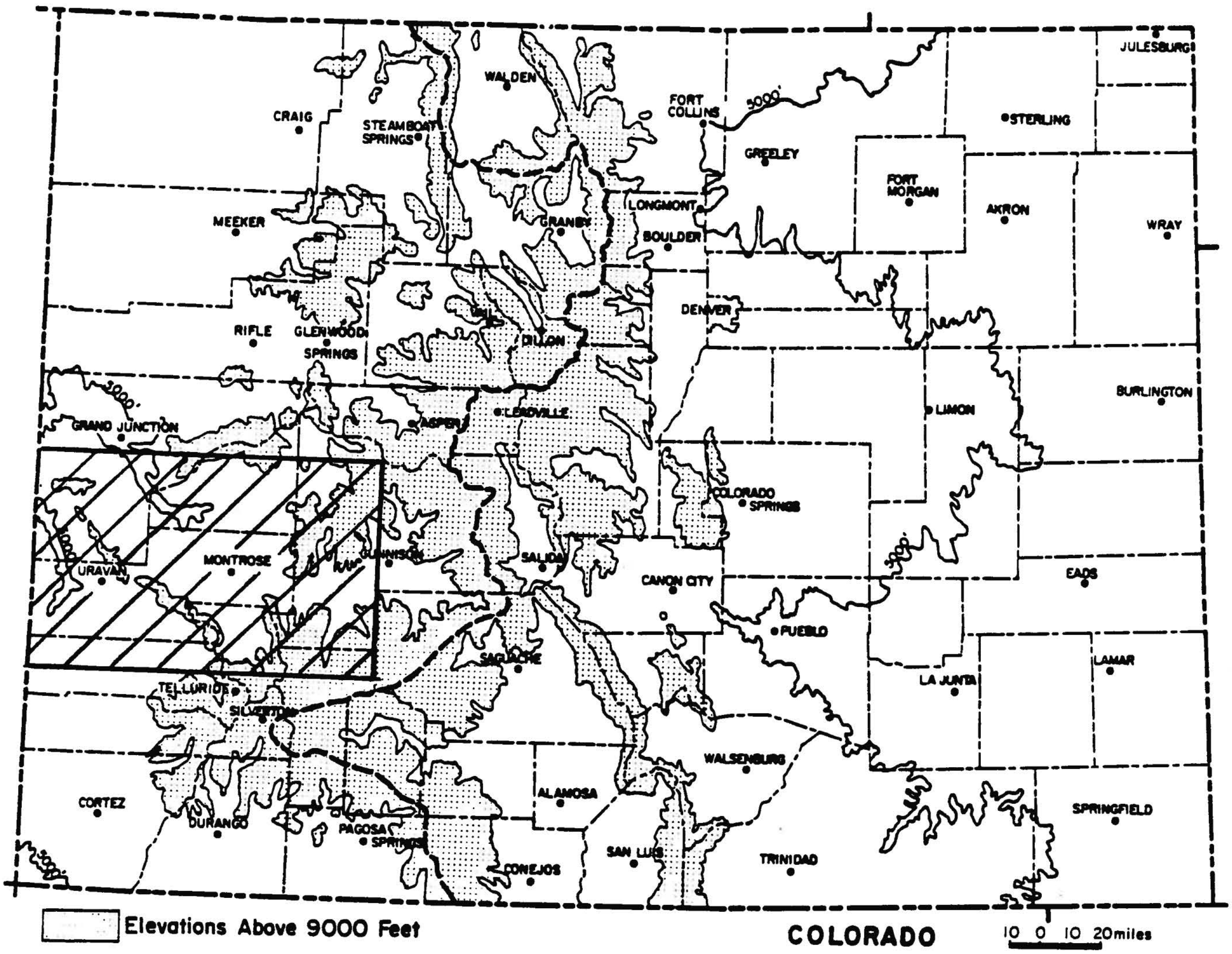


Figure 1. Map of Colorado showing the Bureau of Land Management data representativeness study area (hatched rectangle in west central Colorado.

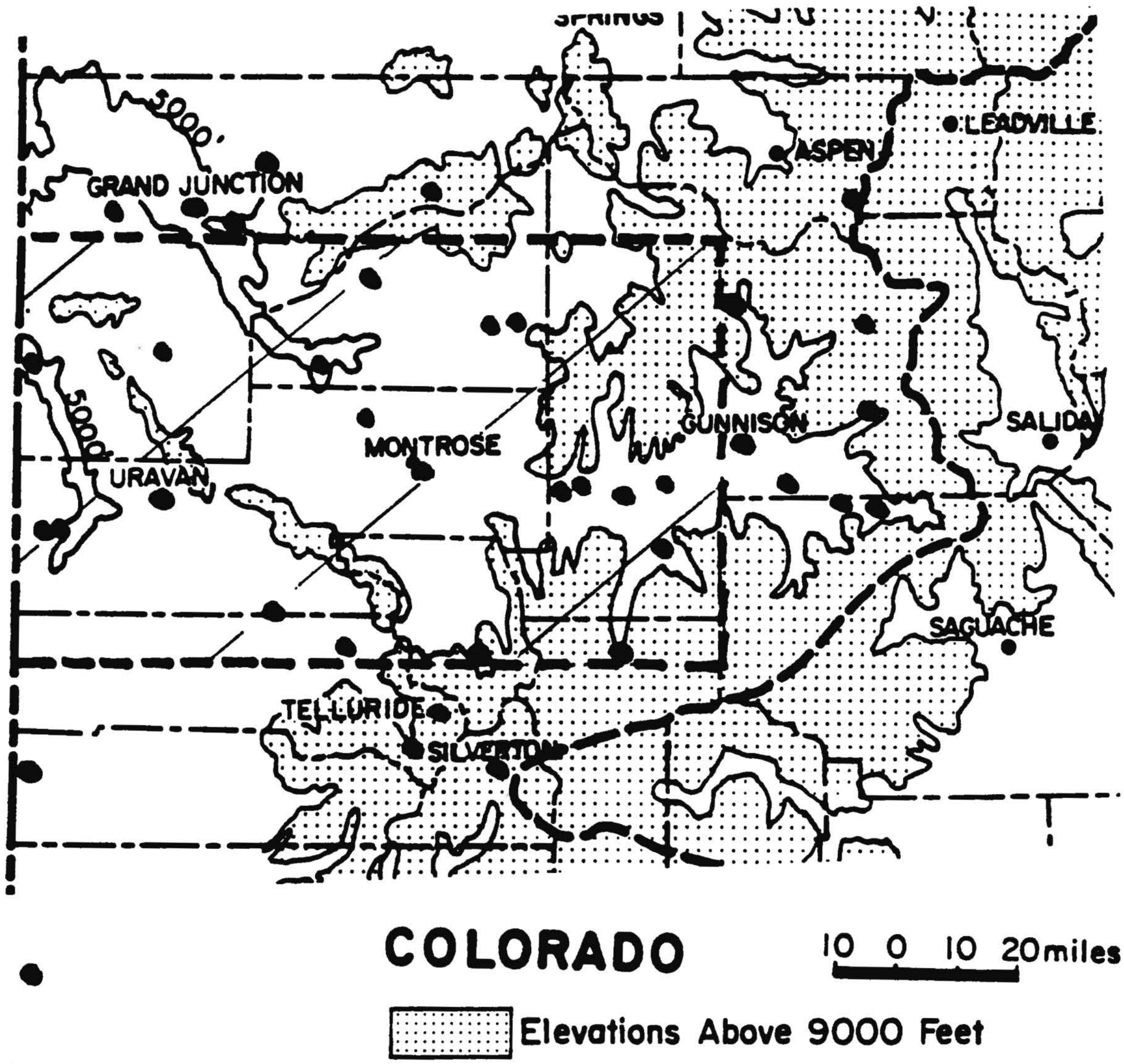


Figure 2. Expanded view of BLM data representative study area. Dots show locations of National Weather Service Cooperative weather stations with at least 8 years of summarized monthly precipitation and/or temperature data.

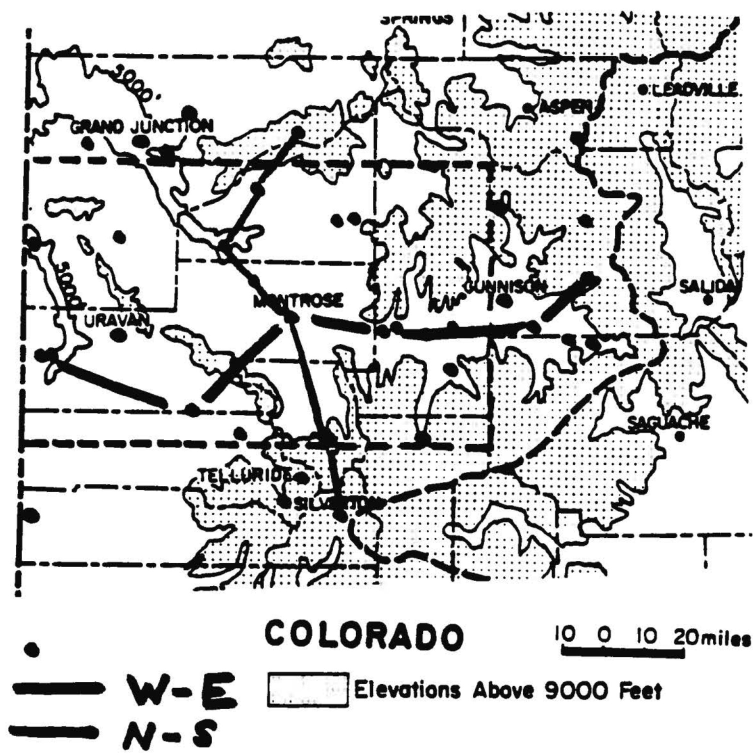
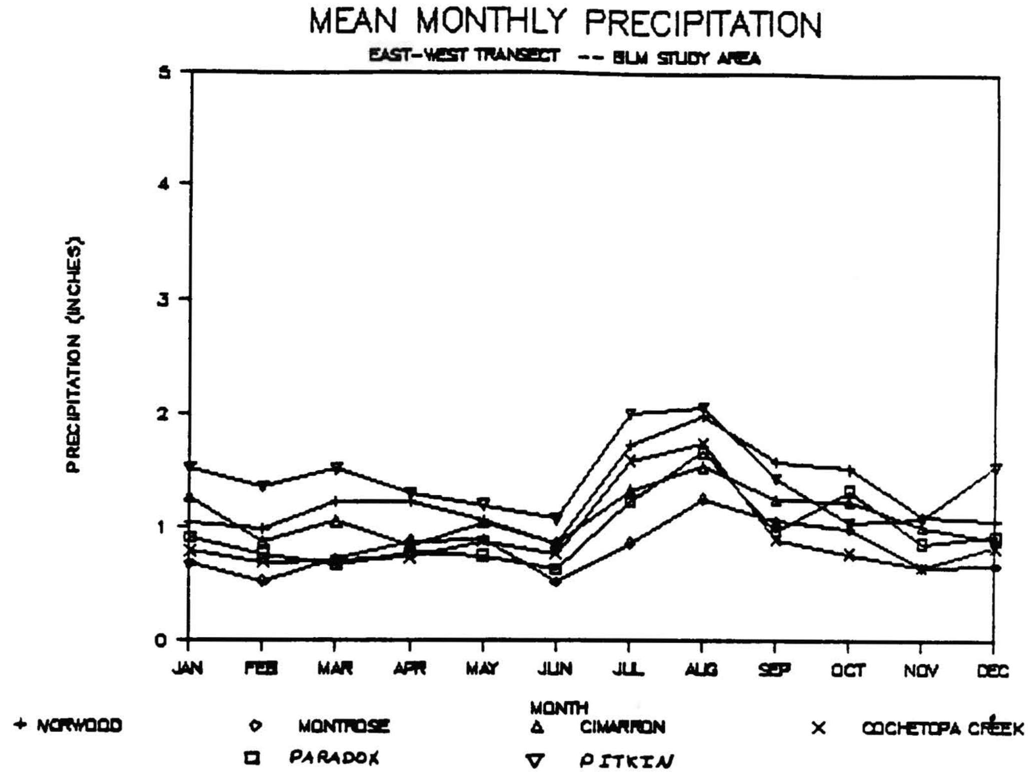


Figure 3. Map of BLM study area showing positions of weather stations used to define a north-south and west-east climate profile.



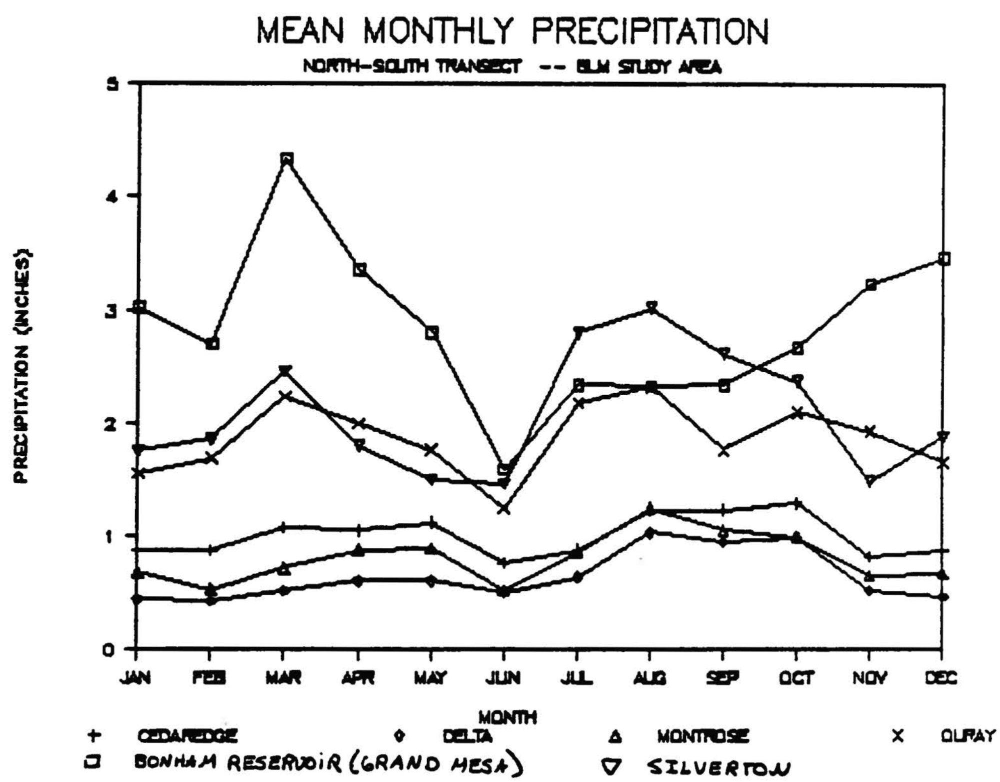


Figure 4. Monthly distribution of average precipitation for the 1961-1980 period from the BLM data representativeness study area. The top figure represents a west-east transect across the study area. The bottom figure includes stations along a north-south transect.

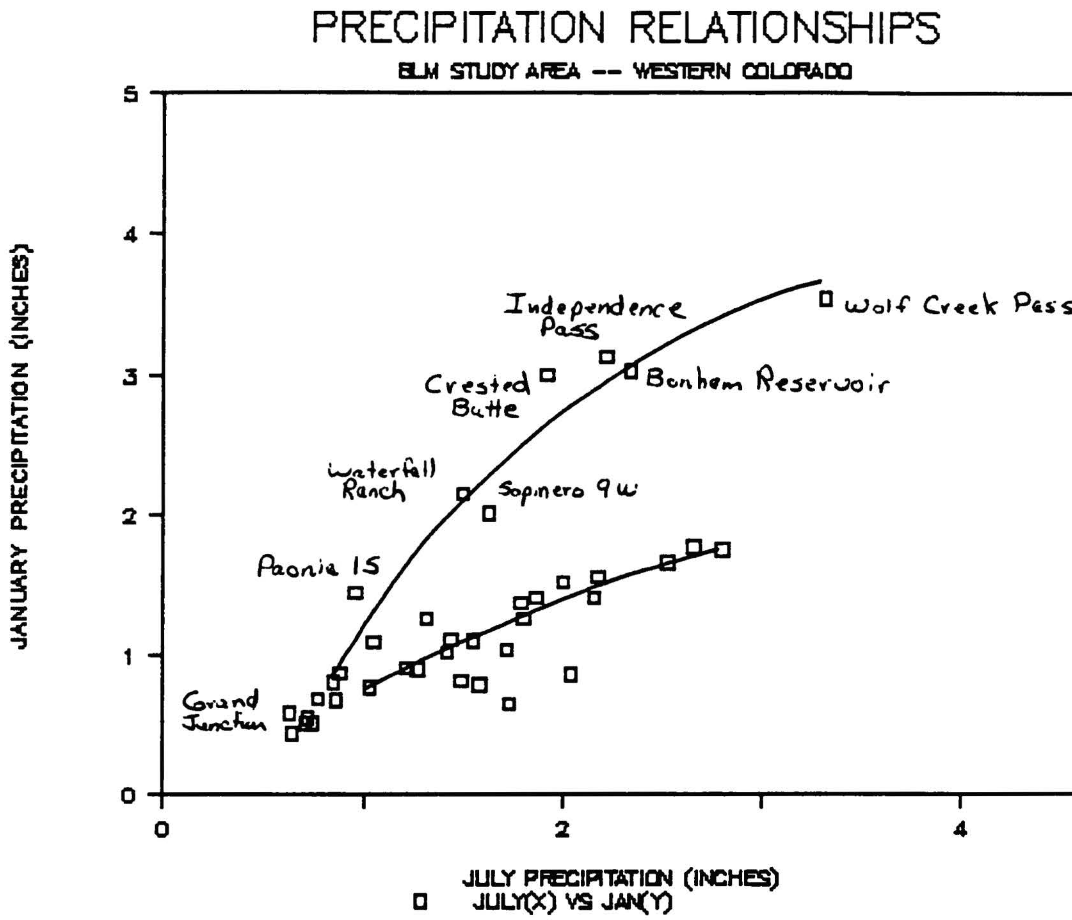
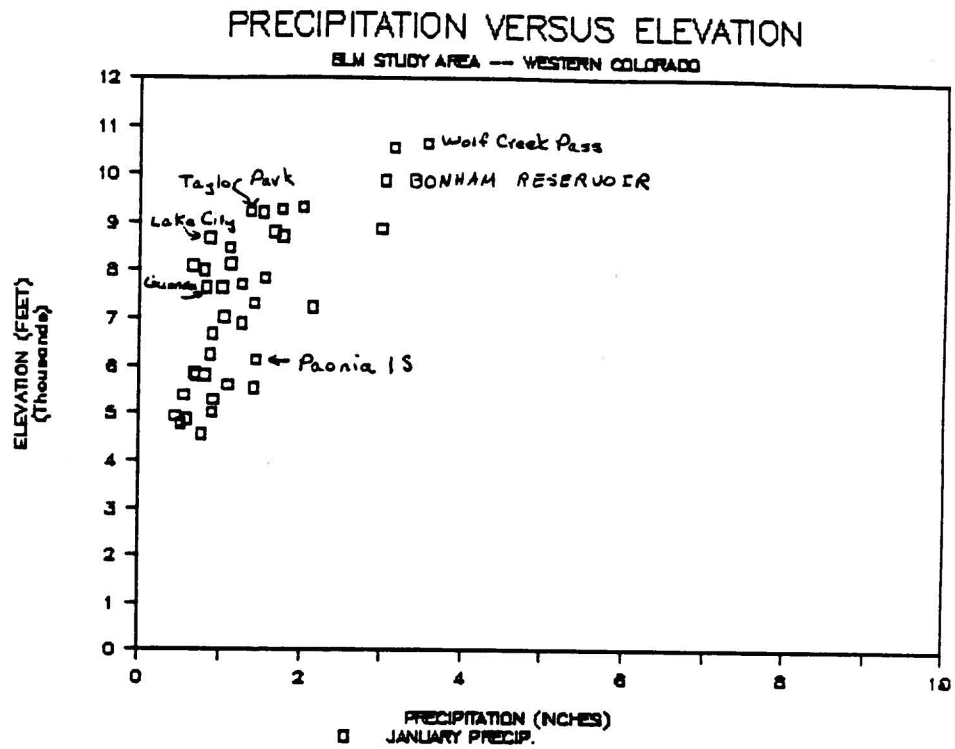


Figure 5. Average July precipitation (x-axis) versus average January precipitation (y-axis) for the 1961-1980 period for weather stations in and near the BLM study area in western Colorado.



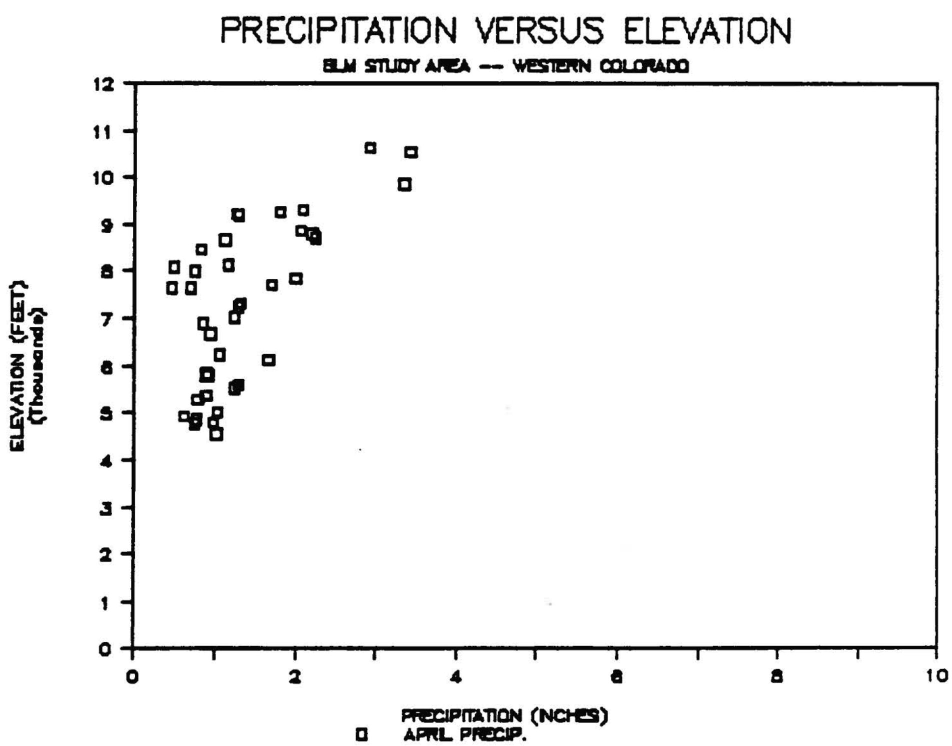
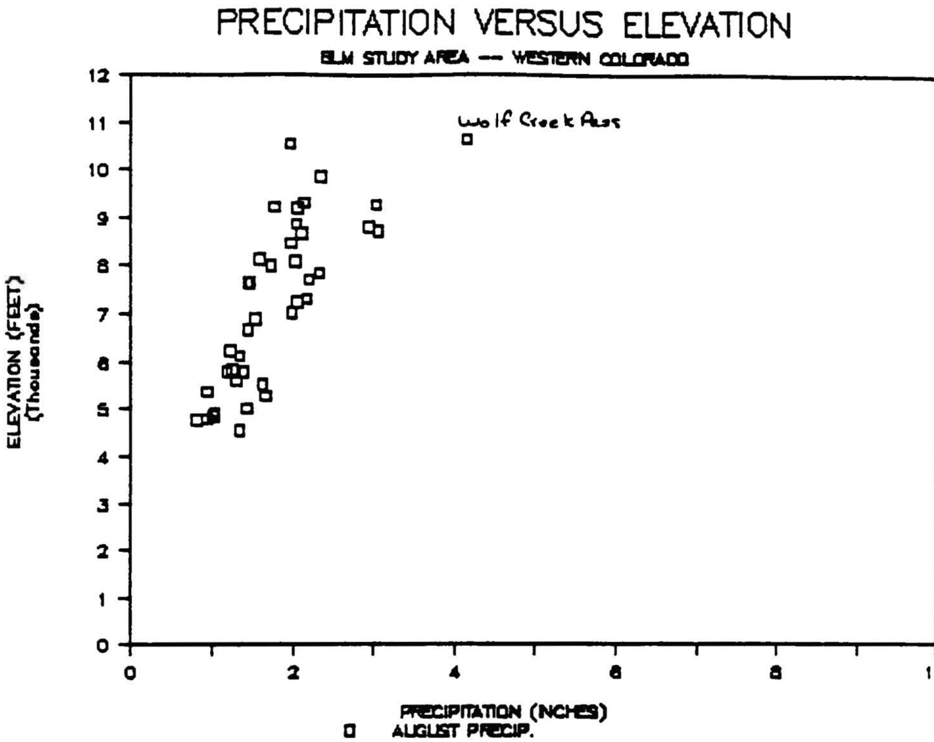


Figure 6. Average monthly precipitation versus elevation for weather stations in and near the BLM study area of western Colorado. Top graph shows January precipitation and the lower graph shows April precipitation.



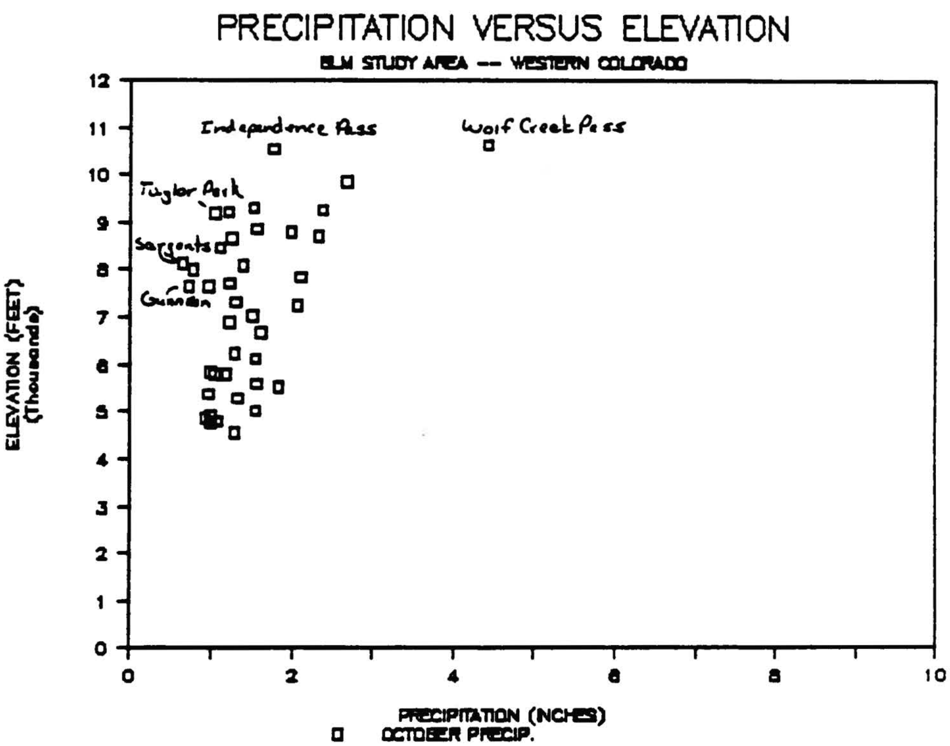


Figure 7. Same as figure 6 except for August (top graph) and October (lower graph).

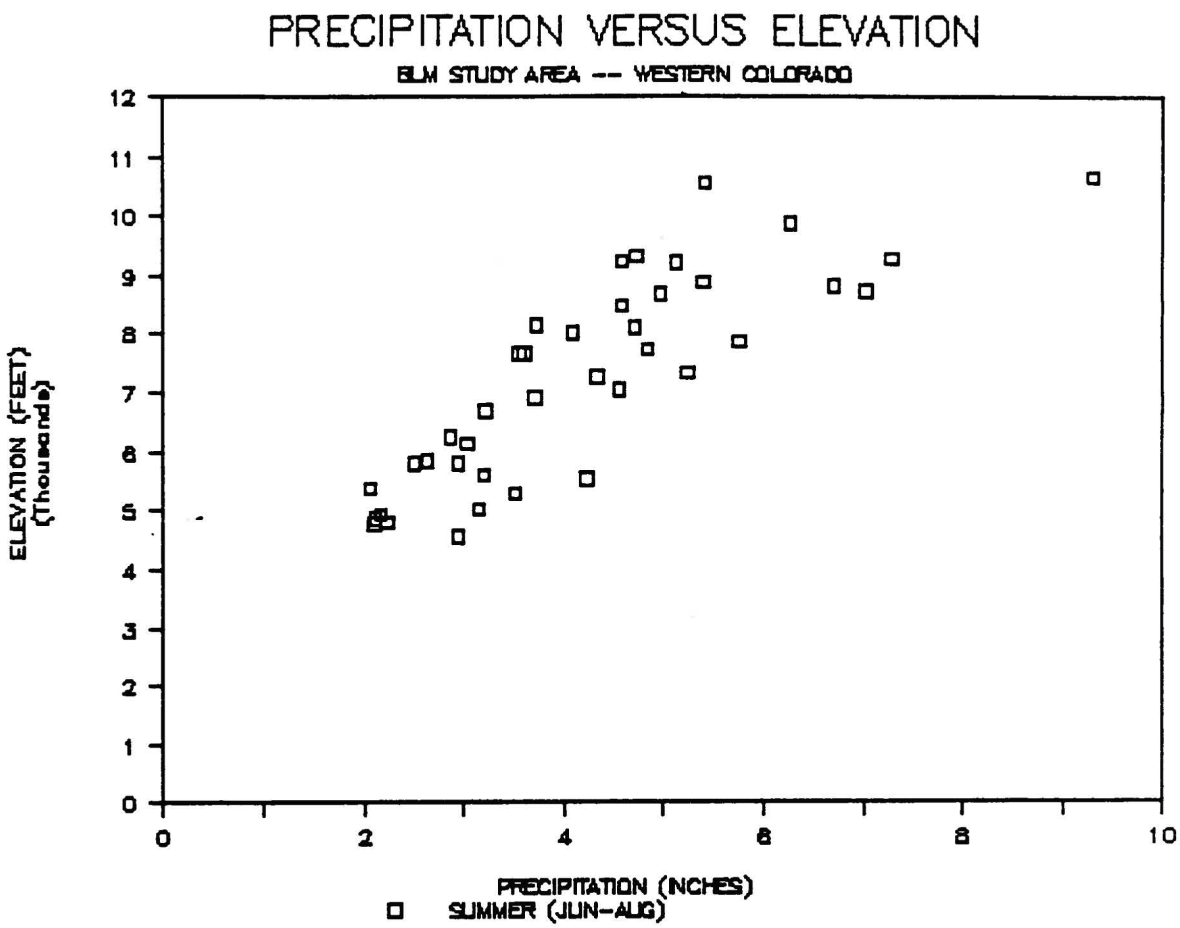
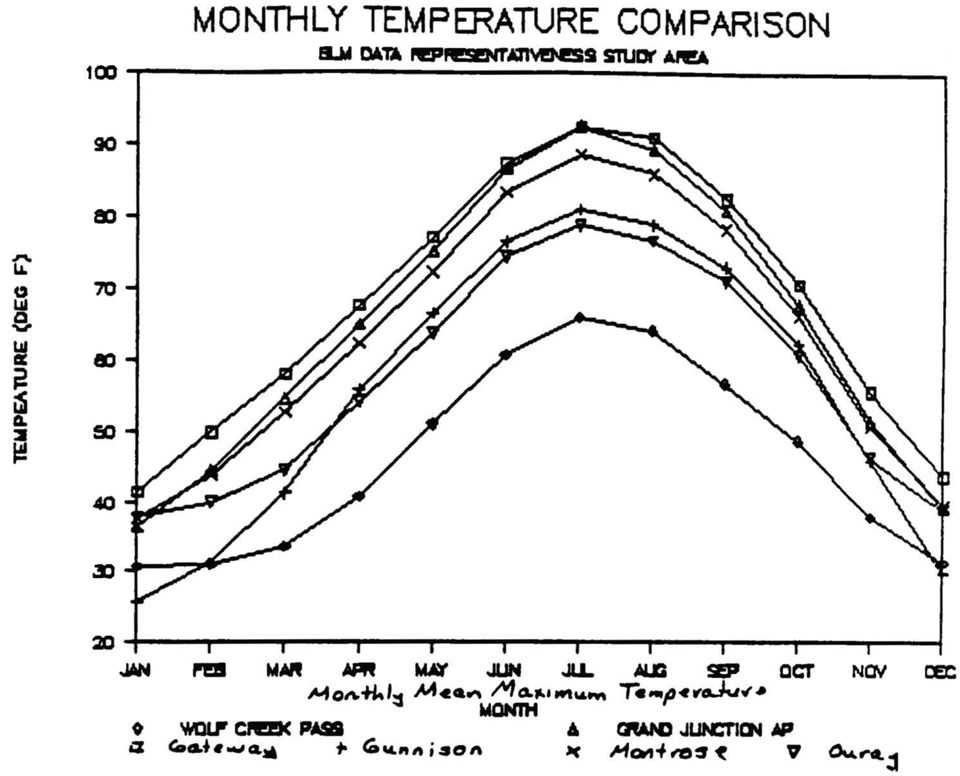


Figure 8. Average summer (June through August) precipitation versus elevation for weather stations in and near the BLM study area in western Colorado.



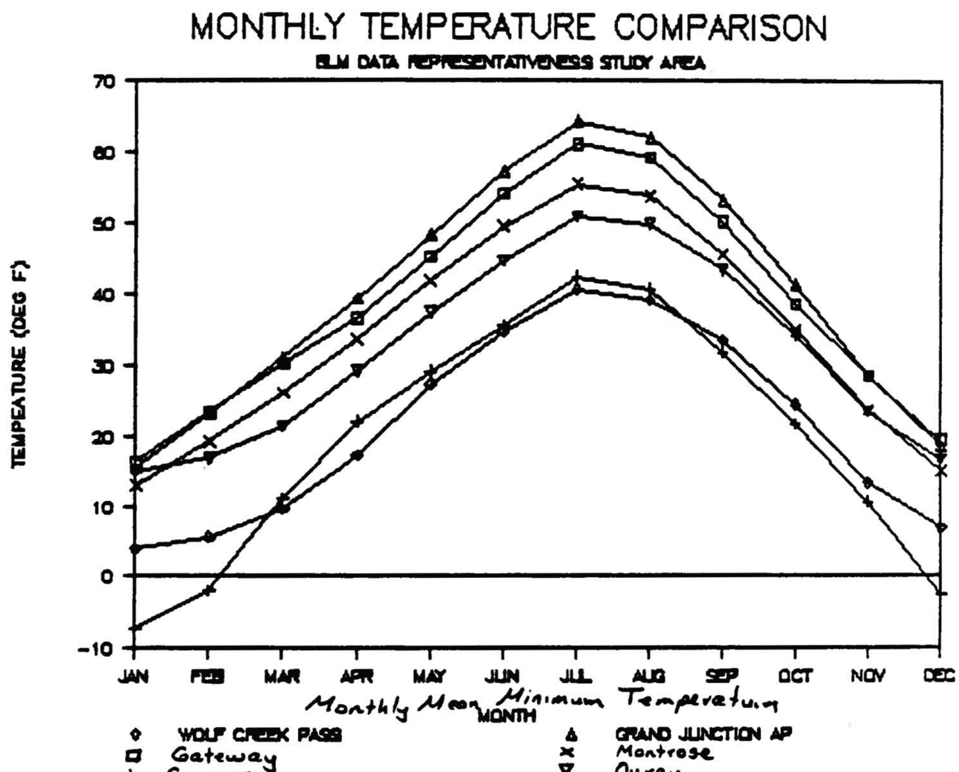
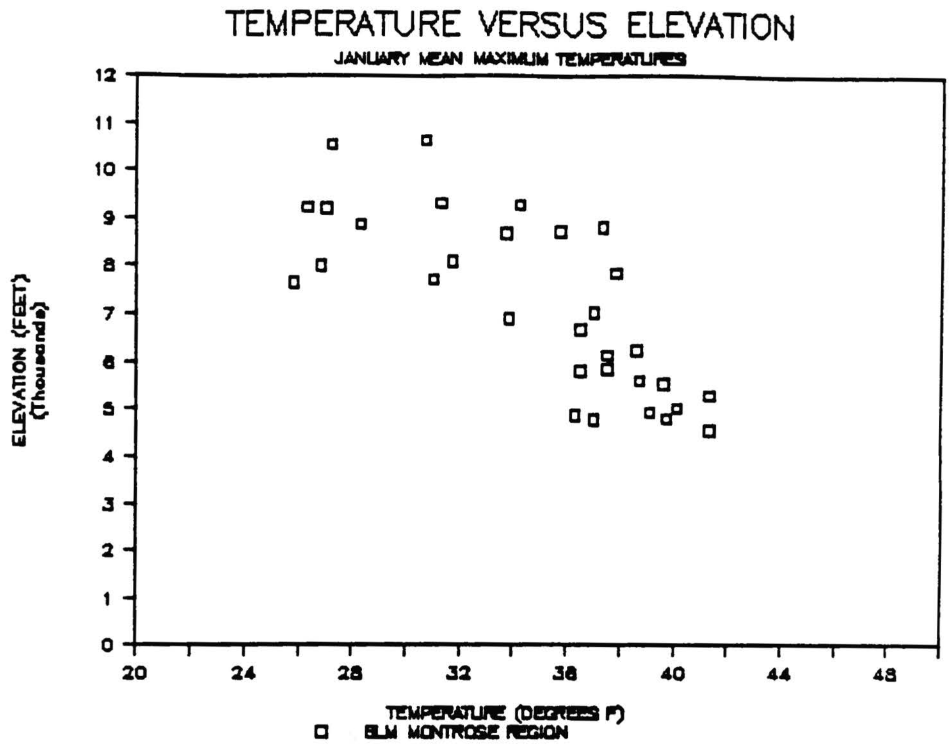


Figure 9. Monthly average maximum temperatures (top) and minimum temperatures (bottom) for weather stations in or near the BLM data representativeness study area in western Colorado.



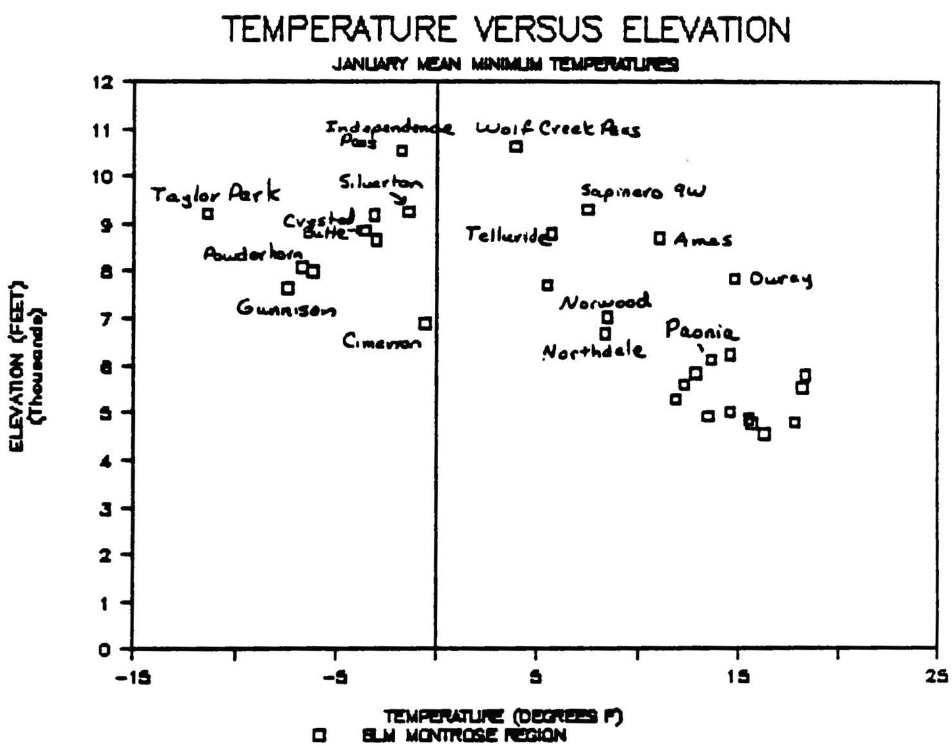
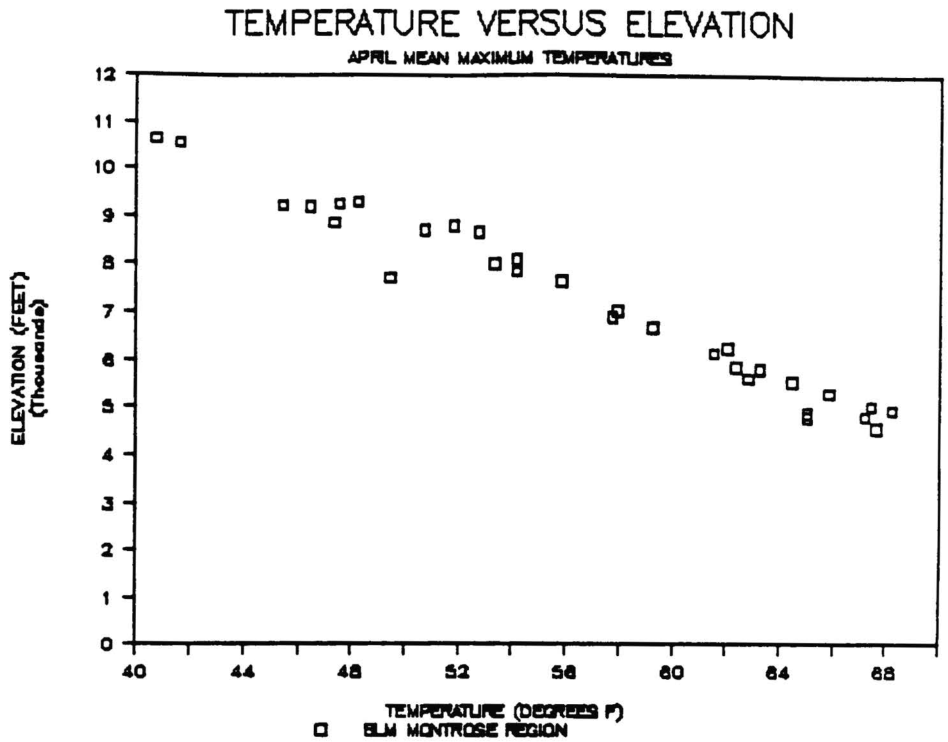


Figure 10. Average January maximum temperatures (top graph) and minimum temperatures (bottom graph) versus elevation for weather stations in or near the BLM study area in western Colorado.



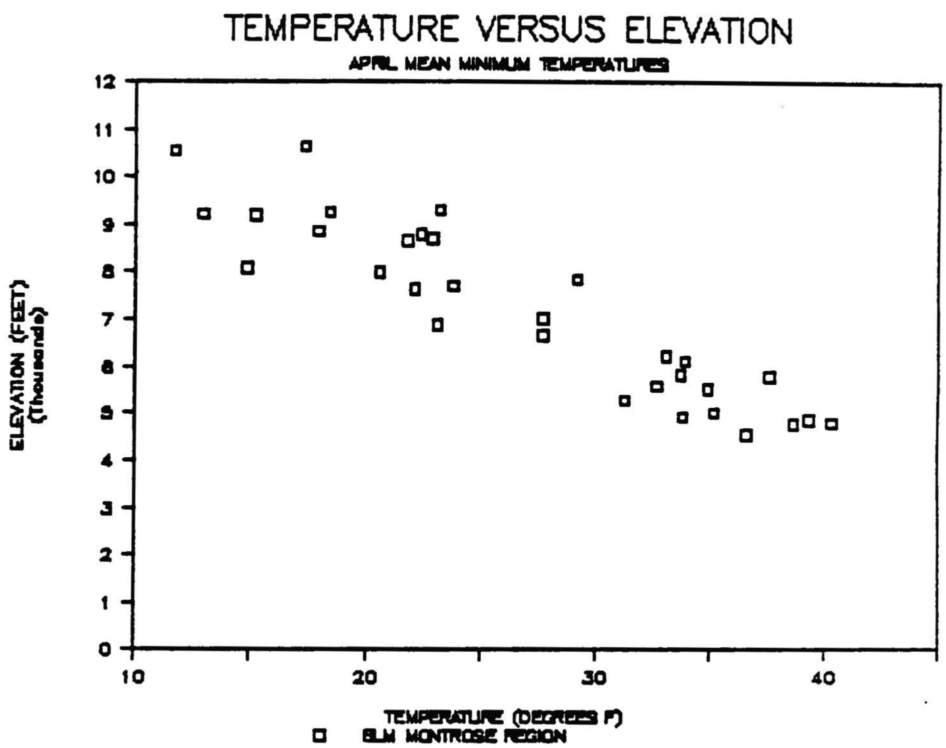
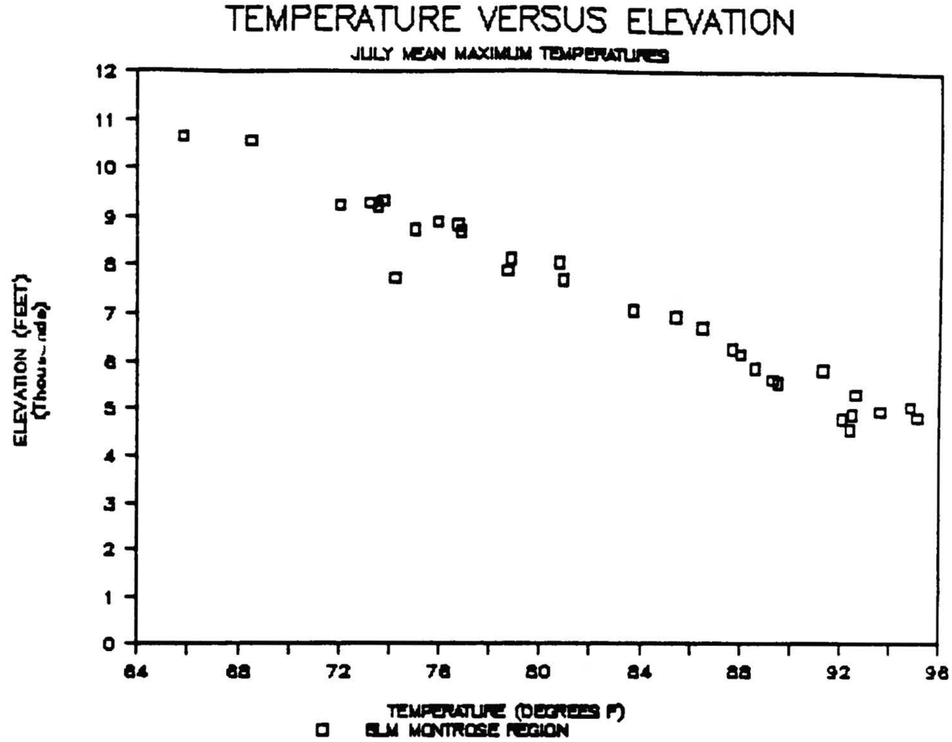


Figure 11. Average April maximum temperatures (top graph) and minimum temperatures (bottom graph) versus elevation for weather stations in or near the BLM study area in western Colorado.



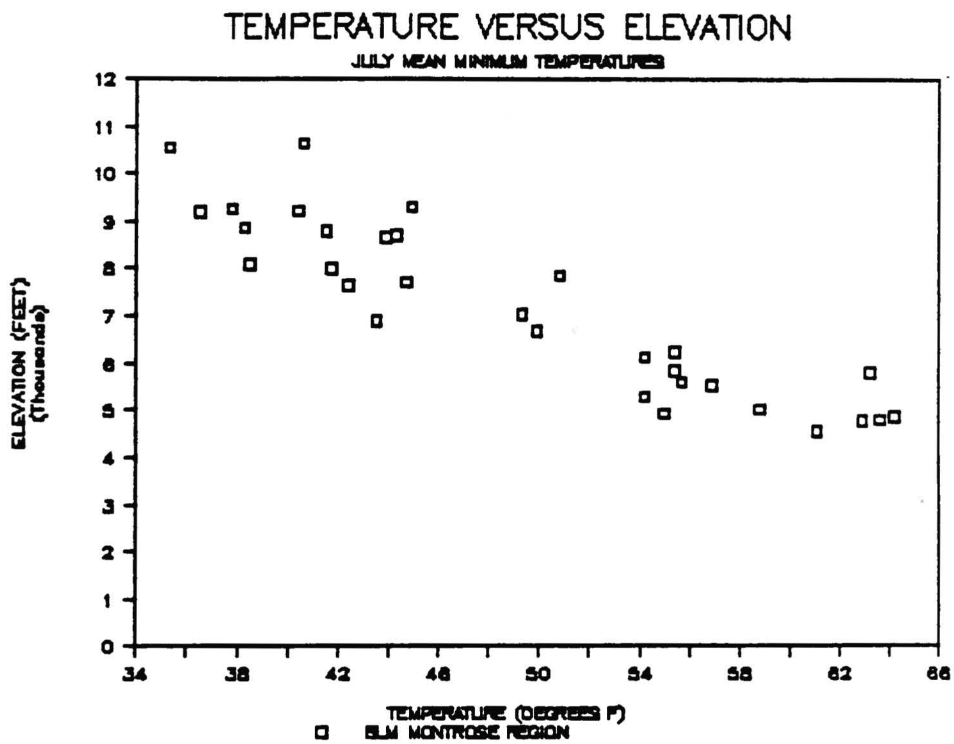


Figure 12. Average July maximum temperatures (top graph) and minimum temperatures (bottom graph) versus elevation for weather stations in or near the BLM study area in western Colorado.

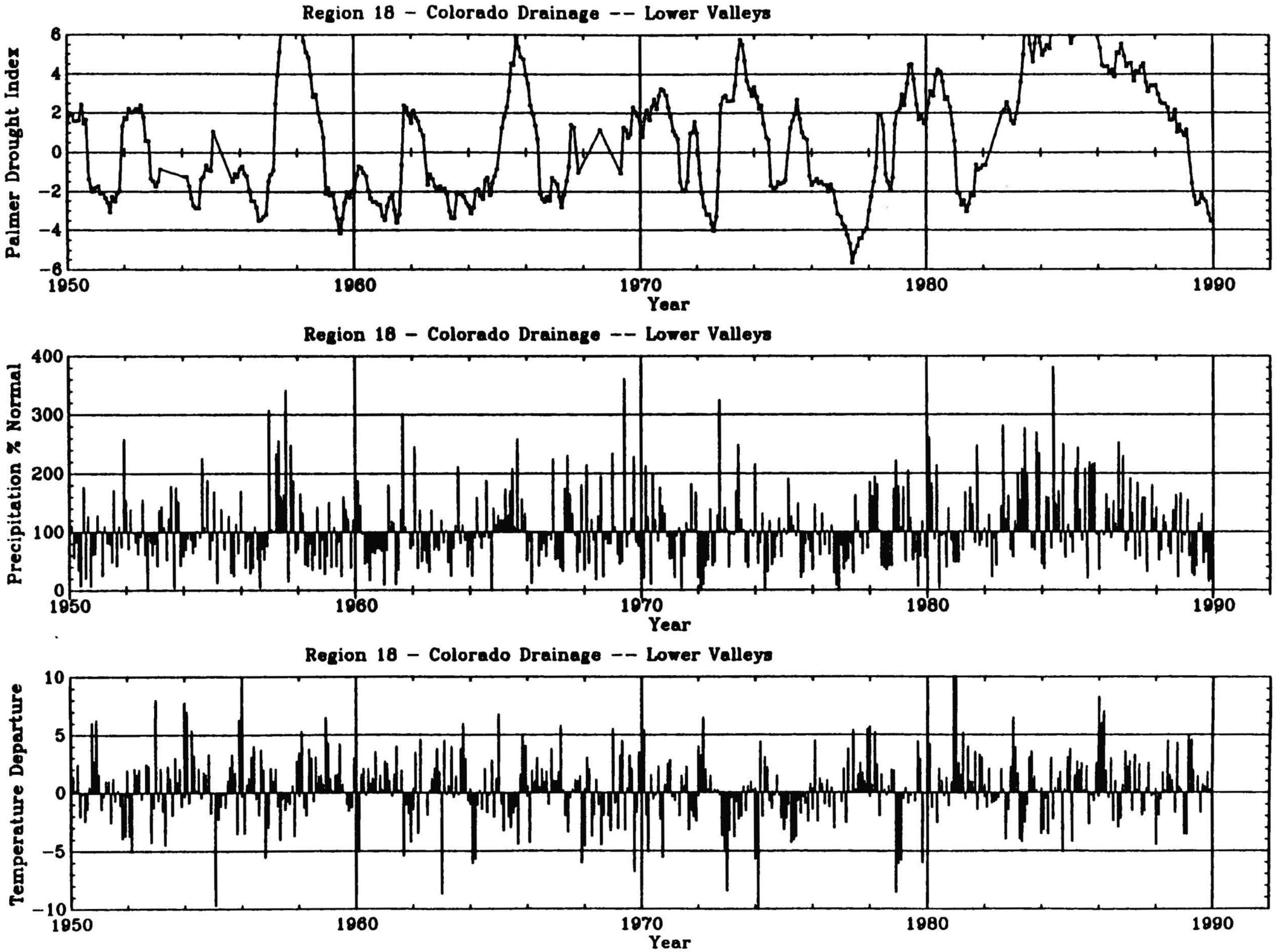


Figure 13. Time series, 1951-1990, of areally averaged monthly precipitation as a percent of the 1951-1980 average (middle graph), monthly temperature departures from the 1951-1980 average and computed monthly Palmer Drought Severity Index for low elevation areas (<6,000 feet) of west central Colorado.

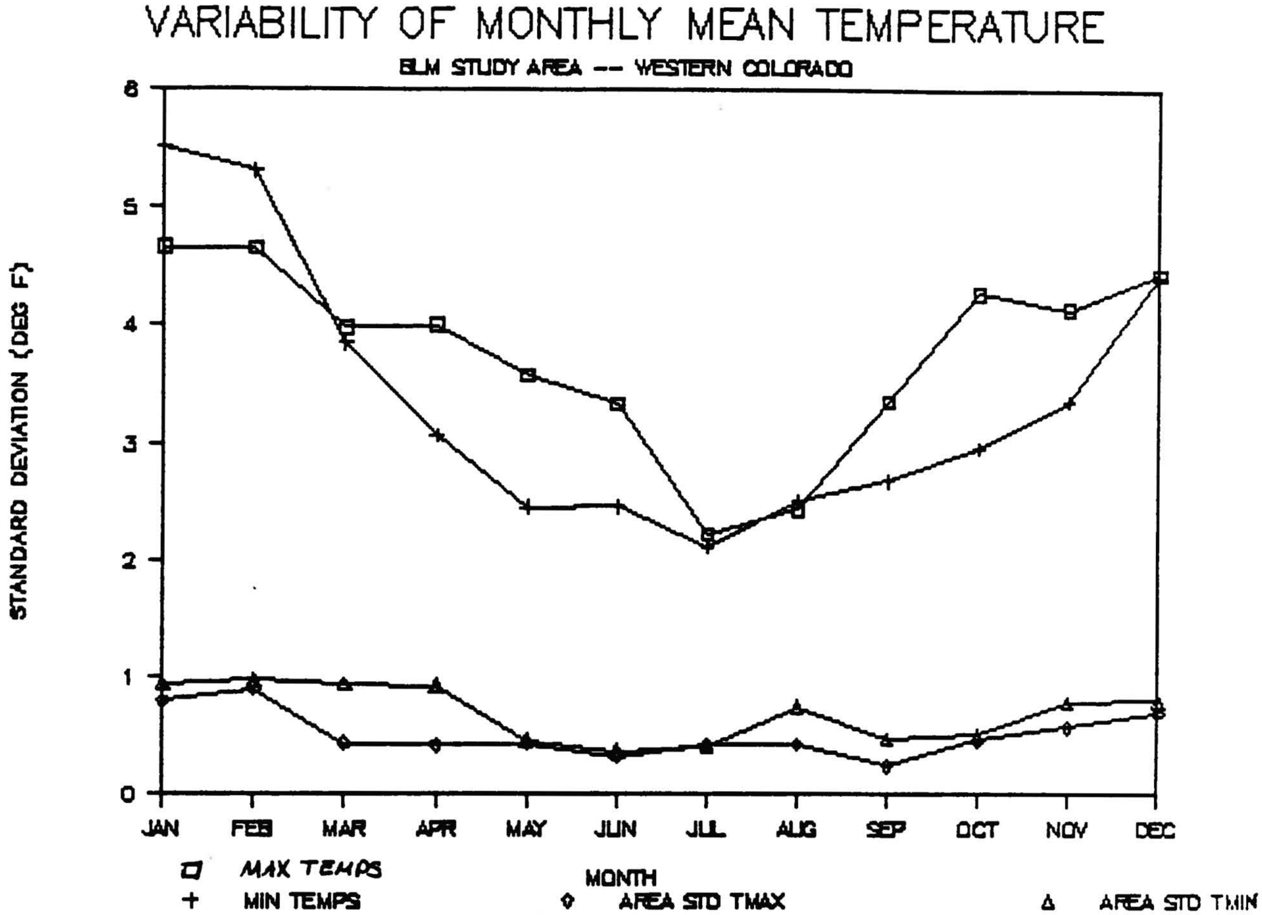


Figure 14. The standard deviation of monthly mean maximum and minimum temperatures. Monthly values of standard deviation were obtained by averaging the standard deviation from all temperature stations with at least 25 years of monthly data. The lower lines on the graph (diamonds and triangles) show the variability across the study area for each month by means of the area standard deviation associated with each monthly mean.

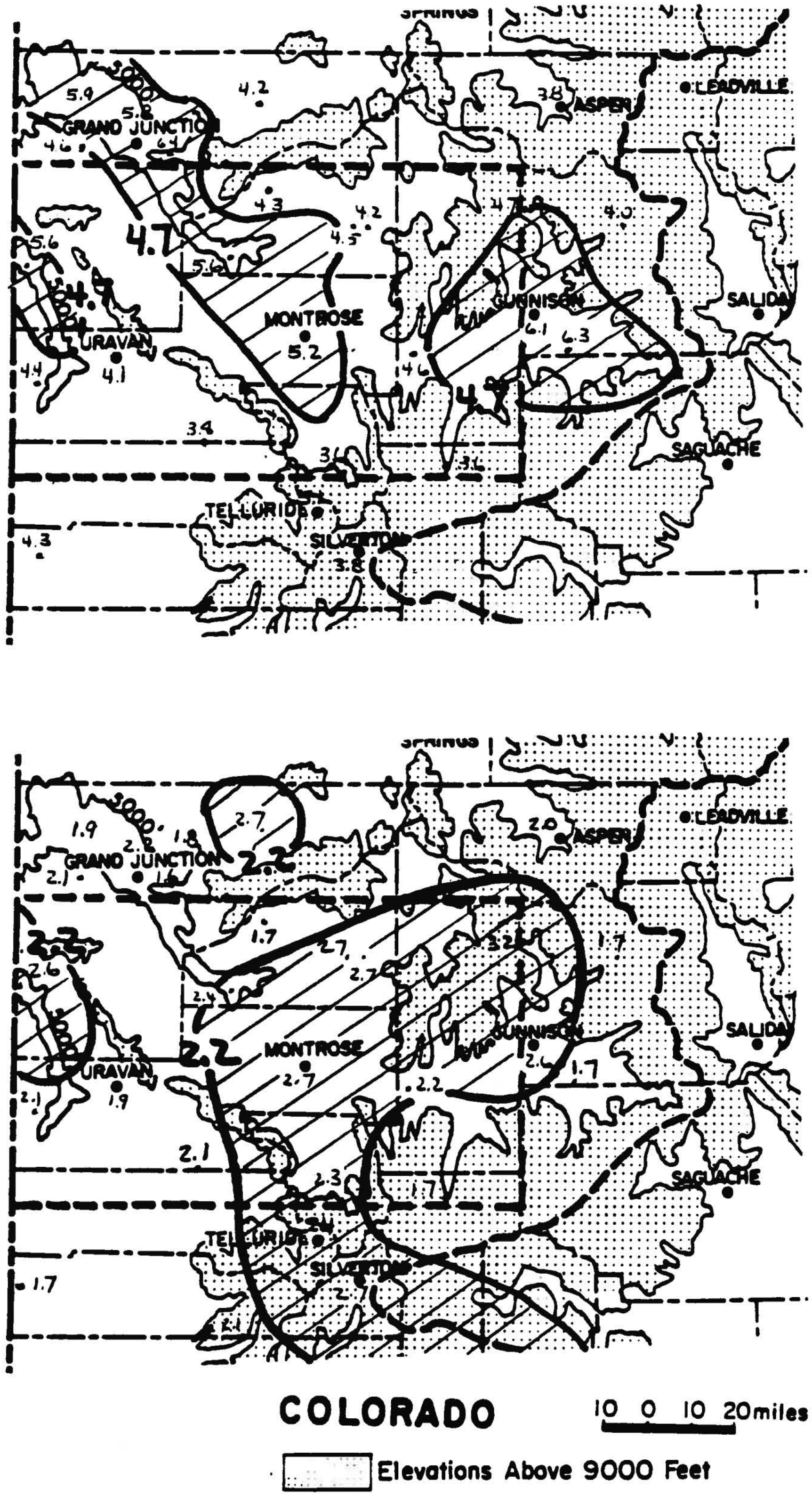


Figure 15. The standard deviation of mean monthly maximum temperatures for January (top) and July (bottom). Areas with more variability than the mean standard deviation for the study area are contoured and hatched.

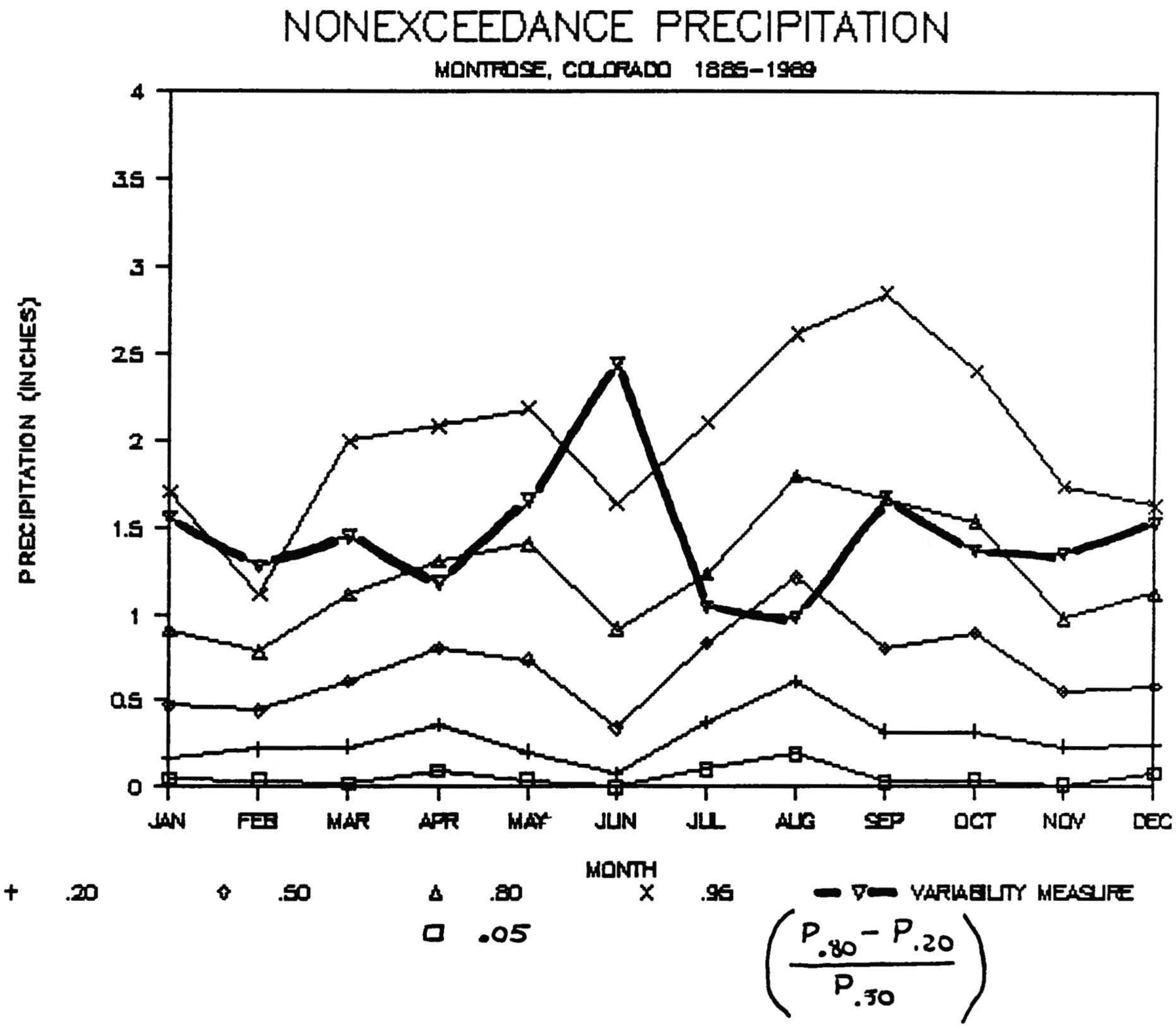
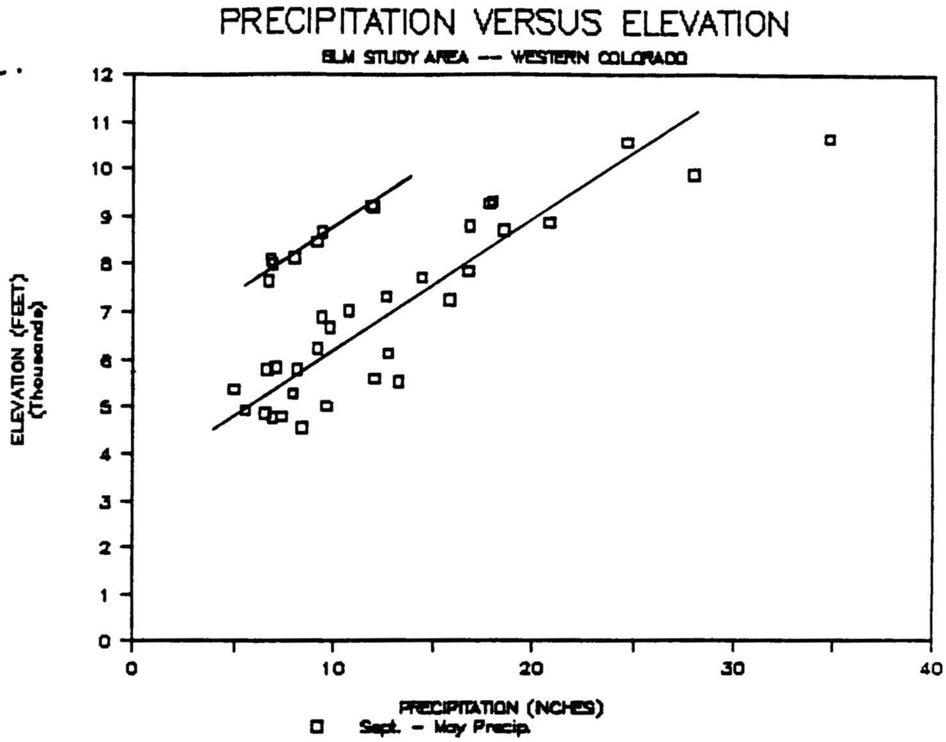


Figure 16. Monthly precipitation amounts associated with nonexceedance probabilities of 0.05, 0.20, 0.50 (median), 0.80 and 0.95 for Montrose, Colorado, based on 1885-1989 data. The heavy solid line is the measure of variability which is: $\frac{P_{0.80} - P_{0.20}}{P_{0.50}}$.

a.



b.

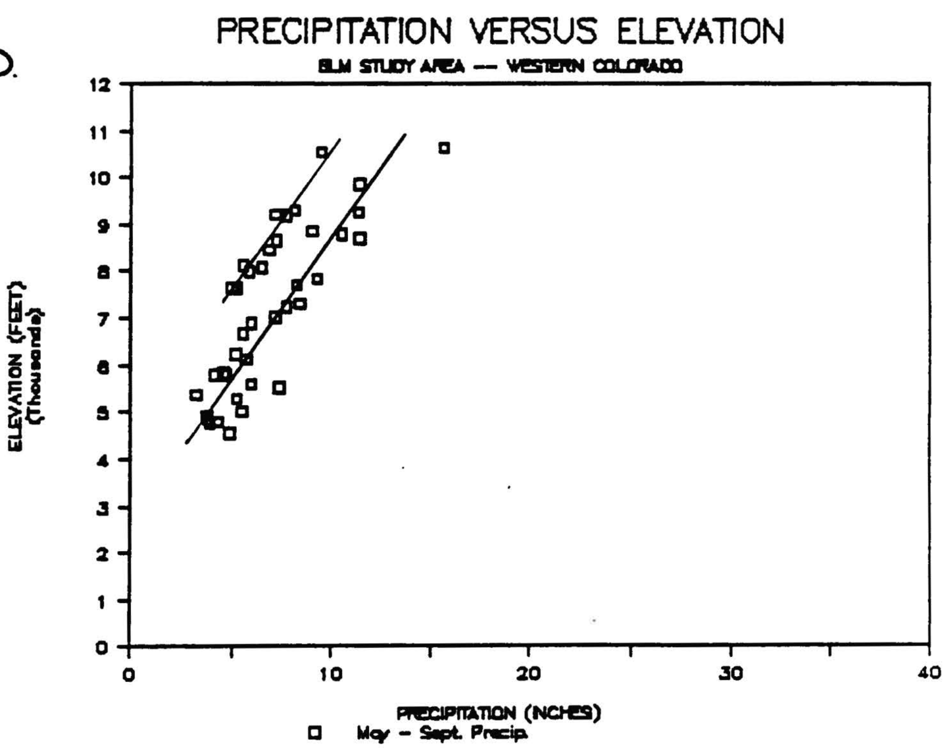


Figure 17. Average precipitation for the September through May "cool" season (top) and the May through September "warm" season (bottom) as a function of elevation for stations in and near the BLM study area in western Colorado.

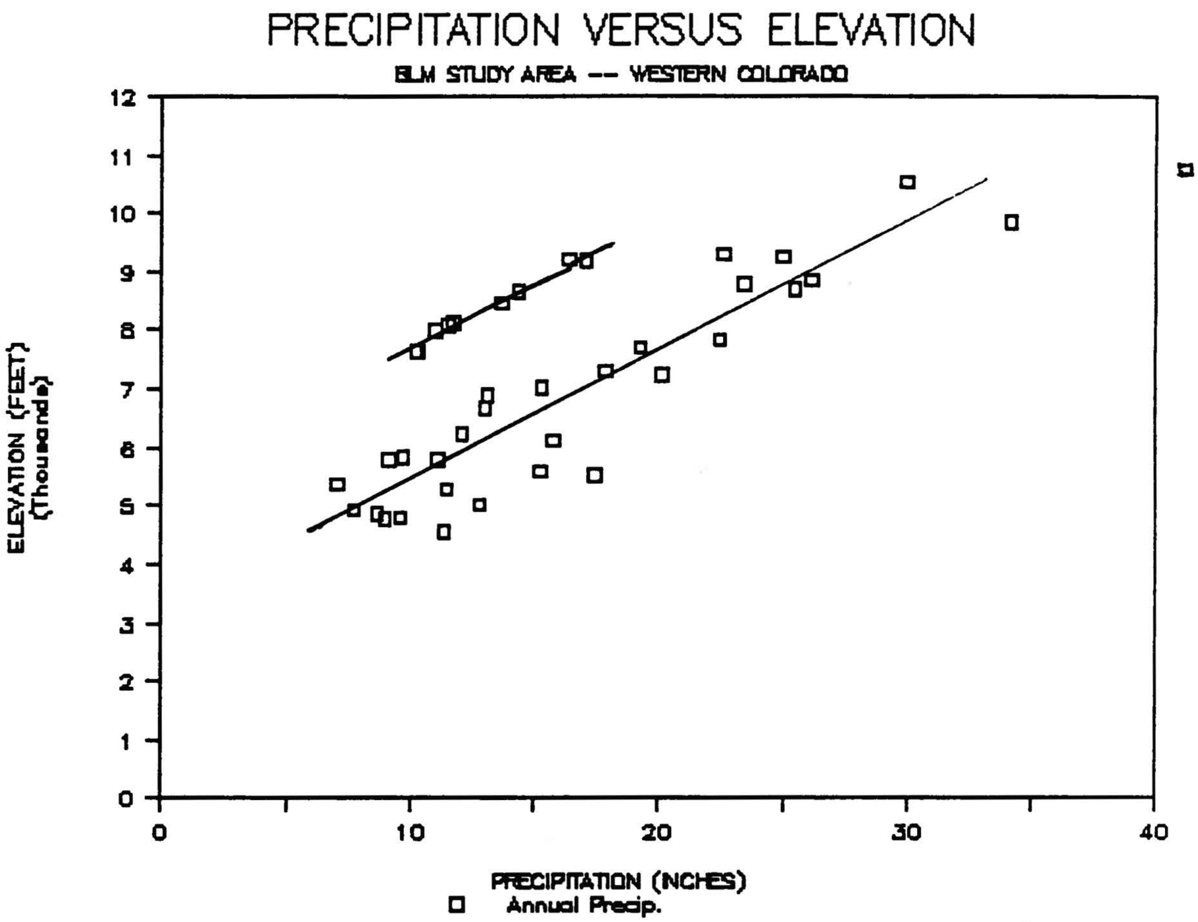


Figure 18. Average water year precipitation (Oct-Sept) as a function of elevation for stations in and near the BLM study area in western Colorado.

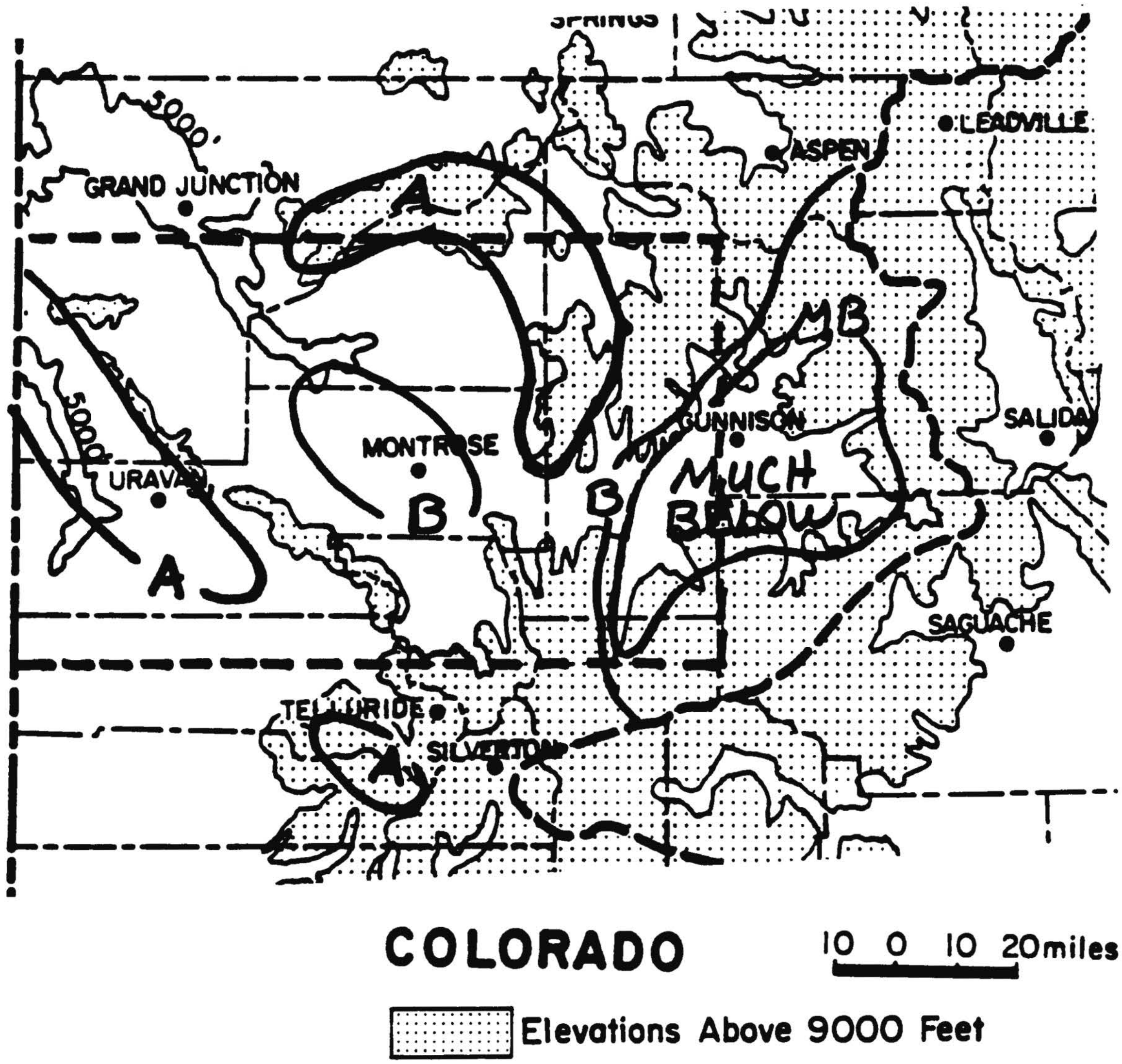


Figure 19. Map of the BLM study area identifying areas that were systematically wetter or drier than predicted by the regionally derived relationship of water year precipitation versus elevation.

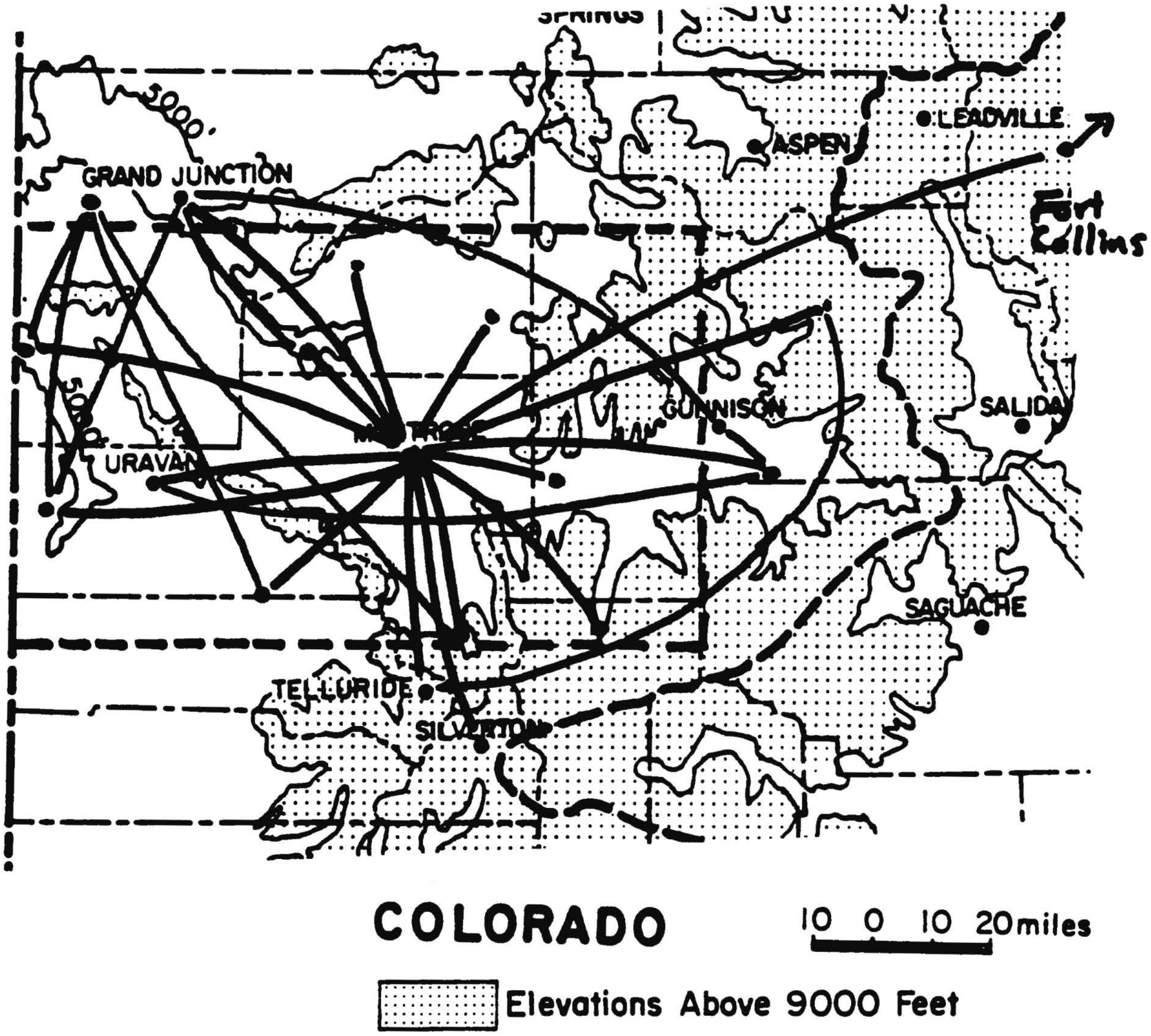


Figure 20. Map of the BLM study area showing the combinations of station pairs used to study precipitation and temperature representativeness.

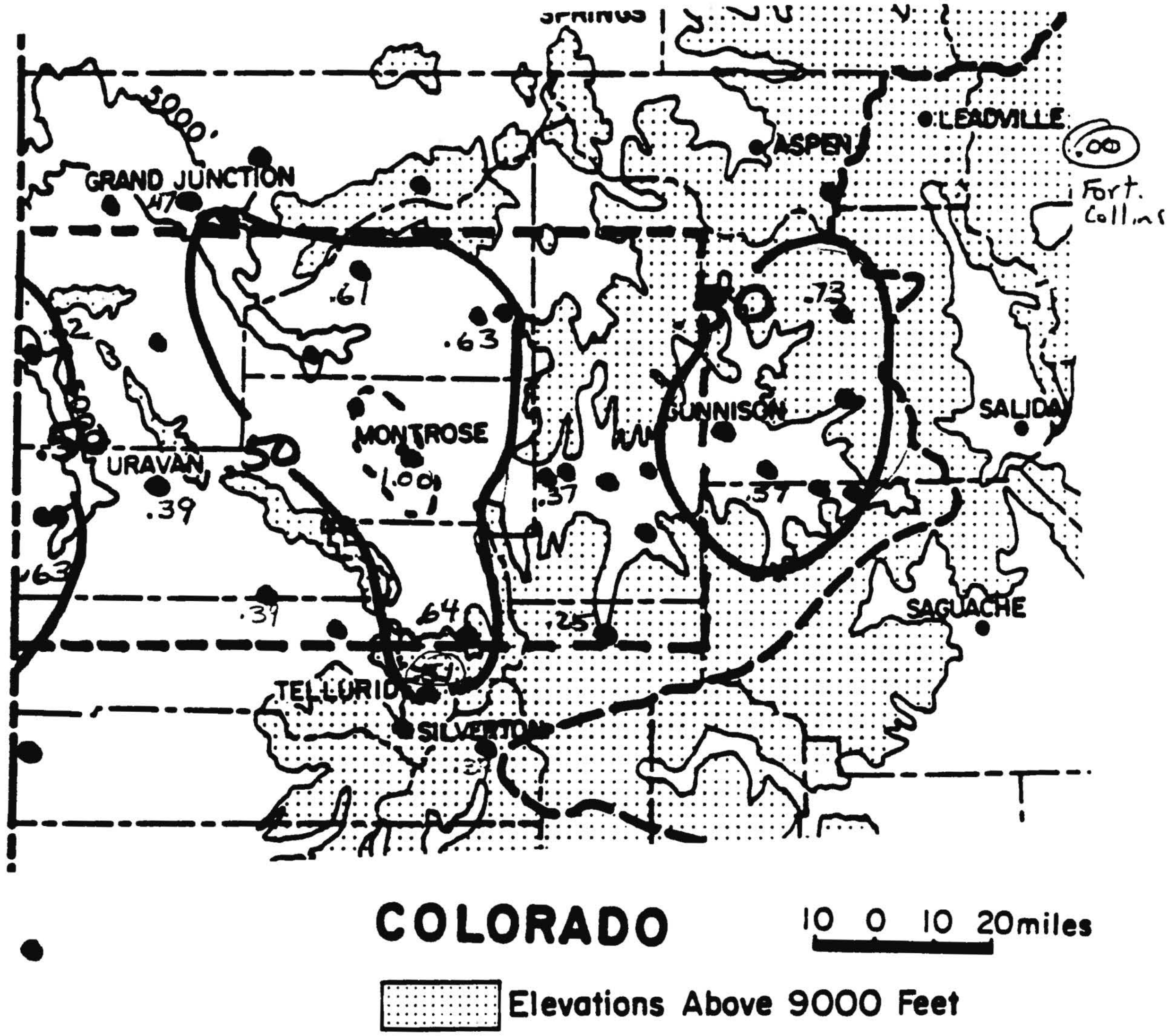


Figure 21. Correlations (r-squared) of total summer (June-August) precipitation with Montrose based on 1962-1988 data. Contours drawn at $r^2 = 0.50$. Dashed line approximates 0.75.

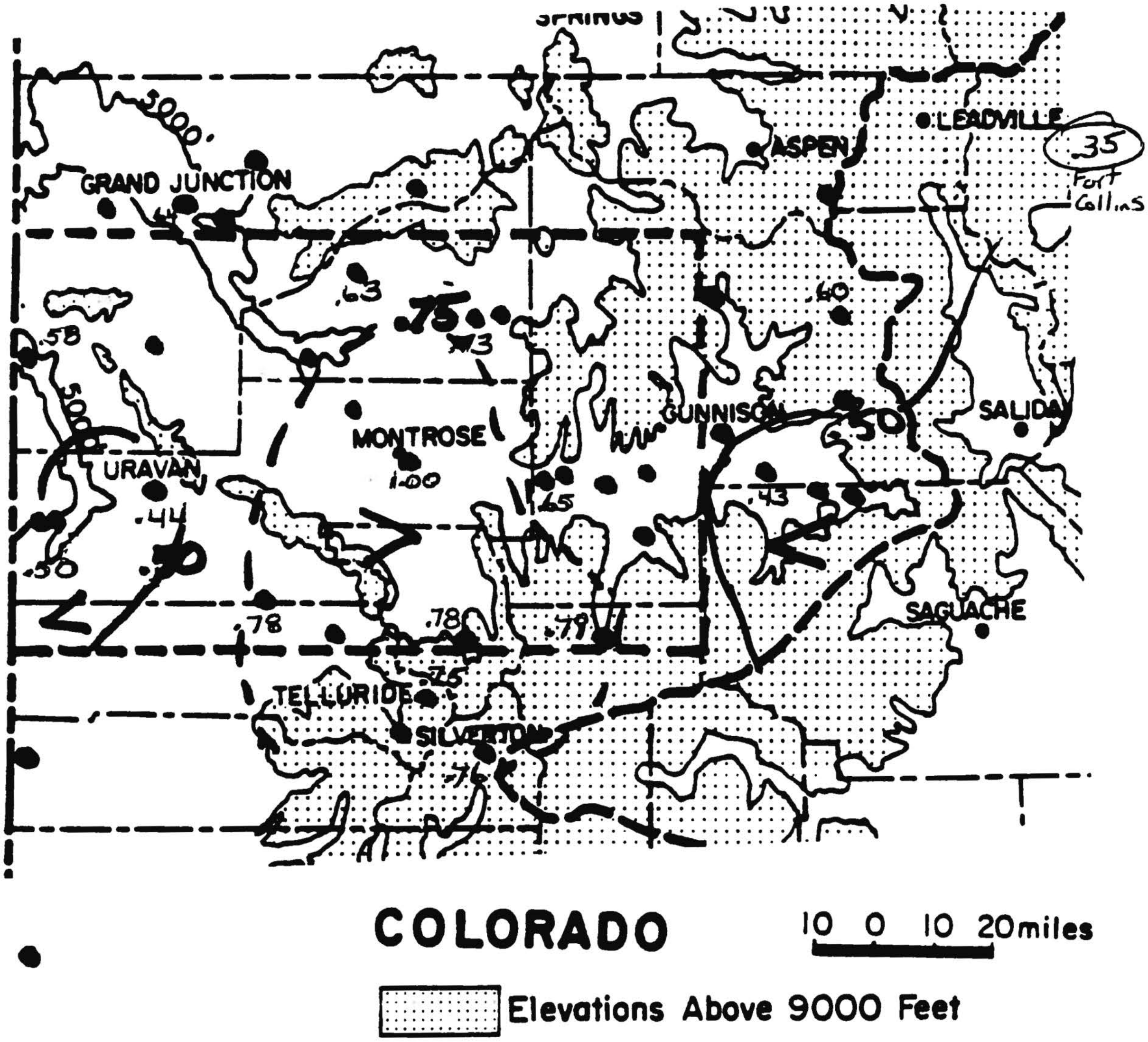


Figure 22. Correlations (r^2) of total September-October precipitation with Montrose based on 1962-1988 data. Contours drawn at r^2 = 0.50. Dashed line approximates 0.75.

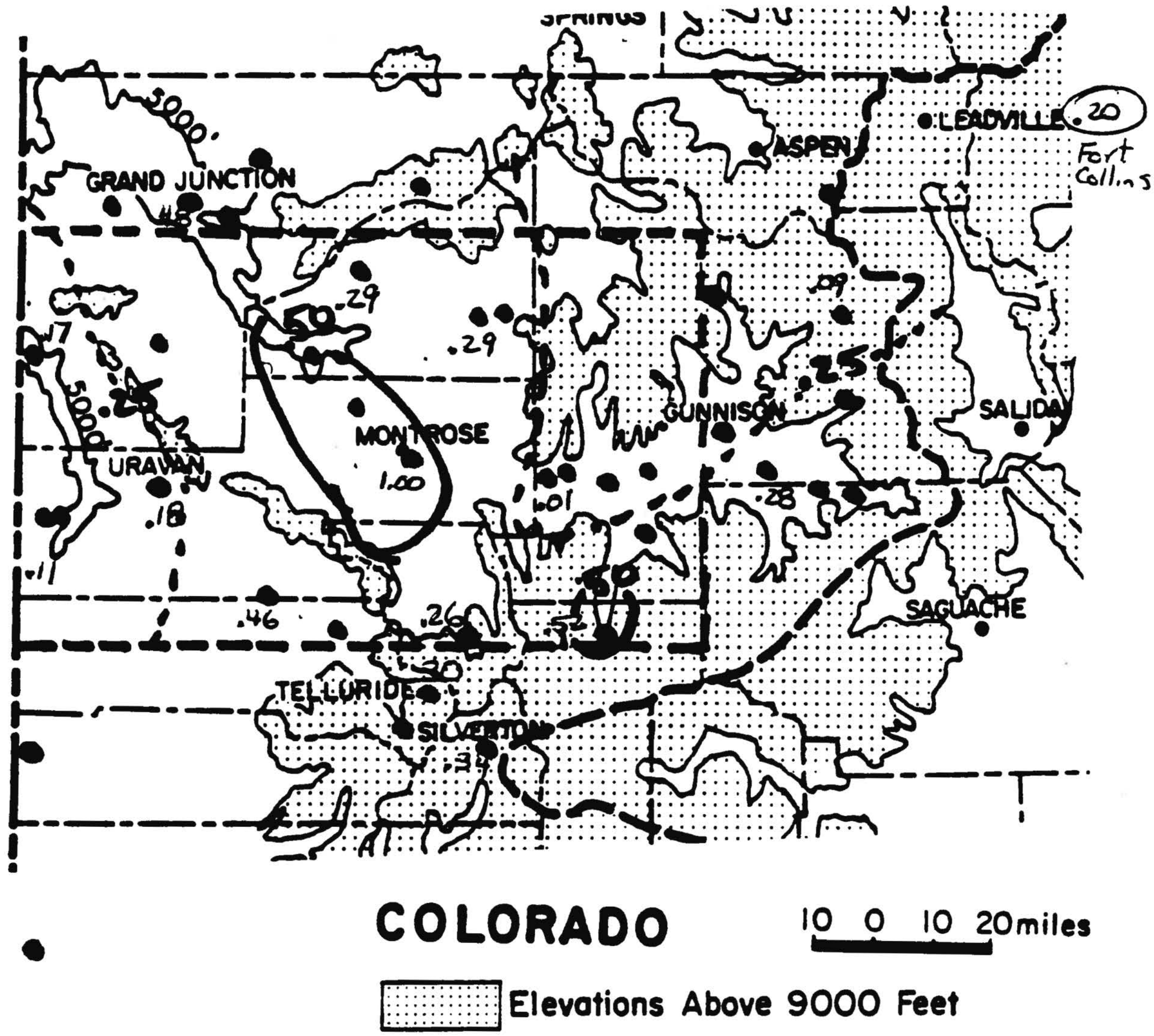


Figure 23. Correlations (r^2) of total November-March precipitation with Montrose based on 1962-1988 data. Contours drawn at r^2 = 0.50. Dashed line approximates 0.25.

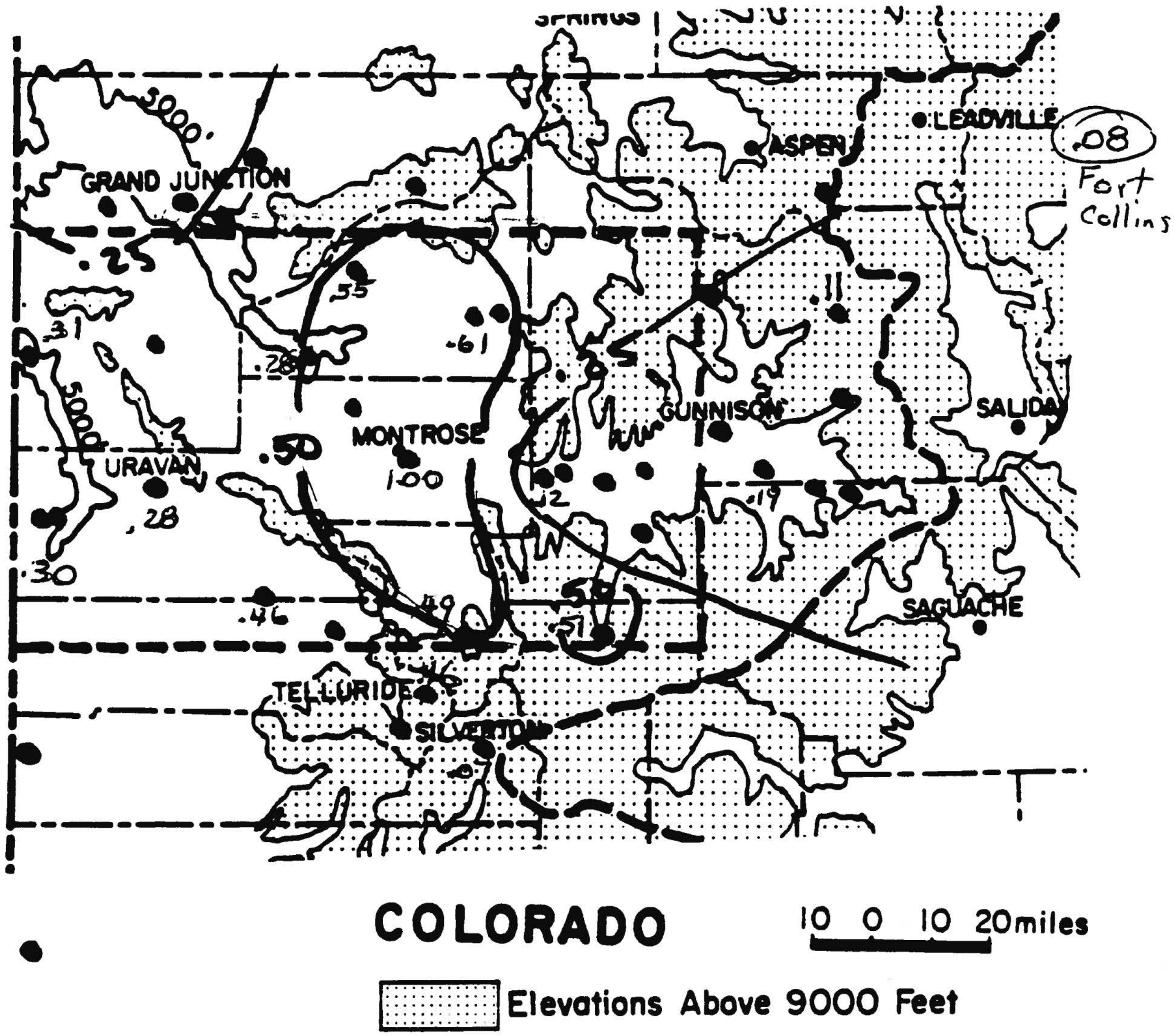


Figure 24. Correlations (r^2) of total April-May precipitation with Montrose based on 1962-1988 data. Contours drawn at r^2 = 0.50. Dashed line approximates 0.25.

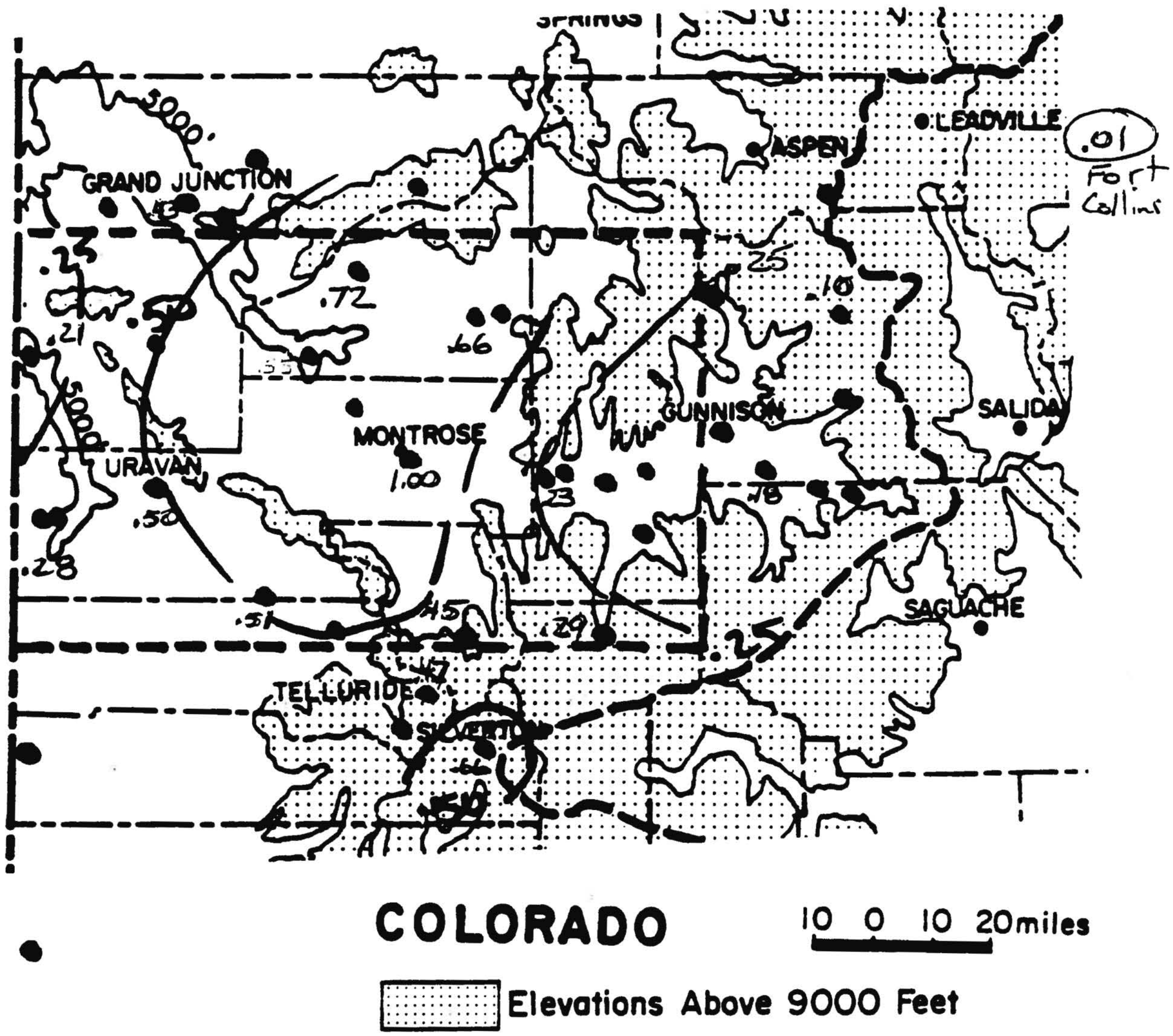
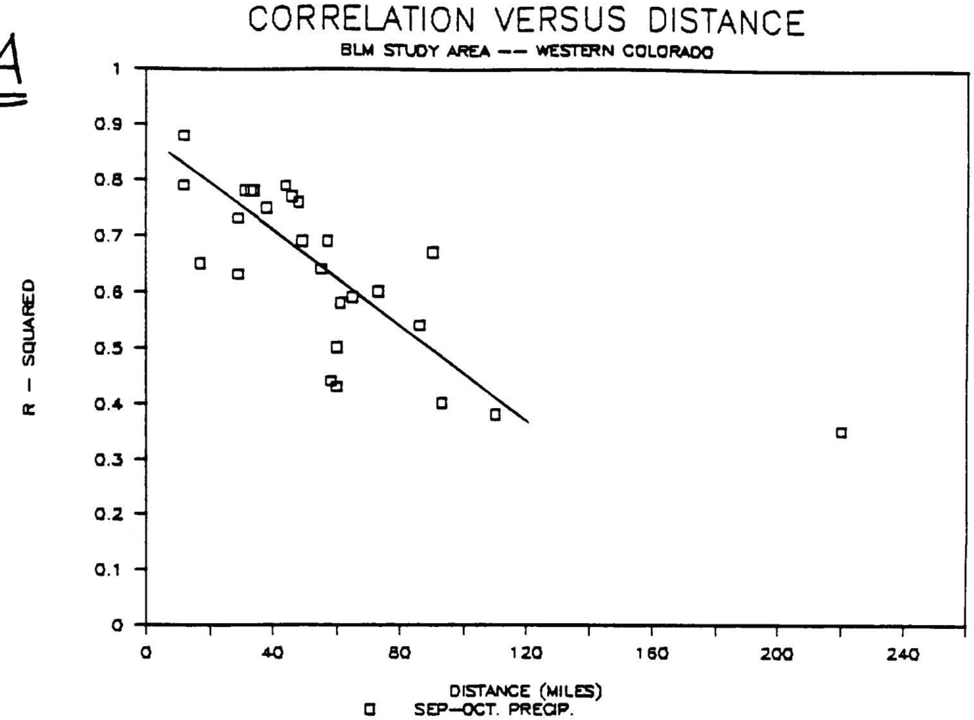


Figure 25. Correlations (r^2) of total cool season (September-May) precipitation with Montrose based on 1962-1988 data. Contours drawn at 0.50 and 0.25.

A



B

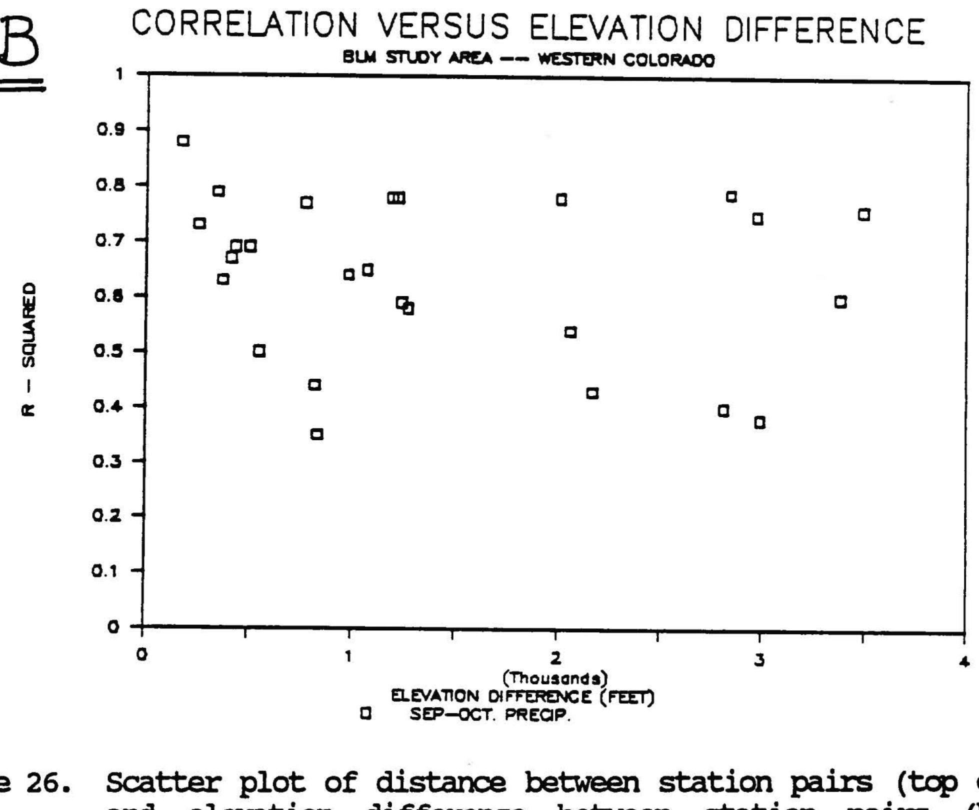
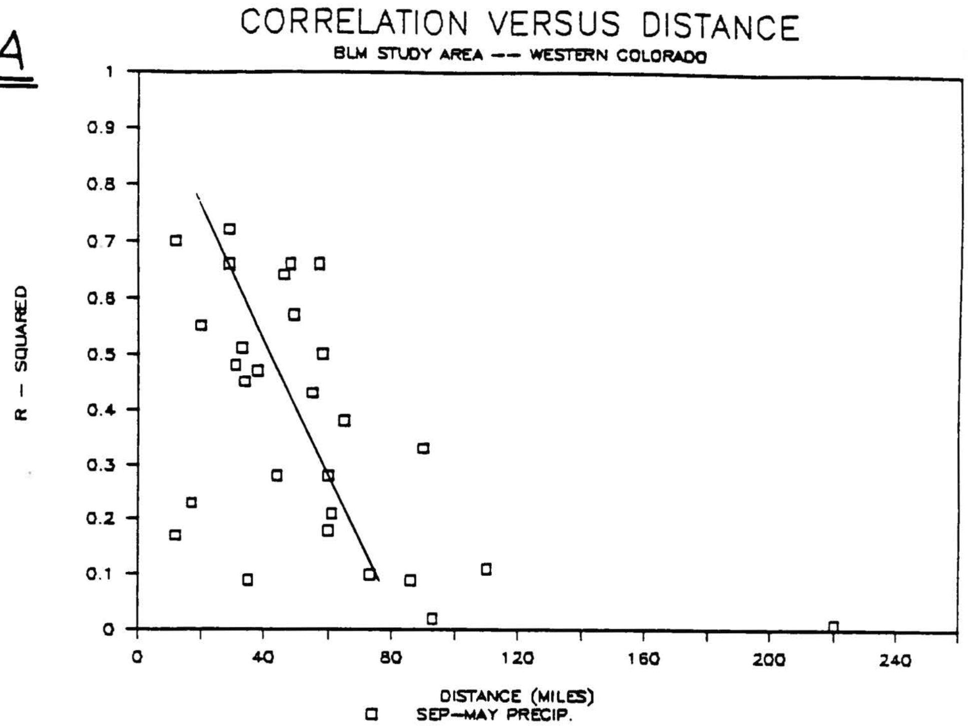


Figure 26. Scatter plot of distance between station pairs (top graph) and elevation difference between station pairs (bottom graph) versus r^2 for September-October precipitation for station pairs shown in Figure 20.

A



B

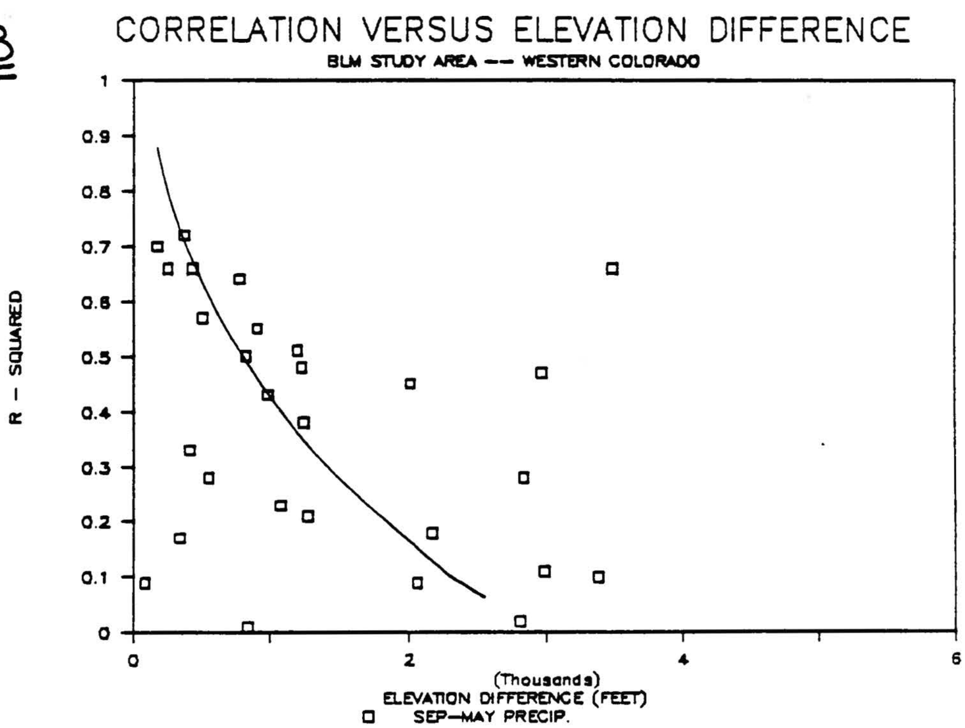


Figure 27. Scatter plots of distance between station pairs (top graph) and elevation difference between station pairs (bottom graph) versus r^2 for September-May precipitation for the station pairs shown in Figure 20.

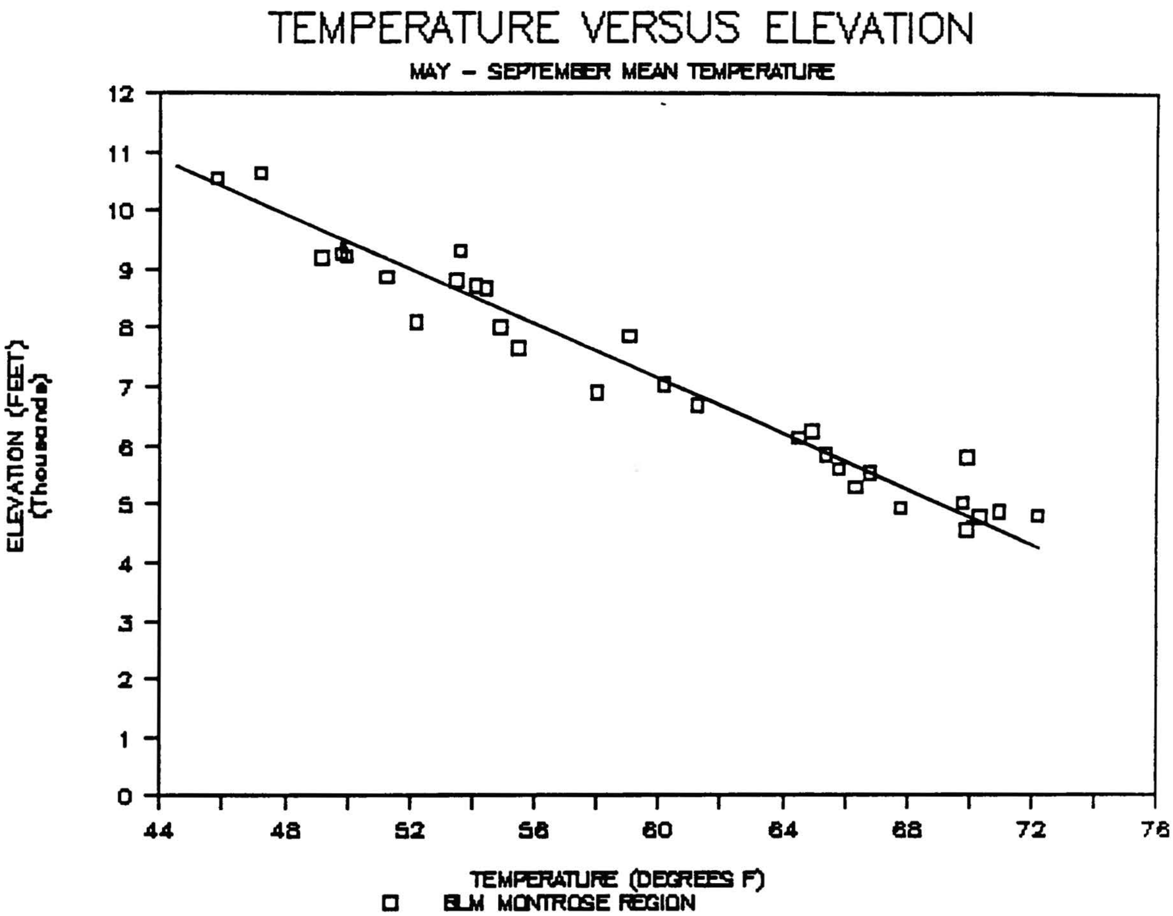


Figure 28. Mean May-September temperature as a function of elevation for stations in and near BLM study area in western Colorado.

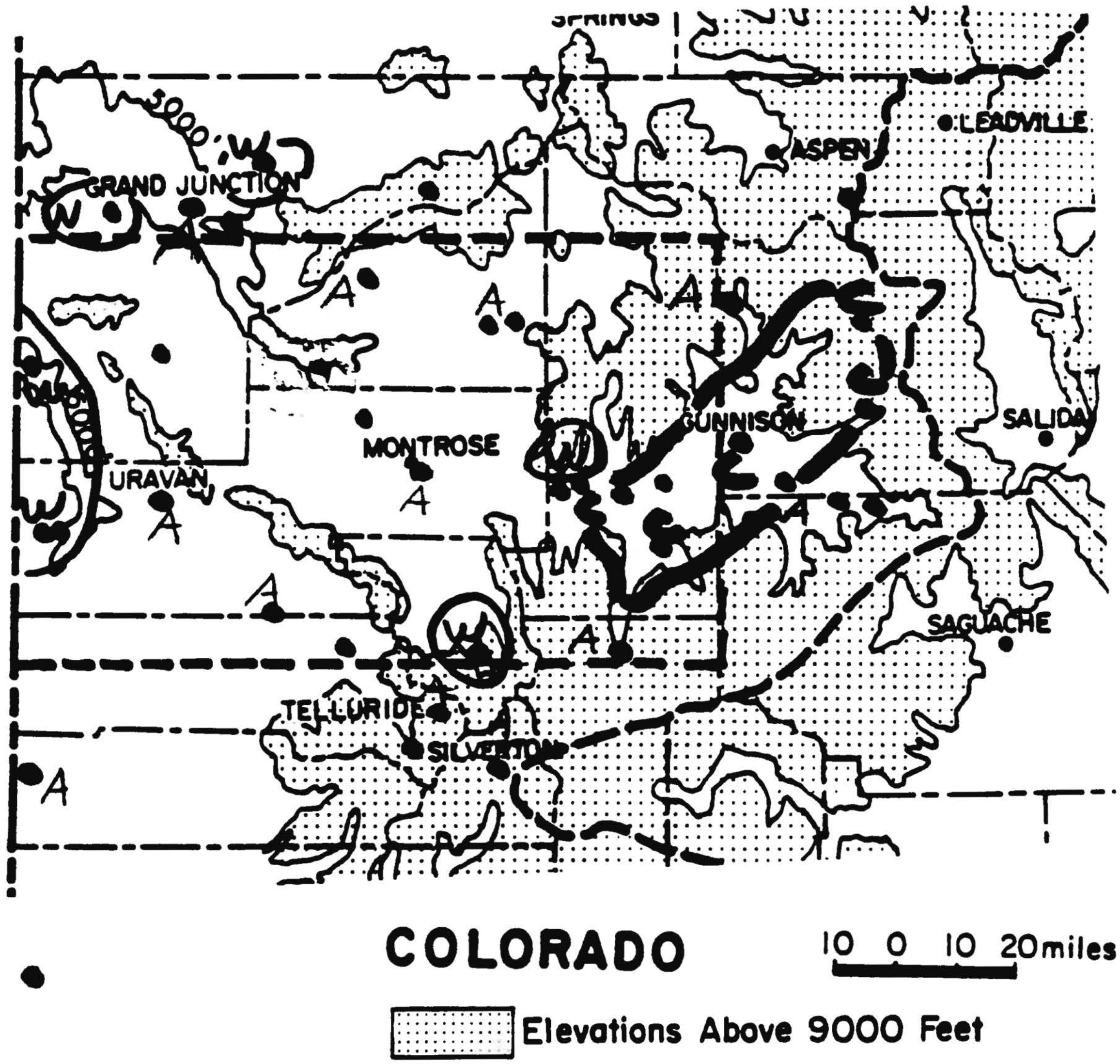


Figure 29. Map of the BLM study area showing areas that were systematically warmer "W", colder "C" and close to the average "A" of the regionally derived May-September mean temperature versus elevation relationship.

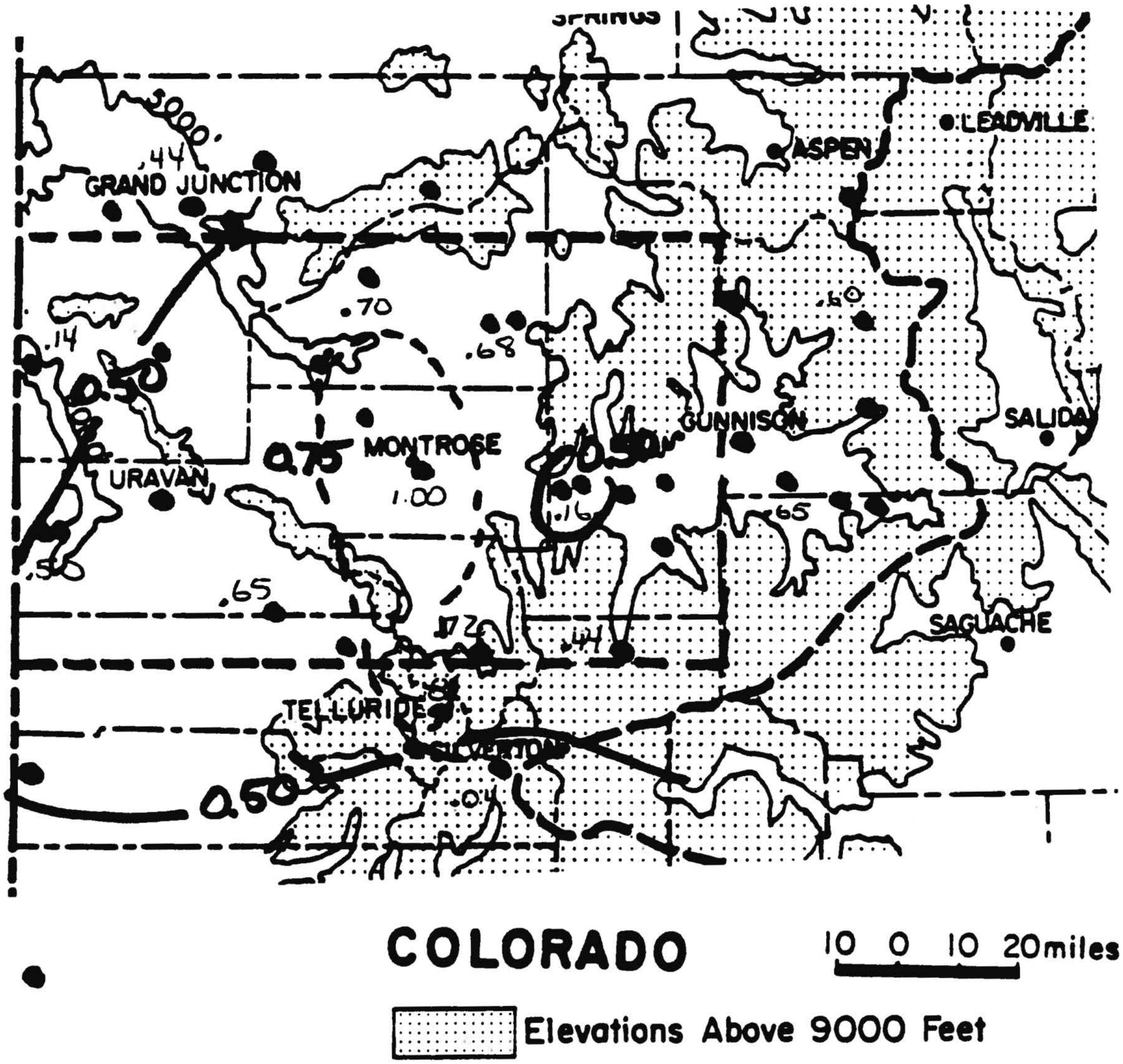
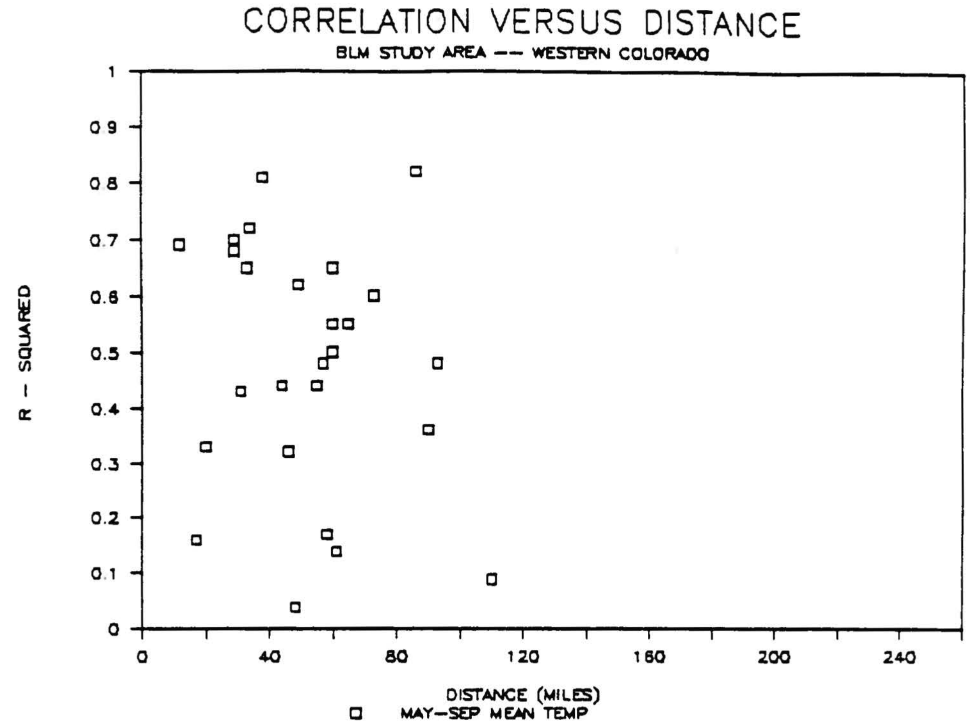


Figure 30. Correlations (r^2) of growing season (May-September) temperatures with Montrose based on 1962-1988 data. Contours are drawn at r^2 = 0.50 with a dashed line approximately 0.75.



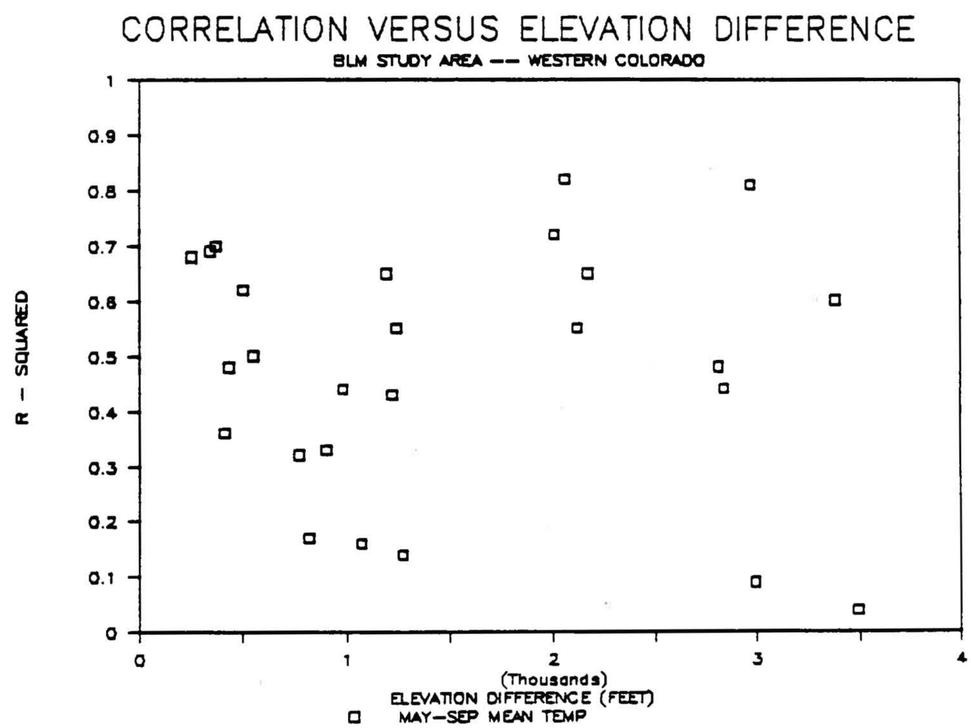


Figure 31. Scatter plots of distance between station pair (top graph) and elevation differences between station pairs (bottom graph) versus r^2 for mean May-September temperatures for the station pairs shown in Figure 20.