Engineering Climatology for California

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BIOGRAPHICAL SKETCH

Jim was born in 1927 in Sacramento and raised in rural Auburn, until 1943 when he escaped from the farm to serve a hitch in the Navy. The first real job was as an observer for Weather Bureau in Sacramento starting on November 18, 1950, in the teeth of a storm that washed out the road into Yosemite. The second job included time in the Reservoir Regulation Section of the Sacramento Office of the Corps of Engineers, on the day when Folsom Dam was declared operational. Finally there was 30 years at the California Department of Water Resources (DWR) retiring from full time work in 1983, but still active in the study of storms.

It was a wonder to learn in 1950 that Sacramento had 100 years of rain record. These were the same records shared by all of the other water agencies to forecast floods, operate projects and design structures. It became apparent that weather records were the life-blood of good Public Works planning everywhere. Preserving weather records for people who are as yet unborn is a worthy task. One that is far from complete.

ABSTRACT

This is a progress report on a long running extreme weather archiving project. It has been a cooperative effort of many people and agencies in compiling and searching for better ways to analyze weather records. The weather being a limiting factor in construction project design, building and operation is a major focus with almost everyone. Compiling these data sets has been a major activity for me for decades. The result is compiled on a CD that is available on request at the address shown above. This study describes an archive of weather data (CAClimate CD) intended originally for engineering applications.

This project started fifty years ago when there was much confusion in assigning return periods to extreme rainfall events. This resulted in chaotic variation in design storms due to small sample size and much controversy regarding choices in frequency distributions. There was a need for procedures where all workers would achieve similar results when analyzing small samples of rainfall records that were located near project sites. This earlier confusion led to a regional approach in rainfall studies.

It became apparent that this archive is also a history of our times and very much worthy of serious consideration as historic record. The interesting part of this activity for me has been the analysis of historic trends in all of the various time series data sets.

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Extreme rainfalls in California fall into two categories. The first category includes the large rainfalls occurring on windward slopes of orographic barriers, such as the 26.12 inches that occurred on January 22, 1943 at Hoegees. Hoegees is on the South slope of Mount Wilson directly up wind from the Pacific Ocean. An example of the second case is a geographically randomly spaced storm (with a large return period) like that which occurred on February 10, 1978. This storm was centered in a rain shadow region near the Tulare Lake on the west side of Kern County. Many stations in the area received 60% of their average annual rain on the February 10, 1978 storm.

Extreme flooding in contrast is more complicated. It can occur from outrageously large orographic or randomly spaced rainfalls, or from snow melt like the New Years storm of 1997. Extreme flooding can also result from building in the wrong place, like in Sacramento during the great inundation of 1850 as shown on Plate 1. Plate 1a is an artist's view of Sacramento City during the 1850 flood and Plate 1b is an artist's view apparently preceding the 1850 flood showing no protective levees.

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This earlier confusion led to a regional approach in rainfall studies. This consisted of averaging dimensionless statistics in regions of similar climate. These statistics were the coefficients of variation, skew and kurtosis. The selection of frequency distributions was accomplished using a skew-kurtosis map, resulting in the selecting the Pearson's Type III distribution for annual series rainfall studies. This regional approach is used here with the analysis of rainfall, stream flow, and snowmelt as described below.

The annual series rainfall extremes described here are largely from NWS as well as many other agencies. It updates and supplements the Department of Water Resources Bulletin 195, “Rainfall for Drainage Design”, published in1976. This has now evolved into a collection of 3200 tabulations of annual series extreme daily rainfalls that were originally developed for dam safety studies. There are 1300 additional records based on hourly records that were an out growth of culvert sizing studies.

Monthly rainfall and its regional frequency analysis are presented for selected stations. This began with studies for wastewater facilities design as well as a forest growth study. A more comprehensive set of raw monthly data is available from the web-site of the Western Region Climate Center located at Desert Research Institute in Reno.

Maximum daily rainfall for each month and its regional frequency is listed for 900 stations. The study of the maximum daily and hourly rain for each month grew out of the 2004 symposium at Davis, where there was a request for a design storm for each month rather than just one annual value. The maximum hourly rain for each month with a regional frequency analysis is listed for 250 stations. These are still experimental in nature because it is felt that there are too many 1000-year storms in the analysis. They are presented on the CAClimate CD because the monthly extreme data may have utility even with a potentially flawed analysis.

Stream flow depth duration frequency is listed for 290 stations that were selected for having a minimum of diversions and upstream storage. These are mainly USGS records. This series started in request for an estimate of the unit runoff in the Sacramento Valley floor. Most of these records show a slight increase in stream-flow trend in recent years reflecting the slight increase in precipitation that is shown by the positive slope of Figure 1a.

Monthly total evaporation (a supplement to DWR Bulletin 73-79) was analyzed as well. This data set was developed in response to requests of wastewater plant designers. Average daily solar radiation for each month of record is listed for 170 stations. These records were originally collected for use in irrigation studies. They may have utility also in energy and snowmelt studies. Snowmelt depth duration frequency is listed for 120 DWR snow sensors. This data set was also analyzed with a regional frequency study. These records represent the negative daily difference in the CDEC snow depth sensors. This was studied to understand characteristics of snowmelt floods, such as the great New Years Day flood of 1997.

The other data sets listed without a regional frequency analysis include:

Monthly average air temperature. Temperatures were of great interest for the evaluation of long term climate trends.

The monthly average dew point temperature was examined for use in moisture flux studies for use in forecasting storm yield and weather modification potential.

Annual tree ring widths indices are tabulated for about 100 sites in the state. It was hoped that tree ring widths indices would have some utility in climate trend studies since some of the records are thousands of years in length.

Water balance studies are listed for 250 watersheds. This study is experimental in that the selection of rain records to represent the watersheds needs more work. This study suggests that runoff coefficients, as used in the rational formula, are available based on stream-flow records rather than from handbooks.

History of rainstorms was studied for 76 storms where any station reported a 1000-year storm. A 1000-year storm is in general one where the greatest reported return period is from a station reporting an extreme rain that is about five standards above the average using regional rather than sample statistics. Some people are troubled by the concept of a once in a thousand-year storm based on 10 or 20 years of data. With 1000 rain gages there should be on an average one 1000-year storm each year, if the records represent independent storm rainfalls from the catch of adjacent gages. The amount of inter-station dependence in rain gage catch can be judged by inter-station correlation and it was estimated that overlap in information was typically about 50%. The overall score was 1490 station years of extreme values for each 1000-year storm in the long duration data based on daily rain records.

All is not peace and harmony in these extreme rainfall studies. There are areas that need more work. The short duration records are represented by 31,189 station years of record on 1315 stations. There are about 200 short duration storms with maximum rainfalls with extremes that are in excess of 5 standard deviations above the mean. This suggests one 1000-year storm for only 156 station years of record. The work I have done on annual series daily records seems reasonable, but there is a problem in the short duration data as well as in the summertime data from the calculations of the frequency of extremes for each month. This problem was addressed by Hoskings and Wallis in their book "Regional Frequency Analysis", Cambridge University Press, 1997. Jim Wallis warned me more than 20 years ago that our return period calculations were too high. This is an area where I would welcome some assistance in applying Wallis's L-moment concept to our spread sheets of annual series extreme rainfalls.

These data sets are all on a CD labeled "CAClimate". It was prepared mainly with Microsoft Excel with macros enabled. The technology of these files was developed with the help of many people and organizations. These studies started at the Department of Water Resources. Their continued support is acknowledged with thanks. This was a DWR activity until my retirement in 1983 and in recent years it is again a DWR activity. Norm Govsalves of Caltrans District 4 is another important recent contributor. His contributions were the macros used to calculate frequency factors and the macros for consolidation the individual spreadsheets that facilitated the recalculation of the regional statistics.

The interesting part of this activity for me has been the analysis of historic trends. An example is the averaging and graphing of all the available California rain records with 100+ years of record, shown here as Figure 1. A notable part of this graph on Part a of Figure 1 is that there was only one year with 35 inches of rain on the first half of the record and six years in the more recent half of the record.

Part b of Figure 1 is a 9-year running value of the coefficient of variation (CV) (Standard Deviation/Average) for the 101 years 1904 to 2004. A notable feature of this graph is the large increase in CV after 1975 that reflected a change or climate fluctuation. This is also reflected the broad trend in the Pacific Decadal Ocillation Index that is plotted on Figure 2b. This is significant when reviewing flood control on the American River. Folsom Dam was designed using only data from before the climatic shift of 1950 and records of the recent large storm events were unavailable for the design. With this type of climate shift, it is possible to have several 100-year storms in a few decades.

Part c of Figure 1 is an accumulated departure from average plot. The historic drought from 1916 to 1934 is the predominate feature. The wet periods 1934 to 1944, 1977 to 1986 and 1992 to 1997 are notable.

Temperature records of California are influenced by urban waste heat. De-trending the record reveals a more realistic temperature history. The de-trended record is shown as Figure 2a. It is compared with the Pacific Decadal Oscillation Index (PDO) on Figure 2b. Temperatures in California clearly reflect sea surface temperature (SST) trends as shown in Figure 2c. The PDO index responds to the location of upwelling of in the North Pacific Ocean. When upwelling is suppressed on our coast like the 1975 to1998 period, then SST and California air temperatures rise. The upwelling the North Pacific Ocean seems to oscillate between the Eastern and Western Ocean as expressed in the PDO. A rising PDO index suggests a suppressed upwelling in the Eastern North Pacific Ocean and warmer West Coast air temperature trends.

There is an almost universal claim that "Global Warming" is occurring now. My recollection of the origin of this belief was when Edward Teller first warned of a runaway green house effect on our Planet. He pointed to Venus with its high atmospheric CO2 content and its associated high temperature. The origin of Teller's bias was his encouragement for the peaceful uses of atomic energy in order to wean us off fossil fuel use. Biologists understand very well the photosynthesis-respiration cycle that has controlled atmospheric CO2 levels on Earth for four billion years.

Temperature trends are generally based on regional averages. When those averages are decomposed into individual records, a pattern of urban bias in long-term temperature trends is plainly reveled. Regions of temperature rise are generally in the urban areas. Rising urban temperature trends seem to over shadows the declining temperatures in the rural areas. Regional temperature trends for California are shown on Figure 3. This represents a plot of California temperature trends in units of degrees F per year from 228 stations with 50 to 90 years of record.

Precision measurements (of .1%) have been made of the solar output from outside of the atmosphere since 1978. There is a high level of correlation of modern satellite based solar irradiance measurements and the historic sunspot records. This suggests that Earth's temperature trend is still recovering from the Little Ice Age that was at a low point in 1660 to 1710.

Solar radiation records for 170 locations are listed on the CAClimate CD. These records are from CIMIS stations located in the agricultural areas and from fire weather stations (CDEC) generally located in mountainous regions. Ground based solar measurements are far too insensitive for solar constant measurements due to variations in atmospheric moisture and cloud cover.

Evaporation records were compiled for use in wastewater management studies, irrigation planning and water balance studies for reservoir operation. With the exception of a few very carefully monitored agro-climate stations with very carefully controlled environmental exposure, most of the station exposures are suffering from the influence of shading from trees or variation in thermal contact with the ground.

There is often concern regarding accuracy in rain record analysis that might be inconsistent with rain gage measurement precision. The snowmelt study resulted in an evaluation of precipitation gage catch in the snow zone. Figure 4 shows ratio of precipitation gage catch to total snow melt as it changes with elevation. It is clear that precipitation gages under catch at elevations above 6500 feet. This result is reminiscent of the classic rain gage study of Koschmieder that was published in Vol.62. No1, January 1934 of the *Monthly Weather Review*. Koschmieder showed a decrease of rain gage catch with increasing wind. Where as Koschmieder worked with rainfall, the rain gage catch in snowfall is much more sensitive to wind effects.

California's most extreme rainfall measurements were from stream-flow gages. The greatest measured one-day stream-flow that I have found was on Day Creek near Etawanda. This was on January 25, 1969 in San Bernardino County when the maximum daily flow was the equivalent of 33.04 inches over the watershed. Fish Creek in Los Angeles County measured 32.34 inches on the same day. Day Creek had a peak flow of 9,450 cubic feet per second (cfs) on 4.58 square miles of watershed and a peak average daily flow of 4,070 cfs according to the USGS. Fish Creek had a peak flow of 13,000 cfs on 6.36 square miles and a peak average daily flow of 5,540 cfs according to Los Angeles County Flood Control. These 32 inch per day runoff values would be even greater if these were based on the maximum 24 consecutive hours rather that the maximum midnight to midnight readings.

Ray Linsley once said, "THE BIGGEST ONE IS YET TO COME". For California it will no doubt be on a windward slope probably in Southern California when warm moist air masses are pushed up-slope by strong Southerly winds.

Weather records are kept mostly for specific applications such as weather forecasting, fire or flood control or irrigation management. They need also to be archived to serve the needs of audiences that are not yet born. The historic long term weather records give perspective to the shorter records. Weather records are the basis of the design of all public works and they are important historic documents.

My personal greed for new rainfall records is still unabated. If you have rain records to share that would supplement those summarized on the CAClimate CD, I would appreciate your contributions. Also when you find errors I would appreciate learning of them.

Plate 1: Sacramento during the great inundation of 1850 and a scene prior to levee construction

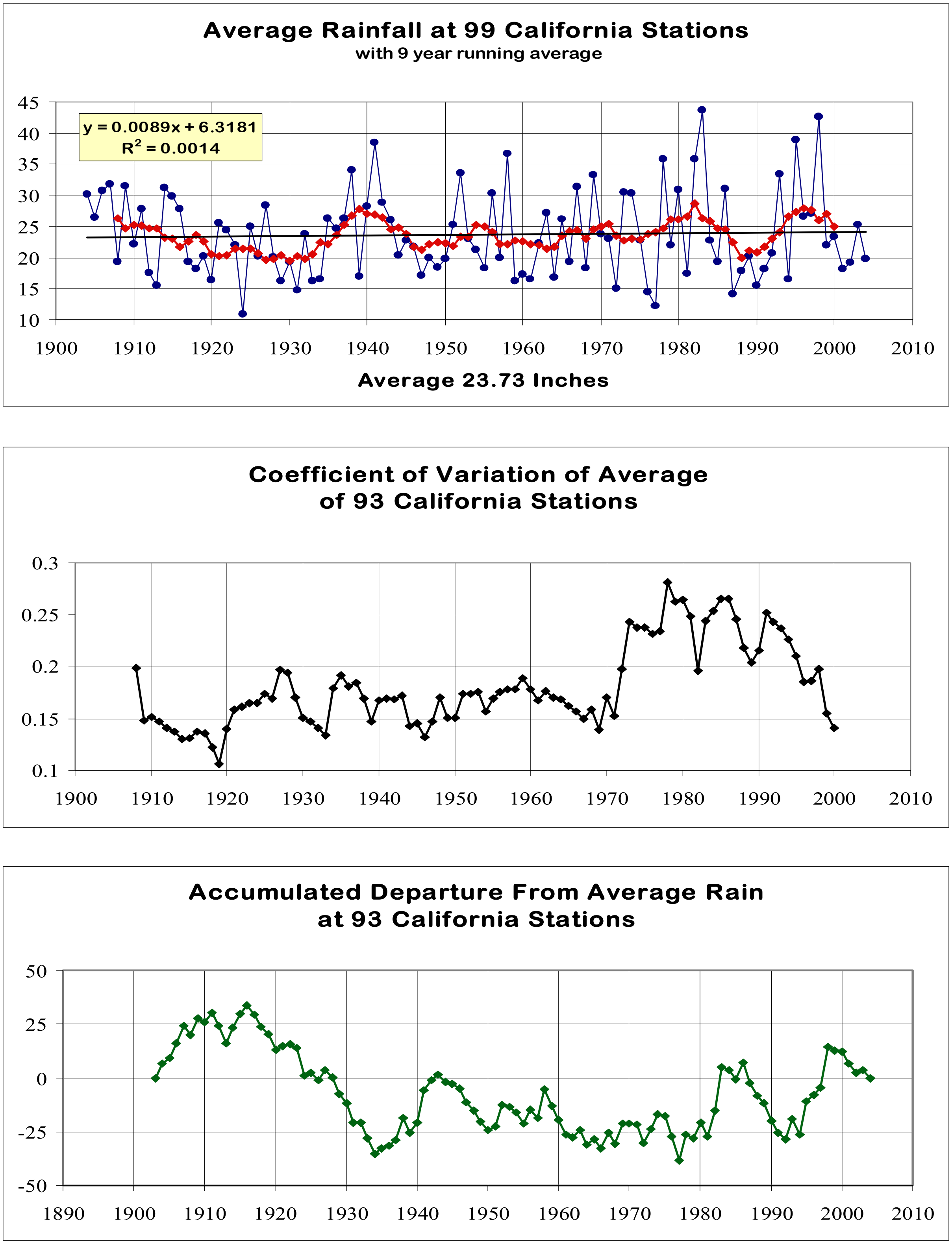
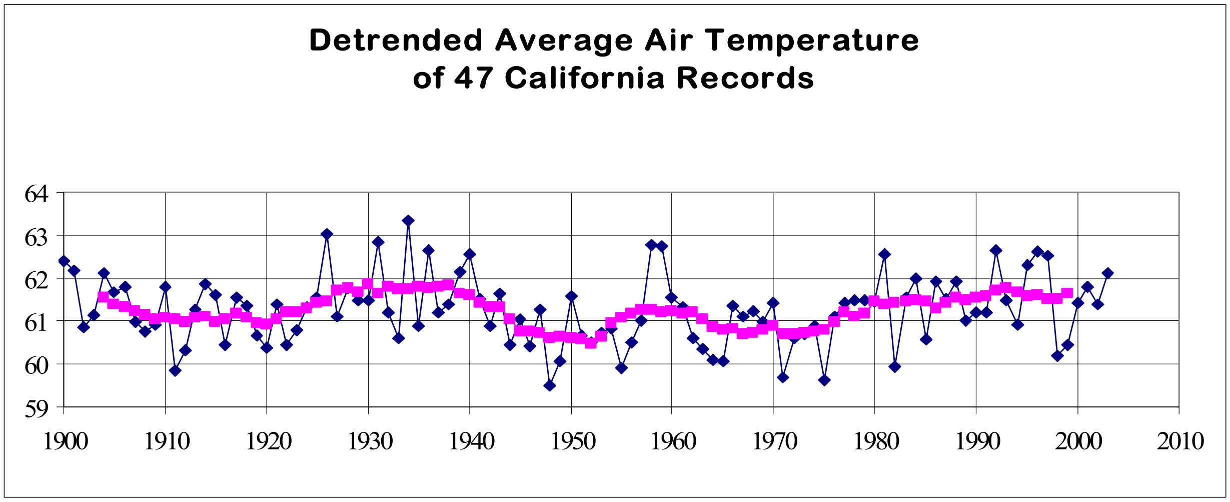
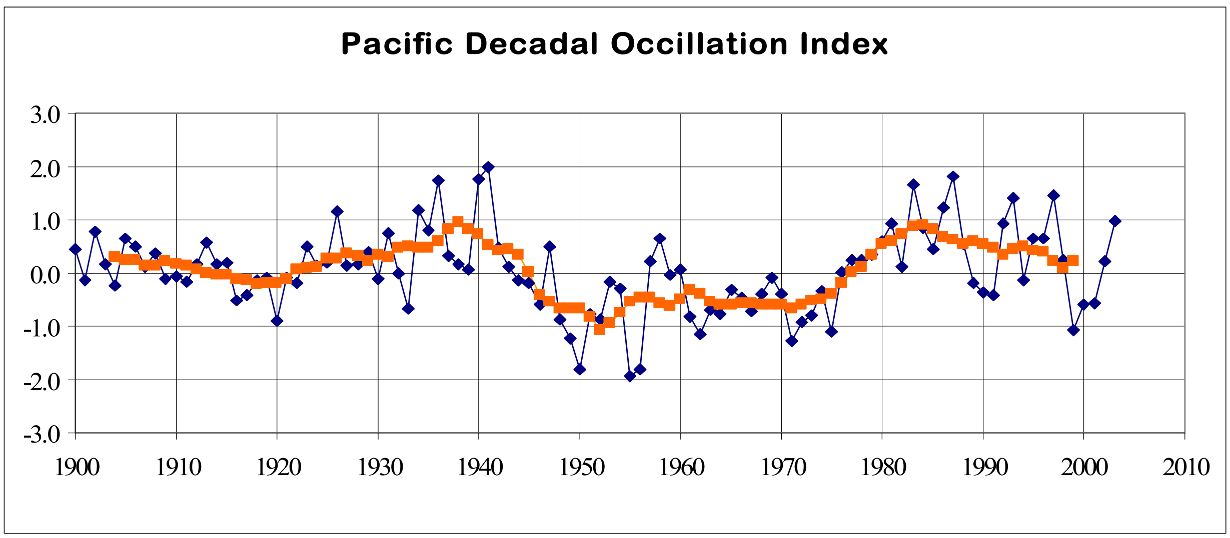


Figure 1: (a) 100 Year Rainfall Trend (b) 9-year Running Coefficient of Variation (c) Accumulated Departure from Average





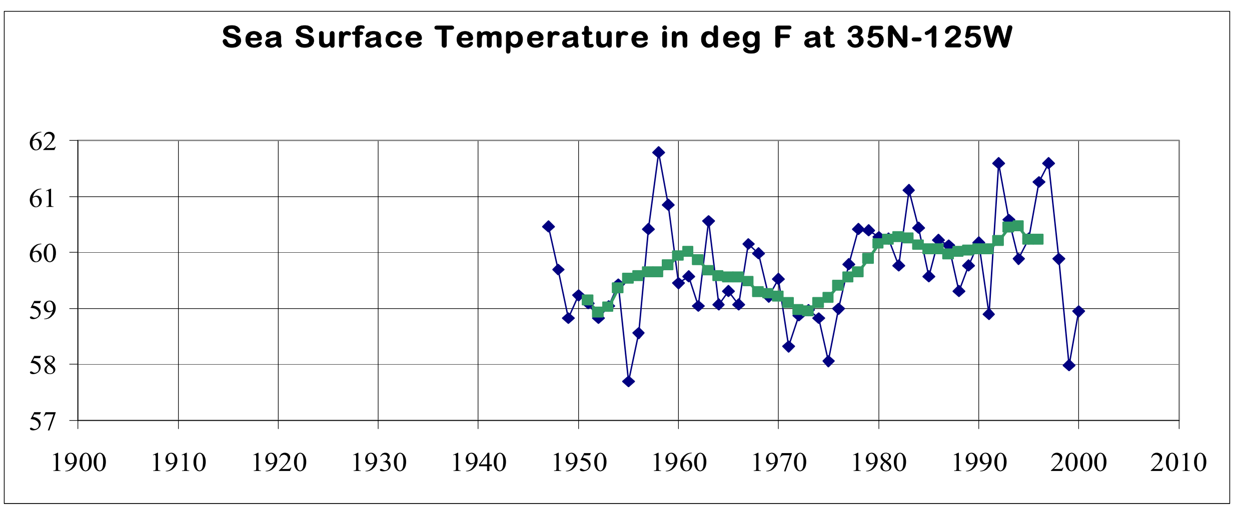


Figure 2: (a) De-trended Average Air Temperature (b) Pacific Decadal Oscillation Index (c) Sea Surface Temp at 39°N and 125°W

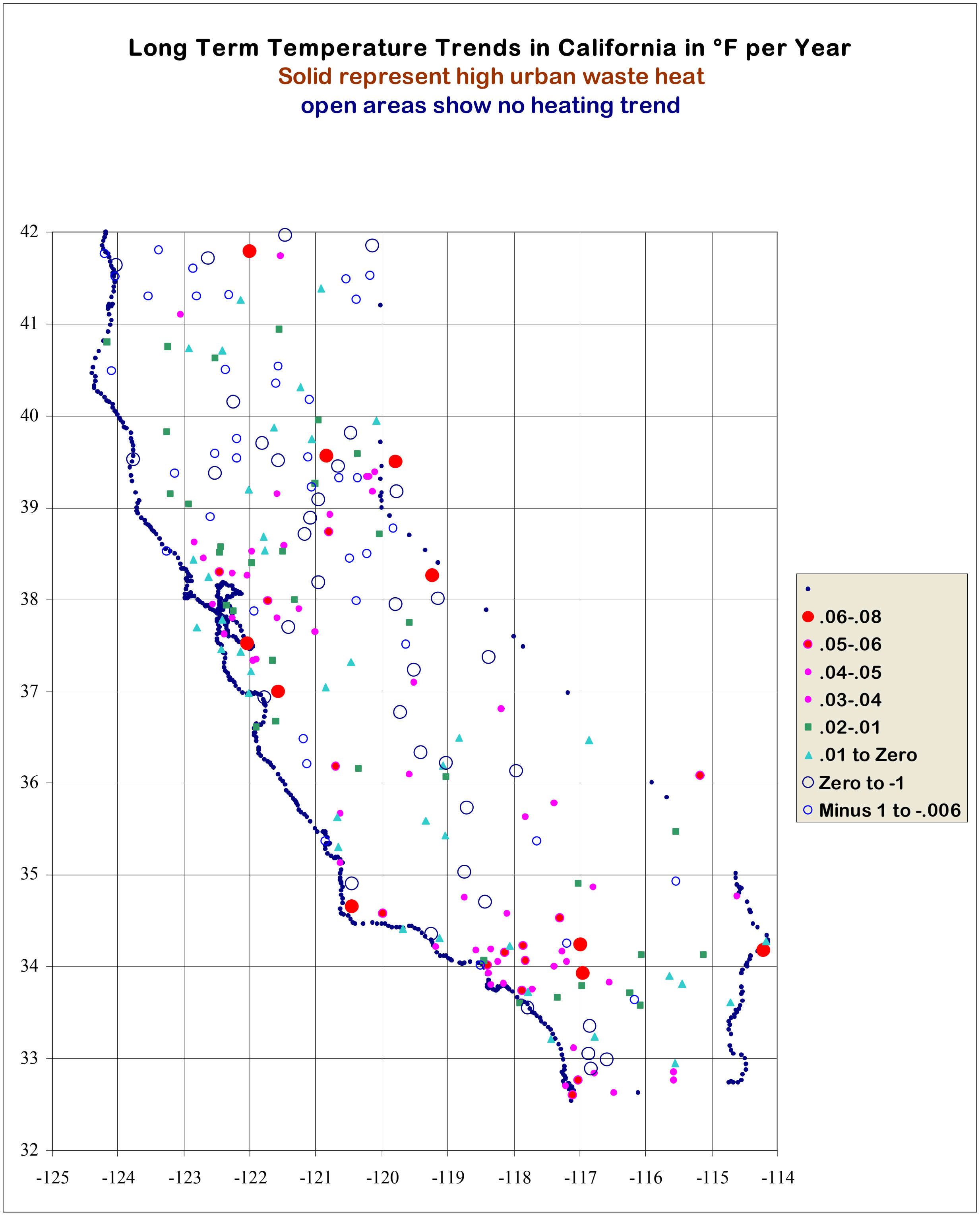
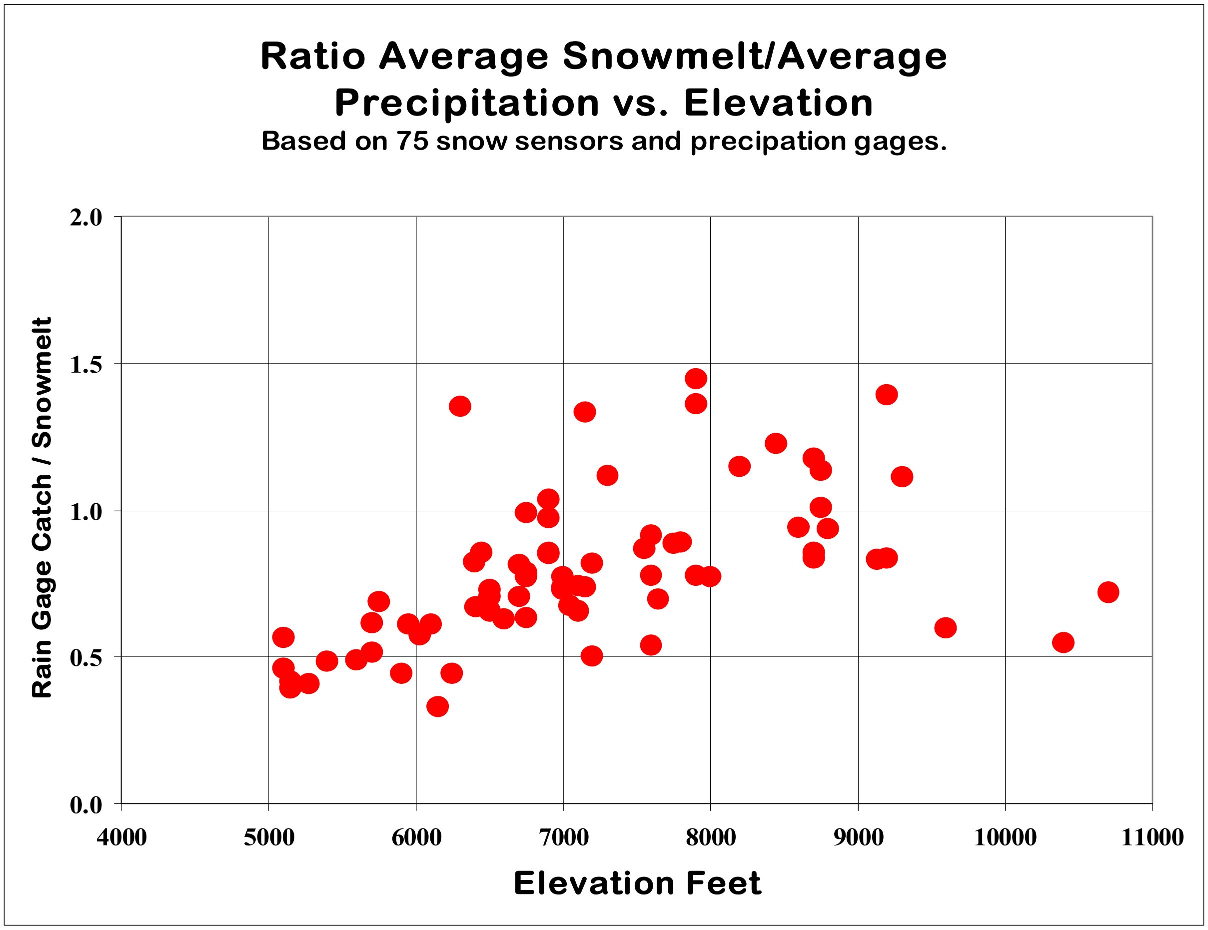


Figure 3: Long Term Temperature Trends in California in deg F per year



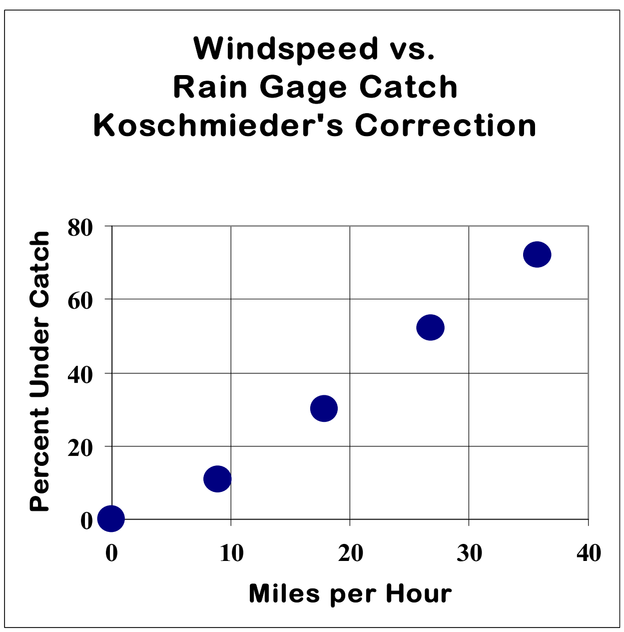


Figure 4: (a) Rain gage accuracy in the snowzone, (b) Rain gage accuracy in wind, from H Koschmieder. 1934, Monthly Weather Review.