Development of Climate Monitoring Indices for California

Laura M. Edwards, Kelly T. Redmond and John T. Abatzoglou

Western Regional Climate Center, Desert Research Institute, Reno, NV

Introduction

State agencies and the general public are in need of simple descriptive measures to track the variability of climate and to illustrate trends if hte are present. California has many climate zones, complex topography, and microclimates. The purpose of this effort is to distill such complexity into a few index values that encompass the diversity within the state but that also summarize the state as a whole.

Some previous studies have presented methods for creating indices of climate. Karl et al. (1996) presented the Climate Extremes Index (CEI) and a U.S. Greenhouse Climate Response Index (GCRI) at the National Climatic Data Center (NCDC). The CEI is used as an annual index to describe how much of the conterminous U.S. is affected by extreme drought, wetness, coolness or warmth. The GCRI is intended to be used as a monitoring index, to anticipate possible greenhouse-induced changes in U.S. climate.

Hansen et al. (1998) describe a method that targets changes in climate that people can feel or perceive. They used annual precipitation and temperature data compared to the 1951-1980 NCDC normals, normalized by the standard deviation (SD). Using this method, a prolonged period (a year) that was outside a +1.0 to -1.0 SD window could be noticeable and likely to be remembered.

Heim et al. (2003) created the REDTI climate impact indices for the conterminous U.S. The first, REDTI, explains climate impact on the energy sector, based on population-weighted Heating Degree Days and Cooling Degree Days. Using a linear scale from 0 to 100, an annual index is calculated.

Methods are needed to regionalize climate variability within the state in a manner that reflects the observed tendencies for different parts of California to vary in the same manner. Empirical Orthogonal Functions, or EOFs, and cluster analysis can be useful in isolating and identifying regions of homogeneity. Previous work by Comrie and Glenn (1998) and Fovell and Fovell (1993) has determined a method for utilizing these tools to regionalize climatological data. Upon identifying climate divisions, one can then define climate indices on a regional basis.

Data and Methods

We employ NCDC's Summary of the Day (SOD) datasets from cooperative stations (COOP) across California to create a monthly database. We focus initially on two key variables, monthly temperature and monthly precipitation. For cases in which more than 7 days of any given month are missing we consider the entire month to be missing. For this preliminary exploration, stations are selected that have at least 75% complete data since 1948, 158 for temperature and 208 for precipitation. Missing monthly data are infilled by generating a series of linear least-squares estimates. This is achieved by identifying the top 50 stations statewide with available data that have the strongest correlation with the missing station. We replace the missing value with the median value of the estimates.

Data are normalized (standard deviation for temperature, cube root for precipitation) to better equalize station influences. This method allows us to focus on how stations co-vary with one another, such that stations with similar patterns may be grouped together in order to concisely explain regional climate patterns in California. We then perform an EOF analysis on this complete dataset. This method objectively groups stations using variance, rather than geography. Various rotation methods, in conjunction with cluster methods, are being considered in order to best categorize climate regions within the state. As EOF analysis (and/or cluster analysis) isolates sectors of the state into climate division we are able to form climate indices. This can be achieved by applying the loadings from the EOF analysis, or a weighting of the cluster stations to either the raw data or standardized anomalies.

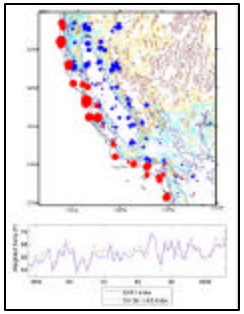

Figure 1. EOF 1 of July mean temperature, with time series of 3 NCDC coastal climate divisions.

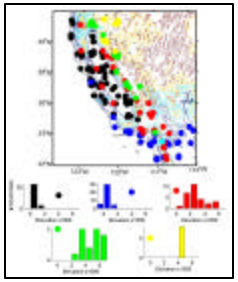

Figure 5. January mean temperature, centroid clustering algorithm.

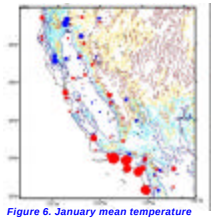

Figure 6. January mean temperature rotated EOF 5 using station data.

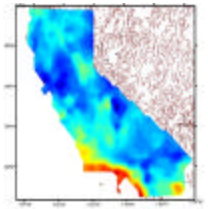

Figure 7. January mean temperature rotated EOF 6 using PRISM data.

Figure 2. NCDC Climate Divisions in California

Figure 3. CEC's Building Climate Zones.

Discussion

We found that the first 10-12 EOF patterns captured a sufficient amount of variability for California temperature and precipitation. A number of interesting patterns emerged.

- **Figure 1**. Summer temperatures vary coherently along the entire coast of California.
- **Figure 2**. NCDC Climate Divisions.
- **Figure 3**. CEC Climate Zones used for building codes.
- **Figure 4**. A common mode of variability was especially exaggerated during the heat wave of July 2006. We speculate that the time series shows changes in Central Valley ventilation beginning in the early 1980s.
- **Figure 5**. Stations in different elevation bands behave similarly to one another.
- **Figures 6 and 7**. Station-based and grid-based (PRISM) data exhibit similar coherent structure along the south coast in winter.
- **Figure 8**. Time series based on station data, gridded data and NCDC Climate Division 6 data are extremely well correlated. The last 30 years of record show a general upward trend in all three representations.
- **Figure 9**. High elevation Sierra Nevada locations co-vary with one another. Recent droughts (1987-94, 2000-03) and wet spells (1982-84, 1995-98) are readily discernible.
- **Figure 10**. Preliminary climate regions as objectively determined by repeating the analysis shown in Figure 9. The pattern of red dots in Figure 9 are represented as turquoise dots in Figure 10. A similar process results in the other delineated regions. Notice how magenta dots in the northwest region resemble NCDC Climate Division 1. However, note that this region as defined by annual precipitation is not consistent with a pattern derived from summer temperature, as seen in Figure 1.

This analysis illustrates the need for compromises in how climate regions are decided. Thus, the process can not be completed by purely objective means.

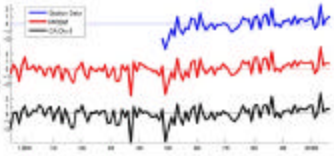

Figure 8. Time series of January mean temperature indices corresponding to figures 6 and 7 at left.

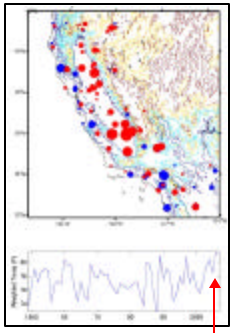

Figure 4. Rotated EOF 2 of July mean temperature. July 2006 Heat Wave

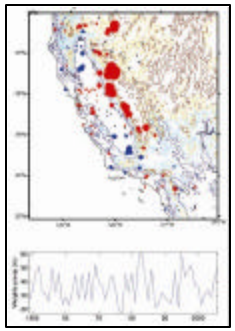

Figure 9. Rotated EOF 6 of Rain Year precipitation (July-June).

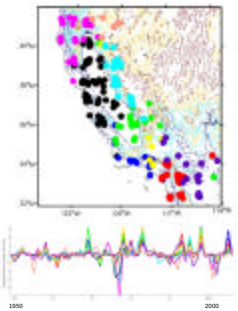

Figure 10. Above: Rain year precipitation climate regions delineated using the maximum loading from the first 9 rotated EOFs. Below: Time series of precipitation indices.

Considerations

Several issues must be taken into account in the development of such indices:

- Adequacy of current NCDC Climate Divisions.
- Number of distinct geographic regions.
- Utility of a single statewide number.
- Do natural geographic regions vary by month?
- Do natural geographic regions vary by element?
  Tmax, Tmin, Tave, Precip
- Do natural geographic regions vary by elevation?
- Do station data and gridded data produce similar clusterings?
- Should the index be based on station data, gridded data, reanalysis data?
- Real-time availability of station data for monthly updates?
- Consistency and homogeneity of station data.
- Preference for records that extend from at least 1900.
- Inclusion or exclusion of urban and agricultural effects?
- Infilling techniques for developing complete time series.

Future Work

- Simplify clusters by compiling temperature and precipitation patterns to define climate divisions that best suit both elements.
- Extend time series to encompass the entire 20th Century.
- Apply results to energy sector. Possible variables may include degree days, wind and/or solar parameters.
- Be able to incorporate near-real time data to update index monthly.
- Distribute index via the CalClim website hosted by WRCC,

www.calclim.dri.edu.

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Contact: laura.edwards@dri.edu