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Some comments on reconstructing the historical climate of California, USA(*)

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Summary. — This paper describes some examples of historical climate reconstruction pertaining to California, USA, focusing mostly on winter climate given the expected strongest teleconnection signals for this season. Climatic data consist of early instrumental data from the US Army Surgeon General at military forts, observers of the Smithsonian Institution, the Signal Service, and some private observers. Documentary (non-instrumental) data were also used in assessing extreme events. Original daily records of these data were carefully assessed for discontinuities from examining diurnal temperature ranges and daily precipitation amounts. The climatic reconstructions conducted were as follows: 1) winter precipitation time series for selected locations since 1850, particularly for Sacramento and San Francisco, 2) winter temperature time series for selected locations since 1850, and 3) analyses of an extreme flooding event in January 1862 and a landfalling tropical cyclone of September 1939. Results indicate distinctive wetter winters for central and northern California in the late nineteenth century, and some of these wetter years correspond to well-known very strong El Niño events. Connections to weaker El Niño and La Niña events, however, are not clearly evident. The flood of January 1862 is considered unprecedented when compared to other floods of the last 130 years. The reconstruction of a landfalling tropical cyclone for September 1939 near Los Angeles suggests its intensity at just below hurricane strength.

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1. – Introduction

The state of California, USA possesses some of the longest documentary and early instrumental climatic data for western North America, well before the modern (twentieth

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century) record. Although extensive temporal coverage is generally less than 200 years, English language materials are particularly dense spatially after 1860 especially for central California, with some site-specific data being plentiful back to the late 1840s. These data provide important information on verifying climatic reconstructions from tree-ring data, examining spatial variations of climate in response to teleconnections such as ENSO (El Niño-Southern Oscillation) and the PDO (Pacific Decadal Oscillation), assessing extreme meteorological events such as floods and snowstorms, and reconstructing the length of the growing season. This paper describes the data and some examples that are available for historical climate reconstructions on California, focusing on nineteenth century winter climate given the strongest teleconnection signals for this season.

2. – Nineteenth century data

The earliest known systematic meteorological data for California were recorded by Russian settlers at Fort Ross from 1838-1842 [1]. Although fragments of records from mariners exist thereafter, continuous records generally did not resume until 1847 with weather observations recorded at Monterey, California and soon thereafter at the Presidio in San Francisco [2]. Thus, most weather observations for California prior to 1849 need to rely on non-instrumental documentary evidence. The instrumental observations were under the supervision of the US Army Surgeon General, stating temperature, prevalent wind direction, precipitation amounts, wind speed on a numerical scale from 0–10, and cloudiness on a numerical scale (0–10) [3]. Occasional records also included barometric pressure. The Smithsonian Institution initiated a national network during the early-mid nineteenth century as well, whereas some observers in California contributed data beginning in the 1850s. In addition, some weather enthusiasts also kept daily weather records [4], and some of these daily records were published in local newspapers. These include records by Thomas Logan of Sacramento (1851-1867), Thomas Tennent of San Francisco (1849-1888), and Henry Gibbons of San Francisco (1850 to through the 1880s). The United States Signal Service set up a national-scale network in 1871, it being the forerunner of the US Weather Bureau, which was established in 1891 and include first-order weather stations such as San Francisco, Los Angeles, and San Diego. These early instrumental data have to be carefully screened for data quality [5,6] . Temperature data problems include different routine fixed observation times that affected the compatibility with modern data, and by different thermometer exposure situations involving azimuth, shelters, and building material [6,7]. Corrections on this averaged temperature data from fixed observation times to convention al maximum/minimum averages are clearly possible from using modern hourly temperature data, but to date no such comprehensive corrections have yet been performed. Precipitation data problems include the conversion of snowfall to liquid, some high placements of rainfall gauges (*e.g.*, 240 cm high and rooftop) that caused lower liquid accumulation due to increasing wind speeds [8], and gaps in time (sometimes several days or more) when precipitation gauges were actually measured that may result in evaporative loss of water. This underestimation of precipitation generally is more apparent in cold-season precipitation [9]. Other problems concerning the accuracy of 19th century precipitation records include changes in the environment surrounding precipitation gauges and in instrumentation. However, similar problems are also evident in modern National Weather Service COOP (Cooperative) precipitation records, and no reasons exist to suggest that 19th century data possesses greater problems. Precipitation data can also be expressed in precipitation frequency instead of magnitude, as these reconstructions can often be directly compared with modern climatic data [10].

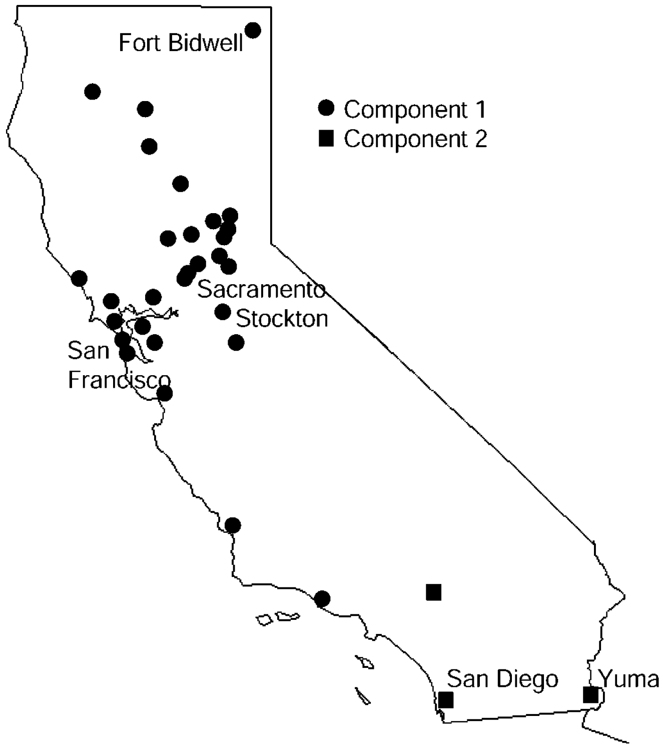

Fig. 1. – Locations of weather stations in California with continuous data from 1872-2003. Stations with names and the principal components are discussed more in the text.

Precipitation frequencies may also more accurately reflect homogeneous responses to synoptic-scale atmospheric circulation [11]. Exactly-dated non-instrumental documentary records such as diaries, ship logbooks, annals, and newspapers are important but often overlooked supplements to instrumental records, filling important temporal and spatial gaps, particularly concerning reconstruction of precipitation frequencies [10, 12]. The documentary materials, however, cannot be taken at face value. Original sources should be used as much as possible because typescripts can provide erroneous edited information. Written descriptions of climate may also reflect individual biases based on diarists' personal background and particular motivation for writing. Thus, a thorough knowledge of the written materials, diarists, a historical background of the time period i n question, and past climatic perceptions must be analyzed. Historical methodologies, such as content analysis, enable quantitative assessments of past climate by analyzing the vocabulary of weather descriptions.

3. – Some examples of California historical climate reconstructions

3·1. *Winter precipitation.* – A principal components analysis with a Varimax rotation was conducted on seasonal winter (December-February) precipitation data for 32 California stations from 1872-2003 (fig. 1). This procedure was conducted to assess the regional homogeneity of precipitation patterns in California. The highest salient (significant)

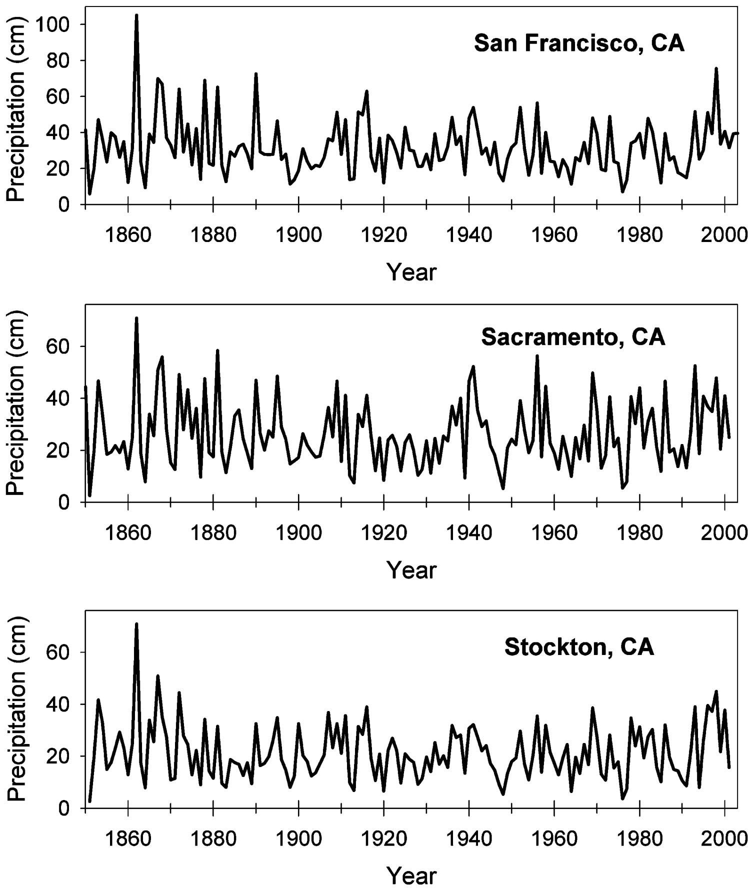

Fig. 2. – Winter (December-February) precipitation at selected locations from 1850-2003.

loading for each station was mapped relative to its related principal component. Three principal components were extracted from the analysis. The first principal component explains 35.4% of the variance, and all but three of the stations have a salient loading related to this component. Most of the loadings are less than −0.800 (higher absolute values), thus indicating that California seasonal winter precipitation is quite homogeneous in response (fig. 1), although clearly individual magnitudes can vary spatially due to topography and from year-to-year. The second principal component explains 9.8% of the variance, and salient loadings are evident for only three stations: Yuma, San Bernardino, and San Diego. A third principal component was extracted that explains 5.0% of the variance. Its strongest loadings relate to some of the central California coastal stations, perhaps related to land/sea breeze processes. No stations exhibited salient loadings related to this component. Several time series of winter precipitation were constructed to illustrate temporal variability through time. Available daily nineteenth century precipitation data for San Francisco, Sacramento, Los Angeles, and San Diego (in manuscript and microfilm forms) were carefully screened for data quality. Higher daily precipitation frequencies mostly correspond with smaller precipitation amounts, thus generally indi-

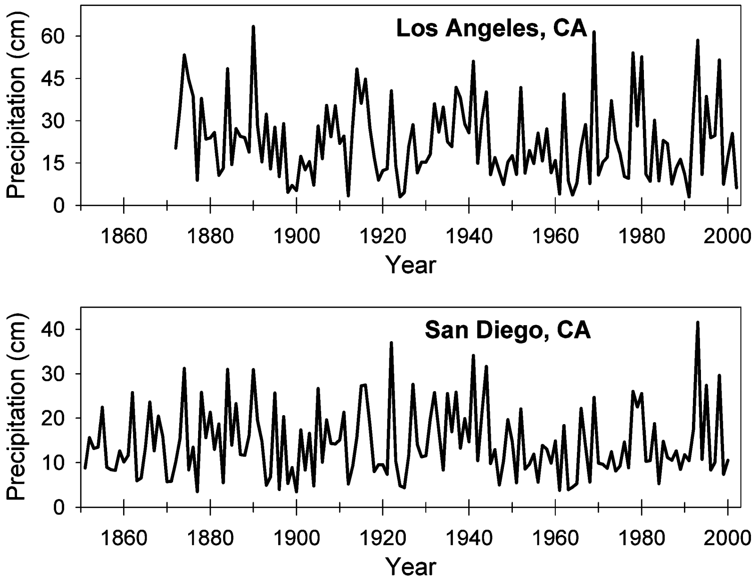

Fig. 3. – Winter (December-February) precipitation at Los Angeles and San Diego from 1850-2003.

cating satisfactory quality. Most of the daily nineteenth century precipitation data for Stockton have still not been located, thus values were taken from Alexander McAdie's compilation [13] and carefully compared with other stations. The time series of winter precipitation for San Francisco and Sacramento exhibit similar trends from 1850-2003 (fig. 2). Increased decadal variability is evident for much of the twentieth century, while stronger interannual variability is evident prior to 1890. Of interest, more frequent winters with higher precipitation are evident for much of the 1860s-1880s as compared to the recent century. Higher amounts of winter precipitation during 1878 and 1891 may relate with very strong El Niño events as reconstructed by historical evidence in South America [14], but of note there are numerous winters where low amounts of California winter precipitation do not relate with medium-to-strong reconstructed El Niño events. Some of the dry winters may relate with La Niña events, though more research is needed to closely compare California reconstructions with La Niña proxy reconstructions from tree-rings. The time series of winter precipitation for Stockton is mostly similar to those of San Francisco and Sacramento, but it has a distinctively drier period from 1870-1900, perhaps due to lower data quality. All three records illustrate that the winter of 1851 is the driest in the last 153 years. Conversely, the winter of 1862 is clearly the wettest, with most of the precipitation occurring in January (this event is described more in subsect. **3**˙3).

The Los Angeles record, in which high quality data are presently limited back to 1872, illustrates increased decadal variability in the 1900-1960 (fig. 3). Its winter interannual variability, however, shows different years with high and low values compared to the records further north. The San Diego record, in contrast, exhibits more interannual variability throughout most of the record, with more marked variability of wet and dry winters from the 1870s through the 1890s. It also illustrates a distinctively dry period from 1950 to 1990.

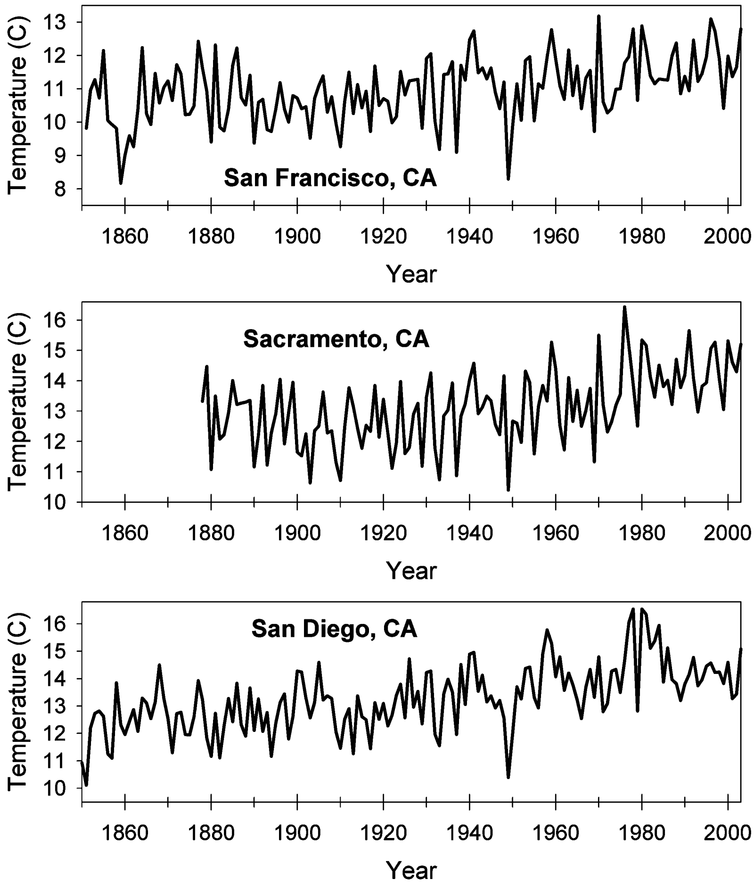

Fig. 4. – Winter (December-February) temperatures at selected locations from 1850-2003.

3˙2. *Winter temperature*. – Some time series of winter temperature are presented for San Francisco, Sacramento, and San Diego (fig. 4). These records have been corrected for fixed observation times to be consistent with post-1871 records that have averages based on maximum/minimum temperatures. However, the time series of nineteenth century data presented here have not been corrected for exposure problems. All three time series illustrate rising trends since 1940, reflective of the urban heat island. The San Francisco temperature time series, relying mostly on the Thomas Tennent record prior to 1871, demonstrates some relatively cold winters from 1858-1862. Close inspection of other daily San Francisco records (*e.g.*, from the Gibbons, Ayers, Presidio and Alcatraz Island records) immediately available suggests that these winters were likely quite cold, including the winter of 1859. The nineteenth century San Francisco record does not compare closely with that for San Diego as well as for Sacramento, and this result may reflect the fact that temperatures at San Francisco are generally not homogeneous in relation to regional California climate.

3˙3. *Examples of extreme events*. – Documentary and instrumental data are crucial to integrate together in order to reconstruct extreme weather events in California, such

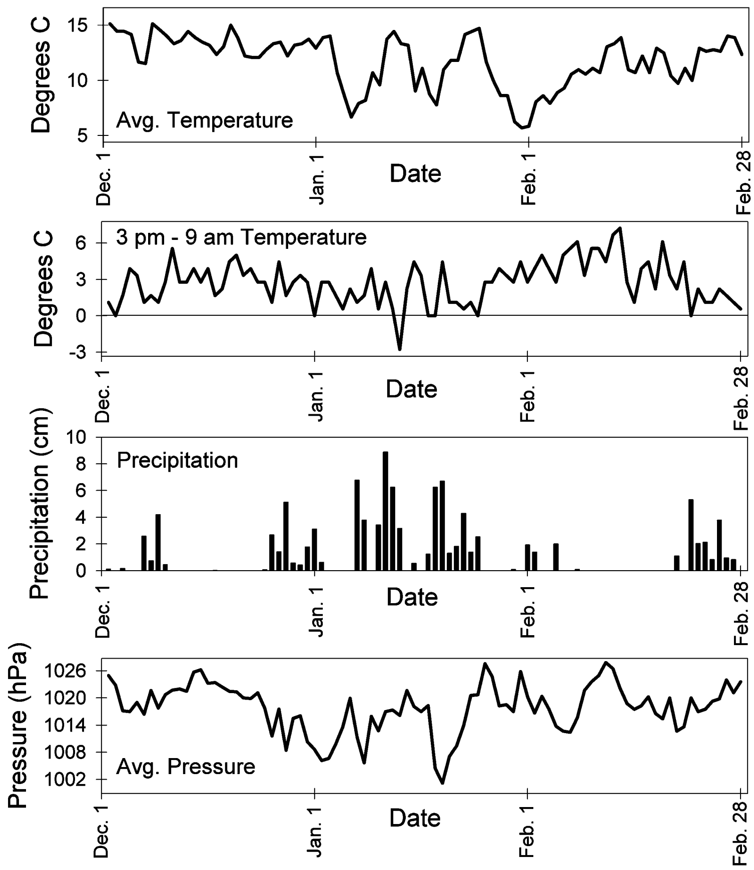

Fig. 5. – Time series of daily data for the winter of 1861-62 for San Francisco, California. Data were recorded by Thomas Tennent.

as extreme flooding events. This aspect is particularly important, as some reconstructed extreme events are clearly "unprecedented" when compared to what we perceive as "normal" and there is a need to improve probabilistic models. Society may not properly prepare for extreme events if it bases their likelihood on only a particular timeframe (*e.g.*, last 50 years) [15]. One particular event that is currently still not that accurately reconstructed at a statewide level is a flooding event in January of 1862, as much additional documentary and instrumental data need to be extracted from the archives. Current general estimates of the magnitude of flooding suggest that it is clearly by far the most serious flood ever witnessed in northern and central California [16], and documentary (non-instrumental) data suggest that extreme flooding was extensive throughout the California Central Valley. This event also is evident into the Pacific Northwest and eastward through Nevada into Utah [17]. Daily meteorological information found in the *Daily Alta California* newspaper for San Francisco reveal the prominent fluctuations during the winter of 1861-62 (fig. 5). Relatively warm conditions in December were replaced by a series of persistent strong storms that brought cold air into the region. These storms brought more than 50 cm of rainfall within two weeks; the rainfall exceeded what is normally experienced in San Francisco for an entire year. Z-scores reveal that the January 1862 event is almost 4 standard deviations above the mean when comparing rainfall values with the entire San Francisco record (J. Goodridge personal communication). Numerous other meteorological stations in California reveal similar results, but some display somewhat smaller z-scores. These smaller z-scores likely reflect poorer data quality in some 1862 weather records, as precipitation was normally underestimated. A landfalling tropical cyclone in southern California in late September 1939 is a rather unique extreme event that also deserves a more detailed reconstruction. The author found evidence in California archives of a sea-level pressure value around 993 hPa off San Diego early on September 25, 1939. Extrapolating this value to an estimated position of the tropical cyclone center suggests a central pressure value that could be as low as about 990 hPa [18, 19]. This pressure value suggests a maximum strength of a tropical cyclone at about 55-60 knots. Documentary evidence of tropical cyclone damage in the Los Angeles area examined to date, however, suggests that the tropical cyclone was just below hurricane strength. The evidence also clearly shows that much of the damage occurred earlier on September 25, thus suggesting that the tropical cyclone moved faster than as illustrated on the track previously constructed by others to date [18]. The $2 million (US dollars) in damages from this storm would likely be over $100 million today if it occurred, given higher population densities along with inflation adjustments.

4. – Closing remarks

Serious comprehensive attempts to reconstruct the nineteenth century historical climate of California has never be en conducted. However, examples discussed in this paper demonstrate that the late nineteenth century contains characteristics of climate variability that differed from the last 100 years, thus deserving attention. Historical climatic reconstructions have important information that can be used to verify climatic reconstructions from tree-ring data and other high-resolution paleoclimatic proxies. Detailed data are also available to study climatic hazards down to block-by-block resolution, such as the extreme flood of 1862. Clearly, examples in this paper illustrate that the spatial density of daily historical climate data is plentiful for central California and other scattered areas of the state back to the 1840s concerning English documents. Spanish documents can additionally extend the record further back for southern California [20]. Nevertheless, any future historical climate study for California will require vast amounts of time—this includes intensive archival data collection for newly discovered meteorological and documentary materials, digitization, as well as the correction of nineteenth century instrumental data that is currently available.

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