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1. INTRODUCTION

Climate change studies have focused on global and regional temperatures, particularly warming trends over the last century (Hansen et al. 2006; IPCC 2007). Precipitation trends at global and regional scales are also important climatic variables that may be influenced by warming. In California, precipitation amounts vary considerably, yet rainfall is vital to the state's multi-billion dollar agriculture industry, which produces 12% of the nation's total agricultural products (Mitchell and Blier 1997). During frequent dry years, water shortages can cripple agriculture and hydro-power, and result in greatly reduced residential consumption. In wet years flooding may also create major disruptions.

Several studies have looked at recent trends in precipitation, both in the United States and in California. Karl and Knight (1998) found a 10% increase in annual precipitation in the United States between 1910 and 1996 with over half of this increase coming from the upper 10 percentile of daily precipitation. In their study, Higgins et al (2000, 2007) also found that daily precipitation events have increased over much of the western U.S. in the last five-decade period. This period of increased precipitation corresponded to similar increases in total annual amounts. Higgins et al (2000, 2007) also found that the total of heavy precipitation days increased substantially over portions of the West during this period. These increases in intensity of rainstorms are particularly apparent in the summer for the U.S. in general (New et al 2001). However, in the West, the largest difference in the frequency of daily precipitation (>1 mm) and in heavy precipitation totals in recent decades occur in the JFM season (Higgins et al 2007). This seasonality nearly corresponds to the peak of California's annual precipitation, as the winter months of December, January, and February account for fifty percent of the states total precipitation (Mitchell and Blier 1997). Similarly, Peterson et al (2008) found heavy precipitation has been increasing over the last half century,



Figure 1. Location of the 20 California stations used in the study, as well as some Oregon stations used for comparisons in some of the calculations.

and that the average amount of precipitation falling on days with precipitation has also been increasing, which they attribute to global warming.

When comparing the 1948-1975 period to the later 1976-2004 years, Higgins et al (2007) found that the large increase in total precipitation could be explained by the Pacific Decadal Oscillation (PDO). This was especially true for explaining the increases in heaviest precipitation (>90%). El Niño events have also been linked to greater precipitation in California, particularly Type 1 El Niños which average between 113 and 174% of normal precipitation for the water year (July 1-June 30) by climatic divisions (Monteverdi and Null 1998). Schonher and Nicholson (1989) also found Type 1 El Niño events were the only El Niño type producing high rainfall statewide. The impacts of El Niño events increase from north to south across the state. For La Niña events, southern California is typically drier than normal, however, northern California, and the Pacific Northwest, show higher than normal rainfall amounts (LaDochy et al 1999). This trend shows a well-known dichotomy between the north and south of the state in terms of precipitation.

Temperature is usually associated with precipitation. With higher temperature, more

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evaporation occurs, leading to higher atmospheric moisture levels. The Intergovernmental Panel on Climate Change studies have shown changes in rainfall distribution worldwide, with less light and more heavy events occurring (IPCC 2007).

Precipitation trends in California are the main topic of this paper. Long-term trends in precipitation amounts and intensities are analyzed for possible linkage to climate change. State temperatures clearly show a long-term warming trend. How is this impacting precipitation ?

2. DATA

All data were retrieved from the National Climate Data Center (NCDC), which is part of National Oceanic and Atmospheric Administration. The NCDC has collected more than 150 years of weather data from meteorology stations located around the world. To cover all regions in California, roughly twenty stations were chosen from North to South and East to West, to represent a variety of climate types such as coastal, valley, mountain, and desert. 10 stations were also selected from various regions of Oregon, to compare Oregon trends with those of northern and southern California and to determine if California trends extend into Oregon. All stations hold long and continuous data sets allowing us to establish long-term precipitation trends.

Only stations with continuous daily precipitation records from 1925 to present were used in this study. Also considered was whether stations were relocated a significant distance from their original positions during the time period. Blanks, zeroes, and trace (T) of rain were removed from the dataset. More stations may be added if missing data can be filled using statistical methods, but for now, these techniques were not used.

3. METHODS AND RESULTS

Unlike temperature, the annual average precipitation trends over a century for all stations in California show no particular trend with very low R squared values. However, the annual amount of rain and the annual number of days with rain demonstrate trends both by region and by station. For annual data, rain years (July 1-June 30) were used since California's rain season is in winter, while summer is relatively dry (Mitchell and Blier 1997). The location of the 20 stations insures that most regions of the state are represented in this study (Figure 1). Stations in Oregon are also shown in Figure 1. When ordered by latitude, the stations show a clear trend of increasing total annual rainfall in the North and a slight decrease or no change in the South (Figure 2). NCDC historical state regional averages of rainfall were used to confirm that the stations chosen are good representatives of their respective areas. The results show that stations align with their corresponding regions. Figure 3 shows that the trend in annual precipitation from

1925 to present increases statewide for all the

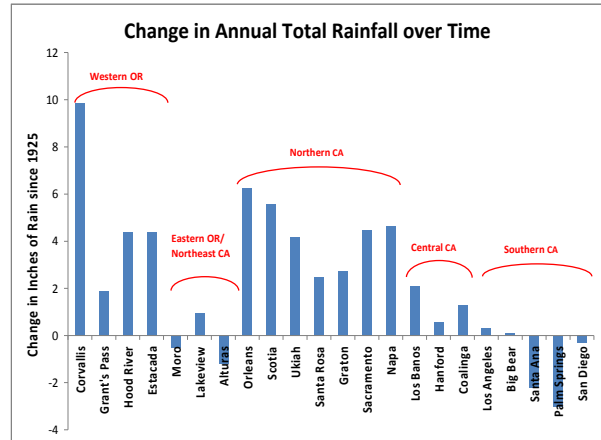


Figure 2. Change in total annual California rainfall organized from North to South, 1925-2008

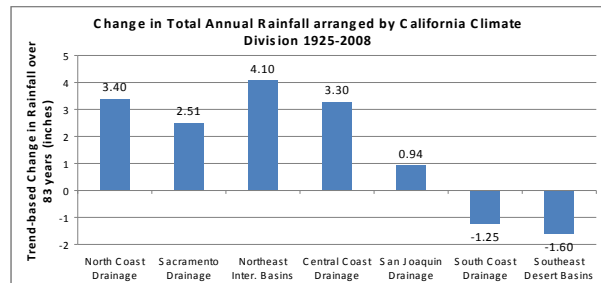


Figure 3. Change in annual (rain year, July1-June30) precipitation for the 7 climatic regions of California, 1925-2008. Source: WRCC.

northern and central Californian climatic regions, but decreases for the two southern regions, South Coast and SE Deserts. The amount of rainfall increase generally intensifies moving further north. After 1975, only the northern region shows a rainfall increase, with the southern region showing dramatic reductions. The numbers of days with precipitation also increase since 1925 in northern California, but decrease in southern California (Figure 4).

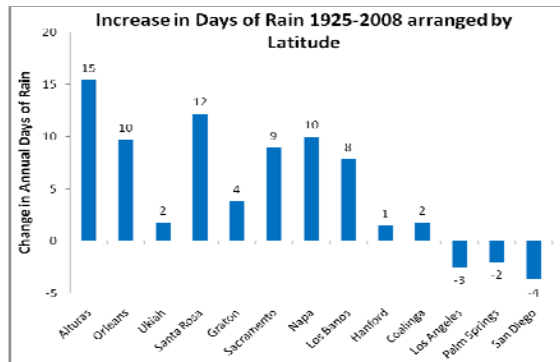


Figure 4. Increased number of days with precipitation for selected stations for the period between 1925 and 2008.

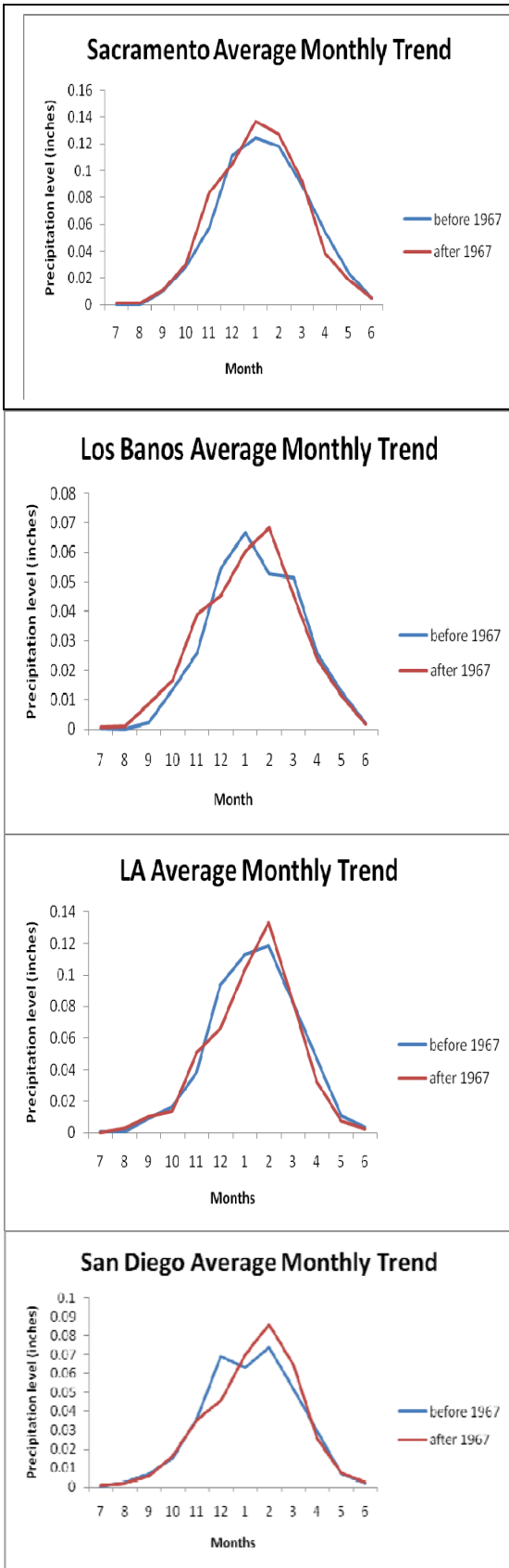


Figure 5. Average monthly rainfall before and after 1967 (Sacramento, Los Banos, LA, SD)

Figure 5 shows how much rainfall occurred in each month over a century. Unlike the average annual trend, the average monthly change between the first and second half of the record shows not only an increase or decrease overall, but a shift in the rainfall season. Stations throughout California show that rainfall has become more frequent in the later winter and early spring months: January, February and March. A corresponding decrease in monthly rainfall occurs in the fall months: October and November (Figure5). This shift in season occurs in northern, central and southern California as a statewide trend.

Additionally, the distribution of rainfall is also analyzed by intensities from light rain to heavy rain to determine if precipitation rate (amounts per day) change across the state. As with monthly trends, rain intensities are compared between the two halves of the century. Generally the second half of the century is characterized by less light rainfall and more heavy rainfall for most of the 20 meteorology stations throughout California. This trend is particularly evident in data from the Sacramento station (Figure 6). as well as for most other California stations (not shown).

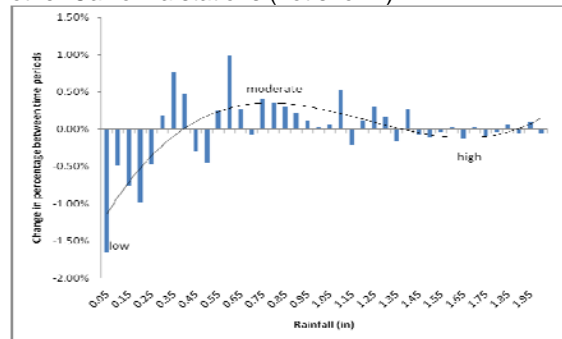


Figure 6. Change in precipitation intensities between first and second halves of 20th Century in Sacramento. Graph shows decreasing light rain and increasing

4. CONCLUSIONS

This preliminary study, indicates that general trends in the rainfall record exist in California. The overall annual precipitation records show increases in most regions. Furthermore the central and northern stations show definite increases in both annual totals and number of days of rain while southern stations show either no significant trend or some decreases.

The daily rainfall totals show a shift from light rains to more moderate and heavy rains in the records from most stations. This shift from light to heavy rains is especially evident in northern regions. The increase in precipitation intensity in

California since the 1920s is similar to results from other regions of the United States.

For the study period there also appears to be a shift in seasonality of precipitation. In general, station data show an increase in winter and early spring precipitation and a decrease in fall precipitation.

These preliminary results may have significant implications for California's water resources. Although the increase in precipitation may be beneficial, especially in winter and spring, the increases in temperature may negate some of the advantages. Higher evaporation and more rain, rather than snow, may mean less overall gains and more runoff and flooding potential.

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