RAINFALL CHANGES IN HAWAII DURING THE LAST CENTURY

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ABSTRACT
A rainfall index for the State of Hawaii and for each of the major islands is developed from more than 100 climate stations with long-period records (>50 yrs). A strong decline in rainfall is apparent in the last 20 years or so of the record for the state as a whole, and is present also for most of the islands. The precipitation changes are examined in terms of possible causal mechanisms, and statistical significance of the change is evaluated using different parametric and non-parametric tests. Changes in different daily and monthly quantiles are also examined.

The recent decline in Hawaiian Island rainfall approximately coincides with the mid-1970s climate change in the Pacific, as depicted by tropical sea surface temperatures (SST). The change may be related to an intensification of the Pacific sector Hadley circulation in northern winter and spring, which implies stronger subsidence over the Islands during that time. We consider the possible impacts of these changes on the State's water resources.

1. INTRODUCTION
In a recent study, Chu and Chen (2004), using a subset of stations with the longest records, showed that a change toward drier conditions in the past couple of decades had taken place in the Hawaiian Islands. This extended dry episode appeared to have been the most severe in approximately the last 100 years. The purpose of this study is to develop a comprehensive Hawaiian Islands precipitation data set, in order to evaluate trends in the data and to develop some understanding of the mechanisms leading to the observed changes.

2. DATA AND METHODS
Serially complete monthly rainfall totals for the 50-yr period 1951–2000 were obtained (principally from the National Climatic Data Center) for all stations across the Hawaiian Islands. The distribution of the 132 stations is shown in Figure 1 (top panel), which indicates a reasonably even distribution among the four major islands (Hawaii, N=27; Maui, N=46; Oahu, N=25; Kauai, N=34). Period-of-record values since 1920 were used to analyze rainfall changes over the Islands relative to a 1951–2000 climatology.

Cluster analysis is used to identify the main seasonal rainfall regimes of each island separately as well as important features of the inter-annual variability. Before clustering, principal components of the rainfall data were computed based on the correlation matrices for all stations for each of the four islands. Here, the variables are the monthly rainfall totals and the cases are the individual stations. Clustering was performed using an agglomerative hierarchical approach and Ward's minimum variance method (Anderberg, 1973). Other linkage methods were tried, but did not give optimal results. The clustering was accomplished using Euclidean distances calculated from the standardized principal component scores and retaining the first two components. Monthly mean rainfall within each cluster is then examined to ensure the reasonableness and validity of the station groupings. Sixteen regions are thus defined among the four major Hawaiian Islands and are shown in Figure 1 (bottom panel).

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In order to derive area weighted island-wide averages, topographic data was utilized with the above results to help us assign climate division boundaries. Sixteen regions were defined for the State of Hawaii (Figure 1, bottom panel), with the divisional area and fractional area weights used to compute island- and state-wide precipitation averages.

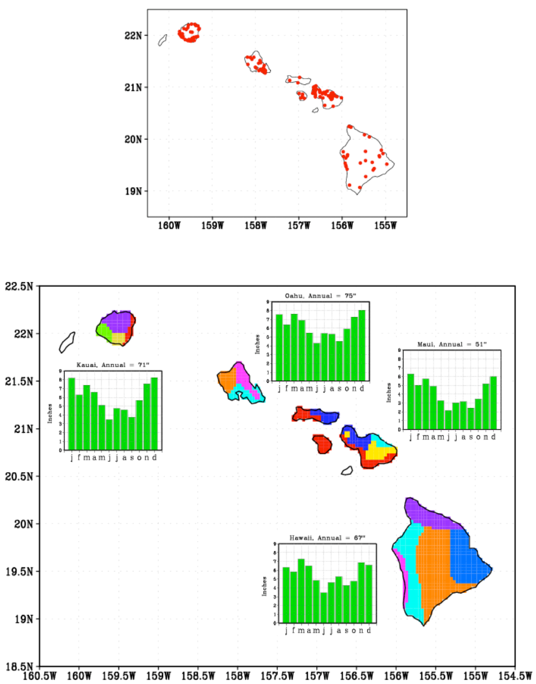

Figure 1. Distribution of the 132 climate stations in Hawaii used here (top panel) and of the 16 climate regions identified in this study (bottom, colored-in areas). For each of the 4 major islands, the seasonal cycle of precipitation is also included.

We have used NCEP/NCAR Reanalysis data to look at changes in the Hadley circulation over the Pacific sector encompassing Hawaii, to determine if changes in the zonally-averaged Hadley circulation, as documented by Quan et al. (2004) have contributed to the observed drying trends.

3. RESULTS

A precipitation series for the State of Hawaii and each of the major islands has been developed at monthly resolution. The behavior of precipitation for the cool months November–April, when most of the precipitation falls, for May–October and the calendar year totals is depicted in Figure 2. A decline in precipitation is evident in the last 15 years or so, amounting to about a 15% decline from the long-term mean, and roughly a 25% reduction from the relatively high values prevalent in the previous 15 years.

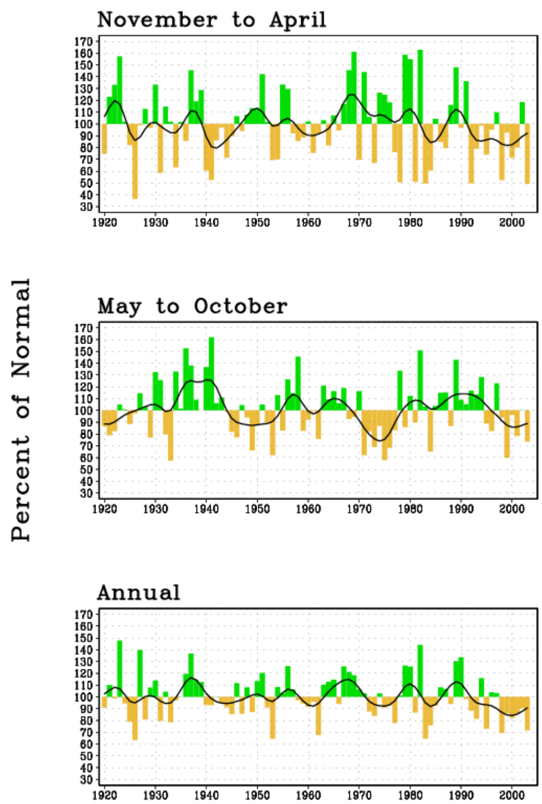

Figure 2. Precipitation time series (1920–2003) averaged over the Hawaiian Islands (in inches). Values are in percent departures from a 1951–2000 mean.

We wondered whether decadal SST and rainfall changes that have occurred in the Indo-Pacific Ocean in the past several decades may be a cause of the observed decline in precipitation over Hawaii. Using the NCEP/NCAR Reanalysis data, we calculated the change in the meridional overturning circulation (the Hadley Cell) over the Pacific sector encompassing the Hawaiian Islands during the period of reduced Island precipitation. The results illustrated in Figure 3 do suggest that changes in the Hadley circulation, apparent throughout the year at the latitude of Hawaii may be associated with the observed drying trend.

4. CONCLUDING REMARKS

A rainfall index for the State of Hawaii has been assembled based on 132 station records, which are serially complete from 1951 to present. Rainfall is shown to have declined in the Hawaiian Islands over the past 15–20 years. The large scale circulation patterns over the Pacific suggest that anomalous sinking motion related to changes in the Hadley circulation is at least partly responsible for this drying trend.

5. REFERENCES

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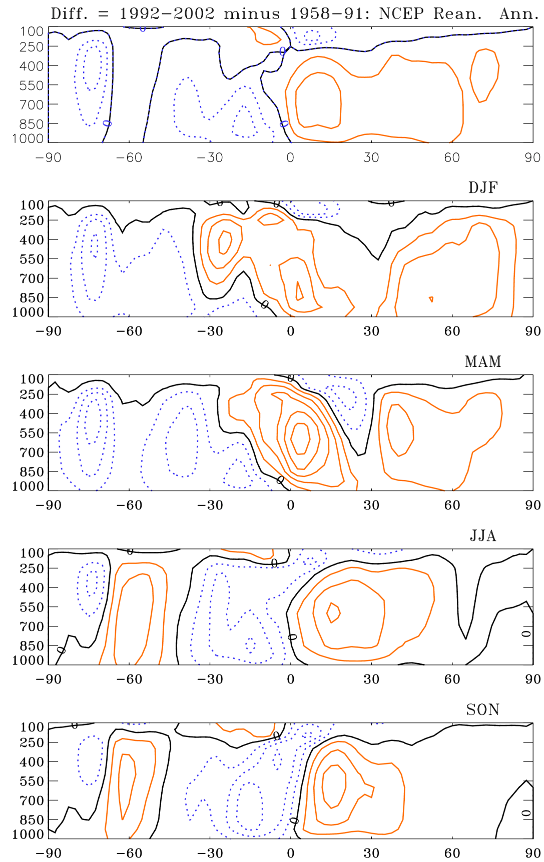

Figure 3. Difference in zonally-averaged mass streamfunction (1992–2002) minus (1958–1991) for the Pacific sector 140˚E–140˚W. Red contours imply stronger clockwise circulation in the meridional plane. Graph indicates enhanced sinking motion in the latitudes of the Hawaiian Islands.