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FIRE-CLIMATE RELATIONSHIPS AND LONG-LEAD SEASONAL WILDFIRE PREDICTION FOR HAWAII

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1. Introduction

Wildfires have inflicted major damage to life and property in the Hawaiian Islands and posed a great ecological threat to numerous flora and fauna found nowhere else in the world. In recent years, the total acres burned (TAB) in Hawaii have increased as a result of increased population density and climate variations associated with strong and recurrent El Niño events. These damages could be reduced with accurate long-lead prediction provided to wildfire control agencies. This study investigates relationships between fire activity and short-term climate variations, in order to estimate fire potential for long-range fire planning and management.

In the Hawaiian Islands, the climate variation and fire behavior in response to El Niño are different from those in other states of the USA. Drought or deficiency of rainfall occurs frequently from winter to spring in the year following an El Niño (Chu 1995), possibly promoting favorable conditions for wildfire occurrence. This study explores the relationship between ENSO and wildfire activities in the Hawaiian Islands. A simple statistical fire-climate model is developed to test feasibility of long-lead seasonal fire prediction.

2. DATA

The Hawaii Department of Land and Natural Resources, Division of Forestry and Wildlife, supplied wildfire records for the islands of Hawaii, Maui, Oahu, and Kauai for the period July 1976 to December 1997. From these, we tabulated monthly and seasonal TAB by island. The Southern Oscillation Index (SOI) is used to represent ENSO activity and large-scale climate variation. The monthly SOI data from 1976 to 1997 are obtained from the NOAA/NCEP.

3. BACKGROUD CLIMATE AND VARIATIONS OF TAB

3.1 Background climate and annual cycle of TAB

The annual cycle of rainfall and temperature in Hawaii is broadly characterized by two seasons: summer, which extends approximately from May to October, and winter, from November to April. Summer is a dry and warm season with persistent northeasterly trade winds from the sea. During the cooler and rainy winter season, trade winds are often interrupted by mid-latitude frontal rainband systems and kona storms (Ramage, 1962; Chu et al., 1993).

The warmer and drier weather in summer naturally increases the potential for fire occurrence. Consequently, TAB in the four islands is expected to be high during the summer months. Indeed, the peak month of TAB for Maui and Oahu is June, while the peak for Kauai and Hawaii occurs in September (Fig. 1).

From October to January, TAB generally decreases, probably because more rainfall occurs during these four months. The larger value of TAB in February (April) for Hawaii (Maui) might be related to the increase in human outdoor activities, such as hiking and camping during these months.

3.2 Fire Activity during ENSO Cycle

A composite of the seasonal standardized anomaly of TAB on Oahu during four El Niño events (1976-77, 1982-83, 1986-87, 1991-92) is shown in Fig.2. The original, three-consecutive-months TAB data are summed to produce a seasonal value. The year in which El Niño occurred is denoted as Yr (0), while the following year is Yr (+1). The composite shows that TAB from fall (September, October, and November) of Yr (0) to fall of Yr (+1) is positive, suggesting that TAB increases after an El Niño event. The only negative value appears in the summer of Yr (0). From winter to summer of Yr (+1), TAB dramatically peaks in response to a prolonged dry climate associated with El Niño event. Usually, El Niño-related drought in Hawaii occurs in winter and spring of Yr (+1) (Chu, 1995). Apparently, TAB follows the El Niño-rainfall cycle with a lag of one season (Fig. 2). The above results suggest that the El Niño effect on wildfire is persistent, lasting for at least six months, and is likely to cause a large TAB event in the following spring and summer. This ENSO-fire relationship implies a potential for long-lead fir forecasting using a statistical model.

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4. LONG-LEAD PREDICTION MODEL

Logistic regression is used to model and predict the conditional probability, *y*, of an event, given that the odds ratio of the event to the non-event is log-linear in a set of independent variables, $\{x_i\}$ (Sharma, 1995):

$$y = \frac{1}{1 + \exp(-(\beta_0 + \sum_{1}^{n} \beta_i x_i))}$$

In this study, we defined *y* as the probability of a large TAB event and modeled the log odds by a simple linear equation. Regression parameters are fitted by a nonlinear equation. The dependent variable of each datum consisted of a binary number, either a one for a large TAB event in the season targeted for prediction or a zero for a TAB event not classified as large. Specifically, an observation is classified as an event if a TAB value exceeds a specified threshold value; otherwise it is classified as a non-event. We used three different thresholds prior to the analysis, corresponding to the 50th, 75th and 90th percentiles of seasonal TAB.

In testing prediction skill, cross validation is used. Table 1 shows the number of observed and predicted events and non-events, sensitivity, specificity, and overall correctness for the median, upper quartile and the 90th percentile criterion for Oahu. Sensitivity, specificity and correctness are three measures for prediction accuracy. Sensitivity is a ratio of the total number of correctly classified events to the total number of events, while specificity is a ratio of the total number of correctly classified non-events to the total number of non-events. Correctness simply gives the probability that the model correctly classified the sample data for each criterion.

The forecast with the upper quartile has the highest correctness (86.4%) and sensitivity (83.3%). For the six observed events, five events are correctly classified and fourteen out of sixteen non-events are also correctly forecasted two seasons in advance using the cross validation method. The logistic model performs reasonably well with the criteria of the median and the 90th percentile; the correctness reaches 68.2% and 72.7%, respectively.

5. Summary and discussion

The statistics of wildfires reveal that most fires and largest total acreage burned occur in summer. The ENSO composite chart (Fig. 2) indicates that positive TAB events on Oahu tend to occur from fall of an El Niño year to fall in the year following an El Niño event (extending over 5 seasons), with the largest anomalies occurring in spring and summer Yr (+1). Typically, when an El Niño event occurs, the local Hadley cell in the central Pacific becomes more vigorous. Hawaii is located in the subsiding branch of this cell, while the rising branch is found in the central and eastern equatorial Pacific. Consequently, this enhanced subsidence retards formation of rain-producing systems (e.g. frontal rain-band and kona storm) in Hawaii and provides Hawaii with a large potential for wildfires.

Since the fire forecast users are concerned more about abnormally large fire activities, the summer TAB data are classified in a binary format, representing large and not-large events according to three criteria, the median, 75th and 90th percentiles. Prediction skill is measured in terms of the sensitivity, specificity, and correctness. For the island of Oahu, five out of six events are correctly forecasted two seasons in advance. It is more difficult to predict non-events, with the exception of Oahu. As a result, this difficulty degrades the overall correctness sharply. It should be reminded that the model used in this study only involves one predictor, the SOI that remotely affects Hawaii's climate variability. At present, local fire-sensitive data such as the Keetch/Byram drought index (KBDI), which considers daily maximum temperature and rainfall, and the drought condition of yesterday should be included as additional predictors. This index has been used operationally by fire agencies in the contiguous United States to monitor fire potential. Currently, we are testing the potential of improvements in fire seasonal prediction when the KBDI is included in the model.

Acknowledgments

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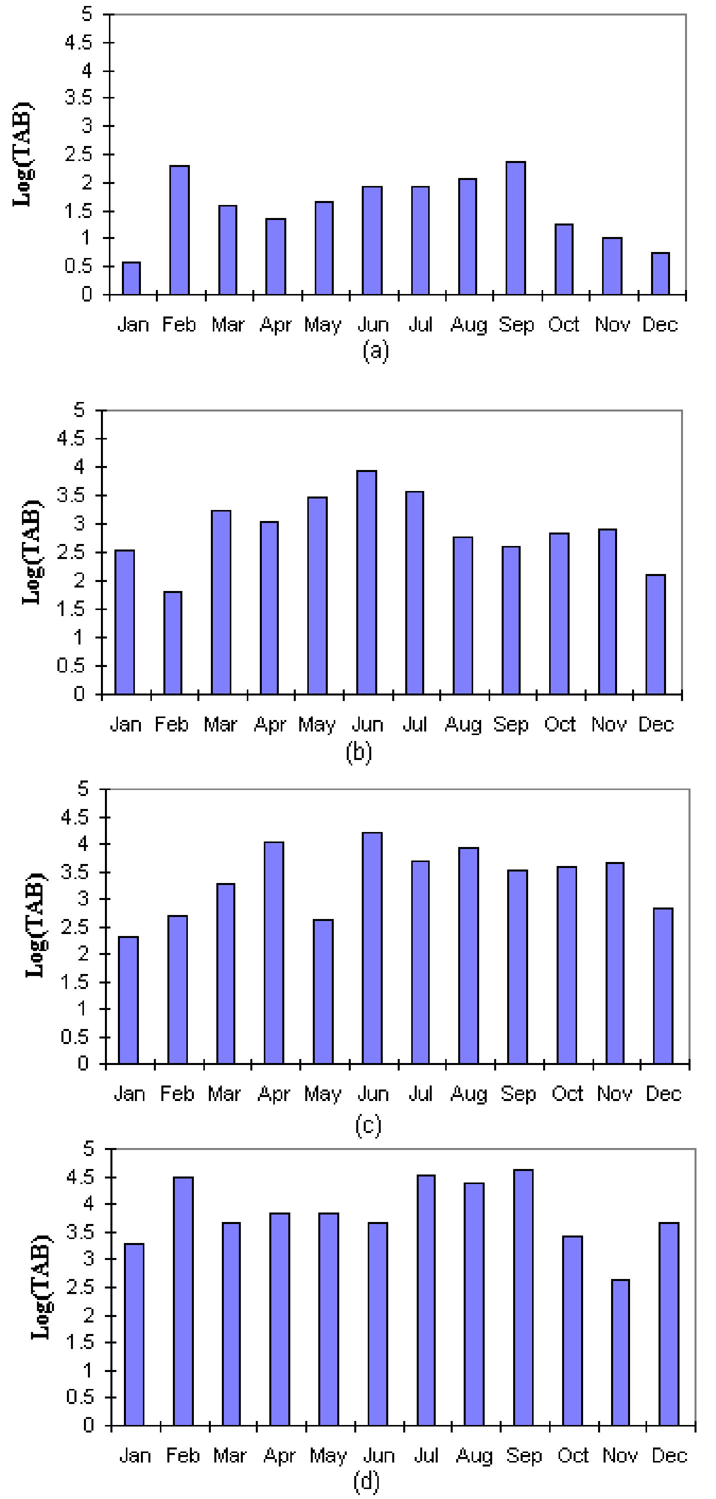

Fig1. Monthly mean Total Acres Burned (TAB) for a) Kauai, b) Oahu, c) Maui and d) Hawaii.

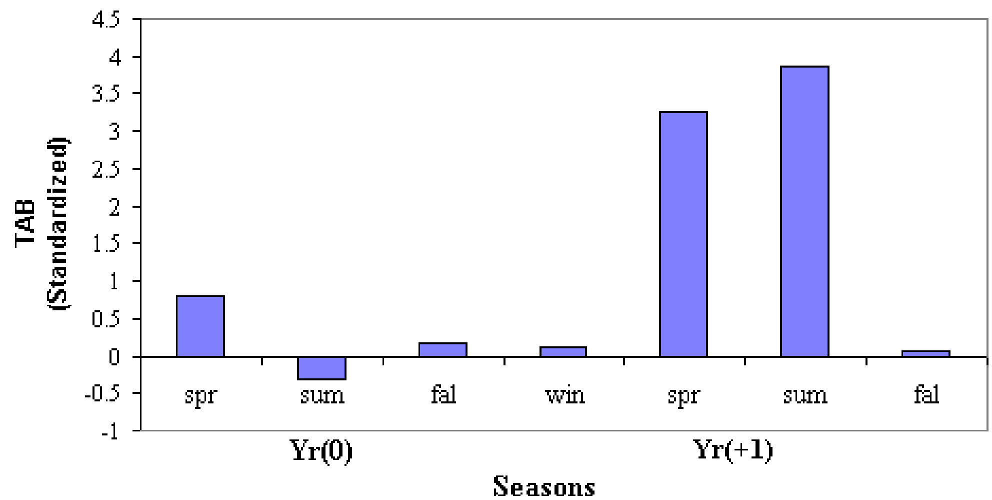

Fig2. Seasonal composite total acres burned for Oahu during the four ENSO events (1976-77, 1982-83, 1986-87, 1991-92).

	Observed Event	Correctly Classified Event	Observed Non-event	Correctly Classified Non-Event	Sensitivity %	Specificity %	Correctness %
Median 98.5	11	6	11	9	54.5	81.8	68.2
Q75 1025	6	5	16	14	83.3	87.5	86.4
Q90 2200	3	2	19	14	66.7	73.7	72.7

Table 1. Logistic classification table for the summer TAB prediction for Oahu using SOI of the preceding winter as predictor. (Q75 and Q95 are the same as Table 3). Various cutoff values for summer TAB (acres) are also indicated in the first column.