EXAMINING THE RELATIONSHIP BETWEEN SNOWFALL AND WILDFIRE PATTERNS IN THE WESTERN UNITED STATES

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Abstract: Spatial and temporal patterns of snowfall influence future moisture availability, plant growth, and soil moisture. Therefore winter and spring snowfall may influence summer wildfire patterns. We conducted an examination of the spatial and temporal relationships and correlations between snowcover and wildfire from 1986 through 1996 in the 11 western states of the United States. Snow-cover and wildfire data were aggregated and normalized for each state, as well as fothe entire western region. Mean annual snow-cover and wildfire extent values were detemined for each geographic unit, and Z-score values were produced indicating departure from the mean for each year. For each of the 11 states and the region, as a whole, graphswere produced illustrating the relationships between snow-cover and wildfire patterns. No strong correlation was found for the entire western United States, nor did state aggregatins show signs of consistent yearly correlation between measures of snow cover and wildfire. Nevertheless, a few states experienced above-average acreage burned totals following winters with above-average snow cover. [Key words: snow cover, wildfire, western United States.]

INTRODUCTION

In many regions of the United States, wildland firefighters take note of snow cover during the winter, perhaps only measured in good ski days. Nevertheless, winter snow pack, and length of snow season are often considered good general indicators of the severity of the upcoming fire season. In this study we provide an initial investigation of this firefighter folk wisdom.

Climate can clearly influence wildfire. Many researchers have examined and identified specific relationships between climate variables and wildfire. Some of these studies have identified individual climatic variables to search for specific indicators of expected fire behavior (Bessie and Johnson, 1995; Byram, 1954; Flannigan and Harrington, 1988; Johnson et al., 1990; Kitzberger et al., 1997; Schaefer, 1957; Schroeder and Glovinsky, 1964). Others have attempted to examine the relation-

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ships between complex phenomena, such as El Niño–Southern Oscillation (ENSO), and fire behavior in specific regions (Simard et al., 1985; Swetnam and Betancourt, 1990, 1998).

In the research presented here, we examine the relationship between the spatial and temporal extent of snow cover and the acreage of land burned by wildfires in the succeeding fire season. This relationship is examined for the entire western United States as well as individually for each of the 11 western states.

Snow-cover and wildfire acreage data are aggregated and normalized for each state, as well as for the entire western region. Mean snow-cover and wildfire acreage values are determined for each geographic unit and Z-score values are produced indicating departure from the mean for each year. For each of the 11 states and the entire region we produce graphs to illustrate the relationships between snow-cover and wildfire patterns. No strong correlation is demonstrated for the entire western United States, nor do state aggregations show signs of consistent yearly correlations between snow cover and wildfire. Nevertheless, a few states experienced above-average acreage burned totals following winters with above-average snow cover, and visual examination of the graphs suggests that other statistical tools and examinations of lagging relationships may find interesting relationships between snow cover and wildfire.

BACKGROUND

Our underlying question is "does winter snow cover determine acreage burned in the following fire season?" For almost a century other researchers have been hypothesizing and researching similar climatic determinants of wildfire. For example, in 1916, S. B. Show published "Climate and forest fires in Northern California," in which he acknowledges fire behavior's relationship to weather (Show, 1919). According to Stephen Pyne, after Show's publication, H. T. Gisborne began using climate data that had been gathered over a 10-year period to investigate the physical factors that could aid in the prediction of severe fire danger (Pyne, 1982). Later in 1954, Byram's "Atmospheric conditions related to blow-up fires" and Schroeder and Glovinsky's "Synoptic weather types associated with critical fire" were published (Byram, 1954; Schroeder and Glovinsky, 1964). In 1957, Schaefer published a study linking jet streams and forest fires (Schaefer, 1957). These and other studies helped to determine the most important weather variables associated with area burned (Flannigan et al., 1988). By the early 1970s, a more complete understanding of the importance of climatic factors led to the specific climatological components of Deeming's National Fire Danger Rating System (Deeming et al., 1974).

In the last 20 years, many studies have linked wildfire to the weather patterns, at several scales, associated with ENSO (Harrington et al., 1992; Simard et al., 1985; Swetnam and Betancourt, 1997). As such links are uncovered and more closely examined, and we improve our understanding of ENSO, we may be better able to predict future wildfire behavior.

Though ENSO may influence many components of weather and climate, the study presented here examines the specific relationship between only snow cover and wildfire. Snow cover was chosen as it is clearly observable from space and

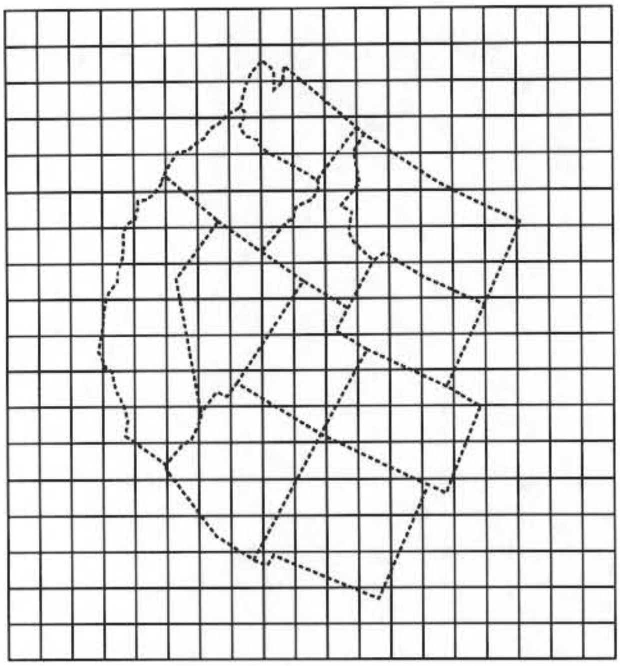

Fig. 1. A portion of the 89-by-89-cell Northern Hemisphere grid. The grid cells containingat least 50% land were used to gather snow-cover data for each of the 11 western states.

multi-year snow-cover data are available. Additionally, both spatial and temporal extent of snow cover directly synthesize and indicate climatic variables such as temperature and precipitation, while snow cover is also implicit in affecting wildfire behavior through its influences on factors such as moister availability and growing season.

METHOD

NOAA meteorologists produced weekly maps of snow extent across Northern Hemisphere lands from a visual interpretation of photographic copies of visible-band satellite imagery. Imagery from the Very High Resolution Radiometer (VHRR: launched in 1972, with a spatial resolution of 1.0 km), and after October 1978 the Advanced VHRR (1.1 km resolution) provided much of the information for the weekly mapping. Imagery from geostationary satellites was also utilized. Imagery was examined daily, and maps depict snow boundaries on the last day of the map week that a region was cloud free. The weekly maps were digitized to the National Meteorological Center Limited-Area Fine Mesh grid. This is an 89 x 89 cell Cartesian grid laid over a polar stereographic projection of the Northern Hemisphere. Cell resolution ranges from 16,000 to 42,000 km^2. Each grid cell in the digitized product has a binary value. Cells with at least 50% of their surface covered with snow were considered snow covered. All other cells were considered snow free (see Robinson, 1993, 2000, for additional information).

To retrieve snow extent for the project period, text files identifying the spatial extent and temporal time frame were entered into the database and the necessary tabular information was extracted and entered into a project spreadsheet. This information consisted of snow cover measured in square kilometers for all weeks within each study year. Figure 1 shows the western United States and the overlaying grid used to collect and record snow-cover data.

Though the snow-cover information dated back to 1966, the U.S. Forest Service digital dataset was limited to the years from 1986 through 1996, and thus determined the time frame of this study. Fire data were acquired from a website published by the Fire Sciences Laboratory at the Rocky Mountain Research Station in Missoula, Montana. The information was in the form of ArcView GIS shapefiles, and consisted of data points representing each individual fire occurrence. Each fire occurrence point had associated attribute information including state, the date of the fire, agency recording the data, as well as acreage burned. These records were extracted for each of the 11 western states and transferred into the project spreadsheet.

Each relevant snow-cover grid cell was assigned to 1 of the 11 western states. Grid cells that occupied several states were assigned to a state using a majority rule. This provided an approximation of weekly snow cover for each state for the study period, enabling the snow-cover data to be directly linked by state to the wildfire data.

Weekly snow-cover area totals were summed for each state for each winter. For the purpose of this study, winter was defined as the period of recorded snow cover extending from earliest fall snow cover to latest spring or early summer snow cover. Therefore, winter length varied from year to year. For each year of the study, each state had a unique single value for total acre-weeks of snow. These values could then be directly compared to the wildfire acreage values for each state for each year.

To facilitate this direct comparison, mean snow-cover and wildfire acreage values were determined for each state, and Z-score values were produced indicating departure from these means for each year. In this way departure from the mean wildfire acreage can be directly compared to departure from the mean snow cover for each year measured in standard deviations departed from the mean. Graphs were produced for each of the states as well as for the entire region (Fig. 2). These graphs allow for intuitive comparison of winter snow cover and acreage burned in the following fire season. A final scatter plot was produced showing a single point indicating departure from the snow-cover and fire acreage means each point for each state for each year (Fig. 3).

For each graph, an R^2 value was also produced. For the individual states these values range from a high .49 for Utah to a low of .002 for Oregon. For the region as a whole the R^2 value is .12.

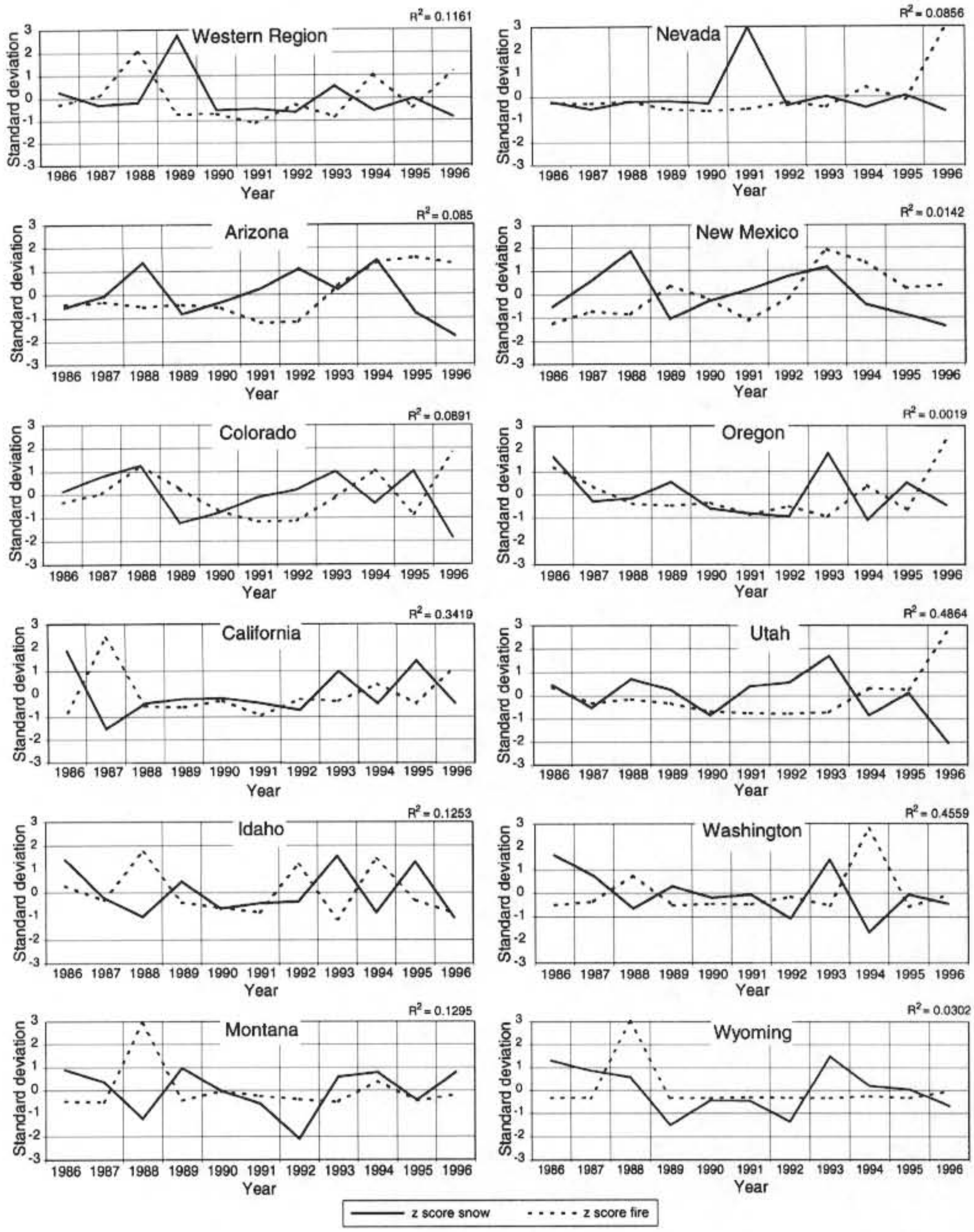

Fig. 2. The first graph shows the departure from men for both snow-cover and wildfire acreage for the entire western United States. The remaiing graphs portray the 11 western states.

DISCUSSION

No strong correlation is demonstrated between fire acreage and snow cover for the entire western United States (R^2 = .12). None of the states shows a correlation

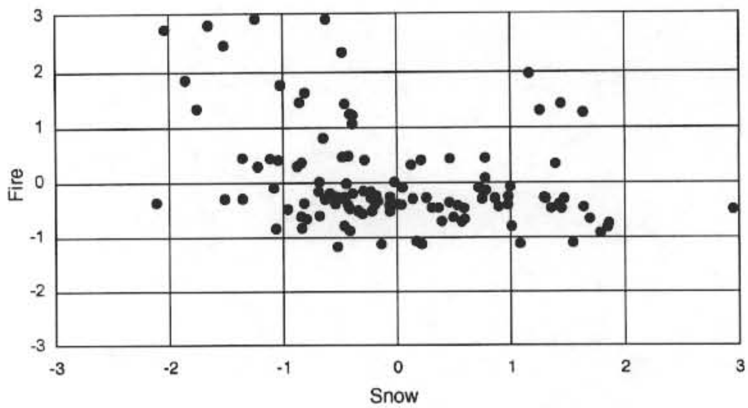

Fig. 3. Scatterplot of Z-scores for westen region. Each point represents a single state for a single year. Note that less than 10% of these points occur with above average snowfall and above average wildfire acreage.

with an R^2 value over .50, with most states demonstrating correlations lower than that. Nevertheless, examination of the scatter plot in Figure 3 shows that only 11 times out of 121 cases did any state experience above average acreage burned totals following winters with above average snow cover. However, the results show only moderate support for the thesis that light snow years may precede severe wildfire seasons.

Visual examination of the graphs suggests that other statistical tools and examinations of lagging relationships may find more significant relationships between snow cover and wildfire. However, any further research into these relationships would greatly profit from improving the spatial and temporal attributes of the data used. For example, this work could be greatly improved with a much longer study period and much higher resolution snow-cover data. As the area of each grid cell was a function of the latitude onto which it was projected, the grid cell used here ranges from 16,000 km^2 to 42,000 km^2. Furthermore, shortcomings of the use of satellite imagery to detect snow cover include the inability to distinguish snow cover from clouds is some cases as well as the incapacity to determine coverage under cloudy conditions, the inability to determine snow coverage under dense forest canopy, and uncertainties in the recognition and delineation of irregular snow cover. In addition, visible satellite data only provide information on snow extent; there is as of yet no means of extracting accurate information on snow water equivalent from satellite sensors. Future research could be improved by examining snow water equivalent from the North American SNOTEL network.

The arbitrary political boundaries of states are also obviously inappropriate for demarking areas with similar wildfire response to snow cover. Perhaps even more important, further research should use snow-cover data with high enough resolution to stratify snow cover by elevation, or better yet link fires to the snow cover at the actual site of each fire. The fire data could also be used much more effectively by separating different types of fire. For example, in some states wildfire acreage numbers may include a large percentage of low elevation grassland fire, while other states may primarily record higher elevation forest fire.

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