CLIMATE VARIABILITY AND SNOW PACK IN THE SIERRA NEVADA

by

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ABSTRACT

An important part of the water supply in California and the western United States is derived from runoff fed by mountain snow melt. Snow accumulation responds to both precipitation and temperature variations, and forms an interesting climatic index, since it integrates these influences over the entire late fall-spring period. The study area includes the Sierra Nevada, which accumulates most of the snow pack and comprises a major portion of the water-bearing region of California. The purpose of this study is to shed light upon the link between climate and year-to-year variability in the snow pack. Specifically, we wanted to determine *(a)* the dependence of snow pack and streamflow upon natural climate variability, and *(b)* if the relationships linking snow and streamflow to climate variations are stable over the history of instrumental records by using pre-1948 historical records to test the results from 1948-present. The basis of the study will be several long series of historical observations containing observed variability over daily-to-seasonal time scales. Our focus is on measurements on/around April 1, when snow accumulation is typically greatest. The primary data is from a network of mountainous snow courses; many have records of six decades or more. For any given year, the spring snow water equivalent (SWE) anomaly at a particular snow course is likely to be 25-60% of its long-term average. Although effects vary with region and with elevation, in general, the anomalous winter precipitation has the strongest influence on spring SWE fluctuations. Anomalous temperature has a weaker effect overall, but it has great influence in lower elevations such as in the coastal Northwest, and during spring in higher elevations. Patterns of the precipitation, temperature, and snow anomalies extend over broad regional areas, much larger than individual watersheds. These surface anomalies are organized by the atmospheric circulation, with primary anomaly centers over the North Pacific Ocean as well as over western North America. For most of the regions, anomalously low SWE is associated with a winter circulation resembling the PNA pattern. With a strong low in the central North Pacific and high pressure over the Pacific Northwest, this pattern diverts North Pacific storms northward, away from the region. Both warm and cool phases of ENSO tend to produce regional patterns with out-of-phase SWE anomalies in the Northwest and the Southwest.

PROBLEM AND RESEARCH OBJECTIVES

In the Western United States snow pack has been measured routinely for several decades in order to gage the water supply, but there have been few studies of its link to climate variability. Snow pack is an important feature of the surface hydrology in California since it serves as a natural storage device for the water supply. Snow pack accumulates in the cool, stormy, wet season and melts in the warm season when seasonal human water consumption begins. The amount of snow that accumulates depends upon winter precipitation and, to some extent, air temperature. The problem we addressed is that there is great year-to-year variability in the snow pack. There is also concern that global climate warming will reduce the average snow pack in mountain watersheds such as those in the California Sierra Nevada.

The study area is the Western United States, particularly the Sierra Nevada, where most of the snow pack accumulates and which makes up the major water-bearing region of the state. The study served to determine the dependence of snow pack and streamflow upon natural climate variability, and to determine if the relationships linking snow and streamflow to climate variations are stable over the history of instrumental records. To address the latter issue, pre-1948 historical records were used to test the results from 1948 to the present. The study was based upon several long series of historical observations over daily-to-seasonal time scales.

(7) 1993 Climate Diagnostics Workshop and the January 1994 Climate Variations Conference of the American Meteorological Society Annual Meeting;
(8) May 1994 University of California Water Resources Center Coordinating Board and Advisory Committee;
(9) April 1994 United States Geological Society Western Region Management Conference;
(10) June 1994 San Francisco Bay Session of the AAAS Pacific Division Meeting; and
(11) May 1995 PACLIM Workshop, Asilomar.

Aspects of this work were also presented in a number of written articles, listed below.

PUBLICATIONS

Aguado, E., D. Cayan, L. Riddle, and M. Roos, 1992: Climatic Fluctuations and the Timing of West Coast Streamflow. *J. of Clim.*, **5**, 1468-1483.

Aguado, E., D. Cayan, B. Reece, and L. Riddle, 1993: Patterns of orographic uplift in the Sierra Nevada and their relationship to upper-level atmospheric circulation. *Proceedings of the Ninth Annual Pacific Climate (PACLIM) Workshop, Asilomar, California, April 21-24, 1992,* K. T. Redmond and V. L. Tharp, (eds.), 153-164.

Cayan, D. R., L. G. Riddle, D. C. Garen and E. Aguado, 1993: Winter climate variability and snowpack in the west. *Proceedings of the Eighth Annual Pacific Climate (PACLIM) Workshop, Asilomar, California, March 10-13, 1991,* K. T. Redmond (ed).

Cayan, D., and L. Riddle, 1992: Atmospheric circulation and precipitation in the Sierra Nevada. *AWRA 28th Annual Conference & Symposium, Reno, NV, November 1-5, 1992,* R. Herrmann, (ed.).

Cayan, D. R., and L. G. Riddle, 1993: A multi-basin seasonal streamflow model for the Sierra Nevada. *Proceedings of the Ninth Annual Pacific Climate (PACLIM) Workshop, Asilomar, California, April 21-24, 1992,* K. T. Redmond and V. L. Tharp (eds.), 141-152.

Cayan, D. R., and D. H. Peterson, 1993: Spring Climate and Salinity in the San Francisco Bay Estuary. *Water Resources Research*, **29**, 293-303.

Cayan, D. R. Cayan, Riddle, L. G., and E. Aguado, 1993: The influence of precipitation and temperature on seasonal streamflow in California. *Water Resources Research*, **29**, 1127-1140.

Cayan, D.R., 1995: Climate variability and snow pack in the western United States. *J. of Clim,* (accepted for publication).

Chen, S.-C. and D.R. Cayan, 1994: Low frequency aspects of the large-scale circulation and West Coast U.S. temperature/precipitation fluctuations in a simplified GCM. *J. of Clim.*, **7**, 1668-1683.

Dettinger, M. D., and D. R. Cayan, 1992: Climate-change scenarios for the Sierra Nevada, California, based on winter atmospheric-circulation patterns. *AWRA 28th Annual Conference & Symposium, Reno, NV, November 1-5, 1992,* R. Herrmann, (ed.), 681-690.

Dettinger, M.D. and D.R. Cayan, 1995: Large-scale atmospheric forcing of recent trends toward early snowmelt runoff in California. *J. of Climate,* **8**, 606-623.

Dettinger, M.D., D.R. Cayan, and D.H. Peterson, 1995: Snowmelt runoff from the Sierra Nevada—why has it come earlier in recent decades? *Interagency Ecological Program Newsletter.* State of California.

Riddle, L., D. Cayan and E. Aguado, 1992: Snow water content as a predictor of streamflow in the Sierra Nevada and coast ranges of California. *AWRA 28th Annual Conference & Symposium, Reno, NV, November 1-5, 1992,* R. Herrmann, (ed.).

Ely, L.L., Y. Enzel, V.R. Baker, and D.R. Cayan, 1993: 5000 year record of extreme paleofloods and associated atmospheric circulation patterns. *Science,* **262**, 410-412.

Ely, L.L., Y. Enzel, and D.R. Cayan, 1994: Anomalous atmospheric circulation and large winter floods in the Southwestern United States. *J. of Climate* , **7**, 977-987.