ELEVATIONAL DIFFERENCES IN SNOWPACK VARIABILITY: A CASE FOR INCREASED MONITORING IN THE OLYMPIC MOUNTAINS

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ABSTRACT

Climate change projections indicate that snowpack could be most affected at mid-elevations due to an increase in rain-on-snow events; these changes at mid-elevations could also be an indicator of potential changes at the higher elevations in the future. For the past three winters, we collected snow and meteorological data from eleven snow courses and six remote mini-meteorological stations in the Dungeness watershed of the Olympic Mountains in western Washington. We compared our mid-elevation snow and weather data with data collected from the Dungeness SNOTEL over the same period. Most of our snowpack data do not correlate well with SNOTEL data, and temperature and relative humidity readings from our stations suggest that there are additional site and elevational differences that suggest that the existing SNOTEL site does not capture the range of variability within the watershed. Our findings indicate that increased permanent monitoring (e.g., by new SNOTEL sites) of snowpack in the Dungeness watershed as well as throughout the rain-on-snow elevation areas of the Pacific Northwest would improve our understanding of potential climate change influences on snowpack at all elevations, improve spatially-explicit snowpack and streamflow modeling efforts, and support improvements in water resources forecasting and management. (KEYWORDS: snowpack variability, climate change, Olympic Mountains, rain on snow, streamflow modeling)

INTRODUCTION

Snowpack is an essential "reservoir" of late summer streamflow in much of the western United States. Climate change could significantly influence seasonal streamflow and water availability, especially in the snowpack-fed watersheds of the Pacific Northwest. Projections indicate that snowpack could be most affected at mid-elevations due to an increase in rain-on-snow events; these changes at mid-elevations could also be an indicator of potential changes at the higher elevations in the future (Mote et al., 2005). To monitor these changes in availability and support the management of over-appropriated water resources, a hydrologic forecasting model was developed for the Dungeness watershed (Wigmosta et al., 2007) in western Washington State (Figure 1). To improve understanding of SWE variability in the mid-elevations (~400-1400 m) and to ground-truth model outputs, we monitored snow and weather data at 11 sites in the Dungeness watershed (Figures 1 and 2) from December 2007 through May 2010.

The Dungeness River originates at an elevation near 2300 m in the high peaks of the Olympic Mountains of Washington state. It is considered the second steepest river in the U.S, falling more than 2000 m to sea level over a length of 50 km. The Dungeness watershed drains an area of approximately 700 km^2 via a mainstem and tributary network of over 500 km. Its position in the rainshadow of the Olympic massif means that annual average precipitation is among the lowest in western Washington (~100 cm/year at the upper end of the watershed; ~40 cm/year at its lower end). The river's mean annual flow at river km 19 is 11 m^3/s (380 cfs), but instantaneous discharge flow can range between 4 and 215 m^3/s (~150-7600 cfs) depending on year and season; highest flows are typically in the winter due to heavier rains as well as rain-on-snow events.

METHODS

Snow samples were collected using standard NRCS snow survey protocols from 11 snow courses (see Kohn et al., 2009 for details). Each course consisted of five sample points spaced approximately 3m apart. Temperature and relative humidity data were collected at six of the sites using remote mini-meteorology stations (Figure 2). We compared SWE by snow course with SWE data from the Dungeness SNOTEL both graphically as well as through correlation analysis. We also compared mean daily temperature data between the snow courses and with the Dungeness SNOTEL data and relative humidity data between snow courses.

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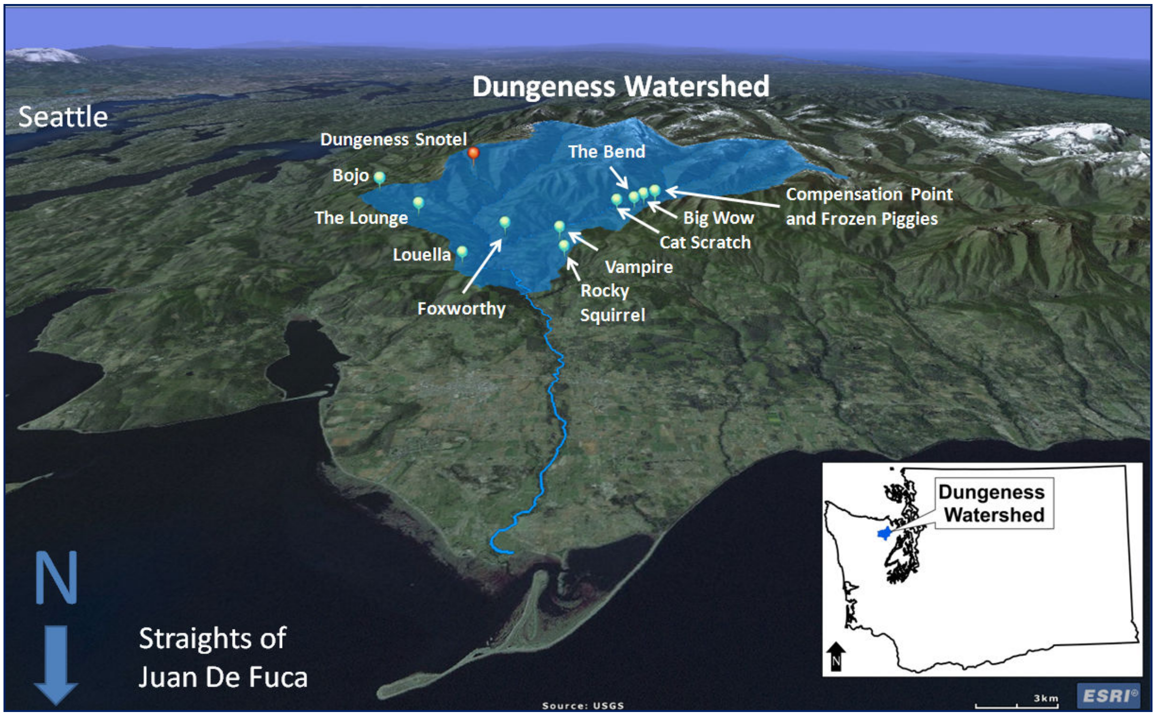

Figure 1. Dungeness Watershed, snow courses, and Dungeness SNOTEL, viewed looking South.

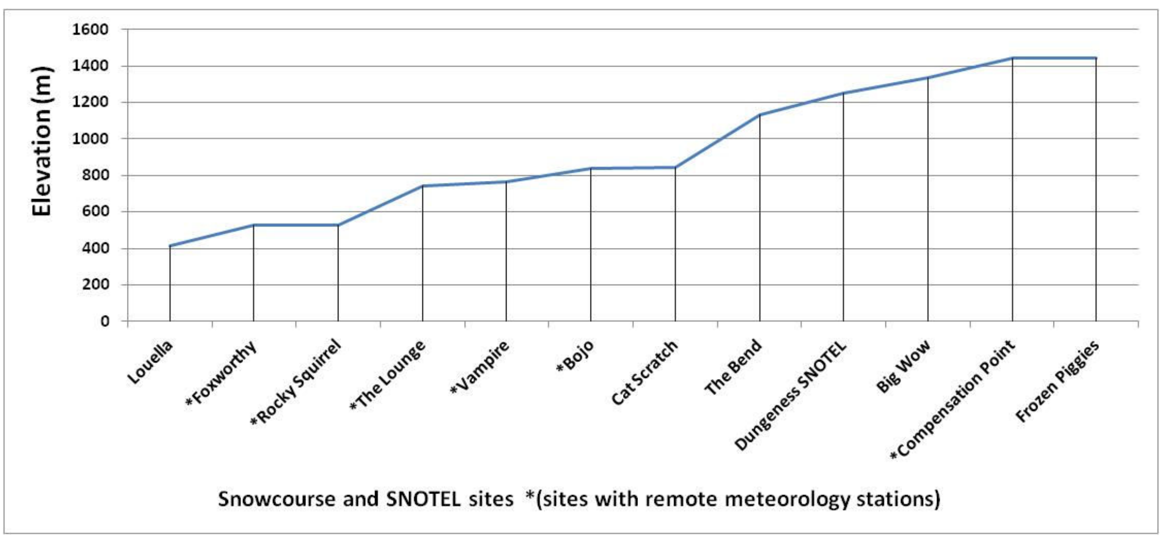

Figure 2. Elevational profile of snow courses, mini-meteorological stations, and Dungeness SNOTEL

RESULTS

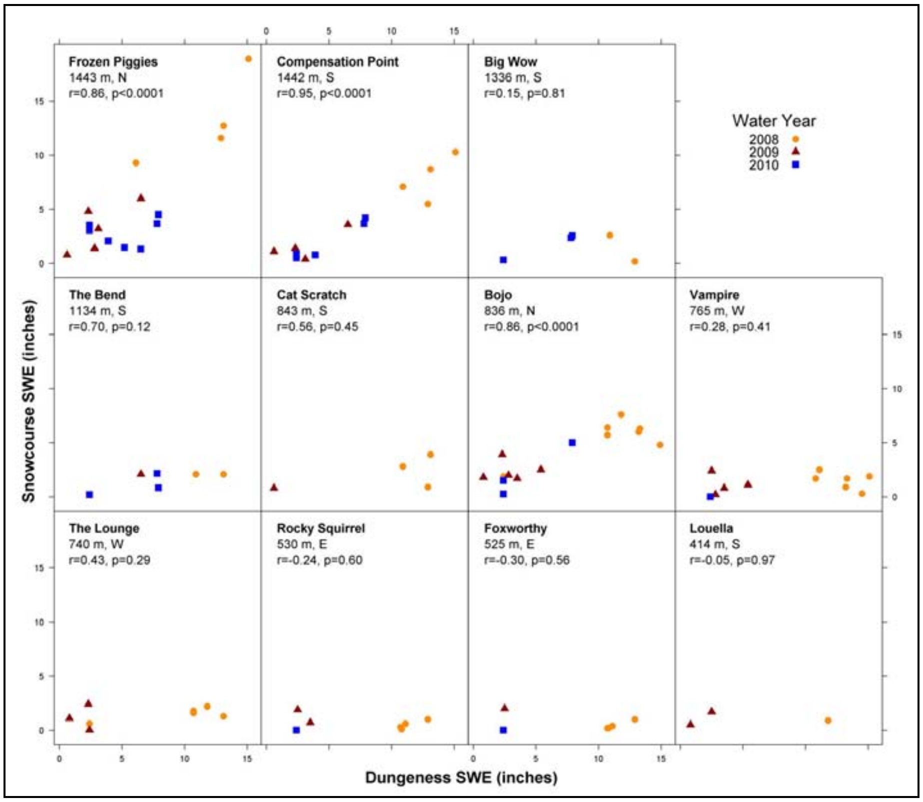

Figure 3. Comparison of snow course SWE with Dungeness SNOTEL SWE by water year. Elevation and aspect are labeled below snow course names.

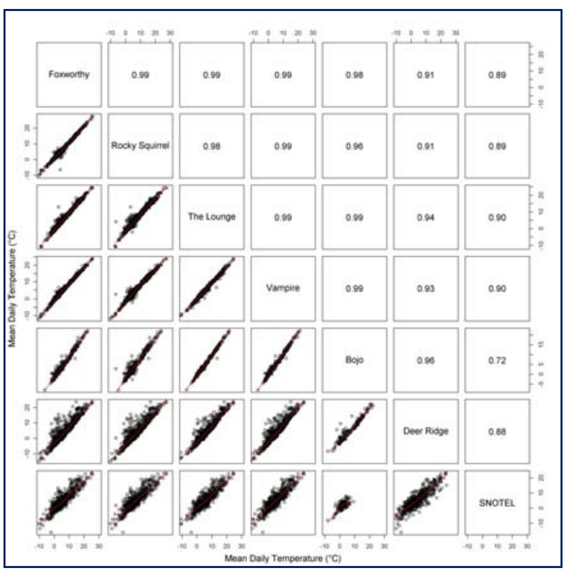

Figure 4. Comparison of Mean Daily Temperature between snow courses and with the Dungeness SNOTEL. Correlation coefficients appear above the diagonal.

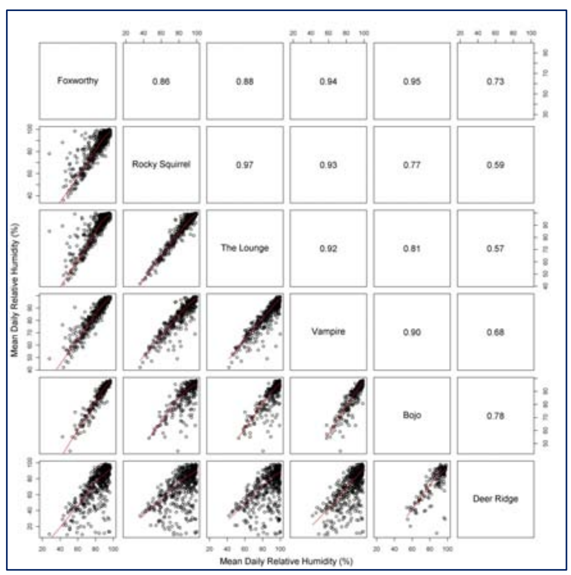

Figure 5. Comparison of mean daily relative humidity between snow courses. Correlation coefficients appear above the diagonal.

CONCLUSIONS

Our initial conclusions are based on the data spread and correlation coefficients. These results suggest that while temperature lapse rate could be modeled successfully in the Dungeness given existing weather stations (Figure 4), moisture regimes are far more variable (Figures 3 and 5). This variability, combined with the rugged terrain and difficult access, supports the need for increased precipitation and SWE monitoring in the mid-elevations of the Dungeness Watershed. Additional mid-elevation SNOTEL stations could greatly improve hydrologic modeling here specifically and in the Western U.S. in general, particularly in areas with frequent rain-on-snow events (McCabe et al., 2007).

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