DIAGNOSIS OF PRECIPITATION IN MOUNTAINOUS TERRAIN[1]

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Abstract.--Winter quantitative precipitation forecasts for the mountains of western Washington are important to several industries, including transportation and recreation, but the variation in orographic precipitation makes site-specific quantitative forecasting difficult. A study is presently being conducted to analyze precipitation patterns associated with large scale wind directions in western Washington. This paper outlines the methods used in the study and explores in detail the rain shadow effect from the Olympic Mountains and from Mount Rainier. An analysis of this effect must account for wind direction, local terrain influences and overall synoptic conditions.

INTRODUCTION

The variation in precipitation in the mountains of western Washington presents an interesting problem for professionals responsible for mountain weather and avalanche forecasts, and for those who must apply site-specific precipitation forecasts to a ski area, highway, or backcountry region. At present, the quantity of precipitation forecast for a given location in western Washington is based solely on the experience of the forecaster in estimating the amount of precipitation that a synoptic event will produce. The ultimate objective of this project is to improve orographic precipitation forecasts by developing a model based on synoptic conditions and windflow patterns. Model results will be compared to precipitation patterns derived from historical precipitation data. This paper will present and analyze two cases of the rainshadow effect verified by empirical precipitation pattern maps and explained by synoptic conditions.

Although theoretical research related to precipitation in Washington State is being conducted, the work does not lead directly to better understanding of site-specific winter precipitation patterns. Much of this research is directed toward solving the microphysics of clouds and precipitation (Hobbs et al,1975; Hobbs,1978), or toward developing a better understanding of wind patterns from which precipitation models may be based (Mass,1981;Overland et al,1979). Schermerhorn(1967) and Rasmussen and Tangborn(1976) conducted practical terrain-related research that increased the understanding of precipitation patterns, but the specific forecast of winter precipitation is beyond their focus.

DATA AND METHODS

General precipitation patterns can be determined by producing a contour map based on historical precipitation data, but a more specific understanding of precipitation related to a given synoptic situation is required. Because the specific quantity of orographic precipitation at any given location is related, at least in part, to the direction and speed of the airflow approaching the mountains, this airflow factor is used to indicate general synoptic conditions. In this study, the

[1] Paper presented at the International Snow Science Workshop, Aspen, Colorado, October 24-27,1984.

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large scale wind is represented by the surface wind along the Pacific coast, since airflow there is relatively unaffected by the complex terrain of the region. Hoquiam, an hourly reporting station on Grays Harbor, has been found to be the most representative coastal wind station. Coincidentally, Hoquiam winds correlate well with the Cascade Pass winds in direction and with the timing of windshifts as surface fronts cross the state(fig. 1), although there is a delay factor involved. This correlation means that upslope precipitation on the east slopes of the Washington Cascades associated with east flow thru the Cascade Passes should be illustrated on the precipitation pattern maps.

Hourly wind records for Hoquiam for the months December, January, February and March from 1977 thru 1981 were grouped into eight wind direction categories. Thruout this paper, the cardinal names will be used to refer to the corresponding numerical wind direction groupings given in table 1. Precipitation pattern maps were produced for each of the eight wind direction groups by calculating hourly precipitation averages corresponding to the hours represented in each wind category.

There are problems with correlating precipitation to surface wind observations. At higher elevations, since the effects of channeling and airflow blocking should decrease, much of the orographic precipitation should be produced by air relatively unaffected by lower elevation terrain. The direction from which this air approaches the mountains may not correspond to that of surface winds at Hoquiam. However, in western Washington, where precipitation forecasting (excepting Paradise on Mount Rainier) is for low elevation sites which are strongly effected by the local terrain, the use of Hoquiam surface wind direction should be satisfactory.

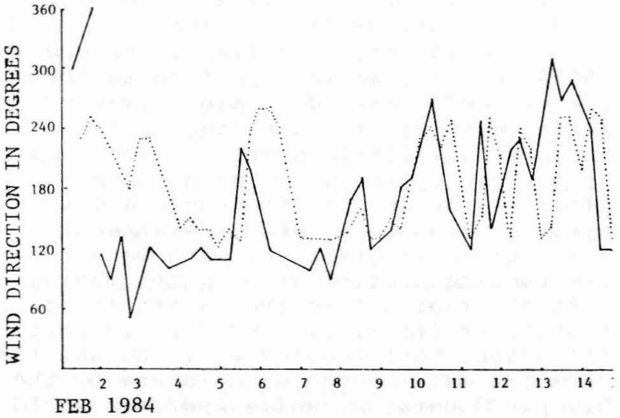


Figure 1.--Time series of wind directions for Hoquiam(——) and Stevens Pass(⋯⋯).

Table 1--Wind direction groupings with numerical categories and equivalent cardinal names given

wind direction (degrees 0-360)	wind direction (cardinal name)
22.5-67.5	NE
67.5-112.5	E
112.5-157.5	SE
157.5-202.5	S
202.5-247.5	SW
247.5-292.5	W
292.5-337.5	NW
337.5-22.5	N

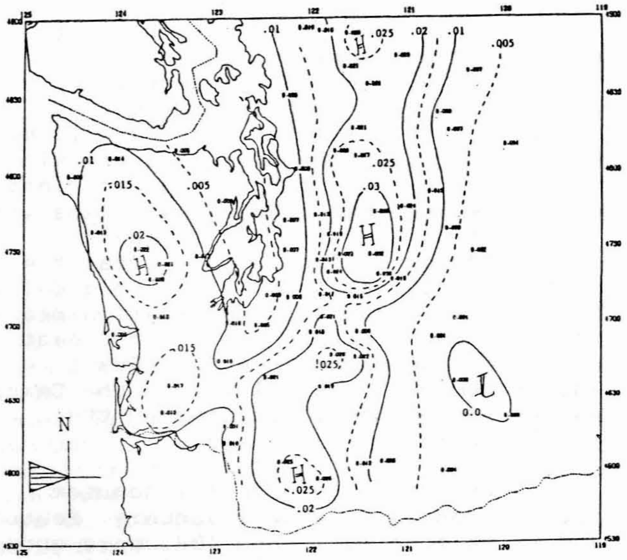
The empirical study of orographic precipitation in western Washington is complicated by several factors. There are a limited number of precipitation gages at higher elevations in the Washington Cascade and Olympic mountains, and at locations with more than one precipitation gage (for example, Stevens Pass), a wide range of water equivalency values have been measured (Marriott and Moore,1984; Krimmel and Tangborn[3], unpublished). This range may result from variations produced by local topography, poor gage placement, or differences inherent in the use of a variety of measuring devices or methods. This last problem can be solved by using standard precipitation gages. In this study, 69 Fisher-Porter weighing bucket gages maintained by the National Weather Service at elevations from sea level up to 4150 feet have been used. Although a denser network of gages would improve the quality of this study, sufficient gages are located at the mountain passes or within dissecting valleys to allow analysis of precipitation patterns.

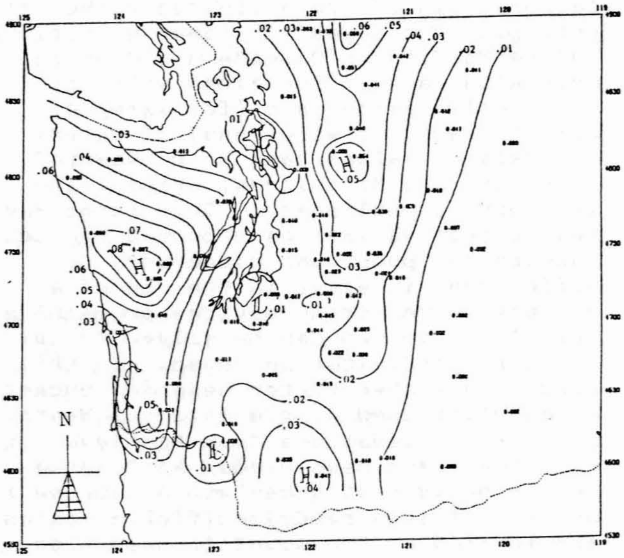
ANALYSIS

Approximately two-thirds of the total amount of precipitation during the study period occured when the wind at Hoquiam was blowing from the S,SW and W. Only the three precipitation pattern maps related to these three wind directions are presented.(fig. 2,a,b,and c) Data from the remaining five wind direction groupings are used in the analysis in figures 4 and 9. The rain shadow effect attributed to the Olympic Peninsula and the Mount Rainier region is explored in detail.

[3] Krimmel and Tangborn, 1970. Unpublished data. US Geological Survey.

The Olympic Peninsula(fig. 3) is effectively an orographic island, with the Chehalis Gap, a lowland passage, to the south; the Pacific Ocean to the west; Puget Sound to the east; and the Strait of Juan de Fuca to its north. The Olympic mountains rise to nearly 8000 feet. The region to the northeast of the Olympic mountains is comparatively dry due to the Olympic rain shadow effect resulting from predominantly SW storms. However, a more complicated situation exists in which the rain shadow moves in relation to wind shifts. This is well illustrated by examining precipitation data from Clearwater and Cushman Dam, two gage sites on opposite sides of the Olympic mountains(fig. 3). When the ratios between the hourly precipitation rates of the two sites (Clearwater/Cushman Dam) are compared for each of the eight wind directions (fig. 4a), it is evident that as the wind shifts in a clockwise direction, there is a corresponding progression from a minimum precipitation ratio at Clearwater during NE winds to a maximum ratio during N winds. Thus, the rain shadow in the lee of the Olympic mountains moves in reaction to wind shifts.





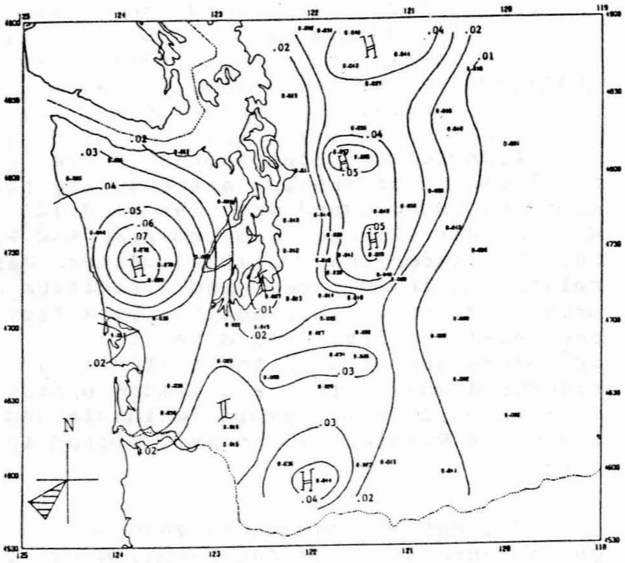


Figure 2.--Precipitation fields corresponding to time periods during which surface winds at Hoquiam were blowing from the: (a) S, (b) SW, and (c) W. Contour interval is .01 inches. Numbers represent average hourly precipitation rates based on: (a) 1390 hours of data, (b) 850 hours of data, and (c) 1207 hours of data.

Although this example follows a regular and explicable pattern, in other cases this method of analyzing precipitation is insufficient to explain many of the resulting ratios. An understanding of the overall synoptic situation must be part of the precipitation ratio analysis. Figure 4b shows the same general pattern as the Clearwater/Cushman Dam case, however, during east winds, Port Angeles has surprisingly little precipitation compared to Aberdeen. East winds at Hoquiam generally occur when the surface low pressure associated with a weather disturbance is offshore, with warm overrunning precipitation often moving into the region from the SW at higher elevations (figs. 5,6 and 7). In this situation, Port Angeles would be shielded from the main source of moisture by the Olympic mountains, while Aberdeen would lie on the upmoisture side of the mountains. In addition, precipitation at

Port Angeles should be light because the easterly flow affecting Port Angeles should contain little moisture, as the air moving downslope from the Cascades to the Straits becomes warmer and drier thru compression. Thus, this seemingly anomalous precipitation finding is predictable if the larger synoptic situation is incorporated into the analysis.

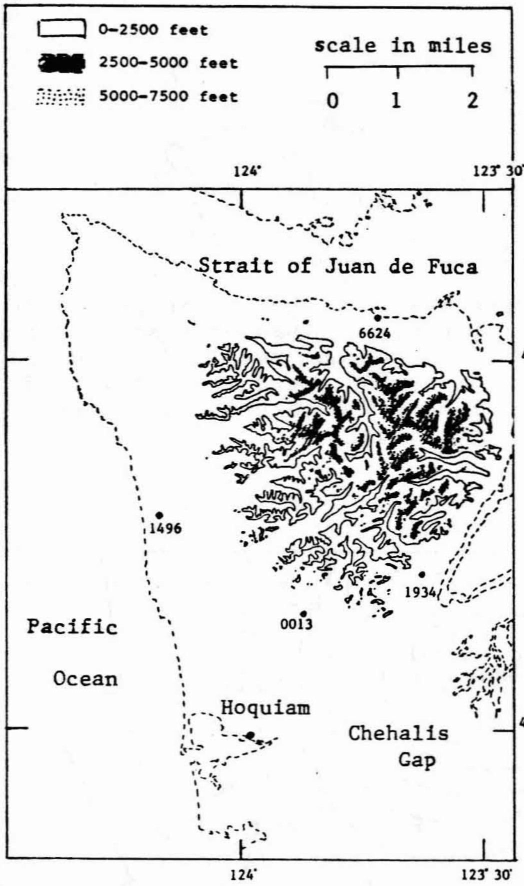


Figure 3.--Topographic map for the Olympic Peninsula, WA. with Clearwater(1496), Cushman Dam(1934), Port Angeles(6624), and Aberdeen(0013) identified by station number.

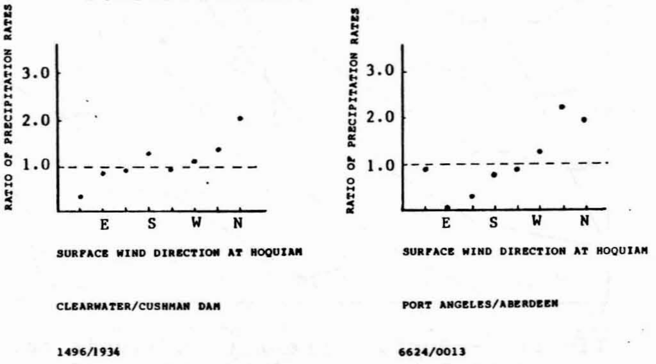


Figure 4.--Ratio of precipitation rates as a function of surface winds at Hoquiam for (a) Clearwater/Cushman Dam and (b) Port Angeles/Aberdeen.

Mount Rainier, an isolated volcano (fig. 8) rising over 14000 feet produces a similar rain shadow effect on the surrounding terrain. When analyzing the precipitation rate ratios for stations in the Mount Rainier area, note that the winds in figure 9 are measured along the Pacific coast. The actual winds near Mount Rainier are greatly affected by local channeling and by deflection around the peak itself and may differ from values obtained at Hoquiam.

The Carbon River Entrance gage and the White River Ranger Station gage, to the east and west respectively of Mount Rainier, in figure 9a demonstrate the rain shadowing effect of Mount Rainier. In the SE wind case, a minimum ratio occurs since the Carbon River Entrance gage is in the lee of Mount Rainier. A maximum ratio occurs in the W thru N directions when the Carbon River Entrance gage is on the windward side of Mount Rainier. This is what one would expect. However, the ratio decrease in the NW wind case relative to the W and N cases could result from funneling of NW winds up the White River Valley toward the White River Entrance, with a resultant increase in precipitation. Figure 6b demonstrates a similar pattern. This figure is particularly interesting from a forecaster's view. Paradise, closely north of Longmire, and Crystal Mountain, east of White River Ranger Station, both receive daily quantitative precipitation forecasts during the winter. Although forecasters have observed that Crystal Mountain, a characteristically low precipitation station, receives large quantities of precipitation during SE winds, this has not been quantified. The SE wind ratio in figure 9b illustrates this phenomenon. This is another instance in which the precipitation ratios cannot be explained by a pure rainshadow effect but must be related to local terrain effects. Presumably, SE winds are channeled toward White River Ranger Station and Crystal Mountain from the Tieton and Ohanepecosh River drainages, while Longmire is shadowed by the Goat Rocks region to its SE. In a pure east wind, White River Ranger Station and Longmire should both be shadowed by upwind terrain barriers, unfortunately, due to missing data at Longmire, the east wind case is not included in the figure. The precipitation rate ratios observed for Longmire and White River Ranger Station could serve as guidance for forecasters issuing winter quantitative precipitation forecasts for Paradise and Crystal Mountain.

CONCLUSION

Using surface wind observations for Hoquiam to represent the large scale winds approaching the Washington Cascade and Olympic Mountains, contoured precipitation pattern maps were produced for eight wind direction categories. Several precipitation rate ratios for adjacent gage sites were analyzed to demonstrate the rain shadow effect attributed to the Olympic Mountains and Mount Rainier. In general, the rain shadow moves in response to wind shifts such that minimum precipitation quantities occur on the downwind side of the orography. However, in several instances,

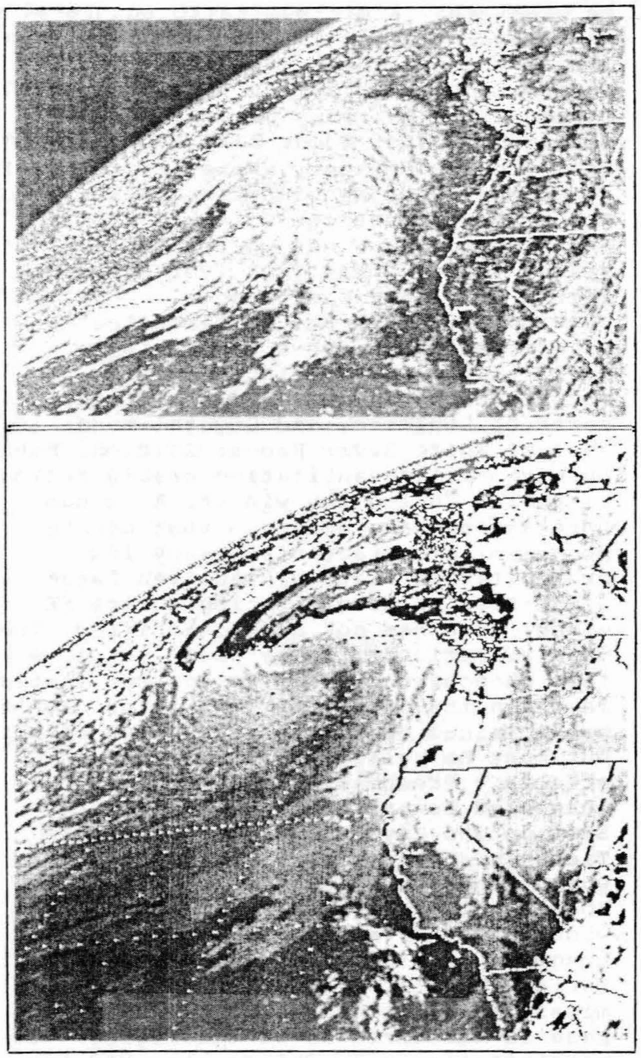


Figure 5--Satellite photographs depicting cyclonic weather disturbance moving into the Pacific Northwest. (A)Visible image for 1630 October 11,1984 with system offshore. (B)Infra red image for 0230 October 12,1984 with warm overrunning clouds in British Columbia and Western Washington.

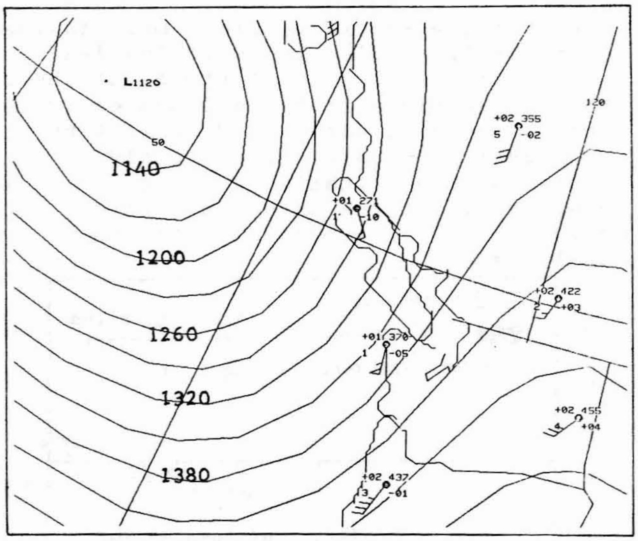


Figure 6--850 mb height analysis for 0500 October 12,1984 with station speed observations overlaid. Wind flags give wind speed in knots. (1/2 barb= 5 knots, 1 barb=10 knots, triangle= 50 knots)

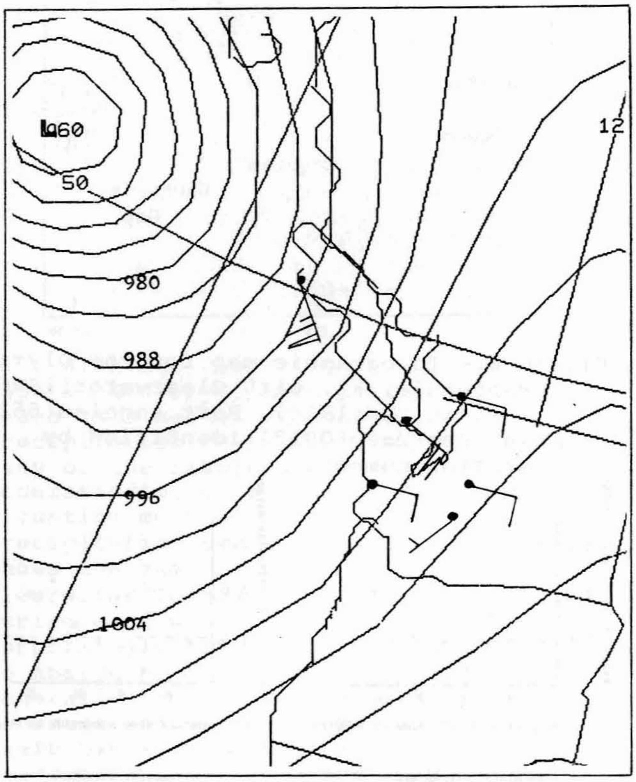


Figure 7--Surface pressure analysis for 0500 October 12,1984 with surface wind observations overlaid. Wind flags as described for figure 6.

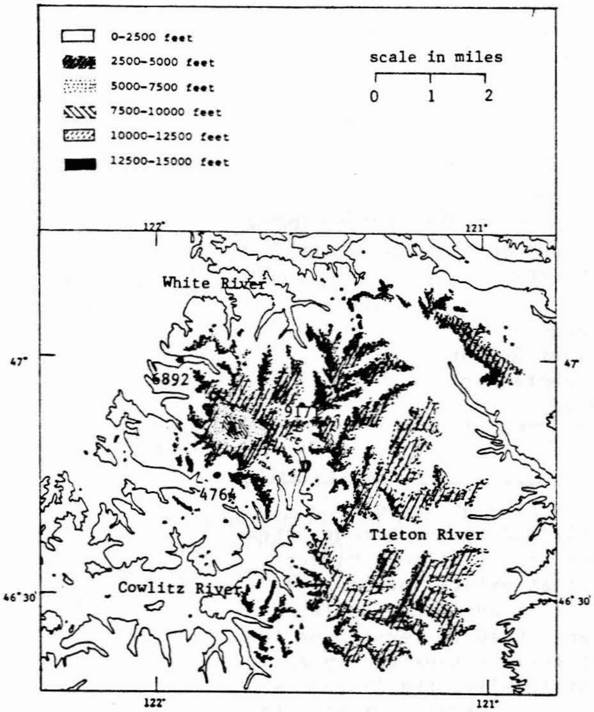
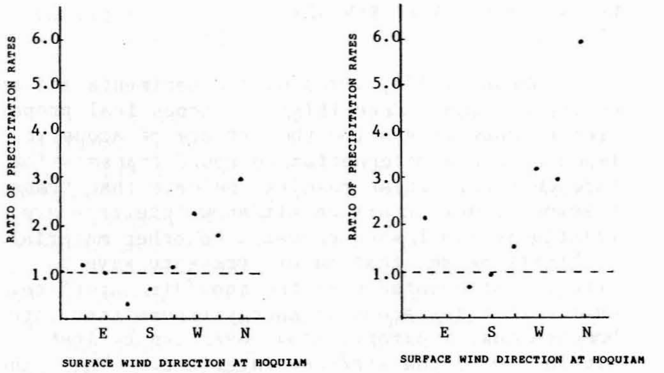


Figure 8.--Topographic map for Mount Rainier, WA and surrounding terrain with Carbon River Entrance(6892), White River Ranger Station(9171), and Longmire(4764) identified by station number. Mount Rainier(A), Paradise(B), Crystal Mountain(C) and Ohanepecosh River(D) are identified by letters.



CARBON RIVER ENTRANCE/
WHITE RIVER RANGER STATION
6892/9171

LONGMIRE/WHITE RIVER RANGER STATION
4764/9171

Figure 9.--Ratio of precipitation rates as a function of surface winds at Hoquiam for (a) Carbon River Entrance/White River Ranger Station and (b) Longmire/ White River Ranger Station.

overall synoptic conditions or specific terrain influences must be accounted for. Analysis of precipitation rate ratios taken from the pattern maps increases our understanding of winter precipitation distribution associated with coastal wind directions in western Washington. Ultimately, this information will be used to verify the output from a simple orographic precipitation model.

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