Flood-producing Heavy Rain in Western Washington � A WES Exercise

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Introduction

This paper examines the episode of heavy rain and river flooding that occurred in western Washington from 17 November 2003 through 20 November 2003.� In particular, it compares the synoptic pattern during the period of flood-producing precipitation to the canonical synoptic pattern associated with such flood events.� It also looks at the role of the Puget Sound Convergence Zone, which focused heavy rain over the Snohomish River basin.� And finally it discusses the contribution of snowmelt runoff to flooding, with some general remarks about the commonly over-estimated importance of this factor.

Background and synoptic environment

Heavy rainfall began over western Washington during the evening of 17 November 2003 and continued into the afternoon of 18 November 2003.� Orographic forcing played an important role � as it does in virtually all western Washington floods � generating the heaviest rain in the mountains, where totals generally ranged from 5 to 10 inches.� Most of the rivers that flow off the Olympic Mountains and the west slopes of the central and north Washington Cascades experienced minor to moderate flooding, with river crests between 2 and 8 year recurrence intervals.

At 0000 UTC 18 November a flat upper ridge remained along the west coast of North America, while a positively tilted upper trough over the northeast Pacific Ocean extended from 60N / 150W to 35N / 165W.� A vigorous Pacific frontal system was nearing the Pacific Northwest coast, at the leading edge of a strong, moist baroclinic zone that trailed back to the base of the upper trough (see Figure 1).� Model estimates of precipitable water within the baroclinic zone were around 1.0 inch, with the core of the associated jet stream in excess of 140 knots.

Heavy rain developed around 0300 UTC 18 November as the system�s warm front quickly swept across western Washington, and its warm sector moved over the area.� The 850 mb temperature and wind within the warm sector were, respectively, +5 C and southwest at 50 to 60 knots.� The cold front reached the coast around 0900 UTC and crossed the Cascades around 1100 UTC.� Surface high pressure built weakly into western Washington behind the cold front, and the low level flow veered toward due westerly while remaining quite strong.� Heavy precipitation continued for several hours under these conditions, especially along the west slopes of the central Cascades, tapering off somewhat after 2100 UTC as another frontal wave approached the coast.

A comparison with the canonical synoptic pattern for flood-producing heavy rain

Figure 2 shows a composite of the synoptic pattern associated with major flooding episodes on rivers that flow off the west slopes of the Cascades, corresponding to the period of heavy rainfall.� The synoptic pattern for the event of late November 2003 has much in common with the composite:� a low amplitude upper ridge is over western Washington with unseasonably high geopotential heights (and freezing levels); a deep layer of moisture extends from the ridge southwest into the base of an upper trough offshore; and a strong westerly component in the lower level wind field is producing strong orographic forcing.

These features are present in almost every significant river flooding episode in western Washington.� The fact that these episodes adhere closely to a well-recognized synoptic pattern explains why WFO Seattle generally forecasts their occurrence with a high degree of accuracy.

The role of the Puget Sound convergence zone

While the Puget Sound Convergence Zone (PSCZ) is more well-known as a warm season phenomenon that occurs in an unstable air mass, it will form any time of the year given the proper synoptic forcing:� synoptic-scale westerly flow in the lower troposphere, which commonly occurs in a post-frontal environment ahead of or with the passage of an upper level trough, is imposed upon the orography of western Washington.� In this case, a PSCZ formed around 1500 UTC 18 November, in the wake of the cold front that had swept across western Washington several hours earlier.� The convergence zone lasted through around 2100 UTC, dissipating as the lower-level flow backed ahead of the next approaching short wave.

While precipitation across western Washington generally decreased after 1500 UTC, the PSCZ helped sustain heavy precipitation along the west slopes of the central Cascades.� In fact, at Snoqualmie Pass the heaviest 6-hour precipitation of the entire event (2.2 inches) occurred between 1500 and 2100 UTC, driving the eventual crest on the Snoqualmie River (see Figure 3).

In this case, the PSCZ does not show up well in either the satellite imagery (being masked by the general cloud cover over the area) or individual radar scans (due to widespread rain and beam blockage by the mountains).� However, both the GFS and MesoETA model forecasts valid at 1800 UTC imply the existence of the PSCZ with enhanced rainfall along the west slopes of the central Cascades (see Figure 4).� The accumulated precipitation from the KATX radar, while it suffers from serious blockage problems, hints at a PSCZ extending east into the Cascades just north of the border of King and Snohomish counties (see Figure 5).

Snowmelt runoff�s contribution to flooding

Members of the news media, and even public officials concerned with flooding, often give snowmelt runoff much of the credit for western Washington flooding.� While it might be tempting to assume snowmelt runoff is a major contributor (as it indeed is in many other parts of the country), an examination of the data from the network of NRCS SNOTEL gauges shows that this is simply not the case.

Figure 6 shows the net change in water content of the snowpack at 9 SNOTEL sites in and near the Snoqualmie River basin, ranging in elevation from just below 3000 feet to just above 4000 feet.� By averaging each site�s decrease in SWE over 3 hour intervals (and counting an increase in SWE as zero), one can get an estimate of the snowpack�s contribution to the runoff for this event.� Figure 7, which shows the snowpack runoff along with the concurrent rainfall at Snoqualmie Pass, illustrates that this was only a minor component of the flood waters.� Further, when one considers that only a fraction of the entire basin contributes snowmelt runoff � typically the portion above 2000 feet and below 4500 feet, which amounts to less than 50 percent of the drainage area � then it becomes clear that snowmelt runoff comprised less than 10 percent of the total runoff.� It is also worth noting that two of the higher elevation gauges measured a net increase in SWE over the duration of the event, suggesting that the higher elevation snowpack actually provided a minor buffering effect on runoff.

The results in this particular case are by no means uncharacteristic.� Analyses of major western Washington flooding episodes over the past 15 years, even for supposedly �classic rain on snow events� like the record February 1996 floods, lead repeatedly to the conclusion that snowmelt runoff contributes only minimally to river flooding in western Washington.

WES Exercise and Objectives

Western Washington counties are among the Nation�s leaders with respect to presidential disaster declarations, and flooding is far and away the primary culprit.� Given its importance in our operations, it is obviously important that WFO Seattle forecasters be entirely familiar with the meteorology of these events.� This case, therefore, was selected because of its similarity to the classic flood patterns of western Washington and had the added character of the PSCZ. The WES Exercise walks the forecaster through a series of medium range forecasts, asking targeted questions that emphasize the fundamental synoptic characteristics and center on key decision points.� Actions from Flood Potential Outlooks, to Watches and Warnings are covered.

While the canonical synoptic pattern that brings flood-producing heavy rain to western Washington is well forecast and easily recognized, the usefulness of river forecasts and flood warnings depends upon accurate quantitative precipitation forecasts on the scale of individual river basins.� During flooding, as with other warning programs, the devil is in the details.� Therefore, a slightly different approach is used during the part of the event when the precipitation was generally decreasing, and a PSCZ dominated the situation along the west slopes of the central Cascades.� Here, forecaster discovery is used to encourage forecasters to identify and consider the potential impact of mesoscale phenomena � in this case the PSCZ.

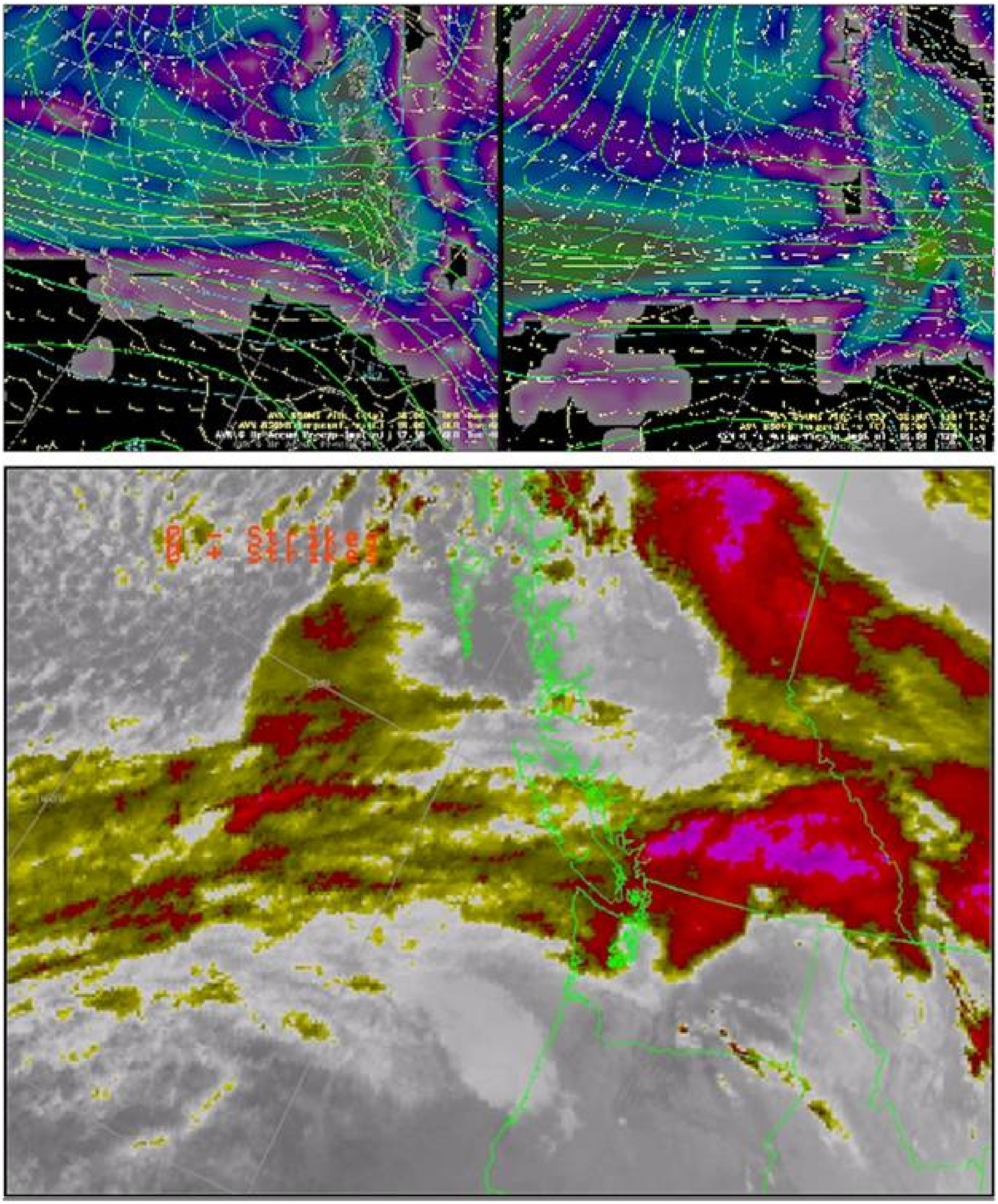

Figure 1. GFS 00-hour forecast valid at 0000 UTC 18 November 2004 (upper left), 12-hour forecast valid 1200 UTC 18 November 2004 (upper right), and IR satellite imagery 1145 UTC 18 November 2004 (below)

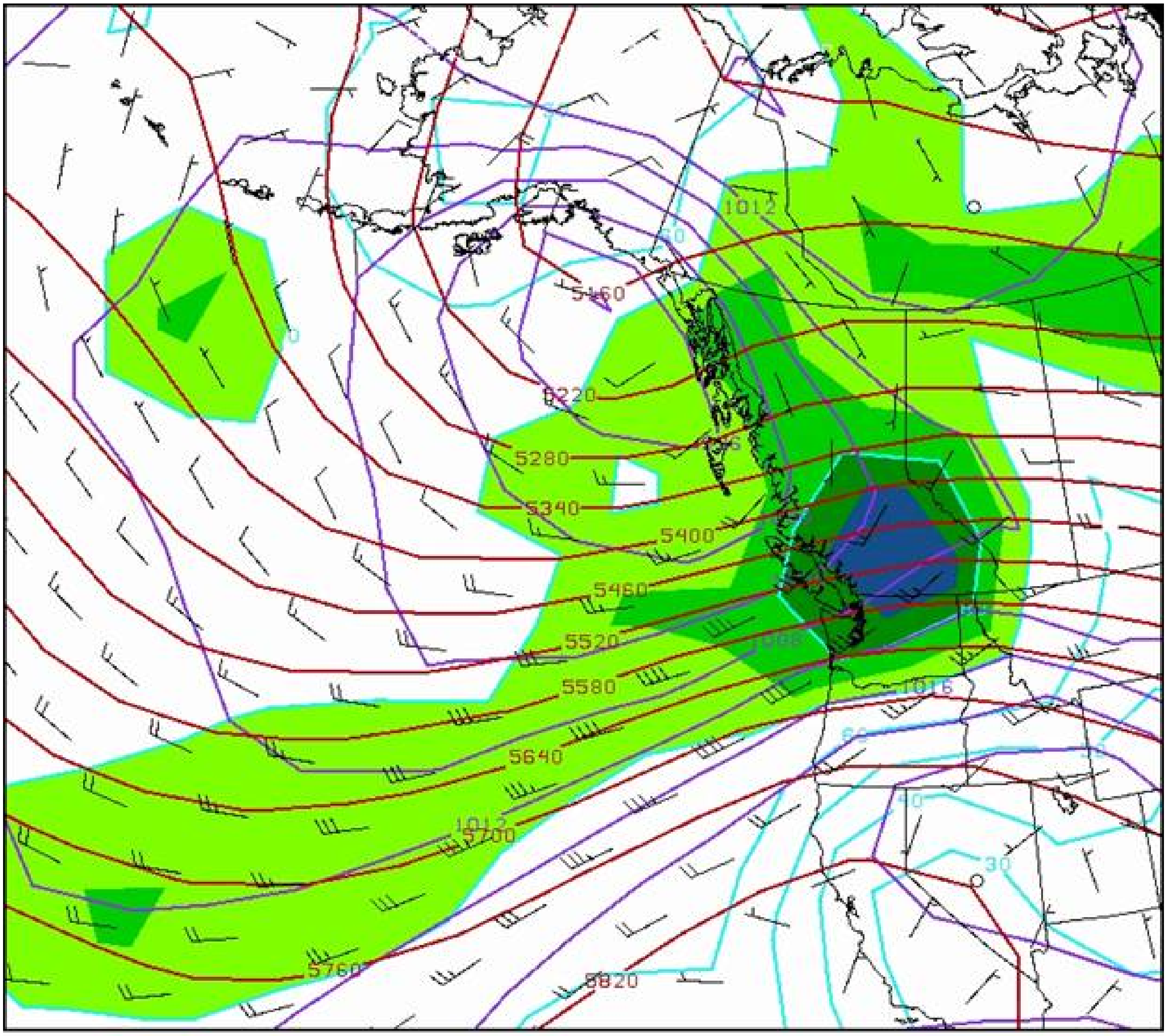

Figure 2. Composite synoptic pattern associated with major flooding episodes of rivers along the west slopes of the Washington Cascades.

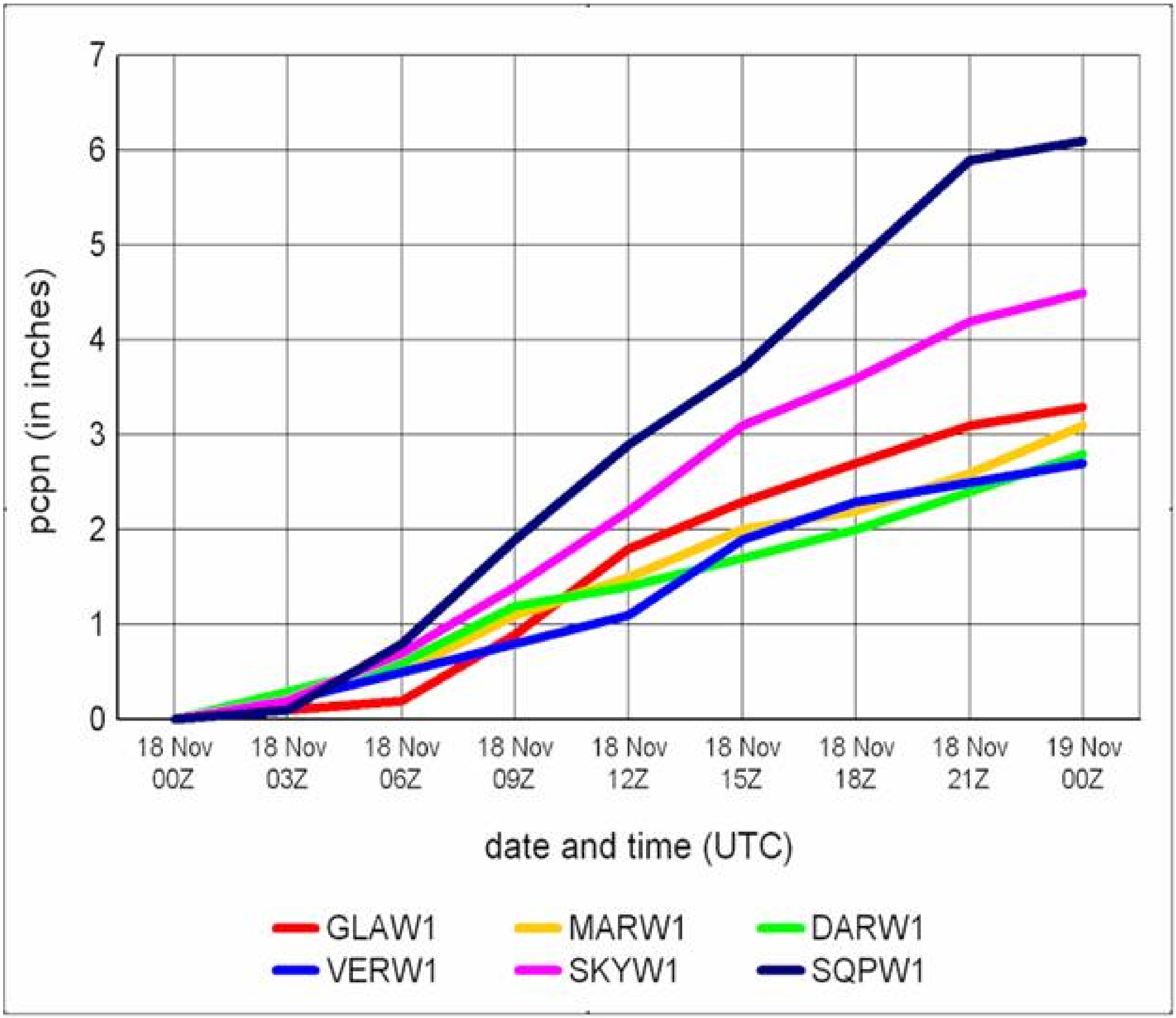

Figure 3. Precipitation measured at gauges along the west slopes of the Washington Cascades, beginning 0000 UTC 18 November 2004.

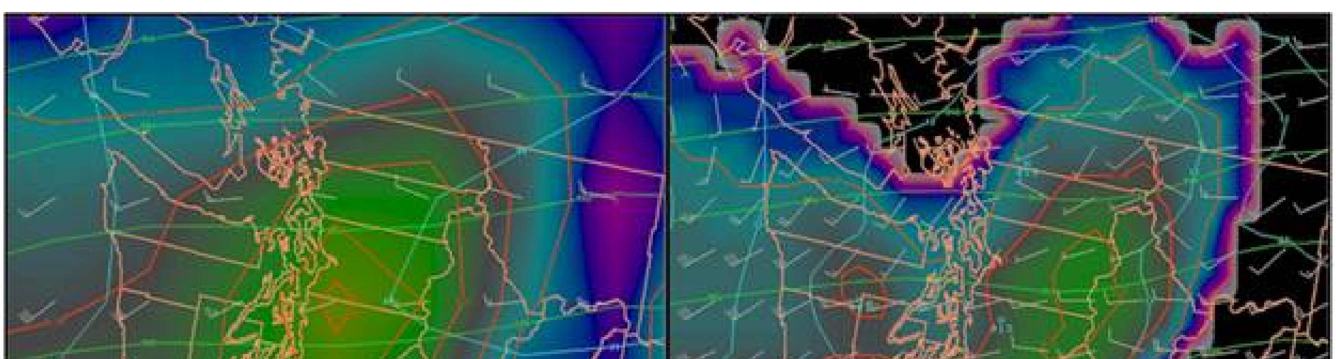

Figure 4. GFS and MesoETA 18 hour forecasts valid at 1800 UTC 18 November 2004.

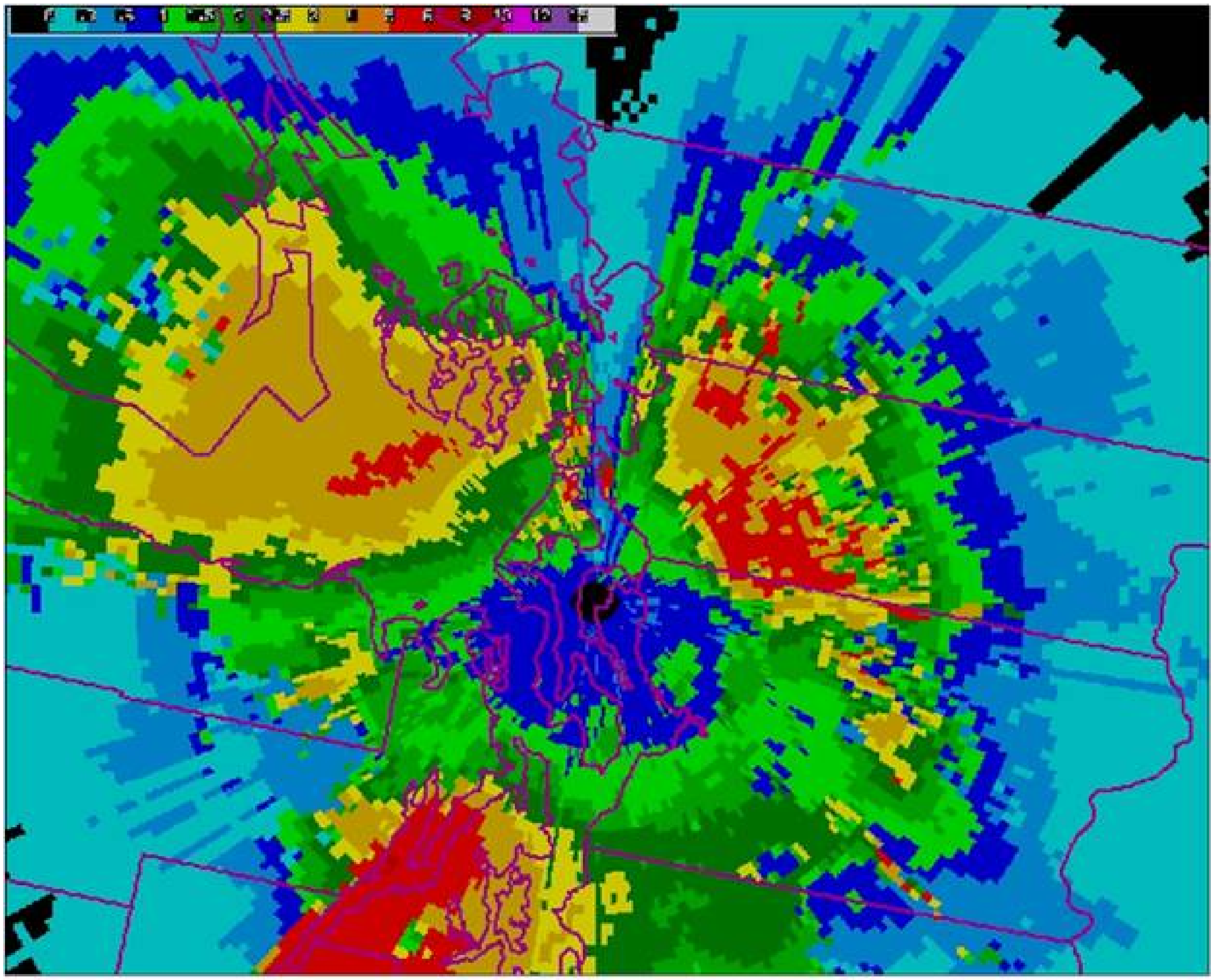

Figure 5. KATX radar image of accumulated precipitation, 2112 UTC 18 November 2004.

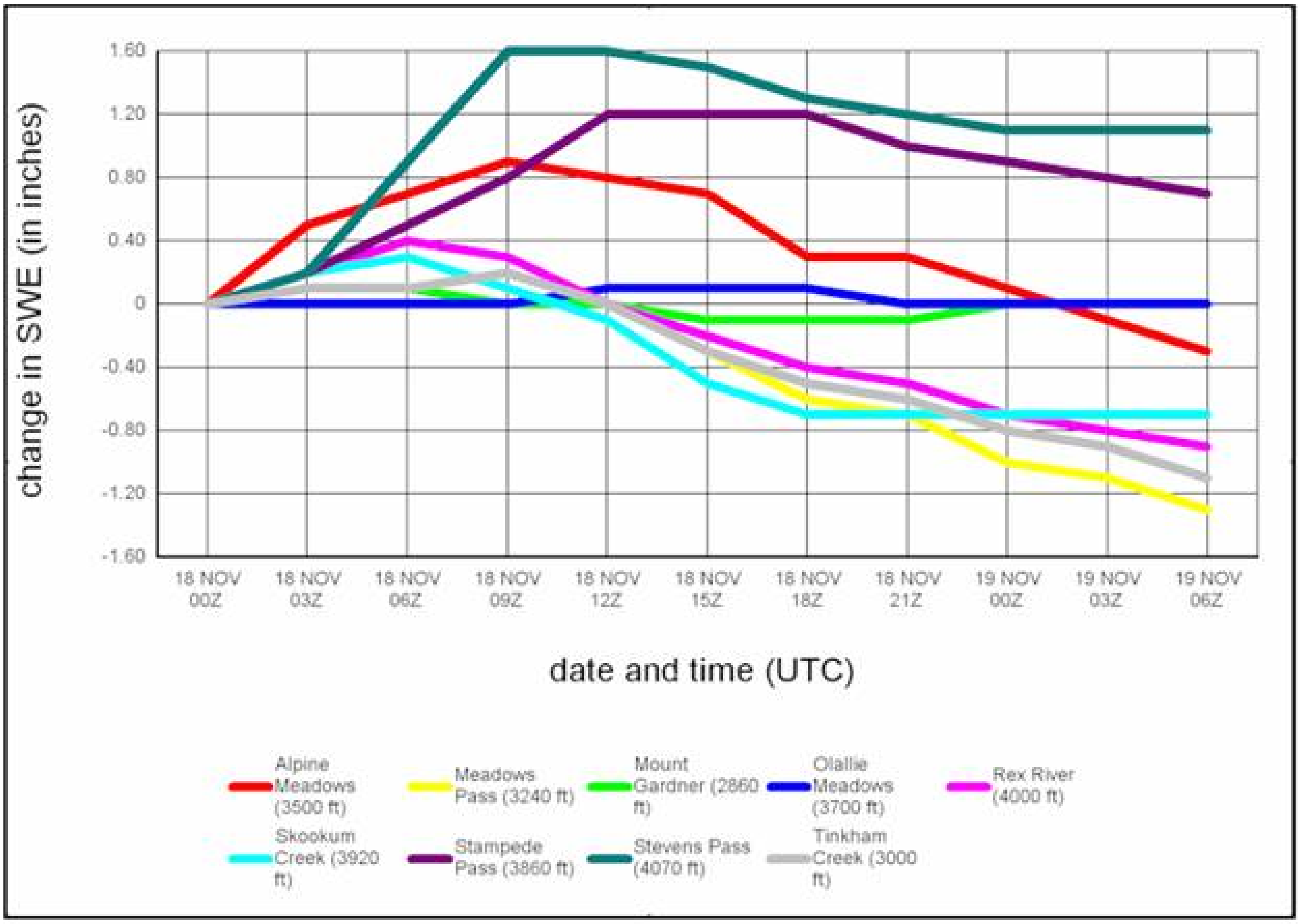

Figure 6. Change in SWE at NRCS SNOTEL sites in and near the Snoqualmie River basin, beginning 0000 UTC 18 November 2004.

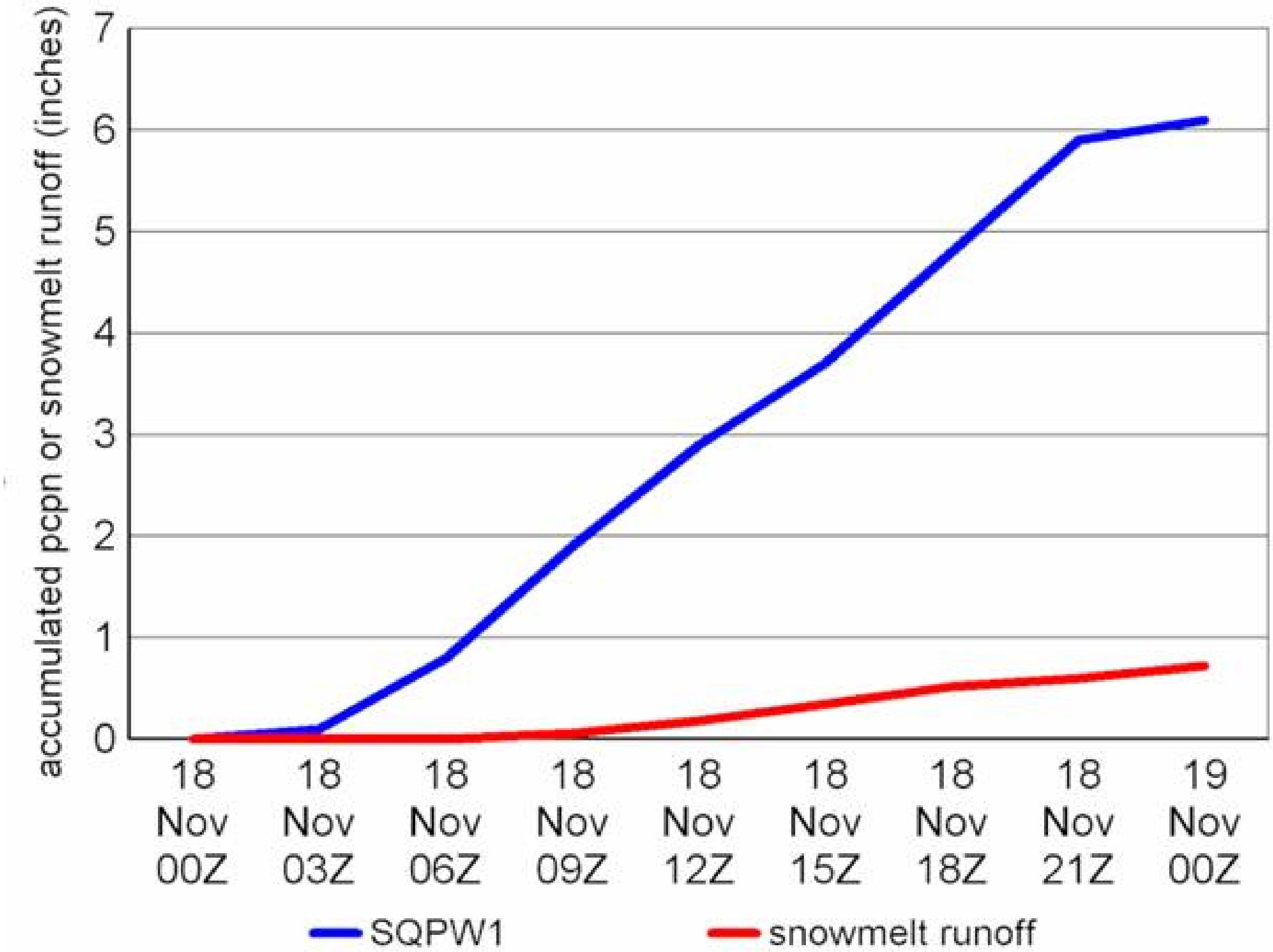

Figure 7. Accumulated precipitation at Snoqualmie Pass and basin snowmelt runoff, beginning 0000 UTC 18 November 2004.