EVALUATION OF A NATIONAL SEASONAL SNOWFALL RECORD AT THE MOUNT BAKER, WASHINGTON, SKI AREA

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Abstract

During the 1988-89 July-June snowfall season, the Mount Baker Ski Area in northwest Washington state reported 1,746 inches of snowfall. As the season progressed and many snow continued to fall, the ski area became increasingly aware of the potential to exceed the existing and accepted record of 1,126 inches set in 1971-72 at the National Weather Service (NWS) cooperative observing station at Perimeter Range Station on the southern slopes of Mount Rainier 150 miles to the south. The 1971-72 snowfall was first published as a new U.S. record by the editors of Weatherwise Magazine (Lauderm 1972). Later that year, the value was also recognized by the NWS (Pauza 1973). The Rainier-Perimeter record has been cited as a North American record snowfall by Krause (1988) and others.

Because the Mount Baker record is to a significant extent a record of informal observation and would likely be referred to for many years unless exceeded, and because a measure of economic and public interest accompanies these measurements, the National Climatic Data Committee (NCDC) was asked to judge whether the measurement program had adequately followed snowfall observing conventions for acceptance as an official record. The NCDC was formed in 1991 to evaluate the validity of climate extremes that challenge existing records or methods and make a recommendation to the National Oceanic and Atmospheric Administration (NOAA) regarding acceptance of the observations in question. The NCDC is comprised of several permanent members, National Climatic Data Center (NCDC) National Weather Service (Andrew Horvitz, Robert Leffler), and the President of the American Association of State Climatologists. Additional experts can also serve on an as-needed basis in particular record in question. For this event, the chairman was Robert J. Leffler. The Committee also included Kelly Redmond (Western Regional Climate Center) and Raymond Downs (NWS Office of Climate, Water, and Weather Services). The comprehensive evaluation leading to the recommendation that a new record was set is discussed herein. The problems in measuring snow depth are also reiterated.

1. Introduction

Some of the heaviest seasonal snowfall totals in the United States and the world have been recorded in the western mountains of the conterminous United States. Especially noteworthy are amounts, which have fallen in the Cascade Mountains of the state of Washington, where annual averages exceed 600 inches on westward slopes at elevations ranging between 4,000 and 7,000 feet. These heavy snowfall totals are the result of several factors. Winter is naturally the wettest season as the west-to-east planetary circulation expands southward and strengthens in speed, with storms moving the Pacific Northwest every two to three days. As laden with moisture, these storms cross the Pacific Ocean, in favor of the Cascade Range, dropping abundant precipitation. The freezing level over the area averages about 4,000 feet for the winter months. Near this altitude, snowfall amounts increase very rapidly with just small increases in elevation.

During the 1988-89 season, a moderately strong La Nina accentuated the normally stormy pattern, with a much higher frequency of wet and cold weather systems especially affecting the area from the Cascade Range westward. Freezing levels remained abnormally and continu
tently low throughout the winter. Therefore, record snow measurements were probable, but had to be evaluated before official acceptance.

The NCEC was formed in 1997 to evaluate the validity of climate extremes that challenge existing national records and to make recommendations to the National Oceanic and Atmospheric Administration (NOAA) regarding acceptance of the observations in question. The NCEC is comprised of several permanent members: National Climatic Data Center (chair), National Weather Service (Andrew Arrizzi, Robert Leffler), and the President of the American Association of State Climatologists. Additional experts can also serve as appropriate to the particular record in question. For this event, the Committee also included Kelly Redmond (Western Regional Climate Center) and Raymond Downs (NWS Office of Climate, Water, and Weather Services).

2. Measurement Site

The 1989-99 Mount Baker snowfall measurement were made at the Mount Baker Ski Area, at an elevation of about 4,200 feet. (This report uses the original American system of units.) The location is about 9 miles northeast of the summit of the Mount Baker volcano (10,781 feet) and 15 miles south of the Canadian border (Fig. 1). The ski area occupies a north-facing bowl below the 8,000-10,000 feet crest of an east-west oriented spur (Shuksan Arm) on the western flank of Mount Shuksan (8,549 feet) whose summit is about 5 miles east. The ski area has been historically known as Heather Meadows. The ski area, which is north of White Salmon Creek and then into the upper reaches of the westward-flowing North Fork the Nooksack River. Just over Shuksan Arm to the south, Swift Creek drains south into southwest-flowing Baker Creek, and then into the westward-flowing Skagit River.

Snowfall measurements are taken in the parking lot adjacent to the employee housing building. The measurements are taken as support of operations for the privately owned and operated Mount Baker Ski Area. The site is open to the wind from all quadrants. After snowfall accumulates to several feet or more, the plowed parking lot increasingly begins to act as a depression or pit, which this year essentially reached a depth at 20-25 feet. The plotted area is approximately 190 by 200 feet.

3. Measurement Methodology

Snowfall is one of the most difficult climatological elements to measure accurately and consistently (Deshon and Saban 1989). It varies, melts, and drifts from place to place when wind is present. The amount measured can vary, greatly depending on the frequency of measurement and the surface upon which it is measured (e.g., ground, snow, or at the height of snow). The National Snowfall Record is called the National Snowfall Record and includes measurements made at the locations of each snowfall measurement location on the north face of Mount Baker. Each snowfall measurement location is identified by a unique snowfall measurement, which is then used as the source for snow depth measurements. The source is then used to determine the accuracy of the snowfall measurements.

The Mount Baker Ski Area measurement were taken by four different ski areas, observed (normally), with 20 to 30 years experience in snow measurement at this location (average was 22 years). None of the observers had special NWS snow measurement training but have been participant in USFS Avalanche Center snow course measurements in the surrounding mountains in years past. According to one ski area manager, "good standard practice" was applied in taking the snowfall measurements.

Daily snowfall measurements were made at least once each day at about 0800 local time. Blowers, vacuuming, or tape measures were used in determining the new snowfall amounts. Measurements were typically taken on the westward asphalt parking lot, with occasional verification of the hoods of vehicles. When temperatures were near or below freezing and snow was melting as it fell, a snowboard was used.

Snow total (depth of snow on the ground) measurements were made each day, also at about 0800 local time, in a semi-open meadow surrounded by mature conifer trees, several hundred feet south of the daily snowfall measurement location (Fig. 2). The snow depth site appeared to be an excellent region open, unaffected by watercourse, pecking, or other activities, set with enough nearby trees to reduce drifting. A snow stake placed on monitoring snowfall measurements.

The site was measured by the same equipment, in the same location, used in the 1970s when the station was established by the NWS as a published cooperative station. At that time, the area was staffed year-round.

4. Snowfall Data

The daily snowfall measurements were made available to the Committee upon request, first as a spreadsheet output, later as part of daily log sheets. Most measurements were to the nearest inch, with a few to the nearest half inch. Two daily totals were determined: a half-inch by the Committee because the values had been rounded up to the nearest inch to obtain the Ski Area's publicly available total, and a full-inch standard practice to retain tenability.
5. Comparison to Other 1998-99 Observations

The Washington Department of Transportation (WDOT) is responsible for plowing the state highway to the Mount Baker-Snoqualmie National Forest (MBSN) area. On many days, separate snowfall measurements were taken and recorded by snowfall readers at a site not far from the end of the plowed road. WDOT snowfall observation times varied daily and thus did not always represent 24-hour totals. This made meaningful comparison to the MBSN area snowfall amounts difficult. Instead, daily snowfall amounts for the MBSN area and WDOT were totaled by calendar month for days when both recorded amounts. The results showed WDOT totals to be 10 to 19 percent lower than the MBSN area totals in all but two months for which comparisons were made.

Some Committee members expressed concern about the conflicting greater amounts at the MBSN area. However, WDOT emphasized their measurements and referred to MBSN area numbers as “an accurate reflection of what actually occurs in the mountains.”

Upon completion and debate, the Committee concluded that the uncertainties in the potentially considerable WDOT snowfall values were sufficiently large to reduce their influence in the evaluations.

Comparisons were sought with climatologically similar locations. A logical choice was the NWS cooperative station at Mount Rainier, Paradise Ranger Station, at elevation 4,300 feet on the south slope. The Rainier - Paradise station is normally snow-covered in the US, with a 30-year (1964-93) average of 126.2 inches (315.8 feet) of snowfall during the period July - June. Comparison of these two 1998-99 monthly and seasonal snowfall totals is presented in Table 1.

During the 1998-99 period, Mount Rainier - Paradise recorded 103.9 inches, the second most snowfall recorded there since the station was established in 1880. Nearly all snowfall in 1998-99 occurred in the winter months, with some snowfall recorded in May. The maximum snow depth at Paradise was 149 inches on March 10 recorded at 336 inches, which was 26 inches less than the Mount Baker-Snoqualmie National Forest maximum depth of 318 inches, also reached on March 30, and a record depth for that site. Snow creep had pushed the steel snow stake at Paradise about 20 degrees from vertical by late winter.

An established USDA Snow Survey snow course and Snow Stake at Beaver Ponds, 25 miles east at 6,660 feet, showed the highest May 1 snow water content in its 47-year record, exceeding the 1933-34 record of 51.6 inches by 9 percent (63 inches). A Pearson III frequency analysis predicts that this will lead to the highest May 1 snow water content in its 47-year record at this site, the 4th largest for May 1.

It should be emphasized that in the Washington Cascades snowfall and snowpack can vary dramatically (mean feet) with small changes (50-100 feet) in topographic orientation and in snowpack patterns. Examples were observed first-hand during the site visit.

6. Physical Evidence

To assist with the evaluation, the Committee visited and photographed the snowfall sites (8 June 1999) and intercompared observations. On that day, the depth of snow on the level ground was observed to be 15.5 feet (334 inches). Ten days later (18 June), WDOT reported that the road at Golenite (route to the ski area) was still closed due to high avalanche danger. This was the latest date in memory that this road had been closed.

Several mature trees were noted in trees in the forest adjacent to the highway as it ascended above 3,000 feet. Intercomparisons with several ski area locations with up to 30 years experience in the area clearly indicated that the number and age of trees snapped by either avalanches or snow creep below downwind precipitation of the heavy snow pack was unprecedented. According to WDOT, 120-year-old trees were observed snapped off in the woods near the road about 2 miles from the ski area. Investigation of nearby avalanche chutes also revealed that 35-year-old trees had been destroyed by recent snow slides (Fig. 3).

7. Comparison of Snowfall Totals to Historical Data

The Cascades have long been noted for heavy snow (Phillips 1979). Intermittent snowfall data exist for Mount Baker (Heather Meadows) from about 1927 to 1950, but there are no years of complete seasonal snowfall records. The present Mount Rainier - Paradise NWS coop station began operation in 1926.

Eleven years of overlapping seasonal snowfall records between Mount Rainier (Heather Meadows) and Rainier - Paradise were compared (1927-38 through 1994-95 and 1936-37 through 1938-39; Table 2). This interval is well known in the region for extended drought conditions evident in the very low snowfall at both sites, and helpful for sitting many researchers.

Evaluation of the 11 overlapping years indicates the Mount Rainier - Paradise station is normally the snowier of the two, averaging 40 inches (18 percent) more than Mount Baker. However, in three of the eleven snow seasons, Mount Baker totals exceeded Mount Rainier - Paradise totals, and in one of these seasons (1926-27),
Mount Baker exceeded Mount Rainier by 96 inches (24 percent).

The historical data show that the 4,200-foot Mount Baker station can readily receive heavier seasonal snowfall than the normally snowier and higher (12,000 feet) Rainier - Paradise trailhead. The 1,140 mm total reported for 1996-97 at Mount Baker Ski Area was 105 inches (10 percent) greater than Rainier - Paradise, well within the historical relationship.

8. Committee Findings and Recommendation

The evaluation of the Mount Baker Ski Area snowfall measurements revealed strengths and weaknesses of the observation methodology and related evidence. The supporting evidence follows.

Table 2: Snowfall Comparisons, overlapping snowfall seasons, Heather Meadows (Mount Baker) and Paradise (Mount Rainier), coop standard: 12, inches

<table>
<thead>
<tr>
<th>Season</th>
<th>Heather Meadows</th>
<th>Paradise</th>
<th>(Rainier)</th>
<th>(Rainier)</th>
<th>Ratio</th>
<th>(Baker)</th>
<th>(Rainier)</th>
<th>(Baker)</th>
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<td></td>
<td>(Baker)</td>
<td>(Rainier)</td>
<td>(Baker)</td>
<td>(Rainier)</td>
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<td>1957-58</td>
<td>503.5</td>
<td>458.9</td>
<td>102.6</td>
<td>85.7</td>
<td>1.20</td>
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<td>490.0</td>
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<td>662.5</td>
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<td>751.6</td>
<td>102.6</td>
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<td>572.5</td>
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<td>40.3</td>
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The snowfall measurement methodology was found to meet measurement guidelines:

- Observations were taken daily at the same time (within 15 minutes of 0000 local time) - consistent with Federal standards and NWS observing handbooks; i.e., FMH-1.2, US Dept. of Commerce 1985, WSGN No. 2, US Dept. of Commerce 1986, and WSGN No. 7, US Dept. of Commerce (1996).
- Observations for the snowfall season were taken daily conservatively - four allowed, no more frequent than once per six hours. 1,140 inches total could have easily been exceeded.
- Surface brushed glare of past snowfall each observation.
- When drifted, observed practice followed of averaging a variety of sample depths.
- Observations were considered acceptable and representative (snowfall and snow depth).
- No observations present at observation site to bias measurements.
- Snowboard use appropriate.
- Road keeping (documentation) of daily snowfall data was found to be satisfactory.
- Observational data provided in a timely fashion by Ski Area staff.
- Observers were knowledgeable in their observations of snow (primary snowfall observers had 10 to 20 years experience with average of 22 years).
- October snowfall did occur but not considered by Ski Area staff or Committee in the 1,140 inch seasonal total. Estimates by Mount Baker personnel (when present) suggest that another 10 inches may have fallen in October. VRCSC statistical analysis strongly suggests an October total closer to 30-30 inches.
- Damage to ski area infrastructure and nearby forests (by avalanches and snowmelt), unprecedented in Mount Baker Ski Area.
- WDOT and others confirmed the 916 inches maximum snow depth (30 March 1996, same day as maximum depth at Mount Rainier, 280 inches).
- USDA Snow Course and Snow parks nearby were covered with up to 200-2000 inch return values.
- For first time in 33-year history, the Mount Baker Ski Area was closed (3-5 February) for too much snow.
- Chairlifts and snow plow parking areas had to be dug out from record-setting snow accumulations.

Areas of concern:

- Many ski areas have low credibility for accurate measurements since economic self-interests is served by reporting favorable snow conditions.
- Significant differences (10-30 percent) in snowfall amounts reported between Mount Baker Ski Area and WDOT personnel. Explanation from snow operator reduces emphasis on these observations.

Although committee members harbored some reservations regarding the measurement process, in the end the preponderance of the physical evidence and record-keeping suggested the conclusion that the measurements met NWS snowfall observance standards and practices, and were thus considered to be an accurate depiction of the snowfall amounts that fell. The Committee voted unanimously to recommend that the Director of NWS accept the measurements as official.
9. NOAA Decision

On 2 August 1999, citing a unanimous recommendation from the six-person National Climate Extremes Committee, the Director of NCDC accepted the Mount Barrel (1998-1999) seasonal snowfall total of 1,140 inches, making it the new official national record for the most snowfall ever measured in the U.S. in a single July through 30 June snowfall season. As it happens, this figure also stands as a world record.

A press release on the decision was disseminated by the NOAA/National Environmental Satellite, Data, and Information Service (NESSDS) on 2 August 1999.

Authors

Robert J. Leffler chaired the National Climate Extremes Committee for this project. He is a physical scientist in the Climate Services Division of the NWS Office of Climate, Water and Weather Services. Mr. Leffler also chaired the committee that evaluated "The Report of the 11-12 January 1997 Montague, New York, 71-inch, 74-hour Lake-Effect Snowfall." He authored the NWS Snow Measurement Guidelines for cooperative observers.

Michael J. Changey, recently retired from NOAA, was the NCDC representative and Chair of the National Climate Extremes Committee. He received B.S. and M.S. degrees in Meteorology from Pennsylvania State University. During his career at NCDC, he was primarily involved in climate applications for NASA, Nuclear Regulatory Commission, National Institute for Science and Technology, Department of Energy and the DOI. During his final two years of government service, he managed the Climate Monitoring Branch at NCDC which provided assessments of global and U.S. climate and extreme events.

Kelly Redmond grew up in southwest Montana, received a Physics degree from the Massachusetts Institute of Technology, and graduate degrees in Meteorology from the University of Wisconsin in Madison. He has served as Oregon State Climatologist and for the past 12 years has been Regional Climatologist and Deputy Director of the Western Regional Climate Center at the Desert Research Institute in Reno, Nevada.

Raymond Downs works in the NWS Office of Climate, Water, and Weather Services, Observing Services Division and is responsible for updating Weather Service Handbooks Numbers 7 and 8, and Federal Meteorological Handbook Number 1. Since 1987, Mr. Downs has been the focal point for Micro Computer Aided Paperless Surface Observation (MAPSO).

George Taylor is the State Climatologist for Oregon, and a faculty member at Oregon State University's College of Oceanic and Atmospheric Sciences. He manages the Oregon Climate Service, the state repository of weather and climate information, and supervises a staff of seven. Recently, he published two books: The Oregon Weather Book and The Climate of Oregon. He served as President of the American Association of State Climatologists during this evaluation. He has been certified by the American Meteorological Society as a Certified Consulting Meteorologist. George received a B.A. in Mathematics from the University of California at Santa Barbara and an M.S. in Meteorology from the University of Utah. He has been active in private and public sector meteorology since 1971.

Andrew Horvitz is the National Cooperative Observer Program Manager for the NWS in the Office of Climate, Water, and Weather Services, Observing Services Division. Mr. Horvitz is a NWX representative of the National Climate Research Committee. Mr. Horvitz is also chair of the NWS Awards Committee.

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