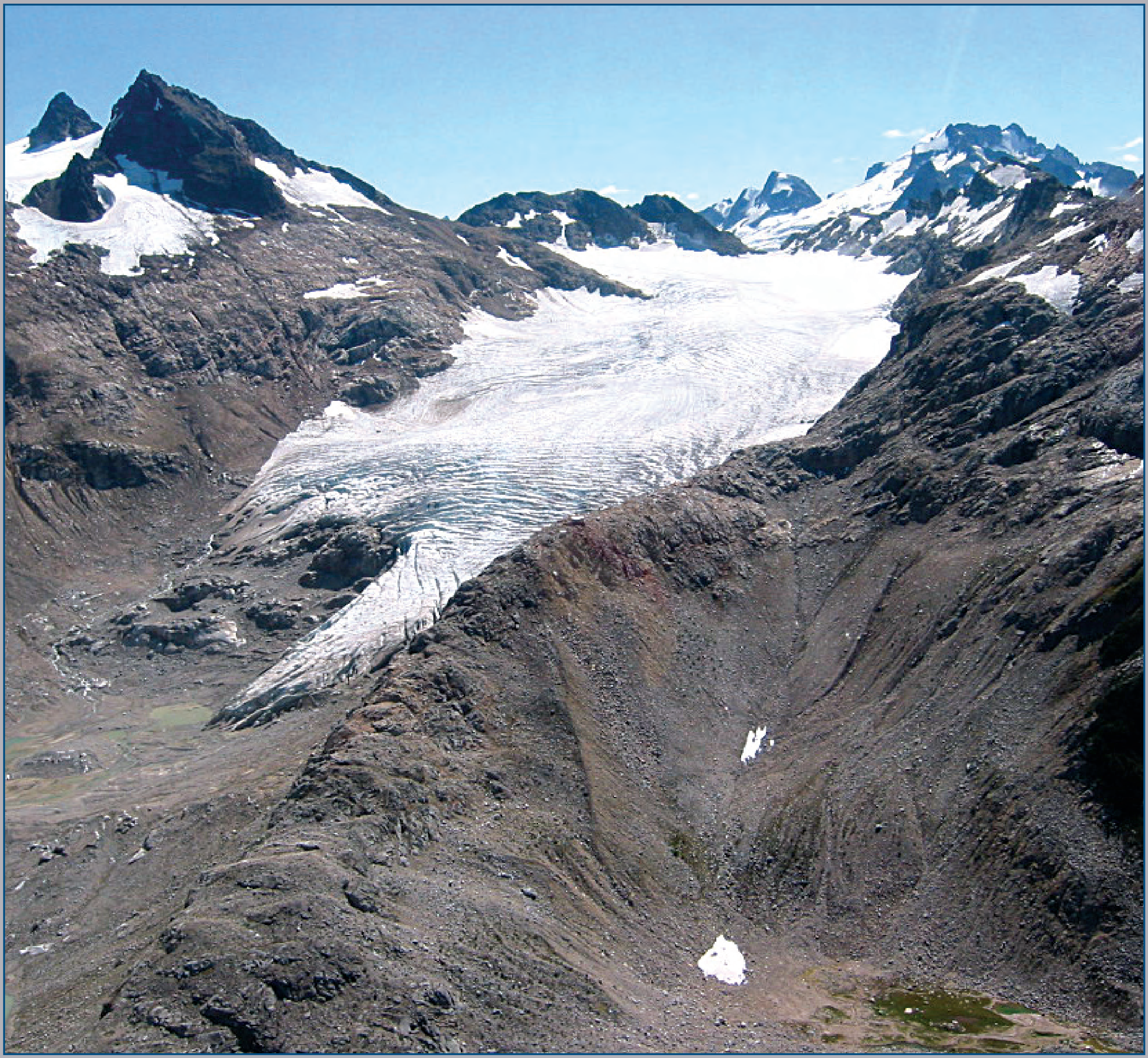
WATER, ICE, AND METEOROLOGICAL MEASUREMENTS AT SOUTH CASCADE GLACIER, WASHINGTON, BALANCE YEARS 2004 AND 2005

Scientific Investigations Report 2007–5055

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY



USGS
science for a changing world

Cover: Photograph of South Cascade Glacier, Washington, from the north-northwest, August 24, 2005 (photograph by Willian Bidlake, U.S. Geological Survey).

Water, Ice, and Meteorological Measurements at South Cascade Glacier, Washington, Balance Years 2004 and 2005

By William R. Bidlake, Edward G. Josberger, and Mark E. Savoca

Scientific Investigations Report 2007–5055

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
DIRK KEMPTHORNE, Secretary

U.S. Geological Survey
Mark D. Myers, Director

U.S. Geological Survey, Reston, Virginia: 2007

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS--the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:
Bidlake, W.R., Josberger, E.G., and Savoca, M.E., 2007, Water, ice, and meteorological measurements at South Cascade Glacier, Washington, balance years 2004 and 2005: U.S. Geological Survey Scientific Investigations Report 2007-5055, 69 p.

Contents

Figures

Figures—Continued

Tables

Tables—Continued

Tables—Continued

Conversion Factors, Datum, Abbreviations, and Symbols

Conversion Factors

Multiply	By	To obtain
cubic meter per second (m^3/s)	35.31	cubic foot per second
kilogram (kg)	2.205	pound avoirdupois
kilogram per cubic meter (kg/m^3)	0.06243	pound per cubic foot
kilometer (km)	0.6214	mile
meter (m)	3.281	foot
meter per second (m/s)	2.237	mile per hour
millimeter (mm)	0.03937	inch
square kilometer (km^2)	0.3861	square mile
watt (W)	0.2388	calorie per second
watt per square meter (W/m^2)	2.388×10^{-5}	calorie per square centimeter per second

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Datum

In this report “altitude” refers to height above the National Geodetic Vertical Datum of 1929 (NGVD of 1929)—a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviations

AAR	Accumulation area ratio
ELA	Equilibrium line altitude
GPS	Global positioning system
SWE	Snow water equivalent
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator

Conversion Factors, Datum, Abbreviations, and Symbols—Continued

Symbols

Symbol	Meaning
$\dot{a}$	Ablation rate
b	Mass balance for a period beginning with time t_0 and ending with time t_1
$\bar{b}$	Glacier mass balance
$\bar{b}_0$	Glacier initial balance increment, the glacier balance between the time of the beginning of the water year and the beginning of the balance year.
$\bar{b}_1$	Glacier final balance increment, the glacier balance between the time of the end of the water year and the end of the balance year
b_{a}	Annual (water year) balance
$\bar{b}_{\mathrm{a}}$	Glacier annual (water year) balance
b_{n}	Net balance
$\bar{b}_{\mathrm{n}}$	Glacier net balance
b_{s}	Summer balance
$\bar{b}_{\mathrm{s}}$	Glacier summer balance
b_{w}	Winter balance
$\bar{b}_{\mathrm{w}}$	Glacier winter balance
$b_{\mathrm{m}}(\mathrm{s})$	Measured winter snow balance
$\bar{b}_{\mathrm{m}}(\mathrm{s})$	Glacier measured winter snow balance
$b_{\mathrm{w}}(\mathrm{s})$	Maximum winter snow balance
$\bar{b}_{\mathrm{w}}(\mathrm{s})$	Glacier maximum winter snow balance
$b(Z_i)$	A relation that describes snow water equivalent or mass balance, in meters water equivalent, as either varies with glacier-surface altitude, evaluated at altitude Z_i
$\dot{c}$	Accumulation rate
m	Slope of a rating curve segment on a logarithmic plot
n	Number of glacier altitude grid points
p	Discharge when the quantity (S–S_0) equals 1
q	Stream discharge
S	Water stage
S_0	Stage of effective zero stream discharge
$\bar{T}$	Average June-through-September air temperature at the Hut
X	Position in local horizontal coordinate system along the X-axis, which increases from west to east
Y	Position in local horizontal coordinate system along the Y-axis, which increases from south to north
Z	Altitude
Z_i	Altitude of a grid point in a glacier altitude grid

Water, Ice, and Meteorological Measurements at South Cascade Glacier, Washington, Balance Years 2004 and 2005

By William R. Bidlake, Edward G. Josberger, and Mark E. Savoca

Abstract

Winter snow accumulation and summer snow and ice ablation were measured at South Cascade Glacier, Washington, to estimate glacier mass-balance quantities for balance years 2004 and 2005. The North Cascade Range in the vicinity of South Cascade Glacier accumulated smaller than normal winter snowpacks during water years 2004 and 2005. Correspondingly, the balance years 2004 and 2005 maximum winter snow balances of South Cascade Glacier, 2.08 and 1.97 meters water equivalent, respectively, were smaller than the average of such balances since 1959. The 2004 glacier summer balance (-3.73 meters water equivalent) was the eleventh most negative during 1959 to 2005 and the 2005 glacier summer balance (-4.42 meters water equivalent) was the third most negative. The relatively small winter snow balances and unusually negative summer balances of 2004 and 2005 led to an overall loss of glacier mass. The 2004 and 2005 glacier net balances, -1.65 and -2.45 meters water equivalent, respectively, were the seventh and second most negative during 1953 to 2005. For both balance years, the accumulation area ratio was less than 0.05 and the equilibrium line altitude was higher than the glacier. The unusually negative 2004 and 2005 glacier net balances, combined with a negative balance previously reported for 2003, resulted in a cumulative 3-year net balance of -6.20 meters water equivalent. No equal or greater 3-year mass loss has occurred previously during the more than 4 decades of U.S. Geological Survey mass-balance measurements at South Cascade Glacier.

Accompanying the glacier mass losses were retreat of the terminus and reduction of total glacier area. The terminus retreated at a rate of about 17 meters per year during balance year 2004 and 15 meters per year during balance year 2005. Glacier area near the end of balance years 2004 and 2005 was 1.82 and 1.75 square kilometers, respectively.

Runoff from the basin containing the glacier and from an adjacent nonglacierized basin was gaged during all or parts of water years 2004 and 2005. Air temperature, wind speed, precipitation, and incoming solar radiation were measured at selected locations on and near the glacier.

Introduction

Long-term investigation and monitoring of South Cascade Glacier, Washington, are elements of a larger U.S. Geological Survey (USGS) Glacier Monitoring Program with the objective of increasing understanding of the relation of glaciers to climate and the effects of glaciers on water resources and hydrologic hazards (Fountain and others, 1997). A keystone of the USGS Glacier Monitoring Program is the system of Benchmark Glaciers, glaciers singled out for intensive study within distinct glacierized regions of the United States. Each Benchmark Glacier serves as an index site, the concerted investigation and monitoring of which is intended to provide a better understanding of the links between glaciers and climate (Hodge and others, 1998; Rasmussen and Conway, 2004) and effects of glaciers on water resources within the home region of the Benchmark Glacier (Krimmel and Tangborn, 1974; Fountain and Tangborn, 1985). Field-based measurements and analysis for Benchmark Glaciers include glacier mass balance and related glaciological, hydrologic, and meteorological phenomena. Glacier mass balance is the difference between annual accumulation and annual ablation of snow, firn, and ice averaged over the area of the glacier. South Cascade Glacier, the Benchmark Glacier for the extensively glacierized North Cascades region in Washington (Post and others, 1971), is a north-northwest-facing valley glacier that occupies approximately one-third of South Cascade Lake Basin near the crest of the Cascade Range (fig. 1). The USGS South Cascade Glacier dataset now spans more than 4 decades. Glaciologists and climatologists from around the world have used these data extensively in a wide range of studies. Mass-balance data for South Cascade Glacier and other selected glaciers around the world are compiled and published periodically by the World Glacier Monitoring Service (Haeberli and others, 2005). Two other USGS Benchmark Glaciers, Gulkana Glacier and Wolverine Glacier, are in glacierized regions of Alaska (March, 1998 and 2003; Mayo and others, 2004).

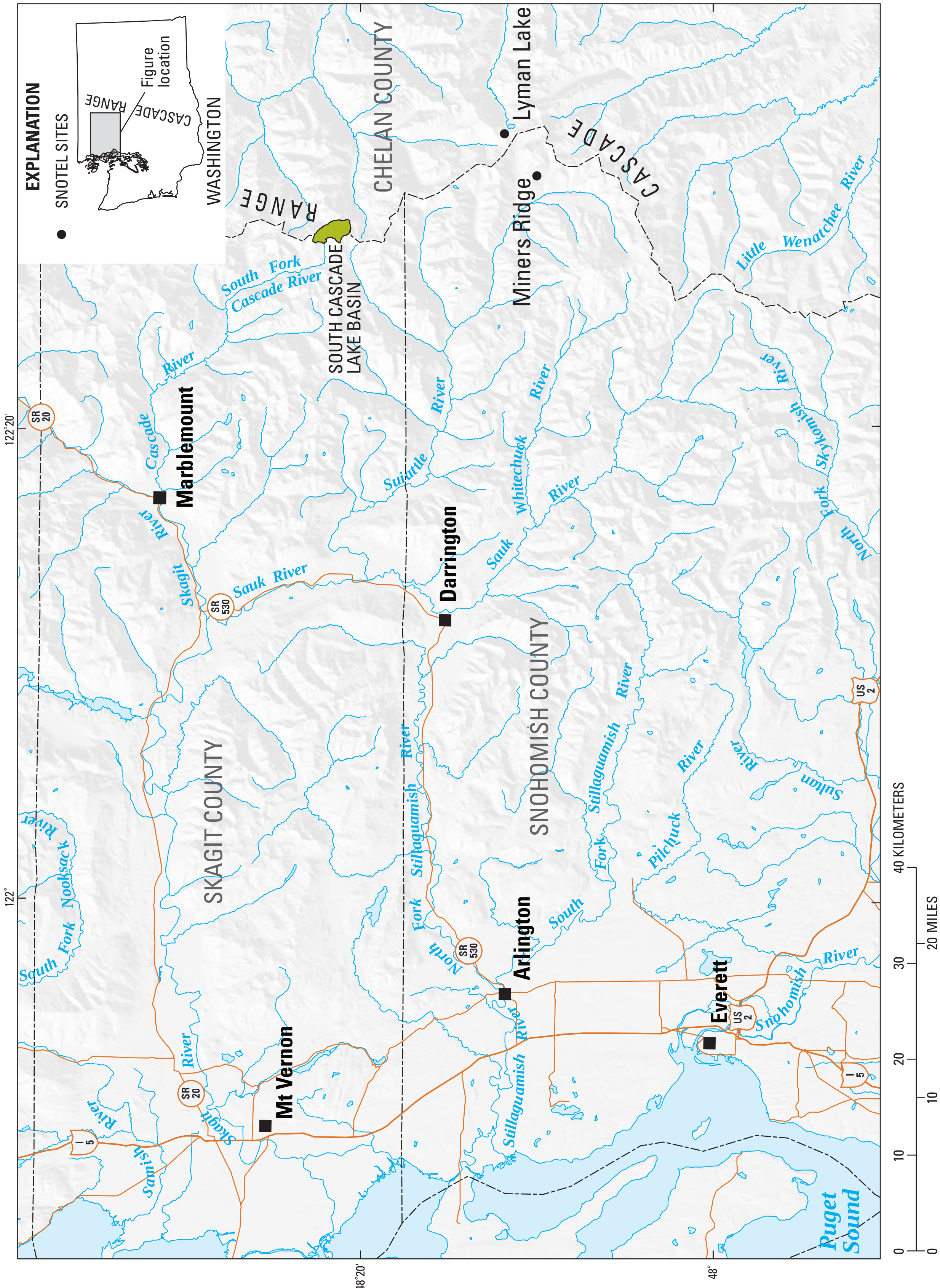


Figure 1. Location of the study area, South Cascade Lake Basin, Washington.

Previous Work

The USGS began intensive study of South Cascade Glacier in 1957 (Meier, 1958), and has since monitored selected glaciological variables, including glacier mass balance and glacier area, as well as selected meteorological and hydrologic variables. Photographs of the glacier taken in 1953 and 1955–57 were used to estimate glacier mass balance for those balance years, and direct glaciological measurements were used to compute mass balance and flow during balance years 1958–64 (Meier and Tangborn, 1965). The balance year is the time between successive annual minima of glacier mass. The annual minimum glacier mass typically occurs in October. Glacier mass-balance studies and some related work for balance years 1965–67 are described by Meier and others (1971) and by Tangborn and others (1977). Hydrologic and meteorological data for 1957–67 are presented by Sullivan (1994). Glacier mass-balance studies for balance years 1959–85 are summarized in Krimmel (1989). Mass-balance studies and related work for balance years 1986–2003 are presented in detail in Krimmel (1993, 1994, 1995, 1996a, 1997, 1998, 1999, 2000, 2001, and 2002) and Bidlake and others (2004 and 2005).

Previous USGS work related to mass balance of South Cascade Glacier indicates the glacier has been losing mass and retreating up its confining valley for more than 4 decades. In 1958, the glacier was about 3.5 km long and occupied an area of 2.71 km^2 (Meier and Tangborn, 1965). Net balance of South Cascade Glacier averaged –0.55 m water equivalent during balance years 1958–2003, and years of negative net balance outnumbered years of positive net balance by a ratio of about 2 to 1 (Bidlake and others, 2005). By 2003, the terminus of the glacier had retreated about 0.6 km from its 1958 position (fig. 2) and the glacier had shrunk to an area of 1.89 km^2 (Bidlake and others, 2005).

Purpose and Scope

This report describes glaciological, hydrologic, and meteorological measurements made at and near South Cascade Glacier during balance years 2004 and 2005, and presents results of those measurements. Glaciological measurements included measurements of snow depth and density, ablation of snow and ice, and photogrammetric measurements of the glacier perimeter and surface altitude. Hydrologic measurements were made to compute runoff from the basin containing South Cascade Glacier and runoff from a nearby, nonglacierized basin. Meteorological measurements included those of air temperature, wind speed, precipitation, and incoming solar radiation.

Description and Climate of Study Area

South Cascade Glacier is at the head of the South Fork of the Cascade River, a tributary to the Skagit River, which flows into Puget Sound about 100 km to the west. The region is dominated by steep terrain, with local relief of more than 1,000 m. Areas within the basin not covered by glacier ice or water are bedrock. The bedrock either is mantled by a thin layer of soil and, in places, with stunted and shrubby conifers, heather, or other vegetation typical of the high North Cascade Range, or is covered by talus, glacial moraines, or glacial outwash material.

South Cascade Lake Basin (fig. 2) has an area of 6.14 km^2, and ranges in altitude from 1,613 to 2,518 m. The area of this basin has been computed previously to be 6.02 km^2 and 6.11 km^2, owing to differing interpretations of the position of the drainage divide. A subbasin of the South Cascade Lake Basin is the 4.46-km^2 Middle Tarn Basin (unofficial name), which constitutes the southern two-thirds of the South Cascade Lake Basin. Virtually all ice melt within South Cascade Lake Basin takes place in Middle Tarn Basin.

Salix Creek Basin is a nonglacierized basin adjacent to South Cascade Lake Basin. It has an area of approximately 0.22 km^2, but its drainage divides are defined poorly. Salix Creek Basin ranges in altitude from 1,587 to 2,140 m and predominantly is south facing.

A local geographic coordinate system for South Cascade Lake Basin described by Krimmel (1994) is used in this report. The Y-axis for the coordinate system is rotated about 1.5 degrees counterclockwise from true north and the Y coordinate increases from south to north. The X-axis is perpendicular to the Y-axis and the X coordinate increases from west to east. Distances are in meters, and the X and Y coordinates can be approximately converted to Universal Transverse Mercator (UTM) zone 10 coordinates by

$$\text{UTM easting} = X \times 0.99985 + 642{,}000, \qquad (1)$$

and

$$\text{UTM northing} = Y \times 0.99985 + 5{,}355{,}000. \qquad (2)$$

The climate of the region is maritime. Near the glacier, typical winter minimum air temperature is about -10°C and typical maximum summer air temperature is about 20°C. Most of the precipitation, which commonly amounts to about 4.5 m annually (Meier and others, 1971), falls as snow during October to May.

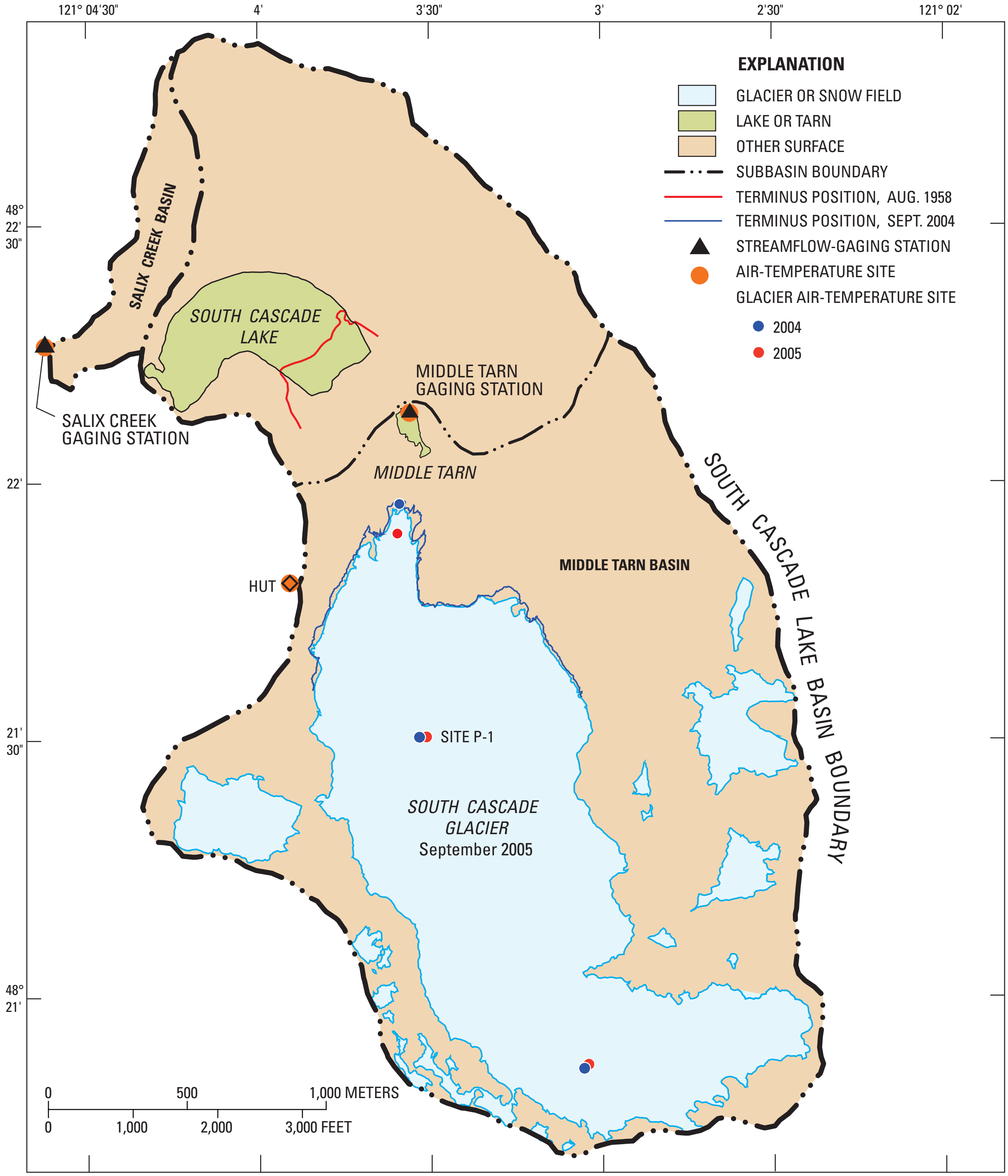


Figure 2. South Cascade Glacier and vicinity, Washington.

Study Methods

Methods of data collection and analysis followed in preparation of this report were similar to those of Bidlake and others (2005). Meteorological and streamflow data were collected predominantly using automated instrument systems. Time-series meteorological and streamflow data were based on Pacific Standard Time. Daily summaries of time-series data were computed assuming that each day ended at midnight. Glaciological measurements for glacier mass balance were made mostly manually during intermittent site visits. These measurements included snow depth and density and height of the glacier surface on ablation stakes that had been installed during April, May, or during the summer of each year. Vertical aerial photography acquired in September was used to produce a map and altitude grid of the glacier near the end of each balance year.

Meteorological and Streamflow Measurements

Air temperature was measured with thermistor-based sensors at the Salix Creek and Middle Tarn gaging stations, at the Hut, and at selected locations over the glacier (fig. 2). Temperature sensors were housed in passively ventilated radiation shields. A self-adjusting sensor mount (Bidlake and others, 2005) was used to maintain air-temperature sensors at a nearly constant 2.0-m height over the glacier surface as it lowered during the summer season. Air temperature was sensed at a height of about 3.5 m above ground at the Salix Creek gaging station and at about 3 m above ground at the Middle Tarn gaging station. Air temperature and wind speed were measured over the roof of the Hut and at a height of about 5 m above ground. Air temperature at the gaging stations and at the Hut was measured every minute and the average was recorded each hour. Air temperature over the glacier was measured and recorded every 10 minutes. Daily minimum and maximum air temperatures presented in this report were the daily extremes of recorded temperature. Wind speed at the Hut was measured every minute using a cup anemometer, and data were averaged and recorded each hour.

Incoming solar radiation was measured at the Hut using a thermopile-based pyranometer as a primary sensor and a photovoltaic-based pyranometer as a backup. The thermopile-based pyranometer was removed temporarily for calibration during part of summer 2004. The backup photovoltaic-based sensor was installed during summer 2004 and it was calibrated using data from the primary sensor. Because of a datalogger programming error, output from the primary sensor exceeded the voltage range of the datalogger when incoming solar radiation was greater than about 920 W/m^2, resulting in erroneous solar radiation data. Data from the backup sensor, when available, were substituted into the incoming solar-radiation record for periods when data from the primary sensor were thought to be unreliable. Solar radiation was measured each minute and averaged and recorded each hour. Daily averages of incoming solar radiation were computed for the 24-hour day.

Precipitation was measured at the Salix Creek gaging station (fig. 2) using an unheated tipping-bucket rain gage with a measurement resolution of 0.254 mm. Precipitation was totaled and recorded each hour. Because the gage was not heated or otherwise equipped to measure precipitation as snow, data are reliable only for periods when precipitation fell as rain at the Salix Creek gaging station.

Runoff from Middle Tarn Basin was computed from discharge of the South Fork of the Cascade River where it empties from Middle Tarn over a mostly bedrock hydrologic control. The stage of Middle Tarn was monitored and recorded at the Middle Tarn gaging station (USGS station number 12181090) every 15 minutes using a submersible pressure transducer on the bed of the tarn. Stage of the tarn also was observed intermittently from a staff gage housed in a stilling well along the shore or from a staff gage that was attached to a large boulder. Recorded stage was corrected as needed on the basis of the intermittent stage measurements.

Intermittent measurements of discharge made with a current meter were used to check and if necessary modify the rating curve describing the relation of stage to discharge at the Middle Tarn gaging station. Two discharge measurements were made at the Middle Tarn gaging station during water year 2004 and one measurement was made during water year 2005. Water year is the 12-month period from October 1 through September 30. The water year is designated in the year in which it ends.

Field measurements of stage and computations of discharge were made using English units to maintain compatibility with measuring equipment and for the convenience of the report author and data reviewers. Because the International System of Units (SI) is the primary system used in this report, however, streamflow quantities are presented in this report using SI units.

Discharge of the river from Middle Tarn was computed from the stage record by applying a rating curve that was developed or modified using intermittent measurements of stage and discharge. The rating curve was based on techniques given by Rantz and others (1982), wherein a rating curve (or a segment of a rating curve) plots as a straight line on a logarithmic graph and can be described by the equation:

$$q = p(S - S_0)^m, \tag{3}$$

where

q is stream discharge, in cubic feet per second;

p is discharge when the quantity $(S - S_0)$ equals 1, in cubic feet per second;

$S - S_0$ is depth of water on the hydrologic control; where

S is stage, in feet; and

S_0 is equal to stage of effective zero stream discharge, in feet;

and

m is slope of a rating curve segment on a logarithmic plot.

The rating curve might be applied to compute discharge directly from stage, or the stage might be "shifted" on the basis of a measured discharge that plots substantially off of the rating curve. Shifting is changing the stage applied to equation 3 from that which is measured to that which makes equation 3 yield discharge that closely approximates measured discharge. The most common rationale for using stage shifts is they are thought to reflect temporary changes in the hydrologic control resulting from scouring and filling of sediments on the control during and after high flows.

The rating curve was developed for ice-free conditions; however, the outlet of Middle Tarn was covered with ice and snow during winter. Because there were no wintertime measurements of discharge to adjust the rating curve for ice- and snow-covered conditions, discharge from Middle Tarn was not computed when such conditions were thought to have existed.

Runoff from nonglacierized Salix Creek Basin was computed in much the same manner as for Middle Tarn Basin. Salix Creek flows under the Salix Creek gaging station (USGS station number 12181200) and is controlled by a weir set on bedrock. The rating curve used for many years (Krimmel, 2002) for the Salix Creek gaging station consists of a single log-linear segment that can be described by the power function

$$q = 2.71S^{2.57}, \tag{4}$$

where all terms have been defined previously.

No discharge measurements were made at the Salix Creek gaging station during water years 2004 and 2005; however, the rating curve was verified with three measurements during water year 2003 that all were within 6 percent of the rating curve (Bidlake and others, 2005).

Glacier Mass Balance and Related Principles

The mass of a glacier, the combined masses of its snow and ice, is constantly changing through the operation of opposing processes of accumulation and ablation. Examples of accumulation processes important for South Cascade Glacier are precipitation in the form of snow, and avalanching or blowing of snow onto the glacier from surrounding terrain. Internal accumulation, caused by freezing of water from snow melt that has percolated into accumulations from previous years, is thought to be of small importance at South Cascade Glacier and is not considered in this report. Ablation is the loss of snow and ice from a glacier. The most important ablative processes at South Cascade Glacier likely operate at or very near the glacier surface: melting of surficial snow and ice, and evaporation. Other much less important ablative processes operate within and at the base of the glacier, such as melting at the contact between the basal glacier ice and the underlying geologic bed, and melt as a result of the kinetic energy of englacial and subglacial flowing water. As a result of the dominant importance of surficial accumulation and ablation processes for grounded, noncalving glaciers in temperate regions, such as present-day South Cascade Glacier, mass balance can be investigated by studying snow and ice near the glacier surface.

The mass balance at a point on a glacier, *b*, for any period of time is given by the equation (Paterson, 1994):

$$b = \int_{t_0}^{t_1} \left(\dot{c} + \dot{a}\right)\, dt, \tag{5}$$

where

t_0 is beginning time of the period;

t_1 is ending time of the period;

$\dot{c}$ is accumulation rate at the point, in meters water equivalent divided by time; and

$\dot{a}$ is ablation rate at the point, in meters water equivalent divided by time.

Thus, increases in mass with time are indicated by positive *b* and decreases in mass with time by negative *b*. All mass balance terms in this report are presented as water-equivalent thickness, with the density of water assumed to equal 10^3 kg/m³. Equation 5 is evaluated in practice by measuring changes in thickness of snow, firn, and ice during specified periods, and by measuring or estimating the density of material that has been gained or lost during each period. Firn is residual snow that has endured at least one melt season without being transformed into ice.

Time periods of most interest at South Cascade Glacier are defined either phenomenologically or by fixed dates. The balance year is the time between successive annual balance minima, and the net balance (b_n) is the change in mass during the balance year (Anonymous, 1969). The beginning of the balance year is defined phenomenologically at the end of summer when accumulation of the winter snow pack begins and forms the summer surface, the reference height that is used to compute accumulation and ablation all during the balance year. The balance year and b_n are components of a “stratigraphic” system of mass-balance measurement and reporting because they are defined with respect to snow, firn, and ice stratigraphic units (Mayo and others, 1972). The stratigraphic system is the primary system of measurement and reporting used in this report.

The balance year can be divided into winter and summer seasons. The winter season begins with the beginning of the balance year, typically in October, is dominated by accumulation, and ends at the time of the greatest annual glacier mass. The summer season follows the winter season, is dominated by ablation, and ends with the conclusion of the balance year. The net balance can thus be partitioned to the winter balance (b_w), the balance for the winter season, and the summer balance (b_s), the balance for the summer season (Anonymous, 1969). Winter melting of ice and firn is thought to be negligibly small at South Cascade Glacier, and b_w is assumed in this report to equal the maximum winter snow balance, b_w(s), the snow balance at the time of maximum snow accumulation during the balance year . The measured winter snow balance, b_m(s), is the winter snow balance computed from snow measurements made approximately at the time of maximum snow accumulation (Mayo and others, 1972). The fixed-dates system used in this report is based on the water year. The water-year mass balance is termed the annual balance (b_a) in this report.

The mass balance of the glacier for any time period is the average of b over the entire area of the glacier. Following the convention given by Mayo and others (1972), mass balance quantities for the entire glacier are indicated with an overbar in this report. For example, the glacier net balance is denoted $\bar{b}_n$. Spatial averaging of local mass balance quantities to obtain glacier quantities is accomplished in this report by the grid-index technique (Krimmel, 1996b), which can be stated using the equation:

$$\bar{b} = \frac{1}{n}\sum_{i=1}^{n} b(Z_i), \qquad (6)$$

where

Z_i is altitude of a grid point in a glacier altitude grid, in meters;

$b(Z_i)$ is a relation that describes snow water equivalent or mass balance, in meters water equivalent, as either varies with glacier-surface altitude, evaluated at altitude Z_i; and

n is the number of glacier altitude grid points.

Snowpack measurements made on South Cascade Glacier near the time of maximum winter snow accumulation each year were used to develop a relation of snow water equivalent (SWE) to altitude that could be used with equation 6 to compute the glacier measured winter snow balance ($\bar{b}_m$(s)). If snowpack measurements were not made at the time of maximum accumulation, glacier maximum snow balance ($\bar{b}_w$(s)) was estimated on the basis of $\bar{b}_m$(s), and observations made before or after the measurements. Winter melting of ice and firn is thought to be neglibibly small, and $\bar{b}_w$(s) is approximately equal to the glacier winter snow balance ($\bar{b}_w$).

Mass balance measurements at selected points on the glacier late in the balance year were used to develop a relation of mass balance to altitude that could be used with equation 6 to compute the glacier net balance ($\bar{b}_n$). The summer balance was then computed as $\bar{b}_n$-$\bar{b}_w$(s). The annual balance ($\bar{b}_a$) was computed from $\bar{b}_n$ using the equation

$$\bar{b}_a = \bar{b}_n + \bar{b}_0 - \bar{b}_1, \qquad (7)$$

where

$\bar{b}_0$ is the glacier initial balance increment, the glacier balance between the time of the beginning of the water year and the beginning of the balance year, in meters water equivalent;

$\bar{b}_1$ is the glacier final balance increment, the glacier balance between the time of the end of the water year and the end of the balance year, in meters water equivalent; and other terms are as defined previously.

Two other glaciological quantities commonly reported in conjunction with mass-balance quantities are equilibrium line altitude (ELA) and accumulation area ratio (AAR). The surface of a classic mountain glacier can be divided into an accumulation area, where net balance is positive, and an ablation zone, where net balance (b_n) is negative. The accumulation area of the classic mountain glacier occupies the uppermost expanses of the glacier and extends down slope where it meets the ablation zone. The division between the accumulation area and ablation zone is the equilibrium line, where net balance is zero, and the ELA is the altitude of the equilibrium line. The AAR is the ratio of the accumulation area to the area of the entire glacier. Many mountain glaciers differ substantially from the classic glacier in that more than one accumulation area and one ablation zone can exist, or an accumulation area can be absent during any given year. The ELA commonly cannot be determined for glacier surfaces comprising multiple accumulation areas and ablation zones.

Glaciological Measurements

Glaciological measurements included measurements of snow depth on the glacier near the time of the maximum winter snow accumulation, measurements of the lowering of the glacier surface due to melt during the summer season, and measurements of snow density. Snow depth near the time of the maximum snow accumulation was measured at selected locations using a flexible probe constructed from 10-mm-diameter radio antenna sections. Measurements of surface lowering were made using ablation stakes installed in holes melted through the snow and ice. Stakes were constructed from 2.0-m-long sections of 32-mm-diameter aluminum tubing. The bottom of each stake was fitted with a wooden or Teflon plug to reduce the amount by which the stake would sink into the glacier under the force of gravity. Lowering of the glacier surface at the stakes was determined from repeated tape measurement of the lengths of the stakes that were exposed during the summer season. A prototype device called a Glacier Ablation Sensor was intermittently deployed to monitor surface lowering automatically (Christopher Roussi, Altarum Institute, written commun., June 2004). The device contained a datalogger and power supply, and it employed an ultrasonic ranger to measure distance to the glacier surface. The device was attached to an ablation stake seated in glacier ice to maintain it in a fixed position relative to that ice.

Density of the snow profile was determined either by using samples taken from the wall of a pit or by using samples extracted from the surface with a specially designed snow corer. Samples taken from a pit wall were obtained using a sampling tube that was pressed or pounded into the snow. Inside diameter of the sampling tube was 72.3 mm. The specially designed corer produced a 60.0-mm-diameter core sample (Philip Taylor, Taylor Scientific Engineering, Seattle Wash., written commun., May 2003). The rim of the bottom end of the corer was serrated and a sawing motion was used to penetrate the snow. Core samples obtained were almost always of uniform diameter with smooth circumferences.

Depth of the core hole typically did not exactly equal the total length of the sample extracted. Hole depth could be greater than the total sample length, which could have been caused by sample compression or settling. Conversely, hole depth could be as much as several centimeters less than the total sample length, which could have been caused by accumulation of snow detached from the hole wall when the sample was pulled to the surface. Although loose scrapings from the wall usually could easily be identified in any subsequent samples brought to the surface, there was no practical means for determining the thickness of snow that had fallen to the bottom of the hole as the final sample was brought to the surface. For this reason, the length of the snow sample was used to compute density, rather than the depth of the hole. Any errors in total-profile density caused by compaction of the snow samples were almost certainly less than 0.01 in all cases.

Photogrammetric Measurements and Glacier Mapping

Color vertical aerial photographs of South Cascade Glacier were obtained on September 10, 2004, and September 21, 2005, using a lens with a 152-mm focal length and film with a width of 230 mm. The camera was mounted in an airplane that flew longitudinally along the glacier. The nominal scale of the photographs was 1:12,000. Diapositives from the photographs were analyzed using a stereo-digitizer system to produce stereo models of the surface of the glacier and of nearby terrain. Measurements made in the models with the stereo-digitizer system were used to delineate the glacier and adjacent snowfields, to produce a glacier altitude grid, and to locate selected features visible on the glacier surface in the local horizontal coordinate system described previously. Stereo-photogrammetric analysis of featureless snow surfaces generally is not reliable, and altitudes of grid points in such regions of the glacier were taken from grids developed during other years when the points could be measured reliably. The nominal horizontal grid spacing of the resulting composite altitude grids was 100 m. Areas of the features delineated by photogrammetric analysis were computed from the coordinates defining the delineations (Bouchard and Moffitt, 1972, p. 237) unless otherwise specified.

Horizontal positions of snow probing and coring sites, ablation stakes, and snow-density-measurement sites were estimated with a global positioning system (GPS) receiver. Local coordinates were computed from UTM northing and easting coordinates read from the GPS receiver. Surface altitude of each coordinate pair was then obtained using photogrammetric measurements. Positions of snow-probing, snow-coring, and density-measurement sites that were associated with an ablation stake were assigned the position of the stake, even though the sites could have been as much as several meters from the stake.

Results and Discussion

The North Cascade Range in the vicinity of South Cascade Glacier accumulated smaller than normal winter snowpacks during water years 2004 and 2005. Maximum SWE at the Miners Ridge SNOTEL site during 2004 was 1.02 m, which was 75 percent of the average maximum for that site (fig. 1; years of record 1989–2005; National Water and Climate Center, 2006). Maximum SWE at the Miners Ridge site during 2005 (0.75 m) was 55 percent as large as the average maximum and was the smallest on record for that site. The Miners Ridge site is west of the crest of the Cascade Range at an altitude of 1,890 m. The Lyman Lake SNOTEL site is east of the crest at an altitude of 1,798 m. Precipitation and snow accumulation typically are greater at the Lyman Lake site than at the at the Miners Ridge site. Maximum SWE at the Lyman Lake site during 2004 was 1.07 m, which was 65 percent of the average maximum for that site (years of record 1980, 1984–2005). Maximum 2005 SWE was 0.91 m, which was 55 percent of the average maximum and the smallest on record for that site. The relatively small North Cascades winter snow accumulations of 2004 and 2005, combined with only an average accumulation in 2003 (Bidlake and others, 2005), set up the potential for substantial loss of ice from South Cascade Glacier by the end of the 2005 summer season.

Water Year 2004 Meteorological and Streamflow Data

Water year 2004 was slightly cooler at South Cascade Lake Basin than the previous year. Average measured air temperature at the Hut during water year 2004 was 2.6°C (table 1), which was 0.4°C less than water year 2003, even though 12 days during the relatively warm summer season were missing from the 2003 record (Bidlake and others, 2005).

Table 1. Daily maximum, minimum, and average of hourly average air temperature at the Hut, 1,842 meters altitude, near South Cascade Lake Basin, Washington, water year 2004.

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average]

Day	Daily air temperature, in degrees Celsius																	
	October			November			December			January			February			March		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	20.2	12.5	14.9	-4.7	-8.4	-6.9	-6.9	0.6	-2.6	-8.4	-10.6	-9.8	-6.9	-9.2	-8.3	-2.5	-5.4	-4.4
2	17.3	12.1	14.4	-8.7	-9.6	-9.0	-9.0	1.7	-5.6	-9.4	-10.9	-10.6	-7.1	-9.7	-8.6	-2.9	-7.0	-5.2
3	17.2	12.5	14.8	-7.5	-11.5	-9.6	-9.6	-6.9	-8.6	-10.4	-16.9	-14.5	.1	-6.2	-3.4	-4.8	-6.2	-5.5
4	19.8	13.2	15.9	-9.3	-12.1	-10.7	-10.7	-.8	-7.9	-15.8	-18.2	-16.9	-3.6	-8.6	-5.9	-5.4	-8.3	-6.6
5	17.0	11.5	13.1	-3.5	-10.1	-7.5	-7.5	-.2	-2.2	-14.1	-17.6	-16.2	.6	-6.7	-2.0	-4.8	-9.3	-7.3
6	14.8	4.6	10.3	.5	-3.9	-1.9	-1.9	-.8	-6.5	-2.0	-16.0	-8.4	-.8	-5.6	-3.3	-3.8	-9.5	-7.3
7	4.7	1.0	2.3	-.5	-3.2	-2.1	-2.1	-5.0	-7.7	-1.3	-2.9	-2.1	-5.0	-7.6	-6.0	2.7	-3.1	1.1
8	4.5	-1.9	1.6	.4	-2.6	-1.2	-1.2	-5.5	-8.2	1.1	-2.2	-.7	-3.4	-7.3	-6.3	10.3	2.1	6.6
9	-.1	-2.1	-1.6	3.5	-1.7	.8	.8	-6.2	-9.2	4.0	-1.0	1.1	1.3	-5.3	-2.4	6.2	-4.6	-.3
10	.9	-2.3	-1.4	-2.1	-3.6	-2.6	-2.6	-5.1	-7.8	.1	-1.7	-1.0	9.5	1.0	3.8	3.6	-5.9	-.7
11	1.6	-2.1	-.3	-1.8	-4.6	-3.6	-3.6	-2.8	-5.0	3.0	-.3	1.8	2.3	-2.5	-.6	8.9	2.2	4.9
12	.4	-2.2	-.6	4.8	-4.3	.5	.5	-3.7	-6.7	3.1	-1.1	.9	5.5	1.7	3.8	2.2	-5.4	-2.4
13	3.4	-1.2	.6	9.4	.1	5.1	5.1	-3.1	-7.2	4.0	-1.4	1.0	5.8	-2.7	2.8	1.5	-4.0	-.3
14	5.2	.4	1.9	1.2	-1.7	-.5	-.5	-6.0	-7.8	3.9	.8	2.5	-2.0	-3.8	-2.8	.1	-3.5	-2.5
15	.3	-2.1	-.8	-.8	-4.4	-2.1	-2.1	-4.1	-7.3	.7	-4.3	-1.4	-1.9	-5.4	-3.8	-2.1	-4.7	-3.8
16	6.2	-1.3	2.9	-3.0	-4.1	-3.5	-3.5	-1.5	-5.6	.9	-6.3	-2.3	-3.2	-6.0	-4.5	-.1	-4.3	-2.0
17	6.7	5.8	6.3	-.7	-5.7	-4.1	-4.1	.9	-5.5	4.0	.6	1.7	-.4	-4.9	-2.9	-.5	-2.8	-1.7
18	10.2	6.5	8.7	1.7	-2.0	.1	.1	4.8	-1.4	1.0	-2.5	-1.1	-1.1	-4.3	-3.0	-.6	-8.3	-4.4
19	6.9	2.9	4.1	1.6	-9.2	-7.0	-7.0	5.6	-.4	-.6	-2.7	-2.0	-1.5	-5.6	-4.1	-6.0	-8.5	-7.4
20	10.0	4.0	8.1	-7.8	-10.4	-9.4	-9.4	-.3	-3.3	1.4	-3.0	-1.5	-1.0	-6.0	-3.1	3.1	-6.0	-2.8
21	13.3	8.5	10.5	-8.4	-14.1	-11.9	-11.9	.2	-3.7	4.9	-1.1	1.4	-1.3	-4.1	-2.9	13.4	3.0	8.3
22	12.7	-2.1	8.4	-7.7	-14.7	-11.6	-11.6	1.7	-5.0	2.7	-4.6	.0	-1.7	-4.9	-3.4	8.6	2.6	4.8
23	-2.3	-4.2	-3.1	-2.1	-6.6	-3.9	-3.9	-2.7	-5.4	.2	-3.4	-1.7	-.7	-3.4	-1.9	2.2	-2.4	-.5
24	5.9	-4.2	.6	-6.9	-9.6	-8.6	-8.6	-2.2	-4.7	-3.9	-9.4	-7.4	-.9	-4.9	-3.0	-.3	-5.8	-3.6
25	13.9	4.3	9.8	-5.9	-7.7	-6.6	-6.6	-4.8	-9.5	-8.1	-9.7	-9.1	-3.8	-6.2	-5.0	-1.9	-5.6	-3.7
26	14.7	8.1	12.0	-6.2	-7.1	-6.7	-6.7	-9.0	-11.8	-4.2	-7.9	-5.8	-2.0	-5.1	-3.2	-2.6	-5.8	-4.2
27	7.8	2.9	4.6	-1.7	-7.0	-5.4	-5.4	-7.9	-10.0	-3.6	-4.6	-4.3	1.7	-4.2	-2.5	-3.2	-4.8	-3.9
28	5.2	-5.6	1.4	-.5	-3.4	-1.3	-1.3	-9.1	-11.9	-1.2	-4.7	-2.8	.4	-4.9	-3.3	3.7	-5.3	.7
29	-2.9	-6.5	-5.1	-.4	-5.3	-2.5	-2.5	-9.7	-12.6	-.3	-2.5	-1.1	-2.1	-6.1	-4.6	7.1	.0	4.2
30	-6.8	-10.4	-9.0	1.2	-3.7	-1.2	-1.2	-7.1	-10.9	-.7	-8.4	-6.3				6.0	-7.9	-1.8
31	-6.5	-11.7	-8.8				-6.6	-8.7	-7.9	-6.7	-9.3	-8.4				-3.4	-9.3	-6.9
Monthly average	7.2	1.6	4.4	-2.2	-6.4	-4.5	-3.1	-6.8	-5.0	-1.8	-5.9	-4.0	-0.8	-5.1	-3.1	1.1	-4.6	-1.9

Table 1. Daily maximum, minimum, and average of hourly average air temperature at the Hut, 1,842 meters altitude, near South Cascade Lake Basin, Washington, water year 2004.—Continued

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average]

Day	Daily air temperature, in degrees Celsius																	
	April			May			June			July			August			September		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	0.5	-8.5	-3.2	14.2	7.0	10.9	5.7	-1.3	2.6	16.2	8.1	11.9	18.7	10.6	14.7	12.3	-0.1	3.7
2	6.1	-.8	2.6	7.3	2.6	4.7	12.4	2.1	7.2	13.0	6.4	9.4	17.5	8.4	13.6	2.6	-.3	1.0
3	10.1	2.8	5.0	8.3	2.6	4.5	16.7	8.3	11.6	10.1	5.5	7.4	12.1	7.4	9.5	6.2	2.4	4.0
4	5.3	-.9	2.4	2.6	-1.8	.6	18.3	8.5	12.9	12.0	4.9	8.0	14.2	7.3	10.6	5.0	3.3	4.0
5	7.7	-.6	3.4	3.3	-3.4	-1.1	9.0	.2	3.7	15.4	6.5	11.9	9.2	5.8	6.8	6.0	3.0	4.3
6	10.0	2.0	6.0	9.7	-2.5	4.3	5.4	-1.2	1.5	9.0	3.3	7.4	9.0	4.0	6.5	12.2	3.3	7.9
7	1.6	-1.7	-.1	7.4	1.2	4.3	5.6	.7	3.0	2.0	-0.3	.9	10.0	4.9	7.4	11.2	5.2	8.4
8	6.3	-3.1	1.2	1.7	-.9	.6	14.7	6.2	9.2	7.0	1.4	4.3	16.2	8.6	12.7	9.0	4.6	7.1
9	8.7	1.3	4.9	2.4	-1.2	.1	11.4	5.0	7.4	8.6	3.8	5.8	21.2	12.2	16.1	6.3	4.0	4.7
10	9.3	4.7	6.8	2.4	-1.6	-.2	4.7	-.4	1.6	4.6	2.2	3.4	21.1	15.4	18.0	11.0	3.9	7.9
11	12.5	4.8	8.0	3.0	-1.9	.3	.9	-1.3	-.1	10.9	2.3	6.1	22.8	17.8	19.9	9.5	2.1	4.8
12	9.7	1.2	6.9	4.2	-1.5	1.3	5.5	-1.4	1.8	17.0	10.2	13.7	24.6	18.9	21.1	3.1	.9	2.1
13	4.4	-1.1	.8	7.8	-.6	2.9	1.9	-.9	.9	17.7	11.9	15.4	25.1	20.1	22.1	3.7	1.5	2.5
14	.6	-3.3	-1.7	9.7	1.6	5.0	1.6	-1.9	-.6	22.2	14.1	17.2	25.8	18.0	21.4	1.8	.0	1.0
15	.8	-3.7	-2.0	7.7	.4	3.7	8.7	-2.2	4.1	17.9	9.9	14.9	22.4	15.7	19.4	4.7	2.4	3.7
16	3.2	-3.4	-1.3	4.2	.0	1.7	16.3	6.6	11.2	19.3	9.3	15.0	22.5	13.8	18.2	3.5	.7	1.7
17	3.9	-3.9	-1.3	9.5	3.4	5.9	16.9	9.0	12.1	23.7	15.4	19.1	16.0	11.8	13.3	3.9	.3	1.5
18	3.8	-3.4	-1.5	11.6	4.6	7.6	13.2	7.5	10.3	18.9	12.6	16.3	18.9	11.9	15.7	.8	-1.3	-.1
19	2.5	-2.7	-.3	10.2	3.7	6.3	15.9	9.7	12.4	14.4	8.1	11.8	20.7	13.7	17.4	2.2	-.6	.3
20	1.4	-4.1	-2.2	11.2	4.1	8.3	17.7	9.8	13.8	9.8	6.2	7.5	15.7	10.0	13.4	.7	-.9	-.2
21	4.0	-3.4	-.3	4.0	.5	2.9	19.8	13.1	16.8	16.3	6.2	12.0	14.7	8.8	10.5	6.7	-.8	3.0
22	10.0	-.5	4.6	4.8	-.4	1.3	21.3	15.6	18.5	22.0	12.7	16.8	8.7	4.0	5.4	8.4	4.3	6.8
23	5.0	-4.2	-.5	7.4	.5	2.9	22.8	17.0	19.7	21.5	15.7	18.8	5.9	3.7	5.0	9.8	4.8	6.3
24	3.5	-4.9	-.4	8.7	2.9	5.7	22.8	13.1	18.9	23.5	16.9	19.9	6.4	3.8	5.5	15.9	9.8	12.0
25	11.1	3.1	8.2	7.8	2.2	4.4	19.6	9.5	15.6	17.3	10.0	15.0	4.8	2.0	4.0	16.3	8.3	11.8
26	15.3	9.6	11.9	4.1	1.8	3.2	9.3	6.1	7.5	16.4	8.9	12.5	7.0	4.5	5.7	16.4	7.6	11.8
27	9.2	-4.9	.5	3.9	-1.0	1.3	11.7	5.2	8.3	17.4	10.8	14.4	6.5	5.4	6.0	18.9	12.5	14.7
28	4.0	-3.7	.2	1.6	-1.6	-.6	15.4	6.8	11.2	20.8	13.5	16.8	7.7	5.6	6.7	16.6	9.8	14.3
29	10.3	1.9	6.9	2.3	-2.2	-.3	17.3	10.3	14.2	18.2	10.7	15.2	13.4	7.2	10.1	9.8	4.9	7.7
30	14.0	6.3	9.6	1.0	-1.3	.1	15.9	9.5	12.4	15.4	10.7	13.0	17.0	9.4	13.2	11.8	6.0	8.1
31				4.8	-1.6	.8				17.5	8.6	13.5	17.3	12.6	14.9			
Monthly average	6.5	-0.8	2.5	6.1	0.5	3.0	12.6	5.6	9.0	15.4	8.6	12.1	15.3	9.8	12.4	8.2	3.4	5.6

Average annual air temperature at the Middle Tarn and Salix Creek gaging stations (tables 2 and 3) was 3.3°C and 4.0°C, respectively, which was 0.4°C and 0.7°C less than the previous year. The minimum recorded air temperature at the Hut during water year 2004 was -18.2°C on January 4, 2004, and the maximum was 25.8°C on August 18, 2004 (fig. 3). December was the coldest month at the Hut, when average temperature was below 0°C for 28 of 31 days, and average air temperature was -5.0°C. August was the warmest month at the Hut, as typically has been the case, when air temperature averaged 12.4°C.

Table 2. Daily maximum, minimum, and average of hourly average air temperature at the Middle Tarn gaging station, 1,631 meters altitude, Middle Tarn Basin, Washington, water year 2004.

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average]

Day	Daily air temperature, in degrees Celsius																	
	October			November			December			January			February			March		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	15.3	11.3	13.8	-3.3	-6.5	-5.2	2.3	-0.2	1.0	-6.7	-10.1	-8.2	-3.3	-7.9	-6.5	-0.5	-6.1	-2.8
2	16.3	9.4	12.6	-6.4	-7.6	-7.0	4.1	-4.2	2.1	-7.3	-10.2	-9.0	-4.3	-7.9	-6.5	-1.4	-7.8	-5.2
3	15.7	12.4	14.0	-6.0	-9.4	-7.8	-2.9	-8.9	-6.3	-8.3	-15.7	-13.0	1.4	-3.8	-1.9	-2.8	-5.3	-3.8
4	15.8	10.6	13.2	-6.5	-10.1	-8.5	2.9	-6.7	-3.2	-13.1	-17.3	-15.3	-1.3	-8.6	-4.5	-3.6	-8.2	-5.1
5	13.6	9.3	11.0	-3.2	-7.9	-5.3	2.8	-.5	1.1	-12.3	-16.4	-14.5	1.3	-8.6	-2.3	-2.7	-7.4	-5.2
6	14.4	6.7	10.3	1.6	-4.7	-.9	1.3	-6.7	-4.1	.2	-13.4	-6.1	1.6	-3.6	-1.3	-1.2	-8.0	-5.1
7	6.9	2.4	4.2	1.3	-1.6	-.3	-3.4	-6.4	-4.3	.0	-1.6	-.6	-3.6	-6.0	-4.5	4.6	-.4	3.0
8	6.6	.4	3.6	2.6	.0	1.3	-4.0	-8.3	-5.5	4.1	-.4	1.4	-2.4	-7.3	-5.4	10.6	3.3	6.8
9	1.1	-.6	.4	4.1	.1	2.4	-4.1	-6.5	-5.4	7.4	.4	4.2	.7	-4.8	-2.8	8.5	-3.3	1.8
10	2.3	-1.0	.1	-.1	-1.9	-.7	-3.5	-5.9	-4.7	1.8	-1.8	.5	9.8	-3.8	2.5	7.7	-5.4	.6
11	3.7	-.7	1.6	-.8	-3.0	-2.1	-.6	-3.5	-1.9	5.3	-.1	2.8	4.0	-.3	1.7	9.1	1.7	4.8
12	2.9	-.6	1.2	3.2	-3.7	.2	-1.5	-5.4	-3.3	7.1	.2	3.2	6.9	2.3	4.3	3.8	-5.5	-.7
13	5.0	.0	2.2	7.8	1.0	3.8	-1.1	-4.9	-3.2	6.3	1.3	3.2	7.7	-2.0	2.8	4.3	-5.2	1.2
14	6.1	.9	2.9	2.8	.4	1.4	-4.5	-5.6	-5.1	6.1	2.1	4.2	-.4	-2.5	-1.2	2.3	-3.2	-.7
15	2.7	.1	1.3	2.5	-2.1	.1	-2.0	-5.9	-4.1	3.1	-4.3	.2	-.2	-3.0	-1.8	.5	-3.8	-2.4
16	8.5	.5	5.4	-.9	-1.7	-1.3	.9	-3.7	-1.0	2.9	-5.9	-1.1	.5	-5.0	-2.3	2.2	-3.2	-.5
17	9.3	8.4	8.9	1.1	-3.7	-2.1	2.0	-4.1	-1.0	4.5	-.1	2.0	1.9	-3.6	-1.0	2.3	-1.4	.3
18	12.5	9.3	11.1	3.8	-.4	2.1	8.2	.2	4.3	2.4	-.8	.5	.7	-2.8	-1.1	2.7	-6.2	-2.1
19	9.0	4.5	6.1	3.7	-7.6	-5.4	10.0	.2	4.7	1.8	-3.9	-1.2	.2	-6.0	-3.2	-4.0	-8.2	-5.9
20	12.7	5.0	10.6	-5.8	-10.0	-8.1	1.7	-1.0	.3	1.1	-3.4	-2.2	1.4	-5.6	-1.7	6.0	-4.3	-.4
21	15.6	10.5	12.1	-8.3	-13.8	-11.3	-.3	-3.3	-1.6	3.9	-3.0	.6	1.2	-2.8	-.5	12.1	5.6	8.8
22	15.7	-.8	9.4	-7.3	-14.4	-10.5	2.8	-3.3	.0	4.2	-3.2	1.6	1.4	-3.6	-1.1	9.8	3.6	5.8
23	-.4	-3.7	-1.8	.1	-5.8	-2.3	-.2	-3.9	-2.2	1.9	-1.9	-.3	2.8	-1.1	.3	4.4	-.9	1.5
24	5.1	-4.0	0.9	-5.3	-8.3	-7.0	2.3	-3.1	-.9	-2.4	-7.7	-5.8	1.3	-3.9	-.8	2.1	-4.1	-1.4
25	10.7	3.5	7.6	-3.9	-5.6	-4.8	-2.7	-7.9	-4.9	-6.4	-8.3	-7.8	-1.9	-5.0	-3.0	.1	-4.9	-1.7
26	15.1	7.6	10.7	-4.4	-5.8	-5.2	-6.4	-12.0	-9.2	-2.4	-6.1	-3.8	.7	-2.9	-1.2	-.9	-4.5	-2.4
27	8.9	4.3	5.9	.7	-6.7	-3.2	-5.3	-9.2	-6.9	-1.4	-3.2	-2.5	5.0	-3.9	-1.0	-.9	-3.3	-2.3
28	6.9	-3.5	3.3	1.4	-1.0	.6	-7.3	-12.0	-8.9	1.0	-2.4	-.5	3.8	-4.0	-2.0	8.4	-5.6	2.6
29	-1.8	-4.5	-3.3	1.3	-4.5	-1.0	-7.6	-12.5	-10.6	1.9	-.9	.6	-.1	-6.7	-2.8	12.2	4.2	8.3
30	-4.9	-8.2	-6.8	2.2	-2.6	-0.3	-5.9	-10.8	-9.0	1.7	-6.7	-4.5				6.0	-6.3	-.2
31	-4.4	-9.5	-6.9				-4.4	-7.4	-6.1	-5.7	-7.7	-6.7				.9	-7.4	-4.7
Monthly average	8.0	2.6	5.3	-0.7	-5.0	-2.9	-0.9	-5.6	-3.2	0.1	-4.9	-2.5	1.3	-4.3	-1.7	3.3	-3.6	-0.2

Table 2. Daily maximum, minimum, and average of hourly average air temperature at the Middle Tarn gaging station, 1,631 meters altitude, Middle Tarn Basin, Washington, water year 2004.—Continued

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average]

Day	Daily air temperature, in degrees Celsius																	
	April			May			June			July			August			September		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	3.8	-8.8	-2.1	12.4	7.8	9.8	6.0	0.6	3.7	17.8	7.8	11.6	19.4	9.1	12.9	11.0	0.9	5.0
2	8.5	.7	4.7	8.7	3.1	6.1	11.8	1.8	6.8	13.0	7.9	9.6	19.4	9.8	13.5	4.2	.2	2.5
3	10.5	5.1	7.0	8.8	2.7	5.1	13.7	8.7	11.3	12.2	6.4	8.9	13.6	7.8	10.2	7.5	3.0	5.5
4	7.7	-.1	3.6	4.7	-.6	2.3	14.6	7.3	10.4	13.5	5.8	8.4	15.1	6.9	10.1	6.7	4.8	5.5
5	9.2	-.2	2.9	6.7	-2.6	.3	8.2	2.4	5.0	17.0	5.5	10.7	9.3	5.9	7.7	8.5	4.3	6.0
6	11.2	-2.0	4.7	9.5	-1.7	5.3	5.9	-.1	2.9	10.2	4.7	8.5	11.3	5.7	8.1	12.5	3.8	7.4
7	3.0	.2	1.4	7.8	2.3	4.9	6.3	1.5	3.4	4.1	.9	2.8	9.7	6.5	7.8	13.4	5.3	8.3
8	6.9	-2.2	2.3	4.8	.1	2.2	12.4	2.9	8.9	9.4	2.9	5.8	15.6	9.2	13.3	10.6	6.2	8.2
9	7.3	2.8	4.8	5.1	-.1	1.9	8.9	5.2	6.7	9.3	4.4	6.4	16.8	14.1	15.1	8.5	5.0	6.6
10	10.0	5.3	8.2	4.0	-.7	1.0	5.7	.9	3.1	6.6	4.0	5.0	22.5	12.0	15.5	12.7	4.3	8.7
11	11.0	7.0	8.7	4.8	-.9	1.6	1.9	-.2	1.0	10.3	3.9	6.7	19.5	13.7	15.9	11.8	3.7	7.0
12	9.6	1.7	6.0	7.8	-1.0	3.1	5.4	.6	3.1	16.6	9.0	13.7	20.8	14.7	17.0	5.2	2.5	3.8
13	4.8	.6	2.2	8.8	-.3	3.6	4.2	.8	3.0	16.5	12.2	13.7	21.8	15.4	17.5	5.5	3.1	4.0
14	1.8	-2.9	-.4	10.1	1.1	5.4	2.0	-.4	.8	18.4	11.7	14.9	22.1	14.6	17.6	3.4	1.8	2.9
15	3.5	-3.5	-.6	6.9	1.3	4.0	10.0	-1.2	4.8	18.9	9.1	13.1	16.9	12.6	14.9	6.8	4.5	5.9
16	5.3	-2.5	.2	4.2	1.2	2.4	12.4	6.4	9.8	17.9	7.7	12.6	16.9	11.3	14.2	5.4	2.6	3.7
17	6.9	-3.6	.3	10.3	3.1	6.8	14.3	8.9	12.0	17.3	13.5	15.5	16.3	9.7	11.7	5.3	2.0	3.3
18	5.9	-2.4	.2	12.1	4.1	7.1	13.6	8.6	10.9	17.1	11.3	13.8	18.4	9.4	13.1	2.4	.1	1.4
19	5.4	-2.2	1.8	9.0	3.3	5.4	13.3	7.4	10.5	15.2	10.2	12.3	19.1	11.2	14.2	3.1	.4	1.8
20	3.4	-3.3	-.8	11.0	3.9	7.5	17.1	8.9	11.9	11.9	6.9	9.3	17.9	9.6	13.6	3.0	.2	1.4
21	6.1	-3.8	1.3	4.9	2.5	3.4	17.9	10.8	13.8	17.3	6.1	10.5	13.8	8.9	10.8	9.0	1.2	4.6
22	10.4	.5	5.1	4.6	1.1	2.4	17.4	11.9	14.6	17.1	11.8	14.7	10.6	5.6	6.9	8.9	5.2	6.8
23	6.5	-2.6	1.4	8.1	1.5	3.7	18.9	13.3	16.0	19.8	13.4	16.7	7.7	4.9	6.1	8.5	5.6	7.0
24	7.4	-3.0	1.4	9.1	3.0	5.9	17.9	9.2	14.4	24.8	14.0	17.9	8.4	5.8	6.7	12.1	8.2	10.0
25	10.5	1.0	7.3	8.8	3.2	5.3	13.8	6.5	10.6	19.4	8.9	14.4	7.4	3.5	5.7	13.9	8.0	10.4
26	13.0	7.3	10.1	5.6	2.8	4.1	9.4	6.0	7.5	18.0	8.0	11.7	8.2	5.6	6.8	12.8	6.3	9.9
27	10.4	-3.3	2.2	5.0	.1	2.5	12.8	5.5	8.5	18.6	9.4	13.3	7.8	5.7	6.9	14.4	11.0	12.6
28	7.1	-2.9	2.1	2.4	-.4	1.0	15.7	6.4	10.0	21.3	11.3	14.6	9.3	6.7	8.1	18.2	8.4	12.8
29	11.1	1.1	7.1	3.6	-.9	1.2	16.7	8.8	11.9	19.8	9.9	14.1	15.1	7.3	10.4	11.8	5.1	7.9
30	12.4	8.0	9.7	3.2	-.1	2.0	13.9	8.1	10.5	18.3	9.3	12.8	16.1	8.5	11.5	11.5	4.4	8.2
31				6.3	-.5	2.1				19.4	7.7	12.2	19.2	11.0	14.1			
Monthly average	7.7	-0.3	3.4	7.1	1.2	3.9	11.4	5.3	8.3	15.7	8.2	11.5	15.0	9.1	11.5	9.0	4.1	6.3

Table 3. Daily maximum, minimum, and average of hourly average air temperature at the Salix Creek gaging station, 1,587 meters altitude, Salix Creek Basin, Washington, water year 2004.

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average]

Day	Daily air temperature, in degrees Celsius																	
	October			November			December			January			February			March		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	21.2	12.7	15.7	-2.2	-6.8	-4.9	2.6	0.3	1.3	-6.9	-9.4	-8.1	-5.1	-7.8	-7.0	0.0	-5.2	-2.4
2	20.1	10.9	15.0	-6.1	-7.6	-6.8	3.5	-3.9	1.8	-7.6	-9.5	-8.8	-4.2	-7.5	-6.1	-1.7	-6.5	-4.5
3	20.3	13.3	16.1	-5.4	-9.3	-7.6	-5.1	-8.1	-6.1	-8.4	-15.9	-12.7	-.2	-3.5	-2.0	-2.1	-4.7	-3.5
4	22.1	12.7	15.9	-6.1	-9.8	-8.2	2.0	-6.4	-3.8	-14.3	-17.3	-16.3	-1.5	-8.4	-4.3	-1.6	-7.8	-4.3
5	17.7	10.6	13.3	-2.4	-8.6	-5.5	2.0	-1.0	.3	-11.7	-15.2	-13.7	1.3	-8.0	-1.6	-2.6	-7.4	-5.3
6	17.0	6.6	11.9	2.9	-3.5	-.4	1.2	-6.5	-4.1	-.3	-12.7	-6.4	1.3	-3.5	-1.2	-2.8	-7.7	-5.2
7	6.7	2.9	4.2	2.0	-.7	.5	-3.5	-5.7	-4.2	-.3	-1.5	-.8	-3.3	-5.8	-4.3	4.7	-1.3	2.9
8	6.4	-.3	3.4	2.8	.4	1.7	-3.8	-7.0	-5.1	3.3	-.8	.4	-2.9	-7.3	-5.2	9.6	4.1	7.3
9	1.0	-.6	.0	6.2	.1	3.0	-3.6	-5.6	-4.9	6.4	.4	3.4	1.2	-5.2	-1.9	8.9	-3.1	2.2
10	3.5	-.8	.3	.0	-1.9	-.9	-3.5	-5.2	-4.4	1.5	-1.2	.4	6.7	-.6	3.5	4.8	-4.1	.8
11	3.1	-.4	1.7	-.6	-3.1	-2.0	-.8	-3.4	-1.9	4.9	.1	2.8	3.2	.0	1.4	7.7	2.6	5.0
12	2.6	-.5	1.0	3.7	-3.9	-.3	-1.8	-5.1	-3.5	5.1	.5	3.2	5.9	2.6	3.9	4.4	-4.4	-.4
13	4.0	-.1	2.0	8.1	2.3	4.7	-1.6	-4.8	-3.5	4.8	.9	2.7	6.9	-1.3	3.1	3.2	-4.2	.8
14	7.8	.6	3.4	2.9	.6	1.5	-4.5	-5.5	-5.0	5.1	2.3	3.9	-.1	-2.4	-1.1	2.6	-2.4	-.5
15	2.8	-.6	1.0	1.5	-2.2	-.1	-2.0	-5.7	-4.3	2.9	-3.3	.3	.0	-2.6	-1.7	1.3	-3.1	-1.9
16	8.8	-.4	4.5	-1.2	-2.3	-1.7	.3	-4.5	-1.5	1.3	-4.4	-.8	-1.6	-3.9	-2.5	2.2	-2.9	-.5
17	9.2	8.1	8.7	.0	-3.8	-2.6	1.1	-4.9	-1.9	3.6	.9	2.1	1.8	-3.2	-1.4	2.0	-1.4	.2
18	12.9	8.7	10.9	3.9	-.7	1.8	6.4	.7	4.2	2.5	-.7	.5	.6	-2.7	-1.3	2.7	-6.2	-2.1
19	9.2	4.8	6.1	3.9	-7.4	-5.1	8.2	.4	4.2	1.0	-2.2	-.9	.0	-5.5	-2.9	-3.5	-7.1	-5.6
20	12.2	5.7	9.9	-7.3	-9.4	-8.1	1.0	-1.1	.2	-0.3	-2.4	-1.5	.5	-5.7	-2.0	4.8	-5.4	-.5
21	15.7	10.4	12.6	-8.6	-13.3	-11.1	.1	-2.2	-1.2	3.4	-1.7	1.1	.7	-2.0	-.7	13.2	5.2	9.1
22	13.7	-.5	9.8	-7.1	-13.6	-10.0	3.6	-1.0	.8	4.8	-3.0	2.0	.2	-2.6	-1.2	8.8	3.9	5.9
23	-.1	-2.8	-1.4	-1.1	-5.8	-2.8	.3	-2.4	-1.4	2.0	-1.9	-.2	2.1	-1.7	.3	4.0	-.8	1.7
24	6.1	-2.7	1.7	-5.2	-8.0	-6.9	-.2	-3.0	-1.7	-2.4	-7.4	-5.6	1.6	-3.6	-.8	1.7	-4.2	-1.7
25	11.8	4.2	8.5	-4.2	-6.3	-5.1	-2.8	-7.6	-4.7	-6.5	-8.0	-7.4	-1.5	-4.7	-3.1	.1	-5.1	-1.9
26	18.5	9.0	12.4	-4.4	-5.6	-5.1	-5.9	-10.8	-8.7	-2.8	-6.4	-4.2	1.7	-2.4	-1.0	-.4	-4.2	-2.4
27	9.6	4.7	6.3	.6	-6.9	-3.4	-5.8	-9.0	-7.1	-1.2	-3.1	-2.6	.8	-3.2	-1.4	-.3	-3.0	-2.0
28	6.9	-3.3	3.2	.8	-1.6	.1	-7.1	-11.6	-8.9	.4	-3.0	-.8	2.2	-3.7	-1.8	6.3	-5.4	2.2
29	-1.2	-4.5	-3.1	1.1	-3.5	-.9	-9.2	-11.4	-10.4	1.9	-.5	.5	-.4	-4.9	-2.6	10.0	3.3	6.9
30	-5.0	-7.9	-6.4	1.8	-1.5	.1	-7.0	-9.6	-8.6	.6	-6.7	-4.6				6.4	-6.2	.1
31	-2.6	-9.4	-6.5				-5.3	-7.0	-6.2	-4.9	-7.6	-6.7				-.9	-7.6	-4.8
Monthly average	9.1	2.9	5.9	-0.7	-4.8	-2.9	-1.3	-5.1	-3.2	-0.4	-4.5	-2.5	0.6	-3.8	-1.6	3.0	-3.3	-0.1

Table 3. Daily maximum, minimum, and average of hourly average air temperature at the Salix Creek gaging station, 1,587 meters altitude, Salix Creek Basin, Washington, water year 2004.—Continued

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average]

Day	Daily air temperature, in degrees Celsius																	
	April			May			June			July			August			September		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	1.6	-7.4	-2.6	13.2	9.0	10.8	7.1	1.0	4.0	20.0	8.9	14.1	22.8	10.7	16.3	12.5	1.0	5.2
2	8.4	-1.0	4.5	9.9	3.8	7.0	11.1	3.2	7.6	16.1	8.3	11.4	21.7	10.2	15.7	4.6	.4	2.9
3	12.0	5.6	7.5	9.6	3.6	5.8	16.2	9.1	11.8	13.7	7.4	10.2	15.2	9.3	11.8	9.3	3.9	6.2
4	5.7	.5	3.1	4.8	-.5	2.4	16.2	8.8	11.9	16.0	6.7	10.3	17.0	8.4	12.1	7.5	5.0	6.0
5	6.6	.1	2.8	4.4	-1.9	.7	9.7	2.4	5.6	18.9	6.6	13.3	10.5	6.9	8.5	10.2	4.7	6.7
6	9.4	-1.5	4.9	8.8	-.8	5.0	7.0	-.1	3.2	11.9	5.1	9.4	11.9	5.8	8.2	15.3	4.5	9.3
7	4.0	.4	1.9	8.1	2.5	5.5	7.4	1.8	3.9	5.7	1.2	3.3	13.4	6.7	9.3	16.1	5.9	10.4
8	6.2	-1.8	2.4	7.0	.2	2.9	14.5	3.5	9.9	11.8	3.2	6.8	20.0	9.0	15.2	11.8	6.9	8.9
9	7.7	2.1	5.2	5.7	-.1	2.1	11.6	6.3	8.1	11.5	5.5	7.9	22.7	14.3	17.8	8.7	5.7	6.8
10	9.6	4.9	8.0	4.4	-.5	1.5	6.1	1.1	3.4	7.7	4.0	5.5	24.5	14.3	18.5	14.4	5.0	9.5
11	11.5	7.2	9.1	5.2	-.8	1.8	2.5	.0	1.4	12.9	4.0	8.2	26.2	16.0	20.0	11.5	3.9	7.1
12	9.4	2.0	6.5	10.4	-.2	3.9	7.2	.7	3.8	20.3	10.2	15.8	26.9	17.4	20.8	6.4	2.8	4.3
13	6.8	.7	2.6	7.4	.7	3.9	4.9	.7	3.2	22.1	13.2	16.6	28.0	17.9	21.7	5.3	3.1	4.1
14	2.0	-2.1	-.3	12.4	2.4	5.9	2.9	-.3	1.1	22.7	13.6	17.8	25.7	17.2	21.0	4.1	1.7	3.0
15	3.9	-3.0	-.3	7.9	1.9	4.6	13.3	-.6	6.4	22.1	11.3	16.1	26.4	15.1	19.5	7.1	3.0	5.7
16	3.9	-1.9	.2	4.2	1.4	2.7	14.7	7.4	11.6	23.6	8.9	16.0	23.9	14.1	18.5	5.5	2.5	3.6
17	6.4	-2.8	.3	10.6	3.5	7.0	16.4	10.7	13.5	23.7	15.1	18.5	19.5	12.1	14.7	6.7	2.3	3.5
18	3.5	-1.9	-.1	14.4	5.7	8.3	16.5	9.8	12.5	22.2	12.9	16.7	23.0	11.9	16.9	3.1	.4	1.6
19	4.9	-1.5	1.6	9.3	4.1	6.0	18.0	9.2	13.1	16.1	10.4	13.6	23.1	13.5	17.5	4.1	.5	2.1
20	4.3	-2.4	-.5	11.2	4.7	8.0	22.2	10.2	14.6	14.4	8.6	10.2	19.6	10.8	15.4	4.0	.4	1.7
21	4.6	-2.7	1.5	6.5	2.5	4.0	22.3	12.8	16.6	19.9	7.5	13.8	17.5	10.6	12.1	11.3	.6	5.2
22	9.3	1.0	5.1	4.8	1.0	2.5	20.7	14.5	17.7	23.5	13.7	18.3	10.7	5.8	7.4	11.7	5.6	7.9
23	7.2	-2.8	1.6	7.1	1.8	3.8	22.0	15.7	18.6	24.9	15.6	20.1	8.2	5.2	6.8	11.1	6.2	8.0
24	5.3	-2.9	.8	9.9	3.9	6.6	22.0	10.4	17.5	27.1	16.8	21.2	8.3	5.8	7.2	18.6	9.5	12.5
25	11.1	1.4	8.0	11.0	3.7	6.1	18.5	7.2	13.3	21.8	10.3	16.6	6.9	3.8	5.8	18.7	9.1	12.8
26	16.5	8.8	11.3	6.9	3.1	4.7	12.1	7.3	9.3	20.3	8.9	14.3	9.7	6.4	7.6	18.2	7.4	12.3
27	10.6	-3.3	2.6	4.4	.3	2.6	16.1	6.5	10.7	22.0	11.2	16.4	9.1	7.0	7.8	20.4	12.1	14.7
28	5.8	-2.3	2.0	3.8	-.3	1.5	19.9	7.5	12.7	23.6	13.5	17.7	9.8	7.1	8.4	20.9	9.7	14.8
29	10.6	2.6	7.5	5.5	-.7	1.6	21.8	9.7	15.1	21.9	11.8	16.4	16.9	8.7	12.1	14.0	6.5	9.5
30	12.5	7.2	10.0	3.5	-.1	2.1	18.5	9.7	13.7	20.5	11.7	15.4	19.6	9.8	14.3	15.3	3.7	8.9
31				6.7	-.4	1.9				21.6	9.6	15.3	21.3	12.7	16.6			
Monthly average	7.4	0.1	3.6	7.7	1.7	4.3	14.0	6.2	9.9	18.7	9.5	13.8	18.1	10.5	13.7	10.9	4.5	7.2

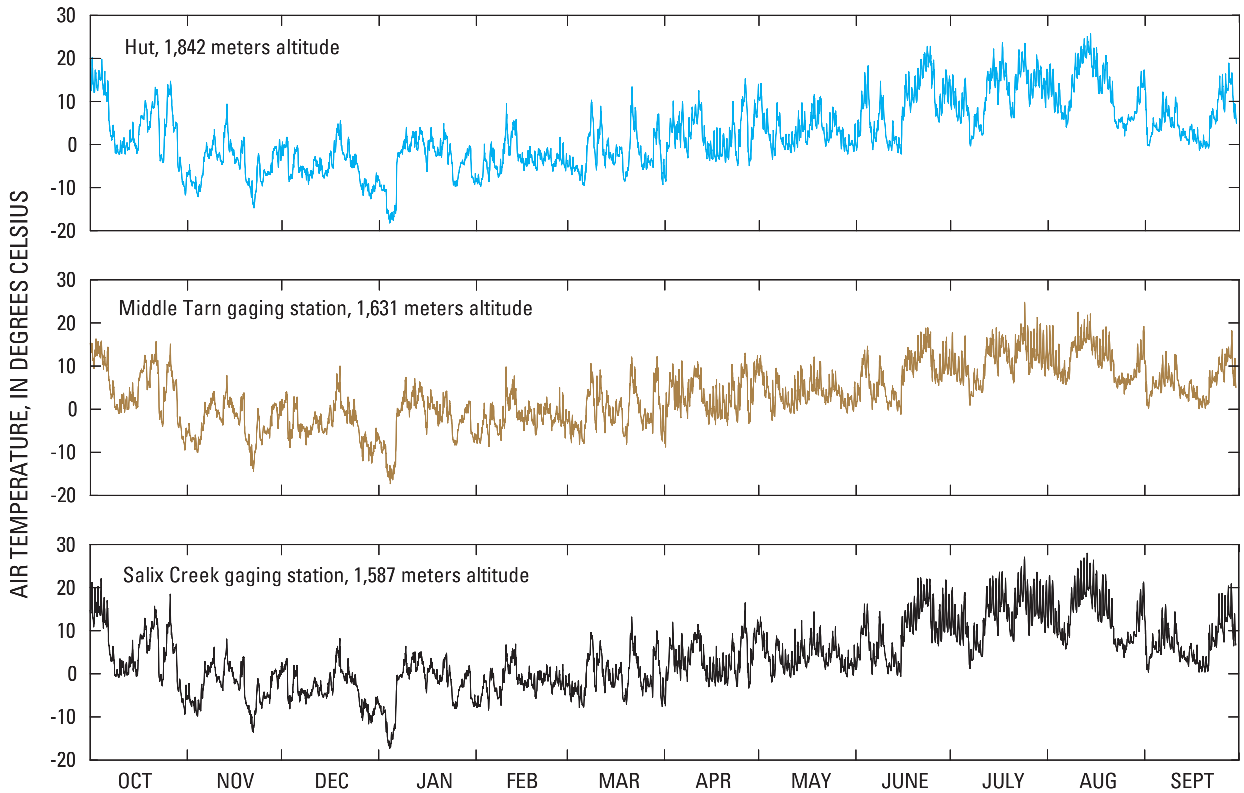


Figure 3. Hourly average air temperature at selected sites in and near South Cascade Lake Basin, Washington, water year 2004. Daily summaries are presented in tables 1–3.

The air-temperature sensors on the glacier were installed in late April and the sensor at site P-1 operated through the end of the water year. The other two sensors operated for periods of 116 and 149 days (figs. 2 and 4) The sensor at the site near the terminus fell during August and was found later that month lying on a patch of stones and gravel immediately downvalley from the terminus. The sensor at the upper glacier site was removed in late September. During April 27 to August 20, when all three sensors were operating, average air temperature at the site near the terminus, at site P-1, and at the upper glacier site was 8.9°C, 6.4°C, and 6.3°C, respectively (tables 4 to 6). The decrease of average temperature with altitude from the site near the terminus to site P-1 was 0.012°C/m, and the decrease with altitude from the site near the terminus to the upper glacier site was 0.0066°C/m. Average temperature decreased with altitude between site P-1 and the upper glacier site, although the difference in temperature (-0.1°C) was within the margin of measurement error.

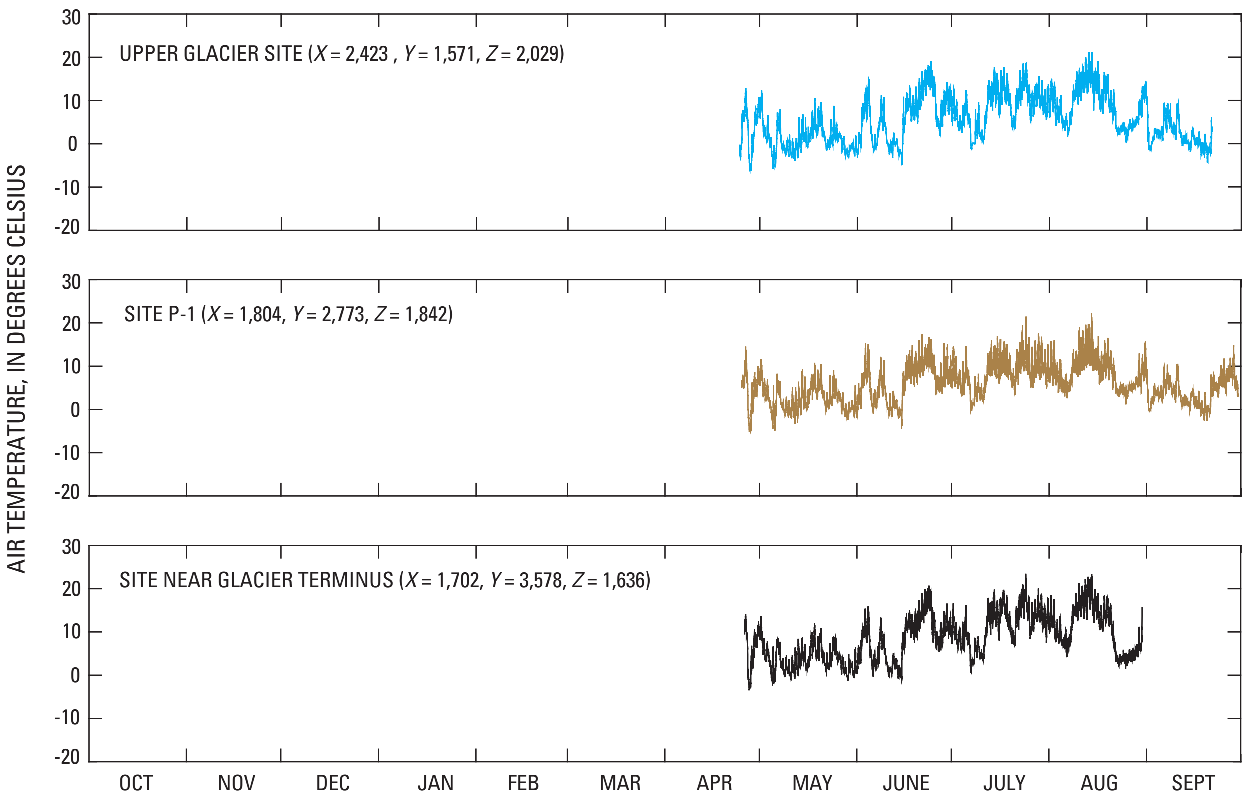


Figure 4. Air temperature recorded at 10-minute intervals at three selected locations on South Cascade Glacier, Washington, April–September 2004. Daily summaries are presented in tables 4–6.

Table 4. Daily maximum, minimum, and average air temperature on South Cascade Glacier, Washington, near the glacier terminus, 1,636 meters altitude, April–August 2004.

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average; –, insufficient data]

Day	Daily air temperature, in degrees Celsius														
	April			May			June			July			August		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	–	–	–	13.6	7.4	10.4	6.9	0.3	3.4	16.6	7.3	11.4	18.5	9.6	13.5
2	–	–	–	8.6	3.6	5.7	11.2	2.7	6.9	12.3	7.0	9.3	17.6	8.5	13.1
3	–	–	–	7.9	3.0	5.0	15.4	8.3	11.4	11.0	6.3	8.3	13.0	7.7	9.9
4	–	–	–	4.6	-.7	1.9	15.9	7.5	11.4	12.3	5.4	8.0	13.8	7.2	10.2
5	–	–	–	6.7	-2.4	.0	9.3	1.9	4.9	16.1	5.4	10.7	9.7	6.0	7.6
6	–	–	–	8.5	-1.6	5.1	5.7	-0.3	2.5	9.8	3.6	8.3	10.6	4.2	7.6
7	–	–	–	8.3	1.8	4.9	6.7	1.1	3.4	3.8	.5	2.4	9.5	6.1	7.7
8	–	–	–	4.1	.0	1.8	13.3	2.7	8.9	8.1	2.7	5.2	16.3	8.8	13.1
9	–	–	–	4.6	-.4	1.3	9.5	4.8	7.0	9.0	4.0	6.2	19.0	13.6	15.5
10	–	–	–	3.7	-.7	.7	5.4	.5	2.9	6.1	3.6	4.6	21.3	12.5	16.2
11	–	–	–	4.7	-1.1	1.2	1.9	-.3	.8	11.0	3.6	6.5	20.7	13.4	17.6
12	–	–	–	6.6	-.8	2.5	5.0	.4	2.7	17.8	9.1	13.6	22.2	13.1	18.2
13	–	–	–	8.5	-.1	3.5	3.9	.4	2.6	17.0	9.3	14.1	22.8	12.8	19.3
14	–	–	–	8.8	2.1	5.0	2.3	-.7	.5	19.8	10.8	15.6	23.4	14.0	18.9
15	–	–	–	7.3	1.4	4.1	9.9	-1.6	4.8	17.3	9.5	13.7	19.8	12.1	16.8
16	–	–	–	4.5	1.1	2.4	14.3	6.2	10.6	18.0	8.0	13.3	19.0	11.8	15.7
17	–	–	–	10.0	3.4	6.8	15.1	9.7	12.3	19.8	14.2	17.3	16.1	10.4	12.4
18	–	–	–	12.0	5.0	7.6	14.1	8.6	11.0	18.6	11.1	14.8	18.4	10.1	14.0
19	–	–	–	9.0	3.3	5.6	15.4	7.5	11.3	14.9	9.7	12.2	18.4	12.0	14.9
20	–	–	–	10.9	4.1	7.8	17.4	8.6	12.4	10.4	7.2	8.6	16.6	10.1	13.2
21	–	–	–	5.3	2.0	3.6	19.0	10.8	14.6	16.0	6.7	11.2	–	–	–
22	–	–	–	5.3	.8	2.2	19.9	12.0	16.1	18.7	10.4	15.8	–	–	–
23	–	–	–	7.5	1.3	3.4	20.7	14.1	17.6	21.0	13.3	17.3	–	–	–
24	–	–	–	9.0	3.3	6.0	19.7	9.4	16.0	23.5	13.0	18.5	–	–	–
25	–	–	–	8.5	2.9	5.2	15.8	7.5	11.4	18.2	9.6	14.6	–	–	–
26	–	–	–	5.3	2.3	3.9	10.1	5.8	7.8	16.8	8.4	11.9	–	–	–
27	9.9	-3.5	1.9	4.4	.1	2.2	12.3	5.5	8.5	17.5	10.0	13.7	–	–	–
28	6.9	-2.8	1.4	3.3	-.5	.7	14.9	6.7	10.3	20.1	12.3	15.3	–	–	–
29	10.6	1.8	7.1	4.8	-1.1	.7	16.6	9.0	12.5	18.8	10.4	14.5	–	–	–
30	12.5	6.3	9.6	3.3	-.2	1.6	14.5	8.4	11.2	16.0	10.1	12.7	–	–	–
31				6.4	-.7	1.7				17.9	7.4	12.4	–	–	–
Monthly average	–	–	–	7.0	1.2	3.7	12.1	5.3	8.6	15.3	8.1	11.7	–	–	–

Table 5. Daily maximum, minimum, and average air temperature on South Cascade Glacier, Washington, at site P-1, 1,842 meters altitude, April–September 2004.

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average; –, insufficient data]

Day	Daily air temperature, in degrees Celsius																	
	April			May			June			July			August			September		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	–	–	–	11.7	5.5	8.0	6.0	-1.9	1.9	14.6	4.9	8.7	15.8	6.1	10.3	9.4	-0.1	3.0
2	–	–	–	7.3	2.0	4.3	8.5	.1	4.8	12.4	5.2	7.6	16.0	5.5	10.1	2.7	-.2	1.0
3	–	–	–	7.0	1.9	3.6	15.3	5.4	8.8	9.4	4.7	6.6	11.0	3.9	7.6	6.1	1.7	3.6
4	–	–	–	2.8	-1.9	.5	15.1	6.1	9.9	11.2	3.0	5.9	11.7	4.0	7.5	5.2	2.8	3.8
5	–	–	–	5.6	-4.9	-1.7	8.8	.2	3.4	14.7	3.6	8.6	7.6	3.0	5.6	5.5	1.8	3.7
6	–	–	–	8.3	-3.1	3.2	4.6	-1.0	1.3	9.0	2.3	6.7	8.2	2.6	5.6	10.0	1.4	5.7
7	–	–	–	6.6	1.0	3.5	6.9	.3	2.9	2.0	-.2	.9	8.1	4.0	5.5	10.4	3.7	6.3
8	–	–	–	2.1	-1.1	.5	12.0	5.0	7.9	7.7	1.1	3.5	13.9	6.1	9.3	7.9	4.2	5.9
9	–	–	–	2.8	-1.5	.0	11.4	3.0	5.8	8.3	1.7	4.5	13.6	8.0	10.5	5.6	3.0	4.2
10	–	–	–	2.1	-1.9	-.5	4.8	-.1	1.6	6.1	1.8	3.0	19.0	7.6	11.1	10.6	1.5	6.3
11	–	–	–	5.1	-2.1	.0	3.8	-1.4	.3	7.4	2.1	4.6	18.3	8.4	12.3	9.5	1.7	4.5
12	–	–	–	5.1	-3.3	.7	4.3	-1.7	1.1	13.1	5.7	9.0	19.6	9.0	12.6	2.9	.7	1.6
13	–	–	–	6.4	-3.1	1.7	2.3	-.8	.9	16.0	7.6	10.3	19.7	10.2	13.5	3.6	.9	2.1
14	–	–	–	9.3	-1.3	3.5	.6	-1.9	-.9	14.9	7.6	10.9	22.3	8.9	14.1	2.1	-.3	1.0
15	–	–	–	7.6	.0	2.4	8.8	-4.5	3.0	16.9	6.3	11.1	14.3	9.0	11.3	4.7	1.9	3.5
16	–	–	–	4.6	.0	1.7	12.5	4.2	8.1	16.3	5.9	10.1	16.9	5.9	11.5	3.1	.5	1.5
17	–	–	–	8.1	2.3	5.4	13.8	7.0	10.1	15.7	8.0	11.6	13.6	5.6	9.2	4.3	.2	1.4
18	–	–	–	10.8	4.0	6.5	14.9	5.9	8.9	15.1	7.5	10.2	16.0	6.6	10.4	2.1	-1.5	-.1
19	–	–	–	9.2	2.3	5.0	13.6	5.2	9.0	13.0	6.8	9.5	16.6	6.7	11.3	4.0	-2.6	.1
20	–	–	–	10.5	3.7	6.6	16.0	5.7	10.3	9.5	4.5	6.6	13.7	6.8	10.8	1.1	-2.6	-.4
21	–	–	–	4.4	.3	2.7	17.4	7.3	11.7	14.0	3.4	7.9	12.0	4.6	8.2	8.1	-1.1	2.6
22	–	–	–	4.0	-.4	.9	15.2	8.4	11.4	15.6	5.6	10.5	8.6	3.6	4.8	7.9	3.0	5.7
23	–	–	–	8.0	.0	2.4	16.8	9.4	12.3	19.5	8.2	13.1	5.5	2.9	4.2	7.5	2.8	4.9
24	–	–	–	9.1	.7	4.4	16.3	8.4	12.0	21.5	8.8	13.1	6.2	3.4	4.7	10.2	5.2	7.3
25	–	–	–	7.1	1.8	3.8	12.7	5.7	9.4	16.7	7.3	11.5	5.2	1.2	3.5	11.8	4.9	7.9
26	14.5	5.0	9.1	4.2	1.3	3.0	7.9	3.3	6.0	14.5	4.9	8.8	6.2	3.7	5.0	9.6	3.6	7.2
27	8.5	-5.0	.3	3.9	-1.0	.9	10.9	4.1	6.5	16.0	6.1	9.9	6.1	4.1	5.3	12.0	6.3	8.8
28	6.2	-5.0	-.3	1.5	-1.7	-.7	15.4	3.6	7.7	17.7	7.7	11.4	7.7	4.9	6.1	14.9	5.5	9.7
29	8.7	.4	5.2	1.8	-2.4	-.5	15.1	5.7	9.5	16.8	6.9	11.0	12.9	5.1	7.9	7.8	2.8	5.6
30	10.0	3.8	6.8	2.1	-1.3	.4	12.6	5.2	8.0	13.9	8.1	10.3	12.9	3.8	8.5	8.0	4.2	5.6
31				5.6	-1.8	.3				15.0	4.7	9.4	15.8	6.7	10.7			
Monthly average	–	–	–	6.0	-0.2	2.3	10.8	3.2	6.5	13.4	5.2	8.6	12.7	5.5	8.7	7.0	1.9	4.1

Table 6. Daily maximum, minimum, and average air temperature on South Cascade Glacier, Washington, near the upper end of the glacier, 2,029 meters altitude, April–September 2004.

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average; –, insufficient data]

Day	Daily air temperature, in degrees Celsius																	
	April			May			June			July			August			September		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	–	–	–	12.5	4.4	8.4	2.7	-3.3	0.0	12.8	4.3	8.2	15.1	5.9	10.8	10.6	-1.5	2.4
2	–	–	–	5.0	1.2	2.8	9.5	-.9	4.9	10.3	3.8	6.5	14.4	5.7	10.2	1.6	-1.4	-.1
3	–	–	–	6.7	.3	2.4	13.0	5.7	8.8	6.6	2.9	4.6	10.7	4.2	6.5	3.6	.8	2.3
4	–	–	–	1.5	-3.1	-.6	15.0	5.7	10.2	9.0	2.5	5.1	11.2	4.8	7.6	3.4	1.6	2.5
5	–	–	–	-.4	-5.9	-3.5	7.2	-.8	2.1	12.5	4.7	9.2	6.3	3.0	4.5	4.1	.9	2.3
6	–	–	–	7.4	-4.7	2.1	2.2	-1.9	-.2	7.2	0.8	5.4	7.1	1.6	4.7	9.5	.7	5.8
7	–	–	–	8.0	-.4	2.7	5.4	-.5	2.0	.6	-1.4	-.3	7.8	3.0	4.9	9.4	2.6	6.1
8	–	–	–	.1	-2.1	-.9	11.2	4.4	6.9	8.0	.0	2.5	13.7	6.7	10.0	9.4	2.8	5.1
9	–	–	–	.9	-2.6	-1.1	10.8	2.9	5.4	9.6	1.2	4.1	16.9	10.2	12.7	4.9	2.1	3.0
10	–	–	–	2.3	-3.1	-1.1	3.8	-1.3	.6	2.8	.8	1.7	17.6	9.0	13.0	9.5	1.0	5.8
11	–	–	–	1.4	-3.4	-1.4	.5	-2.4	-.9	8.9	1.0	4.1	18.1	10.0	14.5	9.1	.4	3.2
12	–	–	–	1.4	-3.9	-1.4	2.6	-3.2	.0	14.8	5.9	11.2	20.0	12.1	15.3	2.0	-.6	.4
13	–	–	–	6.2	-3.3	.7	1.4	-1.9	-.3	14.5	7.7	11.7	21.2	11.6	16.0	2.4	.0	.9
14	–	–	–	6.9	-2.1	2.3	-1.2	-2.9	-2.2	17.8	8.4	12.9	21.2	11.5	16.3	.4	-1.9	-.4
15	–	–	–	6.2	-.6	1.4	10.9	-4.9	1.9	16.3	6.7	11.8	16.9	7.7	13.9	3.2	-.3	2.2
16	–	–	–	4.0	-.8	.6	11.8	4.3	8.4	17.1	6.8	11.7	19.1	10.0	14.2	1.6	-.4	.4
17	–	–	–	7.9	1.1	3.8	13.6	6.8	9.6	17.7	9.6	13.8	12.6	7.4	9.3	2.9	-.6	.5
18	–	–	–	10.6	2.6	5.6	11.2	5.1	7.9	16.4	9.0	12.1	16.6	6.9	12.3	.4	-2.6	-1.3
19	–	–	–	8.7	1.8	5.0	13.2	5.4	9.1	12.7	5.1	9.2	16.1	8.6	12.8	2.3	-3.2	-.8
20	–	–	–	9.7	2.3	5.5	15.3	4.5	10.0	6.6	3.6	4.8	12.5	7.2	9.6	-.8	-4.5	-1.8
21	–	–	–	3.0	-.4	1.6	16.8	8.6	12.6	12.8	3.4	8.4	12.6	5.4	8.0	–	–	–
22	–	–	–	1.2	-1.5	-.4	17.1	11.1	14.8	17.1	8.0	12.1	7.6	2.4	3.6	–	–	–
23	–	–	–	5.7	-.9	.8	18.2	13.2	16.2	18.7	10.1	14.2	4.1	2.1	3.2	–	–	–
24	–	–	–	8.8	-.5	3.2	19.1	11.0	15.4	19.0	11.7	15.2	5.0	2.3	3.6	–	–	–
25	7.9	-1.1	4.1	4.5	.5	2.2	15.5	7.2	12.3	13.7	5.1	10.6	3.8	.3	2.5	–	–	–
26	12.9	5.8	8.8	2.4	.2	1.8	7.0	3.5	5.0	12.0	4.9	8.5	5.7	2.9	4.1	–	–	–
27	7.0	-6.2	-1.0	1.7	-1.9	-.2	10.2	1.9	5.4	13.8	6.8	10.7	5.1	3.4	4.2	–	–	–
28	2.3	-6.2	-2.0	-1.1	-2.9	-2.1	12.2	4.0	8.6	15.7	8.3	12.1	6.3	3.9	5.1	–	–	–
29	8.8	1.0	4.9	-.2	-3.4	-1.7	14.2	6.9	10.9	14.8	7.6	10.9	10.1	4.4	7.4	–	–	–
30	10.8	4.5	7.3	.5	-2.4	-.6	13.2	5.8	9.5	12.7	6.1	9.0	13.4	6.1	10.1	–	–	–
31				2.1	-2.8	-1.1				13.8	5.5	9.9	14.6	9.1	11.8			
Monthly average	–	–	–	4.4	-1.2	1.2	10.1	3.1	6.5	12.5	5.2	8.8	12.4	6.1	9.1	–	–	–

Wind speed at the Hut exhibited seasonality similar to that of previous years, with maximum speeds during November through March (fig. 5). The maximum of recorded hourly average wind speed was 24.1 m/s on December 4, 2003. The windiest day recorded was December 22, 2003, when wind speed averaged 15.4 m/s (table 7). The wind speed sensor probably was locked by ice during days for which average tabulated speed is 0.2 m/s, the starting threshold of the sensor, and wind speeds greater than those recorded could have occurred.

A partial record of incoming daily solar radiation is available for water year 2004 (fig. 5). Data collected before the backup pyranometer was installed and that were suspected to be affected by the previously described datalogger-programming error were considered unreliable and were excluded from this report. Maximum daily incoming solar radiation was 379 W/m^2 on June 20, about the time of the summer solstice (table 8). Monthly average solar radiation for the months with complete records ranged from 27 W/m^2 in December to 258 W/m^2 in July. Ice and snow likely obscured the pyranometers and caused underestimation of solar radiation at times, particularly during winter.

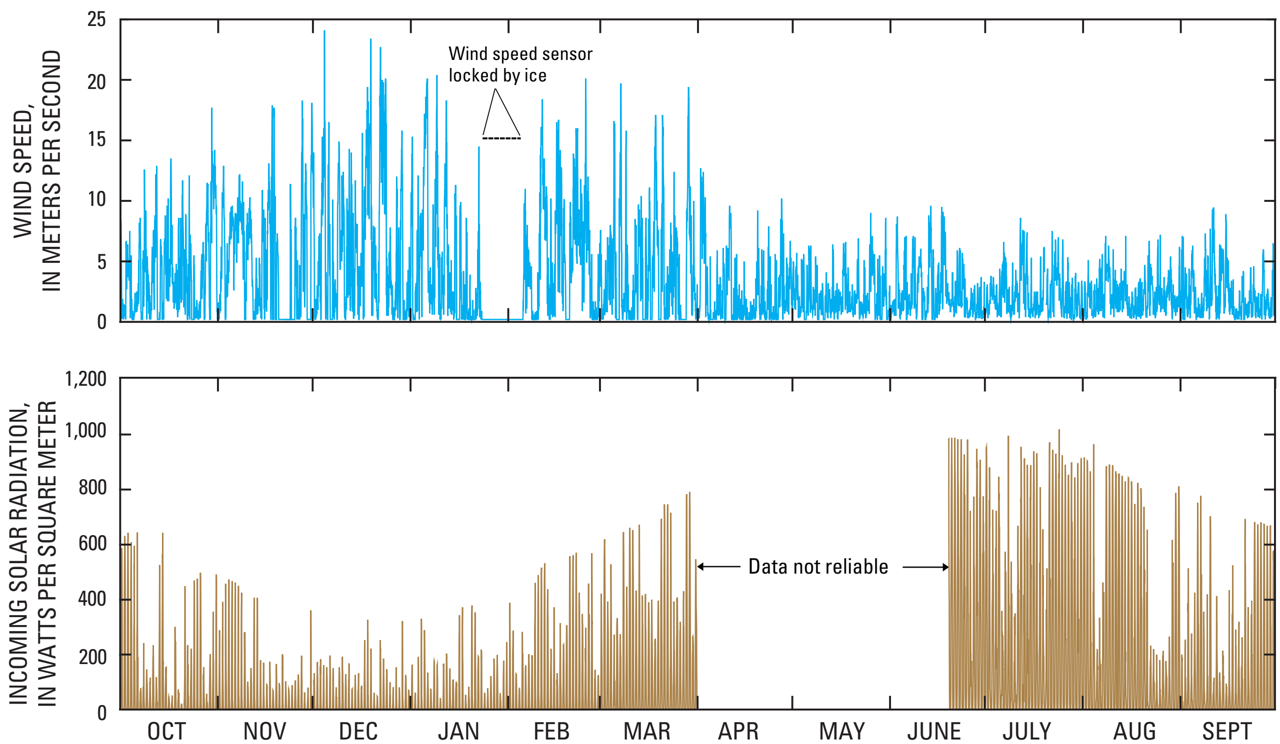


Figure 5. Hourly average wind speed and incoming solar radiation at the Hut, 1,842 meters altitude, near South Cascade Lake Basin, Washington, water year 2004. Daily summaries are presented in tables 7–8.

Table 7. Daily average wind speed at the Hut, 1,842 meters altitude, near South Cascade Lake Basin, Washington, water year 2004.

[**Wind speed**: sensor probably was locked by ice during days for which tabulated wind speed is 0.2. **Symbol**: –, insufficient data or average not computed due to probable sensor icing]

Day	Daily average wind speed, in meters per second											
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	3.4	1.7	5.8	6.6	0.2	2.6	2.4	2.7	0.8	1.5	1.3	3.7
2	1.9	8.7	2.4	1.3	.2	1.8	8.7	2.9	2.0	1.9	1.9	1.9
3	4.7	3.1	5.6	5.6	.2	4.1	5.0	1.4	4.3	2.5	2.0	1.7
4	2.3	5.8	13.3	7.1	.2	4.7	1.4	2.2	1.3	1.7	1.2	3.7
5	.8	8.1	3.4	14.5	1.6	8.0	.3	1.2	3.8	1.6	1.5	1.9
6	2.0	7.3	4.1	10.5	5.4	.9	.5	3.3	1.5	3.2	2.7	.9
7	3.9	9.3	2.5	1.9	4.4	8.8	2.4	1.4	1.5	3.9	2.0	.9
8	4.8	8.4	2.9	5.3	1.5	1.2	1.3	2.6	4.4	1.8	4.8	3.1
9	4.1	3.4	9.8	10.6	.4	5.7	2.5	1.0	2.0	1.4	3.5	2.9
10	1.3	7.4	8.7	2.1	2.8	.4	4.7	1.3	4.8	2.1	2.0	2.6
11	4.8	6.5	2.4	5.4	13.6	.7	5.5	1.3	1.3	1.8	2.3	6.4
12	6.9	.8	5.7	9.7	10.0	3.7	1.2	1.7	.7	5.6	2.1	1.4
13	2.2	2.2	5.6	2.5	4.4	6.1	1.4	2.0	6.8	3.3	2.4	3.0
14	2.3	2.9	5.6	1.4	3.7	3.5	1.0	1.5	2.5	3.4	3.1	3.8
15	5.4	5.1	2.9	4.6	2.9	2.9	1.2	1.3	1.4	1.5	1.2	4.8
16	5.5	5.2	5.4	3.7	10.0	5.2	.5	1.7	2.5	1.2	1.2	2.0
17	5.8	8.3	8.2	1.3	7.8	2.4	.5	4.3	5.4	1.4	1.3	1.3
18	2.6	7.8	14.3	2.8	5.4	11.8	.7	2.1	4.8	1.6	1.4	.5
19	3.2	4.3	10.6	.8	.6	4.2	2.5	1.6	1.9	–	1.8	1.0
20	6.2	.9	4.9	.4	3.9	6.4	2.4	1.3	1.8	–	2.5	2.1
21	4.1	.2	1.7	.7	8.1	4.0	2.9	3.1	1.5	1.3	2.2	.8
22	3.1	.2	15.4	4.3	10.6	1.4	.6	1.1	3.3	3.1	3.3	1.2
23	3.0	1.1	14.2	.8	7.8	4.4	2.7	1.5	3.2	4.5	1.6	2.1
24	1.3	1.7	6.5	.2	5.6	4.7	.7	1.2	2.3	3.7	2.5	1.9
25	.7	3.5	4.4	.2	10.1	4.3	2.0	3.4	1.0	2.5	2.1	1.2
26	2.4	1.7	.9	.2	6.4	.8	1.5	5.0	1.4	1.6	2.0	1.3
27	3.2	8.3	4.0	.2	1.4	.2	5.1	1.2	1.5	2.3	2.0	3.1
28	8.7	7.2	4.6	.2	.4	7.0	2.2	2.6	1.2	1.7	3.6	1.6
29	5.0	1.8	6.9	.2	2.6	10.1	2.8	1.9	1.4	1.7	1.6	1.0
30	12.2	8.8	.9	.2		3.5	3.5	3.4	.9	1.9	1.4	3.5
31	6.3		1.5	.2		1.3		.7		1.3	2.3	
Monthly average	4.0	–	6.0	–	–	4.2	2.3	2.1	2.4	–	2.2	2.2

Table 8. Daily average incoming solar radiation at the Hut, 1,842 meters altitude, near South Cascade Lake Basin, Washington, water year 2004.

[**Symbol**: –, insufficient data]

Day	Daily average incoming solar radiation, in watts per square meter averaged for the 24-hour day											
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	169	57	26	32	72	104	–	–	–	357	333	42
2	173	60	31	13	60	170	–	–	–	225	323	46
3	177	79	30	34	32	97	–	–	–	215	178	113
4	163	88	28	50	18	106	–	–	–	230	201	49
5	121	86	32	53	62	62	–	–	–	314	62	113
6	102	85	37	24	38	95	–	–	–	109	77	221
7	22	83	32	15	49	74	–	–	–	164	166	215
8	33	77	15	37	51	177	–	–	–	197	312	74
9	37	65	33	34	79	97	–	–	–	153	314	55
10	26	24	35	9	92	181	–	–	–	102	308	184
11	58	34	26	37	102	163	–	–	–	208	304	33
12	28	72	29	43	112	115	–	–	–	347	296	90
13	105	70	16	26	102	168	–	–	–	246	294	36
14	137	35	26	23	48	115	–	–	–	281	185	62
15	40	27	22	25	75	111	–	–	–	295	288	23
16	11	19	18	60	35	105	–	–	–	349	289	55
17	10	32	42	67	58	99	–	–	–	259	156	112
18	82	16	49	11	57	75	–	–	–	217	278	54
19	20	32	32	16	78	112	–	–	–	160	245	74
20	5	22	12	67	134	195	–	–	379	120	202	57
21	68	34	10	67	138	203	–	–	369	318	106	162
22	39	21	48	45	141	196	–	–	350	348	63	77
23	50	14	33	41	104	125	–	–	370	344	62	–
24	103	18	28	13	81	84	–	–	314	334	39	202
25	108	23	16	16	58	131	–	–	372	339	31	198
26	116	27	16	26	103	89	–	–	148	313	67	200
27	35	39	26	40	108	118	–	–	247	298	54	198
28	12	10	16	42	34	240	–	–	352	304	69	194
29	48	15	47	13	32	238	–	–	336	275	176	176
30	59	56	27	38		88	–	–	273	247	262	173
31	98		14	54		160		–		331	262	
Monthly average	73	44	27	35	74	132	–	–	–	258	194	110

The three largest storms detected by the precipitation gage at the Salix Creek gaging station during water year 2004 were October 16-17, October 19–21, and August 24–25 (table 9). Gaged precipitation totaled more than 90 mm during each of those events. Precipitation likely was rain over the entire glacier during the storm of October 19–21, an event that resulted in flooding around Middle Tarn and South Cascade Lake and that sent stage of Middle Tarn to 1.47 m, the highest stage of the water year (fig. 6). Precipitation during August 24–25, which likely was rain over all of South Cascade Lake Basin, set off debris flows that came to rest on the glacier. Large winter snow storms possibly occurred during the year that were not detected by the unheated precipitation gage. During June through September, when most precipitation likely was rain at the Salix Creek gaging station, total recorded precipitation was 529.7 mm.

Table 9. Daily total precipitation (gage catch) at the Salix Creek gaging station, Salix Creek Basin, Washington, 1,587 meters altitude, water year 2004.

Day	Daily total precipitation, in millimeters											
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	3.6	0.0	0.0	33.8
2	.0	.0	9.1	.0	.0	.0	.0	1.5	.0	.5	.0	8.1
3	.0	.0	.0	.0	4.6	1.3	.0	.8	.0	.0	.0	.3
4	.0	.0	.8	.0	.0	.3	.0	6.1	.0	.0	.0	.8
5	.0	.0	5.3	.0	.3	.0	.0	3.6	10.9	.0	13.2	3.8
6	5.3	.0	1.0	.0	1.8	.0	.0	.0	10.9	10.7	14.7	.0
7	20.3	.0	.0	.0	.0	5.1	.0	10.2	4.1	10.9	1.3	.0
8	10.7	.0	.0	5.6	.0	.0	.0	6.4	.3	.0	.0	6.1
9	3.0	.0	.0	8.6	2.3	5.3	.0	5.6	6.9	.0	.0	3.3
10	4.8	.0	.0	4.8	1.5	.0	.0	4.6	11.9	8.4	.0	21.6
11	1.8	.0	.0	.0	.0	.0	.0	6.1	3.3	1.3	.0	23.6
12	15.2	6.1	.3	2.5	.0	1.5	2.5	1.3	9.7	0.0	.0	2.3
13	13.7	.0	.0	2.5	.0	.0	3.6	.0	12.7	2.0	.0	26.9
14	.0	.0	.0	21.1	.8	3.0	4.6	.0	8.1	.0	.0	11.4
15	2.5	.8	.0	11.2	2.8	.0	.5	4.8	.0	.0	.0	34.0
16	74.9	.0	.0	.0	.0	2.3	2.3	9.1	.0	.0	.0	19.3
17	17.5	.0	.0	.5	.0	2.8	2.5	9.7	.0	.0	.0	12.2
18	.0	59.7	1.3	5.3	2.3	.3	4.8	4.3	.0	.5	.0	7.4
19	13.5	4.6	1.8	1.5	3.3	.0	3.3	.3	.0	.3	.0	1.5
20	137.2	.0	2.0	.0	.3	.8	3.6	.0	.0	.0	.0	2.8
21	14.2	.0	1.3	.0	.5	.0	.0	5.3	.0	.0	12.4	.0
22	9.9	.0	.0	.0	.3	4.8	.0	9.7	.0	.0	20.8	2.3
23	.0	.0	.0	5.3	.3	2.8	1.0	2.5	.0	.0	5.6	3.0
24	7.4	.0	.5	.0	.8	.8	.0	.0	.0	.0	29.0	.0
25	.0	.0	.0	.0	.0	.0	.0	6.9	.0	.0	74.2	.0
26	.0	.0	.0	.0	.3	4.6	.0	18.0	1.0	.0	6.1	.0
27	1.0	.0	.0	.0	.3	1.3	3.0	13.0	.0	.0	3.6	.0
28	29.7	8.9	.0	.3	4.3	6.4	3.8	4.1	.0	.0	5.8	.0
29	1.3	7.6	.3	24.4	1.0	.0	.0	10.9	.0	.0	.5	.0
30	.0	.0	.0	.5		1.5	.0	24.6	.0	.0	.0	.0
31	.0		.0	.0		2.3		5.1		.0	.0	
Total	383.9	87.7	25.0	94.1	27.8	47.2	35.5	174.5	83.4	34.6	187.2	224.5

Daily average runoff from Middle Tarn Basin for the months data are available ranged from 0.7 mm/d November 14 and 15 to 162 mm/d during flooding October 20 (table 10). Monthly average runoff ranged from 2.9 mm/d in November to 36.0 mm/d in August. Total runoff during June through September was 3,378 mm, which was about six times as great as measured precipitation at the Salix Creek gaging station during the same period. Discharge computed from two measurements in water year 2004 (table 11) differed from the rating curve by less than 1 percent when rating shifts were applied.

Daily average runoff from Salix Creek Basin at the Salix Creek gaging station during water year 2004 ranged from 0.1 mm/d in early October to 124.5 mm/d during flooding October 20 (table 12). Monthly average runoff ranged from 0.7 mm/d in February to 21.1 mm/d during May and June. Total runoff for water year 2004 was 2,910 mm. Total runoff during June through September was 1,087 mm, which was about double the contemporaneous precipitation recorded at the Salix Creek gaging station.

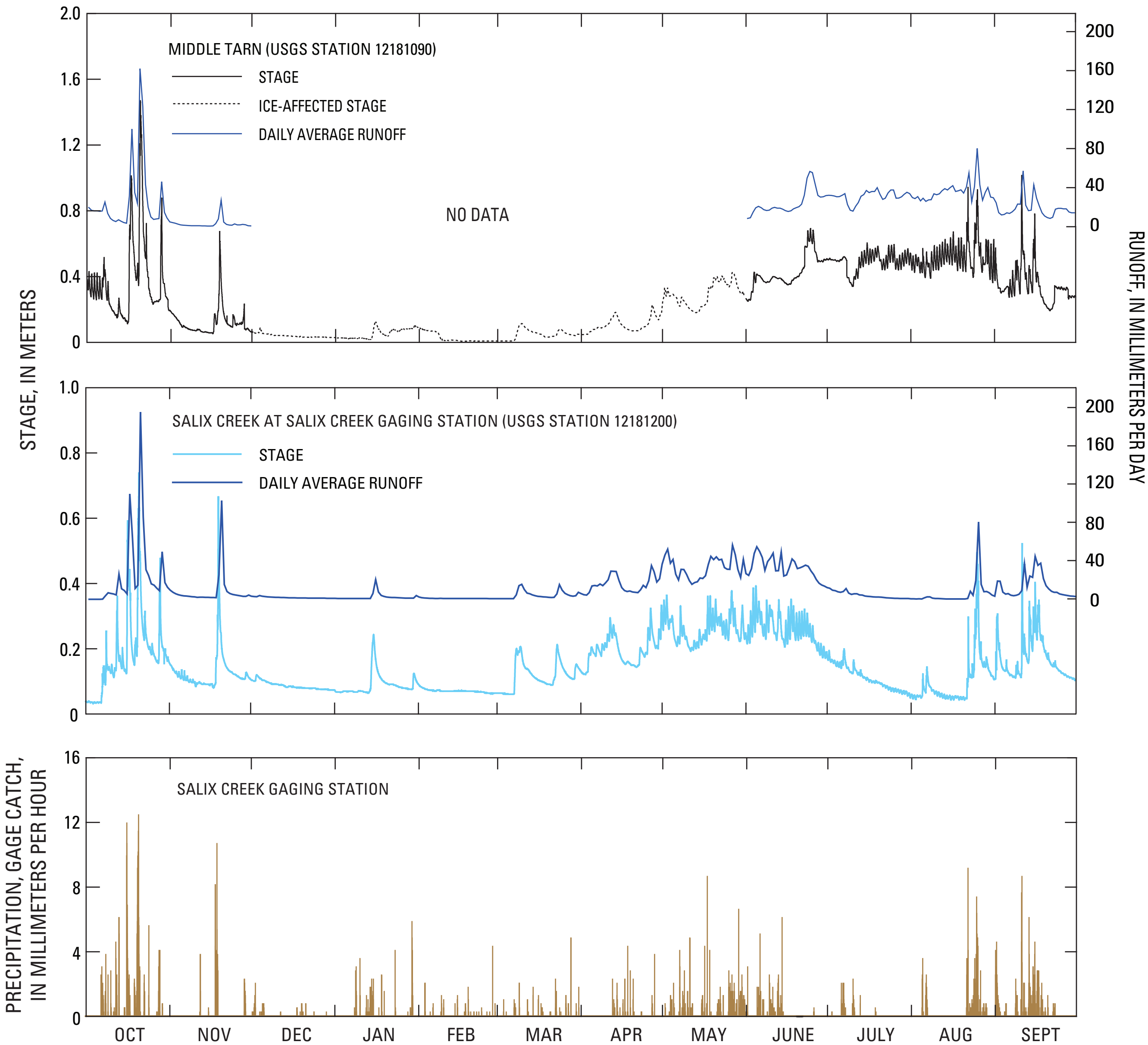


Figure 6. Stage of Middle Tarn and Salix Creek, daily average runoff from Middle Tarn and Salix Creek basins, and precipitation (gage catch) at the Salix Creek gaging station, Washington, water year 2004. Stage was recorded every 15 minutes and precipitation was totaled and recorded each hour. Daily summaries of precipitation and runoff are presented in tables 9, 10, and 12.

Table 10. Daily average runoff from Middle Tarn Basin, Washington, water year 2004.

[Daily average runoff is averaged over the area of the basin (4.46 square kilometers)]

Day	Daily average runoff, in millimeters					
	2003		2004			
	October	November	June	July	August	September
1	19.6	4.2	8.5	32.2	29.8	24.6
2	16.8	3.5	9.2	32.0	28.9	14.5
3	16.3	2.7	15.0	31.5	30.8	12.1
4	16.3	1.9	19.3	30.7	26.4	12.6
5	15.8	1.5	20.9	30.8	29.2	14.2
6	16.1	1.4	19.5	32.3	25.9	13.5
7	25.2	1.2	17.4	33.9	27.5	15.2
8	13.6	1.0	16.7	22.8	27.6	17.9
9	8.4	1.0	17.0	16.9	33.7	23.3
10	6.5	1.0	19.0	15.9	32.8	23.0
11	5.2	1.0	19.8	21.1	33.8	57.1
12	7.1	.8	19.0	24.8	36.8	22.1
13	5.6	.8	19.0	31.2	39.0	16.4
14	4.3	.7	17.9	32.9	37.7	17.0
15	3.5	.7	16.4	37.1	40.0	42.9
16	31.4	.9	15.6	35.0	42.0	29.4
17	100.1	3.0	16.3	36.2	36.2	21.3
18	35.1	8.0	18.3	36.2	36.8	14.2
19	23.9	27.1	19.5	40.1	37.8	11.1
20	162.0	4.8	20.6	33.3	34.5	9.4
21	123.3	2.3	23.0	28.0	40.6	8.4
22	43.2	1.7	32.2	29.2	55.2	9.7
23	20.2	1.6	49.9	34.6	25.6	18.0
24	10.0	2.8	56.6	37.7	41.3	18.9
25	7.5	1.9	55.5	37.7	80.3	18.8
26	8.0	1.9	43.8	29.1	42.9	18.3
27	8.3	2.4	32.0	29.4	27.2	18.4
28	46.2	2.1	30.3	30.7	35.2	15.1
29	14.8	1.1	30.7	33.3	40.2	14.2
30	9.0	.8	31.9	35.3	30.3	14.3
31	5.0			33.9	29.6	
Monthly average	26.7	2.9	24.4	31.2	36.0	18.9

Table 11. Miscellaneous stream discharge measurements made at Middle Tarn outlet, South Fork of Cascade River, Washington, water years 2004 and 2005.

[**Abbreviations**: m, meter; m^3/s, cubic meter per second]

Date	Stream measurement	
	Stage (m)	Discharge (m^3/s)
07-20-04	0.494	1.560
09-22-04	.219	.513
07-15-05	.427	1.070

The differing sources of runoff for Middle Tarn and Salix Creek Basins were reflected in seasonal differences in runoff. Summer runoff from nonglacierized Salix Creek basin was fed primarily by summer storms and melt of the annual snow pack. Because snow was almost all gone from the basin by late July and little precipitation fell during July to late August, runoff decreased to generally less than 2 mm/d (table 12, fig. 6). Summer runoff from Middle Tarn Basin was fed by melt of firn and ice of South Cascade Glacier, as well as by melt of the annual snow pack. Partly as a result of the additional sources of melt, runoff from Middle Tarn Basin during late July through late August, generally in the range of 28–40 mm/d (table 11), was much greater than runoff from Salix Creek Basin.

Table 12. Daily average runoff from Salix Creek Basin at the Salix Creek gaging station, Washington, water year 2004.

[Daily average runoff is averaged over the area of the basin (0.22 square kilometers)]

Day	Daily average runoff, in millimeters											
	2003			2004								
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	0.1	4.8	1.9	0.7	1.2	0.5	3.1	29.5	16.0	7.4	0.4	12.2
2	.1	3.8	1.8	.6	1.0	.5	2.9	33.3	20.4	6.2	.3	12.1
3	.1	3.1	2.6	.6	.9	.5	4.5	24.1	30.6	5.8	.4	4.9
4	.1	2.7	2.2	.7	.8	.5	9.0	26.6	35.0	5.1	.3	3.6
5	.1	2.4	1.9	.7	.8	.5	9.3	16.7	32.0	4.8	1.1	3.9
6	.2	2.3	1.7	.7	.7	.5	9.0	13.0	27.9	5.3	1.7	2.8
7	2.4	2.0	1.6	.7	.7	3.0	10.3	20.0	19.3	7.2	1.7	2.5
8	4.4	1.8	1.5	.6	.8	9.2	9.2	19.9	25.1	4.2	.9	2.8
9	4.0	1.7	1.4	.6	.7	10.0	11.0	16.6	27.5	3.4	.7	3.5
10	3.7	1.4	1.4	.7	.7	6.6	13.1	12.5	30.8	3.8	.6	5.8
11	3.0	1.5	1.3	.7	.7	4.2	18.8	10.0	19.0	3.8	.5	23.5
12	16.8	1.5	1.3	.6	.7	3.8	18.7	11.2	19.1	3.0	.4	8.1
13	7.1	1.4	1.2	.6	.7	3.0	18.6	11.8	31.4	2.9	.3	15.5
14	5.9	1.4	1.1	4.0	.7	2.5	12.6	14.3	15.5	2.3	.3	14.7
15	3.7	1.3	1.1	13.2	.7	2.1	7.9	13.9	16.3	2.1	.3	28.6
16	70.1	1.3	1.1	5.0	.7	1.9	5.9	15.8	21.2	1.9	.3	22.7
17	41.9	1.2	1.0	2.7	.7	1.7	5.3	23.2	26.9	1.7	.3	24.1
18	7.3	16.4	1.0	2.0	.7	1.6	5.6	28.6	25.2	1.6	.3	13.8
19	9.5	65.6	1.0	1.6	.7	1.4	5.0	26.4	20.5	1.6	.3	9.2
20	124.5	9.9	1.0	1.4	.7	1.3	4.8	28.3	21.1	1.5	.3	7.0
21	54.7	5.3	.9	1.3	.7	1.4	4.5	26.2	21.8	1.3	.7	5.4
22	19.7	4.0	.9	1.3	.6	3.7	6.5	26.7	22.8	1.1	5.4	4.8
23	16.0	3.4	.9	1.2	.6	9.8	9.4	21.2	22.0	1.0	2.8	4.7
24	10.4	3.0	.9	1.1	.6	6.1	7.9	20.1	18.9	.9	12.6	3.7
25	9.5	2.7	.9	1.0	.6	4.1	12.4	20.0	16.6	.8	51.5	3.2
26	7.4	2.4	.9	.9	.5	3.1	22.4	36.1	13.2	.8	10.0	2.9
27	5.8	2.1	.9	.9	.5	2.5	18.5	29.7	10.8	.7	5.2	2.6
28	31.6	2.1	.8	.9	.5	2.2	11.6	20.0	9.6	.6	5.3	2.3
29	11.2	2.9	.8	.9	.5	2.5	13.7	14.6	8.9	.6	4.4	2.2
30	8.1	2.2	.8	2.6		4.7	23.4	26.5	7.9	.6	2.9	1.9
31	6.1		.8	1.6		3.9		17.2		.4	2.2	
Monthly average	15.7	5.3	1.2	1.7	0.7	3.2	10.5	21.1	21.1	2.7	3.7	8.5

Water Year 2005 Meteorological and Streamflow Data

Air temperature measured at selected sites in and near South Cascade Lake Basin during water year 2005 was the same or slightly warmer than during water year 2004. Average annual air temperature at the Hut was 2.6°C (table 13), the same as the previous year. Average annual air temperature at the Middle Tarn and Salix Creek gaging stations was 3.6°C and 4.3°C (tables 14 and 15), respectively, which was 0.3°C greater at each site than during the previous year. The minimum recorded air temperature at the Hut during water year 2005 was -16.3°C on January 14, and the maximum was 23.3°C on July 21 (fig. 7). January was the coldest month at the Hut, when air temperature averaged -3.1°C. August was the warmest month at the Hut, as typically has been the case, when air temperature averaged 11.9°C.

Table 13. Daily maximum, minimum, and average of hourly average air temperature at the Hut, 1,842 meters altitude, near South Cascade Lake Basin, Washington, water year 2005.

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average]

Day	Daily air temperature, in degrees Celsius																	
	October			November			December			January			February			March		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	12.8	5.5	8.6	3.0	-5.3	-0.6	-2.0	-8.5	-6.0	-6.6	-8.6	-7.3	1.3	-5.1	-1.7	0.9	-2.7	-0.9
2	16.2	10.7	12.7	2.3	-5.2	-2.1	-2.8	-8.3	-4.7	-7.7	-9.2	-8.5	4.2	-2.6	1.7	1.4	-3.0	-1.0
3	15.8	11.4	12.7	-2.1	-7.1	-4.6	-1.9	-3.6	-2.7	-1.0	-8.7	-5.8	3.9	1.4	3.0	1.8	-2.6	.0
4	15.2	10.5	12.0	3.7	-2.4	.9	-.6	-3.3	-2.0	-4.2	-8.9	-6.5	1.7	-7.1	-3.1	3.5	-.8	.7
5	13.9	5.8	10.0	7.5	2.4	4.8	-3.3	-10.7	-8.2	-.6	-9.0	-4.2	-7.8	-10.3	-9.2	3.2	-1.7	.5
6	6.8	.6	3.5	3.8	1.1	3.0	-5.6	-9.3	-7.9	-7.3	-10.4	-8.8	-7.7	-10.5	-9.0	5.1	-1.0	2.3
7	7.3	-.1	4.2	8.2	3.1	5.8	-4.4	-7.3	-5.6	-8.9	-10.9	-9.9	-5.4	-9.0	-7.4	3.3	.3	1.7
8	8.5	.9	5.3	13.2	7.5	10.3	-2.5	-5.5	-4.2	-9.4	-11.3	-10.5	2.5	-5.7	-1.5	8.1	.2	4.7
9	.9	-1.5	-0.4	6.7	4.1	5.4	1.7	-5.5	-2.9	-8.2	-10.5	-9.5	1.6	-3.3	-1.2	4.6	1.0	2.9
10	4.1	.7	2.5	5.9	3.7	4.9	3.9	.4	2.5	-6.5	-8.8	-7.4	7.7	-.6	4.5	9.4	3.8	6.1
11	7.2	3.7	5.2	10.0	3.8	5.9	-2.1	-7.1	-5.2	-7.2	-10.8	-9.1	8.7	-.8	2.6	7.2	.7	4.7
12	10.9	3.5	7.8	8.0	1.4	5.1	.1	-3.5	-1.4	-7.2	-10.8	-8.8	-1.5	-7.5	-3.7	3.7	-1.6	.8
13	16.2	10.3	12.8	1.4	-.2	.5	2.2	-3.2	-.6	-10.5	-13.0	-11.3	-7.8	-9.9	-9.1	3.9	-1.2	1.3
14	13.3	6.2	10.1	5.0	-.4	3.1	-.9	-2.1	-1.5	-4.8	-16.3	-12.0	-6.4	-11.5	-9.7	3.4	-1.5	1.1
15	6.1	3.8	4.9	6.5	-4.0	-.1	1.5	-4.5	-1.2	1.5	-4.1	-2.0	-5.3	-11.0	-7.2	.7	-3.1	-1.4
16	3.6	1.5	2.6	-2.3	-6.1	-3.5	7.5	.6	4.1	.6	-2.2	-1.1	1.7	-4.8	-.8	-1.6	-6.7	-4.6
17	2.4	-2.3	.4	.4	-7.2	-2.7	5.9	1.7	3.6	3.5	.6	2.0	.8	-4.4	-2.0	-3.4	-6.4	-5.3
18	-1.0	-4.3	-2.3	-1.8	-5.3	-4.1	8.8	3.7	6.1	5.3	1.8	3.8	5.5	-4.0	.2	-.4	-7.1	-5.1
19	.3	-1.2	-.2	-4.7	-8.6	-6.4	8.0	-6.3	-1.3	5.2	3.6	4.2	-2.9	-8.9	-6.0	-.1	-7.1	-3.6
20	2.8	-1.4	.5	.3	-6.9	-3.7	-6.3	-7.8	-7.2	4.5	1.1	3.0	-.6	-9.3	-5.2	.4	-6.9	-1.5
21	.8	-3.6	-2.0	2.3	-2.0	-.4	-4.8	-7.0	-6.0	6.1	1.7	4.1	2.0	-3.7	-.2	-4.7	-8.7	-6.9
22	-.5	-4.8	-2.4	-.3	-2.2	-1.6	-1.6	-7.8	-5.0	5.7	2.7	4.3	6.8	.6	2.7	-2.8	-6.9	-5.1
23	-4.6	-6.5	-5.5	-.2	-2.4	-1.4	5.9	-2.2	1.6	4.8	3.2	4.2	5.3	2.3	3.8	-2.4	-6.9	-5.2
24	-4.1	-5.9	-5.3	1.5	-.3	.7	2.7	-1.5	.1	5.4	3.8	4.4	9.6	2.9	4.9	-3.3	-7.6	-5.8
25	-2.5	-5.0	-3.3	.0	-6.4	-3.6	-1.3	-2.9	-1.9	5.7	3.7	4.8	6.0	1.4	2.8	-2.8	-5.7	-4.3
26	2.3	-3.3	-.8	-4.8	-7.5	-6.6	-2.2	-4.3	-3.5	3.9	-.2	1.9	3.6	.9	2.0	-.2	-3.6	-2.0
27	8.5	1.9	4.3	-3.6	-9.8	-7.2	3.9	-2.2	.7	-.2	-3.1	-1.4	3.9	.6	2.1	1.5	-4.3	-1.2
28	1.9	-2.2	-.4	-5.6	-10.1	-7.8	5.4	-.6	3.0	-1.2	-4.1	-2.0	2.1	-2.7	-.2	-4.5	-6.5	-5.5
29	-1.4	-3.1	-2.3	.1	-6.0	-3.6	-1.5	-4.3	-3.2	-1.8	-3.2	-2.7				-4.4	-6.3	-5.4
30	-1.5	-5.9	-4.5	-5.5	-6.9	-6.2	-3.7	-5.6	-4.4	2.0	-3.1	-.2				-4.0	-7.8	-6.3
31	-4.0	-7.7	-6.5				-5.4	-7.6	-6.7	1.3	-4.9	-2.7				-.3	-5.8	-3.1
Monthly average	5.1	0.6	2.7	2.0	-2.8	-0.5	0.1	-4.4	-2.3	-1.2	-4.8	-3.1	1.2	-4.4	-1.7	0.9	-3.8	-1.5

Table 13. Daily maximum, minimum, and average of hourly average air temperature at the Hut, 1,842 meters altitude, near South Cascade Lake Basin, Washington, water year 2005.—Continued

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average]

Day	Daily air temperature, in degrees Celsius																	
	April			May			June			July			August			September		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	-0.4	-8.0	-4.3	7.4	2.3	4.7	2.3	-0.4	0.9	7.4	2.9	5.5	11.3	5.2	8.0	16.3	8.2	12.8
2	-2.8	-8.7	-5.3	8.5	1.5	4.8	3.4	1.2	2.3	3.5	2.4	3.0	13.3	3.8	8.9	13.2	4.9	8.7
3	1.0	-5.4	-3.2	6.7	.9	3.5	2.4	.3	1.7	11.8	1.9	7.6	20.1	10.8	15.2	6.7	3.7	5.2
4	-4.8	-7.7	-6.0	6.9	3.5	4.9	4.6	-1.1	1.5	16.0	7.8	12.2	22.1	14.8	17.8	3.5	1.7	2.5
5	-.9	-6.9	-3.8	10.3	4.3	6.0	.7	-1.3	-.2	16.0	9.2	12.2	20.7	13.5	16.6	9.4	1.0	5.9
6	5.6	-1.8	2.8	5.6	.9	3.6	5.0	-1.9	1.7	9.3	1.8	5.7	18.5	11.1	15.0	13.4	7.3	9.8
7	6.5	-6.1	.4	4.6	-.2	2.2	.5	-.3	.1	13.2	2.3	7.6	18.1	10.5	13.8	13.0	7.7	10.4
8	-.4	-8.4	-4.6	5.1	3.5	4.3	3.1	-.2	1.2	7.3	3.5	5.7	18.4	11.7	14.9	12.6	5.1	9.5
9	-3.4	-6.9	-5.2	6.6	2.9	4.8	7.4	1.1	4.3	7.5	2.7	4.9	17.5	10.3	14.2	4.0	.0	1.1
10	.5	-5.5	-2.3	5.8	3.1	4.3	7.9	2.9	4.7	9.4	3.3	6.2	12.8	8.4	10.4	5.5	.0	2.6
11	-1.2	-6.5	-4.8	9.2	2.6	5.6	2.5	-1.7	1.0	12.6	5.8	8.9	12.5	6.6	9.5	4.6	2.5	3.6
12	-3.4	-7.5	-5.9	14.5	2.7	8.1	2.7	-2.1	.4	9.2	5.4	7.1	16.9	11.4	14.1	6.9	3.2	4.4
13	-1.2	-8.0	-5.4	12.3	5.3	8.6	2.5	.8	1.5	8.2	5.0	6.3	17.9	10.4	14.4	11.0	3.9	7.1
14	-4.5	-7.0	-5.8	8.3	5.1	6.8	3.3	-.7	1.0	16.9	5.6	11.8	19.8	14.1	16.4	7.0	4.7	5.6
15	.7	-5.6	-2.9	8.0	.9	5.0	10.3	-2.3	3.9	15.2	5.2	10.1	19.6	12.8	16.2	4.3	2.6	3.3
16	2.0	-4.6	-1.2	4.4	-2.0	.6	11.7	4.7	8.0	8.3	5.0	6.4	14.7	8.0	12.2	3.2	2.0	2.6
17	.0	-5.4	-3.6	3.3	-2.9	.2	6.3	2.2	3.9	19.1	9.4	14.0	7.9	6.1	6.9	4.2	.9	2.8
18	2.4	-6.2	-2.1	4.0	-.2	1.4	4.3	2.4	3.5	16.8	10.6	14.3	13.5	6.0	9.7	6.2	1.3	4.2
19	7.0	-2.6	2.9	2.7	-1.4	-.2	11.6	3.6	8.4	13.8	7.9	11.0	17.3	10.4	13.6	4.9	2.1	3.4
20	10.7	2.8	6.3	1.8	-1.8	-.5	18.1	10.3	13.9	14.9	7.2	11.3	19.9	11.9	15.9	4.7	.7	2.2
21	10.0	4.6	7.6	4.2	-2.2	.2	19.4	6.6	13.6	23.3	11.0	18.3	17.4	9.1	14.5	8.4	.8	4.0
22	9.1	5.1	6.7	-.6	-3.1	-1.8	6.7	2.5	4.4	19.2	7.5	11.6	11.9	5.0	8.9	4.1	-.5	1.5
23	9.9	3.3	7.0	2.7	-3.1	-.4	11.1	1.7	6.7	12.1	5.2	8.9	6.6	3.1	4.7	6.1	.2	2.8
24	8.6	3.3	5.8	5.9	-1.4	2.7	12.0	5.6	8.7	13.2	5.3	9.2	14.1	5.0	9.8	7.6	2.0	4.7
25	14.9	7.6	9.8	11.7	4.5	8.5	10.8	4.8	7.4	15.3	6.7	11.6	19.2	10.6	14.0	11.7	4.9	7.9
26	14.4	7.1	10.8	14.5	8.2	11.4	10.1	4.8	6.8	18.4	11.6	15.5	16.3	9.4	13.6	11.2	6.0	8.4
27	9.6	3.5	7.3	17.7	10.2	14.1	5.0	3.9	4.5	21.3	13.9	17.7	16.8	9.3	12.8	10.0	3.5	6.5
28	6.2	.0	2.7	22.3	13.8	17.7	6.5	4.5	5.5	17.8	10.0	15.2	15.6	7.4	11.9	10.8	3.1	8.0
29	5.6	-.6	1.5	18.3	8.0	12.8	10.8	5.2	8.2	16.0	8.7	12.7	6.5	1.9	2.9	8.4	3.4	7.2
30	4.9	.1	2.6	9.4	5.1	7.4	12.1	6.8	9.2	20.2	10.5	15.1	4.9	2.4	3.8	6.4	-1.3	3.0
31				4.8	-.2	1.9				20.5	11.9	15.8	9.9	4.3	7.1			
Monthly average	3.6	-2.7	0.3	8.0	2.3	4.9	7.2	2.1	4.6	14.0	6.7	10.4	15.2	8.6	11.9	8.0	2.9	5.4

Table 14. Daily maximum, minimum, and average of hourly average air temperature at the Middle Tarn gaging station, 1,631 meters altitude, Middle Tarn Basin, Washington, water year 2005.

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average]

Day	Daily air temperature, in degrees Celsius																	
	October			November			December			January			February			March		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	11.6	7.8	9.2	5.4	-3.6	1.4	-1.9	-10.4	-7.1	-4.5	-6.3	-5.3	4.1	-4.8	0.5	3.2	-1.2	1.0
2	12.9	8.6	10.6	4.7	-3.5	-.5	-1.0	-9.0	-3.9	-5.1	-8.5	-6.8	6.5	-.5	3.7	3.0	-2.8	.3
3	14.4	9.5	11.2	-.7	-7.7	-3.9	-.7	-2.3	-1.5	-2.9	-8.7	-6.2	6.5	3.3	5.3	4.8	-3.2	1.6
4	16.5	8.9	11.0	4.1	-2.5	.9	1.5	-1.9	-.3	-3.2	-7.0	-4.9	3.6	-5.5	-1.2	4.8	-.5	1.7
5	15.6	7.9	10.9	9.1	3.7	5.6	-1.5	-8.0	-6.2	-1.4	-8.7	-5.0	-5.2	-10.2	-7.4	5.1	-1.1	2.3
6	9.4	2.2	5.8	6.2	1.4	4.1	-3.8	-8.1	-5.7	-5.2	-9.4	-7.2	-6.7	-9.4	-7.7	6.2	-.9	2.9
7	9.0	1.4	5.6	8.7	4.7	6.9	-1.8	-5.2	-3.4	-5.1	-8.9	-7.5	-.5	-8.4	-5.4	5.5	1.0	3.1
8	11.2	3.3	7.4	11.0	5.8	8.5	.1	-4.2	-2.2	-6.8	-9.5	-8.3	4.3	-8.0	-2.8	8.0	.7	5.2
9	2.7	-.4	1.5	7.7	3.2	5.5	4.6	-3.5	-.9	-6.2	-9.8	-7.9	3.6	-4.0	-1.2	6.8	2.5	4.6
10	5.3	2.2	3.8	8.8	6.3	7.2	6.1	2.0	4.7	-4.1	-10.1	-7.2	8.2	-2.5	2.6	8.7	2.9	6.0
11	8.8	4.7	6.2	7.6	3.8	5.7	-.8	-6.7	-3.7	-5.8	-9.9	-8.1	6.0	-.6	2.9	8.4	2.3	5.3
12	9.8	4.7	7.5	7.2	2.1	4.3	2.5	-2.0	.6	-5.4	-9.3	-7.1	.2	-5.3	-1.7	5.5	-.7	1.8
13	13.6	8.9	11.2	3.5	.2	2.0	4.6	-.7	1.3	-8.5	-12.6	-9.9	-5.7	-8.5	-7.2	6.6	-.6	2.3
14	14.3	6.5	10.0	7.3	1.5	4.7	1.7	-.6	.3	-5.8	-14.4	-10.5	-.9	-13.6	-8.6	6.5	-1.1	2.0
15	7.8	5.3	6.3	8.9	-3.4	1.5	1.1	-5.7	-1.9	2.0	-6.2	-1.7	-3.2	-12.8	-7.4	3.5	-2.8	.0
16	5.2	3.2	4.4	1.4	-4.5	-1.4	9.1	1.3	4.5	2.6	-.7	.8	3.5	-3.5	.1	.5	-5.2	-2.7
17	6.8	-.1	3.3	2.4	-6.4	-1.4	5.7	1.7	3.5	6.1	2.9	4.5	2.6	-2.1	.2	-2.5	-5.2	-4.1
18	1.5	-2.1	-.2	.2	-3.5	-2.1	8.5	3.8	6.1	7.8	4.3	6.1	3.7	-3.3	-.4	1.5	-6.7	-3.7
19	2.2	.7	1.7	-3.4	-8.8	-5.2	10.1	-4.3	.7	7.6	6.0	6.5	-.7	-7.3	-5.4	2.9	-6.3	-1.5
20	3.9	.0	1.5	-.4	-6.6	-3.7	-4.6	-6.3	-5.4	7.1	2.6	5.0	-.3	-7.6	-4.6	3.0	-4.7	.8
21	4.5	-1.7	-.4	1.7	-3.1	-.3	-3.1	-6.1	-4.7	7.5	3.5	5.6	4.4	-5.4	-.6	-2.5	-7.1	-5.3
22	1.5	-3.0	-.4	1.6	-1.1	-.3	-1.1	-7.4	-4.6	7.6	4.7	6.5	6.1	-.8	2.9	-.7	-4.8	-3.0
23	-2.4	-4.3	-3.6	2.3	-1.3	.2	4.3	-2.7	-.5	7.1	4.0	6.1	8.8	3.9	5.6	-.3	-4.9	-3.1
24	-2.6	-5.9	-4.3	3.7	1.3	3.0	1.9	-.2	1.1	7.5	5.1	6.6	6.9	1.2	3.2	-.9	-5.5	-3.8
25	1.7	-3.1	-1.0	2.9	-4.5	-1.6	1.4	-1.0	.5	8.3	4.5	6.4	7.6	.4	2.6	.1	-4.6	-2.7
26	4.0	-1.3	1.2	-1.8	-5.7	-4.9	.1	-2.4	-1.4	6.6	1.0	4.1	6.8	.6	3.7	.7	-1.9	-.2
27	6.5	1.5	3.0	-2.0	-9.5	-6.1	4.1	-.5	1.6	1.9	-.6	.6	7.5	2.1	4.3	2.6	-2.0	.2
28	2.1	-1.0	.2	-4.6	-10.0	-7.7	5.6	1.4	3.5	1.1	-1.8	-.2	4.2	-1.0	1.7	-2.3	-4.2	-3.3
29	.7	-1.8	-.4	-.5	-6.8	-3.4	.6	-3.8	-1.7	.6	-1.8	-1.0				-2.1	-4.6	-3.6
30	.4	-4.1	-2.8	-3.3	-5.8	-4.8	-.9	-4.3	-2.6	4.6	-1.8	1.3				-1.1	-6.2	-4.4
31	-4.2	-6.8	-5.2				-3.3	-5.5	-4.5	3.5	-4.1	-1.0				1.6	-4.6	-1.1
Monthly average	6.3	1.7	3.7	3.3	-2.1	0.5	1.6	-3.3	-1.1	0.6	-3.6	-1.5	2.9	-4.1	-0.8	2.8	-2.7	0.0

Table 14. Daily maximum, minimum, and average of hourly average air temperature at the Middle Tarn gaging station, 1,631 meters altitude, Middle Tarn Basin, Washington, water year 2005.—Continued

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average]

Day	Daily air temperature, in degrees Celsius																	
	April			May			June			July			August			September		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	1.6	-6.6	-2.2	8.8	4.1	6.2	4.1	0.9	2.6	9.5	4.2	6.9	13.3	7.0	10.1	17.1	7.6	11.3
2	2.6	-6.9	-2.6	8.2	2.4	5.8	4.8	2.6	3.7	5.6	4.2	4.7	15.5	4.3	9.2	11.4	6.0	8.9
3	2.9	-3.2	-1.2	5.8	2.0	3.8	3.6	1.7	3.1	13.9	2.8	8.4	16.8	9.1	13.9	8.7	5.6	7.1
4	-1.8	-7.4	-4.3	6.7	4.1	5.3	6.6	.9	3.2	16.8	7.8	11.1	22.3	12.2	15.4	5.7	3.6	4.3
5	2.0	-6.2	-1.5	8.7	4.9	6.7	2.8	.4	1.4	16.8	9.6	12.1	21.9	11.1	15.4	11.3	2.1	6.3
6	8.5	.7	5.6	8.0	1.9	5.0	7.0	-.8	2.9	11.8	3.7	7.9	20.1	9.9	14.3	14.4	6.4	9.5
7	8.8	-4.9	1.8	5.8	1.6	3.1	2.0	.6	1.5	13.6	3.9	7.9	19.7	9.3	13.4	14.8	7.0	9.9
8	3.9	-8.6	-2.7	7.0	5.3	6.1	4.0	.3	2.3	9.7	5.9	7.8	20.2	9.8	13.9	13.9	7.1	10.1
9	-1.3	-5.4	-3.4	8.1	4.8	6.4	8.7	1.7	5.3	9.2	4.7	6.6	19.4	9.2	13.2	6.0	1.3	2.8
10	5.0	-5.0	-0.4	7.7	4.1	5.7	10.1	4.4	6.5	8.8	4.3	6.8	14.8	7.6	10.6	6.9	.2	3.8
11	1.1	-5.5	-2.8	10.2	3.6	5.8	4.1	-.1	2.6	12.4	7.0	9.2	12.5	6.2	8.7	6.4	3.8	4.9
12	.5	-7.0	-3.9	10.8	2.0	6.2	4.4	-.9	1.8	11.2	7.4	8.7	18.7	9.6	13.6	7.5	4.3	5.4
13	3.6	-8.7	-3.6	11.4	1.3	7.2	4.9	2.6	3.8	10.1	6.8	8.2	16.5	11.2	13.4	11.6	4.2	7.7
14	-.7	-5.1	-3.5	9.9	5.7	7.5	4.8	.7	2.9	14.6	5.8	10.1	19.8	11.3	14.3	8.8	5.6	6.8
15	3.0	-4.5	-0.6	10.1	3.4	6.6	10.1	-.8	5.0	13.0	6.8	10.5	20.8	11.0	14.7	6.3	4.1	4.9
16	4.5	-2.4	1.1	4.4	-.7	2.1	13.1	6.2	9.5	9.8	6.3	7.6	16.9	9.5	12.6	4.5	3.1	3.7
17	4.9	-3.5	-1.4	5.2	-1.1	2.1	8.5	3.3	5.3	16.4	8.3	12.1	9.8	6.6	8.2	6.2	2.1	4.3
18	8.9	-6.5	.0	6.2	2.4	3.5	6.3	4.1	5.2	18.9	11.2	14.7	15.4	6.4	9.8	8.1	2.4	5.7
19	9.2	-3.0	3.4	4.1	.4	1.9	13.0	4.2	8.4	16.3	7.3	11.5	15.3	9.3	12.3	7.1	4.1	5.3
20	12.4	1.3	6.1	3.1	.4	1.5	15.9	8.7	12.3	16.9	6.5	11.0	20.2	10.1	13.8	6.9	2.4	4.2
21	11.6	3.4	8.1	6.0	-1.0	2.4	17.8	8.1	13.8	19.6	8.7	15.8	19.5	9.3	14.2	9.7	1.1	5.0
22	10.3	6.8	8.4	1.6	-.4	.4	8.1	4.2	6.3	16.6	8.5	11.7	14.3	6.8	10.1	6.0	.8	3.1
23	12.1	5.4	9.1	4.7	-1.4	1.4	13.5	3.8	8.0	14.4	5.6	9.9	8.9	4.9	6.6	8.8	.8	4.0
24	10.2	5.1	6.9	9.1	.3	4.4	13.7	6.8	9.4	15.5	5.0	9.7	16.1	5.4	9.9	10.3	1.8	5.5
25	12.1	4.1	8.7	13.4	6.4	10.3	12.7	6.1	8.5	17.2	6.4	11.8	15.8	8.8	12.1	12.3	4.8	7.8
26	12.4	4.9	9.1	16.3	10.5	13.1	11.0	5.0	7.3	20.2	9.8	13.9	18.5	8.6	13.0	13.1	6.8	9.3
27	11.8	4.5	8.7	16.0	12.7	14.2	6.5	4.3	5.6	20.2	11.7	14.9	18.0	8.6	12.0	10.7	4.2	7.0
28	9.2	1.9	4.6	18.9	12.4	15.0	7.8	5.0	6.3	19.9	9.2	15.1	16.3	9.5	11.9	13.1	5.3	8.8
29	6.3	1.5	3.2	15.1	8.0	11.2	11.7	5.7	8.7	17.9	8.0	12.7	8.2	3.8	4.6	10.8	5.9	9.5
30	6.2	1.0	3.8	11.2	6.6	8.3	13.7	7.0	10.3	20.8	9.3	13.8	6.1	4.0	5.2	7.4	.3	5.0
31				6.4	1.5	3.7				21.3	10.5	14.8	12.4	5.0	8.0			
Monthly average	6.1	-2.0	1.8	8.7	3.5	5.9	8.5	3.2	5.8	14.8	7.0	10.6	16.3	8.2	11.6	9.5	3.8	6.4

Table 15. Daily maximum, minimum, and average of hourly average air temperature at the Salix Creek gaging station, 1,587 meters altitude, Salix Creek Basin, Washington, water year 2005.

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average]

Day	Daily air temperature, in degrees Celsius																	
	October			November			December			January			February			March		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	16.6	8.0	10.7	5.4	-5.4	0.8	-5.1	-8.2	-6.8	-4.6	-6.0	-5.2	3.7	-4.5	-0.1	3.9	-1.5	1.1
2	19.9	10.3	13.4	4.6	-3.4	-.3	-.7	-8.2	-3.7	-6.1	-7.6	-6.7	6.2	-.4	3.9	2.5	-2.2	.5
3	18.4	11.2	13.5	-1.9	-6.6	-3.7	-.8	-2.5	-1.6	-4.1	-7.6	-5.9	6.7	3.5	5.5	5.1	-1.9	1.6
4	18.6	10.1	13.1	4.6	-1.8	1.3	.2	-1.8	-.7	-2.5	-6.5	-4.8	3.7	-5.2	-1.1	4.9	.2	2.3
5	17.0	7.9	11.9	9.5	4.3	6.1	-1.8	-8.4	-6.3	-2.0	-8.0	-4.5	-5.4	-9.6	-7.1	5.6	-.5	2.6
6	9.1	2.4	5.8	5.5	1.1	4.1	-3.4	-8.0	-5.9	-5.7	-8.8	-7.0	-5.7	-9.2	-7.3	6.2	-.3	3.3
7	11.3	1.7	6.6	8.2	4.0	7.1	-2.3	-5.0	-3.6	-6.7	-8.5	-7.7	-1.9	-7.4	-5.4	5.4	1.8	3.6
8	11.1	3.0	7.3	11.9	6.6	9.2	-.7	-4.0	-2.5	-7.3	-8.7	-8.1	1.5	-6.7	-2.1	8.5	1.4	5.7
9	2.5	-.2	1.4	7.4	4.0	5.7	3.2	-4.2	-2.0	-5.7	-9.5	-7.5	1.1	-2.8	-.8	7.3	2.7	4.8
10	7.1	2.6	4.4	8.3	6.2	7.0	6.1	2.2	4.8	-4.4	-9.0	-6.8	7.4	-1.6	3.6	11.2	3.9	7.0
11	10.8	5.0	7.0	7.8	4.2	5.8	-.7	-6.4	-3.7	-5.9	-9.2	-7.9	7.2	-.3	3.5	9.3	2.2	6.0
12	14.6	5.5	9.4	7.8	2.5	5.1	1.9	-3.2	.1	-5.3	-9.1	-6.9	.6	-5.5	-1.7	7.2	-1.1	2.4
13	19.8	10.0	13.3	3.3	1.1	2.3	3.4	-.6	1.3	-7.9	-11.8	-9.5	-5.3	-8.2	-6.9	8.2	.3	3.3
14	17.2	7.8	11.3	7.1	.7	4.3	.9	-.5	.0	-5.2	-13.7	-10.8	.2	-12.0	-7.0	7.9	-.9	2.9
15	8.0	5.6	6.8	8.7	-2.6	1.7	2.9	-4.4	-.4	2.3	-4.9	-1.5	-3.5	-11.9	-6.5	5.4	-1.8	.9
16	5.3	2.9	4.4	.1	-4.7	-1.6	8.9	1.4	4.7	2.3	-1.1	.3	2.9	-3.9	-.1	.5	-5.0	-2.7
17	5.3	-.2	2.8	2.7	-6.4	-1.5	5.5	2.0	4.0	6.0	1.6	3.7	1.5	-2.4	-.2	-.1	-5.0	-3.2
18	1.3	-2.1	-.2	.2	-3.3	-2.3	9.2	4.4	6.6	7.7	4.1	6.1	3.5	-2.2	.0	.0	-6.1	-3.7
19	2.6	.9	2.0	-3.1	-7.7	-4.9	10.1	-4.2	.8	7.7	6.2	6.7	-2.1	-6.6	-5.1	1.5	-6.2	-1.8
20	6.2	-.1	2.0	-1.7	-6.8	-3.7	-4.2	-6.1	-5.1	6.9	2.9	5.1	-.7	-7.5	-4.2	2.7	-4.7	.5
21	3.1	-1.7	-.4	1.9	-2.4	-.1	-2.6	-5.6	-4.5	7.5	3.8	5.6	3.9	-3.8	-.1	-2.5	-6.4	-5.0
22	1.3	-3.2	-.7	1.3	-.9	-.3	-2.1	-7.1	-4.9	7.9	4.1	6.2	5.8	-.3	2.9	-.1	-4.8	-2.8
23	-2.7	-4.7	-3.7	1.8	-1.1	.1	5.4	-1.9	-.3	7.0	4.2	6.0	7.1	3.3	5.3	-.9	-4.9	-3.0
24	-1.9	-4.9	-3.7	3.6	.8	2.8	2.8	.4	1.4	8.3	5.5	6.8	7.1	2.4	4.1	-1.7	-5.4	-3.8
25	1.0	-2.9	-1.0	2.4	-4.4	-1.6	.9	-1.5	-.2	8.0	5.1	6.5	7.6	1.2	3.2	-1.0	-4.2	-2.5
26	3.6	-1.1	1.2	-4.1	-5.7	-5.1	-.3	-2.6	-1.4	6.1	1.6	4.1	6.2	1.7	3.5	.4	-2.1	-.5
27	6.9	2.2	3.9	-2.8	-8.9	-5.8	3.5	-.4	1.8	1.9	-.2	.8	6.3	1.8	3.9	2.9	-1.9	.2
28	2.8	-.8	.8	-5.7	-9.0	-7.4	4.8	2.2	3.7	1.4	-1.1	.2	4.3	-1.0	1.7	-2.2	-4.3	-3.2
29	.8	-1.5	-.4	-1.8	-6.1	-3.7	1.5	-2.9	-1.4	.3	-1.6	-.9				-1.2	-4.5	-3.4
30	-.1	-4.3	-2.9	-3.2	-5.6	-4.6	-1.2	-3.8	-2.6	4.3	-1.6	1.2				.6	-6.1	-3.6
31	-2.2	-7.3	-5.0				-3.8	-5.3	-4.5	3.5	-3.9	-.9				1.3	-4.3	-1.1
Monthly average	7.6	2.0	4.4	3.0	-1.9	0.6	1.3	-3.0	-1.1	0.5	-3.2	-1.4	2.5	-3.5	-0.5	3.2	-2.4	0.3

Table 15. Daily maximum, minimum, and average of hourly average air temperature at the Salix Creek gaging station, 1,587 meters altitude, Salix Creek Basin, Washington, water year 2005.—Continued

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average]

Day	Daily air temperature, in degrees Celsius																	
	April			May			June			July			August			September		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	1.4	-6.3	-2.5	9.4	4.0	6.5	5.0	1.2	3.0	10.9	4.6	7.9	13.4	7.0	10.4	19.3	8.3	13.6
2	-1.8	-7.1	-3.7	10.5	2.7	6.4	5.2	2.9	4.0	6.5	4.5	5.1	17.7	4.9	11.1	13.0	6.6	10.0
3	3.2	-3.2	-.9	7.4	2.5	4.7	4.1	2.0	3.5	16.1	3.1	9.9	23.9	9.4	16.8	10.5	6.1	7.6
4	-.5	-7.1	-3.7	8.3	4.5	6.1	8.5	.7	3.9	19.9	8.8	13.8	25.5	14.1	18.7	5.9	3.7	4.6
5	1.4	-5.6	-1.6	11.1	4.5	7.4	3.5	.4	1.6	19.0	10.4	13.6	24.2	13.4	18.0	13.8	2.5	7.9
6	7.0	.7	4.9	10.1	2.4	6.0	9.5	-.5	4.0	11.4	3.8	8.1	22.1	11.8	16.8	17.5	7.6	11.6
7	7.7	-4.3	1.8	7.7	1.7	4.1	2.2	.9	1.8	17.3	4.2	10.1	22.2	10.9	15.8	18.0	7.7	11.9
8	2.0	-7.5	-2.7	7.9	3.3	6.3	5.1	.8	2.9	9.2	5.9	7.8	22.7	11.8	16.4	16.5	7.5	11.3
9	-.4	-5.4	-2.9	9.6	5.0	6.8	10.7	1.6	6.3	10.7	5.0	7.3	21.6	11.2	15.8	6.2	1.8	3.4
10	2.6	-4.4	-.7	8.9	4.7	6.4	10.9	4.6	7.2	12.0	4.7	8.0	17.2	9.3	12.5	9.1	.4	4.4
11	.2	-4.9	-2.6	13.6	4.2	7.7	4.2	.0	2.9	15.9	7.4	11.0	14.3	8.1	10.2	7.6	4.3	5.5
12	.7	-6.4	-3.8	15.3	2.8	8.0	6.6	-.7	2.5	12.8	7.7	9.8	20.3	8.8	15.3	9.3	4.8	6.3
13	.8	-7.8	-3.9	15.2	1.9	9.3	6.6	2.5	4.0	11.9	7.2	9.1	22.1	12.6	16.4	14.3	4.7	8.8
14	.2	-4.8	-3.1	11.9	6.3	8.8	5.8	1.0	3.2	20.1	6.5	13.4	23.0	13.0	17.1	10.6	6.5	7.8
15	1.8	-4.1	-.9	10.7	3.2	7.0	12.6	-.4	6.5	14.9	7.1	11.5	23.6	13.3	17.4	6.3	4.3	5.2
16	4.3	-2.6	.6	6.2	-.4	2.6	15.1	6.7	10.5	11.5	6.7	8.5	19.1	9.9	14.5	5.1	3.9	4.3
17	1.2	-3.4	-1.7	6.9	-1.0	2.8	8.1	3.5	5.6	22.8	8.8	15.3	10.8	7.5	8.9	7.3	2.9	4.9
18	5.4	-5.4	-.2	6.8	2.2	3.7	6.8	4.3	5.5	21.0	12.3	16.2	17.8	6.7	11.8	9.8	3.2	6.6
19	9.2	-2.5	3.6	4.8	.4	2.0	15.2	4.9	10.5	18.7	9.0	13.4	20.6	10.7	15.0	8.1	4.2	5.5
20	10.4	3.1	6.9	5.0	.2	1.9	21.8	10.2	15.6	19.4	8.1	13.3	22.5	11.5	16.7	9.4	1.6	4.7
21	11.4	4.6	8.6	7.1	-.6	2.9	23.6	8.3	15.5	25.5	10.2	18.7	21.5	10.8	16.2	12.1	1.6	5.9
22	10.5	7.4	8.7	2.5	-.7	0.5	8.4	4.5	6.6	18.6	9.5	12.8	16.0	7.0	11.5	8.0	.7	3.8
23	12.0	5.8	9.1	7.0	-1.4	2.1	16.0	3.7	9.5	16.8	6.7	11.3	11.2	5.2	7.1	10.9	.4	4.8
24	10.8	5.4	7.6	11.9	.5	5.4	16.0	7.2	10.7	17.6	6.3	11.6	18.4	5.7	11.9	12.9	2.3	6.7
25	13.0	4.2	9.4	15.6	5.2	11.2	15.1	6.6	10.0	19.0	8.1	13.8	21.7	10.3	15.2	14.4	5.5	9.2
26	13.6	5.9	10.3	18.4	10.6	14.2	14.9	6.3	9.0	22.5	11.6	16.5	20.8	10.6	15.3	15.0	7.2	10.1
27	12.1	5.1	8.7	20.2	12.8	16.3	7.0	5.5	6.3	25.0	13.5	18.3	19.8	9.7	14.1	14.5	4.4	8.4
28	11.7	1.8	5.5	24.2	13.4	18.2	8.3	6.1	7.2	22.5	11.2	16.9	17.8	9.5	13.7	14.4	5.3	9.6
29	7.5	1.0	3.4	19.4	9.0	13.6	14.2	6.4	10.3	20.4	9.9	15.0	8.1	3.6	4.8	10.7	5.6	9.2
30	7.1	1.1	4.1	12.1	7.1	9.3	15.4	8.0	11.6	22.9	11.2	16.6	6.7	4.1	5.6	7.8	.5	4.9
31				6.7	1.7	4.0				23.6	12.1	17.2	14.3	5.7	9.4			
Monthly average	5.6	-1.6	1.9	10.7	3.6	6.8	10.2	3.6	6.7	17.3	7.9	12.3	18.7	9.3	13.6	11.3	4.2	7.3

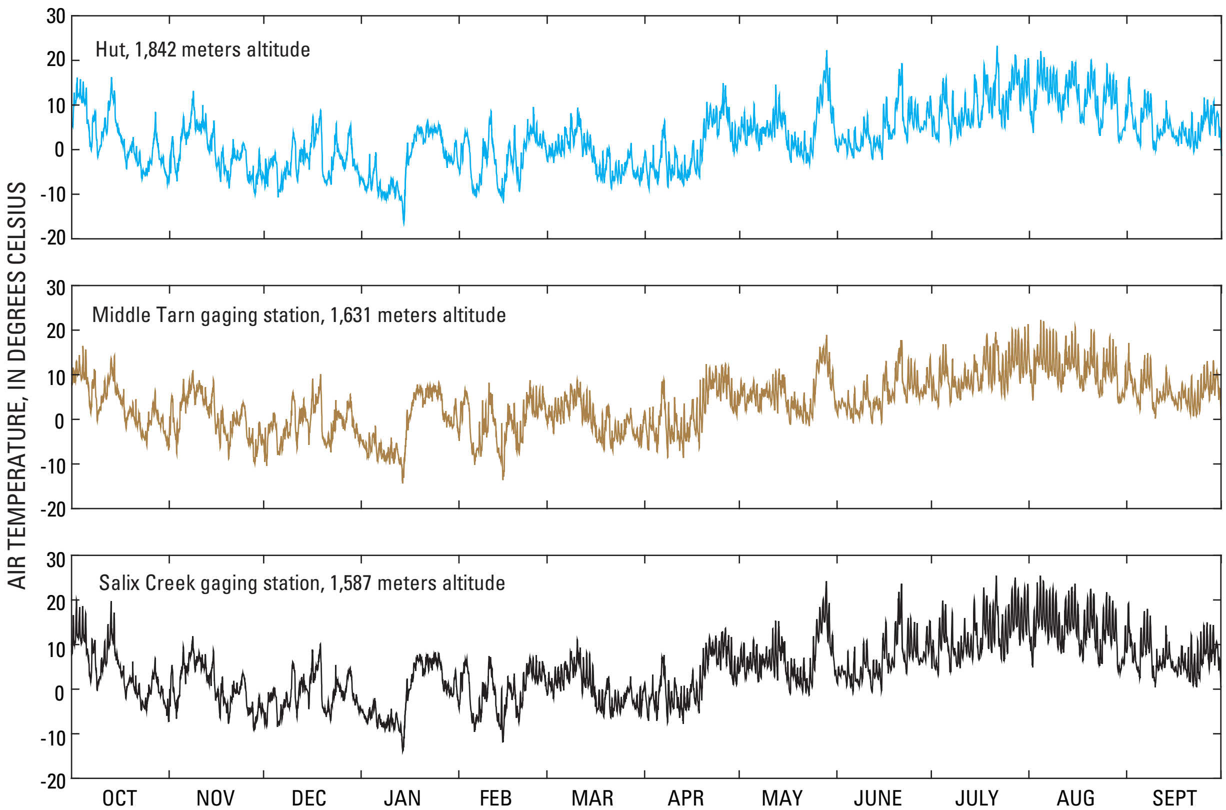


Figure 7. Hourly average air temperature at selected sites in and near South Cascade Lake Basin, Washington, water year 2005. Daily summaries are presented in tables 13–15.

The air-temperature sensors on the glacier were installed mid-May and each operated until late September or through the end of the water year (figs. 2 and 8). During May 14 to September 24, when all three sensors were operating, average air temperature at the site near the terminus, at site P-1, and at the upper glacier site was 7.7°C, 5.8°C, and 5.3°C, respectively (tables 16–18). The decrease of average temperature with altitude from the site near the terminus to site P-1 was 0.012°C/m, and the decrease with altitude from the site near the terminus to the upper glacier site was 0.0069°C/m. The decrease of average temperature with altitude from site P-1 to the upper glacier site was 0.0026°C/m.

A complete record of incoming daily solar radiation is available for water year 2005 (fig. 9). Maximum daily incoming solar radiation was 367 W/m^2 on June 15, about the time of the summer solstice (table 19). Monthly average of incoming solar radiation ranged from 32 W/m^2 in December to 253 W/m^2 in July. Ice and snow likely obscured the pyranometers and caused underestimation of solar radiation at times, particularly during winter. Average daily incoming solar radiation averaged 204 W/m^2 during June through September, months when snow or ice accumulation on the pyranometers occurred infrequently, if at all.

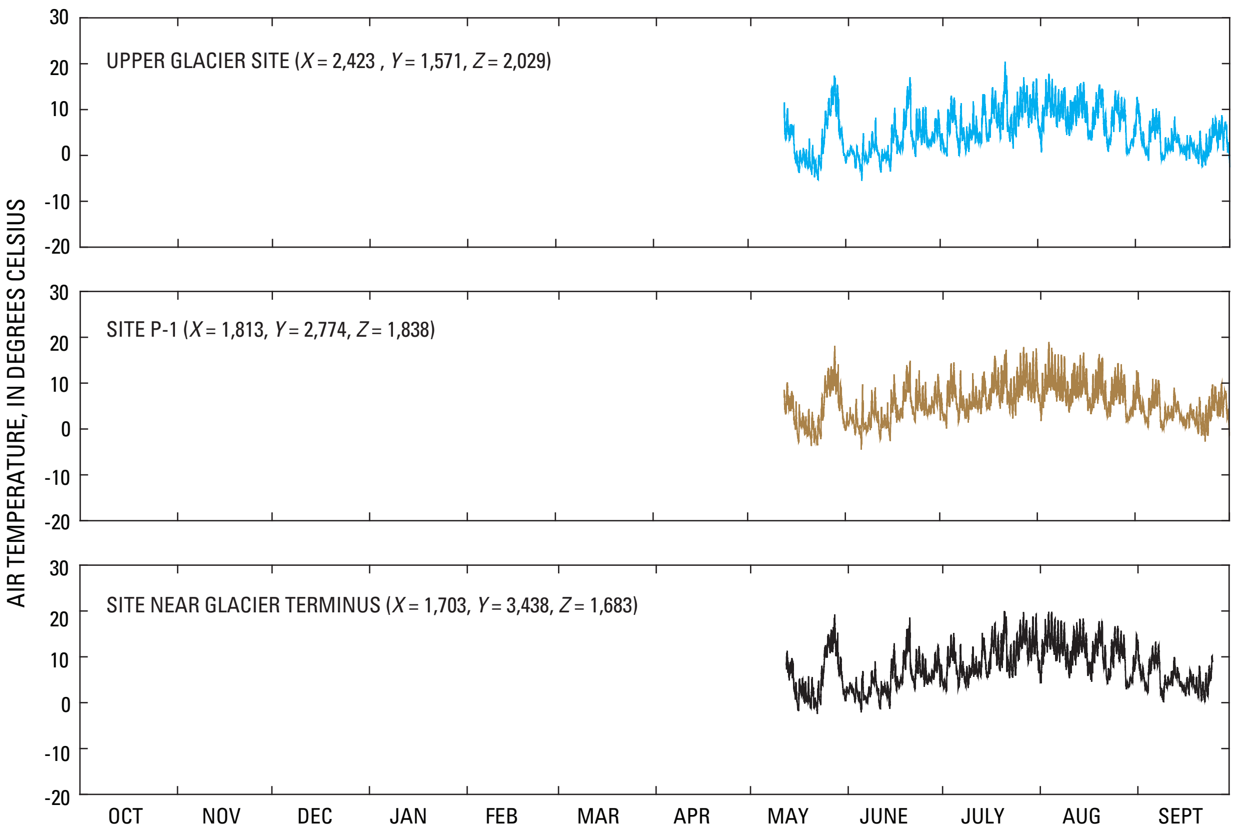


Figure 8. Air temperature recorded at 10-minute intervals at three selected locations on South Cascade Glacier, Washington, May–September 2005. Daily summaries are presented in tables 16–18.

Table 16. Daily maximum, minimum, and average air temperature on South Cascade Glacier, Washington, near the glacier terminus, 1,683 meters altitude, May–September 2005.

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average; –, no data]

Day	Daily air temperature, in degrees Celsius														
	May			June			July			August			Septemer		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	–	–	–	3.6	0.4	1.9	8.3	3.4	6.0	12.2	5.8	8.8	15.0	7.7	11.3
2	–	–	–	4.4	2.1	3.2	5.2	3.2	4.0	13.8	4.2	8.5	13.3	5.2	8.6
3	–	–	–	3.2	.9	2.5	12.4	2.4	7.4	18.2	9.1	13.3	7.9	5.1	6.2
4	–	–	–	5.6	.1	2.4	14.9	7.8	10.6	19.9	10.9	15.3	5.2	2.7	3.7
5	–	–	–	2.5	-.3	1.0	15.2	8.5	11.3	19.8	11.6	14.9	9.5	2.1	5.9
6	–	–	–	6.9	-2.1	2.3	11.0	3.1	6.9	18.2	9.1	13.8	12.5	6.3	9.4
7	–	–	–	1.6	.1	.9	12.8	3.3	7.0	18.0	9.1	12.8	13.3	7.4	9.8
8	–	–	–	3.6	.2	1.8	9.1	5.0	6.7	17.9	8.8	13.3	12.5	6.0	9.8
9	–	–	–	7.1	1.6	4.6	8.0	3.3	5.4	17.4	9.4	12.8	5.9	.6	2.2
10	–	–	–	9.0	3.5	5.5	8.2	3.2	5.9	12.8	7.1	9.8	6.1	.2	3.5
11	–	–	–	3.9	-.6	2.0	12.3	5.7	8.4	11.3	5.4	8.1	5.7	3.1	4.4
12	–	–	–	4.8	-1.4	1.3	10.1	5.7	7.6	16.7	8.1	12.7	6.9	3.6	4.9
13	–	–	–	4.3	1.9	3.0	8.9	5.7	7.2	17.5	8.2	12.4	9.9	4.3	7.3
14	9.1	4.9	7.1	4.7	.2	2.1	15.2	5.6	10.0	18.3	10.0	13.8	7.8	5.3	6.2
15	9.7	2.4	6.1	9.6	-1.2	4.1	14.2	5.7	10.0	18.4	10.9	13.9	5.8	3.3	4.2
16	4.5	-1.1	1.5	13.0	5.2	8.8	9.0	5.5	6.8	15.3	8.0	11.9	3.9	2.3	3.2
17	5.2	-1.8	1.6	8.1	2.5	4.6	16.7	7.3	12.1	8.9	5.7	7.3	5.6	1.4	3.6
18	5.3	1.3	2.9	5.6	3.2	4.4	17.5	10.7	14.0	13.4	4.6	9.2	7.2	1.7	4.9
19	4.7	-.2	1.2	11.5	3.9	7.8	14.7	7.5	10.7	15.1	8.6	12.1	6.3	3.3	4.5
20	5.8	-.5	1.0	16.1	7.2	12.1	15.2	6.9	10.4	17.8	10.1	14.1	5.6	1.7	3.4
21	5.6	-1.3	1.9	18.6	6.9	12.7	20.0	9.3	15.5	17.8	9.2	13.9	8.1	1.1	4.3
22	1.1	-1.2	-.2	7.7	3.6	5.4	18.8	6.7	11.3	12.6	5.7	9.2	4.6	.4	2.4
23	4.8	-2.5	.9	11.7	2.9	6.8	12.7	5.3	8.8	7.5	4.1	5.7	6.6	.1	3.4
24	8.1	-.5	3.7	12.3	5.8	8.5	13.6	5.4	8.9	13.8	5.0	9.4	8.1	1.2	5.0
25	12.5	5.2	9.5	10.7	5.4	7.5	15.3	5.9	11.1	16.7	7.6	12.2	–	–	–
26	15.0	9.8	12.4	9.6	3.5	6.4	18.1	9.3	13.5	16.8	9.5	12.8	–	–	–
27	16.0	10.8	13.2	5.8	3.9	5.0	19.8	11.7	14.9	15.7	9.0	11.5	–	–	–
28	19.3	11.0	15.1	7.2	4.5	5.8	18.0	10.3	14.4	14.9	7.5	11.3	–	–	–
29	15.3	7.3	10.9	11.0	5.0	8.1	16.4	8.6	12.0	7.9	2.9	4.0	–	–	–
30	10.0	5.7	7.4	12.5	6.5	9.4	18.8	9.1	13.4	5.6	3.3	4.6	–	–	–
31	5.8	.8	3.0				19.5	10.5	13.9	10.4	4.3	7.1			
Monthly average	–	–	–	7.9	2.5	5.1	13.9	6.5	9.9	14.9	7.5	11.0	–	–	–

Table 17. Daily maximum, minimum, and average air temperature on South Cascade Glacier, Washington, at site P-1, 1,838 meters altitude, May–September 2005.

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average; –, no data]

Day	Daily air temperature, in degrees Celsius														
	May			June			July			August			Septemer		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	–	–	–	3.7	-0.4	1.0	8.0	1.9	4.8	10.3	4.1	7.1	12.8	4.1	8.4
2	–	–	–	4.8	1.1	2.3	3.3	1.8	2.6	12.3	1.7	6.3	11.7	3.3	6.7
3	–	–	–	3.2	-.1	1.7	10.6	.1	6.1	14.2	5.9	9.2	6.2	3.1	4.5
4	–	–	–	6.6	-1.2	1.4	14.3	4.8	9.0	19.0	8.2	11.7	3.3	1.3	2.1
5	–	–	–	.9	-2.0	-.4	14.5	6.0	9.6	17.7	8.4	12.0	6.8	.3	3.7
6	–	–	–	9.8	-4.6	1.1	9.7	1.4	5.2	16.3	8.2	11.1	10.9	3.0	6.4
7	–	–	–	1.5	-.7	.2	12.8	1.5	6.0	16.3	6.0	10.3	10.8	4.4	7.2
8	–	–	–	3.7	-.6	1.1	7.3	3.3	5.2	16.2	5.9	10.1	10.7	4.3	7.9
9	–	–	–	8.5	.2	3.9	6.6	2.2	4.1	15.9	6.1	10.1	4.6	-.1	1.0
10	–	–	–	9.1	2.4	4.4	7.8	1.4	4.7	10.4	4.9	7.4	5.4	.2	2.3
11	–	–	–	3.9	-1.7	1.1	12.2	4.2	6.7	12.1	3.6	6.4	5.0	1.8	3.0
12	–	–	–	4.8	-2.3	.3	9.4	4.4	6.2	14.4	5.8	10.4	5.0	1.7	3.2
13	10.2	3.2	6.3	3.2	.5	1.6	8.6	4.2	5.7	13.7	6.6	9.1	8.9	2.4	5.5
14	7.8	3.9	5.5	5.8	-.8	.9	11.6	3.2	7.2	16.1	6.9	10.2	6.1	3.7	4.7
15	8.3	.9	4.5	8.6	-2.6	2.9	12.5	4.7	8.1	16.7	7.5	11.1	4.2	1.5	2.8
16	6.0	-2.1	.6	11.9	3.6	7.0	8.8	4.1	5.6	13.2	6.1	9.9	2.5	.7	1.7
17	5.4	-2.9	.5	6.9	1.4	3.5	12.4	5.0	8.5	7.3	3.9	5.5	3.6	.2	2.0
18	3.6	-.1	1.4	4.6	1.9	3.2	16.0	7.8	11.8	12.0	3.2	6.5	5.5	.2	3.2
19	2.8	-1.3	-.1	10.3	2.3	6.4	13.4	5.6	9.4	13.0	5.6	8.5	4.3	1.6	3.0
20	4.4	-1.9	-.2	13.9	6.0	9.8	13.9	4.4	8.5	16.3	5.5	10.6	4.9	.3	1.8
21	3.7	-3.7	.2	14.9	5.9	9.8	16.3	6.4	11.6	15.5	6.2	10.9	7.0	-1.1	2.5
22	.2	-3.0	-1.7	6.2	2.0	4.1	17.3	5.3	9.5	10.6	3.7	7.1	3.6	-1.5	.8
23	3.1	-3.6	-.4	10.9	1.4	5.6	11.0	3.4	7.2	6.0	2.5	4.1	5.2	-2.7	1.3
24	7.5	-2.2	2.2	12.8	3.9	7.2	11.5	2.3	6.6	11.3	2.6	6.7	7.2	-1.5	3.1
25	11.7	2.7	7.4	9.5	3.9	6.0	13.6	2.9	8.5	13.4	5.1	8.6	7.2	-1.5	5.4
26	13.3	6.9	10.1	10.3	2.9	5.0	16.6	6.8	10.5	14.4	6.3	10.0	9.7	1.8	6.6
27	13.7	7.1	9.9	5.0	2.8	3.9	17.9	7.2	11.8	14.1	5.4	8.8	9.3	3.9	4.6
28	18.1	8.4	12.1	7.1	3.3	5.0	16.6	8.1	12.3	11.9	5.1	8.9	8.1	2.7	6.0
29	14.1	4.6	9.4	10.4	3.3	6.8	14.5	6.2	10.1	6.3	1.6	2.5	9.9	2.5	6.8
30	10.1	3.9	6.4	12.0	4.9	7.8	17.0	5.8	10.6	4.8	1.9	3.4	8.3	2.7	2.8
31	4.9	-.2	1.8				17.6	5.6	11.3	9.6	2.7	5.7			
Monthly average	–	–	–	7.5	1.2	3.8	12.4	4.3	7.9	12.9	5.1	8.4	7.0	1.4	4.0

Table 18. Daily maximum, minimum, and average air temperature on South Cascade Glacier, Washington, near the upper end of the glacier, 2,029 meters altitude, May–September 2005.

[**Abbreviations:** Max, maximum; Min, minimum; Avg, average; –, no data]

Day	Daily air temperature, in degrees Celsius														
	May			June			July			August			Septemer		
	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg	Max	Min	Avg
1	–	–	–	0.7	-1.7	-0.3	4.9	1.1	3.1	8.3	2.6	5.5	12.8	4.6	9.5
2	–	–	–	1.9	.0	1.0	2.4	.6	1.3	11.0	.7	6.3	11.4	3.1	6.9
3	–	–	–	1.1	-1.5	.3	10.0	-.2	5.2	16.6	8.6	11.5	5.2	1.5	2.9
4	–	–	–	2.1	-2.9	-.4	13.0	4.8	8.9	17.8	10.2	13.6	1.6	.1	.7
5	–	–	–	-.1	-3.3	-1.7	12.6	6.6	9.4	16.7	8.2	11.5	7.5	-1.2	3.6
6	–	–	–	4.9	-5.5	-.4	8.6	-.1	3.9	15.2	6.2	10.7	10.1	4.9	6.9
7	–	–	–	.3	-1.6	-.7	11.4	.0	5.1	14.4	6.2	9.6	10.3	3.5	7.0
8	–	–	–	3.2	-1.4	.2	6.1	1.6	4.2	14.1	8.1	10.5	9.7	2.6	6.6
9	–	–	–	5.3	.2	2.4	6.3	.9	2.8	14.9	6.3	11.0	2.6	-1.0	-.2
10	–	–	–	8.2	1.0	3.0	7.0	.8	3.9	10.7	4.5	7.1	4.0	-.8	1.0
11	–	–	–	1.1	-2.8	-.3	11.8	3.3	6.4	12.1	4.2	8.3	3.8	.8	1.8
12	–	–	–	1.4	-3.7	-1.2	8.7	2.8	4.9	13.2	7.0	10.5	6.0	.8	2.3
13	10.3	3.2	6.5	.7	-.9	-.1	5.2	2.7	3.8	15.1	6.4	10.2	8.5	2.6	4.9
14	6.8	3.2	4.9	2.3	-2.0	-.6	13.4	2.5	8.6	15.8	8.6	12.2	4.6	2.5	3.6
15	6.6	-.8	3.3	6.8	-3.5	1.7	13.2	3.4	7.7	16.0	8.1	11.9	2.9	.8	1.5
16	1.1	-3.2	-1.0	10.4	2.7	5.8	7.9	3.0	4.7	11.8	4.8	8.9	2.0	.0	1.0
17	1.2	-3.8	-1.5	5.6	.3	2.4	14.9	7.0	10.3	5.5	3.5	4.4	4.4	-1.1	1.3
18	1.6	-1.5	-.2	3.0	.6	1.8	14.2	7.0	10.8	10.6	3.2	7.0	4.4	-.8	2.4
19	1.3	-2.6	-1.3	10.2	1.1	5.9	11.5	5.0	8.1	13.8	6.7	10.3	2.5	.6	1.5
20	3.7	-3.1	-1.5	15.1	6.1	10.9	11.6	3.5	8.1	15.5	8.1	12.3	2.4	-1.0	.2
21	2.2	-4.1	-1.3	17.1	4.0	11.1	20.4	8.0	14.6	14.6	6.2	11.6	5.4	-1.9	1.7
22	-1.1	-4.7	-3.1	5.2	.7	2.8	17.5	5.0	8.8	9.4	2.7	5.9	1.1	-2.6	-.6
23	.1	-5.4	-2.3	10.2	-.4	4.4	9.0	3.0	6.0	3.6	.8	2.5	4.8	-2.2	.4
24	5.8	-2.9	.9	10.2	3.6	6.3	10.9	1.5	6.4	10.7	2.3	6.8	5.8	-.2	2.2
25	9.7	2.3	6.2	10.5	2.3	5.0	13.9	4.0	8.7	14.2	5.1	10.3	8.2	1.7	4.8
26	12.5	5.8	9.1	10.5	2.5	5.8	15.0	7.9	11.3	13.3	6.5	10.5	8.2	3.9	5.8
27	15.0	8.7	11.6	3.4	2.0	2.6	17.0	8.3	12.5	12.8	5.1	9.0	7.7	1.6	4.4
28	17.4	8.6	13.6	5.2	2.1	3.6	15.3	8.5	11.7	12.1	5.1	9.2	8.8	1.0	5.4
29	15.4	5.2	10.7	8.1	2.6	5.7	13.3	6.0	9.4	5.5	.3	1.3	7.4	1.7	5.7
30	7.8	2.7	4.8	10.0	4.1	6.5	16.1	7.1	11.5	3.7	.6	2.2	5.3	-2.4	1.5
31	3.4	-1.4	.6				16.8	7.9	11.7	6.6	2.0	4.2			
Monthly average	–	–	–	5.8	0.2	2.8	11.6	4.0	7.5	12.1	5.1	8.6	6.0	0.8	3.2

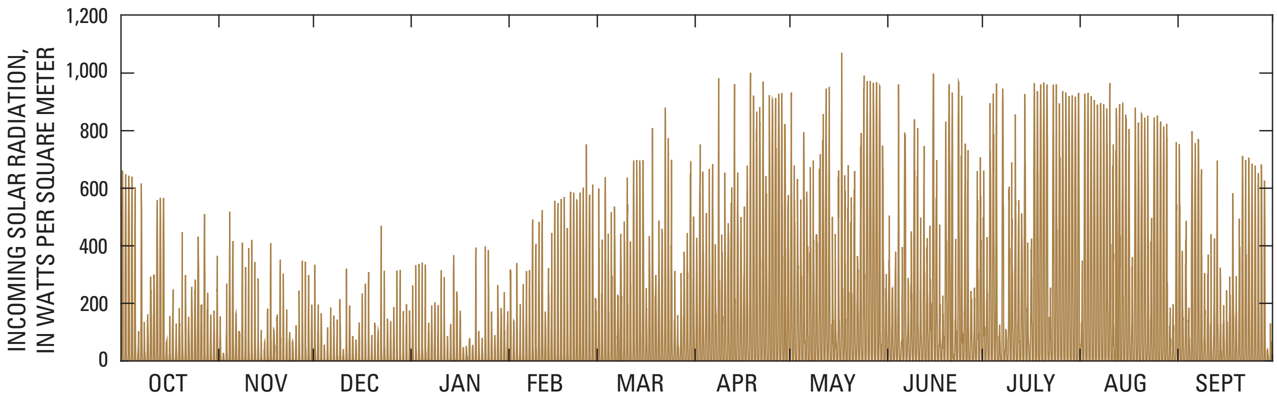


Figure 9. Hourly average incoming solar radiation at the Hut, 1,842 meters altitude, near South Cascade Lake Basin, Washington, water year 2005. Daily average incoming solar radiation is presented in table 19.

Table 19. Daily average incoming solar radiation at the Hut, 1,842 meters altitude, near South Cascade Lake Basin, Washington, water year 2005.

Day	Daily average incoming solar radiation, in watts per square meter, averaged for the 24-hour day											
	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.
1	184	32	50	47	66	146	112	273	124	199	85	230
2	180	7	36	43	32	79	192	194	84	114	312	96
3	179	35	32	50	60	169	158	188	118	319	329	125
4	176	94	11	52	36	96	154	164	198	320	324	50
5	136	81	20	50	55	113	156	241	72	252	320	241
6	18	40	37	28	58	134	212	170	284	37	316	241
7	144	29	29	35	69	62	101	186	89	324	311	245
8	26	82	22	45	93	106	260	179	121	38	312	159
9	44	61	39	36	83	107	136	152	271	182	293	73
10	82	66	9	52	89	160	180	206	210	166	243	94
11	83	74	37	47	114	99	150	286	108	227	195	62
12	144	67	39	18	39	197	176	313	205	178	284	85
13	148	34	18	28	66	198	225	272	125	168	280	171
14	145	17	14	59	72	184	187	114	123	334	259	66
15	20	13	26	48	129	197	150	99	367	95	293	52
16	28	34	43	36	130	62	149	150	221	131	265	46
17	51	72	44	11	135	113	185	270	95	355	95	75
18	26	31	46	11	137	153	268	154	70	332	299	136
19	45	36	16	18	97	88	309	171	284	352	277	59
20	70	65	27	14	144	108	266	145	362	354	289	129
21	60	52	23	67	146	126	294	196	249	355	285	206
22	35	31	61	17	143	208	262	123	87	69	214	176
23	60	21	43	17	149	185	219	217	335	355	120	209
24	66	18	28	71	152	151	230	312	226	303	284	204
25	109	27	25	69	143	65	313	362	222	298	274	200
26	55	40	35	36	154	36	297	363	168	340	278	185
27	114	50	46	18	160	63	323	361	86	337	271	197
28	56	52	46	52	66	114	264	359	73	335	229	155
29	39	47	31	41		115	239	297	221	329	53	11
30	41	42	39	44		192	185	210	225	328	56	25
31	69		35	35		125		89		332	219	
Monthly average	85	45	32	39	101	127	212	220	181	253	247	133

The three largest precipitation events detected by the precipitation gage at the Salix Creek gaging station during water year 2005 occurred during November 23–25, December 9–10, and January 16–18 (table 20). Recorded precipitation exceeded 115 mm during each of those events. Recorded precipitation totals for the November and December events probably were somewhat in error due to subfreezing temperature that affected the precipitation gage at the beginning and end of the events. The January event, a relatively warm winter rainstorm, ended with air temperature about 7°C at the Salix Creek gaging station. Large winter snow storms also possibly occurred during the year that were not detected by the unheated precipitation gage. During June through September, when most precipitation likely was rain at the Salix Creek gaging station, total recorded precipitation was 344.6 mm.

The record of stage at Middle Tarn during water year 2005 was interrupted by snow and ice covering the tarn during winter and by malfunction of the gage in August and September (fig. 10). Computed daily average runoff from Middle Tarn Basin ranged from 3.0 mm/d November 23 to 110.6 mm/d September 29 (table 21). Monthly average runoff for months with a complete record ranged from 7.0 mm/d in November to 28.8 mm/d in July. Discharge computed from a single measurement in water year 2005 (table 11) differed from the rating curve by less than 1 percent when a stage shift was applied.

Table 20. Daily total precipitation (gage catch) at the Salix Creek gaging station, Salix Creek Basin, Washington, 1,587 meters altitude, water year 2005.

Day	Daily precipitation, in millimeters											
	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.
1	0.0	40.9	0.0	0.0	5.3	3.0	1.3	0.0	7.9	1.8	1.8	0.0
2	.0	24.1	.0	.0	1.0	1.3	8.6	3.6	5.6	9.9	.0	.0
3	.0	.0	.3	.0	.0	.0	1.3	1.5	1.8	.0	.0	.0
4	.0	4.8	.3	.0	4.1	.0	4.3	2.8	.3	.0	.0	8.4
5	5.1	.0	.0	.0	.0	.0	1.3	2.0	11.2	3.8	.0	.3
6	3.3	11.7	.0	.0	.0	.0	.3	.0	4.1	11.9	.0	.0
7	2.8	3.3	.0	.3	.0	8.4	3.6	.0	9.9	.0	.0	.0
8	27.9	.0	.0	.0	2.5	.0	3.6	6.4	7.4	18.5	.0	.0
9	12.4	.0	18.8	.0	.0	6.4	.0	18.8	.3	.3	.0	11.4
10	0.8	.0	101.9	.0	.0	.0	.5	5.1	.0	1.5	.0	9.1
11	.3	.0	.3	.0	.0	2.0	.3	1.0	13.5	.0	.0	.8
12	.0	.0	.0	.0	.0	.0	.5	.0	3.6	.0	.0	.0
13	.0	1.3	14.5	.0	.0	.0	.3	.3	2.3	.0	.0	.0
14	.0	6.9	6.1	.0	.0	.0	4.3	3.3	7.6	.0	.0	.3
15	6.4	5.3	.0	1.5	.0	.0	2.3	15.5	1.3	3.6	.0	.3
16	22.4	.0	3.6	7.6	.5	.0	9.7	8.4	4.6	3.6	.0	7.6
17	14.7	.3	1.5	79.2	.0	2.8	.3	4.6	4.1	.0	12.7	.0
18	2.0	.0	.3	57.2	.0	5.3	5.1	10.9	3.8	.0	.0	.0
19	1.8	.0	3.0	1.0	.0	1.0	.0	4.1	.0	.0	.0	.0
20	1.5	.0	.0	11.9	.0	2.0	.0	3.8	.0	.0	.0	.0
21	4.3	.3	.0	1.0	.0	1.8	.0	2.8	3.8	.0	.0	.0
22	8.9	2.3	.0	31.5	.0	.3	.0	1.5	6.4	6.4	.0	.0
23	.0	11.7	.5	4.3	.0	.0	5.6	1.0	.0	.0	1.3	.0
24	.3	94.0	6.4	.0	.0	.0	.3	.0	.0	.0	.0	.0
25	.0	10.2	1.3	.0	.0	2.8	.0	.0	.0	.0	.0	.0
26	1.3	.0	.0	2.8	.0	.3	.0	.0	7.4	.0	.0	.0
27	.8	.0	.3	2.0	.0	11.9	.0	.0	10.7	.0	.0	.0
28	.5	.0	.5	.0	1.8	.0	.0	.0	6.1	.0	1.8	.0
29	2.5	.0	.5	.5		1.3	.0	.0	.0	.0	13.0	74.7
30	.0	.0	.0	4.3		6.6	.0	.3	.0	.0	1.3	14.5
31	.0		.0	.5		.8		17.3		.0	.3	
Monthly total	120.0	217.1	160.1	205.6	15.2	58.0	53.5	115.0	123.7	61.3	32.2	127.4

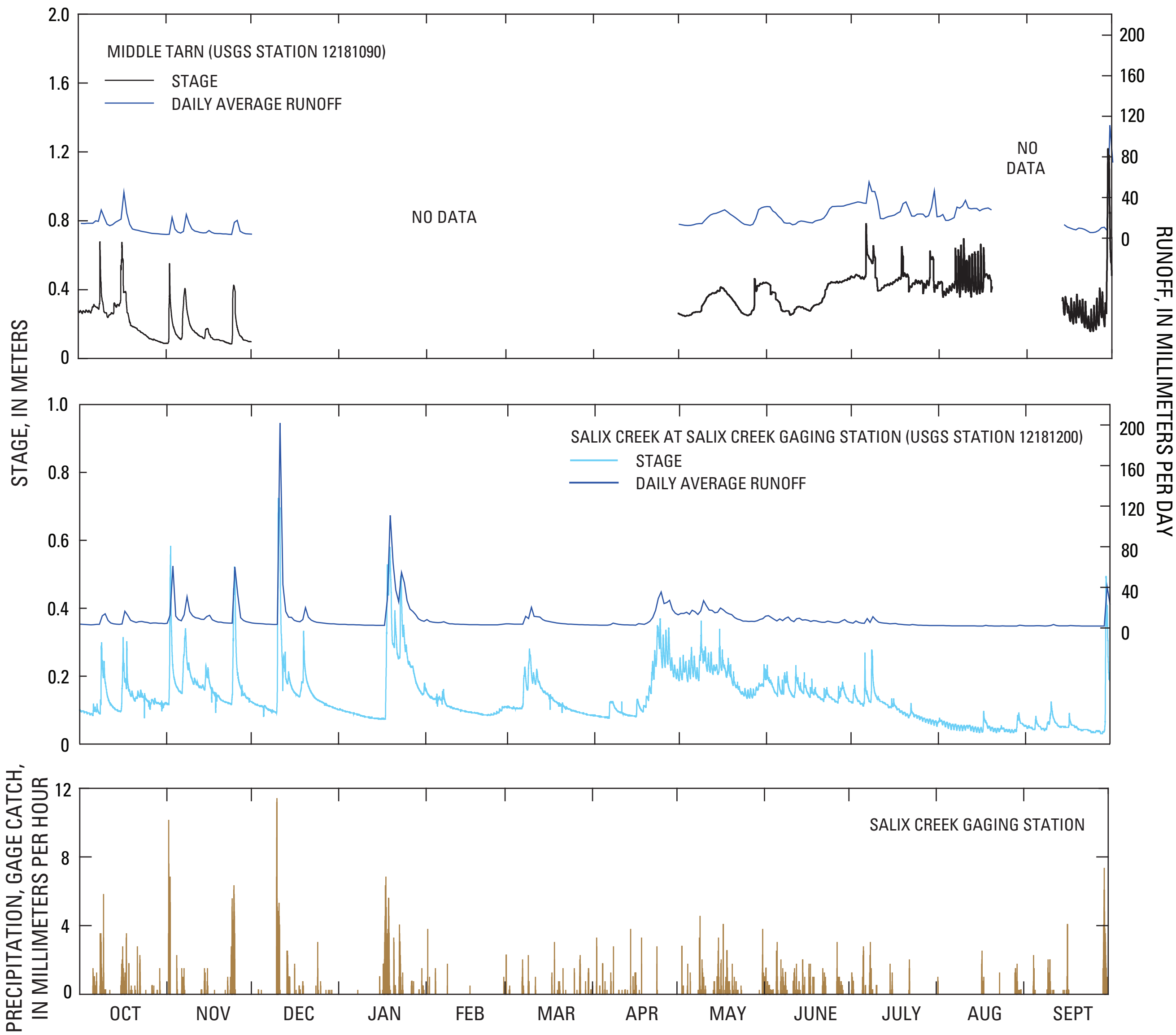


Figure 10. Stage of Middle Tarn and Salix Creek, daily average runoff from Middle Tarn and Salix Creek basins, and precipitation (gage catch) at the Salix Creek gaging station, Washington, water year 2005. Stage was recorded every 15 minutes and precipitation was totaled and recorded each hour. Daily summaries of precipitation and runoff are presented in tables 20–22.

Table 21. Daily average runoff from Middle Tarn Basin, Washington, water year 2005.

[Daily average runoff is averaged over the area of the basin (4.46 square kilometers); –, insufficient data]

Day	Daily average runoff, in millimeters						
	2004		2005				
	October	November	May	June	July	August	September
1	13.9	3.2	12.6	30.3	34.3	22.8	–
2	13.7	19.9	12.1	26.1	35.1	16.9	–
3	14.0	8.3	11.9	24.5	34.8	17.0	–
4	14.0	5.5	12.0	21.1	33.9	18.2	–
5	14.1	4.4	12.6	18.5	33.8	19.6	–
6	16.5	6.1	13.4	14.6	54.6	30.0	–
7	15.9	22.8	13.7	14.0	45.4	29.0	–
8	27.1	14.2	13.7	14.2	45.3	31.2	–
9	20.1	8.4	16.9	12.6	36.0	36.7	–
10	13.3	6.5	19.7	13.2	18.9	29.1	–
11	11.7	5.8	22.2	15.4	18.5	28.4	–
12	12.8	5.0	23.4	16.2	19.9	28.7	–
13	15.1	4.6	23.9	15.9	20.9	28.6	–
14	16.7	4.7	24.9	15.2	21.4	26.3	10.4
15	18.1	6.9	26.2	14.7	22.2	27.9	9.4
16	44.6	5.1	27.3	14.5	24.1	28.6	8.3
17	23.9	4.1	25.3	16.3	25.4	29.1	7.7
18	13.0	3.9	23.1	17.2	33.5	27.4	9.4
19	8.5	3.9	21.2	17.6	35.1	–	9.0
20	7.6	3.6	19.1	19.1	28.5	–	8.2
21	7.1	3.5	16.9	22.8	21.2	–	6.7
22	6.3	3.2	14.8	28.2	21.0	–	5.0
23	5.8	3.0	13.1	30.6	23.1	–	4.9
24	5.2	15.0	12.5	30.7	23.2	–	5.4
25	4.5	16.9	12.1	30.9	23.1	–	6.9
26	4.1	6.3	13.0	30.8	20.2	–	9.7
27	3.9	4.6	18.7	31.1	21.5	–	10.2
28	3.7	3.8	27.5	32.1	29.7	–	7.1
29	3.4	3.6	29.3	32.8	45.9	–	110.6
30	3.2	3.4	30.2	33.6	20.5	–	74.4
31	3.1		30.5		20.9	–	–
Monthly average	12.4	7.0	19.2	21.8	28.8	–	–

The record of stage from the Salix Creek gaging station was complete during water year 2005 (fig. 10), and daily average runoff from Salix Creek Basin ranged from 0.1 mm/d in late September to 202.3 mm/d December 10 (table 22). Monthly average runoff ranged from 0.4 mm/d in August to 15.2 mm/d in January. Total runoff for the water year was 2,472 mm. Total runoff during June through September was 341 mm, or about the same as contemporaneous precipitation recorded at the Salix Creek gaging station.

2004 Winter Balance

Snow depth measured by probing on South Cascade Glacier during April 24 to 26 ranged from 0.10 m near the terminus to 4.90 m at roughly mid-glacier (fig. 11, table 23). Probing for snow depth over firn was unreliable on the upper glacier because the probe apparently penetrated the 2003 summer surface at the base of the snowpack. This lack of detection of the 2003 summer surface by probing was

Table 22. Daily average runoff from Salix Creek Basin at the Salix Creek gaging station, Washington, water year 2005.

[Daily average runoff is averaged over the area of the basin (0.22 square kilometers)]

Day	Daily average runoff, in millimeters											
	2004			2005								
	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.
1	1.7	10.8	2.9	1.9	4.7	2.3	1.2	12.8	10.6	3.1	0.7	0.3
2	1.7	59.8	2.7	1.8	4.1	2.2	1.1	12.8	8.7	5.3	.6	.3
3	1.5	10.0	2.5	1.6	3.7	2.1	1.1	13.9	7.0	3.7	.5	.3
4	1.4	6.7	2.4	1.6	3.6	2.1	1.0	11.9	5.2	3.0	.5	.5
5	1.6	5.5	2.1	1.5	3.8	2.1	1.0	15.9	7.3	2.8	.4	.5
6	1.8	11.4	2.0	1.4	4.4	2.1	1.6	14.5	5.6	7.6	.4	.3
7	1.8	29.4	1.8	1.3	3.2	9.8	3.1	11.7	7.8	3.7	.4	.2
8	10.4	14.6	1.7	1.2	2.4	7.6	2.3	15.3	9.2	9.5	.3	.4
9	12.3	10.3	1.9	1.1	2.3	18.8	1.8	25.4	6.0	6.4	.3	.7
10	5.8	8.5	202.3	1.0	2.1	9.9	1.5	20.5	4.5	4.1	.3	1.7
11	3.2	7.9	41.6	1.0	2.0	9.5	1.4	16.1	7.4	3.4	.4	.7
12	2.4	6.9	14.6	1.0	1.9	9.2	1.3	15.8	7.9	3.1	.3	.4
13	2.0	6.8	9.0	.9	1.8	6.6	1.2	13.4	6.1	2.8	.3	.3
14	1.8	9.6	8.9	.9	1.7	5.4	1.2	13.9	6.4	2.4	.2	.3
15	2.2	10.9	6.0	.9	1.6	4.9	1.1	18.1	6.0	2.6	.2	.3
16	14.9	6.4	5.0	.9	1.6	4.2	2.6	16.3	4.7	2.7	.2	.6
17	10.8	5.1	4.4	26.9	1.5	3.8	2.2	13.8	5.6	2.1	.9	.5
18	6.0	4.1	6.7	110.5	1.5	3.3	1.9	12.4	5.2	1.8	.4	.4
19	4.7	4.0	18.5	63.1	1.4	2.9	3.0	11.6	4.4	1.5	.3	.3
20	3.7	3.4	9.0	35.9	1.3	2.5	4.9	8.6	3.9	1.4	.2	.2
21	4.5	3.2	6.1	24.4	1.3	2.4	8.7	7.1	3.9	1.2	.2	.2
22	4.8	3.0	4.7	53.6	1.3	2.1	15.7	6.4	5.1	1.7	.2	.2
23	4.1	3.0	3.9	43.3	1.3	2.0	27.7	5.1	4.4	1.3	.3	.2
24	3.8	59.1	3.5	25.4	1.3	1.8	34.1	5.1	3.8	1.1	.2	.2
25	2.9	31.6	3.2	17.2	1.4	1.7	22.5	4.7	3.4	1.0	.2	.1
26	3.2	8.4	2.9	14.7	1.7	1.6	23.6	4.9	3.7	.9	.2	.2
27	3.2	5.7	2.6	11.5	2.0	1.5	25.7	4.8	5.2	.8	.2	.1
28	2.9	4.6	2.4	7.5	2.3	1.4	16.6	5.5	6.6	.7	.2	.1
29	2.8	3.9	2.3	5.7		1.3	12.9	6.8	4.4	.7	1.0	39.4
30	2.6	3.3	2.1	4.9		1.2	11.4	7.4	3.5	.6	.6	22.3
31	2.9		1.9	6.6		1.2		10.0		.6	.4	
Monthly average	4.2	11.9	12.3	15.2	2.3	4.2	7.8	11.7	5.8	2.7	0.4	2.4

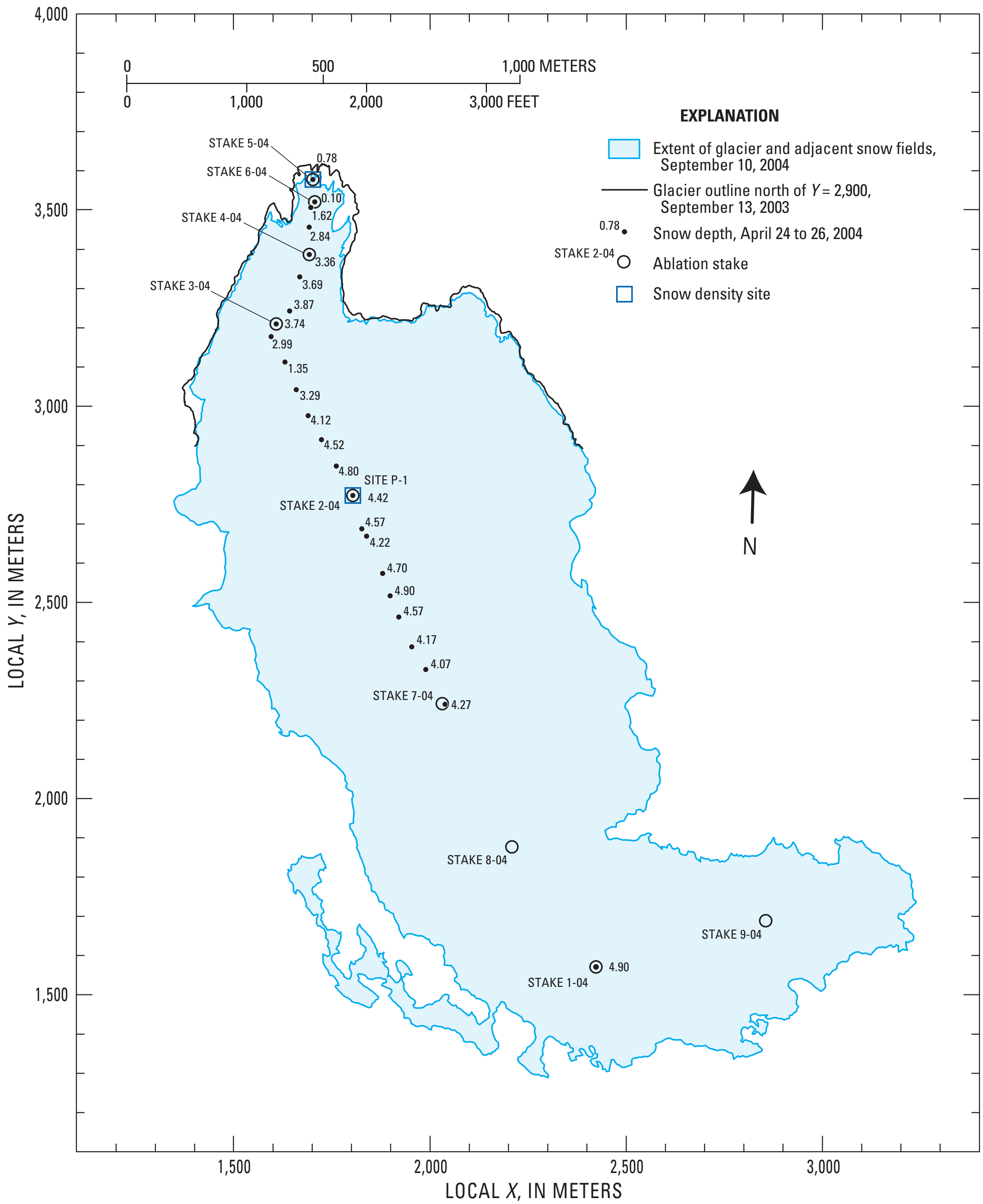


Figure 11. Partial and complete outlines of South Cascade Glacier, Washington, 2003 and 2004, locations of 2004 measurement sites for snow depth and density, and locations of 2004 ablation stakes. Snow depth, in meters, is presented next to the measurement site and also is presented in table 23.

Table 23. Snow depth on South Cascade Glacier, Washington, April 2004.

[***X*** and ***Y*** are easting and northing coordinates in a local coordinate system, meters; ***Z***, altitude, meters]

X	*Y*	*Z*	Snow depth (meters)
April 24			
1,804	2,773	1,842	4.42
1,827	2,688	1,848	4.57
1,839	2,669	1,849	4.22
1,880	2,574	1,859	4.70
1,899	2,517	1,870	4.90
1,921	2,463	1,883	4.57
1,954	2,387	1,902	4.17
1,990	2,329	1,916	4.07
2,039	2,240	1,929	4.27
2,423	1,571	2,029	4.90
April 25			
1,702	3,578	1,636	0.78
1,697	3,507	1,664	1.62
1,693	3,457	1,683	2.84
1,693	3,387	1,704	3.36
1,669	3,330	1,722	3.69
1,643	3,243	1,748	3.87
1,609	3,210	1,759	3.74
1,596	3,178	1,772	2.99
1,631	3,113	1,794	1.35
1,660	3,042	1,812	3.29
1,690	2,976	1,823	4.12
1,724	2,915	1,831	4.52
1,762	2,848	1,839	4.80
April 26			
1,707	3,521	1,659	0.10

confirmed during August 2005 on the basis of coring near stake 1-04, which was near similar stakes placed in 2002, 2003, and 2005. All four stakes could be encompassed in a circle with a radius of about 6 m. Surface material present in August 2005 was residual snow from winter 2005 that lay atop firn formed from snow that fell during 2002. Knowledge of thickness of 2002 firn remaining at the beginning and end of balance year 2003 and at the end of balance year 2005 enabled computation of the thickness of firn lost during 2004 (0.68 m) and height of the 2004 summer surface with respect to the 2003 and 2005 surfaces (fig. 12). Spring 2004 snow depth (4.90 m) was then computed as the difference between total surface lowering at stake 1-04 during 2004 and thickness of firn lost during that balance year.

Late-April density of the snowpack on South Cascade Glacier was measured near the terminus and at site P-1, and it was estimated elsewhere on the glacier. Density was measured from the surface using the specially designed snow corer described previously. Average density of the entire snow profile near the terminus, determined from a single 0.80-m-long snow sample, was 0.43, and average density of the profile at site P-1 to a depth of 4.25 m was 0.44 (table 24). Snow depth in the immediate vicinity of the site P-1 core hole, measured by probing, was 4.47 m. It was suspected the corer was unable to retrieve the bottom 0.22 m of snow sample, although roughness of the underlying ice surface might have accounted for some of the difference between the core-hole and probed snow depths. Average density of the entire snow profile was assumed to equal that to the depth of 4.25 m. Snow density at various locations on the glacier during April 24 to 26 was assumed to scale linearly with surface altitude between the site near the terminus and site P-1, and density at sites higher than P-1 was assumed equal to density at site P-1. Snow density increases during the summer season and density of any residual snow at the two measurement sites was assumed to increase on a trajectory that would bring it to 0.58, the estimated density of all remaining snow, by the end of the balance year. Altitude-related scaling was then used to estimate snow density at various places on the glacier after April 26. Density of snow accumulated late in the summer season was estimated at 0.50.

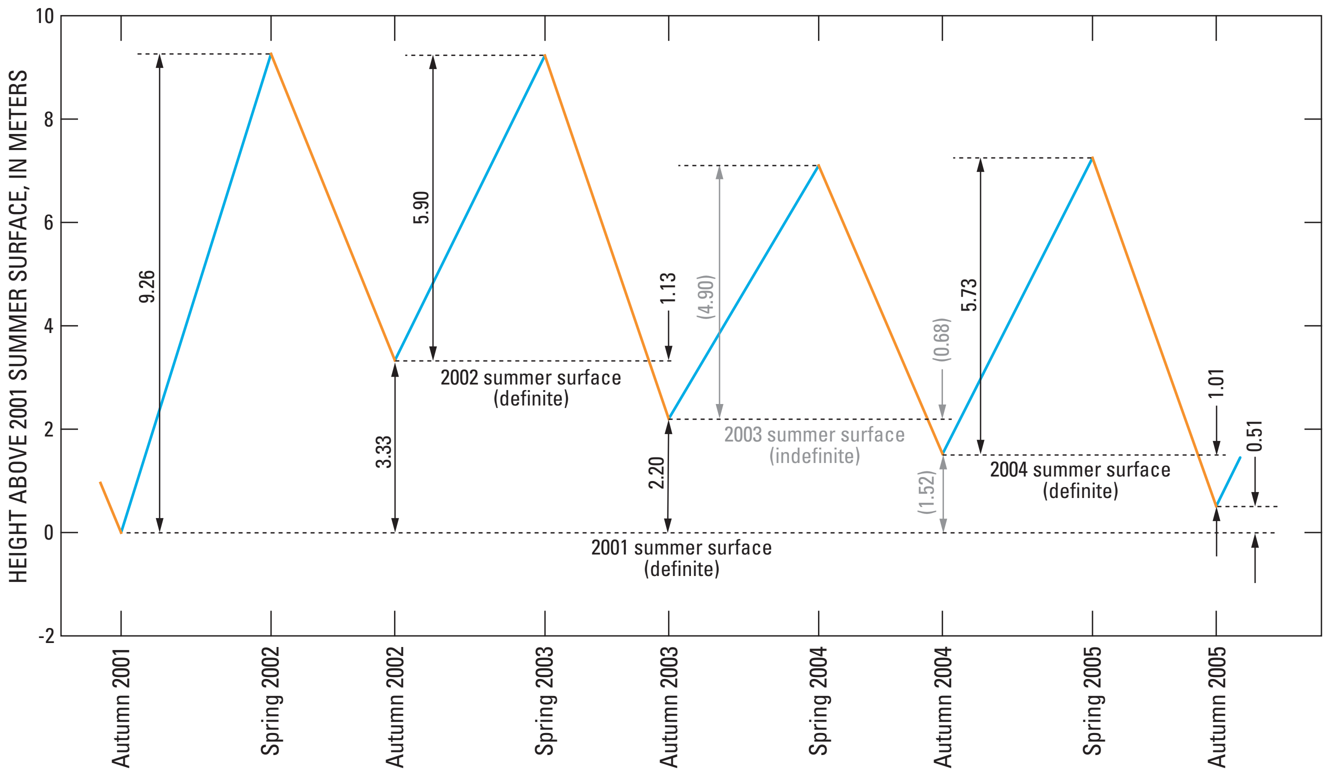


Figure 12. Variations of surface height and selected thicknesses of materials gained and lost in vicinity of stake 1-04 during balance years 2002 to 2005. The 2001 summer surface in the vicinity of stake 1-04 was old firn that was detected in autumn 2002 under residual snow from the previous winter. The 2002 summer surface was marked in autumn 2002 and then found beneath residual snow late in balance year 2003. The indefinite 2003 summer surface was not detected during balance year 2004, but the 2004 summer surface, which had been marked late in 2004, and the 2001 summer surface were found beneath residual snow in summer 2005. Thicknesses are in meters and those given in parentheses for 2004 were computed on the basis of measurements of surface lowering during that year and height of the 2003 summer surface inferred from thickness of remaining 2002 firn in 2003 and 2005.

Table 24. Snow density measured at site P-1 on South Cascade Glacier, Washington, April 25, 2004.

[**Snow density** was computed from 60-millimeter-diameter samples taken with a snow corer; Site P-1 is at ***X*** = 1,804, ***Y*** = 2,773, where ***X*** and ***Y*** are easting and northing coordinates in a local coordinate system, meters; 1,842 meters altitude]

Snow sample			Sample density (fraction of water density)
Bottom (meters)	**Length (meters)**	**Mass (kilograms)**	
0.79	0.75	0.850	0.40
1.63	.85	1.000	.42
2.36	.73	.875	.42
2.83	.47	.575	.43
3.08	.27	.400	.52
4.03	.87	1.150	.47
4.25	.28	.375	.47

Snow water equivalent computed from measured snow depth and measured or estimated snow density was plotted against altitude to develop a curve for estimating measured winter snow balance at any point on the glacier (fig. 13). A line was fitted through the data by eye and points digitized on the curve were used to create an interpolation table for SWE (table 25). The interpolation table defines the relation $b(Z_i)$ used in equation 6 to compute the glacier measured winter snow balance ($\bar{b}_m(s)$).

The 2004 glacier altitude grid was composed of 182 grid points, and all but five of the points were measured using 2004 vertical photography (fig. 14, table 26). Because of glacier shrinkage, the number of grid points in 2004 was four fewer than the number in 2003 (Bidlake and others, 2005). Grid point altitude ranged from 1,665 to 2,122 m. Application of the grid-index technique using the previously described SWE interpolation table and the 2004 glacier altitude grid yielded a glacier measured winter snow balance ($\bar{b}_m(s)$) for April 24–26 of 1.97 m. SWE recorded at the Miners Ridge and Lyman Lake SNOTEL sites peaked in the last week of March or the first week of April, and SWE at each site had decreased by 0.11 m from the peak by April 25. On the basis of the SNOTEL observations, 0.11 m was added to $\bar{b}_m(s)$ to estimate the glacier maximum winter snow balance ($\bar{b}_w(s)$) to be 2.08 m. The end date of the winter season was estimated to be April 3. The 2004 $\bar{b}_w(s)$ of South Cascade Glacier was 77 percent as large as the average for 1959 to 2005 (table 27). The glacier winter balance was smaller only eight times during 1959–2005.

Table 25. Altitude and snow water equivalent values defining a curve used to estimate snow water equivalent as it varied with altitude on South Cascade Glacier, Washington, April 24–26, 2004.

[**Altitude**, meters. **Snow water equivalent**, meters. Snow water equivalent as it varied with altitude is shown in figure 13]

Altitude	Snow water equivalent	Altitude	Snow water equivalent
1,638	0.00	1,771	1.63
1,645	.28	1,825	1.85
1,659	.57	1,895	2.01
1,679	.85	1,975	2.10
1,703	1.12	2,058	2.17
1,732	1.39	2,142	2.21

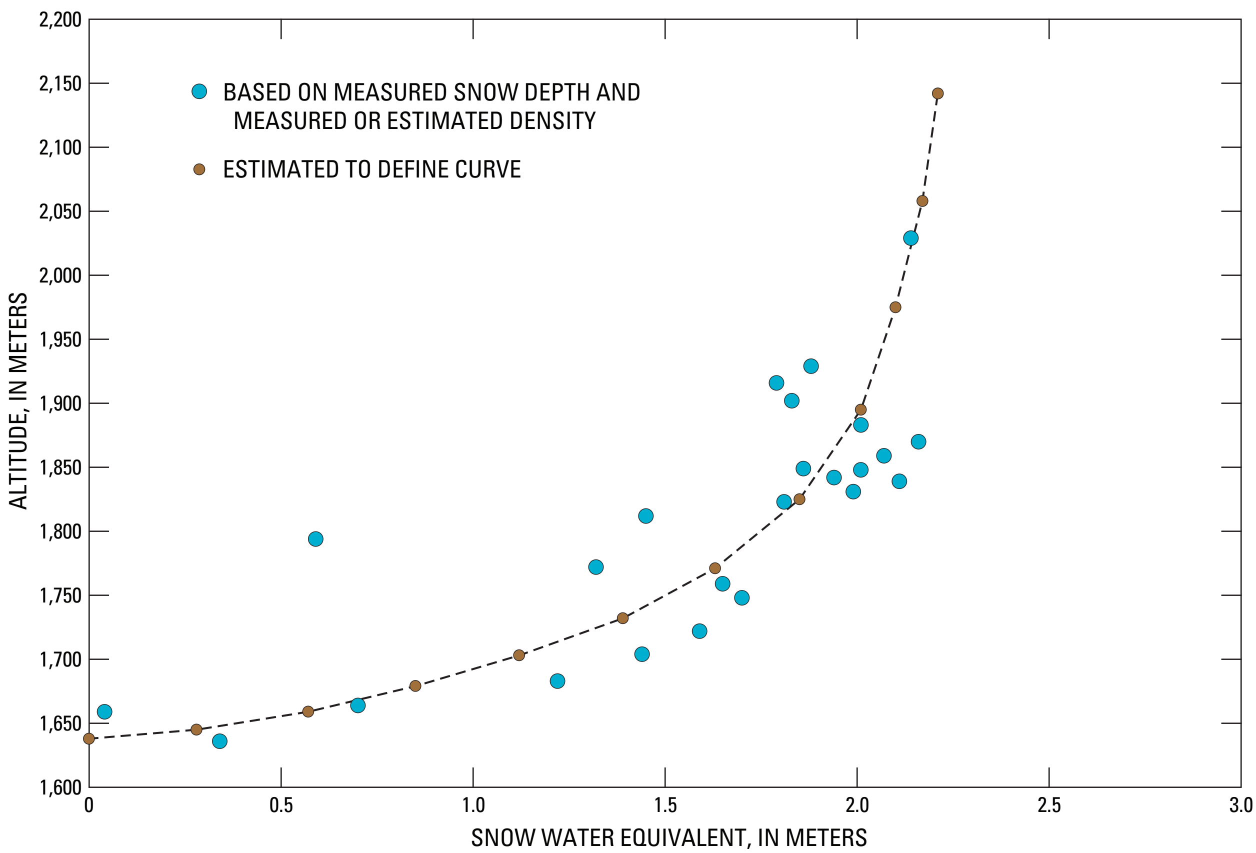


Figure 13. Snow water equivalent as it varied with altitude on South Cascade Glacier, Washington, April 24–26, 2004. The curve was fitted to the data by eye and was defined by the estimated values. Estimated values are presented in table 25.

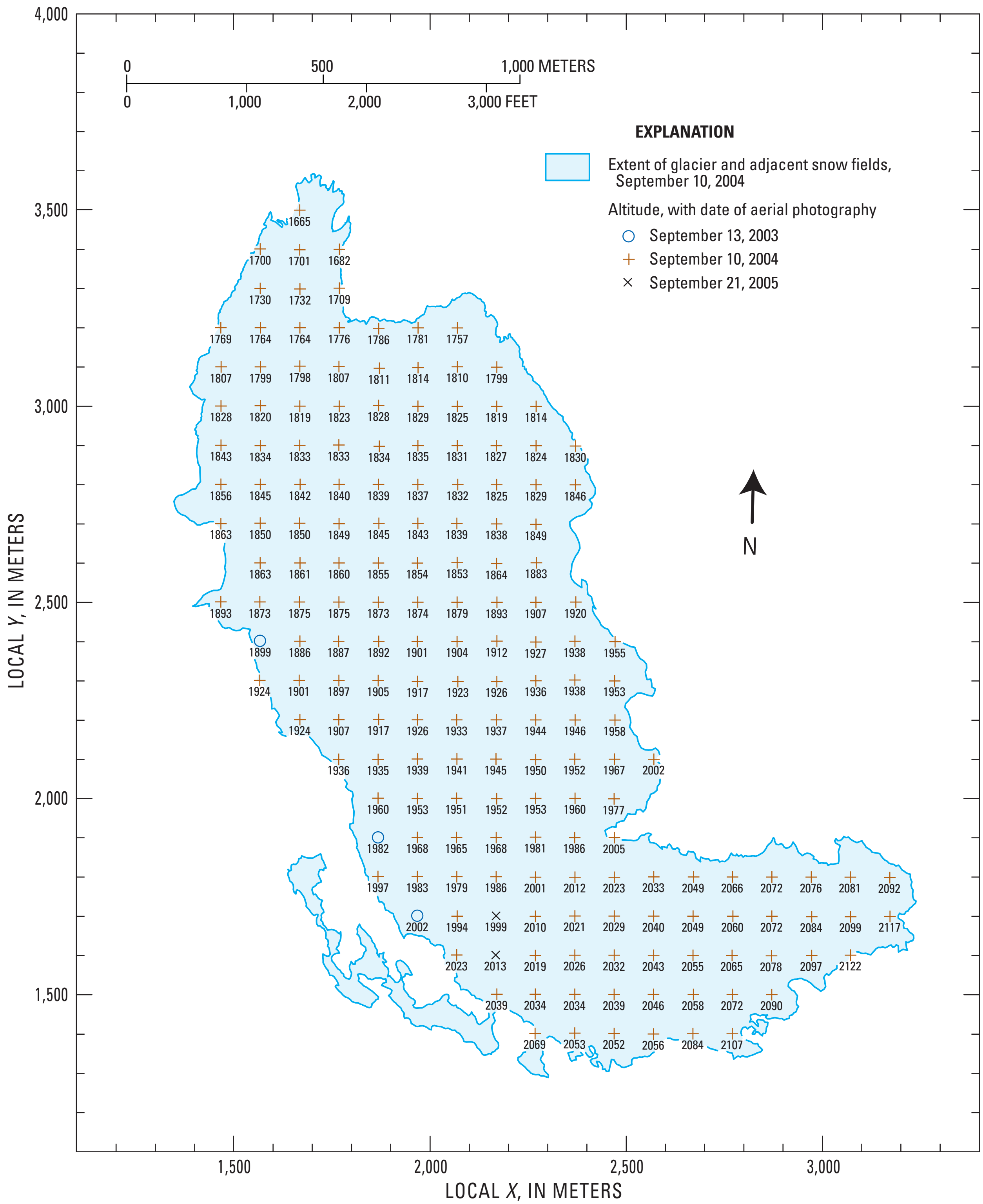


Figure 14. 2004 altitude grid for South Cascade Glacier, measured from variously dated vertical aerial photographs. Grid data also are presented in table 26.

Table 26. Altitude grid for South Cascade Glacier, Washington, 2004.

[**Year**, calendar year of aerial photography; ***X*** and ***Y*** are easting and northing coordinates in a local coordinate system, meters; ***Z*** is altitude, meters]

Year	X	Y	Z
2004	1,669	3,500	1,665
2004	1,569	3,401	1,700
2004	1,669	3,399	1,701
2004	1,770	3,400	1,682
2004	1,569	3,300	1,730
2004	1,670	3,299	1,732
2004	1,770	3,301	1,709
2004	1,469	3,200	1,769
2004	1,570	3,200	1,764
2004	1,670	3,200	1,764
2004	1,770	3,200	1,776
2004	1,870	3,198	1,786
2004	1,970	3,200	1,781
2004	2,070	3,200	1,757
2004	1,470	3,100	1,807
2004	1,570	3,100	1,799
2004	1,670	3,102	1,798
2004	1,769	3,101	1,807
2004	1,872	3,097	1,811
2004	1,970	3,099	1,814
2004	2,070	3,101	1,810
2004	2,170	3,100	1,799
2004	1,470	3,000	1,828
2004	1,570	3,001	1,820
2004	1,670	3,000	1,819
2004	1,770	3,000	1,823
2004	1,870	3,002	1,828
2004	1,970	3,000	1,829
2004	2,070	3,000	1,825
2004	2,170	3,000	1,819
2004	2,270	3,000	1,814
2004	1,470	2,900	1,843
2004	1,570	2,899	1,834
2004	1,670	2,900	1,833
2004	1,769	2,901	1,833
2004	1,872	2,898	1,834
2004	1,970	2,900	1,835
2004	2,070	2,900	1,831
2004	2,169	2,900	1,827
2004	2,270	2,900	1,824
2004	2,370	2,899	1,830
2004	1,470	2,800	1,856
2004	1,570	2,800	1,845
2004	1,671	2,800	1,842
2004	1,770	2,800	1,840
2004	1,870	2,800	1,839
2004	1,970	2,800	1,837
2004	2,071	2,800	1,832
2004	2,170	2,800	1,825
2004	2,270	2,800	1,829
2004	2,370	2,800	1,846
2004	1,470	2,700	1,863
2004	1,570	2,701	1,850
2004	1,670	2,701	1,850
2004	1,770	2,700	1,849
2004	1,871	2,701	1,845
2004	1,970	2,701	1,843
2004	2,069	2,701	1,839
2004	2,170	2,700	1,838
2004	2,270	2,699	1,849
2004	1,570	2,600	1,863
2004	1,671	2,600	1,861
2004	1,770	2,600	1,860
2004	1,870	2,600	1,855
2004	1,969	2,600	1,854
2004	2,070	2,601	1,853
2004	2,170	2,599	1,864
2004	2,271	2,601	1,883
2004	1,470	2,500	1,893
2004	1,569	2,500	1,873
2004	1,670	2,500	1,875
2004	1,770	2,500	1,875
2004	1,870	2,500	1,873
2004	1,970	2,500	1,874
2004	2,070	2,500	1,879
2004	2,171	2,500	1,893
2004	2,270	2,500	1,907
2004	2,371	2,501	1,920
2003	1,570	2,401	1,899
2004	1,671	2,400	1,886
2004	1,769	2,400	1,887
2004	1,871	2,400	1,892
2004	1,969	2,400	1,901
2004	2,070	2,400	1,904
2004	2,171	2,401	1,912
2004	2,270	2,399	1,927
2004	2,369	2,401	1,938
2004	2,471	2,400	1,955
2004	1,569	2,300	1,924
2004	1,669	2,300	1,901
2004	1,770	2,300	1,897
2004	1,870	2,300	1,905
2004	1,970	2,298	1,917
2004	2,072	2,298	1,923
2004	2,171	2,298	1,926
2004	2,270	2,300	1,936
2004	2,369	2,302	1,938
2004	2,470	2,300	1,953
2004	1,671	2,200	1,924
2004	1,770	2,200	1,907
2004	1,871	2,201	1,917
2004	1,970	2,200	1,926
2004	2,069	2,200	1,933
2004	2,170	2,200	1,937
2004	2,270	2,200	1,944
2004	2,370	2,200	1,946
2004	2,471	2,200	1,958
2004	1,770	2,099	1,936
2004	1,870	2,099	1,935
2004	1,970	2,100	1,939
2004	2,070	2,100	1,941
2004	2,169	2,100	1,945
2004	2,270	2,099	1,950
2004	2,369	2,100	1,952
2004	2,470	2,100	1,967
2004	2,570	2,100	2,002
2004	1,870	2,000	1,960
2004	1,970	1,999	1,953
2004	2,069	2,000	1,951
2004	2,171	1,999	1,952
2004	2,270	2,000	1,953
2004	2,370	2,000	1,960
2004	2,469	1,999	1,977
2003	1,870	1,900	1,982
2004	1,970	1,900	1,968
2004	2,069	1,900	1,965
2004	2,170	1,900	1,968
2004	2,270	1,901	1,981
2004	2,369	1,900	1,986
2004	2,470	1,900	2,005
2004	1,870	1,800	1,997
2004	1,970	1,800	1,983
2004	2,070	1,800	1,979
2004	2,170	1,800	1,986
2004	2,270	1,799	2,001
2004	2,370	1,799	2,012
2004	2,470	1,799	2,023
2004	2,570	1,800	2,033
2004	2,671	1,800	2,049
2004	2,770	1,800	2,066
2004	2,870	1,800	2,072
2004	2,970	1,800	2,076
2004	3,069	1,800	2,081
2004	3,169	1,799	2,092
2003	1,970	1,700	2,002
2004	2,071	1,699	1,994
2005	2,170	1,700	1,999
2004	2,270	1,699	2,010
2004	2,370	1,700	2,021
2004	2,470	1,700	2,029
2004	2,570	1,700	2,040
2004	2,670	1,700	2,049
2004	2,771	1,700	2,060
2004	2,870	1,700	2,072
2004	2,971	1,699	2,084
2004	3,070	1,699	2,099
2004	3,170	1,700	2,117
2004	2,070	1,600	2,023
2005	2,169	1,600	2,013
2004	2,270	1,599	2,019
2004	2,370	1,600	2,026
2004	2,470	1,600	2,032
2004	2,570	1,600	2,043
2004	2,670	1,600	2,055
2004	2,769	1,600	2,065
2004	2,869	1,599	2,078
2004	2,971	1,600	2,097
2004	3,070	1,601	2,122
2004	2,172	1,500	2,039
2004	2,270	1,500	2,034
2004	2,370	1,500	2,034
2004	2,470	1,500	2,039
2004	2,570	1,500	2,046
2004	2,671	1,500	2,058
2004	2,770	1,500	2,072
2004	2,870	1,500	2,090
2004	2,269	1,400	2,069
2004	2,370	1,401	2,053
2004	2,470	1,400	2,052
2004	2,570	1,399	2,056
2004	2,670	1,400	2,084
2004	2,770	1,400	2,107

Table 27. Winter, summer, and net balances of South Cascade Glacier, Washington, balance years 1953–2005.

[$\bar{b}_m(s)$, glacier measured winter snow balance; $\bar{b}_w(s)$, glacier maximum winter snow balance; $\bar{b}_s$, glacier summer balance; $\bar{b}_n$, glacier net balance. Balances are in meters water equivalent; data for 1953 and 1955–58 are from Meier and Tangborn (1965); data for 1959–85 and 1992–2001 are from mass-balance summaries and original work presented by Krimmel (1993, 1994, 1995, 1996a, 1997, 1998, 1999, 2001, and 2002); data for 1986–91 are from Krimmel (2000), and data for 2002 and 2003 are from Bidlake and others (2004 and 2005). Glacier maximum winter snow balance ($\bar{b}_w(s)$), if available, is given in preference to glacier measured winter snow balance ($\bar{b}_m(s)$), and in each case, the value given under the heading $\bar{b}_m(s)$ or $\bar{b}_w(s)$ is the best available estimate of the glacier winter balance, $\bar{b}_w$. **Abbreviation:** –, no data]

Balance year	$\bar{b}_m(s)$ **or** $\bar{b}_w(s)$	$\bar{b}_s$	$\bar{b}_n$
1953	–	–	-0.6
1955	–	–	.3
1956	–	–	.2
1957	–	–	-.2
1958	–	–	-3.3
1959	3.28	-2.58	.70
1960	2.21	-2.71	-.50
1961	2.40	-3.50	-1.10
1962	2.50	-2.30	.20
1963	2.23	-3.53	-1.30
1964	3.25	-2.05	1.20
1965	3.48	-3.65	-.17
1966	2.47	-3.50	-1.03
1967	3.29	-3.92	-.63
1968	3.00	-2.99	.01
1969	3.17	-3.90	-.73
1970	2.41	-3.61	-1.20
1971	3.51	-2.91	.60
1972	4.27	-2.84	1.43
1973	2.21	-3.25	-1.04
1974	3.65	-2.63	1.02
1975	3.06	-3.11	-.05
1976	3.53	-2.58	.95
1977	1.57	-2.87	-1.30
1978	2.49	-2.87	-.38
1979	2.18	-3.74	-1.56
1980	1.83	-2.85	-1.02
1981	2.28	-3.12	-.84
1982	3.11	-3.03	0.08
1983	1.91	-2.68	-.77
1984	2.38	-2.26	.12
1985	2.18	-3.38	-1.20
1986	2.45	-3.06	-.61
1987	2.04	-4.10	-2.06
1988	2.44	-3.78	-1.34
1989	2.43	-3.34	-.91
1990	2.60	-2.71	-.11
1991	3.54	-3.47	.07
1992	1.91	-3.92	-2.01
1993	1.98	-3.21	-1.23
1994	2.39	-3.99	-1.60
1995	2.86	-3.55	-.69
1996	2.94	-2.84	.10
1997	3.71	-3.08	.63
1998	2.76	-4.62	-1.86
1999	3.59	-2.57	1.02
2000	3.32	-2.94	.38
2001	1.90	-3.47	-1.57
2002	4.02	-3.47	.55
2003	2.66	-4.76	-2.10
2004	2.08	-3.73	-1.65
2005	1.97	-4.42	-2.45
MEAN 1959–2005	2.71	-3.26	-0.55
MEDIAN 1959–2005	2.49	-3.21	-0.69

2004 Net Balance

The smaller than normal 2004 winter snowpack had almost completely melted from the glacier by August 30, and no snow was remaining at any of the ablation stakes visited on that date (table 28). A cooler-than-normal September brought storms resulting in snow accumulation on the upper glacier and reduced melt. In fact, at stake 1-04, only an additional 0.50 m of firn was lost during August 30 to October 27. The vertical photography acquired September 10 is thought to have captured the glacier without significant accumulation of summer snow (fig. 15), but at least 0.38 m of snow accumulated at stake 1-04 by September 21. Early October brought relatively warm weather that likely melted most of the accumulated snow on the glacier. The 2004 balance year is though to have ended October 15, when a cold, moist storm likely covered the entire glacier in snow.

Computation of the 2004 glacier net balance relied on previous experience, data collected from eight ablation stakes (stake 7-04 was lost to a crevasse), and the analysis of upper-glacier snow and firn stratigraphy described previously. Net balance was plotted as a function of altitude (fig. 16), and a curve and an interpolation table (table 29) were developed as was described previously for the winter balance. Application of the grid-index technique yielded a glacier net balance of -1.65 m. The glacier net balance was more negative than in 2004 only six times during 1953–2005 (table 27).

Table 28. Ablation stake measurements at South Cascade Glacier, Washington, balance year 2004.

[**Surface material:** Snow, snow accumulated on the 2003 summer melt surface; Firn, metamorphosed, old snow that has endured at least one summer season; Late snow, snow accumulated on the 2004 summer surface. **Surface height**: Height of glacier surface above the 2003 summer melt surface, meters. **Balance components**: Specific cryologic materials gained or lost since the beginning of balance year 2004, with thickness of material gained (loss expressed as negative gain), meters, and density of material, expressed as a fraction of the density of water. **Balance**: Combined gain or loss of all balance components since the beginning of balance year 2004, meters water equivalent, ***X*** and ***Y*** are easting and northing coordinates in a local coordinate system, meters; and ***Z*** is altitude, meters. **Abbreviations**: e, estimated or inferred; m, meter]

Date	Surface material	Surface height (m)	Balance components								Balance (m)
			Snow		Firn		Ice		Late snow		
			Thickness gain (m)	Density	Thickness gain (m)	Density	Thickness gain (m)	Density	Thickness gain (m)	Density	
Stake 1-04 [*X* = 2,423, *Y* = 1,571, *Z* = 2,029]											
04-24-04	SNOW	4.90	4.90	0.44e							2.16
07-21-04	SNOW	2.25	2.25	.51e							1.15
08-30-04	FIRN	-.18			-0.18	0.65e					-.12
09-21-04	LSNOW	-.17			-.55	.65e			0.38	0.50e	-.17
10-15-04	FIRNe	-.68e			-.68e	.65e					-.44e
10-27-04	LSNOW	.18			-.68	.65e			.86	.50e	-.01
Stake 2-04 [*X* = 1,804, *Y* = 2,773, *Z* = 1,842]											
04-25-04	SNOW	4.42	4.42	0.44							1.94
06-17-04	SNOW	3.46	3.46	.48e							1.66
07-21-04	SNOW	1.14	1.14	.51e							.58
08-30-04	ICE	-1.41					-1.41	0.90e			-1.27
09-21-04	LSNOW	-1.66					-1.77	.90e	0.11	0.50e	-1.54
10-15-04	ICEe	-2.25e					-2.25e	.90e			-2.03e
10-27-04	LSNOW	-1.82					-2.25	.90e	.43	.50e	-1.81
Stake 3-04 [*X* = 1,609, *Y* = 3,210, *Z* = 1,759]											
04-25-04	SNOW	3.74	3.74	0.44e							1.65
06-17-04	SNOW	2.35	2.35	.48e							1.13
07-22-04	ICE	-.33					-0.33	0.90e			-.30
08-30-04	ICE	-3.42					-3.42	.90e			-3.08
09-22-04	ICE	-3.91					-3.91	.90e			-3.52
10-15-04	ICEe	-4.57e					-4.57e	.90e			-4.11e
Stake 4-04 [*X* = 1,693, *Y* = 3,387, *Z* = 1,704]											
04-25-04	SNOW	3.36	3.36	0.43e							1.44
06-17-04	SNOW	1.70	1.70	.47e							.80
07-22-04	ICE	-.95					-0.95	0.90e			-0.86

Table 28. Ablation stake measurements at South Cascade Glacier, Washington, balance year 2004.—Continued

[**Surface material:** Snow, snow accumulated on the 2003 summer melt surface; Firn, metamorphosed, old snow that has endured at least one summer season; Late snow, snow accumulated on the 2004 summer surface. **Surface height**: Height of glacier surface above the 2003 summer melt surface, meters. **Balance components**: Specific cryologic materials gained or lost since the beginning of balance year 2004, with thickness of material gained (loss expressed as negative gain), meters, and density of material, expressed as a fraction of the density of water. **Balance**: Combined gain or loss of all balance components since the beginning of balance year 2004, meters water equivalent, ***X*** and ***Y*** are easting and northing coordinates in a local coordinate system, meters; and ***Z*** is altitude, meters. **Abbreviations**: e, estimated or inferred; m, meter]

Date	Surface material	Surface height (m)	Balance components								Balance (m)
			Snow		Firn		Ice		Late snow		
			Thickness gain (m)	Density	Thickness gain (m)	Density	Thickness gain (m)	Density	Thickness gain (m)	Density	
Stake 5-04 [X = 1,702, Y = 3,578, Z = 1,636]											
04-25-04	SNOW	0.78	0.78	0.43							0.34
06-17-04	ICE	-1.18					-1.18	0.90e			-1.06
07-22-04	ICE	-4.31					-4.31	.90e			-3.88
Stake 6-04 [X = 1,707, Y = 3,521, Z = 1,659]											
04-26-04	SNOW	0.10	0.10	0.43e							0.04
06-17-04	ICE	-1.32					-1.32	0.90e			-1.19
07-22-04	ICE	-4.06					-4.06	.90e			-3.65
08-30-04	ICE	-7.55					-7.55	.90e			-6.80
09-22-04	ICE	-8.42					-8.42	.90e			-7.58
10-15-04	ICEe	-9.23e					-9.23e	.90e			-8.31e
10-27-04	ICE	-9.08					-9.23	.90e	0.15	0.50e	-8.23
Stake 7-04 [X = 2,032, Y = 2,242, Z = 1,928]											
07-21-04	SNOW	1.97	1.97	0.51e							1.00
Stake 8-04 [X = 2,209, Y = 1,877, Z = 1,979]											
07-21-04	SNOW	2.17	2.17	0.51e							1.11
08-30-04	FIRN	-.60			-0.60	0.65e					-0.39
09-21-04	LSNOW	-.81			-1.04	.65e			0.23	0.50e	-.56
10-15-04	FIRNe	-1.45e			-1.45e	.65e					-.94e
10-27-04	LSNOW	-.73			-1.45	.65e			.72	.50e	-.58
Stake 9-04 [X = 2,856, Y = 1,689, Z = 2,070]											
07-21-04	SNOW	2.09	2.09	0.51e							1.07
10-15-04	FIRNe	-1.26e			-1.26e	0.65e					-.82e
10-27-04	LSNOW	-.63			-1.26	.65e			0.63	0.50e	-.50

Figure 15. South Cascade Glacier, Washington, constructed from vertical photographs, September 10, 2004.

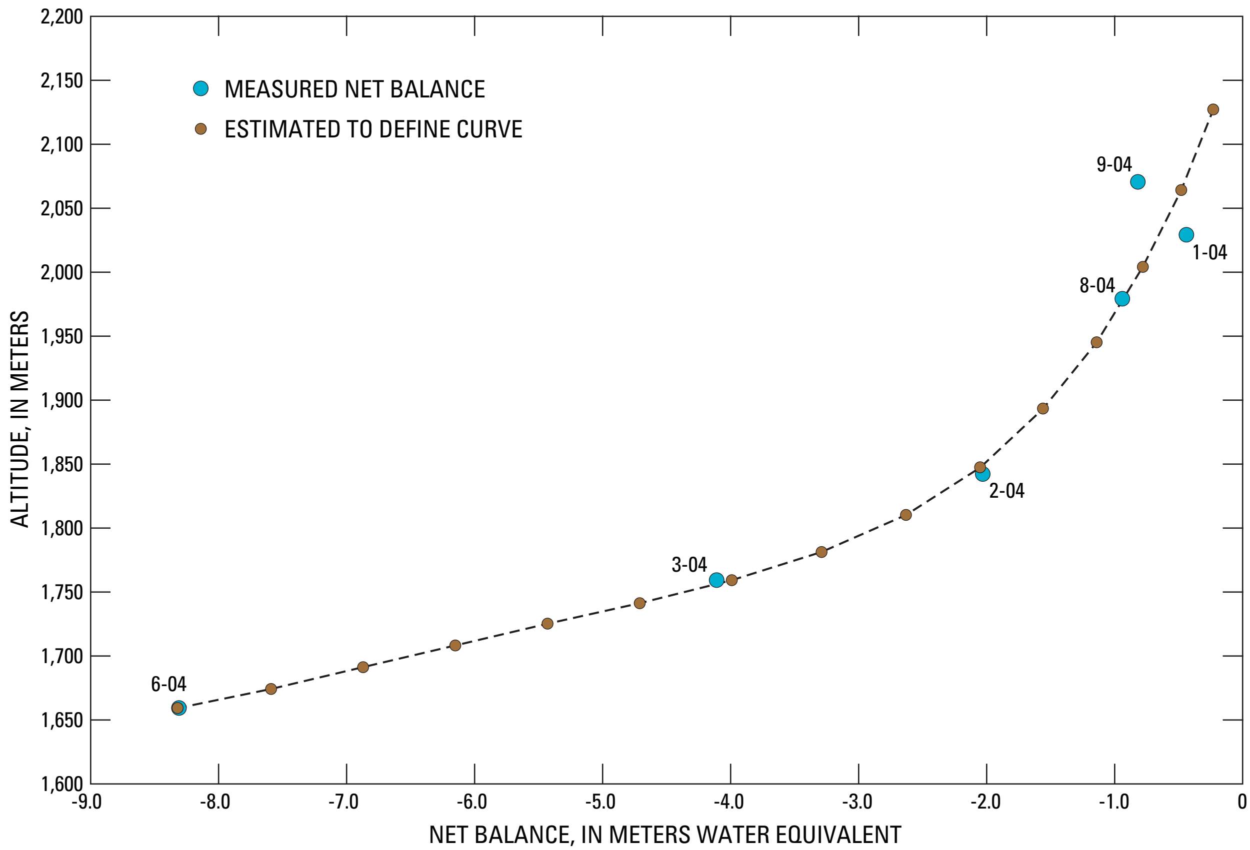


Figure 16. Net balance as it varied with altitude on South Cascade Glacier, Washington, balance year 2004. Ablation stake number is plotted above measured net balance. The curve was fitted to the data by eye and was defined by the estimated values. Estimated values are presented in table 29.

Table 29. Altitude and net balance values defining a curve used to estimate net balance as it varied with altitude on South Cascade Glacier, Washington, balance year 2004.

[**Altitude**, meters; net balance, meters water equivalent. **Net balance,** meters. Net balance as it varied with altitude is shown in figure 16]

Altitude	Net balance	Altitude	Net balance
1,659	-8.32	1,810	-2.63
1,674	-7.59	1,847	-2.05
1,691	-6.87	1,893	-1.56
1,708	-6.15	1,945	-1.14
1,725	-5.43	2,004	-.78
1,741	-4.71	2,064	-.48
1,759	-3.99	2,127	-.23
1,781	-3.29		

2004 Summer and Annual Balances

The computed 2004 glacier summer balance ($\bar{b}_s$) was -3.73 m, which was 14 percent more negative than the average summer balance during 1959 to 2005. Summer balances more negative than 2004 occurred 10 times during 1959 to 2005 (table 27). Available data previously had indicated $\bar{b}_s$ was negatively correlated with average air temperature at the Hut during June through September (the glacier had tended to lose more mass during summers when average June-through-September temperature had been relatively high; Bidlake and others, 2005). The 2004 glacier summer balance and air temperature were consistent with the previously described relation (fig. 17). The relation depicted in figure 17 also was consistent with findings of Rasmussen and Conway (2003), who examined relations of upper-air conditions and summer balance of South Cascade Glacier.

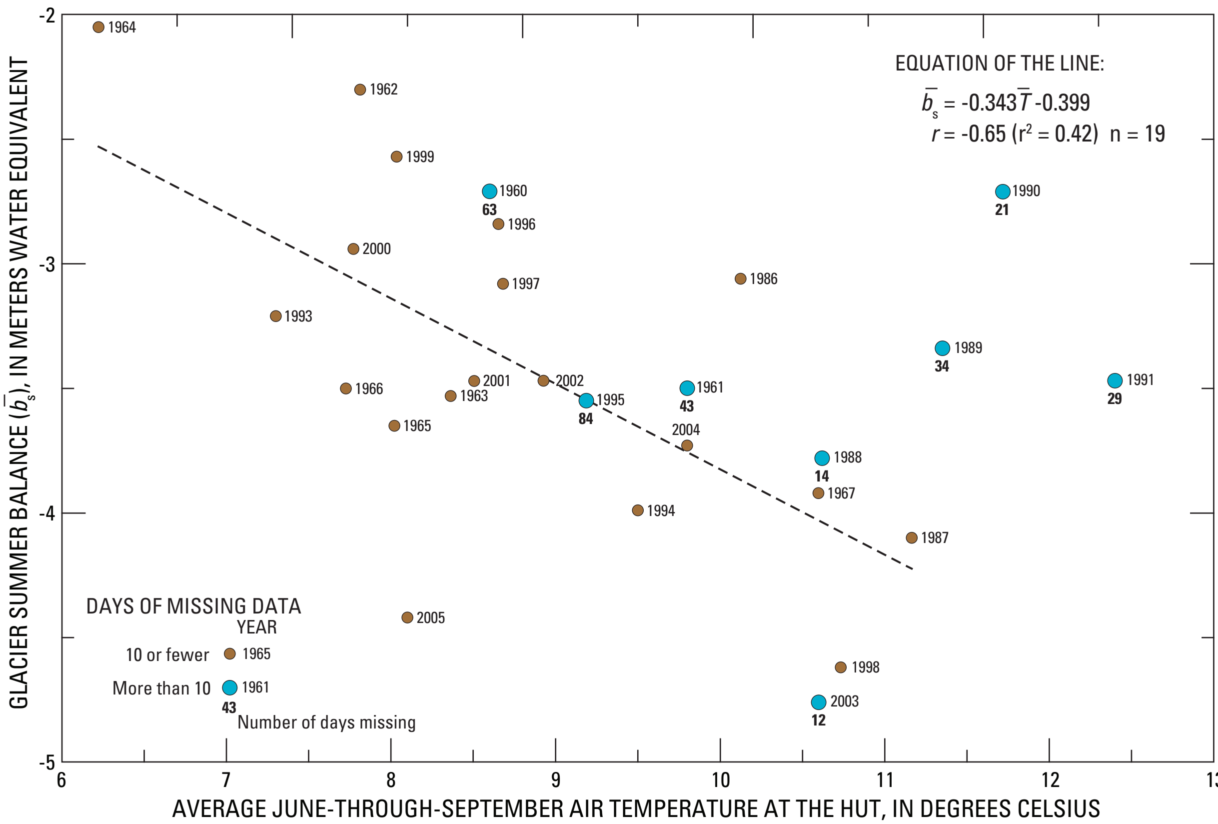


Figure 17. Summer balance of South Cascade Glacier as it varied with average air temperature at the Hut, 1,842 meters altitude, near South Cascade Lake Basin, Washington, June–September.
Data presented are for years for which numerical data have been published (1960–67, Sullivan, 1994; 1986–91, Krimmel, 2000; and 1993–2001, Krimmel, 1994, 1995, 1996a, 1997, 1998, 1999, 2001, 2002; 2002-03, Bidlake and others, 2004, 2005). Regression line and equation are fitted to data from years with 10 or fewer days of missing data.

USGS personnel were not present at South Cascade Glacier on either the beginning or ending days of water year 2004, and the 2004 annual balance of the glacier ($\bar{b}_a$) was computed based on estimates of the initial and final balance increments ($\bar{b}_0$ and $\bar{b}_1$) and equation 7. The water year 2003 $\bar{b}_1$ (-0.25 m) presented by Bidlake and others (2005), was the same as the water year 2004 $\bar{b}_0$.

Water year 2004 $\bar{b}_1$ was estimated using several steps. First, the September 30 balance relative to the 2003 summer surface was estimated at each stake from measurements made September 21 and an estimate of the balance at each stake during September 21 to 30. The latter short-term balances were estimated on the basis of the 0.35 m of additional surface lowering at site P-1 detected by the Glacier Ablation Sensor. Glacier balance on September 30 (-1.48 m) was then computed from the individual stake balances using the grid-index technique. Finally, the September 30 glacier balance was subtracted from the 2004 net balance to obtain $\bar{b}_1$ (-0.17 m). The 2004 $\bar{b}_a$ was then computed from equation 7 as -1.73 m.

2005 Winter Balance

Snow depth on South Cascade Glacier varied considerably among the dates of three late-winter and spring field trips made for winter balance measurements and for placing ablation stakes. Snow depth at site P-1 (altitude 1,838 m) increased from 2.64 m March 11 to 3.97 m April 20 and decreased to 2.88 m by May 12 (table 30, fig. 18). Snow depth at the lowermost ablation stake (altitude 1,683 m) was 1.00 m April 21 and all of the snow and 0.12 m of ice had melted at that stake by May 13. Snow depth at the uppermost ablation stake (altitude 2,069 m) decreased from 4.84 m April 20 to 3.68 m May 12. Given that day length during late April to mid May exceeded 14 hours and air temperature at the Hut generally remained above freezing, most of the decrease in snow depth likely was due to melt rather than to consolidation of the snow pack. That snow melt occurred in the vicinity of the glacier after April 21 also was confirmed by the rapid increase in runoff during April 21 to 23 at the Salix Creek gaging station (table 22). The late-April field trip therefore almost certainly occurred within a few days of the winter maximum snow accumulation on the glacier.

Table 30. Snow depth on South Cascade Glacier, Washington, March, April, and May 2005.

[***X*** and ***Y*** are easting and northing coordinates in a local coordinate system, meters; ***Z***, altitude, meters]

X	Y	Z	Snow depth (meters)
	March 11		
1,813	2,774	1,838	2.64
	April 20		
1,813	2,774	1,838	3.97
2,151	2,024	1,947	4.37
2,427	1,575	2,029	5.73
2,858	1,685	2,069	4.84
	April 21		
1,629	3,438	1,683	1.00
1,632	3,244	1,742	3.08
	May 12		
1,813	2,774	1,838	2.88
1,858	2,664	1,845	2.84
1,894	2,578	1,855	3.09
1,930	2,486	1,873	3.54
1,963	2,390	1,899	2.34
2,012	2,297	1,917	2.84
2,059	2,200	1,929	3.04
2,102	2,115	1,937	3.39
2,151	2,024	1,947	3.22
2,186	1,927	1,962	3.69
2,241	1,831	1,990	4.12
2,300	1,739	2,008	3.87
2,363	1,654	2,019	4.32
2,428	1,574	2,029	4.48
2,548	1,604	2,038	4.47
2,662	1,628	2,051	4.27
2,759	1,651	2,059	3.97
2,858	1,685	2,069	3.68
	May 13		
1,629	3,438	1,683	0.00
1,694	3,429	1,686	.70
1,685	3,365	1,705	1.20
1,690	3,336	1,715	1.45
1,670	3,294	1,727	1.30
1,632	3,244	1,742	1.99
1,607	3,229	1,748	1.94
1,586	3,167	1,771	2.04
1,564	3,118	1,790	1.30
1,593	3,047	1,806	1.94
1,657	2,990	1,817	1.94
1,710	2,911	1,828	3.09
1,755	2,847	1,835	2.79

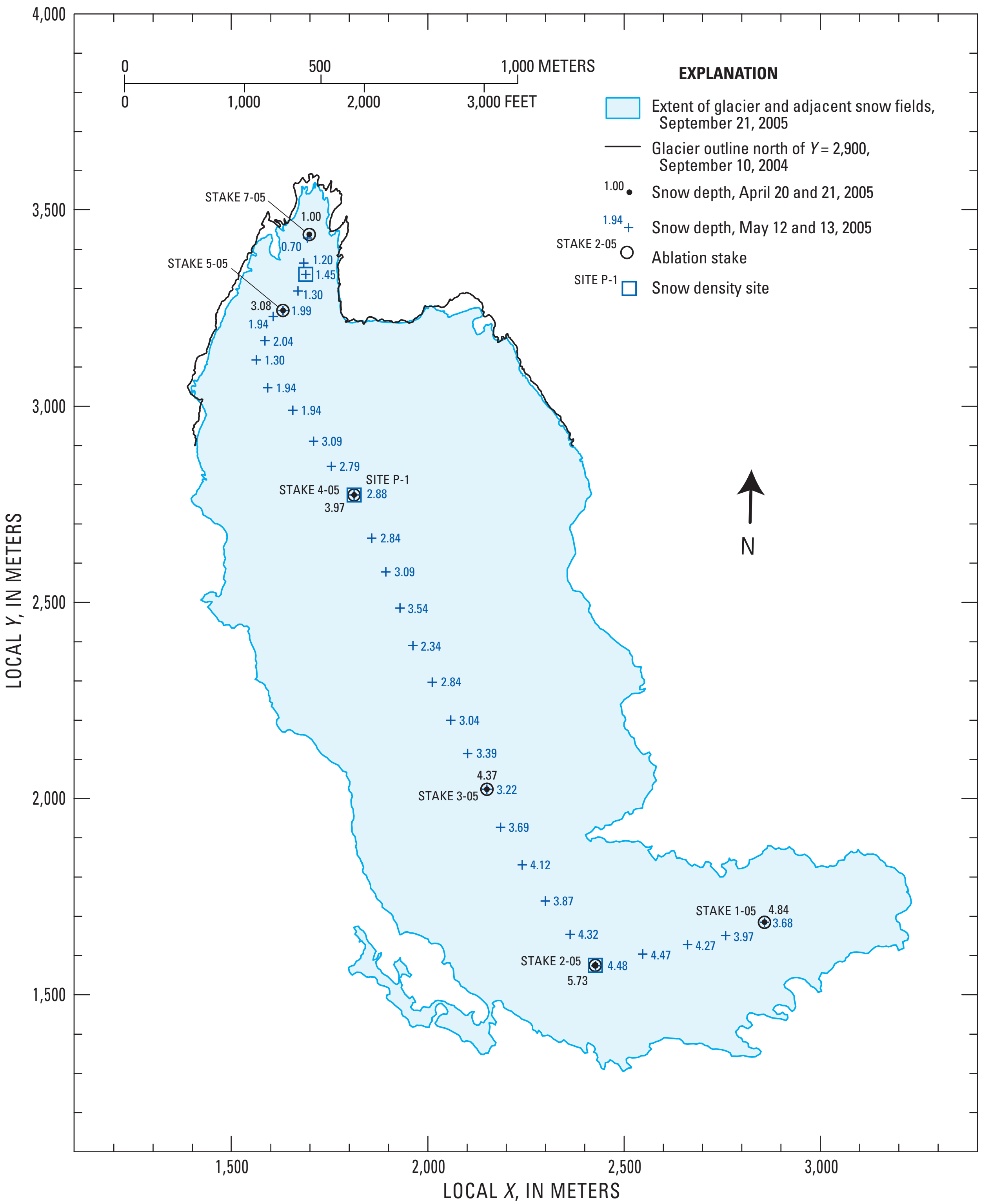


Figure 18. Partial and complete outlines of South Cascade Glacier, Washington, 2004 and 2005, locations of 2005 measurement sites for snow depth and density, and locations of 2005 ablation stakes. Snow depth, in meters, is shown next to the measurement site and also is presented in table 30.

Density of snow on the glacier on April 20 and 21 was estimated on the basis of density measurements made during May 12 and 13 near the terminus, at site P-1, and at a site on the upper glacier (fig. 18). Two similar samples of the entire snow profile were extracted near the terminus. The samples were 1.28 and 1.29 m long and the average density of the samples was 0.43 and 0.45, respectively. Profile-average snow density at site P-1 was 0.50, as was determined from samples taken from the wall of a pit dug through the entire profile (table 31). Profile-average snow density at a site on the upper glacier (fig. 18) was 0.46, as was determined from core samples extracted with the specially designed snow corer (table 32). Assuming the melting snow pack of mid-May had become denser since the time of the winter maximum snow accumulation, snow density on April 20 and 21 was estimated to be 0.42 at the site near the terminus, 0.48 at site P-1, and 0.44 at the site on the upper glacier. Linear interpolation of density versus altitude was used to estimate density at places on the glacier where it was not measured.

Maximum glacier winter snow balance was computed on the basis of snow-depth measurements made April 20 and 21 and estimates of snow density on those dates. Computed snow water equivalent was plotted as a function of altitude (fig. 19) and a curve and an interpolation table (table 33) were developed as was described previously for the 2004 winter balance. Application of the grid-index technique using the 2005 glacier-altitude grid (table 34, fig. 20) yielded a $\overline{b}_m(s)$ of 1.97 m. Because the measurements of late April likely were coincident with the maximum snow accumulation, $\overline{b}_w(s)$ was equal to $\overline{b}_m(s)$.

The 2005 glacier winter balance was equal to 73 percent of the average during 1959–2005; however, the 2005 glacier winter balance was not the smallest on record for the glacier, despite the extraordinarily small winter snowpack in the North Cascades. The smallest reported winter balance was 1.57 m in 1977, followed by 1.83 m in 1980 (table 27). Winter balance for 1983, 1992, and 2001 ranged from 1.90 to 1.91 m, and each was within the margin of uncertainty of the 2005 $\overline{b}_w(s)$.

Table 31. Snow density measured at site P-1, South Cascade Glacier, Washington, May 12, 2005.

[Density of entire snow profile was computed from 72.3-millimeter-diameter samples taken with a sampling tube from the wall of a pit, Site location ***X*** = 1,813, ***Y*** =2,774, where ***X*** and ***Y*** are easting and northing coordinates in a local coordinate system, meters; 1,813 meters altitude]

Snow sample: Bottom (meters)	Snow sample: Length (meters)	Snow sample: Mass (kilograms)	Sample density (fraction of water density)
0.44	0.44	0.86	0.48
.73	.29	.56	.47
1.05	.32	.62	.47
1.40	.35	.75	.52
1.79	.39	.83	.52
2.20	.41	.84	.50
2.54	.34	.68	.49
2.88	.34	.80	.57

Table 32. Snow density measured at a site on upper South Cascade Glacier, Washington, May 12, 2005.

[**Snow density** was computed from 60-millimeter-diameter samples taken with a snow corer. Site location ***X*** = 2,427, ***Y*** = 1,575, where ***X*** and ***Y*** are easting and northing coordinates in a local coordinate system, meters; 2,029 meters altitude]

Snow sample: Bottom (meters)	Snow sample: Length (meters)	Snow sample: Mass (kilograms)	Sample density (fraction of water density)
1.29	1.26	1.55	0.44
2.39	1.13	1.35	.42
3.44	1.05	1.45	.49
4.51	1.16	1.60	.49

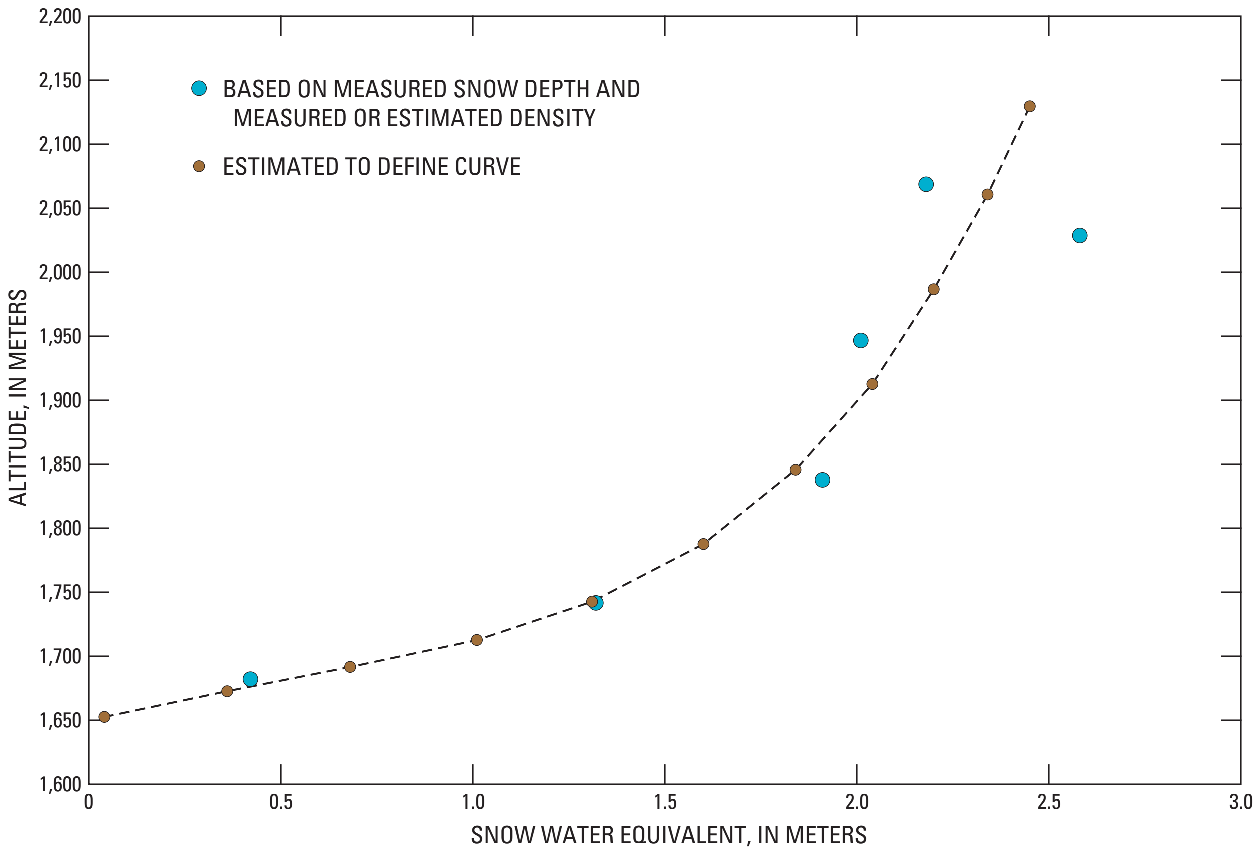


Figure 19. Snow water equivalent as it varied with altitude on South Cascade Glacier, Washington, April 20–21, 2005. The curve was fitted to the data by eye and was defined by the estimated values. Estimated values are presented in table 33.

Table 33. Altitude and snow water equivalent values defining a curve used to estimate snow water equivalent as it varied with altitude on South Cascade Glacier, Washington, April 20–21, 2005.

[**Altitude**: meters. **Snow water equivalent**, meters. Snow water equivalent as it varied with altitude is shown in figure 19]

Altitude	Snow water equivalent	Altitude	Snow water equivalent
1,653	0.04	1,846	1.84
1,673	.36	1,913	2.04
1,692	.68	1,987	2.20
1,713	1.01	2,061	2.34
1,743	1.31	2,130	2.45
1,788	1.60		

Table 34. Altitude grid for South Cascade Glacier, Washington, 2005.

[**Year**, calendar year of aerial photography; ***X*** and ***Y*** are easting and northing coordinates in a local coordinate system, meters; ***Z*** is altitude, meters]

Year	X	Y	Z
2005	1,670	3,500	1,656
2005	1,670	3,400	1,695
2005	1,770	3,398	1,666
2005	1,570	3,300	1,726
2005	1,669	3,300	1,726
2005	1,770	3,300	1,700
2005	1,471	3,200	1,766
2005	1,570	3,200	1,760
2005	1,670	3,200	1,759
2005	1,770	3,199	1,773
2005	1,870	3,200	1,782
2005	1,970	3,200	1,775
2005	2,070	3,200	1,751
2005	1,469	3,100	1,802
2005	1,570	3,100	1,793
2005	1,669	3,101	1,790
2005	1,770	3,101	1,801
2005	1,870	3,102	1,804
2005	1,970	3,100	1,809
2005	2,070	3,100	1,805
2005	2,170	3,100	1,794
2005	1,471	2,999	1,823
2005	1,570	3,000	1,816
2005	1,670	2,999	1,815
2005	1,770	3,000	1,819
2005	1,870	3,000	1,824
2005	1,969	3,000	1,824
2005	2,070	3,000	1,822
2005	2,170	3,000	1,815
2005	2,271	3,000	1,807
2005	1,469	2,898	1,839
2005	1,571	2,900	1,830
2005	1,670	2,900	1,828
2005	1,772	2,899	1,829
2005	1,871	2,899	1,832
2005	1,970	2,899	1,830
2005	2,070	2,900	1,828
2005	2,170	2,900	1,822
2005	2,269	2,899	1,820
2005	1,470	2,799	1,853
2005	1,570	2,799	1,841
2005	1,670	2,800	1,838
2005	1,769	2,800	1,837
2005	1,870	2,801	1,836
2005	1,969	2,800	1,833
2005	2,070	2,799	1,829
2005	2,170	2,801	1,821
2005	2,270	2,801	1,823
2005	2,369	2,800	1,841
2005	1,469	2,700	1,859
2005	1,569	2,702	1,847
2005	1,669	2,699	1,847
2005	1,770	2,701	1,846
2005	1,869	2,702	1,842
2005	1,971	2,700	1,839
2005	2,070	2,701	1,836
2005	2,171	2,700	1,833
2005	2,270	2,700	1,845
2005	1,570	2,600	1,859
2005	1,670	2,600	1,857
2005	1,772	2,600	1,857
2005	1,870	2,601	1,853
2005	1,970	2,600	1,850
2005	2,070	2,601	1,849
2005	2,170	2,601	1,859
2005	2,270	2,600	1,878
2005	1,470	2,500	1,891
2005	1,570	2,500	1,870
2005	1,671	2,501	1,871
2005	1,770	2,500	1,871
2005	1,870	2,500	1,871
2005	1,970	2,500	1,871
2005	2,070	2,500	1,875
2005	2,169	2,501	1,889
2005	2,270	2,500	1,904
2005	2,367	2,500	1,916
2005	1,570	2,400	1,891
2005	1,667	2,400	1,883
2005	1,770	2,400	1,884
2005	1,870	2,400	1,888
2005	1,969	2,398	1,897
2005	2,071	2,398	1,902
2005	2,170	2,400	1,909
2005	2,270	2,400	1,923
2005	2,370	2,400	1,934
2005	2,470	2,400	1,953
2005	1,570	2,300	1,919
2005	1,669	2,299	1,896
2005	1,770	2,300	1,893
2005	1,870	2,300	1,902
2005	1,970	2,298	1,915
2005	2,070	2,299	1,919
2005	2,172	2,299	1,923
2005	2,269	2,301	1,932
2005	2,370	2,299	1,936
2005	2,470	2,300	1,950
2005	1,670	2,200	1,919
2005	1,770	2,200	1,905
2005	1,870	2,201	1,914
2005	1,969	2,200	1,922
2005	2,070	2,200	1,930
2005	2,171	2,200	1,932
2005	2,270	2,200	1,940
2005	2,370	2,200	1,943
2005	2,470	2,200	1,953
2005	1,770	2,100	1,932
2005	1,870	2,100	1,932
2005	1,969	2,100	1,935
2005	2,070	2,100	1,937
2005	2,170	2,100	1,942
2005	2,270	2,100	1,945
2005	2,370	2,100	1,949
2005	2,470	2,100	1,964
2005	1,870	2,000	1,957
2005	1,970	2,000	1,950
2005	2,070	1,999	1,949
2005	2,170	2,000	1,948
2005	2,270	2,001	1,950
2005	2,370	1,999	1,958
2005	2,470	2,000	1,974
2005	1,870	1,899	1,977
2005	1,970	1,899	1,966
2005	2,070	1,899	1,962
2005	2,170	1,899	1,966
2005	2,270	1,900	1,979
2005	2,369	1,899	1,985
2005	1,870	1,800	1,995
2005	1,970	1,798	1,982
2005	2,070	1,799	1,976
2005	2,169	1,800	1,984
2005	2,270	1,800	1,999
2005	2,369	1,799	2,010
2005	2,470	1,800	2,020
2005	2,570	1,799	2,030
2005	2,671	1,799	2,046
2005	2,770	1,799	2,062
2005	2,869	1,799	2,069
2005	2,969	1,799	2,074
2005	3,069	1,799	2,080
2005	3,170	1,800	2,090
2003	1,970	1,700	2,002
2005	2,069	1,700	1,990
2005	2,170	1,700	1,999
2005	2,270	1,699	2,008
2005	2,370	1,698	2,018
2005	2,470	1,699	2,026
2005	2,570	1,700	2,037
2005	2,670	1,700	2,047
2005	2,770	1,699	2,057
2005	2,868	1,699	2,069
2005	2,970	1,699	2,083
2005	3,070	1,700	2,096
2005	3,170	1,700	2,115
2005	2,070	1,599	2,021
2005	2,169	1,600	2,013
2005	2,269	1,600	2,016
2005	2,370	1,599	2,023
2005	2,469	1,599	2,031
2005	2,570	1,599	2,041
2005	2,670	1,600	2,052
2005	2,770	1,600	2,062
2005	2,870	1,600	2,076
2005	2,970	1,600	2,095
2004	3,070	1,601	2,122
2005	2,171	1,501	2,036
2005	2,269	1,499	2,033
2005	2,369	1,499	2,031
2005	2,469	1,499	2,036
2005	2,570	1,499	2,044
2005	2,670	1,499	2,058
2005	2,769	1,499	2,069
2004	2,870	1,500	2,090
2004	2,770	1,400	2,107
2005	2,370	1,399	2,052
2005	2,470	1,400	2,051
2005	2,570	1,398	2,053
2005	2,670	1,399	2,083

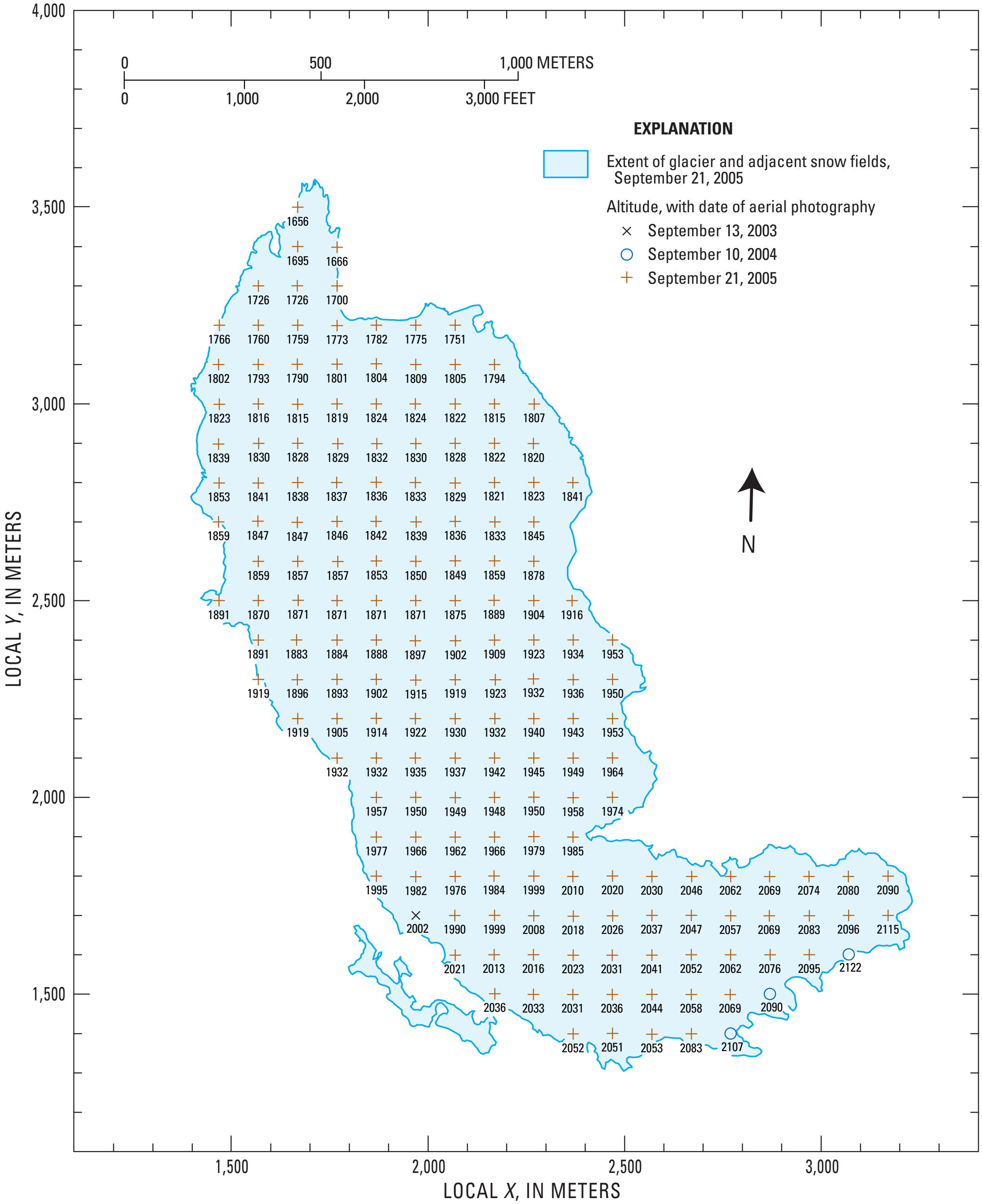


Figure 20. 2005 altitude grid for South Cascade Glacier, measured from variously dated vertical aerial photographs. Grid data also are presented in table 34.

2005 Net Balance

Balance year 2005 is thought to have been ended by accumulation of snow on the upper glacier October 19, a day precipitation was detected every hour at the Salix Creek gaging station. Although air temperature on the upper glacier likely was too high for precipitation there to have been snow as October 19 began, temperature decreased during the day so that snow likely accumulated. Surface heights of firn or ice measured October 22 were assumed to equal those heights on October 19 (table 35). Because of decreasing day length and sun-elevation angle, and air temperature generally being near or below freezing, any additional melt that might have occurred after October 22 is thought to have been negligibly small. The 2005 summer surface was ice at all ablation stakes except stake 2-05, where the summer surface was old firn with an estimated density of 0.70.

The 2005 glacier net balance, computed by the grid-index technique using the 2005 glacier-altitude grid and an interpolation table (table 36) based on the net-balance-altitude relation depicted in figure 21, was -2.45 m. A more negative net balance has been reported only for balance year 1958 (table 27). The exceptionally negative 2005 glacier mass balance was the result of the exceptionally small 2005 winter balance, as was described previously, and an exceptionally negative 2005 summer balance.

Balance year 2005 was the third consecutive year of net balance more negative than -1.6 m and the cumulative 3-year net balance at the end of 2005 was -6.20 m. No equal or greater 3-year mass loss has occurred in the history of USGS glaciology at South Cascade Glacier (fig. 22). As a result of the succession of negative balances, large expanses of ice were exposed on the upper glacier, where accumulation is expected if the glacier is to maintain its present size (fig. 23).

Table 35. Ablation stake measurements at South Cascade Glacier, Washington, balance year 2005.

[**Surface material:** Snow, snow accumulated on the 2004 summer melt surface; Firn, metamorphosed, old snow that has endured at least one summer season; Late snow, snow accumulated on the 2005 summer surface. **Surface height:** Height of glacier surface above the 2004 summer melt surface, meters. **Balance components**: Specific cryologic materials gained or lost since the beginning of balance year 2005, with thickness of material gained (loss expressed as negative gain), meters, and density of material, expressed as a fraction of the density of water. **Balance**: Combined gain or loss of all balance components since the beginning of balance year 2005, meters water equivalent, ***X*** and ***Y*** are easting and northing coordinates in a local coordinate system, meters; and ***Z*** is altitude, meters. **Abbreviations**: e, estimated or inferred; m, meter]

Date	Surface material	Surface height (m)	Balance components								Balance (m)
			Snow		Firn		Ice		Late snow		
			Thickness gain (m)	Density	Thickness gain (m)	Density	Thickness gain (m)	Density	Thickness gain (m)	Density	
Stake 1-05 (nearby stake 9-04 was used after August 18) [X = 2,858, Y = 1,685, Z = 2,069]											
04-20-05	SNOW	4.84	4.84	0.45e							2.18
05-12-05	SNOW	3.68	3.68	.46e							1.69
07-14-05	SNOW	1.86	1.86	.50e							.93
08-18-05	ICE	-.66					-0.66	0.90e			-.59
09-12-05	ICE	-1.66					-1.66	.90e			-1.49
09-25-05	ICE	-2.01					-2.01	.90e			-1.81
10-19-05	ICEe	-2.20e					-2.20e	.90e			-1.98e
10-22-05	ICE	-2.20					-2.20	.90e			-1.98
Stake 2-05 [X = 2,427, Y = 1,575, Z = 2,029]											
04-20-05	SNOW	5.73	5.73	0.45e							2.58
05-12-05	SNOW	4.48	4.48	.46							2.06
07-14-05	SNOW	2.72	2.72	.50e							1.36
08-02-05	SNOW	1.40	1.40	.52e							.73
08-18-05	SNOW	.46	.46	.53e							.24
09-12-05	FIRN	-.58			-0.58	0.70e					-.41
09-25-05	FIRN	-.86			-.86	.70e					-.60
10-19-05	FIRNe	-1.01e			-1.01e	.70e					-.71e
10-22-05	LSNOW	-.89			-1.01	.70e			0.12	0.50e	-.65

Table 35. Ablation stake measurements at South Cascade Glacier, Washington, balance year 2005.—Continued

[**Surface material:** Snow, snow accumulated on the 2004 summer melt surface; Firn, metamorphosed, old snow that has endured at least one summer season; Late snow, snow accumulated on the 2005 summer surface. **Surface height:** Height of glacier surface above the 2004 summer melt surface, meters. **Balance components**: Specific cryologic materials gained or lost since the beginning of balance year 2005, with thickness of material gained (loss expressed as negative gain), meters, and density of material, expressed as a fraction of the density of water. **Balance**: Combined gain or loss of all balance components since the beginning of balance year 2005, meters water equivalent, ***X*** and ***Y*** are easting and northing coordinates in a local coordinate system, meters; and ***Z*** is altitude, meters. **Abbreviations**: e, estimated or inferred; m, meter]

Date	Surface material	Surface height (m)	Balance components								Balance (m)
			Snow		Firn		Ice		Late snow		
			Thickness gain (m)	Density	Thickness gain (m)	Density	Thickness gain (m)	Density	Thickness gain (m)	Density	
Stake 3-05 [X = 2,151, Y = 2,024, Z = 1,947]											
04-20-05	SNOW	4.37	4.37	0.46e							2.01
05-12-05	SNOW	3.22	3.22	.48e							1.55
07-13-05	SNOW	1.19	1.19	.51e							.61
08-18-05	ICE	-1.27					-1.27	0.90e			-1.14
09-12-05	ICE	-2.14					-2.14	.90e			-1.93
09-25-05	ICE	-2.50					-2.50	.90e			-2.25
10-19-05	ICEe	-2.91e					-2.91e	.90e			-2.62e
10-22-05	ICE	-2.91					-2.91	.90e			-2.62
Stake 4-05 [X = 1,813, Y = 2,774, Z = 1,838]											
04-20-05	SNOW	3.97	3.97	0.48e							1.91
05-12-05	SNOW	2.88	2.88	.50							1.44
07-13-05	SNOW	.58	.58	.53e							.31
08-02-05	ICE	-0.69					-0.69	0.90e			-.62
08-17-05	ICE	-1.64					-1.64	.90e			-1.48
09-12-05	ICE	-2.55					-2.55	.90e			-2.30
09-25-05	ICE	-2.84					-2.84	.90e			-2.56
10-19-05	ICEe	-3.23e					-3.23e	.90e			-2.91e
10-22-05	ICE	-3.23					-3.23	.90e			-2.91
Stake 5-05 [X = 1,632, Y = 3,244, Z = 1,742]											
04-21-05	SNOW	3.08	3.08	0.43e							1.32
05-13-05	SNOW	1.99	1.99	.44e							.88
07-14-05	ICE	-0.77					-0.77	0.90e			-.69
08-18-05	ICE	-3.42					-3.42	.90e			-3.08
09-12-05	ICE	-4.63					-4.63	.90e			-4.17
09-25-05	ICE	-5.00					-5.00	.90e			-4.50
10-19-05	ICEe	-5.58e					-5.58e	.90e			-5.02e
Stake 7-05 [X = 1,629, Y = 3,438, Z = 1,683]											
04-21-05	SNOW	1.00	1.00	0.42e							0.42
05-13-05	SNOW	-.12					-0.12	0.90e			-.11
07-14-05	ICE	-2.66					-2.66	.90e			-2.39
08-18-05	ICE	-5.19					-5.19	.90e			-4.67
09-12-05	ICE	-6.35					-6.35	.90e			-5.72
09-25-05	ICE	-6.64					-6.64	.90e			-5.98
10-19-05	ICEe	-7.33e					-7.33e	.90e			-6.60e

Table 36. Altitude and net balance values defining a curve used to estimate net balance as it varied with altitude on South Cascade Glacier, Washington, balance year, 2005.

[**Altitude**, meters. **Net balance**, meters water equivalent. Net balance as it varied with altitude is shown in figure 21]

Altitude	Net balance	Altitude	Net balance
1,656	-7.50	1,808	-3.10
1,676	-6.83	1,856	-2.65
1,696	-6.19	1,911	-2.28
1,715	-5.55	1,968	-1.97
1,734	-4.92	2,027	-1.69
1,753	-4.28	2,087	-1.42
1,775	-3.65	2,140	-1.20

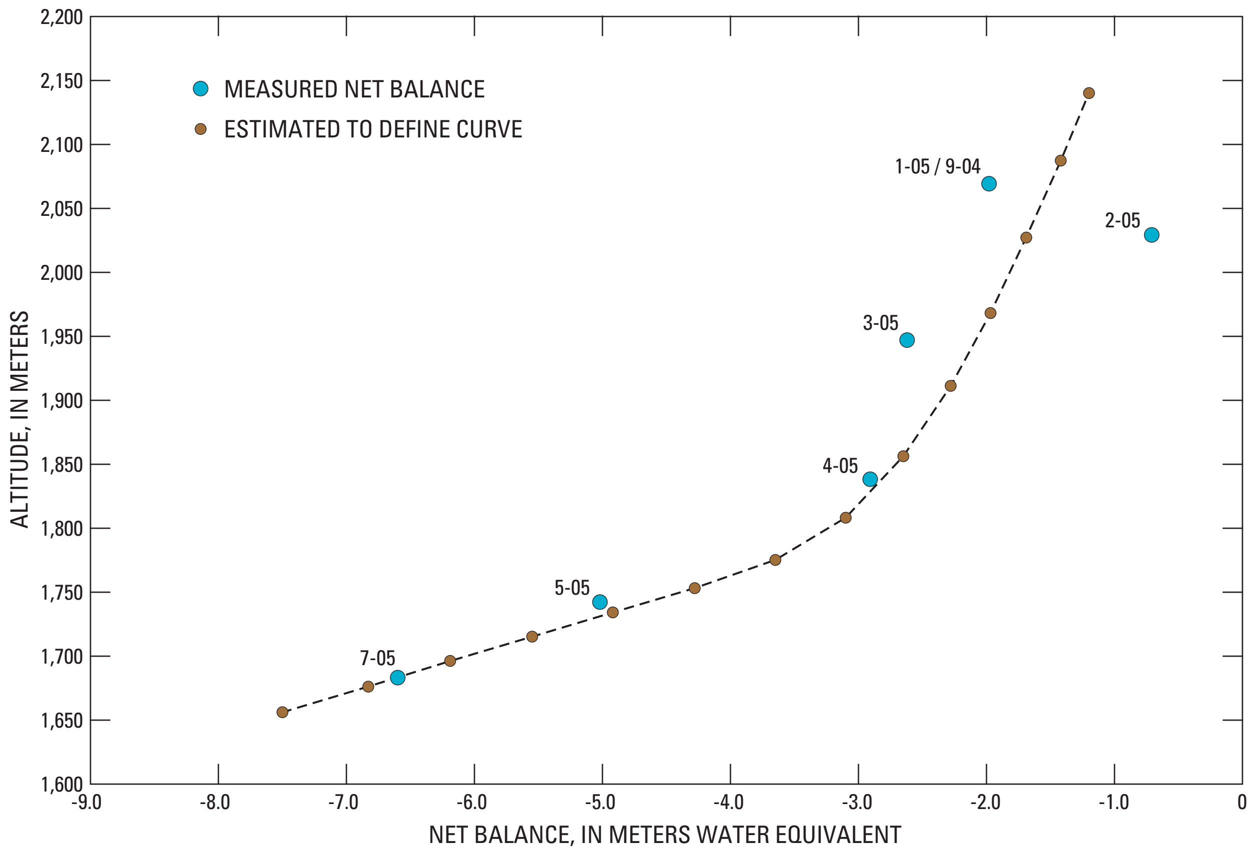


Figure 21. Net balance as it varied with altitude on South Cascade Glacier, Washington, balance year 2005. Ablation stake number is plotted above measured net balance. The curve was fitted to the data by eye and was defined by the estimated values. Estimated values are presented in table 36.

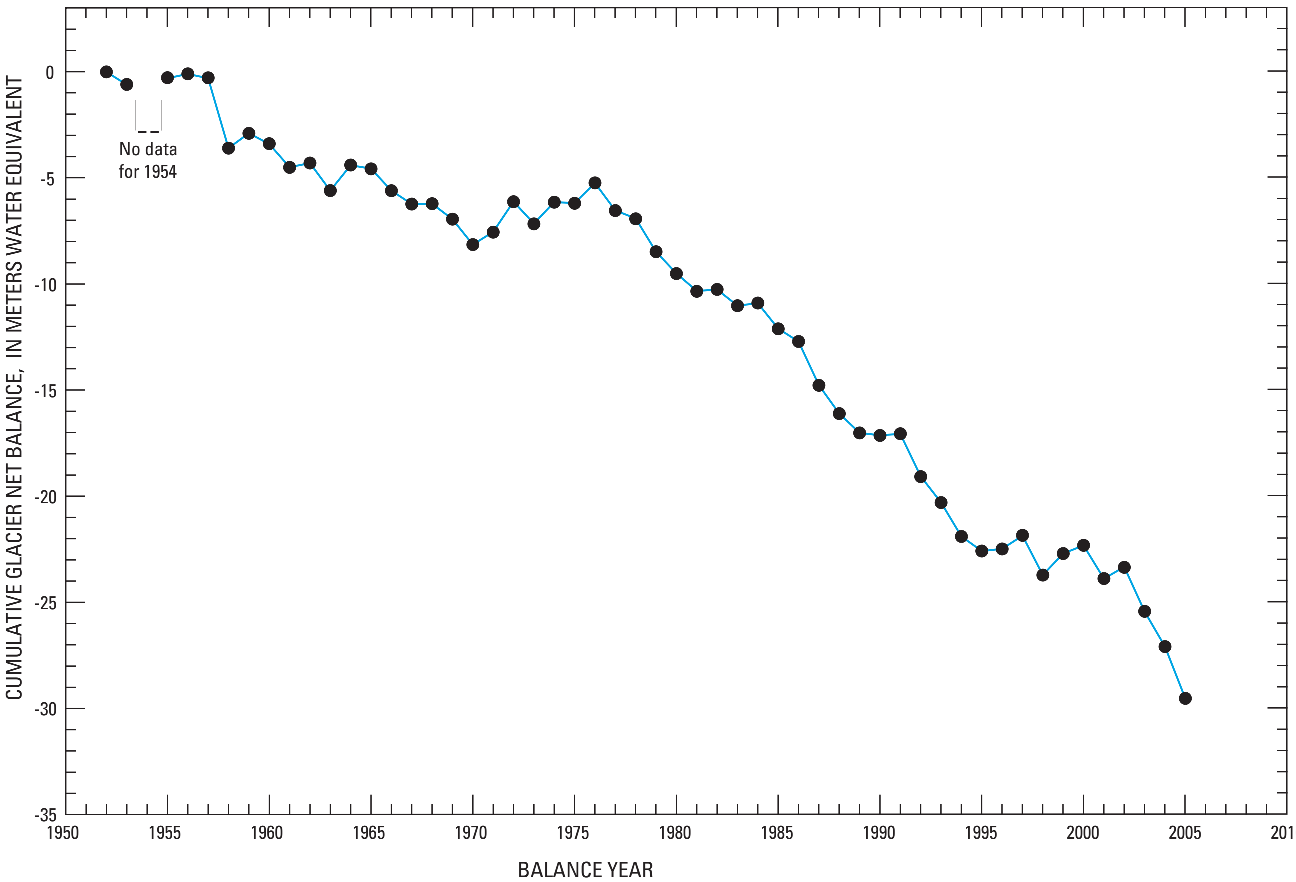


Figure 22. Cumulative net balance at South Cascade Glacier, Washington, balance years 1953–2005.

Figure 23. South Cascade Glacier, Washington, constructed from vertical photographs, September 21, 2005.

2005 Summer and Annual Balances

The computed 2005 glacier summer balance ($\bar{b}_s$) was -4.42 m, which was the third most negative such balance since the record for $\bar{b}_s$ began in 1959 (table 27). The 2005 $\bar{b}_s$ was 39 percent more negative than would be predicted by the previously described relation between $\bar{b}_s$ and average air temperature at the Hut during June through September, making the 2005 $\bar{b}_s$ the single greatest departure from the relation for any year with 10 or fewer days of missing air temperature (fig. 17). Possible causes for the 2005 $\bar{b}_s$ being the most extreme outlier include increased summer melt due to greater exposure of old firn and ice than was typical, decreased summer snow accumulation, and the warmer than normal May. May air temperature at the Hut averaged 4.9°C, making it the warmest May for which complete data are available. The relatively high May temperature accelerated melt and likely decreased May accumulation, two consequences that would have tended to make $\bar{b}_s$ more negative.

The 2005 glacier annual balance ($\bar{b}_a$) was computed from the net balance and estimates of the initial and final balance increments ($\bar{b}_0$ and $\bar{b}_1$). The 2005 $\bar{b}_0$ was the same as the 2004 $\bar{b}_1$ (-0.17 m) presented previously, and the 2005 $\bar{b}_1$ was estimated using a series of steps. First, the September 25 glacier balance relative to the 2004 summer surface was computed from stake measurements using the grid-index technique. This balance was -2.24 m. It was then assumed one-half of the glacier average ablation during September 25 and October 19 occurred during the relatively warm final 5 days of September. This small balance increment (-0.10 m) was then added to the September 25 balance to obtain the September 30 glacier balance of -2.34 m. Finally, the September 30 glacier balance was subtracted from the 2005 net balance to obtain $\bar{b}_1$ (-0.11 m). The 2005 $\bar{b}_a$ was then computed from equation 7 to be -2.51 m.

Some Sources of Mass-Balance Errors

Glacier mass-balance quantities in this report were subject to numerous measurement and sampling errors. Among the potentially most significant measurement errors were errors in depth of snow measured by probing (due to false detection of the base of the snowpack in areas where the snow was underlain by firn), errors in volumes of snow samples used to compute snow density (due to sample disturbance caused by sampling equipment), and errors in computed surface lowering due to sinking of ablation stakes.

Sampling errors, both in time and in space, probably contributed more uncertainty in the computed mass balances than did measurement errors. Sampling errors in time were due to the impracticality of monitoring the glacier daily, which required that conclusion dates of the winter season and balance year be estimated, and also that balance records for individual sites or for the entire glacier be extended to the concluding dates. As a result, errors of estimation likely accompanied the extensions of the balance records. Glacier mass balances computed from measurements of snow depth, surface lowering, and snow density made at selected locations were subject to spatial sampling errors caused by spatial variations of the measured properties that were not accounted for. Sampling errors in space with the grid-index method are apparent in the failure of altitude, as the single explanatory variable, to account for all of the observed variation of snow water equivalent (figs. 13 and 19) and net balance (figs. 16 and 21). Another potential source of sampling error was the spatial variation of profile-average snow density not accounted for by the measured profiles or by the density-estimation schemes described previously.

The total error in each of the glacier mass-balance quantities ($\bar{b}_w$ (s), $\bar{b}_s$, $\bar{b}_n$, and $\bar{b}_a$) in this report due to measurement and sampling errors is not objectively known but probably is a few tenths of a meter water equivalent, which would be consistent with errors reported by Krimmel (2002) for past South Cascade Glacier mass balances. Mass-balance errors due to neglect of internal accumulation and ablation and basal melting are thought to have been much smaller than those due to measurement and sampling errors.

Terminus Retreat, Glacier Area, and Equilibrium Line Altitude

The glacier terminus retreated during 2004 and 2005, as it has during every year of measurement except 1972 (Krimmel, 2002). Retreat rate of the terminus during September 13, 2003, to September 10, 2004, estimated from mapped terminus position on those dates, was 17 m/yr. Retreat rate of the terminus during September 10, 2004, to September 21, 2005, was about 15 m/yr. Some of the terminus margin was in shadow at the times the vertical aerial photography was acquired in 2004 and 2005 (figs. 15 and 23). The shadows obscured the ice margin, and the outline of the glacier mapped in the vicinity of the terminus was that of the visible ice, which could have differed from the actual ice margin by as much as several meters. Estimated uncertainty of both retreat rates was about 5 m/yr.

The retreating terminus was accompanied by decreases in area of the glacier during 2004 and 2005. Glacier area September 10, 2004, was 1.82 km^2, a decrease of 0.07 km^2 since September 13, 2003 (Bidlake and others, 2005). Glacier area September 21, 2005, was 1.75 km^2, a decrease of 0.07 km^2 since the September 10, 2004. Area decreases during 2004 and 2005 were roughly twice as large as annual decreases reported in recent years (Krimmel, 2002; Bidlake and others, 2004, 2005). The accelerated rate of area loss was due to shrinkage of the upper glacier during 2004 and 2005. As a result of the relatively large, sustained loss of snow and ice, the upper glacier south of local *Y* = 2,900 contracted as ice and long-existing perennial snow fields thinned and retreated along the glacier margin.

The continued retreat and loss of mass by South Cascade Glacier during 2004 and 2005 was consistent with overall trends since 1953. These overall trends of decreasing glacier extent and mass indicate that South Cascade Glacier has been responding to climate conditions that will not support the glacier in its recent size and position on the landscape (Rasmussen and Conway, 2001).

The ELA was higher than South Cascade Glacier (>2,125 m) for balance years 2004 and 2005. Some recently accumulated snow and small areas of residual snow from the previous winter might have been present on the upper glacier at the end of 2004; however, those were thought to be too isolated and scattered to define a glacier-wide balance-altitude condition such as is represented by the ELA. Areas of recently accumulated and residual snow on the glacier at the end of balance year 2005 likely were even more scattered than in 2004. The AAR for both 2004 and 2005 was estimated to be less than 0.05.

Summary and Conclusions

The long-term U.S. Geological Survey monitoring of South Cascade Glacier, Washington, a Benchmark Glacier for the extensively glacierized North Cascade Mountains, is part of the larger U.S. Geological Survey Glacier Monitoring Program. Meteorological, hydrologic, and glaciological monitoring of South Cascade Glacier has been carried out for more than 4 decades, and this report present results of monitoring during balance years 2004 and 2005.

Selected glaciological quantities and dates for balance years 2004 and 2005 presented previously in this report are also summarized in table 37. The North Cascade Range in the vicinity of South Cascade Glacier accumulated smaller than normal winter snowpacks during the 2004 and 2005 water years. As a result, the 2004 and 2005 winter snow balances of South Cascade Glacier were 77 and 73 percent as large as the average for 1959 to 2005.

Partly as a result of small winter snow accumulation, the glacier lost mass during both 2004 and 2005. The 2004 net balance was the seventh most negative during 1953 to 2005 and the 2005 net balance was the second most negative. The 2003 glacier net balance also was negative, and the cumulative net balance for 2003 to 2005 (-6.20 m) was more negative than during any comparable period in the history of USGS glaciology at South Cascade Glacier. The 2004 and 2005 glacier summer balances were the eleventh and third most negative summer balances, respectively, during 1959 to 2005.

The terminus of South Cascade glacier retreated during 2004 and 2005, as it has during every year of measurement since 1972. The average retreat rate during balance year 2004 was about 17 m/yr and the average retreat rate during balance year 2005 was about 15 m/yr. Total glacier area decreased by 0.07 km^2 each year during 2004 and 2005. The area reductions were due partly to the continuing terminus retreat and partly to contraction of the upper glacier.

The continued retreat and loss of mass by South Cascade Glacier during 2004 and 2005 was consistent with overall trends since 1953. These overall trends of decreasing glacier extent and mass indicate that South Cascade Glacier has been responding to climate conditions that will not support the glacier in its recent size and position.

Table 37. Selected glaciological quantities and dates for South Cascade Glacier, balance years 2004 and 2005.

[Glacier balances expressed in meters water equivalent. **Abbreviations:** m, meters; m/yr, meters per year; km^2, square kilometers; >, greater than; <, less than]

Glaciological quantity or date	Balance year 2004	Balance year 2005
Glacier maximum winter snow balance ($\bar{b}_w(s)$)	2.08 m	1.97 m
Ending date of winter season	April 3, 2004	April 20, 2005
Glacier summer balance ($\bar{b}_s$)	-3.73 m	-4.42 m
Ending date of summer season	October 15, 2004	October 19, 2005
Glacier net balance ($\bar{b}_n$)	-1.65 m	-2.45 m
Glacier initial balance increment ($\bar{b}_0$)	-0.25 m	-0.17 m
Glacier final balance increment ($\bar{b}_1$)	-0.17 m	-0.11 m
Glacier annual (water year) balance ($\bar{b}_a$)	-1.73 m	-2.51 m
Terminus retreat rate	17 m/yr	15 m/yr
Glacier area on September 10, 2004	1.82 km^2	
Glacier area on September 21, 2005		1.75 km^2
Average equilibrium line altitude	> 2,125 m	>2,125 m
Accumulation area ratio	<0.05	<0.05

Acknowledgments

The authors thank Mark C. Mastin, who reviewed the surface-water computations and the draft report, and Robert M. Krimmel and Al Rasmussen, who reviewed the draft report.

References Cited

Anonymous, 1969, Mass-balance terms: Journal of Glaciology, v. 8, no. 52, p. 3–7.

Bidlake, W.R., Josberger, E.G., and Savoca, M.E., 2004, Water, ice, and meteorological measurements at South Cascade Glacier, Washington, balance year 2002: U.S. Geological Survey Scientific Investigations Report 2004-5089, 38 p.

Bidlake, W.R., Josberger, E.G., and Savoca, M.E., 2005, Water, ice, and meteorological measurements at South Cascade Glacier, Washington, balance year 2003: U.S. Geological Survey Scientific Investigations Report 2005-5210, 48 p.

Bouchard, H., and Moffitt, F.H., 1972, Surveying (5th ed.): Scranton, Pennsylvania, International Textbook Co., 754 p.

Fountain, A.G., Krimmel, R.M., and Trabant, D.C., 1997, A strategy for monitoring glaciers: U.S. Geological Survey Circular 1132, 19 p.

Fountain, A.G., and Tangborn, W.V., 1985, The effect of glaciers on streamflow variations: Water Resources Research, v. 21, no. 4, p. 579–586.

Haeberli, W., Noetzli, J., Zemp, M., Baumann, S., Frauenfelder, R., and Hoelzle, M., eds., 2005, Glacier mass balance bulletin no. 8 (2002–03): Zurich, Switzerland, University and ETH Zurich, World Glacier Monitoring Service, IUGG (CCS)-UNEP-UNESCO-WMO, 100 p.

Hodge, S.M., Trabant, D.C., Krimmel, R.M., Heinrichs, T.A., March, R.S., and Josberger, E.G., 1998, Climate variations and changes in mass of three glaciers in western North America: Journal of Climate, v. 11, no. 9, p. 2161–2179.

Krimmel, R.M., 1989, Mass balance and volume of South Cascade Glacier, Washington, 1958–1985, *in* Oerlemans, J., ed., Glacier fluctuations and climatic change: Dordrecht, The Netherlands, Kluwer Academic Publishers, p. 193–206.

Krimmel, R.M.,1993, Mass balance, meteorological, and runoff measurements at South Cascade Glacier, Washington, 1992 balance year: U.S. Geological Survey Open-File Report 93-640, 38 p.

Krimmel, R.M., 1994, Runoff, precipitation, mass balance, and ice velocity measurements at South Cascade Glacier, Washington, 1993 balance year: U.S. Geological Survey Water-Resources Investigations Report 94-4139, 35 p.

Krimmel, R.M., 1995, Water, ice, and meteorological measurements at South Cascade Glacier, Washington, 1994 balance year: U.S. Geological Survey Water-Resources Investigations Report 95-4162, 41 p.

Krimmel, R.M., 1996a, Water, ice, and meteorological measurements at South Cascade Glacier, Washington, 1995 balance year: U.S. Geological Survey Water-Resources Investigations Report 96-4174, 37 p.

Krimmel, R.M., 1996b, Glacier mass balance using the grid-index method, in Colbeck, S.C., ed., Glaciers, ice sheets and volcanoes—A tribute to Mark F. Meier: U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory Special Report 96-27, p. 62–68.

Krimmel, R.M., 1997, Water, ice, and meteorological measurements at South Cascade Glacier, Washington, 1996 balance year: U.S. Geological Survey Water-Resources Investigations Report 97-4143, 34 p.

Krimmel, R.M., 1998, Water, ice, and meteorological measurements at South Cascade Glacier, Washington, 1997 balance year: U.S. Geological Survey Water-Resources Investigations Report 98-4090, 30 p.

Krimmel, R.M., 1999, Water, ice, meteorological and speed measurements at South Cascade Glacier, Washington, 1998 balance year: U.S. Geological Survey Water-Resources Investigations Report 99-4049, 36 p.

Krimmel, R.M., 2000, Water, ice, and meteorological measurements at South Cascade Glacier, Washington, 1986–91 balance years: U.S. Geological Survey Water-Resources Investigations Report 00-4006, 77 p.

Krimmel, R.M., 2001, Water, ice, meteorological, and speed measurements at South Cascade Glacier, Washington, 1999 balance year: U.S. Geological Survey Water-Resources Investigations Report 00-4265, 36 p.

Krimmel, R.M., 2002, Water, ice, and meteorological measurements at South Cascade Glacier, Washington, 2000–01 balance years: U.S. Geological Survey Water-Resources Investigations Report 02-4165, 63 p.

Krimmel, R.M., and Tangborn, W.V., 1974, South Cascade Glacier—The moderating effect of glaciers on runoff: Western Snow Conference, 42d Annual Meeting, Anchorage, Alaska, 1974, Proceedings, p. 9–13.

March, R.S., 1998, Mass balance, meteorological, ice motion, surface altitude, and runoff data at Gulkana Glacier, Alaska, 1994 balance year: U.S. Geological Survey Water-Resources Investigations Report 97-4251, 31 p.

March, R.S., 2003, Mass balance, meteorology, area altitude distribution, glacier-surface altitude, ice motion, terminus position, and runoff at Gulkana Glacier, Alaska, 1996 balance year: U.S. Geological Survey Water-Resources Investigations Report 03-4095, 33 p.

Mayo, L.R., Meier, M.F., and Tangborn, W.V., 1972, A system to combine stratigraphic and annual mass-balance systems—A contribution to the International Hydrological Decade: Journal of Glaciology, v. 11, no. 61, p. 3–14.

Mayo, L.R., Trabant, D.C., and March, R.S., 2004, A 30-year record of surface mass balance (1966–95), and motion and surface altitude (1975–95) at Wolverine Glacier, Alaska: U.S. Geological Survey Open-File Report 2004-1069, 105 p.

Meier, M.F., 1958, Research on South Cascade Glacier: The Mountaineer, v. 51, no. 4, p. 40–47.

Meier, M.F., and Tangborn, W.V., 1965, Net budget and flow of South Cascade Glacier, Washington: Journal of Glaciology, v. 5, no. 41, p. 547–566.

Meier, M.F., Tangborn, W.V., Mayo, L.R., and Post, Austin, 1971, Combined ice and water balances of Gulkana and Wolverine Glaciers, Alaska, and South Cascade Glacier, Washington, 1965 and 1966 hydrologic years: U.S. Geological Survey Professional Paper 715-A, 23 p.

National Water and Climate Center, 2006, Washington SNOTEL sites: U.S. Department of Agriculture, Natural Resources Conservation Service, data accessed October 2, 2006, at http://www.wcc.nrcs.usda.gov/snotel/Washington/washington.html.

Paterson, W.S.B., 1994, The physics of glaciers (3d ed.): Tarrytown, New York, Elsevier Science, Inc., 480 p.

Post, Austin, Richardson, Don, Tangborn, W.V., and Rosselot, F.L., 1971, Inventory of glaciers in the North Cascades, Washington: U.S. Geological Survey Professional Paper 705-A, 26 p.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow—Volume 2. Computation of discharge: U.S. Geological Survey Water-Supply Paper 2175, 347 p.

Rasmussen, L.A., and Conway, H., 2001, Estimating South Cascade Glacier (Washington, U.S.A.) mass balance from a distant radiosonde and comparison with Blue Glacier: Journal of Glaciology, v. 47, no. 159, p. 579–588.

Rasmussen, L.A., and Conway, H., 2004, Climate and glacier variability in western North America: Journal of Climate, v. 17, no. 9, p. 1804–1815.

Rasmussen, L.A., and Conway, H.B., 2003, Using upper-air conditions to estimate South Cascade Glacier (Washington, U.S.A.) summer balance: Journal of Glaciology, v. 49, no. 166, p. 456–462.

Sullivan, M.E., 1994, South Cascade Glacier, Washington—Hydrologic and meteorological data, 1957–67: U.S. Geological Survey Open-File Report 94-77, 105 p.

Tangborn, W.V., Mayo, L.R., Scully, D.R., and Krimmel, R.M., 1977, Combined ice and water balances of Maclure Glacier, California, South Cascade Glacier, Washington, and Wolverine and Gulkana Glaciers, Alaska, 1967 hydrologic year: U.S. Geological Survey Professional Paper 715-B, 20 p.

Manuscript approved for publication, April 3, 2007

Prepared by the USGS Publishing Network,

Publishing Service Center, Tacoma, Washington
Bill Gibbs
Debra Grillo
Pat Revitzer
Sharon Wahlstrom
Bobbie Jo Richey

For more information concerning the research in this report, contact the
Director, Washington Water Science Center
U.S. Geological Survey, 934 Broadway — Suite 300
Tacoma, Washington 98402
http://wa.water.usgs.gov

Float-equipped airplane on South Cascade Glacier, March 1971. The airplane transported people and supplies to the glacier at a time when helicopters were not readily available for that purpose (photograph by Bob Munro, Kenmore Air Harbor).

USGS

Bidlake and others

Water, Ice, and Meteorological Measurements at South Cascade Glacier, Washington, Balance Years 2004 and 2005

SIR 2007-5055