ESTIMATING DATES OF THE SNOW ACCUMULATION SEASON

by

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INTRODUCTION

The snow accumulation season is here defined as the period of snowpack growth, extending from the first snowfall which does not completely melt, to the time of peak snow accumulation water-equivalent, as measured on a horizontal surface in a location sheltered from the wind. It is often necessary to estimate calendar dates of the average snow accumulation season as a first step in estimating average winter precipitation required for snowmelt models, designing buildings to support snow loads, and designing snow fence systems for sufficient storage capacity (Tabler 1987,1988). In the latter case, the snow accumulation season is more specifically defined as the period of drift growth, beginning with the first blowing snow event causing drifts that persist through the winter, and ending when snowdrifts reach maximum volume for the winter.

Although the National Climatic Data Center (National Oceanic and Atmospheric Administration) reports "snow on ground" for some stations, it is difficult to use this information to determine the snow accumulation season as previously defined. "Snow on ground" is typically measured in locations exposed to the wind. And even at sheltered locations, it is difficult to determine the date of peak water-equivalent from snow depth data because water-equivalent can increase while snow depth is decreasing due to densification.

Snow survey data, such as reported by the Soil Conservation Service (U.S. Department of Agriculture), can be used to estimate snow accumulation dates at locations equipped with recording equipment. Most historical data consist of manual measurements commencing in mid-winter and repeated at monthly or biweekly intervals, with the result that the fall date cannot be estimated, and the resolution of the spring date is poor. Because historical data for seasonal snow accumulation are usually not available for most locations where the accumulation season must be estimated, some other approach is necessary. This paper describes a method for estimating calendar dates of the snow accumulation season using air temperature data.

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AN AIR TEMPERATURE INDEX

The thesis of this paper is that air temperature records can be used to estimate dates of the snow accumulation season with sufficient accuracy for many engineering applications. Although this idea seems reasonable considering the role air temperature plays in snow melting, and the index it provides to the net energy balance, the procedure for using historical temperature data is not self-evident.

The 0°C Date

The search for a suitable temperature index began by formulating a simple hypothesis which subsequent testing failed to reject --- that the snow accumulation season is delimited by the dates when average air temperature reaches 0°C, as computed from mean monthly temperatures. This latter qualification, imposed because monthly mean values are readily available and convenient to use, assumes that the monthly mean temperature applies to the middle of the month. 0°C dates are therefore computed by interpolation between consecutive months having mean temperatures above and below 0°C. Representing this interpolation procedure by equation,

$$N \doteqdot 30(T_+ - T_m)/(T_+ - T_-) \qquad (1)$$

where N is the number of days from the middle of the warmer month to the 0°C date (N is added to the mid-date of the warmer month in the fall, and subtracted from the mid-date of the warmer month in the spring). T_+ and T_- are the mean temperatures of the warmer and colder months, respectively, and T_m is the melting temperature expressed in the units being used (0 if Celsius, 32 if Fahrenheit).

To demonstrate how Equation (1) is used, consider a location where mean monthly temperatures for October and November are 3.8°C (38.8°F) and -4.1°C (24.7°F), respectively. The 0°C fall date would be calculated as follows:

$$N \doteqdot 30(3.8 - 0)/(3.8 + 4.1) = 14; \quad \text{Date} = \text{October } (15 + 14) = \text{October } 29$$

The same result would be obtained if temperatures were expressed in degrees Fahrenheit:

$$N \doteqdot 30(38.8 - 32)/(38.8 - 24.7) = 14$$

If mean monthly temperatures for March and April were -6.0°C (21.2°F) and +2.9°C (37.3°F), respectively, the spring date would be calculated as

$$N \doteqdot 30(2.9 - 0)/(2.9 + 6.0) = 10; \quad \text{Date} = \text{April } (15-10) = \text{April } 5$$

Testing the Hypothesis

The hypothesis that the snow accumulation season is delimited by these 0°C dates was first tested for the case of windswept sites where snowdrifts provide the measure of snow accumulation. Dates of the snow accumulation season near Laramie, Wyoming, have been recorded since 1960 in conjunction with studies reported by Tabler (1975; 1980; 1985; 1988). Comparison of observed dates with 0°C dates (Table 1 and Figure 1) indicates that despite considerable variation within any given year, the 0°C temperature dates provide an excellent approximation of the average snow accumulation season, being within 4 days of the observed fall date, and within 2 days for the spring date.

The second test of the hypothesis was for the case of more sheltered locations in the mountains. Observed dates for the snow accumulation season in this case were derived from climatological data published by the National Climatic Data Center for two stations in Wyoming where snow on the ground is measured in relatively sheltered locations: Foxpark (elevation 2760 m, latitude 41° 05' N, longitude 106° 09' W) and Burgess Junction (elevation 2500 m, latitude 44° 46' N, longitude 107° 32' W). Observed dates for the snow accumulation season were derived by assuming that the beginning of the snow accumulation period was the date of the first persistent "snow on ground," and that peak snowpack water-equivalent occurred at the end of the 7-day period having the highest average "snow on ground," an assumption providing some allowance for snow settlement. Although comparison between observed dates and 0°C dates (Figure 2) shows even greater yearly variability, temperature dates average within 7 days of observed accumulation dates. It is therefore concluded that

> The average snow accumulation season is delimited by the dates when average temperatures reach 0°C (32°F), as computed from mean monthly temperatures.

Table 1. Observed dates of snow accumulation and 0°C average air temperature for study sites near Laramie, Wyoming. The fall date is that of the first blowing snow event causing drifts that persisted throughout the winter, and the spring date is that when snowdrifts reached maximum volume for the winter. Observed dates are for study sites within 60 km of Laramie, having elevations 2300-2400 m. Temperature data are for the Laramie airport at elevation 2215 m, latitude 41° 19' N, longitude 105° 41' W. Dates are expressed as day of the year.

Year	Snow accumulation dates		Dates of 0°C air temperature	
	Fall	Spring	Fall	Spring
1960-61	309	91	318	90
1961-62	301	82	306	89
1962-63	319	77	329	85
1963-64	341	90	328	99
1964-65	318	87	315	93
1965-66	345	81	331	75
1966-67	312	74	324	69
1967-68	306	99	312	108
1968-69	314	82	310	92
1969-70	277	92	288	102
1970-71	280	85	306	88
1971-72	300	63	315	62
1972-73	301	111	306	107
1973-74	302	105	314	74
1974-75	314	102	318	97
1975-76	296	82	312	89
1976-77	331	94	313	87
1977-78	312	75	317	68
1978-79	297	103	314	81
1979-80	302	98	303	92
1980-81	327	95	315	80
1981-82	322	81	327	75
1982-83	292	107	303	114
1983-84	311	107	312	102
1984-85	310	80	288	91
1985-86	305	60	312	53
Means	309	89	313	87

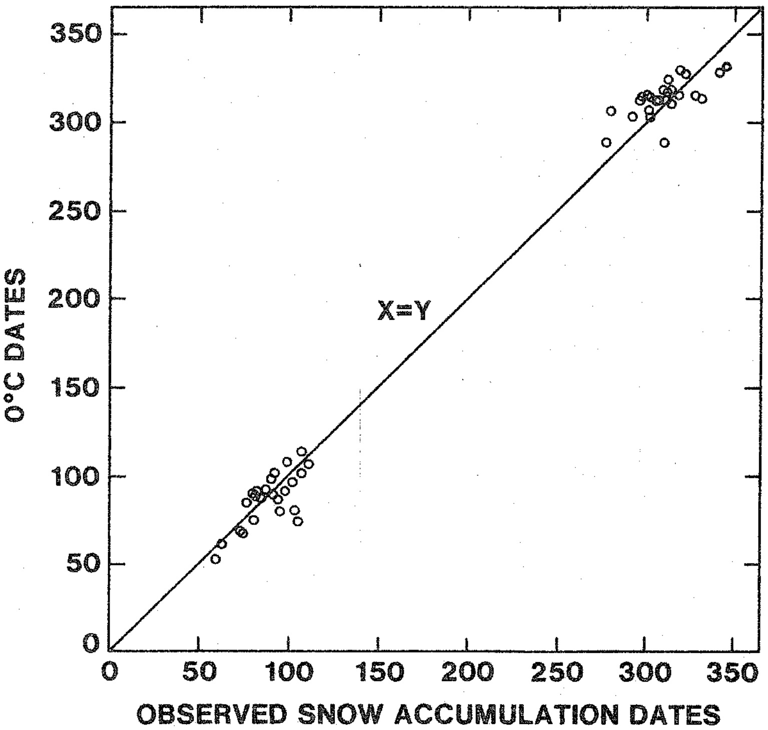

Figure 1. Day of year when average air temperature reached 0°C, versus day of year delimiting observed snow accumulation season as indicated by snowdrift measurements near Laramie, Wyoming, for the period 1960-86 (Table 1).

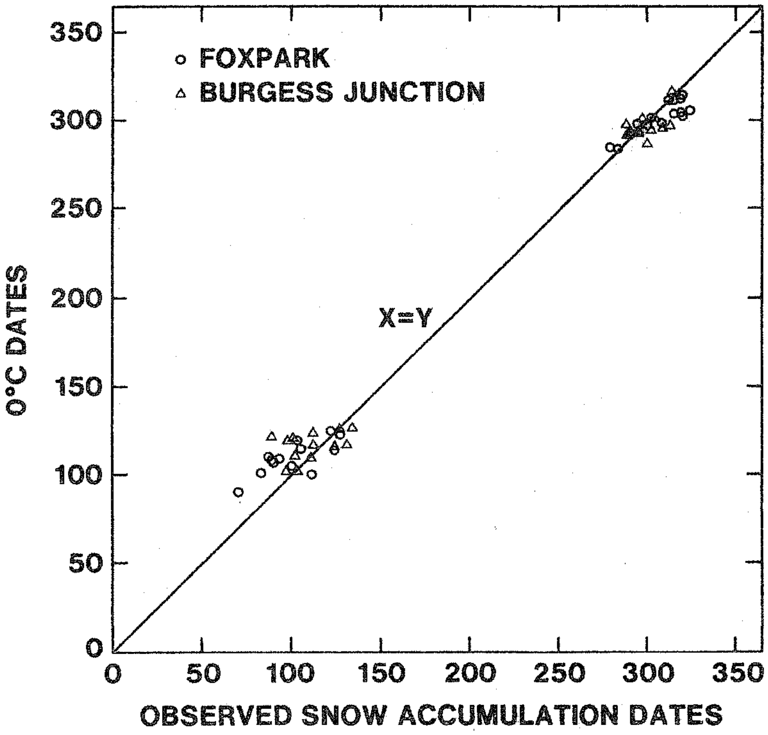

Figure 2. Day of year when average air temperature reached 0°C, versus day of year delimiting observed snow accumulation season as indicated by climatological data published for Burgess Junction and Foxpark, Wyoming, 1961-1981.

METHODS FOR ESTIMATING 0°C DATES

For locations with climatological data, 0°C dates are computed directly using Equation (1). Examples of 0°C dates calculated from data published by the National Climatic Data Center (10-30-year means) are:

Ames, Iowa:	November 27 - March 10
Barrow, Alaska:	September 8 - June 13
Boise, Idaho:	December 16 - January 29
Buffalo, New York:	December 6 - March 12
Denver, Colorado:	December 22 - February 6
Flagstaff, Arizona:	December 5 - February 26
Kalispell, Montana:	November 12 - March 19
Laramie, Wyoming:	November 11 - March 29
Lincoln, Nebraska:	December 3 - February 28
Madison, Wisconsin:	November 21 - March 19
Mansfield, Ohio:	December 12 - February 22
Salt Lake City, Utah:	December 10 - February 6

At locations where temperature data are not available, 0°C dates can be estimated from regression equations relating 0°C dates at other stations to elevation, latitude, and longitude, because the geographic variation of air temperature is reasonably well described by these three variables (Hopkins, 1918; Visher, 1924). Hence,

$$\text{Date} = A + B(\text{Elev}) + C(\text{Lat}) + D(\text{Long}) \tag{2}$$

where Date is day of the year, (Elev) is elevation in meters, (Lat) is latitude (north) in degrees, and (Long) is longitude (west). Values for A, B, C, and D can be determined for a particular area by statistical regression analysis of data from surrounding stations. Once the coefficients in Equation (2) are determined, dates can be estimated for locations lacking data. Areas with relatively few climatological stations may require utilization of regional or statewide data. Table 2 presents values for A, B, C, and D, for selected states, as determined from regression analyses of mean monthly temperatures published by the National Climatic Data Center (10-30-year means), or by Wernstedt (1972).

To demonstrate how snow accumulation dates are computed from this information, consider the example of a site in Wyoming at 2438 m (8000 feet) elevation, 49° N latitude, and 109° W longitude. Beginning date of the snow accumulation season would be computed as

$$667 - 0.0185(\text{Elev}) - 3.47(\text{Lat}) - 1.55(\text{Long}) = 304 = \text{October 31}$$

The spring date would be computed as

$$-216 + 0.0341(\text{Elev}) + 5.70(\text{Lat}) - 0.06(\text{Long}) = 106 = \text{April 16.}$$

Although the state-wide equations provide only rough approximations to snow accumulation dates, the coefficients in Table 2 illustrate how dates vary with elevation, latitude, and longitude within a particular state. As an example, values for the elevation coefficient (B) were used to develop the diagram of snow accumulation season versus elevation in Wyoming (Figure 3), based on the known dates near Laramie.

Table 2. Values of coefficients in the equation 0°C Date = A + B(Elev) + C(Long) + D(Lat), where elevation is in meters, for selected states. Number of stations used in analysis is shown in parentheses after state name. R^2 is the coefficient of multiple determination.

	Fall Date					Spring Date				
State	A	B	C	D	R^2	A	B	C	D	R^2
Alaska (64)	+ 784	-0.0419	- 5.35	-1.02	0.90	-391	+0.0189	+ 4.63	+1.38	0.91
Arizona (19)	+ 255	-0.0339	- 4.74	+3.01	0.40	- 46	+0.0505	+ 3.86	-1.41	0.65
California (13)	+ 652	-0.0308	- 6.36	0.00	0.37	- 2	+0.0484	- 0.57	0.00	0.85
Colorado (80)	+ 713	-0.0236	- 5.05	-1.32	0.70	-270	+0.0389	+ 7.54	-0.34	0.85
Idaho (85)	+ 521	-0.0333	- 3.37	0.00	0.82	-217	+0.0487	+ 4.95	0.00	0.88
Illinois (51)	+ 661	-0.0536	- 7.50	0.00	0.81	-341	+0.0604	+ 9.39	0.00	0.85
Indiana (49)	+ 738	-0.0607	- 9.29	0.00	0.77	-440	+0.0736	+11.68	0.00	0.84
Iowa (86)	+ 600	-0.0144	- 6.25	0.00	0.94	-242	+0.0119	+ 7.28	0.00	0.94
Kansas (54)	+ 895	-0.0138	-13.64	0.00	0.83	-466	+0.0042	+12.81	0.00	0.79
Maine (20)	+ 508	-0.0345	- 3.93	0.00	0.86	-114	+0.0331	+ 4.31	0.00	0.92
Maryland (5)	+ 589	-0.0541	-10.05	+2.42	0.80	-383	+0.0579	+14.67	-2.31	0.70
Michigan (72)	+ 494	-0.0469	- 4.04	+0.33	0.92	-104	+0.0214	+ 6.55	-1.31	0.94
Minnesota (80)	+ 452	-0.0166	- 2.86	0.00	0.90	- 78	+0.0148	+ 3.44	0.00	0.93
Missouri (38)	+ 881	-0.0012	-13.36	0.00	0.80	-501	+0.0015	+13.79	0.00	0.73
Montana (106)	+ 431	-0.0200	- 5.26	+1.45	0.40	+ 2	+0.0318	+ 7.14	-2.68	0.75
Nebraska (53)	+ 552	+0.0004	- 5.21	0.00	0.77	-290	-0.0036	+ 8.56	0.00	0.80
Nevada (34)	+ 222	-0.0057	- 6.65	+3.41	0.59	- 4	+0.0360	+ 8.24	-2.91	0.82
New England[a] (67)	+ 690	-0.0292	- 8.07	0.00	0.76	-285	+0.0313	+ 8.15	0.00	0.86
New Jersey (20)	Same as Pennsylvania					Same as Pennsylvania				
New Mexico (33)	+1073	-0.0413	- 7.43	-3.55	0.59	-615	+0.0606	+ 9.60	+1.77	0.78
New York (61)	+ 519	-0.0329	- 5.80	+0.99	0.89	-204	+0.0329	+ 7.00	-0.41	0.88
North Dakota (71)	+ 373	-0.0115	- 3.35	+1.03	0.86	+ 36	+0.0171	+ 3.81	-1.37	0.88
Ohio (52)	+ 952	-0.0572	- 9.65	-2.36	0.75	-693	+0.0511	+13.45	+2.22	0.83
Oregon (52)	+ 235	-0.0400	- 3.62	+2.61	0.63	-158	+0.0563	+ 7.67	-1.63	0.75
Pennsylvania (60)	+ 631	-0.0449	- 7.87	+0.65	0.71	-249	+0.0454	+ 9.93	-1.45	0.83
South Dakota (84)	+ 367	-0.0131	- 5.65	+2.15	0.75	+ 10	+0.0153	+ 5.42	-1.83	0.76
Utah (72)	+ 361	-0.0252	- 4.03	+1.57	0.56	-141	+0.0436	+ 7.38	-1.53	0.75
Virginia (2)	Same as Maryland					Same as Maryland				
Washington (57)	+1021	-0.0252	-11.73	-0.94	0.80	-772	+0.0408	+10.77	+2.41	0.89
West Virginia (13)	Same as Maryland					Same as Maryland				
Wisconsin (88)	+ 571	-0.0289	- 3.04	-1.16	0.90	-112	+0.0177	+ 4.52	-0.15	0.91
Wyoming (76)	+ 667	-0.0185	- 3.47	-1.55	0.64	-216	+0.0341	+ 5.70	-0.06	0.76

[a] New England states: Vermont, New Hampshire, Massachusetts, Rhode Island, and Connecticut.

According to the bioclimatic law proposed by Hopkins (1918),

> Other conditions being equal, the variation in the time of occurrence of a given periodical event in life activity in temperate North America is at the general average rate of 4 days to each 1 degree of latitude, 5 degrees of longitude and 400 feet of altitude, later northward, eastward and upward in the spring and early summer, and the reverse in late summer and autumn.

Values in Table 2 suggest that this kind of generalization may also be applicable to dates of the snow accumulation season. Elevation coefficients (B), for example, indicate a change of about 1 day per 100 feet of elevation, for both spring and fall dates, as Hopkins proposed. Latitude, however, seems to have a greater effect than suggested by the law. Effect of longitude is more likely to be determined by regional geography for areas as small as most states. To better define average trends, a general regression equation was developed for the contiguous United States, utilizing 1677 stations:

$$\text{Fall Date} = +490 - 0.02093(\text{Elev}) - 4.673(\text{Lat}) + 0.614(\text{Long}), \quad (R^2 = 0.63) \quad (3)$$
$$\text{Spring Date} = -97 + 0.02740(\text{Elev}) + 6.098(\text{Lat}) - 1.233(\text{Long}), \quad (R^2 = 0.71) \quad (4)$$

These relationships suggest the following rule for snow accumulation dates in the contiguous United States:

> Dates of the snow accumulation season vary at the average rate of 2.5 days per 100 meters of altitude, 5.5 days per degree of latitude, and 1 day per degree of longitude, earlier northward, eastward, and upward in the fall, and the reverse in the spring.

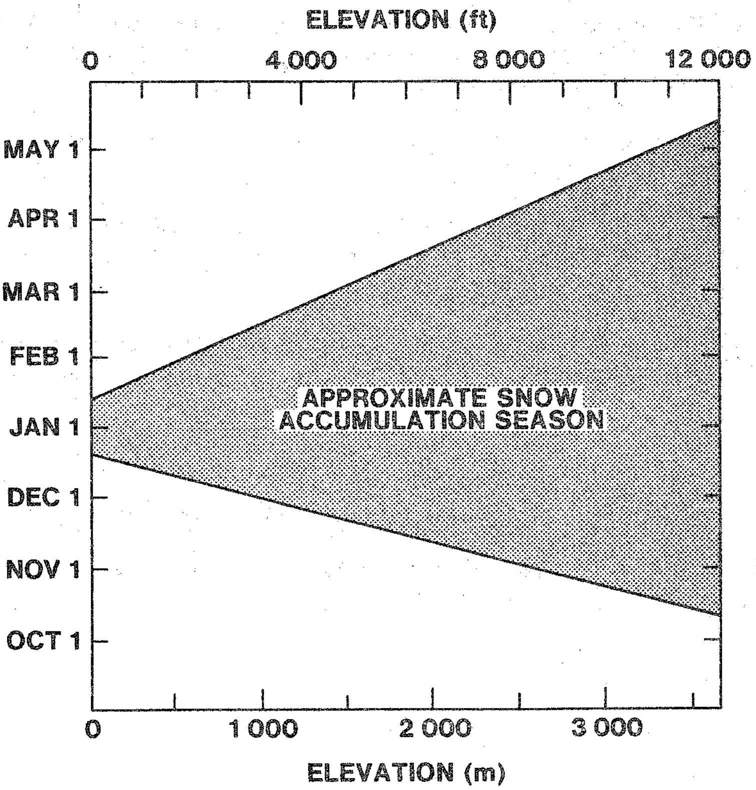

Figure 3. Diagram showing how dates of the snow accumulation season vary with elevation in Wyoming, as derived using the B coefficients in Table 2 and the known dates near Laramie, Wyoming.

ESTIMATING WINTER PRECIPITATION

Precipitation over the accumulation season can be estimated by assuming that the contributions of the first and last months are in proportion to the number of days in the month that are included in the accumulation season. As an example, consider a location having an accumulation season extending from November 11 to March 17, with the following mean monthly precipitation (in millimeters)

Nov	Dec	Jan	Feb	Mar
30	35	36	38	65

The November contribution would be (19/30)(30) = 19 mm, the March contribution would be (17/31)(65) = 36 mm, and so the best estimate for winter precipitation would be (19 + 35 + 36 + 38 + 36) = 164 mm.

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