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The Effect of Observation Time and Sampling Frequency on Mean Daily Maximum, Minimum and Average Temperature

Abstract

The use of long-term temperature data for climatic, ecohydrologic and other studies must be scrutinized carefully because of the average daily differences due to time of observation (TOB). In this study, data from three climatic stations in the Reynolds Creek Watershed in southwest Idaho were used to determine if TOB had the same effect on average daily temperature at each location and if average temperature computed from 144 observations per day was the same as average temperature computed using the traditional method. No consistent differences between sites were found; however, in the spring and fall, average daily temperatures differed by as much as 1°C between 0600 and 1600 TOB. Average temperatures from 0700 and 0800 TOB were closest to midnight observations. Average temperatures from afternoon TOB were all higher than from midnight observations. Average daily temperatures computed from 10 min interval data, ending at TOB, were as much as 0.8°C less than the average computed from daily maximum and minimum values for 0800 through 1900 TOB. For 0600 and 0700 TOB, average temperatures computed from 10 min interval data were both less than and greater than averages computed by the usual method depending on time of year. The significance of our findings is that studies which require historical temperature records and where only small changes in temperature are expected, such as climate change modeling, will be difficult to verify. Also, mean daily temperature will change at locations when several readings are used to compute mean daily temperature rather than computing mean daily temperature from the daily maximum and minimum temperatures.

Introduction

It is often necessary to know maximum, minimum and mean daily temperatures for hydrologic, natural resource, and agricultural planning and development projects. This information is used to estimate rates and amounts of snowmelt, runoff, vegetation yields, and other temperature-related watershed processes through the use of ecohydrologic models such as SPUR (Simulation of Production and Utilization of Rangelands) (Wight and Skiles 1987) and ERHYM (Ekalaka Rangeland Hydrology and Yield Model) (Wight 1987). These models use either historic or synthetically generated daily climatic data as abiotic driving variables.

Historic maximum and minimum temperature records are also used for studies such as determining how emission of CO_2 and other gases affects climate. Based on present estimates, Abrahamson (1989) suggests that at the present rate, emission of gases will raise global temperature by at least 2°C by the year 2030.

Historic maximum and minimum temperatures used for modeling or for computing parameters in climate generation subroutines come from a few first order National Weather Service stations or from numerous cooperative observers who record the maximum and minimum temperatures daily. First order stations' maximum and minimum temperatures are recorded on a midnight to midnight basis, while the cooperative observers record temperature either in the morning or afternoon and the maximum and minimum values represent the 24-hour period ending at times of observation (TOB).

Several investigators, the first of whom was Ellis (1890), showed that in England mean monthly maximum, minimum, and mean temperatures were not the same depending on the ending time of the 24-hour observation period. He found that the mean maximum and minimum temperatures were generally warmer when the 24-hour observation period ended at 9:00 a.m. rather than at midnight. Donnel (1912), Rumbaugh (1934), Baker (1975), and Schaal and Dale (1977) found that mean daily temperatures (average of the daily maximum and minimum temperatures) were higher when the 24-hour period ended in the afternoon than when the period was midnight to midnight. They also found just the opposite effect when the 24-hour period ended at 8:00 a.m. The study by Schaal and Dale (1977) in Indiana showed that daily mean temperature for March was 0.7°C higher for the daily period ending at 7:00 p.m. than at midnight and 0.7°C cooler than midnight observations when the 24-hour period ended at 7:00 a.m. This variation in mean temperature values represents 70 percent of the 2°C temperature rise projected by the year 2030 due to the greenhouse effect (Abrahamson 1989). These mean temperature differences from midnight TOB are because daily maximum temperatures generally occur in the afternoon and thus daily maximum readings occasionally represent the maximum temperatures on successive days with afternoon TOB. The opposite occurs for successive minimum temperatures when the TOB is in the morning. Edwards (1987) discusses errors due to undersampling and Karl *et al.* (1989) provides a lengthy discussion of errors that are due to type of instrumentation and location of instruments, etc. There is a need for accurate climatic data for eco-hydrologic modeling and for other investigations, such as assessment of climatic change.

The purpose of this study was: 1) to investigate the effect of TOB on maximum, minimum, and daily average temperature at three different elevations on a mountainous watershed; and 2) because of the availability of electronic recording equipment, to determine how well daily mean temperature which was calculated from hourly temperature values agree with the mean calculated from the average of the daily maximum and minimum, which is the common method of obtaining average daily temperature.

Study Area and Instrumentation

Temperature data from three locations on Reynolds Creek Watershed in southwest Idaho were used in this study. The watershed is a foothills tributary to the Snake River and is located approximately 64 km southwest of Boise, Idaho (Robins *et al.* 1965). As shown in Table 1, site elevation ranges from 1193 to 1895 m and thus represent different climatic regimes. Mean annual temperature ranges from 8.4°C at site A to 6.6°C at site C. Mean annual precipitation ranges from 233 mm at site A to 508 mm at site C for 1985-88.

At each of the sites, average hourly temperature and maximum and minimum temperatures during the hour were recorded electronically at the end of each hour. Average temperature during the hour was based on readings at 10 minute intervals during the hour. The maximum and minimum temperatures for 24-hour periods were obtained from the instantaneous 10-minute readings during the 24-hour period. Average temperatures were

TABLE 1. Average temperature, precipitation, and number of days of data for the three weather sites on Reynolds Creek Watershed, Idaho.

	Months						
Site	Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec	Annual Average
A (Elev. 1193 m)							
Average temperature (°C)	−0.84	6.01	14.57	20.16	11.36	−0.90	8.39
Average precipitation (mm) (1985-1988)	50	40	56	8	22	57	233
Average precipitation (mm) (1962-1988)	55	48	55	24	33	65	280
Number of days of temperature data	390	395	425	425	407	418	
B (Elev. 1649 m)							
Average temperature (°C)	−1.02	5.26	14.06	19.84	12.13	−0.63	8.27
Average precipitation (mm) (1985-1988)	64	60	65	13	25	65	292
Average precipitation (mm) (1962-1988)	67	66	71	27	40	78	349
Number of days of temperature data	203	228	243	248	235	243	
C (Elev. 1895 m)							
Average temperature (°C)	−1.79	3.20	11.70	17.81	10.19	−1.60	6.59
Average precipitation (mm) (1985-1988)	137	101	74	18	31	147	508
Number of days of temperature data	207	244	223	236	242	234	

computed from the maximum and minimum temperatures during the 24-hour period ending at TOB. The only temperature data used in this study were from days when all data were available during a seven-year period at site A and four-year periods at the other two sites. Temperature sensors were located in pagoda-style self-aspirating radiation shields at sites B and C and in a fan-aspirated shield at site A.

Results and Discussion

Time of Observation

The numerous different TOB used in the United States are evident from the information for Idaho which is listed in Table 2. The data in Table 2 were taken from the December 1987 climatological report (U.S. Department of Commerce 1987). Only six of the 138 climatological stations recorded maximum and minimum temperatures for the 24-hour period ending at midnight. Sixty-two stations' times of observations were during the morning between 0600 and 1000 with 46 stations having an 0800 observation time.

Sixty-nine stations had afternoon TOB between 1300 and 2100. One-half of the stations with afternoon TOB were at 1700 with most of the other observations at either 1600 or 1800. One station's TOB was at sunset.

There are at least two other TOB problems that affect Idaho data and data from other states. Idaho is divided into two time zones, Mountain and Pacific, so stations due north and south of each other with the same TOB are observed an hour apart. Also, Idaho observes daylight savings time which changes TOB of some locations, while other observers do not change the actual TOB. As discussed in the previous section, most times of observation in Idaho are on the hour either from 0600 through 0900 in the morning or 1600 through 1900 in the afternoon. Therefore, results from those hours are used in Table 3 and subsequent tables and discussions.

Average Daily Temperature Deviations

Deviations of average dailiy temperature from midnight observations from the Reynolds Creek Watershed sites are listed in Table 3. Deviations for 0600 are almost all negative and vary from close to zero for May and June to $-0.4°C$ during the fall (September-October). The negative deviations change to almost all positive deviations by the 0900 TOB. The largest deviations for 0900 observations were in May and June when the deviation was about .3°C, while the smallest deviations were during the winter. Average morning TOB temperature deviations varied from $-.22°C$ at 0600 to 0.16 at 0900, which indicates that average temperatures for hydrological and ecological studies from these two TOB will vary 0.38°C. On an annual basis, the 0600 and 0700 TOB average daily temperatures are the closest to midnight observations.

All of the deviations between midnight and the 1600 and 1900 TOB were positive. Deviations ranged from about 0.1°C during the fall for 1900 observations to about 0.9°C during May and June for 1600 observations. Afternoon time of observation temperature deviations were highest during the summer and least during the winter. Considering times of afternoon observations for all months, 1600 observation temperature deviations were

TABLE 2. Time of observation at Idaho climatological stations during 1987.

	AM Stations											
Hour	0600	0700	0800	0900	1000							Total
Number of stations	1	9	46	5	1							62
	PM Stations											
Hour	1300	1400	1500	1600	1700	1800	1900	2000	2100	2400	SS[1]	
Number of stations	1	1	0	9	35	16	4	2	1	6	1	76
												138

[1]Sunset

TABLE 3. Average daily temperature deviations (°C) from observations at midnight and the observation hour in which they occurred. Averages were computed from the maximum plus the minimum temperature divided by 2 for the 24 hour period ending at the time of observation.

Site	A (1193 m)							B (1649 m)							C (1895 m)							Average of 3 Sites
Month	Jan-Feb	Mar-Apr	May-Jun	Jun-Aug	Sep-Oct	Nov-Dec	Avg.[1]	Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec	Avg.	Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec	Avg.	
Time of Observation																						
0600	-.18	-.33	.02	-.25	-.41	-.16	-.22	-.26	-.28	-.01	-.11	-.33	-.15	-.19	-.14	-.35	-.18	-.18	-.40	-.17	-.24	-.22
0700	-.17	-.08	.26	.11	-.28	.19	-.06	-.27	-.11	.21	.16	-.25	-.16	-.07	-.13	-.24	.12	.14	-.37	-.15	-.11	-.08
0800	-.14	.16	.29	.15	.09	-.13	.07	-.20	.13	.30	.20	.03	-.13	.05	-.09	.03	.26	.25	-.06	-.12	.05	.06
0900	.12	.23	.30	.15	.16	.13	.18	-.05	.23	.37	.20	.15	-.01	.15	.02	.22	.38	.29	10	-.05	.16	.16
1600	.64	.73	.87	.60	.58	.41	.64	.30	.77	.91	.65	.49	.27	.57	.52	.76	.95	.75	.45	.35	.63	.61
1700	.51	.60	.72	.45	.39	.28	.49	.25	.67	.81	.53	.34	.21	.47	.46	.65	.84	.65	.29	.27	.53	.50
1800	.42	.47	.59	.31	.23	.20	.37	.21	.54	.63	.37	.19	.14	.35	.39	.50	.65	.49	.16	.21	.40	.37
1900	.38	.38	.44	.21	.11	.12	.27	.18	.43	.49	26	.12	.10	.26	.35	.40	.49	.37	.09	.15	.31	.28

[1]None of the annual average deviations, by time of observation, between sites was significantly different at the 0.05 level of probability.

greatest (0.61 °C) and temperature deviations from 1900 observations were the least (0.28°C).

Average temperature deviations from afternoon observations were greater than from morning observations, which indicates that for climatic studies it is preferable to use data from stations where temperature is observed in the morning. The largest temperature deviation difference, between 0600 and 1600 TOB, was 1.07°C for March and April, which is about half of the projected world temperature increase by the year 2030 (Abrahamson 1989).

Effect of Elevation on Average Daily Temperature Deviations

One of the objectives of this study was to determine if average temperature deviations were affected by location (elevation) on the watershed. Location is of interest because, in mountainous areas, climatological data from valley sites are often adjusted to represent other areas that are at higher elevations. As seen in Table 3, there were no significant average temperature deviation differences between sites for any of TOB's. Because the average daily temperature deviations were not significantly different among sites, only data from site B were used in the following discussion and in Tables 4 and 5.

Average Daily Maximum Temperature Deviations from Midnight Observations

Average daily maximum temperature deviations were all zero or negative for morning times of observation. For each bimonthly period, temperature

TABLE 4. Average daily maximum and minimum temperature deviations (°C) from observations at midnight and 24 hour period ending at the time of observation, site B.

	Maximum Daily Temperature							Minimum Daily Temperature						
Month	J-F	M-A	M-J	J-A	S-O	N-D	Avg.	J-F	M-A	M-J	J-A	S-O	N-D	Avg.
Time of Observation														
0600	−.22	−.11	−.06	−.01	−.09	−.06	−.09	−.30	−.45	.04	−.21	−.58	−.24	−.29
0700	−.22	−.11	−.06	−.01	−.09	−.08	−.09	−.31	−.11	.48	.32	−.41	−.25	−.05
0800	−.20	−.10	−.05	−.01	−.10	−.07	−.09	−.20	.36	.65	.40	.15	−.19	.19
0900	−.13	−.07	.00	.00	−.04	−.04	−.05	.03	.54	.75	.41	.35	.02	.35
1600	.36	1.03	1.07	.95	.69	.28	.73	.25	.51	.76	.35	.29	.27	.41
1700	.26	.83	.89	.73	.40	.18	.55	.24	.50	.72	.33	.28	.24	.39
1800	.21	.60	.62	.43	.12	.11	.35	.20	.49	.63	.32	.26	.17	.35
1900	.21	.44	.41	.22	.01	.06	.23	.15	.43	.57	.30	.23	.14	.30

TABLE 5. Average daily temperature deviations (°C) based on the difference between the average of the maximum and minimum temperatures and the average of 144 observations during the 24 hour period ending at the time of observation, site B (1649 m).

Month	Jan-Feb	Mar-Apr	May-Jun	Jul-Aug	Sep-Oct	Nov-Dec	Average
Time of Observation							
0600	−.14	.26	.03	.10	.20	−.06	.07
0700	−.12	.10	−.18	−.16	.11	−.05	−.05
0800	−.19	−.14	−.26	−.20	−.17	−.09	−.17
0900	−.32	−.25	−.33	−.22	−.31	−.21	−.27
1600	−.65	−.76	−.81	−.68	−.70	−.55	−.69
1700	−.60	−.65	−.69	−.55	−.57	−.49	−.59
1800	−.54	−.53	−.50	−.40	−.42	−.42	−.47
1900	−.51	−.41	−.35	−.29	−.37	−.39	−.39
2400	−.42	−.02	−.03	.00	−.10	−.18	−.13

deviations were about the same for 0600, 0700, and 0800 TOB; however, deviations during the winter were more negative than during the summer. Summer average maximum deviations were very small or zero for the four morning TOB. The 0900 TOB most nearly represented midnight observations of average daily maximum temperature.

Average daily maximum temperatures for the four afternoon times of observation were all higher than midnight observations. The 1600 temperature deviations were up to 1.07°C for May-June. The smallest deviations were from 1900 observations; however, they were as high as +0.44°C for March and April. These results show that morning observations of average daily maximum temperature represent midnight observations closer than afternoon TOB.

One of the problems of using temperature data for long-term climatic studies has been consistent TOB throughout the record (Schaal and Dale 1977). Data from this study indicate that changing TOB between 0600 and 1600 can change the average maximum temperature by 1.1°C during the period, March through June.

Average Daily Minimum Temperature Deviations from Midnight Observations

Morning, average daily minimum temperature deviations vary from mostly negative at 0600 to all positive at 0900. Average minimum temperaures varied almost 1°C between 0600 and 0900 times of observation during the spring and fall. These variations are about the same as observed for morning and afternoon variations for average daily maximum temperatures. On an annual basis, the 0700 TOB represented midnight observations more closely (−0.05°C) than any other TOB; however, during the year, deviations varied from 0.48°C for May and June to −0.41°C for September and October.

Afternoon average daily minimum temperature deviations were all positive and on an annual basis only varied between 0.30°C at 1900 to 0.41°C for 1600 TOB. Average minimum temperature deviations during May and June were highest (0.67°C) and lowest (0.21°C) during the November through February period.

Effect of Sampling Frequency on Average Daily Temperature

The information presented in Table 5 was obtained by subtracting the average temperature based on the maximum and minimum temperature during the 24 hr period ending at TOB from the average of 10 min observations (144 observations/day) during the same time period. These analyses were done to determine how average daily temperatures recorded electronically, the method used presently in most scientific studies, compare with average daily temperatures obtained by the more conventional method of averaging the daily maximum and minimum temperatures for a given TOB.

Most of the deviations for all TOB, except 0600 and 0700, were negative, therefore average daily temperature computed from 10 min data will be cooler than average daily temperatures computed from the average of the daily maximum and minimum temperature. This condition was most pronounced for afternoon TOB where, on an annual basis, the 10 min average temperature was 0.69°C cooler than that from maximum and minimum temperatures for the 1600 time of observation.

Average annual deviations were the least for 0600 and 0700 TOB observation when there were both positive and negative deviations. For 0600 TOB, deviations were negative during the winter and positive the remainder of the year, and were not more than .25°C for any bimonthly period. There were two bimonthly periods, March-April and September-October, at the 0700 TOB, when temperature deviations were positive and temperature deviations were negative for all other TOB.

For three of the bimonthly periods, March-August, inclusive, midnight observation temperature deviations were zero or nearly zero. Temperature deviation for the November-December period was −0.18°C which were temperature deviations in the same range as those for morning TOB. The average temperature deviation was −0.13°C which was one of the smallest values but a greater temperature deviation than that of 0600 and 0700 TOB.

There are two reasons why average daily temperatures computed from 10 min records are less than the average computed from daily maximum and minimum temperatures (Table 5). The first reason is that, in general, the number of hours during a day with warm temperatures is less than the number of hours with cool temperatures in the environment on Reynolds Creek Watershed. Secondly, the higher average daily temperatures computed from daily maximum, and minimum temperatures are more pronounced for afternoon times of observation. This is because maximum readings often fall on or about the time of observation and thus maximum values for successive days were obtained from the same afternoon and could have been the same temperature if the maximum temperature occurred at the TOB.

The average daily temperature computed from 10 min observations was higher than the average based on daily maximum and minimum temperatures for most of the 0600 TOB, and the 0700 TOB during the spring and fall (Table 5). This is because 0600 and 0700 hours are at the time of minimum daily temperature and thus minimum values for successive days actually were obtained from the same morning. This winter minimum temperature effect was greater than that from more hours of minimum temperatures during most days as discussed above.

Conclusions

Analyses of temperature data from three climatic stations in the Reynolds Creek Watershed in southwestern Idaho show the following:

1. Average daily temperature during the March-April period differed by as much as 1°C between 0600 and 1600 TOB when average temperature was computed as the average of the maximum and minimum temperatures between observations.
2. On an annual basis, average daily temperatures from 0700 and 0800 observations were within 0.08°C of midnight observations; 0600 observations were 0.22°C less than midnight observations; and afternoon times of observation temperatures were greater than those computed from midnight observations by as much as 0.61°C for observations at 1600.
3. May-June temperature deviations of about 0.9°C for 1600 TOB were the greatest differences from midnight observations.
4. Average daily temperatures computed from 0800 TOB were the closest to midnight observations for most bimonthly periods and on an annual basis.
5. Average daily maximum temperature computed from morning TOB were within −.09°C of midnight observations but were as much as .22°C cooler for the months of January-February.
6. Average daily minimum temperature computed from afternoon TOB were all higher than from midnight observations and were as high as .76°C for the 1600 TOB during the May-August period. The average deviations varied from .21°C during January and February to .67°C for the May-June period.
7. In general, average daily temperatures computed from numerous observations during a 24-hr period were lower than the daily averages computed from the daily maximum and minimum temperatures. This difference is greatest for 1600 TOB and least for 0600 and 0700 TOB.

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