PERSISTENCE OF WARM WEATHER AT DENVER, COLORADO

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ABSTRACT

A 40-year record of maximum temperatures at Denver is examined to identify sequences of days which show a maximum temperature 10° F. or more above the normal. The actual persistence of a warm-weather regime is compared with that on chance, on an annual basis, and also during particular seasons in which comparable magnitudes of persistence might be expected. The skill scores of persistence forecasts for "tomorrow" and "tomorrow and the day after tomorrow" continuing a warm spell are computed for November–March and September–October regimes.

1. INTRODUCTION

The location of Denver in the rain shadow of the Continental Divide and in an area favorable for chinooks [1], while at the same time high enough to escape many of the polar outbreaks which sweep southward over the Great Plains, is reflected in the length of periods of warm weather. Warm weather spells are closely tied to the persistence of the Great Basin High which prevents influxes of Pacific air from reaching Denver with major force, and they counteract outbreaks of polar air over the Plains [2]. The purpose of this study is to determine the relative importance of the factor of persistence in the length of warm spells at Denver.

2. PROCEDURE

For the purpose of this study, a "warm" day was arbitrarily defined as one on which the maximum temperature reached a value 10° F. or more above normal for that day of the year. A 40-year record (1911–1950) of maximum temperatures was examined. Daily normal maxima were derived from smoothed curves of monthly normal maxima and each day of record was compared with the normal.

Table 1 shows the totals of runs of consecutive warm days for the period of record. Each run was assigned to the month in which the greatest number of warm days in the run fell; if the run was equally divided between two months it was assigned to the month in which the run started. The total number of days in the study was 14,610, of which 2,880 were warm days, as defined above.

Brooks and Carruthers [3] give the following formula for computing the number of runs of different lengths expected in a series in which there is no persistence: $f(N, p, q, r) = Nqp^r$, where N is the total number of days considered, p is the probability of occurrence of a type under consideration in a unit period, q is the probability of non-occurrence $(1-p)$, and r is the length of the unbroken sequence of occurrences. In table 1

$$p = 2880/14610 = .197,\ q = .803,\ N = 14610,$$

and r takes on the successive values 1, 2, 3, . . . 12.

It was recognized that the variation of the weather with the seasons would give differing persistencies, so a division was made into comparable weather regimes. During the late spring and summer, when temperatures are relatively high and thunderstorm activity is a potent factor in keeping maximum temperatures down, the incidence of warm days (as defined in this study) may be expected to be small, and this is borne out by the data in table 1. This also corresponds to the persistence variation noted by Blair [4] for Lincoln, Nebr. In late fall, winter, and early spring there are low average temperatures and a rapid rate of movement of pressure

TABLE 1.—*Number of warm-weather sequences of various lengths by months, totals of those sequences both separately and cumulatively from longest to shortest, and number of those runs expected on chance (Brooks and Carruthers [3]). Data for the years 1911–1950.*

	FULL YEAR—LENGTH OF WARM PERIOD IN DAYS											
	1	2	3	4	5	6	7	8	9	10	11	12
January	64	44	14	4	8	4	2	1			1	1
February	59	30	18	12	4	3	1	1	1			
March	64	31	25	10	8	4	2					
April	57	43	26	13	5	1	1					
May	62	32	14	5	3							
June	66	18	7	3	3	1						
July	26	8	6	2	1							
August	27	11	4	1								
September	54	22	16	5		1			1			
October	68	43	10	10	4	3	4	1	1		1	
November	55	37	25	13	6	4					1	
December	65	30	10	9	7	5	3	2	2	2		
Total	667	349	175	87	49	26	13	5	5	2	3	1
Chance frequency expectation	2,311	455	90	18	3.5	0.68	0.14	0.03	0.01	<0.01	<0.01	<0.01
Cumulative total (reverse)	1,382	715	366	191	104	55	29	16	11	6	4	1

Total days in the 40-year period: 14,610.
Total days of maximum temperature 10° F. or more above normal: 2,880.
Probability of random occurrence of such a day: 0.197.

TABLE 2.—*Totals, both separately and cumulatively from longest to shortest, of sequences of various lengths for warm-weather days for the period NOVEMBER-MARCH, and number of those runs expected on chance (Brooks and Carruthers [3]). Data for the years 1911–1950.*

	NOVEMBER-DECEMBER-JANUARY-FEBRUARY-MARCH—LENGTH OF WARM PERIOD IN DAYS											
	1	2	3	4	5	6	7	8	9	10	11	12
Total	307	172	92	48	33	20	8	4	3	2	2	1
Chance frequency expectation	1,164	303	79	20	5.3	1.4	0.36	0.01	<0.01	<0.01	<0.01	<0.01
Cumulative total (reverse)	692	385	213	121	73	40	20	12	8	5	3	1

Total days in the 40-year period: 6,050.
Total days of maximum temperature 10° F. or more above normal: 1,573.
Probability of random occurrence of such a day: 0.260.

TABLE 3.—*Totals, both separately and cumulatively from longest to shortest, of sequences of various lengths for warm-weather days for the period SEPTEMBER-OCTOBER, and number of those runs expected on chance (Brooks and Carruthers [3]). Data for the years 1911–1950.*

	SEPTEMBER-OCTOBER—LENGTH OF WARM PERIOD IN DAYS										
	1	2	3	4	5	6	7	8	9	10	11
Total	122	65	26	15	4	4	4	1	2	-------	1
Chance frequency expectation	398	81	17	3.4	0.70	0.14	0.03	0.01	<0.01	<0.01	<0.01
Cumulative total (reverse)	244	122	57	31	16	12	8	4	3	1	1

Total days in the 40-year period: 2,440.
Total days of maximum temperature 10° F. or more above normal: 499.
Probability of random occurrence of such a day: 0.204 or approximately 1/5.

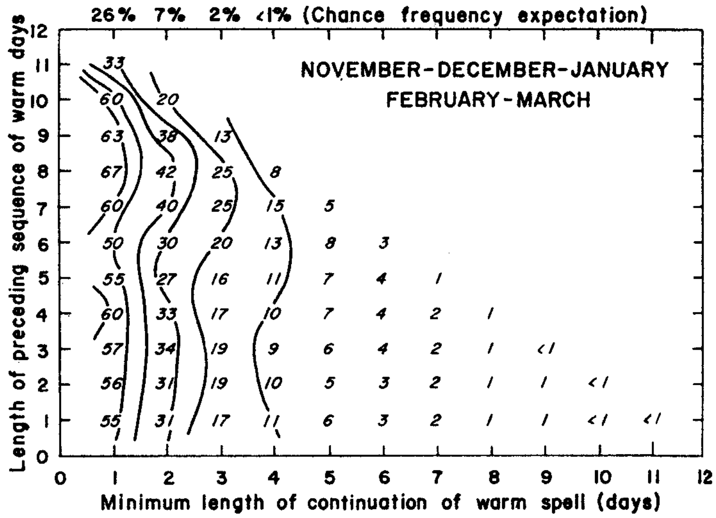

FIGURE 1.—Percent of time a given sequence of warm days was followed by at least 1, at least 2, etc., successive warm days. Isolines are drawn at 10 percent intervals. Data for period November–March, 1911–1950.

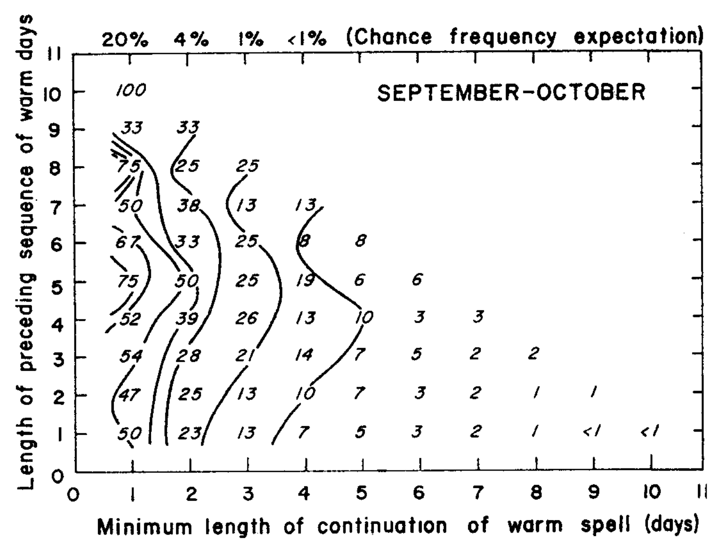

FIGURE 2.—Percent of time a given sequence of warm days was followed by at least 1, at least 2, etc., successive warm days. Isolines are drawn at 10 percent intervals. Data for period September–October, 1911–1950.

systems, while in the early fall the weather is generally fair with occasional storms. Tables 2 and 3 give data derived by separating the two weather regimes just mentioned.

Figures 1 and 2 indicate the percentage of occurrence of various lengths of sequences of warm days following warm spells of different lengths, for the November-March and September-October seasons respectively. The percentages at the tops of the figures indicate those expected on mere chance. The percentages in the bodies of the figures are derived from the "cumulative totals" in tables 2 and 3. For example, taking data from table 2, of the 121 warm spells which lasted for at least 4 days 20, or 17 percent, went on to at least the seventh day, or 3 more days. It will be noted that in figure 1 there is a maximum percentage of persistence expectance of at least one more day of warm weather after a preceding spell of 8 warm days, with a second maximum after 4 days, and there is a bias of maximum expectancies downward and to the right, emphasizing a tendency toward warm periods of about 5 to 6 or of 9 to 10 days duration. In figure 2 it is seen that the maximum persistence percentage for one more warm day is after the fifth or the eighth day, and there is again a bias downward and to the right indicating a tendency toward warm periods of 6 to 7 or of about 9 days duration. While there were only 4 cases of 8-day spells of "warm" weather during September and October for the 40-year period, 3 out of the 4 did extend for at least 1 more day.

Figures 3 and 4 indicate the percent of the time that "tomorrow" should be warm following sequences of warm periods of increasing lengths, on a persistence basis alone, that is, the percent due to pure chance has been eliminated. For example, we note in figure 1 that while an initial day of warm weather was followed 55 percent of the time by at least 1 more warm day, the random chance expectancy of such an occurrence (as given at the top of the table) is 26 percent, the remaining 29 percent being the percent

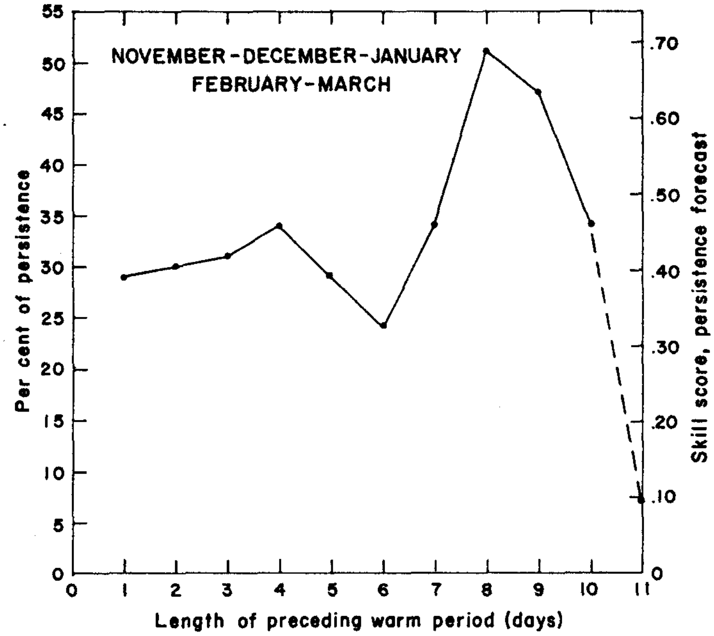

FIGURE 3.—Percent of time that "tomorrow's" weather will be warm following a warm period of given length, according to persistence factor alone, and the skill score to be expected on a persistence forecast. Based on November–March data, 1911–1950. Trend indicated by dashed line is considered to be based on too few cases to be of meteorological significance.

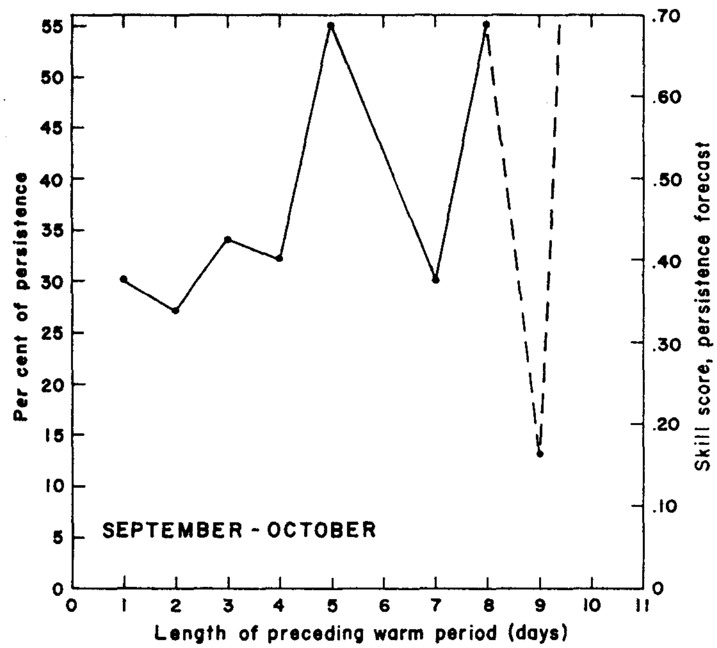

FIGURE 4.—Percent of time that "tomorrow's" weather will be warm following a warm period of given length, according to persistence factor alone, and the skill score to be expected on a persistence forecast. Based on September–October data, 1911–1950. Trend indicated by dashed line is considered to be based on too few cases to be of meteorological significance.

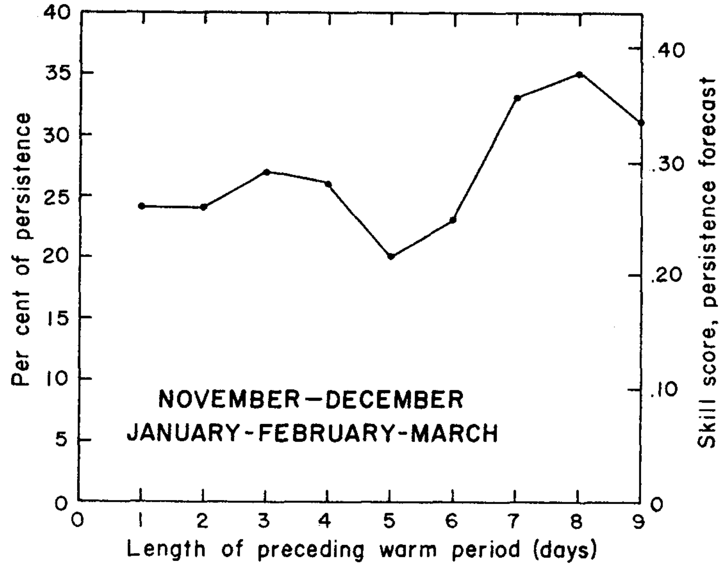

FIGURE 5.—Percent of time that "tomorrow and day after tomorrow" will be warm following a warm period of given length, according to persistence factor alone, and the skill score to be expected on a persistence forecast. Based on November–March data, 1911–1950.

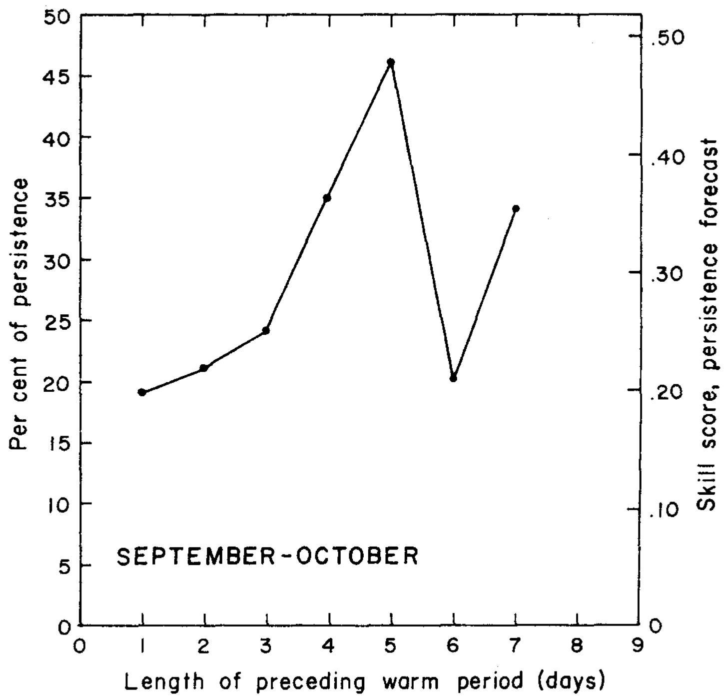

FIGURE 6.—Percent of time that "tomorrow and day after tomorrow" will be warm following a warm period of a given length, according to persistence factor alone, and the skill score to be expected on a persistence forecast. Based on September–October data, 1911–1950.

to be ascribed solely to the persistence effect in figure 3. It is seen that the persistence in the November-March season is highest after a warm spell of 8 days with another peak for a warm day following a sequence of 4 warm days. In September and October the maximum expectancy of persistence is found after the fifth and eighth days, disregarding the one case of a 10-day spell of warm weather which went on to 11 before breaking.

Figures 5 and 6 indicate the percent of time that a warm spell should continue through "day after tomorrow" following sequences of warm periods of increasing lengths, on a persistence basis alone. It is seen that the persistence in the November-March season is highest after a warm spell of 8 days with another peak for 2 warm days following a sequence of 3 warm days. In September and October the maximum expectancy of persistence for at least 2 more days is found after the fifth warm day.

Jorgensen [5] has shown in his study of rain and no-rain periods during the winter at San Francisco that the skill score of a persistency forecast may be obtained by multiplying the percentage of persistency by a common factor. The skill score is given by $S_c=\frac{C-E_c}{T-E_c}$, where C is the number of correct forecasts, T the total number of forecasts, and E_c the number which would be expected correct on a chance basis alone. If persistence is expressed as a percentage P which may be expected to be correct solely due to persistence, we may say $PT=C-E_c$. From figures 1 and 2 we note that E_c takes on the values $.26T$ and $.20T$ respectively for the case of at least one more day of warm weather, hence the values of $T-E_c$ become $.74T$ and $.80T$, respectively. Substituting in the equation for S_c, for the November-March data we get $S_c=\frac{P}{.74}$, and for the September-October data $S_c=\frac{P}{.80}$. Similar reasoning may be applied to the skill score of a persistency forecast for "tomorrow and day after," and the skill scores may be referred to the same graph (with a suitable change in the vertical scale) as the persistence in figures 3, 4, 5, and 6.

3. CONCLUSIONS

1. There is a tendency, especially during the colder portions of the year, for the weather at Denver to remain in a warm regime longer than mere chance would indicate. This tendency to persist seems to favor especially certain lengths of periods of warm weather.

2. Persistence may be assumed to be a meteorological factor inasmuch as it may be a combination of many weighted factors, some of them so obscure as to escape the forecaster's notice.

3. The skill scores for forecasts based upon persistence of warm weather indicate that the forecaster must have a high confidence factor if he is to differ with and verify in excess of a forecast based upon such persistence.

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