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SNOW COVER VARIABILITY ON THE NORTHERN AND CENTRAL GREAT PLAINS

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Abstract: *Winter snow cover duration has varied across the northern and central Great Plains of the United States throughout this century. Decade-to-decade variability has been common, and the timing of these fluctuations has differed considerably across the region. A general trend towards longer snow cover duration was noted from the 1920s and 1930s to the 1970s. Nine stations with continuous records of snow cover, temperature, precipitation, and snowfall dating back 61 to 97 years were studied. Snow cover fluctuations and trends are associated with changes of these other variables. Such relationships are complex and differ across the Great Plains. Correlations between winter snow cover duration and mean maximum temperature are negative in all areas, and are strongest in Nebraska, South Dakota, and southeastern Montana, where snow cover is most variable. Precipitation is correlated positively with snow cover duration in most of the region, although statistically less significant than for temperature. In the future, should the winter climate of the Great Plains deviate from what has been observed this century, it is reasonable to assume that the duration of snow cover will change significantly. Snow cover should play a role in dictating the nature of any such changes, and should also serve as a credible indicator of future winter climate change in this region.*

Across middle and high latitude lands of the Northern Hemisphere the impact of snow on humans and the environment is considerable. Falling snow or snow lying on the ground influences hydrologic, biologic, chemical, and geologic processes at and near the surface of the earth. It exerts an impact on activities as diverse as engineering, agriculture, travel, recreation, commerce, and safety. Empirical and modeling studies also show snow cover to have an influential role within the climate system (Berry 1981; Walsh et al. 1985; Kukla et al. 1986; Barnett et al. 1989). Global models of anthropogenically-induced climate change suggest enhanced warming in regions where snow cover is currently ephemeral (Manabe and Wetherald 1980; Hansen et al. 1984; Dickinson et al. 1987). For this reason, snow cover has been suggested as a useful index for monitoring global climate change (Barry 1985; Schlesinger 1986). Regional and hemispheric snow cover is also relatively simple to map by satellite.

Long records of snow cover are necessary for a full understanding of its role in climate dynamics and climate change. Satellite-derived data are available for only the last two decades, making a long-term assessment of natural snow cover variability impossible and studies regarding the interaction of snow cover with other climate variables suspect. Investigations such as these must therefore rely on lengthy historical station data.

The Great Plains is an excellent location for examining the role of snow cover in the climate system, particularly the northern and central portions of the region. Snow cover generally persists here from several weeks to months each winter and exhibits considerable year-to-year variability. Previous empirical studies have shown the influence of snow cover on short-term climate dynamics in the Great Plains (e.g., Dewey 1977; Namias 1984), while climate models suggest that the interior of continents will be most affected by greenhouse-enhanced climate changes.

Long climate records are available for a number of stations in the Great Plains. Previous studies using these data concentrated on temperature, precipitation, and drought, finding considerable spatial and temporal variability (e.g., Mattice 1934; Borchert 1971; Skaggs 1978; Warrick 1980; Balling and Lawson 1982; Karl and Koscielny 1982; McGregor 1987). While snow cover also exhibits these characteristics, to date, studies utilizing long snow records (more than 50 years) do not exist for the Great Plains. Studies of other regions have been few in number and conducted on a much more local scale (Arakawa 1957; Uttinger 1963; Manley 1969; Lamb 1969; Pfister 1978, 1985). For this study, we utilize long-term historical climate data for nine stations distributed throughout the northern and central Great Plains to examine winter snow cover and potential correlations of cover with records of precipitation, snowfall, and maximum and minimum temperature. This study addresses the following questions: How has the duration of winter snow cover varied across the central and northern Plains this century? Has the duration of winter snow cover changed significantly from the beginning of the century to recent decades? Are the identified variations or changes associated with temperature, precipitation, or snowfall fluctuations? Results will provide another means of assessing the variability of climate in this region. They will also determine the role snow cover may play in future climate change on the Great Plains, and whether snow cover is a credible indicator of such change.

Short-term Impacts of Snow Cover

The distribution of snow cover on the Great Plains influences local

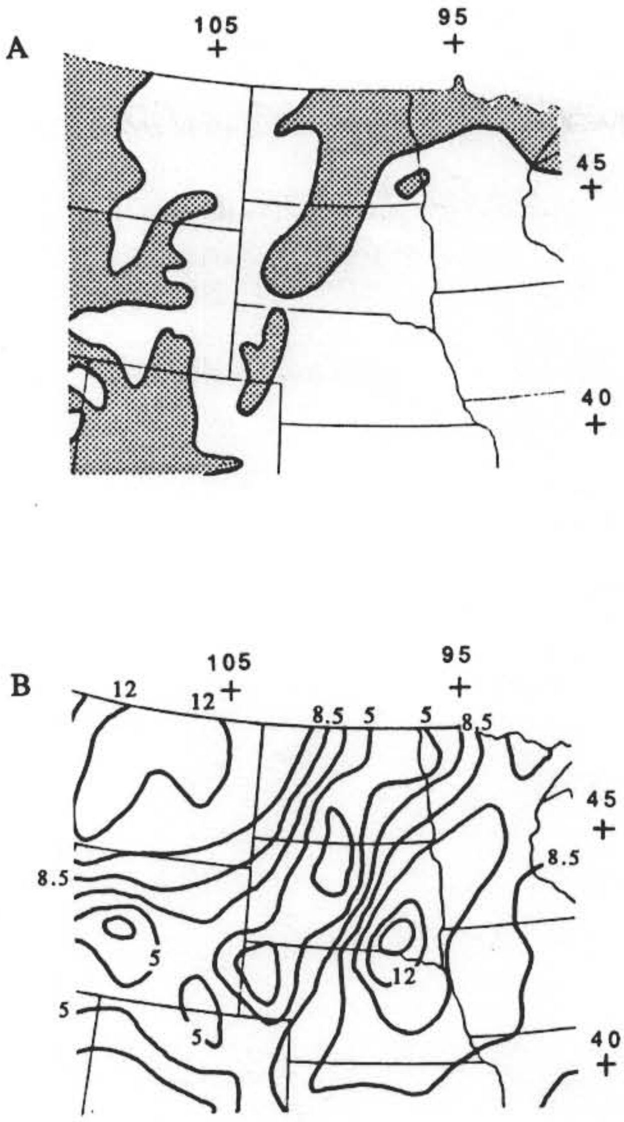

Figure 1. (a) Snow cover (stippled) over the north-central United States on 3-4 March 1987, mapped from visible satellite imagery (from NOAA Northern Hemisphere Snow and Ice Boundaries charts). (B) Temperature departures (°C) for the period 1-7 March 1987 over the same region (from NOAA *Weekly Weather and Crop Bulletin*).

and regional winds and clouds, and may influence atmospheric circulation, including the location and trajectory of cyclone paths traversing the region (Namias 1962, 1984; Walsh et al. 1981; Heim and Dewey 1984; Johnson et al. 1984). On a time scale of several days to a week, Great Plains snow cover has a significant influence on surface air temperatures (Dewey 1977; Kukla 1978). When under the same atmospheric circulation regime, snow-covered regions experience colder temperatures than adjacent snow-free areas. For example, in the first week of March 1987, a 700 mb ridge over the northern and central Great Plains contributed to above normal temperatures throughout the region (Fig. 1). However, in the area from western Nebraska to eastern North Dakota where the ground remained snow covered throughout the week, positive departures were considerably less pronounced than in nearby snow-free areas.

The cooling associated with snow cover is a function of its high surface albedo, low water vapor pressure, high thermal emissivity, and low heat conductivity. Surface albedo over the Great Plains is close to 0.80 under a fresh snow cover of at least 15 cm (6 in; Robinson and Kukla 1985), compared to winter snow-free values of 0.15 (Kung et al. 1964). Thus, when snow cover is present the amount of solar energy available for surface heating is reduced and much of the available heat goes to warming and melting the snow pack. At night, with a dry atmosphere present, the high emissivity of the snow permits surface heat reserves to escape to space, further enhancing the cooling.

Station Climate Data

The climate records for the nine stations used in this study (Table 1, Fig. 2) were selected from a new set of historical daily climate data (Robinson 1988; 1989). This set contains digitized records of snow cover, snowfall, precipitation, and maximum and minimum temperature for 360 United States cooperative observing stations dating from the late nineteenth century, and for 650 stations dating from about 1930. Records, which extend through 1987, were carefully evaluated for inconsistencies and errors. The selected stations are well distributed throughout the northern and central Great Plains and have among the longest and most complete records of the five variables in the region. Station histories show few changes in station location or observing practices. Snow cover data were extended through the 1989/90 winter for these nine stations.

For each winter (December, January, and February) of record for each of the nine stations, the number of days with no snow cover, with 2.5-5.1 cm (1-2 in) of cover, and with at least 7.6 cm (3 in) of cover, total snowfall and precipitation, and mean maximum and minimum temperatures were computed from the daily data. The resultant winter time series

TABLE 1

PRIMARY STATIONS USED IN THIS STUDY
Number of days with ≥7.5cm snow cover[a]

Station	Date	Mean	Std.Dev.	Max.
Crosby, ND	1919	50	28	91
Napoleon,ND	1902	56	27	91
Miles City, MT	1894	36	27	90
Dupree, SD	1924	34	27	90
Gann Valley, SD	1930	27	27	91
Oshkosh,NE	1915	15	15	57
Fairbury, NE	1904	21	15	68
Healy, KS	1903	12	12	52
Independence, KS	1903	5	7	34

[a] Statistics for 1929/30 to 1989/90.

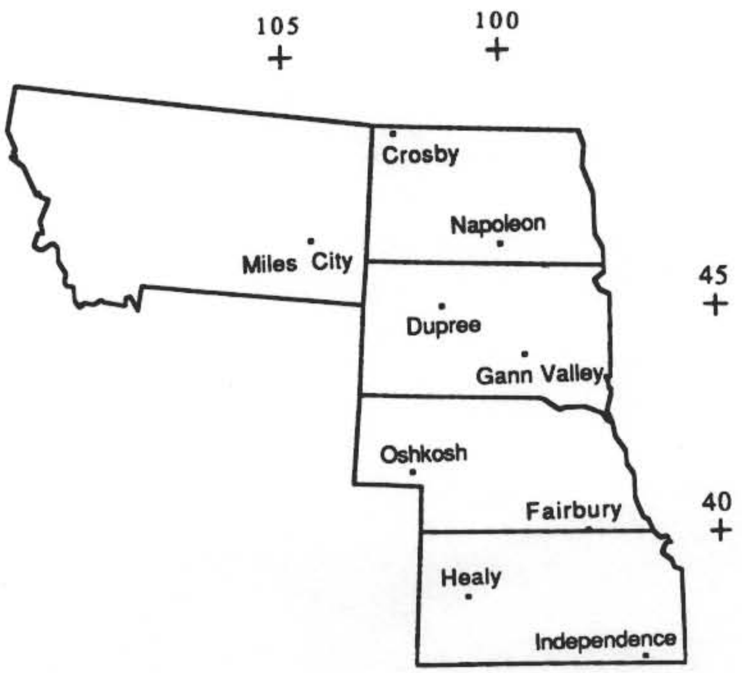

Figure 2. Stations employed in this study.

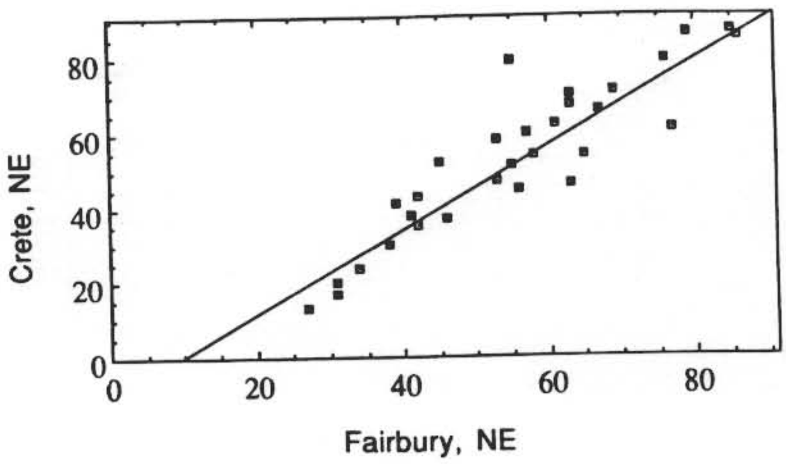

Figure 3. Comparison of the number of winter days without snow cover (at least 2.5 cm) at Fairbury and Crete, NE, for the 30 years when records were complete at both stations. Crete is approximately 60 km north-northeast of Fairbury.

were smoothed using a nine-point binomial filter to average out the year-to-year fluctuations and to facilitate the recognition of potential longer-term variations. Between 2% (precipitation) and 8% (snow cover) of the winter data from the nine stations were missing. Absent values were filled by direct substitution with data from neighboring stations situated within an 80 km radius of the primary station. Some variability in the duration of snow cover amongst neighboring stations exists due to differences in snowfall totals (a common occurrence on the Great Plains, even over 80 km) and measurement practices, however these differences are commonly less than one week (Fig. 3).

Great Plains Snow Cover

At depths of 7.6 cm or more, the impact of snow on surface albedo becomes significant, as the areal coverage of snow tends to be complete and the underlying surface has little influence on albedo. Measurements of shallower snow cover are more observer- dependent, due to the frequently patchy nature of such covers (Robinson 1988), and are not included in this study. Based on the 61-year period (1930-1990), the average duration of snow cover of at least 7.6 cm at sites in North Dakota is between seven and eight weeks (Table 1). In South Dakota and southeastern Montana, the average decreases to between four and five weeks. Further south, snow cover averages from two to three weeks in Nebraska and from almost one week to two weeks in Kansas.

Standard deviations of cover duration show the considerable year-to-year variability in the duration of snow cover at each station. The five northernmost stations had standard deviations of 27 or 28 days, the Nebraska stations 15 days and the Kansas stations from 7 to 12 days. Snow cover duration (Fig. 4) illustrates the year-to-year variability. For example, since 1930 there have been at least two winters at each station where snow cover failed to reach a depth of 7.6 cm. Conversely, the five northernmost stations had at least two winters since 1930 where each day had a snow cover of at least 7.6 cm. In Nebraska, maxima of 57 days at Oshkosh and 68 days at Fairbury were observed. In Kansas, the maximum number of days with at least 7.6 cm of cover was 34 at Independence and 52 days at Healy.

There were few winters where extremes in snow cover duration occurred at every site. Exceptions since 1930 include 1949, 1956, 1978, and 1979, when the duration of cover was above normal at all stations and, in most cases, in the top 20% of all years. In 1931, 1935, 1957, and 1981, snow cover duration was below normal for at least seven of the stations and in the lower 20% at most of these. Prior to 1930, the available station observations suggest that 1912 and 1919 had extensive regional snow cover, while in 1923 and 1928 stations reported little snow cover. Anomalously lengthy or brief durations of snow cover are more commonly subregional in nature. For instance, in 1940, snow cover duration was the longest on record at Fairbury, NE and the second longest at Healy, KS, while in the lowest 25% of years at both South Dakota stations. In 1965, at least 7.6 cm of snow was on the ground for at least 78 winter days at the four northern-most stations while the duration of cover was several days to two weeks less than average at the other stations.

The lack of coherency in the snow duration signature across the northern and central Great Plains in many years may be a function of three factors. An individual snowfall event may lay down a band of heavy snow across a portion of the region and miss other areas. A persistent atmospheric pattern over North America may direct storms across a portion of the Great Plains and leave other areas untouched. A circulation pattern may direct cold air into the northern Great Plains, leaving the central region in a warmer regime.

Fluctuations of snow cover duration on the order of a decade in length are apparent in decadal averages for each station (Table 2). Mean decadal durations differ by three to four weeks at the four northernmost

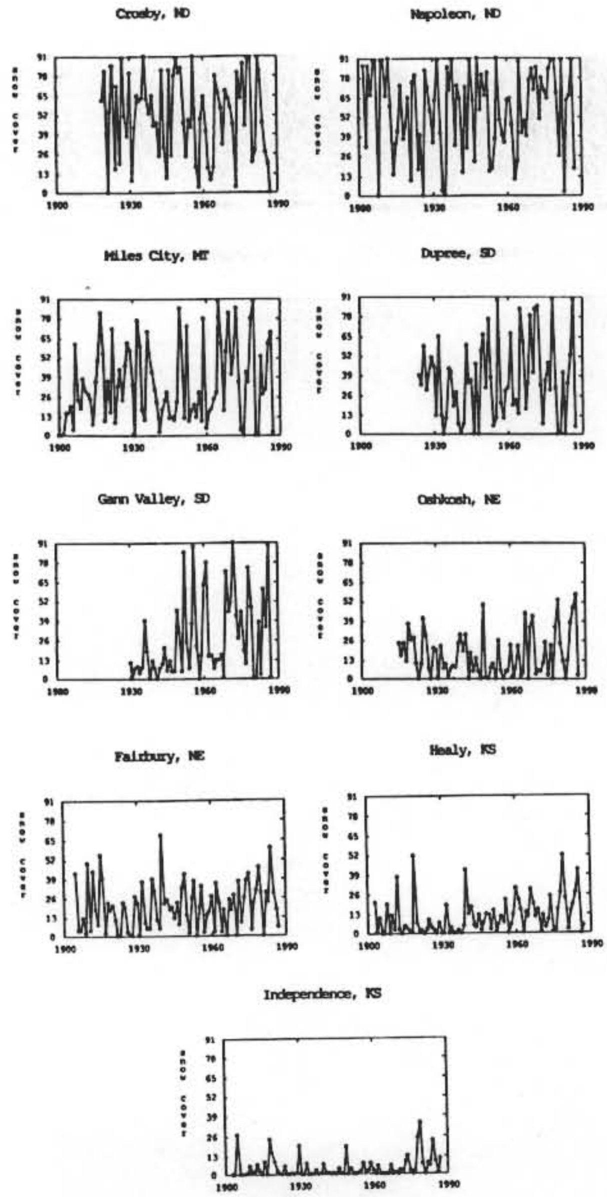

Figure 4. Time series of winter days with at least 7.6 cm of snow cover at each study station. Totals are plotted from the beginning of record through the winter of 1986/87, except only from the winter of 1899/90 at Miles City, MT.

TABLE 2

MEAN NUMBER OF DAYS WITH ≥7.6 CN SNOW COVER

	STATIONS[a]								
Decade[b]	Cr	Na	MC	Du	G/	Os	Fa	He	In
1901-10	-	-	20	-	-	-	-	-	-
1911-20	-	53	36	-	-	-	23	12	7
1921-30	51	47	40	-	17	11	3	3	-
1931-40	56	55	39	23	10	12	21	7	2
1941-50	46	58	27	31	14	14	22	9	3
1951-60	47	50	27	32	35	9	18	11	3
1961-70	45	52	44	44	28	16	15	14	1
1971-80	58	75	43	44	41	19	29	17	10
1981-90	38	48	34	26	36	22	22	15	7

[a] Stations listed in the same order as in Table 1 (top to bottom).
[b] Data given only when a full 10 years of record are available in the decade.

stations, by 31 days at Gann Valley, SD, and from 9 to 18 days at the Nebraska and Kansas stations. Over the past six decades, the 1970s had the most persistent winter snow cover over the northern and central Great Plains. It was the snowiest decade on record for seven stations, and the second whitest at the other two. The 1930s and 1950s were the least snowy.

The smoothed snow cover data also show fluctuations on the order of a decade (Fig. 5). For example, Miles City, MT had brief snow covers during the first decade of this century, whereas the mid-1960s and early 1970s had longer-lasting cover. At Gann Valley, SD, anomalously brief cover in the mid 1960s was followed by persistent cover in the early 1970s. At Independence, KS, intervals of relatively long-lasting cover in the late 1910s to early 1920s, and the late 1970s and 1980s stand out.

These short-term fluctuations in snow cover duration were not temporally coherent across the northern and central Great Plains. Duration maxima occurred in North Dakota close to 1910, in the late 1930s, the late 1940s, and the latter half of the 1970s. In southeastern Montana, duration maxima occurred in the mid-1910s to early 1930s and mid-1960s to early 1970s. South Dakota maxima occurred in the 1950s and early 1970s, while in Kansas and Nebraska maxima occurred in the mid-1910s to early 1920s, the early 1940s, and the mid- to late 1970s.

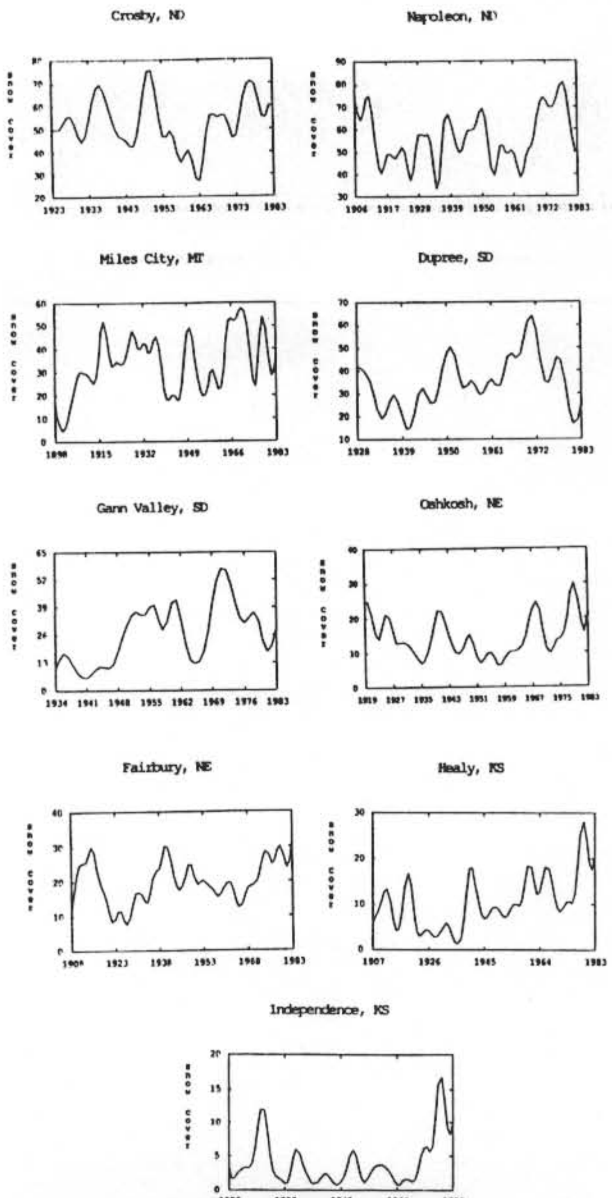

Figure 5. Smoothed time series of winter days with at least 7.6 cm of snow cover at each study station. Data were smoothed using a nine-point binomial filter. Only those points from the fifth year following the commencement of observations through 1983 are plotted.

Duration minima in North Dakota occurred in the mid-1910s to1920s, and at the turn of the century, and in southeastern Montana in the early 1940s. North Dakota and southeastern Montana also had minima in the mid-1950s to early 1960s, and South Dakota in the early 1980s. In Kansas and Nebraska, the 1920s to early 1930s and the late 1960s to early 1970s had brief covers.

The marked variability in snow-cover duration on both annual and decadal scales weakens the statistical significance of any long-term trends of winter cover over the Great Plains. Based on a visual examination of the smoothed duration curve, it appears that a trend towards lengthier cover duration began at Napoleon, ND, Dupree and Gann Valley, SD, and Healy, KS in the 1920s or 1930s and continued up to the 1970s. Trend analyses by linear regression of 1930 to 1980 observations from these stations show increases in the number of snow cover days of between 21 to 34 days from the first to last year of the series. Only at Gann Valley and Healy, with r^2 values of 0.16 and 0.14 respectively, are the trends significant at the 99% level. Trends at Napoleon and Dupree, with r^2 values of 0.06, are significant at the 90% level. Of the other five stations, filtered values have reached maxima for this century in recent decades at Miles City, MT, Oshkosh, NE, and Independence, KA. All but Crosby, ND indicated some increase in cover from 1930 to 1980, however increases were only between six and 14 days and linear regressions were insignificant at the 90% level. There was considerable year-to-year variability of winter snow cover in the 1980s at all stations, and it was the second snowiest decade since 1930 in this region.

Associations of Snow Cover with other Climate Variables

The duration of winter snow cover over the northern and central Plains has varied both temporally and spatially during the course of this century. Results from time series analyses and linear regressions of snow cover duration with maximum temperature and with precipitation suggest complex relationships that appear to differ within the region and at some stations from decade to decade. Smoothed time series of snowfall and precipitation (Fig. 6) suggest that a trend towards greater winter snowfall accompanied the upward trend in snow cover duration at Napoleon, ND between the 1930s and 1970s. Increases in the duration of cover at the South Dakota stations and at Oshkosh, NE during this period accompanied a decrease in precipitation but without any apparent long-term trend in snowfall. The increase in snow duration at Fairbury, NE was accompanied by increasing snowfall, and at Healy, KS snowfall and precipitation increased along with cover duration. There were no apparent associations between duration and precipitation or snowfall at the other stations.

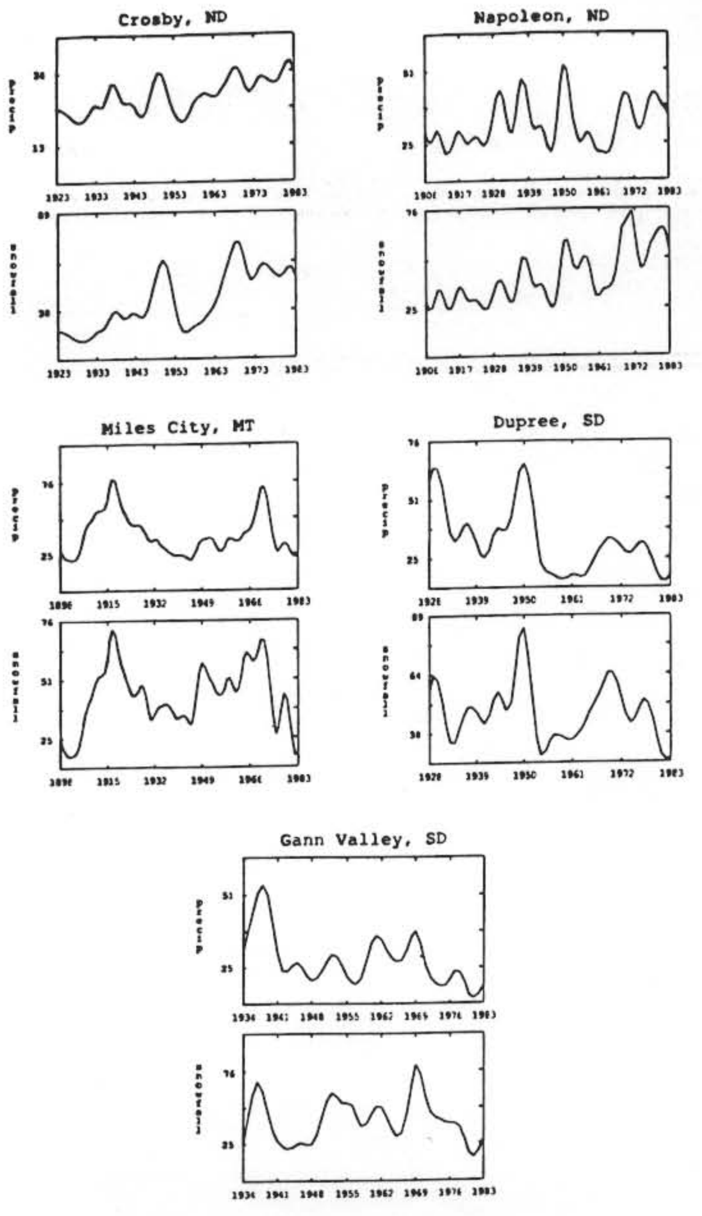

Figure 6. Smoothed time series of winter precipitation (mm) and snowfall (cm) for each study station. Data were smoothed using a nine-point binomial filter. Only those points from the fifth year following the commencement of observations through 1983 are plotted.

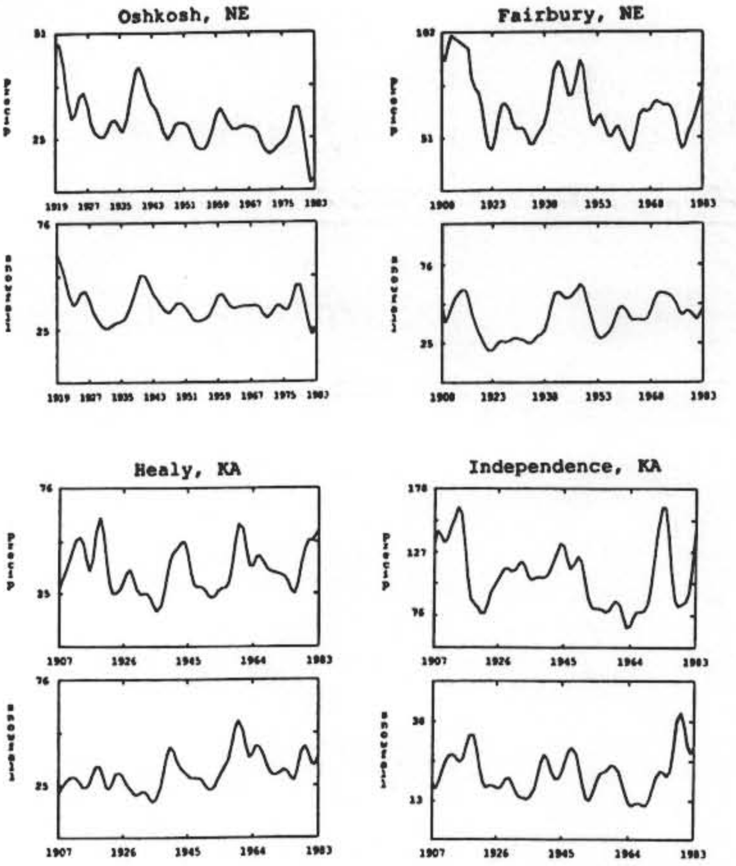

Figure 6. Continued.

Smoothed time series of maximum and minimum temperature (Fig. 7) show the increase in snow cover duration at Gann Valley, SD from the 1930s to the 1970s was accompanied by a trend towards lower temperatures. This relationship was also observed at the easternmost stations in Nebraska and Kansas from the 1930s into the 1980s. Maximum temperatures increased and minima decreased from the beginning of this century into the 1980s at Miles City, MT, while in general, snow cover duration was longer in the second half of the century than the first half. There were no apparent associations between duration and temperature at the other stations.

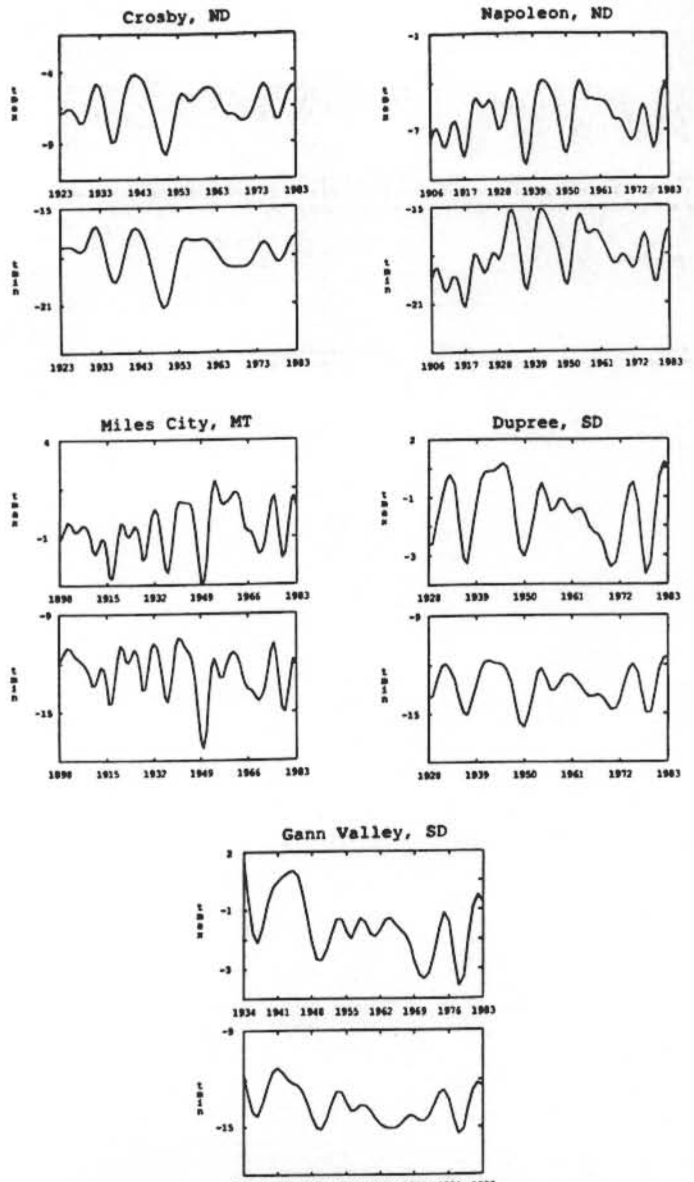

Figure 7. Smoothed time series of winter maximum and minimum temperature (°C) for each study station. Data were smoothed using a nine-point binomial filter. Only those points from the fifth year following the commencement of observations through 1983 are plotted.

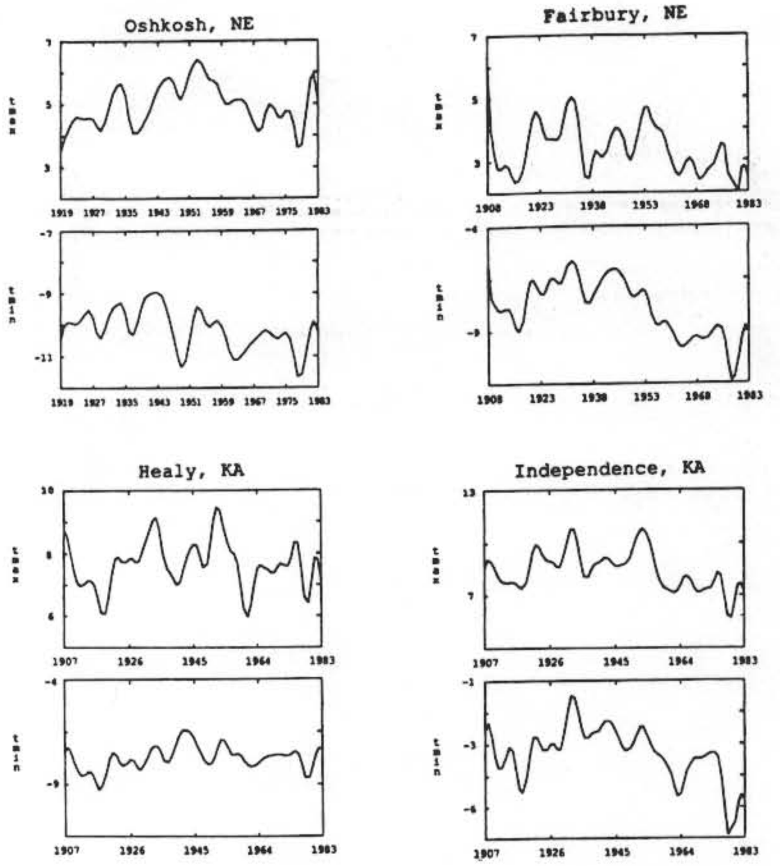

Figure 7. Continued.

Additional relationships between snow cover, temperature, and precipitation that emerged over the period of record warrant further study. For example, anomalously cold temperatures, low precipitation, and meager snowfall accompanied lengthy snow cover duration at Napoleon, ND early this century. Conversely, warmer temperatures and considerably more precipitation and snowfall were associated with the duration maximum at Napoleon in the 1970s.

Negative correlations between snow cover duration and maximum temperature were significant at the 99% level at all stations (Table 3). For example, at Miles City, MT 55% of the total variance of winter maximum

TABLE 3

RELATIONSHIPS BETWEEN THE DURATION OF SNOW COVER ≥7.6 CM AND MEAN MAXIMUM TEMPERATURE AND TOTAL PRECIPITATION.

All values are significant at the 99% confidence level except for precipitation at Gann Valley and Independence. Correlations are negative for temperature and positive for precipitation.

Station	Explained Variance (r^2)[a] Temperature	Precipitation
Crosby, ND	0.44	0.23
Napoleon, ND	0.43	0.16
Miles City, MT	0.55	0.36
Dupree, SD	0.54	0.23
Gann Valley, SD	0.48	0.05
Oshkosh, NE	0.51	0.39
Fairbury, NE	0.53	0.15
Healy, KS	0.45	0.42
Independence, KS	0.36	0.02

[a] Variance in duration of snow cover explained by linear regression with the variable for all years in record. All values are significant at confidence level of 0.99, except precipitation at Gann Valley and Independence. Relationships are direct for precipitation, inverse for temperature.

temperature is associated with winter snow cover duration (Fig. 8). The relationship is also strong in South Dakota and Nebraska, which, along with southeastern Montana, lie in the portion of the Great Plains where winter snow cover is most variable. Positive correlations between longer cover duration and increased precipitation, while weaker than duration-temperature associations, are significant at the 99% level at all stations except Independence, KA and Gann Valley, SD (Table 3). Oshkosh, NE exemplifies one of the stronger relationships, with a duration-precipitation correlation of 0.62 (Fig. 9).

Snow cover affects daily and weekly temperatures. It is reasonable to assume that snow cover is the driving force behind a considerable portion of the snow cover-temperature relationships. Further studies incorporating the effects of the melting point, cloud cover, solar zenith angle, surface pressure, and 700 mb heights as other important covariates are therefore necessary.

Conclusions

Winter snow cover duration has varied across the northern and central Great Plains of the United States throughout this century. Decade-to-decade variability has been common, and the timing of these fluctuations has differed considerably across the region. A general trend towards longer snow cover duration was noted from the 1920s and 1930s to the 1970s, although the statistical significance of this trend is small, given the short-term fluctuations occurring throughout this interval. Correlations between winter snow cover duration and mean maximum temperature are negative in all areas, but are strongest in Nebraska, South Dakota, and southeastern Montana, where snow cover is most variable. Precipitation is correlated positively with snow cover duration in most of the region, although statistically less significant than for temperature.

Should the future winter climate of the Great Plains deviate from what has been observed this century, it is reasonable to assume that the duration of snow cover will change significantly. The monitoring of snow

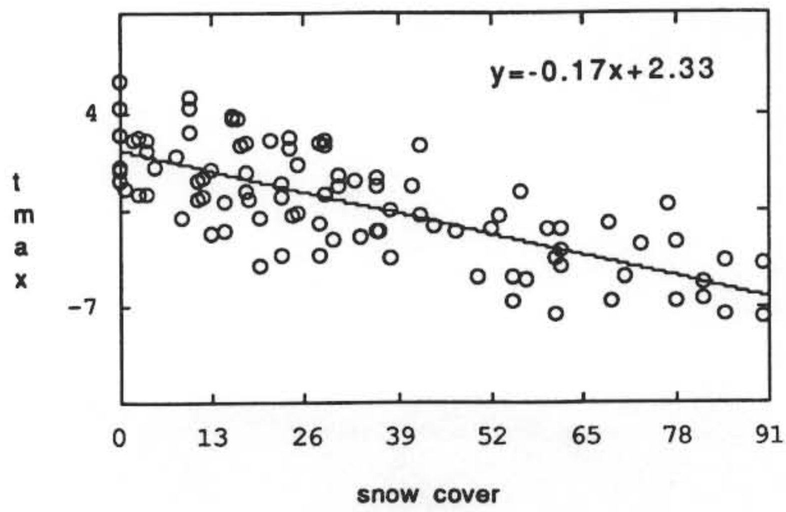

Figure 8. Comparison of winter days with at least 7.6 cm of snow cover and winter mean maximum temperature (°C) at Miles City, MT, for 1893/94 to 1986/87.

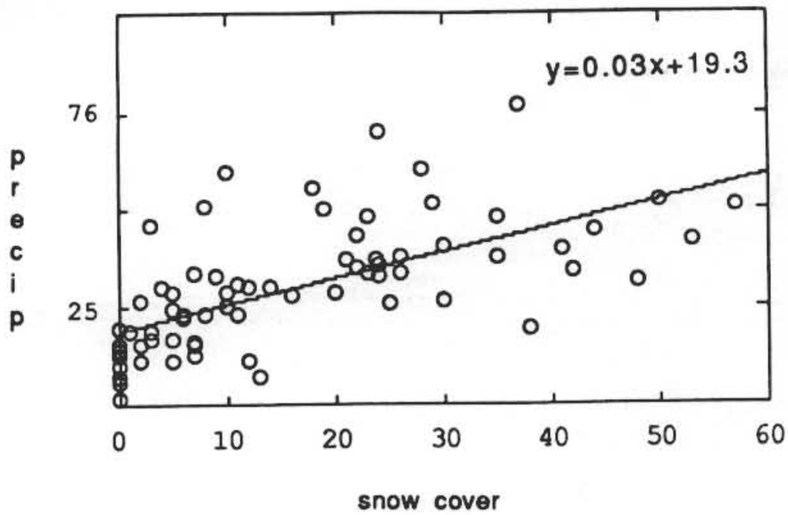

Figure 9. Comparison of winter days with at least 7.6 cm of snow cover and total winter precipitation (mm) at Oshkosh, NE, from 1914/15 to 1986/87.

cover over the Great Plains is particularly important in that snow, or the lack thereof, should play a major role in amplifying any winter climate change over the Great Plains. Given the considerable variability of snow cover observed over the Great Plains this century, careful analysis of climate data will be needed to recognize a shift away from the natural winter snow dynamics of the region. With such efforts, snow cover should serve as a credible indicator of winter climate change in this region.

Acknowledgments

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