Snow cover variability in the Great Plains of the United States: 1910-1988

by
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ABSTRACT

The duration of seasonal (September-May) snow cover over the Great Plains of the United States has varied considerably this past century. A statistically significant trend towards a greater duration of snow cover from 1910 to 1988 shows a region-wide average of 29 days early in the century increasing to 38 days in recent decades. Variability of snow cover duration from year to year has also increased, exhibiting the largest changes in the northwest, central and southeastern parts of the region. Fluctuations on the order of a decade are imbedded in this upward trend i.e, low snow cover in the 1930s, and high snow cover in the 1970s. Decadal variations are associated with changes in both snowfall and temperature; however, only snowfall has shown a statistically significant increase since 1910. The reliance on snow cover for hydrologic and agricultural purposes in this part of the country, the sensitivity of the boundary layer climate to snow cover conditions in the Plains, and the projections by global climate models for this region to become warmer and dryer as a result of increasing atmospheric concentrations of greenhouse gases, necessitates a better understanding of the variability of snow cover over the Plains.

INTRODUCTION

Across much of the United States, falling snow and snow lying on the ground greatly influence hydrologic, biologic, chemical and geologic processes at or near the surface of the earth. Results from modeling studies show an amplification of global anthropogenically-induced warming in regions where snow cover is currently ephemeral (Manabe and Wetherald 1980, Hansen et al. 1984, Dickinson et al. 1987, Folland et al. 1990). The fact that snow cover can be successfully monitored by satellite, makes its potential in climate change research great. One important step towards the use of snow cover in climate change detection is to understand its natural variability. Satellite-derived data extend back for only two decades, not long enough to assess accurately any long-term natural changes in snow cover. For this, historical station data are needed.

To improve our understanding of natural snow cover variability over the U.S., we begin in the Great Plains, and address two questions: 1) how has seasonal snow cover varied both spatially and temporally throughout the past century, and 2) have observed variations in region-wide snow cover been associated with changes in snowfall, precipitation or temperature?

The Great Plains was selected for this study because of its susceptibility to patterns of extreme drought and severe weather and its agricultural importance (Warrick 1980, Rosenzweig 1985). Current global climate models project this region to become warmer and dryer with increasing levels of atmospheric greenhouse gases, placing an environmental and economic strain on the area (U.S. EPA 1990). Earlier studies suggest that this region exhibits considerable variability in snow cover, and that linkages between snow cover and other boundary level climate variables appear to be strong (Robinson and Hughes 1991; Leathers and Robinson 1993).

This study utilizes climate data from the Historical Daily Climate Dataset (HDCD) compiled by Robinson (1993). The development of the HDCD, and the pre-processing methods developed for analyzing this dataset, address the need for daily quality controlled snow data in a usable digital format.

Hughes, M.G. & D.A. Robinson (1993)
Snow cover variability in the Great Plains of the United States: 1910 to 1988, *Proc. 50th Anniv. Meet. Eastern Snow Conf.*, 35-42.

DATA AND ANALYSIS TECHNIQUES

The Historical Daily Climate Dataset contains long-term digitized records of daily snow cover, snowfall, precipitation, and maximum and minimum temperatures. Data are available for over 1100 cooperative climate stations distributed throughout the United States, approximately 230 of which are in the central and northern Great Plains. The HDCD is the only source of digitized long-term daily snow cover data for the United States. Records extend back prior to 1920 for 66% of the stations in the Plains study region, with 44% of the stations reporting data prior to 1910. Earlier than 1910, the reduced number of stations results in inadequate spatial coverage. All of the data have been quality controlled and checked for inconsistencies, errors, and missing values (Robinson 1993).

The Great Plains study region extends from the Rocky Mountains east to the Mississippi River, and from the Canadian border south to the Kansas/Oklahoma border (fig. 1). Here, the snow cover data are found to be of high quality; however, all stations have intervals of missing data. Missing snow cover data average 18%, ranging from a station low of 2% to a high of 62%. Gaps in snow cover are filled when associated daily values of snowfall and temperature are present, using the Depth Change method developed and tested successfully in Hughes and Robinson (1993). This method uses the daily data to develop regionally and seasonally dependent regression equations relating changes in snowdepth to mean temperatures. These equations are then used in conjunction with snowfall to estimate daily snow cover.

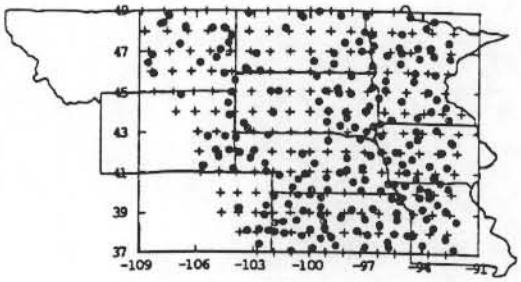

Figure 1. Location of Great Plains stations used for this study (o). Lower left hand corner of grid cells are indicated (+)

For each station, seasonal time series (September-May) are computed for the following variables: 1) number of days reporting at least 7.6 cm (3 in) of snow cover, 2) snowfall, 3) precipitation, 4) average maximum temperature, and 5) average minimum temperature. At depths of less than 7.6 cm, the measurements of snow cover are more observer-dependent due to the frequently patchy nature of such covers (Robinson 1988). Therefore, in this study we will consider snow cover only when depths exceed 7.5 cm. Time series for all climate variables are gridded on an annual basis using an inverse distance method. Gridding decreases any biases that may result from erroneous station observations or from missing data. The resulting grids are 21 columns by 13 rows. Each grid cell is 111 km north/south and 81 km east/west (1° latitude X 1°longitude at 43°N and -100°W) . Region-wide values of the gridded data are computed for every year by averaging all of the grid cells together.

RESULTS

Region-wide snow cover variability

Snow cover on the Great Plains exhibits considerable year-to-year variability (fig. 2). There is

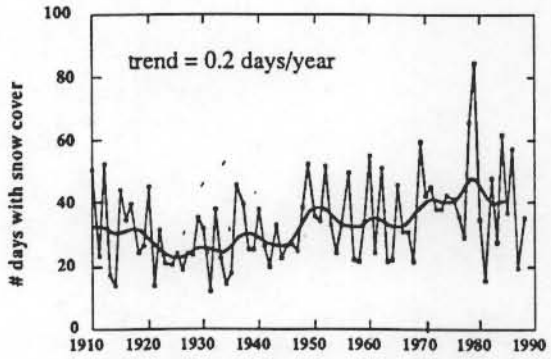

Figure 2. Snow cover duration of ≥ 7.6 cm over the Great Plains for the Snow seasons September 1909-May 1910 through September 1987-May 1988. The data were smoothed using a 9-point binomial filter.

a 14 day standard deviation centered around a mean of 34 snow cover days per year. Within the region, the 79 years of data show a range in cover from over seven weeks in the north to approximately one week in the south. Plains-wide the lowest duration of cover occurred in 1931 with only 12 days, and the highest in 1979 with 84 days. Runs of below normal cover occurred between 1921-1928 and 1941-1947 with duration averaging 22 days and 26 days respectively. From 1969-1976 snow cover was consistently high,

averaging 43 days. From 1910-1949, cover averaged 29 days, with only 13 years above the period average. From 1950-1988 cover averaged 38 days, with only 13 years below the period average. A linear regression analysis of the smoothed time series indicates that the number of days with snow cover has increased significantly (99% level) during 1910-1988 at an average rate of 0.2 days/year. This represents an increase of approximately 2 weeks over this period. The 1920s stand out as the decade with the lowest snow cover with an average of 26 days followed closely by the 1930s with an average of 27 days. Decadal means increased steadily to a high in the 1970s of 47 days. The 1980s averaged 38 days.

Table 1. Variation described by the first eight principal components

Component	*% Variance explained*	*Cumulative % variance*
PC1	12.0	12.0
PC2	14.2	26.2
PC3	13.2	39.4
PC4	7.9	47.3
PC5	10.8	58.1
PC6	10.7	68.8
PC7	11.9	80.7
PC8	3.5	84.2

Sub-regional snow cover

Principal components analysis (PCA) is used to identify areas within the Plains exhibiting temporally similar snow cover characteristics during the study period (SYSTAT 1989). In this analysis a 131 (station) X 79 (season) data matrix is used as input. The PCA identifies eight snow cover components representing 84.2% of the total variance from the original seasonal snow cover duration data matrix (Table 1). The eight components are rotated using an orthogonal varimax rotation to aid in the spatial interpretation. A cluster analysis on the factor loadings is used to assign gridded data to one of the eight sub-regions (fig. 3). Gridded data are then averaged to obtain sub-regional means. From hereon the sub-regions are referred to by the number corresponding to the principal component, i.e. sub-region 1 refers to PC1.

The mean duration of snow cover ranges from a high of 77 days in sub-region 5 in central North Dakota and western Minnesota to a low of 10 days in sub-region 1 in eastern Kansas and western Missouri. Standard deviations for these same sub-regions are 32 days and 8 days respectively. On average, the northern sub-regions have snow cover for seven or more weeks every year. The central sub-regions average between three and four weeks of cover every year, while the southern ones average only one to two weeks of cover. Snow cover generally increases from west-to-east across the Plains, with the largest differences occurring in the north where duration increases from 48 days/year in the west to 77 days/year in the east.

Time series of snow duration from each of the sub-regions exhibit considerable year-to-year variability (fig. 4). Linear regression analysis on these smoothed time series indicates that each of the sub-regions has experienced significant (99% level) increases in snow cover since 1910. A comparison between snow cover duration and variability between the first (1910-1949) and the second (1950-1988) halves of the study period shows that all sub-regions have experienced an increase in the mean number of snow covered days (Table 2). The largest increases are found in sub-region 1 located in eastern Kansas and Missouri, where snow cover has increased from 8 to 12 days/year (50%), and sub-region 7 located in eastern Nebraska where snow cover has increased from 17 to 28 days/year (65%). Increases in the mean number of snow covered days have been accompanied by increases in the standard deviation for five of the eight sub-regions (Table 2). The largest

Table 2. Median, mean, and standard deviation of days with ≥7.6 cm snow on the ground (Sept-May) for 1910-1949 and 1950-1988 for eight Great Plains sub-regions

	Median		*Mean*		*Sdev*	
sub-region	*1910-1949*	*1950-1988*	*1910-1949*	*1950-1988*	*1910-1949*	*1950-1988*
1	6	10	8	12	6	10
2	44	42	43	53	19	30
3	23	30	26	34	17	19
4	17	26	20	28	12	16
5	67	87	68	85	32	30
6	7	11	12	14	11	9
7	15	25	17	28	12	18
8	33	48	38	54	20	19

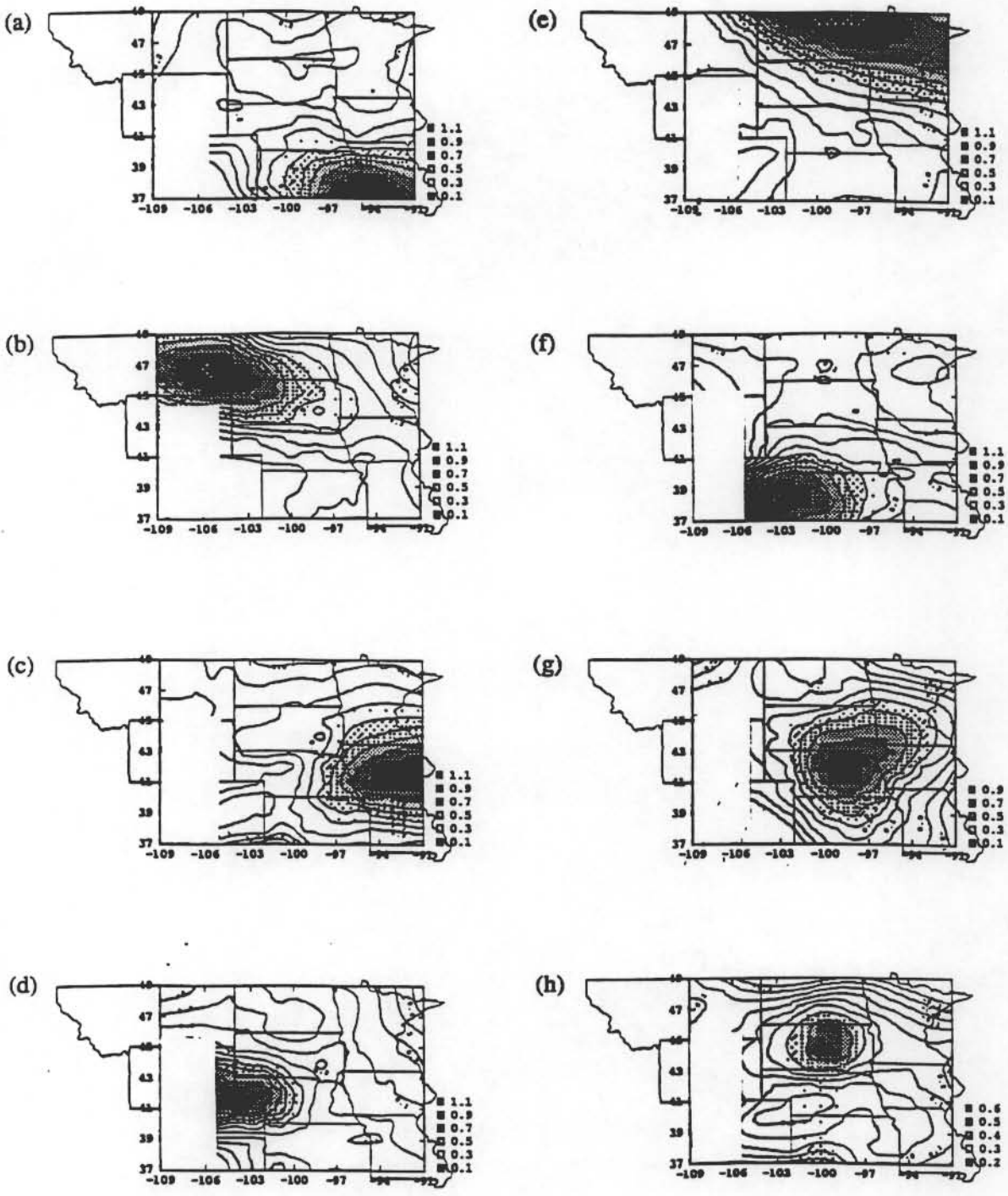

Figure 3. Contour maps of the component loadings from a principal components analysis of Great Plains seasonal (September-May) snow cover duration from the time period 1909/1910 - 1987/88. (a) PC1, (b) PC2, (c) PC3, (d) PC4, (e) PC5, (f) PC6, (g) PC7, (h) PC8.

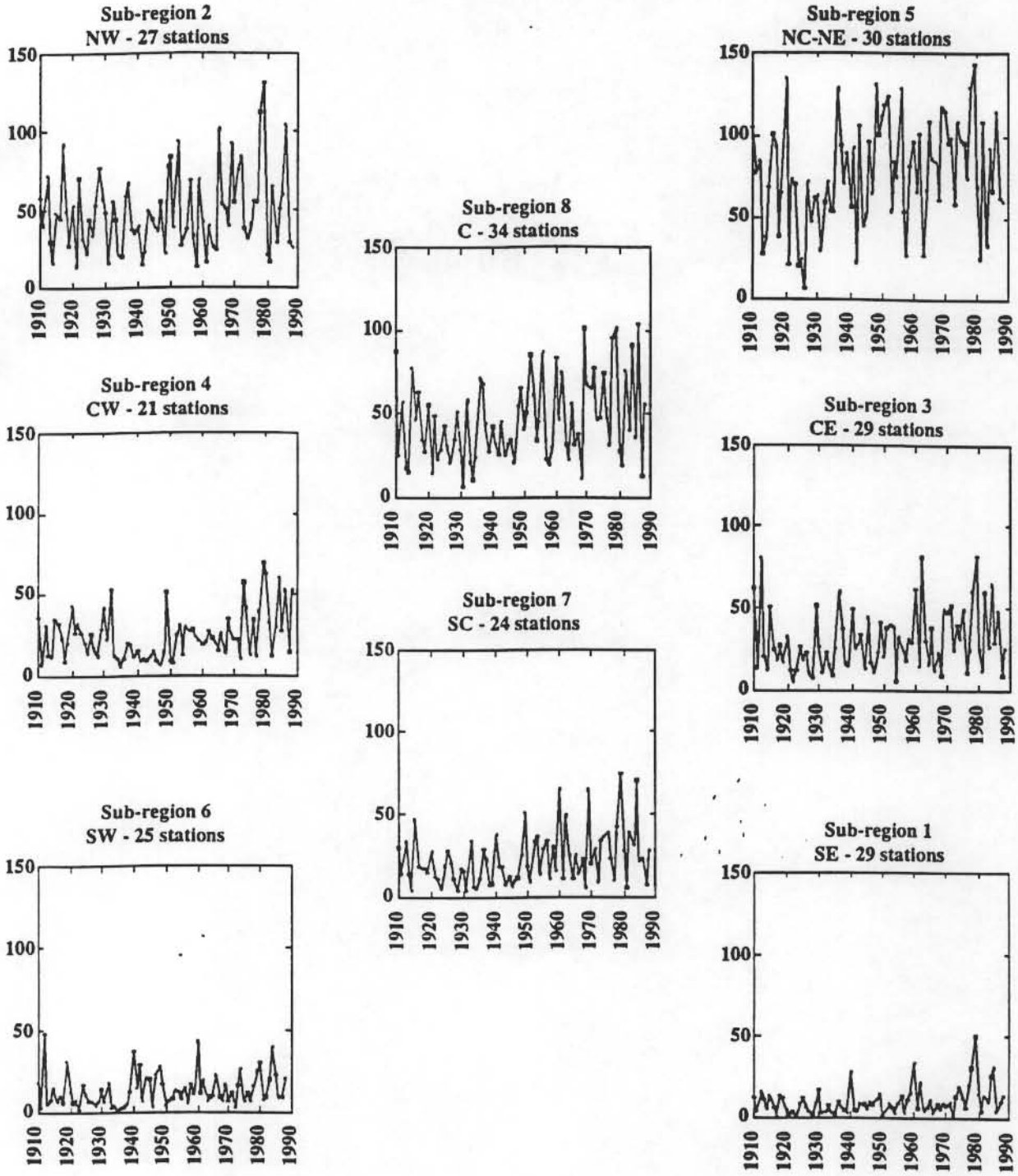

Figure 4. Duration of seasonal (September-May) snow cover ≥ 7.6 cm for the 1909/10 - 1987/88 period for the eight PCA defined sub-regions

Table 3. Mean number of days with ≥ 7.6 cm snow cover (September-May) by decades for the Great Plains sub-regions

Decade	Sub-region							
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1910 to 1919	9	48	33	22	70	15	21	45
1920 to 1929	5	45	19	25	53	8	15	35
1930 to 1939	6	40	24	20	72	7	14	36
1940 to 1949	10	40	29	15	77	20	20	37
1950 to 1959	7	49	27	21	86	10	23	48
1960 to 1969	11	48	33	22	82	15	29	50
1970 to 1979	17	68	42	32	102	13	32	66
1980 to 1988	14	44	33	38	71	18	28	52

increases in variability are found in sub-region 2 located in Montana and western North Dakota, with an increase in standard deviation from 19 to 30 days/year (66%), sub-region 1 with an increase from 6 to 10 days/year (58%), and sub-region 7 with an increase from 12 to 18 days/year (50%).

Decadal fluctuations in snow cover duration are evident on a sub-regional basis and do not uniformly follow the region-wide fluctuations discussed previously (Table 3). The region-wide low cover in the 1920s was associated with the least snow covered decade in North Dakota, eastern South Dakota, Iowa, and eastern Kansas, and the the second least snow covered decade for eastern Nebraska, Colorado and western Kansas. The 1920s in Montana, Wyoming and western Nebraska, however, reported average to above average cover. In the 1940s, the pattern was reversed, whereby low snow cover dominated in Montana, Wyoming and western Nebraska, while the rest of the Plains region had average to above average cover. The region-wide high cover in the 1970s was due to it being the snowiest decade on record for all sub-regions except four and six, located in the southwest, and west central portions of the Plains. Despite generally low snowfall in 1980/81, the 1980s was among the decade with the highest number of snow covered days for all sub-regions.

Association of snow cover with other variables

To determine whether the variability within the snow cover data is associated with changes in the other variables, Plains-wide means of snowfall, temperature, and precipitation are examined. Trend analyses of snowfall, precipitation, and temperature for the study period showed a statistically significant increasing trend in snowfall of 0.28cm/year (0.11 in.) (fig. 5). Similar trends in the other variables are not found. Within decades, snowfall, temperature, and precipitation are associated with snow cover duration, although these associations are not necessarily consistent from one decade to another (fig. 6). For example, the low snow cover in the 1930s was accompanied by the lowest snowfall, and the highest minimum and maximum average temperatures. Despite lower snow cover in the 1920s, snowfall and precipitation were both higher than in the 1930s and associated minimum and maximum temperatures were average to below average. The moderately extensive snow cover recorded in the 1950s is accompanied by moderate snowfall, above average maximum temperatures, and average minimum temperatures, while precipitation for this decade was the lowest in the study period. The extensive snow cover in the 1970s was associated with high snowfall and low maximum and minimum temperatures. The decade of the 1980s like the 1950s, had moderately extensive snow cover across the region despite being one of the warmest decades on record. Unlike the 1950s however, precipitation and snowfall were both well above average.

CONCLUSIONS

This study represents the first region-wide analysis of snow cover variability in the Great Plains. Snow cover duration varies considerably within the Great Plains increasing in general from south to north, and from west to east. From 1910 to 1988, a significant increase in snow cover has occurred within all sub-regions of the Plains, and accompanying increases in variability have been noted for five of the eight sub-regions. The largest increases in variability have occurred in sub-regions one, two, and seven, lying from the northwest to southeast part of the region. Embedded in the high year-to-year variability in snow cover in all parts of

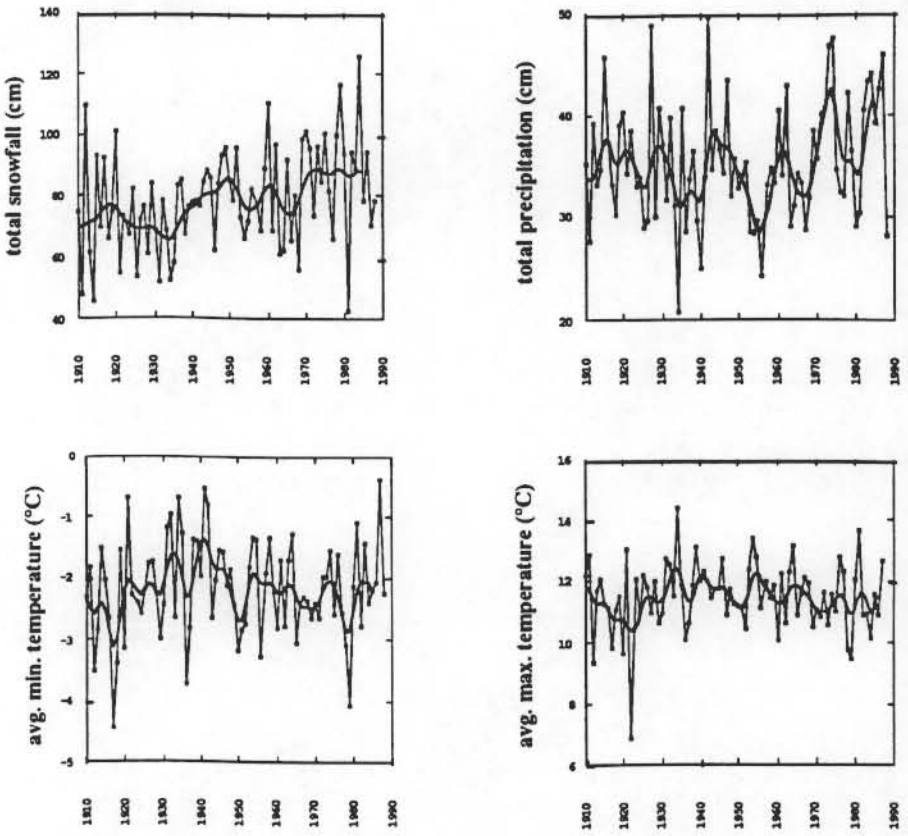

Figure 5. Total snowfall (cm), total precipitation (cm), average minimum temperature (°C), and average maximum temperature (°C) for the Great Plains region for September-May 1909/10 through 1987/88.The data were smoothed using a 9-point binomial filter.

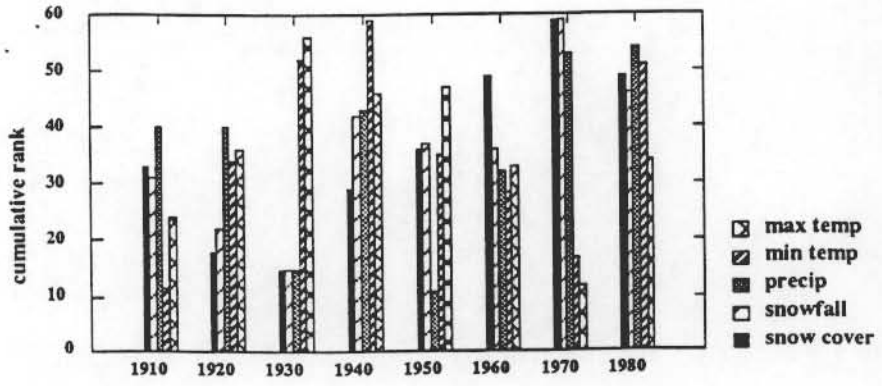

Figure 6. Cumulative rank among snow cover, snowfall, precipitation, and maximum and minimum temperature for the Great Plains region. Data were averaged by decades for each sub-region and ranked from 1 (lowest) to 8 (highest). The ranks were summed to get a region-wide decadal rank.

the region, coherent signals on the order of a decade are evident. Decadal and century long associations among snow cover, snowfall, and temperature are also apparent. Snow cover appears to be sensitive to changes in temperature, and precipitation which bodes well for its use in identifying future natural or anthropogenic climate change should either one occur.

Future work with this dataset will include: 1) an effort to quantify the associations found among snow cover, snowfall and temperature, 2) an analysis of snow cover and associated snowfall, and temperature trends for winter, spring, and fall as they contribute to the seasonal changes in cover noted in this study, and 3) expansion of the study area to other regions in the United States and the Northern Hemisphere.

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