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LONG-TERM VARIABILITY OF SNOW COVER IN THE UNITED STATES AND AN EVALUATION OF RECENT HEMISPHERIC CHANGES

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1. INTRODUCTION

Snow is a key variable in the global climate system. It influences the global heat budget chiefly through its effect of increasing surface albedo (Kung et al., 1964; Robinson and Kukla, 1985). Accurate information on snow cover is essential for understanding details of climatic change (Kukla and Kukla, 1974; Wiesnet and Matson, 1976). It has been suggested that this information might make snow extent a useful index for detecting and monitoring climatic change (Schlesinger, 1986; Barry, 1985).

Snow mapped from satellite imagery for the past two decades has provided useful information on hemispheric cover (Matson et al., 1986). However, this data base is of insufficient length to permit the ascription of changes noted to any pronounced climatic change. One must rely on station records for information on past long-term variations in cover and to place potential ongoing or future changes in proper perspective. Furthermore, evaluating station snow records along with temperature and precipitation observations will establish whether there are relationships among them. Should snow be recognized as a useful climatic integrator, it will further support it's standing as one of the most important indices to monitor in attempts to identify and characterize projected climatic change.

Due to the absence of regional snow data sets, to date studies of snow cover for periods of fifty years or more are limited to individual stations or small regions (Arakawa, 1957; Uttinger, 1963; Manley, 1969; Lamb, 1969; Jackson, 1978; Pfister, 1978, 1985). The creation of a lengthy daily set covering approximately 1000 stations in the conterminous United States is an initial step towards eliminating this deficiency (Robinson, 1988). Here, a portion of this set will be used to examine snow cover in the central U.S. back to the turn of the century, explore relationships between snow, temperature and precipitation and evaluate recent variations in North American and Eurasian cover recognized in the NOAA satellite product.

2. DATA SETS

2.1 U.S. Historical Daily Data

This new set is comprised of digitized daily records from approximately 360 U.S. stations back to about 1910 or earlier and some 650 stations back to about 1930 (Robinson, 1988). Snow cover, snowfall, precipitation and maximum and minimum temperature observations extend through 1988, although at the time the analyses presented here were undertaken data only through 1978 were available. Quality controlling of the set involved a series of queries for each daily variable. Suspicious data were flagged (and retained with the data) and flags for the 300 most temporally complete stations were checked against original records and any errors found corrected.

The 146 central U.S. stations selected for study have records back to at least 1910. For analysis purposes, stations were divided into 1° latitude by 4° longitude cell subsets (Fig. 1) or 11 station central Plains and 9 station Midwest regions (Fig. 2). Results for each cell or region are an average of observations from all stations contained therein.

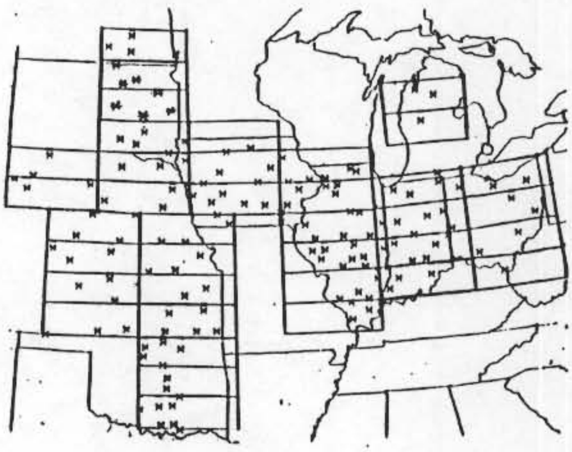

Fig. 1. Central U.S. 1° x 4° cells and 146 station network.

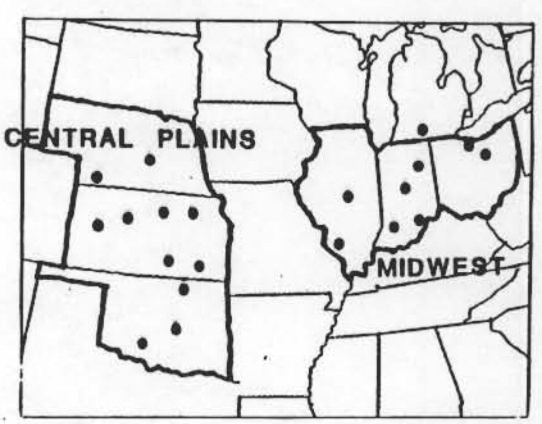

Fig. 2. Central Plains and Midwest study regions and key stations located within them.

2.2 NOAA Weekly Snow Charts

Northern Hemisphere snow charts are produced from a visual interpretation of photographic copies of NOAA satellite imagery by trained meteorologists. The boundary between snow-covered and snow-free land surfaces is delimited by recognizing characteristic textured surface features and brightnesses of snow-covered lands. The weekly charts show the boundary on the last day the surface in a given region is seen.

Charts have been produced since 1966. However, it is recognized that in early years snow was underestimated (Kukla et al., 1981; Kukla and Gavin, 1984; Ropelewski, 1984). Charting from 1972 to present is considered useful for climatic studies. Any inaccuracies during this interval are considered consistent (e.g. charting difficulties in autumn due to extensive cloudiness and problems with recognizing snow in boreal forests) or incidental.

Charts are digitized on a weekly basis using the National Meteorological Center's standard analysis grid, with grid resolution ranging from 16,000 to 42,000 km^2 (Dewey and Helm, 1982). If a cell is 50 percent or more covered by snow it is considered to be completely covered. Continental and hemispheric extents are calculated, although the last published results only ran through 1981 (Matson et al., 1986).

Station and satellite observations in the central U.S. show good agreement during mid-winter (Kukla and Robinson, 1981). Thus, the satellite charts were used to advance the regional snow cover records to 1989.

3. RESULTS

3.1 Snow Cover Variability

While marked interannual variability has occurred throughout the period of record, in recent decades there has been an overall increase in mid-winter snow extent in the central U.S. Each of the first five decades of this century had between 5 and 9 cells with at least five Januaries having sixteen or more days of snow cover (≥2.5 cm) (Fig. 3). Not surprisingly, these were northern cells (Fig. 1). This number increased to 12 and 14 in the 1950's and 1960's, respectively. The 1970's saw 23 cells meeting this criteria. This amounts to a 2-4^{o} southward expansion of snow cover. In the 1980's there was a decrease to 18 cells.

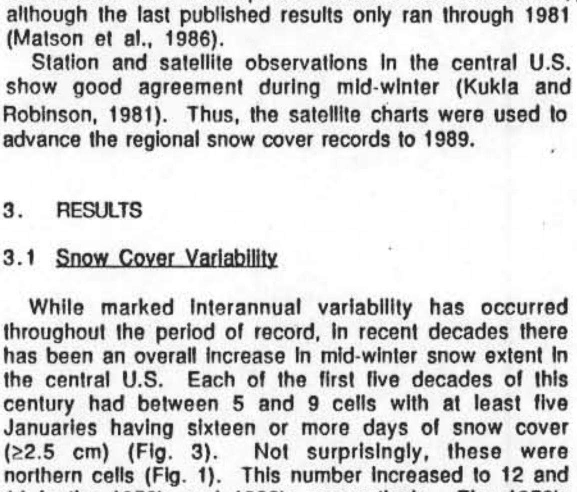

Fig. 3. Decade totals of cells having at least five Januaries with sixteen or more days of snow cover (≥2.5 cm).

3.2 Snow, Temperature and Precipitation Relationships

January snow cover extent and mean temperature are negatively correlated in the central U.S. (Fig. 4). This relationship is stronger in the Midwest than in the central Plains (Fig. 2). Snow departures were calculated from the 1901-1986 average of regional cover and temperature departures are from an unweighted average of departures (1895-1983) for each state (Karl et al., 1984). State departures fall into one of five categories; 1) much below normal (containing 10% of the months), 2) below normal (20% of the months), 3) normal (40%), 4) above normal (20%) and 5) much above normal (10%). Karl's data set shows an abundance of cold Januaries in recent decades.

Departures from the snow-temperature relationship are in part due to the availability of precipitation and whether it falls in frozen or liquid form. The latter point is exemplified by observations showing decreases in winter precipitation in recent decades while the extent of snow cover has increased (Karl et al., 1986; Diaz and Quayle, 1980). It appears from this preliminary study that snow cover is a useful integrator of long-term temperature and precipitation variability.

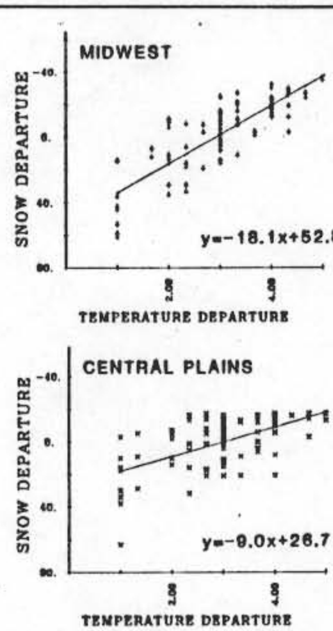

Fig. 4. January departures of snow extent and temperature for the Midwest and central Plains study regions (1901-1983). Departure categories for temperature range from much below normal (1) to much above normal (5). Snow percent departures are from means of 34.8% (Midwest) and 17.1% (central Plains). R^2 = 0.69 (Midwest) and 0.36 (central Plains).

3.3 Evaluating Recent Satellite Snow Observations

The central U.S. snow study shows the necessity of having lengthy historical records when attempting to recognize climatic change from short-term records. For instance, should central U.S. cover rapidly diminish to pre-1950 levels, without knowledge of the historical variability this might be misinterpreted to be a result of anthropogenic climatic change, while indeed it might solely be a function of the natural long-term variability.

Caution must also be applied when examining continental snow extent from the short satellite record. Figs. 5 and 6 show Eurasian and North American cover to currently be at their lowest extents since the advent of reliable satellite records. Some might be tempted to immediately use this information as support of the onset of anthropogenic climatic change. However, prior to having lengthy station-derived time series and placing the conditions in proper perspective, it is premature to ascribe any cause to the decrease. Unfortunately, such time series are presently unavailable for critical countries, including the USSR and Canada.

4. CONCLUSIONS

Mid-winter snow cover across the central United States has been more extensive in recent decades than during the first half of the century. This increase has been associated with colder temperatures and reduced precipitation. This suggests that snow extent may be a useful climatic integrator, thus among the important indices to monitor in attempts to identify and characterize projected climatic change. Whether cover has responded passively to temperature changes or this association is in part a function of a snow-albedo feedback is left for future study.

Long-term natural variations in cover need to be understood prior to ascribing anthropogenic influences to any recent or future regional or hemispheric variations. It is pertinent to stress this, as Eurasian and North American snow covers are currently at their lowest extents since the advent of reliable satellite snow monitoring in 1972. Unfortunately, lengthy (+50 year) data sets of snow cover remain unavailable for most Northern Hemisphere regions.

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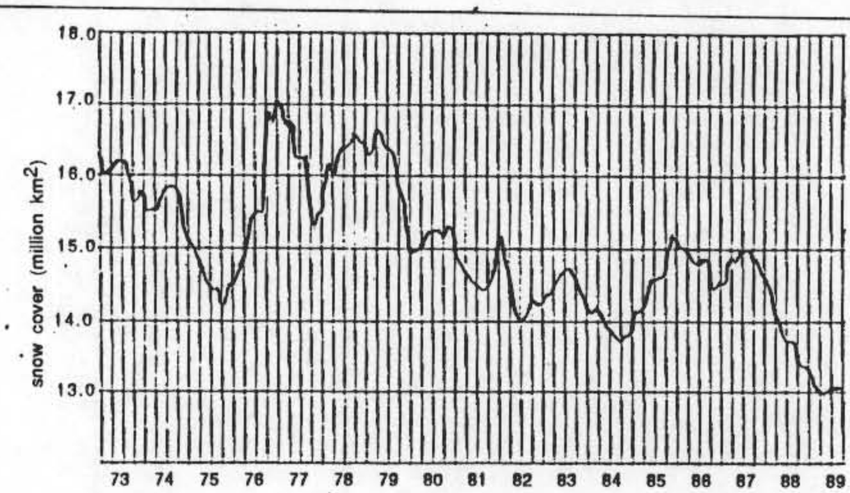

Fig. 5. Twelve-month running mean of monthly Eurasian snow cover as charted from satellite imagery. Means include data from January 1972 to September 1989. (Data courtesy of NOAA)

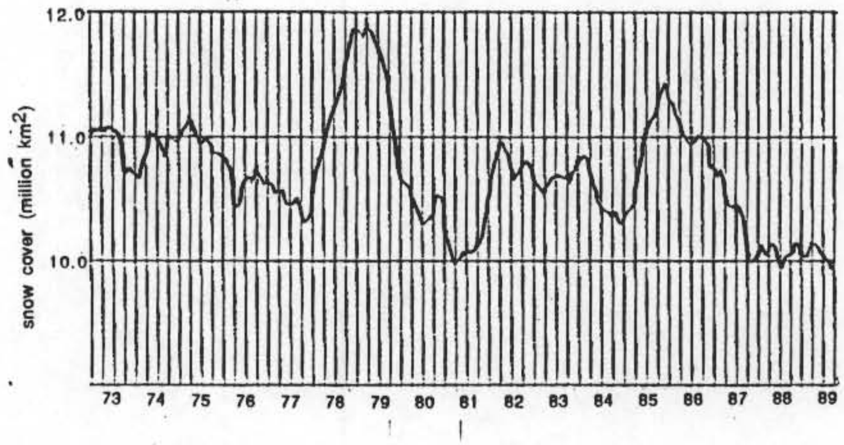

Fig. 6. Twelve-month running mean of monthly North American snow cover as charted from satellite imagery. Means include data from January 1972 to September 1989. (Data courtesy of NOAA)

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