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ABRUPT CHANGES IN THE SEASONAL CYCLE OF NORTH AMERICAN SNOW COVER

Daniel J. Leathers *

University of Delaware
Newark, Delaware

and

David A. Robinson

Rutgers University
New Brunswick, New Jersey

1. INTRODUCTION

The large-scale distribution of snow cover has been a topic of increasing interest over recent decades. This interest has been fueled by concerns associated with potential changes in the global environmental system associated with anthropogenic and natural causes. General circulation model studies have demonstrated that the earth's climate system is sensitive to the large-scale distribution of snow cover, primarily because of the radiative effects of snow (Gray and Male 1981; Robinson 1986; Groisman et al. 1994). Unfortunately, a detailed investigation of the meteorological conditions associated with the annual cycle of continental-scale snow cover has not been initiated. Although atlases of mean snow cover have previously been published (Dewey and Heim 1982; Matson et al. 1986; Schutz and Bergman 1988; Robinson et al. 1993), little attention has been given to the atmospheric forcing associated with the advance and retreat of the continental snow packs.

It is the purpose of this research to examine rapid, large-scale snow cover accumulation events that take place on time scales of one week or less across the North American continent, and the atmospheric forcing associated with them. The magnitude of these events is large. Snow cover extent changes of more than 3 million km^2 occur in many cases, and are important in the gross radiation balance of the North American Continent (Karl et al. 1993; Groisman et al. 1994). In addition, the presence or absence of snow cover extent of this magnitude may also be important in air mass development and subsequently to surface air temperatures remote from the snow covered regions (Leathers and Robinson 1993).

2. DATA

Weekly snow cover extent data for North America are obtained from National Oceanic and Atmospheric Administration (NOAA) snow cover charts (Matson et al. 1986). This dataset covers the entire Northern Hemisphere dating back to 1966. To produce the charts, a visual interpretation of daily images is carried out on an operational basis by a specially trained meteorologist to identify those areas of the land surface that are covered by snow on a given day (Robinson et al. 1993). The daily snow cover information is aggregated to produce weekly snow cover maps that depict the presence or absence of snow cover on the last day of the week that the surface of the earth in a given area is able to be identified (i.e. cloud free). These maps are then digitized to an 89 X 89 grid matrix, covering the entire Northern Hemisphere, and weekly land surface snow cover areas are calculated using a routine developed at Rutgers University (Robinson 1993; Robinson et al. 1993). Previous work has shown that the weekly snow cover product is most representative of the snow cover extent on the fifth day of a given chart week. Also, it has been suggested that the earliest digitized weekly products underestimated the snow

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cover extent (Kukla and Robinson 1981; Ropelewski 1984). Because of the potential underestimation early in the record, weekly snow cover extent values for North America, used in this research, will cover the time period January 1971 through December 1990.

Atmospheric data used in the following analyses are derived from National Meteorological Center octagonal grids (Jenne 1975) and include surface pressure, 850 mb temperature and 500 mb height data. Departures are calculated based on the 1947 through 1988 period.

Storm track information is derived from the NOAA Weekly Weather Map Series. The center position of all North American low pressure areas with at least one closed isobar are plotted for each period of interest. The general storm track for the period is subjectively determined from inspection of the aggregated daily maps.

3. ANALYSIS TECHNIQUES

Snow cover extent differences from one week to the next are calculated for the 20-year period and ranked. The twenty largest accumulation events (largest weekly differences) are selected for analysis. The abrupt accumulation events occur during the autumn months. Furthermore, abrupt accumulation episodes are subdivided equally into early and late accumulation and ablation cases, yielding 10 cases per category. For this study, only late season accumulation events will be considered.

Composite maps of the spatial distribution of one-week snow cover changes are constructed for the late season. First, the composite snow cover extent for the initial week of an accumulation event is constructed by identifying any NOAA grid cell with six or more of the ten weeks considered to be snow covered. The composite area of snow cover change is defined by the grid boxes that are considered not covered in the week prior to accumulation events and subsequently classified as covered in the week after accumulation events.

The atmospheric patterns associated with these rapid accumulation episodes are constructed by calculation of the mean conditions during all days that fall within a category. For example, all 70 days that occur in the 10 weeks included in late season accumulation events are composited to give the average atmospheric conditions during those events. Because the snow cover extent values for a given week are most representative of the fifth day of that week, the composite atmospheric patterns cover the 7-day period from the fifth day of the initial week to the fourth day of the ending week. The mean atmospheric conditions for the same 70 days, calculated with data for the 42-year period from 1947 through 1988, are subtracted from the composite average to give the departure maps that follow in the analysis below.

4. RAPID LATE SEASON ACCUMULATION EVENTS

Late season accumulation events take place at the end of November. Snow cover extent at the beginning of these events is approximately 10.2 million km^2, more than 2 million km^2 below the 20-year average. Snow cover is found across the majority of eastern Canada, within the boreal forest, tundra and mountains of central and western Canada and in the U.S. Rocky Mountains (Figure 1) at the beginning of these events. One week snow cover accumulations averaging 3.7 million km^2 take place during these episodes. The majority of the accumulation takes place across the prairies of Canada and the central and high plains and northern Great Basin regions of the United States. Smaller areas of accumulation occur from the Great Lakes eastward through the Gaspe peninsula (Figure 1)

Figure 1. Mean snow cover extent at the beginning of accumulation episodes (dark shading) and at the end of events (light shading).

Mean atmospheric patterns associated with the late season accumulations are quite strong. The dominant storm track during these events is characterized by storms making landfall along the southern coast of British Columbia. These storms redevelop in the high plains of the United States, and move eastward, through the Great Lakes, into eastern Canada. A region of large surface pressure anomalies (+7 mb) is centered along coastal areas of southern Alaska and northern British Columbia (Figure 2). These surface characteristics lead to anomalously strong cold advection and an abundant supply of Pacific moisture across the western one-third of North America. Temperature departures at 850 mb reach -3° C and lower across the accumulation region (Figure 3). Interestingly, the 850 mb 0° C isoline defines the southern margin of the accumulation region (Figure 4). At 500 mb, a relatively strong trough, in the anomaly sense, is centered across the central United States. This mid-tropospheric pattern is consistent with the lower tropospheric features.

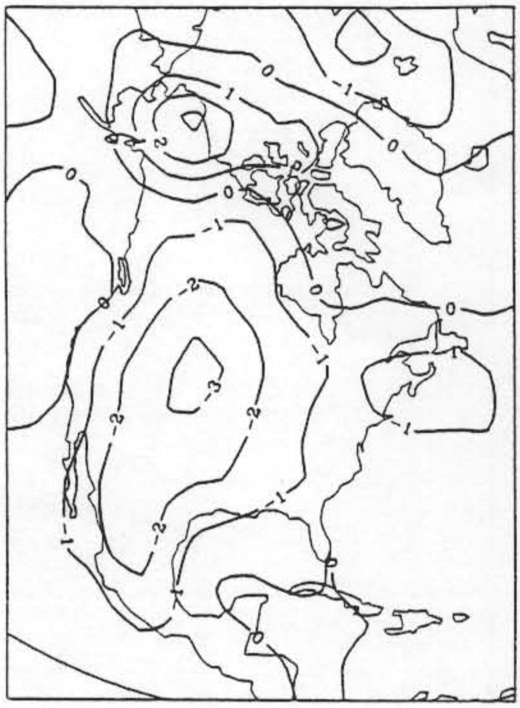

Figure 3. Temperature anomalies at 850 mb (° C) during late season accumulation events.

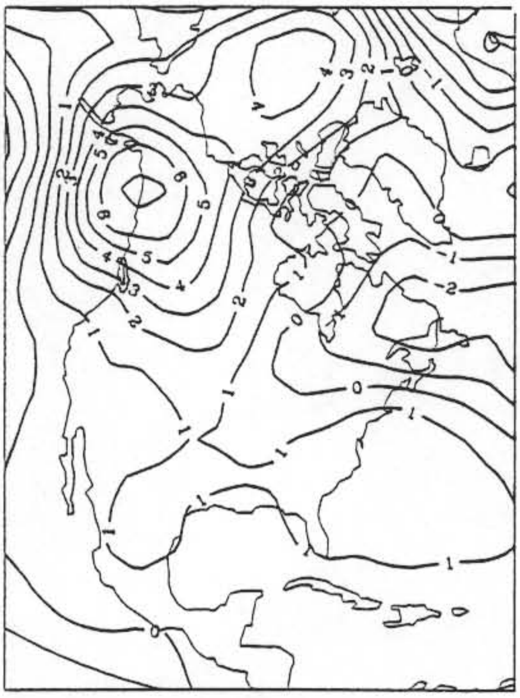

Figure 2. Surface pressure anomalies (mb) during late season accumulation events.

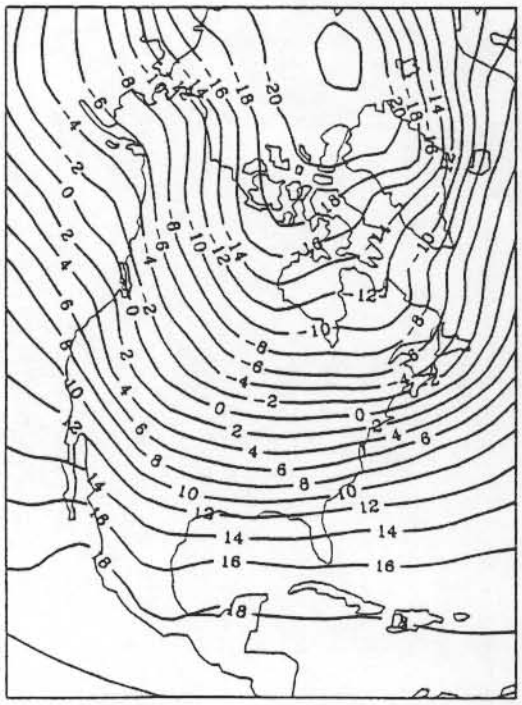

Figure 4. Mean 850 mb temperatures (° C) during late season accumulation events.

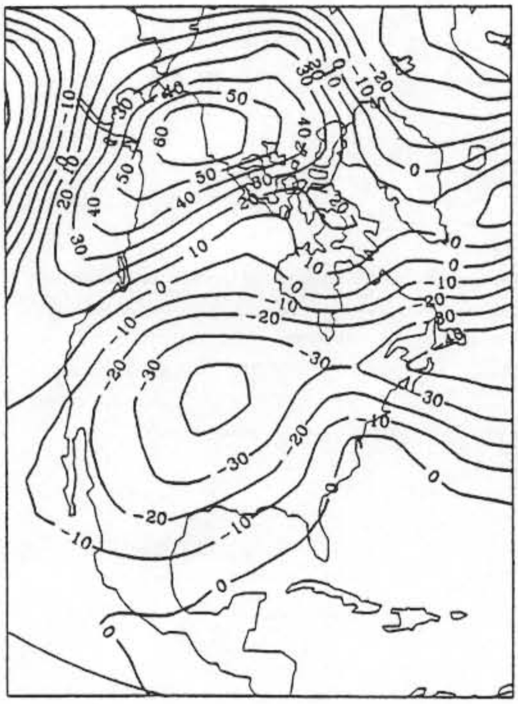

Figure 5. Geopotential height anomalies at 500 mb during late season accumulation events.

5. DISCUSSION

Abrupt changes in snow cover extent have been recognized previously in the NOAA satellite record. A persistent concern has been whether these changes were actually occurring. Given that cloudiness, particularly in the accumulation season, obscures the surface from visible satellite imagery, it was believed that more than a week of change could be displayed in a weekly chart over some portions of the continent if the previous chart week had been completely cloudy. While this concern has not been completely dispelled, our finding that the atmospheric forcings accompanying the charted changes support an abrupt change strongly suggests they are real, and therefore increases our confidence in the NOAA charts.

Before all the abrupt accumulation episodes, snow cover extent was below its 20-year mean for that week. This suggests that surface conditions were climatologically pre-conditioned for change. In the autumn, with temperatures and solar radiation receipt falling rapidly, an area that on average supports snow cover would be expected to become snow covered when atmospheric conditions were appropriate for extensive snowfalls. However, in the cases of abrupt accumulation presented here, something more than this may be involved. The strongest evidence for this is that the snow anomaly changes sign from the beginning to the ending week of the accumulation event. What may be evidenced here are periods of extreme atmospheric variability, leading to large changes in surface boundary variables such as snow cover extent.

6. CONCLUSIONS

This study represents a beginning in understanding the role of atmospheric circulation variations on the annual cycle of continental scale snow cover.

The annual cycle of snow cover extent is an important component of the climate system because of the effect of snow cover on the global radiation balance. Large changes in the annual cycle of snow cover may lead to important changes in the timing of seasonal temperature and moisture variations in middle and high latitude land areas of the Northern Hemisphere (Leathers and Robinson 1993; Groisman et al. 1994). Thus, the synergistic relationship between hemispheric scale atmospheric circulation variations and continental snow cover extent must be understood before any meaningful projections of future climatic states can be made. Additional studies, detailing the atmospheric forcing during early season accumulation episodes and large spring snow cover ablation events are currently underway. We believe that this information will allow for more realistic snow cover/atmosphere linkages in general circulation models and will increase the efficacy of the use of snow cover as an indicator of global environmental change.

Corresponding author address: Daniel J. Leathers, Univ. of Delaware, Center for Climatic Research, Newark, DE 19716

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REFERENCES

Dewey, K.F. and R. Heim Jr., 1982: A digital archive of Northern Hemisphere snow cover, November 1966 through 1980. Bull. Am. Met. Soc., 63, 1132-1141.

Gray, D.M. and D.H. Male: Handbook of Snow: Principles, Processes, Management and Use. Pergamon Press, New York, NY, 776 pgs.

Groisman, P.Y., T.R. Karl and R.W. Knight: Observed impact of snow cover on the heat balance and the rise of continental spring temperatures. Science, 263, 198-200.

Jenne, R., 1975: Data sets for meteorological research. National Center for Atmospheric Research Tech. Note NCAR-TN/IA-111, Boulder CO.

Karl, T.R., P.Y. Groisman, R.W. Knight and R.R. Heim, 1993: Recent variations of snow cover and snowfall in North America and their relation to precipitation and temperature variations. J. Climate, 6, 1327 - 1344.

Kukla, G. and D.A. Robinson, 1981: Accuracy of snow and ice monitoring. Snow Watch 1980, Glaciological Data, Report GD-5, 91-97.

Leathers, D.J. and D. A. Robinson, 1993: The association between extremes in North American snow cover extent and United States temperatures. J. Climate, 6, 1345-1355.

Matson, M., C.F. Ropelewski and M.S. Varnadore, 1986: An Atlas of Satellite-Derived Northern Hemisphere Snow Cover Frequency, NOAA, Washington, DC, 75 pp.

Robinson, D.A., 1986: Initiation of spring snowmelt over arctic lands. Proceedings Cold Regions Hydrology Symposium, Fairbanks, AK, American Water Resources Association, 547-554.

Robinson, D.A., K. F. Dewey & R. Heim, Jr., 1993: Northern Hemispheric snow cover: an update. Bulletin of the American Meteorological Society, 74, 1689-1696.

Robinson, D.A., 1993: Monitoring northern hemisphere snow cover. Snow Watch T92: Detection Strategies for Snow and Ice. Glaciological Data Report, GD-25, 1-25.

Schutz, C. and L.D. Bergman, 1988: Global Annual Snow Accumulation by Months. Rand Note N-2687-RC. Rand Corporation, Santa Monica, CA, 85 pgs.