NORTHERN HEMISPHERE SNOW COVER DURING THE TRANSITION SEASONS

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INTRODUCTION

The distribution of snow cover over northern hemisphere lands has been a topic of increasing attention in recent years. This interest has been spurred, in part, by concerns associated with potential changes in the global climate system occurring naturally or influenced by human activities. Satellite data show that the fall and spring exhibit a larger year-to-year variability in northern hemisphere snow extent than observed in winter. In this paper we will explore the variability of northern hemisphere snow extent, concentrating on these transition seasons. Following an overview of year-round hemispheric variability, time series of fall and spring extents will be presented for Eurasia and North America. Variable snow zones within the transition seasons will be delineated, and regions within these zones exhibiting coherent temporal fluctuations will be identified. Why such variability is observed will be explored by examining atmospheric data during intervals where abrupt changes in snow extent occur.

DATA AND METHODOLOGY

Weekly NOAA snow charts are the primary source of information for this investigation. These charts depict boundaries between snow-covered and snow-free land surfaces, and are produced from visual interpretation of photographic copies of visible-band satellite imagery. Charts are digitized on a weekly basis to the National Meteorological Center (NMC) Limited-Area Fine Mesh (LFM) grid. Data since 1972 are considered to be of a high enough quality for use in climate studies. Monthly means of snow cover area are determined by calculating weekly areas from the digitized snow files and weighting them according to the number of days of a chart week falling in the given month. Prior to the calculations, the digital files are standardized to a common land mask, which includes those and only those LFM cells at least half covered by land. Atmospheric data are derived from NMC octagonal grids, and include surface pressure, 850 mb temperature and 500 mb height data. Departures are calculated based on the 1947-1990 period.

NORTHERN HEMISPHERE VARIABILITY

The variability of snow cover extent over the Northern Hemisphere between January 1972 and October 1994 is expressed in Figure 1 as monthly anomalies and twelve-month running means. Monthly anomalies of greater than 4 million km^2 have occasionally been observed throughout the past 22 years, although they are generally less than 2 million km^2. Extended periods of above average snow extent occurred in the early and late 1970s and the mid 1980s. Somewhat below normal coverage was observed in the mid 1970s and early 1980s. However, it is since the late 1980s that the longest interval of subnormal snow cover in the past two decades has been observed. While the 1994 snow year (Sep 93 - Aug 94) exhibited a return to near normal hemispheric extent, only three months during this period had above normal coverage. Only 11 of the past 88 months (through Oct 1994) have been above the norm.

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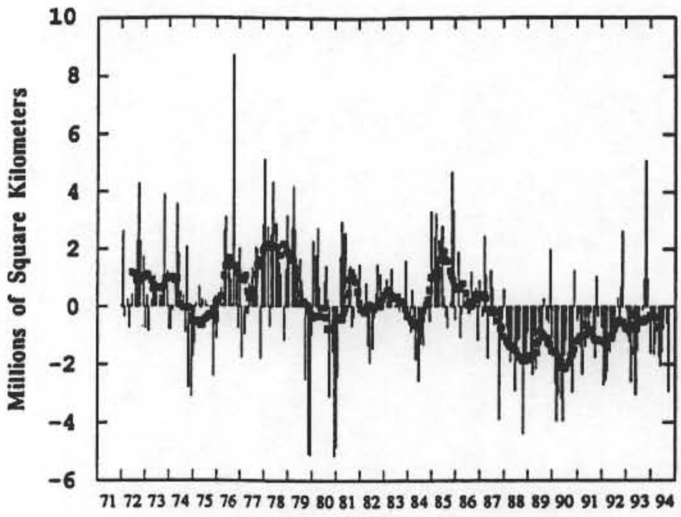


Figure 1. Anomalies of monthly snow cover extent over northern hemisphere lands (including Greenland) between January 1972 and October 1994. Also shown are twelve-month running anomalies of hemispheric snow extent, plotted on the seventh month of a given interval. Anomalies are calculated from a mean hemispheric snow extent of 25.4 million km^2 for the full period of record.

TRANSITION SEASON VARIABILITY

Fall snow extent over Eurasia and North America exhibits greater variability from one year to the next than the other seasons (Fig. 2). There has not been a lengthy run of autumns with above or below normal extent during the past two decades. Negative departures of snow extent have been most pronounced in spring over the past six years in Eurasia and seven years in North America (Fig. 2). Summer coverage has also been below normal in recent years, and winter extent the most stable throughout the satellite era.

Zones exhibiting year-to-year variability during two transition season months are depicted in Figure 3. The November and April variable zones are determined by identifying grid cells covered with snow between 10% and 90% of the time in at least one third of the study years. This rather broad criterion excludes those regions where snow cover is extremely common or rare during these transition months. The variable zone in November straddles the US/Canadian border from coast to coast, and plunges into the US Rockies and high Plains (Fig. 3a). The Eurasian zone lies within approximately 5° of the 50th parallel, except in Europe where it curves poleward. The Himalayan/Tibetan region also has variable cover, which is also the case in April (Fig. 3b). The variable zone in April across the remainder of Eurasia lies between approximately 50° and 60°N. April snow extent is also variable in southern Canada and the US Rockies, a considerably smaller North American zone than in November.

Within these variable zones, Principal Components Analysis (PCA) is used to identify regions of coherent snow cover; that is, areas within which snow time series for grid points are highly correlated to each other. An orthogonal varimax rotation of the components is performed to allow for more clear visualization. Regional signals are found to be dominant over continent-wide signals, with the exception of North America in April. The first two components for November and April are shown in Figure 3. Together, the two November components explain 26% of the hemispheric variance. Component 1 centers on the northern US Rockies and the northern US high plains and western Canadian prairie. Component 2 covers much of the variable zone in eastern Asia. In April, component 1 is found in western Asia, and component 2 covers a region spanning North America, along and just north of the US/Canadian border. Together, these two components explain 27% of the hemispheric variance in April.

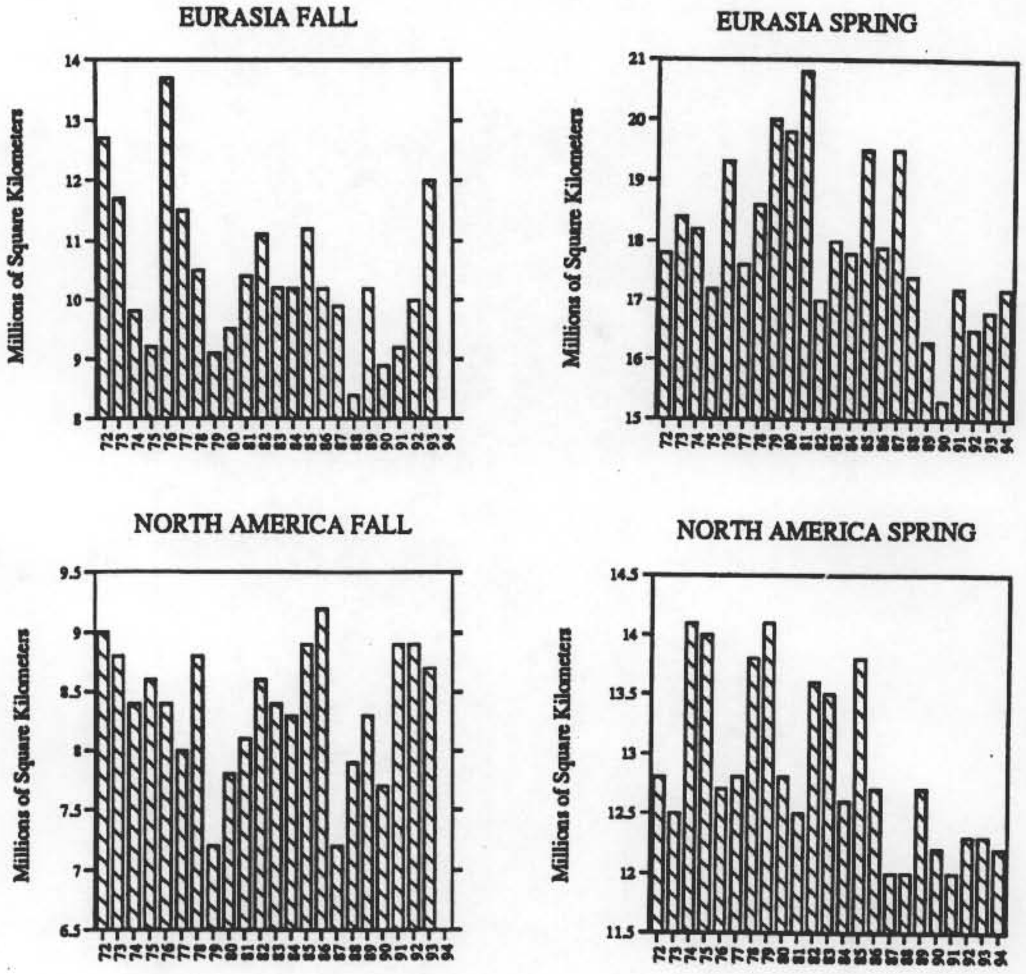


Figure 2. Extent of snow cover over Eurasia and North America (including Greenland) during falls (Sep-Nov) and springs (Mar-May) since 1972.

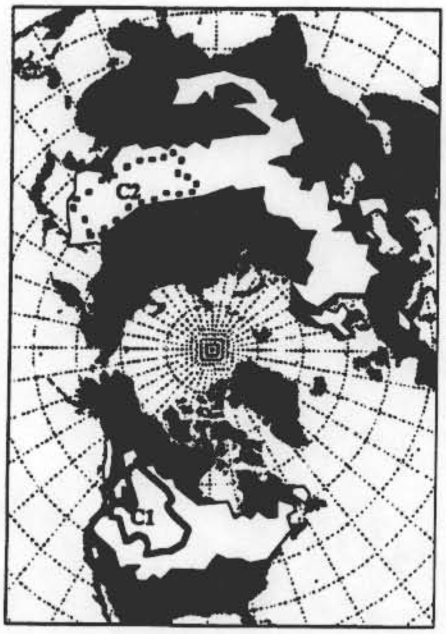
DISCUSSION

The highly variable nature of snow extent within the transition seasons must be associated with fluctuations in atmospheric patterns. We are beginning a detailed examination of these linkages by examining atmospheric conditions during periods of unusually rapid (one week) spatially extensive snow cover accumulation and ablation events across North America. The 20 largest one-week snow cover increases since 1972, as shown in the NOAA snow charts, all occur in fall. Composites of snow and atmospheric conditions during these events show the almost 4 million km^2 increase in snow extent to be associated with distinct and consistent atmospheric anomalies. These atmospheric conditions are conducive to spatially extensive snowfalls.

A composite of ten of these events occurring in late fall shows an abrupt increase in snow over the western area shown as November component 1 in Fig. 3a. The mean atmospheric pattern during this period has a region of anomalously high surface pressure (+7 mb) centered along coastal areas of southern Alaska and northern British Columbia. The major storm track lies roughly between 45° and 50°N, from the Pacific coast eastward into the US high Plains. These surface characteristics lead to unusually strong cold advection and an abundant supply of Pacific moisture across the western portion

(a)

(b)



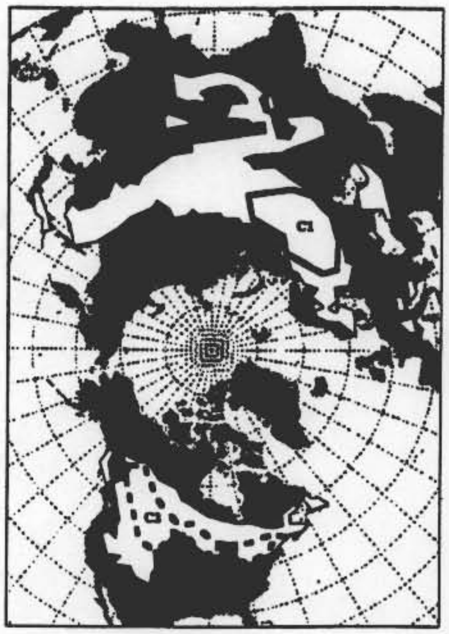


Figure 3. Land areas in white are zones of variable snow extent in November (a) and April (b) (cf. text for explanation). Contours within these zones show the first (solid) and second (dotted) principal components. Contours are plotted at 0.1 increments, starting at $r^2 = 0.3$.

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of North America. Temperature departures at 850 mb are -2°C and lower across the accumulation region, and the 850 mb 0°C isoline defines the southern margin of the accumulation region. At 500 mb, a relatively strong trough, in the anomaly sense, is found centered across the central US, a pattern consistent with the lower tropospheric features.

Decreases in snow extent for the 20 most abrupt weekly events appear to be connected with fluxes of sensible and latent heat associated with strong atmospheric disturbances. These events average almost 2.5 million km^2, and occur from the middle of March through the end of May. Late season episodes appear to be the result of a combination of anomalous heat fluxes and radiation induced melt.

CONCLUSIONS

The annual variability of snow cover extent is an important component of the climate system because of the effect of snow on the global radiation balance, as well as on seasonal temperature and moisture variations. Continued monitoring of hemispheric snow extent, particularly during the transition seasons, is needed to gain a better understanding of snow kinematics. Furthermore, the synergistic relationships between hemispheric-scale atmospheric circulation variations and continental snow extent must be understood before any meaningful projections of future climatic states can be made.

Acknowledgments

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