1. INTRODUCTION

Determination of whether observed global climate fluctuations of the last century result from anthropogenic causes, natural external forcing factors, or natural variability inherent in the climate system remains elusive. The continued warming predicted by many scientists is expected to be enhanced in higher latitudes due to the feedback effects of sea ice and snow cover. Greater understanding of the dynamics of these quantities is critical for understanding climate fluctuations.

Empirical and modeling studies have shown that snow cover affects energy and mass exchange between the surface and the atmosphere (Cess et al., 1991; Baker et al., 1992) and atmospheric dynamics (Ross and Walsh, 1986). Recent work by Leathers and Robinson (1993) show that snow cover over North America affects air temperatures on regional and continental scales. Grosisman et al. (1994) show that on a global scale the earth's radiative balance is most affected by snow cover during the spring. Snow can also have a lagged climatic effect, whereby early spring snow melt can result in low summer soil moisture. Additionally, due to its associations with temperature and other atmospheric variables, snow cover can be an indicator of climate fluctuations. In order to better understand these associations, improved information on the spatial and temporal dimensions of snow cover is required.

In this analysis we examine monthly snow cover variations in the fall and spring between 1972 and 1994. Special effort is given towards identifying regions exhibiting coherent inter-annual snow cover fluctuations during these seasons, which were chosen because of their high inter-annual variability compared with winter (Robinson et al., 1993).

2 DATA SET

National Oceanic and Atmospheric Administration (NOAA) weekly snow charts serve as the primary source of data in our study. NOAA has produced these charts for northern hemisphere lands since 1966. However, only since 1972, with the deployment of the

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5. SUMMARY AND CONCLUSIONS

Both regional and continent-wide snow cover signals are observed in the northern hemisphere during fall and spring. Regions are identified that have coherent, persistent snow cover fluctuations during several months of the year. Regional analyses, such as presented here, are necessary to understand these observations. For example, during the recent period of low Eurasian snow cover during October and March, a shift is observed in the nature of snow cover dynamics.

Prior to the mid-1980s snow cover fluctuations were dominated by one particular region in each month. More recently a continent-wide signal emerges that is dominant in October, but remains weaker than the regional signal in March.

This study is the first time that PCA has been used to analyze the remotely sensed hemispheric snow cover record. These results, which are being expanded to include all months and regions, are being applied to other climatic studies, including: analysis of regional fluctuations to identify potential climatic teleconnections; the application of this procedure to climate model results to aid in model evaluation; comparison to other snow cover observations; and improved climate change monitoring, detection, and prediction.
least three to four percent of the variance for the entire hemisphere usually load onto regions that are clearly bounded spatially. "Strong" regional signals are defined as components that explain at least 50% of the signal in a portion of a region; "weak" regional signals explain 20% to 50% of the variance. The geographic extent of regions are defined according to the strong component unless otherwise stated. Components are numbered such that lower numbers (e.g. C1) explain more of the hemispheric snow cover variance for that month than higher numbers (e.g. C10). An "active" region for a particular month is one in which the grid points are included in the analysis.

4.1 Identifying Regions of Coherent Snow Cover

Regions having coherent snow cover fluctuations are mapped in figure 1. Of the 25 regions identified, 11 have coherent snow cover signals in at least two months. Regions with signals in more than one month are outlined using the outer boundaries of all relevant monthly signals. The absence of coherent signals on a hemispheric scale is clearly indicated by the size and number of regions. No components have even weak signals covering diverse portions of both continents. Figure 2 shows the active areas for October and March overlaid by contour plots of the top component loadings. Figure 2a shows components 1 and 2 (C1, C2) for October, which together explain 29.7% of the variance; figure 2b shows C1 and C2 for March, which together explain 25.7% of the variance. The time series for these months are discussed in section 4.2.

Three key regions are recognized, each of which has strong coherent signals during all months of their accumulation and melt seasons, are described below.

The largest, covering Northern Europe and Western Siberia, is identified in October (C1), November (C5), April (C1), and May (C5). In October, a signal is identified from the Finish border all the way into the Siberian highlands (cf. figure 2a). This is the largest component identified in any one month of either season. In November as the snow season progresses, the active zone shifts southward and the signal concentrates westward: C5 of November lies over the Russian plains west of the Urals. As the melt season begins in April this region is again identified as C1 and covers a large area, stretching from 40° to almost 80° E. In May a signal is identified in the northern European Plains from the Finish border to the Urals, although the weak portion of the signal extends over the Urals into the west Siberian plains. This region is the only one identified as the first component in more than one month.

The most persistent North American region (C5 of October, C3 of November, C4 of April, and C1 of May) is found across the Canadian Shield between the boreal forests of the Northwest Territories and southern Quebec. In October, the onset of the snow season for most of Canada, the region covers the western and southern Canadian Shield from Great Slave Lake to just southeast of Hudson Bay. The signal is concentrated farther southeast across the southern shield in November, from Lake Winnipeg to south of James Bay. In April, as the melt season begins in southern Canada, the signal stretches from central Saskatchewan to southern Quebec. This signal in May covers its largest area of any month, from the Northwest Territories to southern Quebec (70°-115° W).

The third key region, the East Asian Highlands, is centered over the Manchurian plains and the highlands to their north. Strong signals are observed in October (C10), November (C2), April (C3), and May (C2). During November and May, snow cover fluctuations are linked to fluctuations in the central Asian highlands. October coherent signals are found only in the northern
and eastern sections of this region, the remainder of the region falling outside the active zone. November snow cover fluctuations are coherent from the east Asian highlands into central Asia in a region stretching almost from the coast to Lake Baikal.

4.2 Regional Time Series

Previous analyses of snow cover time series have found evidence of coherent continental or hemispheric fluctuations. Global snow cover extent has been inversely related to global temperatures (Robinson and Dewey, 1990); and, positive correlations are found between snow cover fluctuations over widespread areas of the northern hemisphere (Gutzler and Rosen, 1992; Robinson et al., 1994). Examination of PCA results from two months shows that despite continental scale correlations, regional snow cover dynamics have shifted over time.

Figures 3 and 4 show Eurasian snow cover and PCA score time series for October and March. Both of these months have had below average snow cover since 1987. The first components of each of these months explain comparable percentages of the variance (19.8% and 14.2%, respectively). Yet, evaluation of time series reveals that C1 of October is much less correlated ($r^2 = 0.29$) ($r =$ Spearman correlation coefficient) to the Eurasian snow cover signal than is C1 of March ($r^2 = 0.67$). Critical values of $r^2$ at the 0.01 (one-tailed) significance level are 0.26 for October ($n=22$) and 0.25 for March ($n=23$).

In light of observed pan-continental correlations, it is interesting to note changing regional dynamics. During October a change occurred during the mid 1980s, when continental scale fluctuations shifted from being primarily influenced by conditions in one particular region to a more continent-wide signal. Prior to 1987 the correlation between C1 and the hemispheric signal ($r^2 = 0.50$) is much greater than between the sum of other Eurasian components and the hemispheric signal ($r^2 = 0.05$). However, during the period 1987 through 1993, C1 correlates poorly to Eurasian snow cover ($r^2 = 0.29$) while the lesser components are highly correlated ($r^2 = 0.74$). Thus, we observe a fundamental shift in the regional dynamics of snow cover during October.

In March the regional dynamics also changed, but less dramatically. Eurasian snow cover fluctuations are highly correlated to the first component (Eastern Europe) for the entire period of record: $r^2 = 0.65$ prior to 1987, $r^2 = 0.74$ since 1987. The lesser Eurasian components, when combined, are uncorrelated to Eurasian snow cover prior to 1987 ($r^2 = 0.02$). For the period 1987 through 1994, however, the lesser