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A NORTHERN HEMISPHERE SNOW COVER CLIMATOLOGY USING SATELLITE INFORMATION

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1. INTRODUCTION

The large-scale distribution of snow cover over Northern hemisphere lands is a topic that has received considerable attention in recent years. This interest has been spurred by concerns related to potential changes in the global climate system associated with anthropogenic and natural causes. Accurate information on snow extent and depth (or water equivalent) is also critical for understanding the role of snow in the climate system, for developing accurate weather and hydrological forecasts, and for parameterizing and verifying climate models.

Since 1972, weekly visible wavelength satellite maps of Northern hemisphere snow cover produced by the National Oceanic and Atmospheric Administration (NOAA) have provided an extremely useful means of assessing hemispheric snow cover. This paper will examine means and fluctuations of hemispheric snow extent in recent decades using this information. In addition to presenting a time series of monthly snow extent from 1972 to present, observations from March will be used to exemplify regional and temporal characteristics of hemispheric snow.

Studies which have utilized the NOAA snow data for understanding snow cover kinematics include Matson & Wiesnet (1981), Dewey & Heim (1982), Barry (1990), Robinson et al. (1991), Iwasaki (1991), Gutzler & Rosen (1992), and Masuda et al. (1993). Recent studies that use NOAA snow data to investigate snow cover synergistics within the climate system include Leathers & Robinson (1993; 1997), and Karl et al. (1993).

2. NOAA SNOW CHARTS

NOAA Meteorologists produce weekly charts of snow extent across Northern Hemisphere lands from a visual interpretation of photographic copies of visible-band satellite imagery. These charts are subsequently digitized to the National Meteorological Center Limited-Area Fine Mesh (LFM) grid (cf. Matson et al. (1986) and Robinson (1993) for further details on NOAA charts). Charts produced since 1972 are considered useful for large-scale climate studies (Wiesnet et al., 1987). The climate group at Rutgers is in the midst of a project to reanalyze visible imagery and generate improved weekly snow charts for fall 1966 through 1971 (to be completed in 1998). While visible imagery is recognized as a very useful means of assessing regional snow cover, it does have some shortcomings. These include: 1) the inability to detect snow cover when solar illumination is low or when skies are cloudy, 2) the underestimation of cover where dense forests mask the underlying snow, 3) difficulties in discriminating snow from clouds in mountainous regions and in uniform lightly-vegetated areas that have a high surface brightness when snow covered, and 4) the lack of all but the most general information on snow depth (Dewey & Heim, 1982).

Snow extents discussed in this paper use monthly means of snow cover calculated using a routine described fully in Robinson (1993). This routine calculates weekly areas from the digitized snow files, and then to obtain a monthly value, weights them according to the number of days of a chart week falling in the given month. A chart week is considered to center on the fifth day of the published week. To correct for an inconsistency in the original NOAA files, the digital files are standardized to a common land mask, including only those LFM grid cells that contain more than 50% land

3. SPATIAL CHARACTERISTICS OF SNOW

An analysis of the NOAA data finds that mean annual Northern hemisphere snow cover extent is 25.3 million square kilometers, with 14.7 million sq. km. over Eurasia and 10.6 million sq. km. over North America (including Greenland). On average, snow covers from 46.5 million sq. km. of hemispheric lands in January to 3.7 million sq. km. in August (mostly over Greenland).

March snow extent, shown in figure 1, averages 40.8 million sq. km., and has ranged from 37.0 (1990) to 44.1 (1985) million sq. km. Most lands north of 45°N, exclusive of western Europe and inclusive of mountainous areas farther south, are snow covered at least 50% of the time. The potential for at least several days with snow cover reaches well into the middle latitudes. Another way to illustrate the zone of ephemeral March cover is shown in figure 2. Areas with 10% to 90% snow cover during at least 8 of the 23 Marches investigated (1972-94) are shown.

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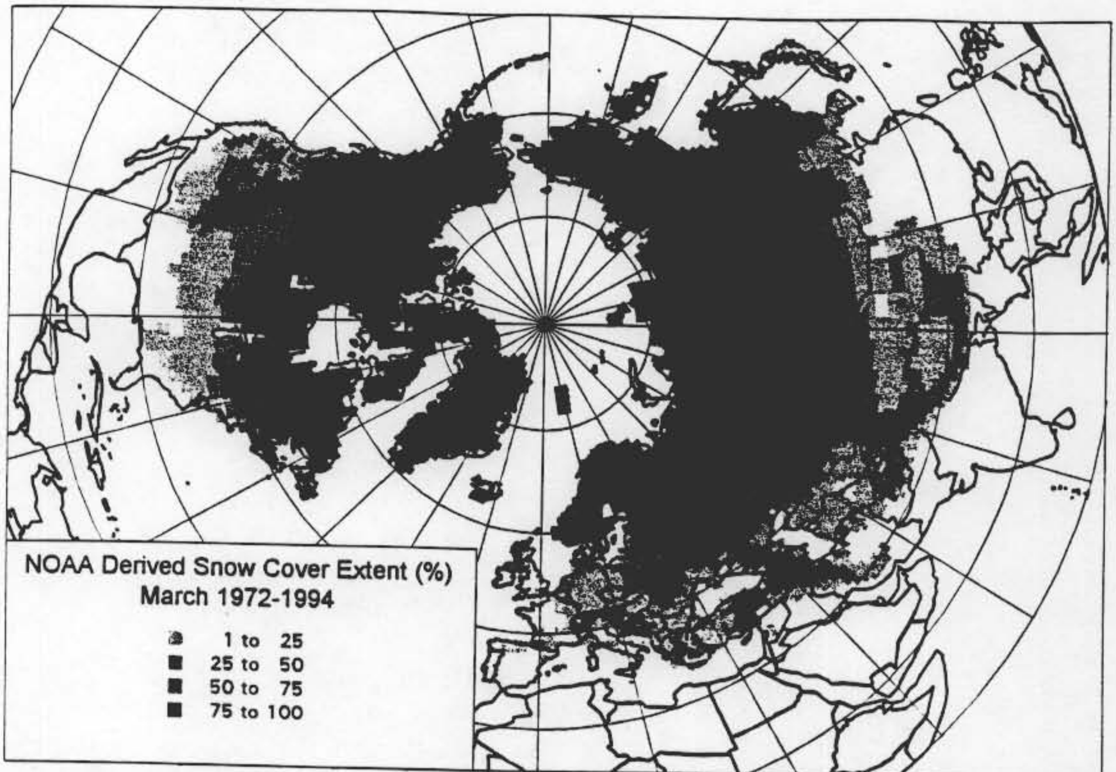

Figure 1. Frequency of snow cover over Northern hemisphere lands during March. Percentages are based on analyses of NOAA weekly charts between 1972 and 1994.

Regions of "coherent" snow extent fluctuations during March are also delineated in Figure 2. Within each region, interannual fluctuations of snow extent have greater than 50% of their variance explained by a common signal. Linear multiple regression analyses indicate that just two signals over North America (one from each coherent region) explain 81% of the variance in the continental snow signal, while the six coherent regions over Eurasia explain 88% of the signal (table 1). Coherent regions vary in size and number from month to month, and explain much of the variance in continental fluctuations, especially from October through April.

4. TEMPORAL CHARACTERISTICS OF SNOW

Monthly anomalies of hemispheric snow extent, although generally less than 2 million sq. km., occasionally exceed 4 million sq. km. (figure 3). During recent years, snow cover has been less extensive than during the earlier part of the satellite record over both Eurasia and North America. This difference is not associated with a steady decrease of snow extent, but rather with a step change. Between 1972 and 1985, twelve-month running means of snow extent fluctuated around a mean of 25.9 million sq. km. A rather abrupt transition occurred in 1986 and 1987, and since then mean annual extent has been 24.2 million sq. km. The means of these two periods are significantly different (T test, $p < 0.01$).

These recent decreases in snow extent are large during the late winter, spring and summer; from fall through mid-winter show no statistically significant change is found. Decreases are observed over both continents. Monthly observations show the decrease beginning in February. During 7 of the first 15 years of record (1972-86), February snow extent exceeded the January value, while this has occurred only once in the past decade.

5. CONCLUSIONS

The 25 year record of Northern hemisphere snow cover derived from weekly NOAA charts permits regional and hemispheric climatologies to generated. This provides useful information on the means, extremes and variability of snow extent. As discussed elsewhere in this volume (Robinson, P1.1), the NOAA set is being combined with microwave satellite and

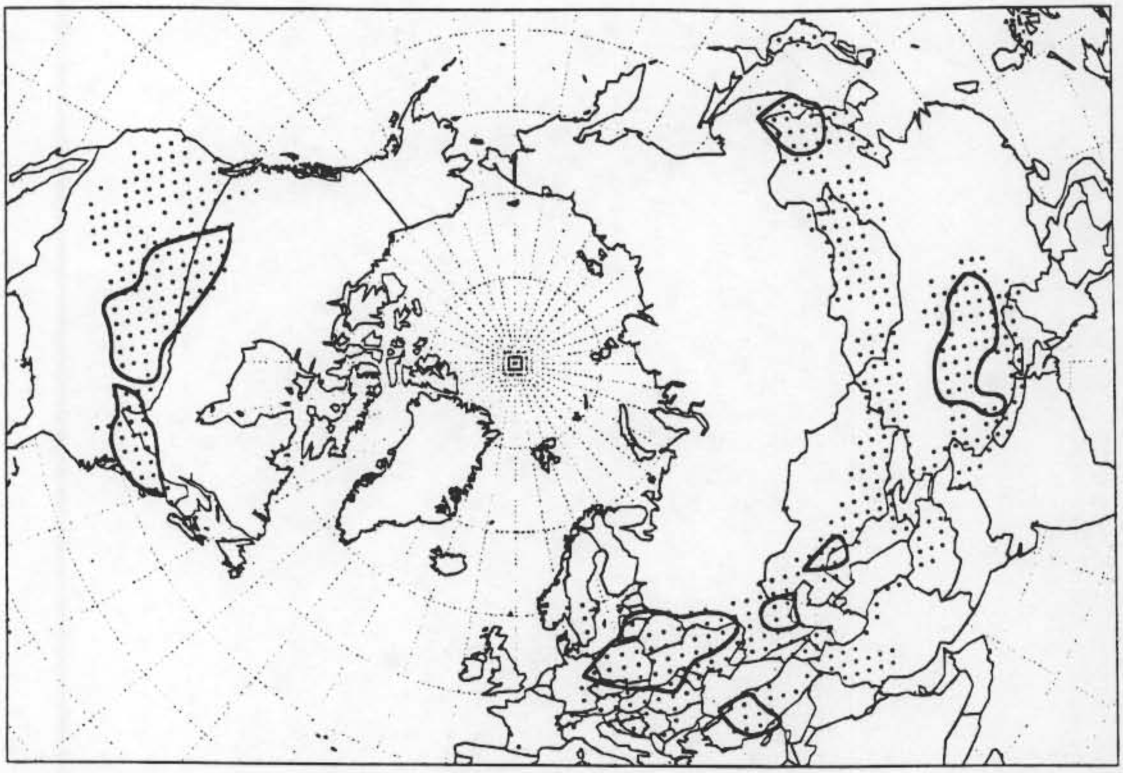

Figure 2. Areas in which snow is ephemeral during March (10-90%) snow cover during at least 8 years within the 1972-94 period) are shown with dots. Regions of coherent snow extent fluctuations during this interval are outlined with bold lines. These are regions within which interannual fluctuations of snow extent have greater than 50% of their variance explained by a common signal.

	Eurasia		North America	
MO	# Reg	r^2 (%var)	# Reg	r^2 (%var)
SEP	6	63	3	35
OCT	5	82	4	89
NOV	7	84	4	82
DEC	7	82	2	73
JAN	8	90	3	63
FEB	7	75	1	88
MAR	6	88	2	81
APR	7	81	2	91
MAY	6	65	3	67
JUN	*4	74	*3	53

Table 1. Summary of results from linear multiple regression analyses of monthly continental snow cover. Shown for Eurasia and for North America are: (# Reg) number of coherent regions; (r^2) percent of variance in observed snow cover explained by predicted continental signal (all values shown are significant at ≥95%, 1-tailed, n=23). * indicates that June was the only month where one PC was associated with a coherent region on each continent.

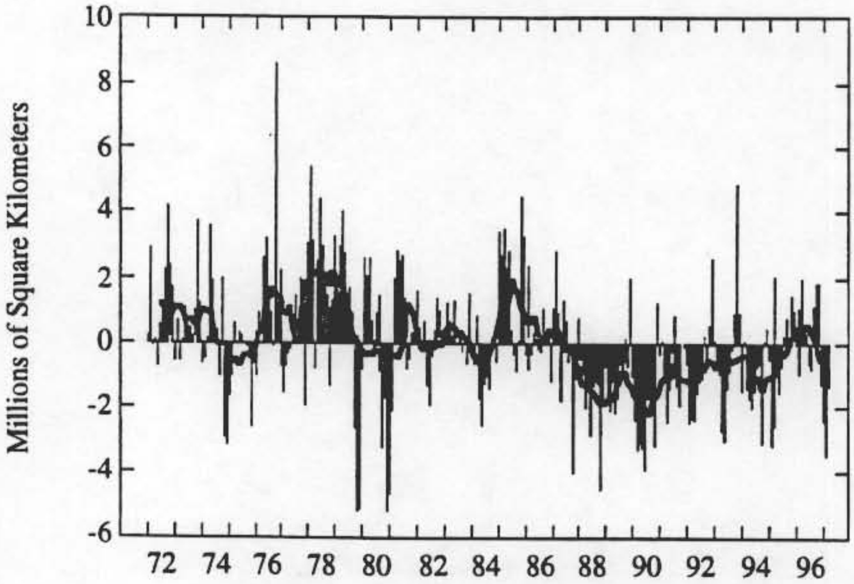

Figure 3. Anomalies of monthly snow cover extent over Northern hemisphere lands (including Greenland) between January 1972 and April 1997. Also shown are twelve-month running anomalies of hemispheric snow extent, plotted on the seventh month of a given interval. Anomalies are calculated from NOAA visible charts. Mean hemispheric snow extent is 25.3 million sq. km. for the full period of record.

station observations into a unique multi-source database. This, along with the 1966-71 recharting of hemispheric snow, will further improve our understanding of continental snow cover.

Given the relatively short time in which hemispheric monitoring of snow cover from space has been possible, it is difficult to fully understand the significance of the apparent stepwise change in snow extent in the middle 1980s. It is certainly premature to ascribe the less-extensive regime in recent years to a global warming. It is noteworthy, however, that the extent of snow cover appears to be inversely related to hemispheric surface air temperature (Robinson & Dewey, 1990), and, particularly in spring, snow cover may be strongly influencing temperature through a feedback mechanism (Groisman et al., 1994).

Studies using the NOAA snow data, in conjunction with other climatic information, are helping us to place recent variations in historic perspective (Hughes and Robinson, 1996) and to better understand the synergistic relationships between hemispheric-scale atmospheric circulation, thermal variations, and regional snow extent (Frei et al., 1996). These and future snow investigations will help establish more meaningful projections of future climatic states.

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