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J7.5 NORTHERN HEMISPHERE SNOW EXTENT DURING THE SATELLITE ERA

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1. INTRODUCTION

The large-scale distribution of snow cover over Northern Hemisphere lands 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 is 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's (NOAA) National Environmental Satellite Data and Information Service (NESDIS) have provided an extremely useful means of assessing hemispheric snow cover (Matson et al., 1986; Robinson et al., 1993). These maps constitute the longest satellite-derived environmental dataset available. Studies which have utilized the NOAA/NESDIS snow data for understanding snow cover kinematics include Matson and Wiesnet (1981), Dewey and Heim (1982), Barry (1990), Robinson et al. (1991), Iwasaki (1991), Gutzler and Rosen (1992), Masuda et al. (1993), and Robinson (1997). Recent studies that use NOAA snow data to investigate snow cover synergistics within the climate system include Leathers and Robinson (1993; 1995; 1997), and Karl et al. (1993). Frei and Robinson (1998) also use the NOAA/NESDIS data to evaluate model output of snow extent.

This paper will examine the variability of hemispheric snow extent in recent decades using this information. Records of Northern Hemisphere snow extent will be presented by season and continent through summer 1998. Efforts to expand the snowmap series back to late 1966 will also be discussed, as will the ongoing transition from a weekly to daily product.

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2. NOAA/NESDIS WEEKLY SNOWMAP

Trained meteorologists produce the weekly NESDIS snow product from visual analyses of visible satellite imagery. The primary data source is visible imagery acquired from NOAA-n polar orbiting satellites and is stored in hardcopy. Secondary data sources include online GOES, GMS, and METEOSAT imagery. Snow cover identification is made by the manual inspection of hardcopy imagery and graphics products, online imagery loops, and the previous week's analysis. Map quality is predicated on the availability of clear sky visible imagery and the meteorologist's experience. After all snow boundaries have been identified and placed on a hardcopy map an electronic version is made through the digitization of a 89 x 89 cell acetate overlay of the polar stereographic map.

Monthly means of snow cover are calculated using a routine described fully in Robinson (1993). Weekly areas are derived from the digitized snow files, and subsequently monthly values are obtained by weighting the weeks according to the number of days of a map week falling in the given month. Prior to the calculations, the digital files are standardized to a common land mask. Only those LFM cells that contain more than 50% land are included. This corrects an inconsistency in the original NOAA/NESDIS files.

3. SNOW COVER VARIABILITY: 1972-PRESENT

The 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). Monthly standard deviations range between 1.0 million sq. km. in August to 2.9 million sq. km. in October. Snow cover was more extensive in the first half of the satellite record than found in the

past decade (figure 1). Between 1972 and 1985, annual means of snow extent fluctuated around a mean of 25.9 million square kilometers. An abrupt transition occurred in 1986 and 1987, and since then the mean annual extent has been 24.2 million sq. km. Means of these two periods are significantly different (T test, $p < 0.01$). Monthly anomalies from the long-term mean are most often less than 3 million sq. km., however on occasion they range to 4 and 5 million sq. km., with October 1976 having a positive anomaly of over 8 million sq. km. What appeared to be a gradual rebound from low extents in the late 1980s and early 1990s as seen in the twelve-month running means culminated, at least temporarily, in 1995. Recently, values have fallen back to those previously observed only between 1988 and 1994.

Throughout the satellite era, Eurasia and North America have exhibited the same broad variations in snow extent (figure 2). However, there are differences on annual and shorter time scales. For instance, the positive anomalies of the latter portion of the 1970s were first observed over Eurasia in the middle of 1976, but did not appear over North America until early 1978. Conversely, negative anomalies began first over North America in late 1986, then in late 1987 over Eurasia. Recently, negative anomalies were seen over Eurasia during the winter of 1996/97, yet not over North America, while North American anomalies were more negative than Eurasian values in the winter of 1997/98.

Recent decreases in snow extent are large during the spring and summer, while winter and fall extents show no statistically significant change (figure 3). The tendency towards less late-season cover in recent years begins in February (not shown). During 7 of the first 15 years of record, February snow extent exceeded the January value. This has occurred only once in the past 12 years.

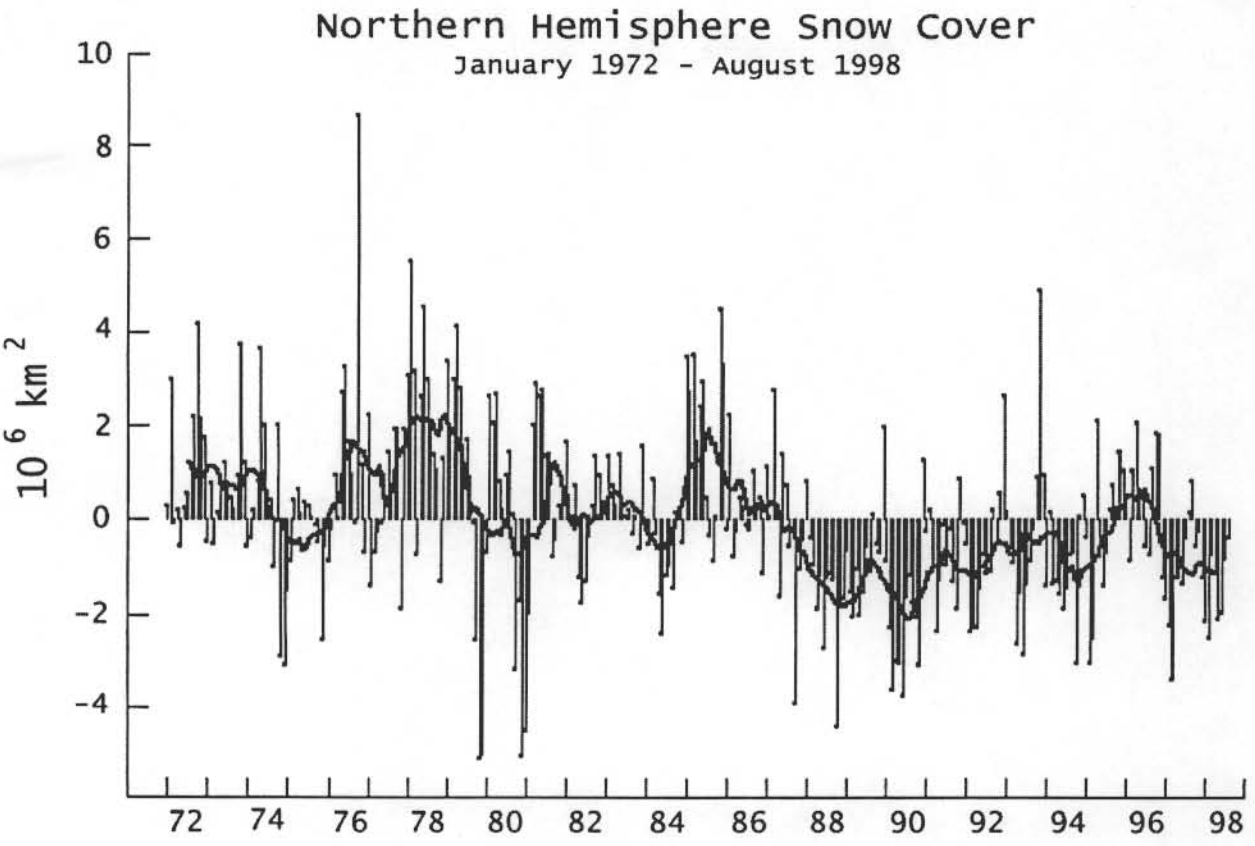

Figure 1. Anomalies of monthly snow cover extent over Northern Hemisphere lands (including Greenland) between January 1972 and August 1998. Also shown are twelve-month running anomalies of hemispheric snow extent, plotted on the seventh month of a given interval. Anomalies are calculated from NOAA/NESDIS snowmaps. Mean hemispheric snow extent is 25.3 million sq. km. for the full period of record.

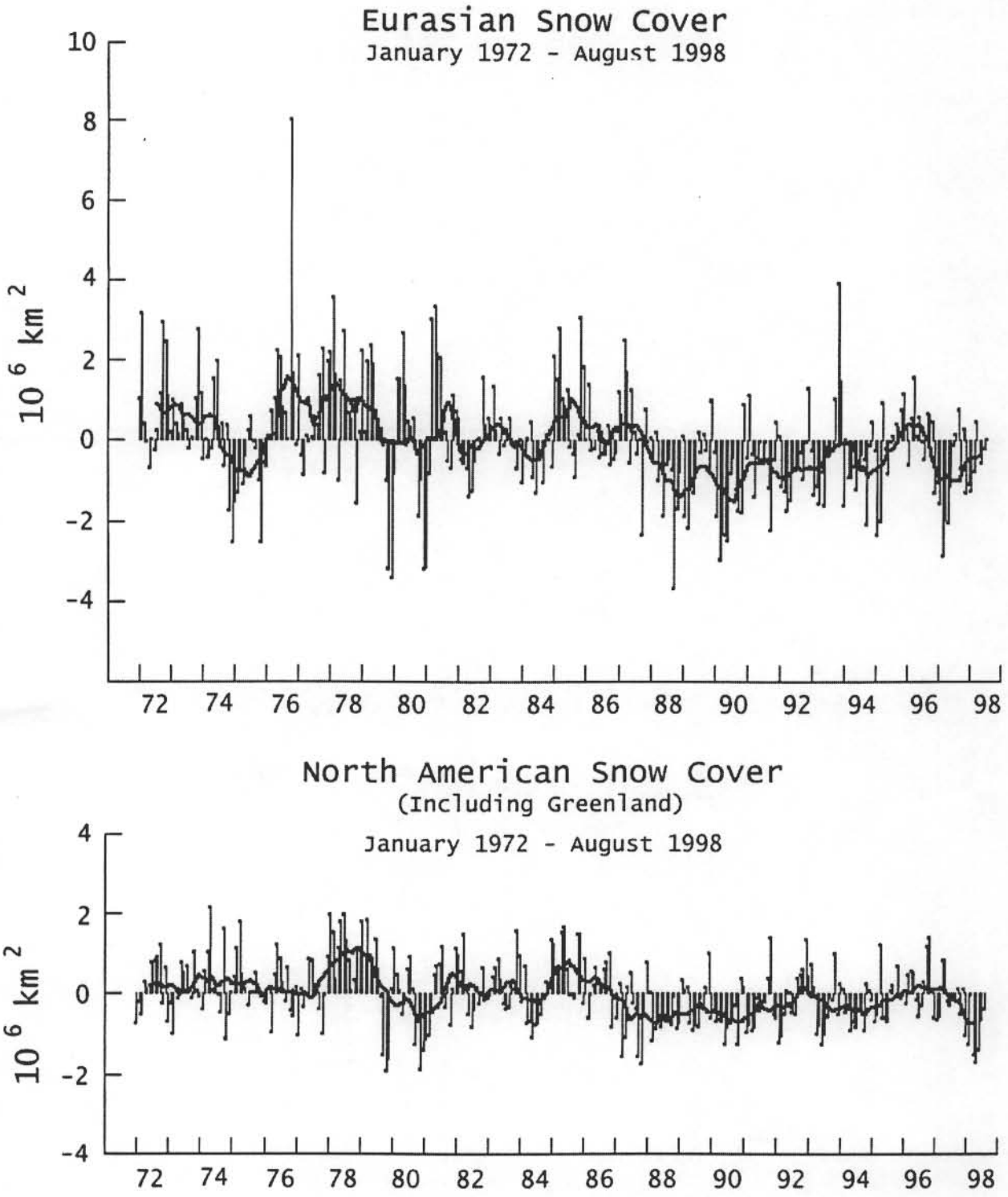

Figure 2. Anomalies of monthly snow cover extent over Eurasia (top) and North America (including Greenland) (bottom) between January 1972 and August 1998. Also shown are twelve-month running anomalies of snow extent, plotted on the seventh month of a given interval. Anomalies are calculated from NOAA/NESDIS snowmaps. Mean snow extent is 14.7 million sq. km. over Eurasia and 10.6 million sq. km. over North America for the full period of record.

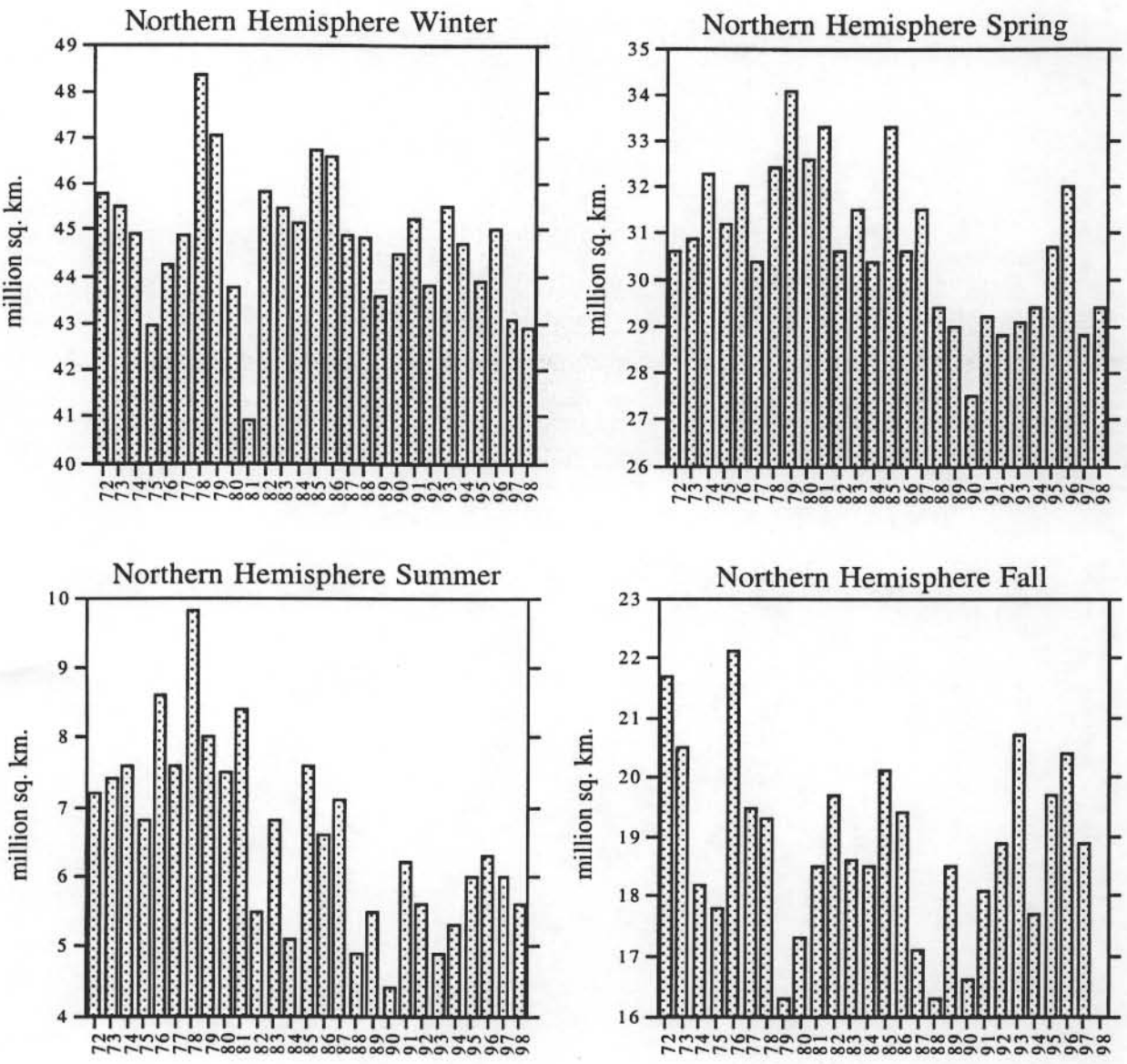

Figure 3. Seasonal snow cover extent over Northern Hemisphere lands (including Greenland) between winter (Dec '71 - Feb '72) 1972 and summer (Jun - Aug) 1996. Calculated from NOAA/NESDIS snowmaps

4. EXPANDING THE RECORD

NOAA/NESDIS weekly snowmaps actually began to be produced in late 1966; however early ones tended to underestimate snow extent, particularly during the fall (Kukla and Robinson, 1981). A major reason for this problem was the early inexperience of analysts in distinguishing snow cover from clouds or even from snow-free ground, compounded by the lower resolution of imagery during this era compared to the post 1972 period. An effort to reanalyze the 1966-71 imagery and produce a new set of snowmaps is underway at Rutgers. Preliminary results suggest that the original late 1960s maps erred on the low side; and extents are somewhere between those observed in the 1970s and those in the past decade. Final results will be available in early 1999.

NOAA will cease production of the weekly snowmaps in May 1999. A daily product produced using the Interactive Multisensor Snow and Ice Mapping System (IMS) is replacing them. The IMS product is generated from a UNIX-based workstation application that provides the analyst the ability to visually inspect imagery and mapped data from various sources to determine the presence of snow over Northern Hemisphere lands. Daily snowmaps are produced from a variety of visible satellite imagery, estimates of snow extent derived from microwave satellite data, and station mapped products. These maps went into routine production in February 1997 and this product was declared operational in November 1997. Along with its climatologic utility, the daily snowmap is being used to specify surface boundary conditions in numerical weather forecast models run by the National Weather Service's National Center for Environmental Prediction (NCEP). NCEP evaluated the daily snowmap and began using it operationally in the NCEP ETA model in June 1998.

NESDIS management agreed to generate both the weekly and daily snowmaps for two complete Northern Hemisphere snow seasons (1997/98 and 1998/99) to minimize uncertainties when merging these to two databases. Initial results of a NESDIS-Rutgers validation effort suggest that a transition from the weekly to daily product will not lead to a major artificial step change in the estimate of snow extent over Northern Hemisphere lands (Robinson et al., 1999).

5. CONCLUSIONS

Given the relatively short time in which hemispheric monitoring of snow cover has been possible from space, it is difficult to fully understand the significance of the stepwise change in snow extent in the middle 1980s. It is noteworthy, however, that the extent of snow cover appears to be inversely related to hemispheric surface air temperature (Robinson and Dewey, 1990), and, particularly in spring, snow cover anomalies may be strongly influencing temperature variations through a feedback mechanism (Groisman et al., 1994). Using station data, estimates of snow cover from the pre-satellite era suggest that fluctuations seen in recent decades are not unusual, and at least over North America, the 1970s and early 80s were one of the snowiest periods this century (Hughes and Robinson, 1996).

The soon to be completed reanalysis of the late 1960s imagery will extend the current satellite record of hemispheric snow extent beyond 30 years, and efforts to make the current transition from weekly to daily mapping as seamless as possible will a confident continuation of this valuable time series. This information will be invaluable to ongoing studies of regional and hemispheric snow cover kinematics and synergistics within the climate system.

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