

AN ANALYSIS OF THE NOAA SATELLITE-DERIVED SNOW COVER RECORD, 1972-PRESENT

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Introduction

The large-scale distribution of snow cover over northern hemisphere lands has been a topic of increasing attention in recent years. This interest has been spurred, at least in part, by concerns associated with potential changes in the global climate system associated with anthropogenic and natural causes. Satellite observations using visible satellite imagery permit a hemispheric analysis of snow extent. For almost three decades the National Oceanic and Atmospheric Administration (NOAA) has been using visible imagery to produce weekly charts depicting the extent of snow cover over northern hemisphere lands. These charts constitute the longest satellite-derived environmental dataset available on a continuous basis and produced in a consistent manner. We will briefly describe the NOAA charts and then provide an update on the variability of snow extent over the hemisphere from January 1972 through August 1995. Concentration will be on snow kinematics, as found formerly in 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, for example, Leathers & Robinson (1993; 1995), and Karl et al. (1993).

NOAA Snow Charts

Weekly snow charts produced by NOAA depict boundaries between snow-covered and snow-free land surfaces. They are produced from visual interpretation of photographic copies of visible-band satellite imagery, primarily Advanced Very High Resolution Radiometer (AVHRR) data. Charts show snow boundaries on the last day that the surface in a given region is observed. Since cloud cover can mask the surface, this is often not the last day of the chart week. On average, charts tend to represent the fifth day of a week. Charts are digitized on a weekly basis 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). While NOAA charts have been produced since 1966, early ones tended to underestimate snow extent, particularly during fall. Charting accuracy improved considerably in 1972, when VHRR and later AVHRR data began to be used. Data since 1972 are considered to be of high enough quality for use in climate studies (Wiesnet et al., 1987).

For our investigation, monthly means of snow cover area are calculated using a routine described fully in Robinson (1993). The Rutgers routine calculates weekly areas from the digitized snow files and to then 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 chart week. Prior to the calculations, the digital files are standardized to a common land mask that includes those and only those LFM cells at least half covered by land. This corrects an inconsistency in the original NOAA files.

Snow Cover: 1972-present

Mean annual northern hemisphere snow cover is 25.4 million km². On average, 14.7 million km² lies over Eurasia and 10.6 million km² over North America (including Greenland). In figure 1, the variability of snow cover over the Northern Hemisphere between January 1972 and August 1995 is expressed through anomalies of individual months and twelve-month running means. Monthly anomalies of greater than 4 million km² have been observed occasionally throughout the past 24 years, although they are generally less than 2 million km².

Two pronounced snow regimes are evident during the period of record. Between 1972 and 1985, twelve-month running means of snow extent fluctuated around a mean of approximately 25.9 million km². A rather abrupt transition occurred in the 1986/87 period to a new regime from 1988 to the present where snow extent fluctuates around a running mean of about 24.2 million km². This recent interval is marked by a decrease in spring and early summer snow extent compared to the earlier period (figure 2). Changes are evident over both North America and Eurasia. Individual years of fall and winter snow cover vary around means that have remained more stable during the satellite era.

Zones exhibiting year-to-year variability in snow cover extent have been identified for each month of the year. Figure 3 shows these "action" areas for November and April, defined as locations where the surface is snow covered between 10% and 90% of the time in at least one third of the years between 1972 and 1994. This rather broad criterion excludes those regions where snow cover is extremely common or rare during a particular month. The variable zone in November straddles the US/Canadian border from coast to coast, and plunges into the US Rockies and high Plains. 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. 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) has been 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 has been performed to allow for more clear visualization. Regional signals are found to be dominant over continent-wide signals in all months. 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.

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 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. However it is noteworthy that the extent of snow cover appears to be inversely related to hemispheric surface air temperature (Robinson & Dewey, 1990), and, particularly in spring, feedbacks associated with the extent of the snowpack may be strongly influencing temperature (Groisman et al., 1994). Further studies using the NOAA set in conjunction with other climatic information are needed to better understand the synergistic relationships between hemispheric-scale atmospheric circulation and thermal variations and continental snow extent before any meaningful projections of future climatic states can be made.

NOAA will soon be discontinuing production of the weekly snow charts and replace them with daily ones. While still incorporating visible imagery, the new product will rely heavily on satellite passive microwave-derived estimates of snow extent. Plans are to conduct at least a twelve-month comparative study of the two products before discontinuing the current visible-only one. The appearance of MODIS-derived snow charts later in this decade will be a welcome addition to hemispheric snow charting efforts. The MODIS channels will provide the ability to better discriminate between snow and clouds. And perhaps with the development of procedures incorporating multiple visible and near infrared channels, snow will be identified more accurately in cloud-free areas. Together, the NOAA and MODIS products will provide an unprecedented means of assessing the seasonal and interannual fluctuations of this influential component of the climate system.

Acknowledgments

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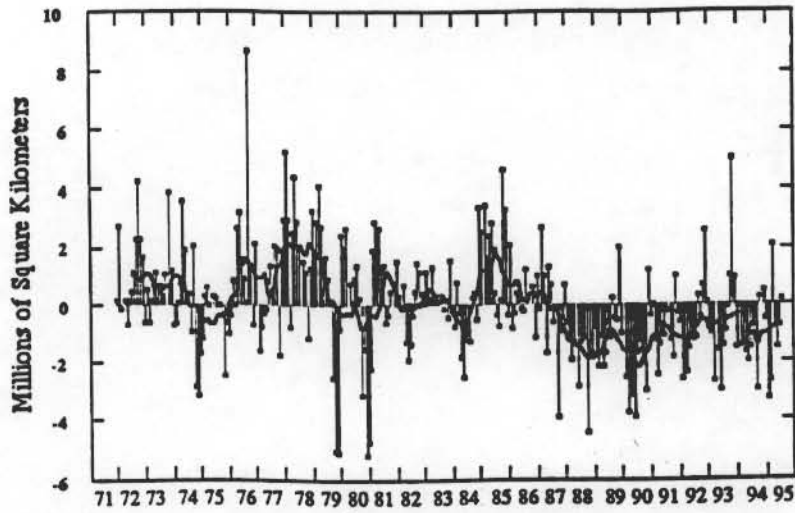


Figure 1. Anomalies of monthly snow cover extent over northern hemisphere lands (including Greenland) between January 1972 and August 1995. also shown are twelve-month running anomalies of hemispheric snow extent, plotted on the seventh month of a given interval. Anomalies are calculated from a mean hemispheric snow extent of 25.4 million km² for the full period of record.

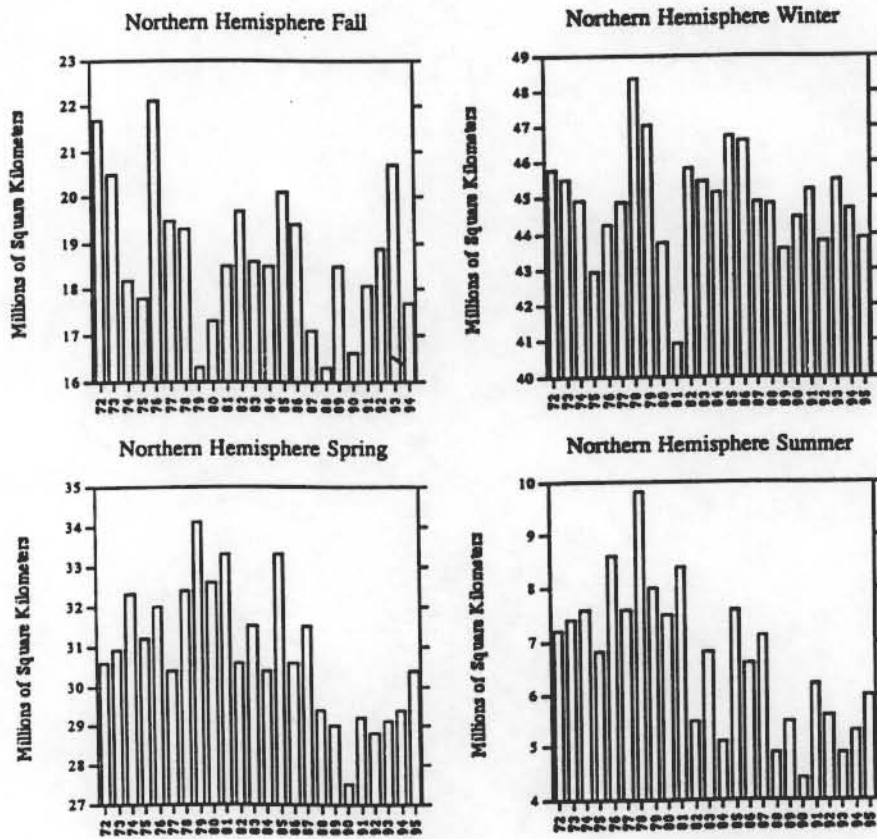
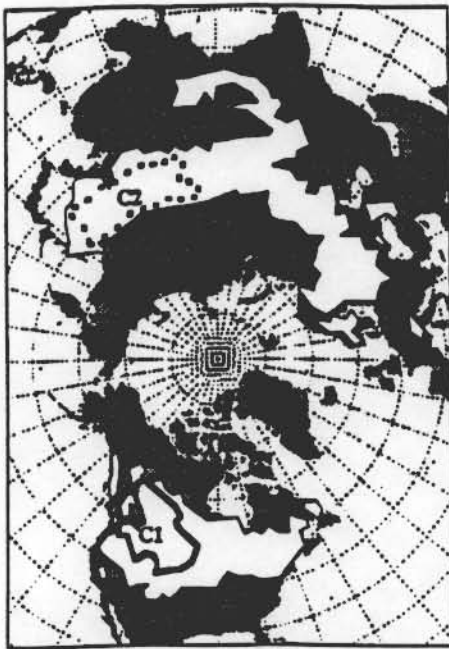


Figure 2. Extent of seasonal snow cover over northern hemisphere lands (including Greenland) since 1972.

(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 (dashed) principal components. Contours are plotted at 0.1 increments, starting at $r^2=0.3$.