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Merging operational satellite and historical station snow cover data to monitor climate change

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ABSTRACT

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Since the middle of 1987, snow cover over Northern Hemisphere lands has been less extensive than at any time since the advent of reliable satellite snow charting in 1972. In fact, 1990 should go down as being the lowest snow year on record: monthly minima have been established for February through September (based on observations through September). However, with less than a two-decade long record of satellite observations of snow cover, it is impossible to place this recent dearth of cover in proper perspective. To do so requires a longer period of record, one which can only be supplied from station data. Regional intercomparisons of visible satellite-derived snow products and networks of station observations agree well on a seasonal time scale, given a network of high-quality stations in non-mountainous terrain. Thus, where these conditions are met, lengthy time series of regional snow cover may be compiled confidently from station observations, permitting documentation of natural fluctuations and trends of cover that may have occurred over the past century. For instance, decadal fluctuations in snow cover have been identified over the United States Great Plains this century, and a trend towards increasing duration of cover from the 1930's to 1970's has been observed in the central Plains. Such information enhances the utility of satellite-derived snow cover observations in identifying and monitoring future climate change.

Introduction

Empirical and modeling studies alike show snow cover to be an important climate variable (Walsh et al., 1985; Barnett et al., 1989). Results from modeling studies show an amplification of global anthropogenically-induced warming in regions where snow cover is currently ephemeral (Manabe and Wetherald, 1980; Hansen et al., 1984; Dickinson et a., 1987). For these reasons, and due to the relative simplicity of mapping regional and hemispheric snow cover by satellite, snow cover should be a useful index for monitoring global climate change (Barry, 1985; Schlesinger, 1986). However, to fully understand the role snow cover plays in climate dynamics and climate change, lengthy snow cover records are necessary. Satellite-derived data extend back for only two decades, providing excellent spatial coverage over the short term, but an insufficient sampling in a temporal sense. Station snow cover observations lack spatial coverage, particularly in mountainous and polar regions; however, they often are of a long duration. In the following, comparisons of visible satellite and station-derived snow observations are made, and time series from each source are presented.

Data

Visible satellite-derived snow cover charts employed in this study are either produced by NOAA or derived from Defense Meteorological Satellite

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Program (DMSP) imagery expressly for this study. NOAA Weekly Snow and Ice Charts depict boundaries between snow-covered and snow-free land surfaces (Wiesnet et al., 1987). These snow lines are delimited by recognizing characteristic textured surface features and brightnesses of snow-covered lands. The charts show boundaries on the last day that the surface in a given region is seen. Similar methodology was employed in producing daily snow charts from DMSP imagery.

Station records used in this study were selected from a new set of historical daily climate data (Robinson, 1988). This set contains digitized records of snow cover, snowfall, precipitation, and temperature for 360 stations in the United States dating back to the turn of the century, and for 650 stations dating back to about 1930. Observations used in this study extend through February 1990, and they were carefully evaluated for inconsistencies and errors.

Satellite–station comparisons

Daily

A running estimation of daily snow cover was gleaned from satellite imagery over a 160,000 km^2 portion of the middle Mississippi Valley in March 1979. The area of snow cover was calculated on a daily basis once the entire surface had been observed from the imagery, which took nine days, leaving the last 22 days of the month for comparing with cover estimated from 60 stations in the region. Any areas that were cloudy during these 22 days were considered to retain the same surface conditions as when last seen. Station data were available for all days.

Overall, there was a 79% agreement between the two approaches (Fig. 1). Where differences occurred, the satellite product tended to overestimate snow cover. This was a result of cloudiness over ablation areas, leading to lags of as much as a week in identifying the loss of snow cover, as was the case between the 17th and 23rd. Clear skies throughout the region on the 24th and 25th permitted the satellite results to fall into line with the station observations, only to have clouds return at the end of the period, leading to further errors in the satellite product. In only a few cases did the satellites underestimate cover. Thus, in non-mountainous terrain, daily information on snow cover can best be obtained from station reports, given a sufficiently dense network.

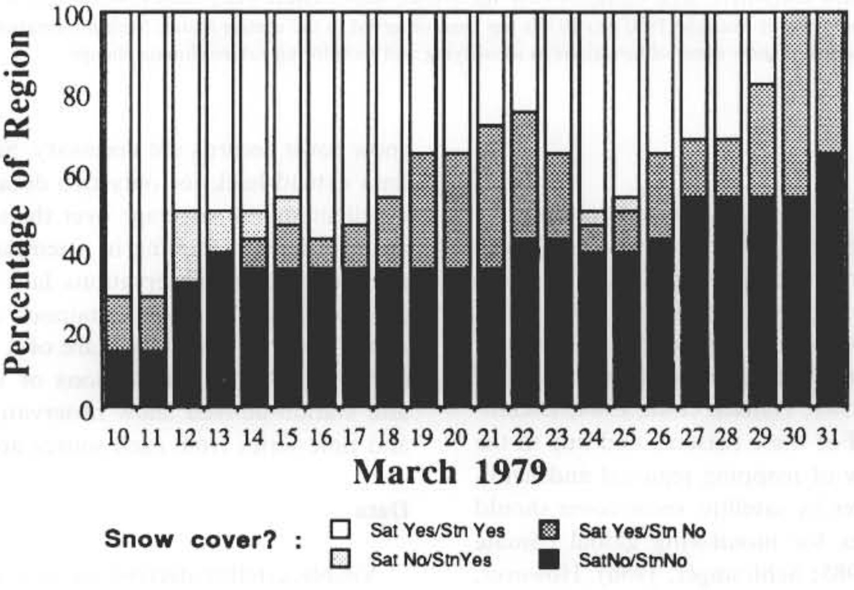

Fig. 1. Comparison between satellite (*Sat*) and station (*Stn*) derived snow cover estimates over the middle Mississippi Valley from March 10 to 31 March, 1979.

Seasonal cover: single station

Seasonal associations between satellite-derived snow cover and station data were examined in the vicinity of nine stations in the Great Plains of the United States. The state of the surface within approximately 50 km of a given station was determined from NOAA weekly snow charts for the winters (December–February) 1971/72–1989/90. Weekly tallies were subsequently converted to winter days with cover. These were compared with station observations of the number of days with snow cover of at least 2.5 cm (1 inch) and 7.6 cm (3 inches) for each of the 19 winters. There was a reasonably close agreement between the two sources of data at all stations, as seen at Oshkosh, a station in the Nebraska panhandle that had a broad spread of winter snow cover conditions during the study period (Fig. 2). There is a tendency for the satellite to show slightly greater frequencies of cover than the 2.5 cm station reports. This is probably a function of satellite-derived observations of scattered snow cover in the countryside surrounding a station, while the snow has melted at the station observing plot. This is further substantiated by more pronounced differences of several weeks between satellite durations and station 7.6 cm observations. Thus, it seems that station data are a good surrogate for satellite data on a seasonal basis as long as station depths of as low as 2.5 cm are used in the comparison.

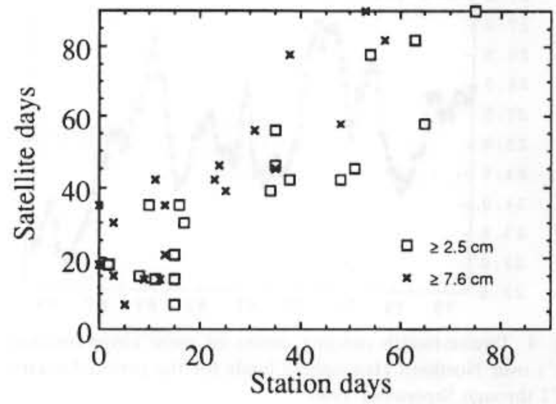

Fig. 2. Winter days with snow cover in the vicinity of Oshkosh, Nebraska as gleaned from NOAA satellite-derived snow charts compared to days with ≥ 2.5 cm and ≥ 7.6 cm of snow cover as reported at the Oshkosh cooperative station. Observations include the 1971/72–1989/90 winters.

Seasonal cover: multiple stations

A further test of the efficacy of merging seasonal satellite and station snow observations compares snow cover estimates over the central and northern Great Plains of the United States. The mean area of winter snow cover was calculated

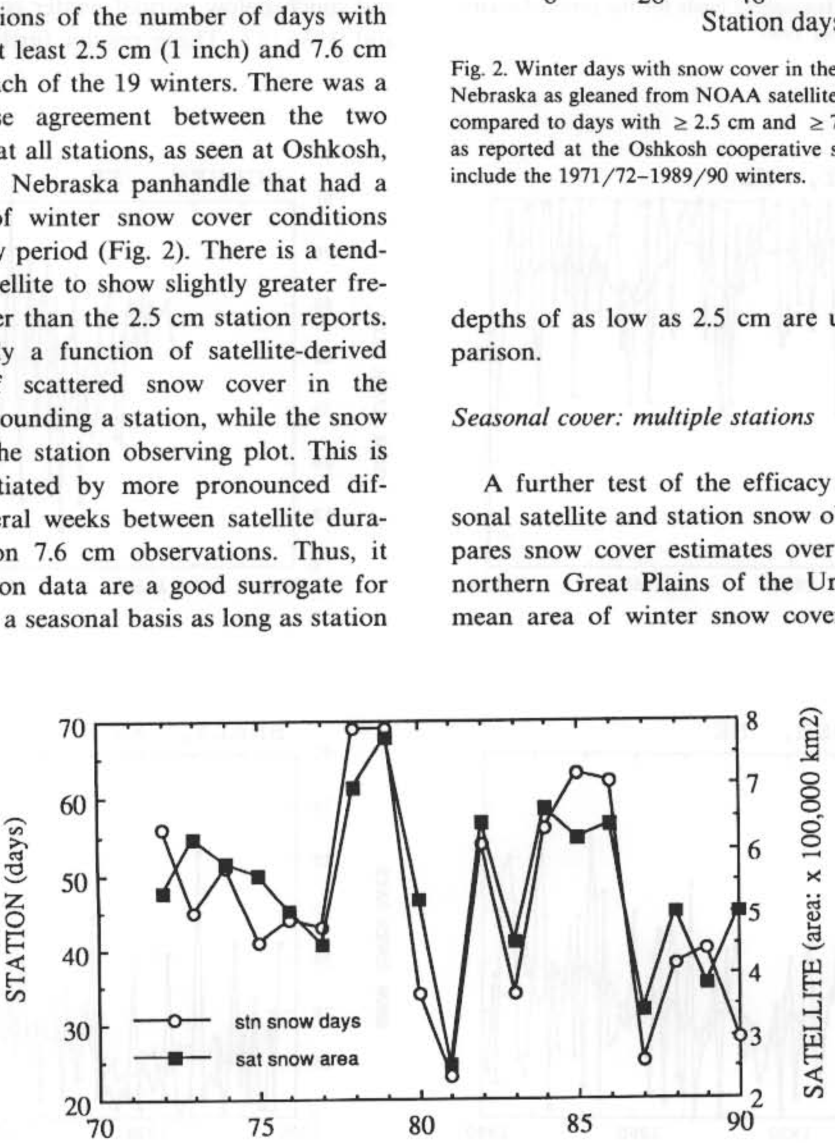

Fig. 3. Satellite and station-derived winter snow cover over the central and northern Great Plains of the United States between 1971/72 and 1989/90. Mean snow areas are derived from NOAA Weekly Snow and Ice Chart digital files, and mean snow duration determined from nine stations located in Kansas (2), Nebraska (2), South Dakota (2), North Dakota (2), and eastern Montana (1).

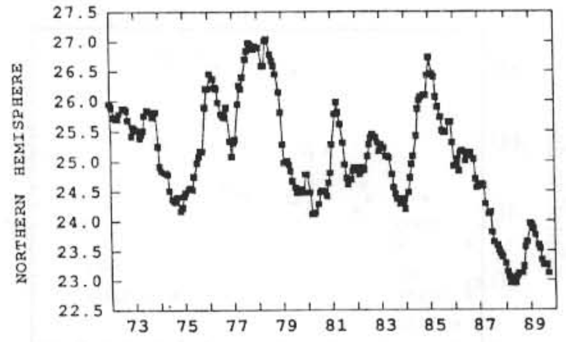

Fig. 4. Twelve-month running means of snow cover (million km^2) over Northern Hemisphere lands for the period January 1972 through September 1990.

from digitized NOAA weekly snow charts. Some 28 grid cells, covering 826,000 km^2, were evaluated. Areas were compared with the average duration of snow cover of ≥ 2.5 cm computed from a network of nine stations within the satellite region, lying from Kansas to North Dakota. Results show a strong correlation between the satellite and station values, which is particularly striking given the limited number of stations used in the study (Fig. 3). For instance, both showed extensive regional snow cover in the winters of 1977/78 and 1978/79 and much below normal winter cover in 1980/81 and 1986/87. These results further substantiate

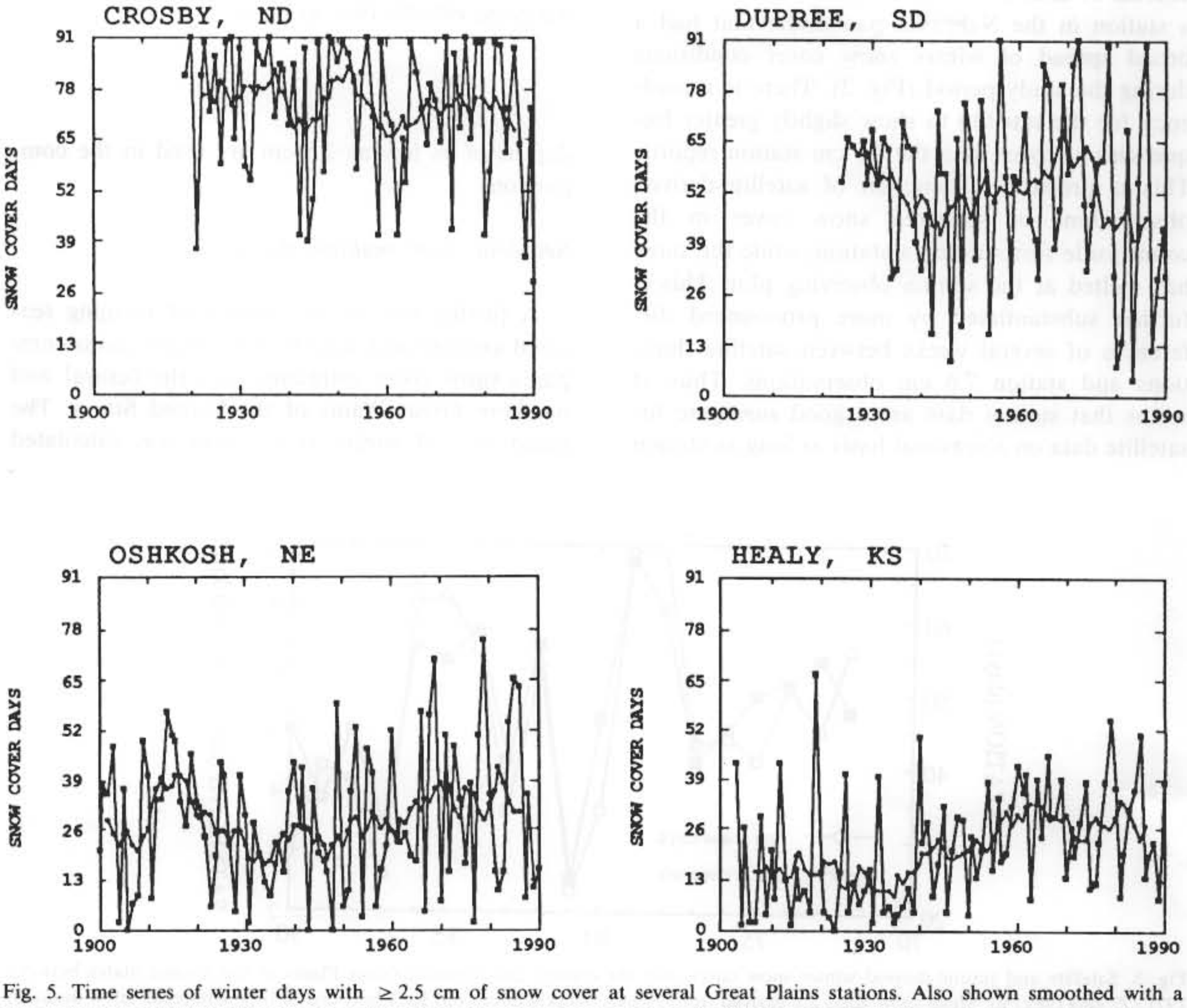

Fig. 5. Time series of winter days with ≥ 2.5 cm of snow cover at several Great Plains stations. Also shown smoothed with a nine-point binomial filter. Only those points where nine years were available for filtering are plotted (e.g. plotted year ± 4 yr).

the utility of employing station data to estimate seasonal snow cover when satellite data are lacking.

Satellite and station-derived time series

Since the middle of 1987, snow cover over Northern Hemisphere lands has been less extensive than at any time since the advent of reliable satellite snow charting in 1972 (Robinson and Dewey, 1990; Robinson et al., 1991). Based on observations through September, 1990 should go down as being the lowest year on record: monthly minima for the past 19 years have been established for February through September. Only two of the past 38 months (beginning August 1987) have had above normal hemispheric snow cover (January 1988 and December 1989). Thus, the recent snow drought has occurred in all seasons, as well as over Eurasia and North America. Twelve-month running means of hemispheric snow extent have averaged 25.0 million km^2 over the past 19 years (Fig. 4). Periods of above normal cover have included the late 1970's and mid-1980's, while the mid-1970's and early 80's were on the low side. Neither of the latter are close to the recent deficit on a hemispheric level, although Eurasian cover in the mid-1970's and North American cover in the early 1980's approached recent lows.

With less than a two-decade long record of satellite observations of snow cover, it is impossible to place this recent dearth of cover in proper perspective. To do so, requires longer records, which must be gleaned from station observations. As shown above, regional intercomparisons of visible satellite-derived snow products and networks of station observations show reasonably good agreement on a seasonal time scale, given a number of high-quality station records in non-mountainous terrain. Where these conditions are met, lengthy time series of snow cover may be compiled confidently from station observations, permitting documentation of natural fluctuations and trends of cover that may have occurred over the past century. For instance, decadal fluctuations in winter snow cover have been identified over the Great Plains of the United States this century, and a trend towards increasing duration of cover from the 1930's to 1970's has been observed in the central Plains. Figure 5 illustrates this at four of the stations employed in the seasonal satellite–station comparisons presented above. An insufficient number of years has passed since the 1970's maximum to determine whether subsequent decreases indicate an end to the upward trend or are simply short-term lows. Certainly winter snow cover in the past decade showed wide year-to-year fluctuations throughout the Plains.

Examination of snow observations in all seasons over the United States continues, and similar studies of lengthy Soviet, Canadian, and Chinese data are planned for the near future. While lacking the spatial coverage provided by satellites, these analyses will lead to a better understanding of the recent snow fluctuations charted from imagery.

Conclusions

On a daily time frame, it is difficult to interchange regional snow observations gleaned from visible satellite imagery with station observations of snow due to the presence of clouds. However, they do complement each other, and, with the addition of microwave-derived snow analyses, provide the best means of accurately delimiting snow conditions on any given day. On a seasonal basis, satellite and station observations of snow duration compare favorably, given a network of high-quality stations in non-mountainous terrain. Thus, where these conditions are met, lengthy time series of snow cover may be compiled confidently from station observations, permitting documentation of natural fluctuations and trends of cover that may have occurred over the past century. Such information enhances the utility of relatively short-term satellite-derived snow cover observations in identifying and monitoring future climate change.

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References

Barnett, T.P., Dumenil, L., Schlese, U., Roeckner, E. and Latif, M., 1989. The effect of Eurasian snow cover on regional and global climate variations. J. Atmos. 661–685.

Barry, R.G., 1985. The cryosphere and climate change. Detecting the Climatic Effects of Increasing Carbon Dioxide, DOE/ER 0235, pp. 109–148.

Dickinson, R.E., Meehl, G.A. and Washington, W.M., 1987. Ice-albedo feedback in a CO_2-doubling simulation. Clim. Change, 10: 241–248.

Hansen, J., Lacis, A., Rind, D., Russell, G. Stone, P., Fung, I., Ruedy, R. and Lerner, J., 1984. Analysis of feedback mechanisms. Climate Processes and Climate Sensitivity (Geophys. Monogr., 29). Am Geophys. Union, Washington, DC, pp. 130–163.

Manabe, S. and Wetherald, R.T., 1980. On the distribution of climate change resulting from an increase in CO_2-content of the atmosphere. J. Atmos. Sci., 37: 99–118.

Robinson, D.A., 1988. Construction of a United States historical snow data base. In: J. Lewis (Editor), Proc. 45th Eastern Snow Conference, Lake Placid, NY, pp. 50–59.

Robinson, D.A. 1989. Evaluation of the collection, archiving, and publication of daily snow data in the United States. Phys. Geogr., 10, 120–130.

Robinson, D.A. and Dewey, K.F., 1990. Recent secular variations in the extent of Northern Hemisphere snow cover. Geophys. Res. Let., 17:1557–1560.

Robinson, D.A., Keimig, F.T. and Dewey, K.F., 1991. Recent variations in northern hemisphere snow cover. Proc. 15th Ann. Cli. Diag. Workshop., NOAA, Asheville, NC, pp. 219–224.

Schlesinger, M.E., 1986. CO_2-induced changes in seasonal snow cover simulated by the OSU coupled atmosphere-ocean general circulation model. In: G. Kukla, R. Barry, A. Hecht and D. Wiesnet (Editors), Snow Watch '85, Glaciological Data, Report GD-18, pp. 249–270.

Walsh, J.E., Jasperson, W.H. and Ross, B., 1985. Influences of snow cover and soil moisture on monthly air temperature. Mon. Weather Rev., 113: 756–768.

Wiesnet, D.R., Ropelewski, C.F., Kukla, G.J. and Robinson, D.A., 1987. A discussion of the accuracy of NOAA satellite-derived global seasonal snow cover measurements. Large Scale Effects of Seasonal Snow Cover, Proc. Vancouver Symp., IAHS Publ. No. 166, pp. 291–304.