1.6 TRENDS AND VARIABILITY OF SNOWFALL AND SNOW COVER ACROSS NORTH AMERICA AND EURASIA. PART 2: WHAT THE DATA SAY

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1. INTRODUCTION

Snow is a significant factor in the national economy and also in the water resources of Northern Hemisphere countries. Snow has an important climatic role reflecting climatic changes and fluctuations, as well as exerting an influence on climate. The availability of satellite monitoring of weather and climate variables enabled scientists to develop and analyze hemispheric snow cover extent using a consistent database. Unfortunately, the satellite snow record goes back only four decades. In situ observations of snow cover as well as snowfall are available for some stations going back to the beginning of the Twentieth Century.

The research presented in this paper and a companion contribution (cf. Heim and Robinson, Trends and variability of snowfall and snow cover across North America and Eurasia. Part 1: Data quality and homogeneity analysis) includes some preliminary results from a comprehensive analysis of in situ snow observations from stations in the United States, Canada, and the Former Soviet Union (FSU) using a consistent methodology applied to all of the stations. This paper discusses the second portion of the effort, beginning with brief synopses of information presented in Part 1, including data sources and variables analyzed, the quality control that was applied, and the snow indices that were computed from the daily snow observations. This is followed by a brief description of the satellite-derived snow cover extent data that will be compared with station-derived results. Finally, preliminary results from spring (March - May) analyses over North America will be presented. Discussion of multi-seasonal results and Eurasian results will be included in the conference presentation and in subsequent manuscripts.

2. STATION DATA

Daily snowfall, snow depth, precipitation, and maximum and minimum temperatures were utilized in the general Heim and Robinson study. In this paper we use data from the US Cooperative Station Summary of the Day (TD-3200) database and the Daily Climatological Data (DLY02, DLY04) from Canada. We do not employ FSU data, nor North American data gathered prior to 1950 (1955 for snow depth). Continent-wide assessments were not possible earlier in the 20th century over North America due to the absence of sufficient Canadian or Alaskan data, and remain questionable over the FSU throughout the observational record. As part of our intention here is to compare station data with continent-wide satellite evaluations of snow extent, we choose to only examine continental records.

Station data were put through routines that included checks for internal consistency, nonzero snowfall values at warm temperatures, factor of ten errors, extreme limits, questionable snowfall-to-precipitation ratios, and questionable decreases in snow depth. The results from the quality assurance checks were combined with an inventory analysis to create quality control and inventory statistics that were used to identify stations to use in the analysis. Further explanation of station data is provided in the companion paper.

3. SATELLITE DATA

From late 1966 through May 1999, trained meteorologists produced the weekly NOAA/NESDIS hemispheric snow extent product from visual analyses of visible satellite imagery. The primary data source was visible imagery acquired from NOAA-n polar orbiting satellites and stored in hardcopy. Secondary data sources included online GOES, GMS, and METEOSAT imagery. Snow cover identification was made by the manual inspection of hardcopy imagery and graphics products, online imagery loops, and the previous week's analysis. Map quality was predicated on the availability of clear sky visible imagery and the meteorologist's experience. After all snow boundaries were identified and placed on a hardcopy, polar stereographic map, an electronic version was made through the digitization of a 89 x 89 cell acetate overlay (mid and high latitude portion of a hemispheric 128 x 128 cell (half mesh) overlay).

June 1999 saw the introduction of a daily hemispheric snow product by NOAA/NESDIS. The new Interactive Multisensor Snow and Ice Mapping System 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. Daily maps are produced from a variety of visible satellite imagery, estimates of snow extent derived from microwave satellite data, and station mapped products. Maps are

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digitized to a 1024 x 1024 cell (sixteenth mesh) polar grid.

Before the weekly map series ended, there was a two-year period in which both maps were produced. We are currently using data from this interval to develop an accurate means of converting the daily maps to a weekly product at the lower half mesh resolution. At the moment, we have calculated preliminary areas based on a routine developed by Don Garrett at the NOAA Climate Prediction Center that considers a half mesh cell as being snow covered if 38% or more of the co-located sixteenth mesh cells are mapped as snow covered on the last day (Sunday) of the longstanding weekly chart period. We are confident that this method provides sufficiently accurate values for use in continental and hemispheric evaluations. NOAA/NESDIS maps and a variety of products derived from this valuable time series may be viewed at the Rutgers Global Snow Lab web site (http://climate.rutgers.edu/snowcover).

4. SNOW PARAMETERS

For this preliminary study, time series of station snow parameters computed for each station from the daily snowfall and snow depth data include total seasonal snowfall amount, number of days with snowfall greater than or equal to 0.25 cm. (0.1 in.), and the number of days with snow depth greater than or equal to 12.7 cm. (5.0 in.). To construct the seasonal time series, stations were weighted by area using a Thiessen polygon method before being averaged into continental aggregates. The weights for the US-Canadian stations are shown in Figure 1 of the companion paper. In addition to an area-averaged continental value for each monthly/seasonal parameter for each year, this methodology also provides an estimate of the percentage areas with data and without data for each year, which can be used as an indicator (confidence value) of how representative the annual values are. Snow percent areas over the US and Canada are generally in the 85 to 95% range. Station coverage is at the lower end of this range in the 1950s (snowfall totals) and in the late 1990's to early 2000's (all variables).

Snow cover extents from the NOAA/NESDIS maps 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 grid cells that contain more than 50% land are included. Monthly results are subsequently summed and averaged to compute seasonal values.

5. RESULTS

It is not the intention of this study to ascertain much meaning from the absolute values of the spring station-derived snow variables depicted in figures 1-3. Rather it is the variable nature of the interannual signal being reported that has meaning. More detailed future analyses will subdivide the results in time and space, however our initial intention is to examine North America (US and Canada) as a whole. On the other hand, the satellite-derived snow extents are worthy of consideration in an absolute sense. However a main purpose for the satellite data being included here is to determine if there are similar interannual and decadal fluctuations between the satellite and station records.

Considerable interannual variability is noted in each time series, be it for a station variable or the satellite record. While a perfect one-to-one annual match amongst the highs and lows of the station variables or between the station and satellite values is not observed, or for that matter to be expected, similar fluctuations are common. Rare is the year when inverse relations are found.

At a decadal scale, all station variables were at their highest magnitudes from the early 1960s to early 1980s. Spring snowfall totals were lower than this period in the 1950s; as to some extent were spring days with snowfall greater than or equal to 0.25 cm. (0.1 in.), though not to as great an extent as the former. Spring snowfall totals and days declined from the mid 1980s into the early 2000s. The decline in days with snow depth greater than or equal to 12.7 cm. (5 in.) began in the late 1970s. A considerable amount of interannual variability has been observed in the late 1990s and early 2000s. This had not been observed since the 1960s and 1970s for snowfall. It was not noted at any time in the past for snow depth days.

Satellite-derived snow extent was highest in the springs of the middle 1970s to middle 1980s. While somewhat less extensive in the late 1960s and early 1970s, extents during this period generally exceeded those of the late 1980s to present. Similar tendencies have been observed over Eurasia.

6. CONCLUSIONS

The results presented in this paper represent a first look at what promises to be a valuable database of historic station snow observations. The addition of satellite-derived snow extent data only further strengthens our evaluation of snow variability and potential trends. Results show that snowfall and snow cover was more pervasive in the 1960s and 1970s than in the 1950s or in the past 20 years. In particular, recent decades exhibit the lowest spring snow values observed in the past half-century.

Care must be taken not to over extend the spatial limits of the database, particularly earlier than the 1950s. Also, while a strength of the database is the considerable number of stations within it, a more meticulous evaluation of data quality would likely eliminate some of them from detailed consideration. Thus analyses using a database of this kind should focus on the benefit of having multiple stations, while avoiding the temptation to place too much weight on observations from one or several stations without further quality assessment.

7. ACKNOWLEDGMENTS

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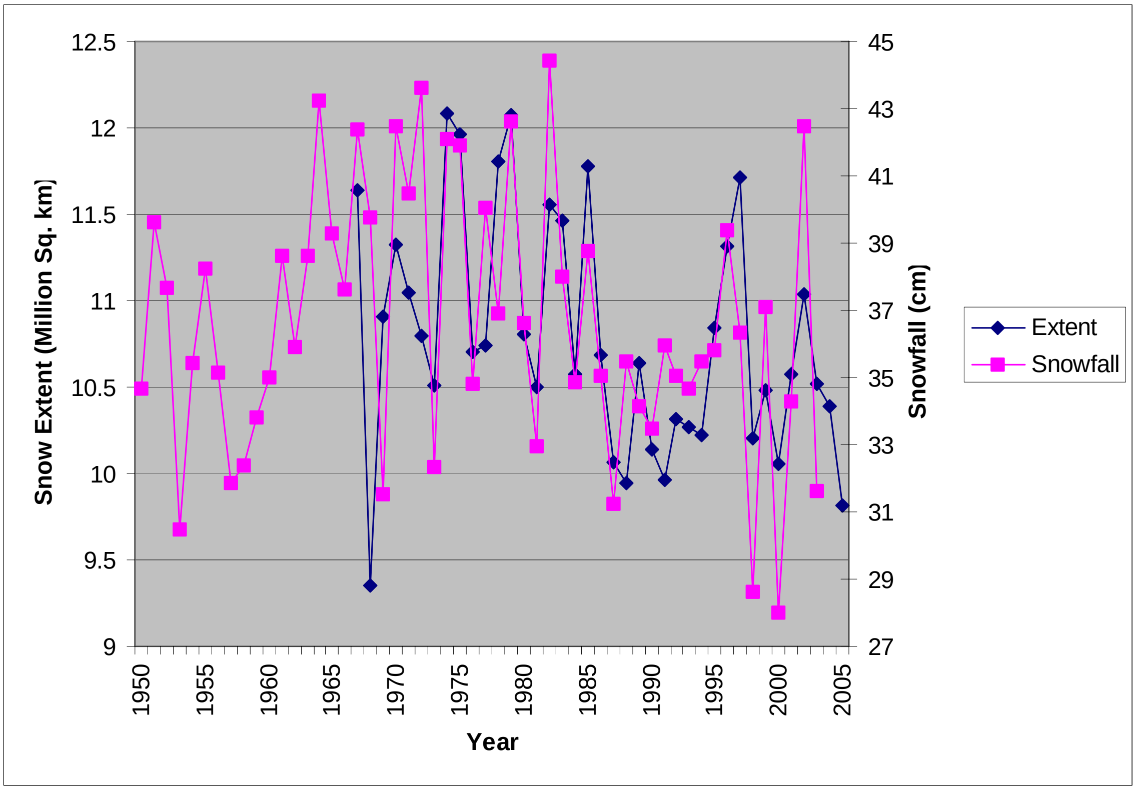

Figure 1. North American spring snowfall as derived from US and Canadian station data between 1950 and 2003 (Snowfall) (cm). Spring snow cover extent over North America between 1967 and 2005, as calculated from NOAA/NESDIS snow maps (Extent) (million sq. km).

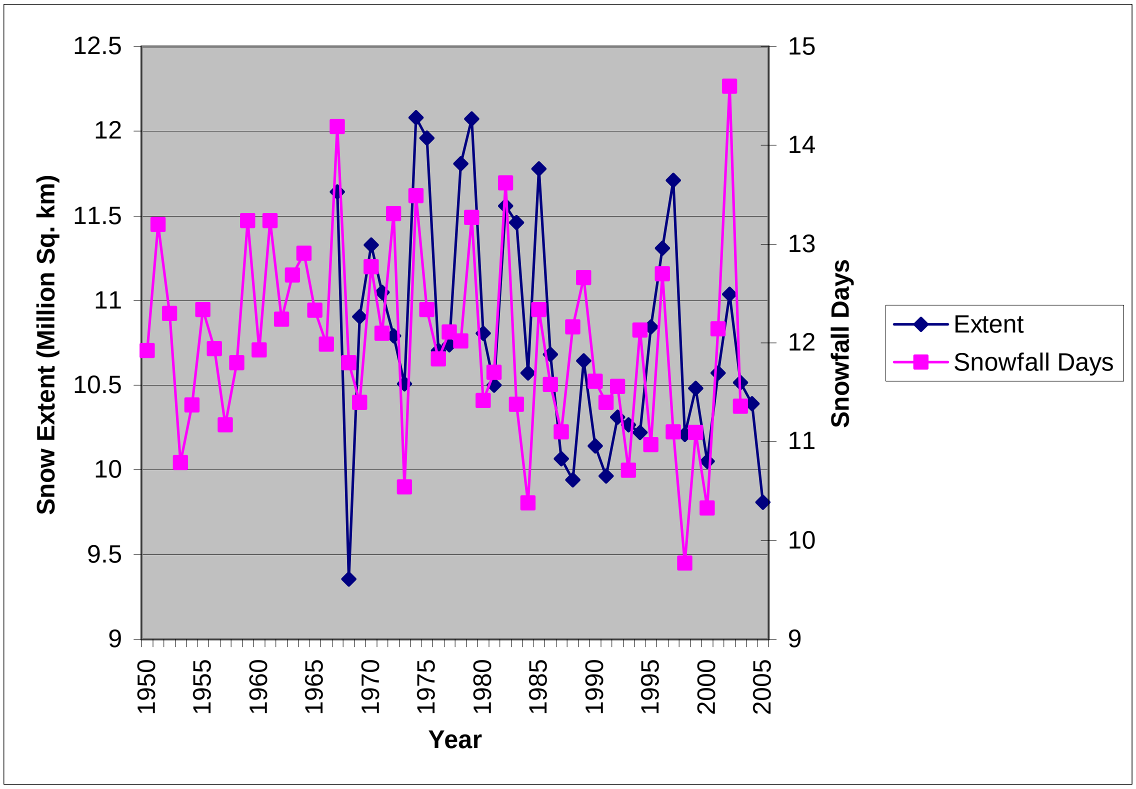

Figure 2. Number of spring days with snowfall greater than or equal to 0.25cm (0.1") over North America, as derived from US and Canadian station data between 1950 and 2003 (Snowfall Days). Spring snow cover extent over North America between 1967 and 2005, as calculated from NOAA/NESDIS snow maps (Extent) (million sq. km).

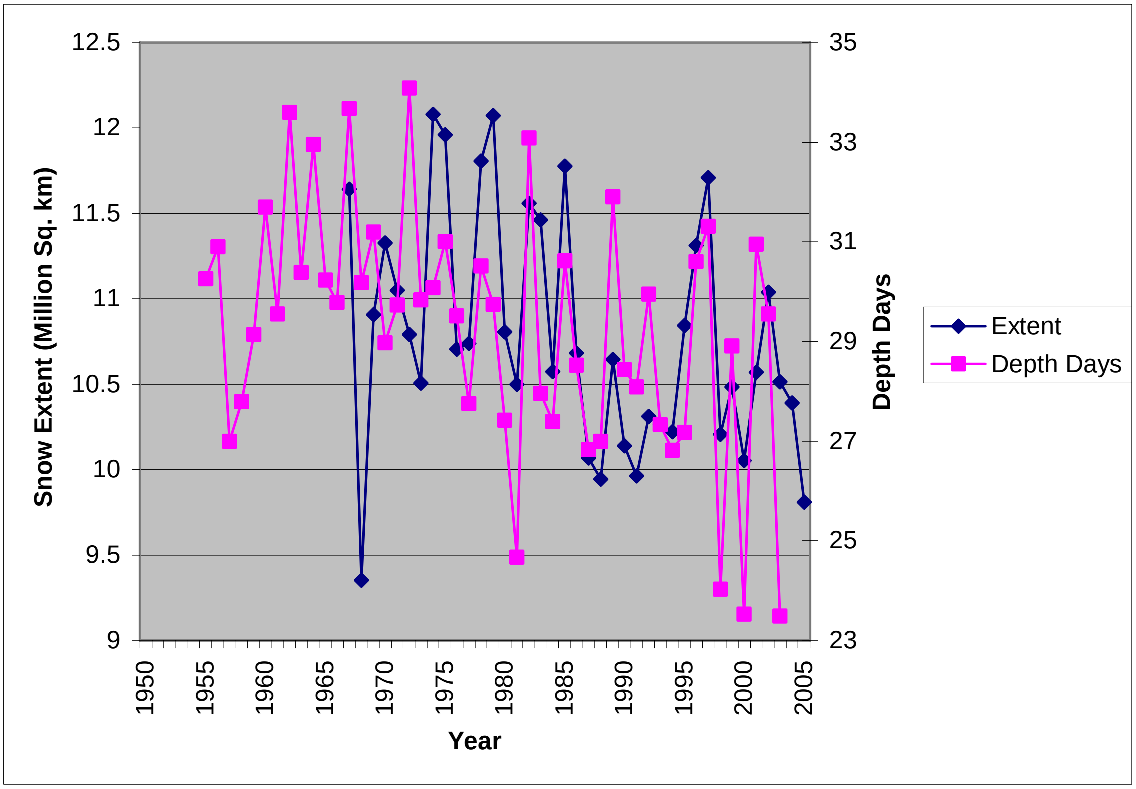

Figure 3. Number of spring days with snow depth greater than or equal to 12.7 cm (5") over North America, as derived from US and Canadian station data between 1955 and 2003 (Depth Days). Spring snow cover extent over North America between 1967 and 2005, as calculated from NOAA/NESDIS snow maps (Extent) (million sq. km).