Changes in transitional snowfall season length in northern Eurasia

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[1] An earlier study suggested that snow season length over large parts of northern Eurasia has increased due to earlier dates of first snowfall and later dates of last snowfall during 1937–94. In this study, much smaller increases in the length of continuous snow cover have been found over very limited areas of northern Eurasia, while decreases in continuous snow cover have been found over southern Siberia. The transitional snowfall season, defined by the difference between the first (last) snowfall date and the first (last) date of continuous ground snow cover, showed significant increases over much of Siberia. The increase in spring transitional snowfall season length is partly attributable to a later last snowfall date and partially due to earlier disappearance of continuous snow cover. The increase in fall transitional snowfall season length is mostly attributable to an earlier starting date of first snowfall. *INDEX TERMS:* 1863 Hydrology: Snow and ice (1827); 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 9315 Information Related to Geographic Region: Arctic region; 1833 Hydrology: Hydroclimatology. **Citation:** Ye, H., and M. Ellison, Changes in transitional snowfall season length in northern Eurasia, *Geophys. Res. Lett.*, *30*(5), 1252, doi:10.1029/2003GL016873, 2003.

1. Introduction

[2] Studies of snowfall changes over high latitudes that might be associated with climate warming have suggested that winter snow accumulation has increased while spring snow cover has decreased [*Brown and Goodison*, 1996; *Brown*, 2000; *Robinson et al.*, 1993; *Robinson and Frei*, 2000; *Serreze et al.*, 2000; *Ye*, 2000, 2001a; *Ye et al.*, 1998; *Ye and Mather*, 1997]. A recent study by *Ye* [2001b] found that snowfall season length has increased during 1937–94 due to earlier and later snowfall dates over north central and northwest Asia. The trend toward later snowfall dates appears to contradict the decreased snow cover during spring. This apparent contradiction also gives rise to questions about the length of the continuous snow cover season. In other words, is the increase in snowfall season length related to increased continuous snow cover duration or increased transitional snowfall season in the fall and spring or both? One possibility is that earlier snowfall resulting in higher snow accumulation prolongs melting time and thus increases continuous snow cover duration. A second possibility is that increases in variability and extremes under a warmer climate [*International Panel on Climate Change*, 2001] as have been found in many parts of the world [*Parker et al.*, 1994; *Hulme*, 1992; *Trenberth and Hurrell*, 1994; *Rogers and Rohli*, 1991; *Downton and Miller*, 1993] result in earlier fall snowfalls and later spring snowfalls while the continuous snow cover length during winter has not changed much.

[3] In this study, trends in starting and ending dates and length of continuous snow cover over northern Eurasia have been examined to test the above hypotheses. Also, the length of the transitional snowfall season has been examined to further verify these hypotheses.

2. Data and Method

[4] The first and last dates of continuous snow cover are derived from the Historical Soviet Daily Snow Depth CD version II, compiled and quality-controlled by the National Snow and Ice Data Center [*Armstrong*, 2001]. The original daily snow records were measured by averaging three permanent snow stakes surrounding each station. Readings were rounded to the nearest centimeter. The authors examine daily records visually and identify the starting and ending dates of continuous snow cover in accordance with the longest period of observed snow cover on the ground for each station.

[5] The dates are expressed in Julian days (from 1–365). The Julian days are changed into "relative" Julian days when the first date of continuous snow cover falls in January or later. For example, if continuous snow cover starts on January 3rd, the first snow cover date is set to 368 instead of 2. After stations with more than 9 years of missing values are removed, 107 stations are used for starting snow cover dates and 80 stations for ending snow cover dates for the time period of 1936/37–94/95 (Figure 1). The authors speculate that more stations are missing during spring because observers may not have been attentive to isolated snowfalls with transient cover as suggested by *Brown* [1997] and *Fallot et al.* [1997].

[6] The length of continuous snow cover season is calculated by subtracting the first date from 365 and adding the last date of continuous snow cover. To standardize the calculation procedure, each year is considered to have 365 days ignoring leap years since they occur every 4 years throughout the entire study period and therefore will not affect general trends.

[7] The transitional fall snow season length is defined as the number of days between the date of first snowfall and the first date of the continuous snow cover season. Similarly, the transitional spring snow season length is defined as the number of days between the last date of continuous snow cover and the last snowfall date. For detailed

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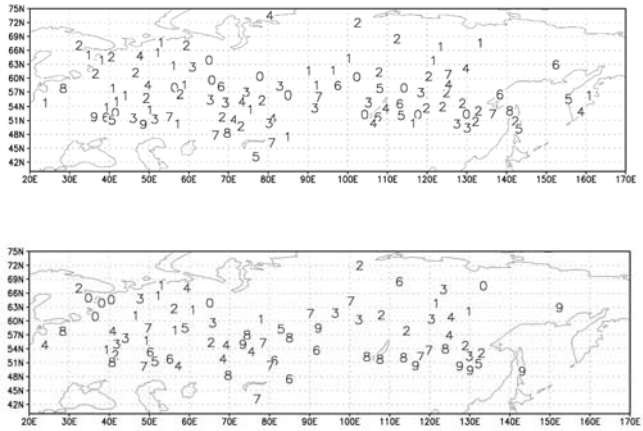

Figure 1. Station distribution and missing number of years during 1936/37–94/95.

definition of first snowfall and last snowfall dates, please refer to *Ye* [2001b].

[8] Linear least-square regression is applied to starting and ending dates and the length of continuous snow cover at each station. The slopes from the regression line representing the rate of change per year are plotted to reveal geographical regions where statistically significant trends occurred at a 95% confidence level.

3. Results

[9] The mean continuous snow cover length ranges from 70 to 225 days from south to north in the study region. The starting dates of continuous snow cover range from early October to late December (280 to 360 Julian days; Figure 2a) and the ending dates of continuous snow cover range from early March to late May (70 to 140 Julian days; Figure 2b). Based on satellite observations, fall snow cover usually started over northeastern Siberia. Due to sparse station distribution over northeastern Siberia, it does not show clearly in this figure.

[10] Negative trends of around 2 days/decade for starting date are found over northern European Russia (Figure 3a) and for ending date are found over southeastern Siberia and

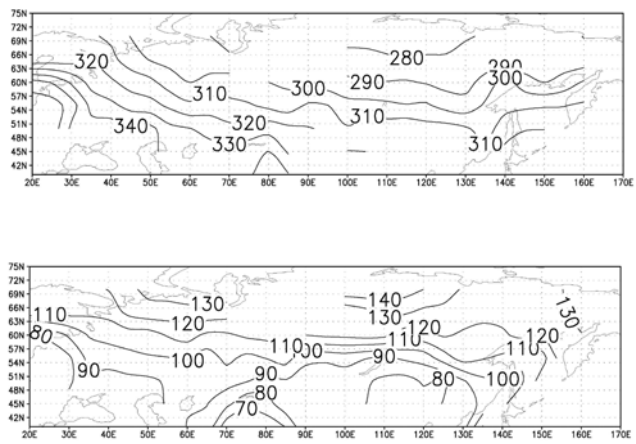

Figure 2. Mean dates of a. starting; b. ending continuous snow cover.

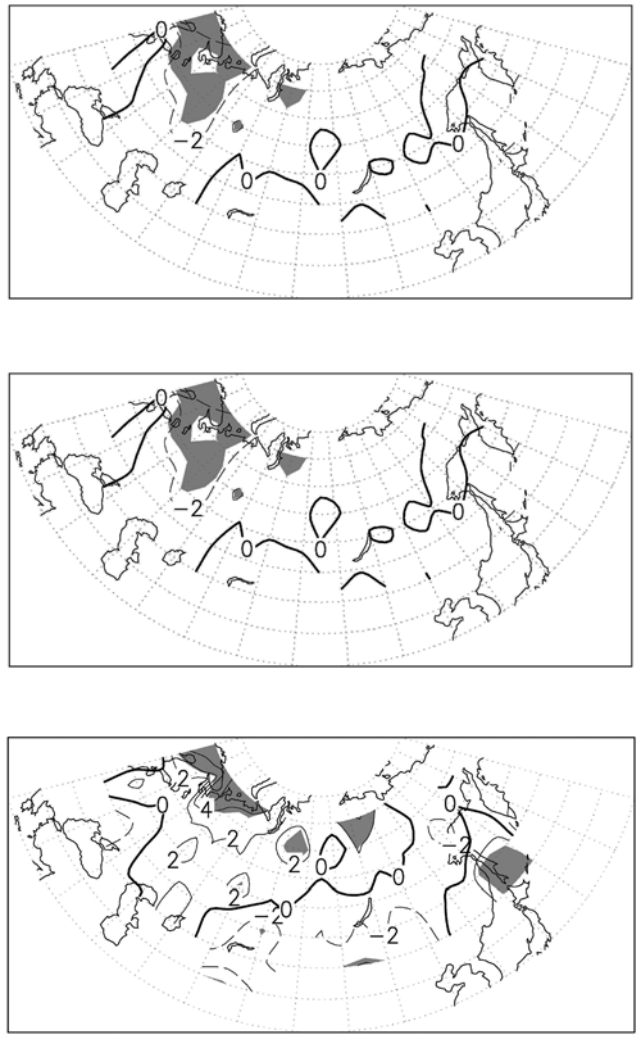

Figure 3. Trends (day/decade) in a. starting date; b. ending date; c. length of continuous snow cover. Shaded areas are statistically significant at a 95% confidence level.

a smaller area over northern European Russia (Figure 3b). This suggests that continuous snow cover has started earlier over northern European Russia and disappeared earlier over southeastern Siberia and part of European Russia. The length of continuous snow cover has increased about 4 days/decade over northern European Russia and over small areas of western and central Siberia, but decreased about 2 days/decade over some areas of southern and southeastern Siberia (Figure 3c). The magnitude of continuous snow cover length increase is much smaller in Siberia compared to the length of the snowfall season (Figure 2 in *Ye* [2001b]) and statistically significant areas are more limited. The areas of statistically significant trend pass a field significant test at a 95% confidence level in Figure 3.

[11] Positive trends of 2–4 days/decade are found over much of Siberia and European Russia during the fall transitional season (Figure 4a) and of 2–6 days/decade over much of northern Eurasia during the spring transitional season (Figure 4b). This suggests that the transitional snowfall season has increased in both spring and fall with the most significant increases occurring in spring over southeastern

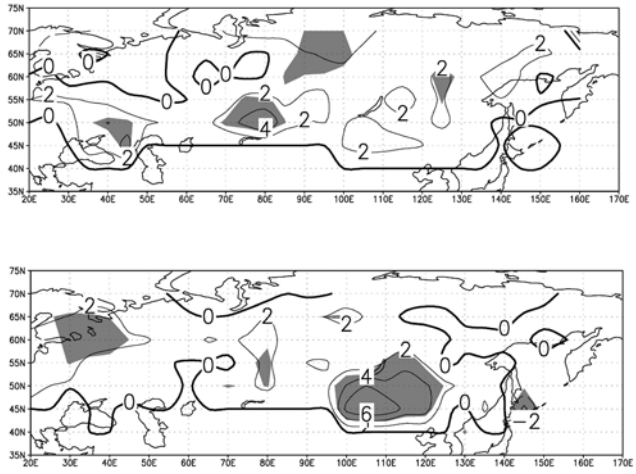

Figure 4. Trends in the length of transitional snowfall season for a. fall; b. spring. Shaded areas are statistically significant at a 95% confidence level.

Siberia. The areas of statistically significant trend in spring transitional season pass the field significance test at a 95% confidence level, but the fall transitional season does not.

4. Conclusions

[12] The transitional snowfall season length during both spring and fall has increased in much of the study region except for northern European Russia. The statistically significant increase areas (at a 95% confidence level) are over southern European Russia and central Siberia for fall snowfall transitional season and northern European Russia and southeastern Siberia for spring snowfall transitional season. The longer autumn snowfall season length is mostly due to earlier snowfall dates while the longer spring snowfall season is related to later dates of snowfall and earlier ending dates of continuous snow cover. The earlier disappearance of continuous snow cover is evident in northern European Russia and the southern study region, consistent with remote sensing observations [*Brown*, 2000].

[13] The length of continuous snow cover has increased slightly over northern European Russia and western Siberia and decreased over southern Siberia. The generally earlier onset of continuous snow cover, especially over northern European Russia, may contribute to the trends in winter Arctic atmospheric circulation suggested by studies showing that fall season snow cover has the most significant influence on winter atmospheric circulation [*Cohen and Entekhabi*, 1999, 2001; *Saito et al.*, 2001]. The increased length of transitional snowfall season may indicate a higher frequency of anomalous weather conditions under a warmer climate during spring and fall in high-latitude areas.

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References

Armstrong, R., *Historical Soviet Daily Snow Depth Version 2 (HSDSD)* [CD-ROM], http://www.nsidc.org/data/g01092.html, Natl. Snow and Ice Data Cent., Boulder, Colo., 2001.

Brown, R. D., Historical variability in Northern Hemisphere spring snow covered area, *Ann. Glaciol.*, *25*, 340–346, 1997.

Brown, R. D., Northern Hemisphere snow cover variability and change, 1915–97, *J. Clim.*, *13*, 2339–2355, 2000.

Brown, R. D., and B. E. Goodison, Interannual variability in reconstructed Canadian snow cover, 1915–1992, *J. Clim.*, *9*, 1299–1318, 1996.

Cohen, J., and D. Entekhabi, Eurasian snow cover variability and Northern Hemisphere climate predictability, *Geophys. Res. Lett.*, *26*, 345–348, 1999.

Cohen, J., and D. Entekhabi, The influence of snow cover on Northern Hemisphere climate variability, *Atmos. Ocean*, *39*, 35–53, 2001.

Downton, M. W., and K. A. Miller, Freeze risk to Florida citrus, part II: Temperature variability and circulation patterns, *J. Clim.*, *6*, 364–372, 1993.

Fallot, J.-M., R. G. Barry, and D. Hoogstrate, Variations of mean cold season temperature precipitation and snow depths during the last 100 years in the former Soviet Union, *Hydrol. Sci. J.*, *42*, 301–327, 1997.

Hulme, M., Rainfall changes in Africa: 1931–1960 to 1961–1990, *Int. J. Climatol.*, *12*, 685–699, 1992.

International Panel on Climate Change, *Climate Change 2001: The Scientific Basis: Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, edited by J. T. Houghton et al., 944 pp., Cambridge Univ. Press, New York, 2001.

Parker, D. E., P. D. Jones, C. K. Folland, and A. Bevan, Interdecadal changes of surface temperature since the late nineteenth century, *J. Geophys. Res.*, *99*, 14,373–14,399, 1994.

Robinson, D. A., and A. Frei, Seasonal variability of Northern Hemisphere snow extent using visible satellite data, *Prof. Geogr.*, *52*, 307–315, 2000.

Robinson, D. A., K. E. Dewey, and R. R. Heim, Global snow cover monitoring: An update, *Bull. Am. Meteorol. Soc.*, *74*, 1689–1696, 1993.

Rogers, J. C., and R. V. Rohli, Florida citrus freezes and polar anticyclones in the Great Plains, *J. Clim.*, *4*, 1103–1113, 1991.

Saito, K., J. Cohen, and D. Entekhabi, Evolution of atmospheric response to early-season Eurasian snow cover anomalies, *Mon. Weather Rev.*, *129*, 2746–2760, 2001.

Serreze, M. C., J. E. Walsh, F. S. Chapion III, T. Osterkamp, M. Dyurgerov, V. Romanovsky, W. C. Oechel, J. Morison, T. Zhang, and R. G. Barry, Observational evidence of recent change in northern high-latitude environment, *Clim. Change*, *46*, 159–208, 2000.

Trenberth, K. E., and J. W. Hurrell, Decadal atmosphere-ocean variations in the Pacific, *Clim. Dyn.*, *9*, 303–319, 1994.

Ye, H., Decadal variability of Russian winter snow accumulation and its associations with Atlantic sea surface temperature anomalies, *Int. J. Climatol.*, *20*, 1709–1728, 2000.

Ye, H., Quasi-biennial and quasi-decadal variations in snow accumulation over northern Eurasia and their connections to the Atlantic and Pacific Oceans, *J. Clim.*, *14*, 4573–4584, 2001a.

Ye, H., Increases in snow season length due to earlier first snow and later last snow dates over north central and northwest Asia during 1937–94, *Geophys. Res. Lett.*, *28*, 551–554, 2001b.

Ye, H., and J. R. Mather, Polar snow cover changes and global warming, *Int. J. Climatol.*, *17*, 155–162, 1997.

Ye, H., H. Cho, and P. E. Gustafson, The changes in Russian winter snow accumulation during 1936–83 and its spatial patterns, *J. Clim.*, *11*, 856–863, 1998.

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