Determination of Canadian Snow Regimes Using Passive Microwave Radiometry

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Abstract

Snow water equivalence (SWE) is an important factor in the control of regional and global climate systems, hydrologic cycles, and atmospheric processes. Daily monitoring of SWE using passive microwave radiometry provides datasets capable of defining long-term spatial-temporal patterns in SWE. Using spatial-temporal patterns of SWE, it is possible to distinguish unique regimes of snow cover in Canada. Knowledge of the distribution of these SWE regimes will help analysts answer key questions regarding their impact on human and ecological processes. The current research uses novel temporal metrics derived from long-term SWE estimates, and spatially constrained cluster analysis, to objectively define the major SWE regimes across Canada.

Background and Relevance

The spatial distribution of terrestrial snow cover impacts local snowmelt release (Luce *et al.*, 1998), global and regional atmospheric circulation (Derksen *et al.*, 1998a; Barnett *et al.*, 1989), and global and local climate and hydrological cycles (Wulder *et al.*, 2007; Derksen and McKay, 2006; Derksen *et al.*, 2000; Serrezez *et al.*, 2000). The sensitivity of terrestrial snow cover to atmospheric conditions and overlying air temperatures also makes snow cover a useful indicator of climate change (Derksen *et al.*, 2000; Goodison and Walker, 1993).

Snow cover is often measured as snow water equivalent (SWE), which refers to the amount of water (expressed as a depth in millimeters) stored in a snow-pack that would be available upon melting (NSIDC, 2007). SWE regimes describe the regular spatial and temporal patterns of SWE accumulation in individual regions, and are a major control of spatial and temporal patterns and processes in many ecosystems (Walker *et al.*, 1999). Characterization of SWE regimes is of primary concern for analysts concerned with biodiversity monitoring (e.g. Duro *et al.*, 2007), meso-scale controls of biological systems (e.g. Walker *et al.*, 1993), species and community distribution (e.g. Walker *et al.*, 1999), and many anthropogenic processes such as tourism, recreation, and urban and agricultural water supply (Walker *et al.*, 1993).

Traditionally, data on snow cover and depth measurement have been spatially and temporally sparse (Walker and Goodison, 2000; Wulder *et al.*, 2007; Tait, 2005). However, over the past two decades, high quality SWE datasets over large areas throughout Canada (Derksen *et al.*, 2000; Derksen and McKay, 2006; Walker and Goodison, 2000) and the world (Tait, 1996; Pulliainen and Halliskainen, 2001)have been developed using passive microwave radiometry. The Scanning Multichannel Microwave Radiometer, and the Special Sensor Microwave/Imager provide over two decades of continuous satellite data for North America from which SWE can be derived. The large spatial and temporal extents of this dataset provide a unique opportunity to study the spatial and temporal patterns in SWE, and to delineate Canadian SWE regimes. The goal of this paper is to examine the temporal patterns of SWE through time, and quantify if and how they vary across the study region in order to delineate relatively homogenous SWE regimes. Consideration of large spatial and temporal extents, with relatively fine spatial and temporal resolutions, is a development over previous space-time SWE research which has generally focused on examining the spatial distribution of SWE over time, emphasizing the spatial patterns of snow cover and SWE over short time periods (*e.g.*,Derksen *et al.*, 1998b,1998c), or the coarse-scale spatial patterns of snow cover and SWE for longer time-series (*e.g.*, Brown, 2000; Laternser and Schneebeli, 2003).

Methods and Data

SWE estimates used in the present analysis are based on brightness temperatures (in Kelvin) acquired by the SSM/I passive microwave radiometer onboard the Defense Meteorological Satellite Program (DMSP) F13 satellite. The data are provided in the Equal Area Scalable Earth Grid (EASE-Grid) format (see Armstrong and Brodzik, 1995) from the National Snow and Ice Data Center (Knowles *et al.*, 1999; Armstrong *et al.*, 1994), and are represented by 25 km grid cells. The analysis is applied over the entire Canadian landmass, and uses SWE estimates for the period from 1987 to the present.

A daily SWE estimate is computed for each pixel in the dataset, generating approximately 365 SWE estimates per pixel, per year. This analysis is carried out over the entire study period (19 years), generating approximately 6,935 SWE estimates per pixel. Because SWE is a seasonal variable, the time-series' form relatively simple sinusoidal SWE accumulation curves. The various temporal components of the waves can be separated into representative temporal metrics by treating each grid cell within the study region as a separate sinusoidal time-series. The temporal components that can be derived from the time series' include the period, amplitude, and frequency of the temporal wave, as well as temporal metrics such as mean yearly accumulation, maximum SWE, minimum SWE, mean time to maximum SWE, yearly mean SWE, and total mean SWE.

Once the number of temporal metrics has been reduced to a few representative measures, a classification based on a spatially constrained multivariate cluster analysis (e.g. Oliver and Webster, 1989) will be employed to ensure that the SWE regimes include spatially contiguous pixels. The result will be a map which delineates the major SWE regimes across Canada. This map can then be used to define ecologically relevant study regions for SWE related research, including climate modeling, snow-atmosphere interaction studies, biodiversity monitoring, and ecosystem characterization.

Conclusions

The methodology presented in the current analysis provides a means for determining the natural SWE regimes across Canada. By implementing a method for analyzing long-term, spatially-referenced SWE datasets, the regular spatial and temporal patterns of SWE accumulation can be used to define representative SWE management units for both ecological and anthropogenic processes. This analysis also has implications for other types of spatial-temporal analysis in the natural and human environments, and may be particularly useful for analysts interested in obtaining objective estimates of animal home-ranges, soil and atmospheric regimes, as well to derive estimates of representative scales for spatial analysis. In addition, this type of analysis will be useful for analyzing the growing number of spatial datasets collected over long time periods, at fine spatial and temporal resolutions.

References

Armstrong, R. and Brodzik, M., 1995, An earth-gridded SSM/I data set for cryospheric studies and global change monitoring, Advanced Space Research 16: 10155-10163.

Armstrong, R., Knowles, K., Brodzik, M. and Hardman, M., 1994 – 2002, DMSP SSM/I Pathfinder daily EASE-Grid brightness temperatures, Boulder, CO, National Snow and Ice Data Center. Digital media and CD-ROM.

Barnett, T., Dumenil, L., Schlese, U., Roeckner, E. and Latif, M., 1989, The effect of Eurasian snow cover on regional and global climate variations. Journal of the Atmospheric Sciences, 46: 661-685.

Bokariu, R. and Gimeno, L., 2003, The role of snow cover fluctuations in multiannual NAO persistence. Geophysical Research Letters, 30: 1156-1159.

Brown, R., 2000, Northern Hemisphere snow cover variability and change, 1915-97. Journal of Climate, 13: 2339-2355.

Cohen, J. and Rind, D., 1991, The effect of snow cover on the climate. Journal of Climate, 4: 689-706.

Derksen, C. and McKay, M., 2006, The Canadian boreal snow water equivalent band. Atmosphere-Ocean, 44: 305-320.

Derksen, C., LeDrew, E. and Goodison, B., 1998a, SSM/I derived snow water equivalent data: the potential for investigating linkages between snow cover and atmospheric circulation. Atmosphere-Ocean. 36(2): 95-117.

Derksen, C., LeDrew, E. and Goodison, B., 2000, Temporal and spatial variability of North American prairie snow cover (1988-1995) inferred from passive microwave-derived snow water equivalent imagery. Water Resources Research, 36: 255-266.

Derksen, C., Wulder, M., LeDrew, E. and Goodison, B., 1998b, Associations between spatially autocorrelated patterns of SSM/I derived Prairie snow cover and atmospheric circulation. Hydrological Processes, 12: 2307-2316.

Derksen, C., Wulder, M., LeDrew, E. and Goodison, B., 1998c, Application of the Getis statistic to hemispheric and regional scale passive microwave derived snow water equivalent imagery. Geoscience and Remote Sensing Symposium Proceedings, IGARSS '98. 1998 IEEE International, 2: 977-979.

Duro, D., Coops, N., Wulder, M., and Han, Tian., 2007, Development of a large area biodiversity monitoring system driven by remote sensing. Progress in Physical Geography, 31: 235-260.

Goodison, B. and Walker, A. 1993: Use of snow cover derived from satellite passive microwave data as an indicator of climate change. Annals of Glaciology, 17: 137–142.

Kazuyuki, S., Tetsuzo, Y., and Judah, C., 2004, Changes in the sub-decadal covariability between northern hemisphere snow cover and the general circulation of the atmosphere. International Journal of Climatology, 24: 33-44.

Knowles, N., Dettinger, M., and Cayan, D., 2006, Trends in snowfall versus rainfall for the western United States. Journal of Climate, 19: 4545-4559.

Laternser, M. and Schneebeli, M., 2003, Long-term snow climate trends of the Swiss Alps (1931-99). International Journal of Climatology, 23: 733-750.

Luce, C., Tarboton, D. and Cooley, K., 1998, The influence of the spatial distribution of snow on basin-average snowmelt. Hydrological Processes, 12: 1671-1683.

NSIDC, 2007, National Snow and Ice Data Center. http://nsidc.org/ (Last visited Sep. 2007)

Oliver, M. and Webster, R., 1989, A geostatistical basis for spatial weighting in multivariate classification, Mathematical Geology, 21: 15–35.

Pulliainen, J. and Halliskainen, M., 2001, Retrieval of regional snow water equivalent from space-borne passive microwave observations. Remote Sensing of Environment, 75:76-85.

Rey, S. and Janikas, M., 2006, STARS: Space-time analysis of regional systems. Geographical Analysis, 38: 67-86.

Serreze, M., Walsh, J., Chapin, F., Osterkamp, T., Dyurgerov, M., Romanosky, V., Oechel, W., Morison, J., Zhang, T. and Barry, R., 2000, Observational evidence of recent change in the northern high-latitude environment. Climatic Change, 46:159–207.

Tait, A., 1996, Estimation of snow water equivalent using passive microwave radiation data. Geoscience and Remote Sensing Symposium, 2000. Proceedings. IGARSS 2000. IEEE 2000 International, 4:2005-2007.

Walker, A. and Goodison, B., 2000, Challenges in determining snow water equivalent over Canada using microwave radiometry. Geoscience and Remote Sensing Symposium, 2000. Proceedings. IGARSS 2000. IEEE 2000 International, 4: 1551-1554.

Walker, D., Halfpenny, J., Walker, M., and Wessman, C., 1993, Long-term studies of snow-vegetation interactions. BioScience, 43: 287-301.

Walker, M., Walker, D., Welker, D., Arft, A., Bardsley, T., Brooks, P., Fahnestock, J., Jones, M, Losleben, M., Parsons, A., Seastedt, T., and Turner, P., 1999, Long-term experimental manipulation of winter snow regime and summer temperature in arctic and alpine tundra. Hydrological Processes, 13: 2315-2330.

Wulder, M., Nelson, T., Derksen, C. and Seemann, D., (2007), Snow cover variability across central Canada (1978-2002) derived from satellite passive microwave data. Climatic Change, 82: 113-130.